KAI E‘E – MOUNTING SEAS

PACIFIC TSUNAMI AND CLIMATE CHANGE CURRICULUM

Grades 6 and 8 Appendices

ICAP

University of Hawai'i Sea Grant College Program

Center for Island Climate Adaptation and Policy

Hawai'i's Changing Climate

Briefing Sheet, 2010

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Hawai'i's Changing Climate


Average rainfall has declined in Hawai'i, yet rain intensity has increased. Hanalei Valley, Kaua'i, before (left) and after (right) intense rainfall in Fall, 2009.

The average temperature of Earth's surface and shallow ocean have increased over the past century, markedly so since the 1970's. Globally, 2009 tied with several other years as the second warmest year on the instrumental record (since 1880).

How is global warming influencing the climate in Hawai'i? The purpose of this briefing sheet is to describe what is known in answer to this question as published in peer-reviewed scientific journals and in government reports and websites. Hawai'i's climate is changing in ways that are consistent with the influence of global warming.

In Hawai'i:

- Air temperature has risen;
- Rainfall and stream flow have decreased;
- Rain intensity has increased;
- Sea level and sea surface temperatures have increased; and,
- The ocean is acidifying.

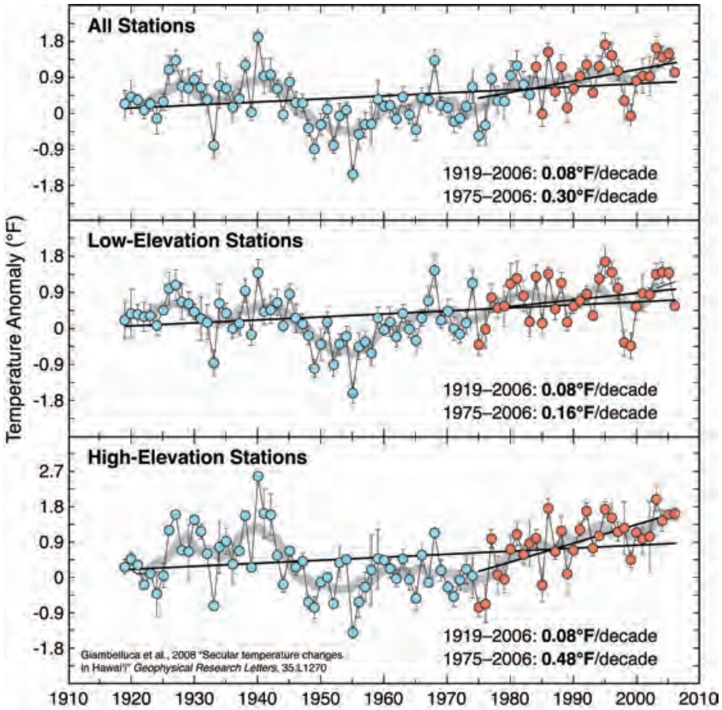
Because these trends are likely to continue, scientists anticipate growing impacts to Hawai'i's water resources and forests, coastal communities, and marine ecology. There is a significant need for sustained and enhanced climate monitoring and assessment activities in Hawai'i; and a compelling requirement for focused research to produce models of future climate changes and impacts in Hawai'i.

Surface Air Temperature

Hawai'i is getting warmer. Data[1] show a rapid rise in air temperature in the past 30 years (averaging 0.3°F per decade), with stronger warming at high elevations (above 2600 feet). The rate of temperature rise at low elevations (below 2600 feet), 0.16°F per decade, is less than the global rate (about 0.36°F per decade); however, the rate of warming at high elevations in Hawai'i, 0.48°F per decade, is faster than the global rate. Most of the warming is related to a larger increase in minimum temperatures compared to the maximum—a net warming about 3 times as large—causing a reduction of the daily temperature range. This response to global warming is consistent with similar trends[2] observed in North America. Despite recent years where the rate of global warming was low[3], surface temperatures in Hawai'i have remained high. The greater warming trend at high elevations threatens water resources and may have significant ecological impacts such as the spread of avian disease, decreased rainfall and cloud water, and threats to native forests[4].

Rainfall and Stream Discharge

Perhaps nothing is as critical to life in the islands as rain, and in Hawai'i there are two principal delivery systems: trade winds, and Kona storms. Cloud formation by trade winds is the most reliable and abundant source of water to the aquifers we rely upon. Although atmospheric circulation in the topical Pacific has decreased and global warming is identified[5] as the cause, it is not yet clear how the Hawaiian trade winds will change in the future. It also remains unclear how future rainfall will respond to global warming; the results of modeling studies[6] have been equivocal although to some extent they indicate that we should expect decreased rainfall. Indeed, studies of rainfall records in Hawai'i confirm this. Rainfall in Hawai'i has steadily declined[7] about 15% over the past 20 years.



Air temperature data in Hawai'i show a warming trend that has accelerated in recent decades.

Streams are one beneficiary of rain. Rainfall feeds streams in two ways: storm flow and base flow. Storm flow responds very quickly to rainfall and causes stream levels to rise and stream discharge to increase during and immediately after rainfall. Base flow, on the other hand, is supplied by groundwater discharge and maintains streamflow during periods between rainfall events. Base flow also responds to changes in rainfall over time, but much more slowly than storm flow. Beginning in the early 1940's, base flow has declined around the state[8] and the cause is likely related to decreased rainfall. In Hawai'i, rainfall combines with steep geographic features to produce unique ecosystems that support diverse plants and animals. This pattern is threatened by rising air temperatures and decreased rainfall and stream discharge. Taro farming, a form of wetland agriculture common on low-lying coastal plains, is also tied to stream flow, but vulnerable to sea level rise. Between intruding salt water and declining stream flow, some farmers may be experiencing the impacts of global warming.

Rain Intensity

Between 1958 and 2007, the amount of rain falling in the very heaviest downpours (defined as the heaviest 1% of all events) has increased approximately 12% in Hawai'i[9]. Heavy rainfall in Hawai'i means more than simply getting wet; it is a major challenge for civil defense agencies and emergency responders. Intense rains trigger a domino effect of other impacts including flash flooding, mudslides and debris flows, road and business closure, infrastructure damage, and loss of public services to isolated communities. It was heavy rain that caused over $80 million dollars of damage in Mānoa Valley, O'ahu, isolated Hana, Maui for weeks, flooded the first floors of homes in Laie, O'ahu, and swept houses off their foundations in Hilo, Hawai'i. When intense rains struck on New Year's Eve 1987, 40,000 people in Hawai'i Kai, Waimanalo, Aina Haina and other east Honolulu communities went without power, emergency aid, communication, and road access for up to 24 hours. While these events cannot be directly tied to global warming, they illustrate the severe impacts associated with intense rains. Ironically, global warming appears to be taking Hawai'i into a time of declining fresh water resources while enduring more intense rainstorms.

Other Potential Water Cycle Impacts

Look to the mountains and see the nearly perpetual band of clouds on their slopes. Scientists infer that rising temperatures in Hawai'i could result in a shallower cloud zone because of a possible rise in the lifting condensation level, which controls the bottom of the cloud, and a decline in the height of the trade wind inversion, which controls the top of the cloud. Where clouds intercept the land (forming fog) they deposit water droplets directly on the vegetation and soil. This process is a significant source of water to the mountain ecosystems of Hawai'i; especially at windward exposures. With a smaller cloud zone, less cloud water would be available to these important forests.

Another concern is changes in the process of evapotranspiration. While rainfall and cloud water are the sources of water to the ecosystem, evaporation and transpiration (the emission of water vapor through the leaves of plants) return water to the atmosphere, thus reducing the amount going into streams and groundwater. Effects of warming on evapotranspiration are as yet unknown, but changes could further impact water resources already being affected by reduced rainfall.

Because surface air temperature, cloudiness, and rainfall depend on the trade winds, forecasting Hawai'i climate is dependent on accurately modeling trade wind changes. Intergovernmental Panel on Climate Change[10] models do not agree on these aspects of climate for the region around Hawai'i. Other modeling[11] has shown that wind and rainfall responses to warming around the Pacific are not uniform, and depend strongly on the climate model being used. Skillful projections of island climate must take into account the interaction of trade winds with island topography and will rely on continued and enhanced monitoring of key climate variables.

Sea Level

Sea level has risen in Hawai'i at approximately 0.6 inches per decade over the past century[12] and probably longer[13]. This may not seem like a substantial rate, however, long-term sea-level rise, when considered over a century, can lead to chronic coastal erosion, coastal flooding, and drainage problems, all of which are experienced in Hawai'i. This long-term trend has increased the impact of short-term fluctuations on coastal sea level[14] leading to episodic flooding and erosion along the coast due to extreme tides.

Although coastal erosion is not uniquely tied to global warming, it is a significant factor in managing the problem of high sea levels. Waves, currents, and human impacts to sand availability are the principal causes of erosion. Sea-level rise accelerates and expands erosion, potentially impacting beaches that were previously stable. Chronic erosion in front of developed lands has historically led to seawall construction resulting in beach loss[15]. Approximately 25% of beaches on O'ahu have been lost to seawall construction. Losses are similar on other islands, where the average long-term rate of coastal erosion is about 1 foot per year[16]. On Kaua'i for instance, 72% of beaches are chronically eroding and 24% of these are accelerating.

Although the rate of global mean sea level rise has approximately doubled since 1990[17] sea level not only did not rise everywhere, but actually declined in some large areas. The pattern of sea level change is complex[18] due to the fact that winds and ocean currents affect sea level, and those are changing also. In Hawai'i, improving our understanding of sea level impacts requires attention to local variability with careful monitoring and improved modeling efforts. Because of global warming, sea level rise is expected to continue, and accelerate, for several centuries. Research[19] indicates that sea level may exceed 3 feet above the 1990 level by the end of the 21st century. Continued sea-level rise will increase marine inundation of coastal roads and communities. Salt intrusion will intensify in coastal wetlands and groundwater systems, taro lo'i, estuaries, and elsewhere. Extreme tides already cause drainage problems in developed areas and Hawaiian communities located at the intersection of intensifying storm runoff and rising ocean waters will endure increased flooding.

Sea Surface Temperature
At Station ALOHA (62 miles north of Kahuku Point, O'ahu), marine researchers at the University of Hawai'i and cooperating institutions have measured an increase

Reefs in Hawai'i are generally in good health and continue to be deserving of our careful management.

of sea surface temperature of 0.22°F per decade, a result that is consistent with other estimates[20] for the latitudes of Hawai'i in the eastern North Pacific. Because of global warming this rate is likely to rise, potentially exposing coral reefs and other marine ecosystems to negative impacts related to temperature increases, including coral bleaching[21]. Bleaching results when corals lose the symbiotic algae that provide them with their principal source of food. Hawai'i is located in the cooler subtropical waters of the North Pacific. Although bleaching has become a major ecosystem catastrophe for many reefs around the world, Hawaiian reefs have largely escaped major, widespread bleaching events. However, continued warming of Hawaiian surface waters may eventually lead to bleaching.

Ocean Acidification
As rising carbon dioxide in the atmosphere mixes with seawater, the ocean acidifies. Measurements[22] at station ALOHA over two decades document that the surface ocean around Hawai'i has grown more acidic at exactly the rate expected from chemical equilibration with the atmosphere. Continued acidification may have a host of negative impacts on marine biota, and has the potential to alter the rates of ocean biogeochemical processes.

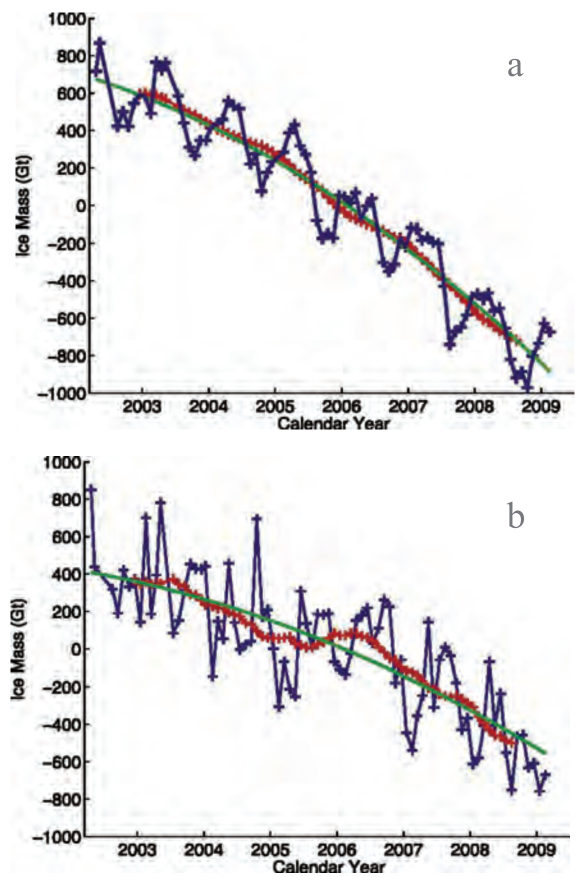
When carbon dioxide reacts with seawater it reduces the availability of dissolved carbonate. Carbonate (CO_3) is vital to shell and skeleton formation in corals, marine plankton, some algae, and shellfish. Ocean acidification could have profound impacts on some of the most fundamental biological and geochemical processes of the sea in coming decades. Plankton is a critical food source that supports the entire marine food chain. Declining coral reefs will impact coastal communities, tourism, fisheries, and overall marine biodiversity. Abundance of commercially important shellfish species may decline, and negative impacts on finfish may occur. This rapidly emerging scientific issue and its potential ecological impacts have raised concerns across the scientific and fisheries communities.

Sea level is projected to reach over 3 feet (1 meter) above present by the end of the century. The blue line marks the 1 meter contour above modern high tide.

Global Warming

From one year to the next global warming may not be evident. But measured by decade, the instrumental record beginning in 1880 shows that the temperature of Earth's surface and shallow ocean have increased over the past century, and accelerated since the 1970's. According to the National Aeronautics and Space Administration[23] global surface temperatures have increased about 1.44°F since the late-19th century, and the linear trend for the past 50 years of 0.36°F per decade is nearly twice that for the past 100 years. 2009 was only a fraction of a degree cooler than 2005, the warmest year on record, and tied with a cluster of other years — 1998, 2002, 2003, 2006 and 2007— as the second warmest year since record keeping began. Scientific analysis of modern and past climates has shown that Earth is warmer now than at any time in the past 1300 years[24] and perhaps longer.

Global warming is having measurable impacts on human communities and natural ecosystems[25] (for instance, because of climate change, ecosystems have to migrate an average 0.25 miles per year to stay within their natural climate zone[26]). Antarctica has warmed[27] at a rate commensurate with global patterns, about 0.22°F per decade since 1957, for a total average temperature rise of 1°F. In Greenland, 2007[28] marked an overall rise in the summertime melting trend over the highest parts of the ice sheet. Melting in areas above 6,560 feet rose 150% above the long-term average, with melting occurring on 25-30 more days in 2007 than the average in the previous 19 years. As measured by satellite, melting from Greenland and Antarctic ice sheets has accelerated[29] during the period April 2002 to February 2009.

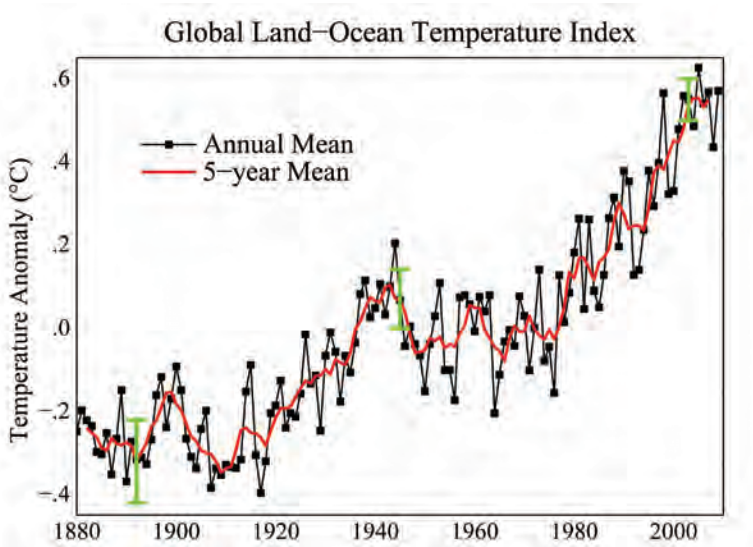


Ice loss from (a) Greenland and (b) Antarctic ice sheets (gigatons/year).

Conclusions

Global warming is evident in Hawai'i: surface temperature is rising, rainfall and stream flow has decreased, rain intensity has increased, sea level and sea surface temperatures have increased, and the ocean is acidifying. Because these trends are likely to continue:

- Scientists anticipate growing impacts to Hawai'i's water resources and forests, coastal communities, and marine ecology;
- It is timely to consider adaptation and mitigation strategies;
- There is significant need for sustained and enhanced climate monitoring and assessment activities;
- There is a compelling requirement for focused research to produce models of future climate changes and impacts.



Although 2008 was the coolest year of the decade -- due to strong cooling of the tropical Pacific Ocean -- 2009 saw a return to near-record global temperatures. The past year was only a fraction of a degree cooler than 2005, the warmest year on record, and tied with a cluster of other years -- 1998, 2002, 2003, 2006 and 2007 -- as the second warmest year since recordkeeping began[23].

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ICAP

Center for Island Climate Adaptation and Policy

The University of Hawai`i Sea Grant College Program (UH Sea Grant) has served Hawai`i and the Pacific for over 40 years and is dedicated to achieving resilient coastal communities characterized by vibrant economies, social and cultural sustainability and environmental soundness. In partnership with the William S. Richardson School of Law, the School of Ocean and Earth Science and Technology, the College of Social Sciences, and the Hawai`inuiākea School of Hawaiian Knowledge, UH Sea Grant established the Center for Island Climate Adaptation and Policy (ICAP).

FROM UH TO YOU

ICAP connects individuals and institutions to the rich, climate knowledge at the University of Hawai`i. The Center offers work product in the areas of law, policy, planning, and science to mitigate and adapt to climate change while embracing the wisdom of local, traditional cultures.

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The following document is an excerpt of the key findings from "Climate Change Indicators in the United States." Information for downloading the full 80-page document from the Environmental Protection Agency is listed on the first page. A table of contents for the full document is provided.

How to Obtain Copies

You can electronically download this document from EPA's Climate Indicators Site at www.epa.gov/climatechange/indicators.html. To request free copies of this report, call the National Service Center for Environmental Publications (NSCEP) at 1-800-490-9198.

For Further Information

For further information, please e-mail climateindicators@epa.gov or call the EPA Climate Change Division hotline at 202-343-9990.

Contents

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Summary of Key Findings

The indicators in this report present clear evidence that the composition of the atmosphere is being altered as a result of human activities and that the climate is changing. They also illustrate a number of effects on society and ecosystems related to these changes.

Greenhouse Gases

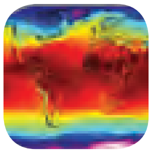
U.S. Greenhouse Gas Emissions. In the United States, greenhouse gas emissions caused by human activities increased by 14 percent from 1990 to 2008. Carbon dioxide accounts for most of the nation's emissions and most of this increase. Electricity generation is the largest source of greenhouse gas emissions in the United States, followed by transportation. Emissions per person have remained about the same since 1990.

Global Greenhouse Gas Emissions. Worldwide, emissions of greenhouse gases from human activities increased by 26 percent from 1990 to 2005. Emissions of carbon dioxide, which account for nearly three-fourths of the total, increased by 31 percent over this period. Like in the United States, the majority of the world's emissions are associated with energy use.

Atmospheric Concentrations of Greenhouse Gases. Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have risen substantially since the beginning of the industrial era. Almost all of this increase is attributable to human activities. Historical measurements show that the current levels of many greenhouse gases are higher than any seen in thousands of years, even after accounting for natural fluctuations.

Climate Forcing. Climate or "radiative" forcing is a way to measure how substances such as greenhouse gases affect the amount of energy that is absorbed by the atmosphere. An increase in radiative forcing leads to warming while a decrease in forcing produces cooling. From 1990 to 2008, the radiative forcing of all the greenhouse gases in the Earth's atmosphere increased by about 26 percent. The rise in carbon dioxide concentrations accounts for approximately 80 percent of this increase.

Weather and Climate



U.S. and Global Temperature. Average temperatures have risen across the lower 48 states since 1901, with an increased rate of warming over the past 30 years. Seven of the top 10 warmest years on record for the lower 48 states have occurred since 1990, and the last 10 five-year periods have been the warmest five-year periods on record. Average global temperatures show a similar trend, and 2000–2009 was the warmest decade on record worldwide. Within the United States, parts of the North, the West, and Alaska have seen temperatures increase the most.

Heat Waves. The frequency of heat waves in the United States decreased in the 1960s and 1970s, but has risen steadily since then. The percentage of the United States experiencing heat waves has also increased. The most severe heat waves in U.S. history remain those that occurred during the "Dust Bowl" in the 1930s, although average temperatures have increased since then.

Drought. Over the period from 2001 through 2009, roughly 30 to 60 percent of the U.S. land area experienced drought conditions at any given time. However, the data for this indicator have not been collected for long enough to determine whether droughts are increasing or decreasing over time.

U.S. and Global Precipitation. Average precipitation has increased in the United States and worldwide. Since 1901, precipitation has increased at an average rate of more than 6 percent per century in the lower 48 states and nearly 2 percent per century worldwide. However, shifting weather patterns have caused certain areas, such as Hawaii and parts of the Southwest, to experience less precipitation than they used to.

Heavy Precipitation. In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. Eight of the top 10 years for extreme one-day precipitation events have occurred since 1990. The occurrence of abnormally high annual precipitation totals has also increased.

Tropical Cyclone Intensity. The intensity of tropical storms in the Atlantic Ocean, Caribbean, and Gulf of Mexico did not exhibit a strong long-term trend for much of the 20th century, but has risen noticeably over the past 20 years. Six of the 10 most active hurricane seasons have occurred since the mid-1990s. This increase is closely related to variations in sea surface temperature in the tropical Atlantic.

Oceans

Ocean Heat. Several studies have shown that the amount of heat stored in the ocean has increased substantially since the 1950s. Ocean heat content not only determines sea surface temperature, but it also affects sea level and currents.

Sea Surface Temperature. The surface temperature of the world's oceans increased over the 20th century. Even with some year-to-year variation, the overall increase is statistically significant, and sea surface temperatures have been higher during the past three decades than at any other time since large-scale measurement began in the late 1800s.

Sea Level. When averaged over all the world's oceans, sea level has increased at a rate of roughly six-tenths of an inch per decade since 1870. The rate of increase has accelerated in recent years to more than an inch per decade. Changes in sea level relative to the height of the land vary widely because the land itself moves. Along the U.S. coastline, sea level has risen the most relative to the land along the Mid-Atlantic coast and parts of the Gulf Coast. Sea level has decreased relative to the land in parts of Alaska and the Northwest.

Ocean Acidity. The ocean has become more acidic over the past 20 years, and studies suggest that the ocean is substantially more acidic now than it was a few centuries ago. Rising acidity is associated with increased levels of carbon dioxide dissolved in the water. Changes in acidity can affect sensitive organisms such as corals.

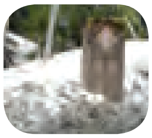
Snow and Ice

Arctic Sea Ice. Part of the Arctic Ocean stays frozen year-round. The area covered by ice is typically smallest in September, after the summer melting season. September 2007 had the least ice of any year on record, followed by 2008 and 2009. The extent of Arctic sea ice in 2009 was 24 percent below the 1979 to 2000 historical average.

Glaciers. Glaciers in the United States and around the world have generally shrunk since the 1960s, and the rate at which glaciers are melting appears to have accelerated over the last decade. Overall, glaciers worldwide have lost more than 2,000 cubic miles of water since 1960, which has contributed to the observed rise in sea level.

Lake Ice. Lakes in the northern United States generally appear to be freezing later and thawing earlier than they did in the 1800s and early 1900s. The length of time that lakes stay frozen has decreased at an average rate of one to two days per decade.

Snow Cover. The portion of North America covered by snow has generally decreased since 1972, although there has been much year-to-year variability. Snow covered an average of 3.18 million square miles of North America during the years 2000 to 2008, compared with 3.43 million square miles during the 1970s.

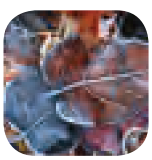


Snowpack. Between 1950 and 2000, the depth of snow on the ground in early spring decreased at most measurement sites in the western United States and Canada. Spring snowpack declined by more than 75 percent in some areas, but increased in a few others.

Society and Ecosystems

Heat-Related Deaths. Over the past three decades, more than 6,000 deaths across the United States were caused by heat-related illness such as heat stroke. However, considerable year-to-year variability makes it difficult to determine long-term trends.

Length of Growing Season. The average length of the growing season in the lower 48 states has increased by about two weeks since the beginning of the 20th century. A particularly large and steady increase has occurred over the last 30 years. The observed changes reflect earlier spring warming as well as later arrival of fall frosts. The length of the growing season has increased more rapidly in the West than in the East.



Plant Hardiness Zones. Winter low temperatures are a major factor in determining which plants can survive in a particular area. Plant hardiness zones have shifted noticeably northward since 1990, reflecting higher winter temperatures in most parts of the country. Large portions of several states have warmed by at least one hardiness zone.

Leaf and Bloom Dates. Leaf growth and flower blooms are examples of natural events whose timing can be influenced by climate change. Observations of lilacs and honeysuckles in the lower 48 states suggest that leaf growth is now occurring a few days earlier than it did in the early 1900s. Lilacs and honeysuckles are also blooming slightly earlier than in the past, but it is difficult to determine whether this change is statistically meaningful.

Bird Wintering Ranges. Some birds shift their range or alter their migration habits to adapt to changes in temperature or other environmental conditions. Long-term studies have found that bird species in North America have shifted their wintering grounds northward by an average of 35 miles since 1966, with a few species shifting by several hundred miles. On average, bird species have also moved their wintering grounds farther from the coast, consistent with rising inland temperatures.

Climate Change and Pacific Islands: Indicators and Impacts

Executive Summary of the 2012 Pacific Islands Regional Climate Assessment (PIRCA)

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This executive summary has been adapted from the full-length report, which can be accessed at www.EastWestCenter.org/PIRCA.

ISLANDPRESS

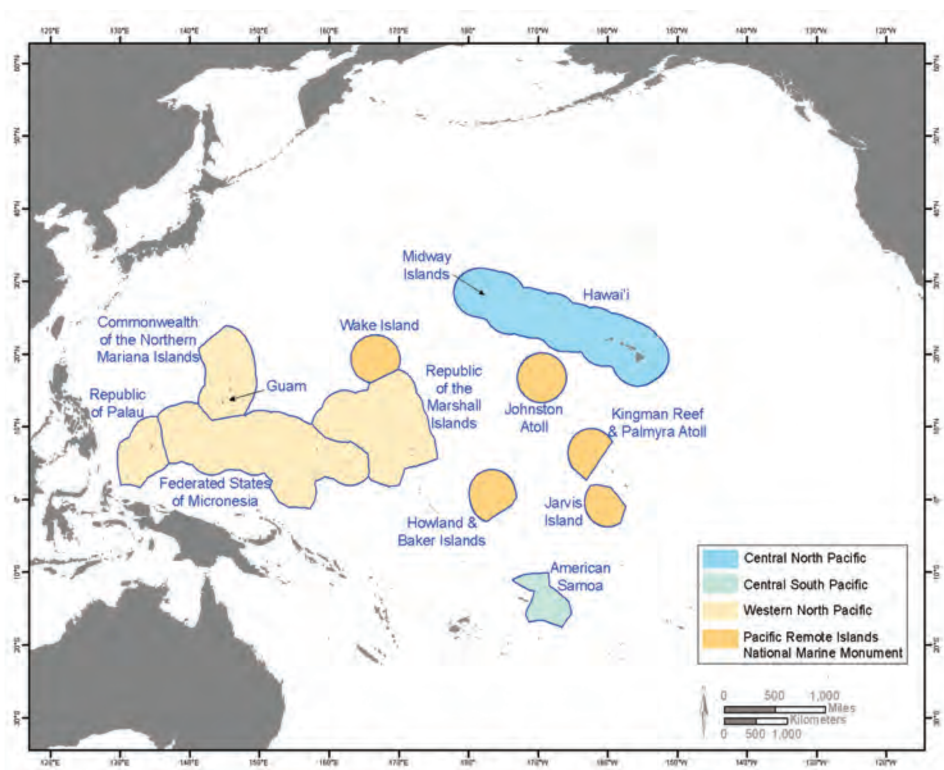
Pacific Islands Regional Climate Assessment (PIRCA)

The Pacific Islands Regional Climate Assessment (PIRCA) is an ongoing process of assessment and information exchange among scientists, natural and cultural resource managers, government agencies, businesses, and communities in the Pacific Islands region. In 2012, PIRCA published a report on the state of climate change knowledge, indicators, impacts, and adaptive capacity in Hawaiʻi and the US-Affiliated Pacific Islands. PIRCA contributes to the US National Climate Assessment, conducted under the auspices of the US Global Change Research Act of 1990.

Hawaiʻi and the US-Affiliated Pacific Islands

The Pacific Islands region is spread across millions of square miles of the Pacific Ocean. The Hawaiian archipelago and the US-Affiliated Pacific Islands include more than 2,000 islands with about 1.9 million inhabitants, representing numerous languages and cultures. These islands attract millions of tourists every year and support a large US military presence. The region includes diverse terrestrial and marine ecosystems, ranging from mountainous alpine environments to abyssal environments deep under the ocean. The islands and surrounding ocean are home to some of the most pristine habitat in the world and possess tremendous biodiversity. They are thus of immeasurable value to all people.

Across these islands, the weather and climate are highly variable. El Niño-Southern Oscillation (ENSO), for example, has a large influence on year-to-year changes in rainfall, sea level, and other climate variables. ENSO is a multiyear pattern of shifting atmospheric pressure, wind patterns, and ocean temperatures. In recent decades, scientists have made great improvements in our understanding of ENSO and other climate-related phenomena in the region, but the high level of natural variability makes it difficult to distinguish shorter-term cycles from longer-term trends.



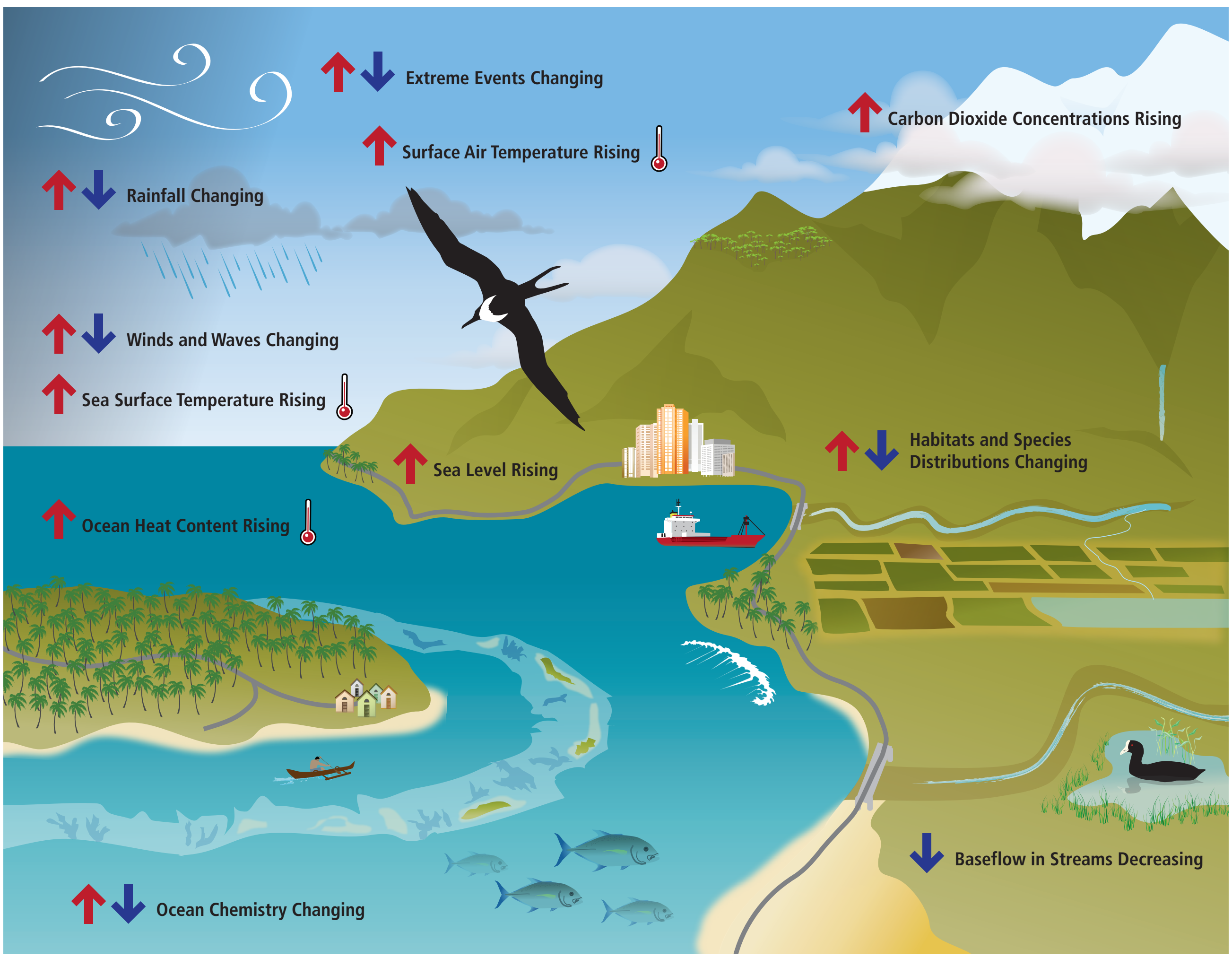
Map of Hawaiʻi and the US-Affiliated Pacific Islands region and sub-regions. The region includes islands in the Central North Pacific (blue), the Western North Pacific (light orange), the Central South Pacific (light green), and the Pacific Remote Island Marine National Monument (dark orange). Shaded areas indicate each island's exclusive economic zone (EEZ). *Source*: *Miguel Castrence, East-West Center.*

Cover photos: (*Top*) View from Makapuʻu Point on the Island of Oʻahu in Hawaiʻi, courtesy of Zena N. Grecni. (*Middle Left*) Tropical Pacific coral reef, Palmyra Atoll National Wildlife Refuge, courtesy of J. Maragos. (*Middle Right*) Pacific fish hook collection, Bishop Museum, Honolulu, Hawaiʻi, © 2008 Debbie Long, "hooked," used under a Creative Commons Attribution-NonCommercial-ShareAlike license. (*Bottom*) Clouds around Mt. Konahuanui in the Koʻolau Mountain Range, Oʻahu, courtesy of Zena N. Grecni.

Climate Change Is a Reality: Key Indicators

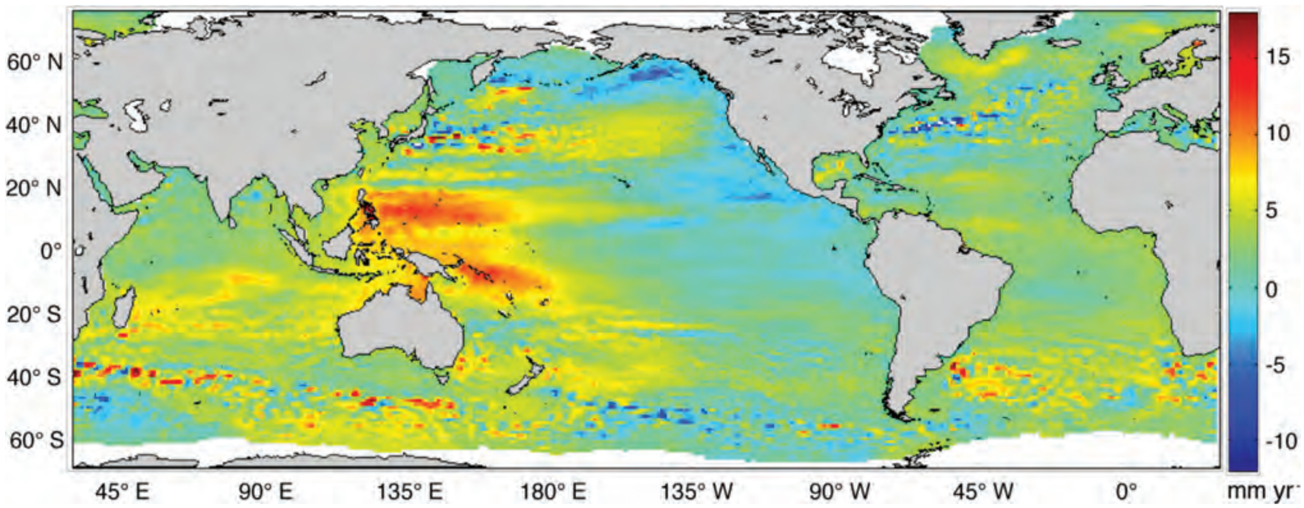
The 2012 Pacific Islands Regional Climate Assessment (PIRCA) identified several important indicators of climate change in the region, such as:

- Average surface air temperatures are rising, with the largest increases found at high altitudes in Hawaiʻi.
- Over the past century, rainfall has decreased across much of the region. There has been a slight increase in rainfall in the westernmost Micronesian islands.
- In Hawaiʻi, groundwater discharge to streams has significantly decreased over the past 100 years. This trend indicates a decrease in groundwater storage.
- Mean sea levels are rising, particularly in the Western Pacific.
- Across the region, the frequency and intensity of climatic extremes are changing. Drought has been more frequent and prolonged, and there have been fewer tropical cyclones.
- Pacific Island habitats and species distributions have changed. For example, increasing temperatures are facilitating the upward migration of mosquito-borne diseases that cause mortality in Hawaiian native forest birds.
- Ocean heat content is rising and ocean chemistry is changing.



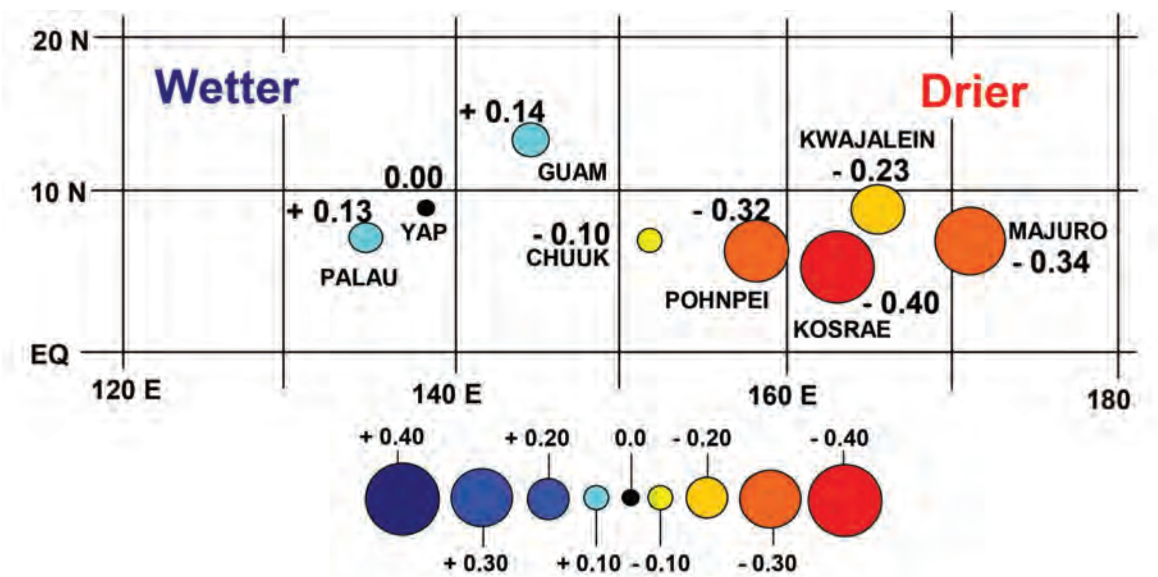
Key indicators of climate change in the Pacific Islands region. *Source*: *Susan Yamamoto, adapted from "Ten Indicators of a Warming World," in NOAA National Climatic Data Center, State of the Climate in 2009 (report).*

Sea Level



Between 1993 and 2010 **global mean sea level rose**, with the highest rise in the Western Pacific. Extreme water levels will occur when sea-level rise related to longer-term climate change combines with seasonal high tides, inter-annual and interdecadal sea-level variations, and surge or high runup associated with storms. *Source*: *Merrifield (2011), by permission of American Meteorological Society.*

Rainfall



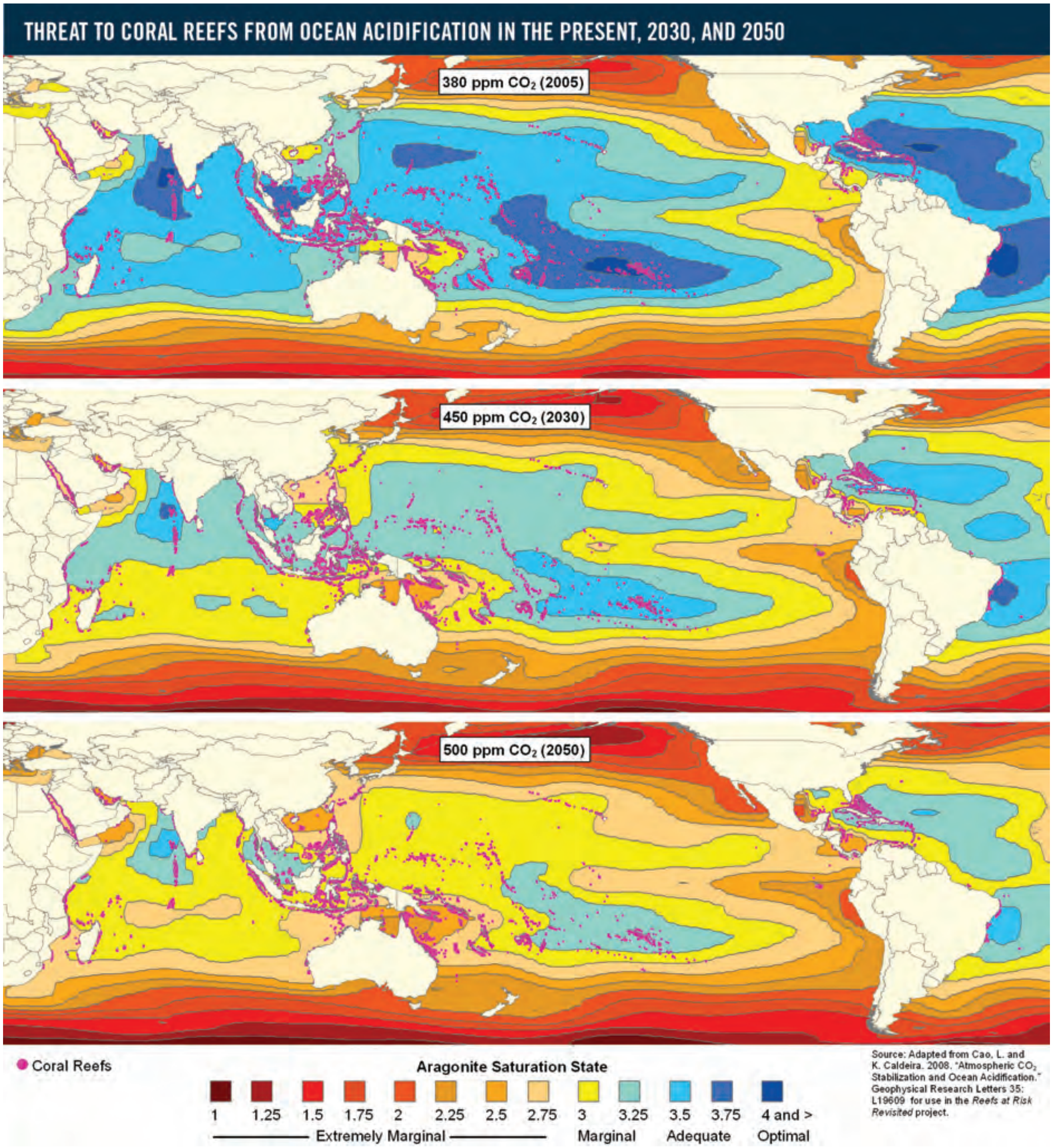
Changes in annual rainfall (inches per month per decade) in the Western North Pacific sub-region from 1950 to 2010 show that **islands in the west are getting slightly more rainfall than in the past, while islands in the east are getting much less. Annual rainfall has decreased also in Hawai'i**, which is even farther to the east (not shown). Darker blue shading indicates that conditions are wetter, while darker red shading indicates drier conditions. The size of the dot is proportional to the size of the trend as per the inset scale. *Source*: *Modified and updated from Lander and Guard*, *2003; Lander*, *2004.* Decreased rainfall is reflected in groundwater discharge to streams, which has decreased by 20% to 70% at eight out of the nine long-term streamflow gauges in Hawai'i over the past 100 years. This downward trend has **serious implications for health and well-being** because 99% of Hawai'i's drinking water comes from groundwater. *Source*: *Oki*, *2004; Bassiouni and Oki*, *2012.*

Climate Change Poses Serious Challenges

The indicators of climate change suggest multiple concerns for human and natural communities in the Pacific Islands region.

- Warmer and drier conditions mean that **freshwater supplies will decrease** on some Pacific Islands. Atolls and low-lying islands are especially vulnerable to freshwater shortages due to their small size and limited resources.
- Rising sea levels, exacerbated by storms, will **increase coastal flooding and erosion**, damaging coastal ecosystems and infrastructure and affecting agriculture, tourism, military bases, and other industries.
- Higher sea-surface temperatures will **increase coral bleaching**, leading to a change in coral species composition, coral disease, coral death, and habitat loss.
- Increasing ocean acidification and changing ocean chemistry will have **negative consequences for the entire marine ecosystem**. Although potentially dramatic, the exact nature of the consequences is not yet clear.
- Distribution patterns of coastal and ocean fisheries will be altered, with potential for increased catches in some areas and decreased catches in others. Overall in the long term, **open-ocean fisheries will decline**.
- Rising temperatures, and in some areas reduced rainfall, will stress native Pacific Island plant and animal populations and species, especially in high-elevation ecosystems. This stress, coupled with increased exposure to non-native biological invasions and fire, will **increase the risk of extinctions**.
- Threats to the traditional lifestyles of indigenous communities may include destruction of coastal artifacts and structures, reduced availability of traditional food sources and subsistence fisheries, and the loss of the land base that supports Pacific Island cultures. These losses will **make it difficult for Pacific Island communities to sustain their connection with a defined place and their unique set of customs, beliefs, and languages**.
- Mounting threats to food and water security, infrastructure, and public health and safety will **lead to human migration** from low islands to high islands and continental sites.

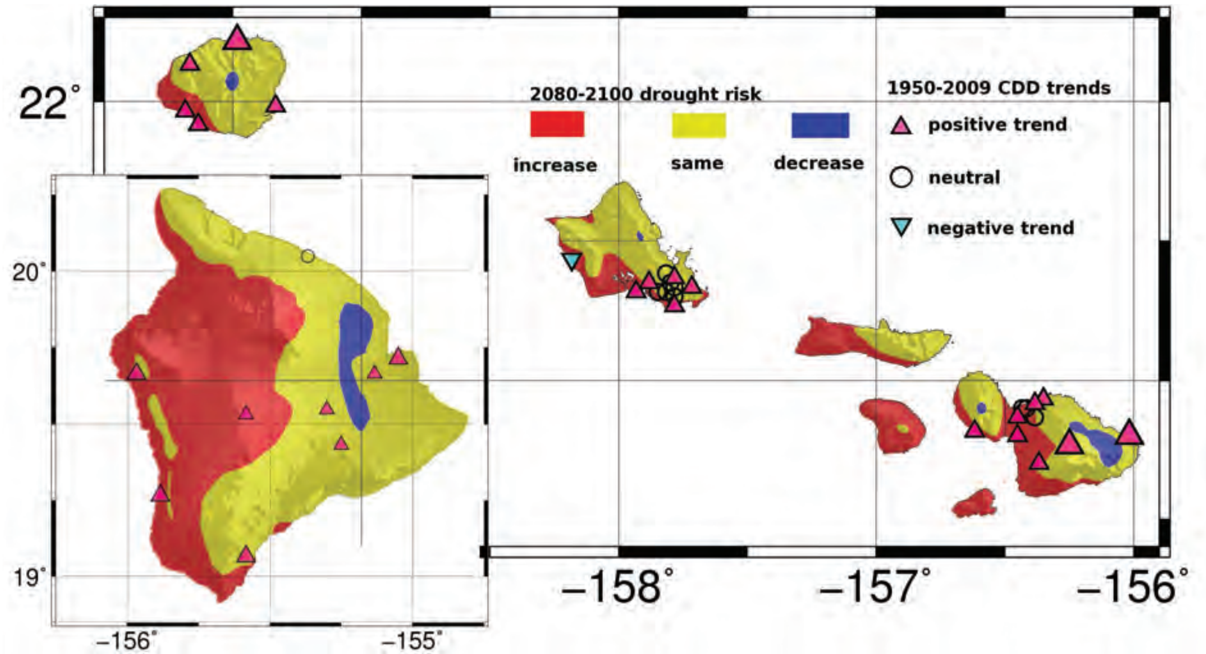
A Hawaiian monk seal (*Monachus schauinslandi*) resting on the North Shore of O'ahu, Hawai'i. Sea-level rise is of critical concern to low-lying islands where **inundation will contribute to loss of terrestrial ecosystems**. Climate influences on erosion and inundation could also **harm key habitats** such as mangroves and coastal wetlands. *Photo source*: *Victoria Keener, East-West Center.*



Ocean acidification reduces the availability of minerals, such as aragonite, which are essential building blocks for corals. If global carbon dioxide emissions continue at current levels, scientists estimate that by 2030, growth conditions for most coral reefs will be marginal at best. By 2050, the situation will be even worse. *Source*: *Burke et al., 2011.*

Projecting Climate Change into the Future

Decision makers often call for projections of climate change over the next few decades to help with planning and management at the island or community level. To generate climate projections at a resolution that encompasses island-level microclimate dynamics and windward versus leeward differences, researchers use a variety of techniques to "downscale" global climate models (GCMs). While downscaling climate models is difficult and computationally challenging, the results are useful for resource managers and policymakers in the Pacific Islands region. For instance, we can compare models of future drought in the Hawaiian Islands with episodes of historical drought already recorded.



All four major Hawaiian Islands (O'ahu, Kaua'i, Maui, and Hawai'i Island) have experienced **more severe winter droughts since the 1950s**, defined by a longer annual number of consecutive dry days. Upward triangles denote increasing drought, while downward triangles denote decreasing drought. Background colors highlight predicted changes in drought risk from 2080 to 2100, measured by the number of low-precipitation months during the wet season (November–April). **The majority of the Hawaiian Islands are predicted to have either similar or increasing levels of drought risk**. *Source*: *Figure courtesy of Oliver Elisen Timm based on data from Chu et al., 2010*; *Takahashi et al., 2011.*

Climate Information Is Needed to Support Planning and Management

- Many Pacific Islands lack long-term, high-quality data on rainfall, streamflow, waves, and ecosystems. Planners, managers, and researchers all need continuous long-term monitoring of climate variables to understand trends and evaluate projections from downscaled climate models. Yet **throughout the region, monitoring activities are being curtailed**, largely due to insufficient funding.
- **We need to understand how organisms and ecosystems respond to climate change**. Some islands in the region have no human inhabitants and few human impacts, offering a relatively pristine setting in which to assess the impacts of climate change on natural settings.
- Existing biological, geochemical, and physical models need to be integrated to **ensure that natural resource management strategies are based on a comprehensive understanding** of ecological responses to climate change.
- **A comprehensive evaluation of the effectiveness of alternative adaptation strategies** is needed as a basis for planning and management decisions.

Building an outrigger canoe from a breadfruit log in the Republic of the Marshall Islands. Threats from climate change for traditional lifestyles may include the destruction of artifacts, reduced subsistence fisheries and traditional foods, and the loss of a land base that supports Pacific Island cultures. *Photo source*: *Kanchi Hosia, used under a Creative Commons Attribution-NonCommercial-NoDerivs license.*

Adaptation Is Essential

Many of the projected impacts of climate change on Pacific Islands and their communities are now unavoidable, making some degree of adaptation essential. Within the region, **adaptive capacity differs with the availability of socioeconomic and institutional resources**. Informed and timely responses are necessary, especially on low-lying islands and atolls, to improve communities' resilience to the challenges posed by climate change.

Additional research, continued monitoring, a sustained assessment process, and public engagement in the development and sharing of useful information will enhance Pacific Islanders' ability to address the climate challenges they confront. Several regional coordination efforts are facilitating data collection, analysis, and access to information, which contributes to significant progress in developing adaptation plans and policies. Regional communication and collaboration provides a strong foundation for ongoing efforts to build resilience in the face of challenges from a changing climate.

Namdrik Atoll in the Republic of the Marshall Islands has a land area of 1.1 square miles and a maximum elevation of 10 feet. Namdrik and other **low-lying Pacific Islands are the first places that will face the possibility of climate-induced human out-migration as global warming leads to sea-level rise**. *Photo source*: *Darren Nakata.*

Acknowledgments

Primary responsibility for the PIRCA is shared by the Pacific Regional Integrated Sciences and Assessments (RISA) program, funded by the US National Oceanic and Atmospheric Administration (NOAA) and supported through the East-West Center; NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) National Climatic Data Center (NCDC); Pacific Climate Information System (PaCIS); and the Pacific Islands Climate Change Cooperative, funded by the US Fish and Wildlife Service. The editors extend special acknowledgment to the many experts who presented research, discussed findings, and authored or reviewed sections of the full report.

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Tsunami Survivor Interview Protocol - High-quality Video Interviews

Introduction

Interviews with tsunami survivors have now become a regular part of social science studies of tsunami events. More recently, the use of interviews as a way to collect data of value to physical scientists has also been recognized. Our experience has been that details of the tsunami event provided by survivors closely matches and augments physical data. Tsunami survivor stories also have great value for tsunami education. There is no messenger more credible for tsunami education than someone who has actually gone through the experience. Written collections of tsunami stories have been used as part of education programs in school curricula in Hawaii and by the U.S. Geological Survey. Questionnaires and written accounts can be valuable for tsunami education and as an aid for social science studies and for integrating physical data acquired through field surveys, but they lack the emotive power of video recording the first-hand experiences told by tsunami survivors in their own words. There is nothing like receiving the message in your own language and dialect, from someone your own age, who lives in a place similar to yours. Video interviewing of tsunami survivors is therefore, we believe, one of the most effective and efficient ways to gather physical and social science data and create compelling educational tools because they contain visual emotive elements not found in other media. It is important that a consistent and pragmatic protocol be adopted so that the technology of modern media can be can effectively harnessed.

There are several disadvantages to using a professional media crew for these interviews. In addition to the appreciable cost of a professional crew, our experience has been that communities respond better to scientists and their local student assistants, whose objective is not to make a television news story or commercial documentary, but to create materials for education that can be used at the local level. The typical community experience with professional media is that they come, they shoot, they leave, and the community never hears from them again. Furthermore, professional media are often more concerned with the quality of their production than with community sensibilities. If used appropriately, the process of video interviewing can show sensitivity to individuals being videotaped and to the community. Furthermore, the finished products can contain important physical and social science information, and at the same time provide a valuable education tool for both the local community and international use.

Video Interview Techniques

For over a decade the Pacific Tsunami Museum has sponsored the collection of video oral histories of tsunami survivors. At present the museum's archives contain over 400 survivor interviews representing first-hand accounts of 12 different tsunami events in the Pacific and India Ocean from 1923 to 2009. Accounts prior to 1998 were recorded many years after the events and memories may have changed over time, or even been replaced with details learned during the intervening years (the archival material provide a useful database to study this metamorphosis of memory). Accounts collected from survivors of the 2004 IOT and the 2006 Java tsunami were recorded as soon as was feasible, and survivors of the 2009 South Pacific tsunami were interviewed within three weeks of the event.

The current protocol is based upon a combination of scientific and pragmatic lessons learned during the time that we have been carrying out tsunami survivor interviews. It is critical that the interview protocol be customized to recognize the local culture and customs and avoid offending local sensibilities, especially during a time of community stress and grieving. The progression from set questionnaires, to written accounts, to a combination of audio tapes and their transcription, and finally to a combination of video recordings and their transcription, is indicative of this learning process. From our experience, scientifically and pragmatically, video recordings and their transcription provide the richest data source. These videos are of excellent quality, having been recorded with sophisticated digital video equipment. The current model in use is a Sony HDR FX1 high-definition (1080i) digital video camera with a BeachTek DXA-FX audio adaptor to allow for XLR stereo microphone inputs. Good equipment however, is only one aspect of achieving high quality interviews. During a decade of video interviewing we have developed a protocol, which has proved successful under a wide range of different and challenging circumstances in a variety of nations around the world.

Protocol

Ideally a team of four people is used, though by combining roles, three people can successfully carry out the interviews. The team consists of a Project Director (PD), typically a scientist with interest and/or colleagues in the region, who serves as producer, camera operator, and sound/light technician. A Field Coordinator (FC) serves as production assistant and is chosen on the basis of previous experience in the region. The On-Site Facilitator (OSF) is typically a local resident, with expertise and/or sincere interest in tsunami preparedness, knowledge of the tsunami event(s) in question, fluency in local languages and the ability to translate interviews into English (if required). A Logistical Coordinator (LC) liaises between interviewees and team members. Normally the OSF serves as interviewer (after on-site coaching), although the role can also be carried out by either the FC or LC. For organizational purposes, the process of collecting video interviews is divided into three phases: pre-interview, interview, post-interview.

Pre-interview Phase

The OSF contacts potential interviewees, explains the reason why the data are being collected and the interview process. This may involve intermediate steps, for example, in Samoa and American Samoa, immediately upon entering a village, the local chief or a respected elder was sought and our mission thoroughly explained. The chief or elder then assisted in the OSF in selecting appropriate survivors to be interviewed. Among the factors the OSF considers in the selection of potential interviewees are:

- The individual's personal experience during the tsunami event.
- The ability to effectively communicate this experience.
- The lesson(s) that can be learned from the experience.

Care must also be taken in the selection of interviewees because of the emotional impact on survivors of reliving a painful experience through their interview, especially if it is soon after the event. Though often emotional, interviews usually prove to be cathartic for most interviewees. When possible, interviewees should also reflect a range of ages, sexes, and community positions.

If the OSF believes the interviewee meets the necessary criteria, an appointment for the video interview will be set up and a location chosen. Typically the location is one that makes the interviewee feel comfortable, but where feasible it also needs to fulfill certain criteria to ensure the overall quality of the video product. The site should not be a high noise area and, where possible, should be away from all motor traffic noise. The OSF uses their judgment and local knowledge to select the initial interview site. It is often desirable to schedule time to meet with, and potentially arrange to interview, local leaders or other community members. This serves two purposes. It helps establish community cooperation for the project and also makes it more likely that there will be effective use of the outputs in sustainable local community disaster education programs.

Several important steps are followed before the first on-site interview. A test interview is carried out by the entire crew and reviewed for all aspects of the process to include interview technique, camera work, lighting and sound. At this time the OSF is provided with a list of recommended interview questions which include queries designed to gather important physical and social science data, as well as deliver a powerful tsunami experience. They are coached in the interviewing techniques required and practice asking the questions to ensure that they are grammatically and culturally appropriate. This is particularly important when dealing with material translated from English. If necessary, culturally appropriate behavior is discussed with the OSF once the mix of interviewees is known.

The LC ensures that all appropriate documentation is in order to record key personal information for each interviewee (Fig. 1a). Each individual (or authorized guardian for minors) signs a release form which allows use of the recording for educational purposes (Fig. 2). The contents and reasons for completing the Biographical Data Sheet (Fig. 1a) and Oral/Video Tape Release Form (Fig. 2) are explained to the interviewee prior to completion. Where possible, the forms should be translated into the local language so that the interviewee understands fully what they are signing. The nature and extent of the questions to be asked are also discussed at this time either by the LC or OSF (Sample questionnaire: Fig. 3). Prior to the interview, all forms (biographical, release) and the tape (and case) for each interviewee are assigned a unique Interview Code number consisting of a location abbreviation, the date of interview, and the interview number in the series for the particular assignment. Photos of the site and interviewee (full face) are taken either prior to, during, or after the interview, whichever is felt to be least intrusive. These actions help to minimize the likelihood of incorrect archiving in the future.

Interview Phase

Tsunami survivor interviews are unlike most video pieces in that it is such an intense emotional experience that there can be no second takes. It has been suggested that interviewees might embellish their stories to make them more interesting or exciting. Our experience has been, that for nearly all the survivors interviewed, it was not the simple telling of a story but the reliving of the most traumatic experience of their lives, thereby putting them in a state in which invention or embellishment was highly unlikely.

In some cases interviewees are multilingual. They should be allowed to tell their story using the language in which they feel most comfortable even if this means that their interview will require later translation.   We typically ask interviewees to begin their story with when they woke up on the day of the event and to describe the day and their activities prior to tsunami. They invariably become more relaxed using this approach. However, emotion builds as they describe events leading up to and including the tsunami itself. Interviewees must be allowed to recall and describe events without coaching. They must also be allowed to tell their story without interrupting their train of thought and should never be interrogated with closed-questions, such as those which could be answered with a “yes” or “no”. Interviewees should also never be “led”. This can give the interviewee a sense of what the interviewer might be “looking for” leading them to give the responses that they perceive are desired. When the initial narrative is complete however, the interviewee may be gently prodded for additional information, overlooked details, and other useful information. The line of specific questioning at this point depends on the actual experience of the survivor as illuminated through the preceding portion of interview itself. When appropriate, follow-up questions may be asked about the appearance, number, height, direction, and timing of waves. The final questions we use to terminate each interview are: “What advice would you give to others about tsunami safety” or words to that effect, followed by “Is there anything you would like to add?”

Ideally, interviews should be scheduled for a minimum of two hours. This includes travel to and from the site, equipment set-up and repacking, and pre-interview and interview activities. In practice however, interviews vary in length from as little as 15 minutes to over an hour, thereby often permitting the collection of three or four interviews in as little as two hours at the same site. Experience has shown that, depending upon travel times between sites, location and availability of interviewees, a maximum of about six interviews can be accomplished in a full day. It should also be noted that during the process of conducting the interviews, the team members themselves may respond to and internalize some of the trauma of the event told in the story. The team needs time to recover from the stories they have heard as well as time to organize their materials and maintain equipment.

If an interviewee is willing and able, additional footage may be shot at sites meaningful to the story, otherwise background footage (B-roll) is shot separately. Upon arrival at the interview site it is important for the PD and FC to determine if it meets the criteria for sound, light and movement. If not, then an alternative site must be chosen in consultation with the OSF. A powerful interview will be ruined by the sounds of passing motorcycles, trucks, motorboats, barking dogs, or background conversations. Once a suitable site has been found with reasonable sound quality, it must be checked for appropriate lighting. It is important to take as much advantage of the “golden hours” as possible, those hours of the day when the sun is low in the sky producing gentle, warm light effects. It is impossible however, to carry out all interviews at dusk, so in order to avoid the harsh light of mid-day a partially shaded area should be selected. In these circumstances, the subject is placed in the shade with their face illuminated by reflected light without making them squint. Greenery, such as a backyard garden or jungle back drop, makes a good background because it absorbs and diffuses light, allowing most skin colors to show adequate contrast. It is important though to choose an area where nothing can move behind the subject. People or animals wandering around in the background are distracting to the viewer. One way to mitigate these effects is to use a low “F stop” on the camera to help blur the background while keeping the subject in clear focus. Spending time on site selection is vital, but ensuring that the interviewee is well set-up is equally important. The subject should always be comfortably seated so that they do not fidget, and on a seat that does not squeak. It is important to let the subjects attach the microphone themselves, only providing assistance when asked, so as to do nothing offensive in the host culture. Nothing should actually touch the microphone however, such as a scarf or jewelry and this often requires assistance to ensure the interviewee understands. A lavaliere microphone attached at shirt collar level works best. Under windy conditions the interviewee is shielded from direct wind blowing over the microphone. A microphone windscreen is also used to further dampen wind noise. It also pays to check on regularly scheduled events in the area such as a soccer game or evening prayers, which may require adjusting the scheduled interview time to avoid intrusion of potential loud background noise.

Immediate Post-interview Phase

Following each interview our practice has been to have the OSF immediately provide a short written summary of the story in English. This applies equally to interviews carried out in English or another language. The summary is given to the LC and placed with the basic personal data collected about each survivor (Fig. 1b). It is important to allow time for this process immediately after the interview. While this can sometimes be difficult when several interviews are scheduled in one session, it is crucial to double-check the information on Biographical Data Sheet and the interview summary (e.g. do we have the name of all the children mentioned in the interview on the biographical data sheet? Was the child mentioned a daughter or son?). The immediate post-interview phase also offers the opportunity to arrange for the copying of any documentation of the tsunami provided by the interviewee (e.g. photos), and to accept and process any donated memorabilia. At the end of the day, the team meets to review the day's interviews. Any necessary revisions or additions to the descriptive data that accompany the interview tapes are made immediately while the details are still fresh. An electronic summary interview document is set-up for each assignment. This is updated daily with each reference number assigned to the appropriate interviewee photograph, and brief biographical details.

Some interviews are naturally more powerful than others and some contain new or critical information. Our practice has been to create a backup copy of these particular interview tapes during the evening following the interview. It would be best for all originals to be backed-up immediately, but because copying occurs in real-time this is time consuming and as such is not feasible during an expedition. To partially address this issue it is best to have the capability to simultaneously record directly to a hard drive. This will produce a digital videotape and a hard drive copy of interviews, thereby eliminating the chore of making backup videotape copies during an expedition. If traveling by plane during or at the end of an expedition, the original videotapes should never be placed in the airline's checked baggage. Immediately following an expedition, all interview tapes are backed up and the back-up copies stored in separate, secure, climate-controlled locations. The process is lengthy because as mentioned it is carried out in real-time, but we also simultaneously burn a DVD copy of each interview. These DVDs are complete, unedited copies of the interview and contain the time code recorded on the original videotape.

Transcription and Translation of Interviews

Where translation is necessary the DVDs are sent to the OSF who carries out or supervises the transcription and translation of the interviews. The video time code must be entered at frequent intervals alongside the translated transcription of the interview in order to permit editing of the video. Typically we ask that the time code be entered at two to five minute intervals depending upon the context and before and after every important "sound bite" (i.e. a statement of special value). These transcriptions can then be easily converted into a video storyboard. A typical interview lasts between 20 and 40 minutes, although we have had interviews of up to two hours (requiring two 60-minute videotapes). All archived interview transcripts are recorded in a searchable archive database keyed to specific tsunami events.

Selected interviews may be edited to a three-to-four minute final product, which includes the most important lessons learned. This is a suitable length without exceeding the typical listener's attention span. Our practice has been to offer DVD copies of the interviews to the interviewee whenever feasible, typically in full-length form. Due to the different video standards used internationally (NTSC, PAL, SECAM), providing copies of interviews for commercial video players can be both an unexpectedly problematic and expensive component of any project., however the provision of videotape copies is often a necessary expense.

Fig. 1. a) Summary Biographical Data Sheet used by the Pacific Tsunami Museum (it should be noted that legal requirements may cause variations in the format). When working in predominantly non-English speaking countries this form is translated into the appropriate language. The OSF and LC liaise to produce the summary of the interview. A unique Interview Code is assigned to each interviewee record; b) Tsunami Recollection Summary used by the Pacific Tsunami Museum –this is filed together with the Biographical Data Sheet.

Fig. 2. (below). Summary Oral/Video Tape Release Form used by the Pacific Tsunami Museum (it should be noted that legal requirements may cause variations in the format). A unique Interview Code is assigned to each interviewee record. Separate archival numbers are logged in the searchable database (For Museum Reference only). When working in predominantly non-English speaking countries this form is translated into the appropriate language, so that interviewees understand what they are signing, although the English form is to be signed.

Note: The release form is provided in the Grade 6 Unit, Lesson 4.

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Grades 6 and 8
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