El Niño and La Niña in Hawai‘i

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Figure 1 Puʻukoholā Heiau National Historic Site
Above, rainy season, 12/27/10, an El Niño year. Below, rainy season, a La Niña year.
Photos by S. Businger.

Title: El Niño and La Niña in Hawai‘i
Grades: 6-8, modifiable for 9-12
Time: 2-5 hours

Nā Honua Mauli Ola, Guidelines for Educators, No Nā Kumu: Educators are able to sustain respect for the integrity of one’s own cultural knowledge and provide meaningful opportunities to make new connections among other knowledge systems (p. 37).

EARTH AND SPACE SCIENCES (A Framework for K-12 Science Education, NRC, 2012)
Standard ESS2D: Weather And Climate
By the end of grade 8 students should know that weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. Weather, the condition of the atmosphere at a given place and time varies daily and seasonally. Climate, the range of a region’s weather from one to many years, depends on latitude and geography, and thus varies from place to place. The ocean influences weather and climate by absorbing, storing, and slowly releasing large amounts of energy from the sun. Energy is redistributed globally through ocean currents and atmospheric circulation (winds). Greenhouse gases absorb and retain the energy radiated from land and ocean surfaces, thus regulating Earth’s average surface temperature. These patterns are very complex and winds are chaotic in nature. Therefore, weather cannot be predicted with any accuracy more than a couple of weeks in advance. Seasonal climate predictions show about a 60% success in predicting whether temperatures and precipitation at a given site will be above or below normal, because they rely on slowly changing
El Niño and La Niña in Hawai‘i

sea surface temperatures that force the largest atmospheric circulations. These seasonal predictions are very important for decision makers regarding energy consumption, water conservation, and agriculture.

**Standard ESS3.B: Natural Hazards**

By the end of grade 8 students should know that mapping the history of natural hazards in a region, combined with an understanding of related geophysical forces can help forecast the locations and likelihoods of future events. Through observations and knowledge of historical events, people know where certain of these hazards—e.g., earthquakes, tsunamis, volcanic eruptions, severe weather, floods, and coastal erosion—are likely to occur. Understanding these hazards helps us prepare for and respond to them.

**ESS3.C: Human Impacts On Earth Systems**

By the end of grade 8 students should know that human activities have significantly altered the biosphere and geosphere. Typically, as human populations and per-capita consumption of natural resources increase, so do negative impacts on Earth. Burning of fossil fuels that produce carbon dioxide, a greenhouse gas that absorbs and retains the energy radiated from land and ocean leads to increased global temperatures and higher probability of more severe weather events.

**Hawaii Content and Performance Standards (HCPS) III**

http://standardstoolkit.k12.hi.us/index.html

<table>
<thead>
<tr>
<th>STRAND THE SCIENTIFIC PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard 1:</strong> The Scientific Process: SCIENTIFIC INVESTIGATION: Discover, invent, and investigate using the skills necessary to engage in the scientific process</td>
</tr>
<tr>
<td><strong>Benchmark SC.8.1.1</strong> Determine the link(s) between evidence and the conclusion(s) of an investigation.</td>
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<tr>
<td><strong>Benchmark SC.8.1.2</strong> Communicate the significant components of the experimental design and results of a scientific investigation.</td>
</tr>
</tbody>
</table>

| **Standard 2:** The Scientific Process: NATURE OF SCIENCE: Understand that science, technology, and society are interrelated |
| **Benchmark SC.8.2.1** Describe significant relationships among society, science, and technology and how one impacts the other. |
| **Benchmark SC.8.2.2** Describe how scale and mathematical models can be used to support and explain scientific data. |

| **Standard 3:** Life and Environmental Sciences: ORGANISMS AND THE ENVIRONMENT: Understand the unity, diversity, and interrelationships of organisms, including their relationship to cycles of matter and energy in the environment |
| **Benchmark SC.7.3.3** Explain how biotic and abiotic factors affect the carrying capacity and sustainability of an ecosystem. |

| STRAND PHYSICAL, EARTH, AND SPACE SCIENCES |
El Niño and La Niña in Hawai‘i

July 25, 2014

Standard 8 EARTH & SPACE SCIENCE: Understand the Earth and its processes, the solar system, and the universe and its contents.

**Benchmark SC.ES.8.1** Describe how elements and water move through solid Earth, the oceans, atmosphere, and living things as part of geochemical cycles.

**Benchmark SC.ES.8.4** Describe how heat and energy transfer into and out of the atmosphere and their involvement in global climate.

**Benchmark SC.ES.8.6** Describe how winds and ocean currents are produced on the Earth's surface.

**Benchmark SC.ES.8.7** Describe climate and weather patterns associated with certain geographic locations and features.

To the Teacher: Connections to Place and Culture, ENSO – El Niño Southern Oscillation

It may come as little surprise to the people of Hawai‘i that the Pacific Ocean has a large impact on our weather. But, just how profound that impact is was only recently fully appreciated. It turns out that an eastward shift in the warmest sea-surface temperatures (SST) in the tropical Pacific Ocean causes an eastward shift in the location of deep tropical thunderstorms, which in turn affects the general circulation of the winds over the entire ocean basin and beyond (see Figure 2). These changes in the global winds in turn cause changes in global ocean currents that cause the SST patterns to shift. So we see that we have come full circle with the winds and ocean performing an artful dance in a cycle of cause and effect. And all these changes impact our local weather in ways such as seen in photographs above of Puʻukoholā Heiau National Historic Site that our new understanding may help us to predict (Figure 1).

We named this ENSO lesson "Uē ‘o Kānepūniu i ka Wela o Lā" ["Kānepūniu Cries in the Heat of the Sun"] because it beautifully and visually describes from a Hawaiian perspective how the El Niño pattern is experienced here in Hawai‘i. It is a quote from “The News of Hāmākua” from the Hawaiian-language newspaper Ka Nupepa Kuokoa, 23 December 1893, that describes an extreme drought in Hāmākua. People reported that their crops had all dried up, there was not a single rain shower and they had to fetch water from the forest. The author exclaims that it was so hot that even Kāne in his form of a coconut, Kānepūniu, complained of the heat of the sun. We will discuss this and other articles below.

The name El Niño (referring to the Christ child) was originally given by Peruvian fisherman to a warm current that appeared every few years around Christmas. It was first mentioned in 1891 in a Lima Geographical Society article (Kessler, n.d.). Today the term El Niño is used more broadly to refer to a dramatic warming of the sea-surface temperatures (SSTs) in the eastern and central equatorial Pacific Ocean, beginning along the north-central coast of South America and extending westward to the date line (see Figure 2). As stated above, the changing SST pattern results in large-scale changes in winds and rainfall patterns.
Figure 2 Surface winds (arrows) and sea surface temperatures (SST, shading) for El Niño conditions in December 1997 (top), and for La Niña conditions in December 1998 (bottom). The eastward shift in the location of prevailing thunderstorms is indicated by the “T”s. Location of the Hawaiian Islands is given by the red ellipse.

The Southern Oscillation was named by Sir Gilbert Walker in 1923, who first observed that when atmospheric pressure was unusually high in the Pacific Ocean it tended to be unusually low in the Indian Ocean. Walker, Director of Observatories in India, was mostly concerned with variations in the Indian monsoon, but he recognized that changes in atmospheric pressures across the tropical Pacific and beyond were not isolated but part of a larger oscillation in equatorial sea surface temperatures (SST) we now refer to as El Niño and La Niña.

Thus, El Niño and La Niña are SST anomaly patterns across the tropical Pacific Ocean that deviate from average SSTs. These SST anomaly patterns have a counterpart in the atmospheric pressure/wind patterns, which are called Southern Oscillation. In 1969 Jacob Bjerknes of the University of California, Los Angeles described the physical mechanisms connecting these two phenomena (Sarachik and Cane 2010). Together these phenomena are called El Niño – Southern Oscillation or ENSO. The warm El Niño phase typically lasts for 8 - 10 months or so. The entire ENSO cycle lasts usually about 3 - 7 years, and includes a cold phase, known as La Niña, that may be similarly strong (Figure 2). However, the ENSO cycle is not a regular oscillation like the change of seasons, but can be highly variable in strength and timing, reflecting the underlying chaotic nature of the atmosphere.
**El Niño and La Niña: Impact on Pacific and Pacific-Rim Peoples**

During La Niña easterly winds over the equator are stronger than usual, and the result, which involves the Coriolis force (described in Lesson 1), is more upwelling along the equator and colder SST.Southeasterly winds and the Coriolis force also cause surface water in the eastern Pacific to move toward the west away from the coast of South America. Deep, cold, nutrient-rich water upwells to take its place. This nutrient-rich water leads to a vibrant ecosystem (plankton, fish, birds, etc.) that supports one of the world's biggest fisheries off the Peruvian coastline, with annual catches ranging between 5-10 million metric tons (Science Daily, 2013).

During El Niño, the sustained easterly tradewinds along the equatorial Pacific weaken and are replaced by westerly winds in the western Pacific such that downwelling takes place there. Downwelling causes warm water to accumulate at the ocean surface. Sea level over the western Pacific is higher than it is in the eastern Pacific because it is warmer there and warm water takes up slightly more volume than cool water. During an El Niño, the easterly winds become much weaker, and the upwelling along the west coast of South America dies out and is replaced by remotely forced downwelling of nutrient-poor water from off shore (Figure 2). The ecosystem that depends on the nutrient-rich upwelling waters crashes, including the fish that people catch. The effects were usually observed around Christmas time, thus the name El Niño, the boy, after the Christ child.

Early European explorers who wondered how Polynesians sailed eastward against the prevailing trade winds found that Polynesian navigators knew about westerly winds. Along with the technology of double-hulled canoes that carried people, plants, and animals across wide expanses of open ocean, navigator knowledge of local and global winds enabled them to use westerlies to colonize Pacific islands in the east Pacific north and south of the equator. Ben Finney, Richard Rhodes, Paul Frost, and Nainoa Thompson (1989), authors of "Wait for the West Wind" observed that "during 1982–3, when the strongest El Niño event recorded so far occurred, the westerlies began to reach the Marquesas in December, and were dominant there during the following March and April. These westerlies — both the regular monsoonal type and those intensified and extended during El Niño events — must have facilitated the movement of people eastwards into the Pacific" (p. 268).

The Southern Oscillation Index (SOI) illustrates the development and intensity of El Niño or La Niña events in the Pacific Ocean (Figure 3). The SOI is based on the sea-level pressure differences between Tahiti in the Pacific Ocean and Darwin, Australia in the Indian Ocean. The SOI is negative during El Niño, reflecting the tendency for more westerly winds near the equator during El Niño, and positive during La Niña, reflecting strong easterly winds near the equator.

Finney et al (1989) argue that ancient mariners would wait for the westerly winds to blow before setting out eastward to explore the ocean for new islands to populate. Westerly winds are a hallmark of strong El Niño events, creating favorable conditions for sailing eastward. During ENSO neutral or La Niña years easterly winds prevail. Finney et al. note, “While double-canoes can sail to windward, they cannot do so as well as a yacht equipped with a deep keel or centerboard. In fact, to attempt to sail a shallow-draft, keel-less vessel like a double-canoe too close into the wind can be self-defeating. As it points closer and closer into the wind,
a double-canoe slows noticeably and begins to make so much leeway that little progress can be made directly into the wind, particularly when sailing against a strong current.”

Figure 3 The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia. Southern Oscillation Index (SOI) time series 1876-2011. The black line is a 5-y running mean (Source: Wikipedia Commons).

In the late 20th century, scientists and policy makers in Pacific island and Pacific rim countries most likely to be affected became interested in the ENSO phenomena because of its profound impact on agriculture and the economy. The broader impacts of ENSO on the climate system include large areas that experience extreme droughts and other areas that experience extreme precipitation and floods. Droughts lead to increased wild fires, and water supply shortages. Extreme precipitation in other areas produces floods, erosion, disease, and disruption of transportation. Both floods and droughts impact agricultural productivity, the food chain, and the economy. ENSO has a noticeable impact on the global mean temperature, which reflects the global reach of the ENSO phenomenon (Figure 3).

Only the stronger El Niño and La Niña years are highlighted in Figure 4. For example 2006 doesn’t show up as a La Niña year though Hawai‘i had 42 days and 42 nights of rain, and the 2005-2006 winter shows a significant negative dip in Southern Oscillation Index (Figure 3) but is not highlighted as an El Niño year.
Hawai‘i is located close to the center of action for ENSO (Figure 2). As a result our swings in weather associated with ENSO are pronounced. Note the tendency for a ridge of high surface pressure over Hawai‘i and light winds during El Niño in Figure 5a, and by contrast the trough of lower pressure and moist southerly wind anomalies over Hawai‘i during La Niña conditions (Figure 5b). Regions of high surface pressure are characterized by light winds that spiral clockwise and outward and suppressed clouds and rainfall. In contrast, regions of low surface pressure are characterized by enhanced winds that spiral counterclockwise and inward and enhanced clouds and rainfall. The Hawaiian Islands tend to experience drought conditions and a greater hazard of hurricanes, because of warmer SSTs in the central Pacific during El Niño, and enhanced subtropical cyclones, also known as kona lows, during La Niña, because of the displacement of a wave of low pressure in the jet stream toward Hawai‘i.

The anomalous wind patterns during El Niño (Fig. 5a) also produce high winter surf in Hawai‘i (note that enhanced winds are pointed at Hawai‘i from an anomalous low to our northwest), flood events in California (note the anomalously warm air moving onshore from the south), and warm and dry conditions over Washington and western Canada. The anomalous wind patterns during La Niña (Fig. 5b) result in cold weather with unusual snowstorms in Seattle (because of cold northerly winds) and flood events in Hawai‘i (because of the greater occurrence of southerly winds that carry more moisture originating over the warmer ocean to the south).
Figure 5 Composite surface air temperature and wind anomalies during a) El Niño winters and b) during La Niña winters. Note that by showing anomalies, this map shows the air temperature departures and wind vectors from average conditions. Hawai‘i’s location is indicated by the red ellipse.

The influence of the ENSO cycle on Hawai‘i precipitation is illustrated in Figure 6. The greatest difference between El Niño and La Niña conditions during different years occurs in January-February when El Niño years (blue bars) produce lower-than normal rainfall, and La Niña years (yellow bars) produce higher-than-average rainfall. The May-June and September-October times show the opposite relationship (El Niño is wetter than average and La Niña is drier than average), but the effects are more subtle.
Figure 6 Hawaiʻi rainfall index normalized by the monthly climatological mean rainfall for each of the 27 Hawaiian stations that make up the index. The analysis includes data from 1906 to 2001. There are no units on the y-axis because the values are a ratio that indicates departure from average values. Blue histogram is for El Niño and the yellow histogram is for La Niña (Adapted from Chu and Chen Journal of Climate, 2005).

**Historical ENSO Cycles and Reports of Droughts and Floods**

Could 19th century Hawaiian language newspaper articles provide insight into El Niño and La Niña events in Hawaiʻi even before these events were known to western science? References to droughts, floods, and heavy rains in Hawaiian-language newspapers were collected (see next section) and the results compared to a record of ENSO from the 19th century. This record of El Niño and La Niña events was reconstructed using proxy data sets, such as tree rings and ice cores in areas sensitive to ENSO cycles (Figure 7; McGregor et al. 2010).

We tallied the number of articles reporting on droughts and floods in the O‘ahu newspaper *Ka Nupepa Kuokoa*. The number of articles was normalized by the number of *Kuokoa* issues published per month so that it more accurately reflects differences in weather rather than changes in the number of newspapers issued. Our analysis show that the normalized number of droughts per month during El Niño years is 0.536, whereas during La Niña years it is 0.157. The normalized number of heavy rains per month are 0.305 during El Niño years and 1.1 during La Niña years (Figure 8). These results suggest that more droughts and fewer heavy rains accompany El Niño events. Conversely, there are fewer droughts and more heavy rain events during La Niña years. This finding is consistent with the relationship between ENSO and Hawaiian rainfall shown in Figure 6.

![Figure 8](image)

Figure 8 Histograms of the number of Hawaiian language newspaper reports of a) heavy rain and b) droughts events between 1869 and 1900. The events are normalized by the number of *Ka Nupepa Kuokoa* issues published per month, and the bars are colored to indicate El Niño (red), La Niña (blue) or neither (black) years based on the data of McGregor *et al.* (2010).
Accounts of Drought and Rainfall Events in *Ka Nupepa Kuokoa*

Articles in their entirety can be found after the activities at the end of the lesson. Excerpts below of newspaper articles from *Ka Nupepa Kuokoa* tell of unusual, extended drought periods. Looking at the dates of these accounts, we can say that these are likely El Niño events. The article below from Maui tells of a great drought never before seen in Kaupō and Kahikinui. This article was printed on October 26, 1878, an identified El Niño year as seen in Figure 7.

No Kaupo.—He nui ka pilikia o keia aina i keia wa, aole haule mai ka ua, maloo ka aina, me he mea la ua kaupale ke Akua i ka pono maanei o Kipahulu, a ma Kaupo aku aole ua malaila...

About Kaupō.—There is a crisis now in this land. The rain hasn't fallen, the land is parched and it's as if God is keeping prosperity on this side of Kīpahulu, and from Kaupō on, there's no rain...

No Kahikinui.—O na hiona o keia aina i keia wa, aole e like me mamua, me he mea la, ua puhi ia i ke ahi, ke hele a owela ka mauna, aole wahi mauu ulu ae...

About Kahikinui.—The features of the land at this time are not like before. It's as if it has been burned by fire; the mountain is scorching and there is no grass growing...

Two years earlier on November 11, 1876, Bila Kupa reports that the rivers of Makawao have not been this dry for the past 30 years, and people have to find water in the mountains.

Maloo o Makawao—Mai ka peni mai a Bila Kupa e hai mai ana, no ka nui loa o ka wela ma ia wahi, ua maloo loa ka wai o ko laila mau kahawai, pau na bipi i ka make, a ke huli hele la ka poe kanu ko i ka wai iloko o na kuahiwi [...] Aole maloo nui ana o na kahawai o Makawao elike me keia, iloko o na makahiki he 30 i hala aku nei, wahi ana, a ke uwe nui la na mahiko no keia pilikia.

Makawao is dry—From the pen of Bila Kupa, telling of the intense heat of the area. The water has dried in the streams there, the cattle have all died, and the sugar cane planters are searching for water in the mountains [...] The rivers of Makawao have not been this dry for the past 30 years, according to him, and the sugar planters are lamenting about this problem.

Because of great heat in Honolulu, an article on September 5, 1868 encourages people to call upon Kū in his form of the mythical pond in the sky, Kūlanihākoʻi, to bless the earth with much needed rain.

No ka nui loa o ka wela i keia mau la, nolaila hoi, ua hahana loa o loko nei o ke kulananakauhale aole he ahehea makani olu o ka uka, a aole hoi i haule mai ka ua iloko o keia mau hebedoma i hala aku nei, a no ka nele o ka ua mai na kuahiwi mai iloko o keia mau hebedoma, a no ka nui loa hoi o ka wela pono ole o ka la, nolaila, ua emi mai ka wai o uka [...] A he mea pono no ke heahea ae i ka lokomaikai o kulanihakoi, i wehe ia mai kona manowai lani e mauu ai na puu o ka lehulehu honua.
Because of this heat these days, the town is hot, and there are no cooling breezes from the uplands, and no rain has fallen these past weeks. Because there was no rainfall from the mountains, and because of the extreme heat of the sun, the amount of water in the uplands has decreased [...] We should call on the graces of the sacred pool in the sky, Kūlanihākoʻi, so that its heavenly levees may be opened and slake the thirst of the earthly multitudes.

Another account on December 23, 1893 describes people having to go three miles into the forest to get water. It is so hot that Kānepūniu, Kāne who takes the form of a coconut, cries in the heat of the sun.

_Na mea Hou o Hamakua. He nui loa ka la ma Hamakua nei, ua pau loa na mea kanu i ka maloo e like me ke ko, kulina, uala, kalo [...] Nele loa i ka wai, a ma kahi o ekolu mile iloko o ka ululaau kahi o ka wai e kii ia nei [...] ke hele la a uwe o Kanepuniu i ka wela o ka la._

The News of Hāmākua. It has been very sunny here in Hāmākua, and crops are dried up, such as corn, sweet potato, taro [...] There is no water, and people have to go about three miles into the forest to get water [...] and Kānepūniu complains of the heat of the sun.

In conclusion, Hawaiian-language newspaper articles as well as meteorological data show that the weather of the Hawaiian Islands is influenced by many different factors. These include terrain, elevation, latitude, longitude, proximity to the ocean, land use, and others. Some of the factors that influence our local weather are ocean-wide atmospheric patterns that derive from an interaction of the surface winds and sea-surface temperature patterns. ENSO is one of them. ENSO strongly influences the weather across the Pacific Ocean, including Hawaiʻi, especially during winter months.

In Hawaiʻi, variations in observed precipitation totals (Figure 6) and in surface air temperature can be attributed to the phase of ENSO that we are in. Because ENSO refers to the oscillation between two extremes we are typically not in an ENSO year. It is common for precipitation to be suppressed during the peak of El Niño, because of the proximity of high surface pressure that strengthens subsidence (or sinking motion) and warms surface air temperatures (SST) over our islands. Hawaiʻi tends to have beautiful sunny winter days with light trades during El Niño years. During La Niña winters, the trade winds are more likely to be disrupted more often than average by moist southerly or southeasterly flow, bringing more precipitation than during non-La Niña years. The temperature also tends to be cooler, locally and globally (Fig. 4).
INSTRUCTIONAL ACTIVITIES

1. Engage:
   • Where you live, describe how the winters are in terms of precipitation and temperature.
   • Where you live, ask your parents if they remember a year of drought and a year of intense precipitation (during the winter months).
   • Check with a list of ENSO years if the dry winter and the wet winter coincide with El Niño or La Niña years.

2. Explore:
   • Explore how climatology is important for a region.
   • Explore how the Pacific Ocean sea surface temperature can influence Hawai‘i.

3. Explain:
   • How do you expect the winter months’ weather to be during the next El Niño compared with normal weather?
   • How do you expect the winter months’ weather to be during the next La Niña compared with normal weather?

4. Elaborate/Extend:
   • Arrange a field trip to the National Weather Service at the University of Hawai‘i-Mānoa and ask about ENSO. Ask them to show you maps of current and future SST.
   • Find three different maps showing ENSO anomalies and climatology and compare them in terms of temperature and precipitation.
   • Research how ENSO may affect future weather in Hawai‘i.
   • Research how knowledge of ENSO may affect long distance sailing plans of Pacific voyagers in the past and future.

5. Evaluate:
   • Teacher considers evaluates student learning, effectiveness of lesson and activities, and areas for improvement.
   • Students evaluate their learning and what they would like to learn more about.
Activity 1: Sea Surface Temperatures and Precipitation

We can see the effects of the ENSO cycle in the islands by examining the correlation of El Niño/La Niña events and extreme drought and rainfall events. Data show that there was a strong El Niño during the winter of 1892/1893. A Hawaiian-language newspaper article from 1893 describes the drought experienced in Hāmākua, Hawai‘i in December of that year: “…crops are dried up, such as sugar cane, corn, sweet potato, taro, and others…sunny weather began in June and has lasted until now…without a single shower.”

Although there was no mention of an El Niño in the paper, today we know this drought did indeed occur during a strong El Niño event. The rainfall recorded for this month was only 2.64 inches. Hāmākua's average rainfall in December is 10.54 inches. Quite a difference!

Let’s look at Hāmākua's rainfall during a La Niña event, for example February of 1918: a whopping 24.19 inches of rain was recorded, compared to an average of 8.27 inches for February in Hāmākua. We see that El Niño has the effect of reducing precipitation, whereas La Niña enhances it. So can we determine the ENSO phase given ocean temperatures along the equator and precipitation data over Hawai‘i?

See For Yourself

Part 1: Sea Surface Temperature

Figure 9 on the next page gives monthly mean ocean temperatures for a vertical cross-section through the tropical Pacific for December 1997 (the x-axis is longitude and the y-axis is depth). Draw the isotherm (line showing the same temperature) where the temperature is 26º C. Then draw the isotherms for 20, 17, 14, 11 and 9º C. The first line has been started for you.

Using colored pencils, color the space between isotherms according to the following key:

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<tr>
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<td>Orange</td>
</tr>
<tr>
<td>20-23</td>
<td>Yellow</td>
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<tr>
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<td>Light Blue</td>
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<tr>
<td>9-11</td>
<td>Dark Blue</td>
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<tr>
<td>&lt;9</td>
<td>Violet</td>
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Repeat this procedure for Figure 10, which gives monthly mean ocean temperatures for the tropical Pacific for December 1998.
Monthly Mean Ocean Thermal Structure (Temperatures) - December 1997

Figure 9 Tropical Pacific Ocean temperatures for December 1997 (source NOAA)
### Monthly Mean Ocean Thermal Structure (Temperatures) - December 1998

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Figure 10: Tropical Pacific Ocean temperatures for December 1998 (source NOAA)
Questions:
1. Where do you see the deepest layer of warm water in the vertical cross section in 1997? In 1998?

2. Estimate the regions of high and low pressure in each of the figures. How is this different from the ENSO neutral state of the equatorial Pacific? (Hint: relatively warm water results in low sea-level pressure, whereas cool water supports high sea-level pressure.)

3. From what direction do you expect the wind to blow in each of the figures? How can you tell? Hint: along the equator, the Coriolis force is negligible, thus with winds blow directly from higher pressure towards lower pressure.

4. Where would you expect strong convection (and thus thunderstorms) in each of the figures? (Hint: Thunderstorms form over the region of warmest SST.)

Part 2: Precipitation

Now take a brief look at the corresponding rainfall amounts for Hawai‘i from 1997-98 and 1998-99. We choose Hāmākuapoko, Maui as our target location. Hāmākuapoko is located on the windward side of Maui. Rainfall in Hāmākuapoko is not overly influenced by terrain enhancement and it is a station that shows little uncertainty. Go to http://rainfall.geography.hawaii.edu/interactivemap.html and choose station 485 at Hāmākuapoko. (Latitude: 20.913˚N, Longitude: 156.346˚W)(See Figure 11).

Figure 11 Screenshot of Interactive Map on Rainfall Atlas of Hawaii website. The location of Station 485 is indicated by the green square in the red ellipse.

Record the average rainfalls for November, December, January, February, and March. Find the average of these values. This gives you the average for winter rainfall (Table 1).
Table 1  Rainfall for Hāmākuapoko, Maui (in inches):

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 1997</td>
<td>8.48</td>
</tr>
<tr>
<td>December 1997</td>
<td>7.09</td>
</tr>
<tr>
<td>January 1998</td>
<td>1.06</td>
</tr>
<tr>
<td>February 1998</td>
<td>1.76</td>
</tr>
<tr>
<td>March 1998</td>
<td>2.87</td>
</tr>
</tbody>
</table>

Questions:

1. Calculate the average winter rainfall for each table (you will get two values, one for 1997-98 and one for 1998-99).

2. How does Hāmākuapoko's recorded rainfall for 1997-98 compare to the average winter rainfall value?

3. How does Hāmākuapoko's recorded rainfall for 1998-99 compare to the average winter rainfall value? Based on these results, along with what you now know about ENSO, what ENSO phase do you expect for 1997-98? For 1998-99?
Activity 2: ENSO and the Tropical Atmosphere

During El Niño, the atmosphere over the equatorial waters in the central Pacific is heated by an anomalously warm sea-surface. The atmosphere redistributes the extra heat by enhanced moist convection (think thunderstorms). One way we can observe changes in convection is via satellite observations of the outgoing longwave radiation (OLR). The OLR observations tell us the temperature of the surface that the satellite sees. If the atmosphere between the satellite and the Earth's surface is clear, then the satellite essentially sees the OLR from the ocean or land surface. However, if the atmosphere is full of deep clouds, then the satellite sees radiation emitted by the top of the clouds. Because the cloud tops of thunderstorms typically range from 10-16 km above the surface, they are much colder than the surface. Air cools as it expands while rising up in a thunderstorm. The thunderstorm anvils or cloud tops end up being very cold. Therefore, when we see areas of low OLR, we can interpret this as the location of deep thunderstorms.

Look at the OLR anomaly for December 1982-February 1983 in Fig. 12.

Questions:
1. Where are the most positive OLR anomalies found?
2. Where are the most negative OLR anomalies found?
3. What ENSO phase does the pattern in Figure 12 suggest?
4. What can you infer from this about cloud behavior during this ENSO phase compared to average conditions?
5. What is the sign of the OLR anomaly over Hawai‘i? What does this imply about the likelihood of deep convection over Hawai‘i during this time period?
Activity 3: ENSO and Biological Productivity

We noted earlier that ENSO can have a profound effect on agriculture and the economy. This is a huge motive for understanding the phenomenon. Let’s look at one aspect of this economic link: the changes ENSO can cause in biological productivity in the ocean.

Phytoplankton are at the base of the aquatic food web; they feed everything from tiny zooplankton to massive whales. Therefore, their presence in the ocean is important in determining the populations of other aquatic animals. Phytoplankton use chlorophyll and other nutrients to survive. The availability of chlorophyll is closely tied to changes in ocean temperature and nutrient density. Based on what you know about warm water movement throughout ENSO, can you determine the relationship between El Niño and bio-productivity?

First collect data from the following online source:

2. Click on the link to “Get Data.”
3. Choose a date from December 1997.
4. Select “Sea Surface Temperature” under “Which Data?”
5. Examine both the map and graph under “Which View?”
6. Repeat, this time choosing “Chlorophyll a” as your data parameter.
7. Examine both the resulting map and graph.
8. Repeat steps 3-7, this time using December 1998.

Use the December 1997 and December 1998 maps and graphs to answer the following four questions.

1. What differences do you see in chlorophyll concentrations between the two years? In which regions are these differences most obvious?

2. What sea surface temperatures support the largest concentration of chlorophyll?

3. From what we know about ocean currents during an El Niño event, what do you think causes the changes in chlorophyll availability along the west coast of Peru?

4. What are implications for biological productivity (high biomass = good fishing) when sea surface temperatures are high? When they are low?
TEST YOURSELF: What have you learned from this lesson and activities?

1. What is ENSO?
2. What causes El Niño to form?
3. Find a world map and identify the area where El Niño has the strongest signal in the tropical sea surface temperature (SST) in its mature phase.
4. What are the expected changes in seasonal climate in Hawai‘i due to El Niño and La Niña?
5. Predict how salinity in Hawaiian waters might be affected during an El Niño event.
6. How often does El Niño occur on average, based on past observations?
7. What influence does ENSO have on the distribution of thunderstorms in the equatorial Pacific?
8. What influence does ENSO have on the distribution of surface winds in the equatorial Pacific?
9. What influence does ENSO have on the distribution of chlorophyll in the equatorial Pacific?
10. What would be the effect of ENSO phase on sea level measurements made in the western equatorial Pacific? (Hint: Warmer water takes up a little more space than cooler water.)

Figure 13 Heavy rain on the Pali Highway at noon, 31 March 2006, a La Niña year. (Photo by Aaron Businger).
Hawaiian-language Newspaper Articles

*Ka Nupepa Kuokoa.* 26 October 1878, pg. 1

The News of East Maui.

About Kaupō.—There is a crisis now in the land. The rain hasn't fallen, the land is parched and it's as if God is keeping prosperity on this side of Kīpahulu, and from Kaupō on, there's no rain. There has been plenty of rain in Kīpahulu. All the people of Kaupō are going to Wailuku, Makawao, Kīpahulu and Hāna in search of sustenance and to farm. The only food is cactus fruit cooked over a fire. At some places of Kaupō, dried goat takes the place of taro, and raw goat is the fish, but some people continue to survive off wild taro. At Nu‘u, there are no resources at all, and all the people have gone. This is a crisis from God, for the Lord's effort there have not gone well.

About Kahikinui.—The features of the land at this time are not like before. It's as if it has been burned by fire; the mountain is scorching and there is no grass growing. That well-known Portuguese man, M. Paiko, is living there, raising cattle, goats, and sheep. Life for people is even hard in Wailuku, so it's best to follow wherever the horses are heading (look for what you can find).

*Ka Nupepa Kuokoa.* 11 November 1876, pg. 2

Makawao is dry—From the pen of Bila Kupa, telling of the intense heat of the area. The water has dried in the streams there, the cattle have all died, and the sugar cane planters are searching for water in the mountains. Perhaps it is a drought, for Hōkūloa [Venus] is in plain sight, placed proudly in the sky. The rivers of Makawao have not been this dry for the past 30 years, according to him, and the sugar planters are lamenting about this problem.
Pipe Water.—Because of this heat these days, the town is hot, and there are no cooling breezes from the uplands, and no rain has fallen these past weeks. Because there was no rainfall from the mountains, and because of the extreme heat of the sun, the amount of water in the uplands has decreased, and the water pipes down here by the shore are without water for some hours of the day. If this drought continues, it seems that this town will be in a crisis from lack of water. We should call on the graces of the sacred pool in the sky, Kūlanihā'ī, so that its heavenly levees may be opened and slake the thirst of the earthly multitudes.

The News of Hāmākua

It has been very sunny here in Hāmākua, and crops are dried up, such as sugar cane, corn, sweet potato, taro, and others. There is no water, and people have to go about 3 miles into the forest to get water, some by cart and others by horse. Sunny weather began in June and has lasted until now in November, with not a single shower, and Kānepūniu complains of the heat of the sun.
El Niño and La Niña in Hawai‘i

Ka Nupepa Kuokoa. 14 March 1868, pg. 3

Water struggles of the sugar mills here in Hilo.

Kuokoa Newspaper, Greetings:—

You and I both know these words printed above.

And Hilo is recognized as a land recounted in songs "about the rain."

Therefore, part of A.D. 1867 until the first part of this year, there has been drought, and the land is like a barren field, for the soil is dry. And because of this terrible downturn in Hilo, famous for rain that falls all day long, the water sources are all dried up, and there is little water left in the streams. Therefore, the sugar mills have struggled over the water, between Po‘onahōhoa and Capt. Borras. The reason for this is the lack of water.

There I now boast that Hilo is at peace these months, and this is the news that the natives of Hilo are loudly declaring, "Peace! Hilo is at peace!"

It is a true fact, expressing that Hua has indeed arrived in Hilo, the one whose name is uttered, "The bones of Hua rattle in the sun."

Some people are wondering, why is Hilo peaceful?

I say, without pretense, that He who makes the rain was stingy, so the people would realize, half of who are absorbed in drinking sweet potato liquor.

They plant, and the heat of the sun strikes violently, dries the leaves, and stunts the growth, a frustration from something that we should chatter about, that taro, the usual staple of Hilo, has been abandoned, and the sweet potato has replaced it, banging heads up against the law and cracking the jaws of other people's children.

The recurrence of this disaster here in Hilo is a fearful thought, and I am calling the people who are doing these things, the goats enticed by John. Flee.

And these are my thoughts to our prized newspaper.

With gratitude.

J.P. Iwa.

ʻAlae, Hilo February 24, 1868.
No rain.—In the many letters that we have received from friends in Hilo, Kohala, and other areas on the island of Hawai‘i, heat and drought are spreading through those areas. There has not been any rainfall for two months, and if that problem persists, then, this will be an extremely dry season.

Concerning the Sun. There has been a lot of clear, sunny weather these past three years, and there has not been any rain. The fields look burnt.

Concerning the Famine. Here in Honua‘ula, there is great famine; salvation is at Wailuku. Those who have horses travel to Wailuku. Those without horses will not get pounded taro. The sweet potato is the usual staple of Honua‘ula, however, the land is now without it.
References


6. Ka Nupepa Kuokoa. 23 December 1893, pg. 4. "Na Mea Hou o Hamakua."


8. Ka Nupepa Kuokoa. 5 April 1879, pg. 3. "Aohe Ua."


10. Ka Nupepa Kuokoa. 11 November 1876, pg. 2. "Maloo o Makawao."


ANSWER KEY

ACTIVITY 1
Part 1 – Sea Level Pressure

(See attached graphs at end of answer key)

1. In 1997-98 (Figure 9), the deepest layer of warm water is in the central to eastern Pacific from longitude ~160W to 100W.

2. In 1997-98 (Figure 10), high pressure is in the west Pacific and low pressure is in the central to eastern Pacific. In 1998-99, high pressure is in east Pacific and low pressure is in the west Pacific.

In an ENSO-neutral state, the warm water region is in the west Pacific, and so there’s a western low-pressure region there. This is very different from the 1997-98 case, where there is high pressure in the western Pacific. The ENSO-neutral state is similar to the 1998-99 case, but a neutral state shows a shallower thermocline.

3. In the absence of a Coriolis force along the equator, wind blows from high pressure to low pressure. In the 1997-98 case, the pressure change is only enough to weaken the easterly winds along the equator, not to reverse them. This weakening of the flow is sufficient to cause the ocean water to warm (Figure 2). The pressure change in the 1998-99 case strengthens easterly winds along the equator, enhancing the cold water upwelling.

4. In 1997-98 (Figure 9), the warmest temperatures are in the central and east Pacific. This is where we expect strong convection. In the 1998-99 (Figure 10), the warmest temperatures occur in the western Pacific. This is where we expect strong convection.

Part 2 – Precipitation

1. Average 1997-98 = 4.25 inches
   Average 1998-99 = 6 inches

2. Hāmākuopokō’s winter rainfall average is 5.04 inches. This is more than the winter of 1997-98, and dryer than the winter of 1998-99. Given that dry conditions in Hawai‘i are associated with El Niño, we expect 1997-98 was an El Niño year. Heavy rainfall in Hawai‘i is associated with La Niña, so we expect 1998-99 was a La Niña year.

ACTIVITY 2

1. The most positive OLR anomalies are found in the west and north Pacific.

2. The most negative OLR anomalies are found in the east and equatorial Pacific

3. Since deep convection is occurring in the mid-Pacific and eastern Pacific regions, there must be anomalously low pressure there. This is typical of the El Niño phase.
4. Negative OLR anomalies over the eastern and central Pacific during an El Niño indicate thick cloud cover (and deep thunderstorms) over this region, while the positive OLR anomalies to the west suggest a cloud-free region.
5. The OLR anomaly over Hawai‘i is about 25-28. This is a large positive anomaly, meaning much of Earth’s emitted radiation is reaching space uninterrupted. This indicates a cloud-free region. Indeed El Niño is associated with dry weather in Hawai‘i.

ACTIVITY 3

1. In 1997, there is a relatively low concentration of chlorophyll in the equatorial Pacific. Relatively high concentrations occur around latitudes 10°N and 10°S. There are also high concentrations between Papua New Guinea and Australia, where the reef supports large ecosystems. In 1998, there are high concentrations across the equatorial Pacific. There are also much higher concentrations along the west coast of South America (near Peru) than in 1997. We see low concentrations at 10°N and 10°S.
2. The regions with high concentrations of chlorophyll are associated with regions of low sea surface temperature. Conversely, regions of high temperature show relatively low concentrations of chlorophyll.
3. During an El Niño event, warm water spreads from the eastern Pacific westward across the ocean. We see this is associated with relatively low concentrations of chlorophyll along the west coast of Peru. As upwelling of cold water slows along the coast and is replaced by warmer surface water, fewer nutrients from cold, deep water are available to feed chlorophyll at the surface.
4. When sea surface temperatures are high, as a result of decreased upwelling along Peru’s coast, there is less chlorophyll. This means every organism that feeds on chlorophyll will have less food. This pattern continues up the food chain, and general biological productivity decreases. Conversely, during a La Niña event, cold water upwelling along Peru’s coast is also enhanced. This increases chlorophyll availability, increasing biological productivity.
TEST YOURSELF

1. ENSO is a shift that happens in the Pacific Ocean, usually every 4-7 years. It’s noted by the coupling of anomalous changes in sea surface temperature and surface air pressure across the Pacific. The ocean surface temperature component is called El Niño/La Niña, and the air pressure/wind component is called the Southern Oscillation.

2. El Niño is caused by an anomalously warm ocean current that begins in the eastern Pacific and extends westward across the ocean as a result of a decrease in the westerly component of the wind and less cold water upwelling.

3. In its mature phase, El Niño has the strongest signal in the equatorial Pacific, particularly along the western coast of South America and in the western Pacific near Australia.

4. In Hawai‘i we expect a drier than average winter season during El Niño.

5. During El Niño, warm waters develop southwest of Hawai‘i along the equator. Since warm water is capable of holding more dissolved salt than cold water, we expect salinity to rise during El Niño.

6. According to the Climate Prediction Center, El Niño/La Niña episodes typically occur every three to five years, although the historic record suggests a range in intervals of two to seven years.

7. In an ENSO-neutral state, deep convection happens in the western Pacific. During El Niño, the location of prevailing thunderstorms is shifted eastward, toward the central Pacific. During La Niña, prevailing thunderstorms occur in the far west Pacific, near Indonesia.

8. In an ENSO-neutral state, northeasterly trade winds dominate the equatorial Pacific year-round. During El Niño, the anomalous low pressure in the equatorial Pacific weakens trade winds. During La Niña, the normal trade winds are intensified.

9. In an ENSO-neutral state, upwelling along the west coast of South America provides a steady population of chlorophyll in the eastern Pacific, with relatively low chlorophyll populations in the central and west equatorial Pacific. During El Niño, trade winds weaken and upwelling slows. This reduces the chlorophyll population in the eastern Pacific, while chlorophyll in the western Pacific increases. During La Niña, upwelling along Peru’s coast is enhanced, and chlorophyll populations in the east Pacific increase.
Figure 9 Key
Figure 10 Key

Kahua A’o, A Learning Foundation:
Using Hawaiian-language Newspaper Articles for Place- & Culture-based Geoscience Teacher Education & Curriculum Development
is funded under NSF-OEDG Award 1108569