

Sea Level Rise in the U.S. Affiliated Pacific Islands (USAPI)

Pacific Islands Climate Education Partnership



What is sea level? How has sea level been changing?

The ocean holds the vast majority (97%) of Earth's water. Ocean water is salty. Water in rivers, lakes, glaciers and in the atmosphere is fresh.

Even though the ocean has different names in different parts of our planet, the ocean is really one huge body of water that covers most (71%) of Earth's surface area. The Pacific Ocean is the largest part of the ocean that has its own name. In addition to the Pacific Ocean there are four others: the Atlantic Ocean, the Indian Ocean, the Southern Ocean, and the Arctic Ocean (**Figure 1**). The ocean in different places does have characteristics that are related to the different locations. For example, ocean water near the equator is much warmer than ocean water near the North Pole.

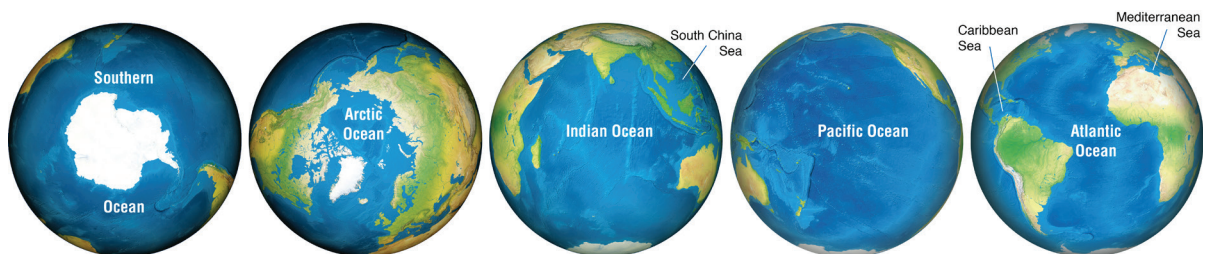


Figure 1 Earth has five oceans: Southern, Arctic, Indian, Pacific, and Atlantic. There are also a number of small water bodies called "seas." These are all connected which is why we say that Earth has one ocean.

Our planet is more than four billion (4,000,000,000) years old. During Earth's very long history, the level of the ocean has changed many different times. For example, during an **ice age**, the **sea level** – the average height of the ocean surface – may be 100's of feet lower. This happens because during an ice age more of the planet's water is located as ice in massive land glaciers that can be more than 1 mile (1.6 kilometers) thick. As a result, the ocean has less water in it, and sea level is lower.

At the coldest part of the last ice age (about 20,000 years ago), the sea level was about 400 feet (120 meters) lower than it is today. So the Pacific islands then were bigger. Some of the islands that are now separate were connected to each other. However, people had not yet arrived on the islands.

As the ice melted after the ice age, the sea level rose to its current level. We know from scientific measurements that the planet's average sea level became stable and did not change very much in the past 2,000 years. Today, because climate is changing, the sea level has been rising for about the past 200 years. The scientific evidence strongly shows that **global warming** has caused this **sea level rise**.

Scientists predict that global warming will cause our planet's average sea level to rise by about 2 to 3 feet (0.6 to 0.9 meters) or more by the end of the century. These estimates are averages for the whole planet. So some places will see more sea level rise and some places will see less. Additional research may cause scientists to change these estimates as they learn more about how global warming affects the ocean.

Unfortunately, the sea level is rising faster in the western tropical Pacific around Micronesia than the average for the rest of the planet. Scientists think this is because winds blowing to the west are pushing water into the western Pacific. These higher sea levels in the western Pacific are causing significant damage to many islands, including: **coastal erosion**, flooding, damage to crops and soil, and damage to fresh water resources. Higher sea levels due to global warming will cause even greater problems in the future. A very high tide or storm surge that might have caused minor damage in the past could cause more damage today and in the future as sea level continues to rise.

What causes sea level to rise?

One reason that global sea level is rising is that higher air temperatures are melting more of the ice that is on land. The liquid water from this melted ice then flows into the ocean. Another reason that the sea level is rising is that the ocean has been getting warmer. When water gets warmer it expands in volume and takes up more space; this causes the ocean surface to rise. Because there is so much water in the ocean, even a small increase in the average temperature of ocean water can cause the level of the whole ocean to rise.

Global warming over this century will cause sea level to keep rising. Warmer ocean water causes sea level to rise, and more melting of land-based ice also causes sea level to rise. Some scientists are especially concerned because there are huge amounts of ice on the polar lands of Greenland and Antarctica and in the mountains of the world. Melting of this ice could raise global sea level enough to completely drown many coastal areas of the world. There is a lot that we still do not understand about how much and how quickly the melting of ice will cause sea levels to rise in this century. But scientists are very certain that sea level rise will be a problem that coastal communities need to prepare for.

We all see the level of the ocean changing during the day, and from one day to the next day. These changes happen because of tides, winds, and storms. These short-term changes make it hard for us to directly see that the sea level is rising over the course of years or decades. Scientists can observe the long-term rise in sea level because they use very precise technologies to measure local and global sea level. Scientists then compare the observations that have been made over many years, and their research tells us that sea levels are rising around the world.

As the sea level rises, it can cause beaches and coastal lands to erode and wash away. We might notice this impact of rising sea levels on our islands by the loss of trees, beaches or homes (**Figure 2**). Scientists can also document the loss of coastal land by comparing old and new photographs of the same area taken from planes or satellites.

When the average sea level is higher, anything that normally causes the sea level to rise can cause more damage to islands and coasts. Some normal forces of nature that cause the sea level to temporarily rise are **king tides**, winds, hurricanes (typhoons) and **tsunamis**. When any of these events occur they cause flooding of salt water into places where we grow food and get fresh drinking water. As sea level rise continues, these problems will get worse.



Figure 2 On the island of Kosrae, chronic coastal erosion has caused beach loss, undermined trees, and threatens coastal roads and buildings.

What do we know about tides in the Pacific islands?

The sea level on all the islands in the USAPI changes during each day (See Appendix A for a map of the U. S. Affiliated Pacific Islands). In some parts of the day, the sea level continuously rises until it stops increasing, and we call that a **high tide**. Then the sea level falls until it stops decreasing, and we call that a **low tide**. The times of low tide and high tide change a little from one day to the next day.

The two graphs (**Figure 3**) show how sea level generally changes in the tropical Pacific. The graphs show what we generally experience: the daily cycle has two high tides and two low tides. In most Micronesia and Hawaii locations, one of the day's high tides is higher than the other high tide, and one of the day's low tides is lower than the other low tide. Tides during a day in American Samoa are a little different than in Micronesia. Each of a day's high tides is equally high, and each of the day's low tides is about equally low.

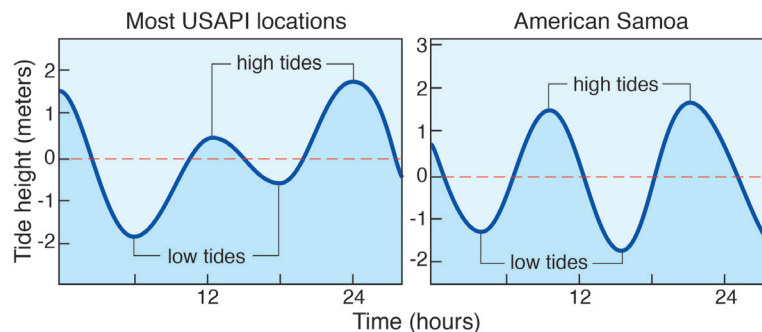


Figure 3 The USAPI has two general tide patterns.

Tides are caused mainly by the pull of gravity from the Moon and the Sun acting on Earth's surface. The Moon pulls more on Earth's water than the Sun does because the Moon is much closer to our planet. When the Moon is in one of its half-moon phases, the gravitational attraction of the Moon and Sun are pulling in different directions. During those times of the month, the high tides are not very high and the low tides are not very low.

When the Moon looks very full or is nearly completely dark, the gravitational attraction of the Moon and the Sun are both pulling on the ocean in the same direction. During those times of the month, the high tides are higher than average and the low tides are lower than average. That is why the king tides (highest tides of the year) happen close to the full Moon or new Moon times. (See Appendix B for data about the range of tide heights in the USAPI.)

What do we know about how winds affect sea level in the Pacific islands?

The atmosphere is a very important part of the Earth system. The atmosphere holds Earth's air. However, since air is an invisible gas, many people do not realize that air is made of matter and takes up space, just like a rock is made of matter and takes up space. Wind is invisible gaseous matter and rock is visible solid matter.

Wind is simply moving air. Because we can feel wind, especially when it is blowing hard, winds should remind us that air is matter that can push us in one direction or make it hard for us to go in the opposite direction. Winds move so fast that air can travel all the way around our planet in less than a month.

Just as winds can push us around or make objects fly in the air, winds also push the water at the ocean's surface. People who live near the ocean know that blowing winds make the water rougher, and cause more and bigger waves. Even if you live by the ocean, you may not know that when the wind over the ocean blows a lot in a particular direction, it will cause sea levels to be higher in that direction. This fact is very important in the tropical Pacific because winds generally blow from the east towards the west. These winds are called **trade winds**.

These west-blowing trade winds cause the rate of sea level rise to be higher in the western tropical Pacific than in more eastern locations. For example, the rate of sea level rise at Pohnpei and Majuro tends to be higher than the sea level rise at Hawaii and California. The trade winds, moving water across the Pacific to the west, is causing sea level to rise faster in the western tropical Pacific than most other places in the world.

In some years, the trade winds, particularly in the Southern Hemisphere, temporarily become weaker or collapse entirely and are replaced by winds from the west blowing toward the east. This condition is known as **El Niño**. As a result, the warm water of the west Pacific moves to the east and heats up the ocean surface in the central and eastern Pacific. Sea level temporarily drops in Micronesia and drought may also occur.

In other years, the trade winds may become stronger than normal. This condition is known as **La Niña**. As a result, more warm water than usual moves from the east to the west Pacific. Sea level temporarily rises even higher in Micronesia, and storms and king tides cause more damage than normal.

What do we know about how storms and tsunamis affect sea level in the Pacific islands?

The local sea surface rises and falls each day with the tides. Two other natural phenomena cause much larger and more dangerous changes in local sea levels, but they occur much less frequently than the daily tides. These natural events are called **tropical cyclones** and tsunamis.

Tropical cyclones are natural extreme weather events. A tropical cyclone is a large storm system characterized by numerous thunderstorms, heavy rain, and strong winds that circulate a central area (called the “eye”) that has an unusually low atmospheric pressure. In the western Pacific tropical cyclones are usually called “typhoons,” while in the eastern Pacific and the Atlantic they are usually called “hurricanes.” Typhoon and hurricane are two different names for the same thing. Tropical cyclones are especially damaging when they approach land. These huge storms bring powerful winds and high sea level that can destroy trees and houses.

Typhoons cause very dangerous flooding produced by ocean **storm surge** and by heavy rains. As we have discussed, strong winds can cause the ocean level to rise. Typhoons feature some of the strongest winds on our planet, and the very high waves caused by these winds can make ocean water flood over the coasts. In addition, these tropical cyclones have a low atmospheric pressure. Pressure from the atmosphere always pushes down on the ocean. The lower atmospheric pressure during a typhoon pushes down less on the ocean, so the ocean rises and the storm surge becomes bigger. Storm surge in a strong tropical cyclone can raise sea level along the coast by several feet.

In the western Pacific, the typhoon season peaks in early September and the fewest typhoons occur in February and March. In the Southern Hemisphere the tropical cyclone season runs from early November until the end of April with the largest frequency of storms occurring in mid-February to early March.

Unlike tropical cyclones, tsunamis are not weather events. Instead tsunamis are waves that are caused by sudden movement of the seafloor. Natural events such as earthquakes, volcanoes, and landslides can produce sudden movements in the bottom of the ocean that cause tsunamis. Tsunami waves can travel across the ocean as fast as an airplane. The wave is not very high in the deep ocean, but when it reaches the shore, it grows taller and can rapidly flood the land, especially where the land is flat and low-lying.

Tsunamis have inundated the Pacific Islands in the past. One example is the tsunami that hit American Samoa on September 29, 2009. The tsunami was caused by a magnitude 8.0 earthquake located 120 miles (193 kilometers) south of Samoa, one of the most active earthquake regions in the world. The first tsunami wave reached Pago Pago Harbor just 14 minutes after the earthquake occurred. The wave was about 15 feet (4.5 meters) high and reached about a quarter of a mile (0.4 kilometer) inland (**Figure 4**). The tsunami caused more than 150 deaths and led to major damage in Samoa, American Samoa and Tonga.



Figure 4 The 2009 tsunami in Pago Pago Harbor, American Samoa. This image shows water draining off the land after the tsunami did extensive damage to the community.

Tropical cyclones and tsunamis have both caused immense damage to human communities living on Pacific Islands. Combined with higher sea levels due to global warming, stronger winds, more rain, and following new tracks, these extreme events are more dangerous now, and will be even more dangerous in the future as sea level continues to rise. While global warming will not affect how strong a tsunami will be, it is likely that global warming will affect the strength of tropical cyclones, and also change how often they occur and where they occur in the Pacific.

What kinds of damage do high sea levels cause in the Pacific islands?

The higher sea levels caused by global warming are already causing significant problems in the USAPI, and these problems will get much worse as sea level continues to get higher. These problems will be most severe for atolls and other locations where the coastal land is at low elevation. As shown in **Figure 5**, a small rise in sea level causes a much larger amount of land to be under water, especially when the coast is not steep. This is called coastal erosion.

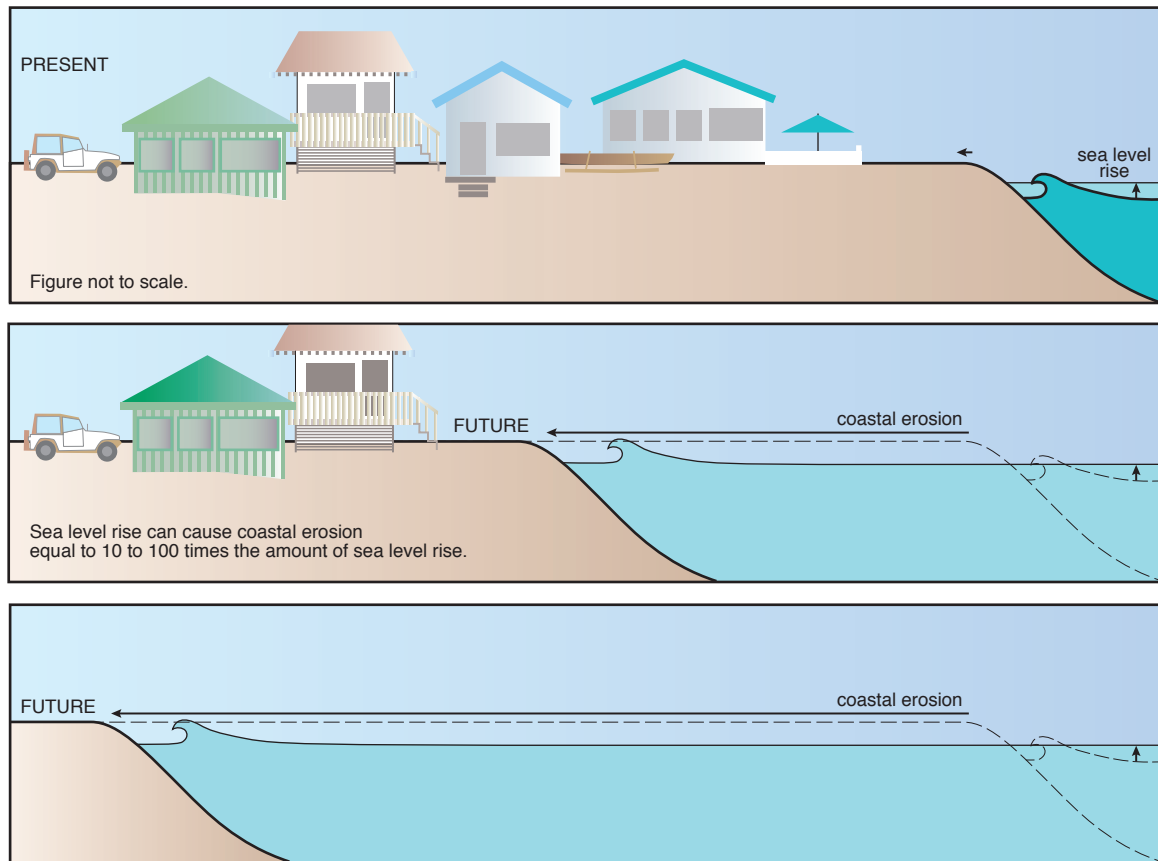


Figure 5 A small rise in sea level can lead to the loss of a much larger amount of land.

Erosion of coastlines is particularly hazardous when homes are located close to the water, and especially in locations such as atolls where there are few or no choices to live or grow food or get freshwater at higher elevations. Even when the rising sea level does not flood the land, it can cause severe problems because the salty ocean water that is under ground is also rising, and can contaminate groundwater that had been fresh and used for drinking and growing food.

Places that had been used to grow taro and other salt-sensitive crops can become useless and take a very long time to recover, or may never recover. Breadfruit trees, coconut, banana and other foods can die when their roots reach saltwater in the ground. King tides (**Figure 6**), which are episodes of very high tides once or twice a year, can cause ocean water to flood across the beach and over the land and destroy food crops. King tides also cause the fresh groundwater to be intruded by saltwater and destroy wetlands, taro patches, lakes, and other



Figure 6 King tides in 2007 and 2008 flooded low coastal lands and destroyed food and drinking water supplies throughout Micronesia.

freshwater ecosystems. Because of this problem, food and drinking water are threatened, especially on atolls (**Figure 7**).

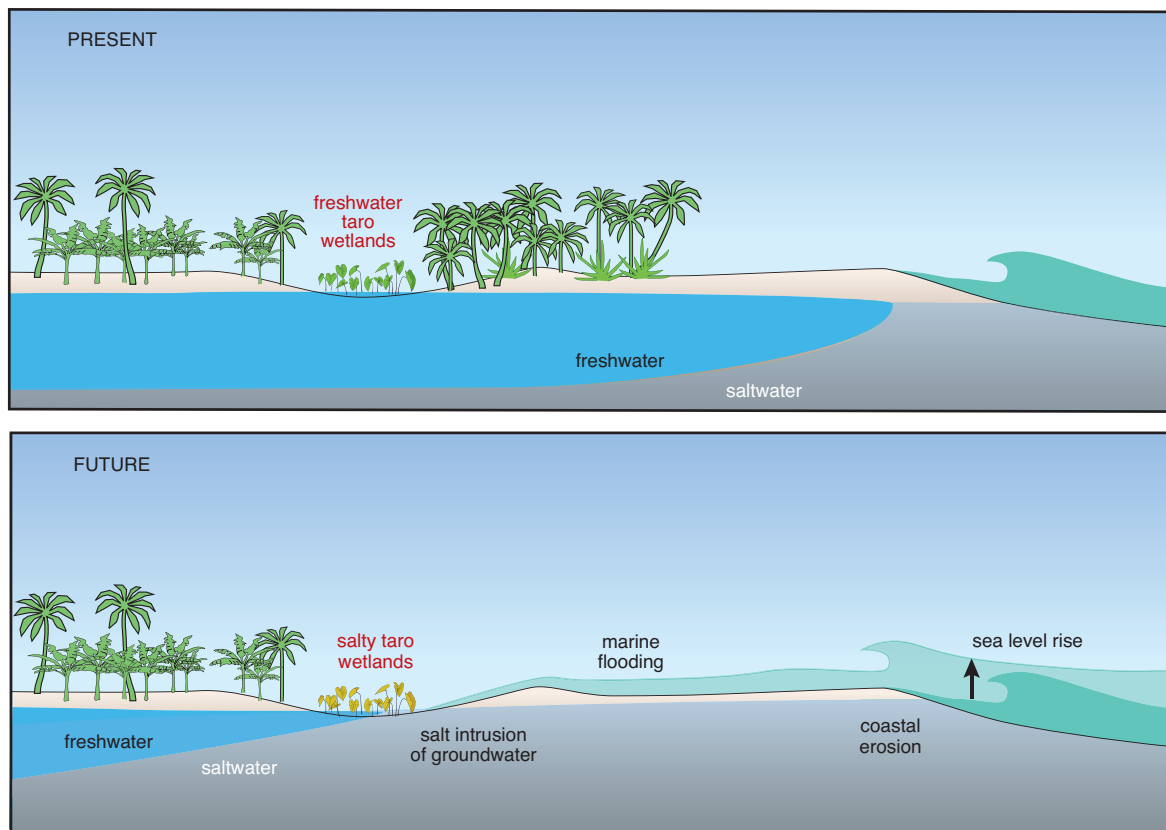


Figure 7 In addition to causing more coastal erosion, rising sea level harms islands by increasing marine flooding and by raising the level of salty water underground. Flooding above ground and salt intrusion from below ground damage agriculture and reduce supplies of fresh water.

A rising level of underground salt water also directly impacts the ability to get fresh drinking water from wells. As with other issues related to rising sea level, this issue will cause more problems for people living on atolls than for communities on volcanic islands where people can get freshwater from streams and springs.

Rising sea level can cause significant problems on high islands because homes, recreational areas, roads and drinking water wells are often very close to the ocean. As mentioned earlier, the problems caused by rising sea levels become particularly severe when there is a king tide, a typhoon or a tsunami. An event that would have caused minor problems in the last century could be a catastrophe for a Pacific island in this century.

Rising sea levels will also cause health problems. When people have difficulty finding a safe place to live, and getting healthy food and fresh water, they become weaker and more likely to become sick. Flooding from high sea level leaves pools of contaminated water that can be breeding areas for insects and diseases. In addition, the mental stress caused by rising sea level and its potential impacts harm the body and the mind.

How can people in the Pacific islands adapt to the impacts of rising sea levels?

We use the term **climate adaptation** to describe the things that people, communities and governments can do to help protect themselves from harmful climate impacts. A Pacific Island community that has not done any climate adaptation planning is much more likely to be damaged by the harmful impacts of rising sea levels than a community that has planned and implemented strategies that make their homes, roads, water supplies and food supplies safer from rising sea levels (**Figure 8**).

Communities that have not planned any climate adaptation activities are more vulnerable to the harmful impacts of rising sea levels. Communities that have engaged in thoughtful practices of climate adaptation are more **resilient** (safer) with respect to the impacts of rising sea levels and other climate changes. Being more resilient means that the community will probably suffer less damage and recover more quickly from flooding events related to rising sea levels.

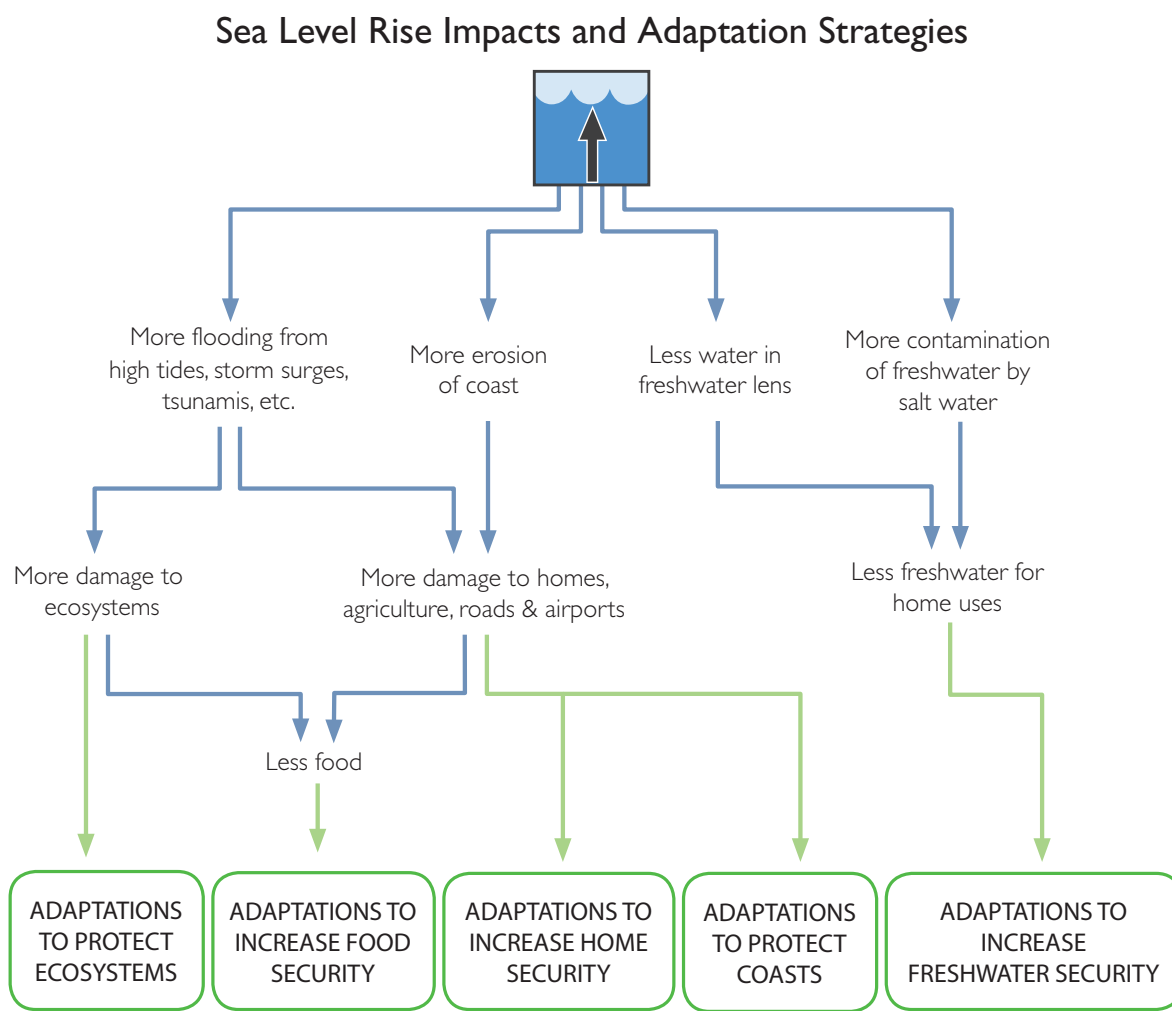


Figure 8 Impacts of sea level rise and kinds of adaptation strategies.

In general, there are three kinds of climate adaptation activities that can help make people, communities, and nations safer with respect to rising sea levels and other climate impacts. These kinds of adaptation activities are:

- Protecting local ecosystems to help these ecosystems be more resilient
- Increasing the resiliency of the communities' physical systems such as homes, roads, water supplies, and food supplies
- Making the community's cultural systems stronger and healthier so people in the community effectively plan and implement climate adaptation strategies that work in and for that community

The Micronesia Conservation Trust has produced materials that help Pacific Island communities understand climate impacts. These materials provide guidance with respect to planning and implementing climate adaptation activities. Under the title *Adapting to a Changing Climate*, these materials include large flipcharts that can be brought to local communities and a booklet that summarizes and explains the information in the large charts¹.

There are a wide variety of adaptations that can increase the resiliency of ecosystems, human physical systems, and human cultural systems. Examples include:

- Raising homes and roads above the ground and away from the shoreline,
- Reducing pollution and damage to ecosystems,
- Installing and maintaining efficient water catchment systems,
- Eradicating invasive species that threaten ecosystems, and
- Growing taro in cement patches that protect the plants from saltwater.

Other resource materials from the Pacific Islands Climate Education Partnership (PCEP) explain more about the science of climate change and its impacts on Pacific island communities. These materials can be accessed at <http://pcep.prel.org>

¹ The booklet *Adapting to a Changing Climate* can be accessed at <http://www.cakex.org/virtual-library/3439>

Appendix A

The U.S. Affiliated Pacific Islands (USAPI)



The United States Affiliated Pacific Islands (USAPI) region includes American Samoa, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia (Chuuk, Kosrae, Pohnpei, and Yap), Guam, Hawaii, the Republic of the Marshall Islands, and the Republic of Palau.

Appendix B

Range of Tide Heights in the U.S. Affiliated Pacific Islands (USAPI)

Hawaiian Islands

Average range: 0.0 ft in Hanamaulu Bay, Kauai to 1.8 ft in Hana, Maui.
High range: 1.2 ft in Hanamaulu Bay, Kauai to 2.5 ft in Hana, Maui.

Micronesia:

Guam

Average range: 1.6 ft at Apra Harbor
High range: 2.4 ft at Apra Harbor

Federated States of Micronesia

Average range: 1.3 ft at Namonuito Atoll to 3.0 ft at Ngulu Islands
High range: 1.8 ft at Ifalic Atoll to 3.8 ft at Ngulu Islands

Northern Mariana Islands

Average range: 1.3 ft in Saipan Harbor, Saipan to 1.5 ft on Tinian Island
High range: 1.8 ft on Tinian Island to 2.2 ft in Tanapag Harbor, Saipan

Republic of Marshall Islands

Average range: 2.0 ft at Wake Island to 4.2 ft at Port Rhin, Mili Atoll
High range: 2.4 ft at Wake Island to 5.9 ft at Port Rhin, Mili Atoll

Republic of Palau

Average range: 3.3 ft in Shonian Harbor to 3.9 ft in Malakal Harbor
High range: 4.4 ft in Shonian Harbor to 5.1 ft in Malakal Harbor

Samoan Islands (Tutuila, Manua, Rose and Swain)

Average range: 2.5 ft in Pago Pago Harbor, Tutuila to 3.7 ft in the Manua Islands
High range: 2.7 ft in Pago Pago Harbor, Tutuila to 4.6 ft in the Manua Islands

Information collected from: <http://tidesandcurrents.noaa.gov/tides08/tab2wc3.html#163>

Glossary

Climate adaptation Actions taken by people, communities and governments that help protect themselves, and ecosystems, from harmful climate impacts.

Coastal erosion Wearing away and loss of beaches and land due to waves. Coastal erosion gets worse when sea level rises.

El Niño A natural climate event, lasting typically less than 1 year, which occurs in the Pacific when the normal trade winds weaken (or die). This causes warm water in the western tropical Pacific to surge into the central and eastern Pacific. El Niño can cause temporary global changes in the climate and weather.

Global warming When the air in the lowest portion of the atmosphere (the troposphere) gets significantly warmer than normal. Global warming is caused by an increase in the amount of heat-trapping greenhouse gases when humans burn fossil fuels (coal, petroleum, natural gas) for energy. Other types of greenhouse gases produced by humans also contribute to the problem.

High tide High tide is the highest level reached by the tide. The tide is the alternating rising and falling of the sea, usually twice in each day, due to the gravitational attraction of the Moon and Sun.

Ice age A period of time in Earth history, usually lasting tens of thousands of years, when Earth's air temperature is significantly lower than average. During an ice age northern lands are covered in glacial ice that may be over half a mile (1 kilometer) thick. Ice ages are natural events caused by changes in Earth's exposure to sunlight.

King tide Unusually high tide, usually the highest tides of the year. King tides may cause flooding on low-lying coastal lands.

La Niña A natural climate event, lasting typically less than 1 year, which occurs in the Pacific when the trade winds grow stronger than normal. This causes a body of warm water to accumulate in the western tropical Pacific and is an opposite state to El Niño.

Low tide Low tide is the lowest level reached by the tide. The tide is the alternating rising and falling of the sea, usually twice in each day, due to the gravitational attraction of the Moon and Sun.

Resilient Resilient communities are better able to bounce back from disasters and disruptions in a sustainable way and maintain a good quality of life for all. They are better prepared for uncertainties and able to adapt to changing conditions.

Sea level The average level of the surface of the ocean.

Sea level rise When the average level of the surface of the ocean rises, especially as a result of global warming that melts glaciers (increasing the amount of water in the ocean) and warms the ocean (causing ocean water to expand, upwards).

Storm surge A rising of the sea level caused by low atmospheric pressure and high winds associated with a tropical cyclone. Storm surge causes damaging flooding of coastal lands when a cyclone hits a coastline.

Trade winds A wind blowing steadily toward the equator from the northeast in the northern hemisphere or the southeast in the southern hemisphere, especially at sea.

Tropical cyclone A rotating system of strong winds, clouds and thunderstorms that produce heavy rain. Tropical cyclones are organized around a center, or eye, where there is low air pressure.

Tsunami A long, high sea wave produced by sudden movement of the seafloor. Tsunamis are often caused by earthquakes, but may also be caused by undersea landslides or volcanic eruptions.

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Illustrations by Nancy Hulbirt, Anita Moorjani, and Jennifer Mendenhall.

Photographs

Figure 2. Photograph of eroding shoreline, Kosrae, FSM.

Figure 4. Photograph of flooding and damage from 2009 tsunami, Pago Pago Harbor, American Samoa. NOAA, National Centers for Environmental Information, Image Database.
www.ngdc.noaa.gov/hazardimages/picture/list?tag=pago+pago&max=10&offset=10

Figure 6. Photograph of flooding 2007 king tide, Kosrae Island
Resource Management Agency

Feedback

What do you like or do not like about this booklet? We want any comments or advice that can help improve this booklet. Please share these with us by email to fletcher@soest.hawaii.edu and asussman@wested.org