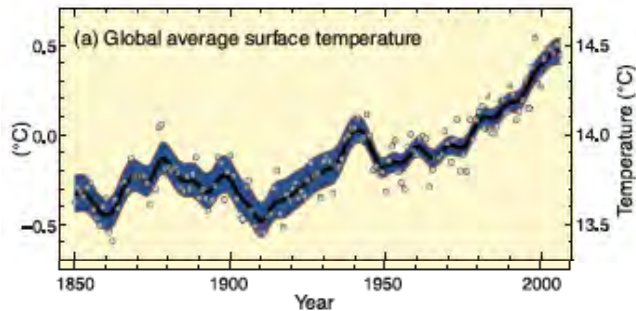


# Emerging Climate Science: A Brief Survey of Scripps Research

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Scripps Partnership for Hazards and Applied Environmental Research (SPHEAR)



## Introduction and Overview:

Working Group I of the IPCC's Fourth Assessment Report presents the "state of the science" regarding climate change. "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. ... Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)." (Climate Change 2007 Synthesis Report, Summary for Policy Makers, footnotes omitted). While some discourse remains in the media, blogosphere and outlier segments of the scientific community; major scientific endeavors have moved beyond the "settled science" of warming and the causes of the global warming and are now focusing on regional impacts of climate change along with mitigation and adaptation.

This report, "Emerging Climate Science: A Brief Survey of Scripps Research" summarizes a presentation at the Catastrophe Modeling Forum II on June 11-12 in New York City. CMF II was a unique and intimate gathering of researchers, catastrophe modelers and insurance/reinsurance executives. The goal of the forum was to discuss the primary issues within the broad topic of climate change that are of importance to the insurance sector. These issues involve multiple categories of risk that lead to widespread catastrophic property damage. Climate change is a global phenomenon but the local effects are of primary concern to those who underwrite catastrophic risk.

Innovations in climate modeling (downscaling techniques) allow studies to focus on the regional impacts of climate change and on important variables such as the availability of fresh water for consumption, irrigation and industrial use. Impact studies test varying scenarios of future climate, population growth and resource management practices. The output of these studies demonstrate,

in probabilistic terms, the ramifications of many scenarios, some of which are controllable by human decision makers.

Apart from water, the character of extreme heat events appears to be changing across California. Quantifying this particular variable can serve as a basis for predicting events that have a widespread influence on human health, energy consumption and agriculture. The following pages focus on three studies from the Scripps Institution of Oceanography at UC San Diego addressing these topics. Two studies have recently published ("Human-induced changes in the hydrological cycle of the western United States" and "When Will Lake Mead go dry") and one is still underway ("California Heat Waves: the Baja Connection").

Scripps recently launched a new initiative with the goal of forging direct connections between the research community and the business sector. The "Office of Business Development" at Scripps has three primary initiatives: (1) Executive Education focused on the link from weather, climate, and natural hazards to business; (2) Research partnerships (including SPHEAR); and (3) Scripps innovation and new venture creation.

The Scripps Partnership for Hazards and Applied Environmental Research, SPHEAR, is a global consortium geared to serve those in the private sector who link financial risk to weather, climate and natural catastrophes. SPHEAR's mission is to bring corporate partners face-to-face with thought-leaders across the research community in order to develop applications for weather forecasters, risk managers, investors, and insurers.

## Survey of:

### Human-induced changes in the hydrological cycle of the western United States

Tim Barnett<sup>1</sup>, David Pierce<sup>1</sup>, Hugo Hidalgo<sup>1</sup>, Tapash Das<sup>1</sup>, Celine Bonfils<sup>2</sup>, Ben Santer<sup>2</sup>, G. Bala<sup>2</sup>, Art Minin<sup>2</sup>, Andy Wood<sup>4</sup>, Toru Nozawa<sup>3</sup>, Dan Cayan<sup>1</sup>, Mike Dettinger<sup>1</sup>

<sup>1</sup>Scripps Institution of Oceanography  
<sup>2</sup>Lawrence Livermore National Lab  
<sup>3</sup>National Inst. Environmental Sciences (Japan)  
<sup>4</sup>Univ. Washington

### When Will Lake Mead go dry?

Tim Barnett<sup>1</sup>, David Pierce<sup>1</sup>

<sup>1</sup>Scripps Institution of Oceanography

### California Heat Waves: the Baja Connection

Alexander Gershunov<sup>1</sup>, Dan Cayan<sup>1</sup>

<sup>1</sup>Scripps Institution of Oceanography

SCRIPPS INSTITUTION OF OCEANOGRAPHY  
UC San Diego

Rady | UC San Diego School of Management

**Climate Change and Business**  
Demystifying Science, Risk and Reward  
June 6-7, 2008

## **Human Induced Changes in the Hydrological Cycle of the Western U.S.**

Barnett, T. P., Pierce, D. W., Hidalgo, H. H., Bonfils, C., Santer, B. D., Das, T., Bala, G., Wood, A. W., Nozawa, T., Mirin, A. A., Cayan, D. R., and Dettinger, M. D., 2008: Human-Induced Changes in the Hydrology of the Western United States Science, published online 31 Jan 2008, doi:10.1126/science.1152538.

Abstract: “Observations have shown that the hydrological cycle of the western United States changed significantly over the last half of the 20th century. We present a regional, multivariable climate change detection and attribution study, using 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.”

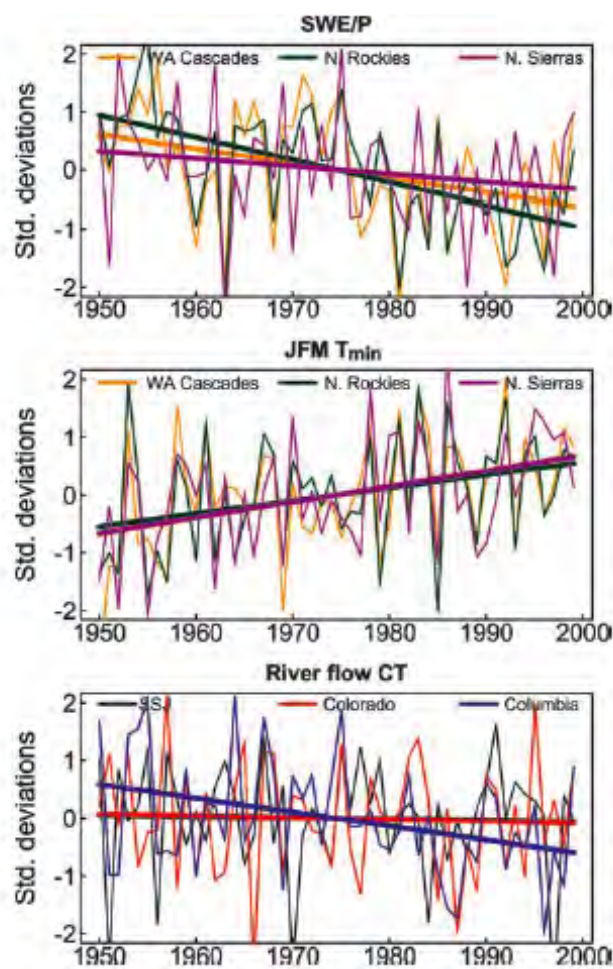


Fig. Above: Observed time series of selected variables (expressed as unit normal deviates) used in the multivariate detection and attribution analysis. Taken in isolation, seven of nine SWE/P, seven of nine JFM Tmin, and one of the three river flow variables have statistically significant trends.

## **When Will Lake Mead Go Dry?**

Barnett, T. P. and Pierce, D. W., 2008: When will Lake Mead run dry? J. Water Resources Research, in press.

Abstract: “A water budget analysis shows that under current conditions there is a 10% chance live storage in Lakes Mead and Powell will be gone by about 2013 and a 50% chance it will be gone by 2021 if no changes in water allocation from the Colorado River system are made. This startling result is driven by climate change associated with global warming, the effects of natural climate variability, and the current operating status of the reservoir system. Minimum power pool levels in both Lakes Mead and Powell will be reached under current conditions by 2017 with probability 50%. While these dates are subject to some uncertainty, they all point to a major and immediate water supply problem on the Colorado system. The solutions to this water shortage problem must be ‘time dependent’ to match the time varying, human induced decreases in future river flow.”

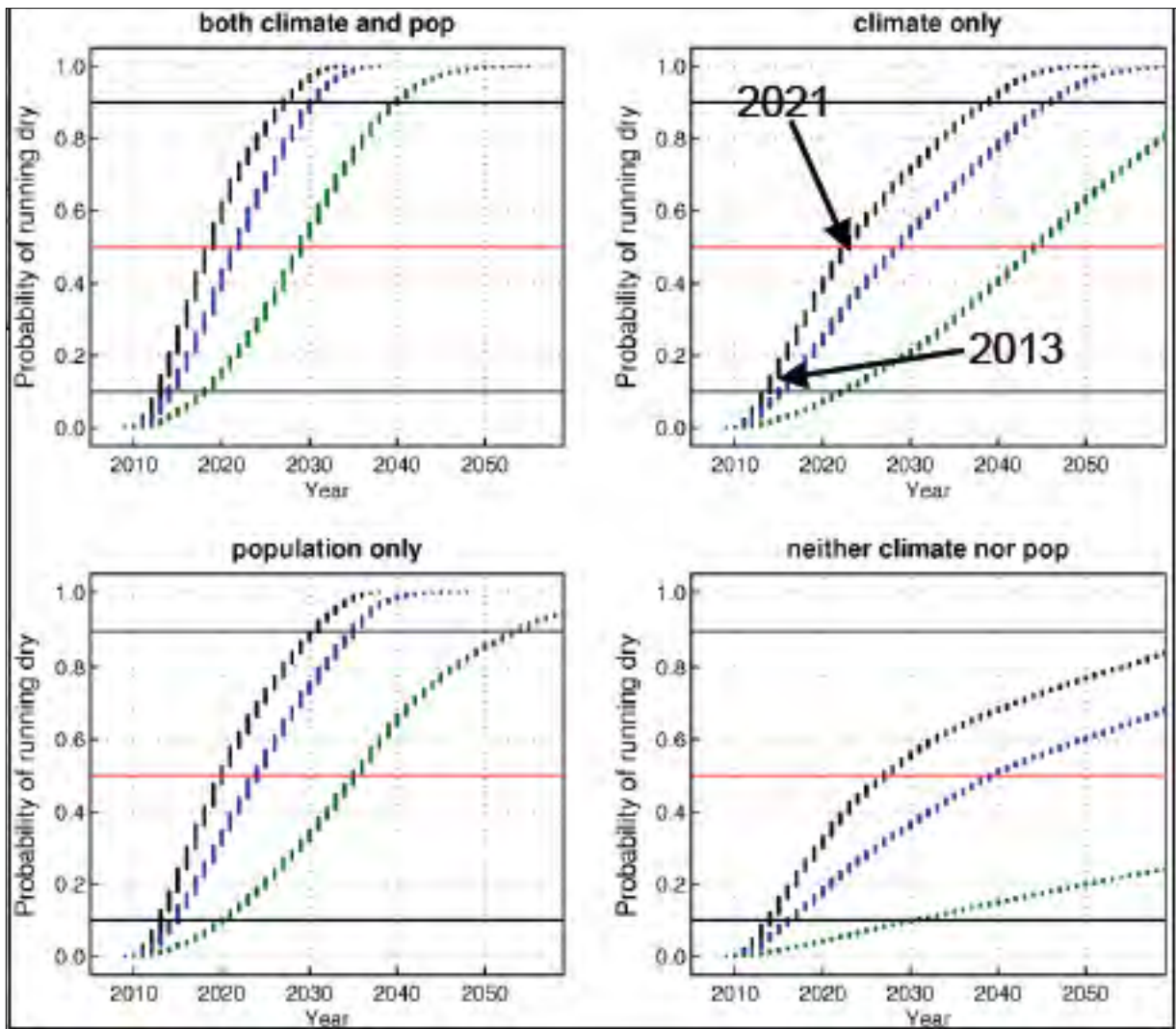
Three primary variables were studied across a network of nine snow courses representing three drainage basins using hundreds of individual station measurements. Observations indicate that the amount of snowpack available in April (SWE/P) has declined while the average minimum temperature in winter (JFM Tmin) has increased since 1950. The third variable, center of timing (CT - the day of the year on which one-half of the of the total water flow for the year has occurred) is occurring earlier in the year on the Columbia River.

Downscaling techniques were applied to global climate models to produce inputs for a regional hydrological model. The downscaled model results were then used to estimate an anthropogenic “fingerprint” for the global climate models. Different forcing mechanisms were applied within the model in an attempt to replicate the observed trends across the three variables.

How are the changes related to natural variability as compared to anthropogenic climate change?

The conclusion of this analysis is simply stated. When observed natural phenomena such as precipitation cycles, atmospheric cycles, and solar/volcanic cycles are used as forcing mechanisms, the model does not replicate observed changes to the system. When anthropogenic forcing is applied, the model replicates observations within a 95% confidence interval. The results imply that declines in “water storage” are not likely to reverse even when considering natural variability in jet stream positioning that leads to cycles in precipitation patterns. Using the model to predict changes out to 2100 reveals that the snow pack in the Northern Rockies and Colorado decreases considerably.

Fig. Below: Probability curves under differing management, climate change and population growth scenarios. Curves represent the probability (and uncertainty) for the Lake Mead/Lake Powell system to drop below “dead pool” elevation by the year noted on the x-axis. Black curves represent the probability of dropping below “dead pool” assuming no changes to water management practices. Blue curves represent a 10% restriction for water deliveries during drought years and green curves represent a 25% restriction for water deliveries during drought years.

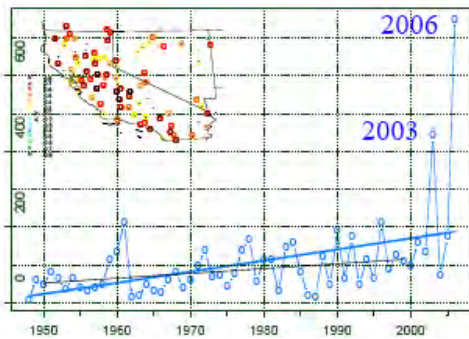


This study is not only a water budget study but it is also a demonstration of scenario analyses that can form the foundation for management or investment decisions. The study demonstrates that currently scheduled depletions from the Lake Mead/Lake Powell system are not likely to be sustainable over the long-term. This appears true at an 80% likelihood even if the population is held constant and there is no further trend in temperature and no trend in precipitation by the 2050s. This is true because net outflows from the system (stemming from consumption and evaporation/infiltration) exceed inflows (driven by precipitation and melting snow).

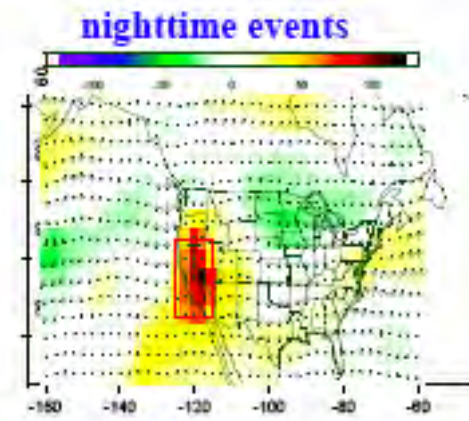
Precipitation is allowed to vary naturally, meaning this model includes strings of wet years and strings of dry years in its simulations much as have been observed in the historic record. Even considering the possibility of returning to a “wet regime” across the West, it seems likely that current depletions are not sustainable. There is an even higher probability of accelerated depletion under the assumption that climate change will impact temperature (which would then lead to increased evaporation and more rapid runoff from snowpack.) and considering US Census projections for population growth in the Southwest. Under these assumptions the system is projected to go dry with a 90% probability before 2030 and a 50% chance of being dry around 2020.

Of course management decisions can change the outcome. A 25% cut in water deliveries during drought years extends the life of the reservoirs with a 50% chance of being dry by 2030 and 90% chance of being dry by 2040. These analysis highlight the criticality of management decisions today since this system is responsible for the water consumption of 12 to 36 million people in the Southwest and these reservoirs are utilized for hydroelectric generation powering a large section of the region.

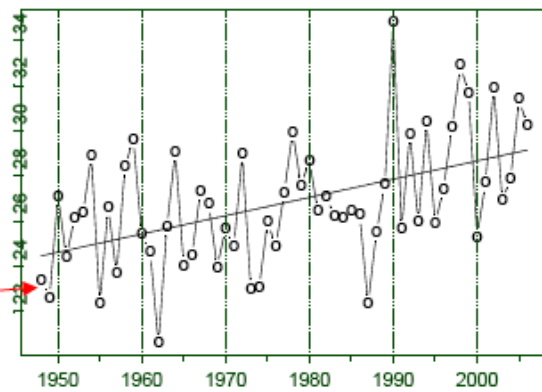
DN99: overall **nighttime** magnitude



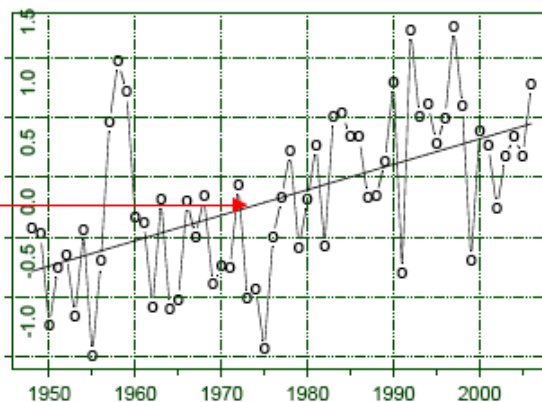
Atmospheric moisture % normal



PWTR Trend off Baja California  
130-117.5W, 25-27.5N



SST Trend off Baja California



## California Heatwaves: The Baja Connection

Alexander Gershunov and Dan Cayan, in progress.

Heat waves in California are driven by regional short-term anomalies in weather variables such as surface pressure, jet stream positioning, and moisture patterns. Weather variables are often considered random at timescales longer than 60 to 90 days. Global climate models project changes in the large-scale circulation but regional analyses are necessary to understand more skillfully project changes in weather extremes such as heat waves.

This study first defines a “heat wave” through an index of extreme heat relevant to the study of human health/mortality, energy consumption and agriculture. The index combines the magnitude of temperature (relevant to the historic distribution per station), spatial extent of heat, and number of consecutively hot days or nights.

Observed daytime and nighttime temperatures, considered separately since 1948 indicate that heat waves during the day show a slight upward trend (but perhaps not statistically significant). Nighttime heat waves, on the other hand, show a significant upward trend with the strongest event on record occurring in 2006 (over twice the second strongest event in 2003).

Outlier heat events during the day and night were then studied along with coincident synoptic weather patterns.

Synoptic conditions causing the most extreme heat waves are similar for daytime and nighttime events. Circulations bring air from the south and show a recent coincidence with elevated nighttime humidity levels. No clear trend in summertime humidity is observed over California, however, a strong upward trend in humidity is observed to the west of Baja California, precisely the region tapped by the heat wave circulations, making intense heat waves more humid and causing them to be expressed more strongly at night. This moisture trend coincides with a strong upward trend in Pacific sea surface temperatures (SST) west of Baja California .

The dramatic rise in minimum temperature across California (but a lesser rise in maximum temperature) is consistent with global trends. Increasing SST west of Baja California appears to be part of a global warming pattern and thermodynamic principals can explain the associated rise in humidity levels in this region. Thus, when heat wave circulations develop, they now favor the transport of hot and humid air into California and the risk for extreme nighttime heat increases. Hotter early mornings encourage higher daytime temperatures as well as longer durations and greater spatial extent.

These results imply that intense humid heat waves could become more probable than the long-term climate record would indicate. However, the specific mechanisms of the regional SST trend west of Baja California must be investigated and understood more fully to allow skillful detailed long-term projections of heat wave activity over California. Further application is possible for meteorologists wishing to project extreme events days or weeks in advance as well as for climatologists projecting seasonal likelihood of specific extremes. Advance notice of extreme events allows preparation and can limit losses. This analysis can also serve as the foundation for building a regional risk analysis on the changing character of extreme heat.

Top Fig: Nighttime heat wave magnitude, linear trend, and 99% percentile events per station (mapped). 2nd Fig: Humidity (precipitable water) composite for nighttime heat waves at and above the 99th percentile. Colors represent departure from the mean. 3rd Fig: Humidity (precipitable water) time series for Baja California and linear trend. Bottom Fig: SST and linear trend around Baja.

## **Climate Change and Business: Demystifying Science, Risk and Reward**

A partnership between UC San Diego's Rady School of Management and Scripps Oceanography  
Executive Education Course: June 6-7, 2008

Scripps Oceanography teamed with the Rady School of Management to bring nearly fifty business executives from around the nation to the UC San Diego campus to discuss the topic of climate change and its impact on the business community. The course began with lectures from several lead authors of the IPCC 2007 fourth assessment who presented the basics of climate science. Course participants then opened a line of discussion regarding the consumption of scientific material. Scientists provided participants with a methodology for business executives to evaluate the validity of scientific claims that are presented in the media. The next set of course modules focused on the communication process and effective corporate "messaging" when considering the topic of climate change. Participants studied several business cases ranging from The Weather Channel's on-air strategy to Envision Solar's uniquely designed products that blend alternative energy with architecture and corporate branding opportunities. Keynote speakers addressed environmental entrepreneurship as well as an institutional investor's view of new markets that are emerging due to climate change. A large component of the program was devoted to panel discussions on risk management and investing opportunities. Participants ranged from a senior executive with a Fortune 500 energy company to investors, investment advisors, entrepreneurs, and managers in both large and small firms. Course instructors ranged from scientists to investment analysts to CEO's and managing directors across the spectrum of alternative energy.

Given CMF II's unique participant base spanning scientists, insurance executives and catastrophe modelers, it seems that some of the observations discussed at the Scripps/Rady executive education course are not only relevant but could serve as "food for thought" in planning future CMF events.

"While there is still not a 100% certainty that greenhouse gas emissions are the main responsible for global warming, the scientific community gives it in the latest IPCC report a 90% chance, which is "statistically significant".

"Waiting until we get even more evidence is of course always an alternative.

"But it seems to us that this attitude would be, like trying to buy automobile insurance after an accident has occurred.

Dr. Andreas Hoferl,  
Chief Economist, UBS Wealth Management  
Research

UBS research focus

### **• What do I tell my executives in the boardroom or my colleagues at the water cooler??**

Course participants largely embraced the notion that human-induced climate change is not only occurring but has become or is becoming a major factor for business models and corporate strategy. Some participants, however, felt that such understanding does not prevail across their organizations. There was a call for scientists to provide simple explanations assisting business professionals who can address the common misconceptions about climate science in causal conversations with their colleagues.

### **• Scientific credibility can be enhanced by the corporate sector.**

One participant noted that his management team is inherently distrustful of scientists and "raw" scientific research which is presented in the media. It was suggested that scientific leaders who partner with business leaders to present scientific findings in a business context are more effective in "getting the message across."

### **• Changing level of scrutiny by the media?**

One speaker cautioned that he expects growing media scrutiny of "greenwashing" claims in the near future. It was suggested that the media is likely to become more critical and investigative of companies who make "green claims" but fail to implement reasonable sustainability practices.

### **• Effective Messaging**

A discussion of consumer behavior revealed that the most effective communication campaigns are those that link an outcome to an individual. It was suggested that a campaign to "save yourself" will be significantly more effective than a campaign to "save the world."

**Thomas J. Basile**  
Managing Director, The Middleberg Sustainability Group

- We are witnessing a shift in coverage. It has already started.
- The press are now expecting results.
- Greenwashing charges on the rise

**THE CONSUMER**

- Decision-making from the inside out.
- Sustainability is about choice.
- Remember the ME FACTOR

4. NATION/LARGER WORLD  
3. LOCAL COMMUNITY  
2. HOUSEHOLD  
1. CONSUMER

## Conclusion and References

### Human Induced Changes in the Hydrological Cycle of the Western U.S.

Barnett, T. P., Pierce, D. W., Hidalgo, H. H., Bonfils, C., Santer, B. D., Das, T., Bala, G., Wood, A. W., Nozawa, T., Mirin, A. A., Cayan, D. R., and Dettinger, M. D., 2008: Human-Induced Changes in the Hydrology of the Western United States Science, published online 31 Jan 2008, doi:10.1126/science.1152538.

<http://www.sciencemag.org/cgi/rapidpdf/1152538?ijkey=P8RkK7hb9o3vM&keytype=ref&siteid=sci>

When observed natural phenomena such as precipitation cycles, atmospheric cycles, and solar/volcanic cycles are used as forcing mechanisms, a downscaled climate model does not replicate observed changes to the hydrological system across the western U.S. When anthropogenic forcing is applied, the model replicates observations within a 95% confidence interval. The results imply that declines in “water storage” are not likely to reverse even when considering natural variability in jet stream positioning that leads to cycles in precipitation patterns.

### When Will Lake Mead Go Dry?

Barnett, T. P. and Pierce, D. W., 2008: When will Lake Mead run dry? J. Water Resources Research, in press.

[http://meteora.ucsd.edu/~pierce/papers/Barnett\\_Pierce\\_2008\\_JWRR\\_Lake\\_Mead.pdf](http://meteora.ucsd.edu/~pierce/papers/Barnett_Pierce_2008_JWRR_Lake_Mead.pdf)

*“A water budget analysis shows that under current conditions there is a 10% chance live storage in Lakes Mead and Powell will be gone by about 2013 and a 50% chance it will be gone by 2021 if no changes in water allocation from the Colorado River system are made.”*

### California Heatwaves: The Baja Connection

Alexander Gershunov and Dan Cayan, in progress.

Results from a study of daytime and nighttime heat waves in California imply that nighttime heat waves could become more probable than the long-term climate record would indicate. Nighttime heat waves are typically coincident with increased levels of humidity which increases stress on the both the human body and the electrical grid. The source of rising humidity appears to be linked to an increase in sea surface temperature near the Baja of California. These observations can form the basis for weather forecasters to predict such events. Advance notice of extreme events allows preparation and can limit losses. This analysis also can serve as the foundation for building a regional risk analysis on the changing character of extreme heat.

### Climate Change and Business: Demystifying Science Risk and Reward

UC San Diego Rady School of Management in partnership with Scripps Institution of Oceanography

<http://www.rady.ucsd.edu/exec/open/climate-change/>

Selected course content will post this summer.

Scripps recently launched a new initiative with the goal of forging direct connections between the research community and the business sector. The "Office of Business Development" at Scripps has three primary initiatives: (1) Executive Education focused on the link from weather, climate, and natural hazards to business; (2) Research partnerships (including SPHEAR); and (3) Scripps innovation and new venture creation. As part of this initiative, Scripps Oceanography partnered with the Rady School of Management to present this two day executive education course. Climate change has become a central variable in much of the business community. Senior executives, entrepreneurs and investors are beginning to review the risk/reward metrics in a new market focusing on adapting to and mitigating the effects of climate change as well as the challenges in the energy complex. Beyond this, however, mid-level executives are seeking (or being placed into) positions where they influence corporate policy regarding sustainability and climate change initiatives. Educational content for these professionals allows a valuable discourse between the business and scientific communities.



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**Scripps Partnership for Hazards and Environmental Applied Research**

*The Scripps Partnership for Hazards and Applied Environmental Research, SPHEAR, is a global consortium geared to serve those in the private sector who link financial risk to weather, climate and natural catastrophes. SPHEAR's mission is to bring corporate partners face-to-face with thought-leaders across the research community in order to develop applications for weather forecasters, risk managers, investors, and insurers.*