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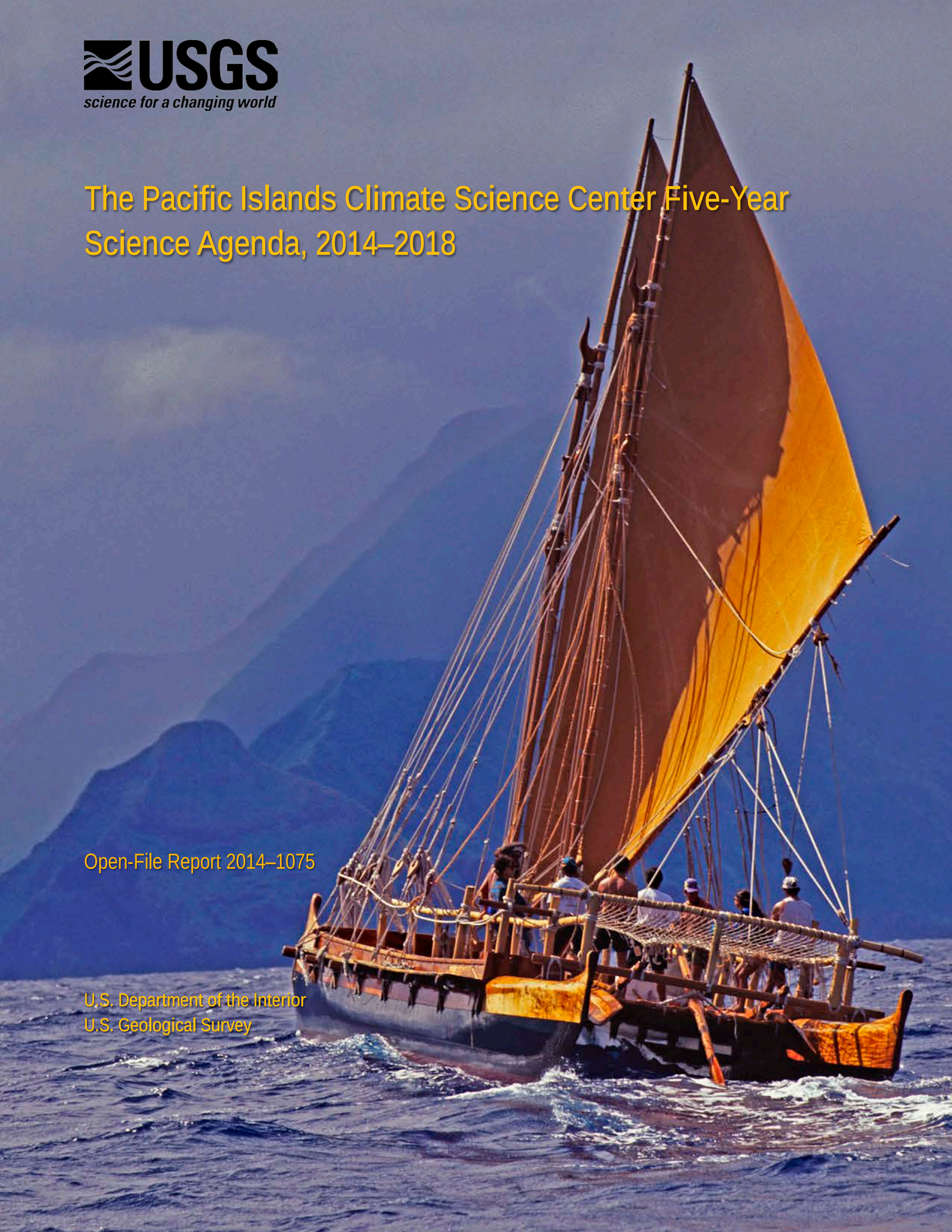
# The Pacific Islands Climate Science Center Five-Year Science Agenda, 2014–2018



Open-File Report 2014–1075

U.S. Department of the Interior
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FRONT COVER IMAGE: The Hawaiian voyaging canoe *Hawai'iloa*, seen here along the windward shores of Moloka'i, was built in the early 1990s in the traditional way, but using two Sitka spruce trees given by the Tlingit and Haida tribes of Alaska instead of the massive native koa trees, now depleted in Hawai'i's forests. Maritime traditions of Native Hawaiian and Pacific peoples are strong and deep in community and cultural identity and reflect complex linkages between society, land, sea, and sky. Photograph © Monte Costa/Photo Resource Hawaii.

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By David A. Helweg, Sarah A. B. Nash, and Dan A. Polhemus

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U.S. Department of the Interior
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SALLY JEWELL, Secretary

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# Contents

# Figures



# Abbreviations

| | |
|---|---|
| DAR | Division of Aquatic Resources, DLNR |
| DLNR | Hawaii State Department of Land and Natural Resources |
| DMWR | Department of Marine and Wildlife Resources, American Samoa |
| DOFAW | Division of Forestry and Wildlife, DLNR |
| DOI | Department of the Interior |
| ENSO | El-Niño Southern Oscillation |
| MCT | Micronesia Conservation Trust |
| NMFS | National Marine Fisheries Service, NOAA |
| NOAA | National Oceanographic and Atmospheric Administration |
| NPS | National Park Service, DOI |
| NRCS | Natural Resources Conservation Service, USDA |
| OIA | Office of Insular Affairs, DOI |
| PaCIS | Pacific Climate Information Services, NOAA |
| PDO | Pacific Decadal Oscillation |
| PICCC | Pacific Islands Climate Change Cooperative |
| PICSC | Pacific Islands Climate Science Center |
| RISA | Pacific Regional Integrated Sciences and Assessments Program |
| TNC | The Nature Conservancy |
| USDA | U.S. Department of Agriculture |
| USFWS | U.S. Fish and Wildlife Service, DOI |
| USGS | U.S. Geological Survey, DOI |

# The Pacific Islands Climate Science Center Five-Year Science Agenda, 2014–2018

David A. Helweg,[1] Sarah A. B. Nash[2], and Dan A. Polhemus[3]

## Climate Change in Pacific Islands

From the heights of Mauna Kea on Hawai‘i Island to the depths of the Mariana Trench, from densely populated cities to sparse rural indigenous communities and uninhabited sandy atolls, the Pacific region encompasses diverse associations of peoples and places that are directly affected by changes to the atmosphere, ocean, and land. The peoples of the Pacific are among the first to observe and experience the effects of global climatic changes (fig. 1).

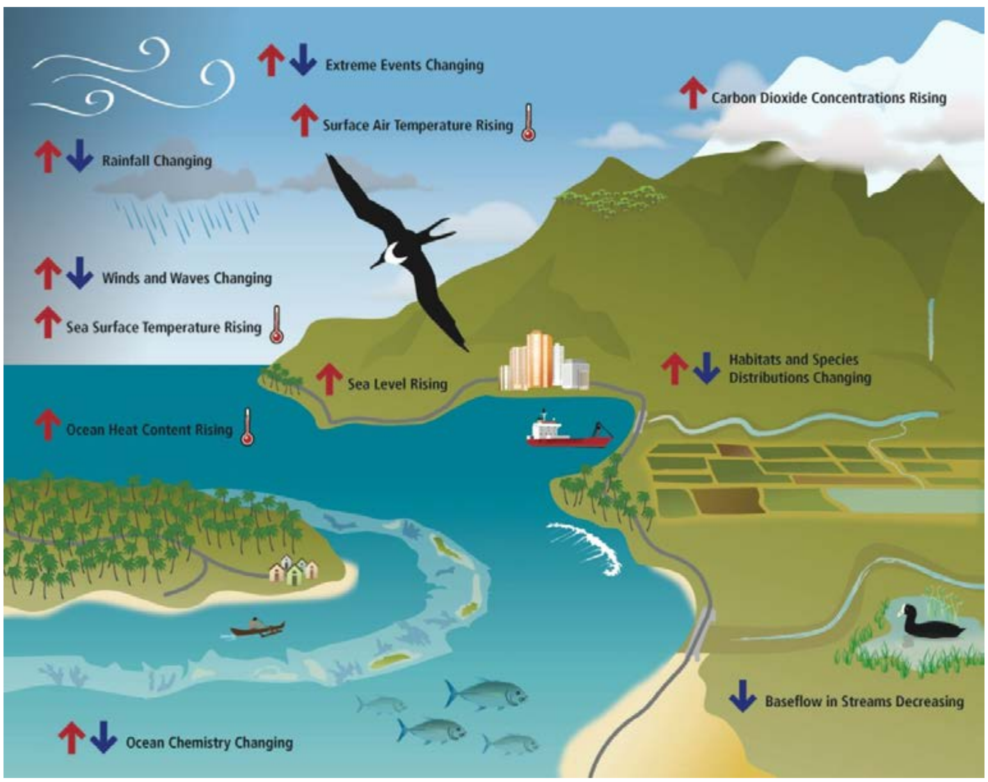


Figure 1. Diagrammatic view of a Pacific region land- and seascape, showing climate change indicators. (Image courtesy of Pacific Regional Integrated Science and Assessment and Susan Yamamoto, Geovision. Adapted from “Ten Indicators of a Warming World,” in National Oceanic and Atmospheric Administration National Climatic Data Center, report on “State of the Climate 2009.”)

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[3] Pacific Islands Office, U.S. Fish and Wildlife Service.

Because the Pacific region is predominantly composed of vast ocean expanses punctuated only by small, isolated emergent islands and atolls, marine processes are critical factors in the region's climate systems, and their impacts occur here to a greater degree than in continental regions. Rates of sea-level rise in the region during the modern altimetry period exceed the global rate, with the highest increases occurring in the western North Pacific (Cazenave and Llovel, 2010; Nerem and others, 2010; Timmermann and others, 2010). The ocean has also warmed during this period. Since the 1970s, sea-surface temperature has increased at a rate of 0.13 to 0.41 °F (0.07 to 0.23 °C) per decade, depending on the location (Keener and others, 2012a). Ocean chemistry has changed during this period as well, with surface pH having dropped by 0.1 pH units (Feely and others, 2009; Doney and others, 2012).

Over the past century, air temperature has increased throughout the Pacific region. In Hawaiʻi, average temperatures increased by 0.08 °F per decade during the period 1919 to 2006, and in recent years, the rate of increase has been accelerating, particularly at high elevations (Giambelluca and others, 2008). In the western North Pacific, temperatures also increased over the past 60 years (Lander and Guard, 2003; Lander, 2004; Lander and Khosrowpanah, 2004; Kruk and others, 2013), with a concurrent warming trend in the central South Pacific since the 1950s (Australian Bureau of Meteorology and CSIRO, 2011).

Precipitation has shown varying trends in the Pacific region over the past century. Rainfall has decreased throughout Hawaiʻi (Oki, 2004; Chu and Chen, 2005; Diaz and others, 2005, 2011; Elison Timm and others, 2011; Giambelluca and others, 2011) and also at eastern Micronesian islands such as Majuro and Kwajalein, based on records from 1954 to 2011 (Keener and others, 2012b). By contrast, rainfall has increased slightly in western Micronesia (Bailey and Jenson, 2011; Jacklick and others, 2011), while in the central South Pacific, long-term precipitation records show no visible or significant trend (Young, 2007).

Extreme weather events have also changed in the region. Since the 1950s, there have been fewer extreme rainfall events in Guam and the Commonwealth of the Northern Mariana Islands (Lander and Guard, 2003; Lander and Khosrowpanah, 2004). Tropical cyclone formation has also decreased in the western North Pacific (Knapp and others, 2010; Maue, 2011) and the central North Pacific (Chu, 2002). Tide-gauge observations at Midway Atoll, however, suggest that the number of storm wave events originating from outside the tropics has increased significantly over the past 50 years (Aucan and others, 2012).

The above changes in climate factors have produced noticeable ecological effects. Distributions of pelagic fish species, including important fishery stocks such as tunas, are changing in response to shifting ocean temperature regimes (Polovina and others, 2011). Throughout the Pacific many coral reefs are deteriorating and potentially dying as a result of changes in ocean temperature and chemistry (Cooper and others, 2008; Veron and others, 2009) coupled with cumulative impacts from fishing, land-based sources of pollution, coastal development, and invasive species. Rising sea levels are also causing existing coastal wetlands and mangrove areas to become more saline over time, with increased inundation from high waves (Gilman and others, 2008); although some of these ecological communities may migrate inland with changing shorelines, others may be topographically restricted by steep coasts, particularly on high islands. Changes in precipitation are also affecting freshwater streams, with eight of the nine long-term stream gages in Hawaiʻi showing statistically significant decreases in base flow (the groundwater component of stream flow) from 1913 to 2008 (Oki, 2004; Bassiouni and Oki, 2012), with a resulting reduction in available freshwater habitat. At higher elevations, some wet native montane ecosystems will no longer exist by 2100 because they will have been pinched off the tops of steep-sided mountain ridges by upward migration of climate zones (Keener and others, 2012a). And at the highest elevations, Hawaiian alpine ecosystems are already beginning to show effects from drought and warmer temperatures (Cao and others, 2007), as seen through the severe decline over the past two decades of the

Haleakalā silversword plant (Krushelnycky and others, 2011), which is found only on the Hawaiian island of Maui.

The overall scientific consensus is that the atmosphere and the ocean will continue to warm over the next 50–100 years, sea level will rise because of thermal expansion of water and melting of glaciers, ocean pH will decline as more carbon dioxide is absorbed, and circulation patterns in both the oceans and atmosphere are likely to change at local, regional, and global scales (Bindoff and others, 2007). Storm intensity may also increase, and extreme flood and drought events may become more frequent (Solomon and others, 2007). All of these aspects of climate change will impact the ecological and social systems of the Pacific islands.

The warming projected over the next century will create heat-related stress for human communities, agricultural systems, transportation and other infrastructure, and for native plant and animal species. Seasonal changes in precipitation patterns, coupled with increased temperature and evapotranspiration, have the potential for widespread and significant effects on water resources, which will create both societal and ecological problems. Based on historical and projected patterns of land-cover change in this region, impacts from invasive species and human development are likely to amplify the adverse effects of climate change on habitats and species.

As noted in the report for the Pacific Islands Regional Climate Assessment (PIRCA; Keener and others, 2012a):

> In general, the proximity of human settlements and major infrastructure to the ocean increases the vulnerability of all Pacific islands. Almost without exception, international airports are sited on or within one to two miles of the coast, and the main (and often only) road network runs along the coastline (Walker and Barrie, 2006). Because Pacific islands are almost entirely dependent on imported food, fuel, and material (Austin and others, 2011), the vulnerability of ports and airports to incremental increases in sea level and to extreme events, especially tropical cyclones, is of great concern.

A considerable amount of current infrastructure lies at elevations that are vulnerable even to current sea states and weather conditions, and these vulnerabilities will only be increased as the climate trends discussed above play out across the Pacific region and the world as a whole.

Recent analyses point to future impacts to terrestrial ecosystems and communities. One of the key concerns of the PIRCA report is that sea-level rise will eventually lead to overwash, erosion, or inundation of low islands and the coastal zones of high islands, causing displacement of both human communities and native ecosystems and further threat for trust species (that is, species with a defined Federal interest) or species of cultural significance (Parker and Miller, 2012). Furthermore, the advent of increasingly rapid climate change threatens to drive new functional responses from invasive plants, animals, and diseases, in many cases intensifying their synergy with wildfire and their interactions with the native species on remote Pacific islands (Parker and Miller, 2012). In forest ecosystems on higher islands, bioclimate modeling of potential future plant distributions in Hawaiʻi (Price and others, 2012) suggests that certain native wet forest ecosystems that currently occupy limited ridgetop areas will no longer exist by 2100.

These observed and projected climate changes present real challenges to the people of the Pacific. People need to make decisions about current and future impacts to infrastructure, community development, natural resource management, education, policy, agriculture, recreation, traditional livelihoods, tourism, and more. There is a great need for scientists to connect and share climate information with all the peoples of the Pacific islands so that they are better informed to sustain their natural and cultural resources and ways of life.

For more than a decade, regional community developers, scientists, and local leaders have contended with the difficulties arising from climate change. As the need for more rigorous science and investigation increases, the Federal government is responding with regional climate programs and assessments for the Pacific and other regions across the country.

## Introduction to Climate Science Centers

The U.S. Department of the Interior (DOI) recognizes and embraces the unprecedented challenges of maintaining our Nation's rich natural and cultural resources in the 21st century. The magnitude of these challenges demands that the conservation and natural resource management communities work together to develop integrated adaptation and mitigation strategies that address the impacts of climate change and other landscape- and seascape-scale stressors. On September 14, 2009, DOI Secretary Ken Salazar signed Secretarial Order 3289 (amended February 22, 2010) titled, "Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources." The order establishes the foundation for two types of partner-based entities to address these unprecedented challenges: Climate Science Centers (CSCs) and Landscape Conservation Cooperatives (LCCs). CSCs and LCCs represent a department-wide approach for applying scientific tools to increase our understanding of climate change and to coordinate an effective response to its impacts on people and the land, water, ocean, fish and wildlife, and cultural-heritage resources that DOI manages.

The following excerpt from the draft DOI Climate Change Adaptation Plan for FY 2013[4] outlines the relationship between CSCs and LCCs:

> DOI CSCs function as part of a nationally coordinated network and provide region-focused management-related climate science. Their scope includes the full range of natural and cultural resources, and their focus is on information needed to manage these resources in the face of climate change and other stressors such as invasive species and changing land use. Working closely with the LCCs, the DOI CSCs are helping to build five- to ten-year strategic science plans that focus on key fundamental science questions needed to develop adaptation strategies.

Eight CSCs have been established and managed through the U.S. Geological Survey (USGS) National Climate Change and Wildlife Science Center (NCCWSC); each CSC works closely with other CSCs across the nation to guarantee the best and most efficient science is produced. This close collaboration ensures that CSCs share resources and information across institutional boundaries.

In addition, it is a priority of the DOI to work with "American Indians, Alaska Natives, Native Hawaiians, and Pacific Islanders" and residents of insular areas to anticipate and prepare for climate change impacts on their lands, oceans, streams, communities, and ways of life. The CSCs seek to integrate multiple knowledge systems and modes of investigation, without compromising or misappropriating culturally sensitive information, so that the analysis of environmental change can benefit all community groups and peoples.

## The Pacific Islands Climate Science Center and Its Partners

The Pacific Islands Climate Science Center (PICSC) was established in 2012 to address the challenges presented by climate change and variability for Federal, state, nongovernmental, community, and indigenous Pacific islanders and resource managers in Hawai‘i and the U.S.-Affiliated Pacific Islands (USAPI) region (fig. 2). The purpose of the PICSC is to provide scientific information, tools, and techniques regarding land, water, wildlife, and cultural resources to managers, community members, and decisionmakers in order to anticipate, monitor, and adapt to climate change and variability.

[4] Accessed online at http://www.doi.gov/greening/sustainability_plan/index.cfm.

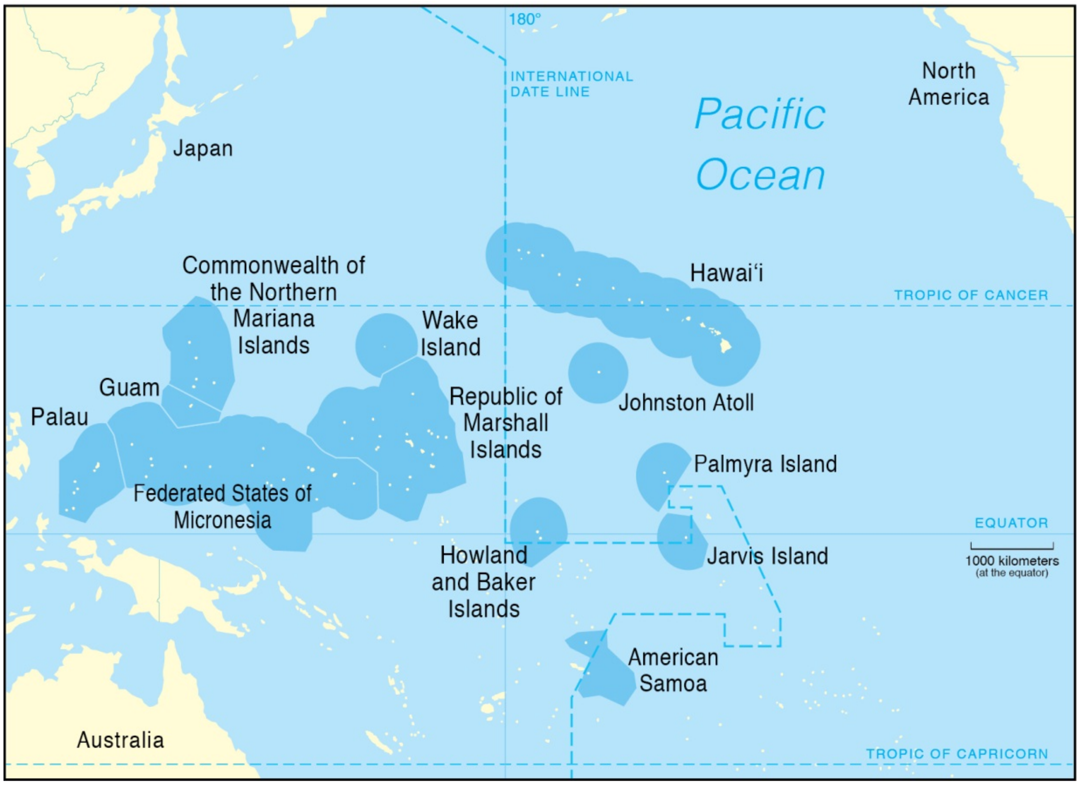


Figure 2. Map of the Pacific region, showing the areas—Hawai‘i and the U.S.-Affiliated Pacific Islands (dark blue shading)—served by the Pacific Islands Climate Science Center.

In close partnership with the PICSC is the Pacific Islands Climate Change Cooperative (PICCC; www.fws.gov/pacific/climatechange/lcc/), which is funded through the U.S. Fish and Wildlife Service and serves as the LCC for Hawai‘i and the USAPI. The PICSC and PICCC, with their unique one-to-one relationship, work in conjunction to provide scientific research and interpretation for the region. Created in 2009, the PICCC is governed by its Federal, state, and nongovernmental members, overseen by a steering committee and managed by a coordinator. The PICCC is a boundary organization, with membership and participation not limited to governmental organizations, intended to assist its member organizations by developing climate change adaptation strategies and tools for the region’s natural and cultural resources.

The PICSC can serve the region through one or more roles, cooperating within the network of climate organizations to effectively generate, transform, and transmit climate information (Marra, pers. comm.). When gaps in knowledge or new needs are found, “generators” fill this need through scientific or cultural investigation scaled to the requirements of the recipients. “Transformers” recast data and knowledge resulting from the investigations into products that can be easily understood and used. “Transmitters” take the transformed information and deliver it to the end users at the local level. Transmitters also serve to communicate feedback and potential for additional knowledge gaps for further investigations or improvement. The PICSC is not only a generator of climate information, but by working directly with managers and communities, and by cooperating with partners in the climate network, the PICSC also provides supporting transformation and translation in order to provide robust climate products and services.

As a closed consortium, the PICSC brings together the expertise of a university consortium; Federal, state, and local government agencies; and international and local nongovernmental institutions. The center is headed by a director and receives advice from executive leadership within the U.S.

Geological Survey and a Stakeholder Advisory Committee (SAC). Additionally, a Science Implementation Panel is responsible for peer and technical review of proposed research projects, with membership that may vary as a function of science topics. The Stakeholder Advisory Committee (appendix 1), a committee with membership restricted to Federal, state, and local government representatives, provides counsel on strategic direction and identification of priorities. Importantly, stakeholder counsel also is sought from other government programs and nongovernmental organizations.

The PICSC is hosted by a university consortium, consisting of the University of Hawaiʻi (UH) at Mānoa (www.uhm.hawaii.edu), UH Hilo (www.hilo.hawaii.edu), and the University of Guam (www.uog.edu), along with partner universities across the nation (appendix 1). This formal arrangement is represented by a cooperative agreement, including Federal funds for climate-related efforts that are flowed to the host institutions. Research is supported in departments and programs at the co-hosting institutions, as well as the academic institutions outside of the Pacific region. This partnership with academia provides not only a basis for geophysical, biological, and social scientific expertise, but also instantiates the PICSC's commitments to capacity building in the region through education, training, and professional development opportunities.

Both the Pacific Climate Information System (PaCIS; www.pacificcis.org) and the Pacific Regional Integrated Sciences and Assessments (Pacific RISA; www.pacificrisa.org) are regional programs sponsored by the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce. Both programs support Pacific communities by providing climate information in order to support making practical decisions and managing risk. The PaCIS serves to disseminate climate research and forecasting services through outreach, education, and collaboration. As an interdisciplinary research program, the Pacific RISA, whose core office is housed at the East-West Center in Honolulu, Hawaiʻi, supports island and coastal communities as they manage risks and build resilience to climate impacts affecting natural resources, economic sectors, and public health.

In 2013, the U.S. Department of Agriculture (USDA) announced the founding of a climate science program for the Pacific region. Regional Climate Hubs are tasked to "deliver science-based knowledge and practical information to farmers, ranchers, and forest landowners…to support decision-making related to climate change" for agricultural production, natural resource management, and rural economic development (www.usda.gov/oce/climate_change/regional_hubs.htm).

Research collaboration comes from government agencies (for example, USGS, PICCC, USDA Forest Service) within the partnership, the university consortium, and organizations associated with the consortium. Development of research concepts and collaborations may be facilitated through workshops, training, or educational opportunities. PICSC science is implemented by three mechanisms: (1) release of a national Request For Proposals; (2) direct solicitation of research proposals or work plans by the PICSC Director; and (3) solicitation of research proposals by the university host directors. All three mechanisms use review processes to ensure the quality of proposals, including relevance to PICSC science priorities, connection with resource stewardship, and cost effectiveness.

## Vision—Sustainability

The vision for the PICSC is to develop science and other knowledge products, tools, and capabilities designed to support policy and management directed toward sustainability of human and ecological communities, conservation of species of concern, and other aspects of interconnected natural and anthropogenic systems in the Pacific islands.

In Hawaiʻi and the USAPI, seascapes and landscapes are woven into the identity and practices of dozens of cultures with more than 20 spoken languages and thousands of cultural sites, places, and landforms. The region is largely dependent on rainfall-fed ground water and aquifers for freshwater, and virtually everyone lives, works, or harvests food in the coastal zone, including the major population centers as well as other ports and associated critical infrastructure across the region. Climate change is already impacting uplands, coastlines, nearshore reef environments, and leeward or low-rainfall areas as a result of atmospheric CO2 (carbon dioxide) and other greenhouse gases driving warming of air and water and increasing ocean acidity. The resulting potential for cascading impacts will present risks to food, water, and economic security as well as cultural continuity.

In recent years there has been an increasing focus on the concept of "sustainability" (for definitions of selected terms, see appendix 2.) in regard to island communities as such communities seek to maintain their ways of life in the face of increasingly rapid social and ecological change. Some change to communities has been brought about by economic uncertainty, increasing pollution, accelerated development, and other nonclimate factors. However, further changes have been driven by global-scale, climate-mediated shifts in atmospheric, oceanic, and terrestrial processes. Factors limiting sustainability of an ecosystem or region change through time and can include changes in physical processes, habitable space, ecosystem integrity, community composition, availability of goods and services, and cultural connectivity.

Striving for sustainability, as it is envisioned within this agenda, means to respect, conserve, support, and build resources and communities on into the future by identifying the priorities of community members and decisionmakers and providing scientific products that will guide the development of effective management options in anticipation of likely future conditions. This can only be accomplished by comprehending the factors that affect regional resource availability within the context of a shifting local, regional, and planet-wide climate.

## Translating the Vision into Actionable Science

In this document we lay out the PICSC science agenda for the period 2014–2018 in the context of major science themes to be addressed through research. The focus of the agenda is on topics where climate and climate variability will create significant challenges for resource managers, cultural stewards, and decisionmakers, rendering existing tools ineffective or requiring new plans and approaches in anticipation of predicted changes. The themes and science agenda emphasize "actionable science"—science designed to be integrated into strategic planning and decisionmaking, with the outcomes motivating further investigation and application.

To connect the concept of ecological and cultural sustainability to actionable science, three broad competencies are required: (1) management-relevant climate time scales; (2) factors and thresholds that affect sustainability; and (3) the effects of these factors on future land management practices. The first step towards addressing this vision is an ability to assess current status and trends of atmospheric, marine, freshwater, and terrestrial systems, and predict or project their likely future condition based on differing management and adaptation scenarios.

In order to maximize the relevance of climate data, it is necessary to work across multiple time scales. This enables resource managers to respond to near-term challenges and also to plan for what the coming decades may bring. Policy and management plans often work in shorter time periods than climate projections use, rendering 50-year projections too distant to embrace. Climate information should be packaged to effectively aid those who need it in the near term. To do this we will work alongside programs and agencies that integrate modern scientific approaches with traditional knowledge systems and modes of investigation to produce products relevant to time scales that appropriately reflect the needs of the region.

While such baseline understanding is being acquired, it is also essential to delve into more complex interactions, such as the factors and thresholds that affect biological, community, and cultural sustainability and carrying capacity. In other words, how much change can occur before a system or process is irrevocably compromised or a place loses its social value or meaning? How vulnerable, resilient, or adaptable are key elements? These complex questions hold significance for societies, wildlife populations, and island ecosystems.

In addition, social, economic, cultural, biophysical, and logistical factors must be coupled with an understanding of how resource management paradigms will need to shift to accommodate climate-related environmental change. For example, given that changing climate likely will cause changes in the spatial distribution of key species and habitat resources, current practices of defending and managing specific delineated spaces (for example, a wildlife refuge, a marine protected area, or cultural park) may or may not continue to remain effective and potentially inspire a new philosophy of reserve design. The tools that resource managers use will require evaluation and adaptation to improve their efficacy as these shifts take place.

## Science Themes

### Identifying Priorities and Developing Themes.

To implement this core concept of climate-related sustainability in the context of the communities and ecosystems of Hawai‘i and the USAPI, the PICSC identified four initial Science Themes, conceptually covering both terrestrial and marine domains, which will provide science to support pressing climate adaptation needs. Development of this science agenda began with extensive review of climate-related biophysical literature in November–December 2012. This review also supported an informal sorting of major issues, identifying those already well-served by other programs and those that presented opportunities for the PICSC to help advance knowledge and potentially fill gaps. On May 9, 2013, the SAC was advised of the timeline for development of this agenda, and their input was solicited in identifying both high-priority issues as well as directions that might be set aside for consideration in later years. Input was solicited from nongovernmental stakeholders and managers of relevant programs at the same time. From May to August 2013, listening and brainstorming sessions with cultural and scientific professionals from the university consortium and partner government agencies and local institutions were conducted. Through these processes, major science needs consistently emerged, integrated as four Science Themes in this agenda. Potential priorities were flagged for inclusion in the Work Plan. A draft agenda was submitted to the SAC and nongovernmental stakeholders for comment on September 12, 2013. The draft agenda received substantial positive feedback, and a summary of the review was presented to the SAC and other stakeholders on November 14, 2013. The revised (final) agenda was made available to the SAC and nongovernmental stakeholders on December 24, 2013. The development process resulted in the creation of a regionally relevant and effective science agenda. It is recognized that the agenda is a living document, and opportunities to review and update are anticipated.

Science Themes to be addressed through research are:

- Theme 1: Guidance for Anticipated Intermediate-Term Climate Changes
- Theme 2: Potential Effects of Changing Climate on Freshwater Resources
- Theme 3: Anticipating and Addressing Change in Coastal and Low-Lying Areas
- Theme 4: Forecasting Sustainability for Resource Management and Planning

Examples of connections between these Science Themes and strategic plans available for several Federal, state, and regional agencies and organizations are illustrated in appendix 3. The set of strategic plans and the crosswalk in appendix 3 are by no means comprehensive and will benefit from discussions with partner agencies and organizations over time. Within the context of this initial five-year science-planning window, current knowledge and research tools will allow advancement on some objectives in the near term, while others are anticipated to yield results in subsequent years. Objectives are listed within each theme.

## Theme 1: Guidance for Anticipated Intermediate-Term Climate Changes

Projections of future climates are generated using atmospheric and oceanographic models (reviewed in Finucane and others, 2012). These projections and their data layers are then used as input for subsequent analyses that address specific research questions and also underlie decisionmaking applications such as scenario analysis and risk management. These projections and applications are core products that inform a wide range of users about predicted future conditions. Much of the effort in climate projection with numerical models has focused on determining the forced response to anticipated scenarios for atmospheric composition over the next century (that is, determining how predicted changes in the atmosphere may cause or induce changes to terrestrial and marine climate and weather). The actual climate experienced in a given decade depends as well on nonpredictable ("chaotic") variability created by local conditions ("internal variability"). In the tropical and subtropical Pacific, interdecadal variability of the atmosphere-ocean system is known to be important for rainfall and oceanic and atmospheric temperature. Examples of such multiyear cycles include the El-Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO).

Resource management planning and execution tends to occur on seasonal and multiannual timeframes, thus it is important to develop practical guidance[5] on anticipated climate changes for both longer-term (century-plus) and shorter-term (multiannual and decadal) windows. Results from global models suggest that skillful prediction (that is, based on nonchaotic processes) of interannual temperature variations—even for a regional average—is possible only out to a decade or less, and rainfall projections are even more challenging.

***Objective 1.***—The future of climate states over the next year, decade, or century can be considered to be a result of both a forced "global warming" response to factors such as increased atmospheric greenhouse gas concentrations, combined with a chaotic internal variability not directly related to the climate forcing. To address the need for shorter-term climate guidance, existing global model results (prediction and predictability) should be assessed with a focus on the tropical and subtropical Pacific region. These results, together with knowledge of present-day internal variability and the best projections for the externally forced climate signal, should be combined into projections of climate change and uncertainty that can provide practical guidance to a range of potential users. Aspects of the current regional modeling efforts also need to be assessed and models improved in terms of their performance and capabilities (for example, to simulate direct deposition of cloud water—fog and dew—onto surfaces).

***Objective 2.***—Resource managers and community planners need access to climate information and data upon which to base their decisions, and it will be valuable to understand how such knowledge is incorporated into decisionmaking. The PICSC will assess statistical and dynamical downscaled projections to understand the strengths and limitations of various approaches for specific timescales, seasons, and regions and work with users to develop best practices for decision-support applications. Furthermore, the PICSC will work with partners to incorporate characterizations of uncertainty and the role of stochastic processes and identify practical ways to move beyond uncertainty paralysis in planning and decision processes.

***Objective 3.***—In order to anticipate and manage for climate-related factors, it must be possible to predict, detect, and track climate-related change. Model verification and improvement requires environmental data collected with scale-dependent design and deployment of sensors, plus an

[5] In the context of this Science Theme, "guidance" is used as a technical term. Consistent with its use in Meteorology, "guidance" here consists of numerical outlooks for climatic conditions. They are created by starting with current conditions and the dynamical downscaled model projections (over century timescales), and then estimating intermediate (decadal-scale) values that combine the forced value (atmospheric warming) plus variability that might be introduced by factors such as ENSO. The value of guidance lies in not requiring additional modeling runs (which take weeks to months on supercomputers), as well as providing climate outlooks that do not push the modeling beyond rational limits.

assessment of baseline conditions and evaluation through repeated sampling over time. Given the model and region in question, it may be that data being generated by existing networks[6] are sufficient to address verification and improvement. The design specifications of the sensor networks will be catalyzed by the management questions being addressed. The question identifies both the signal (for example, change in ambient temperature, presence of keystone species) and the size of the region of interest from which spatial coverage and temporal sampling are required. PICSC will work with managers, climate modelers, and scientists to develop proposals for sensor networks to collect environmental data that will be used to verify, evaluate, and refine climate models and predictions feeding into management decisions. Sensor networks may have additional value for long-term monitoring, which would be identified in proposals but not as a primary target of PICSC funding.

### Theme 2: Potential Effects of Changing Climate on Freshwater Resources

Clean freshwater is essential to sustain life in terrestrial and nearshore ecosystems. Changing climate is predicted to bring changes in precipitation amounts and patterns. Whether a locale is projected to receive increased or decreased rainfall, any change will create repercussions and require informed decisionmaking to manage this essential resource.

***Objective 1.—***Freshwater assessments are a core product for ecosystem management, community planning, and risk management. PICSC will work with partners to support continuing assessments and develop new ones, including regional-level baselines for selected streams and groundwater recharge. Baseline estimates of current (1) low-flow characteristics of ungaged streams and (2) groundwater recharge can be developed using existing modeling capabilities. These estimates are needed as a first step toward developing models to project climate-change impacts to freshwater resources. Projections of stream base flows and groundwater recharge are in turn critical for (1) managing limited freshwater resources and (2) understanding how climate change will impact ecosystems and communities that may be entirely dependent on freshwater. For example, the traditional cultural practice of wetland taro cultivation in Hawaiʻi is entirely dependent on freshwater in streams. Modeling will be enhanced to provide predictions for base stream flow[7] and groundwater recharge[8].

***Objective 2.—***Reduced rainfall is predicted for some regions (see, for example, Keener and others, 2012b); thus it will be critical to develop drought and dryness projections and associated measures of variability. Climate models generate datasets of predicted rainfall, humidity, and soil moisture. These predictions will be combined to show spatial and temporal trends during dry intervals. Examples of application include considering or modifying policies or strategies for interagency wildfire management, identifying zones where particular types of habitat are likely to change (for example, mesic forest), or identifying zones where potential for change in land cover or vegetation is highest.

***Objective 3.—***The models underlying the assessments should be as robust as possible. Watershed, aquifer, or island-wide models that synthesize all available climate and land-cover information are most relevant and robust for understanding climate-change impacts on freshwater resources. For example, existing watershed models can be enhanced by including additional sources of

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[6] Examples include HaleNet http://climate.socialsciences.hawaii.edu/HaleNet/HaleNet.htm, RAWS http://www.raws.dri.edu/, StationAloha http://aco-ssds.soest.hawaii.edu/ALOHA/, NPS Inventory and Monitoring networks http://science.nature.nps.gov/im/networks.cfm, PacIOOS http://oos.soest.hawaii.edu/pacioos/index.php.

[7] Example models include Precipitation-Runoff Modeling System (PRMS, http://pubs.er.usgs.gov/publication/wri834238), which simulates runoff based on precipitation and user-defined watershed characteristics. PRMS is now typically run within a geospatial context provided by the Modular Modeling System (MMS, http://pubs.er.usgs.gov/publication/70035157). Another model has used Distributed Hydrology, Soil, and Vegetation Model (DHSVM) to forecast the effect of climate change and invasive species in Hāmākua. One report on this model can be seen at http://www.academia.edu/2755513/Modelling_of_a_vanishing_Hawaiian_stream_with_DHSVM.

[8] Groundwater is typically modeled using either the code SEAWAT or the code SUTRA, both developed by the USGS (http://pubs.usgs.gov/sir/2013/5216/ , http://pubs.usgs.gov/sir/2012/5009/).

freshwater inputs (such as cloud intercept) to better characterize sources of storage and loss (such as soil moisture or evapotranspiration). The PICSC will also look to expand the capability to measure, model, and predict interactions of fresh and marine groundwater and their effects on water availability and quality in freshwater lenses. PICSC will begin support for model refinement by working with partners to secure needed funding.

### Theme 3: Anticipating and Addressing Change in Coastal and Low-Lying Areas

Changing climate is predicted to deliver multiple impacts to coastal and low-lying areas, including impacts to fisheries and habitat, weakening of infrastructure, and threats from inundation and wave impact (and resulting coastal erosion), as well as from flooding, pollution, and sedimentation from runoff. It is essential to develop products and capabilities for coastal and wetland management, bio-cultural and community planning, and risk and crisis management applicable to the region. Product development will be undertaken with partners to transform scientific understanding of various sectorial impacts (e.g., environmental, socioeconomic) and aid in development of best management practices.

***Objective 1.—***Regional-level baselines of oceanic incursion (such as sea-level rise, storm-surge, wave overwash) are a core product for resource managers (for example, Hawaii State Coastal Hazards program, http://planning.hawaii.gov/czm/initiatives/coastal-hazards/). In addition to planning for immediate needs, managers need such metrics for evaluating sustainable habitat (extent and quality) and regional-level impacts at decadal timescales. This objective would use existing modeling capabilities.

***Objective 2.—***Regional-level baselines of land cover and land use categories are a core product that would enable several essential follow-on analyses. For example, their integration into scenario analysis could help to understand and anticipate potential conflict due to changes in land cover and land use. Once baselines of land use and land cover are developed, subsequent analyses could include refined and expanded modeling of oceanic incursion, runoff, and sediment dynamics. Moreover, there is a continuing need to further the capability to measure, model, and predict coastal-zone interactions of marine and fresh waters, including the effects of these interactions on community infrastructure and wastewater management, among others. This continuing objective is intended to begin in full once funding and data availability can support further action.

***Objective 3.—***Anticipating the implications for climate variability on coastal and low-lying habitats also implies effects on the goods, services, and values they represent. Not only do the wetland and coastal areas provide essential habitat to wildlife, they are also vital community resources through their relation to fisheries and aquaculture, livelihoods, recreation, and cultural practices. The PICSC will look to partnerships to investigate how to incorporate best available climate information into community valuation of coastal and wetland goods and services and methods of decisionmaking. This continuing objective is intended to begin in full once funding and data availability can support further action.

### Theme 4: Forecasting Sustainability for Resource Management and Planning

In order to incorporate climate predictions into decisionmaking and management at all levels and across a variety of environments and communities, we are faced with the significant challenge of understanding what key resources communities need and value. To sustain these resources in the face of changing climate requires:

- Defining the resource(s) to be sustained (for example, goods and services, cultural practices, habitats, populations, places).
- Understanding how much change can happen before a system or place becomes impaired, that is, rendered unsustainable, or loses its value or meaning.

- Evaluating options to maintain the resource(s), such as resilience, restoration, adaptation, or mitigation; plus valuation of these options.

Almost all aspects of this are challenging because we need to identify not only what is important to be sustained but also be able to forecast ecosystem structure and function. Such forecasts will yield the first indications of the degree to which sustainability may be compromised by changing climate. These ecosystem forecasts will depend on understanding a suite of factors such as:

- Process functions (including identifying nonlinearities and environmental limits on function).
- Primary productivity and nutrient flow, sources, and sinks in ecosystems.
- Influence of habitat structure and fragmentation on vulnerability and resilience.
- Effects of climate change and variability on successional processes, for example, (i) implications (if any) for loss of key elements or dominant components of ecosystems; (ii) invasive species or other stressors; (iii) impacts of disasters or extreme events.
- Insight provided by traditional ecological knowledge, local ecological knowledge, and phenology in development and (or) verification of models for ecosystem forecasts.

***Objective.—***The PICSC will address these issues by initiating efforts to develop and validate tools that support management of specific resources or cultural values. To get started on this challenge, the PICSC will seek to identify collaborative interagency proof-of-concept projects to generate forecasts and evaluate "climate sustainability" metrics catalyzed by specific management questions. These projects will serve as the initial steps in the development of a more generalized framework for anticipating and preparing to sustain priority bio-cultural factors. Three examples are offered here that span a wide range of community and ecological issues.

- Incorporate climate change and variability into management of montane forest plant communities and related community goods and services, with an initial focus on Hawai‘i Volcanoes National Park.
- Incorporate climate change and variability into management of coastal habitat and community goods and services, with an initial focus on James Campbell National Wildlife Refuge.
- Combine climatology, hydrology, and vegetation ecology to provide long-lead-time indices of habitat conditions, with an example being agricultural conditions on the islands of Micronesia.

## Portfolio Development—Implementing the Themes

The PICSC has limited resources to apply to the broad portfolio outlined above. In order to meet the needs of the stakeholders, the PICSC must prioritize and seek to optimize and leverage its investments. One way to do this is to address the issues on regional or subregional scales—providing science that can be used by multiple parties and follow-on programs. Leveraging science and technology programs in other institutions based on shared or unique mission goals will also help to save on limited resources. By virtue of the PICSC relationship with the host universities and the network of cooperators and stakeholders, the center facilitates educational training and capacity building. Likewise, communications and outreach may be accomplished by sharing of knowledge developed by the PICSC through publically accessible media and by relationships with organizations that focus on these capabilities, as well as by university hosts as part of campus life.

### Prioritization—What To Include

To guide the work across multiple organizations, partners, mandates, and programs, a system of prioritizing goals and tasks must be developed and implemented. Within each Theme in this agenda, objectives are identified that will advance knowledge and capabilities that were identified during the development process. Objectives may contain more than one science element. Some may be addressed with existing knowledge and research methods, while others may need to wait until essential information or tools are developed.

Strategic direction and priorities of the PICSC are shaped by counsel received from the SAC and other stakeholders. Potential priorities identified during Theme development were flagged and incorporated into the Work Plan in this document (see below). Priorities are tempered by funding limitations, again reflected in the Work Plan. Each year, the PICSC will summarize progress on each Theme and offer opportunities for stakeholders to provide input to identifying priorities to be funded either directly or by requests for proposals. University hosts will consider science agenda priorities to guide investment of their host funds, also contributing to progress on Themes.

The PICSC science agenda emphasizes local priorities, but the PICSC is also one of eight regional climate science centers striving to embrace a range of themes as a national network. There are thus opportunities to contribute on a nationwide scale as well as at the regional scale. Presently, national-level CSC themes include “ecological drought” and “tribal and indigenous activities” (national labels). If the PICSC priorities dovetail with national themes, this allows Pacific island perspectives to be included in the national synthesis and increases national awareness of major conservation issues for Hawaiʻi and the Pacific islands. For example, ecological drought in the contiguous United States focuses mostly on large agricultural lands. In the Pacific islands, by contrast, although drought has impacts on agriculture, natural communities and sociocultural aspects are also relevant. The activities of a diversity of cultures are woven in the fabric of every island in the Pacific, affecting land use, conservation management, and other issues, and should be considered at every step. The PICSC will remain attentive to opportunities to contribute to national themes.

## Filters—What To Exclude

Another prioritizing filter is to focus the domains of the investigations. The subtropical and tropical Pacific is not only geographically immense, but is characterized by a multitude of cultures, landscapes, and ecosystems, along with substantial biodiversity and species endemism, much of which could be affected by changing climate. Deciding what research questions to exclude is daunting but necessary to the success of this plan.

- The PICSC is tasked with focusing on climate impacts at various spatial and temporal scales, so it follows that spatial domains with little predicted climate change are not addressed in the current agenda for this center.
- Individual management units, such as a marine protected area or National Park Service unit, are by their nature already overseen by an agency or institution to address particular mandates, thus will not be a focus of efforts by the PICSC agenda. However, these managed units should benefit from regional products and services generated by the PICSC and its partners.
- Federally listed species with highly restricted distributions will not be a focus of efforts by the PICSC agenda. However, managed species are once again likely to benefit from the regional products and services of the PICSC and its partners.
- Finally, ecosystems with highly restricted distributions, such as alpine and anchialine pool habitats, will not be a focus of efforts in this current PICSC agenda. However, these ecosystems may also benefit from regional products and services of the PICSC and its partners.

This is not to say that research will not be conducted in specific management units or with specific species, and PICSC anticipates extensive collaboration on climate-related management concerns with managers and stewards of natural and cultural resources. However, research within specific management units or with specific species must inform regional climate-related questions and serve to advance broader site-independent knowledge and capabilities.

### Deferred at the Start of Planning Cycle, Pending Evaluation by Resource Management

Through the process of actionable science and adaptive management, research results are evaluated and incorporated into management tools and planning. This process often helps to identify gaps in understanding or technical capabilities and is a sensible source of emerging needs that could become priorities for the PICSC.

Within the insular Pacific, one endeavor currently underway is development of a climate adaptation strategy for the Papahānaumokuākea Marine National Monument in the northwestern Hawaiian Islands, which is in an advanced stage of completion. It is anticipated that final completion of this strategy will help to reveal further research needs that could be considered later in the PICSC planning cycle.

Work already funded by the PICSC and PICCC in recent years also will be producing scientific results and products within the next few years. This research includes factors limiting recovery of Hawaiian forest birds, terrestrial and marine paleoclimate reconstructions, and reef vulnerability studies in Hawaiʻi and the Marianas. For this planning cycle, further investment in this research will be paused until outcomes have been achieved and the anticipated products are available for consideration by resource management agencies.

## Work Plan

### Overview: 2014–2018

***2014.—***The scope and timing of some projects are dependent on funding allocated to the PICSC. Seek and leverage partnerships and funds; when funds are identified, begin baseline determination of land cover/use, streams (Themes 2, 3), and groundwater status (Theme 2).

***2014/15.—***Existing and leveraged funds are anticipated to be sufficient to initiate some work. Assess existing climate downscaling results and improve regional model capabilities; assess results of global models for intermediate-term climate projections in the Pacific region (Theme 1); generate decadal rainfall and drought/drying statistics for Hawaiʻi (Theme 2) and consider the implications of global and regional climate model results for these aspects of climate in the future (Themes 1, 2); regional-level baselines of oceanic incursion and threats (Theme 3); implement proof of concept projects (Theme 4) and attract/leverage additional funds.

***2016.—***Mid-Cycle Update. Evaluate progress, identify emerging needs, and adjust priorities; second-phase studies of water-related resource valuation (Theme 2); expand watershed models (Themes 2, 3); coastal fisheries, biological and cultural integration (Theme 3).

***2018.—***End cycle. Prepare next five-year agenda.

### Implementation 2014: Begin Seeking Partnerships and Funds

#### Focus: Work with Partners to Create “Snapshots” Used as Baselines for Detecting Change Over Time

Three regional baseline products in Hawaiʻi and the USAPI:

- Land-cover and land-use categories
- Base flow for selected streams
- Groundwater recharge for selected aquifers

### Approach

- Workshops or meetings to identify what people are doing, what is already out there, what gaps are there
- Preparation of a white paper outlining the issues involved, with plan of action and budget
- Agency networking to bring in needed funds

### Outcome

- Funds and implementation
- Follow-on applications such as risk management

## Implementation 2014/15: Theme 1 [Climate Models]

### Focus: Assess Global Model Simulations for the Tropical and Subtropical Pacific and Assess Fine Resolution Downscaling Results; Improve Regional Modeling Capability

Existing climate datasets can be assessed at this time, continuing the process of making these models more useful for the Pacific region. The uncertainty introduced into the forced climate downscaling results by global model uncertainty should be quantified as well as the uncertainty in forecast introduced by unpredictable natural variations. Regional model capability should be expanded by inclusion of treatments of wet deposition from clouds onto the surface. The focus in this work initially will be on Hawai‘i but may be expanded to other island areas in the USAPI with appropriate biomes.

This focus relates to all the Themes by feeding in to rainfall, drought, coastal and wetlands change, and forecasting ecosystem responses. Ultimately, the results of improved, more robust models will support resource managers in directed resource sustainability.

### Outcome

- Improved standard of practice for understanding strengths and limitations of using these predictions and projections
- Higher user confidence in model output and identifying what to use in applications

## Implementation 2014/15: Theme 2 [Freshwater Resources]

### Focus: Generate Decadal Rainfall and Drought/Drying Statistics (Likelihoods and Multiannual Spatiotemporal Patterns) for Selected Locations in Main Hawaiian Islands

Datasets exist that can be explored at this time for freshwater availability forecasting. Trends and patterns of abundance or scarcity of rainfall will affect the sustainability of inland and coastal ecosystems, thereby affecting in turn human and wildlife communities. This is relevant to the USGS national ecological drought priority.

### Outcome

- Results tailored to fit timeframes of managers, planners, and other users
- Greater understanding of variability and likelihoods of either extremely dry or wet weather
- Ability to map multivariate patterns of aridity (for example, irradiance, wind, humidity, soil moisture)

- Applications may include plant habitat vulnerability, watershed forest stand structure, and land use and value
- Identify research paths into ecosystem resilience thresholds
- Capability to reproduce these results for new places or timeframes

## Implementation 2014/15: Theme 3 [Change in Coastal and Low-Lying Zones]

### Focus: Develop Regional-Level Baselines of Oceanic Incursion (for example, sea-level rise, storm-surge, wave overwash)

Datasets and models exist that can be applied at this time for development of regional baselines. Methods currently implemented may be applied to new regions, but some regions may require development of modeling parameters and (or) partnerships with managers and other user communities. This is relevant to the national tribal and indigenous activities priority.

### Outcome

- Results tailored to fit timeframes of managers, planners, and other users
- Implementation can feed into improvements of models and environmental measurements for verification and change detection
- Follow-on applications such as community planning and risk management

## Implementation 2014–17: Theme 4 [Forecasting Sustainability]

### Focus: Identify Collaborative Interagency Proof of Concept Projects To Generate Forecasts and Evaluate "Climate Sustainability" Metrics Catalyzed by Specific Management Questions

Three examples of cooperative projects are described below. These were developed by PICSC through informal consultation with partners. Each project incorporates elements of at least three of the four PICSC Science Themes. The timing of each project is dependent on the availability of funding and necessary datasets. These projects will serve as the initial steps in the development of a more generalized framework for anticipating and preparing to sustain priority bio-cultural resources. These examples illustrate the process of working with resource managers or community planners to identify issues likely to be affected by changing climate, translating that into research and analytic objectives, and then transforming the subsequent results into products usable by managers to inform their plans and decisions. It should be borne in mind that these represent examples that may or may not be implemented. The PICSC will continue to expand dialogue with its partners to refine these, as well as to build and implement other concept demonstrations.

### Outcome

The analytic objectives and outcomes of these endeavors will support progress on multiple themes, involving multiple partners and informing many stakeholders as well. As these projects proceed, it will be essential to continue to solicit community input and feedback wherever possible. Not only will this keep the PICSC focused on the "big picture" of sustainability, but it will create more traction with outreach and communication partners, as well as the end users of these products.

Although there is some inherent investment risk in these challenging projects, the lessons learned in the process itself will outweigh the risks involved.

Examples of Projects Connecting Science, Resource Management, and Community Engagement

*1. Partner with Hawai'i Volcanoes National Park to incorporate climate change and variability into the management of montane forest plant communities*

Hawai'i Volcanoes National Park (HAVO), with its extensive ecosystem resources and management practices, is an excellent test bed for the inclusion of climate information. By teaming with HAVO resource managers and applying the substantial existing knowledge and datasets for the region, this integration could begin immediately. The potential effects could be seen in the next few years because their vegetation community management is planned within short-term (multiannual) timescales.

This project addresses these sustainability themes:

- Assessment of downscaled rainfall data (Theme 1)
- Analyses of multiannual rainfall/drought statistics (Theme 2)
- Forecasting sustainable resource management and planning (Theme 4)

In addition to assessing the impacts on natural communities in the montane forest, the PICSC will seek participants to lead investigations into the implications of climate forecasts on user-community topics such as the sustainability of traditional herbal practices that require similar habitat types. To further develop the project, depending on initial outcomes, a second phase will explore the environmental economics of various management strategies, conducted in collaboration with partners.

Although the analytic aspect of this project is set within the borders of HAVO, it will likely benefit others managing montane forests and plants of interest on other high Pacific islands, such as the National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), local entities such as Hawai'i Division of Forestry and Wildlife (DOFAW) and Department of Marine and Wildlife Resources (DMWR) in American Samoa, and nongovernmental organizations such as The Nature Conservancy (TNC) and Micronesia Conservation Trust (MCT). These benefits would include both a broader understanding of how to incorporate climate factors in management planning, as well as specifics related to analytic products. This project will also reflect the priorities of drought and tribal goals put forth by the USGS national climate science center.

*2. Partner with James Campbell National Wildlife Refuge to incorporate climate change and variability in the management of coastal wetland habitat*

The James Campbell National Wildlife Refuge (NWR) manages waterbirds by providing protected wetland habitat on the northeast coast of O'ahu. This site serves as an excellent test bed for the inclusion of climate information because of its ties to terrestrial, coastal, and marine ecosystems. There are substantial existing datasets for this area, so research could start mid-cycle (~2016) when products are ready from current projects (downscaling climate models, hydrology statistics).

This project addresses these sustainability themes:

- Assessment of downscaled rainfall data (Theme 1)
- Analyses of multiannual rainfall/drought statistics (Theme 2)
- Anticipating coastal change (Theme 3)
- Forecasting sustainable resource management and planning (Theme 4)

Climate change and variability will have far-reaching impacts on coastal and low-lying areas. Because human communities are likely to be influenced by many of the same vulnerabilities experienced by coastal wildlife and vegetation, the PICSC and its partner institutions will initiate further exploration into human community vulnerabilities. Additionally, if landscape-level or regional coastal or wetland forecasts can be developed, the PICSC will seek participants to explore implications for waterbird management strategies throughout the Pacific.

Although the focus of this example is on James Campbell NWR, its resulting products will likely benefit a host of other agencies and management units including, but not limited to, USFWS, Hawai‘i state agencies, and the U.S. Navy, as well as other western Pacific institutions. This project will also reflect the priorities of drought and tribal goals put forth by the national climate science center.

*3. Multiagency collaboration to combine climate and vegetation ecology for long-lead indices of habitat conditions in Micronesia*

This demonstration is in its initial stages of development. However, it directly addresses the concept of “climate sustainability” metrics created for specific human community needs. Examples would be a forecast of agricultural conditions in the Marshall Islands or of forest stress in the Federated States of Micronesia. Such a forecast encompasses the needs of the communities; rainfall, reservoir, and aquifer predictions; and plant stress thresholds, as well as short-term and decadal climate impacts. This forecasting would inform local communities and serve as an alerting system for relief programs if conditions are predicted to be poor.

This project addresses these sustainability themes:

- Development of shorter-term climate projections (Theme 1)
- Analyses of multiannual rainfall/drought statistics (Theme 2)
- Depending on the focus, anticipating coastal change (Theme 3)
- Forecasting sustainable resource management and planning (Theme 4)

Currently there are very preliminary discussions underway among PaCIS, RISA, PICCC, and PICSC. The next steps in this process are planned for April 2014, including networking with other important collaborators such as USDA and MCT. This level of collaboration requires substantial work to develop, but it is included here as an example of a type of sustainability issue to which the PICSC would be able to contribute.

## Mid-Cycle Progress Evaluation

The PICSC Mid-Cycle Progress Evaluation (beginning in the end of year 2) will serve to put some perspective on the projects still moving forward and those about to begin while being cognizant of national and regional priorities. The following is a list of the foci of the evaluation; however, these items are likely to change depending on progress with partnerships and funds.

Evaluate Progress:

1. Assess current projects for attainment of scientific and bio-cultural objectives.
2. Revisit issues deferred at the start of this planning cycle. Are there implications of new results that need to be explored? Are there data available to incorporate into follow-on efforts?

Identify Potential New Objectives:

1. Determine whether management considerations of project results have revealed science gaps or workshop opportunities.
2. Gain a better understanding of how society will value and balance competing land uses such as native ecosystem management, water catchment, and food production, among others, as the availability of water resources changes in response to changing climate.

3. Expand watershed models by combining climate, vegetation ecology and physiology, and hydrology. Further considerations could involve the connections among these variables: freshwater inputs, saltwater intrusion, soil salinity, nutrient deposition, evapotranspiration, soil moisture availability, and biogeochemistry of nutrient availability.
4. Assess the implications of climate change and variability for primary productivity or carbon fixation in terrestrial and marine ecosystems.
5. Initiate coastal fisheries and human community projects. Examples of these could include integrating local ecological knowledge into fishpond research in Hawaiʻi and investigating the mutual impacts of climate variability and change to aquaculture, its farmers, and coastal and marine spatial planning (CMSP).

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# Appendix 1. University Consortium and Stakeholder Advisory Committee

## University Consortium

| Host Institutions |
|---|
| University of Hawai‘i – Mānoa |
| University of Hawai‘i – Hilo |
| University of Guam |
| **Partners** |
| Carnegie Institution for Science |
| Pacific Regional Integrated Science and Assessment program (Pacific RISA) |
| Stanford University |
| University of California – Santa Barbara |
| U.S. Department of Agriculture, Forest Service |
| Yale University |

## Stakeholder Advisory Committee (SAC)

| Federal, State, and Local Government members |
|---|
| U.S. Geological Survey, Pacific Region Office (Chair) |
| Hawaii State Department of Land and Natural Resources, Division of Aquatic Resources |
| Hawaii State Department of Land and Natural Resources, Division of Forestry and Wildlife |
| Hawaii State Office of Hawaiian Affairs |
| Hawaii State Office of Planning |
| National Oceanic and Atmospheric Administration (NOAA), NESDIS Climate Services Pacific |
| NOAA, Office of National Marine Sanctuaries |
| NOAA, Pacific Islands Region Office |
| NOAA, Pacific Regional Integrated Sciences and Assessments program |
| NOAA, Pacific Services Center |
| National Park Service, West Region |
| Pacific Islands Climate Change Cooperative |
| U.S. Army Corps of Engineers |
| U.S. Department of Agriculture, Agricultural Research Services |
| U.S. Department of Agriculture, Natural Resources Conservation Service |
| U.S. Department of Defense |
| U.S. Department of Interior, Office of Insular Affairs |
| U.S. Department of Interior, Office of Native Hawaiian Relations |
| U.S. Fish and Wildlife Service, National Wildlife Refuge System |
| U.S. Fish and Wildlife Service, Pacific Islands Office, Ecological Services |
| U.S. Geological Survey, Pacific Island Ecosystems Research Center |
| U.S. Geological Survey, Pacific Islands Water Science Center |
| **Additional Stakeholders include** |
| American Bird Conservancy |
| Hawaii Conservation Alliance |
| Kamehameha Schools Bishop Estate |
| Micronesia Conservation Trust |
| NOAA-sponsored Pacific RISA program |
| The Nature Conservancy |

# Appendix 2. Definitions

| | |
|---|---|
| actionable science | Science that can be integrated into strategic planning and decisionmaking with outcomes motivating further investigation and application |
| base flow | The groundwater component of stream flow |
| generator | Role of an institution to fill knowledge gaps through scientific or cultural investigation scaled to the requirements of the recipients |
| sustainability | In regard to island communities, the ability to maintain ways of life in the midst of increasingly rapid social and ecological change |
| transformer | Role of an institution to recast the research into usable products that can be easily understood and used |
| transmitter | Role of an institution to take transformed information and deliver it to the local end user and to communicate feedback and additional climate gaps from the local level |
| trust species | Species with a defined Federal interest—those that are listed under the Endangered Species Act as endangered/threatened; other marine mammals; and migratory species |

# Appendix 3. Example Connections of Strategic Plans with Science Plan Themes

| Partner Plans and Programs | Theme 1: Intermediate-Term Climate Guidance | Theme 2: Freshwater Resources | Theme 3: Coastal Change | Theme 4: Forecasting Sustainability |
|---|---|---|---|---|
| [1]Pacific RISA—The Pacific Islands Regional Climate Assessment (PIRCA) | *Summary, key challenge 3:* Need for higher resolution projections | *Conclusions, highlight 2:* Need for long-term monitoring of freshwater resources | *Summary, key challenge 2:* Need for increased ecosystem study sites across region | *Advancing Knowledge, human responses and Conclusions, highlight 8:* Need for evaluation of changes in cultural practices and of adaptation strategies |
| [2]PaCIS—Towards a PaCIS Plan for Regional Climate Services | | *Focus area 1:* Preserving freshwater resources and minimizing the impacts of drought | *Focus area 2:* Fostering community resilience to the impacts of sea-level rise, coastal inundation, and extreme weather | *Focus area 3:* Sustaining marine, freshwater, and terrestrial ecosystems |
| [3]PICCC—Integrated Science Framework and 2012 Science Priorities | *Priorities 1 and 3:* Need for island-relevant-scale climate projections and adaptive models amenable to management | *Climate factor 1:* Precipitation change and storm frequency/intensity | *Climate factors 2 and 3:* Sea-level rise and ocean chemistry and sea surface temperature | *Science focus areas 1 and 3:* Maintain or improve ecosystem function and preserve key cultural and natural resources and their uses |
| [4]U.S. Fish and Wildlife Service Strategic Plan for Responding to Accelerating Climate Change | *Goal 2, Objective 2.1:* Access to experts in climate science and modeling who have the capability of putting climate data and projections into forms that are useful for biological planning and conservation design | *Goal 3, Objective 3.4:* Ensure water resources of adequate quantity and quality to support biological objectives for fish and wildlife are incorporated [into freshwater management planning] | *Goal 3, Objective 3.5:* Understand the vulnerability of our coastal resources to sea-level rise and storms | *Goal 2, Objective 2.2:* To promote wildlife adaptation to accelerating climate change, we need the capability to develop, test, implement, and monitor conservation strategies<br>*Goal 2, Objective 2.3:* Develop methodologies to assess species and habitat vulnerability and to test and apply these methodologies on the ground |
| [5]National Park Service Climate Change Response Strategy | *Goal 2:* Development of models that can be used by managers to plan for and adapt to climate change impacts | | | *Goal 6:* Acquire and develop tools such as vulnerability assessments and scenario planning to inform the development of adaptation plans at appropriate scales |

| Partner Plans and Programs | Theme 1: Intermediate-Term Climate Guidance | Theme 2: Freshwater Resources | Theme 3: Coastal Change | Theme 4: Forecasting Sustainability |
|---|---|---|---|---|
| [6]Department of Defense FY 2012 Climate Change Adaptation Roadmap | *4.A General Assessment:* Overlay regional climate models with installation locations, in order to appropriately downscale climate variables for individual locations | *4.F Pacific Islands:* Need for climate change studies to assess the impacts on DoD facilities in the Pacific. Changes in sea level, precipitation, and storm patterns can have significant impact on the island infrastructure that supports DoD missions in the region | *4.F Pacific Islands:* Need for climate change studies to assess the impacts on DoD facilities in the Pacific. Changes in sea level, precipitation, and storm patterns can have significant impact on the island infrastructure that supports DoD missions in the region | *4.F Pacific Islands:* Need for climate change studies to assess the impacts on DoD facilities in the Pacific. Changes in sea level, precipitation, and storm patterns can have significant impact on the island infrastructure that supports DoD missions in the region |
| [7]USDA Climate Change Science Plan | *Coordination with Other Agencies and Departments (1):* Improved regional climate change forecasts at scales appropriate for research and decisionmaking | *Coordination with Other Agencies and Departments (2):* Assessments of regional water availability for industrial, societal, ecological, and agricultural needs | *Coordination with Other Agencies and Departments (4):* Assessments of sea-level rise and threats to coastal zones, including wetland loss and aquaculture systems | *USDA Climate Change Science Elements* *Element 1:* Understand the direct and indirect effects of climate change on natural and managed ecosystems, including feedbacks to the climate system. Element 2: Develop knowledge, institutional models, and tools to enable adaptation to climate change and to improve the resilience of natural and managed ecosystems |
| [8]USGS Climate and Land Use Change Mission Area strategic science plan | *Goal 7:* Need region-specific climate information—downscaled climate predictions to be used as a point of reference for resource managers in each region | *Goal 5:* How do climate change and land use (1) affect water uses, runoff, stream flow, groundwater recharge, freshwater availability, and (2) affect the availability of water to terrestrial and aquatic ecosystems and thereby affect ecological patterns and processes? | *Goal 6:* How will changes in seasonal storm activity and intensity affect coasts? How will sea-level rise and climate change affect small islands in the Pacific? Develop datasets on coastal inundation by storm surge for use in coastal hydrodynamic modeling. Develop assessments of SLR and climate change for U.S. islands and insular territories | *Subset of Goal 4:* How will changes in land use, cover, and condition affect the ability of ecosystems to provide essential goods and services? *Goal 7:* Need for thresholds in biotic responses to change; how will changes in habitat fragmentation and other critical ecological processes interact with climate change to affect ecosystem components and processes and affect |

| Partner Plans and Programs | Theme 1: Intermediate-Term Climate Guidance | Theme 2: Freshwater Resources | Theme 3: Coastal Change | Theme 4: Forecasting Sustainability |
|---|---|---|---|---|
| | | | | the ability of species and ecosystems to adjust their geographic distributions in response to global change? |
| [9]USGS Ecosystems Mission Area strategic science plan | *Goal 2:* Advance understanding of how drivers influence ecosystem change; quantify the uncertainties in forecasting change in drivers of ecosystems<br>*Goal 4:* Improve methods to analyze and use multiscale data to project the effects of changes in the drivers of natural resource systems<br>*Goal 5:* Develop models designed to inform management decisions and assess their utility | *Goal 2:* Identify and quantify the important drivers of ecosystem change; investigate potential future changes in drivers and forecast how species and ecosystems are likely to respond | *Goal 3:* Assess the associations among multiple ecosystems services<br>*Goal 5:* Use ecological and decision sciences to guide strategies for achieving management, conservation, mitigation, and restoration objectives in the face of continuing climate and land-use change | *Goal 1:* Improve understanding of ecosystem structure, function, and processes; including resilience, carrying capacity, and system variability<br>*Goal 2:* Investigate changes in climate drivers and forecast how species and ecosystems are likely to respond<br>*Goal 3:* How climate change affects ecosystem services; critical thresholds |
| [10]USGS Geology Mission Area strategic science plan | *Goal 2, Strategic Action 4:* Model and forecast potential future changes in the Earth's climate and ecosystems | *Goal 2, Strategic Action 2:* Monitor processes and changes at the Earth's surface to understand variation and disturbances in natural cycles | *Goal 1, Strategic Action 1:* Understand and predict geologic processes and rates of change related to water, hazards, energy, minerals, ecosystems, and climate change | *Goal 2, Strategic Action 1:* Characterize and understand the key physical, chemical, and biological components and processes that determine ecosystem structure and function |
| [11]USGS Water Science Mission Area strategic science plan | | *Goal 1:* Provide information on water in all components of the water cycle at high temporal and spatial resolution, nationwide<br>*Goal 2:* Advance understanding of processes that determine water availability<br>*Goal 3:* Predict changes in the quantity and quality of water resources in response to changing | *Goal 2, objective 3:* Comprehensive understanding of the interactions among aquatic ecosystems, hydrology, and hydrochemistry | *Goal 2:* Advance understanding of processes that determine water availability |

| Partner Plans and Programs | Theme 1: Intermediate-Term Climate Guidance | Theme 2: Freshwater Resources | Theme 3: Coastal Change | Theme 4: Forecasting Sustainability |
|---|---|---|---|---|
| | | climate, population, land use, and management scenarios | | |
| [12]Hawai‘i State Office of Planning—HRS §226-109 Climate change adaptation priority guidelines | *(9):* Use management and implementation approaches that encourage the continual collection, evaluation, and integration of new information and strategies into new and existing practices, policies, and plans | | *(5):* Encourage the preservation and restoration of natural landscape features, such as coral reefs, beaches and dunes, forests, streams, floodplains, and wetlands, that have the inherent capacity to avoid, minimize, or mitigate the impacts of climate change | *(7):* Promote sector resilience in areas such as water, roads, airports, and public health, by encouraging the identification of climate change threats, assessment of potential consequences, and evaluation of adaptation options |
| [13]Hawai‘‘i State Comprehensive Wildlife Conservation Strategy | *Monitoring Needs and Recommendations, Improve Ecosystem Monitoring:* To go beyond post-hoc monitoring towards ecological prediction and forecasting, more attention needs to be focused integrating information from different sources to evaluate trends and assess threats or conservation actions | | | *Statewide Conservation Objective 1:* Maintain, protect, manage, and restore native species and habitats in sufficient quantity and quality to allow native species to thrive |
| [14]American Samoa Comprehensive Strategy for Wildlife Conservation | *Section 6.3:* (1) Obtain frequent, detailed, and accurate maps or images of land use patterns in the territory | *Section 6.3:* (2) Use [geospatial] data to identify priority sites for conservation or land-use modifications | *Section 6.3:* (2) Use [geospatial] data to identify priority sites for conservation or land-use modifications | *Section 6.3:* (3) Implement measures and activities to improve habitat quality, expand the extent of native habitats, and protect endangered or critical habitats<br>*Section 7:* Fostering of a local, culture-based conservation ethic |
| [15]Guam Comprehensive Wildlife Conservation Strategy | | | *Chap. 4, Coral Reef Fisheries and Habitat:* To continue the implementation of local action strategies (LAS), to include the | *Chap. 4, Terrestrial Habitat Assessment and Rehabilitation:* Need to assess the state of habitats throughout the island is vital |

| Partner Plans and Programs | Theme 1: Intermediate-Term Climate Guidance | Theme 2: Freshwater Resources | Theme 3: Coastal Change | Theme 4: Forecasting Sustainability |
|---|---|---|---|---|
| | | | determination of land-based sources of pollution … climate change, and coral bleaching and disease | Introduction: Economic prosperity and preservation of the Chamorro culture are dependent on the successful recovery and sustainable use of the island's natural resources |
| [16]Commonwealth of the Northern Mariana Islands Comprehensive Wildlife Conservation Strategy | | | | *Chap. 6. Terrestrial conservation actions:* Improve management of terrestrial conservation areas in the southern islands; develop island-wide habitat conservation plans for all islands in the archipelago |
| [17]Climate Change and the Micronesia Challenge: Ways Forward in Collaboration and Adaptation (2010) | *Summary:* To be able to project climate-related risks, it is important to understand ENSO cycles and effects, including El Niño and La Niña events, on key climate parameters like rainfall, monsoon activity and sea-level rise, and their related societal impacts | *Summary:* To be able to project climate-related risks, it is important to understand ENSO cycles and effects, including El Niño and La Niña events, on key climate parameters like rainfall, monsoon activity and sea-level rise, and their related societal impacts | *Summary:* To be able to project climate-related risks, it is important to understand ENSO cycles and effects, including El Niño and La Niña events, on key climate parameters like rainfall, monsoon activity and sea-level rise, and their related societal impacts | *Climate Change Adaptation Strategies, 4.5 Sustaining Actions:* To deal with sea-level rise, increased temperatures, potential growth of invasive species, coral bleaching, fisheries movements, and other ecosystem impacts from climate change, Micronesian communities will likely need to develop innovative strategies that blend traditional ecological knowledge with technological and scientific management techniques |

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BACK COVER IMAGES

(clockwise from top) Aerial photograph of Honolulu city coastline (photograph from Wikimedia Commons, WT-shared Sapphire); waterfall in American Samoa (photograph by National Park Service); Chamorro children performing a traditional dance, Guam (photograph by Staff Sgt. Melissa B. White, U.S. Air Force); Ofu Lagoon, American Samoa (photograph by National Park Service); young hula dancer, heir to our islands and environmental choices (public access photograph).