Activity #2

Why Does It Rain on the Rain Forest?

● ● ● Class Period One *Rain Forest Location and Characteristics*

Materials & Setup

- "Maui Map Pack" acetates (masters, pp. 21-26)
- Overhead projector and screen

For each group of 3 or 4 students

- Student Page "Maui Map Pack" (pp. 28-30)

For each student

- Student Page "Why Does It Rain on the Rain Forest?" (pp. 31-34)

Instructions

1) Draw a simple diagram on the board or overhead showing the ocean and Haleakalā. Ask students to predict what the average annual rainfall is over the open ocean. Then ask them to predict the highest annual rainfall ever measured at 1650 meters (5412 feet) in the Haleakalā rain forest. After gathering student ideas, share the actual data. Over the open ocean near Maui, an average of 56 to 71 centimeters (22-28 inches) of rain falls each year. In 1994, a rain gauge placed at 1650 meters in the Haleakalā rain forest measured more than 14 meters (46 feet or 551 inches) of rainfall in one year.

2) Ask students to hypothesize why there is such a huge difference in rainfall between the open ocean and the rain forest. Each student should write down a hypothesis. This activity will help students determine whether their hypotheses are correct.

3) Divide students into groups of three or four. Give each group a copy of the Student Page "Maui Map Pack." Have them look at these maps and answer the questions on the student page.

4) Bring the class back together and discuss the questions on the student page. Use the acetates as visual aids, and work from the teacher's notes to guide the discussion. (These are the same maps students received, along with a map of the location and extent of rain forests on Maui.)

5) Assign the Student Page "Why Does It Rain on the Rain Forest?" as homework.

● ● ● **Class Period Two** *Condensation Demonstration and Discussion*

Materials & Setup

- Three shiny metal cans
- Room temperature water to fill each can half full
- A tray of ice cubes
- Two thermometers (Celsius)
- A stirring tool
- "Condensation Demonstration Data Table" posted on the board or overhead (master, p. 27)
- "Condensation Demonstration Relative Humidity Table" posted on board or overhead, or handed out (master, p. 27)

Instructions

1) Ask students to discuss the factors that affect the rainfall pattern on the windward slopes of Haleakalā, where the East Maui rain forest is. (The factors include the interplay among topography, the prevailing wind patterns, and how water behaves at different temperatures.)

2) Ask students to discuss how condensation plays into the cycle of rainfall on the Haleakalā rain forest. (They should be able to link condensation to the formation of clouds and discuss the lifting condensation level.)

3) With the class, brainstorm a list of examples of condensation from daily life.

4) So that students may see the condensation of water in action, do the "Condensation Demonstration" following the instructions (pp. 16-17).

5) After the demonstration, go through the discussion questions in the teacher background (p. 18) with the class.

6) Discuss student responses to the questions in the Student Page "Why Does It Rain on the Rain Forest?" If you need more information to help students understand the atmospheric forces that form the trade winds and trade wind inversion see Marie Sanderson (ed.), *Prevailing Trade Winds,* University of Hawai'i Press, Honolulu, 1993, or Alpine/Aeolian Unit 2 of this curriculum.

Journal Ideas

- What did you learn during this activity that confirms or refutes your original hypothesis about what explains the difference in rainfall between the open ocean and the Haleakalā rain forest?
- Have you ever been in the clouds or fog? What does it feel like compared to being in the rain?

Assessment Tools

- Participation in class discussion
- Student Page "Maui Map Pack" (teacher version, pp. 13-15)
- Student Page "Why Does It Rain on the Rain Forest?" (teacher version, pp. 19-20)
- Journal entries

Teacher Version

Maui Map Pack

Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

   Most rainfall on Maui and Haleakalā occurs on the windward slopes of the mountains. (On the maps, the highest rainfall looks to be about 1/3-1/2 way up the mountain.) On Haleakalā, the heavy rainfall occurs in a band that runs across the northeast flank of the mountain and wraps around a bit toward the south.

   Students do not have a lot of information to work from yet to attempt to explain the pattern of rainfall. They might speculate that the winds pick up moisture from the ocean and dump it when they reach land.

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

   Note that this anticipated rain forest area goes all the way to the ocean for the majority of the northeast coast of East Maui.

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all of the maps provided for information.)

   From the wind map, students might speculate that a lot of the rain forest area would have light winds most of the time and that winds would tend to be blowing across the face of the mountain there.

   From the solar radiation map, they might speculate that the rain forest is cloudy.

Map Notes

(To accompany the map acetates, pp. 21-27)

Average Annual Rainfall on Maui (inches)

1) Notice that rainfall will support a rain forest all the way to the coastline on much of the northeast coast of East Maui. Driving the Hāna Highway will confirm that you are going through wet forest terrain. On maps of present day ecosystems, though, the native rain forest meets the coastline in very few areas. This is due to human disturbance in the lower reaches of the rain forest from Polynesian settlement onward.

2) Recent data suggest that average rainfall estimates for the rain forest on windward Haleakalā are low. Hawaiʻi has many precipitation gages, but the rainfall of its more inaccessible reaches (e.g., much of the East Maui rain forest) is largely conjectural. Beginning in 1992, researchers began collecting climate information in this rain forest area, providing a new base of information.

New Estimates of Rainfall

Students do not have this information in their Maui Map Packs. Use it to show them the evolution of knowledge about the rain forest, comparing it to the rainfall map that is included in the student page.

In 1992, researchers established HaleNet II, a network of four microclimate sensing stations on windward Haleakalā. This network is currently providing data in an area where very little climatic data have been available. These measurements provide the first solid evidence to date of the extremely high rate of rainfall (Lloyd L. Loope and Thomas W. Giambelluca, "Vulnerability of Island Tropical Montane Cloud Forests to Climate Change, with Special Reference to East Maui, Hawaii," *Climatic Change,* Vol. 39, 1998, pp. 503-517). In addition, the data collected are providing evidence of extreme spatial gradients for other climate variables such as humidity and solar radiation.

Based on these new data, as well as older and ongoing research and calculations, rainfall maps for East Maui are sure to change. The data from HaleNet II suggest that past maps probably underestimate the amount of precipitation within the wettest part of the Haleakalā rain forest.

Prevailing Wind Patterns on Maui

This map shows how Haleakalā diverts most air flow around its slopes. The prevailing trade winds from the east-northeast split and most of the airflow goes around the mountain rather than over the top of it.

In *Prevailing Trade Winds* (Marie Sanderson, (ed.), University of Hawaiʻi Press, Honolulu, 1993), Thomas Schroeder explains that this effect has to do, in part, with the trade wind inversion:

> In Hawaiʻi the combination of mountainous islands and persistent trade winds creates mesoscale systems that dominate local climate.
>
> If the mountains are below the inversion, a substantial amount of trade wind air will pass over the barrier. This is the case for Oʻahu, where the maximum elevation in the windward Koʻolau Range is 960 m (3150 ft). On the island of Hawaiʻi, Mauna Loa and Mauna Kea are more formidable barriers. Most trade winds are diverted around these mountains except for a small amount that penetrates the high, 2 km (6600 ft) saddle between them (p. 22).

See the teacher version of the Student Page "Why Does It Rain on the Rain Forest?" (pp. 19-20) and Alpine/Aeolian Unit 2 for more information about the trade wind inversion and its effect on the climate of Haleakalā.

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Average annual solar radiation received on Maui differs from place to place. The highest levels occur along leeward coastal areas and at the tops of mountains.

Many factors can affect the amount of solar radiation that is absorbed and reflected before it can reach the ground. These include air pollutants, “vog” (smog-like air pollution caused by volcanic gases and particulates), particles of salt suspended in the air, and water vapor in the atmosphere.

Higher areas tend to receive more solar radiation because radiation traverses shorter distances through the atmosphere to reach them.

Clouds are the most important cause of variation in solar radiation intensity (based on *Atlas of Hawai‘i,* 3rd ed., p. 50).

Limits of Native Ecosystems Before and After Human Settlement

Students do not have this information in their Maui Map Packs. Use it to show them the current location of the native rain forest on Haleakalā, as well as its past extent.

As background, you may want to look on pages 122-123 of *Atlas of Hawai‘i*, 3rd ed., for generalized maps of the extent of native ecosystems before human settlement and today. These maps help to show patterns in where rain forests are located on all of the islands (i.e., windward mountain slopes) and that rain forests once extended to the ocean on Maui. (Sonia P. Juvik and James O. Juvik, editors, University of Hawai‘i Press, Honolulu, 1998.)

Human disturbance of the lower reaches of the rain forest, from the time of Polynesian settlement onward, has converted most of the low-elevation native rain forest into a rain forest dominated by nonnative species. This effect is clear on the acetate maps “Native Ecosystems on Maui Before Human Habitation” and “Limits of Native Ecosystems on Maui Today.” Native rain forests still exist over much of their historic extent, where climate conditions are conducive, but the lower elevations are now dominated by nonnative species.

Teacher Background

Condensation Demonstration

This demonstration is designed to help students visualize the behavior of water vapor in the trade winds that are pushed upslope on the windward side of Haleakalā. You may also use it to demonstrate the concept of a microclimate created when moist air is trapped in a steep valley such as Kīpahulu. As this air is pushed upward through the valley, it reaches the "lifting-condensation level" the altitude at which water vapor condenses out of rising air, forming clouds and/or rain), and the water vapor condenses, forming clouds and rain.

In this demonstration, you will determine the dew point of the air in your classroom and calculate the relative humidity. "Dew point" is the temperature at which water vapor in the air begins to condense. "Relative humidity" is the ratio between the amount of water vapor in the air and the highest amount of water vapor possible in the current air temperature.

Materials

Listed in the activity instructions

Instructions

1) Measure the air temperature in the classroom.

2) Fill one can half full of room temperature water.

3) Slowly stir the water with a stirring rod, adding small amounts of ice. Ask the class to help you watch for condensation to appear on the outside of the can. Record the water temperature when that happens, being careful not to let the thermometer touch any ice. This is the dew point.

4) Subtract the dew point temperature from the air temperature. Use the relative-humidity table to determine the relative humidity in the air around the beaker. (For a more accurate calculation, use the equations that follow at the end of the questions for discussion.)

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
Trial 1				
Trial 2				
Trial 3				

Data Table
Relative-Humidity Table

Air Temp. (°C)	**Temperature Difference (°C)**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**
10	88	76	65	54	44	33	23	14	4			
12	89	78	67	57	47	39	29	20	11	3		
14	89	79	69	60	51	42	33	25	17	9		
15	90	80	71	62	54	45	37	29	22	14		
18	91	81	73	64	56	48	41	33	26	19	6	
20	91	82	74	66	58	51	44	37	30	24	11	
22	91	83	75	68	60	53	46	40	34	27	16	5
24	92	84	76	69	62	55	49	43	37	31	20	9
26	92	85	77	70	64	57	51	45	39	34	23	14
28	92	85	78	72	65	59	53	47	42	37	26	17
30	93	86	79	73	67	61	55	49	44	39	29	20
32	93	86	80	74	68	62	56	51	46	41	32	23

———Relative Humidity Around Beaker———

Questions for Discussion

1) Why did we have to wait for condensation to form?

   The water temperature (and therefore the temperature of the outside surface of the can) had to drop to the dew point.

2) When condensation formed, was the air right around the can saturated?

   Yes. Relative humidity is the ratio of the actual amount of moisture in the atmosphere to the amount of moisture the atmosphere can hold. At the dew point, condensation begins to form because the air can hold no more moisture.

3) Why would there be a relationship between relative humidity and the dew point temperature?

   At lower temperatures, the atmosphere can hold less moisture (under constant pressure conditions).

4) As the moist trade winds are pushed up along the windward slopes of Haleakalā, what is happening to their temperature? At some point, would you expect the air temperature to reach its condensation point? What factors could influence the elevation at which that happens?

   - As air rises, temperature drops.
   - Yes, depending upon the moisture level in the air
   - Air pressure, moisture level in the winds

5) The level at which water vapor in a rising air mass begins to condense is called its "lifting-condensation level." How does the lifting-condensation level relate to cloud formation?

   The lifting-condensation level is the altitude at which clouds begin to form.

Teacher Version

Why Does It Rain on the Rain Forest?

Use the information and graphics provided in this article along with what you learned in class to answer the following questions:

1) On Figure 1:
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

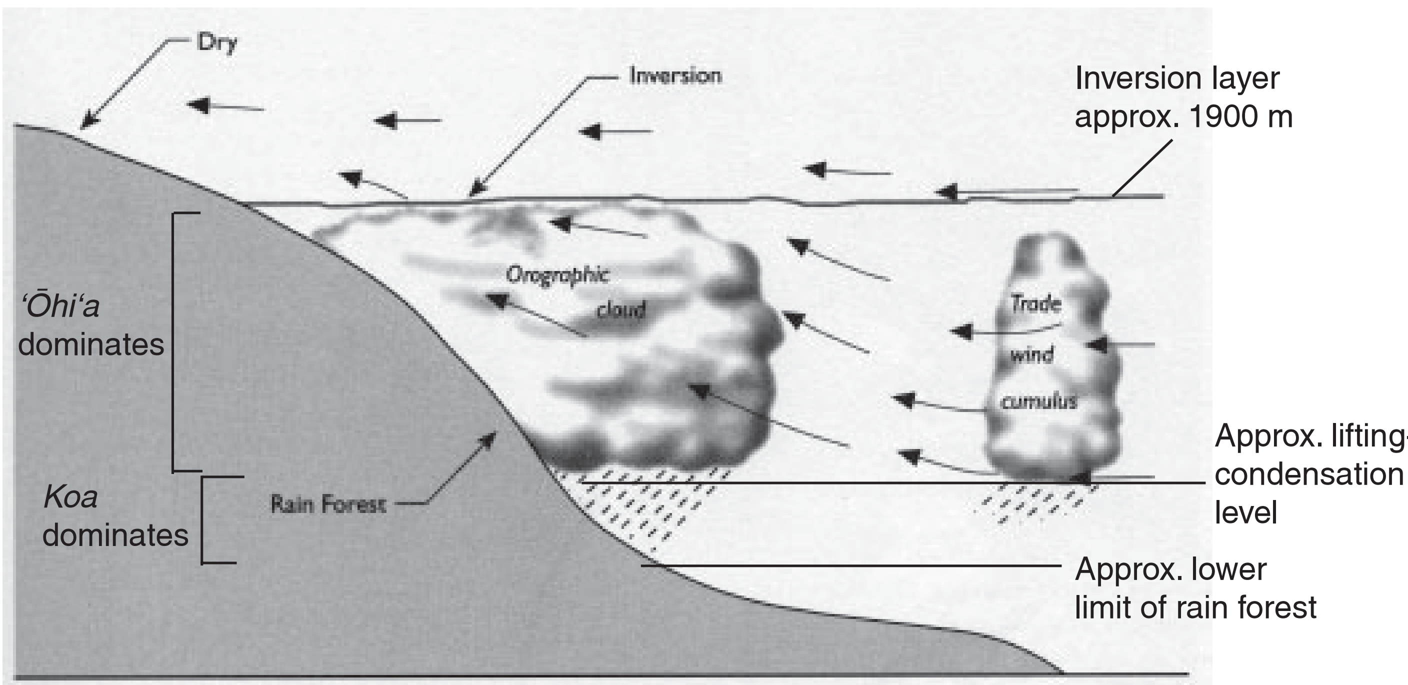


Figure 1: General weather patterns on windward Haleakalā *From Marie Sanderson (ed.),* Prevailing Trade Winds*, University of Hawai'i Press, Honolulu, 1993.*

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

   Look for well-reasoned responses. In this image, the rain forest would probably not extend all the way to the coast. The rain falling from the orographic cloud stops well short of the coastline, leaving a broad coastal bench without orographically generated rainfall. However, if the orographic cloud regularly gets bunched up and extends further over the coastal bench, then there could be enough rain to support a rain forest to the coastline.

3) Part of the rain forest on Haleakalā is a zone called the "cloud forest." The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture from the clouds as well as rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).

How do you think the lower limit of the cloud forest relates to the lifting-condensation level? Explain your reasoning.

The lower limit of the cloud forest is approximately the same as the usual lifting-condensation level. The lower limit of the cloud forest would not be below the lifting-condensation level because there are not clouds below that level. At and above the lifting-condensation level, clouds are continually generated in the rising and cooling air being pushed by the prevailing trade winds.

4) On Figure 1, draw a line that indicates the approximate lifting-condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

The lifting-condensation level should correspond with the bottom of the cloud layer because that is where condensation/cloud formation begins. The lifting-condensation level should roughly correspond with the lower limit of the cloud forest, or approximately 1000 meters (3280 feet).

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

No. As we learned in the dew point demonstration, air pressure and atmospheric moisture content can affect the dew point (lifting condensation level).

While the lifting-condensation level would not always be exactly the same, it should be relatively constant, reflecting the usual range of atmospheric conditions.

6) *ʻŌhiʻa* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *ʻŌhiʻa* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *ʻōhiʻa*. More commonly, the koa will grow taller than the *ʻōhiʻa*, sometimes forming a distinct upper canopy layer above the *ʻōhiʻa*.

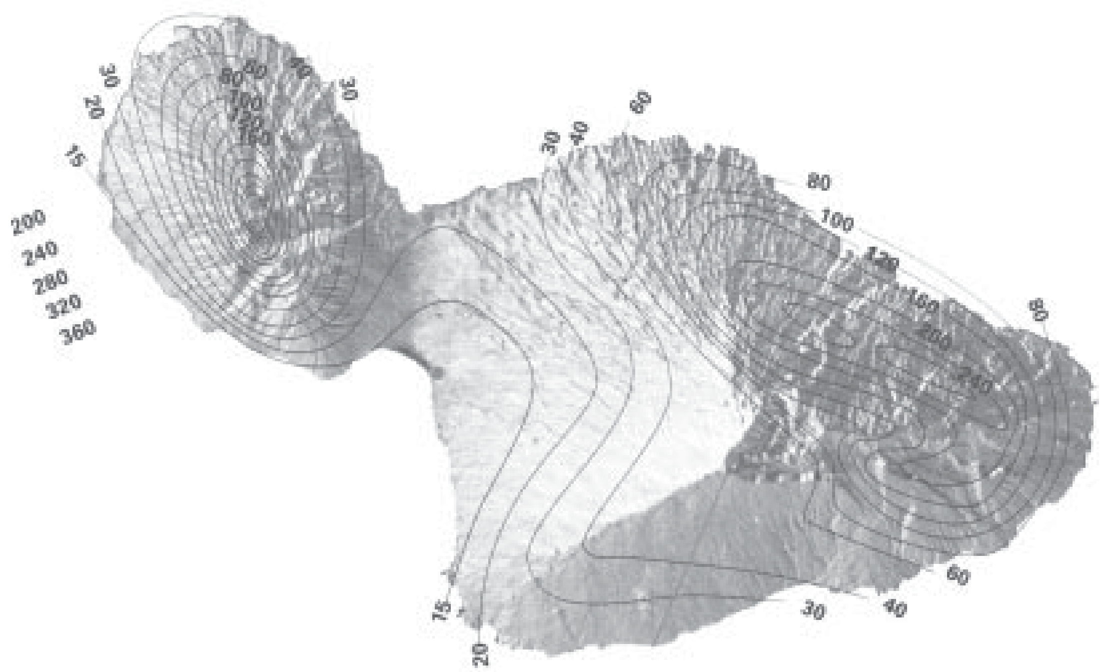
On Figure 1, indicate where you expect *ʻōhiʻa* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.

See the graphic (p. 19) for the expected range of *ʻōhiʻa* and *koa*.

One might expect *koa* and *ʻōhiʻa* to codominate at the lower limit of the cloud forest, where rainfall is still relatively high but lessening with loss of elevation.

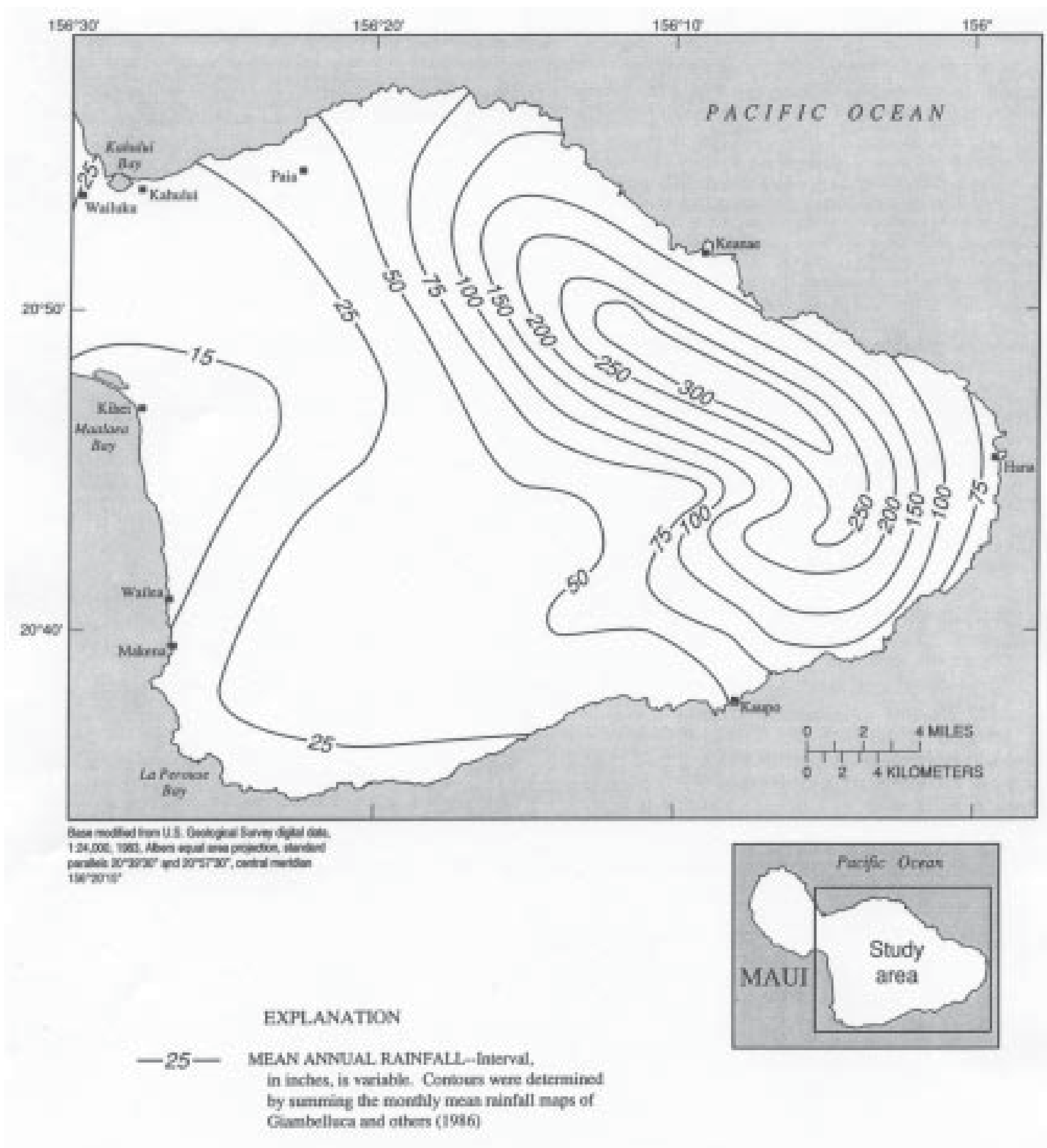
Maui Map Pack Acetate Masters

Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

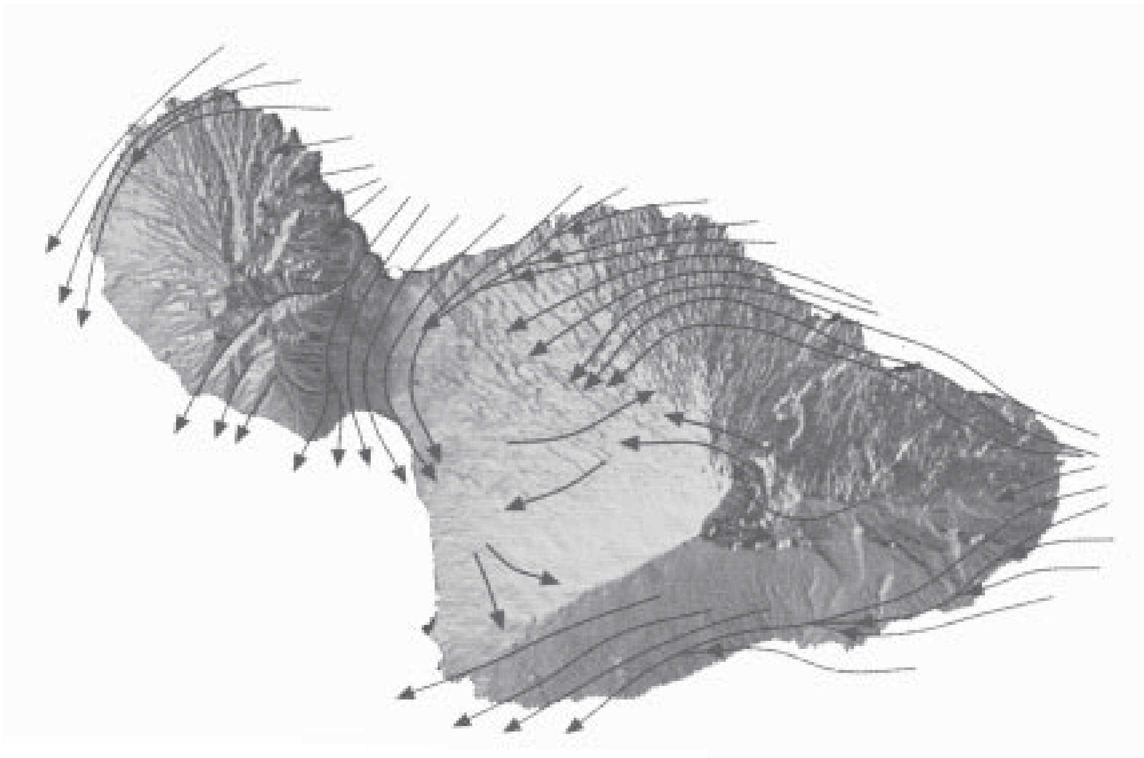
New Estimates of Rainfall



P. J. Shade, Water Budget of East Maui, Hawaii,
U.S. Geological Survey, Honolulu, 1999.

Prevailing Wind Patterns on Maui

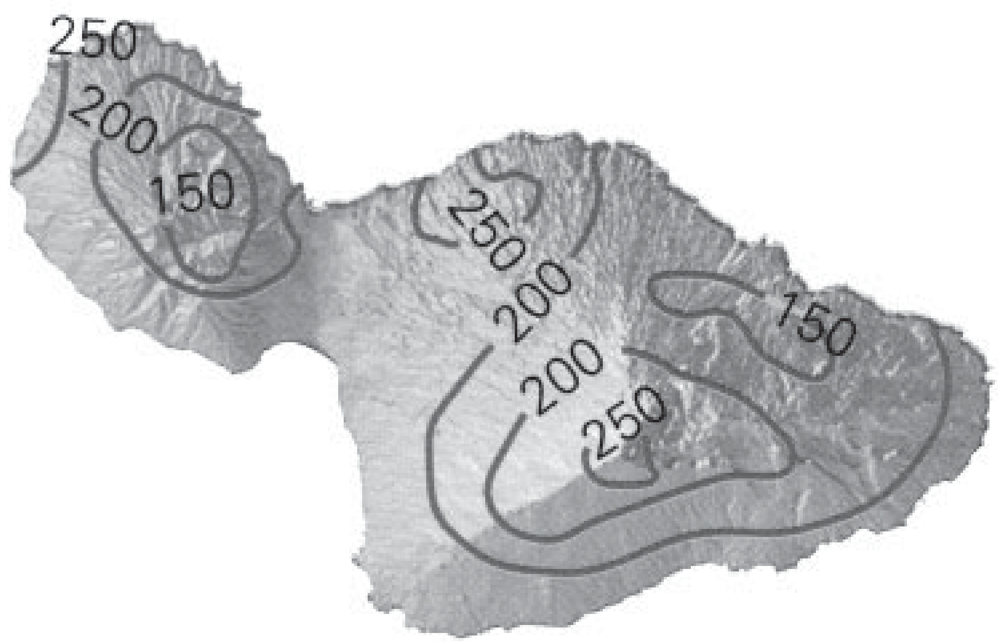
Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



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Atlas of Hawai'i, *3rd ed., University of*
Hawai'i Press, Honolulu, 1998.

Native Ecosystems on Maui Before Human Habitation

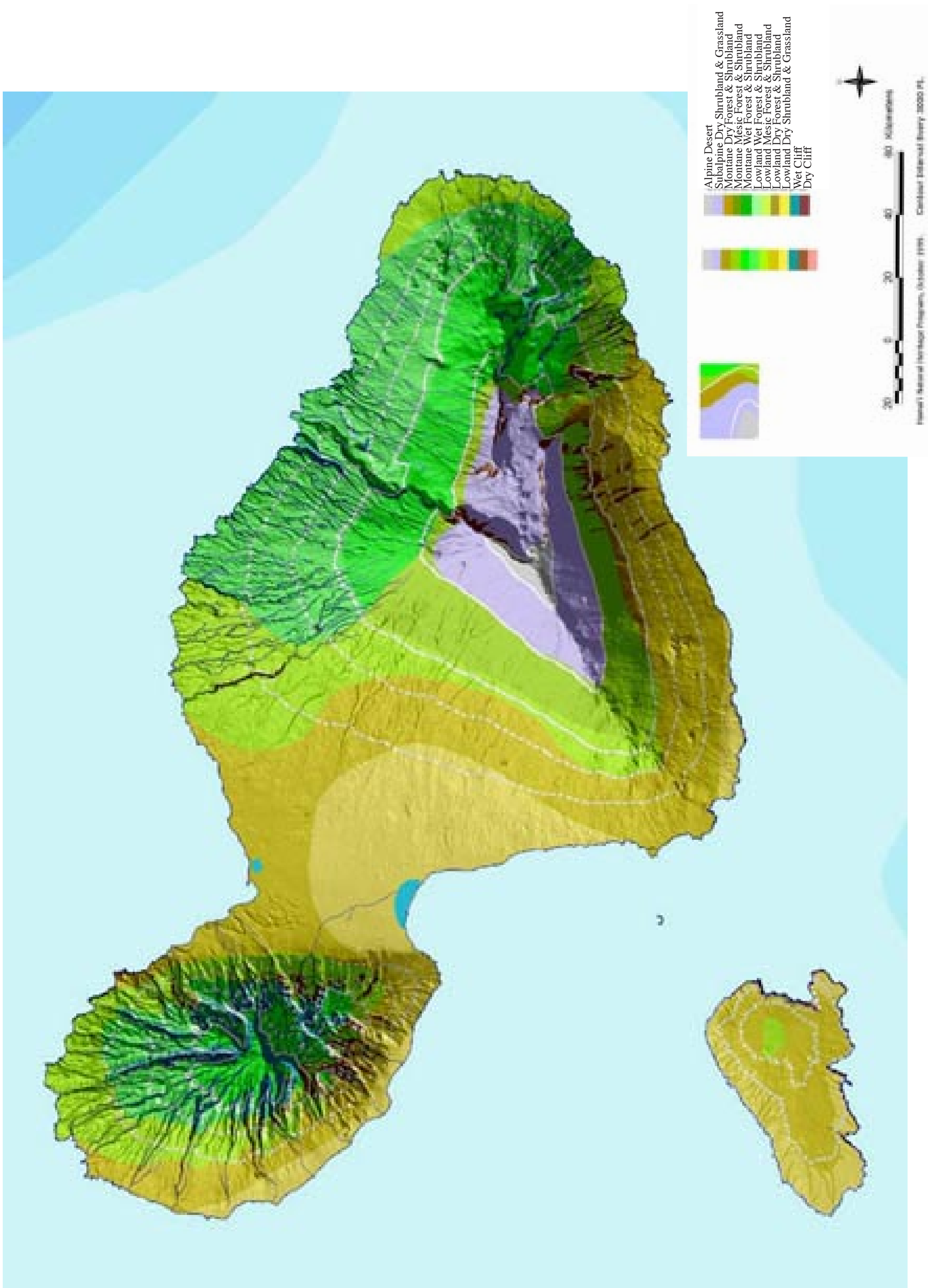

Image: Hawai'i Natural Heritage Program

Limits of Native Ecosystems Today

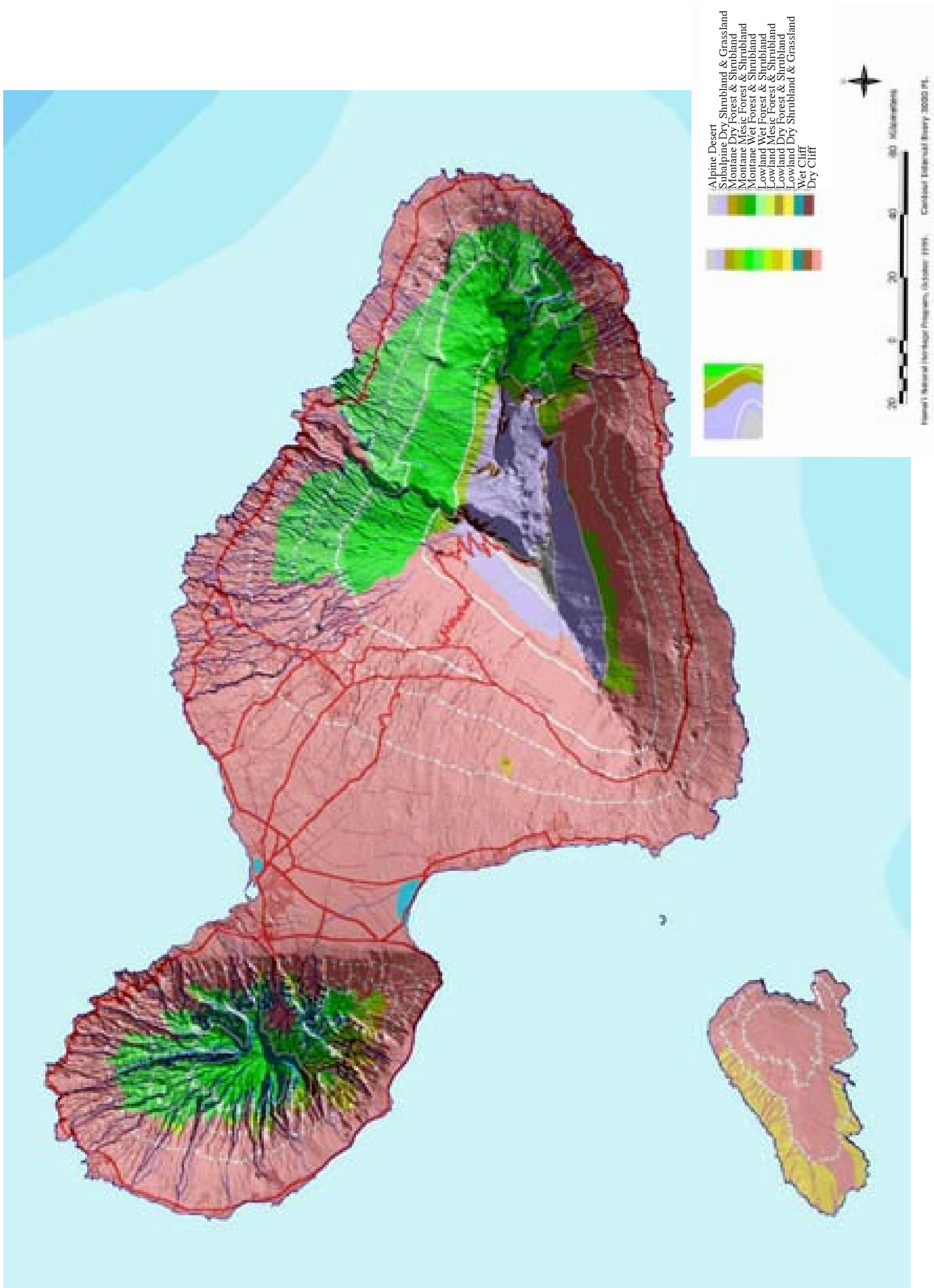

Image: Hawai'i Natural Heritage Program

Data Table

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
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Trial 2				
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Relative-Humidity Table

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———Relative Humidity Around Beaker———

Maui Map Pack

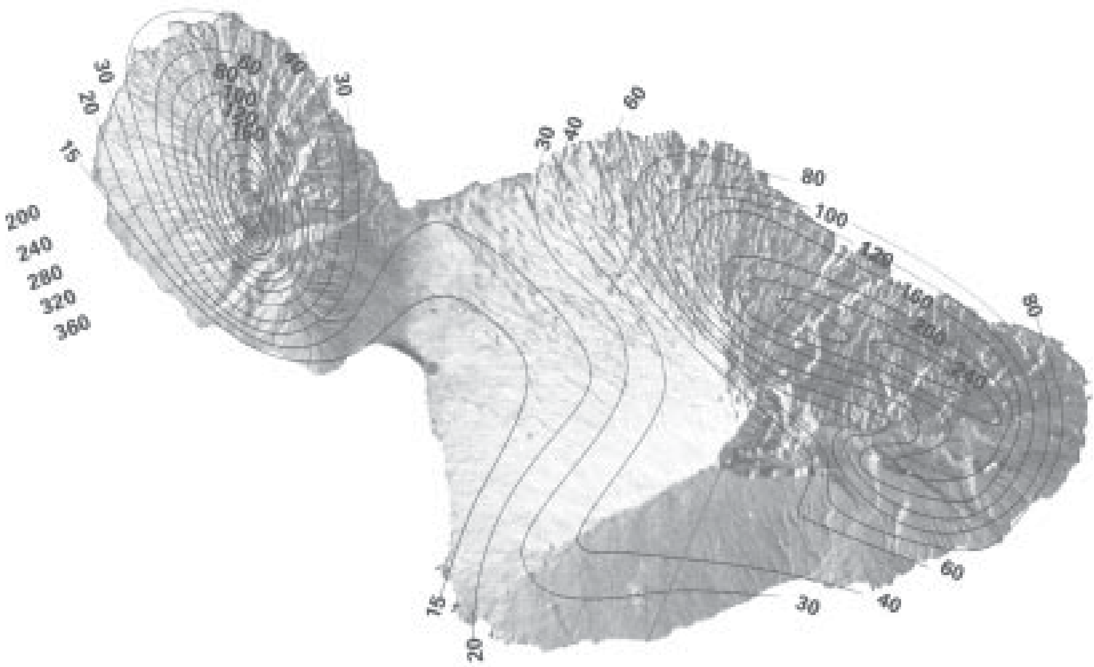
Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all the maps provided for information.)

Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.),
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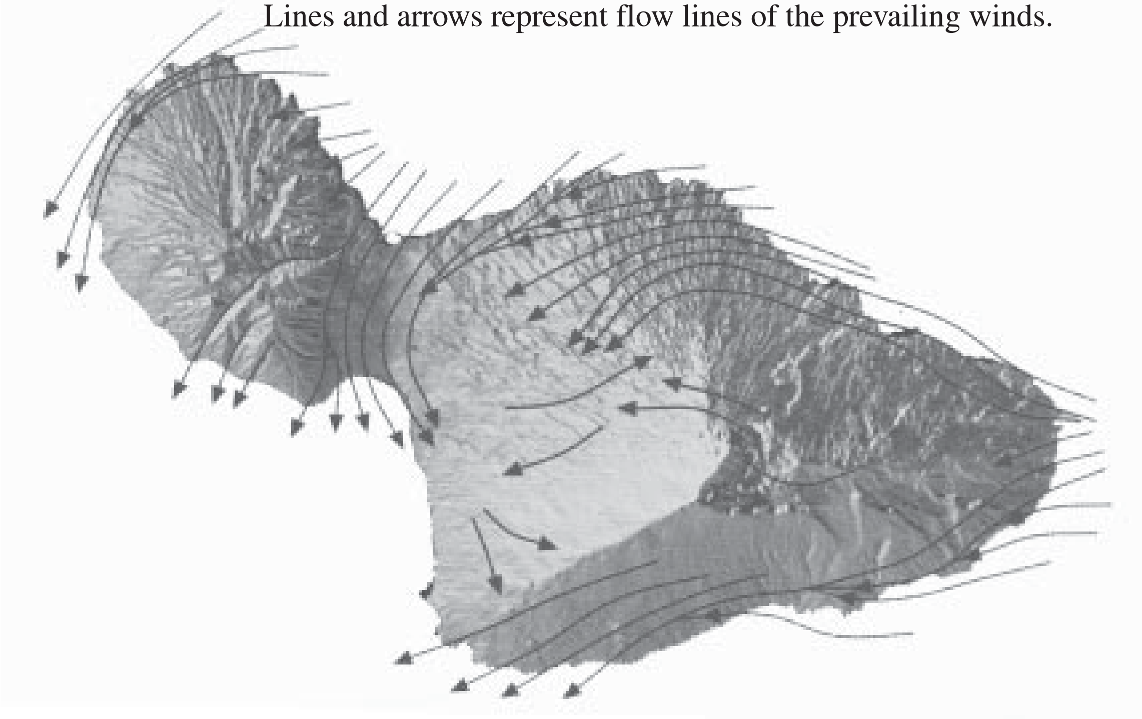
Prevailing Wind Patterns on Maui

Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.),
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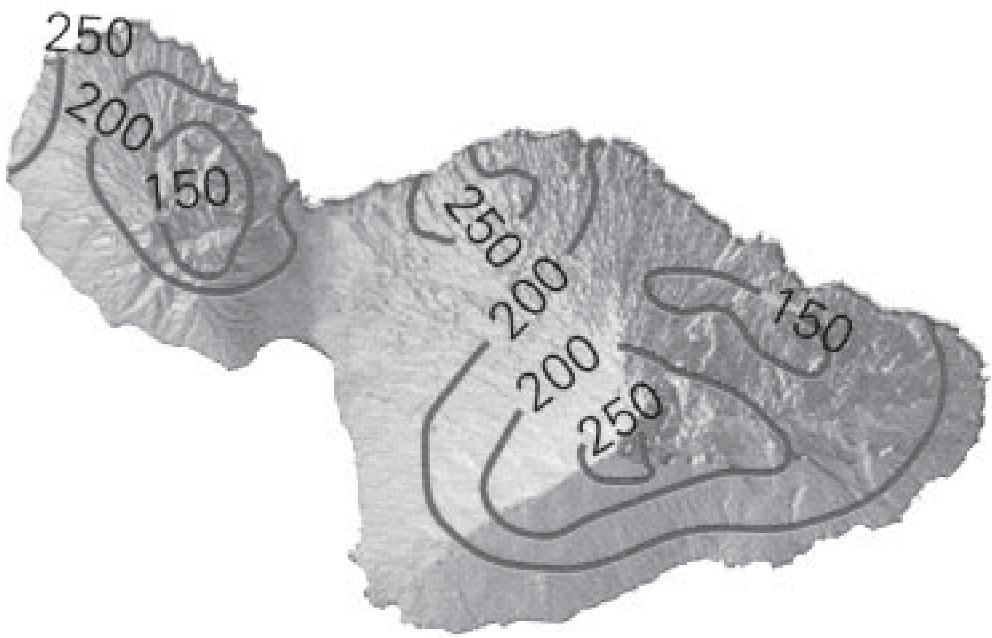
Average Annual Solar Radiation Intensity (Watts/Meter^2)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Why Does It Rain on the Rain Forest?

Over the open ocean near Maui, between 56 and 71 centimeters (22-28 inches) of rain falls in an average year. In 1994, a rain gauge placed at 1650 meters (5412 feet) in the rain forest on the windward flank of Haleakalā measured more than 14 meters (45.92 feet or 551 inches) of rainfall *in one year*! What accounts for this difference?

One factor that accounts for this difference is Haleakalā itself. Trade winds blowing across the ocean from the northeast hit the mountain broadside and are forced upward. Some of the wind is deflected to the sides, flowing around the mountain. But much of the moist air is forced up the mountain's steep slopes in a phenomenon known as "orographic lifting." As the air travels upward it cools. As it reaches the "dew point," or condensation point, clouds form along the mountain slope. The moisture from these clouds and the "orographic rain" that falls from them is what accounts for the rain forest climates on windward Haleakalā.

The elevation at which clouds begin to form is called the "lifting-condensation level." In other words, this is the level at which air that is orographically lifted reaches its condensation point.

So now you know how the clouds are formed that make the rain that enables the rain forest to thrive. There is more to the picture, though, if you want to understand why the rain forest occurs in a belt along the northeastern flank of Haleakalā. Why isn't there rain forest all the way to the summit?

The answer to that question has to do with the trade wind "inversion layer." When the rising and cooling clouds meet the warm descending air in the Hadley Cell (see Figure 2, p. 31), the inversion layer is formed. The warm air overlying the

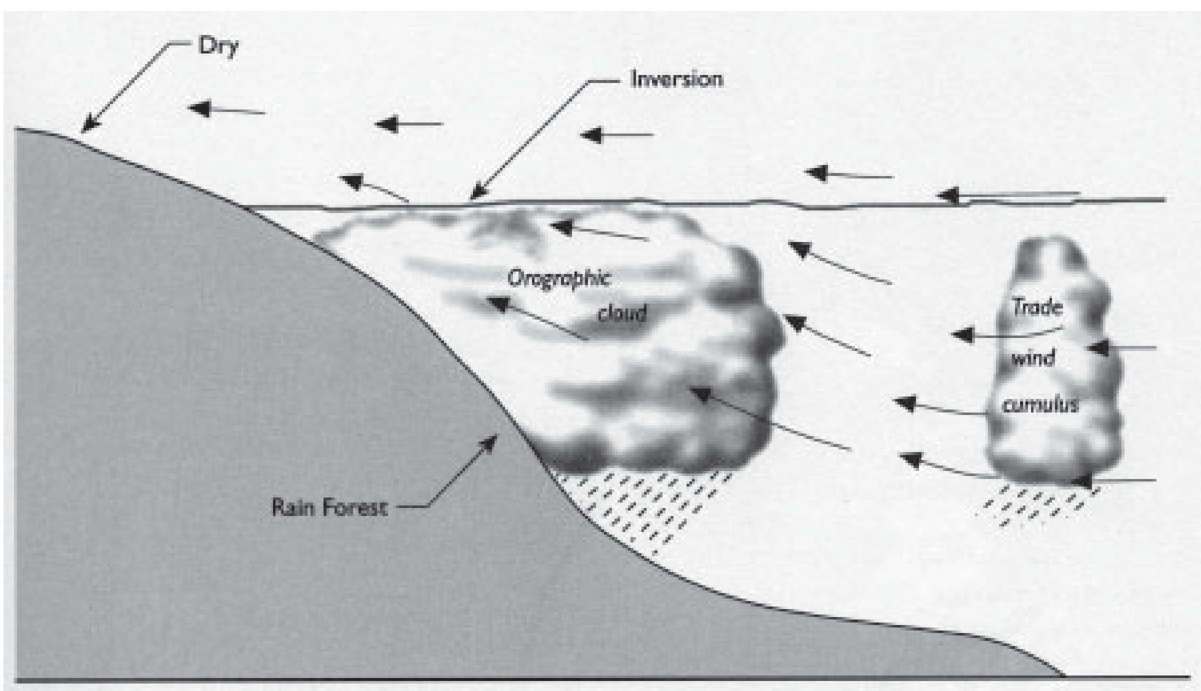


Figure 1: General weather patterns on windward Haleakalā (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

cooler air forms a barrier to clouds—any cloud that is forced through the inversion layer rapidly evaporates in the dry air above it.

Figure 1 (p. 30) illustrates the general pattern of trade wind weather on windward Haleakalā.

The clouds and rainfall are restricted to elevations below the level of the inversion layer. On windward Haleakalā, a good way to estimate the typical elevation of the inversion layer is to look at the upper limits of the rain forest, which are at about 1900 meters (6232 feet).

Before humans settled on Maui, the native rain forest extended all the way to the coastline along much of the northeast coast of Haleakalā. This entire area receives more than enough rain to support a rain forest. Now, however, in most of the lower elevation areas, there are only scattered remnants of native rain forest. It is still wet and lush, as a drive along the Hāna Highway will prove. But ever since the time of Polynesians, these lower reaches of the rain forest have been favored for human settlement, farming, and other activities. This activity has dramatically changed the ecosystem from one dominated by native rain forest species to one dominated by nonnative rain forest species. In some areas, such as around Hāna, the native rain forest did not extend all the way to the coast, even before human settlement. Looking at the rainfall map will show you one reason why this is the case.

Use the information and graphics provided in this article along with what you already know to answer the following questions about how the interaction of climate and topography forms the limits to the rain forest on Haleakalā.

The Hadley Cell

The Hadley Cell is a part of the large-scale circulation of the earth's atmosphere. Warm air rises near the equator and moves toward the north pole at high altitudes. As it reaches 30° N latitude, the air sinks and circulates back toward the equator completing the Hadley Cell.

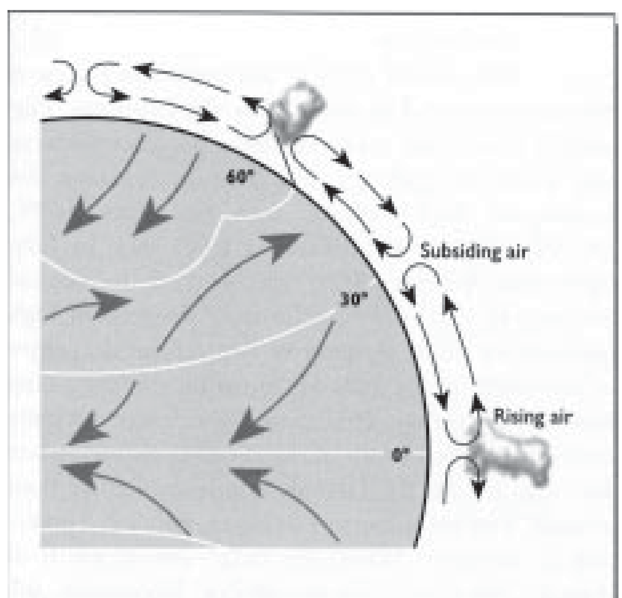


Figure 2: Idealized Hadley Cell, showing vertical and horizontal wind patterns (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

Questions

1) On Figure 1of the reading (p. 30):
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

3) Part of the rain forest on Haleakalā is a zone called the "cloud forest." The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture directly from the clouds as well as from rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).
   How do you think the lower limit of the cloud forest zone relates to the lifting-condensation level?

4) On Figure 1 of the reading (p. 30), draw a line that indicates the approximate lifting condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

6) *‘Ōhi‘a* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *‘Ōhi‘a* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *‘ōhi‘a*. More commonly, the *koa* will grow taller than the *‘ōhi‘a*, sometimes forming a distinct upper canopy layer above the *‘ōhi‘a*.

   On Figure 1 of the reading (p. 30), indicate where you expect *‘ōhi‘a* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.