Sea Level Rise in the U.S. Affiliated Pacific Islands (USAPI) (2/1/12)

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

The ocean holds the vast majority (97%) of Earth's water. The saltiness of ocean water is the major difference between the ocean and Earth's water that is in rivers, lakes, glaciers or in the atmosphere.

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 (see 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 – is much lower. This happens because during an Ice Age more of the planet's water is located as ice in massive glaciers on the land 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 that 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 increase in sea level.

Scientists predict that global warming will cause our planet's average sea level to rise by about 1 foot (32 centimeters) by the middle of the century, and to rise somewhere between 2.5 to 6.2 feet (0.75 to 1.9 meters) by the end of the century. These estimates are averages for the whole planet. 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 Micronesia. These higher sea levels in the western Pacific are already damaging Pacific islands. 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 today could cause much more damage in the year 2050, and could be a huge disaster in the year 2100.

What causes the planet's 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 increase.

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. There is a lot that we still do not understand about how much and how quickly the melting of that ice will cause sea levels to rise in this century.

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 more of the coastal area to erode and wash away. We might notice this impact of rising sea levels in our locations 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.

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

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.

What do we know about tides in the Pacific islands?

The sea level on all the islands in the USAPI changes during each day. 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 equally low.

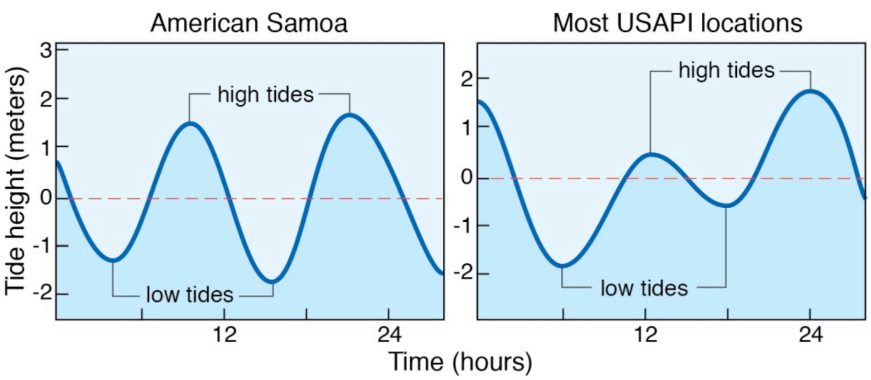

Figure 3. The USAPI has two general tide patterns.

Tides are caused by the Moon and the Sun pulling on Earth's oceans and lakes. The Moon pulls more on Earth's water than the Sun does because the Moon is much closer to our planet than is the Sun. 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 Earth's water 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 has 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. The wind is invisible gas stuff and the rock is visible solid stuff - they are both made of 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 above the ground move so fast that air over your head right now can travel all the way around our planet and be back over your head 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 there do generally blow from the east towards the west. These winds are called "trade winds." Several centuries ago, when all ships needed wind to travel, sailors relied on these west-blowing winds to plan their routes and sail on the ocean.

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.

On occasion, the trade winds, particularly in the Southern Hemisphere, temporarily become weaker. 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 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 blows from the east to the west Pacific. Sea level temporarily rises even faster in Micronesia, storms increase, and floods may occur.

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 rarely rather than every day. These natural events are large storms 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." Tropical cyclones are especially damaging when they approach land. These huge storms bring powerful winds that can destroy trees and houses.

Typhoons also 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 also 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 even higher and the storm surge becomes even bigger. Storm surge in a strong tropical cyclone can raise sea level along the coast by more than 20 feet (more than 6 meters).

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 November 1 until the end of April with the largest frequency 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 large movements in the bottom of the ocean that cause tsunamis. Tsunami waves can travel across the ocean as fast as a plane. 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, the most recent example being the tsunami that hit American Samoa on September 29, 2009. This tsunami was generated by an earthquake near Samoa that affected the islands of Samoa, American

Samoa and Tonga. 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. The tsunami caused more than 150 deaths and led to major damage in Samoa, American Samoa and Tonga.

Figure 4: First wave of the 2009 tsunami in Pago Pago Harbor, American Samoa. The red arrow points to a man avoiding the rushing water by clinging to the roof[1].

Tropical cyclones and tsunamis have both caused immense damage to human societies living on Pacific Islands. Combined with higher sea levels due to global warming, these extreme events are more dangerous now, and will be even more dangerous in the future. 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 the 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 length of land to be under water, especially when the coast is not steep.

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[1] Gibbons, Helen. USGS Scientists Respond to Deadly Samoa Tsunami. USGS Soundwaves Monthly Newsletter. Nov. 2009. Web: http://soundwaves.usgs.gov/2009/11/fieldwork2.html. Accessed 10/28/11. Photograph taken by National Oceanic and Atmospheric Administration fisheries biologist Gordon Yamasaki from his second-floor office in Pago Plaza. Yamasaki estimated that the first wave was about 3 meters high at the site of his office more than 100 meters from the shore. The wave was much larger at many locations in American Samoa.

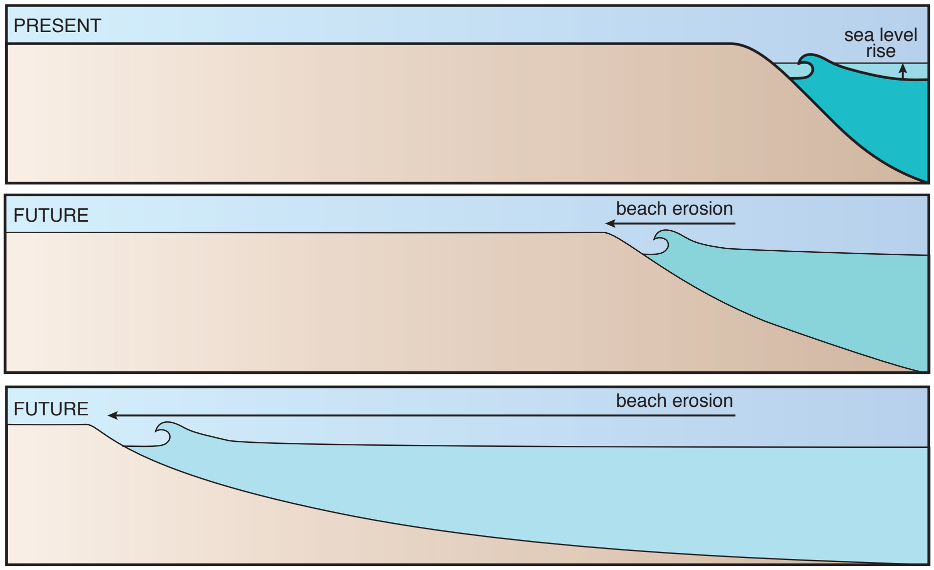


Figure 5: A small rise in sea level can lead to the loss of a much larger length of beach.

Erosion of beaches 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, 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 (Figure 6) also cause the fresh groundwater to be intruded by saltwater and destroy wetlands, taro patches, lakes, and other freshwater ecosystems. Because of this problem, food and drinking water are threatened, especially on atolls.


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

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.

Even volcanic islands can have significant problems because of rising sea levels because homes, recreational areas, and infrastructure such as roads 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 later in this century.

Rising sea levels will also cause health problems. When people have problems with having 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.

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.

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

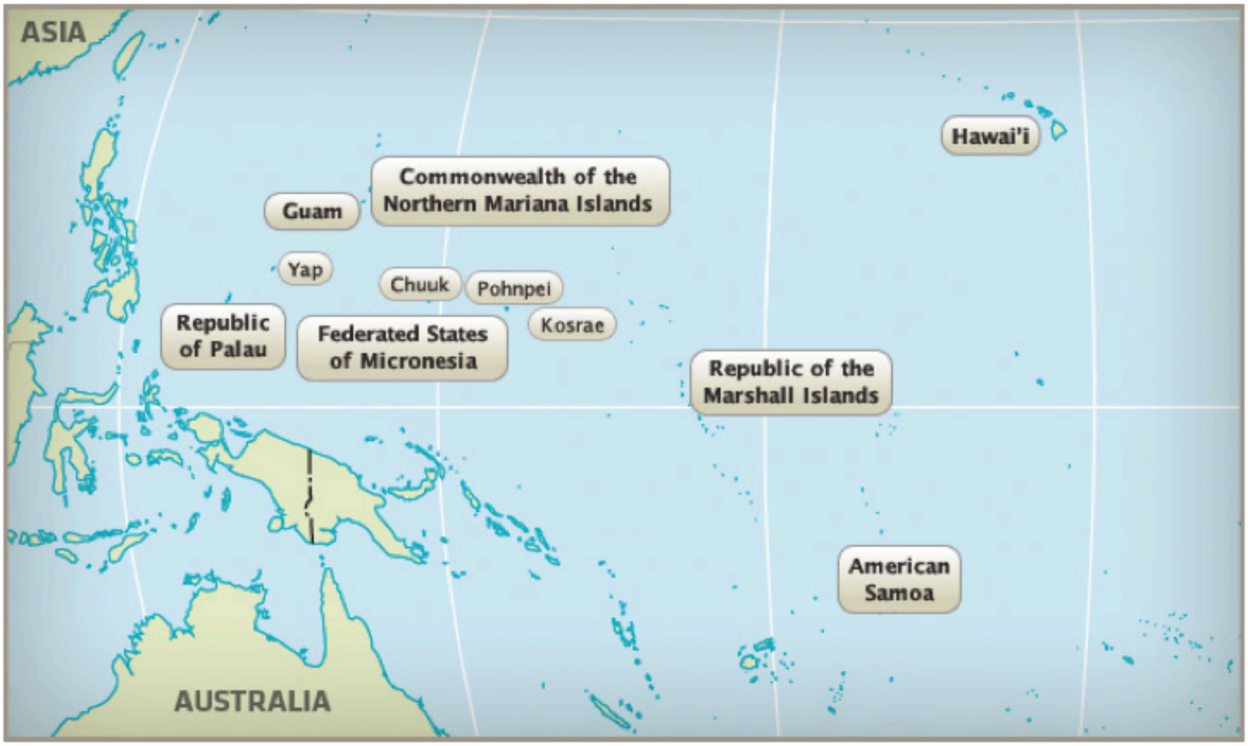
The Micronesia Conservation Trust has produced materials that help Pacific Island communities understand climate impacts. These materials provide guidance with respect to planning and implementing climate adaptation activities. Under the title *Adapting to a Changing Climate,* these materials include large flipcharts that can be brought to local communities and a booklet that summarizes and explains the information in the large charts.[2]

There are a wide variety of adaptations that can increase the resiliency of ecosystems, human physical systems, and human cultural systems. Examples include moving homes and roads to higher elevations, reducing pollution of ecosystems, installing efficient water catchment systems, eradicating invasive species that threaten ecosystems, and growing taro in cement patches that protect the plants from saltwater.

Future essays in this series will explain more about the science of climate change and its impacts on Pacific Island communities. These essays will also provide more information about climate adaptation activities that can increase the resiliency of Pacific Island communities with respect to food security and freshwater security.

[2] The booklet *Adapting to a Changing Climate* can be accessed at http://pcep.dsp.wested.org/content_items/1524355

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 US 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: 2.02 ft at Wake Island to 4.2 ft at Port Rhin, Mili Atoll
High range: 2.36 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: 2.72 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

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