Project ATMOSPHERE

AMERICAN METEOROLOGICAL SOCIETY

HIGHS AND LOWS

TEACHER'S GUIDE

NATIONAL SCIENCE FOUNDATION

Project ATMOSPHERE

This guide is one of a series produced by Project ATMOSPHERE, an initiative of the American Meteorological Society. Project ATMOSPHERE has created and trained a network of resource agents who provide nationwide leadership in precollege atmospheric environment education. To support these agents in their teacher training, Project ATMOSPHERE develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of Atmospheric Education Resource Agents in your state, please contact:

Project ATMOSPHERE
American Meteorological Society
1701 K Street, NW, Suite 300
Washington, DC 20006

This material is based upon work supported by the National Science Foundation under Grant No. TPE-9340055.

This project was supported, in part,
by the
National Science Foundation
Opinions expressed are those of the authors
and not necessarily those of the Foundation

Foreword

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

Introduction: Highs and Lows

"What's the weather?" and "What's the weather going to be?" are questions people frequently ask because weather and its changes strongly influence our activities and lives. The informed choices that can be made when we are aware of current and anticipated weather range from selecting appropriate clothing for the day to those that might be related to work and recreation. Less frequently, but by no means less important, the decisions and actions we take can reduce the amount of property damage, and the number of injuries and lives lost due to hazardous weather.

Adequate answers to questions we might have about weather can often be found on the day's weather map. Prominent on the maps appearing on television and in newspapers are the words "High" and "Low" or the letters "H" or "L". These words or letters are symbols for centers of broad-scale weather systems. They and their locations are key to describing and understanding probable weather conditions throughout the map area. They also provide information that enable meteorologists to predict possible atmospheric conditions up to a day or so in advance.

The Highs and Lows or H's and L's on maps represent centers of broad regions of relatively high or low surface air pressure. We can think of air pressure as the weight of a column of air per unit area. Highs and Lows govern atmospheric conditions throughout their expanses. Highs are generally fair weather systems. Changing and stormy weather conditions are associated with Lows.

Mid-latitude Highs and Lows tend to move from west to east, changing the weather at locations in their paths. Highs are followed by Lows and Lows are followed by Highs in an endless procession. No two Highs or two Lows are exactly alike, but they share enough characteristics in common that descriptive models of each can be employed to make sense of the weather.

The purpose of this guide is to introduce you to descriptive models of Highs and Lows. As a result of successfully completing this guide, you will be able to:

1. Describe in general terms (a) descriptive models of Highs and Lows and (b) the weather associated with each.

2. Apply these models to interpret weather maps and to describe probable current and future weather at different locations on a weather map.

Basic Understandings

Weather Systems

1 The weather of middle latitudes is dominated by broad-scale weather systems called Highs and Lows.

2 Highs and Lows are regions of relatively high and low surface air pressure, respectively. Air pressure can be thought of as the weight of a column of air per unit area (e.g. pounds per square inch).

3 Highs are generally fair-weather systems hundreds or even thousands of kilometers across. Lows, typically less expansive, exhibit changeable and often stormy weather conditions.

4 Highs and Lows display circulation and structural patterns organized around their pressure centers. The weather at a specific place depends to a large extent on its location relative to the centers of nearby Highs or Lows.

5 In middle latitudes, Highs and Lows tend to migrate, one following the other, from west to east across the continent with their paths showing north or south swings.

6 Weather at particular locations under the influence of migrating Highs and Lows will often change in predictable sequences depending on the paths of the pressure centers.

7 Highs and Lows are atmospheric features that last for several days or sometimes a week or longer. Mid-latitude Highs tend to persist for longer periods of time than do Lows.

8 Highs and Lows are modified by the effects of the Earth surfaces over which they travel. They become more humid when traveling over bodies of water and warm or cool depending on the temperatures of the underlying surface.

Weather Characteristics of a High

9 Highs (or H's) depicted on surface weather maps typically mark the high-pressure centers of air masses. Air masses are broad domes of air in which temperatures and humidity are relatively uniform in the horizontal.

10 Air masses form when air resides for weeks over a fairly uniform land or water surface. The overlying air gradually takes on the temperature and moisture characteristics of the underlying surface.

11 Warm surfaces produce warm air masses and cold surfaces produce cold air masses. Dry air masses form over land areas and humid air masses form over bodies of water. Dry, cold air masses form over Central Canada. The Gulf of Mexico is a source of warm, humid air masses. Air masses from the North Pacific Ocean or North Atlantic are humid and cool.

12 Sooner or later, air masses move away from their source regions. They carry their temperature and humidity characteristics with them and display internal circulations aligned with their high-pressure centers.

13 Air near the centers of surface Highs flows outward towards lower pressure. The Earth's rotation plus the frictional effects of the surface cause the air to spiral outward. In the Northern Hemisphere the spiral is clockwise as seen from above. In the Southern Hemisphere, it is counter-clockwise.

14 The circulation in Highs has a sense of rotation opposite to that of the Earth's rotation, so it is called anticyclonic. Since this circulation and relative high atmospheric pressure co-exist, Highs are also commonly called <u>anticyclones</u>.

15 Air sinks within Highs and replaces the outward spiraling air.

16 Sinking air in Highs is warmed by compression. Clouds, if present, vaporize and clear skies tend to prevail.

17 Air pressure varies little in a broad region about the center of a High so that winds are light and sometimes calm.

18 The circulation within Highs transports colder air from higher to lower latitudes in regions generally to the east of the pressure center. In the western flanks, warmer air flows from lower to higher latitudes.

19 In North American winters, cold Highs tend to track from the northwest towards the southeast. In summer, warm Highs tend to drift slowly from west to east and can stall for several days or even weeks.

20 The generally clear and relatively calm conditions in Highs favor night-time cooling and the possible formation of dew, frost, or fog.

Weather Characteristics of a Low

21 Lows (or L's) appearing on surface weather maps mark a weather system organized around a center of relatively low pressure. The low-pressure center is typically located along a boundary (front) between air masses that have contrasting temperatures and/or humidity.

22 Lows are weather systems characterized by a variety of weather including cloudy and stormy conditions, warm and cold sectors, air-mass boundaries called fronts (labeled warm, cold, or stationary depending on their movement), and rapidly changing conditions over short distances across fronts.

23 Air flowing towards the center of a surface Low is deflected by the Earth's rotation and the frictional effects of the surface to produce an inward spiral. In the Northern Hemisphere, this spiral is counter-clockwise as seen from above. In the Southern Hemisphere, it is clockwise.

24 The circulation in Lows has a sense of rotation that is the same as that of the Earth's rotation, so it is called cyclonic. Because this circulation and relative low pressure co-exist, Lows are commonly called <u>cyclones</u>.

25 Air spiraling into Lows also exhibits upward motion. Rising air expands and cools, clouds form and precipitation can develop.

26 Within Lows, along the horizontal plane, changes in air pressure are typically greater than those found in Highs; thus, Lows tend to have significantly higher wind speeds.

27 In winter over North America, the principal tracks of Lows and their stormy conditions are over the coterminous 48 states. Cyclogenesis (the formation of a Low) tends to occur over the Pacific Ocean, the Gulf of Mexico, on the Great Plains just east of the Rocky Mountains, and off the mid-Atlantic coast.

28 Winter storms tend to track towards the east and northeast, exiting North America through New England and Maritime Canada.

29 Winter Lows are generally more intense than summer Lows primarily because of greater temperature contrasts between neighboring air masses. Central pressures are lower and winds are stronger.

30 In spring and early summer, Lows over the Great Plains are often accompanied by lines of thunderstorms, some of which may be severe.

31 In summer, over North America, the principal storm track is across southern Canada.

Activity: Air Motion - The High and Low of It

Introduction

Weather can be fair or stormy. Generally, fair weather is associated with high surface air pressure while stormy weather is associated with low surface air pressure. Broad-scale areas of high and low surface pressure dominate weather in middle latitudes and are simply called **Highs** and **Lows**.

Highs and Lows are regions where air pressures are higher or lower compared to surrounding areas and are typically hundreds or even a thousand or more kilometers across. On a weather map, a large "High" or "H" symbolizes the location of highest pressure in a High whereas a large "Low" or "L" symbolizes the position of lowest pressure in a Low. Highs and Lows generally travel from west to east while exhibiting at least some motion toward the north or south. As they travel, they bring changes in the weather at places in their paths.

This activity investigates (1) the horizontal and vertical air motions in Highs and Lows, and (2) the impacts of these motions on weather at locations under the influence of Highs and Lows.

Upon completing this activity, you should be able to:

- Describe the general air motions and weather conditions associated with a high pressure system, or High.
- Describe the general air motions and weather conditions associated with a low pressure system, or Low.
- Based upon the locations of the centers of Highs and Lows, as shown on a weather map, predict general wind directions and weather conditions for different locations.

Materials

- Pencil

Procedure: Construction of a Model High Pressure System

1. Turn to Figure 1: High. Lightly draw a circle an inch or so in diameter around the large "H" appearing on the map.

2. Place the map flat on your desk. If possible, stand up. (This exercise works better standing up.) Bring the thumb and fingertips of your left hand (if you are right-handed) or your right hand (if your are left-handed) close together and place them on the circle you drew.

3. Rotate your hand slowly clockwise, as seen from above, and gradually spread out your thumb and fingertips as your hand turns. Do not rotate the map. Practice this until you achieve as full a twist as you can comfortably.

4. Place your thumb and fingertips back in your starting position on the circle. Mark and label the positions of your thumb and fingertips 1, 2, 3, 4, and 5, respectively.

5. Slowly rotate your hand clockwise while gradually spreading your thumb and fingertips. Go through about a quarter of your twisting motion. Stop, mark, and label the positions of your thumb and fingertips on the map. Follow the same procedure in quarter steps until you complete your full twist.

6. Connect the successive dots for each finger and your thumb using a smooth curved line. Place arrow heads on the lines to show the directions your thumb and fingertips moved.

7. The spirals represent the general flow of surface air that occurs in a typical **High** pressure system.

Procedure: Construction of a Model Low Pressure System

1. Turn to Figure 2: Low. Lightly draw a circle an inch or so in diameter around the large "L" shown on the map.

2. Again, if possible, stand up. Place your non-writing hand flat on the map with your palm covering the circle.

3. Practice rotating your hand counter-clockwise as seen from above while gradually pulling in your thumb and fingertips as your hand turns until they touch the circle. Do not rotate the map. Practice until you achieve a maximum twist with ease.

4. Place your hand back in the spread position on the map. Mark and label the positions of your thumb and fingertips 1, 2, 3, 4, and 5, respectively.

5. Slowly rotate your hand counter-clockwise while gradually drawing in your thumb and fingertips. Stopping after quarter turns, mark and label the positions of your thumb and fingertips. Continue the twist until your thumb and fingertips are on the circle.

6. Connect the successive dots for each finger and your thumb using a smooth curved line. Place arrow heads on the lines to show the directions your thumb and fingertips moved.

7. The spirals represent the general flow of surface air that occurs in a typical Low pressure system.

Investigations: Characteristics of High & Low Pressure Systems

Directions: Refer to the Activity Introduction and the Model Highs and Lows you constructed to complete the following questions.

1. Moving in the direction towards the center of a **High**, the surface atmospheric pressure (*increases*, *decreases*). When moving towards the center of a **Low**, the surface atmospheric pressure (*increases*, *decreases*).

2. Which of the following best describes the surface wind circulation around the center of a High pressure system (as seen from above)?

   a) counterclockwise and spiraling outward
   b) counterclockwise and spiraling inward
   c) clockwise and spiraling outward
   d) clockwise and spiraling inward

3. Which of the following best describes the surface wind circulation around the center of a Low pressure system (as seen from above)?

   a) counterclockwise and spiraling outward
   b) counterclockwise and spiraling inward
   c) clockwise and spiraling outward
   d) clockwise and spiraling inward

4. On your desk, repeat the hand twists for the High and Low pressure system models. Note the vertical motions of the palm of your hand. For the High, the palm of your hand (*rises*, *falls*) during the rotating motion, whereas for the Low, the palm of your hand (*rises*, *falls*) during the rotating motion.

5. The motions of your palms during these rotations represent the directions of vertical air motions in Highs and Lows. Vertical motions in a High are (*upward*, *downward*) while vertical motions in a Low are (*upward*, *downward*). Note that horizontal surface winds in a High and Low are considerably stronger than vertical air motions.

6. In a High pressure system, air flows

   a) downward and outward in a clockwise spiral.
   b) downward and inward in a counter-clockwise spiral.
   c) upward and outward in a clockwise spiral.
   d) upward and inward in a counter-clockwise spiral.

7. In a Low pressure system, air flows

   a) downward and outward in a clockwise spiral.
   b) downward and inward in a counter-clockwise spiral.
   c) upward and outward in a clockwise spiral.
   d) upward and inward in a counter-clockwise spiral.

8. The weather associated with a **Low** can be significantly different than that of a **High**. Different vertical motions account for some of these differences. Vertical motions lead to temperature changes in the rising or sinking air. The temperature changes occur because air warms when it is compressed and cools when it expands. (That is why a bicycle pump heats up as it compresses air and why air coming out of a tire valve cools as it expands while rushing from the higher pressures in the tire into the lower pressure of the atmosphere.) In the open atmosphere, air pressure decreases with increasing altitude. Consequently, air expands and cools when (*ascending*, *descending*). Air is compressed and warms when (*ascending*, *descending*).

9. In a **Low**, air generally exhibits ascending motion. The rising air experiences (*increasing*, *decreasing*) atmospheric pressure. The ascending air (*expands*, *is compressed*) and its temperature (*increases*, *decreases*).

10. In a **High**, air displays descending motion. The sinking air experiences (*increasing*, *decreasing*) atmospheric pressure. Consequently, the descending air (*expands*, *is compressed*) and its temperature (*increases*, *decreases*).

11. Most clouds form by the cooling of air. Air, if sufficiently cooled, will become saturated with water vapor. Continued cooling will result in condensation, cloud formation, and possible precipitation. The vertical motion in a (*High*, *Low*) often leads to cloud formation.

12. Warming causes clouds to evaporate. Cloudy air is saturated with water vapor. With sufficient warming, it will become unsaturated and existing cloud particles (water droplets or ice crystals) will evaporate. The vertical motions in a (*High*, *Low*) produce warming, promote cloud dissipation, and lead to clear skies.

13. Descending air in a **High** leads to (*fair*, *stormy*) weather and ascending air in a **Low** tends to make weather (*fair*, *stormy*).

14. The broad horizontal expanses of Highs and Lows cover large geographical areas such that their circulations transport colder air from higher latitudes and warmer air from lower latitudes. Consequently, in a High, air to the east of the system's center is generally (*colder*, *warmer*) than air to the west.

15. In a Low, air to the east of the system's center is generally (*colder*, *warmer*) than air to the west.

16. Turn to Figure 1: HIGH, examine the model High you constructed on the map. The hand-twist model of a High indicates the sky is probably (*clear*, *cloudy*) at St. Louis.

17. Surface winds at Topeka are probably from the general direction of (*north*, *south*), and temperatures are (*higher*, *lower*) than those in Cincinnati.

18. The center of the High is forecast to be near Cincinnati tomorrow. The weather at St. Louis tomorrow will probably be most like the weather in (*Cincinnati*, *Topeka*, *Birmingham*) today.

19. Turn to Figure 2: LOW, examine the model Low you constructed on the map. The hand-twist model of a Low indicates that the sky is probably (*clear*, *cloudy*) at St. Louis.

20. Surface winds at Topeka are probably from the general direction of (*north*, *south*), and temperatures are (*higher*, *lower*) than those in Cincinnati.

21. In the table below, describe the typical characteristics of Highs and Lows. Within each box, the related question number is listed for easy reference.

	HIGH	LOW
Pressure Change Towards Center (increase, decrease)	1	1
Surface Winds Around Center (clockwise, counter-clockwise)	2	3
Surface Winds Around Center (inward, outward)	2	3
Vertical Motion (up, down)	5	5
Change in Temperature of Vertically Moving Air (increases, decreases)	10	9
State of the Sky Around Center (clear, cloudy)	12	11
General Weather (fair, stormy)	13	13

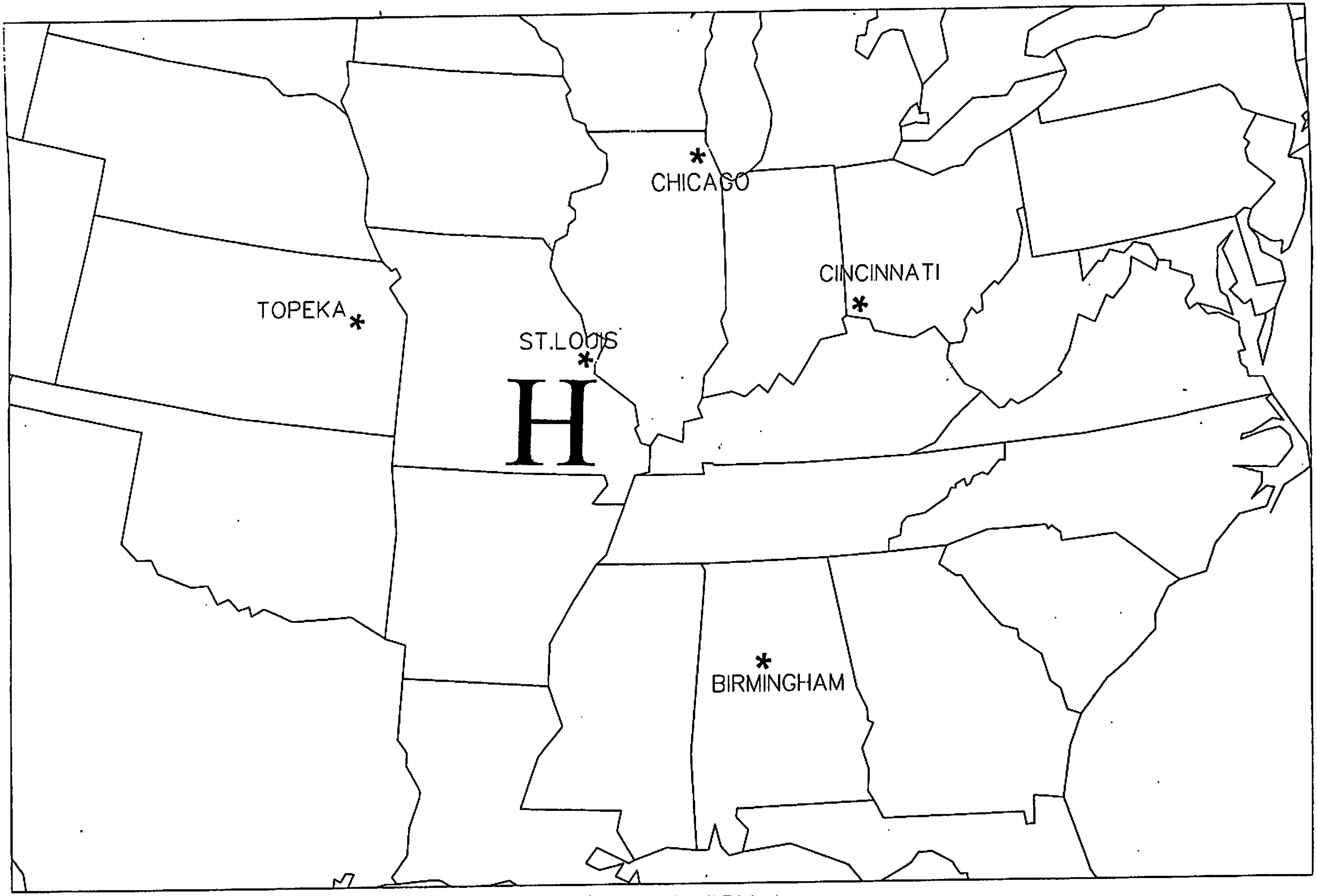


Figure 1 HIGH

Figure 2 LOW

Information Sources

Books

Lehr, Paul E., Burnett, R. Will, and Zim, Herbert S. Weather: Air Masses, Clouds, Rainfall, Storms, Weather Maps, Climate. New York: Golden Press, 1975.

Ludlum, David M. The American Weather Book. Boston: Houghton Mifflin, 1982.

Mogil, H. Michael and Levine, Barbara G. The Amateur Meteorologist, New York: Franklin Watts, 1993.

Ruffner, J.A., and Bair, F.E. The Weather Almanac, New York: Avon, 1977.

Schaefer, Vincent J. and Day, John A. A Field Guide to the Atmosphere. New York: Houghton Mifflin, 1981.

Williams, Jack. The Weather Book, New York: Vintage Books, 1992.

Periodicals

Weatherwise. Bimonthly magazine published in association with the American Meteorological Society for the layperson. Weatherwise, 1319 Eighteenth St., NW, Washington, DC 20036.

USA Today. National newspaper with extensive weather page. Available at local newsstands and by subscription.

Radio and Television

NOAA Weather Radio. The voice of the National Weather Service. Local continuous broadcasts from over 300 stations nationwide.

The Weather Channel. A continuous cable television program exclusively devoted to reporting weather. Includes frequent broadcast of local official National Weather Service forecasts.

Project ATMOSPHERE

AMERICAN METEOROLOGICAL SOCIETY

SUBARU

Introduction: Jet Streams

As World War II was approaching its conclusion, the United States introduced the first high-altitude bomber plane called the B-29. It could fly at altitudes well above 20,000 feet (6.1 kilometers). When the B-29s were being put into service from a Pacific island base, two air force meteorologists were assigned the task of producing a wind forecast for aircraft operations at such altitudes.

To make their prediction, the meteorologists used primarily surface observations and what is known in meteorology as the "thermal wind" relationship. In plain language, this relationship implies "that if you stand with your back to the wind, and the air is colder to the left and warmer to the right, the wind will get stronger on your back as you ascend in the atmosphere." Using this relationship, the meteorologists then predicted a 168-knot wind from the west. Their commanding officer could not believe the estimate. However, on the next day, the B-29 pilots reported wind speeds of 170 knots from the west! The ***jet stream*** was discovered.

Actually atmospheric scientists had theorized the existence of jet streams at least as early as 1937. The bomber pilots just confirmed it. Now almost every television weathercast mentions the positions of jet streams and their impact on daily weather events.

Jet streams are relatively strong winds concentrated as narrow currents in the upper atmosphere. The polar-front jet stream is of special interest to meteorologists because of its association with the regions where warm and cold air masses come in contact and middle latitude storm systems evolve. The polar-front jet stream encircles the globe at altitudes between 6 and 8 miles (9 and 13 kilometers) above sea level in segments thousands of kilometers long, hundreds of kilometers wide, and several kilometers thick. It flows generally from west to east in great curving arcs. It is strongest in winter when core wind speeds are sometimes as high as 250 miles (400 kilometers) per hour.

Meteorologists study the polar-front jet stream as they forecast weather. Changes in it indicate changes in weather. The jet stream is also of importance in aviation, as the B-29 pilots quickly found out. Westbound high-altitude flight routes are planned to avoid the jet-stream head winds. Eastbound flights welcome the time-saving tail winds. However, the jet stream produces strong wind shears in some locations because of large changes in wind speeds over short vertical and horizontal distances. The resulting air turbulence can be very hazardous to aircraft.

The polar-front jet stream's location is one of the most influential factors on the daily weather pattern across the United States.

Basic Understandings

Characteristics of the Polar-Front Jet Stream

1 Jet streams are relatively high speed west-to-east winds concentrated as narrow currents at altitudes of 6 to 9 miles (9 to 14 kilometers) above sea level. These meandering "rivers" of air can be traced around the globe in segments thousands of kilometers long, hundreds of kilometers wide and several kilometers thick.

2 Two high-altitude jet streams affect the weather of middle latitudes; they are the subtropical jet stream and the polar-front jet stream.

3 The subtropical jet stream is located between tropical and middle latitude atmospheric circulations. Although not clearly related to surface weather features, it sometimes reaches as far north as the southern United States. It is an important transporter of atmospheric moisture into storm systems.

4 The polar-front jet stream is associated with the boundary between higher latitude cold and lower latitude warm air, called the polar front. Because of its link to surface weather systems and features, the polar-front jet stream is of special interest to weather forecasters.

5 The polar-front jet stream is embedded in the general upper-air circulation in the middle latitudes where winds generally flow from west to east with broad north and south swings. As seen from above, these winds display a gigantic wavy pattern around the globe.

6 The maximum wind speeds in the polar-front jet stream can reach speeds as high as 250 miles (400 kilometers) per hour.

7 The average position of the polar-front jet stream changes seasonally. Its winter position tends to be at a lower altitude and at a lower latitude than during summer.

8 Because north-south temperature contrasts are greater in winter than in summer, the polar-front jet stream winds are faster in winter than in summer.

9 Small segments of the polar-front jet stream where winds attain their highest speeds are known as jet streaks. Across the United States, one or two jet streaks are commonly present in the polar-front jet stream.

What Causes the Polar-Front Jet Stream?

10 Fundamental to the formation of the polar-front jet stream is the physical property that warm air is less dense than cold air when both are at the same pressure.

11 The polar front represents the boundary between higher latitude cold air and lower latitude warm air. This temperature contrast extends from the Earth's surface up to the polar-front jet stream altitude.

12 Air pressure is determined by the weight of overlying air. In the vicinity of the polar front, air pressure drops more rapidly with an increase in altitude in the more dense cold air than in the less dense warm air.

13 The effect of temperature on air density results in air pressure at any given altitude being higher on the warm (equatorward) side of the polar front than on the cold (poleward) side.

14 When cold and warm air reside side by side, the higher the altitude the greater the pressure difference is between the cold and warm air at the same altitude.

15 Across the polar front, at upper levels (including the jet stream altitude), horizontal pressure differences cause air to flow from the warm-air side of the front towards the cold-air side of the front.

16 Once air is in motion, it is deflected by the Earth's rotation (called the Coriolis effect). Upper-level air flowing poleward from higher pressure towards lower pressure is deflected to the right in the Northern Hemisphere (or to the left in the Southern Hemisphere). The result is a jet stream flowing generally towards the east, parallel to, and above the polar front.

Relationships Between the Polar-Front Jet Stream and Our Weather

17 The polar-front jet stream exists where cold air and warm air masses are in contact. Hence, your weather is relatively cold when the polar-front jet stream is south of your location and relatively warm when the jet stream is north of your location.

18 The polar-front jet stream can promote the development of storms. Storms are most likely to develop under a jet streak.

19 As a component of the planetary-scale prevailing westerly circulation, the polar-front jet stream steers storms across the country. Hence, storms generally move from west to east.

Jet Stream Investigation

Introduction

The location of the polar-front jet stream is often closely related to the daily weather pattern across the United States. The following two activities investigate the causes of jet streams and the relationships of the polar-front jet stream with surface weather in the United States.

Each activity can stand alone. One does not need to be done before the other. However, Activity 1 requires the construction of two sets of five pressure blocks. The instructions for making the pressure blocks are on the next page and an alternate suggestion appears at the bottom of this page for the construction of a permanent set of pressure blocks. Finally, Activity 1 typically requires more time to complete than Activity 2.

Alternative Construction of Pressure Blocks

Cut blocks from solid materials such as wood or insulation material. The blocks should all have the same size square bases. The tall blocks should be twice the height of the short blocks. All blocks should weigh the same. Adjust the weight by drilling holes in the short blocks and inserting metal weights. Paint short blocks blue and tall blocks red.

Pressure Blocks Construction

Materials

- 1 red file folder, 1 blue file folder, tape, scissors, ruler, pencil

Procedure

You will be making two sets of pressure blocks, 5 large red blocks and 5 small blue blocks. Both sizes of blocks will be constructed from the same size card shown below.

The pattern below has guidelines for the large and small blocks. Copy and cut out the pattern. On the red file folder, trace the pattern edges for a set of 5 cards. Make tick marks indicating the position of the LARGE guidelines. Draw the LARGE guidelines across each card. On the blue folder, repeat the process except make tick marks for and draw in the SMALL guidelines across each card. Cut out all 10 cards.

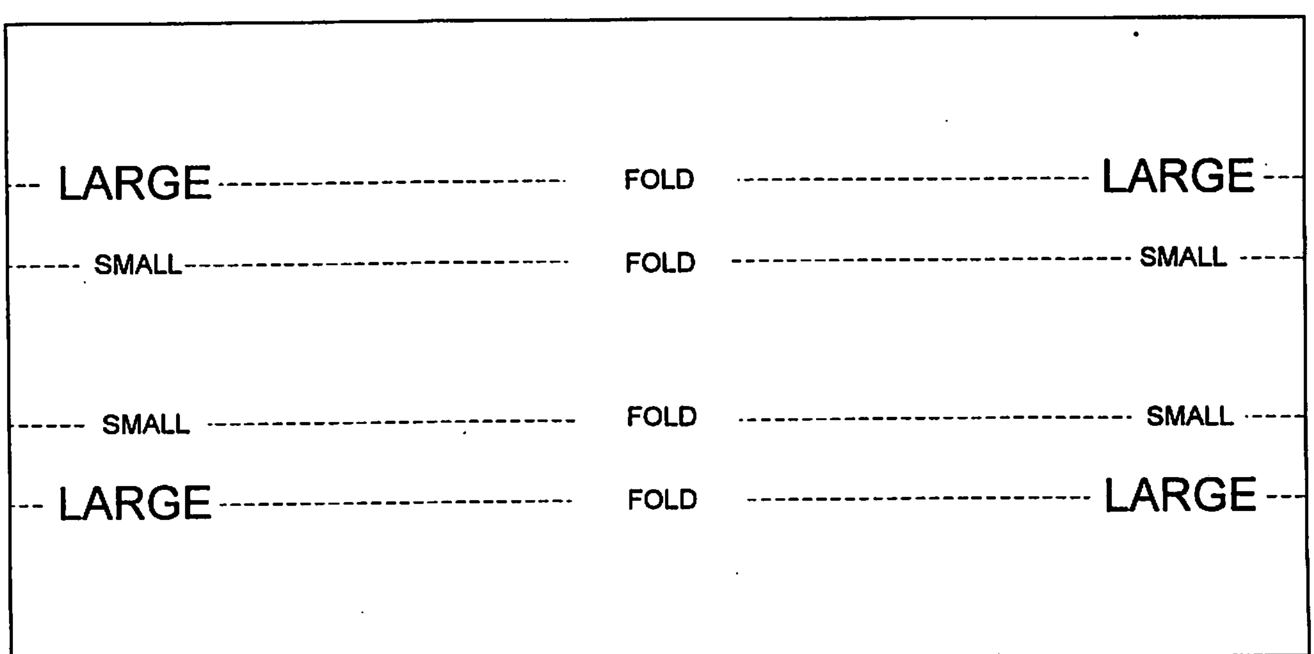
To form a block, fold a card along the top and bottom guidelines you have drawn. Make a sharp crease. Unfold the card.

Fold the card in half, bringing the short sides together. Make a sharp crease. Fold the card in half again in the same direction. Make a sharp crease. Unfold the card.

With scissors, clip the long edge of the card on the fold creases up to the line you drew.

Fold the card into a box (short sides together). Tape edge. Fold and tape down flaps at either end. Repeat for all cards (blocks).

Since the same size card was used in every block, you now have 10 blocks each of equal weight. The bases of the blocks also have the same size.



Activity 1: Pressure, Air Pressure, and Jet Streams

Introduction

One of the most important properties of the atmosphere is air pressure. It is important because differences in air pressure from place to place put air into motion (just as in the case of air rushing out of the open valve of an inflated tire). Pressure differences at altitudes of nine or more kilometers lead to the development of high-speed winds, called Jet Streams.

This activity uses sets of blocks to investigate basic understandings about pressure and pressure differences produced by density variations. These understandings are then applied to the atmosphere to introduce the basic causes of jet streams.

Upon completing this activity, you should be able to:

- Explain what pressure is and how it can vary vertically and horizontally.
- Describe how density contrasts between warm and cold air produce pressure differences at different levels in the atmosphere.
- Explain how pressure differences in the atmosphere can lead to high-speed winds called jet streams.

Materials

- Two 5-block sets (See **Pressure Blocks Construction**, page 5)
- Two 3×5 index cards, pencil, straight edge

Investigations

To study pressure, we must first define it. Pressure is a force acting on a unit area of surface (e.g., pounds per square inch is a pressure measurement). Air pressure is the weight (weight is a force) of a column of air acting on a unit area of horizontal surface. To represent the concept of pressure concretely, two sets of blocks with the following characteristics will be used:

a) all blocks have the same weight,
b) all blocks have the same size square bases,
c) all blocks exert the same downward pressure on the surface beneath them (because the same weight is acting on the same size base).

1. Take one block from each set and place it on its square base on a table surface. Because both blocks weigh the same and their bases have the same area, the blocks exert (*equal*), (*unequal*) pressure on the table.

2. The shorter blocks have half the volume of the taller blocks while containing the same mass (we know this since they weigh the same). Because density is mass per unit volume, the smaller blocks are (*twice*), (*half*) as dense as the larger blocks.

3. Place another identical block on top of each block already on the table. Each stack is now exerting (*the same*), (*twice the*) amount of pressure on the table as it did initially. The pressure exerted on the table by the tall stack is (*equal*), (*not equal*) to the pressure exerted on the table by the short stack.

4. Position the two stacks side-by-side and add another identical block to each stack (for a total of 3 in each). Insert an index card horizontally through the two stacks so that two shorter blocks and one taller block are positioned beneath the card. Compare the pressures exerted **on the card** by the overlying blocks. The taller-block stack exerts (*greater*), (*equal*), (*less*) pressure **on the card** than does the shorter-block stack.

5. Add a short block to its respective stack. Lift the top tall block and overlay the stacks with another index card. Add the rest of the blocks to their respective stacks. The pressure exerted on the table by the tall stack remains (*equal*), (*unequal*) to the pressure exerted on the table by the short stack.

6. Each block exerts one unit of pressure (1 UP) on the surface beneath it. In the table below, indicate the pressure in UP units each stack exerts on each surface. For each surface, compute and record the pressure difference between the two stacks.

	Tall-Block Pressure (UP)	Short-Block Pressure (UP)	Pressure Difference (UP)
On Top Card			
On Lower Card			
On Table Top			

7. Starting at the table top and moving upward, the difference in downward pressure exerted by the overlying portions of the stacks (*increases*), (*decreases*). In the (*taller less dense*), (*shorter more dense*) stack, the pressure decreases more rapidly with height .

8. Look at Figure 1: Pressure Blocks, Side View. Following the examples shown, draw lines on the chart to record the positions of the tops/bottoms of all the blocks so the chart represents a side view of the two stacks. Place a large dot at the mid-point of each top/bottom line you drew. Following the examples given, use a straight edge to draw lines from the dots in one stack to the dots in the other stack representing the same pressures. These lines connecting equal pressure dots become (*more*), (*less*) inclined with an increase in height.

9. Figure 2: Vertical Cross-Section of Pressure shows a cross-section of the atmosphere based on upper-air soundings obtained simultaneously at Norman, Oklahoma (OUN) and at The Pas Airport, Manitoba, Canada (YQD) approximately 1,350 miles (2,175 kilometers) to the north of Norman. Air pressure values in millibars (mb) are plotted as dots at the elevations where they were observed, starting with nearly identical values at the surface. The millibar (mb), a commonly used pressure unit in meteorology, is a metric unit of force per square centimeter. At Norman (OUN), the air pressure at approximately 12,300 meters above sea level was (*300*), (*250*), (*200*) mb.

10. Air above the northern weather station, YQD, was colder and therefore more dense than the air above the more southern station, OUN. Following the examples shown at the surface and at 925 mb, draw straight lines connecting equal air-pressure dots on the graph. Above the Earth's surface these lines representing equal air pressures are (*horizontal*), (*inclined*).

11. Compare the lines of equal pressure you drew on the two figures. They appear quite different because one deals with rigid blocks while the other deals with air, and secondly, their scales are much different. However, both reveal the effect of density on pressure. The lines of equal pressure slope (*downward*), (*upward*) from the lower-density tall blocks or warm air column above OUN to the higher-density short blocks or cold air column above YQD, respectively.

12. Because of the sloping of the equal-pressure lines in Figure 2, it can be seen that at 12,300 meters above sea level the air pressure in the warmer air at OUN is (*higher than*), (*the same as*), (*lower than*) the air pressure in the colder air at YQD .

13. Because air is gaseous, air pressure at any point acts in all directions. Differences in air pressure arising from differences in air density produce horizontal forces directed from higher to lower pressure. Thus, air is put into motion horizontally from where the pressure is higher towards where the pressure is lower. Draw a horizontal arrow at the altitude of 12,300 meters to show the direction the horizontal force is acting at that elevation. This arrow points towards the (*north*), (*south*).

Figure 1: Pressure Blocks, Side View

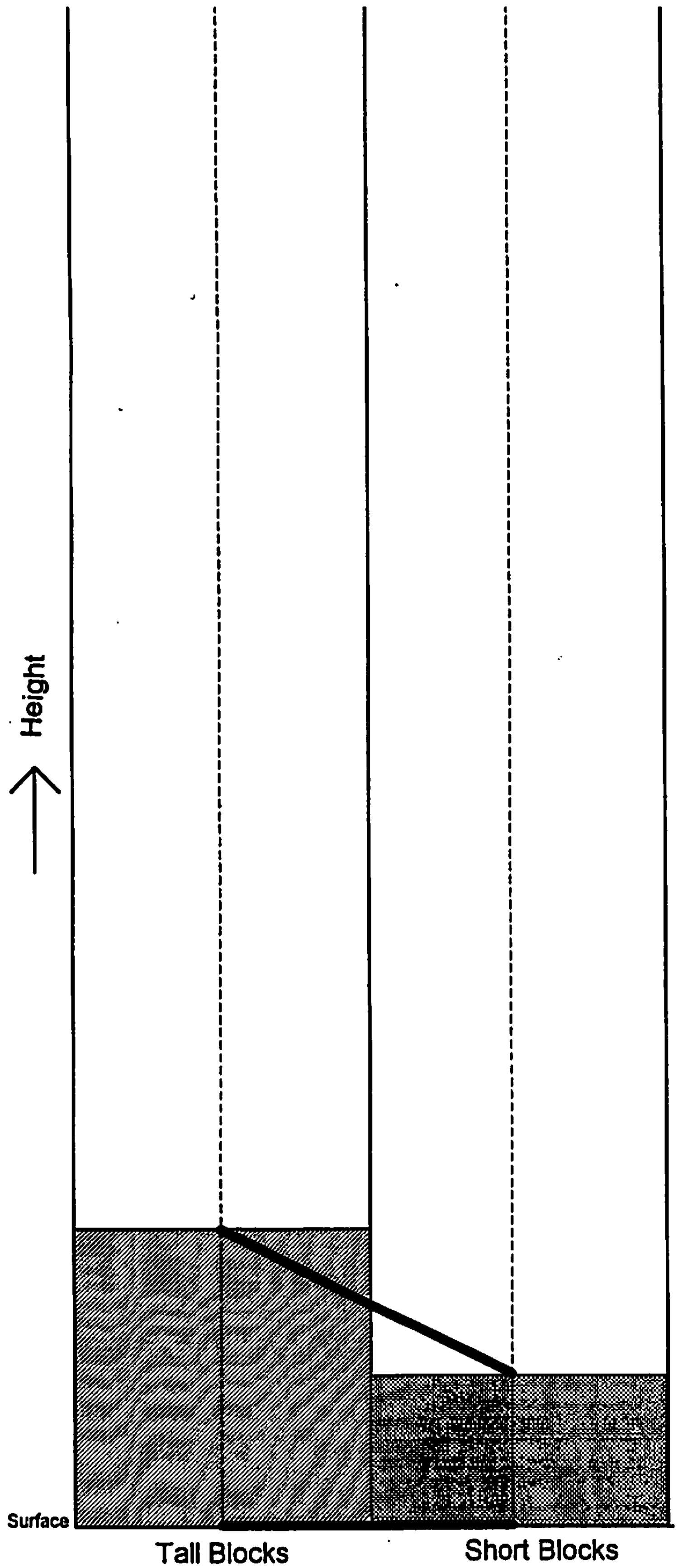
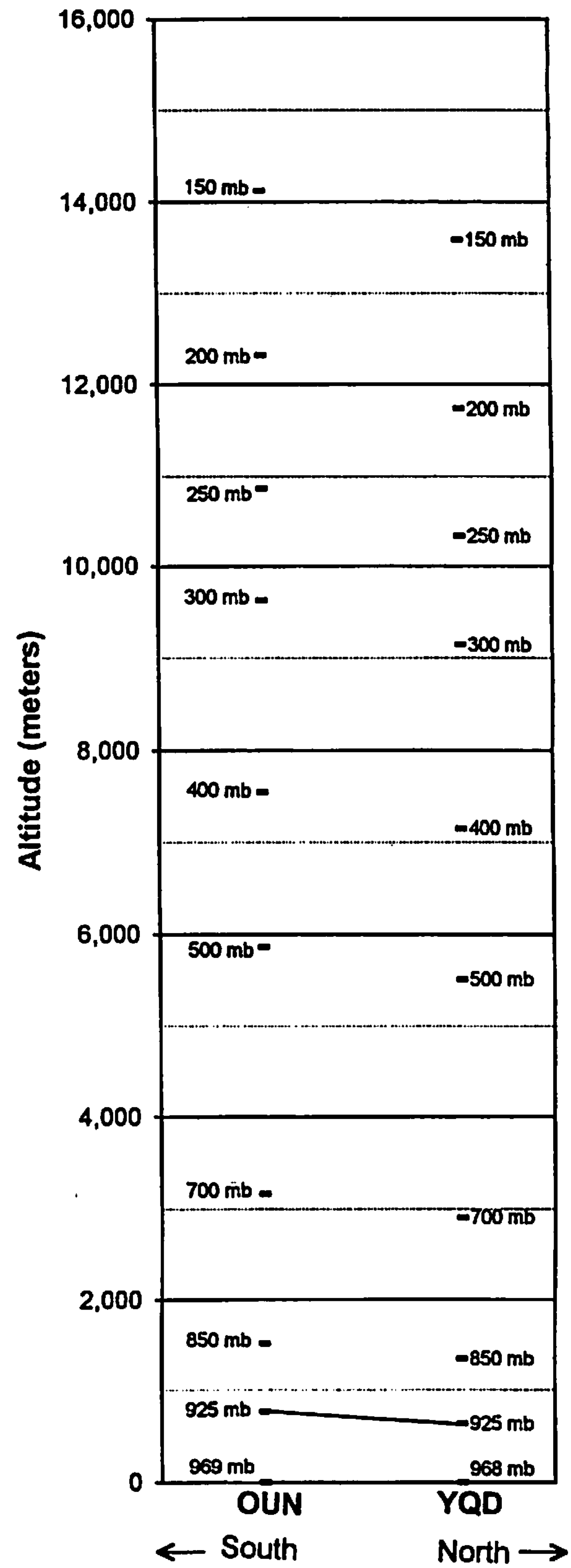


Figure 2: Vertical Cross-Section of Air Pressure (00Z 12 September 1993)



14. Air put into motion by these horizontal forces does not flow directly towards lower pressure. It is deflected by Earth's rotation. This change in direction is called the Coriolis effect. In the Northern Hemisphere, air is deflected to the right of the direction towards which it is moving until it is traveling along a path perpendicular to the pressure-generated force. Which statement best describes the motion of the air under the influence of a pressure generated force (represented by your arrow) and the Coriolis effect?

   a) *Air flowing southward turns right until it is moving towards the west.*
   b) *Air flowing northward turns right until it is moving towards the east.*

15. At the time the upper-level observations were made, the highest wind speeds were recorded where the air pressure was near 200 mb. Accordingly, the maximum wind speed was probably occurring near the altitude of (*10,000*), (*12,000*), (*14,000*) meters above sea level.

16. These upper-level high-speed winds, produced in large part by the density differences between warm and cold air, tend to concentrate in "rivers" of air. They are called jet streams. Below in Figure 3: Upper-Level 200-mb Map, the dark line represents the approximate location of the jet stream at the time the OUN and YQD observations were made. Draw an arrowhead on one end of the jet stream to show the direction the air is flowing.

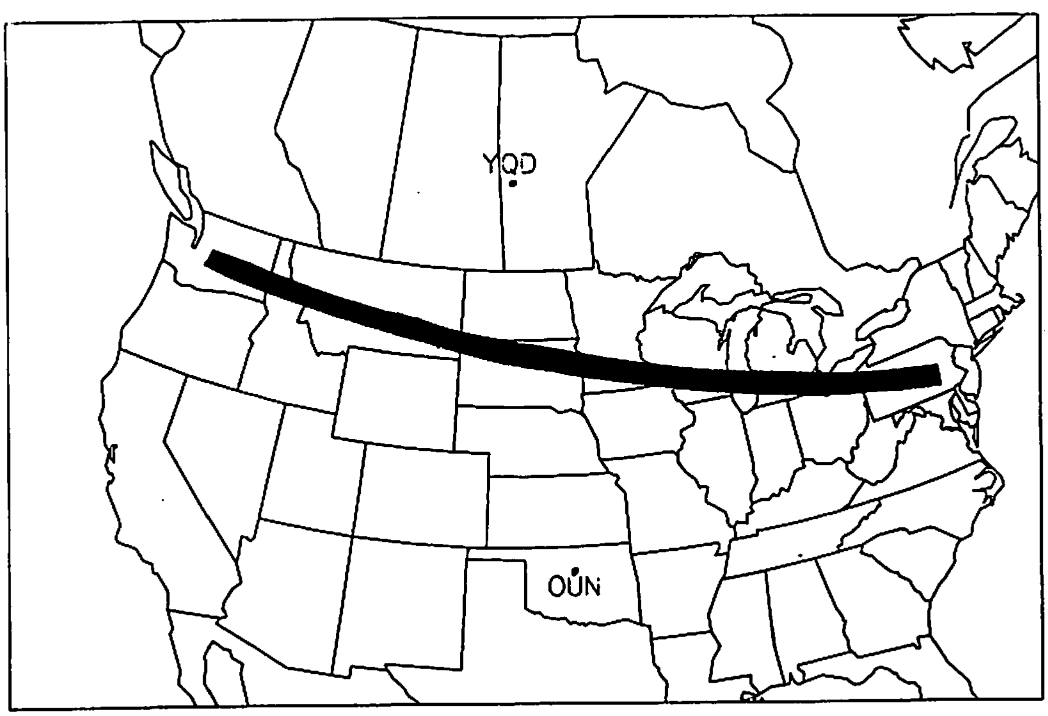


Figure 3: Upper-Level 200-mb Map

Activity 2: The Polar-Front Jet Stream

Introduction

The polar-front jet stream is like a high-speed river of air in the upper atmosphere. It separates warm and cold regions at the Earth's surface. It may be several hundred miles across from north to south, 5,000 to 10,000 feet (1,500 to 3,000 meters) thick and at an altitude of 30,000 to 43,000 feet (9,000 to 13,000 meters). The polar-front jet stream generally flows from west to east, and is strongest in the winter when core wind speeds are sometimes as high as 250 miles (400 kilometers) per hour. Changes in the jet stream indicate changes in the circulation of the atmosphere and associated local weather.

Upon completing this activity, you should be able to:

- Determine the location of the polar-front jet stream based upon upper-atmosphere wind data.
- Describe influences of the polar-front jet stream on weather and aviation.

Materials

- pencil

Investigations

The highest upper-level wind speeds are frequently observed at altitudes of approximately 6 to 8 miles (9 to 13 kilometers) above sea level. Figure 1 is an upper air chart displaying wind speeds and directions observed one day at 00Z (7 pm EST) at altitudes where the air pressure was 200 millibars. At map time, the actual altitudes at which the air pressure was 200 millibars varied from 37,666 to 40,750 feet (11,480 to 12,420 meters) above sea-level. Upper-level data are routinely displayed on constant-pressure charts because of the usefulness of such charts to meteorologists. The data were acquired by tracking balloon-borne weather instruments, called radiosondes, which measure and transmit weather data as they rise through the atmosphere.

Wind information is depicted by "arrows" shot into circles at locations on the map where radiosondes were launched. On the arrow, the straight line represents wind direction while the feathers represent wind speed. Winds are named for the direction from which they are blowing. For example in Figure 1, a west wind was reported at Green Bay, Wisconsin. Wind speed is reported in knots (1 knot equals 1.0 nautical mile per hour or 1.15 statute miles per hour); a full length feather represents 10 knots, a half feather stands for 5 knots, and a flag means 50 knots. The wind speed at Green Bay, Wisconsin, at 200 millibars, was 60 knots.

1. Look at the accompanying Figure 1. With a pencil, draw a line or lines to enclose the region where wind speeds are 60 knots or greater. Lightly shade the enclosed area. Draw a dark, heavy, smooth, curved arrow through the core of highest wind speeds. Add an arrow head to show wind direction.

2. The large arrow you drew on your map approximates the location of the existing polar-front jet stream across the United States. Now imagine that you are in a gondola attached to a helium-filled balloon that is located over central Washington State. Assuming your balloon stays at the 200-millibar level, describe your path as you travel across the country. Through what state or states are you likely to leave the United States?

   ____

   ____

3. What is your approximate speed measured with respect to the surface of the Earth?________________________________

4. Even though the wind speed is 60 knots or greater, as measured relative to the ground, an anemometer attached to the gondola shows the wind to be calm. Explain why. ______________________________

   ____

   ____

5. Look at winds on either side of the jet. The winds on either side of the jet are (*slower*), (*faster*) than the jet stream winds and have (*the same*), (*a different*) direction.

6. The polar-front jet stream varies considerably in location and strength from time to time. Examples of this variation can be seen in Figures 1 and 2. Both report upper-air wind information at the levels where speeds were generally highest.

   The two lines drawn in Figure 2 enclose the jet stream that existed at map time. On this map, only winds of 100 knots or higher were enclosed to locate the highest speed winds. As you did in Figure 1, lightly shade the enclosed area and draw an arrow and arrow head to highlight the high-speed core of the jet stream winds.

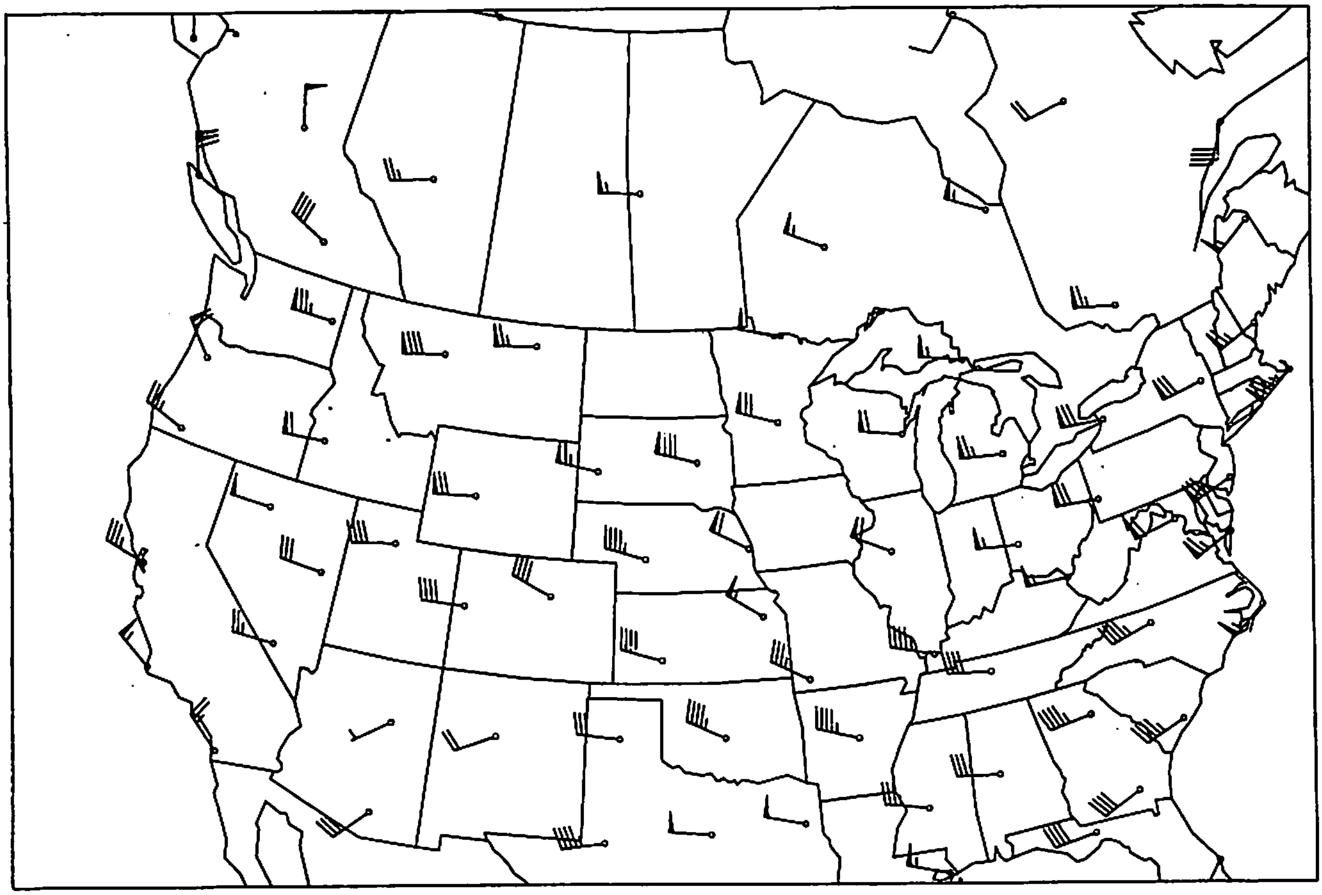


Figure 1: Upper-Air Chart of Winds at the 200-Millibar Level (0Z 12 SEP 93)

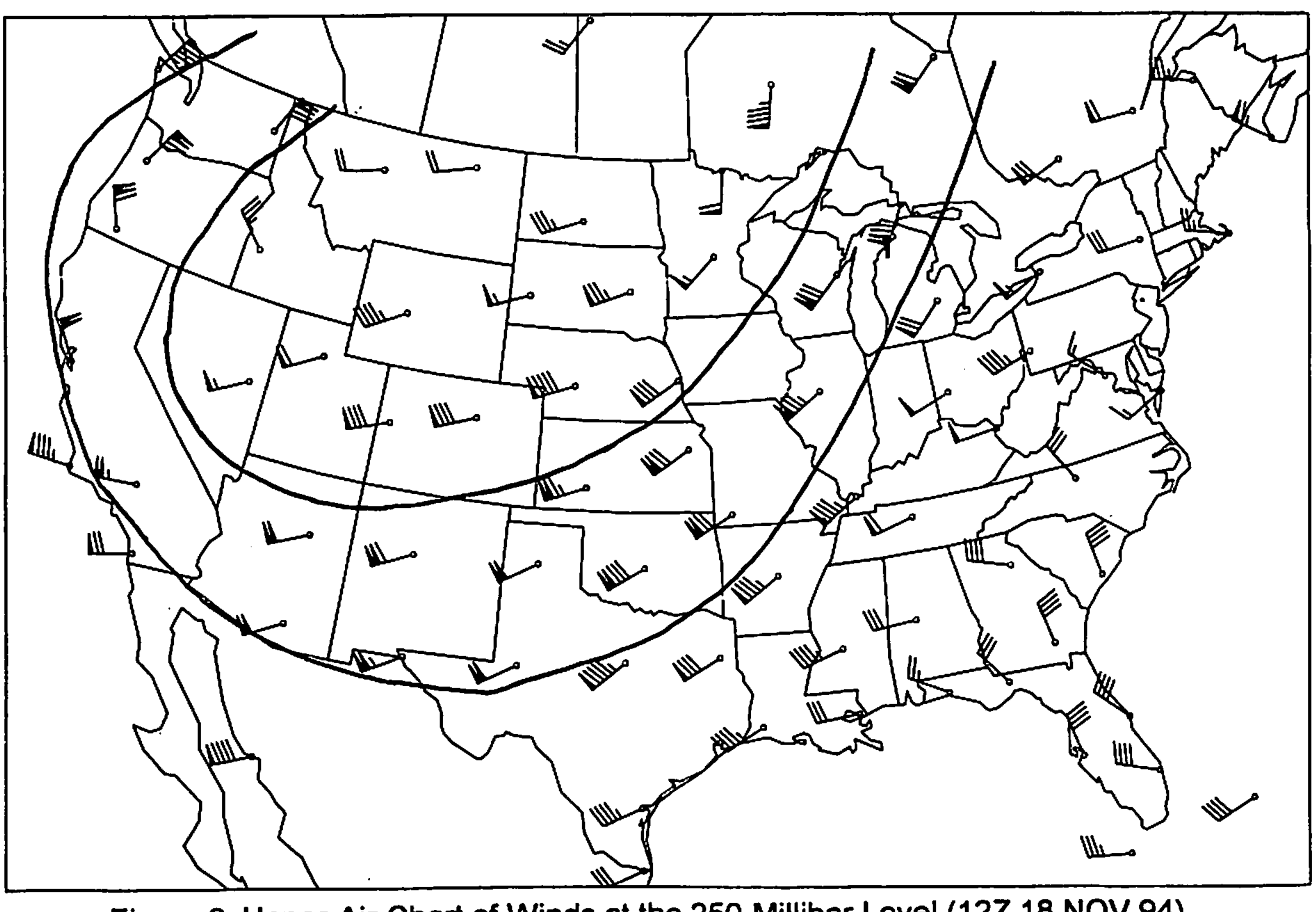
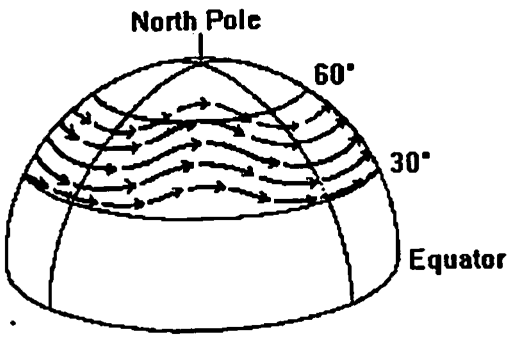
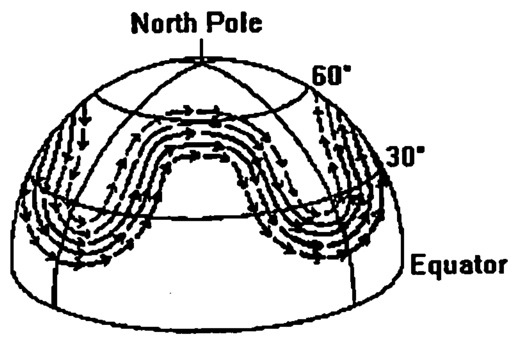


Figure 2: Upper-Air Chart of Winds at the 250-Millibar Level (12Z 18 NOV 94)

7. The polar-front jet stream is like a "river" of high speed air embedded in the planetary-scale circulation of the atmosphere. The drawings below illustrate the wavy and generally eastward flow of air at upper levels in the middle latitudes of the Northern Hemisphere (planetary-scale circulation). The wave pattern can vary considerably in amplitude (latitude range). Indicate which drawing better matches the upper-air flow of Figures 1 and 2.





Matches: (*Figure 1*), (*Figure 2*) Matches (*Figure 1*), (*Figure 2*)

8. The polar-front jet stream roughly aligns with the polar front separating higher-latitude cold air from lower-latitude warm air. Wind information in Figure 2 suggests that surface temperatures across the coterminous United States are (*low*), (*high*) in the east compared to those in the west.

9. Across the United States, storms tend to follow the path of the polar-front jet stream. In Figure 2, a storm in the Oklahoma area at map time is likely to be moving towards (*the Great Lakes*), (*Florida*).

10. Knowledge of the location of the jet stream is very important to commercial aviation. Explain why at Figure 2 map time an airline flight from Chicago to Los Angeles would take considerably more time than a flight from Los Angeles to Chicago.

____

____

Websites

American Meteorological Society Education Page
http://ametsoc.org/amsedu/

DataStreme Website
http://amsedu.ametsoc.org/amsedu/dstreme/index.html

Project Atmosphere Canada
http://www.on.ec.gc.ca/skywatchers/bothguides_e.html

Environment Canada
http://www.weatheroffice.gc.ca/canada_e.html

Satellites:

1. RAMSDIS Online
   a. http://rammb.cira.colostate.edu/ramsdis/online/goes-west_goes-east.asp
2. GOES
   a. http://www.goes.noaa.gov/ - Infrared, visible, & water vapor individual images or loops
3. RAP (UCAR- University Corporation for Atmospheric Research)
   a. http://rap.ucar.edu/weather/ - Various satellite data that can be looped for up to 12 hours
4. National Environmental Satellite, Data, and Information Service (NESDIS)
   a. http://www.oso.noaa.gov/poes/index.htm - offers a description of different satellites, including GOES and POES
5. NASA Modis
   a. http://modis.gsfc.nasa.gov/
6. NASA
   a. http://science.nasa.gov/realtime/jtrack/3d/JTrack3D.html - track satellites in space (Java)

Radar:

1. National Weather Service Radar (NWS)
   a. http://radar.weather.gov/Conus/ - nationwide look at radar or can click on local area
2. RAP (UCAR)
   a. http://rap.ucar.edu/weather/radar/ - can loop radar data for up to 12 hours
3. National Severe Storms Laboratory (NSSL) – for research purposes
   a. http://www.nssl.noaa.gov/par/ - describes Phased Array Radar (new technology)
   b. http://www.nssl.noaa.gov/dualpol/ - describes Dual Polarization Radar

Surface data:

1. Hydrometeorological Prediction Center (HPC)
   a. http://www.hpc.ncep.noaa.gov/ - Current Weather, National Forecast, Surface Analysis, Short Range Forecasts, Days 3-7 Forecasts, QPF, Excessive Rainfall, Winter Weather Forecast maps
2. RAP (UCAR)

CoCoRaHS State Climate Series ~~.colostate.edu~~

MOS www.weather.gov/mdl/synop/products.php

See Other, last page

a. http://rap.ucar.edu/weather/surface/ - can click to zoom in & can loop surface data for up to 24 hours

Upper Air data:

1. RAP (UCAR)
    a. http://rap.ucar.edu/weather/upper/ - Skew T diagrams (pick location and pressure level)
2. University of Wyoming
    a. http://weather.uwyo.edu/upperair/sounding.html - Upper air charts including Stuve and Skew-T diagrams for the continental US and other locations worldwide
3. Unisys
    a. http://weather.unisys.com/upper_air/index.html - all you need to know about upper air charts (including how to read upper air data plots - under 'More Information on Plots')

Forecasting Models: models are not forecasts

1. National Centers for Environmental Prediction (NCEP) may not work — use first part and click on numerical models
    a. http://www.nco.ncep.noaa.gov/pmb/nwprod/analysis/ - choose a model and then choose what you want to see and either an individual time period or a loop
2. National Center for Atmospheric Research (NCAR)
    a. http://www.rap.ucar.edu/weather/model/ - forecast models from 12 hours to 10 days
3. NWS Meteorological Development Lab (MDL)
    a. http://www.weather.gov/mdl/synop/products.php - provides MOS data for different models for locations across the country
4. Environmental Modeling Center
    a. http://www.emc.ncep.noaa.gov/ - maintain, enhance, and develop numerical forecasts

Severe Weather:

1. National Weather Service (NWS)
    a. http://www.weather.gov/ - nationwide forecast, including current watches and warnings (can click on local area on map or can type in zip code/city name)
    b. http://www.weather.gov/view/largemap.php – larger nationwide map of current watches/warnings
2. Storm Prediction Center (SPC)
    a. http://www.spc.noaa.gov/ - provides forecasts and watches for severe thunderstorms and tornadoes over the U.S.
        i. They also monitor heavy rain, snow, and fire weather events
3. National Severe Storms Laboratory (NSSL)
    a. http://www.nssl.noaa.gov/ - Studies severe weather processes and develops tools to help National Weather Service forecasters, among others (research focused)
4. National Hurricane Center (NHC)
    a. http://www.nhc.noaa.gov/ - monitors the Eastern Pacific and Atlantic Oceans for tropical development and links to tropical centers worldwide

Climate:

1. Climate Prediction Center (CPC)
    a. http://www.cpc.ncep.noaa.gov/ - includes 6-10 day and 8-14 day outlooks (temperature and precipitation), monthly outlooks (temperature and precipitation), U.S. drought assessment, U.S. Hazards Assessment (Temp/Wind, Precip, Soil/Wildfire, Composite)
        1. Also includes El Nino and La Nina along with other large-scale circulations
            a. http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml - link to CPC's ENSO page
2. National Climatic Data Center (NCDC)
    a. http://www.ncdc.noaa.gov/ - world's largest archive of weather data

Space Weather:

1. Space Weather Prediction Center
    a. http://www.swpc.noaa.gov/ - offers space weather products and services
2. *Space Weather: The International Journal of Research and Applications*
    a. http://www.agu.org/journals/sw/ - AGU (American Geophysical Union)
        i. Devoted to space weather and its impact on technical systems

Others:

1. Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS)
    b. http://www.cocorahs.org/
2. Automated Surface Observing System (ASOS)
    c. http://www.nws.noaa.gov/asos/ - all you need to know about ASOS (what it is, what data it collects, how the instruments work, pictures of ASOS, and much more) from the NWS
2. UV Forecast (by the EPA)
    a. http://www.epa.gov/sunwise/uvindex.html - look up the UV forecast for your area and explore the UV index forecast across the U.S. (out to day four)
3. NASA Earth Observatory
    a. http://earthobservatory.nasa.gov/ - check out the 'Image of the Day' along with other environmental news
4. National Weather Service Jetstream Program
    a. http://www.srh.noaa.gov/srh/jetstream/index.htm - Online School for Weather (modules)
5. U.S. Storm Events Database
    a. http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms - search NCDC's database to find various types of severe weather in any area of the U.S.
6. Aviation Weather Center
    a. http://aviationweather.gov/
7. Ocean Prediction Center
    a. http://www.opc.ncep.noaa.gov/ - responsible for forecasts along with watches and warnings for portions of the North Atlantic and North Pacific Oceans

Ron Gurd
ron.gurd@noaa.gov
~~[illegible]~~