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CLIMATIC DATA COLLECTION, ANALYSES, AND MODELING — PHASE II

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Scripps Institution of Oceanography

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Prepared By:
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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Climatic Data Collection, Analyses, and Modeling—Phase II is the final report for the project Climatic Data Collection, Analyses, and Modeling—Phase II (UC-MR-025) conducted by Scripps Institution of Oceanography. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

Acknowledgements

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Abstract

The California Climate Change Center, with core activities at Scripps Institution of Oceanography, has continued to conduct research to better monitor and understand climate change and its impacts over California. The work includes 1) upgrading and maintaining an archive of historical climate data for the state; 2) installation, maintenance and data management of instrumentation for climate observations in climate-sensitive mountain, watershed and coastal settings; 3) statistical and dynamical regional climate modeling; and 4) diagnosing past and potential future climate variations and changes.

Keywords: California Climate Change Center; climate change impacts; historical climate data; regional climate modeling

Executive Summary

Introduction

Scripps Institution of Oceanography/University of California at San Diego contributes with core climate change research for the Energy Commission's Public Interest Research Program. This report presents a summary of the scientific advances generated by Scripps on regional climate change science.

Purpose

The Scripps Institution of Oceanography contributed in four key areas:

- upgrading and maintaining an archive of historical climate data for the state;
- installation, maintenance and data management of instrumentation for climate observations in climate-sensitive mountain, watershed and coastal settings;
- statistical and dynamical regional climate modeling; and
- diagnosing past and potential future climate variations and changes.

Project Objectives

This research aimed to assemble a more accessible and meaningful historical archive of California climate data; to create better strategies and methodologies for monitoring climate-sensitive areas of the state; to understand how snowmelt and direct precipitation infiltrate and recharge upper-layer soil moisture; to remove regional-level biases from regional climate simulations; and to study the effects of climate variations on the abundance of certain disease-vector mosquito populations.

Project Outcomes

In assembling a more accessible and meaningful archive of historical climate data for the state , the Western Regional Climate Center (WRCC) has developed the California Climate Tracker, which identifies 11 coherent regions within the state and provides temperature and precipitation histories and graphics for these regions in order to track past and recent changes and assess potential trends. In addition, WRCC has continued to update and provide access to hourly, daily, monthly and annual datasets that describe the state's climate.

To better monitor climate-sensitive areas of the state, a transect of meteorological and hydrological stations were maintained across the west slope of the Sierra Nevada in Yosemite National Park, and six new meteorological stations were installed along the west slope of the White Mountains, from near the floor of the Owens Valley to 10,000-feet elevation. This transect is a backbone that provides the means to understand how air masses and climate properties vary across the Sierra Nevada and up the White Mountain slope. Installations were also developed and maintained in the Santa Margarita Ecological Reserve.

A set of observations from the Gin Flat location at Yosemite Park were studied to understand how water from the melted snow pack and from direct precipitation infiltrates to recharge the moisture in the upper soil layers. Dynamical modeling capabilities over the California region were investigated in studying the effects of irrigation and land use changes due to urbanization in a collaborative effort with other regional modelers. It was found that the irrigated soils are heated strongly during the day and release heat at night, leading to increased nighttime temperatures.

A bias correction scheme, called Scale Selective Bias Correction, was developed to remove the effect of the regional model domain on regional climate simulations. Statistical downscaling, using the method of "Constructed Analogues" was developed and evaluated to allow fast, computationally efficient downscaling of coarse global climate model (GCM) output at daily levels in contrast to existing methods that operate at the monthly level of GCM aggregated output. Climate scenarios for California were selected and evaluated from a subset of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment climate model simulations. Two main emissions scenarios were chosen on the basis of covering potential higher and lower emissions pathways and to take advantage of available IPCC model runs. These emissions scenarios include the SRES A2 scenario, which is a medium-high scenario that results from a heavy reliance on fossil fuel burning and an inhomogeneous global economy, and the SRES B1 Scenario, which is the result of a more globally unified approach to greenhouse gases and environmental policy. Simulations of the regional climate over California was extracted from these runs and assessed in terms of salient climate impacts. Along with that, sea level scenarios using the climate warming from the GCM runs were investigated, under the assumption that sea level rise along the California coast will follow the global sea level changes.

In addition, studies were carried out that described the impacts of climate variations upon changes in the abundance of the population of *Culex tarsalis* mosquitoes, which carries encephalitis and West Nile viruses, were investigated, as was climate-driven aridity in California and the western United States, the influence of atmospheric rivers on California's precipitation, changes and variations in model-simulated heat waves, and a demonstration of the detectability of anthropogenic climate change effects on hydrological conditions over the western United States, including the California Sierra Nevada.

1.0 Introduction

1.1. California Climate Data Archive

At the Western Regional Climate Center, the California Climate Data Archive has continued to develop and provide access to the major climate data networks in the state and to summarize products for those networks. Other efforts have focused on monitoring of spatial and temporal patterns, with updates on an hourly, daily, monthly and annual basis as appropriate; preparation of special reports; response to a high volume of requests; analysis of events; and development of tools to improve access to climate monitoring activity.

1.2. California Climate Tracker

Variations in climate are at the forefront of both the public mind and of climate researchers, and the group at the Western Regional Climate Center has developed the California Climate Tracker as a tool to view and analyze regional climate in the state. California's varying landscape gives way for a number of physical mechanisms that not only influence the average climate, but also climate variability across the state. The analysis of climate variability and trends is a crucial and necessary component in understanding the role of climate change. Although a clear indication of changes in the global surface temperature exists, the regional manifestation of climate change is not well quantified at the present time. Driven by the interests of the governmental, economic, and scientific communities, it is pertinent to develop an objective method to define and monitor climate not only for the state as a whole, but also for its distinct climate regions.

2.0 Methods

2.1. Upgrading the Historical Climate Archive

The National Climatic Data Center has developed climate divisions that span the contiguous United States, whereby each state has been subdivided into 10 or fewer climate divisions. Across much of the western United States climate divisions were guided mostly by watershed and river basins, as opposed to climatological patterns. Consequently, the divisions suffer from a number of problems in the western United States, where complex topography plays a strong role in dictating regional climate patterns. For example, the current climate divisions in California make no distinction between the Sierra Nevada Mountains and the Central Valley. Thus, the group at the Western Regional Climate Center has developed the California Climate Tracker, http://www.wrcc.dri.edu/monitor/cal-mon/index.html.

The initial steps in creating the California Climate Tracker were undertaken to identify cohesive regions of climate variability within the state. Using an infilled dataset, the researchers performed an Empirical Orthogonal Function (EOF) analysis on the Cooperative Observer Program (COOP) station data using both monthly precipitation and average monthly mean temperature. This analysis focuses on how stations vary with one another. The researchers identify 11 distinct regions across the state wherein stations located within a region vary with one another in a similar fashion. An analogous analysis is performed with the Polar Radar for Ice Sheet Measurements (PRISM) data, resulting in striking similar results. These 11 regions define the climate tracker climate regions.

The collection of data from both station and PRISM data from these regions is used to create a single value for each variable for each month. This is a two step process, dependent on the timing of data availability of both COOP station-based data and the gridded PRISM-based data. An effort is made to create a seamless translation between these two datasets. At the beginning of each month, only COOP data is available, and often from around only 60% of the 195 stations statewide. Data is first screened for outliers (defined as a data anomaly that exceeds more than two standard deviations from any other anomaly within the state). Temperature datasets are also screened for in homogeneities that lead to an abrupt, non-climatic change in the time series of a given station. An effort is then made to estimate missing stations from anomaly regression with highly correlated reference stations. At this point, the regional value is computed by the average of the collection of COOP stations within a region. Further adjustment is then made to adjust for inherent biases between the COOP-based value and the PRISM-based areal average (e.g., COOP stations in mountainous terrain are generally located at elevations lower than the mean topography of the region, and are regularly warmer than the areal average of the domain of interest). The monthly value reported at the second and final stage of this process is a hybrid value that is weighted equally for PRISM-based data and station-based data. The statewide average is computed by weighting the regional value by the area covered by each region. An extensive time series dating back to the late 19th century is formed for each region and for the state as a whole. These time series are used to both categorize and track climate across the spatially diverse state of California in order to place the present climate in context with climate variations back to the late 19th century.

Statewide, regional, and station-based graphics and time series are produced each month. Preliminary products for the last available month will be updated by the 3rd of each month, once the initial COOP station reports come in. A second update will appear near the 10th of each month once the PRISM dataset is updated. The COOP and PRISM products are combined into a single dataset to improve difficulties with sampling errors and the insufficiencies with each dataset. Data from up to twelve months ago is considered provisional, as data continues to filter in and undergoes quality control procedures.

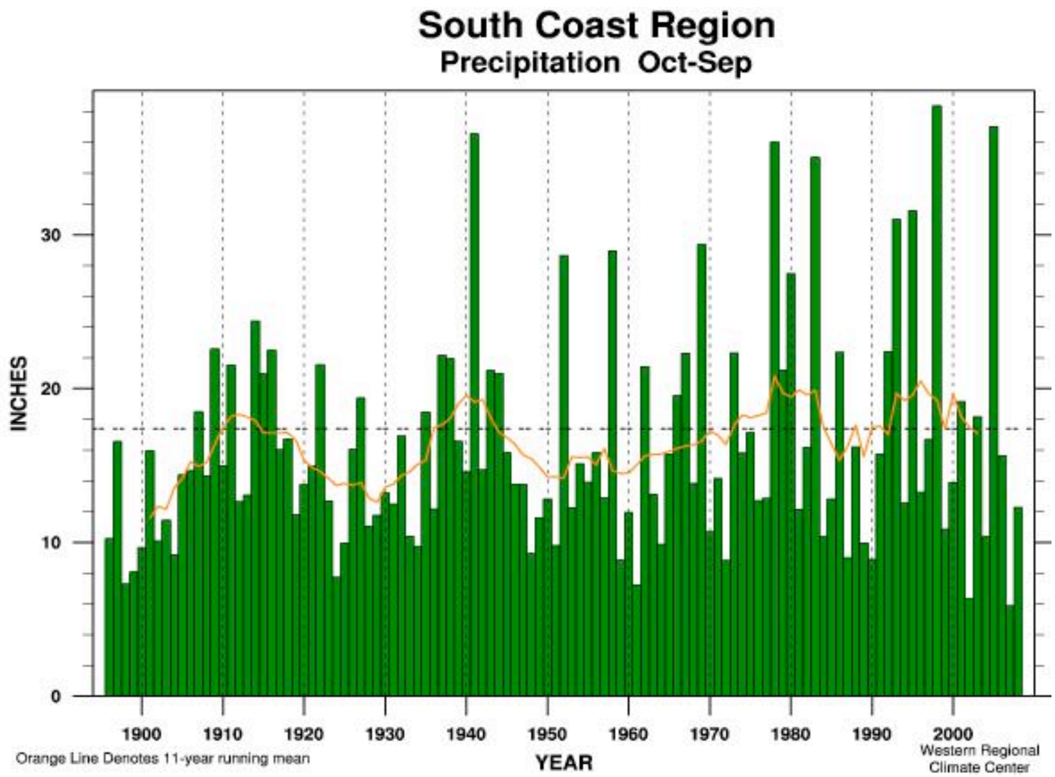

Figure 1. South Coast Region

Source: Abatzoglou et al., submitted

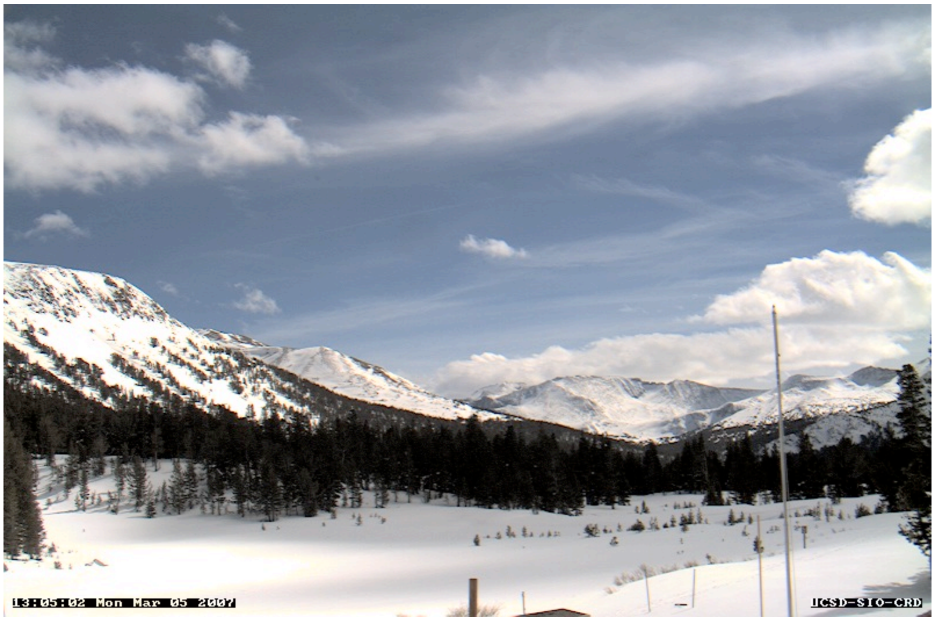

Figure 2. Tioga Pass

Source: Authors

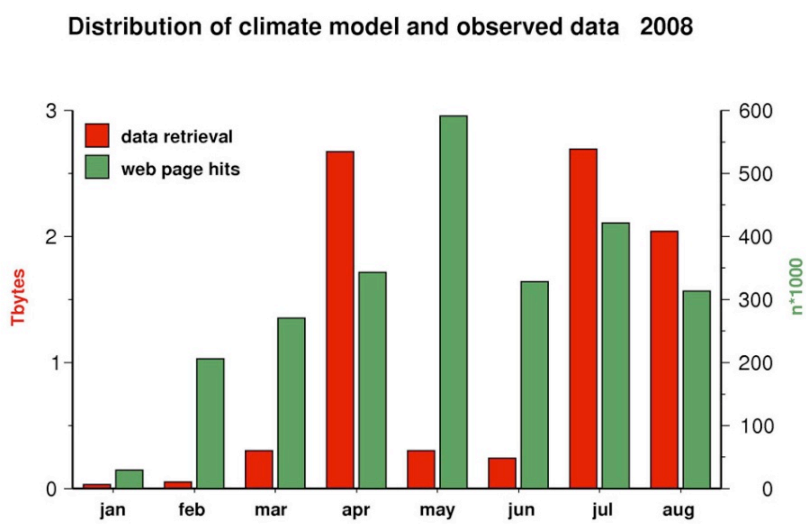

Figure 3. Distribution of Climate Model and Observed Data

Source: Authors

2.2. Climate Monitoring

In Central California, Alden and others, working under Cayan and Dettinger at the Scripps Institution of Oceanography (SIO), installed new hydro climate monitoring stations that fill gaps in the climate observation transect across the White Mountains. These stations include sensors for: humidity, temperature, barometric pressure, solar radiation, precipitation, fuel moisture, fuel temperature, soil moisture, and soil temperature.

The White Mountain stations complement existing permanent climate stations at Crooked Creek (10,200 feet elevation), Barcroft (12,500 feet elevation) and White Mountain peak (14,250 feet elevation). Some of these permanent stations have climate data going back to the 1950's and include some of the best long term records of winter climate for high alpine environments in North America (Morrison and Scewczak 2002). The data will also complement and augment information about climate and hydrology in the Owens Valley, a watershed which has been intensively monitored for nearly 100 years as part of the Los Angeles aqueduct project.

Information provided from our data and our experience in a USGS-SIO-California Department of Water Resources experimental network of stream sensors, meteorological and snow stations are providing an important component of to the Sierra Observatory design study. Our team has, over the last five years, deployed stream, weather and snow stations along the grade of elevation from lower (approximately 5000 feet) to higher approximately 10000 feet in Yosemite National Park and the surrounding region to study effects of climate variability and ultimately, climate change, on the hydrologic system. The data we are collecting in our Yosemite network (Lundquist et al. 2003; Peterson. et al. 2005) is unique in providing an underpinning for the spatial/temporal variability along the western portion of this network. The new White Mountain stations will provide a high resolution, sampling at approximately 1,000-1,500 feet elevation increments that will allow us to characterize the climate and its variability along this leg of the transect. Such observations are important to understanding ecosystems, hydrology and geological/chemical processes across the range, and will provide vital background to understand possible climate changes.

Figure 4: Hydro climate monitoring station

Source: Authors

Maintenance of existing hydrometeorological stations was needed in Yosemite Park. Maintenance was conducted on the Tioga Pass Web Cam, and our existing hydroclimate monitoring stations at Dana Meadows, Tuolumne Meadows water tank, Gin Flat and Hodgdon Meadows, and also on the meteorological and stream monitoring site at Devils Postpile National Monument. Simeral, Redmond and colleagues from the Western Regional Climate Center (WRCC) maintained existing weather and hydrological monitoring stations in the central Sierra, White Mountains and coastal watersheds.

Alden worked with Ned Andrews from the USGS to build two additional time lapse camera systems for his study on Tenaya Lake. The researchers delivered 20 DL4-IO3-Snow/Soil Loggers to Bob Rice at UC Merced for deployment in Yosemite Park and helped him install the first six at Olmsted Pit. The remaining loggers were installed by UC Merced at Merced Grove and Gin Flat.

After the White Mountains stations were installed, in collaboration with the White Mountain Research Station, University of California, Tte researchers upgraded and maintained six weather stations along an elevational transect from the Owens Valley upslope to 10,000 feet

At the Santa Margarita Ecological Reserve, Alden and others maintained the existing network of 20 weather stations: http://meteora.ucsd.edu/weather/observations/sio_other/crd_obs.html. With Jim Thorne, a eco-statistician at UC Davis, the researchers are working to extend the Yosemite mountain transect down slope to cover the lower forest zone between the Sierra Nevada foothills and the western boundary of Yosemite National Park. In summer and fall 2008, the researchers visited potential sites and secured permission for four new sites along the Highway 120 corridor from the Stanislaus National Forest in Groveland, from Hetch Hetchy Water and Power, and from a private inn-holder at the Sunset Inn.

Figure 5. Yosemite Park

Source: Authors

2.3. Water Infiltration

Infiltration of water into bedrock in mountainous terrain represents a significant portion of recharge in the western United States, especially under conditions of a melting snowpack. Under anticipated increases in air temperature associated with global warming, snowmelt processes and the associated runoff in the Sierra Nevada Mountains are likely to occur earlier in the springtime (Dettinger et al., 2004), with uncertain implications regarding recharge. Developing a better understanding of the processes contributing to mountain block recharge under these conditions is deemed prudent. The U.S. Geological Survey, working with the SIO, has established a research field site located in Yosemite National Park at a Department of Water Resources SNO-TEL station on the western boundary of the park at Gin Flat (*Figure 1*) to study soil moisture processes under the accumulation and melting of snow. This research is part of the California Climate Change Center's research program to understand how climate change will influence California future economic, social, and natural systems. Soil moisture field data were collected under a melting snowpack at Gin Flat in Yosemite National Park. A conceptual model was developed that suggests that as the snow melts it infiltrates into the soil and percolates vertically downward until it contacts the soil-bedrock interface. As the snow melt and soil infiltration rate exceed the bulk bedrock permeability, the soil-bedrock interface eventually becomes saturated, ponds, and starts to infiltrate into the bedrock fracture system. As the snow pack refreezes at night the soil water continues to drain at the bedrock permeability rate until the next morning when the snowpack again begins to melt, resulting in diurnal changes in soil water content. This cycling continues until the snowpack is gone. There is the potential for some lateral flow to be occurring during this time but the flow away from the instruments is replaced by snowmelt from up gradient. Numerical modeling in 1- and 2-dimensions supports this hypothesis and generally reproduces the diurnal and seasonal signatures. Further data collection in 2006, along with additional refinement of the numerical model will be used to refine and support the conceptual model of snowmelt and soil processes.

2.4. Regional Modeling

2.4.1. Dynamical Modeling

21-year CaRD10 version 2 for REBI contribution

A dynamical downscaling simulation at 10 km with improved physics was performed over a larger domain than the CaRD10 (California Reanalysis Downscaling at 10 km; Kanamitsu and Kanamaru 2007) to better simulate the South west monsoon, including western US and Mexico and eastern Pacific Ocean, for 1979-1999. This is an extension of the project with major changes in physical processes (cloud and land) to reduce the known precipitation bias, improve near surface parameters and a 4-fold extension of usable domain size allowing more synoptic scale systems coming in from Pacific Ocean. The raw simulation data from Scripps are archived at San Diego Super Computing Center and are available to the public through http://cec.sdsc.edu. The simulation for 1980-1989 was re-formatted and uploaded to the UC LLNL data server. A paper with intercomparison analyses will be submitted by the REBI group.

Incremental Interpolation

The variability of global warming simulations among different GCM's is known to be very large. The downscaling of global warming simulations needs to consider this large variability among models, but such study is strongly restricted by the requirement of the regional model to have very high temporal and vertical resolution output from global model, exceeding the capability of the data storage and distribution in most of the cases. Currently, downscaling of global simulation is restricted to a few simulations from NCAR, GFDL, ECHAM and UKMO models over the continental U.S. for NARCAPP project.

Hemispheric and global downscaling and improvement of SSBC

The Scale Selective Bias Correction (SSBC) method developed by Kanamaru and Kanamitsu (2006) has an advantage of making the downscaling insensitive to the domain size. Using this characteristics, the researchers experimented the downscale of coarse resolution reanalysis over very large area, including Hemispheric domain (Kanamaru and Kanamitsu, 2008, accepted for publication in Mon. Wea. Rev.) and global domain (Yoshimura and Kanamitsu, 2008, accepted for publication in Mon. Wea. Rev.) Both were quite successful in reproducing small scale detail not found in the reanalysis, and improving simulations of precipitation and other near surface parameters. The global downscaling is considered to be much more accurate than the regional downscaling due to the lack of the influence of lateral boundaries.

The global downscaling technique is also applied to simulate the global distribution of stable water isotope by incorporating isotope processes into the model, and using the SSBC with low resolution global model. This method forces the atmospheric circulation to that of the observed, but water isotope process included in the model provides water isotope distribution consistent with the atmospheric circulation. This is a new way to obtain global distribution of various trace gasses and materials without developing special data assimilation. This part of the work is submitted for publication in JGR (Yoshimura et al, 2008). The researchers are also trying to extend this work to obtain CO2 distributions in collaboration with Kalnay at Maryland and Fung at UC Berkeley.

Diagnostic Study of the warming of daily minimum temperature due to irrigation.

As an extension of the paper by Kueppers et al (2007) on the intercomparison of the effect of irrigation over California, the researchers performed diagnostic study of the warming of night time daily minimum temperature found in our simulation by performing additional integrations and conducting detailed surface energy balance diagnostics. It was found that the change in soil heat conductivity due to irrigation caused more rapid heating of soil during the daytime, which is released during the night time to warm the near surface temperature, resulted in the warming of minimum temperature. This work has been accepted for publication in J. Hydrometeorology (Kanamaru and Kanamitsu 2008).

2.4.2. Statistical and Hybrid Downscaling Techniques

The general circulation models used for climate simulations typically have horizontal spatial resolutions of a few hundred kilometers. However, to properly evaluate regional and local effects of climate variations (for example, in projecting hydrologic changes in a watershed), researchers require a much higher level of detail—on the order of 10 kilometers—because many effects are sensitive to the nuances of the local climate. *Downscaling* is the process of transferring the climate information from a coarse-scale climate model to the fine scale required by models that address effects on climate. Although downscaling can be achieved using a regional climate model, it is computationally expensive and currently is not practical for processing multidecade and/or multimodel simulations from general circulation models. A viable alternative is to use statistical downscaling, which has the advantage of requiring considerably less computational resources. Underpinning this approach is the assumption that analogues from the present climate can be identified and applied, statistically, to determine the day-to-day patterns that will characterize the future climate.

At Scripps, Hidalgo Dettinger and Cayan have developed of a new method for statistically downscaling daily precipitation and temperature from general circulation models using the "constructed analogues" method. The method is based on the premise that an analogue for a given coarsescale daily weather (target) pattern (for example, from a general circulation model simulation) can be constructed by combining the weather patterns for several days (predictors) from a library of previously observed patterns. In this application the analogue pattern is constructed at coarse scale, but a similar construction can be made using a companion library of high resolution patterns using the same days as the coarse-scale predictors. Thus, a fine resolution downscaled estimate is created for the given pattern of that particular day.

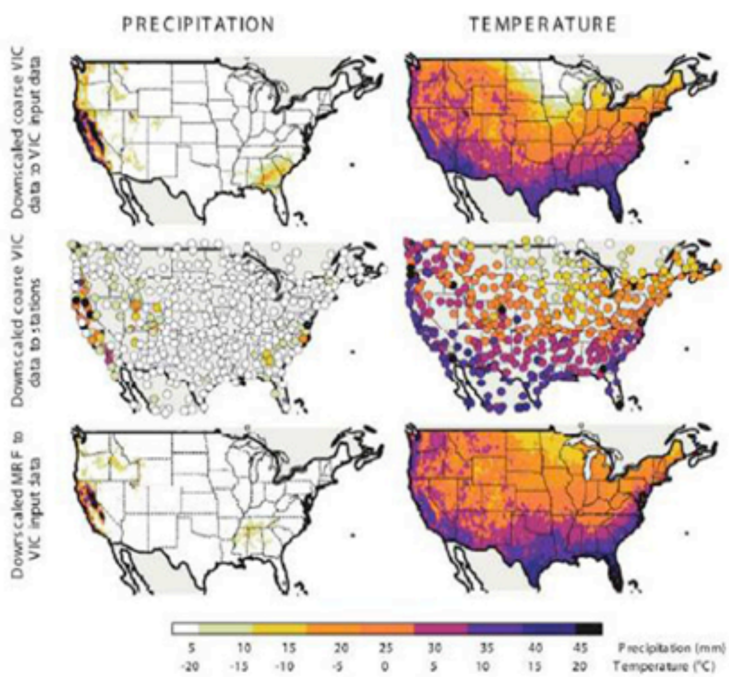

Figure 6. Downscaled Precipitation (mm) and average air temperature (°C) versions of the January 27, 1983, California Storm using constructed analogues applied to coarse VIC data (top), station data (middle), and medium-range forecast (bottom).

Source: Authors

2.5. Analyses of Climate Variability and Change

2.5.1. Climate Scenarios for California

In May 2005, the California Energy Commission (Energy Commission) and the California Environmental Protection Agency (Cal/EPA) commissioned a report describing the potential impacts of climate change on key state resources. It was recognized that current climate-change projections agree on certain broad and troubling aspects of the future climate and climate influences in twenty-first century California.

Despite considerable uncertainty in some key details (especially, regional details) of future climate change and a good measure of contrast between different global climate models, an up-to-date appraisal of potential impacts from the projections available would help to inform decision makers as they begin to address and plan for these impacts. Although precise prediction is impossible, it was agreed that it would be worthwhile to examine a selection of scenarios of possible climate change, targeted regionally to explore California's future climate, in a manner similar to previous and ongoing efforts by the Intergovernmental Panel on Climate Change (IPCC) (Houghton et al. 2001), an examination of ecological and related changes in California (Field et al. 1999), the U.S. National Climate Change Assessment (National Assessment Synthesis Team 2001), and by scientists in Great Britain to examine potential climate changes in the United Kingdom.1 Because of the tight timeframe in which this work was to be completed, this assessment focuses on a small subset of available global climate models. This work builds upon previous climate model-based studies of possible climate change impacts on various sectors in the California region, including a broad assessment of possible ecological impacts by Field et al. 1999; an assessment of a range of potential climate changes on ecosystems, health, and economy in California described by Wilson et al. 2003; a study of how a business-as-usual emissions scenario simulated by a low sensitivity climate model would affect water resources in the western United States, overviewed by Barnett et al. 2004; and a multisectoral assessment of the difference in impacts arising from high versus low greenhouse gas (GHG) emissions in Hayhoe et al. 2004. As reported by the WMO (2005) "since the start of the twentieth century, the global average surface temperature has risen between 0.6°C and 0.7°C (1.08°F and 1.26°F). But this rise has not been continuous. Since 1976, the global average temperature has risen sharply, at 0.18°C (0.32°F) per decade. In the northern and southern hemispheres, the 1990s were the warmest decade with an average of 0.38°C (0.68°F) and 0.23°C (0.41°F) above the 30-year mean, respectively." The 10 warmest years for the earth's surface temperature all occurred after 1990 (Jones and Palutikof 2006) and the second or first warmest year on record appears to have occurred in 2005 (Jones and Palutikof 2006;Hansen et al. 2006). Much of the warming during the last four decades is attributable to the increasing atmospheric concentrations of climate change emissions due to human activities (Santer et al. 1996; Tett et al. 1999; Meehl et al. 2003). Possible future climate changes in California are investigated from a varied set of climate change model simulations. These simulations, conducted by three state-of-the-art global climate models, provide trajectories from three greenhouse gas (GHG) emission scenarios. These scenarios and the resulting climate simulations are not "predictions," but rather are a limited sample from among the many plausible pathways that may affect California's climate. Future GHG concentrations are uncertain because they depend on future social, political, and technological pathways, and thus the IPCC has produced four "families" of emission scenarios.

To explore some of these uncertainties, emissions scenarios A2 (a medium-high emissions) and B1 (low emissions) were selected from the current IPCC Fourth climate assessment, which provides several recent model simulations driven by A2 and B1 emissions. The global climate model simulations addressed here were from PCM1, the Parallel Climate Model from the National Center for Atmospheric Research (NCAR) and U.S. Department of Energy (DOE) group, and CM2.1 from the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluids Dynamics Laboratory (GFDL).

As part of the scenarios assessment, a statistical technique using properties of historical weather data was employed to correct model biases and "downscale" the global-model simulation of future climates to a finer level of detail, onto a grid of approximately 7 miles (12 kilometers), which is more suitable for impact studies at the scales needed by California decision makers. In current climate-change simulations, temperatures over California warm significantly during the twenty-first century, with temperature increases from approximately +3ºF (1.5ºC) in the lower emissions scenario (B1) within the less responsive model (PCM1) to +8ºF (4.5ºC) in the higher emissions scenario (A2) within the more responsive model (CM2.1). Three of the simulations (all except the low-emission scenario run of the low-response model) exhibit more warming in summer than in winter.

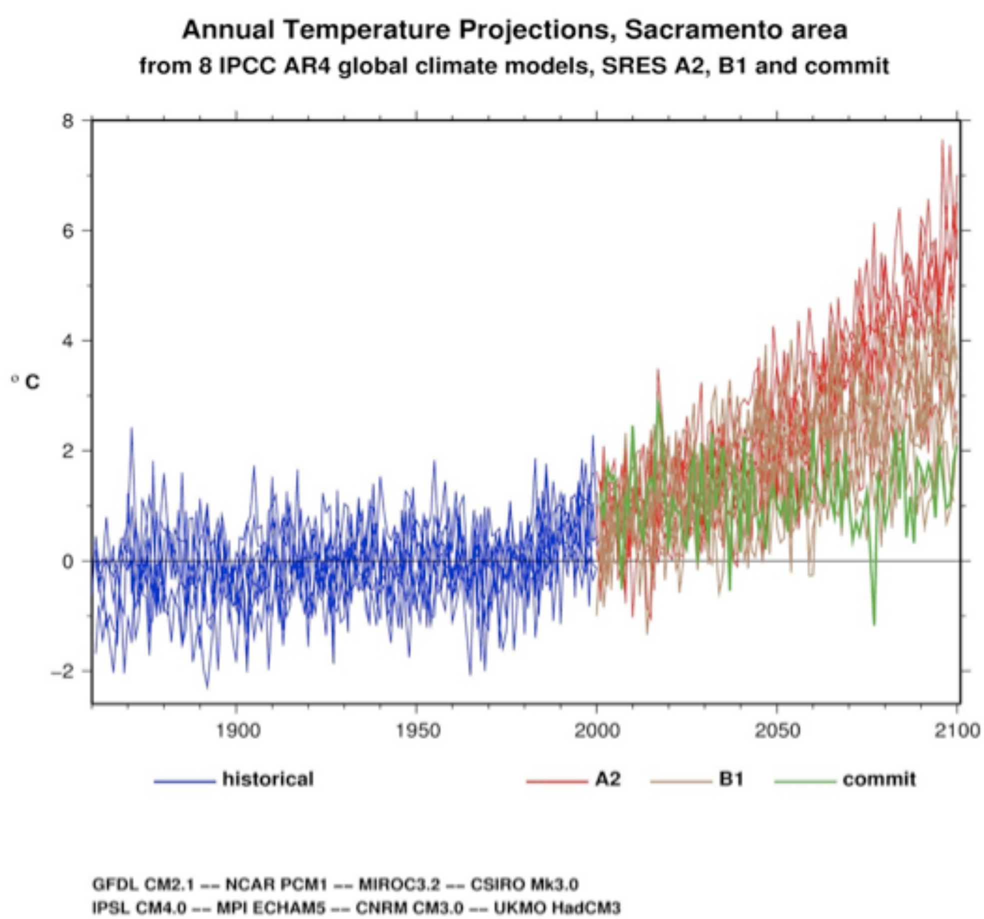

Figure 7. Annual Temperature Projections

Source: Authors

2.5.2. Climate Change and California Sea Level Rise

California has about 1800km of coastline, numerous estuaries including the San Francisco Bay and Delta, wetlands, and coastal aquifers. These are susceptible to harmful effects if sea level rises too much or too fast in the 21st Century. California's coastal observations and global model projections indicate that California's open coast and estuaries will experience rising sea levels over the next century. During the last several decades, the upward historical trends, quantified from a small set of California tide gages, have been approximately 20 cm per century, quite similar to that estimated for global mean sea level. In the next several decades, warming produced by climate model simulations indicates that sea level rise could amplify. Rates projected could exceed substantially the rate experienced during modern human development on the California coast and estuaries. A range of future SLR is estimated from a set of climate simulations governed by lower (B1), middle-upper (A2), and higher (A1fi) GHG emission scenarios. Projecting SLR from the ocean warming in GCMs, observational evidence of SLR, and separate calculations using a simple climate model yields a range of potential sea level increases, from 11 cm to 72 cm, by the 2070-2099 period.

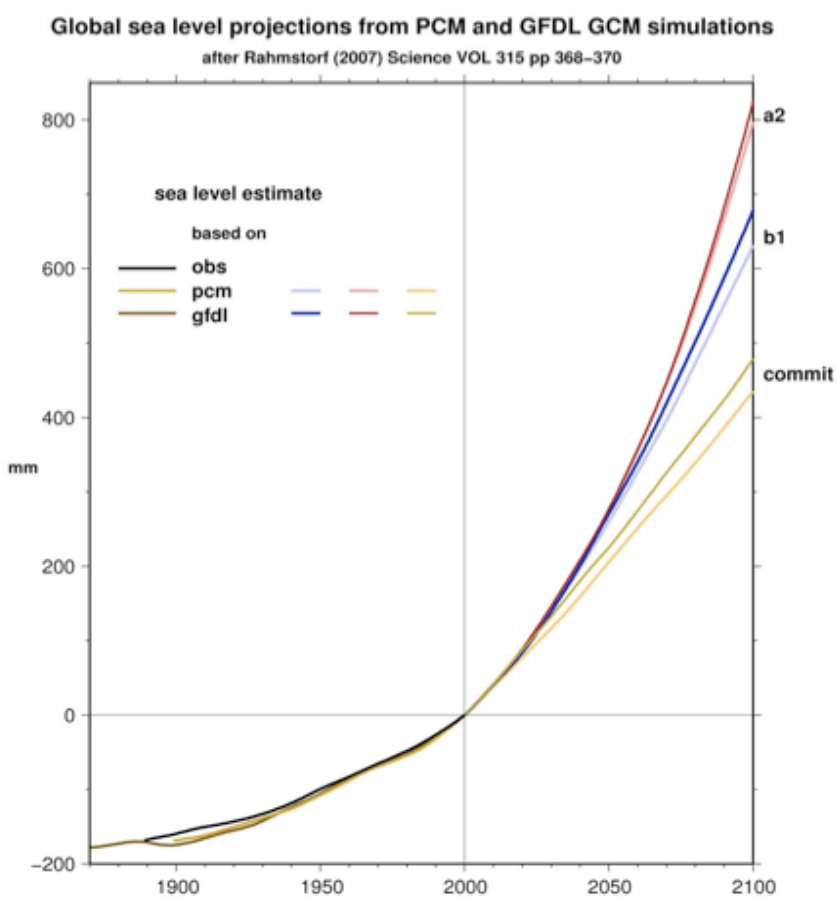

Figure 8. Global Sea Level Projections

Source: Authors

2.5.3. Climate and Culex tarsalis *mosquito populations*

In the western United States, the mosquito-borne encephalitides of public and veterinary health concern include western equine encephalomyelitis (WEEV), St. Louis encephalitis (SLEV), and now West Nile (WNV) viruses. These viruses are maintained and amplified in nature in similar enzootic transmission cycles involving several mosquito species within the genus *Culex* and multiple bird species (Reisen and Monath 1989, Komar 2003, Reisen 2003). Outbreaks occur sporadically, due partly to climate driven population fluctuations of the primary rural vector mosquito, *Culex tarsalis* Coquillet. California has had a comprehensive mosquito surveillance program for more than 50 years making it possible to investigate the impact of climate variation on mosquito dynamics measured at different spatial and temporal scales (Cayan et al. 2002). Climate variation affects the population dynamics of mosquitoes such as *Cx. tarsalis* because body temperatures approximate ambient conditions and larvae develop in aquatic habitats created directly or indirectly by precipitation (Reisen and Reeves 1990). In studying the California mosquito population data, Dr. William Reisen and colleagues, including Cayan, Dettinger and Tyree, found that temporal variation in the abundance of the encephalitis virus vector mosquito, *Culex tarsalis* Coquillet, was linked significantly with coincident and antecedent measures of regional climate, including temperature, precipitation, snow pack, and the El Niño/Southern Oscillation anomaly. Although variable among traps, historical records that spanned two to five decades revealed climate influences on spring and summer mosquito abundance as early as the previous fall through early summer. Correlations between winter and spring precipitation and snow pack and spring *Cx. tarsalis* abundance were stronger than correlations with summer abundance. Spring abundance was also correlated positively with winter and spring temperature, whereas summer abundance correlated negatively with spring temperature and not significantly with summer temperature. Correlations with antecedent climate provide the opportunity to forecast vector abundance and therefore encephalitis virus risk, a capability useful in intervention decision support systems at local and state levels.

2.6. Water and Energy Resources

2.6.1. Aridity in the West

It is often remarked that most of the western US (Figure 1) is "always in drought," especially by visitors from wetter climates. The plants and landforms of the West, however, are more or less adapted to the region's relatively dry but variable climates, and so important variations in the levels of drought, or aridity, characterize the landscape.

During "real" droughts, broad areas of the West are subjected to drier conditions than normal, imposing—at least temporarily—arid climatic conditions on many semiarid and even humid areas. In response to these climatic conditions, the hydrologic balances between waters that run off and those that evaporate back into the atmosphere are transformed temporarily in ways that color the entire region's water supplies and vegetation.

In an article by H. Hidalgo, M, Dettinger and Cayan contributed to California DWR's climate volume, the researchers describe the major changes that droughts wreak on the "normal" partitioning of precipitation between evaporation and runoff, as depicted by a hydrological model that simulates historical variations of the region's surface hydrology. Actual evapotranspiration (AET) is the combined flux of water to the atmosphere from soil surfaces and plants by evaporation and through plants by transpiration. AET depends on the availability of both water and energy. Potential evapotranspiration (PET) is the atmospheric demand of water from the soil and free water surfaces, and represents the amount of evapotranspiration that would occur if water were not a limiting factor. A body of previous research has demonstrated that there are well-defined connections between droughts and the ratio of AET/PET in the western US. This ratio is called evaporative efficiency or ß. Extremely low values of are common in arid regions where PET is high and lack of water limits AET rates. High values of ß occur in semi-humid and humid regions (usually at the top of the mountains in the West), where energy availability limits AET rates. Intermediate values of ß, when the annual demand for water is considerably higher than the supply of water but not as strong as in the arid regions, occupy the largest part of the western US; these regions are classified as "water limited" and include areas that are often described as semi-arid. "Green water" is a name given to AET by Falkenmark and Rockström (2004), with "blue water" the name given to the remaining fraction of water that is not consumed by evapotranspiration (P-AET). Blue water is thus the water that runs off into streams or recharges into aquifers. A key point in this article is how drought shifts the flow of water from blue to green. Even as it shifts water from blue outflows to green uses, in most cases, drought reduces the overall availability of water for evapotranspiration in a region, lowering the AET efficiency along with the total AET. This results in temporary increases in the aridity (as measured by ß) in the drought affected region. Thus during a drought, regions that are semiarid on long-term average can experience hydroclimatic conditions similar to the ones normally found in arid regions. Similarly, during droughts, regions in which AET is energy-limited, on long-term average, can become water limited (or even extremely water-limited). The temporary increase in aridity of a region can have severe impacts on ecological systems in general, wildfire potential and soil erosion. This article also investigates the geographic extend of the changes in aridity conditions during droughts and pluvial

The most general finding describes how droughts change the geographic distributions of hydrologic conditions across the West landscape. Arid conditions occupied as little as 15% of the western US landscape in 1983 and swelled to as much as 51% during the 2002 drought. Water supplies, plants and animals adjusted as best they could to drought-pluvial changes—whether of short or long duration--in order to weather the episodic character of historical droughts. The partitioning of whatever precipitation falls between blue water (runoff and recharge) and green water (consumptive use by either evaporation or evapotranspiration) also varies with drought and pluvial. Climate warming, which is already occurring over the West and very likely to be amplified in following decades, may expand extent of arid conditions within the western US. Two separate mechanisms have been suggested: higher evaporation demands in a warmer climate and the potential for more frequent droughts (Seager et al. 2007).

The former would be expected to push western water budgets towards larger green-water fractions and smaller blue-water fractions. On the basis of analyses presented here, any persistent reductions in precipitation might be expected to shift water budgets even more towards less overall blue-water generation and more green-water use, because the blue fractions decline more than the precipitation in drought years. Green-water components of the western water budgets are vital parts of the western landscape and ecosystems but represent components that are largely beyond human uses and management. Thus, increases in green-water demands in a warming world must be viewed, to a certain extent, as necessary evils, not to be stopped unless the researchers want very desolate future landscapes indeed.

Shifts in the mean aridity of the west, associated with climate change, even if small compared to the historical year-to-year variations, will be superimposed onto those kinds of variations. That superposition is likely to yield new extremes, both in the areas subjected to unusual aridity and in the severity of drought episodes, so that future drought extremes may be particularly challenging.

Because most western landscapes are adapted to accommodate past drought variability that often has been dominated by short-term drought episodes, a gradual but persistent increase in aridity associated with current projections of climate change may be especially important for the redistribution of the species and desertification.

More monitoring of soil moisture and other drought-sensitive variables is needed in order to detect changes, and to some extent avoid unpleasant surprises as the western climate changes in response to increasing greenhousegas concentrations in the atmosphere. Better monitoring will also provide foundations for proper improvements in hydrologic models and predictions, and for calibration of remote-sensing observations. Such measurements will be of increasing value as this century unfolds and—in the case of soil moisture--have only recently become feasible for widespread deployment. Given the importance and complexity of drought impacts and the possibility of more frequent and perhaps more intense drought in the future, a proactive approach to monitoring is ever more necessary.

2.6.2. Atmospheric Rivers

It has long been known that the atmosphere accomplishes most of its midlatitude horizontal water vapor transport in narrow, elongated regions located within the warm sector of extratropical cyclones [e.g., Browning and Pardoe, 1973]. These regions are characterized by warm air temperatures, large water vapor content, and strong winds at low altitudes. Only recently, however, have the narrowness and importance of these features been adequately quantified.

Zhu and Newell (1998) used a global numerical model to diagnose that >90% of the total meridional water vapor transport in the midlatitudes takes place in narrow corridors that constitute <10% of the Earth's circumference at midlatitudes. These characteristics led to the term ''atmospheric river.'' More recently, observational studies [Ralph et al., 2004, 2005] used research aircraft and satellite observations over the eastern Pacific Ocean to quantify the horizontal and vertical structure of atmospheric rivers, as well as their synoptic environment and interannual variability. Bao et al. [2006] then used a mesoscale numerical model to study the possible tropical origins of water vapor in several major West Coast storms. These types of storms are sometimes referred to as ''Pineapple Express'' events [Higgins et al., 2000].[3] While it is generally known that when storms move inland across the West Coast of the U.S. they can yield heavy rainfall and flooding, the contribution of atmospheric rivers to the heavy rain and flooding has not been fully documented. The atmospheric river concept provides a new and objective framework in which to examine and quantify atmospheric conditions related to rainfall intensity. This concept can help distinguish landfalling storms that generate heavy rainfall from those likely to produce lighter rain. This study uses experimental meteorological measurements from field studies near the Russian River of northern California (Figure 1) and Special Sensor Microwave Imager (SSM/I [Hollinger et al., 1990]) polar-orbiting satellite observations of vertically integrated water vapor (IWV) since 1997 to examine the connection between atmospheric rivers and flooding on the Russian River (12-hourly composites of IWV data from several satellites were used to provide adequate spatial coverage). First, a focused case study of the flood-producing storm on 16–18 February 2004 is presented. Second, all floods on the Russian River between 1 October 1997 and 28 February 2006, i.e., the period when SSM/I data and experimental meteorological measurements are available, are examined for evidence of atmospheric river conditions.

Observations from an 8-year-long series of field observations near the flood-prone Russian River of northern California were combined with SSM/I satellite observations offshore to explore the possible role of atmospheric rivers in creating the precipitation that led to flooding events on the Russian River. The contribution of atmospheric river conditions to the production of heavy orographic rainfall and ultimately to the flood of 16–18 February 2004 was documented most fully.

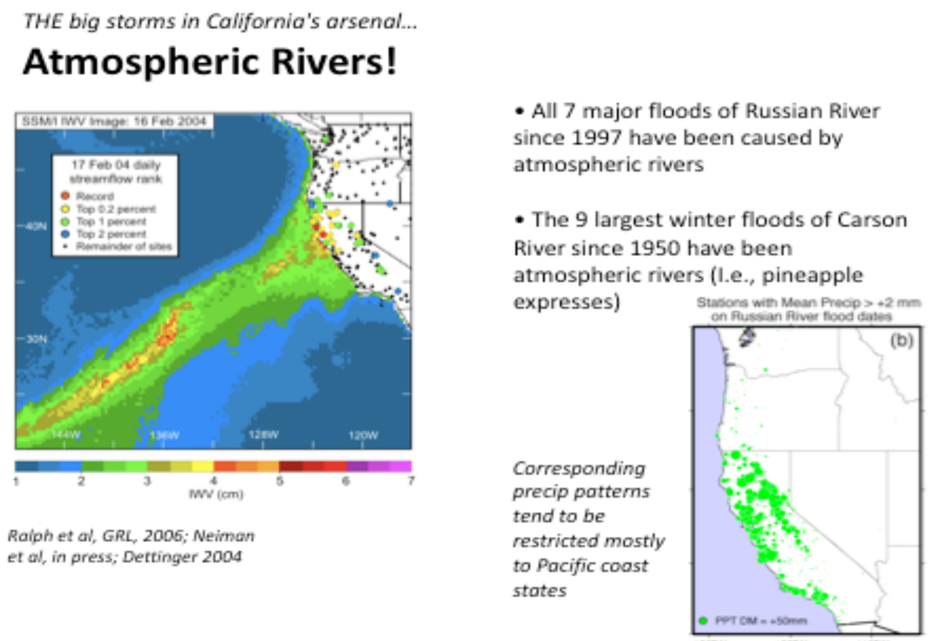

Figure 9. Composite SSM/I satellite image of IWV (cm; color bar at bottom) constructed from polar-orbiting swaths between 1400 and 1830 UTC 16 February 2004. Statistical analyses based on the 7 flood- and monitor-stage events on California's Russian River at Guerneville (Table 1): (a) Percentage among the 7 events with daily streamflows in the top 0.8 percentile recorded by gauges spanning 30 years (see inset key); (b) departure from daily mean precipitation (sized for scale). The streamflow data are based on dates in local time coordinates ending at 11:59 p.m., whereas the daily precipitation data correspond to a 24-h period ending mid-morning local time (which may vary from site to site). The inset boxes mark the Russian River basin.

Source: Ralph et al., Submitted

2.6.3. Heat waves

Alexander Gershunov (Scripps) and colleague H. Douville (Météo-France/CNRM, Toulouse, France) studied extensive summer hot and cold extremes under current and possible future climatic conditions. The spatial scale of a heat wave is an important determinant of its impacts. Extensive summer hot and cold spells are considered over Europe and North America in observations and coupled model projections.

In this work, an index is defined that *explicitly* reflects the spatial scale of hot and cold outbreaks as well as, although implicitly, their magnitude and duration. The spatial extent of European and North American summertime extreme temperature outbreaks is then considered in the context of decadal and interannual observed variability and coupled model projection of anthropogenic climate change given different scenarios for future emissions and socio-economic development.

Instead of aggregating observed and modeled data in samples of several decades to represent present and future climates as was done in recent studies, the researchers present time series of hot and cold spell indices at annual resolution computed for each summer on record, observed and modeled. The researchers then provide a qualitative assessment of the temporal character of spatially extensive temperature extremes over Europe and North America.

The regional hot and cold spell indices employed in this study plainly describe the behavior of regional extreme temperature outbreaks in a way complementary to but fundamentally different from examinations of temperature magnitudes on local or global scales. One important and robust feature of regional hot and cold spell occurrence is their strong low-frequency modulation. Global analyses mask regional decadal variability by averaging over it; local analyses tend to obscure it in higher frequencies. Super outbreaks of hot and cold air rarely occur in a temperature sense counter to prevailing decadal and longer-term trends. Recent trends towards more frequent and extensive hot spells, as well as rarer and less extensive cold outbreaks, can be explained through a combination of natural multi-decadal and anthropogenic influences. Coupled model projections reflect these natural and anthropogenic influences with their relative contributions depending on the particular scenarios assumed for global socio-economic development.

Europe appears to have gotten an early warning in 2003 of conditions projected for the second half of the 21st century assuming a "business as usual" emissions scenario. North America, on the other hand, in spite of a general summer warming, has not seen the extent of summer heat that it can potentially experience even if global emissions of carbon dioxide and sulfate aerosols remain fixed at their current levels.

To better understand the unusual recent summer temperature regime over North America and its likely near-future developments, a specific focus is finally made on the effect of precipitation on regional summer temperatures. Extensive and persistent heat waves naturally occur in association with widespread drought. The recent warming over North America is unusual in that it occurred without the large-scale encouragement of a dry soil associated with precipitation deficit. Regional precipitation anomalies together with global anthropogenic influences can explain the atypical spatial pattern of recent North American summer warming. A decrease of precipitation to more normal amounts over the central and eastern United States is expected to result in a substantial summer warming over that region. Drought has the potential to seriously exacerbate the recent warming over North America to levels more in line with the warmest current model projections. From climate warming scenarios, a long-term anthropogenic increase (decrease) in the frequency and spatial extent of regional hot (cold) spells is projected to be strong and strongly modulated by decadal-scale variability throughout the 21st Century.

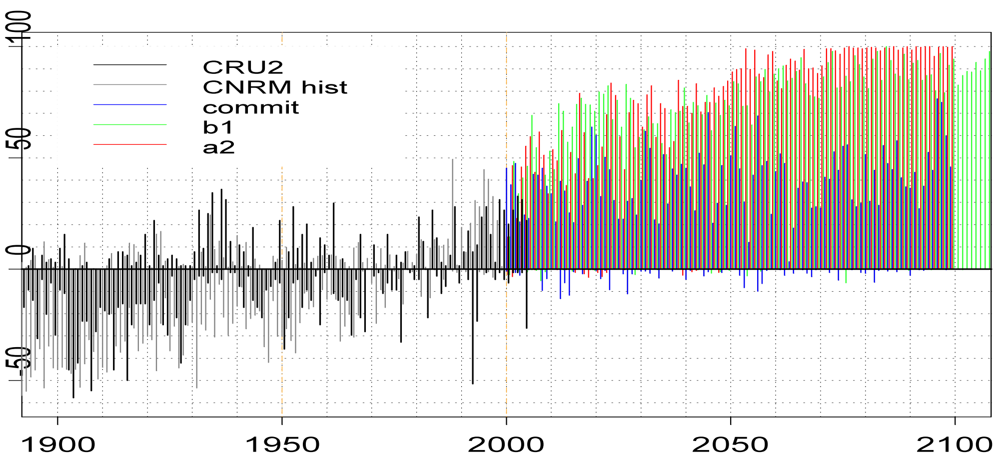

Figure 10. Hot and cold spell indices displayed as percentage of North American grid points with summer temperatures above the 90th or below the 10th percentiles of their local summer 1950 – 1999 climatology. HSI (CSI) is displayed in positive (negative) values. By definition, during the base period, the mean values are 10% of the area experiencing unusually hot or cold temperatures.

Source: Authors

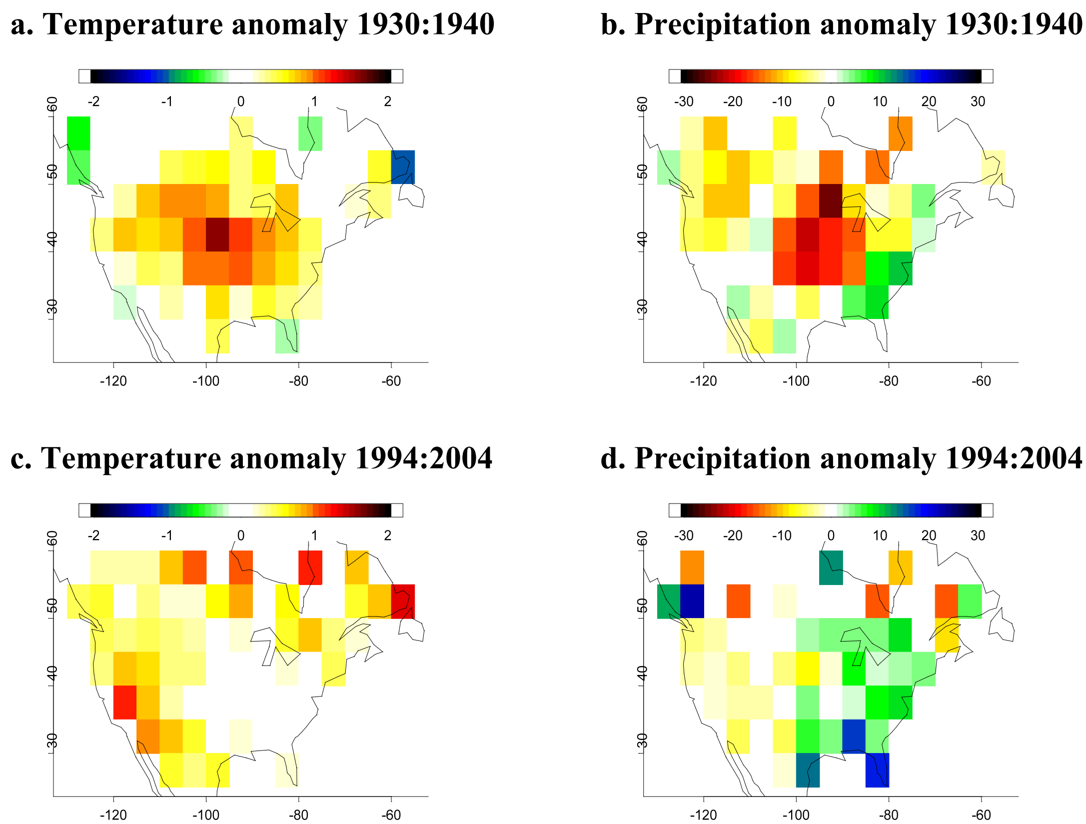

Figure 11. Climate anomalies relative to 1950:1999 base period. Summer temperature (a,c) and precipitation (b,d) anomalies for two 11-year periods: 1930-1940 (a,b) and the most recent period of record, 1994-2004 (c,d). Notice the reversed color scale on the precipitation plots. Canadian precipitation records suffer from missing data at the end of the record accounting for the visible discontinuity along the US-Canada border on panel d.

Source: Authors

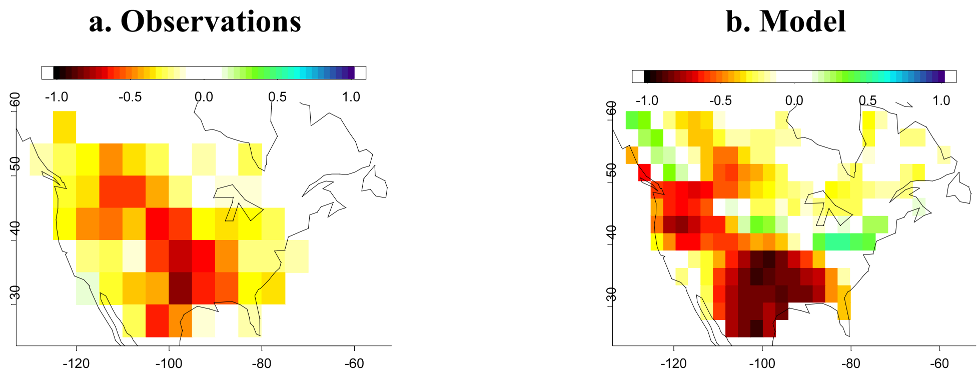

Figure 12. June-August precipitation/temperature correlation. Correlation coefficient between local June-August average temperature and precipitation in observations (a: GHCN V2 and CRU2 evaluated over the period of record, 1900 – 2004, or slightly shorter based on data availability for the individual grids) and in the model (b: the commit run, 100 years).

Source: Authors

North America, while also warming, has not yet felt the feasible level of heat projected for the current stage of anthropogenic climate change. Interestingly, the current warm period, although at least in spatial extent comparable with the 1930s Dust Bowl, does not involve the same region of North America, is not associated with severe drought and is, therefore, very much unlike the similar-scale 1930s warming (and other more common warm events). The recent summertime warming over North America has occurred notably in the mountainous west, where it is consistent with observed hydrological changes initiated by warming trends in the winter and spring. Specifically, the western summertime warming occurred alongside with a strong observed trend towards warmer winter and spring and earlier snowmelt (Cayan et al. 2001) as well as decreasing snow/rainfall ratios (Knowles et al. 2006). The hydrological changes initiated by these trends in winter and spring result in drying of the soil into the summertime and can partially explain the western summertime warming. It is possible that European-Alpine-type water vapor feedback processes (e.g. Philipona et al. 2005) may also explain a part of this western summertime warming. Supporting such a possibility, as well as giving further verification of a large-scale environmental change, is the fact that North American warming also has a broad Canadian footprint. However, Canadian data were mostly excluded from index calculations here.

The CGCM driven with anthropogenic forcing reproduces well the warming observed over Europe and North America. It also reproduces well the coupling of summertime temperature and precipitation. Model results interpreted in light of the observations, suggests that, even at anthropogenic output fixed at current levels, the researchers can expect much larger heat waves than have been observed up to now in North America as soon as natural decadal variability (e.g. precipitation) turns to conspire with, or at least stops to counteract, the anthropogenic signal. The model also provides variants of likely further evolution of summer heat. The A2 and B1 warming scenarios are indistinguishable from each other in the next several decades mostly due to the fact that each model run is strongly modulated by its own natural decadal variability. However, by the middle of the century, the two scenarios clearly diverge with the B1 stabilizing at a temperature anomaly of about 3ºC and HSI between 75 and 98%, while the A2 saturates at HSI=100% by about 2070 with temperatures continuing to rise.

Over North America, a spatially extensive heat wave of the magnitude of Europe 2003 has not occurred in observed history. However, the probability of such an event may be significant and increasing. The observed current level of warming agrees with the cooler decades projected by the model run with anthropogenic forcing fixed at current levels. However, even with this fixed forcing, 22% of the projected heat waves cover over half of North America, a level heretofore not reached in observations. Realistically, this level and spatial extent of summer heat, were it to occur in the near future and in its preferred location, will be coupled with drought. It is clear that if such extensively hot and dry summers were to occur in reality, especially if unanticipated, would produce adverse consequences for North America. Observational and model results both suggest, furthermore, that such extremes exhibit natural cycles and tend to congregate in decadal sequences of hot summers.

3.0 Results

3.1. Upgrading the Historical Climate Archive

At Scripps, climate model data archiving and distribution commanded much of the attention of Mary Tyree. In an effort to seamlessly reach a larger group of researchers, data from climate models and observations were distributed via a network-attached storage device linked to a set of web pages off our main server at Scripps (tenaya.ucsd.edu). Individual researchers with specific requests for large volumes or highly tailored needs were also supported. More than 3.5 Tbytes of data were available to the community via the web server tenaya. During the year more than 18.4 Tbytes were downloaded by users working on the Scenarios Project as well as other climate researchers. The greatest amount of data was downloaded between July and December since the 2008 Scenarios Project began in earnest in June (see attached plot with red bars showing monthly number of Kbytes retrieved). The number of hits the web pages received peak in May and December (see green bars on attached plot). The number of hits reflects the level of activity within the Scenarios Project, but also is strongly affected by the web cam at Tioga Pass (entrance to Yosemite National Park). The Tioga Pass web cam, which is supported by this grant under Task 2, receives thousands of requests (hits) each day from a growing set of state, national and international viewers. Interestingly, the number of hits falls off dramatically when the image is not available.

More than 30 individual researchers, mostly from the Scenarios Project, were assisted with specific data requests in 2008. These requests ranged from those who needed help accessing files for a specific area to those who needed further data processing for specific applications. These requests often included a need for graphical explanation. Approximately 5 of the requests required less than 5 hours of work. The great majority of the requests required around 40 hours of work. Less than 5 of the requests required more than 80 hours of work.

3.2. Regional Modeling

3.2.1. Downscaling Techniques

The author examined the degradation of the downscaling by performing a number of experiments changing the number of pressure levels of the input global forcings. It was found that the accuracy of the downscaled results indeed degrades as the vertical resolution of the forcing decreases. In order to overcome this problem, the researchers developed a new incremental interpolation method. The method uses a global model short range forecast as a guess and interpolates the difference between the guess and the pressure level forcing to model levels. This method was shown to make significant improvement to the downscaling and reasonably accurate downscaling can be obtained from just a daily 3-5 levels outputs. This method allows us to downscale many global warming simulations, which was not possible until now. The paper describing the detail of the method will be submitted to the PIER project report as well as to the Monthly Weather Review (Yoshimura, K. and M. Kanamitsu, Specification of external forcing fields for regional model integrations) in very near future. The draft paper is available from http://g-rsm.wikispaces.com/Incremental+Interpolation.

The purpose of the constructed analogues downscaling method is to produce daily precipitation and temperature maps, at fine spatial resolution, from a general circulation model. These estimates can be used to study impacts of climate changes and climate variability, for example, as input to a distributed hydrological model focusing on California watersheds. The research team sought to develop a new method to statistically downscale daily patterns from a climate general circulation model. By applying this "constructed analogues" method to historical weather patterns, the team evaluated its performance in downscaling precipitation and temperature over the conterminous United States, and, in particular, the western United States.

3.3. Analyses of Climate Variability and Change

3.3.1. Climate Scenarios

In all of the simulations, most precipitation continues to occur in winter, with virtually all derived from North Pacific winter storms. Relatively little change in overall precipitation is projected. Climate warming has a profound influence in diminishing snow accumulations, because there is more rain and less snow, and earlier snowmelt. These snow losses increase as the warming increases, so that they are most severe under climate changes projected by the more sensitive model with the higher GHG emissions.

3.3.2. Climate Change and Sea Level Rise

The combination of predicted astronomical tides with projected weather forcing, El Niño related variability, and secular SLR, gives a series of hourly sea level projections for 2005-2100. Gradual sea level rise progressively worsens the impacts of high tides and the surge and waves associated with storms, and also freshwater floods from Sierra and coastal mountain catchments. The occurrence of extreme events, relative to current levels, follows a sharply escalating pattern as the magnitude of future sea level rise increases.

3.3.3. Atmospheric Rivers

The spatial pattern of satellite-observed IWV conforms to the criteria used by Ralph et al. [2004] to characterize atmospheric rivers offshore; the GPS IWV observations at BBY exceeded 2 cm during the precipitation; and the wind profiler confirmed that the event occurred primarily within the warm sector of the storm and that LLJ conditions with strong upslope flow were prevalent. While the single case study provides a solid example of this relationship, all 7 flooding events on the Russian River at Guerneville since the suitable satellite and wind profiler data became available also were examined, and it was found that atmospheric river conditions were present and caused heavy rainfall through orographic precipitation for all 7 events. The regional extent of the heavy precipitation, warm temperatures, and flooding illustrated the regional impact of atmospheric rivers and the representativeness of the Russian River events. It should be recognized, however, that not all atmospheric rivers are flood producers, since individual atmospheric rivers may not generate sufficiently intense rainrates or because they may propagate too quickly across a given watershed. Additionally, if an atmospheric river is preceded by relatively dry conditions, the soil will have a much greater capacity to absorb heavy rainfall, thereby mitigating the potential for heavy runoff and flooding. In other words, while the presence of an atmospheric river was a necessary condition in all of the floods on the Russian River during this period, it was not a sufficient condition. Future work includes determining the predictability of this phenomenon (such as, distinguishing the characteristics of ‘‘null’’ cases where atmospheric rivers do not produce floods), and evaluation of the current forecast system with respect to the detection and prediction of atmospheric rivers, and their overall role in the climatology of western U.S. precipitation.

4.0 Conclusions and Recommendations

Water is perhaps the most precious natural commodity in the western United States. Numerous studies indicate the hydrology of this region is changing in ways that will have a negative impact on the region. Between 1950 and 1999, there was a shift in the character of mountain precipitation, with more winter precipitation falling as rain instead of snow, earlier snow melt, and associated changes in river flow. In the latter case, the river flow experiences relative increases in the spring and relative decreases in the summer months. These effects go along with a warming over most of the region that has exacerbated these drier summer conditions.

The west naturally undergoes multidecadal fluctuations between wet and dry periods. If drying from natural climate variability is the cause of the current changes, a subsequent wet period will likely restore the hydrological cycle to its former state. However, global and regional climate models forced by anthropogenic pollutants suggest that human influences could have caused the shifts in hydrology. If so, these changes are highly likely to accelerate, making modifications to the water infrastructure of the western United States a virtual necessity.

A regional climate change detection and attribution (D&A) study by Barnett, Pierce, Das and other Scripps and LLNL colleagues demonstrated statistically that the majority of the observed low-frequency changes in the hydrological cycle (river flow, temperature, and snow pack) over the western United States from 1950 to 1999 are due to human-caused climate changes from greenhouse gases and aerosols. This result was obtained by evaluating a combination of global climate and regional hydrologic models, together with sophisticated data analysis. The researchers used a multivariable D&A methodology to show that the simultaneous hydroclimatic changes observed already differ significantly in length and strength from trends expected as a result of natural variability (detection) and differ in the specific ways expected of human-induced effects (attribution).

Focusing on the hydrological cycle allows us to assess the origins of the most relevant climate change impacts in this water limited region. Barentt et al. (YEAR) investigated simultaneous changes from 1950 to 1999 in snow pack (snow water equivalent), the timing of runoff of the major western rivers, and average January through March daily minimum temperature in the mountainous regions of the western United States. These three variates arguably are among the most important metrics of the western hydrological cycle. By using the multivariable approach, the researchers obtain a greater signal-to-noise ratio than from univariate D&A alone.

Thus, this effort represents the most comprehensive multivariable climate change detection and attribution study for the western United States. It uses a high-resolution hydrologic model forced by global climate models, focusing on the changes that have already affected this primarily arid region with a large and growing population. The results show that up to 60% of the climate-related trends of river flow, winter air temperature, and snow pack between 1950 and 1999 are human-induced. These results are robust to perturbation of study variates and methods. They portend, in conjunction with previous work, a coming crisis in water supply for the western United States.

4.1. Support for the Activities of the California Climate Change Research Center

Cayan and colleagues have helped to design research, lead, administrate and represent the California Climate Change Research Center. This has involved interacting with numerous state officials and scientists, other government representatives, decision makers from the private as well as public sectors, scientist colleagues, and the public at large. Data processing and distribution to a broad sector of the California climate research community has been provided. An active web site http://meteora.ucsd.edu/cap/ has been constructed and maintained, and a partnership with the federally funded (by NOAA) California Applications Program has been forged. Our group has been very active in supporting the 2005-2006 and the emerging 2008-2009 California Climate Change Scenarios Assessments.

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