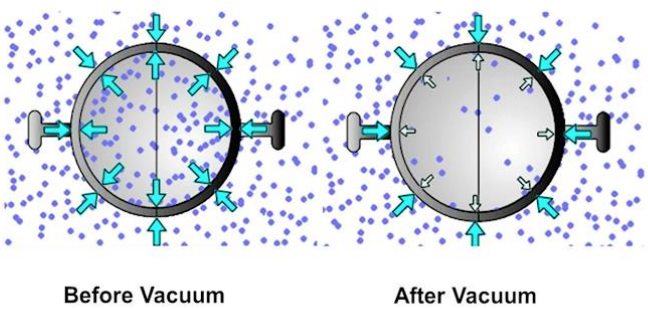
Pressure Learning Module



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Earth's atmosphere constantly seeks to achieve equilibrium. Contrasting temperatures and pressure differences cause imbalances in the earth's atmosphere and lead to the weather we see all around us. In this learning module, you will discover how air pressure varies in the atmosphere and why the wind blows. As you dig into this topic, pay close attention to how pressure differences are related to wind speed and direction. A little history first – check out this video!

Pressure in Earth's Atmosphere (7:00)

Video Lecture Notes [1]

- Air has mass.
- Before removing the air out of the Magdeburg sphere, the pressures inside and outside of the sphere were equal. By removing air, and therefore mass, inside the sphere, the pressure inside to decreased and created a pressure gradient from the inside to the outside of the spheres.
- The cloud in a bottle demonstration showed us how we can relate air pressure changes and pressure gradients to the weather by creating an area of low pressure inside the bottle that allows water vapor to condense into cloud droplets.

Defining Air Pressure

In this video lecture, we will define air pressure. Pay close attention to the units of air pressure used by meteorologists and also the normal range of sea-level pressure observed on Earth.

Defining Air Pressure (6:49)

Created by Tyra Brown, Nicole Riemer, Eric Snodgrass and Anna Ortiz at the University of Illinois at Urbana-Champaign. 2015-2016. Supported by the National Science Foundation CAREER Grant #1254428.
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Pressure

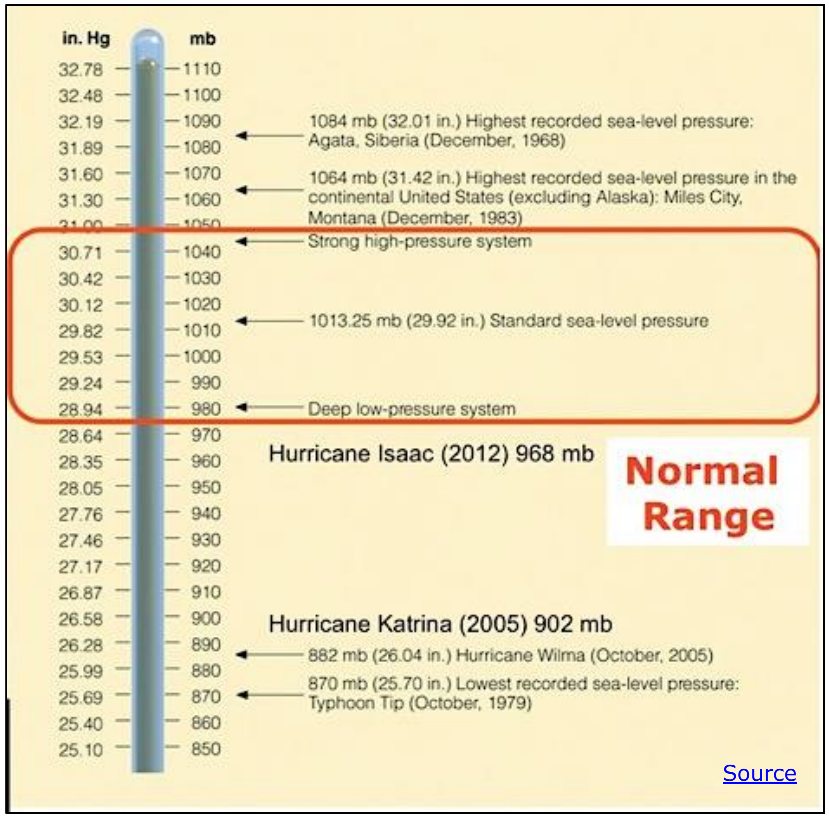
Definition:

Force per unit area applied by the air

→ equivalent to…

Weight of the air in a column over an area (like a square inch).

Unit = millibar (mb)



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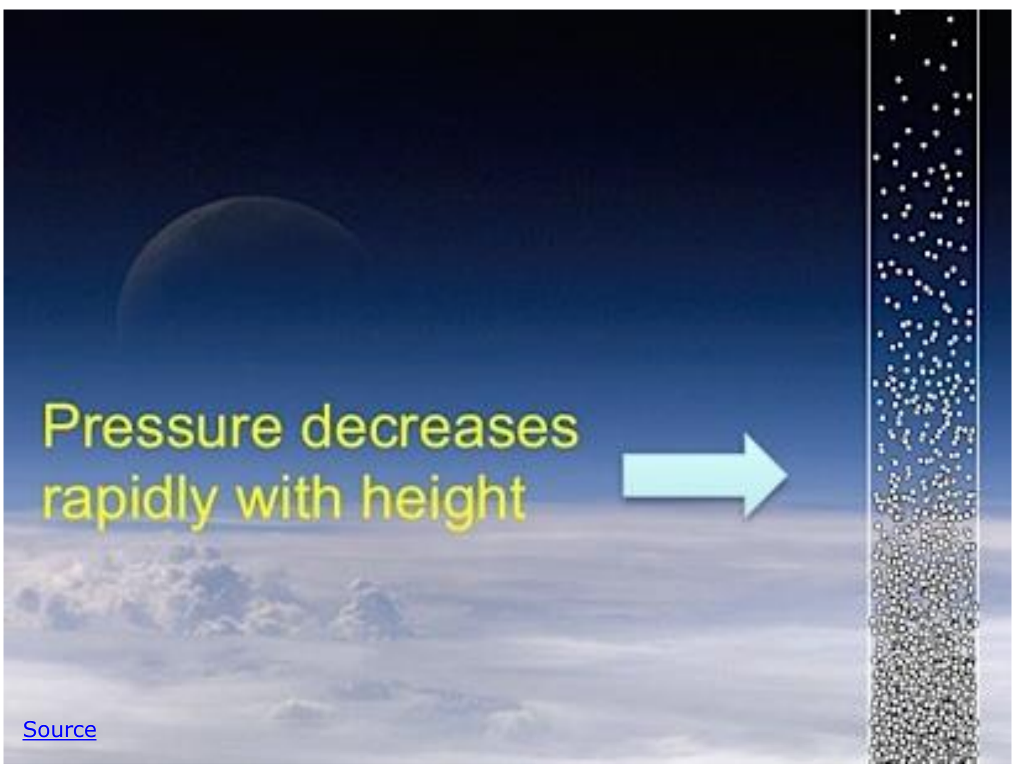
Typical values:
Avg. Sea Level Pressure =
1013.25 mb = 14.7 lbs/in^2 = 29.92 in Hg

High Sfc pressure = 1045 mb
Low Sfc pressure = 980 mb



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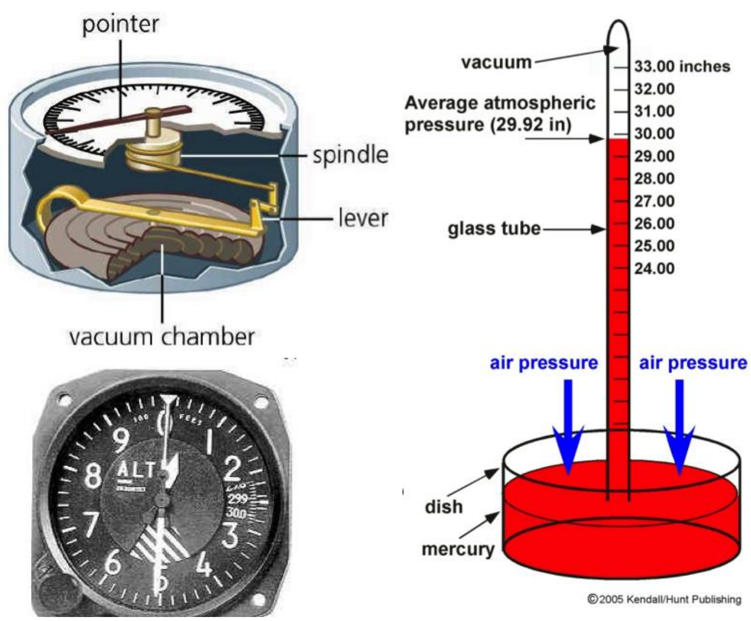
Video Lecture Notes [1]

- **Air pressure** is defined as the force per area applied by the air.
- The unit we will use in the class to measure air pressure is the **millibar (mb)**.
- Standard sea level pressure is 1013.25 mb and the range of pressure typically experienced at sea-level is 980 mb - 1045 mb.
- The lowest observed air pressure at sea-level was in Super Typhoon Tip (1979), which recorded 870 mb!

Measuring Air Pressure

Did you know that the deepest a well can be without installing a submersible water pump is only about 35 feet? It is true! If you are trying to suck water up a tube from the bottom of a well, under standard atmosphere pressure the water can only be sucked up about 35 feet. Any well that is deeper than this requires a submersible pump to push the water up and out of the well. To understand how this works, let's learn how meteorologists measure air pressure. Check out the video below to learn about the barometer and how pressure is related to weather!

Measuring Air Pressure (9:40)



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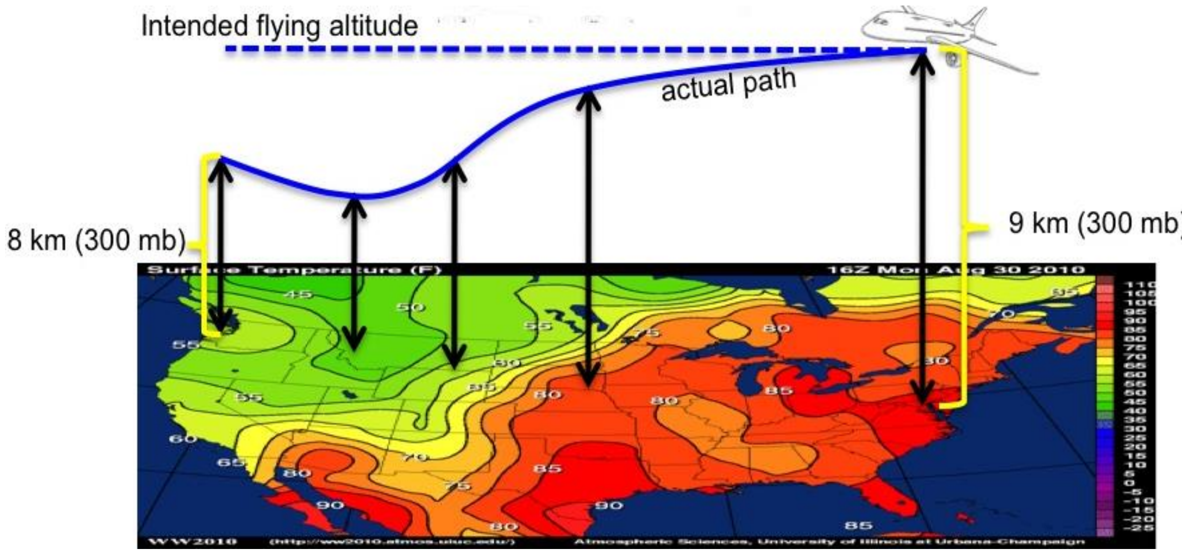

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Video Lecture Notes [1]

- The device that measures air pressure is called the **barometer**.
- Clear skies, light winds, and fair weather are associated with high surface air pressure systems.
- Cloudy, rainy/snowy and generally inclement weather is associated with surface low air pressure systems.
- On a map of sea-level pressure, isobars are lines of constant pressure. Most maps contour isobars in a 4-mb increment.

Extreme Air Pressure Event in 2010

One of the lowest measured air pressure readings in the United States occurred on October 26, 2010. A large low-pressure system formed across the Great Plains and matured over parts of Minnesota, North Dakota, and Wisconsin. At its strongest, the pressure fell to 955 mb, approximately 30 mb lower than a typical strong low-pressure system. Below is a satellite image of the clouds as they swirled around this intense low-pressure system. Under this image is a mean sea-level pressure map contoured with isobars. Notice how the clouds wrap around the low-pressure center. When this image was taken, many of the states in the north central part of the United States experienced sustained winds at 50–80 mph!

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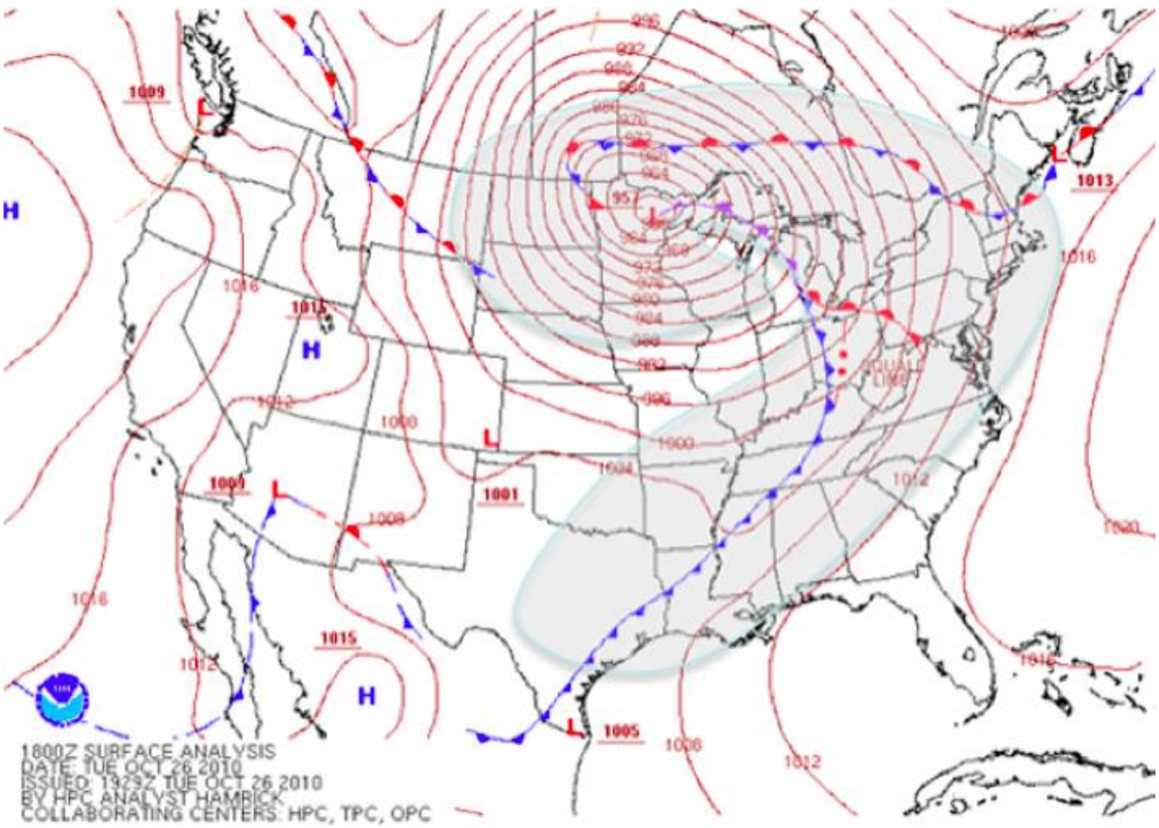
Satellite image of the low-pressure system.
Source



Surface air pressure map where red lines are isobars (constant lines of sea level pressure).
Source

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Here is a link to a video that shows a satellite animation of the clouds as they spiral around the extreme low-pressure system.

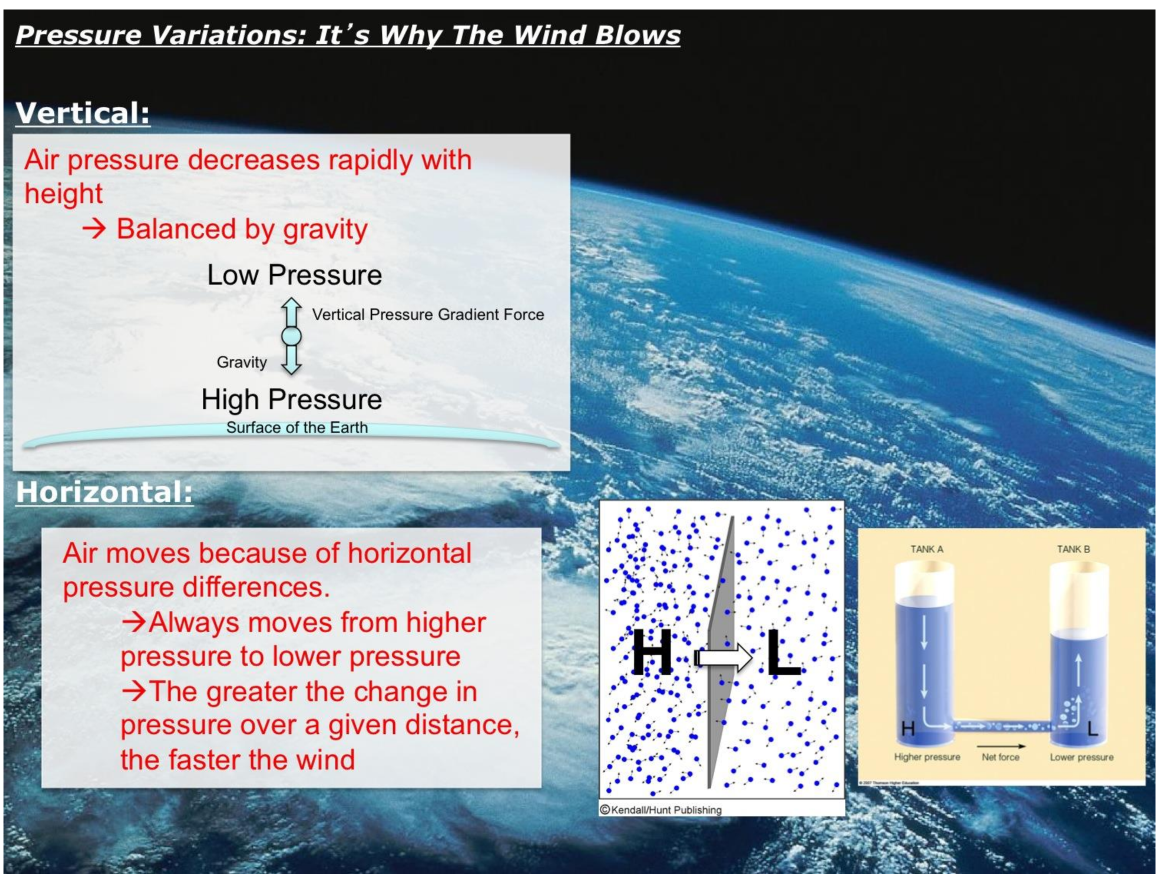
Satellite Animation of Extreme Low Pressure System (0:13)

Extreme Air Pressure Event in 2010

In these last two video lectures on air pressure, we will explore the concept of a pressure gradient. We will also answer the question, "Why does the wind blow?" As you watch these videos, take note of how the pressure changes in the vertical and horizontal directions.

Vertical & Horizontal Pressure Gradients 1 (7:32)

Vertical & Horizontal Pressure Gradients 2 (4:00)



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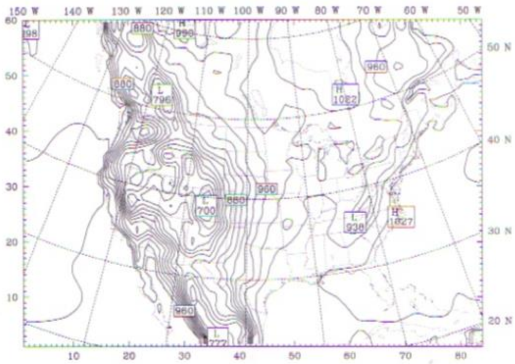
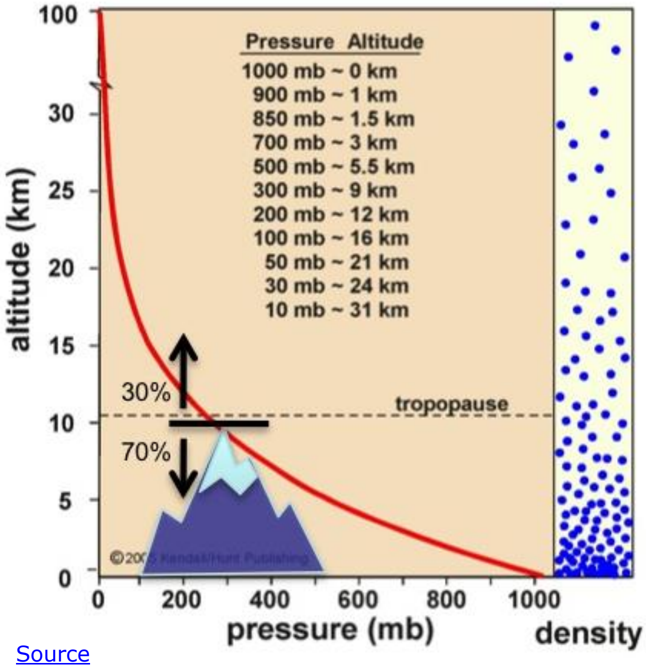
Vertical Pressure Variations



Key Point:
To find the wind speed and direction, we must compare the pressure at a constant altitude.



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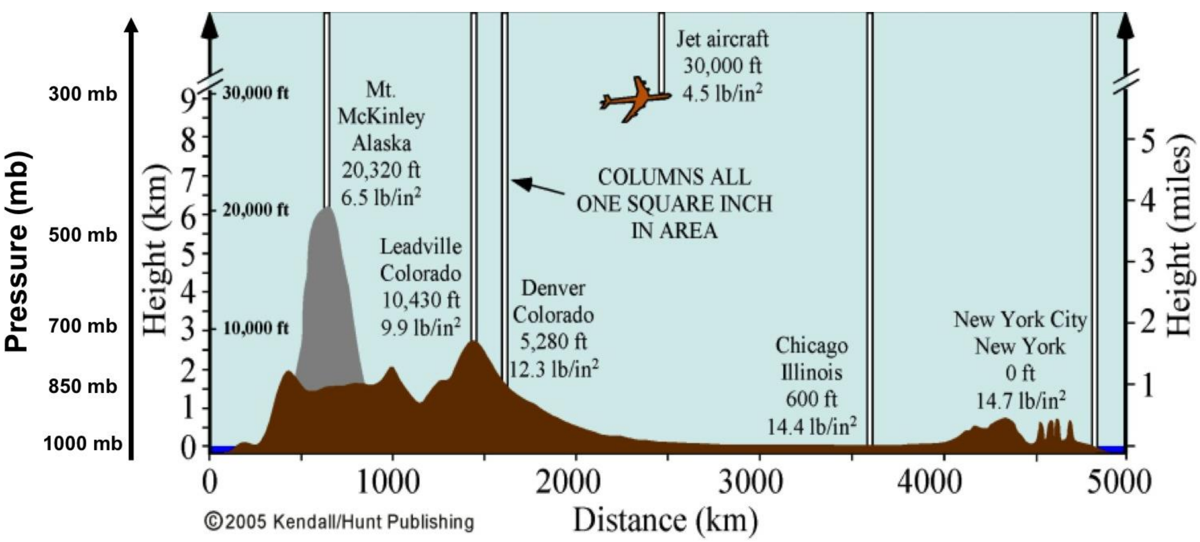

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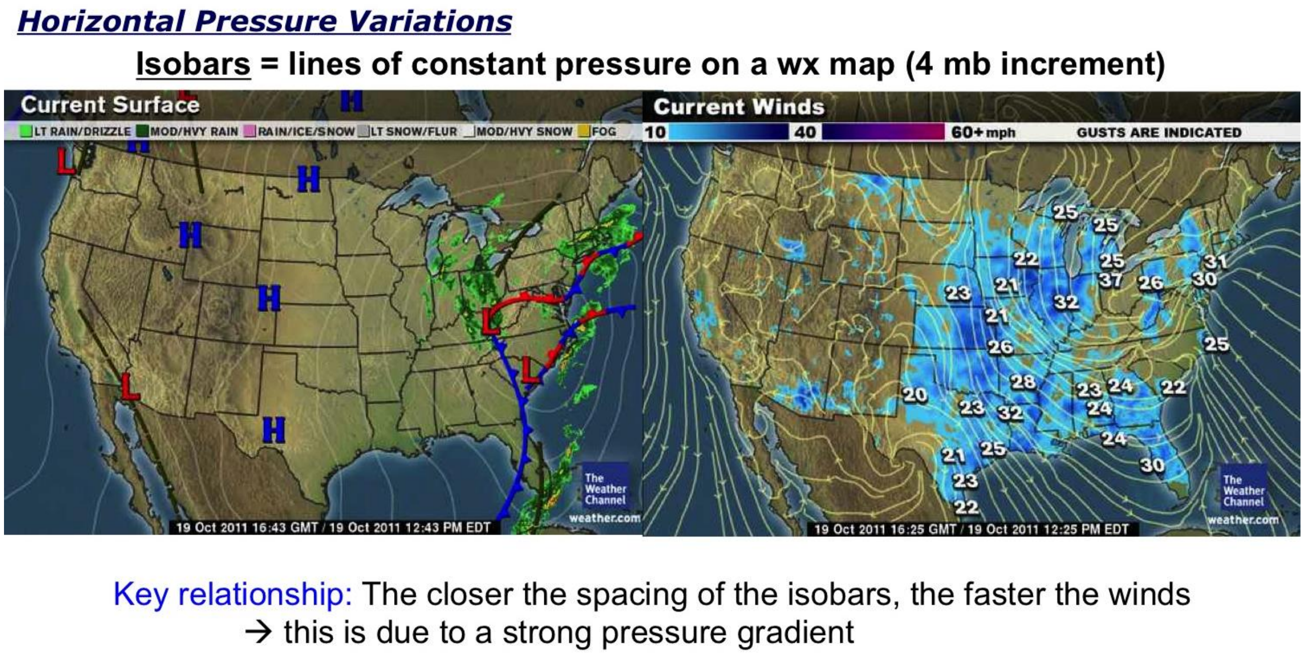

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Video Lecture Notes [3]

- **Isobars** are lines of constant pressure on a weather map.
- A **pressure gradient** is a change in pressure over a distance.

Vertical Pressure Gradients

- There is a very strong vertical air pressure gradient because air pressure and air density decrease rapidly with height.
- The highest air pressure at any given location will be found closest to the ground and the pressure will fall rapidly with height above that point.
- The measured air pressure in Denver, CO will always be lower than the measured air pressure in Chicago, IL because Denver is at a higher altitude.

- The resulting **pressure gradient force** is trying to cause the air to escape to space.
- Gravity balances the vertical pressure gradient force and holds the air on the surface of the earth.
- Due to this balance, air resists vertical motion. But if we could magically turn off gravity, the air would rush to space at hundreds of miles per hour.

Horizontal Pressure Gradients

- Horizontal pressure differences cause the wind to blow.
- Air will always move from higher pressure regions to lower pressure regions.
- The speed of the wind is determined by how strong the pressure gradient is in a particular location.

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Weather Maps

On a surface weather map, isobars are lines of constant air pressure that are drawn in 4-mb increments. The closer these isobars are together, the stronger the pressure gradient and the faster the winds.

For a quick look at the current surface weather map and surface winds map, check out the links below. When you look at these maps, be sure to draw the connection between the spacing of the isobars and wind speed.

[Surface Weather Maps]

Air Pressure's Impact on Human Life

As the air pressure changes, the human body can react in many ways. The most common first response is your ears popping, but you may not know about these other physiological responses.

Fun Facts

- Blood pressure changes as air pressure changes.
- Many people suffer from *altitude sickness* when the air pressure drops below about 800 mb.
- Water will boil at lower and lower temperatures as you ascend in elevation due to the decreased air pressure. This is why people living at high altitude often pressure-cook their food to ensure it reaches the desired temperature.
- If you are an athlete, you should always train at high altitude, like the 2012 U.S. Olympic Team did by training in Colorado Springs, CO. At high altitude, your body will adjust to lower oxygen levels so that when you compete at lower altitudes, you have greater strength and stamina.
- If you travel from a high altitude place to a low altitude, be sure to pack your shampoo bottles in plastic bags as they may pop open!
- Automobiles run differently at high altitude because the air density is lower. They therefore must adjust their air fuel mixture to compensate for the lower air pressure. This also means that cars at high altitude make less power.

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Pre-Class Activity

Instructions: Before teaching about atmospheric pressure, have the students answer the questions below, followed by the scenario question for in-class discussion between you and your students. If time permits, try a live demonstration of the cloud in a bottle experiment! [1]

1. What causes the wind to blow?
   a. Variations in the amount of moisture in the air
   b. Variations in air pressure
   c. Variations in gravity
   d. Variations in terrain

2. Why do your ears pop when you change elevation?
   a. Your body is adjusting to colder temperatures at higher elevations
   b. Your body is adjusting to decreasing air pressure at higher elevations
   c. Your body has more force applied to it at higher elevations

3. What causes the weather?
   a. Changes in the amount of water vapor in the atmosphere
   b. Uneven heating of Earth that cause pressure differences across the globe
   c. The ozone layer and how much heat is trapped in the atmosphere
   d. The amount of carbon dioxide in the atmosphere
   e. Doing the rain dance

Take a guess at the fastest wind speed ever measured on Earth (not in a tornado or hurricane).

Discussion Question: A climber reaches the top of Mount Everest. Why do you think it becomes more difficult for the climber to breath (aside from performing strenuous exercise)?

Cloud in a Bottle Demonstration Instructions [4]

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In-Class Activity

Part 1. Multiple Choice (Circle one) [2]

1. Pressure is defined as
    a. the force per volume applied by the air.
    b. the total number of air molecules.
    c. the force per area applied by the air.
    d. none of the above

2. Which of the following represents standard sea-level pressure?
    a. 999.9 mb
    b. 1010.33 mb
    c. 1013.25 mb
    d. 100.45 mb
    e. None of the above

3. If a large hurricane were approaching your area, how would you expect the readings on the barometer to change as the hurricane approached you?
    a. Pressure would increase
    b. Pressure would decrease
    c. Pressure would stay the same

4. How does air pressure change vertically?
    a. Pressure decreases rapidly with height
    b. Pressure increases rapidly with height
    c. Pressure only changes slightly with height
    d. Pressure does not change in the vertical, only the horizontal direction

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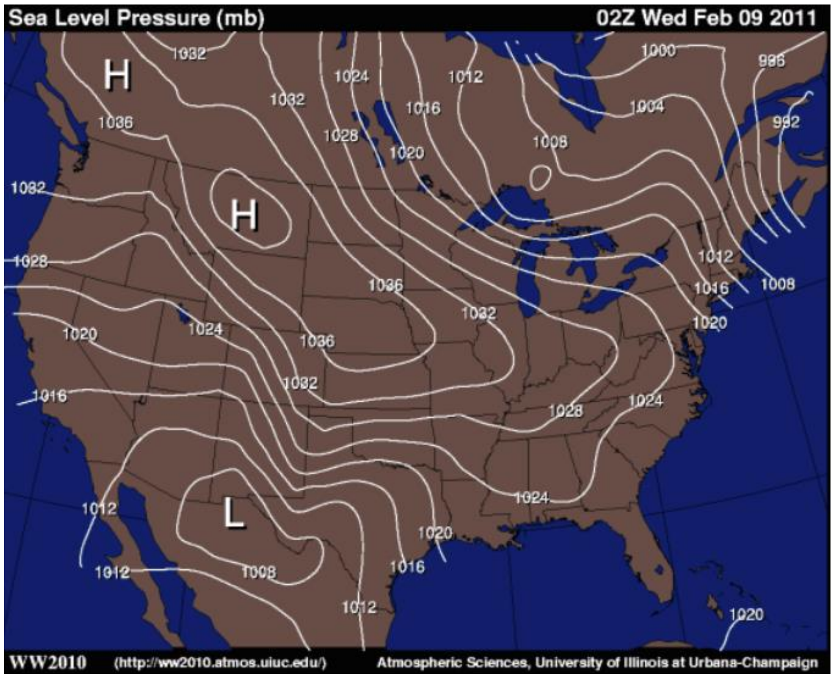
5. Examine the sea-level pressure map below (white lines are isobars). Within which state would you expect the fastest winds given the behavior of the isobars on this map? [1]



a. Georgia
b. Montana
c. Illinois
d. New Mexico
e. None of the above because you cannot infer the wind speed given the horizontal pressure gradient shown on this map.

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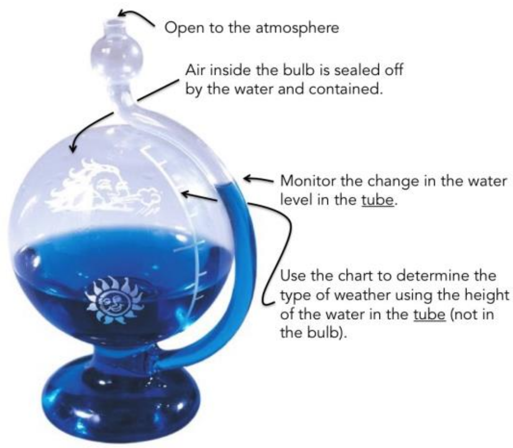
Part 2. Short Answer [1]

Instructions: Use what you have learned about measuring atmospheric pressure and the figure below to answer the following questions in 1-2 sentences.



1. What will happen to the water level in the tube above if the atmospheric pressure increases?

2. Given the following scenario, how would you expect the weather to change from Monday to Tuesday?

   Monday: Water level is very low in the tube
   Tuesday: Water level is near the top of the tube

3. If you were to go hiking and you took this barometer above with you, how would the level of the water in the tube change as you climbed a mountain? Explain why.

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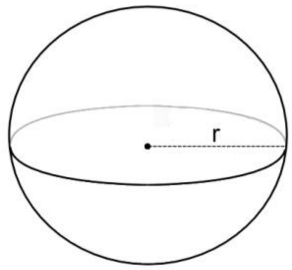
Part 3. Calculation 5

Instructions: Calculate the force needed to pull apart a Magdeburg sphere that has a diameter d = 2 feet if 90% of the air is removed from inside the sphere. Assume the original pressure, before any air is removed, is standard sea-level pressure.



Step 1: Convert the diameter of the sphere to inches.

Step 2: Calculate the radius of the sphere in inches (***r* = ½ *d***).

Diameter, d	in
Radius, r	in

Step 3: Calculate the cross sectional area (in^2) using the following equation:

Cross Sectional Area, $A_{cs} = \pi r^2$ where $\pi = 3.14$

Area, A_{cs}	in^2

Recall, air pressure is defined as the force per area applied by the air. Using this definition and standard sea-level pressure *SLP*, calculate the force needed to pull the Magdeburg sphere apart.

Step 4: Using the following conversions of sea-level pressure, calculate the pressure inside (90% removed, 10% remaining) and outside (100%) of the Magdeburg sphere.

$$SLP = 1 \text{ atm} = 1013.25 \text{ mb} = 14.7 \text{ lbs./in}^2$$

Pressure Inside, P_I	lbs/in^2
Pressure Outside, P_O	lbs/in^2

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Step 5: Now that we know the pressure inside and outside of the sphere, use the pressure values from Step 4 to calculate force, *F* (lbs.) inside and outside using the definition for pressure. Make sure your units make sense!

$$\textbf{Pressure = Force/A}_{\textbf{cs}}$$

Force Inside, F_I	lbs.
Force Outside, F_O	lbs.

Step 6: Take the difference between the force outside and the force inside the sphere. This is how much force it would take to pull the sphere apart if 90% of the mass inside was removed.

$$\textbf{Force} = \mathbf{F_O - F_I}$$

Force, *F*	lbs.

Discussion Questions

1. How many people do you think that it would take to pull the Magdeburg sphere apart?

2. If only 70% of the air inside the Magdeburg sphere was removed instead of 90%, how would you expect the force needed to pull them apart change? Why?

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Take Home Activity

Part 1. Recording Air Pressure [1, 6]

Instructions: Using a smartphone, download a weather app that has barometric pressure! Over the next few days, record the weather conditions and sea-level pressure in the table below. Do this everyday for 3 days. *Be sure to include units!*

Alternatively, click the link below and type in your zip code in the box in the upper left corner of the webpage. Click Go. From this page, you will see a link for '3 Day History' on the right side of the current conditions for your location.

Weather.gov

Date/Time	Weather	Sea-level Pressure

Using the table above, answer the following questions in 1-2 sentences.

1. How did the pressure change between Day 1 and Day 3?

2. Are these pressure values typical of a high or low pressure system?

3. Using what you have learned about how high and low pressure systems are related to the weather, do your observations make sense? Briefly explain why or why not.

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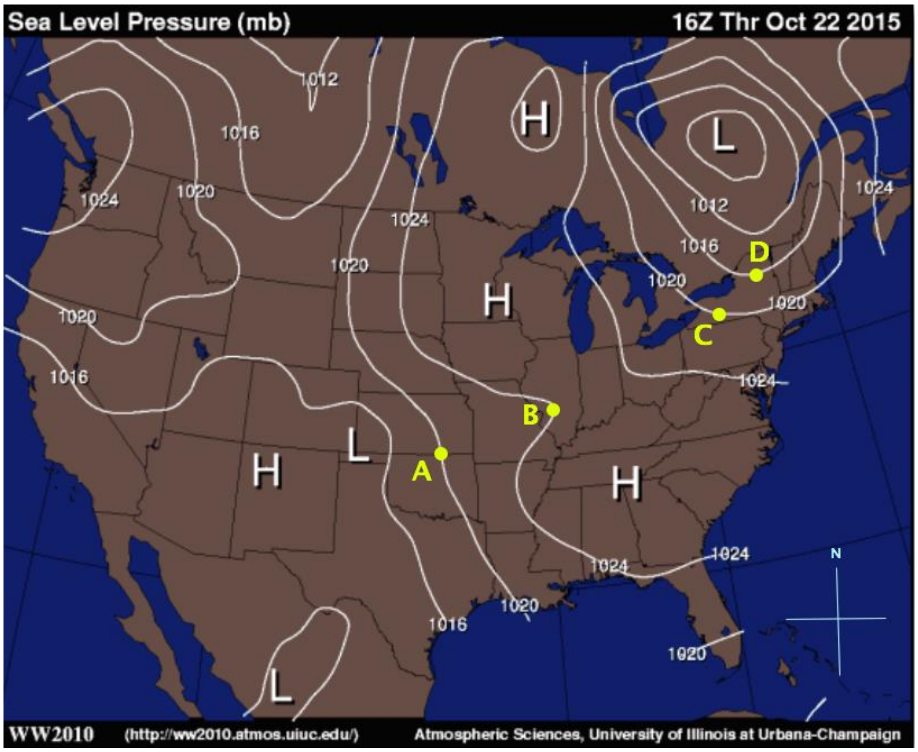
Part 2. Calculating the Pressure Gradient [1]

Instructions: A pressure gradient (PG) is defined as a change in pressure (ΔP) over a change in horizontal distance (ΔD). Using the sea-level pressure map below, calculate the pressure gradient in millibars per kilometer between Points A and B. Do the same calculation for Points C and D and answer the questions below.



Distance between Points A and B ($\Delta D_{A,B}$) = 385 miles
Distance between Points C and D ($\Delta D_{C,D}$) = 190 miles

Step 1: Convert the change in distances from miles to kilometers (1 mile = 1.609 km).

$\Delta D_{A,B}$	km
$\Delta D_{C,D}$	km

Step 2: Use the map to determine the change in pressure between the two points.

$\Delta P_{A,B}$	mb
$\Delta P_{C,D}$	mb

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Step 3: Use the following equation to calculate the pressure gradient.

$$PG = \Delta P / \Delta D$$

$PG_{A,B}$	mb/km
$PG_{C,D}$	mb/km

Questions 1

1. Between which two points is there a stronger pressure gradient?

2. Between which two points would you expect there to be faster wind speeds? Why?

3. What weather conditions would you expect in Illinois today? Why?

Part 3. True/False (Circle One) 7

1. Earth's atmosphere constantly seeks to achieve equilibrium. T F

2. At low surface pressure, the air in the column above has less mass. T F

3. Typical values of sea-level pressure range from 880 – 1000 mb. T F

4. A barometer is used to measure air pressure. T F

5. Many people suffer from altitude sickness at pressures < 800 mb. T F

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<u>Student Evaluation</u> [1, 2]

<u>Instructions</u>: After completing the lesson on pressure, please have the students answer the following questions below.

1. Changes in air pressure can cause
    a. changes in air temperature.
    b. clouds to form.
    c. the wind to blow.
    d. all of the above

2. Which of the following is <u>not</u> a unit for pressure?
    a. Millibars (mb)
    b. Pounds per square inch
    c. Inches of Mercury (in Hg)
    d. Knots (kts)
    e. Pascal (Pa)
    f. Atmosphere (atm)

3. A hurricane is associated with
    a. a low pressure system
    b. a high pressure system
    c. clear skies
    d. average sea-level pressure

4. Air pressure
    a. increases rapidly with height
    b. is caused by the winds
    c. decreases rapidly with height
    d. is the same everywhere
    e. only varies in the horizontal

5. A change in pressure over a distance is
    a. an isobar
    b. a barometer
    c. a low pressure system
    d. a high pressure system
    e. a pressure gradient

6. Air always moves
    a. from higher pressure to lower pressure
    b. from lower pressure to higher pressure
    c. faster around high pressure systems than low pressure systems
    d. slower around low pressure systems than high pressure systems
    e. from west to east

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7. Which of the following is true?
    a. There are less air molecules per volume of air in a high pressure system than in a low pressure system.
    b. There are less air molecules per volume of air when the wind blows.
    c. There are less air molecules per volume of air at the surface than at 800 mb.
    d. There are less air molecules per volume of air at 800 mb than at the surface.

8. You are flying in an airplane at 30,000 feet. How will the pressure change as the airplane lands at the airport?
    a. Pressure will decrease.
    b. Pressure will increase.
    c. Pressure will stay the same as you land on the ground.

9. Why are the horizontal winds much stronger than vertical winds? Which two forces cause this balance in vertical motion? Draw a diagram to help explain.

10. Calculate how the vertical pressure gradient in the lowest 5 kilometers of the atmosphere using the following equation:

$$\mathbf{PG = \Delta P / \Delta D}$$

$$P_{0km} = 1013.25 \text{ mb}$$
$$P_{5km} = 500 \text{ mb}$$

    a. PG = -102.65 mb/km
    b. PG = +102.65 mb/km
    c. PG = -0.1026 mb/km
    d. PG = +0.1026 mb/km
    e. PG = -0.0097 mb/km
    f. PG = +0.0097 mb/km

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Common Core State Standards (CCSS) Initiative
To learn more, visit http://www.corestandards.org

Next Generation Science Standards (NGSS)
To learn more, visit http://www.nextgenscience.org

The following standards are met in this learning module:

1. **NGSS.MS-ESS2.5**

MS-ESS2-5. Weather and Climate
Provide evidence for air pressure systems and resulting weather conditions.
Lecture: Introduction, Defining Air Pressure, Measuring Air Pressure; Pre-class Activity; In-class Activity: Parts 1 & 2; Take Home Assignment: Part 1 & 2; Student Evaluation

2. **CCSS.ELA-LITERACY.RST.6-8.4**

Grade 6-8: Science and Technical Subjects
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific science or technical context relevant to grades 6-8 texts and topics.
Lectures: Bolded text; In-class Activity: Part 1; Student Evaluation

3. **NGSS.MS-PS2.2**

MS-PS2.2. Forces and Interactions
Emphasis on balanced and unbalanced forces in a system and an object's motion (F = ma). This includes a specification of units.
Lecture: Extreme Air Pressure Event in 2010

4. **CCSS.ELA-LITERACY.RST.6-8.9**

Grade 6-8: Science and Technical Subjects
Compare and contrast the information gained from experiments, simulations, video or multimedia sources that gained from reading a text on the same topic.
Pre-class Activity: Cloud in a Bottle Demonstration

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5. **CCSS.MATH-CONTENT.7.G.B.4**

Grade 7: Geometry
Solve real-world and mathematical problems involving angle measure, area, surface area, and volume.
In-class Activity: Part 3

6. **CCSS.ELA-LITERACY.RST.6-8.3**

Grade 6-8: Science and Technical Subjects
Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.
Take Home Activity: Part 1

7. **CCSS.ELA-LITERACY.RST.6-8.8**

Grade 8: Science and Technical Subjects
Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.
Take Home Activity: Part 3

8. **CCSS.ELA-LITERACY.RST.6-8.7**

Grade 6-8: Science and Technical Subjects
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
Video lectures

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