Activity #2

Mauna Lei Mystery

• • • Class Period One *Solving the Mystery*

Materials & Setup

- *He Lei Keakea* acetate (master, p. 11)
- Overhead projector and screen

For each group of four to six students

- Student Page "Solving the *Mauna Lei* Mystery" (pp.17-25)

Instructions

1) Show the *He Lei Keakea* acetate to the class and read the Hawaiian chant, or have one or all the students read it. Then read the English translation and ask students whether they have ever noticed this *lei* of clouds around Haleakalā. What do they think causes it?

2) Divide the class into groups of four to six and pass out the Student Page "Solving the *Mauna Lei* Mystery." Allow groups to work together to explain the regular formation of the "cloud lei" around the upper slopes of Haleakalā, using the clues provided.

   Teaching Option
   If you prefer that your students work with graphs instead of data tables, substitute the four graphs and one table in the "Optional Graphs for Solving the *Mauna Lei* Mystery" (master, pp. 12-16) for data tables 1-5 in the Student Page "Solving the *Mauna Lei* Mystery." Have students use these graphs instead of the tables to fill in the Climate Conditions Clues Summary Table (p. 18).

3) If students are having difficulty working through the clues, you may want to prompt them with questions. For the Climate Conditions Clues (pp. 18-21), these questions may be helpful:
   a) Looking at the grid, how would you characterize the climate at each of the five elevations?
   b) Which of the climatic conditions do not change in a linear fashion according to the elevations? What do you think might explain unexpected changes in conditions at the middle elevations?

   For the Global Forces Clues (pp. 22-24), these questions may help:
   a) What happens to moisture in the air as the air cools or is under less pressure?
   b) It's generally true that "hot air rises," but is there any evidence that a warmer air mass may be found on top of cooler air in the atmosphere?
   c) What effect would a layer of warmer air over cooler air have on cloud formation?

● ● ● Class Period Two *Team Presentations*

Instructions

1) Group by group, have students present their findings to the class, explaining how they resolved the *mauna lei* mystery and what evidence and reasoning they used to support their conclusions. Either have each group present its answers to all the questions posed on the student sheet, or ask different groups to cover each question in turn.

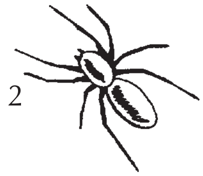
2) Culminate the discussion by asking the final question posed on the student page, "What are the main climatic conditions and patterns within the alpine/aeolian zone?" Ask students to consider what living conditions are like for plants and animals that live in the alpine/aeolian zone, and to compare them to likely conditions on other parts of Haleakalā.

Journal Ideas

- There is a weather phenomenon known as a Kona storm that occasionally occurs in the Hawaiian Islands. These spectacular winter storms are associated with strong winds from the south that bring large amounts of rain. When Kona storms hit Haleakalā, maximum rainfall generally falls at the summit, and rainfall decreases with elevation. Where do you find evidence of Kona storms on Table 5 of the Student Page "Solving the *Mauna Lei* Mystery"? Explain your answer and hypothesize about how a strong season of Kona storms might skew other climate data you have been working with in this activity.
- In addition to the *mauna lei*, what other weather phenomena can you think of that seem to have regular daily patterns of change?
- Ancient Hawaiians did not live in the summit area of Haleakalā, which is a sacred place in Hawaiian tradition. What would it have been like for early Hawaiians to visit the summit area? How might they have protected themselves from climate extremes without modern technology?

Assessment Tools

- Student Page "Solving the *Mauna Lei* Mystery" (teacher version, pp. 9-10)
- Cooperation and participation in group work
- Team presentations: Evaluate on the basis of reasoning, clarity, and accuracy of the presentation, and completeness.
- Journal entries



Teacher Version

Solving the *Mauna Lei* Mystery

[This teacher version contains only the portions of the student page that require student responses.]

1) At what time of day and approximate elevation does the *mauna lei* usually appear and disappear?

   • On leeward Haleakalā, the *mauna lei* generally appears on the following cycle: 7:00 a.m., clear skies; by 10:00 a.m., cloud begin to form; 3:00 p.m., a band of clouds obscures the view of the summit; by 6:00 p.m., clouds have dissipated, as the intensity of solar radiation decreases and the temperature and pressure gradients shift again. (Students will not be able to figure the exact times based on the information provided in the student page, but they should be able to reason their way to the general pattern.)

   • Using the Climate Clues Summary Table, students should reason that the *mauna lei* occurs in the middle elevations above 1650 meters (5412 feet), more likely higher up around 2130 meters (6986 feet) or even higher. In the “Solar Radiation” and “Rainfall” columns, students see that the relationship between these variables and elevation is not linear, suggesting the presence of cloud cover. The drop in solar radiation at the 1650-meter (5412 feet) level suggests shading by cloud cover, and increased rainfall at the 2130-meter (6986 feet) station suggests that this station may be just below the usual lower limit of the *mauna lei*. The width of the cloud formation is not apparent from the clues that students have been provided.

2) What are the climate conditions above and below the *mauna lei*?

   • Above the *mauna lei*: coldest, driest air, greatest wind speed, greatest solar radiation, low rainfall

   • Below the *mauna lei*: warm temperatures, high relative humidity, low solar radiation, rainier than above the *mauna lei*

3) Why doesn’t the *mauna lei* form higher on the mountain, around the summit?

   • Cloud formation is capped by the trade wind inversion. When rising and cooling clouds meet warm descending air in the Hadley Cell, the inversion layer forms. Warm air overlying the cooler air is a barrier to clouds—clouds forced through the inversion layer rapidly evaporate in the dry air above it. From the Climate Clues Summary Table, students should surmise that this inversion layer typically occurs between 2130 meters (6986 feet) and 2600 meters (8528 feet). (The trade wind temperature inversion occurs at altitudes between 1525 meters (5000 feet) and 3050 meters (10,000 feet). Students are not given enough information to determine this range.)

4) What global factors are involved in the formation of the *mauna lei*? Explain.

- Global air circulation patterns including the Hadley Cell cause the inversion layer, and in combination with the Coriolis effect give rise to the trade winds themselves. (See the Student Page “Solving the *Mauna Lei* Mystery” for more details.)

5) What are the different causes of the *mauna lei* on the leeward vs. the windward side of Haleakalā? Explain the effects of temperature and pressure on the formation of the *mauna lei* on windward and leeward Haleakalā.

- On the windward side, the *mauna lei* is formed when moist trade winds are blown up the slopes of Haleakalā. As the air rises, temperature and air pressure drop, and the moisture in the air condenses to form clouds.

- On the leeward side, the sun heats the slopes of Haleakalā and the surrounding air. This creates a zone of warmer air at higher elevations where solar radiation is more intense. As air over the heating slopes rises, this creates a pressure differential that draws air from over the ocean up the mountain’s slopes. This moister air cools as it is forced upward, forming a layer of clouds.

6) What are the main climatic conditions and patterns within the alpine/aeolian zone?

- Dry air and little rain, hot during the day, clear skies, sunny, windy.

Climate Conditions Clues Summary Table

Elevation	Air Temperature	Relative Humidity	Wind Speed	Solar Radiation	Rainfall
950 m (3116 ft)	5	5	1	2	4
1650 m (5412 ft)	4	4	2	1	3
2130 m (6986 ft)	3	3	3	3	5
2600 m (8528 ft)	2	2	4	4	2
3000 m (9840 ft)	1	1	5	5	1

Photo: Ann Fielding

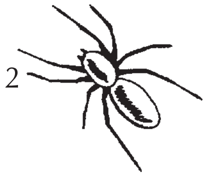
He Lei Keakea

He lei keakea noho mai la i ka mauna
Ka mauna ki‘eki‘e i luna kū kilakila
Kilakila nō luna
Nō luna i ke ao
Ke ao ua malu nā kumu la‘au
La‘au ho‘ohu‘ohu
‘Ohu‘ohu ho‘ohiehie
Ho‘ohiehie launa ‘ole!
‘A‘okle lua na‘e ke ‘ike aku
He‘ike aku nā moku ‘o Hawai‘i
Hawai‘i ke kuine ‘o ka Pākipika
Ka Pākipika ua la‘i i ka lā
Ka lā ho‘olewa i ka nalu
Ka nalu kohu lei ana
Lei ana i ke aloha
Pumehana me ke aloha
Aloha e!

— *From Winona Desha Beamer,* Talking Story With Nona Beamer, *The Bess Press, Honolulu, 1984.*

The White Lei

The soft white lei encircles the crest of the mountain
The mountain high above standing in great majesty
Majestic on high,
Bedded in clouds.
The clouds cast a shadow on the trees
The trees so haughty;
So haughty and proud,
This is splendor beyond compare!
There is no beauty to equal this sight
The sight of the islands of Hawai‘i
Hawai‘i, the Queen of the Pacific.
The Pacific lies calm in the sun
The sun, moving on the waves
The waves bedeck, as a lei
A lei of love,
Warm is this love,
It is love, indeed!



Optional Graphs for Solving the *Mauna Lei* Mystery

You may substitute the four graphs and one table contained in this resource section for the five tables provided in the Student Page "Solving the *Mauna Lei* Mystery." You may put the graphs up on the overhead or allow each student or group to work with its own copies. (Note: Because these graphs may be tricky to read, you could have students trace over the data line for each elevation in a different color pen or pencil. You could do the same on your overhead.)

Graphics and all data in the tables below are taken from Minyard, W. P., T. W. Giambelluca and D. Nullet, *Elevational Patterns of Climate on the Leeward Slope of East Maui, Hawaii,* Cooperative National Park Resources Studies Unit, University of Hawai'i at Manoa, 1994 (used with permission of the Pacific Cooperative Studies Unit).

Table : Rainfall (mm/day)

	Elevation (m)				
	950	1650	2130	2600	3000
January	3.0	5.6	7.4	4.3	5.5
February	2.3	2.1	4.6	1.9	2.9
March	1.5	3.2	10.0	7.2	6.3
April	0.2	0.7	0.6	0.6	0.6
May	0.4	0.8	1.9	0.8	0.2
June	0.4	0.8	2.2	0.9	0.4
July	0.3	1.1	2.0	1.0	0.9
August	0.5	2.1	4.3	3.2	1.6
September	0.6	3.8	3.5	2.2	2.0
October	0.5	2.3	2.6	2.0	2.0
November	4.2	3.2	5.8	9.5	12.5
December	3.7	3.8	5.2	6.3	7.1
Totals	17.6	29.5	50.1	39.9	42.0
Average	1.47	2.46	4.18	3.33	3.50

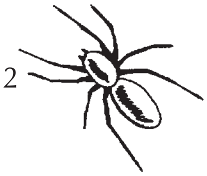


Figure 1: Monthly Mean Air Temperature (° C)

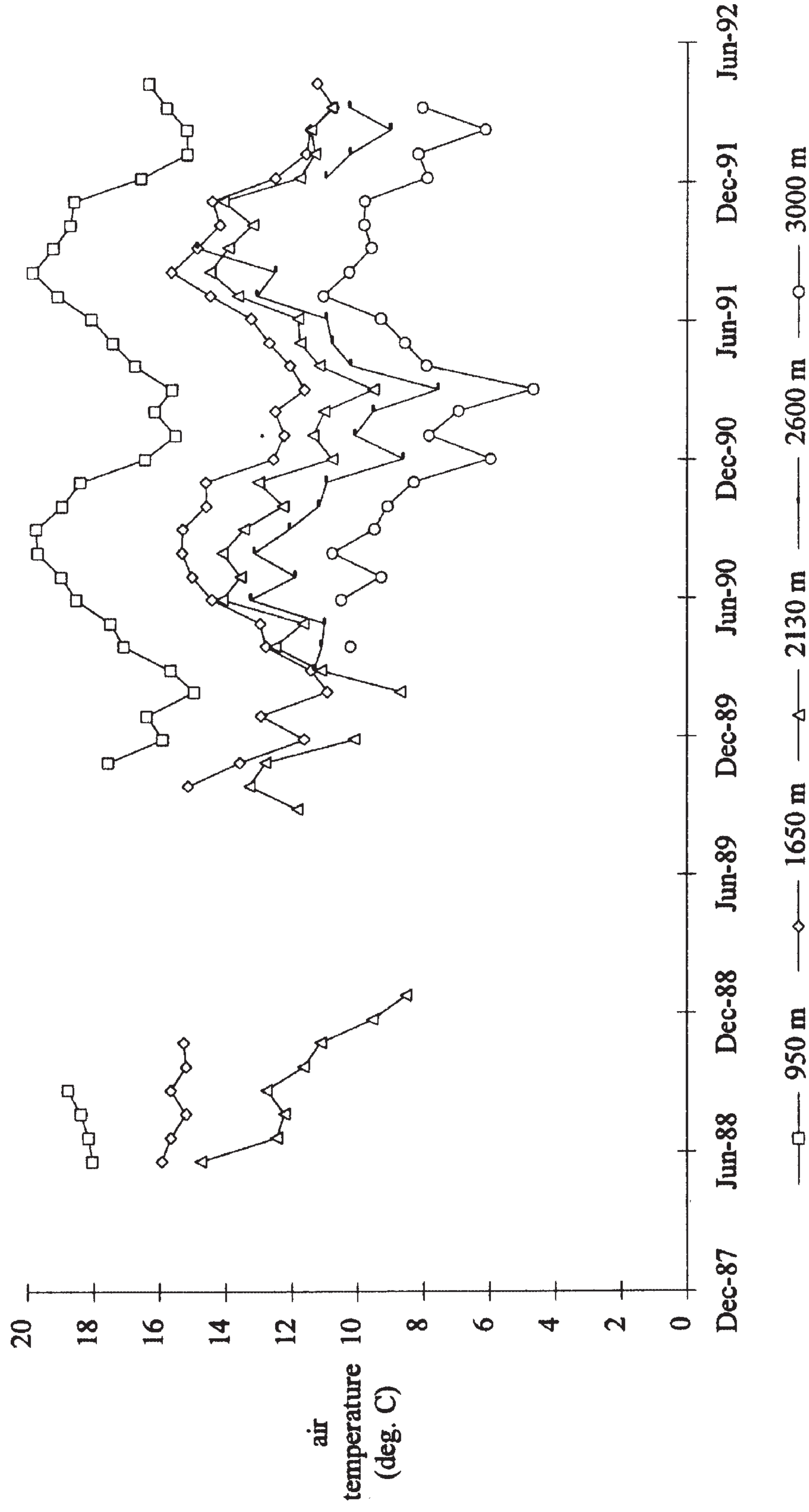
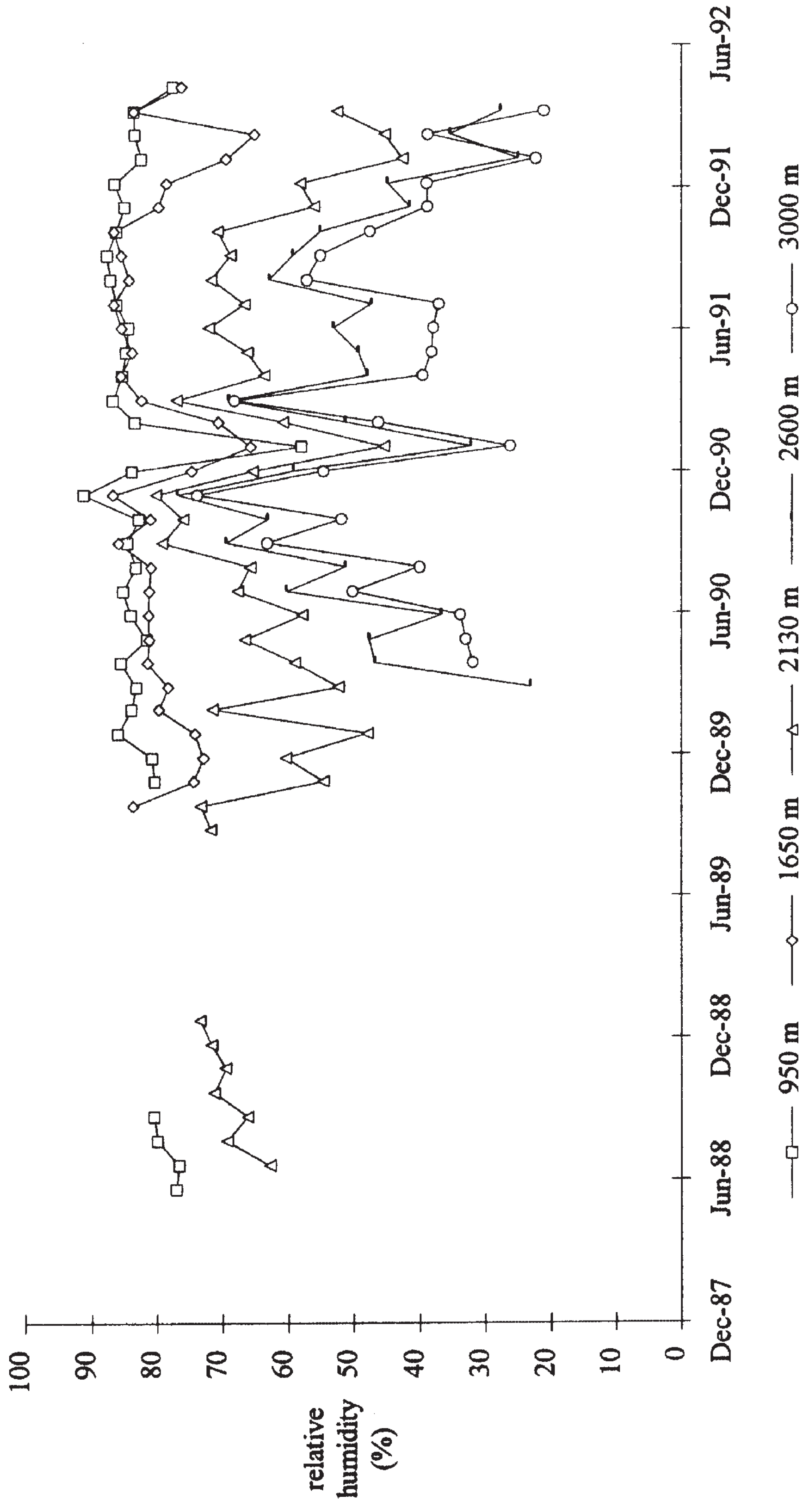


Figure 2: Monthly Mean Relative Humidity



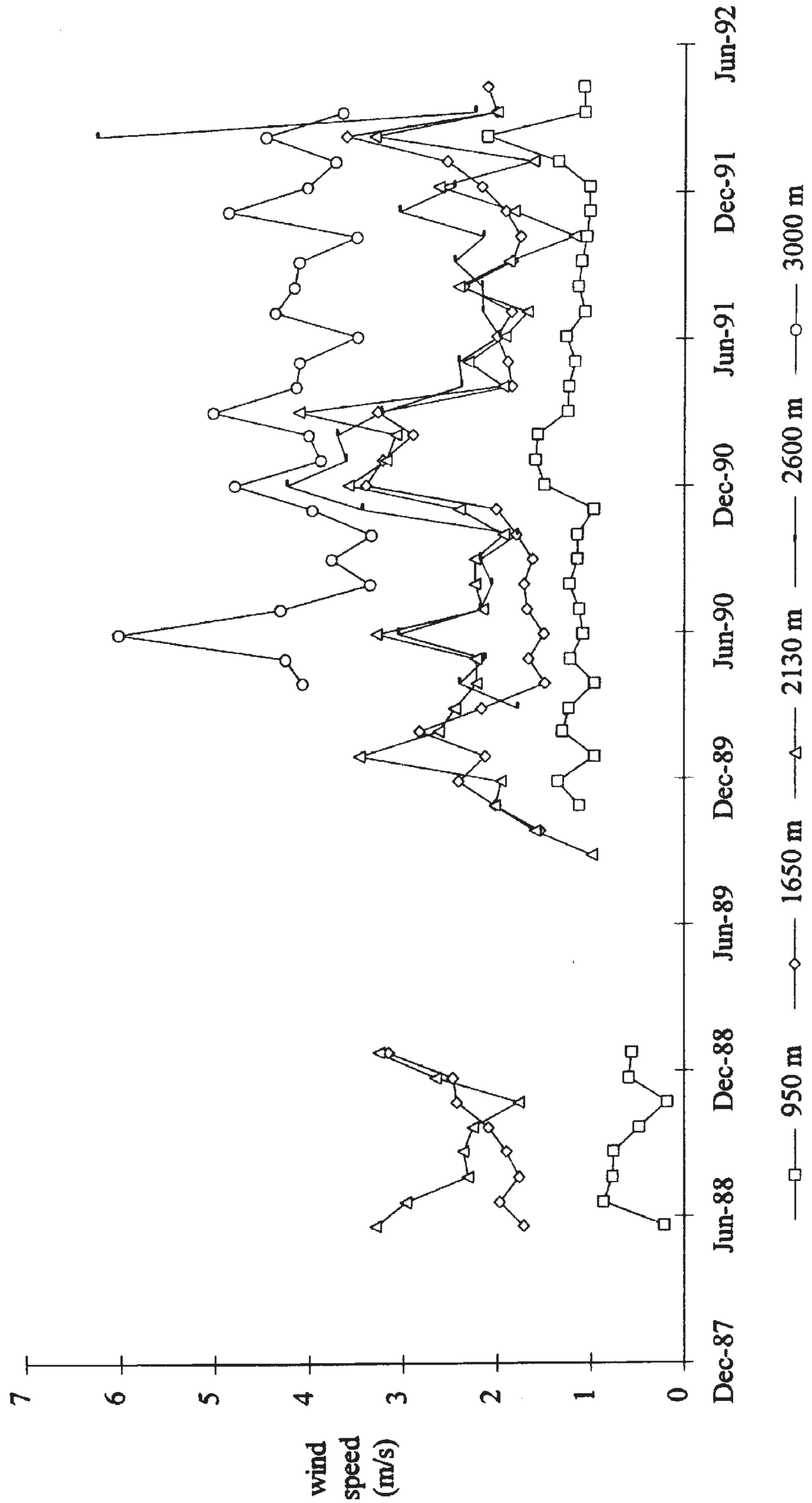
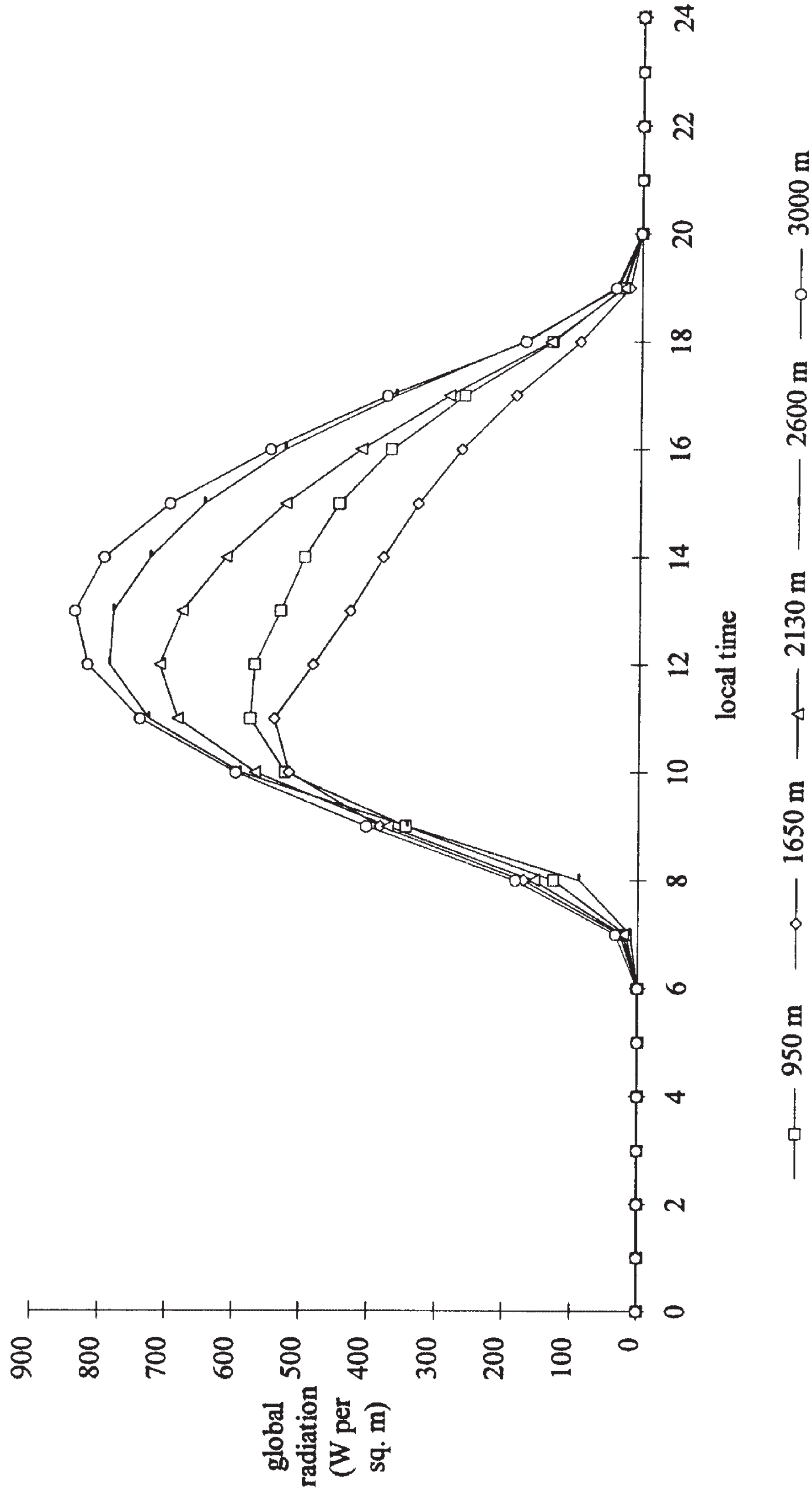


Figure 3: Monthly Mean Wind Speed

Figure 4: Mean Diurnal Cycle of Global Radiation



Solving the *Mauna Lei* Mystery

The clouds that form around the slopes of Haleakalā and other tall Hawaiian volcanoes have been called a *mauna lei*, or a “mountain lei.” On most days, at about the same elevation and time, this cloud lei mysteriously appears. Usually by the evening, it is gone. Another term for these clouds is *nāulu*. That name refers to the shaded, moist band created by the clouds, which created an ideal environment for growing breadfruit (*ulu*).

> If you stand at the Haleakala National Park Visitor Center and look into the crater you can often see clouds ascending Ko‘olau and Kaupō Gaps . . . . [T]he clouds often disappear as they enter the crater floor. “Two gaps, thousands of feet deep, broke the rim of the crater, and through these Ukiukiu (a Haleakalā wind) vainly strove to drive his fleecy herds of trade-wind clouds. As fast as they advanced through the gaps, the heat of the crater dissipated them into thin air, and though they advanced always, they got nowhere.”
>
> —Jack London, *Cruise of the Snark*, quoted in *Maui: How It Came To Be*, Will Kyselka, University of Hawai‘i Press, Honolulu, 1980, pp. 138-139.

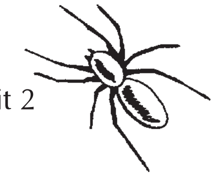
Understanding why the *mauna lei* forms when and where it does can tell you a lot about the climate in the alpine/aeolian zone near the top of Haleakalā. In order to do that, you and your team will become “climate detectives.” Unravel the clues and solve the *mauna lei* mystery.

Instructions

Use the clue cards provided to answer the following questions:

1) At what time of day and approximate elevation does the *mauna lei* usually appear and disappear?
2) What are the climate conditions above and below the *mauna lei*?
3) Why doesn’t the *mauna lei* form higher on the mountain, around the summit?
4) What global factors are involved in the formation of the *mauna lei*? Explain.
5) What are the different causes of the *mauna lei* on the leeward vs. the windward side of Haleakalā? Explain the effects of temperature and pressure on the formation of the *mauna lei* on windward and leeward Haleakalā.
6) What are the main climatic conditions and patterns within the alpine/aeolian zone?

Your team will present its conclusions and the evidence you used to the rest of the class. You may use written summaries, graphic representations, models, or other means of presentation you believe will best present your case to the class.



Climate Conditions Clues

Use the information presented in Tables 1-5 to fill in the grid below. Follow the instructions below to rank each characteristic of the climate in order using the numbers from 1-5. The patterns you see in the grid will provide clues you can use.

Air temperature (Use Table 1.)
Number the elevation zones in order from 1 to 5. 1 = lowest temperature, 5 = highest

Relative humidity (Use Table 2.)
Number the elevation zones in order from 1 to 5. 1 = lowest relative humidity, 5 = highest

Wind speed (Use Table 3.)
Number the elevation zones in order from 1 to 5. 1 = lowest wind speed, 5 = highest

Solar radiation (Use Table 4.)
Number the elevation zones in order from 1 to 5. 1 = lowest radiation level, 5 = highest

Rainfall (Use Table 5.)
Number the elevation zones in order from 1 to 5. 1 = lowest rainfall, 5 = highest

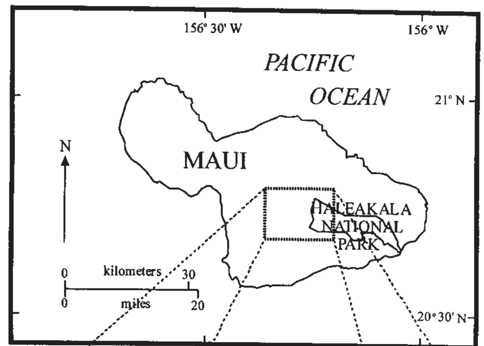
Climate Conditions Clues Summary Table

Elevation	Air Temperature	Relative Humidity	Wind Speed	Solar Radiation	Rainfall
950 m (3116 ft)					
1650 m (5412 ft)					
2130 m (6986 ft)					
2600 m (8528 ft)					
3000 m (9840 ft)					

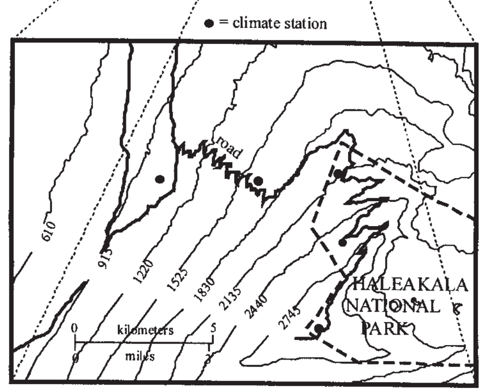
Climate Conditions Clues

Since about 1990, researchers have been studying the climate at 5 different elevations along Crater Road, in order to quantify (attach numbers to or measure) the climate instead of generalizing about it. In other words, they wanted to be able to say *how* windy it is, *how* rainy or dry, *how* hot or cold. And they wanted to be able to track those changes throughout the day, as well as from month to month and from year to year.

These researchers set up climate stations at 950 m (3116 ft.), 1650 m (5412 ft.), 2130 m (6986 ft.), 2600 m (8528 ft.), and 3000 m (9840 ft.) on the west (leeward) slope of Haleakalā. These stations recorded continuous hourly data, some of which are presented below. By reading the graphs you will know with more accuracy what the climate is like at the different elevations, including the top of the mountain, in the alpine/aeolian zone.



Map of study area



Location of Climate Stations along Crater Road (contour interval in meters)

Graphics and all data in the tables below are taken from:
Minyard, W. P., T. W. Giambelluca and D. Nullet, *Elevational Patterns of Climate on the Leeward Slope of East Maui, Hawaii,* Cooperative National Park Resources Studies Unit, University of Hawai‘i at Manoa, 1994 (used with permission of the Pacific Cooperative Studies Unit).

Table 1: Monthly Mean Air Temperature (°C)

	Elevation (m)				
	950	1650	2130	2600	3000
January	15.7	12.3	11.0	10.2	8.1
February	15.5	11.7	10.5	9.3	6.6
March	15.7	11.3	10.5	9.5	6.6
April	16.9	12.4	11.8	10.7	8.3
May	17.5	12.8	11.7	10.9	8.7
June	18.3	14.3	13.3	12.1	9.9
July	18.8	15.0	13.2	12.5	10.2
August	19.3	15.4	13.7	12.8	10.5
September	19.5	15.3	13.4	12.6	9.5
October	18.9	14.8	12.7	11.2	9.5
November	18.2	14.4	13.2	11.0	9.0
December	16.3	12.3	10.6	9.4	6.9
Totals	210.6	162.0	145.6	122.8	103.8
Average	17.55	13.50	12.13	10.23	8.65

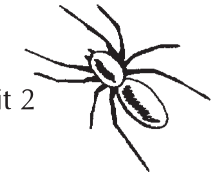
Climate Conditions Clues

Table 2: Monthly Mean Relative Humidity (%)

	Elevation (m)				
	950	1650	2130	2600	3000
January	74.9	69.9	47.5	28.7	24.3
February	83.7	72.6	58.9	43.3	42.6
March	84.6	81.5	61.1	42.4	41.9
April	84.9	82.8	61.4	47.4	37.2
May	83.2	82.6	66.5	48.5	35.7
June	82.8	83.4	65.0	47.0	35.9
July	82.7	84.0	66.0	52.8	43.7
August	83.4	82.7	69.0	57.2	48.7
September	85.6	85.7	72.0	64.4	59.2
October	84.8	84.0	72.9	59.2	49.7
November	85.4	80.5	64.3	59.2	56.4
December	83.8	75.5	64.0	52.8	46.8
Totals	999.8	965.2	768.6	602.9	522.1
Average	83.32	80.43	64.05	50.24	43.51

Table 3: Monthly Mean Wind Speed (meters/second)

	Elevation (m)				
	950	1650	2130	2600	3000
January	1.3	2.7	2.8	3.6	3.8
February	1.7	3.1	3.0	4.7	4.2
March	1.2	2.5	2.9	2.5	4.1
April	1.1	1.7	2.1	2.4	4.1
May	1.2	1.8	2.3	2.3	4.2
June	1.0	1.8	2.7	2.5	4.8
July	1.0	1.8	2.3	2.2	4.4
August	1.1	2.0	2.3	2.1	3.8
September	1.0	1.8	2.1	2.3	3.9
October	1.0	1.8	1.7	2.0	3.4
November	0.9	2.0	2.1	3.2	4.4
December	1.1	2.6	2.7	3.4	4.4
Totals	13.6	25.6	29.0	33.2	49.5
Average	1.13	2.13	2.42	2.77	4.13



Climate Conditions Clues

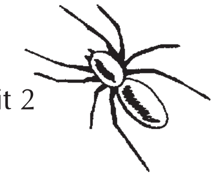
Table 4: Mean Diurnal Cycle of Global Radiation (watts/square meter)

Global radiation is a measure of the solar radiation that reaches the earth. It is the sum of the radiation that reaches the earth from the direction of the sun and the radiation that has been scattered and reflected by the atmosphere.

	Elevation (m)				
	950	1650	2130	2600	3000
January	153.2	144.7	199.6	208.3	214.1
February	170.9	160.5	222.0	217.2	235.0
March	186.5	165.6	231.9	239.0	259.6
April	200.9	163.1	219.0	280.0	315.7
May	221.9	178.8	250.1	295.8	321.8
June	218.1	184.8	278.4	291.5	326.9
July	214.7	174.7	260.4	283.4	309.4
August	208.4	177.8	248.1	292.7	298.9
September	190.0	157.9	206.3	239.3	267.7
October	169.4	143.0	174.4	213.9	236.2
November	141.9	132.5	155.9	177.6	170.9
December	139.9	129.5	155.0	165.8	172.5
Totals	2215.8	1912.9	2601.1	2904.5	3128.7
Average	184.65	159.41	216.76	242.04	260.73

Table 5: Rainfall (mm/day)

	Elevation (m)				
	950	1650	2130	2600	3000
January	3.0	5.6	7.4	4.3	5.5
February	2.3	2.1	4.6	1.9	2.9
March	1.5	3.2	10.0	7.2	6.3
April	0.2	0.7	0.6	0.6	0.6
May	0.4	0.8	1.9	0.8	0.2
June	0.4	0.8	2.2	0.9	0.4
July	0.3	1.1	2.0	1.0	0.9
August	0.5	2.1	4.3	3.2	1.6
September	0.6	3.8	3.5	2.2	2.0
October	0.5	2.3	2.6	2.0	2.0
November	4.2	3.2	5.8	9.5	12.5
December	3.7	3.8	5.2	6.3	7.1
Totals	17.6	29.5	50.1	39.9	42.0
Average	1.47	2.46	4.18	3.33	3.50



Global Forces Clues

For much of the year, the winds on Maui are predominantly “trade winds,” which blow from the northeast. The trade winds and a phenomenon called the “trade wind inversion” are a bit of a mystery in themselves but one that you can solve using these clues.

Pressure, Altitude, and Temperature

Keeping straight the relationships among pressure, altitude, and temperature helps when you are trying to understand the trade wind inversion. Here is a quick review:

One way to illustrate these relationships is to think about what it takes for humans to survive at high altitudes. Airplanes are pressurized and heated so humans can survive at nine kilometers in altitude (5.6 miles or about 30,000 feet). If an airplane loses air pressure the oxygen masks are released from the ceiling. Jet pilots in fighters wear oxygen masks rather than having pressurized cockpits. People climbing Mt. Everest reach 8848 m (29,028 ft) and most wear oxygen masks and very warm clothes!

A look at this table shows the relationship between altitude and air pressure:

Altitude	Percent Sea-Level Pressure
0 (sea level)	100
5.6 km (3.5 mi)	50
16.2 km (10.0 mi)	10
31.2 km (19.3 mi)	1
79.2 km (49.1 mi)	0.001
100 km (62.0 mi)	0.00003

Altitude Correlations

- Increasing altitude = decreasing pressure, and decreasing temperature
- Decreasing altitude = increasing pressure, and increasing temperature

Global Forces Clues

Global Air Circulation Patterns

At the equator, air heated by the sun rises up into the troposphere, an atmospheric layer below the stratosphere. In the troposphere, clouds form, massive air currents and disturbances occur, and temperature decreases with increasing altitude. The troposphere is about 16 km (9.92 miles) high at the equator and 9 kilometers (5.58 miles) high over the poles. Since the air is rising up, it leaves behind an area of low pressure at the equator. (See Figure 1: Idealized Hadley Cell.) The rising air and formation of high cumulus clouds produce large amounts of rainfall for equatorial rain forests.

As the air rises it passes through regions of successively lower pressure. It cools at the rate of 10°C for every kilometer it rises.

As the air reaches the "tropopause" — the boundary between the troposphere and the stratosphere, where the drop in temperature with increasing altitude ceases — it stops rising and begins flowing toward the polar region.

As the upper flow moves poleward, it begins to subside between 20 and 35 degrees latitude. This air is relatively dry, as it has released its moisture near the equator. This zone of subsidence is the site of the world's subtropical deserts (e.g., central Australia and the Sahara and Sonoran deserts). The sinking air warms due to compression. Where it comes back to earth it produces areas of high air pressure which have weak and variable winds. (Tracking the weather around the Hawaiian Islands illustrates this. When the Pacific High is near Hawai'i the winds tend to be light.)

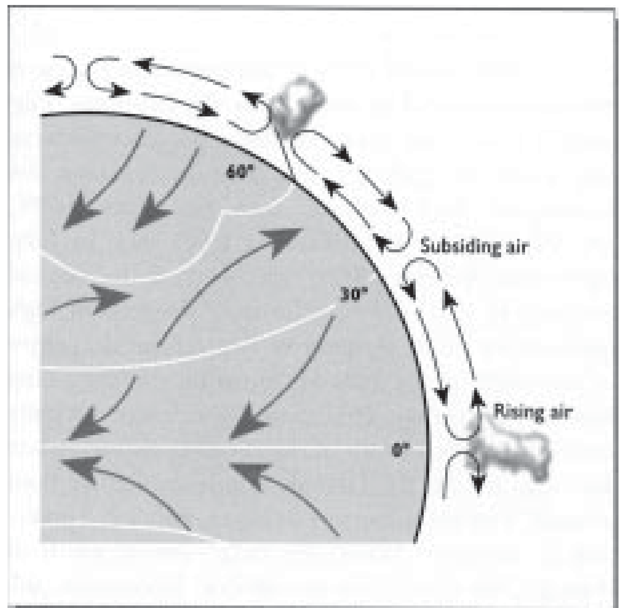


Figure 1: Idealized Hadley Cell, showing vertical and horizontal wind patterns. (From Marie Sanderson, (ed.), Prevailing Trade Winds, *University of Hawai'i Press, 1993.)*

As it approaches the surface, the air flow splits. Some of it flows towards the subpolar low, while the rest of it flows toward the equatorial low at the equator. The air flows "downhill" or down the pressure gradient from a high pressure area to a low pressure area. This completes the Hadley Cell.

Both winds are deflected by the spinning of the earth. This is called the "Coriolis effect." This effect forms the westerlies in high latitudes and the trade winds in tropical latitudes.

These high and low pressure areas and wind patterns affect the climate of the entire globe.

Global Forces Clues

The Trade Wind Inversion

As the trade winds reach Maui they are forced up the mountains on the windward (NE) side. As the wind rises it cools and forms clouds.

There is usually a level on the mountain slopes where the subsiding dry and warming air from the Hadley Cell meets the rising moist and cooling air from the trade winds. This is where the trade wind "inversion" forms. This atmospheric phenomenon is called an inversion because air on top is warmer than the air beneath. Generally speaking, rising air cools at a constant rate (the "lapse rate"). When an inversion is present, however, it interrupts the pattern of consistent rising and cooling.

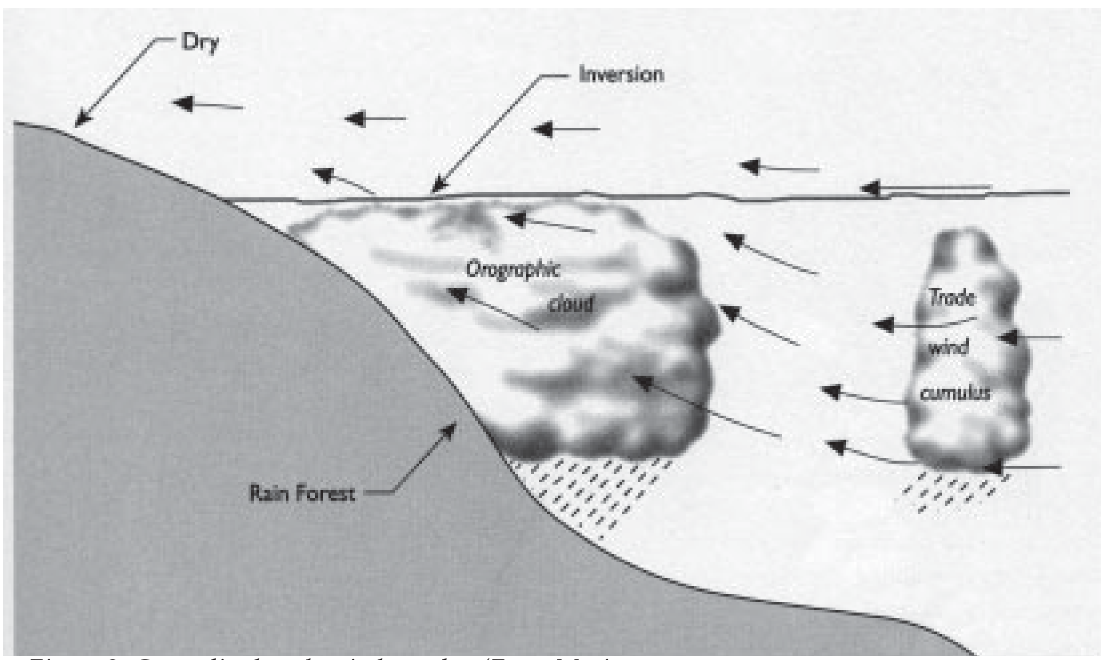


Figure 2: Generalized trade wind weather (From Marie Sanderson, (ed.), Prevailing Trade Winds, *University of Hawai'i Press, 1993.)*

Global Forces Clues

Windward Haleakalā

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*!

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", a term that is taken from "orography," a branch of physical geography having to do with mountains.

Leeward Haleakalā

During the day, solar radiation heats the ground surface and air, creating a zone of warmer air at the higher elevations where solar radiation is more intense.

As the leeward slopes and summit of Haleakalā heat up and the warm air over them rises, moist air is pulled from over the ocean up the mountain's slopes. This moister air cools as it is forced upward.