

Circulation of the Atmosphere

Scales of Motion: can be thought of occurring over some amount of space and some amount of time.

Planetary or Global scale

Synoptic Scale

Mesoscale

Microscale

Local Winds (mesoscale) - minutes to days and roughly 1 to 100 km in size.

Remember that all winds have the same basic cause: temperature differences that arise because of unequal heating of the Earth's surface. And can be called **Thermal Circulations**.

These temperature differences generate pressure differences and local winds are a simply a result of locally generated pressure gradients.

Remember the COR force is a planetary force - does it occur over short distances?

1) Land and Sea Breezes - due to the uneven rates of heating and cooling between land and water.

Daytime - Land heats up quicker, forms a shallow thermal low, when this happens there is a PGF created from the slightly higher pressure over the water. This PGF causes a **sea breeze** to blow inland. The rising air over land produces clouds inland from the coast.

Strongest winds occur along the land/sea boundary and during time of maximum heating.

Nighttime - Land cools down quicker, creating a shallow high, the water is now warmer and a shallow low forms. This shifts the

direction of the PGF and creates a land breeze or wind blowing off the land out to sea. If clouds do form at night, they will form offshore.

Land breezes are weaker than sea breezes because the temperature and pressure contrasts are much less at night.

Ex: Lake Michigan

2) Mountain and Valley Breezes - are similar winds to land and sea breezes that occur in mountainous regions.

Daytime - daytime heating of the mountain slopes causes air right above the slopes to warm and rise, creating an area where the air pressure is lower than over the valley. Relatively cooler valley air then flows along the PGF up the mountain slope - **valley breeze**.

Nighttime - at night the slopes radiate at a quicker pace than does the valley bottom and therefore the air cools. This cooler, denser air then flows down into the valley in what is called the **mountain breeze**.

- Mountain and Valley Breezes are most developed during the spring and summer when heating is at a maximum.
- They are also most developed on south facing slopes.

3) Chinook Winds - warm, dry winds that move down the east slopes of the Rockies. Also called **Foehn Winds** in the Alps of Europe.

Happens when a PGF sets up with a relatively high pressure region over the mountains and lower pressure over the plains.

The PGF causes the wind to be pulled down the mountains in which it is compressed, warms, and dries out!

The native American Indians called this type of wind a chinook or “**snow eater**” because it tends to melt any snow on the ground along the front range or plains. Is considered to be beneficial to farmers but can also severely dry out a region.

Another chinook-like wind is the **Santa Ana** of Southern California. Where hot, desiccating winds blow out of the high desert plateau to the east. Can be very strong and dry out the vegetation, effectively increasing the risk of fire.

4) Katabatic Winds - similar to chinook winds but occurs in winter when very cold air rushes down from a high plateau, mountain area, glaciers, or ice sheets. The air still compresses and warms but it so cold it does not make much difference.

The result is a very cold wind blowing into a lower lying region. **Ex: Mistral of the French Alps and the Bora of Serbia and Croatia.**

5) Desert Winds - Haboob, where sand is picked up by strong, hot winds blowing off a high desert plateau and onto a flatter region. Causes a wall of dark clouds.

Global Circulation:

Knowledge of global winds comes from two sources:

- Patterns of pressure and winds observed worldwide.
- Theoretical studies of fluid motion.

First, George Hadley (1735) took a look at a theoretical planet with **water only, non-rotating, but with differential heating.**

The thermal gradient between the poles and equator would set-up a giant **single cell model** of global circulation.

Equator - heating, rising air, a region of low pressure.

Poles - cold, dense, sinking air, a region of high pressure.

The winds would always want to blow from H to L or from the poles to the equator.

Although this single cell model in theory was sound, it did not adequately represent the real world.

1920s - a three-cell circulation model (**water only, and rotating**) was developed to help explain how the Earth's heat balance was maintained. Remember - surplus of energy between 38° N and S!

Note that the surface flow has a much greater east-west component of flow than a north-south component.

1) Equator - vast region around the earth's middle with low PGF and winds. The region has been called the **doldrums**. This region is also known as the **ITCZ or Intertropical Convergence Zone**. Here huge convective towers drive the upward motion in the **Hadley Cells** - rising air encounters the tropopause, the COR deflects it to the right in the N.H (left in the S.H.).

As the air moves poleward, it radiatively cools and converges producing an upper level low - at approximately 30° N and S the air descends creating a surface anticyclone (region of high pressure). Air here is warm, dry, and clear and is called the:

2) Horse Latitudes - called that because when explorers were traveling through the horse latitudes, their ships would be becalmed and they either threw the horses over to lighten the load or ate them because they ran out of food drifting for days.

What else do these anticyclones produce?

The descending air of these vast subtropical anticyclones also helps produce the largest deserts.

3) Westerlies - region from roughly 35° N and S where the winds shift and become predominantly westerly - the **midlatitudes**.

4) Polar Front - a frontal or battle zone where interaction occurs between the westerlies and the colder air to the north. Called the **Subpolar Low**.

5) Polar High - polar region where cold, dense air produces vast areas of high pressure and therefore a spreading flow outwards or south. Called the **Polar Easterlies**.

*** Note how air from the tropics is transported poleward and air from the poles is transferred equatorward!**

But we know that the planet is not **water only**, when you put the continents into the system these idealized zonal, continuous belts around the globe become somewhat broken (equator and Southern Hemisphere oceans only true zonal features) and produce **semipermanent cells of high and low pressure.**

Note that the **semipermanent cells of high and low pressure** become elongated, cellular features and that the subtropical highs are situated over the eastern margins of the oceans - greatly influencing the climates of places like the west coast of the U.S.

Looking at a figure (7.7 a and b), we can see that some of the features are semipermanent and others are seasonal. The features also shift with the seasons and the relative amount of incoming solar radiation.

Names of some the features:

Bermuda or Azores High
Pacific or Hawaiian High
S. Pacific High
S. Atlantic High
Aleutian Low
Icelandic Low

Movements and Seasonality:

ITCZ - south in winter, north in summer
Subtropical Highs - south in winter, north in summer
Thermal Low over SW U.S. - summer only feature
Siberian High - winter only feature
Indian Low - summer only feature

This leads us to the greatest seasonal change in global circulations - the **Monsoon systems**.

The word monsoon refers to wind systems that exhibit a pronounced seasonal reversal in direction. Kind of a large-scale sea and land breeze.

Occurs in many locations:

SW U.S. and Mexico

Central and SW Africa

NE Brazil, Suriname, Guiana, and French Guyana

SE Asia and India

Winter - overall flow off the continents

Summer - overall flow onto the continents from the oceans

Best known - S and SE Asia. Creates a large seasonality in precipitation with dry conditions over much of the fall, winter, and spring and large amounts of rain in only a few months during the summer.

Cherruapunji, India averages over 500 inches of rain per year and has recorded as much as 82.5 feet during one four month rainy season.

Importance of the Monsoon system - over half of the world's population lives in monsoonal-type climates and since most of the people in these regions depend upon subsistence agriculture for their livelihoods, timely arrival of the rains can mean the difference between adequate nutrition and starvation.

Westerlies - Prior to WW II we knew very little about the winds in the upper atmosphere.

What we did know was that:

The westerly winds were driven by temperature differences between the poles and the equator. The vertical changes in pressure brought about by the temperature differences create a sloping pressure field in

the upper atmosphere. This creates a PGF from low latitudes to higher latitudes and when balanced by the COR force it causes the winds to blow from west to east (**geostrophic type winds**).

This PGF also increases as you head upward in the atmosphere, until you reach the tropopause. Therefore the wind speeds increase as you go upward also and the point at which the winds are at a maximum is where you will find the **jet streams**.

Jet Streams - are fast streams of air that meander around the globe in the midlatitudes at roughly 7500 - 12000 meters (25000 - 40000 feet). The jets are generally not very big - less than a few hundred kilometers wide and only a few kilometers thick, but wind speeds are fast - from 200 - 400 km per hour (120 - 240 miles per hour).

Story about the Bombing of Japan.

The origin of the jet streams are regions with the greatest temperature contrasts between the poles and the equator. The regions where this occurs is along fronts, especially the **polar front**. There are generally two midlatitude jets - the **polar front jet** and the **subtropical jet**.

The polar front jet affects our weather the most.

The polar front jet moves seasonally and changes strength seasonally with the changes in incoming solar radiation and the surface heating.

- **Winter** - the PFJ is found generally south near 30° and is roughly 50% stronger.
- **Summer** - the PFJ is found generally north near 55° and is much weaker.

Often called the **midlatitude jet stream**, you can see how seasonal shifts of the jet control major surface systems and by locating the relative position of the jet stream, forecasters can to a large degree predict the weather.

Jet Streams and Waves in the Westerlies - since the jet stream is an integral part of the westerlies we can follow its pattern over the globe

and see waves that set up places where cold air is being displaced southward and warm air is being displaced northward.

These waves are called **Rossby Waves**, after their discoverer. From 3 - 6 waves exist at any one time and create a wavy path around the globe. They define the boundary between warm and cold air. The cold air over the poles can be looked at as a blob of thick, dense syrup which oozes out over the globe and is confined by the jet stream.

The waves define regions of ridges and troughs that give indication of the direction of flow and the temperatures around the region.

The Rossby Waves move round the globe at rates of up to 15° of longitude per day. Also at the edge of the Rossby Waves are fast cores of high winds, these tend to be at the locations of the strongest surface cyclones - evacuating air from above!

The nature of the waves in the westerlies gives us an indication of how the Earth's heat budget is balanced as cold polar air is carried southward and warmer equator air is carried northward where the waves meander.

Straight flow - E - W zonal flow

Curved flow - N - S, meridional flow and transport of energy

Global Winds and Ocean Currents:

Anywhere the atmosphere and oceans meet, energy is passed from the moving air to the water through friction! As a consequence, the drag the air creates as it blows over the oceans generates surface motions in the water.

Winds are therefore the primary driving forces behind ocean currents and waves!

Compare the general circulation of the atmosphere to the general circulation of the oceans.

A series of fairly permanent **ocean gyres** are created which help transport heat energy northward. Cold currents are found along the west coasts of continents and warm currents are found along east coasts of continents. These currents have a strong influence on the temperatures of the various regions they encounter.

Ex: the North Atlantic Drift and Europe's weather.

Note that coasts where warm currents come into contact have more precipitation and where cold currents come into contact are mostly where the driest regions including deserts are found.

Therefore the winds, the subtropical highs and the ocean currents combine to produce most of the desert regions of the world.

Ocean Currents and Upwelling:

In addition to producing surface currents, winds also generate vertical motions within the ocean. The result is upwelling, or movement of bottom water to the surface.

This occurs mostly along the western coasts of continents (eastern margins of oceans) where cold currents are moving southward. Ex. **Peru, California, West Africa.**

Main affect of upwelling is to bring dissolved nutrients, such as nitrates and phosphates, to the surface. This promotes the growth of phytoplankton, zooplankton, and a rich fish and bird population. Which leads us to:

El Nino and Global Weather:

El Nino a reversal of the normal ocean-atmosphere system in the equatorial tropics from Oceania to South America.

Peruvian fisherman have noted the existence of El Nino for perhaps as long a couple of thousands years (so its nothing new!).

Sir Gilbert Walker studied its affect on the Indian Monsoon as early as the turn of the century.

While the mechanism that drives El Nino has not been definitively found, it is clear that changes in the longitudinal circulation in the tropics show its effects.

This is called the **Walker Circulation**. The major portion of the Walker Circulation that is related to El Nino is called the **Southern Oscillation**, and the entire phenomenon is sometimes called **ENSO**.

The start of an El Nino usually begins with a weakening of the Trade Winds over the tropical Pacific. This allows the large warm pool of water to migrate slowly across the Pacific and create a vastly different pattern of cloud cover and precipitation.

This also alters the normal strong upwelling currents off the coast of South America and decimates the food chain in the region.

This change in the position of the warm ocean waters have some broad ranging affects on many regions of the world. These are called **teleconnections**, or how changes in climate in one region of the world teleconnect their affects outward to other regions of the world.

- Largest affect is seen in the tropical Pacific region.
- The affect is minimized as you move away from the center of action.

Droughts, floods, hurricanes, etc.

Global Distribution of Precipitation:

Now that we have seen the overall patterns of global circulation we can better understand the general global patterns of precipitation.

A look at the zonal distribution of precipitation shows how the pattern is related to the major circulation features that we just covered.

- **Equator:** 0 - 15° N & S, abundant precipitation in all seasons.

- **Horse Latitudes:** 15 - 35° N & S, summer wet-winter dry to the south, winter wet-summer dry to the north, and dry all seasons in the middle of the subtropical highs.
- **MidLatitudes:** 35 - 65° N & S, polar front, ample precipitation in all seasons.
- **Polar High Regions:** 65 - 90° N & S, sparse precipitation in all seasons.

Distribution of Precipitation across the Continents:

Continents break-up this general pattern of precipitation with some variability found on the different coasts. This is largely controlled by the position relative to the semipermanent anticyclones.

Eastern margins of oceans (western margins of continents), where cold ocean currents are found, there tends to be large scale subsidence of air giving very stable, dry conditions - **Arid regions**.

But on the western margins of the oceans (eastern margins of continents), where warm ocean currents are found, more moisture is provided to the air and you have rising, unstable air - **Humid Subtropical regions**.

Global Precipitation Patterns:

Now combine the zonal and continental influences to produce an annual look at precipitation variation.

The zonal pattern approximates the general global circulation with the exception of the east-west continent differences.