Chapter 6
Air Pressure & Winds
Air Pressure

1. The pressure of any gas is due to the continuous bombardment by air molecules

2. Definition - Air pressure is the force per unit area exerted against a surface via the continuous bombardment by air molecules
1. **Air Pressure** at a point is the pressure (force per unit area) exerted by the weight of the air above.

2. Weight is also force per unit area.

3. Average air pressure is 101,235 N/m$^2$ (N = Newtons) (14.7 lbs/square inch).

4. The air pressure is the same in all directions around a point.
Pressure exerted by the atmosphere

1 kg/cm\(^2\) or 14.7 lbs/in\(^2\)

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Measuring Air Pressure

1. *Units* - newtons/square meter (called a pascal), millibars, mm of mercury, atmospheres

2. One millibar = 100 newtons/square meter (pascals) - *definition* of mb

3. One atmosphere = 101,325 N/m $^2$ or 1012.35 mb
Highest recorded sea level pressure: 1084 mb (32.01 in.)
Agata, Siberia (December, 1968)

Highest recorded sea level pressure in United States:
1064 mb (31.42 in.) Miles City, Montana (December, 1983)

Strong high pressure system (anticyclone)

Average sea level pressure: 1013.25 mb (29.92 in.)

Strong low pressure system (cyclone)

Hurricane Katrina (August, 2005): 902 mb (26.71 in.)

Hurricane Wilma (October, 2005): 882 mb (26.12 in.)

Lowest pressure recorded for an Atlantic hurricane

Lowest recorded sea level pressure: 870 mb (25.70 in.)
Typhoon Tip (October, 1979)
1. Measured by mercury barometers and aneroid (without liquid) barometers
2. Air pressure measurements are converted to sea-level equivalents
3. Horizontal variations in pressure are small
4. Pressure ranges between 30 and 60 millibars above or below average sea-level pressure
Factors Affecting Air Pressure (Appendix D)

1. **Ideal Gas Law** --- $pV = nRT$

2. $p = \text{pressure}$, $V = \text{volume}$, $n = \text{number of moles in } V$ (amount of gas), $R$ is the Universal Gas Constant, and $T$ is the absolute temperature
Temperature & Pressure

• The air pressure is **HIGH** if the temperature is LOW, because there is more air in the column of air above you.
• e.g. Siberian Winter LOW – give off-shore winds (dry)
• The air pressure is **LOW** if the temperature is HIGH
• e.g. SW Asia or US in Summer (moist winds blow onshore)
Water Content and Pressure

- Water (H$_2$O) has a molecular weight of 1+1+16 = 18. [O has 8p+8n]
- Nitrogen (N$_2$) has a molecular weight of 14 +14 = 28
- Oxygen has a molecular weight of 16 +16 = 32
- Therefore water vapor is lighter than air.
- Therefore humid air is lighter than dry air.
- Therefore humid air exerts lower pressure.
Pressure Changes with Altitude

1. As the altitude increases, the amount of air above it decreases, and the pressure therefore decreases.

2. Pressure drops by about \( \frac{1}{2} \) for every 5.6 km increase in altitude.
Aircraft follow surfaces of constant pressure (not altitude)

- Altimeter reads 10 km at 260 mb
- Altimeter reads 8 km at 360 mb

Cold air column
Warm air column

Ground
San Francisco, CA

Sea level

1008 mb

0 mb

1008 mb

Pressure reading
Correction

Denver, CO

1600 m
(5300 feet)

840 mb

172 mb

1012 mb

Corrected value
Air Flow & Pressure

- **Convergence** – winds blow air into a region. If the air cannot move horizontally, it piles up (nowhere else to go) & pressure rises. E.g. bottleneck (accident) on highway.

- **Divergence** – winds blow air away from a region, lowering the pressure. E.g., you have cleared the bottleneck.
Factors Affecting Wind

1. *Wind* is the horizontal movement of air

2. Wind results from horizontal differences in air pressure

3. Winds do not blow directly from the high pressure region to the low pressure region because the *Earth is rotating*, and because of *Earth-air friction*. 
Factors Affecting Wind 2

1. Winds are controlled by a combination of:

   (1) pressure-gradient force
   
   (2) the Coriolis force
   
   (3) friction (braking)
Pressure-Gradient Force

1. The force that drives the winds results from the gradient (rate of change of pressure with distance) of pressure.

2. Isobars are contours that connect places on the Earth that have the same pressure.

3. If the isobars are close together, the pressure gradient is large.
Isobars

High pressure

1016 mb

1012 mb

1008 mb

1004 mb

1000 mb

996 mb

992 mb

Low pressure

Weak pressure gradient

Weak winds

Steep pressure gradient

Strong winds
Pressure Gradient Force

- $F_{PG} = \frac{\text{[change in pressure]}}{\text{[change in distance]}} / \text{[density of air]}
- Pressure is in pascals (1 mb = 100 Pa)
- Distance is in meters
- Density is in kg/m$^3$ [0.75 kg/m$^3$ for air at 5 km]
Pressure-gradient Force  - 2

1. Pressure gradients are at right angles to the isobars

2. Pressure differences arise from unequal heating of Earth's land-sea interface.
1. **Sea breezes** are an example of how temperature differences can generate a horizontal pressure gradient.

2. During the day, the land heats up more than the sea. This means that the *pressure at a particular altitude* increases over the land, but not the sea. The resulting horizontal pressure gradient drives a horizontal wind out to sea.

3. At night, the sea is warmer than the land, and a sea breeze blows towards the land.
Sea breezes

(a) Before sunrise

(b) After sunrise

(c) Sea breeze established
1. Once the pressure gradient force starts the air in motion, the **Coriolis force** and **friction** greatly modify the air flow.

2. Air does not flow vertically upwards, even though the pressure decreases upwards. This is because the upward pressure gradient force is matched by the downward force of gravity. This balance is known as **hydrostatic equilibrium**.

3. The equilibrium is not always perfect, so there is usually some slow vertical movement
Coriolis Force

1. Not really a force. Coriolis Effect. Caused by the rotation of the Earth during the time that an object (or parcel of air) takes to complete its journey.

2. All freely moving objects are deflected to the right of their path in the northern hemisphere, and to the left in the southern hemisphere, regardless of whether they are travelling north or south.

3. Same thing happens for west-east flow, as the Earth turns underneath the wind, except at the equator.
(a) Nonrotating Earth

(b) Rotating Earth
**Coriolis Force** is

- always at right angles to the direction of the wind
- affects only wind direction, not speed
- is affected by wind speed
- is strongest at the poles, and zero at the equator.
Pressure Gradient Force (and Fronts)
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Friction

1. Friction between the Earth and the winds at the surface acts to slow the winds down.

2. Winds increase with altitude because friction with ground disappears.

3. Examined in more detail later.
Winds Aloft & Geostrophic Flow

1. We consider winds at altitudes of a few km, where there is little friction.

2. The only horizontal force acting on a stationary parcel of air is the pressure-gradient force. As the parcel starts to accelerate to higher speeds, the Coriolis force deflects it to the right (in NH).

3. As the wind speed increases, the deflection increases until the flow of a parcel of air (wind) is parallel to the isobars.
1. In idealized geostrophic flow, the winds flow parallel to the isobars, with a speed that increases as the isobars get closer together,

2. Since winds cause pressure patterns, pressure patterns can be derived from measurements of the pressure.

3. On a 500 mb map, the heights in meters are greatest where the pressure is higher (have to go higher for the pressure to drop to 500 mb).
Winds Aloft & Geostrophic Flow - 3

1. **Buys Ballot's Law** "If you stand with your back to the wind, low pressure will be found to your left, and high pressure to your right." Holds for high altitudes.

2. At the surface, because of friction and topography, you have to turn clockwise by 30 degrees after you have stood with the wind at your back.
Curved Flow & the Gradient Winds

1. **Gradient winds** - winds blow at constant speed parallel to isobars, even curved one.

2. When air flows into a region of low pressure, the Coriolis force deflects it to the right, and the resulting winds blow anticlockwise.

3. **Cyclones** are centers of low pressure. The winds flowing around them are called cyclonic winds. Counterclockwise in NH.

4. Anticyclonic flow around **anticyclones** (regions of high pressure) clockwise in NH.
(a) Cyclonic flow (Northern Hemisphere)

(b) Anticyclonic flow (Northern Hemisphere)
(a) Upper-level wind (no friction)

(b) Surface wind (smooth terrain)

(c) Surface wind (rugged terrain)
Surface Winds

1. Pressure gradient force is not affected by wind speed, but the Coriolis force decreases if the wind speed drops.
2. If friction slows down the wind, the Coriolis force gets weaker, and the winds move across the isobars.
3. If the surface is smooth, friction is small, and air moves at an angle of about 10 to 20 degrees to the isobars, at speeds roughly 2/3 that of geostrophic flow.
A snow fence slows the wind down, reducing its ability to transport snow. Snow accumulates on the downwind side of the fence.
(a) Upper-level wind (no friction)

(b) Surface wind (effect of friction)
Surface Winds - 2

1. Over rugged terrain, the higher friction leads to angles as great as 45 degrees, and speed about 1/2 that of geostrophic flow.

2. Friction causes a net inflow (convergence) around a cyclone, and a net outflow (divergence) around an anticyclone.

3. Winds blow into and counterclockwise about a surface cyclone, and outward and clockwise about a surface anticyclone.
Cyclonic & anti-cyclonic flow in the northern hemisphere
Gulf of Alaska
Brazil
How Winds Generate Vertical Air Motion

1. The movement of air can itself produce pressure changes, and hence generate winds.

2. We examine the interrelationship between horizontal and vertical flow, and its effects on the weather.
Vertical Airflow Associated with Cyclones & Anticyclones

1. Winds blow into low pressure regions (cyclones).
2. The area of the low into which the air can flow gets smaller as the wind penetrates the low.
3. This causes horizontal convergence, and the height of a column of air increases (air moves upwards).
Vertical Airflow Associated with Cyclones & Anticyclones - 2

1. But this would increase the pressure, which would make the low disappear.
2. What really happens is that the rising air diverges when it gets aloft.
3. Vertical movement is usually slow, about 1 km/day.
1. The rising air often results in cloud formation and precipitation, so the passage of a low pressure center is often related to unstable conditions and stormy weather.

2. Similar story for high pressure regions.

3. Lows move roughly **west to east** across the US, taking about 3 to 7 days.
Factors that Promote Vertical Airflow

1. *Friction* can cause both convergence and divergence.

2. For example, when wind blows off a smooth sea onto rougher land, the increased friction decreases the wind speed. The air over the land slows down, resulting in a pile-up of air upstream. This causes convergence, and the air will rise over the ocean.

3. Flow from land to sea results in divergence, as the wind speeds up over the ocean.
1. **Mountains** can also cause convergence and divergence.

2. As the air rises vertically over the mountains, it is compressed vertically, resulting in horizontal divergence aloft.

3. When the air reaches the lee side of the mountains, it experiences vertical expansion, which causes horizontal convergence.
Wind Measurement

1. We need to know the speed of the wind, and the direction from which it comes.
2. A wind vane always points into the wind - gives direction.
3. Winds that blow consistently from the same direction are called prevailing winds.
Wind Measurement - 2

1. A **Wind Rose** is used to show how often wind blows from each direction around a circle.

2. A **cup anemometer** is used to measure wind speed.

3. **Wind socks** give estimates of wind direction and size.
Aerovane
GOES upper-level winds
Wind Energy
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* The total amount of electricity that could potentially be generated each year, measured in billions of kilowatt hours. A typical American home would use several hundred kilowatt hours per month.
Wind potential for the U.S.
End Chapter 6

Chapter 6 homework: GIST: 7, 10, 11, 12

Problem 2 IF YOU DARE!!!!