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 Koʻolau 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 Hawaiʻi Press, Honolulu, 1980, pp. 138-139.

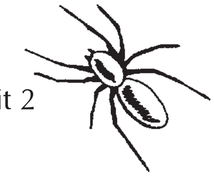
Understanding why the *mauna lei* forms when and where it does can tell you a lot about the climate in the alpine/aeolian zone near the top of Haleakalā. In order to do that, you and your team will become "climate detectives." Unravel the clues and solve the *mauna lei* mystery.

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

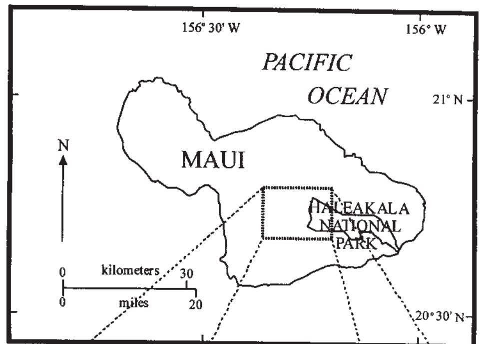
Climate Conditions Clues Summary Table

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)					

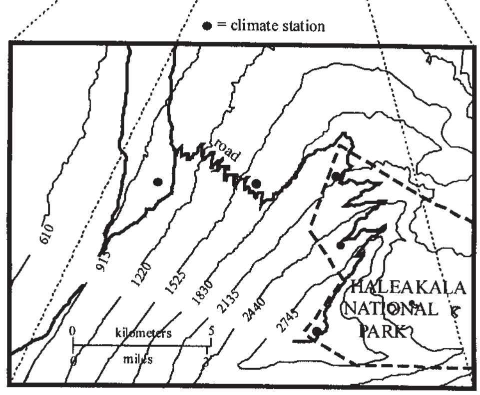
Climate Conditions Clues

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

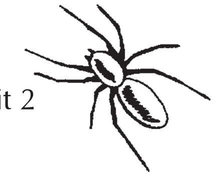


Location of Climate Stations along Crater Road (contour interval in meters)

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



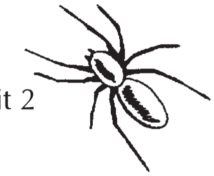
Climate Conditions Clues

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

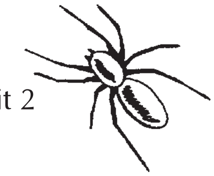
Table 4: Mean Diurnal Cycle of Global Radiation (watts/square meter)

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.)

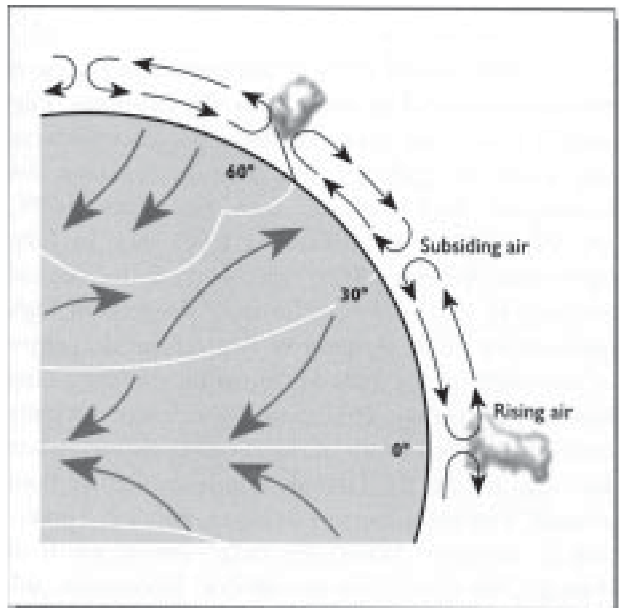


Figure 1: Idealized Hadley Cell, showing vertical and horizontal wind patterns. (From Marie Sanderson, (ed.), Prevailing Trade Winds, *University of Hawai'i Press, 1993.)*

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.

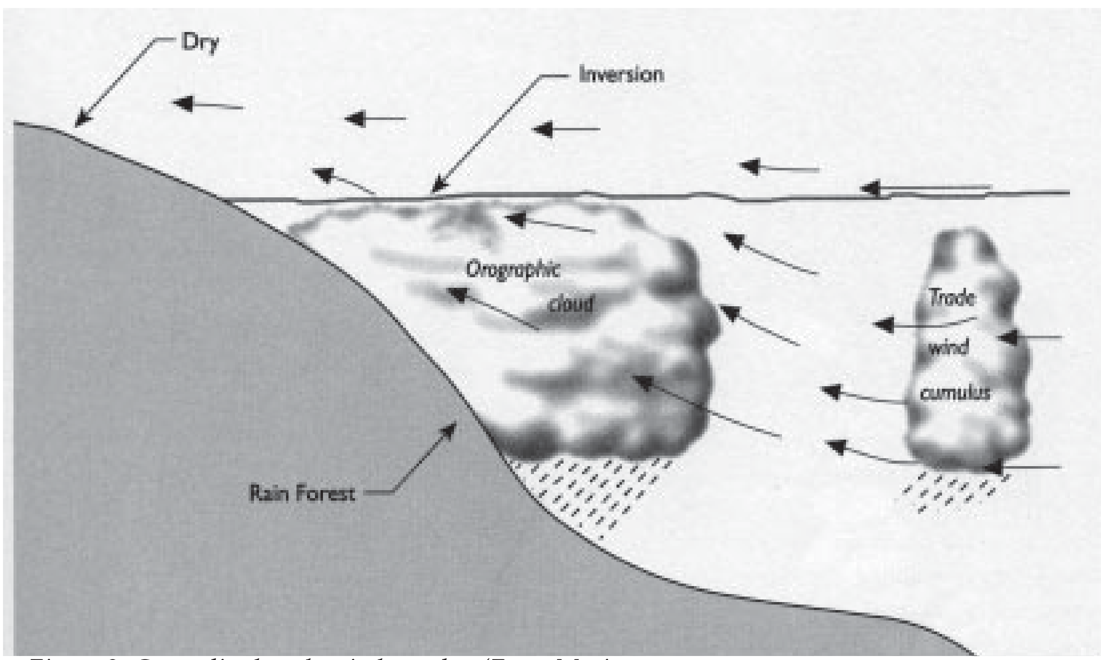


Figure 2: Generalized trade wind weather (From Marie Sanderson, (ed.), Prevailing Trade Winds, *University of Hawai'i Press, 1993.)*

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.