Mapping New Terrain
Climate Change and America's West

Anticipating Challenges to Western Mountain Ecosystems and Resources

The Consortium for Integrated Climate Research in
Western Mountains
(CIRMOUNT)

July 2006

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CIRMOUNT is endorsed as a regional pilot project of the Mountain Research Initiative

CIRMOUNT on the Web: **http://www.fs.fed.us/psw/cirmount/**

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From the Consortium Chairs

CIRMOUNT

The Consortium for Integrated Climate Research in Western Mountains

Daunting challenges confront the mountains of the American West. Among the greatest of these is maintaining a sustainable water supply in the face of a growing population together with a variable and changing climate. Global warming may have far-reaching, though as yet unknown, consequences for the mountain environments of western North America. Consensus has been developing among a diverse group of researchers and resource managers in the West that climate change will seriously alter the mountain snowpack—the principal source of the West's precious water—and with it, ecosystem function, landscape integrity, and concomitant socioeconomic activity in the region, and, ultimately, the nation.

Out of the growing recognition 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 the like, a group of scientists representing a wide range of disciplines has developed an informal consortium to 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.

With this publication, *Mapping New Terrain*, Consortium participants intend to promote effective responses to the problems identified. We wish to inform decision makers and the public of the nature of our concerns, and highlight critical areas where monitoring and research are needed to develop appropriate coping strategies for future changes.

CIRMOUNT Co-Chairs

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Statement of Purpose

CIRMOUNT is a collaborative, open consortium dedicated to enhancing understanding of climate variability and change and its role in sustaining western North American society. The goals of CIRMOUNT are to define regional vulnerabilities to climate variability and change; to measure and understand climate-driven changes in the unique landscapes that define western North American mountains; to develop information, products, and processes to assist natural resource decision makers throughout the West; and to respond to the needs and challenges of western society for mountain resources by anticipating potential impacts of future climate change.

CIRMOUNT responds to four urgent situations in western mountains:

- Mountain regions are vastly underinstrumented for measuring climate and long-term changes.
- Research on western mountain climates and ecosystems is intensive, but scattered and poorly integrated.
- Demands on western mountain ecosystems are escalating, placing new and cumulative stresses on mountain communities and the natural resources that sustain them.
- Climate change has been widely overlooked in mountain land-use planning and natural-resource policy.

The recent severe and sustained drought in the West (2000–2004), which exposed the region's vulnerability to water shortages, huge forest fires, widespread tree mortalities, insect infestations, and outbreaks of disease, demonstrates an urgent need to pool the region's and the nation's resources to address these problems more effectively.

CIRMOUNT's specific goals include the following:

- Promote and implement coordinated high-elevation climate, hydrologic, and ecosystem monitoring.
- Catalyze and coordinate integrated research within and among mountain regions.
- Communicate research findings among diverse disciplines and provide sound science for effective resource planning and management.
- Develop and promote long-term, policy-relevant mountain-climate and ecosystem databases for public information and decision support.
- Develop CIRMOUNT as a pilot regional model at the international scale and engage CIRMOUNT projects and scientists in global mountain-climate science and assessments.

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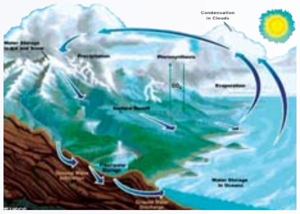

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Executive Summary




The Consortium for Integrated Climate Research in Western Mountains

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

Climate variability and sustained change presage far-reaching transformations across America's West, an expanse dominated by immense mountain ranges and interspersed with important urban centers. These mountains provide the region's life blood—water that courses through its streams and runs out its faucets, power that fuels its industries and lights its cities, and natural resources that feed its economy and provide many of its jobs. The West is a land where life is written in water—from vast ranchlands and farmlands, to large densely populated urban areas—and the communities of the West are intricately tied to it.

Why should we be concerned about how climate change is affecting the mountains? Despite their imposing grandeur and apparent fortitude, the mountains 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. Each of these ecosystems has specific requirements for temperature and precipitation. 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.

The following scientific and societal themes have emerged as common throughout the West:

- **Water Supply:** Local and region-wide drought have affected cities and agriculture repeatedly over the past quarter century. Higher temperatures have raised snow levels, shortened the accumulation season, reduced the peak snowpack, and hastened spring melt. Meanwhile, rapid population growth has accelerated demand for assured water. Together, these trends increase chances of significant regional water shortages.

- **Forest Dieback:** Recent severe drought, superimposed on decades of fire exclusion and livestock grazing, have increased susceptibility of trees to insects and disease, and are resulting in widespread and rapid forest diebacks throughout western forests.

- **Urban-Wildland Issues:** Accelerating suburban development on city fringes and exurban development of rural lands are increasing scarcity of wildlands and associated resources; wildfire is placing homes in these developments at risk. Poor air quality is moving uphill from urban centers. Climate changes are accentuating these problems.

- **Wildfire:** Enormous, destructive crown fires, outside the range of 20th-century sizes and severity, are consuming forests stressed from drought, extensive tree mortality, and long-term fire exclusion. These fires burn severely, threatening biodiversity, watershed stability, water supply, and human lives and property.

- **Biodiversity and Wildlife:** Development of sparsely settled areas, massive forest dieback, extensive high-severity crown fires, landscape fragmentation, and changes in high-altitude ecosystems are threatening biodiversity and wildlife habitat.

Despite our best current efforts, substantially more information is needed to develop a fuller and more integrated understanding of these critical issues. Research studies are intensive but fragmentary across mountain ranges, few systematic studies exist to date, and weather and hydrological stations are scarce at critical high elevations. Scientists cannot yet respond meaningfully to specific questions managers are asking about climate change, such as how water flows will be affected locally, what species may be at risk, and to what extent increased wildfire looms on the horizon.

The recent meetings and forums undertaken by researchers representing a broad cross-section of science disciplines have set the stage for unprecedented cooperation among scientists, policy makers, and resource managers to identify and begin to address the most important questions about how climate variability and change will affect the West. As a key outcome of these grass-root efforts, a consortium of experts whose work relates to climate change in mountainous regions was established, the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT). Priority goals set by CIRMOUNT address all the action goal categories of the U.S. National Climate Change Science Program (CCSP) and include the following:

- **Observation:** Implement coordinated high-elevation climate, hydrologic, and ecosystem monitoring throughout the western mountains of North America. Install networks of high-altitude meteorological, hydrological, and ecological stations to conduct long-term climate and ecosystem observations.

- **Research:** Promote integrated research within and among mountain regions. Specifically, improve knowledge of the past and present climate variability in the West, better characterize the responses of ecosystems to climate, and improve future scenarios of regional climate change.

- **Decision Support:** Communicate research findings among diverse disciplines and provide sound science for effective resource planning and management. For long-term planning, develop accurate projections related to climate change and effects on natural systems and resources of the West. Assist policy makers and land-use professionals in managing risks and opportunities related to climate variability and change, especially water, forest management, and amenity values and resources.

- **Communication:** Develop long-term, policy-relevant mountain climate and ecosystem databases for resource management and policy decision support. Share findings through Web sites, publications, scientific meetings, focus groups, and workshops. Organize monitoring data and research results in easily accessible Internet-based databanks. Integrate western climate change information into current environmental assessment efforts.

- **International Relations:** Develop CIRMOUNT as a pilot regional model at the international scale and engage CIRMOUNT projects and scientists in global mountain-climate science and assessments. Endorsement of CIRMOUNT by the International Mountain Research Initiative provides a bridge for developing CIRMOUNT within the global mountain-climate science and policy community.

Six work groups at present tackle specific CIRMOUNT goals. Work groups include Mountain Climate Network; Hydrologic Observatories; North American GLORIA (alpine plant monitoring); Mountain Ecosystem Responses to Climate; International Relations; and Paleoclimatic Archives for Resource Management. CIRMOUNT sponsors the ongoing MTNCLIM science conferences, the intent of which is to communicate new and relevant integrative research, enhance relevance of scientific findings for resource management and policy, and provide a forum for CIRMOUNT work group activity. In 2006, MTNCLIM will be held at Timberline Lodge, Mt. Hood, Oregon, September 19–22. CIRMOUNT also sponsors a special session annually on topical themes at the December meeting of the American Geophysical Union in San Francisco, California.

CIRMOUNT is an open, transparent consortium, welcoming all interested scientists, managers, and policy makers to join one or more work groups, attend MTNCLIM conferences and other meetings, sign up for the CIRMOUNT mailing list, and join in other Consortium endeavors.

CIRMOUNT is built on a foundation of interdisciplinarity. The CIRMOUNT executive committee includes scientists from NOAA, USDA Forest Service, USGS, Montana State University, University of Arizona, University of California, the NOAA/DRI Western Regional Climate Center, and the international Mountain Research Initiative (MRI). CIRMOUNT is endorsed as a pilot regional program within MRI, and in turn cosponsors and endorses the international Mountain Invasions Research Network (MIREN) and the Western Mountain Initiative (WMI).

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Climate and Society: Challenges Facing America's West

Change and variability are two of the principal attributes of the Earth's climate system. This has been true at all time and space scales. The accelerating rate and direction of change since the 1980s, however, extend beyond the natural range of variability and are largely attributed to human emissions of greenhouse gases. CIRMOUNT seeks to identify critical issues facing western North America under this new era of human-dominated climate change, and to develop priorities for action to address them. A few of the most important issues identified are listed below.[1]

What are the vital components of our western environment that may be transformed by human actions and that might, in turn, feed back upon the climate system and lead to irreversible harmful changes in the environment?

What components must remain operational for those systems and resources to remain viable and sustainable?

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

What are the characteristic regimes and timescales of natural variability in the climate of the region and in the renewable resources that help to sustain our society? What controls and modulates those regimes and scales? Will long-term changes also exhibit those regimes and scales?

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

How vulnerable are western mountain ecosystems to projected future climate variability?

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

What role have abrupt and extreme natural events played in the evolution and sustainability of western mountain systems? How are future abrupt, extreme, and/or sustained climatic events likely to be managed through the coping and adaptation mechanisms of natural and social systems and their interactions?

To address such issues, a set of operational questions will need to be considered and appropriate actions taken. These questions are meant to open the way for the development of policy and programmatic instruments to define the West's vulnerability to changes in global climate and to transformations resulting from continuing sociodemographic changes.

[1] This list was modeled on global-scale issues identified in: Clark, W.C., Crutzen, P.J., and Schellnhuber, H.J., 2004; Science for global sustainability—Towards a new paradigm, in Schellnhuber, H.J., Crutzen, P. J., Clark, W.C., Claussen, M., and Held, H. (eds.), Earth Systems Analysis for Sustainability; Cambridge: MA: MIT Press, 1-28.

Key questions include:

What fundamental components of natural and human systems in the West must be included and quantified to model, understand, and predict systemic responses to disturbances and climate changes?

What levels of complexity and resolution have to be achieved for adequate modeling of the key aspects of western mountain responses to disturbances and climate change?

Is it possible to describe the coupled land-atmosphere-biosphere system in the West as a combination of weakly coupled components and subregions, and to reconstruct the mechanisms of response from these subsystems?

What might be the most effective global strategy for generating, processing, and integrating relevant system-level data sets?

What are the best technologies for analyzing and possibly predicting irregular, abrupt, or extreme events and evaluating the possible range of responses?

In addition there are strategic questions regarding climate and society that form a contextual background within which decisions will be made and policies implemented:

What are the general criteria and principles for distinguishing sustainable from nonsustainable futures and what kind of natural living space do we want to sustain in the West?

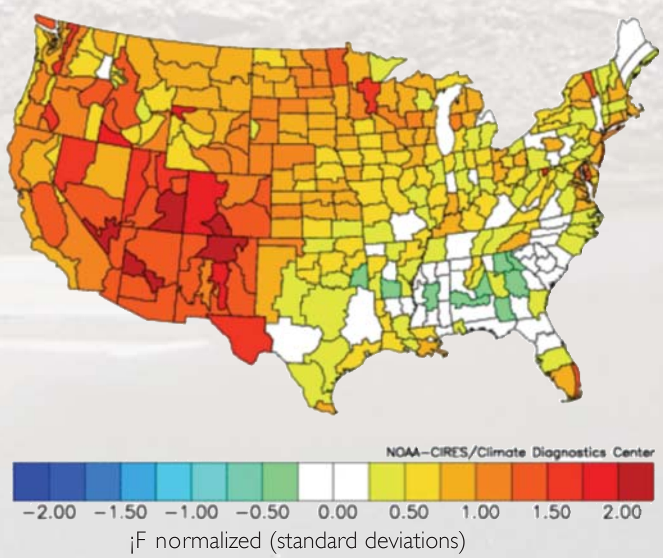
What are the ecologic and economic carrying capacities of the region under scenarios of the future?

What are the most appropriate mechanisms for improving the integration of natural-science insights and scientific advances into practical land management stategies and social actions at this regional scale?

What equity principles should govern the We□s environmental stewardship?

How do we apply insights obtained from modeling potential future lsandscape scenarios to practical land-management strategies?

In the following pages we describe a set of critical problems related to climate variability and change affecting the mountain regions of western North America. We underscore that these problems are likely to get much worse in the future from the interplay of nature and humans, yet impacts can be significantly reduced through knowledge, anticipation, and preparation.



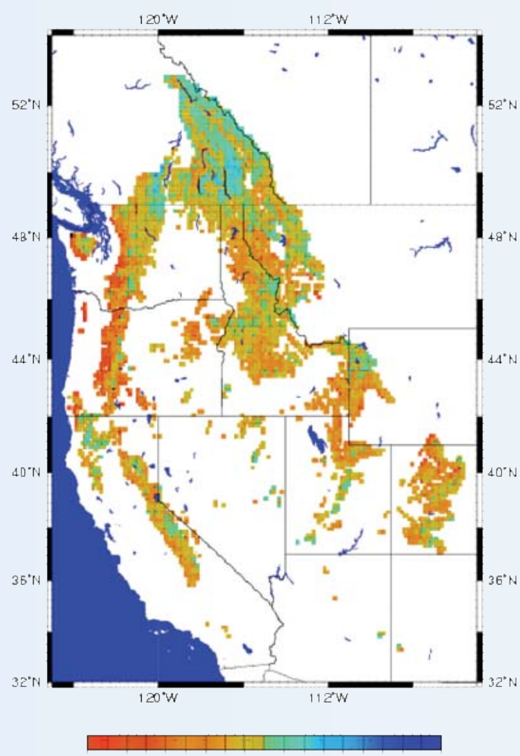
Western mountain regions dominate recent warming as this map of standardized temperature anomalies of 2000—2005 versus 1895—2000 long-term averages shows.

Climate Change

Scientists are concerned that . . .

climate change in western mountains will lead to significant unforeseen consequences to society and natural systems. The West is a largely arid region, where the primary source of our life-sustaining water is the winter snowpack. Changes in temperature and precipitation will affect water supplies, aquifer recharge, the health of the forests that mantle the lower slopes, the life cycles of insect pests that feed upon them, wildlife and aquatic life, and the cherished outdoor recreational opportunities afforded by the region's higher elevations, nearly all of which are publicly owned.

Winter maintenance at Slide Mountain Climate Station, NV. Photo: A Huggins, DRI.



Cumulative trend in simulated timing of peak snowpack (number of days changed from 1951 to 2000).
From: Hamlet A.F., Mote P.W., Clark M.P., Lettnmaier, D.P., 2005; Effects of temperature and precipitation variability on snowpack trends in the western U.S.; Journal of Climate, 18 (21) 4545–4561.

What we know

In simple terms, the globe is warming because of a shifting balance between energy received from the Sun and the energy the Earth emits to space. The Earth must warm to relieve this imbalance, caused principally by trace gas increases, particularly carbon dioxide, that result from human activity. The West has been warming steadily for 30 years, and temperature changes are much greater in the West than in the rest of the United States.

The climate of the West is characterized by large variability at all time scales. Variability within a season and from one year to the next affects a broad range of socioeconomic sectors ranging from the ski industry to water supplies. At the same time, droughts present western society with some of its greatest challenges. The most extensive drought on record occurred in 2000–2004, when 42.3 percent of the western United States experienced a severe and sustained drought.

Early snowmelt and retreating glaciers contribute to water supply shortages. Dana Glacier, Sierra Nevada. Photo: C. Millar, USFS.

Key Questions and Research Directions

As the climate warms, what will happen to winter snowpack? Will higher rates of evapotranspiration lead to more frequent and persistent drought, and if so, what are the consequences for wildland fire and ecosystem health?

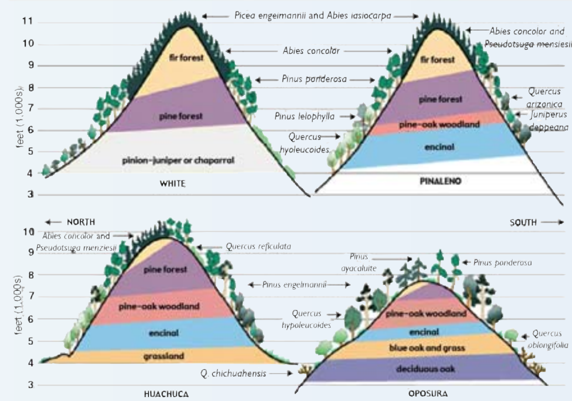
The region where most of the snowpack accumulates in the West is sparsely sampled. We need to significantly reinforce the network of climate observations at the higher elevations.

Are changes in climate reflected in changes in phenology—the timing of seasonal life stages in plants and animals—and their elevation ranges? Conversely, are changes in life behavior corroborated by nearby climate measurements?

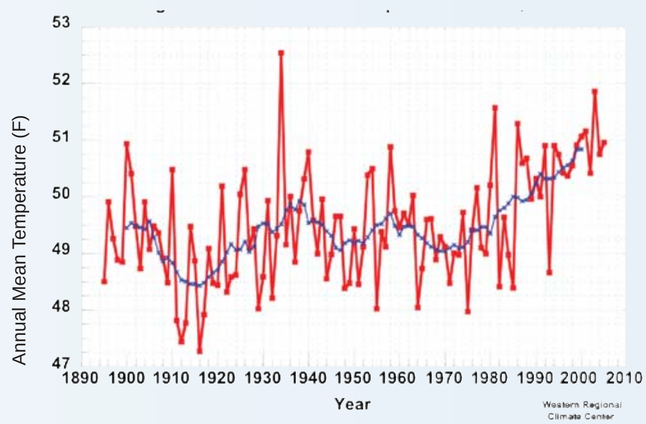
What are the implications of climate change on species distributions and abundance? For example, recent cases of widespread infestation of western forests by the pine bark beetle, which have laid waste to hundreds of thousands of woodland acres, illustrate the tremendous risk to the West from future outbreaks.

Better integration is needed of information developed about past climatic variations with global and regional scale climate models. Paleoclimate studies suggest that in the past 1,500 years, the West has suffered great droughts that would be devastating to our modern western society if they occurred today. We should be able to model the temporal and spatial features of such major droughts.

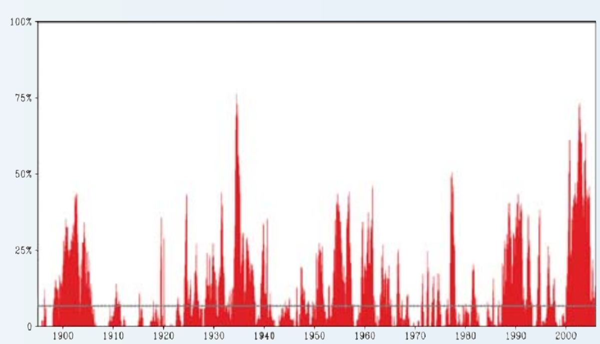
The effects of climate change will likely be highly synergistic, affecting a host of physical and natural systems in unknown ways. We need to support strongly the development of partnerships among agencies and institutions involved in environmental (including climate) monitoring and research, the public resource management agencies, and nongovernmental organizations involved in resource sustainability.



Vertically stacked mountain ecosystems may be at risk as climate changes. H. Diaz, NOAA.



Warming trends of the 20th century seen in annual temperature for 11 western United States. Blue line is 11-year mean. K. Redmond, WRCC.

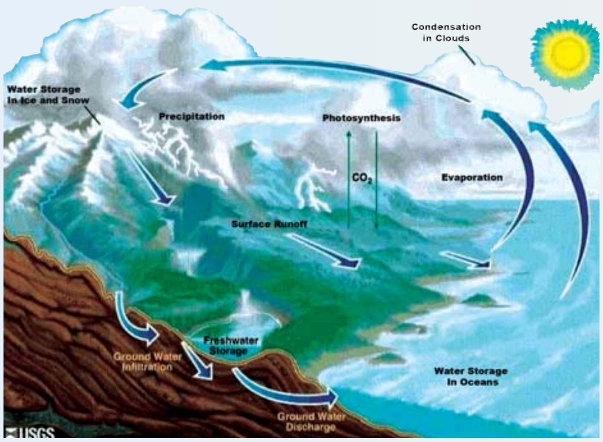


Percentage of western United States in severe drought during 1895–2005 (Palmer Drought Severity Index). H. Diaz, NOAA.

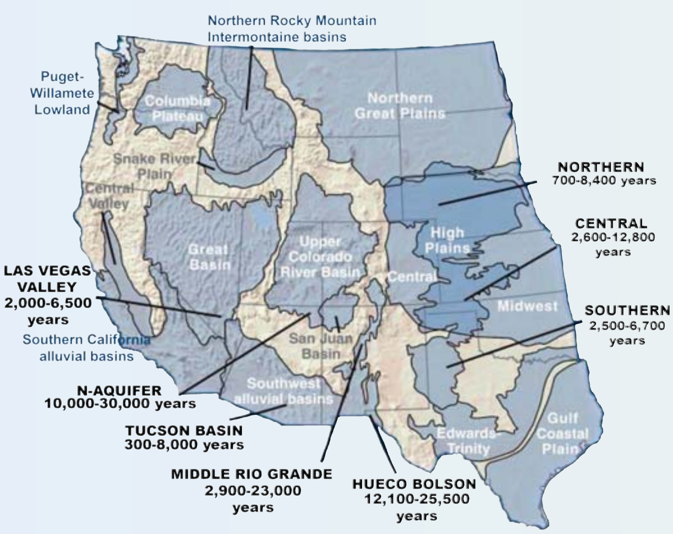
Water Supply

Scientists are concerned that . . .

warming trends are dramatically shrinking overall mountain snowpacks in the West and shifting the timing of runoff to earlier in spring. The consequences of these trends, if they continue, could be snowmelt and runoff seasons that arrive up to a month earlier by historical standards, increased risks of winter floods in some basins, region-wide diminished streamflows during the summer, depleted groundwater supplies, and increased drought stresses on plants and animals.



Hydrologic Cycle. USGS.



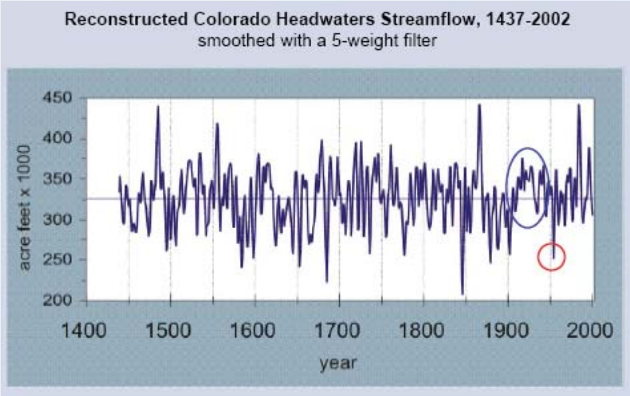
Groundwater ages for selected western aquifers.
M. Anderson, USGS.

What we know

The mountain snowpack can be thought of as the equivalent of massive continental water towers for society. As much as 75 percent of western water supplies come from mountain snowmelt.

Western water resources are highly vulnerable to changes in climate because demand now equals or exceeds the renewable supply from precipitation in many parts of the region. Under warming trends, a larger fraction of precipitation will come as rain, and the region's snowpacks will melt earlier, yielding higher winter and spring runoff rates, and less summer runoff. Spring snowmelt is already occurring weeks earlier in the year than in past decades, and more precipitation falls as rain in much of the region. Continuation of these trends will result in increased winter flood risks in some basins, smaller warm-season reserves and rates of runoff, and warmer water temperatures in many of the region's rivers and lakes, disrupting many of the region's river-management systems and procedures, potentially reducing the reliability of supplies.

The West is home to much of America's wilderness and wildlands, and its mountains are the source of the great rivers that supply most of its water. Plant- and wildlife-rich riparian zones support concentrations of rich and productive habitat that are increasingly threatened by impacts of climate change and human activities. Urban centers increasingly rely on groundwater in addition to rivers to support burgeoning demands. During droughts, new wells are typically constructed, and groundwater and reservoirs are further depleted to meet new demands on already stressed water supplies. In wet years, the new wells are still available and often continue to be used. Thus, each drought ratchets up the demands on groundwater irreversibly. Meanwhile, much western groundwater recharge derives from deep percolating snowmelt in and near the mountains. The renewal of groundwater supplies thus may be threatened by warming trends and declining snowpacks.



Colorado River Headwaters streamflow, reconstructed from tree-ring data, 1437–2002. C. Woodhouse, NOAA.

Key Questions and Research Directions

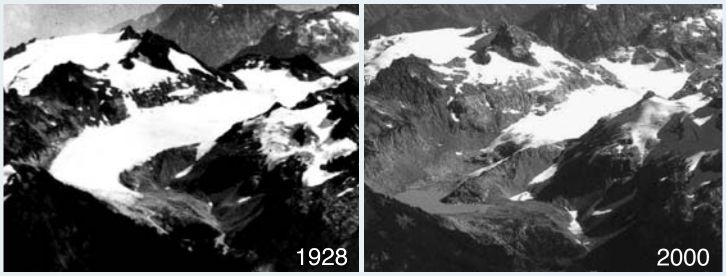
How are the diverse hydrologic cycles and amounts of water in various forms of storage changing in the West?

How will changes in mountain snowpacks affect western rural community and urban water supplies in the future?

- Systematic monitoring of surface and groundwater supplies near their mountain sources is needed. This requires maintaining an appropriate number of routine monitoring stations to adequately gauge trends in precipitation, evapotranspiration, and groundwater storage. Two sensitive, but underobserved, integrators of long-term change in the water cycle of mountains are soil moisture and discharge from high-altitude springs and streams. Groundwater has been considered the invisible water reservoir, and its characterization must be enhanced.

- To better characterize snowpacks in the complex terrains and plant canopies of western mountains, improved snowpack observations and modeling are needed. Among the major challenges needing resolution are how best to use remotely sensed data in snowpack estimation and prediction models, and how to merge remotely sensed data and on-the-ground snow networks to remedy the weaknesses of each.

- Programs to assess, clarify, and, ultimately, reliably quantify the potential impacts of warming trends on snowmelt-driven streamflows and on groundwater recharge in the West need to be developed. Key issues are how to identify and predict vulnerable components and processes in the mountain water cycle, and how vegetation-water responses will play out.



Retreat of S. Cascade Glacier, WA 1928 (USFS)–2000 (USGS).

NATIONAL PHENOLOGY NETWORK USA

http://www.uwm.edu/Dept/Geography/npn/

The flora and fauna of the West, and especially of western mountains, are key components of how its watersheds and water resources function. In particular, the year-to-year changes in the timing of various plant life stages and the arrivals of migratory species are powerful and integrative measures of the state and trends of ecosystem health. In recognition of the importance of these changes, the mountainous West was home to the most extensive long-term networks of phenological (life stage) observations in the nation, from the mid 1950s to the mid 1990s, in the form of the Western Lilac Network, which collected observations of the annual growth stages of over 2,000 lilac and honeysuckle bushes across the West, and was operated by Joe Caprio, the longtime Montana State climatologist, until his retirement in 1994. Currently a concerted effort by scientists and resource managers from across the country is underway to resurrect, greatly enhance, and expand phenological observations of all sorts into a multitiered National Phenology Network. This network promises to greatly expand our understanding of the workings and changes of western watersheds, water supplies, and ecosystems by illuminating hydrological and ecological processes that are effectively invisible to us at present because we have not made regular observations of nature's own calendars.

Forest Dieback

Scientists are concerned that . . .

cumulative stresses in western mountain forests, triggered by climate change and fire exclusion, are affecting the resilience of forests. When periodic multiyear droughts, common in western North America, occur against a backdrop of rising temperatures and unnaturally dense stands resulting from fire exclusion, forests are vulnerable to insect and disease epidemics and severe fires, which can cause significant changes in forest composition and structure and extensive forest diebacks.

Increasing forest density and decades of fire exclusion create vulnerable conditions. Photo: C. Allen, USGS.

Extensive forest mortality in pinyon pine, Jemez Mountians, NM. Photo: C. Allen, USGS.

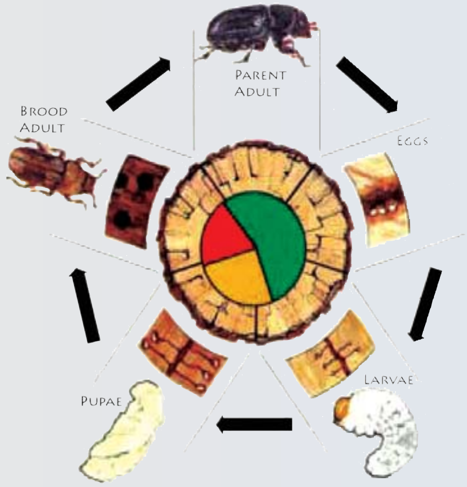
Lodgepole pine forests in British Columbia killed by mountain pine beetle, 2002. Photo: Northern Forests Products Assn.

What we know

Trees are often assumed to be highly resistant to change, being long-lived and possessing other life-history factors that favor resilience. Pinyon pine and ponderosa pine forests of the Colorado Plateau, lodgepole pine forests of Washington and British Columbia, mixed conifer forests of southern California, and Engelmann spruce forests of the eastern Great Basin, however, are among many forest types that have undergone recent massive forest diebacks in western North America. Forest dieback, defined as spatially extensive and rapid death in forests as a response to environmental triggers, has been caused by complex and cumulative interactions of stress factors. Widespread mortality events during the 20th century in forests of the West have led to conditions outside ranges of variability documented in past centuries in western North America.

The recent drought centered on 2000–2004 caused extensive forest dieback in the West. On the Colorado Plateau, 1.5 million hectares of pinyon pine and 1.0 million hectares of ponderosa pine died. Bark beetles were frequently the ultimate cause of death in dense and climate-stressed forests of this region. With the loss of forest habitat come associated impacts to forest-dependent fauna and understory plant species.

In British Columbia, mountain pine beetle epidemics have spread rapidly through dense and climate-stressed lodgepole pine forests. Four million hectares died between 1999 and 2002, causing massive declines in forest inventory for this timber-dependent region as well as dramatic losses of forest habitat. A particularly alarming threat is the potential that warming climates will enable mountain pine beetles to successfully traverse the Continental Divide, and invade new hosts in Canada and the eastern United States (see box).



Key Questions and Research Directions

What thresholds of forest stand density and climate stress lead to outbreaks of insect and disease and massive forest dieback in different forest types across the West?

How do the dieback events of the 20th and 21st centuries compare to historical diebacks?

- Studies of the ecological role of disturbance, in particular, insect outbreaks, in forest ecosystem structure and function are needed.

- Paleoecological studies of forest diebacks associated with long- and short-term climate changes are needed.

To what extent do extensive dead forests present an increased risk of catastrophic fire, or are they "flashy" only for a short time?

How are watershed values (snowpack retention, runoff, groundwater discharge, and ultimately water delivery to urban centers) affected by massive forest dieback?

- Models of fire and watershed risks associated with fuel conditions presented by massive forest dieback are needed.

What mitigation and adaptation strategies could be developed for forest restoration?

What economic losses accrue from massive forest diebacks to resource values in western mountain regions for rural recreation-dependent communities?

- There is a need to monitor natural recovery and succession in dieback regions and to conduct controlled reforestation and restoration studies to evaluate site capacity following diebacks.

J. Logan, USFS.

MOUNTAIN PINE BEETLE

Mountain pine beetle is a native species on pines of western North America, in particular, lodgepole pine. Cold conditions in eastern British Columbia historically prevented the beetle from spreading east of the Continental Divide. Warming temperatures, combined with drought-weakened pines during the late 1990s, have allowed beetle outbreaks to spread east of the Continental Divide, only 50 kilometers from jack pine. If this gap is crossed, beetles may leapfrog along a chain of susceptible host pine species across the continent to eastern North America. Should mountain pine beetle populations reach the east coast, it is highly likely that they would eventually spread into the distant, critical industrial pine belts of southeastern United States, where infestation would have serious economic impacts.

Wildfire

Scientists are concerned that . . .

in western mountains, large, destructive crown fires have increased in frequency. Ponderosa pine and some mixed conifer forests have become increasingly susceptible to extensive conflagrations. These fires, which are difficult and costly to extinguish, constitute a major hazard to life, property, and natural resources in western mountains. The combination of enormous, hard-to-control wildfires and exponential development in mountain wildlands puts human communities and natural habitats at risk.

The Rodeo-Chedeski Fire, AZ, burned over 450,000 acres and was the largest fire on record in the state.
Photo: Tucson Citizen.

The 2003 Encebado Fire burned in drought-stressed ponderosa pine forests within one-half mile of Taos Pueblo, NM. Photo: Ignacio Peralta, USFS, Carson National Forest.

What we know

Humans have wrought changes in vegetation and forest structure. This is especially the case in the drier, pine-dominated forests that sustained frequent, low-intensity surface fires before Euro-American settlement. Causes of these changes include land uses such as grazing, logging, and fire suppression, which lead to fuel build-up and encourage overly dense stands of stressed trees. For example, the broad extent and high severity of recent crown fires in southwestern ponderosa pine forests do not represent historical and ecological patterns typical of these forests prior to settlement. Fire exclusion over the past century, and consequent forest changes, were primarily responsible for the unusual severity and intensity of these fires, but recent extreme droughts undoubtedly also played a large role. Several western states had their worst fires in history during the 2000–2004 drought.

In contrast, chaparral-dominated ecosystems, pinyon pine woodlands, and high-elevation forests with moderate moisture, such as lodgepole pine and spruce/fir forests, typically burned in high-severity crown fires under extreme drought conditions. During the last century, these ecological communities have changed less than many others in terms of their fire patterns, although recent multiyear droughts put them at high risk.

In some regions and vegetation types, either human-caused forest change or climate variability and change is primarily responsible for an increase in destructive fire in recent years. In other cases, both factors play important roles.

Climate has varied considerably over the past millennia, with decade-to-centuries-long drought not unusual. In western mountains, large-fire years during the last two to three centuries coincide with drought years, and in some areas they also correlate with preceding years of wet conditions. This underscores the importance of ground vegetation in setting the stage for extensive fire, especially in drier ecosystems where understory fuel amounts and extent are limiting to fire ignition and spread.

Regionally or continentally synchronous fires occur during some climatic events. Regional fire occurrence patterns often track an asynchronous "dipole" of wet/dry conditions in the Pacific Northwest and northern Rockies versus the southwest. These broad-scale fire-climate patterns are often linked to ocean-atmosphere processes, such as El Niño/Southern Oscillation and the Pacific Decadal Oscillation, indicating that the state of these climate processes provides opportunities for interseasonal fire hazard forecasting.

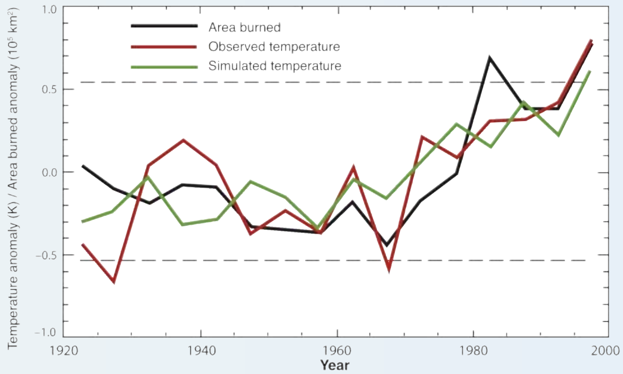
Over the past century, and at the scale of the whole western United States and Canada, variations and trends in temperature have been significantly correlated with numbers of large fires and areas burned. This suggests that regional to continental warming patterns are beginning to influence fire activity at the broadest scales.

Key Questions and Research Directions

How does climate variability between years and decades, including the incidence of drought and extremely wet episodes, affect the frequency, extent, severity, and seasonal timing of wildfire in western mountains?

What have been past fire responses to drought and temperature trends of long duration, that is, decades, centuries, and millennia?

- A need exists to develop more complete, regional-to-global-scale fire history data sets using historical records and reconstructions from tree rings, charcoal layers, and other proxies.

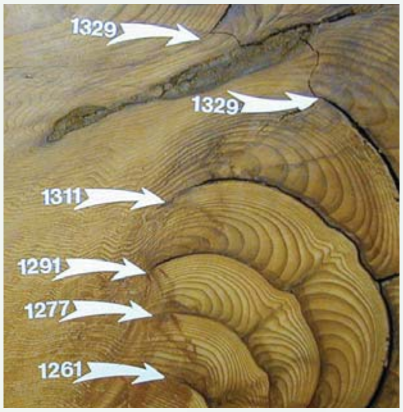


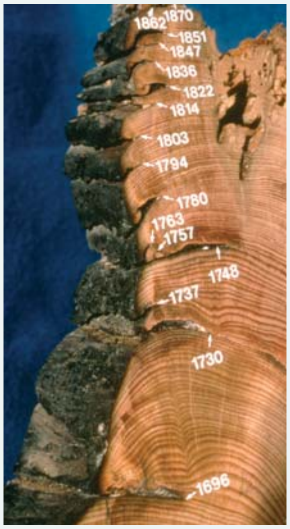
Area of land burned in Canada increased dramatically in the late 20th century, and correlates with observed and modeled summer temperature. From: Gilett, N.P., Weaver, A. J., Zwiers, F.W., and Flannigan, M.D., 2004; Detecting the effects of climate change on Canadian forest fires; Geophysical Research Letters, 31: L18211.

What are the implications of past and potential future fire occurrences in western North America for carbon emissions and sequestration?

- We need to incorporate past long-term drought responses into future-fire response modeling.
- Documenting wildfire patterns across time and space in the mountainous regions of the West will be key to managing fires.

How can knowledge and understanding of climate-fire patterns be used in fire prediction and forecasting?





Fire scars recorded in pine cross-sections showing dated fire events.
Photos: T. Swetnam, Univ. Arizona.

DATA ARCHIVES

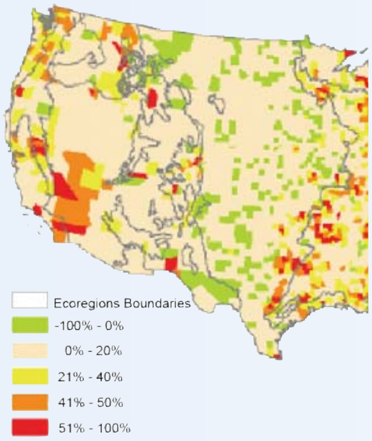
Networks of fire histories are being compiled to study past fires, as recorded in fire scars, charcoal, and pollen. The current network in the western United States consists of data from more than 250 sites (http://www.ncdc.noaa.gov/paleo/impd/). In combination with another independent network of 850 drought-sensitive tree-ring chronologies throughout the United States and Mexico and into Canada (http://www.ncdc.noaa.gov/paleo/pdsi.html), scientists can study the relationship between fire and climate during the past 300 to 500 years.

Urban-Wildland Issues

Scientists are concerned that . . .

climate change may exacerbate the ecological stresses already created by rapid land use change in mountain regions, ranging from wildlands, forestry, and agriculture to rural residential-suburban-urban-development. Persistent land-use traditions such as fire exclusion, livestock grazing, and timber harvest complicate interpretations of climate change effects. Together, two potent drivers of global change—land use and climate—amplify each other's impact and more rapidly deplete the Western mountains of the qualities for which they are valued, including wilderness, wildlife, and natural resources.

Climate-induced shifts in species' ranges and increasing urbanization in mountains lead to undesired wildlife impacts. Photo: Chuck Bartlebaugh, FHWA.



Percentage changes in area of exurban usage, 1950–2000. Modified from Brown, D.G., Johnson, K.M., Loveland, T.R., and Theobald, D.M., 2005; Rural land-use trends in the conterminous United States, 1950-2000; Ecol. Apps., 15: 1851-1863.

What we know

Low-density rural residential land use is the fastest growing type of land use in the western United States, where it now covers over 25 percent of land. This trend is particularly accentuated in areas rich in amenities. Today, Americans are moving into western mountains to enjoy scenery, wilderness, public lands, and outdoor recreation. The revolution in the computing industry has further enabled migrations to mountain areas, as it provides a means for transporting urban jobs to rural areas via telecommuting. While the extent of urban and suburban development has increased three-fold over the past half century, low-density rural residential development in areas rich in amenities has grown five-fold. Areas surrounding national parks are frequently subdivided to home sites and webbed with roads.

Low densities of settlement have impacted ecosystems in the vicinity of large protected areas such as parks where biodiversity is concentrated. Conversion of a landscape surrounding parks reduces the size of its effective ecosystem. Reduction in functional size can degrade the reserve's ability to recover from natural and anthropogenic disturbances, and increases species extinction rates. Changes in land use may inhibit flows of nutrients, energy, and organisms through a park's surrounding ecosystem. Settlement may drastically change the incidence of characteristic disturbances such as fire and may greatly alter water availability to both ecosystems and people. Conversion of surrounding lands may eliminate or isolate unique habitats outside of parks, such as dispersal and migration habitats or important source populations. Edge effects from adjacent land use may introduce invasive species, and alter community structure within parks by altering forest composition and impacting predator communities.

When climate change is overlaid on this already modified landscape, the capacity for response by natural systems and rural communities may be severely constrained by land use. Resources that otherwise would have existed may no longer be available. Migration and movement corridors may be broken. Fires and floods may be accentuated and their attendant losses many times greater than previously experienced. New influences tied to land use (invasive plants, animals; nutrient loads) may further stress ecosystems.

Key Questions and Research Directions

How do social and economic forces drive land use and development in the mountains of the West?

How do land use and climate change jointly affect social and ecological processes?

How do the joint effects of land use and climate change affect the delivery of ecosystem goods and services, and the capacity of the landscape to support communities and economies?

What institutional options exist for improving the use of global-change science in land use decisions in western mountains?

To address these questions, there is a need to:

- Understand the range of forces (from globalization of trade to specific development projects) and the mechanisms by which they drive land-use change.
- Improve understanding of how land use in the mountains is changing and determine the rate of change.
- Model future land use along with different climate scenarios.
- Investigate the impacts of different land uses along the wildland-urban gradient on key ecological attributes.
- Develop a common modeling framework that supports assessment of combinations of land use and climate change scenarios at landscape, state, and regional levels on ecosystem structure and function.
- Track the impact of climate changes and land-use change on potential losses to natural hazards (fire, flood, avalanche), agriculture, forestry, and tourism.
- Characterize the networks of authority that govern land-use decisions in different western watersheds and especially the points at which facts enter decision making.
- Develop best management practices to maximize the utility and acceptability of scientific information for those networks.

Ranchettes in Montana suffered losses in recent wildfires. Photo: A. Hansen, Montana State Univ.

Biodiversity and Wildlife

Scientists are concerned that . . .

climate change, especially warming temperatures, could cause large-scale local extinction, especially in western mountains where temperatures are rising more quickly than at lower altitudes. Ecosystem alteration, habitat fragmentation, and massive dieback may prevent many species from adapting to global warming.

Mountain yellow-legged frog populations have drastically declined in the 20th century due to multiple stresses including climate. Photo: Museum of Vertebrate Zoology, UC Berkeley.

Information archived in tree rings of long-lived limber pines reveals century-long historic droughts. Photo: C. Millar, USFS.

What we know

Broad-scale tree die-offs, insect and pathogen outbreaks, stand-replacing fires, and regional denudation of highlands have resulted in synchronous dynamic landscape changes in the past. In turn, these have sometimes led to increased hillside runoff and erosion, as well as higher levels of deposition along rivers.

Ecological resetting events have precipitated similar changes in the past. They include the 16th-century megadrought and the 1950s drought, which illustrate the ecological role of natural multidecadal climatic variability.

Multiyear drought causes mortality of many species, opening niches, the positions that organisms hold within an ecological community. In some cases, the original niche-holders regenerate. In others, invading new species fill the open slots, either through range expansion or colonization.

With critical fuel thresholds exceeded, a climate shift from wet to dry, an earlier spring melt, and a longer, hotter growing season, some mountain landscapes in the West have become “flashy”—that is, they are prone to broad, disturbance-driven, multispecies die-offs followed by surges in tree recruitment. Further, in the Mediterranean climate regions of western North America, earlier runoffs lengthen the already stressful summer dry periods.

Resilience to perturbations, establishment of invasive species, and local extinction depend in large part on the degree of climatic stress that occurs directly before and after large ecological disturbances.

Recent efforts to repeat vertebrate surveys initially carried out by Joseph Grinnell and Tracy Storer in Yosemite National Park between 1911 and 1919 suggest that mammalian species ranges are moving up slope. Additionally, scientists found many species of birds at higher elevations than in the earlier studies. These changes are consistent with models of animal response to warming in the mountains.

TRACKING SPECIES MIGRATIONS

Scientists study contraction and expansion of plant species in response to historic climate by examining records of the past. These include tree rings, which reveal colonization dates; pollen microfossils, which can be dated using chemical methods and indicate presence of specific species; and fossilized woodrat middens, which may contain fossilized plant parts as old as 40,000 years.

Key Questions and Research Directions

What are the major effects of climate change on native mountain plants and animals?

How do invasive species, which often establish following climate-related disturbance, alter ecosystems and ecosystem services in the short and long term?

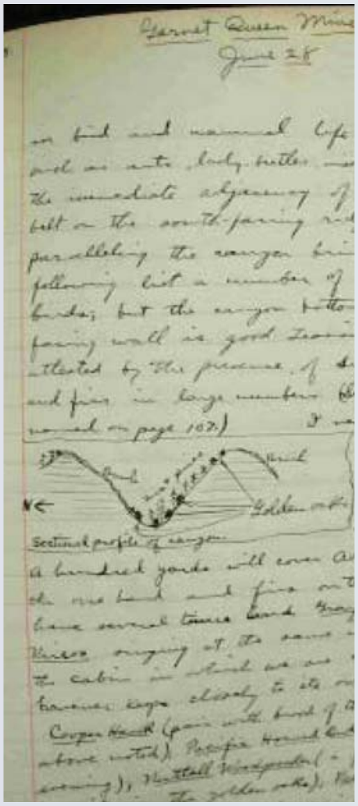
How do climate variability and related disturbances affect colonization, migration, local population extinction, and range expansion of sensitive plant and animal species?

There is a need to:

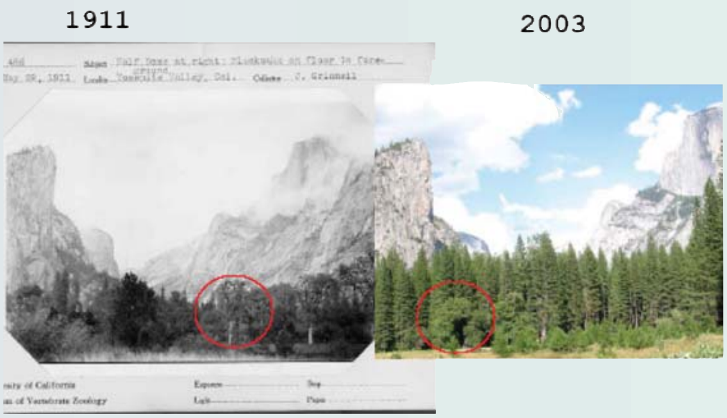
- Develop predictive models of climatic effects on ecosystems.
- Better characterize establishment of invasive species; for example, examine how distance from source populations, landscape structure, and fire influence movement of species into new areas.
- Continue to exploit natural history databases and historic photos for repeat survey opportunities.

THE GRINNELL RESURVEY PROJECT

Collecting mammals, birds, amphibians, and reptiles from over 700 locations, Joseph Grinnell, Tracy Storer, and colleagues documented California vertebrate diversity between 1904 and 1940. Their legacy includes over 20,000 specimens, 13,000 pages of field notes, and 2,000 photos, which are stored at the Museum of Vertebrate Zoology, UC Berkeley, CA. Museum scientists and colleagues are currently resurveying many locations to document changes in communities, geographic range, and species abundance.



Photos: Museum of Vertebrate Zoology, UC Berkeley.



Stoneman Meadow (Upper end of Yosemite Valley).

Launching CIRMOUNT

Background

Climate plays a pivotal role in shaping the natural environment, and, in turn, our environment plays a key part in the healthy functioning of society—providing water, arable soil, timber, recreation, and other invaluable goods and services, many necessary for our survival. The national U.S. Climate Change Science Program states as its guiding vision that the nation and the global community should be "empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems." The Canadian 2005 Climate Change Plan supports similar recommendations. CIRMOUNT seeks to develop the necessary scientific understanding to evaluate the effects of climate variability on western North American mountains, and the management tools to help this region prepare for and adapt to the effects of natural climate variability and anthropogenic climate change.

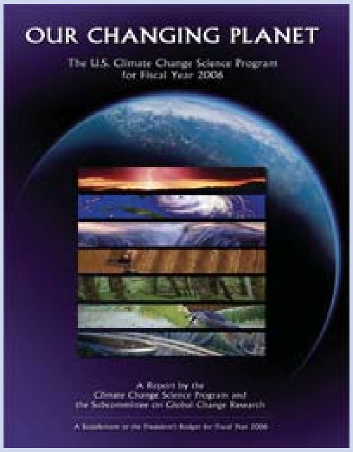
A Regional Endeavor

The dominance and ubiquity of high mountains in western North America create formidable challenges to observing, documenting, and interpreting the region's climate. Scientists face similar physical and technical obstacles when monitoring basic ecosystem functions in western mountains. For example, in California there are only three long-term climate monitoring stations over 2,700 meters among the 404 stations in the state's cooperative program. The numbers are generally worse in other mountain regions in the West.

The future of the western landscape and its response to climate change are uncertain. The United States and Canada have invested considerable resources in developing the human capital

THE U. S. CLIMATE CHANGE SCIENCE PROGRAM (CCSP)

www.climatescience.gov



In July 2003, the main climate-related research projects of 13 U.S. federal agencies were united under a single national program, the Climate Change Science Program. The CCSP's overall goal is to accelerate and enhance scientific understanding of global climate change through coordinated short- and long-term research. CIRMOUNT aligns with this overall vision, emphasizing mountain regions of western North America, and it actively promotes each of the five principal goals of the CCSP:

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

and infrastructure necessary to understand the range of possible future climate scenarios. This includes developing global and regional observing systems and computing capabilities to model the climate and project possible futures for assessment and planning. As a result, a basic understanding of many aspects of the global climate system has emerged, with prediction capabilities for global phenomena, such as El Niño/Southern Oscillation. However, we still lack a basic understanding of how long-term low-frequency variations in oceanic and atmospheric conditions influence the region's climate, and we are just beginning to invest in learning how large-scale changes play out at the scale of mountain ranges and watersheds. Through studies at this level, we will best be able to develop sustainable plans for managing natural resources while responding appropriately to local needs.

Western Mountain Ecosystems

Mountain ecosystems of western North America are complex, and include grass, shrub, and forestlands at middle elevations, cold desert and alpine biomes in the upper tree-line zone, and tundra ecosystems above timberline. The alpine ecosystem that extends from North America into Central America is the only one that exists in all different climatic zones from the equator to the polar region. This environment is among the most sensitive to climatic changes occurring on a global scale, and comprises glaciers, snow, permafrost, frozen ground, liquid water, and the uppermost limits of vegetation and other complex life forms.

Four GLORIA alpine plant monitoring sites have been established in western North America, this one in the White Mountains, CA.
Photo: C. Millar, USFS.

The stratified, elevationally controlled vegetation belts found on mountain slopes represent an analogue to the different latitudinally controlled climatic zones, but these condensed vertical gradients are known to support unique hotspots of biodiversity and provide vital corridors for endemic mountain species. High relief, steep gradients, and isolated "island effects" of high summit zones make mountain ecosystems highly sensitive to slight changes in climate.

The mountain regions of western North America are thus especially vulnerable to changes in climate and to the ensuing changes in snowpack, streamflow, and ecosystem functioning. The recent sustained, severe drought in western North America has highlighted the region's sensitivity to climate and other environmental changes. The past few decades have experienced declines in spring snowpack and earlier runoff in many watersheds within the western mountain zones. The role of mountains in providing life-sustaining water to downstream ecosystems and communities means that climatic and other environmental changes in the mountains of the West will have a large impact on the regional society, and thus, on the nation as a whole.

Opportunity for Collaboration

The initiative for CIRMOUNT arose in the early 2000s, when a group of physical and ecological scientists working on mountain climate and ecosystem sciences of western North American mountains recognized the regional ecologic, physical, and social vulnerability to climate variability and change. This group realized the value of working jointly to improve observation systems and better integrate scientific studies. An ad hoc committee formed to pursue opportunities.

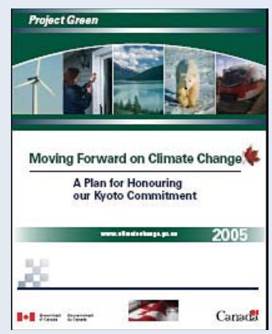
The ad hoc group organized technical sessions, science conferences, and task force meetings during 2002–2003, and encountered broad interest and momentum for establishment of a framework for a research consortium. The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) was unveiled when it organized the Mountain Climate Sciences Symposium held at Lake Tahoe, California, in 2004. Symposium participants concluded by proposing a research initiative aimed at

Workshop for natural-resource managers as part of the MTNCLIM 2005 Conference. Photo: C. Millar, USFS.

improving our understanding of climate and ecosystem changes in the West and our ability to predict such changes. Specifically, attendees agreed to encourage close collaboration among researchers from many disciplines for optimal progress toward Consortium goals.

CIRMOUNT Goals

The overall goal of CIRMOUNT is to contribute to national efforts to better understand and predict climate and environmental changes at regional scales, with a principal focus on the mountain regions of western North America. CIRMOUNT attempts to improve integration and coordination among physical, ecological, and economic process studies; encourage analytical and numerical modeling; foster partnerships across disciplines and agencies; enhance education; and develop an adequate infrastructure.



The U.S. Climate Change Science Program describes a set of core approaches to meet its goals. CIRMOUNT is proposed as a regional entity to help achieve each of those goals. It will also support research activities promoted by the Canadian 2005 Climate Change Plan (http://www.climatechange.gc.ca). Below, we describe the key aspects of work undertaken by CIRMOUNT participants.

Riparian restoration in the Mono Basin, Sierra Nevada, CA. Photo: C. Millar, USFS.

Scientific Research

Contributors to CIRMOUNT include scientists from key areas of climate, earth, and ecological sciences. Among these are climatologists from NOAA, hydrologists from USGS, ecologists from USGS and USFS, and university faculty specializing in atmospheric sciences, forest ecology, paleoclimatology, biology, and biogeochemistry, as well as social scientists focusing on the economies and sustainability of mountain communities. CIRMOUNT seeks an integration of climate, physical, ecological, and social sciences.

Initial efforts are focused on better understanding the basic drivers of climatic changes, both natural and anthropogenic. Research efforts include climate diagnostics, modeling, paleoclimatic reconstructions (describing and understanding the patterns of past climates), and selected process studies (understanding the basic pathways for energy flows throughout the coupled ocean-atmosphere-biosphere system).

Installation of high-elevation long-term climate monitoring stations is a high priority for CIRMOUNT; Mt. Warren, Sierra Nevada, CA. Photo: C. Millar, USFS.

Observations and Data Management

Several contributors to the Consortium are associated with regional or national climate data archives. They have decades of experience in data quality issues, data set development, and user support. A key goal of

CIRMOUNT is to make available comprehensive climate data sets for climate analysis and diagnostics, climate change assessments, and development of decision-support tools for resource managers. CIRMOUNT also endeavors to increase the region-wide sharing of observational methods and data.

Communication of Scientific Findings at Regional to International Scales

The members of the Consortium have extensive national and international contacts through which communication protocols have been established. In particular, CIRMOUNT has been endorsed as a pilot regional program of the international Mountain Research Initiative, a UNESCO, IGBP, and European Union-based consortium to promote science and its effective use in decision making globally. CIRMOUNT is a cosponsor of the international Mountain Invasions Research Network, which conducts a core of systematic elevational gradient studies of plant invasions into mountains around the world. CIRMOUNT also works closely with the USGS-based regional research project, the Western Mountain Initiative.

Early Accomplishments

In the past several years, the ad hoc group of scientists working to promote CIRMOUNT has sponsored several activities to encourage discussion about mountain climate topics, and to assess the need and interest for a consortium, as well as to instigate on-the-ground projects. These early successes motivated the group to carry momentum for a consortium forward. The following list represents a sample of early accomplishments:

Launched: An electronic communication network. This includes the CIRMOUNT Website http://www.fs.fed.us/psw/cirmount/ and an e-mail distribution list that includes over 500 members.

Sponsored: Sierra Nevada Climate Change & Implications for Resource Management. Special session of the Sierra Nevada Science Symposium, October 2002, Lake Tahoe, CA. This session communicated current climate-related research information to an interdisciplinary science and resource-management audience at the scale of the Sierra Nevada mountain range.

Coring through ice to lake sediments at Grass Lake Research Natural Area, CA, as part of integrated historic climate research. Photo: C. Millar, USFS.

Proceedings:
http://www.fs.fed.us/psw/publications/documents/psw_gtr193/index.shtml

Sponsored: Integrated Climate Research in Western North American Mountains. Two-day special session at the 20th Annual PACLIM (Pacific Climate) Workshop, April 2003, Asilomar, Pacific Grove, CA. Topical presentations on current research, multi-mountain-range scale.
Proceedings:
http://tenaya.ucsd.edu/~dettinge/proc_2003.html

Sponsored: Mountain Climate Science Symposium (MCSS), May 2004, Lake Tahoe, CA. This key symposium was convened to develop a framework and agenda to guide the CIRMOUNT initiative in coming years, and provided the detail and impetus for launching the consortium and its action agenda.
Presentations:
http://www.x-cd.com/mcss04/program.html

Installed: Four GLORIA Target Region Stations in North America as of 2005 at: Glacier National Park, MT; Sierra Nevada, CA; and the White Mountains, CA. GLORIA (Global Observation Research Initiative in Alpine Environments) is an international program for monitoring global change through long-term analysis of alpine vegetation, and uses standardized protocols on mountain summits. Target regions are installed at over 50 areas worldwide, but prior to CIRMOUNT's efforts, none had been installed in North America. Seven additional target regions in the West are scheduled for installation in 2006.
http://www.fs.fed.us/psw/cirmount/wkgrps/gloria/

Installed: Eleven new high-elevation long-term meteorological stations have been established via CIRMOUNT support in Alaska, California, and Montana as of 2005.

Sponsored Special Sessions: (1) Challenges to Mountain Water Resources and Ecosystems and (2) Extreme Events in Mountain Climate, Resources and Ecosystems, at the American Geophysical Sciences Meetings, December 2004 and December 2005, San Francisco, CA.
Presentations and posters in pdf:
http://www.fs.fed.us/psw/cirmount/meetings/archives.shtml

Initiated: The MTNCLIM Conference Series. The first of CIRMOUNT's regular conference series on integrated mountain climate research was held March 2005 at Chico Hot Springs, Pray, MT. The conference included technical sessions, work-group meetings, and a resource manager's workshop.
Presentations:
http://www.fs.fed.us/psw/cirmount/meetings/archives.shtml

Planned: MTNCLIM 2006. The second conference on western mountain climate sciences will be held September 16–19, 2006, at Timberline Lodge, Mt. Hood, OR.
Conference Website:
http://www.fs.fed.us/psw/mtnclim/

Mt. Morgan rock glaciers above Convict Lake, Sierra Nevada, CA. Photo: C. Millar, USFS.

CIRMOUNT Work Groups: Integrated Research and Monitoring

In spring 2005, CIRMOUNT established six Work Group Projects as a way to achieve specific CIRMOUNT goals and products. Initial themes and goals evolved from focal group discussions convened during earlier CIRMOUNT-sponsored meetings. Work group leaders and participants are self-identified, and themes, goals, projects, and products are determined through group discussion. As the breadth and definition of themes are heterogeneous among groups, each work group begins at a somewhat different stage and the groups have varying schedules for progress.

Ideas for new work groups continue to evolve. The six CIRMOUNT work groups presently active are:

Mountain Climate Network (MONET) coordinates a three-tier strategic approach to installing a network of mountain-climate monitoring stations and analysis in western mountains.
Leaders: Kelly Redmond, WRCC, Reno, NV, and Mark Losleben, Univ. Colorado, Nederland, CO
http://www.fs.fed.us/psw/cirmount/wkgrps/monet/

Mountain-Based Hydrologic Observatories (HO) is developing a consistent strategy for mountain observatories to monitor and conduct research on western water resources including snow, groundwater, and hydroclimatic interactions.
Leaders: Roger Bales, UC, Merced, and Mike Dettinger, USGS, La Jolla, CA
http://www.fs.fed.us/psw/cirmount/wkgrps/hydro/

North American GLORIA (Global Observation Research Initiative in Alpine Environments) promotes coordinated and integrated monitoring of alpine plant response to climate change using the international GLORIA protocol and additional research approaches.
Leaders: Connie Millar, USFS, Albany, CA, and Dan Fagre, USGS, West Glacier, MT
http://www.fs.fed.us/psw/cirmount/wkgrps/gloria/

Mountain Ecosystem Responses to Climate encourages scientific knowledge on effects of climate change to ecosystems, and specifically to incorporate this information in land and water resource planning and conservation.
Leaders: Jeremy Littell, UW, Seattle, WA, and Jeff Hicke, Colorado State University, Ft. Collins, CO
http://www.fs.fed.us/psw/cirmount/wkgrps/ecosys_resp/

International Relations promotes and links the work and benefits of CIRMOUNT to related mountain-climate programs at the international scale, especially the Mountain Research Initiative.
Leaders: Greg Greenwood, Mountain Research Institute, Berne, Switzerland, and Craig Allen, USGS, Los Alamos, NM
http://www.fs.fed.us/psw/cirmount/wkgrps/int_rel/

Paleoclimatic Archives for Resource Management promotes access and application of paleoclimatic and paleoecologic data for users that range from scientists in other disciplines to regional resource managers, both land and water.
Leaders: Connie Woodhouse, NOAA, Boulder, CO, Franco Biondi, UN, Reno, NV, and Greg Pederson, USGS, Bozeman, MT
http://www.fs.fed.us/psw/cirmount/wkgrps/paleo/

CIRMOUNT Moving Forward

With the establishment of six work groups, CIRMOUNT has taken steps toward integrating its early accomplishments into coordinated actions that focus on specific goals and action items. Increasing scientific and communication activities on multiple consortium fronts and growing commitment to the consortium from scientists and natural-resource managers in the United States, Canada, and other nations internationally point to the need and value for developing an institutional framework. CIRMOUNT is currently in the process of seeking sponsors and funding for a program office and administrative support.

Coordination of CIRMOUNT

CIRMOUNT is integrated within the goals of the U.S. Climate Change Science Program and the Canadian 2005 Climate Change Plan. Other key international, national, and regional collaborators of CIRMOUNT include the following:

Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI)
http://www.cuahsi.org/
The NSF-funded Consortium of Universities for the Advancement of Hydrologic Science has proposed to move modern hydrologic sciences forward by investing in several large-scale, long-term hydrologic observatories (HOs). These HOs would become test beds for instrument and method developments and would help improve the scientific bases of predictions of water-resource systems on daily to century time scales. Such observatories could serve as focal points for development of new methods and new interpretations of hydrologic variability and change in western mountains. Motivated by CUAHSI's initial proposals, teams of hydrologists are already working to plan and establish HOs in western mountains with or without CUAHSI's eventual support.

Global Observation Research Initiative in Alpine Environments (GLORIA)
http://www.gloria.ac.at/res/gloria_home/
The Global Observation Research Initiative in Alpine Environments is an international alpine science program based in Vienna, Austria, which promotes monitoring the responses of high-elevation plants to long-term climate change. GLORIA capitalizes on standardized protocols developed by an international collaboration of research scientists, and exploits the relative comparability of alpine summit environments worldwide. The basic GLORIA approach depends on establishing Multi-Summit Target Regions. In 2005, CIRMOUNT launched a North American GLORIA chapter and is coordinating establishment of new sites.

Mountain Research Initiative (MRI)
http://mri.scnatweb.ch/
The international Mountain Research Initiative is a multidisciplinary scientific organization that addresses global change issues in mountain regions around the world. MRI is based in Berne, Switzerland, and works within the framing vision and endorsement of the International Geosphere-Biosphere Programme, the International Human Dimensions Programme on Global Environmental Change, the Global Terrestrial Monitoring System, and the United Nations Educational, Scientific and Cultural Organization's Man and the Biosphere Programme. MRI's main goal is to promote an integrated approach for observing, modeling, and investigating global change phenomena and processes in mountain regions, including their impacts on ecosystems and socioeconomic systems. MRI's central focus is to coordinate efforts at the global scale. A critical element in reaching this goal is the promotion of successful efforts at regional integration. In November 2003, MRI endorsed CIRMOUNT as a pilot project for integrated research and applications at a regional scale. CIRMOUNT strives to reach the standards set by MRI and its affiliated global monitoring and research arms, and to focus on concrete efforts that improve integration of climate science into management. CIRMOUNT played a supporting role at the MRI's recent international Open Science Conference on Global Change in Mountain Regions, October 2005, Perth, Scotland.

Long-Term Ecological Research Network (LTER)
http://www.lternet.edu/
Founded by the National Science Foundation in 1980, the Long-Term Ecological Research Network is a collaborative effort that investigates ecological processes over long temporal and broad spatial scales. The network promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs. Twenty-six LTER sites represent diverse ecosystems and

research emphases. CIRMOUNT leaders and participants include key LTER program managers and scientists, and CIRMOUNT leverages integration by promoting monitoring and research in mountain LTER sites of western United States.

Mountain Invasion Research Network (MIREN)
http://www.miren.ethz.ch/
MIREN is a new international research and monitoring project aimed at inventorying and interpreting plant invasions into mountain regions. CIRMOUNT is a founding sponsor and supporter of MIREN, which is headquartered in Zurich, Switzerland. MIREN, emphasizes priority ecological research in key mountain areas around the world, focused on mechanisms of biological invasions, patterns and impacts of global climate and land-use change, and threats to mountain systems as natural heritage areas. A standardized research design uses an elevational-gradient approach for systematic comparison worldwide; one of the key sites is located in the mountains of western North America.

National Ecological Observatory Network (NEON)
http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13440&org=DBI
NEON is an emerging monitoring and research program funded and coordinated by the National Science Foundation with a goal of organizing a nationwide network of observatories to address eight important topics in ecology: invasive species, biogeochemistry, biodiversity and ecosystem functioning, climate change, land-use change, emergent diseases, hydroecology, and emerging issues. Regional NEON projects focus on geographic areas and topical themes of priority interest to CIRMOUNT, but no unit is yet proposed that will integrate mountain issues across the West. CIRMOUNT seeks to promote linkages to NEON through its activities on topics of common interest.

NOAA Climate Program Office (NOAA/CPO)
http://www.climate.noaa.gov/
The Climate Program Office, created in October 2005, incorporates the Office of Global Programs, the Arctic Research Office, and the Climate Observations and Services Program and coordinates climate activities across all NOAA. The new CPO focuses on developing a broader user community for climate products and services, provides NOAA a focal point for climate activities within NOAA, leads NOAA climate education and outreach activities, and coordinates international climate activities. NOAA's climate goal is to "understand and describe climate variability and change to enhance society's ability to plan and respond." This is an end-to-end endeavor focused on providing decision makers a predictive understanding of the global climate system and to "translate" this information so the public can incorporate the information and products into their decisions. These outcomes are achieved through implementation of a global observing system, focused research to understand key climate processes, improved modeling capabilities, and the development and delivery of climate information services. NOAA's Climate Progam Office has supported the CIRMOUNT initiative through support of its outreach and scientific workshops in North Lake Tahoe, CA, in 2004 and Pray, Montana, in 2005. In addition, support from CPO's Regional Integrated Sciences and Assessments (RISA) program, which supports research that addresses complex climate-sensitive issues of concern to decision makers and policy planners at a regional level, has provided funding support through its centers at the University of Arizona (Climate Assessment for the Southwest—CLIMAS), the University of Colorado at Boulder (Western Water Assesssment—WWA), Scripps Institution of Oceanography (California Applications Program—CAP), and the University of Washington (Climate Impacts Group—CIG).

USFS National Global Change Research Program (USFS NGCRP)

http://www.fs.fed.us/ne/global/fsgcrp/index.html

The U.S. Forest Service National Global Change Research Program, one of the participating agencies to the Climate Change Science Program, provides the scientific basis to address three broad questions:

1. What processes in forest ecosystems are sensitive to physical and chemical changes in the atmosphere?
2. How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems, and to what extent will forest ecosystems change in response to atmospheric changes?
3. What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health, and diversity?

Scientists from the USFS NGCRP have been instrumental as founding and participating members of CIRMOUNT, and the USFS program specifically seeks to support and augment CIRMOUNT projects through leverage of agency projects and staff.

USGS Global Change Research Program (USGS GCRP)

http://geochange.er.usgs.gov/

The USGS Global Change Research Program activities strive to achieve a whole-system understanding of the interrelationships among earth surface processes, ecological systems, and human activities. Activities of the program focus on documenting, analyzing, and modeling the character of past and present environments and the geological, biological, hydrological, and geochemical processes involved in environmental change, so that future environmental changes and impacts can be anticipated. Scientists from the USGS GCRP have been instrumental as founding and participating members of CIRMOUNT, and the goals and programs of the USGS overlap those of CIRMOUNT.

Western Mountain Initiative (WMI)

http://www.cfr.washington.edu/research.fme/wmi/

The Western Mountain Initiative is a newly formed, integrated research program of the USGS and U.S. National Park Service in western North America. WMI's overall objective is to understand and predict the responses—emphasizing sensitivities, thresholds, resistance, and resilience—of western mountain ecosystems to climatic variability and change. As such, the goals of WMI and CIRMOUNT are closely linked. WMI has a specific grant-driven set of research goals and projects focused on geographically grouped national park ecosystems, including Olympic, North Cascades, and Glacier National Parks, Sequoia-Kings Canyon and Yosemite National Parks, Rocky Mountain National Park, and Bandelier National Park. CIRMOUNT works closely to complement WMI's research efforts by coordinating efforts at scales and scopes of geography and disciplines different from WMI's, and by encouraging efforts at establishing regional monitoring networks, hosting western research meetings, and communicating widely with resource managers and policy makers in pubic agencies and across private jurisdictions in western mountains.

From

Here Is a Land Where Life Is Written in Water

Here is a land where life is written in water
The West is where the water was and is
Father and son of old mother and daughter
Following rivers up immensities
Of range and desert thirsting the sundown ever
Crossing a hill to climb a hill still drier
Naming tonight a city by some river
A different name from last night's camping fire.

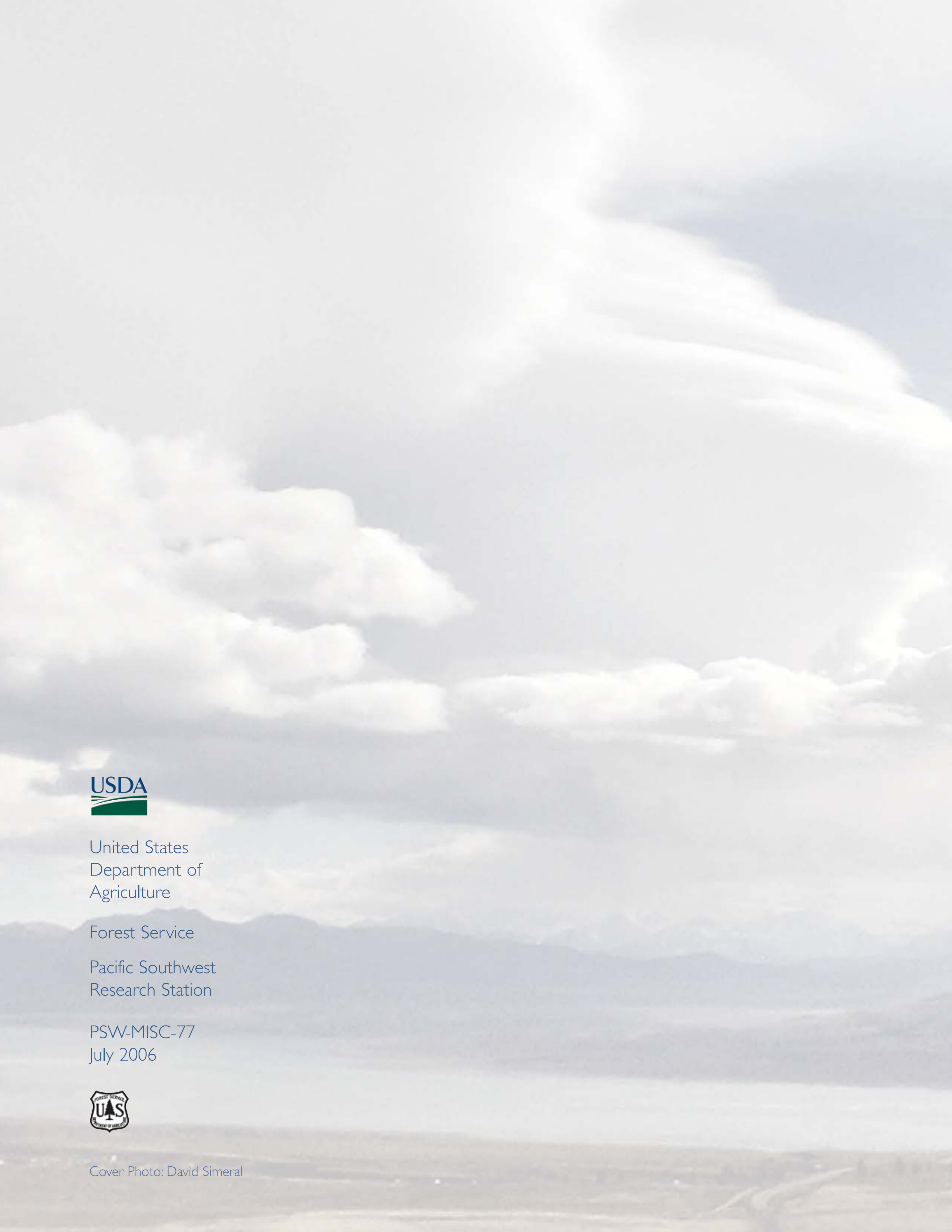
Look to the green within the mountain cup
Look to the prairie parched for water lack
Look to the Sun that pulls the oceans up
Look to the clouds that give the oceans back
Look to your heart and may your wisdom grow
To power of lightning and to peace of snow.

—Thomas Hornsby Ferrill

Closing Remarks

Western mountains are a priceless resource and a fragile one. CIRMOUNT aims to focus scientific and institutional attention on the future of our common heritage. Over the past few years, responses to CIRMOUNT efforts have met with almost unanimous enthusiasm. These responses are a source of great optimism to the Consortium leadership. We envision great scientific strides being made in understanding the physical and social landscapes in the West in the next few decades. We hope that *Mapping New Terrain* will serve as a nucleus for the varied efforts being carried out at different institutional and organizational levels to address the issues raised here.

Science writer Anne Rosenthal contributed to the development and early drafts of this report, and graphic artist Martha Shibata designed and produced it.



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