

Joint Issue

Mountain Views/ Mountain Meridian

Consortium for Integrated
Climate Research in Western Mountains

CIRMOUNT

Mountain Research Initiative

MRI



Volume 10, Number 2 • December 2016



Kelly Redmond (1952-2016) by Lake Tahoe attending a workshop on “Water in the West” in late August of 2016. Photo: Imtiaz Rangwala, NOAA

Front Cover: Les trois dent de la Chourique, west of the Pyrenees and a study area of the P³ project (page 13). The picture was taken enroute from Lake Ansabere to Lake Acherito, both of which have been infected by *Bd* since 2003, although they still have amphibians. Photo: Dirk Schmeller, Helmholtz-Center for Environmental Research, Leipzig, Germany.

Editors: Connie Millar, USDA Forest Service, Pacific Southwest Research Station, Albany, California. and Erin Gleeson, Mountain Research Initiative, Institute of Geography, University of Bern , Bern, Switzerland.

Layout and Graphic Design: Diane Delany, USDA Forest Service, Pacific Southwest Research Station, Albany, California.

Back Cover: Harvest Moon + 1 Day, 2016, Krenka Creek and the North Ruby Mountains, NV. Photo: Connie Millar, USDA Forest Service.

Read about the contributing artists on page 86.

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Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT)
and Mountain Research Initiative (MRI)

Volume 10, No. 2, December 2016

www.fs.fed.us/psw/cirmount/
<http://mri.scnatweb.ch/en/>

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EDITORS WELCOME

Welcome to this joint issue of the Mountain Research Initiative's (MRI) *Mountain Meridian* and the Consortium for Integrated Climate Research in Western Mountains' (CIRMOUNT) *Mountain Views Chronicle*. This year, as with the Autumn 2015 issue, CIRMOUNT has joined forces with MRI to highlight a range of mountain-science projects at the international scale, as well as to include articles and updates from western North America.

In this issue, MRI brings a roundup of articles about one of the community's central efforts, the Global Network of Mountain Observatories (<http://gnomo.ucnrs.org/>). GNOMO grew out of the 2014 "Global Fair and Workshop on Long-Term Observatories of Mountain Social-Ecological Systems" held in Reno, Nevada. Now led by the Organization of Biological Field Stations, the goal of the network is to share experiences, methods, and strategies for long-term observations and monitoring of global change effects on mountain social-ecological systems.

The GNOMO section describes the efforts of some of the GNOMO Working Groups and provides examples of some of the observatories that populate the GNOMO network. The observatory network is now over 100 sites strong and spread all over the globe (see map at: <https://www.google.com/maps/d/viewer?hl=en&hl=en&authuser=0&authuser=0&mid=1S2O5oUZJ-pfSWNz494jXe92aEzQ&ll=39.92252420912146%2C-60.3966668828125&z=2>). Through a variety of working groups, researchers are collaborating to develop and apply protocols that support comparative analysis, forecasts of likely outcomes, and public and private decision-making. Two of the articles describe sites in the International Network for Alpine Research Hydrology (INARCH); although focused primarily on mountain hydrology, these are also great examples of the types of observing efforts GNOMO is working to support.

Earlier this year, MRI teamed up with the six recently funded Belmont Forum (<https://belmontforum.org/funded-projects>) projects to share news, insights, and adventures as these projects evolve over the next years. The projects are funded under the call "Mountains as Sentinels of Change" and integrate natural and social sciences in interdisciplinary, multinational approaches. Although these projects are still quite young, you can read about how they evolved and their challenges and discoveries to date in the Belmont Projects section.

Our mountain climate-science community mourns the passing in early November of a key leader, colleague, and friend, Kelly Redmond. Among many other circles, Kelly was foundational to CIRMOUNT and MRI. He made many important contributions locally and nationally in mountain-climate monitoring, climate communication, and climate implications for resource management and policy. We feature a memorial section about Kelly that includes recollections and stories contributed from some of Kelly's many, many friends.

We draw your attention in the CIRMOUNT Updates section to the article by Jessica Halofsky and Dave Peterson, which summarizes a decade's worth of progress in promoting climate adaptation strategies for US forest ecosystems. Jessica and Dave are key leaders in this effort, and much of what they report is the result of many decades of their boundary-spanning groundwork.

This would not be *Mountain Views Chronicle* without expressions of art and poetry, in this issue contributed by research colleagues from both the MRI and CIRMOUNT communities. We hope you enjoy these as bookends to the mountain science, climate adaptation, and natural history contained herein.



Connie Millar

CIRMOUNT, www.fs.fed.us/psw/cirmount/
USDA Forest Service, PSW Research Station
Albany, California, USA



Erin Gleeson

MRI, <http://mri.scnatweb.ch/en/>
Institute of Geography, University of Bern
Bern, Switzerland

BELMONT PROJECTS

Creating ClimateWise

Kate Brauman¹, and Leah Bremer²

¹*Institute on the Environment, University of Minnesota, Saint Paul, Minnesota*

²*Stanford Woods Institute for the Environment, Stanford, California*

Project Partners

Alexandra Ponette-Gonzalez¹, Humberto Rocha², Martina Flörke³

¹*University of North Texas, Denton, Texas, USA;* ²*University of São Paulo, São Paulo, Brazil;* ³*University of Kassel, Kassel, Hesse, Germany*

After a gripping five-hour drive, winding over skinny mountain roads through goat traffic, we arrive in the tiny town of Huamantanga (Fig. 1). The water that flows through this town eventually ends up in Lima, Peru, and Huamantanga is one of the first community partners to work with AquaFondo - Lima's water fund. Like other water funds, AquaFondo works with rural communities to support watershed conservation and restoration to secure clean and ample water supplies for both up and downstream water users. It turns out the community of Huamantanga and the city of Lima have one major thing in common: they both face water shortages in the dry season.

Building on the work of a local NGO, Alternativa, AquaFondo, CONDESAN, and Huamantanguinos came up with two innovative solutions. First, they're restoring ancient pre-Incan

infiltration channels that the community believes "seeds" water from the wet season to feed springs in the dry season (Fig. 2). And, second, they're running an experiment to see if removing wild rodeo cows from their highland native grasslands (the *puna*) might help to restore the natural soil "sponge" that slowly releases water during the dry season.

We're excited about water funds. They're an example of an Investment in Watershed Services (IWS) project designed to improve downstream water resources by engaging upstream residents in watershed conservation, restoration, and sustainable management. We're not the only ones excited about IWS projects – they're becoming more and more popular around the world, especially in Latin America. We think that's because they have a ton of potential for win-win solutions that provide water and improve livelihoods. On the other side of South America, Brazilian farmers have signed on to the Extrema and Guandu "water producer" projects not only because they, too, want less sediment in their water but because the programs provide income and offset the cost of riparian restoration.



Figure 1. Goat traffic on the voyage from Lima to the town of Huamantanga



Figure 2. Don Pedro, water manager of Huamantanga, shows me a restored mamanteo – a pre-Incan infiltration channel, which the community believes increases water availability during the dry season.

But we don't really know if IWS projects work. And we definitely don't know if they are going to work as the climate changes. That's in part because there are still a lot of unanswered scientific questions about hydrology and climate change in South American mountains. And it's also because a lot of these IWS projects are only just beginning to measure and monitor their impact.

The trip to Huamantanga was part of a partnership with CONDESAN, the Natural Capital Project, AquaFondo, Huamantanga, The Nature Conservancy, and Forest Trends to help figure out whether these unique investments in natural infrastructure are working for ecosystems and people. The water monitoring focuses on two watersheds, measuring flow in one where rodeo cows will be removed and another where they will continue stomping around for a while longer. CONDESAN started collecting data before conservation activities started to establish a baseline and continue to collect data now that the cows have been rounded up. These datasets will help us determine whether those cows really do affect the amount of water available during the dry season (Fig. 3).

Although different than AquaFondo, the Extrema and Guandu projects in Brazil are starting to ask a similar question: will all this upstream conservation work improve hydrologic services important to people?

Extrema, Guandu, and AguaFondo are among six IWS programs that have installed hydrologic monitoring programs. A few are even working to monitor social outcomes as well.



Figure 3. CONDESAN's Luís Acosta works with community members to install weirs in paired microwatersheds to evaluate the impact of reducing cattle in the high grasslands on water availability in the dry season.

Working with these programs to help them understand the data they're collecting and to learn more about the hydrology and climate of South American mountains in general is where ClimateWise comes in. Our first step is to really dig in and understand what various water benefits stakeholders expect these programs to deliver. Next, we'll use the growing pool of data to assess whether the programs are achieving these objectives. Finally, we'll use models to understand how climate change will alter hydrologic outcomes of water funds and how these programs can use this information to increase their long-term effectiveness and resilience.

By linking with IWS programs in mountains across South America, we can learn a lot about how land use and climate

change will affect water resources and, in the process, help improve the programs themselves (Fig. 4).

ClimateWise: Climate-Smart Watershed Investments in the Montane Tropics of South America is a Belmont Forum-funded project that will run from 2016-2019. Scientists from the University of Minnesota, the University of North Texas, the University of Sao Paulo, the University of Kassel, Germany and the Natural Capital Project will work to evaluate Investments in Watershed Services projects, right now and in the face of climate change. Find out more on our website: <http://environment.umn.edu/discovery/gwi/our-work/climatewise/>

Pictures by Leah Bremer.



Figure 4. Monitoring teams from water funds across Latin America who will partner on the ClimateWise project.



CLIMTREE: Ecological and Socioeconomic Impacts of Climate-Induced Tree Diebacks in Highland Forests

Carlos Lopez Vaamonde
URZF INRA Orléans, France

Project Partners

Christophe Bouget¹, Rodolphe Rougerie², Laurent Larrieu³, Philippe Deuffic⁴, Elisabeth Herniou⁵, Jörg Müller⁶, Marius Mayer⁷, Michael T. Monaghan⁸, Diego Fontaneto⁹, Davide Pettenella¹⁰, Jun He¹¹, and Douglas Yu¹²

¹IRSTEA Nogent-Sur-Vernisson, France; ²MNHM Paris, France; ³Dynafor, INRA Toulouse & CNPF-IDF, France; ⁴IRSTEA Bordeaux, France; ⁵IRBI CNRS-Université François Rabelais de Tours, France; ⁶Bavarian Forest National Park, Germany; ⁷University of Greifswald, Germany; ⁸Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Germany; ⁹Institute of Ecosystem Study, CNR Italy; ¹⁰Padova University, Italy; ¹¹Kunming Institute of Botany, China; ¹²Kunming Institute of Zoology, China

Background

Mountain forests play a major role in the preservation of biodiversity and provide important ecosystem services such as climate regulation. However, some of these forests show extensive tree mortality (“forest diebacks”) caused by a combination of factors, such as severe and recurrent summer drought, pollution, and insect and pathogen outbreaks. Some of the most spectacular cases of forest diebacks are caused by bark beetle outbreaks, which have killed millions of hectares of conifer forests worldwide (Fig. 1).

Forest diebacks are expected to become more widespread, frequent and severe. Indeed, warm and dry climate conditions increase the number of bark beetle generations per year and decrease tree vigor. Diebacks are accompanied by changes in tree species composition, which can happen either by natural regeneration or by artificial replacement with better-adapted species (i.e., those less sensitive to drought). The question of how to manage forest diebacks is a significant concern for forest stakeholders. Which tree species should be replanted? What should be done with the large volumes of deadwood? The ecological impact of harvesting and removing dead, dying trees (salvage logging, sanitation salvage) is the subject of heated debate.

How forest diebacks and associated tree replacements affect changes in biodiversity and ecosystem functions and services remains poorly known. Similarly, how global changes in mountain forests affect local economic activities is poorly understood. The lack of data on the ecological impact of mountain forest diebacks is partly due to insufficient biomonitoring. Traditional biomonitoring schemes are expensive and very labor-intensive, as they require managing large amounts of samples and taxa (Fig. 2).



Figure 1. Entomologists sampling stands of Norway spruce dieback in the Bavarian Forest National Park, Germany. Photo: Heiner M.-Elsner.



Figure 2. A Malaise sample containing thousands of flying insects kept in ethanol.

Fortunately, the recent development of affordable high-throughput sequencing is revolutionizing the field of biomonitoring. High-throughput sequencing allows the user to simultaneously amplify and sequence specimens of all species in mixed samples, a technique known as meta-barcoding.

Main Objectives

- To measure the ecological impact of mountain forest die-offs and the salvage harvest of four ecologically and economically important conifers: Norway spruce (*Picea abies*) in the German Bohemian forest; silver fir (*Abies alba*) in the French Pyrenees; Scots pine (*Pinus sylvestris*) in the Italian Alps, and Yunnan pine (*Pinus yunnanensis*) in China by inventorying terrestrial and freshwater invertebrates and fungi in experimental forest plots.
- To develop a new biomonitoring pipeline that will be simple to use and provide an affordable, reliable, and verifiable way of monitoring forest biodiversity at a large geographical scale.
- To measure the socioeconomic impact of forest mountain die-offs and salvage logging from surveys in Europe and China.
- To identify the ecological and economic factors that influence stakeholder decisions and recommend more specific policy actions based on the findings of the socio-economic study.

ClimTree Consortium

Our team comprises researchers from 13 institutions and four countries (China, Italy, Germany and France) with strong expertise in community ecology, social science, economy, geography, entomology, DNA (meta)barcoding, biostatistics, freshwater ecology and forest management. Three PhD students and seven Master students will be trained during the three-year project.



Figure 3. Laurent Larrieu, Philippe Deuffic and Marius Mayer assessing the level of silver fir dieback in the Pyrenees

Current Work

Experimental plots with various degrees of forest decline have been identified in the French Pyrenees (France), Bavarian Forest National Park (Germany), and Yunnan mountains (China). Environmental characterization of experimental plots using both dendrometric measurements and dieback assessment is underway (Fig. 3). Malaise traps have been set up in the Bavarian Forest National Park and Yunnan mountains (Fig. 4). Samples will be metabarcoded in the forthcoming months. Flying saproxylic beetles are sampled with two cross-vane flight interception traps (PolytrapTM) per plot. Terrestrial micro-invertebrates living in leaf litter (meiofauna) are extracted in the lab from soil samples collected in the field.



Figure 4. Flying insects are sampled using one Malaise trap per plot.

ClimTree held its first meeting 10-11 October 2016 at INRA Toulouse in southern France (Fig. 5). We visited some experimental plots that show various degrees of forest diebacks of silver fir in the Pays de Sault in the eastern Pyrenees (Fig. 6). Silver fir is a drought sensitive tree species with low nutrient demands but high moisture requirements. Since 2003, silver fir shows severe growth decline in the Pyrenees and Southern Alps, particularly below 1000 m of altitude and on south facing slopes, rocky crests, and limestone areas (Figs. 7 & 8).

A field campaign is currently planned for 2017, including qualitative and quantitative socio-economic surveys.

Pictures by the authors unless noted otherwise.



Figure 5. Participants of the 1st ClimTree meeting at Espezel (Pays de Sault, France)



Figure 7. Silver fir showing signs of dieback in Pays de Sault

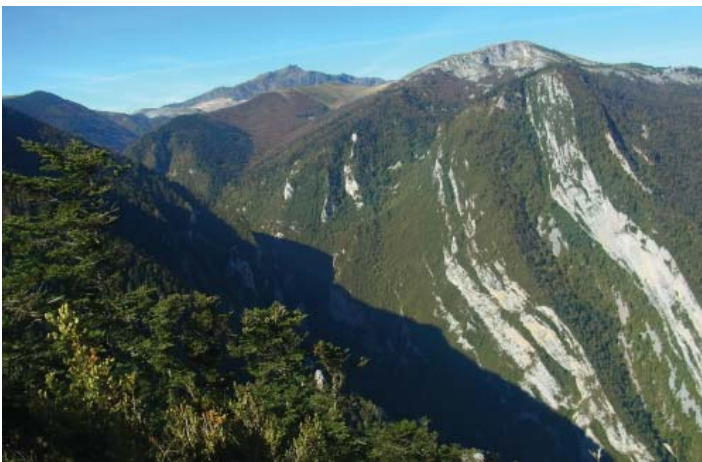


Figure 6. Pic Frau, Eastern Pyrenees



Figure 8. Extensive forests of silver fir in Pays de Sault under threat by climate change

Ecological Calendars and Climate Adaptation in the Pamirs, Central Asia

Kassam Research Group
Cornell University, Ithaca, New York

What are Ecological Calendars?

Calendars enable us to anticipate future conditions and plan activities. Ecological calendars keep track of time by observing seasonal changes in our habitat (Fig. 1). The nascence of a flower, emergence of an insect, arrival of a migratory bird, breakup of ice, or last day of snow cover - each is a useful cue for livelihood activities, such as sowing crops, gathering plants, herding animals, hunting, fishing, or observing cultural festivals.

Many human communities have developed unique and reliable systems to recognize and respond to climatic variability (Fig. 2). Over the course of multiple generations living in particular landscapes, people have accumulated knowledge of the relational timing of celestial, meteorological and ecological phenomena. Historically, these diverse ecological calendars enabled communities to coordinate livelihood activities with seasonal processes. However, due to colonization and industrialization, these calendars fell into disuse. In the third millennium, these calendars are pregnant with promise and require recalibration to new conditions and increasing variability due to anthropogenic climate change.

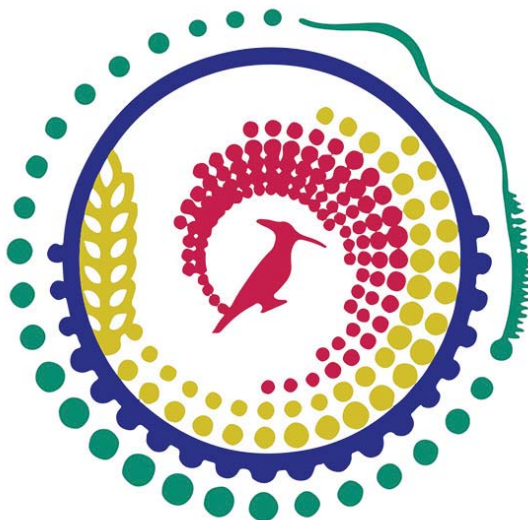


Figure 1. ECCAP Logo, designed by Navajo Artist, Natani Notah, and Karim-Aly Kassam.



Figure 2. Gathering fodder in Guddara. Photo: Karim-Aly Kassam.

Why are Ecological Calendars Relevant?

The greatest challenge of anthropogenic climate change is lack of predictability due to irregular and unprecedented weather patterns. Developing anticipatory capacity – the ability to envision possible futures and develop a dynamic plan to deal with uncertainties – is urgent. In the context of climate change, ecological calendars will contribute to food and livelihood security. An estimated 70 to 80% of the world's population continues to rely on food produced by small-holder farmers and herders (Figs 3, 4). Producing crops and raising animals, as well as hunting, fishing, and gathering, all require the ability to anticipate patterns of temperature and precipitation. Communities and researchers must develop innovative systems to recognize climate trends and adapt to a greater range of possible scenarios.

The Project

The overarching aim of this project is to revitalize, recalibrate, and develop new ecological calendars by integrating place-based and indigenous knowledge with science (Fig. 5). Such a project demands an effective partnership with specific communities that are at the vanguard of anthropogenic climatic variation. In our project, transdisciplinarity is not where climatologists, ethnographers, botanists, ecologists, educationists talk to each



Figure 3. Women sorting grain in Roshorv. Photo: Karim-Aly Kassam.

other, but where they collectively engage in conversation with ecological professionals such as farmers, pastoralists, gatherers, hunters, fishers and draw upon their practical wisdom. We have found in our research, from the Standing Rock Sioux Nation in the USA to the Pamir Mountains of China, that the conception of ecological calendars is alive and well. In many pockets of the world, communities are in tune with the seasonal rhythms of their lands and how it affects their daily livelihoods.

This project aims to establish a proof-of-concept for ecological calendars in collaboration with six diverse indigenous and rural communities in the Pamir Mountains and the continental USA.



Figure 5. Speaking to Wakhi pastoralists in the Tashkurgan Valley. Photo: Siyu Guo.

With support from the Belmont Forum, along with the National Science Foundation (USA), the National Science Foundation (China), Consiglio Nazionale delle Ricerche (Italy), and Deutsche Forschungsgemeinschaft (Germany), our international research team is collaborating with communities in the Shugnan Valley of Badakhshan, Afghanistan; Alai Valley of Osh Province, Kyrgyzstan; Tashkurgan Valley of Xinjiang, China; and Bartang Valley of Gorno-Badakhshan, Tajikistan. In addition, we are undertaking similar partnerships with the Standing Rock Sioux Nation in the Midwest and communities in the Lake Oneida Watershed in New York State, USA.



Figure 4. Roshorv. Photo: Karim-Aly Kassam.

In July 2016, an international team of scholars and students hosted workshops in the Alai Valley in Osh Province, Kyrgyzstan, and in the Tashkurgan Valley in Xinjiang, China, to conceptualize ecological calendars research in the Pamirs. In addition to preliminary research, climate stations were established in the high altitude mountainous communities.

In 2017, the research team will be returning to these communities to continue participatory human ecological mapping (Figs. 6, 7). In addition, we will be establishing the project in the Bartang Valley in Gorno-Badakhshan, Tajikistan and Shugnan Valley in Badakhshan, Afghanistan. We will integrate bioclimatic data with human ecological mapping to generate hybrid maps for these regions. From 2017-19 we will be working with international partners and communities to develop:

- (1) Workable ecological calendars integrating place-based ecological knowledge with scientific data;
- (2) Proof-of-concept for application of ecological calendars internationally;
- (3) Transfer of knowledge between communities in different bioclimatic zones;
- (4) Curricula for inter-generational transfer and continued adaptation of calendars; and
- (5) High-profile international conference on ecological calendars for food and livelihood security.

Who Is Involved?

The project team in the Pamir Mountains includes: Lead PI – Karim-Aly Kassam, Cornell University, USA; Partner PIs – Antonio Trabucco, Euro-Mediterranean Center on Climate Change, Italy; Jianchu Xu, Kunming Institute of Botany, Chinese Academy of Sciences, China; Cyrus Samimi, University of Bayreuth, Germany; Ariff Kachra, University of Central Asia, Kazakhstan, Kyrgyzstan & Tajikistan; and, Graduate Research Assistants – Talia Chorover and Kayla Scheimreif.

The project team in the US includes: PI – Karim-Aly Kassam, Co-PIs – Christopher Dunn, Amanda Rodewald, David Wolfe, Arthur Degaetano, Post-Doc – Morgan Ruelle, Undergraduate Intern – Tamar Law.

Our civil society partners are: AgWeatherNet (Washington State University); American Geophysical Union; Cornell Biological Field Station at Shackleton Point; Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); FOCUS Humanitarian Assistance (Tajikistan); International Centre for Integrated Mountain Development (ICIMOD); International Society of Biometeorology – Phenology Commission; International Union for Conservation of Nature; Man and the Biosphere Programme (UNESCO); Mountain Research Initiative (MRI); US Department of the Interior - Climate Science Centers; US National Phenology Network; Wakhan Pamir Research Project (Ca' Foscari University of Venice); and World Agroforestry Centre (ICRAF).



Figure 6. Focus group meal in the Alai Valley, Photo: Tobias Kraudzun.



Figure 7. Installing a climate station in the Alai Valley. Photo: Tobias Kraudzun.

NILE-NEXUS: Opportunities for a Sustainable Food-Energy-Water Future in the Blue Nile Mountains of Ethiopia

Ben Zaitchik
Johns Hopkins University

Project Partners

Jeremy Foltz¹, Paul Block², Detlef Mueller-Mahn³, Gianni Gilioli⁴, Andrea Sciarretta⁵, and Belay Simane⁶

¹*University of Wisconsin-Madison*; ²*University of Wisconsin-Madison*; ³*University of Bonn, Germany*; ⁴*Universita di Brescia, Italy*; ⁵*University of Molise, Italy*; ⁶*Addis Ababa University, Ethiopia*

I first met Belay Simane at a United Nations negotiation in Germany. We were both on government delegations to the United Nations Framework Convention on Climate Change and during one of the many, many procedural delays we struck up conversation. It turned out neither of us were full-time negotiators. In fact, we were both researchers, and we were both looking at the same place but from very different scales. Belay is an agronomist, and he'd spent years working with farming communities of the Blue Nile Mountains of Ethiopia to advance household and village level climate resilience. I am a climate scientist and hydrologist, and I'd been working with NASA to study transboundary flows across the Nile basin with satellites and regional models. Over several cups of overpriced conference hall coffee, we began a discussion that has occupied both of us over the six years since: how can we understand, quantify, and, ultimately, contribute to optimal solutions for the multi-scale environment and development challenges that face the Nile, from household to basin? The Belmont Forum NILE-NEXUS project is founded on this question.

Like mountainous regions around the world, the highlands of Ethiopia are stunningly beautiful (Fig. 1). They are also climatically and ecologically diverse, and the conditions in the highlands are critically important for human population centers downstream. But the Blue Nile Highlands also differ from many other mountainous regions in that they are densely populated, with villages, agriculture, and pastoral activities extending nearly to the highest mountain peaks. This sets up a complex, multi-scale dynamic for resource management in the area. Smallholder, primarily subsistence-based, farming communities cover the highlands (Fig. 2). Rapid population growth and declining soil fertility conditions have driven deforestation and tightening resource scarcity, which in turn contribute to some of the highest erosion rates in the world (Fig. 3). This causes a



Figure 1. Waterfall in the Blue Nile Mountains. Photo: Jose Molina.

poverty trap for many in the highlands and degrades downstream water value. But at a larger scale, the Blue Nile basin is central to ambitious national and regional development plans. These plans include the biggest hydropower dam in Africa (the Grand Ethiopian Renaissance Dam, currently under construction), work to improve productivity of irrigated agriculture in lowland Sudan and on into Egypt, and continued efforts to form satisfying transboundary water agreements and mutually beneficial electric grid interconnections.

This is a complex problem, and it demands an interdisciplinary and creative research approach. For NILE-NEXUS, we've assembled a team that includes experts in social dynamics of rural development (Detlef Muller-Mahn, University of Bonn), smallholder agricultural economics (Jeremy Foltz, University of Wisconsin), Nile basin hydropower (Paul Block, University of Wisconsin), highland biodiversity (Andrea Sciarretta, University of Molise), and integrated socio-ecological systems modeling



Figure 2. Harvest season in the Blue Nile Mountains. Photo: Ben Zaitchik.



Figure 3. Gully erosion. Photo: Sara Rasmussen.

(Gianni Gilioli, Università di Brescia). Each of us had worked on interdisciplinary projects before, but the range of disciplines, language, and time zones on the NILE-NEXUS team has brought us all of the excitement and all of the maddening challenges that come with integrating diverse perspectives and different (disciplinary) languages.

The NILE-NEXUS team met in person for the first time this past July on the banks of Lake Tana, at the center of the Blue Nile highlands (Fig. 4). We met with local collaborators, made student advising commitments at the local university (Bahir Dar University), and visited candidate study villages. The result of this meeting was a draft for an integrating social-ecological systems model designed to capture multi-scale food energy and water dynamics. Not surprisingly, we came away with more questions than answers. How will we quantify social dynamics for integrated modeling? Which aspects of biodiversity can we

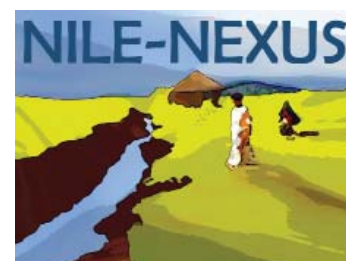
measure and monitor? How will we capture decision making processes and development opportunities across a huge, culturally diverse and rapidly evolving basin?

Moving forward, our team will fan out over the mountains to find answers to these questions. Transects designed to capture the topographic and cultural diversity of the basin are underway for soils, cropping systems, and biodiversity. Focused erosion studies will begin in 2017, as will interviews and surveys in villages affected by dams and irrigation developments. Observations and models are being integrated to generate retrospective climate and streamflow reconstructions, which will in turn be rolled forward as climate projections. Hydropower sensitivity to climate and reservoir operation is being examined with hydroeconomic models, and field data on crop production are being applied to calibrate process-based agricultural models. It's a dizzying number of tasks, and each has its own research questions and complications. Ultimately, we will bring all of these studies together to answer our guiding question: what options exist to address emerging food-energy-water risks and opportunities in a rapidly changing tropical mountain system in coming decades, and what roles do local, regional, and national interests and actors play in the selection of these options?

When we meet again in the Blue Nile Mountains in 2017, we hope to be closer to answering that question.



Figure 4. Lake Tana, at the headwaters of the Blue Nile River. Photo: Ben Zaitchik.



P³: People, Pollution, and Pathogens— Mountain Ecosystems in a Human-Altered World

Dirk Schmeller

Helmholtz-Center for Environmental Research, Leipzig, Germany

Project partners

Gael Le Roux¹, Vance Vredenburg², and Ji Shen³

¹Paul Sbatier University, National Center for Scientific Research, Paris, France; ²San Francisco State University, San Francisco, USA; ³Nanjing Institute of Geography and Limnology, Nanjing, China

Trouble in Paradise

We just had arrived in the French Pyrenees. The beauty of the Pyrenees was stunning, somehow reminiscent of the mighty Canadian Rockies in its wildness and remoteness. We marveled at the sharp peaks, clear waters and wonderfully green vegetation, and pondered the multitude of research threads we could explore in such a setting. As we discussed our priorities, a colleague mentioned *Batrachochytrium dendrobatidis*. This unpronounceable jumble of letters represents one of the most devastating amphibian diseases, and perhaps the single biggest threat to frogs, toads and salamanders. *Bd*, our colleague told us, had taken hold in the beautiful mountain watersheds of the Basque country and was killing off amphibians at a frightening rate (Fig. 1).

Bd, luckily referred to by its abbreviation, is also known as amphibian chytrid fungus. You've probably heard of it: it's

responsible for amphibian declines all over the world and extinctions of up to 120 species. Since 2008, we've spent many, many months rummaging around the Pyrenees in search of amphibians, marveling at their diversity on the one side and the devastation we found on the other (Fig. 2). After having visited 80 plus lakes and their proximal ponds and pools over almost the full range of the Pyrenees, we've started to see patterns in the distribution of *Bd*.

East, West and Central: Patterns in *Bd* Distributions

In the eastern Pyrenees, the Mediterranean influence is quite obvious: granite outcrops, sparse vegetation, trees with needles rather than leaves, bright, clear lakes and rivers. To the west, the Pyrenees are characterized by red limestone, leafy trees and darker, even reddish water bodies. The Pyrenees in the center, especially in the department Ariège, are dominated by oak trees and much denser vegetation due to more frequent precipitation events. Was it a coincidence that we never found *Bd* in Ariège, but only in the rockier limestone regions to the west? Could it be that something in the water hampers the establishment of this devastating amphibian pathogen?

The theories began to fly. Perhaps the vegetation released some sort of natural protection. Or maybe the local climate conditions



Figure 1. Lake Acherito (Ibon Acherito) on the Spanish side of the Pyrenees. The lake harbors several amphibian species, including the endemic *Calotriton asper*. It is located at 1900 m elevation, and is the first site in the Pyrenees for which *Bd* was reported.



Figure 2. The Bassies watershed in the Pyrenees of the Ariège at 1650 m elevation. It is home to newts, toads, frogs and many other freshwater species, and consists of a multitude of water bodies of different sizes. The largest water bodies, however, are artificial reservoirs for hydroelectric power plants.

somehow inhibit *Bd*, or the chemical composition of the surrounding geology. Maybe amphibians in the central Pyrenees have somehow built up a natural resistance, or perhaps *Bd* has some sort of natural predator that only lives in this region (Fig. 3). As a scientist, though, you don't just think of reasons why, you think of ways to test your ideas. And so we started running experiments, many of them.

What Stops *Bd*?

In a first set of experiments, we found that water from uninfected lakes reduced cultured zoospores much faster than water from infected lakes, but that this effect vanished when we filtered the water. This told us that it wasn't the chemicals in the water that prevented *Bd* growth, but something else. We then heated the water, and found that it had a similar effect to filtration. Whatever caused the rapid decline in *Bd* zoospores must therefore be alive. So we set up a range of experiments using tiny zooplankton... and hit the jackpot. We were able to establish that zooplankton were preying on *Bd* zoospores, protecting amphibians from infection (see References). That was a fantastic find, and a definite milestone in understanding how chytridiomycosis might be stopped (Fig. 4).

For better or worse, however, zooplankton itself is sensitive to many environmental impacts. For example, the excrement of livestock can introduce an excess of nutrients to the water, or zooplankton can be eaten by introduced fish (fish don't occur naturally in mountain lakes!). Climate change and direct or indirect pollution from heavy metals, trace elements or organic pollutants coming from pesticide use can also impact on the diversity and density of zooplankton. Hence, a change in the environment in which zooplankton live will very likely

be reflected by the composition, density and dynamics of the zooplankton community. A healthy, undisturbed ecosystem is likely to harbor a greater number of zooplankton species in higher densities than a disturbed, polluted system.



Figure 3. An *Alytes obstetricans* (midwife toad) tadpole metamorphosing (ca. Gosner stage 39) in a highly eutrophic lake in the Pyrenean Mountains. In altitudinal populations, midwife toad tadpoles can overwinter over several years before becoming small toadlets.



Figure 4. *Alona guttata*, an example of *Bd*-eating zooplankton.

New Research Directions

These were the ideas that led up to the newly funded project, People, Pollution, and Pathogens (www.p3mountains.org). The negative impacts of global change on mountain freshwater ecosystems and their biota are expected to greatly outweigh any potential benefits. Although mountains are often thought of as untouched landscapes, far from pollution and other human impacts, the truth is that they are highly vulnerable and face multiple threats from climate change, human impacts and other sources. The goal of People, Pollution, and Pathogens is to understand these threats, and our options for controlling them.

PEOPLE: Humans have exploited the timber, mining and pasture resources of mountain environments for millennia. These activities and others have impacted mountain ecosystems to varying degrees. Today, the rapid flux of people and resources into and out of mountains compounds the challenges facing mountains.

POLLUTION: Human activities, even those carried out far from mountains, pollute pristine mountain areas at high altitudes. Potentially harmful chemicals can be transported to mountains by orographic effects and may enrich in lake sediments and peat bogs. Habitat destruction can therefore lead to profound disturbances in entire mountain ecosystems with strong impacts on human society.

PATHOGENS: Food webs in destabilized mountain ecosystems can be strongly altered, as illustrated by the zooplankton example above. Such changes can result in the introduction of, and increased vulnerability to, pathogens affecting both humans and wildlife, such as diarrheic diseases.

The P³ project will conduct ecological research and policy relevant actions on pollution, pathogens and anthropological impacts in mountain ecosystems, especially at the interface of aquatic and terrestrial habitats and in the socio-ecological system. The research will be conducted in four mountain ranges: the Pyrenees (France), Dhofar Mountains (Oman), Sierra Nevada (USA) and the Great Hinggan Mountain (China). In a first step, P³ will develop a common database and collect data on pollution and pathogens in the socioecological context along gradients, then use this data to model different biotic and abiotic parameters. Based on historical and newly collected data, P³ will develop dynamic indicators and essential biodiversity variables relevant for the mountain context to facilitate the engagement with the general public, stakeholders and policymakers.

The P³ consortium has already started to roam the different mountain ranges and is getting ready for an extensive field season in 2017. We will be talking to local authorities and all the hikers we meet on our way (Fig. 5)— maybe you will be one of them!

All photos by Dirk Schmeller



Figure 5. The Pyrenees have been traditionally used for grazing live stock. Here, we were discussing grazing with a shepherd at the Chapelle d'Isard in the Pyrénées Ariégeoises.

References

Online articles about zooplankton predation on *Bd* zoospores:

<http://www.scientificamerican.com/article/fungus-chomping-micro-predators-could-protect-amphibians-from-decimating-skin-disease/>

http://grist.org/climate-energy/can-a-hungry-microbe-help-us-turn-back-the-clock-on-extinction/?utm_source=syndication&utm_medium=rss&utm_campaign=feed

<http://colorado.icito.com/biodiversity-natural-micropredators-key-to-controlling-frog-killing-chytrid-pathogen/>



VULPES: VULnerability of Populations under Extreme Scenarios

Rachid Cheddadi

CNRS, The Center for Scientific Research, Paris, France

Project Partners

Mark Bush¹, Pierre Taberlet², Kangyou Huang³, Anne-Marie Lézine², Paulo De Oliveira⁴, Louis François⁵

¹Florida Institute of Technology, Melbourne, Florida, USA;

²CNRS, The Center for Scientific Research, Paris, France; ³Sun Yet-sen University, Guangdong Sheng, China; ⁴University of São Paulo, University of São Paulo, São Paulo, Brazil; ⁵University of Liège, Liège, Belgium

The following is a summary of the project aims; an article about the origins of the project and its progress to date was not available at the time of publication.

VULPES will evaluate the impact of past climate change on mountain ecosystems and their genetic diversity from around the world, and forecast potential impacts of future climate change. Employing primarily existing fossil records from Morocco, Cameroon, South Africa, China, Ecuador, Peru, Bolivia and Brazil, VULPES will carry out a multi-disciplinary integration of quantified climate variables from fossil records, ancient and modern DNA (aDNA and mDNA), vegetation modeling, agent-

based modeling and statistics. Our goal is to answer the overall question: "Are microrefugia the key to ecosystem sustainability in montane ecosystems under projected climate change?".

This project will consider variability in mountain ecosystems across the last 21,000 years; a period of extreme natural climate change (e.g. transition from the last glacial period) and the more recent, increasing impact of humans. VULPES will evaluate the migration capacity of species, their potential in situ adaptation/response, ecosystem turnover through time, the tipping points that could lead to population extinctions, the rate of change and, ultimately, define a vulnerability index/threshold. This investigation will determine a global perspective on the effect of different climate types and changes on montane ecosystems encompassing semi-arid, tropical and temperate humid zones. Also included will be socio-ecological analyses regarding landuse, a key to establishing future food security. Combined, our assessments will enable optimised conservation policies for ecosystems, species, and genetic resources. This product will be a valuable tool allowing local stakeholders to establish appropriate management strategies for the mitigation of climate and land use impacts on mountain ecosystems.



GNOMO SITES

Poleka Kasue Mountain Observatory, Los Nevados Natural Park, Colombia

Daniel Ruiz-Carrascal
*Universidad EIA, Colombia, and
International Research Institute for Climate and Society
Columbia University, New York, New York*

In the heart of the Colombian Andes lies the magical Los Nevados Natural Park, one of the few places on Earth that has the unique and fascinating páramo ecosystem. The páramo is home to a great variety of plants and wildlife, many of them endemic to this environment. Hundreds of people live in Los Nevados, thousands of tourists visit the park every year, and a million people drink from its waters in the lowlands. The overwhelming peacefulness and beauty of the park immediately enchants. Unfortunately, we have seen changes in Los Nevados that have made us question how we can preserve something we do not fully understand. We began a research initiative, the Poleka Kasue Mountain Observatory, to preserve the valuable páramo ecosystem and to make the magnificence and richness of our mountains known to all.

The goal of our long-term, multi-tiered research project (now in its ninth year) is to deepen our understanding of the function and importance of páramo environments and assess the best suite of adaptation strategies for their conservation. Our socio-ecological,

mountain monitoring system integrates seven components of analysis:

- (i) long-term changes in key circulation dynamics (e.g. convective processes);
- (ii) diagnostics of water balance and potential changes in hydrological regimes;
- (iii) assessments of biodiversity levels and vulnerabilities;
- (iv) role of anthropic disturbances;
- (v) carbon capture and storage in soils, peatlands and aquatic microhabitats;
- (vi) socio-economic factors (e.g. ecosystem services valuation, community perceptions, land-use practices, and prevalent concerns of stakeholders); and
- (vii) long-term changes in climatic conditions (past climate reconstructions, analysis of instrumental periods, hindcasts, and climate model projections).



Lupinus alopecuroides and *Senecio isabelis* individuals on a steep slope in the Lupinus Valley, north face of Poleka Kasue/Santa Isabel Nevado.



Espeletia hartwegiana individuals in the headwaters of the Claro River watershed.



Cushion bog at about 4,600 masl feeding downstream Laguna Verde.

Research activities are supported on the analysis of primary data collected by weather and gauging stations, georeferenced photographs, biological parameters from vegetation experimental plots, and sets of temperature and relative humidity data loggers installed along ~4,000 m altitudinal gradients.

The Field Work

Our history of quarterly field trips to monitor on-the-ground climatic and environmental variables in Los Nevados spans back almost nine years. We learned to overcome the challenge of coping with extreme weather conditions that characterize the upper altitudinal range of the natural park. We set up campsites within walking distance from local community-owned farm houses that are located on the buffer zone of the protected area, and carry all the weight to base camps. The weight in our backpacks comes from a short list of devices, including optical USB stations, which are required to read out data loggers that were deployed in the protected area. Digital sensors fill in the gaps of historical climatic information in Colombian high-altitude environments and allow us to assess the impacts of the faster tropical upper-tropospheric warming on the overall integrity of páramo environments.

Climate and Water

A faster warming of the tropical upper troposphere worsens the already rapid shrinkage of tropical mountain glaciers and disrupts key local circulation dynamics. Our loggers were deployed at elevational intervals of 300-500 meters, and are currently measuring near-surface air temperature, relative humidity and dew point at hourly intervals. Data are read out during quarterly

field campaigns and processed to characterize ground-based environmental lapse rates and time of occurrence of vertical motions. Historical records, which span back to December 2008, are shared with the main institutions involved in research activities, and are periodically posted to data library sites to provide free access and visual representation.

The upper tropospheric warming also changes the altitudinal distribution of solid and liquid precipitation in the headwaters of local watersheds. Spatially-distributed hydrological modeling is implemented to assess the potential changes in their eco-hydrologic response. On-the-ground activities aimed at measuring changes in snowpack melting, peatland and lagoon water storage, instant streamflow, horizontal precipitation, and water retention in páramo vegetation are being conducted in two key watersheds (the Claro and Otún rivers) to support the study.



Andean condor.

Biodiversity and Anthropogenic Disturbance

Our initiative also includes assessments of biodiversity levels and vulnerabilities. The project integrates different ecological scales (from general ecosystem approach to specific species level) and multiple methodological approaches (from geographical modelling to in-situ observations and long-term monitoring). We are studying potential changes in the extent of life zones and the current distributions of plant growth forms and species. We are also assessing the vulnerability to climate change of several plant species through the implementation of the Nature Serve Vulnerability Index. We have installed experimental plots along the altitudinal gradients to describe species presence and abundance, and to gather baseline data for composition and distribution of plant communities. A detailed photographic record of experimental plots and plant species is also being stored for comparison throughout the years to assess potential changes over time.

We are also studying the role of anthropic disturbances such as high-altitude fires, which are causing almost-irreversible damage to páramo soils, wetlands, fauna, and flora. In the surroundings of Los Nevados, fires are still set to regenerate grass for livestock, prepare land after harvesting potato crops, and expand utilized and cultivated land areas. In the absence of appropriate techniques for controlling fires, they can rapidly spread into non-targeted natural vegetation inhabiting páramo zones. Our group is currently working on understanding the slow recovery time of páramo ecosystems by observing several places that were

affected by small-scale high-altitude fires. We have also collected soil samples from different horizons in several locations along the altitudinal transects to determine the total amount of organic material in soils and its fraction of non-labile carbon. The aim of this activity is to properly determine the amount of carbon stored in páramo soils and quantify potential carbon releases under different scenarios of environmental pressure.

Looking to the Past, Valorizing the Present

As part of a larger investigation of the role of the tropics in the global climate, our group teamed up with researchers from the University of Maine (USA) to study the geologic record of glaciation in the northern Andes in order to assess tropical climate variability over the last ~20,000 to 30,000 years. We are studying unconsolidated glacial debris and other geological formations that may keep a record of the timing and magnitude of past glacial advances. Field work activities involve detailed mapping of glacial landforms and sample collection from several moraines for surface-exposure dating. Weather station data are also processed to determine changes in climatic patterns over the instrumental record. Retrospective and prospective simulation outputs of several global climate models, as well as reanalysis data, are processed to assess historical and projected changes in prevalent climatic conditions. Multi-model ensemble prospective simulation runs are analyzed to assess climate change scenarios at different spatial scales.



Slowly drying high-altitude water body.



Unique flora on the Laguna Verde trail.



Paramo and the Olleta crater, Kumanday/El Ruiz Nevado.



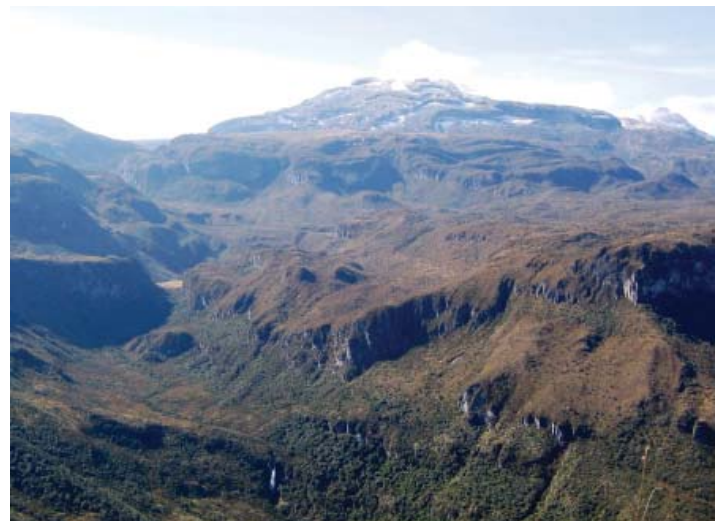
North face of Poleka Kasue/Santa Isabel Nevado



Retreating glacier tongues on Kumanday/El Ruiz Nevado

Finally, our multidisciplinary team is including socio-economic assessments. We have been interacting with multiple stakeholders, local communities, visiting tourists and other potential users of the environmental services of Los Nevados and its surrounding areas to inform them about our scientific findings and to obtain monetary values for the attributes and functions of Colombian páramos. The results of the valuation process allow us to evaluate and rank how the communities value high mountain ecosystem environmental services. They also provide us with key information to be shared with planning and conservation institutions and policy makers in charge of designing and implementing adaptation strategies. In this way, we successfully link our role as researchers to the interests and concerns of the communities, contribute to the social construction and appropriation of knowledge, and inform policy- and decision-making processes.

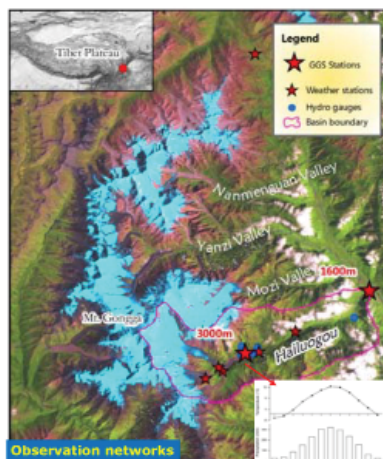
Photos by: Maria Elena Gutierrez and Daniel Ruiz-Carrascal, Universidad EIA, Colombia



Headwaters of the Claro River watershed

Gongga Alpine Ecosystem Observation and Research Station (GAEORS) Chinese Ecological Research Network (CERN)

Institute of Mountain Hazards and Environment, Chinese Academy of Sciences (CAS)



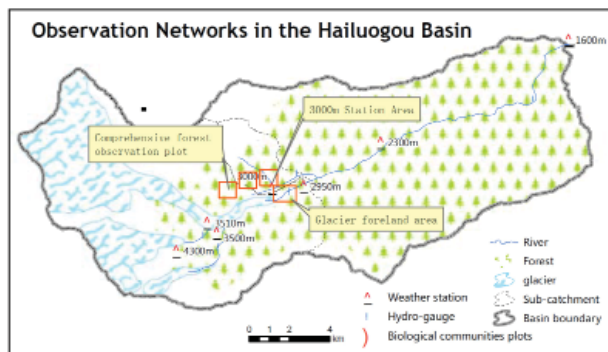
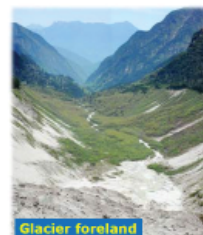
LOCATION AND PHYSICAL SETTING

- GAEORS (29.6°N, 101.9°E) is located on the eastern slope of Mt. Gongga (7556 m a.s.l.) on the southeastern edge of the Tibetan Plateau. Mt. Gongga is the highest peak of the central Hengduan Mountains.
- Set up in 1987, GAEORS became a member of CERN in 1997 and a "State Key Station" of China in 2001.
- GAEORS consists of two stations, one at 1600 m a.s.l., the other at 3000 m a.s.l. Annual average temperature at the lower station is 13°C, and 4°C at the upper station. An annual average precipitation ranges from 1000 mm at the lower station to 1900 mm at the upper station.
- There are remarkable differences in weather, soil and vegetation from low to high elevations along the valley. The transect includes subtropical farmlands, alpine primary forests and maritime-type glaciers along its 16-km horizontal length, making it an ideal natural laboratory for exploring changes in the high mountain environment.



MAIN OBJECTIVES

- Monitor climate change and its impacts on alpine cryospheric, hydrological and biological systems;
- Recognize the mechanism of the construction and productivity formation and evolution of high alpine ecosystems;
- Understand the interactions between cryosphere, biosphere and human activities;
- Provide the scientific basis and key technologies for ensuring ecological security and regional sustainable development.



OBSERVATION ITEMS

Atmosphere

- ◆ Mountain climatology (AWS)
- ◆ ChinaFLUX (Flux towers at five elevations)
- ◆ Atmospheric background (1600 m)

Cryosphere

- ◆ Mountain glacier dynamics
- ◆ Temperate glacier mass balance
- ◆ Mountain snow and permafrost

Hydrosphere

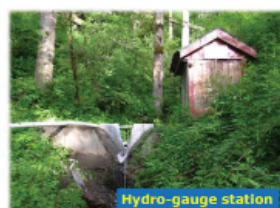
- ◆ Forest hydrological cycle
- ◆ Isotope hydrology
- ◆ Ground water

Pedosphere

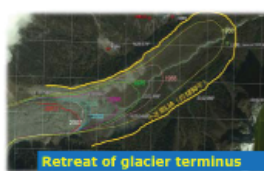
- ◆ Soil moisture and temperature
- ◆ Soil C, N, P
- ◆ Soil erosion

Biosphere

- ◆ Regeneration of forest plant communities
- ◆ Seasonal dynamics of forest litter
- ◆ Forest phenology and biomass
- ◆ Biogeochemical cycles
- ◆ Trait along mountain vertical gradient

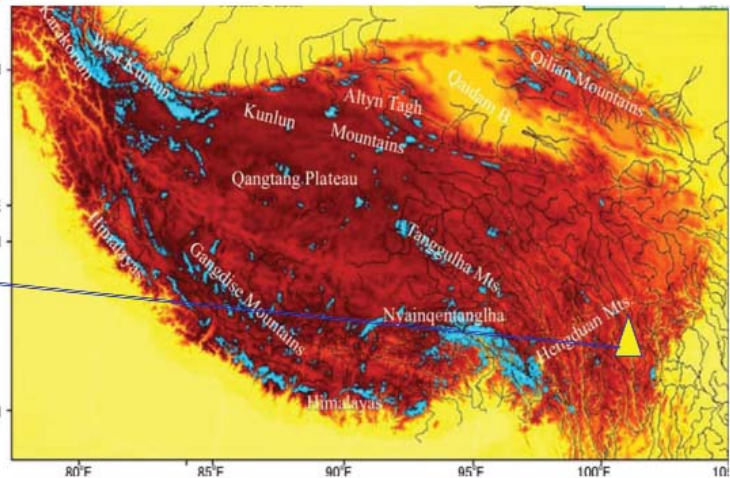
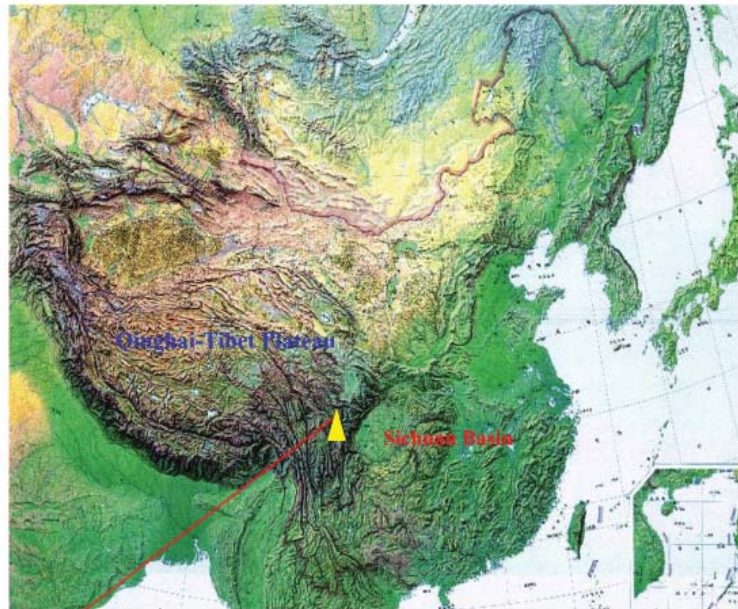


Glacier monitoring



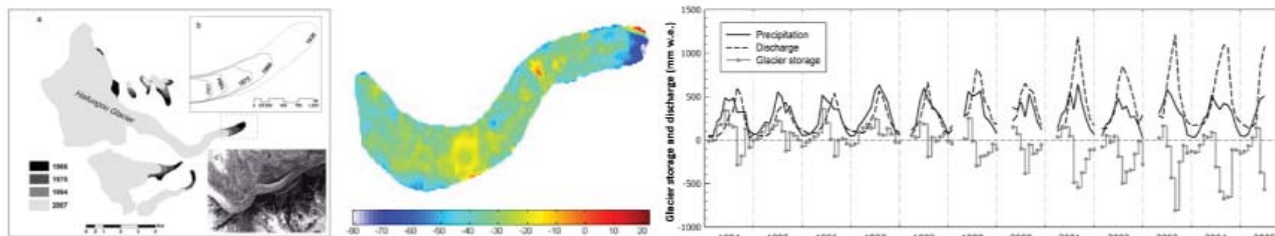
Location of Gongga Mt. Station

- Bound on eastern Qinghai-Tibet Plateau and western Sichuan Basin
- Part of the Hengduan Mountains
- > 7550m at elevation



Case Studies

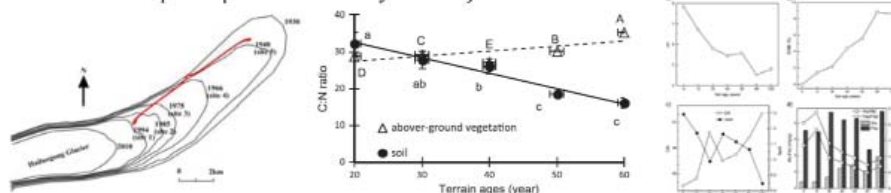
(1) Response of temperate glacier dynamics and hydrological processes to climate change



- ◆ Glacier retreat and area shrinkage: mean terminal retreat rate ~ 20 m/a; surface area decreased by 3.5% between 1966 and 2007
- ◆ Ice thinning: surface elevation decreased 33.9 ± 11.2 m between 1989 and 2008 (mean rate of 1.8 ± 0.6 m/a)
- ◆ Hydrological response: remarkable increase in annual runoff (mostly during July–September) since 1999

(2) Nutrients dynamics and use efficiency in broad-leaf forest during primary succession

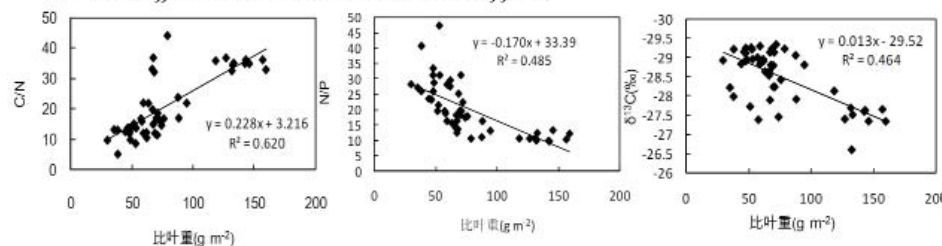
(a) Carbon temporal-spatial traits and dynamics of C:N



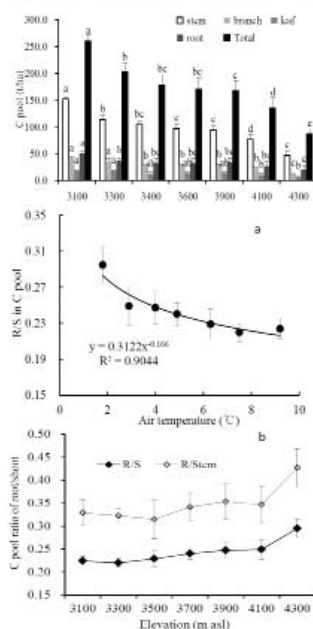
- ◆ The aboveground vegetation became a primary ecosystem C pool in the broad-leaf forest.
- ◆ N element could be the limiting factor for local plants to survive in competition.



(b) Trade-off between WUE and NUE in broad-leaf forest



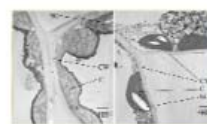
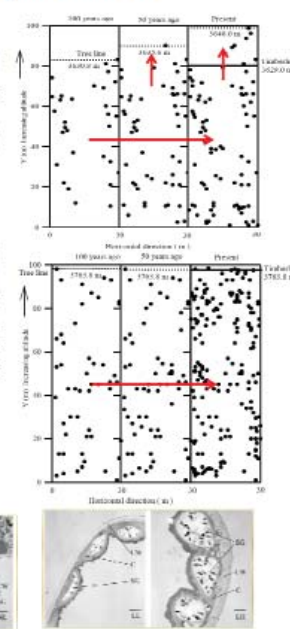
(3) Variations in the live biomass and carbon pools of *Abies georgei* along an elevation gradient on the Tibetan Plateau



- ◆ The aboveground biomass and C stocks of *A. georgei* declined along an elevation gradient following a nonlinear parabolic model, with the total live biomass of the forest nonlinearly declining by 66.2% with the elevation gradient.
- ◆ The biomass C pool ratio in the roots increased significantly with increasing elevation, which suggests a marked shift in biomass and C allocation from above to belowground with increasing elevation, possibly due to the limitation of the N supply and the effect of lower temperatures.
- ◆ Annual air temperature and precipitation were positively correlated with the live biomass and C stocks along the elevation gradient. The live biomass C is allocated more to aboveground components with increasing temperature and precipitation.

(4) Spatial-temporal dynamics of *Abies fabri* populations near the alpine tree line

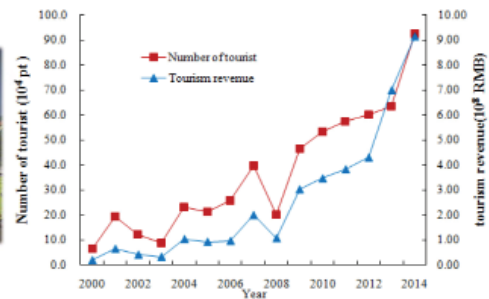
- ◆ We observe a gradual increase in recruitment over the last 100 years, and an abrupt increase in the last 50 years
- ◆ Based on variations in the plant physiological index, it is found that warming favors growth of *Abies fabri* at the tree line, but limits growth at lower elevations.



RECENT FOCUS The Response and Adaptation of Key Ecosystem Functions Along Montane Gradients

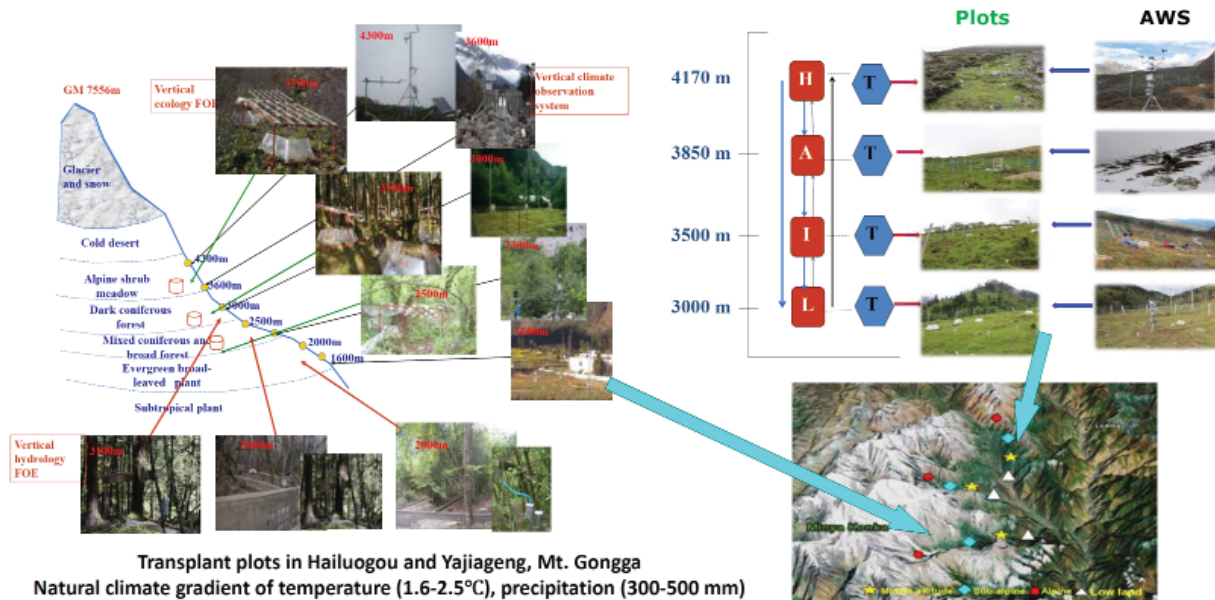
(1) Interactions between regional economic development and the mountain ecosystem

- ◆ There has been a continuous increase in tourists (92% increase) and tourism revenue (320% increase) over the last 15 years
- ◆ Tourism and tourism revenue have increased especially rapidly since 2006.
- ◆ The challenge now is to determine how to protect the glacier and the natural ecosystem – sustainable tourism strategy?



(2) Transplant Project for Mountain ecology to climate change along elevation gradient

A collaborative research project between China and Norway



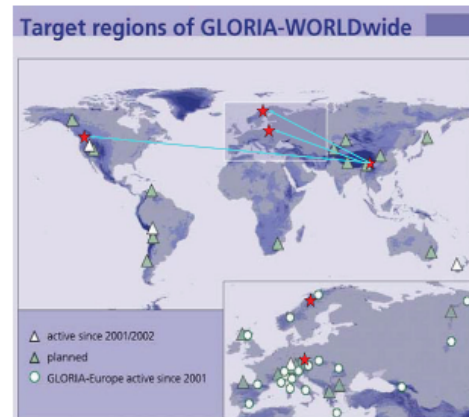
(3) Comparing responses of mountain ecology to climate change at different latitudes

- ◆ To develop GLORIA monitoring systems
- ◆ To compare the response of natural ecosystems to climate change: high latitude vs. high altitude at lower latitude

Director: Prof. Wang Genxu, wanggx@imde.ac.cn

Vice director: Dr. Liu Qiao, liuqiao@imde.ac.cn

Contacts: Dr. Yang Yan, yyang@imde.ac.cn



Mount Elgon Forestry Resources and Institutions Monitoring Program, Uganda

Daniel Waiswa

*Uganda Forestry Resources & Institutions Center (UFRIC)
School of Forestry, Environmental & Geographical Sciences
Makerere University, Kampala, Uganda*

Mount Elgon is a unique cross-border afro-montane ecosystem between Uganda and Kenya that provides a variety of goods and services essential to human livelihoods. It is not only an important biodiversity hotspot but also a major water tower for both Uganda and Kenya, serving as a catchment area for the drainage systems of many lakes and rivers. The Mt. Elgon region supports a high population density (about 1000 people/km²), and the people are heavily dependent on both subsistence farming and the forest ecosystem for their livelihoods. It is thus an important ecosystem that needs to be conserved. However, the ability of forest managers, policy analysts, and scholars to understand the nature of the human-forest nexus and how to sustainably manage forest resources is severely hindered by the lack of clear and systematic time series social and biological data.

The International Forestry Resources and Institutions (IFRI) Research Program began at Indiana University in 1992 with the aim of devising a rigorous way to collect, store and analyze data regarding communities (institutions) and their forests. IFRI differs from other research programs in three distinct ways:

(i) IFRI is a network of Collaborating Research Centers (CRCs) that use the same methods and database to collect environmental and social data. There are about 13 CRCs globally and these are located in Africa, Asia, Latin America and North America. Uganda Forestry Resources and Institutions Center (UFRIC) at Makerere University, which is involved in monitoring Mt. Elgon, is one of the CRCs.

(ii) IFRI methods use the Institutional Analysis and Development (IAD) framework, which allows researchers to transcend the boundaries of typical academic disciplines by focusing on a variety of elements that influence individual choice in complex environments such as the human-forest nexus.

(iii) The IFRI database contains both environmental and social data, thus facilitating rapid and sophisticated analyses concerning how humans interact with their forests.

It is because of IFRI's uniqueness from other research programs that it was deemed appropriate for understanding the human-forest nexus on Mt. Elgon as it utilizes an interdisciplinary



Participatory Rural Appraisal (PRA) session for collecting socio-economic data.



Capturing forest inventory data.

approach in addition to enabling the collection and integrated analysis of both environmental and social data necessary for understanding the human-forest connection.

The IFRI Methodology (Nagendra 2007) is thus being employed by Uganda Forestry Resources and Institutions Center (UFRIC), Makerere University, to monitor forest resources and institutions on Mt. Elgon. Two study sites, Kapkwai in Kapchorwa District and Bufuma in Bududa District in eastern Uganda, were established on Mt. Elgon in 1997 for the monitoring studies.

An additional two sites were established by the Kenya Forestry Research Institute, another CRC in the region, on the Kenyan side of Mt. Elgon. These sites are also employing the IFRI methodology. Each site consists of a tropical high forest and a neighboring settlement that is known to be utilizing the forest. The IFRI methodology consists of a set of 9-10 protocols (questionnaires) that are used to collect biological data about the forest and socio-economic data about the settlements and their people. The Forest Inventory utilizes a minimum of 30 randomly established sample plots in which data about the ground cover are captured. These data include the identification and size of all vegetation present, as well as plot-level assessments of canopy cover, slope orientation, elevation, soil characteristics and evidence of human use/disturbance. On the other hand, the social economic (livelihoods) survey focuses on site description, history of the settlements, demographics, economic activities, forest products and their valuation, rules associated with access to forest resources and forest governance, among other variables. It is worth noting that the IFRI protocols offer the flexibility of collecting additional user-defined data concerning any issue of interest, such as climate change. As such, each site is truly a socio-ecological laboratory for data and knowledge generation.

Data collection is repeated every 2-4 years at each site as a way of creating a monitoring dataset. All of the data collected (biological and socio-economic) are kept in a single database.

Since 1997, these two sites have been revisited at least three times and the data in a Microsoft Access Database are available



Measuring soil moisture and pH in the field.

to the public, especially researchers, free of charge by contacting the Database Manager. In addition to the data, the other outputs of the monitoring research program include:

- (i) Baseline information about forest conditions (including biodiversity and rates of deforestation) and social measures (including rules communities have with regard to forest use);
- (ii) Reports on important changes in forests and their conditions;
- (iii) History of communities and their forests;
- (iv) Analysis and publications of how socio-economic, demographic, political and legal factors affect the sustainability of a forest's ecological system;
- (v) Policy reports and briefs of immediate relevance to forest users, government officials, nongovernment organisations, donors and policy analysts;
- (vi) Trained interdisciplinary teams able to conduct rigorous and policy-relevant research.

It should, however, be noted that further monitoring activities are on hold due to lack of funding. Yet, the research program has the potential to build on the existing data to address emerging issues on mountain ecosystems such as landslides, climate change and its impacts, adaptation and mitigation approaches, and the promotion of the sustainable management of mountainous ecosystems. For example, questions like:

- (i) How can forest resources contribute more to the well-being of local communities in mountainous areas as they grapple with climate change impacts?
- (ii) What roles can the existing datasets play in addressing emerging issues like socio-economic declines in mountainous areas?
- (iii) How can sustainable management be ensured in mountainous areas where deforestation and forest degradation are on the increase?
- (iv) How can mountain ecosystems in developing countries be managed sustainably in the face of inadequate or no funding?

As such, we are seeking partners who are interested in working with us to build on this long-term dataset and to lend their expertise to research efforts that contribute to the well-being of mountain ecosystems and their inhabitants. This includes defining new research themes in areas of forestry, institutions, climate change and livelihoods, among others. If you are interested, please contact me at waiswa@caes.mak.ac.ug or daniel.waiswa@fulbrightmail.org!

Photos by Daniel Waiswa.

Reference

Nagendra, H. 2007. Drivers of reforestation in human-dominated forests. *Proceedings of the National Academy of Sciences* 104:15218-15223.



Village with gardens on the sides of Mt. Elgon National Park.

INARCH SITES

The Canadian Rockies Hydrological Observatory (CRHO)

John Pomeroy, Cherie Westbrook, and Warren Helgason

Centre for Hydrology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

Contact: Angus Duncan, Univ. of Saskatchewan Coldwater Laboratory, Barrier Lake Field Station, Kananaskis, Alberta, angus.duncan@usask.ca

The Canadian Rockies Hydrological Observatory (CRHO) aims to improve the understanding of, and capacity to predict, the changes in water yield from headwater basins where cold climate processes predominate. It examines the water supply response to climate variability in a range of mountain headwater eco-hydrological site types, incorporating the transient responses of both climate forcing and cryospheric and basin hydrological response. Particular attention is paid to how snowpacks, forests, glaciers, groundwater, wetlands, and frozen soils interact and modulate the response of water supply to variability in climate. The project supports improved water resource modelling and management over larger river basins such as the Saskatchewan and Columbia River basins by contributing advanced mountain headwater hydrological modelling capability and future flows under downscaled climate scenarios. It does so by strengthening the hydrological and glaciological science foundation for estimating water resource impacts from future climate scenarios, and by testing and improving hydrological models that can be used for current and future water resource assessments.

The CRHO includes 35 high elevation snow and weather observation stations and streamflow stations in the headwaters of the Saskatchewan River Basin in Alberta (Fig. 1), and are focused at Marmot Creek Research Basin, Fortress Mountain Snow Laboratory, Burstall Creek Basin, in Kananaskis Country; Peyto Glacier and Helen Creek Basin in Banff National Park and Athabasca Glacier in Jasper National Park. These sites include a large variety of terrain, including valley bottom meadows, forests (aspen, lodgepole pine, white spruce, sub-alpine fir and larch), treeline, alpine, glacier and glacier forefields. 20 stations are concentrated in clusters at Fortress Mountain (2099 – 2565 m) and Marmot Creek (1436 - 2470 m) which are small, mountain catchments covering a large elevation range and vegetation types.

A Typical CRHO Weather Station Includes:

Meteorological sensors:

- Air temperature and relative humidity (Rotronic HC2-S3)
- Wind speed and direction (RM Young 05103)
- Radiation (Kipp & Zonen CNR4)
- Snow depth (Campbell Scientific SR50A)
- Barometric pressure (Vaisala PTB110)
- Soil heat flux (Huskeflux HFP01)
- Soil moisture and temperature (Campbell CS650)
- Weighing Precipitation Gauge (Geonor TB200)

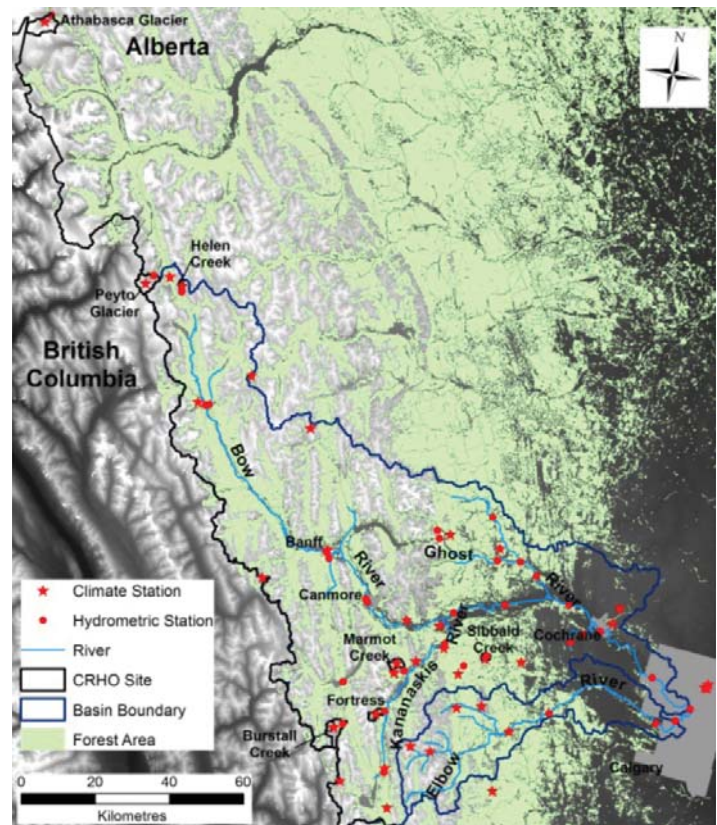


Figure 1. Location of CRHO stations in the headwaters of the Saskatchewan River Basin.

Additional sensors at select sites include (Figs. 2, 3):

Hanging tree (Coniferous tree lysimeter hanging from a load cell on tower in a mature spruce forest to measure snow interception by forest canopy – Upper Forest at Marmot Creek)

Snow Pack Analyzer (Measures snow water equivalent (SWE), snow density, liquid water content, ice content and snow depth – Fortress Mountain, Helen Lake, Marmot Creek).

Pluvio (All-weather precipitation gauge that uses weight-based technology to measure the amount and intensity of rain, snow and hail – Fortress Mountain, Helen Lake).

Snow Scale (Measures snow pack SWE using load cell technology. Unlike snow pillows, no antifreeze is necessary, and the large measuring surface minimizes snow-bridging effects – Fortress Mountain).

Parsivel (Laser disdrometer measures precipitation type and intensity, drop size distribution and radar reflectivity – Fortress Mountain).

All stations record data at 15 minute intervals on Campbell Scientific CR3000 dataloggers, housed in weatherproof logger boxes. Power is supplied by 90 Watt Solar panels with 120 Ah gel-cell sealed batteries housed in an insulated box on the ground. Instruments are mounted on 3 m to 10 m triangular towers, based on maximum snow depth. Data is transmitted through a combination of cellular modems, spread-spectrum radios and Geostationary Operational Environmental Satellite (GOES) transmitters.

Snow surveys (using a combination of ESC30 and Mt Rose snow tubes, and snow pits) are conducted at most sites every month



Figure 2. Powerline site at Fortress Mountain, including met tower, Pluvio, SPA, snow scale (buried) and Parsivel (not visible).

in the winter (bi-weekly in the spring) to measure snow depth, density and SWE. Hydrometric surveys using a combination of Solinst Levelloggers for stage and Sontek Flowtrackers for velocity using acoustic sounding are conducted bi-weekly during snow-free months to measure discharge from the mountain catchments.

LIDAR (Marmot Creek and Fortress Mountain) and UAV - Unmanned Aerial Vehicle (Fortress Mountain) flights have been flown, the latter using aerial photography to produce orthomosaics and Digital Surface Models. These products allowing for excellent classification of land type and vegetation, making the areas well suited for assessing the effects of forest cover and terrain type on SWE, snow melt and albedo. Airborne LiDAR and UAV have been used to measure snow depth in alpine areas of Marmot Creek Research Basin and Fortress Mountain Snow Laboratory.

Photos by John Pomeroy



Figure 3. CHRO Fortress Ridge weather station at Fortress Mountain.

Wolf Creek Research Basin

Principal Investigator:

Dr. John Pomeroy
Canada Research Chair in Water Resources
and Climate Change
Centre for Hydrology, University of Saskatchewan
john.pomeroy@usask.ca
403-679-1425 (mobile), 306-966-1426 (Saskatoon, SK)

Contact:

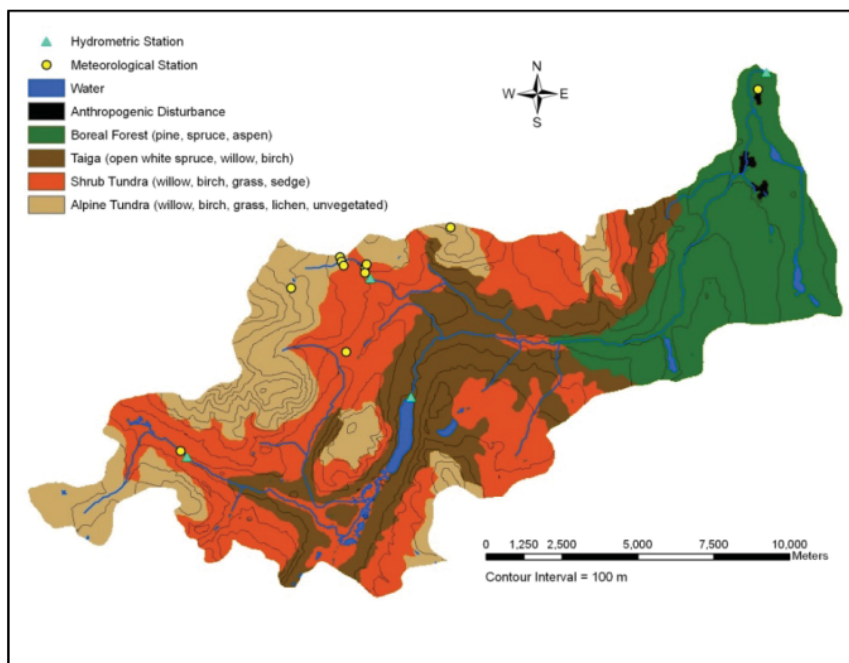
J. Richard Janowicz,
Manager, Hydrology
Water Resources Branch,
Yukon Environment
richard.janowicz@gov.yk.ca
867-667-3223 (Whitehorse, Yukon)

Introduction

Wolf Creek Research Basin (WCRB) was established in 1992 to carry out water and climate research. The mountainous basin (800 to 2250 m) drains an area of 179 km², and is immediately south of Whitehorse, Yukon Territory. The basin consists of three distinct ecological zones; boreal forest (22%), shrub tundra & taiga (58%), and alpine tundra (20%). WCRB includes hydrometric stations at several tributary streams and the outlet of Wolf Creek, meteorological stations distributed across the basin, and continuous snowpack and snowfall records. In 2012, the Shrub Tundra - Taiga station in Wolf Creek became a Canadian site for the WMO Solid Precipitation Intercomparison Experiment (C-SPICE). The diversity of the basin, combined with the available long term comprehensive hydrometeorological data, is responsible for the popularity of Wolf Creek Research Basin as a site to carry out cold regions research by scientists from across Canada and abroad. Road access in summer, local accommodation, a major airport and upper air station in Whitehorse, simple winter logistics, data availability and ecological diversity make WCRB an ideal location for remote sensing validation and snow modeling activities. A tent-based field camp is often used in the Granger Creek sub-basin in spring when melting snow complicates road access. WCRB is operated by Yukon Environment, University of Saskatchewan and McMaster University, and is a key site for GEWEX's Changing Cold Regions Network and International Network for Alpine Research Catchment Hydrology.

Weather Stations and Snow Surveys

With several smaller meteorological stations located around the basin (see map), primary meteorological measurements are taken at three main stations, located in each ecological zone: Alpine Tundra, Shrub Tundra – Taiga, and White Spruce Forest. Meteorological measurements at each main station include air temperature, relative humidity, wind speed, wind direction, incoming and outgoing short-wave and long-wave radiation, soil heat flux, soil temperature, soil moisture content, precipitation (rainfall and snowfall), and snow depth. All stations record data at 30 minute intervals with continuous records for several parameters at the main stations beginning September 1993. All stations use Campbell Scientific dataloggers and data will be transmitted using cellular modems and spread-spectrum radios beginning in 2016. Snow depth and density surveys are conducted monthly at the main stations along +100 m transects when sites are snow covered.





White Spruce Forest

White Spruce Forest Station

60°35.76 N 134°57.17 W, 750 m elevation.

Dense canopy of mature white spruce forest (12-18 m) near the Wolf Creek basin outlet. Well suited for assessing the effects of forest cover on SWE. Archived weighed tree lysimeter and subcanopy radiation and turbulence transfer measurements are available for this site. Sensors are mounted on a 21 m triangular tower at various heights below, in and above the forest canopy. AC Power is supplied by the Whitehorse Cadet Summer Training Centre. Additional snow sensors: Geonor T200B, Nipher Snowfall gauge.



Geonor at White Spruce Forest

Shrub Tundra – Taiga Station

60°31.34 N 135°11.84 W, 1250 m elevation.

East-facing, moderate hillslope consisting of undulating terrain. Vegetation is tall shrubs (1-3 m) with sparsely scattered spruce (spaced about 100 m apart). The presence of strong winds but restriction on snow redistribution by shrubs makes this an ideal site for snowfall wind undercatch studies. Sensors are mounted on a 5.2 m triangular tower, powered by 12V AGM batteries and charged by solar panels. Additional snow sensors: Pluvio (2), Geonor T200B, BC Standpipe Precipitation Gauge, Nipher Snowfall gauge, Snow Scale Load Cell Weighing SWE gauge, Snow Pack Analyzer Dielectric SWE gauge, Campbell CS725 Gamma SWE gauge, Snow Pillow Weighing SWE gauge.



Shrub Tundra – Taiga



Alpine Tundra

Alpine Tundra Station

60°34.04 N 135°08.98 W, 1615 m elevation.

Windswept, high alpine tundra plateau along the drainage divide at the northern edge of the basin. Vegetation is sparse consisting of moss and lichens with scattered boulders up to 1 m tall. Sensors are mounted on a 3 m tower, powered by 12V AGM batteries and charged by solar panels. Additional snow sensors: Geonor T200B, Nipher Snowfall gauge.

GNOMO WORKING GROUPS

GNOMO Looks Toward the Future of Mountain Social Ecological Systems (SES) Research

Derek Kauneckis

*Voinovich School of Leadership and Public Affairs
Ohio University, Athens, Ohio*

The Voinovich School of Leadership and Public Affairs at Ohio University, in partnership with the Mountain Research Initiative (MRI), will soon begin a scoping study of the social science data needs and research themes for a global system of mountain observatories. The goal is to provide guidance for efforts to establish an intellectual platform for sharing data and cross-site analysis of mountain socio-ecological systems (SES) globally into the next several decades. This forward-looking scoping process will identify emerging research questions and data needs, and highlight existing integrative research. The sample will include members of partner research sites associated with MRI and the Global Network of Mountain Observatories (GNOMO) in order to take advantage of the wide geographic and disciplinary diversity represented in the group. A short survey instrument

will be co-designed by a team of GNOMO members working on integrating social data into ecological systems and include a range of questions on current methods, data availability and gaps, common research questions, and reflections on the structure of a global system of mountain socio-ecological system observatories. The final product of the study will be a co-authored research paper written for the community of mountain researchers engaged, as well as practitioners, managers and policy-makers. The paper will provide an assessment of current efforts, research and data needs, and strategic directions to drive a global system of mountain SES observatories. GNOMO members should look forward to an email invitation to partner on the project. For additional information, contact Derek Kauneckis at kaunecki@ohio.edu.



Working Towards a Global Network with Universal Data Access: A Data Publication Project with the Global Network of Mountain Observatories

Jon Pollak and Liza Brazil

Consortium of Universities for the Advancement of Hydrologic Science, Inc., Medford, Massachusetts

Data dissemination is a challenging task for many researchers who operate monitoring stations. Data format, technology requirements, and having a way for researchers to discover the data must be considered and resources to develop and execute a plan are often limited. Many members of the Global Network of Mountain Observatories (GNOMO), which formed in the summer of 2015, face these challenges even when knowing with whom they want to share their data. Community data tools are being developed, sustainability maintained, and utilized to lower the barrier for researchers to publish their data so that the scientific endeavor can reap the benefits of efficient collaboration around data and broader data reuse.

CUAHSI (the Consortium of Universities for the Advancement of Hydrologic Science Inc.) is one organization, funded by the US National Science Foundation, trying to solve the problem of data dissemination so that researchers and educators can spend more time researching or teaching and less time on tasks like discovering, reviewing, downloading, and reformatting data. CUAHSI is championing a pilot data publication project with GNOMO that is taking advantage of existing tools for uploading, publishing, discovering, and analyzing time series



Figure 1. The majority of GNOMO survey respondents indicated that they had time series data that they would be willing to share openly.

data. This project has consisted of three major components. First, representatives from the observatories responded to a brief survey to describe their data holdings and availability. Second, CUAHSI staff have worked with various observatories to format and upload data to CUAHSI's system, the Hydrologic Information System. Finally, CUAHSI staff have developed tutorials so that GNOMO members can learn the basics of using CUAHSI data tools.

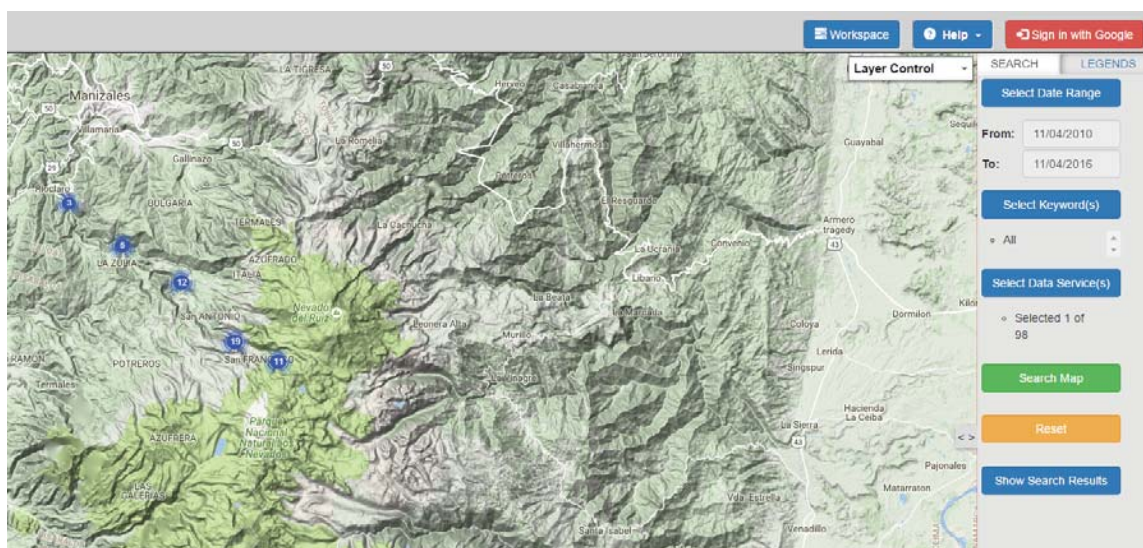


Figure 2. Locations of observations in Los Nevados, Colombia as seen in CUAHSI's HydroClient (<http://data.cuahsi.org>).

The first aspect of this data sharing project was to assess the data holdings of the interested observatories, which was completed in November 2015, with sixteen observatories affiliated with GNOMO responding. The first, and most basic, question posed to the observatories was whether or not they had data that they were willing to share freely and openly. Of the sixteen, eleven indicated that they would indeed be willing to share their data freely and openly, which is currently a requirement to publish data with CUAHSI.

Out of the eleven observatories that indicated the willingness to share their data, four are now available using CUAHSI tools:

- Rocky Mountain Biological Laboratory
- Sagehen Creek Field Station
- Poleka Kasue - Los Nevados
- NevCAN: Nevada Climate-Ecohydrological Assessment Network

Data sets from these observatories are easily accessible using CUAHSI data tools, such as HydroClient (<http://data.cuahsi.org>),

which is a web application for discovering and downloading data. Data from these sites can also be retrieved and analyzed using the WaterML R Package (<https://cran.r-project.org/web/packages/WaterML/index.html>), which has been developed specifically for use with data from CUAHSI's catalog in the R programming environment.

This pilot project has enabled an exploration into what is possible if existing data resources from mountain observatories become integrated with other data providers such as US government agencies like NASA and the USGS, in addition to providing GNOMO community members who are not already sharing their time series data a means to do so. Future efforts will focus on expanding the number of observatories who are publishing data and work towards building a community that is willing, and has the resources, to disseminate data efficiently with modern internet technologies to enable global mountain science. If you are interested in learning more, please visit the GNOMO website (<http://gnomo.ucnrs.org>) or contact CUAHSI by sending a note to help@cuahsi.org.



Figure 3. A visualization of relative humidity from Los Nevados, Colombia and NASA soil moisture data as seen in the Data Series Viewer in HydroClient.

GNOMO_Soil: Globally Assessing the Impacts of Disturbances on Montane Soil Diversity and Function

Thomas Spiegelberger¹, Aimee T. Classen², and Zachary T. Aanderud³

¹*University of Grenoble Alpes, Irstea, Mountain Ecosystems, Saint-Martin d'Hères, France*

²*Museum of Natural History, Copenhagen, Denmark*

³*Plant and Wildlife Sciences, Brigham Young University, Provo, Utah, USA*

Understanding how changes in biodiversity are related to changes in function is a critical challenge, especially in a time of profound global change. In addition to the normal cycle of environmental changes, mountain ecosystems are also challenged by climate change and intensive human management all along their steep vertical gradients. In mountains, climate change is already resulting in reduced snowpack and fewer freeze-thaw events, with consequences for water availability, erosion processes, disease and pest resistance, and biodiversity, among others. These changes are compounded by gradients of land use intensity, which further contribute to the transformation of ecosystem patterns and processes. In particular, human activities have altered the rate, pathways, and efficiency of the

movement of nutrients within and between the various biotic or abiotic ecosystem compartments. For example, herd animals mobilize essential nutrients, stimulating primary productivity and enhancing decomposition as grazers remove vegetation and deposit feces on soil surfaces (Fig. 1).

These changes not only affect how ecosystems function today, but may also result in long-term legacy effects on ecosystem processes in the future, as soil retains a long memory of changes. Thus, the health of soil today has long-lasting implications for the resilience of tomorrow's ecosystems and their capacity to adapt and sustain ecosystem services. Changes in the climate, such as increasing temperature and decreasing soil moisture, are likely to enhance the degree to which land-use alters ecosystem form and function. While our understanding of montane ecosystems is critical to maintaining global patterns of biodiversity and ecosystem functioning, our ability to quantify the biodiversity in these regions and predict how changes in biodiversity alter important ecosystem functions remains limited.

The goal of GNOMO_soil is to assess the impact of land-use and climate change on the links between microorganisms and ecosystem function using soil samples collected from mountain ranges around the world. The steep altitudinal gradients of mountains can be used as space-for-time substitutions, allowing us to draw conclusions regarding ecosystems processes under future climate. We can also test ecological theories in the wide range of globally distributed mountain systems in the GNOMO network. Moreover, depending of the number of participating sites and their access to weather data, we can draw insights on the impacts of climate change on soil microbial diversity and soil functioning. We will analyse bacteria, fungi, and soil fauna (e.g., nematodes, tardigrades, and mites) using 16S and 18S rDNA target-metagenomics and mid/near infrared spectrometry. Combining these approaches should enable us to assess multiple ecosystem processes and functions simultaneously. The molecular analysis will identify baseline changes in soil biota, specific bacterial clades influencing certain ecosystem functions such as



Figure 1. Soil sample from one of our transects at around 1500 m elevation.

methanogenesis and nitrification, and offer a functional profile of the bacterial genes influencing processes through Phylogenetic Investigation of Communities by Reconstruction of Unobserved States (PICRUSt).

Using this approach and partnerships within the GNOMO network, we will be able to test hypotheses related to soil biodiversity and land use change at a global scale. In particular, we hypothesize that shifts in soil biodiversity are linked to key soil functions (i.e., C mineralization, N mineralization, and nitrification), and that land use (as a disturbance) disrupts these links. We expect that the effects on climate change (e.g., decreasing snow pack, increasing temperatures) will only serve to further disrupt links between form and function (Fig. 2).

After a first call for contributions, which was launched in January 2016 within the GNOMO network but rapidly spread to the LTER-community and beyond, 53 sites in 24 countries distributed across Asia, North and South America, Australia

and Europe expressed interest in participating in our project.

We ask participants to sample soils at three points along a high elevational gradient, namely at the upper, lower and mid points of the gradient. At each site, 5 soil cores are collected from a plot in pristine or near-natural environment, and 5 soil cores are taken from an area altered by direct human interference. A first batch of samples along eight gradients was taken this summer (2016) in the Northern Hemisphere. Further samples will be collected at sites in the Southern Hemisphere in the coming months. We will soon begin analyzing the first samples using mid/near infrared spectrometry.

We expect that about 20 gradients will be sampled in this first year, which would add up to 120 plots and 600 soil cores in total. That makes for a unique common sampling effort, and a lot of data to analyse!

Photos by Thomas Spiegelberger



Figure 2. Schema of the distribution of the plots along a gradient.

From Email Silence to Starting Line: Progress in GEO-GNOME

Greg Greenwood

Mountain Research Initiative, Bern, Switzerland

There are good reasons to go to big meetings, and maybe even better reasons to go to ones you haven't attended before! In the space of 24 hours, and by talking to variety of people at the GEO XIII Plenary meeting on 8-10 November 2016 in St-Petersburg, Russia, I've made more progress in advancing our GEO-GNOME project than I've made in months. In short, I seem to have found a way forward for our mountain data portal issue (Fig 1).

The GEO project Global Network for Observations and Information on Mountain Environments (GEO-GNOME) is the central effort by MRI and our colleagues from CNR (National Research Council) in Italy to organize the mountain data realm. By working within the GEO framework, we have the best chance of attracting resources and expertise to the goal of making mountain data available and pertinent.

A few weeks ago, with the outstanding help of Jürg Krauer of CDE (Centre for Development and Environment, University of Bern), Davnah Payne of GMBA (and Roger Sayre of USGS Global Ecosystem Mapping, we were able to achieve Task 1 of GEO-GNOME – *Delineate accurately mountain regions using best available data*. Jürg applied two different definitions of mountains (the so-called Kapos and Körner definitions) to a best available 250m DEM to produce two coverages that he subsequently combined with a landform coverage based on the same DEM used at USGS. He then overlaid all three coverages so that we could compare and contrast these coverages. Davnah



Figure 1. The ice jam is finally breaking up, at least where GEO-GNOME and data portals are concerned! Open source image: the Neva River in St. Petersburg.

ensured that these coverages are available on the ILEAS server at Bern (Fig. 2).

This first task is not quite finished because the results are not yet easily discovered by other users (had I not told you, would you have known?) nor easily explored. At the moment, you can only view the data if you are an experienced GIS user who can download the coverages and open them in a GIS. We hope to develop a user interface in early 2017 with the help of the USGS; stay posted!

Task 2 of GEO-GNOME - *Compiling data that quantify ecosystem services, socio-economic measures, and drivers arising from or impinging upon mountains* – is the central task

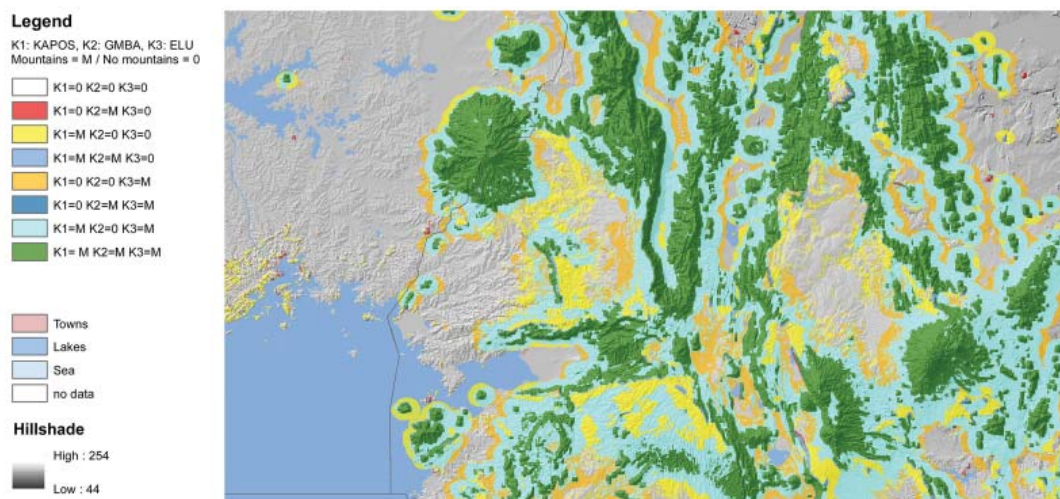


Figure 2. Comparison of the three coverages for Uganda/Kenya, where the differences are especially visible. Green indicates complete agreement between the three definitions. The USGS (ELU) coverage is most generous (orange); the GMBA definition the most stringent.

of GEO-GNOME. Task 2 focuses on discovering (and making discoverable) mountain-relevant data, making them usable and purveying them to users. Task 2 would, for example, render the mountain coverages described above discoverable, viewable, and downloadable by other users. But coverages are just the tip of the potential mountain data iceberg!

To incorporate the multitude of mountain-relevant data, we need a mountain data portal, a web-based application optimized for the mountain social-ecological research community. About two weeks ago, I sent around an email to people associated with this kind of technology within GEO-GNOME to launch a discussion about specifications. No one replied, which was rather discouraging. That's where I was when I left for the GEO XIII plenary in St-Petersburg: at a standstill.

Upon arriving in St-Petersburg, I immediately joined a dinner meeting organized by the GEO Secretariat staff (Gary Geller and Vanessa Aellen). The objective of the meeting was to explore common interests between GEO-GNOME and a number of other projects: GEO Cold Region Initiative (GEOCRI), GEO Biodiversity Observing Network (GEOBON), ILTER, WMO Global Cryosphere Watch, WMO Integrated Global Observing System and Sustained Arctic Observing Network. It quickly became obvious to me and Hannele Savela and Yuboa Qiu of GEO CRI (Group on Earth Observations Cold Regions Initiative) that we had a common interest in community portals.

The next day, we sat down at lunch with Basanta Shrestha of ICIMOD (International Centre for Integrated Mountain Development in Nepal) (as ICIMOD has a data portal, too) and hammered out a quick description of a potential workshop. The workshop would bring together solutions known to us (e.g. the HydroServer of CUASHI that holds time series data from GNOMO sites, the ICIMOD web GIS server, etc.) so that we could all see the different functionalities. It seems likely to me that participants would eventually agree on a set of generic functionalities common to all efforts, with a few bells and

whistles for each community. We might then be able to pool our resources as a group to engage a software engineer to build something that would work for all of us.

Literally three hours later, I found that consultant: the European Space Agency! In fact, just before the afternoon coffee break, ESA's consultant presented a demo of the new GEOSS portal (<http://www.geoportal.org/>), which seems to do quite a lot of what I would want in a mountain data portal (Fig. 3). Right after the demo, I went to the ESA booth and asked the consultant if he thought that the portal could be adapted for use by specific communities (e.g. the mountain community, the Arctic community, the cryosphere community), and if so, would ESA be willing to run a training program to instruct the different communities in the use and adaptation of the portal. The answer was a tentative yes to each question, provided that the training programs were approved as GEO activities. Barb Ryan, the Executive Director of GEO, replied that she thought this was a great initiative. And so, in a very short time, I went from email silence to a potential project early next year!

To be clear, this workshop would only accomplish part of Task 2's objectives: it would provide us with a way to find, purvey, and use data, but it would not provide the data themselves. Still, if you are going to make wine, you better have the vat ready before you start pouring the juice! If we can develop a web-based application that performs these tasks, then the conversation with data holders would shift from "Would you be willing to provide you data, someday, somehow" to "Can you please put your data here now?" This would be real progress!

If you want to try the GEOSS data portal and provide feedback, go here <https://docs.google.com/forms/d/e/1FAIpQLSc1-ESlw5gOQcrS72OeEPMba39YN6PhWRABnJsocdcodb-Sew/formResponse>

You will find short instructional videos that lead to some exercises and quiz questions.

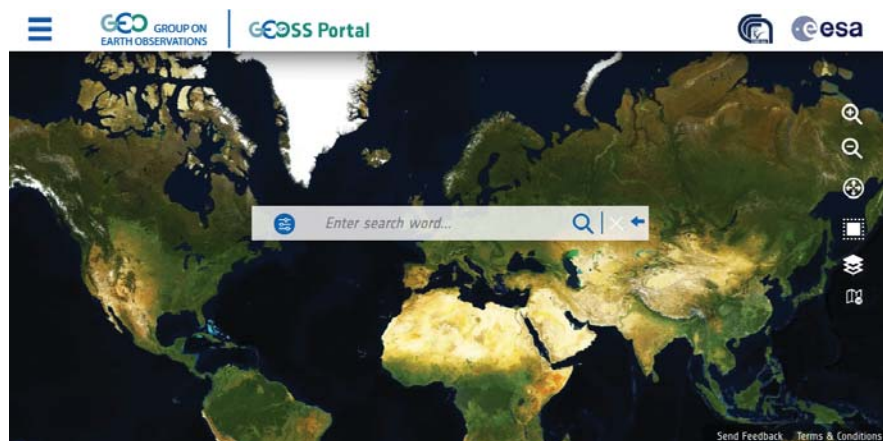


Figure 3. GEOSS Portal.

GNOMO Working Group – Station Siting and Data Standards

Eric Kelsey

Mount Washington Observatory and Plymouth State University, Plymouth, New Hampshire

Mission

Measuring climate and hydrologic variables in montane environments is challenging on many fronts: logistics of maintaining instrumentation at typically remote sites, best instrumentation choice for the range of environmental and atmospheric conditions, best location in highly variable topographic conditions (e.g., vegetation, aspect, slope, exposure to sun and wind), properly cataloging metadata, and that measurements can be compared with observations from other montane regions globally. This sample of logistical challenges must be resolved to ensure that measures of global montane climate changes are fundamentally sound. Currently, standards for instrument siting for measuring climate and hydrologic variables do not exist, which is a problem that the World Meteorological Organization (WMO) recognizes and has struggled with for several years. While WMO and National Oceanic and Atmospheric Administration (US) standards exist for relatively flat (and hence generally low elevation) locations, climate and hydrological measurement standards are a necessity for proper global monitoring of montane climate, which is a critical and urgently need to understand modern montane climate change.



Mount Washington Observatory technicians work on the 1370 m weather station located along the Cog Railway that ascends Mount Washington on its west side.

Progress and Future Work

This GNOMO Working Group will soon begin meeting with the Commission for Instruments and Methods of Observations (division of WMO) to develop a plan to address this pressing issue. GNOMO members who work in montane environments and regularly face these siting and measurement challenges will contribute needed expertise to develop standards within the established procedural framework of WMO-CIMO. GNOMO members are also developing a Mountain Research Methods guidebook, which will include discussion on current and best methods for climate and hydrological monitoring.



De-Icing: Observer Tom Padham deices the instruments atop the parapet at the summit of Mount Washington, New Hampshire.



Deck Slinging: Observer Rebecca Scholand performs the hourly ritual of using a sling psychrometer to measure temperature and humidity atop Mount Washington, New Hampshire. Hourly temperature and humidity have been measured using this same method since 1932.

CIRMOUNT UPDATES

Adapting to Climate Change in Western National Forests: A Decade of Progress

Jessica E. Halofsky¹ and David L. Peterson²

¹*University of Washington, School of Environmental and Forest Sciences, Seattle, Washington*

²*USDA Forest Service, Pacific Northwest Research Station, Seattle, Washington*

National forests in the western United States comprise a large proportion of the forested landscape of the Western states, providing many ecosystem services, including timber, water, food, bioenergy, plant and animal habitat, recreation opportunities, and cultural values. Climate change will likely affect the provisioning of these forest ecosystem services, shifting ecosystem productivity, disturbance regimes, and species composition. With increases in temperatures over the last several decades, changes in hydrological processes, including reductions in snowpack, mountain precipitation, and streamflow have already become apparent in some locations. Across the western U.S., there have been increases in area affected by wildfire and insect outbreaks. These trends are likely to continue with increasing temperatures in the coming decades, with disturbance driving forest ecosystem change.

To minimize the negative effects of climate change on forests and the services they provide, natural resource managers need to both understand the potential effects of climate change and have options to address those effects. In recent years, governmental

and nongovernmental organizations have been developing climate change vulnerability assessments and exploring adaptation options (Fig. 1). Federal land management agencies in the United States are required to evaluate the potential risks associated with climate change to minimize short- and long-term effects on their operations and mission. As mandated in Executive Orders 13514 and 13653 issued by President Obama, many federal agencies have now developed general climate change vulnerability assessments, adaptation plans, and strategies for addressing climate change. For example, the U.S. Forest Service provided specific direction to the National Forest System in the form of the National Roadmap for Responding to Climate Change and the Performance Scorecard for Implementing the Forest Service Climate Change Strategy. Similarly, the U.S. National Park Service released a Climate Change Response Strategy that provided direction to the agency and employees in addressing climate change, followed by a Climate Change Action Plan, which contained further guidance for national park managers for responding to climate change.



Figure 1. Glacially carved landscapes, dense coniferous forest, and deep lakes are common in the Northern Rockies, where the Northern Rockies Adaptation Partnership was conducted. Photo: National Park Service.

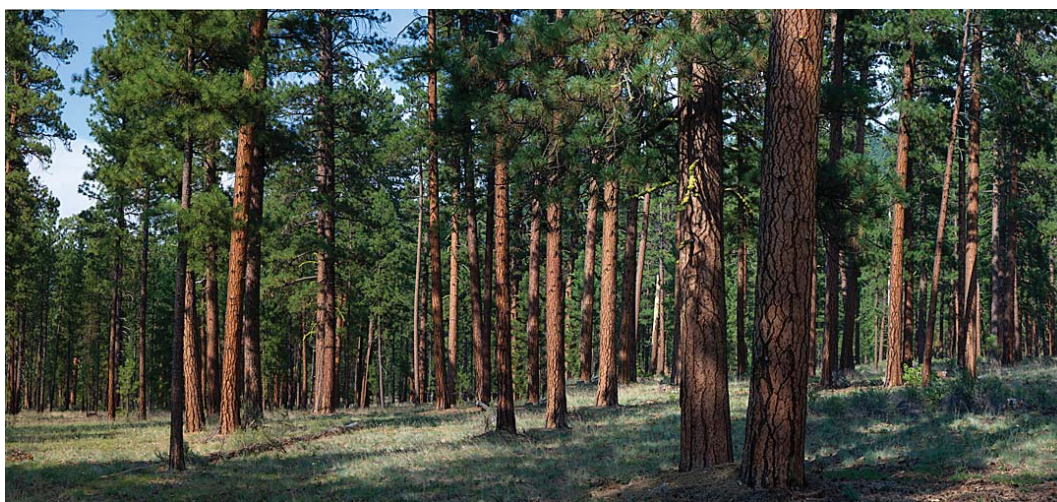


Figure 2. Dry forest dominated by ponderosa pine (shown here in Deschutes National Forest) is common at low to mid elevations in south central Oregon, where the South Central Oregon Adaptation Partnership was conducted. Photo: Miles Hemstrom.

Despite recent progress in climate change assessments and plans, development of local to regional-scale vulnerability assessments and adaptation plans has been slow and uneven across agencies and organizations. Much of the progress to date has been accomplished through science-management partnerships, which have emerged as effective catalysts for developing vulnerability assessments and land management adaptation plans at both strategic (general) and tactical (on-the-ground) levels (Fig. 2). Science-management partnerships typically involve iterative exchange of information on regional climatology and climate change effects from scientists, and of information on local climate (and weather), ecology, and management from managers. This iterative information sharing aids identification of key vulnerabilities to climate change at the local scale, setting the stage for developing place-based adaptation strategies and tactics.

The Process

Our journey started in 2007. Prompted by the Fourth IPCC Assessment released that year, the American public and political leadership became more engaged in the realities of climate

change, and federal agencies started to make progress, typically led by scientific efforts within the agencies. The first climate change vulnerability assessments in national forests were initiated in Tahoe and Inyo National Forests (Connie Millar, Toni Lyn Morelli) and in Olympic National Forest (Jessica Halofsky, Dave Peterson). There was no recipe or guidebook, and although assessments for various topics are common in federal agencies, addressing climate change was a new topic, and we made things up as we went along, while building relationships with local resource managers.

These seminal climate-change assessments led to a four-stage process that has now been institutionalized in the Forest Service (Fig. 3). First, education is provided to federal resource managers to ensure a common understanding of basic climate science and how it applies to terrestrial and aquatic ecosystems. Education takes place in workshops or webinars. Second, the assessment is conducted by teams of scientists, resource managers, and often stakeholders to project the effects of climate change on vegetation, water resources, fisheries, etc. Although some new analyses are often conducted (e.g., vegetation modeling), most of

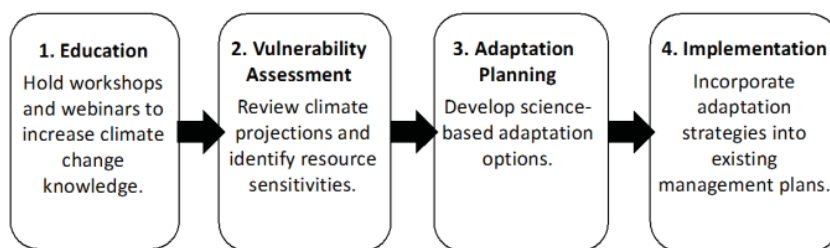


Figure 3. The process used by Adaptation Partners to build organizational capacity for climate change in the U.S. Forest Service and other agencies.

the assessment consists of synthesizing existing information and developing inferences about climate change effects. Third, the assessment is used as the basis for developing adaptation options in response to potential climate change effects. Adaptation options are elicited from resource managers in a workshop setting. Finally, all of the preceding information is (potentially) implemented in national forests operations, including land management plans, NEPA documents, project plans, and monitoring programs. Implementation is at the discretion of national forest leadership, and although it has generally been slow, the pace of implementation is accelerating, motivated by the Forest Service Planning Rule (2012) and recent guidance issued by the Council on Environmental Quality (2016).

Science-management partnerships have been the foundation for all assessments conducted during the past decade. Consisting of a group of researchers and resource managers who work together over a two-year period, the partnership implies both trust and commitment in producing a final product that will be useful to the national forests. That product is typically a published report (a Forest Service General Technical Report), but also includes journal articles that document the science, in addition to face-to-face meetings with national forest leadership and planners responsible for incorporating climate change into operations.

Most climate change assessments in the western U.S. have been conducted by our Adaptation Partners organization (adaptationpartners.org). Although funded mostly by the Forest Service, we work with a wide range of federal, state, university, tribal, and non-governmental partners (the more perspectives the better). And we normally conduct assessments using an all-lands approach that includes lands outside national forest boundaries.

Making Progress

To date, we have established seven climate change partnerships located in Washington, Oregon, Idaho, Montana, North Dakota, Utah, Nevada, and Wyoming, encompassing 38 national forests, 29 national park units, and other lands (Fig. 4). These projects cover about 27 million hectares of forest and rangeland. The partnerships have been small (Olympic Peninsula: 1 national forest, 1 national park), medium-sized (South Central Oregon: 3 national forests, 1 national grassland, 1 national park), and large (Northern Rockies: 15 national forests, 3 national parks) (Fig. 5). Assessments that include larger geographic areas are of course more work and more complex. They also include more partners and stakeholders, which strengthen the project, but also make it more complex in terms of subject matter and communication.

The focus of climate change assessment and adaptation is evolving. In early assessments, the highest priority resource areas were water resources, fisheries, vegetation, and wildlife. The scientific literature contains a large amount of information on the first three of these topics, but not much on wildlife. In addition, existing information on water, fish, and vegetation can often be supplemented by modeling the effects of climate change with respect to hydrology, stream thermal characteristics, and altered plant distribution and abundance, respectively. As a result, we are relatively confident about the projections for these resource areas.

More recently, federal managers have become increasingly interested in recreation, infrastructure, and cultural resources, for which little scientific information is available. We have pioneered assessment approaches to these topics in collaboration with scientists and local resource experts, typically with minimal



Figure 4. National forests (greens) and national parks (brown) involved in seven adaptation partnerships across the western U.S.



Figure 5. Dry upland herblands dominated by Idaho fescue occur on the Umatilla National Forest in northeastern Oregon, where the Blue Mountains Adaptation Partnership was conducted. Photo: Mark Darrach.

published documentation, although observation and experience provide the basis on which high-quality inferences can be based. In addition, resource managers usually have creative ideas for how to adapt to different climate change scenarios for these resource areas. Ecosystem services are another topic often addressed in recent assessments. This category can cover issues such as water supply, timber production, carbon sequestration, and pollination. Because ecosystem services are so diverse, it is necessary to be specific about priority services for any given location. The amount of scientific information is variable, but as above, resource managers can typically provide feasible adaptation options.

A New Resource for Adaptation

In all of the partnerships, we identified adaptation strategies (general, strategic), and adaptation tactics (specific, on the ground) for each strategy. This information was recently compiled in the Climate Change Adaptation Library for the Western United States (adaptationpartners.org/library.php), to be used as a resource for anyone interested in climate change adaptation in natural resources. The Adaptation Library includes adaptation options for forest vegetation (Table 1), non-forest vegetation, riparian/wetland systems, wildlife, water resources, fisheries, and recreation. Around 150 adaptation strategies and

450 tactics are currently in the Library, and more will be added in the new future. We are currently in the process of converting the Library into a searchable database, and plan to add additional categories for cultural resources and ecosystem services.

The Adaptation Library can be used by the U.S. Forest Service, National Park Service, and other public agencies in many ways, including the following aspects of natural resource management agency operations:

- Planning documents and their components: Provide objectives, standards, and guidelines (e.g., land management plans, general management plans)
- Resource management strategies: Incorporate information into conservation strategies, fire management plans, infrastructure planning, and state wildlife action plans
- Project design/implementation: Provide mitigation and design tactics at specific locations.
- Monitoring evaluations: Provide periodic evaluation of monitoring questions.

In the process of incrementally building the Adaptation Library, we found considerable concurrence in adaptation strategies and tactics among different regions and management units. This suggests that there is a finite set of responses to potential

Table 1. A sample of climate change sensitivities, adaptation strategies, and adaptation tactics associated with forest vegetation, from the Climate Change Adaptation Library.

Sensitivity to climate change	Adaptation strategy	Adaptation tactics
Large disturbances will create the potential for mortality events and regeneration failures	Mitigate consequences of large disturbances by planning ahead	Maintain a tree seed inventory with high-quality seed for a range of species, particularly species that may do well in the future under hotter and drier conditions
		Increase production of native plant materials for post-disturbance plantings
Increased drought stress will decrease forest productivity at lower elevations	Use judicious managed relocation of genotypes where appropriate	Relax seed zone guidelines to include genotypes from warmer locations; use a variety of genotypes rather than just one
	Increase resilience in forests	Increase the amount of thinning and possibly alter thinning prescriptions
Increased warming, drought and wildfire will reduce tree vigor and increase susceptibility to insects and pathogens, with increased potential for large and extensive insect and pathogen outbreaks, particularly of non-native insects and pathogens	Increase resilience of forest stands to disturbance by increasing tree vigor	Use girdling, falling and leaving trees, prescribed burns, and wildland fire to reduce stand densities and drought stress
		Maximize early-successional tree species diversity by retaining minor species during pre-commercial thinning activities to promote greater resilience to drier conditions
		Consider including larger openings in thinning prescriptions and planting seedlings in the openings to create seed sources for native drought-tolerant species
		Thin to decrease stand density, increase tree vigor and accelerate development of late-successional forest conditions
		Harvest to variable densities
		Reduce density of post-disturbance artificial regeneration
		Plant disease-resistant species or genotypes where species-specific insects or pathogens are a concern
		Increase stand-scale biodiversity and minimize monocultures
		Treat existing pathogen outbreaks more aggressively

climate change effects, and that although the Library is intended as a dynamic resource, the accretion of adaptation options in the Library over time will be asymptotic. This concurrence also exists between the Library and a large, independent effort conducted for forest systems in the eastern U.S. thus providing confidence in the universality of at least a core of adaptation options. Finally, a large proportion of adaptation options in the Library is already established as tools and techniques used in sustainable resource management. Rather than revamping existing principles and practices, climate-smart management will often be most effective for establishing priorities for specific resources and locations within management units.

Although climate change adaptation is not a cookbook process, the Adaptation Library provides a science-based foundation for resource managers who want to develop adaptation responses to climate change. Adaptation strategies and tactics in the library can be used “off the shelf” because they have already been thoroughly vetted and peer reviewed. They can also be revised for local conditions, and new options can be added. Resource managers may find comfort in the fact that the Library is based on information elicited from other managers like themselves, and is not developed by scientists without real-world input.

Toward Full Implementation

A relatively new endeavor for public land managers, climate change adaptation is typically complex and filled with uncertainty, and science-based processes and guidelines are still evolving and being tested. Climate change vulnerability assessments are increasingly a component of risk assessment for resource planning and management, and adaptation is increasingly a component of risk management. Including climate change as a component of resource planning and management, which was viewed in the recent past as merely desirable, is now required in the U.S. Forest Service and National Park Service, and is becoming a more common element of agency operations.

The biggest challenge for U.S. federal agencies in embracing climate change has been building the organizational capacity to address a complex issue that affects multiple resources. Most resource specialists are already fully committed to ongoing projects and regulatory requirements, and agencies have seen a steady decline in budgets and personnel over the past 20 years, making it difficult to take on new responsibilities. Although education and training on climate change have generally been available, they are only a precursor to aspects of decision making and management that require assessment of climate change effects and responses to them.

Implementing adaptation options in local management units can be challenging. We anticipate that this will gradually occur over time as policies change, as plans and programs are revised, and especially when extreme weather events (e.g., multi-year droughts) and major disturbances (e.g., large wildfires) capture the attention of agencies, local communities, and stakeholders. Adaptation is more likely to be successful when multiple parties collaborate on implementation across large landscapes, rather than acting independently.

We are optimistic that climate change awareness, climate-smart management and planning, and implementation of adaptation in U.S. federal agencies will continue to improve. We anticipate that within the next 10 years:

- Climate change will become an integral component of business operations.
- The effects of climate change will be continually assessed on natural and human systems.
- Monitoring activities will include indicators to detect the effects of climate change on species and ecosystems.
- Agency planning processes will provide opportunities to manage across boundaries.
- Restoration activities will be implemented in the context of the influence of a changing climate.
- Institutional capacity to manage for climate change will increase within federal agencies and local stakeholders.
- Managers will implement climate-informed practices in long-term planning and management.

As adaptation options are implemented, it will be critical to monitor their effectiveness across different landscapes. Monitoring data provide feedback that can be used to validate existing options, inform their modification, or develop new options to be tested. Working across multiple jurisdictions and boundaries and collaborating with the research community will ensure that diverse perspectives are represented and that effectiveness monitoring is robust. This approach requires a multi-decadal commitment to integration of climate-smart thinking in all aspects of resource management.

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Celebrating Kelly Redmond

(1952-2016)



Kelly on Hardscrabble Mountain, Bridger Mountains, Montana, 2013

An important innovator and one of our foremost leaders of mountain-climate science in general, and CIRMOUNT specifically, has passed. Kelly Redmond died Wednesday, November 2, 2016, at his home in Reno, Nevada, 2½ years after diagnosis of pancreatic cancer. Kelly was Regional Climatologist and Deputy Director of the Western Regional Climate Center, and Research Professor in Climatology at the Desert Research Institute, Reno, Nevada. Foremost to CIRMOUNT circles, Kelly was a mountain-climate scientist, fascinated by the challenges and importance of understanding climate processes and trends in complex topography. In the early 2000s, Kelly and a handful of other climate-scientists of the West (including Dan Cayan, Mike Dettinger, Henry Diaz, Malcolm Hughes) and mountain ecologists (including Dan Fagre, Lisa Graumlich, Greg Greenwood, Connie Millar, Nate Stephenson, Tom Swetnam) worked together to develop an informal network that would bring together mountain scientists of diverse disciplines to focus on climate and climate effects on ecosystems. Thus CIRMOUNT was born, and with it, CIRMOUNT's flagship effort, the now-biennial *MtnClim* climate conferences.

Kelly had been a devoted participant to the PACLIM workshops, which focus on climate science of the Pacific Ocean and the West, attending and presenting annually since the first meeting in 1983. Kelly loved the informality, interdisciplinary nature, high-quality and current science, small group size, and retreat-environment that characterizes PACLIM. He championed a parallel event focused on mountain-climate issues for mountain scientists and those interested in climate-related management

and policy of mountain regions. At both PACLIM and *MtnClim*, Kelly became the regular and much-anticipated opening keynote speaker, during which he would present a synthesis of climate events across western North America since the last meeting of the group. In CIRMOUNT's early years Kelly led many efforts to promote CIRMOUNT, for instance, shepherding as PI the submission of a research coordination network proposal to the National Science Foundation (which was rejected, with the justification that CIRMOUNT was already too coordinated!). Even in his last year, worn down by illness, Kelly was advocating CIRMOUNT efforts, practicing and promoting mountain-climate monitoring, and actively consulting and collaborating with national park managers and other resource managers concerned with mountain issues. Those of us who attended *MtnClim 2016*, held in mid-October in Leavenworth, WA just weeks before he passed, were blessed to have Kelly once again in our midst – Elder of the clan – presenting his regular kick-off lecture, discussing the latest science over posters and beers, making newcomers feel welcome, admiring the magical mountain beauty of the Cascades, and talking late into the evenings with old friends.

Kelly grew up in beautiful Gallatin Valley of southwest Montana in Belgrade, next to the Bozeman Airport, where his father worked for the FAA for 27 years as a Flight Service Specialist. His father also recorded the official weather records for the Bozeman airport during this time, and passed his love of mountain weather and challenges to young Kelly. From his Montana home, surrounded by mountains on every horizon, Kelly spent many days hiking with his four brothers and parents. Those early hiking days influenced his interest in mountain climate, observing at an early age that “mountains make their own weather” and that “mountain weather could be so different from that out in the middle of the valley”. Kelly earned a B.S. in Physics from the Massachusetts Institute of Technology (1974), and M.S. and Ph.D. in Meteorology from the University of Wisconsin-Madison (1977 and 1982). Before moving to DRI, Kelly was Assistant- and then State Climatologist of Oregon for seven years. In this position, Kelly had ample opportunity to develop and hone what became his remarkable talent and passion for communicating climate information to the layman, and to resource-management and policy audiences. In his words, “I had about 35,000 one-on-one conversations with people from every walk of life about nearly every facet of climate. Maybe 10-20 of these conversations were about climate change; the large majority was just about the ongoing effects of climate variability.” Kelly was always engaged and enthusiastic about new scientific

findings and methods but merciless about holding every one up to the clarifying light of real-world observations and usefulness. His insistence on real-world usefulness, derived from his thousands of conversations with real people, set the standard for us all.

For his wide-reaching climate-science impact, Kelly was recognized as Fellow of the American Meteorological Society in 2009, and earned many professional awards for his work, a number of which are related in comments and links from colleagues below. His CIRMOUNT colleagues were particularly proud that Kelly was nominated by the American Geophysical Union as the annual 2014 awardee of the Tyndall History of Global Environmental Change Lecturer (John Tyndall being not just a climate scientist but also a mountaineer and lover of mountains). Kelly was selected as the Tyndall Lecturer in recognition of his outstanding contributions to understanding of global environmental change, and he delivered his lecture during the annual Fall AGU meeting on December 18, 2014 (link to video below). The lecture was vintage Kelly—informative, humorous and insightful—and is well worth viewing.

Kelly's wide interests and voracious reading habits roved to topics far beyond climates and mountains, and he was fond of discussing, and then speculating, on problems of metaphysical and cosmic dimensions. There seemed to be no topic for which he didn't have appetite and knowledge. In his words, "My basic affliction is an interest in everything, something that Richard Feynmann called 'the pleasure of finding things out.' I am interested in every part of Nature."

More than anything, Kelly's friends loved his wit, warmth, and easy, gregarious nature. Kelly welcomed everyone who came within his wake into earnest conversation, and he was interested in learning from each person's experiences and perspectives. Many students spoke of how he drew them into his circle, put them at ease, and introduced them to important opportunities. Old friends invariably mention late night emails and phone conversations—wandering from the initial cause for communication onto topics as big as the universe. From PACLIM and *MtnClim* weather roundup talks to those easy one-on-one chats, our world is greatly diminished by Kelly's absence.

A memorial service for Dr. Kelly Redmond will be held on Friday, January 13, 2017 at 2:00 pm in Reno, Nevada. Details and RSVP here: <https://www.dri.edu/newsroom/news-releases/5431-in-memorial-dr-kelly-redmond>. Information about donations to the Kelly Redmond Memorial Fund may be found at the same link.

"In fond memory of Kelly Redmond" by John Fleck, Inkstain, Nov. 4, 2016: <http://www.inkstain.net/fleck/2016/11/fond-memory-kelly-redmond/>

"Nevada climate change expert Redmond remembered as expert communicator" by Henry Bean, Nevada Review Journal, Nov. 4, 2016: <http://www.reviewjournal.com/news/politics-and-government/nevada/nevada-climate-change-expert-redmond-remembered-expert>



Kelly's Tyndall Lecture AGU, 2014 video: <https://www.youtube.com/watch?v=SjSwPMvBsCM>



"RevkinInterview" A video interview in August 2016 with Kelly Redmond by Andy Revkin, Pace University Researcher and dot.earth blog editor; posted with permission from Andy Revkin, Nov. 2016: <http://drive.google.com/file/d/0B88iFXWgVKt-YkhQSW9yZ3o0UEk/view?usp=sharing>

Introduction to Kelly's Talk for the Applied Climatology Award, August 2008 http://www.fs.fed.us/psw/cirmount/publications/pdf/IntroductionAppliedClimAward_Aug2008.pdf

Kelly's Talk when receiving the Applied Climatology Award, August 2008 http://www.fs.fed.us/psw/cirmount/publications/pdf/KellysPresentationForAppliedClimAward_Aug2008.pdf



Kelly in his DRI office, by Phil Pasteris.

Recollections of Kelly from his CIRMOUNT Friends and Colleagues

REMEMBERING KELLY REDMOND

In crisp autumn light, liquidamber
turning scarlet, bright blue sky,
I learned another colleague
has died.

I ran into him last year:
his wan smile, thinning hair.
Among the conference posters
we talked about the drought,
the blocking ridge of high pressure,
El Niño's promise,
and the shocking pace of climate change.

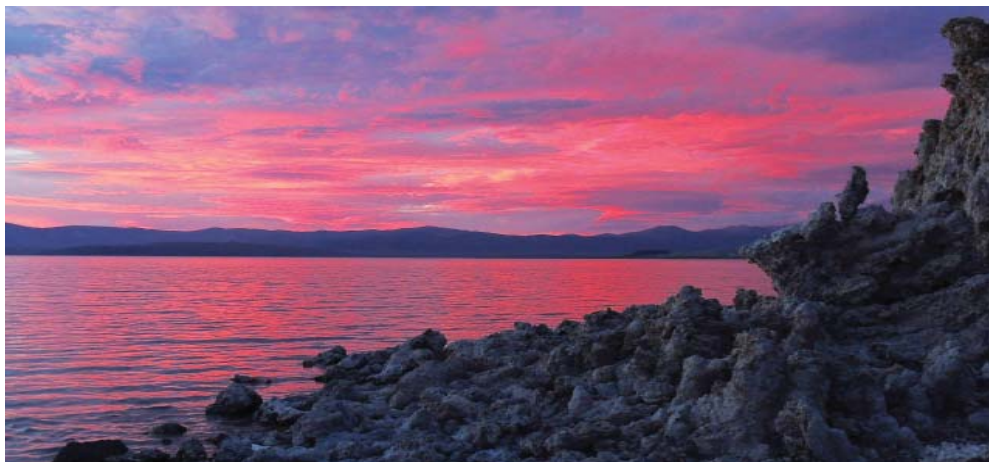
Then he spoke of the crab in his pancreas,
and the chemo, how hard it was.
He was steadfast and cheerful
though we both knew the odds.

He would have loved this change of seasons:
the clear Washoe light,
Mount Rose frosted with new snow,
mares' tails streaming in from the Pacific
and high over-head,
wild geese calling.

—Robert Coats, Hydroikos Ltd.

November 2016

Sunset over Mono Lake



Kelly Redmond, August 2014

Martha Apple, Montana Tech

Kelly had a great influence on many people. Just tonight I mentioned some of his sayings and quips to my friend who lives in Oregon, and she is planning to tell other people. And so it goes, with his wise thoughts and eloquence traveling out into the future. Eloquence seems like an overly fancy word to use, though, for someone who was so easy to be around and who had such a great sense of humor.

One time James and I saw Kelly on a corner in San Francisco (I think it was somewhere near Union Square and outside of that gallery where they used to have the Chagall paintings). Anyway, we stopped to talk about Montana since he grew up in Bozeman and one of his brothers went to MTech. He told us a great little story about stopping off in Butte to get new tires.

During his talk at *MtnClim 2016*, Kelly showed a picture of a Glory that he had taken from the airplane, showing the airplane's shadow and a small circular rainbow directly opposite of where he was sitting. He said something to the effect of, "There's my glory, and I was sitting right there. Glories are always right across from you."



Kelly's Glory

Jill Baron, U.S. Geological Survey

Leonard Cohen's Hallelujah is going constantly through my mind, and I am breaking into tears almost at random these days, so this tribute to Kelly comes at a particularly low point.

I did not know Kelly well, being a relative newcomer to the MtnClim circle of warm and loving mountain people. I've never been to a PACLIM meeting. Kelly didn't care; he welcomed me into his sphere anyway. In his wonderful matter-of-fact way—oh, Jill's one of us now—he made me comfortably at home among so many eminent scientists with whom he had shared many more years of camaraderie. We need to spread Kelly's warmth and quiet faith in people more than ever now. I will carry him in my heart.

Leonard Cohen, Hallelujah: <https://www.youtube.com/watch?v=YrLk4vdY28Q>

Erik Beever, U.S. Geological Survey

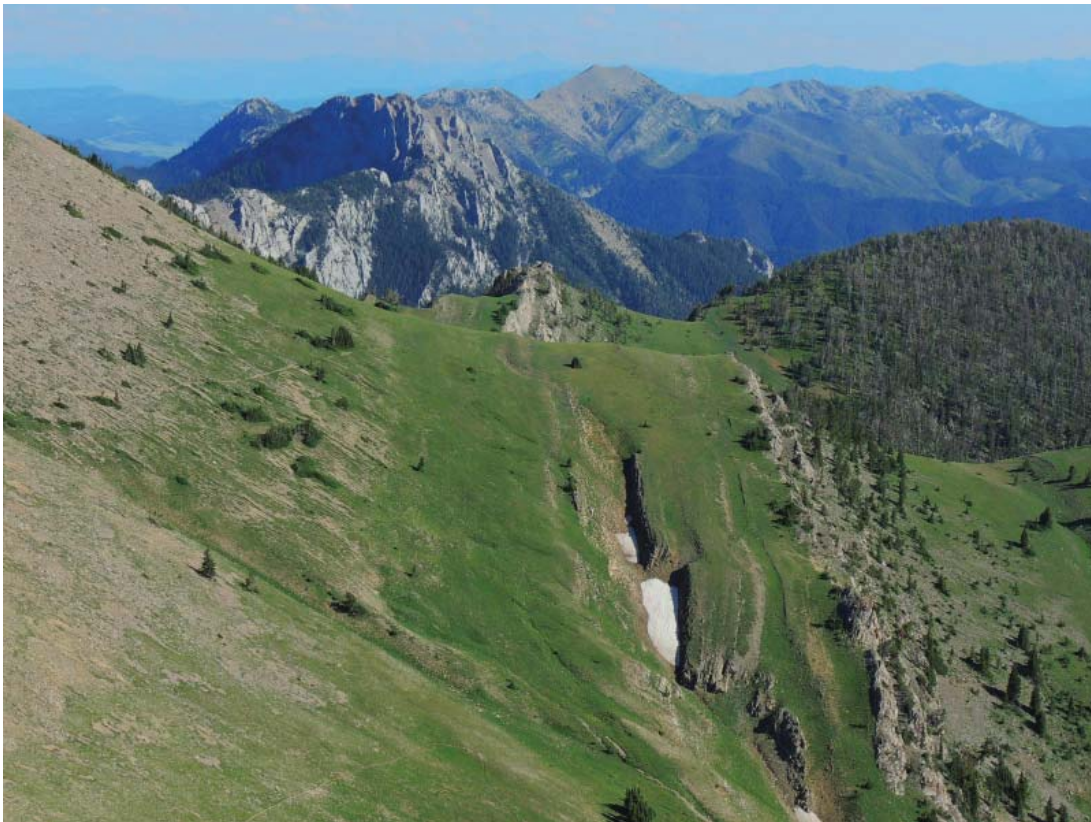
Although I have known Kelly for the better part of two decades (having done my Ph.D. and first postdoctoral research in Reno, where Kelly was based at DRI), I have had the pleasure of getting to know Kelly on a more-personal level in the past several years as well.

Things that make me smile as I remember Kelly include his ability to literally (not figuratively) fit over 120 slides in a 25-minute presentation (with only a handful of pictures), yet still not feel like too much information was being shoved down the audience's throat or that the presentation was rushed. I also loved his ability to weave together different scales of examples to illustrate any given point, from remarkable temperature gradients across a single valley in western Nevada that were quantified with sensor arrays, all the way to synoptic patterns across the entire West that spanned several decades.

Kelly and his colleagues catalyzed work that proved an invaluable inventory for many of the U.S. national park units. I worked for 2.5 years in the NPS Inventory and Monitoring Program, and I saw first-hand that a lot of the analyses, approaches, suggestions, syntheses, and interpretations not only were hugely instrumental in shaping the initial direction of climate and weather monitoring in NPS, but the legacy of that influence can still be pervasively seen across the Nation, even today.

I loved the pensive nature of Kelly, and how he would respond to questions not only in person but also over email. Scientifically, Kelly had a playful, gentle, and tireless sense of curiosity that sparked him to accomplish many great things.

We are a more depauperate community without him.



Hardscrabble Peak, July 2013, by Kelly Redmond

Andy Bunn, Western Washington University

I had the great pleasure of being able to be present for what turned out to be Kelly's final scientific presentation. As one of the organizers of the 2016 *MtnClim* conference I had worked to bring Kelly in for his traditional talk reviewing the state of mountain weather in the west. I knew Kelly was frail and tried to give him an easy out if he wasn't feeling well enough to travel. But of course, he was having none of it. He arrived just in time for his talk and had spent the day driving around the east side of the Cascades taking pictures and being the keen observer of the world that he was. Towards the end of the meeting I was chatting with a contingent of folks from the Northwest Indian College who were new to *MtnClim*. Kelly had gone out of his way to have lunch with them and welcome them to the conference. One of the students remarked to me that Kelly was clearly an important elder in our community. He was. We all knew it. I hope that Kelly knew it. I'll miss him as a scientific mentor but mourn the loss of Kelly as an elder for our community even more.



Kelly speaking at MtnClim 2016, by Imtiaz Rangwala

Link to Kelly's MtnClim 2016 presentation: <http://www.fs.fed.us/psw/cirmount/publications/pdf/KellyMtnClim2016.pdf>

Dan Cayan, Scripps Institution of Oceanography

Kelly loved atmospheric measurements and unraveling the structure and processes they revealed. Of course he dealt with an enormous bundle of these in his office life, but he also carried this to a very personal level. Years ago he introduced me to the thermometer he had tethered to a readout on the dash of his Volvo (which, though more than 10 years more aged, I think is still parked in his garage). After retrieving me from the Reno Airport, he proudly demonstrated this device, which he hung out his window as drove through the surface streets. He operated this as a profiler, his brain being the recorder. On our drive to his house it quickly became clear that this was a survey across the hilly terrain that he did routinely to the point that he could enthusiastically predict how much change the nighttime layered atmosphere would present as we descended the next valley.

Kelly fit very well the position he occupied (invented, I guess) at Western Regional Climate Center, which I will call "Chief Climate Scientist for the Western U.S.". This gave him license to poke into a vast universe of interesting problems. His personal statement says that he "*maintains an interest in all facets of climate and climate behavior,*" which indeed was true. I have to confess that, being a co-investigator on various projects, I sometimes got a bit frustrated with Kelly's less-than-straight line trajectory in achieving deliverables. But this was part of the Kelly-package, which was, in the end, a great virtue, because of the experience he brought from high level issues he contributed to and real-time monitored, and the impeccable standards he maintained.

The Western landscape was one of his intense fascinations. He tromped and catalogued weather stations across many of the National Parks in the West, and he personally surveyed and located several of the NOAA Climate Reference Network station sites. This on-the-ground knowledge made him a really effective advocate for better observations and for improved regional modeling. In attending the astounding number of meetings and conferences he was invited to, he made a lot of flights, and he always took a window seat. Here's how he spent his air time—

From: Drought Monitor Discussion Group [DROUGHT@LISTSERV.UNL.EDU] on behalf of Kelly Redmond
[Kelly.Redmond@DRI.EDU]

Sent: Saturday, February 21, 2015 10:55 PM

To: DROUGHT@LISTSERV.UNL.EDU

Subject: [DROUGHT] a few photos

“Took a couple hundred photos coming and going to Boise.

A lot of people fly over the Great Basin and think it's just a big wasteland.

Some of us find it totally fascinating. And it wears drought on its sleeve.”

7478 Lake Mead, Overton Arm, it's helpful if boat ramps reach the marina

7443 old droughts and shorelines of Lake Bonneville, looking east into Utah

7479 drought outline on Lake Mead, still dropping, 73 % of normal inflow now expected

7485 Lake Mead, Boulder Dam, electricity from water, new bridge, Black Canyon

7491 Lake Mead bathtub rings.”

Kelly would be classified as a Type 10 Workaholic, but he had so much fun that I'm sure to him it wasn't work, just part of his continuing voyage of discovery. I think he saved phone calls until after he'd dealt with the mountain of emails, press queries and office interactions he maintained. Often, at the very end of an already long day my phone would ring and there would be Kelly and we'd be off on an hour conversation, inevitably off-topic, but always a delight. How I'll miss those and that gentle inquisitive soul!



Airborne view of the White Mountains and Long Valley, CA, December, 2013, by Kelly Redmond

Chris Daly, Oregon State University

Kelly ranks as one of the top three most influential people in my professional career. He achieved that status by helping to promote my early work within the larger community, providing a steady and encouraging presence, contributing novel (and sometimes hilarious) ideas, and perhaps most importantly, contributing his time and energy to help out when things looked bleakest. I know that I am not alone, which makes his influence all the more remarkable. At meetings and conferences, I would watch Kelly go over to the young participants to introduce himself, and ask really great questions about their work. Everyone was important and worthy. I will strive to honor Kelly's legacy by trying to do more of that myself. Of course, this is in addition to working through the list of great things he thought I should be doing! That will certainly keep Kelly in my thoughts for many years to come. Rest easy, my friend.

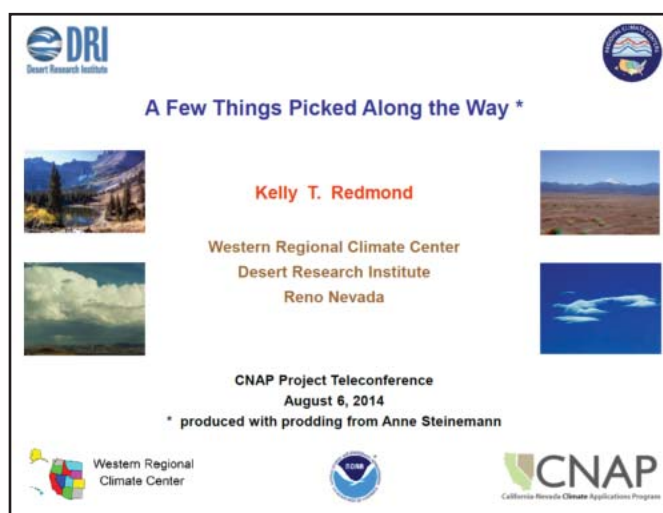
Mike Dettinger, U.S. Geological Survey

For the community, Kelly was the ultimate team player and philosopher scientist. And it is sure going to be a lot less fun out there without Kelly at the dais.

On a more person-to-person basis, Kelly and I have been working together regularly since the late 1990s. I think we worked well together, and certainly he always always made it fun, but at some level we were always a bit wary of each other: I tend to be a loose cannon and Kelly always retained that careful state-climatologist thing. As recently as last fall, we put together a public forum in Carson City to talk about what the Great El Niño of 2016 was going to mean...Kelly kind of called that one, arguing "who really knows?" Who indeed? The upshot for me is that Kelly's passing means another "professional friend" gone and that maybe its time to internalize his care and caution as best I will remember it. And again a lot of the fun will be gone from meetings from now on. I'll miss him.

I think that the "pull quote" from Kelly that is most cited in the literature and that will last longest into the future may be from his "Depiction of Drought" commentary in BAMS in 2002, wherein he wrote "What is meant by drought? Early definitions focused on purely meteorological or hydrological causes...[but] through time I have come to favor a simple definition; that is, insufficient water to meet needs." So simple and yet really game changing, much cited, and sure to stand the test of time. I see it mentioned in talks and in articles all the time.

Kelly's BAMS article on drought is here: <http://journals.ametsoc.org/doi/pdf/10.1175/1520-0477%282002%29083%3C1143%3ATDO%3E2.3.CO%3B2>



Cover slide from Kelly's presentation at CNAP (courtesy of Anne Steine)

PDF of Kelly's presentation here: <http://www.fs.fed.us/psw/cirmount/publications/pdf/AFewThingsPickedUpAlongtheWay.pdf>.

Henry Diaz, emeritus NOAA

If my memory serves me, I first met Kelly at one of the earlier PACLIM meetings—likely in the late 1980s. Since then, our paths crossed many times, at numerous American Meteorological Society conferences, at the annual AGU conferences in San Francisco, and many, many workshops all around the country. Kelly kept his travels mostly within the confines of the USA, and he travelled quite frequently. When he passed away recently I reflected on my times and experiences with him and our many friends and colleagues. One thing that always struck me as I now look back on our various peregrinations is the realization that whenever we were together during those late afternoon and evening social gatherings, it was clear how Kelly enjoyed the camaraderie, the scientific, political and cultural discussions, and the personal feedback and learning from those groups of people that his travels afforded him.

We became an extended family, and we shared personal news and plans for the future. And when we got together again at some later time, we would bring each other up to date on the things—personal and professional—that had happened to us in the interim.

I will miss Kelly's friendship and his unique talents as a great science communicator and message taker to the greater community of fellow citizens.



Kelly enjoying friends at his last *MtnClim* conference, October 2016, in Leavenworth, WA, with Imtiaz Rangwala (left) and Sudeep Chandra (center). Photo by Jill Baron.

Deanna Dulen, National Park Service

Writing from Bhutan:

Dear Kelly's spirit soared to lofty heights, embracing the wisdom of a sage and knowledge of a scholar, all of which he shared with colleagues, and all with a twinkle in his eye. I dearly appreciated how, during our interagency group developing management implications of climate refugia, he said with his wry wit that we most certainly need a refugium for climate scientists.

Kelly also wrapped scientific complex physics into clear concepts like the climate refugium concept for Devils Postpile National Monument along the San Joaquin River corridor and all the moisture laden rain and snow releasing on west wall of Mammoth Mountain to make the right combination of topography, geology, wetland, river, and shade, with no known analog.

Thank you Kelly, and may your spirit continue to soar. Namaste

Sasha Gershunov, Scripps Institution of Oceanography

I will miss Kelly's intrepid philosophical attitude and optimism about humanity and love for Life and his thirst for knowledge in many diverse fields that he so generously shared. Every conversation with Kelly was a priceless gem, especially the late-night ones he loved so much, when the most essential questions of human existence percolated up to the surface. He truly stood out among us all unique human beings.



"Greetings, earthlings," from the east end of the Extraterrestrial Highway, Nevada Route 375, near Hiko Nevada, by Kelly Redmond.

Jessica Lundquist, University of Washington

My favorite memories of Kelly are of how he always monitored meteorology during his travels to any meeting. He would begin with, "So, I had my thermometer on my car as I was driving on I-80 this morning, and as I went over the pass from Reno, it got cooler at exactly 4,000 feet and got warmer suddenly when I passed an elevation of 5,000 feet, but when I descended on the other side, there was no such cold pocket..." and he would rattle off exact temperatures and elevations and patterns with such precision that I was always seriously concerned that he was not watching the road at all and was going to crash his car. The same observations could be seen in the photos out his airplane window that accompanied every weather year in review.

In the field, Kelly taught me how to site weather stations—make sure you're not next to a building or in the shade of a tree, try to find a nice big clearing, not too windy if measuring precip, but at the very top of a mountain if you only want temperature and wind.

In the breaks between meetings, Kelly taught me what it meant to be a good citizen scientist, telling me, "No matter what, you have to keep working to explain your science to everyday people. It's hard to do, but it's the most important thing we can do. We have to make sure people understand what we're doing and why it matters."

And his book recommendations were always spot on -- I still haven't finished the list from the Tyndall lecture.

He loved the weather in the mountains, and he loved people, and I really appreciate having Kelly as a role model from graduate school onwards.



First Yosemite Hydroclimate Workshop, 2002, Yosemite Valley. Photo from Bruce McGurk.

Bryan Mark, The Ohio State University

I'm pleased to share a few words; the mere moments I had with Kelly were poignant. He so very quickly impressed me as a man of integrity and kindness.

I was fortunate to have met Kelly just before his death, while attending the *MtnClim 2016* meeting in Leavenworth, WA, in October 2016. I had only two conversations with him, and I was unaware of his condition. But in the midst of our discussion, I related that I was taking over the role of State Climatologist for Ohio. He took great interest, and followed up with personal reflections on the job. His advice was direct and simple, and bears sharing here: "be patient." He assured me that I would find moments to voice how climate is important, and it will make a difference, but it can often seem to be a difficult and uncertain path. The prophetic truth of that is only beginning to become clear given the uncertain times we live through. I left inspired and encouraged. I've subsequently learned how Kelly was a valued mentor for my former graduate student, Karin Bumbaco, who is now Assistant State Climatologist of Washington.

With my sincere gratitude for Kelly's life, and condolences to all.

Bruce McGurk, McGurk Hydrologic

As the organizer of the Yosemite Hydroclimate meeting, I solicit presentations from respected and favorite researchers to speak at the annual meeting. Kelly Redmond represented both of those attributes: everyone looked forward to hearing his musings on the past winter, and what the new water year would bring. Kelly had a special place in the lineup because he was part of the group of scientists who started these annual meetings in the Park in 2002. He had been to every meeting, and always brought his special brand of thoughtful presentation and insightful questions for the other attendees. His talks were full of colorful graphics from the Drought Tracker, El Niño/SOI status and trends, precipitation extremes, trends in wintertime minimum temperatures, and more. He could interpret those complex patterns and issues, and make everyone feel like they understood what was going on. And just for fun, he would then add a plot of the Lake Tahoe water level and how it had declined during the drought and how long it had been below the rim. His musings on the coming winter were often preceded by a cartoon featuring a fortune teller's shop with a sign such as "Madame Olga's Stochastic Scenarios." Kelly would smile as people laughed, but would then marshal all the bits of evidence and weave them into a great forecast. Kelly was an amazing scientist, a terrific communicator, and a delight to sip beers with at the bar when the meeting was over. I was lucky for the time I got to spend with him, and miss him very much.



Madame Olga's scenarios in Kelly's slide show.



"So Far So Good", another of Kelly's lighter moments from one of his Yosemite HC talk. Both images sent by Bruce McGurk.

Connie Millar, USDA Forest Service

Trying to remember when I first met Kelly, I had been distraught in not being able to find that memory. My oldest mental images are of times when we were already close friends. In reading stories about Kelly, I realize that one of those memories surely was my first acquaintance: it is just like Kelly to make everyone feel like an old friend from the start. I respected Kelly for his science, capacity to communicate climate information clearly, and dedication to his work; I loved Kelly for so much more. Trained as a forest geneticist and evolutionary biologist, when I first ventured to learn about climate, I had absolutely no background that would provide a basis for interacting with climate scientists. Add to that a big dose of personal insecurity, my first participation in a PACLIM meeting in 1994 (when these were held on Santa Catalina Island, CA) was filled with trepidation. This, I think, is where I met Kelly, and one of those "old-friend" memories is from the boat ride back to the mainland. With ocean spray flying, we huddled on the deck and talked about topics metaphysical and only vaguely related to credible science. Of course Kelly was extremely widely read, so he had basis for his conjectures; he let me ramble on with my wild speculations, which were based on little known evidence. From there on, all our interactions had this comfy and easy manner, filled with awe at the beauty and wonder of Planet Earth and Beyond.

Kelly clearly loved his homelands of Montana, and spoke often and fondly of the mountains, the community, life in his early days in that region, his beloved parents and brothers, and, more recently, the nieces and nephews of his clan who meant so much to him. I think his heart was grounded in Montana, even though, Wallace-Stegner-like, he embraced every nook and cranny of the West through which—or over which—he traveled. In that I am far more parochial and see little beyond the Great Basin, I reveled to talk with Kelly of the hidden mountains ranges, isolated tree populations, and American pika sites I had explored in the Great Basin. Kelly would listen intently to my stories of "new places". Then he would add his own comment on a canyon or peak nearby that he had visited, and there would come pictures of these as well.

I visited Kelly at Renown Hospital in Reno in the days following his first surgery in 2014. Although it was clear that his cancer was terribly serious with little hope for long-term treatment, Kelly was calm and circumspect, relaying the medical details from his doctors, and the near-term plans to hold the cancer at bay. Soon, however, the conversation left the bedside, and starting roaming Kelly-esque to big topics: speculative, philosophical, existential. I was comforted by Kelly's perspective and capacity to talk as we always did, even with the terrifying news in his lap.

While I am more than a little embarrassed to confess, I secretly harbored the notion that I was special to Kelly. As I talk to friends and colleagues, I realize that many felt this way. Now I see the beautiful truth that we *all* were special to Kelly, each in our own way, just as he was special to each and every one of us.



For you, dear Kelly: a view from an American pika's front porch of the Sierra Nevada crest from near Rickey Peak on the day before Thanksgiving 2016, with love from Connie.

Toni Lyn Morelli, DOI Northeast Climate Science Center

Although I knew him half as well as most of you, I'm grateful for the calm, friendly, and wise man that I got to know over the last 7 years, and consider myself lucky to have had those times.

I also had the experience of both learning from him and butting heads (a little) with him on scientific matters, for which I consider myself very lucky.

In this moment of national and scientific upheaval that was left after Election Day, I find myself playing the game "What Would Kelly Say?" and wishing that I didn't have to guess.

—Toni Lyn, burgeoning climate scientist, inspired by Kelly and all of you to keep giving it my all



Phil Pasteris and Kelly, by Rosemary Pasteris

Phil Pasteris, Global Water Resources, CH2M Hill

I first met Kelly in the early 1990s when he made a presentation at the local AMS chapter meeting in Portland. As usual, Kelly was fully prepared with a stack of color overheads containing graphs, tables and all manner of images to illustrate the climate of Oregon and the Pacific Northwest. This could have been intensely boring to a mixed audience, but Kelly worked his story telling magic and after just a few minutes had their undivided attention. Kelly made climate, hydrology and meteorology come alive and relevant to all he met. He did that because he listened before he talked.

When I transferred from NOAA NW River Forecast Center to the SCS Snow Survey and Water Supply Forecasting Program in July 1990, Kelly was right there in Reno to help me when I visited. He had just moved from Corvallis where he was the State Climatologist to the Western Region Climate Center. He and I immediately hit it off. He knew I had plenty to learn and suggested that I attend the American Association of State Climatologists annual meeting in Atlantic City, NJ that next week. Wow! Talk about jumping into the deep end of the pool. With Kelly's help I got to meet the "climate gang" and was given 10 minutes to outline some concepts to create a national climate service. A regional and national climate service was something Kelly had in mind too and the saga began.

Kelly's work with Greg McCurdy and Dick Reinhardt at the Western Regional Climate Center (WRCC) resulted in a regional climate service making data and applications available to process and interpret climate data. The timing was right because the Internet was in its infancy and that a wider audience was possible to fulfill the WRCC mission. This concept aligned precisely with the USDA concept for a nationwide climate service for all USDA agencies. Kelly threw his full support into creating a Unified Climate Access Network (UCAN), now the Applied Climate Information System (ACIS). As part of the UCAN Design Team, Kelly gladly shared all his knowledge gained from the WRCC system to ensure UCAN provided data processing methods that were scientifically correct. The rest is history. ACIS is now fully integrated with National Weather Service webpages and provides meteorologists with the historical context for climate events nationwide with NOWData.

Kelly stayed in touch with the Oregon State crew. Chris Daly and George Taylor were cooking up a way to map climate nationwide. The existing maps of the West were a hodge-podge created by a variety of entities. The contours never matched at the borders and the period of record used for the analysis never matched either. Kelly threw his full support behind the PRISM project and hosted a

special State Climatologist forum in Reno to get expert comments to improve the PRISM process. That was the turning point for the project and Kelly was very pleased that the forum was a success. Input from the State Climatologists and others resulted in a suite of state climate maps that were congruent in period analyzed and edge-matched at the borders. Kelly's vision to support the process resulted in the WestMap – Climate Analysis Toolbox, which provides a full suite of maps and time series information.

Kelly's contribution to the National Integrated Drought Information System (NIDIS) once again was critical to its success. He provided the necessary perspective to put the complexities of drought into both scientific and human terms. He worked closely with all of the NIDIS cooperators to ensure that they were all heard and the process kept on track. His weekly comments to the Drought Monitor team were more often than not written in a style of an author Kelly studied and loved - Mark Twain. Kelly's "Demise of an orphaned rain drop" will be published in a separate article.

Kelly and I talked for hours on the phone and when we attended conferences. I don't know of a kinder person who ever roamed the planet. Being half Italian, I would get excited about something that didn't happen the way I hoped it would. We would talk it out together and Kelly always provide the opposing perspective that would settle me down. Rosemary and I loved to visit Reno and Lake Tahoe. We always tried to track Kelly down and take him to dinner. Bertha Miranda's Mexican restaurant was one of his favorites and he loved to listen to what we doing with our life and with our kids, Julie and Karri. Kelly and Karri shared an interest in Mark Twain and would exchange e-mails on some of this writings and observations.

News of Kelly's ailment caught me cold. I thought that if anyone could beat a bad set of dice, it would be Kelly. On the other hand, Kelly knew the diagnosis and probabilities. He decided to move on with what he did best, climate, and live the life he had left to spread his knowledge to as many as he could. Kelly had always met a deadline for a paper or presentation, but this was something he could not control and I am sure he was dismayed that he had not accomplished all he set out to do.

Kelly was in Portland in August 2016 to watch his brothers ride bikes in the annual Bridge Pedal, something he had participated in over the years. I met up with him and we walked the parkway near the Willamette River. His sense of humor was still there, as dry as a D6 drought. We knew that this might be our last time together on the planet, but did not dwell on the topic. I was in Joliet, IL when Kelly passed. I left him a voicemail message that we would meet again and that I loved him. That was the best I could do.

I recently attended a concert and "The Grand Canyon Suite" by Ferde Grofe was performed. If there was a piece of music that could be identified with Kelly, that is it. The piece has wonderful textures the five movements – Sunrise, Painted Desert, On the Trail, Sunset, and Cloudburst. Kelly played the trumpet in high school and I play the clarinet so we shared an interest in music. I think of Kelly whenever I hear this piece. Kelly understood the textures and variety of the Western climate like no other person.

Mark Twain once asked "to acquire, by courtesy of the press, access to my standing obituaries, with the privilege - if this is not asking too much - of editing, not their Facts, but their Verdicts. This, not for present profit, further than as concerns my family, but as a favorable influence usable on the Other Side, where there are some who are not friendly to me." He offered to correct them, "replacing them with clauses of more judicious character."

Kelly, you had nothing to fear from the Other Side. Your many friends that remain on this earth will testify to your selfless dedication to your craft. You have amassed and disseminated a storehouse of climate knowledge that will benefit generations to come. We will miss you.

Rest in peace my dear friend.

"I do not fear death. I had been dead for billions and billions of years before I was born, and had not suffered the slightest inconvenience from it." – Mark Twain



Kelly in his office at the Desert Research Institute, Reno, NV, by Phil Pasteris.

Dave Peterson, USDA Forest Service

I didn't have a lot of interaction with Kelly over the years, but we did coauthor one paper, so I'll base my comments on my experience with that:

In the 1990s, we developed a reconstruction of the lake level of Crater Lake, which is not only a gigantic "rain gauge" (no inlets or outlets), but has an unusually long record of lake-level measurements. We were well along with the analysis when Kelly joined the project at the recommendation of a colleague at Oregon State University, where Kelly worked at that time. This was the first time that I had worked with him, and suffice it to say that he kept our feet to the fire on statistical aspects of the study. He had a gentle way of telling us that some of our early inferences were incorrect, without making us feel like idiots. And of course the final analysis was much improved by his advice. I'm proud to say that I published a paper with Kelly Redmond:

Peterson, D.L., D.G. Silsbee, and K.T. Redmond. 1999. Long-term hydrological patterns at Crater Lake, Oregon. *Northwest Science* 138:121-130.

Roger Pulwarty, NOAA

(Extracts from letters that Roger has written about Kelly prior to his death): Dr. Redmond has been a fundamental contributor to and producer of innovative research in the field of climate variability and change, and their impacts in the Western United States. He has also been an intellectual stalwart in the effort to sustain climate monitoring and to confront and improve models through the development of stronger data records.

Dr. Redmond is exceptional for the quality of his publications and his dedication to ensuring that research is not done in a vacuum but informs choices made for the public good. Such is Dr. Redmond's proficiency and expertise in the area of climate research that he is widely-referred, by academic researchers, natural resources managers, and policy-makers at a variety of levels across the Western U.S., as "the Climate Ambassador of the West".

Dr. Redmond's is a voracious, yet critical, consumer of new ideas in communication and the use of science for decision-making. His enthusiasm and his desire for rigor are infectious to all around him. He will continue to stand as an inspiration to many, including young innovative thinkers with a modern view of use-inspired research in field of the physical and environmental sciences, especially climate.

Dr. Redmond stands above others and he has led the way in developing pathways that have then been adopted by Federal and State agencies, private sector interests, and across the academic community. He has always been a willing and gracious collaborator, embodying the increasing recognition that research-based solutions to complex environmental problems exceed the capabilities of any single researcher, or the purview of any single discipline.

Email forwarded by Roger from Jim Angel (State Climatologist, Champaign, IL):

"Of the millions of emails I've read over the years, this one written by Kelly Redmond to the Drought Monitor in September 2001 is by far my favorite. So much so that I kept it in my desk over the years to take out and read. I retyped this from the paper copy this morning and had a little trouble with watery eyes - must be those seasonal allergies. Enjoy ...

"Our ticker for the Water Year is still 2.04 inches, and not counting. Sure is dry. Can't even keep up with Death Valley, which in the same time had 2.46 inches, and now has parrots and orchids and coconuts and cantaloupes, draped in a smothering blanket of kudzu.

We had 0.00001 inches (e.g., a trace) in August. The drop that fell, August 8th, was reportedly about 0.6 mm in diameter, striking the gage with a resounding "plink" at about 3 degrees from vertical. Like comets, all our drops are named after their discoverer, so this one was known as Raindrop Dapm. Athletic and educated, but sensitive and shy, it was described as "a bit of a loner," grew up in a good neighborhood but kicked out by its parents when it couldn't carry its own weight. When the medics arrived, the badly injured droplet was undergoing dehydration and heat stroke; despite mouth to mouth resuscitation, all hope soon evaporated. The drop was survived by no ancestors or descendants. Cremation occurred at death, and its molecules scattered to the four winds. One was seen near Kentucky just the other day."

Imtiaz Rangwala, NOAA

Knowing Kelly is to reaffirm the basic goodness and beauty that life has in store for us. When I first met Kelly as a shy and wary graduate student, I was deeply struck by the amazing openness and attention I received from him. And that I received time and time again, and all those who were fortunate enough to cross path with him. No wonder that he was the persona par excellence when it came to the vocation of climate services. He demonstrated better than anyone I know the importance of listening and respectfully receiving the viewpoint from the other side. And, then there was the deep wisdom and humor that ever oozed out of him. It pains me deeply that I will not have the joy of his company anymore, and this loss will only grow with time. I am a different person now because I once ran into one Kelly Redmond.



Kelly at Lake Tahoe, August 2016, by Imtiaz Rangwala

Nate Stephenson, U.S. Geological Survey

Here are two from emails I have from Kelly to share, the first written to me:

3/16/14 “Hey Nate, Thanks for the thoughtful note, appreciate that very much. Am doing ok, just mild to moderate pain these days, really helps to have so many brothers and a lot of friends who have been wonderful. There's still another ring or two to add to this tree.

Now in between the initial operation and the chemo treatments.

Have had a chance to finally see a day go by at its natural astronomical pace. Kind of a treat.

More later. Thanks a lot. -Kelly”

The second is an excerpt from an email to some of us here in the southern Sierra Nevada about our attempts to understand recent climate and its trends. It is Kelly at his best, talking about the efforts of us frail humans to understand something as unfathomably complex as the climate system:

1/22/14 “So it’s like a case of uncertainty multiplied by uncertainty, uncertainty squared. Amidst all this noisy stochastic behavior, actually what is somewhat amazing and gratifying to my little speck of a mind is that we are still able to nevertheless discern some elements of regularity in system behavior. Nature is tossing us enough tantalizing crumbs that we succumb to our curiosity and keep looking for more. And though the previous might come off as somewhat pessimistic, I think there are good reasons to think we will keep finding better crumbs. And some of those crumbs will be useful.”

Scotty Strachan, University of Nevada, Reno

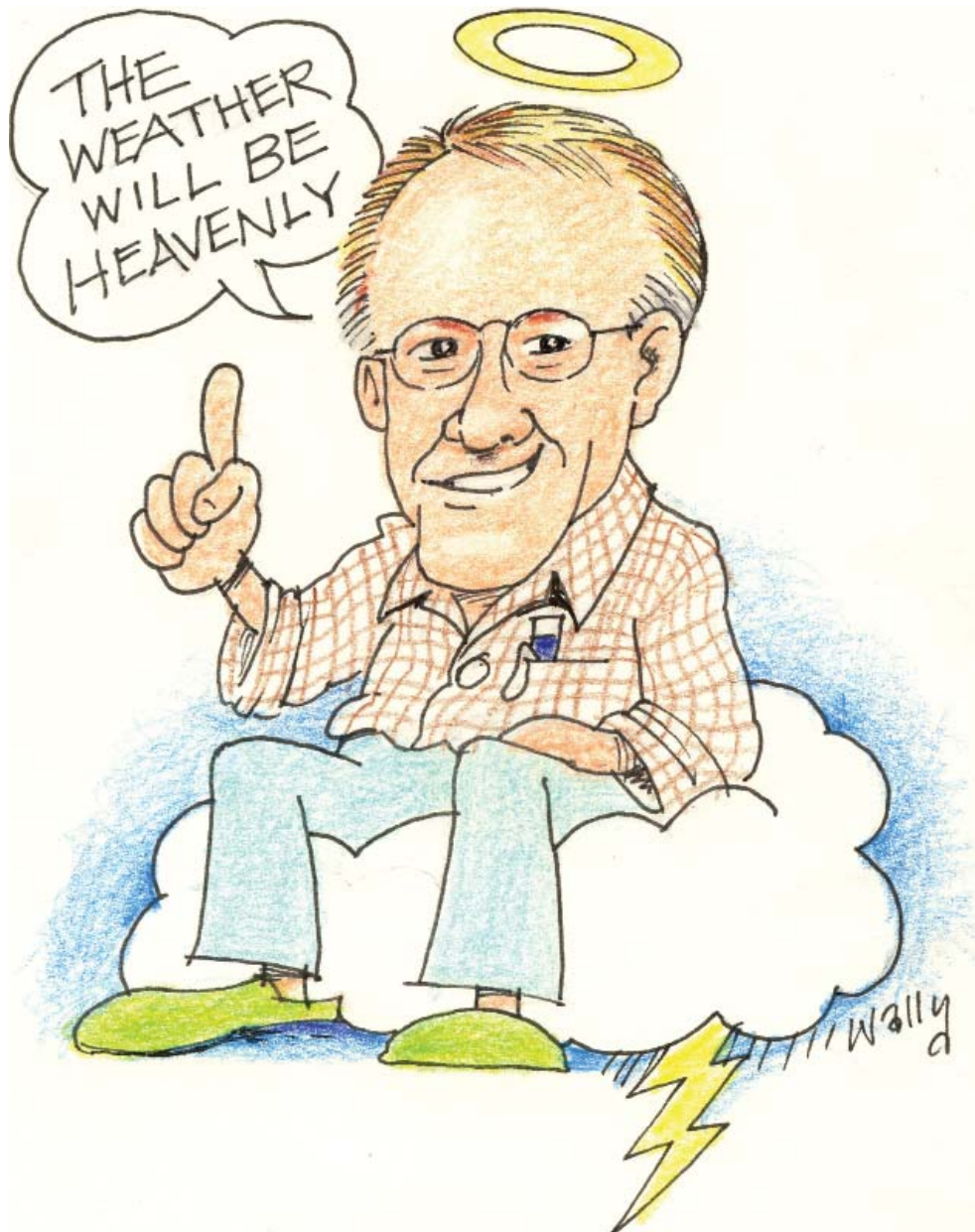
Kelly Redmond represented a kind of person and scientist that is altogether uncommon, combining a keen inquisitive nature with great stability and even keel. Sure, he possessed the ability to wander a sinuous conversational path or presentation as well as the next curious intellectual, but always his next comment could snap back to the crux of the matter with razor-sharp agility. Kelly understood the Big Picture in ways that few of us do, and knew how each of the little parts fit into it. More importantly, he cared about all of them. Kelly cared about young and old alike, and was not above investing his personal time in letting folk ramble on with crazy ideas. After patiently listening, he would share a few of his own—fostering interchanges that were not bounded by scientific or political dogma. Kelly lived beyond such restrictions, and his personal and scientific legacies reflect that transcendence. He maintained a selfless vision of people and the world that drove his actions, and while the first abrupt hospital bed detour forced deep reflection and a certain re-prioritization, he never wavered. In fact, Kelly’s last years with us may have brought out the best Kelly. May all of us keep the example of Kelly’s grace with us now, as we continue the journey.



Tufa in dusk light, Mono Lake, by Kelly Redmond, August 2014.

Bob Westfall, USDA Forest Service

I've observed that he engaged with everybody. That was especially evident at AGU and PACLIM poster sessions. Any comments he made were straight to the point. I also appreciated his wry humor—he expressed that both in his presentations and in conversation. He still showed that at *MtnClim 2016*, even though he was obviously in pain. Also—even though he held a very important and prominent position, he carried himself as an ordinary guy.



Kelly Redmond, by Wally Woolfenden USDA Forest Service (retired), November 2016



Kelly T. Redmond

Applied Climatology Award



*For his vision and dedication to the advancement of climate services, scientific contributions to applied climatology, and promotion of climatic issues unique to the Western United States
August 2008*



Kelly's poster award for the Applied Climatologist, by the American Meteorological Society, August 2008

Reprinted from Autumn 2014, *Mountain Views*.

An Interview with Kelly Redmond; 2014 Awardee of the Tyndall History of Global Environmental Change Lecturer, American Geophysical Union

Kelly Redmond is Regional Climatologist and Deputy Director of the Western Regional Climate Center, and Research Professor in climatology at the Desert Research Institute, Reno, NV. This summer he was selected as the “Tyndall History of Global Environmental Change Lecturer” for the Fall 2014 meeting of the American Geophysical Union in San Francisco. This award recognizes the life and work of physicist (also mountaineer), John Tyndall, whose measurements in the late 1850s and early 1860s verified the importance of the greenhouse effect that had been proposed by Fourier in 1824. Kelly was selected as Tyndall Lecturer in recognition of his outstanding contributions to understanding of global environmental change. Specifically, this lecture focuses on the development of the science underlying global environmental change and provides a historical perspective. Kelly will deliver his lecture during the December meeting (Thursday afternoon, Dec. 18), which will also be available as a webcast and as an archived presentation on the AGU website. As a founder and key coordinator of CIRMOUNT we are tremendously excited about this award, proud of Kelly, and offer our sincere congratulations. We look forward to his thoughts in the Tyndall lecture as we do his insights on all things climatological during the many other lectures Kelly presents annually.

—Editor



“The wind is a musical instrument with a certain range of tones, beyond which in both directions we have an infinite silence”

—John Tyndall

Connie: Give us some personal history – what first got you interested in climate as a research focus and what motivated your passion to communicate climate information and knowledge so broadly?

Kelly: I grew up in Southwest Montana in Belgrade, next to the Bozeman Airport, where my dad worked for the FAA for 27 years as a Flight Service Specialist. He also recorded the official weather records for BZN airport during this time. In Montana, everybody a) is interested in the weather, or b) is dead. My dad had a lot of weather material from his training, and I memorized it all. I remember well a 5th-grade science project on clouds. My freshman advisor at MIT, Fred Sanders, was a highly respected and motivated meteorologist. As a physics major (astrophysics, which I still follow closely) I took some courses in meteorology, and hung around the map room often. My undergraduate advisor, Rainier Weiss, who along with Kip Thorne was one of the two co-founders of today's LIGO project, told me that he considered climate prediction to be among the hardest problems in science. This just totally intrigued me, because I love hard problems. Astronomers are often clouded out; rather than look **through** the atmosphere, I decided to look **at** the atmosphere. Further, I am interested in every part of Nature, and climate eventually touches all other earth science disciplines, has deep connections to fundamental processes, is strongly nonlinear, and is hugely important to society, so this appeals very strongly to me. My basic affliction is an interest in everything, something that Richard Feynmann called “the pleasure of finding things out.”

As state climatologist for Oregon for 7 years, I had about 35,000 one-on-one conversations with people from every walk of life about nearly every facet of climate. Maybe 10-20 of these conversations were about climate change; the large majority was just about the ongoing effects of climate variability. I always

received a lot of positive feedback from these encounters, and spent more and more time giving talks and presentations, always very well received, which provided further encouragement. Also, I feel very strongly that society does not support science and climate studies just so that we can indulge our personal passions (although, it should for that reason as well), but so that it will receive useful payback on its investment. Also, it is a wonderful challenge to learn how to transfer intact a thought from one mind to another. It helps greatly that the public has a direct and intimate connection with climate and weather, a natural and major advantage for our profession.

Connie: OK, great. Like John Tyndall, mountains are clearly important in your work. In what ways do you find mountain climates – their process, patterns, and challenges -- so compelling?

Kelly: I grew up in the beautiful Gallatin Valley, something I would not trade for anything, surrounded by mountains on every horizon, spent many days in them with my four brothers and my mom and dad. I was fascinated by the way mountain weather could be so different from that out in the middle of the valley. Mountains make their own weather, and modify much of the rest of weather. There are exceptionally sharp spatial gradients in so many atmospheric and climatic properties, something not widely appreciated by those who do not live, work, and play in such surroundings. My job covers the 11 western states and Alaska and Hawaii, with mountains galore and complex topography a defining property of that entire region. It's one of many reasons why I really love this job. Throughout the West, we are strongly affected by mountains, even if we do not directly live in them. And there is the simple fact of how inspiring they are. Meteorology becomes far more complex in such terrain, and more difficult to observe. We specialize in observations, and mountain observations probably take 2-3 times, or more, effort and resources to produce successful high quality measurements. We also suffer from insufficient density of long-term high quality observations, because of the many difficulties involved.

Connie: What do you see as urgent problems to be tackled or needs to be addressed in the near future in relation to our work in mountain climates and ecosystems in order to make important progress on societally critical issues of anthropogenic global warming?

Kelly: We need to learn how mountain climates work, fundamentally, in the absence of climate change. Climate change is simply another source or type of variability. An important issue is how large-scale patterns (global, continental) of atmospheric variability translate to the small-scale realm (meters



Kelly shares a light moment with Chris Daly at the recent *MtnClim 2014* conference. Photo: Scotty Strachan.

to a few kilometers) in complex environments. Orographic enhancement of precipitation is affected by topographic details, wind patterns, vertical stability, and other subtle factors, a subject about which we need to learn more. Elevation and aspect effects on insect pests and pathogens are still in need of further understanding. Mountains reach up and "grab" water from the sky, and serve as reservoirs that meter this water out over the warm season and maintain base flows for streams. How will this function be affected by changes in temperature and precipitation? A big challenge is to close the surface water budget on scales of a kilometer or less. Especially important is assigning better numbers to groundwater flows and reservoirs, and better understanding the physical processes by which this is accomplished.

Mountains were once regarded as largely unapproachable and forbidding environments (e.g., read Mary Shelley's *Frankenstein*). Improved physical, and now electronic, access has greatly changed this attitude. Now, by contrast with the past, mountains are increasingly being populated, with pushes to higher elevations, and the wildland-urban interface, and the exurbs, are leading to fire and wildlife issues in places where formerly few people lived. Climate change, and warming temperatures, may act as a force driving people to higher and cooler elevations. For much of human history, mountains were regarded as mysterious and sacred places. In my own view, this latter distinction may have decreased, even though (again, my view) we should be regarding all of Nature, all biomes and climates and settings, as sacred.

Connie: How would you suggest CIRMOUNT scientists can contribute best to these challenges?

Kelly: The MtnClim Conferences are one great tradition to keep going. We might be ready for a next rendition of Mapping New Terrain [CIRMOUNT's early document], though many things in that publication are still relevant and timely. Keep up a tradition of interdisciplinary communication. Mountain Views Newsletter is one of those forms of communications, and you all have given an excellent start and example to that. Continue to advocate for monitoring.

Connie: So what about the El Niño we hear about for winter 2014? Isn't summer too early to be predicting ENSO? [I had asked this question earlier this year to Kelly]

Kelly: As of this writing (early Nov 2014) a weak to moderate El Niño still seems on track. This year a potential El Niño for winter 2014-15 was suggested at a very early lead time (May or so, highly unusual), leading to much speculation about a possible strong El Niño come winter. Then the situation slipped during summer as El Niño, especially a strong version, appeared much less likely. In the last few months, models and other signs have

consistently pointed to about a 2/3 probability of a weak to moderate El Niño. The ocean temperatures have been showing mildly warm conditions in the ENSO area on the equator, giving credence to expectations of a minimal to modest El Niño. As we have pointed out in a recent fact sheet, various indicators caution us not to expect a savior on a white horse in the form of El Niño to end the severe drought conditions. El Niño is only one factor that can affect western U.S. winter climate.

Connie: Anything else to add in light of your Tyndall Award and its significance?

Kelly: I am very much honored and surprised by this. It's an excellent fit to my interests. Tyndall worked on three main facets: the physics of radiative transfer in the atmosphere (CO₂ effect), he was a lifelong accomplished mountaineer and has a peak named after him in the Sierra Nevada, and most importantly he felt a duty to translate science to the citizenry and took this responsibility very seriously. This award gives me motivation to expand my thinking on several fronts, and the talk will be something of an experiment.



Kelly atop Hardscramble Peak looking northwest. Bridger Mountains, Montana. Photo: Patrick Redmond.

INTERVIEW

Dave Clow is a respected USGS research hydrologist with the Alpine Hydrology Research Group in the Colorado Water Science Center Group, Lakewood, CO. With over 25 years of experience in alpine hydrology, geochemistry, and geostatistics, Dave's interests have focused on effects of climate change for water resources in mountains of western North America and sensitivity of alpine ecosystems to atmospheric pollution. Given that "Mountains Without Snow" is a topic of high current attention in the mountain-science community and was the theme for the recent MtnClim 2016 Conference, I thought to corner Dave with questions about his career in mountain hydrology, and for his perspectives about mountain water research and resources in the future.

—Editor



Connie: What questions and/or research problems are attracting your current interest and attention in regard to mountain hydrology?

Dave: One of the key questions that our group is currently working on is how water, nutrient, and carbon cycles interact with each other, and with changes in land cover and climate. These interactions are complex, and have a strong influence on how ecosystems respond to stressors, such as climate change and atmospheric deposition of nutrients and acids. These issues have important implications for ecosystem health and carbon sequestration in natural environments.

Connie: What has been your professional path to this research – well, what I mean is: have you always been focused on these topics or have your interests and research directions changed significantly over the course of your career? Can you identify a time in your earlier life when mountains and water/snow studies first captured your interests?

Dave: In my early career, acid rain was a big deal, and some of the first papers I read dealt with how mineral weathering affects water chemistry and helps neutralize acid deposition. Quantifying the acid buffering capacity of ecosystems was a major scientific objective at the time, but it seemed really difficult to get a handle on because so many things can affect it: bedrock lithology, and the amount and type of soil and vegetation are all important. As an aspiring geologist/geochemist, I considered soil and vegetation to be pesky confounding variables, which led me to conduct my studies in the alpine zone, where the effects of soil and vegetation could be minimized. Fortunately, I've come to appreciate soil and vegetation since then, but still enjoy working above treeline.

Connie: You've worked in many mountain regions of the west. Do some offer better opportunities to address questions and problems of your interest or are there other reasons for focusing geographically?

Dave: I've been fortunate to work in mountain across the west, which are incredibly diverse. The Rocky Mountains have a wide range of bedrock types (sedimentary, metamorphic, and igneous) and climate, so every basin looks a little different. In the Sierra, most of the range is granitic rock, which tends to weather really slowly, so a lot of the landscape is bare rock with little soil. Because the rocks weather so slowly, Sierran streams and lakes tend to be super dilute, which makes them very sensitive to acid rain and nitrogen deposition. That's good for detecting changing water quality conditions, but bad for ecosystems subjected to atmospheric pollution.

Connie: Can you give a few examples of what you expect to be among the most significant consequences of diminishing future snowpacks across western mountains?



Dave measuring snow during a legendary Rocky Mountain winter.

Dave: Approximately 1.5 billion people in the Northern Hemisphere depend on snowmelt as a water source for drinking, agriculture, and industry (Mankin et al. 2015). Of these, 10–27 million live in areas where it is likely that snowmelt will no longer be able to provide sufficient runoff to meet summer/fall demand by 2060 (Mankin et al. 2015). Changes in the timing and magnitude of snowmelt may lead to drier soil conditions and lower stream flows during late summer and fall. These changes may stress aquatic and terrestrial ecosystems, posing challenges for threatened and endangered species, and have been shown to increase the risk of large fires in the western U.S. (Abatzoglou and Williams 2016).

Connie: Related to that question: in light of changing climates and reduced snowfall and snowpack, are there areas of hydrologic research that are currently under-addressed that you encourage young mountain hydrologists to engage?

Dave: The alpine zone is under-represented in the U.S. in terms of hydrologic monitoring and research, despite its importance as a source of water and ecosystem services. Alpine environments are a challenge to work in because of harsh climate conditions and difficult access, and as a result, research and monitoring in the alpine zone has been limited mostly to a few small research watersheds. We need the energy and enthusiasm of young mountain hydrologists to test existing hypotheses in new locations in the alpine zone, and develop new hypotheses to explain the patterns we see in snowpack distribution and evolution, and in hydrochemical responses to shifts in climate and land cover.

Connie: Do you have new areas of research you would like to approach yourself in the future, or perhaps other aspects that you would like to emphasize (e.g., decision-support, education, program administration?) in the next, say, five years?

Dave: I really enjoy working with the younger scientists on my team and at local universities. They have skill sets that will allow us to move beyond our small research watersheds to develop



Dave heads to his favorite work environment.

datasets and models at regional and national scales. They have also been essential for collecting the really cool datasets that we have in Loch Vale and other small research watersheds. Working together and using data from our local, regional, and national networks, we're hoping to develop "big picture" synthesis products that will be most useful to resource managers and the public.

References

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NEWS AND EVENTS

MtnClim 2016: Serious Science in an Informal Mountain Setting

Adapted from the CIRMOUNT Blog at Mountain Research Initiative:

<http://www.blogs-mri.org/mtnclim-2016-serious-science-informal-mountain-setting/>

Connie Millar

USDA Forest Service, Pacific Southwest Research Station,
Albany, CA, USA

A central activity of CIRMOUNT is to sponsor the biennial Mountain Climate Conferences – *MtnClim*. *MtnClim* conferences aspire to advance sciences related to climate and its interaction with physical, ecological, and social systems of western North American (and beyond) mountains by providing a forum for communicating current research; promoting active integration among disciplines and of science into resource-management; and encouraging tangible opportunities for mountain professionals to network. The meetings convene at venues in rural mountain regions around western North America and maintain a relatively small attendance (~100-130), which heightens chances to interact. Formal descriptions aside, *MtnClim* is one of our community's favorite meetings – meaning we have fun, we share a lot of great science, we learn the latest in our respective fields, and we strengthen our bonds as a mountain clan.

MtnClim 2016 convened October 10-13 in the Cascades Mountains at Leavenworth, Washington, and continued the tradition of excellence established by over a decade of *MtnClim* meetings. The 7th *MtnClim* Conference (the first was held

in 2003 at Lake Tahoe, California) explored a central theme of *Mountains Without Snow: What are the Consequences?* Through invited and contributed oral and poster sessions, *MtnClim* participants investigated roles that snowpack plays in water resources, power generation, ecophysiology, and human communities, with particular focus on the question: *How ready are we to foresee the full range of consequences of mountains without snow?*

The conference began with a field trip on fire ecology of the eastern Cascade Range, led by Richy Harrod (USFS, Okanogan-Wenatchee National Forest), followed by our legendary opening keynote talk on “*MtnClim* Weather Since 2014” by Kelly Redmond (Desert Research Institute). Kelly has presented a similar round-up of recent weather patterns, statistics, anomalies (which seem always to occur), and forecasts at every *MtnClim* meeting we have held; this year brought from Kelly's monitoring data no fewer extremes, records, and unusual events than in prior years: just different ones. Ray Bradley (University of Massachusetts) presented a second keynote talk, “Elevation-Dependent Warming (EDP)”, a young topic that Ray has contributed much to pioneer and lead. I have been following his updates avidly, as the research jury has seemed out on whether EDP is occurring or not. The increasing evidence Ray presented



MtnClim 2016 participants. Photo: Scotty Strachan.



MtnClim 2016 poster hall and discussions. Photo: Andy Bunn.

from observational data worldwide, proxy records, and models convinced me for the first time that the interpretations are strong in favor of answering “Yes” to the question: Are high mountains experiencing elevation-dependent warming? Steve Wright’s (Chelan Public Utility District) keynote talk explained how climate change is likely to have tremendous effects on electric utilities in the Pacific Northwest (and elsewhere) through its impact on generation supply, the amount and shape of demand, and environmental stewardship obligations. Steve addressed the operational and policy challenges facing the industry as climates change. A final keynote talk from Tom Painter (Jet Propulsion Lab) elaborated exciting new wall-to-wall “Advances in Snow Hydrology and Water Management with the NASA Airborne Snow Observatory” (<http://aso.jpl.nasa.gov/>), for which Tom is primary architect. The data and the capacities for interpreting snowpacks and forecasting water resources from this project are staggering, and will go far beyond point data such as SNOTEL sites have provided.

Beyond these keynotes, invited sessions brought speakers to address “The Role of Climate in Mountain Lakes and Streams (organized by Jill Baron, USGS); “Mountains Without Snow—What are the Consequences?” (organized by Mike Dettinger, USGS); the Machida Session, honoring Dennis Machida, deceased director of the California Tahoe Conservancy (organized by Greg Greenwood, Mountain Research Initiative); “Why Does it Rain in Mountains?” (organized by Joe Casola, University of Washington); “Mountains Without Snow = Mountains Without Glaciers” (organized by Dan Fagre, USGS); and a post-conference Workshop for Resource Managers organized by Bob MacGregor (USFS), Dave Peterson (USFS), and Jessica Halofsky (UW). Jon Riedl (National Park Service) gave both a talk in the glacier session and also presented a special evening program of photographs that illustrated changes in glaciers of the Pacific Northwest over the past century. A large set of contributed talks and posters brought the usual array of stunning new research across a range of topics in mountain climate- and climate-related science.

MtnClim 2016 was splendidly organized and hosted by **Andy Bunn** (Western Washington University), **Scotty Strachan** (University of Nevada at Reno), and **Dave Peterson** (USFS, PNW Research Station), to whom I give my deepest thanks and congratulations. Watch for information on the CIRMOUNT website about the next meeting, *MtnClim 2018*, to be held at the Rocky Mountain Biological Lab, Crested Butte, Colorado.

Oral and poster presentations will be posted as usual on the CIRMOUNT meeting archive website. Look for them in a month or so at:

<http://www.fs.fed.us/psw/cirmount/meetings/archives.shtml>



Sleeping Lady Resort, Leavenworth, Washington, where *MtnClim 2016* convened. Photo: Courtesy of SleepingLady.com.

Yosemite Hydroclimate Workshop 2016

October 5-6, 2016, Yosemite Valley, CA

Bruce McGurk

McGurk Hydrologic, Orinda, California

Over 50 participants attended the 15th annual *Yosemite Hydroclimate Workshop* this past fall in Yosemite Valley, Yosemite National Park, CA. The weather cooperated and left Tioga Pass open, and there were no downpours on the folks who were camping in the valley floor. There was a useful session on data networks and plans, and a lunch panel on manager information needs versus research priorities and products.

Find the program here: http://www.fs.fed.us/psw/cirmount/publications/pdf/MVFall16_NewsYosemiteProgram.pdf

Presentations from the 2016 meeting are posted at: <http://www.cafiresci.org/events-webinars-source/category/yosemite-hydroclimate-meeting-2016>

And a write-up from the resource-management panel is here: http://www.fs.fed.us/psw/cirmount/publications/pdf/MVFall16_NewsYosemitePanel.pdf



PACLIM 2017: The Annual Pacific Climate Workshop

Asilomar Conference Grounds, Pacific Grove, California, March 5-8, 2017

PACLIM is a multidisciplinary workshop that broadly addresses the climatic phenomena occurring in the eastern Pacific Ocean and western North America. The purpose of the workshop is to understand climate effects in this region by bringing together specialists from diverse fields including physical, social, and biological sciences. Time scales from weather to the Quaternary are addressed in oral and poster presentations. The theme for the 2017 conference is: “Pacific meets Atlantic: Ocean-Atmosphere Interactions”

The workshop will begin this year on Sunday evening with a memorial and remembrance of Kelly Redmond, who was a longtime participant and traditional keynote speaker.

The abstract deadline is February 8th 2017.

Find information at: <https://sites.google.com/site/paclimconference/>

For questions contact the organizers, Michelle Goman (goman at sonoma.edu) or Scott Mensing (smensing at unr.edu).



Tufa towers, Mono Lake, by Kelly Redmond.

VOICES IN THE WIND

In this section, I query members of the CIRMOUNT community for their perspective on a topic of current interest. In the spirit of the MtnClim 2016 Conference theme this year of “Mountains Without Snow (or Ice)”, I posed the following question to several colleagues. — Editor

Q: Given the trend toward less snow, melting glaciers, and relatively more rain than snow in mountains (and associated effects) how does (or doesn't) this affect your research directions for the coming 5 years or so, and what new questions might you ask? Will this trend change the kinds of research technology you employ; if so, how?

Jim Roche, Yosemite National Park, El Portal, CA

We have been collaborating with the hydroclimate research community for nearly two decades and have built a framework of monitoring to examine spatial variability in snow, temperature, humidity, runoff, and soil moisture in the complex topography that characterizes the Yosemite area. Future basic research/monitoring needs include quantifying plant-available water in soil and regolith as snow ceases to be an important component of storage, as well as obtaining better measurements of precipitation across higher elevations as snow pack becomes a less reliable measure of precipitation. Science that directly supports management of these lands, however, is where real change is needed. We are watching massive die-off of lower and mid-elevation conifer forests that is perhaps a combination of California's warm drought coupled with an overdue correction due to fire exclusion (too many straws!). Activities to restore ecological function or adapt to changing rain-snow dynamics are substantially constrained by policy (fire in particular) and management designations such as wilderness, which occupies much of the snow-dominated landscape in the west. Rigorous applied science including the social and policy fields is required to develop sound management alternatives with associated probabilities for success and means by which they may be actually achieved. At present, we do well with site or species-specific science and associated treatments. Expanding our ability to address needs at the landscape level is where the next challenges lie.



Polly Buotte, Department of Geography, University of Idaho, Moscow, ID

There have always been good and bad snow years, but we haven't really seen the drastic reduction in snow pack anticipated for the future in many mountain ranges. We have seen a tremendous amount of tree mortality. This leads me to wonder...

How is high elevation tree mortality changing snow accumulation and melt patterns? Are those changes influencing available soil moisture during the growing season, which in turn is influencing tree growth and defenses? Is there a negative feedback loop in progress, whereby recent tree mortality is changing snow pack dynamics such that future water availability is further reduced, leading to more tree mortality? Will less future snowpack exacerbate such a loop? Are we seeing the start of a genetic-selection event for trees that are drought tolerant? Can we alleviate any of this potential mortality through stand management?

The prospect of no-analog future climates means we need to understand the mechanisms that result in the climate relationships we see in historical data. For example, we've found summer precipitation has an important influence on whitebark pine mortality from mountain pine beetles. But what is the mechanism? Does less available water result in poor growth, making trees a less attractive food source to beetles? Does less



water result in lower tree defenses, making them easier for beetles to kill? Both? We are basing our current understanding on a relatively snowy past. How much does the winter snow pack contribute to the need for summer precipitation? Is there a point where no amount of summer precipitation can make up for lost winter water?

How much longer will I be able to celebrate Mother's Day by going backcountry skiing? Long enough for my 9-year-old daughter to join me?

These are some of the questions that thoughts of a future with less snow bring to mind for me.

Bruce McGurk, McGurk Hydrologic, Orinda, CA

Having spent the last 20 years as a runoff forecaster and reservoir operator, I'll approach this question from that perspective. As the rain-snow line rises in most basins in the west, more reservoirs are getting increased winter inflow because less of the basin has snow. Reservoirs that are small compared to their snowmelt inflow can use that winter inflow for power generation and pass it downstream to the larger reservoirs. However, operators of the larger mid-elevation reservoirs in the Sierra Nevada, have to be more cautious about using the winter inflow. Because the snowmelt volume is decreasing, if they take too much too early, they can end up far from full when snowmelt runoff is over. This can cause higher water temperatures with their summer releases, and with less carry over they are more at risk if the next year is dry.

The shift in inflow timing places extra importance on runoff forecasting, but our input information for that forecasting is also being affected by less snow and higher snowlines. Snow courses and automated snow sensors at the lower elevations in Sierran basins are increasingly bare or subject to only intermittent snow cover. Snow cover in the next higher elevation band may also be less, so empirical equations used to predict runoff are suspected of becoming less accurate. And all the snow stations melt out earlier with warming, so the forecaster is left with little information long before runoff actually tapers off.

An important advance that is helping to compensate for the loss of snow at our historical stations is the NASA/JPL Airborne Snow Observatory (ASO). This LiDAR and spectrometer payload is being flown over all or parts of 3-5 basins in the Sierra



Nevada, as well as some basins in Colorado. ASO produces maps of depth, and by incorporating modeled density, snow water equivalent (SWE) is calculated as well. For the first time, we are measuring the total basin SWE, and the information is being used in new forecasting tools as well as being able to correct the SWE estimation in hydrologic simulation models used for daily inflow forecasting. The number of basins being flown by ASO will increase in the next 2-4 years, until finally all major basins in the Sierra will have detailed SWE information 4-8 times per winter. This new information will compensate for the loss of the old snow stations and allow managers to better understand how much water is above their reservoirs. As we better understand the losses to soils, groundwater, and evapotranspiration, operators will have greatly improved tools to respond to higher rain-snow lines and the shift from snowmelt runoff to mixed rain and snow runoff.

Meagan Oldfather, Department of Integrative Biology, University of California, Berkeley, CA

I started the fieldwork for my dissertation research during a historic drought in California. Working in these past years on the range-wide demography of an alpine plant in the White Mountains, CA has been eye-opening experience to the importance of the magnitude, timing, and type of moisture additions on alpine systems. The trend toward less snow led me to ask how longer-term reductions in snowpack will differentially influence the life-history stages of alpine plants, and the overall population growth of populations at the edges of species ranges. For example, an earlier snowmelt date may have a negative effect on life-history stages dependent on later season moisture but a positive effect on stages positively correlated with growing season length. The overall effect on the stability of these alpine plant populations could be quite complex! In addition, due to trends in both temperature and precipitation, it seems important to quantify which life-history stages are sensitive to changes in temperature and which to changes in snow pack and soil moisture. In my work I have included an experimental treatment across a wide elevation range that will enable the disentanglement of the effects of heating and increased rain on alpine plant demography and community structure.

The trends toward less snow also prompted me to extensively measure both temperature and soil moisture across the alpine zone of the White Mountains over many years. Across my study



area I use over 100 temperature data-loggers and bi-weekly soil moisture measurements to understand the effect of topography on the seasonality of temperature, snow cover, and soil moisture. With these microclimate measurements I hope to assess the spatial and temporal variability in microclimate experienced by alpine plants across the landscape. This variability can be quite high in alpine environments, demanding long-term monitoring of these microclimate variables.

These observations have led me to many additional questions that I hope to address in my future research including: Do strong monsoonal rains ameliorate the effects of low snow years on alpine plant population stability? How does alpine plant physiology and demography respond to longer mid-winter periods with no insulation from snow cover? How might alpine species respond to a shift from temperature-limitation to moisture-limitation at their range edges?

Jeff Hicke, Department of Geography, University of Idaho, Moscow, ID

Snow plays a major role in influencing forest structure and function through availability of moisture for growth and decomposition and through effects on forest disturbances. The effects of climate change that reduce snowpack and advance snowmelt lead to longer potential growing seasons but longer periods of summer drought in some locations such as the western US. The longer summer drought means that trees experience a greater respiration cost but don't make up for this in terms of increased growth because of limitations associated with soil moisture availability and/or evaporative demand. Thus, trees in the western US are likely to experience greater drought stress every summer. Opportunities for extreme drought that causes tree mortality or severe growth reductions are then higher. The higher stress suggests that trees will be more susceptible to attack from insects and pathogens. Many tree species have evolved defenses against these enemies, yet a stressed tree may not have the resources needed to fend off attack. Finally, wildfires in these systems are likely to be larger, more frequent, and more severe as a result of the longer fire season and drier fuels.

Key questions related to precipitation and forests that I am interested in include the role of insects and pathogens in tree mortality associated with increased stress. How important is

increased summer stress in initiating or driving outbreaks? We know that severe droughts in the early 2000s and in the last few years killed many trees. Can outbreaks arise because of increased annual drought? If so, for which insects and pathogens? Some of these disturbance agents require stressed trees, others (especially some pathogens) do better under moister conditions. How stressed will trees become in late summer given a reduced spring snowpack? This is particularly relevant in many areas of the western US that experience little summer precipitation. Will snow droughts (normal precipitation but reduced snowpack) lead to tree mortality, either through direct physiological means or indirectly through insects and pathogens? Addressing these questions will lead to a better understanding of the ecology of forests in the western US. In addition, such understanding will increase the capacity for vegetation models to simulate these disturbances given future climate change.

Jessica Lundquist, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA

Professionally, I've accidentally started studying melting glaciers (instead of my usual seasonal snow) because those were the dominant signal in the 2015 streamflow in both Yosemite and Olympic National Parks. I've deliberately been studying mountain precipitation (both rain and snow) for a while, and recent patterns have made me much more interested in the seasonal timing of rain. If we get rainfall at a time of year when we typically get snowmelt, we're actually okay from a water resources perspective. But forecasting future spring and summer rain is a lot more tricky than forecasting melt amounts from winter snow that's "already in the bank." To do this, I need to learn more meteorology related to summer convection, monsoon moisture transport, and paleoclimate. Since that's a lot of background to acquire, I'm focusing on snow surface temperature in the immediate future. Modeling snow melt that occurs in the winter is harder than modeling snow melt in the spring because one has to accurately know when the snow is "ripe" to melt vs. cold enough to just absorb extra energy or extra rain. To be able to model this right, we need to measure the snow's temperature, which we can fortunately do with thermal remote sensing.



Lorrie Flint, California Water Center, U.S. Geological Survey, Sacramento, CA

As we watch the current snow trends in the west we're already asking some pertinent questions. What if all the precipitation fell as rain, how would the hydrology change? If we consider mountains without snow, some first pass analyses are suggesting that for most snow covered locations throughout the western US, if there were no snow cover in the future, there would be more recharge relative to runoff in comparison to current snow covered conditions. Additionally, when snow melts earlier in the season, it melts more slowly because the sun is lower on the horizon. This all has a lot of implications for water availability, in many cases positive because recharge is more resilient to climate than runoff. However, existing infrastructure for water supply, for both people and fisheries, is based on historical climatic patterns. Early snowmelt also lengthens the dry season and accumulates more deficit, making the forests a tinderbox. These findings, along with the recent drought in the west, are pushing our research in a direction to develop an understanding of how changes in climate impact the underlying hydrologic mechanisms, including how changes in snow cover and timing of snowmelt play a role in the relative occurrence of runoff and recharge. Most of these analyses employ computer modeling, so I suspect that advances in computing and storage would be the most obvious changes in technology required, although remote sensing with the associated ground truthing, is becoming more and more relevant at the large regional scales that we study.



Don Falk, School of Natural Resources and the Environment, University of Arizona, Tucson, AZ

As a mountain pyro-dendroclimer, I think a lot about systems that are in disequilibrium. Changing precipitation regimes, coupled with increasing temperatures, are altering the template for fire to move up into parts of many mountains that haven't seen much fire for a long time, or for different kinds of fire to be expressed on the landscape. We have reason to anticipate increasing fire size and severity, and post-fire recovery will be taking place in a climate that is very different from the one in which these forests established originally. To me that suggests the likelihood of fire-climate interactions driving many systems past tipping points into new alternative metastable states, about which we know really very little. Are these alternative states "permanent" (*sic*) or transient? And what, if anything, can we do to alter these trajectories?



FIELD NOTES

Llamas and Lytles: Unexpected Mountain Meetings

Scotty Strachan
University of Nevada, Reno
Reno, Nevada

You never know whom or what you are going to run across when out doing fieldwork. The craziest things can happen (I think of my pal Naked Ben and his Cow Shower adventure), and you may see the most unlikely events (like when I saw fighter aircraft collide, and then assisted the ejected pilots). But some of the most lasting memories from fieldwork come from people you meet. People that come from all walks of life and turn up in the least expected places. Some of these meetings simply result in a great tale (i.e. Crazy Bob and the Lizard Hunters), but every once in a while you cross paths with folks who become friends for life. The hardened field scientists reading this are thinking, “Yeah, I’ve got enough stories to fill a book myself. Tell us something we don’t know, eh?” But for the younger crowd or the student, it would be well to prepare your mind to not only encounter the wild and crazy in the field, but also make lasting and impactful acquaintances. The lesson here is to not take anything for granted in the field. Such has been the case for me more than once, but nowhere more obviously than when I ventured into an obscure corner of Nevada called Little Spring Valley (Fig. 1).

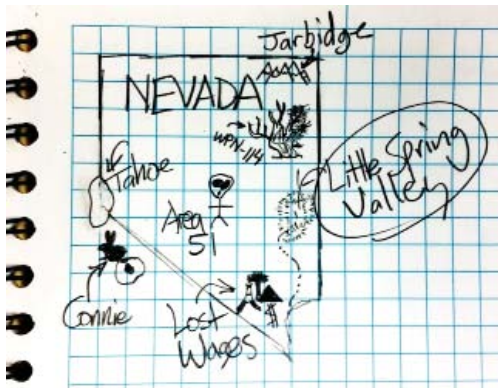


Figure 1. Map of the state of Nevada and the location of Little Spring Valley.

Back in '08, I was drafted to assist in field scouting and sampling for a project incorporating tree-ring work in southeastern Nevada. Ever the consummate palaeo bird-dog, I packed a couple of vehicles with tools and grad students, and off we went. Our travels took us to many interesting nooks and crannies, but Little Spring Valley was a primary target because it serves as the headwaters of the mighty Meadow Valley Wash. Unlike most of the Basin & Range, the mountains surrounding Little

Spring Valley actually form a closed horseshoe layout rather than remaining openly parallel in classic regional style. Accordingly, we sniffed out several locations around the rimming hills for old-growth pine trees to serve as tree-ring proxies of moisture input to the region (Fig. 2).



Figure 2. The Meadow Valley Wash flows year-round from Little Spring Valley, and provides water for a large group of historical agricultural communities.

To serve as a base camp, we set up shop in Spring Valley State Park, which maintains a small reservoir for fishing and associated developed campgrounds. I decided to query the local rangers about the possibility of coring trees within Park lands, as it turned out that a small population of *Pinus ponderosa* were taking refuge on certain areas of ash flow tuff geology. While ponderosa pines are generally known to inhabit the region, the populations that have survived the Holocene and post 1850's timber cutting are widely dispersed in this part of the world. A visit to the Park headquarters and a discussion with the folks there netted us permission to sample the trees, providing that we informed them later as to the age characteristics. I agreed readily to this, and proceeded on our first little sampling expedition that afternoon. The trees were spectacular in appearance, and later proved to have several old (~500 years) individuals in the ponderosa population, but in the end the chronology was not as useful as the other *Pinus monophylla* populations for hydroclimatic information due to the perched geology (Fig. 3).



Figure 3. Scotty cores an isolated ponderosa pine in Spring Valley State Park. Photo: Kurt Solander.

The next day, we rambled farther afield to the north end of the mountain horseshoe in search of ancient pinyon pine. My team took a winding dirt road past historic ranches and fields up Camp Canyon. The watershed we had in mind was a good 90 minutes from our base, and off the beaten path a little. At last we came around a bend to view, surprisingly, a grassy field with a number of emu grazing about. Off to one side, a small ranch house presided over this exotic scene. We wrote it off as a lingering effect of the “emu craze” of the 1990’s, and continued up the canyon. We reached the toe of a wooded ridge that looked pretty decent from the tree age perspective (ITRDB Rule #8: tree-ring chronologies are 95% likely to be within 1 kilometer of navigable roads), and went for a walk. We sampled medium- and old-age single-needle pinyon pine up the ridge and over into a side drainage with a number of nice specimens hidden among some rolling outcrop formations (Fig. 4).

We collected a satisfactory number of cores from 30 different trees, and then dropped into the wash to make our way back to the main canyon. It was early afternoon, and the summer wind was hot and dry. The chit-chat between our crew was kept lively by the sharing of a Gatorade™ bottle that someone had thoughtfully dropped in their pack to augment our water supplies. We bantered along down the dusty single-track stock trail at the wash margin, occasionally pushing great sage branches out of the

way and inhaling the wonderful scent of the Great Basin. Now, it is not unusual to run across free-range cattle or invasive horses in these situations, but I will admit it was a bit of a shocker to round a turn and come face-to-face with, of all things, a pair of llamas. I was in the lead and hit the brakes hard, trying to come to terms with the fuzzy faces looking at me, completely out of context. There seemed to be a twinkle in the creatures’ eyes as the rest of the crew piled into me and stared back. There was no sign of an owner or human guide – these llamas were free to do as they pleased from Pioche to Panaca. Not sure how they would react to this abrupt meeting in the wilderness, I took a hesitant step forward and greeted them, “Why hello there, what are you doing in this part of the world?” The llamas continued to gaze with raised eyebrows, and I wondered if the reply would be an infamous salivary delivery. After some long seconds, the creatures had mercy and departed down the trail in front of us. We watched this strange sight not without a bit of incredulity, and then followed. They outpaced us however, and by the time we reached the main canyon they were nowhere to be seen. They had vanished into the sage and woodland as if they belonged to the desert country. We packed into the truck, with Alex summarizing, “Well, that was random!”



Figure 4. One of the author’s specialties is sniffing out the ancient *Pinus monophylla* of the Great Basin, and this site was no exception. This tree went 578 years, and was well-behaved with only 15 locally absent rings. Photo: Kurt Solander.

Reversing our drive, we made it back to camp earlier than planned, around 4pm. This turned out to be fortuitous, as a handwritten note was left on our picnic table: "If you are the ones from UNR doing tree samplings, Farrel Lytle might have some valuable information from you. You might want to contact him." A sketched map accompanied this curious tip, apparently referencing the small agricultural community of Eagle Valley downstream about 4 miles from our campground (Fig. 5). I looked around the group and shrugged, "Well, we've got a couple hours until dinner. Who wants to go see what's up?" This decision to explore the human geographical dimension of our study area would influence my career trajectory as a scientist.

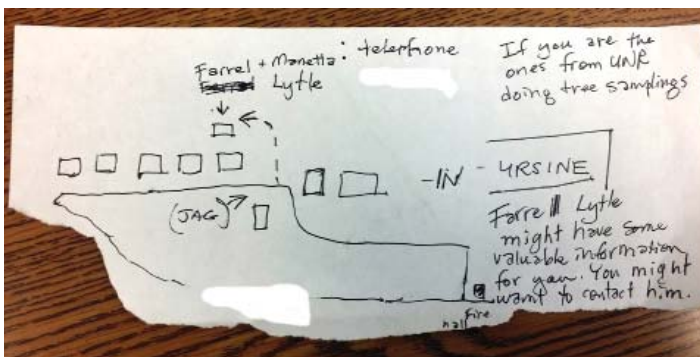


Figure 5. It turned out that Andrew Porter, a young local ranger and Lytle relative, left this note at our camp leading the way to the Lytle homestead.

After locating the Fire Hall, the rest of the detective work wasn't too hard, and we soon pulled into a dirt drive that was lined with 8-foot tall juniper stockade fencing. Behind this deer- and bunny-proof barrier was a beautiful two-story house of classic ranch design but newer construction, a lush green lawn, and about a half-acre of various greenery hinting at a diverse gardening effort. I stopped the truck near a posting that read "Varmint Hunter Parking Only" and walked through the open gate and up to the broad porch, leaving my companions in the vehicle for the moment. I reached the front door without any dogs or shotguns taking out my ankles, so I took this as a good sign (Fig 6).

Figure 6. Scotty, Manetta, and Farrel outside their home in Eagle Valley.



A knock on the door revealed a gentleman around his 70's, a straw hat, and a neutral but friendly expression. I may have interrupted a foray into the garden for weeding. I hurriedly explained: "Hello, I'm looking for Farrel Lytle. I'm Scotty, and I'm from the University of Nevada in Reno. We're studying trees and climate around here, and we were told by the folks at the State Park that you might have some interest in what we are doing...." I trailed off as the reaction was not immediately obvious. Farrel's eyes moved from me to the truck outside the gate, and then to my field garb. Then, "Oh, you're from the University are you? Tree rings? I'm interested in dendrochronology. Tell your students to come over and have a seat." He indicated the porch seats before turning back inside. I nearly had to peel my eyebrows off my hat brim on the way back to the truck – I'd never heard the term "dendrochronology" brought up by a local Nevada resident before, let alone pronounced correctly. This would be a curious meeting indeed (Fig. 7).



Figure 7. The Lytles have a fantastic annual garden, and take the business seriously.

The next two hours involved discussions of tree rings, drought, and solar cycle harmonics as we chatted in the gathering shade of late afternoon. Farrel also relayed recollections of his time as a student at UNR in the 1950's, where he earned a Master's degree in chemistry out of the same building that I am still based in. It turned out that both he and his wife Manetta (who also holds a degree from UNR) descended from settler families in the local area and eventually ended up in Seattle as Farrel managed a career as a senior research scientist for Boeing. "In fact," he commented, "are you familiar with the Fast Fourier Transform procedure? That's what we used for analysis of the EXAFS phenomenon. It works in dendrochronology too." Farrel had led the breakthrough team that pioneered a crucial technique in elemental analysis using x-ray spectroscopy in 1971. As I later discovered, this down-to-earth rural Nevadan is a AAAS Fellow, recipient of several awards in his fields of science, and developer of techniques still used in every synchrotron light source in operation today. Needless to say, I had expected a laid-back afternoon following our sampling efforts, rather than the in-depth discussion that took place on the Lytle's porch!

As it approached dinnertime, Farrel brought us through his garden for some early-season vegetables. After picking a bag full of ripe-looking items, we said our goodbyes and promised to return. Back at camp, Alex pulled out his fishing license and scavenged some cast-off line and hooks from the reservoir beach ("I had no idea there would be fishing out here!"). In less than an hour, as we were chopping the vegetables, he showed back up with a spectacular trout, which rounded out the day nicely (Fig. 8).



Figure 8. Alex caught this fine fish and we all had a taste.

After that first visit, I have been back many times to visit Farrel and Manetta. Several follow-up tales are now embedded in my memory of Eagle Valley, including the Decadal Apple Crisp, Dendroarchaeology of the Ancestral Twin Boarding Houses, Pioche Labor Day BBQ, the Case of the Disappearing Corn, Legendary Lurch the 1954 Chevy, and the Spooky Solar-Active Petroglyphs. Gee whiz, gang! The main contribution of the Lytles to my life, however, has been their friendship and encouragement as I dove headfirst into graduate school and finally emerged, worn down but successful, eight years after the events of this story. Farrel took the role of a "retired science advisor" seriously, keeping a steady stream of articles, books, and questions coming my way. The day that the new edition of Don Grayson's treatise on Great Basin prehistory arrived in my mailbox from Farrel was definitely a special one. Even better was when the Lytles showed up at my doctoral defense, having driven all the way across the state. That alone was motivation to pull off a decent presentation! Farrel's personal stories of defeating school and research hardships by persistence stayed with me and still help today. The concept of constantly exploring new avenues of investigation and thinking outside my specialty has been repeatedly reinforced by the Lytles' example. Plus, seeing over 60 years of anniversaries in action is a real treat. I'll always be in debt to them; fellow Nevadans that I never would have met except for fieldwork and curiosity (Fig. 9).

** Except as noted otherwise, photos are by the author.*



Figure 9. The Lytle's garden is ever open to visitors and friends, and Farrel has forgotten more about semi-arid farming than I am certain I will ever learn.

DID YOU SEE IT?

This section of Mountain Views relates sense-based encounters of mountain weather, climate, and environments. Wally Woolfenden has contributed articles and artwork to prior issues of Mountain Views. His remarkable new pastel, “Spring Thaw” prompted me to invite him to develop a brief explanation of sun cups, which he shares here. —Editor

Sun Cups: The Beauty of Mathematics Illuminates the Beauty of the Patterns of Nature

Wally Woolfenden
*Retired, USDA Forest Service
Bishop, California*

Most of us who tour the alpine heights of the mountains during summer have seen suncups and know how difficult is to hike their hollows and ridges (Fig. 1). We’ve noticed their internal luminosity with colors of turquoise and violet, and yellow reflections from open ground (Fig. 2). It is commonplace knowledge that they are formed from the sun’s radiation, which warms and melts or sublimates the snow during summer. Hence the term, “sun cups”. They have less poetically been termed “ablation hollows”.

Observations and experiments led to several, sometimes contradictory, qualitative ideas about the formation of these quasi-periodic snow ablation polygons, as similar patterns seem to result from different causes. Direct and reflected solar radiation is considered by many researchers to be the primary source of heat, resulting in surface instability due to more reflected light at the base of a depression and, therefore, faster

melting than the peaks. Other postulates are that air is the primary heat source that promotes suncup growth with warmer air temperatures and higher wind speed augmenting growth; it was noticed that they do not grow in direct sunlight and disappear when solar radiation is greater. Researchers have also suggested dirt as a variable driving suncup formation. Since a thin layer of dirt on snow speeds up ablation by inhibiting reflected light and thicker dirt slows ablation, as snow ablates, dirt accumulates on higher surfaces and the thinner dirt remains on lower surfaces causing hollows to deepen and ridges to form.

These observations and experiments on ablation structures, however, the mechanics of their formation and their shapes, had not been quantified until physicists proposed a few mathematical models (Betterton 2001, Tiedje, et al. 2006). The process of suncup formation is very complex so the models use only the essential, simplified, and approximate factors. Both models consider the evolution of variable surface topography of snow from initial conditions based on diffusive smoothing (Betterton) and Gaussian-smoothed white noise (Tiedje, et al.), which interacts with the absorption and scattering of sunlight leading to differential radiation intensity, instability and formation of ablation structures. Betterton also developed a model for the dynamics of dirt on snow, which calculates the effect of dirt thickness on light wavelengths and rate of ablation. Although the models simulate observed conditions fairly accurately the authors acknowledge that some important physical processes may have been overlooked due to shortcomings in predictions and suggest the need for field experiments.



Figure 1. Wally climbing to Mt. Abbot cirque, Sierra Nevada, California, while avoiding nascent spring suncups. Photo: Gary Milano.



Figure 2. Spring Thaw. Pastel by Wally Woolfenden.



Figure 3. Suncups on Mt. Conness above Alpine Lake, July 17, 2016. Photo: Connie Millar

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- Betterton, M.D. 2002. Theory of structure formation in snowfields motivated by penitents, suncups, and dirt cones. *Physical Review E*, 63, 056129: 3-12.

CONTRIBUTING ARTISTS

Bob Coats is a Research Hydrologist and Principal of Hydroikos Ltd. in Berkeley, CA. Bob has been studying climatic, hydrologic, and ecological processes in the Lake Tahoe Basin—and writing poetry—for more than 40 years. His poems have appeared in *Orion*, *Zone 3*, *Windfall*, *The Acorn*, and the *Pudding House* anthology, *Fresh Water: Poems from the Rivers, Lakes and Streams*, *Harsh Green World*, and elsewhere. See Sugartown Publishing for Bob's recent book.

Adrienne Marshall has interests in hydrology, watershed studies, and mountain systems and is pursuing a PhD in Water Resources at the University of Idaho, Moscow, ID. Adrienne is an avid mountain walker, and has spent considerable time in the Sierra Nevada of California, where she sketches mountains, lakes, skies, trees, and animals. You can view paintings on her gallery site at: <https://adriennehikes.wordpress.com/>

Dirk Schmeller is a Senior Researcher in the Department of Conservation Biology at the Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany and leader of the Belmont Forum P3 project, summarized in the Belmont

Projects section. Dirk is also a passionate amateur nature photographer and documents his work in the Pyrenees and elsewhere. He has a foible for mountain panoramas, but also likes macro photography.

Wally Woolfenden is retired paleoecologist and archeologist formerly with the US Forest Service, Pacific Southwest Region, California. Wally's research focused on vegetation and climate reconstruction using pollen from sediment cores of lakes, including the 800,000 yr Owens Lake, California record. Wally's geosciences training gives him ample expertise to read the geomorphology as he passes through the landscapes of his Sierra Nevada homeland.

Jeff Wyneken is a manuscript editor based in Albany, CA, and works for Stanford University and University of California Presses as well as private clients. He often undertakes book projects in their natural history and physical sciences divisions. A veteran field assistant to the *Mountain Views* editor, as well as a devoted mountain trekker, he takes advantage of the mountain scenery through which he walks for his photography.



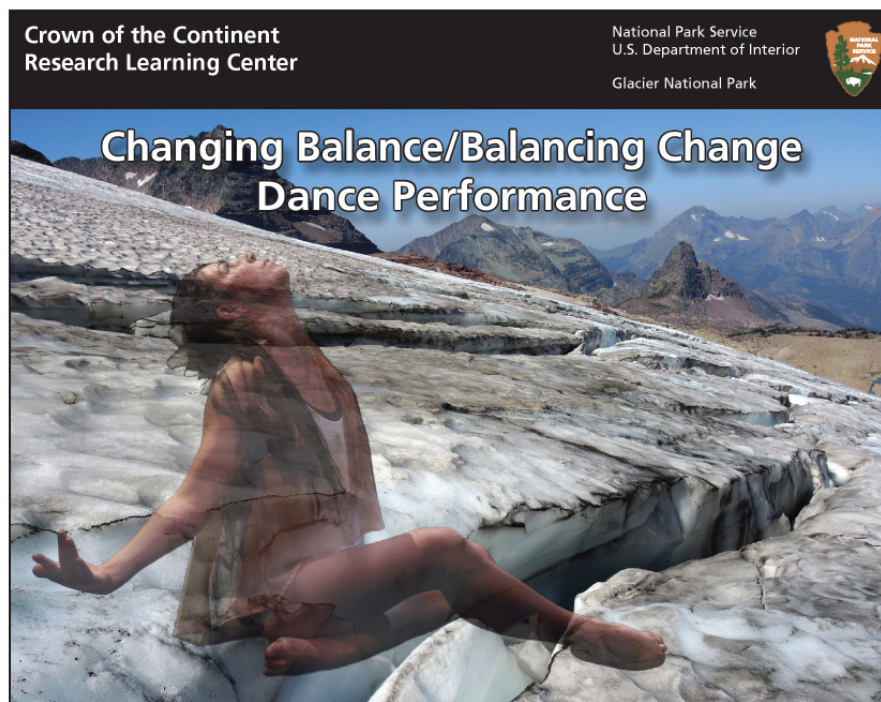
Rubber rabbitbrush (*Ericameria nauseosa*) in central Nevada, by Kelly Redmond

MOUNTAIN VISIONS

Although these performances occurred last summer, the concept seems important to share, in that art and dance have great capacity to communicate science and motivate social response. Hopefully there will be more projects like this.

Changing Balance/Balancing Change

Changing Balance/Balancing Change was a dance performance that explored climate science and climate change impacts occurring in northwest Montana. The CoMotion Dance Project, from the University of Montana, was commissioned by the Glacier National Park Conservancy to create this new, interactive performance that examined current and predicted changes impacting our planet. Using visible changes in Glacier as a fulcrum, the piece communicated basic understandings about climate change in the Northern Rockies and provided a framework for dialogue. The piece wove artistic dance, original music, choreographed narration, video projection, and live interactions with the audience into an immersive arts experience designed to engage audiences with the ideas and emotions at the heart of climate change. Developed for all ages, *Changing Balance/Balancing Change* included content such as rate of temperature change, greenhouse gases, and positive action we can take in response to the realities facing our planet.



Performance Dates, Times, and Locations

Sunday, July 24: Lake McDonald Lodge Auditorium at 8:30 p.m.

Monday, July 25: Lake McDonald Lodge Auditorium at 8:30 p.m.

Wednesday, July 27: West Glacier Community Building at 8:00 p.m.

Changing Balance/Balancing Change is an hour-long dance performance that explores climate science and climate change impacts occurring in northwest Montana. Brought to you by the CoMotion Dance Project, the piece weaves artistic dance, original music, choreographed narration, and live interactions with the audience into an immersive arts experience designed to engage audiences with the ideas and emotions at the heart of climate change.

Sponsored by: Glacier National Park Conservancy, Glacier National Park, University of Montana-UM Grant Program, Cadeau Foundation, CoMotion Dance Project, Bear Run Studios, LLC, Montana Cultural Trust, & U.S. Forest Service-Rocky Mountain Research Station

Free and open to the public! For more information, contact 406-888-7894 or www.nps.gov/glac/learn/climatedance.htm

Studies in Granite

Moonlight on Kearsarge Pinnacles, Adrienne Marshall



Half Dome, Yosemite National Park, Kelly Redmond



Second Lake, The Palisades, Sierra Nevada, C.A, Jeff Wynneken



Study in Granite, Wally Woolfenden



