Chapter 4: Pressure and Wind

- Pressure, Measurement, Distribution
- Hydrostatic Balance
- Pressure Gradient and Coriolis Force
- Geostrophic Balance
- Upper and Near-Surface Winds

One Atmospheric Pressure

- The average air pressure at sea level is equivalent to the pressure produced by a column of water about 10 meters (or about 76 cm of mercury column).
- This standard atmosphere pressure is often expressed as 1013 mb (millibars), which means a pressure of about 1 kilogram per square centimeter (14.7 lbs/in²).

Units of Atmospheric Pressure

- **Pascal (Pa):** a SI (Systeme Internationale) unit for air pressure.
  
  - $1 \text{ Pa} = \text{force of 1 newton acting on a surface of one square meter}$
  
  - $1 \text{ hectopascal (hPa)} = 1 \text{ millibar (mb)}$ [hecto = one hundred = 100]

- **Bar:** a more popular unit for air pressure.
  
  - $1 \text{ bar} = 1000 \text{ hPa} = 1000 \text{ mb}$

- **One atmospheric pressure** = standard value of atmospheric pressure at sea level $= 1013.25 \text{ mb} = 1013.25 \text{ hPa}$.

Measurement of Atmos. Pressure

- **Mercury Barometers**
  - Height of mercury indicates downward force of air pressure
  - Three barometric corrections must be made to ensure homogeneity of pressure readings
  - First corrects for elevation, the second for air temperature (affects density of mercury), and the third involves a slight correction for gravity with latitude

- **Aneroid Barometers**
  - Use a collapsible chamber which compresses proportionally to air pressure
  - Requires only an initial adjustment for elevation
Pressure Correction for Elevation

- Pressure decreases with height.
- Recording actual pressures may be misleading as a result.
- All recording stations are reduced to sea level pressure equivalents to facilitate horizontal comparisons.
- Near the surface, the pressure decreases about 100mb by moving 1km higher in elevation.

Isobar

- It is useful to examine horizontal pressure differences across space.
- Pressure maps depict isobars, lines of equal pressure.
- Through analysis of isobaric charts, pressure gradients are apparent.
- Steep (weak) pressure gradients are indicated by closely (widely) spaced isobars.
Pressure Gradients

- **Pressure Gradients**
  - The pressure gradient force initiates movement of atmospheric mass, wind, from areas of higher to areas of lower pressure

- **Horizontal Pressure Gradients**
  - Typically only small gradients exist across large spatial scales (1mb/100km)
  - Smaller scale weather features, such as hurricanes and tornadoes, display larger pressure gradients across small areas (1mb/6km)

- **Vertical Pressure Gradients**
  - *Average vertical pressure gradients are usually greater than extreme examples of horizontal pressure gradients* as pressure always decreases with altitude (1mb/10m)

Hydrostatic Balance in the Vertical

- **vertical pressure force = gravitational force**

\[-(dP) \times (dA) = \rho \times (dz) \times (dA) \times g\]

\[dP = -\rho gdz\]

\[dP/\Delta z = -\rho g\]

*The hydrostatic balance!*

What Does Hydrostatic Balance Tell Us?

- **The hydrostatic equation tells us how quickly air pressure drops with height.**

  - The rate at which air pressure decreases with height (\(\Delta P/\Delta z\)) is equal to the air density (\(\rho\)) times the acceleration of gravity (\(g\))
The Ideal Gas Law

- An equation of state describes the relationship among pressure, temperature, and density of any material.
- All gases are found to follow approximately the same equation of state, which is referred to as the “ideal gas law (equation)”. 
- Atmospheric gases, whether considered individually or as a mixture, obey the following ideal gas equation:

\[
P = \rho R T
\]

- Pressure
- Density: \( \rho = m/V \)
- Temperature (degree Kelvin)
- Gas constant (its value depends on the gas considered)

Hydrostatic Balance and Atmospheric Vertical Structure

- Since \( P = \rho RT \) (the ideal gas law), the hydrostatic equation becomes:
  \[
dP = -\frac{P}{RT} \times gdz
  \]
  \[
  \frac{dP}{P} = -\frac{g}{RT} \times dz
  \]
  \[
  P = P_s \exp\left(-\frac{gz}{RT}\right)
  \]
  \[
  P = P_s \exp\left(-\frac{z}{H}\right)
  \]

- The atmospheric pressure decreases exponentially with height.

Temperature and Pressure

- Hydrostatic balance tells us that the pressure decrease with height is determined by the temperature inside the vertical column.
- Pressure decreases faster in the cold-air column and slower in the warm-air column.
- Pressure drops more rapidly with height at high latitudes and lowers the height of the pressure surface.

Wind Changes with Height

- (from Weather & Climate)
Pressure Gradient Force

- PG = (pressure difference) / distance
- Pressure gradient force goes from high pressure to low pressure.
- Closely spaced isobars on a weather map indicate steep pressure gradient.

(from Meteorology Today)

Balance of Force in the Horizontal

H (high pressure)
L (low pressure)

Can happen in the tropics where the Coriolis force is small.

(from Weather & Climate)

Force that Determines Wind

- Pressure gradient force
- Coriolis force (Earth’s Rotation)
- Friction (near Earth’s surface)
- Centrifugal force

Coriolis Force

- First, Point A rotates faster than Point B (U_A > U_B)
  - U_A > U_B
  - A northward motion starting at A will arrive to the east of B
  - It looks like there is a “force” pushing the northward motion toward right
  - This apparent force is called “Coriolis force”:

\[
\text{Coriolis Force} = fV
\]

where \( f = 2\Omega \sin(\text{lat}) \) and \( \Omega = 7.292 \times 10^{-5} \text{ rad s}^{-1} \)
Coriolis Force

- Coriolis force causes the wind to deflect to the right of its intent path in the Northern Hemisphere and to the left in the Southern Hemisphere.
- The magnitude of Coriolis force depends on (1) the rotation of the Earth, (2) the speed of the moving object, and (3) its latitudinal location.
- The stronger the speed (such as wind speed), the stronger the Coriolis force.
- The higher the latitude, the stronger the Coriolis force.
- Coriolis force is zero at the equator.
- Coriolis force is one major factor that determine weather pattern.

Coriolis Force Change with latitudes

Upper Atmospheric Winds

- By doing scale analysis, it has been shown that large-scale and synoptic-scale weather system are in geostrophic balance.
- Geostrophic winds always follow the constant pressure lines (isobar). Therefore, we can figure out flow motion by looking at the pressure distribution.
**Upper Atmosphere Geostrophic Flow**

![Images showing cyclonic and anticyclonic flows in the Northern and Southern Hemispheres.](figures from Weather & Climate)

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**Frictional Force**

- A force of opposition which slows air in motion.
- Initiated at the surface and extend, decreasingly, aloft.
- Important for air within 1.5 km (1 mi) of the surface, the *planetary boundary layer*.
- Because friction reduces wind speed it also reduces Coriolis deflection.
- Friction above 1.5 km is negligible.
- Above 1.5 km = the *free atmosphere*.

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**Scales of Motions in the Atmosphere**

![Scales diagram showing different atmospheric scales and phenomena.](figures from Weather & Climate)

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**Surface Winds**

- Surface friction force slows down the geostrophic flow.
- The flow turns into (out of) the low (high) press sides.
- Convergence (divergence) is produced with the flow.
Surface Geostrophic Flow

Cyclonic Flow
Anticyclonic Flow

(From Weather & Climate)

Surface High and Low Pressure Systems

(Centripetal Force)

The force that changes the direction (but not the speed) of motion is called the centrifugal force.

Centrifugal Force = \( \frac{V^2}{R} \)

V = wind speed
R = the radius of the curvature

(From The Atmosphere)
Gradient Wind Balance

- The three-way balance of horizontal pressure gradient, Coriolis force, and the centrifugal force is called the gradient wind balance.

- The gradient wind is an excellent approximation to the actual wind observed above the Earth’s surface, especially at the middle latitudes.

Super- and Sub-Geostrophic Wind

- For high pressure system
  - gradient wind > geostrophic wind
  - supergeostrophic.

- For low pressure system
  - gradient wind < geostrophic wind
  - subgeostrophic.

(From Meteorology: Understanding the Atmosphere)

Troughs, Ridges, Cyclones, and Anticyclones

Wind direction always indicates the direction from which wind blows.

An aerovane indicates both wind speed and direction.

Measuring Winds