

# Abstracts of Talks and Posters from AGU 2005

## Global Climate Change Session

---

### Extreme Events in Western Mountain Climate, Resources, and Ecosystems I

*Presiding:* C I Millar, USDA Forest Service, Sierra Nevada Research Center; M Dettinger, U.S. Geological Survey, Water Resources Discipline; M Losleben, Institute of Arctic and Alpine Research, University of Colorado

#### TALKS:

#### GC32A-01 INVITED

##### Temporal Variability of Climatic Extremes in Mountain Environments

\* Redmond, K T (kelly.redmond@dri.edu) , Desert Research Institute, Western Regional Climate Center, 2215 Raggio Parkway, Reno, NV 89512-1095 United States

In contrast to humans insulated by heating and air conditioning, natural biological systems notice and respond to every nuance in their physical environment. The presence of certain extremes nearly always limits behavior in some manner, and the lack of certain extremes may similarly permit new kinds of behavior. For example, winter temperatures insufficiently low to kill insects can permit an early start to spring growth, or perhaps two generations in a summer where normally only one might occur. We have few homogeneous long term records at the highest elevations to help assess whether changes are occurring. However, selected homogeneous long term records from middle elevations show that there have been recent systematic changes in both means and extremes in the western U.S. Instrument exposure and local circumstances can affect spatial patterns of temporal variability in extremes, but there is also reasonable correspondence between elevations in this behavior. Recent years show that several types of extremes show apparent changes in frequency, in the direction of warmer conditions, more notably in minimum temperatures than in maximum temperatures.

#### GC32A-02

##### The Potential for Long-Term Impacts of Extreme Events in the Front Range of Colorado

\* Losleben, M V (markl@cultur.colorado.edu) , Institute of Arctic and Alpine Research, 1560 30th Street, Boulder, CO 80309 United States  
Caine, N (cainen@Colorado.edu) , Institute of Arctic and Alpine Research, 1560 30th Street, Boulder, CO 80309 United States  
Flanagan, C (colleen.flanagan@Colorado.edu) , Institute of Arctic and Alpine Research, 1560 30th Street, Boulder, CO 80309 United States  
McKnight, D (Diane.Mcknight@colorado.edu) , Institute of Arctic and Alpine Research, 1560 30th Street, Boulder, CO 80309 United States  
Monson, R (Russell.Monson@colorado.edu) , Dept of Ecology and Evolutionary Biology, Campus Box 334, Boulder, CO 80309 United States

Extreme climatic events can trigger a cascade of events, or cause a step function change, in environmental systems that changes the balance of one or more environmental systems, such as bio-, geo-, hydro-, or chemical. They occur at all spatial, temporal, and intensity scales, some easily measurable, others more difficult. Moreover, not all extreme events have lasting environmental impacts. Whether they affect the environmental clock or not is dependent on the particular system sensitivity in the geographic

area of interest, as well as the type of event. Obviously, sufficient environmental data are necessary to detect and evaluate the potential of an extreme event to cause long-term change, and data scarcity is often a problem in the mountains of the western US. We look at the available data for five extreme events affecting the Front Range of the Colorado Rocky Mountains, and find a range of effects, suggesting that Front Range systems are more sensitive to drought than excessive moisture, and to events of longer duration. The events are defined by the surface climatic parameters of snow, rain, or temperature, and characterized by their synoptic atmospheric circulation pattern. Factors assessing the environmental impact include net ecosystem carbon dioxide exchange, alpine lake algal populations and hydrologic residence times, rock glacier temperatures, snowpack, and reservoir storage. The events are the April 15-16, 1921 record U.S. 24-hour snowfall at Silver Lake, CO, the 1981-86 upper elevation cold period in central Colorado and southern Wyoming, an anomalously high April and May 1995 snowfall, the 2002 drought, and the March 17-19, 2003 anomalously high snowfall in the South Platte and Arkansas River basins of Colorado.

### **GC32A-03**

#### **Trends in Extreme Precipitation Events in the Western U.S. Since 1979**

\* Wolter, K (klaus.wolter@noaa.gov) , Climate Diagnostics Center, R/CDC1 325 Broadway, Boulder, CO 80305-3328 United States  
Eischeid, J K (jon.k.eischeid@noaa.gov) , Climate Diagnostics Center, R/CDC1 325 Broadway, Boulder, CO 80305-3328 United States

Several hundred automated SNOTEL sites have been established and maintained in the subalpine zones of the Western U.S. for more than two decades. Daily precipitation and snow water equivalent (SWE) data are two key measurement variables that are screened for extreme events, defined here as the highest precipitation totals and (positive) SWE changes over running five day (pentad) windows. From October 1978 through September 2003, the most extreme pentadal events are established for each water year, as well as for the full station record. Analogous computations are performed for conventional COOP climate stations in the Western U.S. Questions to be addressed include: 1. Are the most extreme pentadal events of each year increasing in size since 1979? If so, where? Are such trends statistically significant? 2. Are these extreme events at the SNOTEL sites the same as the corresponding events at adjacent COOP sites? How much can we trust COOP sites to monitor extreme events at higher elevations? 3. Is there a difference between trends in extreme rain (no SWE change) and snow events? 4. In the absence of strong trends, what is the role of ENSO? Does it fit previously established ENSO associations with U.S. precipitation?

### **GC32A-04 INVITED**

#### **"And What is There to be Gained, if we Never Question our Hydrologic Paradigms?" Extreme Events and Mountain Hydroclimatology**

\* Barros, A P (barros@duke.edu) , Ana P. Barros, Duke University, 2457 Fitzpatrick Bldg., Box 90287, Durham, NC 27708 United States

The title of this abstract is the last sentence from the first Chester C. Kiesel Memorial Lecture given by Nick Matalas at the University of Arizona in 1982. It seems fitting for this session on Extreme Events and Mountain Climate. Indeed, over the last three decades, the working paradigms in Mountain Hydrology were vigorously questioned, and much was gained in interdisciplinary scientific understanding. Here, the focus is on precipitation processes and the trajectory that lead us from asking questions such as -What is the best (statistically defensible) spatial distribution of precipitation in mountainous regions at seasonal

and annual time-scales that can be derived from incomplete and sparse raingauge networks? to asking - What are the fundamental processes that control the spatial organization of distinct orographic precipitation regimes at multiple scales, and how do these processes affect the diurnal cycle of precipitation and extreme events? Advances in observational systems and modeling capability have provided the means to study mountain environments from the level of specific physical processes to the level of entire mountain ranges. The view of mountains as bulk obstacles, elevated heat sources, and rough boundaries for large-scale atmospheric flows was extended and refined to integrate the role of landform as the organizing canvas for weather and precipitation at sub-seasonal and diurnal timescales. Likewise, the view of orographic precipitation phenomena evolved from the textbook description of stationary 2D humps in isohyetal maps to complex 4D features that result from the multi-scale interactions between synoptic flows with regional topography and modulation via land-atmosphere interactions on hydro-ecological gradients. Scaling studies show that there are strong and stable relationships between the spatial and temporal variability of rainfall and snow, landform and land-cover, and hydrometeorological regime. These findings provide a basis for localized (high spatial resolution), physically constrained estimation of extreme precipitation in mountainous regions. Results from recent work with regard to Probable Maximum Precipitation (PMP) estimation will be presented.

### **GC32A-05 INVITED**

#### **The Sensitivity of Snowmelt Processes to Meteorological Conditions and Forest Cover During Rain-on-Snow**

\* Marks, D (danny@nwrc.ars.usda.gov) , USDA Agricultural Research Service, Northwest Watershed Research Center, Boise, ID 83712-7716 United States

Devastating floods in the intermountain western US can result from rapid snowmelt during mid-winter rain-on-snow (ROS) events. Key components of snowmelt flooding during ROS are conditions prior to the storm, the combination of temperature, humidity and wind during the event, and the extent to which the snowcover is exposed to the wind. The critical antecedent condition is extension of the snowcover to lower elevations spanning the rain/snow transition zone. In the intermountain west this significantly increases the snow-covered area (SCA) and the volume of water stored in the snowcover. During ROS events warm storm conditions cause the elevation of the rain/snow transition to rise causing rain to occur over large areas with snowfall only in the highest elevations. In the intermountain west the snowcover is generally cooled by evaporation (latent heat flux) and warmed by sensible heat flux, such that turbulent fluxes have little effect on the energy state of the snowcover. However, during ROS condensation occurs on the snow such that most of the energy for snowmelt comes from the combination of sensible and latent heat exchange. If the SCA is extensive and exposed to the wind, the surface water input (SWI) may be more than doubled by the addition of snowmelt to the rain. Vegetation shelters the snowcover from the wind reducing turbulent exchange and causing significant differences between forested and open slopes. Examples of these effects are illustrated using data from recent ROS storms in early February, 1996, and January, 1997, which caused extensive damage across the western US.

### **GC32A-06 INVITED**

#### **Effects of a Warmer Climate on Stress Complexes in Forests of Western North America**

\* Peterson, D L (peterson@fs.fed.us) , USDA Forest Service, Pacific Northwest Research Station, 400 N. 34th Street, Suite 201, Seattle, WA 98103 United States  
McKenzie, D (donaldmckenzie@fs.fed.us) , USDA Forest Service, Pacific Northwest Research Station, 400 N. 34th Street, Suite 201, Seattle, WA 98103 United States

Littell, J (jlittell@u.washington.edu) , College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195 United States

A warmer climate in western North America will first affect those forests that are most susceptible to soil moisture stress. Increased water deficit will accelerate the normal stress complex experienced in forests, which typically involves some combination of multi-year drought, insects, and fire. Symptoms of prolonged drought and insects are currently manifested in extensive dieback of pine species in the pinyon-juniper forest of the American Southwest, an area where only a few tree species can survive. Less severe dieback has occurred in mixed conifer forests of the Sierra Nevada, an area also subjected to air pollution stress. Bark beetles are proliferating and killing millions of hectares of dry forest in the northern interior of western North America, setting up the prospect of large and intense fires. Recent analyses of area burned by fire in the 11 large Western states of the conterminous United States indicate that fire area will be at least twice as high in the warmer climate predicted by general circulation models. Such a large increase in disturbance superimposed on forests with increased stress from drought and insects may have significant effects on growth, regeneration, and long-term distribution and abundance of forest species.

## **GC32A-07**

### **Potential for Loss of Breeding Habitat for Imperiled Mountain Yellow-legged Frog (*Rana muscosa*) in High Sierra Nevada Mountain Water Bodies due to Reduced Snowpack: Interaction of Climate Change and an Introduced Predator**

\* Lacan, I (ilacan@nature.berkeley.edu) , University of California, Berkeley, Department of Environmental Science, Policy and Management, 137 Mulford Hall, Berkeley, CA 94720 United States  
Matthews, K R (kmatthews@fs.fed.us) , USDA Forest Service, Pacific Southwest Research Station, PO Box 245, Berkeley, CA 94701 United States

Year to year variation in snowpack (20-200% average) and summer rain create large fluctuations in the volume of water in ponds and small lakes of the higher elevation (> 3000 m) Sierra Nevada. These water bodies are critical habitat for the imperiled mountain yellow-legged frog, *Rana muscosa*, which has decreased in abundance by 90% during the past century, due in part to the loss of suitable habitat and introduction of a fish predator (trout, *Oncorhynchus* spp.). Climate change is predicted to reduce the amount of snowpack, potentially impacting amphibian habitats throughout the Sierra Nevada by further reducing the lake and pond water levels and resulting in drying of small lakes during the summer. Mountain yellow-legged frogs are closely tied to water during all life stages, and are unique in having a three- to four-year tadpole phase. Thus, tadpole survival and future recruitment of adult frogs requires adequate water in lakes and ponds throughout the year, but larger lakes are populated with fish that prey on frogs and tadpoles. Thus, most successful frog breeding occurs in warm, shallow, fishless ponds that undergo wide fluctuations in volume. These water bodies would be most susceptible to the potential climate change effects of reduced snowpack, possibly resulting in lower tadpole survival. This study explores the link between the changes in water availability -- including complete pond drying -- and the abundance and recruitment of mountain yellow-legged frog in Dusy Basin, Kings Canyon National Park, California, USA. We propose using the low-snowpack years (1999, 2002, 2004) as comparative case studies to predict future effects of climate change on aquatic habitat availability and amphibian abundance and survival. To quantify the year to year variation and changes in water volume available to amphibians, we initiated GPS lake mapping in 2002 to quantify water volumes, water surface area, and shoreline length. We tracked these changes by repeated mapping of water surface and volume (bathymetry) during the summer, and concurrently counting all the life stages (adults, subadults, tadpoles) of frogs. As a baseline in this analysis, we present 2002 data when pond volume declined 40-100% during summer in three breeding lakes. The lakes that completely dried up in 2002 were repopulated by adults in 2003 but showed no recruitment of metamorphosed frogs from previous year's tadpoles. The lakes that retained water -- even if they underwent a large reduction in water volume (-60%), surface area (-70%) and

shoreline length (-70%) during the summer -- show consistent tadpole-to-subadult recruitment in the following year (2003). Similar results are obtained using frog counts from 1999-2000 and 2004-2005 and estimates of water volume in those years. Our results suggest that more frequent summer drying of small ponds -- as may be induced by climate change -- will severely reduce frog recruitment. When combined with the invasive fish that prevent frog breeding in larger lakes, such effect of climate change may cause loss of local frog populations, and push the entire species towards extinction.

## **GC32A-08**

### **Late Glacial to Early Holocene Climate Oscillations in the American Southwest**

\* Cole, K L (ken\_cole@usgs.gov) , USGS Southwest Biological Science Center, Colorado Plateau Research Station, P.O. Box 5614, Northern Arizona University, Flagstaff, AZ 86011 United States

The late Glacial to early Holocene climate shifts in American southwest between about 16 and 8 ka have often been depicted as a trend of increasing temperature and/or declining winter precipitation, usually with a sharp step change around 13 ka (11,000 yr B.P.) signaling the shift from Pleistocene to Holocene climates. But as paleoclimatic proxies are becoming increasingly sophisticated in their stratigraphic detail and dating resolution, a much more complex picture of these climatic changes is emerging. Compilation of data from multiple proxy sources suggest that not only are shifts in temperature and precipitation not concurrent, but shifts in summer vs. winter temperature and precipitation are also not necessarily concurrent. The maximum disparity between summer vs. winter solar insolation that developed during this period is probably responsible for some of these changes in seasonality. Proxy data from packrat middens suggest that although winter temperatures were only 4.5 to 6.5 ° C below modern during the Bolling/Allerod, these temperatures quickly shifted to 7.5 to 8.7 ° C below modern during the early Younger Dryas, only to rebound rapidly by at least 4 ° C between ca. 11.8 ka and 11.5 ka. Considering the error inherent in this radiocarbon chronology, the timing and rate of this rapid warming at the end of the Younger Dryas is indistinguishable to similar increases observed in the better-dated records from Greenland ice cores and Eastern Pacific ocean cores. Proxy records reflecting summer temperatures from high elevation fossil pollen data reflect similar changes but of much lower magnitude. Other proxy data from packrat middens using higher elevation species sensitive to precipitation changes suggest well developed monsoonal precipitation occurred during the Bolling/Allerod through the early Holocene. This interpretation is supported by other proxy data as disparate as isotopic studies from New Mexico and soil development series from the Mojave Desert. Although all of these climate shifts are complex and in need of much more detailed study, the traditional scenario of the winter rainfall regime Pleistocene suddenly yielding to warmer temperatures and summer precipitation at 13 ka is not supported.

## **POSTERS:**

### **GC33A-1239**

#### **An Analysis of Extreme Heat and Energy Demand**

\* Miller, N L (nlmiller@lbl.gov) , UC-Berkeley National Lab, 90-1116 One Cyclotron Road, Berkeley, CA 94720 United States

Jin, J (jimingjin@lbl.gov) , UC-Berkeley National Lab, 90-1116 One Cyclotron Road, Berkeley, CA 94720 United States

Hayhoe, K (hayhoe@atmosresearch.com) , AtmosResearch, 1234 Boring Lane, Lubbock, TX 12345 United States

Summer temperatures in the southwest U.S. are projected to increase more rapidly than previously expected, accompanied by longer, more frequent, and more severe extreme heat conditions. A heat and energy impacts analysis was performed using three Atmosphere-Ocean General Circulation Models, the HadCM3, GFDL, and the PCM, forced with the A1fi, A2, and B1 greenhouse gas emissions detailed in the IPCC Special Report on Emission Scenarios, and statistically downscaled to specific urban locations in California. Results show summer average temperature increases of 2-5oC under the lower B1 scenario and 4-8oC under the higher A1fi scenario. Results indicate that heat waves become longer and more frequent, with projections for California heat wave onset occurring by as much as 30 days earlier than present by 2050 and 70 days earlier by 2099. In addition, the number of heat wave days for six metropolitan areas in California (Los Angeles, Riverside/San Bernardino, San Francisco, Sacramento, Fresno and El Centro) show an increase by 15 to 40 more heat wave days in the 2050s than during the 1990s, and by the 2090s, the increase in heat wave days rises by 30 to 50 days under B1 and 70 to 100 days under A1fi. Heat waves are also projected to become more intense, with higher temperatures sustained over longer periods. Increases in mean and extreme heat events during the summer months have significant implications for energy demand in the heavily air-conditioned Southwest summers. Electricity load in these areas have a strong correlation with high temperature and increases proportionally, primarily due to increased air conditioning use. California's state-wide electricity demand at present increases by approximately 400 MW/oC for temperatures above 28oC, and the power grid is strained as temperatures increase, as this recent summer has seen energy alerts for Southern California. The projected temperature increases discussed here will likely further strain the California power grid requiring a combination of increased energy efficiency practices, conservation, and alternative energy sources.

## **GC33A-1240**

### **Modeling Studies of Climate Impacts and Extreme Events in California Mountain Ecosystems**

Shupe, J (jshupe@mail.arc.nasa.gov) , California State University, Ecosystem Science and Technology Mail Stop 242-4, Moffett Field, CA 94035 United States

\* Potter, C (cpotter@mail.arc.nasa.gov) , NASA Ames Research Center, Ecosystem Science and Technology Mail Stop 242-4, Moffett Field, CA 94035 United States

Kramer, M (mkramer@mail.arc.nasa.gov) , California State University, Ecosystem Science and Technology Mail Stop 242-4, Moffett Field, CA 94035 United States

Genovese, V (vbrooks@mail.arc.nasa.gov) , California State University, Ecosystem Science and Technology Mail Stop 242-4, Moffett Field, CA 94035 United States

Gross, P (pgross@mail.arc.nasa.gov) , California State University, Ecosystem Science and Technology Mail Stop 242-4, Moffett Field, CA 94035 United States

This study describes research using the CASA (Carnegie-Ames-Stanford) ecosystem model with HYDRA surface hydrologic model for the state of California to understand the effects of potential land cover and climate events on mountain ecosystems and regional water resources. The models are run at 1-km resolution to capture localized topographic effects at the regional scale. To assess HYDRA's ability to estimate actual water flows in both extreme and non-extreme years, we have compared HYDRA's results with gauge station data throughout the state. Historical predictions for the Northern Coastal Range show that HYDRA's estimate of actual water flow improves as the model progresses downstream within a watershed. Other complex watersheds that display similar characteristics include the Klamath and the San Joaquin Valley. High resolution studies of land cover and surface hydrology are presented for the Central Coast Range of California, which is impacted by extreme events of fire and rapidly changing climate gradients.

## **GC33A-1241**

## **Sensitivity of Spring-Summer Drought to Warming in Montane and Arid Regions of The Western US**

\* Hidalgo, H G (hhidalgo@ucsd.edu) , Scripps Institution of Oceanography, 9500 Gilman Drive, MC 0224, La Jolla, CA 92093 United States  
Cayan, D R (dcayan@ucsd.edu) , Scripps Institution of Oceanography, 9500 Gilman Drive, MC 0224, La Jolla, CA 92093 United States  
Dettinger, M D (mdettinger@ucsd.edu) , United States Geological Survey / SIO, 9500 Gilman Drive, MC 0224, La Jolla, CA 92093

Soil moisture and actual evapotranspiration (AET) simulated by the Variable Infiltration Capacity (VIC) model provide informative depictions of the historical variations of spring-summer drought conditions and their connections with winter precipitation in montane and arid regions of the western US. Analysis of such simulations provides a basis for better understanding the determinants of warm-season drought, and comparisons of simulated drought conditions with warm-season observations of satellite-derived Normalized Vegetation Difference Indices (NVDI) helps confirm those conclusions, especially in the arid zones. In certain parts of the montane regions, sufficient water is usually available during spring and early summer, as runoff and soil moisture remnants of winter snowpacks, so that AET rates are limited primarily by the energy available. In these regions, spring-summer drought is most sensitive to temperature (T). In arid regions, T is not as significant a determinant of spring-summer drought and AET rates depend on water availability from both winter and warm-season precipitation. Winter precipitation can be an important determinant of spring-summer drought in the montane regions, but essentially always is the primary determinant in semi-arid to arid regions. In the lowlands, correlations between winter precipitation and soil moisture are very strong at lags of three months, although in some regions like southern California, significant correlations were found as lags of five months. In montane regions, the storage of winter precipitation in the natural reservoirs provided by snowpack adds extra lags of land memory to those provided by soil moisture storage. In these regions, the strongest correlations were found between DJF precipitation and MJJ soil moisture (lag five months). In this context, warming trends in the montane regions of the western US may be expected to result in wetter than historical soils during winter and early spring (due to larger rain/snow ratios and earlier snowmelt) and drier conditions during late spring and summer (due to increased AET rates).

### **GC33A-1242**

#### **Winter circulation anomalies in the western United States associated with antecedent season and interdecadal ENSO variability, 1948-1998**

\* Brown, D P (david.brown@unh.edu) , University of New Hampshire, Department of Geography 56 College Road, Durham, NH 03824 United States

Many users of climate information across the western United States look to fall season conditions in the El Niño-Southern Oscillation (ENSO) system as an indicator of potential winter season precipitation anomalies. In this study, the reliability of fall season ENSO conditions as a predictor of Western U.S. winter circulation anomalies associated with canonical precipitation impacts is shown to vary over multi-decadal time periods consistent with phasing of the Pacific Decadal Oscillation (PDO) pattern. During the PDO cold phase of 1948-1976, fall season El Niño events tended not to precede the canonical winter troughing pattern over the West typically associated with above-Normal precipitation in many areas, particularly the southwestern states. During the PDO warm phase of 1977-1998, fall season El Niño conditions were more reliably associated with winter troughing, but typically only during moderate-to-strong El Niño events. Fall season La Niña conditions during both the cold and warm phases of the PDO generally correlated well with the occurrence of wintertime high-pressure ridging centered off the Pacific coast. The results presented here highlight uncertainty over multi-decadal time scales surrounding the use

of fall ENSO conditions, particularly during El Nino events, as a seasonal climate forecast tool for winter precipitation in the western United States.

### **GC33A-1243**

#### **Paleoflood Hydrology and its Contribution in Interpreting the Effects of Climate Change on the Magnitude of Flooding in Mountain Ecosystems**

\* Jarrett, R D (rjarrett@usgs.gov) , U.S. Geological Survey, PO Box 25046, MS 412, Denver, CO 80225 United States

Climatic conditions naturally vary over time; however, there is growing concern that anthropogenic effects also have influenced climatic variability. Substantial modeling has been done to assess the potential effects of assumed future climate change on mean annual temperature, precipitation, and streamflow. However, there has been little research related to the effects of climate change on extreme flooding. One approach to help understand and anticipate effects of climate change on the magnitude and frequency of future flooding is to document and analyze evidence of paleofloods preserved in mountain riverine ecosystems. Paleoflood hydrology is the study of flood-deposited sediments and botanical evidence preserved in rivers and their floodplains. Paleoflood data provide a means of assessing maximum floods and their ages associated with Holocene climates. This presentation compares contemporary flood data (historical and systematic streamflow-gaging station records) and Holocene paleoflood data in four distinct mountain ecosystem regions in the western United States. For each regional study area, envelope curves (graph of flood discharge versus drainage-area size with a maximum enveloping curve) defining maximum flooding were developed for contemporary and paleoflood data. These envelope curves of maximum contemporary floods and paleofloods were used to infer the effects of climatic variability on Holocene flood magnitude. The paleoflood envelope curves are slightly larger than the envelope curves of contemporary floods and differ between the mountain ecosystems; most likely, the differences stem from each ecosystem's hydroclimatic characteristics. Generally the difference between maximum contemporary and paleoflood magnitudes in each ecosystem are within the measurement error (about 10 to 30 percent) associated with the methods used to estimate flood magnitude. Thus, differences in climate and watershed conditions across the range of Holocene climates appear to have had relatively minor effects on flood magnitude in the mountain ecosystems investigated.

### **GC33A-1244**

#### **The Record of Extreme Hydrologic Events in Annually-laminated (Varved) Lake Sediments, Southern Coast Mountains, British Columbia, Canada**

\* Menounos, B (menounos@unbc.ca) , Geography University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9 Canada

Gilbert, R , Department of Geography Queen's University, Mackintosh Corry Hall, Kingston, ON K7L 3N6 Canada

Clague, J , Department of Earth Sciences Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6 Canada

Crookshanks, S , Department of Geography Queen's University, Mackintosh Corry Hall, Kingston, ON K7L 3N6 Canada

Hodder, K , Department of Geography Queen's University, Mackintosh Corry Hall, Kingston, ON K7L 3N6 Canada

Long hydro-climatic records are required to detect changes in the magnitude and frequency of extreme events, but are often absent in mountain environments. Varve chronologies from five proglacial lake

basins detail changes in the regional hydro-climate of southern British Columbia over the past 400 years. This region is ideally suited to assess the relation between hydro-meteorology and sediment transport given the quality and length of parallel instrumental records. Lake sedimentation documents snowmelt and glacier runoff, and floods. Despite significant differences in lake basin size and contributing watershed character, substantial correspondence is observed among the records. Thickest varves are produced in years with significant floods. However, the strength of the relation between flood magnitude and lake sedimentation varies within a given lake and between lake basins. Flood deposits consisting of graded laminae and beds can be identified and measured in thick (> 5 mm) varves and clarify the relation between hydrologic forcing and sediment response. A pronounced change in the nature of lake sedimentation, accompanied by higher inter-annual variability, occurred in 1980. The change coincides with an increase in the frequency and magnitude of autumn flooding and is coincident with a re-organization of the North Pacific climate system. These results highlight new directions for paleo-environmental research using varve records to study the magnitude and spatial extent of past hydro-climatic events and to distinguish them from other catastrophic events such as landslides and glacier surges unrelated to hydro-climatic forcing.

### **GC33A-1245**

#### **The Documentation of Extreme Hydrometeorological Events: Two Case Studies in Utah, Water Year 2005.**

Bardsley, T (timothy.bardsley@ut.usda.gov) , NRCS Snow Survey, 245 N. Jimmy Doolittle Rd., Salt Lake City, UT 84116 United States

Losleben, M (Mark.Losleben@colorado.edu) , Mark Losleben, 818 County Road 116, Nederland, CO 80466 United States

\* Julander, R (randall.julander@ut.usda.gov) , NRCS Snow Survey, 245 N. Jimmy Doolittle Rd., Salt Lake City, UT 84116 United States

The Natural Resources Conservation Service, formerly the Soil Conservation Service, has monitored mountain snowpack and precipitation in the Western United States since 1934. The automation of measurement sites began in the late 1970s and now over 700 snow telemetry (SNOTEL) sites are installed, most reporting hourly. The established length of record and hourly records now make it possible to evaluate and document extreme hydrometeorological events. Two recent events brought the documentation of extreme events to the attention of the Utah Snow Survey office. During October 20 - 22, 2004, the twenty four hour precipitation intensities for six Utah sites exceeded the National Weather Service estimated 100 year average return interval, and eleven of seventy seven Utah sites with 15 years or longer record, measured the maximum twenty four hour precipitation intensity of record. A second event, Jan 8 - 12, 2005, ravaged SW Utah with high intensity rains and snow leading to the flooding of the Santa Clara River and the destruction of over twenty homes. This event is particularly relevant to the precipitation form issues of rain, snow, or rain-on-snow. This paper will evaluate the atmospheric circulation conditions that drove these events, and present precipitation intensities, absolute precipitation, snow water equivalent storm totals, and stream flows. The Utah NRCS Snow Survey office is working towards a Snow Survey system wide protocol for the documentation of extreme events recorded by SNOTEL stations that will provide validation and documentation of extreme events, easily accessed by current and future data users.

### **GC33A-1246**

#### **Coupled Teleconnections and River Dynamics for Enhanced Hydrologic Forecasting in the Upper Colorado River Basin USA**

\* Matter, M A (mmatter@lamar.colostate.edu) , Colorado State University, Department of Civil Engineering Mail Delivery Code 1372, Fort Collins, CO 80523-1372 United States  
Garcia, L A (garcia@engr.colostate.edu) , Colorado State University, Department of Civil Engineering Mail Delivery Code 1372, Fort Collins, CO 80523-1372 United States  
Fontane, D G (fontane@engr.colostate.edu) , Colorado State University, Department of Civil Engineering Mail Delivery Code 1372, Fort Collins, CO 80523-1372 United States

Accuracy of water supply forecasts has improved for some river basins in the western U.S.A. by integrating knowledge of climate teleconnections, such as El Niño/Southern Oscillation (ENSO), into forecasting routines, but in other basins, such as the Colorado River Basin (CRB), forecast accuracy has declined (Pagano et al. 2004). Longer lead time and more accurate seasonal forecasts, particularly during floods or drought, could help reduce uncertainty and risk in decision-making and lengthen the period for planning more efficient and effective strategies for water use and ecosystem management. The goal of this research is to extend the lead time for snowmelt hydrograph estimation by 4-6 months (from spring to the preceding fall), and at the same time increase the accuracy of snowmelt runoff estimates in the Upper CRB (UCRB). We hypothesize that: (1) UCRB snowpack accumulation and melt are driven by large scale climate modes, including ENSO, PDO and AMO, that establish by fall and persist into early spring; (2) forecast analysis may begin in the fall prior to the start of the primary snow accumulation period and when energy to change the climate system is decreasing; and (3) between fall and early spring, streamflow hydrographs will amplify precipitation and temperature signals, and thus will evolve characteristically in response to wet, dry or average hydroclimatic conditions. Historical in situ records from largely unregulated river reaches and undeveloped time periods of the UCRB are used to test this hypothesis. Preliminary results show that, beginning in the fall (e.g., October or November) streamflow characteristics, including magnitude, rate of change and variability, as well as timing and magnitude of fall/early winter and late winter/early spring season flow volumes, are directly correlated with the magnitude of the upcoming snowmelt runoff (or annual basin yield). The use of climate teleconnections to determine characteristic streamflow responses in the UCRB advances understanding of atmosphere/land surface processes and interactions in complex terrain and subsequent effects on snowpack development and runoff (i.e., water supply), and may be used to improve seasonal forecast accuracy and extend lead time to develop more efficient and effective management strategies for water resources and ecosystems.

## **GC33A-1247**

### **Snow Avalanche Climate and Extremes of the Western United States Mountain Ranges**

\* Mock, C J (mockcj@sc.edu) , Department of Geography, Department of Geography University of South Carolina, Columbia, SC 29208 United States  
Birkeland, K W (kbirkeland@fs.fed.us) , U.S. Forest Service National Avalanche Center, P.O. Box 130, Bozeman, MT 59771 United States  
Shinker, J J (jshinker@uwyo.edu) , University of Wyoming, Department of Geography University of Wyoming A&S 206, Laramie, WY 82071 United States  
Bergen, M (Michelle.Bergen@trimble.co.nz) , Trimble Navigation Ltd, New Zealand, Christchurch, PO 8729 New Zealand

Previous snow avalanche climatic research on the mountains of western North America, based primarily on field data, have traditionally classified three main avalanche climate zones: coastal, intermountain, and continental. The coastal zone of the Pacific mountain ranges is characterized by abundant snowfall, higher snow densities, and higher temperatures. The continental zone of most of the Rocky Mountains is characterized by opposite conditions and extensive faceted crystal growth. The intermountain zone of Utah, Montana, and Idaho is intermediate between the other two zones. We revisit a quantitative assessment snow avalanche climate of the western mountains based on Westwide Avalanche Network data, encompassing mostly the period 1969-1998, and assessed the synoptic climatic conditions and

snowpack processes responsible for continental and coastal extremes. A binary seasonal classification, based on avalanche thresholds of snowpack and climatic variables, quantitatively confirm the existence of the three major climate zones. The winter of 1985-86 exhibited the most widespread spatial shift towards more coastal conditions, and the winter of 1976-77 exhibited the most widespread continental shift. Height anomalies at 500 mb explain many of these spatial changes at monthly to seasonal timeframes, but examination of daily plots of weather and avalanche variables during seasonal extremes also illustrate the importance of understanding snowpack and climatic variations that occur at daily to weekly timescales, which also generally correspond to avalanche hazard and accident extremes. A principal components analysis on daily data for selected Westwide sites indicate different combinations of climatic and snowpack variables that are conducive for big avalanche events. Composite anomaly maps of 500 mb heights reveal that strong southwesterly flow is responsible for many avalanche extremes, but some sites are exceptions due to the influence of topographic features on large-scale atmospheric circulation.

## **GC33A-1248**

### **Climate Influences on Large-Magnitude Natural Snow Avalanches in John F. Stevens Canyon, Montana**

\* Reardon, B A (blase\_reardon@usgs.gov) , USGS Northern Rocky Mountain Science Center, Glacier National Park, West Glacier, MT 59936 United States

Fagre, D B (dan\_fagre@usgs.gov) , USGS Northern Rocky Mountain Science Center, Glacier National Park, West Glacier, MT 59936 United States

Pederson, G T (gpederson@montana.edu) , Big Sky Institute Montana State University, 106 AJM Johnson Hall P.O. Box 173490 Montana State University, Bozeman, MT 59717 United States

Caruso, C J (christiancaruso@mac.com) , Big Sky Institute Montana State University, 106 AJM Johnson Hall P.O. Box 173490 Montana State University, Bozeman, MT 59717 United States

Snow avalanches are usually characterized as natural hazards. Most literature describes mitigation measures or snow properties and weather processes that contribute to avalanche initiation, with recent research focusing on the spatial variability of snow properties. Some analyses have linked extreme avalanche events (those marked by widespread, large-magnitude, destructive avalanches) with synoptic weather patterns. This study examines the temporal variability of large magnitude natural avalanches in John F. Stevens Canyon in Montana using a long-term (96 winters) historic record and dendrochronology. Results show that shifts in multi-decadal climate patterns such as the Pacific Decadal Oscillation change the frequency and severity of large-magnitude natural avalanches. From their immediate impacts, which include downed trees and dammed streams, such events appear destructive. Cumulatively, however, these events create ecotones and structural diversity in montane forests and dampen reforestation after wildfires. Large magnitude natural avalanches are thus recurring, climate-influenced disturbances that have significant, long-lasting, landscape-level effects. However, potential changes in multi-decadal climate patterns and projected changes in snowpack may lead to changes in natural avalanche frequency and severity, and thus long-term, landscape scale changes in montane forests in the northern Rocky Mountains.

## **GC33A-1249**

### **Volatility of California Precipitation: Effects of Moisture Supply and Topography in a Mediterranean Climate**

\* Gershunov, A (sasha@ucsd.edu) , Scripps Institution of Oceanography, UCSD 9500 Gilman Drive, La Jolla, CA 92093-0224 United States

Kanamaru, H (hkanamaru@ucsd.edu) , Scripps Institution of Oceanography, UCSD 9500 Gilman Drive,

La Jolla, CA 92093-0224 United States

Panorska, A (ania@unr.edu) , Anna Panorska, Department of Mathematics and Statistics University of Nevada, Reno, NV 89557 United States

Cayan, D (dcayan@ucsd.edu) , Scripps Institution of Oceanography, UCSD 9500 Gilman Drive, La Jolla, CA 92093-0224 United States

Cayan, D (dcayan@ucsd.edu) , US Geological Survey, 9500 Gilman Dr., La Jolla, CA 92093-0224 United States

California's climate is marked with infrequent but copious precipitation events preferentially enhanced by complex topography. In California, the presence or absence of daily precipitation extremes contributes significantly to the annual water supply and largely determines flood risk. We explore the intimate connection between topography and the volatility of daily precipitation in California, i.e. the magnitude of extreme events relative to typical amounts. Physical mechanisms producing extreme precipitation amounts will be elucidated with respect to synoptic systems and how they interact with California's topographic features. We will show that volatility is closely linked to the direction of moisture flux in individual storms relative to aspect and slope of major mountain ranges. We will also examine the contribution of daily extremes to total seasonal precipitation in wet and dry years. Parallel investigations will be performed on daily precipitation from station observations and a fine resolution dynamical Reanalysis over California. These results will contribute to the understanding of synoptic meteorological conditions that give rise to extreme hydrologic events over California's complex topography. The insight applied on climatic timescales to observations and modeling of storm tracks will also advance the conceptual understanding of possible effects of global climate change on California mountain hydrology.

## **GC33A-1250**

### **Rainstorms Falling on the Sierra Nevada Snowpack: Comparing Radar Observations with Surface Measurements to Better Understand Flood Potential**

\* Lundquist, J D (Jessica.Lundquist@noaa.gov) , NOAA-CIRES Climate Diagnostics Center, 325 Broadway, R/CDC1, Boulder, CO 80305-3328 United States

Ralph, F M (Marty.Ralph@noaa.gov) , NOAA Environmental Technology Laboratory, 325 Broadway, R/ETL, Boulder, CO 80305-3328 United States

Neiman, P J (Paul.J.Neiman@noaa.gov) , NOAA Environmental Technology Laboratory, 325 Broadway, R/ETL, Boulder, CO 80305-3328 United States

Kingsmill, D E (David.Kingsmill@colorado.edu) , NOAA-CIRES Environmental Technology Laboratory, 325 Broadway, R/ETL, Boulder, CO 80305-3328 United States

White, A B (Allen.B.White@noaa.gov) , NOAA-CIRES Environmental Technology Laboratory, 325 Broadway, R/ETL, Boulder, CO 80305-3328 United States

Gottas, D J (Daniel.Gottas@noaa.gov) , NOAA-CIRES Environmental Technology Laboratory, 325 Broadway, R/ETL, Boulder, CO 80305-3328 United States

Heavy rain falling on dense snowpacks has caused some of the most dramatic floods of the past century, and coastal basins spanning a wide range of elevations, such as the American River Basin in California, are extremely sensitive to these events. Many studies of climatic change show that these same river basins are extremely sensitive to regional warming, which yields a greater percentage of precipitation falling in the form of rain rather than snow, thus increasing the frequencies of floods. In the maritime mountain ranges of North America, most precipitation falls during the winter months, with a large percentage falling in the form of snow. Particularly warm storms result in floods primarily because rain falls at higher elevations and over a much larger contributing area than during a typical storm. Because of the different sizes and fall speeds of rain and snow, Doppler radars are able to detect the melting level in the atmosphere, and automated algorithms are available to make this information available to river forecasters. However, how well do these free-atmosphere observations compare with what happens at the

surface? Do hourly radar melting levels, which are beneath the altitude of the  $0^{\circ}\text{C}$  isotherm, correspond better with surface observations than temperature profiles from twice-daily operational soundings? Can coastal radar observations provide early information for storms approaching the Sierra Nevada from the Pacific Ocean? Do patterns of rising and falling melting levels provide key information for flood forecasts? This study compares surface temperature, precipitation, and snowfall data from 10 California Department of Water Resources snow pillow stations at elevations ranging from 1610-2190 m in the American River Basin west of Sacramento with observations from 3 wind profiling radars located roughly west (upstream) of the watershed. These observations are augmented by observations of river discharge and by temperature data from the Oakland radiosonde. Case studies from winter 2005 storms are presented along with statistical correlations between the various datasets.

## **GC33A-1251**

### **Limber Pine Forest Mortality Event in Response to 1990s Persistent Low Precipitation and High Minimum Temperatures**

\* Millar, C I (cmillar@fs.fed.us) , USDA Forest Service, Sierra Nevada Research Center, 800 Buchanan St, Albany, CA 94710 United States  
Westfall, R D (bwestfall@fs.fed.us) , USDA Forest Service, Sierra Nevada Research Center, 800 Buchanan St, Albany, CA 94710 United States  
Delany, D L (ddelany@fs.fed.us) , USDA Forest Service, Sierra Nevada Research Center, 800 Buchanan St, Albany, CA 94710 United States

Limber pine (*Pinus flexilis*) is a long-lived, precipitation- and temperature-sensitive conifer of dry high-elevation habitats in western North America. Our previous dendrochronological analyses of live trees and deadwood in the eastern Sierra Nevada and western Great Basin revealed major colonization and extirpation events occurring at centennial scale and related to extensive dry periods over the last 3700 years. To better understand limber pine response to variation in precipitation and temperature, we analyzed climate relations of a recent short-term but extreme forest mortality event in the northeastern edge of the species range in the central Sierra Nevada, California. We collected increment cores from 135 dead trees and 30 live trees from three stands (mean elevation, 2740 m) in which mortality exceeded 50%. Two stands were infected with limber pine dwarf mistletoe (*Arceuthobium cayanocarpum*), and bark beetle signs were evident on dead trees in all stands. Tree ages were relatively young for limber pine, less than 200 years old. Mortality occurred from 1993-1998. Using individual and composite instrumental records from nearby mid-elevation weather stations, we evaluated precipitation and minimum temperatures from 1957-present based on K-means partitioning of principal component composite time series of three eastern Sierran weather records. Although other severe short droughts occurred in this period, the years 1985-1997 were unique in the combination of low winter and total precipitation (1987-1997), high winter, spring, and annual minimum temperatures (1985-1996), and low interannual variability in precipitation (1987-1997). The limber pine mortality event appears to have been a response to multiple stressors, triggered by extreme climate years and exacerbated subsequently by mistletoe and bark beetle infestations.

## **GC33A-1252**

### **Bristlecone Pine (BCP) Paleoclimatic Model for Archaeological Patterns in the White Mountain of California**

\* Ababneh, L (linah@ltrr.arizona.edu) , Deep Springs College, HC 72 Box 45001 Deep Springs, CA, Dyer, NV 9803 United States

Climatic factors like temperature and precipitation play a major role in tree growth and the resulting tree-ring widths. Temperature governs tree ring growth patterns at upper elevation subalpine trees in the presence of sufficient amount of soil moisture. The tie between paleoclimate and archaeology is an evolving interdisciplinary field of study that aims to facilitate a better understanding of archaeological patterns and settlements through climatic variability and how it altered human settlements. In this research, I use a paleoclimatic model; reconstructed temperature based on tree-ring widths of bristlecone pine in the White Mountains of California to explain aboriginal subsistence-settlements in Owens Valley and the White Mountains of California. Temperature reconstruction is compared visually and statistically with archaeological 14C dates and precipitation reconstruction from the same region. Basic results suggest the rule of water availability in the frequency and intensity of settlements, as 88% of the 14C dates fall within drought periods. Two dates, A.D. 1662 and A.D. 1530 fall within drought periods, while the rest cluster around precipitation maxima. The magnitude of the drought period is a possible reason for the presence of those settlements during drought periods. I provide an explanation of the observed subsistence-settlements and tie those patterns with climate variability in the area within the past 900 years. The model presents a new approach to the applications of tree-ring analysis in understanding archaeological settlements in Eastern Sierra.