Why doesn't the wind blow from high pressure to low?

A laboratory experiment from the
Little Shop of Physics at
Colorado State University

Overview

The wind blows because of differences in air pressure caused by uneven heating of the earth's surface -- the equator is hot, and the poles are cold. So why doesn't wind blow directly from areas of high pressure (the poles) to areas of low pressure (the equator)? This would happen, but for one fact: The earth rotates. The spin of the earth causes the air to spin, and we call this the Coriolis effect.

Necessary materials:

- A clear area such as an open field or gym
- Students

This works best in smaller groups but can be done with 30 - 40 people at once if you have a large enough space.

Theory

The sun heats up the equator and the poles unequally. Air at the equator warms and rises, moves toward the poles, and finally cools and sinks, as in Figure 1. However, the earth is rotating, complicating the otherwise easy flow of air to balance the energy between the equator and the poles. This "sideways" motion of the earth causes air to deflect to the right as it moves in the Northern Hemisphere. In the Southern Hemisphere air is deflected to the left. This deflection of air produces the jet stream that travels east-west in direction! Storms and fronts are left to finish the job of transporting energy from the equator to the poles.

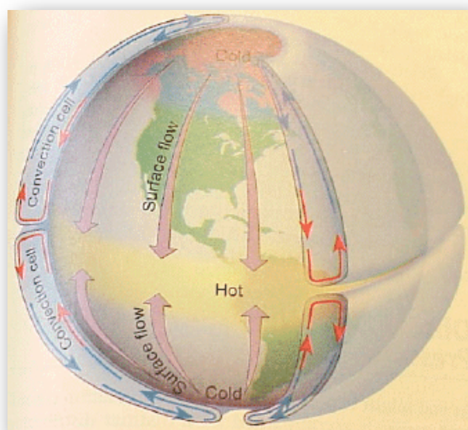


Figure 1: If Earth did not rotate, energy would travel directly from equator toward poles.

Doing the Experiment

Show students weather maps portraying air traveling clockwise around a high pressure system, and counter-clockwise around a low pressure system. Ask them to hypothesize about why air would behave differently around these two systems, and whether there are there any situations in which this wouldn't be the case.

To start, explain to your class that they will be taking part in a kinesthetic activity to demonstrate why air doesn't blow directly from high to low pressure in macroscopic situations, where the rotation of the Earth must be considered.

Have the students form a large circle facing inward. Explain that person is going to pretend to be a parcel of air able to be influenced by differences in air pressure and the Coriolis effect.

Start by telling the class to pretend that there is low pressure at the center of the circle, and high pressure outside the circle (at their backs). If pressure difference was the only factor in wind direction, the low pressure system would collapse, with students all congregating at the center, and that would be the end of it. However, we have the Coriolis effect to consider, so as students start moving toward the center of the circle, they are also deflected to the right, as the Coriolis effect always deflects objects 90 degrees to the right of the direction of travel. They'll end up walking in a counter-clockwise circle (as seen from the top), showing the Coriolis effect balances with the pressure force.

Try several scenarios. Tell them that now there is high pressure at the center of the circle and low pressure outside the circle. (Have them turn around to face outward so they're not walking backwards). Ask them how they should move. (Clockwise!) Have them act this out for storms in the Southern Hemisphere. What would be different? (The Coriolis effect would now act 90 degrees to the *left*!) What would be the same? Have them act this out. In each case, keep track of the direction of movement.

Participants rotating clockwise around a high pressure system.

Summing Up

This is a great way to illustrate how wind direction, on a macroscopic model, varies not only with pressure but also the direction of the Coriolis effect. Once students have done this, they will be able to visualize more readily the reason why high pressure systems spin in opposite directions of low pressure systems.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Why do hurricanes go counterclockwise in the northern hemisphere?

A laboratory experiment from the Little Shop of Physics at Colorado State University

CMMAP

Reach for the sky.

Overview

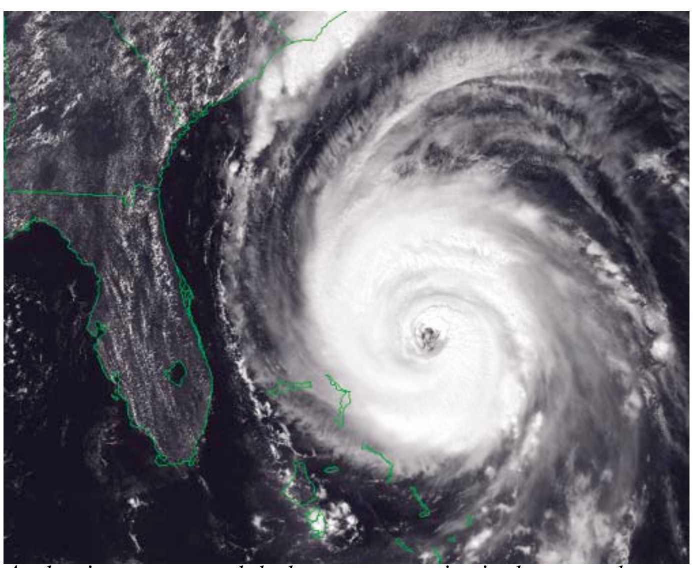
The Coriolis force is part of the reason that hurricanes in the Northern Hemisphere rotate counterclockwise. If the Earth didn't spin, we would have wicked 300 mph winds from the tropics to the poles and back again. The Earth does spin however, and in the mid-latitudes, the Coriolis force causes the wind—and other things—to veer to the right. It is responsible for the rotation of hurricanes.

But the Coriolis force on earth only works on very large scales. It doesn't affect such small things as toilets and sinks. You may have heard of people claiming that toilets and sinks swirl counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere due to this force. As cool as that would be, it's just not true. It turns out that the way the water swirls has to do with a number of conditions such as the shape of the bowl and the way the water enters the bowl. Alistair B. Fraser lists other goofy examples people attribute to the Coriolis force in the different hemispheres, including, the way dogs circle before lying down, and the way women's ringlets curl. The website is called Bad Coriolis and can be found at www.ems.psu.edu.

Necessary materials:

- One foam ball
- A large area to form a circle with your students
- An even number of participants

You may want to demonstrate with just 2 to 6 people in the circle before attempting this with your class. It is also helpful to have a few adults participating in the circle. This activity will be successful if students understand the directions and also are dexterous enough to catch a ball. We know! We tried this with 4th graders and eventually they caught on to how this worked and what was happening.



As the air moves toward the low pressure region in the center, the Coriolis force causes a rightward deflection—leading to the counter-clockwise rotation of the hurricane.

Theory

So what is the Coriolis force? Let's look at a scenario before discussing it further.

Imagine two people playing catch. They are running in a straight line, parallel to each other and tossing the ball back and forth. The ball is easy to catch because they are always directly across from each other. Now, let's make this game more complicated. Our two players opt to continue their game of catch, but decide to run in a circle where they are still across from each other. As they circle counterclockwise, the ball is tossed. Rather than go directly to the catcher, the ball appears to veer to the right. They try it again and the same thing happens. They think something mysterious is pushing the ball to the right. When they ask their friends who have been watching the game, the friends say the ball went straight and the two players just missed it. What is going on?

Why did the players think the ball veered to the right, yet their friends watching from the sidelines, clearly saw that the ball traveled a straight path. It all has to do with frame of reference and Newton's 1st Law: All objects in motion stay in motion unless acted upon by an outside force. The ball does travel in a straight line... but the players don't!

The Coriolis force is an example of a ficitious force, and can be compared to another such force, the centrifugal force. You most likely have felt this while riding in a car. You are traveling straight ahead in a car, when suddenly the driver has to make a sharp left turn. Your body continues to travel forward, but it feels as if your body is pushing out on the car door. Actually, the car door is pushing in on you!

Doing the Experiment

- Have your group form a circle. Have each person point to their partner directly across from them, so they know whom they will toss the ball to.
- Have them take turns tossing the ball underhanded to their partners, so they get a feel for how hard they need to toss the ball to get it across the circle.
- Explain to the class that they will now turn their bodies to the right and start circling to the east, just like the Earth in its orbit. They will continue to toss toward their partner, but the ball can only be caught if it comes directly to an individual. The partner is not supposed to reach across and grab it from someone else.
- Students will soon see that the ball starts out aimed at the partner, but by the time it reaches the other side, is caught by the person to the right of the partner.
- It should appear as if the ball is veering to the right, by the participants in the circle.

Summing Up

The Coriolis force is a complicated concept that is difficult for many to grasp. Be patient and give your students as many experiences as you can with this concept. You may want to show them video clips to reinforce this activity. If you can find a merry-go-round in your area, use it with your students to reinforce this concept.

For More Information

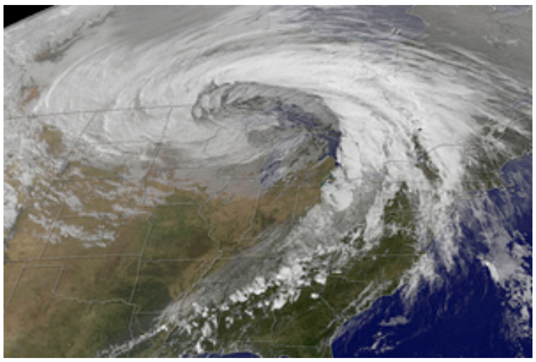
CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

<u>**Midlatitude Cyclones**</u> **– Identifying High/Low Pressure Areas and Warm/Cold Fronts**

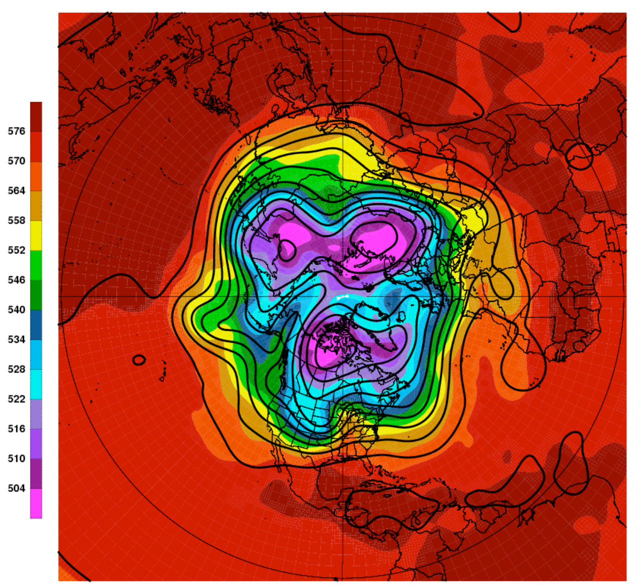
What is a Midlatitude Cyclone?

Midlatitude cyclones are the result of baroclinic waves in the upper atmosphere, which act to lessen earth's equator-to-pole temperature gradient.



-In more detail, midlatitude cyclones occur because of the energy imbalance between the equator and the poles. The temperature gradient that results from the energy imbalance (warm in the tropics, cold at the poles) tilts pressure surfaces and produces the westerly jet in the midlatitudes. Waves within the jet induce convergence and divergence higher in the atmosphere, which then lead to areas of high and low pressure at earth's surface. The eddies, or midlatitude cyclones, within the jet explain much of our wintertime weather.

- Think of the north-south temperature gradient as a source of potential energy. Midlatitude cyclones convert this energy to kinetic energy as they develop and allow the atmosphere to lower its center of mass.



981110/1200V000 1000–500 Thickness (decameters)

November 10, 1998
This activity will allow us to look more closely at a specific midlatitude cyclone from November 10, 1998. This particular storm brought strong winds and heavy rain and snow to much of the central United States.

-Sioux Falls, South Dakota received 12.6 inches of snow in 24 hours. That is the largest snowfall ever recorded on a single November day in Sioux Falls. Strong winds (50-60mph gusts) followed to create blizzard conditions.

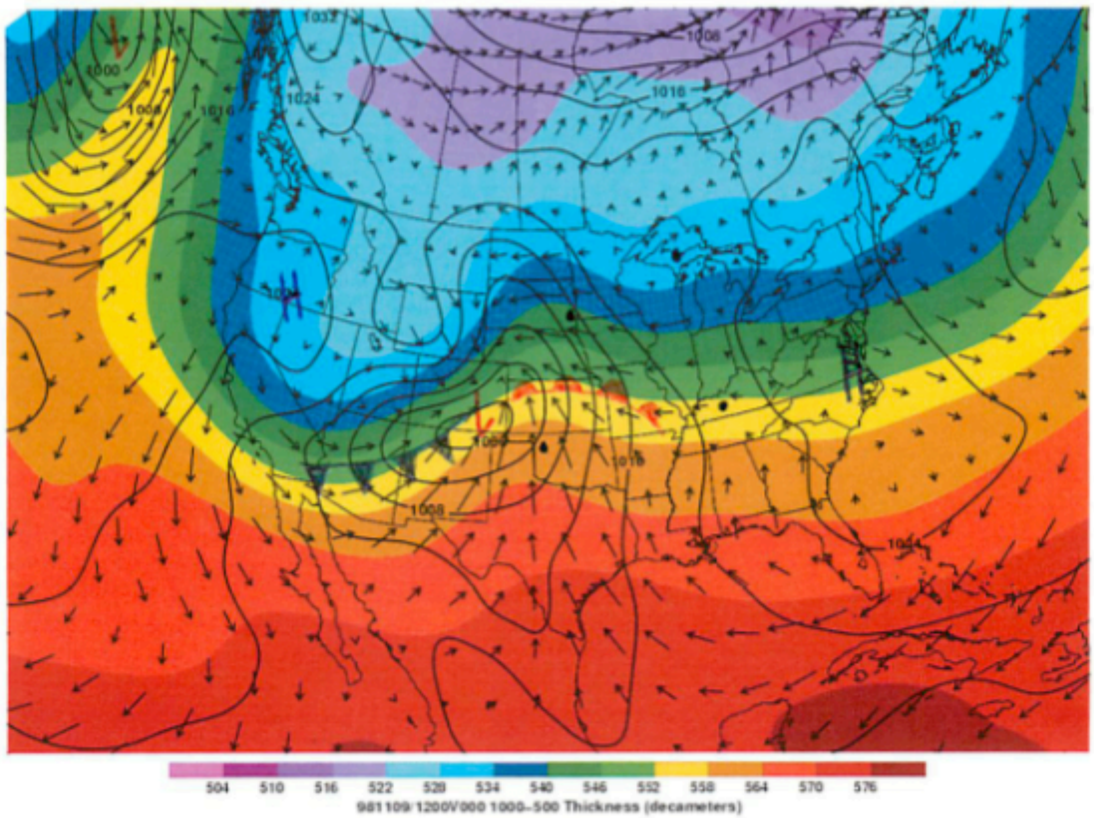
-Wave heights of 15-20 feet were recorded in Lake Michigan and several Michigan towns experienced wind gusts of up to 95mph. High winds from this storm caused 10 deaths, 34 injuries, and over $40 million in damages.

-Minnesota set a state record for low pressure with readings of 963mb. Pressures that low are recorded in Category 3 hurricanes. The speed with which the pressure dropped is astounding. In general, storms are referred to as “bombs” if the central pressure drops more than 24mb in 24 hours (1mb/hour). Storms like “The Perfect Storm” of 1993 fall into this category. The November 1998 storm dropped 30mb in only 18 hours!

This case is unusually intense, but typifies many features of midlatitude cyclones.

Part 1: Interpreting a Basic Weather Map
As we begin to look at the November 1998 storm it will be helpful to understand the most common data and symbols found on weather maps.

The map below contains three main variables: pressure, temperature, and wind.



-<u>PRESSURE</u>: The solid black lines indicate isobars (or lines of constant pressure). The numbers associated with these lines indicate the pressure in mb (i.e. 1006mb).

-<u>TEMPERATURE</u>: The different colors on the map indicate temperature. You may notice that the key below the map indicates that the "thickness" of the 1000mb-500mb layer is being shown. For all intents and purposes this can be thought of as temperature. The warm colors indicate higher temperatures (or thicker layers) and the cool colors indicate colder temperatures (or thinner layers). Atmospheric scientists often use thickness as a measure of temperature because it is a better indicator of the mean temperature of an air mass, which could be different from temperature measurements taken just at the surface.

-<u>WIND</u>: The arrows indicate wind direction and speed. The longer the arrow the greater the wind speed. Refer to the wind direction as the direction the wind has COME from. For example, → would be a westerly wind.

Other symbols contained on this map include:

- HIGH pressure center (local area of highest pressure)

H

- LOW pressure center (local area of lowest pressure)

L

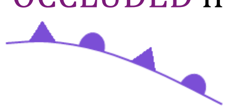
- COLD front

- WARM front

Common symbols not found on this map include:

- STATIONARY front (winds blow parallel to the front; thus, the front does not move)

- OCCLUDED front (occurs when the cold front catches the warm front)



Part 2: Identify and Label the Midlatitude Cyclone
The goal of this section is to increase your understanding of the life cycle of a midlatitude cyclone. You will make use of your weather map skills to identify the midlatitude cyclone (central low pressure with the associated warm and cold fronts) as it develops on November 10, 1998.

Important Characteristics of Cold and Warm Fronts

A COLD FRONT is associated with
- Rapid temperature change (cooing)
- Precipitation (rain and/or snow) - can be of high intensity
- Cumulus (convective) clouds along the front
- A wind shift: winds are S/SW ahead of the front and gusty W/NW behind the front
- Being located along a kink in the pressure lines
- Dry, clear air behind the front
- Pressure falling ahead of the front, rising behind the front
- Fast movement (speed of 10-50mph)

A WARM FRONT is associated with
- Temperature Change (warming)
- Light precipitation or fog well ahead of front
- Stratus clouds well ahead of the front
- A wind shift: winds are E/NE ahead of the front and non-gusty S/SW behind the front
- Pressure falling
- Slow movement (Speed of 5-10mph)

1) On each of the following maps from November 10, 1998, identify the area of lowest pressure and mark with the low pressure symbol. (Hint: Focus on the black isobars. Wind arrows may help as well).

2) On each of the following maps locate the warm and cold fronts and label with the appropriate symbols. Feel free to refer back to the characteristics of warm and cold fronts.

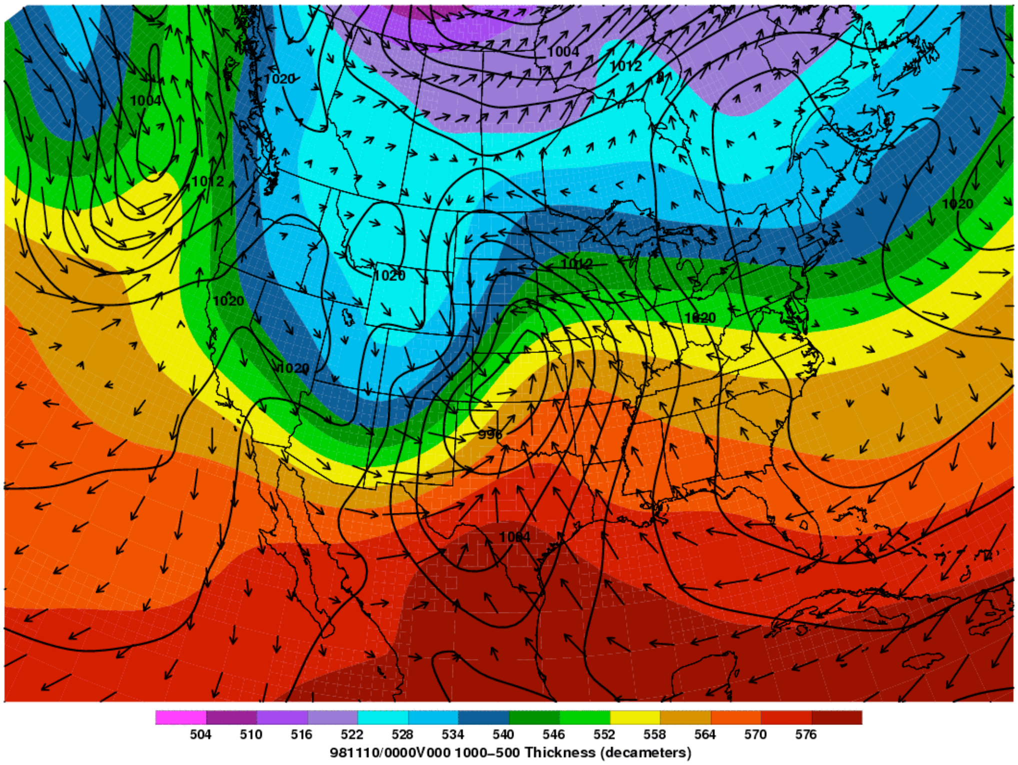
3) Look at the progression of maps and what you have drawn. What do you notice?

4) Can you identify the cold and warm sectors of the midlatitude cyclone? Please label.

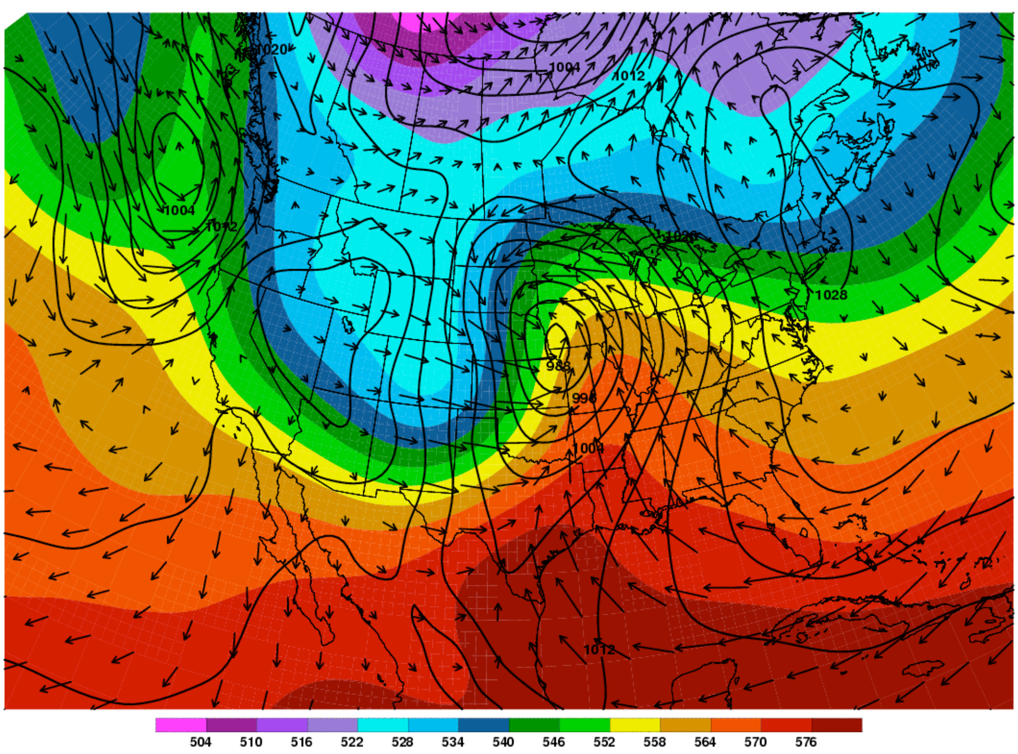
In which direction (north or south) is each of these sectors moving?

Why do you think that is?

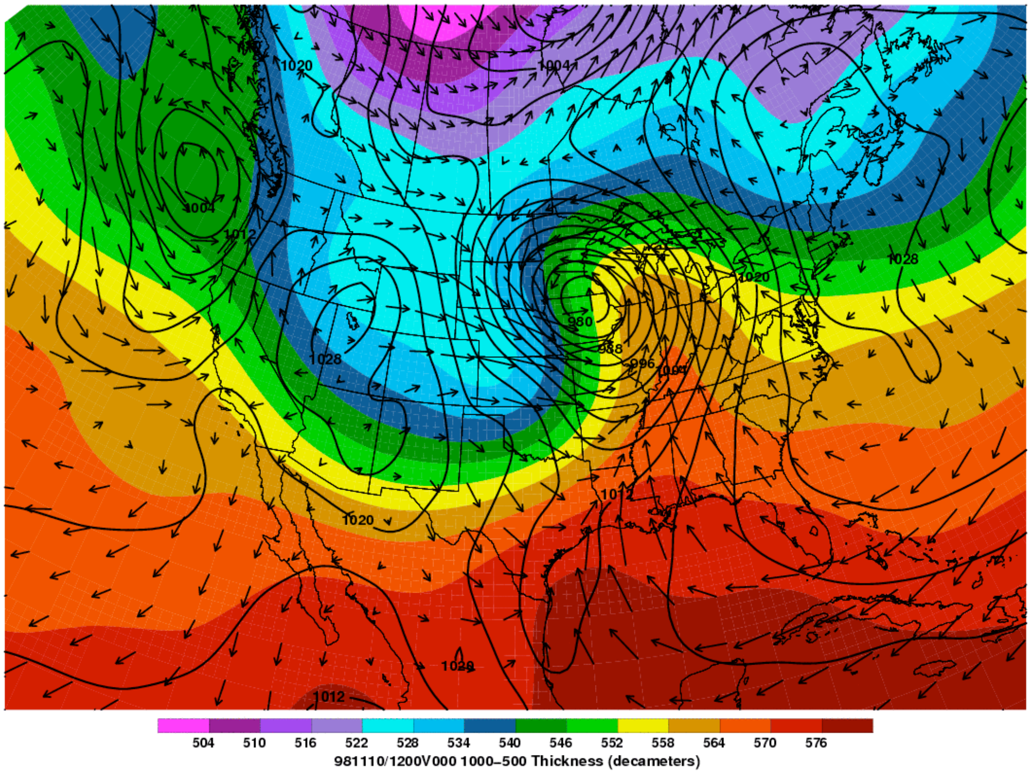
MAP 1



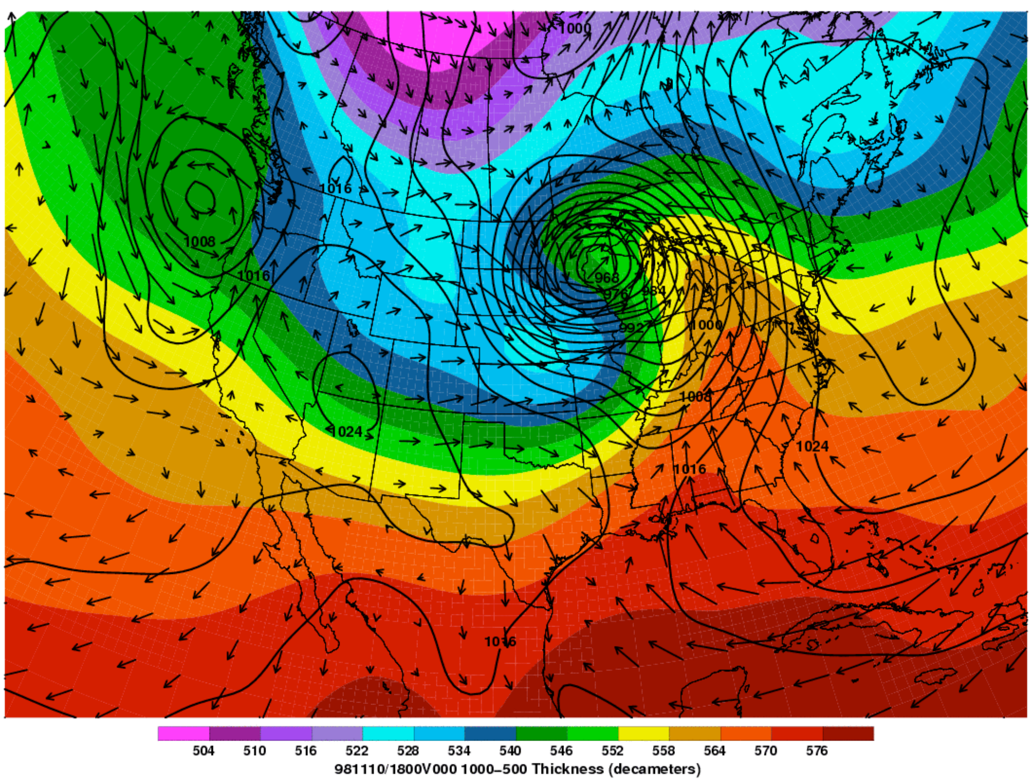
MAP 2: 6 Hours Later



MAP 3: 6 Hours Later



MAP 4: 6 Hours Later



Part 3: Forecast Weather Associated with a Midlatitude Cyclone
This exercise began by describing the weather associated with the November 10, 1998 midlatitude cyclone. You may know what types of weather to expect from this storm, but do you know where and when?

Let's be weather forecasters! We will focus on forecasting for four different cities:

Gage, Oklahoma

Bowling Green, Kentucky

Sioux Falls, South Dakota

Marquette, Michigan

We will be making two forecasts for each of these locations. One forecast for MAP 1 and one forecast for MAP 4 (18 hours later). You can mark each of these cities on your MAP 1 and MAP 4 by using the map on page 3 as a reference. Each city is marked with a small black dot.

Based on what you have learned about midlatitude cyclones and the tendencies in pressure, temperature, and wind associated with warm and cold fronts make a prediction at each time for:

Precipitation (Rain, Snow, or None)

Wind (Direction)

Temperature (Rising, Falling, or Steady) – Initial value given

Pressure (Rising, Falling, or Steady) – Initial value given

1) Fill in the table below.

LOCATION	MAP 1	MAP 4 (18 HOURS LATER)	HAS A FRONT PASSED? IF SO, WHAT KIND?
1 Gage, OK	*Precipitation* *Wind* *Temperature* 50°F *Pressure* 996mb	*Precipitation* *Wind* *Temperature* *Pressure*	
2 Bowling Green, KY	*Precipitation* *Wind* *Temperature* 55°C *Pressure* 1016mb	*Precipitation* *Wind* *Temperature* *Pressure*	
3 Sioux Falls, SD	*Precipitation* *Wind* *Temperature* 43°C *Pressure*	*Precipitation* *Wind* *Temperature* *Pressure*	
4 Marquette, MI	*Precipitation* *Wind* *Temperature* 35°C *Pressure*	*Precipitation* *Wind* *Temperature* *Pressure*	

2) Pick one city and compose a forecast for November 10, 1998. Write your forecast as if it would be read over the radio or on television.

City:
Forecast:

<u>Midlatitude Cyclones</u> – Identifying High/Low Pressure Areas and Warm/Cold Fronts

****KEY**********************************

Part 2: Identify and Label the Midlatitude Cyclone

1) On each of the following maps from November 10, 1998, identify the area of lowest pressure and mark with the low pressure symbol. (Hint: Focus on the black isobars. Wind arrows may help as well). *See maps*

2) On each of the following maps locate the warm and cold fronts and label with the appropriate symbols. Feel free to refer back to the characteristics of warm and cold fronts. *See maps*

3) Look at the progression of maps and what you have drawn. What do you notice?

The midlatitude cyclone is . . .

- *moving northeastward*
- *becoming stronger/the pressure is dropping*
- *has become occluded*
- *gradients in pressure and temperature are increasing (lines and colors are more tightly packed as time goes on)*
- *etc.*

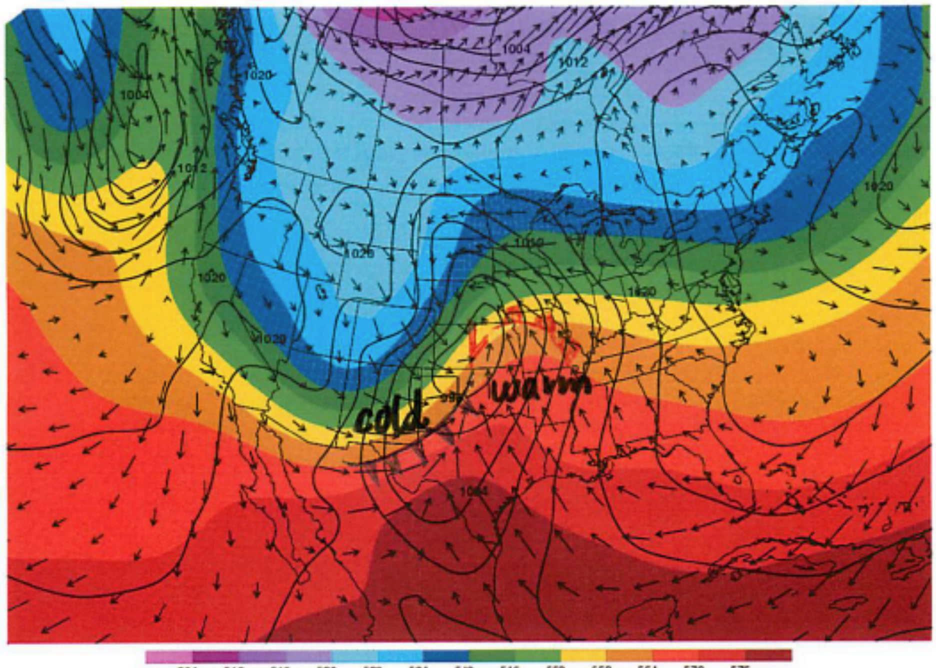
4) Can you identify the cold and warm sectors of the midlatitude cyclone? Please label. *See maps*

In which direction (north or south) is each of these sectors moving?

Cold – moving south
Warm – moving north
Why do you think that is?

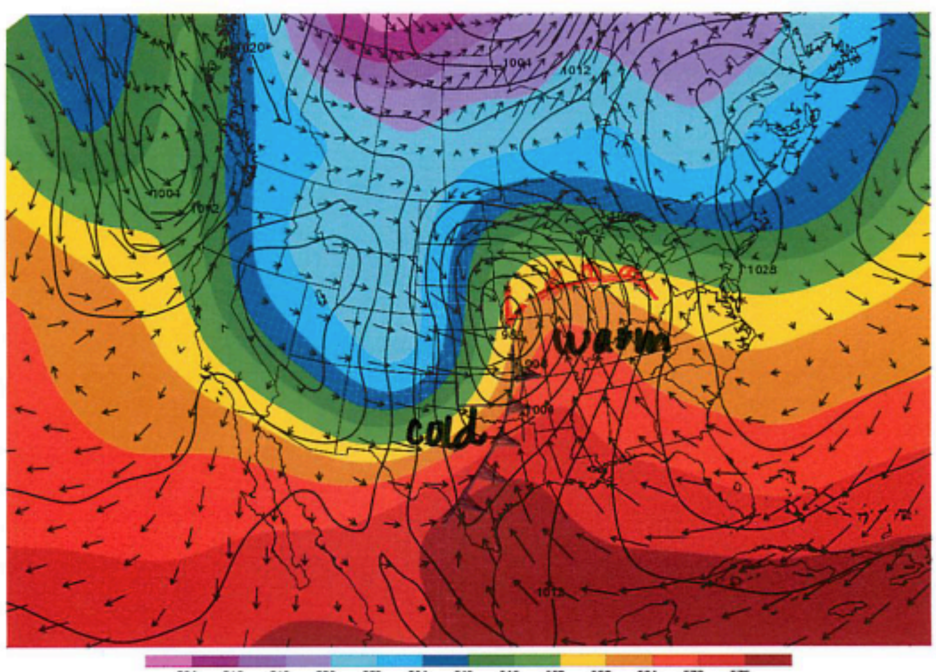
The cyclone is doing its job of balancing the energy discrepancy between the pole and equator. It is moving arm air northward and cold air southward.

MAP 1



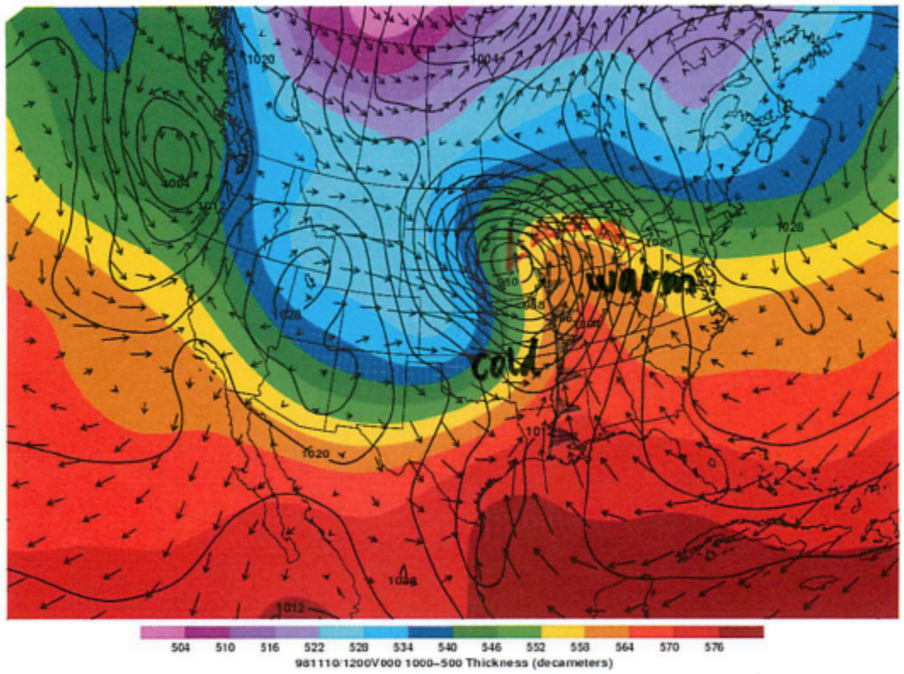
981110/0000V000 1000-500 Thickness (decameters)

MAP 2: 6 Hours Later

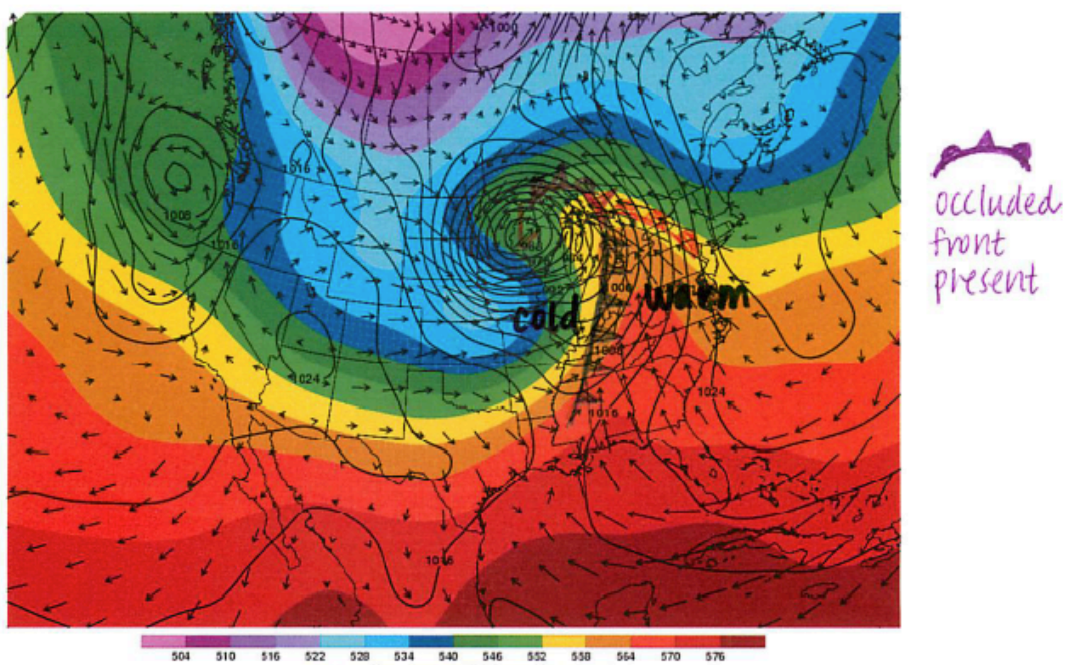


981110/0600V000 1000-500 Thickness (decameters)

MAP 3: 6 Hours Later



MAP 4: 6 Hours Later



Part 3: Forecast Weather Associated with a Midlatitude Cyclone

1) Fill in the table below.

LOCATION	MAP 1	MAP 4 (18 HOURS LATER)	HAS A FRONT PASSED? IF SO, WHAT KIND?
1 Gage, OK	*Precipitation* Rain (Moderate) *Wind* SW or NW (depends on where the front has been drawn; front is either about to pass or just has) *Temperature* 50°F *Pressure* 996mb	*Precipitation* None *Wind* W *Temperature* Falling *Pressure* Rising	Yes, Cold
2 Bowling Green, KY	*Precipitation* Fog or light rain *Wind* E/SE *Temperature* 55°C *Pressure* 1016mb	*Precipitation* None (Or, if cold front has reached KY, moderate rain) *Wind* S (Or, if cold front has reached KY, W) *Temperature* Rising (Or, if cold front has reached KY, falling) *Pressure* Falling (Or, if cold front has reached KY, rising)	Yes, Warm (Or, if cold front has reached KY, warm and cold)

3 Sioux Falls, SD	*Precipitation* Rain (moderate) *Wind* E *Temperature* 43°C *Pressure* 1002mb	*Precipitation* Snow (moderate) *Wind* NW *Temperature* Falling *Pressure* Falling	No, this location has always been on the western side of the midlatitude cyclone; colder air has moved into the area from the north
4 Marquette, MI	*Precipitation* None *Wind* E *Temperature* 35°C *Pressure* 1018mb	*Precipitation* Rain (moderate) *Wind* SE *Temperature* Steady rise then fall *Pressure* Falling	Yes, Occluded

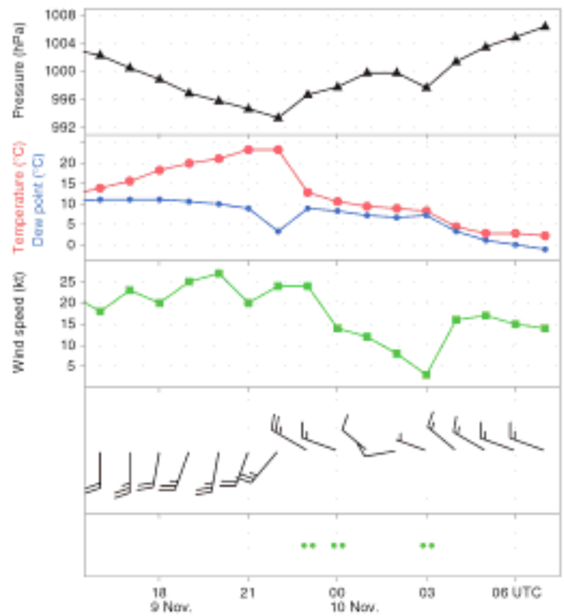
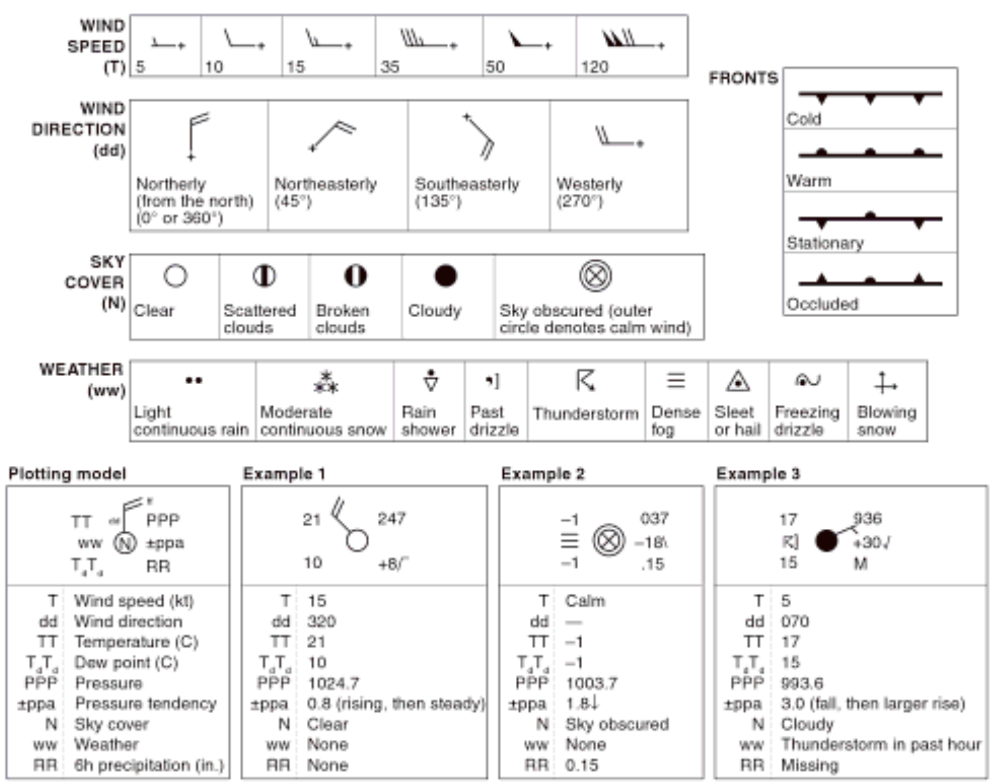


Fig. 8.10 Hourly surface observations at Gage, Oklahoma (KGAG in Fig. 8.36) showing the passage of the primary and secondary cold fronts. The locations of Gage and the other stations for which time series of hourly station observations are shown are indicated in Fig. 8.36 at the end of Section 8.2. [Courtesy of Jennifer Adams, COLA/IGES.]



2) Pick one city and compose a forecast for November 10, 1998. Write your forecast as if it would be read over the radio or on television.

These responses are very open-ended and can vary greatly.

City: *Gage, OK*
Forecast: *Anticipate moderate rain, strong westerly winds, and falling temperatures this morning as a cold front moves through the area. Things should clear later in the day and westerly winds will prevail, along with rising pressure.*

City: *Bowling Green, KY*
Forecast: *(Written as if the cold front has not yet reached town) Anticipate light drizzle as a warm front moves towards us this morning. As the rain recedes temperatures will rise and winds will come from the south.*

City: *Sioux Falls, SD*
Forecast: *Expect a great deal of precipitation today. Moderate rain in the beginning of the day will transition to snow as colder air moves in from the north. Expect snowfall amounts near 12" and high winds. Beware of blizzard conditions.*

City: *Marquette, MI*
Forecast: *Easterly winds and warmer temperatures early in the day will give way to south-easterly winds and quickly falling temperatures as an occluded midlatitude cyclone moves over the region today. Moderate rain can be expected later in the day.*