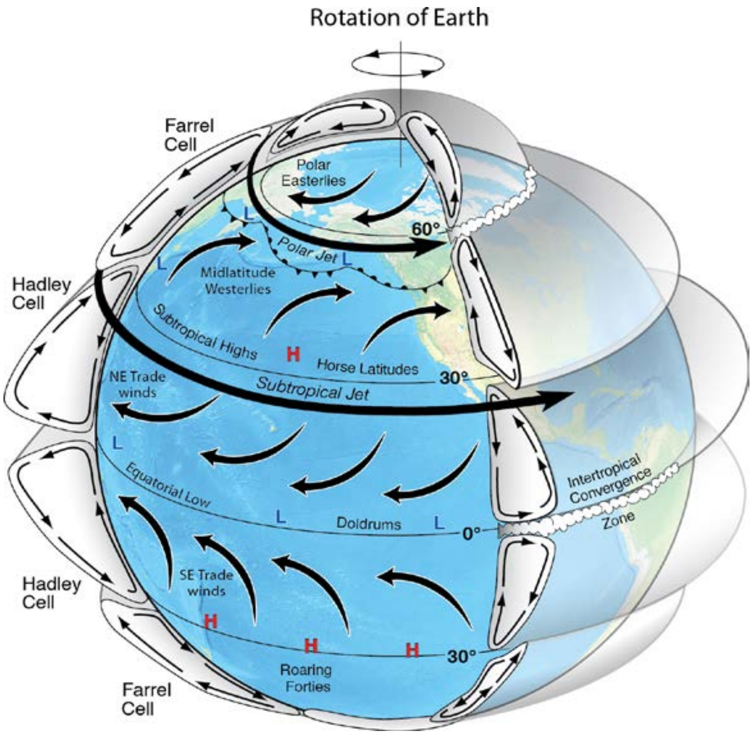

Figure 1. Schematic of global circulation

Hadley Cell and the Trade Winds of Hawai‘i:

Nā Makani Mau

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Grades: 6-8, modifiable for 9-12

Time: 2 - 10 hours

***Nā Honua Mauli Ola*, Guidelines for Educators, *No Nā Kumu*:** Educators are able to sustain respect for the integrity of one’s own cultural knowledge and provide meaningful opportunities to make new connections among other knowledge systems (p. 37).

Standard: Earth and Space Science 2.D ESS2D: Weather and Climate
Weather varies day to day and seasonally; it is the condition of the atmosphere at a given place and time. Climate is the range of a region’s weather over one to many years. Both are shaped by complex interactions involving sunlight, ocean, atmosphere, latitude, altitude, ice, living things, and geography that can drive changes over multiple time scales—days, weeks, and months for weather to years, decades, centuries, and beyond for climate. The ocean absorbs and stores large amounts of energy from the sun and releases it slowly, moderating and stabilizing global climates. Sunlight heats the land more rapidly. Heat energy is redistributed through ocean currents and atmospheric circulation, winds. Greenhouse gases absorb and retain the energy radiated from land and ocean surfaces, regulating temperatures and keep Earth habitable. (A Framework for K-12 Science Education, NRC, 2012)

Hawai‘i Content and Performance Standards (HCPS) III
http://standardstoolkit.k12.hi.us/index.html

STRAND THE SCIENTIFIC PROCESS	
Standard 1: The Scientific Process: SCIENTIFIC INVESTIGATION: Discover, invent, and investigate using the skills necessary to engage in the scientific process	
Topic: Scientific Inquiry	**Benchmarks:** SC.8.1.1 Determine the link(s) between evidence and the conclusion(s) of an investigation. SC.8.1.2 Communicate the significant components of the experimental design and results of a scientific investigation.
Standard 2: The Scientific Process: NATURE OF SCIENCE: Understand that science, technology, and society are interrelated	
Topic: Science, Technology, and Society	SC.8.2.1 Describe significant relationships among society, science, and technology and how one impacts the other
Topic: Unifying Concepts and Themes	SC.8.2.2 Describe how scale and mathematical models can be used to support and explain scientific data.
STRAND PHYSICAL, EARTH, AND SPACE SCIENCES	
Standard 8 EARTH & SPACE SCIENCE: Understand the Earth and its processes, the solar system, and the universe and its contents.	
Topic: **Forces that Shape the Earth**	SC.ES.8.1 Describe how elements and water move through solid Earth, the oceans, atmosphere, and living things as part of geochemical cycles SC.ES.8.4 Describe how heat and energy transfer into 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. SC.8.8.4 Explain how the sun is the major source of energy influencing climate and weather on Earth SC.8.8.6 Explain the relationship between density and convection currents in the ocean and atmosphere.

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

Knowledge of winds has always been important in Polynesian culture, especially for voyaging, such as the voyages that first brought people to Hawaiʻi. On the star compass developed by navigator Nainoa Thompson, the four quadrants are named after winds: *Koʻolau* for the northeast, *Malanai* for the southeast, *Kona* for the southwest, and *Hoʻolua* for the northwest. These are only four of the hundreds of Hawaiian names describing the different winds and breezes that flow towards the islands, on the islands and from the islands. However, this lesson is focused on the prevailing circulation in the Hawaiian Islands, which we call the trade winds.

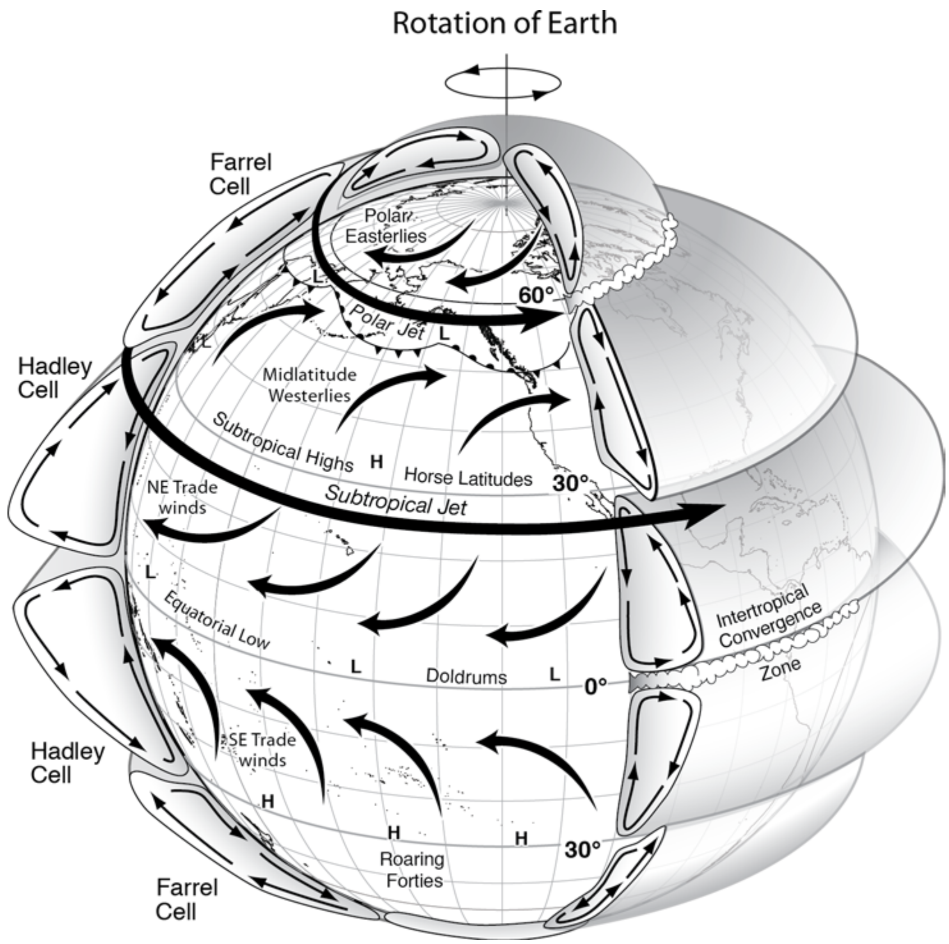

Figure 1 Schematic of global circulation

While the term "trade winds" was created by European sailors who found the winds favorable for their voyages, the Hawaiian system of naming winds was place-based, resulting in many different names for trade winds across the islands. A common trade wind name, though, was "*Aʻe*", which can also mean "diagonal." Look for the Hadley Cell and the Hawaiian Islands between the Equator (0 degrees N. latitude) and Tropic of Cancer (30 degrees N. latitude) in Fig. 1 above. You will see that our familiar northeast trade winds come from an angle between North and East. Regional variations on this name include "*Aʻe Loa*", "*Moaʻe*", "*Moaʻe Kū*", "*Moaʻe Pehu*", and "*Naʻe*". The more general description "*nā makani mau*" [regular winds] might also be used to refer to trade winds, depending on the location. These prevailing trade winds are linked to a very large circulation in the atmosphere called the Hadley Cell. References to the trade winds can be found in two Hawaiian newspaper articles from the 1860s attached as readings for this lesson.

Nā makani mau rule the circulation over the Islands of Hawaiʻi. However, Hawaiʻi also has many other named winds, many of them local and regional. (We focus on local winds in another lesson.) One example of a local trade wind is found in a letter written in 1865 to the Hawaiian-language newspaper *Ke Au Okoa*. In the letter, the writer, L. S. Kailiehu, describes several common winds found in Hāna, Maui. Kailiehu writes of one wind, the *Kaomi,"He makani mau a he makani kamaaina keia no Hana. He malie ke kai, aohe nui o ka ua, he oluolu ka aina a pau o Hana, a he mahana maikai ka la.* [This is a regular wind and a familiar wind for Hāna. The sea is calm, there is not a lot of rain, the entire expanse of Hāna is comfortable, and the sun has a pleasant warmth.]" Like trade winds across the Hawaiian islands, the *Kaomi* is regular and pleasant, bringing favorable conditions.

According to meteorologists, weather specialists, weather and climate are closely related to global circulation patterns. Our trade winds emanate from the descending branch of the Hadley Cell. As seen in Fig. 1, the Hadley Cell is part of a three-cell model that maps the general nature of the global circulation. Winds are caused by temperature differences produced by the sun's light striking the earth more strongly in the tropics than further north or south. The general circulation redistributes heat from the Equator to the North (90 degrees N) and South (90 degrees S) Poles. If winds and ocean currents did not redistribute this heat, the equatorial regions would become continuously warmer while the polar regions would cool down continuously.

Articles found in Hawaiian-language newspapers show us that Hawaiians were aware of global wind patterns. In 1866, D. A. K. Aloikeanu wrote in *Ke Au Okoa*, *"O ka la wela no, ka mea e holo ai ka makani. Aia a wela ka makani i ka la, ua mamama iho la a pii; hooholo mai la ka makani mai na wahi e, mai na wahi anu mai, a piha ka hakahaka oia wahi.* [The heat of the sun is what causes wind to blow. Once wind is heated by the sun, it becomes light and rises, and then winds blow from other places, cold places, to fill the empty space at this place.]" This describes Hadley Cell circulation, as winds blow down from cooler climates in the north to replace rising air at the equator.

The Hadley Cell starts at the Equator and ends at the Tropic of Cancer (30˚ N. Latitude in the Northern Hemisphere) and Tropic of Capricorn (30˚ S. Latitude in the Southern Hemisphere). Weak winds, clouds, and rainfall are found in the doldrums (also known as the Intertropical Convergence Zone, see Fig. 1) where warm, moist air rises to 10–15 kilometers. As it moves away from the Equator, it carries the motion of the rotation of the Earth with it (Fig. 2). As a result there is an increasingly strong component of westerly flow (moving from west to east) as the air moves north and south away from the Equator. The westerly winds dominate the airflow aloft to roughly 30˚ N. and S. Latitude which mark the limit of the Hadley circulation (see Fig. 3). These strong westerly winds aloft are known as the subtropical jet streams.

Where Hadley and Farrel Cells meet there is converging air aloft (Fig. 1), which leads to sinking motion and the formation of the subtropical high-pressure regions at the surface, which in turn causes our trade winds to blow. The rotation of the Earth causes the trade winds emanating from the subtropical high to turn increasingly easterly as noted by the Hawaiian word *A'e*, which can mean "diagonal." This turning of the wind is due to the Coriolis effect.

In 1862, D. W. Poliwela writing in *Ka Hoku o ka Pakipika*, described the Coriolis effect to explain why trade winds blow from the northeast, "*No ke kaa ana o ka honua mai ke komohana a i ka hikina, holo e ko ka honua, holo e ko ka makani; hahai no ka makani mahope ae o ka la, nolaila, ua mau na makani mai ka hikina mai. Ua kapaia na makani mau ma ka aoao akau o ka poaiwaena, oia ma na Mokupuni o Hawaii nei, e puhi ana na makani mau, mai ka Hikina Akua mai, a ma ka aoao hema o ka poaiwaena, ua puhi na makani mau, mai ka Hikina Hema mai*. [Because the earth spins from west to east, the land goes one way and the wind goes another way. The wind follows after the sun, so the winds are regularly from the east. The regular winds in the Northern Hemisphere, such as those in the Hawaiian Islands, blow from the Northeast, and in the Southern Hemisphere the regular winds blow from the Southeast.]"

As air from the Hadley Cell circulation descends to the surface, the Coriolis effect, caused by the rotation of the earth, makes the air flow east to west, resulting in regular northeasterly trade winds. Honolulu, Hawai'i is located at 21 degrees N. latitude, south of the descending branch of the Hadley Cell (http://en.wikipedia.org/wiki/Hadley_cell), thus prevailing trade winds blow throughout the year (Fig. 4). Biodiversity, early explorations by sailing canoes, and agriculture depend closely on the regular trade wind pattern. Geography and orography (mountains) play an important role in precipitation (rainfall) patterns that are driven by the trade winds.

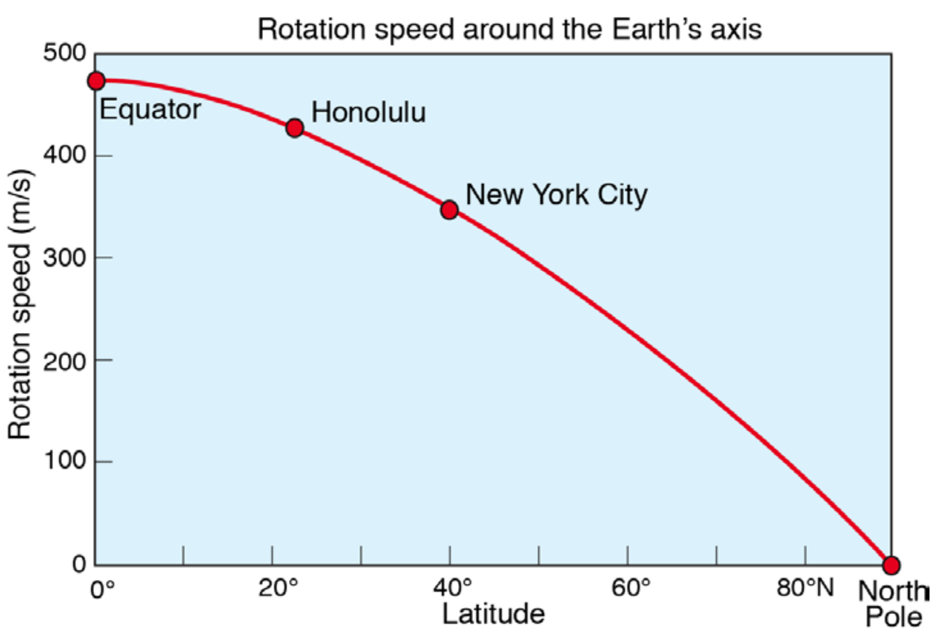

Fig. 2: The rotational speed of a point on the Earth's surface as it moves from the equator to the north pole.

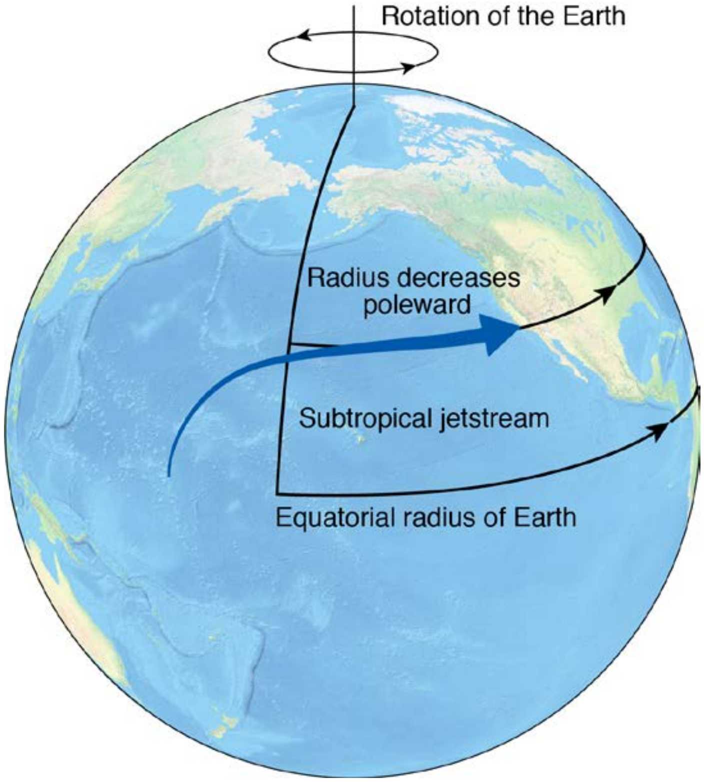

Figure 3: Subtropical Jetstream: As air moves away from the Equator aloft, it carries the motion of the rotation of the Earth with it. As a result there is an increasingly strong component of westerly flow leading to subtropical jet streams (note how arrow changes) as the air moves north (or south) away from the Equator.

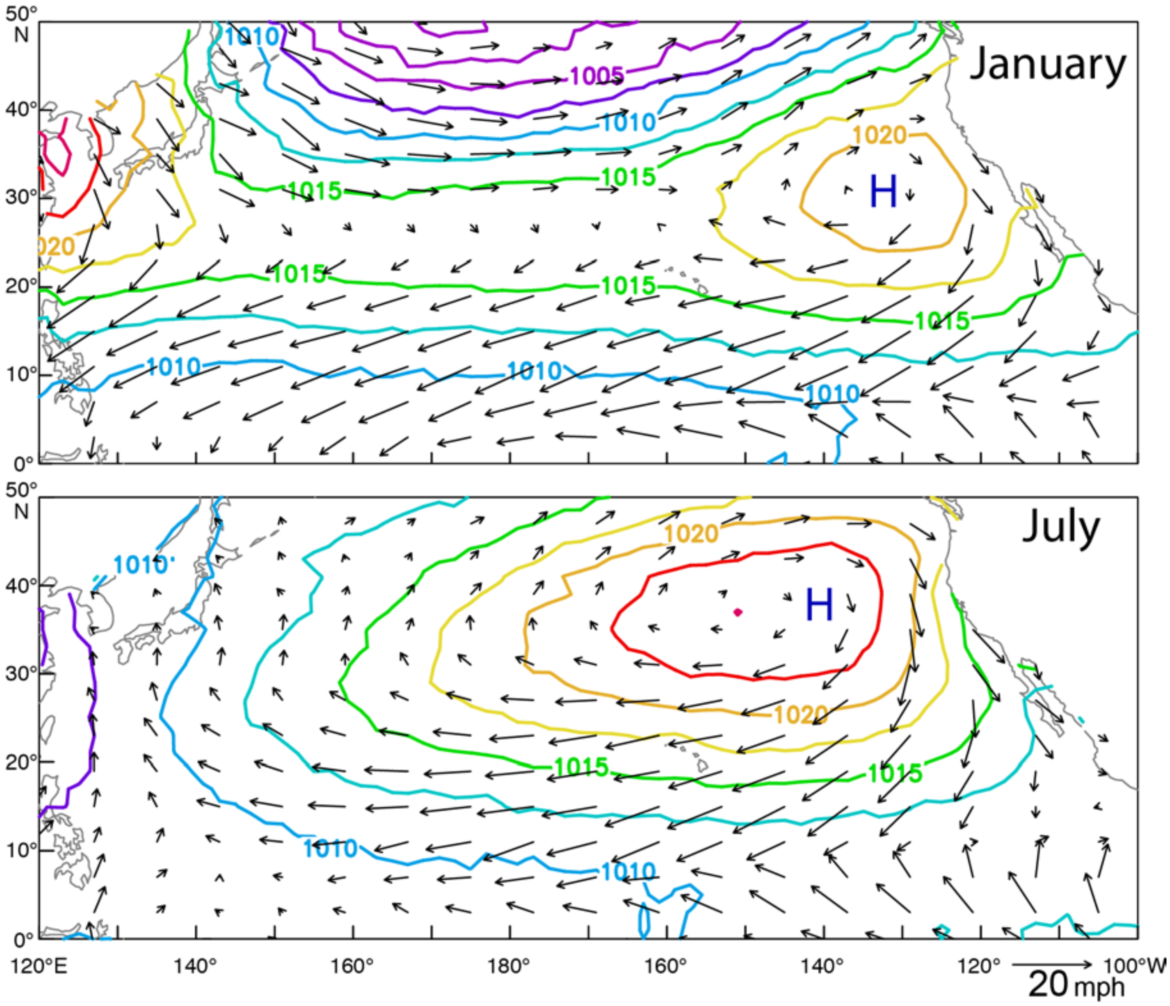

Figure 4 Mean surface winds over the North Pacific Ocean in January (top) and July (bottom). Colored contour are sea-level pressure (mb). Arrows show wind direction and speed (scale given in lower right of figure). Seasonal changes in wind patterns are due to the 23.5 degree tilt of Earth on its axis leading to greater solar input in the northern hemisphere in summer and less in winter.

Monsoon

On the Equatorial side of the Hadley circulation there are lines of converging air (Figs. 1 and 4). These lines over the Pacific Ocean are where the northeast trade winds in the Northern Hemisphere meet the southeast trade winds in the Southern Hemisphere. The position of these lines shifts north (summer) and south (winter) with the sun (Fig. 5). When Polynesian navigators entered the region of the equatorial convergence, they experienced low winds, cloudy weather and persistent tropical rains. When the convergence line passes over India and Southeast Asia, the result is the onset of the summer wet monsoon. Although the monsoon over India and southwest Asia is best known, other regions of the Earth also experience large swings in rainfall on an annual basis. Thus, areas of northern Australia, Africa, and South and Central America also experience large annual changes in the amount of rainfall (Fig. 6).

The monsoon is a large-scale weather phenomenon that occurs most prominently over Asia. The monsoon is characterized by is a reversal in the wind direction from winter to summer (Fig. 6). In the summer the winds blow from ocean to land bringing clouds and rain. In winter dry air flows from the north causing a dry season.

The main cause of the monsoon is unequal heating of the surface that results in a difference between the temperature over the land and over the sea. The temperature difference causes gradients in pressure that in turn create winds. Over the Asian tropical region solar radiation is stronger during the summer months generating strong heating of the landmass. The ocean heats much more slowly, because of its large heat capacity and ocean mixing. The monsoon has a dry phase (in winter) and a wet phase (during summer).

When the land heats during the summer, low pressure is generated over land as warm air rises. Meanwhile the air over the ocean remains at a lower temperature. Cooler air causes higher pressure over the ocean. The pressure difference between ocean and land results in an influx of air from the ocean to the land that is maintained for as long as the solar forcing is strong, i.e., during the summer.

The monsoon starts abruptly once the land heats sufficiently. It generally lasts for several months without stopping, bringing much needed rainfall and moisture towards dry lands. Because the high pressure over the sea weakens gradually at the end of summer, the monsoon fades gradually. Usually people in Asia see monsoons as a blessing for nurturing needed crops. On occasion the rainfall of the Monsoon can be heavy enough that flooding and destruction of crops occurs.

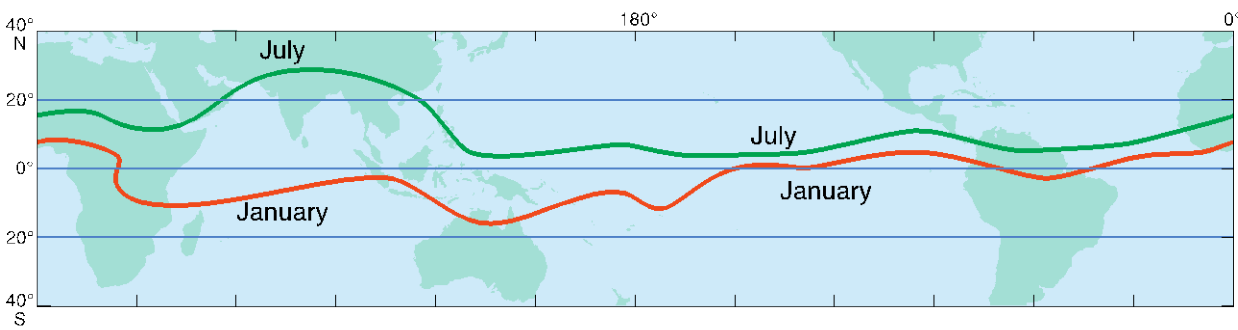

Figure 5 Tropical convergence zones in January and July (green and red lines), where winds collide to produce clouds and rain.

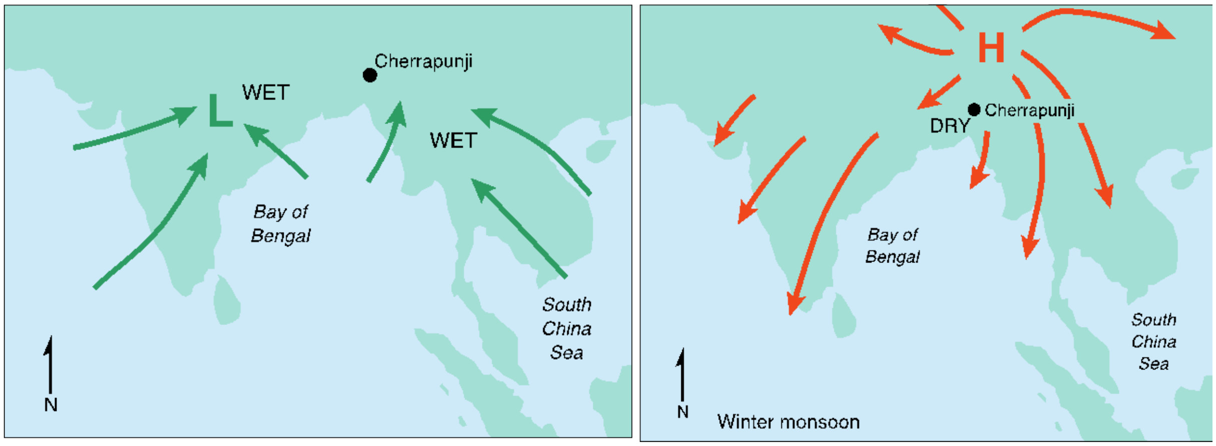

Figure 6 Monsoon winds in summer (left) and dry-season winds in winter (right).

The attached Hawaiian newspaper articles from the 1860s discuss local and global winds and their causes, including monsoons. D. W. Poliwela wrote in 1862, *"Aia ma ka moana Iniana, ua huli ka makani mau a kekahi mau malama mai, e puhi ana mai ke Komohana Hema mai, a kekahi mau malama ua puhi mai ka Hikina Akau mai, ua kapaia ka inoa oia makani o Monesune*. [In the Indian ocean, the regular wind changes for several months and blows from the Southwest, and for several months blows from the Northeast; this wind is called a Monsoon.]" When we consider that such global knowledge appeared in the newspapers less than a century after Western contact (1778) and the development of Hawaiian as a written language, this shows that writers recognized the importance of newspapers for sharing knowledge about an expanding world.

INSTRUCTIONAL ACTIVITIES

Engage:

- How would you say trade winds in Hawaiian?
- Why is a word meaning "diagonal" in many Hawaiian names for trade winds?
- From your experience, how does heated air or smoke move?

Explore: Refer to the diagrams and readings.

- In which Tropic and approximately what latitude are the Hawaiian Islands located?
- On a map of Hawai‘i, draw trade winds as arrows. Why are they the main wind circulation in Hawai‘i?
- Would you expect to see trade wind showers on windward or leeward side of islands? Explain your answer.
- Read Articles 1 & 2, *Na Makani*, The Winds. What causes winds in general? What causes winds over land close to the ocean to change in direction over a 24-hour period?

Explain:

- Why do trade winds blow from the northeast?

- What causes the Hadley Cell and what form of energy does it distribute?
- What is general circulation?
- If you want to measure trade wind speed would you do this on leeward or windward sides? Explain your choice.
- Though India and SE Asia lie in the zone of the Hadley Cell, explain how the land mass of Asia leads to the monsoon.

Elaborate/Extend:

- Explore the importance of winds to Polynesian navigators, to trade and commerce in the 1800s, to people today.
- What would you do if you wanted to investigate the winds throughout the day?
- Articles 1 & 2, *Na Makani*, The Winds describe winds that are thousands of miles from or seldom seen in Hawai'i. What does this suggest about changes in education, economics, travel, and interests of Hawaiians in the 1860s, less than 100 years after western contact?

Evaluate, teacher and students:

- What questions and concepts are difficult to the students?
- Can students explain the relationship between the Hadley Cell and trade winds?
- Can students explain why trade winds blow northeast to southwest?
- Can students explain the importance of the winds to navigation?
- Can students explain the fundamental causes of winds?

VOCABULARY

Coriolis Effect: The main cause of the Coriolis effect is the earth's rotation. As the earth spins in a counter-clockwise direction on its axis anything flying or flowing over a long distance above its surface is deflected. This occurs because the motion of a point on the surface of the Earth changes as a function of latitude as the distance to the axis of rotation changes. (http://geography.about.com/od/physicalgeography/a/coriolis.htm)

Hadley Cell: circulation pattern that dominates the tropical atmosphere between 30 degrees N and 30 degrees S latitude, rising near the equator, flowing poleward at 10–15 kilometers above the surface, descending in the subtropics and flowing equator ward near the surface. This circulation includes trade winds, Equatorial convergence and rain belts, subtropical deserts, and subtropical jet streams.

Latitude: angular distance north or south from the earth's equator measured through 90 degrees

Meteorology: a science that deals with the atmosphere and its phenomena and especially with weather and weather forecasting

Orography: a study of the formation and relief of mountains.

Tropic of Cancer: the parallel of latitude north of the equator that is the northernmost latitude reached by the overhead sun. (http://en.wikipedia.org/wiki/Tropic_of_Cancer)

HANDS ON SCIENCE

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

Winds

Wind is the word we use to describe horizontal movement of air. Whenever we want to speak about vertical movement of air we say updraft, when the air is moving up, and downdraft, when the air is moving down. Wind exerts a force and just like any other force it has intensity and direction. These two quantities describe the wind itself at any given point and time. We use an anemometer to measure wind intensity, and a wind vane to detect which direction the wind is blowing from.

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

1. The **pressure gradient force** originates when two locations have different pressures. Because of the difference, called a gradient, the air is forced to move from high to low pressure and a wind is formed.

2. **Centrifugal force** results when the wind follows a circular path, as it does in a hurricane. It is an apparent force because it only appears after the air is in motion.

3. **Coriolis force** is derived from the movement of the earth around its axis. Because the earth is a rotating sphere, winds that blow across the surface of this sphere move in curved paths. The Coriolis force is an apparent force used to explain these curved paths. The Coriolis force is not visible in motions with small horizontal scales, because the time it takes to move a small distance is small compared to the length of a day.

4. **Gravitational force** is always present in everything on earth. It is a vertical force that points towards the center of the earth.

5. **Frictional force** exists because the surface of the earth presents resistance to the wind. There is a frictional or drag force in the opposite direction of the winds motion.

Now, let’s investigate some of the processes involved in the creation of winds.

Lab 1: Balloon Rocket Experiment: Pressure Gradient Force

You will need:

1. balloon
2. string or fishing line
3. straw
4. clear tape

How to do it:

1. Thread the string through the straw and have one person hold one end while you hold the other.
2. Blow the balloon up, but do not tie it. With the help of your partner, tape the balloon to the straw (Fig. 7).
3. Pull the string tight and move the straw to one end of the string.
4. Let go of the balloon and observe what happens. Record your observations.
5. Repeat the process two more times. Record any additional observations.

Can you answer these questions?

- When the balloon was released what happened to the air inside the balloon? Why did that happen?
- Can you identify the forces that are involved in this process?
- What atmospheric forces are not important here?
- Can you draw a simple vector (arrow) diagram of the forces involved?

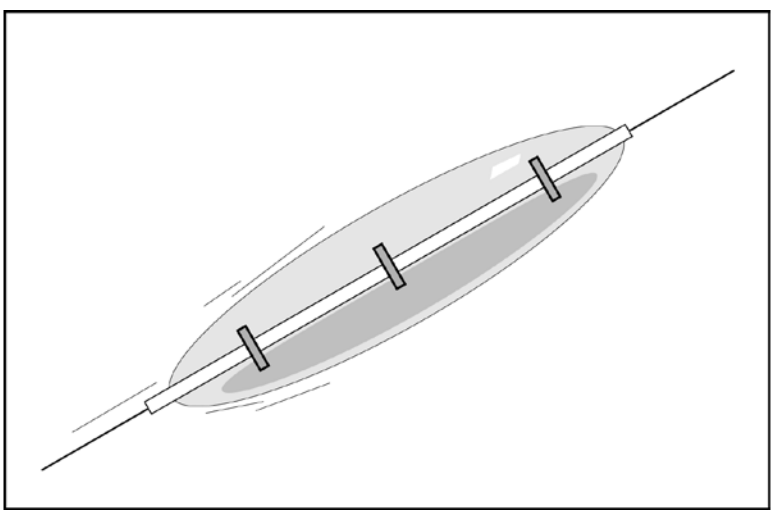

Fig. 7: Schematic diagram

Lab 2: Coriolis Force Caused by Earth's Rotation

The earth is a planet rotating around its own axis. Due to this rotational motion, all objects moving in a linear path are deflected towards the right in the Northern Hemisphere and towards the left in the Southern Hemisphere. This deflection is what we call Coriolis Force. In the next experiment we will see how the Coriolis force effects motion on a sphere.

You will need:

- a globe that rotates
- plastic wrap to cover the northern hemisphere.
- an erasable pen
- towel or sponge

1. With the globe stationary, start near the North Pole, and lightly draw a line moving your hand straight south toward the equator.
2. With the globe stationary, start near the South Pole, and lightly draw a line moving your hand straight north toward the equator.

3. Predict the shape of the lines when the globe is rotating while the lines in steps 5-6 are drawn.
4. Rotate the globe counter clockwise looking down on the North Pole.
5. As the globe rotates, start near the North Pole and lightly draw a line moving your hand straight south toward the Equator.
6. As the globe rotates, start near the South Pole and lightly draw a line moving your hand straight north toward the Equator.

Fig. 8: Schematic diagram of globe

Can you answer these questions?

1. How did your lines differ when the globe was stationary and when it was rotating? Why?

2. Were you able to predict which way the path was going to be deflected?

3. Draw a diagram of the Earth and explain how the Coriolis force affects the direction of winds in the atmosphere.

If you start at the equator and draw a line northward on a rotating globe, the line will curve to the left in the Northern Hemisphere, which is opposite that of the expected Coriolis force. Why is this? The reason is that in the real atmosphere the air is moving with the Earth, so when air parcels travel northward, their eastward momentum causes them to deflect to the right.

Summary of Winds in Hawai‘i

After completing these lessons it should be easier to understand the large-scale wind patterns that affect the Hawaiian Islands and the tropical latitudes in general. The tropics, including Hawai‘i, are dominated by a large-scale wind circulation called the Hadley Cell. The Hadley Cell's rising air near the Equator produces a high-level wind that moves away from the Equator and forms a westerly subtropical jet stream. Depending on the season, the Hadley circulation extends to 30˚ N & S latitude, where the air sinks in regions of subtropical high surface pressure. The return flow towards the Equator near the surface is known as the trade winds. Understanding the surface trade winds was important to people in Hawai‘i, not only for local and open ocean navigators past and present, but also for farmers, fishermen, and the inventors of the sport of surfing.

We hope you have enjoyed this lesson. In our next lesson we will focus on local winds that are influenced by daily heating of our islands and by the mountainous terrain.

READINGS

Article 1. ***Ka Hoku o ka Pakipika*, 1 May 1862.**

Na Makani.

Ke kuhihewa nei kekahi poe o Honolulu nei i ka makani e pa mai nei he ulu moku, oia ka mea i holo wikiwiki mai nei. He kuhihewa ia!

O ka wela no, oia ka mea e holo ai ka makani, aia wela ka makani i ka la, ua mama iho la a pii, hoholo mai ka makani mai na wahi e, na wahi anu mai, a piha ka hakahaka. Ina no ma na aina puni i ka moana ma na wahi wela o ka honua, he mau makani elua i kapaia he makani o uka a me ka makani o kai. I ka po, i ka manawa i anu ai ka aina, hoholo mai ka makani o uka, no ka mea, ua mama ko kai makani. I ka wela ana mai hoi o ka aina i ka la, hoholo mai ka makani o kai, no ka mea, ua pii i ka la.

Ma ke kaei wela, o na wahi malalo iho o ka la kai wela loa; a no ke kaa ana o ka honua mai ke komohana a i ka hikina, holo e ko ka honua, holo e ko ka makani; hahai no ka makani mahope ae o ka la, nolaila, ua mau na makani mai ka hikina mai. Ua kapaia na makani mau ma ka aoao akau o ka poaiwaena, oia ma na Mokupuni o Hawaii nei, e puhi ana na makani mau, mai ka Hikina Akau mai, a ma ka aoao hema o ka poaiwaena, ua puhi na makani mau, mai ka Hikina Hema mai.

Aia ma ka moana Iniana, ua huli ka makani mau a kekahi mau malama mai, e puhi ana mai ke Komohana Hema mai, a kekahi mau malama ua puhi mai ka Hikina Akau mai, ua kapaia ka inoa oia makani o Monesune. He makaui ikaika loa na mumuku, aia no lakou ma na aina wela, ua hina na mea ulu ke pa mai ia makani.

He puahiohio kekahi makani, no ka pa ana mai o na makani kue elua, ka puahiohio, pa mai na makani kue elua, a wili ae la me he poai la e ume i na mea mama a lawe aku i luna, nolaila, e pau na kaao o na ipu makani a Laaomamao. E aloha pua oliana auanei, ke hoi nei au i ka lai o Lawelawela.

D. W. Poliwela.

Lawelawela, Makiki, Oahu, Aper. 12, 1862.

Article 1 Translation:

The Winds

Some people here in Honolulu mistakenly think that the wind currently blowing is generated by the island, which makes it speed along. That is a misconception!

Heat is the thing that causes the wind to flow. When the wind is heated by the sun, it becomes lighter and rises, so wind comes from other places, the cold places, and fills the gap. If a land is surrounded by water in the warm parts of world, then it has two winds, called the upland wind and the sea wind. At night, when the land cools, the upland wind blows, because the sea wind has become lighter. When the land is warmed by the sun, the sea wind blows, because the upland wind has risen due to the sun.

In the torrid zone, the places right below the sun, it is quite hot; and because the earth spins from west to east, the land goes one way and the wind goes another way. The wind follows after the sun, so the winds are regularly from the east. The regular winds in the Northern Hemisphere, such as those in the Hawaiian Islands, blow from the Northeast, and in the Southern Hemisphere the regular winds blow from the Southeast.

In the Indian ocean, the regular wind changes for several months and blows from the Southwest, and for several months blows from the Northeast; this wind is called a Monsoon. The Mumuku winds are extremely strong, and they are found in warm places; plants fall over if this wind blows.

A whirlwind is another wind. When two opposing winds blow, a whirlwind is formed. The two opposing winds blow and intertwine together like a circle, pulling light things and taking them upwards. So the tales of the wind gourd of Laʻamaomao should draw to a close. We shall meet again in the oleander flowers, I now return to the calm of Lawelawela.

D. W. POLIWELA.
Lawelawela, Makiki, Oʻahu, Apr. 12, 1862.

Article 2. ***Ke Au Okoa,*** **7 May 1866.**

Na Makani.

O ka la wela no, ka mea e holo ai ka makani. Aia a wela ka makani i ka la, ua mamama iho la a pii; hoohola mai la ka makani mai na wahi e, mai na wahi anu mai, a piha ka hakahaka oia wahi. I na no ma na aina i puni i ka moana, na wahi wela o ka honua, he mau makani elua ua kapaia he makani o uka, a me ka makani o kai. I ka po i ka manawa i anu ai ka aina, hoholo mai la ka makani o uka, no ka mea, ua mama ko kai makani. I ka manawa e wela ai ka aina i ka la, hoholo mai ka makani o kai, no ka mea, ua mama ko uka makani. O na wahi malalo iho o ka la, kai wela loa; a no ke kaa ana o ka honua mai ke komohana a i ka hikina; holo e ko ka makani, hahai no ka makani mahope ae o ka la. Nolaila, ua mau na makani mai ka hikina mai, ua kapaia he makani mau.

Ma ka aoao akau o ka poaiwaena, e puhi ana na makani mau, mai ka hikina akau mai a ma ka aoao hema o ka poaiwaena, ua puhi na makani mau, mai ka hikina hema mai. Aia ma ka moana Iniana, ua huli ka makani mau, a i kekahi mau malama, e puhi ana mai ke komohana hema mai, i kekahi mau malama ua puhi mai ka hikina akau mai.

Ua kapaia ia makani he monesune. He mumuku kekahi makani ikaika loa. Aia no ka nui o lakou ma na aina wela, ua hina na mea e ulu ana ke pa mai ia makani. Ua hina na laau nui, na hale a me na moku, ua pau lakou i ka hookahuli ia.

O ka puahiohio kekahi makani. No ka pa ana mai o na makani kue elua, ka puahiohio. Pa mai na makani elua, a lauwili ae me he poai la e ume ana i na mea mama, a lawe aku ia lakou i luna. Ma na waoakua o Aferika ua ume no na puahiohio i ke one, me he kia la a make koke no na mea ola hanu ke pa mai ia makani. O na puahiohio ma ka moana, ua ume aku i ka wai iluna, ua kapaia he waipuilani.

Ina ka makani wela ma na waoakua o Aferika a me Arabia. Ua kapaia o Samuela; ua make koke ka mea nona ka hanu ana. I ka pa ana mai oia makani, eia ka pakele, e hina koke ma ka lepo paa na lima i ka ihu a me ka waha, a hala aku ua makani la, alaila, loaa ke ola.

Ma ka aoao hema o Europa, ka makani wela i kekahi manawa mai Aferika mai no. O Siroko ka inoa oia makani, he mai, a he nawaliwali koke kanaka ke pa mai ia makani he Siroko.

Ke oki nei au maanei, ke pau nei au maanei, ke halii mai la ka ohu iluna o Lihau. Me ka Lunahooponopono ke aloha.

D. A. K. ALOHIKEANU.

Article 2 Translation:

The Winds

The heat of the sun is what causes wind to blow. Once wind is heated by the sun, it becomes light and rises, and then winds blow from other places, cold places, to fill the empty space at this place. On lands encircled by the sea, in the hot places of the earth, there are two winds called the shore wind and the sea wind. At night, when the land cools, the shore wind blows, because the sea wind has become light. When the land is heated by the sun, the sea wind blows, because the shore wind has become light. The places right below the sun are the warmest; and because the earth rotates from west to east, wind blows the other way, so that the wind follows the sun. Therefore, the regular winds come from the east, and are called trade winds.

In the northern hemisphere, the trade winds blow from the northeast, and in the southern hemisphere, the trade winds blow from the southeast. In the Indian Ocean the regular wind changes. For several months, it blows from the southwest, and in other months it blows from the northeast.

This wind is called a monsoon. The Mumuku is another extremely strong wind. The majority of them are in the hot places, where plants fall over when the wind blows. Large trees, buildings and ships tumble, all overturned.

The whirlwind is another wind. A whirlwind is caused by two winds blowing in opposition. The two winds blow and twist together like a circle, pulling light things and carrying them up. In the deserts of Africa the whirlwinds pull up sand, becoming like a pillar, and living, breathing things immediately die if struck by this wind. Whirlwinds over the ocean pull up water, and are called waterspouts.

The hot wind in the deserts of Africa and Arabia is terrible. It is called Samuel, and the one who breathes it in immediately dies. When this wind blows, to escape it one must quickly fall to the ground, covering the nose and mouth with the hands until that wind passes, and thus one is saved.

In the southern part of Europe, there is a hot wind that sometimes comes from Africa. Siroko is the name of this wind, and people soon become ill and weak when this Siroko wind blows.

I finish here, I am done here, and the mist is spreading atop Līhau. My greetings to the Editor.

D. A. K. ALOIKEANU.

Forces, Wind, and Weather Maps (Advanced, Optional, Answer Key Follows)

Motion in the atmosphere is governed by forces, as it was mentioned before. Now how do meteorologists see those in a weather map? This an advanced exercise.

1. Suppose the air at **X** is initially at rest and then a pressure field--L is low and H is high, is introduced causing the air to move. Draw an arrow showing the direction that the air will move (if no other forces are acting on it).

L **(AIR) X** **H**

2. In Fig. 9, 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. In the absence of friction the wind blows parallel to the pressure lines.

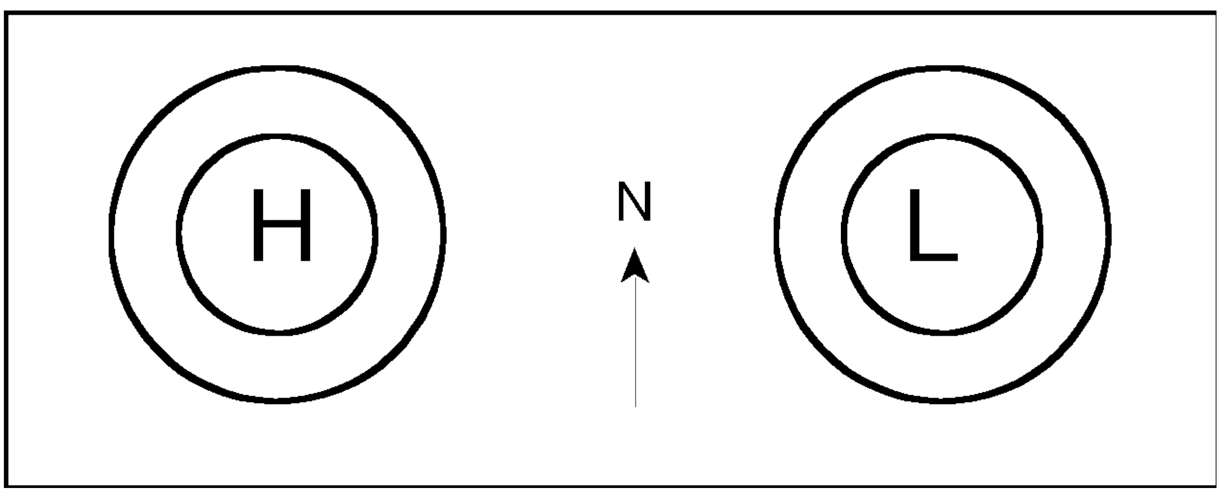

Fig. 9: Schematic diagram

3. a. On Fig. 10, 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 the relative wind strength. In the absence of friction the wind blows parallel to the pressure lines.
   b. Are the winds stronger at point A or point C? Explain.
   c. Sketch a thin dashed 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.

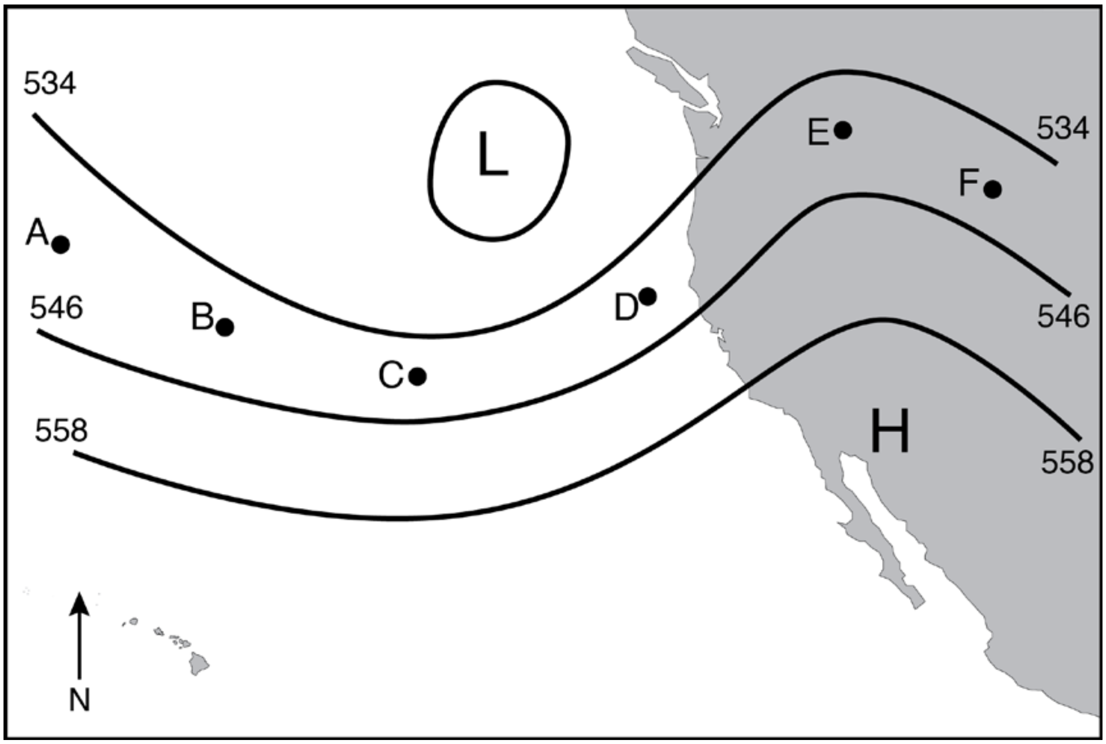

Fig. 10: Map showing contours of constant height (tens of meters) above sea level of the 500-mb pressure surface.

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. 11 below 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.

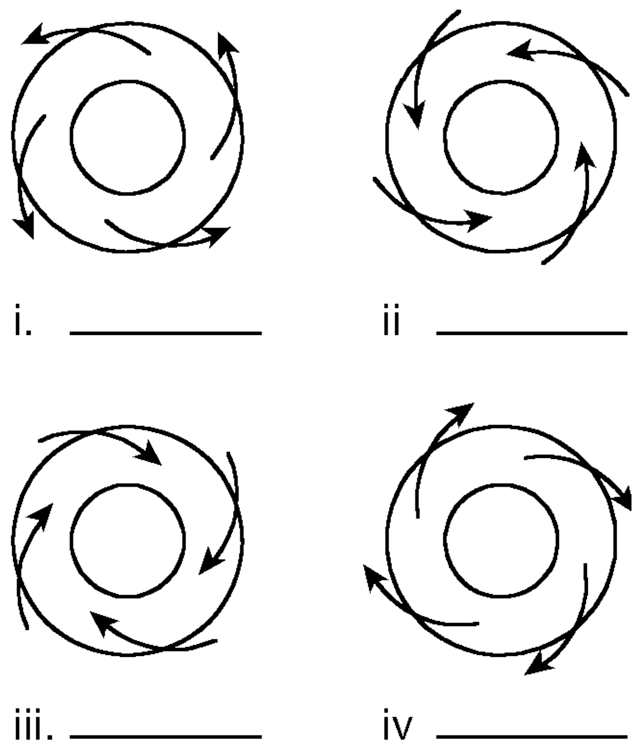

Fig. 11: Schematic diagram

6. a. Friction induces horizontal motion into a surface low and out of a surface high pressure center (e.g., Fig. 11). 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. 11 above will be rising or sinking.

7. On Fig. 6 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. Be sure to include the effect of friction in you analysis.

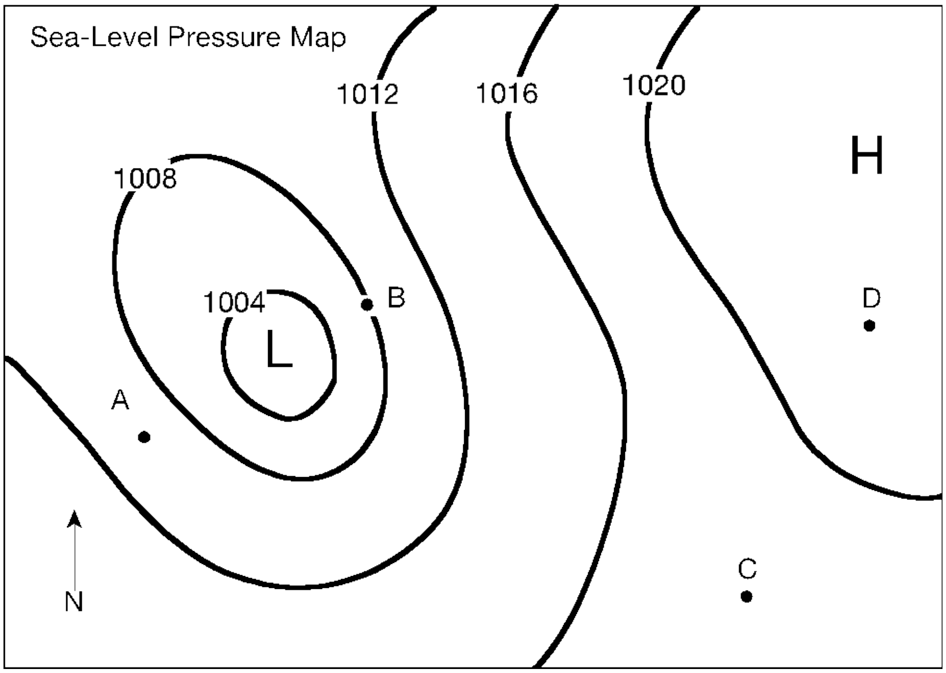

Fig. 12: Sea-level pressure map showing isobars (mb).

Can you answer these questions?

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?

h. How important is friction in the motion of the air?

i. How can you expect friction to act on the wind at a certain place?

LESSON 1 – TRADE WINDS TEACHER KEY

1. What happened to the air in the balloon when the balloon was released? Why?

A In the absence of other balancing forces air flows from areas of high pressure to areas of low pressure. The elastic walls of the balloon exert a pressure on the air in the balloon forcing it out through the balloon's opening. The difference in pressure of the air inside and outside the balloon results in a pressure gradient force. Ultimately it is this pressure gradient force that causes the air inside the balloon to move, and thus propel the balloon.

2. In your trials, what force(s) caused your balloon to slow or stop?

A If the string is held approximately horizontal, friction between the string and the straw and between the sides of the balloon and the outside air causes the balloon to slow. As the balloon deflates, the pressure gradient force (difference in pressure inside and outside the balloon) decreases and eventually friction causes the balloon to stop.

3. What forces that are generally important for winds in the atmosphere are not important here?

A For large scale motions in the atmosphere the rotation of the Earth results in a perceived deflection of the wind direction for an Earth-bound observer. This deflection is attributed to a fictitious force called the Coriolis Force. Because the scale of this experiment is so small compared to the size of the Earth, the Coriolis Force does not come into play here. In rotating storms (hurricanes or tornadoes) centrifugal force becomes important for the winds. Since the string is held relatively straight here (little or no curvature), centrifugal force can also be neglected. Gravity may play a small role in this experiment if the angle of the string is not held horizontal.

Coriolis Effect:

1. Describe the path of the ink lines in the case of no rotation.
   A The line follows parallel to a longitude line running north-south.

2. How did you do in your prediction of the line shapes given a rotating globe?
   A Most students will intuit that the line will become curved.

3. How does the direction of travel of the pen, north vs. south, affect the resulting line shape?
   A The Coriolis force is larger at higher latitude so the tendency for curvature is greater at higher latitude.

4. Compare the shape of the lines in Steps 7 and 8. What is the difference?
   A On the Equator the line should remain straight, reflecting the lack of Coriolis force. At 45˚ latitude the line should drop to the south of 45˚ as the globe spins away.

5. How does the change in the direction of rotation affect the resulting shape of the lines?

A The curvature reverses.

6. When you turn the demonstrator in a counterclockwise direction, which hemisphere is it representing? And if you turn it clockwise, which hemisphere is represented?
   A When you turn the demonstrator in a (counter) clockwise direction it represents the (Southern) Northern Hemisphere.

7. Can you formulate your observations into a set of general rules describing the impact of rotation on the path of air parcels in the free atmosphere?
   A An air parcel moving in the free atmosphere is deflected to the right (left) of its path in the Northern (Southern) Hemisphere as a result of the rotation of the Earth beneath the air parcel. This curvature in the parcel's path relative to an observer fixed to the Earth is explained by invoking a fictitious or apparent Coriolis Force.

For Alternative Coriolis Demonstrator

Questions:

1. Describe the path of the ball bearing in the case of no rotation.
   A The ball bearing will travel across the plate in a straight line.

2. Rotate or spin the plate in a counterclockwise direction and roll the ball bearing across it. Describe the ball bearing's motion.
   A The ball bearing will trace a constant curve across the plate in a clockwise direction.

3. Predict the motion of the ball bearing if the plate was rotated in a clockwise direction.
   A The track of the ball will curve counterclockwise.

4. Rotate the demonstrator in a clockwise direction. How does your prediction compare with what happened?
   A By making a careful observation in (2) and applying some intuition, your prediction should match your observation.

5. The center of the plate represents the poles of the Earth. Predict what would happen if you released the ball bearing from the center of the plate when it was rotating clockwise. Predict what would happen if you released the ball bearing from the center of the board when it was rotating counterclockwise.
   A Your predictions should be consistent with (2) - (4) above.

6. Release the ball bearing from the center of the plate when it is rotating clockwise. What happened?
   A The plate (Earth) rotates underneath the ball bearing (wind) which is actually traveling in a straight path according to Newton's 1st law of motion. However, the resulting track on the plate is curved in a counterclockwise direction.

7. Release the ball bearing from the center of the plate when it is rotating counterclockwise. What happened?
   A See (6) above. The resulting track on the plate is curved in a clockwise direction.

8. When you turn the demonstrator in a counterclockwise direction, which hemisphere is it representing? And if you turn it clockwise, which hemisphere is represented?
   A When you turn the demonstrator in a (counter) clockwise direction it represents the (Southern) Northern Hemisphere.

Resources:

1. Aloikeanu, D. A. K. (1866). "*Na Makani*." *Ke Au Okoa*, 7 May.
2. Businger, S. (2007). *Eye to the Sky: Exploring Our Atmosphere*. Ojai, CA: Novus Publishing.
3. Hadley Cell, http://en.wikipedia.org/wiki/Hadley_cell.
4. Kailiehu, L. S. (1865). "*Na inoa o na makani o Hana*." *Ke Au Okoa*, 12 June.
5. *Nā Honua Mauli Ola, Hawai'i Guidelines for Culturally Healthy and Responsive Learning Environments* (2002). Developed by the Native Hawaiian Education Council in partnership with *Ka Haka 'Ula O Ke'elikölani* College of Hawaiian Language, UH-Hilo.
6. National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, http://www.nap.edu/catalog.php?record_id=13165
7. Poliwela, D. W. (1862). "*Na Makani*" *Ka Hoku o ka Pakipika*, 1 May.

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