Collaboratively Assessing Critical Social-Ecological System Buffers to Help Build Regional Climate Resilience

Progress Report: June 1, 2019 — May 31, 2020

CLIMAS
Climate Assessment for the Southwest
A NOAA RISA TEAM

CLIMAS
BY THE NUMBERS
2019–2020

4,463
CLIMAS-related Twitter Followers

78
Presentations Given to Stakeholder and Academic Audiences

14
Advisory Roles Served

15
Academic Articles Published

12
Reports Produced for Stakeholders

29
Climate Briefings Disseminated

3
Policy Briefs Produced

13
Hosted Seminars

Dan Ferguson | The Colorado River in northern Arizona at Marble Canyon.

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Table of Contents

Cover Photos

Top Photo: Dan Ferguson | The 2020 Bighorn Fire burns Mt. Lemmon north of Tucson, AZ.

Bottom Photo: Ben McMahan | Hiking trail in Ironwood Forest National Monument.

CLIMAS
BY THE NUMBERS
2019–2020

12 Podcasts Recorded

Workshops & Trainings **9** Facilitated

Appearances in the **34** Media

Online Tools **9** Developed

Master's Theses Written **5**

14 New Leveraged Grants Funded

6 Website Developed

2 Dissertations Completed

What is CLIMAS?

The Climate Assessment for the Southwest (CLIMAS) is a NOAA-funded program that connects researchers at the University of Arizona and New Mexico State University to partners from the private sector, academia, and local, state, federal, and tribal governments. Since 1998, CLIMAS researchers have brought the best available scientific knowledge to weather and climate-related challenges in the Southwest. CLIMAS is funded by the Regional Integrated Sciences and Assessments (RISA) program and the National Integrated Drought Information System (NIDIS), both of which are designed to improve the use of climate information in decision making.

2019 — 2020
CLIMAS Research Team

Principal Investigators

Daniel Ferguson (Program Director, Lead PI)
Heidi Brown
George Frisvold
Michael Crimmins
Connie Woodhouse

Co-Principal Investigators

Stephanie Carroll
Ben McMahan
Bonnie Colby
Alison Meadow
David DuBois
Gigi Owen
Ladd Keith
Jeremy Weiss

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Craig Rasmussen
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Nupur Joshi
Sean Schrag-Toso
Norma Villagomez-Márquez

2020
Kunal Palawat*
JoRee LaFrance*
Rachel Rosenbaum*
Emily Cooksey*

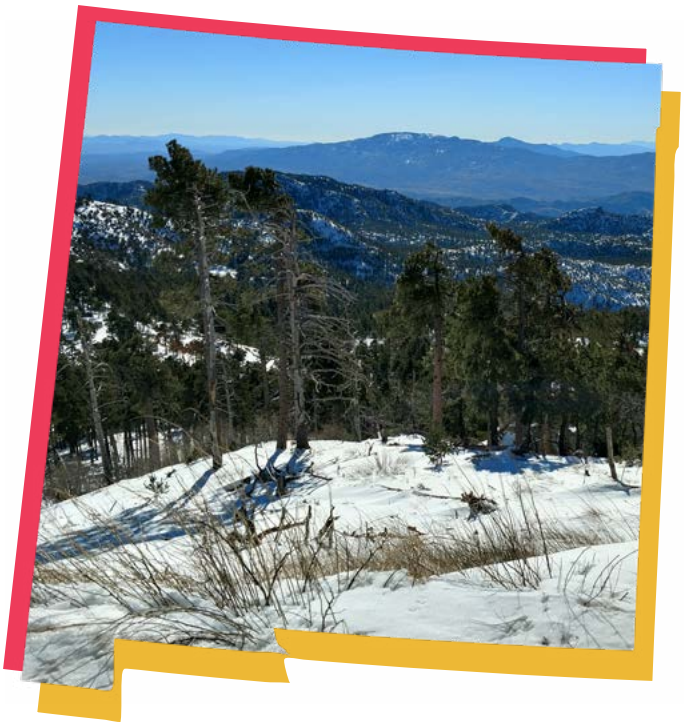
* New additions to the CLIMAS team during the reporting period.

Ben McMahan | Sunset across the Southwest desert.

Climate Services and Outputs 2019-2020

New Mexico

- Pueblo of Laguna, NM and Adaptation International are using findings in the *Climate Profile for the Pueblo of Laguna* to inform their vulnerability assessment and climate change adaptation plan. – Community Climate Profiles
- New Mexico State University used CLIMAS research on dust storms to make a new module for the University's vehicle training program. Every person driving a University vehicle must pass this module about what to do during a dust storm. – Impacts of Climate Extremes to Interstate and Local Trucking Industries



Dave Dubois | Snow in the Chuska Mountains in New Mexico.

Climate Services and Outputs 2019-2020

Arizona

- Tucson Electric Power is directly using data analysis from the *Greenhouse Gas Reduction Goal Planning Report* in their 2020 Integrated Resource Plan and their presentations to the Arizona Corporations Commission. – Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

- Merkin Vineyards used coverage of chill and heat accumulation in the January through April issues of the monthly Climate Viticulture Newsletter to schedule their spring activities. – Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico

- Barilla Corporation is using findings in the *Improving Water Footprint Calculations Using Local Agronomic and Environmental Data* report to inform their decisions about sourcing durum wheat. – Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

- The Pima County Flood Control Office and the Oro Valley Police Department are using aggregated rainfall data in the Monsoon Viewer to help them prioritize post-monsoon event cleanup and recovery, such as materials removal and road clearing following heavy rain events. – Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

- The National Weather Service office in Tucson used monsoon season precipitation maps in their overview of the 2020 Arizona Monsoon YouTube video. – Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

- Arizona dairy producers are using data from a Master's thesis to understand the economic impacts of fallowing large-scale alfalfa on their industry and rural economies. – A Colorado River Shortage Declaration: Planning, Responses, and Consequences

Gigi Owen | A cat lounges in a front yard garden in Tucson, AZ.

- City of Sedona is using information in *Climate Profile for The Verde Valley* to inform the City's climate change adaptation plan. – Community Climate Profiles

- Salt River Project (an AZ utility) is using CLIMAS research findings to improve their understanding about the climatic influences on streamflow in the Salt, Tonto, and Verde River basins. Snowpack already melts early in these watersheds, therefore, expected increases in spring and summer temperatures will not impact these basins as much as they will in the Rocky and Sierra Nevada Mountains. – The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

- Barilla Corporation used a report about *Tools for Nitrogen Management of Wheat* to make informed decisions about optimizing nitrogen fertilizer application to increase farmer profit and reduce the carbon footprint of their supply chain. – Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

Outreach Highlights

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

Tucson Electric Power (TEP) contracted with CLIMAS to explore plausible scenarios for greenhouse gas and carbon reduction in their energy portfolio. Researchers constructed an **open-source data repository** with all the models, code, data, and analysis. Anyone can replicate, test or improve the analysis, or update it with new data. Throughout the project CLIMAS and TEP presented project updates to and solicited feedback from TEP's Stakeholder Advisory Committee. Members of the committee responded positively to the transparency of the data and the research process.

Southwest Tribal Data Summit: Partnering with Southwest Indigenous Communities to Identify Data

Project partners developed an online archive with video, slides, and written outputs of the 2019 Indigenous Data Sovereignty Summit in Arizona. Attendees and others interested in learning more about tribal interests and needs related to Indigenous data sovereignty use this site, which provides access to video and slide decks that were previously unavailable. It represents a collaboration among the Native Nations Institute and the Inter Tribal Council of Arizona, with additional support from the Arizona State University, American Indian Student Support Services; Office of Tribal Relations at The University of Arizona; Arizona State University Office of American Indian Initiatives; and, Indigenous Strategies, LLC.

https://nni.arizona.edu/programs-projects/policy-analysis-research/indigenous-data-sovereignty-and-governance/summits-conferences/indigenous-data-sovereignty-summit-2019

Melissa Merrick | View of Sulphur Springs Valley from the Pinaleño Mountains.

Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards

To communicate about timely climate topics relevant to wine grape growing in Arizona and New Mexico, this research team developed The Climate Viticulture Newsletter. Monthly and mid-month special issues are sent via email and posted online. The newsletter was the product of stakeholder feedback about the need for climate information tailored to wine grapes. So far 82 people have subscribed.

https://cals.arizona.edu/research/climategem/content/climate-viticulture-newsletter

Collaborative Research on Environmental Risks and Built Environment in the Borderlands of the Southwest

This project team launched **a new website about the EcoCasa** project in Nogales, Sonora. The website aggregates their recent work on solar and sensor technology, as well as more than 10 years of previous work about environmentally friendly technology amongst a network of partners in the Nogales border region. The website provides summaries about the feasibility and capacity for community solar power in Nogales and the role of sensor technology in tracking environmental risks.

https://nogalesecocasa.arizona.edu/

The team also held **a workshop at the EcoCasa** on October 17, 2019, focused on sensor technology, solar energy, climate, and the environment. Around 85 high school students, 10 teachers and community members, and five media representatives attended.

Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making

Research connections from this project contributed to development of the University of Arizona **Extreme Heat Network,** an interdisciplinary community of research and practice on the causes, impacts, and strategies to increase resilience to extreme heat. The network hosts a webinar series. Six webinars were hosted during the reporting period with an average of 50 participants each. One topic, Extreme Heat and Real Estate, drew 200 registrants.

https://heat.arizona.edu

The Southwest Climate Outlook (SWCO)

SWCO summarizes climate and weather information from disparate sources in nonscientific language, providing more than 1,600 people with monthly climate-related information. Since SWCO's inception in 2002, stemming from the END InSight project, the publication has evolved into a tool for two-way communication with stakeholders and a platform for responding to needs throughout the region. Twelve issues were distributed between June 2019 through May 2020. Issues from June, July, and August 2019 had the highest number of viewers. The reservoir diagram is regularly used by various agencies. For example, this year the Arizona Department of Water Resources used the diagram in *The Late-Winter Water Report: Drier Weather Makes An Unwelcome Return.*

www.climas.arizona.edu/swco

https://new.azwater.gov/news/articles/2020-27-02

The Southwest Climate Podcast

CLIMAS scientists discuss climate-related issues in monthly climate podcasts. The podcasts synthesize information from disparate sources that often do not have a Southwest bent, translating the national and global discussions into what it means for the Southwest. Eleven episodes aired between June 2019 through May 2020. The top episodes aired in June, July, and August 2019.

www.climas.arizona.edu/media/podcasts

NMSUCCESS NMSU Climate Change Education Seminar Series

Between September 2019 through March 2020, seven public seminars were held at NMSU. Events were advertised through local media, email lists, NMSU classes, and flyers. Each event brought 150-250 people. People were interested in climate change, its impacts, and finding ways to help. After attending some events, the Las Cruces City Council provided financial support to bring in more visiting speakers.

New Mexico Climate Twitter. David DuBois continued his use of Twitter via the NM Climate Center account (@nmclimate). This account had 2185 followers as of June 2020, which increased by 525 people over the past 12 months. Activity on this Twitter account has generated many off-line conversations with local and national media.

CLIMAS Twitter. The CLIMAS program's Twitter account (@CLIMAS_UA) has more than 800 followers as of June 2020. Posts that generated the highest amount of interest were related to the summer monsoon, the Southwest Climate Podcast, and winter precipitation.

2020 Team Accomplishment

The current CLIMAS grant was developed to purposefully integrate projects and researchers within the program. Nearly all of the projects contained in our proposal and this report reflect direct collaborations between two or more CLIMAS investigators. Our collective goal is to advance a genuine web of knowledge about climate and climate impacts in the Southwest, rather than isolated strands of insight. To move toward this goal, CLIMAS investigators convened in January 2020 to start synthesizing research findings across team project and research expertise. Three areas of focus emerged:

1) demonstrating the CLIMAS program's shift from disciplinary research toward more interdisciplinary and transdisciplinary approaches;

2) reviewing buffers that will help the Southwest be resilient to climate risk, especially in the areas of drought and water resources, human health, and policies and planning; and

3) understanding the complexity and different framings of drought for the Southwest to develop better monitoring and adaptation strategies.

Dan Ferguson | Left: Rare snowfall on cactus and aloe plants in Tucson, AZ. Below: View of saguaro cactuses from a hiking trail in southern Arizona.

New Areas of Focus and Partnerships 2019-2020

Regional Food System Resilience in Southern Arizona – Learning from COVID-19

CLIMAS Investigator: G. Owen

Research Partners: University of Arizona – Center for Regional Food Studies; University of Iowa – Department of Geographical and Sustainability Science and Global Health

End Users: City of Tucson; Local food producers in Tucson, AZ; UNESCO City of Gastronomy organization

Additional Support: University of Arizona – Center for Regional Food Systems

Gigi Owen | An array of fresh local produce and eggs grown across southern Arizona.

COVID-19 and its associated risks and quarantine policies have brought rapid change to people's lives in all kinds of ways. One thing that has not changed is people's need for food; but the ways that people access and prepare their food, and provide food for others, has shifted greatly. Understanding the types of changes and adaptations that people are making – in the midst of a crisis – will provide lessons about building resilient and more just food systems that can respond to future health, environmental, and climate risks.

The 2020 pandemic has uncovered more evidence of several long-standing injustices and inequities that are embedded U.S. political, economic, and healthcare systems. Inequities tied to race, gender, and income have been magnified in food systems, including inequities in food access, food policy, food production and distribution, and food sovereignty. While many people face food insecurity, a large percentage of food system is wasted in landfills, which emits a significant amount of the greenhouse gases responsible for climate change.

An initial scoping survey was distributed in May 2020 about how people's experiences with food access, preparation, and provision has been impacted by COVID-19 and their strategies to adjust to or cope with these impacts. Findings highlight the need for flexibility in operations and policies, for support to protect essential workers, and new strategies for food distribution, processing, and sales. This preliminary data is informing the next phase of research, which focuses on innovations and strategies in food production, processing, distribution, and waste management, as well as current inequities and injustices in the Tucson and Southern Arizona food system.

This project evolved from the "Evaluating Adaptation Responses" project outlined in the CLIMAS proposal and represents a partnership with researchers in the University of Arizona's Center for Regional Food Studies. Each year this Center develops a "State of the Tucson Food System" report. Results from this project will directly inform the 2021 report.

USDA Livestock Forage Disaster Program and Ranching in the Southwest U.S.

CLIMAS Researchers: M. Crimmins, M. McClaran, C. Greene

Research Partners: National Weather Service; USDA Natural Resources Conservation Service; Arizona Section of the Society for Range Management

End Users: Ranchers in AZ and NM; AZ and NM state drought monitoring committees; U.S. Drought Monitor authors; Regional drought monitoring experts

Additional Support: National Integrated Drought Information System (NIDIS)

The 2014 Farm Bill permanently authorized the USDA Livestock Forage Program (LFP), which provides compensation to livestock producers who suffer grazing losses caused by drought and wildfires. The LFP bases payment eligibility on drought status categories of the U.S. Drought Monitor. Yet, there is evidence that Drought Monitor categories do not accurately capture the timescales of climate variability driving forage production and drought impacts across Arizona and New Mexico. Therefore, the current system may understate the extent of losses and need for compensation of Southwest ranchers. This study evaluates how the current application of the Drought Monitor in the LFP addresses drought and wildfire risks faced by Arizona and New Mexico ranchers and will seek out drought monitoring best practices specifically for rangeland systems. In January 2020, researchers presented on drought monitoring tools to 60 federal and state land managers and ranchers in Arizona. This project connects with several other projects in the Southwest aimed to improve the efficiency and efficacy of drought monitoring across the region. These projects support drought early warning as conceived by NIDIS and will identify best practices in employing more relevant, timely, and unique drought monitoring strategies.

Upcoming Initiatives in 2020-2021

Community-Based Responses to Climate-Water Challenges in Arizona and New Mexico

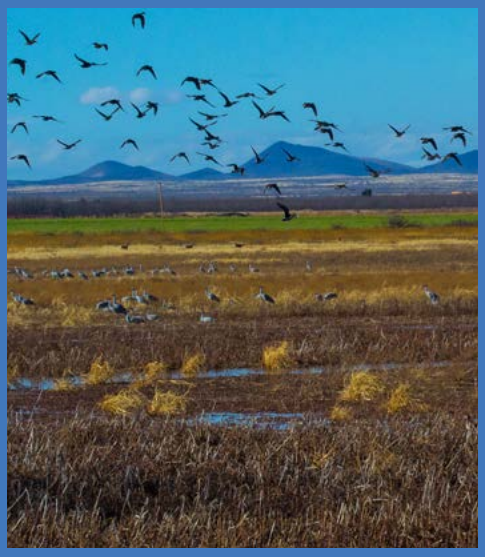
Bonnie Colby will begin new research to evaluate existing water-related buffers, such as groundwater supplies, including the extent to which these buffers are currently effective and whether these buffers are likely to be sufficient in the future. Other strategies to be evaluated include investments in reservoirs and pipelines and incentive-based risk-sharing agreements.

Urban Heat and Health Interventions and Evidence Gaps

Ladd Keith will extend his research on urban heat, which will include a policy analysis for heat governance mapping, interviews, and testing the Plan Integration for Resilience Scorecard (PIRS) for heat.

Economic Valuation of Weather and Climate Information

George Frisvold, Michael Crimmins, and Daniel Ferguson will begin a new project to understand economic values of weather and climate information, particularly in connection to how forestry and transportation agencies in AZ and NM use this information.



Melissa Merrick | Above: Wetlands in the Whitewater Draw Wildlife Area, in Sulphur Springs Valley. Below: Sandhill cranes gather in the Whitewater Draw Wildlife Area, in Sulphur Springs Valley.

Economic Impact

A Colorado River Shortage Declaration: Planning, Responses, and Consequences

CLIMAS Investigators: G. Frisvold; C. Hu; X. Wu

USDA's Natural Resource Conservation Service (NRCS) announced that it will invest $10 million in the partner-driven Central Arizona Regional Irrigation Efficiency project. This project is a part of NRCS's Regional Conservation Partnership Program (RCPP), which funds solutions to natural resource challenges on agricultural land. Funding will be used to rehabilitate and improve well infrastructure in five Pinal County irrigation districts. Local entities in AZ cited economic estimates from this CLIMAS project in drafting their grant application. Economic analysis showed that reducing water supply by 300,000 acre-feet to Pinal County agriculture would result in $30.7 million USD and 448 fewer jobs. This information impacts the livelihoods of more than 1,300 farm producers and 2,800 farm workers in the county.

Program Evaluation

CLIMAS Investigator: G. Owen

The CLIMAS program evaluation model uses data collected from annual report templates and from periodic interviews with CLIMAS investigators. CLIMAS defines societal impacts as the ways that research, and the process of conducting research, influences the world beyond the academic realm. Societal impacts refer to the changes that research makes in the world, how, and for whom. We use the following five categories of impact:

1. Instrumental applications – tangible changes to plans, decisions, practices, or policies
2. Conceptual impacts – changes in people's knowledge about or awareness of an issue
3. Capacity building impacts – enhancing the skills, expertise, or resources of an organization or group of people
4. Connectivity impacts – new or strengthened relationships, partnerships, or networks that endure after a project ends
5. Socio-environmental impacts – changes to social and/or ecological systems that result from actions taken because of research

G. Owen and A. Meadow continue to refine an approach to assessing the societal impacts of climate-related research. They were named as 2020 Fellows in Advancing Research Impacts in Society to develop a guidebook for evaluating the societal impact of climate change research. Examples in the guidebook draw from CLIMAS and the Southwest Climate Adaptation Science Center projects. As part of this work, Owen and Meadow conducted a workshop on "Identifying and Documenting the Societal Impacts of Your Research" in April 2020 with approximately 30 attendees from diverse departments at the University of Arizona.

> *connectivity outcomes lay the groundwork for societal and environmental change*

Findings from an evaluation of CLIMAS projects during the 2012-2017 funding cycle are described in G. Owen's dissertation (2019), were presented at the American Geophysical Union, and are currently in review for publication in an academic journal. A key finding draws attention to the mutual learning that occurs in CLIMAS projects. While the intensity of relationships fluctuates over time—sometimes interactions are frequent and other times sporadic and informal—the connections built through repeated interactions are crucial: partners learn from CLIMAS researchers and CLIMAS researchers learn from their partners. Perhaps less tangible than instrumental outcomes like economic policies or operational decisions, connectivity outcomes lay the groundwork for societal and environmental change.

Evidence and Case Studies of Societal Impact

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

CLIMAS Investigators: B. McMahan, A. Gerlak

Tucson Electric Power (TEP) contracted with CLIMAS researchers, based on a previous project, to explore plausible scenarios for greenhouse gas and carbon reduction in their energy portfolio. TEP depends more heavily on fossil fuels than the average U.S. electric utility. Researchers found that in 2019 TEP used coal and natural gas for 87% of its electricity supply—while the national average is 62%. TEP is using results from this research to switch from fossil fuels to more sustainable renewable energy use.

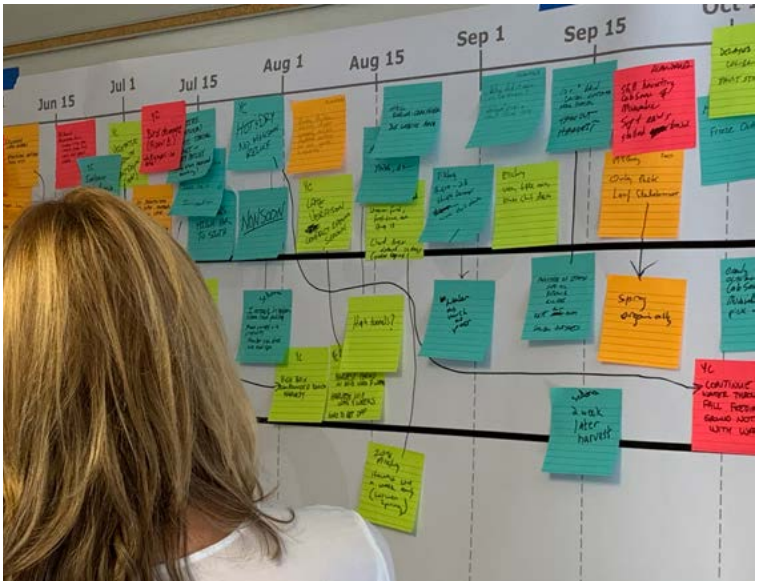
In a series of 5 workshops between 2019-2020, researchers shared updates on activities and preliminary findings and solicited feedback from Tucson Electric Power's Stakeholder Advisory Council. Feedback included that researchers were valued as honest brokers of a politically contentious issue. Stakeholders also appreciated the transparency of the research process and that the data was stored in an open access data repository. In a forum in Spring 2020, researchers presented a cumulative emissions framework—which empirically tracks the *timing and intensity of emissions reductions*, an innovation from tracking percentage reduction only. Several attendees

> *TEP is using this research to switch from fossil fuels to renewable energy*

asked how they might adapt this framework for their own utilities to track emissions and reductions. In May 2020, researchers presented their final findings at an all-day workshop to solicit public comment about TEP's plans to reduce greenhouse gas emissions, while providing affordable electric service.

Tucson Electric Power, their sister company UniSource Energy Services, and their parent company UNS Energy Corporation, are subsidiaries of Fortis, which owns utilities serving more than 3 million customers across Canada, the United States, and the Caribbean. The analysis and framework used in this project demonstrate the value of starting sooner than later to reduce emissions, as well as the impact of overall percent reductions. TEP's current Integrated Resource Plan reflects much more aggressive reductions targets than before. It also includes a more transparent and empirical process to justify the recommendations in their plan than other utilities.

Adobe Stock | Solar panels and wind power generation equipment.



Jeremy Weiss | Developing a decision calendar with stakeholder partners.

Evidence and Case Studies of Societal Impact

Community Climate Profiles

CLIMAS Investigators: A. Meadow, J. Weiss, L. Keith, S. LeRoy

From the Sustainability Coordinator in Sedona, AZ:

> "We have been conducting our Climate Action Plan virtual open houses over the past few weeks and the Climate Profile has been invaluable." The City Manager's office received a question from a Sedona City Councilmember about a chart for average annual temperature. The Sustainability Coordinator sought the data from CLIMAS researchers to answer this and other questions from the Sedona community. The Sedona City Council used information in the report to inform their plans for climate adaptation. However, in March 2020, the Council decided not to adopt the Global Covenant of Mayors for Climate and Energy; rather they would seek their own steps toward sustainability.

From The Highlands at Dove Mountain:

> "You have gathered so much information that has given us the perspective we need as we prepare the report on our project. When we started our project, we never imagined that we could obtain such a relevant perspective. As you recall, our Project Team is considering variability over the next five to ten years in four factors: climate change, aging and the changing lifestyles of our potential and present residents, trends in golfing--costs as well as interest in the sport--and the development of the Dove Mountain and Marana areas. What makes your report of such importance is that climate change will have a significant effect on the other three factors." This retirement community is using the profile to guide their 5-year action plan. The profile has been of particular value to their Architecture and Landscape and Common Area Committees.

Dan Ferguson | A view of the Vermillion Cliffs of northern Arizona.

Impacts of Climate Extremes to Interstate and Local Trucking Industry across NM and AZ

CLIMAS Investigators: D. DuBois; A. Arredondo; Z. Ghodsizadeh; J. Fuentes; J. Gutierrez; J. Consford; T. Ramirez; S. Engle; M. DeAntonio

From New Mexico Department of Transportation:

> "Through this [interaction with CLIMAS RISA] we were able to quickly build up a level of knowledge about dangers in the area and the frequency of dust storms."

Impacts from this project were also covered by news media:

> "DuBois uses nine cameras set up along I-10 to capture footage of dust storms. As of 2018, he had nearly 100 million images in his archive, he said. In 2019, one of his graduate students used the footage to develop an artificial intelligence algorithm to classify certain types of dust storms on the Lordsburg playa. 'The computer can tell if it's a dust storm or not, and I'm having my students train the computer to do that for us. The ultimate goal would be to have something that's automated and can send out an alert once the computer thinks there's a dust storm,' he said. 'This work will lead to providing an early warning to Department of Public Safety officers and NMDOT staff on impending dust storms.'
>
> In a 2018 environmental assessment, NMDOT reported that DuBois' cameras captured several convective storm outflow events, which formed during afternoon thunderstorms and covered large areas with dust. The cameras also recorded unpredictable high-wind events that created dust plumes with concentrations of loose sediment, resulting in zero visibility, according to the report. The dust originates from soil particles on the surface of the nearby playa and surrounding areas, and it is generated by a regular surface disturbance by livestock and vehicle traffic; alteration of surface hydrology; depleted vegetation; and the presence of exposed saline-sodic soils.
>
> Additionally, DuBois and NMDOT are evaluating the effectiveness of certain dust mitigation strategies, including water-flow rebatement and revegetation. However, revegetation can be difficult due to the alkaline nature of the soil, DuBois said. 'The pH is really high, so almost nothing grows on that. But some native grasses, such as alkali sacaton, which grows on the outskirts of the playa, are very adaptable to salty soils. The problem is they grow up really slow, and it may take several years for it to germinate,' he said, adding that the dust mitigation research is ongoing. 'There's is still a lot more work to be done out there to make it safer,' he added."

Dave Dubois | Dust storm conditions developing across the I-10 Freeway.

> *"There's is still a lot more work to be done out there to make it safer"*

New Mexico State University research aimed at making I-10 safer. Carlos Andres Lopez. Deming Headlight

https://www.demingheadlight.com/story/news/2020/04/20/new-mexico-state-university-research-aimed-making-10-safer/5165983002/

CLIMAS Contributions to the **NIDIS Regional Drought Early Warning System**

Several CLIMAS projects aim to advance drought early warning systems in the Southwest U.S. These projects will help identify best practices in employing more relevant, timely, and unique drought monitoring strategies needed for Arizona and New Mexico and will inform the Inter-Mountain West Drought Early Warning System (IMW-DEWS). Current findings are described for each project below:

The Lower San Pedro Conservation Collaborative: Stakeholder Engagement on Climate and Environmental Vulnerability

CLIMAS Investigators: B. McMahan; D. Ferguson; M. Crimmins

This project aimed to better characterize the complexity of drought vulnerability in the Lower San Pedro watershed. CLIMAS investigators engaged with a mix of stakeholders with shared interest in better understanding how drought and climate vulnerability might shape future climate risks.

- Stakeholders varied on whether current drought was a new phenomenon or part of natural variability. Drought and climate are not the primary area of concern among stakeholders.
- Stakeholders discussed general data and information needs related to regional sustainability, rather than specific needs or gaps; however, tailored tools and information were preferred over broad decision support.
- The variable timescale, duration, and intensity of drought means existing climate services may offer competing or contradictory perspectives on regional drought impacts and management.

USDA Livestock Forage Disaster Program and Ranching in the Southwest U.S.

CLIMAS Researchers: M. Crimmins, M. McClaran, C. Greene

The US Drought Monitor categories do not accurately capture the timescales of climate variability driving forage production and drought impacts across Arizona and New Mexico. Therefore, the current system may understate the extent of losses and need for compensation of Southwest ranchers. This study evaluates how the current application of the Drought Monitor in the LFP addresses drought and wildfire risks faced by Arizona and New Mexico ranchers and will seek out drought monitoring best practices specifically for rangeland systems.

Evaluating Existing and Developing New Drought Indices Using Modeled Soil Moisture Time Series

CLIMAS Investigators: M. Crimmins, M. Schaap, C. Rasmussen, D. Ferguson, T. McKellar

This research focuses on the Las Cienegas National Conservation Area (NCA) to examine longer-term drought impacts. The assessment shows how seasonality and precipitation timing and frequency relate to monthly scale precipitation-based drought indices. The modeling approach was also used to assess the performance of temperature-based indices and further explore the role of increasing temperatures in driving drought stress across the region. CLIMAS researchers are working with the Las Cienegas Watershed group and may be able to recommend specific drought indices for their ongoing State of the Watershed monitoring.

An Assessment of Drought and Climate Vulnerability and Resilience in the Rio Grande Basin

CLIMAS Investigators: C. Greene; D. Ferguson; B. McMahan

The 2018 New Mexico Drought Plan calls for more in-depth assessments of NM drought vulnerabilities. This project contributes to this need by identifying stakeholder concerns and drought research priorities along the Rio Grande Basin. This assessment engages areas of concern identified by the NM Drought Task Force, including water, economy, fire, recreation, health, agriculture, and the environment.

A Colorado River Shortage Declaration: Planning, Responses, and Consequences

CLIMAS Investigators: G. Frisvold, C. Hu, X. Wu

In response to prolonged drought conditions and declining storage capacity in Lake Mead, the Bureau of Reclamation called upon Colorado Basin States to develop new drought contingency plans to limit the draw-down of Lake Mead. Arizona's Drought Contingency Plan (DCP) calls for significant reductions in surface water supplies delivered to irrigated agriculture in Pinal County. This project considers the effects of these reduced water supplies on: crop production in Pinal county; Arizona dairy production and non-agricultural sectors in the Pinal County economy; and recreational demand around Lakes Mead and Powell. These surface water reductions may reduce the sustainability of agricultural production in Central Arizona.

- Reducing water supply by 300,000 acre-feet to Pinal County agriculture would result in an estimated $30.7 million USD and 448 fewer jobs.
- Alfalfa land fallowing could lead to price increases which would affect Arizona's dairies, the primary purchasers of the state's alfalfa. A 10% drop in Arizona alfalfa acreage due to land fallowing would initially increase AZ alfalfa prices by 11.6%.

Sectoral Impacts of Drought and Climate Change

CLIMAS Researchers: G. Frisvold, M. Crimmins

Project results estimate how drought affects value in agriculture and tourism industries in AZ.

- Short-term drought measures such as the one-month or three-month Standard Precipitation Indexes do not capture negative effects of drought to park visitation or agriculture. Long-term drought measures of 24 months or more are better at capturing negative impacts.
- Drought affects AZ agriculture, as measured by crop insurance indemnities, in fundamentally different ways than in other parts of the country. Drought has little effect, as long as growers have access to irrigation water. Prolonged drought affects agriculture by reduced availability of irrigation water. Effects are not lower crop yields, but rather reductions in acres planted. These non-linear effects make forecasting drought effects especially difficult.
- Drought has different effects on visits to AZ state parks, depending on the time frame. Drier conditions during a month increase visits in that month and wetter conditions discourage visits. Longer term drought, as measured by the 24-month Standard Precipitation Index, are associated with reductions in visits to park sites.

Southwest Tribal Data Summit: Partnering with Southwest Indigenous Communities to Identify Data

CLIMAS Investigators: S. Carroll, D. Ferguson, S. Leroy

A paper resulting from the 2018 summit explores the implications of Indigenous data sovereignty and Indigenous data governance for Native nations and others. Researchers argue for the repositioning of authority over Indigenous data back to Indigenous peoples. At the same time, there are also significant obstacles to rebuilding effective Indigenous data systems and the process will require resources, time, and partnerships among Native nations, other governments, and data agents. This document, intended for governments, institutions, and others working with Indigenous data, provides broad guiding principles for the governance of Indigenous data within big data, open data, and open science contexts. Such principles include collective benefit, authority to control, responsibility, and ethics.

Education and Training

Environment & Society Fellowship Program

The Environment & Society Fellowship was created in 2013 by CLIMAS, with support from the University of Arizona Office of Research, Innovation, and Impact. The fellowship, managed by Investigators G. Owen and B. McMahan, provides training and funding for graduate students to practice use inspired research and science communication. Since its inception, the Fellowship program has funded 24 graduate students.

https://www.climas.arizona.edu/education/fellowship-program

2019 Environment and Society Fellows

Hybrid Waters: Informal Water Provision, Municipal Governance and Household Water Security in Nairobi's Informal Settlements

Nupur Joshi, PhD Student, School of Geography and Development

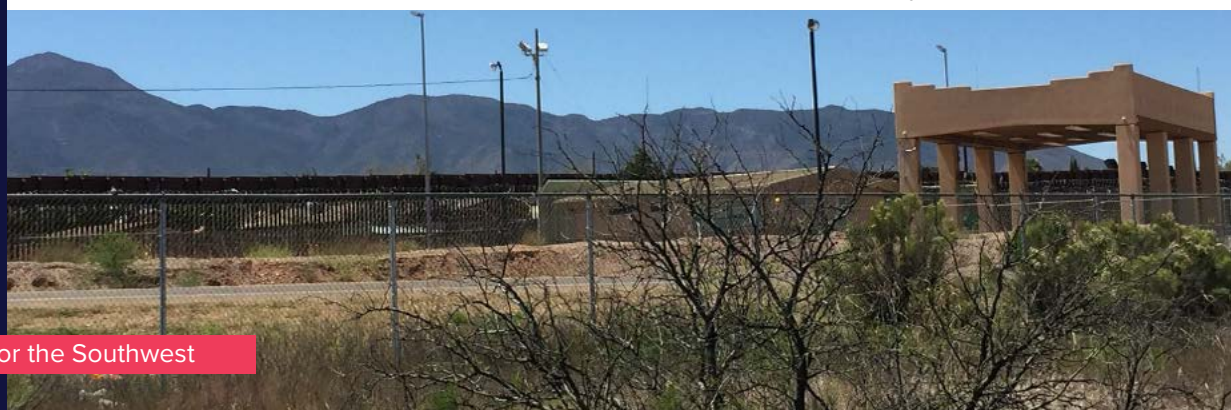
This project included a spatial analysis of informal water infrastructures, locally called 'water cartels,' and their health implications on women. It addressed water quality, affordability, and accessibility issues. The fieldwork supported by this fellowship led to sharpening and modifying research questions, methodology, and instruments for a dissertation research proposal and grant applications. Affiliations with University of Nairobi were developed, and research permits were secured for dissertation fieldwork. When Nupur returns to the field, she will present preliminary findings to municipal officials, community members. The fellowship helped Nupur align her research questions to what local communities need and provided her the skills to communicate research findings with wider audiences.

Building a Risk Assessment at Naco Elementary School: A combined effort between Naco Elementary School, Cochise County Health and Social Services, and the University of Arizona

Alma Anides Morales, MS Student, Department of Environmental Science

Transboundary untreated wastewater flows have affected Ambos Nacos (Naco, Sonora and Arizona) since the mid-1980s. During summer monsoon and winter rains, elevated storm water flows create an overstrain on wastewater collection and treatment systems in Naco, Sonora which results in Sanitary Sewer Overflows (SSOs) that flow northward. Her research objectives were to: a) build capacity by co-implementing a water and soil sampling plan; b) assess potential health risks to Naco Elementary students; and c) share results with the Naco community and produce educational materials to promote a larger awareness around SSOs. With the Cochise County Health and Social Services, she co-developed an environmental monitoring plan and collected soil samples were collected in February, April, and July 2019. Alma also developed three surveys to use at Naco Elementary for parents, teachers, and the school's principal. Questions addressed students' hand-to-mouth behavior, duration (time) and outside location where students play/congregate, risk perception and risk communication. Data collection and analysis continues in 2020.

Alma Anides Morales | View of the US-Mexico border from Naco Elementary School.



Norma Villagomez Marquez's Project | A 10-year old's drawing conception of a rainwater harvesting system.

Discovering the Quality of Harvested Rainwater

Norma Villagomez Marquez, PhD candidate, Department of Environmental Science

Project Harvest engages community members through citizen science about the health of their harvested rainwater, soil, and plants. This project has over 200 participants in four communities throughout AZ. Norma set out to discover how much the children of Project Harvest participants knew about the citizen science work their parents were doing. Children were asked to illustrate their answers to four rainwater harvesting related questions. The illustrations were remarkably consistent. Typical illustrations of rainwater collection systems included roofs, buckets, cisterns, and gutters. There were also drawings that included non-traditional forms of collecting rainwater which included materials such as clay and bamboo. Three of the children who participated illustrated knowledge of rainwater contamination both microbial and organic as well as basic rainwater treatment in the form of nets or sieves.

Isotopes, geochemistry, citizen science and local partnerships as tools to build upon a fractured understanding of the hydrology of the Patagonia Mountains

Sean Schrag-Toso, MS Student, Department of Hydrology and Water Resources

This work built upon existing knowledge of the groundwater hydrology of the Patagonia Mountains in southeastern Arizona. It is intended to advance not only the understanding of groundwater movement in the mountains by the scientific community, but also further develop a basic understanding of groundwater movement by residents within the area. The project was planned with residents living within the Sonoita Creek watershed. Initial results indicate that most springs recharged at a high elevation during the winter months, and that there is hydrologic separation between the mountain block and the adjacent alluvial aquifer south of the Town of Patagonia. These insights helped develop a more holistic conceptual model of groundwater flow within the Patagonia Mountains. This conceptual model will inform the creation of a community-based monitoring plan. Regular collection of data by the group will contribute to future hydrologic studies within the basin and aid in making management decisions around water use by the Town Council.

2020 Environment and Society Fellows

Emily Cooksey

A PhD student in Environmental Health Science is collaborating with Southern California Coastal Water Research Project to conduct groundbreaking research with oysters to reduce human health risk from exposure to pathogenic Vibrio. She hopes to influence current oyster harvesting policy in Southern California.

JoRee LaFrance

A PhD student in the Department of Environmental Sciences, is researching surface water quality within the Little Bighorn River watershed. This project will determine which contaminants are elevated and which will have long lasting impacts. JoRee aims to support her tribe, the Apsáalooke/Crow, in their own efforts in setting their own water quality standards on the basis of cultural practices.

Education and Training

continued

UA AIR Research Computing Working Group

This group highlights what computer science and research computing can bring to natural and social science applications in environmental research, in terms of novel project development, data visualization and analysis, and science communication. Project development within this working group emphasizes student involvement and training to give students in computer science experience in real world examples. This framework also gives natural and social science researchers opportunities to collaborate across disciplines and in data or computer science intensive projects, and to work with student teams exploring options for innovative data aggregation, analysis, and visualization.

Melissa Merrick | A glowing sun sets behind a burned forest mountain top.

Transdisciplinary Environmental Science for Society Professional Development Program

CLIMAS Investigators: C. Woodhouse, D. Ferguson, G. Owen

Research Partners: G. Garfin, School of Natural Resources and the Environment; M. Ramirez-Andreotta; Department of Environmental Sciences; Office of Digital Learning; and Continuing and Professional Education program, University of Arizona.

https://science4society.sites.arizona.edu/

The Transdisciplinary Environmental Science for Society (TESS) program is designed to train researchers, practitioners, and educators to be well-equipped to successfully address and help solve complex environmental challenges. The focus is on theoretical insights and practical skills to improve research collaborations between many different kinds of experts. The program is currently designed as a series of three 20-hour online professional development courses:

1. fundamentals of transdisciplinary research,
2. practicing collaborative research, and
3. communication strategies and skills.

The first course ran in July 2019 and the second course is currently in development. The goal of the TESS program is to provide training in the theory and practice of transdisciplinary research so that students have the knowledge and perspectives needed carry out successful collaborative research.

Kunal Palawat

A MS student in Environmental Science, is creating a climate change and soil contamination informed community cookbook. They are working with the Mission Garden in Tucson, as well as community members in Dewey, Globe, Hayden, Tucson to develop recipes using foods grown in each of these places. The cookbook will include historical narratives of each dish.

Rachel Rosenbaum

A PhD student in Anthropology, is working with Recycle Lebanon in Beirut to facilitate the design and implementation of a data visualization platform. The platform, "Regenerate Lebanon," is an open source online platform visualizing interconnected environmental and infrastructural issues around the country and connecting people to solutions.

Making the Connection between Science and Decision Making" Graduate Seminar

CLIMAS Investigator: C. Woodhouse

Additional Support: University of Arizona – School of Geography and Development

This seminar, aimed at graduate students from any relevant discipline, explored concepts at the intersection between environmental science and decision making, including scientific information supply and demand, boundary organizations, co-production of knowledge, and knowledge networks, as well as recognition of the political context for decision making. After being taught for the past 10 years, this seminar has been discontinued along with the CESD certificate program. In spring 2020, a related grad seminar, Practicing Collaborative Research was taught with a focus on more of the practical aspects of collaborative research. In Spring 2021, the content from both of these seminars will be used in a core course—Change Research, Application, and Decision-making—required for the Global Change Graduate Interdisciplinary Program PhD minor.

Gigi Owen | Three night blooms opened on an organ pipe cactus.

Ben McMahan | A full moon sky across the Sonoran desert.

Appendix A: 2019-2020 Publications

Anderson T., C. Woodhouse, D. Ferguson. 2019. Upper Lake Mary: Lake Level Response to Climate Variability. Report to Flagstaff Water Services.

Austhof E., V. Berisha, B. McMahan, G. Owen, L. Keith, M. Roach, H.E. Brown. 2020. Participation and Engagement of Public Health Stakeholders in Climate and Health Adaptation. *Atmosphere* 11(265): 1-12. DOI: 10.3390/atmos11030265

Bickel A.K., D. Duval, G. Frisvold. 2019. Simple approaches to examine economic impacts of water reallocations from agriculture. *Journal of Contemporary Water Research & Education* 168: 29-48. DOI: 10.1111/j.1936-704X.2019.03319.x

Carroll S.R., D. Rodriguez-Lonebear, A. Martinez. 2019. Indigenous Data Governance: Strategies from United States Native Nations. *Data Science Journal* 18(1):31. DOI: 10.5334/dsj-2019-031

Carroll S.R., M. Hudson. 2019. CARE Principles for Indigenous Data Governance. Research Data Alliance International Indigenous Data Sovereignty Interest Group, September 2019. The Global Indigenous Data Alliance.

Carroll S.R., A. Martinez. 2020. Policy Brief: Indigenous Data Sovereignty in Arizona. Tucson: Native Nations Institute, University of Arizona and the Inter Tribal Council of Arizona. https://nnigovernance.arizona.edu/policy-brief-supporting-tribal-data-governance-indigenous-community-climate-resilience

Colby B. 2020. Acquiring environmental flows: ecological economics of policy development in western *U.S. Ecological Economics* 173: 106655. DOI: 10.1016/j.ecolecon.2020.106655

Crimmins T.M., M.A. Crimmins. 2019. Biologically-relevant trends in springtime temperatures across the United States. Geophysical Research Letters 46: 12377– 12387. DOI: 10.1029/2019GL085251

Crimmins M.A., and T.M. Crimmins. 2019. Does an early spring indicate an early summer? Relationships between intraseasonal growing degree day thresholds. *Journal of Geophysical Research: Biogeosciences* 124: 2628– 2641. DOI: 10.1029/2019JG005297

Frisvold, G. 2020. Improving Water Footprint Calculations Using Local Agronomic and Environmental Data. Final Report to Barilla Corporation.

Fuentes J. 2019. Using time-lapse footage to estimate mineral dust concentrations at heights correlating to passenger and commercial vehicles. MS Thesis, New Mexico State University.

Gutierrez J. 2019. Automated detection of dust storms from ground-based weather station imagery using neural network classification. MS Thesis, New Mexico State University.

Hiraldo D., S.R. Carroll. 2020. Policy Brief: Native Nation Rebuilding Lessons for Tribal Research and Data Governance. Tucson: Native Nations Institute, University of Arizona.

Hu, C. 2019. Econometric Analysis of the Arizona Alfalfa Market. MS Thesis. Department of Agricultural & Resource Economics. University of Arizona. https://repository.arizona.edu/handle/10150/634264

Isaaks R., B. Colby. 2020. Empirical application of rubinstein bargaining model in western U.S. water transactions. *Water Economics and Policy* 6(1): 1950010. DOI: 10.1142/S2382624X19500103

Jäger M.B., C. Behe, D.B. Ferguson, et al. 2019. Building an Indigenous Foods Knowledges Network Through Relational Accountability. *Journal of Agriculture, Food Systems and Community Development* 9(B): 45-51. DOI: 10.5304/jafscd.2019.09B.005

Keith L. 2019. Assessing Policy Innovation: Climate Action Planning in the U.S. Southwest. PhD Dissertation. University of Arizona, Tucson.

Keith L., B. McMahan, T. Wagner. 2019. Urban heat island maps and decision-making. University of Arizona, Climate Assessment for the Southwest (CLIMAS).

LeRoy S., A.M. Meadow, J. Weiss. 2018. Climate-Related Hazards in the Town of Oro Valley, Arizona. In *CLIMAS Community Climate Profiles.* Tucson: University of Arizona.

Martin J., G.T. Pederson, C.A. Woodhouse, E.R. Cook, M. McGuire, D. Broman, J. Lanini, et al. 2019. 1200 years of Upper Missouri River streamflow reconstructed from tree rings. *Quaternary Science Reviews* 224: 105971. DOI: 10.1016/j.quascirev.2019.105971

McGowan G. 2019. Geospatial analysis and quality control of monsoon season precipitation data from citizen reporters near Tucson, Arizona. MS Thesis, Geographic Information Systems Technology. University of Arizona.

Meadow A.M., S. LeRoy, J. Weiss, L. Keith. 2020. Climate Profile for The Verde Valley. In *CLIMAS Climate Profiles.* Tucson: CLIMAS, University of Arizona.

Meadow A.M., J. Weiss, S. LeRoy, L. Keith, S. Hausam, E. Nasser, S. Petersen, A. Basaraba, N. Russell. 2019. Climate Profile for the Pueblo of Laguna. In *CLIMAS Climate Profiles.* Tucson: CLIMAS, University of Arizona.

Ottman M., P. Brierly, G. Frisvold. 2020. Tools for Nitrogen Management of Wheat. Final Report to Barilla Corporation.

Owen G. 2020. What makes climate change adaptation effective? A systematic review of the literature. *Global Environmental Change* 62: 102071. DOI: 10.1016/j.gloenvcha.2020.102071

Owen G. 2019. Evaluating Effectiveness in Climate Change Adaptation and Socially-Engaged Climate Research. PhD Dissertation, School of Geography and Development, University of Arizona.

Smarik S.G., S. Aney, A. Boes, D. Brown, D. DuBois, B. Edwards, E. Elias, M. Eve, R. Steele, N. Webb, M. Wilson, G. Zwicke. 2019. Dust Mitigation Handbook. Washington, DC: U.S. Department of Agriculture. https://dust.swclimatehub.info/

Weiss J., M.B. Roudaut. 2020. Bud Break at Buhl Memorial Vineyard, 2016-2020, Climate Assessment for the Southwest (CLIMAS), University of Arizona.

Weiss J., M.B. Roudaut. 2019. Bud Break at Buhl Memorial Vineyard, 2016-2019, Climate Assessment for the Southwest (CLIMAS), University of Arizona.

Weiss J., M.B. Roudaut, A.M. Meadow. 2020. Review of the 2019 Winegrape Growing Season in Arizona, Climate Assessment for the Southwest (CLIMAS), University of Arizona.

White S., S.R. Carroll. 2019. Policy Brief: Supporting Tribal Data Governance for Indigenous Community Climate Resilience. Tucson: Native Nations Institute and Climate Assessment for the Southwest, University of Arizona.

Woodhouse C.A., D.M. Meko, E. Bigio. 2020. A long view of southern California water supply: perfect droughts revisited. *Journal of the American Water Resources Association* 56: 212-229. https://doi.org/10.1111/1752-1688.12822

Wu X. 2019. Recreation Visits to Lake Mead and Glen Canyon National Recreation Areas: A Replication Study. MS Thesis. Department of Agricultural & Resource Economics. University of Arizona. https://repository.arizona.edu/handle/10150/634266

Appendix B: Current CLIMAS Projects

Identifying gaps in stakeholder needs regarding the climate-health connection

CLIMAS Investigators: H. Brown, D. Ferguson, E. Austhof
Research Partners: Arizona Department of Health Services (ADHS); Arizona State University
End Users: ADHS; Center for Disease Control and Prevention (CDC); Pinal County Department of Public Health; Maricopa County Department of Public Health
Additional Support: ADHS; CDC

As part of the Climate-Ready States and Cities Initiative in 2009, the CDC engaged 16 states and two large cities to implement a five-step program Building Resilience Against Climate Effects (BRACE). The CDC is now supporting the monitoring and evaluation of the efforts developed under BRACE: Climate and Health Adaptation Monitoring Program (CHAMP). To support these monitoring and evaluation efforts, this project seeks to quantify the scope of BRACE initiatives through a national survey, which will be distributed in Summer 2020. ADHS has helped design this survey. Results will be reported to ADHS and the CDC. CLIMAS investigators are also working to map the Arizona network of climate/health advocates and to identify knowledge gaps about climate and health connections. This information is informing adaptation and mitigation plans for the state of Arizona as well as Pinal and Maricopa County's Implementation and Monitoring Strategies.

2019-2020 Outputs:

Publications: Austhof et al. 2020. Participation and Engagement of Public Health Stakeholders in Climate and Health Adaptation. This paper describes various relationships between scientists and public health stakeholders; these relationships helped scientists develop more collaborative projects over time.

Is adaptation maladaptation: an assessment of mosquitoes and water harvesting

CLIMAS Researchers: H. Brown, L. Keith, M. Ruiz
End Users: Tucson Water; Pima County Vector Control
Additional Support: Pacific Southwest Regional Center of Excellence for Vector-Borne Disease Research at the University of California; Center for Disease Control and Prevention

Rainwater harvesting design techniques are heralded as tools for building a sustainable community and resilience against climate change impacts. When rainwater harvesting strategies fall into disrepair or are designed improperly, they may inadvertently become sources of mosquitoes. We hypothesize that well-maintained green infrastructure design strategies have the greatest impact on conservation while limiting the negative consequences of mosquitoes. If green infrastructure is to be used as an adaptation technique, then it is important to better understand when it works best. Partnering with Tucson Water, which is responsible for some green infrastructure installation and Pima County Vector control represents two key stakeholders in addressing whether this is maladaptation.

Southwest Tribal Data Summit: Partnering with Southwest Indigenous Communities to Identify Data

CLIMAS Investigators: S. Carroll, D. Ferguson, S. Leroy
Research Partners: D. David-Chavez (Borikén Taíno), Colorado State University; A. Curley (Diné), University of North Carolina; S. Yazzie (Diné), Albuquerque Area Southwest Tribal Epidemiology Center; T. Lane (Diné), Inter Tribal Council of Arizona
Additional Support: National Integrated Drought Information System (NIDIS); Native Nations Institute, via the Morris K. Udall and Stewart L. Udall Foundation

As Indigenous communities in the U.S. and around the world confront ongoing climate hazards and plan for future problems related to climate change such as threats to human health, a variety of challenges have arisen related to the data necessary to support decision-making. As Native nations seek to utilize the best available data and information to build climate resilience and healthy, sustainable communities, issues around data relevance, ownership, access, possession, and control arise. For example, a Native nation may collect their own data or have access to culturally sensitive traditional knowledge useful to inform climate-related decisions, but they may not wish to make that data widely available even though it may be helpful when seeking funding or engaging in regional climate adaptation planning.

2019-2020 Outputs:

Publications: 1) Carroll et al. 2019. Indigenous Data Governance: Strategies from United States Native Nations. Data Science Journal. This paper explores the implications of Indigenous data sovereignty and Indigenous data governance for Native nations and others. We argue for the repositioning of authority over Indigenous data back to Indigenous peoples. We also recognize that there are significant obstacles to rebuilding effective Indigenous data systems and the process will require resources, time, and partnerships among Native nations, other governments, and data agents. 2) CARE Principles for Indigenous Data Governance. 2019. The Global Indigenous Data Alliance. This document, intended for governments, institutions, and others working with Indigenous data, provides broad guiding principles for the governance of Indigenous data within big data, open data, and open science contexts. Such principles include collective benefit, authority to control, responsibility, and ethics. *https://www.gida-global.org/care*

Policy Briefs: 1) Supporting Tribal Data Governance for Indigenous Community Climate Resilience. 2019. This brief, written with community partners summarizes the workshop and identifies next steps for tribes, universities, federal agencies, and others who want to learn more about tribal interests and needs related to Indigenous data sovereignty in Arizona. *https://nnigovernance.arizona.edu/policy-brief-indigenous-data-sovereignty-arizona-setting-agenda*. 2) Indigenous Data Sovereignty in Arizona. 2020. 3) Native Nation Rebuilding Lessons for Tribal Research and Data Governance. 2020. These two briefs were produced for tribes, universities, federal agencies, and others who want to learn more about tribal interests and needs related to Indigenous data sovereignty in AZ. *https://nnigovernance.arizona.edu/policy-brief-supporting-tribal-data-governance-indigenous-community-climate-resilience*

Presentations: Three presentations about indigenous data sovereignty and governance to stakeholder and academic audiences.

Website: Indigenous Data Sovereignty Summit in Arizona 2019. Attendees and others interested in learning more about tribal

interests and needs related to Indigenous data sovereignty use this site, which provides access to video and slide decks that were previously unavailable. It represents a collaboration among the Native Nations Institute and the Inter Tribal Council of Arizona, with additional support from Arizona State University, American Indian Student Support Services; Office of Tribal Relations at The University of Arizona; Arizona State University Office of American Indian Initiatives; and Indigenous Strategies, LLC. *https://nni.arizona.edu/programs-projects/policy-analysis-research/indigenous-data-sovereignty-and-governance/summits-conferences/indigenous-data-sovereignty-summit-2019*

Adaptation Strategies for Water and Energy Sectors in the Southwest

CLIMAS Investigators: B. Colby, G. Frisvold, C. Woodhouse, R. Young, E. Joiner
Research Partners: G. Garfin; B. McGreal, A. Walker – University of Arizona; U.S. Bureau of Reclamation, U.S. Department of Agriculture; NM Office State Engineer; University of Nevada Reno; University of Colorado; Sonoran Institute; Nature Conservancy; Walton Family Foundation
End Users: U.S. Bureau of Reclamation; U.S. Department of Agriculture; Arizona Department of Water Resources; Central Arizona Project; Salt River Project; New Mexico Office of State Engineer; NM Interstate Stream Commission; NM State University; Lower Rio Grande Water Users Association; Tucson Water; Tucson Electric Power
Additional Support: NOAA Regional Climate Centers; NOAA Sectoral Applications Research program, Bureau of Reclamation, Walton Family Foundation, Sonoran Institute
Persistent drought and climate change affect water and energy costs, and hence choices made by farms, cities and industrial water and energy users, as well as energy and water providers' operations. This project examines potential climate change and variability adaptation strategies related to water and energy in the Colorado River and Rio Grande Basins, including northwestern Mexico. Researchers are investigating how climate influences the market price of water and developing a menu of water and energy supply reliability tools with guidelines for using these tools.
2019-2020 Outputs:
Publications: 1) Colby B. 2020. Acquiring environmental flows: ecological economics of policy development in western U.S. 2020. Ecological Economics. Presents development of water policies that support water acquisitions for environmental needs. 2) Isaaks R., B. Colby. 2020. Empirical application of rubinstein bargaining model in western U.S. water transactions. Water Economics and Policy. Presents bargaining strategies for acquiring water for urban and environmental needs.
Presentations: Three presentations on water trading and water settlements to stakeholder and academic audiences.

USDA Livestock Forage Disaster Program and Ranching in the Southwest U.S.

CLIMAS Researchers: M. Crimmins, M. McClaran, C. Greene
Research Partners: National Weather Service; USDA Natural Resources Conservation Service; AZ Section of the Society for Range Management
End Users: Ranchers in AZ and NM; AZ and NM state drought monitoring committees; U.S. Drought Monitor authors; Regional drought monitoring experts
Additional Support: National Integrated Drought Information System (NIDIS)
The 2014 Farm Bill permanently authorized the USDA Livestock Forage Program (LFP), which provides compensation to livestock producers who suffer grazing losses caused by drought and wildfires. The LFP bases payment eligibility on drought status categories of the U.S. Drought Monitor. Yet, there is evidence that Drought Monitor categories do not accurately capture the timescales of climate variability driving forage production and drought impacts across Arizona and New Mexico. Therefore, the current system may understate the extent of losses and need for compensation of Southwest ranchers. This study evaluates how the current application of the Drought Monitor in the LFP addresses drought and wildfire risks faced by Arizona and New Mexico ranchers and will seek out drought monitoring best practices specifically for rangeland systems. This project connects with several others in the Southwest aimed to improve the efficiency and efficacy of drought monitoring across the region. These projects support drought early warning as conceived by NIDIS and will help identify best practices in employing more relevant, timely, and unique drought monitoring strategies needed for AZ and NM.
2019-2020 Outputs:
Presentation: One presentation on drought monitoring tools for AZ rangelands to federal and state land managers and ranchers.

Evaluating Existing and Developing New Drought Indices Using Modeled Soil Moisture Time Series

CLIMAS Investigators: M. Crimmins, M. Schaap, C. Rasmussen, D. Ferguson, T. McKellar
Research Partners: The Nature Conservancy
End Users: Las Cienegas Watershed Group; Land managers in USDA Natural Resources Conservation Service and the U.S. Bureau of Land Management; Drought monitoring committees in AZ; U.S. Drought Monitor authors
Additional Support: National Integrated Drought Information System (NIDIS); NASA Space Grant
In partnership with The Nature Conservancy, CLIMAS researchers are assessing the impacts of precipitation variability and temperature changes on vegetation production and mortality and identifying optimal drought monitoring metrics. It focuses on the Las Cienegas National Conservation Area (NCA) to examine longer-term drought impacts in this multi-use Bureau of Land Management NCA. The assessment shows how seasonality and precipitation timing and frequency relate to monthly scale precipitation-based drought indices. The modeling approach was also used to assess the performance of temperature-based indices and further explore the role of increasing temperatures in driving drought stress across the region. CLIMAS researchers have also been working with the Las Cienegas Watershed group as well and may be able to recommend specific drought indices for their ongoing State of the Watershed monitoring.
2019-2020 Outputs:
Web application: Prototype app to explore model data for the

Appendix B: Current CLIMAS Projects

Las Cienegas NCA study area
Presentations: Six presentations on HYDRUS soil moisture modeling to stakeholder and academic audiences.

Impacts of Climate Extremes to Interstate and Local Trucking Industry across NM and AZ

CLIMAS Researchers: D. DuBois; A. Arredondo; Z. Ghodsizadeh; J. Fuentes; J. Gutierrez; J. Consford; T. Ramirez; S. Engle; M. DeAntonio
Research Partners: NOAA NWS—Santa Teresa; NOAA NWS—Phoenix; U.S. Bureau of Land Management, Las Cruces; Jornada Experimental Range; National Wind Erosion Network; NM Department of Transportation; University of Texas El Paso; Mesilla Valley Transportation
End Users: NOAA NWS—Albuquerque, Santa Teresa, Phoenix, and El Paso Weather Forecast Offices; NM Department of Transportation; AZ Department of Transportation; Mesilla Valley Trucking; NM Trucking Association; Bureau of Land Management, Las Cruces Office
Additional Support: NOAA NWS; NM Department of Transportation; Bureau of Land Management, Las Cruces Office
Extreme weather impacts our transportation system in many ways. This project focuses on dust storms, particularly as they connect to drought. One goal is to increase the safety of drivers during these events along the Interstate 10 in southwestern New Mexico, where danger from dust storms often occurs. An early warning dust forecast system could minimize the number of vehicle accidents and associated fatalities on New Mexico highways. A neural network camera study indicated an accuracy of 97% and a precision of 94% for dust storm classification utilizing a combination of hue, saturation, and value bands. Researchers successfully acquired additional instrumentation to test a new early warning system that is different from roadway information systems often installed along highways. A Vaisala CL51 ceilometer was purchased by NMDOT in 2019 to sense dust plumes as they form over the dust source areas. The instrument is currently being tested in the laboratory and will be tested outside during Summer 2020 to determine locations where it will be most useful.
2019-2020 Outputs:
Publications: 1) Gutierrez J. 2019. Automated detection of dust storms from ground-based weather station imagery using neural network classification. Demonstrates a methodology to classify dust storms from continuous time-lapse camera imagery using a feed-forward-neural-network of Red-Green-Blue (RGB) and Hue-Saturation-Value (HSV) color spaces. This information will help develop tools to sense dust storms and provide early warning to decision makers and first responders. 2) Fuentes J. 2019. Using time-lapse footage to estimate mineral dust concentrations at heights correlating to passenger and commercial vehicles. This study used particle size distribution measurements and time-lapse imagery of dust events to determine the feasibility of estimating the mass concentration of dust during high-wind dust events.
Presentations: Two presentations about dust storms to stakeholder audiences.
Curricula: Research from this project informed a new module of the NM State University's vehicle training. Every person who drives a NMSU vehicle must listen to this module and pass a quiz about what to do during a dust storm.
Reference: This research project was highlighted in the 2019 NOAA Science Report, page 40. https://nrc.noaa.gov/Portals/0/edited%20final%20report.pdf

Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

CLIMAS Investigator: G. Frisvold
Research Partners: USDA – Natural Resource Conservation Service; University of Arizona Water Resources Research Center; Yuma County Water Users Association
End Users: Yuma County Water Users' Association; Arizona Small Grains Research and Promotion Council; Yuma Center for Excellence in Desert Agriculture; Greater Yuma Development Corporation; Arizona Cotton Growers Association; USDA Office of the Chief Economist: World Agricultural Outlook Board; Barilla Corporation
Additional Support: USDA – National Agricultural Statistics Service; USDA – Economic Research Service; Bureau of Reclamation; Cotton Incorporated; Barilla Corporation
This project examines the role of water management information and irrigation technologies in agricultural adaptation to climate variability and change in the 17 westernmost US states. Frisvold conducted statistical analysis to examine how factors such as farm size, water costs, and drought affect demand for water management information. The research examines trends in agricultural water management, investments in irrigation improvements, and water productivity. It also considers a "water footprint" or water use per unit of output.
Findings: Rather than being at odds, agricultural and environmental objectives can be compatible. Durum wheat producers in Yuma produce three things: durum wheat, vegetables grown as part of wheat-vegetable rotations, and ecosystem services to the Lower Colorado River Delta in the form of agricultural return flows. Over the last 30 years, Yuma agriculture transformed itself from perennial and summer-centric crop production systems to winter-centric, multi-crop systems that focus on high-value vegetable crops grown in rotations with durum wheat. This transformation has made Yuma one of the most productive and profitable agricultural areas in the world. To achieve this transformation, Yuma growers have made extensive changes in irrigation technologies and production practices and made substantial investments in irrigation infrastructure. These changes have led to actual, overall water conservation.
This project informed product sourcing decisions with direct impacts on more than 180 durum wheat producers in Arizona. Arizona wheat producers had sales averaging nearly $50 million per year over the past three years. The analysis of the project is pertinent to the purchasing decisions of a major buyer of this wheat.
2019-2020 Outputs:
Publications: 1) Tools for Nitrogen Management of Wheat. 2020. Final Report to the Barilla Corporation. This report explains how nitrogen management tools, such as optical sensors and the spectral indices, can optimize nitrogen fertilizer application, increase farmer profit, and reduce greenhouse gas emissions. 2) Improving Water Footprint Calculations Using Local

Appendix B: Current CLIMAS Projects

Agronomic and Environmental Data. 2020. Final Report to Barilla Corporation. Making use of local irrigation and precipitation data, this report shows how Yuma County's durum wheat water footprint is among the lowest of areas in the world producing durum wheat.
Presentation: One presentation on water footprint calculations for wheat producers and buyers.

A Colorado River Shortage Declaration: Planning, Responses, and Consequences

CLIMAS Investigators: G. Frisvold, C. Hu, X. Wu
Research Partners: NOAA National Climatic Data Center; U.S. Bureau of Reclamation; US Department of Agriculture; AZ Department of Water Resources; University of Arizona Water Resources Research Center; Central Arizona Irrigation Districts
End users: U.S. Bureau of Reclamation; AZ Department of Agriculture; AZ Farm Bureau; Agribusiness and Water Council of AZ; AZ Department of Water Resources; City, County, and Tribal government staff in Central Arizona; Irrigation districts in Central Arizona; Office of the Governor of Arizona; University of Arizona Water Resources Research Center; Pinal and Maricopa County Extension Offices
Additional Support: National Integrated Drought Information System (NIDIS); NOAA Regional Climate Centers; USDA Climate Hubs; USGCRP National Climate Assessment; US Bureau of Reclamation
In response to prolonged drought conditions and declining storage capacity in Lake Mead, the Bureau of Reclamation called upon Colorado Basin States to develop new drought contingency plans to limit the draw-down of Lake Mead. Arizona's Drought Contingency Plan calls for significant reductions in surface water supplies delivered to irrigated agriculture in Pinal County. This project considers the effects of these reduced water supplies on: crop production in Pinal county; Arizona dairy production and non-agricultural sectors in the Pinal County economy; and recreational demand around Lakes Mead and Powell. These surface water reductions may reduce the sustainability of agricultural production in Central Arizona.
2019-2020 Outputs:
Publications: 1) Bickel et al. 2019. Simple approaches to examine economic impacts of water reallocations from agriculture. Journal of Contemporary Water Research & Education. This article introduces three basic modeling approaches, using relatively low-cost and accessible data, to examine local economic impacts of water reallocations from agriculture. Given imminent water cutbacks, access to low-cost data and information that are easy to interpret is essential for effective community dialogue. 2) Hu, C. 2019. Econometric Analysis of the Arizona Alfalfa Market. MS Thesis. Alfalfa land fallowing could lead to price increases which would affect Arizona's dairies, the primary purchasers of the state's alfalfa. A 10% drop in Arizona alfalfa acreage due to land fallowing would initially increase AZ alfalfa prices by 11.6%. There is concern among state dairy producers, local government officials and rural stakeholder groups about how land fallowing could have negative spillover effects to the state's dairy industry. 3) Wu, X. 2019. Recreation Visits to Lake Mead and Glen Canyon National Recreation Areas: A Replication Study. MS Thesis. A replication analysis of the relationship between lake volumes and monthly recreation visits to Lake Mead and Glen Canyon National Recreation Areas found that gasoline prices, which was omitted from the previous study, had a statistically significant negative effect on visits.
Presentation: One presentation about the economic impacts of the drought contingency plan to agricultural producers, input suppliers, farm lenders, conservation groups, and local government officials.

Sectoral Impacts of Drought and Climate Change

CLIMAS Researchers: G. Frisvold, M. Crimmins
Research Partners: USDA – Natural Resource Conservation Service; Gila River Indian Community; University of Arizona Federally Recognized Tribes Extension Program; Maricopa Food County Foods Coalition; Department of Agricultural and Resource Economics, University of Arizona; Department of Agricultural and Consumer Economics, University of Illinois; The Nature Conservancy
Additional Support: National Integrated Drought Information System (NIDIS); AZ Department of Water Resources; University Corporation for Atmospheric Research
This project examines the impacts of drought and climate change on agriculture and outdoor recreation and tourism in the Southwest. This project is part of a larger 4-state effort (Arizona, Utah, Colorado, and New Mexico) to evaluate economic effects of drought. This project has further multi-state collaboration, while highlighting Arizona's unique responses to drought. Arizona agribusiness is a $23 billion per year industry. The project results will estimate how drought affects the value of this industry in every county in Arizona.
Findings: Short-term drought measures such as the one-month or three-month Standard Precipitation Indexes do not capture negative effects of drought to agriculture to park visitation or agriculture. Long-term drought measures of 24 months or more do better to capture negative impacts.
Drought affects AZ agriculture, as measured by crop insurance indemnities, in fundamentally different ways than in other parts of the country. Drought has little effect, as long as growers have access to irrigation water. Prolonged drought affects agriculture by reduced availability of irrigation water. Effects are not lower crop yields, but rather reductions in acres planted. These non-linear effects make forecasting drought effects especially difficult.
Drought has different effects on visits to AZ state parks, depending on the time frame. Drier conditions during a month increase visits in that month and wetter conditions discourage visits. Longer term drought, as measured by the 24-month Standard Precipitation Index, are associated with reductions in visits to park sites.

An Assessment of Drought and Climate Vulnerability and Resilience in the Rio Grande Basin

CLIMAS Investigators: C. Greene; D. Ferguson; B. McMahan
End users: NM Drought Task Force Members
Additional Support: National Integrated Drought Information System (NIDIS)

Appendix B: Current CLIMAS Projects

The 2018 New Mexico Drought Plan calls for more in-depth assessments of NM drought vulnerabilities. This project contributes to this need by identifying stakeholder concerns and drought research priorities along the Rio Grande Basin. This assessment engages areas of concern identified by the NM Drought Task Force, including water, economy, fire, recreation, health, agriculture, and the environment. This project aims to expand CLIMAS network of collaborators and stakeholders in New Mexico and identify emergent drought research priorities that feed into subsequent years of CLIMAS/NIDIS project work.

Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making

CLIMAS Investigators: L. Keith; B. McMahan; T. Wagner
Research Partners: Arizona State University; Sonoran Institute; Trust for Public Land; Green Infrastructure/Low Impact Development Working Group; Urban Land Institute; American Planning Association
End Users: Bernalillo County, City of Albuquerque, City of Buckeye, City of Avondale, City of Las Cruces, City of Santa Fe, City of Tucson, City of Phoenix, Dona Ana County, Pima Association of Governments, New York City, NY, City of Miami, FL; New York City, Mayor's Office of Resiliency and the Urban Design Forum
Additional Support: University of Arizona – College of Architecture, Planning, and Landscape Architecture; University of Arizona – Office of Research, Innovation, and Impact
The impacts of the urban heat island (UHI) and extreme heat events are well documented, including increases in heat-related public health issues, stresses on urban ecology, and energy usage to mitigate the higher temperatures. Increases in urban heat is of particular concern to cities in the Southwest, since it counteracts the cooling that otherwise normally occurs at night. While UHI mapping and modeling has become more sophisticated in recent years, there is still an information gap between the heat maps and models, urban planning and design strategies to decrease heat, and the use of that information in policy decision making. This study documented the current use of urban heat maps and models in communities in Arizona and New Mexico and evaluated best practices and opportunities to increase their usability.
2019-2020 Outputs:
Webinar Series: Research connections from this project contributed to development of the University of Arizona Extreme Heat Network, an interdisciplinary community of research and practice on the causes, impacts, and strategies to increase resilience to extreme heat. The network hosts a webinar series. Six webinars were hosted during the reporting period with an average of 50 participants each. *https://heat.arizona.edu*
Publications: 1) Keith L. 2019. Assessing Policy Innovation: Climate Action Planning in the U.S. Southwest. PhD Dissertation. Focuses on climate action planning in arid lands with an overarching research question: How are cities in the U.S. Southwest planning for climate change? 2) Urban heat island maps and decision-making. 2019. CLIMAS Report. 3) Reviewer for Scorched: Extreme heat and real estate. Urban Land Institute. Report explains contributions to extreme heat and current innovations in planning, design, and real estate to mitigate extreme heat. *https://americas.uli.org/wp-content/uploads/sites/2/ULI-Documents/Scorched_Final-PDF.pdf*
Presentations: Ten presentations about urban heat island mapping or planning for extreme heat to stakeholder and academic audiences.
Podcast: Fundamentals of Extreme Heat and Climate Change with Dr. Ladd Keith of University of Arizona. America Adapts: The Climate Change Podcast. January 12, 2020. *https://www.americaadapts.org/episodes/fundamentals-of-extreme-heat-and-climate-change-with-dr-ladd-keith-of-university-of-arizona*

Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

CLIMAS Investigators: B. McMahan; M. Crimmins; P. Bunn; G. McGowan; H.-I Chang; R. Driesen; R. Dennis; T. Lorenzo; M. Herrera; B. Delgado
Research Partners: Arizona Institutes for Resilience – University of Arizona; National Weather Service Tucson; Institute for Energy Solutions – University of Arizona
End Users: NOAA NWS – Tucson and Phoenix; NOAA NWS Regional Climate Services Director; County Flood Control Districts; Pima County Office of Emergency Management; Oro Valley Police Department Municipal/Irrigation Outreach; Pima County Natural Resources Division
Additional Support: NOAA NWS – Tucson; Arizona Institutes for Resilience – University of Arizona; Research Innovation & Impact – University of Arizona; College of Agriculture and Life Sciences – University of Arizona; Institute for Energy Solutions – University of Arizona
This project aggregated data from numerous sources and created an improved visualization of monsoon heterogeneity for multiple regions in southern Arizona. Researchers identified a range of datasets, developed a data scraping and organization protocol, and curated these data into a dataset to be queried, visualized, or analyzed by current project personnel or anyone with access via the closed database API. The API is being finalized for public consumption. While the data visualization tools are available to the general public, the API will also grant access to any researcher interested in using these data for their own research or proposal development. These efforts resulted in significant improvements in small scale estimations and visualizations for monsoon precipitation.
2019-2020 Outputs:
Data: 1) CLIMAS Monsoon Data GitHub Repository: A shared data and code repository, where project personnel developed and shared code (R and Python), and which formed the core group that subsequently became the AIR Research Computing Working Group. 2) Aggregated Precipitation Database for Southern AZ: This dataset assembled precipitation data from state, federal, and local sources. It developed a protocol to clean and organize the data to make it usable and comparable within and across the networks. This process is a prototype for database development at a larger scale. 3) Database API: Beyond simply aggregating and using the data internally within the project team, the end goal is an open data repository for use by other researchers. These data will be made available to other

organizations or entities to develop research questions and applications with these data.
Online Tools: 1) The Monsoon Viewer shows current monsoon precipitation patterns, based on specific requests from National Weather Service as well as other emergency management stakeholders. They want next day decision support tools for post-event management – researchers designed the viewer with this application in mind. We are exploring a real-time use for the dataset, but the focus is on short term post-event recovery and management. http://monsoon.environment.arizona.edu/ 2) The Southwest U.S. Summer Monsoon Season Precipitation Mapping tool is a near real-time monsoon season precipitation mapping system developed in May 2019. https://cals.arizona.edu/climate/misc/SWMonsoonMaps/current/swus_monsoon.html.
Workshop: At the Pima County Hazard Mitigation Workshop, we presented the results of the ongoing monsoon data aggregation project in the afternoon session. Additional collaborative opportunities were made with those in attendance, including the Pima County Flood Control office, and the Oro Valley Police Department. Both were interested in using the aggregated data as a short turnaround decision support product for prioritizing post-monsoon event cleanup and recovery.
Publications: McGowan G. 2019. Geospatial analysis and quality control of monsoon season precipitation data from citizen reporters near Tucson, Arizona. MS Thesis.

Collaborative Research on Environmental Risks and Built Environment in the Borderlands of the Southwest

CLIMAS Investigators: B. McMahan, G. Rodriguez, L. Bishop, I. Palomo, R. Driesen, L. Pilli
Research Partners: NOAA NWS – Tucson; AZ Department of Environmental Quality; Asociación por Revegetación en Ambos Nogales; Sonora Environmental Research Institute; Borderlands Restoration
End Users: Schools and teachers in Ambos Nogales, Sonora and Arizona
Additional Support: Agnese Nelms Haury Program in Environment and Social Justice; EPA Border 2020 – Border Environment Cooperation Commission
This project emphasizes network development in the Sonora-Arizona border around environmental risks and air quality issues, small scale computing and technology, and small-scale solar feasibility. A possible outcome is to inform decisions about community solar prospects in Nogales, Sonora, such as a shared solar bank that multiple NGOs could use for power. Ongoing participation and presence are requisite parts of building and sustaining collaborative partnerships. The Covid-19 pause in travel shows how things begin to fade a little, although we are maintaining contact with the network through email, WhatsApp, and texting.
2019-2020 Outputs:
Website: La EcoCasa en Nogales, Sonora website aggregates recent work on solar and sensor technology, as well as more than 10 years of previous work in this network of partners. It summarizes information about the feasibility and capacity for solar power in Nogales and the role of sensor technology in tracking environmental risks https://nogalesecocasa.arizona.edu/.
Workshop: EcoCasa Site Launch – Oct 17, 2019, Nogales, Sonora. This workshop about climate, environment, sensor technology, and solar energy hosted 10 teacher and community members, 5 media, and 80-90 high school students. Provided an opportunity to pilot test docent materials for the EcoCasa, the website, and other educational materials about environmental education. This workshop was added to an existing Border 2020 meeting held in Nogales and was covered by local media. http://eldiariodesonora.com.mx/notas.php?nota=137881

The Lower San Pedro Conservation Collaborative: Stakeholder Engagement on Climate and Environmental Vulnerability

CLIMAS Investigators: B. McMahan; D. Ferguson; M. Crimmins
Research Partners: U.S. Bureau of Land Management; U.S. Bureau of Reclamation; Saguaro National Park; USFS Coronado National Forest; USFS Fish and Wildlife Service; AZ Department of Forestry and Fire Management; AZ Game and Fish Department; AZ State Land Department; Cochise County; Graham County; Pima County; Pinal County; San Carlos Apache Tribe; Aravaipa Property Owners Association; Cascabel Conservation Association; Lower San Pedro Watershed Alliance; Audubon; Sierra Club; Sky Island Alliance; The Nature Conservancy; Archeology Southwest; ASARCO; Salt River Project
End Users: Lower San Pedro Conservation Collaborative: Includes representatives from federal, state, and local government agencies, NGOs, local communities, the University of Arizona, and the private sector.
Additional Support: National Integrated Drought Information System (NIDIS)
Drought risks and vulnerability varies within regional stakeholder networks. This project aimed to better characterize the complexity of drought vulnerability in the Lower San Pedro watershed. CLIMAS investigators engaged with a mix of stakeholders with shared interest in better understanding how drought and climate vulnerability might shape future climate risks. The project takes a local-to-regional perspective on drought and climate vulnerability and asks how that could inform a drought early warning system.
Findings: 1) Stakeholders have a nuanced perspective on drought and climate as it relates to their specific concerns or area of expertise. Drought- and climate-focused activities will benefit from integration into regional stakeholder networks of experts. 2) Stakeholders varied on whether current drought was a new phenomenon or part of natural variability. Drought and climate are not the primary area of concern among stakeholders. 3) Stakeholders discussed general data and information needs related to regional sustainability, rather than specific needs or gaps; however, tailored tools and information were preferred over broad decision support. 4) The variable timescale, duration, and intensity of drought means existing climate services may offer competing or contradictory perspectives on regional drought impacts and management. Local experts who understand these issues, and can assess and integrate stakeholder concerns, will be well positioned to provide these networks with not only the data, but the context of the data, both of which will inform their use for various stakeholder

applications.

Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

CLIMAS Investigators: B. McMahan, A. Gerlak
End Users: Tucson Electric Power (TEP); Salt River Project; AZ Public Service
Research Partners: TEP; Western Energy Institute
Additional Support: TEP; Western Energy Institute

TEP contracted with CLIMAS, based on a previous research partnership, to explore plausible scenarios for greenhouse gas and carbon reduction in their energy portfolio. These scenarios focus on data internal to TEP regarding the economics of portfolio decisions and external social, environmental, or climatic factors that might affect these decisions. CLIMAS provided a critical assessment of the overall process to ensure that robust data and models were used in this scenario development.

The project analyzed energy portfolios based on emissions reduction targets and cumulative carbon budgets. These results identify whether the portfolio will hit specified warming targets (e.g., 1.5°C, 2°C) based on the carbon emissions. They also suggest expected temperature increases for each portfolio. Results from this project will inform the company's 2020 integrated resource plan.

Cumulative emissions offer a robust and empirical method to assess the warming impact of utility energy portfolio scenarios. They assess both the timing and intensity of emissions reductions, and highlight the additional emissions reductions that result when reductions move more quickly than a straight linear reduction. This emphasizes that the way these targets are achieved may be just as important as the targets themselves.

2019-2020 Outputs:

Publication: Greenhouse Gas Reduction Goal Planning Report - A report for Tucson Electric Power and their Stakeholder Advisory Council. Part 1 of this report provides an overview of the current scientific understanding of observed and projected global climate change, with an emphasis on the evidence behind these global processes and their impacts. Part 2 summarizes the frameworks for carbon reduction targets, describes the goals and targets of a sample of electrical utilities, and summarizes the characteristics of these utilities, such as size, fuel source, history, or target setting, and how it relates to their emissions. Findings were used in TEP's Integrated Resource Plan (June 2020). Results were also presented to the AZ Corporations Commission. *https://www.tep.com/wp-content/uploads/UA-TEP_Report_Phases-1-and-2_July2019_Revised-11.08.19-FINAL.pdf*.

Data: TEP Carbon Goals – Data and Process GitHub Repository. This repository contains the data and analysis University of Arizona researchers used to guide Tucson Electric Power's carbon goals as part of their 2020 IRP process. The models, assumptions, code, documentation, and results are publicly available. The code is open source and fully transparent. Anyone can replicate, test, or improve our analysis, or update it based on new information or data. The repository was cited in a news story, published on TEP's 2020 IRP web page, and cited in their 2020 IRP. Members of TEP's Stakeholder Advisory Council have given comments, responded to ideas, and provided suggestions for the repository. *https://github.com/CLIMAS-UA/tepcarbon/*.

Presentations: Five presentations about project findings and updates to representatives from TEP and TEP's Stakeholder Advisory Council. One presentation about final results to TEP, Fortis executives, the public, and media.

Media Coverage: Davis T. Tucson Electric Power gets an earful about how to cut greenhouse gases. Arizona Daily Star. June 8, 2020. *https://tucson.com/news/local/tucson-electric-power-gets-an-earful-about-how-to-cut-greenhouse-gases/article_6665fc8b-adf1-533e-997c-49c6dc85978f.html*

Community Climate Profiles

CLIMAS Investigators: A. Meadow, J. Weiss, L. Keith, S. LeRoy
Research Partners: Adaptation International; City of Sedona, AZ; Pueblo of Laguna, NM
End Users: Pueblo of Laguna, NM; Verde Valley region of the City of Sedona, AZ; AZ Land and Water Trust; City of Flagstaff; Tohono O'odham Nation Office of Emergency Management; Town of Oro Valley, AZ Office of Emergency Management; The Highlands at Dove Mountain
Additional Support: Adaptation International

Climate change adaptation planning requires decision-makers to envision the future of their communities, and make well-grounded assumptions about economic, demographic, and cultural trends that are likely to affect that vision. However, many communities lack the technical resources to compile and analyze climate data and research findings, thus making the information essentially inaccessible to them. This project addresses the lack of access to appropriate climate change information by producing climate profiles for communities to support their adaptation planning efforts.

2019-2020 Outputs:

Publications: 1. Climate Profile for The Verde Valley. 2020. In CLIMAS Climate Profiles. Tucson: CLIMAS. 2. Climate Profile for the Pueblo of Laguna. 2019. In CLIMAS Climate Profiles. Tucson: CLIMAS.

Presentations: Two presentations about research findings to Pueblo of Laguna stakeholders. One presentation to desert horticulturists about urban heat islands.

Regional Food System Resilience in Southern Arizona – Learning from COVID-19

CLIMAS Investigator: G. Owen
Research Partners: University of Arizona – Center for Regional Food Studies; University of Iowa – Dept. of Geographical and Sustainability Science and Global Health
End Users: City of Tucson; Local food producers in Tucson, AZ; UNESCO City of Gastronomy organization
Additional Support: University of Arizona – Center for Regional Food Systems

COVID-19 and its associated risks and quarantine policies have brought rapid change to people's lives in all kinds of ways. One thing that has not changed is people's need for food; but the ways that people access and prepare their food, and provide food for others, has shifted greatly. Understanding the types of changes and adaptations that people are making – in the midst of a crisis – will provide lessons about building resilient

and more just food systems that can respond to future health, environmental, and climate risks. The 2020 pandemic has uncovered more evidence of several long-standing injustices and inequities that are embedded U.S. political, economic, and healthcare systems. Inequities tied to race, gender, and income have been magnified in food systems, including inequities in food access, food policy, food production and distribution, and food sovereignty. While many people face food insecurity, a large percentage of food system is wasted in landfills, which emits a significant amount of the greenhouse gases responsible for climate change.

This project evolved out of the "Evaluating Adaptation Responses" project outlined in the CLIMAS proposal and represents a partnership with researchers in the University of Arizona's Center for Regional Food Studies. Each year this program develops a "State of the Tucson Food System" report. Results from this project will directly inform the 2021 report.

Findings: An initial scoping survey was distributed in May 2020 about how people's experiences with food access, preparation, and provision has been impacted by COVID-19 and their strategies to adjust to or cope with these impacts. Findings highlight the need for flexibility in operations and policies, for support to protect essential workers, and new strategies for food distribution, processing, and sales. This preliminary data is informing the next phase of research, which focuses on innovations and strategies in food production, processing, distribution, and waste management, as well as current inequities and injustices in the Tucson and Southern Arizona food system.

Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico

CLIMAS Investigators: J. Weiss, M. Crimmins, D. DuBois, G. Frisvold, A. Meadow, M. Roudaut

Research Partners: University of Arizona Cooperative Extension; New Mexico State University Cooperative Extension; Yavapai College Viticulture and Enology Program; Merkin Vineyards

End Users: University of Arizona Cooperative Extension; New Mexico State Cooperative Extension; Yavapai College Viticulture and Enology Program; Fruit and nut tree growers; Winegrape growers

Additional Support: NOAA NWS; NOAA NCEI; PRISM Climate Group; TopoWx; AZ Meteorological Network; U.S. Geological Survey

Orchards and vineyards are particularly sensitive to temperature and are increasingly important to rural economies of the Southwest. However, growers of these high-value perennial fruit and nut crops have limited climate information to support critical decisions about selecting sites and cultivars. This project involves Cooperative Extension in AZ and NM and individual growers to survey a set of orchards and vineyards currently under production to gather information about their siting and cultivars. An assessment will be made of the required temperature conditions for current cultivars, whether these have historically been met, and if they are likely to be met in the coming decades. Crop insurance indemnity records will be used to perform a financial assessment of how site and cultivar selection are functioning in the current regional climate. The suitability of present-day cultivars will be evaluated in the context of anticipated increases in regional temperature.

Findings: Based on established climate-viticulture indices used in academics and industry, 2 of 3 American Viticultural Areas in AZ and 2 of 3 in NM are at the warm end of the winegrape growing spectrum. Excessive heat in these areas can cause negative impacts to plant physiology and fruit quality and composition.

2019-2020 Outputs:

Publications: 1) Bud Break at Buhl Memorial Vineyard, 2016-2020. A comparative analysis of vine bud break dates 2016-2020 for individual cultivars collected by the stakeholder with chill and heat accumulation that will aid in predicting the start of the growing season. Requested by Merkin Vineyards and Yavapai College to better understand vineyard in the context of weather and climate. 2) Review of the 2019 Winegrape Growing Season in Arizona. 2020. A synthesis of attendee input during activities at the two 'Growing Season in Review' workshops.

Data: Climate, Soil, and Topography of American Viticultural Areas (AVAs) in Arizona. To help inform the expanding winegrape-growing industry in Arizona, we are compiling and visualizing data of several relevant aspects of climate, soil, and topography specific to the proposed Sonoita, Willcox, and Verde Valley AVAs. This standard information about winegrape-growing regions does not exist for Arizona AVAs. *https://cals.arizona.edu/research/climategem/content/arizona-avas*.

Newsletter: The Climate Viticulture Newsletter provides a quick look at timely climate topics relevant to winegrape growing in Arizona and New Mexico. Monthly and mid-month special issues are sent via email and posted online. Coverage of chill and heat accumulation in January-April helped schedule spring activities at Merkin Vineyards. *https://cals.arizona.edu/research/climategem/content/climate-viticulture-newsletter*.

Workshops: 1) Growing Season in Review Workshop for Arizona Winegrape Growers in Southeastern Arizona. 2) Growing Season in Review Workshop for Arizona Winegrape Growers in the Verde Valley. These workshops helped us strengthen and expand our stakeholder network.

Presentation: One presentation to an academic audience.

Colorado River State of the Science Report

CLIMAS Investigator: C. Woodhouse

Research Partners: US National Center for Atmospheric Research; US Bureau of Reclamation; NOAA - National Snow and Ice Data Center; University of Nevada-Reno, University of Colorado, Boulder; ETH Zürich; Lynker

End Users: AZ Department of Water Resources; US Bureau of Reclamation; California's Six Agency Committee; Central AZ Water Conservation District; Colorado River Water Conservation District; Colorado Water Conservation Board; Denver Water; Metropolitan Water District of Southern California; NM Interstate Stream Commission; Southern Nevada Water Authority; Utah Division of Water Resources; Wyoming State Engineer's Office

Additional Support: US Bureau of Reclamation; Colorado Water Conservation Board; Southern Nevada Water Authority

In spring 2018, a group of Colorado River basin water providers

approached the CLIMAS and Western Water Assessment (WWA) RISAS with a request for a comprehensive, state-of-the-science synthesis of the science related to Colorado River climate and hydrology. WWA took the lead in working with 15 researchers and 14 water agencies to develop a report. The final report, over 500 pages in length, was the culmination of 2 years of work to compile and interpret the latest research on this topic. By synthesizing the state of the science in the Colorado River Basin regarding climate and hydrology, this report seeks to establish a broadly shared understanding that can guide the strategic integration of new research into practice.

2019-2020 Outputs:

Publications: Colorado River Basin Climate and Hydrology: State of the Science. Western Water Assessment, University of Colorado Boulder. By synthesizing the state of the science in the Colorado River Basin regarding climate and hydrology, this report seeks to establish a broadly shared understanding that can guide the strategic integration of new research into practice. For Colorado River water providers and water managers. *https://wwa.colorado.edu/publications/reports/CRBreport/*.

Fact Sheet: Colorado River Basin Climate and Hydrology: State of the Science, A Collaborative Research Case Study. This web page documents the process through which this report was generated. *https://sway.office.com/F1DIHYaF36kgDuqK?ref=Link*

The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

CLIMAS Investigators: C. Woodhouse, D. Ferguson, T. Anderson

Research Partners: Flagstaff Water Services

End Users: Ron Doba Management Services, LLC; Central Arizona Project; US Forest Service; Salt River Project; Flagstaff Water Services

The overarching goal of this study is to evaluate the seasonal climatic components that control surface water supplies in the lower Colorado River basin (LCRB), with a specific focus on the influence of temperature on annual streamflow in recent decades. The project team identified interested resource management partners in the LCRB to help shape a research agenda that addressed climatic controls on surface water supplies in ways that are relevant to resource management. We began a dialogue in late summer 2018 with a small group (10-12) of potential research partners to identify research questions and have continued to work with a subset of these partners over the past year.

Findings: In an examination of the main climatic controls on annual streamflow, it was surprising to find that temperature may be less important in the lower Colorado River basin than in the upper Colorado River basin. In below-flow years, monsoon season precipitation was not a significant factor in explaining the variance in annual streamflow, except in the upper Gila River. However, in those years, monsoon season precipitation explains more of the variability than cool season precipitation.

2019-2020 Outputs:

Publications: Upper Lake Mary: Lake Level Response to Climate Variability. Report to Flagstaff Water Services about the climatic influences of upper Lake Mary levels. Flagstaff Water Services wanted to better understand control on their main surface water supply.

Data: Lower Colorado River basin Fact Sheets. This set of fact sheets describe the main results for the climate and streamflow analysis of the Salt, Gila, and Verde Rivers. They highlight the main points regarding streamflow and climate relationships, trends in key climatic variables, and the role of climate during multi-year droughts. *https://cwoodhouse.faculty.arizona.edu/content/influence-climate-lower-colorado-streamflow-variability*.

Presentations: Two presentations about temperature and streamflow in the LCRB to stakeholder audiences.

Melissa Merrick | View of sunset from the Pinaleño Mountains.