# Chapter 5 – Air-Sea Interactions

Chapter overview

- The atmosphere and the ocean are an interdependent system.
- Earth has seasons because it is tilted on its axis.
- There are three major wind belts in each hemisphere.
- The Coriolis effect influences atmosphere and ocean behavior.
- Oceanic climate patterns are related to solar energy distribution.

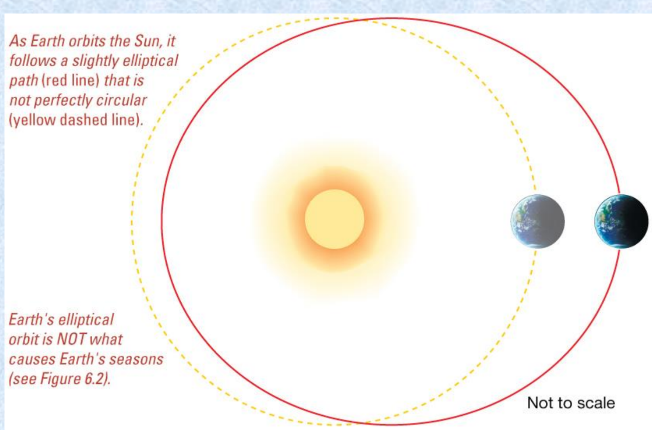
# Chapter 5 – Air-Sea Interactions

# Atmosphere and Oceans

- Solar energy heats Earth, generates winds.
- Winds drive ocean currents.
- Extreme weather events may be related to ocean.
- Global warming affects oceans.

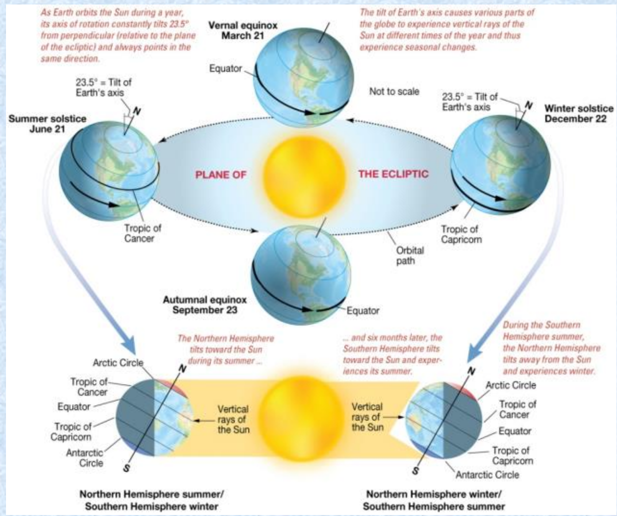
# Earth's Seasons

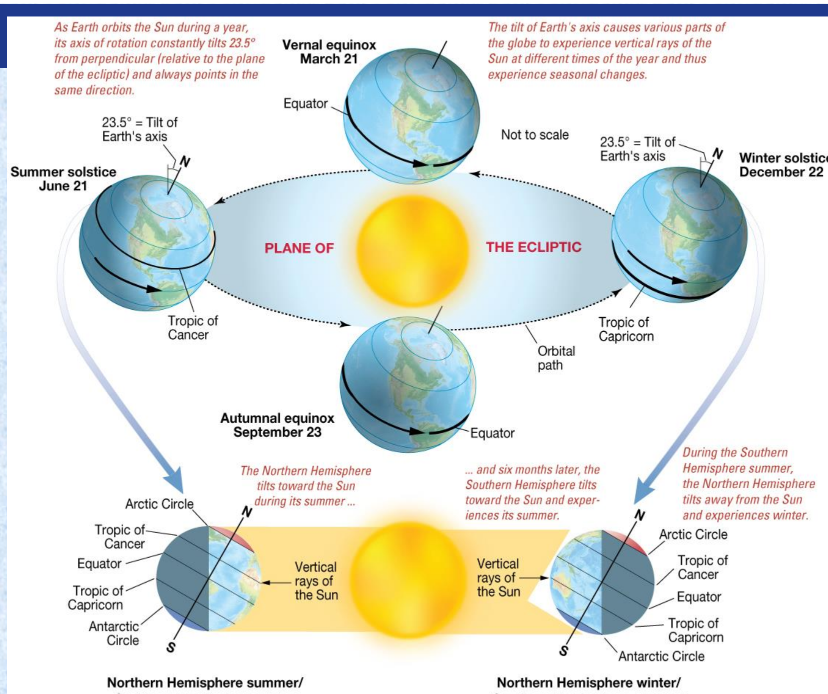
- Earth's orbit is slightly elliptical.
- Not the cause for seasons.



## Earth’s Seasons

- Earth’s axis of rotation is tilted 23.5 degrees with respect to **plane of the ecliptic.**
  - **Plane of the ecliptic** – plane traced by Earth’s orbit around the Sun



## Earth's Seasons

- **Vernal (spring) equinox**
  - About March 21
- **Autumnal equinox**
  - About September 23
- Sun directly overhead at the equator on equinoxes

## Earth's Seasons

- **Summer solstice**
  - About June 21
  - Sun directly overhead at **Tropic of Cancer** – 23.5 degrees north latitude
- **Winter solstice**
  - About December 21
  - Sun directly overhead at **Tropic of Capricorn** – 23.5 degrees south latitude

## Earth's Seasons

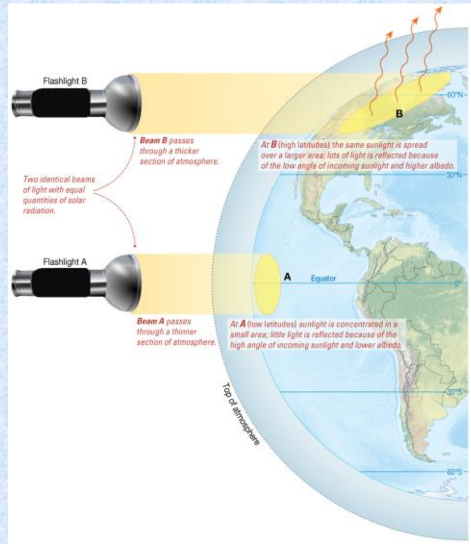
- Sun's **declination** varies between 23.5 degrees north and 23.5 degrees south latitudes.
  - **Declination** – angular distance of Sun from equatorial plane
- Region between these latitudes called the **tropics.**

## Earth's Seasons

- **Arctic Circle**
  - North of 66.5 degrees north latitude
  - No direct solar radiation during Northern Hemisphere winter
- **Antarctic Circle**
  - South of 66.5 degrees south latitude

## Distribution of Solar Energy

- Concentrated solar radiation at low latitudes
  - High angle of incidence
- Solar radiation more diffuse at high latitudes
  - Low angle of incidence




## Distribution of Solar Energy

- Atmosphere absorbs radiation
  - Thickness varies with latitude
- **Albedo** – 0–100%
  - Reflectivity of a surface
  - Average for Earth is 30%
- Angle of sun on sea surface
  - Reflection of incoming sunlight

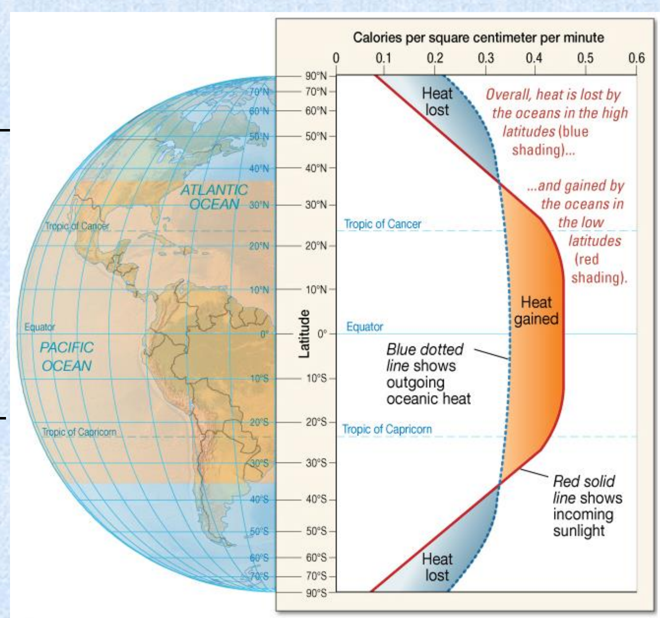
## Sun Elevation and Solar Absorption

**TABLE 6.1 REFLECTION AND ABSORPTION OF SOLAR ENERGY RELATIVE TO THE ANGLE OF INCIDENCE ON A FLAT SEA**

| Elevation of the Sun above the horizon | 90° | 60° | 30° | 15° | 5° |
|---|---|---|---|---|---|
| Reflected radiation (%) | 2 | 3 | 6 | 20 | 40 |
| Absorbed radiation (%) | 98 | 97 | 94 | 80 | 60 |

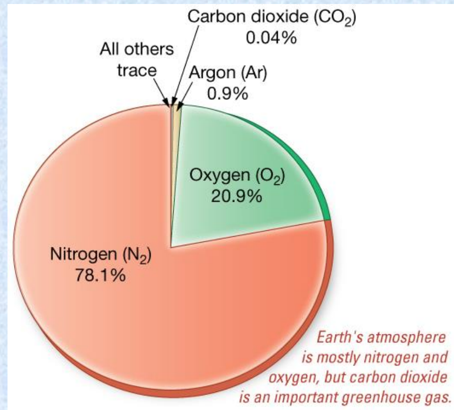
## Oceanic Heat Flow

- High latitudes – more heat lost than gained
  - Ice has high albedo
  - Low solar ray incidence
- Low latitudes – more heat gained than lost



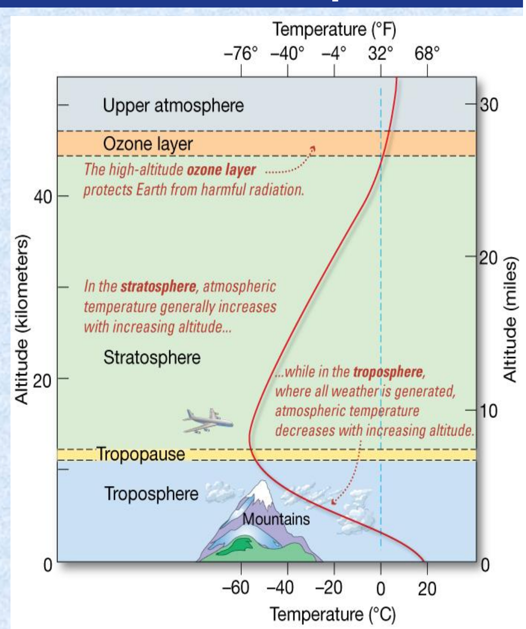
## Physical Properties of the Atmosphere

- Composition
- Mostly nitrogen ($N_2$) and oxygen ($O_2$)
- Other gases significant for heat- trapping properties



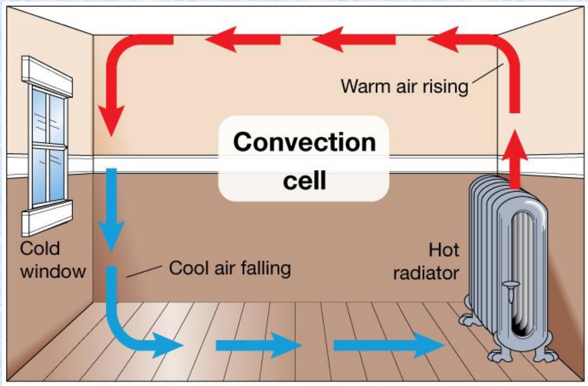

## Temperature Variation in the Atmosphere

- **Troposphere** – lowest layer of atmosphere
  - Where all weather occurs
  - Temperature decreases with altitude
  - Extends from surface to about 12 km (7 miles) up



## Density Variations in the Atmosphere

- **Convection cell** – rising and sinking air
- Warm air rises
  - Less dense
- Cool air sinks
  - More dense
- Moist air rises
  - Less dense
- Dry air sinks
  - More dense




*A circular-moving loop of air (a* ***convection cell****) is created in this room by warm air rising and cool air sinking.*

## Atmospheric Water Vapor Content

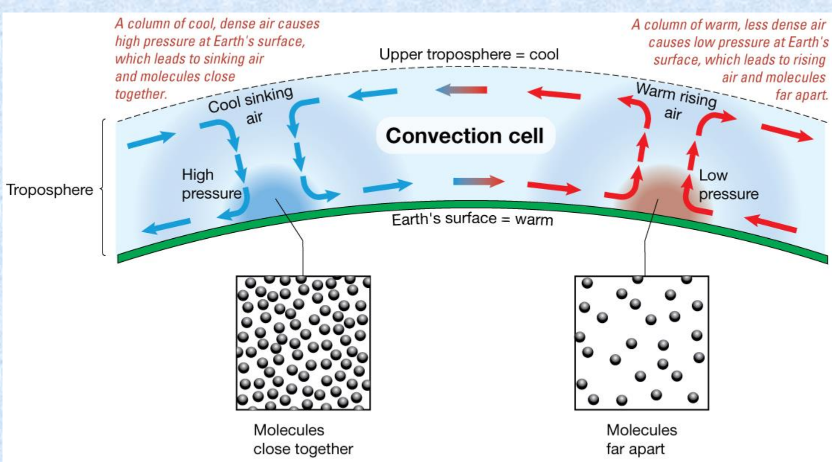
- Partly dependent upon air temperature
  - Warm air typically moist
  - Cool air typically dry
- Influences density of air

## Atmospheric Pressure

- Thick column of air at sea level
  - High surface pressure equal to 1 **atmosphere** (14.7 pounds per square inch)
- Thin column of air means lower surface pressure
- Cool, dense air sinks
  - Higher surface pressure
- Warm, moist air rises
  - Lower surface pressure

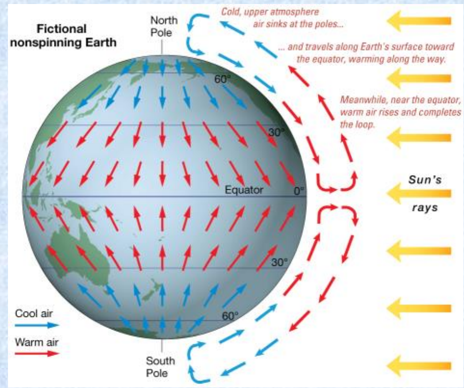
## Movement of the Atmosphere

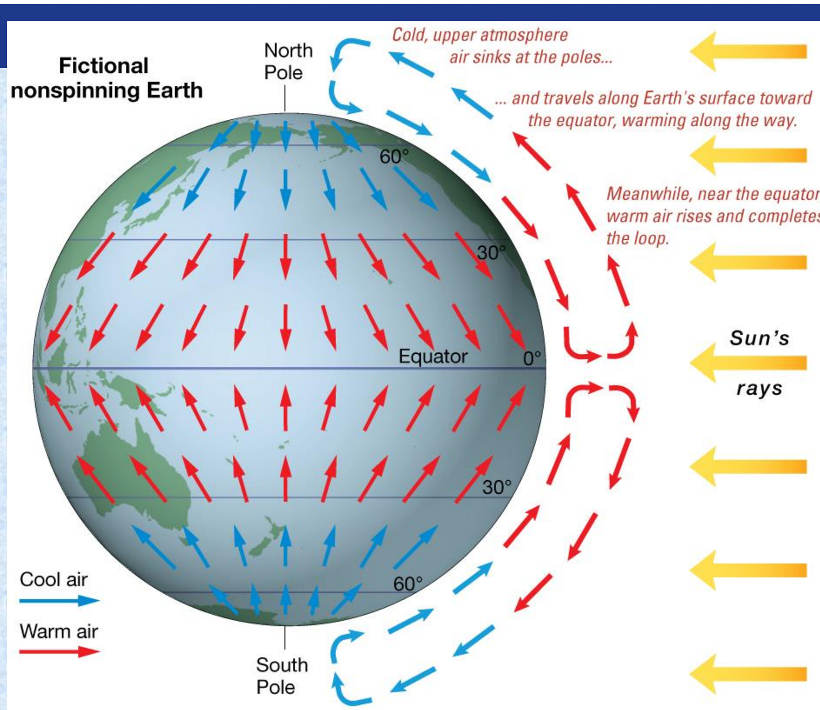
- Air *always* flows from high to low pressure.
- **Wind** – moving air



## Movements in the Air

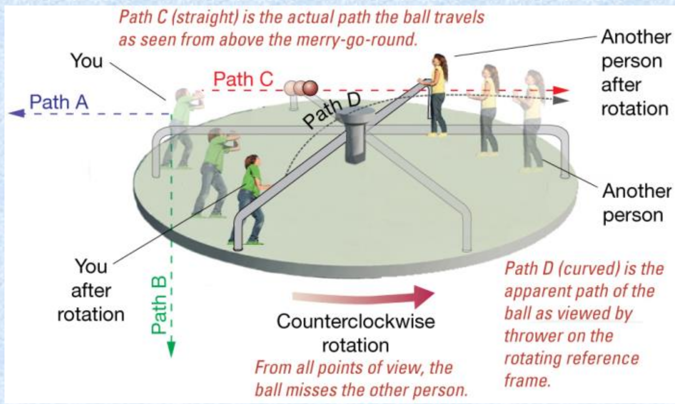
- Hypothetical nonspinning Earth
- Air rises at equator (low pressure)
- Air sinks at poles (high pressure)
- Air flows from high to low pressure
- One **convection cell** or **circulation cell**



## The Coriolis Effect

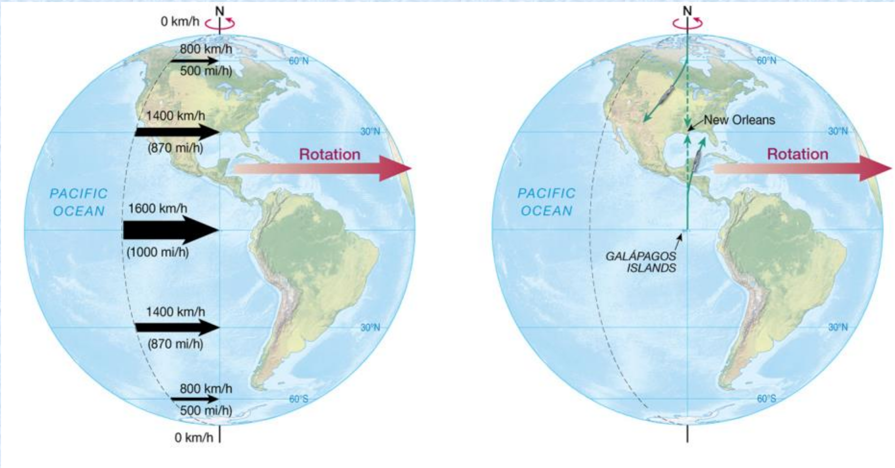
- Deflects path of moving object from viewer's perspective
  - To right in Northern Hemisphere
  - To left in Southern Hemisphere
- Due to Earth's rotation




## The Coriolis Effect

- Zero at equator
- Greatest at poles
- Change in Earth's rotating velocity with latitude
  - 0 km/hour at poles
  - More than 1600 km/hour (1000 miles/hour) at equator
- Greatest effect on objects that move long distances across latitudes

## The Coriolis Effect




(a) The velocity of any point on Earth varies with latitude from about 1600 kilometers (1000 miles) per hour at the equator to 0 kilometers per hour at either pole.

(b) The path of missiles shot towards New Orleans from the North Pole and from the Galápagos Islands on the equator. Dashed lines indicate intended paths; solid lines indicate paths that the missiles would travel as viewed from Earth's surface.

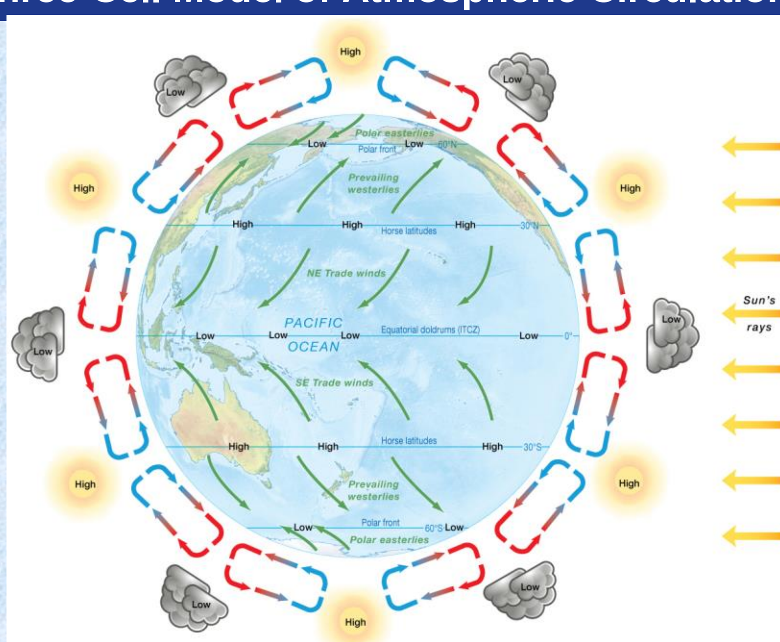
## Global Atmospheric Circulation

- Circulation Cells – one in each hemisphere
  - **Hadley Cell:** 0–30 degrees latitude
  - **Ferrel Cell:** 30–60 degrees latitude
  - **Polar Cell:** 60–90 degrees latitude
- Rising and descending air from cells generate high and low pressure zones

# Global Atmospheric Circulation

- High pressure zones – descending air
  - **Subtropical highs** – 30 degrees latitude
  - **Polar highs** – 90 degrees latitude
  - Clear skies
- Low pressure zones – rising air
  - **Equatorial low** – equator
  - **Subpolar lows** – 60 degrees latitude
  - Overcast skies with abundant precipitation

# Three-Cell Model of Atmospheric Circulation



## Idealized Three-Cell Model

- More complex in reality due to
  - Tilt of Earth's axis and seasons
  - Lower heat capacity of continental rock vs. seawater
  - Uneven distribution of land and ocean

- Boundaries between wind belts
  - **Doldrums** or **Intertropical Convergence Zone (ITCZ)** – at equator
  - **Horse latitudes** – 30 degrees
  - **Polar fronts** – 60 degrees latitude

## Global Wind Belts

- Portion of global circulation cells closest to surface generate winds
- **Trade winds** – From subtropical highs to equator
  - **Northeast trade winds** in Northern Hemisphere
  - **Southeast trade winds** in Southern Hemisphere

- **Prevailing westerly wind belts** – from 30–60 degrees latitude
- **Polar easterly wind belts** – 60–90 degrees latitude

## Characteristics of Wind Belts and Boundaries

SmartTable 6.2 CHARACTERISTICS OF WIND BELTS AND BOUNDARIES

| Region (north or south latitude) | Name of wind belt or boundary | Atmospheric pressure | Characteristics |
|---|---|---|---|
| Equatorial (0–5 degrees) | Doldrums (boundary) | Low | Light, variable winds. Abundant cloudiness and much precipitation. Breeding ground for hurricanes. |
| 5–30 degrees | Trade winds (wind belt) | — | Strong, steady winds, generally from the east. |
| 30 degrees | Horse latitudes (boundary) | High | Light, variable winds. Dry, clear, fair weather with little precipitation. Major deserts of the world. |
| 30–60 degrees | Prevailing westerlies (wind belt) | — | Winds generally from the west. Brings storms that influence weather across the United States. |
| 60 degrees | Polar front (boundary) | Low | Variable winds. Stormy, cloudy weather year round. |
| 60–90 degrees | Polar easterlies (wind belt) | — | Cold, dry winds generally from the east. |
| Poles (90 degrees) | Polar high pressure (boundary) | High | Variable winds. Clear, dry, fair conditions, cold temperatures, and minimal precipitation. Cold deserts. |

## Weather vs. Climate

- **Weather** – conditions of atmosphere at particular time and place
  Example: Today's temperature
- **Climate** – long-term average of weather
  Example: Average temperature for 10/27 for the last 20yrs.
- Ocean influences Earth’s weather and climate patterns.

# Weather or Climate?

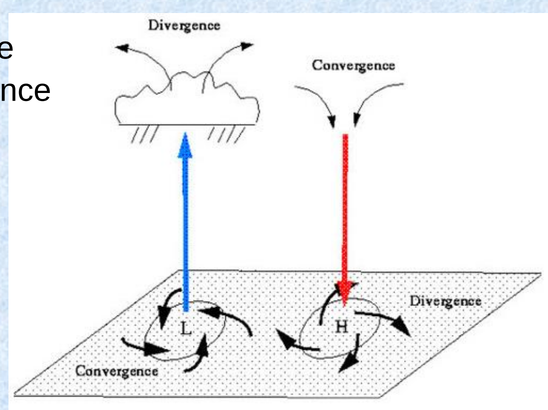
- "Cumulus clouds are presently covering Manhattan skies"
- "Rainiest month in Seattle is January"
- "Average January temperature in Chicago is -3C"
- "Snow is falling at a rate of 6cm per hour"

# What generates winds?

Atmospheric pressure differences moves air masses, this movement is what we know as wind.

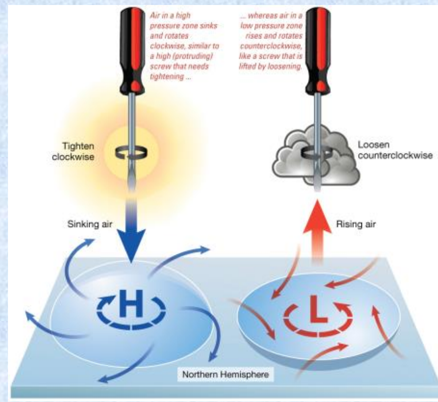
High Pressure Systems are associated with divergence of winds.

Low Pressure Systems are associated with convergence of winds.



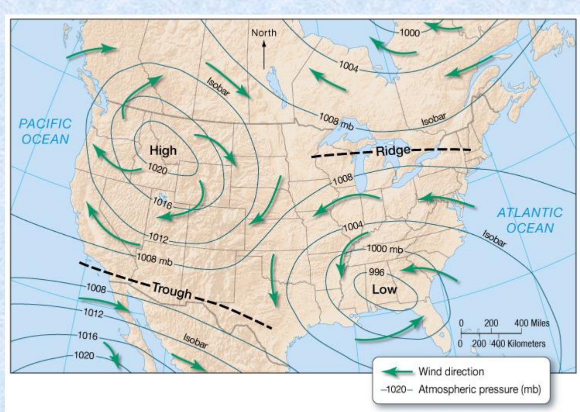
## Winds

- **Cyclonic flow**
  - Counterclockwise around a low in Northern Hemisphere
  - Clockwise around a low in Southern Hemisphere
- **Anticyclonic flow**
  - Clockwise around a low in Northern Hemisphere
  - Counterclockwise around a low in Southern Hemisphere



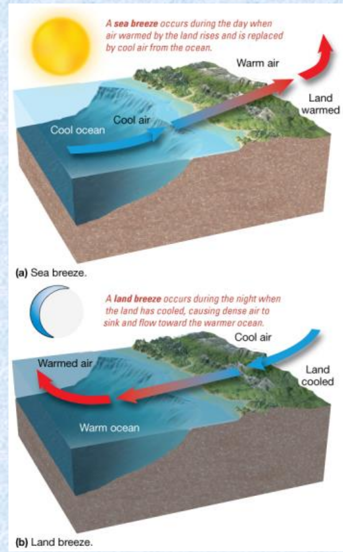

## Winds

- Weather maps show pattern of wind flow relative to high and low pressure regions.



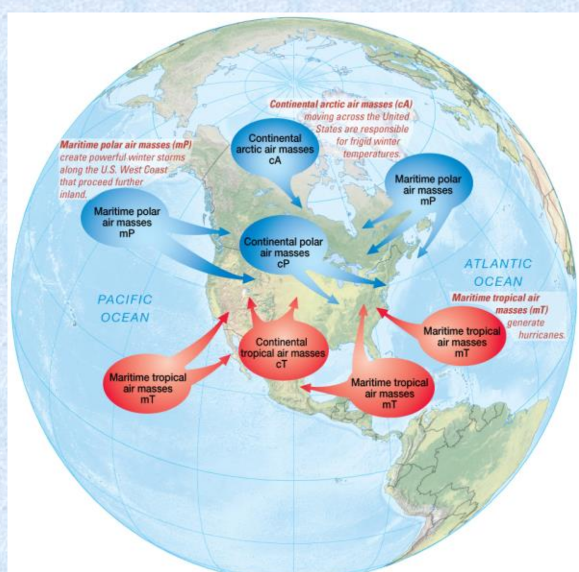
## Sea and Land Breezes

- Differential solar heating is due to different heat capacities of land and water.
- **Sea breeze**
  - From ocean to land
- **Land breeze**
  - From land to ocean



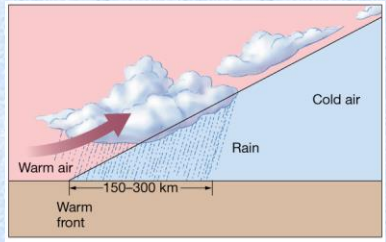

## Storms and Air Masses

- **Storms –** disturbances with strong winds and precipitation
- **Air masses –** large volumes of air with distinct properties
  - Land air masses dry
  - Marine air masses moist

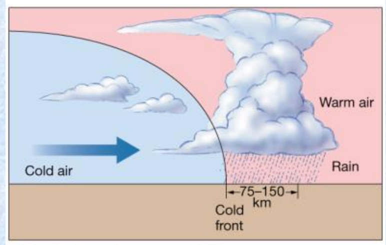


## Fronts

- **Fronts –** boundaries between air masses
- **Warm front**
  - Contact where warm air mass moves to colder area
- **Cold front**
  - Contact where cold air mass moves to warmer area



**(a)** Profile view of a gradually rising warm front.



**(b)** Profile view of a steeper cold front.

## Fronts

- Storms typically develop at fronts.
- **Jet Stream** – narrow, fast-moving, easterly air flow
  - At middle latitudes just below top of troposphere
  - May cause unusual weather by steering air masses

## Tropical Cyclones (Hurricanes)

- Large rotating masses of low pressure
- Strong winds, torrential rain
- Classified by maximum sustained wind speed
- **Typhoons** – alternate name in North Pacific
- **Cyclones** – name in Indian Ocean

## Hurricane Origins

- Low pressure cell
- Winds feed water vapor
  - Latent heat of condensation
- Air rises, low pressure deepens
- Storm develops

## Hurricane Development

- **Tropical Depression**
  - Winds less than 61 km/hour (38 miles/hour)
- **Tropical Storm**
  - Winds 61–120 km/hour (38–74 miles/hour)
- **Hurricane or tropical cyclone**
  - Winds above 120 km/hour (74 miles/hour)

## Saffir-Simpson Scale of Hurricane Intensity

SMARTTABLE 6.3 THE SAFFIR-SIMPSON SCALE OF HURRICANE INTENSITY

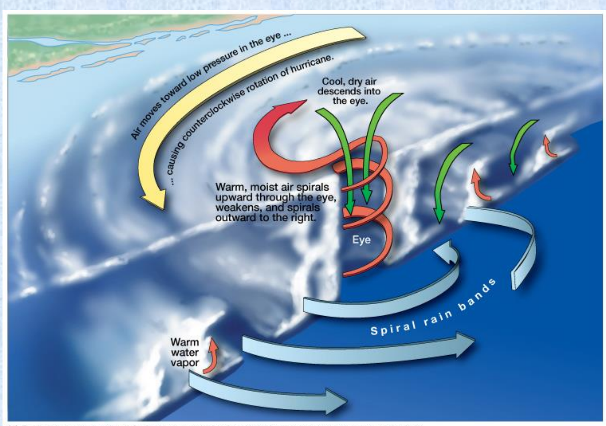
| | Wind speed | | Typical storm surge (sea level height above normal) | | |
|---|---|---|---|---|---|
| Category | km/hr | mi/hr | meters | feet | Damage |
| 1 | 120–153 | 74–95 | 1.2–1.5 | 4–5 | Minimal: Minor damage to buildings |
| 2 | 154–177 | 96–110 | 1.8–2.4 | 6–8 | Moderate: Some roofing material, door, and window damage; some trees blown down |
| 3 | 178–209 | 111–130 | 2.7–3.7 | 9–12 | Extensive: Some structural damage and wall failures; foliage blown off trees and large trees blown down |
| 4 | 210–249 | 131–155 | 4.0–5.5 | 13–18 | Extreme: More extensive structural damage and wall failures; most shrubs, trees, and signs blown down |
| 5 | >250 | >155 | >5.8 | >19 | Catastrophic: Complete roof failures and entire building failures common; all shrubs, trees, and signs blown down; flooding of lower floors of coastal structures |

## Hurricanes

- About 100 worldwide per year
- Require
  - Ocean water warmer than 25°C (77°F)
  - Warm, moist air
  - The Coriolis effect
- Hurricane season is June 1–November 30

## Hurricane Anatomy

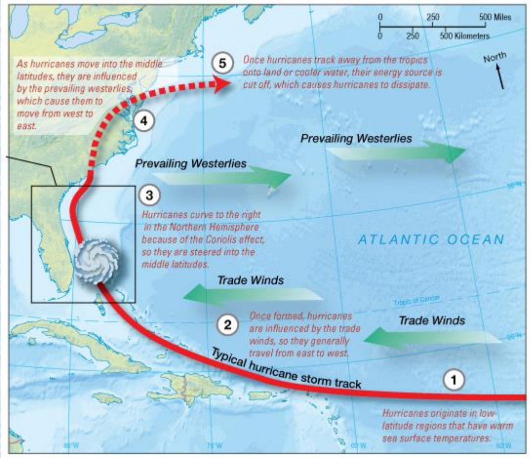
- Diameter typically less than 200 km (124 miles)
  - Larger hurricanes can be 800 km (500 miles)
- **Eye of the hurricane**
  - Low pressure center
- Spiral rain bands with intense rainfall and thunderstorms




(c) Enlarged cut-away view of a hurricane showing its components, internal structure, and winds.

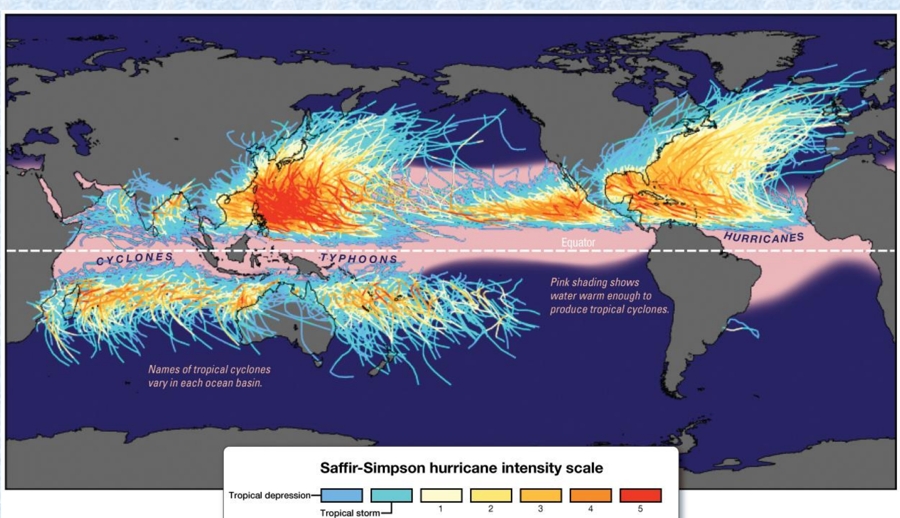
# Hurricane Movement


(a) Satellite photo of Hurricane Andrea off the U.S. East Coast in 2007.



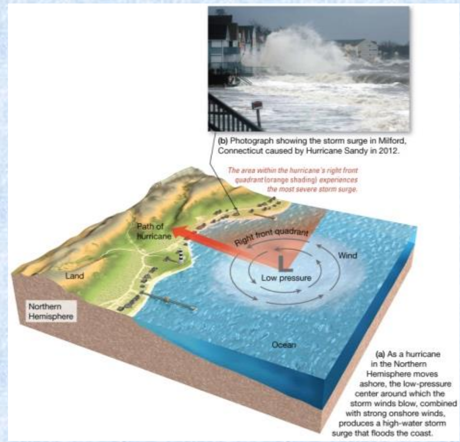

(b) Map showing a typical hurricane storm track, including the steps involved in its origin, movement, and dissipation.

# Historical Storm Tracks



## Hurricane Destruction

- High winds
- Intense rainfall
- **Storm surge** – increase in shoreline sea level




## Storm Destruction

- Historically destructive storms
  - Galveston, TX, 1900
  - Andrew, 1992
  - Mitch, 1998
  - Katrina, 2005
  - Ike, 2008
  - Irene, 2011
  - Sandy, 2012

## Hurricane Sandy, 2012

- Category 1
- Largest Atlantic hurricane on record
- Storm surge coincided with peak high tides in heavily populated New York and New Jersey.
- Severe coastal erosion
- Extreme flooding
- 233 deaths, more than $68 billion in damages.
  - Second costliest hurricane after Katrina

## Damage in New Jerseyfrom Hurricane Sandy, 2012

## 2005 Atlantic Hurricane Season

- Most active season on record
  - 27 named storms
  - 15 became hurricanes
- Season extended into January 2006
- Five category 4 or 5 storms
  - Dennis, Emily, Katrina, Rita, Wilma

## Hurricane Katrina

- Costliest and deadliest U.S. hurricane
- Category 3 at landfall in Louisiana
  - Largest hurricane of its strength to make landfall in U.S. history
- Flooded New Orleans

(a) Satellite view of Hurricane Katrina coming ashore along the Gulf Coast on August 29, 2005, showing the hurricane's counterclockwise direction of spin and prominent central eye. Hurricane Katrina, which had a diameter of about 670 kilometers (415 miles), was the largest hurricane of its strength to make landfall in the United States in recorded history.

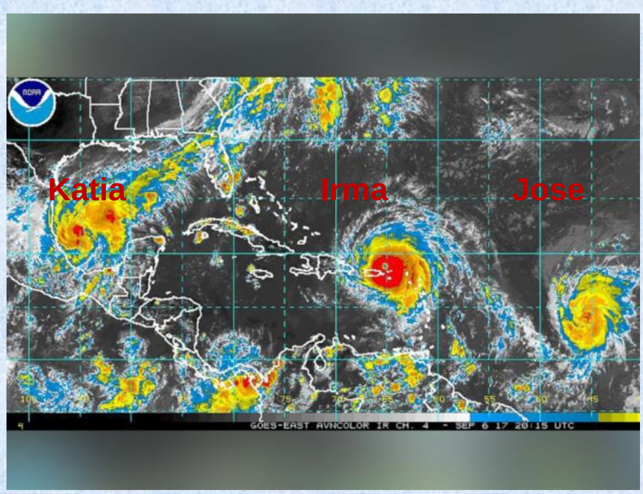
(b) Hurricane Katrina breached levees and flooded New Orleans, Louisiana, causing damages of more than $75 billion and claiming at least 1600 lives.

## Hurricanes Rita and Wilma

- Rita – September 2005
  - Most intense Gulf of Mexico tropical cyclone
  - Extensive damage in Texas and Louisiana
- Wilma – October 2005
  - Most intense hurricane ever in Atlantic basin
  - Multiple landfalls
  - Affected 11 countries

## 2017 Hurricane Season: Major Hurricanes

- Harvey, Cat4
- Irma, Cat5
- Maria, Cat5



## Harvey - Texas

- Extreme floodings due to rainfall primarily.
- First major hurricane to make landfall in US since Wilma (2005).
- Over $70 billion in damages.
- 67 direct deaths, 27 indirect deaths

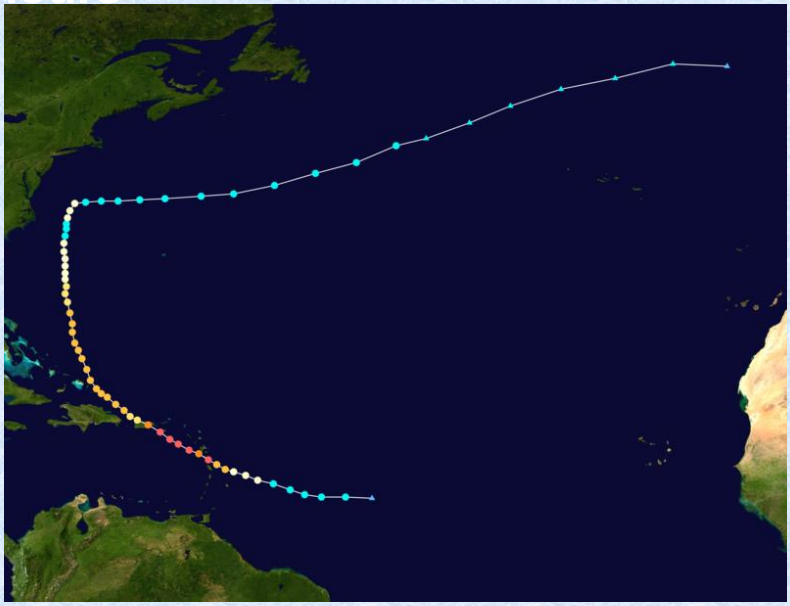
## Irma

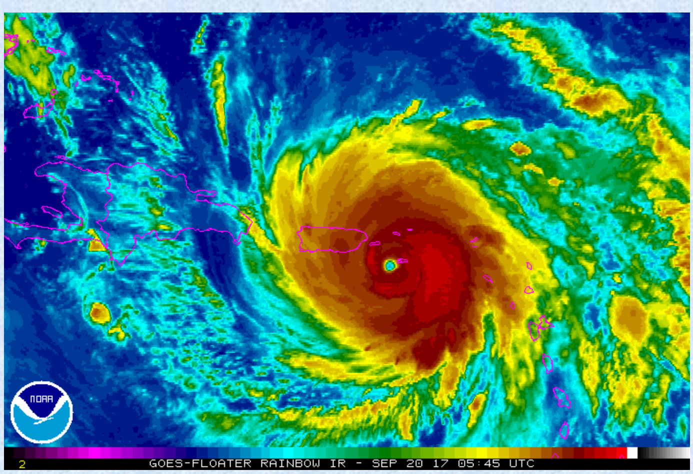
- Strongest since Wilma in terms of winds.
- 185 mph maximum sustained winds.
- First hurricane, on record, to strike the Leeward Islands.
- Complete destruction of Barbuda, St.Barthelemy, St. Martin, Anguila and the VI.
- Extreme storm surge inundations in Fl.
- Over $63 billions in damages.
- 134 deaths

## Maria

- Strongest and more devastating hurricane in Puerto Rico in almost 100 years.
- First major hurricane to hit PR since 1998.
- 175mph maximum sustained winds, 908mb minimum pressure.
- Devastation in Dominica and PR.
- Spawned an island wide humanitarian crisis in PR.
- Damages estimated in $90 billion in PR alone.
- 68 deaths, 28 indirect, probably higher

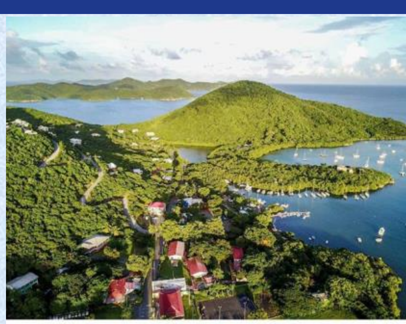
## From tropical storm to Cat5 in 18 hours





## Causes for Intensification

- Very little wind shear.
- Compactness/organization of the storm.
- Small eye ( "pin-hole"), allows for more rapid rotation.
- Appropriate ocean temperatures.
- Moist in the atmosphere.



## Historic Hurricane Destructions

- Most hurricanes in North Pacific
- Bangladesh regularly experiences hurricanes
  - 1970 – massive destruction from storm
- Southeast Asia affected often
- Hawaii
  - Dot in 1959
  - Iwa in 1982

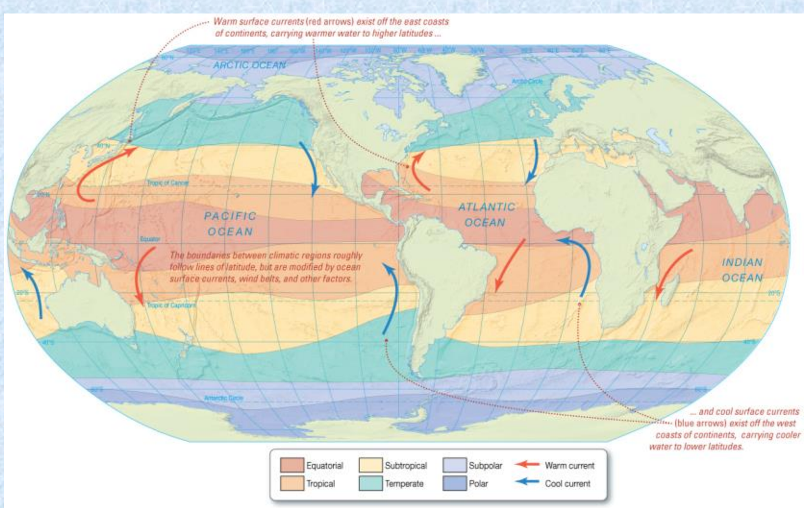
## Future Hurricane Threats

- Loss of life decreasing due to better forecasts and evacuation
- More property loss because of increased coastal habitation

## Ocean’s Climate Patterns

- Open ocean’s climate regions are parallel to latitude lines.
- These regions may be modified by surface ocean currents.

## Ocean’s Climate Patterns



## Ocean’s Climate Zones

- **Equatorial**
  - Rising air
  - Weak winds
  - Doldrums
- **Tropical**
  - North and south of equatorial zone
  - Extend to Tropics of Cancer and Capricorn
  - Strong winds, little precipitation, rough seas
- **Subtropical**
  - High pressure, descending air
  - Weak winds, sluggish currents

## Ocean’s Climate Zones

- **Temperate**
  - Strong westerly winds
  - Severe storms common
- **Subpolar**
  - Extensive precipitation
  - Summer sea ice
- **Polar**
  - High pressure
  - Sea ice most of the year