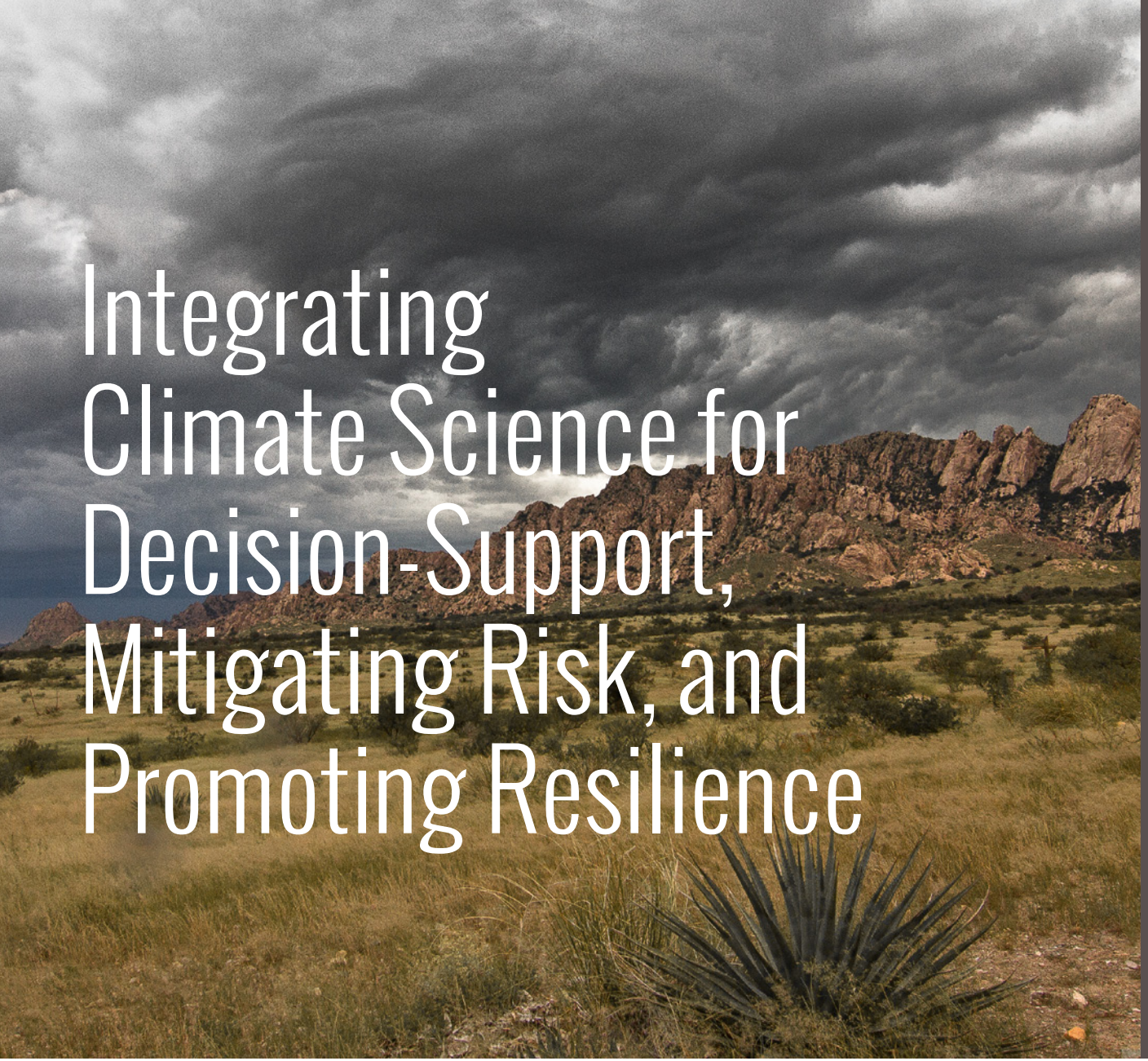

# Integrating Climate Science for Decision-Support, Mitigating Risk, and Promoting Resilience

2007-2013

**Climate Assessment for the Southwest**

PHASE III FINAL REPORT

CLIMAS

Climate Assessment for the Southwest

SKY JACOBS

# Contents




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**More Information:**
Daniel Ferguson
CLIMAS Program Director
dferg@email.arizona.edu
(520) 622-8918


climas.arizona.edu

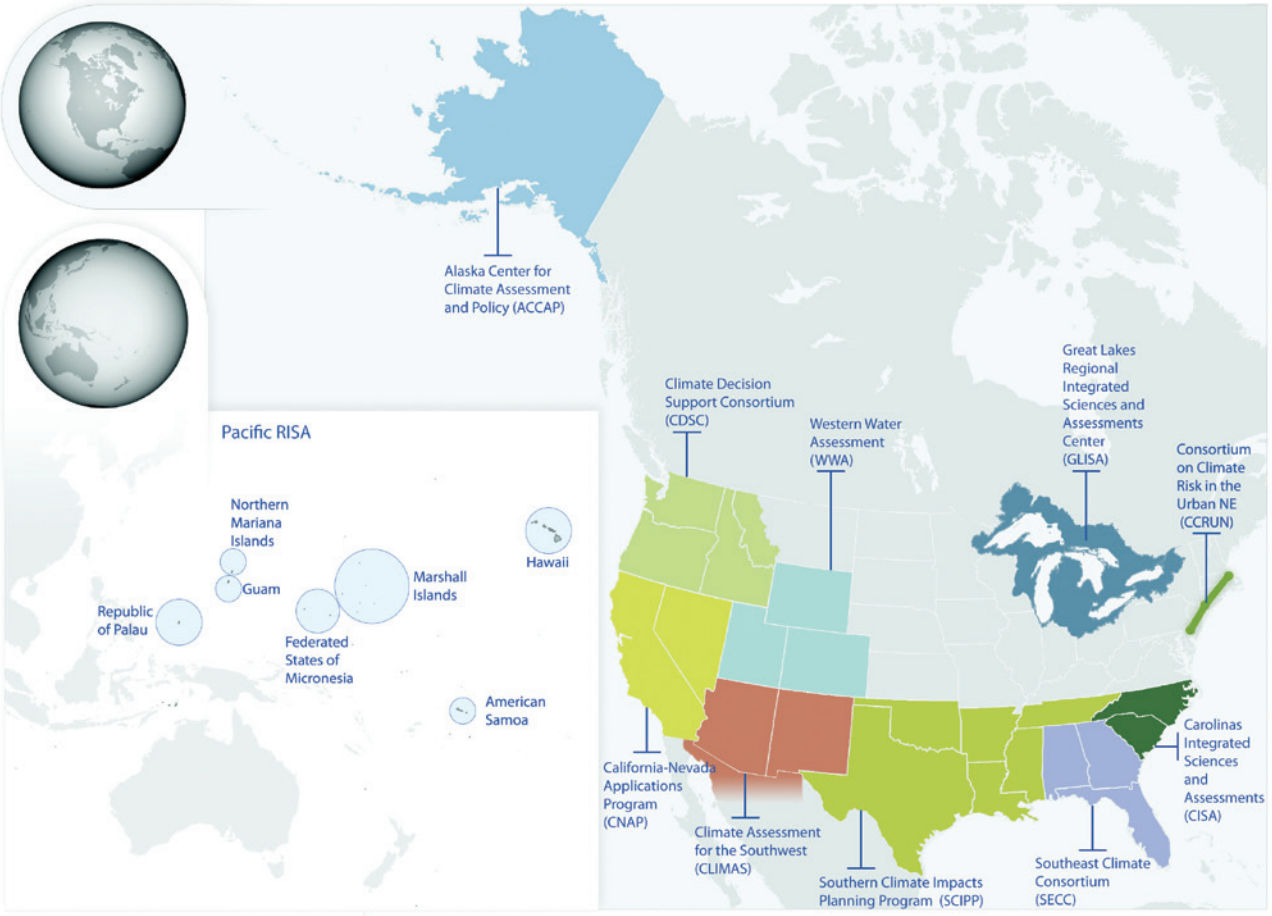
COVER: Monsoon storm clouds swirl around the Dragoon mountains near Cochise Arizona in September, 2013.

PHOTO CREDIT: ZACK GUIDO

# RISA

**A REGIONAL APPROACH TO CLIMATE SERVICES: REGIONALLY INTEGRATED SCIENCES AND ASSESSMENTS (RISA)**

In the mid-1990s, the National Oceanic and Atmospheric Administration (NOAA) created the Regional Integrated Sciences and Assessments (RISA) program to support research that addresses complex climate-sensitive issues of concern to decision makers and planners at a regional level. The number of these regional teams has grown over the last 15 years as the need for climate information in support of decision making has also increased. As of November 2013, 11 RISA teams are funded, covering much of the United States and U.S. territories in the Pacific.



# Climate Assessment for the Southwest (CLIMAS)

**CLIMAS, established in 1998, is the RISA program in the Southwest.** The CLIMAS mission is to improve the Southwest region's ability to respond sufficiently and appropriately to climatic events and changes. This report highlights some of the CLIMAS team's achievements during the phase III funding cycle, which lasted from Spring 2007 through Spring 2013.

The overarching theme for the CLIMAS program during this time period was "Integrating Climate Science for Decision-Support, Mitigating Risk, and Promoting Resilience." Projects focused on: **(a)** integrating decision-support tools for climate information delivery, forecast evaluation, and assessment of societal vulnerabilities to climate, **(b)** assessing and quantifying water and growth-related risk and resilience in the energy sector, irrigated agriculture, U.S. border cities, Native American communities, and critical watersheds, **(c)** understanding climate variability and change, including spatial variability, paleohydrology, drought, floods, and their impacts, **(d)** furthering knowledge about climate-related diseases and public health, and **(e)** enhancing means for communicating climate information and knowledge.

The following report summarizes some of the accomplishments CLIMAS has made in each of these areas.

**BACK ROW** M. Wilder, H. Hartmann, G. Frisvold, J. Overpeck, B. Colby, D. Ferguson, T. Brown
**FRONT ROW** D. Liverman, Z. Guido, G. Garfin, C. Woodhouse, K. Hirschboeck, A. Comrie, M. Crimmins, G. Owen

**NOT PICTURED** D. DuBois, J. Galayda

## Current CLIMAS Team

**PRINCIPAL INVESTIGATORS**
Bonnie Colby, Andrew Comrie, Michael Crimmins, David DuBois, Daniel Ferguson, George Frisvold, Gregg Garfin, Jonathan Overpeck, Margaret Wilder, Connie Woodhouse

**STAFF RESEARCHERS**
Jaimie Galayda, Zack Guido, Gigi Owen

**AFFILIATE MEMBERS**
Heidi Brown, Timothy Brown, Julia Cole, Diana Liverman, Alison Meadow, Kiyomi Morino

**POST DOCTORAL RESEARCHERS**
Cory Morin, Jeremy Weiss

**GRADUATE RESEARCH ASSISTANTS**
Mindy Butterworth, Gouro Camara, Jessica Conroy, Todd Gaston, Gan Jin, Saeahm Kim, Ron Klawitter, Brewster Malevich, Tatiana Marquez, Zeyn Mirza, Cody Routson, Xuan Vu

## Former CLIMAS Team

MEMBERS 2007-2013

**PRINCIPAL INVESTIGATORS**
Timothy Finan, Holly Hartmann, Katherine Hirschboeck, Rolston St. Hilaire

**POST-DOCTORATE RESEARCHERS**
Alison Meadow, Jennifer Rice, Julie Brugger, Adrian Quijada-Máscareñas

**GRADUATE RESEARCH ASSISTANTS**
Deepti Akula, Salman Al-Kohafi, Donald Anderson, Gaurav Arora, Rosalind Bark, Luis Barros, Rachel Beaty, Laurel Bellante de Escalante, Erica Bigio, Bhagyam Chandrasekharan, Shailaja Deva, Pavan Dhanireddy, Rolando Díaz, Kyle Emerick, Jeannette Estes, Holly Faulstich, Brett Fleck, Miriam Gay-Antaki, Christina Greene, Daniel Griffin, Eric Holthaus, Casey Kahn-Thornbrugh, Sarah Kelly, Fan Li, Melissa Mauzy, Stephanie McAfee, Jonathan McLeod, Matthew Mealy, Cory Morin, Fenbiao Ni, Kate Sammler, Jeremy Slack, Brintha Subramaniam, Peter Taber, James Tamerius, Sarah Truebe, Erika Wise, Fei Yi, Diana Zamora-Reyes

# Stakeholders & Partners

CLIMAS researchers have delivered information to, collaborated with, and partnered with several types of stakeholder groups between 2007-2013. The following data represent a snapshot of the diversity of these stakeholders.

**601** STAKEHOLDER PRACTITIONER RESEARCHER INTERACTIONS

| | |
|---|---|
| Presentations given to stakeholders/practitioners | 244 |
| Presentations given to academia/researchers | 144 |
| Workshops and Trainings facilitated | 81 |
| Publications of Southwest Climate Outlook | 64 |
| Interviews with media conducted | 31 |
| Online briefings, webinars, and podcasts facilitated | 26 |
| Participation in Working Groups and Advisory Boards | 10 |
| Videos filmed and edited | 1 |

## TYPES OF ORGANIZATIONS

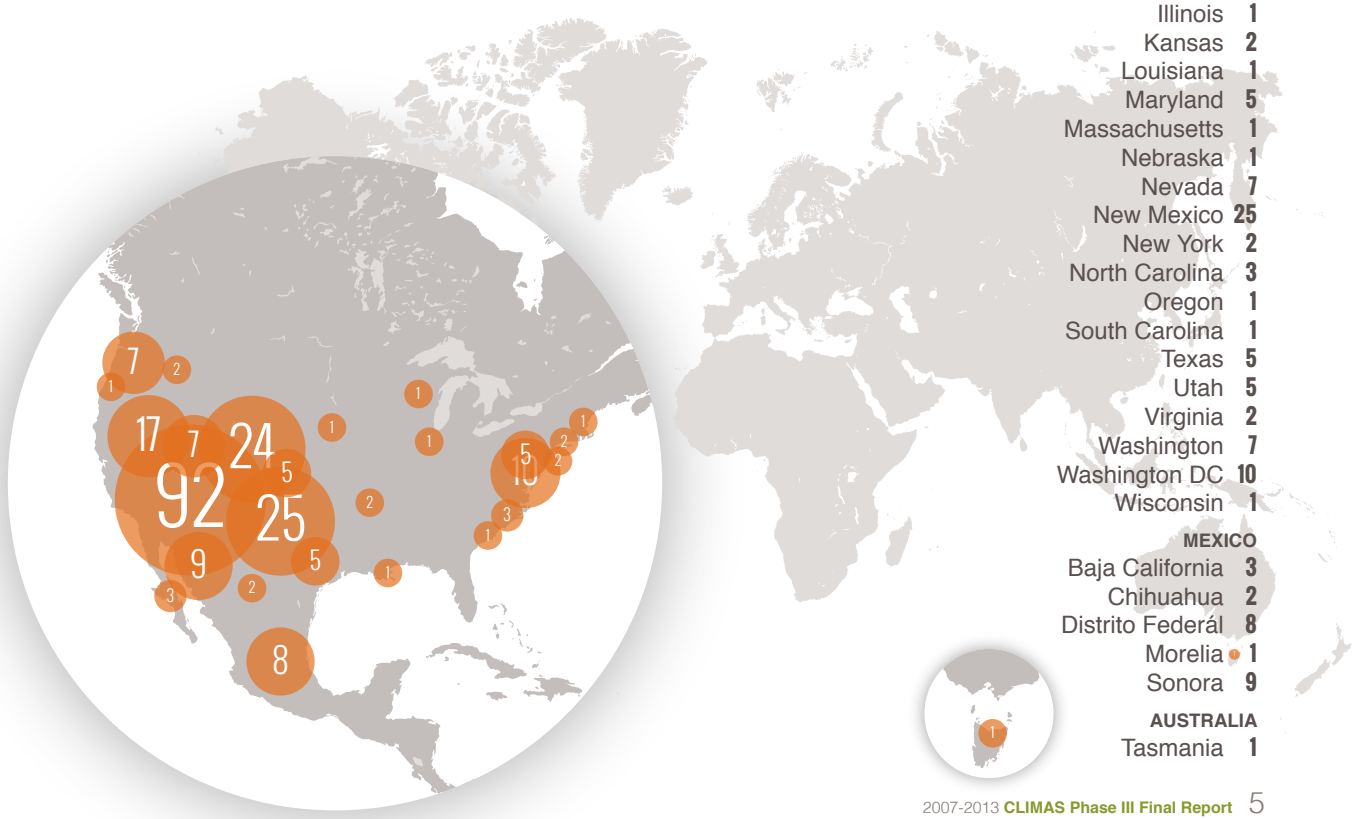
NON-GOVERNMENT

- Academic/Research Institution **58**
- Business **14**
- Non-Profit Organization **57**

GOVERNMENT AGENCIES

- City **17**
- County **7**
- Federal **56**
- State **29**
- Tribal **6**

**272** ORGANIZATIONS IN 14 SECTORS SERVED


**LOCATIONS AROUND THE WORLD 239**

**UNITED STATES**

| | |
|---|---|
| Arizona | 92 |
| California | 17 |
| Colorado | 24 |
| Idaho | 2 |
| Illinois | 1 |
| Kansas | 2 |
| Louisiana | 1 |
| Maryland | 5 |
| Massachusetts | 1 |
| Nebraska | 1 |
| Nevada | 7 |
| New Mexico | 25 |
| New York | 2 |
| North Carolina | 3 |
| Oregon | 1 |
| South Carolina | 1 |
| Texas | 5 |
| Utah | 5 |
| Virginia | 2 |
| Washington | 7 |
| Washington DC | 10 |
| Wisconsin | 1 |

**MEXICO**

| | |
|---|---|
| Baja California | 3 |
| Chihuahua | 2 |
| Distrito Federál | 8 |
| Morelia | 1 |
| Sonora | 9 |

**AUSTRALIA**

| | |
|---|---|
| Tasmania | 1 |

# Areas of Focus

The following report shows the evolution of selected CLIMAS research and outreach projects in each of the following areas.








GREGG GARFIN

# Adaptation & Vulnerability

## Adaptation Strategies for Water, Energy, and Environmental Sectors in the Southwest

**CLIMAS Investigators:** B. Colby, G. Frisvold, H. Hartmann, B. Fleck, & R. Klawitter

**Other Collaborators:** E. Schuster & A. Kerna (University of Arizona-Agricultural and Resource Economics); Sonoran Institute; Western Water Assessment; U.S. Bureau of Reclamation; U.S. Department of Agriculture

**Partners:** Arizona Department of Water Resources, Central Arizona Project, Salt River Project, Arizona Electric Power Cooperative, Arizona Public Service Corporation, Nature Conservancy-Western Regional Office, Environmental Defense, Sonoran Institute, ProNatura, Western Resource Advocates

**Leveraged Funding:** NOAA-Sectoral Applications Research Program; University of Arizona-Office of Arid Lands Studies; U.S. Bureau of Reclamation; Walton Family Foundation; Sonoran Institute

This project has helped alert electric utilities and water supply organizations throughout the Southwest to the impacts of climate change on peak electricity and water demand during hot, dry summers in the Southwest. Electric power contracts tend to be long term and inflexible, but persistent drought and climate change affect energy and water management operations and policy. Water and power costs are likely to increase, leading to increased financial stress for households and businesses as well as reductions in the amount of water available for environmental purposes.

Research began in 2008 by investigating the influence of drought on the market price of water by using an econometric analysis of water transaction and climate data from 1987-2008. The research team produced several tools and guidebooks aimed to enhance water supply reliability and to help agencies manage higher water demands and competing water needs. Researchers found that incorporating climate information can significantly reduce forecast error in electricity load forecasts by improving model performance in estimating the economic value of water across wet and dry climate cycles. Peak season electricity loads are highly sensitive to moderate increases in summer temperatures, which can have a huge impact in arid regions such as the Southwest.

**BOTTOM LINE**

Electric utilities need to prepare to meet an increased demand during the peak warm seasons. Water providers must prepare for increased year-to-year and decadal variability in water supplies. Agencies responsible for securing water for environmental needs must plan their budgets accordingly and negotiate with other water demands to secure their water needs. This research team helped develop new techniques for predicting and adapting to climate impacts in the urban water supply, environmental water supply, and electric utility sectors.

## Sky Island Climate Adaptation

**CLIMAS Investigators:** G. Garfin & Z. Guido

**Other Collaborators:** L. Misztal, J. Neeley, & M. Emerson (Sky Island Alliance); L. Hansen, R. Gregg, A. Score, & J. Hitt (EcoAdapt); L. Fisher, K. Caringer, G. Brooks, & M. McCaffrey (U.S. Institute for Environmental Conflict); R. Mesta (Sonoran Joint Venture); C. Conway & C. Hutchinson (University of Arizona); M. Falk (Fish and Wildlife Service); L. Meyers & C. Vojta (Desert Landscape Conservation Cooperative)

The Sky Island Alliance, a non-profit environmental organization in Tucson, AZ, contacted Garfin in 2010 for assistance in connecting planners and thinkers in natural resource management and conservation with experts on regional climate change impacts and adaptation. CLIMAS researchers helped design an online climate change

adaptation survey and helped organize a climate change adaptation workshop. Workshop participants noted that megadrought could be a game-changer for Southwest ecosystems, due to its potential to push ecosystems into new quasi-equilibrium states, such as from pine-oak forests to oak scrub woodlands. A new project emerged from the workshop called the Spring and Seep Inventory, Assessment, and Management Planning Project, to develop new information on the current biological, hydrological, geomorphological, and management status of springs and seeps. The project is being implemented by Sky Island Alliance in coordination with several regional resource managers, including Pima County, the U.S. Forest Service, and the National Park Service.

**BOTTOM LINE**

CLIMAS is a recognized source to help connect other organizations to stakeholders in the Southwest who are interested in climate change adaptation.

# Climate Change Analysis for the City of Tucson

**CLIMAS Investigators:** G. Garfin, G. Frisvold, A. Comrie, B. Colby, & J. Weiss

**Other Collaborators:** T. Kong & D. Garcia (University of Arizona-School of Natural Resources and the Environment); C. Carrillo (University of Arizona-Department of Atmospheric Sciences); Cascadia Consulting Group, Inc.

**Partners:** L. Ethen & J. Brown (City of Tucson-Office of Conservation and Sustainable Development); City of Tucson Climate Change Committee

**Leveraged Funding Sources:** City of Tucson

Beginning in 2011, CLIMAS investigators assisted the City of Tucson and its contractors in a vulnerability assessment for the community regarding anticipated climate change impacts. The city wanted to know the best estimates of projections of future climate and hydrology of the Tucson basin and Colorado River surface water supplies. Based on the SRES A2 emissions scenario, researchers found the following projected changes between the late 20th and mid 21st centuries: 1) Maximum temperatures above the user-defined threshold of 100 degrees F will increase by an average of ~42 days per year; this is likely to affect public health (heat stress), water, and electricity demand. 2) Extreme high precipitation (precipitation greater than 0.5 in/day and precipitation greater than 1.0 in/day), which is a concern for floodplain managers, increased slightly but not outside the average of the historic range. 3) Precipitation with a return period of 100 years is projected to occur twice as frequently. The research team produced climate and society risk maps for the City of Tucson, which overlaid neighborhood-level socioeconomic status with extreme temperature and flood risks. These maps will aid the city's climate change committee in their future development and prioritization of adaptation strategies.

**BOTTOM LINE**

CLIMAS research findings were incorporated into the City of Tucson's vulnerability assessment, which was used to design the city's plans for future development. CLIMAS researchers are sought out for their expertise in climate science and climate adaptation planning.

# Adaptation and Resilience to Climate Change, Drought, and Water Demand in the Urbanizing Southwestern United States and Northern Mexico

**CLIMAS Investigators:** M. Wilder, G. Garfin, G. Frisvold, & J. Slack

**Other collaborators:** R. Diaz (University of Arizona)

**Partners:** National Center for Atmospheric Research, El Colegio de Sonora, Universidad de Sonora, NOAA Sectoral Applications Research Program, NOAA Earth Systems Research Laboratory

Adaptation to climate change across national borders will become increasingly important as shared water supplies are affected by climate change. The U.S.-Mexico border is one of the most significant border regions in the world, linked by biophysical (e.g., climate, water) and socioeconomic (e.g., commerce, tourism, industry, culture) interdependencies.

In 2008, Garfin and Wilder began a project that targeted four urban hotspots for climate change and water supply vulnerability in the US-Mexico border region. Researchers worked to build adaptive capacity for water management in the transboundary region; to understand the role of climate information within governance networks; to develop innovations in communicating climate science; and to develop of a set of metrics for assessing adaptive capacity in arid and border regions.

This project targeted four rapidly urbanizing hotspots within the region: Tucson, AZ; the twin border cities of Nogales, AZ and Nogales, Sonora; Hermosillo, the capital of Sonora; and the area surrounding the coastal resort town of Puerto Peñasco, Sonora.

Between 2008 and 2010, the team held 5 major workshops with 350 stakeholders engaged in defining regional climate-related vulnerabilities and prioritizing adaptation activities. A team of multidisciplinary authors recently completed four urban water resources and climate case studies focused on prioritizing vulnerabilities and identifying adaptation strategies for the binational region.

The periodically published Border Climate Summary (Resumen del Clima de la Frontera) featured up-to-date climate information for the Arizona-Sonora region, including information on the North American monsoon, regional drought, and cyclone activity. Published in Spanish and English, the Border Climate Summary invited stakeholders to provide articles and information to encourage more discussion about climate and climate impacts in the border region.

**BOTTOM LINE**

By leveraging related research projects housed at CLIMAS and the Udall Center for Studies in Public Policy at the University of Arizona, this research team set a new standard for integrated assessment in a binational and bicultural context in the Arizona-Sonora urban corridor.

USGS

# Climate Science

## Hydroclimatology and Paleohydrology for Decision Support

**CLIMAS Investigators:** K. Hirschboeck, H. Hartmann, G. Garfin, A. Coles, & K. Sammler

**Other Collaborators:** M. Garcia, A. Coles, J. Culp & N. Henderson (University of Arizona); J. Kiang & N. Paretti (U.S. Geological Survey); B. Cosson (Arizona Department of Water Resources); N. Steinberger (Federal Emergency Management Agency)

**Partners:** Tucson NWS, Pima County Flood Control, U.S. Geological Survey, Environmental Protection Agency

**Leveraged Funding Sources:** USGS Arizona Science Center; NSF-Southern Arizona Geosciences Union for Academics, Research, and Outreach (SAGUARO) Flood

This project began in 2007 with the development of an online Flood Hydroclimatology Database, linking climate, floods, and paleofloods to provide a climatic perspective on the causes and variability of past extreme flood events and their probability of occurrence under different types of atmospheric circulation patterns. The research team explored ways to address risk and resilience related to hydroclimatic extremes in both the upper and lower tails of streamflow probability distributions.

In 2010, researchers determined the flood recurrence intervals for individual components of mixed flood populations (floods produced by different kinds of storms) for several streams in Arizona. Mixed population analysis was used to make realistic, probability-based projections of future flooding in Arizona under different scenarios of climate change.

The team also explored “pineapple express/atmospheric river” (PE-AR) storms that produce nearly all major winter floods in California. Using their flood hydroclimatology database, researchers found that these storms were only one of several types of winter storms that led to flooding in Arizona and that there were large geographic differences in their importance. PE-ARs were responsible for more floods in central and northern Arizona than in southern Arizona, especially in the relatively small watershed that drains the Mogollon Rim.

**BOTTOM LINE**

A distinct regionality of climate-sensitive flood behavior exists in Arizona, which can improve flood frequency estimates in different watersheds. Temporal variations in the heterogeneity of flood-causing weather and climate mechanisms (e.g., atmospheric rivers, summer convective versus winter storms) can be used in scenario planning to address future flood hazards due to climate change.

# Patterns and Causes of Southwest Drought Variability

**CLIMAS Investigators:** J. Overpeck, C. Woodhouse, J. Conroy, C. Routson, & J. Weiss

**Other Collaborators:** T. Ault (National Center for Atmospheric Research); B. Udall (Western Water Assessment); J. Cole & D. Meko (University of Arizona)

**Partners:** Intergovernmental Panel on Climate Change, U.S. Bureau of Reclamation, U.S. Department of Defense, Tucson Water, federal and state judges Leveraged Funding Sources: NOAA Climate Change Data and Detection (C2D2), National Science Foundation, Department of Defense

Droughts are one of the major concerns for the future of the Southwest, and yet the causes of drought in the region remain only partly understood. The situation is particularly acute when it comes to the decades-long megadroughts observed in the paleoclimatic record of the Southwest, and in the growing awareness that global warming is making droughts of the Southwest more intense. State-of-the-art climate models (like those used by the IPCC) likely underestimate future drought risk.

A 2200-year long tree-ring record from southern Colorado suggests that medieval period megadroughts, which are well-documented in a number of different paleoclimatic records, are not unique. A megadrought in the 2nd century likely matched the severity of medieval droughts in the Southwest, and may have had similar causes. Researchers found that the frequency, severity and duration of decadal megadroughts are influenced by variations in both the North Atlantic and tropical Pacific sea surface temperature. Additionally, the ongoing drought in the Southwest has had unprecedented impacts primarily because of temperature increases and greater drought in the pre-monsoon season.

**BOTTOM LINE**

The project has shed new light on the observations of current and past drought, as well as the causes and impacts of these droughts, including the role of ENSO versus Atlantic sea surface temperatures in modulating drought, the exact nature of medieval megadroughts in the Four Corners, the ecological impacts of drought, the evaluation of how well climate models simulate drought, and strategies for overcoming climate model deficiencies in assessing future drought.

# Reconciling Projections of Future Colorado River Streamflow

**CLIMAS Investigators:** J. Overpeck, H. Hartmann, & K. Morino

**Other Collaborators:** J. Vano & D. Lettenmaier (University of Washington); B. Udall (Western Water Assessment); D. Cayan, T. Das, & H. Hidalgo (California Nevada Applications Project); L. Brekke (U.S. Bureau of Reclamation); M. Hoerling & R. Webb (NOAA Earth Systems Research Laboratory); G. McCabe (U.S. Geological Survey); K. Werner (Colorado Basin River Forecast Center)

Several recent studies estimate that the future streamflow of the Colorado River will decline due to drought and climate change. However, estimates from these projections range from less than 10% to a 45% decline by 2050. This cross-RISA research team explored why this large range exists and suggested ways that scientists and other stakeholders could apply these projections for future research and adaptation efforts.

Although the projections show drastically different amounts of streamflow reduction, it is still evident across all studies that Colorado River streamflow will be reduced due to climate change. Additionally, current reconstructions of the worst possible drought for the Colorado River are underestimates of the severity and duration of drought that has occurred, and that could occur, in the Colorado River Basin.

**BOTTOM LINE**

Cross RISA program collaborations provide useful answers to research questions that exist on a larger geographical scope than the individual RISA regions.

# Communicating Science

## CLIMAS Contributions to the U.S. National Climate Assessment

***Assessment of Climate Change in the Southwest United States:* A Report Prepared for the National Climate Assessment**

**CLIMAS Investigators:** G. Garfin, A. Comrie, M. Crimmins, D. Ferguson, G. Frisvold, H. Hartmann, J. Overpeck, M. Wilder, J. Galayda, A. Jardine, C. Greene, & D. Liverman

This 20-chapter assessment provided a snapshot of the current state of climate change information and knowledge related to the region. Because the report was intended to be relevant to public policy and resource management decisions, stakeholders were actively engaged in defining the scope of this report and in reviewing the document. This assessment gathered contributions from more than 100 authors, an effort led and organized by Garfin.

The assessment examined the implications of climate and climate change for the health and wellbeing of human populations and the environment throughout the southwestern United States, an area of about 700,000 square miles. The region includes Arizona, California, Colorado, Nevada, New Mexico, and Utah, vast stretches of coastline, an international border, and the jurisdictions of 182 federally recognized Native American tribes.

### SELECTED RESULTS

»Snowpack and streamflow amounts are projected to decline, decreasing water supply for cities, agriculture, and ecosystems. »The Southwest produces more than half of the nation's high-value specialty crops, which are irrigation dependent and particularly vulnerable to extremes of moisture, cold, and heat. »Reduced yields from increased temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.

### BOTTOM LINE

CLIMAS researchers were well suited to lead and contribute to the Southwest Climate Assessment, due to their nationally recognized expertise in regional climate science, adaptation, and climate impacts.

## Southwest Climate Outlook

**CLIMAS Investigators:** Z. Guido, G. Garfin, M. Crimmins, G. Owen, & J. Swetish

**Other Collaborators:** N. Selover (Arizona State Climatologist); S. Doster (University of Arizona)

The Southwest Climate Outlook (SWCO) is a monthly e-publication that synthesizes and interprets recent climate and weather conditions in the Southwest, including forecasts based on data and products issued by disparate, credible sources. Currently SWCO provides more than 1,700 people with timely, climate-related information. SWCO began in 2002, stemming from the END InSight project, and has evolved into a tool for communication with stakeholders and a platform for responding to needs throughout the region. Since August 2007, CLIMAS has produced 64 issues of the Outlook. CLIMAS continues to refine the Outlook based on user-needs and changing technology. In 2012, Guido and Swetish began producing online videos that briefly outlined each month's climate summary.

The most popular feature articles since 2007 include: "Phenology, citizen science, and Dave Bertelsen" from August 2008; "Climate Data: the ins and outs of where to find what" (parts 1, 2, & 3 from 2009); and "Coping with Drought on the Rio Grande" from August 2012, which had an additional video component (http://vimeo.com/48612070).

**BOTTOM LINE**
The Southwest Climate Outlook has played an important role in connecting CLIMAS researchers with people who live in the Southwest. SWCO is often the first regular interaction people have with CLIMAS and has become a valuable monthly climate product in the region.

## Online Briefings and Podcasts

**CLIMAS Investigators:** G. Garfin, M. Crimmins, & Z. Guido

**Partners:** NOAA National Weather Service forecast offices (Las Vegas, Flagstaff, Phoenix, Tucson, Albuquerque, El Paso); NOAA Colorado Basin River Forecast Center

Since Fall 2006, CLIMAS has provided online, interactive seasonal climate briefings and podcasts for the Southwest and northern Mexico. The briefings have provided an interactive supplement to the monthly Southwest Climate Outlook, including an up-to-date summary of seasonal hydroclimate conditions and forecasts. Stakeholders can ask questions about climate information and receive answers immediately. In 2008 and 2009, regional National Weather Service offices became active partners in the briefings, presenting analyses of recent conditions and forecasts. These briefings also generated news articles in local newspapers and radio shows.

**BOTTOM LINE**
Interactive online briefings and podcasts complemented climate and weather issues raised in the monthly Southwest Climate Outlook. Information discussed was timely, relevant, and based on current climatic issues in the region.

WING-CHI POON

# Decision Support

## Climate Change Projections and Scenarios for the Southwest

**CLIMAS Investigators:** H. Hartmann, G. Garfin, J. Overpeck, K. Hirschboeck, K. Morino, & J. Estes

**Other Collaborators:** L. Moriniere, K. Waser, & M. Crescioni-Benetiz (University of Arizona)

**Partners:** National Park Service, Carpe Diem West, Wildlife Conservation Society, Leadership Management International Inc.

**Leveraged Funding Sources:** National Park Service

A workshop on scenario planning that took place in Joshua Tree National Park in 2007 turned into a long-term collaboration to demonstrate a practical process for using scenario planning to consider climate change in the context of multiple stressors. This research team helped the National Park Service develop scenarios to incorporate climate change, uncertainty, and non-stationarity into their planning efforts. The approach has been adapted and is currently being used within the agency. Additionally researchers developed a comprehensive curriculum for improving climate change literacy in the agency.

From this process, researchers learned that 1) a combination of potential future climate/environment senarios plus discussion support is needed to move beyond “uncertainty paralysis”; and 2) leading-edge, early adopter stakeholders have embraced uncertainty as a platform for discussion and exploration of future climate change scenarios, research needs, monitoring needs, and communication with their publics.

**BOTTOM LINE**
Government agencies and other organizations need new ways to think about and plan for uncertain futures. CLIMAS has helped innovate new methods and approaches that organizations can use in their efforts to plan for a wide range of possible climatic changes.

## TreeFlow

**CLIMAS Investigators:** C. Woodhouse, K. Hirschboeck, H. Hartmann, D. Griffin, & K. Morino

**Other Collaborators:** J. Lukas (Western Water Assessment); J. Littell (Uniersity of Washington)

**Partners:** Salt River Project

**Leveraged Funding Source:** NIDIS Coping with Drought 2009-10

TreeFlow is a Web-based information source for water resource managers. It was developed in collaboration with water resource managers to make data and information on reconstructions of streamflow accessible, understandable, and useful for placing the record of gauged hydrology in a long-term context. The paleotool component of TreeFlow, under development since 2008, was completed in 2012, after being tested by several water resource managers.

Paleohydrologic information collected from tree rings has become a valuable tool for drought planning and water resources management. This project has expanded the usefulness of tree rings to include a broader range of water providers and resource managers. The website includes pages for accessing, evaluating, and downloading reconstructions of streamflow for a number of western river basins and contains examples of applications to water resource management.

**BOTTOM LINE**
TreeFlow blends results of scientific research and applications of science to resource management. It is designed to continually expand as new reconstructions and applications are developed. Feedback indicates that it is useful for both scientists and resource managers.


USGS

# Drought

## Tribal Drought Information for Monitoring, Assessment, and Planning (Tribal DrI-Map)

**CLIMAS Investigators:** D. Ferguson, M. Crimmins, C. Woodhouse, A. Meadow, H. Faulstich, A. Kimbrough, & L. Barros

**Other Collaborators:** S. Marsh, W. Van Leeuwen, & B. Orr (University of Arizona, Arizona Remote Sensing Center)

**Partners:** Hopi Department of Natural Resources, Navajo Nation Department of Water Resources, Colorado Basin River Forecast Center, & Bureau of Reclamation

**Leveraged Funding Sources:** NOAA-Sectoral Applications Research Program; NASA Space Grant; National Science Foundation

The Hopi Tribe and Navajo Nation have experienced widespread and persistent drought conditions for more than a decade, due to mounting deficits in the winter and summer precipitation seasons. Drought has impacted vegetation and local water resources in ways that threaten agricultural systems and ecosystems that are critical to supporting the Hopi and Navajo people. Limited hydroclimatological and ecological monitoring across the region has made it difficult to assess current drought impacts and anticipate future impacts.

Ferguson and Crimmins began to work with Hopi colleagues in 2009 to help them devise a comprehensive drought monitoring strategy that incorporated both traditional hydroclimatic drought indicators as well as locally-gathered drought impacts information. In response to a request from the Navajo Nation Water Management Branch, the research team, led by Crimmins, also provided a technical review of the drought monitoring component of the Navajo Nation's Drought Contingency Plan.

As part of this project, Faulstich and Woodhouse developed a collection of 15 tree-ring chronologies to

reconstruct climate history for the Four Corners region, framing the ongoing 21st century drought in the context of the past four decades. The instrumental record did not adequately represent the full range of natural climatic variability possible on tribal lands, meaning that pre-instrumental drought events have far exceeded anything witnessed in the region in the modern era. Droughts characterized by winter precipitation deficits followed by a failed monsoon can have devastating consequences in the Four Corners.

**BOTTOM LINE**

Understanding current drought conditions in their historical and current sociological contexts can lead to new approaches for monitoring, planning, and adaptation.

ARDETH BARNHART

# Economics & Livelihoods

## Climate Change Mitigation Strategies and Policies

**CLIMAS Investigators:** G. Frisvold

**Other Collaborators:** L. Li & B. Subramanium (University of Arizona)

**Partners:** Tucson Water; Navajo Nation; American Farmland Trust; Arizona Research Institute for Solar Energy; University of Arizona Eller School of Management; Cotton Incorporated; New Mexico State University; Western Water Assessment

**Leveraged Funding Sources:** American Farmland Trust; Cotton Incorporated

Frisvold and his research team compared and contrasted state energy and climate mitigation policies using a multivariate regression analysis. They examined the economic feasibility and resource constraints facing carbon emission-reduction strategies in the U.S. Southwest. This research began in 2009 and was guided by stakeholder interaction. The initial dissemination of information stimulated more demand for outreach presentations and additional analysis. Stakeholders proved vital in helping clarify the research questions, and in identifying new questions and outreach needs.

Additional water requirements needed to meet Arizona's Renewable Energy Standard by 2025 using concentrated thermal solar power amounted to 0.65% of the state's consumptive use. Average water use per MWh of electricity for solar facilities is lower than water used for existing coal or nuclear plants. Solar facilities can use considerably less water per acre than other commercial uses of land such as commercial real estate development or agriculture. An analysis of the economic efficiency of an initial prototype solar desalination system shows that if users were only required to pay to recover the operation,

maintenance, and replacement (OM&R) of the prototype system, the costs would range from $1.97 - $2.07 per 100 gallons depending on the brine disposal method. Estimated OM&R costs per 100 gallons for the prototype were lower than rates paid by water haulers in the region. If Arizona met its 2030 15% renewable electricity portfolio standard using combinations of photo voltaic and solar thermal generation, water requirements would be less than 0.25% of current use.

Research results from this project were timely and readily understandable to general audiences and were distributed widely, including press coverage in newspapers and also on various stakeholder groups' websites. Interest and positive feedback from stakeholders allowed for additional grant support from the USDA, Department of the Interior, and farm groups.

**BOTTOM LINE**

CLIMAS has been investigating solar energy as a mitigation strategy in the Southwest. Contrary to popular belief, solar thermal electricity production would not place a significant burden on the Southwest's water or land resources.

# Sectoral Impacts of Drought and Climate Change

**CLIMAS Investigators:** G. Frisvold & X. Ma

**Other Collaborators:** K. Konyar (California State University San Bernardino Department of Economics); S. Ponnaluru (Washington State University School of Economic Sciences Impact Center); S. Hecht (University of California Los Angeles School of Law)

**Partners:** National Parks Conservation Association

This project answers several questions regarding the economic impacts of drought and climate change on agriculture, outdoor recreation, and tourism. Using a multi-commodity, multi-region agricultural sector model to assess the impacts of water supply reductions on water price increases on Southwest agriculture, researchers found that weather variables are important predictors of crop abandonment, but that irrigation significantly reduces abandonment risk. In Arizona, cold and excess moisture are main sources of crop losses. In both Arizona and New Mexico, virtually all agriculture is irrigated. While drought is not listed as a major source of loss, irrigation supply disruption is. Higher crop prices from reduced production imposed direct losses of $130 million on first purchasers of crops, which included livestock and dairy producers, and cotton gins. In New Mexico (with significant dryland farming) drought is a more prominent cause of crop insurance claims, but cold and excess moisture are also important.

In the tourism and recreation sector, multivariate regressions estimated how changes in climate, water availability, gas prices, and other variables affect park visitation. Summer warming reduces visits to the Southwest, but winter warming increases them, except in low-desert parks. The most significant climate-related impacts are reduced reservoir levels, which decrease the amounts of water-based recreation.

**BOTTOM LINE**

This research provides useful indicators based in U.S. dollars, regarding the future impacts of climate change within particular sectors important to the Southwest region. Economic analyses are critical to people whose livelihoods are connected to climate and weather factors.

USDA FOREST SERVICE

# Evaluation

## Evaluation of Fire Forecast Products to Enhance U.S. Drought Preparedness and Response

**CLIMAS Investigators:** G. Owen, D. Ferguson, J. McLeod, & T. Brown

**Other Collaborators:** C. Kolden (University of Idaho); S. Trainor & P. Duffy (Alaska Center for Climate and Policy)

**Partners:** National Interagency Fire Center, Southwest Geographic Area Coordination Center-Predictive Services

**Leveraged Funding Sources:** NIDIS Coping with Drought 2009-2010

This project evaluated the impact that the National Seasonal Assessment Workshop (NSAW) seasonal and monthly fire potential outlooks had on wildfire management professionals in the western U.S. It was previously not well-documented who used these products, for what purposes, or the economic benefits of using them. Researchers asked how these products were being used and also analyzed network patterns across regional and federal networks of fire management to see how information was communicated across agencies. Social network analysis was used to study the patterns of relations between actors and groups in the network.

Communication on the part of Predictive Services meteorologists in the Southwest increased the use and number of applications for climate information in fire management. Climate information helped lengthen the planning window for fire management. Many fire managers begin thinking about and planners for the upcoming fire season much sooner than in previous years.

**BOTTOM LINE**

Predictive Services meteorologists occupy vital positions in the Southwest's fire management network in terms of information production, distribution, and communication. Increased access to climate information has enabled a more proactive approach to wildfire management, rather than a reactionary one.

## Evaluation of Arizona DroughtWatch: The State's Drought Impacts Reporting System

**CLIMAS Investigators:** A. Meadow, M. Crimmins, & D. Ferguson

**Partners:** County-level local drought impact groups across Arizona

**Leveraged Funding Sources:** National Drought Mitigation Center

Local drought impacts information is critical for monthly drought status reports, but the lack of local-level observations limits the state's ability to assess and mitigate drought effects. Arizona DroughtWatch was an online tool developed to increase and collect impact observation, but did not generate sufficient stakeholder interest. This evaluation project, therefore, looked at factors that inhibited volunteer use of the system and approaches that would help more effectively bring qualitative data into the drought response decision-making process.

The research team found several weaknesses in the public-participation reporting-system model. Participation was reduced due to participants' over-commitment and time constraints, consultation fatigue, and confusion about the value of qualitative impact reports.

**BOTTOM LINE**

Relying on citizen participation for data as complex and inscrutable as drought impacts is not the most effective approach. In the case of drought impacts monitoring, professional resource managers who are intimately familiar with a particular region, monitor the same areas on a regular basis, and are equipped with the specialized knowledge to discern drought impacts are best suited to collect routine drought impacts information.

## La Niña Drought Tracker/ Monsoon Tracker

**CLIMAS Investigators:** Z. Guido, G. Garfin, M. Crimmins, & J. Swetish

One of the strongest La Niña events in the last 60 years occurred in August 2010, persisting for two consecutive winters, signaling that the Southwest U.S. was likely to experience below average precipitation during the winters. These events provided a good opportunity to develop a regional climate service that informed people about the evolving drought conditions and the underlying climate connections. La Niña Drought Tracker was a two-page document published each month between December 2011 and April 2012, when La Niña impacts were most heavily experienced in the Southwest. Based on an online evaluation survey, approximately 400 people consulted the Tracker each month. More than 90% of the respondents indicated that the product improved their understanding of climate and drought. Many survey respondents indicated that they prepared for drought conditions by reading the Tracker, some of which helped mitigate economic losses.

**BOTTOM LINE**

The evaluation results demonstrated that routine interpretation and synthesis of existing climate information can help enhance people's access to and use of climate information in decision making.

S. ELLIS

# Health

## Climate, Health, and Mosquitos

**CLIMAS Investigators:** A. Comrie, C. Morin, & M. Butterworth

**Other Collaborators:** P. Robbins, W. Van Leeuwen, E. Willott, & J. Jones III (University of Arizona – School of Geography and Development); K. Ernst, Y. Carriere, M. Riehle, & K. Walker (University of Arizona-College of Public Health)

**Partners:** Santa Cruz County Health Department; Arizona Department of Health Services

**Leveraged Funding Sources:** National Science Foundation – Urban Long-Term Research Area (ULTRA)

Climate change and variability can strongly control the population dynamics of disease vectors such as mosquitoes, altering their location and seasonality and possibly increasing the risk of disease transmission to humans. This research began in 2007 as the development of the Dynamic Mosquito Simulation Model (DyMSiM), to understand and project climate effects on mosquito population dynamics, developing results that would help climate-health scientists and public health decision makers better understand and project the role of climate in actual disease cases. In the last two years, the research team conducted interviews with public health officials to understand their conceptions of climate and disease in their health districts and the potential uses of dynamic modeling as a tool.

Climate is an important controller of mosquito population dynamics, and its effects can be well-simulated for theoretical and applied studies. After refining the model, DyMSiM was able to simulate mosquito population dynamics in both moist and dry climates. In general, under a changing climate, mosquito seasons across the southern U.S. will be longer, extending from earlier in spring to later in the fall, with lower mid-summer abundance in some locations. However, populations decline in the summer months due to loss of habitat from drought or increased mortality from high temperatures. The details are spatially unique because of differing land

use patterns and the sensitivity of mosquitoes to complex interaction between temperature and precipitation. Eventually the viral pathogens were added into the models to better assess the risk of increase disease transmission. Many envrionments can maintain a stable vector population but not a viral transmission.

Model files for DyMSiM were made available online, along with examples of how to use the tool (http://sites.google.com/site/dymsimmodel/home).

**BOTTOM LINE**

Use-inspired science is incredibly valuable for the initial stakeholder and for a much wider range of potential users, often worldwide. In the case of mosquitos, CLIMAS researchers developed a tool to figure out climate-driven mosquito and disease futures, not just for the U.S. Southwest, but ultimately for many kinds of mosquitoes around the world.

# Air Quality and Climate

**CLIMAS Investigators:** D. DuBois

**Other Collaborators:** M. Bean, R. Armenta, E. Smith, R. St. Hilaire, S. Sanogo, M. Bleiweiss, S. Engle, C. Runyon, S. Brown, & K. Wiberg (New Mexico State University); R. Fitzgerald & T. Gill (University of Texas El Paso); M. Green, D. Koracin, & R. Vellore (Desert Research Institute); M. Pitchford (NOAA Special Operations & Research Division; Environmental Protection Agency-Office of Air Quality); I. Kavouras (University of Arkansas); J. Flores Margez (Universidad Autonoma de Ciudad Juarez); M. Baca (New Mexico Environment Department–Air Quality Bureau)

**Partners:** New Mexico State University–Cooperative Extension, New Mexico Environment Department–Air Quality Bureau, New Mexico Department of Health–Border Health, NOAA-NWS Albuquerque, Santa Teresa, and El Paso Weather Forecast Offices, The Joint Advisory Committee for the Improvement of Air Quality in the Paso del Norte, U.S. Environmental Protection Agency Region 6, Texas Commission on Environmental Quality, Procuraduría Federal de Protección al Ambiente, Gobierno del Estado de Chihuahua, Gobierno Municipal de Ciudad Juarez, Border Partners, U.S. Army Research Laboratory-White Sands Missile Range, Secretaría de Medio Ambiente y Recursos Naturales

**Leveraged Funding Sources:** New Mexico Department of Health-Border Health; Office of the New Mexico State Climatologist; New Mexico State University College of Agricultural, Consumer, and Environmental Science; U.S. Environmental Protection Agency Border 2012; UCAR-UNIDATA; American Association of State Climatologists

Dave DuBois joined the CLIMAS team in 2010 when he was hired as the New Mexico State Climatologist. His research interests focus on the connections between air quality, climate, and air mass transport patterns. Data collection in this project included tracking the frequencies, intensities, and locations of dust storms and wildfires over time. The research team created a tool to extract regional dust events based on satellite imagery. Researchers also analyzed climate model outputs to understand the potential effects of climate change in the regions surrounding the monitoring networks.

Information was delivered to stakeholder agencies regarding the effects of climate on air quality. The research team created a community data portal to make public data sets available that have been archived at New Mexico State University, the Center for Applied Remote Sensing in Agriculture, Meteorology and Environment (CARSAME), and New Mexico Climate Center.

**BOTTOM LINE**

Public access to air quality and climate data helps support organizations' policies and planning efforts. Since this project began, rural visibility has improved over time due to controls on sulfur and nitrogen oxide emissions. Dust and fires remain the key sources of most aerosols in New Mexico.

# Publications

## 2007-2013


### A

Al-Kofahi, S. 2011. *Mapping Land Cover in Urban Residential Landscapes: Implications for Water Budget Calculations.* Ph.D. dissertation, Plant and Environmental Sciences, New Mexico State University.

Al-Kofahi, S., G. Garfin, C. Fraisse, M. Bean, and R. St. Hilaire. 2009. Establishing a decision making tool to reduce drought vulnerability in residential urban landscapes. *HortScience* 44: 1162.

Al-Kofahi, S., C. Steele, D. VanLeeuwen, and R. St. Hilaire. 2010. Mapping land cover in urban residential landscapes using fine resolution imagery. *HortScience* 45(8): 93-94.

Al-Kofahi, S., R. St. Hilaire, Z. Samani, M. Bean, and L. Stanton. 2010. Creating a landscape water budget calculator for a desert city. *HortScience* 45(8): 262-263.

Anderson, C., D. Cayan, M. Dettinger, K. Dow, H. Hartmann, J. Jones, E. Miles, P. Mote, J. Overpeck, M. Shafer, B. Udall, and D. White. 2009. Climate services: The RISA experience. *A Report of the Regionally Integrated Sciences and Assessments Programs.* NOAA Climate Program Office. Washington, D.C.

Artiola, J., M. Crimmins, and M. Yoklic. 2008. Doing our part to help conserve Arizona's water resources and reduce global warming by saving energy at home. Arizona Cooperative Extension, AZ1485.

Ault T., J. Cole, J. Overpeck, G. Pederson, S. St. George, B. Otto-Bliesner, C. Woodhouse, and C. Deser. 2013. The continuum of drought variability in western North America: Insights from instrumental, paleoclimate and global climate model data. *Journal of Climate* 26: 5863-5878.

### B

Bark, R. and B. Colby. 2011. Climate, changing snowpack, and the economics of winter recreation. *Risk and Resilience: The Economics Of Climate-Water- Energy Challenges In The Arid Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Bark, R., D. Osgood, B. Colby, and E. Halper. 2011. How Do Homebuyers Value Different Types of Green Space? *Journal of Agricultural and Resource Economics* 36(2): 395–415.

Bark, R., D. Osgood, B. Colby, G. Katz, and J. Stromberg. 2008. Habitat preservation and restoration: Do homebuyers have preference for quality habitat? *Ecological Economics* 68(5): 1465-1475.

Basta, E. 2010. *Urban Water Supply Reliability and Climate Change*. Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

Basta, E. and B. Colby. 2010. Water market trends: transactions, quantities, and prices. *The Appraisal Journal* 78(1): 50-69.

Bilal, M., J. Nichol, M. Bleiweiss, and D. DuBois. 2013. A Simplified high resolution MODIS Aerosol Retrieval Algorithm (SARA) for use over mixed surfaces. *Remote Sensing of Environment* 136: 135-145.

Brickey C., K. Engel, K. Jacobs, J. Matter, D. Luecke, M. Miller, J. Overpeck, and B. Udall. 2010. How to take climate change into account: a guidance document for adjudicating water disputes. *Environmental Law Reporter* 40: 11215-11228.

Brugger, J. and M. Crimmins. 2013. The art of adaptation: Living with climate change in the rural American Southwest. *Global Environmental Change* (In Press).

Brugger, J. and M. Crimmins. 2012. Weather, Climate and Rural Arizona: Insights and Assessment Strategies. *Technical Input to the National Climate Assessment.*

Brugger, J., M. Crimmins, and G. Owen. 2011. Finding a place for climate science in the rural West. *Rural Connections* 5: 5-10.

Butterworth, M. 2010. *Dynamic mosquito simulation model (DyMSiM) user's guide and tutorial*. https://sites.google.com/site/dymsimmodel/tutorial

### C

Chalbot, M., I. Kavouras, and D. DuBois. 2013. Assessment of the contribution of wildfires on ozone concentrations in the central US-Mexico border region. *Journal of Aerosol and Air Quality Research* 13: 838-848.

Chessin, L. and G. Garfin. 2008. A closer look at listening: Interdisciplinarity and the varieties of languages employed in the conveyance of problem and solution. *Art, Design and Communication in Higher Education* 7(1): 5-18.

Colby, B. 2009. Water management in urbanizing, arid regions: Innovative voluntary transactions as a response to competing water claims. In *Policy and Strategic Behaviour in Water Resource Management.* A. Dinar and J. Albiac (eds). London: Earthscan Publications Ltd., 47-66.

Colby, B., and R. Bark. 2008. Task 5 Final Report: Summary report and supporting documentation. *Economic Considerations in Using Colorado River System Conservation to Replace Bypass Flow, Lower Colorado Region.* Report to US Bureau of Reclamation under Cooperative Agreement.

Colby B. and R. Bark. 2009. Inter-sectoral water trading as a climate change adaptation strategy. In *Water Resources Planning and Management.* Q. Grafton and K. Hussey (eds). Cambridge University Press.

Colby, B., E. Basta, and K. Pittenger. 2011. Temporary water transactions and climate change adaptation. *Risk and Resilience: The Economics Of Climate-Water-Energy Challenges In The Arid Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Colby, B. and G. Frisvold. 2011. The climate-water-energy nexus in the arid Southwest. *Adaptation and Resilience: The Economics of Climate-Water-Energy Challenges in the American Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Colby, B. and G. Frisvold. 2011. Modes of adaptation and regional resilience to climate change. *Adaptation and Resilience: The Economics of Climate-Water-Energy Challenges in the American Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Colby, B., L. Jones, and K. Pittenger. 2011. Economic tools for climate adaptation: water transaction price negotiations. *Risk and Resilience: The Economics Of Climate-Water-Energy Challenges In The Arid Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Colby, B. and P. Tanimoto. 2010. Using climate information to improve electric utility load forecasting. *In Risk and resilience: The economics of climate-water-energy challenges in the arid southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Cole, K., K. Ironside, J. Eischeid, G. Garfin, P. Duffy, and C. Toney. 2011. Past and ongoing shifts in Joshua Tree support future modeled range contraction. *Ecological Applications* 21(1): 137-149.

Coles, A. 2007. Perhaps our science is only as good as society's willingness to use it. *Weather and Society Watch* 1(3): 5.

Coles, A. 2008. *Managing flash floods: Risk perception from a cultural perspective*. Master's thesis, School of Geography & Development, University of Arizona.

Conroy, J., J. Overpeck, J. Cole, and M. Steinitz-Kannan. 2009. Variable oceanic teleconnections to Western North American drought over the last 1200 years. *Geophysical Research Letters* 36: L17703.

Crimmins, M., N. Selover, K. Cozzetto, and K. Chief. 2013. *Technical Review of the Navajo Nation Drought Contingency Plan - Drought Monitoring*. Submitted to the Navajo Nation Water Management Branch.

### D

Dhanireddy, P. 2010. *A Simultaneous Model of Disaster Assistance and Crop Insurance Participation.* Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

Díaz-Caravantes, R. 2009. *Water, rural livelihoods and global transformations: Geographies of peri-urban areas in Mexico.* Ph.D. dissertation, School of Geography & Development, University of Arizona.

Díaz-Caravantes, R. and E. Sánchez-Flores. 2011. Water transfer effects on peri-urban land use/land cover: a case study in a semi-arid region of Mexico. *Applied Geography* 31(2): 413-425.

Díaz-Caravantes, R. and C. Scott. 2010. Water management and biodiversity conservation interface in Mexico: A geographical analysis. *Applied Geography* 30(3): 343-354.

**E**

Ellis, A., G. Goodrich, and G. Garfin. 2009. A hydroclimatic index for examining patterns of drought in the Colorado River Basin. *International Journal of Climatology* 30(2): 236-255.

Emerick, K. 2007. *Upstream Market Power in Water Transfers*. Department of Agricultural & Resource Economics. Master's Thesis, University of Arizona.

Enquist, C., A. Bradley, M. Cross, G. Garfin, D. Gori, P. McCarthy, and R. Oertel. 2010. *Jemez Mountains climate change adaptation workshop: Process, outcomes and next steps.* Santa Fe: The Nature Conservancy.

**F**

Faulstich, H. 2012. *Reconstructed cool- and warm-season precipitation over the tribal lands of northeastern Arizona.* Master's Thesis, School of Geography & Development, University of Arizona.

Faulstich, H., C. Woodhouse, and R. Griffin. 2012. Reconstructed cool- and warm-season precipitation over the tribal lands of northeastern Arizona. *Climatic Change* 118: 457-468.

Feldman, D., K. Jacobs, G. Garfin, A. Georgakakos, B. Morehouse, P. Restrepo, R. Webb, B. Yarnal, D. Basketfield, H. Hartmann,J. Kochendorfer, C. Rosenzweig, M. Sale, B. Udall, and C. Woodhouse. 2008. Making decision-support information useful, useable, and responsive to decision-maker needs. In *Decision Support Experiments and Evaluations using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research*. N. Beller-Simms, H. Ingram, D. Feldman, N. Mantua, K. Jacobs, and A. Waple (eds). Asheville, NC: National Climatic Data Center, 101-140.

Frisvold, G. 2009. Strategic Behavior in Transboundary Water and Environmental Management. In P*olicy and Strategic Behaviour in Water Resource Management*. A. Dinar and J. Albiac (eds). London: Earthscan Publications Ltd.

Frisvold, G. 2011. Implications of climate change legislation for U.S. cotton growers. In *Proceedings of the Beltwide Cotton Conferences.* S. Boyd, M. Huffman, and B. Robinson (eds). Memphis, TN: National Cotton Council, 408-416.

Frisvold, G., A. Boor and J. Reeves. 2009. Simultaneous diffusion of herbicide resistant cotton and conservation tillage. *AgBioForum* 12: 249-257.

Frisvold, G. and S. Deva. 2010. Irrigation technology choice: The role of farm size, energy costs, climate, and soils. In *Risk and resilience: The economics of climate-water-energy challenges in the arid southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and S. Deva. 2010. Irrigator demand for information, management practices, and water conservation program participation: The role of farm size. In *Risk and resilience: The economics of climate-water-energy challenges in the arid southwest*. B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and S. Deva. 2012. Farm size, irrigation practices, and conservation program participation in the US Southwest. *Irrigation and Drainage* 61: 569–582.

Frisvold, G. and K. Emerick. 2008. Rural-urban water transfers with applications to the U.S. Mexico border region. In *Game Theory and Policy Making in Natural Resources and the Environment*. A. Dinar, J. Albiac, and J. Sanchez-Soriano (eds). New York: Routledge Press, 155-180.

Frisvold, G. and K. Emerick. 2010. Applying bargaining theory to western water transfers. In *Risk and resilience: The economics of climate-water-energy challenges in the arid southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and K. Konyar. 2009. *Impacts of water shortages on Arizona and southwestern agriculture: Market responses and policy options.* Report to the Marvin and June Morrison Chair in Agribusiness at Arizona State University.

Frisvold, G. and K. Konyar. 2011. Water shortages in the southern mountain states: economic impacts on agriculture. *Adaptation and Resilience: The Economics of Climate-Water-Energy Challenges in the American Southwest*. B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and K. Konyar. 2012. Less water – how will agriculture in Southern mountain states adapt? *Water Resources Research* 48: W05534.

Frisvold, G., X. Ma, and S. Ponnaluru. 2011. Climate, water availability, energy costs, and national park visitation. *Adaptation and Resilience: The Economics of Climate-Water-Energy Challenges in the American Southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and A. Murugesan. 2011. Use of climate and weather information for agricultural decision-making. In *Risk and resilience: The economics of climate-water-energy challenges in the arid southwest.* B. Colby and G. Frisvold (eds). Washington, DC: Resources for the Future Press.

Frisvold, G. and A. Murugesan. 2013. Use of weather information for agricultural decision making. *Weather, Climate & Society* 5: 55–69.

Frisvold, G., W. Patton, and S. Reynolds. 2009. *Arizona solar energy and economics outlook: Report prepared for Arizona solar energy and economics summit.* Tucson, AZ: Arizona Research Institute for Solar Energy (AzRISE).

Frisvold, G. and J. Reeves. 2010. Resistance management and sustainable use of agricultural biotechnology. *AgBioForum* 13: 343-359.

**G**

Garfin, G. 2007. *Assessment of the Navajo Nation Hydroclimate Network*. Final Report.

Garfin, G. 2008. Climate change and Arizona water. *The AWPCA (Arizona Water and Pollution Control Association) Newsletter* 25(2): 1, 36-37.

Garfin, G. 2009. Dry heat: An overview of climate changes and their impacts on North America's arid regions. *Sonárida* 27. Hermosillo, Sonora, Mexico.

Garfin, G, J. Eischeid, M. Lenart, K. Cole, K. Ironside, and N. Cobb. 2010. Downscaling climate projections in topographically diverse landscapes of the Colorado Plateau in the arid southwestern United States. *The Colorado Plateau IV: Proceedings of the 9th Biennial Conference on Colorado Plateau Research, October 2007*. C. van Riper III, B. Wakeling, and T. Sisk (eds). Tucson: University of Arizona Press.

Garfin, G., D. Ellis, N. Selover, D. Anderson, A. Tecle, P. Heinrich, and M. Crimmins. 2008. *Assessment of the Navajo Nation hydroclimate network*. Final report to Navajo Nation Department of Water Resources and the Arizona Water Institute.

Garfin, G., C. Enquist. 2008. Mitigating Climate Change in the American Southwest. *Eos Trans. AGU*, 89(1): 3.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2013. Chapter 20: *The Southwest in the National Climate Assessment*. Washington, DC: US Global Change Research Program.

Garfin, G., H. Hartmann, M. Crescioni-Benitez, T. Ely, J. Keck, J. Kendrick, K. Legg, and J. Wise. 2011. Climate-Friendly Park Employees: The Intermountain Region's climate change training assessment. *Park Science* 28(1): 30-36.

Garfin, G., K. Jacobs, and J. Buizer, 2008. Beyond brainstorming: Exploring climate change adaptation strategies. *Eos Trans. AGU*, 89(25): 227.

Garfin, G., K. Jacobs, and J. Buizer. 2009. Climate change adaptation lessons from the land of dry heat. In *Planning for an uncertain future—Monitoring, integration, and adaptation.* R. Webb and D. Semmens (eds). Proceedings of the Third Interagency Conference on Research in the Watersheds: U.S. Geological Survey Scientific Investigations Report 2009-2049.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy (eds). 2013. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Garfin, G. and T. Kong. 2012. *Observed and Projected Climate Impacts for the City of Tucson.* A White Paper prepared for the City of Tucson Office of Conservation and Sustainable Development.

Garfin, G., N. Lee, V. Magaña, R. Steward, and J. McEvoy. 2009. *International workshop for CHANGE (Climate and Hydrology Academic Network for Governance and the Environment).* Project Report for Foreign Affairs and International Trade Canada (DFAIT).

Garfin, G., N. Lee, V. Magana, R. Stewart, T. Rolfe, and J. McEvoy. 2011. International workshop for CHANGE: climate and hydrology academic network for governance and the environment. *Bulletin of the American Meteorological Society* 92: 1045-1048.

Garfin, G. and M. Lenart. 2007. Overview of Climate Change Effects on Southwest Water Resources. Southwest Hydrology 6(1): 16-17, 34.

Garfin, G., P. Romero Lankao, and R. Varady. 2013. Editorial: Rethinking integrated assessments and management projects in the Americas. *Environmental Science & Policy* 26: 1-5.

Garrick, D., K. Jacobs, and G. Garfin. 2008. Models, assumptions, and stakeholders: planning for water supply variability in the Colorado River basin. *Journal of the American Water Resources Association*, 44(2): 381-398.

Gaston, T. 2012. *Agricultural Water Demand along the Lower Colorado River Mainstem: Developing and Testing a Three-Model Approach for Econometric Analysis.* Master's Thesis, Department of Agricultural & Resource Economics, University of Arizona.

Guido, Z. 2011. *Hydrologic Extremes and Water Management in a Warmer World – California Perspectives.* Workshop Report.

Guido, Z. 2013. Drought on the Rio Grande, *Rural Connections* 7(1): 7–10.

Guido, Z., D. Ferguson, and G. Garfin. 2009. Putting knowledge into action: *Tapping the institutional knowledge of U.S. Fish and Wildlife Service regions 2 and 8 to address climate change.* Climate Assessment for the Southwest.

Guido, Z., D. Hill, M. Crimmins, and D. Ferguson. 2013. Informing Decisions with a Climate Synthesis Product: Implications for Regional Climate Services. *Weather, Climate, and Society* 5(1): 83-92.

## H

Hammond, D. and E. Lay. 2008. *Tutorial: How to connect products to CLIDDSS.* Arid Lands Information Center, Office of Arid Lands Studies, University of Arizona.

Hartmann, H. 2007. Decision support for water resources management. In *CCSP SAP 5.1, Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions.* US Climate Change Science Program.

Hartmann, H. 2008. Decision support for water resources management. In *Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions. A Report by the US Climate Change Science Program and the Subcommittee on Global Change Research.* M. Macauley (ed). Washington, D.C: NASA Applied Science Program, 45-55.

Hartmann, H. 2012. Strategies and tactics for the design of hydroclimatic decision support tools. In: *Managing Resources of a Limited Planet: Sixth International Congress on Environmental Modeling and Software.* R. Seppelt, A. Voinov, S. Lange, and D. Bankamp (eds). International Environmental Modeling and Software Society.

Hartmann, H., J. Buizer, P. dos Santos, R. Moss, L. Patton, and L. Welling. 2011. Appendix 4 - Participatory scenario planning in regional and sectoral stakeholder activities in the National Climate Assessment. *In Scenarios and Regional Summaries, Report to National Climate Assessment Development and Advisory Committee.* Washington, D.C.

Hartmann, H., J. Schneider, and J. Wiener. 2009. *Supporting climate-responsive range management: Serving a diverse, distributed, and stressed sector.* White Paper submitted to NOAA Climate Program Office. Silver Springs, MD.

Hirschboeck, K. 2009. Flood flows of the San Pedro River. In *Ecology and Conservation of the San Pedro River.* J. Stromberg and B. Tellman (eds). Tucson: University of Arizona Press.

Hirschboeck, K. 2009. Future hydroclimatology and the research challenges of a post-stationary world. *Journal of Contemporary Water Research and Education* 142: 4-9.

Hirschboeck, K. and D. Meko. 2008. *The current drought in context: A tree-ring based evaluation of water supply variability for the Salt-Verde River Basin.* Final Project Report.

Hurd, B., C. Goemans, G.Frisvold, and J. Stone. 2010. *Impacts of climate change legislation on agriculture in the rocky mountain states: Arizona, Colorado and New Mexico.* White Paper Prepared for the American Farmland Trust. Center for Agriculture in the Environment, Dekalb, IL.

## J

Jacobs, K., G. Garfin, and J. Buizer. 2010. New techniques at the science-policy interface: Climate change adaptation in the water sector. *Science and Policy* 36(10): 791-798.

Jones, J. 2008. *Water and border area climate change: An introduction.* Special Report for the XXVI Border Governors Conference. State of California, Department of Water Resources.

Jones, L. and B. Colby. 2010. Farmer participation in temporary irrigation forbearance: portfolio risk management. *Rural Connections* 4(2): 43-48.

Jones, L. and B. Colby. 2010. Weather, climate, and environmental water transactions. *Weather, Climate, and Society* 2(3): 210-223.

Jones, L. and B. Colby. 2012. *Measurement, Monitoring and Enforcement of Irrigation Forbearance Agreements.* Guidebook.

Jones, L. and B. Colby. 2013. *Prioritizing Water Acquisitions To Achieve Environmental Objectives.* Guidebook.

## K

Karl, T., J. Melillo, and T. Peterson. 2009. *Global Climate Change Impacts in the United States.* Cambridge University Press. (Overpeck was a co-author).

Kerna, A. 2012. *Environmental Flows: A CVM Study and Water Market Activity Analysis.* Master's thesis, Department of Agricultural & Resource Economics, University Of Arizona.

Koracin, D., R. Vellore, D. Lowenthal, J. Watson, J. Koracin, T. McCord, D. DuBois, L. Antony Chen, N. Kumar, E. Knipping, N. Wheeler, K. Craig, and S. Reid. 2011. Regional source identification using Lagrangian stochastic particle dispersion and HYSPLIT backward-trajectory models. *Journal of the Air & Waste Management Association* 61(6): 660-672.

## L

Li, L. 2010. *State adoption of greenhouse gas emission targets and renewable portfolio standards.* Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

Liu, Y., M. Mahmoud, H. Hartmann, S. Stewart, T. Wagener, D. Semmens, R. Stewart, H. Gupta, D. Dominguez, D. Hulse, R. Letcher, B. Rashleigh, C. Smith, R. Street, J. Ticehurst, M. Twery, H. van Delden, and D. White. 2008. Formal scenario development for environmental impact assessment studies. In *Developments in Integrated Environmental Assessment*, *Volume 3.* A. Jakeman, A. Voinov, A. Rizzolli, and S. Chen (eds). Amsterdam: Elsevier, 145-162.

**M**

Mahmoud, M., Y. Liu, H.C. Hartmann, S. Stewart, T. Wagener, D. Semmens, R. Stewart, H. Gupta, D. Dominguez, F. Dominguez, D. Hulse, R. Letcher, B. Rashleigh, C. Smith, R. Street, J. Ticehurst, M. Twery, H. van Delden, R. Waldick, D. White, and L. Winter. 2009. A formal framework for scenario development in support of environmental decision-making. *Environmental Modeling and Software* 24(7): 798-808.

Meadow, A., M. Crimmins, and D. Ferguson. 2013. Field of Dreams or Dream Team?: Assessing Two Models for the Drought Impact Reporting in the Semiarid Southwest. *Bulletin of the American Meteorological Society* 94: 1507-1517.

McAfee, S. and J. Russell. 2008. Northern Annular Mode impact on spring climate in the western United States. *Geophysical Research Letters* 35(17): L17701

McEvoy, J. and M. Wilder. 2012. Discourse and Desalination: Potential Impacts of Proposed Climate Change Adaptation Interventions in the Arizona-Sonora Border Region. *Global Environmental Change* 22(2): 353-363.

Meadow, A., D. Ferguson, and M. Crimmins. 2013. Helping a community develop a drought impacts reporting system. *Rural Connections* 7(1): 15-18.

Mealy, M. 2010. *The Misinterpretation of Climate Forecasts and Their Economic Impacts to the Agricultural Sector.* Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

Miller, J., H. Safford, M. Crimmins, and A. Thode. 2008. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. *Ecosystems* 12(1): 16-32.

Morin, C. 2008. *A climate driven dynamic mosquito population model with applications to climate change scenarios.* Master's thesis, School of Geography & Development, University of Arizona.

Morin, C. 2012. *Climate and Environmental Influences on the Ecology of Vectors and Vector-borne Diseases.* Ph.D. Dissertation. School of Geography & Development, University of Arizona.

Morin, C. and A. Comrie. 2010. Modeled response of the West Nile virus vector *Culex quinquefasciatus* to changing climate using the dynamic mosquito simulation model. *International Journal of Biometeorology* 54: 517-529.

**N**

National Research Council. 2008. *Ecological Impacts of Climate Change.* Washington, D.C.: National Academy Press. (J. Overpeck is a co-author).

National Research Council. 2012. *The National Weather Service Modernization and Associated Restructuring: A Retrospective Assessment.* Committee on the Assessment of the National Weather Service's Modernization Program. National Academy Press: Washington, D.C. (Hartmann is a co-author).

National Research Council. 2012. *Weather Services for the Nation: Becoming Second to None.* Committee on the Assessment of the National Weather Service's Modernization Program. National Academy Press: Washington, D.C. (Hartmann is a co-author).

Neely, B., P. McCarthy, M. Cross, C. Enquist, G. Garfin, D. Gori, D. Hayward, and T. Schulz. 2010. *Climate change adaptation workshop for natural resource managers in the Gunnison basin: Summary.* Boulder: The Nature Conservancy.

Neff, J., A. Ballantyne, G. Farmer, N. Mahowald, J. Conroy, C. Landry, J. Overpeck, T. Painter, C. Lawrence, and R. Reynolds. 2008. Recent increases in eolian dust deposition due to human activity in the western United States. *Nature Geoscience* 1(3): 189-195.

Norman, L., N. Tallent-Halsell, W. Labiosa, M. Weber, A. McCoy, K. Hirschboeck, J. Callegary, C. van Riper III, and F. Gray. 2010. Developing an ecosystem services online decision support tool to assess the impacts of climate change and urban growth in the Santa Cruz watershed: where we live, work, and play. *Sustainability* 2: 2044-2069.

Novak, Rachael. 2007. *Climate Variability and Change in the Chuska Mountain Area: Impacts, Information, and the Intersection of Western Science and Traditional Knowledge.* Masters thesis, Geosciences, University of Arizona.

**O**

O'Donnell, M. 2010. *Innovative Water Supply Reliability Arrangements.* Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

O'Donnell, M. and B. Colby. 2009. *Dry-year water supply reliability contracts: A tool for water managers.* Department of Agricultural and Resource Economics, University of Arizona.

O'Donnell, M. and B. Colby. 2009. *Water auction design for supply reliability: Design, implementation, and evaluation.* Department of Agricultural and Resource Economics, University of Arizona.

O'Donnell, M. and B. Colby. 2010. *Water banks: A tool for enhancing water supply reliability.* Department of Agricultural and Resource Economics, University of Arizona.

O'Lenic, E., H. Hartmann, M. Ou, K. Pelman, S. Handel. 2011. An emerging protocol for research-to-operations (R2O) at CPC. In *Climate Prediction S&T Digest*, Science and Technology Infusion Climate Bulletin Supplement. National Weather Service, Silver Springs, MD.

Overpeck, J., Z. Guido, J. Conroy, S. Truebe, M. Crimmins, and C. Routson. 2010-11. 23 Southwest Climate Change Network (SWCCN) blog posts. http://www.southwestclimatechange.org/blog

Overpeck, J. 2009. Keep the west vibrant with a strong climate change policy. *Southwest Hydrology* 8(2): 24-30.

Overpeck, J., G. Meehl, S. Bony, and D. Easterling. 2011. Climate data challenges in the 21st century. *Science* 331(6018): 700-702.

Overpeck, J., M. Miller, and D. Liverman. 2011. Global climate change as a local phenomenon. *Navigating Climate Change in a Federal System.* E. Schlager, K. Engel, S. Rider (eds). Tucson: University of Arizona Press.

Overpeck, J., and B. Udall. 2010. Dry times ahead. *Science* 328: 1642-1643.

Owen, G., K. Averyt, and K. Werner. 2010. *Using & Improving the Tools Available at the Colorado Basin River Forecast Center: A Toolkit for User Engagement.* Progress Report.

Owen, G., J. McLeod, C. Kolden, D. Ferguson, and T. Brown. 2012. Wildfire Management and Forecasting Fire Potential: The Roles of Climate Information and Social Networks in the Southwest United States. *Weather, Climate, and Society* 4: 90-102.

**P**

Patton, W., G. Frisvold, S. Reynolds, and A. Barnhart. 2009. *Arizona Solar Energy and Economics Outlook.* Final Report Prepared for Arizona Solar Energy and Economics Summit.

Pineda Pablos, N., A. Browning-Aiken, and M. Wilder. 2007. Equilibrio de bajo nivel y manejo urbano del agua en Cananea, Sonora. *Frontera Norte* 19(37).

Pullen, J. and B. Colby. 2008. Influence of climate variability on the market price of water in the Gila-San Francisco Basin. *Journal of Agricultural and Resource Economics* 33(3): 473-487.

**R**

Ray, A., G. Garfin, M. Wilder, M. Vásquez-León, M. Lenart, and A. Comrie. 2007. Applications of Monsoon Research: Opportunities to Inform Decision Making and Reduce Regional Vulnerability. *Journal of Climate* 20(9): 1608-1627.

Routson, C., C. Woodhouse, and J. Overpeck. 2011. Second century megadrought in the Rio Grande headwaters, Colorado: How unusual was medieval drought? *Geophysical Research Letters* 38: L22703.

**S**

Schuster, E. 2012. *Farm Resilience to Water Supply Variability: An Econometric Analysis of Risk Management Strategies in the Mexicali Valley, Mexico.* Master's thesis, Department of Agricultural and Resource Economics, University of Arizona.

Scott, C., F. Meza, R. Varady, J. McEvoy, M. Wilder, L. Farfán, G. Garfin, and N. Piñeda Pablos. 2013. Water Security and Adaptive Management in the Arid Americas. *Annals of the Association of American Geographers* 103(2): 280-289.

Stewart, S., M. Mahmoud, Y. Liu, H. Hartmann, T. Wagener, and H. Gupta. 2007. Scenario development for water resources planning and management. In *Changes in Water Resources Systems: Methodologies to Maintain Water Security and Ensure Integrated Management*. N. van de Giesen, X. Jun, D. Rosbjerg and Y. Fukushima (eds). Wallingford, UK: International Association of Hydrological Sciences, 192-198.

St. Hilaire, R. and M. Al-Ajlouni. 2009. Linking landscape types to water use in residential landscapes. *HortScience* 44: 1162.

Subramaniam, B. 2010. *Per Capita Energy Consumption and CO2 Emissions: How and Why Do States Differ?* Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

**T**

Tamerius, J., E. Wise, C. Uejio, A. McCoy, and A. Comrie. 2007. Climate and human health: Synthesizing environmental complexity under uncertainty. *Stochastic Environmental Research and Risk Assessment* 5: 601-613.

Tamerius, J. 2007. *Sub-regional winter precipitation variability in the southwest US: A study of contrasting precipitation anomalies*. Master's thesis, School of Geography & Development, University of Arizona.

Tanimoto, P. 2008. *Forecasting the impact of climate change for electric power management in the Southwest*. Master's thesis, Department of Agricultural & Resource Economics, University of Arizona.

**V**

Varady, R., C. Scott, M. Wilder, B. Morehouse, N. Piñeda Pablos, and G. Garfin. 2013. Transboundary adaptive management to reduce climate-change vulnerability in the western U.S.-Mexico border region. *Environmental Science & Policy* 26: 102-112.

Vasquez-Leon, M., B. Wolf, C. West, and D. Anderson. 2007. Water is Life: A Community-Level Assessment of Climate Vulnerability in the Upper Gila River Valley. CLIMAS Report.

**W**

Wall, T., G. Garfin, and J. Galayda. 2012. *Evaluating Our Capacity: A Discussion of Capability for Ongoing Climate Assessment in the Colorado River Basin.* Tucson, AZ: CLIMAS.

Werner, K., K. Averyt, and G. Owen. 2013. River Forecast Application for Water Management: Oil and Water? *Weather, Climate, & Society* 5: 244-253.

West, C. and M. Vásquez-León. 2008. Misreading the Arizona landscape: Reframing analyses of environmental degradation in Southeastern Arizona. *Human Organization* 67(4): 373-383.

Weiss, J., C. Castro and J. Overpeck. 2009. The changing character of climate, drought, and the seasons in the Southwestern U.S.A. *Journal of Climate* 22: 5918-5932.

Wilder, M. 2008. Equity and water in Mexico's changing institutional landscape. In *Water and Equity: Apportioning Water among Places and Values*. R. Perry, H. Ingram, and J. Whiteley (eds). Cambridge: Massachusetts Institute of Technology Press.

Wilder, M. and R. Diaz. 2008. *Assessing Public Values Towards Wetlands Conservation in a Binational Context: The Lower Colorado River and Delta*. Final Report.

Wilder, M. 2009. Drought risk and hazard. In *Sage Encyclopedia of Geography*. B. Warf (ed). Los Angeles: Sage Publications.

Wilder, M. 2010. Political and economic apertures and the shifting state-citizen relationship: Reforming Mexico's national water policy. In *Water Policy Entrepreneurs: A research companion to water transitions around the globe.* D. Huitema and S. Meijerink (eds). Cheltenham, UK: Edward Elgar.

Wilder, M. and G. Garfin. 2010. Drought hazard and risk. In *Encyclopedia of Geography*. B. Warf (ed). London: Sage Publications, Inc.

Wilder, M., C. Scott, N. Pineda, R. Varady, G. Garfin, and J. McEvoy. 2010. Adapting across boundaries: climate change, social learning, and resilience in the U.S.-Mexico border region. *Annals of the Association of American Geographers* 100(4): 917-928.

Wise, E. 2009. Climate-based sensitivity of air quality to climate change scenarios for the southwestern United States. *International Journal of Climatology* 29: 87-97.

**Z**

Zeng, X., H. Gupta, P. Troch, P. Brooks, K. Jacobs, C. Castro, M. Crimmins, F. Dominguez, J. Duan, H. Hartmann, S. Kurc, R. Kursinski, T. Maddock, S. Mullen, J. Valdes, and C. Woodhouse. 2009. *Evaluation, improvement, and development of NOAA's hydroclimate services.* White Paper submitted to NOAA Climate Program Office, Silver Springs, MD.