# Climate Change in the Commonwealth of the Northern Mariana Islands

PIRCA | 2021

## Indicators & Considerations for Key Sectors

Report for the Pacific Islands Regional Climate Assessment (PIRCA)

EAST-WEST CENTER

pirca PACIFIC ISLANDS REGIONAL CLIMATE ASSESSMENT

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The East–West Center hosts the core office of the Pacific RISA grant, providing administrative and research capabilities for the program. The Pacific RISA is one of the 11 National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Sciences and Assessments (RISA) teams that conduct research that builds the nation's capacity to prepare for and adapt to climate variability and change. This work is supported by funding from NOAA. The Pacific RISA provided primary oversight of this and the 2012 PIRCA report.

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# About PIRCA and this Report

***Climate Change in the Commonwealth of the Northern Mariana Islands: Indicators and Considerations for Key Sectors*** is a report developed by the Pacific Islands Regional Climate Assessment (PIRCA). It is one in a series of reports aimed at assessing the state of knowledge about climate change indicators, impacts, and adaptive capacity of the US-Affiliated Pacific Islands (USAPI) and the Hawaiian archipelago. PIRCA is a collaborative effort engaging federal, state, and local government agencies, non-governmental organizations, academia, businesses, and community groups to inform and prioritize their activities in the face of a changing climate.

The initial phase of PIRCA activities was conducted during June–October 2019 and included meetings and workshops in American Sāmoa, the Republic of Palau, the Commonwealth of the Northern Mariana Islands (CNMI), and Guam. Draft PIRCA reports were developed and refined through engagement with the PIRCA network. The material presented in this report is based largely on published research and insights from participants in PIRCA activities. The PIRCA Advisory Committee reviewed this report. Workshop participants and reviewers independent of the PIRCA workshops who made contributions are recognized as Technical Contributors.

The Pacific Regional Integrated Sciences and Assessments (Pacific RISA) program has primary oversight of the 2020 PIRCA. The Pacific RISA is funded by the US National Oceanic and Atmospheric Administration (NOAA) and supported through the East-West Center. Key partners and supporters are NOAA's National Centers for Environmental Information (NCEI), the Department of the Interior's Pacific Islands Climate Adaptation Science Center (PI-CASC), and the US Global Change Research Program (USGCRP).

This series represents the latest assessment in a sustained process of information exchange among scientists, businesses, governments, and communities in the Pacific Islands region that began with the 2012 PIRCA (which produced *Climate Change and Pacific Islands: Indicators and Impacts*, Island Press). We anticipate that in conjunction with other collaborative regional assessment efforts, the PIRCA reports will provide guidance for decision-makers seeking to better understand how climate variability and change impact the Pacific Islands region and its peoples.

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**Songsong Village and Mt. Tapingot occupy a narrow peninsula on the island of Rota.**
Photo: Junji Takasago; courtesy of the Marianas Visitors Authority

# Key Issues for Managers and Policymakers

**Changing air temperatures** — Hot days have increased, while the frequency of cool nights has decreased in the CNMI. Air temper-atures will continue to rise under all future warming scenarios.

**Stronger tropical storms and typhoons** — Tropical cyclone intensity is expected to increase. While tropical cyclones are expected to decrease in number in the future, those that do form are more likely to be intense (higher category), delivering higher wind speeds and more rainfall. The CNMI experienced profound impacts to the economy, infrastructure, and public health from recent typhoons.

**Threats to natural areas and infrastructure from sea level rise** — Sea level is rising in the CNMI and is expected to become damaging by exacerbating high tide and wave flooding, storm surge, and coastal erosion. More frequent and intense coastal flooding and erosion are anticipated to affect properties and infrastructure in the coming decades as sea level rise accelerates.

**Human health and safety** — More extreme storms and heatwaves, increased risk of wildfire, transmission of disease, and declining ecosystems all threaten human health and safety. Local preparedness and global action to significantly cut greenhouse gas emissions can greatly reduce these health impacts.

**Equity considerations** — Climate change is expected to disrupt many aspects of life in the CNMI, and some groups will be affected disproportionately. Those who are already vulnerable, such as children, elderly people, people with pre-existing medical conditions, and low-income communities, are at greater risk from extreme weather and climate events.

**Coral reef bleaching and loss** — Oceans are warming, causing coral reef bleaching that is already severe. Coral reefs and ocean ecosystems contribute more than $100 million annually to the CNMI's economy. In the next few decades, more frequent coral bleaching events and ocean acidification will combine with existing stressors to threaten widespread mortality for coral reefs.

**Uncertain total rainfall amounts** — Global and regional climate model outputs avail-able for the Mariana Islands region show a range of possible future precipitation changes, from as much as 7% lower to as much as 20% higher in the CNMI overall in the long term.

**Risks to fresh water** — Hotter temperatures increase the demand for water and decrease the supply of fresh water available. The combination of possible increased pumping and sea level rise threaten to bring saltwater contamination into wells that supply drinking water.

**Threats to ecosystems and biodiversity** — Changes in temperature, rainfall, and tropical cyclone characteristics promote the spread of invasive species and reduce the ability of terrestrial habitats to support rare and protected species. Measures that enhance biodiversity and improve ecosystem resilience can support communities in adapting to climate variability and change.

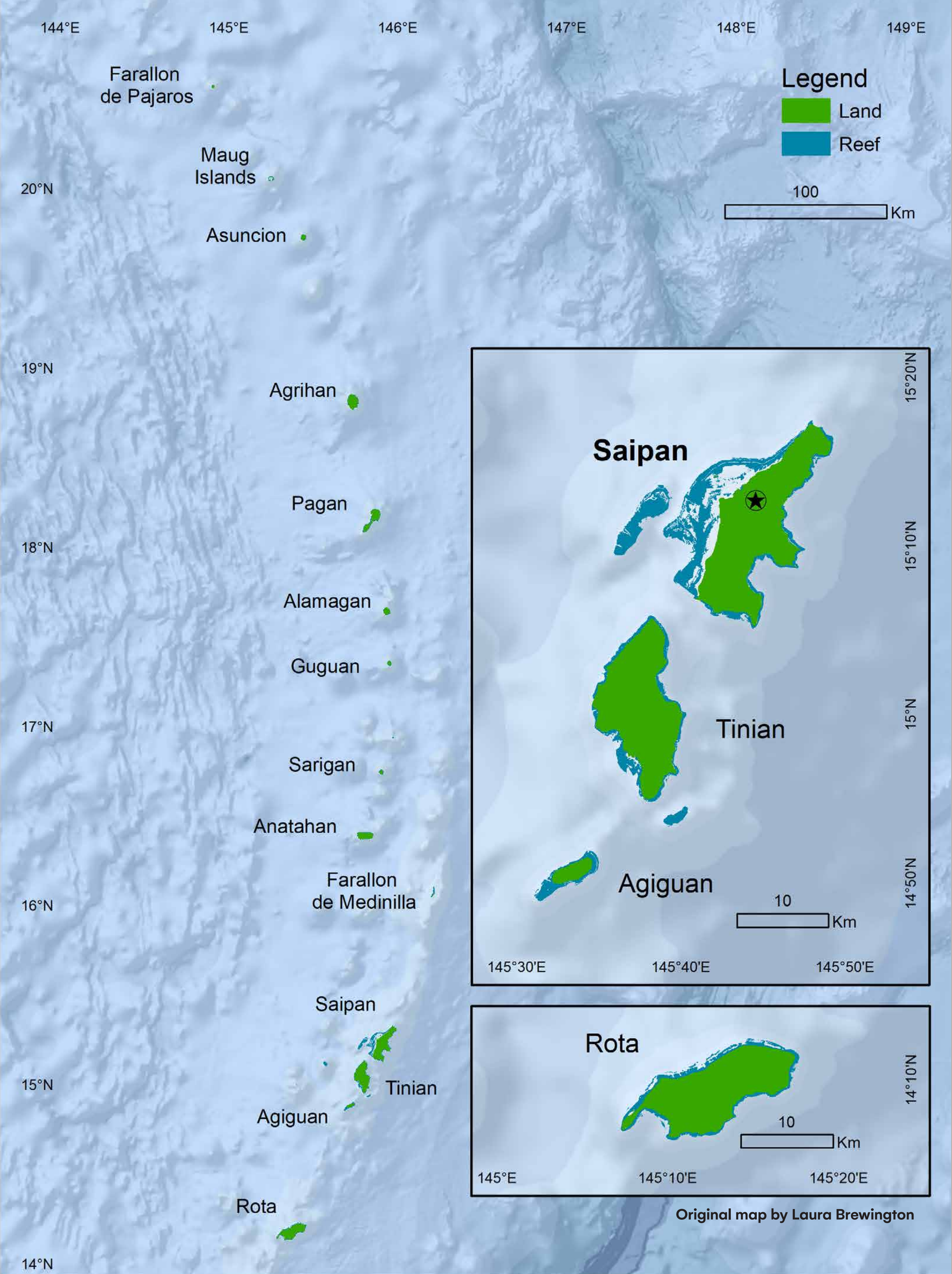
**Limestone cliffs, sea caves, and pocket beaches punctuate Tinian's coast.**
Photo: istock.com

# Climate Change in the Commonwealth of the Northern Mariana Islands: Indicators and Considerations for Key Sectors

## Report for the Pacific Islands Regional Climate Assessment (PIRCA)

**Coordinating Authors: Zena Grecni**, East-West Center; **Erin M. Derrington**, CNMI Office of Planning and Development; **Robbie Greene**, Lynker on contract to the National Oceanic and Atmospheric Administration (NOAA); **Wendy Miles**, East-West Center and US Fish and Wildlife Service; **Victoria Keener**, East-West Center

**Technical Contributors: Frank Ada**, Department of Lands and Natural Resources (DLNR) Forestry; **Lorenza Aldan**, Northern Marianas College Cooperative Research and Extension Education Services; **James Arriola**, Brabu Behavioral Health Services; **Merrill Ayuyu**, Bureau of Environmental and Coastal Quality (BECQ); **David Benavente**, BECQ Division of Coastal Resources Management (DCRM); **Laura Brewington**, East-West Center; **Richard Brooks**, BECQ DCRM; **Viktoria Buniag**, Northern Marianas College Cooperative Research and Extension Education Services; **Darsha Camacho**, Office of Grants Management and State Clearinghouse; **Rodney Camacho**, BECQ DCRM; **Jonathan Camacho**, Commonwealth Utilities Corporation; **Kevin Camacho**, DLNR Division of Fish and Wildlife; **Gregory Camacho**, DLNR Division of Fish and Wildlife; **Manny Camacho**, Office of Planning and Development; **Janice Castro**, BECQ DCRM; **Joey Castro**, Department of Public Works; **Wilgene Dela Cruz**, DLNR Division of Fish and Wildlife; **Dolan Eversole**, University of Hawai'i Sea Grant College Program; **Colleen Flores**, BECQ DCRM; **Abby Frazier**, East-West Center; **Leila Deleon Guerrero**, BECQ DCRM; **Katy Hintzen**, University of Hawai'i Sea Grant College Program; **Edwin Hofschneider**, BECQ DCRM; **Omar Hossain**, Division of Parks and Recreation; **Malcolm Johnson**, BECQ; **Sowm Kaipat**, Micronesia Islands Nature Alliance; **Larry Manacop**, Commonwealth Utilities Corporation; **Kelsey McClellan,** BECQ DCRM; **Steve McKagan,** NOAA; **Mallory Muña**, BECQ DCRM; **Kodep Ogumoro-Uludong**, Office of Planning and Development; **Ruby Pap**, University of Hawai'i Sea Grant College Program; **Austin Piteg**, BECQ DCRM; **Julius Reyes**, BECQ DCRM; **Bradley Romine**, University of Hawai'i Sea Grant College Program; **Atdao Rosario**, BECQ DCRM; **Arnold Route,** Northern Marianas College Cooperative Research and Extension Education Services; **Agnes Sablan**, BECQ DCRM; **Frances Sablan**, DLNR Division of Fish and Wildlife; **Yimanuel Sablan**, DLNR Division of Fish and Wildlife; **Rich Salas**, BECQ DCRM; **Amy Sanchez**, BECQ DCRM; **Laurina Sebaklim**, BECQ DCRM; **Maureen Sebangiol**, Northern Marianas Trades Institute; **Elsan Tadios**, Department of Public Works; **Lee Tenorio**, Saipan Mayor's Office; **Lance Tudela**, BECQ DCRM; **Nicolette Villagomez**, Commonwealth Utilities Corporation; **Roseanne Germinaro**, Department of Public Works; **Matthew J. Widlansky**, University of Hawai'i Sea Level Center; **Jihan Younis**, BECQ DCRM; **Joseph Takai** DLNR Division of Agriculture



Original map by Laura Brewington

# Inside this Report

**Mañagaha Island, a Marine Conservation Area and popular tourism site, is already experiencing erosion, making it particularly vulnerable to sea level rise.**
Photo: istock.com

# Global Climate Change: Causes and Indicators

## The causes of climate change

Scientists have researched the physical science of climate change for almost two centuries. Carbon dioxide and other greenhouse gases that naturally occur in the atmosphere capture heat from the Sun's energy that radiates from Earth's surface, preventing some of the heat from escaping to space (USGCRP 2018, Ch. 1: Overview). Known as the "greenhouse effect," this process keeps Earth habitable for life. However, human activities have emitted an increasing amount of greenhouse gases into the atmosphere since the late 1800s through burning fossil fuels (such as oil, gas, and coal) and, to a lesser extent, through changes in land use and global deforestation. As a result, the greenhouse effect has intensified and driven an increase in global surface temperatures and other widespread changes in climate. These changes are now happening faster than at any point in the history of modern civilization (USGCRP 2018, Ch. 1; USGCRP 2017, Ch. 2: Physical Drivers of Climate Change; IPCC 2014, SPM.1.2).

Although natural climate cycles and other factors affect temperatures and weather patterns at regional scales, especially in the short term, the long-term warming trend in global average temperature documented over the last century cannot be explained by natural factors alone (USGCRP 2018, Ch. 2, Key Message 1). Human activities, especially emissions of greenhouse gases, are the only factors that can account for the amount of warming observed over the last century (USGCRP 2018, Ch. 2, KM 1; IPCC 2014, SPM.1.2). The largest contributor to human-caused warming has been carbon dioxide. Natural factors alone would have actually had a slight cooling effect on climate over the past 50 years (USGCRP 2018, Ch. 2, KM 1).

## How is climate changing?

Long-term scientific observations show a warming trend in the climate system and the effects of increasing greenhouse gas concentrations in the atmosphere. The factors observed to be changing are known as **indicators** of change. Data collected from around the world show, for example:

- Globally, annual average temperatures over land and oceans have increased over the past century;
- Oceania's five warmest years in the past century have occurred since 2005, with the warmest year on record being 2019 (NOAA 2020a);
- Seas are rising, warming, and becoming more acidic;
- Some ocean species are moving toward cooler waters;
- Ice sheets and sea ice are decreasing, and glaciers and snow cover are shrinking.

These and many other changes are well documented and are clear signs of a warming world (USGCRP 2018, Ch. 1, Fig. 1.2, and Ch. 2, KM 3–7; IPCC 2014, SPM.1.1; also see USGCRP Indicators and EPA Indicators websites).

As in all regions of the world, the climate of the Pacific Islands is changing. The top panel of

Figure 1 summarizes the changes observed by scientists through several key indicators. The impacts of climate change (Fig. 1, lower panel) are already being felt in the Pacific Islands and are projected to intensify in the future (Keener et al. 2018).

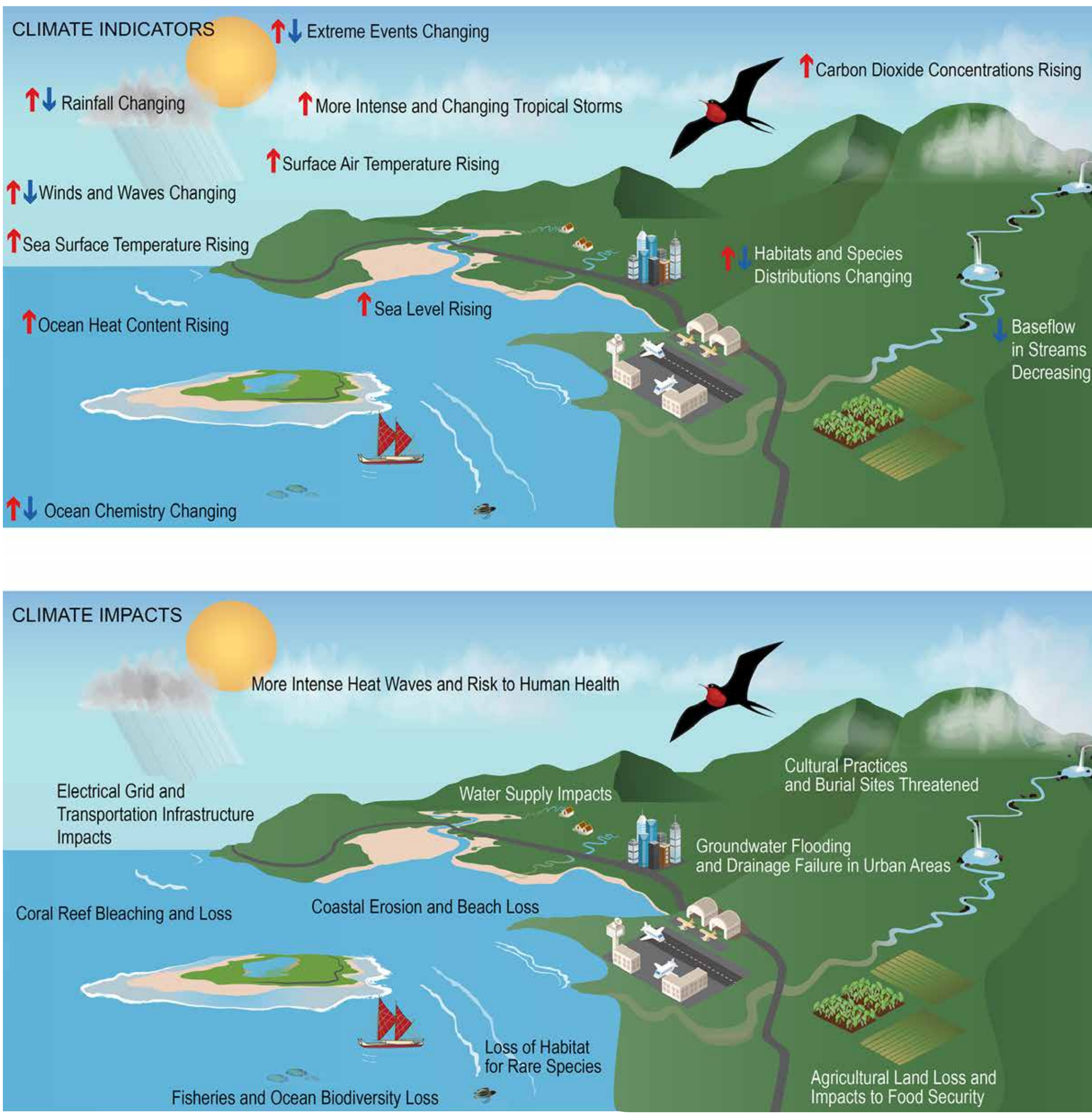



**Figure 1.** Observed changes in key climate indicators in the Pacific Islands, such as carbon dioxide concentration, sea surface temperatures, and species distributions result in (bottom) impacts to multiple sectors and communities, including built infrastructure, natural ecosystems, and human health. Source: Keener et al. 2018.

## Future changes

Greenhouse gas emissions from human activities will continue to affect the climate over this century and beyond; however, efforts to cut emissions of certain gases could help reduce the rate of global temperature increases over the next few decades (USGCRP 2018, Ch. 1 and Ch. 2, KM 2).

The largest uncertainty in projecting future climate conditions is the future levels of greenhouse gas emissions (USGCRP 2018, Ch. 2, KM 2; IPCC 2014, SMP.2.1). Those emissions could vary widely depending on the actions that human society takes in the coming years (USGCRP 2018, Ch. 2, KM 2; IPCC 2014, SMP.2.1). Climate models representing our understanding of historical and current climate conditions are often used to project how our world will change under future conditions. To understand how different levels of greenhouse gas emissions could lead to different climate outcomes, scientists use plausible future scenarios—known as Representative Concentration Pathways (RCPs)—to project temperature change and associated impacts (USGCRP 2018, Guide to the Report). In this summary, the "high scenario" (RCP8.5) represents a future where reliance on fossil fuels and annual greenhouse gas emissions continue to increase throughout this century. The "low scenario" (RCP4.5) is based on reducing greenhouse gas emissions (about 85% lower emissions than the high scenario by the end of the 21st century).

Current greenhouse gas emissions far outpace lower emissions pathways and are currently tracking higher than the high scenario (RCP8.5). Human activities have caused approximately 1.0°C of warming above pre-industrial levels (IPCC 2018, A.1). Limiting global warming to 1.5°C, while physically possible, would require rapid and far-reaching transitions in energy, land use, cities, transportation, and industrial systems (IPCC 2018, C.2).

This report summarizes the changes and future projections in key climate indicators in the Commonwealth of the Northern Mariana Islands (CNMI). Later sections describe climate-related issues affecting families and households in the CNMI; extreme weather and climate change risks and considerations for managers and decision-makers; and needs for information and research. The findings are drawn from published literature on climate science, climate-related risks in the Pacific Islands, and risk management approaches. NOAA's Office for Coastal Management and the Pacific RISA held workshop sessions in Saipan in July 2019 that gathered knowledge, informed the report content, and identified research and information needs.

# Indicators of Climate Change in the Commonwealth of the Northern Mariana Islands

This discussion of indicators of climate change in the CNMI builds on previous work that includes the report *State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands under a Changing Climate: 2017* (Marra and Kruk 2017). Indicators included in this foundational effort were derived through a series of formal and informal discussions with a variety of stakeholders in the public and private sectors and members of the scientific community. Criteria for their selection included regional and local relevance and an established relationship to climate variability and change (Marra and Kruk 2017).

## Air temperature

| Indicator | How has it changed? | Projected future change |
|---|---|---|
| Hot days | ↑ | ↑ |
| Cool nights | ↓ | ↓ |
| Average air temperature | ↑ | ↑ |

Air temperature factors into many realms of decision-making, from public health to utilities and building construction. Air temperature is also a key indicator of climate change. The longest complete air temperature dataset for the Mariana Islands available from NOAA is the Andersen Air Force Base (Guam) record from 1953 to 2002. Recent data (after 2002) are not available from NOAA for this station. Although temperature records for Saipan, Tinian, and Rota do exist, they are mostly short and discontinuous. A continuous record of 30 years or more is generally considered suitable for climate studies.

The annual number of **hot days** in the Mariana Islands has increased (see Figs. 2 and 3). Days with temperatures at or above 88°F (31.1°C) recorded at the Andersen Air Force Base weather station have increased, with 5 days per year exceeding 88°F (31.1°C) on average in the 1950s, compared to 36 days per year on average in the 1990s (Fig. 2). Recent air temperature measurements at the Francisco C. Ada Saipan International Airport also show an increasing trend in the annual number of hot days (90°F/32°C or warmer) since 2006 (NOAA 2020c).

Similarly, there has been a drop in the annual number of **cool nights** (below 74°F, or 23.3°C) observed at Andersen Air Force Base between 1953 and 2002 and at the international airport in Saipan from 2006 to 2020 (Figs. 4 and 5; NOAA 2020c).

Fig.2

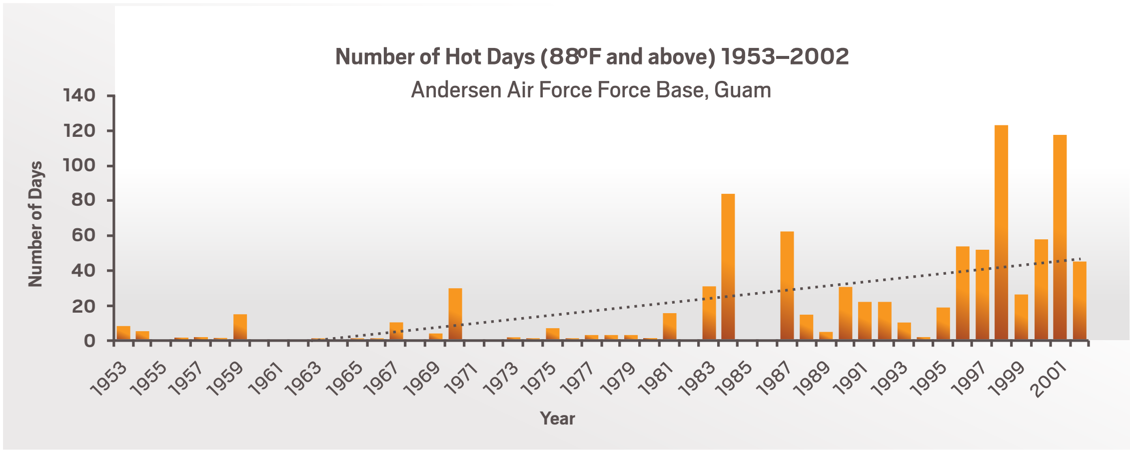



**Figure 2.** Annual number of days with maximum temperature 88ºF (31.1ºC) or hotter (at or above the 95th percentile of the data record) at Andersen Air Force Base in Guam from 1953 to 2002. The trendline (black, dotted line) shows there has been a long-term increase in the annual number of hot days. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1953–2002 (NOAA 2020c; Menne et al. 2012).

Fig.3

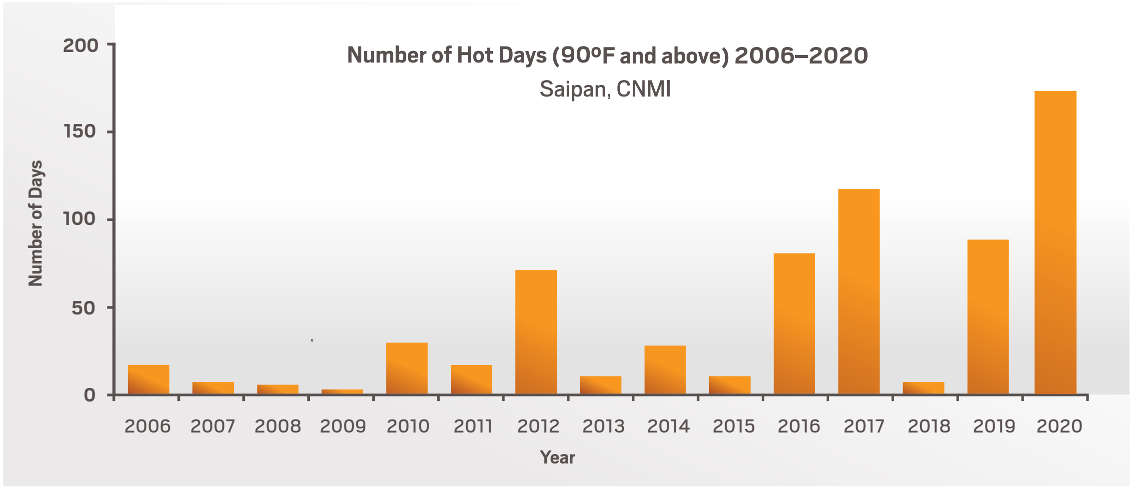



**Figure 3.** Annual number of days with maximum temperature at or above 90ºF (32ºC)—the 95th percentile of the data record—at the Francisco C. Ada Saipan International Airport from 2006 to 2020. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

Fig.4

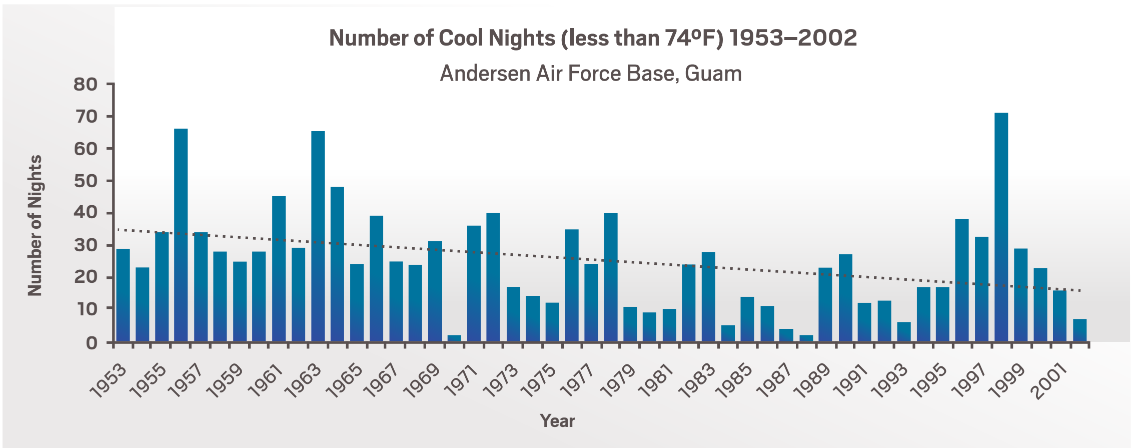



**Figure 4.** Annual number of nights with minimum temperature less than 74ºF (23.3ºC)—the 10th percentile of the data record—at Andersen Air Force Base in Guam from 1953 to 2002. The trendline (black, dotted line) shows a decrease on average in the frequency of cool nights during 1953–2002. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

Fig.5

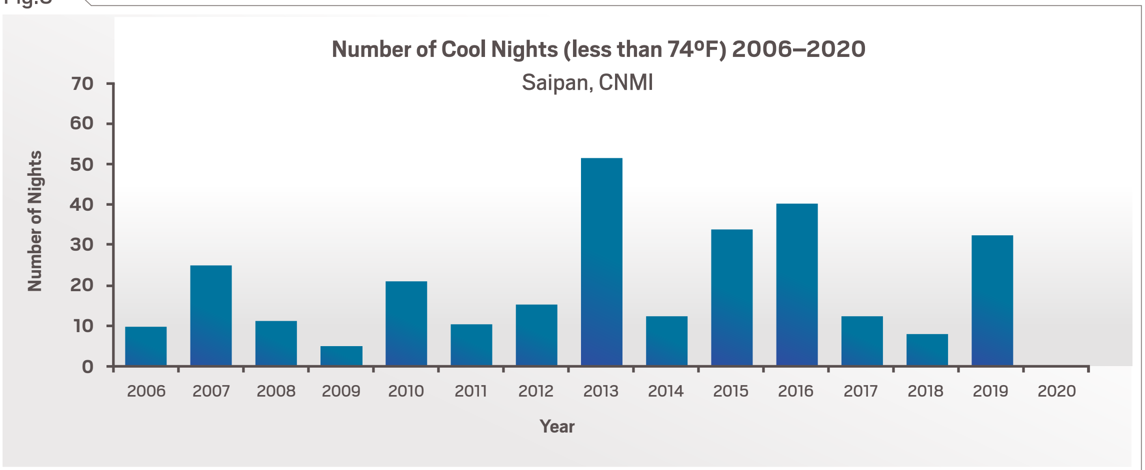



**Figure 5.** Annual number of nights with minimum temperature less than 74ºF (23.3ºC)—the 10th percentile of the data record—at the Francisco C. Ada Saipan International Airport from 2006 to 2020. There were zero nights with minimum temperatures below 74ºF in 2020. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

**Average air temperature**, measured at Andersen Air Force Base from 1953 to 2002 (Fig. 6) and Saipan's airport from 2006 to 2020 (Fig. 7), has risen overall (NOAA 2020c; Marra and Kruk 2017).

No future projections downscaled to the island level are currently available for the CNMI. Average daily temperatures in Guam are projected to rise by 2.7–3.6°F (1.5–2.0°C) under a low warming scenario and by 5.4–6.3°F (3.0–3.5°C) under a high scenario by 2080–2099 (Zhang et al. 2016; Wang et al. 2016). Model projections for Guam indicate hot days over 90°F may increase to 257 days per year under a high scenario by the end of this century. In other words, more than 70% of days in the year are expected to see temperatures over 90°F (Zhang et al. 2016).

Fig.6

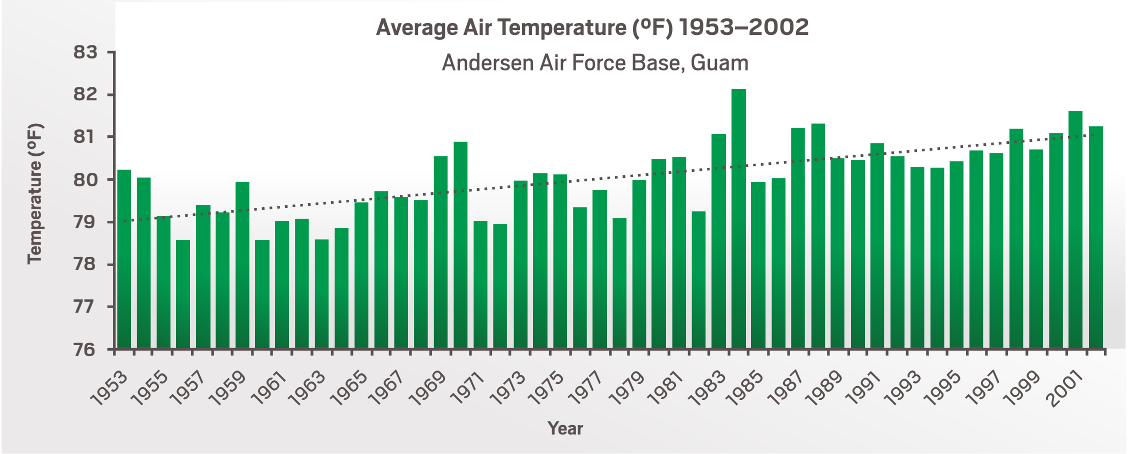



**Figure 6.** Average annual air temperature at Andersen Air Force Base in Guam 1953–2002. The long-term linear trend indicated by the black, dotted line shows an increase over time. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1953–2002 (NOAA 2020c; Menne et al. 2012).

Fig.7

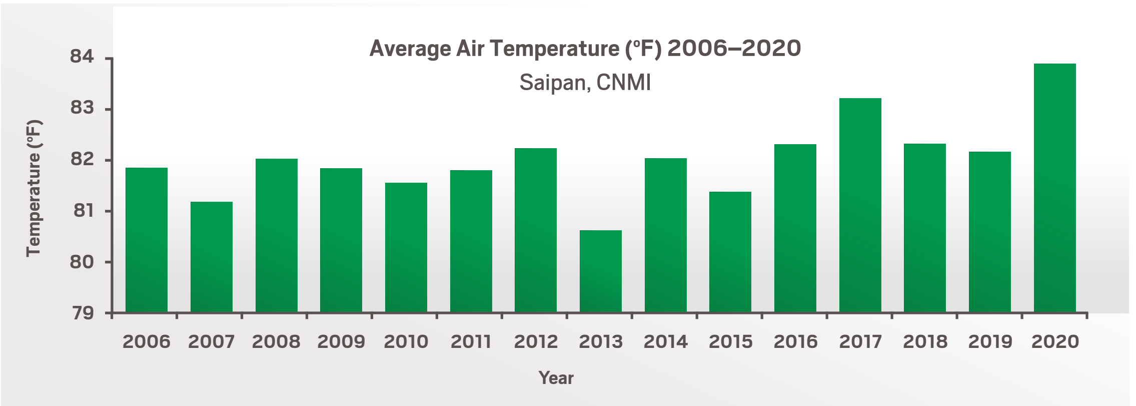



**Figure 7.** Average annual air temperature from 2006 to 2020 at the Francisco C. Ada Saipan International Airport in the CNMI. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

## Rainfall

| Indicator | How has it changed? | Projected future change |
|---|---|---|
| Average rainfall | No change | ? |
| Extreme rainfall days | No change | ↑ |
| Drought frequency and intensity | ? | ? |

On islands, rainfall is the primary source of all fresh water, making it essential to human communities and ecosystems. Rainfall patterns across the Marianas region are strongly linked to monsoons of the Eastern Hemisphere and the El Niño–Southern Oscillation (ENSO). As a result, annual rainfall is highly variable. Precipitation records in the CNMI contain significant gaps and are not representative of the geography of the islands. Thus, CNMI rainfall data is inadequate for climate studies. The nearest station with sufficient data, and thus considered the best available record relevant to the CNMI, is at Andersen Air Force Base in Guam. Rainfall patterns are consistent between Saipan and Guam, which can be attributed to both locations reacting similarly to ENSO (Fig. 8; Lander 2004). Thus, Guam's long-term rainfall record can be used to make inferences about the character of rainfall in the southern islands of the CNMI, including Saipan, Tinian, and Rota. At Andersen Air Force Base, the driest year recorded was 1998, during a strong El Niño, when rainfall was more than 39 inches (1000 mm) below normal (Marra and Kruk 2017). The wettest year was 1976, when the station recorded more than 49 inches (1250 mm) of above-normal rainfall.

Fig.8

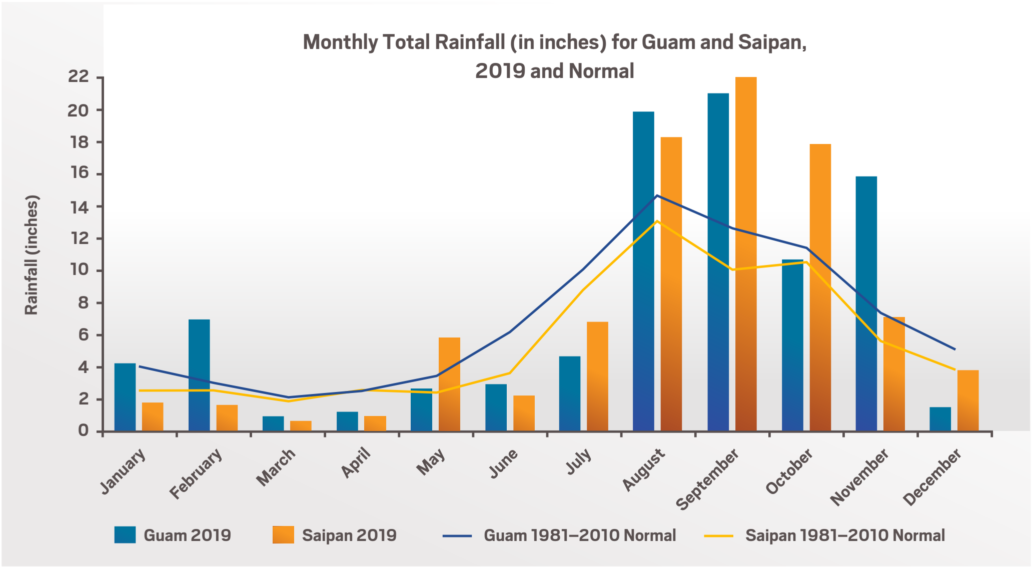



**Figure 8.** Monthly rainfall totals at Guam's international airport (blue) and Saipan's international airport (yellow) in 2019 (bars) and a normal year (lines). During an El Niño, including the 2018–2019 event, rainfall responds similarly in Guam and Saipan, with a drier-than-normal first half of the year following the onset of El Niño. Figure adapted from NOAA NCEI 2020b.

**Annual total rainfall** at Saipan's airport from 1989 to 2020 shows little change on average over 30 years and high year-to-year variability. This agrees with annual rainfall at Andersen Air Force Base (a proxy for CNMI rainfall), which is near the long-term normal value and shows no statistically significant change from the 1950s to present (Marra and Kruk 2017).

Global climate models project a 10–20% increase in average annual precipitation for the area of the Pacific including the CNMI by the end of the 21st century under the high scenario relative to 1986–2005 (IPCC 2013a). Under the low scenario, future change in annual rainfall is projected to range from no change to a 10% increase on average by the end of the century (IPCC 2013b). However, it should be noted that a subset of models downscaled to the island level for Guam project an average decrease in annual rainfall (7% overall) under the higher scenario for late this century relative to 1990–2009 (Zhang et al. 2016). The projections for Guam indicate reduced wet season rainfall (July to December), while dry season rainfall (January to June) is projected to increase slightly (Zhang et al. 2016).

The frequency of **extreme rainfall** at Saipan's airport (Fig. 9) and Andersen Air Force Base has changed little on average over the length of the records (since 1989 and the 1950s, respectively) (NOAA 2020c; Marra and Kruk 2017). The annual number of extreme rainfall days from 1994 to 2020 at the Benjamin Taisacan Manglona International Airport on Rota is shown in Figure 10. Variability in the monsoon and other factors means rainfall is much greater in some years than others. In the future, the Marianas region is expected to experience more frequent and intense extreme rainfall events with global warming (IPCC 2013a; Zhang et al. 2016). Increased heavy rainfall events will result in increased runoff and increased potential for flooding and erosion.

Fig.9

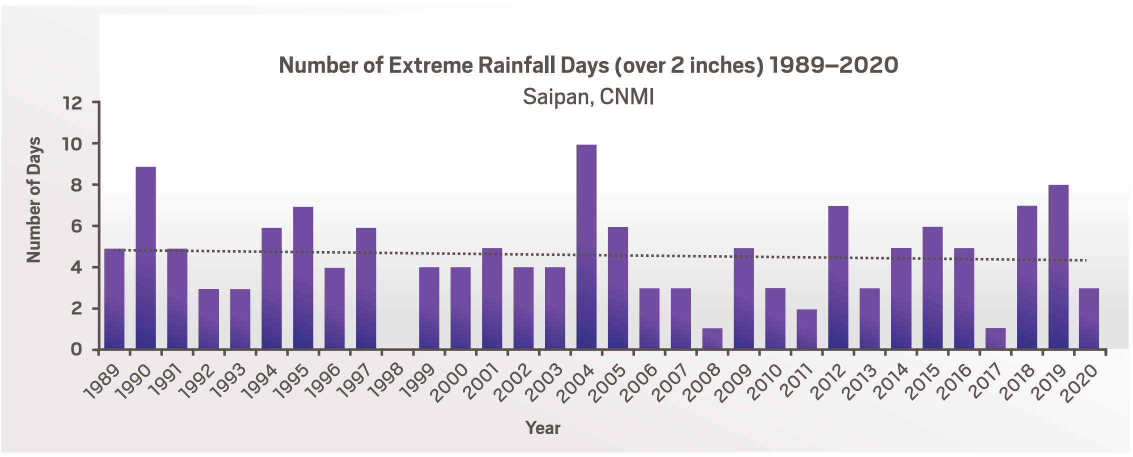



**Figure 9.** Annual number of extreme rainfall days, with daily rainfall totals exceeding the 99th percentile of the distribution (approximately 2 inches, or 51 mm) from 1989 to 2020 at the Francisco C. Ada Saipan International Airport. The linear trend line (black, dotted line) shows no significant change over the record. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

Fig.10

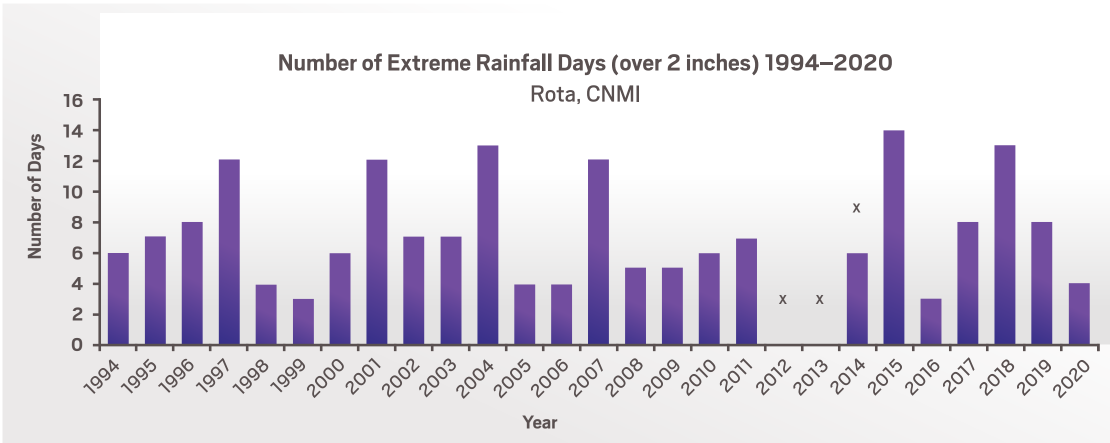



**Figure 10.** Annual number of days with daily rainfall totals exceeding 2 inches (51 mm) from 1994 to 2020 at Rota's international airport. The asterisks (*) represent years in which significant data were missing. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

Currently, future projections for **drought frequency and intensity** are not available for the CNMI. However, it is noteworthy that since 2015 the National Weather Service (NWS) has issued drought information statements for the Marianas for below-normal rainfall in every year except 2018. The frequency of days with no rainfall at Saipan's international airport (Fig. 11) was above average in recent years. In the first half of 2020, the Marianas experienced exceptional drought.

Saipan's international airport had the second driest January–May on record in 2020 (NOAA NCEI 2020a). Downscaled climate projections for nearby Guam indicate drought conditions (defined here as more than 20% below mean annual historic rainfall) are projected to occur in 4 out of 10 years on average in 2080–2099 under the high scenario. This is an increase from the historic rate of 1.6 years out of 10 years on average (Gingerich et al. 2019; Zhang et al. 2016).

Fig.11

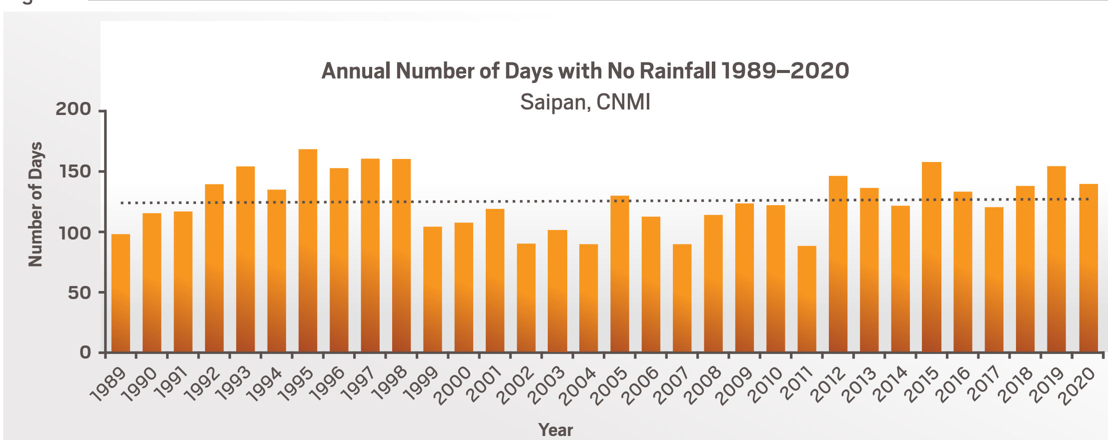



**Figure 11.** Annual number of days with no rainfall from 1989 to 2020 at Saipan's international airport, CNMI. The black, dotted trend line shows no significant linear trend over time. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database (NOAA 2020c; Menne et al. 2012).

## Typhoons and storms

| Indicator | How has it changed? | Projected future change |
|---|---|---|
| Tropical cyclone intensity | No change | ↑ |
| Tropical cyclone frequency | No change | ↓ |

Typhoons, tropical storms, and tropical depressions—referred to collectively as tropical cyclones—can bring intense winds, torrential rain, high waves, and storm surges to islands near their path. The effects of a tropical cyclone strike or near miss can severely impact lives and property. The Northern Mariana Islands lie within one of the most active regions in the world for tropical cyclones. There is an increased risk of typhoons and tropical storms striking in El Niño years (PEAC Center 2015). The CNMI is at a lower risk of experiencing tropical cyclones during La Niña years.

The number of named tropical storms and typhoons affecting the Marianas has remained constant on average over the long-term record (Lander 2004, Marra and Kruk 2017). The CNMI and Guam have historically expected two to eight storms in any given year on average. In the northwestern Pacific basin, including the CNMI, the overall frequency of tropical cyclones decreased 15% from 1980 to 2013 (Lin and Chan 2015) and storm tracks generally shifted northward. As a result, tropical cyclone exposure decreased in the Marianas region during 1992–2013 compared to previous decades (Kossin et al. 2016; Lin and Chan 2015). Wind speeds in the CNMI are mostly low (10–20 kts) except in and near typhoons and storms. Between 2015 and 2019, two Category 5 "super typhoons" (Soudelor and Yutu) and a Category 2 typhoon (Mangkhut) made landfall in the Northern Marianas, resulting in three federally declared disasters.

There is scientific consensus that **tropical cyclone intensity** is likely to increase in a warmer climate for most regions, including around the Marianas (USGCRP 2017; IPCC 2013a; Marra and Kruk 2017; Knutson et al. 2015; Sobel et al. 2016; Zhang et al. 2016; Widlansky et al. 2019; Kossin et al. 2020). The change in tropical cyclone intensity is projected to affect stronger storms the most (resulting in increased maximum intensities), which would amplify the potential for severe damage (Widlansky et al. 2019).

Fewer tropical cyclones are projected to occur by the end of this century, both globally and around the CNMI (Kossin et al. 2016; Zhang et al. 2016; Wang et al. 2016; USGCRP 2017). The overall decrease in **tropical cyclone frequency** (occurrence) is expected because climate models suggest that the atmosphere will become more stable with continued greenhouse warming (USGCRP 2017; Widlansky et al. 2019; Murakami et al. 2020). Compared to the historical two to eight tropical cyclones yearly tracking near Guam and the Northern Mariana Islands, in the future, the occurrence is likely to decrease to one to six storms per year (Widlansky et al. 2019). Thus, the likely overall outlook for the Northern Mariana Islands is for fewer but stronger storms in the future.

## Sea level

| Indicator | How has it changed? | Projected future change |
|---|---|---|
| Sea level | ↑ | ↑ |
| High water frequency | ↑ | ↑ |

Sea level rise poses many challenges to island communities and infrastructure because it brings more frequent and extreme coastal erosion, coastal flooding, and saltwater intrusion into coastal aquifers. The **sea level** around the CNMI is rising. Saipan's tide gauge for measuring long-term sea level trends recorded an average rise of 0.07 inches (1.7 mm) per year since 1978 (NOAA 2020b).

In the CNMI, sea levels fluctuate on timescales from weeks to years to decades. The largest year-to-year variability in sea level is associated with El Niño and La Niña events (lower or higher than average by as much as 1 foot [30 cm], respectively). Low sea level events, as during El Niño, can result in massive coral exposures and die-offs (Raymundo et al. 2017). Furthermore, sea levels vary annually due to the seasonal cycle of ocean temperature and on shorter timespans

Fig.12

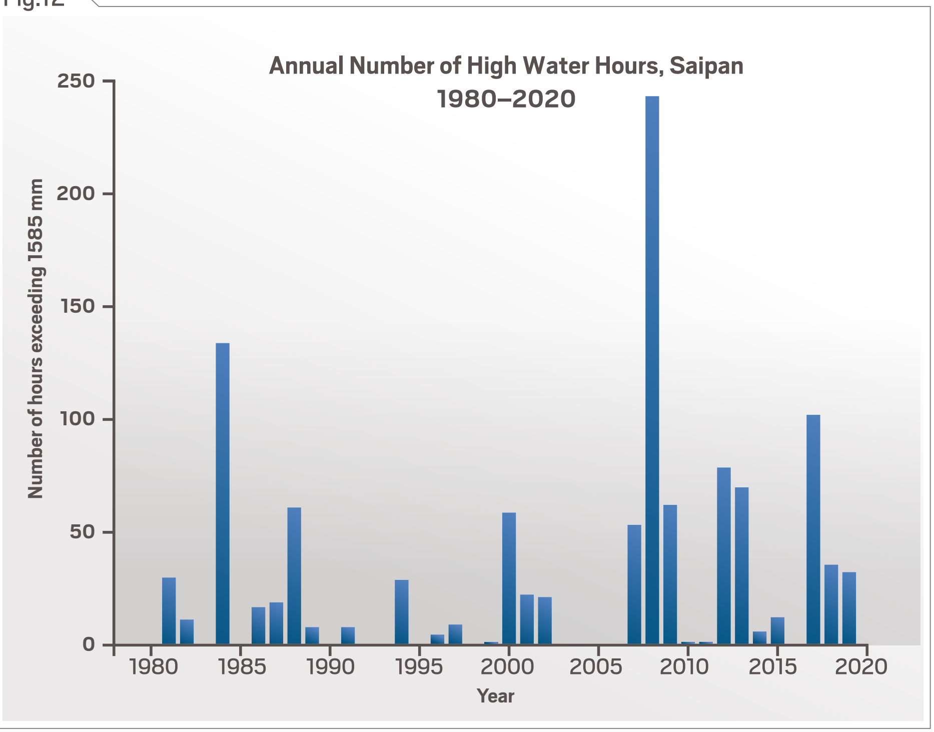



**Figure 12.** The number of high water hours per year at Saipan's coast, 1980 to 2019. The high water threshold (1585 mm, 62 inches) is defined as the Mean Higher High Water level plus 1/3 of the difference between that and the Mean Lower Low Water level at the tide gauge (that is, water levels above the daily average highest tide plus a factor of the typical tidal amplitude). Source: Figure courtesy of Matthew Widlansky, with data from the University of Hawai'i Sea Level Center Station Explorer (https://uhslc.soest.hawaii.edu/stations/?stn=028#datums).

due to abrupt changes in the winds and atmospheric pressure (for example, storm surges).

Relatively small changes in mean sea level can have large effects on **high water frequency** and severity. High water days (also called "tidal flooding") affect coastal areas when exceptionally high tides combine with high wave events. Sea level rise causes high water days to become more common. Although not as damaging as coastal floods during typhoons, the impacts of minor high water can cumulatively cause problems such as increased erosion of buildings, roads, beaches, and vegetation, as well as increased risk of saltwater intrusion into groundwater aquifers.

Sea level rise will almost certainly continue in the Northern Mariana Islands, and the rate of sea level rise is projected to accelerate in the future. Global Mean Sea Level is projected to rise 0.3–0.6 feet (0.1–0.2 m) by 2030. For 2050, the projected range of Global Mean Sea Level rise is 0.5–1.2 feet (0.2–0.4 m), and by 2100 the projected range is 1.0–4.3 feet (0.3–1.3 m) (USGCRP 2017). Emerging climate science suggests that Global Mean Sea Level rise of more than 8 feet (2.4 m) by 2100 is possible, although the probability of this extreme outcome cannot currently be assessed (USGCRP 2017; Sweet et al. 2017). There is *very high confidence* in the lower bounds of these projections, and it is *extremely likely* that global sea levels will continue to rise after 2100 (USGCRP 2017, Ch. 12).

For the Marianas and tropical Pacific Islands, which are far away from the decreasing gravitational attraction of melting land ice, sea level rise is expected to be higher than the global average (USGCRP 2017, 12.5.4; Sweet et al. 2017; Kopp et al. 2014). For example, if Global Mean Sea Level rises 1 foot (or 0.3 m—the low end of the rise likely by 2100), the CNMI is expected to see 1.2 feet (0.36 m) of sea level rise. With 3.3 feet (1.0 m) of Global Mean Sea Level rise by 2100 relative to historical levels (considered likely by 2100 under a high scenario), the CNMI is expected to see 3.8 feet (1.17 m) of rise by 2100. It is possible that sea level rise may even exceed these levels (Sweet et al. 2017). (Sea level rise scenarios can be found at https://geoport.usgs.esipfed.org/terriaslc/ and viewed on NOAA's Sea Level Rise Viewer, https://coast.noaa.gov/digitalcoast/tools/slr.html). Sea level rise will cause coastal flooding to become more frequent and severe, which could be exacerbated by future increasing sea level variability associated with more extreme El Niño and La Niña events (Widlansky et al. 2015).

## Ocean changes

| Indicator | How has it changed? | Projected future change |
|---|---|---|
| Sea surface temperature | ↑ | ↑ |
| Frequency and intensity of heat stress on coral | ↑ | ↑ |
| Ocean acidification | ↑ | ↑ |

Human activities have resulted in changes in the chemical composition, temperature, and circulation of oceans, which have ramifications for marine ecosystems. Changes in **sea surface temperature**—the temperature of water at the ocean's surface—can dramatically alter conditions for marine organisms. Sea surface temperature has increased globally since 1880.

The **frequency of heat stress**, which is responsible for coral reef bleaching, is increasing in the Northern Mariana Islands. The number of days per year that at least some coral reefs were exposed to accumulated heat stress, as categorized by the NOAA Coral Reef Watch, has risen from 12 days per year (in 1982–1991) to 43 days per year (in 2007–2016) on average, a 258% increase (Marra and Kruk 2017). The **intensity of heat stress** has also increased. The Degree Heating Week metric shows how much heat stress has accumulated in an area over the past 12 weeks. In the past decade, the entire region of the Northern Mariana Islands was exposed to Alert Level 1 (Degree Heating Week value ≥4°C-weeks, when ecologically significant bleaching is likely) or higher in 2013, 2014, 2016, and 2017.

High sea surface temperatures produced severe, widespread bleaching of CNMI reefs in 2013, 2014, and 2017, during a global bleaching event. In 2017, the most severe coral bleaching event ever recorded occurred across the region, impacting coral in Saipan down to 20 m in depth (Maynard et al. 2019). Data indicate that 90% of *Acropora* corals and 70% of *Pocillopora* corals died on Saipan's shallow reefs from the 2017 event (CNMI Coral Reef Initiative 2019). Between 2012 and 2018, coral cover declined 67% on average across 35 sites surveyed in Saipan (Fig. 13; Maynard et al. 2019).

Unless coral species adapt to ocean warming, all coral reef areas in the CNMI are projected to begin experiencing annual severe bleaching before 2045, and some areas are expected to experience annual severe bleaching beginning in about 2030 (Fig. 14; van Hooidonk et al. 2016).

As extra carbon dioxide in the atmosphere reacts with sea water, the ocean becomes slightly more acidic. Data collected over 30 years at Station ALOHA north of O'ahu, Hawai'i, are considered the best available documentation of ocean acidity for the western and central Pacific and show that **ocean acidification** has been slowly increasing (roughly by 9%) since records began in 1988 (Marra and Kruk 2017). Ocean chemistry will continue to change, and under a high warming scenario, all coral reefs are projected to exist in acidified conditions that will impede their ability to grow by the end of the century (Australian BOM and CSIRO 2014).

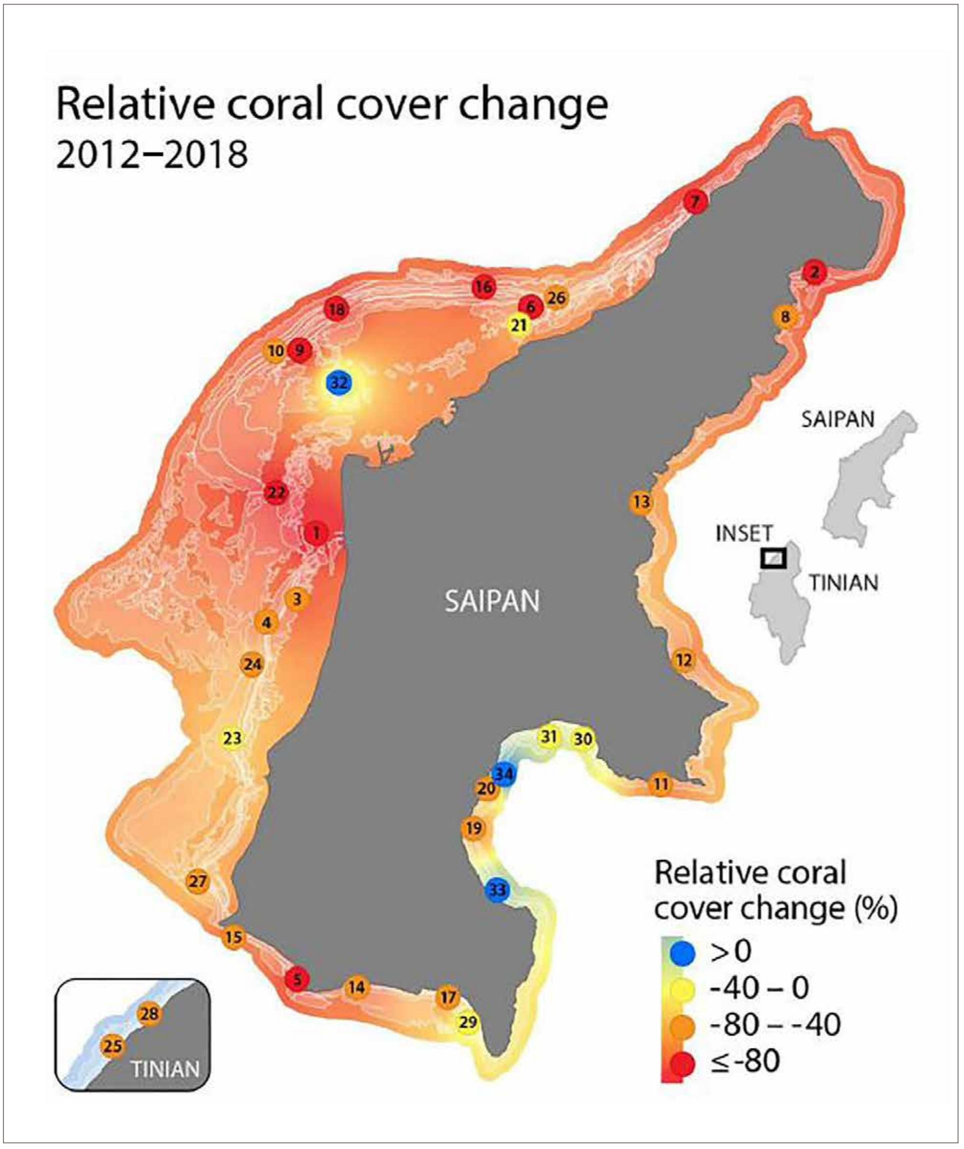



**Figure 13.** Coral cover change around Saipan between 2012 and 2018. The May 2018 surveys and analysis were led by Steven McKagan and Jeff Maynard, and were funded by the NOAA Coral Reef Conservation Program under a domestic grant to the Marine Applied Research Center (www.symbioseas.org). Numbers on the map refer to specific sites. Source: Maynard et al. 2019.

▶ **Indicators of Climate Change** in the Commonwealth of the Northern Mariana Islands

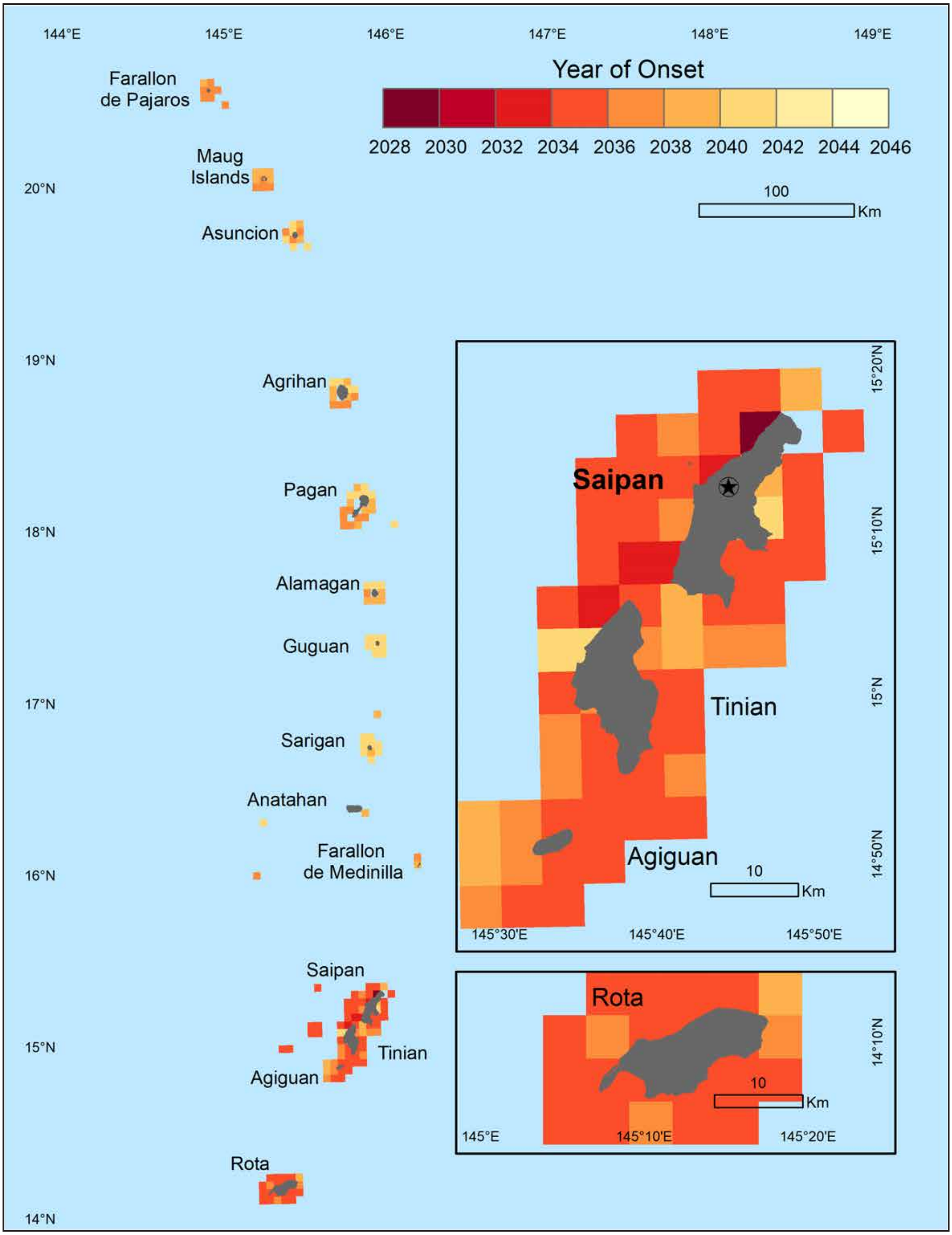



**Figure 14.** Projected year of onset of annual severe bleaching conditions for corals in the waters of the Commonwealth of the Northern Mariana Islands under a high warming scenario (RCP8.5). Source: Figure by Laura Brewington, adapted from USGCRP 2018, using data from van Hooidonk et al. 2016.

# Managing Climate Risks in the Face of Uncertainty

Climate change impacts are often difficult to predict, leading to uncertainties in the timing, magnitude, or type of impacts. Resource managers are responding with various risk management approaches that can be used to plan for uncertainty. Risk management typically involves identifying, evaluating, and prioritizing current and future climate-related risks and vulnerabilities (even those with uncertainties that are difficult to characterize with confidence), and assigning effort and resources toward actions to reduce those risks (USGCRP 2018, Ch. 28, KM 3). Future economic and social conditions are considered alongside climate risks. Often risk management allows for monitoring and adjusting strategies to risks and vulnerabilities as they evolve. Addressing equity, economics, and social well-being are important parts of effective climate risk management efforts (Fatorić and Seekamp 2017).

Two such approaches, that can be used either separately or together, are: (i) **scenario planning**, which involves the creation of several potential scenarios that might develop in the future, based upon a set of variables or projections; and (ii) **adaptive management**, in which resource managers monitor, evaluate, and adapt management practices to changing environmental conditions, such as rising sea levels and temperatures. Scenarios are used to assess risks over a range of plausible futures that include socioeconomic and other trends in addition to climate. Adaptive management approaches can benefit from technical analysis of hazards, as in critical infrastructure vulnerability assessment.

In some cases, comprehensive risk management helps to avoid adaptation actions that address only one climate stressor, such as sea level rise, while ignoring other current or future climate impacts. **Maladaptation** arises when actions intended to address climate risks result in increased vulnerability. For example, if a city builds new infrastructure designed to minimize the impacts from sea level rise, and the sea level rise turns out to be higher than expected, the infrastructure can actually contribute to flooding if stormwater and sewer systems are unable to handle the rising water. To avoid maladaptation, policymakers and managers can consider a range of future scenarios and projected impacts over the lifetime of a project and communicate across sectors when designing solutions.

# What Do Extreme Weather and Climate Change Mean for CNMI Families, Households, and Vulnerable Populations?

Climate change is anticipated to disrupt many aspects of life. More intense extreme weather events, declining water quantity and quality, increased risk of wildfire, poor air quality, and the transmission of disease all threaten the health and well-being of families and communities (USGCRP 2018, Summary of Findings). Additionally, climate-related risks to energy and food production and to the global economy are projected to cause large shifts in prices and availability of goods, potentially leading to price shocks and food insecurity (USGCRP 2018, Ch. 16, KM 1 and 3).

Although climate change is expected to affect all people in the CNMI, some populations are disproportionately vulnerable. Social, economic, and geographic factors shape people's exposure to climate-related impacts and how they are able to respond. A social vulnerability index created for Saipan shows how social and economic factors affect vulnerability at the village level (Fig. 15; Greene and Skeele 2014).

Those who are already vulnerable, including children, older adults, low-income communities, those facing discrimination, and people with disabilities, are at greater risk from extreme weather and climate events, in part because they are often excluded in planning processes (USGCRP 2018, Ch. 14, KM 2, Ch. 15, KM 1–3, and Ch. 28, Introduction). Vulnerable populations will likely be affected in many ways, including:

- Children have a higher rate of heat stroke and heat-related illness than adults and will be increasingly affected as hot days become more frequent (USGCRP 2016; EPA 2016).
- Older adults and persons with disabilities are more vulnerable to extreme events, such as storms, that cause power outages or require evacuation. Emergency response plans specifically accommodating these groups can lessen the risks (USGCRP 2016; EPA 2016).
- Some of the first to be exposed to the effects of heat and extreme weather are people who work outdoors, including tourism and construction workers, fisher people, farmers, and other outdoor laborers (USGCRP 2016; Schulte and Chun 2009).
- People who live in small, isolated communities experience higher risks to health and safety during extreme weather events and the aftermath. Also, people who live, work, go to school, or otherwise spend time in locations with high exposure, such as coastal and other flood-prone areas, are more directly affected by weather extremes (USGCRP 2016).
- In the face of stronger storms, people living in houses constructed of wood, tin, and other non-reinforced materials are more vulnerable than those who live or can shelter in reinforced structures.

Certain populations may also be affected more than others by actions to address the causes and impacts of climate change, if these actions are not implemented in ways that consider existing inequalities (USGCRP 2018, Ch. 11, KM 4, and Ch. 28, KM 4). Management and emergency response plans that include specific accommodations for more vulnerable groups can help to address inequalities and save lives.

Global action to significantly cut greenhouse gas emissions can reduce climate-related risks. For example, the health-related impacts and costs across the United States are projected to be 50% lower under a lower warming scenario (RCP4.5) than a higher warming scenario (RCP8.5) (USGCRP 2018).

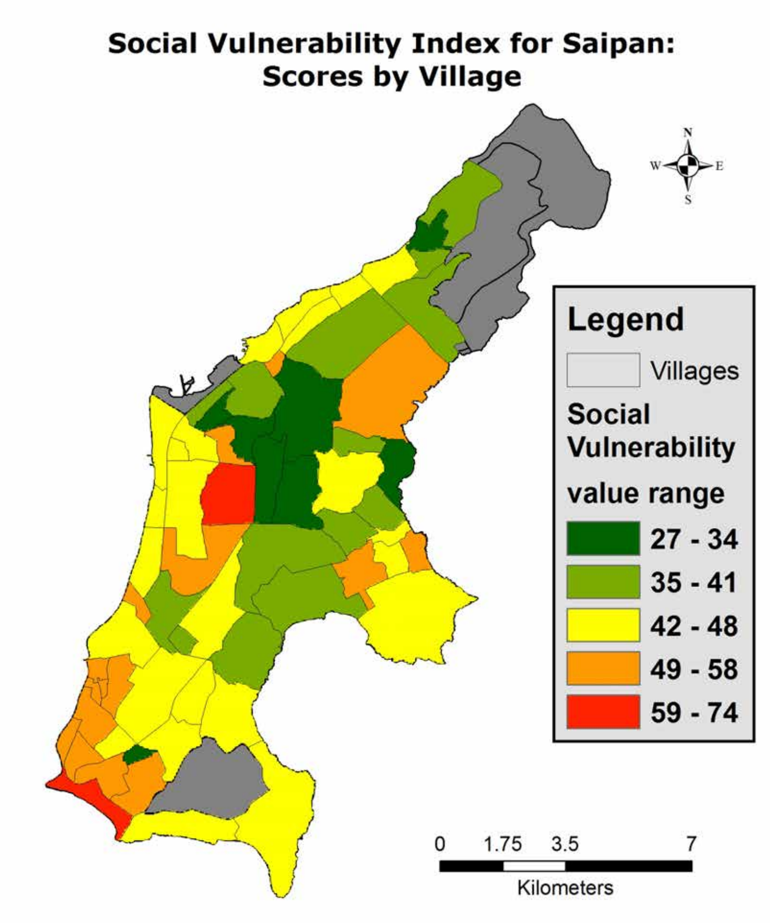



**Figure 15.** Map of social vulnerability score by village. A social vulnerability index was built for the island of Saipan using 22 socioeconomic variables. Economic and educational features contribute to a population's sensitivity to climate-related hazards and the ability to adapt to them. Higher scores indicate greater vulnerability. The socioeconomic variables for the index and map were selected based on the findings of Heinz Center 2000, Heinz Center 2002, and Wongbusarakum and Loper 2011. Source: Figure reproduced from Greene and Skeele 2014.

## What Do Extreme Weather and Climate Change Mean for Key Sectors in the CNMI?

The PIRCA suggests the following considerations for managers working in key sectors based on an up-to-date review of published literature on climate science, climate-related risks in the Pacific Islands, and risk management approaches.

### If you are a water or utilities manager...

- ***Expect hotter conditions to increase water demand and decrease available fresh water.*** The majority of Saipan's public water supply comes from groundwater aquifers and is pumped from shallow wells. The population and agricultural sector on Tinian and Rota rely on particularly vulnerable freshwater sources, with Tinian using shallow wells to draw from the top of a freshwater lens aquifer, and Rota relying entirely on discharge from cave springs perched at a high elevation (Stafford et al. 2002; CNMI OPD 2020). Rising temperatures are expected to increase evapotranspiration, affecting both the amount of fresh water available and the demand for water (Keener et al. 2018; Zhang et al. 2016; Wang et al. 2016). The increased rate of water evaporation from soils, plants, wetlands, lakes, and streams means less water will likely be available to replenish the groundwater aquifers of the Northern Marianas. At the same time, rising temperatures and aging, leaky water infrastructure increase the demand for water. Understanding potential impacts to island-specific water budgets (amount coming in and out of the system) can help water managers plan for sustainability and identify solutions such as increasing conservation measures, as well as storage and recharge mechanisms.

- ***Monitor salinity levels in aquifers, and plan for reduced recharge.*** As on other small oceanic islands, Saipan, Tinian, and Rota have freshwater aquifers (called the freshwater lens) that are underlain by salt water. For Saipan and Tinian those freshwater aquifers are the source for household use and drinking water. The combined effects of increased pumping, more frequent drought, and sea level rise could turn an island's underground water supply salty. If the freshwater lens is not replenished, ocean water can begin to contaminate wells, as it did most wells on Saipan during the 1998 El Nino drought (Carruth 2003). Water conservation, particularly during dry spells, may be necessary more often in the future.

- ***Consider proactive strategies to mitigate the impacts of drought, sea level rise, and stronger typhoons.*** In the water management sector, making changes in pumping depth or withdrawal rates for areas of the aquifer that may experience salinity problems could reduce the vulnerability of water resources. Infrastructure age and disrepair make failure or service interruptions resulting from extreme weather more likely (ASCE 2017). Loss of revenue from leaks, theft, and improper billing directly impacts sector managers' abilities to implement adaptive actions. Updating infrastructure and reducing this loss can help to lessen the need for pumping, increase revenue, and improve adaptive capacity. Additionally, comprehensive plans for public works and utilities can maximize effectiveness by considering and incorporating trends in climate indicators and future projections.

- ***Hardening measures to protect electrical, water, wastewater, and other infrastructure can improve reliability, resilience, and energy and water security.*** Electrical supply outages during major storms with high wind speeds cause cascading impacts on critical sectors. Considering both extreme weather and climate change in the reconstruction of electrical and other infrastructure can help to avoid future costs and limit outages. Possible measures include reinforcing assets that are vulnerable to wind damage, adding redundancies and microgrids capable of isolating for local self-sufficiency during outages, and relocating certain assets (USGCRP 2018, Ch. 14). For example, Saipan's power plant and electrical infrastructure are concentrated in a FEMA flood zone and within the zone exposed under the CNMI Coastal Management Program's sea level rise planning scenario. Resilience could be improved through a combination of measures. Evaluating vulnerabilities, planning for long-term asset management, and outreach and communications to raise public awareness are priorities to support the sustainability of CNMI water systems (CNMI OPD 2020).

- ***Monitor the El Niño–Southern Oscillation (ENSO) and its effects on rainfall.*** Rainfall amounts vary greatly from year to year in the Northern Mariana Islands as a result of ENSO. The climatic response to El Niño produces a period of above normal precipitation, often delivered in extreme precipitation events, followed by a period of drought (Fig. 16). A strong El Niño can cause severe drought. Seasonal forecasts can help water managers to prepare for potential water shortages during drought years and help in planning maintenance and upgrades.

Fig.16

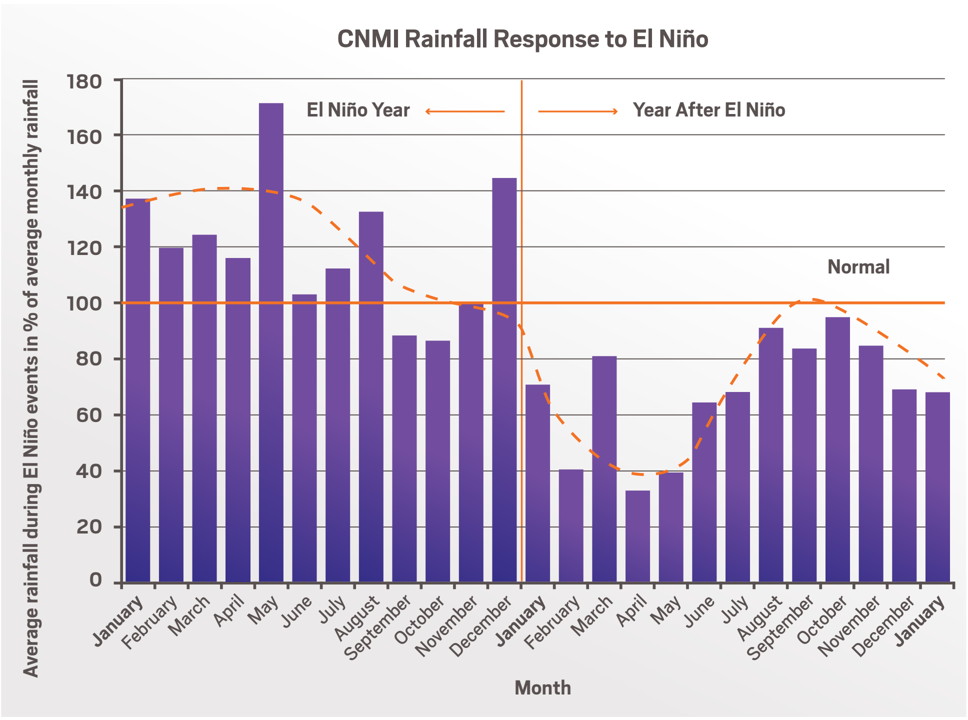



**Figure 16.** Average rainfall in the Commonwealth of the Northern Mariana Islands during El Niño events, shown as the percent of average monthly rainfall. Source: PEAC Center 2015.

## If you work in public health or disaster management...

- ***Account for the consequences of climate change at multiple levels across the health sector.*** Climate change and extreme events are anticipated to affect individuals and communities, and also affect healthcare facilities and public infrastructure. When they overlap with disease outbreaks, weather extremes can disrupt the public health sector's response and negatively impact health outcomes, as during the COVID-19 pandemic (Salas et al. 2020). Adaptation actions at multiple scales are needed to prepare for and manage health risks in a changing climate (USGCRP 2018, Ch. 14, KM3).

- ***Prepare for more frequent extreme heat events that are expected to increase heat-related illness and death.*** Even small increases in average air temperatures can increase extremes and in some places are observed to result in illness and death. Some groups have a higher risk of becoming ill or dying due to extreme heat, including people with chronic illnesses, older adults, and children (Sarofim et al. 2016). Plans to address extreme heat should consider vulnerable populations. To assess the risks of rising air temperatures and other climatic changes on local health, the US Centers for Disease Control and Prevention developed the "Building Resilience Against Climate Effects" (BRACE) framework (CDC 2019), which could be used to inform local climate and health strategies (Marinucci et al. 2014).

- ***Plan for increased wildfires, already frequent and extensive in the CNMI.*** Human activities cause (intentionally and unintentionally) nearly all wildfire ignitions in the CNMI (CNMI OPD 2020). The potential for wildfire greatly increases in hot and dry weather because wildfires ignite more easily and spread faster under those conditions. Drought events can significantly increase the area burned by wildfire, even on very wet islands like Saipan (Trauernicht 2017). In spring 2019, the CNMI experienced a post-El Niño drought and rampant wildfires that threatened homes and caused at least one temporary school closure (Bautista 2019). Similarly, wildfires were witnessed on Tinian and Rota during recent droughts. Wildfire has consequences for health beyond the direct threat to safety around fire. Fine particles produced by fires pollute the air and create a respiratory health hazard (Fann et al. 2016).

- ***Expect water supply impacts and more frequent floods.*** Heavy rains have periodically caused flooding in parts of the CNMI. In August 2018, several heavy downpours caused flash flooding that closed roads, caused silt and mud to erode, and affected residents and tourists who were caught off guard by the sudden flooding, particularly in Garapan (Bautista 2018). Similar floods are expected to become more frequent, and flooding is expected to intensify in a warmer future climate. In addition to direct health risks, heavy rainfall and flooding are linked to increased levels of pathogens in drinking water and can increase waterborne disease, such as diarrheal illness (Bell et al. 2016; Brunkard et al. 2011).

- ***Expect stronger tropical cyclones.*** Although they may occur less frequently in the future, the tropical cyclones that do affect the Mariana Islands are expected to bring stronger winds and greater rainfall amounts. Coral reefs protect the shoreline by weakening wave energy. Projected sea level rise and a decline in coral cover can reduce the protection of the shoreline from waves and storm surge. Injuries, fatalities, and mental health impacts are associated with strong storms. Super Typhoon Yutu in October 2018 was one of the strongest storms in recorded history to strike the Marianas and it destroyed 3,000 houses and caused more than 130 injuries. Health risks increase after a storm when infrastructure and housing are damaged, and electricity, sanitation, safe food and water supplies, communication, and transportation are disrupted.

- ***Prepare for disaster response and recovery from stronger storms.*** Government and non-governmental organizations can increase adaptive capacity, for example by


Electric and communications infrastructure downed and damaged by Typhoon Yutu. Photo by FEMA, 2018, courtesy of CNMI Office of Planning and Development.

providing early warning systems, evacuation assistance, and disaster relief (McIver et al. 2016; Bell et al. 2016). To protect infrastructure, engineers and government policymakers can account for the risk of future changes in extreme weather when planning and designing infrastructure (including buildings, communication and energy systems, transportation, and water and wastewater systems) and when rebuilding after disasters (Olsen 2015). Many local governments and communities exposed to strong storms have developed pre-disaster recovery plans (Schwab 2014; FEMA 2017). Pre-planning for disaster recovery can help communities to seize opportunities and funds to improve resilience to future disasters during the recovery and rebuilding phase (FEMA 2017). Without an organized community planning process ready to implement after a disaster, recovery may occur but is likely to be uneven, slow, and inefficient (FEMA 2017).

- ***Prepare for more food insecurity in CNMI households.*** Disruption of food supply and production systems is a key risk in the health sector. Currently most food consumed in the Northern Mariana Islands is imported and the local commercial agriculture sector is small (USDA 2009). This situation increases local vulnerability to food insecurity because climate change is likely to drive up the prices of imported foods (USGCRP 2018, Ch. 16 and 17).

Dry periods affect existing cattle ranching on Tinian, which suffers declines in drought years (Polhemus 2017). Increasing storm intensities may also threaten food supply by disrupting operations at harbors and ports within the CNMI and other ports internationally. Additionally, more intense tropical cyclones combined with a projected decline in coral reef health threaten local food subsistence and market fisheries. On the other hand, future projections for waves and winds suggest areas along windward coasts may be less hazardous and more accessible for fishing in the future (Storlazzi et al. 2015). Sufficient and nutritious food available to CNMI populations is essential to supporting human health.

- ***Monitor emerging research on the climate's effects on diseases.*** Dengue and other mosquito-borne pathogens have increased as global health threats in recent years (Beard et al. 2016). Globally, future warming and rainfall changes will likely increase the suitable habitat for pathogens and vectors, thereby increasing the risk of outbreaks of dengue fever, malaria, diarrhea, salmonellosis, and other diseases (Mora et al. 2018; Trtanj et al. 2016). Climate-related extreme events, including heatwaves, typhoons, droughts, and wildfires, can also affect the response to disease outbreaks, adding challenges for the public to limit disease spread and for healthcare facilities to provide needed care (Salas et al. 2020). Community-level adaptation measures can limit human vulnerability to disease (Beard et al. 2016; Radke et al. 2012; Reiter et al. 2003). For example, the Commonwealth Healthcare Corporation's efforts to map and track vector-borne disease can increase preparedness and the ability to respond to outbreaks should they occur.

## Visioning Sustainability—Building Back Better, Safer, and Smarter in the CNMI

Experiencing two 100-year super typhoons within a three-year period has prompted dialogues about how to reduce risks to people, the economy, and the environment. Since the landfall of typhoons Soudelor and Yutu, planning partners under the CNMI's Office of the Governor worked to develop the *Guidance Manual for Smart, Safe Growth* with support from the US Federal Emergency Management Agency and US Environmental Protection Agency's Region IX Pacific Islands Office. "Safe, Smart Growth" (SSG) is a set of development strategies that aims to ensure the growth of communities with thriving economies and healthy environments that are resilient to natural disasters. SSG uses a concept of "comprehensive planning" that emerges from the intersection of three key areas of practice—hazard mitigation, climate impact adaptation, and smart growth—each associated with its own policy guidance and best practices. Combining elements of these best practices can help to identify opportunities to successfully implement SSG principles in planning and development. Adopting policies that anticipate plausible scenarios for projected climate change conditions is a primary focus of this effort. By assessing and planning for future risks through incorporation of smart growth, hazard mitigation, and adaptive management principles, the CNMI is working to invest in critical infrastructure and address resource needs to ensure communities can continue to grow while withstanding current and future weather events and natural hazards with minimal physical damage or disruption.

By Erin M. Derrington, Lead Planner, CNMI Office of Planning and Development

## If you are involved in recreation or tourism...

- ***Anticipate that coral reefs and marine ecosystems may support fewer tourism opportunities in the future.*** Visitors and residents of the Northern Mariana Islands enjoy significant economic, cultural, and recreational benefits (particularly snorkeling and fishing) from coral reefs. Coral reefs and marine protected areas play a central role in the tourism industry (van Beukering et al. 2006; Spalding et al. 2017). For instance, Mañagaha Island and the surrounding lagoon attract a significant number of visitors and are managed so as to limit degradation from human use and to preserve fish diversity and coral habitat. The value of coral reefs and interconnected seagrass habitats to the tourism industry was estimated at $73.6 million, or 5.6% of GDP (Eastern Research Group, 2019). In the next few decades, more frequent coral bleaching events and ocean acidification will combine with other stressors to threaten coral reefs. By 2040 or earlier, severe coral bleaching is projected to occur across the CNMI annually, potentially resulting in widespread coral mortality (van Hooidonk et al. 2016). There could be negative impacts on the CNMI's tourism brand as coral reefs decline. Also, significant ecological loss is anticipated, with consequences for recreational and culturally important practices and challenges for the sustainability of certain activities such as seasonal traditional fishing. With the intent to preserve these practices and aid the tourism economy, managers are undertaking coral propagation and restoration on high-value reefs. The first pilot projects for structure-building coral propagation (coral nurseries) are being implemented in the Saipan Lagoon in the vicinity of Mañagaha Island.

Mañagaha Island, a National Historical Site, Marine Conservation Area, and popular tourism site. Photo by Ai Amo, 2009; Attribution 2.0 Generic (CC BY 2.0) license.

- ***Worsening coastal erosion can increase the need for management and conservation measures.*** Beach loss and seasonal sand migrations are already apparent. One area identified as experiencing erosion and vulnerable to sea level rise is Mañagaha Island, a National Historical Site, Marine Conservation Area, and popular tourism site off the west coast of Saipan (Fletcher et al. 2007; Greene and Skeele 2014). Sea level rise will accelerate existing erosion problems on the small island. There are concerns about Mañagaha being entirely eroded as the health of the barrier reef protecting it declines. Other hot spots for recreation (swimming, diving, snorkeling, etc.) on Saipan, such as Micro Beach and the collapsed Sugar Dock, have erosion issues that are costly to manage. Certain erosion-control structures (such as seawalls) installed on chronically eroding beaches typically have the unintended consequence of exacerbating shoreline erosion and beach loss on unprotected neighboring property. The protection or restoration of natural habitats (for example, reefs, beaches, and living shorelines) can mitigate erosion and improve the resilience of coastal communities. Such actions can protect the integrity of natural features that are valued for tourism and recreation (USGCRP 2018, Ch.8).

- ***Water quality at beaches and shoreline areas is expected to decline.*** In addition to beach loss and seasonal sand migrations, bacterial and sediment pollution following heavy rainfall periodically causes visitors and residents to avoid beaches and shores. Poor water quality following extreme precipitation events also compromises traditional shore-based fishing activities, particularly talaya (cast net) methods used to harvest culturally significant species. Water quality is expected to be impaired more severely and frequently in the future as storm drain systems and on-site sewage disposal systems are compromised by intense rainfall and sea level rise.

- ***Cleanup and recovery after storms is costly for tourism and temporarily occupies the workforce for coastal management and tourism sectors.*** Tourism is vital to the CNMI economy. Incomes sharply decline from events that disrupt tourism, as during the COVID-19 pandemic. Following major typhoons and storms, the tourism sector must spend resources and time on recovery. Visitors are deterred and arrivals decrease significantly, leading to lost revenues. Debris and pollution necessitate area closures after a strong storm. Members of the coastal and ecosystem management workforce, on which tourism relies, are involved in recovery and rebuilding efforts. Coastal managers and tourism professionals can work with local government and communities to develop pre-disaster recovery plans (Schwab 2014; FEMA 2017). Such plans can ensure the affected community is prepared to undertake recovery and rebuilding that is more resilient to disasters (including typhoons) and climate change (for example, see: *Guidance Manual for Smart, Safe Growth*, CNMI 2018).


Destruction inside the Francisco C. Ada Saipan International Airport after Typhoon Yutu passed over the island. Photo by FEMA, 2018, courtesy of CNMI Office of Planning and Development.

## If you manage ecosystems and biodiversity…

- ***Monitor and prepare for changes in temperature, rainfall, and storminess that promote the spread of invasive species and reduce the ability of habitats to support protected species.*** The waters of the Northern Mariana Islands contain some of the most pristine marine ecosystems in the United States (Paulay 2003). Unprecedented changes in air temperatures, along with intensifying rainfall and erosion, bring new threats to the fringing reefs, seagrass beds, estuaries, and open ocean ecosystems and the species they support. On land, deforestation and invasive plants and animals threaten what little remains of native limestone forest ecosystems (now mainly located on highland conservation lands and on steep slopes at lower elevations). Wetlands and forests are known for high plant and animal species diversity, and the CNMI is home to about 20 unique bird species, two bat species, and several threatened reptile species found nowhere in the world outside of the Marianas (Liske-Clark 2015). New and potentially invasive species are arriving more frequently than in the past. Unprecedented changes in air temperatures, along with intensifying drought, rainfall, and erosion, bring additional challenges for native species conservation (Keener et al. 2018; Goulding et al. 2016). Temperature rise, for example, can constrict island species' ranges or result in complete habitat loss for rare species with limited geographic distributions and small population sizes (Raxworthy et al. 2008).

- ***Prepare for elevated wildfire risk and soil loss, which threaten CNMI forests and coral reefs.*** Following a wildfire, burned areas are prone to the spread and establishment of invasive grasses (Minton 2006). Grasslands readily replace forests that are affected by wildfires. Grasslands burn easily, so this replacement of vegetation type heightens the fire risk. Forests protect soil from erosion, while grasslands are not as effective at preventing soil loss. Sediment runoff from burned lands and grasslands contaminates nearshore ocean waters, with the potential to impact reefs. As dry periods increase, fire risk rises, so these stresses on CNMI terrestrial and marine ecosystems are expected to increase in the future.

- ***Promote measures that protect and enhance biodiversity and ecosystem services as a critical way to support communities in adapting to climate change.*** Natural resources underpin the sustenance and resiliency of Pacific Island communities (Barnett and Campbell 2010). For example, mangrove forests provide storm protection and building materials, and are productive estuaries relied on for food (Victor et al. 2004). Historically threatened by clearing and cutting, mangroves are now stressed due to sea level rise (Gilman et al. 2008; Gilman et al. 2006). The remaining mangroves in the CNMI, limited to a few small patches along the Saipan Lagoon, are particularly vulnerable to sea level rise, and are adjacent to critical juvenile fish habitat, including a puppery for the endangered scalloped hammerhead shark. Restoring mangrove forests and preserving nearby spaces to accommodate estuarine wetland migration can help to protect communities against storm surge and coastal inundation, enabling them to adapt, while also providing secondary benefits such as maintenance of fisheries (Hills et al. 2013).

Saipan's Achugao Watershed in April 2019, days after a large wildfire tore through the area. Photo by Robbie Greene, 2019.

## If you are involved in fisheries or managing ocean resources...

- ***Expect declining coral reef health. Watershed conservation measures can protect refugia for coral populations.*** Ocean warming and acidification will likely combine with other stressors, such as fluctuating sea levels, fishing pressure, and pollution, to threaten nearshore and open-ocean ecosystems and the livelihoods they support. The total economic value of coral reefs and seagrass in the CNMI (including all goods and services that reefs provide, the value to tourism, and the cultural and social value) is estimated at $114.8 million per year (in 2018 USD), or 8.6% of GDP (Eastern Research Group 2019). Across the Central and Western Pacific, widespread severe coral bleaching is projected to occur annually before 2050 (van Hooidonk et al. 2016). In some locations in the CNMI, annual severe bleaching is projected to begin before 2035. Near-annual bleaching events from 2013 through 2017 resulted in mass mortality of branching corals around the Saipan Lagoon, and significant loss of coral cover throughout the southern archipelago (Maynard et al. 2019).

- ***Expect reduced available catch for subsistence and commercial fishing.*** Climate change and ocean acidification are expected to produce declines in coral reef fish of 20% by 2050 in tropical Pacific Island countries and territories (Bell et al. 2013). Rapidly changing conditions also affect open ocean fisheries, and declines in maximum potential catch of more than 50% are projected under a business-as-usual scenario by 2100 for most of the islands in the Central and Western Pacific including the CNMI (Asch et al. 2018; Bell et al. 2013).

## If you are a coastal resources manager…

- ***Prepare for more frequent coastal flooding and increased erosion to affect coastal properties and infrastructure.*** Both sea level rise and more frequent and intense heavy rainfall events are likely to produce flooding in coastal and urban areas. (See Fig. 17 for the possible extent of flooding in southern Garapan.) The majority of the CNMI population and infrastructure is located in Saipan's low-lying western coastal plain, including the seaport, the hub of Garapan, and coastal villages (Greene and Skeele 2014). Because several main roads throughout the CNMI already experience inland flooding and erosion, sea level rise threatens to cut off access to critical services. Sea level rise will increase tidal (full moon) flooding that can affect homes, businesses, and infrastructure. When strong winds from the west or typhoons produce wave energy that hits Saipan's west coast and sandy beaches, the result can be damaging erosion (loss of land due to waves, currents, tides, and wind-driven water) in areas such as American Memorial Park, Micro Beach, Mañagaha Island, and Kilili Beach Park (Greene and Skeele 2014). On Rota, the village of Songsong and the roadway between the village, the airport, and Rota Resort experience coastal erosion (BECQ DCRM 2015). Seawalls and other structures intended to reduce erosion have often caused beach loss and worsened erosion on unprotected neighboring property. Restoring natural shorelines and ecosystems provides alternatives to hard structure approaches and can improve the resilience of coastal communities. This approach combined with built features can provide cost savings from avoided flood damages (Arkema et al. 2013; Spalding et al. 2014).

- ***Expect stronger typhoons and storm surges.*** Combined with continued accelerations in sea level rise, storm surge associated with tropical cyclones has the potential to destroy built and natural infrastructure at the coast and severely disrupt communities. Maintaining and restoring the health of the coral reefs has the potential to greatly reduce coastal damage due to storm events. Additionally, critical infrastructure such as roads, utilities, airports, and hospitals can be relocated or "climate-proofed" (see Needs for Research and Information section, p. 45; Olsen 2015).

- ***Monitor new scientific understanding of the timing and magnitude of future global sea level rise as it continues to improve.*** Regular updates of management plans and engineering codes may be increasingly important as new information about sea level rise and shorter-term climate variability becomes available. Understanding the effects of ENSO on regional water levels and weather can enable appropriate adaptation actions (Fig. 16). Planning that considers a combination of seasonal extremes, storm surge, and long-term sea level rise (Fig. 18) can assist the development of more adaptive regulations (for example, shoreline setbacks) (USACE 2014).

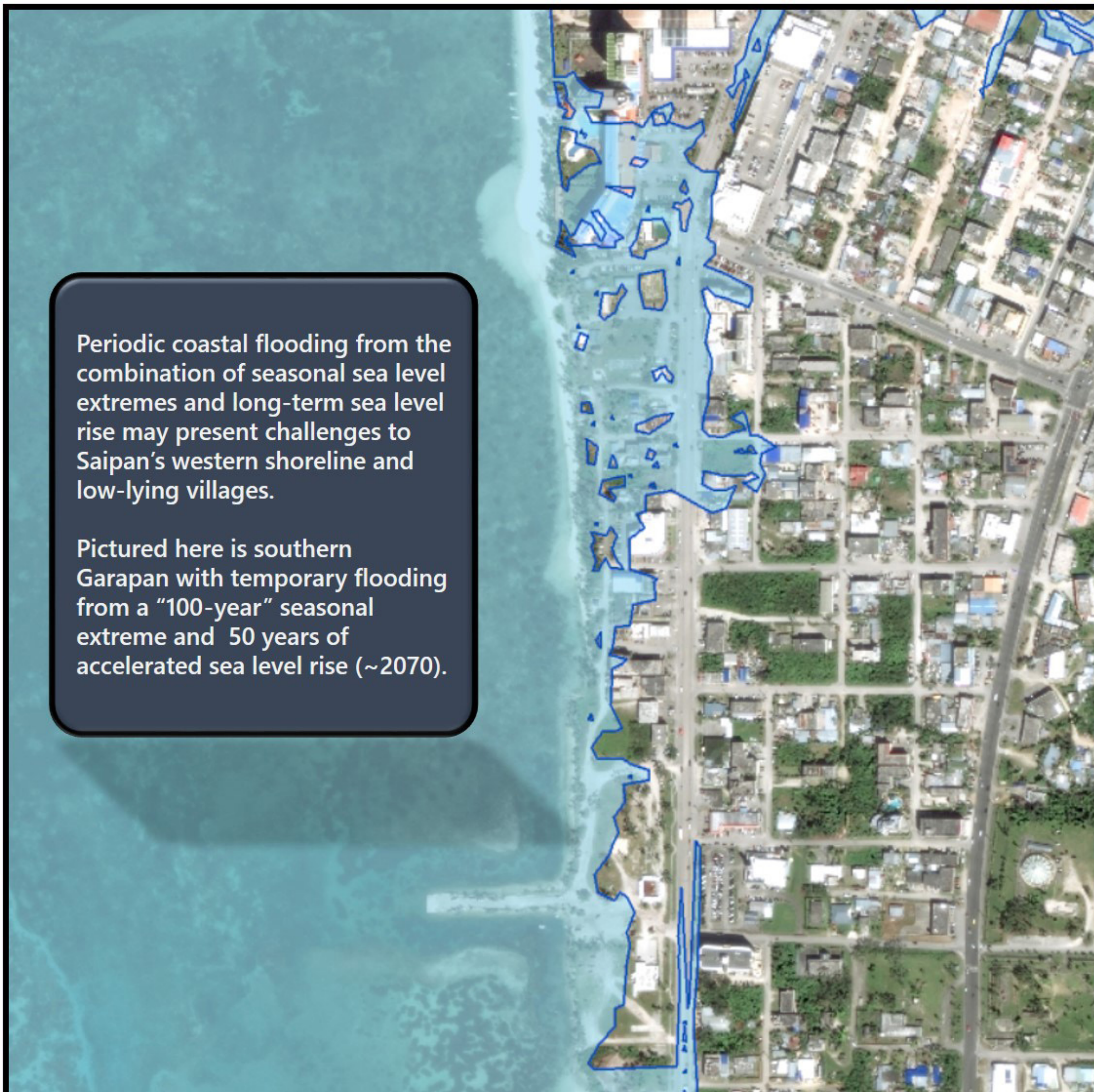



**Fig. 17.** Satellite image of southern Garapan with an overlay showing the extent of possible future coastal flooding from a combination of an extreme sea level event and long-term sea level rise. The map illustrates the scale of potential flooding, not the exact location, and does not account for erosion, subsidence, or future construction. Water levels are shown as they would appear in 2070 with sea level rise under a high warming ("business-as-usual") scenario and with a "100-year" high seasonal sea level event. Planning for structures with an expected 50-year or greater lifespan might consider such a scenario. Source: Figure courtesy of Robbie Greene and CNMI BECQ.

## If you are a cultural resources steward...

- ***Coastal historical and cultural sites will likely be affected by erosion, storm surge, and coastal inundation from sea level rise.*** Although it is not known how climate change will specifically affect individual archeological and cultural sites in the Northern Mariana Islands, coastal areas are likely to be affected by erosion, storm surge, and coastal inundation from sea level rise. For example, American Memorial Park is situated on a low-lying sandy area, which already experiences coastal erosion and shifting position of the shoreline (Greene and Skeele 2014). Figure 18 makes visible the potential scale of flooding in American Memorial Park from sea level rise of 4 feet. Numerous pre-contact cultural sites are situated along shoreline areas and as sea levels rise these sites may become increasingly hard to study, access, or maintain. Many jurisdictions are already discussing what management actions can meet community goals for resource stewardship given challenging future conditions (*pers. commun.*, Erin Derrington, 2019). The CNMI Historic Preservation Office is supporting such efforts through planning updates and sharing of "potential sensitivity" maps to enable early issue identification in project scoping.

- ***Climate change exacerbates challenges to the continued availability of cultural foods and culturally significant plants and animals.*** Changes in environmental conditions, such as warming oceans, reduced streamflow, saltwater intrusion, and long periods of drought, threaten the ongoing cultivation and availability of traditional foods such as fish and other seafood, edible seaweed, and coconut (Keener et al. 2018). Certain medicinal plants may also be threatened if outcompeted by invasive vegetation.

## If you are involved in agroforestry and farming...

- ***Expect climate change to worsen impacts on agriculture and agroforest production.*** CNMI commercial cattle ranches and farms producing coconuts, breadfruit, tomatoes, and other local produce account for approximately $1.6 million annually, or just 0.1% of GDP (USDA 2020). Subsistence food production is the predominant agricultural activity. Farms and agroforests are already exposed to impacts from flooding, drought, high winds and storms, diseases and pests, soil erosion, and clearing for development. Major typhoons damage or destroy tree crops, delay fruiting and flowering, and affect pollinator species. In southern Saipan, trees such as mangoes did not produce fruit during the normal fruiting season in the year after Typhoon Yutu struck. Climate change will likely exacerbate these impacts for some crops and locations. Changing rainfall and higher temperatures, for example, are expected to increase pest and disease problems in staple crops such as bananas and taro (Taylor et al. 2016). Resilience to climate change is expected to require changes in farming methods and cultivars (Bell and Taylor 2015).

- ***Plan for warmer weather and shifting rainfall patterns.*** Rising temperatures will increase evapotranspiration, affecting the

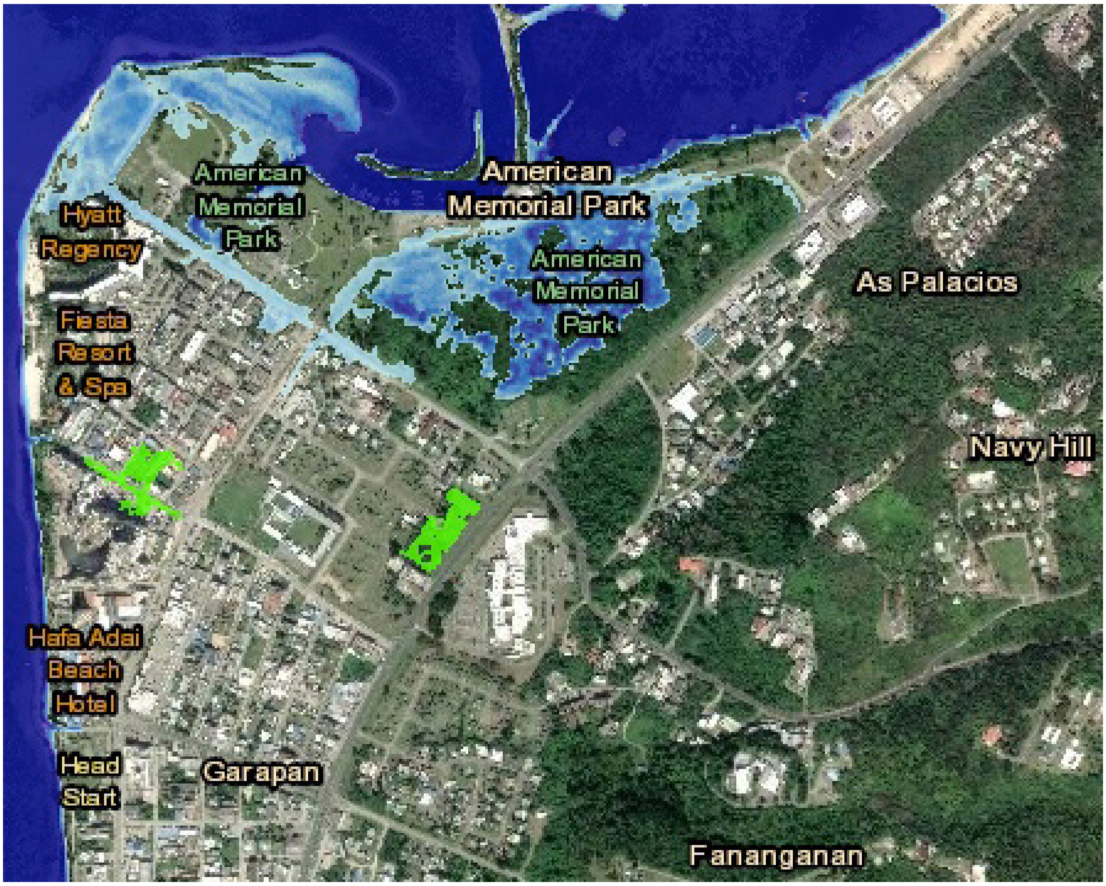



**Fig. 18.** American Memorial Park and Garapan with 4 feet of sea level rise. Areas that are hydrologically connected to the ocean (according to the digital elevation model used) are shown in shades of blue. Low-lying areas on land that are not directly linked to the ocean are shown in green. The map illustrates the scale of potential flooding, not the exact location, and does not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excludes wind-driven tides). Source: NOAA Sea Level Rise Viewer v3.0.0, https://coast.noaa.gov/digitalcoast/tools/slr.html.

amount of water crops require. Therefore, hotter weather could increase drought stress on farming and ranching regardless of any future changes in rainfall in the dry season. Severe drought following strong El Niño events will present challenges for livestock, as both food and water supply may become periodically scarce. The 1998 drought that brought widespread hardship and mortality to Tinian's cattle highlighted the need to plan for additional capture and storage of rainfall prior to dry seasons (BECQ DCRM 2015).

- ***Monitor research and development of farming methods that improve food security and ecosystem resilience.*** With a gradual shift away from agroforestry, the food production systems in the Pacific Islands have become more vulnerable (Taylor et al. 2016). Traditional farming systems have demonstrated the ability to enhance resilience to external shocks and help to bolster food security (McGregor et al. 2009).

## If you are involved in finance or economic development...

- ***Expect economic disruptions and increased costs from necessary disaster prevention, cleanup, recovery, and operation of essential services during disasters.*** Climate changes—both gradual and abrupt—disrupt the flow of goods and services that form the backbone of economies (Houser et al. 2015). They also stress or damage natural ecosystems, such as coral reefs, that supply goods and services. The revenue lost during extreme events can extend recovery time. An increased frequency of "shocks" (in the form of extreme events) means that the time it takes for essential services that underpin the economy to recover may exceed the time between events. A series of shocks creates compounding impacts and prolonged recovery times (Keener et al. 2018). This was experienced with Typhoon Yutu striking just three years after Typhoon Soudelor when recovery from the first storm was still underway.

- ***Plan for rising import prices and challenges for local businesses.*** Climate change is expected to increasingly affect trade and economies internationally beyond the CNMI and the United States. Import and export price fluctuations and unanticipated second- or third-order consequences (on supply chains and customers) can disrupt local businesses (Smith et al. 2018; Goldstein et al. 2019). To reduce risk, businesses can proactively research and prepare for the impacts of climate change on their customers, employees, communities, supply chain, and business model (Goldstein et al. 2019).

- ***Monitor and research innovative insurance mechanisms.*** The risks posed by climate change are often too great for companies, individuals, and local governments to cover on their own. Countries with greater insurance coverage across sectors are found to experience better GDP growth after weather-related catastrophes (Melecky and Raddatz 2011). There are an array of options to manage climate-related risks, such as weather-indexed insurance products and risk transfer-for-adaptation programs. Some cities and states have bought catastrophe bonds or parametric insurance policies. For example, the government of Quintana Roo, Mexico, purchased a parametric policy that would provide up to $3.8 million to repair hurricane damage to their coral reef (Gonzalez 2019). This kind of policy provides a fast payout to quickly address impacts from a triggering event. The government could consider similar mechanisms for protecting the CNMI's significant ecological resources.

## If you are an educator or education decision–maker…

- ***Expect greater public health threats to students.*** Children are especially vulnerable to heat-related illness, including dehydration, heat stress, fever, and exacerbated respiratory problems. The increasing frequency and intensity of hot days, as well as stronger storms, could result in health impacts for students (Sarofim et al. 2016). The experience of destructive typhoons and other extreme events affect children's mental health acutely. Providing mental health services and on-site health professionals at schools can help students to understand and cope with trauma and loss.

- ***Prepare for stronger typhoons and storm surges, and consider options for schools and educational facilities at the coastline.*** Schools in the path of major storms and in low-lying coastal areas are exposed to high winds, erosion, flooding, or a combination of these, causing temporary school closures and the need for repairs or rebuilding. Locating and designing buildings to accommodate high winds, storm surge, and sea level rise can avoid costs and protect students.

- ***Anticipate compound risks from climate-related events and other crises.*** As the COVID-19 pandemic has demonstrated, the multiple challenges faced by the education system can exacerbate one another and lengthen recovery time. The structural destruction to schools from typhoons in recent years, temporary shuttering of schools during the pandemic, and impacts of the economic crisis have lasting consequences for students, their families, and educators. Coordination and cooperation across sectors of government can help prevent potential conflicts in emergency response, take advantage of co-benefits, and help to ensure continuity of basic services, including education (Phillips et al. 2020).

Due to extensive storm damage from Typhoon Yutu, Hopwood Middle School moved to temporary canvas tent classrooms set up on the campus of Koblerville Elementary School on Saipan. Power outages following the relocation made it difficult for students to work in extreme heat in the tent classrooms (Bautista 2019). Photo by Zena Grecni, 2019.

# Needs for Research and Information

This assessment identified the following research and information needs, which if met could enhance and support responses to extreme weather and climate change:

- ***Assessments of community vulnerability*** – Risks posed by extreme weather and climate change vary by the vulnerability of the people experiencing impacts. Particularly needed are assessments of risks from weather extremes and climatic changes that account for the social, economic, and locational factors that drive the vulnerability of people in the CNMI (Spooner et al. 2017). Such studies can improve understanding of who is at greatest risk. Because low-income households and communities face barriers when preparing for and recovering from climate-related threats, research into the ability of poverty-reduction actions to protect communities may be useful to decision-makers.

- ***Research on "climate proofing" critical infrastructure*** – Governments and resource managers commonly use various forms of vulnerability assessment as a foundational tool to tailor solutions and policies to address the specific ways critical infrastructure is threatened. Existing vulnerability assessments for Saipan (Greene and Skeele 2014) and Rota and Tinian (BECQ DCRM 2015) evaluated exposure, sensitivity, and adaptive capacity, and ranked the seriousness of various climate risks. Technical analysis is needed to evaluate changing hazards for highly vulnerable infrastructure and areas of concern previously identified. Decision-makers can utilize the existing vulnerability assessments to explore climate proofing and relocation options. Climate resilience infrastructure projects could be piloted on a small/individual scale to demonstrate and support problem-solving. Methods and guidance are available (see for example: Canadian Engineering Qualifications Board 2014; Olsen 2015; USGCRP 2018, Ch. 28) and are being incorporated into ongoing updates of the *Guidance Manual for Smart, Safe Growth* (CNMI 2018), as well as the CNMI Draft Comprehensive Sustainable Development Plan (in development) and the Community Development Block Grant Disaster Recovery Action Plan (CNMI NMHC 2020).

- ***Quality controls and expanded coverage in climate data*** – Stations collecting climate data (air temperature, rainfall, wind speeds, etc.) have changed location and station records are not continuous. Consistent data records of 30 years at the same location are needed for tracking climate trends and changes, and to improve and validate future projections. An assessment of the quality of the data at each station, especially temperature and rainfall data, would provide a foundation for planning a comprehensive data collection and management program. Developing localized predictive modeling and other applications would require more data collection stations. To reduce uncertainty in future rainfall projections, it is crucial to maintain and expand observed measurement networks and models. Likewise, expanding the limited network of ocean data sensors, and building new capacity into long-term reef monitoring methods (for example, ocean acidity and calcification rates) will allow for more localized assessments of reef resiliency and prioritization of marine ecosystem restoration.

- ***Renewable energy potential analysis*** – The Commonwealth is interested in developing solar and other renewable energy sources as a way to increase resilience in the energy and water sectors and reduce greenhouse gas emissions. An understanding of climate projections that would impact the amount and duration of solar exposure, or wind speed and direction, can assist managers to plan and site renewable energy projects.

- ***Modeling potential impacts of climate change to island-specific water budgets*** – Insight into surface water and groundwater systems can help water managers enhance water sustainability and identify solutions, such as conservation measures or storage and recharge mechanisms. Understanding spatial variation in well fields, pumping activities, and salinity levels can help in adapting water infrastructure to sea level rise.

- ***Access to safe drinking water in the context of climate change*** – The CNMI has a history of management challenges regarding disposal of military, industrial, and municipal solid waste, which in some cases has resulted in freshwater and marine contamination (Denton et al. 2009; Denton et al. 2014). The Commonwealth Utilities Corporation issues periodic warnings of drinking water contamination when it is unsafe for communities to drink, cook, or make ice for consumption with tap water (for example, Perez 2020, *Saipan Tribune* 2019). Converting sea water to drinking water ensured residents had access to uncontaminated potable water following Super Typhoon Yutu (Gilbert 2018). Policy-relevant research that supports the provision of safe drinking water to all CNMI communities is needed. Examples of such research include vulnerability assessments of CNMI drinking water supply to both climate and non-climate threats.

- ***Research on future drought and extreme precipitation*** – Impacts to the utilities and coastal infrastructure sectors are greater when storms and heavy precipitation follow an extended dry period. Understanding the likelihood and nature of future changes in the frequency of wet and dry days and potential impacts to surface and groundwater is critical to supporting planning and adaptation. Modeling and studies that reduce uncertainties concerning how El Niño and La Niña may change in the future will be important to projecting future drought and extreme precipitation in the Marianas region.

- ***Valuation of coral reefs that includes coastal protection services*** – There is a need to evaluate the protective capacity of reefs around Saipan, Tinian, and Rota at a higher resolution and informed by modeling of future reef erosion or accretion. Previous research has attempted to quantify the value of CNMI coral reefs, yet additional research could better capture the nuances in the data and account for the full range of benefits that reefs provide, including estimates of the economic benefit from coastal protection (Storlazzi et al. 2019).

- ***Research at the nexus of behavioral health, wellness, and environmental change*** – Both acute weather events and long-lasting climate-related changes impact mental health (Palinkas and Wong 2020). Extreme climate-related events—such as the super typhoons that have hit the CNMI—are known to cause post-traumatic stress disorder, anxiety, and depression (Dodgen et al. 2016). The threat of long-lasting climate change can cause psychological distress, including feelings of anxiety, fear, anger, despair, and depression (Dodgen et al. 2016; Palinkas and Wong 2020). The US Global Change Research Program warns, "communities that rely on the natural environment for sustenance and livelihood, as well as populations living in areas most susceptible to specific climate change events, are at increased risk for adverse mental health outcomes" (Dodgen et al. 2016). While climate change may not be a primary risk factor for behavioral health and well-being in the CNMI, it may exacerbate existing stressors on the health system and individuals. New research is emerging on how to build personal resilience to climate change among frontline workers and climate adaptation practitioners (Moser et al. 2019). This report's contributors recommend an assessment of the stressors of environmental change that affect behavioral health and ways to support the resilience of CNMI individuals and families to climate change.

- ***Community-based research on local climate change readiness*** – PIRCA technical contributors recommend taking a community-based research approach to assess "community readiness" to climate change. This could include an assessment of community strengths and actions people can take. Community-based research approaches can help to integrate local knowledge and community priorities into climate resilience planning. Also, community-led climate resilience pilot initiatives can foster social innovation and share lessons learned.

- ***Research on wildfire in the CNMI and associated public health risks and impacts*** – Research utilizing existing data collected on wildfire and public health would allow plans to account for wildfire and its impacts. Analyses of post-fire vegetation recovery and succession are needed to allow resource managers to restore impacted areas with native vegetation and prevent the spread of invasive species.

- ***Assessment of vulnerability of cultural and historical sites*** – Technical assessments of the vulnerability of cultural sites and maps that highlight vulnerable locations (while not identifying the exact location of sites to protect the resources from degradation) are useful in prioritizing preservation activities. Various agencies have this data; it would need to be compiled.

- ***Incorporation of climate projections and Smart, Safe Growth into large development planning*** – There is a need for researching options to incorporate climate change projections into planning and prioritization for large development projects and military expansion in the CNMI. For example, Environmental Impact Assessments and Environmental Impact Statements completed for larger-scale projects could integrate CNMI Smart, Safe Growth criteria, adopted 50-year sea level rise scenarios, and mid- or end-of-century climate projections (CNMI ODP 2020). A related informational need identified is clear and concise communications between the US Department of Defense, government agencies, and the public, with mechanisms for the public to provide meaningful feedback to inform the design of projects. Integrating climate scenarios into project proposal and development dialogues would mainstream climate considerations across management areas and safeguard resources that will be increasingly threatened by climate change.

▶ **Needs for Research and Information**

- ***Development of adaptive tourism plans*** – A comprehensive study of CNMI tourism infrastructure, activities, and their vulnerability to climate change and extremes could foster a more resilient economy. Sea level rise, erosion, and coastal flood planning for hotels will be essential, while marine sports operators will need to adopt new storm safety protocols in the face of intensifying tropical cyclones.

- ***Exchange of adaptation experiences with other Pacific Islands*** – Exchange of experiences and lessons learned from targeted efforts to address climate-related vulnerabilities can assist decision-makers in understanding the benefits and risks of such measures. For example, there is interest in understanding how other jurisdictions are handling sensitive issues relating to culturally significant resources and species that are threatened.

# CNMI Sources of Climate Data and Projections

**BECQ Public Permitting App (with Adopted Flood Scenario):** https://dcrm.maps.arcgis.com/apps/webappviewer/index.html?id=8981814f5914421380b9158427853b44

**NOAA Coral Reef Watch:** https://coralreefwatch.noaa.gov/satellite/index.php

**NOAA Digital Coast Sea Level Change Curve Calculator:** https://coast.noaa.gov/digitalcoast/tools/curve.html

**NOAA Quarterly Climate Impacts and Outlook for Hawai'i and US-Affiliated Pacific Islands:** https://www.drought.gov/drought/climate-outlook/Pacific%20Region

**NOAA Sea Level Rise Viewer:** https://coast.noaa.gov/digitalcoast/tools/slr.html

**PacIOOS (Pacific Islands Ocean Observing System):** http://www.pacioos.hawaii.edu/

**Relative Sea Level Trend at Saipan, CNMI (NOAA):** https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=700-011

**University of Hawai'i Sea Level Center's Sea Level Forecasts:** https://uhslc.soest.hawaii.edu/sea-level-forecasts/

**USGS, USGCRP, NOAA, and Terria Sea Level Change Map:** https://geoport.usgs.esipfed.org/terriaslc/

# Traceable Accounts

The findings in this report are based on an assessment of the peer-reviewed scientific literature, complemented by other sources (such as gray literature) where appropriate. These Traceable Accounts document the supporting evidence and sources of uncertainty, and draw on guidance by the IPCC and USGCRP (2018), to evaluate the conclusions reported in the "Indicators of Climate Change in the Commonwealth of the Northern Mariana Islands" section in terms of:

- **Confidence** in the validity of a finding based on the type, quantity, quality, and consistency of evidence; the skill, range, and consistency of model projections; and the degree of agreement in literature.
- **Likelihood**, based on statistical measures of uncertainty or on expert judgment as reported in literature.

▸ **Traceable Accounts**

| Indicator | How has it changed? | Source | Data Range | Projected future change | Source |
|---|---|---|---|---|---|
| Hot days | ↑ | Global Historical Climatology Network—Daily (GHCN-Daily), Andersen Air Force Base (GQC00914025) and Saipan international airport (CQC00914855) | 1953–2002 (AAFB); 2006-2020 (Saipan) | ↑ | Zhang et al. 2016 (CMIP5); IPCC 2013a |
| Cool nights | ↓ | GHCN-Daily, Andersen Air Force Base and Saipan international airport | 1953–2002 (AAFB); 2006-2020 (Saipan) | ↓ | Zhang et al. 2016 (CMIP5); IPCC 2013a |
| Average air temperature | ↑ | GHCN-Daily, Andersen Air Force Base and Saipan international airport | 1953–2002 (AAFB); 2006-2020 (Saipan) | ↑ | Zhang et al. 2016 (CMIP5); IPCC 2013a; IPCC 2013b |
| Average rainfall | No change | GHCN-Daily, Saipan international airport and Andersen Air Force Base | 1989–2020 (Saipan); 1953–2002 (AAFB) | ? | Zhang et al. 2016 (CMIP5); IPCC 2013a; IPCC 2013b |
| Extreme rainfall days | No change | GHCN-Daily, Saipan international airport, and Rota airport (CQC00914801) | 1989–2020 (Saipan); 1994-2020 (Rota) | ↑ | Zhang et al. 2016 (CMIP5); IPCC 2013a |
| Frequency of drought | ? | No analysis available; GHCN-Daily, Saipan international airport (annual number of days without rainfall shows no change 1989–2020) | 1989–2020 | ? | No projection available |
| Duration of drought | ? | No analysis available | | ? | No projection available |
| Tropical cyclone intensity | No change | Marra and Kruk 2017; Kruk et al. 2015 (using GHCN-Daily)—analysis of annual 1-day extreme rainfall amounts showed a near-zero trend for Guam | | ↑ | USGCRP 2017; Marra and Kruk 2017; Knutson et al. 2015; Sobel et al. 2016; Zhang et al. 2016; Widlansky et al. 2019 |

| Indicator | How has it changed? | Source | Data Range | Projected future change | Source |
|---|---|---|---|---|---|
| Tropical cyclone frequency | No change | Marra and Kruk 2017; Knapp et al. 2010 | 1980–2013 | ↓ | Kossin et al. 2016; Zhang et al. 2016; Wang et al. 2016; US-GCRP 2017; Widlansky et al. 2019 |
| Sea level | ↑ | NOAA 2020b | 1993–2020 | ↑ | Sweet et al. 2017; US-GCRP 2017 |
| High water frequency | ↑ | NOAA 2020b; UH Sea Level Center | 1993–2020 | ↑ | Marra et al. 2015 |
| Sea surface temperature | ↑ | NOAA NCEI ERSSTv5—Huang et al. 2017 | 1854–2020 | ↑ | Bopp et al. 2013; US-GCRP 2017 |
| Frequency and intensity of heat stress on coral | ↑ | NOAA Coral Reef Watch 2018 (Liu et al. 2014)—Daily Global 5km Satellite Coral Bleaching Heat Stress Monitoring | 1985–2020 | ↑ | van Hooidonk et al. 2016 |
| Ocean acidification | ↑ | Marra and Kruk 2017, Data collected at Station ALOHA | 1988–2020 | ↑ | USGCRP 2017; Australian CSIRO and BOM 2014 |

***Temperature*** – Daily air temperature at Andersen Air Force Base has been measured since 1953. While other records—from Saipan's, Tinian's, and Rota's international airports, the Weather Forecast Office (WFO) in Guam, and the NOAA Weather Service Meteorological Observatory (WSMO), for example—do exist, Andersen Air Force Base has the longest continuous record, which yields the best available data.

Annual mean temperatures show a warming trend during the period of record. Hot days are days that maximum temperature exceeds the 95th percentile of the distribution—88°F (31.1°C) at Andersen Air Force Base and 90°F (32°C) at Saipan's international airport. Cool nights are days for which minimum temperatures were colder than the 10th percentile of the distribution—roughly 74°F (23.3°C)—at both Andersen Air Force Base and Saipan's international airport.

Further temperature increases in the US-Affiliated Pacific Islands region are considered *extremely likely*. In 2016, researchers at the University of Hawaiʻi used general circulation model (GCM) simulations taken from the international Coupled Model Intercomparison Project Phase 5 (CMIP5) to project fine-resolution future climate changes over Guam and American Sāmoa by the late 21st century (2080–2099) with both a high emissions scenario (RCP8.5) and a low emissions scenario (RCP4.5). While the geographic area of the projections for Guam did not encompass the CNMI, the islands share main climate features, and so the projections for Guam are considered applicable in the CNMI context, with differences mainly arising from the variations in topography. For example, current rainfall distribution varies greatly across Saipan, differing as much as 15 inches (20%) from location to location (Lander 2004).

***Rainfall*** – There are very few locations in the CNMI where rainfall has been measured consistently for over a decade, and only one of the records—at Saipan's airport—approaches the length of time (minimum of 30 years) considered sufficient for computing monthly and annual averages and making accurate estimations of recurrence intervals of extreme rainfall events. Therefore, this assessment reports long-term trends from the Saipan airport and Andersen Air Force Base in Guam, a nearby station with sufficient, consistent data, and thus considered the best available record relevant to the CNMI. Records show a strong coherence of monthly rainfall patterns between Saipan and Guam, which is attributed to both locations reacting similarly to the El Niño–Southern Oscillation (ENSO) (Lander 2004). Thus, Guam's long-term rainfall record can be used to make inferences about the character of Saipan's and CNMI rainfall. Daily rainfall records in Rota are available from 1994 to 2020, with a few years of incomplete data. Years with fewer than 300 days of observations are marked with an asterisk in Fig. 10.

There is *high confidence* that the frequency and intensity of extreme rainfall events will increase because: (a) a warmer atmosphere can hold more moisture, so there is greater potential for extreme rainfall (IPCC 2012); and (b) increases in extreme rainfall in the Pacific are projected in all available climate models (IPCC 2013; Zhang et al. 2016). However, there is *low confidence* in the magnitude of these changes.

***Drought*** – Drought (defined here as more than 20% below mean annual historic rainfall) was projected to occur more frequently in Guam under the high scenario (RCP8.5). The Guam projection is given here as the closest available peer-reviewed downscaling study. This projection comes from a University of Hawaiʻi run of GCM simulations taken from the CMIP5 to project fine-resolution future climate changes over Guam and American Sāmoa by the late 21st century (2080–2099), as compared to historical conditions (1990–2009) (Zhang et al. 2016). In the GCM simulations the future projected duration of mild, moderate, severe, and extreme drought events was not assessed. ENSO will continue to play a large role in future droughts, but there is no consensus on how ENSO may change in the future. Recent research shows climate change has caused more frequent extreme El Niño events since the 1970s (Wang et al. 2019). Climate model results suggest an increase in frequency of both extreme El Niño and extreme La Niña events in the 21st century as compared to the 20th century under scenarios with more warming, including the higher scenario (RCP8.5) (Cai et al. 2014; Cai et al. 2015; Widlansky et al. 2015).

***Typhoons and storms*** – The future is less certain for tropical cyclone frequency than other elements. The environmental conditions to produce a cyclone are at timescales much shorter than GCM simulations, for example, the state of ENSO and the intensity and phase of the Madden-Julian Oscillation (Diamond and Renwick 2015). There is *medium confidence* that globally tropical cyclone frequency will decrease (USGCRP 2017). A likely overall decrease this century in the number of tropical storms and typhoons affecting the western North Pacific and CNMI is projected (Widlansky et al. 2019; Murakami et al. 2020). For western North Pacific typhoons, increases are projected in tropical cyclone precipitation rates (*high confidence*) and intensity (*medium confidence*) (Knutson et al. 2015; USGCRP 2017). The frequency of the most intense of these storms is projected to increase in the western North Pacific (*low confidence*) (USGCRP 2017). Recent studies (Kossin et al. 2020) detect increasing trends in tropical cyclone intensity in observations from 1979 to 2016 and raise confidence in projections of increased tropical cyclone intensity with continued warming. Because tropical cyclone damage potential increases exponentially with tropical cyclone intensity, the increasing intensity of strong storms is expected to cause more damage overall, even if the total number of tropical cyclones declines (Guard and Lander 1999; Nordhaus 2006).

***Sea level rise*** – Global sea level has risen by 7–8 inches (16–21 cm) since 1900, with 3 of those inches occurring since 1993 (*very high confidence*; USGCRP 2017, Ch. 12). The rate of sea level rise since 1993 has been about 0.12 inches (3 mm) per year on average, but the rate is not uniform around the globe. In Saipan, the average rate of sea level rise has been positive since 1978. However, the long-term trend is uncertain owing to the short length of the record and high inter-annual and multidecadal variability in measured sea level. The relative sea level trend at Saipan is 0.07 inches (1.7 mm) per year with a 95% confidence interval +/- 0.08 inches (2.0 mm) per year based on monthly mean sea level data from 1978 to 2016. This is equivalent to a change of 0.6 feet in 100 years (NOAA 2020b). ENSO-driven variation in sea level is on the order of 12 inches (300 mm) in the CNMI (Becker et al. 2012). These patterns of variability make it difficult to discern a reliable long-term trend in local sea level in records of less than 50 years. Tide gauge records have been recently cross-validated with satellite altimetry, showing that tide gauges and satellite data correlate well.

Fig.13

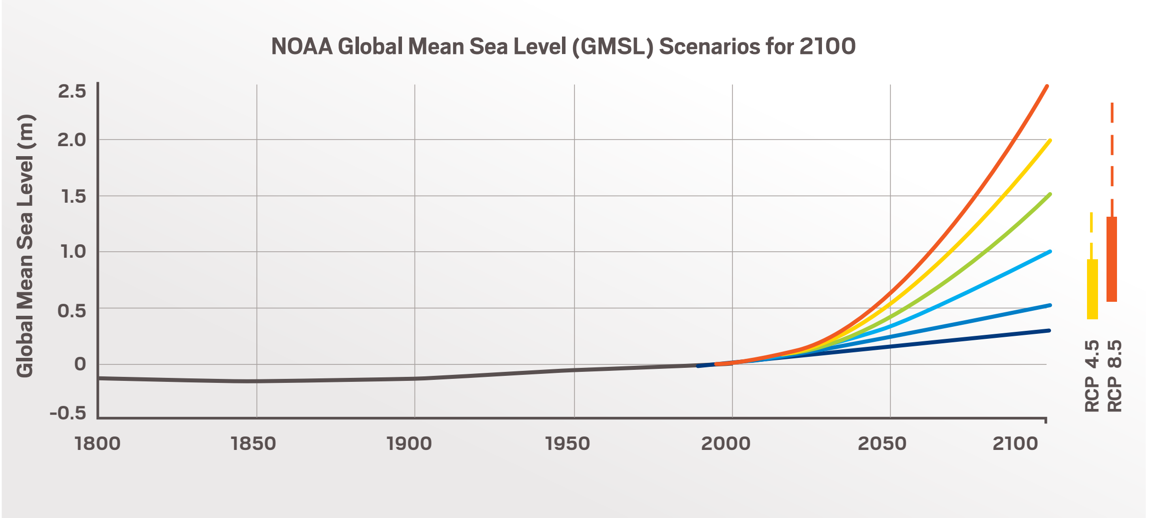



**Figure 19.** Six representative Global Mean Sea Level (GMSL) rise scenarios for 2100 (6 colored lines) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800 to 2015. The colored boxes show central 90% conditional probability ranges of RCP-based GMSL projections from recent studies. Dashed lines extending from the boxes show the median contribution from Antarctic melt from recent studies. Source: Sweet et al. 2017.

▶ **Traceable Accounts**

| GMSL Rise Scenario | RCP4.5 | RCP8.5 |
|---|---|---|
| Low (0.3 m) | 98% | 100% |
| Intermediate-Low (0.5 m) | 73% | 96% |
| Intermediate (1.0 m) | 3% | 17% |
| Intermediate-High (1.5 m) | 0.50% | 1.30% |
| High (2.0 m) | 0.10% | 0.30% |
| Extreme (2.5 m) | 0.05% | 0.10% |

**Table 1.** Probability of exceeding Global Mean Sea Level scenarios in 2100. Source: Adapted from Sweet et al. 2017, based on Kopp et al. 2014.

Scientific understanding of the timing and magnitude of future global sea level rise continues to evolve and improve. The *Fourth National Climate Assessment, Vol. 1: Climate Science Special Report* (USGCRP 2017), "Chapter 12: Sea Level Rise," KM 2, states:

"Relative to the year 2000, Global Mean Sea Level (GMSL) is *very likely* to rise by 0.3–0.6 feet (9–18 cm) by 2030, 0.5–1.2 feet (15–38 cm) by 2050, and 1.0–4.3 feet (30–130 cm) by 2100 (*very high confidence in lower bounds; medium confidence in upper bounds for 2030 and 2050; low confidence in upper bounds for 2100*). Future pathways have little effect on projected GMSL rise in the first half of the century, but significantly affect projections for the second half of the century (*high confidence*). Emerging science regarding Antarctic ice sheet stability suggests that, for high emissions scenarios, a GMSL rise exceeding 8 feet (2.4 m) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed. Regardless of pathway, it is *extremely likely* that GMSL rise will continue beyond 2100 (*high confidence*)."

Table 1 shows the probability of exceeding each of six scenarios for global mean sea level in 2100 (Fig. 19) under RCP4.5 and RCP8.5. However, new evidence regarding the Antarctic Ice Sheet would support much higher probabilities of exceeding the Intermediate-High, High, and Extreme sea level rise scenarios in 2100 (Sweet et al. 2017).

Because the CNMI and other islands in the tropical Western Pacific are far from all sources of melting land ice, sea level rise is projected to be greater than GMSL due to static-equilibrium effects (Sweet et al. 2017; USGCRP 2017, Ch. 12). The closest NOAA-maintained tide gauge with USACE-calculated sea level change scenarios is at Apra Harbor, Guam. At this tide gauge, GMSL rise of 1.6 feet (0.5 m) in 2100 translates into approximately 1.7 feet of local sea level rise. A GMSL rise of 6.6 feet (2.0 m) in 2100 would mean a local sea level rise of about 8.6 feet in Guam (NOAA et al. 2017). For local relative sea level change scenarios, see the NOAA Digital Coast Sea Level Change Curve Calculator (https://coast.noaa.gov/digitalcoast/tools/curve.html) and the Terria Sea Level Change Map from USGS, USGCRP, and NOAA (https://geoport.usgs.esipfed.org/terriaslc/).

A range of factors, including vertical land motion, tides, waves, and storms, also affect the sea level experienced in a place and at various times. Table 2 gives scenarios developed for the CNMI that combine future sea level rise scenarios and other sources of sea level variability (for example, typhoons, high tides, and waves).

| Scenario | Data Code | Seasonal Extreme (meters) | Seasonal Extreme Description* | Sea Level Rise (m.) | Sea Level Rise Description | Cumulative Sea Level Change (m.) |
|---|---|---|---|---|---|---|
| OND Seasonal Extreme (Typhoon Year) | OND_TY | 1.85 | Historically derived (1978–2003) maximum sea level for 100-year recurrence at Saipan Harbor, during the months of Oct.–Dec. including data from years with typhoon passage. | 0 | Climate change-related sea level rise not factored into this scenario. | 1.85 |
| 50 years SLR | SLR50 | 0 | No seasonal extreme estimates factored into this scenario. | 1.31 | Sea level projection for 2067 based on NOAA 2017 "High" curve and US Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement) | 1.31 |
| 30 years SLR + OND Seasonal Extreme | SLR30_ OND | 0.63 | Historically derived (1978–2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.–Dec., with typhoon-affected data removed. | 0.74 | Sea level rise projection for 2047 based on NOAA 2017 "High" curve and US Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement) | 1.37 |
| 50 years SLR + OND Seasonal Extreme | SLR50_ OND | 0.63 | Historically derived (1978–2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.–Dec., with typhoon-affected data removed. | 1.31 | Sea level rise projection for 2067 based on NOAA 2017 "High" curve and US Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement) | 1.94 |
| 75 years SLR + OND Seasonal Extreme | SLR75_ OND | 0.63 | Historically derived (1978–2003) maximum sea level estimate for 100-year recurrence at Saipan Harbor for months Oct.–Dec., with typhoon-affected data removed. | 2.14 | Sea level rise projection for 2093 based on NOAA 2017 "High" curve and US Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement) | 2.77 |
| 50 years SLR + OND Seasonal Typhoon Year | SLR50_ ONDTY | 1.85 | Historically derived (1978–2003) maximum sea level for 100-year recurrence interval at Saipan Harbor, during the months of Oct.–Dec., including data from years with typhoon passage. | 1.31 | Sea level rise projection for 2067 based on NOAA 2017 "High" curve and US Army Corps sea level curve calculator for Apra Harbor tide gauge (local vertical land movement) | 3.16 |

**Table 2.** Sea Level Rise Scenarios for the Commonwealth of the Northern Mariana Islands. Source: Robbie Greene, NOAA Office for Coastal Management, 2017.

***Ocean changes*** – The third global bleaching event caused more reefs in the Pacific to be exposed to heat stress than any time before. In the CNMI, bleaching began in June 2014 with Alert Level 1, bleached again in 2016 during an El Niño event, and again in 2017. There is *very high confidence* in the increased risk of coral bleaching as the ocean warms but only *medium confidence* in the rate of sea surface temperature change for the western North Pacific (Australian BOM and CSIRO 2014). Internal tides could delay the onset of bleaching fewer than 10 years at certain locations, depending on future warming scenarios (Storlazzi et al. 2020). NOAA's Pacific Reef Assessment and Monitoring Program studied coral heat stress at 17 sites in the Northern Mariana Islands and Guam and found coral bleaching heat stress at all depths from the surface down to 38 meters; thus, there is no meaningful refuge from heat stress for corals at depths (Venegas et al. 2019).

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The **latte** is a stone pillar with a cup-shaped capstone, made and used as a house support by the ancient people of the Marianas. In modern times the latte stone has become a symbol of Chamorro cultural identity and appears on the CNMI flag and seal.

EastWestCenter.org
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For information,
please contact:

East–West Center
1601 East–West Road
Honolulu, Hawai‘i 96848–1601

Ph (808) 944–7111

info@PacificRISA.org

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