topic 1 weather & climate

3.1 defining weather & climate

3.2 variations of air temperature across earth's surface

3.3 variation of precipitation across earth's surface

3.4 variation of wind direction & wind speed across earth's surface

topic 2 climate change

2.1 natural variability of climate

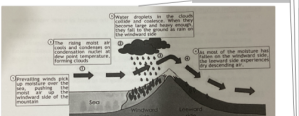
2.2 anthropogenic factors on climate change

2.3 how climate change affects natural systems

2.4 how climate change affects human systems

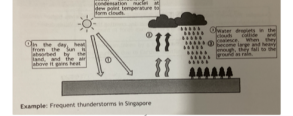
water cycle
- sun's heat -> water bodies evaporate -> water vapour formed
- plants transpire -> give out water vapour
- water vapour rises & enters atmosphere thru evapo-transpiration -> cool & condense into tiny water droplets at dew point temp -> form clouds
- water droplets in clouds get big and heavy enough -> fall to ground as precipitation -> water on ground surface infiltrate subsurface soil & rock -> water moves horizontally above impermeable rock as groundwater flows
- water that cannot infiltrate ground -> flows over ground surface as surface runoff & enter water bodies

relief rain formation



Example: Windward side of Sierra Nevada mountain ranges, USA, receives higher rainfall and has lush forests. The leeward side is hot and dry, creating the Death Valley desert.

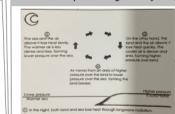
FORMATION: CONVECTIONAL RAIN



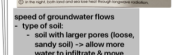
Example: Frequent thunderstorms in Singapore

conventional rain formation
- rainfalls often occur in afternoons in SG

cloud & rain formation
- air rise up atmosphere -> air cools -> reduce amt of water vapour air can hold -> water vapour present in air exceeds max amt of water vapour air can hold over time (RH = 100%) (air saturated)
- at dew point temp -> air condense into water droplets on condensation nuclei (provide surfaces for water vapour to become water droplets/solid ice crystals) -> clouds formed
- water droplets in clouds collide & coalesce -> water droplets in clouds become bigger & heavier -> droplets fall to earth as raindrops
- once water droplets are large & heavy enough



determining wind speed
- strength of pressure gradient
  - smaller = smaller diff in pressure between 2 areas = slower wind speed
  - larger = larger diff in pressure between 2 areas = faster wind speed
- friction
  - moving air comes into contact with variations in earth's topography (differing altitudes = hopes & slopes) -> frictional drag experienced -> wind speed decreased
  - uneven relief & rough surfaces on land (valleys & mountains) -> effect of frictional drag greatest



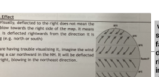
speed of groundwater flows
- type of soil:
  - soil with larger pores (loose, sandy soil) -> allow more water to infiltrate & move quicker -> water flow faster
  - soil with smaller pores (clayey soil) -> water flow slower
- presence of built-up area:
  - built-up areas have concrete ground surfaces (tiny pores) -> lower infiltration rates
- presence of natural vegetation:
  - vegetation (roots of plants) -> loosens soil -> create more open spaces for water to flow -> water flow quicker

variations of wind direction: local scale
- land breeze
  - wind blows from land to sea
  - regulates temp of coastal areas at night -> smaller annual temp range
- sea breeze
  - wind blows from sea to land
  - lowers temp of coastal areas during day -> smaller annual temp range

monsoon

southeast monsoon
- season & temp: june to sept
  - NH = summer & higher temp
  - SH = winter & lower temp
- pressure difference:
  - NH = air warm up & rises -> area of lower pressure over central asia
  - SH = air cools & sinks -> area of higher pressure over australia
- wind direction & Coriolis effect:
  - air moves from australia towards central asia
  - when winds cross into NH -> deflected to right -> form southeast monsoon -> experienced by SG & Msia & India
- effect on climate:
  - india = winds move over indian ocean -> winds pick up moisture over indian ocean -> heavy rain
  - SG & Msia = winds move over south china sea -> winds pick up moisture from water vapour -> heavy rain
  - australia & indonesia = winds cross over to SH -> deflected to left -> pick up moisture over indian ocean -> rain

northwest monsoon
- season & temp: october to februrary
  - NH = winter & cooler temp
  - SH = summer & higher temp
- pressure difference:
  - NH = air cools & sinks -> area of higher pressure over central asia
  - SH = air warm up & rises -> area of lower pressure over australia
- wind direction & Coriolis effect:
  - air moves from central asia towards australia
  - when winds travel to india -> deflected to right -> form northeast monsoon -> experienced by SG & Msia & India
- effect on climate:
  - india = little moisture picked up from central asia -> northeast monsoon dry & cool -> little rain
  - SG & Msia = winds move over south china sea -> winds pick up moisture from water vapour -> heavy rain
  - australia & indonesia = winds cross over to SH -> deflected to left -> pick up moisture over indian ocean -> rain



wind drive southwards-> face south -> deflect to its right -> blow in southwest direction

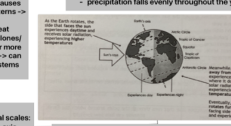
variations of wind direction: regional scale
- unequal distribution of energy across earth's surface -> air moves over different regions from high pressure to low pressure zone (varied pressure zones)
- winds travel over large distances -> deflected by Coriolis force (occurs due to earth's rotation)
- northern hemisphere -> winds deflected to right
- southern hemisphere-> winds deflect to left

winds formation
- horizontal movement of air across earth's surface
- due to unequal distribution of air temp -> uneven distribution of pressure gradients
- diff pressure results -> pressure gradient
- air moves from region of higher pressure to lower pressure to fill in void -> wind formed

weather & climate
- weather classified using characteristics: air temperature/ cloud cover/precipitation/wind speed/wind direction
- climate classified into: different climatic types

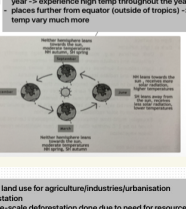
climatic types - can be represented using climograph (shows a place's avg monthly temp & rainfall over a year)
- tropical equatorial climate
  - (between 10°N & 10°S of equator) (Havana, Cuba, SG)
  - high temp all year round - 27°C
  - small annual temp range - 2°C to 3°C
  - high annual precipitation of >2000mm
  - precipitation falls evenly throughout the year
- tropical monsoon climate
  - (between 5°N to 30°N & 5°S to 30°S)(India, Chittagong, Bangladesh Kochi)
  - high temp all year round - 25°C
  - small annual temp range ~3°C to 4°C
  - high annual precipitation of around 1500mm
  - distinct wet & dry seasons
- cool temperate climate
  - (between 45°N to 60°N & 45°S to 60°S)
  - four distinct seasons of spring/summer/autumn/winter
  - large annual temp range ~21°C
  - annual precipitation between 300mm to 900mm
  - precipitation falls evenly throughout the year

climatic hazards
- climates -> changing due to natural & human-induced causes -> predictable weather patterns -> unpredictable
- extreme weather events (heat waves/droughts/floods/cyclones/ wildfires) expected to occur more often/with greater severity -> can impact natural & human systems significantly



in a day - rotation on earth's axis
- moves due to earth's rotation on its own axis
- 1 complete rotation = 24h
- as earth rotates, diff times of day = diff temp
- midday
  - sun position: directly overhead
  - radiation spread over: smaller area
  - solar radiation: highest of day
  - example in SG: 31°C to 33°C
- before & after midday
  - sun position: not directly overhead
  - radiation spread over: larger area
  - solar radiation: lower than midday
  - example in SG: 25°C to 31°C
- before sunrise
  - sun position/radiation spread over/solar radiation: -> no solar radiation emitted & earth's surface loses heat as long wave radiation
  - temp lowest just before sunrise (place just experience max heat loss)
  - example in SG: 23°C to 25°C

in a year - revolution around sun
- due to earth's revolution around sun
- axis tilted around 23.5°
- as earth revolves around sun, hemispheres receives diff amts of solar radiation across a year
- places closer to equator (tropics) -> receive direct/non-direct solar radiation throughout the year -> experience high temp throughout the year
- places further from equator (outside of tropics) -> temp vary much more



spatial variation: caused by differences in latitude & altitude
- latitude (global-scale)
  - due to earth's spherical shape, sun's rays strike the earth's surface at various angles
  - lower latitudes (closer to equator) -> solar angle smaller -> radiation spread over smaller area -> radiation more concentrated -> higher temp
- altitude (local scale)
  - temp within smaller regions -> vary based on terrain -> affects local altitude
  - high altitude -> air molecules pulled to ground surface by gravity -> air less dense -> air pressure lower
  - fewer air molecules -> air has lower ability to absorb/radiate heat -> lower temp
  - low altitude -> air molecules pulled to ground surface by gravity -> air more dense -> air pressure higher
  - more air molecules -> air has higher ability to absorb/radiate heat -> higher temp

variations can be seen across 2 temporal scales:
- over time in a day - rotation on earth's axis
- over time in a year - revolution around the sun

variation in specific sites
- type of surface
  - dark surfaces vs light surfaces
  - dark surfaces (exposed soil/forests) -> absorb more solar radiation & radiate more heat -> higher temp
  - light surfaces (clouds/snow) -> reflect more solar radiation & radiate less heat -> lower temp
  - urban areas tend to have higher temp than surrounding rural areas
    - urban areas: comprise of larger dark surface areas (roads) -> absorb more solar radiation & radiate more heat than forests & water bodies
    - glass-covered sky scrapers reflect sunlight to ground surface by-> increased absorption of solar & heat radiation
  - e.g might time temp at SG's CBD 2°C warmer than area near Macritchie reservoir (dense vegetation)
- distance from the sea
  - coastal area (maritime effect)
    - summer & winter temp: cooler summers, warmer winters
    - annual temp range: lower (summer temp not as high, winter temp not as low)
    - explanation:
      - sea heats up & cools down more slowly than land
      - summer: sea cooler than land, cools down air along coastal areas
      - winter: sea warmer than land, warms air along coastal areas
    - e.g.: Anchorage, Alaska, USA -> coastal city that has lower annual temp range of 23°C
  - inland area (continental effect)
    - summer & winter temp: warmer summers, cooler winters
    - annual temp range: higher (summer temp higher, winter temp lower)
    - explanation: don't experience moderating influence of sea, experience continental effect
    - e.g.: Fairbanks, Alaska, USA -> inland city that has higher annual temp range of 40°C

speed of surface runoff
- type of soil:
  - ground surfaces with larger pores -> water mainly infiltrate -> less surface runoff
  - pores fully occupied with water -> ground surface no more pores -> surface runoff occurs & flows quickly
- presence of built-up area:
  - built-up area -> fewer obstructions & less friction -> surface runoff faster on smoother ground surface (roads/pavements)
- presence of natural vegetation:
  - vegetated areas have stems/roots of plants -> act as barriers -> + surface roughness -> surface runoff slower

relative humidity (RH)
- [actual amt of water vapour present in air (g/m^3)]/ max amt of water vapour air can hold (g/m^3)] x 100%
- temp increase -> amt of water vapour air can boiled increase -> RH decrease
- air hold max amt of water vapour -> air saturated -> RH = 100%
- more water vapour evaporated into air/air temp decrease -> RH > 100% -> condensation occurs

10%

example:
- volcanic eruption of Mount Pinatubo in 1191 -> drop in global temp of about 0.6°C over 15 mths after eruption

large-sale volcanic eruption
- lower global temp
- releases large volume of carbon dioxide/water vapour/sulfur dioxide/ dust/ash into atmosphere
- sulfur dioxide/dust/ash spread around lower atmosphere of earth -> absorb & reflect solar energy back into space -> temporarily offsets greenhouse effect -> lower temp

sunspots
- temporary spots on the sun that are darker than surrounding areas
- has lower temp
- areas surrounding radiate more energy -> more solar radiation emitted from sun -> higher temp
- number of sunspots rise & fall every 11 years
- higher sunspot activity -> higher amt of solar radiation
- periods of max sunspot activity -> periods of high annual surface temp

climate zones: variability
- earth's climate zones expanded & contracted over time
- temp (most importantly variable) -> used to determine if boundaries of climate zones have changed

climate variability: natural causes
- changes in orbit shape & angle of tilt
- sunspots
- large-scale volcanic eruption

example:
- 18000 yrs ago -> earth experienced cooler temp -> large ice sheets formed over continents near Arctic Ocean
- earth transit from glacial to interglacial period -> warmer temp -> ice sheets melt
- current rising sea levels & air temp -> tropical climate zones expanded in coverage across earth

climate change: past 200 years
- changes due to both natural & anthropogenic (human related) factors
- growth in population & modern industrialisation -> more burning of fossil fuels & changing land use -> produced >100000 times more GHG (carbon dioxide & methane & nitrous oxide) in atmosphere than natural causes -> unprecedented rise in global avg temp

greenhouse effect
- natural process by which GHG in earth's atmosphere trap long wave radiation emitted from earth's surface
- sun to earth = shortwave radiation -> absorbed -> warms earth's surface
- remaining radiation -> absorbed/ reflected by clouds in atmosphere before reaching earth's surface
- earth to sun = long wave radiation periods of-> absorbed by GHG -> re-emitted back to earth -> warms earth's surface further

burning of fossil fuels
- fossil fuels -> high carbon content ->
- when burnt to create energy for human activities
- burning fossil fuels -> produce large amt of carbon dioxide & other GHG
- contribute to enhanced greenhouse effect
- example: steep increase in fossil fuels use since 1880 (start of industrial revolution)
  - -> contributed to > 35 billion tonnes of carbon dioxide emissions per year

enhanced greenhouse effect
- 1850 -> + anthropogenic activities -> + conc of atmospheric GHG -> more GHG, less heat to escape into space -> more heat radiated back to earth's surface -> more heat trapped -> + global temp
- anthropogenic factors:
  - burning of fossil fuels
  - changing land use for agriculture/ industries/urbanisation

changing land use for agriculture/industries/urbanisation
- deforestation
  - large-scale deforestation done due to need for resources & land
  - cut down/burnt trees -> release stored carbon back into atmosphere as carbon dioxide
  - reduced number of trees that absorb carbon dioxide through photosynthesis (stores carbon)
  - expose soil beneath trees to sunlight -> + soil temp & rate of carbon oxidation
  - globally -> contribute to 20% of annual GHG emission
- agriculture
  - + population -> forests cleared to make space for agriculture -> meet + demand for food
  - burn fossil fuels -> produce energy for farm machinery
  - nitrogen in chemical fertilisers become nitrous oxides
  - livestock rearing & natural decomposition processes -> release methane
  - globally -> contribute to 30% of annual GHG emissions

increases atmospheric & ocean surface temp
- since 1880s, earth temp increasing
- most of heat trapped by GHG -> absorbed by oceans -> + avg temp of ocean
- over last century -> sea surface warmed by slightly over 1°C
- increase in temp -> some part of ocean warm faster, some parts remain cool -> uneven

example:
- ocean current in atlantic ocean slowed by 15%

changes to ocean circulations
- global ocean circulation = large-scale movement of water in oceans
- normal: due to winds -> warm surface water moves from equator to poles -> water cools -> water become denser & sinks to form cool subsurface flows -> water rises back to surface
- climate change -> global ocean circulation slow down -> surface water gain heat due to rising temp in atmosphere -> water become less dense -> water moves towards poles -> sinking of water at poles reduced -> slow down subsurface flows

changes to precipitation on land
- wet regions
  - + occurrences of excessive rainfall -> + precipitation -> get wetter
  - + evaporation (conventional rainfall -> warmer air -> can hold more water vapour -> + water vapour in atmosphere (esp in areas with surface water)
- dry regions
  - + occurrences of drought -> - precipitation -> get drier
  - warmer atmospheric temp -> + evaporation -> - surface water/dry out soil & vegetation -> lack of moisture -> - occurrences of rain
  - places experience dry climates (subtropics - most of world's deserts & mid-latitudes)-> droughts more likely to occur

example:
-wet regions
- poles, parts of southeast asia, central africa

- dry regions
- southwest usa, parts of sahel region in africa

- industries
  - fossil fuels burnt -> generate energy to run machinery/other factory processes
  - globally -> contribute to 43% of annual GHG emissions
- urbanisation
  - + conc of vehicles & household activities -> cities demand energy -> + burning of fossil fuels for energy -> enhanced greenhouse effect
  - cities consume 78% of world's energy -> contribute significantly to GHG emissions

changes in orbit shape & angle of tilt
- orbit shape
  - alternates between circular & elliptical shape over 100000 year cycle
  - most elliptic: earth travels in a more oval shape
  - earth at closest approach to sun -> more radiation reaches it than farthest departure
  - more variability throughout year
- tilt
  - earth's axis varies back & forth between 21.5° & 24.5°
  - warmer winters, cooler summers -> hemisphere tilts more further away from sun -> tilt decreases -> enable buildup of large ice sheets in higher latitudes -> cools earth

past climates variability
- temp & carbon dioxide levels have increased & decreased cyclically in the past 650000 years (natural variability earth's climate)
- conditions of past climates -> determined by analysing sediments from sea floor & oxygen isotopes
- higher conc of light oxygen (O-16) = earth's climate warmer
- higher conc of heavy oxygen (O-18) =earth's climate cooler
- O-18 heavier & harder to evaporate -> at lower temp O-18 relatively harder to evaporate-> leave more O-18 behind

climate change: impacts on human systems
- direct impacts: extreme weather events -> occur with greater severity -> loss of human lives/+ poverty/destruction of property
  - heat waves/wildfires/droughts/floods/tropical cyclones
- indirect impacts:
  - provisioning ecosystem services (food & production) affected
  - regulating ecosystem services (diseases regulation) impacted
  - cultural ecosystem services (melting of arctic ice & degradation of natural landscapes) affected

example:
-170 birds tracked in north america expanded range northwards by 50km on avg during 4 past decades
- temperate forests (advancing northwards) replacing boreal forests (advancing northwards to tundra)
- mountain top too warm -> mountain species don't have anywhere to go -> compete with species moving upwards -> greater extinction risk
- wallabies migrate to higher altitudes -> found herb fields (suitable food sources) -> species flourish -> + population -> overgrazing -> herb fields change to grassy lawns -> other species no more food -> greater competition -> + risk of extinction

climate change's impact: natural systems
- increases atmospheric & ocean surface temp
- changes to ocean circulations
- changes to precipitation on land
  - wet regions
  - dry regions

climate change's impact: aquatic ecosystems
- threats to coral reefs
- ocean acidification
- disruption of marine food webs
  - due to slowing down of global ocean circulation
  - due to increase in ocean surface temp
    - changes in geographic distribution of aquatic species
    - changes in composition of aquatic ecosystems

threats to coral reef
- corals -> highly fragile ecosystems & vulnerable to coral bleaching
- corals -> symbiotic rs with algae -> corals' primary food source + gives colour
- + ocean temp -> algae living in corals leave -> corals turn white & lose major source of food -> more likely to die -> other species lose food source & habitat -> population of anthropogenics decline

ocean acidification
- presence of phytoplankton (absorb carbon dioxide during photosynthesis) & + carbon dioxide emissions -> oceans absorb excessive amts of carbon dioxide -> natural carbon sinks
- + carbonic acids formed -> dissolve calcium carbonate -> harm aquatic organisms (corals/mussels/oysters) -> cannot form skeletons & shells
- at this rate -> corals eroding faster than new corals forming -> coral skeletons shrink -> species depending on corals for food/shelter/habitat negatively affected/may go extinct

disruption of marine food webs
- due to slowing down of global ocean circulation
  - ocean circulation = transport heat from tropics to poles & allows for exchange of nutrients between surface & deep waters
  - slowing down -> - water sinking -> - mixing of warm surface waters & cool deep waters -> separates near-surface aquatic life (phytoplankton) from nutrients below -> - phytoplankton -> species higher up in food chain (fish & whales) suffer lack of food -> ecosystem & food webs negatively affected
- due to increase in ocean surface temp
  - changes in geographic distribution of aquatic species
    - aquatic species migrate to area with more favourable temp (polewards, deep & cool waters) -> - biodiversity in equatorial regions & + biodiversity in poleward regions
  - changes in composition of aquatic ecosystems
    - geographic distribution of species change -> mix of prey/predators/competitors change -> disrupt food webs & aquatic ecosystems
    - aquatic ecosystems = complex -> uncertain of evolution
      - some species -> migrate & flourish (winners), some do find abundance of suitable food sources -> + population (winners)/some do not -> - population (losers)
    - some species -> migrate not fast enough (corals) -> unable to adapt to higher sea temp at current location/food sources & habitats disappear -> environment = unsuitable -> local/global extinction (losers)
    - winners flourish & losers risk extinction

example:
- great barrier reef, australia -> + sea temp -> severely affected in 2016 & 2017 -> 2/3 corals died in NH -> - species diversity

example:
- since industrial revolution (1800s) -> ocean acidity + 25%
- great barrier reef, australia -> partly due to ocean acidification -> avg coral cover - 30% of what it was in 1960s

example:
- phytoplankton in north atlantic -> dropped by 10% since 1800s
- tropical species (parrotfish & rabbitfish) migrated towards poles/cooler waters (japan & australia) -> diversity of tropical species dropped significantly in past 50 years
- species feed on kelp in cooler waters -> decline in kelp -> affect other species (abalone & lobster) depending on kelp for food & extinction from predators

extreme weather events -> threaten terrestrial ecosystem
- droughts:
  - plants unable to move elsewhere for water -> plants drier & weaker -> vulnerable to insect attacks & diseases -> wither & die
  - trees die -> habitats damage & food supplies fall -> species unable to adapt -> + risk of extinction
  - animals forced to relocate -> search for food & water & habitat -> risk spread of diseases that thrive in dry & warm conditions (cholera & botulism) -> + threats to terrestrial species -> + risk of loss of biodiversity
- excessive rainfall:
  - intense rainfall -> floods -> destroy habitats -> cause species to drown & die

climate change: varying impact in human systems -> uneven distribution of impacts around world
- varying climate variables of place
  - places with diff climate variables (temp/precipitation) -> diff climate change responses
- diff local & social-economic factors
  - developing countries -> low level of economic development -> lack of financial resources -> longer to recover -> prolong economic losses

climate change's impact: terrestrial ecosystems
- changes in geographic distribution of terrestrial species
- terrestrial species migrate to higher altitudes & higher latitudes (lower temp -> cooler)
- changes in composition of terrestrial ecosystems
  - geographic distribution of species change -> mix & population densities of prey/predators/competitors in ecosystems change -> fod webs disrupted -> new terrestrial communities develop -> present competition to existing terrestrial communities
  - some species -> migrate & flourish (winners), some do find abundance of suitable food sources -> + population (winners)/some do not -> - population (losers)
  - some species -> migrate not fast enough (corals) -> unable to adapt to higher sea temp at current location/food sources & habitats disappear -> environment = unsuitable -> local/global extinction (losers)
  - winners flourish & losers risk extinction

3.4 effectiveness of adaptation strategies in building community resilience to climate change

institutional
- explanation/advantages:
  - help organise strategies on national/regional scale
  - allows implementation of large scale measures - presence of resources/expertise/funding
  - national policies
    - established organisations/agencies to coordinate climate action (Ministry of Sustainability and the Environment, SG - creates national frameworks)
  - regional policies
    - regional strategies implemented -> safeguard interests of southeast asia -> allow countries to collaborate & develop climate outlooks for region -> countries can adapt & manage to climate risks
- limitations:
  - institutional/economic
    - countries may have competing national priorities (urgent development projects) -> no capacity to dedicate national budget to finance adaptation projects -> harder for regional cooperation

adaptation strategies: building community resilience
- efforts to adjust to climate change & effects -> reduce harm to people/environment/properties
- no one-size-fits-all approach -> strategies to be assessed based on place & context (country's tech/economic/social/institutional) implemented in

effectiveness adaptation strategies
- structural
- technological
- social
- institutional

structural
- explanation/advantages:
  - seawall
    - wall constructed along coast -> prevent sea from advancing onto land -> protect people/properties/environments from coastal floods
  - polders
    - low-lying land surrounded & protected by barriers (dykes)
    - excess water pumped out from polder
  - water storage tank
    - stores excess storm water during periods of excessive rainfall -> slow water flow from rushing into canals/drains
- limitations:
  - economic
    - costly to build & maintain (esp for developing countries)
    - climate change worsens -> higher flood. levels -> needs frequent monitoring & enhancement to protect communities
  - social
    - construction -> eviction of informal communities -> don't have anywhere to go

social
- explanation/advantages:
  - raise awareness & educate communities on responding to climate change impacts
  - allow communities to be aware of warning signs of climatic hazards -> take steps to protect self -> + community resilience
- limitations:
  - social
    - due to reasons -> people may be unwilling to change behaviours

technological
- explanation/advantages:
  - produces food -> tackle food security problems -> + community resilience
  - funding provided by gov -> develop high-tech farms (optional conditions maintained, prevent spread of diseases) -> produce high-quality food efficiently (checks done quicker, food harvested within shorter time)
- limitations:
  - economic
    - costly, not viable in countries with limited funding

continuation of 2.4

2.4 how climate change affects human systems

climate change: extreme weather events
- heat waves
- droughts
- floods
- wildfires
- tropical cyclones

climate change: indirect impacts on human systems
- climate change impacts -> interconnected
- natural systems affected -> humans impacted directly & indirectly
- ecosystem services impacted:
  - provisioning
  - regulating
  - cultural

heat waves
- effect:
  - abnormal period of excessively hot weather
  - lasts several days/longer
  - temp >45°C
  - climate change -> higher temp & more intense & frequent heat waves
- impacts:
  - people suffer from heat stroke/breathing difficulties/death
  - high temp -> deplete soil moisture -> crop failure -> - food supply

tropical cyclones
- effect:
  - intense circular storms
  - originate over warm tropical oceans
  - accompanied by strong winds/heavy rainfall/storm surges
  - climate change -> + temp -> warmer oceans & + water vapour in atmosphere -> driving force for intense tropical cyclones
- impacts:
  - strong winds/heavy rainfall/storm surges -> flooding/landslides/collapsed buildings & infrastructure -> loss of lives
  - strong winds -> destroy buildings & crops -> economic losses & threaten food security

droughts
- effect:
  - lack of precipitation (rain/snow) in area for extended period of time -> resulting in water shortage
  - + evaporation -> + temp -> - surface water -> dries out soil & vegetation
  - dry climate areas -> drier seasons -> droughts
- impacts:
  - shortage of clean water -> dehydration/death
  - lack of water -> crop failure -> people die from hunger/malnourishment
  - people may be displaced

floods
- effect:
  - + temp -> + excessive precipitation
  - + temp -> snowmelt -> + sea level -> sea level rise -> + coastal flood risk
- impacts:
  - drowning/injuries -> loss of human lives
  - moving floodwaters -> destruction of buildings/properties -> homelessness/economic losses & food/water supply cut off/reduced
  - floodwaters enter drinking water sources (wells) -> + risk of waterborne diseases (cholera)

wildfires
- effect:
  - unplanned & uncontrolled fires
  - burn in natural areas (grasslands/forests)
  - climate change -> warmer & drier conditions
  - + dead trees/vegetation -> wildfires easier to start & harder to put out (spread quickly)
- impacts:
  - suffocations/injuries/burns
  - + carbon dioxide &carbon monoxide & fine particulate matter -> enter atmosphere -> air pollution -> respiratory illnesses -> deaths
  - destruction of buildings/properties -> homelessness/economic losses

cultural ecosystem services (melting of arctic ice, degradation of natural landscapes)
- climate change -> physical environmental changes -> affect people's ability to improve wellbeing through recreational activities & reap economic returns from tourism opportunities

provisioning ecosystem services (food production)
- climate change -> physical environmental changes -> affect environment's ability to provide resources for food production -> impact economic livelihoods & food security

regulating ecosystem services (disease regulation)
- climate change -> physical environmental changes -> affect environment's ability to regulate spread of disease

melting of arctic ice
- negative impact:
  - + temp -> melting of arctic ice -> affect cultural practices (storing food in ice cellars/breeding sled dogs used for travel & hunting) of arctic indigenous people

vector-borne disease
- negative impact:
  - + temp -> + conducive environment for vectors (mosquitoes/ticks) to survive 7 breed
  - + temp -> mosquitoes able to move to higher latitudes & altitudes (+ temp) -> + areas worldwide prone to vector-borne disease -> loss of lives/people sick -> reduced economic productivity/+ healthcare costs (experienced unevenly, affects poor most)

agricultural yield
- negative impact:
  - + frequent/severe extreme weather events -> + difficulty of crop survival -> - food production
  - - food supply -> + food prices -> poor people spend more of income to buy food -> buy lesser food -> malnutrition/starvation

fish production
- negative impact:
  - climate change -> + ocean acidity & temp -> threatens aquatic life & fishermen
  - warmer oceans -> species cannot adapt -> die
  - warmer oceans -> species search for cooler waters -> distribution of aquatic life changes -> affect fishermen fishing locations & what they can catch -> fish caught reduced -> reduce food security for places
  - sea level rise -> salt water enters freshwater -> threaten freshwater fisheries -> affect economic livelihoods of fishermen
- positive impact:
  - more fish migrate to cooler waters polewards -> fisheries at higher latitudes catch more diverse range of seafood

degradation of natural landscapes
- negative impact:
  - climate change -> degrades natural landscapes -> impact tourism industry
  - since ecosystem = interconnected -> provisioning & regulating ecosystem services affected
  - reduced fish catch -> fishermen switch jobs -> affect traditional ways of life & economic livelihoods

topic 3 climate action

3.1 climate action on achieving sustainable development

climate action
- when implemented well -> communities can resist & absorb & adapt to & recover from impacts of climate change -> helps build community resilience
- climate action -> require additional investments -> often small compared to costs & losses incurred from impacts of climate change
- fewer losses -> - money needed to rebuild -> development gain achieved -> contribute to sustainable development

complementary strategies -> both be implemented effectively combat climate change -> can create risks & benefits varying across places
- mitigation -> slow down & prevent
  - efforts (renewable energy instead of fossil fuels) to reduce GHG emissions & enhance carbon sinks to slow down climate change
- adaptation -> combat already happenings
  - efforts (food tech like greenhouses -> manage food security that may be caused by climate change) to adjust to climate change & its effects in order to reduce harm from people/properties/environment

uneven impacts: developing countries & disadvantaged communities
- uneven impacts -> widens inequalities -> hinders sustainable development
- disadvantaged communities:
  - many live with no shelter from weather elements -> experience + risks from heatwaves/flooding/tropical storms
    - limited ability to get medical attention -> weaker & less fit -> vulnerable to disease spreading
- developing countries:
  - many lack financial ability -> cannot implemented measures to reduce potential impacts of climate change
  - no money -> cannot construct sea walls along coats to manage sea level rise -> cannot avoid coastal flooding

climate change: threat multiplier
- worsens threats/further adds stress to natural & human systems -> contributes to uneven climate-related effects

climate change: constraining development paths
- threaten current & future water/food supply -> limit ability of generations to meet own needs
- destruction of buildings/industries -> extensive economic losses -> erode development gains
- money for development -> channelled to rebuild -> slow down progress of infrastructure/education/economic development -> detrimental to developing countries (funds may be lacking)

3.2 variations of climate risks across places

climate risks
- vary according to 3 factors
  - nature of climate-related hazards
    - intensity/duration(shorter/longer-term events)
  - vulnerability
    - physical/social/economic/environmental conditions -> increase susceptibility to impacts of hazards
    - extreme weather -> suffer from lack of water/food/health resources
  - exposure
    - extent of people exposed to climate-related hazards
    - proximity to coastal/dry environments

vulnerability
- poverty
  - extreme weather events (floods & droughts) -> crop failures -> reduced food supply -> food prices increase -> those in poverty unable to cope -> economically vulnerable to food shortages
  - those in poverty unable to cope -> infected with diseases -> cannot afford health resources -> weaker & die after complications
- lack of access to piped water
  - extreme weather events (cyclones & floods) -> contaminate water sources (wells)
  - communities in rural areas -> rely on wells/rivers -> not connected to piped water systems -> forced to drink from contaminated sources of water -> + risk spread of diseases (cholera) -> suffer

nature of climate-related events
- shorter-terms events (cyclones & floods)
  - brief & sudden
  - forms & lasts over shorter duration of time
  - immediate climate risk
  - often lead to quick widespread destruction of properties/loss of lives/disruptions to services
  - less predictable -> people have less time to evacuate
- longer-term events (sea level rise & droughts)
  - longer time to develop & last for longer period of time
  - delayed risks
  - gives communities ample time to prepare & adapt
  - impacts' risk unnoticed

exposure
- proximity to coastal environments
  - communities living near coasts -> + exposure to hazards (storms/sea level rise)
- proximity to dry environments
  - towns located in arid/dry environments -> + exposure to hazards (droughts)

3.3 effectiveness of mitigation strategies in building community resilience to climate change

mitigation strategies: building community resilience
- efforts to reduce GHG emissions & enhance carbon sinks -> slow down climate change
- involves changing how societies produce & use energy & land
- no one-size-fits-all approach -> strategies to be assessed based on place & context (country's tech/economic/social/institutional) implemented in

effectiveness of mitigation strategies: enhancing carbon sinks (reabsorbs >50% of carbon dioxide emitted -> - amt of GHG in atmosphere)
- managing land-use change (protect oceans & forests)
- protection of forests through forest regeneration

managing land-use change (protect oceans & forests)
- explanation/advantages:
  - land use change accounts for ~ 10% of global emissions (including carbon dioxide) during deforestation & methane emission (rearing livestock & cultivating rice)
  - reducing deforestation
    - deforestation -> fewer trees to absorb carbon dioxide -> + conc of GHG
    - deforestation -> soil particles not anchored by tree roots -> soil erosion -> carried by surface runoff -> cover corals & aquatc plants -> suffocate organisms
    - can be done by encouraging consumers to buy sustainable wood/implement stricter laws
  - restoring mangroves
    - mangroves -> absorb & store GHG in soils 4x as much as tropical forests & filter pollutants in rivers & prevent them reaching ocean -> reduce harm to corals & aquatic species -> crucial coastal ecosystems
    - can be done by planting mangrove seedlings along coastal areas/creating optimal conditions of growth (reduce water pollution)/limit clearance of mangrove trees by locals
- limitations:
  - growing economies -> competing land use for industries/agriculture/urban spaces -> difficult to reduce deforestation

protection of forests through forest regeneration
- explanation/advantages:
  - forest regeneration -> + number of trees -> + ability to absorb & store carbon dioxide
  - can be done by planting trees in new areas/re-planting trees in areas
  - agroforestry - international integration of trees & shrubs into crop & animal farming systems -> allow for diff species of trees to grow effectively on land
- limitations:
  - social
    - large scale afforestation -> create completion for land for other uses (urbanisation/industrialisation/agriculture) -> limited land for agriculture -> + food prices -> threaten food security
  - technological
    - large scale tree planting programme -> long time frame to remove full effect of removing large scale carbon dioxide from atmosphere

effectiveness of mitigation strategies: reducing GHG emissions
- international agreements & cooperation
- use of low-carbon technologies
- use of clean energy sources
- changing consumption patterns

international agreements & cooperation
- explanation/advantages:
  - stabilise GHG emissions at a level that prevents irreversible anthropogenic impacts & provides sufficient time for ecosystems to adapt naturally to climate change
  - developed & industrialised countries -> main source for most past & current GHG emissions -> expected to cut the most emissions
  - developed & industrialised countries -> provide financial support to developing countries for climate action
  - countries required to regularly report on climate change policies & GHG emissions -> monitoring & control
  - meet yearly to review & make decisions on climate action & promote effective reduction of GHG emissions
- limitations:
  - diff country -> diff priorities
  - some countries believe it will undermine country's economy

changes in consumption patterns
- explanation/advantages:
  - consumption -> carbon footprint (GHGs) emitted during prediction & transportation of goods
  - food choices
    - food production -> contribute over a quarter of all GHG emissions
    - eat less meat, more vegetables/shift to plant-based diet -> - emissions from livestock & agriculture (to feed livestock)
    - buy local produce -> - transportation of goods -> - carbon emissions
  - food waste
    - food enters landfills & decompose -> produce methane -> contribute climate change
    - practice mindful consumption -> make shopping list -> prevent overbuy
    - repurpose of food waste -> use as fertilisers
  - use of plastics
    - chemicals sourced from fossil fuels to make plastic/plastics incinerated/lastics biodegrade over hundreds of years
    - refuse single-use plastics/use reusable products/learn right way to recycle diff plastics -> - amt of plastic water going into incinerator/landfills/ocean
  - fashion
    - -> + demand for frequent design changes -> + apparel production -> + need for high levels of energy & water -> + carbon emissions
    - check for sustainable production criteria before purchasing
    - repair/upcycle/donate clothing
    - buy only what is needed/opt for second-hand clothing
- limitations:
  - social
    - long time to change mindsets/consumption patterns/habits
  - economic
    - changing consumption depends on consumers & companies
    - sustainable alternatives -> cost more -> eroded companies' profit margins -> companies may be reluctant

use of low-carbon technologies (CCUS)
- explanation/advantages:
  - carbon capture (CC)
    - process of separating & capturing carbon dioxide from power plants/other industrialisation sources of emissions
  - utilisation & storage (US)
    - carbon dioxide captured -> stored for long periods of time -> prevent it from reaching atmosphere through carbon storage (storing carbon dioxide in oceans) & carbon utilisation (carbon dioxide as raw material -> other use materials to be sold for profit (cement))
- limitations:
  - economic
    - requires public funding & subsidies for private research & development -> expensive -> not viable for developing countries (focusing on fundamental priorities - healthcare/education)
  - technological
    - current concerns that carbon will leak out from oceans/products made from it over time

use of clean energy courses
- explanation/advantages:
  - don't emit GHG/pollute environment -> renewable sources -> clean energy
  - solar energy
    - energy from sun (cleanest & most abundant energy source) -> thermal/electrical energy
  - hydro-electric power
    - hydropower plants capture energy of moving water (rivers) -> electricity
  - geothermal
    - heat in earth's crust -> hot rocks that heat up groundwater -> steam formed -> steam harnessed -> electricity
  - nuclear (more stable supply)
    - splitting of radioactive atoms -> heat -> produced steam -> steam harnessed -> electricity
- limitations:
  - economic
    - research/development/construction of renewable energy technology -> expensive -> depends heavily on gov policies & financial support

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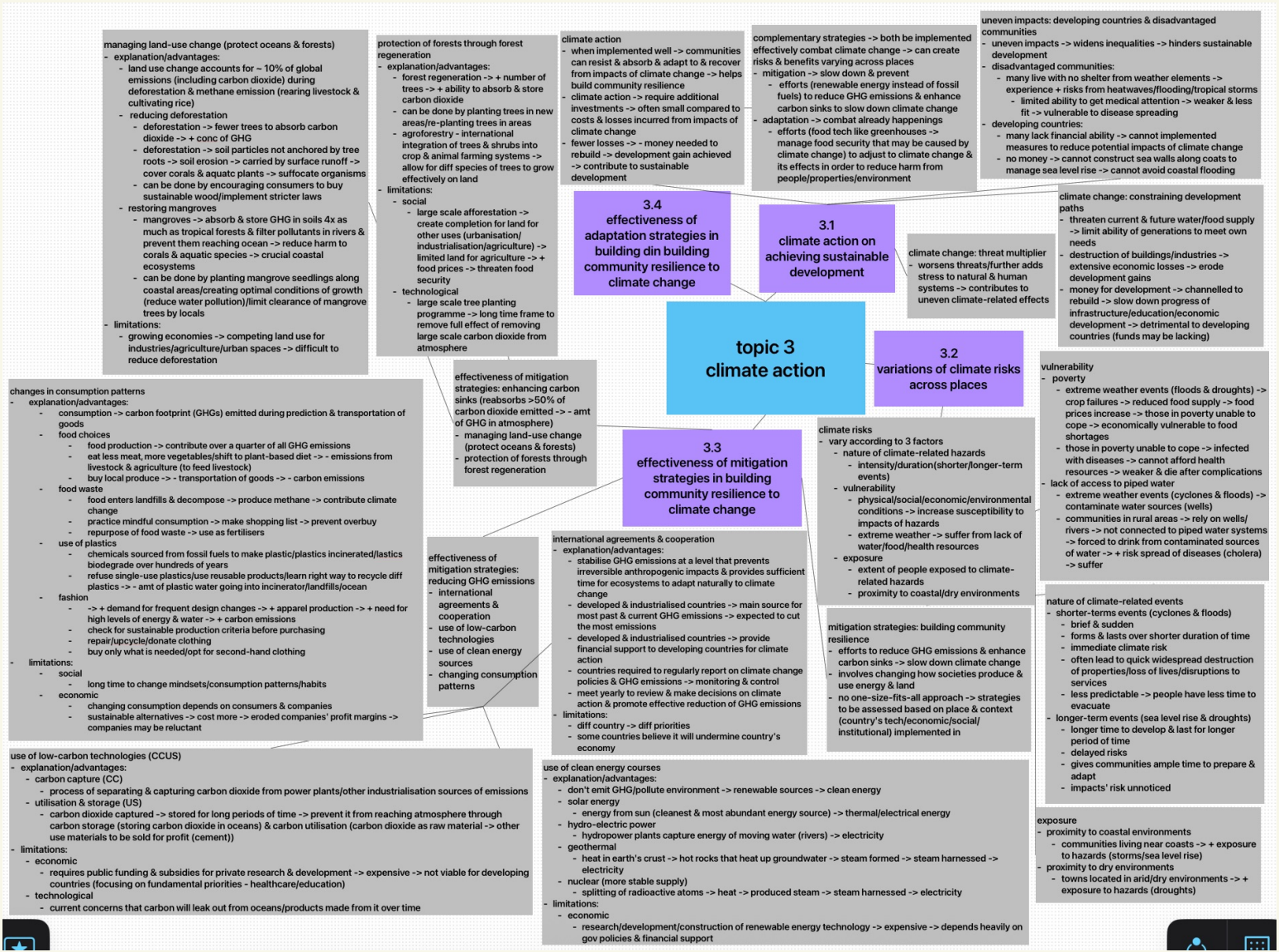
topic 3
climate action
3.1
climate action on achieving sustainable development
3.2
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3.3
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topic 2 climate change

2.1 natural variability of climate

climate variability: natural causes
- changes in orbit shape & angle of tilt
- sunspots
- large-scale volcanic eruption

sunspots
- temporary spots on the sun that are darker than surrounding areas
- has lower temp
- areas surrounding radiate more energy -> more solar radiation emitted from sun -> higher temp
- number of sunspots rise & fall every 11 years
- higher sunspot activity -> higher amt of solar radiation
- periods of max sunspot activity -> periods of high annual surface temp

large-sale volcanic eruption
- lower global temp
- releases large volume of carbon dioxide/water vapour/sulfur dioxide/ dust/ash into atmosphere
- sulfur dioxide/dust/ash spread around lower atmosphere of earth -> absorb & reflect solar energy back into space -> temporarily offsets greenhouse effect -> lower temp

example:
volcanic eruption of Mount Pinatubo in 1191 -> drop in global temp of about 0.6°C over 15 mths after eruption

climate zones: variability
- earth's climate zones expanded & contracted over time
- temp (most important variable) -> used to determine if boundaries of climate zones have changed

example:
- 18000 yrs ago -> earth experienced cooler temp -> large ice sheets formed over continents near Arctic Ocean
- earth transit from glacial to interglacial period -> warmer temp -> ice sheets melt
- current rising sea levels & air temp -> tropical climate zones expanded in coverage across earth

climate change: past 200 years
- changes due to both natural & anthropogenic (human related) factors
- growth in population & modern industrialisation -> more burning of fossil fuels & changing land use -> produced >100000 times more GHG (carbon dioxide & methane & nitrous oxide) in atmosphere than natural causes -> unprecedented rise in global avg temp

changes in orbit shape & angle of tilt
- orbit shape
  - alternates between circular & elliptical shape over 100000 year cycle
  - most elliptic: earth travels in a more oval shape
  - earth at closest approach to sun -> more radiation reaches it than farthest departure
  - more variability throughout year
- tilt
  - earth's axis varies back & forth between 21.5° & 24.5°
  - warmer winters, cooler summers -> hemispheres lean further away from sun -> tilt decreases -> enable buildup of large ice sheets in higher latitudes -> cools earth

past climates variability
- temp & carbon dioxide levels have increased & decreased cyclically in the past 650000 years (natural variability earth's climate)
- conditions of past climates -> determined by analysing sediments from sea floor & oxygen isotopes
- higher conc of light oxygen (O-16) = earth's climate warmer
- higher conc of heavy oxygen (O-18) =earth's climate cooler
- O-18 heavier & harder to evaporate -> at lower temp O-18 relatively harder to evaporate-> leave more O-18 behind

2.2 anthropogenic factors on climate change

greenhouse effect
- natural process by which GHG in earth's atmosphere trap long wave radiation emitted from earth's surface
- sun to earth = shortwave radiation -> absorbed -> warms earth's surface
- remaining radiation -> absorbed/ reflected by clouds in atmosphere before reaching earth's surface
- earth to sun = long wave radiation periods of-> absorbed by GHG -> re-emitted back to earth -> warms earth's surface further

burning of fossil fuels
- fossil fuels -> high carbon content -> burnt to create energy for human activities
- burning fossil fuels -> produce large amt of carbon dioxide & other GHG
- contribute to enhanced greenhouse effect
- example: steep increase in fossil fuels use since 1880 (start of industrial revolution) -> contributed to > 35 billion tonnes of carbon dioxide emissions per year

enhanced greenhouse effect
- 1850 -> + anthropogenic activities -> + conc of atmospheric GHG -> more GHG, less heat to escape into space -> more heat radiated back to earth's surface -> more heat trapped -> + global temp
- anthropogenic factors:
  - burning of fossil fuels
  - changing land use for agriculture/ industries/urbanisation

changing land use for agriculture/industries/urbanisation
- deforestation
  - large-scale deforestation done due to need for resources & land
  - cut down/burnt trees -> release stored carbon back into atmosphere as carbon dioxide
  - reduced number of trees that absorb carbon dioxide through photosynthesis (stores carbon)
  - expose soil beneath trees to sunlight -> + soil temp & rate of carbon oxidation
  - globally -> contribute to 20% of annual GHG emission
- agriculture
  - + population -> forests cleared to make space for agriculture -> meet + demand for food
  - burn fossil fuels -> produce energy for farm machinery
  - nitrogen in chemical fertilisers become nitrous oxides
  - livestock rearing & natural decomposition processes -> release methane
  - globally -> contribute to 30% of annual GHG emissions

- industries
  - fossil fuels burnt -> generate energy to run machinery/other factory processes
  - globally -> contribute to 43% of annual GHG emissions
- urbanisation
  - + conc of vehicles & household activities -> cities demand energy -> + burning of fossil fuels for energy -> enhanced greenhouse effect
  - cities consume 78% of world's energy -> contribute significantly to GHG emissions

increases atmospheric & ocean surface temp
- since 1880s, earth temp increasing
- most of heat trapped by GHG -> absorbed by oceans -> + avg temp of ocean
- over last century -> sea surface warmed by slightly over 1°C
- increase in temp -> some part of ocean warm faster, some parts remain cool -> uneven

example:
- ocean current in atlantic ocean slowed by 15%

changes to ocean circulations
- global ocean circulation = large-scale movement of water in oceans
- normal: due to winds -> warm surface water moves from equator to poles -> water cools -> water become denser & sinks to form cool subsurface flows -> water rises back to surface
- climate change -> global ocean circulation slow down -> surface water gain heat due to rising temp in atmosphere -> water become less dense -> water moves towards poles -> sinking of water at poles reduced -> slow down subsurface flows

2.3 how climate change affects natural systems

climate change's impact: natural systems
- increases atmospheric & ocean surface temp
- changes to ocean circulations
- changes to precipitation on land
  - wet regions
  - dry regions

changes to precipitation on land
- wet regions
  - + occurrences of excessive rainfall -> + precipitation -> get wetter
  - + evaporation (conventional rainfall -> warmer air -> can hold more water vapour -> + water vapour in atmosphere (esp in areas with surface water)
- dry regions
  - + occurrences of drought -> - precipitation -> get drier
  - warmer atmospheric temp -> + evaporation -> - surface water/dry out soil & vegetation -> lack of moisture -> - occurrences of rain
  - places experience dry climates (subtropics - most of world's deserts & mid-latitudes)-> droughts more likely to occur

example:
- wet regions
  - poles, parts of southeast asia, central africa
- dry regions
  - southwest usa, parts of sahel region in africa

climate change's impact: aquatic ecosystems
- threats to coral reefs
- ocean acidification
- disruption of marine food webs
  - due to slowing down of global ocean circulation
  - due to increase in ocean surface temp
    - changes in geographic distribution of aquatic species
    - changes in composition of aquatic ecosystems

threats to coral reef
- corals -> highly fragile ecosystems & vulnerable to coral bleaching
- corals -> symbiotic rs with algae -> corals' primary food source + gives colour
- + ocean temp -> algae living in corals leave -> corals turn white & lose major source of food -> more likely to die -> other species lose food source & habitat -> population of organisms decline

example:
- great barrier reef, australia -> + sea temp -> severely affected in 2016 & 2017 -> 2/3 corals died in NH -> - species diversity

ocean acidification
- presence of phytoplankton (absorb carbon dioxide during photosynthesis) & + carbon dioxide emissions -> oceans absorb excessive amts of carbon dioxide -> natural carbon sinks
- + carbonic acids formed -> dissolve calcium carbonate -> harm aquatic organisms (corals/mussels/oysters) -> cannot form skeletons & shells
- at this rate -> corals eroding faster than new corals forming -> coral skeletons shrink -> species depending on corals for food/shelter/habitat negatively affected/may go extinct

example:
- since industrial revolution (1800s) -> ocen acidity + 25%
- great barrier reef, australia -> partly due to ocean acidification -> avg coral cover - 30% of what it was in 1960s

disruption of marine food webs
- due to slowing down of global ocean circulation
  - ocean circulation = transport heat from tropics to poles & allows for exchange of nutrients between surface & deep waters
  - slowing down -> - water sinking -> - mixing of warm surface waters & cool deep waters -> separates near-surface aquatic life (phytoplankton) from nutrients below -> - phytoplankton -> species higher up in food chain (fish & whales) suffer lack of food -> ecosystem & food webs negatively affected
- due to increase in ocean surface temp
  - changes in geographic distribution of aquatic species
    - aquatic species migrate to area with more favourable temp (polewards, deep & cool waters) -> - biodiversity in equatorial regions & + biodiversity in poleward regions
  - changes in composition of aquatic ecosystems
    - geographic distribution of species change -> mix of prey/predators/competitors change -> disrupt food webs & aquatic ecosystems
    - aquatic ecosystems = complex -> uncertain of evolution
      - some species -> migrate & flourish (winners), some do find abundance of suitable food sources -> + population (winners)/some do not -> - population (losers)
    - some species -> migrate not fast enough (corals) -> unable to adapt to higher sea temp at current location/food sources & habitats disappear -> environment = unsuitable -> local/global extinction (losers)
  - winners flourish & losers risk extinction

example:
- phytoplankton in north atlantic -> dropped by 10% since 1800s
- tropical species (parrotfish & rabbitfish) migrated towards poles/cooler waters (japan & australia) -> diversity of tropical species dropped significantly in past 50 years
- species feed on kelp in cooler waters -> decline in kelp -> affect other species (abalone & lobster) depending on kelp for food & protection from predators

2.4 how climate change affects human systems

climate change: varying impact in human systems -> uneven distribution of impacts around world
- varying climate variables of place
  - places with diff climate variables (temp/precipitation) -> diff climate change responses
- diff local & social economic factors
  - developing countries -> low level of economic development -> lack of financial resources -> longer to recover -> prolong economic losses

- extreme weather events -> threaten terrestrial ecosystem
- droughts:
  - plants unable to move elsewhere for water -> plants drier & weaker -> vulnerable to insect attacks & diseases -> wither & die
  - trees die -> habitats damage & food supplies fall -> species unable to adapt -> + risk of extinction
  - animals forced to relocate -> search for food & water & habitat -> risk spread of diseases that thrive in dry & warm conditions (cholera & botulism) -> + threats to terrestrial species -> + risk of loss of biodiversity
- excessive rainfall:
  - intense rainfall -> floods -> destroy habitats -> cause species to drown & die

climate change: impacts on human systems
- direct impacts: extreme weather events -> occur with greater severity -> loss of human lives/+ poverty/destruction of property
  - heat waves/wildfires/droughts/floods/tropical cyclones
- indirect impacts:
  - provisioning ecosystem services (food & production) affected
  - regulating ecosystem services (diseases regulation) impacted
  - cultural ecosystem services (melting of arctic ice & degradation of natural landscapes) affected

example:
- 170 birds tracked in north america expanded range northwards by 50km on avg during 4 past decades
- temperate forests (advancing northwards) replacing boreal forests (advancing northwards to tundra)
- mountain top too warm -> mountain species don't have anywhere to go -> compete with species moving upwards -> greater extinction risk
- wallabies migrate to higher altitudes -> found herb fields (suitable food sources) -> species flourish -> + population -> overgrazing -> herb fields change to grassy lawns -> other species no more food -> greater completion -> + risk of extinction

climate change's impact: terrestrial ecosystems
- changes in geographic distribution of terrestrial species
  - terrestrial species migrate to higher altitudes & higher latitudes (lower temp -> cooler)
- changes in composition of terrestrial ecosystems
  - geographic distribution of species change -> mix & population densities of prey/predators/competitors in ecosystems change -> fod webs disrupted -> new terrestrial communities develop -> present competition to existing terrestrial communities
  - some species -> migrate & flourish (winners), some do find abundance of suitable food sources -> + population (winners)/some do not -> - population (losers)
  - some species -> migrate not fast enough (corals) -> unable to adapt to higher sea temp at current location/food sources & habitats disappear -> environment = unsuitable -> local/global extinction (losers)
  - winners flourish & losers risk extinction

topic 1 weather & climate

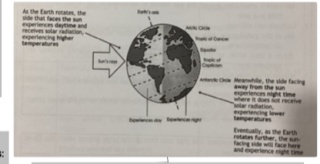
3.1 defining weather & climate

climatic hazards
- climates -> changing due to natural & human-induced causes -> predictable weather patterns -> unpredictable
- extreme weather events (heat waves/droughts/floods/cyclones/ wildfires) expected to occur more often/with greater severity -> can impact natural & human systems significantly

weather & climate
- weather classified using characteristics: air temperature/ cloud cover/precipitation/wind speed/wind direction
- climate classified into: different climatic types

climatic types - can be represented using climograph (shows a place's avg monthly temp & rainfall over a year)
- tropical equatorial climate
- (between 10°N & 10°S of equator)(Havana, Cuba, SG)
  - high temp all year round - 27°C
  - small annual temp range ~2°C to 3°C
  - high annual precipitation of >2000mm
  - precipitation falls evenly throughout the year
- tropical monsoon climate
- (between 5°N to 30°N & 5°S to 30°S)(India, Chittagong, Bangladesh Kochi)
  - high temp all year round - 25°C
  - small annual temp range ~3°C to 4°C
  - high annual precipitation of around 1500mm
  - distinct wet & dry seasons
- cool temperate climate
- (between 45°N to 60°N & 45°S to 60°S)
  - four distinct seasons of spring/summer/autumn/ winter
  - large annual temp range ~21°C
  - annual precipitation between 300mm to 900mm
  - precipitation falls evenly throughout the year

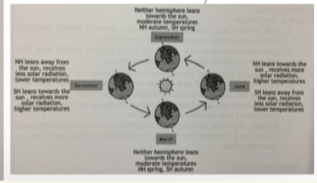
3.2 variations of air temperature across earth's surface



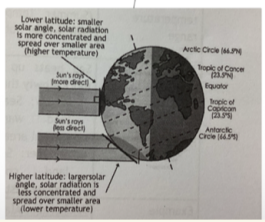
in a day - rotation on earth's axis
- moves due to earth's rotation on its own axis
- 1 complete rotation = 24h
- as earth rotates, diff times of day = diff temp
- midday
  - sun position: directly overhead
  - radiation spread over: smaller area
  - solar radiation: highest of day
  - example in SG: 31°C to 33°C
- before & after midday
  - sun position: not directly overhead
  - radiation spread over: larger area
  - solar radiation: lower than midday
  - example in SG: 25°C to 31°C
- before sunrise
  - sun position/radiation spread over/solar radiation:
    - no solar radiation emitted & earth's surface loses heat as long wave radiation
    - temp lowest just before sunrise (place just experience max heat loss)
  - example in SG: 23°C to 25°C

variations can be seen across 2 temporal scales:
- over time in a day - rotation on earth's axis
- over time in a year - revolution around the sun

in a year - revolution around sun
- due to earth's revolution around sun
- axis tilted around 23.5°
- as earth revolves around sun, hemispheres receives diff amts of solar radiation across a year
- places closer to equator (tropics) -> receive direct/non-direct solar radiation throughout the year -> experience high temp throughout the year
- places further from equator (outside of tropics) -> temp vary much more



spatial variation: caused by differences in latitude & altitude
- latitude (global scale)
  - due to earth's spherical shape, sun's rays strike the earth's surface at various angles
  - lower latitudes (closer to equator) -> solar angle smaller -> radiation spread over smaller area -> radiation more concentrated -> higher temp
- altitude (local scale)
  - temp within smaller regions -> vary based on terrain -> affects local altitude
  - high altitude -> air molecules pulled to ground surface by gravity -> air less dense -> air pressure lower
  - fewer air molecules -> air has lower ability to absorb/radiate heat -> lower temp
  - low altitude -> air molecules pulled to ground surface by gravity -> air more dense -> air pressure higher
  - more air molecules -> air has higher ability to absorb/radiate heat -> higher temp

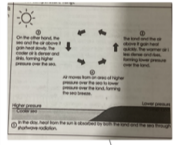


3.3 variation of preciptation across earth's surface

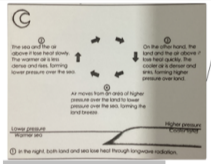
relative humidity (RH)
- [actual amt of water vapour present in air (g/m^3)]/ max amt of water vapour air can hold (g/m^3)] x 100%
- temp increase -> amt of water vapour air can boiled increase -> RH decrease
- air hold max amt of water vapour -> air saturated -> RH = 100%
- more water vapour evaporated into air/air temp decrease -> RH > 100% -> condensation occurs

determining wind speed
- strength of pressure gradient
  - smaller = smaller diff in pressure between 2 areas = slower wind speed
  - larger = larger diff in pressure between 2 areas = faster wind speed
- friction
  - moving air comes into contact with variations in earth's topography (differing altitudes = hopes & slopes) ->frictional drag experienced -> wind speed decreased
  - uneven relief & rough surfaces on land (valleys & mountains) -> effect of frictional drag greatest

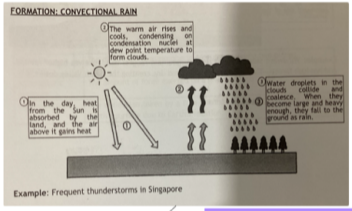
variations of wind direction: local scale
- land breeze
  - wind blows from land to sea
  - regulates temp of coastal areas at night -> smaller annual temp range
- sea breeze
  - wind blows from sea to land
  - lowers temp of coastal areas during day -> smaller annual temp range



cloud & rain formation
- air rise up atmosphere -> air cools -> reduce amt of water vapour air can hold -> water vapour present in air exceeds max amt of water vapour air can hold over time (RH = 100%)(air saturated)
- at dew point temp -> air condense into water droplets on condensation nuclei (provide surfaces for water vapour to become water droplets/solid ice crystals) -> clouds formed
- water droplets in clouds collide & coalesce -> water droplets in clouds become bigger & heavier -> droplets fall to earth as raindrops once water droplets are large & heavy enough

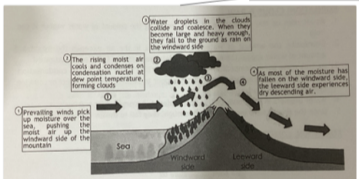


speed of groundwater flows
- type of soil:
  - soil with larger pores (loose, sandy soil) -> allow more water to infiltrate & move quicker -> water flow faster
  - soil with smaller pores (clayey soil) -> water flow slower
- presence of built-up area:
  - built-up areas have concrete ground surfaces (tiny pores) -> lower infiltration rates
- presence of natural vegetation:
  - vegetation (roots of plants) -> loosens soil -> create more open spaces for water to flow -> water flow quicker



conventional rain formation
- rainfalls often occur in afternoons in SG

relief rain formation



speed of surface runoff
- type of soil:
  - ground surfaces with larger pores -> water mainly infiltrate -> less surface runoff
  - pores fully occupied with water -> ground surface no more pores -> surface runoff occurs & flows quickly
- presence of built-up area:
  - built-up area -> fewer obstructions & less friction -> surface runoff faster on smoother ground surface (roads/pavements)
- presence of natural vegetation:
  - vegetated areas have stems/roots of plants -> act as barriers -> + surface roughness -> surface runoff slower

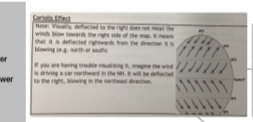
variation in specific sites
- type of surface
  - dark surfaces vs light surfaces
  - dark surfaces (exposed soil/forests) -> absorb more solar radiation & radiate more heat -> higher temp
  - light surfaces (clouds/snow) -> reflect more solar radiation & radiate less heat -> lower temp
  - urban areas tend to have higher temp than surrounding rural areas
    - urban areas: comprise of larger dark surface areas (roads) -> absorb more solar radiation & radiate more heat than forests & water bodies
    - glass-covered sky scrapers reflect sunlight to ground surface by-> increased absorption of solar & heat radiation
  - e.g night time temp at SG's CBD 2°C warmer than area near Macritchie reservoir (dense vegetation)
- distance from the sea
  - coastal area (maritime effect)
    - summer & winter temp: cooler summers, warmer winters
    - annual temp range: lower (summer temp not as high, winter temp not as low)
    - explanation:
      - sea heats up & cools down more slowly than land
      - summer: sea cooler than land, cools down air along coastal areas
      - winter: sea warmer than land, warms air along coastal areas
    - e.g.: Anchorage, Alaska, USA -> coastal city that has lower annual temp range of 23°C
  - inland area (continental effect)
    - summer & winter temp: warmer summers, cooler winters
    - annual temp range: higher (summer temp higher, winter temp lower)
    - explanation: don't experience moderating influence of sea, experience continental effect
    - e.g.: Fairbanks, Alaska, USA -> inland city that has higher annual temp range of 40°C

water cycle
- sun's heat -> water bodies evaporate -> water vapour formed
- plants transpire -> give out water vapour
- water vapour rises & enters atmosphere thru evapo-transpiration -> cool & condense into tiny water droplets at dew point temp -> form clouds
- water droplets in clouds get big and heavy enough -> fall to ground as precipitation -> water on ground surface infiltrate subsurface soil & rock -> water moves horizontally above impermeable rock as groundwater flows
- water that cannot infiltrate ground -> flows over ground surface as surface runoff & enter water bodies

monsoon

southeast monsoon
- season & temp: june to sept
  - NH = summer & higher temp
  - SH = winter & lower temp
- pressure difference:
  - NH = air warm up & rises -> area of lower pressure over central asia
  - SH = air cools & sinks -> area of higher pressure over australia
- wind direction & Coriolis effect:
  - air moves from australia towards central asia
  - when winds cross into NH -> deflected to right -> form southeast monsoon -> experienced by SG & Msia & India
- effect on climate:
  - india = winds move over indian ocean -> winds pick up moisture over indian ocean -> heavy rain
  - SG & Msia = winds move over south china sea -> winds pick up moisture from water vapour -> heavy rain
  - australia & indonesia = winds leave australia -> will not bring moisture towards continent -> dry

northwest monsoon
- season & temp: october to february
  - NH = winter & cooler temp
  - SH = summer & higher temp
- pressure difference:
  - NH = air cools & sinks -> area of higher pressure over central asia
  - SH = air warm up & rises -> area of lower pressure over australia
- wind direction & Coriolis effect:
  - air moves from central asia towards australia
  - when winds travel to india -> deflected to right -> form northeast monsoon -> experienced by SG & Msia & India
- effect on climate:
  - india = little moisture picked up from central asia -> northeast monsoon dry & cool -> little rain
  - SG & Msia = winds move over south china sea -> winds pick up moisture from water vapour -> heavy rain
  - australia & indonesia = winds cross over to SH -> deflect to left -> pick up moisture over indian ocean -> rain



wind drive southwards-> face south -> deflect to its right -> blow in southwest direction

variations of wind direction: regional scale
- unequal distribution of air temp across earth's surface -> air moves over different regions from high pressure to low pressure zone (varied pressure zones)
- winds travel over large distances -> deflected by Coriolis force (occurs due to earth's rotation)
- northern hemisphere -> winds deflect to right
- southern hemisphere-> winds deflect to left

winds formation
- horizontal movement of air across earth's surface
- due to unequal distribution of air temp -> uneven distribution of pressure gradients
- diff pressure results -> pressure gradient
- air moves from region of higher pressure to low pressure to fill in void -> wind formed

3.4 variation of wind direction & wind speed across earth's surface

10%