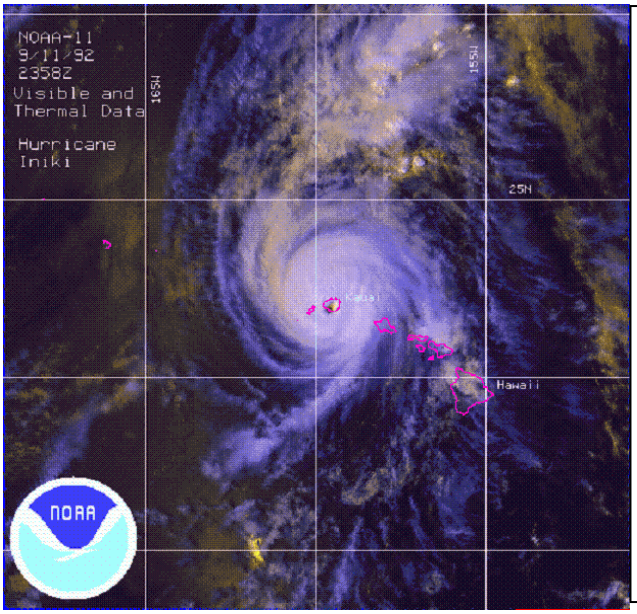

Hurricane ‘Iniki making landfall over Kaua‘i,
11 September 1992.

Nā ‘Ino Ma Hawai‘i Nei:

Weather Maps and Hazardous Storms in Hawai‘i

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Title: Nā ‘Ino Ma Hawai‘i Nei: Weather Maps and Hazardous Storms in Hawai‘i
Grades: 6-8, modifiable for 3-5, 9-12
Time: 2 - 10 hours

Standard 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. 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)

Standard ESS3.B: Natural Hazards. Some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions. Others, such as earthquakes, occur suddenly and with no notice, and thus they are not yet predictable. However, mapping the history of natural hazards in a region, combined with an understanding of related geological forces can help forecast the locations and likelihoods of future events (*ibid*).

Hawai‘i Standard 8: EARTH AND SPACE SCIENCE: Understand the Earth and its processes, the solar system, and the universe and its contents **Topic:** Forces that Shape the Earth	**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

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

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

Weather influences our lives in many ways, from how we choose to dress, to what activities we do, and the plants we choose to grow. Hawai‘i's weather is influenced by peaceful tradewinds on most days. As a result our lives are outdoors-oriented and the weather is often on our minds. This naturally fosters an interest in understanding our local weather. On occasion, especially in the winter, large-scale disturbances and storms pass the islands. These storms sometimes generate severe thunderstorms that can bring damaging winds, thunder and lightning, hail, or a rare waterspout or tornado to the islands. Additionally, in summer there is the possibility of a tropical storm or hurricane passing over or near to the islands.

Learning to understand weather maps and the tools of weather forecasting is valuable knowledge for our students and plays into our interest in Hawai‘i’s beautiful and sometimes hazardous weather. Hawaiian newspaper articles show people were keenly interested in sharing observations of current weather events as well as historical and ancestral, legendary events. These stories transmitted historical knowledge that help people know where certain of these hazards—such as earthquakes, tsunamis, volcanic eruptions, severe weather, floods, and coastal erosion—are likely to occur. Understanding hazards helps us prepare for and respond to them.

While 19th-century Hawai‘i did not have tools such as radar that we rely on for today's weather forecasts, people in that time were still able to make predictions based on recognized patterns. Some examples of these predictions appear in article entitled "Na Hoailona e pili ana i na wa Ino a me na wa Malie" [The Signs of Stormy Times and Calm Times], which was printed in Ka Nupepa Kuokoa on April 4th, 1891. Some of the signs were seen by observing wind patterns, such as:

> *Ina he malie a papaala iloko o ka pule holookoa me ka makani hema no 6 a 7 paha la, me ka pa ikaika mau ana o ka makani ma ia ino, e hala ana he wa loihi no ka malie a me ka papaala a pau ia hapaha.*
> [If it is calm, dry and sunny for the whole week with a southerly wind for 6 or 7 days, and the wind is blowing strongly in this way, a long time will pass that is calm, dry and sunny, until the quarter is done.]

Only through close observation of the natural world could such a pattern be discovered. Other signs are based on the relationship between other parts of nature and the weather:

> *Ina e hoomaka mai ana na Nananana e ulana i na punawelewele, alaila, he mea maopopo he malie a me ka papaala no 10 a 12 paha la.*
> [If the Spiders are beginning to weave webs, then it is known that things will be calm, dry and sunny for 10 or 12 days.]

This shows that the natural world was viewed as one interconnected system, an idea present in other Hawaiian traditions, such as navigation. While guiding a canoe's voyage, a navigator observes everything happening in the sky and sea, such as stars, currents, winds, and birds. By combining these different elements, the navigator is able to understand the big picture and find a path through the ocean.

INSTRUCTIONAL ACTIVITIES

1. Engage:

- "The Signs of Stormy Times and Calm Times" describes natural patterns, such as spiders weaving webs, as indicators for weather prediction. Where you live, can you describe what indicates good weather for the next few hours?
- Where you live, can you describe what indicates severe weather in the next few hours?
- What are your experiences of severe weather? How did you learn about the weather event? How did you and your family prepare?
- When you're planning outdoor activities, what sources of information do you use to prepare for weather conditions?

2. Explore:

- Explore how symbols are used to describe weather where you are: take observations and data then make a station model for your location. See Lab 1, Figure 1.
- Read the introduction to Lab 3. What are other ways to investigate hail, besides what J. H. Maikunu describes?
- Lab 3. Explore how hail is formed then explain the role of condensation nuclei in raindrops and hail.
- Lab 4. Explore how the speed of sound is measured to 1) estimate the distance of a fireworks display or lightning flash and 2) apply the principle to sonar used by bats and submarines.

3. Explain:

- See Lab 1, Activity 1. Write a short weather report for Moscow. Then use your local weather data to write a short weather report for your location.
- Read Ka Makani Pāhili (Hurricanes). D. U. Hairama describes a storm on August 26, 1871. Select detailed observations from his letter and use the Beaufort Scale (below) to

estimate highest wind speeds. Use the Saffir/Simpson Scale (below) to determine the kind of storm it was.
- Explain how hurricanes get their energy, how storm surges form, and why hurricanes die out over land or as they move over cooler waters.

4. Elaborate/Extend:

- Invite a weather reporter or arrange a field trip to the National Weather Service at the University of Hawai‘i at Mānoa.
- Set up a weather station to monitor weather at your school.
- Research how climate change may be affecting weather in Hawai‘i, other places in the Pacific, and around the world.

5. Evaluate:

- Teacher evaluates student learning, effectiveness of lesson and activities, areas for improvement.
- Students evaluate their learning, what they would like to learn more about.

LAB 1: INTRODUCTION TO ANALYZING A WEATHER MAP

INTRODUCTION

There are many types of weather maps that the National Weather Service distributes to aid forecasters. One of the most important types is an *analysis* of the current weather showing observations collected by a global network of instruments. An analysis can depict many things related to the weather, including positions of weather fronts and contours of constant pressure and temperature, etc. Another type of weather chart shows forecasts of the future state of the weather (called *prognoses* or *progs* for short) through a period of several days, and is generated by numerical weather predictions models run on super computers at the National Centers for Environmental Prediction located near Washington D.C. In this lab, we will concentrate on a surface analysis chart.

Universal Time

Observations from around the world are plotted on weather maps, allowing the meteorologist to see weather patterns across the United States and the Pacific Ocean. By convention, atmospheric scientists use a twenty-four hour clock, and use one time zone, Universal Time (UTC), which refers to the time kept on the Greenwich meridian (longitude zero). To convert to local time, we must know the time difference between UTC and local time for both standard time and daylight savings time. Not all locations use daylight savings time in the summer. For example Hawai‘i does not use daylight savings time, so the local time in **Hawai‘i is always 10 hours earlier than**

UTC. Use of UTC as a time label for observations makes it easy to plot observation made at the same time on a weather map to be analyzed.

Station Model

A **station model** (Fig. 1) is a symbolic illustration showing the weather occurring at a given reporting station. Meteorologists created the station model to plot a number of weather elements in a small space on weather maps (http://en.wikipedia.org/wiki/Station_model).

Data on a surface analysis are plotted in a uniform manner around the point locating the observing station on the map (Fig. 1). Once the observations are plotted on the map, meteorologists analyze the map to become familiar with current patterns of low and high pressure, temperature, dew point, etc. Contours are drawn for lines of constant pressure, called *isobars,* and lines of constant temperature, called *isotherms*.

Sea level pressure is given in our weather reports. When home barometers are set to match the local weather reports, they measure pressure converted to sea level, not the actual local pressure. Average *sea-level pressure* can be measured in different ways and units: **101.325 kPa**, **1013.25 mbar**, or **29.92 inches** of mercury (inHg) or **760 millimeters (mmHg)** (http://en.wikipedia.org/wiki/Atmospheric_pressure). Atmospheric pressure is plotted in millibars (mb) after rounding. For example 1011.1 is plotted as 111 and 996.7 is plotted as 967.

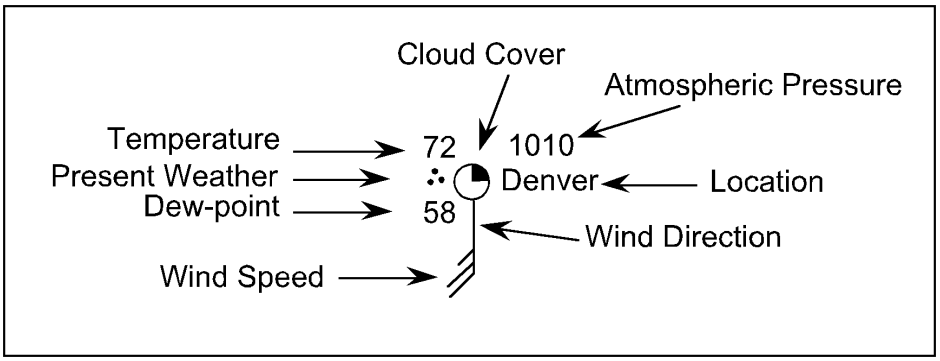


Figure 1 Station Model for plotting of surface weather observations

Cloud Cover - This represents the amount of cloud cover over the station. One quarter of the circle is filled in for one-quarter cloud cover, one half for one half-cloud cover, etc. If the sky is obscured an X is put in the circle.

Atmospheric Pressure - This is the atmospheric pressure measured in millibars (mb). Meteorologists draw contours of equal pressure called *isobars*. In practice the number recorded on the station model includes only the last two numbers and the decimal place. However, for this lab, the entire pressure is plotted in whole millibars.

Temperature - This is the temperature measured in ˚F at the top of each hour. Isotherms designate areas of equal temperature.

Dew-point Temperature - This is the dew point temperature measured in ˚F at the top of the hour. You will recall that the dew point temperature is the temperature at which water droplets form.

Wind Direction - This line represents the direction from which the wind is blowing.

Wind Speed - The small barbs represent the wind speed. Each full line represents ten knots (1 kt =1.15 mph). Shorter lines represent wind speed increments of 5 knots. If the winds speed exceeds 50 knots, a triangle shaped barb is used. The total wind speed is determined by adding the barbs (See Fig. 2).

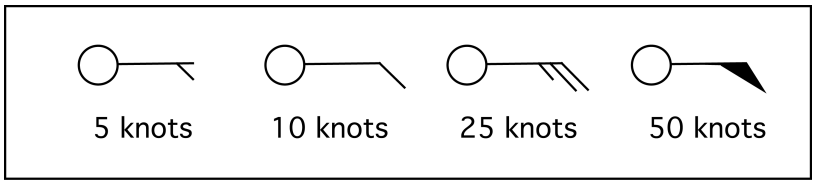


Figure 2 Convention for plotting wind speed and direction.

If you think of wind speed barbs as feathers on an arrow, the circle represents the arrowhead. The arrow points in the direction the wind is blowing to. In meteorology the wind direction is given as the direction from which the wind is blowing. Therefore, if an arrow points to the *west*, the wind direction is actually called *east* (Fig. 2). We know for example that a north wind is cold because it blows from the north.

Present Weather - Symbols show the weather occurring at the time of observation (Fig. 3).

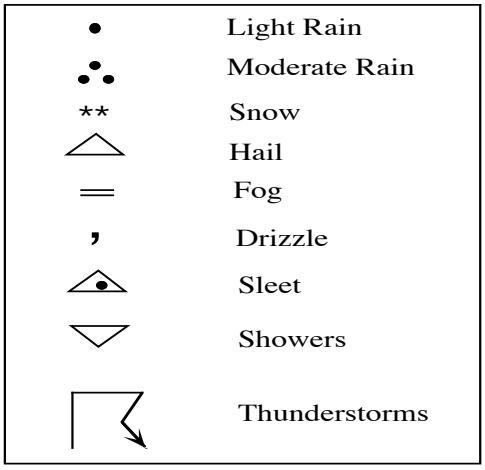
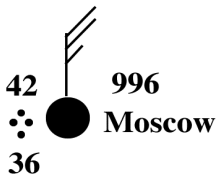


Fig. 3

Charts depicting current conditions in the upper atmosphere called *upper-air maps* are similar to surface maps showing observations for a particular time and valuable to forecasters.

OBJECTIVE: These activities introduce the art of analysis and interpretation of weather data.
PROCEDURES:

1. Write a short weather report by decoding each symbol for the station observation in Moscow.



2. Analyze the data below by drawing contours with values of 3 and 8.

10	**10**	**10**	**10**	**10**	**10**	**10**
5	**5**	**5**	**5**	**5**	**5**	**5**
1	**1**	**1**	**1**	**1**	**1**	**1**

3. Analyze the data below by drawing contours with values of 3, 6, 9, 12, 15, and 18. Label your contours.

10	**10**	**10**	**13**	**15**	**20**	**21**
5	**5**	**10**	**12**	**13**	**15**	**18**
1	**2**	**4**	**8**	**10**	**13**	**14**
1	**1**	**4**	**7**	**8**	**9**	**11**

4. Analyze the data below by drawing contours with values of 120, 140, 160, and 180. Label your contours.

100	**100**	**100**	**100**	**100**	**100**	**100**
100	**110**	**120**	**150**	**120**	**110**	**100**
100	**120**	**150**	**180**	**150**	**120**	**100**
100	**150**	**180**	**200**	**180**	**150**	**100**
100	**140**	**170**	**190**	**170**	**140**	**100**
100	**120**	**150**	**180**	**150**	**120**	**100**

100 100 100 100 100 100 100

5. Explain why the *isopleths* in Fig. 4 are not physically possible. An *isopleth* is a line on a map connecting places registering the same amount or ratio of a meteorological phenomenon.

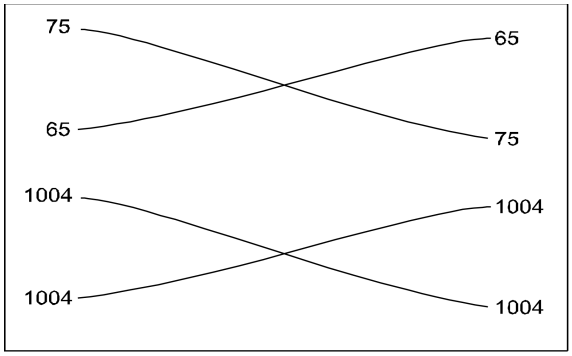


Figure 4 Physically impossible isopleths

6. Analyze the temperature data in Fig. 5 by drawing contours of constant temperature (isotherms) with values of 40, 50, 60, and 70˚ F. Label your contours.

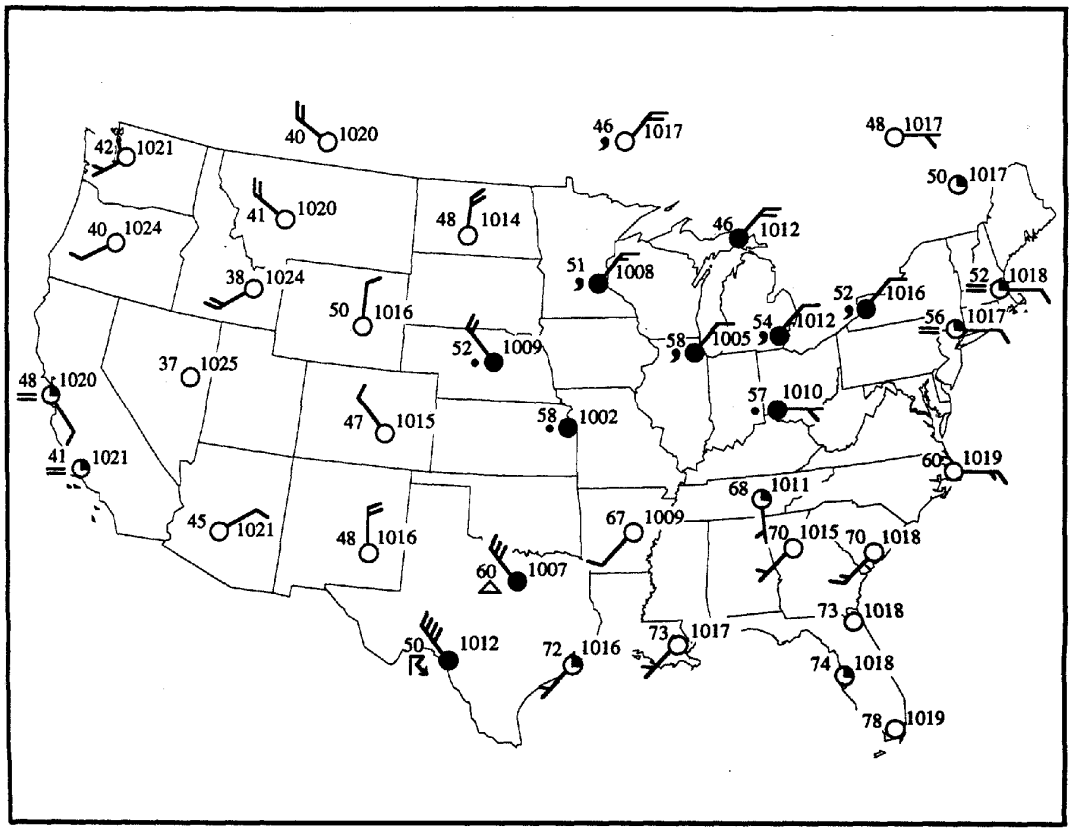


Figure 5 Plotted weather map

7. Analyze the pressure data below by drawing contours of constant pressure (isobars) with values of 1004, 1008, 1012, 1016, 1020, and 1024. Label your contours.

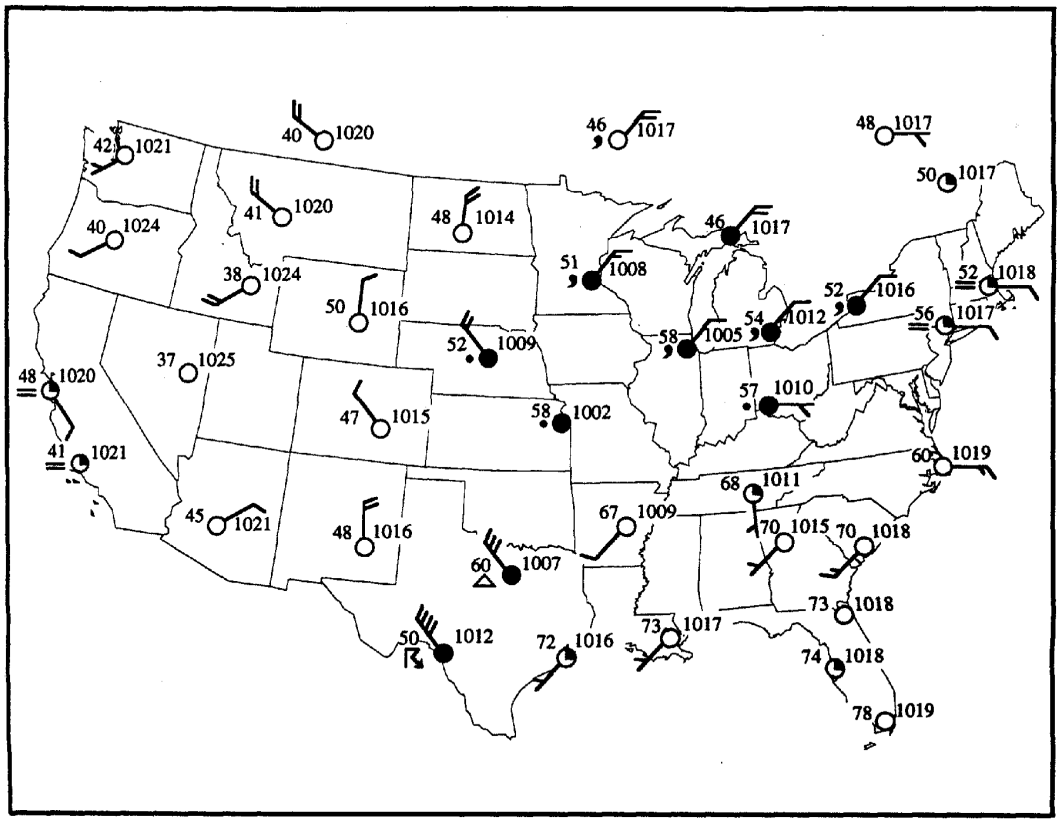


Figure 6 Plotted weather map

8. Qualitatively, explain the relationship between your isobars above and the wind direction shown by the station plots.

LAB 2: FORCES, WIND, AND WEATHER MAPS

INTRODUCTION

Specific forces control the movement of air in the atmosphere. The exercises in this lab explore the relationship between these forces and the resulting winds as represented on weather maps.

OBJECTIVE: Examine how combinations of atmospheric forces balance, leading to the air motions we observe.

QUESTIONS:

1. Suppose the air at **X** is initially at rest and then a pressure field, given below, is introduced causing the air to move. Indicate with an arrow the direction that the air will move if no other forces are acting on it.

   L **x** **H**

2. In Fig. 7 below, height contours at 700 mb (above the friction layer) show regions of high and low pressure in the Northern Hemisphere. Sketch a series of arrows to indicate the direction the wind blows around the areas of low and high pressure.

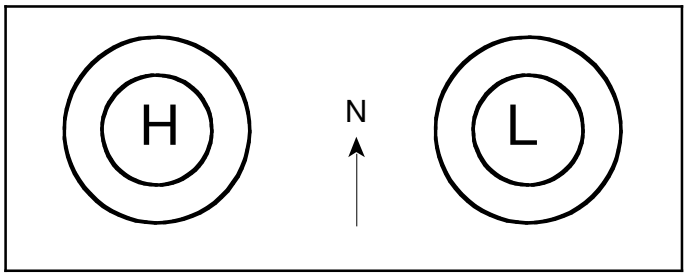


Figure 7 Schematic diagram

3. a. On Fig. 8 below sketch wind vectors for each of the labeled points. The wind vectors are arrows that point in the direction of the wind and whose length indicates relative wind strength.

   b. Are the winds stronger at point A or point C? Explain.

   c. Sketch a **solid line** indicating the ridge axis, or axis of higher heights.

   d. Sketch a **bold, dashed line** showing the trough axis, or axis of lower heights.

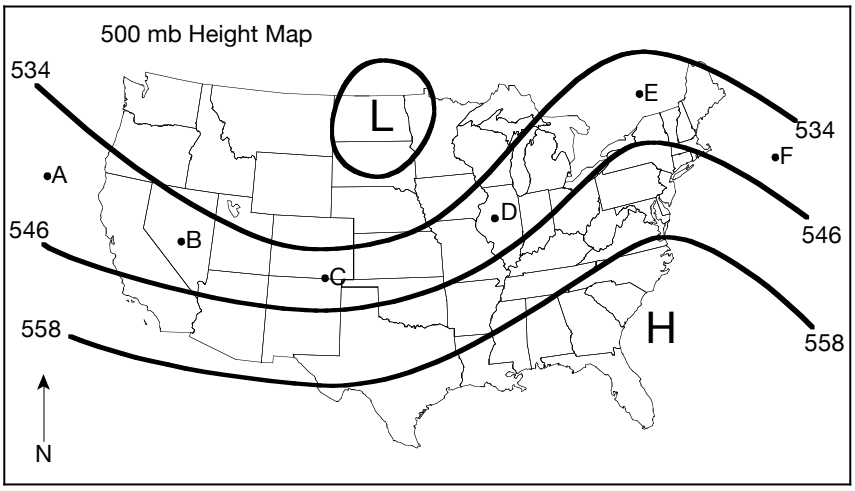


Figure 8 Map showing contours of constant height (tens of meters) above sea level of the 500-mb pressure surface.

4. Indicate the forces and wind direction at point **X** below assuming:

a) A gradient wind balance

L **x**

b) A frictionally modified gradient wind model

L **x**

5. Each of the panels in Fig. 9 represents the wind pattern around a region of low or high pressure.
   a. Below each figure indicate which hemisphere (NH or SH) the figure is in.

   b. Indicate whether the circulation seen is a center of low or high pressure.

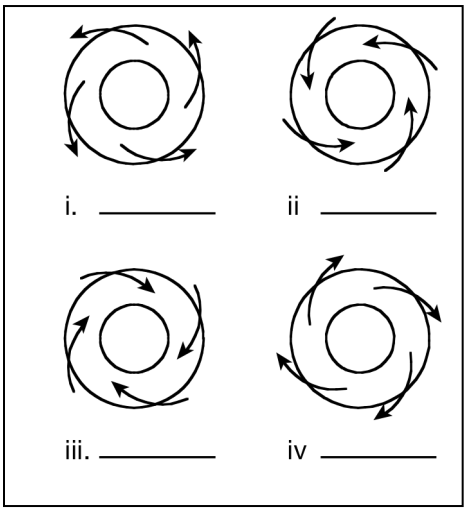


Figure 9

6. a. Friction induces horizontal motion into a surface low and out of a surface high pressure

center (e.g., Fig. 9). Air cannot accumulate indefinitely in a low (it would eventually become a high if it did), or continuously flow out a high (it would eventually become a low). Therefore, what does the air flow have to do above a surface low to keep it from filling up with air? What does it have to do above a surface high?

b. Indicate whether the air above each panel in Fig. 9 above will be rising or sinking.

7. On Fig. 10 below sketch wind vectors for each of the four labeled points. The wind vectors are arrows that point in the direction of the wind and whose length indicates the relative wind strength.

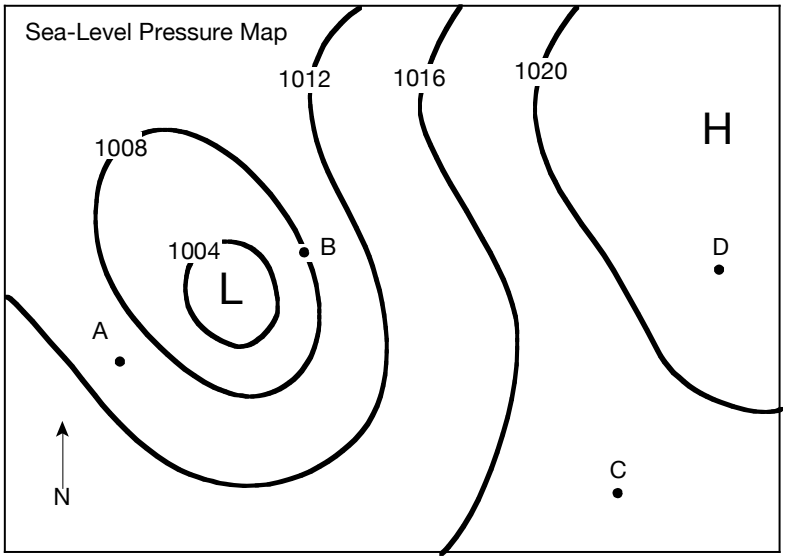


Figure 10 Sea-level pressure map showing isobars (mb).

a. What is the sea-level pressure at point B?

b. Toward which direction is the wind at point A blowing?

c. The pressure gradient force at point B is directed toward which point? L, C, H, D?

d. Toward which direction is the wind at point C blowing?

e. Toward which direction is the wind at point B blowing?

f. At which point is the wind strength the greatest?

g. At which point is the wind strength the weakest?

8 a. In a standard atmosphere, the air exerts a force of 14.7 pounds per square inch downward on the ground at sea level. This pressure is due to the gravitational force of the earth pulling the atmosphere downward. What force, directed upward, balances this gravitational force?

b. The change in atmospheric pressure with increasing elevation near sea level is approximately 10 mb per 100 meters. Estimate the pressure at sea level give the surface pressure is 955 mb at an elevation of 500 meters (see Fig. 11 below).

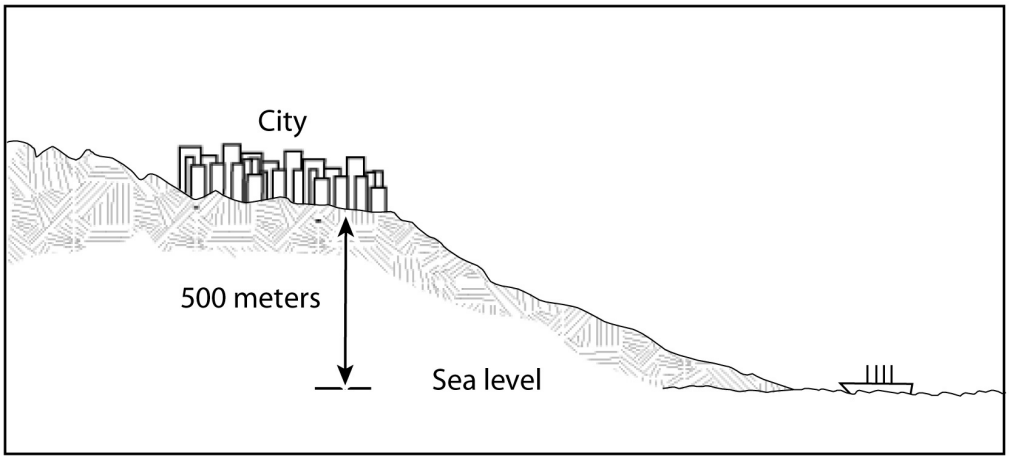


Figure 11 Schematic diagram

LAB 3: KA HUA HEKILI (HAIL)

INTRODUCTION

Hail does not visit us too often here in Hawai‘i, but occasionally thunder storms allow hail to appear. On March 9, 2012, Hawai‘i recorded its largest hailstone at 4-1/4 by 2-1/4 by 2 inches (http://content.usatoday.com/communities/sciencefair/post/2012/03/hailstone-hawaii-state-record/1#.T9ED18WWj-4). The Hawaiian word for hail is *hua hekili*, which can be interpreted as either “fruit of thunder” or “the result of thunder.” In both respects the close relationship between hail and thunder is recognized. There are reports of *hua hekili* in the old newspapers. Our ancestors reacted similarly as we would today. It was an exciting and sometimes frightening new thing and they might try to measure and keep the *hua hekili*, only to have it melt away. An example is found in a letter printed in *Ka Nupepa Kuokoa* on 22 February, 1862. J. H. Maikunu writes:

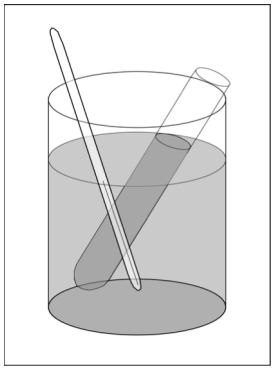
> *Ma ka hora akahi o ka la 14 o Feb. nei, hoomaka ka ua ana me ka hekili pu; a he hapa hora paha mahope iho o ka hoomaka ana o ka ua, ike iho la makou ma ka ili o ka honua, ua paapu i na puupuu keokeo, i kapaia he Hua Hekili; a ma-o ka ua ana, pau ae la ka haule ana. [...] he keokeo na wahi a pau, e like me ko makou i ike aku i ke aiai o ka hau ma Maunakea. He mea hou ia i ko makou ike nui ana i keia mea, i keia hapa o ka la, he mau hora wale no ka ua ana. A ua lawe makou i na puupuu hua hekili ma na ipu, a ma na omole, aole liuliu, a hehee iho la a lilo i wai*.
>
> [At 1 o’clock on the 14th of this February, rain and thunder had started, and about half an hour after the rain started, we saw that the ground was covered with white lumps, known as hail. When the rain ceased, it stopped falling. [...] Everywhere was white, just like when we saw the glitter of snow on Maunakea. This was something new that we witnessed for a part of the day, as the rain fell for only a few hours. We took the pieces of hail in dishes and bottles but in no time, it melted into liquid.]

Hail particles are ice pellets that are greater than five millimeters in diameter. As mentioned previously, hail forms in thunderstorm cells where there are strong updrafts, great vertical development. It is an interesting trick of nature that allows hail to form. That trick is the fact that cloud droplets in the atmosphere usually remain liquid even at temperatures well below freezing. In the absence of freezing nuclei to initiate crystallization, a clean liquid water droplet surrounded by air will not freeze until it is cooled to around -40˚C! Liquid droplets at temperatures below freezing are called *supercooled*. There are special particles in the air that mimic the shape of ice crystals and fool the water drops into freezing. These are called *freezing nuclei.* Of course ice crystals make the best freezing nuclei. In hailstorms, strong updrafts exist that can catch ice particles and carry them back upward into the cloud. Many additional super-

cooled cloud droplets crystallize on the ice particle during this journey, adding a new layer of ice each time the hailstone rises and falls again. This cycle is responsible for the layered growth observed of hailstones. The cycle continues and the hailstone grows in size until the force of gravity overcomes the force of the updraft.

ACTIVITY

OBJECTIVE: The purpose of this experiment is to investigate an interesting twist of nature that is essential to the production of hail. The same principles demonstrated here also apply to the formation of most rain over the United States, in that 95% of our rainfall begins in the upper parts of clouds as snow. As snow crystals fall they sweep up super-cooled droplets in a process called *accretion.*



MATERIALS:
§ crushed ice
§ large test tube
§ 400-600 ml beaker
§ salt
§ distilled water
§ thermometer
§ stirring rod

PROCEDURE:
1. Wash the test tube, being sure that no dust or dirt remains on the inside.
2. Fill the beaker not quite half full of water and add the salt. Pour in enough salt so that after stirring, you can still see salt on the bottom of the beaker. It is better to have too much salt than not enough.
3. add crushed ice to the mixture so that the beaker is nearly full; leaving room for the test tube.
4. Fill the test tube with cold distilled water so that the level of water in the test tube is just below the level of water in the beaker when the test tube is placed in the beaker.
5. Put the thermometer in the beaker and then put the test tube in the beaker.
6. Stir occasionally with the stirring rod for ~6 minutes. The temperature in the beaker should fall below zero. If the temperature does not fall below 0˚ C (32˚ F), add more salt and ice.
7. Once the temperature in the mixture has clearly fallen below freezing, record the temperature.
8. Remove the test tube and immediately drop a small piece of crushed ice into it. Record your observations in the Data Table.
8. Empty the test tube and repeat steps 3 through 7.

Data Table

Trial	Temperature (˚C)	Observations
1		
2		

QUESTIONS:

1. What was the temperature in the beaker at the end of six minutes? What physical principle caused the temperature to drop below zero?

2. What happened when the piece of ice was placed in the test tube?

3. The water in the test tube was below its freezing point before the piece of ice was inserted. Why do you think that the water did not freeze before the ice was inserted?

4. Why do you think it is important to clean the test tube so well before you use it for this activity? Why did you use distilled water?

5. In this experiment, "hail" formed in the test tube. How does this compare with what happens in the atmosphere?

LAB 4: KA HEKILI (THUNDER)

INTRODUCTION

Kānehekili is the god of thunder. He is a brother of Pele, the goddess of the volcano. Kānehekili, along with Pele and his other brothers and sisters, came to Hawai‘i from Tahiti, led by their shark brother Kamohoali‘i. Kānehekili lives in the sky with his brothers Kāne-wāwahi-lani, the breaker of the heavens, and Ka-uila-nui-mākēhā-i-ka-lani, the god of lightning. When thunder crashes, it is said to be the crackling voice of Kānehekili, or the rolling stones of Kāne. This tradition is found in the newspapers as well. We see an example of this in a chant for Prince Albert Kalanikauikeaouli composed by Ami, printed in *Ka Hae Hawaii* on 25 July 1860:

> *Ka pu kani iloko o Ikuwa,*
> *Kani oleole ka leo o Kanehekili,*
> *Ke akua leo nui hana e kapapa ka moku*
> [The clarion trumpet of the stormy month of Ikuā,
> The voice of Kānehekili incessantly roars,
> The loud-voiced god that devours islands]

The entire right side of Kānehekili’s body is black, as he appears when manifesting himself into a human body. According to Mrs. Pukui’s *Nānā I Ke Kumu*, Vol. 1, there was a man on Maui known as Hekili, who was the god of thunder in mortal form. “Everyone knew Hekili as a man who had mana, so that everything he said was fulfilled. He had but to speak to the thunder and lighting and they avenged him instantly upon his enemies.” It was also known of Kānehekili that his touch “could char and blacken the living on earth.” A famed chief of Maui, Kahekili claimed to be a direct descendant of Kānehekili, and tattooed the entire right side of his body black in Kānehekili's likeness. Kahekili's highest ranking warriors, known as the pahupū, tattooed both sides of their bodies. There are some people today born with black birthmarks on the entire right side of their faces who are said to be children of thunder, the descendants of the great Kānehekili. Hāmākua-loa, Maui is said to be the land of thunder. And within Hāmākua-loa, in Ke‘anae, is where a war heiau for Kānehekili stood.

The cause of thunder is one of the oldest riddles. Aristotle published the first thunder theory more than two thousand years ago. He believed that thunder was the result of air smashing against the clouds and, as the air struggled its way through the clouds, it kindled a flame that was lightning. In the mid-seventeenth century, British physicist Robert Hooke suggested that the duration of thunder was dependent upon the distance between the lightning stroke and the observer. Benjamin Franklin, who proved in his famous kite experiment that lightning was an electrical discharge, reasoned that if a spark produced in the laboratory produced a loud snap,

then lightning should also produce a sound. “How loud must be the crack of 10,000 acres of electrified cloud?” he wondered.

Many theories were proposed until at the beginning of the 20th century a consensus evolved that assumed thunder must begin with a shockwave in air due to the sudden thermal expansion of the ionized air (plasma) in the lightning channel. The only experimental support for this theory came from optical temperature measurements up to 36,000 K, hotter than the surface of the sun. However, recent experiments with short atmospheric arcs of lightning strength revealed much higher temperatures than those found previously. Arc photography proved conclusively that the air did not expand thermally in all directions, but preferentially at right angles to the current, as if driven by organized electrodynamic action. Thus, despite being described as “well understood” in modern meteorology textbooks, the underlying cause of thunder remains a topic of speculation and active research.

Sound waves from all segments of the lightning stroke are produced almost simultaneously, typically over a time interval much less than a second in length. What variations we hear in a thunder peal result from the time required for the sound from different segments of the lightning bolt to reach our ears, the nearest segments being heard before the more distant. This time differential, coupled with the length and orientation of the larger segments of the lightning flash, determines the unique character of each thunder peal we hear.

The velocity of sound waves depends on the material through which they are traveling. As you might expect, the speed of sound through water is greater than its speed through air. Knowing the speed of sound through materials allows us to use sound waves to determine distances. The system used for finding distances in water is called sonar, short for sound navigation ranging. This system is used to find the depth of the ocean at various locations (map the ocean floor) and to locate objects underwater. Sonar was invented in the 1920s by August Hayes. By bouncing sound waves off of objects, he found you could measure distance. The system is similar to those used by bats and porpoises to navigate. But before sonar can be used, the speed of sound waves must be known.

ACTIVITY: How can the speed of sound waves be found?

OBJECTIVES: Determine the speed of sound (e.g., thunder) in air and gain an understanding of how sonar works.

MATERIALS:
§ Two metal objects (1 kg weights work well)
§ A meter stick or tape measure

§ A watch or clock with a second hand

PROCEDURE:

1. Find a large flat wall: a school hallway with no side corridors works indoors or a gymnasium wall outdoors. You will reflect sound waves off the wall to determine the speed of sound.
2. Position yourself 15 to 20 feet away from the wall. Measure the distance accurately.
3. Tap the two weights together and listen for the echo. You will need to be very quiet to hear.
4. Once you have produced a suitable echo, tap the weights together at a steady rate so that you hear the echo exactly halfway between taps. This will take a little practice.
5. Now that you have the rhythm of the experiment, count how many taps you make in two seconds. Don’t count the echoes. Repeat the experiment two more times. Record your results in a data table.
6. The speed of sound can be determined by using this equation: velocity = distance ÷ time. The distance that the sound wave traveled was twice the distance from you to the wall (round trip). The time it took was one half the time between taps.
7. Compute the speed of sound for the three trials and compare your results with a reference value for the speed of sound in air.

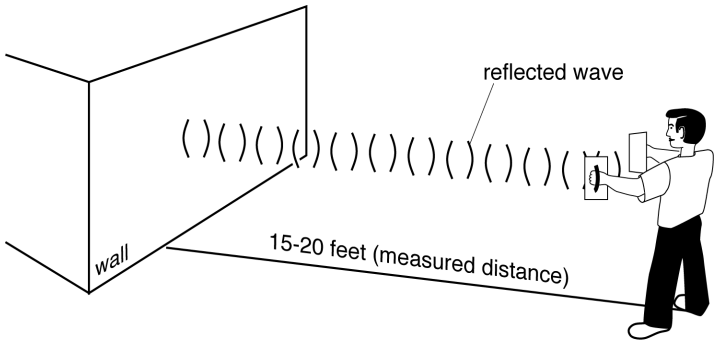


Figure 16 Schematic diagram for finding the speed of sound in air.

QUESTIONS:

1. How far away would you estimate a bolt of lightning struck the earth if you heard the thunder eight seconds after you saw the lightning?

2. What is the minimum time it would take an autofocus camera using a sonic ranging device to determine the distance to an object that is 40 feet from the camera?

3. If a distant thunderstorm is 10 miles away, how long will it take for the thunder generated in the storm to reach your ears?

4. How much time would elapse between a sonar system’s “ping” on the surface and the return of the echo if the depth of a lake is 450 meters?

5. How deep would the Atlantic Ocean be beneath your ship if the time between your sonar’s ping and the return of the echo was consistently 4.5 seconds?

KA MAKANI PĀHILI (HURRICANES)

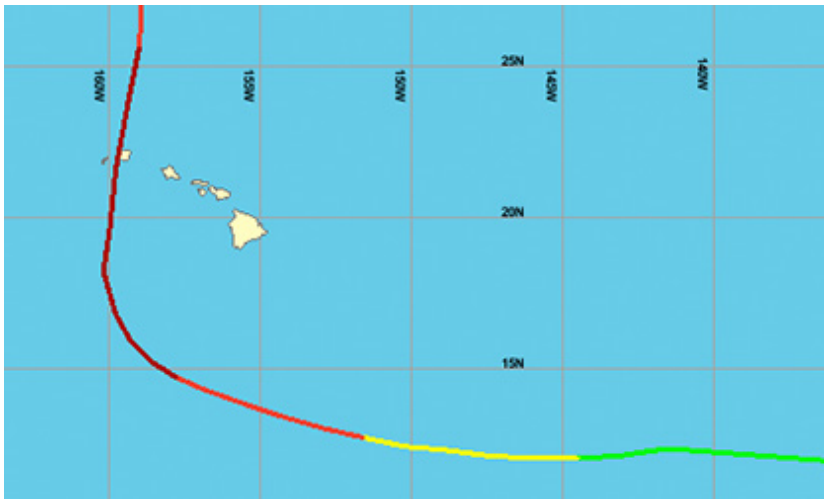


Figure 17 Hurricane ‘Iniki's path, September 1992.

Many hurricanes have hit the Hawaiian Islands in the past, the most recent being Hurricane ‘Iniki in 1992. While several of our islands were hit, the greatest damage was caused on Kaua‘i. Hurricanes generally hit the western islands of our chain, but a notable exception occurred in 1871, when a hurricane hit Kohala on the island of Hawai‘i. In a letter printed in *Ka Nupepa Kuokoa* on August 26, 1871, D. U. Hairama writes of the wind:

> *Ma ko'u kaupaona ana i ka ikaika o keia makani, ua pa-lua a oi aku no paha, ka ikaika o keia makani i ko na makani Kona e ae mamua. A ua ninau aku no hoi au i ka poe kahiko, i mai lakou, 'Aohe lua e like me keia,' aole lakou i ike, a aole no hoi lakou i lohe mamua aku, hookahi wale no ka makani kona i like me ka hapa-kolu o keia. Oia ka makani Kona i ka makahiki 1848, he oki pau aku no nae keia. [...] pau na hale i ka hoohioloia, o ka nui o na hale i hoohioloia 122 [...] Hao mai ka ua me ka makani, aole i kana mai, koe na hulu i ka maha. O na wahi aole i hoolana mua ia, ua halana ia lakou e ka wai. O na laau kanu o kahawai a me na laau e ulu wale ana, pau i ka hakihaki, ke ku poomoku nei lakou i keia wa. Ina o ka pa ana o keia makani, a i ka po, aohe ahai lono o kekahi mau hale a me kekahi poe. Mai ka hoomaka ana o keia makani, a hiki i kona pau ana.*
>
> [In my estimating the strength of this wind, its force was perhaps two times or more the strength of any previous Kona wind. I also asked the old timers, and they said, “There’s been no other like this,” they had neither seen nor heard of one before. There was only one Kona wind that was about one-third of this. That was a Kona wind in the year 1848, but this greatly exceeded it. [...] The houses were all knocked over and the number of collapsed houses was 122 [...] The rain and wind struck with incredible force, leaving only fuzz at one's temples.

> Places that had never been flooded were flooded with water. Trees planted by the streams and those growing wild were snapped, and now stand with their tops broken off. If this wind had hit at night, there would be no survivors from some houses and groups of people, from the start of this wind, until its end.]

Tropical cyclones form in areas of enhanced thunderstorms over warm, tropical oceans and are the most destructive storms on Earth. The deadliest hurricane in U.S. history occurred in Galveston, TX in 1900 when an estimated 6000 people perished. The costliest natural disaster ever to hit the U.S. was Hurricane Katrina, which resulted in more than $81 billion in losses, with at least 1836 related deaths. In the western North Pacific, the storms that annually threaten the Philippines and Japan are called typhoons. Over the Indian Ocean the same type of storm is called a cyclone. Strong cyclones have swept into countries with low-lying coastal zones such as such as Bangladesh and India, bringing extensive ocean flood waters (storm surge) and stunning fatalities (>300,000 in Bangladesh with a 1970 storm surge).

Hurricane Energy Source: The energy source for hurricanes is the release of latent heat when water vapor condenses into storm clouds. Ninety percent of a hurricane’s total energy is released as latent heat, while only three percent of this energy is available to drive the winds. If three percent of the total energy released by a hurricane could be converted to electricity, in one day a hurricane could provide more than six months supply of electrical power for the entire United States. Given a source of moisture from a warm ocean surface, hurricanes typically last for a week to 10 days. Only one in ten tropical disturbances (winds up to 38 mph) develops into a tropical storm (winds 39 to 74 mph), but fully seven in ten tropical storms do develop into hurricanes (winds >74 mph).

Anatomy of a Hurricane: A hurricane is characterized by a small central region known as the eye, within which the winds are light and there are few clouds. The eye is usually 12 to 24 miles in diameter. Winds increase rapidly as one moves out of the eye and into a surrounding ring of thunderstorms referred to as the eye wall; maximum speeds are generally found in the eye wall at a distance of ~18 miles from the center of the storm. A hurricane's overall diameter is typically between 300 and 600 miles (500-1000 km).

Hurricane Impact: Hurricanes impact society through the combined effects of strong winds, elevated ocean levels, large waves, possible tornadoes, and torrential rains on coastal and inland areas. These destructive forces are amplified on the right-leading side of the eyewall when facing in the direction the hurricane is moving. A storm surge is a rise in the level of the sea due to effects of wind and low atmospheric pressure on the ocean. The magnitude of the storm surge depends on wind strength, length and duration of the ocean fetch, angle between storm path and coastline (perpendicular is optimal), the shape of coastline and continental shelf, and the stage of

the astronomical tide. Convergence of wind-driven currents in bays and estuaries tend to amplify the surge, as does a gentle sloping continental shelf. Wave action induced by hurricane winds is superimposed on the storm surge. In very strong hurricanes, the winds can exceed 224 mph and the storm surge can exceed 30 feet. In addition to their destructive winds and storm surge, hurricanes also produce a great deal of rain that can cause local severe flooding but can also have a beneficial side for agriculture.

Hurricane Formation: There are five prerequisites for hurricane formation:

1) Warm ocean water with a temperature > 80˚ F (26˚ C) to a depth of ~100 feet (50 m), so that cooler water cannot easily be mixed to the surface by winds.
2) A pre-existing disturbance with cyclonic circulation. As the air in the disturbance converges, angular momentum is conserved and the wind speed increases.
3) Small wind shear or little change in the wind speed or direction with height in the vicinity of the developing storm.
4) Unstable troposphere characterized by enhanced thunderstorm activity.
5) Large relative humidity in the middle troposphere. Moist air weighs less than dry air, making it buoyant and contributing to lower surface pressures.

Hurricanes that affect Hawai‘i typically form near the coast of Mexico in a region of low pressure and thunderstorms. The storms are commonly are carried westward in the trade winds, but, as they approach Hawai‘i, they tend to curve toward the north (as a result of the influence of the Earth’s rotation on the hurricane motion) and then northeast (due to the influence of the prevailing westerlies at higher latitudes). In Hawai‘i, hurricanes have likely played a role in bringing animal and plant life to the prehistoric island chain. Tropical birds have been found in New England in wake of hurricanes and exhausted birds have been observed to completely cover the decks of ships in storm tossed seas.

Hurricanes affecting the eastern United States grow in intensity over the warm water of the Gulf Stream, Caribbean Sea and the Gulf of Mexico. As over the eastern Pacific, these storms are carried westward in the trade winds, but, as they approach the United States, they tend to curve toward the north and then northeast. When a hurricane moves over land or cold water, the supply of energy is reduced, and the wind speeds diminish. Over land, frictional forces also act to weaken the storm.

When a hurricane vortex moves over the ocean, the winds create large waves. Along coastlines, the winds cause an increase in the water level and flooding of low-lying coastal lands. Such a wind-induced, abnormal rise of the sea, called a *storm surge*, is responsible for most of the hurricane fatalities and damage historically. The effects of the storm surge are accompanied by heavy rains and strong winds. When hurricanes move over mountainous regions, the orographic

lifting can lead to torrential rains and flooding, even at inland locations.

Weather satellites can effectively detect and track hurricanes over the entire Earth. When the storms get within a few hundred kilometers of land, radar and specially instrumented airplanes can also be used to observe a storm's intensity and the path it is following. When a hurricane is approaching a coastal location, early evacuation to higher ground of those people susceptible to the destructive force of the storm surge is essential. A *hurricane watch* is issued by the National Weather Service when there is a possibility of landfall within 36 hours. A *hurricane warning* is issued when landfall is likely within 12 to 24 hours. Large cities along the Gulf of Mexico are especially vulnerable to hurricanes and should be adequately prepared for them.

Tropical Cyclones: Characteristics

Non-frontal low pressure systems
Cyclonic wind circulation (in Northern Hemisphere)
Anticyclonic outflow at upper levels
Warm Core
Winds decrease with height
Vertical structure, symmetric about clear "eye"
Condensation of water vapor primary energy source
Formation over warm tropical and subtropical oceans

1. *Tropical Depression:* surface wind < 39 mph (33 knots)
2. *Tropical Storm:* 39 ≤ surface wind ≤ 74 mph (64 knots)
3. *Hurricane:* surface winds > 74 mph

Saffir/Simpson Hurricane Scale:

Category 1	74 - 95 mph	Storm surge 4 - 5 ft	Iwa '82
Category 2	96 - 110 mph	Storm surge 6 - 8 ft	Kristy ‘94
Category 3	111 - 130 mph	Storm surge 9 - 12 ft	Gilma '82
Category 4	131 - 155 mph	Storm surge 13 - 18 ft	'Iniki '92
Category 5	> 155 mph	Storm surge > 18 ft	John ‘94

See List of Hawaii Hurricanes at http://en.wikipedia.org/wiki/List_of_Hawaii_hurricanes for satellite photos, weather tracks, radar images, and information on tropical cyclones dating from 1843. See "Saffir-Simpson Hurricane Scale" *http://www.aoml.noaa.gov/general/lib/laescae.html*

Beaufort Wind Scale Developed in 1805 by Sir Francis Beaufort

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects	
			On the Water	On Land

0	Less than 1	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	1-3	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	4-6	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	11-16	Moderate Breeze	Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	Fresh Breeze	Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	22-27	Strong Breeze	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	28-33	Near Gale	Sea heaps up, waves 13-19 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	34-40	Gale	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
9	41-47	Strong Gale	High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
10	48-55	Storm	Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	56-63	Violent Storm	Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced	
12	64+	Hurricane	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	

LAB 5: TRACKING HURRICANE 'INIKI

Introduction

Because of their destructive nature, it is very important to accurately track and forecast the movement of hurricanes. The location of the center of a hurricane is obtained through a combination of observations from satellites, aircrafts, ships, and islands. The motion thus obtained can then be extrapolated into the future and compared with computer simulations of the storm track in order to make predictions of the future speed and direction of the storm's motion. The National Weather Service issues hurricane watches and warnings to the public based on the expected storm track to give people in the affected areas time to prepare and evacuate as needed.

Useful Information

Hawaiian Standard Time (HST) = Universal Time Coordinate (UTC) – 10 h

A **hurricane watch** is issued when a hurricane *may* threaten an area in the next 36-48 hours, while a **hurricane warning** is given when landfall is *imminent* in next 12-24 hours.

1° latitude = 111 km
1 mile = 1.6 km
1 km = 0.6 miles
1 kt (nautical term) knot = 1.15 mph

ACTIVITY

OBJECTIVE: Follow the track of Hurricane 'Iniki for several days, with the goal of anticipating the storm's landfall. Learn the meaning of hurricane watches and warnings and when they should be issued.

PROCEDURES

1. Study the storm track data in the Table below. It contains:
   a. date/time of the observation
   b. location of the hurricane's eye (latitude & longitude)
   c. maximum wind speed (*intensity*) of the hurricane (NOT the speed of storm motion)
   d. minimum sea-level pressure (MSLP), an alternate measure of *intensity*
   e. whether the pressure was *estimated* or measured in situ with an *instrument*

2. Plot the track data (LAT/LONG) on the map provided (Fig. 18). For each point, write the minimum sea-level pressure. Mark the date for the beginning of each day (0000 UTC). Color code the track according to the Saffir-Simpson hurricane intensity scale

3. Answer the accompanying questions.

Table – Hurricane ‘Iniki Track Data – September 6-12, 1992

Date/Time (UTC time)	Eye Position LATLONG	Max. Wind (kts)	MSLP (mb)	pressure est./inst.
06/1800	12.2 -140.0	30	1008	est.
07/0000	12.3 -141.1	25	1008	est.
07/0600	12.3 -141.7	25	1006	est.
07/1200	12.2 -142.2	30	1006	est.
07/1800	12.1 -143.0	30	1004	est.
08/0000	12.0 -144.5	35	1002	est.
08/0600	12.0 -146.0	40	1000	est.
08/1200	12.1 -147.5	40	1000	est.
08/1800	12.3 -149.0	50	996	est.
09/0000	12.4 -150.2	60	996	est.
09/0600	12.7 -151.6	65	992	est.
09/1200	13.0 -152.9	65	992	est.
09/1800	13.4 -154.3	80	984	est.
10/0000	13.8 -155.5	85	980	est.
10/0600	14.3 -156.9	90	960	inst.
10/1200	14.7 -157.8	100	960	est.
10/1800	15.2 -158.6	100	951	inst.
11/0000	15.9 -159.3	110	948	inst.
11/0600	16.8 -159.8	115	939	inst.
11/1200	18.2 -160.2	120	938	inst.
11/1800	19.5 -160.0	125	938	inst.
12/0000	21.5 -159.8	115	945	inst.
12/0600	23.7 -159.4	100	959	inst.
12/1200	25.7 -159.0	80	980	est.
12/1800	28.1 -158.9	80	980	est.

Questions

1. Based on the track you plotted, estimate the time (in HST) that ‘Iniki’s eye crosses Kaua‘i.

2. Based on the time you found in #1, when should the National Weather Service have issued its hurricane watch and warning?

    a. Watch

b. Warning

3. How does the timing of the watch and warning fit logistically into most people’s daily routines? Would you make any changes to account for this?

4. What was the hurricane’s speed of motion (in mph) at the time that the **eye crosses Kaua‘i**? What about when the **watch** and **warning** were issued? [remember: speed = distance/time]

5. Based on the speeds calculated in #4, what is the range of maximum wind speeds (in mph) as Iniki crosses Kaua‘i? On which side of Kaua‘i would you expect the greatest damage from high winds and storm surge?

6. Describe the relationship between MSLP and maximum wind speed over the course of ‘Iniki’s lifetime.

7. The strongest hurricanes (Category 5) have slower wind speeds than the strongest tornados (EF-5), but a hurricane will inflict more total damage – why?

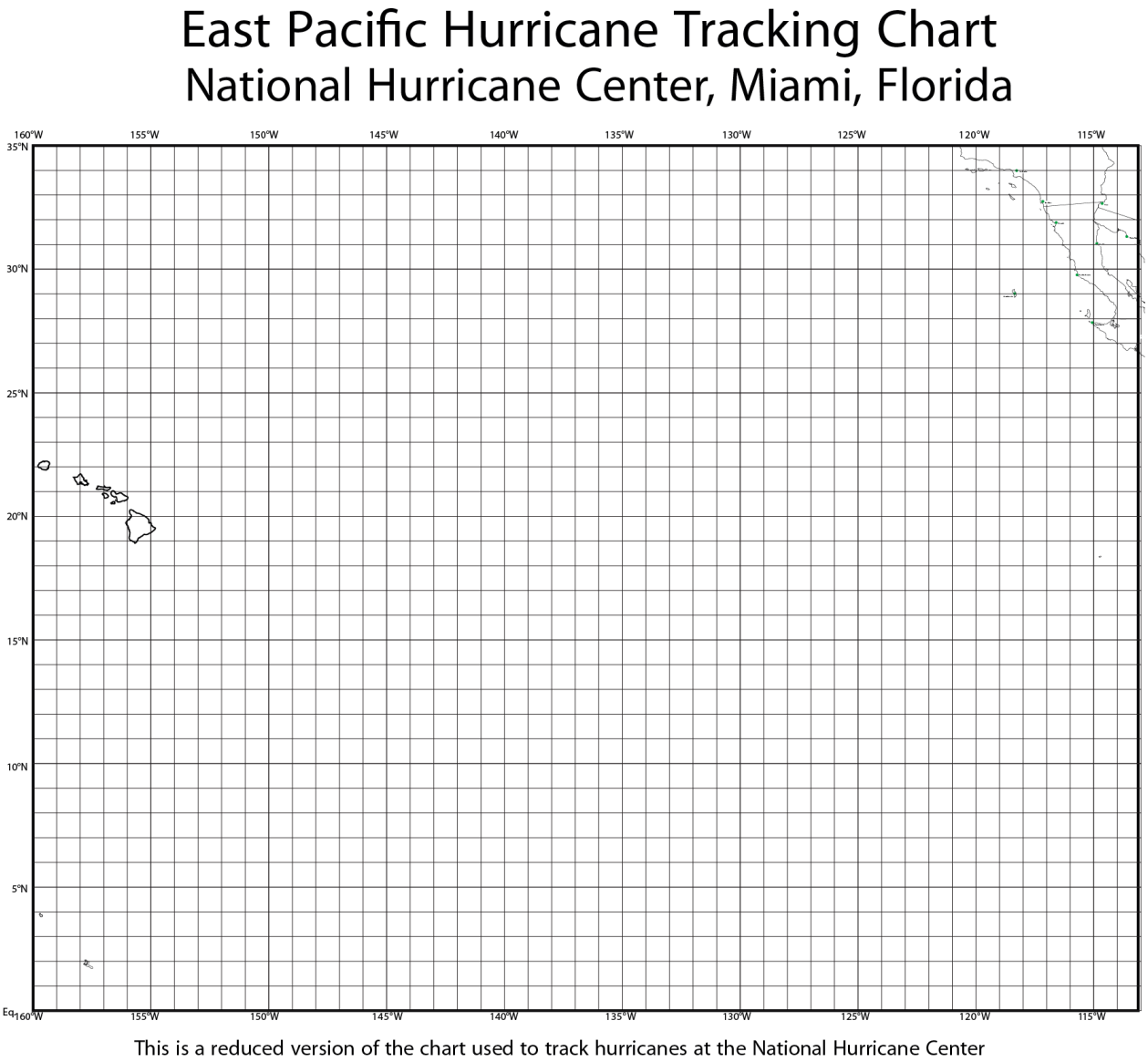


Figure 18 Hurricane tracking chart for the central Pacific Ocean.

Article 1: *Ka Nupepa Kuokoa*. 4 April 1891, pg. 2

Na Hoailona e pili ana i ua wa Ino a me na wa Malie.

Ke hoike aku nei makou i kela mau hoike maialo iho i hoomaopopo pono ia e kekahi kanaka naauao o na au i hala:

1. Ina he makani ma ka akau, komohana akau, hikina a huli koke ae ma ka akau hikina, e hoomau mai no elua a ekolu la, me ka ua ole; a huli hou mai ma ka hema me ka ua ole; a ina mailaila koke ae e loli ana, a he wahi ua liilii paha, a i ka hikina akau a hoomau pela, alaila, he wa maikai a malie e hoomau ana no elua mahina.

2. Ina he malie a papaala iloko o ka pule holookoa me ka makani hema no 6 a 7 paha la, me ka pakaika mau ana o ka makani ma ia mo, e hala ana he wa loihi no ka malie a me ka papaala a pau ia hapaha.

3. Ina e hoomaka mai ana na Nmanana e ulana i na punawelewele, alaila, he mea maopopo he malie a me ka papaala no 10 a 12 paha la.

4. Ina aole e ike ia na hoku lele e maalo ana ma ka poai lani i ka makalii ma ke ahiahi, e ike koke no oe he wa malie loa ia.

5. Ina e loli ae ka pa ana o ka no a lilo i kalae a papaala i ka wa o ka piha mahina ana, a i ole he wa pokole mamua a mahope iki paha a mau ia pela a hiki i ka elua o ka la o ka mahina piha ana, e malie ana a pau ia hapaha.

6. Ina e kokoke aku ana i ka wa u hi na piha, a he noe me ka ua liilii mamua o ka puka ana ae o ka la, a i ole, e lele ana na ao keokeo i ka Hikina Akau, he malie a hala kekahi mau la loihi.

7. I ka wa e hoea mai ai o ka la i e ike nui ia aku ana na ao ma ke kukulu hema a nalo koke aku, alaila, he wahi wa malie pokole.

8. Mamua o ka puka ana ae o ka la, a he noe me ka ua liilii ma o a maanei ke ikeia aku ana, alaila he malie no ka wa pokole.

9. Ina o na ao i ka puka ana ae o ka la, e lele ana i ke kamohana, he malie pokole.

Article 1 Translation: *Ka Nupepa Kuokoa*. 4 April 1891, pg. 2

The Signs of Stormy times and Calm times.

We are showing these reports below that were clearly remembered by someone wise from the eras past.

1. If a wind comes from the north, then the northwest, the east, and then soon changes to the northeast, it will continue for two or three days, without rain; then it shifts again to the south, without rain; and if from there it soons changes, with perhaps a little rain, and it goes to the northeast and continues in that way, then there will be a time of nice calm continuing for two months.

2. If it is calm, dry and sunny for the whole week with a southerly wind for 6 or 7 days, and the wind is blowing strongly in this way, a long time will pass that is calm, dry and sunny, until the quarter is done.

3. If the Spiders are beginning to weave webs, then it is known that things will be calm, dry and sunny for 10 or 12 days.

4. If shooting stars are not seen passing the horizon at the Makali‘i [Pleiades] in the evening, you will soon see a period of persistant calm.

5. If the blowing of the storm changes and becomes clear, dry and sunny when the moon is full, or for a short time a little before or after, and continues in that way until the second day of the full moon, there will be calm until the end of the quarter.

6. If the time of the full moon is drawing nearer, and there is a mist with a little rain before the sun comes up, or white clouds are floating in the northeast, there will be calm for a long period of several days.

7. When the sun appears and clouds are seen at the southern point that soon vanish, then there will be a short period of calm.

8. If before the sun comes up there is a mist with a little rain everywhere in sight, then there will be calm for a short period.

9. If the clouds at sunrise are floating to the west, there will be a short calm.

Article 2: *Ka Nupepa Kuokoa*. 22 February 1862, pg. 2

☞ Ua loaa ia makou he palapala na J. H. Maikunu o Puueo, Hilo, Hawaii. E hai mai ana no ka *Hua Hekili*, a penei kana mau olelo:

"Ma ka hora akahi o ka la 14 o Feb. nei, hoomaka ka ua ana me ka hekili pu; a he hapa hora paha mahope iho o ka hoomaka ana o ka ua, ike iho la makou ma ka ili o ka honua, ua paapu i na puupuu keokeo, i kapaia he Hua Hekili; a ma-o ka ua ana, pau ae la ka haule ana. A i ka lua o ke kuaua, ua ike maka makou i ka haule pu ana mai me ka ua, a paapu ma na wahi a pau; ma na alanui, ma ka nahelehele, maluna o na hale, a he keokeo na wahi a pau, e like me ko makou ike aku i ke aiai o ka hau ma Maunakea. He mea hou ia i ko makou ike nui ana i keia mea, i keia hapa o ka la, he mau hora wale no ka ua ana. A ua lawe makou i na puupuu hua hekili ma na ipu, a ma na omole, aole liuliu, a hehee iho la a lilo i wai.

Eia hoi, i ka haule ana mai o keia mea a pa ma ka papa o na halelaau, ua ko-ele e like me ka pohaku i nouia, a pa ma ka puka aniani o ko J. H. Maikunu hale, ua naha."

Article 2 Translation: *Ka Nupepa Kuokoa*. 22 February 1862, pg. 2

We received a letter by J. H. Maikunu of Pu‘u‘eo, Hilo, Hawai‘i, telling us of the hail. This is what he said:

“At 1 o’clock on the 14th of this February, rain and thunder had started, and about half an hour after the rain started, we saw that the ground was covered with white lumps, known as hail. When the rain ceased, it stopped falling. During the second shower, we saw it falling with the rain, covering everywhere - on the roads, in the forest, on the houses. Everywhere was white, just like when we saw the glitter of snow on Maunakea. This was something new that we witnessed for a part of the day, as the rain fell for only a few hours. We took the pieces of hail in dishes and bottles but in no time, it melted into liquid.

Also, when this was falling and hit the boards of the wooden buildings, it rattled like a rock had been thrown, and when it struck the window of J. H. Maikunu’s house, it shattered.”

Article 3: *Ka Hae Hawaii*. 25 July 1860, p. 72

He Mele no ka Haku Hawaii.
He Inoa keia nou e Kalanikauikeaoli,
A Iolani no kou makuakakane
A Emma--lani no kou makuahine,
Na laua keia makahiapo,
Ku ka mahu o ka uila i ka Lani,
O ka wewena ula ia o ke ahi,
Iluna o ka Hae Alii Anuenue,

[...]

O na kolu ia a Kahekili,
Ka pu kani iloko o Ikuwa,
Kani oleole ka leo o Kanehekili,
Ke akua leo nui hana e kapapa ka moku,
Hiolo ka pali paa o ke kapu,
Naha ka pukoa nui pani awa,
Ka pukoa i noho ia e ka ina--uli,
Mimiki ke kai ku i ka wana,

[...]

Na AMI, i Haku.
Honolulu, Mei 14, 1860.

Article 3 Translation: *Ka Hae Hawaii*. 25 July 1860, p. 72

A Chant for the Hawaiian Prince,
This is a name song for you, O Kalanikauikeaouli,
‘Iolani, indeed, is your father,
And Emma—lani your mother,
From the two of them comes this firstborn child,
The fuming lightning strikes in the Heavens,
It is the red streak of fire,
Above the Royal Rainbow-hued Flag,

[...]

The third of the Kahekili line
The clarion trumpet of the stormy month of Ikuā,
The voice of Kānehekili incessantly roars,
The loud-voiced god that devours islands,
The solid cliff of the taboo falls,
The great coral reef that closes the harbor is smashed,
The coral reef that was resided by the dark sea urchin,
The sea recedes, revealing the sea urchins,

[...]

Composed by AMI.
Honolulu, May 14, 1860.

Article 4: *Ka Nupepa Kuokoa*. 26 August 1871, pg. 2

Haneri iwakaluakumamalua Hale i POINO MA KOHALA AKAU NEI.

E KA NUPEPA KUOKOA E; *Aloha oe:*—

No ka loaa ana mai o kahi ukana e hooili aku ai, nau e hoikeike ae ma ke akea, i keia makani nu hou ma Kohala Akau nei, alaila, ke waiho aku nei.

Aia i ke ahiahi o ka la 8 o keia mahina. Oabeabe mai ana he wahi makani me ka ua. pu, mai ke kukulu Akau Hikina mai o Kohala Akau nei, a i ke aumoe, huli hoolua mai la, a i ka wanaao o ka la 9, huli kahoolawe mai la, aole nae he ikaika loa. Eia no ka ikaika ana mai, a huli pono mai ana ma Kona, aole i kana mai. Lele liilii ka lehu o kapuahi, koe na pae i ke kaumaha.

Ma ko'u kaupaona ana i ka ikaika o keia makani, ua pa-lua a oi aku no paha, ka ikaika o keia makani i ko na makani Kona e ae mamua. A ua ninau aku no hoi au i ka poe kahiko, i mai lakou, "Aohe lua e like me keia," aole lakou i ike, a aole no hoi lakou i lohe mamua aku, hookahi wale no ka makani kona i like me ka hapa-kolu o keia. Oia ka makani Kona i ka makahiki 1848, he oki pau aku no nae keia. "Ku kahau okala ka hulu," aole i kana mai, pau na hale i ka hoohioloia, o ka nui o na hale i hoohioloia 122, a penei ka hoonoho ana, 1 no Pa Honokano, 2 no Pololu, he 11 no Waiapuka, 5 no Niulii, 8 no Makapala, 6 no Aamakoa, 41 no Halawa, 36 no Halaula, no lole, Kapaau, Ainako, Honopueo, 6 no Honomaka'u, 6 no Kahei, 3 no Puuepa, Upolu, Honoipu, 7 no Puakea, 2 no hale i hooneeia, 1 no Homakau oia ka hale kula, 4 kapuai kona nee ana i ka akau, i paa i ke kumu Inia, mai huli ke alo o Hana iluna, 1 no Honoipu. Oia ka hale kula o ka ehu kai o Honoipu, 1 kapuai me hapa kona nee ana, o ka paepae pohaku ma kona noao akau, pau i ka hiolo, e ole e kau ka hale i luna o kekahi mau kun e ae i waiho ia ai malaila, ina ua "Kikii kapakahi o Kekeli."

Hao mai ka ua me ka makani, aole i kana mai, koe na hulu i ka maha. O na wahi aole i hoolana mua ia, ua halana ia lakou e ka wai. O na laau kanu o kahawai a me na laau e ulu wale ana, pau i ka hakihaki, ke ku poomoku nei lakou i keia wa. Ina o ka pa ana o keia makani, a i ka po, aohe ahai lono o kekahi mau hale a me kekahi poe. Mai ka hoomaka ana o keia makani, a hiki i kona pau ana.

Oia iho la kahi mea hou o ka makani apaapaa o Kohala, ke hoi nei au i ka uka anu, nou ke aloha e ka Luna Hoponopono a me ou hoa luhi. D. U. HAIRAMA.

Kohala Akau, Augate 17, 1871.

Article 4 Translation: *Ka Nupepa Kuokoa*. 26 August 1871, pg. 2

One Hundred Twenty-Two Houses Damaged Here in North Kohala.

Nupepa Kuokoa; Greetings to you:—

Because I have something here to relay, it’s for you to display to the public about this newsworthy wind here in North Kohala, so I submit it to you.

On the evening of the eighth of this month, a gentle breeze was blowing with rain from the Northeast here in North Kohala; and in the middle of the night, it turned into a strong North wind. Then at dawn on the 9th, it came from the direction of Kaho‘olawe, but wasn’t terribly strong. Then it strengthened, turning to come directly from Kona, ever so strong. The ashes from the fireplace scattered, the banked ashes remaining, being heavier.

In my estimating the strength of this wind, its force was perhaps two times or more the strength of any previous Kona wind. I also asked the old timers, and they said, “There’s been no other like this,” they had neither seen nor heard of one before. There was only one Kona wind that was about one-third of this. That was a Kona wind in the year 1848, but this greatly exceeded it. “The strike hits, raising the hair”; incredible. The houses were all knocked over and the number of collapsed houses was 122, in this order: one in Pā Ho‘okano, two in Pololū, eleven in Wai‘āpuka, five in Niuli‘i, eight in Makapala, six in Aamakoa, forty-one in Hālawa, thirty-six in Hala‘ula, Lole, Kapa‘au, Ainako, and Honopueo, six in Honomaka‘u, six in Kāhei, three in Pu‘uepa, ‘Upolu, and Honoipu, and seven in Puakea. There were two buildings that were moved, one in Homakau, which was the school house. It moved four feet to the right, and was stopped by an ‘Īnia tree, the Hana side almost turned upward. And there was another in Honoipu; it was the school house of the sea spray of Honoipu. It moved one and a half feet and the rock platform on its right side collapsed. Thankfully the house was set atop other beams, so it remained there, or “The ship Kate Lee would have been tilted sideways.”

The rain and wind struck with incredible force, leaving only fuzz at one's temples. Places that had never been flooded were flooded with water. Trees planted by the streams and those growing wild were snapped, and now stand with their tops broken off. If this wind had hit at night, there would be no survivors from some houses and groups of people, from the start of this wind, until its end.

That is the news from the land of the ‘Āpa‘apa‘a wind of Kohala, for I am returning to the cool uplands. Regards to you, Editor, and your fellow laborers.

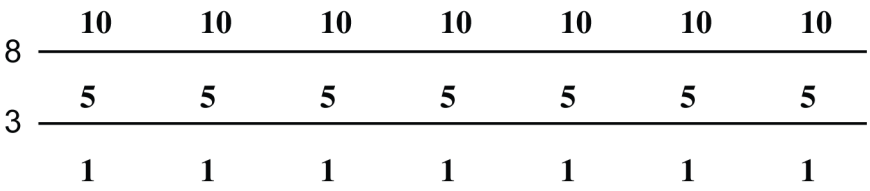
D.U. Hairama

North Kohala, August 17, 1871.

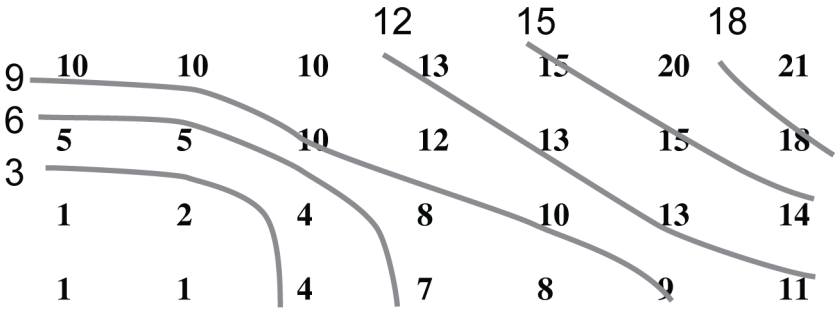
LESSON 3 – NĀ ‘INO O HAWAI‘I NEI – KEY

Lab 1: Introduction to Analyzing a Weather Map

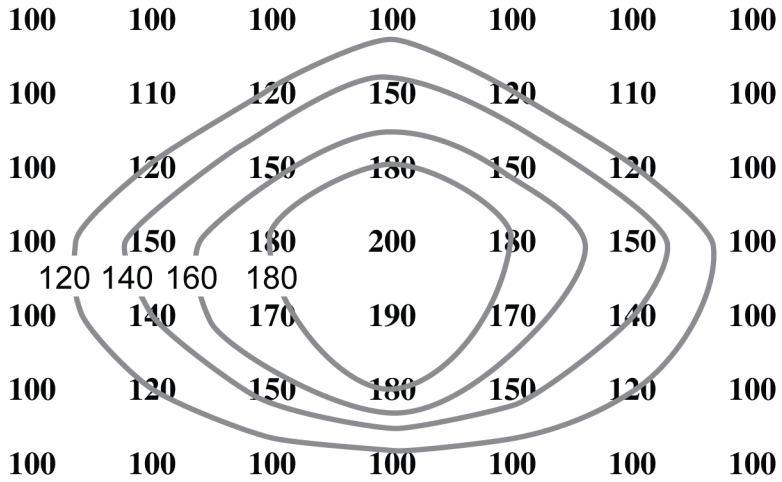
1. Analyze the data provided below by drawing contours with values of 3 and 8.



2. Analyze the data provided below by drawing contours with values of 3, 6, 9, 12, 15, and 18. Label your contours.



3. Analyze the data provided below by drawing contours with values of 120, 140, 160, and 180. Label your contours.



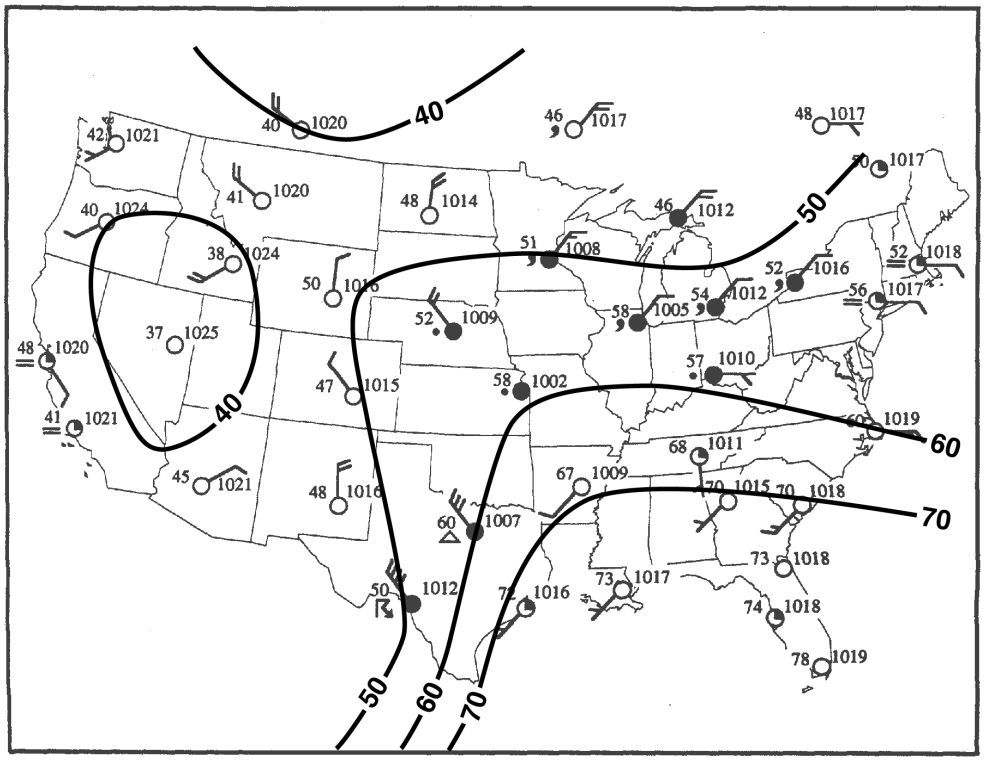
4. Decode the following observation.

A Wind: 25 knots from the north, Atmospheric pressure: 996 mb
Location: Moscow, Cloud cover: full cloud cover (cloudy/overcast)
Dew point temperature: 36° F, Present weather: heavy rain
Temperature: 42° F

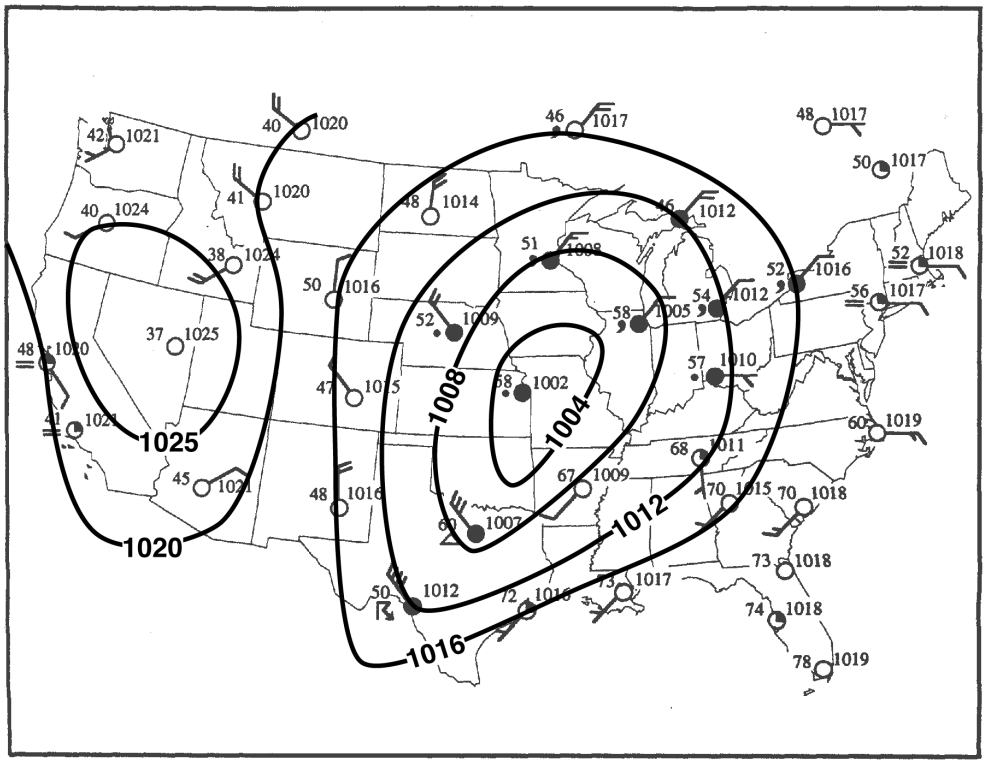
5. Explain why the isopleths in Fig. 4 are not physically possible.

A Isopleths cannot cross because it is impossible to have two different temperatures or pressures at the same location at the same time.

6. Analyze the temperature data provided in Fig. 5 by drawing contours of constant temperatures (isotherms) with values of 40, 50, 60, and 70° F. Label your contours.



7. Analyze the pressure data provided below by drawing contours of constant pressure (isobars) with values of 1004, 1008, 1012, 1016, 1020, and 1024. Label your contours.



8. Qualitatively, what is the relationship between your isobars above and the wind direction shown by the station plots?

   A The wind direction at the various stations tends to follow the isobars, suggesting geostrophic wind (wind that flows parallel to the isobars).

Lab 2: Forces, Wind, and Weather Maps

1. Suppose the air at **X** is initially at rest and then a pressure field, given below, is introduced causing the air to move. Indicate with an arrow the direction that the air will move if no other forces are acting on it.

   L ← **H**

   A The air will move from high pressure to lower pressure, so from right to the left.

2. In Fig. 7 below, height contours at 700 mb (above the friction layer) show regions of high and low pressure in the Northern Hemisphere. Sketch a series of arrows to indicate the direction the wind blows around the areas of low and high pressure.

A Winds around the high will rotate clockwise and winds around the low will rotate counterclockwise, parallel to the contours of constant height (isoheights), which are analogous to isobars on a surface weather map.

3. a. On Fig. 8 below, sketch wind vectors for each of the labeled points. The wind vectors are arrows that point in the direction of the wind whose length indicates the relative wind strength.

A The wind vectors are arrows that will be locally directed parallel to the isoheights.

b. Are the winds stronger at point A or point C? Explain.

A Winds are stronger at point C because the isobars are closer together indicating a large pressure gradient over a smaller area.

c. Sketch a solid line indicating the ridge axis, or axis of higher heights.

A The ridge axis runs from the high (H) pressure center north through point E.

d. Sketch a bold dashed line showing the trough axis, or axis of lower heights.

A The trough axis runs from the low center over North Dakota southward to the Texas coast.

4. Indicate the forces and wind direction at point **X**, below, assuming:
   a. A gradient wind balance

A In the Northern Hemisphere the wind will blow from the south and an westward directed pressure gradient force will balance eastward directed Coriolis and centrifugal forces.

b. A frictionally modified gradient wind model

A In this case the only change will be the addition of a small friction vector that will cause the wind to turn counterclockwise and blow from the southeast (a direction change from due south of 10˚ over the ocean, and ~30˚ over land).

5. Each of the panels in Fig. 9 represents the wind pattern around a region of low or high pressure.
   a. Below each figure indicate which hemisphere (NH or SH) the figure is in.

b. Indicate whether the circulation seen is a center of low or high pressure.

A a and b. i. High pressure center in the SH, ii. Low pressure in the NH, iii. Low pressure in the SH, iv. High pressure in the NH.

6. a. Friction induces horizontal motion into a surface low and out of a surface high pressure center (e.g., Fig 9). Air cannot accumulate indefinitely in a low (it would eventually become a high if it did), or continuously flow out of a high (it would eventually become a low). Therefore, what does the air flow have to do above a surface low to keep it from filling up with air? What does it have to do above a surface high?

A Above a surface low the air rises and at some distance above the surface (e.g., the top of the troposphere) this air diverges (spreads out). Above a surface high the air sinks towards the surface so that the air that is displaced by the high pressures center is replaced.

b. Indicate whether the air above each panel in Fig. 9 above will be rising or sinking.

A i. sinking, ii. rising, iii. rising, iv. sinking.

7. On Fig. 10 below sketch wind vectors for each of the four labeled points. The wind vectors are arrows that point in the direction of the wind whose length indicates the relative wind strength.
   a. What is the sea-level pressure at point B?
   b. Toward which direction is the wind at point A blowing?
   c. The pressure gradient force at point B is directed toward which point? L, C, H, D?
   d. Toward which direction is the wind at point C blowing?
   e. Toward which direction is the wind at point B blowing?
   f. At which point is the wind strength the greatest?
   g. At which point is the wind strength the weakest?

A a. 1008 mb
   b. East
   c. Towards L
   d. Northwest
   e. West-northwest or west
   f. B has the strongest winds because the isobars are closest together at this point.
   g. C has the weakest winds because the isobars are spaced furthest apart at this point.

8. a. In a standard atmosphere, the air exerts a force of 14.7 pounds per squares inch downward on the ground at sea level. This pressure is due to the gravitational force of the earth pulling the atmosphere downward. What force, directed upward, balances this gravitational force.

A The pressure gradient force balances gravity in the vertical.

b. The change in atmospheric pressure with increasing elevation near seal level is approximately 10 mb per 100 meters. Estimate the pressure at sea level given the surface pressure is 955 mb at an elevation of 500 meters (see Fig. 11 below).

A The pressure at sea level will be about 1005 mb. (500 m/100 m) x 10 mb + starting pressure (955 mb).

Lab 3: Ka Hua Hekili (Hail)

1. What was the temperature in the beaker at the end of six minutes? What physical principle caused the temperature to drop below zero?

   A The observed temperature will be -6° to -10° C. By dissolving salt in the water/ice mixture, the freezing point of the liquid is lowered. The temperature of a mixture of solid and liquid tends towards its freezing point temperature. If the mixture is warmer than its freezing point temperature, the excess heat will be used to melt the solid and the temperature of the solution will drop. Therefore, in the presence of ice, the temperature of salt water drops to its lower freezing point temperature and will remain there until all of the ice is melted.

2. What happened when the piece of ice was placed in the test tube?

   A The water in the test tube does not contain salt, so its temperature is below the freezing point of water, thus this water is said to be “supercooled”. When ice is placed in the test tube, it immediately triggers freezing in the supercooled water. The ice provides a surface (the molecular blueprint) on which the supercooled water can freeze.

3. The water in the test tube was below its freezing point before the piece of ice was inserted. Why do you think that the water did not freeze before the ice was inserted?

   A The supercooled water did not freeze because it lacked the pattern or blueprint provided by the freezing nuclei to tell the water molecules how to line up. In the absence of a freezing nuclei, the water does not crystallize and its temperature can drop below zero without changing phase. Supercooled droplets can exist in the atmosphere to temperatures as low as -40° C.

4. Why do you think it is important to clean the test tube so well before you use it for this activity? Why did you use distilled water?

   A It is important to clean the test tube to eliminate particles that might serve as freezing nuclei. For this reason it was also important to use distilled water. Tap water, although clean enough to drink, contains many minute particles not necessarily visible to the naked eye. Most particles, however, are not effective freezing nuclei. Only particles that approximate the molecular structure of ice are effective freezing nuclei. For this reason

freezing nuclei are relatively rare in the atmosphere except in regions of the air where there is already a lot of ice crystals present. This is the basis for cloud modification by cloud seeding.

5. In this experiment, "hail" formed in the test tube. How is this different from what happens in the atmosphere?

   A In the atmosphere, supercooled water exists as tiny cloud droplets. These supercooled droplets freeze when a freezing nuclei collides with them. When a hail stone encounters supercooled droplets the hail serves as a freezing nucleus and the droplets freeze onto its surface. When the hail stone grows too heavy for the updraft to suspend it, the hail stone falls to the ground.

Lab 4: Ka Hekili (Thunder)

1. How far away would you estimate a bolt of lightning struck the earth if you heard the thunder eight seconds after you saw the lightning?

   A The speed of sound depends on the density of the air, which in turn depends on the temperature and pressure of the air. The following relationship: $v = 331.4+0.6T$, provides an approximate value for the speed of sound (v) in meters per second at typical surface pressure. T in this equation is the air temperature in degrees Celsius. At 20˚C (68˚F) the speed of sound is ~344 m/s which is ~770 mi/hr, which works out to about 5 seconds per mile. Thus, if you hear the thunder 8 seconds after seeing the bolt, the lightning was roughly 1.5 miles away.

2. What is the minimum time it would take an autofocus camera using a sonic ranging device to determine the distance to an object that is 40 feet from the camera?

   A The signal must travel to the object and back. At 344 m/s or 1127 ft/s it would take about 7 hundredths of a second (~0.07 s).

3. If a distant thunderstorm is 10 miles away, how long will it take for the thunder generated in the storm to reach your ears?

   A If the sound takes roughly 5 seconds to travel a mile, it would take 50 seconds or nearly a minute to reach your ears.

4. How much time would elapse between a sonar system’s “ping” on the surface and the return of the echo if the depth of a lake is 450 meters?

   A The speed of sound in water is roughly 1500 m/s; therefore it would take ~0.3 seconds.

5. How deep would the Atlantic Ocean be beneath your ship if the time between your sonar’s ping and the return of the echo was consistently 4.5 seconds?

   A At 1500 m/s x 4.5 s = ~6750 meters deep.

Lab 5: Tracking Hurricane ‘Iniki

1. Based on the track you plotted, estimate the time (in HST) that ‘Iniki’s eye crosses Kaua‘i.

   A

2. Based on the time you found in #1, when should the National Weather Service have issued its hurricane watch and warning?

   A

3. How does the timing of the watch and warning fit logistically into most people’s daily routines? Would you make any changes to account for this?

   A

4. What was the hurricane’s speed of motion (in mph) at the time that the **eye crosses Kaua‘i**? What about when the **watch** and **warning** were issued? [remember: speed = distance/time]

   A

5. Based on the speeds calculated in #4, what is the range of maximum wind speeds (in mph) as Iniki crosses Kaua‘i? On which side of Kaua‘i would you expect the greatest damage from high winds and storm surge?

   A

6. Describe the relationship between MSLP and maximum wind speed over the course of ‘Iniki’s lifetime.

   A

7. The strongest hurricanes (Category 5) have slower wind speeds than the strongest tornados (EF-5), but a hurricane will inflict more total damage – why?

   A

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