Climate Change through the 20th and 21st Centuries

Climate Change and California's Mountain Snow Pack—How Much Could be Lost? **DANIEL R. CAYAN** (Scripps Institution of Oceanography, University of California San Diego and U.S. Geological Survey, Nierenberg Hall, Room 201A, 8810 Shellback Way, La Jolla, CA 92037; dcayan@ucsd.edu).

An important part of California's water supply has traditionally derived from mountain snowpack, but with projected climate warming in future decades, it is likely that the snow pack will diminish. Historically, in response to fluctuations in precipitation, the snow pack has varied considerably between years--VIC hydrological model representation of spring snow water over snow-laden areas of California varies by nearly a factor of 10 (highest to lowest). In today's climate, the variation in spring snow pack is only incrementally affected by seasonal variations in temperature. In the future, an ensemble of downscaled climate model simulations under two emissions scenarios exhibits +1°C to more than +3°C warming by 2100 over the California snow region. Precipitation over the region shows considerable variability but little trend. While precipitation fluctuations continue to contribute strongly to the year-to-year variation in snow pack, the temperature influence in diminishing spring snowpack becomes substantial in future decades. Under these simulations, achieving California spring snow water volume that meets or exceeds historical median fades to much smaller odds while the occurrence of historically light spring snow pack grows considerably higher.

Evidence for Climate Change in the Satellite Cloud Record, **JOEL R. NORRIS[1]*, AMATO T. EVAN[1], ROBERT J. ALLEN[2], MARK D. ZELINKA[3], CHRISTOPHER W. O'DELL[4], and STEPHEN A. KLEIN[3]** ([1]Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093, USA; [2]Department of Earth Sciences, University of California at Riverside, Riverside, CA 92521, USA; [3]Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA 94551, USA; [4]Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO 80523, USA; jnorris@ucsd.edu).

Clouds play a key role in the climate system and are intimately tied to the hydrological cycle. They reflect solar radiation back to space and restrict the emission of thermal radiation to space. They are also one of the biggest uncertainties in our understanding of climate change. Depending on how the location, fractional coverage, height, and thickness of clouds change, global warming can be exacerbated or mitigated. Previously, global climate models and observational datasets disagreed over what cloud changes have occurred in recent decades due to inconsistencies among models and spurious variability in the observations. After removal of observational artifacts, we show that several satellite records exhibit similar regional patterns of cloud change between the 1980s and 2000s. Moreover, the observed cloud changes resemble those produced by the majority of model simulations of the late 20th century climate and for a doubling of CO2. Observed and simulated cloud change patterns are consistent with expansion of subtropical dry zones, increasing cloud optical thickness at high latitudes, and increasing height of the highest cloud tops at all latitudes. These results indicate that cloud changes robustly predicted by global climate models are currently occurring in nature.

Vegetation and Urban Climate in a Changing World, **G. DARREL JENERETTE (**Department of Botany and Plant Sciences, University of California Riverside, Riverside, CA 92512; darrel.jenerette@ucr.edu).

Urban surface temperatures vary greatly in space and time. This variation is in part regulated by impervious surface characteristics, vegetation, water availability, and regional climate changes. The effects of urban surface temperature variation can influence distributions of urban risks and when moderated by potential coping can lead to drastically different vulnerabilities. To better understand future vulnerabilities we conducted two analyses focused on the Phoenix, AZ metropolitan region, a model system of a high temperature urban environment with potentials for limitations in water availability. First, we examined microscale variation in surface temperature patterns and compared these with parcel level variation for a subset of more than 30 neighborhoods. Temperatures of each parcel and different land covers within the parcel were compared within and across neighborhoods. We are linking these data with interviews conducted for a subset of residents within each neighborhood. These studies are showing a strong relationship between neighborhood variation and surface temperature patterns. We extend this research by evaluating potential scenarios of future land cover, social stratification, and climate to identify potential future patterns of vulnerability to urban warming. These scenarios suggest different future trajectories of land surface temperatures depend on interactive changes in these dominant drivers. Together these studies highlight the both the microscale variation and potential future variation in vulnerability to extreme surface temperature in this hot arid metropolitan region.

The Importance of Anthropogenic Aerosols to Recent Precipitation Trends in the Southwest United States, **MAHESH KOVILAKAM* and ROBERT J. ALLEN** (Department of Earth Sciences, University of California Riverside, Riverside, CA, USA; mvarma@ucr.edu).

Perhaps the most important component of the hydrological cycle is precipitation, particularly for the semi-arid Southwest United States. Observations indicate the region has experienced significant multi-decadal precipitation variability, with an increase from 1950 to ~1980, followed by a decrease since. Model simulations from the Coupled Model Inter-comparison Project v5 (CMIP5) also yield similar changes, with anthropogenic aerosols accounting for nearly all of the simulated response and about 1/3 of the observed trends. Moreover, aerosol only simulations reproduce the observed Sept-Oct-Nov maximum in SW U.S. precipitation trends. Consistent with these precipitation changes, both observations and models forced with anthropogenic aerosols yield a reversal in the trend of the leading pattern of sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation. By modulating the Pacific Decadal Oscillation and its associated atmospheric teleconnections, our results suggest that anthropogenic aerosols have perturbed Southwest US precipitation and have significantly contributing to the recent—and perhaps future—drying trend.

An Analysis of Future Changes in Precipitation and Tropical Cell Width Through the 21st Century using CAM3, **OSINACHI AJOKU[1]* and ROBERT J. ALLEN[1]** (Department of Earth Sciences, University of California Riverside, Riverside, CA 92521,

USA; oajok001@ucr.edu).

For this work, anthropogenic aerosols are compared to GHGs to measure the effects each may have in perturbing the planet's hydrological cycle and tropical cell width. The effects of anthropogenic aerosols and greenhouse gases (GHGs) on Earth and its environment remain a growing concern. As future emissions of anthropogenic aerosols and GHG's are projected to change, so will the resulting impact. More importantly, anthropogenic aerosols carry a dynamic influence on the planet's hydrological cycle through an alteration of the planet's surface radiation budget. If changes in rainfall intensity and distribution are substantial, they pose one of the most serious risks associated with climate change including an increase in extreme weather events and reduced precipitation in sub-tropical areas. As an invaluable natural resource, from uses in agriculture and daily consumption, an understanding of changes in water distribution is essential for the global economy. Furthermore, future changes in anthropogenic aerosols, including a progressive decrease in sulfates (SOx) pose the highest risk of expanding tropical cell width due to its negative radiative forcing in the atmosphere. As future emissions are projected to change, this work has quantified resulting perturbations to precipitation and tropical cell width due to anthropogenic aerosols and GHG's. Our results show that future changes in GHG's and sulfates significantly expand the width of the tropics. Moreover, the expansion associated with sulfate emissions is as large as GHG's in the northern hemisphere.

Re-assessing the Role of Forests in Climate and Water Security, **B. LARRY LI*, ANASTASSIA MAKARIEVA, and VICTOR GORSHKOV** (Ecological Complexity and Modeling Laboratory, University of California, Riverside, CA 92521-0124; bai-lian.li@ucr.edu).

The effects of forest ecosystems on climate are often viewed solely in terms of moisture recycling. That is, evaporation from the forest returns moisture to the atmosphere where it can increase local rain. However, our recent studies indicate that vegetation, especially forested landscape, influences rainfall patterns more than is generally recognized. Here we argue that the existing global circulation models cannot be used for evaluation of the climatic effects of deforestation because of their inability to reproduce various phenomena that we have ascribed to a new mechanism we have termed the "biotic pump" - by this mechanism forests generate large-scale pressure gradients that cause winds to flow and bring moisture from oceans to land, and forest cover plays a major role in maintaining rainfall. We also show that studying vegetation will have an increasing role in understanding climate and its vulnerability to changes in land use/cover.