Chapter 7
Winds and the Global Circulation System
What is atmospheric pressure?
Atmospheric Pressure

- We live at the bottom of an ocean of air
- Since this air has mass, it will exert pressure on the surface below it
- The more air, the greater the pressure – thus, pressure decreases with altitude
- Air is easily compressible – thus, its density decreases with altitude
Atmospheric Pressure

Column of atmosphere one cm in cross section

(a)

Column of atmosphere one inch in cross section

(b)

1kg

15 lb

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- The density of the atmosphere decreases with height, therefore the force (pressure) of the overlying atmosphere also decreases.

- Half of the molecules are held within 5.5 km of the surface.
What determines atmospheric pressure?
Atmospheric Pressure

- Pressure = force per unit area

-Due to gravity the atmosphere exerts a force
According to the Ideal Gas Law: density ($\rho$) and temperature ($T$) control atmospheric pressure ($P$)

$$P = \rho RT$$

$R$ is a constant
Pressure, Density & Temperature

**Density \( (\rho) \)**

- Amount of matter (mass) per unit volume \( (\text{kg/m}^3) \)
- Density (of a gas) is directly proportional to pressure
- Density varies with altitude
Pressure, Density & Temperature

**Temperature (T)**

- Molecules move faster in hot air than cold air
- Faster = more collisions (more force) and therefore higher pressure
- Temperature is directly proportional to pressure
In the atmosphere density and temperature do not change independently.

Example:

When air in the atmosphere is heated it expands and causes a decrease in density and pressure.
Because of the changes in air density, a surface of constant pressure (the shaded gray area) rises in warm, less dense air and lowers in cold, more dense air. These changes in elevation of a constant pressure (500-mb) surface show up as contour lines on a constant pressure (isobaric) 500-mb map.
How is atmospheric pressure measured?
Atmospheric pressure is often measured in millibars (mb)

Atmospheric pressure at sea level is 1013.25 millibars (standard pressure)

At the earth’s surface, pressure varies from 980 mb to 1030 mb (about 5%)
Atmospheric Pressure

- Atmospheric pressure is measured using an instrument called a barometer.

- A mercurial barometer measures atmospheric pressure with a column of mercury.

- Sea-level pressure can also be defined as 29.92 inches of mercury (in. Hg).
A Mercurial Barometer

Diagram details:
- Vacuum
- Glass tube
- Mercury
- Atmospheric pressure
- Dish
- Height of mercury column: 76 cm (30 in.)

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Atmospheric Pressure

- A more common type of barometer is the **aneroid barometer**
- It uses the pressure exerted against a partial vacuum to measure air pressure
What causes differences in pressure?
Surface Heating and Vertical Motion

Warm surfaces encourage upward vertical motion

Upward airflow

Converging Horizontal Air

Warm Surface
Temperature Gradient

- **Temperature Gradient** – variation in air temperature from one place to another

- Warm air is less dense than cold air, so it exerts less pressure than cold air

- Temperature gradients create pressure gradients
FIGURE 2
Because of the changes in air density, a surface of constant pressure (the shaded gray area) rises in warm, less dense air and lowers in cold, more dense air. These changes in elevation of a constant pressure (500-mb) surface show up as contour lines on a constant pressure (isobaric) 500-mb map.
Atmospheric Pressure

- **Pressure Gradient** – variation in atmospheric pressure from one place to another

- In nature, anytime a gradient exists, there will be a force created that attempts to equalize the gradient

- With pressure, we call this gradient the **Pressure Gradient Force**

- The pressure gradient force always acts in a direction from higher to lower pressure
Atmospheric Pressure

- In the presence of the pressure gradient force, the air will be forced to move – *wind*
- Winds flow from an area of higher pressure to an area of lower pressure
- *Isobars* – lines of constant pressure
- Winds usually flow across isobars
Atmospheric Pressure

- Winds, however, are defined in the direction from which they come.
- Thus, a north wind comes from the north, even though it is moving south.
Since land heats faster and cools down faster than water, we should expect pressure gradients to exist.

In the afternoon, the land is warmer than the water. Thus, a low pressure forms over the land and a high pressure forms over water.

Air is forced to flow onshore — a sea breeze.
A Sea Breeze

Diagram showing the formation of a sea breeze with a warm land mass at 90°F and a cooler ocean at 65°F.
Land/Ocean Contrasts

- In the evening, the opposite situation exists

- The water is warmer than the land. Thus, a high pressure forms over the land and a low pressure forms over water.

- Air is forced to flow offshore – a *land breeze*
A Land Breeze

H
50°F

L
65°F
Factors that determine wind speed and direction

1. Pressure Gradient Force (pgf)
2. Coriolis effect (force*)
3. Friction force
Pressure Gradient Force causes the wind to blow
Coriolis Effect (Force)

- Because of the rotation of the earth, any object moving freely near the surface appears to deflect to the right in the NH and to the left in the SH.
FIGURE 9-6 Latitudinal variation in the Coriolis force: deflection is zero at the equator, increases with latitude, and is most pronounced at each pole (note the percentages along the right side of the globe).
Winds and Global Circulation

Let’s start simple:

A homogeneous, non-rotating earth
Winds and Global Circulation

- Homogeneous – no land-water contrasts
- Non-rotating – no rotation about an axis
- Forces in Action:
  - Pressure Gradient Force
Northern Hemisphere

Pressure Gradient Force

Direction of Wind Flow
Southern Hemisphere

Pressure Gradient Force

Direction of Wind Flow
Winds and Global Circulation

- Homogeneous – no land-water contrasts
- Rotating – rotation about the earth’s axis
- Forces in Action:
  - Pressure Gradient Force
  - ???
Winds and Global Circulation

- Homogeneous – no land-water contrasts
- Rotating – rotation about the earth’s axis
- Forces in Action:
  - Pressure Gradient Force
  - Coriolis Force – apparent force caused by the rotation of the earth. Causes objects to be deflected to the right of their path of motion in the Northern Hemisphere and to the left of their path of motion in the Southern Hemisphere
Northern Hemisphere

Pressure Gradient Force

Direction of the Wind

Coriolis Force
Northern Hemisphere

Pressure Gradient Force
Direction of the Wind

Coriolis Force
Northern Hemisphere

Pressure Gradient Force

Coriolis Force

Direction of the Wind

H

L
Coriolis Force
Pressure Gradient Force

Southern Hemisphere
Southern Hemisphere

Pressure Gradient Force

Coriolis Force

Direction of the Wind
The Effect of Friction

- **Friction** is a drag force that inhibits forward movement.
- Friction always works in the opposite direction of motion.
- Thus, friction will cause the wind to cross the isobars, but not at a perpendicular angle.
- Low friction – shallow angle
- High friction – steeper angle
Northern Hemisphere

Pressure Gradient Force

Friction

Coriolis Force

Direction of the Wind
Foucault Pendulum

http://www.astro.louisville.edu/foucault/
Frictional Force

- Friction will cause the wind to cross the isobars at an angle
Circulation around Highs and Lows

Low Pressure System = **Cyclone**

- Inward spiral of air (pressure gradient force)
- Rising air in center of cyclone (convergence)
- Counter-clockwise spiral in NH
- Clockwise spiral in SH
- Usually small systems and strong winds
Circulation around Highs and Lows

High Pressure System = **Anticyclone**

- outward spiral of air (pressure gradient force)
- Descending air in center of cyclone (divergence)
  - clockwise spiral in NH
  - **Counter-clockwise spiral in SH**
- Usually large systems and light winds
Cyclones and anticyclones are about 1000 kilometers (approx. 600 mi) across, or more.

They can remain in one location or they can move rapidly, to create weather disturbances.
Winds and Global Circulation
Surface Winds on an Ideal Earth

- **Hadley cell** – air rises over the equator, flows poleward, and descends at about 30 degrees latitude

- Air converges toward the equator to replace the air that is moving aloft (**Intertropical Convergence Zone**)
Surface Winds on an Ideal Earth

- **Subtropical High Pressure Belts** – poleward of the Hadley cell, air descends and surface pressures are high (at about 30 degrees latitude)
  - A number of large surface anticyclones are formed
  - Winds are weak at the center of these anticyclones

- **Trade Winds** – winds around the subtropical highs that are spiraling out
  - The winds moving equatorward are the strong and dependable trade winds
  - Northeast trades (NH), southeast (SH)
Surface Winds on an Ideal Earth

- **Westerlies** – poleward of the subtropical anticyclones, air spiraling outward produces the “westerlies”
  - Pressure and wind patterns are more complex in the mid-latitudes.... On average, winds are more often from the west
  - This latitudinal belt is a zone of conflict between air bodies with different characteristics... cool, dry air move into the region, from the pole (polar outbreaks)
  - The border is known as the **polar front**
Surface Winds on an Ideal Earth

- **Polar Easterlies**— at the poles, the air is intensely cold causing high pressure
  - Outspiraling of winds around a polar anticyclone should create polar easterlies
Figure 5-2: Winds for a homogeneous, rotating earth. Note that the Hadley Cells extend vertically in the troposphere whereas the other winds are surface winds.
Winds and Global Circulation

This is the wind pattern on an idealized earth....
(no seasons, and no land/water contrasts)

On the real earth, we see more complex wind patterns that vary seasonally
Local Winds
A Sea Breeze

90°F

65°F
A Land Breeze

H 50°F  L 65°F
Mountain and Valley Winds

- **Day:** Sun direction heats the mountain, causing air to rise by convection. Air is drawn up to replace convected air.

- **Night:** Air cools rapidly on the mountain, creating a pressure difference with the valley. Denser air flows downslope into the valley, creating a valley breeze.
Mountain and Valley Winds

- Local winds that alternate in direction like the land and sea breezes

**Mountain Winds** – during the day, mountain side is heated intensely by the sun, causing air to rise. This causes wind to blow from the plains below, up the mountain slopes

**Valley Winds** – At night, the mountain cools rapidly. The cooler, denser hill slope air then flows down the valley to the plains below
Upper Level Winds

Geostrophic Winds: are influenced by pgf and coriolis

- Winds flow perpendicular to the pressure gradient
- These winds are often called “jet streams”
Upper Level Winds

**Geostrophic Winds**: occurs in the upper atmosphere (no friction)
Surface Winds

- Friction reduces the wind velocity which reduces the coriolis force.
- Coriolis force no longer balances the PGF, so wind blows across the isobars toward the Low.
Upper Level Winds

Jet Streams = narrow zones of very fast winds at a high altitude (top of the troposphere, lower part of the stratosphere)

Polar-Front Jet Stream: located along the polar front (fluctuating boundary between cold polar air and warmer tropical air)
  windspeeds of ~ 400km/hr (225 mph)

Subtropical Jet Stream: located in the subtropics at the tropopause just above the Hadley cell
  windspeeds of ~ 350 km/hr (200 mph)
Rossby Waves

Rossby Waves = undulations in the polar jet streams

- The waves arise in a zone of contact between cold polar air and warm tropical air

- As a result, warm air pushes north and cold air is brought south

- Eventually, the air mass intrusions are cut off, leaving a pool of cold air at a latitude far south of its normal location
Waves are strongly developed. The cold air occupies troughs of low pressure. When the waves are pinched off, they form cyclones of cold air.
Heterogeneous, Rotating Earth

- Land/Water differences in pressure systems

- In Winter, differences are pronounced at about 60° latitude
  - Highs over land, Lows over water

- In Summer, differences are pronounced at about 30° latitude
  - Lows over land, Highs over water
Summary of the Forces

- A parcel of air in motion near the surface is subjected to *three influences*:
  - I. Pressure Gradient Force
  - II. Coriolis Force
  - III. Friction

- Therefore, air will move away from high to low pressure at an angle to the pressure gradient
Local Winds

- **Drainage Winds** – occur when cold, dense air flows under the influence of gravity from higher to lower regions (occurs around mountains and ice sheets)

- **Chinook Winds** – occur on the leeward side of mountains. The descending air is heated and dried thus producing hot and dry winds
Oceanic Circulation

- Circulation of the Oceanic Mixed Layer
- Wind-driven
  - “The Wind Sets the Ocean in Motion”
- Since the ocean is a bounded basin, oceanic flow will be in a circular motion – Gyres
- Unlike winds, ocean currents are defined in the direction to which they flow
  - e.g., a flow from south to north in the Northern Hemisphere is called either a northerly current or a warm current
Several of the 60,000 Nike shoes spilled in May 1990