

Climate Adaptation Partnership for the Pacific (CAPP): Pacific RISA Phase II Final Report, 2010-2016

Current Pacific RISA Team Members

Principal Investigators

H. Annamalai, Laura Brewington, Maxine Burkett, Aly El-Kadi, Melissa Finucane, Victoria Keener, Nancy Davis Lewis, John Marra

Research Assistants

Zena Grecni, Krista Jaspers

Affiliate Researchers

Steven Anthony, Henry Diaz, Tom Evans, Jan Hafner, Dave Helweg, Adam Johnson, Alan Mair, Susanne Moser, Raymond Tanabe, Richard Wallsgrove, Chunxi Zhang

Post-Doctoral Researchers

Carlo Fezzi, Olkeba Tolessa Leta, Matthew Widlansky

Graduate Research Assistants

Christopher Schuler

Former Pacific RISA Team Members (2010-2016)

Principal Investigators

Cheryl Anderson, Kevin Hamilton, James Weyman

Research Assistants

Rodney Lui, Duncan McIntosh, Rachel Miller, Rachel Nunn

Affiliate Researchers

Carlos Andrade, Charlene Felkley, Klaus Hagedorn, Scott Kiefer, Axel Lauer, Lisa Miller, Carl Noblitt, Delwyn Oki, David Penn

Post-Doctoral Researchers

Kati Corlew

Graduate Research Assistants

Tazebe K. Beyene, Joe Jackrell, Pradip Raj Pant



The Pacific RISA team (left to right): H. Annamalai, Tom Giambelluca, Aly El-Kadi, Krista Jaspers, Victoria Keener, Maxine Burkett, Kirsten Oleson, Richard Wallsgrove, Laura Brewington, Nancy Lewis, John Marra.

Pacific Regional Integrated Sciences and Assessments (RISA) Program

The Pacific RISA program began in 2003 to create and sustain partnerships in Hawai‘i and the US-Affiliated Pacific Islands (USAPI) region. The Pacific RISA vision is to promote resilient and sustainable Pacific communities using climate information to manage risks and support practical decision-making about climate variability and change. During Phase II of the program (2010-2016), many Pacific Island communities made significant strides in pursuing progressive and science-based policies that facilitate adaptation to climate variability and change at the local, state, and regional levels. At a regional level, on September 5, 2013, leaders of the Pacific Islands Forum nations signed the Majuro Declaration in the Republic of the Marshall Islands, which highlighted the impacts of climate change in the Pacific and served as a call for action and broader climate leadership around the world. In the state of Hawai‘i, Climate Change Adaptation Priority Guidelines were passed into law in the 2012 state legislative session, mandating collaboration between local, state, and federal agencies, businesses and non-profits as they incorporate climate impact planning (Act 286). The Marshall Islands and American Sāmoa initiated groundwater monitoring for saltwater intrusion in low-elevation aquifer systems to help local organizations address public concerns, particularly during drought conditions.

Pacific RISA Phase II focused on a major cross-cutting issue of concern to Pacific Island stakeholders and decision makers: *How will climate variability and change, in combination with other population and environmental stressors, impact sustainable development in the Pacific region?* Four main research, assessment, and outreach activities were focused on building adaptive capacity to climate variability and change in diverse islands settings:

1. Conducting assessments of risk and vulnerabilities, and developing adaptation strategies.
2. Supporting the implementation of adaptation strategies for Pacific Island communities.
3. Evaluating adaptation plans and policy making in the Pacific region.
4. Evaluating the Pacific RISA program.

This report summarizes some of the Pacific RISA’s accomplishments in each of these areas.

Pacific RISA Partners

East-West Center (EWC)

RAND Corporation

Pacific ENSO Applications Climate Center (PEAC)

University of Hawai'i (UH):

- International Pacific Research Center (IPRC)
- School of Ocean and Earth Science and Technology (SOEST)
- Water Resources Research Center (WRRC)
- William S. Richardson School of Law
- SeaGrant
- Social Science Research Institute (SSRI)
- Island Climate Adaptation and Policy (ICAP)

University of Guam Water and Environmental Research Institute (WERI)

NOAA Climate Program Office (CPO)

NOAA Climate Prediction Center (CPC)

NOAA National Weather Service Pacific Region (NWS)

NOAA National Centers for Environmental Information (NCEI)

NOAA Pacific Islands Regional Office (PIRO)

Pacific Risk Management 'Ohana (PRiMO)

Secretariat of the Pacific Regional Environment Programme (SPREP)

Pacific Islands Applied Geoscience Commission (SOPAC)

National Center for Atmospheric Research (NCAR)

Pacific Disaster Center (PDC)

US Geological Survey (USGS) Pacific Islands Water Science Center (PIWSC)

US Fish and Wildlife Service (USFWS)

US National Park Service (NPS)

US Army Corps of Engineers (USACE)

US Army Garrison Hawai'i (USAG-HA)

Western Regional Climate Center (WRCC) Desert Research Institute (DRI)

Pacific Islands Climate Change Cooperative (PICCC)

Pacific Islands Climate Science Center (PI-CSC)

Pacific Islands Ocean Observation System (PacIOOS)

Pacific Climate Information System (PaCIS)

Pacific Islands Climate Services (PICS) Panel

US Department of Agriculture (USDA) Southwest Regional Climate Hub

Hawai'i Department of Land and Natural Resources (DLNR)

Hawai'i Commission on Water Resource Management (CWRM)

Hawai'i Department of Health

Hawai'i State Legislature

Honolulu Board of Water Supply

Honolulu Office of Planning

Blue Planet Foundation

American Sāmoa Environmental Protection Agency (ASEPA)

American Sāmoa Power Authority (ASPA)

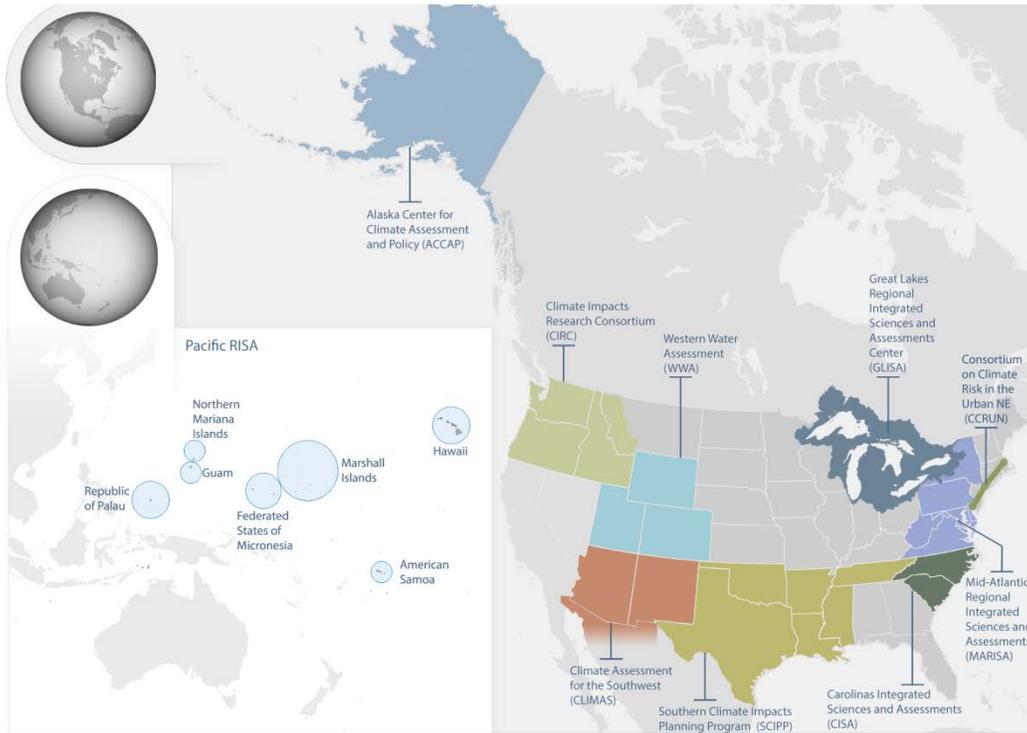
American Sāmoa National Park Service (ASNPS)

American Sāmoa Community College (ASCC)

Regional and local community groups, non-profits, and private enterprise

Stakeholder Engagement

Between 2010 and 2016, the Pacific RISA collaborated with and delivered information to hundreds of stakeholders, partners, and decision makers. Stakeholder engagement occurred through presentations in both academic and policy-making contexts, through workshops, webinars, publications, white papers, reports, policy briefings, newsletters, media interviews, documentary films, and participation in working groups and advisory boards.



Currently-funded RISA teams throughout the United States and Affiliated Pacific Islands.



Number of presentations and webinars around the world where the Pacific RISA has had an impact.

Table of Contents

I.	Climate Science	6
	Climate Projections for Hawai‘i and other Pacific Islands	6
	Hawai‘i Regional Climate Model Calibration and Testing.....	7
	Dynamical Seasonal Prediction of Precipitation for the Hawaiian Islands.....	7
II.	Freshwater Resources	9
	Future Climate Variability and Freshwater in American Sāmoa	9
	Streamflow and Precipitation Trends in Hawai‘i, American Sāmoa, and Guam.....	10
	Perceptions of Drought Risk by Farmers, Ranchers, and Service Providers	11
	The Central O‘ahu Watershed Project	12
	Estimating Groundwater Recharge under Future Climate Conditions: Maui	13
III.	Decision Support.....	14
	Future Scenario Planning for Maui	14
	Integrating Climate in Disaster Risk Assessment	15
	El Niño and Pacific Island Fact Sheets	16
	Drought Dashboard for Republic of the Marshall Islands	16
	Social Network Analysis.....	17
	Hawai‘i Law and Policy Toolkit.....	18
	American Sāmoa Water and Policy Analysis	19
IV.	Science Communication	20
	Regional Input to the US National Climate Assessment (the PIRCA)	20
	The PIRCA Forum.....	21
	‘O Ke Au I Kahuli: Pehea La Ka Hawai‘i E Pono Ai Traveling Forum.....	22
	Preserving Freshwater Resources in American Sāmoa.....	23
	Pacific Climate Information System Dialogues	24
	Hawai‘i-Pacific Highlights of the Third U.S. National Climate Assessment	24
V.	Education and Outreach	25
	Social Media Platforms	25
	Climate Matters “Documoments”	25
	United Nations Development Programme “Best Practice”	26
	East-West Center New Generations Seminar	26
VI.	Impact Evaluation	27
	Focused Independent Evaluation	27
	Traceable Policy Impacts	28
	The Pacific RISA Advisory Committee.....	30
VII.	Project Integration: An Example of Use-Inspired Research and Stakeholder Engagement	31
VIII.	Linkages with Other NOAA Programs	32
IX.	Publications.....	33

I. Climate Science

Climate Projections for Hawai'i and other Pacific Islands

Leads: H. Annamalai, Kevin Hamilton, Axel Lauer, Chunxi Zhang

Partner Institutions: IPRC

The availability and spatial scale of regional climate model projections for the Pacific Islands region is limited. Because of the small relative size and topographical diversity of Pacific Islands, significant downscaling of global model projections is needed to make them applicable to island-scale decision making. Climate modeling research has focused on the calibration, testing, and generation of regional models capable of accurately simulating the ocean-atmosphere physics and climate for Hawai'i and the Pacific Islands. The Pacific RISA has improved simulations of historic and projected climate at both regional and island scales. The climate modeling team evaluated the CMIP5 global models for their ability to simulate climate fields around major Pacific Island groups, performing and evaluating extensive high resolution (3 km and 1 km) Hawai'i regional climate model (HRCM) simulations for Hawai'i and compared to late 20th century observations (1990 to 2009). Conditions for late 21st century (2080 to 2099) were simulated at the 1 km grid scale for Maui, and 0.8 km scale for O'ahu and Kaua'i; meanwhile, they are currently extending those simulations to other Pacific Islands. This research was used as an input to efforts conducted by the Pacific RISA and the USGS to assess the effects of projected climate changes on aspects of the natural and manmade environments of interest to Hawai'i.

Key Findings:

- “Present day” (1990 to 2009) simulations with the 3 km HRCM capture the overall observed pattern of rainfall within the state of Hawai'i,
- Major inter-annual fluctuations of rainfall are well represented by the model, including the complicated structure of the diurnal rain cycle,
- “Future” (2091 to 2100) projection results for Hawai'i indicate a warming of the long-term mean surface air temperature, with the largest warming expected at higher elevations,
- Mean rainfall patterns are also projected to change significantly (up to 30%), with increased rainfall over areas that currently have high mean rainfall, and decreasing rainfall over currently dry areas (i.e. wet areas get wetter, and dry areas get drier), and
- Deficiencies in the IPRC's simulated rainfall distributions on Maui and O'ahu were attributed to the 3 km topographic resolution in the models, and were tested for Maui by analyzing the 11-year simulation at 1 km resolution. The result was improved realistic distribution of mean rainfall on Maui. Comparison of the 3 km model resolution and the 1 km model resolution results from Maui also shows that the fine resolution version does significantly alter the projected rainfall changes as well as the mean rainfall in the base climate simulation.

A 20-year time series, triply-nested version of the model with a single outer domain and two sets of inner domains for Guam and American Sāmoa at the 0.8 km grid scale was also configured and successfully run. Initial efforts focused on further tuning of the model to be appropriate for these new focus areas, which feature more convective rainfall than in the Hawai'i region and are also more affected by hurricanes.

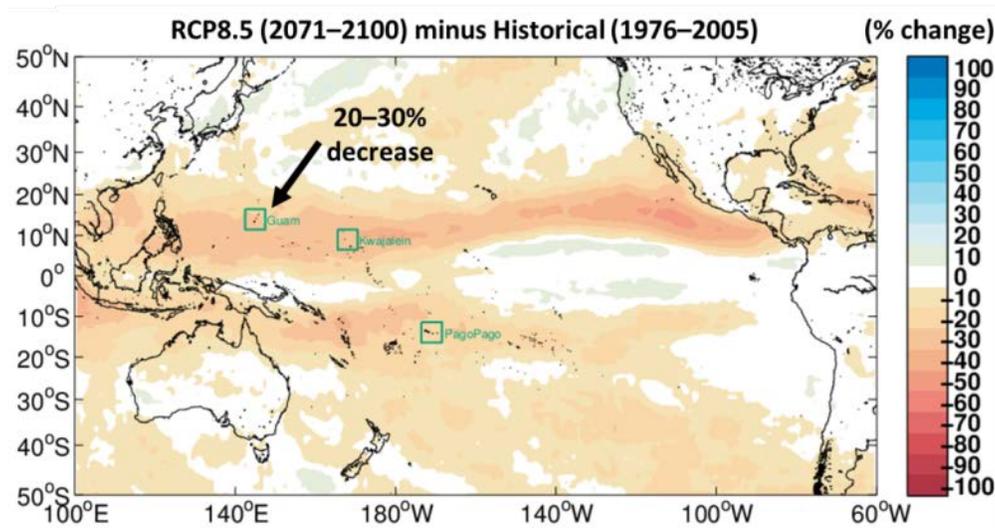
Hawai'i Regional Climate Model Calibration and Testing

Leads: H. Annamalai, Kevin Hamilton, Matt Widlansky

Partner Institutions: IPRC, Meteorological Research Institute at Tsukuba University

This project had four main goals: 1) assessment of CMIP5 models in their ability in representing climate variability and change over the Pacific Islands; 2) High-resolution Regional Climate Model (HiRAM) simulations of present-day and future climate over the Pacific Islands; 3) tropical cyclone diagnostics in a 20 km resolution GCM for present-day and future scenarios over the Pacific Islands; and 4) regional model data transfer to end-users. The Pacific RISA collaborated with modeling scientists from Japan in examining cyclone characteristics in high-resolution (20 km) GCM simulations, both for the present-day and future climates. HiRAM simulations over the Hawaiian Islands have been completed.

Key Findings: The results for tropical cyclone modeling using the high resolution GCM simulations were broadly consistent with those obtained from the CMIP5 solutions, implying that in the future, the number of tropical cyclones that could impact the Pacific Islands region is expected to decrease.



Projected percent change in tropical cyclone frequency for the Pacific by end of 21st century.

Dynamical Seasonal Prediction of Precipitation for the Hawaiian Islands

Leads: H. Annamalai, Matthew Widlansky

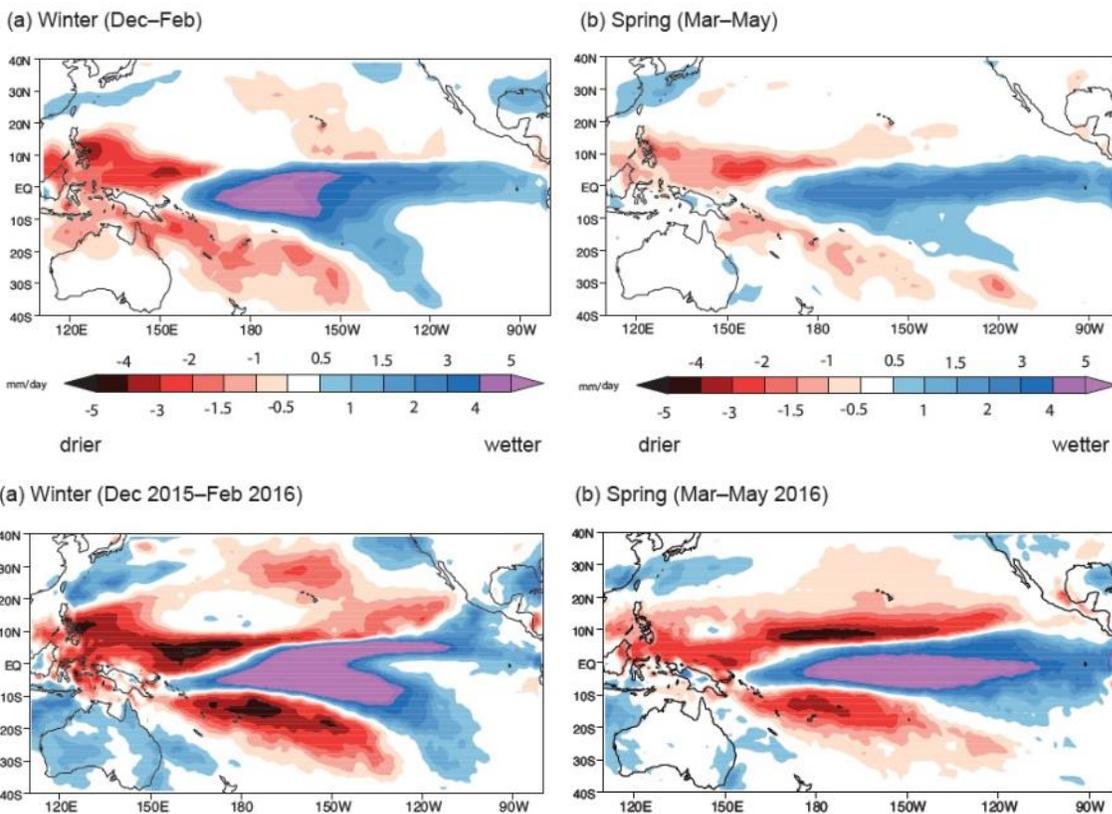
Partner Institutions: IPRC

This project had three main objectives: 1) Seasonal prediction of precipitation over the Pacific Islands during the El Niño winter/spring of 2015-2016; 2) Evaluation of the NOAA prediction model capacity to forecast regional rainfall during El Niño (2015-2016) and La Niña (2016-2017); and 3) Configuring the Hawai'i regional model to assess its ability to capture regional distribution of rainfall during an ongoing El Niño/Southern Oscillation (ENSO) event (2015-2017).

The ENSO evolution of warm conditions (El Niño in 2015) followed by cold conditions (La Niña in 2016) provides a classic test-bed for validating seasonal predictions of precipitation over the Pacific Islands made by the NOAA prediction model. The project team has been monitoring the ongoing La Niña and will bring out an experimental forecast of precipitation for the ensuing seasons. Additionally, they are

Phase II Final Report, 2010-2016

collecting station-level rainfall observations for 2015-2016 and are in the process of model validation. Daily forecast data was downloaded from NOAA and archived locally to diagnose the solutions and update the forecast every 10 days. The model shows a high level of skill in forecasting winter/spring rainfall anomalies over the Pacific Islands, with a drought moving through the region brought by one of the strongest El Niño events since record keeping began 60 years ago. It started in the southwest Pacific, where it brought famine to Papua New Guinea and Vanuatu, reaching the South Pacific, tropical West Pacific, and Hawaiian Islands between December 2015 and May 2016. While the effects of El Niño in the Pacific Islands received little global attention, it proved severe, particularly among vulnerable island populations. Prolonged drought can compromise not only freshwater supplies and food security, but can also have cascading impacts on public health, economies, food distribution, and even trigger civil unrest. Past experiences with regional drought, current actions being taken, and the most current predictions for El Niño’s effects on the Pacific Islands, suggest strategies that governments and aid groups can take to prepare for this powerful climate event.



Historical rainfall and drought conditions during past El Niño events (top); Predicted rainfall and drought conditions for El Niño 2015-2016 (bottom).

The Hawai‘i regional model will continue to be tested and fine-tuned for the regional spatial distribution of rainfall over the Hawaiian Islands with a focus on ENSO 2015-2017, during both the El Niño and La Niña phases. Ensemble simulations will be performed and the results will be compared with island-level rainfall observations.

II. Freshwater Resources

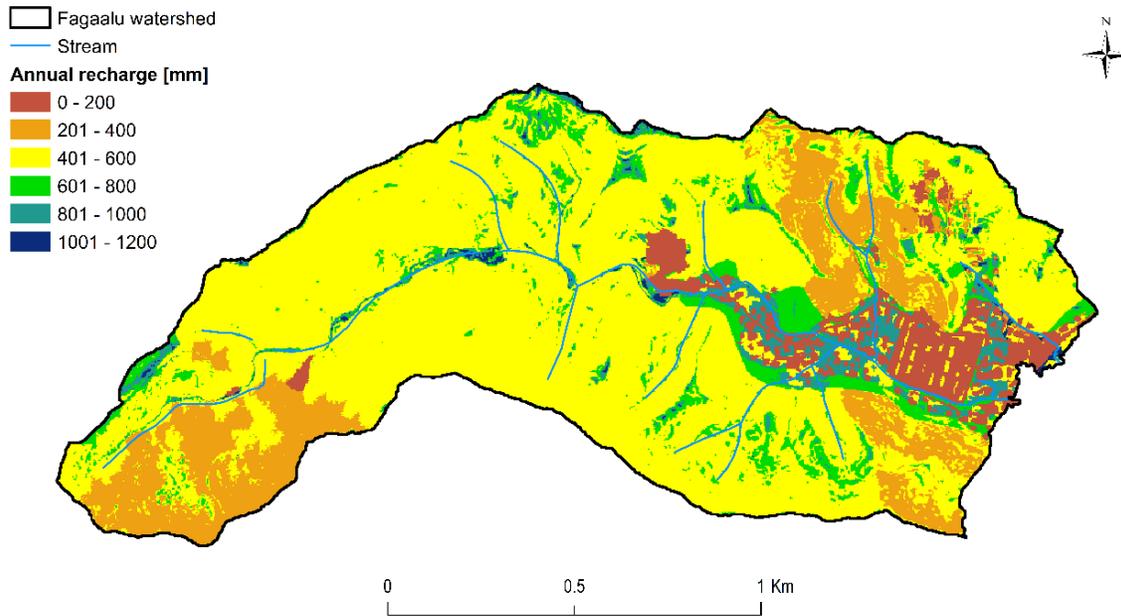
Future Climate Variability and Freshwater in American Sāmoa

Leads: Aly El-Kadi, Olkeba Tolessa Leta, Christopher Schuler

Partner Institutions: ASEPA, ASPA, ASCC

This project evaluated how groundwater quality and quantity on the island of Tutuila, American Sāmoa, are influenced by climate variability and change, as well as land use decisions, to address sustainable management of future water resources. In Faga’alu Valley, a federal priority watershed management area, anthropogenic contaminant sources have been implicated in degraded reef health and have resulted in the consistent failure of stream and coastal waters to meet the American Sāmoa EPA's 303(d) water quality standards. Also, the US Coral Reef Advisory Group (CRAG) has classified the watershed as a priority for conservation and mitigation measures. Although investigations of surface water-derived pollutants have been undertaken, there have been no studies conducted to quantify groundwater quality, movement, or flux rates in Faga’alu Bay. This project developed a conceptual model of surface water/groundwater interactions within Faga’alu Stream, and quantified surface water/groundwater exchange and associated nutrient flux with a sampling and discharge survey. The research team included graduate and post-doctoral fellows at UH as well as local collaborators at the American Sāmoa Community College. Temporal variability was assessed by scaling the spatial information measured in the survey by a time-series groundwater tracer measurement at a single location over a 48-hour period. Measurements were also validated with modeled estimates of groundwater flux and nutrient loading based on land use and watershed modeling results developed with the Soil and Water Assessment Tool (SWAT).

Key Findings: Measurements allowed quantification of the rate of groundwater discharge and associated nutrient flux from the coastal aquifer to the reef environment, and indicated that nutrient delivery via groundwater is an important process in Faga’alu Valley. This modeling effort has created more complete understanding of groundwater-derived nutrient fluxes, which are needed to begin assessing the degree of anthropogenic impacts and nutrient loading from groundwater sources to the coastal ecosystem.



Modeled groundwater recharge for Faga’alu Valley from the SWAT model.

Streamflow and Precipitation Trends in Hawai‘i, American Sāmoa, and Guam

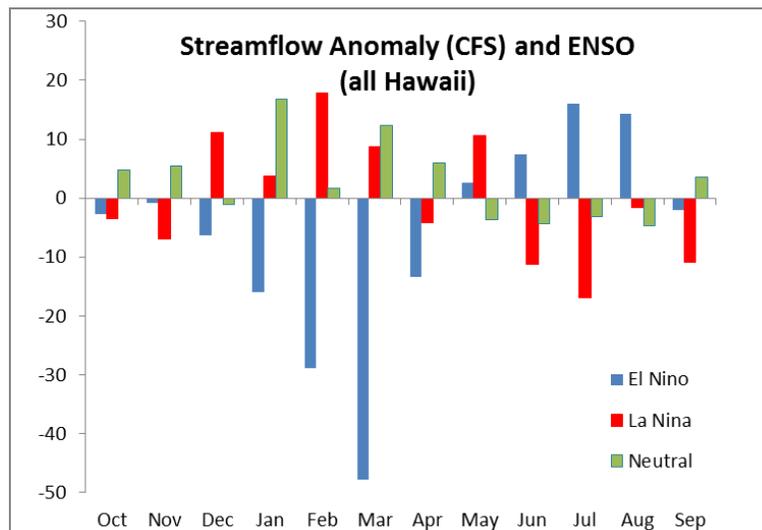
Leads: Victoria Keener, Lisa Miller, Delwyn Oki

Partner Institutions: USGS-PIWSC

The Pacific RISA collaborated with the USGS Pacific Islands Water Science Center (PIWSC) to look more generally at the effects of seasonal climate variability on historic streamflow and precipitation at sites throughout Hawai‘i, American Sāmoa, and Guam. Streamflow represents the combined precipitation over a large spatial area and multi-day timeframe, and is a good indicator variable to observe the short-term climatic fluctuations that impact the Pacific Islands region, such as ENSO. Researchers also studied how ENSO has historically affected trends in streamflow across the Pacific Islands, and how those effects may be shifting with climate change and the potential advent of new ENSO regimes. Previous work by the USGS found significant annual decreases in baseflow (the groundwater component of streamflow) over the last century across the Hawaiian Islands, and this new research found that the majority of decreasing streamflow trends occur in the dry season summer months (May to August). In addition, the shift in large atmospheric circulation patterns over the mid-latitude and tropical North Pacific result in fewer weather disturbances reaching the islands during the rainy season months of November and December.

Key Findings: Researchers identified a potential post-1990 distribution shift and decreased streamflow potential related to increasing El Niño Modoki events, characterized by central Pacific warming. Other findings include:

- Significantly decreasing streamflow trends in the dry-season months (May-August) across Hawai‘i from 1978 to 2008;
- At most sites on O‘ahu and Kaua‘i, and half on Maui, dry season flows post 1990 have significantly decreased; and
- Analysis of flow trends with ENSO indices show a potential for increased winter drought, especially in La Niña years.



Patterns of monthly average streamflow when NIÑO 3.4 SST designations are used to separate El Niño, La Niña, and Neutral phases. ENSO patterns associated with rainfall are seen even more clearly in the streamflow patterns.

Perceptions of Drought Risk by Farmers, Ranchers, and Service Providers

Leads: Melissa Finucane

Drought is a part of the natural climate cycle and will continue to occur in Hawai‘i. To be better prepared, agricultural decision makers need to consider drought impacts on both natural and human systems. However, information about drought risk perceptions, experiences, and responses are not easily quantified. The Pacific RISA assessed the human dimensions of drought impacts among farmers, ranchers, and service providers in the agricultural sector in Hawai‘i. The specific aims were to: 1) describe mental models of drought risk, with a focus on identifying specific socio-cultural impacts; and 2) identify links between drought mental models and management activities. Farmers, ranchers, and service providers across the Hawaiian Islands were interviewed to understand their perceptions of drought risk and values, as well as traditions relevant to coping with drought. Their interpretations of an image of a landscape in drought-stricken Hawai‘i and a screenshot from the US Drought Monitor showing a map and numeric information about current conditions in the state were also recorded.

Key Findings: Participants described drought as a “natural disaster in slow motion” and defined it predominantly in terms of a cyclical lack of rainfall. Articulating the social and cultural impacts was difficult for many. Nonetheless, significant adverse impacts were reported: increased burdens of responsibility, reduced cash flows, belt-tightening, restricted educational opportunities, interpersonal conflict, loss of cultural traditions, and physical and mental health problems. Participants also tended to characterize themselves and others in terms of their time working in the agricultural sector (newer vs. older) or in terms of their approach to understanding and responding to drought (analytic vs. holistic). These distinctions were linked with variation in the nature, amount, and timing of information and resources used in drought planning and management activities. Only a few participants (the self-described “analytic” type) reported using information and resources available from sources such as the Drought Monitor. Most tended to collapse the five levels of drought intensity portrayed by the Drought Monitor into three main categories: (1) no drought or dry; (2) drought; (3) extreme drought. They emphasized practical experience and local knowledge as key sources of information, but also highlighted the difficulty in making decisions based on experience when current conditions no longer seem to reflect the past. Qualitative information delivered in “natural” modes of expression (e.g., narratives) might complement technical information about drought conditions and planning and management strategies.

Recommendations for drought policy include: helping farmers and ranchers enhance their economic, social, and cultural well-being; supporting the development of tools for multi-pronged drought planning and impacts assessment; supporting the development and delivery of finer resolution climate information; enhancing access to support services; and encouraging research on risk-communication strategies.



Severe drought in the Ka‘u region, Big Island, Hawai‘i.

The Central O‘ahu Watershed Project

Leads: Maxine Burkett, Melissa Finucane, Victoria Keener

Partner Institutions: ICAP, USGS PIWSC

The Central O‘ahu watershed includes the Pearl Harbor aquifer, which serves most of the 1 million people who reside on the island of O‘ahu and the millions of tourists who visit annually. Most sources agree that existing permit allocations for the Pearl Harbor aquifer are close to the aquifer’s sustainable yield. Demand for water is expected to increase with population growth, new construction, and military uses. In a freshwater lens system like the Pearl Harbor aquifer, increased withdrawals will result in a long-term decline in water levels, an increase in the size of the brackish transition zone between freshwater and saltwater, and a reduction of natural groundwater discharge to the ocean. The extent to which water levels decline and the transition zone grows is also dependent on future changes in climate. An inventory of groundwater research studies was carried out in Hawai‘i’s Pearl Harbor aquifer with an emphasis on modeling as a tool for quantifying and managing potable water resources under a changing climate. Variability of meteorological, geological, and land use conditions is a major hurdle for the successful application of models. The final report presented modeling tools capable of improving understanding of the influence of climatic parameters on groundwater availability in Hawai‘i. To bridge the gap between science and decision making, the Pacific RISA characterized the climate-sensitive decisions and information needs of freshwater managers in Hawai‘i, conducting interviews with O‘ahu’s water resource managers, administrators in state and federal agencies, policy makers, landowners and land managers, neighborhood board members, cultural practitioners, and water users. The team also sent out a web-based survey concerning freshwater resources and climate information needs to over 140 targeted stakeholders. A wide variety of information was sought about climate literacy, trusted sources of information on climate change, their assumptions about climate impacts on water resources, and how uncertainty affects their ability to use climate information.

Key Findings: People managing freshwater resources in Hawai‘i are highly educated and experienced, perceiving climate change as posing a worrisome risk, and they would like to be better informed about how to adapt to climate change. Decision makers with higher climate literacy are more comfortable dealing with uncertain information, while those with lower climate literacy seem to be more trusting of climate information from familiar sources. The climate information most relevant to decision makers includes vulnerability assessments incorporating long-term projections about temperature, rainfall distribution, storms, sea-level rise, and streamflow changes at an island or statewide scale. Results suggest that an integrated approach is needed to determine where and when uncertain climate information is useful and how a larger set of organizational and individual variables affect decision making.

Responses to the question: How likely do you think it is that each of the following will occur in Hawai‘i during the next 50 years as a result of climate change?

	Not at all likely (%)	Somewhat likely (%)	Very likely (%)	Extremely likely (%)	Do not know (%)
Sea level rise	2	12	39	44	2
Worse droughts	2	21	42	33	0
Saltwater intrusion into groundwater	2	28	28	30	9
Worse storms and hurricanes	5	26	39	26	2
Water shortages	2	28	44	23	0
Worse flooding of cities	7	23	46	21	0
Food shortages	7	53	19	14	5
Increased rates of disease	14	23	28	12	19

Estimating Groundwater Recharge under Future Climate Conditions: Maui

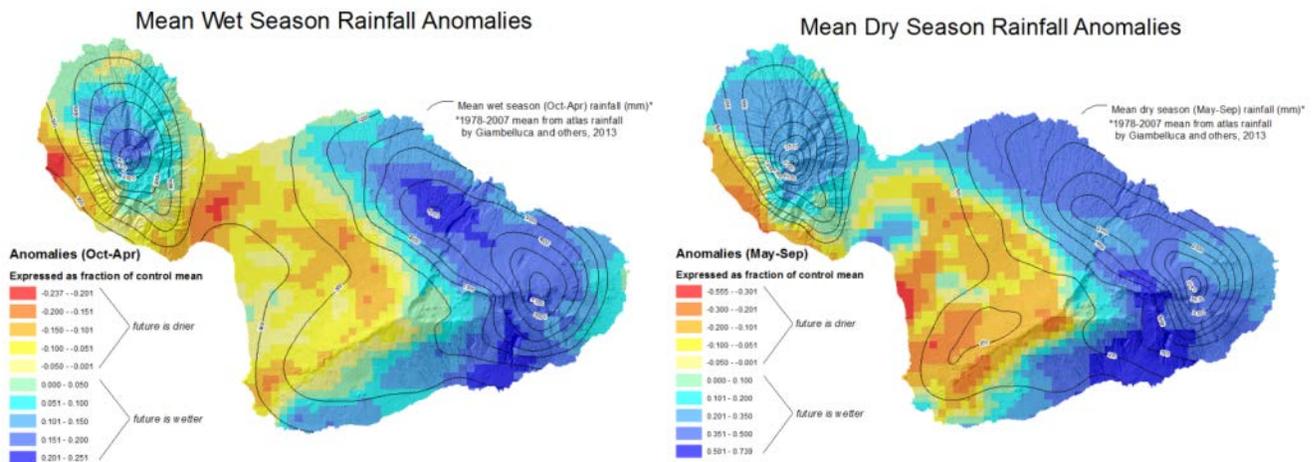
Leads: Steve Anthony, Adam Johnson, Alan Mair

Partner Institutions: IPRC, USGS-PIWSC, WRRC

The Pacific RISA and the USGS-PIWSC have estimated changes in groundwater recharge under future climate conditions on the island of Maui, Hawai‘i. Previous streamflow research by the USGS found significantly decreasing trends in the dry season months (May – August) across the state of Hawai‘i, with significant dry season decreases since 1990 at half of the sites on Maui. A water budget model was developed for the island of Maui to derive preliminary estimates of groundwater recharge using dynamically downscaled climate input datasets from the IPRC, preparing projections of rainfall, direct runoff, evapotranspiration, and groundwater recharge by aquifer system. A modified 2010 land cover surface for Maui Island was developed based on recent aerial photography, satellite imagery, and ground truth data to serve as the baseline input for the water budget model. Other climate input datasets of rainfall and reference evapotranspiration were developed, and 20-year IPRC climate simulations from 1990 to 2009, and projections from 2089 to 2099, were run to evaluate hydrological processes under the current land cover scenario.

Key Findings: The comparison of the water budget model output using future and control climate scenarios for a 2010 land cover condition indicate that:

- Mean annual rainfall increases by 29%
- Mean annual evapotranspiration increases by 7%
- Mean annual direct runoff increases by 54%
- Mean annual recharge increases by 26%
- Wet regions of Maui get wetter, while some dry regions get wetter and others get drier
- There is little change in cloud base elevation and trade wind inversion height



Mean wet season and dry season rainfall anomalies for 2080-2099, minus 1990-2009.

III. Decision Support

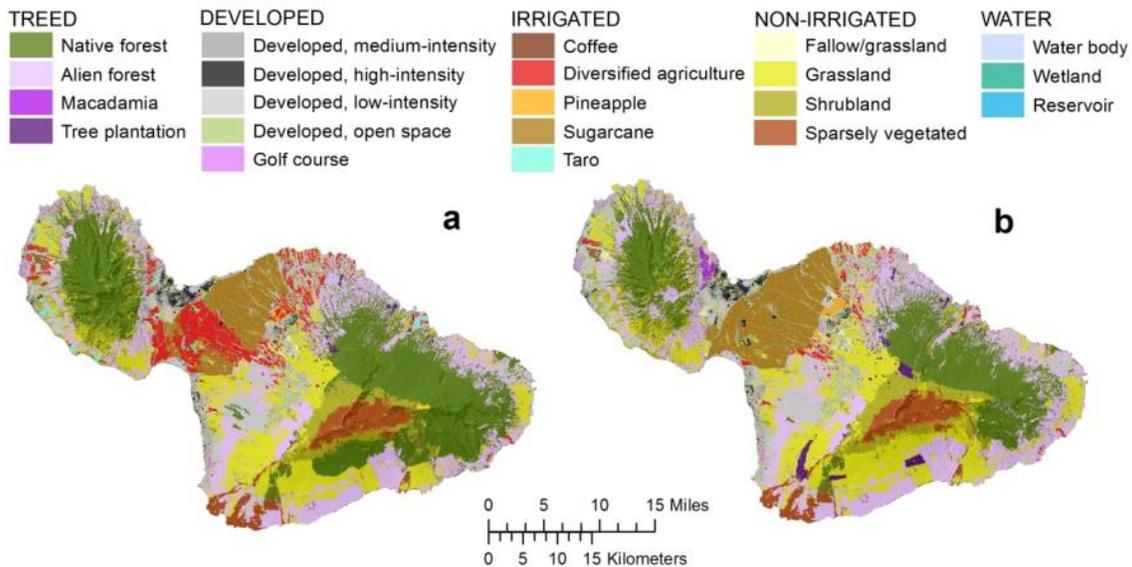
Future Scenario Planning for Maui

Leads: Laura Brewington, Melissa Finucane, Victoria Keener

Partner Institutions: Maui County Department of Water Supply, Maui County Department of Planning, CWRM, USGS-PIWSC; IPRC, WRRC

The Pacific RISA used a participatory scenario process to identify key stakeholders making short and long-range decisions about freshwater resource management, and defined climate, land use, and development futures for the island of Maui. Four future land cover scenarios were defined based on extensive stakeholder interviews to represent desirable and undesirable management decisions that could impact future water resources under a changing climate. These were translated into spatially explicit GIS layers for input into a USGS-PIWSC water-budget model (see Estimating Groundwater Recharge under Future Climate Conditions: Maui, above). Key contrasting variables related to forest cover, development, agriculture, ranching, and surface water management reflected the complex socioeconomic and biophysical parameters that the scenarios represent. The final land cover scenarios were meant as a visual tool informed by the best possible science and local knowledge, so that managers and decision makers could begin to implement climate adaptive water management strategies that have the ability to be resilient to a range of potential futures.

Key Findings: As climate models and projections are generally unfamiliar to most decision makers, the scenario process was a useful education tool for climate modeling in addition to creating a useful future planning tool. In general, the process has been popular with state agencies and planners, who are interested in recreating similar processes for all the main Hawaiian Islands. This led to the development of a scenarios-based collaboration on O‘ahu with the Honolulu Board of Water Supply and consulting team Brown and Caldwell, with funding from the Water Research Foundation. The O‘ahu project, which focuses on water resources management and modeling under projected climate change, kicked off in 2016. Additionally, in January 2016, Hawai‘i Commercial & Sugar Company announced that they would suspend all sugarcane operations on Maui (30,000 cultivated acres) and transition to a diversified agriculture model. One of the four future land use scenarios represented exactly this scenario (below, left), giving stakeholders the ability to utilize that model in planning sooner rather than later.



Two future land cover scenarios for Maui: a) Conservation-Focused; b) Business-as-Usual.

Integrating Climate in Disaster Risk Assessment

Leads: Cheryl Anderson

Partner Institutions: SSRI

The Pacific RISA facilitated the integration of climate risk analysis and adaptation into disaster management plans by engaging the disaster management community as a primary stakeholder in climate activities. Discussing climate vis-à-vis the analysis of impacts from extreme climate events created a foundation for considering future climate change. Researchers, meteorologists, and climatologists built on experiences with tropical storms, hurricanes, and typhoons to plan for the impacts of climate variability and ENSO cycles. Hazard risk and vulnerability assessments, specifically for climate-related risks, have been established as an interdisciplinary methodology that underpins the development of disaster risk-reduction plans. The Pacific RISA also reviewed existing disaster risk-reduction plans and suggested areas in which island governments could improve climate-related disaster planning.

Key Findings:

- For the US Flag Islands (Hawai‘i, American Sāmoa, CNMI, and Guam), the Federal Emergency Management Agency requires that plans be updated every three years. Of the FEMA-approved plans, only Hawai‘i assesses risks from climate change and has implemented drought mitigation plans. Multi-hazard mitigation plans were required in 2004 from FSM and RMI, but they did not include risks from sea level variability, sea level rise, or other effects of climate change;
- Hawai‘i and American Sāmoa identify hazard threats from climate change, but Hawai‘i is the only US Pacific Island to attempt to identify potential losses and projected impacts from climate change. Hawai‘i’s hazard mitigation plan is also the only one to propose hazard mitigation actions to address climate change;
- Climate change will exacerbate hazard impacts and necessitate changing the calibration of models for projected impacts. The methods of projecting impacts currently rely on historical records, and impacts will be different from these records. Furthermore, hazard assessments don’t factor in cumulative and secondary climate-related impacts such as those occurring during an ENSO cycle;
- Methods for projecting losses rely heavily on historic damage and economic losses. These records are not consistent for climate-related hazards. Magnitude of loss based on economic data does not help prioritize action because the losses are not comparable. Qualitative values of impacts and projected socio-cultural losses need to be improved and used in hazard mitigation and climate adaptation planning;
- Hazard mitigation actions are often similar to climate adaptation actions, although climate adaptation requires a look at longer timescales for addressing impacts and reducing risks. Key areas for climate adaptation include: structural mitigation measures for buildings (hardening and retrofit, improved design); building codes, permits, and enforcement; coastal zone management; conservation and natural resource management; infrastructure and critical lifelines design improvements and hardening; insurance; land use designation and zoning; public health interventions and planning; public education, awareness, and training; and water resource, floodplain, and watershed management;
- Key sectors that need to be considered in hazard mitigation and climate adaptation planning to minimize impacts and develop resilience: agriculture, communications, economy and finance, education, energy, environment, health, society and culture, transportation, waste, and water; and
- Capacity building, education, and outreach are essential to risk reduction and to developing resilient governments and communities that can adapt to climate impacts.

El Niño and Pacific Island Fact Sheets

Leads: Victoria Keener, John Marra

Partner Institutions: NOAA CPC, NOAA NCEI, PEAC

The strong El Niño event that occurred between 2015 and 2017 has had significant impacts in Hawai‘i and the Pacific Islands region, including extended drought conditions, enhanced risk of damaging tropical cyclones, increased risk of coral bleaching, and possible spread of vector borne disease and illness. Impacts vary by island, however, and in fall of 2015 the NOAA Hawai‘i and Pacific Islands ENSO Tiger Team created seven fact sheets outlining different physical impacts on different sectors and projected trends in relevant climate variables for Hawai‘i, American Sāmoa, Guam and the Commonwealth of the Northern Marianas Islands (CNMI), the eastern and western Federated States of Micronesia (FSM), the Republic of Palau, and the Republic of the Marshall Islands (RMI). Drs. Marra and Keener worked closely with the PEAC Center and UH to help raise awareness and answer common questions about the ENSO phenomenon and related impacts, such as sea-level rise, tropical cyclones, and altered rainfall, in particular sub-regions of the Pacific. Brief, targeted messages on sectoral impacts were tailored for stakeholders in water management, public health, ocean and coastal resources, tourism, and agriculture.

Drought Dashboard for Republic of the Marshall Islands

Leads: Melissa Finucane, Victoria Keener, John Marra

Partner Institutions: PI-CSC, PaCIS (now PICS), NWS, NOAA, MCT, USDA, USFS

In collaboration with partners from the PICS panel, the Pacific RISA supported the development of a Drought Dashboard for the RMI by identifying key characteristics of regional stakeholders and their climate-sensitive decisions and information needs, as well as the broader contextual factors that influence drought management decisions. Interviews were conducted with decision makers from a range of organizations, including the College of the Marshall Islands, the International Federation of the Red Cross, the Micronesia Conservation Trust, NOAA National Weather Service and Weather Service Office, the US Department of Agriculture, and the US Forest Service. Information from the final stakeholder report was instrumental in the development of the drought dashboard.



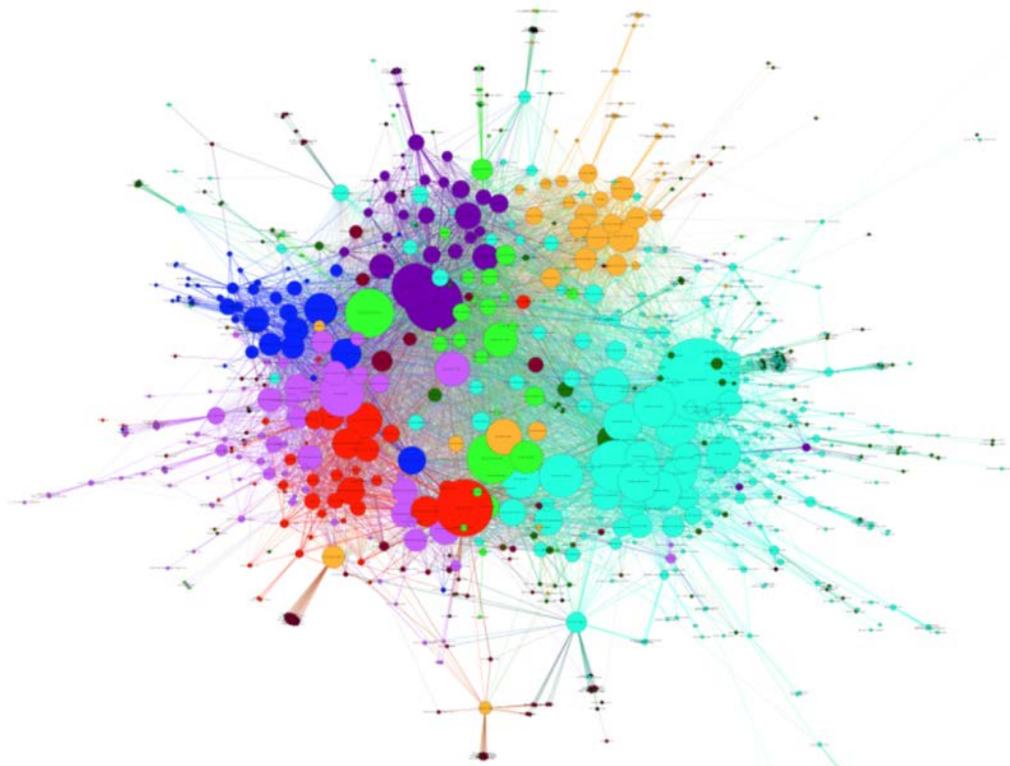
Stakeholders participate in the Climate Indicators Research Discussions in Majuro, RMI (left); Water tanks outside the College of the Marshall Islands (right). The majority of the freshwater supply in Majuro, the capitol of the RMI, comes from rainwater catchment systems such as these.

Social Network Analysis

Leads: Kati Corlew, Victoria Keener

Funding from NOAA and the DOI Pacific Islands Climate Science Center (PI-CSC) supported research on communication patterns and how climate information spreads across different sectors and countries in the Pacific Islands region. Using the release of the Pacific Islands Regional Climate Assessment (PIRCA) report as a springboard, the team collected data to analyze the professional and scientific networks of climate stakeholders in Hawai‘i and the USAPI. By tracking information flows, key hubs, and isolated groups using network analysis and statistical methods, the researchers mapped strengths and gaps in the communication and flow of climate information, allowing the Pacific RISA and other groups to focus research and resources on areas that may have been previously ignored. More than 1,000 climate change professionals in the Pacific Islands were invited to complete a network analysis survey, which solicited information about professional and personal demographics, network connectedness, climate change risk perception and resiliency, and sense of community. Email, phone, and face-to-face follow-up inquiries were conducted for the entire list of respondents, and 340 surveys were completed and returned.

Key Findings: Based on analysis of the survey results, a network of 966 individuals was identified, with over 9,000 connections distributed among the Pacific Islands. The average distance across the network was three people, meaning that any single individual is only three connections away from all others. While Hawai‘i contained the majority of network members (576), even small networks still proved to be highly connected: Palau, the smallest, had 30 survey respondents and a total of 50 networked individuals identified, with 245 connections. Prior to this study, there were no formal analyses that tracked the flow, sources, and quality of this information across the Pacific Islands region, and this project helped address the blind spot that researchers and agencies have regarding the communities and stakeholders that may or may not have access to key knowledge.



Pacific Islands region full map from Social Network Analysis: Palau (dark blue), Hawai‘i (light blue), Guam (light green), FSM (light purple), CNMI (dark purple), RMI (red), other (dark red).

Hawai‘i Law and Policy Toolkit

Leads: Maxine Burkett, David Penn, Richard Wallsgrove

Partner Institutions: ICAP

The Pacific RISA, in collaboration with ICAP, produced a white paper titled “Water Resources and Climate Change Adaptation in Hawai‘i: Adaptive Tools in the Current Law and Policy Framework,” which evaluated Hawai‘i’s water resources policy framework for adaptive capacity. After reviewing recent case studies and peer-reviewed literature on adaptive governance, the team found that four characteristics define the “adaptive capacity” of laws and policies:

1. Forward-looking—focused on crisis avoidance over crisis mitigation;
2. Flexible—able to adjust to changing needs and conditions;
3. Integrated—able to address climate-related impacts that cut across political and geographical boundaries; and
4. Iterative—utilizing a continuous loop of monitoring, feedback, and reevaluation.

Key Findings: The report, with incorporated stakeholder input, was presented to the State Water Commission, water resource managers, and policymakers. Lessons learned have been considered when repeating the streamlined process for the USAPI. The report identified 12 potentially adaptive tools that are not presently implemented in Hawai‘i, or are implemented only in part. Each tool is consistent with the existing law and policy framework, and each exhibits adaptive characteristics. These tools include:

- Incorporating climate change scenario planning into the Hawai‘i Water Plan;
- Adopting existing models of integrating watershed conservation with water resource planning;
- Implementing mandatory water conservation and recycling plans;
- Enforcing statewide water resource monitoring and reporting;
- Adopting more adaptive conditions for all water use, well construction, and stream diversion permits;
- Encouraging water-conscious construction and modifications with green building tax credits, rebates, and other incentives; and
- Relating Water Commission fees more closely to the cost of water management.

Building off of climate adaptation legislation passed in 2014 and the resulting ongoing efforts related to adaptation, the Hawai‘i state legislature passed at least two bills in 2016 to increase adaptive capacity for water resources. Climate adaptation and appropriate planning horizons were issues raised in the deliberation of both bills. Work is progressing on the Interagency Climate Adaptation Committee Act 83, implemented in 2014, with public engagement to commence shortly and the committee's report anticipated in 2017. Hawai‘i legislators and regulators continue to look to the Pacific RISA for assistance in understanding and developing climate adaptation laws and policies.

The Hawai‘i Commission on Water Resource Management has also continued the process of updating Hawai‘i’s primary and comprehensive water planning policy tool – the Water Resource Protection Plan and its components – including efforts to address Pacific RISA recommendations regarding climate change adaptation. Climate change adaptation is one of five key elements of this update, and Pacific RISA's climate research and law and policy research is incorporated. Other components (e.g. Maui County Water Use and Development Plan) are directly addressing climate adaptation using RISA scientific research. As that planning update proceeds, the Commission is continuing to implement adaptation recommendations in other ways. For example, Commission staff recently recommended a proposal to jointly fund an evaluation of water monitoring needs with the USGS-PIWSC.

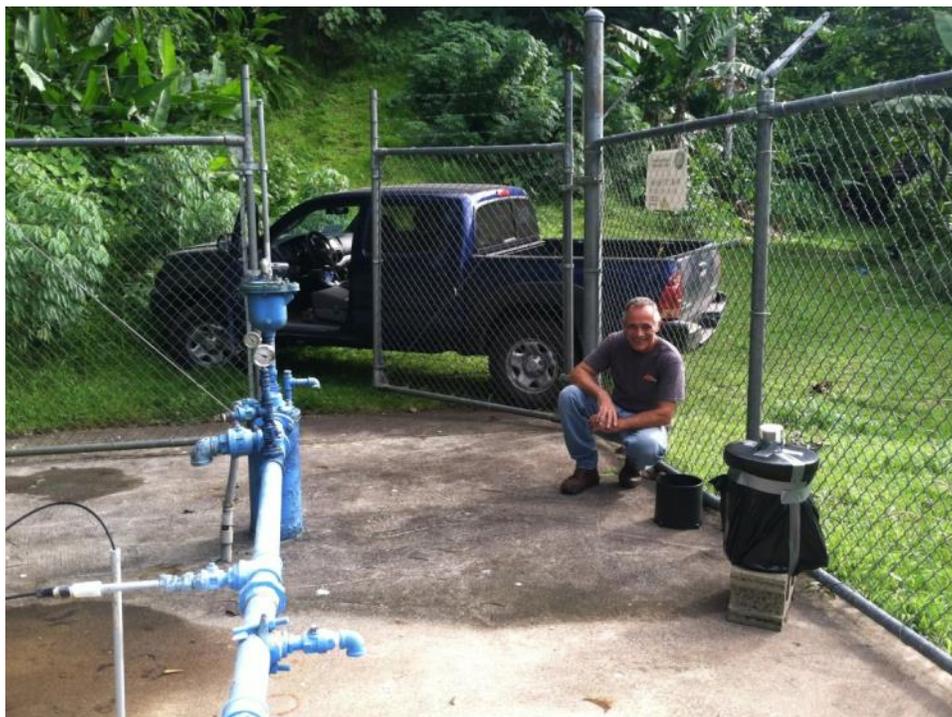
American Sāmoa Water and Policy Analysis

Leads: Zena Grecni, Richard Wallsgrove

Partner Institutions: ASPA, ASEPA, WRRC

The law and policy research team analyzed water issues and policies in American Sāmoa more broadly, with the goal to evaluate adaptive tools in a Pacific Island context beyond Hawai‘i. As new scientific information about water resources becomes available, researchers need to know how that information can best be utilized in a policy and resource management context. A better understanding of the law and policy framework, cultural context, and local knowledge and information gaps can help partners such as the UH WRRC set priorities for research and monitoring and also can inform the design and delivery of products and tools for water managers. The Pacific RISA completed an assessment of American Sāmoa’s water resource issues and policies after: 1) Gathering existing information on American Sāmoa’s water resources, climate science, climate adaptation, and existing legal frameworks; and 2) Holding informational meetings and conference calls with resource managers and other on-the-ground experts.

Key Findings: The report highlighted ENSO as a crucial predictor of impacts for decision makers, including the American Sāmoa Power Authority (ASPA), the American Sāmoa Environmental Protection Agency (ASEPA), and the American Sāmoa Department of Commerce. The report, “Water Resources in American Sāmoa: Law and Policy Opportunities for Climate Change Adaptation” also identified water quality research as a critical need for planning for future water resources. ASEPA and ASPA are incorporating recommendations that resulted from this research in their water monitoring and management protocols.



ASPA implementing upgraded groundwater monitoring protocols on Tutuila, American Sāmoa.

IV. Science Communication

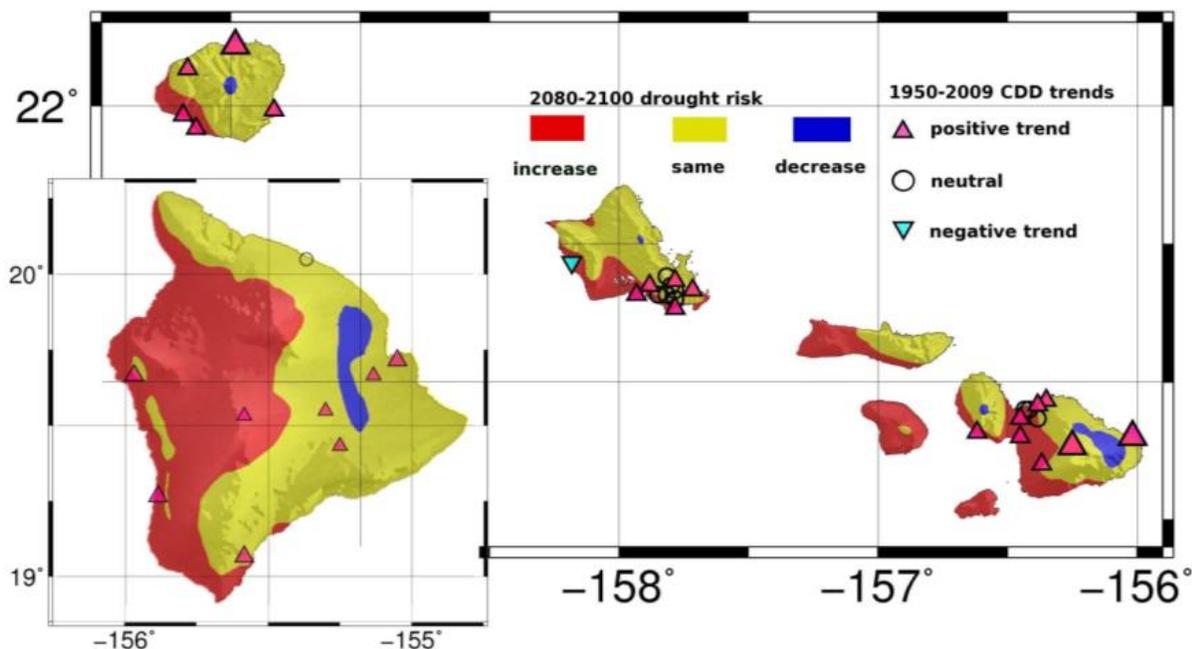
Regional Input to the US National Climate Assessment (the PIRCA)

Leads: Melissa Finucane, Victoria Keener, John Marra, Deanna Spooner

Partner institutions: Numerous

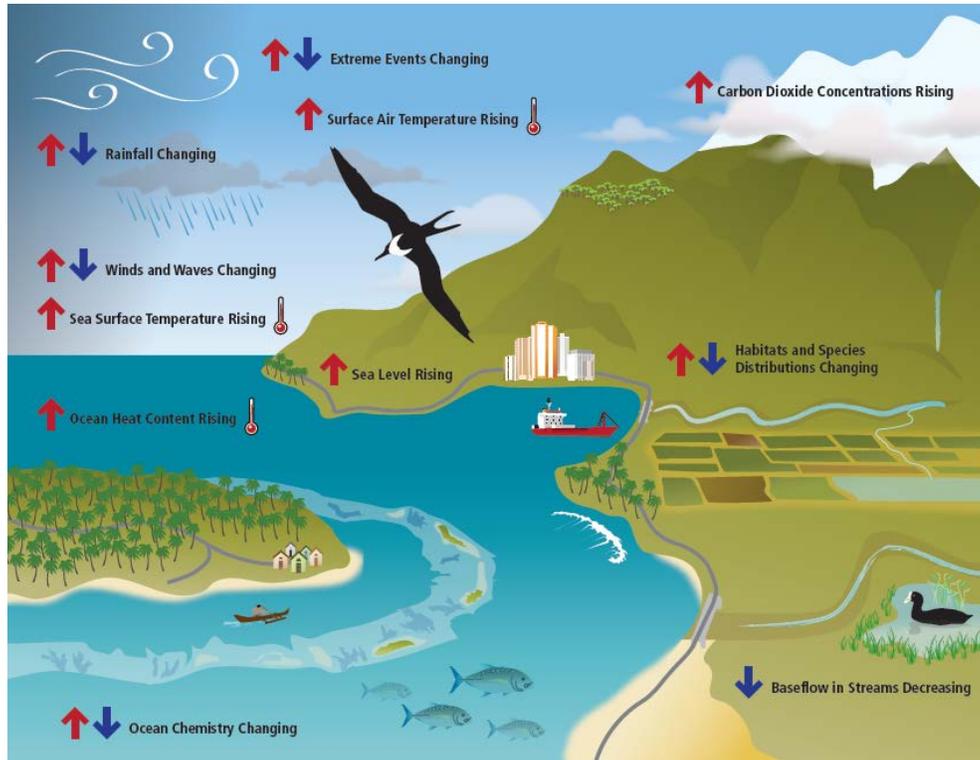
The PIRCA is a Pacific region-wide collaboration of over 100 experts in Hawai‘i and the USAPI that was formed to support the regional contribution to the 2013 National Climate Assessment. Scientists and other experts discussed the state of climate knowledge relevant to three focus areas: 1) preserving fresh water resources and minimizing impacts of drought; 2) fostering community resilience to the impacts of sea-level rise, coastal inundation, and extreme weather; and 3) sustaining aquatic and terrestrial ecosystems. The PIRCA generated a regionally comprehensive report assessing climate impacts and adaptive capacity in the region. Through the PIRCA coordination and writing process, the Pacific RISA linked with many different NOAA offices, especially the NOAA Pacific Regional Climate Services Director (RCSD), Dr. John Marra. The report editors included two Pacific RISA representatives, the Pacific Islands Climate Change Cooperative (PICCC) Coordinator, and the NOAA RCSD, who worked together extensively to organize three supporting technical workshops, manage large teams of people and timelines, and write and edit contributions.

An additional result of the PIRCA process was that Pacific RISA brought together researchers who agreed to integrate their individual data to make new images and products. One such image, highlighted in Chapter 3 of the PIRCA report, is a figure showing past and future drought risk in Hawai‘i. The combination of research from PIRCA contributors Dr. Pao-Shin Chu (historic drought trends) and Dr. Oliver Timm (future drought risk) creates a powerful image that demonstrates the evolution of increased drought risk in areas previously identified as vulnerable.



The major Hawaiian Islands have experienced increasing winter drought since the 1950s. Larger triangles indicate where trends are significant with 90% confidence. Background colors highlight changes in the number of low precipitation months during the wet season (Nov-Apr) based on statistically downscaled climate change scenarios from six models of the IPCC AR4 report for the years 2080-2100.

Other original figures and tables were created to better communicate specific aspects of climate knowledge in the Pacific Islands to decision makers. An original PIRCA product, the “Indicators of Climate Change in the Pacific Islands” graphic serves to make a global issue regionally specific, using facts discussed in the PIRCA report and images immediately recognizable by island resource managers. Positive feedback has been received for the graphic, which is highlighted through outreach programs.



Indicators of climate change in the Pacific Islands.

The PIRCA Forum

Leads: Melissa Finucane, Victoria Keener, John Marra, Deanna Spooner

Partner Institutions: PICCC, PaCIS, PI-CSC, East-West Center

Pacific RISA hosted the PIRCA Forum in partnership with the Pacific Islands Climate Change Cooperative (PICCC) and PaCIS, with support from the PI-CSC December 10-12, 2012 in Honolulu at the East-West Center’s Hawai‘i Imin International Conference Center. The purpose of the forum was twofold: (1) to officially release the PIRCA reports; and (2) to gather a group of diverse stakeholders to disseminate the PIRCA information, discuss the usefulness and gaps in that information, and discuss the National Climate Assessment (NCA) process more generally. The sessions featured: a keynote speech by Hawai‘i Lieutenant Governor (now US Senator) Brian Schatz; an overview presentation by Dr. Keener that summarized PIRCA findings across all sub-regions and technical areas; and a panel of high-level sector representatives from across Hawai‘i and the Pacific region, who spoke about the importance of climate information to their specific sectors (education, security, agriculture, land management, urban planning, and international negotiations). Panel members included William Aila Jr., former Chairperson, Hawai‘i Department of Land and Natural Resources (DLNR); Russell Kokubun, former Chairperson, Hawai‘i Department of Agriculture; Jesse Souki, former Director, Hawai‘i State Office of Planning; Neil Hannahs, former Director of Land Assets Division, Kamehameha Schools; J. Scott Hauger, Associate

Professor, Asia-Pacific Center for Security Studies; Ngedikes Olai Uludong, former Alliance of Small Island States Lead Negotiator. Follow-on discussions highlighted the following points:

- Wider community outreach and knowing what information needs and formats are required;
- The lack of understanding of climate information in the Pacific region because of language barriers, lack of trust, and complex political systems;
- The need for local “champions” to strengthen trust when providing information to people; and
- A need for government mandates and a regulatory/policy framework to guide planning processes with climate change information.



Dr. Keener presented findings from the PIRCA report to an audience of 200 stakeholders.

‘O Ke Au I Kahuli: Pehea La Ka Hawai‘i E Pono Ai Traveling Forum

Leads: Carlos Andrade, Maxine Burkett, Melissa Finucane

Partner Institutions: ICAP, UH Kamakakuokalani Center for Hawaiian Studies

In February 2011, The Pacific RISA, ICAP, and the UH Kamakakuokalani Center for Hawaiian Studies convened a roundtable of natural resource specialists and decision makers to review current trends affecting water supply and explore approaches to improve resiliency in Hawai‘i’s freshwater systems. Held in Halau O Haumea, the event was second in the ‘O Ke Au I Kahuli: Pehea La Ka Hawai‘i E Pono Ai series of traveling forums. Over 70 members of the campus and broader community were in attendance, including water resource decision-makers from state, county, and federal agencies, as well as businesses and non-profit organizations. Speakers included William Aila, Jr., former Director of the State of Hawai‘i Department of Land and Natural Resources and Dr. Tom Giambelluca, Professor of Geography at UH. Panelists identified a number of potential adaptation tools and several possible priority areas for revising existing programs, laws and administrative procedures.

Preserving Freshwater Resources in American Sāmoa

Leads: Laura Brewington, John Marra

Partner Institutions: NOAA, WRRC, PEAC

Dr. Brewington assisted in the “Preserving Freshwater Resources and Minimizing the Impacts of Drought” workshop in Pago Pago, American Sāmoa in July 2014. Workshop participants included community freshwater managers and planners, decision makers, and climate experts from American Sāmoa, Sāmoa, Fiji, Tonga, and Hawai‘i. At the workshop, Dr. Brewington presented the initial results of Richard Wallsgrove’s water and policy report. The presentation evaluated the effectiveness of American Sāmoa’s adaptive policies and planning tools next to the criteria of being forward-looking, adaptive, integrated, and iterative, and suggested nine opportunities in which adaptive capacity could be improved in American Sāmoa. UH Graduate Research Assistant Christopher Schuler gave a presentation on his research describing the status of a groundwater model for the island of Tutuila being developed by the WRRC. Through the collaborative efforts of the workshop participants, local knowledge was combined with specialist technical advice to identify accurate, timely and regionally-relevant content that helps to preserve freshwater resources and minimize the impacts of drought. As a result of the dialogue, the user community is better informed about the current state of knowledge of climate variability and its impacts, and the provider community is better informed about what problems and questions are most relevant and better able to match products and services to user requirements.



UH Graduate Research Assistant sampling Faga’alu stream for dissolved radon, nutrients, and isotopes.

Pacific Climate Information System Dialogues

Leads: Melissa Finucane, John Marra

Partner Institutions: NOAA, PEAC, PICCC

In 2010, Pacific RISA Project Assistant Rachel Miller participated in two dialogues conducted by PaCIS in Guam and American Sāmoa, “Dialogue with Local Decision-makers about Water Resource and Drought-related Issues in Light of a Changing Climate.” Miller traveled with a team of 5 researchers from various branches of NOAA and PEAC as well as the Pacific Islands Climate Change Cooperative (PICCC) to Guam and American Sāmoa. The team conducted meetings in both places with diverse stakeholders to discuss local needs, capacity, and decision-making capabilities in regard to water resources and climate change more broadly. Meetings in Guam included stakeholders from the Telecommunication and Distance Education Operation (TADEO) PeaceSat; US Senator B.J. Cruz’s office; University of Guam Water and Environmental Research Institute (WERI), Marine Lab, Center for Island Sustainability; the US National Park Service; National Weather Service Guam, Weather Forecast Office; Bureau of Statistics and Planning; and the Department of Agriculture. Meetings in American Sāmoa included stakeholders from American Sāmoa Community College Land Grant Office; National Weather Service Sāmoa, Weather Forecast Office; Department of Marine and Wildlife Resources; Haleck Enterprises; Pago Pago Pure Water; Department of Homeland Security; National Park Service; ASPA; Island Breeze Water; Department of Agriculture; Department of Commerce; Pacific Energy; Coral Reef Advisory Group; Department of Health; Department of Public Works; Department of Education; Bluesky Communications; Department of Parks and Recreation; American Sāmoa Visitors Bureau; and ASEPA.

Hawai‘i-Pacific Highlights of the Third U.S. National Climate Assessment

Leads: Victoria Keener, John Marra

Partner Institutions: NOAA CPO, UH, Hawai‘i State Legislature, DLNR, SeaGrant, UHFWS

On May 6, 2014 the East-West Center and Pacific RISA hosted a briefing for the release of the Pacific Islands Regional chapter of the Third National Climate Assessment. Moderated by Dr. Keener, the event featured an introduction by William Aila, then-Director and Chair of the Hawai‘i Department of Land and Natural Resources, as well as a panel of authors from the Pacific chapter of the report. The briefing was well attended by local media, including three local TV stations that featured the event on the evening news. More than 80 people were in attendance, including Rep. Chris Lee, Chairman of the House Environment committee; Bill Tam, former Deputy Director of the Department of Land and Natural Resources; other state and federal employees working on climate change; staff members from Rep. Hanabusa and Rep. Gabbard’s offices; UH faculty; East-West Center staff; and students. Local news stations, Hawai‘i Public Radio, and print media conducted interviews with Pacific RISA team members Drs. Keener and Marra, resulting in highly visible news reports and publications. Media coverage for this event included articles in SCIENCE magazine, the Huffington Post, the Honolulu Star Advertiser, and the FIJI Times; radio appearances on local and international stations; and interviews with chapter authors, legislators, and the Hawai‘i Department of Land and Natural Resources.

V. Education and Outreach

The Pacific RISA team has been involved in numerous outreach and media events during the reporting period, and has been featured in print and on television via outlets such as the Honolulu Star-Advertiser, Honolulu Civil Beat, Hawai'i News Now, ThinkTech Hawai'i, ClimateWire, Honolulu Weekly, Insights, Hawai'i Public Radio, SCIENCE magazine, the Huffington Post, Radio New Zealand, and KITV. Some examples of the type of public events Pacific RISA has engaged in include:

- SOEST Workshop on the Science of Climate Change, University of Hawai'i (Jan, 2011)
- Water Resource Sustainability Issues on Tropical Islands, Honolulu, HI (Nov, 2011)
- Hawai'i Water Law Conference, Honolulu, HI (Jan, 2012)
- Pacific Islands Leadership Program, East-West Center (Oct, 2013)
- Women in Climate Change Event, University of Hawai'i (Feb, 2014)
- National Climate Assessment Engagement Workshop, USGCRP, D.C. (Feb, 2014)
- Pacific Risk Management 'Ohana (PRiMO) Conference (Mar, 2014)
- Bishop Museum Science Alive Day (Mar, 2014)
- Earth Day Celebrations, University of Hawai'i (Apr, 2014)
- National Climate Assessment Release Event, East-West Center (May, 2014)
- Australian American Leadership Dialogue, Honolulu, HI (Oct, 2014)
- Lyon Arboretum, Honolulu, HI (Jan, 2015)
- Earth Day Celebrations, University of Hawai'i (Apr, 2015)
- Australian American Leadership Dialogue, Honolulu, HI (Oct, 2015)
- HIGICC Island Futures Conference on Smart Growth and GIS, Honolulu, HI (Oct, 2015)
- Hawai'i GIS Day, Honolulu, HI (Nov, 2015)
- East-West Center Alumni Conference, Manila, Philippines (Jan, 2016)
- WMO and the Pacific International Training Desk, Honolulu, HI (Mar, 2016)

Social Media Platforms

Continuous outreach activities occur through the Pacific RISA's social media platforms such as Facebook and Twitter. A large demographic of Facebook fans comes from the United States, Australia and Fiji, and are between the ages of 25 and 44. Twitter followers have increased from 110 followers in 2014 to over 300 in 2016. Facebook saw an increase in traffic beginning in early 2015 as the content of posts diversified to include climate and health, climate induced migration impacts, and regional Pacific issues. The Pacific RISA website houses an updated collection of information and knowledge products generated through activities and research completed under the RISA team of lead investigators. The Pacific RISA also has regular email digests that are sent out as needed to share news and announcements.

Climate Matters "Documoments"

Leads: Melissa Finucane, Victoria Keener

Partner Institutions: East-West Center

The Pacific RISA worked with professional filmmakers to create five Climate Matters video documentaries, or "Documoments." Each video clip focuses on a different aspect of how climate information matters to people of different professions in Hawai'i. On the Big Island, cattle rancher Michelle Galimba described how drought on her Ka'u ranch affects both her livelihood and locally produced food. At the PVT construction landfill on O'ahu, Vice President Steve Jacobs showed how PVT responded to a climate forecast of a strong La Niña event by upgrading its storm drains, avoiding potential catastrophe when 10 inches of rain fell in 24 hours. On the famous beaches of Waikiki, Kyo-Ya

Company president Greg Dickens described changes in the Waikiki shoreline over the last 50 years, and how sea-level rise could be devastating for the local tourist economy. Ray Tanabe, the Director for the Pacific Region of the National Weather Service, shared his experiences understanding weather and climate as a child growing up on O‘ahu’s North Shore and his passion for providing timely information to a region that is under the threat of change. Tova Callender of the West Maui Ridge-to-Reef initiative and Chris Brosius of the West Maui Mountains Watershed Partnership explained why climate change matters for conservation, emphasizing the need for better partnerships and communication between scientists and natural resource managers. The Documentments have been viewed over 3,000 times in dozens of countries, and have been regularly used in meetings, invited talks, and for educational purposes. They are an excellent tool for people to learn about how climate change is already impacting people in Hawai‘i, and how to link scientific statements that may be difficult to understand with a story.



“Climate Matters for Waikiki Beach” (left); “Climate Matters for Ranchers in Hawai‘i” (right).

United Nations Development Programme “Best Practice”

Leads: Richard Wallsgrove

Partner Institutions: UNDP

In 2014, the Pacific RISA was selected as one of five UNDP “best practices” for integrating climate data into risk management, inviting us to participate in the Climate Risk Management Experts Group Meeting of the Integrated Climate Risk Management Programme (ICRMP) in Kathmandu, Nepal, in 2014. Project Specialist Wallsgrove was invited to present best practice findings from Pacific RISA’s climate hazard assessment work. The workshop also provided an opportunity for Pacific RISA to evaluate and learn about approaches to climate adaptation across a spectrum of six developing countries where opportunities, needs, and resources may be similar to needs in developing portions of the Pacific region.

East-West Center New Generations Seminar

Leads: Victoria Keener

Partner Institutions: East-West Center, NOAA

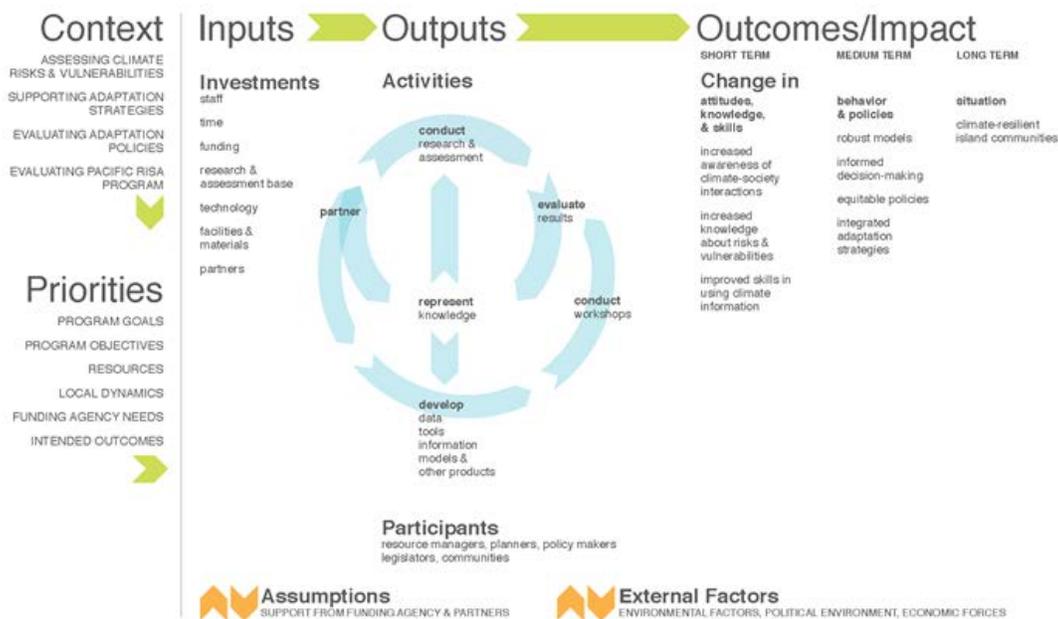
Also in 2014, Dr. Keener traveled with 14 young leaders in politics chosen from across the US and the Asia-Pacific region as part of the East-West Center’s New Generation Seminar to Miami, Florida and Washington, DC to explore regional and federal level adaptation efforts to the impacts of climate change. Participants were able to meet with the NOAA Climate Program Office, as well as representatives from the US National Climate Assessment in Washington, and gained insight and connections into the national RISA program and how it interacts with policymakers at the local and national level as an example for how similar programs could work in their own countries or the US.

VI. Impact Evaluation

Focused Independent Evaluation

Leads: Melissa Finucane, Victoria Keener, Susanne Moser

Program evaluation was a key component of Phase II of the Pacific RISA, and with input from an external evaluator, Pacific RISA developed an action-logic model (ALM) to evaluate various factors influencing the effectiveness of Pacific RISA program activities. Annual evaluations focusing on different aspects of performance resulted in a set of tools and an annual report that was used to guide and improve program design, integration, and effectiveness at the beginning of each new program year. Like a road map, the ALM shows the steps taken to achieve the long-term goal of building climate-resilient island communities. The ALM also indicates that review and adjustment of components are an ongoing, iterative process—both in initiating the program and developing the model of change. This process reflects the essential “translational” role of RISA programs in converting climate science into a change in attitudes, knowledge, skills, behaviors, and policies. By evaluating the perception of Pacific RISA and the utility of methods and products by decision makers, collaborators, and external partners – as well as Pacific RISA’s leading role in the PIRCA and NCA – the team has refined their research relevance and responded to evolving needs. Based on Dr. Moser’s independent evaluations and the final evaluation for Pacific RISA Phase II, the team is in the process of updating the ALM to better reflect the iterative and policy-oriented nature of the Pacific RISA process.



The current Pacific RISA Action-Logic Model.

More recent research has concerned how the Pacific RISA contributes to climate adaptation planning in Hawai‘i. This work, in turn, has informed the team about how the PIRCA continues to affect the state and region. Most relevant for measuring program-level impact, in the last two annual independent evaluations Dr. Moser’s research has been able to trace the Pacific RISA products to specific policy outcomes, mainly concerning the intersection of freshwater sustainability and climate change adaptation at the county and state level.

Traceable Policy Impacts

Leads: Laura Brewington, Melissa Finucane, Victoria Keener, Susanne Moser, Richard Wallsgrove

Pacific RISA works with diverse stakeholder groups at the federal, regional, state, and county levels on issues of climate change adaptation, planning, and policy (see page 4). Representatives from these groups have been reached via extensive stakeholder engagement to 1) target growth in stakeholder involvement or create new partnerships; 2) monitor ongoing developments related to prior research; 3) gather ongoing guidance and information on law and policy options to assist research; and 4) evaluate or assist stakeholder climate adaptation policy decisions based on research. There is continued evidence of climate change adaptation measures being incorporated into water law and policy, and evidence of interest in new island settings. The multi-disciplinary work conducted by the Pacific RISA team is of clear significance to the Pacific Islands region. Outcomes demonstrate not only an enhanced awareness of climate change impacts, but also concrete steps to address those impacts.

Key Findings:

- Because of the established relationships with the disaster management community in the Pacific, climate has been embedded in formal multi-hazard mitigation plans required by the Federal Emergency Management Agency (FEMA) for provision of post-disaster recovery and pre-disaster mitigation funding. For the State of Hawai‘i, the plan describes the types of hazards associated with climate variability and change, attempts to evaluate risks from climate-related impacts (more data and research is needed in this area), describes institutions and organizations that contribute to risk reduction, and recommends mitigation actions. In a document adopted by the Governor of Hawai‘i and approved by FEMA, the Pacific RISA is one of the institutions specifically mentioned in the plan for risk assessment and reduction through climate risk assessment and adaptation (State of Hawai‘i, Chapter 6, Section 6.5.1).
- After a conference in August of 2013 on freshwater sustainability needs in Hawai‘i convened by US Senator Brian Schatz (D-Hawai‘i), Chairman of the Energy and Natural Resources Subcommittee on Water and Power, at which Dr. Keener spoke about Pacific RISA projects and climate and freshwater needs and gaps, Senator Schatz announced the SECURE Water Amendments Act of February 2014 (S.2019), legislation to conserve water resources and promote sustainability. The SECURE Water Amendments Act of 2014 will expand grants and increase funding for water conservation and drought projects, provide resources for better data collection and analysis of water supply and use, and finally make Hawai‘i water conservation projects eligible for grants, all ideas put forward during the August 2013 meeting to increase Hawai‘i’s freshwater security in the face of climate change. The Senate bill was co-sponsored by Senators Martin Heinrich (D-NM), Mazie Hirono (D-HI), Mark Udall (D-CO), Tom Udall (D-NM), and Ron Wyden (D-OR).
- Former Governor Neil Abercrombie of Hawai‘i was appointed as a member of President Obama’s Climate Change Task Force. His policy document, “Navigating Change: Hawai‘i’s approach to adaptation,” was released in December 2013 following review by the Pacific RISA, and recommends actions in language taken directly from NOAA RISA program goals. Figures co-created by Pacific RISA and the PIRCA are also featured in the report. The Pacific RISA contributed resources to the passing into law of HI Act 286 (2012) calling for statewide climate change adaptation planning, and the incorporation of future climate projections into the Hawai‘i Water Resources Protection Plan. Pacific RISA researchers also analyzed Hawai‘i’s law and policy framework to identify ways of enhancing climate adaptation for Hawai‘i’s water resources, proposing 12 tools to improve climate adaptation. Workshops with state and local decision makers led to the incorporation of climate scenario analysis into freshwater planning documents.

- The Hawai‘i Commission on Water Resource Management has continued the process of updating Hawai‘i’s primary and comprehensive water planning policy tool – the Water Resource Protection Plan and its components – including efforts to address Pacific RISA recommendations regarding climate change adaptation. Climate change adaptation is one of five key new elements of this update, and Pacific RISA’s climate research and law and policy research is incorporated, while components (e.g. Maui County Water Use and Development Plan) are directly addressing climate adaptation using Pacific RISA scientific research. As that planning update proceeds, the Commission is continuing to implement adaptation recommendations in other ways. For example, Commission staff recently recommended for approval a proposal to jointly fund an evaluation of water monitoring needs the with USGS-PIWSC.
- Building off of climate adaptation legislation passed in 2014 and the resulting efforts related to adaptation, the Hawai‘i legislature passed at least two bills in 2016 to increase adaptive capacity for water resources. House Bill 2040 implemented a funded two-year pilot program for a water security advisory group to enable public-private partnerships that would utilize state matching funds for projects that increase groundwater recharge, encourage water reuse for landscape irrigation, and improve the efficiency of agricultural and potable water use. House Bill 2626 limits the issuance of permits for underground fuel tanks in the shoreline areas that may be susceptible to climate change, and which may subsequently impact groundwater and coastal water quality. Climate adaptation and appropriate planning horizons were issues raised in the deliberation of both bills. Work is progressing on the Interagency Climate Adaptation Committee Act 83, implemented in 2014, with public engagement to commence shortly and the committee’s report anticipated in 2017. Hawai‘i legislators and regulators have looked to the Pacific RISA for assistance in understanding and developing climate adaptation laws and policies.
- Research by the Pacific RISA continues to contribute to efforts to designate the Keauhou aquifer (located on Hawai‘i Island) as a groundwater management area (WMA), a classification that requires existing and new source owners, with the exception of individual domestic users and those on rain catchment systems, to obtain a water use permit from the Commission on Water Resource Management and justify their withdrawals and uses. The petition for this designation relies in part on climate trends, and an increasing need to manage water resources at the Kaloko-Konokahau National Park from a climate adaptation standpoint. This is a potentially contentious issue amongst various Hawai‘i Island residents, businesses, agencies, and other stakeholders, who resist what is perceived as additional top-down regulation. In the designation process, climate adaptation principles and future planning could easily be lost under the volume of public debate. The Pacific RISA’s research on climate adaptation and water policy has been included in the evidence supporting the WMA designation, and cited frequently in outreach materials and debate. In 2014, in a preliminary decision on the petition, the Commission on Water Resource Management ordered the development of refined forecasts of water demand and supply in order to reconcile land use planning with projected water supply and demand. This decision is consistent with the climate adaptation policy recommendations developed by the Pacific RISA.
- The Honolulu Board of Water Supply has budgeted for new capital improvement projects that are consistent with adaptation recommendations from the Pacific RISA, including recycled water mains and water storage facilities.
- The American Sāmoa Power Authority has moved forward with plans to increase stream and rainfall monitoring capacity, consistent with opportunities identified by the Pacific RISA.
- The American Sāmoa EPA has begun to include groundwater monitoring in their standard monitoring protocols, consistent with recommendations from the Pacific RISA.

The Pacific RISA Advisory Committee

Leads: Melissa Finucane, Victoria Keener

Partner Institutions: East-West Center

A 14-person international Advisory Committee was established in Phase II, representing academic, business, community, resource management, and agency representatives from Hawai'i, NOAA entities such as SeaGrant and the National Marine Sanctuary, and multiple Pacific Island and Pacific Rim countries and territories including Sāmoa, American Sāmoa, Guam, RMI, and Palau. The Advisory Committee serves the purpose of providing program-level feedback to PIs on research and stakeholder relevance of climate services across the Pacific, and advises the team from an external vantage point on potential regional barriers and opportunities. Committee meetings are conducted on a biennial basis due to the distances involved; however, members are updated on Pacific RISA projects through annual newsletters and periodic emails. Most recently, in 2016 the Pacific RISA Advisory Committee met with the program PIs to discuss successes and gaps in the Pacific RISA Phase II five-year award and showcase new research and plans for the Phase III award (2015-2020). Participants from different sectors across the Pacific Islands region were brought together to discuss research and collaboration opportunities going forward for the RISA. Key themes that emerged included how to improve regional communication, finding new opportunities for collaboration and improving existing partnerships, identifying effective strategies for synthesizing and disseminating information, and ways of improving and leveraging existing Pacific RISA projects with other regional efforts. Biennial meetings will continue in Phase III, and the composition of the Advisory Committee will be confirmed and re-assessed to identify missing sectors of stakeholders or Pacific Islands regions.



Pacific RISA Principal Investigators and Advisory Committee members, April 2016.

VII. Project Integration: An Example of Use-Inspired Research and Stakeholder Engagement

Pacific RISA research projects are designed in collaboration with stakeholders to directly meet and be responsive to their needs, yet still produce high-quality and impactful basic science research. Research on the impacts of future climate and land use scenarios on groundwater recharge on the island of Maui was designed in conjunction with collaborators at the USGS-PIWSC and water managers, state agency representatives, and large land owners. Pacific RISA researchers developed and calibrated the HRCM for Maui (see [CLIMATE SCIENCE](#)), worked with over 100 stakeholders to design detailed future climate scenario GIS maps over a range of development and restoration land use futures (see [DECISION SUPPORT](#)), input the climate projections into groundwater recharge models for the different climate scenarios (see [FRESHWATER RESOURCES](#)), and used the results in the final year of Phase II funding to inform the update of the Hawai'i State Water Resources Protection Plan and Maui Water Use Development Plan (see [IMPACT EVALUATION](#)).



Native forest cover on Maui (left), and I'ao Valley on Maui, where some plantation-era diversions still capture base flow from streams (right). Some groups advocate restoring historic flows to these streams.

VIII. Linkages with Other NOAA Programs

Through the PIRCA coordination and sustained assessment process, the Pacific RISA has linked with many different NOAA offices. In the PIRCA process, the report Lead Editors included two Pacific RISA representatives (Finucane & Keener), the PICCC Coordinator (Deanna Spooner), and the NOAA RCSD (Marra). In this context, they worked together extensively to organize three supporting technical workshops, manage large teams of people and timelines, and write and edit contributions. The Pacific RISA has also interacted with Dr. Marra regularly through his work as the Director of the former Pacific Climate Information System (PaCIS), and is in constant collaboration on outreach activities to the community, policy makers, and other stakeholders, providing support for each other's research and organizations, and filling gaps as needed.

The Pacific RISA has also addressed many of the NOAA-CSI Next Generation Strategic Plan Synergy goals, by improving the technical understanding of regional climate dynamics, assessing future climate impacts, partnering with collaborative regional climate groups, translating climate futures to ecosystem impacts, improving freshwater sustainability under future climate conditions, and bringing climate science to adaptation and policy.

Additionally:

- The NOAA Pacific Regional Climate Service Director, Dr. Marra, is one of Pacific RISA Co-PI's, and has a collaborative research relationship with several different researchers and groups within the Pacific RISA program;
- The Meteorologist In Charge of the NWS Pacific Office, Raymond Tanabe, (formerly James Weyman) is also a Co-PI on the RISA project, and provides guidance, data, and support to researchers;
- The Pacific RISA has a close working relationship with the NOAA Pacific ENSO Applications Center (PEAC). RISA representatives attend the monthly PEAC conference call on ENSO and climate conditions throughout the Pacific region. PEAC representatives have also agreed to include Pacific RISA's forthcoming newsletter and fact-sheet series in the mail with their quarterly newsletter;
- The Pacific RISA has a close working relationship with the NOAA NESDIS NCEI Center, coordinating access to and use of databases about extreme climate events;
- The Pacific RISA collaborates with the NOAA Pacific Services Center by participating in the Navigator's Council of the Pacific Risk Management 'Ohana (PRiMO);
- In addition to their joint involvement with the PIRCA process, the Pacific RISA works closely with UH SeaGrant in the organization of workshops and publication review; and
- Through the PIRCA process, the Pacific RISA leveraged and has continued to sustain partnerships with the following NOAA entities:
 - National Environmental Satellite, Data, and Information Service (NESDIS)
 - National Climatic Data Center (NCDC)
 - Climate Prediction Center (CPC)
 - National Ocean Service Coastal Storms Program (NOS-CSP)
 - Coral Reef Conservation Program (CRCP)
 - Pacific Services Center (PSC)
 - Pacific Islands Fisheries Science Center (PIFSC)
 - Center for Operational and Oceanographic Products and Services (COOPS)
 - Coastal Services Center (CSC)
 - National Marine Fisheries Service (NMFS)
 - National Geodetic Survey (NGS)

IX. Publications

- Anderson, C.L. (2012). Overview of Climate Risk Reduction in the US Pacific Islands Hazard Mitigation Planning Efforts. Honolulu: Hazards, Climate & Environment Program, University of Hawai'i Social Science Research Institute, Technical Report No. 201103A. Available at <http://www.pacificrisa.org/wpcontent/uploads/2013/02/Anderson-Overview-of-Climate-Risk-Reduction-in-the-US-PIHazard-Mitigation-Planning.pdf>
- Anderson, C.L. (2012). Overview of Climate Risk Reduction in the US Pacific Islands Freely Associated States. Honolulu: Hazards, Climate & Environment Program, University of Hawai'i Social Science Research Institute, Technical Report No. 201103B. Available at <http://www.pacificrisa.org/wp-content/uploads/2013/02/AndersonOverview-of-Climate-Risk-Reduction-in-the-US-PI-FAS.pdf>
- Anderson, C.L. (2012). Analysis of Integrating Disaster Risk Reduction and Climate Change Adaptation in the US Pacific Islands and Freely Associated States. Honolulu: Hazards, Climate & Environment Program, University of Hawai'i Social Science Research Institute, Technical report No. 201105. Available at <http://www.pacificrisa.org/wp-content/uploads/2013/02/Anderson-Analysis-of-Integrating-Disaster-Risk-Reduction-and-Climate-Change-Adaptation.pdf>
- Annamalai, H., Keener, V., Widlansky, M.J., and Hafner, J. (2015). El Niño Strengthens in the Pacific: Preparing for the Impacts of Drought. *AsiaPacific Issues*, 122: 1-10. Available at <http://www.eastwestcenter.org/system/tdf/private/api122.pdf?file=1&type=node&id=35429>
- Brewington, L., Keener, V., Finucane, M. and Eaton, P. (in press). Participatory Scenario Planning for Climate Change Adaptation Using Remote Sensing and GIS. In S.J. Walsh (ed), *Remote Sensing for Societal Benefits*. Amsterdam: Elsevier.
- Burkett, M. (2011). In Search of Refuge: Pacific Islands, Climate-Induced Migration, and the Legal Frontier. *AsiaPacific Issues*, 98: 1-8. Available at <http://www.eastwestcenter.org/fileadmin/stored/pdfs/api098.pdf>
- Chowdhury, R., Barnston, A.G., Guard, C., Duncan, S., Schroeder, T.A., and Chu, P.S. (2010). Sea-Level Variability and Change in the US-Affiliated Pacific Islands: Understanding the High Sea Levels During 2006–2008. *Royal Meteorological Society* 65(10): 263-268. Available at <http://www.soest.hawaii.edu/MET/Hsco/Paper/Weather-65-10263-68.pdf>
- Corlew, K. (2015). Disaster and Climate Change Preparedness in American Sāmoa: A Handbook for Communities. Honolulu: East-West Center. Available at <http://www.pacificrisa.org/resources/publications/>
- Corlew, K. (2015). Disaster and Climate Change Preparedness in Maui: A Handbook for Communities. Honolulu: East-West Center. Available at <http://www.pacificrisa.org/resources/publications/>
- El-Kadi, A.I. (2013). Assessing Ground Water Sustainability of the Island of Tutuila, American Sāmoa: Technical Report. Honolulu: University of Hawai'i Water Resources Research Center.
- Ferguson, D.B., Finucane, M.L., Keener, V.W., and Owen, G. (2016). Evaluation to Advance Science Policy: Lessons from Pacific RISA and CLIMAS. In A. Parris, G. Garfin, et al. (eds), *Climate in Context: Science and Society Partnering for Adaptation*. West Sussex: Wiley. ISBN: 978-1-118-47479-2.
- Finucane, M.L. and Keener, V.W. (2015). Understanding the Climate Sensitive Decisions and Information Needs of Island Communities. *Journal of the Indian Ocean Region*, DOI: 10.1080/19480881.2015.1021181.

- Finucane, M.L., Marra, J.J., Keener, V.W., and Smith, M.H. (2012) Pacific Islands Region Overview. In *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA)*. Washington, DC: Island Press.
- Hagedorn, K.B., Mair, A. and El-Kadi, A.I. (2011). Inventory of Research, Tools, and Information to Support Decision Making about the Pearl Harbor Aquifer under a Changing Climate. Honolulu: University of Hawai‘i, Water Resources Research Center.
- Hamilton, K. (2014). Projecting Climate Change in Hawai‘i. *IPRC Climate*, 14(1), 3-11.
- Helweg, D.A., Keener, V., and Burgett, J. (2016). Report from the Workshop on Climate Downscaling and its Application in High Hawaiian Islands, September 16-17, 2015. US Geological Survey Open-File Report 2016-1102. Reston: US Geological Survey. DOI:10.3133/ofr20161102.
- Johnson, A.G., Engott, J.A., and Bassiouni, M. (2014). Spatially Distributed Groundwater Recharge Estimated Using a Water-Budget Model for the Island of Maui, Hawai‘i, 1978–2007. US Geological Survey Scientific Investigations Report 2014–5168. Reston: US Geological Survey. DOI: 10.3133/sir20145168.
- Keener, V.W. and Izuka, S.K. (2012). Fresh Water and Drought on Pacific Islands. In *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA)*. Washington, DC: Island Press. Available at www.pacificrisa.org/projects/pirca/.
- Keener, V.W., Hamilton, K., Izuka, S.K., Kunkel, K.E., Stevens, L.E., and Sun, L. (2013). Regional Climate Trends and Scenarios for the US National Climate Assessment: Part 8. Climate of the Pacific Islands. Technical Report NESDIS 142-8. Washington, DC: NOAA.
- Keener, V.W., Marra, J.J., Finucane, M.L., Spooner, D., and Smith, M.H. (2012). Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA). Washington, DC: Island Press. Available at www.pacificrisa.org/projects/pirca/.
- Lauer, A., Hamilton, K., Wang, Y., Phillips, V.T.J., and Bennartz, R. (2010). The Impact of Global Warming on Marine Boundary Layer Clouds over the Eastern Pacific- A Regional Model Study. *Journal of Climate*, 23(21): 5844-5863. Available at <http://iprc.soest.hawaii.edu/users/kph/paper/2010jcliLaueretal.pdf>
- Lauer, A., Zhang, C., Elison-Timm, O., Wang, Y., and Hamilton, K. (2013). Downscaling of Climate Change in the Hawai‘i Region using CMIP5 Results: On the Choice of the Forcing Fields. *Journal of Climate*, 26: 10,006-10,030, DOI:10.1175/JCLI-D-13-00126.1.
- Leong, J.-A., Marra, J.J., Finucane, M.L., Giambelluca, T., Merrifield, M., Miller, S.E., Polovina, J., Shea, E., Burkett, M., Campbell, J., Lefale, P., Lipschultz, F., Loope, L., Spooner, D., and Wang, B. (2014). Ch. 23: Hawai‘i and U.S. Affiliated Pacific Islands. In J.M. Melillo, T.C. Richmond, and G.W. Yohe (eds.), *Climate Change Impacts in the United States: The Third National Climate Assessment*, pp. 537-556. Washington, DC: US Global Change Research Program. DOI: 10.7930/J0W66HPM.
- Leta, O.T., El-Kadi, A.I., Dulai, H., Ghazal, K.A. (2016). Assessment of Climate Change Impacts on Water Balance Components of Heeia Watershed in Hawai‘i. *Journal of Hydrology: Regional Studies*, 8: 182-197.
- Moser, S.C. (2015). Supporting Hawai‘i’s Adaptation Efforts: The Role of the Pacific RISA. Santa Cruz: Susanne Moser Research & Consulting.

- Moser, S.C. (2013). PIRCA Evaluation: Development, Delivery, and Traceable Impacts – With Particular Emphasis on the Contributions of the Pacific RISA. Santa Cruz: Susanne Moser Research & Consulting.
- Wager, K. (2012). Climate Change Law and Policy in Hawai‘i Briefing Sheet, 2012. Center for Island Climate Adaptation and Policy. Available at <http://www.pacificrisa.org/wp-content/uploads/2016/03/CClawpolicy.pdf>
- Wallsgrave, R. and Penn, D. (2012). Water Resources and Climate Change Adaptation in Hawai‘i : Adaptive Tools in the Current Law and Policy Framework. Honolulu: Center for Island Climate Adaptation and Policy. Available at <http://icap.seagrant.soest.hawaii.edu/icap-publications> and www.islandclimate.org
- Wallsgrave, R. and Grecni, Z. (2016). Water Resources in American Sāmoa: Law and Policy Opportunities for Climate Change Adaptation. Honolulu: East-West Center. Available at <http://www.eastwestcenter.org/system/tdf/private/wateramericanSāmoa-2016.pdf?file=1&type=node&id=35601>
- Wang, Y., Zhang, C., and Lauer, A. (2013). Dynamical Downscaling of Regional Climate for the Hawaiian Islands: An Overview. In J.M. Fernandez-Palacios et al. (eds), *Climate Change Perspectives from the Atlantic: Past, Present and Future*, pp. 563-597. San Cristóbal de La Laguna: Universidad de La Laguna.
- Zhang, C., Wang, Y., Lauer, A., and Hamilton, K. (2012). Configuration and Evaluation of the WRF Model for the Study of Hawaiian Regional Climate. *Monthly Weather Review*, 140: 3259-3277.
- Zhang, C., Wang, Y., Lauer, A., Hamilton, K., and Xie, F. (2012). Satellite and Ground-Based Determinations of Cloud Base Height, Cloud Top Height and Cloud Thickness in the Hawaiian Region. *Geophysical Research Letters*, 39(15): L15706. DOI: 10.1029/2012GL052355.
- Zhang, C., Wang, Y., Hamilton, K. and Lauer, A. (2016). Dynamical Downscaling of the Climate for the Hawaiian Islands. Part I: Present-Day. *Journal of Climate*, 29: 3027-3048. DOI: 10.1175/JCLI-D-15-0432.1.
- Zhang, C., Wang, Y., and Hamilton, K. (2011). Improved Representation of Boundary Layer Clouds over the Southeast Pacific in WRF-ARW using a Modified Tiedtke Cumulus Parameterization Scheme. *Monthly Weather Review*, 139: 3489-3515. DOI: 10.1175/MWR-D-10-05091.1.