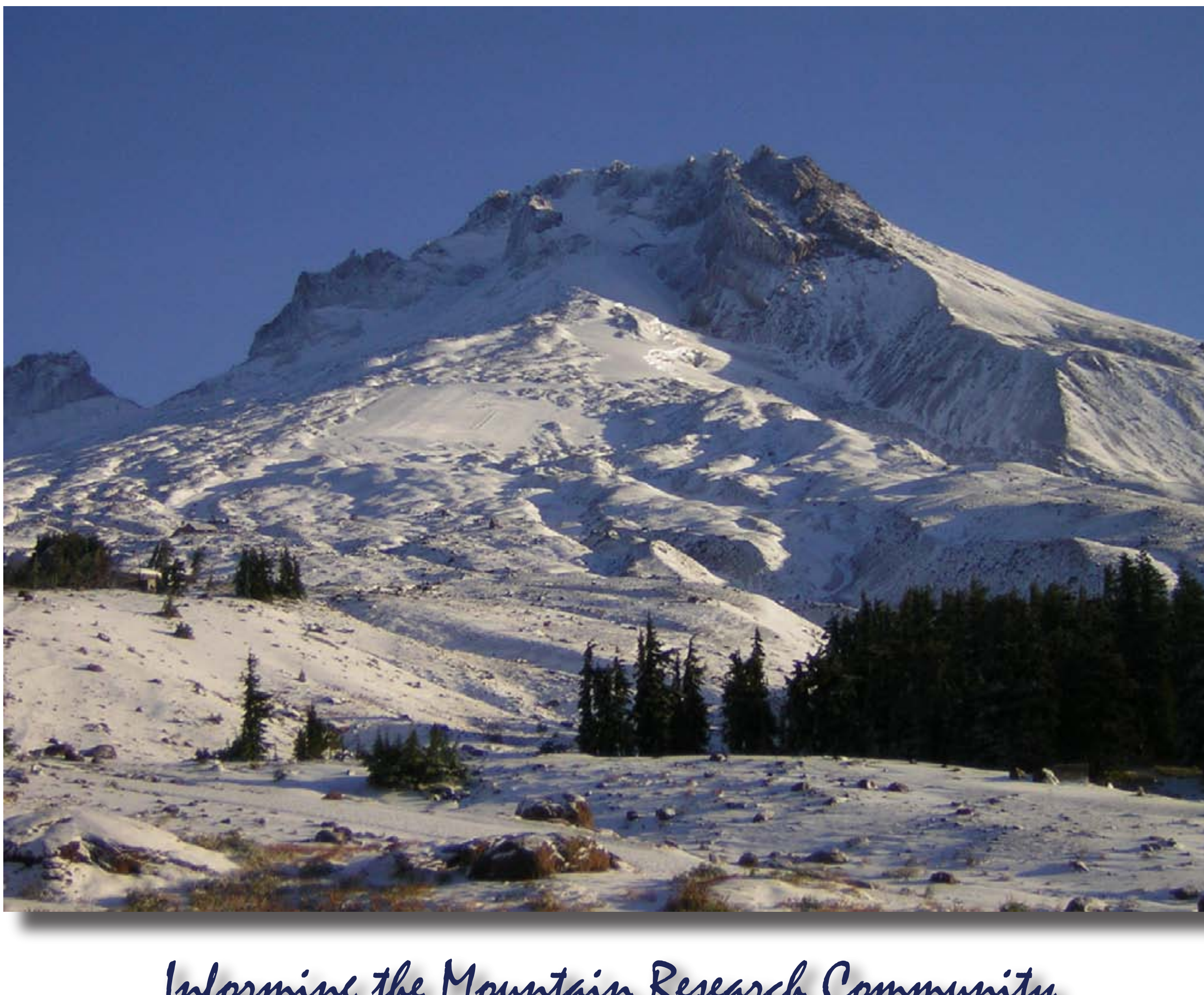
MOUNTAIN VIEWS

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

CIRMOUNT



Informing the Mountain Research Community

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Mountain Views

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

http://www.fs.fed.us/psw/cirmount/
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Mountain Views—the Newsletter Of The Consortium For Integrated Climate Change In Western Mountains (Cirmount)

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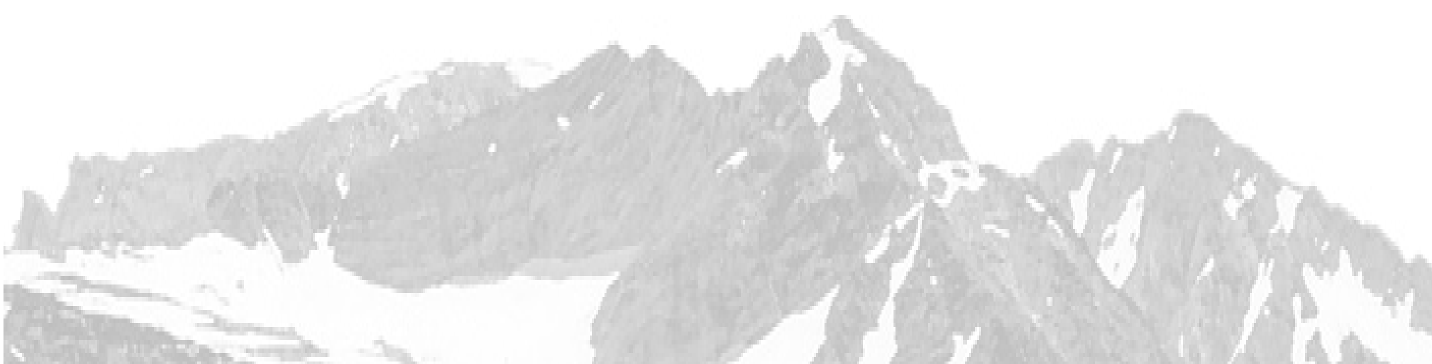
The United Nations designated the year 2002 as the "International Year of Mountains". The aim was "to promote the conservation and sustainable development of mountain regions, and to ensure the well-being of mountain and lowland communities". That year was a worldwide celebration of mountain communities with a focus on maintaining mountain biodiversity and promoting sustainable development.

Like the earth's oceans and rainforests, mountains are crucial to life. Mountains are the source of freshwater for half of humanity. They are storehouses of genetic diversity that help feed the world. Unlike many of the world's mountain regions, which is home to some 840 million people, many of whom are chronically undernourished, the people living in the mountain regions of western North America are among the World's wealthiest. Nevertheless, the West is under threat from rapid climate change and demographic changes. These changes are already evident in the form of massive forest dieback, massive insect outbreaks, such as the mountain pine beetle, and looming water scarcities.

Out of the growing recognition that the climate of the West is changing, a group of scientists representing a wide range of disciplines organized themselves into a professional network, the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), to promote public awareness of these looming problems and efforts to address them. One recent outgrowth of that effort was the mid-2006 publication of Mapping New Terrain (consult the website to download or order a free copy of the report: http://www.fs.fed.us/psw/cirmount/publications/pdf/new_terrain.pdf). A stated goal of the publication is to, "inform decision makers and the public of the nature of our concerns, and [to] highlight critical areas where monitoring and research are needed to develop appropriate coping strategies for future changes."

Launching of the new Mountain Views CIRMOUNT Newsletter represents another tangible outcome toward the accomplishment of this goal—to inform our fellow citizens of the latest developments regarding the evolution of western climate, and the evolving natural and societal impacts associated with those changes. The newsletter is meant to be a clearinghouse for information about the state of regional and larger-scale climate patterns, and about climate- and related environmental and ecological-science activities bearing on western society.

Mountain regions have been referred to as the "Third Pole of the Planet" and "Water Towers for the 21st Century." The imagery is not only effective in highlighting the fundamental importance of mountains for human well being, it also embodies practical and aesthetic concepts that are useful for communicating the need for action to mitigate and adapt to the impacts of ongoing and future climate changes. To paraphrase Sir George Mallory, we need to do these things, "because they are there". We invite your inquiries about, and contributions to, the new CIRMOUNT Mountain Views Newsletter.



Water Year 2006 — Another ‘Compressed’ Spring In The Western United States?

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Spring 2004 broke many historical records in the western US with its early start and severe snowpack losses (Pagano et al., 2004); remarkably, the spring of 2006 was something of a replay of those events in the interior West, with significant impacts on streamflow in the Colorado and Platte Basins. Once again lack of precipitation and warm temperatures combined to turn reasonable expectations of near average runoff into disappointment.

Across much of the western US (excepting mostly Arizona and New Mexico), snowpacks were more abundant than normal on April 1 2006. However, in April and May unusually warm and dry weather throughout much of the interior West reduced snowpacks dramatically and hastened the onset of spring by as many as three weeks. Most of Utah, Colorado, Wyoming and Montana were in their warmest historical deciles (10%; >+1ºC above normal throughout the region) during April and May. At the same time, Colorado and large parts of the surrounding states were in the driest historical decile or quartile (<75% and <50% of normal April and May precipitation throughout this part of the region). The result was a reduction of snowpacks from near-normal conditions on April 1, to less than about 75% of normal by May 1, and even less by June 1, in much of the interior West (Fig. 1). Snow sublimated, evaporated, and melted without much replenishment under this climatic onslaught, and the normal springtime snowmelt-onset pulses in the rivers of this interior region came as much as three weeks earlier than normal as a result (Fig. 2).

In contrast to Spring 2004, the Pacific coast states from California-Nevada to Washington-Idaho, experienced a moderately wet winter, with unusually cool conditions in March, followed by unusually wet conditions and near-normal temperatures in April. This sequence of weather conditions formed, preserved, and then enhanced the springtime snowpacks and forestalled the onset of spring snowmelt until two to three weeks later than normal. March throughout California was in the coolest historical decile, more than –2ºC below normal in most of the State. Across the Pacific states, temperatures were generally less than 1ºC cooler than normal in April, but by May had risen to >+1ºC and, on the eastern slopes of the Sierra Nevada, even >+2ºC warmer than normal. April precipitation was 150% to >400% of normal in much of the Pacific states area, exceeding the wettest 20% and, even, 10% of historical Aprils. As a result, snowpacks were generally increased by the late-season storms of April from

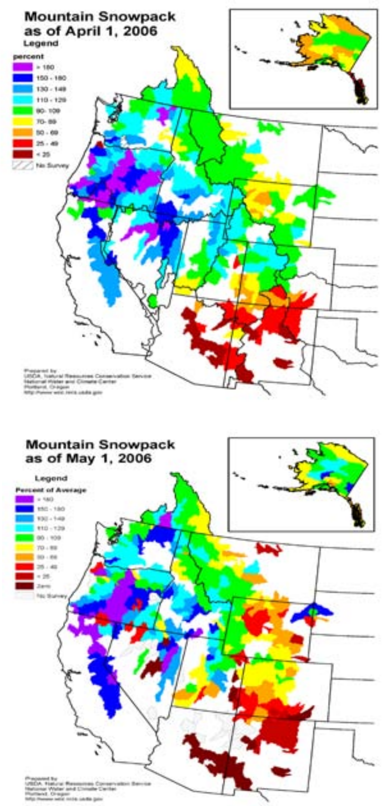

Figure 1. Percentages of normal snowpack water contents on April 1 (top) and May 1 (bottom), 2006, in the western US [from Natural Resources Conservation Services’ datasets at: http://www.wcc.nrcs.usda.gov/cgibin/westsnow.pl

the already above-normal April 1 conditions (Fig. 1a) to widespread spectacular snowpacks of May 1 (Fig. 1b), reaching 150% to as much as 200% of normal in many areas. Eventually, in May and June, as the very warm temperatures of summer 2006 set in, snowmelt commenced and streamflows reached remarkable and sustained heights. The snowmelt-onset pulses in the rivers of the Pacific coast states were as many as two to three weeks later than usual. The April increases in snowpack came during a time of year when large storms are normally relatively weak and infrequent, and when snowmelt usually begins in earnest in most of the area; not so, this year.

These large deviations from normal springtime conditions pose significant challenges to western water managers, whether resulting in less-than-expected warm-season runoff (in the

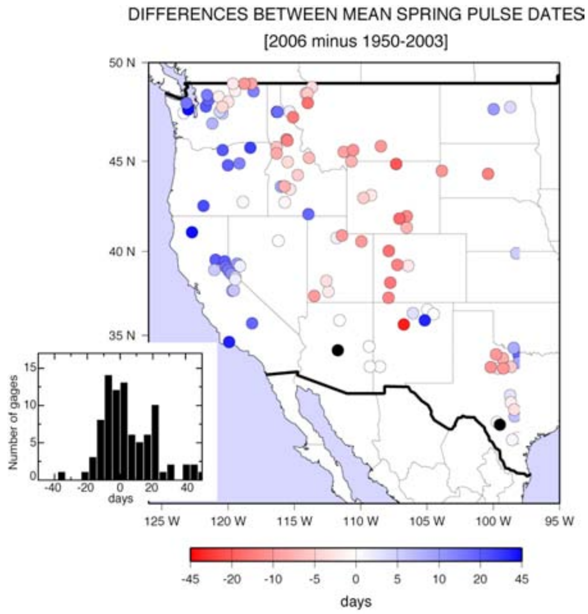

Figure 2. Date anomalies of the first major snowmelt pulse in western rivers during spring 2006, relative to the average of corresponding dates from 1950-2003. Dot circle indicates the number of days before or after normal that the spring pulses began; inset shows distribution of onset-date anomalies in 2006. Stations shown are streamgages from the U.S. Geological Survey's Hydroclimatic Data Network of stream gages that are minimally influenced by upstream water use and management, described at http://water.usgs.gov/GIS/metadata/usgswrd/XML/hcdn.xml.

interior West) or in dangerously late and voluminous runoffs (in the coastal states). For example, near-normal to above-normal snowpacks (and thus warm-season streamflow forecasts) in Colorado on April 1, amounting to a statewide snowpack that was 94% of normal, were replaced by statewide snowpack totals of 65% and 26% of normal by May 1 and June 1. NRCS spring and summer streamflow volume forecasts declined by 20% or more in most of the interior West from the April 1 forecasts to the May 1 forecasts—see http://www.wcc.nrcs.usda.gov/cgibin/sssf.pl. These late-season revisions to water outlooks threaten to catch many water managers by surprise to the detriment of their water users. Meanwhile, in California, the unexpectedly (as of April 1) large and late streamflows that resulted from the unusual late-season precipitation totals and late snowmelts had state agencies fretting over the potential for flooding and levee breaches. The high springtime flows in California filled river channels almost to overflowing, flows that continued for weeks in many rivers (e.g., the Merced River in Yosemite Valley), bearing down on and threatening damage to many flood control and water supply structures.

Thus, in the interior West, conditions moved quickly and unexpectedly from winter to summer; in the coastal states, the winter to summer transition was quick but late. In both cases, spring was all but missing. Most notably, the similarities between the early and dessicating spring of 2006 in the interior West and the westwide record-breaking early and dessicating spring of 2004, just two years previous, raise concerns that we have entered a climatic phase in which, for whatever reasons, springtime conditions have been "temporally compressed," resulting in reduced overall yield of western watersheds when compared to the historical record.

The potential for such a shift in the influence of springtime climate on western water supplies challenges traditional models and monitoring systems to capture rapid changes in springtime snowpacks that are influenced by a combination of very warm temperatures and lack of precipitation. The water-supply changes in question are occurring in the highest elevations of the western landscapes, where our monitoring networks are the least comprehensive. Although the West's NRCS (and State of California) SNOTEL snow-instrumentation network is widespread and continually being modernized, the unmet challenges posed by these "compressed" springs include even more complete monitoring networks, more measurements of conditions within and beneath the snowpacks, even the rudiments of regional monitoring of evaporation and sublimation from the snowpacks, and—of course—better forecasts of the monthly-to-seasonal climatic conditions that will drive unexpected water-supply changes. Western water supplies now commonly operate on a knife-edge margin of error, and only continued maintenance and enhancements of our abilities to track and predict the springtime evolution of western snowpacks—especially of the climatic demands on, and disruptions to, those snowpacks—will allow us to remain within the manageable limits that we are establishing in our water supplies.

Response Of Western Mountain Ecosystems To Climatic Variability And Change: The Western Mountain Initiative

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Mountain ecosystems within our national parks and other protected areas provide valuable goods and services such as clean water, biodiversity conservation, and recreational opportunities, but their potential responses to expected climatic changes are inadequately understood. The Western Mountain Initiative (WMI) is a collaboration of scientists whose research focuses on understanding and predicting responses of western mountain ecosystems to climatic variability and change. It is a legacy of the Global Change Research Program initiated by the National Park Service (NPS) in 1991 and continued by the U.S. Geological Survey (USGS) to this day as part of the U.S. Climate Change Science Program (http://www.climatescience.gov/). All WMI scientists are active participants in CIRMOUNT, and seek to further its goals.

Framing the Questions

The rate and magnitude of ecosystem responses to climatic warming are variable and uncertain, ranging from gradual to abrupt, from moderate to profound. The least understood and least predictable responses are perhaps those of greatest importance to NPS natural resource managers: responses that are both abrupt and profound (NRC 2001; Gunderson and Pritchard 2002). Recent examples of such responses include ongoing drought-induced tree mortality on millions of hectares of forest in New Mexico, Arizona, and southern California (Breshears et al. 2005; U.S. Forest Service 2003), and an increase in area burned by severe wildfires in the western United States during the past two decades (Westerling and Swetnam 2003). In both cases, thresholds of ecosystem resistance to change were quickly exceeded, leading to large and often unexpected changes that will have long-term consequences for protected areas.

Against this backdrop, the Western Mountain Initiative is guided by four major questions that address ecosystem patterns and processes at large spatial scales across the West, with an emphasis on mountainous national parks:

1. How are climatic variability and change likely to affect spatial and temporal patterns of ecological disturbance (particularly fire)?
2. How are changing climate and disturbance likely to affect the composition, structure, and productivity of vegetation (particularly forests)?
3. How will climatic variability and change affect hydrologic processes in the mountainous West?
4. Which mountain resources and ecosystems are likely to be

Figure 1. The Western Mountain Initiative is a coordinated research program focusing on understanding and predicting responses of western mountain ecosystems to climatic variability and change. Study sites are located in national parks in five western states.

most sensitive to future climatic change, and what are pos sible management responses?

Western mountain ecosystems are well suited to address these and related questions because they have (1) compressed climatic and biogeographic zones containing many ecosystems within relatively small areas, (2) rich paleoecological resources, which record past environmental changes and consequent ecosystem responses, and (3) common ecological drivers, such as snowpack and fire, which facilitate comparisons across ecosystems.

The WMI Network—Historical Perspective

Data collected in several western national parks since the inception of this research program in 1991 have improved our understanding of the effects of climatic variability on mountainous ecosystems. Most of the major forested and alpine ecosystems in the West are represented within the WMI network (Figure 1). A brief summary of the sites and results to date follows.

Pacific Northwest and Northern Rockies

Global change research projects within Olympic, North Cascades, and Glacier National Parks (Washington and Montana) joined forces in 1998 to form the CLIMET (Climate-Landscape Interactions on a Mountain Ecosystem Transect) research program. This transect ranges from maritime to continental climates, with striking westside (wet) versus eastside (dry) contrasts at each of the three primary study locations. CLIMET focuses on ecosystem productivity, hydrology, and fire, with empirical studies at a variety of spatial and temporal scales.

Simulation modeling was used to quantify responses of natural resources to climatic variability and change (Fagre et al. 2005) and statistical modeling was used to establish the biophysical "niche" of dominant tree species in the region (McKenzie et al. 2003). Ecosystem models were used to quantify potential major changes in snow distribution, annual watershed discharge, and stream temperature under the warmer, wetter climate for the Pacific Northwest region. For example, if warming continues at the current rate (about 0.16˚ C or 0.29˚ F per decade) all glaciers in Glacier National Park are predicted to disappear by 2030 (Hall and Fagre 2003); there were 150 glaciers in 1850, but today only 27 persist (Figure 2). Modeling also predicts increased productivity in some low-elevation forests, which could generate higher fuel loads that in turn could increase fire severity, particularly in a changing climate (McKenzie et al. 2004).

CLIMET documented growth increases in high-elevation tree species over the past century (McKenzie et al. 2001) and widespread establishment of trees in subalpine meadows (Peterson 1998). This research program also demonstrated strong relationships between regional tree growth patterns and variability of snowpack and drought. Rapid establishment of subalpine fir *(Abies lasiocarpa)* has occurred in meadows in response to reduced snow duration, paralleled by increased krummholz (shrubby tree growth) density at tree line and increased colonization of alpine tundra by upright trees. Major fire years were linked to drought and may be associated with cycles of El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation.

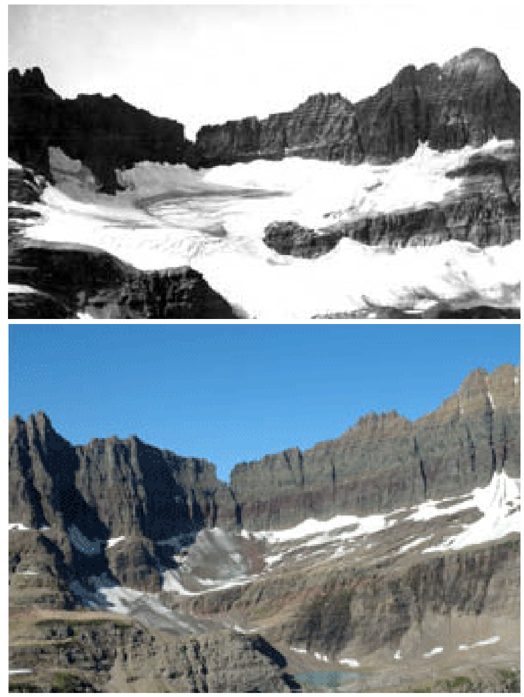

Figure 2. Photographs from 1913 (above) and 2005 (below) vividly illustrate a decline in glacial mass at Sperry Glacier in Glacier National Park, Montana. Modeling conducted as part of the Western Mountain Initiative research project predicts that all park glaciers will disappear by 2030 if the current rate of climate warming continues. Credit—1913 photo USGS/W. C. Alden. Credit—2005 photo USGS/B. Reardon.

Sierra Nevada

With Sequoia, Kings Canyon, and Yosemite National Parks (California) forming the core study areas, the Sierra Nevada project has focused on understanding the effects of changing climate and fire regimes on montane and subalpine forests, combining contemporary ecology (emphasizing natural climatic gradients), paleoecology (emphasizing tree-ring and palynological, or pollen, studies), and modeling. Scientists have found that forests in warmer climates are more dynamic than those in cooler climates, with higher rates of tree birth and death (Stephenson and van Mantgem 2005). Thus, climatic warming might lead to higher forest turnover rates, hence younger forests, with potentially cascading effects on wildlife, biodiversity, and ecosystem services. Investigations of fire effects on forest pattern and dynamics have led to modifications in prescribed fire programs. Modeling results provided land managers with projections of the consequences of natural fire, prescribed fire, mechanical thinning, and climatic change on Sierra Nevada forests. The project's detailed reconstructions of past fire regimes (Swetnam and Baisan 2003) are now used by land managers to help set targets for restoring fire to mixed conifer forests.

Central Rockies

Located in Rocky Mountain National Park (Colorado) the central Rockies project has focused on the vulnerability of forest ecosystems, aquatic ecosystems, and hydrology to variability in climate, fire, insect outbreaks, and herbivory by large mammals. Empirical data, modeling, and monitoring have quantified the effects of climatic variability (e.g., ENSO) on fire and insect outbreaks over the past 400 years. Tree line expansion into tundra has not occurred since the mid-1800s, although changes in growth form from krummholz to upright trees have occurred. Old coniferous forests responded to changes in disturbance regimes rather than directly to changing climate. Quaking aspen (Populus tremuloides) forests, which have high native plant and insect diversity, are also the vegetation type most heavily invaded by nonnative species (Chong et al. 2001).

Research has shown that hydrologic systems in the central Rockies are particularly sensitive to variation in temperature and precipitation. Simulations of stream discharge and ecosystem processes show that the timing of snowmelt, though not water volume, is particularly sensitive to climatic warming (Baron et al. 2000a). In addition, regional climate has responded to changes in land use that add moisture and pollutants to the atmosphere near mountains (Baron et al. 2000b). Finally, elevated deposition of atmospheric pollutants, especially nitrogen, has affected the vegetation and soils of some alpine and subalpine ecosystems in the central Rockies.

Southern Rockies

Focused on locations in New Mexico and Colorado, the southern Rockies project assesses the sensitivity of semiarid forests and woodlands to climatic change. The project analyzed recent forest dieback caused by past droughts (Allen and Breshears 1998) and extensive dieback of woody plants caused by the extended current drought, which began in 1996 (Breshears et al. 2005) (Figure 3). The dominant vegetation across extensive portions of this region has shifted in just a few years from pinyon pine *(Pinus edulis)* forest to juniper *(Juniperus species)* forest as a result of pinyon pine dieback, with associated changes in understory vegetation and wildlife habitat.

Figure 3. In the southern Rocky Mountains, dieback of pinyon pine in 2003 was the result of an extended drought that began in 1996. Researchers with the Western Mountain Initiative have documented a shift in portions of this once-dominant regional vegetation type to juniper, with associated changes in understory plants and wildlife habitat. Photo Credit: Craig Allen, USGS.

Also in the southern Rockies, tree-ring reconstruction of crown-fire dates revealed strong associations between past droughts and regional-scale surface-fire years. Charcoal deposits from sediment cores recorded abundant evidence of past fires during the Holocene and suggest that the post-1900 cessation of widespread fire is a phenomenon that has not occurred during the past 9,000 years (Allen 2002). Monitoring of responses of vegetation cover and composition, tree growth, water runoff, and surface erosion to interannual climatic variation started in 1991 during the wettest 15-year period of the last millennium. This monitoring has continued through the ongoing severe drought that began in 1996, documenting ecosystem responses to different climatic conditions.

Scientific Approach

Building on the strengths of these regionally focused projects, the Western Mountain Initiative emphasizes synthesis across sites and regions. WMI is conducting modeling and cross-site syntheses of long-term data, and sponsors workshops that bring together regional and subject-matter experts. We seek to further improve our mechanistic understanding of how climatic variability and change affect western mountain ecosystems directly (e.g., by affecting plant populations and vegetative productivity) and indirectly (as mediated through altered patterns of ecological disturbance and hydrology). To this end, we organize our work around (1) natural experiments in time, (2) natural experiments in space, and (3) ecosystem modeling in order to best examine responses of western mountain ecosystems to climatic variability and change.

For example, previous WMI studies and other sources have developed proxy reconstructions (natural experiments in time) of past changes in climate, fire regimes, and ecosystem responses that provide an important context for evaluating future trends in climate and natural resources. At millennial time scales, pollen and charcoal in sediments reveal ecosystem responses to widespread and long-term climatic shifts (Whitlock and Anderson 2003). At decadal to millennial time scales, tree rings reveal annual to seasonal changes in climate and fire (Swetnam and Baisan 2003) and consequent trends in populations of forest trees (Swetnam and Betancourt 1998). At time scales of a few years to a century, instrumental records, written records, photographs, and plot data offer fine resolution for mechanistic understanding. Also, quasi-periodic climatic phenomena such as the Pacific Decadal Oscillation (Mantua et al. 1997) and El Niño-Southern Oscillation (Diaz and Markgraf 2000) offer a context for climatic change, particularly when they drive climatic extremes.
Regarding natural experiments in space, our network of research and monitoring sites allows us to generalize across temperature regimes (continental vs. maritime [longitudinal comparisons], warm vs. cool [latitudinal comparisons]), and precipitation regimes (e.g., Mediterranean vs. monsoonal [Sierra Nevada vs. southern Rockies], wet vs. dry [Pacific Northwest to southern Rockies]). The network also offers researchers steep elevational gradients that are associated with steep temperature and moisture gradients.

Finally, the RHESSys (Regional Hydro-EcoSystem Simulation) model (Tague and Band 2001, 2004; Band et al. 1993, 1996) provides a framework for organizing our understanding of ecosystem change. This modeling approach relies on empirical data collected in western mountain ecosystems to (1) frame hypotheses based on past modeling results, (2) scale up empirical results, and (3) identify sensitivities of specific mountain landscapes to climatic change (Urban 2000).

Western Mountains in the Greenhouse: A Sense of Urgency

The past century has been a period of dynamic change for many western mountain ecosystems. By documenting the past response of natural resources to climatic variability at annual, decadal, and centennial scales we have established an important context for inferring the effects of a warmer climate.
Forest dieback in the southern Rockies and parts of the Sierra Nevada is a particular concern because it signals that long-term drought caused an ecological threshold to be exceeded. Dieback at large scales not only changes the structure of current forests, but may be a precursor to future changes in forest composition and structure. Dieback also alters fire behavior, likely predisposing forests to more widespread or severe wildfires. Insect outbreaks appear to be increasing throughout much of the Rockies and eastern Cascades, causing even more concern about dieback and fire (Logan and Powell 2001).

The effects of a warming climate must be assessed in the context of contemporary land use and other human-caused changes. For example, elevated nitrogen deposition in some western mountains is affecting high-elevation lakes and streams and the aquatic organisms that inhabit them (Fenn et al. 2003). Similarly, oxidant air pollutants transported from the San Francisco Bay area and San Joaquin Valley of California are reducing photosynthesis and productivity in ponderosa pine *(Pinus ponderosa)* and Jeffrey pine *(Pinus jeffreyi)* in the mixed conifer forests in the Sierra Nevada (Bytnerowicz et al. 2003). These findings suggest that natural resources in locations with multiple stresses may be more susceptible to climatic change in the future than those resources in locations that experience few to no such stresses.
Based on empirical data and modeling, we expect several significant changes in western mountain ecosystems during this century. The extent and severity of wildfire will likely increase as a result of increased temperature and drying of fuels (McKenzie et al. 2004), compounded in areas where fuels have accumulated for several decades in the absence of fire. Warmer winters will mean less snowpack, earlier melting, and less water storage as snow during summer, lowering summer streamflows in creeks and rivers and reducing water supply for downstream uses such as irrigation, recreation, and municipal consumption (Stewart et al. 2004). At the current rate of warming, most glaciers will disappear from the northern Rockies and will continue to decrease in the Cascades (Hall and Fagre 2003). Finally, continued warming may alter species composition at upper and lower treelines, as species that are better adapted to the new conditions begin to dominate (McKenzie et al. 2003).
The Western Mountain Initiative has demonstrated the value of long-term research and monitoring in U.S. national parks to

detect significant changes over time and their causes—including climate and other factors. It has linked with international efforts to monitor mountain ecosystems, and national parks in the western United States are now contributing to a global network seeking early warnings of the effects of climatic variability and change on natural resources. The activities of the Western Mountain Initiative permit resource managers to be better prepared for a climate altered by greenhouse gases wherever they have high-quality scientific data available to detect changes in the condition of natural resources.

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PROMOTING GLOBAL CHANGE RESEARCH IN THE AMERICAN CORDILLERA

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The Mountain Research Initiative (MRI) collaborated with NOAA, IANIGLA, the World Bank, IAI, IHDP, Forecos, UNESCO MAB and UNESCO IHP on a regional research framing conference, Climate Change: Organizing the Science for the American Cordillera (CONCORD). This conference summarized current research and identified scientific gaps and research needs to support adaptation to global change along the Cordillera from Alaska to Tierra del Fuego. Immediately after the conference the MRI sponsored the "Cordillera Transect Workshop" in order to design concrete projects to fill these research gaps.

CONCORD: The First Inter-American Conference on Global change research along the American Cordillera

Mendoza, Argentina, is the home of IANIGLA, the Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (Argentine Institute for Snow Studies, Glaciology and Environmental Sciences). From April 4 to 6 2006 IANIGLA's director, Ricardo Villalba hosted CONCORD with its 150 participants as well as three side events (a meeting of the Working Group on Snow and Ice of the UNESCO Latin American Hydrological Program; an IHDP Networking in the Andes meeting chaired by Fausto Sarmiento and the Cordillera Transect Workshop organized by MRI). The MRI was part of the Organizing Committee (co-chaired by Henry F. Diaz of NOAA and Ricardo Villalba), and the manager of program development and invitations. Mountain regions of the western American Cordillera may be especially vulnerable to changes in climate, to the ensuing changes in snowpack, streamflow, ecosystem functioning, and to a host of impacts on human and natural systems. In these mountain regions small perturbations in global processes can cascade to produce large changes in both highlands and lowlands, ultimately affecting the health, safety and prosperity of people throughout the region.

Outcomes of the Conference

Excellent presentations over three days yielded insights into topics, methods and findings of current global change research along the American Cordillera.

Some of the urgent topics identified with respect to earth system functions:

- A dearth of meteorological observations in high altitudes.
- Uneven geographical distribution of monitoring sites.
- Scaling up from benchmark stations.
- Determination of the true range of historic variation in climate and environmental conditions.
- Linkage of climate to hydrology.
- Monitoring multiple variables in same areas (climate, biology, hydro).
- Interaction of climate with fire and insects in changing forest composition.
- Lack of central depository for climate data from all sources (national meteorological services, power companies and individual researchers or programs).

Some of the urgent topics identified with respect to impacts on people and resources:

- Thresholds of climatic change and variability: when does a change in climate translate into an important impact?
- Linkage of fundamental research to applied concerns.
- Relevance of stakeholder perception in defining scientific questions.
- Mechanisms by which scientific results influence policy.
- Adaptation of existing reservoir and water management systems.
- Interaction with additional global change drivers in Latin America: economic development, population movements, rapid and extreme land cover change with impacts on air quality, water use.

The program and the presentations (as webcasts) are available at the MRI website: http://mri.scnatweb.ch/content/category/7/44/66/. Here you also find the abstracts volume and the list of participants.

The American Cordillera Transect for Global Change Research

Immediately after the CONCORD conference MRI and UNESCO MAB chaired a workshop on the creation of an American Cordillera Transect (ACT) a set of 24 sites along the American

Cordillera where research could be pursued on the regional compelling themes within the GLOCHAMORE[1] strategy. This workshop offered the opportunity to sign up for concrete collaboration addressing the issues raised in the CONCORD conference through the development of specific research projects in sites along the Cordillera.

The ACT workshop participants established the following workgroups:

1. Hydrological and Meteorological Modelling, chaired by Ricardo Villalba (IANIGLA) and Alan Hamlet (University of Washington).
2. Cordillera Forest Dynamics Network (CORFOR), chaired by Nate Stephenson (USGS) and Alvaro Duque (University of Colombia-Medellin).
3. Land Use and Land Cover, chaired by Jennifer Lipton (University of Texas) and Fernando Salazar (IDEAM, Colombia).
4. Cordillera Climate Data (CORDCLIM) chaired by Howard Diamond (NOAA).
5. Science and Stakeholders, chaired by Jorge Recharte (The Mountain Institute, Peru).
6. Biodiversity, chaired by Mary Kalin Arroyo (University of Chile)

Please go to website http://mri.scnatweb.ch/content/category/3/45/67/ for more information on the activities and the participants of the workgroups.

[1] The GLOCHAMORE (GLObal CHange in MOuntain REgions) Project was an EU funded project coordinated by MRI and the University of Vienna. It's ultimate goal has been to establish a strategy for gobal change research in moutains, based on the inputs of site managers and the international scientifc community (http://mri.scnatweb.ch/content/category/3/10/31/)

MONITORING ALPINE PLANTS FOR CLIMATE CHANGE: THE NORTH AMERICAN GLORIA PROJECT

Connie Millar (USFS, Sierra Nevada Research Center, Albany, CA)
and Dan Fagre (USGS, Glacier Field Station, W Glacier, MT)

Alpine Environments

Globally, alpine environments are hotspots of biodiversity, often harboring higher diversity of plant species than corresponding areas at lower elevations. These regions are also likely to experience more severe and rapid change in climate than lowlands under conditions of anthropogenic warming (Theurillat & Guisan 2001; Halloy & Mark 2003; Pickering & Armstrong 2003). Such climatic effects are already being documented by instrumental monitoring in the few places in western North America where long-term climate stations are available at high elevations as well as new planned sites (see GCOS article, pg 19). Augmenting concern for alpine vegetation given these climatic changes is the fact that habitat diminishes at increasingly higher elevations. This constitutes an "elevational squeeze" threat, whereby the geometry of mountain peaks means that escape routes to cooler environments uphill are dead ends for migrating alpine species. While monitoring and modeling efforts have begun to elucidate climate of alpine environments in North America, very little is known about corresponding responses of alpine plant species to changing climate. Indeed, for many mountain regions in the West, little information exists even about alpine plant distribution and abundance.

Monitoring Alpine Plants; the GLORIA Approach

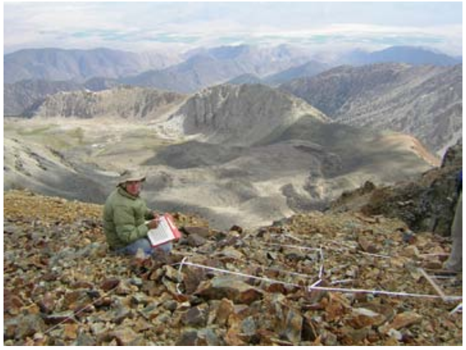
The Global Observation Initiative in Alpine Environments (GLORIA; http://www.gloria.ac.at/) is an international science program based in Vienna, Austria that promotes monitoring responses of high-elevation plants to long-term climate change worldwide. Results of repeat monitoring in the 1980s of historic vegetation studies in the Alps of Europe altered alpine scientists to high rates of change related to climate, and motivated the GLORIA effort (Pauli et al. 2003). Recognizing that the alpine life zone is globally distributed, from polar to tropical latitudes and occurs across oceanic and continental climates and that many alpine regions are among the remaining most pristine environments on earth, scientists gathered in the 1990s to develop a protocol that would be applicable throughout alpine areas of the world. The resulting approach was applied first in Europe (Grabherr et al. 2000; Pauli et al. 2006), then in Asia and S. America. Surprisingly, North American mountains remained unrepresented.

The GLORIA approach uses a standardized protocol and exploits the relative comparability of alpine summit environments worldwide. The fundamental unit for global monitoring is the "Multi-Summit Target Region", for which inventory and monitoring are prescribed on four mountain summits per target region. The summits are selected to be within a single bioclimatic region and to extend from treeline elevation to the nival zone. At each summit, comprehensive measurements are made of plant species composition, distribution, and abundance. Sites are instrumented with temperature dataloggers, and are extensively photo-documented. All data are archived at the international headquarters and are available to all interested scientists via the worldwide web.

Figure 1. Laying out standard 3 m x 3 m grids.

A. Seward Mountain summit (2717 m), Glacier National Park, MT Target Region; 39 species were tallied on this summit.

B. Dunderberg Mountain summit (3570 m), Sierra Nevada, CA Target Region; 13 species were tallied.



C. The White Mountain Peak summit (4285 m); 7 species were tallied.

Establishing the North American GLORIA Project

In 2003, recognizing the need for GLORIA representation in North America, CIRMOUNT committed to sponsor and coordinate a North American chapter of GLORIA (http://www.fs.fed.us/psw/cirmount/wkgrps/gloria/). This became the primary mission of the current CIRMOUNT Work Group, whose goals are to:

- Promote coordinated and integrated monitoring of alpine floral response to climate change in western North American mountains using the GLORIA Multi-Summit Target Region approach.

- Promote research on other aspects of alpine ecology and alpine environmental change beyond those in the Multi-Summit Target Region approach, including expanded floral diversity assessments, vertebrate and invertebrate ecology, soils and carbon relations, and hydrologic and periglacial processes.

The second goal follows the international model for GLORIA Master Stations, whose objectives are to:

- Further develop and test additional and extended field methods for long-term monitoring;
- Include other organismic groups besides vascular plants, including vertebrates and invertebrate animal species, and conduct physical, climatic, and hydrologic studies in addition to ecology;
- Carry out in-depth studies on region-specific ecological impacts in alpine environments caused by climate warming and their consequences for biodiversity & ecosystem functioning.

Multi-Summit Target Regions in the North American GLORIA Project

As of August 2006, nine GLORIA Multi-Summit Target Regions have been installed in North American mountain regions, and data are archived on the international GLORIA website. The nine Target Regions, their installation years, and lead organizers are:

Glacier National Park, MT 2004 (D. Fagre, K. Holzer)
Sierra Nevada, CA 2004 (A. Dennis, C. Millar)
White Mountains, CA – Non-dolomite substrates 2004 (A. Dennis, J. Smiley, C. Millar)
White Mountains, CA – Dolomite substrate 2005 (A. Dennis, J. Smiley, C. Millar); Lake Tahoe Basin, CA 2006 (A. Dennis); San Juan Mountains, CO 2006 (K. Nydick); Front Range, CO 2006 (B. Bowman); Whistler Mountain, BC 2006 (K. Swerhun, G. Jamison); Mt Arrowsmith Biosphere Reserve, BC 2006 (K. Swerhun, G. Jamison)

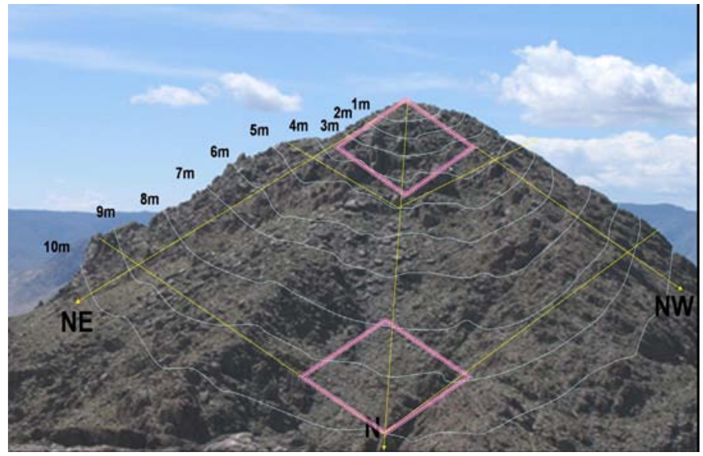


Figure 2. In the White Mountain Target Region, CA, the standard GLORIA protocol for 5 m and 10 m summit area sections (orange lines) was modified. Addition of a fixed area (10 m x 10 m) plot within each summit area section (pink lines) facilitated comparisons between sites, and also helped field workers calibrate cover estimates for irregularly shaped summit area sections. Widespread use of such fixed area plots to standard GLORIA measurements would improve accuracy of comparisons among summits.

Multi-summit Target Regions are planned for the following regions; installations of some will begin in 2008:

North Cascades, WA (S. Mitchell)
Brooks Range, AK (J. Jorgenson, K. Holzer)
Nelson Range, BC (M. Reasoner)
Wind River Range, WY (A. Well, D. Dahms)
Pintlar/Highland Ranges, MT (M. Apple)

North American GLORIA Master Stations

In addition to the Multi-Summit Target Regions established, two GLORIA Master Stations have been launched in North America. One is associated with the White Mountains (CA) Target Region and the other with the Glacier National Park (MT) Target Region. The White Mountain Master Station[1] is supported and administered by the University of California's White Mountain Research Station (WMRS) in coordination with CIRMOUNT. The Master Station was launched in May 2006 with an interdisciplinary strategic workshop in Bishop, CA, which was followed by a WMRS-sponsored field week in July 2006. The field week was based at the WMRS's Crooked Creek facility at

[1] White Mountain Master Station: http://www.wmrs.edu/projects/GLORIA%20project/.

3110 m in the White Mountains. More than 20 researchers gathered to conduct alpine-climate related field-work; evening discussions convened to discuss results and project collaborations. Nine projects currently are affiliated with the WMRS Master Station effort, with studies including vertebrate and invertebrate monitoring, bristlecone and limber pine recruitment, montane plant community relations with climate, extended GLORIA plant monitoring, soil monitoring, and periglacial studies. Similar field weeks are anticipated for summer 2007 and subsequent years, and other interested researchers are invited to join. The WMRS computer facility is archiving data derived from the Master station Projects. A conference reporting results from the Master Station and related research is in planning.

Glacier National Park Master Station. Diverse alpine research studies are ongoing. A primary task is to resurvey a network of monitoring sites that was established previously. A goal of the Master Station is to expand the summit vegetation surveys to lower elevations, and increase climate monitoring efforts.

Initial Results from the First Three North American GLORIA Multi-Summit Target Regions

The first three Multi-Summit Target Regions were established in 2004 in the Northern US Rocky Mountains, MT (Glacier National Park), Sierra Nevada, CA, and White Mountains, CA. Initial results indicate the following comparisons among the three sites:

Number of Species

	Summits					
	Low	Mid 1	Mid 2	High	Total	Exotic Total
Rocky Mountains	51	82	59	39	136	1
Sierra Nevadas	38	36	13	22	65	0
White Mountains	25	26	21	7	54	1

These early results suggest the following generalizations and hypotheses:

- The Northern US Rocky Mountains have considerably greater species diversity of the Mediterranean and Great Basin Ranges, although differences in size of the summit area sections render comparisons among Target Regions approximate;

- Slope, aspect, and proximity to scouring winds are more important in the Rocky Mountain alpine environments than in the California ranges; highest diversity occurred on the north and east slopes.

- Five species were common throughout the Rocky Mountain summits: Smelowskia calycina var. americana, Polemonium viscosum, Erigeron compositus var. glabratus, and Potentilla fruticosa. The E. compositus was also cosmopolitan in the California sites.

- Of the two California Target Regions, 25 species were common to both; greater species diversity was found in lower than higher summits; two major structural elements included a widespread, cosmopolitan montane (Sierran/Great Basin) group and an alpine (ground-hugging/cushion plant) community;

- Exotic species were rare and low in abundance in these alpine environments.

References and Additional Information

For information on North American GLORIA projects contact Connie Millar (cmillar@fs.fed.us) or Dan Fagre (dan_fagre@usgs.gov), and website at: http://www.fs.fed.us/psw/cirmount/wkgrps/gloria/.

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THE U.S. GLOBAL CLIMATE OBSERVING SYSTEM (GCOS) PROGRAM: PLANS FOR HIGH ELEVATION GCOS SURFACE NETWORK SITES BASED ON THE BENCHMARK U.S. CLIMATE REFERENCE NETWORK (CRN) SYSTEM

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The U.S. GCOS program (see website at [http://www.ncdc.noaa.gov/oa/usgcos/index.htm] based at NOAA's National Climatic Data Center supports the international GCOS effort. This support fits in with a proactive process approach for GCOS implementation planning with the goal of obtaining a sustainable and robust GCOS observing network for international atmospheric, oceanographic, and terrestrial climate observing. Actions have been taken and plans are in place regarding international, regional, bi-lateral, and U.S. national level GCOS activities. Performance measures are being used to determine where and how best to fill gaps in GCOS surface and upper air network global coverage.

Meteorological surface-based networks, utilized for climate purposes, make observations of important climate factors, atmospheric profiles, and pollutant emissions, aerosols, and ozone. These surface-based networks are intended to provide the basic observational set needed to define the status and trends in climate of the world, and also to calibrate and validate satellite-based observations. Although hundreds of millions of dollars are spent each year on developing and operating space-based observation systems, surface-based meteorological networks are "under reporting" their observations in many parts of the developing world. This is because of declining economies and the lack of understanding of how these observations contribute to the global effort to monitor climate. Consequently, these networks are operating substantially below their design standards and important observations are either not being made, or are not being communicated to users.

The support for GCOS in developing nations fits in with plans for possibly extending the capability of the U.S. Climate Reference Network (CRN) [see http://www.ncdc.noaa.gov/crn] into a larger effort for establishing an international surface reference monitoring effort aligned with GCOS. The first Synthesis and Assessment product produced by the U.S. Climate Change Science Program, Product 1, *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences,* which was released in April 2006 and has specific recommendations related to GCOS with particular emphasis on the need for reference climate observing sites. That report is posted at http://www.climatescience.gov/Library/sap/sap1-1/finalreport/default.htm. The CRN began deploying 114 climate-monitoring stations across the USA in 2000; 77 stations are now operational. Network completion will be late 2008. CRN will give national decision-makers high-confidence information on national climate variances, as well as providing benchmark-quality data for climatologists.

As such, the U.S. GCOS Program at NCDC is interested in developing partnerships for installing a network of CRN sites, which could be used as part of a global long-term climate reference network to be used in data sparse high elevation locations (e.g., the American Cordillera). The scope of this extension will depend on the availability of resources. The goal is to partner with other national meteorological services in these areas that can assist with on-going maintenance and operations expenses.
A U.S. regional-level network is being prototyped. Like CRN, the regional network is autonomous and provides climate-quality temperature and precipitation data at 5-minute intervals. Derivative CRN stations are proposed for use as the Global Climate Observing System (GCOS) for high-elevation surface observations in a World Bank initiative for tropical glacier monitoring in South America as well as for observing in remote and unique Pacific island locations. Finally, this technology is being considered for a mountain backbone network of research and operational stations known as the Mountain Research Institute, which includes several meteorological and other research institutions along the Andean portion of the Great American Cordillera. The Canadian Reference Climate System, also using CRN technologies and monitoring principles, is locating stations in the Canadian Rockies.

Climate Monitoring in the Cordillera

A long-term climate monitoring network is proposed for the

Greater Andean/Sierras Region of the American Cordillera from Tierra del Fuego, Argentina to Barrow, Alaska. State-of-the-art climate stations can instrument the Andes and Sierra Mountains of South and Central America. A Cordillera Climate (CORD-CLIM) network would be laddered vertically at three cordilleran elevations. The highest stations would be spaced at selected intervals along a chain at or near the upper treeline. Medium-level stations would be near the lower treeline. A third chain could tie into at least 13 national meteorological networks at low elevations. The eventual goal would be to have a network populated by between 197 to 235 automatic stations, using existing, proven technology. Observations would be reported via satellite to national and international archives.

However, this effort cannot be realistically or practically accomplished with the most high-end sustainable GCOS quality stations. As such, this is our opportunity to build on the work discussed at the CONCORD workshop in Mendoza, Argentina in April 2006 in order to matrix more research-level, but existing observations, along with more sustainable long-term GCOS observations (e.g., NOAA Climate Reference Network sites as discussed at the CONCORD workshop) in order to begin providing systematic climate observations without having to build a more long-term and cost prohibitive system. This approach takes advantage of existing activities to help lay the foundation for providing better climate observations in a more flexible fashion in order to address a number of applications (e.g., glacier monitoring, climate change, biodiversity, etc.) along the Cordillera.

The Great Andean Cordillera of Latin America stretches for over 8000 km, or 86 latitudinal degrees, from Tierra del Fuego (55º S) to Northern Mexico (31º N). The integrated Great Cordillera of the Americas includes the Andes of South America, the Sierras of Central America, and the Rockies of North America. The combined, tri-continental mountainous chain runs from the Antarctic Peninsula (76º S) northwards along the long Andean spine of South America, through Central America and Mexico (34N), and continuing though the Greater Rocky Mountain chain of the U.S. and Canada, ending in Northern Alaska (71º N at the shores of the Arctic Ocean. Including the Antarctic Peninsula (76º S), this vast feature runs a nearly unbroken straight-line distance of over 14,000 km, south-to-north.

This vast south-north, intercontinental mountainous platform of the Americas, despite its subset of names, is essentially one unit—and more markedly, it is the largest contiguous land feature on the Planet Earth.

Due to its interactions with the global atmosphere from near-pole to near-pole, the Great Cordillera of the Americas offers an unmatched global opportunity to gather very high-value, long-term, stable climate observations using three pole-to-pole chains of permanent locations distributed vertically through the lower troposphere. The advantages of using this inter-hemispheric mountain system as a monitoring resource are many: it is a stationary platform; it offers multi-altitudinal observing points for repeated, periodic observations; access and maintenance are easier and operational costs are lower than the more expendable balloon-borne radiosonde, ship, buoy, or aircraft platforms; and it is a unusually rich repository of well-preserved and meaningful climate proxy data (e.g., dendrochronological, glaciological, pedological, lacustrine and limnological, and palynological evidences) related to primary atmospheric processes ranging from long/medium/short-term climate events such as major Pleistocene and Holocene Events to El Niño-Southern Oscillations as well as Pacific Decadal Oscillations. The value of these climate proxy data has increased markedly during the past decade with the increased science productivity of glaciological, dendrochronological and other climate proxy evidence centers in Canada, the U.S., Mexico, Chile, Argentina, Bolivia, and Peru.

Additionally, the American Cordillera provides a permanent platform for the collection of a deep vertical slice of the lower troposphere through automatic, continuous, precision instrumental observations, which may be collected without harm accruing to human observers in even the most extreme conditions. Also important for long-term climate monitoring is that the vast majority of these regions are removed or largely removed from major human disturbances and influences. This provides an environment, which reduces questions concerning climate influences of human constructs, heat sources, or direct human modification. As with any climate network, station sites must be carefully chosen using expert local knowledge, and in accordance with defined WMO standards for the siting of climate monitoring stations.

A reasonable next stage for the pan-American climate community is to coordinate, certify, and integrate common climate surface observations networks over large regions. This is a new and great opportunity for the Americas. A principal focal point could be coordinated deployment of standardized climate observations using automatic reference stations along the eastern and western slopes of the Great Cordillera.

Canada and the United States are now beginning such a coordinated deployment of their respective national climate surface observations networks in the combined Rocky Mountains. The two nations have now exchanged equipment at sites within each nation, are already exchanging data, have developed common data processing and quality control procedures, and are developing common scientific analysis techniques and product generation formats this year. Mexico has also joined in the drought monitoring and analysis efforts of Canada and the U.S., and individual national and joint international drought products are now being operationally generated for decision-makers at the national and regional levels in all economic sectors within and among all three nations. This Mexico-U.S.-Canada drought monitoring partnership is one model of international science success, which has developed without impinging upon sovereignty issues.

For observing climate in mountainous areas in a systematic and common way, the United States joined with Canada beginning in 2004 in instrumenting individual mountain sites within each nation as well as developing a coordinated line of Climate Reference Stations along the spine of the "Andes of the North", the integrated Rocky Mountains. To date, 18 stations have been installed or are slated for installation from Arizona and New Mexico north to Montana and Idaho. About 40 Canadian stations have been upgraded or are slated for upgrades from southern Canada in British Columbia and Alberta northwards to Alaska. In Alaska, two stations have extended this chain northwards to the Arctic Ocean, and have been operating since 2002. Another eleven Alaskan mountain stations are planned for deployment in the next several years. The CORDCLIM would tie into the comparable Canadian and U.S. climate networks now extending to Point Barrow in northernmost Alaska. The result of this proposal would be a permanent, land-based, latitudinal and altitudinal climate-monitoring network that would almost extend from pole-to-pole across the Americas.

For maximum resource efficiencies, it is wise to standardize technology and deployment of long-term climate monitoring stations along the entire Cordillera. Up to three vertical station chains may suffice with latitudinal spacing of about 1.5˚–2.5˚ to allow inclusion of existing stations for this near pole-to-pole network. The science extensions and benefits of such an integrated multi-hemispheric, permanent and in-situ atmospheric monitoring network are enormous, not just in scale, but in disciplinary and international breadth, enrichment, and leveraging.

Finally, it should be noted that a geographical gap in an integrated, international Arctic-to-Antarctic montane monitoring program is the lack of a standardized U.S. montane network. Individual high-quality U.S. stations exist. Although the CRN has a few western mountain stations, these may be insufficient in geographic and ecotonal representation and may not be fully appropriate in configuration for an integrated montane climate-monitoring program. A systematic census of existing monitoring stations is necessary for this region prior to proceeding further.

A Possible Way Forward

In order to move forward on establishing the CORDCLIM as a viable effort, the following issues and activities (there are probably others, but this is just a start) need to be addressed:

- Establishment of a steering group of interested individuals to shepherd this program along (most business can be done via teleconference and e-mail; with occasional meetings as opportunities arise.
- The compilation of candidate sites and stations, which are prepared to be considered as part of the CORDCLIM effort. The steering group would then look at which sites were the best candidates from a physical, as well as from an institutional basis.
- The development of a policy governing the collection and sharing of climate data from CORDCLIM sites; in order for this effort to succeed it is key for the data from CORDCLIM sites to be freely available.
- The determination of what climatic variables should be part of the system, and that could also include the incorporation of paleoclimatic data elements.
- The establishment of a data center that is able to manage, steward, and provide easy access to the data from CORDCLIM sites. This includes all the required metadata regarding who has collected the data, the equipment configuration, site information, etc. NOAA/NCDC may be a candidate for being that data center, but we do not want to preclude other institutions that may want to take on that role.
- Investigate possible cost-sharing partnerships such as the Earth Observation Partnership of the Americas (EOPA) initiative. The EOPA initiative is a regional effort under the Global Earth Observation System of Systems detailed at http://earthobservations.org. Through EOPA, the U.S. is exploring partnerships with countries and scientific organizations in the Americas and the Caribbean to share Earth observations develop and strengthen data networks and enhance delivery of benefits to society.

Partnerships

The first EOPA meeting took place in Argentina in June 2005, with representatives from Argentina, Belize, Bolivia, Brazil, Chile, Costa Rica, El Salvador, Guatemala, Guyana, Honduras, Mexico, Netherlands Antilles and Aruba, Panama, Paraguay, Peru, Uruguay and the United States agreed that "the formation and growth of Earth observation partnerships in the Western Hemisphere will promote the successful development of the Global Earth Observation System of Systems (GEOSS). Regional partners committed to continue their work to enhance availability of and access to data and information from their respective Earth observing systems, both satellite and in situ."

One of the key partnerships which has evolved as a result of the EOPA process has been the possibility of a joint NOAA/World Bank project involving the monitoring of 10 high elevation tropical glacier sites in South America. EOPA has provided a framework and focus for building partnerships such as the one with the World Bank. To date, resources have still not been secured, but planning is well underway should resources become available. First, we envision this taking up to three seasons to implement given the fairly short, high-elevation field seasons with which to have sufficient time for such installations.

We are estimating that each field season has 8-10 weeks in it where one can get about, do field work, do the labor, and do all of that without getting into weather trouble. Other considerations involve the following elements:

- Working with the local meteorological services or interested research institutes to assist in finding the most appropriate and practical sites. Train national personnel for handling incoming data (e.g., communications, QA/QC, algorithms applied, data flows, health-of-the-network training, data archival and distribution, data-to-products, GIS, data-to-decision makers, etc.).
- Work with local meteorological services on a variety of technical issues (e.g., maintenance capable, calibration capable, engineering/logistics) so that they can replicate these systems within three years
- Ensure that the data remains in the public domain.
- Ensure station integrity and security.
- Conduct a regional workshop in order to establish a common framework for the operation of all sites.
- Translation of technical manuals and supporting materials.
- Logistics and Customs—identify the appropriate organizations that we must interface/coordinate with and get those relationships going smoothly and positively rather than creating roadblocks.

The genesis of the cooperation and partnerships established with respect to this CORDCLIM effort was initiated at the Climate Change: Organizing the Science for the American Cordillera Conference (CONCORD) that took place in Mendoza, Argentina, in April 2006. CONCORD was organized with help from the Mountain Research Innitiative [http://mri.scnatweb.ch/], and they have become a key partner in helping to facilitate progress on the CORDCLIM proposal process in the region.

Dr. Raymond Bradley of the University of Massachusetts set a very positive tone at CONCORD by proposing an integrated approach calling for a mix of long-term CRN-like stations along with a set of shorter time scale research level stations, and this has become the underlying operational philosophy for the CORDCLIM project.

Final Remarks

The U.S. GCOS Program Office at NCDC has identified high elevation surface observing sites as being a high priority for filling critical gaps in global surface observing. The partnerships and associated activities identified here have been keys in beginning to address these gaps on a long-term and sustainable basis.

NOAA'S HYDROMETEOROLOGY TESTBED (HMT) PROGRAM—ACCELERATING THE INFUSION OF SCIENCE AND TECHNOLOGY INTO DAILY FORECASTING

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"With conditions already primed by a wet winter and much above normal March precipitation, a prolonged storm period stretching from Sunday, April 2nd through Thursday, April 06, 2006 brought renewed flooding to California." So begins the April 2006 storm summary[1] from the California-Nevada River Forecast Center in Sacramento, CA. The challenge presented by this situation is faced by forecasters across the United States, but is particularly acute in the mountainous regions of the Western U.S.

The Hydrometeorological Testbed (HMT) (http://hmt.noaa.gov/) of the National Oceanic and Atmospheric Administration (NOAA) was conceived to address this challenge. HMT is a demonstration program intended to accelerate the infusion of new technologies, models, and scientific results from the research community into daily forecasting operations of the National Weather Service (NWS) and its River Forecast Centers (RFCs). The program focuses the use of advanced tools on quantitative precipitation estimation (QPE) and quantitative precipitation forecasting (QPF) for the purpose of improving hydrologic forecasts and warnings.

The Testbed Concept

Figure 1 schematically illustrates the testbed concept and motivation. The testbed concept, in which forecasters and researchers join forces in an operational setting, has been identified as a key new R&D approach for improving stream flow and flood forecasts in a number of recent guidelines, including NOAA's Strategic Plan, the NWS Hydrology Science and Technology Infusion Program (STIP) and the U.S. Weather Research Program (USWRP).

The HMT is being developed and implemented within the auspices of NOAA's Weather and Water Mission goal.
The HMT plan calls for a sequential deployment of advanced research tools in different regions of the United States to address different hydrologic forecasting problems, as indicated in Figure 2. Fieldwork will be conducted for several years in each regional

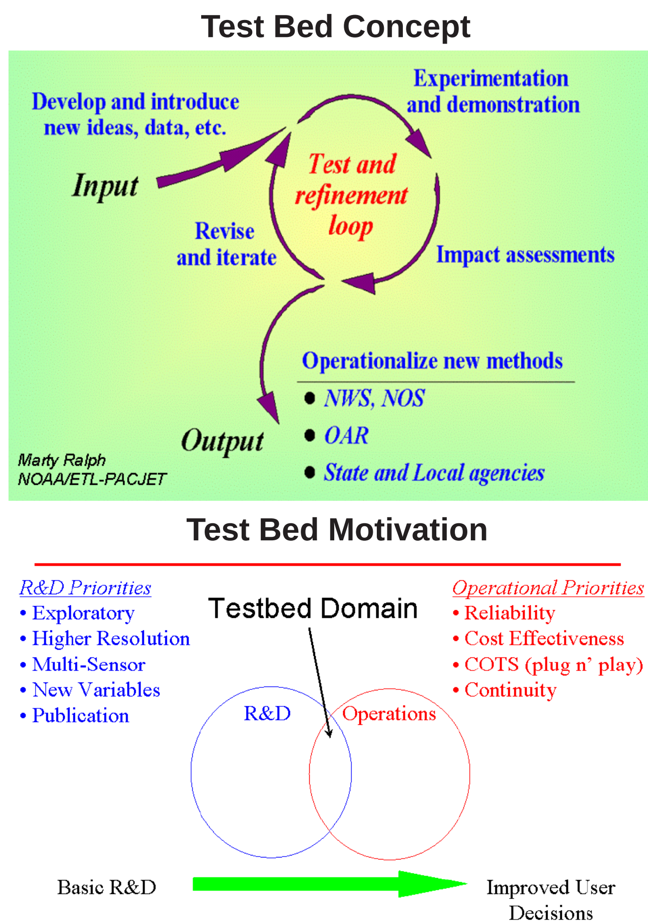

Figure 1. Schematic illustrations of the Testbed concept and motivations. In a testbed, new ideas can be demonstrated and their impacts assessed through a refinement-loop approach. A major motivation is to bridge the gap between research and operations

demonstration to determine which new tools are the most useful there for improving QPE and QPF.

The most successful tools will become an HMT legacy facility that will remain in place in the first region and serves both as a template for potential expansion within a region as well as a

[1] http://www.cnrfc.noaa.gov/

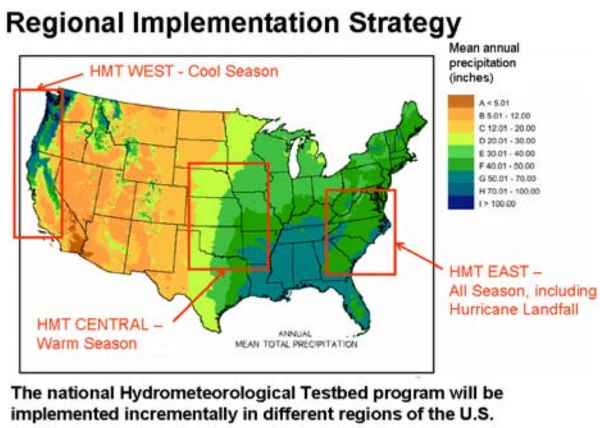

Figure 2. NOAA's HMT will be implemented in different regions in a sequential manner, beginning by addressing West Coast cool-season hydrologic problems.

model to be duplicated in the next region as the project moves. Through NOAA funding, HMT will provide a foundation level of effort and infrastructure each year in the test region. It is expected that this foundation will be augmented by occasional ramping-up to more intensive activities that include additional participants and specialized instrumentation, as shown schematically in Figure 3.

HMT Objectives

Primary HMT objectives include:

- Fostering closer working relations among NOAA operational forecasters and researchers and providing a framework in which end-users (such as water resource managers, dam operators, etc.) needs can be practically and effectively considered
- Accelerating the infusion of new instruments, models, and study results from research to operational uses
- Evaluating the practical usefulness of the new tools for hydrologic and weather forecasting operations
- Stimulating physical process studies of hydrologically significant storms for improved fundamental understanding, the development of conceptual models and numerical model parameterizations
- Applying multi-sensor QPE systems, including combinations of data from gap-filling, polarimetric and operational radars, augmented gauge networks, and satellites over the demonstration basins for use and testing in distributed hydrologic models
- Demonstrating and evaluating QPF improvements using new high-resolution forecast models tailored to the HMT region
- Accurate mapping the height of the melting layer and monitoring its evolution, and improving the understanding of orographic influences on storm airflow and precipitation

A Western Odyssey: HMT in California's American River Basin

While the HMT is a national strategy, its origins are in the west as is suggested in Figure 3. It is especially challenging to forecast storms and flooding in the U.S. West Coast states because of the combination of sparse up-stream observations and mountain-range barriers that force moist fetches of airflow from the Pacific Ocean to rise abruptly and condense. In addition to the recent programmatic calls for implementing a test-bed, the HMT plan is also an outgrowth of research projects that have examined West Coast winter storms in detail. These include the recent CALJET and PACJET projects led by NOAA from 1997 to 2003 to study land-falling winter storms along the coastline of California and Oregon.

Lessons from these research projects highlighted the desirability and opportunity for a more formal testbed kind of approach to QPE and QPF for hydrologic applications and, in part, made California a natural place to locate the first testbed. Preliminary work for HMT was conducted near the coastline in the Russian River region northwest of San Francisco.

The first full-scale demonstration of the HMT, known as HMT-West, began in the winter of 2005-2006 (http://www.esrl.noaa.gov/psd/programs/2006/hmt/). The focus of HMT-West has shifted inland to the American River Basin (ARB; 4740 km2)

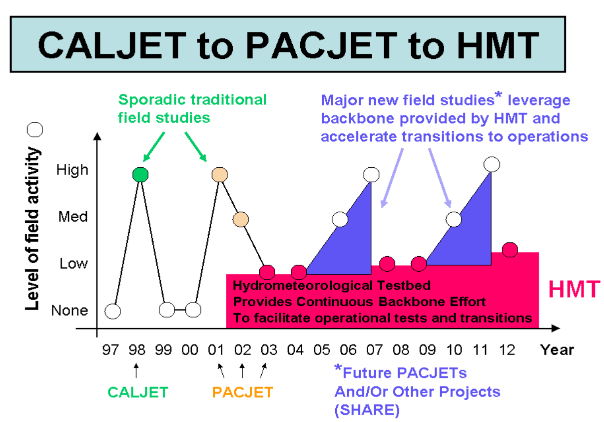

Figure 3. Schematic timeline view of HMT's ongoing infrastructure foundation and occasional ramp-up activities. Years beyond 2004 are approximate on the timeline.

on the western slopes of the Sierra Nevada for socio-economic reasons.

The ARB watershed, located approximately between Sacramento and Reno, is tremendously important to California's economy and natural habitats. Furthermore, the threat of catastrophic flooding from the ARB is an extremely serious concern for the Sacramento area. Many experts believe Sacramento ranks just behind New Orleans as the nation's metropolitan area most vulnerable to a devastating flood (e.g., this headline from a series of newspaper articles: "Tempting fate: Are We Next? Sacramento's Flood Peril Highest in U.S.", Sacramento Bee, 30 October 2005). The frequent impact of prolonged heavy winter

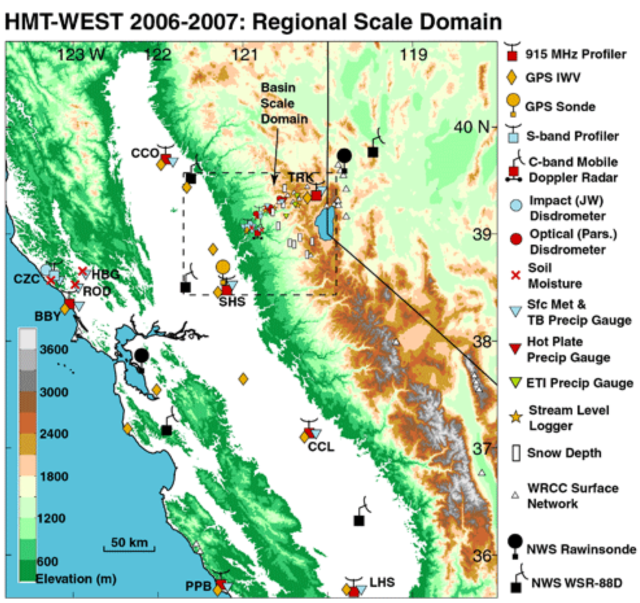

Figure 4. Regional-scale map of the HMT-West domain. Intensive operations are focused on the American River Basin indicated by the black box.

precipitation, delivered to the ARB by atmospheric rivers from the tropical Pacific, underscores the area's flood vulnerability. Thus, the ARB represents a strategically important choice as the first HMT demonstration, where accurate hydrologic forecasts in the American River Basin have direct practical benefits there for public safety and for a far-reaching economy.

HMT-West began its second full year in the ARB on November 30, 2006 (http://www.esrl.noaa.gov/psd/programs/2007/hmt/). A regional perspective of the project is offered in Figure 4. Note that a focused, densely sampled region is couched within a broader operational observation network.

Because of the vulnerability of the low-lying areas of the central valley of California, improved flood prediction at finer spatial and temporal resolutions can help minimize the risks. The first step is to accurately measure and predict spatially distributed precipitation. This is particularly true for river basins with complex orography where the processes that lead to the development of precipitation and determine its distribution and fate on the ground are not well understood.

The HMT-West deployment strategy is focused on the North Fork of the ARB (875 km2), which is the least-controlled portion of the entire catchment. This basin was selected as a test basin because it has reliable stream flow records dating back to 1941 and has been well characterized by prior field studies (e.g. the Sierra Cooperative Pilot Project) and modeling efforts, focusing on both short-term operations and long-term climate scenarios. Several experimental, high-resolution numerical weather prediction models are being run by NOAA, to supplement the operational model guidance already available to operational forecasters. In addition, the second phase of the Distributed Hydrologic Model Intercomparison Project (DMIP-2) has a major component of its effort focused on hydrologic modeling of the American River Basin, particularly the North Fork. HMT-West datasets will be critical tools in evaluating the hydrologic models evaluated in DMIP-2 as well as the physical processes that the models attempt to represent.

Some Initial Results

These studies have produced new insights about the physics of coastal winter storms and have demonstrated how new observational tools may aid precipitation forecasting in the area. The findings include assessments of the critical importance of concentrated plumes of water vapor from the tropical Pacific, called "atmospheric rivers" by Ralph and colleagues in 2004; strong correlations between boundary layer winds measured by wind profiling radars and the intensity of rainfall in the downwind mountains; automated determination of the melting layer altitude with profiling radars; and important distinctions in raindrop size distributions deduced from observations with new precipitation profiling. Figure 5 shows a recent example of how information from a variety of new technologies were combined to provide valuable pre-cursor indicators for a serious flood that occurred in northern California's Coast Range.

With respect to research-to-operations, what was learned last year? Among other things, statistical analyses have documented a relationship between the bulk integrated water vapor flux (i.e., the product of the upslope flow and integrated water vapor content) measured by a collocated wind profiler and GPS unit along he California coast and the rain rate in the downstream coastal mountains. NOAA anticipates operations periods (IOPs) from the 2005–2006 season were used to calibrate the ensemble probabilistic forecasts that will be implementing new real-time product derived from this work later this year.

These forecast products will be provided via new, prototype next-generation AWIPS workstations to be deployed in the WFOs and at the CNRFC.

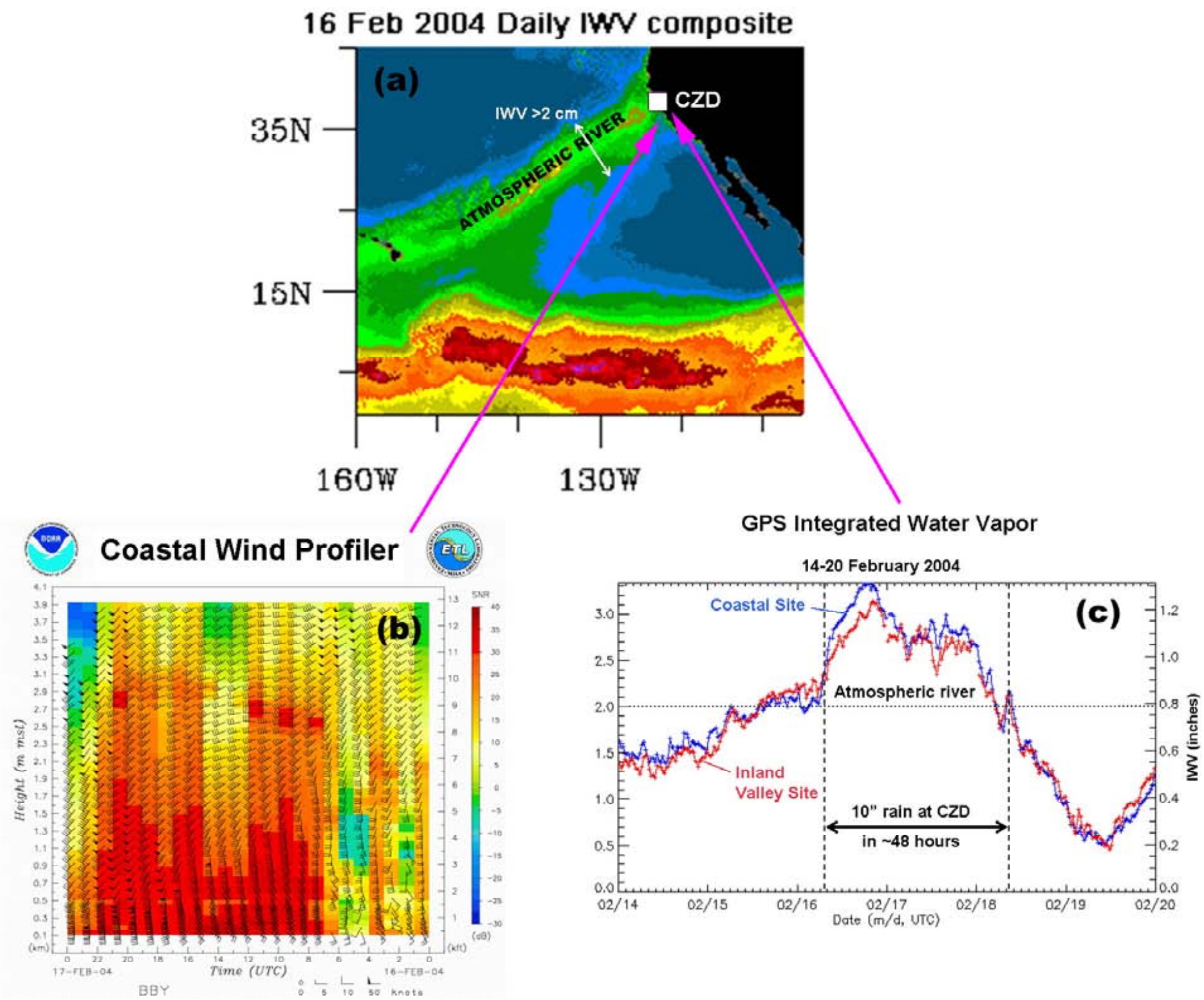

Figure 5. Data from three advanced technology sources provided important clues for predicting 10-inch flood-producing rains in northern California's coastal mountains: (a) vertically integrated water vapor from SSM/I on polar-orbit satellite, showing a potent atmospheric river extending from Hawaii to California; (b) wind vectors and precipitation echo data aloft from a 915-MHz profiler at the coastline; (c) vertically integrated water vapor from ground-based GPS systems upwind and downwind of the coastal mountains.

COMMUNICATING WESTERN MOUNTAIN CLIMATE SCIENCE: THE MTNCLIM 2006 CONFERENCE AND AGU 2006 ELEVATIONAL GRADIENTS SESSION

Connie Millar (USFS, Sierra Nevada Research Center, Albany, CA),
Lisa Graumlich (Department of , University of Arizona, Tucson, AZ),
Henry Diaz (NOAA Earth System Research Laboratory, Boulder, CO), and
Mike Dettinger (USGS, Scripps Institution of Oceanography, La Jolla, CA)

The MTNCLIM 2006 Mountain Climate Sciences Conference

The MTNCLIM Conferences are CIRMOUNT's flagship forum for scientific exchange. The first CIRMOUNT-sponsored mountain climate conference convened at Lake Tahoe, CA, in May 2004, the second at Chico Hot Springs, MT, in March 2005, and, most recently, a third at Timberline Lodge, Mt. Hood, OR, September 19–22, 2006. Modeled after the successful PACLIM (Pacific Climate) Workshops, the goal of the MTNCLIM conferences is to engage interdisciplinary mountain climate science in a retreat-like mountain setting. Specifically the MTNCLIM events afford an opportunity to exchange current research in technical sessions, convene work groups, develop policy and synthesis perspectives, and offer resource-management educational workshops.

At MTNCLIM 2006, invited theme sessions highlighted progress in remote sensing of mountain climates, environments, and ecosystems; ecological responses to climate in mountains; and advances in western regional mountain climate policy. Sample highlights and recurring themes from these sessions included the following:

* A diverse array of satellite remotely sensed data valuable for mountain climate environmental and ecological monitoring is managed and archived by the USGS Center for Earth Resources and Observation (EROS) in coordination with NASA's Applied Science Program and Earth Observing System. Many of these are being used actively to monitor widespread changes in western North American mountain climates and environmental change. A prototype experiment is simulating decision support analysis leading to priorities in policy and assessing uncertainties in alpine areas at watershed scales.

* Ecological monitoring case studies have used remote sensed satellite data in innovative ways, for instance to compare with ground-based vegetation surveys and examine vegetation response to climate change in montane meadows (Greater Yellowstone Ecosystem); to assess trends among vegetation communities in photosynthetic activity in high latitudes (AK); and to demonstrate declining forest productivity over much of the mountainous West. The newly established National Phenology Network likewise plans to capitalize on remote sensed data.

* Insect herbivory is annually affecting areas many times greater than that associated with fire; recent years have resulted in unprecedented levels of bark-beetle related disturbance. About 2 million ha of spruce forest have been killed since 1990. Concern for unprecedented spread of mountain pine beetle beyond its historic range in lodgepole pine forests has actualized, with outbreaks in fall 2006 found not only in hybrid populations of lodgepole and jack pines east of the Continental Divide, but also in pure jack pine stands.

* Many causal connections of climate change and ecological responses are being documented in mountain environments. For example, resurveys of early 1900s mammal and invertebrate distribution and abundances (Sierra Nevada, CA) indicate many species have moved upslope, while others have remained stable, and a few have shifted downslope. Changes in snowpack depth and earlier snowmelt have resulted in increased frost damage to flower buds in several subalpine plant species (Rocky Mountains), especially mountain sunflower, with frost killing of buds up to 100% and population sizes declining dramatically.

* Climate policy in the West is evolving rapidly, providing strong leadership to national and international communities. There is growing recognition of the need to move beyond traditional science approaches toward more integrated analyses of earth systems in mountain regions. An example of a coordinated science-based decision support system for management and policy-making is the NOAA-supported Regional Integrated Sciences and Assessments (RISA) program, with active projects in the West in Colorado, California, and the Pacific Northwest. Signs of success in these science-policy RISAs include water managers focusing increasingly on long-term climate predictions as well as taking into consideration information from research that indicates diminishing snowpacks

and earlier snowmelt. Water managers are also increasingly using paleohydrologic reconstructions on timing, magnitude, and climate mechanisms to plan reservoirs and water delivery.

* The Columbia River Treaty, an international agreement, provided an example of successful community-based public involvement in decision-making, with emphasis on building community capacity, developing effective outreach and extension, understanding how decision are made locally. Empowering communities to act, and promoting participatory processes that ensure diverse values are integrated in science and economic discussions and decisions.

Three keynote addresses at MTNCLIM 2006 were presented. Kelly Redmond, Western Regional Climatologist at the Desert Research Institute, Reno, NV, summarized the past year's climate of the West, highlighting the following observations about 2006:

– The year was wetter than average in the Pacific Southwest (PSW), and drier than average in the Pacific Northwest (PNW) and central & northern US Rockies;
– This pattern set up late in winter, after March 1 (before March 1 the trends were reversed);
– Other than large fires in Texas in March, the number of wildland fires in the West was below the average although total hectares burned was highest since 1960;
– June through September was wetter than average in the Southwest and central Rockies regions, and drier than average in the PSW, PNW, and northern US Rockies;
– Lake Powell reservoir was only 49% full as of April;
– 2000-2005 temperature departures in the western states relative to the 1895–2000 mean were 1–3°F higher; the West continued to dominate recent warming trends.

Jon Jarvis, Western Regional Director of the National Park Service, Oakland, CA, presented perspectives from a career's worth of experience on how science can and does inform decision-making in natural-resource management and policy. The National Park Service has active climate-related projects ongoing in many western park units, including climate monitoring, visitor education and interpretation, and green-energy programs. While science and resource-management cultures have different traditions and communication styles, there are many examples of successful collaboration where patience and commitment are central. CIRMOUNT scientists are actively engaged in several park projects.

Charlie Crisafulli, Research Ecologist for the Mt. St. Helens (MSH) National Volcanic Monument, USFS, Amboy, WA, summarized 26 years of environmental change and ecological succession following the 1980 eruption of MSH. The dramatic redistribution of watersheds and plant communities, as well as rapid colonization by native plants following the eruption, provides a model case study in ecosystem science and restoration. Similarly, the interaction of ecosystem science with forest management that occurred in the MSH case provides important lessons in adaptive science and management (see Dale, V., Swanson, F., and Crisafulli, C., Eds. 2005. *Ecological Responses to the 1980 eruption of Mount St. Helens*. Springer Publishing, New York, 348 pp).

Several of the CIRMOUNT workgroups convened during MTNCLIM 2006; progress reports are available at http://www.fs.fed.us/psw/cirmount/wkgrps/ (click Pubs/Rpts/Resources under each Work Group page), with key points as follows:

<u>Mountain Climate Monitoring</u>: Several new long-term high-elevation climate-monitoring stations have been installed or are in planning in western mountain ranges, and experience is gathering in how to maintain these despite environmental challenges. Real-time data from many of these are available on the web, and are already providing valuable insights into the differences and similarities of high- to low-elevation observations.

<u>Hydrologic Observatories</u>: Projects in discussion for the work group include developing standardized protocols and methods for west-wide hydrologic monitoring, field-testing new technology (such as cosmic snow sensors, tripod lidar, and snow/rain discriminators), compiling and disseminating for analysis available mountain hydrologic information such as sublimation and evaporation data, and investigating opportunities to set up hydrologic monitoring at the NOAA Climate Reference Network sites and NRCS Benchmark Network sites..

<u>Ecosystem Responses</u>: The group is working to develop a short list of critical research gaps related to mountain ecosystems and climate; an archive of key research results (case studies and broad syntheses); and a presentation suitable for broad use that describes the most compelling results from these case studies.

GLORIA North America Alpine Plant Monitoring: Nine GLORIA Multi-Summit Target Regions are now installed in western North American mountain ranges, and two GLORIA Master Stations (Glacier National Park and White Mountain Research Station) have been launched to promote expanded research in alpine environments and ecology related to climate change.

Paleoclimatic Archives for Resource Management: A set of web pages that is designed to provide information about and access to tree-ring based reconstructions of streamflow for resource managers and non-specialists is under development. The series currently contains web pages for Colorado (http://www.ncdc.noaa.gov/paleo/streamflow/) and California http://www.ncdc.noaa.gov/paleo/streamflow/ca/.

This Group is working to expand the effort to AZ, NM, and other regions. Another website recently developed is on Past Climate Variability and Impacts (PCVI; http://bsi.montana.edu/web/pcvi/). However, after initiation, a shortfall in funding resulted in placing the project on hold awaiting future interest and funding. A Paleo-Perspective webpage on the Colorado River, with information for water managers, is also under development. A series of technical workshops on hydrologic reconstructions from tree rings has been offered to water managers in Boulder and Alamosa, CO, and Tucson, AZ, with others planned in CA and NM.

The MTNCLIM 2006 conference was sponsored by CIRMOUNT in collaboration with the USDA Natural Resources Conservation Service (Portland office, Phil Pasteris) and Portland State University, Department of Geology (Andrew Fountain). In addition to CIRMOUNT's contributing agencies (NOAA, USGS, USFS, University of Montana, Scripps Institution of Oceanography, UC White Mountain Research Station, the Mountain Research Initiative, Western Regional Climate Center, Desert Research Institute), contributions in support of MTNCLIM 2006 also came from NRCS, PSU, NASA Science Mission Directorate, and the CalFed Bay-Delta Authority.

Plans are underway for the next conference, MTNCLIM 2008 for May 2008. With this date, we hope to establish a future biennial schedule for the MTNCLIM conferences, alternating annually with the PACLIM workshops (next PACLIM meeting scheduled for May 2007). Several locations and venues are being explored for MTNCLIM 2008, and volunteers are always welcome for organizing and hosting.

Oral presentation and poster pdfs archived at: http://www.fs.fed.us/psw/mtnclim/talks/.

A webcast archive of the talks is available through the Mountain Research Initiative website: http://mri.scnatweb.ch/content/view/141/43/

Elevational Gradients in Mountain Climates, Ecosystems, and Resources Session, AGU 2006
Oral presentation and poster pdfs archived at: http://www.fs.fed.us/psw/cirmount/meetings/agu/agu2006.shtml

CIRMOUNT organized technical oral and poster sessions related to mountain climate sciences, ecosystems and resources at the past three annual meetings of the American Geophysical Sciences Union in San Francisco. This year (December 13, 2006) the CIRMOUNT sessions focused on changes observed or anticipated in climatic, environmental, ecological, and natural resources along elevational gradients in western mountain regions. Water, wildfire, insect-caused forest mortality, biodiversity impacts, and policy actions were major themes through the sessions. Decreases in overall snowpack, changes in patterns of snow accumulation and ablation and consequent snow distribution lead to important insights into changes in rain/snow elevations and highlight significant elevation zones that are most vulnerable to climate change. An example of a mid-May 2005 extreme flood demonstrated how reduced snowcover at high elevations provided an unusually large run-off area for a heavy rainfall event, leading to unprecedented flooding in mid-montane elevations (e.g., Yosemite Valley). Gradients in elevation were not the best predictors for water availability and forest productivity in the Pacific Northwest–Northern Rocky Mountains, whereas a complex set of biophysical indicators were more robust.

Other climatic research on elevational gradients of temperature, derived from a large network of dataloggers, indicated that conventional linear gradients of temperature with elevation (lapse rates) are highly variable and irregular, varying with type of storm circulation, inversion events, cis-montane locations, among other patterns. Considerable insight into shifts in species distribution ranges were highlighted, including not only "leading edge" (upper elevation) changes but also complex analyses at lower elevations and internal range limits.

We will plan another CIRMOUNT session for AGU 2007. Ideas for session themes and coordination are welcome!

Publication Announcement:

Mapping New Terrain

Climate Change and America's West

Climate variability and sustained change presage far-reaching transformations across America's West. In July 2006, the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) published a white paper—*Mapping New Terrain*—intended to promote effective responses to a range of problems identified as connected to global warming and to concurrent demographic changes in the Western United States. With the publication of *Mapping New Terrain,* Consortium participants aimed to inform **decision makers and the public of the nature of their concerns, and highlight critical areas** where public investments in climate system monitoring and research are needed to develop appropriate coping strategies to respond to future changes.

The members of CIRMOUNT recognized that the climate of the West is changing, and that impacts are rapidly emerging in the form of changes in streamflow patterns, plant phenology, ecosystem structure, wildfire regimes, and other physical and socioeconomic systems. The Consortium represents a wide range of disciplines and has come together as an informal consortium to help address these issues. By crossing traditional disciplinary lines, exchanging ideas, and coordinating research efforts, **Consortium participants seek to identify the greatest threats to western mountains arising** from climate change and to develop priorities for a research strategy that addresses those concerns.

The following scientific and societal themes related to climate change are common throughout the West: *Water Supply, Forest Dieback, Urban-Wildland Issues, Wildfire, and Biodiversity and Wildlife*.

Why should we be concerned about how climate change is affecting the mountains? Despite their imposing grandeur, western landscapes contain highly sensitive environments that support delicately balanced physical and natural systems. A warming of only a few degrees has major implications for mountain regions—for the integrity of the seasonal snowpack, the extensive forests that western mountains support, and for the people who make their home there.

Such changes are already affecting water supply, energy availability, fire severity, and recreational opportunities. Continuing climate change may significantly alter the western landscape, where one encounters distinct ecological communities as successive layers from the lowlands to the high peaks. As climate variability increases and global warming continues, complex changes in montane plant and animal communities will occur, increasing vulnerability of species to dramatic shifts in distribution and local extinctions.

Consult the following website to download or order a free copy of the report: http://www.fs.fed.us/psw/cirmount/publications/pdf/new_terrain.pdf).

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