Climate Change in American Sāmoa

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 American Sāmoa: 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 2020–2021 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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Corals in Ofu's shallow lagoons can survive in very warm waters.
Photo: Valentine Vaeoso

Key Issues for Managers and Policymakers

Increasing air temperatures — Hot days have increased, while the frequency of cool nights has decreased in American Sāmoa. Air temperatures will continue to rise under all future warming scenarios.

More extreme rainfall and flooding — Extreme rainfall events are projected to become more frequent and intense for American Sāmoa, increasing runoff and the risk of flooding.

Uncertain rainfall amounts — There is uncertainty in how total rainfall will change this century in American Sāmoa. The majority of climate models project only small changes in future rainfall amounts, although some project changes of up to 20% in either direction. A wetter, drier, or unchanged future climate is possible.

Coral reef bleaching and loss — Oceans are warming, causing coral reef bleaching to become more frequent and severe in the Territory. Coral reefs and ocean ecosystems contribute millions of dollars annually to American Sāmoa's economy and provide natural protection from floods and storms.

Sea level rise — Global and local sea level rise has accelerated. Land subsidence (the sinking of Earth's surface) from a major earthquake in 2009 compounds the effects of sea level rise and associated coastal erosion. Sea level rise is also affecting the groundwater table in coastal plains, already infiltrating drinking water supplies. Currently, sea level rise inhibits crops, such as the Aunu'u taufusi (wet-cropped taro), in some low-lying areas.

Equity considerations — Climate change is expected to disrupt many aspects of life in American Sāmoa, and some groups will likely be affected disproportionately. Those who are already vulnerable, such as children, elderly people, people with pre-existing medical conditions, and low-income communities, as well as those living in villages located in low-lying coastal or rural areas, are at greater risk from extreme weather and climate events. Traditional systems of land and marine tenure complicate relocation out of ancestral areas, and communities do not want to be separated from their lands and waters.

Threats to community health — Changes in rainfall and drying patterns are likely to lead to increased mosquito populations, which can increase communities' exposure to mosquito-borne illnesses such as dengue, Zika, chikungunya, and lymphatic filariasis. These diseases disproportionately affect people living without screens on their windows, or without the means to seal their houses, and near objects that collect rainwater.

Risks to fresh water — Hotter temperatures increase the demand for water and decrease the fresh water available. Additionally, sea level rise threatens many groundwater systems in low-elevation areas. Increasing knowledge and awareness among community members about how water systems may be impacted, and communication among agencies and sectors that manage water, have the potential to boost resilience to climate change and other shocks and stressors.

Threats to ecosystems and biodiversity — Changes in temperature, rainfall, and storminess promote the spread of invasive species and reduce the ability of marine and terrestrial habitats to support rare and protected species. Measures that enhance biodiversity and improve ecosystem resilience can help communities to adapt.

Threats to infrastructure — More frequent and severe coastal flooding and increased coastal erosion are affecting coastal properties and infrastructure. These issues will be amplified in the coming decades as sea level rise continues to accelerate.

Suiga o le Tau i Amerika Sāmoa: Faailo & Mau Iloiloina e Vaega Autu

Ripoti mo le Iloiloga o le Tau i le Itulagi o Motu o le Pasefika (PIRCA) 2021

Manatu Autu mo Taitai ma ē Faia Aiaiga

Siisii le vevela o le ea — Ua faaopoopo aso vevela, a'o faaitiiti ifo po malulu i Amerika Sāmoa. E faaauau pea le siisii o le mafanafana i si'omaga uma i le lumana'i.

E faaopoopo lologa i timuga — Ua vaaia o le a tupu soo pea timuga mamafa ma le matuiā i Amerika Samoa i le lumana'i, ma e faaopoopo atili ai tafega ma le lamatia i lologa.

Lē mautinoa le fua o timuga — E le mautinoa se suiga o le fua o timuga i lenei senituri atoa i Amerika Sāmoa. O le tele o vaaiga mamao i le tau o loo folasia mai, e faapea, na'o nai suiga laiti i le fua o timuga to'ulu i le lumana'i e oo i le 20% le alu ifo poo le alu i luga. E ono susū tele, mago tele, poo le leai se suiga o le tau i le lumana'i.

Velasia ma Faaleagaina 'amu — O loo siisii le mafanafana o ogasami, ua mafua ai ona velasia soo le 'amu ma ua ogaoga tele i le Teritori. E faitau i miliona tala i le tausaga e maua i 'amu ma figota o le sami e faaopoopo i tamaoaiga o Amerika Sāmoa ma maua ai le puipuiga faanatura mai lolo ma afā.

Siisii le maualuga o le suāsami — Ua saosaoa le siisii o le suāsami i le kelope atoa ma le gataifale. Ua tuufaatasi le goto ifo o le eleele i le lalolagi ona o mafui'e tetele o le 2009, ma le siisii o le aafia o le suasami ma le 'āia o eleele o matafaga. Ua aafia foi le suavai i le eleele i laufanua mafola e lata i le talafatai ona o le siisii o le suasami, ua lofia ai le suavai taumafa. I le taimi nei, ua oo i laau toto le lofia i le siisii o le suasami, e pei o taufusi i Aunu'u (e maua ai talo i le pala), i nisi o eleele maulalo.

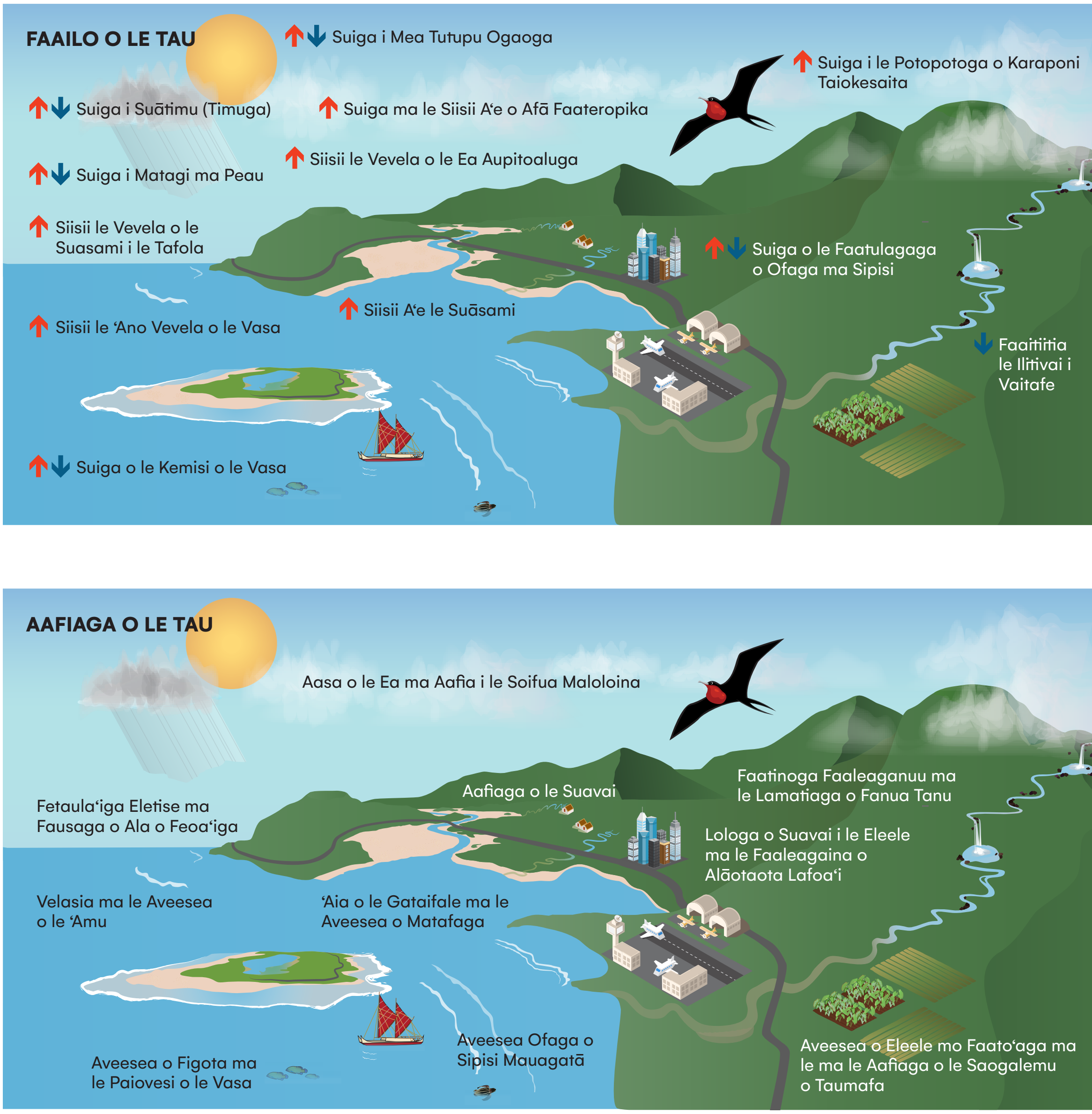
Manatu e Fai Tutusa — Ua faatalitalia le luluina o vaega e tele o le soifuaga i Amerika Sāmoa ona o le suiga o le tau, ma o le a aafia tele nisi vaega. O i latou e ma'ale'ale e pei o tamaiti, tagata matutua, i latou e iai gasegase tumau, ma komiuniti e maulalo le tupemaua, atoa ma i latou o loo nonofo i nuu e maulalo eleele tu lata i le talafatai ma nuu i tua, e sili ona lamatia i mea e tutupu i le tau. E lavelave le mataupu e uiga i le se'e ese o tagata mai nofoaga o tua'a ona o aganuu i fanua ma faasinomaga tau gataifale, ma e le fia o ese komiuniti mai o latou laueleele, vai, ma le sami.

Lamatiaga o le soifua maloloina o le komiuniti — O suiga i timuga ma gasologa o le mago e ono faatetele ai le namu, e ono fatetele ai le fetaia'i o tagata ma faama'i fe'avea'i e namu e pei o le dengue, Zika, chikungunya, ma le mumū tutupa. O nei faama'i e tele ina aafia ai tagata e leai ni uaea valavala i faamalama, poo nisi puipuiga i o latou fale, ma latalata i mea e to'a ai le vaitimu. E atili aafiaga i faama'i pepesi faamatagi malosi i le utiuti o punaoa o le soifua maloloina i le Teritori.

Lamatiaga o le vaiauli fou — E faatetele le moomia o le vai i le vevela o le 'ea, ae faaitiitia ai le suavai. I le ma lea, o le siisii o le suasami e lamatia ai le vai i gasologa o le eleele i itulagi e maulalo le eleele. E iai le aogā o le faaopoopo o le iloa ma le nofo uta i tagata o le komiuniti e uiga i le aafia o gasologa o le suavai, ma fesoota'iga manino i le va o lālā ma vaega e pulea le suavai, e faaoso ai le malosi e tali ai suiga i le tau ma isi tulaga tugā e faate'ia ai.

Lamatiaga o le fetaula'iga ola faanatura – ekosisitema, ma le lasilasi o meaola – paiotaivesi — O suiga i le vevela o le 'ea, timuga, ma afā ua atili salalau ai manu ninii faalafuā ma faaitiitia ai le malosi o meaola i le vai, sami ma le eleele e tausi ai ma puipui meaola mauagatā. E mafai ona fesoasoani ni taumafaiga e una'i le paiotaivesi ma faalelei le talitali atu a le ekosisitema ina ia mafai e komiuniti ni fetuuna'iga e tali ai.

Lamatiaga i le tino o le si'omaga — O le tupu soo ma le malolosi o lologa i talafatai ma le 'āia o matāfaga ua aafia ai meatotino ma eleele o le si'omaga. O le a faateteleina nei tulaga i le faitau ta'isefulu o tausaga o loo lumana'i nei a'o saosaoa atili le siisii o le suasami.



Ata 1. Suiga ua vaaia i faailo autu o le tau i Motu o le Pasefika (pito i luga)—nofoaga e mamafa le kasa karaponi okesaita, fua o le 'ea i le tai tafola, ma nofoaga o sipisi eseese—e mafua ai le (pito i lalo) aafiaga o vaega eseese ma komiuniti, e aofia ai meatotino fausia, ekosisitema faanatura, ma le soifua maloloina o tagata. I le laupapa pito i luga, o 'āū mumu e iloa ai o loo siisii a'e lea faailo, a'o 'āū lanu moana e iloa ai o loo alualu ifo le faailo. O 'āū mumu ma lanu moana tutu faatasi e iloa ai se suiga, ma e eseese foi itu e alu aga'i i ai le suiga. Source: Keener et al. 2018.

O se tuufaatasiga lenei o le *Suiga o le Tau i Amerika Samoa: Faailo ma Manatu mo Vaega Aafia Autu* – (*Climate Change in American Sāmoa: Indicators and Considerations for Key Sectors*) (https://eastwestcenter.org/PIRCA-AmericanSamoa).

Pago Pago Harbor is a natural deepwater harbor and is surrounded by several villages, including the administrative capital.
Photo: Valentine Vaeoso

Climate Change in American Sāmoa: Indicators and Considerations for Key Sectors

Report for the Pacific Islands Regional Climate Assessment (PIRCA)

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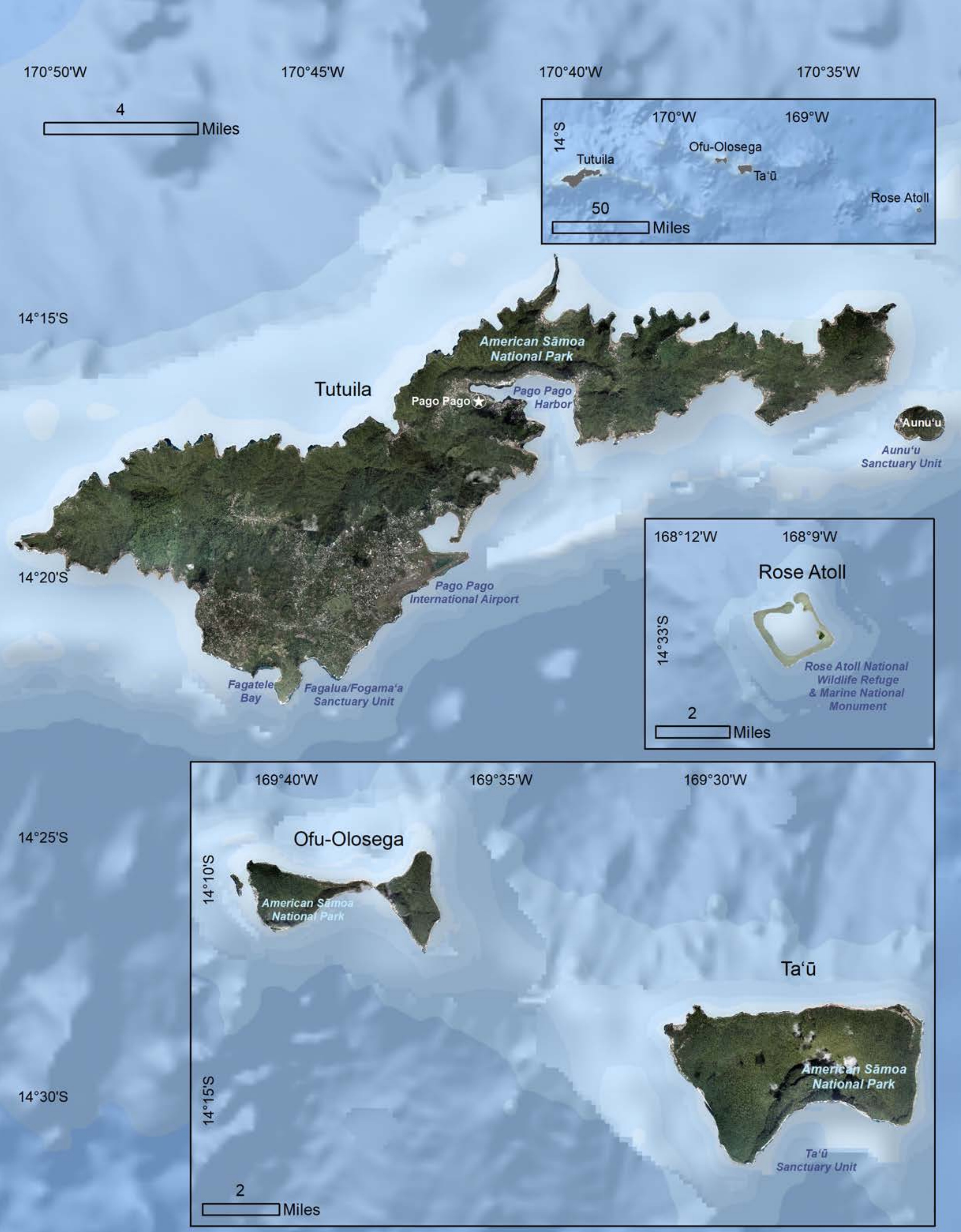

Original map by Laura Brewington

Inside this Report

The bridge connecting Ofu and Olosega in the Manu'a Island Group is built across a shallow reef flat. Photo: DJ Sene

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 the 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, humans have emitted an increasing amount of greenhouse gases into the atmosphere since the late 1800s by 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 and the rate at which they are happening are unprecedented in the history of modern civilization (USGCRP 2018, Ch. 1: Overview; 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 globe 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 poleward as waters warm;
- Sea ice is decreasing and glaciers, ice caps, 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: Overview, Fig. 1.2, and Ch. 2, KM 3–7; IPCC 2014, SPM.1.1; also see USGCRP Indicators and EPA Indicators websites).

▶ **Global Climate Change:** Causes and Indicators

As in all regions of the world, the climate of the Pacific Islands is changing. The top panel of Figure 1 summarizes the changes that have been 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).

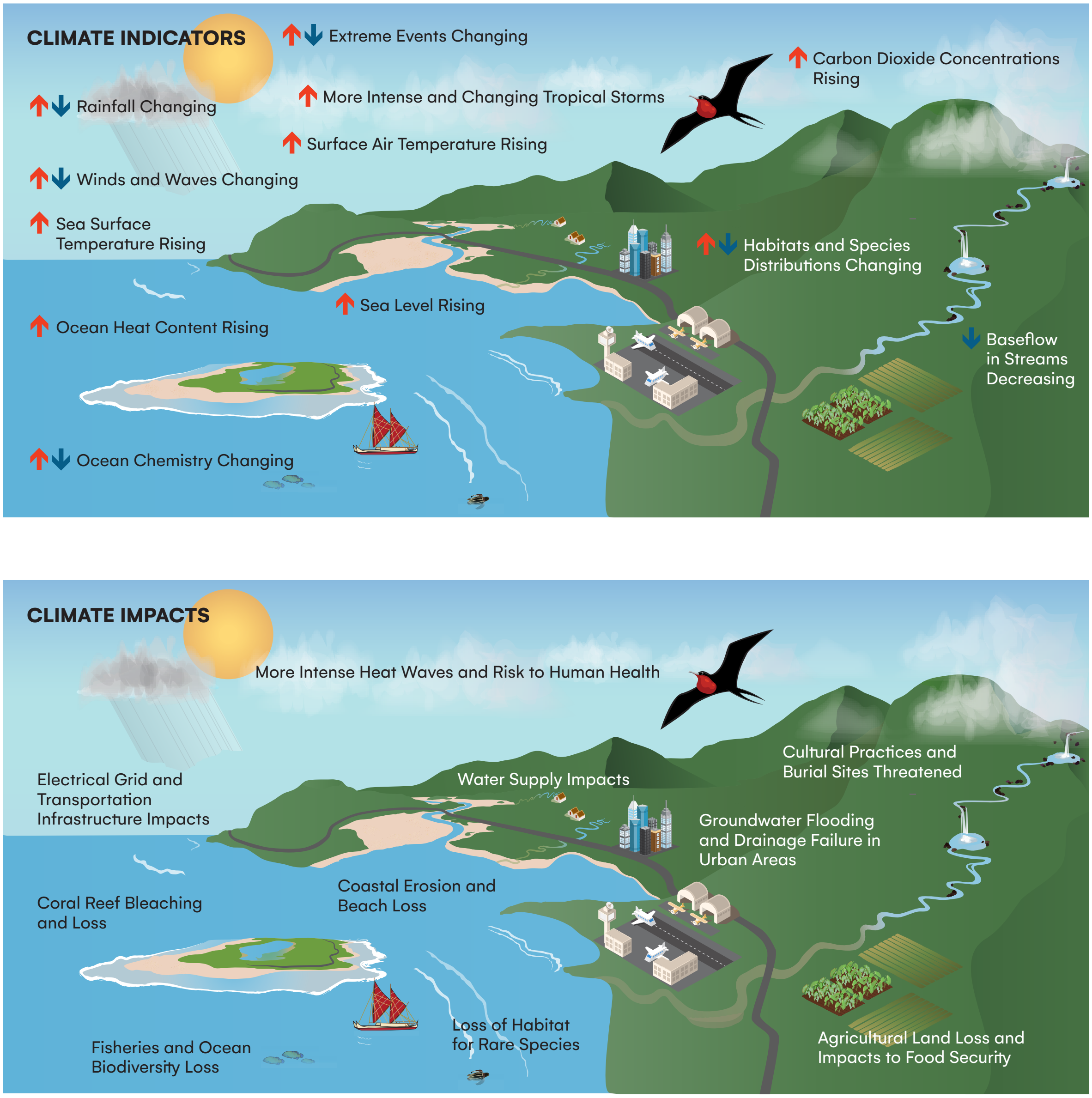

Figure 1. Observed changes in key climate indicators in the Pacific Islands (top)—such as carbon dioxide concentration, sea surface temperatures, and species distributions—result in (bottom) impacts to multiple sectors and communities, including built infrastructure, natural ecosystems, and human health. In the top panel, red arrows signify an indicator is increasing, while blue arrows show the indicator is decreasing. Red and blue arrows appear together for an indicator that is changing and the direction of change varies. 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: Overview and Ch. 2, KM 2).

Globally, the largest uncertainty in projecting future climate conditions is the level of future greenhouse gas emissions, which 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). In American Sāmoa, future changes in rainfall are also highly uncertain. 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 to project temperature change and associated impacts (USGCRP 2018, Guide to the Report). In this summary, the “high scenario” represents a future where reliance on fossil fuels and annual greenhouse gas emissions continue to increase throughout this century. The “low scenario” 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 1.8°F/1.0°C of warming above pre-industrial levels (IPCC 2018, A.1). Limiting global warming to 2.7°F/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 observed changes and future projections in key climate indicators in American Sāmoa. Later sections describe climate-related issues affecting families and households; 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. The American Sāmoa Community College and the Pacific RISA held a workshop in June 2019 that gathered knowledge, informed the report content, and identified research and information needs.

Indicators of Climate Change in American Sāmoa

This discussion of indicators of climate change in American Sāmoa builds on previous work that includes *State of Environmental Conditions in Hawai'i and the U.S. Affiliated Pacific Islands under a Changing Climate: 2017* (Marra and Kruk 2017), *Climate Variability, Extremes and Changes in the Western Tropical Pacific: 2014* (Australian BOM and CSIRO 2014), and work of the Intergovernmental Panel on Climate Change (IPCC). Indicators 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 average annual temperature from 1967 to 2020 was 80.6°F. The number of **hot days** (above 90°F/32°C) in American Sāmoa has increased from an average of about 9 days in the first decade records were kept (1967–1976), to an average of about 22 days per year in the last decade (NOAA 2020b) (Fig. 2). The best available data (longest continuous record) is from the weather station at the Pago Pago International Airport in Tāfuna. A secondary dataset is available from the NOAA Atmospheric Research Observatory in Tula but is not included in this analysis due to issues with data consistency and equipment changes.

The number of **cool nights** (with minimum temperature below 73°F/23°C) has decreased. Pago Pago experienced an average of about 85 cool nights per year in the first decade that records were kept (1967–1976). In the last decade, the number of cool nights decreased to an average of 4 nights per year (NOAA 2020b) (Fig. 3).

Fig.2

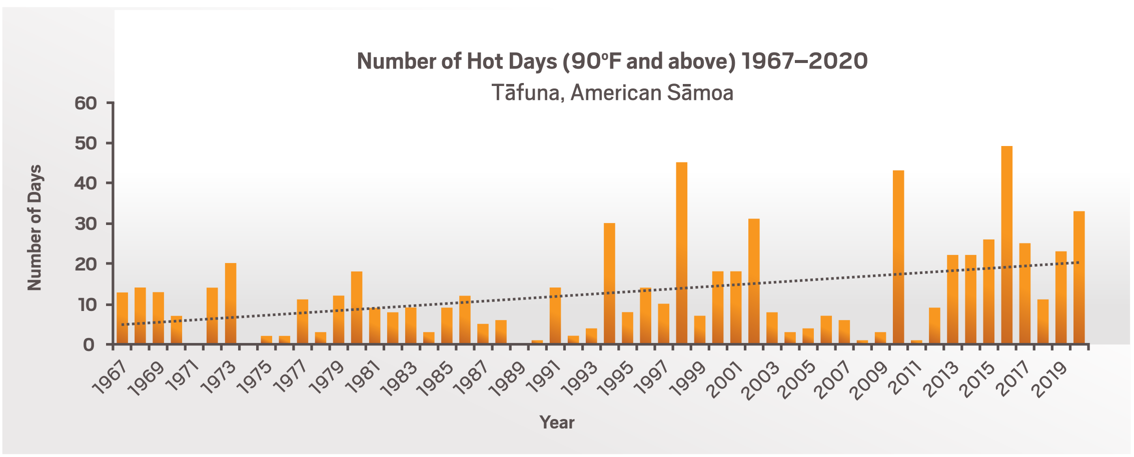

Figure 2. The annual number of days with maximum temperature of 90°F (approximately 32°C) or hotter (at or above the 95th percentile) from 1967 to 2020 at Pago Pago International Airport in American Sāmoa. The trendline (black, dotted line) shows an increase in hot days at a rate of 0.29 days per year on average. Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1967–2020 (NOAA 2020b; Menne et al. 2012).

Fig.3

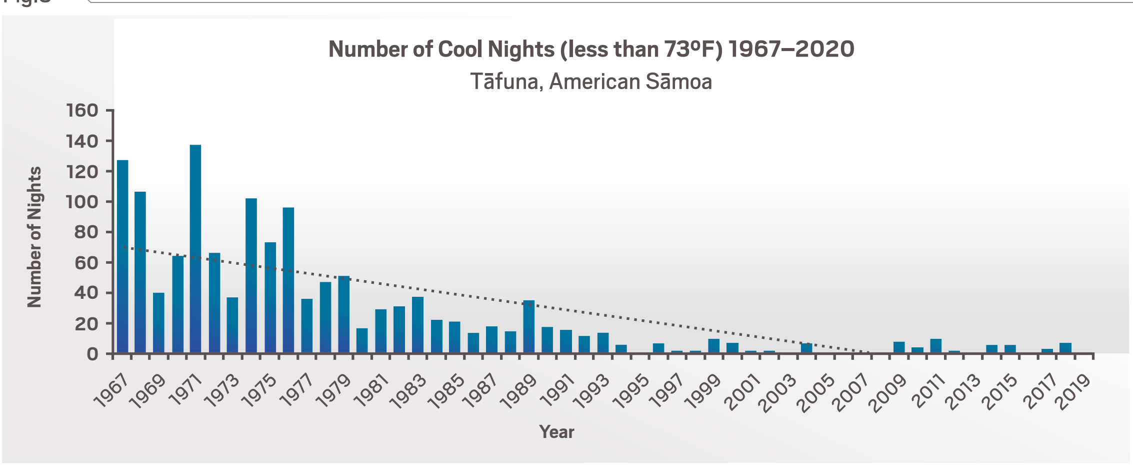

Figure 3. The annual number of days with a minimum temperature less than the 10th percentile (roughly 73°F or 23°C) for the entire record from 1967 to 2020 at Pago Pago International Airport in American Sāmoa decreased at a rate of 1.67 nights per year on average (black, dotted line). Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1967–2020 (NOAA 2020b; Menne et al. 2012).

At the Pago Pago International Airport, observed **average air temperature** has increased from 1967 to 2020 (Fig. 4). The meteorological station in Apia in the Independent State of Sāmoa, just 76 miles from Pago Pago, has a 118-year record of observations, which is the longest record in the entire insular Pacific region (Salofa and Aung 2004). At this station, maximum air temperatures have increased more in the wet season (November–April) than in the drier season (May–October) (Australian BOM and CSIRO 2014). Surface air temperature is expected to continue to increase this century. Average annual air temperature at Apia is expected to rise by 1.3–3.4°F (0.7–1.9°C) by 2050 and could rise as much as 3.6–7.2°F (2.0–4.0°C) above the present average by 2090 (Australian BOM and CSIRO 2014).

Fig.4

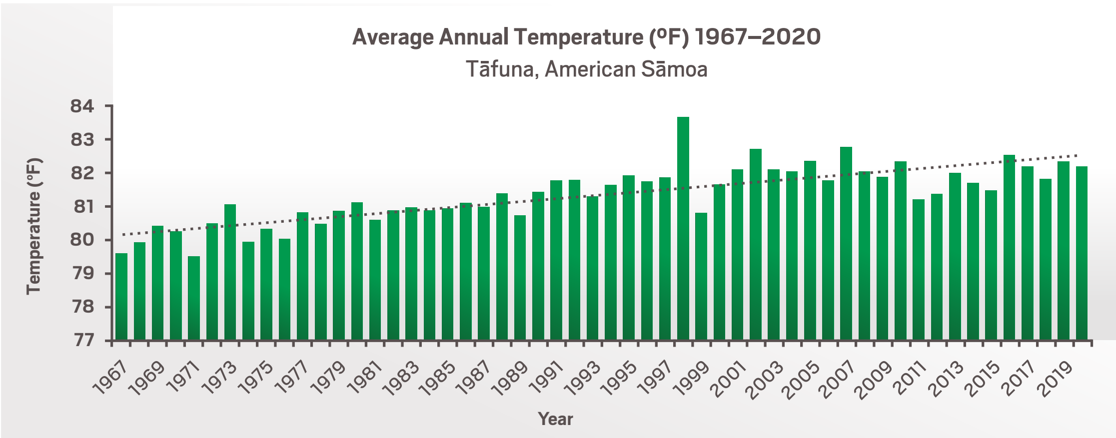

Figure 4. The annual average air temperature from 1967 to 2020 at Pago Pago International Airport in American Sāmoa increased at a rate of 0.04ºF per year (black, dotted line). Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1967–2020 (NOAA 2020b; Menne et al. 2012).

Rainfall and streamflow

Indicator	How has it changed?	Projected future change
Average rainfall	↑	?
Extreme rainfall days	↑	↑

American Sāmoa has a tropical climate with wetter and drier seasons. On islands, rainfall is the primary source of all fresh water, making it essential to human communities and ecosystems. Rainfall patterns across the region are strongly linked to El Niño–Southern Oscillation (ENSO) events. American Sāmoa's rainfall is highly variable from year to year. For Pago Pago, the driest year on record from 1967 to 2020 was 1998, during an El Niño, when rainfall was more than 59 inches below normal (Marra and Kruk 2017).

At Apia in Sāmoa, **average annual rainfall** has increased since 1890, and in Pago Pago, eight of the last ten years have had above normal rainfall

(Marra and Kruk 2017). The increase in rainfall is likely due to a shift in the average location or intensity of the South Pacific Convergence Zone (SPCZ), which brings heavy localized rains when positioned closer to American Sāmoa. The increase in rainfall is mainly evident in the drier season, May through October. Meanwhile, there has been little change in rainfall from November through April (Australian BOM and CSIRO 2014). Models show a range of projected future annual rainfall change, from an increase to a decrease, and the model average is near zero change (Widlanksky et al. 2013; Brown et al. 2020). One set of dynamically downscaled model projections indicates an increase on average in annual precipitation of 11% to 18% by the end of the century (Zhang et al. 2016; Shuler et al. 2021).

The frequency and intensity of **extreme rainfall events** are projected to increase. The average number of extreme rainfall days per year shows a non-significant increase since the 1960s (Fig. 5). The frequency of extreme rainfall events is projected to increase with continued global warming. A 1-in-20-year event would become, on average, a 1-in-9-year event by 2090 under the low warming scenario and a 1-in-6-year event under the high warming scenario (Australian BOM and CSIRO 2014). Increased heavy rainfall events will likely result in increased runoff and increased potential for flooding.

Fig.5

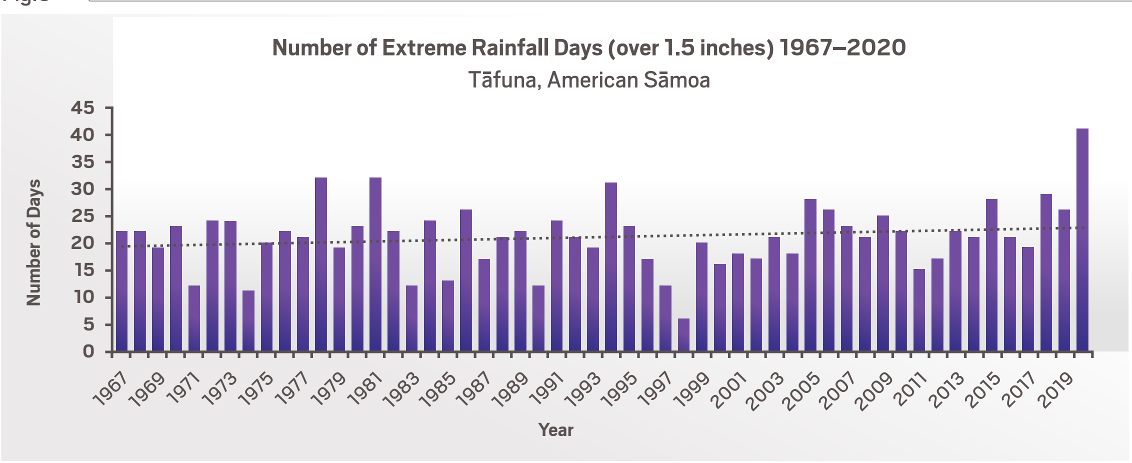

Figure 5. The annual number of days with extreme rainfall (over 1.5 inches per day) from 1967 to 2020 at the international airport in American Sāmoa showed no statistically significant change (dashed black line). Original figure by Abby Frazier, using data from the NOAA GHCN-Daily database for 1967–2020 (NOAA 2020b; Menne et al. 2012).

Indicator	How has it changed?	Projected future change
Frequency of drought	No change	No change
Duration of drought	?	No change
Streamflow	?	↑

The **frequency and duration of drought** is expected to remain approximately the same in the future. In American Sāmoa and the Independent State of Sāmoa, long-term records show no significant trends in consecutive dry days (Australian BOM and CSIRO 2014; Wimhurst and Greene 2021). ENSO effects on drought in American Sāmoa vary with the strength of the event. During strong El Niño events, the islands are significantly drier; during weak El Niño events, reduced tropical storm activity causes conditions that are drier than average.

Streamflow records available for American Sāmoa are relatively short and discontinuous, and only one stream gauge has more than 35 years of record and is unaffected by artificial diversions (Keener et al. 2012). The Atauloma Stream gauge on the island of Tutuila showed a slight and insignificant downward trend from 1959 to 1997 (Keener et al. 2012). Projected rainfall increases may cause both increased streamflow and runoff relative to historic levels (Shuler et al. 2021).

Tropical cyclones and storms

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

Cyclones and tropical storms (referred to collectively as tropical cyclones) bring intense winds, torrential rainfall, high waves, and storm surge to islands near their path. The effects of a tropical cyclone strike or near miss can severely impact lives and property. As defined by the US National Weather Service, cyclones generally occur between November and April in American Sāmoa, and the risk of tropical storms and cyclones increases during medium-to-strong El Niño events. The southwest Pacific over the short-term has seen below-average tropical cyclone activity from 2010 to 2015 compared to the 30-year normal (1981–2010) (Marra and Kruk 2017; Knapp et al. 2010); however, ENSO events during the period of record may have obscured long-term trends.

There is scientific consensus that the **intensity of tropical cyclones** is likely to increase in a warmer world due to the increase in sea surface temperatures (USGCRP 2017; Marra and Kruk 2017; Knutson et al. 2015; Sobel et al. 2016; Zhang et al. 2016; Zhang and Wang 2017; Wang et al. 2016; Widlansky et al. 2019). Basins that warm more than the tropical average will show the largest increases. The change in tropical cyclone intensity is projected to affect stronger storms the most (in other words, increased maximum intensities), which would amplify the potential for severe damage (Widlansky et al. 2019).

Globally, **tropical cyclone frequency** shows a slow downward trend since the early 1970s. The number of tropical cyclones is projected to decrease across the Pacific and globally by the late 21st century (Kossin et al. 2016; USGCRP 2017). In the area surrounding American Sāmoa and the southeast Pacific basin, the future projection is for an overall decrease in the occurrence of tropical cyclones, ranging between 5% and 50%, with high confidence (Australian BOM and CSIRO 2014; Wang et al. 2016). Thus, the overall outlook is for fewer but stronger storms in the future.

From 1981 to 2015, the frequency of **gale-force winds** has increased in the central south Pacific. Gale-force winds are responsible for moderate to high waves, which impede boating (Marra and Kruk 2017; Kanamitsu et al. 2002). Furthermore, strong winds create choppy seas and push water inland, causing increased coastal erosion and flooding (see Fig. 4.2 in Marra and Kruk 2017).

Sea level

Indicator	How has it changed?	Projected future change
Sea level	↑	↑
Tidal flood 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. A great deal of American Sāmoa's infrastructure is located on the narrow band of flat land along the coast, making it highly vulnerable. The South Pacific experiences large fluctuations in sea level from year to year related to basin-scale processes such as El Niño. Sea levels also vary annually due to the seasonal ocean temperature cycle and on shorter timespans due to abrupt changes in winds and atmospheric pressure (in the case of storm surges). Despite this variability, the average **sea level** is increasing over decades and this increase is projected to accelerate in the coming decades.

Relatively small changes in average sea level can have large effects on **tidal flood frequency**. In Pago Pago and other areas around Tutuila, land subsidence and sea level rise have caused high tide flooding (also called nuisance coastal flooding) to become more common. On June 23, 2017, the NOAA tide gauge in Pago Pago recorded a daily maximum water level of 1.3 feet (41 cm) above the Mean Higher High Water (MHHW) level during the 1983 to 2001 tidal epoch, and residents reported coastal flooding. Since 2014, the water level exceeded that same level during at least 20 days every year, whereas prior to the 2009 earthquake there was only one such daily observation. During 2019, 90 days exceeded the level at which flooding was observed. Changes in sea level coupled with high tide events can also exacerbate coastal erosion problems, although local erosion data is lacking.

Fig.6

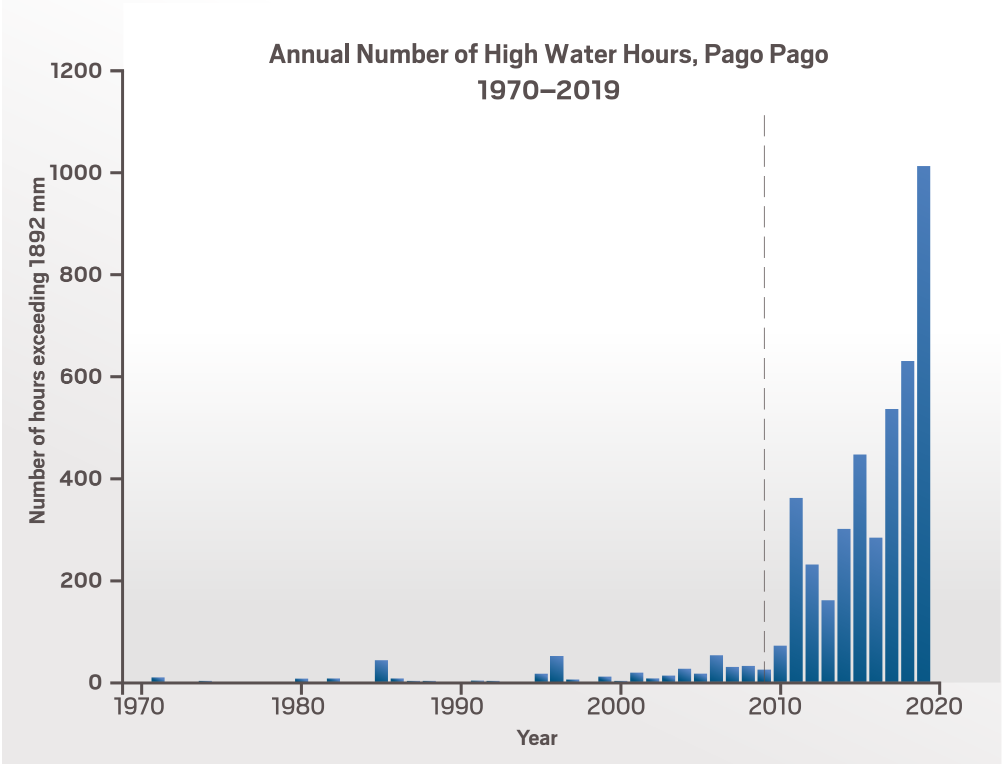

Figure 6. The number of high water hours per year at Pago Pago, American Sāmoa, from 1970 to 2019. The high water threshold (1892 mm) is defined as the Mean Higher High Water level plus one-third of the difference between that and the Mean Lower Low Water level at the tide gauge (i.e., water levels above the daily average highest tide plus a factor of the typical tidal amplitude). Note that since the 2009 earthquake (dashed line), vertical land motion (i.e., subsidence of the archipelago) contributed to the increased occurrence of high water hours. Also note that data during 2020 is not shown because the tide gauge stopped operating early that year. Original figure by Matthew Widlansky, with data from the University of Hawaiʻi Sea Level Center Station Explorer (https://uhslc.soest.hawaii.edu/stations/?stn=056#datums).

Relative to the year 2000, Global Mean Sea Level is projected to rise 0.3–0.6 feet (9–18 cm) by 2030. For 2050, the projected range of Global Mean Sea Level rise is 0.5–1.2 feet (15–38 cm), and by 2100 the projected range is 1.0–4.3 feet (30–130 cm) (USGCRP 2017). However, these global projections do not account for relative sea level rise that is occurring due to the gradual sinking of the ground, or subsidence, still taking place after the September 2009 earthquake. In the decades prior to the 2009 earthquake and subsequent subsidence, the ocean around American Sāmoa is estimated to have risen 0.08–0.12 inches (0.2–0.3 cm) per year, which is comparable to the global average rate (IPCC 2014; HHF Planners and USACE 2020). In the two to three years following the earthquake, Tutuila subsided 7 to 9 inches (18 to 23 cm), increasing the relative sea level rise experienced (Mörner et al. 2018). Because of this, American Sāmoa is expected to experience an additional sea level rise of 12–16 inches (30–40 cm) during this century, which is approximately five times faster than the global average (Han et al. 2019).

Using GPS satellite data while considering subsidence since the earthquake and ENSO influences, NOAA and the US Army Corps of Engineers (USACE) estimated a relative sea level change trend of 0.35 inches (0.89 cm) per year with a high margin of error (+/- 0.386 inches; 0.98 cm) (USACE 2019). The USACE's Sea-Level Change Curve Calculator (Version 2019.21) estimated a sea level rise of 3 feet over 45 years (from 2020 to 2065) and approximately 7 feet in 80 years (from 2020 to 2100) for American Sāmoa under a high scenario (USACE 2019) (Fig. 7). Emerging climate science suggests that Global Mean Sea Level rise of more than 8 feet by 2100 is possible, though the probability of this extreme outcome cannot be assessed (USGCRP 2017). 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).

Fig.7

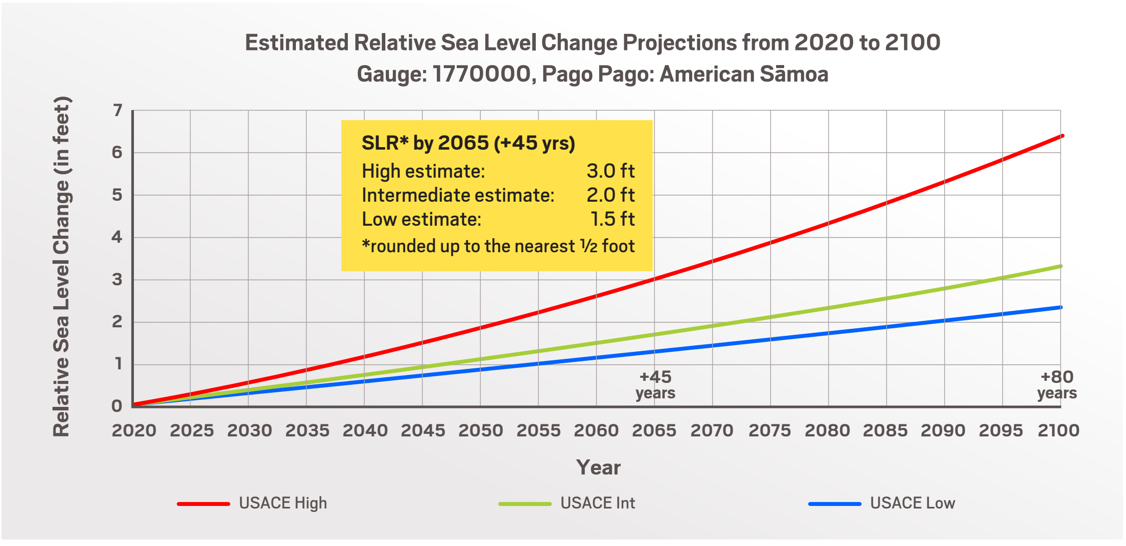

Figure 7. Regional sea level rise scenarios considering subsidence are estimated at 3 feet in a period of 45 years (from 2020 to 2065) and approximately 7 feet in 80 years (from 2020 to 2100). Source: Prepared by HHF Planners in cooperation with the US Army Corps of Engineers (USACE), 2020.

Ocean changes

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

Human-caused greenhouse gas emissions 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 on the rise in American Sāmoa. The number of days per year that coral reefs are exposed to heat stress, as categorized by the NOAA Coral Reef Watch, has risen 8 days per year (in 1982–91) to 50 days (in 2007–16) per year on average. The **intensity of heat stress** has also increased. Although not as severe as the impacts on the Great Barrier Reef, the Samoan region was repeatedly exposed to intense heat stress during 2000–2016, and especially during the third global bleaching event, 2014–2017 (Fig. 8). Prolonged high temperatures led to significant coral death in American Sāmoa in 2015 and early 2017. Bleaching affected both shallow and deeper corals (Eakin et al. 2016); some staghorn corals that bleached annually since 2003 have recovered (Fenner and Heron 2009; Fenner 2019). With projected warming, coral reefs in American Sāmoa will experience annual severe bleaching beginning in about 2040 (Fig. 9) (van Hooidonk et al. 2016). Bleached corals typically do not reproduce in a year that they bleach and are more prone to disease and death in the future if they do recover.

Figure 8. Before and after images illustrating bleaching in one area of the reef flat in American Sāmoa. The image of coral at far left was taken in 2014, and the image of bleached coral at right was taken in 2015 during a survey in response to the bleaching alert. Photo credit: Underwater Earth / XL Catlin Seaview Survey [Rights Reserved].

While ocean water has a basic pH, data show that **ocean acidification**, caused by the ocean's uptake of carbon dioxide from the atmosphere, has been slowly increasing in the waters of the Western Pacific (Kuchinke et al. 2014). This increase threatens coral reefs by making it harder for corals to build healthy skeletons.

To this point, high temperatures have been far more damaging to coral reefs, but ocean chemistry will continue to change, and under the high scenario, all coral reefs are projected to exist in acidification conditions that will impede their ability to grow by the end of the century (Australian BOM and CSIRO 2014).

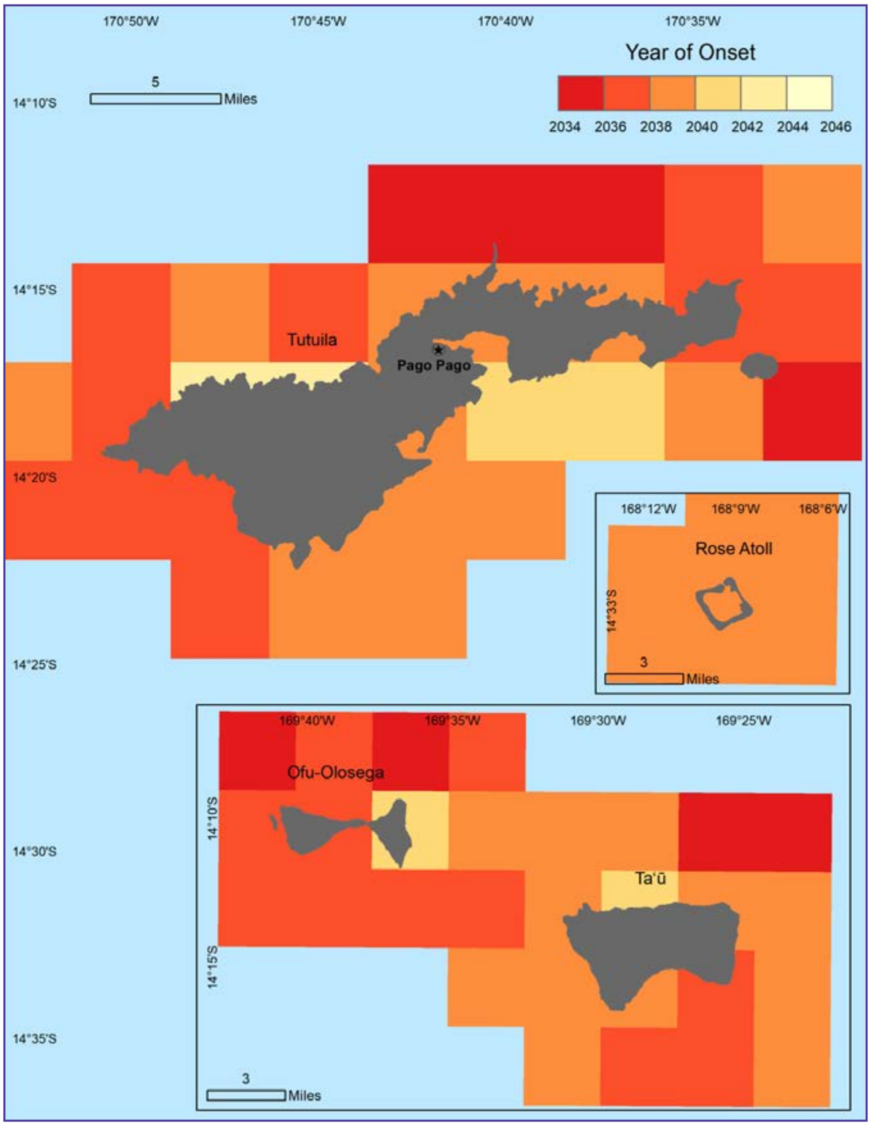

Figure 9. Projected year of onset of annual severe bleaching conditions for corals in American Sāmoa under a high warming scenario (RCP8.5), not considering potential adaptation of coral populations. Source: Figure by Laura Brewington, adapted from USGCRP 2018, using data from van Hooidonk et al. 2016.

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 to actions that 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 (Fatoric 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, for example 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 American Sāmoa's Families, Households, and Vulnerable Populations?

Climate change is anticipated to disrupt many aspects of life. Globally, more intense extreme weather events, flooding, the transmission of disease, and failing ecosystems 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 and lead to price shocks and food insecurity (USGCRP 2018, Ch. 16, KM 1 and 3). In American Sāmoa, economic dependence on the cannery as a major employer means that closures due to drought or changes in fishery productivity or global disasters may have a disproportionate impact on communities (Dworsky and Crawley 1999).

Although climate change is expected to affect all people in American Sāmoa, 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. Those who are already vulnerable, including children, older adults, low-income communities, and those experiencing discrimination, are at greater risk from extreme weather and climate events, in part because they are often excluded from planning processes (USGCRP 2018, Ch. 14, KM 2; Ch. 15, KM 1–3; Ch. 28, Introduction).

Vulnerable populations will likely be affected in many ways, including:

- Children, who have a higher rate of heat stroke and heat-related illness than adults, are at greater risk from increasing hot days (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).
- People who work outdoors, such as tourism and construction workers, fisherpeople, farmers, and other outdoor laborers, are some of the first to be exposed to the effects of heat and extreme weather (USGCRP 2016; Schulte and Chun 2009).
- People who live, work, go to school, or otherwise spend time in locations that are more directly affected by climate risks, such as coastal and other flood-prone areas, are more likely to experience higher risks to health and safety (USGCRP 2016).
- Pacific Islanders, including Samoans, have an inseparable connection to and derive their sense of identity from the lands, territories, and resources of their islands (Keener et al. 2018). Traditional systems of land ownership complicate relocation out of ancestral areas that are exposed to climate impacts because communities prioritize remaining on familial land (US Department of Commerce 2012).

Actions to address the causes and impacts of climate change can also affect certain populations, such as those with lower incomes, more than others if such actions do not 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, and the design of climate-ready infrastructure can encourage widespread participation in decision-making.

Global action to significantly cut greenhouse gas emissions can reduce climate-related risks and increase opportunities for these populations in the long term. For example, health-related impacts and costs across the United States are projected to be 50% lower under a lower warming scenario (RCP 4.5) than a higher scenario (RCP 8.5) (USGCRP 2018).

What Do Extreme Weather and Climate Change Mean for American Sāmoa's Key Sectors?

The PIRCA suggests the following considerations for managers working in these 10 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 resources or utilities manager...

- ***Prepare for increased land-based pollution in groundwater and surface water.*** Land-based pollution has been a persistent problem affecting drinking water quality in American Sāmoa, particularly in the central water system (Shuler et al. 2019). The projected increase in the frequency and intensity of extreme rainfall events means that pathogens will be flushed into the water systems at greater rates and that spikes in contamination of groundwater will likely become more frequent and extreme (Wallsgrove and Grecni 2016; Shuler et al. 2021).

- ***Monitor salt concentrations in groundwater wells that already have high chloride levels.*** Some wells on the east side of Tutuila and on Aunu'u island (Izuka 1996; Shuler and El-Kadi 2018) have high chloride (or salt) levels when there is less rainfall than usual, putting them at a greater risk of becoming saltier as the sea level rises. The projected increase in rainfall and groundwater recharge might compensate for this increase in salinity (Shuler et al. 2021). Since it is uncertain exactly how these wells will change in the future, it is important to maintain a robust observation and monitoring network for wells near the coast.

- ***Hardening measures to protect electrical, water, wastewater, and other infrastructure can improve reliability and resilience of core services.*** Sea level rise will cause a rise in groundwater in nearshore developed areas. Buried utilities in these areas may be subject to sub-surface inundation through exposure to the saturated zone. This could cause increased corrosion of utilities, increased inflow and infiltration of wastewater lines, and even potential contamination of drinking water lines (Habel et al. 2017). Damage to utility infrastructure from sea level rise, or major storms, can cause cascading impacts on critical sectors. Considering both extreme weather and sea level rise in the design or reconstruction of infrastructure can help to avoid future high costs and outages.

An ASCC student intern takes water quality samples from high-level springs on Tutuila. Photo by Christopher Shuler.

- ***Expect hotter conditions to increase water demand and decrease available fresh water.*** Rising temperatures will increase evapotranspiration. The increased rate of water evaporation from soils, plants, wetlands, and streams means less water will be available to replenish groundwater aquifers. While changes in future rainfall amounts are uncertain, extreme rainfall is projected to increase and is more likely to run off into the ocean, rather than recharging groundwater. At the same time, rising temperatures increase the human population's demand for water.

- ***Energy consumption is projected to increase, driven by a combination of hotter weather and increasing population.*** Energy is used to pump and distribute water for use in households, agriculture, and industries. Increased hot days will generally increase the need for water and its loss through evaporation. Thus, a greater amount of energy is expected to be required to pump and distribute water (Gingerich et al. 2019) and cool homes on hot days in the future. While the population of American Sāmoa decreased from 2000 to 2010, approximately one-third of the population is below 15 years of age and may produce significant population growth, possibly increasing the demand for water and electricity (HHF Planners and USACE 2020; Wendt et al. 2019). On the other hand, the small islands in American Sāmoa such as Manuʻa have lost half their population over the past several decades, and may continue along this trajectory.

- ***Monitor ENSO and its effects on rainfall.*** The El Niño–Southern Oscillation (ENSO) strongly influences rainfall amounts, which vary greatly from year to year in American Sāmoa. Although the relationship is complex and variable, El Niño events typically bring dry weather to the Samoan region in the following spring and summer, and a strong El Niño can cause severe local drought (Fig. 10). Water managers can use seasonal forecasts to prepare for potential water shortages or saltwater intrusion during drought years.

Fig.10

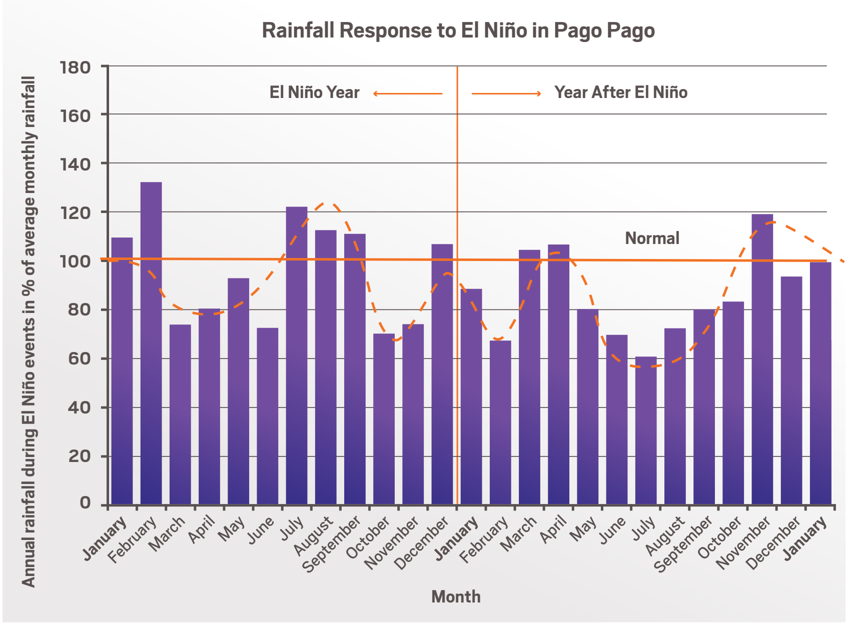

Figure 10. Average rainfall in Pago Pago during El Niño events shown as the percent of average monthly rainfall. The red horizontal line indicates the average rainfall compared to the red dashed line showing the polynomial trend. Source: Pacific ENSO Applications Climate Center 2018 (www.weather.gov/peac).

Floodwaters, like those pictured here in Nu'uuli after heavy rain, carry pathogens and pose a direct risk to safety. Heavy rains and flooding can threaten homes, close roads, down powerlines and trees, and cause landsides. Such floods become more likely as the climate warms. Photo by Valentine Vaeoso.

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 as well as healthcare facilities and public infrastructure. When they overlap with disease outbreaks, weather extremes can disrupt the public health sector's response, as during the COVID-19 pandemic. 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.*** Even small increases in seasonal average 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). Rising temperatures can also affect the management of non-communicable diseases, including diabetes, since hot weather makes it uncomfortable and even unsafe to exercise outside. 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 in American Sāmoa (Marinucci et al. 2014). Shock events can exacerbate existing heat and socioeconomic stressors. After the 2009 tsunami, compounding impacts at different scales included lack of electricity and fresh water, increase in insect vectors, barriers to receiving medical care, and an increase in dehydration and heat stress injuries (Choudhary et al. 2012).

- ***Expect more frequent water supply contamination and more frequent floods.*** Heavy rains have periodically caused flooding in parts of the Territory, and the NWS issues flash flood warnings when rainfall rates of more than 2 inches per hour are predicted. This is also the approximate rainfall rate at which the American Sāmoa Power Authority observes groundwater wells under the direct influence of surface water, or "GUDI" wells, are at risk for contamination by pathogens (Shuler et al. 2019); also this is when there is high flow into sewers. On New Year's Day in 2017, flash flooding closed roads, downed power lines and trees, and produced landslides. Similar floods are expected to become more frequent, and flooding will 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). The island's only hospital, Lyndon B. Johnson Tropical Medical Center (LBJ Hospital), is located near the high-hazard flood zone and landslide zone (Jamie Caplan Consulting, LLC 2015). The hospital has flooded in the past and will be increasingly at risk of flooding and associated problems in the future. During King Tides and storm surge, travel along the coast and access to medical services may be jeopardized. Preparing for these challenges is most effectively done through a multi-sectoral approach.

- ***Expect stronger tropical cyclones.*** Although they may occur less frequently in the future in the Samoan Archipelago, the tropical cyclones that do affect American Sāmoa are expected to bring stronger winds, higher storm surges, and greater precipitation amounts. Coral reefs protect the shoreline by weakening wave energy. Sea level rise and a decline in coral cover could reduce the protection from storms. Injuries, fatalities, and mental health impacts are associated with strong storms, especially in vulnerable coastal populations. Health risks increase after a storm when infrastructure and housing is damaged, and electricity, sanitation, safe food and water supplies, communication, and transportation are disrupted. Government and non-governmental organizations can increase adaptive capacity, for example by providing early warning systems, evacuation assistance, and disaster relief (McIver et al. 2016; Bell et al. 2016). Federal building codes and flood prevention infrastructure are often too expensive for vulnerable communities to implement. There is a need for less-costly alternatives.

- ***Monitor emerging research on climate and vector-borne diseases.*** American Sāmoa experienced outbreaks of dengue and Zika in 2016. Dengue, lymphatic filariasis, and other mosquito-borne pathogens have increased as global health threats in recent years (Beard et al. 2016). Researchers are concerned that future warming and precipitation changes will increase the suitable habitat for pathogens and vectors, thereby increasing the potential for instances of malaria, dengue fever, diarrhea, salmonellosis, and other diseases (Mora et al. 2018). Community-level adaptation measures can limit human vulnerability to vector-borne disease (Beard et al. 2016; Radke et al. 2012; Reiter et al. 2003).

King Tides flooded roads and other infrastructure in Leloaloa. Sea level rise causes tidal flooding to become more frequent, extensive, and severe, bringing financial impacts to individuals and communities. Photo by KVZK-TV.

If you are a coastal infrastructure decision-maker...

- ***Prepare for more frequent coastal flooding and increased erosion to affect coastal villages and infrastructure.*** Both sea level rise and more frequent and intense heavy rainfall events will produce flooding along the coasts of American Sāmoa. The majority of the Territory's villages and infrastructure are located on the floodplains of Tutuila—including the hospital and international airport. Coastal roads impacted by floods and landslides slow the transport of goods and limit access to health care. American Sāmoa is particularly vulnerable to coastal erosion where there are both narrow fringing reefs and only thin bands of land available for coastal infrastructure, though Tutuila is less at risk than Ofu-Olosega and Taʻū. Furthermore, "maladaptation" is occurring. For instance, seawalls are built with the intention of reducing erosion, but often have the unintended consequence of causing beach loss at other locations along the shore, worsening the erosion problem. Coral reefs already protect 435 buildings valued at over $46.5 million in American Sāmoa from floods that would result from a 10-year storm event (Storlazzi et al. 2019). Prioritizing reef conservation and facilitating replanting of mangroves provides additional coastal protection (Ferrario et al. 2014). Stream restoration is another nature-based solution that can slow the flow of sediment and nutrients to coasts and nearshore marine environments.

- ***Expect less frequent but more intense tropical cyclones and storm surges.*** When combined with continued acceleration in global average sea level rise, the storm surge associated with tropical cyclones has the potential to destroy built and natural infrastructure at the coast and severely disrupt communities.
- ***Monitor new scientific understanding of the timing and magnitude of future global sea level rise.*** 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.

In 2019, Coconut Point, Nu'uuli, experienced a King Tide that, combined with wind and ocean swell, led to homes being flooded. Photo by Kelley Anderson Tagarino.

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

- ***Coral reefs in American Sāmoa have already experienced increased frequency of bleaching.*** In the next few decades, more frequent coral bleaching events and ocean heatwaves will combine with other stressors such as erosion, sedimentation, pollution, and overfishing to increasingly threaten coral reefs and the livelihoods they support. The overall value of coral reefs is estimated to be at least $10 million per year in American Sāmoa (US Department of Commerce 2012). By 2040, widespread coral bleaching and mortality is projected to occur annually (van Hooidonk et al. 2016). Some populations of staghorn corals in backreef pools were observed to have partial colony bleaching annually since 2003 and have recovered (Fenner and Heron 2009; Fenner 2019). However, repeated or extreme global ocean heatwaves are linked to local coral death. The identification, cultivation, and out planting of resilient corals can be a locally effective management strategy (Score 2017), although it should not be viewed as a panacea—even farmed corals will be challenged by high temperatures, and storms can damage farms. Greenhouse gas emissions reductions on a global scale may aid the survival of resilient corals locally. Studies have found that reefs with the highest future resilience potential are in geographically defined zones, with northeastern Tutuila scoring the highest, northwest and southwest zones rated as having intermediate resilience, and southeastern Tutuila scoring the lowest (Schumacher et al. 2018).

Coral reefs experienced bleaching from high water temperatures in 2020. Here, staff from the Coral Reef Advisory Group (CRAG) are shown monitoring coral bleaching in pools at Tāfuna. Photo by Valentine Vaeoso, July 17, 2020.

US Coast Guard personnel observed a diversion boom placed in waterways in and around Leone Bay to protect environmentally sensitive areas from any potential release of pollution from an 88-foot commercial fishing vessel, Chui Zai Fa No. 1, that was grounded in American Sāmoa during Cyclone Gita. US Coast Guard photo by Petty Officer 2nd Class Tara Molle/Released, February 2018; Attribution-NonCommercial-NoDerivs 2.0 Generic (CC BY-NC-ND 2.0).

- ***Expect reduced available catch for subsistence and commercial fishing.*** Climate change and ocean acidification are expected to cause coral reef fish to decline 20% by 2050 (Bell et al. 2013). Fishing and exploitation of coral reef resources are expected to further exacerbate the effects on reef fish populations (Cheng and Gaskin 2011). 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 American Sāmoa (Asch et al. 2018; Bell et al. 2013). Increased drought and declines in potential catch could both have negative impacts on StarKist Samoa Tuna Cannery operations in Pago Pago, which traditionally has employed more than 1,500 workers (Frazier et al. 2019).

- ***Expect increased temperatures to negatively affect aquaculture.*** There are about 25 tilapia farms on Tutuila that are used for subsistence purposes. Tilapia aquaculture in American Sāmoa already exists at the upper limit of the temperature threshold. With the minimum expected temperature rise, fry (juvenile fish) will die and stocks will decrease in the absence of modifications to control water temperatures (personal communication, Kelley Anderson Tagarino, 2019).

Ocean inundation threatens taro crops in low-lying areas, as in the above photo of farmland on the island of Aunu‘u. Already, high seawater periodically affects some areas of taro production. Photo by Valentine Vaeoso.

If you are involved in agroforestry and farming...

- ***Expect climate change to worsen impacts on agriculture and agroforest production.*** In American Sāmoa the value of locally grown agricultural goods is large, accounting for $49.3 million annually or 9% of GDP (Polhemus 2017). Farms and agroforests are already exposed to impacts from flooding, drought, winds, diseases, pests, soil erosion, and clearing for development. Climate change will 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 (Taylor et al. 2016). Farmers have already reported earlier harvest cycles for staple crops such as dryland taro. Aunu‘u Island has reported that swamp taro crops have been negatively impacted by saltwater intrusion (personal communication, Matt Erickson, 2019; Ian Gurr, ASCC, 2021). Resilience to climate change is expected to require changes in farming methods and cultivars (Bell and Taylor 2015).

- ***Plan for warmer weather.*** Despite projections for increased future rainfall, rising temperatures will increase evapotranspiration, increasing the amount of water crops require. Warmer temperatures can increase the incidence and spread of disease, as higher nighttime temperature does for taro leaf blight.

- ***Prepare for more food insecurity in American Sāmoa's households.*** More than 95% of food in American Sāmoa is imported. It is highly likely that climate change will drive up the prices of imported foods, threatening food security (USGCRP 2018, Ch. 16). Traditional farming systems can enhance resilience to external shocks and help to bolster food security (McGregor et al. 2009). With a gradual shift away from agroforestry, the food production systems in the Pacific Islands have become more vulnerable (Taylor et al. 2016).

If you are involved in recreation or tourism...

- ***If land-based pollution is not reduced, water in streams and at shorelines and beaches will be polluted more often.*** Poor stream and beach water quality is an ongoing issue in American Sāmoa. Of the 41 watersheds, 28 were recently classified as impaired, meaning their streams or shorelines, or both, do not safely support recreational uses (Wallsgrove and Grecni 2016). Land-based pollution, including human and pig waste, often contaminates streams and nearshore waters (US Department of Commerce 2012). As both the number of heavy rainfall days per year and the amount of rain falling during those events increase, users of streams, shorelines, and beaches should expect more days of unsafe water per year and more watersheds categorized as impaired.
- ***Prepare for coral reefs to support fewer recreational opportunities.*** Although the number of tourists visiting American Sāmoa has declined and is relatively small, coral reefs generate approximately $1.07 million per year in direct tourism and reef-adjacent activities for American Sāmoa (Spurgeon et al. 2004; Spalding et al. 2017) (Fig. 11). In the next few decades, more frequent coral bleaching events and ocean acidification will combine with other stressors to threaten coral reefs. By 2040, coral bleaching is projected to occur annually in American Sāmoa's waters, potentially resulting in widespread coral mortality (van Hooidonk et al. 2016).

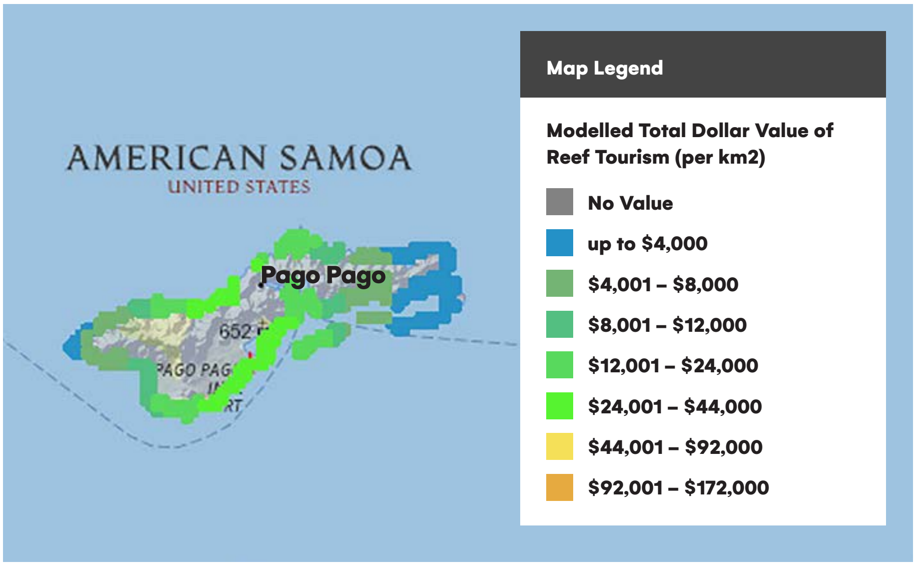

Figure 11. Estimated dollar value of direct and adjacent reef-based and coastal tourism on Tutuila, American Sāmoa. Source: Mapping Ocean Wealth Explorer 2017.

- ***Erosion of beaches and shoreline areas will increase.*** Coastal erosion and beach loss are already issues in American Sāmoa, and certain erosion-control structures (such as seawalls) have the unintended consequence of beach loss and ecosystem damage when installed on chronically eroding sandy shorelines. Alternative erosion control practices include protecting and restoring coral reefs, using vegetative buffers, and augmenting sand in specific areas. Even with the potential for negative effects on beaches and ecosystems, hard engineered shoreline protection may be necessary in some instances to protect critical infrastructure.

If you manage ecosystems and biodiversity...

- ***Changes in temperature, rainfall, and storminess promote the spread of invasive species and reduce the ability of terrestrial habitats to support protected species.*** Lowland deforestation, landslides, erosion, runoff, and invasive alien plants and animals threaten American Sāmoa's native rainforest ecosystems. American Sāmoa's forests have low-to-medium plant and animal species diversity, and are home to several protected animal species, as well as endemic and rare trees and other culturally important plants. Changing climatic conditions pose an additional risk to native plants and animals (ASCC 2010).

- ***Expect declining ocean ecosystem health.*** Watershed conservation measures can protect refugia for coral populations. American Sāmoa has experienced significant outbreaks of crown-of-thorns (COTS) sea stars in the last several decades and as recently as 2015, which damaged local reefs. Successful eradication efforts have largely controlled COTS populations, but increases in storms and nutrient runoff could increase them again (Clark 2013), which in turn would damage reefs and decrease beach protection.

- ***Measures that protect and enhance biodiversity and ecosystem services are critical to support communities in adapting to climate change.*** Natural resources underpin the sustenance and resilience of Pacific Island communities (Barnett and Campbell 2010). For example, mangrove forests can provide storm protection and building materials, and are productive estuaries (Victor et al. 2004). Significant portions of mangrove forests have been lost to human land use in American Sāmoa; only five stands across two islands remain, and replanting has had varying success (EcoAdapt 2016). Despite existing policies, clearing and cutting already threaten mangroves, which will be additionally stressed by projected climate impacts such as storm surge, extreme high-water levels, changing precipitation patterns, and sea level rise (Gilman et al. 2008; Gilman et al. 2006). Restoring mangrove forests, as is being done in Leone on Tutuila, 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 (US Department of Commerce 2012; Hills et al. 2013).

- ***Consider traditional ecological knowledge and management practices when developing adaptation strategies.*** Local customary knowledge is crucial for forest conservation solutions. Much of the lowlands in the south side of Tutuila have been cleared for development and agriculture, though rainforest on steep slopes remains uncut. This conversion threatens native plants and animals that play important roles in traditional medicine and culture as well as the islands' ecology and natural beauty (ASCC 2010).

The "Valley of the Giants" on Taʻū contains some of the oldest and largest coral heads in the world. The *Porites* coral head pictured here is Fale Bommie, named in honor of Fale Tuilagi, the biologist from American Sāmoa who monitored it and revealed it. Photo credit: Underwater Earth / XL Catlin Seaview Survey / Christophe Bailhache.

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). Climate change impacts are expected to increasingly affect trade and economies internationally beyond American Sāmoa and the United States. Import and export price fluctuations and unanticipated impacts on supply chains and customers can disrupt local businesses (Smith et al. 2018). Some financial institutions are requiring demonstrated climate adaptation plans to secure financing for new development.

- ***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.

If you are a cultural or historical resources steward...

- ***Coastal historical and cultural sites will likely be affected by erosion, storm surge, and coastal inundation from sea level rise.*** Significant ancient villages and World War II historical sites exist across American Sāmoa. Although it is not known how climate change will specifically affect individual archeological and cultural sites, coastal areas will likely be affected by erosion, storm surge, and coastal inundation from sea level rise (Addison et al. 2010). For example, Fagatele Bay features a historic coastal village occupied from prehistoric times through the 1950s. The Bay contains one of the few marine archaeological records in the territory: grinding holes or bait cups, known as foaga, carved by ancient Samoans into the shoreline along the reef edge (Leach and Witter 1985; US Department of Commerce 2012). Increased coastal erosion threatens these and other significant cultural sites in American Sāmoa.

- ***Climate change exacerbates challenges to the continued availability of cultural foods and medicinal plants.*** Changes in environmental conditions such as warming oceans, reduced streamflow, saltwater intrusion, and long periods of drought threaten the ongoing cultivation of coconut and the availability of traditional foods such as fish, other seafood, and edible seaweed (Keener et al. 2018). The distribution and presence of medicinal plants may be impacted by changing temperature and rainfall regimes (ASCC 2010), while increasing imports of staple foods such as banana and taro may be needed.

- ***Climate change may necessitate village relocations and change village structure.*** Pacific Islanders, including American Samoans, have an inseparable connection to and derive their sense of identity from the lands, territories, and resources of their islands (Keener et al. 2018). Traditional systems of land and marine tenure complicate relocation out of ancestral areas, and communities do not want to be separated from their lands and waters, which also complicates Federal Emergency Management Agency (FEMA) assistance funding that may be contingent upon relocation. Coastal or remote villages may be more vulnerable to these impacts.

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), especially if the schools are in locations more vulnerable to increased heat.

- ***Utilize locally translated resources to better communicate about climate impacts with village leaders and educators.*** It is important that Samoans be able to communicate about environmental and climate change processes in a consistent manner, using the same English and Samoan terms and definitions. The Resilient Resources Samoan Language glossary provides a common and accepted set of words and definitions to be used by all relevant agencies and organizations when discussing climate change and resilience issues in Samoan. (American Sāmoa Coral Reef Advisory Group Project Lotonuu 2018).

- ***Consider the potential impacts of hotter days on student learning and classroom design.*** Research has found that cumulative exposure to heat negatively impacts students' ability to learn (Goodman et al. 2018). Innovative school building designs that reflect local environmental conditions—including projected increases in air temperature—can benefit students' health and learning outcomes.

- ***Prepare for stronger hurricanes and storm surge, and consider options for schools and educational facilities at the coastline.*** Erosion, storm surge, and coastal inundation from sea level rise will likely affect schools along the coast or in low-lying areas, causing temporary school closures and the need for repairs or rebuilding. Continually updating building and energy codes is known to improve community safety and resilience. Locating and designing buildings to accommodate sea level rise can avoid costs and protect students.

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 vulnerability*** – Risks posed by extreme weather and climate change vary by the vulnerability of the people experiencing impacts. Particularly needed are assessments of risks that account for the socioeconomic and other factors that drive vulnerability of people in American Sāmoa to climate extremes and changes. Such studies can improve understanding of who is at greatest risk and inform pre-disaster recovery plans. Due to the traditional land tenure system in American Sāmoa, where extended families communally own land that is managed by a chief, or matai, not by the government, it is necessary to engage the chiefs at the village level in order to create effective resilience plans (Page et al. 2012).
- ***Critical infrastructure vulnerability assessment*** – 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. Assessing climate vulnerability involves technical analysis of changing hazards, often evaluates exposure, sensitivity, and adaptive capacity, and provides rankings of the seriousness of various climate risks. With the exception of the Climate Related Vulnerability Assessment for Transportation Infrastructure (HHF Planners and USACE 2020) completed for the American Sāmoa Department of Public Works, American Sāmoa currently lacks vulnerability assessments of coastal, wastewater, and other critical infrastructure. Governments and engineers can learn from methods of completed assessments and guidance developed by engineering associations and non-governmental organizations (see for example: Canadian Engineering Qualifications Board 2014; HHF Planners and USACE 2020).
- ***Centralized expertise to coordinate climate adaptation efforts and policies*** – There is a pervasive need for high-level expertise to work directly within the Territory's agencies to support mainstreaming climate change information, strategies, and actions into their existing programs, plans, and projects. It is extremely difficult for jurisdictional governments to identify and hire the high-level experts needed. Direct support from the federal government could be used to fund short-term sit-in positions to help build capacity within and across local agencies (Spooner et al. 2017).
- ***Educational resources for local K–12 and college students and teachers*** – One of the most impactful things that individuals can do to help increase preparedness for climate change is to talk about the issues with their families and communities. Educational climate science resources specific to American Sāmoa are needed to further the conversation at home and at school, as well as training for educators in climate and environmental science.
- ***Quality controls and expanded coverage in climate data records*** – Stations collecting climate data (air temperature, rainfall, wind speeds, etc.) have changed location and some station records are not continuous. Consistent data records of 30 years or more at the same location are needed for tracking climate trends and changes, and to improve and validate future projections. An assessment

University of Hawai‘i researchers worked with staff and interns from the American Sāmoa Power Authority to install weather data collection stations. Stations such as this one collect data that is needed for tracking climate indicators and modeling future change. Photo courtesy of Chris Shuler.

of the quality of the data at each station, especially temperature data, would provide a foundation for determining which data is best suited to climate studies. At present, only a single stream gauge on the island of Tutuila has more than 35 years of observations on record unaffected by upstream diversions.

- ***Data detailing specific coastal erosion rates and impacts, and a comprehensive shoreline inventory*** – Impacts from coastal erosion in American Sāmoa are severe. To enable local adaptation projects and infrastructure design, islandwide data are needed.

- ***Research and modeling on future saltwater intrusion into coastal aquifers*** – The impacts of sea level rise on coastal aquifers and potential saltwater intrusion are largely unknown. This knowledge gap hinders development of effective adaptation strategies for water resources.

- ***Island-scale climate projections for mid-century*** – Many territorial and federal government agencies work on five-year or shorter funding cycles, and existing end-of-century climate projections are not useful for shorter-term adaptation and infrastructure planning.

- ***Development and trials for stormwater management*** – Plans are needed that account for combined sources of flooding, including inland flooding and coastal/tidal flooding.

- ***Detailed sea level rise modeling and exposure mapping*** – For exposed shorelines like those in American Sāmoa, the existing bathtub models of sea level rise are not sufficient for assessing exposure. More detailed modeling and mapping are needed, including areas of projected erosion and the spatial extent of wave runup. The University of Hawai‘i is developing a relative sea level rise viewer that combines island subsidence and global sea level rise and provides an anticipated timeline of impacts.

- ***Economic loss from sea level rise scenario mapping*** – Research on the potential economic impacts of sea level rise—mapped in formats that can be used by policymakers and community planners—can inform climate adaptation planning at multiple scales (for example, the 2017 Hawaii Sea Level Rise Vulnerability and Adaptation Report).

- ***Documented adaptation experiences of other Pacific Islands*** – Literature that conveys 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 how other Pacific Islands have implemented less expensive alternatives to current guidelines for hurricane-resistant buildings and flood preparation.

American Sāmoa Sources of Climate Data and Projections

American Samoa Coral Reef Advisory Group (Project Lotonuu): https://www.crag.as/coral-management/climate-change

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

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

NOAA Quarterly Climate Impacts and Outlook for Hawaiʻi 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

Pacific Climate Change Data Portal: http://www.bom.gov.au/climate/pccsp/

Pacific Climate Change Portal: https://www.pacificclimatechange.net/

Pacific Islands Ocean Observing System (PacIOOS): Short-term Sea Level Projections: http://www.pacioos.hawaii.edu/shoreline-category/highsea/

PacIOOS Hawaiʻi and Pacific Islands King Tides Project: http://www.pacioos.hawaii.edu/king-tides/map.html

University of Hawaiʻi Sea Level Center Experimental Seasonal Sea Level Forecasts: https://uhslc.soest.hawaii.edu/sea-level-forecasts/

US Army Corps of Engineers (USACE) Sea-Level Change Curve Calculator: https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

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 American Sāmoa" 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.

Indicator	How has it changed?	Source	Data Range	Projected future change	Source
Hot days	↑	NOAA Global Historical Climatological Network–Daily (GHCN-Daily), Station AQW00061705, Pago Pago International Airport	1967–2020	↑	Australian BOM and CSIRO 2014 (CMIP5)
Cold nights	↓	GHCN-Daily, AQW00061705, Pago Pago International Airport	1967–2020	↓	Australian BOM and CSIRO 2014 (CMIP5)
Average air temperature	↑	GHCN-Daily, AQW00061705, Pago Pago International Airport	1967–2020	↑	Australian BOM and CSIRO 2014 (CMIP5)
Average rainfall	↑	GHCN-Daily, AQW00061705, Pago Pago International Airport	1967–2020	?	Australian BOM and CSIRO 2014 (CMIP5); Zhang et al. 2016
Extreme rainfall days	No change	GHCN-Daily, AQW00061705, Pago Pago International Airport	1967–2020	↑	Australian BOM and CSIRO 2014 (CMIP5)
Frequency of drought	No change	Australian BOM and CSIRO 2014; Wimhurst and Greene 2021 (no significant change in Consecutive Dry Days)	1961–2011; 1971–2017	No change	Australian BOM and CSIRO 2014 (CMIP5)
Duration of drought	?	No analysis available		No change	Australian BOM and CSIRO 2014 (CMIP5)
Streamflow	?	USGS Pacific Islands Water Science Center, 16931000, Ataulոma Stream	1959–1997	↑	Australian BOM and CSIRO 2014 (CMIP5); Zhang et al. 2016
Tropical cyclone intensity	↑	Kossin et al. 2020; Knapp et al. 2018	1979–2017	↑	USGCRP 2017; Marra and Kruk 2017; Knutson et al. 2010; Sobel et al. 2016; Zhang et al. 2016; Widlansky et al. 2019

▸ **Traceable Accounts**

Indicator	How has it changed?	Source	Data Range	Projected future change	Source
Tropical cyclone frequency	No change	Australian BOM and CSIRO 2014; Marra and Kruk 2017	1969–2011	↓	Kossin et al. 2016; Zhang et al. 2016; Wang et al. 2016; USGCRP 2017; Widlansky et al. 2019
Sea level	↑	NOAA 2020c	1948–2019	↑	Sweet et al. 2017; US-GCRP 2017
High water frequency	↑	NOAA 2020c	1948–2019	↑	Marra et al. 2015
Sea surface temperature	↑	NOAA NCEI ERSSTv5—Huang et al. 2017	1854–2019	↑	USGCRP 2017
Frequency and intensity of heat stress on coral	↑	NOAA Coral Reef Watch 2018 (Liu et al. 2014)—Daily Global 5 km Satellite Coral Bleaching Heat Stress Monitoring	1985–2020	↑	van Hooidonk et al. 2016
Ocean acidification	↑	Marra and Kruk 2017	1988–2020	↑	USGCRP 2017; Australian BOM and CSIRO 2014

Temperature – The daily air temperature record at Pago Pago International Airport extends from 1967 to 2020. Hot days are days that maximum temperature is at or above the 95th percentile of the distribution, corresponding to 90°F (32°C). Cool nights are days for which minimum temperatures were colder than the 10th percentile of the distribution—roughly 73°F (23°C). Due to equipment changes in the temperature sensors between 1995 and 2003, breakpoints were found in the maximum temperature dataset. Therefore, the daily maximum temperature values were statistically homogenized to account for these sensor changes (see Wang and Feng 2013; Wang et al. 2008a; 2008b).

In 2014, the Australian government used general circulation model (GCM) simulations taken from the international Coupled Model Intercomparison Project Phase 5 (CMIP5) to project future climate conditions in the broad geographic region encompassing the Samoan islands. Average annual air temperature at Apia in the Independent State of Sāmoa, 78 miles northwest of Pago Pago, is expected to rise by 1.8–3.4°F (1–1.9°C) by 2050 under the higher scenario (RCP 8.5, that assumes a business-as-usual future development path with no major policy changes to reduce greenhouse gas emissions) and by 1.3–2.5°F (0.7–1.4°C) under the lower scenario (RCP 4.5, that is based on reducing greenhouse gas emissions to be about 85% lower than the high scenario by the end of the 21st century) (Australian BOM and CSIRO 2014). There is *very high confidence* that air temperatures will rise, but *medium* *confidence* in the projected amount of average temperature change.

Rainfall – Missing data in the long-term record is an ongoing challenge. This happens when observations recorded at stations are not transmitted to NOAA's National Weather Service and National Centers for Environmental Information archives. Airport stations are more reliable because data is transmitted hourly via satellite (Marra and Kruk 2017). See location of selected Pacific region precipitation measurement sites (Marra and Kruk 2017, Fig. 3.4). Extreme rainfall is denoted as the number of days per year in which total rainfall exceeded 1.5 inches.

There is less certainty in the CMIP5 models as to the direction of projected change in average annual rainfall than found previously (and reported in CSIRO's 2011 reports) (Australian BOM and CSIRO 2014; Brown et al. 2020). There is *high confidence* that the frequency and intensity of extreme rainfall events will increase under both the lower scenario (RCP 4.5) and the higher scenario (RCP 8.5) 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. However, there is *low confidence* in the magnitude of these changes (Australian BOM and CSIRO 2014). There is one set of dynamically downscaled climate projections available for American Sāmoa (Zhang et al. 2016). Those projections indicate an increase in annual average precipitation of 11% and 18% in the RCP8.5 and RCP4.5 scenarios, respectively, by 2100. There is *low confidence* in those projections.

Drought – The frequency and duration of drought events is expected to remain approximately the same under the higher scenario (RCP 8.5). The overall proportion of time spent in drought in Sāmoa is expected to remain stable, except for a slight decrease under a very low (RCP 2.6) scenario (*low confidence*) (Australian BOM and CSIRO 2014).

Streamflow – There is only a single streamflow record available for American Sāmoa from the USGS Pacific Islands Water Science Center with more than 35 years of record that is unaffected by artificial diversions (Keener et al. 2012). The Atauloma Stream gauge on the island of Tutuila showed a slight and insignificant downward trend from 1959 to 1997 (Keener et al. 2012), which does not provide enough information to determine a significant long-term trend. There is *low confidence* that projected increases in rainfall will cause increased streamflow and runoff relative to historic levels (Zhang et al. 2016; Shuler et al. 2021).

Tropical cyclones and storms – The future is less certain for tropical cyclones than other elements. The environmental conditions to produce a cyclone are at timescales much shorter than global climate model simulations; for example, the state of ENSO and the intensity and phase of the Madden-Julian Oscillation (Diamond et al. 2013). There is a *medium* level of confidence that global tropical cyclone frequency will decrease (USGCRP 2017). In the area surrounding Sāmoa, there is *high confidence* that there will be a decrease in tropical cyclone frequency (Chapter 12, Australia BOM and CSIRO 2014). Recent studies detect increasing trends in tropical cyclone intensity in observations from 1979 to 2017 and raise confidence in projections of increased tropical cyclone intensity with continued warming (Kossin et al. 2020).

Sea level – The long-term sea level trend for American Sāmoa is positive, likely indicating sea level rise. The relative sea level trend at the Pago Pago Harbor, Tutuila, is equivalent to

▶ **Traceable Accounts**

0.72 feet per 100 years from 1948 to 2009, with a 95% confidence (Fig. 12, NOAA 2020c). The earthquake in 2009 caused a rise in the tide gauge record, with the water levels mirroring the post-seismic land subsidence in the Samoan Archipelago. The tide gauge in Pago Pago was attached to a seawall, which moved downward as the island subsided, resulting in a relative rise in sea level. While the 2009 earthquake initially caused Tutuila to rise about 2 to 3 inches, it subsequently subsided by about 7 to 9 inches over the next several years due to "relaxation from the earthquake deformation" (Mörner et al. 2018). There is currently no working tide gauge in Pago Pago, as it stopped operating in early 2020.

Fig.12

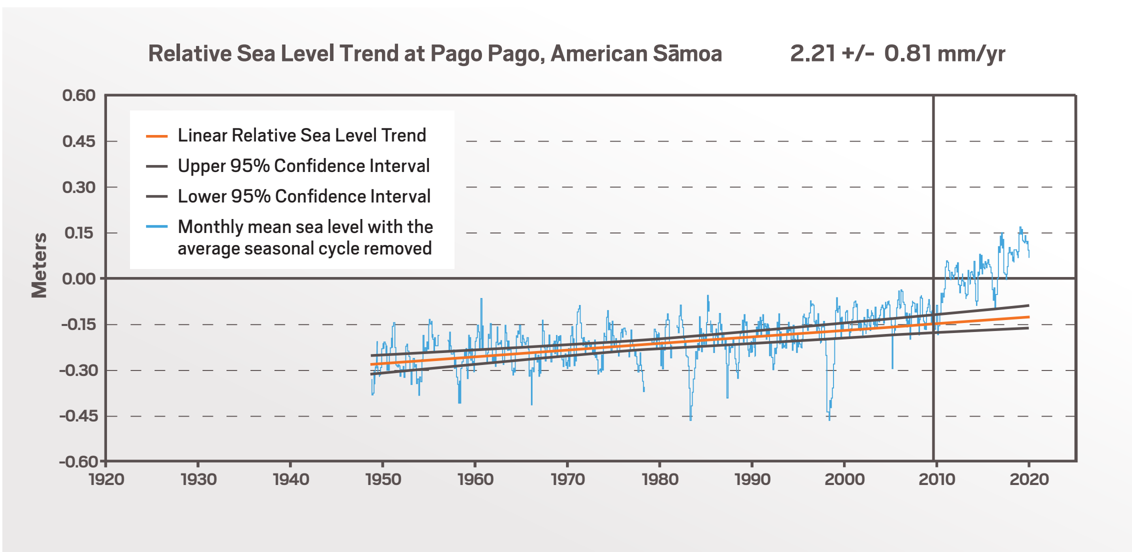

Figure 12. The plot shows the monthly mean sea level at Pago Pago Harbor without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend is also shown (red line), including its 95% confidence interval (black lines). The plotted values are relative to the most recent Mean Sea Level datum established by NOAA CO-OPS. The calculated trends for all stations are available as a table in millimeters/year and in feet/century (0.3 meters = 1 foot). The solid vertical line in 2009 indicates a major earthquake in the vicinity of the station. Source: NOAA Tides & Currents. Relative sea level trend at Station 1770000 Pago Pago, American Samoa, 2020.

For local relative sea level change scenarios, see the NOAA DigitalCoast Sea Level Change Curve Calculator: https://coast.noaa.gov/digitalcoast/tools/curve.html and the USACE Sea-Level Change Curve Calculator: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html. Using the GPS record and tapering subsidence while considering thermal and regional ENSO influences, NOAA and the US Army Corps of Engineers estimated a relative sea level change trend of 0.35 inches (0.89 cm) per year with a high margin of error (+/- 0.386 in; 0.98 cm) (USACE 2019) (*low confidence*). The USACE Sea-Level Change Curve Calculator (Version 2019.21) estimated a sea level rise of 3 feet in a period of 45 years (from 2020 to 2065) and up to 7 feet (rounded up) in 80 years (from 2020 to 2100) (USACE 2019) (Fig. 7).

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," Key Message 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*)." (Fig. 13)

Table 1 (next page) shows the probability of exceeding each of six scenarios for global mean sea level in 2100 under three of the Representative Concentration Pathways (RCPs). However, new evidence regarding the Antarctic Ice Sheet would support much higher probabilities of exceeding the Intermediate-High, High, and Extreme scenarios in 2100 (Sweet et al. 2017). In American Sāmoa and other islands in the South Pacific, because they 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: 12.5.4). Thus, GMSL rise of 1.6 feet (0.5 m) in 2100 translates into approximately 1.7 feet of local sea level rise in American Sāmoa. And, GMSL rise of 6.6 feet (2.0 m) in 2100 would mean about 8.6 feet in American Sāmoa (Sweet et al. 2017).

Fig.13

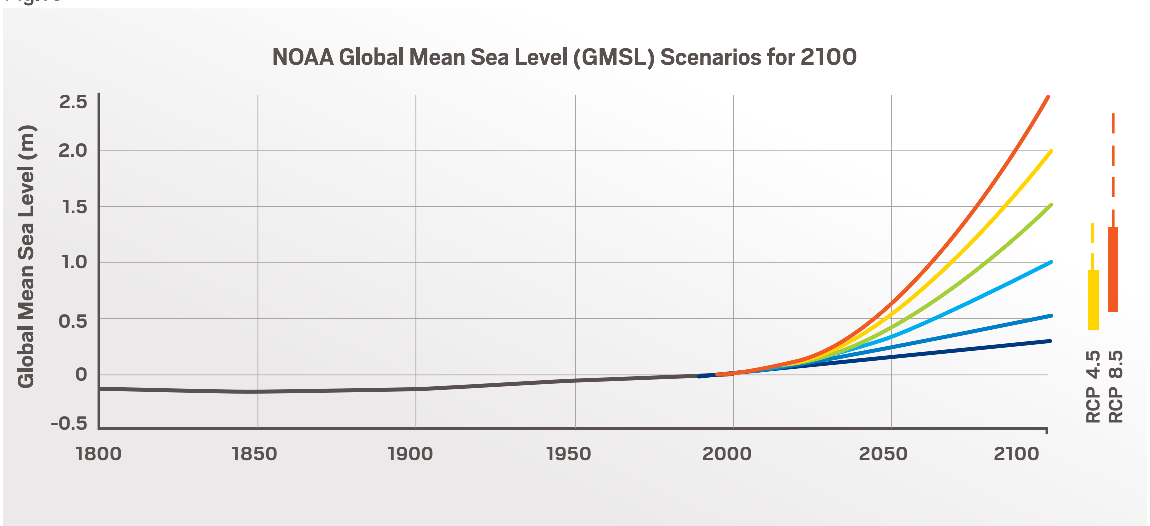

Figure 13. Six representative Global Mean Sea Level (GMSL) rise scenarios for 2100 (six colored lines) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800 to 2015. The colored boxes show central 90% conditional probability ranges of RCP-based GMSL projections 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)	0.5%	1.3%
High (2.0 m)	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.1%

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.

Ocean changes – The region was mostly free from long-lasting severe bleaching stress during the first half of the assessment period. Using NOAA Coral Reef Watch satellite data, a shift in the regime of bleaching heat stress seems to occur around 2001. Whereas no years prior to 2000 recorded heat stress at Alert Level 1 or higher for 90% of reef grids, 9 of the most recent 16 years had >90% of the reef grids exposed to Alert Levels 1 or 2 (and 7 of those years had 100% exposure). See Fig. 6.2 in Marra and Kruk 2017 (Average Sea Surface Temperature Anomaly for the central South Pacific). There was local bleaching recorded in 1994 (Goreau and Hays 1995), demonstrating that local heat stress conditions may not always correspond to satellite monitored ocean temperatures. There is *very high confidence* in the increased risk of coral bleaching as the ocean warms, and *medium confidence* in the projected rate of change for the waters around Sāmoa because there is *medium confidence* in the rate of change of SST, and the changes at the reef scale (which can play a role in modulating large-scale changes) are not adequately resolved (Australian BOM and CSIRO 2014).

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Notes

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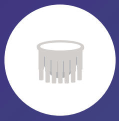

The **tanoa** is a bowl, usually made from the wood of the ifilele tree, that is used for drinking ʻava (kava) in the Samoan archipelago. The symbol often represents service to the chief.

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