Local Winds and Rains of Hawai‘i: 
*I Kamaʻāina I Nā Makani A Me Nā Ua*

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Figure 1 Sea breeze and land breeze circulations are driven by differential heating.

**Title:** Local Winds and Rains of Hawai‘i: *I Kamaʻāina I Nā Makani A Me Nā Ua*

**Grades:** 6-8, modifiable for 3-5, 9-12

**Time:** 2 - 10 hour

**Standard:** Earth and Space Science 2.D ESS2D: Weather and Climate

Weather varies day to day and seasonally; it is the condition of the atmosphere at a given place and time. Climate is the range of a region’s weather over one to many years. Both are shaped by complex interactions involving sunlight, ocean, atmosphere, latitude, altitude, ice, living things, and geography that can drive changes over multiple time scales—days, weeks, and months for weather to years, decades, centuries, and beyond for climate. The ocean absorbs and stores large amounts of energy from the sun and releases it slowly, moderating and stabilizing global climates. Sunlight heats the land more rapidly. Heat energy is redistributed through ocean currents and atmospheric circulation, winds. Greenhouse gases absorb and retain the energy radiated from land and ocean surfaces, regulating temperatures and keep Earth habitable. (A Framework for K-12 Science Education, NRC, 2012).

**Hawai‘i Standard 8 EARTH & SPACE SCIENCE:**

Understand the Earth and its processes, the solar system, and the universe and its contents.

**Benchmarks:**

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

*SC.ES.8.4* Describe how heat and energy transfer into
Topic: **Forces that Shape the Earth**

and out of the atmosphere and their involvement in global climate.

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

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

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**To the Teacher: Connections to Place & Culture(s)**

*I Kamaʻāina I Nā Makani A Me Nā Ua*, One is seen as a local native by one's knowledge of the winds and rains

Local winds and clouds are the result of the influence of complex terrain and the daily or diurnal heating cycle of the Hawaiian Islands on the large-scale winds and moisture arriving from over the open ocean. Large scale winds here refer to surface winds arising over the open ocean as a result of surface high and low pressure systems that have a scale of ~1000 km, such as the Hadley circulation or kona lows. Each of the main Hawaiian Islands has many local wind regimes that depend critically on the height of the mountains and the areal size of the islands.

The mountains of Hawaii have a profound impact on the weather, both on the wind field and on the climatology of cloud and precipitation. As moist air is forced upslope, it cools and since cool air can hold less moisture, some moisture condenses. As a result clouds and then rain form, which are sometimes referred to as *orographic* clouds and rain. As the undisturbed flow over the ocean approaches the Hawaiian Islands, the mountains and daily heating cycle over the islands disturbs the flow, resulting in “local” winds. The direction of the flow at large scales interacts with the topography to produce gradients in cloud and rainfall, that in turn help define the local climate; e.g., wet windward and dry leeward slopes. The height of the mountains and the strength of the flow determine if the flow can pass over the top of the mountain or if the flow is forced to split and go around the mountain (see Figs. 2 and 3). Mountains can act both to trigger and anchor thunderstorms which can produce prodigious rainfall rates up to 8 inches (200 mm) per hour.

The fact that topographic features are fixed makes the interaction between large-scale storms systems and mountains somewhat easier to anticipate. The greatest accuracy in weather forecasting is associated with the largest scale systems, so if one has detailed knowledge of topography, it is fairly straightforward to forecast the general character of the topographically forced winds, clouds, and rainfall that will occur with various large-scale weather systems. For example, UH scientists using O'ahu rainfall data, statistics, and General Circulation Models predict more frequent heavy rainfall events but reduced rainfall intensity through 2040 for the south shoreline of O'ahu as Earth undergoes unprecedented warming. Heavy rainfall and flash
floods have economic and environmental costs: slope and coastal erosion, pollution of marine environment, and damage to coral reefs (http://www.hawaii.edu/news/article.php?aId=4710).

Hawai‘i’s Local Winds and Rains

The Hawaiian Islands are diverse in terms of topography and geographic extent. Each island has unique combinations of mountains, valleys, sea, land, and windward and leeward features that influence the local circulation of air and the distribution of rain. The local circulations or “local winds” have very different characteristics from the large-scale wind circulation over the open ocean. The several hundred local Hawaiian wind and rain names result from and reflect the diverse topography, cultural traditions, and ecological settings that have a defining role in how people think and talk about Hawaiian weather.

The oral and written literature of Hawai‘i reveal deep interest in and knowledge of winds, rain, and the water cycle, for example, see Water of Kane, p. 28. We can see the cultural importance of knowledge of the weather in the following tradition. To be considered a local or kama‘āina (child of the land), you may be called upon to recite the winds or rains of that place. If you could name them, you were then deemed to be a kama‘āina; if not, you would be considered a malihini, a stranger. The chants listing winds and rains were often published in the newspapers as part of stories, or to simply inform the public about the nature of the winds in a certain area. At times these would even be challenged and disputed, with a reply such as, "No, that person was wrong, for they are only a malihini. I am the true kama‘āina, and these are the correct winds of this area." Our ancestors valued this information as it was crucial in the everyday lives of a sea-faring and farming people.

Many names of local winds can be found in the story of the Wind Gourd of La‘amaomao, (Nāku‘ina, 1902, 2005) which tells of a boy named Pāka‘a, whose mother gives him a gourd that contains the bones of his grandmother, La‘amaomao. With this gourd, and the chants of wind names that his mother teaches him, Pāka‘a is able to control the winds. Pāka‘a then passes on this knowledge to his son, Kūapāka‘a, and a key moment of the story is when Kūapāka‘a chants to impress the chief Keawenuia‘umi, naming winds from Hawai‘i island to the tiny island of Ka‘ula, out past Kaua‘i. (A calabash named the Wind Gourd of La‘amaomao is in the Bishop Museum.)

There were over 300 names for the different winds and breezes that blow near and over the islands. These names are important because they reflect our ancestors' emphasis on keen observations and their deep knowledge of the local topography, for the wind names describe their nature and often convey natural and cultural information specific to the place. People shared knowledge about weather in more than 100 Hawaiian language newspapers published between 1834 and 1948 (http://seagrant.soest.hawaii.edu/hawaiian-language-newspaper-translation-project).

Articles reveal the names of local winds often provide information on characteristics, direction, origin, force, and timing. The keen observations of ancestors recognized the wind-rain relationship in naming a wind of Hilo the ‘Alahonua ki ‘i ua, the "fragrant earth wind that fetches
the rain" (Nogelmeier, 2007). Navigation close to Hawai‘i Island is affected by the wind from the mountains, the Mumuku, while the Ho‘olua wind comes from the shore. An article in *Ke Koo o Hawaii*, 29 August 1883 (attached below) tells of the *Kula‘ipau*, a strong wind of Kona that has capsized the ship ‘Iwalani. The name *Kula‘ipau* is a warning--it means to completely knock over. The wind between Lahaina and Moloka‘i is called the Kaomi. If this wind is strong, then a great deal of rain is expected in Kā‘anapali. The Kona wind originating in Kona storms, a cold upper level storm that develops around Hawai‘i during Ho‘oilo, the winter season, is mentioned many times throughout Hawai‘i nei.

An excerpt from an article describing an unusually windy night in Kona, Hawai‘i not only gives insight into the culturally embedded traditions of Kūapāka‘a, son of Pāka‘a, but also compares the windy weather conditions of Hilo to calm Kona. The writer hypothesizes the wind may have come from Hilo, referring to the tradition of kite flying in Hilo made possible by its consistent winds. The article (attached below) is entitled "Hele Uluulu Ka Makani (The Wind Blew Violently)" (*Ka Nupepa Kuokoa*, 18 December 1869).

[T]he wind blew extremely violently, shaking things, and our sleep was startled by the terrible blowing of this great wind. We are used to a pleasant sleep at night in our land embraced by calm, so where did this despicable one come from to startle our sleep? Perhaps from Hilo, since that is a windy land where the children fly kites, or perhaps Kūapāka‘a has come with his wind gourd."

In a series of articles related to the story of the wind gourd, Pāka‘a tells his son Kūapāka‘a to call the winds. He calls the winds of Hawai‘i Island, one of which is the Uahiapele wind of Kīlauea, literally the smoke of Pele. This name is very fitting, for it dwells in Kīlauea, the famous home of Pele. He also calls the Nāulu sea breeze of Kawaihau, interpreted as “sudden shower.” In another article, Kūapaka‘a calls the wind of Puna the Moa niʻala, meaning the light, fragrant wind. The name reveals the connection of local wind names to local plants as Puna is often referred to in songs and chants as *Puna paia ʻala i ka hala*, Puna, the forest bower fragrant with pandanus.

We see descriptive wind names of Kaua‘i in an article (attached below) by S. K. Kuapu‘u (1902). The area of Manenene on Kaua‘i has the *Onehali* wind, the “carried sands” wind. The recognition of the wind-rain relationship is seen in the name of Wailua's *Waiʻōpua* wind, the “water-bearing cumulus cloud” wind. *Hiʻiakaikapoliopele* (Nogelmeier, 2007) tells of Līhu'e's Pāhola wind, *ke kiu holo kiʻi makani lele kula o Līhuʻe* the scout that fetches the winds sweeping the Līhuʻe plains. The word Pāhola itself means to extend; to spread about.

**Hawai‘i‘i’s Sea-Land Breezes**

The contrast between the ocean and the island temperatures drives sea-land breeze circulations on each of the Hawaiian Islands (Fig. 1). Sea and land breezes exist due to the difference in temperature over land and sea during the day and night. During the day the land heats up more rapidly than the sea, so for the same altitude the temperature over land will be warmer than over the sea. Because air that is warm relative to its surroundings rises, this generates a difference in the pressure between the air over the land and the sea, specifically, with lower pressure over the
land and higher pressure over the sea. Therefore, the rising warm air is replaced by cool moist air from over the sea. The influx of air from the sea is called a sea breeze, and it often produces clouds and showers over the mountains.

![Figure 2 Island of Hawaii with color shading indicating elevation (colors change every 3000 ft) and average winds (mph) during a six-week period during July and August, 1990.](image)

During the night, especially when there are no clouds, both the land and ocean radiate heat to space, but the land loses its heat much faster than the sea because water has such a high heat capacity (ability to store heat in a given mass of substance) and wind driven motions in the water mix warmer water up from just below the surface. Therefore, the land cools faster than the sea. Pretty soon the relatively warmer air over the ocean begins to rise. Air that is cooled over the land flows downslope toward the ocean to form a land breeze.

The strength of the sea-land breezes varies from island to island, depending on the height of the island’s mountains and the overall size of the islands, and the strength of the large-scale winds. The taller volcanoes on Maui and the Island of Hawai‘i block the large-scale flow, allowing heat to build up on the leeward sides even when the large scale winds are moderately strong and thus increasing the strength of the daily sea breeze over the lee slopes of these islands (Figs. 2 and 3). Conversely, the taller mountains also produce cooler air at altitude and a stronger land breeze at night. Note the flow splitting in Figs. 2 and 3. The smaller islands such as Kaua‘i and O‘ahu have lower mountains that do not block the flow. Therefore, these islands only experience well developed sea-land breezes under lighter large-scale winds conditions.

If you study the winds at Keāhole Airport, you find there is a daily cycle in wind direction ([http://www.weather.gov/data/obhistory/PHKO.html](http://www.weather.gov/data/obhistory/PHKO.html)) that includes all compass directions! The winds at Keāhole Airport are characteristic for winds in general along the leeward side of the island. The forecast winds for the Island of Hawai‘i can be viewed at [http://weather.hawaii.edu/](http://weather.hawaii.edu/). Click on the lower right thumbnail to access WRF model output. Then change field to surface
winds and domain to Big Island to get a detailed view the impact of the large volcanoes on the flow and the diurnal sea-land breeze cycle across the island.

Figure 3 Stream or flow lines (red lines) are drawn everywhere parallel to the local wind direction and show the impact of the mountains on the flow during the afternoon on a typical trade-wind day.

Several Hawaiian newspaper articles mention the channel between Moloka’i and Lāhaina, Maui. The channels between the Hawaiian Islands are sometimes dangerous for navigating. This is because the trade winds are funneled through the narrow area between two islands causing the pressure gradient to increase between the entrance and exit of the channel, which in turn causes the wind speed to increase. The waves generated by these higher winds can interact with ambient swells, particularly those coming up from the south, to produce very steep standing waves. This is the reason why many boating accidents occur in the island channels.

Moloka’i is considered by Hawaiians to be the island of the winds. This is partly due to the fact that the mountains play a less important role in affecting winds here than on the other islands. The winds can pass easily over the lowest parts of this island without having to split or even rise very far. The western half of Moloka’i is dry because it lacks orographic rainfall, rainfall that occurs when moist air is forced to rise over mountains, cooling and therefore condensing and precipitating. The forced ascent by terrain is the reason why the windward sides of all the Hawaiian Islands are lush and green with vegetation in the satellite view in Fig. 4. Conversely, the air which has already lost much moisture becomes even drier as it descends and warms along the lee slopes, thus the lee areas of all the islands are relatively dry. The exception
is the Kona coast of the Island of Hawaii where the trade winds are blocked by Mauna Loa, and a well-developed (and almost daily) sea breeze brings clouds and rainfall upslope there (see Figs. 4 and 5).

Figure 4 NASA true-color satellite image of the Hawaiian Islands showing the influence of the mountains on rainfall and vegetation.

Another location that is often referenced is Hana, on the windward side of the Maui at its eastern end. There is a headland at this point that causes the winds to split, swirl around and break in many directions (see Fig. 3). This is the major reason why the prevailing trades have so many different names according to speed and direction at Hana in the newspaper references. Being on the windward side of Maui, Hana also receives copious rainfall (Fig. 5).
Figure 5  Mean annual rainfall map of the State of Hawaii
**Instructional Activities:**

1. **Engage:**
   - Hawai'i has over 300 named winds. Why do you think there are so many?
   - Where have you experienced strong winds in Hawaii? What do you think causes them?
   - It is common in Hawai'i, but not elsewhere, to say windward and leeward when giving directions. To a long-time resident, what information about winds, rains, and vegetation is included in these simple words?
   - Share a story you know about local winds or rain.

2. **Explore:**
   - Draw a sea-land breeze system. When does the sea breeze occur? When does the land breeze occur?
   - Which sides of the islands are more likely to have sea-land breezes? Why?
   - What physical mechanism generates a sea-land breeze system?
   - Why are the windward areas of most of our islands greener than the leeward areas?

3. **Explain:**
   - Explain why channels between islands may be hazardous for navigation.
   - Choose one of the winds described in this lesson then explain the science conveyed in its Hawaiian name.
   - How do local winds affect rainfall and vegetation on windward and leeward areas?
   - What is orographic rain? Can you identify a place where and why we can see it almost every day?
   - Do one of the “Hands on Science” activities and explain how it relates to winds or rain.
   - Why is it important to know and name the winds for a navigator? a farmer? a fisherman?

4. **Elaborate/Extend:**
   - Research at least one wind on your island and explain its pattern and its origin. If the name is unknown, what would you name it?
   - Design a project to investigate the winds and rains where you live.
   - How can we take the knowledge that we gained about specific winds in our area and use this to utilize and maximize wind-powered energy?

5. **Evaluate:**
   - Can students explain the relationship between local winds, rainfall, and orography?
   - Can they explain why some areas around the islands are easier to navigate than others?
   - Can students explain why Kona and Hilo have such different winds?
Hands on Science

In this section we will explore key concepts through experiments that will help us understand the science in more depth.

Winds

Wind is the word we use to describe horizontal movement of air. Whenever we want to speak about vertical movement of air we say updraft when the air is moving up, and downdraft when the air is moving down. Wind exerts a force and just like any other force it has intensity and direction. These two quantities describe the wind itself at any given point and time. We use an anemometer to measure wind intensity, and a wind vane to detect which direction the wind is blowing from. Winds are usually described by the direction they are blowing from, not by the direction they are blowing to.

In physical terms, winds are the balance between different forces in the atmosphere. There are five different forces active in the atmosphere, pressure gradient, centrifugal force, Coriolis force, gravitational force and frictional force. The balance between these five forces generates a wind vector for that precise location and time. So for each time, there is a balance of all the forces.

Let’s begin by investigating local winds with two simple instruments that indicate direction and wind speed.

1: Measuring Wind Speed and Direction

Let’s go outside with a compass and a hand held anemometer and record wind direction and speed. Then compare your observation with those collected at the same time by the National Weather Service (see http://www.prh.noaa.gov/hnl/pages/obs.php).

<table>
<thead>
<tr>
<th>Location and Time</th>
<th>Wind Speed</th>
<th>Wind Direction</th>
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</table>

Plot the winds on a map of your island and see how the mountains affected your results. Repeat this exercise at school and at home several times during the day. Does a pattern emerge to the local winds and does that pattern change with time of day?
2: Surface Heating (Land Sea Breezes)

We’ve all walked across hot black top in a parking lot with our bare feet in the summer. Similarly, it is cooler to wear a white shirt in the hot sun than a black one. Why is this so and what affect does it have on the world around you?

The darker a surface is, the more light it absorbs and the faster it heats up. Conversely, a surface appears light when it has a relatively high reflectivity (albedo) for visible light. The relative ability of different surfaces to absorb light is referred to as absorptivity. The higher a surface's absorptivity the more light it absorbs and is converted to heat. A perfectly black surface absorbs 100 percent of the light that strikes it (albedo = 0). A perfectly white surface reflects 100 percent of the light that strikes it (albedo = 1).

The air above a warm surface is heated as the surface absorbs increasing amounts of light. As the air heats, it becomes less dense and rises. A convection current is generated as cooler air replaces the warmer air and then is subsequently heated as well. This convective motion contributes to the formation of winds.

When adjacent air over the ocean remains much cooler than that over the land, the warm air rises over the land and it is replaced by cooler air from over the ocean. The resulting circulation is referred to as a sea breeze. The temperature contrast from sea to land can be large due the fact that the ocean has a much larger specific heat than the land, and sunlight is absorbed through a greater depth of water. The opposite of a sea-breeze circulation often develops at night when the land cools more quickly than the ocean, and the resultant wind blowing off shore is called a land breeze.

ACTIVITY

OBJECTIVE: The objective of this activity is to investigate the phenomena of differential heating of surfaces.

MATERIALS:
§ reflector lamp with 100-Watt bulb
§ 2 black cups
§ 1 white cup
§ two insulated lids with slits
§ two thermometers
§ ruler or meter stick
§ sand
§ water
§ piece of glass or Plexiglas
PROCEDURE:

1. Slide the thermometers through the slits in the insulated lids so that the bulb of each will be about half way down in the cups.
2. Place the lids on the cups and put the cups side by side, about 10 cm from the lamp as shown in Fig. 6.

![Schematic diagram](image)

Figure 6: Schematic diagram

3. Record the initial temperature of each cup in the Data Table. In the space below predict what will happen to the temperature in each cup when the light is turned on, and explain your prediction. *Will there be any differences between the cups?*
4. Turn on the light and record the temperatures every two minutes for ten minutes.
5. Table 1. Record your results in Table 1 below and graph your results on graph paper.
6. Table 2: Place a piece of glass between the light source and the thermometers and repeat steps 3, 4, and 5. If there are any differences in the rate of temperature change with the glass inserted explain briefly below.
7. Table 3: Fill one black cup with dry sand and the other black cup with wet sand. Repeat steps 1 through 4 above. In the space below predict *any differences between the cups* when the light is turned on, and explain your prediction.

**TABLE 1. AIR ONLY**

<table>
<thead>
<tr>
<th></th>
<th>TEMPERATURE (°F) vs TIME (MINUTES)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>BLACK</td>
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<tr>
<td>WHITE</td>
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</table>
**TABLE 2. GLASS BETWEEN CUPS AND LIGHT**

<table>
<thead>
<tr>
<th></th>
<th>TEMPERATURE (° F) vs TIME (MINUTES)</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
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<tr>
<td>BLACK</td>
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<tr>
<td>WHITE</td>
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</tbody>
</table>

**TABLE 3. BLACK CUPS WITH DRY OR WET SAND**

<table>
<thead>
<tr>
<th></th>
<th>TEMPERATURE (° F) vs TIME (MINUTES)</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>DRY SAND</td>
<td></td>
</tr>
<tr>
<td>WET SAND</td>
<td></td>
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</tbody>
</table>

**QUESTIONS:**

1. What happened to the temperature measured in the two cups as variables changed? Were your predictions correct?

2. How, if at all, would the results differ if a silver cup is used instead of a white one?

3. Predict how temperature would change if you left the cups under the light for a longer period of time.

4. A glider is an airplane with no engine. In order to stay aloft, glider pilots sometimes look for fields that have been recently plowed. Explain why based on your results above.

5. How can you relate this experiment to land-sea breezes?

6. Why do you expect land to heat up faster than the ocean?

7. Sea land breezes are only noted at certain locations of Hawai'i. Explain what causes this.
3: Recycled Water—The Hydrologic Cycle

INTRODUCTION

In considering the hydrology of the Earth, remember that the oceans cover about 70% of the Earth's surface and that they represent more than 97% of the Earth's water. Another 2.2% is locked up in ice caps and glaciers. As global temperatures increase or decrease, the quantity of land-held ice decreases (by melting) or increases (by precipitation), resulting in important changes of sea level. The atmosphere contains only 0.001% of the planet's water, but this water crucially affects the lives of people, animals, and plants.

In this activity, a distillation apparatus is used to model the hydrologic cycle. Keep in mind the distinctions between the distillation model and the hydrologic cycle as it occurs in nature.

Reading: Water of Kane (p. 27)

ACTIVITY

OBJECTIVE: The objective of this activity is to investigate the hydrologic cycle.

MATERIALS:
- clear plastic shoebox with lid
- small plastic cup
- Baggie filled with sand or soil
- water
- ice
- lamp with reflector

PROCEDURE:
1. Set up the apparatus shown in Fig. 7.
2. Cut a hole in one corner of the lid of the shoebox, just large enough for the cup to fit halfway through the lid.
3. Add enough water to cover the bottom of the clear shoebox, a depth of about one inch.
4. Position the sandbag at one end of the box, directly under the opening of the cup.
5. Fill the small plastic cup with ice and place it in the opening of the lid.
6. Position a gooseneck lamp so that its light is shining onto the water inside the box.
7. Periodically check the set-up to observe the progression of events. Record your observation over the course of the class and diagram the movement of the water through the set-up.
Figure 7 Schematic diagram

QUESTIONS:
1. Where in this activity does evaporation occur? Condensation?

2. What causes water droplets to form on the outside of the cup that is in the shoebox?

3. Where in the Earth's hydrologic cycle does evaporation occur? Condensation?

4. From what you observed in this activity, what are the key processes in the hydrologic cycle?

5. Was water lost from the system in any part of this activity? If so, where?
4: Formation of Clouds

INTRODUCTION

There are three conditions in the atmosphere that are met before a cloud forms. First, there must be sufficient moisture in the air. Secondly, the air must cool so that it becomes saturated and condensation can occur. And finally, there must be some type of particulate or condensation nuclei suspended in the air such as dust, smoke, or pollen for the excess water to condense on.

ACTIVITY

OBJECTIVE: The purpose of this experiment is to investigate the conditions which must be present in order for clouds to form.

MATERIALS:
§ 32-oz. clear glass jar with lid
§ ice cubes or crushed ice
§ hot water
§ matches
§ can of aerosol spray (air freshener is best)
§ black construction paper
§ safety goggles
§ flashlight (optional)

PROCEDURE:
1. Fill the jar with hot water.
2. Pour out the hot water leaving only ~2 cm of water in the bottom of the jar. Place the jar in front of the upright construction paper.
3. Turn the lid of the jar upside down and fill it with ice. Place the lid on the jar as shown in Fig. 8. Observe the jar for three minutes. Darken the room and shine the flashlight on the jar as you make your observations. Record your observations in the Data Table.
4. Pour the water out of the jar and repeat steps 1 and 2.
5. Move all loose papers away from the jar. Wearing your safety goggles, strike a match and drop the burning match into the jar.
6. Immediately cover the mouth of the jar with the lid full of ice as you did in step 3 and observe what happens for three minutes. Record your observations in the Data Table.
7. Pour out the water and repeat steps 1 and 2.
8. Spray a very small amount of aerosol in the jar and immediately cover the mouth of the jar with the ice filled lid. Observe what happens for three minutes and record the observations in the Data Table.
Figure 8  Schematic diagram

Data Table

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No match or aerosol</td>
<td></td>
</tr>
<tr>
<td>Match</td>
<td></td>
</tr>
<tr>
<td>Aerosol</td>
<td></td>
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</table>

QUESTIONS:

1. Comment on the differences on your observations, and the reasons for these differences.

2. If a layer of sand were on the bottom of the jar instead of water, would a cloud form? Why or why not?

3. What would have happened if cold water had been used instead of hot water? Why?

4. Describe any motion observed inside the jar. Explain your observation.
5. Rain Makers (Orographic Rain)

INTRODUCTION

As discussed in the introduction, the mountains of Hawai'i have a profound impact on the weather, both on the wind field and on the climatology of cloud and precipitation. As moist air is forced upslope, it condenses and first forms clouds, and then rain. The direction of the flow at large scales interacts with the topography to produce gradients in cloud and rainfall, that in turn help define the local climate; e.g., wet windward and dry leeward slopes. The height of the mountains and the strength of the flow determine if the flow can pass over the top of the mountain or if the flow is forced to split and go around the mountain (see Figs. 2 and 3).

ACTIVITY

OBJECTIVE: The goal of this activity is to learn about the impact of mountainous terrain on the climatological distribution of wind and rainfall by analyzing wind and rainfall data collected during an extended field experiment called the Hawaiian Rainband Project (HaRP). You will also learn about orographic lifting and discover the relationship between rainfall amounts and islands terrain.

MATERIALS: Two maps are provided with contours for elevation plotted every 3000 ft and wind data plotted in knots (kt) per hour (Fig. 9), and rainfall data in mm (Fig. 10). (1 knot, or nautical mile, is 1.15 mile per hour.)

PROCEDURE:

1. Draw streamlines on Fig. 9. Streamlines are everywhere parallel to the instantaneous wind direction. Unlike contours, streamlines have no numerical value and can join other streamlines and even cross each other at col or saddle points in the wind field.
2. Label the leeward and windward sides of the island.
3. On Fig. 3 draw isohyets (contours of equal rainfall) every 20 mm (i.e. 20, 40,...160).
4. Label all your isohyets and label the areas of maximum and minimum rainfall with a large ‘MAX’ or ‘MIN’.
Figure 9 Island of Hawaii with contours for elevation plotted every 3000 ft and average winds (kt = knot) during a six-week period during July and August, 1990.

QUESTIONS (pertaining to Fig. 9):

1. Do your streamlines indicate flow splitting is taking place? If it is, explain why?

2. Where on average is the wind speed the greatest? Why?

3. Can you explain by looking at the map why Kona is so dry?

4. Where are the strongest winds located? Why? Where are the weakest? Why?
Figure 10 Island of Hawaii with contours for elevation plotted every 3000 ft and average rainfall (mm) during a six-week period during July and August, 1990.

QUESTIONS (pertaining to Fig. 10):

1. Did you find the minimum rainfall where you expected to? What about the maximum rainfall? Explain.

2. Why are there no maxima in rainfall at the summits of Mauna Kea and Mauna Loa?

3. Identify the wettest regions. Identify the driest. Relate Kona’s rainfall to Hilo’s rainfall.
Please mention everything you know.

**Summary of Local Winds and Rains of Hawai‘i: I Kamaʻāina I Nā Makani A Me Nā Ua**

After completing this lesson it should be easier to understand the interaction of the winds and the mountains to create the weather we experience in Hawai‘i. You can now understand why the local winds are important to Hawai‘i, not only for agriculture, but also for navigation. Navigators had to know more than the general circulation (Hadley Cell) and the prevailing trade winds that are the surface branch of the Hadley Cell because many local wind patterns develop, some of which can be hazardous to sailing. In areas where the trades are blocked then the local diurnal circulation becomes the dominant wind pattern.

In recognizing and utilizing these winds, their names and nature, we are perpetuating the great legacy that was left by our ancestors. In these articles and excerpts from the epic of *Hi‘iakaikapōliopele*, these winds are recognized because they have a unique nature and help describe the places in which they reside. A reference to a wind could also be a reference to that particular place. Or perhaps a wind was especially cold, strong or abrupt; one may be referring to this quality that is also exemplified in us as people. Therefore, let us follow in the footsteps of those before us and recognize and learn about the many winds here in Hawai‘i.

We hope you have enjoyed this lesson, and are inspired to know and teach more about our islands’ weather phenomena and features.

**Resources:**

4. *Ka Hae Hawaii*. 8 May 1861, pg. 24
5. *Ka Hoku Loa*. July 1860, pg. 4
6. *Ka Nupepa Kuokoa*. 18 December 1869, pg. 3
7. Kauanui, G. W. P. Lahaina, April 26, 1871
8. Kawaihae, Hawaii, Nov. 17, 1860
9. *Ke Koo o Hawaii*. 29 August 1883, pg. 5
10. *Ko Hawaii Pae Aina*. 22 March 1884
Article 1: Home Rula Repubalika. 15 March 1902, pg. 1

I ko Laamaomao manawa e ola ana, ua kaulana oia no ka hoolohe o na makani iaia, a hiki iaia ke kahea aku i na inoa, a i kona make ana, ua hooili oia i ka mana kahea makani i kana keiki.

E ka mea helu helu, eia keia mau helu eono o ka hae, nolaila, ke hoopokole nei au a mahope aku, aka, e hai e aku nae au ia oukou i kekahi mau makani i kaheaia e Kuapakaa, oia hoi ka Pakaa keiki ana i moe ai me ke alii o Molokai, a ua a’o aku o Pakaa iaia i na hana a pau ana i imi ai no Keawenuiaimi, a ua ike mua no ho kau kou ma ka Hokuloa i na makani o Hawaii. Nolaila, ke hai aku nei au i ko Kauai mau makani a me Niihau, na inoa a me ko kau kou mau wahi, perie:

“A-la i ka nana mai e oe,
Ka’ makani a Laamaomao,
O ke kiu o Koolau, wahine o Kauai,
Ka’u i waiho aku——
Ke uvalu ‘la i ke kini i ka pae mauna,
He ao hoailona, makahi puaa,
Ile makani hono ia no Kapaa,
Aia ka makani ia i Kauai,
Ile Moae ko Lehua,
He Mikioi ko Kawaihoa,
He Naulu ko Niihau,
He Naulu ko Kaulakahi,
Ile Lawakua ko na Pali,
He Lanikuuwa ko Kalalau,
He Lauae ko Honopu,
He Aikoo ko Nualolo,
He Makani Kaehukai ko Milolii,
He Puuapae ko Maui,
He Moehau ko Kekaha,
He Waipao ko Waimea,
He Kapaaoha ko Kahana,
He Maka’hili ko Pepea,
He Aao ao Hanapepe,
He Unulau ko Wahiwaha,
He Ki‘i Anu ko Kalaeo,
He Ae hoi ko Lawai,
He Malanai ko Koloa,

He Kuiamanini ko Weliweli,
He Makahuna ko Kapaa,
He Onehali ko Manene,
He Koomakani ko Mahaulepu,
He Puapua ko Kipu,
He Alaoi ko Hulaia,
He Waikai ko Kalapaki,
He Kaa ko Hanamaulu,
He Waikua-aal a Makanikulai
Hale no Koneola,
He Waipoua ko Waiala,
He Waiolohia ko Nahanahanai,
He Inuwai ko Waipouli,
He Hooluamakani ko Makaiwa,
He Kehau ko Ka-Paa,
He Malamalamaiki ko Kealia,
He Makanihulilua ko Hanaikawao,
He Anu ko Anehola,
Ile Kolotio ko Moloa,
Ile Kiinuuai ko Koolau lele wahi,
He Maheu ko Kalihiwai,
He Nau ko Kalihikai,
He Luha ko Hanalei,
He Waiamau ko Waioli,
He Kuhunaheko Waipa,
He Huakolo ko Lumahai,
He Lupa ko Wainiha,
He Pahelehala ko Naue,
He Limahuli ko Haena,
O Kawaikuanhoo o ka pali,
O ka welela o kela makani,
Puili puahioho lele ae la i kai,
Pae ae la aia i uka—e pae he ino,
I nehinei ka la malie,
I holo ia mai ina, ua pae.

O keia ae la na inoa a ua keiki ‘la i kahea ai, a o ua inoa io no ia a hiki i keia wa i ko laila poe keiki papa, ua like pu no. Nolaila, ma ka Ileu 2 o keia moolelo, e hoomakaia ke kaaion i ka hoowahawa ana o Keawenuiaimi i kana kauwa.

—Na S. K. Kuapin.
(Aole i pau.)
When Laʻamaomao was living, she was famous because the winds obeyed her, and she could call their names. When she died, her child inherited the power to call the winds.

O reader, here are these six issues from the newspaper Ka Hae, so I am shortening this for later. However, I will tell all of you some of the winds that were called by Kūapāka’a, the child of Pāka’a from his union with a Moloka‘i chiefess. Pāka’a taught him all the duties that he sought out on behalf Keawenuiaumi, and we already saw the winds of Hawai‘i in the newspaper Ka Hokuloa. So I recite to you the winds of Kaua‘i and Ni‘ihau, their names and the places in which they reside, as follows:

“Awaken and take heed, O you,
The wind of Laʻamaomao,
The secret observer of Koʻolau, woman of Kaua‘i,
This is what I have to present before you—
I call out to the multitude on the row of mountains,
Clouds of omen, pressing a bank of clouds,
There is a bad-smelling wind at Kapa‘a,
The wind is at Kaua‘i,
Lehua has a Moa‘e wind,
Kawaihoa has a Miki‘oi wind,
Niʻihau has a Nāulu wind,
Kaʻulakahi has a Nāulu wind,
Nāpali has a Lawakua wind,
Kalalau has a Lanikuʻua wind,
Honopū has a Lauaʻe wind,
Nuʻalolo has an ‘Aikoʻo wind,
Miloliʻi has a Makani Kaʻehukai wind,
Mānā has a Puʻukapele wind,
Kekaha has a Moeāhua wind,
Waimea has a Waipao wind,
Kahana has a Kapaʻahoa wind,
Peʻapeʻa has a Makaʻupili wind,
Hanapēpē has an ‘Aoʻao wind
Wahiawā has an Unulau wind,
Kalāheo has a Kiu Anu wind,
Lāwaʻi has an Aʻe wind,
Kōloa has a Malanai wind,
Weliweli has a Kuiamanini wind,
Kapaʻa has a Makahūʻena wind,
Manenene has an Onehali wind,
Māhāʻulepū has a Koʻomakani wind,
Kīpū has a Puapua wind,
Hulāʻia has an Alaʻoli wind,
*Kalapakī has a Waikai wind,
*Hanamāʻulu has a Kāʻao wind
Waikuaʻaʻala is the house-tumblin wind from Konolea,
*Wailua has a Waiʻōpua wind,
Nāhanahanai has a Waiolohia wind,
Waipouli has an Inuawai wind,
Makaʻiwa has a Hoʻoluaamakani wind,
Kapaʻa has a Kēhau wind,
Keālia has a Mālamalamaiki wind,
Hanaikawao has a Makanihulilua wind,
Anahola has an Amu wind,
Moloaʻa has a Kololio wind,
Koʻolau has a Kiuinuwai wind that flies beyond,
Kalihiwai has a Maheu wind,
Kalihikai has a Nau wind,
Hanalei has a Luha wind,
Waiʻoli has a Waiamau wind,
Waipā has a Kuʻunahele wind,
Lumahaʻi has a Haukoloa wind,
Wainiha has a Lūpua wind,
Naue has a Pahelehala wind,
Hāʻena has a Limahuli wind,
The Kawaikūʻauhoe waters on the cliff,
The tip of that wind,
It grasps like a whirlwind and then rushes out to sea,
When it comes ashore, it will come as a storm,
Yesterday was calm,
To be overrun, should it come ashore.

These are the names that this child called, and they are indeed the true names to this day. According to the natives of those places, the names are the same. So, in the second volume of this story, the legend starts with Keawenuiaumi reviling his servant.

—By S. K. Kuapuʻu.
THE WIND BLEW VIOLENTLY—Our true friend G. W. P. of "Kona of the calm seas that mirror the cumulus clouds" writes in, and here is what he says: "At dawn this morning, Tuesday, December 7, the wind blew extremely violently, shaking things, and our sleep was startled by the terrible blowing of this great wind. We are used to a pleasant sleep at night in our land embraced by calm, so where did this despicable one come from to startle our sleep? Perhaps from Hilo, since that is a windy land where the children fly kites, or perhaps Kuapakaa has come with his wind gourd."
The Passing Of Time.

What is the song that is always sung for people struck with bad luck? Here is what the Water-Drinking League prays for such people:

“The Hala is evil-hearted, the Lehua is unfriendly,  
The Keho‘i waters do wondrous deeds,  
The native of Līhu‘e returns, struck by emptiness,  
For the first time to have no rich day.”

What would you say for the unlucky fishermen? They must pray to the one-eyed people, the god of those with bad luck, like so:

“Plundering on the border of the fishing ground where fish bite,  
The fish look at the foul bait with disdain,  
The unlucky fisherman's belongings are soaked,  
Chilling the skin of the bait carrier.”

What do you brag about when the visitor sees the ocean of Punalu‘u? I can pray to the wind of Kona that capsized the ‘Iwalani.
“My love is at Punalu‘u,
In the ocean that astonishes the visitor,
The Kula‘ipau wind is from Kona,
That heels the ‘Iwalani to one side,
We reach outside of Kailua,
The wildly twisting wind will arrive.”

WATER OF KANE

A query, a question, I put to you: Where is the water of Kane?
At the Eastern Gate, Where the Sun comes in at Haehae;
There is the water of Kane.

A question I ask of you: Where is the water of Kane?
Out there with the floating Sun, Where cloud-forms rest on Ocean's breast. Uplifting their forms at Nihoa, This side the base of Lehua;
There is the water of Kane.

One question I put to you: Where is the water of Kane?
Yonder on mountain peak, On the ridges steep, In the valleys deep, Where the rivers sweep;
There is the water of Kane.

This question I ask of you: Where, pray, is the water of Kane?
Yonder, at sea, on the ocean, In the driving rain, In the heavenly bow, In the piled-up mist-wraith, In the blood-red rainfall, In the ghost-pale cloud-form;
There is the water of Kane.

One question I put to you: Where, where is the water of Kane?
Up on high is the water of Kane, In the heavenly blue, In the black piled cloud, In the black-black cloud. In the black-mottled sacred cloud of the gods;
There is the water of Kane.

One question I ask of you: Where flows the water of Kane?
Deep in the ground, in the gushing spring, In the ducts of Kane and Loa, A well-spring of water, to quaff,
A water of magic power - The water of life!
Life! O give us this life!

Questions about Local Winds for Students

After this lesson, the causes of local winds and rains should be a bit clearer and you should be able to express in your own words the concepts you have learned. Please share with family and friends the knowledge and wisdom you have gained. Now let’s check your knowledge with a few questions.

1. What have you observed and learned about the local winds in your and community?
2. How would you describe the behavior of winds around your neighborhood?
3. If you had to explain local winds to your parents or friends, what examples would you provide?
4. In what ways are the local winds you observed different than large-scale winds over the ocean?
5. Can you explain in your own words why mountains are so important for rainfall?
6. How are sea and land breezes formed?
7. If you wanted to observe sea and land breezes in the Hawaiian Islands, which island and location would you choose to have the best chance of mapping out the sea and land breeze? Briefly explain.
8. When and where do you expect showers to occur during sea and land breeze circulations? Why?
9. Why does it rain so much in Hilo while Waikaloa on the Kona side is so dry?
10. If you go sailing for great distances what would be the most important, large scale or local winds? What if you were just going to sail around your island for a day?
11. Can you explain to others how the Hawaiian names of the winds reveal a lot of science?
12. What learning activities did you like the most? Please share what you learned with us!