Chapter 8
Circulation of The Atmosphere

Scales of Atmospheric Motion

Atmospheric circulations are broken-down into different scales bases on physical size and duration.

- *Macroscale* – This is the largest scale, and includes two important sub-scales
  - Planetary scale – These circulations last for weeks or months, and extend in size from 5000 to 40,000 km.
    Examples are the Asian monsoon, El Nino, and La Nina.
  - Synoptic scale – These circulations last from days to weeks, and range in size from 100 to 5000 km.
    Examples are the high- and low-pressure systems we see on weather maps. Also, hurricanes are synoptic scale phenomena.
- *Mesoscale* – These circulations last from minutes to hours, and range in size from 1 to 100 km.
  Examples are thunderstorms, tornadoes, and land-sea breezes.
- *Microscale* – These are the smallest circulations, lasting under a few minutes, and being less than 1 km in size.
  Examples are wind gusts and dust devils.

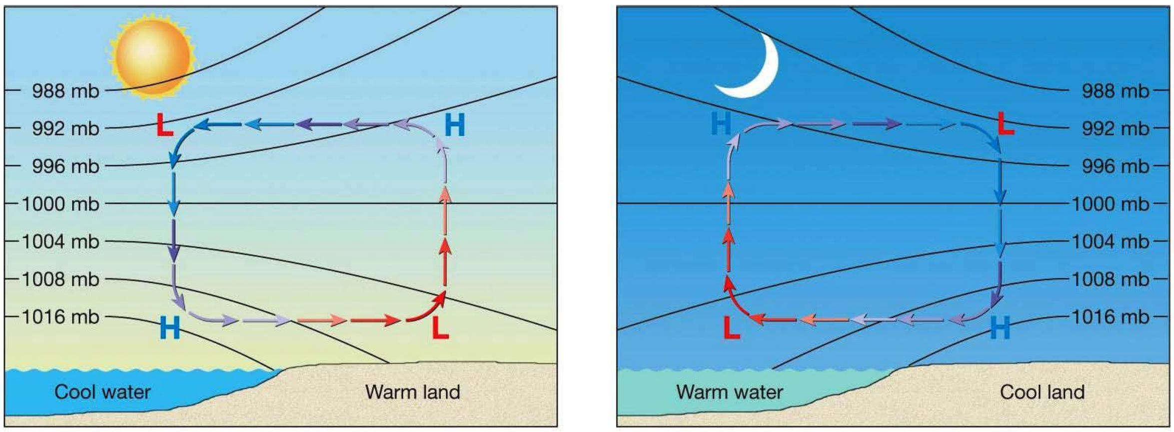
The scales are not independent. A synoptic scale circulation may have mesoscale circulations embedded in it. For example, a hurricane (synoptic scale) contains numerous thunderstorms (mesoscale).

Some Mesoscale Circulation

Many mesoscale circulations are the result of differential heating. The hypsometric equation tells us that if a layer is warmed, its thickness will increase. If the heating (or cooling) is not uniform in the horizontal, the change in thickness can result in a horizontal pressure gradient, which will drive the circulation.

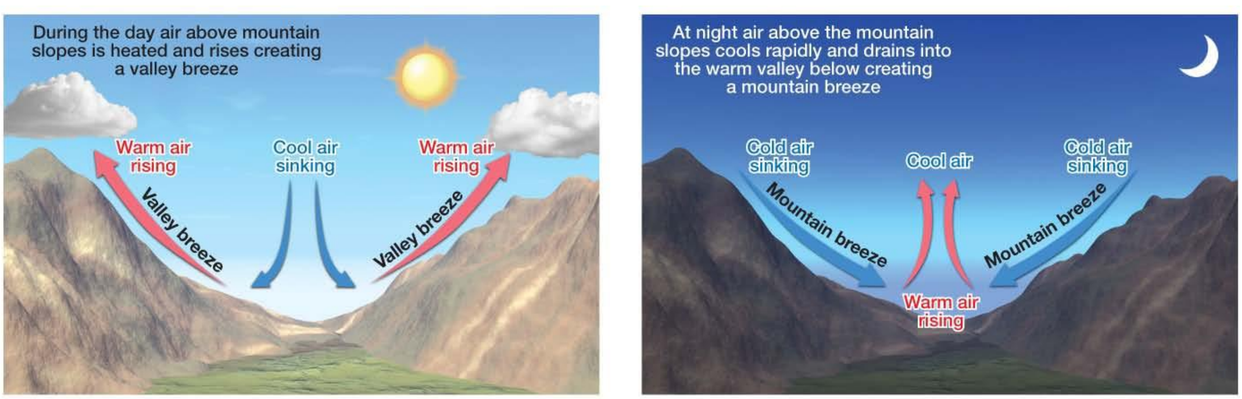
- *Land-sea breezes* – These occur because water and land are heated at different rates.
  - During the afternoon the land is hotter than the water. This causes the thickness over the land to increase, and results in a shallow circulation from the sea to the land in the low levels (called a sea-breeze), and from the land to the sea in the upper levels.
  - During the night the land becomes cooler than the water. This causes a decrease in thickness over the land, and results in a circulation that is the reverse of the sea-breeze (called a land-breeze). The land-sea breeze circulation occurs only near the coastline (within 100 km or so), and is very regular.

- The contrast between the cool ocean air moving over the land and displacing the warm air often sets up a sea-breeze front. In humid locations (such as Florida) this often triggers afternoon thunderstorms.
- The land-sea breeze circulation doesn't have to occur by the ocean. Large lakes can also have these circulations.



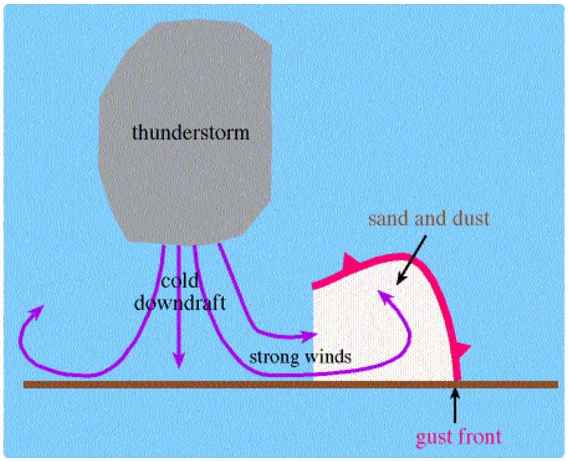
(a) Sea breeze (b) Land breeze

- *Mountain and valley breezes* – These breezes occur because of differential heating between mountain peaks and valley.
  - Valley breeze – During the day the air along the mountain slopes gets heated more than air at the same elevation over the valley. This generates upward flow over the mountains, and a breeze from the valley toward the mountains.
    - The valley breeze is often why thunderstorms develop over the mountains in the afternoon.
  - Mountain breeze – At night the air over the mountain slopes cools much more quickly than the air over the valley. This sets up a circulation with flow down the mountain slopes, and down the valley.



(a) Valley breeze (b) Mountain breeze

- *Drainage flow* – Cold air is denser than warm air, and so cold air tends to collect in low-lying areas such as hollows or river bottoms, and this flow can generate light winds over terrain with little relief.
  - Since the cold air collects in low lying regions, these regions are often the first to experience frost or radiation fog.
- *Chinook (or foehn)* Winds
  - These winds occur when air moves up over a mountain barrier and then down the leeward side. As the air descends it is adiabatically compressed and warmed. These relatively warm winds are also very dry.
  - They usually occur over the east slope of the Rocky mountains during the winter. Here they are called chinook, which is the American Indian word for snoweater.
  - A similar wind occurs in the Alps, where they are called foehns.
- *Katabatic (fall)* winds
  - Katabatic winds are formed when air over snow-covered, high terrain is cooled and becomes very cold. It then drains down slope (similar to the mountain breeze). However, this air is very cold and dense, and moves down slope very rapidly.
  - Even though it is adiabatically warmed, it still arrives in the valley at very cold temperatures and causes a cold, stiff wind.
  - The most famous of the katabatic winds is the Mistral of the French Alps, which blows downward into the Mediterranean Sea.
- *Country breeze* – Though the name sounds pleasant, the country breeze is actually a result of the urban heat island, which sets up a circulation from the surrounding countryside into the city.
- *Haboob* – A *haboob* is a sand and/or dust storm.
  - Generated as a thunderstorm produces a downdraft of cold air
  - The downdraft air descends, strikes the surface and spreads out generating strong surface winds
  - The strong surface winds are able to loft sand and dust into the air
  - The leading edge of the cold, sandy, dusty air is called the thunderstorm gust front



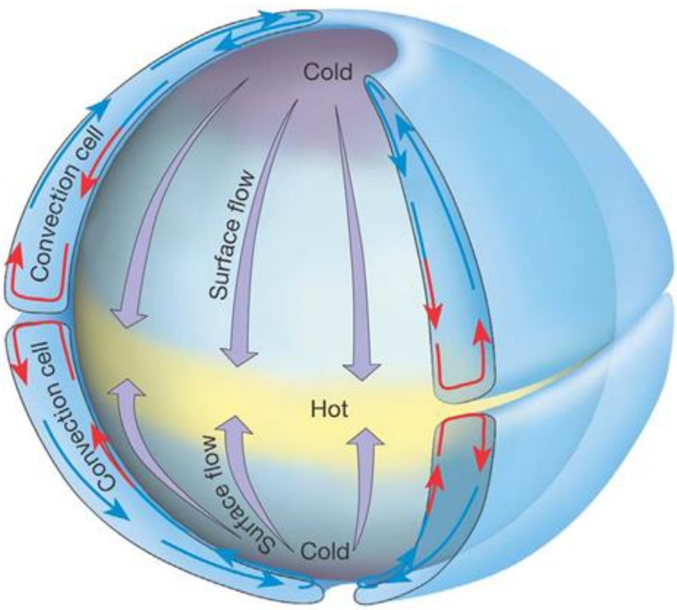
Local Winds

Khamaseen is a dry, hot, sandy local wind, blowing from the south, in North Africa and the Arabian Peninsula. Similar winds in the area are sirocco and simoom. From the Arabic word for "fifty", these dry, sand-filled windstorms often blow sporadically over a fifty-day period in Spring, hence the name.

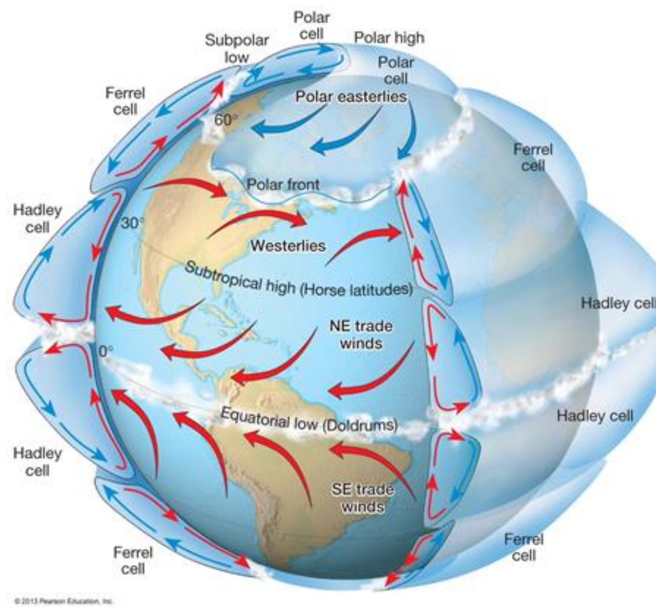
Shamal is a northwesterly wind blowing over Iraq and the Gulf states (including Saudi Arabia and Kuwait), often strong during the day, but decreasing at night. This weather effect occurs anywhere from once to several times a year, mostly in summer but sometimes in winter. The resulting wind typically creates large sandstorms that impact Iraq, most sand having been picked up from Jordan and Syria.

Macroscale - Global Circulation

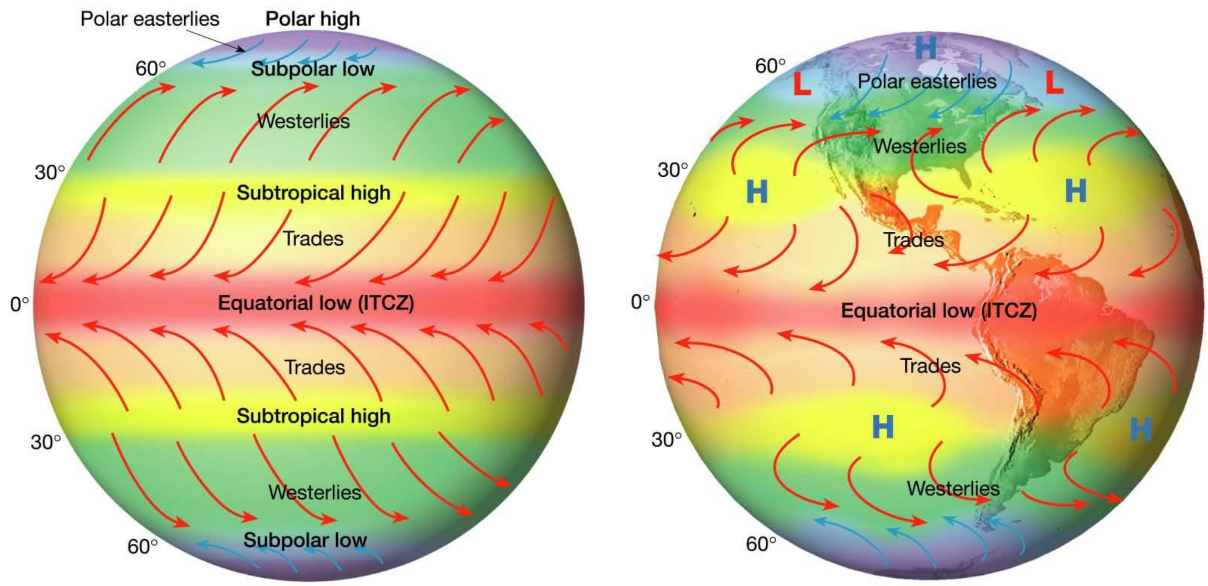
- Latitudinal heat imbalance – The tropics receive more radiation than they emit. The polar regions emit more radiation than they receive. This causes an imbalance in heat.
- If there were no heat transferred between the tropics and the polar regions, the tropics would get hotter and hotter, while the poles would get colder and colder.
- THE LATITUDINAL HEAT IMBALANCE IS WHAT DRIVES THE CIRCULATION OF THE ATMOSPHERE AND OCEANS.
  - THE CIRCULATION OF THE ATMOSPHERE AND OCEANS BOTH ACT TO TRANSFER HEAT FROM THE TROPICS TO THE POLES.
- One way to accomplish the transfer of heat from the equator to the poles would be to have a single circulation cell that was upward in the tropics, poleward aloft, downward at the poles, and equatorward at the surface. This is the **single-cell** circulation model first proposed by Hadley in the 1700's.
- Because the earth rotates, instead of a single-cell circulation there is a **three-cell** circulation.
- Because the Coriolis force act to the right of the flow (in the Northern Hemisphere), the flow around the 3-cells is deflected. This gives rise to the three main wind belts in each hemisphere at the surface:
  - The easterly *trade winds* in the tropics
  - The *prevailing westerlies*
  - The *polar easterlies*
- The *doldrums* are the region near the equator where the trade winds from each hemisphere meet. This is also where you find the *InterTropical Convergence Zone (ITCZ).* It is characterized by hot, humid weather with light winds.
- The *horse latitudes* are the region between the trade winds and the prevailing westerlies. In this region the winds are often light or calm, and were so-named because ships would often half to throw their horses overboard due to lack of feed and water.
- The *polar front* lies between the polar easterlies and the prevailing westerlies.



Single-Cell Circulation Model



Three-Cell Circulation Model



(a) (b)

Uniform Earth Real Earth

Observed Global Distribution of Pressure and Wind

- The three-cell circulation model described previously would have associated with it the following pressure belts.
  - Equatorial low – A belt of low pressure associated with the rising air in the ITCZ.
  - Subtropical high – A belt of high pressure associated with the sinking air of the horse latitudes.
  - Subpolar low – A belt of low pressure associated with the polar front.
  - Polar high – A high pressure associated with the cold, dense air of the polar regions.
- The three-cell circulation model is an idealization. In reality, the winds are not steady, and the pressure belts are not continuous. There are three main reasons for this
  - The surface of the earth is not uniform, or smooth. There is uneven heating due to land/water contrasts.
  - The wind flow itself can become unstable and generate "eddies."
  - The sun doesn't remain over the equator, but moves from 23.5N to 23.5S and back over the course of a year.
- Instead, there are *semi-permanent high- and low-pressure systems*. They are semi-permanent because they vary in strength or position throughout the year.

- Wintertime
  - Polar highs over Siberia and Canada
  - Pacific High and Azores High (parts of the subtropical high pressure system)
  - Aleutian Low and Icelandic Low
- Summertime
  - The Azores high migrates westward and intensifies to become the Bermuda High
  - Pacific high also moves westward and intensifies
  - Polar highs are replaced by low pressure
  - Heat low forms over southern Asia

Monsoons

- A *monsoon* is defined as a wind system that has a pronounced seasonal reversal.
- The most famous monsoon is the *Asian monsoon*.
  - In the summer a heat low forms over southern Asia. The flow into the heat low brings in moist, tropical southwesterly flow over India and Southeast Asia.
  - The rainiest regions are in the Himalayas, where orographic lifting creates massive rainfall (25000 mm of rain in a year!).
  - In the winter, a strong high-pressure system dominates over Asia, bringing dry, northeasterly flow off of the continent over Southeast Asia and India.
- The North American Monsoon
  - A weaker monsoon occurs over the deserts of Arizona and Northern Mexico in summer. A heat low forms, and brings in moist air from the Gulf of California and the Gulf of Mexico.

The Jet Stream

- The thermal wind leads to westerly wind aloft over the midlatitudes.
- The thermal wind is strongest in the region of the Polar front, and leads to the formation of the *Polar jet stream* in the region of the polar front.
  - A jet stream is a ribbon of fast moving air, almost like a river of air.
  - Jet streams are found just below the tropopause.
  - The polar jet is not continuous. It can sometimes split.
  - The polar jet is located in the vicinity of the polar front, and meanders with the polar front. It is farther south in the winter, and moves to the north in the summer.
  - The polar jet is stronger in the winter than in the summer, due to the greater temperature contrast across the polar front.
  - Since migratory low-pressure systems move along the polar front, the polar jet stream is sometimes thought to steer the lows. This is why the T.V. weatherman refers to the polar jet as the storm track.
- There is another jet stream that is only found in the winter. It is the *subtropical jet stream*.
  - The subtropical jet is found to the south of the polar jet.

- The subtropical jet is not associated with a surface front.
- The subtropical jet exists and is maintained due to conservation of angular momentum.

El Nino and La Nina

- The west coast of South America usually experiences a cold current called the Peruvian current. There is also upwelling of cold, deep water during their summer.
- This cold, upwelling is important for fisheries, since the cold water is nutrient rich.
- At intervals of 3 to 10 years the warm current stays and becomes unusually strong. It is these strong events that we now refer to as *El Nino*.
- Usually the warm water is driven to the Western Pacific by the trade winds. El Nino occurs when the trade winds become very light, or even reverse, allowing the warm surface water to flow eastward. This also shuts off the upwelling of cold water that would normally occur.
- These warmer waters in the East Pacific not only devastate the fisheries, but impact weather patterns around the globe, far from the tropical oceans.
- *La Nina* is the name for the opposite of El Nino, when the surface waters off the west coast of South America become abnormally cold. It also effects weather patterns far from the tropics.