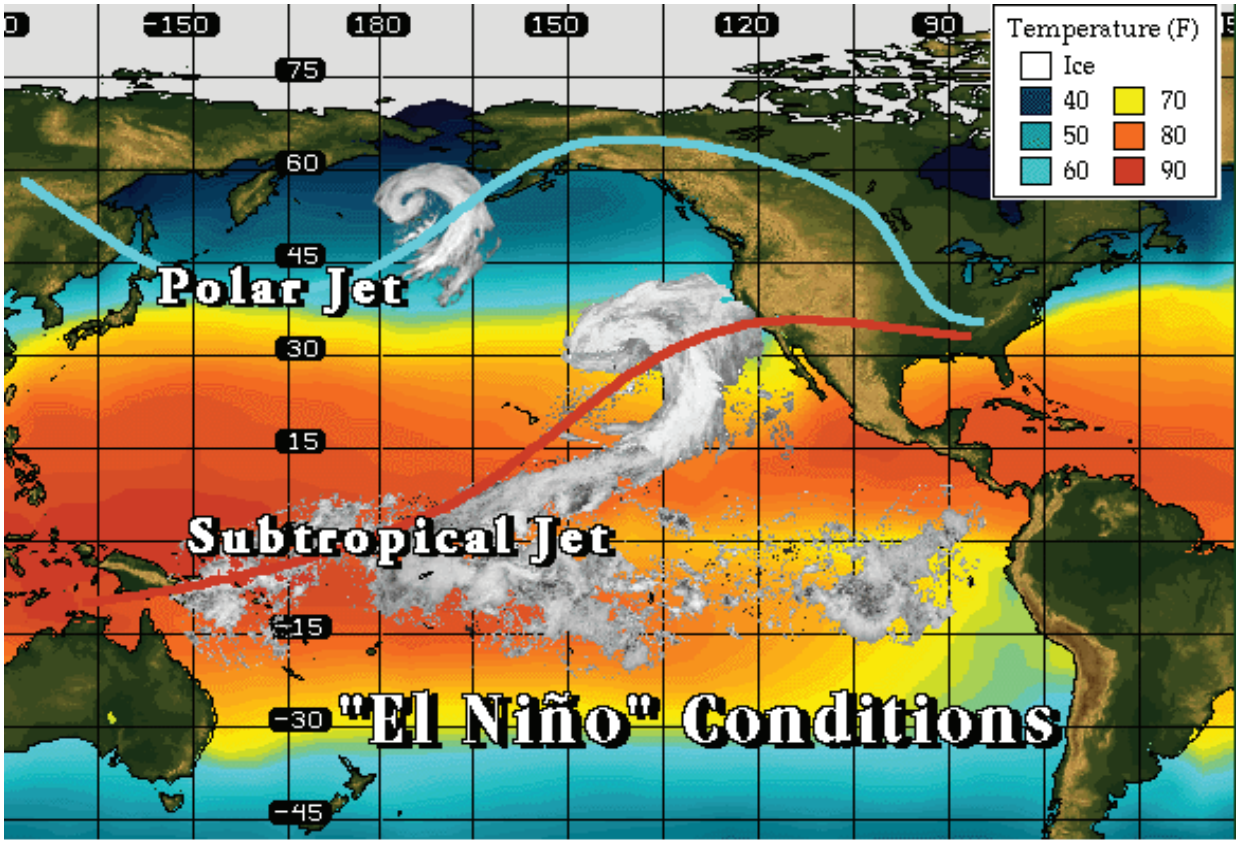
PACLIM 2009

ABSTRACTS

What happens in the Pacific …



…doesn't stay in the Pacific.

Marine-Terrestrial Connections --
Seasonal Variability to Millennial Records

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HOLOCENE HYDROCLIMATE OF THE UPPER COLORADO RIVER BASIN: DECADE-TO- CENTURY-SCALE VARIABILITY FROM SMALL, CALCAREOUS ALPINE LAKES

LESLEIGH ANDERSON (1), JOSEPH G. ROSENBAUM (1), ERIK T. BROWN (2), AND MARK D. SHAPLEY (3)

(1) U.S. Geological Survey, Denver Federal Center Box 25046, Denver, CO 80225

land@usgs.gov

(2) Large Lakes Observatory, University of Minnesota Duluth, Duluth, MN 55812

(3) Idaho State University, Pocatello, ID 83209 and the Limnological Research Center, Minneapolis, MN 55455

Isotopic data from sediments from strategically selected lakes in headwater regions of the Upper Colorado River have the potential to extend our understanding of Holocene hydroclimate variations back beyond the tree-ring record. We focus on calcareous terrains where biologically productive alpine lakes have rapidly accumulating sediments that contain endogenic calcium carbonate suitable for oxygen and carbon isotope analyses with decade-to-century resolution. The White River Plateau in west-central Colorado is a limestone massif at ~3,000 m a.s.l. in the central Rocky Mountains. Sediment cores spanning the Holocene were collected along depth transects from Yellow Lake (39.652˚N, 107.453˚W, 3,140 m a.s.l.) and Bison Lake (39.764˚N, 107.346˚W, 3,255 m a.s.l.), headwater lakes of Grizzly Creek and Deep Creek respectively, both tributaries of the Upper Colorado River. The oxygen and hydrogen isotope ratios of modern lake-water, streams, springs and snow around the area indicate that both basins experience summer evaporation in addition to snow-melt and groundwater recharge. All of these factors in addition to the source of water vapor and storm trajectories influence lake-water $\delta^{18}O$ through time but we are able to narrow the range of possibilities by utilizing isotope-hydrology modeling tools and by comparisons with other paleoclimatic records from the region. Yellow Lake's sediment $\delta^{18}O$-stratigraphy is noisy suggesting that evaporation and snowmelt/groundwater fluxes are equally affecting the data. In contrast, Bison Lake has a clear signal-to-noise difference that indicates a long-term -4.5‰ shift since ~4,000 cal yr B.P., including century-scale 3‰ excursions and the lowest values of the Holocene during the last two millennia. These data suggest that Bison Lake is dominantly sensitive to snowmelt/groundwater fluxes that are likely reflecting changes in seasonality of moisture source (summer monsoon *vs*. winter northwest flow) and(or) variations in North Pacific synoptic-scale atmospheric patterns.

NORTHERN HEMISPHERE MODES OF VARIABILLITY AND THE TIMING OF SPRING

TOBY R. AULT (1), ALISON K. MACALADY (2), GREG PEDERSON (2,3), JULIO L. BETANCOURT (4) AND MARK D. SCHWARTZ (5)
(1) *Department of Geosciences, University of Arizona, Tucson, AZ 85721*
tault@email.arizona.edu
(2) *Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721*
(3) *School of Natural Resources, University of Arizona, Tucson, AZ 85721*
(4) *U.S. Geological Survey Desert Research Lab, Tucson, AZ 85719*
(5) *Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201*

Spring Indices (SI), based on seasonally integrated changes in temperature and calibrated with continental-scale, first bloom and first leaf lilac data, have been used to document ecological impacts of northern hemisphere warming (*e.g*., Schwartz *et al*., 2006). The SI models can be generated at any location that has daily maximum–minimum temperature time series. In this analysis, we perform principal component analysis on an SI dataset from western North America to identify large-scale patterns of variability in the onset of spring. We then use observational climate data to assess the physical mechanisms and dynamics associated with those patterns. Our results show that at least two significant and independent modes of climate variability control the timing of spring throughout much of the West. The first shows a regional trend towards earlier springs and is associated most strongly with warm March temperatures. In addition to the long-term trend, there is a strong correspondence between early springs in this mode and the positive phase of the Pacific North American pattern. The second mode of spring variability exhibits a north-south dipole and correlates strongly with conditions in the tropical Pacific. It likely reflects teleconnections between the El Niño-Southern Oscillation and western North American temperatures. Our analyses also suggest that knowledge of large-scale patterns during the antecedent winter could help forecast the onset of spring. Finally, a continuing challenge for climate change detection and attribution studies, including advances in the onset of spring, is the ability to discriminate decadal-scale variations in synoptic and hemispheric-scale circulation patterns from directional trends associated with the buildup in greenhouse gases.

Schwartz, M. D., Ahas, R., and Aasa,.A., 2006, Onset of spring starting earlier across the Northern Hemisphere: Global Change Biology, v. 12, n. 2, p. 343-351.

MARINE AND TERRESTRIAL RECORDS ALONG THE PACIFIC COAST OF NORTH AMERICA REVEAL ENHANCED EXPRESSION OF ENSO CYCLES AFTER ~4,200 YEARS B.P.

JOHN A. BARRON
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
jbarron@usgs.gov

North Pacific climate was characterized by suppressed ENSO conditions (La Niña-like state) during the middle part of the Holocene between ~8,000 and 4,200 cal yr B.P. The Aleutian Low was weaker during the winter and located more to the west, while the North

Pacific High was stronger during the summer and located more to the north. As revealed by lake records, extensive drought occurred throughout the southwestern U.S. and Great Plains, while ice core data suggest southeast Alaska experienced reduced wintertime precipitation compared to today. Off California, coastal upwelling was enhanced during summer and fall but suppressed during spring. Proxy sea surface temperatures (SST) from diatoms and alkenones appear to have been cooler, except in the Santa Barbara Basin, where planktic foraminiferal assemblages and isotopes suggest warmer conditions.

A transition to late Holocene conditions, marked by enhanced expression of ENSO cycles occurred between ~4,200 and 3,000 cal yr B.P. Compared with the middle Holocene, late Holocene records appear (on average) to be more El Niño-like (a positive PDO state). The Aleutian Low is intensified during the winter and located more to the east, while the North Pacific High is weaker and displaced more to the south. Enhanced winter precipitation occurs in the southwestern U.S. and southeast Alaska, especially during intervals of positive PDO. Off California, coastal upwelling increased during the spring but was suppressed during the fall. Proxy SST appear to have been warmer, recording the shoreward migration of subtropical gyre waters during the fall, while spring upwelling (cooler SST) is enhanced in the Santa Barbara Basin.

CLIMATE CHANGE AND CULTURAL RESPONSE IN THE PREHISTORIC AMERICAN SOUTHWEST

LARRY V. BENSON
U.S. Geological Survey, 3215 Marine Street, Boulder, CO 80303
lbenson@usgs.gov

Comparison of regional tree-ring cutting-date distributions from the southern Colorado Plateau and the Rio Grande region (hereafter referred to as the study area) with tree-ring-based reconstructions of the Palmer Drought Severity Index (PDSI) and with the timing of archaeological stage transitions indicates that southwestern Native American cultures were periodically affected by major climatic oscillations between A.D. 600 and 1600. Site-specific information indicates that violence, aggregation, abandonment, and out-migration from many archaeological regions occurred during several widespread megadroughts, including the well-documented middle-12th- and late-13th-century droughts. I suggest that the demographic response of southwestern Native Americans to climate variability primarily reflects their dependence on a maize-based subsistence regimen within a region in which dryland farming was highly sensitive to climate change.

DROUGHT IN THE WEST: ASPECTS OF HISTORY AND SCALE

W.H. BERGER
Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093
wberger@ucsd.edu

The history of drought in the West is well documented in tree-ring data, for the last 2,000 years, thanks to the efforts of E. Cook, D. Meko, W. Stockton, C. Woodhouse, and colleagues (data are available from NOAA). Using these data, the suggestion of A.E. Douglass (made in the 1920s) that drought closed down thriving cities in the Southwest at the end of the 13th century, can be examined. It appears that one should distinguish at least two types of drought narratives: drought with immediate impact on harvests, and drought leading to the drying up of springs and rivers. The differences in timing implied by their relative importance may play a role in differences regarding building activities and abandonment across the region. While the patterns of drought are similar across large areas, from southern California to New Mexico, they differ from patterns to the north; that is, those of Montana and Idaho. Southern patterns are greatly influenced by ENSO variations in the eastern Pacific, and also show correlations with the North Atlantic Oscillation. Northern patterns reflect a strong influence of the North Pacific Decadal Oscillation.

DECADE-SCALE TRENDS SHOWING PHYSICAL, BIOLOGICAL, AND ECONOMIC INTERCONNECTIONS IN CALIFORNIA FISHERIES, 1928-2004

CINDY BESSEY (1), SAMUEL F. HERRICK (2), TORBJORN LORENTZEN (3), JANET E. MASON (4), AND JERROLD G. NORTON (4) (authors listed in alphabetical order)
(1) Joint Institute for Marine and Atmospheric Research, Haleiwa, HI 96712
Cindy.Bessey@noaa.gov
(2) Southwest Fisheries Science Center, La Jolla, CA 92037
Sam.Herrick@noaa.gov
(3) Bjerknes Centre for Climate Research, Bergen, Norway NO-5007
Torbjorn.Lorentzen@bjerknes.uib.no
(4) Southwest Fisheries Science Center, Pacific Grove, CA, 93950
Janet.Mason@noaa.gov, Jerrold.G.Norton@noaa.gov

Decade-scale trends and fluctuations in physical, biological and economic indicators, spanning the 80 year period from 1920 to 2000, were examined using the hypothesis that physical ocean occurrences off California may be traced through the ecosystem to the commercial catch and from there into the fisheries economic system. We have examined the records of quantity landed and ex-vessel revenue (payment for fish at dockside) for 23 distinct species landed from within 400 km of the California coast. The relative proportions of these 23 species in the landings (sought by commercial fishers since the late 1800s and representative of demersal, pelagic and migratory life histories) are taken as ecological indicators. The species composition and quantity landed is also proportional to the fisher's economic opportunities. There were two results from retrospective correlative testing with variables representing physical

ocean variability on an annual temporal scale with range in spatial scale from the southern California sea surface temperature to global surface air temperature anomalies. First, there appear to be definite links from the physical environment to the ecological and economic systems that determine the fisher's business options. These links appear to operate through distinct interannual scales of less than seven years and interdecadal scales of more than 20 years. Second, the common variability in local physical variables and ecosystem and fishery variables appears greatest when the local physical variables reflect both global and local variability. The physical forcing of the ecosystem appears to arise from forcing on both scales.

THE DYNAMIC NATURE OF DESERT WETLANDS: HOLOCENE CHANGES IN SEDIMENTATION AND FIRE REGIME ON THE ARIZONA-MEXICO BORDER

ANDREA BRUNELLE (1), THOMAS MINCKLEY (2), SHAWN BLISSETT (1), BRENDA GUZMAN (3), AND SCOTT STARRATT (4)
(1) *Department of Geography, University of Utah, Salt Lake City, UT 84112*
andrea.brunelle@geog.utah.edu
(2) *Department of Botany, University of Wyoming, Laramie, WY 82071*
(3) *Universidad Autonoma de Baja California, Baja California Sur 23000, Mexico*
(4) *U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025*
sstarrat@usgs.gov

Desert wetlands (ciénegas) are dynamic systems that respond quickly to changes in climate conditions. Sediments from the San Bernardino Ciénega near Douglas, Arizona and Agua Prieta, Mexico were examined in order to reconstruct the paleoenvironment of this region, including changes in sedimentation, water availability, vegetation assemblages, and fire regimes to inform restoration efforts. Periods of rapid sedimentation between *ca*. 4,400 to 4,100 cal yr B.P. and ca. 1,100 to 700 cal yr B.P. at San Bernardino are associated with a highstand at pluvial Lake Cochise, the presence of aquatic pollen taxa in New Mexican packrat middens and periods of incision in river channels in the San Pedro and Santa Cruz river valleys. These results suggest that ciénega deposits represent records of hydrological change which can inform ciénega restoration efforts by highlighting the importance of subsurface and surface water flow through these environments. Effective restoration requires the development of conditions where groundwater maintains surface vegetation and seasonal floods are allowed to inundate the surface.

An early Holocene vegetation and fire history record was reconstructed using fossil pollen and charcoal. Results from the fire reconstruction show an increase in fire activity with the onset of ENSO *ca*. 4,500 cal yr B.P., and a distinct increase in fire frequency associated with the Medieval Climate Anomaly. Preliminary pollen data show that plants that reflect winter-dominated precipitation correspond to times of greater fire activity. These fire data shed light on the long-term history of fire in desert environments that may be helpful in understanding what fire regimes may be expected with global warming and how to best incorporate fire into management plans.

A RECORD OF PALEOENVIRONMENT AND FOREST DISTURBANCE FROM SOUTHEASTERN WYOMING

VACHEL A. CARTER (1), ANDREA BRUNELLE (1), AND ELLIOTT LIPS (2)
(1) *Department of Geography, University of Utah, Salt Lake City, UT 84112*
vachel.carter@gmail.com, andrea.brunelle@geog.utah.edu
(2) *Great Basin Earth Science, Salt Lake City, UT 84109*
elips@gbearthscience.com

Recent mountain pine beetle (*Dendroctonus pondersae*) activity along the Snowy Mountain Range in southeastern Wyoming has motivated this project which is examining the Holocene disturbance history from Long Lake, Wyoming. Long Lake is located in the Snowy Mountain Range in Medicine Bow National Forest at an elevation of 2,700 m. The forest canopy is dominated by Lodgepole pine (*Pinus contorta*) which is one of the main forest types that mountain pine beetle infest. A 4.5-m-long sediment core was collected from Long Lake in September 2007 using a Livingstone corer. Seven identifiable macrofossils were submitted for radiocarbon dating and were used in creating an age-depth model. The bottom age for this core is ~12,500 cal yr B.P., which indicates the age of deglaciation for the area. Macrofossil and charcoal analysis was used to reconstruct the insect and fire history for the area. Preliminary charcoal data suggest wildfire activity roughly every 250 years. So far there has been no macrofossil evidence of mountain pine beetle outbreak found within this core. Pollen analysis was used to reconstruct the vegetation history for the area and will be used to further examine mountain pine beetle history. The results of this project will provide a pre-historic baseline of fire and beetle activity that can be used to better understand the modern outbreak.

CLIMATE CHANGE IN THE TAHOE BASIN: TRENDS, IMPACTS AND DRIVERS

ROBERT COATS
Tahoe Environmental Research Center, University of California, Davis, CA 95616
rncoats@ucdavis.edu

This study quantifies the decadal-scale time trends in air temperature, precipitation phase and intensity, spring snowmelt timing, and lake temperature in the Tahoe basin. Temperature data from five long-term weather stations in the Tahoe region were analyzed for trends in annual and monthly means of maximum and minimum daily temperature. Precipitation data (1910-2007) at Tahoe City were analyzed for trends in phase (rain *vs*. snow), decadal standard deviation, and intensity of rainfall. Daily streamflow data for nine gaging stations in and around the Tahoe basin were examined for trends in snowmelt timing, by two methods, and an existing record for the temperature of Lake Tahoe was updated. The results for the Tahoe basin, which contrast somewhat with the surrounding region, indicate strong upward trends in air temperature, a shift from snow to rain, a shift in snowmelt timing to earlier dates, increased rainfall intensity, increased interannual variability, increase in the temperature of Lake Tahoe, and a weak but discernible link between some of the basin trends and both the PDO and ENSO.

Two hypotheses are suggested to explain why the Tahoe basin is warming faster than the surrounding region. First, the lake itself, with its low albedo and high heat storage capacity, may be enhancing the climate-warming effects of increasing greenhouse gas concentrations. Second,

deposition of soot (black carbon) in the basin may be diminishing the albedo of the snowpack, and thus accelerating spring snowmelt. The resulting exposure of dark soil to earlier spring insolation may increase air temperature, creating a positive feedback mechanism.

NEVADA INFRASTRUCTURE FOR CLIMATE CHANGE SCIENCE, EDUCATION, AND OUTREACH

GAYLE L. DANA (1), NICHOLAS LANCASTER (2), SCOTT A. MENSING (3), AND THOMAS PIECHOTA (4)
(1) Division of Hydrologic Sciences, Desert Research Institute, Reno, NV 89512
Gayle.Dana@dri.edu
(2) Division of Earth and Ecosystem Sciences,
Desert Research Institute, Reno, NV 89512
nick.lancaster@dri.edu
(3) Department of Geography, University of Nevada, Reno, NV 89557
smensing@unr.edu
(4) Department of Civil and Environmental Engineering, University of Nevada,
Las Vegas, NV 89154
Thomas.Piechota@unlv.edu

The Nevada system of Higher Education, including the University of Nevada, Las Vegas, the University of Nevada, Reno, the Desert Research Institute, and Nevada State College has begun a five year research and infrastructure building program, funded by the National Science Foundation Experimental Program to Stimulate Competitive Research (NSF EPSCoR) with the vision "to create a statewide interdisciplinary program and virtual climate change center that will stimulate transformative research, education, and outreach on the effects of regional climate change on ecosystem resources (especially water) and support use of this knowledge by policy makers and stakeholders."

Six major strategies are proposed: 1) Develop a capability to model climate change and its effects at regional and sub-regional scales to evaluate different future scenarios and strategies (Climate Modeling Component), 2) Develop data collection, modeling, and visualization infrastructure to determine and analyze effects on ecosystems and disturbance regimes (Ecological Change Component), 3) Develop data collection, modeling, and visualization infrastructure to better quantify and model changes in water balance and resources under climate change (Water Resources Component), 4) Develop data collection and modeling infrastructure to assess effects on human systems, responses to institutional and societal aspects, and enhance policy making and outreach to communities and stakeholders (Policy, Decision-Making, and Outreach Component), 5) Develop a data portal and software to support interdisciplinary research via integration of data from observational networks and modeling (Cyberinfrastructure Component), and 6) Develop educational infrastructure to train students at all levels and provide public outreach in climate change issues (Education Component).

As part of this new infrastructure, two observational transects will be established across Great Basin ranges, one in the Spring Mountains of southern Nevada, and the second in the Snake Range of eastern Nevada. The eastern site will reach bristlecone pine stands. Climatic, hydrologic and ecological data from these transects will be downloaded into high capacity data

storage units and made available to researchers through creation of the Nevada climate change portal. Our research will aim to answer two interdisciplinary science questions: 1) How will climate change affect water resources and linked ecosystem resources and human systems? and 2) How will climate change affect disturbance regimes (*e.g.*, wildland fires, invasive species, insect outbreaks, and droughts) and linked systems?

SEDIMENT GEOCHEMICAL RECORDS OF PRODUCTIVITY AND OXYGEN DEPLETION ALONG THE MARGIN OF WESTERN NORTH AMERICA DURING THE PAST 60,000 YEARS: TELECONNECTIONS WITH THE GREENLAND ICE AND THE CARIACO BASIN

WALTER E. DEAN
U. S. Geological Survey, MS980, Federal Center, P.O. Box 25046, Denver, CO 80225
dean@usgs.gov

Many sediment records from the margins of the Californias (Alta and Baja) collected in water depths between 60 and 1,200 m contain anoxic intervals (laminated sediments) that can be correlated with interstadial intervals as defined by the oxygen-isotope composition of Greenland ice (Dansgaard-Oeschger, D-O, cycles). These intervals include all or parts of oxygen isotope stage 3 (OIS 3; 60,000-24,000 cal yr B.P.), the Bölling-Alleröd warm interval (B-A; 15,000-13,000 cal yr B.P.), and the Holocene. This study uses organic carbon (C_{org}) and trace element proxies for anoxia and productivity in these laminated sediments to suggest that productivity may be more important than ventilation in producing changes in bottom-water oxygen (BWO) conditions on open, highly productive continental margins. The main conclusion from these proxies is that during the last glacial interval (LGI; 24,000-15,000 cal yr B.P.) and the Younger Dryas cold interval (YD; 13,000-11,600 cal yr B.P.) productivity was lower and BWO levels were higher than during OIS 3, the B-A, and the Holocene on all margins of the Californias. The C_{org} and trace element profiles in the LGI to Holocene transition in the Cariaco Basin on the margin of northern Venezuela are remarkably similar to those in the transition on the northern California margin. Correlation between D-O cycles in Greenland ice cores with gray-scale measurements in varved sediments in the Cariaco Basin is also well established. Synchronous climate-driven changes as recorded in the sediments on the margins of the Californias, sediments from the Cariaco Basin, and in the GISP-2 Greenland ice core support the hypothesis that changes in atmospheric dynamics played a major role in abrupt climate change during the last 60,000 years. Millennial-scale cycles in productivity and oxygen depletion on the margins of the Californias demonstrate that the California Current System was poised at a threshold whereby perturbations of atmospheric circulation produced rapid changes in circulation in the eastern North Pacific. It is likely that the Pacific and Atlantic Oceans were linked through the atmosphere. Warmer air temperatures during interstadials would have strengthened Hadley and Walker circulation, which, in turn, would have strengthened the subtropical high-pressure systems in both the North Pacific and the North Atlantic, producing increased rainfall over the Cariaco Basin and increased upwelling along the margins of the Californias.

PALYNOLOGICAL RECONSTRUCTION OF CONDITIONS FOR THE FORMATION OF PEAT IN THE SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA

IRINA DELUSINA
Department of Geology, University of California, Davis, CA 95616
delusina@geology.ucdavis.edu

A palynological study, carried out within the framework of Project REPEAT, delineates the role of vegetation and plants communities in the formation of peat deposits in Sacramento-San Joaquin Delta of California. The study determined how the general climatic setting affected the process of peat formation and delineated the influence of the local environmental and hydrological conditions. The study compared three cores, situated in different locations: Webb Track levee, Browns Island and Franks Tract wetland. Three hundred and twenty pollen samples were analyzed using standard palynological procedures. The pollen data indicate that since about 6,500 yr B.P., when peat first started to form, general climatic conditions in the area have not changed dramatically. However, recognizable shifts in forest vegetation occurred at least twice: once between about 5,000 and 4,500 yr B.P. and again between 3,000 and 2,500 yr B.P. In both cases, higher percentages of conifer pollen are found at all three locations. Local variations in wet(dry) conditions at the different locations can be tracked using the proportion of pollen from sedge and grasses species. The ratios of arboreal/non-arboreal pollen for Browns Island and Franks Tract wetland are similar but there are significant differences in pollen percentages of species within both groups, which can also be related to differences in local conditions. Pollen concentrations are consistent with peat accumulation rates: the higher the concentration, the higher the rate. The minimum accumulation rate occurred between 2,500 and 1,000 yr B.P., which coincides with the least developed arboreal plant communities. A salinity index calculated from pollen criteria shows a minimum for the same period. The pollen data correlate well with environmental magnetic results and with sedimentary records.

NINETEENTH CENTURY PRECIPITATION VARIATIONS IN WESTERN NORTH AMERICA

STEPHANIE FOWLER DODDS
Department of Geography, University of South Carolina, Columbia, SC 29208
doddss@mailbox.sc.edu

Variations of annual precipitation in western North America effect the environment and society. The greatest amount of precipitation in the region occurs during and surrounding the winter months, with variations based on climatological changes and topographic relief. Historical records of precipitation exist for numerous locations along the west coast. This study includes the digitization and incorporation of hundreds of historical sources to enhance precipitation reconstructions within the region. Instrumental records were kept at forts and various cities, but additional documentary sources provide a control for the subjectivity of individual observers and increase the density of data. Written documents describing weather and daily activities for several posts in British Columbia, in isolated mining camps, or in smaller communities were used for precipitation frequency analysis. Logs from military and merchant

ships often kept hourly observations of weather conditions and have provided a unique record for coastal cities or weather events along shipping lanes. Several unique events stood out in the historical records that enhance knowledge about recurring events and possible future climate changes. Daily records showed precipitation responses over a large region to the well-known El Niño events of 1867-68 and 1877-78. Other correlations between precipitation and teleconnections were found through multivariate statistics. Monumental floods of the 1850, 1862, 1868, and 1881 are evident in instrumental records as well as within documentary evidence. Droughts in the southern region have also caused aeolian movement due to lack of rainfall from winter precipitation, summer monsoons, and(or) tropical systems. Two historic long-term droughts spanning the late 1850s through the early 1860s and the first half of the 1870s affected the region; these events are quite outstanding in duration and extent within the long-term record. Incorporating exceptional events into time series of precipitation in the region only enhance the knowledge of the precipitation variability over a longer, high-resolution temporal extent.

A 1600-YEAR LAKE LEVEL AND VEGETATION HISTORY OF ISLA ISABELA, GULF OF CALIFORNIA

A.C. ENGLEBRECHT (1), B.L. INGRAM (1, 2), R. BYRNE (2), U. KIENEL (3), AND H. BÖHNEL (4)

(1) Department of Earth and Planetary Science, University of California, Berkeley, CA 94720

aenglebrecht@berkeley.edu

(2) Department of Geography, University of California, Berkeley, CA 94720

(3) GeoForschungsZentrum Potsdam, Section 3.3 Climate Dynamics and Sediments, Potsdam, Germany

(4) Centro de Geociencias, Campus UNAM Juriquilla, Querétaro, México

We have used a laminated sequence from Isabela Crater Lake, located in the southern Gulf of California (21° 52' N, 105° 54' W) to produce a subdecadal stable isotope record that spans the past 1,600 years. Here, we develop a multi-proxy reconstruction of lake level and vegetation history on Isla Isabela using oxygen and carbon isotope compositions of authigenic carbonate, as well as nitrogen and carbon isotope compositions of bulk organic matter. The carbonate record shows long term, low frequency variability in lake level, punctuated by sharp drops in lake level and stronger evaporative conditions. The relative contribution of phytoplankton and land plants to the sedimentary biomass also varies through time, and is broadly correlative with lake level. Generally, there is a shift toward more land plant biomass during wetter periods. Lake level at this site has been linked to changes in the El Niño/Southern Oscillation phenomenon, with the most notable peaks in El Niño frequency (warmer, drier Gulf of California conditions) from 1175-1075, 850-600, and 150-50 yr B.P.

D/H RATIOS OF BIOMARKERS AS A TOOL FOR PALEOHYDROLOGY

SARAH FEAKINS
Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089
feakins@usc.edu

Hydrogen isotope ratios in biomarkers preserve a signature of hydrological conditions. Biomarkers are marker molecules derived from a source organism or group of organisms and thus provide a highly specific archive. In this way, lake sediment organic matter can yield paired records of lake algae and terrestrial vegetation. Modern calibration studies sampling leaf wax from Californian vegetation show that the D/H ratio of waxes records the D/H ratio of precipitation, with a secondary effect from transpiration. Lipids from aquatic organisms in lacustrine sediments record the D/H ratio of lake water, which is a function of the water budget of the lake. Progress in establishing these tools and applications to paleohydrologic reconstructions will be discussed for sites in the American West.

MAKING CONNECTIONS IN THE NORTHAST PACIFIC: LAND AND SEA, NORTH AND SOUTH

BRUCE FINNEY (1) AND JASON ADDISON (2)
(1) Department of Biological Sciences, Idaho State University, Pocatello, ID 83209
finney@isu.edu
(2) Department of Geology and Geophysics, University of Alaska, Fairbanks, AK 99775
ftjaa1@uaf.edu

Climatic changes affecting the North Pacific Ocean over decadal to millennial timescales appear to be characterized by multiple modes with coherent and recognizable spatial patterns (*i.e*., PDO). Comparisons of paleo-records from widespread regions allow recognition of how these modes shifted over time, and suggest several periods of reorganization of ocean-atmospheric circulation during the Holocene. High-resolution paleoproductivity reconstructions based on multiproxy analysis of sediment cores from the Gulf of Alaska suggest persistent variability over multidecadal scales, punctuated by abrupt state changes in overall productivity level. Such "mega-regime shifts" are of a different nature and larger amplitude than historical regime-shifts. Two such shifts likely occurred during climatic transitions into and out of the Little Ice Age (LIA; *ca*. A.D. 1200 - 1850). Recent paleoclimatic studies from Mount Logan ice cores and elsewhere suggest these transitions reflect shifts between atmospheric circulation modes of more zonal *vs*. more meridional flow. These shifts in climate and productivity can be tracked into higher trophic levels, such as pelagic fish. Records of Alaskan salmon and southern California sardine and anchovy abundance reveal differing interspecies relationships during the LIA relative to historical observations, consistent with the idea that the differing circulation patterns during these periods resulted in different relationships between these regional ecosystems. These changes in climate also effected connections between land and sea. Pacific salmon migrate across the ocean-continent boundary, transporting nutrients obtained at sea into freshwaters. Higher Alaskan salmon abundance during the LIA resulted in greater fertilization of

coastal lakes by salmon carcasses, which greatly increased their productivity relative to nearby lakes that did not contain salmon.

EXPLORING THE SCALES OF FIRE HISTORY IN THE PACIFIC NORTHWEST AND POTENTIAL LINKS TO ENSO

DOUGLAS J. HALLETT
School of Environmental Studies, Queen's University, Kingston, ON K7L 3N6 Canada
hallettd@queensu.ca

Historic forest fire records demonstrate how climate controls the occurrence of large lightning-lit fires and area burned across much of western Canada, Alaska and the Pacific Northwest (PNW). Climatic control is expressed on seasonal, yearly and decadal timescales through coupled ocean and atmospheric modes of variability such as the Pacific North American (PNA) pattern, PDO/ENSO and the Arctic Oscillation (AO). In western Canada and the PNW, persistent midtropospheric anomalies at the 500 kPa level lasting >10 days are needed to dry forest fuels and increase the probability of large fires. Dry blocking highs are associated with the position of the western Canadian Ridge (WCR) over the cordillera, and generally, fires occur when there is lightning activity, little rainfall, and strong winds. British Columbia (BC) shows a decrease in area burned over the last fifty years, which is in contrast to other regions in the Canadian boreal forest, Alaska, and PNW where large burned areas have increased, and is associated generally with the positive mode of PDO-ENSO. British Columbia seems to be in antiphase with boreal forest regions east of the great divide and north to the Yukon and Alaska. It is interesting to note that most of the area burned in BC occurred during the negative mode of PDO-ENSO, while other studies in the PNW emphasize more large fires during the positive phase although considerable variability exists. If we extend to century and millennial timescales, we see significant paleo-fire synchrony at four southern BC lake sites from 5,000 cal yr B.P. to present. Fire synchrony occurs across 100 to 800-year windows, especially over the last 2,500 years, suggesting there was strong climatic control of fire response across distinct subalpine forest regions. There are a growing number of proxy ENSO records that demonstrate an increase in frequency and magnitude from ~5,000 cal yr B.P. to present and synchronized paleo-fires may indicate a response to this long-term dynamic of the climate system. Climate variability due to enhanced PDO-ENSO activity probably exerted more control on fire regimes across western North America over the last ~2,500 years. A network of paleo-fire dates may increase our understanding of forest ecosystem disturbance across longer timescales. Future changes in the climate system will no doubt produce shifts in forest disturbance regimes across western North America.

SUMMER FOG VARIABILITY FROM HOURLY TO CENTURY SCALES IN THE COAST REDWOOD REGION OF NORTHERN CALIFORNIA

JAMES A. JOHNSTONE (1) AND TODD E. DAWSON (2)
(1) Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720
jajstone@berkeley.edu.
(2) Departmet of Environmental Science, Policy, and Management and Center for Stable Isotope Biogeochemistry, University of California, Berkeley, CA 94720
tdawson@berkeley.edu.

Coast redwood (*Sequoia sempervirens*) has long been associated with the presence of fog, due to its restricted distribution along the northern California coastal margin, where low-level stratus clouds dominate the summer climate. Here, we use a database of hourly cloud ceiling height from airport stations to examine summer (June-September) fog frequency in northern California from hourly to multi-decadal time scales. We show that the limits of the redwood distribution correspond approximately to coastal areas with >30% fog frequency in summer. On interannual time scales, fog variability is significantly enhanced(reduced) with the formation of anomalous mid-tropospheric ridges(troughs) over the northeast Pacific, and varies in association with quasi-annular pressure patterns over both hemispheres. Summer fog totals also vary in conjunction with Pacific-wide SST patterns resembling the Pacific Decadal Oscillation (PDO), though ENSO connections in the tropics are considerably weaker. Since 1951, northern California fog varies strongly with the interior-coast summer T_{MAX} gradient over California. Long-term temperature records show considerable weakening of this gradient since 1900, suggesting a long-term decline in fog frequency of perhaps 50% since the early 20th century.

EFFECTS OF CLIMATE CHANGE ON THE ALTITUDINAL DISTRIBUTIONS OF PREDATORY GROUND-BEETLES OF GENUS *NEBRIA* (INSECTA: COLEOPTERA: CARBIDAE) IN WESTERN NORTH AMERICA.

DAVID H. KAVANAUGH
Department of Entomology, California Academy of Sciences, 55 Music Concourse Drive, San Francisco, CA 94118
dkavanaugh@calacademy.org

This presentation will introduce predatory ground beetles of the genus *Nebria* (Coleoptera: Carabidae: Nebriini) in North America and their geographical and habitat distributions. Nearly 90 species occur in this region, mainly in the West, and most are restricted to particular mountains ranges. Many areas support diverse *Nebria* faunas, with up to 13 different species occurring in the same area, and each area with partially overlapping patterns of altitudinal zonation among the species. Monitoring changes in these patterns may provide sensitive measures of local and regional climate change. Results from fieldwork in 2007 and 2008 suggest measurable upward range shifts of *Nebria* species in response to a warming climate

in several sites in the western U.S., including the Rocky Mountains, Cascades, Sierra Nevada, and Trinity Alps.

HOLOCENE MULTI-DECADAL-TO-CENTENNIAL SCALE HYDROLOGIC VARIABILITY IN SOUTHERN CALIFORNIA (LAKE ELSINORE, CALIFRONIA)

MATTHEW E. KIRBY (1), STEVE P. LUND (2), WILLIAM P. PATTERSON (3), MICHAEL A. ANDERSON (4), BROXTON W. BIRD (5), LUISSA IVANOVICI (1), PEDRO MONARREZ (1), AND SHAUNA NIELSEN (1)

(1) Department of Geological Sciences, California State University, Fullerton, CA 92834
mkirby@fullerton.edu

(2) Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089
slund@usc.edu

(3) Department of Geological Sciences, University of Saskatchewan, Saskatoon, SK S7N 5E2 Canada
Bill.Patterson@usask.ca

(4) Department of Environmental Sciences, University of California, Riverside, CA 92521
Michael.anderson@ucr.edu

(5) Department of Earth Sciences, University of Pittsburgh, Pittsburgh, PA 15260
bwb8@pitt.edu

High-resolution, continuous terrestrial records of Holocene climate from Southern California are scarce. Recent research on Lake Elsinore, however, has shown that the lake's sediments hold excellent potential for paleoenvironmental analysis and reconstruction. Kirby *et al.* (2007) use environmental magnetic susceptibility, loss-on-ignition, %Al, and total inorganic P to infer a wet early Holocene followed by a long-term drying trend. Superimposed on the long-term hydrologic trend is higher frequency variability. New 1-cm-interval contiguous grain size data reveal a more complex Holocene climate history for southern California than previously recognized at the site. A modern comparison between 20th century lake level change, San Jacinto River discharge, and percent sand suggests that sand content is a reasonable, qualitative proxy for hydrologic variability at both multi-decadal to centennial as well as at event (*i.e.*, storm) timescales. The sand-hydrologic proxy data reveal several intervals of wet and dry climate throughout the Holocene with notable dry intervals from 9,550 to 9,150, 8,900 to 6,900, 6,400 to 5,800, 3,300 to 1,850, and 1,400 to 600 cal yr B.P. Individual sand spikes are frequent between 9.800 and 3.300 cal yr B.P. (n=40), but they are nearly absent from 3,300 to 400 cal yr B.P. (n=2); this disparity is interpreted as a change in storm activity. Interestingly, there is no evidence for complete desiccation of Lake Elsionore before 500 cal yr B.P. Regionally, there is an intriguing relationship between Sierra Nevada precipitation (Hughes and Graumlich, 2000) and Lake Elsinore hydrologic variability over the past 8,000 cal yr B.P. A comparison to other regional hydrologic proxies (six sites) show occasional similarities with the exception of the Little Ice Age interval, which is interpreted consistently across the region as wetter than average.

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Kirby, M.E., Lund, S.P., Anderson, M.A., and Bird, B.W., 2007, Insolation forcing of Holocene climate change in southern California: A sediment study from Lake Elsinore: Journal of Paleolimnology, v. 38, p. 395-417.

A PALEOECOLOGICAL ANALYSIS OF MEADOW SEDIMENTS FROM THE KLAMATH MOUNTAINS OF CALIFORNIA

JENNIFER E. KUSLER AND JAMES A. WANKET
Department of Geography, California State University, Sacramento, CA 95819
jenniferekusler@gmail.com

The Klamath region of northern California hosts a wide array of species and serves as a catchment area for waters flowing into the Central Valley Project. However, little is known about the environmental history of the region. This study aims to build upon the existing body of paleoenvironmental research in this area. Multiple proxies were derived from meadow sediments, and analyzed to reconstruct prehistoric environmental change. Visual stratigraphy, organic content, bulk density, fossil pollen assemblages, and charcoal particles were analyzed to provide a record of vegetation productivity and composition, disturbance events, and local fire activity throughout the last millennium. The results suggest that the study site experienced environmental changes that align well with the Medieval Warm Period (MWP) and Little Ice Age (LIA) climatic events. The MWP was characterized by a relative abundance of coniferous species, high vegetation productivity, and fire activity. During the LIA, the site supported more grasses, herbs, and riparian vegetation. Disturbance events were more frequent, and fire activity was reduced. Modern conditions appear to be analogous to those of the MWP. However, if temperatures continue to rise, as is predicted, the Klamath Mountains of northern California may undergo environmental changes not experienced in the last thousand years.

A CLIMATE OF STEWARDSHIP IN THE SIERRA NEVADA

JOHN MUIR LAWS
California Academy of Sciences, 55 Music Concourse Drive, San Francisco, CA 94952
jlaws@calacademy.org

Naturalist, educator and artist John (Jack) Muir Laws delights in exploring the natural world and sharing this love with others. For six years, John Muir Laws backpacked the Sierra Nevada to research and illustrate *The Laws Guide to the Sierra Nevada*, a richly illustrated (2,710 original watercolor paintings), pocket-size field guide to over 1,700 species found in the Sierra Nevada. This guide helps visitors and residents of the Sierra Nevada understand and appreciate the biodiversity of the region.

Laws will present an illustrated lecture about the natural history of the Sierra Nevada, and the process of creating a field guide. This engaging program will highlight some of the beautiful and amazing species in the Sierra Nevada and the relationships between them. Laws will also discuss some of the conservation challenges in the Sierra Nevada and what stewards of nature are doing to confront them.

Jack has worked as an environmental educator for over 25 years in California, Wyoming, and Alaska. He teaches classes on natural history, conservation biology, scientific illustration,

and field sketching. He is trained as a wildlife biologist and is an associate of the California Academy of Sciences. His illustrations capture the feeling of the living plant or animal, while including details critical for identification. In the summer of 2004, Laws published *Sierra Birds: a Hiker's Guide*. He is also a regular contributor to *Bay Nature* magazine with his "Naturalists Notebook" column. He is currently coordinating efforts to create sixth through eighth grade curriculum to help teachers convey a love of nature and an understanding of biodiversity to their students through field studies and nature sketching

TREE-RING CARBON ISOTOPES IN THE U.S. SOUTHWEST: INFERENCE OF MOISTURE AND MONSOON

STEVEN W. LEAVITT (1), CONNIE A. WOODHOUSE (2),
DAVID M. MEKO (1), AND RAMZI TOUCHAN (1)

(1) Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85710
sleavitt@ltrr.arizona.edu
(2) Department of Geography, University of Arizona, Tucson, AZ 85710

Ecophysiological modeling of stable-carbon isotope ratios in tree rings ($^{13}C/^{12}C$ expressed as $\delta^{13}C = [^{13}C/^{12}C_{sample} \div {}^{13}C/^{12}C_{standard}) - 1] \times 1000$) indicates $\delta^{13}C$ is determined in large part by rates of leaf photosynthesis and stomatal conductance. These rates may be variably influenced by environmental parameters such as sunlight, temperature, and precipitation/moisture, but in semi-arid environments, moisture often dominates the $\delta^{13}C$ signal. Early studies with pinyon pine (*Pinus edulis*, *Pinus monophylla*) from throughout the U.S. Southwest found $\delta^{13}C$ in 5-year tree-ring groups could be used to identify spatial patterns of drought (perhaps best termed "leaf-level ecophysiological drought"), and more recent pinyon $\delta^{13}C$ investigation has captured inter-annual variability related to moisture. Within-ring $\delta^{13}C$ analysis offers the potential to track environmental moisture on a finer time scale, and applied to ponderosa pine (*Pinus ponderosa*) in Arizona and New Mexico. Separate analysis of earlywood and latewood, guided by the presence of false latewood bands (forming in late June), allowed characterization of moisture in the early and late part of the growing season, the latter showing some particularly high correlations with precipitation amount. This $\delta^{13}C$ climate proxy is being incorporated into a new project using multiple tree-ring proxies to assess the spatial and inter-annual history and characteristics of the Southwest Monsoon over several centuries. This project is intended to improve understanding of the long-term behavior of the monsoon, which plays a key and sometimes critical role in the annual water budget of a region whose rapid population growth and climate variability (and anticipated climate change) are straining available water resources.

COMPARISON OF MILLENNIAL TO SUB-MILLENNIAL SCALE ENVIRONMENTAL VARIABILITY BETWEEN WESTERN USA LAKES AND MARINE SEQUENCES: A 50,000-13,000 YEAR RECORD FROM PYRAMID LAKE

STEVE LUND (1), LARRY BENSON (2), SCOTT MENSING (3), JOE SMOOT (4), JOE LIDDICOAT (5), ROBERT NEGRINI (6), AND MARTHA SCHWARTZ (1)
(1) Department of Earth Sciences, University of Southern California, Los Angeles 90089
slund@usc.edu
(2) U.S. Geological Survey, 3215 Marine Street, Boulder, CO 80303
(3) Department of Geography, University of Nevada, Reno 89557
(4) U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 22092
(5) Department of Environmental Science, Barnard College, New York, NY 10025
(6) Department of Geology, California State University, Bakersfield, CA 93311

We have recovered a 17-m lacustrine sediment core (PLC08-1) from Pyramid Lake, Nevada, near the site of core PLC92-2 (Benson *et al*., 1997). Core PLC08-1 can be correlated with the well-dated PLC92-2 core on the basis of three volcanic ashes and lithostratigraphic variability. Natural remanent magnetization (NRM) and rock magnetic measurements have produced an estimate of the paleomagnetic secular variation and relative paleointensity recorded in the PLC08-1 sediments. We see evidence for two magnetic field excursions (older Laschamp Excursion and younger Mono Lake Excursion) associated with two broad relative paleointensity lows in the core. The secular variation pattern above the younger excursion is consistent with and correlatable to secular variation above the Mono Lake Excursion at Mono Lake (Lund *et al*., 1988). The overall relative paleointensity variation and secular variation is consistent with and correlatable to our previous studies at Mono Lake and the North Atlantic Ocean (Benson *et al*., 1998). Fourteen radiocarbon dates from PLC92-2 and 20 radiocarbon dates from PLC08-1 core provide independent age estimates consistent with our paleomagnetic correlations. We have used the radiocarbon-based chronology and paleomagnetic-based chronology to correlate the Pyramid Lake record to marine records from the subtropical North Atlantic Ocean and western tropical Pacific Ocean. Our rock magnetic data indicate strong millennial to sub-millennial scale environmental variability that is synchronous with the marine Dansgaard-Oeschger (D-O) cyclicity. Pyramid lake-level lows are associated with D-O cold cycles and Heinrich events 3-5.

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RECORDS OF HOLOCENE HYDORCLIMATOLOGY FROM THE BEAR RIVER RANGE, SOUTHEASTERN IDAHO

ZACHARY LUNDEEN AND ANDREA BRUNELLE
Department of Geography, University of Utah, Salt Lake City, UT 84112
Zachary.lundeen@geog.utah.edu

The Bear River Range is the northernmost extension of the Wasatch Mountains. The range lies in the central portion of the Bear River Basin and is a primary hydrologic recharge area for the Bear River, which supplies more than half of the total inflow to the Great Salt Lake and is expected to be a significant water resource for growing populations in northern Utah. Long-term records of hydroclimatic variability are being generated from multiple archives in the Bear River Range to shed light on the range of variability that Bear River water resources have exhibited in the past, and how those resources might change in the future. Pollen, macroscopic charcoal, and loss-on-ignition data from Plan B Pond, a small moraine dammed lake, are being used to infer paleoenvironmental conditions for the last 13,000 years. In addition, stable carbon and oxygen isotope data from speleothems in nearby Minnetonka cave will be used to compliment and verify the lake proxies. Preliminary data and conclusions are presented here.

THE STRATIGRAPHIC RECORD OF THE LOWER COLORADO RIVER – POSSIBLE CLIMATE CONNECTIONS

DANIEL V. MALMON (1), KEITH A. HOWARD (1), PETER M. MARTIN (2), JOHN P. MCGEEHIN (3), ELMIRA WAN (1), AND SHANNON MAHAN (4)
(1) U.S. Geological Survey, MS 973, 345 Middlefield Road, Menlo Park, CA 94025
dmalmon@usgs.gov, ewan@usgs.gov
(2) U.S. Geological Survey, 4165 Spruance Road, Suite 200, San Diego, CA 92101
pmmartin@usgs.gov
(3) U.S. Geological Survey, MS 926A, 12201 Sunrise Valley Road, Reston, VA 20192
mcgeehin@usgs.gov
(4) U.S. Geological Survey, MS 974, Box 25046, Denver Federal Center, Denver, CO 80225
smahan@usgs.gov

Climatic control on the volume of flow of the Colorado River is well established for the last 100+ years from historical records and inferred for the past ~1,000 years from tree ring records. Sedimentary deposits of the Colorado River below the Grand Canyon also partly reflect the influence of climatic changes over a large portion of southwestern North America over the past ~5 m.y. A general stratigraphic framework for these deposits is emerging from 150 years of geologic studies, but the paleoenvironmental implications of these deposits have barely been explored. Recent progress in correlating and dating the Pleistocene and Holocene record demonstrates the interplay between upstream climatic influences and downstream changes in eustatic sea level. A late Pleistocene fine-grained aggradational sequence and earlier undated depositional sequences are widely exposed throughout the region and reflect change(s) in the sediment balance of the Colorado River, the result of upstream forcing such as regional climate changes in the Colorado Plateau and Rocky Mountains. The best-preserved sequence, the

Chemehuevi Formation, tentatively dates to OIS 4. The age of deposition of wood fragments buried beneath the modern floodplain, recovered from cores near Topock, Arizona, coincides with rising sea level during the early Holocene, and so likely reflects a rising base level control. Better age control would allow interpretion of this stratigraphy within the context of regional paleoclimate information, and to exploit possible paleoclimatic and paleoecological proxies in these sediments.

INFERRING MOISTURE-ANOMALY GRADIENTS FROM TREE RINGS

DAVID M. MEKO (1), DAVID W. STAHLE (2),
AND TROY A. KNIGHT (3)
(1) Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721
dmeko@LTRR.arizona.edu
(2) Department of Geosciences, University of Arkansas, Fayetteville, AR 72701
dstahle@uark.edu
(3) Department of Geography and Regional Development, University of Arizona, Tucson, AZ 85721
tak@email.arizona.edu

Although tree-ring data have been widely used for climate reconstruction on various spatial scales, little attention has been directed to the ability of a densely sampled network of tree-ring data to capture patterns of contrasting moisture anomaly over distance of just a few hundred kilometers. Such high-resolution tree-ring signals are critical to understanding past variations in storm tracks, particularly at the watershed scale, where a relatively small shift in storm track can adversely affect moisture delivery and water supplies. A newly developed network of *Quercus douglasii* from the Central Valley of California, is applied for long-term information on temporal changes in spatial patterns of cool-season precipitation delivery. It is demonstrated that such a signal can be extracted from the network, and that important changes in moisture contrast have occurred in the past. Larger-scale context for variations over four centuries years is gleaned from comparison of regional precipitation reconstructions for California from *Quercus douglasii* with paleo-drought patterns previously mapped using tree-ring data on the continental scale.

CHRONOLOGY OF PLUVIAL LAKE COYOTE, CALIFORNIA, AND IMPLICATIONS FOR 25,000 TO 10,000 CAL YR B.P. MOJAVE RIVER PALEOHYDROLOGY

DAVID M. MILLER, STEPHANIE L. DUDASH, AND JOHN P. MCGEEHIN,
(1) U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
(2) Montrose, CO 81401
(3) U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston VA 20192
dmiller@usgs.gov

Pleistocene lakes have been used to infer climate conditions, including differential responses across wide regions. We investigated a Mojave Desert lake system to address regional lake response in the western U.S. During the late Pleistocene, the Mojave River episodically fed

pluvial Lake Coyote, in the central Mojave Desert, California. Lake Coyote was a sub-basin of Lake Manix until about 25,000 cal yr B.P., when Lake Manix failed and the Mojave River alternately fed either Lake Coyote or Lake Mojave, located farther downstream (*e.g.*, Meek, 2004). Shoreline geomorphology and lacustrine depositional sequences (dated with *Anodonta*) associated with Lake Coyote can be combined to show four pluvial lake episodes after 25,000 cal yr B.P.: 1) a brief lake rise ~23,600 cal yr B.P.; 2) a sustained rise between ~19,700 to ~18,300 cal yr B.P., which included one or more fluctuations in lake level; 3) a sustained rise between ~17,200 and ~16,300 cal yr B.P. that included one fluctuation; and 4) a brief ~15,500 cal yr B.P. lake. Lake episodes 2 and 3 correspond to shoreline features at 542 and 541 m altitude, respectively, and probably coincide with overflow from the Coyote basin back into the Mojave River drainage. Lakes 1 and 4 probably did not overflow. Combining our Lake Coyote chronology with the Lake Mojave chronology of Wells et al. (2003) shows well-correlated lake-level records, with periods of low levels in one lake coincident with high levels in the other. The composite chronology indicates fluctuating(?) deep lakes between 25,000 and ~13,500 cal yr B.P. except for a period of shallower lakes between ~23,000 and ~22,000 cal yr B.P.. Shallow fluctuating lakes characterized the period from ~13,500 to ~9,900 cal yr B.P., but lakes were deeper and more frequent during the Younger Dryas part of this interval. Our new chronology indicates that levels of lakes fed by the Mojave River fell at the same time as did pluvial Lake Bonneville in the northern Great Basin, which suggests that latitudinal shifts in weather patterns at the termination of OIS 2, if they occurred, were rapid.

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MICROCHARCOAL CONCENTRATIONS ANALYSES TO RECONSTRUCT WILDFIRE HISTORY

TRACIE MILLER (1), ROB NEGRINI (1), PETER WIGAND (1),
AND DALLAS RHODES (2)
(1) Department of Geology, California State University, Bakersfield, CA 93301
rnegrini@csub.edu
(2) Department of Geology and Geography, Georgia Southern University, Statesboro, GA 30460
DRhodes@GeorgiaSouthern.edu

Charcoal and pollen separates have been prepared from four 1.5 m drives (NSL-1A2, NSL-1A3, NSL-1B8 and NSL-1B9) acquired as part of a 40 m core taken from Soda Lake in the Carrizo Plain, San Luis Obispo County, California. Individual samples spanned 2 cm of depth. Two intervals were sampled continuously in an effort to characterize maximum pluvial and interpluvial conditions as well as the nature of the transitions between extreme conditions. The

lowermost interval (17.4 to 17.0 mbgs) starts in a pluvial maximum that may correspond to OIS 6 and ends in low-lake sediments intervals (15.9 to 15.5 mbgs) that may correspond to OIS 5. The uppermost interval (3.6 to 3.3 mbgs and 1.9 to 1.5 mbgs), that may correspond to OIS 3 and the oldest part of OIS 2, the Last Glacial Maximum.

Sample preparation consisted of breaking up the sample using deionized water and adding two tablets of *Lycopodium* spores to help determine concentration of charcoal in a sample. Sodium polytungstate (Poly-G) (density 2.1 g/cm^3) was used to float the charcoal and pollen for extraction. Ethyl alcohol and tert-buytl alcohol was added at the end to facilitate drying, followed by centrifuging for 5 minutes at 50 rpm. Silicone oil was then added and the tert-buytl alcohol was then evaporated. The residual material plus silicone oil was dropped onto a glass slide and covered. Initial inspection of prepared samples shows abundant charcoal in distinct intervals. The morphology of the charcoal is geometrical in shape (*i.e.*, angular texture). The size increments used for charcoal counts were 25-50 microns, 51-100 microns, and greater than 100 microns. Final charcoal abundances will be based on 300 counts per slide. Charcoal concentrations will be calculated by the number of charcoal divided by the known quantity of *Lycopodium* spore introduced as a tracer. Pollen was also preserved and included the genera *Artemisia* (sagebrush), *Atriplex* (saltbush), *Pinus* (pine), and *Juniperus* (juniper). Blue-green algae are also present.

A PALYNOLOGICAL CALIBRATION STUDY OF SPRUCE BEETLE EPIDEMICS FROM THE HIGH PLATEAUS OF UTAH

JESSE MORRIS AND ANDREA BRUNELLE
Department of Geography, University of Utah, Salt Lake City, UT 84112
jesse.morris@geog.utah.edu

Stand-replacing disturbance events such as wildfire or bark beetle infestation generally recur at intervals on the order of many decades to centuries. Since historic records only go back to the late 1800s in the intermountain region of the western U.S., interpretations of ecological cycles become problematic without reliable, longer temporal datasets. Research suggests that bark beetle outbreaks in subalpine forests are as ecologically significant as wildfire, and in some ecosystems may be more important than fire. The frequency of bark beetle outbreaks and how they interact with fire is not well understood at present, and this is particularly true over longer timescales. Lake sediments are important archives of ecological change that have been applied to a vast number of Holocene-length fire chronologies, but applications for insect and pathogen outbreaks are limited. This research analyzes lake sediments from six subalpine basins across central and southern Utah with documented spruce beetle outbreaks. Pollen data from these cores demonstrates understory vegetation increase following the loss of canopy dominant spruce concurrent with widespread bark beetle activity. Analysis of sedimentary charcoal allows for beetle disturbances to be distinguished from fire events. Macrofossils can be important in identifying past outbreaks, though factors controlling the deposition and preservation of beetle remains are not fully understood. The results presented here provide a calibration point for applying lacustrine sediments to reconstruct prehistoric bark beetle activity.

A 200,000-YEAR RECORD OF LAKE-LEVEL CHANGE FROM THE CARRIZO PLAIN, CENTRAL COASTAL CALIFORNIA

ROB NEGRINI (1), TRACIE MILLER (1), RANDY STEPHENSON (1), RAQIEL RAMIERZ (1), JASON LEIRAN (1), PETER WIGAND (1), DALLAS RHODES (2), AND THOMAS ALGEO (3)

(1) Department of Geology, California State University, Bakersfield, CA 93301
rnegrini@csub.edu

(2) Department of Geology and Geography, Georgia Southern University, Statesboro, GA 30460
DRhodes@GeorgiaSouthern.edu

(3) Department of Geology, University of Cincinnati, Cincinnati, OH 45221
algeot@email.uc.edu

Two cores acquired in the past five years provide evidence of a long-lived lake that occupied the Carrizo Plain during the Pleistocene. Both cores come from an elevation of ~584 m a.s.l. on a portion of the former lake floor that was abandoned during the Holocene probably due to tilting associated with the nearby San Andreas Fault. The longer of the two cores (~42 m) has been sampled for a variety of analytical studies (*e.g.*, palynology, environmental magnetism, SEM-petrography, spectral gamma-ray log, density log, diatom and ostracode paleontology, sulfate mineralogy, *etc.*). The magnetic susceptibility and the U-component of the gamma-ray signal are generally lower and higher, respectively, in intervals where the lithology suggests reducing conditions. The magnetic susceptibility signal contains two particularly striking features corresponding to lithologies consistent with reducing conditions. The younger of these features occurs near the surface, the older at ~18 m depth. Two ^{14}C dates on charcoal and seed pods from the upper reduced zone place the age of this zone between 23,500 and 20,000 cal yr B.P., within the interval of the most recent glacial and pluvial maximum. This date is consistent with the oldest OSL dates (16,700 cal yr B.P.) on clay dunes formed after the most recent highstand at 595 m a.s.l.

Assuming that reducing conditions correspond to deeper water, the ^{14}C dates suggest that the upper reduced zone represents an OIS 2 pluvial maximum lake in the Carrizo Plain that attained a maximum water depth of 17 m. If the lower reduced zone has a similar origin, then the Carrizo Plain has held an internally drained lake since well before OIS 6. High amplitude swings in whole core susceptibility in a depth range from 5-15 m below the surface may correspond to millennial-scale climate change. Thus, the Carrizo Plain record may represent an onshore counterpart to the Santa Barbara Basin record of Hendy and Kennett (1999).

Hendy, I.L., and Kennett, J.P., 1999, Latest Quaternary North Pacific surface-water responses imply atmosphere-driven climate instability: Geology, v. 27, n. 4, p. 291-294.

RESPONSE OF NORTH CASCADE GLACIERS TO CLIMATE CHANGE: METHODS FOR FORECASTING THEIR MASS BALANCE AND SURVIVAL

MAURI S. PELTO
Department of Environmental Science, Nichols College, Dudley, MA 01571
mspelto@nichols.edu

North Cascade glacier retreat is currently rapid and ubiquitous, with all 47 monitored glaciers undergoing significant retreat. Four glaciers have disappeared. The result is reduced later summer glacial runoff, which is already evident in glaciated basins. North Cascade glacier annual balance measured on 10 glaciers from 1984-2008 yielded a balance of -0.49 m/yr, and -12.38 m cumulatively. This is a 20-40% volume loss for glaciers that average 30-60 m in thickness. Two observed glaciers, Lewis Glacier and Spider Glacier, no longer exist. The data indicate broad regional continuity in North Cascades glacial response to climate. The balance of North Cascade glaciers is reliably calculated based on April 1 snowpack water equivalent and ablation season temperature. Unfortunately winter snowpack/precipitation ratios have declined and summer ablation rates have increased since 1984, both reducing the balance. April 1 forecasting of the annual balance using the PDO and the MEI ENSO circulation indices correctly determined the sign of balance in 45 of 48 years, an important step for summer water resource management in glacier runoff dominated stream systems. In the long term temperate alpine glaciers survival is dependent on the consistent presence of an accumulation zone. The lack of a persistent accumulation zone leads to substantial thinning of the glacier in the accumulation zone. This thinning is evident in satellite imagery and photographs, by the emergence of new rock outcrops or the recession of the margin of the glacier in the accumulation zone. In the North Cascades and Wind River Range, Wyoming two-thirds of examined glaciers have extensive accumulation zone thinning and are forecast not to survive the current climate or future additional warming. The results vary with adjacent glaciers having different survival forecasts, emphasizing the danger of extrapolating survival from one glacier.

INCORPORATING HIGH-RESOLUTION QUANTITATIVE ESTIMATES OF JULY AIR TEMPERATURE IN SIMULATING THE DYNAMIC BEHAVIOR OF A SIERRA NEVADA GLACIER DURING THE YOUNGER DRYAS

DAVID F. PORINCHU (1) AND MITCHELL A. PLUMMER (2)
(1) Department of Geography, The Ohio State University, Columbus, OH 43201
porinchu.1@osu.edu
(2) Idaho National Laboratory, Idaho Falls, ID 83415-2107
mitchell.plummer@inl.gov

A multi-proxy paleolimnological investigation of sediment recovered from small lakes in the eastern Sierra Nevada, California provides evidence of thermal variability and shifts in the hydrologic regime in this region during the late Quaternary. Application of a newly developed midge-based inference model for mean July air temperature (MJAT) provided a quantitative estimate of the thermal conditions that existed during the Younger Dryas (YD) chronozone (12,900 – 11,600 cal yr B.P.). In addition, qualitative inferences of paleohydrologic variability

were obtained through the analyses of diatoms and stable isotopes. Lake Barrett and Starkweather Lake, located near Mammoth Mountain, California, warmed immediately following de-glaciation, with water temperatures increasing approximately 2-3^{o}C during the Bølling–Allerød (B-A; ~14,500–12,900 cal yr B.P.). However, post-glacial climatic amelioration was interrupted during the YD with surface water temperatures depressed ~2-4^{o}C relative to the B-A. Diatom and stable isotope records suggest that the latest Pleistocene was characterized by dry conditions in the latter part of the BA, by relatively moist conditions during the initiation of the YD, and by a reversion to drier conditions during the late YD. One question that these results raise relates to the lack of evidence for a glacial re-advance in the eastern Sierra Nevada during the YD. The available data indicate that Recess Peak ice had retreated by 13,100 cal yr B.P., with no apparent YD re-advance. We incorporated the midge-based MJAT climate reconstruction into a 2-D snow/energy balance model to calculate the implied changes in net annual snow accumulation that would have occurred in an eastern Sierra basin during the YD. The changes in net annual snow accumulation were used to drive a transient, 2-D, in-the-plane, glacier flow model, which simulated the advance and retreat of glaciers resulting from this forcing. The simulations demonstrate both the general magnitude of the resulting glacial advance, as well as the accelerations and decelerations of the glacier snout that control the development of terminal and lateral moraines. This study reveals that the less pronounced chironomid-based temperature variations result in glacier advances very similar to those described by Recess Peak moraines, suggesting a slightly later date than is currently accepted for those deposits.

DECADAL VARIABILITY IN GROUNDWATER AS RECORDED IN A CORAL PROXY RECORD FROM MOLOKA'I, HAWAI'I

NANCY G. PROUTY AND MIKE E. FIELD
U.S. Geological Survey, 400 Natural Bridges Drive, Santa Cruz, CA 95060-5792
nprouty@usgs.gov

Recently the rare earth elements including yttrium (REY) have been used as hydrologic tracers of groundwater flow paths through basalt aquifers. The source of the REY is the dissolution of labradorite and olivine. In this work we analyzed a suite of trace elements in coral cores, including select groundwater tracers such as the REY, which are normalized to calcium to develop proxies of coastal groundwater input over several decades from sites along the south shore of Moloka'i, Hawai'i. The strongest relationship between calculated base flow and coral REY/Ca is during the fall and winter rainy seasons. There was also a statistically significant downward trend in seasonally resolved REY/Ca ratios over the last century. This is consistent with instrumental records of long-term stream discharge from Molokai, which reveal a downward trend in base flow. This pattern is observed statewide and is consistent with the long-term downward trend in annual rainfall over much of Hawai'i. Thus the coral geochemical records appear to respond to changes in groundwater discharge associated with a decrease in base flow since 1913.

EVIDENCE FOR RECENT EFFECTS OF CLIMATE ON THE RAPIDLY SHRINKING DISTRIBUTION OF THE AMERICAN PIKA

CHRIS RAY (1), ERIK A. BEEVER (2, 3),
PHILIP W. MOTE (4), JENNIFER L. WILKENING (1),
AND PETER F. BRUSSARD (5)
(1) Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309
cray@colorado.edu, niferwilkening@gmail.com
(2) 1301 West 11th Avenue, Ashland, WI 54806
(3) current address: U.S. Geological Survey, Alaska Science Center, Anchorage, AK 99508
ebeever@usgs.gov
(4) JISAO/CSES Climate Impacts Group, University of Washington, Seattle, WA 98195
philip@atmos.washington.edu
(5) Program in Ecology, Evolution and Conservation Biology, University of Nevada, Reno, NV 89557
brussard@biodiversity.unr.edu

The distribution of the American pika (*Ochotona princeps*), an inhabitant of alpine mammal communities in western North America, is presumed to have waxed and waned in concert with glacial cycling and associated climate change. But now it may be waning five times faster over the past decade than over the previous century, and about 20 times faster than reported for other species. In the Great Basin, the patchy distribution of *O. princeps* coincides with montane habitats, and previous research has shown that the elevational range of this distribution has contracted since the late Wisconsinan (*c.* 40,000-10,000 radiocarbon years ago) as populations have been lost from lower elevations. Between the late Wisconsinan and 1994, the average elevation of pika populations in the Great Basin had risen at least 783 m, including a rise of at least 152 m during the past century. New data on additional losses suggest continued acceleration of this upslope retraction in range. Since 1999, populations have retracted upslope by another 141 m. The rate of recorded extirpations is also accelerating, from roughly one extirpation every 11 years prior to 1999, to one every two years since 1999. These extirpations can be predicted using climate and biogeography, and climate-related variables are increasingly important when predicting extirpations within the past decade. A previous model-selection analysis suggested that extirpations were best predicted by the maximum elevation of local habitat (a climate surrogate) rather than by anthropogenic factors such as grazing intensity or distance to roads. Because the elevation of montane habitats is confounded by latitude in the Great Basin, we have used residual analysis and model updating to clarify the increasing importance of the maximum elevation of local habitat, independent of latitude, in predicting extirpations. Other important predictors include metrics of physiological stress, such as average summer temperature.

THE WEATHER AND CLIMATE OF PACLIM YEAR 2008-2009

KELLY REDMOND

NO ABSTRACT SUBMITTED

LATE PLEISTOCENE SHORELINE FLUCTUATIONS OF LAKE MANIX, MOJAVE DESERT: PALEOCLIMATE IMPLICATIONS

MARITH C. REHEIS (1), DAVID M. MILLER (2), AND JOHN P. McGEEHIN (3)
(1) U.S. Geological Survey, MS-980 Federal Center, Denver, CO 80225 mreheis@usgs.gov
(2) U.S. Geological Survey, MS-975, 345 Middlefield Road, Menlo Park, CA 94025
dmiller@usgs.gov
(3) U.S. Geological Survey, MS-926A, National Center, 12201 Sunrise Valley Drive, Reston, VA 20192
mcgeehin@usgs.gov

Marine and ice cores provide highly detailed proxy records of past climate conditions. However, such climate conditions when manifested in continental interiors may produce complex terrestrial stratigraphic records that are difficult to interpret. Previous work on pluvial lake levels in the western U.S. has shown an apparent pattern of latitudinal shifts of the jet stream in response to advance or retreat of the Laurentide ice sheet. However, new dating of deposits of Lake Manix, the main terminal lake for the Mojave River until about 24,000 cal yr B.P., indicates that the lake achieved multiple highstands during OIS 3 and early OIS 2. Thus, Lake Manix experienced highstands at times when the Laurentide ice sheet was well below its maximum height and geographic extent, and long before the Great Basin lakes to the north. Our preliminary lake-level curve, constrained by >30 calibrated ^{14}C ages on *Anodonta* shells, indicates four highstands (43,000-42,000, 39,000-37,000, 35,000-33,000, and 32,000 cal yr B.P.) within 8 m of the 543-m upper threshold for Lake Manix. Two more highstands at 31,000-30,000 cal yr B.P. and 27,000-26,000 cal yr B.P. reached 543 m and probably spilled eastward to initiate downstream Lake Mojave. In addition to climatic factors, Lake Manix records are influenced by episodic diversion of Mojave River water to other basins. A poorly understood diversion to Harper basin farther upstream may account for one Manix lowstand in the interval 30,000-27,000 cal yr B.P. A direct river feed to the Coyote Lake sub-basin of Lake Manix may have occurred 36,000-35,000 cal yr B.P., causing significant evaporative loss and a consequent drawdown in the remainder of Lake Manix. Correlations of Manix highstands with ice and marine records suggest that some highstands coincide with colder periods, whereas others may coincide with warmer periods. Notably, highstands between 42,000 and 30,000 cal yr B.P. occurred at times of low to moderate(?) levels of pluvial lakes farther north. Thus, the Lake Manix data suggest complex marine-terrestrial couplings that may reflect drivers other than jet stream position.

A PALEOCLIMATE CHANGE RECORD FROM BIG SODA LAKE, NORTHWEST NEVADA

LIAM REIDY AND ROGER A BYRNE
Department of Geography, University of California, Berkeley, CA 94720
lreidy@berkeley.edu, arbyrne@berkeley.edu

Here we present the initial results of the analyses of a finely laminated short core (~50 cm) recovered from Big Soda Lake (a maar lake), near Fallon, Nevada. The core provides a record of environmental change in the northwestern region of the Great Basin during the last few centuries.

The pollen and microscopic charcoal reflect changes in the local and regional vegetation and fire history, presumably indicating changing climatic conditions and(or) human impacts in the area. Furthermore, variations in stable isotopes and geochemistry indicate changes in the limnology of the lake itself.

Based on initial varve counting the core represents the last ~500 years. A chronology for the near surface sections of the core is provided by the first appearance of exotic pollen markers (*Salsola* spp., *Rumex acetosella*, *Ulmus* sp., and *Plantago lanceolata*). Radiocarbon and ^{210}Pb dating is currently underway as a check on the varve counts.

There is some debate as to the origin of the lake, but it is possible that the lake has been in existence throughout the Holocene and therefore can provide a high-resolution climate record for the Great Basin. We will return to Soda Lake this year to retrieve longer cores that will extend well into the Holocene to continue our paleoenvironmental investigation and determine whether or not the lake basin is a remnant of Lake Lahanton or formed after the disappearance of the Pleistocene lake.

A MULTI-PROXY RECONSTRUCTION OF HOLOCENE PALEOCLIMATE CONDITIONS IN THE GREAT BASIN, UNITED STATES

SCOTT A. REINEMANN (1), DAVID F. PORINCHU (1), AND
AMY M. BLOOM (2)
(1) Department of Geography, The Ohio State University, Columbus, Ohio 43210
reinemann.2@osu.edu, porinchu.1@osu.edu
(2) Department of Geography–Geology, Illinois State University, Normal, Illinois 61790-4400
ambloom@ilstu.edu

A sediment core recovered from Stella Lake, a small sub-alpine lake in the Snake Range, Nevada, was analyzed for subfossil diatoms and sediment organic content (estimated by loss-on-ignition (LOI)). Chronologic control for the sediment sequence was developed using AMS ^{14}C dating and indicates the calibrated age of the basal sediment is ~ 7,000 years. A chironomid-based mean July air temperature (MJAT) reconstruction was developed using an inference model (2-component WA-PLS) consisting of 79 lakes and 54 midge taxa (r^2_{jack} = 0.55, RMSEP = 0.9°C). Subfossil chironomid analysis indicates that Stella Lake was characterized by a warm, middle Holocene, followed by a cool "Neoglacial", with the last two millennia characterized by a

return to warmer conditions. This interpretation is based on the high relativly abundance of thermophilous chironomid taxa, such as *Chironomus* and *Psectrocladius semicirculatus/sordidellus*, during the middle Holocene and the *Cladotanytarsus mancus* group during the late Holocene. Throughout the majority of the core, the Stella Lake diatom community is dominated by small, periphytic taxa which are suggestive of shallow, cool, alkaline, oligotrophic waters with extensive ice cover. Comparison of the chironomid-inferred temperature record to regional paleoclimate reconstructions of middle Holocene conditions suggests that the inferred temperatures correspond well to regional patterns. This record provides valuable insight into regional Holocene climate and environmental conditions by providing a quantitative reconstruction of peak Holocene warmth and aquatic ecosystem response to these changes in the Great Basin, a region expected to experience increased aridity and higher than normal temperatures in the near future.

HOLOCENE VEGETATION HISTORY IN NORTHWEST COLORADO AND SOUTHWEST WYOMING: NEW RESULTS FROM PACKRAT MIDDENS AND POLLEN CORES

DAVID RHODE (1) AND LISBETH A. LOUDERBACK (2)
(1) Earth and Ecosystem Sciences, Desert Research Institute, Reno, NV 89512
dave.rhode@dri.edu
(2) Department of Anthropology, University of Washington, Seattle, WA 98195
lisbeth9@u.washington.edu

The Rockies Express Pipeline Project, stretching from Wamsutter, southwest Wyoming, southward across the Piceance Basin in northwest Colorado, has provided the basis for extensive archaeological investigations along its length. As part of this archaeological effort, we obtained paleoenvironmental information spanning the period of human occupation in the area, to better understand human responses to late Quaternary climate change in the region. Fossil woodrat middens from lower elevation contexts along the pipeline provide evidence of local vegetation change during the late Holocene. Pollen records from Grizzly Lake and Cow Camp Bench on the White River Plateau (Flat Tops Wilderness Area) provide a high-elevation perspective of Holocene vegetation and climate change for the region. Together these records show patterns of regional vegetation change that will complement geomorphic models of Holocene landscape evolution and the archaeological record of human adaptations. Of notable interest are findings that 1) Colorado pinyon pine (*Pinus edulis*) extended its Holocene range as far north as the Yampa River, northwest Colorado, by ~3,500 cal yr B.P., 2) extirpation of local populations of Utah juniper may signal episodes of increased winter cold during the late Holocene, and 3) high-elevation pollen records show significant fluctuations of spruce and other conifers on century to millennial scales that document probable climatic shifts affecting the western slope of the Colorado Rockies, possibly including an enhanced middle Holocene summer monsoon.

LAKE SEDIMENT D/H RATIOS: A POTENTIAL TRACER FOR DECADAL SCALE HYDROCLIMATE VARIABILITY IN THE SEIRRA NEVADA

LYDIA D. ROACH (1), DANIEL C. CAYAN (1), ALEX L. SESSIONS (2), CHRISTOPHER D. CHARLES (1), AND R. SCOTT ANDERSON (3)
(1) *Department of Geosciences, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093*
lroach@ucsd.edu
(2) *Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125*
(3) *Center for Sustainable Environments, Northern Arizona University, Flagstaff, AZ 86011*

Persistent drought looms as one of the most prominent risks of future greenhouse warming. Full assessment of these risks requires multiple realizations of decadal and centennial scale hydrologic variability. Existing instrumental records capture fluctuations in many aspects of Sierra Nevada hydroclimate over the 20th century, but paleoclimatic (proxy) observations must be developed to extend the records of snowfall-dominated watersheds of the Sierra Nevada. Recent investigations indicate that lake sediment hydrogen isotope ratios (δD) may reflect surface water δD, which is in turn influenced by hydrologic processes both local (precipitation amount, rain vs. snow partitioning, and evaporation) and remote (moisture origin and storm track). Here we evaluate lake sediment δD as a monitor of decadal-scale hydrologic fluctuations in the Sierra Nevada, with the ultimate goal of reconstructing these fluctuations over the last 1,500 years. In the fall of 2006 and 2007 we collected two types of sediment cores, Bolivia and freeze cores, from Swamp Lake (37º57'N, 119º46'W, 1,554 m) in Yosemite National Park. The Bolivia cores reached sediment over 1,000 years old, while the freeze cores successfully captured and preserved the most recently deposited sediments, allowing for a direct comparison between the sedimentary (proxy) and instrumental climate records. Analysis of organic compound specific δD from this most recent (20th century) sediment reveals significant correlation between the δD time series and a variety of local and regional instrumental records including total annual precipitation, April 1 snowpack and Palmer Drought Severity Index. When evaluated alongside results of a simple water-balance model, these correlations suggest that snowfall amount and summertime evaporation may play a dominant role in driving the observed δD variability in Swamp Lake sediments and the relationship of this variability to that observed in instrumental climate records. With this interpretative context for sedimentary δD, we discuss our measurements throughout the last millennium. The discussion will be centered on the medieval warm period (A.D. 900-1300), an interval characterized by periods of severe and prolonged drought in the western U.S.

WY 2009: WILL THERE BE ENOUGH WATER FOR CALIFORNIA?

MAURICE ROOS
California Department of Water Resources, P.O. Box 219000,
Sacramento, CA 95821-9000
mroos@water.ca.gov.

The last PACLIM meeting in May of 2007 took place at the beginning of a dry year. As a single year, 2007 was not unusually dry, ranking of about the 15th percentile in the Sacramento River system, and with its 10.3 million acre-feet (MAF) of runoff twice that of 1977, the driest year of record. The San Joaquin River system was a bit worse and its 2.5 MAF of runoff ranked at about the10th percentile level.

We had a lot of hope for WY 2008 in early spring as precipitation and snowpack were near or above average on March 1. This was followed by the driest spring in history, with very little moisture falling in March, April, and May, a period that normally contributes 25 percent of our annual precipitation. Eventually WY 2008 runoff turned out to be almost the same as 2007 in the Sacramento River system. It was somewhat better in the southern Sierra Nevada, with about 3.5 MAF runoff (60 percent of average) for the San Joaquin four-river total. That moved that system to about a 25 percentile mark (lower quartile) for a single year.

However, the ranking for two consecutive water years was just under the 10 percentile threshold we commonly use for drought. The other drought parameter yardstick was statewide reservoir storage which was projected to fall to 70 percent of average by the end of the water year. This was enough for the Governor to declare an official drought in early June. Actual statewide storage dropped to 72 percent at the end of the water year in September and to 70 percent at the end of October. By the end of the calendar year on December 31, storage had declined further to 68 percent, some 7 MAF below average. Storage was only 40 percent of reservoir capacity.

The northern Sierra Nevada eight station precipitation average is a closely watched yardstick for water supply accumulation. On December 31, 2008, it was 82 percent of average for the date. January, our biggest precipitation month, came through with only about 1/3 normal. Slightly past the halfway point for our rainy season in early February the situation was looking grim with only 66 percent of average seasonal northern Sierra precipitation. Even with normal future precipitation, the runoff forecasts were for a 55 percent water year, which basically would be a repeat of the two preceding dry years, but with storage now at 66 percent, nearly 20 percent less than the previous year. The State's two biggest reservoirs, Shasta and Oroville, held only about 30 percent of their capacity.

Finally in mid-February, a couple of slow moving storms dumped sufficient amounts of rain and snow to increase the snowpack up to about 90 percent and the northern Sierra precipitation to normal in the first few days of March. The 20 days of rain added about 1/3 of a full season but were not enough to end drought conditions. The remaining quarter of the rainy season would hold the key to that. As of this writing, the forecasts call for about 65 percent of average water year runoff in 2009.

On top of the drought, there is a basic structural problem for the California water system. More storage and conveyance are needed. The main problem is in the transfer of surplus northern California water across the Sacramento-San Joaquin Delta to export users in the southern half of the state. Continuing fishery restrictions on export pumping during the winter

and spring have cost a lot of yield which was available during the previous 1987-92 drought. Meanwhile, demand has increased and the consequences of delivery cuts are higher. Many San Joaquin Valley growers have shifted from annual crops to higher paying permanent crops. Now some are letting orchards die. Southern California, too, does not have as much access to Colorado River supplies as before, with the state's diversions now reduced to our permanent annual allocation of 4.4 MAF.

Will there be enough water for California? Hopefully, supplies for most users will be a little better than last year. But there is not enough for California as we know it. A Sacramento-San Joaquin Delta transfer project would help. But the short range outlook in dry years is bleak until major additions can be made to our water system. The basic resources are there on the average, but it requires more storage of wet year floods for the drier years.

VULNERABILITY OF LAKE TAHOE (CALIFORNIA-NEVADA) MIXING PATTERNS TO CLIMATE CHANGE

GOLOKA BEHARI SAHOO, S.G. SCHLADOW, J.E. REUTER, AND ROBERT COATS
Tahoe Environmental Research Center, One shields Avenue,
University of California, Davis, CA 95616
gbsahoo@ucdavis.edu

Problem statement: Due to its extraordinary clarity and deep blue color, Lake Tahoe (California-Nevada) is a national treasure. In response to climate change, the lake has warmed over the last 35 years, and as a result its thermal stability has increased. Lake Tahoe is an ice free warm-monomictic lake with deep mixing only in the winter. Although deep winter mixing occurs once or twice in three to four years, deep mixing might be stopped if the warming trend continues. Since deep mixing supplies dissolved oxygen from surface to bottom, reduced mixing may result in evolution of anoxic condition near the sediment-water interface. The Intergovernmental Panel on Climate Change report (2007) indicates continued warming over the next few decades. Therefore, the objectives of this study are to 1) assess the future trends of climatic variables that cause lake warming and 2) estimate the maximum mixing depth using the hydrodynamics modules of Lake Clarity Model.

Methodology: To estimate the mixing depth of Lake Tahoe due to climate change, we used our lake clarity model (LCM) to simulate lake hydrodynamics. We used available inputs from 11 years (i.e. 1994 – 2004) to populate the LCM runs for the period of 2000-2040. The GCM-predicted trends in meteorological variables for the grid cell (*i.e.*, ~ 39^{o} N and ~120^{o} W) that includes Lake Tahoe were obtained from 1) Model for Interdisciplinary Research on Climate V. 3.2 High Resolution (MIROC-HIRES) Japan, 2) National Center for Atmospheric Research, Community Climate Model (NCAR CCM V. 3.0), and 3) National Oceanic and Atmospheric Administration (NOAA) - Geophysical Fluid Dynamics Laboratory V CM2.1 (NOAA GFDL CM2.1). Progressive changes in weather variables estimated from the trends were added to the daily meteorological values of the 40-year data.

Results: Results of 40-year simulations show that the lake continues to become warmer at the rate of 0.015 ^{o}C per year and more stable. With continued climate change, deep mixing (full or greater than 300 m) will cease after one–two decades. This indicates that Lake Tahoe may be

permanently stratified because of reduced mixing and increasing stability. This may result in water quality problems over time.

COFFIN-LID EFFECT OF CLAY-RICH FLOOD AND TURBIDITE LAYERS IN SEDIMENT FROM SANTA BARBARA BASIN, CALIFORNIA

ARNDT SCHIMMELMANN
Department of Geological Sciences, Indiana University, Bloomington, IN 47405-1405
aschimme@indiana.edu

Paleoceanographic reconstructions based on microfossil, geochemical, and isotopic proxies in marine sediments operate under the assumption that each layer is only influenced by new sediment supplied from the water column. However, close inspection of the laminated sedimentary record below and above clay-rich turbidite and flood layers in Santa Barbara Basin indicates that deposition of clay-rich flood and turbidite layers can diminish and delay the biodegradation and early diagenesis of sedimentary organic matter (SOM) immediately below gray layers, by blocking chemical and biological access to SOM. The total organic carbon (TOC) content of laminated sediment just below gray layers is typically higher than above gray layers. A freshly deposited, relatively dense and TOC-poor gray clay layer acts as a "coffin lid" that is avoided by biota and acts as a diffusion barrier for dissolved oxygen and sulfate from overlying waters when sediment is still close to the sediment/water interface. The deposition of a coffin lid on regular varves catastrophically changes the redox conditions of the last buried varves and any associated bacterial mat and infauna. In contrast, new SOM just above coffin lids tends to be more extensively biodegraded. Decreased upward diffusive flux of ^{13}C-depleted dissolved inorganic carbon (DIC) from remineralization of SOM to the habitat of benthic foraminifera after the deposition of a coffin lid should result in dominance of DIC from bottom water with higher ^{13}C content in biomineralization. Global warming is expected to increase the frequency and severity of floods. Consequently, flood layer coffin lids will more frequently bury and shield TOC from biodegradation in near-coastal sediments. This may provide a small negative feedback in the global carbon cycle by increasing carbon sequestration, via increased efficiency of organic carbon burial.

QUANTIFICATION OF LARGE WOOD RECRUITMENT RATE AND VOLUME TO FORESTED MOUNTAIN RIVER CHANNELS

ANNE E. SENTER
Land, Air, Water Resources Department, Hydrologic Sciences, University of California, Davis, CA 95616
aesenter@ucdavis.edu

Large wood pieces (LW, >1 m length, >10 cm diameter) are organic materials that dynamically influence fluvial and riparian ecosystems by providing geomorphic and ecological services to watersheds. Conversely, LW is potentially dangerous to human safety and personal property, especially when large amounts of LW aggregate in developed areas during floods. In

watersheds across the Sierra Nevada, little is known about the rate and volume of LW recruited to river channels and transported downstream. There are many processes that govern LW recruitment and transport, including recent and current climate conditions, vegetation patterns, watershed area, channel morphology, fire history, geology, and land use practices. Recruitment rates have been estimated at the reach scale (<10 km) in the Pacific Northwest, but no studies have evaluated landscape-level responses of LW processes in a Mediterranean climate watershed. The ability to develop a watershed-specific model of LW recruitment will improve decision-making capabilities for river and reservoir managers, foresters, river rehabilitation practitioners, and other watershed stakeholders.

A PhD research proposal in development intends to use remote sensing techniques coupled with field data collection to measure recruitment in the North Fork Yuba River watershed above New Bullard's Bar Reservoir in the north central Sierra Nevada, California. A preliminary study is in progress collecting reflectance data from wood pieces obtained from the study watershed. A spectral library will be built and used in developing target detection techniques for situations where spectral information alone must be used for detection and recognition. The initial question to be answered: what size LW piece can target detection analysis recognize within an image of 3 m resolution? In-progress results of the preliminary study will be presented.

COMPARISON OF ORBITAL PARAMETERS AND DEVILS HOLE NEVADA $\delta^{18}O$ TIME SERIES DURING THE LAST FOUR GLACIAL CYCLES SUPPORTS INTERHEMISPHERIC CONCURRENCE

SAXON E. SHARPE
Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512
saxon.sharpe@dri.edu

The Devils Hole, Nevada $\delta^{18}O$ time series provides a precise chronology for glacial and interglacial periods for the past ~ 500,000 years (Winograd *et al*., 2006). Accurately-dated, continuously-deposited calcite layers from this series record isotopic variation in atmospheric precipitation in the Spring Mountains, the primary recharge area of the regional aquifer supplying Devils Hole. The shape of the Devils Hole $\delta^{18}O$ isotopic curve compares well with other paleoclimatic records worldwide (northeastern Pacific marine cores, Greenland, Antarctica, China, the Indian Ocean, the western equatorial and southwest Pacific, Siberia, South America, and Europe), suggesting interhemispheric concurrence for these climate proxy records.

The timing of Earth's orbital parameters (obliquity, eccentricity, and precession index) can be constructed accurately from celestial mechanics calculations. Comparison of the Devils Hole time series with past orbital parameter chronology establishes a consistent pattern linking precession, eccentricity, and onset and terminations of glacial and interglacial cycles during the past ~400,000 years. This pattern shows that each ~100,000-year cycle can be divided into glacial, interglacial, and intermediate (transitions between glacial and interglacial and vice versa) climate states paced by eccentricity minima and based on precession index values.

Interhemispheric concurrence among climate proxy records worldwide provides critical evidence that orbital parameters represent, at a minimum, a clock that signals the approximate beginning and end of glacial and interglacial periods and suggest global climate forcing

mechanisms. These mechanisms likely involve complex interactions among orbital, solar, marine, and terrestrial climate-forcing functions that operate in different ways. Interestingly, correspondence between the timing of the last four interglacial termination events in the Devils Hole record and maximum precession (increased summer solar radiation) in the southern hemisphere summer indicates that northern hemisphere climate begins a cooling trend when heat is being added to the southern hemisphere. This relation indicates that a link between glacial and interglacial periods and tropical insolation may exist.

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CLIMATEWNA - ACCESS TO HIGH SPATIAL RESOLUTION CLIMATE DATA FOR WESTERN NORTH AMERICA

DAVE SPITTLEHOUSE (1), TONGLI WANG (2), ANDREAS HAMANN (3), MICHEAL MBOGGA (3), AND TREVOR MURDOCK (4)
(1) Research Branch, BC Ministry of Forests and Range, Victoria, BC V8W 9C2 Canada
dave.spittlehouse@gov.bc.ca
(2) Department of Forest Sciences, University of British Columbia, Vancouver, BC V6T 1Z4 Canada
(3) Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2E3 Canada
(4) Pacific Climate Impacts Consortium (PCIC), University of Victoria, Victoria, BC V8W 3P6 Canada

Applying climate data in resource management requires matching spatial scales of climate and resource databases. This activity is a critical to assessing the vulnerability of resources to future climate change. A software package originally developed to provide high spatial resolution data BC and the Yukon (Wang *et al*. 2006) has been expanded to cover North America from 100º W and north of 20º N. The reference database for this work is the monthly temperature and precipitation climate grids for 1969-90 produced by PRISM (Daly *et al*. 2002) at 2.5 arc minutes (~4 km). The database for the Northwest Territories and northern Alberta and Saskatchewan is based on a spline fit to weather station data. Elevation adjustment functions that depend on latitude, longitude, and elevation were developed from the reference data. Through the combination of bilinear interpolation and elevation adjustment, gridded base data are adjusted to specific locations of interest. Numerous derived variables such as degree days, frost free period, and moisture indices are produced from the monthly data. Historic climate (1901 to the present) and future possible climates for a range of global climate models are also downscaled and integrated with high-resolution baseline data. Predicted future climate data are determined from the reference period using the delta approach and 1° latitude by 1° longitude grids of change data. Accuracy in interpolating historic climate data was evaluated using weather stations. Correlation was high for 1930s to current for most variables. Reduction in data quality was found for individual months (as opposed to annual, decadal, or 30-year climate averages) and for the early decades of the last century. The stand-alone package can produce data for individual or multiple locations. To facilitate broad access to the gridded data we have developed web-based data visualization and access system based on the PCIC regional analysis tool for

showing climate change data from GCMs. The software package and the web-based application are available at no charge.

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WESTERN CANADIAN INTERIOR STREAMFLOW TIME SERIES: TRENDS AND VARIABILITY

JEANNINE-MARIE ST. JACQUES (1), DAVID J. SAUCHYN (1), AND JODI AXELSON (2)
(1) Prairie Adaptation Research Collaborative, University of Regina, SK S4S 7J7 Canada
stjacqje@uregina.ca, sauchyn@uregina.ca
(2) Pacific Forestry Centre, Natural Resources Canada, Victoria, BC V8Z 1M5 Canada
Jodi.Axelson@NRCan-RNCan.gc.ca

There has been much recent research on the detection and projection of climate change trends in western Canada, and particularly in Alberta streamflow records. The implied or explicit conclusion of this research is that western Canada, particularly southern Alberta, is running out of water due to global warming. There are many problems with using the instrumental streamflow records simplistically to reach such a conclusion: 1) these records are short, ~40-50 years in the north and at most ~95 years in the south, 2) they are frequently discontinuous, especially in the 1930s-40s, 3) there is heavy human impact from water consumption, diversion, and storage, especially in southern Alberta, which obscures the natural hydrology, and 4) there is frequent residual autocorrelation which will cause a disproportionate rejection of a null hypothesis of no trend if classical linear regression and non-parametric methods are used. The Pacific Decadal Oscillation (PDO) is a major factor controlling streamflow in the western Interior, with south-central Alberta being drier during a positive phase PDO, and wetter during a negative phase PDO. The ~65-year low-frequency PDO cycle can potentially generate a declining linear trend in short instrumental streamflow records. If the influence of the PDO is not incorporated into an analysis of instrumental hydroclimatic records, this can produce detected declines that could be attributed to global warming, but they are actually artifacts of the sampling period and the PDO phase changes. We perform a reanalysis of the instrumental data, using a void-filled and naturalized streamflow dataset compiled by Alberta Environment to ameliorate the first three problems. We address the last two issues by using Generalized Least Squares regression to explicitly model the impact of linear trends and the atmospheric-ocean climate oscillations such as the PDO and ENSO on Alberta streamflow. We also present a 600–year tree-ring reconstruction of the annual flow of the South Saskatchewan River to illustrate the strong interdecadal variability in the regional hydroclimate.

CORRELATING LATE GLACIAL AND HOLOCENE MARINE AND LACUSTRINE CLIMATE RECORDS IN NORTHERN CALIFORNIA

SCOTT W. STARRATT AND JOHN A. BARRON
U.S. Geological Survey, 345 Middlefield Road, Menlo Park CA 94025
sstarrat@usgs.gov, jbarron@usgs.gov

Evidence of long-distance connections between the marine and terrestrial realms along the northern California margin is affected by both latitude and elevation. In this study, the late glacial and Holocene history of the California Current derived from a marine core is compared with the records from two lakes.

The 16,000-year-long marine record (ODP Site 1019) is based on the analysis of the diatom and pollen assemblages, alkenones, sediment geochemistry, and physical properties (density, biogenic silica, and environmental magnetism). The terrestrial record at Medicine Lake, located on the Modoc Plateau in northeastern California at an elevation of more than 2,000 meters, contains an 11,400-year-long record derived from diatom and pollen assemblages, sediment geochemistry, and physical properties. The 19,000-year-long record from Swamp Lake, located near the northern boundary of Yosemite National Park at an elevation of about 1,500 meters, includes pollen (Smith and Anderson, 1992) and diatom assemblages, biogenic silica, loss-on-ignition, and magnetic susceptibility. The extent of the record in both of the lakes is limited by late Wisconsin glaciation.

The marine and Swamp Lake records indicate cooler temperatures and decreased productivity during the transition from the Bølling-Allerød to the Younger Dryas, followed by warmer conditions prior to the end of the Younger Dryas. This interval was not covered at Medicine Lake.

The early Holocene (11,500-8,000 cal yr B.P.) is characterized by a transition from warmer and wetter to cooler and drier conditions along the coast and in inland areas, indicating declining July insolation. This interval was characterized by warm winter sea surface temperatures and a California Current of moderate strength. Warmer winters led to earlier snowmelt and an increase in the volume of both lakes. Biogenic silica levels in Swamp Lake increase during this time as does the abundance of oligotrophic planktonic taxa. Clastic input decreased in both lakes during this period, suggesting increases vegetation in the watershed. The pollen record indicates that along the coast, the warmest temperatures occurred early in this interval, followed by cooling and increased moisture. At Medicine Lake, conditions were relatively stable whereas the warmest temperatures were reached toward the end of the early Holocene at Swamp Lake.

The early part of the middle Holocene (8,000-3,000 cal yr B.P.) was characterized by weaker, less regular El Niño events, and more sustained La Niña-like conditions resulting in lower coastal sea surface temperatures and drier conditions inland. Gradual strengthening of the California Current due to a stronger thermal gradient led to increased seasonal (spring-summer) coastal upwelling and associated fog along the coast during the latter half of this interval. At Swamp Lake, biogenic silica values leveled off after reaching their highest values in the record, and pollen suggests an increase in effective moisture. However, the record is equivocal, because it suggests this increase in moisture may have been seasonal; there appears to be a hiatus of several thousand years in the shallower part of the lake. The pollen record from Medicine Lake also indicates an increase in effective moisture.

The late Holocene (3,000-0 cal yr B.P.) is distinguished by increasing winter precipitation and enhanced ENSO cycles. The marine record suggests warmer winter sea surface temperatures and a stronger seasonal gradient. The pollen records at both lakes show an increase in effective moisture. However, the productivity in Medicine Lake decreases to levels recorded in the earliest Holocene, while the productivity in Swamp Lake remains at middle Holocene values. This may reflect not only the difference in latitude and elevation, but also the characteristics of the watershed. During the late Holocene, marine and lacustrine records show several extended periods of lower precipitation, alternating with wetter periods.

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RECENT TRENDS IN CALIFORNIA SNOWMELT RUNOFF

IRIS T. STEWART
Environmental Studies Institute, Santa Clara University, Santa Clara, CA 95053
IStewartFrey@scu.edu

Human-induced climatic changes are generally expected to hasten spring snowmelt and further increase the demands on California's overextended water resources. Thus, this study examines the most recent trends in snowmelt runoff in California, and systematically explores gauge-to-gauge differences in the observed streamflow timing trends based on the physical characteristics of the watershed above the gauge. To this end, the very recent trends in streamflow timing measures (such as the timing of the start of the spring snowmelt pulse, the timing of the center of mass for flow, the annual flow, and the timing of the day when maximum flow occurs) for approximately 60 snowmelt-dominated gauges in California were analyzed in conjunction with a GIS-based data base of the watershed characteristics (such as elevation distribution, slope, aspect, and vegetation) through the 2008 runoff season. Snowmelt dominated streamflow in California has continued to come earlier by both the CT and start of the spring pulse timing measure over the 1948-2008 period, while yearly flows have essentially remained the same. Interestingly, the shifts towards earlier streamflow timing do not appear to have accelerated for the very recent very warm years. In addition, our results suggest that the response of streamflow timing is not as closely tied to elevation as previously thought, but determined by a complex combination of physical watershed characteristics.

HYDROLOGIC VARIABILITY IN THE WESTERN SIERRA NEVADA SINCE THE LAST GLACIAL MAXIMUM FROM D/H RATIOS IN LEAF WAXES

JOSEPH H. STREET (1, 2), ALEX L. SESSIONS (3), R. SCOTT ANDERSON (4), JEFFREY M. WELKER (5), AND ADINA PAYTAN (1)

(1) Institute of Marine Sciences, University of California, Santa Cruz, CA 95064

jstreet@stanford.edu

(2) Department of Geological & Environmental Sciences, Stanford University, Stanford, CA 94305

(3) Division of Geological & Planetary Sciences, California Institute of Technology, Pasadena, CA 91125

(4) Center for Sustainable Environments, Northern Arizona University, Flagstaff, AZ 86011

(5) Biology Department and Environmental and Natural Resources Institute, University of Alaska, Anchorage, AK 99508

High resolution records of hydrologic variability in the western Sierra Nevada and Sacramento-San Joaquin basin are scarce prior to the late Holocene, hindering efforts to understand the drivers of regional climate change and water availability on sub-millennial timescales. The continuous, ~20,000-year sedimentary record from Swamp Lake, a small intermediate elevation (1554 m) lake in Yosemite National Park, provides a rare opportunity to examine more detailed relationships among climate variability, drought, and ecosystem responses since the Last Glacial Maximum. In this study we present the results of geochemical and isotopic analyses of sedimentary organic matter from a 10 m core from Swamp Lake. In particular, we evaluate the utility of compound-specific hydrogen isotope (D/H) measurements on leaf-wax *n*-alkanes extracted from the sediment as a means of reconstructing the hydrologic status of the lake and watershed. The D/H values of leaf waxes are influenced by both the δD of precipitation, which reflects air temperature and storm track, and by subsequent evapotranspiration in the watershed and from the leaves themselves. Both effects are evident in the Swamp Lake record, and can be partially separated by comparing D/H values of *n*-alkanes derived from both aquatic and terrestrial plants. In addition, we utilize carbon and nitrogen elemental abundances (TOC, TN, C/N) and isotopic compositions ($\delta^{13}C$, $\delta^{15}N$) of bulk organic matter, biogenic silica content and ratios of biomarker compounds to reconstruct changes in lake productivity, organic matter sources, and lake level in relation to climatic variables. Our proxy records indicate dry but highly variable conditions in the Sierra Nevada during the early and middle Holocene, and a distinct shift toward wetter conditions at the transition to the late Holocene (~3,100 yr B.P.) corresponding to warmer SSTs off northern California. A long-term decline in D/H of terrestrial leaf waxes reflects a gradual shift toward cooler, early winter (DJF) precipitation driven by precession. Higher frequency D/H variations correspond to changes in warm ENSO frequency (from proxy records), and may reflect shifts in precipitation timing and temperature (rain *vs*. snow) and aridity (P/E). Periodic, century-scale variability in lake productivity and organic matter source proxies may be linked to climatic changes influenced by solar variability and low-frequency shifts in ocean conditions.

A ~13,000-YEAR RECORD OF ENVIRONMENTAL CHANGE FROM THE NORTHWESTERN COLORADO RIVER BASIN INFERRED FROM DIATOMS

ABBIE H. TINGSTAD (1), KATRINA A. MOSER (2), AND GLEN M. MACDONALD (1)
(1) Department of Geography, University of California, Los Angeles, CA 90095-1524
abbie1@ucla.edu
(2) Department of Geography, University of Western Ontario, London, ON N6A 5C2 Canada

The Uinta Mountains are located in northeastern Utah (Central Rocky Mountains region) and are part of the upper Colorado River Basin. This range is presently situated in an area sensitive to changes in both Pacific Ocean storm track and North American Monsoon dynamics. Thus, long records of past environmental change from the Uinta Mountains are of great academic interest and have the potential to inform water and other resource management policies in Utah and the western U.S. We present results from the analysis of an 879 cm (~13,000-year-long) lake sediment core from a lower elevation alpine lake in the central Uinta Mountains. Changes in diatom species assemblages as well as dissolution (F) index values are examined. The results of statistical analyses performed on a 62-lake surface sample (0-1 cm) calibration set and lake water chemistry dataset from the Uinta Mountains are also reported.

STABLE HYDROGEN ISOTOPES IN BONE COLLAGEN AS A PALEOENVIRONMENTAL INDICATOR

KATARINA TOPALOV (1), ARNDT SCHIMMELMANN (1), DAVID POLLY (1), PETER E. SAUER(1), AND MARK LOWRY (2)
(1) Department of Geological Sciences, Indiana University, Bloomington, IN 47405-1405
topalovk@indiana.edu
(2) NOAA Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA 92037

Organic deuterium/hydrogen stable isotope ratios (*i.e.*, D/H, or $^{2}H/^{1}H$, expressed as δD value in ‰) in animal tissues are related to the D/H of precursor hydrogen in its diet and ingested water. Bone collagen preserves the original environmental D/H isotopic signal in the δD_n value of collagen's non-exchangeable hydrogen. Therefore, δD_n preserved in fossil bone collagen can potentially be used to constrain paleoenvironmental conditions. We present a preliminary dataset of δD_n values of modern collagen calibrated in terms of environmental forcing factors in preparation for future work on archeological and fossil specimens. The main factors that affect δD_n are the D/H of environmental water and the trophic level of an individual. Minor isotopic variation occurs among individuals of a population, possibly even among different body parts of an individual, due to dietary and time differences associated with collagen biosynthesis and bone mineralization. We collected data on δD_n from (a) many vertebrate species from a single location - Bloomington, Indiana, (b) individuals of white-tailed deer and southern mule deer across climate gradients in the contiguous US, and (c) several individuals of California sea lion from San Nicolas Island, California. Strong isotopic correlation was found between most collagens and their associated meteoric waters. The δD_n values of collagens from arid Joshua Tree National Park indicate evapotranspirative deuterium-enrichment of physiological fluids relative to local spring (oasis) water. Collagen δD_n values from terrestrial species collected in Bloomington

(local meteoric average δD_{water} ~-47‰) ranged from -100‰ to +100‰ and thus reflect strong trophic differences. Herbivores tend to have low δD_n values, omnivores rank intermediately, and carnivores express the highest δD_n values. Body size and metabolic rate may be additional factors since smaller animals with typically faster metabolic rates and relatively high evapotranspiration tend to be enriched in deuterium (*e.g*. white-footed mouse). California sea lions' δD_n variance of 20‰ indicates intraspecific diversity that can arise from individual dietary differences (*e.g*. pre-weaned infants *vs*. adults). Although ocean water is relatively deuterium-enriched, our preliminary data suggests that marine carnivores have lower δD_n values than terrestrial carnivores, possibly because the latter are more affected by evapotranspiration.

RATE OF GEOLOGIC SUBSIDENCE IN THE SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA

KENNETH L. VEROSUB, IRINA DELUSINA, AND ROY J. SHLEMON
Department of Geology, University of California, Davis, CA 95616
verosub@geology.ucdavis.edu

The decrease in land-surface elevation of artificial islands and tracts in the Sacramento-San Joaquin Delta of California is generally attributed to the draining of peat-rich wetlands and the subsequent disappearance of organic material through oxidation, wind erosion, and other processes. This anthropogenic subsidence is of great concern because it increases the pressure on the levees that surround the islands and tracts. Failure of Sacramento-San Joaquin Delta levees can have serious consequences not only locally, but for the entire water distribution system of the state of California. However, the anthropogenic subsidence is superimposed on natural geologic subsidence that, for the most part, has received little attention in risk assessments. Ages for basal peat deposits in cores at 18 sites obtained as part of Project REPEAT indicate that peat formation began about 6500 years ago. At most sites the basal peat is about 9 m below current sea level. Global sea level curves suggest that about 6,500 years ago, sea level was only 3 m below current sea level. Because peat is generally assumed to form at or slightly below sea level, the most parsimonious interpretation of the data from the basal peat deposits is that about 6 m of natural geologic subsidence has occurred in the Delta over the past 6,500 years. A subsidence rate of about 1 m/1,000 yr is in good agreement with estimates published by Shlemon and Begg (1975) from tilted, older alluvial fans in the Sacramento Valley and is comparable to the recent rate of sea level rise due to anthropogenic global climate change. These observations have profound implications for risk assessment of levee failure in the Sacramento-San Joaquin Delta and its mitigation.

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HOLOCENE CLIMATE VARIABILITY IN THE RUBY MOUNTAINS, NEVADA: A PERSPECTIVE FROM THE NORTH-CENTRAL GREAT BASIN

DAVID WAHL (1), ELMIRA WAN (1), SCOTT STARRATT (1), JIM WANKET (2), HOLLY OLSON (1), THOMAS LLOYD-DAVIES (1), JENNIFER KUSLER (2)
(1) U.S. Geological Survey, 345 Middlefield Road, Menlo Park CA 94025
dwahl@usgs.gov, ewan@usgs.gov, sstarrat@usgs.gov
(2) Department of Geography, California State University, Sacramento, CA 95819
jwanket@csus.edu, jenniferekusler@gmail.com

Few records of Holocene climate variability have been produced from high elevation sites in the Great Basin. Presented are preliminary data from sediments in a series of piston cores collected from Favre Lake (2,899 m elevation; 12 m deep), Liberty Lake (3,077 m elevation; 32 m deep), and core samples from a small bog in Lamoille Canyon (~2677 m elevation). All of these sites are located in the northern Ruby Mountains. By combining proxy data from these localities, changes in watershed vegetation, lake levels, and limnological conditions can be assessed and increase our understanding of millennial to secular scale changes in the climate of the region.

The basal sediment in the Favre Lake core is comprised of the Mazama ash, which, coupled with three ^{14}C AMS age determinations on plant matter, indicates a continuous sedimentary record that extends to ~7,600 cal yr B.P. Varves are present in the upper portion of the Liberty Lake core, providing the potential for a regional high-resolution biochronostratigraphic framework and a detailed paleoclimatic history. Bathymetric maps, and temperature, pH, and conductivity profiles have already been generated for Favre and Liberty lakes. In addition, pollen, diatom, magnetic susceptibility, loss-on-ignition, density, grain-size, and, sediment geochemistry data are currently being collected from the sediment cores. Moreover, surface samples recovered from a number of high elevation lakes in the Ruby Mountains (Favre Lake, Liberty Lake, Castle Lake, Dollar Lakes, and Lamoille Lake) will be used to establish baseline data for future studies. Preliminary fieldwork has also been carried out at Echo Lake, a deep (3,000 m elevation; 47 m deep), possibly meromictic lake on the western side of the mountain range.

Lastly, future research on sediment cores from a perennial wetland on the eastern edge of the range, Ruby Marsh, will provide a low elevation paleoclimatic counterpoint to the alpine sites.

USING LAKE SEDIMENT CORES TO INVESITGATE PAST MOUNTAIN PINE BEETLE OUTBREAKS

JENNIFER H.WATT (1), ANDREA BRUNELLE (1),
AND BARBARA BENTZ (2)
(1) Department of Geography, University of Utah, Salt Lake City, UT 84112
Jennifer.watt@utah.edu
(2) USDA-Forest Service, Rocky Mountain Research Station, Logan, UT 84321

Current mountain pine beetle (MPB) outbreaks are threatening both lodgepole and whitebark pine communities in the western U.S. It is believed that the increased severity of mountain pine beetle outbreaks is a response to climate change. Warming climate allows for faster reproduction of the MPB and can also contribute to a forest's susceptibility to MPB outbreaks. In addition to the MPB, there is a secondary suite of bark beetles that attack the host trees before and after an outbreak. The role of these secondary bark beetles in the outbreak dynamic is not well understood. Lake sediment cores (specifically short cores) from the Pioneer Mountains in Montana and the Sawtooth Mountains in Idaho will provide a record of the past 150-200 years of forest disturbance. This study is a calibration and will use the overlap with the historical record to show the accuracy of using bark beetle remains (elytra), in lake sediments to indicate past bark beetle outbreaks.

Once the relationship between historical outbreaks and lake sediment records of beetles is demonstrated, long cores will be taken from the same sites to reconstruct a Holocene record of environmental history for those locations. In addition to indicating MPB outbreaks in the past, the records will show the relationship among outbreaks, climate, and fire. A baseline for the frequency and severity of past disturbances (specifically bark beetle outbreaks) and climate conditions is needed to understand if the current outbreaks are unprecedented or just a cyclical forest regeneration pattern. The data provided by this project will help researchers and land managers understand how climate has affected outbreaks in the past which will be useful for understanding and trying to mitigate present and future outbreaks, especially as climate continues to change.

CLIMATE CHANGE AND SPECIES RESPONSES: GETTING DOWN TO THE CLIMATE NEAR THE GROUND

STUART B. WEISS
Creekside Center for Earth Observation, Menlo Park, CA 94025
stu@creeksidescience.com

The effects of climate change on ecosystems and the distribution and abundance of organisms must be considered within a spatial hierarchy that extends from macroclimate, mesoclimate, topoclimate and microclimate. Macroclimatic forcings, the result of atmospheric circulation over scales of 100+ km, are progressively filtered by broad terrain features to create mesoclimates (1-100 km), then by local topography to create topoclimates (10-100 m), and finally by fine-scale surface features and plant canopies to create microclimates. Topoclimatic temperature gradients, driven by insolation across slopes during the day and cold air pooling at

night, can locally exceed projected changes in macroclimatic forcings. Local population processes of organisms - survival, reproduction, and dispersal - occur at the topoclimatic and microclimatic scales. The need to downscale macroclimatic change to the topoclimatic scale is illustrated by two examples. The dynamics of Bay checkerspot populations are driven by an intricate phenological relationship between butterflies and plants that exhibit great temporal variability among years, and spatial variability across slopes along well-defined insolation gradients. Vegetation change in the White Mountains includes shifts along topoclimatic gradients, including upward movement to cooler high elevations, lateral movements across insolation gradients driven by aspect, and downward movement of subalpine trees into cold air sinks. Nighttime temperature inversions during summer in the White Mountains are on the order of 8-10ºC across a subalpine valley. Because topoclimatic gradients are defined by well-understood physical processes, it is possible to downscale data from 1 km to the ecologically relevant scales at which populations respond using empirically derived relationships between topographic variables and surface temperatures.

CLIMATIC CONTROLS ON SUMMERTIME FOG AND LOW STRATUS CLOUDINESS ALONG THE US WEST COAST

A. PARK WILLIAMS, JOEL MICHAELSEN,
AND CHRISTOPHER J. STILL
Geography Department, University of California, Santa Barbara, CA 93106
williams@geog.ucsb.edu

The presence of marine stratus clouds along the west coast of the U.S. during summer months is ubiquitous with the moderating effects of temperature that make life habitable for diverse and unique ecosystems as well as large population centers. There is evidence, however, that as global temperatures warm due to increased greenhouse gas concentrations and atmospheric circulation responds, summer stratus-cloud behavior along this Mediterranean-climate coast may change. Cloud frequency is the key climate parameter governing summer temperatures along much of the U.S. west coast, and any change in summer stratus formation would cause regional temperature changes that may easily outweigh those anticipated by current climate models. Despite the clear importance of summer stratus clouds to life in these coastal zones, global and regional climate models still have difficulty characterizing them. Therefore, there is high uncertainty in the estimates of future summer temperature, upon which we depend when developing environmental management strategies for these biologically diverse and highly populated coastal regions. In this study, we compared spatially continuous records of global reanalysis climate data to hourly records of summertime cloud heights from 19 coastal stations on the west coast of the U.S. By identifying the climate parameters that are most strongly correlated with the interannual summer cloud records, and the locations where those climate parameters have the strongest explanatory power, we created a statistical model that utilizes the organization of global sea surface temperatures and atmospheric pressures to estimate relative summer fogginess at various locations along the U.S. west coast. We then used global circulation outputs based upon several climate change scenarios to predict how coastal summer fog frequency may be expected to change during the 21st century.

CLIMATIC RESPONSE OF THE INTERMOUNTAIN WEST TO THE PACIFIC NORTHWEST – DESERT SOUTHWEST DIPOLE

ERIKA K. WISE
Department of Geography, University of Arizona, Tucson, AZ 85721
ekwise@email.arizona.edu

Studies of precipitation variability across the western U.S. have identified atmospheric circulation centers of action in the Pacific Northwest and the Desert Southwest. These areas are characterized by opposing patterns of precipitation and teleconnection signals (described as a dipole) and exert a strong influence on hydroclimatic variability in the West. Less is known about the hydroclimatology of the transition zone between the centers of action, located primarily in the Intermountain West. Particularly uncertain are how this transition zone varies through space and time and how strongly this zone is influenced by circulation controls at much larger scales. This study addresses these issues through an investigation of the spatiotemporal characteristics of transition zone climate. Spatial boundaries of dipole influence are examined for linkages with oceanic circulation controls at much larger scales. Past changes in the spatial boundaries of dipole influence and the potential impacts of climate change (*e.g.*, shifting jet stream patterns) on the transition zone are assessed. Results suggest that the Intermountain West transition region is linked to broad-scale precipitation patterns and moisture tracks that are influenced by oceanic conditions. Although the dipole pattern is clearly present over broad space and time scales, local topographic and climatic effects are dominant under certain conditions, and the spatial limits of the transition zone have shifted over time.

MAPPING PATTERNS OF PAST DROUGHT IN CALIFORNIA: LATE HOLOCENE LAKE SEDIMENTS AS MODEL DIAGNOSTICS

SUSAN ZIMMERMAN, TOM BROWN, AND TOM GUILDERSON
Center for AMS, Lawrence Livermore National Lab., Livermore, CA 94550
zimmerman17@llnl.gov; tabrown@llnl.gov, tguilderson@llnl.gov

Lakes are natural climate observation stations, and paleoclimate records from lake sediments have the potential to have similar resolution but span much longer periods of time than tree-ring chronologies. Reconstructions derived from tree-rings and a limited number of lacustrine records have documented that the recent past has been unusually wet in the American west; climate models may therefore have a limited range of predictive ability, biased toward the (geologically) anomalously-wet conditions of the modern observations to which they are compared. In order to make useful predictions under changing climate conditions, the length of the records used for model control runs and diagnostics must be extended to capture a wider potential range of climate variability, including the megadroughts of the medieval period (A.D. 900-1300).

We are in the process of recruiting collaborators who are developing paleoclimate records in California lakes for the last 2,000-3,000 years, to create high-resolution and -precision radiocarbon chronologies for those records. With robust detailed chronologies, records can be correlated in space with good accuracy, enabling us to create maps of net hydrological

(precipitation-evaporation and(or) runoff) variability in California at approximately 100-year intervals over the last 2,000 years. In addition, the individual records will be explored using spectral analysis to determine the dominant periods of variability (*e.g.* multi-decadal to centennial). The spectral character and the covariance of the records can be used to elucidate the forcing (coupled ocean-atmosphere) that resulted in the variability. We anticipate that these records can be utilized as diagnostic tools to help improve regional climate models, as well as contributing to efforts to compare and improve model predictions on larger scales.