

Structure of Atmosphere**Lecture 1 (Priority: Low)**

<i>Thermopause</i>	✓ Temperature rise sharply to 1200 °C<
THERMOSPHERE [80 - 480 km]	
<i>Mesopause</i>	✓ Coldest portion of atmosphere: -90 °C
MESOSPHERE [50 - 80 km]	✓ Very low pressures
<i>Stratopause</i>	
STRATOSPHERE [18 - 50 km]	✓ <u>Temperature inversion</u> : Temperature increases as latitude increases (-57 °C at 18 km to 0 °C at 50 km) <ul style="list-style-type: none"> ○ Caused by <u>high [O₃]</u> as incoming UV radiation from Sun absorbed
<i>Tropopause</i> [Equator: 18 km, Mid-lat: 13 km, Poles: 8 km]	✓ Average -57 °C, exact elevation varies across places
TROPOSPHERE [0 - 18 km]	✓ Occurrence of <u>principal weather activity</u> ✓ Unstable layer, contains most of H ₂ O (g), cloud, dust & pollution ✓ <u>Temperature decreases as latitude increases</u> <ul style="list-style-type: none"> ○ <u>Normal lapse rate</u>: average 6.4 °C ○ <u>Environment lapse rate</u>: change with local weather conditions

Energy Pathways & Principles**Lecture 1 (Priority: Medium)**

Earth's atmosphere & surface heated by incoming solar energy unevenly, distributed by latitude and fluctuates seasonally!

1. Refraction

- ✓ Insolation entering atmosphere from space into atmospheric gases refracted (direction & speed changes)

2. Insolation Input

- ✓ Single energy input driving atmospheric system
- ✓ Insolation decreases poleward from about 25°N & S
- ✓ Equator / tropical lat: 180 - 220 W/m² due to consistent daylength & high Sun altitude
- ✓ Low-lat deserts: 240 - 280 W/m² due to frequently cloudless skies

3. Albedo & Reflection

- ✓ Albedo: reflective quality of surface (0%: total absorption, 100%: total reflection)
- ✓ Part of insolation reflected back to space without absorption
- ✓ Angle of solar rays on water influence albedo: lower angle, higher albedo
- ✓ Smooth surface higher albedo, rough surface lower albedo
- ✓ Earth and atmosphere reflect ~31% of all insolation on average

4. Atmospheric albedo: Clouds

- ✓ Clouds reflect insolation, cooling Earth surface
 - Cloud-albedo forcing: higher albedo by clouds
- ✓ Clouds also insulate by trapping longwave radiation from Earth
 - Cloud-greenhouse forcing: greenhouse warming by clouds
- ✓ Other influences on atmospheric albedo: air pollution

5. Scattering (Diffuse Radiation)

- ✓ As insolation travels towards surface, encounter higher density of atmospheric gases absorbing and re-emitting radiation
- ✓ Changes direction of light's movement, represent 7% of albedo
- ✓ Incoming insolation diffused by clouds and atmosphere and transmitted to Earth as diffuse radiation
- ✓ Dust particles, pollutants, ice, water & cloud droplets produce further scattering

6. Absorption

- ✓ Insolation not reflected is absorbed by Earth's surface & atmosphere, thereby raising temperature
- ✓ 45% of incoming insolation absorbed by land & water surfaces, 24% absorbed by atmospheric gases, dust, clouds & stratospheric O₃

7. Conduction, Convection & Advection

- ✓ Conduction: intermolecular transfer of heat energy
- ✓ Convection: energy transfer in gases & liquids by strong vertical motion (horizontal motion: advection)

8. Greenhouse Effect

- ✓ Infrared radiation emitted by Earth's surface absorbed by greenhouse gases, trapping heat in troposphere
- ✓ Cloud cover & cloud type affect lower atmosphere heating
 - Higher clouds albedo of 50% (net greenhouse-forcing, atmospheric warming)
 - Lower clouds albedo of 90% (net albedo-forcing, atmospheric cooling)

Earth-Atmosphere Radiation Balance**Lecture 1 (Priority: High)**

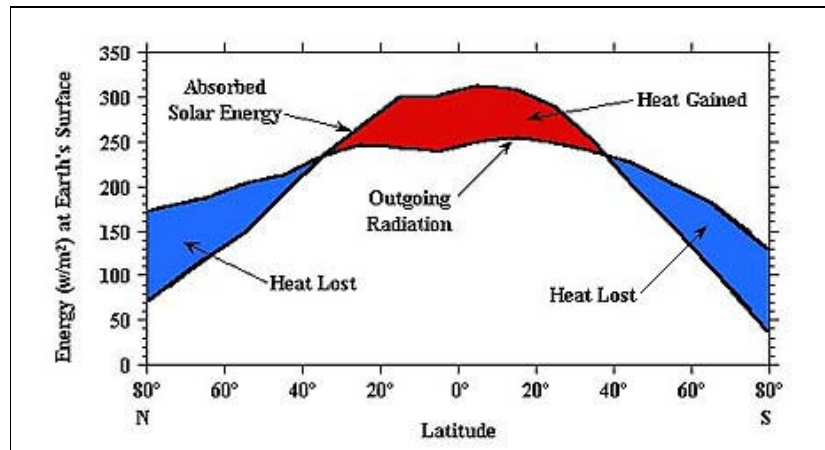
Earth-atmosphere energy system naturally balances itself in steady-state equilibrium.

- ✓ Energy surplus on earth's surface, energy deficit in atmosphere
- ✓ Energy surplus = energy deficit for overall energy balance
- ✓ Natural energy balance occurs through energy transfers both non-radiative and radiative
 - Non-radiative: convection, conduction, latent heat of evaporation (removal of heat through evaporation)
 - Radiative: infrared radiation
- ✓ Arriving insolation: 100%
 - 31% reflected back to space
 - 21% absorbed in atmosphere

- 3% absorbed & radiated by stratospheric O₃
- Remaining 45% reaches Earth's surface (direct & diffuse radiation)
- ✓ 69% in Earth re-radiated into space as infrared radiation
- ✓ Longwave radiation generally latitudinal: lower radiation nearer Equator, higher radiation in deserts

Factors affecting Insolation**Lecture 2 (Priority: High)**

Insolation: intensity at specific time / period of direct solar radiation on Earth's surface. Amount of insolation depends on angle of Sun's rays and length of time of exposure to rays



http://www.fas.org/irp/imint/docs/rst/Sect14/Sect14_1a.html

1. Solar constant

- ✓ Average insolation received, varies by Earth's distance from Sun, changing with Earth's elliptical orbit
- ✓ Also varies with sunspot activity

2. Latitude

- ✓ Earth's curved surface presents continually varying angle to incoming parallel rays of insolation
- ✓ Differences in angle of incidence of insolation cause uneven distribution of heating and insolation
 - Equatorial region receive more [] of energy from more direct solar beam
 - Higher lats receive oblique rays and more diffuse energy
 - Lower-angle rays towards poles must pass through thicker atmosphere → further loss of energy from scattering, absorption & reflection

3. Seasons

- ✓ Seasons result of Earth's revolution in orbit around Sun, daily rotation on axis and tilted axis
- ✓ Seasonal variation of Sun's position above horizon and changing daylength throughout the year influences insolation
- ✓ Extreme daylength occurs on June & December solstice

- June solstice (June 20 / 21): Arctic Circle 24h daylight, Antarctic Circle 24h darkness
- December solstice (December 21 / 22): vice-versa
- ✓ Equal daylength worldwide (12h) occurs on March & September equinox
- ✓ Trend of general decrease in insolation from equatorial regions northward and southward towards poles (latitude factor & consistent 12h daylight)
- ✓ However in June, North Pole receive highest insolation as 24h daylight, ditto for December in South Pole

4. Aspect

- ✓ Aspect: orientation of face of slope
- ✓ In N hemisphere, south-facing slope receives more insolation than north-facing
- ✓ In S hemisphere, north-facing slope receives more insolation

5. Cloud cover

- ✓ Reduce incoming and outgoing radiation: thicker cloud, more absorption, radiation and scattering of insolation & terrestrial radiation
- ✓ Reduce daytime temperatures and act as insulating blanket at night

Formation of Winds

Lecture 2 (Priority: Medium)

Because of global energy imbalance (surplus in lower lats, deficit at higher lats), atmospheric circulation must transport heat across latitude from surplus regions to deficit regions. Winds are horizontal air movements, drafts are vertical air movements.

1. Pressure Gradient Force

- ✓ Tendency for large movement of air from region of higher pressure to region of lower pressure. With pressure gradient, air tends to drift in same direction as gradient
- ✓ Magnitude of force directly proportional to steepness of gradient

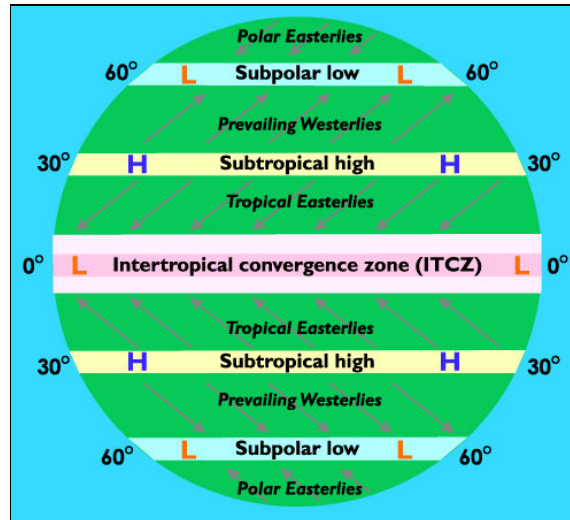
2. Coriolis Effect

- ✓ Occurs as result of Earth's rotation from West to East
- ✓ Deflection of wind / currents to the right in N hemi and to the left in S hemi
- ✓ Coriolis effect absent at Equator, effect increases towards poles

3. Surface Pressure Systems

- ✓ Equatorial trough: equatorial belt of lower pressure
- ✓ Subtropical high pressure belt (30°N & S): belt of higher pressure
- ✓ S Hemi Pressure Cells
 - 65°S: sub-Antarctic low pressure belt (subpolar low)
 - Antarctica: polar high, permanent high pressure centre
- ✓ N Hemi Pressure Centers
 - Vast continents prevent formation of pressure belts

- In winter, high pressure centers develop over cold land areas (Siberian & Canadian High) and low pressure centers over warmer oceans (Aleutian Low & Icelandic Low)
- In summer, opposite of in winter, Azores High & Hawaiian High form



http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Easterly_Waves/Trade_Winds/Trade_Winds.htm

Global Wind Circulation

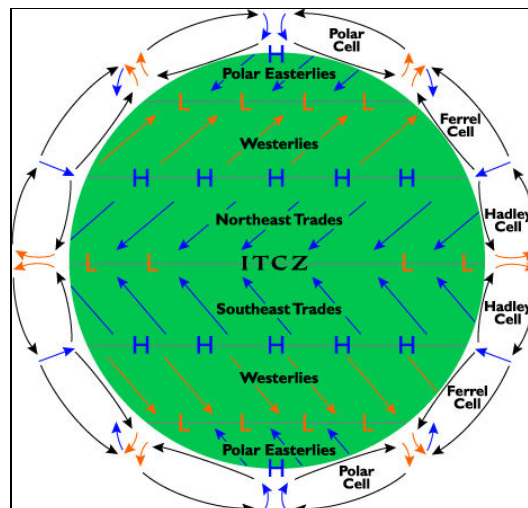
Lecture 2 (Priority: High)

- ✓ In tropics, winds from subtropical high pressure belts traveling equatorward meet at the ITCZ and rise as they meet (NE & SE trade winds)
- ✓ Along parts of equatorial trough at certain periods, trade winds do not converge, instead forming belt of calm winds (doldrums)
- ✓ Trade winds, doldrums & ITCZ shift seasonally north and south, along with pressure belts due to annual march of seasons
 - Seasonal variation of Sun's position above horizon as Earth revolves around Sun
 - June, Sun directly overhead at Tropic of Cancer, N hemi summer, ITCZ shifts north in July
 - December, Sun directly overhead at Tropic of Capricorn, S hemi summer, ITCZ shifts south in January
- ✓ ITCZ migrates N & S by few degrees lat over Pacific & Atlantic Oceans but 20 - 30° latitude over S Am, Africa, SEA & Indian Ocean, due to land-water contrasts / continental-maritime influence
- ✓ In subtropical high (25 - 40°N & S), large stagnant high-pressure cells (anti-cyclones) exist at horse latitudes centered over the oceans
- ✓ Over the oceans, surface winds spiral outward, feeding trades & Westerlies, making climate of adjacent continents dryer
- ✓ Between 35 - 60°N & S, belt of prevailing Westerlies
 - Rapidly moving cyclonic storms (low pressure zones) common here
 - In S hemi almost unbroken ocean belt, thus Westerlies gather great strength here
- ✓ In polar zones, polar easterlies exist (more applicable in South pole)

Global Energy Circulation: Tricellular Model Lecture 3 (Priority: High)

There is energy surplus at the Equator and energy deficit in the outer atmosphere and nearer the poles. 80% of heat transfers from ITCZ by winds, 20% by ocean currents.

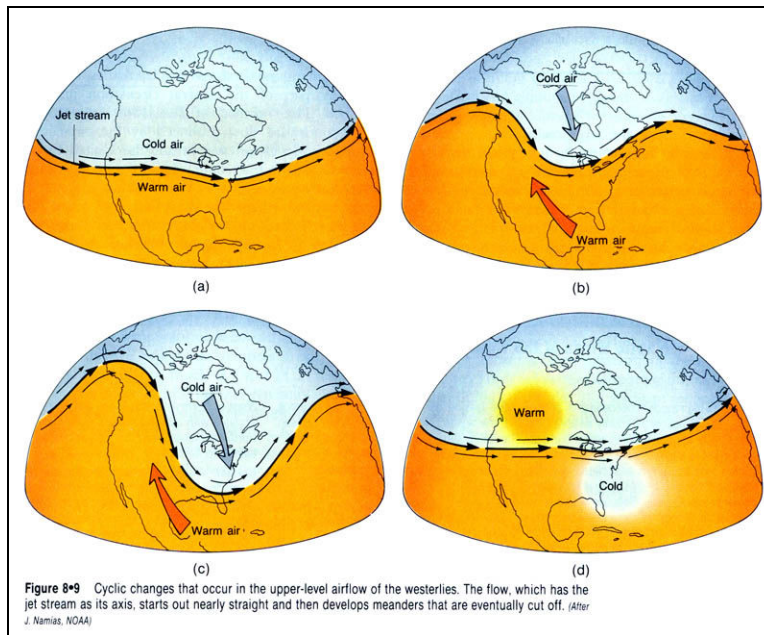
- ✓ Hadley cell: forms as insolation at Equator / ITCZ heats Earth more strongly than other places, causing low pressure & heated air to rise
 - Air rises above the Equator, cools to temperature of surrounding air, ceases uplift and then flows polewards, descending at 30° lat as the cool air becomes denser
 - Trade winds meeting at the ITCZ pick up latent heat while crossing warm tropical oceans, and forced to rise by violent convection currents
 - Unstable, warm, moist air rapidly cooled adiabatically to produce cumulonimbus clouds & frequent afternoon thunderstorms
 - These strong upward currents form powerhouse of global energy circulation
 - Surface pressure at 30° high due to descending limb of Hadley cell, forming 2 subtropical high-pressure belts
 - 2 - 4 large stable anticyclones form within belts at horse lats
- ✓ As air diverges on reaching Earth's surface, some of air returned to Equator as trade winds, rest divert polewards forming prevailing warm Westerlies between 30° & 60° lat, collecting moisture as crossing oceans
- ✓ These warm winds meet cold Arctic air in N hemi / cold Antarctic air in S hemi (60°N & S) and are uplifted to form low pressure areas and rising limbs of Ferrel & Polar cells
 - Resultant unstable conditions produce heavy cyclonic rainfall (mid-lat depressions)
 - Some of rising air eventually returns to tropics, some travel towards poles where, having lost heat, descends at poles forming area of high pressure
 - Cold winds returning to polar front are polar easterlies



http://www.newmediastudio.org/DataDiscovery/Hurr_ED_Center/Easterly_Waves/Trade_Winds/Trade_Winds.htm

1. Rossby waves

- Upper-air Westerlies following meandering path
- Waves arise from contact between cold polar air & warm tropical air, number of meanders / waves vary seasonally, forming complete pattern around globe
- For some days - weeks smooth flow, then undulation develops and warm air pushes polewards while tongue of cold air brought south
- Eventually, tongue is pinched off, leaving pool of cold air further south till it warms up, influencing local weather conditions

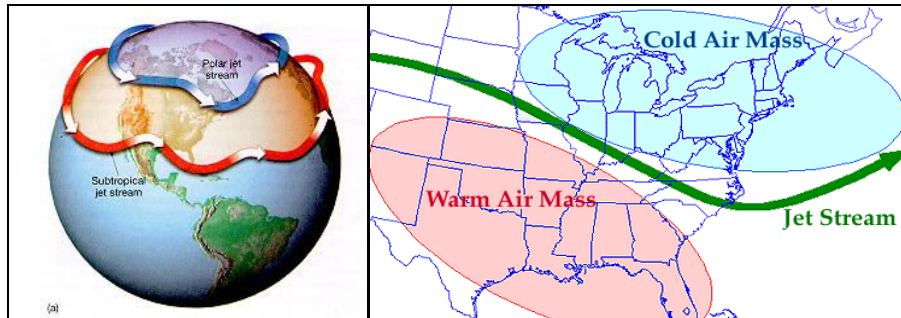


http://www.earth.rochester.edu/fehnlab/ees215/fig17_9.jpg

2. Jet streams

- Narrow bands of extremely fast-moving air at high altitude (10 - 12km) occurring where atmospheric temperature gradients are strong (velocity of upper Westerlies not uniform!)
- Along jet stream, pulse-like movements of air follow broadly curving tracks
- 3 kinds of jet streams: westerly wind streams & weaker easterly jet stream (develops in Asia during summer monsoon)
- Polar-front jet stream / polar jet (35 - 65° lat): most poleward jet stream located along polar front
- Usually follows Rossby waves edges since they mark strong temperature boundary between cold & warm air
- Subtropical jet stream: in tropopause just above Hadley cell
- Tropical easterly jet stream: runs east → west, opposite to directions of other 2 jets and occurs only in summer over SEA, India & Africa

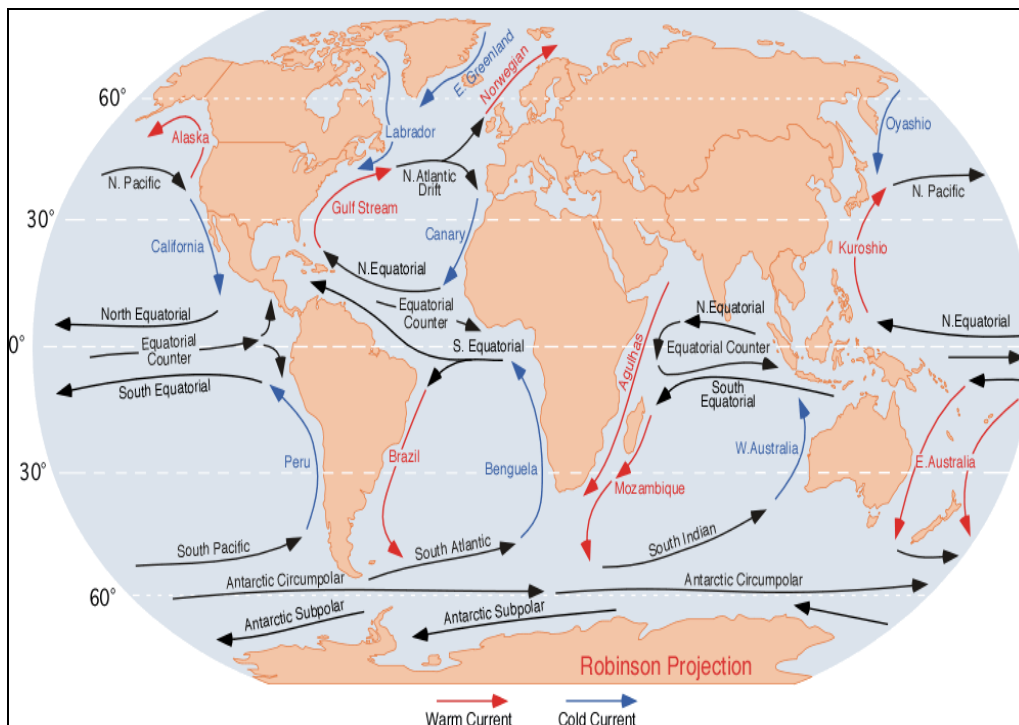
- The Northern Hemisphere Westerly Jet caused havoc when it steered a low-pressure zone over UK in summer 2007 → rain in UK but hot spell in Western Europe



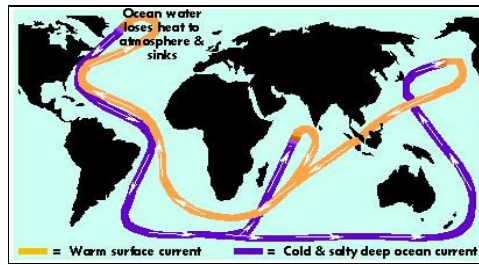
<http://www.crystalinks.com/jetstream.html> & [http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/maps/upa/jet.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/maps/upa/jet.rxml)

Oceanic Thermohaline Circulation Lecture 3 (Priority: High)

- Also known as ocean / great conveyor belt
- Ocean current: persistent, dominantly horizontal flow of ocean water
- 2 types of ocean currents: surface currents & deep currents
 - Surface currents driven by prevailing winds
 - Deep currents powered by changes in temp & density (water salinity) in surface waters
- Warm, salty surface water chilled & sinks in N Atlantic to flow south towards Antarctica, then further cooled to flow outward at bottom of oceans into Atlantic, Indian & Pacific basins
- After upwelling primarily in Pacific & Indian oceans, water returns as surface flow to N Atlantic
- Note N Atlantic Drift & Gulf Stream!



<http://blue.utb.edu/paullgj/geog3333/lectures/oceancurrents-1.gif>

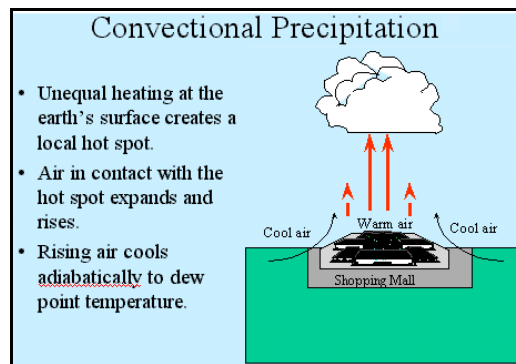


http://www.fas.org/irp/imint/docs/rst/Sect14/Sect14_1a.html

Types of Precipitation **Lecture 4 (Priority: Medium)**

1. Convective rain

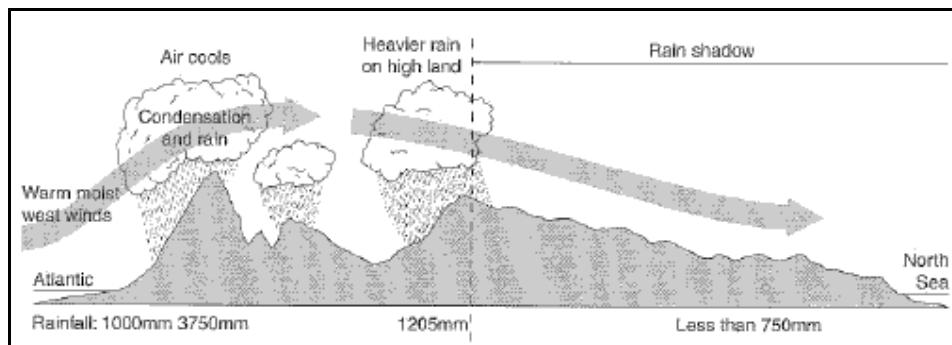
- Heating of Earth's surface causing air to rise rapidly → cools and moisture in air condenses into clouds → falls as rain
- Common in tropics, characteristic afternoon showers
- Often associated with cumulonimbus clouds & thunderstorms
- E.g. Singapore



<http://members.aol.com/pakulda/images/atpctcn.gif>

2. Relief / orographic rain

- Warm moist air of ocean forced to rise by large mountains
- As air rises it cools → moisture in air condenses into clouds → precipitation falls on windward side of mountain
- Leeward side of mountain receives less / no rain, usually very dry / deserts form on leeward side (rain shadow)
- Common in mountainous regions
- E.g. Vancouver (windward) & Calgary (leeward)



<http://geographyfieldwork.com/ReliefRain3.gif>

3. Cyclonic / frontal rain (NOT IN SYLLABUS)

Temporal Variations in Precipitation **Lecture 4 (Priority: Medium)**

Short-term variability (amount of rainfall over number of hours) greatest in Tropics, less in temperate regions

Variability in precipitation important in arid areas, since small storms rare!

1. Short Term Variability

- Steady rain rare
- Convictional rain variations associated with convection zones across land (updraught): strong updraught, rain do not fall out, weak updraught, raindrops fall easily
- Orographic rain may produce prolonged steady rain if moist air blows in from sea at constant speed and conversion of water vapour to water droplets at constant rate

2. Seasonal Variability (Rainfall cycles throughout year)

- Related to latitudinal migration of wind & pressure systems
- Areas with high precipitation associated with areas of convergence & uplift (ITCZ) tend to shift polewards in summer & equatorwards in winter
- Mid-latitudes: rainfall associated with cyclones, more precipitation in late summer & autumn
- Tropics & sub-tropics: convectional rain, more precipitation in summer (max heating)
- Areas under monsoon influence: significant wet-dry seasons

Spatial Variations in Precipitation **Lecture 4 (Priority: Medium)**

Factors to consider for spatial variations include: limit on maximum moisture content of atmosphere by air temperature, distribution of land masses & mountainous regions and global wind systems

Precipitation increases with increasing altitude, and may fall as SNOW

Region	Condition	Reasons
Sub-tropic deserts	Little rain	No mechanism for lifting air masses, subsiding air here results from global circulation patterns
Continental areas	Dryer	Greater distance from moisture sources
Polar areas	Dryer	Cold air holds less moisture
Equatorial tropics	High rain	Constant solar heating → convection, global circulation patterns cause air masses to converge → frontal lifting
Mountain ranges	High rain	Orographic uplift (only if prevailing winds in favour), leeward slopes thus less rain (rainshadow effect)