

# 2014-2016 El Niño Assessment Report

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## An Overview of the Impacts of the 2014-16 El Niño on the U.S.- Affiliated Pacific Islands (USAPI)



**National Oceanic and  
Atmospheric Administration**

U.S. Department of Commerce

**Michael Rupic, Lauren Wetzell, John J. Marra, Seema Balwani**

NOAA National Centers for Environmental Information (NCEI)

Inouye Regional Center (IRC), 1845 WASP Blvd., Building 176, Honolulu, Hawaii 96818

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## **Summary**

The 2014-2016 El Niño was one of the strongest events on record. It was similar to previous strong events such as the ones in 1982/83 and 1997/98, however, the intensity of the physical forcings and the extent of the social impacts were unprecedented. Anomalous climatic conditions included above average rainfall during the initial stages of the event, below average sea level during the peak of the event, below normal rainfall during the final stages of the event, and elevated sea surface temperatures during the peak of the event. Additionally, the tropical cyclone season across the region was longer than usual with more frequent, more intense storms developing during the event.

The physical forcings and the social impacts of the event were observed in a succession across the Pacific Basin. A “wave” of conditions affected the region, progressing from the Western Pacific to the Eastern Pacific. The islands were impacted at different times and in different places, with the U.S.-Affiliated Pacific Islands (USAPI) impacted roughly in the following order: Palau, Guam/Commonwealth of Northern Mariana Islands, Federated States of Micronesia, Republic of Marshall Islands, American Samoa, Hawaii.

The 2014/16 El Niño impacted the public safety of island communities as well as the disaster management practices of government officials. A weakening of the easterlies and a strengthening of the westerlies was associated with an increase in rainfall which inundated several coastal, low-lying areas such as Palau, Marshall Islands, and Guam/Northern Mariana Islands. An increase in both the frequency and magnitude of tropical cyclones was associated with strong winds, heavy rainfall, and storm surges which caused infrastructure damage, coastal erosion, and saltwater intrusion. Strong winds were associated with unsafe harbor conditions which limited the ability for island communities to connect with the world. Heavy rainfall was associated with an increase in flooding which caused damage to critical infrastructure such as airports, harbors, and roadways and irrigation systems such as canals and dams. Human settlements across the region were at-risk as lines of communication and modes of transportation were interrupted by the extreme weather conditions.

The 2014/16 El Niño impacted the availability of freshwater resources as many island communities experienced the effects of drought. Several parts of the region declared a state of emergency of the result of the drought induced by El Niño: Palau, Marshall Islands, and Guam/Northern Mariana Islands. Rainfall is the primary source of freshwater for island communities. People were forced to depend on sources beyond natural rainwater such as the limited supply of groundwater in order to survive. The falling of the groundwater level and the depletion of reservoirs caused water scarcity which severely impacted the ability to accomplish

activities such as irrigation and drinking. Additionally, the endangered freshwater supply caused a reduction in staple crop yields as well as a loss in subsistence agriculture in some places. The dry, low-moisture ground resulted in wildfires that burned lands primarily used for agriculture and horticulture. Drought in the region threatened the livelihoods of millions of people in the region by endangering the supply of one of the most precious natural resources—water .

The 2014/16 El Niño impacted the general well-being of island communities by affecting the public health of local populations. The impacts of the extreme weather conditions on the well-being of people in the islands changed as the physical conditions switched from an abundance of water to a lack of water. Flooding caused an increased risk of disease outbreaks associated with an abundance of water including dengue fever, chikungunya, and zika virus. Drought caused an increased risk of disease outbreaks associated with a lack of water including diarrhea, leptospirosis, and typhoid. Insecurity in freshwater and food caused an increased risk of malnutrition and undernourishment. Wildfires caused an increased risk of respiratory diseases associated with poor air quality including the common cold, asthma, and pneumonia. Also, the migration of people away from their homelands was a side effect of the event as some island communities were no longer habitable. Displacement caused an increased risk of mental disorders including anxiety, depression, and schizophrenia.

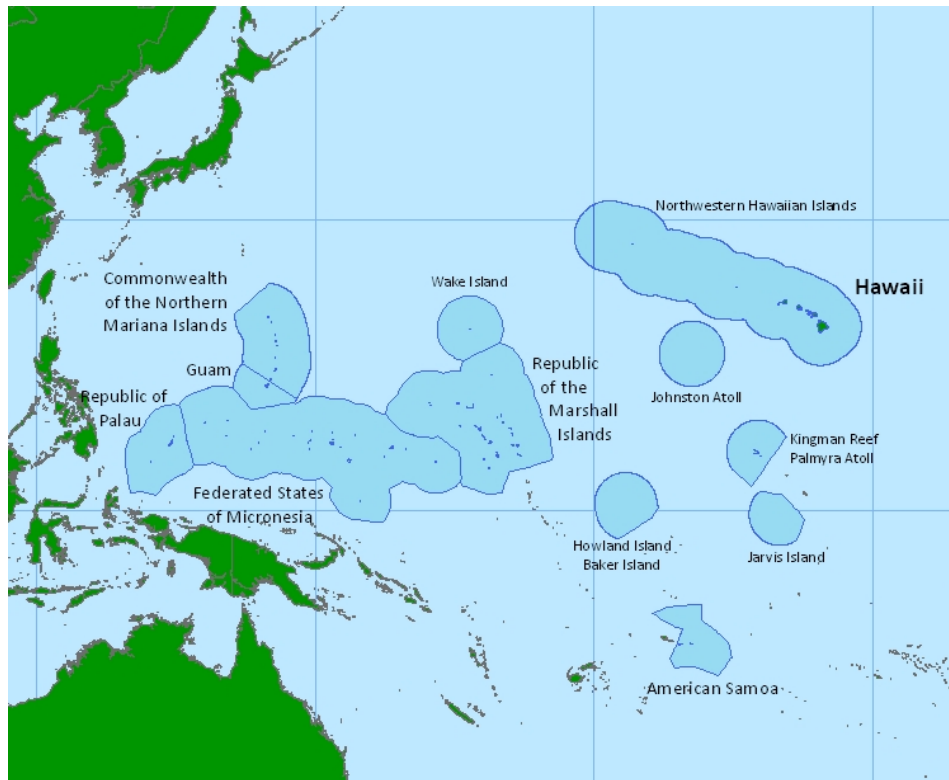
The 2014/16 El Niño impacted the well-being of ecosystems by bringing about unlivable, uninhabitable conditions for wildlife. Ocean conditions such as sea level and sea surface temperature were the main forcings that impacted marine ecosystems. The general trend was an initial drop and then a rise in sea level as well as an initial decrease and then an increase in sea surface temperature. Sea level drop exposed shallow reefs that protect the islands leading to catastrophic die-offs of coral and fish resulting in *taimasa* (“foul-smelling tide”) from the decaying marine life. Above average sea surface temperatures overly stressed coral reefs causing color and nutrient loss and widespread coral bleaching. Coral reef ecosystems provide important ecosystem services, the benefits obtained from the regulation of a natural ecosystem, such as the supply of cultural/social resources.

The 2014/16 El Niño raised awareness of the inextricable link between biological and cultural resources. The degradation of natural resources through the die-offs of coral reefs caused an increased risk of the disappearance of livelihoods, cultural heritage, and traditional ecological knowledge. Water shortages, extreme droughts, and social unrest caused the migration of people away from their homelands which changed the cultural/social mosaic of communities. The inundation of low-lying islands threatened a land base that supports traditional lifestyles inclusive of practices such as subsistence agriculture and fishing.

Placing the lives and livelihood of millions of people at-risk, the 2014/16 El Niño underscored the interaction between anthropogenic climate change and natural climate variability.

## **Introduction**

The 2014-2016 El Niño Assessment Report is an overview of the impacts of one of the strongest El Niño events to have affected island communities in the Pacific Ocean, specifically the U.S.-Affiliated Pacific Islands (USAPI). The report describes the physical characteristics of the 2014-2016 El Niño with an emphasis on the USAPI; summarizes the impacts of the event both by sector and by region; and provides case studies that highlight the impacts to a particular sector and/or region. The report represents the synthesis of information about the event collected from multiple sources and using various methods, including media reports, internal reports, questionnaire and interview results, etc. It was prepared on behalf of the Pacific Island ENSO Tiger Team as a means to better inform stakeholders in the region about what happened during the 2014-2016 El Niño and what to expect during the next strong event.

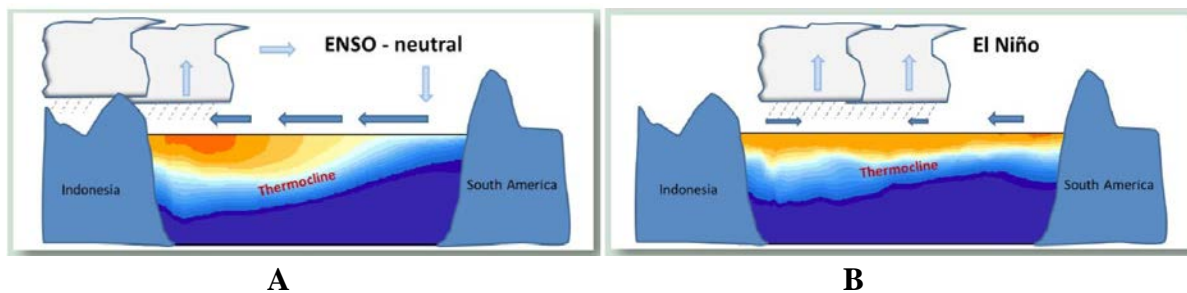


**Hawaii and the U.S. Pacific Islands.** Shading indicates each island's Exclusive Economic Zone (EEZ).

## What is El Niño?

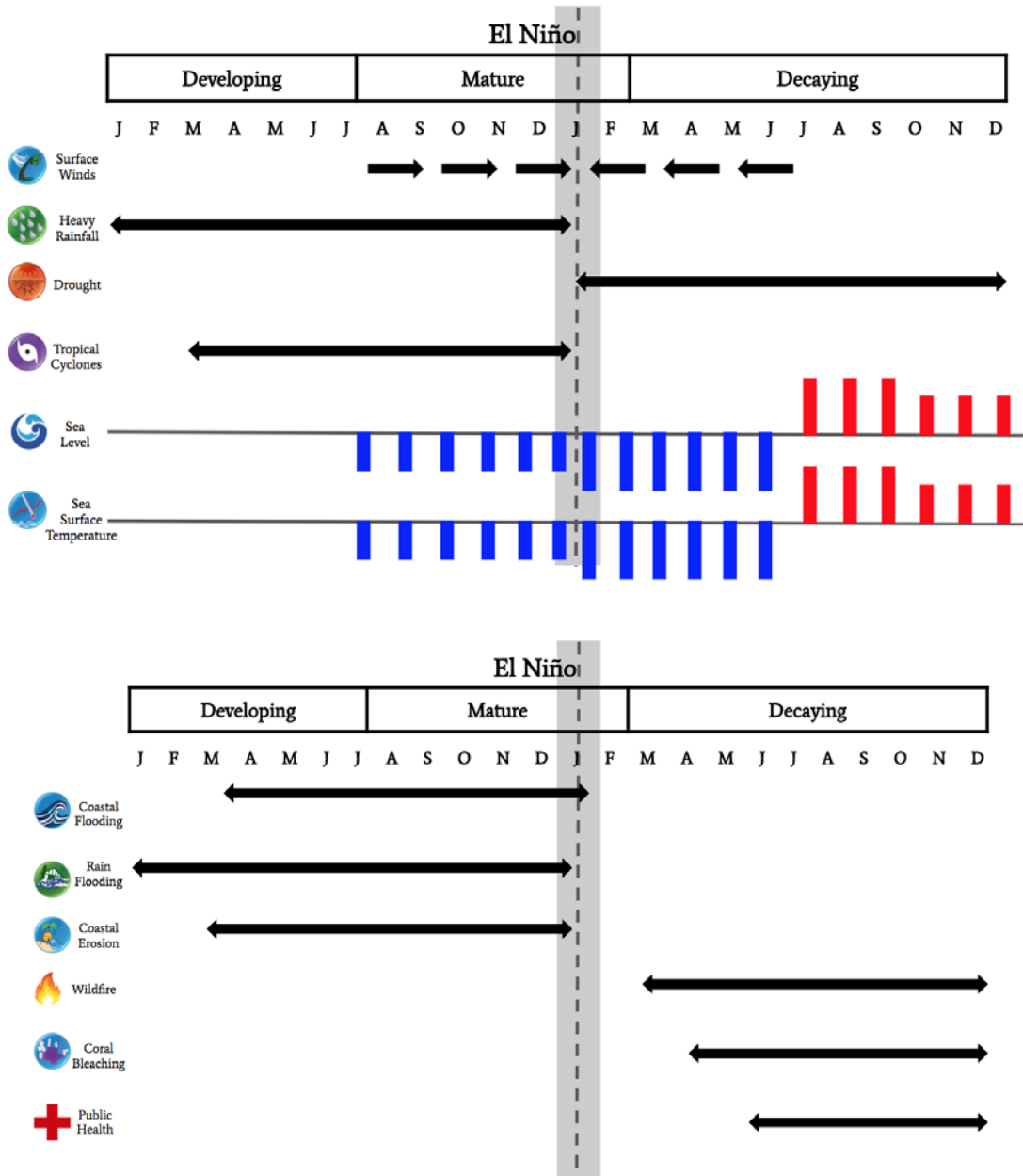
The NOAA National Weather Service describes the El Niño-Southern Oscillation (ENSO) as “the irregular (every two to seven years) oscillation between warm and cool patterns of sea surface temperatures which are referred to as El Niño and La Niña, respectively.”<sup>1</sup> In addition to changes in the temperature of waters in the central and eastern tropical Pacific Ocean, it involves changes in the patterns of sea level pressure, lower- and upper-level winds, rainfall and sea level across the Pacific Basin.<sup>2</sup>

Usually, winds blow strongly from east to west causing warm water to pile up in the western Pacific; the winds pull up cool water from the deep ocean in the eastern Pacific (Figure 1A).<sup>3</sup> El Niño conditions occur when abnormally warm waters accumulate in the tropical latitudes of the central and eastern Pacific Ocean (Figure 1B).<sup>4</sup> The conditions are typically associated with a weakening of the easterly trade winds and a strengthening of the westerly trade winds.<sup>5</sup> Consequently, tropical rains that usually fall over Indonesia move eastward; sea level decreases in the western Pacific; and the vertical, thermal structure of the ocean as well as coastal, upwelling currents are changed.<sup>5</sup>



**Figure 1 A-B. Summary of the primary phases of the ENSO Cycle.** ENSO-neutral or “normal” conditions (A) are characterized by strong trade winds that blow from the east along the equator, pushing warm water into the western Pacific Ocean. El Niño conditions (B) occur when abnormally warm waters build in the tropical region of the central and eastern Pacific Ocean; the conditions are usually associated with a weakening of the easterly trade winds, sometimes even reversing to westerlies. Source: NOAA.

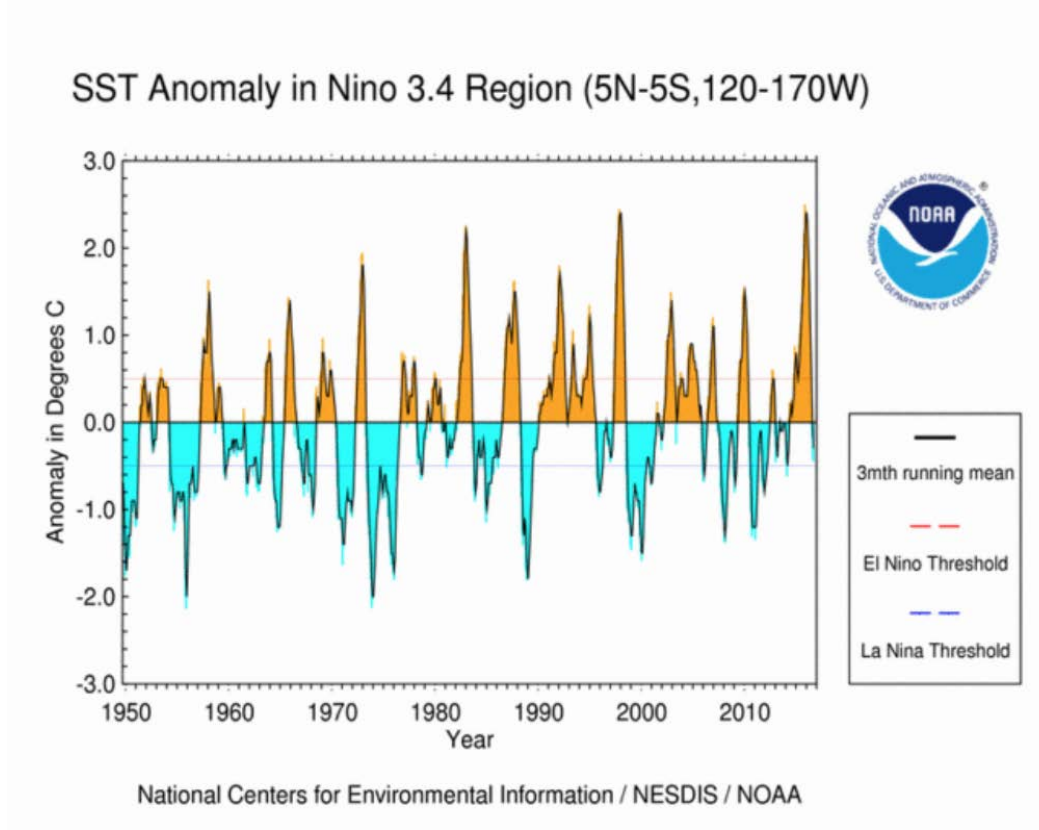
El Niño conditions can start to develop as early as May/June and then subside by June of the following year (Figure 2A).<sup>3</sup> The peak of the event tends to occur at the end of the calendar year around Christmas, giving it its Spanish name “El Niño”—“Christ Child”.<sup>5</sup> The evolution, duration, strength, and impacts of individual events can greatly vary, which makes constant monitoring and awareness extremely important for decision-makers across multiple sectors (Figure 2B).<sup>6</sup>



**Figure 2 A-B. Summary of forcings and impacts during a strong El Niño.** Note, the 2014-2016 El Niño was defined as a strong event, however, both the forcings and the impacts observed during this event differed from the phenomena observed during a typical event. See Appendix A for additional timelines on the U.S.-Affiliated Pacific Islands (USAPI).

The Oceanic Niño Index (ONI) is the primary indicator for monitoring El Niño and La Niña.<sup>2</sup> ONI is a measurement that tracks the running three-month average sea surface temperatures in a region referred to as Niño 3.4—the east-central tropical Pacific between 5°N-5°S, 120°-170° W.<sup>2</sup> Scientists calculate average sea surface temperature in Niño 3.4 for each month and then average the value from the current month with the values from the prior month and the subsequent month

to calculate the index (Figure 3).<sup>7</sup> The running three-month average is compared to the thirty-year average and the observed difference between the average temperatures in the region is the index value for that “season.”<sup>7</sup> The index standardizes anomalies in sea surface temperature in order to provide insight into the strength of an event.<sup>5</sup> For example, a weak El Niño is defined by sea surface temperature that are between 0.5 °C-1.0 °C above average (ONI: +0.5-1.0), while a strong El Niño is defined by sea surface temperatures that are at least 1.5 °C above average (ONI: +1.5).<sup>5</sup> Scientists also track water temperatures below the ocean surface as well as air pressure above the ocean surface then input data into forecast models.<sup>5</sup>



**Figure 3. Plot of sea surface temperature anomaly in Niño 3.4 Region (1950-2017).** Variations in sea surface temperature illustrate that the surface waters across a large swath of the tropical Pacific Ocean warm or cool by nearly plus/minus 3 °C compared to normal. Source: NOAA NESDIS NCEI.



## **2014-2016 El Niño Physical Conditions**

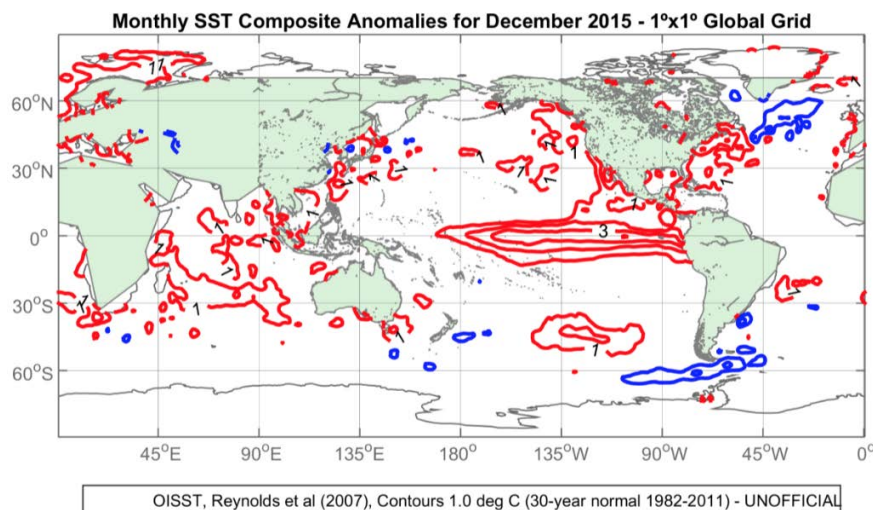
The 2014-2016 El Niño was one of the most powerful of such events observed, causing extreme droughts, floods, and weather and helping to push global temperatures to record levels.<sup>1</sup> The 2014-2016 El Niño event technically started in December 2014, peaked in November 2015, and concluded in June 2016 for a total of 19 consecutive months with the Oceanic Niño Index (ONI) above 0.5.<sup>2</sup> The peak of the 2014-2016 El Niño was comparable in strength to the very strong 1982-1983 and 1997-1998 El Niños.<sup>2</sup> For example, ONI for November 2015-January 2016 is +2.3 which is tied with the same period for 1997/98.<sup>2</sup> However, the eastern Pacific was warmer in 1997/98, while the western Pacific was warmer in 2015/16.<sup>2</sup> As is typical, the event entailed a warming of the eastern equatorial Pacific Ocean that resulted in unusually warm waters between the coast of South America and the International Date Line.<sup>2</sup> The abnormally warm waters influenced global weather in a number of ways, which in turn significantly influenced various parts of the world including the U.S.-Affiliated Pacific Islands (USAPI).<sup>1</sup>

During January 2014, the World Meteorological Organization (WMO) warned that there was an enhanced possibility of a weak event happening during 2014.<sup>3</sup> Over the next few months, the Pacific Ocean began exhibiting features that suggested the impending onset of an El Niño.<sup>4</sup> The features over the ocean included a rapid fall of the sea level in western Micronesia as well as a large area of enhanced sea surface temperatures that were present at low latitudes near the International Date Line.<sup>4</sup> The features in the atmosphere included persistent westerly winds at equatorial latitudes which were displaced towards the eastern tropical Pacific.<sup>4</sup> A large area of atmospheric convection was present at low latitudes near the International Date Line in association with an unusual amount of early season tropical cyclones near the Marshall Islands.<sup>4</sup> As a result of some of these conditions, an El Niño Watch was issued by NOAA's Climate Prediction Center (CPC) and the International Research Institute for Climate and Society (IRI) in March 2014.<sup>5</sup>

Over the next few months, the atmosphere failed to respond in order to reinforce the developing event.<sup>3</sup> The monsoon trough remained weak and tropical cyclone activity slowed while no episodes of strong westerly winds at a low latitude occurred.<sup>4</sup> Some of the oceanic indicators of an event also failed to develop further with a cooling of sea and subsurface temperatures over the tropical Pacific.<sup>4</sup> By the end of 2014, several of the indexes that were used to judge the state of ENSO indicated that weak El Niño conditions had developed over the Pacific Ocean.<sup>4</sup> A few of the international meteorological agencies reported that an event developed during the year, while others considered it to be a near miss.<sup>4</sup> At the time, scientists thought that the ENSO state would continue to hover at the borderline of El Niño conditions before easing back to ENSO-neutral conditions.<sup>3</sup>

During February 2015, a new forecast scenario was suggested after a typhoon developed in Pohnpei, Federated States of Micronesia (FSM): El Niño might strengthen and persist through 2015.<sup>6</sup> The scenario was supported by the same climate features that predicted the weak event developing in the previous year.<sup>4</sup> NOAA and IRI reported that El Niño conditions were observed after the above average sea surface temperatures became weakly coupled with the tropical atmosphere.<sup>5</sup> By January 2015, westerly wind burst activity picked up again.<sup>7</sup> During March 2015, a Kelvin wave prevented cool, deep water from affecting the warm, shallow water, so sea surface temperatures were above average.<sup>7</sup> During July 2015, a strong westerly wind burst event took place as a result of twin tropical cyclones straddling the equator.<sup>7</sup> El Niño conditions were forecast to intensify into strong conditions by fall/winter.<sup>7</sup> In addition to the warmer than normal waters generated by El Niño, the Pacific Decadal Oscillation was also creating above average sea surface temperatures in the northeastern Pacific.<sup>7</sup> In August 2015, NOAA predicted that the 2015 El Niño could be among “the strongest in the historical record dating back to 1950.”<sup>6</sup>

During November and December 2015, NOAA’s Oceanic Niño Index (ONI) peaked with a value at 2.4 °C (4.3 °F) which surpassed December 1997 with a value at 2.2 °C (4.0 °F) (Figure 4).<sup>8</sup> NOAA reported that the three-month average from November 2015 to January 2016 peaked at 2.3 °C (4.1 °F) which meant that the 2014/16 El Niño was tied with the 1997/98 El Niño for the strongest values on record.<sup>9</sup> Overall, the 2014/16 El Niño is considered to be one of the three strongest events since 1950 since there was a number of different ways to measure the strength of an event.<sup>8</sup> The event subsequently started to weaken with sea surface temperature anomalies decreasing.<sup>9</sup> During May 2016, the event dissipated as near to below average sea surface temperatures expanded across the eastern tropical Pacific Ocean.<sup>8</sup> Anomalies became consistent with ENSO-neutral conditions.<sup>9</sup> The traditional and equatorial southern oscillation indices were becoming near zero and upper/lower level winds were becoming near average.<sup>8</sup> All international meteorological agencies declared that the record-tying event ended in late May/early June 2016.<sup>9</sup>



**Figure 4. Map of monthly sea surface temperature anomalies (December 2015).** Red indicates above normal, blue indicates below normal. Source: *Dr. Howard Diamond*.

The 2014/16 El Niño was characterized by changes in the following physical conditions: surface winds, rainfall, tropical cyclones, sea level, and sea surface temperature (Figure 2A-B and Maps 1-3).<sup>3</sup> Surface winds were sporadic shifting from easterlies to westerlies and strength intensifying over time.<sup>3</sup> Heavy rainfall was observed in the initial stages of the event, while extreme drought was observed in the final stages of the event.<sup>3</sup> Tropical cyclones were more numerous and more intense as tropical cyclones season was prolonged across the region.<sup>3</sup> Generally, sea level tended to drop before the peak of the event and rise after the peak of the event, however, the specific observations vary depending on location.<sup>3</sup> Sea surface temperature followed a similar trend, dropping during the early stages of the event and rising during the late stages of the event.<sup>3</sup> Importantly, the climatic conditions of the event were observed in a progression from east to west; in other words, the Pacific Basin was impacted by a “wave” of extreme weather conditions moving from the Western Pacific to the Eastern Pacific.<sup>3</sup> For example, the peak of the event differed for each subregion as the region in its entirety was differentially impacted on both scales—spatial and temporal (Appendix A: El Niño Sub-regional Timelines).<sup>3</sup>

(1) Developing



**Maps 1-3. Summary of the forcings during the three phases of the event:** (1) developing, (2) mature, and (3) decaying. The forcings of the event include the following: surface winds, heavy rainfall, drought, tropical cyclones, sea level, and sea surface temperature. See Figure 2A for key to the forcing symbols.

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## (2) Mature



## (3) Decaying



The 2014-2016 El Niño was one of the strongest events on record; however, several previous events have been defined as more impactful.<sup>1</sup> A few key differences between the 2014/16 El Niño and the 1997/98 El Niño include the following: (a) the duration of the events with the 2014/16 event lasting longer; (b) the initial stages of the events with the 1997/98 event ensuing after a “cool” state and the 2014/16 event ensuing after a “warm” state; and (c) the changes in sea level during the events with the 1997/98 event seeing much greater drops in sea level.<sup>2</sup> Additionally, the physical characteristics of the events, such as anomalies in rainfall, sea level, and tropical cyclones, differentially impacted the islands within the region.<sup>2</sup> The differences between the events can be summarized by the variations in the climatic forcings between the hemispheres.<sup>2</sup> For example, the Northern Hemisphere experienced a similar intensity of impacts both in 1997/98 and 2014/16, while the Southern Hemisphere experienced more intense impacts in 1997/98 and less intense impacts in 2014/16.<sup>1</sup> A correlation exists between the strength of El Niño and the severity of its side-effects, however, scientists emphasize the fact that impacts of the events are *likely* but not *certain*.<sup>8</sup>

## 2014-2016 El Niño Impacts

Pacific Island communities and ecosystems are highly susceptible to seasonal climate extremes such as droughts, floods, and ocean inundation during storms. The 2014-2016 El Niño was notable for its series of such impacts. Due to the persistence for 12-16 months of the above average sea surface temperatures that define El Niño, as well as the extensive geographic range of the event, the impacts of the 2014-2016 El Niño were far reaching.

Sectors that exhibited impacts during this event include public safety/disaster management, freshwater resources, public health, ecosystems, and biocultural resources. Impacts during the three phases of the event are illustrated graphically in Maps 4-6. Impacts are summarized in detail by region, sector, and the three phases of the event: developing, mature, and decaying in Table 1. They are also summarized graphically by subregion in Appendix A and again detailed by region, forcing and sector for each phase of the event in table form in Appendix B. They are considered briefly by sector in the text that follows.

### (1) Developing



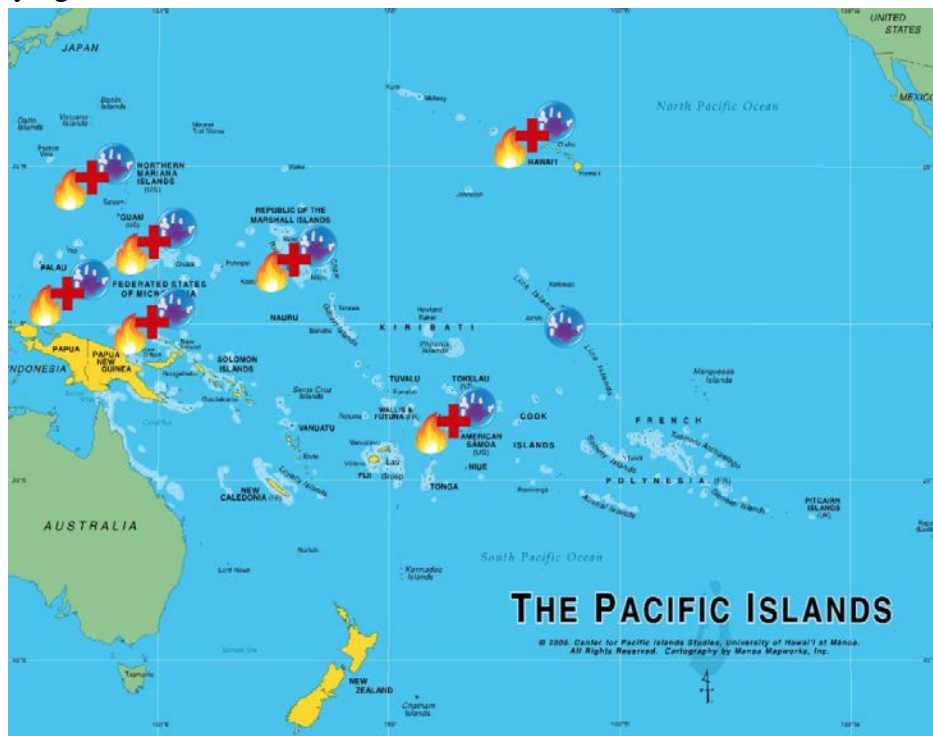
**Maps 4-6.** Summary of the impacts during the three phases of the event: (1) developing, (2) mature, and (3) decaying. The impacts of the event included changes in the following: coastal flooding, rain flooding, coastal erosion, wildfire, coral bleaching, and public health. Island communities were differentially subjected to the impacts of the event. See Figure 2B for key to the impacts symbols.



(2) Mature



(3) Decaying



**Table 1—Summary of Impacts of 2014-2016 El Niño**

Region—Where?	Impact—What?	Time—When?
<p><b>Central North Pacific</b></p>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Rising sea levels causing coastal erosion, extreme high tides (king tides), saltwater intrusion</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Above average sea-surface temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> </ul>	<p>Developing/Mature/Decaying</p> <p>Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Decaying</p> <p>Mature/Decaying</p>
<p><b>Western North Pacific</b></p>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Weakening of easterlies, strengthening of westerlies bringing an increase in rainfall, unsafe harbor conditions</li> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of malnutrition, undernourishment due to freshwater, food insecurity</li> <li>● Increased risk of disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of disease outbreaks including dengue fever, chikungunya, zika virus due to flood</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Sea level drop exposes shallow reefs that protect islands leading to catastrophic coral, fish die-offs as well as <i>taimasa</i> (“foul-smelling tide”) from decaying marine life</li> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> <li>● Above average sea-surface temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> </ul>	<p>Developing</p> <p>Developing/Mature/Decaying</p> <p>Developing/Mature/Decaying</p> <p>Developing/Mature/Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Developing</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p>



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	<p><b>Biocultural Resources</b></p> <ul style="list-style-type: none"> <li>● Coral reef die-out causing disappearance of natural resources as well as livelihoods, cultural heritage, traditional ecological knowledge</li> <li>● Water shortages, extreme droughts, social unrest causing migration of people bringing changes to cultural/social mosaic of communities</li> <li>● Inundation of low-lying islands threatens land base that supports traditional lifestyles, subsistence agriculture/fisheries</li> </ul>	<p>Decaying</p> <p>Decaying</p> <p>Decaying</p>
<p><b>Central South Pacific</b></p>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Weakening of easterlies, strengthening of westerlies bringing an increase in rainfall, unsafe harbor conditions</li> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of malnutrition, undernourishment due to freshwater, food insecurity</li> <li>● Increased risk of disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of disease outbreaks including dengue fever, chikungunya, zika virus due to flood</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Sea level drop exposes shallow reefs that protect islands leading to catastrophic coral, fish die-offs as well as <i>taimasa</i> ("foul-smelling tide") from decaying marine life</li> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> <li>● Above average sea-surface temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> </ul> <p><b>Biocultural Resources</b></p> <ul style="list-style-type: none"> <li>● Coral reef die-out causing disappearance of natural resources as well as livelihoods, cultural heritage, traditional ecological knowledge</li> <li>● Water shortages, extreme droughts, social unrest causing mass migration of people bringing changes to cultural/social mosaic of communities</li> <li>● Inundation of low-lying islands threatens land base that supports traditional lifestyles, subsistence agriculture/fisheries</li> </ul>	<p>Developing</p> <p>Developing/Mature/Decaying</p> <p>Developing/Mature/Decaying</p> <p>Developing/Mature/Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Developing</p> <p>Mature/Decaying</p> <p>Mature/Decaying</p> <p>Decaying</p> <p>Decaying</p> <p>Decaying</p>

## Public Safety/Disaster Management

The 2014-2016 El Niño experienced an above average tropical cyclone season in more ways than one.<sup>1</sup> Meteorological analysis centers across the Pacific indicated above average numbers of tropical cyclones for the 2015/16 season (November 2015-April 2016).<sup>1</sup> Tropical cyclone activity was elevated for a majority of the Pacific Islands, especially those situated close to or east of the International Date Line; in other words, the cyclone season was longer with more intense systems forming over a wider area.<sup>1</sup>

El Niño-Southern Oscillation (ENSO) creates strong variations in sea surface temperature in the eastern equatorial Pacific, leading to major climatic impacts.<sup>1</sup> Large-scale environmental conditions conducive to tropical cyclone activity such as formation, track, frequency, lifespan, landfall, and/or intensity occur during El Niño.<sup>1</sup> Storm activity in the tropical Pacific was super-charged, fueled by the record-breaking El Niño, which boosted ocean temperatures in the central and eastern tropical Pacific.<sup>1</sup> Tropical cyclones thrive off of warm ocean waters where temperatures soared to previously unsurpassed levels in vast expanses of the Pacific.<sup>1</sup> El Niño effectively discharges heat into the ocean, leading to intensified tropical cyclones.<sup>1</sup> Warm pools of seawater, low-level westerlies, and tropical convection shift from the western Pacific to the central or eastern Pacific at the height of El Niño.<sup>1</sup> Every section of the Pacific Basin experienced the most intense storms in at least 20 years during the 2015/16 season: the northeast Pacific, the central Pacific, and the northwest Pacific.<sup>1</sup> Overall, more intense, longer-lasting tropical cyclones with less predictable tracks were observed during the most recent event.<sup>1</sup>

The main effects of tropical cyclones include heavy rainfall, strong winds, and storm surge.<sup>2</sup>

- **Heavy Rainfall.** Heavy rainfall results in flooding, mudslides, and landslides.<sup>2</sup> Inland rainfall eventually flows into coastal estuaries, damaging marine life.<sup>2</sup> The destruction of sanitation facilities combined with a warm, tropical climate can induce epidemics of disease which claims lives long after the storm passes.<sup>2</sup> Infections of cuts and bruises can be greatly amplified by wading in sewage-polluted water.<sup>2</sup> Large areas of standing water caused by flooding also contribute to mosquito-borne illnesses.<sup>2</sup> Crowded evacuees in shelters increase the risk of disease propagation.<sup>2</sup>
- **Strong Winds.** Strong winds can damage or destroy property such as commercial buildings and individual residences, turning loose debris into flying projectiles.<sup>2</sup> Cyclones can knock out power, preventing vital communication and hampering clean-up and rescue efforts.<sup>2</sup> Tropical cyclones can destroy bridges, overpasses, and roads, complicating efforts to transport food, water, and medicine to the areas that need it.<sup>2</sup> The damage caused by cyclones to buildings and dwellings can result in a diaspora of the population.<sup>2</sup> Strong winds can destroy vegetation thereby changing ecosystem dynamics and destroying animal/plant habitats.<sup>2</sup>

- **Storm Surge.** Storm surge is a rising of the sea as a result of atmospheric pressure changes and wind associated with a tropical cyclone.<sup>2</sup> The relatively quick surge in sea level can move far inland, flooding the region and cutting off escape routes.<sup>2</sup> Storm surges change the landscape near coastal areas by moving and reshaping sand dunes and causing extensive erosion along the coast.<sup>2</sup> Erosion damages existing vegetation and leaves the area exposed to even more erosion.<sup>2</sup> Storm surge can also cause saltwater intrusion or the movement of saline water into freshwater aquifers, which can lead to the contamination of water used for drinking and irrigation. Additionally, the rise in sea level can lead to coastal erosion or the wearing away of land and the removal of beach by wave action, which can severely damage critical infrastructure.

Across the Pacific, coordination between disaster management agencies was extensive during the 2014/16 El Niño.<sup>3</sup> Most countries in the region were well aware of their respective roles in responding to the tropical storms as the responsibilities of each agency were well-defined before the event.<sup>3</sup> Fundamental to enabling preparedness and response activities is the dissemination of climate warnings to local scientists as well as the communication of action-oriented messages to community members.<sup>3</sup> A particular useful mechanism for the communication of climate information and warnings was through national approaches based on the United Nations Cluster System—an international coalition aimed to strengthen partnerships between countries and to improve the accountability of humanitarian action by clearly defining the roles of aid organizations.<sup>3</sup> The system was employed by several countries in the region including the Marshall Islands, the Solomon Islands, and Papua New Guinea.<sup>3</sup>

Impacts from severe drought associated with El Niño to Public Safety/Disaster Management are considered below.

### **Freshwater Resources**

The 2014-2016 El Niño was responsible for the drought that moved through the Pacific Islands.<sup>1</sup> The reduced rainfall started in the Northern Hemisphere's winter and persisted into the Northern Hemisphere's spring of the following year, resulting in about six months of drought conditions in most of the Pacific Islands.<sup>2</sup> Eventually, the drought affected approximately 4.7 million people.<sup>1</sup>

The severe drought associated with El Niño affected freshwater quantity and quality.<sup>2</sup> On atoll communities where freshwater resources are already strained, the consequences were most severe.<sup>2</sup> Extreme drought conditions were observed in several island countries including the Marshall Islands, the Solomon Islands, Papua New Guinea, Samoa, Tonga, Vanuatu, and Fiji.<sup>2</sup> One of the most severe droughts was experienced across the islands of Palau.<sup>2</sup> The severe drought prompted international aid efforts with military and aid organizations bringing food, water, and reverse osmosis units for desalinating ocean water.<sup>3</sup>

Islands contending with drought conditions faced food security issues, especially on more remote islands or atolls which often depend on subsistence agriculture and fishing.<sup>3</sup> Warm ocean temperatures disrupted normal fisheries and fishing locations which tended to move eastward in search of cooler waters.<sup>3</sup> Agriculture was affected as both irrigated and nonirrigated crops and trees become less productive or destroyed.<sup>3</sup> The dry, low-moisture ground resulted in wildfires that burned lands primarily used for agriculture and horticulture.

Papua New Guinea was among the first islands in the Pacific to be severely impacted by drought from El Niño; for example, the highlands where more than 80% of food consumed is grown were severely impacted by the drought, resulting in crop failure and famine.<sup>3</sup> El Niño conditions resulted in a severe frost at the highest elevations where most subsistence crops are grown.<sup>3</sup> The result was that communities already suffering from a compromised food supply became increasingly vulnerable to the country-wide drought.<sup>3</sup> Dozens reportedly died from famine with children and elderly populations most at risk.<sup>3</sup>

Drought and humanitarian crises are considered national security issues because of the danger to the well-being of large populations, the role militaries play in providing aid, and the potential movement of large numbers of people in response to scarce resources.<sup>2</sup> The dual threats of decreased freshwater supplies and increased saltwater inundation contend with local agriculture making it necessary to import both food and water.<sup>2</sup>

Prolonged drought can compromise not only freshwater supplies and food security, but also bring about cascading impacts on the well-being of local communities and global economies.<sup>1</sup> On islands with surface water supplies in rivers, streams, or reservoirs, an increased reliance on pumping from groundwater wells during times of drought required the additional use of electrical power, limited hydropower production, and increased the need for oil and gas imports.<sup>2</sup> Collectively, the issue is part of the “water-energy nexus”—the relationship between how much water is needed to create energy and how much energy is needed to transport, store, and clean water.<sup>2</sup> The consequences of the nexus affect supply chains in addition to local and regional economies.<sup>2</sup> The potential water-energy use footprint of the Pacific Islands grows higher during times of drought when pumping groundwater or importing freshwater becomes necessary.<sup>2</sup> Cargo transport distances and the financial costs of fuel and supplies factor into the calculation of determining a footprint.<sup>2</sup>

## **Public Health**

The El Niño cycle is associated with increased risks of climate-sensitive diseases including (1) vector- and rodent-borne diseases such as malaria, dengue, chikungunya, zika, and leptospirosis and (2) food- and water-borne diseases such as cholera, rotavirus, giardia, shigella, and typhoid.<sup>1</sup>

Outbreaks of certain diseases are often associated with extreme weather events.<sup>1</sup> In the western Pacific countries where below average precipitation is foreseen during El Niño, diarrheal diseases due to scarcity of potable water as well as infectious, respiratory illnesses are the major concerns.<sup>1</sup> In the eastern Pacific countries where above average precipitation is foreseen during El Niño, extended rainfall and floods may destroy roads, hospitals, and clinics thereby restricting access to healthcare.<sup>1</sup> Damaged water and sanitation infrastructure can lead to contaminated drinking water causing diarrhea and other enteric disease outbreaks.<sup>1</sup> The magnitude of health impacts associated with El Niño varies depending on how intensely the event influences the local climate of an area as well as the local health vulnerabilities, levels of preparedness, and response capacities.<sup>1</sup> The health implications are usually more intense in developing countries with fewer capabilities to reduce the consequences of El Niño.<sup>2</sup>

The 2014-2016 El Niño was one of the most severe events in recent history in terms of its impacts on public health.<sup>2</sup> El Niño-induced drought in the Pacific Islands affected millions of people across various sectors.<sup>3</sup> Water shortage and lack of sanitation created alarming food, nutrition, and health conditions, especially in communities affected by tropical storms such as Cyclone Pam and Typhoons Dolphin & Soudelor.<sup>3</sup> Hundreds of thousands of people were reliant on water shipments as the primary source of freshwater following the devastation created by tropical cyclones.<sup>3</sup> Island communities are particularly vulnerable to outbreaks, especially in areas with poor water and sanitation infrastructure such as squatter settlements and poor neighborhoods in and around the capital cities.<sup>3</sup> Decreased water quantity and quality also caused an increased incidence of vector-borne diseases.<sup>3</sup> In dry, hot climates, heavy rainfall can create puddles that provide ideal breeding conditions for mosquitoes.<sup>3</sup> In very humid climates, droughts can turn rivers into strings of pools that are preferred breeding sites of other types of mosquitoes.<sup>3</sup>

Drought conditions related to El Niño impacted approximately one third of the country's total population in Papua New Guinea.<sup>1</sup> The primary determinants of health and survival in this crisis were access to effective health care as well as access to clean water, adequate food intake, and environmental sanitation/hygiene.<sup>1</sup> Major public health threats included the interruption of critical infrastructure, water- and food-borne diseases, vector-borne diseases, food insecurity/malnutrition, and civil unrest relating to distribution of drought relief supplies.<sup>3</sup> Some deaths attributable to the drought were reported.<sup>1</sup> Health care facilities require safe, accessible water supplies in order to be functional.<sup>1</sup> Facilities faced challenges including access to clean water which affected the ability for the appropriate personnel to provide basic health care services.<sup>1</sup> Lack of water led to the closing of health facilities which is a special concern in the most affected areas, some of which have an immunization coverage as low as 29%.<sup>1</sup> Additionally, hot, dry conditions lead to heat waves, wildfires, and poor air quality which caused respiratory diseases and heat stress.<sup>1</sup>

Heavy rainfall in the eastern Pacific and the above-normal cyclone season and caused flooding-related destruction of health infrastructure.<sup>2</sup> Projected cyclones and flooding destroyed and damaged health facilities, disrupted the provision of health services, and created the conditions for epidemics of water-borne diseases such as diarrhoeal diseases and leptospirosis.<sup>1</sup> Floods triggered an epidemic of diarrhea.<sup>1</sup> Several thousand cases of diarrhoeal diseases were reported with the outbreak spreading from the capital to the provinces.<sup>2</sup> Disasters also lead to population displacement and overcrowding with a higher risk of transmissible disease outbreaks.<sup>1</sup> Natural disasters were connected to psychosocial impacts as the disintegration of island communities created stress and tension within select populations.<sup>2</sup> Extreme weather closed and damaged health facilities thus reducing regular health service delivery and restricting access to healthcare during the emergency and well beyond the event.<sup>2</sup>

## **Ecosystems**

The 2014-2016 El Niño highlighted the impacts of naturally occurring climate patterns as well as anthropogenic climate change on ecosystems—terrestrial and marine.<sup>1</sup> The Papahānaumokuākea Marine National Monument is a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site encompassing 583,000 square miles (1,510,000 km<sup>2</sup>) of ocean waters, including islands and atolls of the Northwestern Hawaiian Islands.<sup>2</sup> Internationally known for its cultural and natural values, the monument is one of the world's largest protected areas; however, climate change poses a threat to the ecosystems within the monument.<sup>2</sup> Research has indicated that the populations of several endangered species have crashed following strong El Niños.<sup>2</sup>

One significant feature of a strong El Niño is widespread coral bleaching, as corals are particularly sensitive to small increases in water temperature. Bleaching is the process of corals expelling their zooxanthellae, the symbiotic algae that give corals their distinctive colors, resulting in the white coral skeleton being exposed.<sup>3</sup> Coral bleaching occurs when water temperatures rise 1°-2°C (1.8°-3.6°F) above the warmest normal summer temperatures and persist over three to four weeks.<sup>3</sup> Bleached corals are susceptible to damage and prolonged bleaching can result in the death of the coral.<sup>3</sup> Additional causes of bleaching are runoff/pollution, over-exposure to sunlight, and extreme low tides.<sup>4</sup>

The 2014/16 El Niño triggered a multi-year global bleaching event which was the longest ever recorded.<sup>3</sup> Global ocean temperatures during the peak of the event were nearly 0.6°C higher than the twentieth-century average—a record high.<sup>3</sup> Bleaching was particularly severe in several areas such including the first ever observed bleaching in the northernmost Great Barrier Reef.<sup>3</sup> Reefs off of several Pacific Islands including Samoa, Tonga, Vanuatu, Fiji, and the Solomon Islands were impacted by the increase in sea surface temperature associated with El Niño.<sup>3</sup> The world's coral reefs experienced a mass die off—a “white death” spanning the globe.<sup>3</sup>

## Biocultural Resources

The 2014-2016 El Niño impacted biocultural resources in the Pacific Islands. A “biocultural resource” is defined as a landscape, object, or natural feature of significance to a group of people traditionally associated with it.<sup>1</sup> The term “biocultural” encapsulates the interaction between biological factors and cultural/social factors as biological factors in the natural environment allow for certain cultural/social behaviors.<sup>1</sup>

Coral ecosystems are of cultural, social, and ecological importance in the Pacific Islands.<sup>2</sup> Early Polynesians recognized the importance of corals and the coral reef as a major component of their islands.<sup>2</sup> Healthy coral reefs are among the most biologically diverse and economically valuable ecosystems on the planet.<sup>3</sup> Reefs provide valuable and vital ecosystem services.<sup>3</sup> Coral ecosystems are a source of food for millions; protect coastlines from erosion and storms; provide habitat, nursery, and spawning ground for many species of fish; produce jobs and income to local economies from fishing, recreation, and tourism; and supply sources of new medicines.<sup>3</sup> Major hotspots of marine biodiversity, coral reefs are of great cultural importance in many regions around the world such as Melanesia, Micronesia, and Polynesia.<sup>3</sup>

Coral reefs are among the most precious biocultural resource in the Pacific that was affected by the 2014-2016 El Niño. In addition to the impacts on corals due to enhanced ocean temperatures during the 2014-2016 El Niño, coral reefs were threatened by swings in sea levels linked to El Niño-Southern Oscillation (ENSO). Sea levels in the region can drop during El Niño by up to 20-30 cm (7.9-11.8 in).<sup>4</sup> The most extreme sea level drops are in the southwestern Pacific during very strong El Niños.<sup>4</sup> Sea level drops expose the shallow reefs that circle the islands leading to catastrophic coral and fish die-offs.<sup>2</sup> Samoans refer to very low sea level as *taimasa*.<sup>4</sup> The translation from Samoan to English is “foul-smelling tide” referring to the odor from decaying marine life.<sup>4</sup> *Taimasa* has major ramifications for the reefs that protect small islands.<sup>3</sup>

The intrinsic value of coral ecosystems has been recognized internationally with the creation of marine national monuments such as Pacific Remote Islands, Marianas Trench, and Papahānaumokuākea.<sup>5</sup> Elevated sea levels during storms pose additional threats in these areas, as the monuments contain archaeological sites with an array of prehistoric structures such as *heiau*—ancient temples or sacred sites that largely have not been subject to the anthropogenic disturbances that have occurred in the main Hawaiian Islands.<sup>6</sup> These cultural resources and those located elsewhere on low-lying islands were subjected to an increased likelihood of damage due to enhanced storm activity during the 2014-2016 El Niño.

## **Conclusion**

Hawaii and the U.S.-Affiliated Pacific Islands (USAPI) cover a region that spans north to south from American Samoa to the Northwestern Hawaiian Islands and east to west from the main Hawaiian Islands to the Commonwealth of the Northern Mariana Islands. The region has been experiencing increased ocean temperatures, rising sea levels, increased ocean acidity, lower ocean productivity, and more extreme weather. Many of these changes were intensified by the 2014-2016 El Niño. To support disaster risk reduction, climate adaptation planning, and sustainable development, policy and decision-makers need information on the nature of El Niño and other climate-related impacts to the region's valuable resources—biological, cultural/social, and ecological. In assessing the impacts of the 2014-2016 El Niño it is noteworthy that:

1. The 2014/16 El Niño was one of the strongest events on record in terms of its physical forcings; however, several previous events have been defined as more intense in terms of their social impacts including the 1982/83, 1991/92, and 1997/98 El Niños.
2. The U.S.-Affiliated Pacific Islands (USAPI) experienced direct, indirect, and cumulative impacts across various sectors including public safety/disaster management, freshwater resources, public health, ecosystems, and biocultural resources.
3. The 2014/16 El Niño placed vulnerable groups of people at increased risk, especially individuals who were not necessarily prepared to cope with the consequences of extreme weather events.

The 2014/16 El Niño underscored the fact that island communities are at the frontline of a changing climate. The event not only placed the lives and livelihood of millions of people at risk of, but also jeopardized the integrity of numerous cultures/societies.

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## Case Studies

### **I. Typhoons Dolphin/Soudelor—Guam/Commonwealth of Northern Mariana Islands (CNMI)**

El Niño is associated with an increase in both the frequency and strength of tropical cyclones in the Pacific as exhibited by the cyclones that impacted Guam and the Commonwealth of the Northern Mariana Islands (CNMI).

Typhoon Dolphin was a tropical cyclone that severely impacted island nations in the Western North Pacific.<sup>1</sup> The seventh named storm of the 2015 Pacific typhoon season, Dolphin formed in the vicinity of the Federated States of Micronesia (FSM) on May 6.<sup>1</sup> The storm slowly organized before beginning a north, west-northwest trajectory.<sup>1</sup> Dolphin intensified into a typhoon before passing between Guam and Rota on May 15 while producing typhoon-force winds on both islands.<sup>1</sup> The storm rapidly intensified as it curved to the north.<sup>1</sup> The Joint Typhoon Warning Center (JTWC) designated the storm as a super typhoon with ten-minute sustained winds at 185 km/h (115 mph) and one-minute sustained winds at 260 km/h (160 mph).<sup>1</sup> Dolphin turned to the northeast and weakened becoming extratropical on May 20 and exiting the Western Pacific Basin on May 24.<sup>1</sup>

The Federated States of Micronesia (FSM) was the first territory impacted by the storm.<sup>2</sup> Winds peaked at 60 km/h (37 mph) on Kosrae.<sup>2</sup> Outer rainbands produced heavy rainfall as well as gusts of 88 km/h (55 mph) on Pohnpei.<sup>2</sup> The precipitation reached 603 mm (23.73 in) of rainfall over three days including 388 mm (15.26 in) in one day.<sup>2</sup> High winds downed hundreds of trees, some of which fell onto cars and homes killing one person.<sup>2</sup> Residents lost power and water access for up to two weeks. Several hundred homes were damaged or destroyed.<sup>2</sup> Crops sustained damage from high waves causing saltwater intrusion which affected taro patches.<sup>2</sup> On June 8, the government declared a state of emergency in response to the damage.<sup>2</sup> Damage was estimated at \$1 million.<sup>2</sup>

Guam closed businesses, schools, and public transit in preparation for the cyclone.<sup>3</sup> The Federal Emergency Agency (FEMA) deployed approximately fifteen representatives to the island to reduce the response time in the wake of the storm.<sup>3</sup> Schools were opened as shelters and thousands of residents sought refuge during the height of the storm.<sup>3</sup> Airports and seaports between the islands in the region were shut down.<sup>3</sup> Typhoon Dolphin produced the first typhoon-force winds on Guam since Typhoon Pongsona (2002).<sup>3</sup> Andersen Air Force Base recorded sustained winds of 135 km/h (84 mph), while gusts reached 171 km/h (106 mph).<sup>3</sup> The National Weather Service (NWS) recorded gusts of 130 km/h (81 mph) in the central portion of island.<sup>3</sup> Dolphin dropped heavy rainfall during its passage reaching over 460 mm (18 in) of which 240 mm (9.3 in) fell within a 12-hour period. Wave heights offshore topped 6.1 m (20 ft).<sup>3</sup>

Heavy rainfall caused flooding in areas lacking proper drainage.<sup>4</sup> The Guam Memorial Hospital sustained about \$1 million in damage from storm-related flooding.<sup>4</sup> High winds left about 40% of the island without power, mostly in the northern, central portions of the island.<sup>4</sup> Power outages disrupted generators for water levels leaving thousands of people without access to clean water.<sup>4</sup> Residents in some areas were under a boil-water advisory—a public health advisory or directive given by government or health authorities to consumers when a community’s drinking water is contaminated by pathogens.<sup>4</sup> Utility damage was estimated at \$3 million.<sup>4</sup> Businesses sustained \$1.9 million in damage.<sup>4</sup> Crop damage was estimated at \$1.2 million.<sup>4</sup> The typhoon damaged thousands of banana trees as well as dozens of the endangered ironwood trees.<sup>4</sup> Rough waves sank a boat in requiring workers to clean oil spills that escaped from the damaged vessel at Apra Harbor.<sup>4</sup> Overall, damage was estimated at nearly \$10 million.<sup>4</sup>

The storm damaged hundreds of houses on the island—390 were damaged, 55 were severely damaged, and 9 were destroyed.<sup>3</sup> Thousands of people were left homeless.<sup>3</sup> Governor Eddie Calvo declared a state of emergency in response to the damage.<sup>3</sup> On June 5, President Barack Obama signed a major disaster declaration for the territory allowing for federal aid to be used.<sup>3</sup> Ultimately, the government provided about \$4.7 million in aid, mostly in the form of public assistance.<sup>3</sup> A federal grant provided hundreds of temporary jobs toward cleaning and repairing damage.<sup>3</sup>

The Commonwealth of the Northern Mariana Islands (CNMI) was the last territory impacted by the storm.<sup>5</sup> Typhoon Dolphin produced the first typhoon-force winds on Rota since Typhoon Chaba (2004).<sup>5</sup> The storm damaged many homes on the island.<sup>5</sup> High winds knocked down trees and power lines causing an island-wide power outage.<sup>5</sup> Wind gusts reached 101 km/h (63 mph), while rainfall totaled 89 mm (3.5 in).<sup>5</sup> High waves from the typhoon caused challenging, difficult conditions for ships trying to bring supplies to the country after store supplies began running out.<sup>5</sup> Workers quickly repaired power outages and cleared roads of any storm debris.<sup>5</sup> The government declared the island a disaster area meaning emergency funds could be allocated toward relief and reconstruction.<sup>5</sup> Damage was estimated at \$2.5 million.<sup>5</sup>

Typhoon Soudelor was one of the most intense tropical cyclones in history.<sup>6</sup> The thirteenth named storm of the 2015 Pacific typhoon season, Soudelor formed as a tropical depression near Pohnpei on July 29.<sup>6</sup> The system strengthened slowly at first before entering a period of rapid intensification on August 2.<sup>6</sup> Owing to favorable environmental conditions, the typhoon further deepened and reached its peak intensity on August 3.<sup>6</sup> The Joint Typhoon Warning Center (JTWC) designated the storm as a super typhoon with ten-minute sustained winds at 215 km/h (130 mph) and one-minute sustained winds at 285 km/h (180 mph).<sup>6</sup> Steady weakening ensured as the storm moved west-northwest. The typhoon made landfall and degraded to a tropical depression by August 9.<sup>6</sup>

Soudelor was the worst storm to strike Saipan in the Northern Mariana Islands in nearly 30 years.<sup>7</sup> The National Weather Service's anemometer at Saipan International Airport broke after recording a gust of 146 km/h (91 mph).<sup>7</sup> Winds downed trees and power lines leaving much of the island without power and rendering roads impassible.<sup>7</sup> Damage to infrastructure was tremendous. Cars were flipped over by the force of the wind in some areas.<sup>8</sup> Countless homes were damaged or destroyed and power was expected to take a month to restore.<sup>8</sup> Initial assessments show hundreds of homes affected—354 were damaged, 296 were severely damaged, and 158 were destroyed.<sup>8</sup> Hundreds of residents sought refuge in public shelters.<sup>9</sup> Repairs to the electric grid, water supply network, and wastewater systems were expected to take three to four weeks.<sup>9</sup> Total damage exceeded \$21 million.<sup>9</sup>

Governor Ralph Torres declared a state of disaster and significant emergency.<sup>10</sup> Supplies were sent from the mainland United States, Hawaii, and Guam.<sup>10</sup> Members of the Guam National Guard, Power Authority, and Coast Guard also provided assistance.<sup>10</sup> On August 6, President Barack Obama declared the islands a federal disaster area allowing residents to receive government aid.<sup>10</sup> The Federal Emergency Management Agency (FEMA) approved \$25.9 million in aid to residents of the island.<sup>10</sup>

Typhoons Dolphin/Soudelor are primary examples of the impacts of an above average tropical cyclone season in terms of both the number and the magnitude of storms that are observed during an El Niño.

## **II. Extreme Drought Conditions—Palau**

El Niño is associated with a decrease in precipitation in the Western Pacific Basin as exhibited by the extreme drought that impacted small island countries such as Palau.

The last thing you would expect to hear from an island surrounded by vast ocean is that there is a shortage of water, yet El Niño has caused widespread drought across the Pacific.<sup>1</sup> Pacific Islands may be surrounded by water, but they rely on fresh rainwater for drinking and irrigation.<sup>1</sup> The event tends to dry out the islands because it shifts the main area of storm activity eastward and away from the region following the commensurate eastward displacement of the pool of warm waters that fuel those storms.<sup>1</sup>

El Niño shifts the Walker Circulation—an equator-wide atmospheric circulation that normally means rising air/wet conditions across the western Pacific and sinking air/dry conditions over the central, eastern Pacific.<sup>2</sup> During El Niño, the rising air and subsequent rainfall follows the anomalously warm waters to the central, eastern Pacific, leaving normally wet areas much drier

than normal.<sup>2</sup> Severe droughts associated with El Niño can significantly impact food security, public health, and the economy.<sup>2</sup>

One of the strongest events on record, the 2014-2016 El Niño curtailed the rains that are the lifeblood of most of the region's communities and ushered in an extreme drought that has left inhabitants in a precarious situation.<sup>3</sup> Water rationing was limited to a couple of hours a day in some of the worst-hit communities, while expensive reverse-osmosis machines were shipped out to the most far-flung atolls to desalinate seawater.<sup>4</sup> Staple foods like breadfruit, bananas, dragonfruit, mango, and passionfruit were inedible as the fruit-producing trees were shriveled up because of the lack of freshwater for irrigation.<sup>3</sup>

On March 23, 2016, Palau declared a state of emergency as the island nation struggled with an extreme drought.<sup>5</sup> Cumulative rainfall in the capital of Koror for the first part of the year was the lowest recorded in 65 years.<sup>5</sup> The nation's largest town observed about 27% of its average rainfall.<sup>5</sup> Generally, rainfall over the region was less than 10% of average with some islands seeing no rainfall at all.<sup>5</sup> The Ngerikiil River which is the city's only source of drinking water was at a fraction of its capacity—19%.<sup>5</sup> The Ngerimel Dam which supplies water to the capital dried up. The capital was simply running out of water.<sup>5</sup> Water rationing was introduced with residents only able to turn on taps for six hours daily—three hours per day, three hours per night.<sup>5</sup> Public health concerns about islanders drinking dirty water were raised because wells on some of the remote islands were drying up.<sup>5</sup> A lack of access to clean water generated hygiene and sanitation risks for populations.<sup>5</sup>

The island nation which is home to 18,000 residents and approximately 15,000 tourists a month was hit by a life-threatening drought fueled by El Niño.<sup>6</sup> Palau was at risk of completely drying up, leaving locals scrambling to conserve water and government officials seeking emergency aid from neighboring countries.<sup>7</sup> Additionally, the functioning of hospitals, schools, and prisons were all at serious risk due to the shortage of potable water.<sup>6</sup> President Tommy Remengesau declared the country in an extreme drought.<sup>7</sup> Koror was in the spotlight as the extreme drought in the city led to water rationing, emergency shipment of bottled water, and public health concerns.<sup>6</sup>

The water crisis impacted daily life in the region.<sup>7</sup> People were not necessarily prepared for the extent to which a natural disaster could impact the islands.<sup>7</sup> Levels of burden, stress, and worry among residents were extremely high as a total water outage was inevitable.<sup>7</sup> Chip Guard, the National Weather Service's Warning Coordination Meteorologist warned of the impacts of an extreme drought on the island including endangered freshwater supply, insecure food supply, and threats to human health: "Droughts can be a matter of life and death."<sup>7</sup> Government officials across the region declared states of emergency in response to the extreme drought conditions observed during the peak of El Niño.<sup>7</sup>

The drought was exacerbated by the country's fledgling tourism industry.<sup>8</sup> Ecotourism destinations were at risk as a result of extreme drought and warmer temperatures.<sup>9</sup> Jellyfish Lake is one of the region's most treasured attractions as tourists are drawn by the promise of a close encounter with one-of-a-kind inhabitants.<sup>8</sup> The lake offers visitors a chance to swim with millions of golden, non-stinging jellyfish, however, a drastic decline in jellyfish numbers was observed during El Niño.<sup>9</sup> Scientists said that without the rain the lake had become saltier and the jellyfish were deprived of vital nutrients delivered to them by run-off.<sup>8</sup> People in the industry were alarmed by the fact that the numbers declined dramatically in such a short amount of time.<sup>9</sup>

Extreme drought is a primary example of the impacts of below average precipitation that is observed during an El Niño.

### **III. Coral Bleaching—Jarvis Island**

El Niño is associated with an increase in average sea surface temperature during the peak of the event which causes stress to marine ecosystems as exhibited by the coral bleaching events in the United States Minor Outlying Islands such as Jarvis Island.

Jarvis Island is part of the U.S. Pacific Remote Marine National Monument—a group of unorganized, mostly unincorporated Pacific Island territories managed by numerous entities including the Fish and Wildlife Service (FWS), United States Department of the Interior, and the National Oceanic & Atmospheric Administration (NOAA) of the United States Department of Commerce.<sup>1</sup> The remote refuges are the most widespread collection of marine- and terrestrial-life protected areas on the planet under a single country's jurisdiction.<sup>1</sup> The monument protects many endemic species including corals, fish, shellfish, marine mammals, seabirds, insects, and vegetation not found elsewhere.<sup>1</sup>

Jarvis is an unpopulated island about 1,500 miles south of Honolulu—halfway between Hawaii and the Cook Islands.<sup>2</sup> The area around the island typically teems with life such as birds, fish, turtles, dolphins, and sharks which are all supported by the coral reefs.<sup>2</sup> Scientists on an expedition to the remote island discovered devastating loss of corals due to record warm ocean temperatures from April 2015 to May 2016.<sup>2</sup>

The island is normally a treasure trove of biological diversity.<sup>3</sup> According to the National Oceanic & Atmospheric Administration (NOAA), the area has the highest fish biomass which measure the total amount of fish species in a given area.<sup>3</sup> Jarvis is a tiny island in which deep nutrient-rich currents collide into shallow reefs below the ocean surface.<sup>3</sup> Upwelling and the equatorial sun generate a prolific abundance of productivity culminating in a diverse reef teeming with myriad fish and coral species.<sup>3</sup>

One of the world's most lush and isolated tropical marine reserve has been severely impacted by changes in water temperature.<sup>4</sup> Huge swaths of once vibrant coral reefs that were teeming with life are not stark white villages disintegrating into the sea.<sup>4</sup> Bernardo Vargas-Angel, a scientist with NOAA Fisheries' Pacific Islands Science Center (PIFSC) Coral Reef Ecosystem Program, described the reefs as a "coral graveyard": "One would have never believed that just a year before this was a vibrant and colorful coral reef."<sup>4</sup>

Scientists estimate that approximately 95% of the coral colonies died from coral bleaching caused by high, prolonged water temperatures associated with El Niño.<sup>5</sup> The El Niño event combined with the impacts of human-caused global warming to send ocean temperatures soaring to record levels around the world with widespread coral reef mortality found in places including Australia, Fiji, Guam, Hawaii, and the Commonwealth of the Northern Mariana Islands (CNMI).<sup>5</sup> The warmer waters caused widespread coral bleaching and mortality in the waters surrounding Jarvis.<sup>5</sup>

The Equatorial Pacific upwelling at Jarvis alternates between warm El Niño years when upwelling is weak and ocean productivity is low, and cold La Niña years when upwelling is strong and ocean productivity is high.<sup>6</sup> Unusually warm sea surface temperatures and a strong El Niño triggered the third recorded global coral bleaching event lasting three years: 2014-2017.<sup>6</sup> Heat stress during the event caused mass bleaching in several reefs that never bleached before including the Great Barrier Reef; 93% of the reef was bleached and over a third of the corals died.<sup>6</sup>

Coral bleaching occurs when corals expel symbiotic, photosynthetic algae known as zooxanthellae that lives in its tissue providing its color and nutrients.<sup>7</sup> Bleaching caused by stress such as too-warm or too-cold water and pollution leaves the coral skeleton exposed making it more susceptible to disease, heat, and pollution.<sup>7</sup> The algae gives the coral its color, so when it's expelled the coral turns white.<sup>7</sup> Bleached corals can recover if the ocean waters cool fast enough or pollutants diminish, however, corals can die if the stress lasts too long.<sup>7</sup>

Ocean temperatures in the area around the island remained in the lethal range for eight months and were conducive to bleaching for more than a year.<sup>7</sup> Water temperatures were about 4 °C (7.2 °F) above average at the peak of the event.<sup>7</sup> The long duration of unusually high temperatures decimated the coral reef ecosystems in one of the world's largest marine conservation areas.<sup>7</sup>

Scientists surveyed the area by diving from research vessels shortly before El Niño began to affect the area and re-surveyed it a year later just as the water returned to lower temperatures.<sup>7</sup> Many of the previously bleached corals observed during a prior research trip were covered with a thick mat of reddish algae—a telltale sign of coral death.<sup>7</sup>

The coral bleaching event is killing reefs around the world, but the event also offers an opportunity for scientists to study what makes some species of coral more resilient than others.<sup>7</sup> For example, some colonies of corals survived the bleaching event.<sup>7</sup> Rusty Brainard, leader of the Coral Reef Ecosystem Program, expressed a sense of hope in finding relatively healthy corals: “The exceptional biological productivity and remoteness of Jarvis Island will be the harbinger to a successful recovery of these unique coral reef ecosystems.”<sup>7</sup>

Bleaching is a grave threat to corals.<sup>8</sup> Wide swaths of the world’s coral were bleached thanks to warm water temperatures brought on by climate change and El Niño.<sup>8</sup> As global warming continue to push air and ocean temperatures higher, marine scientists are working to determine which corals are more resilient and may need to be protected from other man-made threats such as pollution and overfishing.<sup>8</sup>

Researchers at Stanford University published a study that highlighted coral reef “bright spots,” places where reefs were healthy and teeming with fish.<sup>9</sup> The study found that most of the reefs were managed by humans.<sup>9</sup> According to the study, local involvement in how the reefs were managed, local ownership rights, and traditional management practices were all apparent in these reefs.<sup>9</sup>

Scientists are trying to shift the conversation to what can be done to conserve these living organisms in the face of this unprecedented bleaching event.<sup>8</sup> Conservation efforts such as protecting coral reefs from being over-visited are being considered, however, conservation measures are not enough to protect corals from bleaching in the long term.<sup>8</sup> The world needs to curb its greenhouse gas emissions which are increasing ocean temperatures and acidity.<sup>8</sup>

The situation facing coral reefs is dire.<sup>9</sup> Ruth Gates, president of the International Society for Reef Studies, summarized the primary objective shared by scientists and managers: “What we have to do is to really translate the urgency.”<sup>9</sup> Scientists are bracing for the next round of coral bleaching, however, managers are hoping the previous mass event will serve as a learning lesson.<sup>9</sup>

Widespread coral bleaching is a primary example of the impacts of above average sea surface temperature that is observed during an El Niño.

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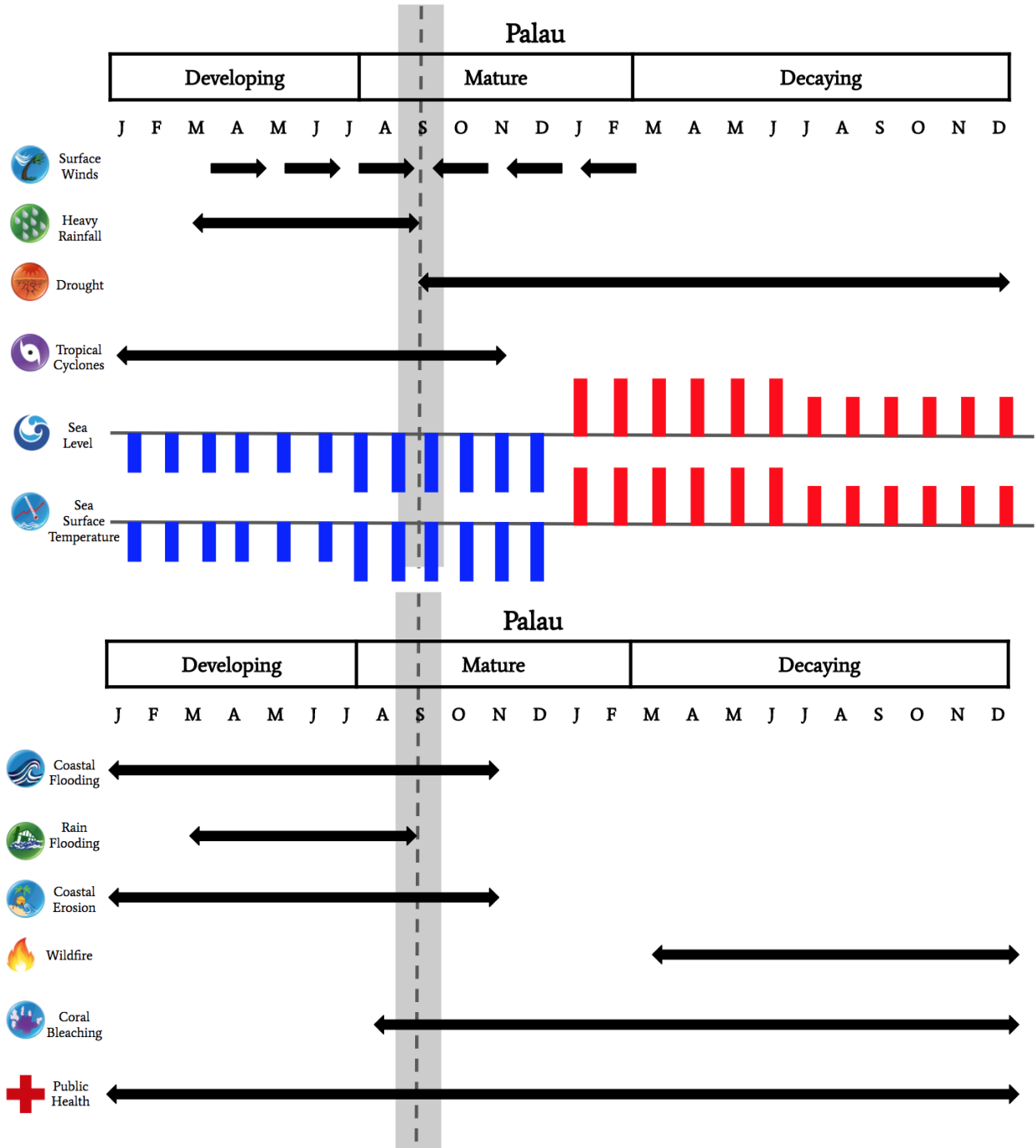
### Case Study—Coral Bleaching

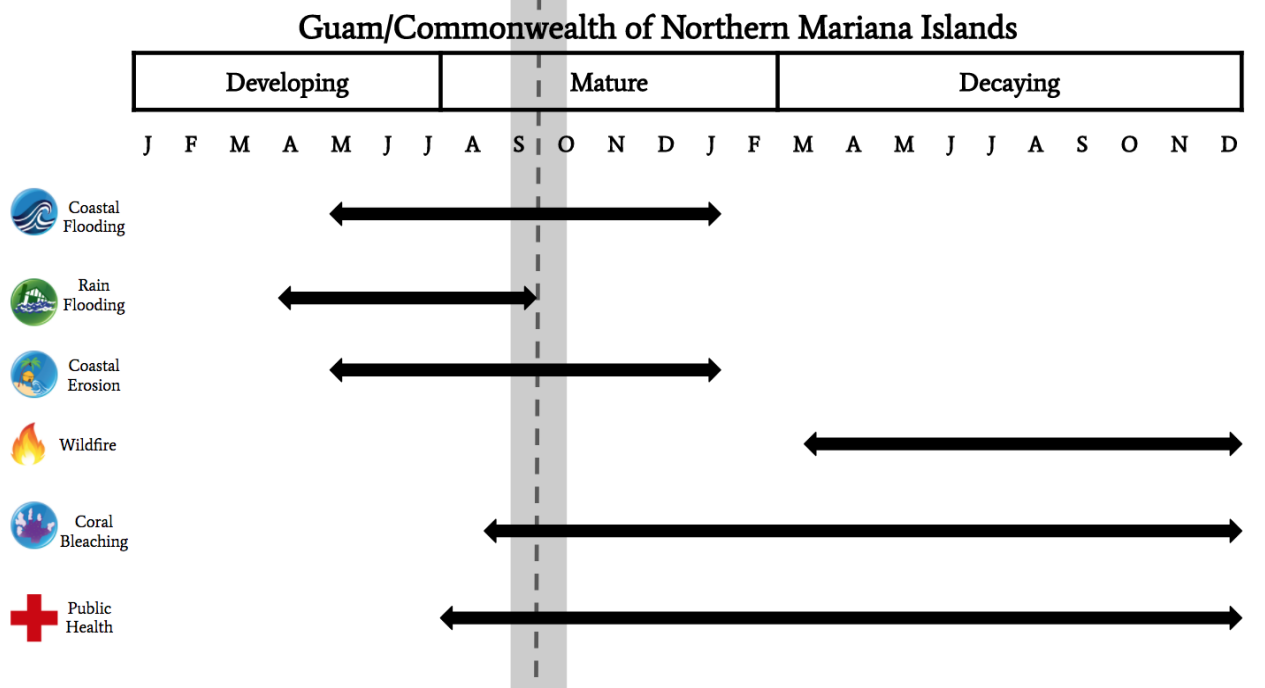
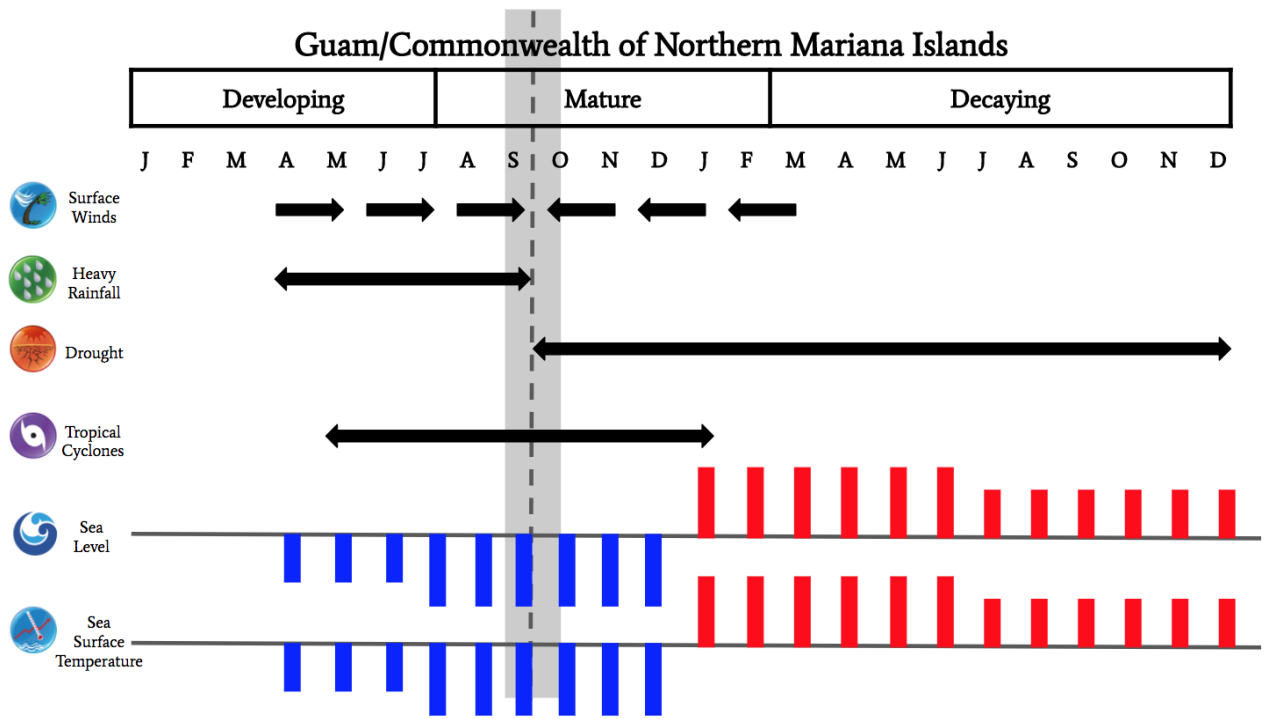
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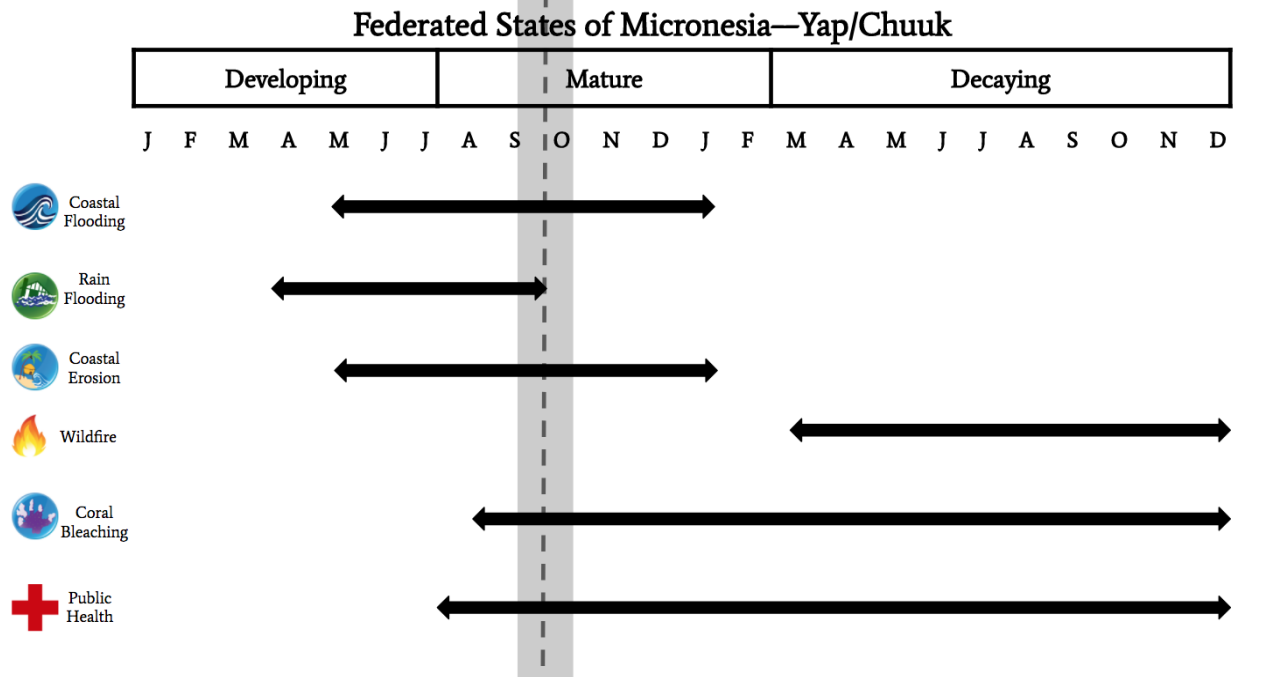
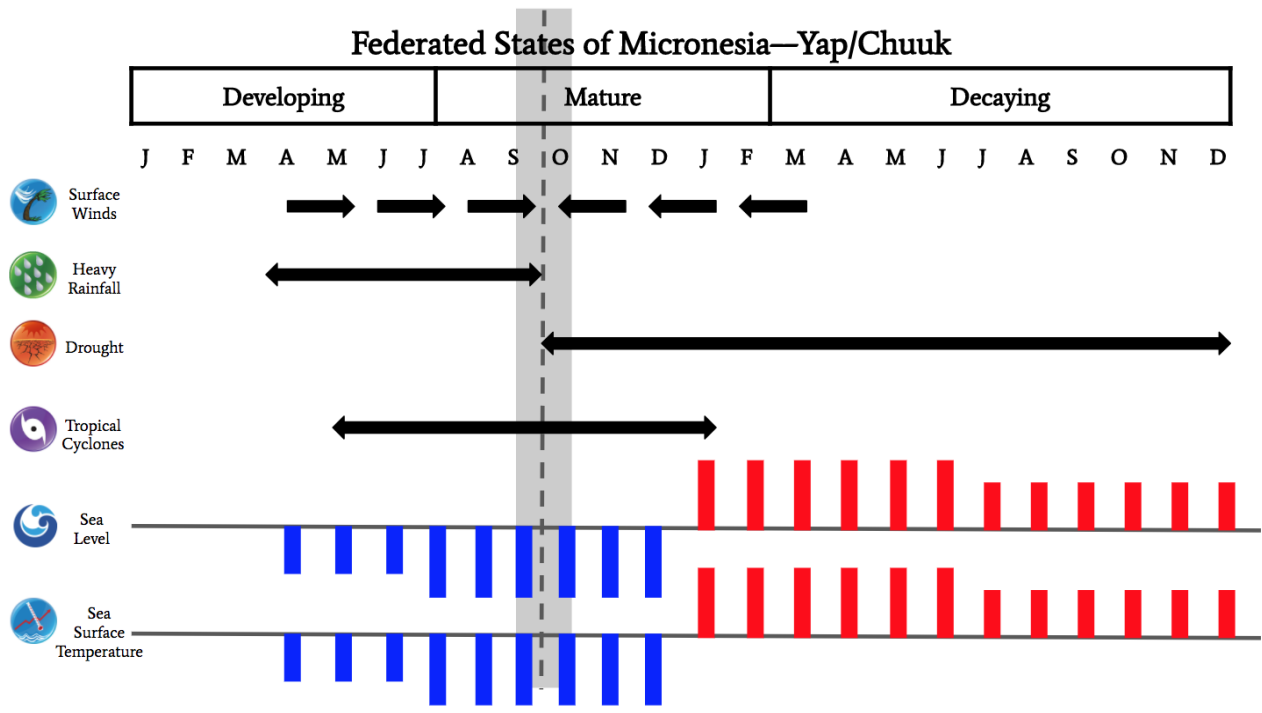
## Appendix A: El Niño Sub-regional Timelines

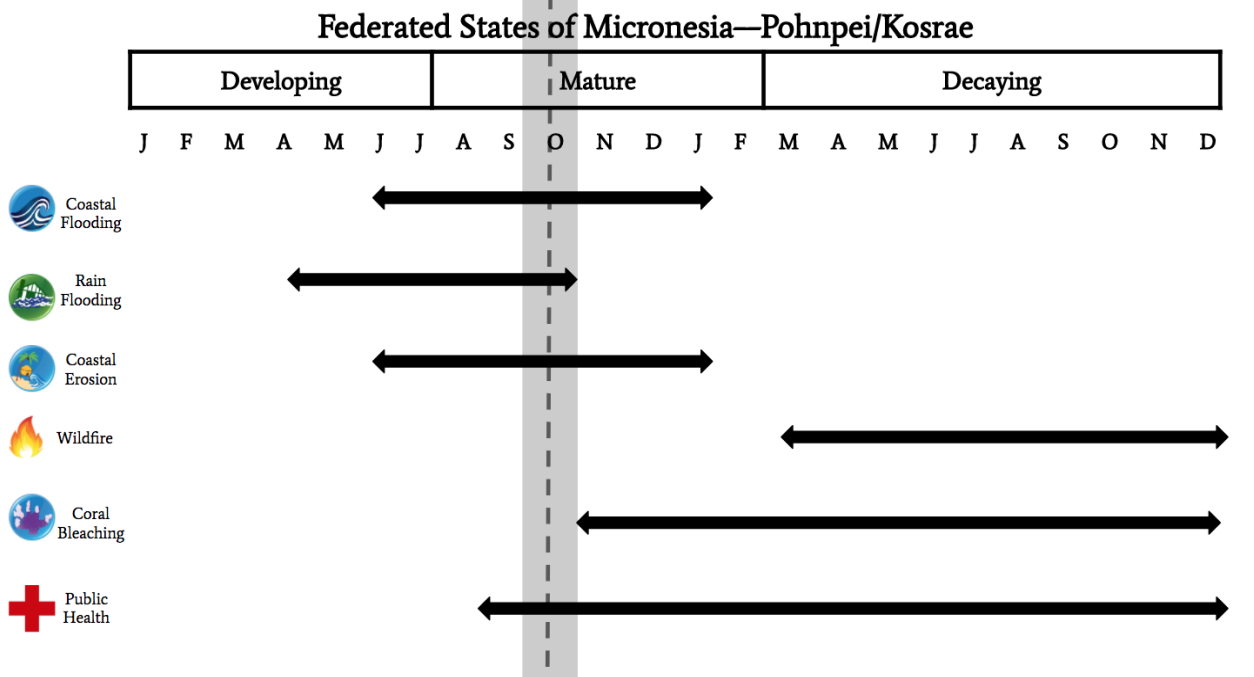
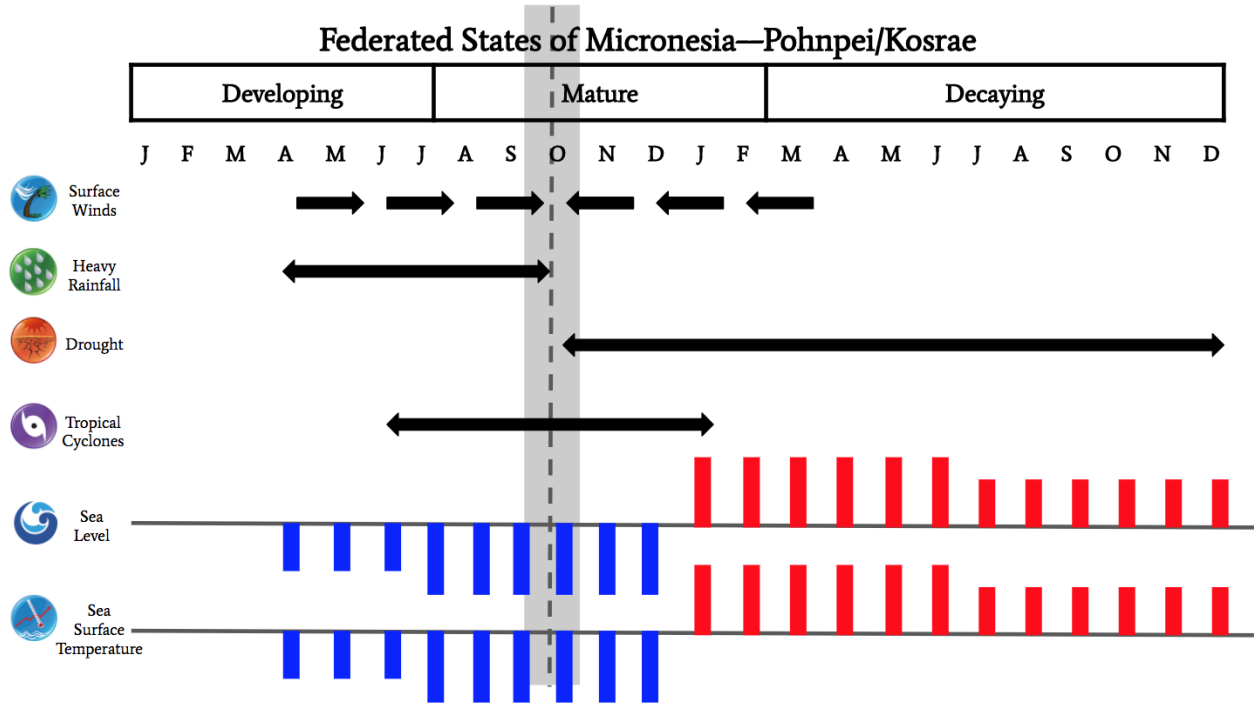
Chronology of both the forcings and the impacts of the 2014-16 El Niño. The dashed line represents the “peak” of the event during which time the most anomalous conditions were observed. U.S.-Affiliated Pacific Islands (USAPI) impacted by the event include the following: Palau, Guam/Commonwealth of Northern Mariana Islands, Federated States of Micronesia, Republic of Marshall Islands, American Samoa, and Hawaii.

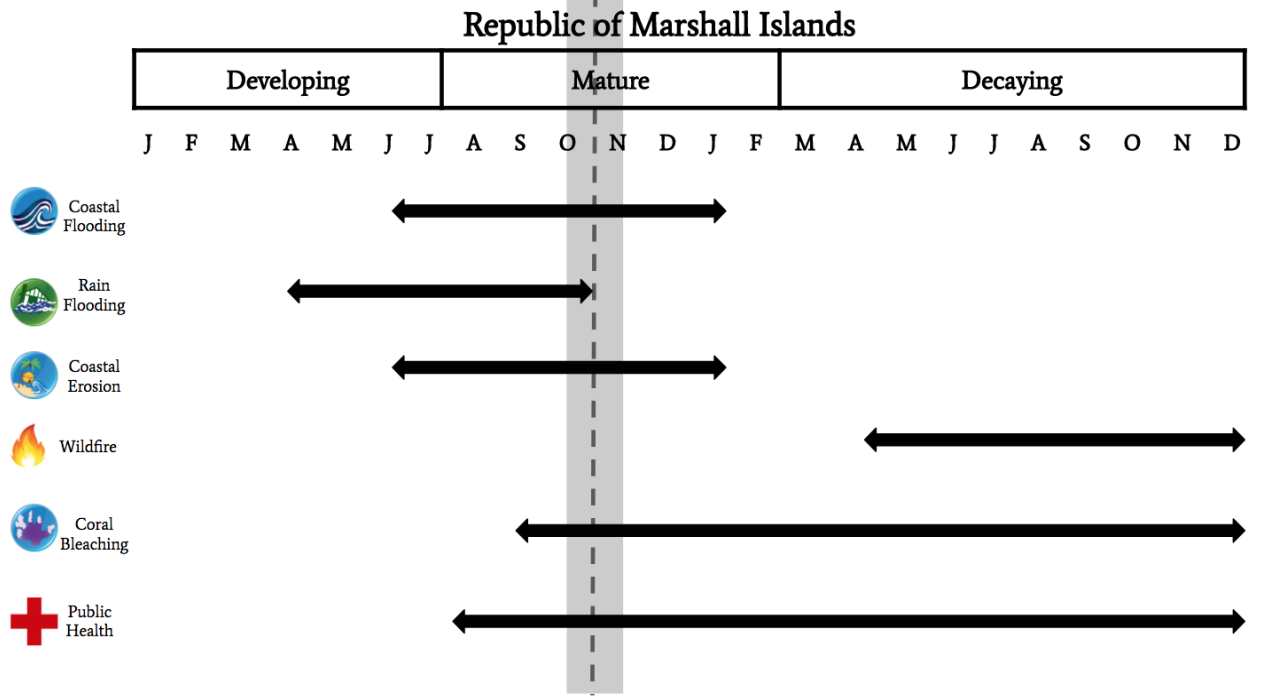
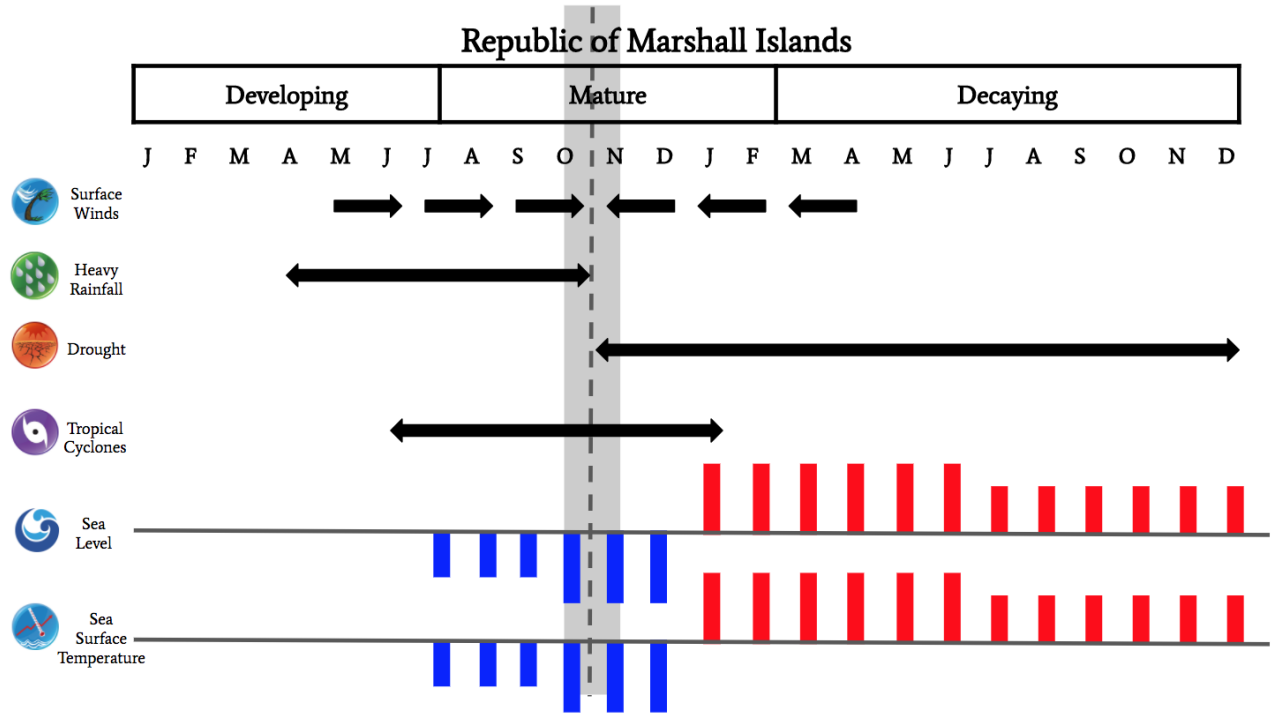


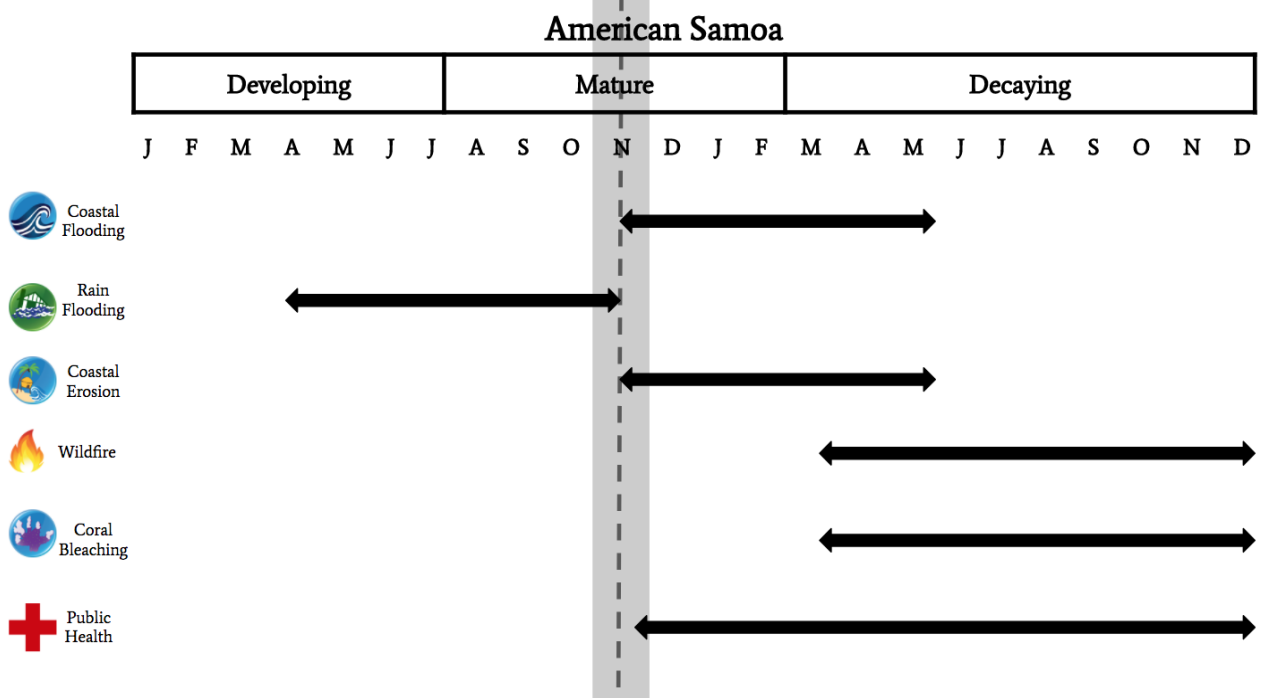
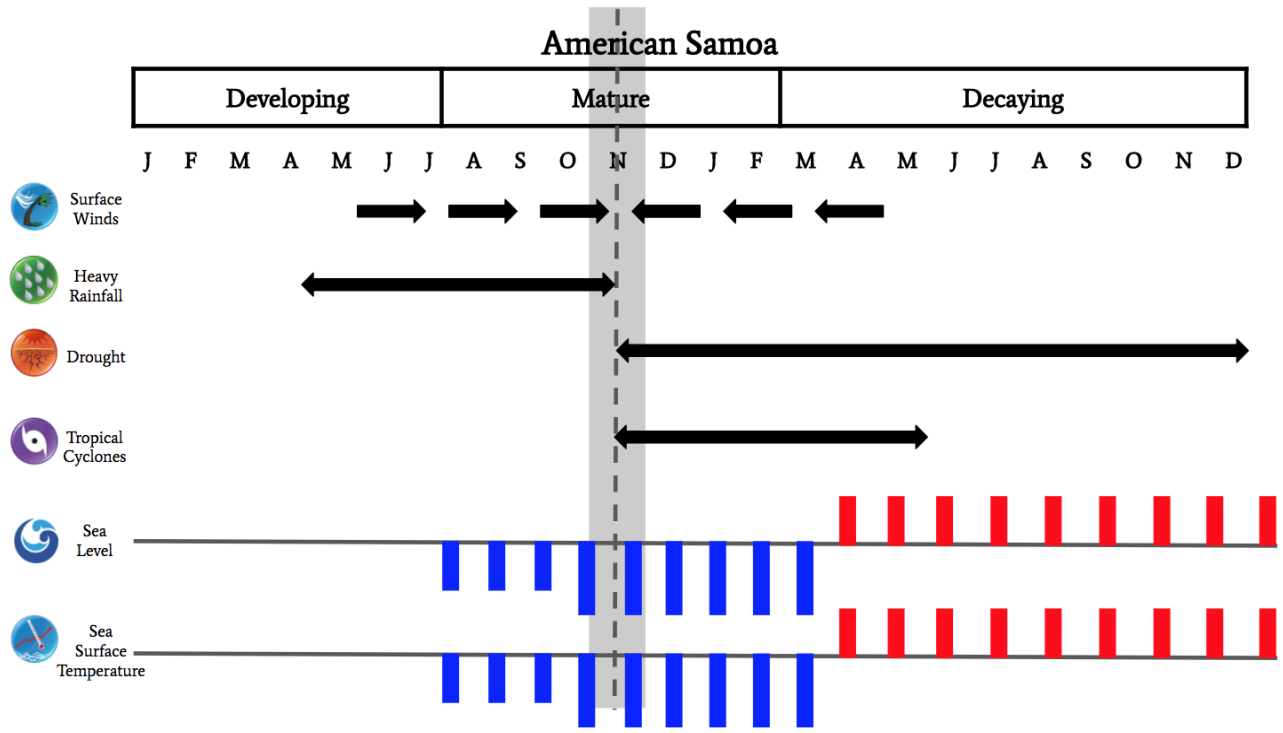


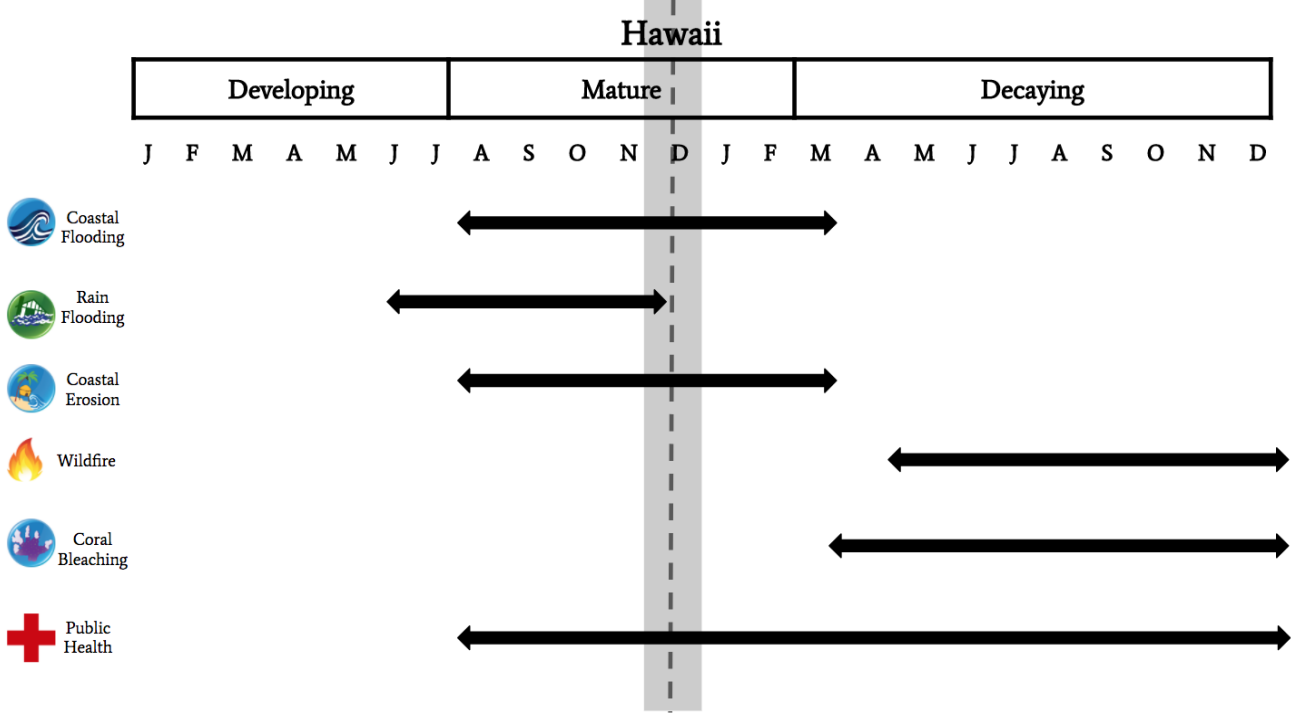
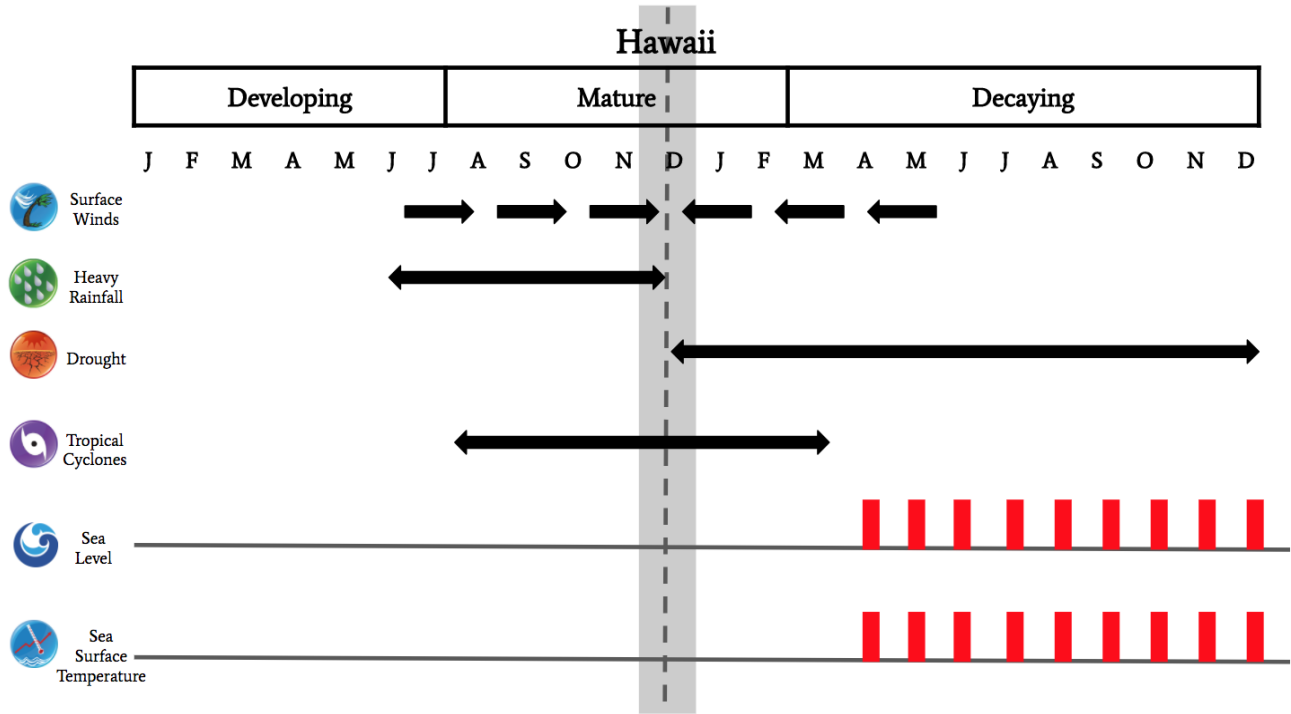












## Appendix B Tables of Impacts by El Niño Phase

**Table B1—Impacts during “Developing” Phase of 2014-2016 El Niño**

Region	Forcing	Impact
Western North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Heavy Rainfall</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Tradewinds</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Sea Level</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Weakening of easterlies, strengthening of westerlies bringing an increased frequency of rainfall, unsafe harbor conditions</li> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Sea level drop exposes shallow reefs that protect islands leading to catastrophic coral, fish die-offs as well as <i>taimasa</i> (“foul-smelling tide”) from decaying marine life</li> </ul>
Central North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Hawaii</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> </ul>
Central South Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—American Samoa, Samoa, Tonga, Fiji, Vanuatu</li> <li>● <b>Heavy Rainfall</b>— American Samoa, Samoa, Tonga, Fiji, Vanuatu</li> <li>● <b>Tradewinds</b>—American Samoa, Samoa, Tonga, Fiji, Vanuatu</li> <li>● <b>Sea Level</b>—American Samoa, Samoa, Tonga, Fiji, Vanuatu</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Weakening of easterlies, strengthening of westerlies bringing an increased frequency of rainfall, unsafe harbor conditions</li> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Sea level drop exposes shallow reefs that protect islands leading to catastrophic coral, fish die-offs as well as <i>taimasa</i> (“foul-smelling tide”) from decaying marine life</li> </ul>

**Table B2—Impacts during “Mature” Phase of 2014-2016 El Niño**

Region	Forcing	Impact
Western North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Heavy Rainfall</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Drought</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Sea Surface Temperature</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of disease outbreaks including dengue fever, chikungunya, zika virus due to flood</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul>
Central North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Hawaii</li> <li>● <b>Drought</b>—Hawaii</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul>

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<p><b>Central South Pacific</b></p>	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Tuvalu</li> <li>● <b>Heavy Rainfall</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Tuvalu</li> <li>● <b>Extratropical Cyclones</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Vanuatu</li> <li>● <b>Drought</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Vanuatu</li> <li>● <b>Sea Surface Temperature</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Vanuatu</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of disease outbreaks including dengue fever, chikungunya, zika virus due to flood</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul>
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Table B3—Impacts during “Decaying” Phase of 2014-2016 El Niño

Region	Forcing	Impact
Western North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Drought</b>—Federated States of Micronesia, Republic of Marshall Islands, Guam, Palau</li> <li>● <b>Sea Surface Temperature</b>—Federated States of Micronesia, Northern Mariana Islands, Republic of Marshall Islands, Guam, Palau</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of malnutrition, undernourishment due to freshwater, food insecurity</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> <li>● Increased risk of disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Above average temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul> <p><b>Biocultural Resources</b></p> <ul style="list-style-type: none"> <li>● Coral reef die-out causing disappearance of natural resources as well as livelihoods, cultural heritage, traditional ecological knowledge</li> <li>● Water shortages, extreme droughts, social unrest causing mass migration of people bringing changes to cultural/social mosaic of communities</li> <li>● Inundation of low-lying islands threatens land base that supports traditional lifestyles, subsistence agriculture/fisheries</li> </ul>
Central North Pacific	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—Hawaii</li> <li>● <b>Drought</b>—Hawaii</li> <li>● <b>Sea Level</b>—Hawaii</li> <li>● <b>Sea Surface Temperature</b>—Jarvis Island</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Rising sea levels causing coastal erosion, extreme high tides (king tides), saltwater intrusion</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Above average sea-surface temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> </ul>

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		<ul style="list-style-type: none"> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul>
<p><b>Central South Pacific</b></p>	<ul style="list-style-type: none"> <li>● <b>Tropical Storms</b>—American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Tuvalu</li> <li>● <b>Drought</b>—Australia, American Samoa, Papua New Guinea, Samoa, Tonga, Fiji, Kiribati, Vanuatu</li> <li>● <b>Sea Surface Temperature</b>—Australia, Samoa, Tonga, Fiji, Vanuatu, Tuvalu, Solomon Islands</li> </ul>	<p><b>Public Safety/Disaster Management</b></p> <ul style="list-style-type: none"> <li>● Strong winds, storm surges causing infrastructure damage, coastal erosion, saltwater intrusion</li> <li>● Flood causing damages to critical infrastructure,, irrigation systems</li> </ul> <p><b>Freshwater Resources</b></p> <ul style="list-style-type: none"> <li>● Dry, low-moisture ground resulting in wildfires that burn lands used for agriculture, horticulture</li> <li>● Falling of groundwater level, depletion of reservoirs causing water scarcity for irrigation, drinking</li> <li>● Endangered freshwater supply causing reduction in staple crop yields, loss in subsistence agriculture</li> </ul> <p><b>Public Health</b></p> <ul style="list-style-type: none"> <li>● Increased risk of malnutrition, undernourishment due to freshwater, food insecurity</li> <li>● Increased disease outbreaks including diarrhea, leptospirosis, typhoid due to drought</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> <li>● Increased risk of psychological, mental disorders including anxiety, depression, schizophrenia due to displacement</li> <li>● Increased risk of respiratory diseases including common cold, asthma, pneumonia due to wildfires</li> </ul> <p><b>Ecosystems</b></p> <ul style="list-style-type: none"> <li>● Above average sea-surface temperatures overly stress coral causing nutrient, color loss leading to bleaching</li> <li>● Limited availability of freshwater, drying-up of streams causing loss of habitat, resources for animals, plants</li> </ul> <p><b>Biocultural Resources</b></p> <ul style="list-style-type: none"> <li>● Coral reef die-out causing disappearance of natural resources as well as livelihoods, cultural heritage, traditional ecological knowledge</li> <li>● Water shortages, extreme droughts, social unrest causing mass migration of people bringing changes to cultural/social mosaic of communities</li> <li>● Inundation of low-lying islands threatens land base that supports traditional lifestyles, subsistence agriculture/fisheries</li> </ul>