Climate

Topic 1.1 Weather and Climate

1. Climate

- An average state of atmosphere at a place over a period of time [25 years]
  - Tropical equatorial (Between 10°N and 10°S of equator)
    - Generally high temp (27°C)
    - Small annual temp range
    - High annual evenly spread precipitation (2000mm)
    - E.g. Singapore
  - Tropical monsoon climate (Between 30°N and S of equator)
    - Generally high temp (25°C)
    - Small annual temp range (3-4°C)
    - High annual precipitation (1500mm) with distinct wet and dry seasons
    - E.g. Kochi, India
  - Cool temperate climate (Between 45° and 60°, N and S of equator)

- 4 distinct seasons (spring, summer, autumn, winter)
- Large annual temperature range (21°C)
- Moderate evenly spread precipitation (300-900mm)
- E.g. London, UK | Paris, France

Describing annual temperature range	
Temperature(°C)	**Description**
Below 5	Small
5 to 15	Moderate
15 to 30	Large
Above 30	Very large

Describing mean monthly / annual temperatures	
Above 30	**Very high**
20 to 30	High
10 to 20	Warm
0 to 10	Cool
-10 to 0	Cold

Describing annual rainfall	
Annual rainfall	**Description**
Over 1500	Very high
1000 to 1500	High
500 to 1000	Moderate
250 to 500	Low
Below 250	Very low

2. Climatic hazards

- Changes due to natural and human-induced causes
- Weather patterns become increasingly unpredictable
  - Extreme weather events (heat waves, droughts, floods)

Topic 1.2 Weather and Climate - Variations in Air Temperature Across the Earth's Surface

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1. Variations of air temperatures across time

- Air temp over time in a day (due to rotation of earth's own axis)
  - Midday (***Due to Earth's spherical shape***)
    - Sun is directly overhead, radiation spread over a smaller area and is more concentrated
    - Temp is highest of the day
  - Before and after midday (***Due to Earth's spherical shape***)
    - Sun is not directly overhead, radiation spread over a larger area and is less concentrated
    - Temp is lower than midday
  - Before sunrise (Night)

        - Does not receive solar radiation
            - Loses heat in form of longwave radiation
            - Temp lowest just before sunrise as place lost heat over longest time

- Air temperature variations over time in a year (due to Earth's revolution around sun at 23.5° tilt)
    - June:
        - Northern hemisphere leans towards sun > Receive more direct solar radiation > Higher temp
        - Southern hemisphere leans away from sun > Receives less direct solar radiation > Lower temp
    - December:
        - Northern hemisphere leans away from sun > Receives less direct solar radiation > Lower temp
        - Southern hemisphere leans towards sun > Receive more direct solar radiation > Higher temp
    - March & September
        - Neither hemisphere lean towards sun > Moderate temp
        - Northern hemisphere > Spring (March) & Autumn (Sep)
        - Southern hemisphere > Autumn (March) & Spring (Sep)
    - Areas in topics (close to equator) receive direct solar radiation throughout year > Higher temp throughout
        - Variations more significant in places outside of tropics

2. Variation of air temperatures across places

- Latitude **(Due to Earth's spherical shape...)**
    - Temp are generally lower at at higher latitudes > Solar angles changes varies at different parts of Earth

        - Higher altitude: Solar radiation less concentrated > Spread over a larger area > Lower temp
        - Lower altitude: Solar radiation more concentrated > Spread over a smaller area > Higher temp
    - E.g. Beijing (40°N) has temp averaging 12°C while in SG (1°N) has average temp of 29°C
- Altitude
    - Higher altitude > Air less dense and air pressure is less (gravity pulls air molecules towards surface)
        - Fewer molecules > Lower ability to absorb and radiate heat > Lower temp
    - Every 1000m, temp changes by ~6.5°C
    - E.g. Genting Highlands (1700m) has an average temp of 21°C while surrounding areas is about 32°C

3. Factors affecting air temperature at specific places

- Type of surface
    - Dark surface (soil) > Absorb more solar radiation & radiate more heat > Higher temp
    - Light-coloured surface (cloud) > Reflect more solar radiation & radiate less heat > Lower temp
    - Urban areas have higher temp (Urban Heat Island Effect)
        - Has large area with dark surfaces > Absorb more solar radiation & radiate more heat
        - Has glass-covered skyscrapers that reflect sunlight to the ground > Increase solar radiation absorption
        - E.g. Night time SG
            - CBD generally 2°C warmer as compared to MacRitchie Reservoir
- Distance from sea

- Coastal areas
  - Maritime effect > Cooler summers and warmer winters
  - Annual temp range is lower
    - Summer > Sea is cooler than land > Heat up slower than coast > Cools coast
    - Winter > Sea is warmer than land > Cools down slower than coast > Warms coast
- Inland areas
  - Continental effect > Warmer summers and cooler winters
  - Annual temp range is higher
    - Summer > Heats up quickly > Higher temp
    - Winter > Cools down quickly > Lower temp
- E.g. Alaska, USA
  - Anchorage (coastal) has a temp range of 23°C
  - Fairbanks (inland) has a temp range of 40°C

Topic 1.3 Weather and Climate - Variations in Precipitation Across Earth's Surface

1. Water cycle

- Water vapour enter atmosphere thru evapotranspiration
  - Heat from sun causes water bodies to evaporate > From WV
  - Plants give out WV during transportation
- As WV rises > Cools & condense into tiny water droplets at dew pt temp > Form clouds
- Water droplets in cloud become big and heavy enough > Fall back to ground as precipitation
  - Water on surface infiltrates subsurface soil & rock
  - Water flows as surface runoff and enters a body of water

- Water moves horizontally above impermeable rock and moves at different rates due to...
  - Type of soil
    - Infiltrate faster in soil which has larger pores (sandy) than soil with smaller pores (clayey)
  - Built up areas
    - Infiltrate rates lower in build up areas > Covered in concrete
    - Fewer obstructions > Speed of surface run off higher on smoother ground surface (roads)
  - Presence of natural vegetation
    - More vegetation > More roots to loosen soil > More open space > Infiltrate and groundwater flows faster
    - Stems and roots of plants act as barriers > Increase surface roughness > Surface runoff slower on vegetated areas

2. Affect of temperature on relative humidity on place at specific time

- Relative humidity is the ratio of amount of WV in air to the max amount of WV the air can hold at given temp
  - Temp increase > Amount of WV air can hold increase > Humidity decrease
    - Water molecules move faster and spread further apart > Max amt of WV that can hold increase
  - When humidity is 100% air is now saturated and hits dew point temperature
    - When >100% achieved condensation occurs when WV is added to the air via evaporation or temp drops

3. Cloud formation

- Air rises up > Cools > Reduce amt of WV it can hold
- Amt of WV exceeds max amt air can hold at dew point temp > Air condense into water droplets on condensation nuclei

- Condensation nuclei provides surfaces where WV can change into water droplets or solid ice crystals and form clouds

4. Rain formation

- Formation of conventional rain
  - Daytime > Heat from sun warms surface > Air gains heat and rises
    - Condenses at dew pt temp on condensation nuclei > Clouds formed
      - Water droplets in the clouds collide and coalesce > Become heavier and bigger > Large enough > Fall back onto surface as rain
- Formation of relief rain
  - Prevailing winds pick up moisture over sea > Push moist air up windward side of mountain
    - Condenses at dew pt temp on condensation nuclei > Clouds formed
      - Water droplets in the clouds collide and coalesce > Become heavier and bigger > Large enough > Fall back onto windward side as rain
  - Most of the moisture fallen on windward side > Leeward side experiences dry descending air
  - E.g. USA
    - Sierra Nevada mountain ranges (windward) receive higher rainfall > Lush forests
    - Leeward side hot and dry > Create Death Valley Desert

Topic 1.4 Weather and Climate - Variations in Wind Direction and Wind Speed Across the Earth's Surface

1. Wind formation

- Wind occurs due to unequal distribution of air temperature > Uneven distribution of pressure gradients
  - Place with higher temp > Air gains heat and rise > Create area with low pressure

    - Place with lower temp > Air lose heat and sink > Create area with high pressure
    - Air moves from area of high to low pressure to fill void > Winds formed

2. Speed of winds

- Strength of pressure gradient
    - Smaller pressure gradient > Smaller difference in pressure > Slower wind speeds
    - Larger pressure gradient > Larger difference in pressure > Faster wind speeds
- Friction
    - Winds come in contact with variations of Earth's topography > Frictional drag formed > Reduce wind speeds
        - Greatest when there is uneven relief and rough surface on land

3. Variations in direction of winds at local scale

- Land breeze
    - At night, sea will lose heat slower than land
        - Sea and air above lose heat slowly > Warmer air less dense and rises > Form area of lower pressure
        - Land and air above it lose heat quickly > Cooler air denser and sinks > Form area of higher pressure
        - Air moves from area of higher to lower pressure > Form land breeze
- Sea breeze
    - In daytime, land will gain heat faster than sea
        - Land and air above it gain heat quickly > Warmer air is less dense and rises > Form area of lower pressure
        - Sea and air above it gain heat slowly > Cooler air denser and sinks > Form area of higher pressure
        - Air moves from area of higher to lower pressure > Form sea breeze

4. Variations in direction of winds at regional scale

- Northeast Monsoons (Sep to Feb)
  - Northern hemisphere experiences winter and cool temp > Cool air sinks > Form area of higher pressure over Central Asia
  - Southern hemisphere experiences summer and warm temp > Warm air rise > Form area of lower pressure over Oceania
  - Air moves from northern to southern hemisphere > Winds form
    - As winds moves southwards towards & cross into southern hemisphere > Deflected to the left due to Coriolis Effect
  - Effects on climate
    - India: Little moisture picked up from Central Asia > Little rainfall
    - Singapore: Winds pick up moisture over South China Sea > Brings heavy rainfall
    - Indonesia and Australia: Winds cross over into Southen hemisphere > Deflected to the left > Pick up moisture over Indian Ocean > Brings rainfall
- Southwest Monsoon (June to Sep)
  - Northern hemisphere experiences summer and warm temp > Warm air rises > Forms an area of lower pressure over Central Asia
  - Southern hemisphere experiences winter and cool temp > Cool air sinks > Forms an area of lower pressure over Oceania
  - Air moves from northern (Australia) to southern (Central Asia) hemisphere
    - As winds moves northwards and cross equator > Winds deflected to the right due to Coriolis Effect
  - Effect on climate
    - India: Winds move over Indian Ocean > Pick up moisture > Brings heavy rainfall

Topic 2.1 Climate Change - Natural Variability of Climate

1. Change in Earth's climate over the geological timeline

- Natural variability
  - Temperature and CO2 levels in atmosphere has increased and decreased in a cyclical pattern over 650k years
- Past climates are determined by analysing sediments and oxygen isotopes
  - High concentration of light oxygen (oxygen-16) isotopes > Warmer climate
  - High concentration of heavy oxygen (oxygen-18) isotopes > Cooler climate
- Temperature determine climate zones > Expand or contract overtime

2. Natural causes of climate variability over time

- Changes in Earth's orbit and angle of tilt
  - Orbit shape
    - Stretches from circular to elliptical shape and back again
      - Cycle spans for 100k years
    - Most elliptic > Travel in more oval shape > More radiation reaches Earth at closest approach to sun
      - Applies to furthest away as well (coolest)
  - Tilt
    - Axis varies between 21.5° to 24.5°
      - Cycle spans for 41k years
    - Tilt decrease > Lean further away from sun > Warmer winters & cooler summers > Enable large ice sheets to be built up at high latitudes > Cool Earth
- Sunspot occurrences
  - High sunspot activity > Higher amount of solar radiation
    - Sunspots have low temp > Area surrounding spot radiate more energy > More solar radiation > Higher temp
  - Periods of maximum sunspot activity > High annual surface temp

        - Number of sunspots rise & fall in a cycle > Approx 11 years
    - E.g. 2000 to 2008
        - Solar radiation decreased > Temp continue rising > Suggest that human activity play larger role in influencing temp
- Large-scale volcanic eruption
    - Release large volumes of CO_2, water vapour, SO_2 dust and ash > Spread around lower atmosphere
        - Particles absorb and reflect solar energy back into space
        - Temporarily offset greenhouse effect > Lower temp > Grow large enough > Fall back down to Earth
            - E.g. Mt Pinatubo [1991]
                - Led to a drop in global temp of 0.6°C over 15 months

Topic 2.2 Climate Change - Anthropogenic Factors Contributing to Climate Change

1. Change in climate in past 200 years

- Climate changes due to natural and anthropogenic factors
    - Anthropogenic factors have produced 100 more times > CO_2 as compared natural causes > Rise in global temp
        - Contributed increased greenhouse gases (CO_2, N_2O, CH_4)

2. Greenhouse effect

- Shortwave radiation travel from sun to surface
    - Most shortwave radiation is absorbed by surface
    - Some shortwave radiation is absorbed & reflected by clouds
- Longwave radiation from Earth escapes towards space (Emitted by Earth)
    - Some long wave radiation is absorbed by greenhouse gases > Re-emitted in atmosphere > Keep Earth warm

3. Enhanced greenhouse gases

- Anthropogenic factors > Concentrations of greenhouse gases increase > Enhanced greenhouse effect > Heat gets trapped > Increase in temp
    - More greenhouse gases > Less heat escape into space > Radiated back towards Earth's surface

4. Anthropogenic factors

- Burning fossil fuels
    - Fossil fuels (oil, coal, gas) have high carbon content
        - Burnt > Produce large amounts of CO2 and other greenhouse gases > EGHE
    - Fossil fuels used to create energy for human activites
        - E.g. Fossil fuels increased steeply since Industrial Revolution > 35 billion tonnes of carbon dioxide per year
- Changing land use (Require fossil fuels for energy)
    - Agriculture
        - Growth in population > Forests cleared > Make space for agriculture > Meet demand for food
        - Contributes 30% to greenhouse gases emissions
            - Burning fossil fuels to produce for machinery
            - Nitrogen in chemical fertilisers converts to nitrous oxides
            - Livestock rearing and natural decomposition > Release methane
        - E.g. Paddy fields
            - Decomposition rapid > High amount of moisture in soil > 5-20% of total methane emissions
    - Deforestation
        - Changing land use of industries, agriculture and urbanisation > Deforestation > Clear land
        - Removal of forests
            - Resources (Timber & wood > Paper & building materials)

        - Land (Urban development)
    - Deforestation > Increased levels of CO2
        - Reduce number of trees (absorb CO2 through photosynthesis)
        - Cut down trees > Carbon released back into atmosphere as CO2
        - Carbon oxidation > Exposes soil surface to sun > Soil temperature increase > Formed carbon dioxide
    - E.g.
        - Tropical deforestation contributes to 20% annual greenhouse emissions
- Industries
    - Fossil fuels > Generate energy > Run machine and factories
        - About 43% of greenhouse gases contributed annually
- Urbanisation
    - Fossil fuels burnt to power vehicles and household activites (heating, cooling, lighting)
        - Cities consume about 78% of world energy supply > Contribute to greenhouse gas emissions

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Topic 2.3 Climate Change - Impact of Climate Change on Natural Systems

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1. Climate impact on natural systems

- Increase in atmospheric & ocean surface temp
    - Since Industrial Revolution > Temp have been rising
    - Most heat trapped absorbed by oceans
        - Average temp of oceans increasing > Last century > Sea warmed slight by 1°C
        - Increase in uneven some warm & cool
- Changes to ocean circulation

    - Water in oceans is constantly moving around world > Known as ocean circulation
        - Warm surface water moves from equator to poles due to winds
            - Water cools > Denser > Sink
            - Cold water spreads along bottom of ocean > Form cool subsurface flows
                - Water eventually rises back towards surface of ocean
        - Climate change > Slow down circulation
            - Water at surface gain heat due to rising temp > Less dense
            - Sinking of water at poles > Reduced > Slows down flow
            - E.g. Ocean current in Atlantic Ocean slowed down by 15%
- Changes in precipitation on land
    - Climate change > Strengthening in precipitation patterns
        - Wet regions > Wetter > Increased precipitation > Occurrences of excessive rainfall increase
            - Warmer air > More WV
                - Warmer air > Hold more WV (Humidity)
                - Increased evaporation
            - E.g. Poles, parts of SEA and Central Africa
        - Dry regions > Drier > Decreased precipitation > Occurrence of drought increase
            - Warmer atmospheric temp > Increase evaporation > Reduces surface water > Dries out soil and vegetation
                - Lack of moisture > Reduce occurrences of rain
            - E.g. Southwest USA and parts of Sahel Africa

2. Impact of climate change on aquatic ecosystems

- Threats to coral reefs

- Corals are highly fragile ecosystems > Vulnerable to coral bleaching
  - Corals have symbiotic r/s with algae
    - Live in them > Algae are corals' primary food source & give colour
  - Increase ocean temp > Algae leave corals > Turn white
  - More likely to die
- Corals die > Species lose habitat > Population decline > Affect other species that depend on corals > Entire ecosystem affected
- Population of reefs expected to decline by 90% when temp rises by 1.5°C
- E.g. Australia
  - GBR in Australia > Severely affected in 2016 & 17 due to rising sea temp
    - Up to 2/3 died at northern section of reef
    - Species diversity decreased

- Ocean acidification
  - Ocean are carbon sinks (Presence of phytoplanktons > Absorb CO_2 & Photosynthesise)
  - Increase in CO_2 > Absorb excess CO_2
    - Carbonic acids form in water > Ocean acidic
      - Ocean acidity increase by 25% since IR (1800s)
    - Carbonic acids dissolve calcium carbonate
      - Needed by corals, mussels and oysters to form their skeleton & shell
  - As coral skeleton shrink > Species that rely coral for food and habitat from predators > Negatively affected > Potentially go extinct
  - E.g. Australia
    - Average coral cover dropped by ~30% at GBF of what it was in 1960s due to acidification

- Disruption of marine food webs
  - Slowing down of global ocean circulation
    - Ocean circulation transports heat from tropics to poles > Exchange of nutrients between surface and deep water
      - Slowing down > Reduces sinking of water to poles > Warm surface waters mix less with cooler deeper waters
        - Separates near-surface aquatic life from nutrient below > Reduction of phytoplanktons
        - Species higher up in food chain suffer lack of food > Entire ecosystem negatively affected
        - E.g. Phytoplankton levels in North Atlantic dropped by 10% since IR
  - Increase in ocean surface temperatures
    - Changes in geographical distribution of species
      - Warming oceans > Migrate to areas that are cooler and more favourable
      - Move poleward (cooler)
        - Equatorial regions experience decrease in biodiversity
        - Poleward regions will experience increase in diversity
      - E.g.
        - Parrotfish & rabbit fish have migrated polewards
        - Diversity at tropical waters decreased significantly past 50 years
    - Changes in composition of aquatic ecosystems
      - Geographic distribution of species changes > Complex
        - Mix of prey, predators and competitors change > Disrupt food webs and changing aquatic ecosystems
      - Changes in ecosystems:

        - Some flourish, some will not
        - Some may find an abundance of suitable sources of food > Increase in population
        - Some may not find suitable sources of food and their population decreases
    - E.g. Aquatic species
        - Tropical fish (parrotfish & rabbitfish) > Migrated to cooler waters in Australia & Japan
            - Species feed on kelp in cooler waters > Decline in kelp > Affects other species
            - Southern JP > Population of lobsters decreased with disappearance of kelp
    - Species unable to migrate or move fast enough > Not able to adapt to high temp
        - Unsuitable environment for them > Habitat and food disappear > Face extinction

3. Impact of climate change on terrestrial ecosystems

- Threats to flora and fauna
    - Increase in atmospheric temperatures
        - Change in geographical distribution of terrestrial species
            - Species generally migrating to higher latitudes and altitudes where temp is cooler
            - E.g.
                - 170 species in North America expanded their range northwards up to 50km on average past 4 decades
                - Temperate forests advancing northwards & replacing boreal forests > Boreal forests advancing northwards into tundra
        - Changes in composition of terrestrial ecosystems

- Geographic distribution of species changes > Complex
    - Mix of prey, predators and competitors change > Disrupt food webs > New terrestrial communities develop
- Observations made:
    - Species population decline > Cannot find suitable habitat to migrate to
        - Mountain species > Prefer cold environments > Might not have anywhere to go if mountain too warm
        - Face competition with species from lower altitudes who are moving up
- E.g. Australia
    - Wallabies migrating to higher altitudes
        - Found herbfields > Suitable source of food > Flourish
        - Overgrazing > Threatens to reduce into grassy lawns
        - Broad-toothed rats > Face competition > Risk of extinction
- Plant species > Cannot move > Decline if can't adapt fast enough
- Some species flourish as they migrate to new habitats

- Changes in extreme weather patterns
    - Droughts
        - Plants vulnerable to droughts > Not able to move anywhere else for water
            - Plants wither and die
            - Vulnerable to disease and insect attacks when weak
            - Trees die > Habitats damaged > Food supply decline
        - Animals move to new locations to search for food, water and habitat
            - Results in spread of diseases (botulism & cholera - thrive in warm conditions)

        - Loss of biodiversity
    - Some may not be able to adapt > Become extinct
    - E.g. California [2012 - 16]
        - Lack of water + Diseases > 102m forest trees died
        - Wetlands dried up > Insects, dish and plants died + Migratory birds starved to death
        - Thousands of duck and geese crowd in wetlands
            - Resulted in spread of cholera > Died
- Excessive rainfall
    - Results in floods > Destroy habitats > Terrestrial species to drown and die
    - Soil erosion occurs
        - Get rid of nutrient rich soil
        - Trees vulnerable to uprooting
    - E.g. Assam India
        - [2020] Excessive rainfall > Flood > 200 animals killed (including 8 endangered rhinos)

Topic 2.4 Climate Change - Impact of Climate Change on Human Systems

1. Direct and Indirect impacts

- Direct
    - More often or severe extreme weather event > Loss of lives, increased poverty and destruction
        - Heat waves, droughts, floods, tropical cyclones, wildfires
- Indirect
    - Ecosystems services affected
        - Provisioning - Food pollution

        - Regulating - Diseases regulation
        - Cultural ecosystem services - Melting of ice caps and degradation of natural landscapes
    - Human ecosystems affected unevenly
        - Varying climate variables
        - Differing social and economic factors

2. Climate change and more extreme weather events

- Heat waves
    - Period of excessively hot weather (abnormal) > Lasting several days of longer > Temp of over 40°C
        - Climate change > Higher temperatures > Make heat waves more intense and more frequent
    - Impacts on humans
        - People suffer from heat stroke, difficulties in breathing and death
            - Caused thousands of deaths worldwide
        - High temperatures > Deplete soil moisture > Widespread crop failure > Food supply affected
    - E.g. [2003] Europe
        - 70k died heat wave in 2 weeks
        - Harvest for agriculture crops (wheat) affected > Crops died
            - Price of bread increased significantly > Less affordable for people
        - [2019] Heatwave again
            - Broke many record 45°C recorded in France
- Droughts
    - An area or region experiences a lack of precipitation (rain or snow) > Extended period of time > Water shortage

        - Climate change > Higher atm temp > Increased evaporation > Reduces surface water and dries out soil and vegetation
            - Dry seasons > Drier
            - Droughts more likely to occur in places exp dry climates (subtropics - deserts located)
    - Impact on humans
        - Shortage of clean water > Dehydration & death
        - Lack of H2O > Cause crop failure > Die from malnourishment or hunger
        - Displacement of humans
            - E.g. [2030] 700m people risk of being displaced by droughts
    - [2018-19′] Afghanistan
        - 2/3 of country affected
            - 10m displaced and lack food
- Wildfires
    - Unplanned and uncontrolled fires > Burn natural areas (forests or grasslands)
        - Warmer and drier conditions > More dead trees & vegetation > Easier for wildfire to start > Harder to put out
    - Impact of humans
        - Causes suffocation, injuries and burns
            - Large amounts of CO2, CO and fine particulate matter > Released in atm > Air pollution > Respiratory illness > Death
        - Destruction of buildings and property > Homelessness and economic loss
    - [2019-20′] Australia
        - Widespread fires > Affect entire continent

        - Difficult to get under control due to persistent hot and dry conditions
    - Air quality hazardous & human health risk
        - Sydney > Air quality measured x11 greater than hazardous level
    - 34 people died and thousands of buildings burnt down
        - Many people left homeless due to wildfires

- Floods
    - Increases flood risks
        - Warmer temp > Excessive precipitation > Especially in places with high precipitation
        - Warmer temp > More snowmelt > Increase in sea level > Higher coastal flood risk
    - Impacts on humans
        - Loss of human lives due to drowning and injuries
        - Destruction of buildings and properties by fast-moving floodwaters > Homelessness and economic losses
        - Food and supplies affected
            - Waterborne diseases such as cholera become increasingly prevalent (when enter wells)
    - E.g. Bangladesh
        - Densely-populated, low-lying country > Live near coastal
        - Monsoon climate > Often exp seasonal flooding
        - Receives melt from mountains

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- Indirect
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        - Regulating - Diseases regulation
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    - An area or region experiences a lack of precipitation (rain or snow) > Extended period of time > Water shortage
        - Climate change > Higher atm temp > Increased evaporation > Reduces surface water and dries out soil and vegetation
            - Dry seasons > Drier
            - Droughts more likely to occur in places exp dry climates (subtropics - deserts located)
    - Impact on humans
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        - Destruction of buildings and properties by fast-moving floodwaters > Homelessness and economic losses
        - Food and supplies affected
            - Waterborne diseases such as cholera become increasingly prevalent (when enter wells)
    - E.g. Bangladesh
        - Densely-populated, low-lying country > Live near coastal
            - Vulnerable to coast flooding (sea level rise)
        - Monsoon climate > Often exp seasonal flooding
        - Himalayans icecaps and glacier > Meltwater
        - [2020] Worst monsoon > Intense rainfall > Flooding
            - Death: 260 people

        - Homes: 1.3B destroyed
        - Agricultural crops damaged (worth millions) > Lost essential food supply

- Tropical Cyclones
    - Intense circular storms > Originate over warm tropical oceans
        - Accompanied by strong winds, heavy rain and storm surges
    - Climate Change > Warmer oceans > More WV in atm > Driving force for intense cyclones
    - Impact on humans
        - Cyclones > Flooding, landslides, collapsed builds and infrastructure > Loss of life
            - Destroy buildings + crops > $$ losses > Threaten food security
        - E.g. [2020 Oct to Nov] Philippines
            - 4 Weeks > Hit by 6 tropical cyclones
            - Strongest typhoon (Typhoon Goni) > Strong destructive winds + High rainfall
                - Loss of lives + Massive destruction
                - Evacuation (1M people)
                - $36M worth of crops destroyed
                - Power supplies cut
            - Developing country > Infrastructure cannot cope w severe floods
                - No time to recover b4 another cyclone

3. Indirect impact of climate change on humans

- Provisioning ecosystem services
    - Impacts on fish production
        - Ocean temperatures increase > Acidity increase > Threaten aquatic life

- Warmer oceans
    - Species cannot cope > Die
    - Distribution of species change > Fishermen catches affected > Economic livelihoods affected
- Sea level rise
    - Saltwater enter freshwater > Threaten freshwater fishes

- Fish supplies dwindle > Food security decrease
    - E.g. Tonle Sap Lake, Cambodia
        - Main economic activity: Fishing
        - Climate change led to...
            - Increased temperatures & unpredictable rainfall > Water levels decline > Reduce availability of fishes
            - Higher temp > Surrounding forests burn more easily during dry seasons > Destroy fish habitats and reduce availability of fishes
- Changes at aquatic ecosystems > +ve impacts to provisioning services at certain areas
    - Higher latitude > Fish species migrate to cooler (polewards) > Fisheries able to catch more diverse array of seafood
        - E.g. Portugal > Fishermen able to catch new species (previously found in only warmer regions)

- Impacts on crop yield
    - Climate change > Cause more severe/ frequent extreme weather events > Difficult for crops to survive > Reduce food production
        - E.g. [2020] Thailand
            - Worst drought in 4 decades
            - Lack of rain + Shorter monsoon seasons > Dried up reservoirs & dried up land > Unable to grow crops

        - Economic livelihoods impacted
    - Impacts unevenly distributed
        - Food production fall > Prices increases
            - Poor most affected > Large proportion of income spent on food > Malnutrition and starvation
            - Sub-Saharan Africa & South Asia > Poorest regions in world > Most vulnerable
- Regulating ecosystem services
    - Increase in vector-borne diseases
        - Warmer temp > More conducive environment 4 mosquitos and ticks 2 survive and breed
            - More to higher altitudes and latitudes since warmer > More at risk
        - People sick leads to:
            - Loss of lives
            - Reduced economic productivity > Cannot work
            - Increase in healthcare costs for country
        - E.g. [2018] Bhutan
            - Mosquitos previously nonexistent in mountain regions > Too cold
            - [2019] Suffered first national dengue epidemic > Many areas reported dengue cases
- Cultural ecosystem services
    - Melting of Arctic Ice
        - Climate change > Melting of ice > Changes everyday cultural practices of Arctic indigenous people
            - Traditional practices (storing food in ice cellars) threaten > Cultural services disrupted
            - Ice melting > Decline in sled dogs > Imprt part of culture > Used for hunting and travel

- Degradation of natural landscapes
  - Climate change causes degradation of natural landscapes > Affect tourism industry
    - E.g. Maldives
      - Low-lying islands (relies heavy on tourism)
        - Many parts > Uninhabitable
      - Corals (huge tourist attraction) > Warmer oceans > Affected by coral bleaching
      - Lead to reduction in tourist revenues as fewer tourists
  - Ecosystem service interconnected
    - Cultural ecosystem services impacted when provisioning and regulating affected
      - Cambodian fishermen @ Tonle Sap exp reduced catch > Switch jobs > Changed traditional way of life

Topic 3.1 Climate Action - Achieving Sustainable Development Through Climate Action

1. Climate action (Stepped-up efforts to combat climate change + Impacts)

Mitigation

- Efforts to reduce greenhouse gas emmisions + Enhance carbon sinks > Slow down climate change

Adaptation

- Efforts to adjust to climate change and its effects > Reduce harm to ppl + envt.

- Strategies > Complementary
  - Mitigation > Slow down + Prevent worsening impacts
  - Impacts of climate change > Already happening > Adaptation needed > Minimise harm caused > More future-ready
- Build community resilience + Sustainable development
  - Communities can resist, absorb, adapt to and recover from impacts

- Costs from investment for climate action > Smaller than cost of losses during impact
    - Fewer losses > Minimise money needed to rebuild
- Strategies may cause risks > Vary in severity > Carefully consider

2. Climate change as a threat multiplier

- Worsens threats to natural and human systems that may be cause by other reasons
    - E.g. Coral Bleeching > Already occurring due to pollution
        - Climate change > Makes it more likely > Put stress on> Threaten ecosystem
        - Loss of biodiversity > Fishing communities pushed to poverty
- Places already struggling to manage threats > More negatively impacted
    - E.g. Sahal Region, Africa
        - Deforestation > Droughts
            - Agricultural productivity affected > Cereal production drop by 13% by 2050 > Pushed into poverty

3. Constrain in development paths

- Limit ability to current and future gen to meet needs
- Erode development gains achievement by countries
- Slow down development process > Money meant for social services > Channelled into rebuilding after climate-related hazards
    - Detrimental to developing countries > Funds may be lacking

4. Disadvantaged communities and developing countries affected more

- Disadvantaged:
    - Many live in open + no shelter from water elements > Experience increasing risks (e.g. heatwave, flooding, storms)
    - May not be able afford higher food prices

    - Vulnerable to vector-borne diseases > Limited ability to get medical attention
- Developing
    - Lack financial ability to put in place measure to reduce impacts
        - E.g. Unable construct sea walls along coast > Manage flooding and sea level rise
- Widens inequality & sustainable development

Topic 3.2 Climate Action - Variations of Climate Risks Across Places

1. Climate risks

- May result in loss of lives and damage to properties
    - Climate-related hazards
    - Vulnerability
    - Exposure

2. Climate-related hazard's influence on climate risks

- Varying intensity, duration and nature
    - Short-term vs long-term
- Short-term
    - Brief & Sudden > Floods and cyclones > Shorter duration (Days to weeks)
    - Immediate risk > Widespread destruction of properties, loss of lives and disrupt services
        - E.g. [2013] Typhoon Haiyan, Philippines
            - Over 6k deaths and left millions displaced
- Long-term
    - Take a long time to develop > Sea level rise & droughts > Longer duration
        - Droughts > Develop due to changes in temp and precipitation
        - Sea level rise occur incrementally over decades

- Delayed risks > Communities have ample time to prepare
  - May remain unnoticed
- E.g. Western region of USA
  - Experience multi-decade drought event from 2000
  - Two major reservoir shrunk + Increase in forest fires

3. Vulnerable climate's influence on climate risks

- Conditions that increase susceptibility of community to suffer from extreme weather
  - Poverty
    - Crop failures > Reduce availability of supply > Food prices increase > Unable to cope with increase > Shortage
      - E.g. [2018-2019] Afghanistan
        - Widespread poverty > Drought > 10m people to suffer food crisis
    - Not able to afford health resources when infected with diseases
      - E.g. Malawi
        - Malaria spread to highlights due to increase in temp
        - Lack health resources to get treated > Loss of lives
  - Lack of access of piped water
    - Cause contamination of water sources
    - Rural areas may not be connected to piped water > Rely on rivers and wells > Not clean
      - Drink contaminated water > Diseases (Cholera)
    - E.g. Dar Es Salaam
      - Access to piped water limited
      - Floods in cities > Contamination in wells > More than 5000 cases recorded

4. Exposure influence climate risks

- Proximity to coastal environments
  - Exposure to storm surges and sea level rise
    - E.g. USA
      - Hawaii > Likely to be exposed to coastal hazards (floods)
      - Coastal city > New Orleans > Exposed to damage from storms
- Proximity to dry environments
  - Towns in arid or dry envt. > More likely exposed to hazards (droughts)
    - E.g. Central Asia, Australia > Face severe droughts by end of century

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Topic 3.3 Climate Action - Effectiveness of Mitigation Strategies in Building Community Resilience to Climate Change

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1. Mitigation strategies to build community resilience to climate change

- Refer to efforts to reduce greenhouse gas emissions and enhance carbon sinks to slow down climate change
  - Changes how people produce and use energy and land
- Climate change slows down > Better resist, absorb and adapt to and recover from impacts
  - Builds community resilience
  - Mitigation strategies vary from place to place

2. Effectiveness of mitigation strategies

- International agreements and cooperation
  - United Nations Framework Convention on Climate Change (UNFCCC) > Treaty focused on addressing climate change
    - Signed by 197 countries
    - Focused on stabilising emissions > Prevent irreversible anthropogenic impacts + Provide sufficient time for ecosystems to adapt

- How does it work?
  - Greater responsibility on developed countries > Considered main source of emissions > Expected to cut
  - Funds directed to climate action in developed
    - Provide financial support to developing nations
    - Share technology to mitigate and adapt to climate change (LDCs)
  - Monitoring progress of policies > Report policies and emissions
- Members (know as Conference or Parties) meet every year discuss on climate action
  - E.g. [2015] Paris Agreement
    - A legally binding treaty on climate change > Signed by 191 countries in Paris > Requirements to set targets
- Limitations
  - Dependent on parties' commitment to act > Different priorities > Commitment vary
    - E.g. [2017] USA, Donald Trump
      - Announced withdrawal from Paris Agreement > Thinks that
  - Contributions to reduce emissions not legally binding > No level action can be taken to enforce if refuse to take action

- Use of low carbon technologies
  - Carbon capture
    - Process of separating and capturing CO2 from industrial sources of emission
  - Utilisation & storage
    - CO2 stored from a long period of time > Prevent from reaching atmosphere
      - Storage: Storing in oceans

        - Utilisation: Used as raw materials to produce useful materials > Profits
    - Limitations of CCUS
        - Economic: Expensive and require heavy funding for private research and development
            - E.g. Singapore
                - $49m set aside yo fund low carbon energy research + testing
        - Technological: Concerns of leaking out
- Use of clean energy sources
    - Do not emit greenhouse gases and pollute the atmosphere
    - Solar energy
        - Energy from sun converted into electrical energy
        - E.g. Singapore
            - [2030] Increase solar capacity to met 4% of Singapore's total demand
    - Hydro-electric power
        - Capture energy from moving waters (rivers)
    - Geothermal
        - Derived from heart in Earth's crust > Hot rocks heat up groundwater > Steam formed > Harnessed to generate electricity
    - Nuclear
        - Splitting up of radioactive atoms > Generate heat > Produced steam > Harnessed to generate electricity
        - Stable in terms of supply
    - Limitations
        - Development & construction are expensive > Dependent on government policies and financial support > Viable (Cost-competitive)

        - E.g. Indonesia
            - Solar system may cost around 900-1300 USD per kW
            - Only accounts for 1.7% of country's electricity in 2019
- Changes in consumption patterns
    - Contributes to carbon footprint because greenhouse gases released during production & transportation of goods
    - Food choices
        - Food production contribute 1/4 of emmisions > Diff. types of food > Varied environmental impacts
        - Eat less meat and more vegetables + Buy local produce > Reduce agricultural and transportation emissions
    - Food waste
        - Enter landfill > Rots > Produce methane > Contribute to climate change
        - Buy only what is needed (make a list) + Repurpose (Ground coffee used as fertilisers)
    - Use of plastics
        - Greenhouse gases produced
            - Chemicals sourced from fossil fuels > Used to make plastics
            - Plastics inecenerate or biodegrade
        - Refuse single-use plastics + Right way to recycle
    - Fashion
        - Production of apparel > High levels of water & energy needed > Greenhouse gases
        - Consumers demand changes in design > Production increase
        - Before buying > Ask if manufactured sustainably
        - Repair or up-cycle, donate, buy what is needed, opt second-hand
    - Limitations

        - Takes a long time to change people's mindsets
        - Many companies reluctant to change to sustainable methods > Likelihood of reduced profits
        - E.g. Singapore
            - Availability of tap water > More than 460m bottled water consumed (Convenient)
            - People still associate tap water as unclean

3. Effectiveness of mitigation strategies that enhance carbon sinks

- Important more than 50% of emittted carbon dioxide reabsorbed by forests and ocean > Reduce greenhouse gases in atmosphere
- Protection of oceans & oceans through managing land-use
    - Land-use change account for 10% of global emissions from deforestation and methane from agriculture
    - Reducing deforestation
        - Deforestation leads to...
            - Increased concentration of greenhouse gases
            - Soil erosion > Soil particles no longer anchored by roots > Enter into water bodies > Suffocate aquatic life
        - Ensures natural system's capacity in absorbing CO2 is not reduced
        - Reduced by...
            - Consumers buying products that is certified as sustainable
            - Banning illegal deforestation with stricter laws
    - Restoring mangroves
        - Very important to ecosystem
            - Absorb and store greenhouse gases x4 as much as trop forests
            - Filter pollutants in rivers and prevent them from reaching oceans and harming aquatic life

        - Planting more mangroves in coastal areas
            - Create optimal conditions for mangroves to grow (reduce water pollution)
            - Correcting problems that caused its loss in the 1st place
    - Limitations
        - Economic: Difficult to reduce deforestation in growing economy due to competing land uses
        - E.g. [2020] Indonesia
            - Lost more than 100k hectares of forest cover
                - Despite tightening of laws > Forests cleared for palm oil, mining, e.t.c.
                - Largest exported of palm oil, valued at $18B and 3m jobs
- Forests regeneration
    - Afforestation: Planting trees in new areas that previously didn't have trees
    - Reforestation: Re-planting trees in an area that had trees in the past
    - Agroforestry encourage > Different species of trees to be grown effectively on piece of land
    - Limitations
        - Social: Large-scale afforestation > Competition for land > Limit land > Increase in food prices > Threat to food security
        - Tech: Large-scale tree planting programmes take 50 to 100 years to have full effect of removing 200B tonnes of greenhouse gases

Topic 3.4 Climate Action - Effectiveness of Adaptation Strategies in Building Community Resilience to Climate Change

1. Adaptation strategies to build community resilience

- Efforts to adjust to climate change in order to reduce harm to people, envt., and properties

    - Structural approaches
    - Tech approaches
    - Social approaches
    - Institutional approaches
- Strategies vary from place to place and no one-size fits all approach
    - May be limited due to technological, social, economical and institutional challenges

2. Effectiveness of structural approaches in building community resilience

- Involved construction of physical structures to ensure water and flood management
    - Sea walls
        - Constructed along coast to prevent sea from advancing into land > Protects people, properties and envt. from floods
        - E.g. ECP, Singapore > Seawalls protect from sea level rise
    - Polder
        - Low-lying land surrounded & protected by barriers known as dyke > Excess water is pumped out > Protects people, properties and envt. from floods
        - E.g. Netherlands building polders since 12th century
    - Water shortage tanks
        - Store excess storm water > Slow water from rushing into canals
        - E.g. Singapore
            - Stamford Detention Tank > Excess water stored > Water released back when sensors detect water levels in drain fall
- Limitations
    - Economic: Costly to build structures that are strong enough to protect communities esp. in LDCs

        - Need to be monitored closely to protect with worsening climate change
        - E.g. Fiji > Seawalls costly to build even though uses local materials supplied by gvt + Require manpower to build
    - Social: Involved eviction of informal communities > May resist against it + No where else to go
        - E.g. Jakarta & Bangkok > Informal communities displaced to make room for construction of flood structures

3. Effectiveness of technological approaches in building community resilience

- Produce food can help communities to remain food secure > Increases food security
    - E.g. Singapore's 30 by 30 plan
        - Increase local food supply to 30% by 2030
            - Now, 90% of food imported > Dependent on global food supply
        - Space constraints > Less than 1% used for farming > Invent innovative ways to produce locally more efficiently
    - High tech farms:
        - Vegetable > Monitored remotely > Ensure crops grown optimally > Harvested faster
        - Egg > Automated > Undergo checks faster > Manpower allocated elsewhere
        - Fish > Water tanks monitor water quality and diseases > Swift actions taken to prevent spread of diseases
- Limitations
    - Economic: Can be very costly > Not possible in other nations

4. Effectiveness of social approaches in building community resilience

- Raising awareness and educating public > Respond well to impacts

    - More aware of warning signs of hazard > Take steps to protect oneself > Increase community reselience
    - E.g. Singapore
        - Public educate when flash flood occurs or how to prevent heat stress in warm weather > Keep hydrated and watch out for early signs
- Limitations
    - Social: People not willing to change behaviour

5. Effectiveness of social approaches in building community resilience

- National policies
    - Established organisations and agencies to coordinate climate action
        - MSE oversees how SG can become more resilient > Creates framework + roadmap
        - Centre for Climate Research Singapore > Conducts research > Gain understanding on climate in SG > Support in planning
- Regional policies
    - ASEAN Cooperation on Environment > Safeguard interests of SEA
        - Regional strategies like Climate Outlook Forum > Enables countries to collaboratively develop climate outlooks
- Limitations
    - Institutional/economic: Countries have different priorities > Not have capacity to draw on their national budget

!!!Note/Disclaimer: Content is strictly based off textbook. Cover picture is also taken by myself. Notes were previously personalised so there can be some inconsistencies especially with abbreviations (governmental organisations). Hope these notes help! All the best for your exams :D