ES5001 NATURAL HAZARDS AND SOCIETY

H2 Natural Hazards Overview

- Natural Hazards: Natural events that poses threat or risk
  - Disaster: event that causes damage and death, but not too extensive
  - Catastrophe: extreme death and damage
- Mechanics of hazards
  - Everyday geological processes produces accumulating large effects
  - Disruption of temporary equilibrium between opposing influences
- Humanity may be more vulnerable today than in the past
  - Effects of climate change: increased greenhouse gas emissions
  - Drastic increase in cost of disasters
  - Industrialisation and Scientific progress
    - Increased population density, human activity
    - BUT we now have the power to mitigate (more data and more detailed analysis)
- Most damaging hazards are *long-term weather patterns* that cause heat waves, droughts, storms and floods
- Hazard impact is *variable year to year* due to the *unpredictability* of natural hazards and their effect
  - Cost of natural disasters are *increasing in general*
  - spatial and temporal variations
    - Higher *fatality in LDCs* & poorer communities in general: Trends in leisure activity, inadequate safety measures
    - More costly *economic losses in DCs*: higher property prices
- General approaches in mitigating hazards
  - Role of government: Land use planning, Public awareness
    - Developers & individuals often oppose restrictions
      - Cheaper/Better resources/Better access/Don't know or understand hazard
  - Geological Organisations: Catastrophe predictions and warnings
    - Conservation of energy: $M \propto 1/f$
      - Less frequent events are more destructive
    - predictable cycles: Past records give Recurrence Intervals & expected Magnitude
      - Disasters *can occur anytime*, but they are more likely to follow cycles

- positive/negative Feedback Loop: A disaster can be worsen or dampened by a separate event
  - Moderate events can become unexpectedly larger disasters if more than one type of event occurs at the same time, amplifying the effect
  - Climate change worsens disasters, disasters worsen climate change
  - Overlap and reinforce, OR Overlap and cancel out
  - Past events leave lasting damage that worsen future events.
- *Predictions are not completely accurate*
  - Too many variables of hazard and factors affecting impact
  - earth system too interconnected Butterfly Effect
  - data may also be limited, especially in LDC
- Insurance industry thrives off damages from disasters
  - but they do not cover all types of disasters (some are just too big)
- Living with nature: adaptation measures should be the focus
  - Attempt to control nature often fails; Adapt not prevent, that requires behavioural change
  - Merely temporarily hinder them, or may redirect damage elsewhere
  - Cause energy to build up Conservation of Energy

H2 Plate Tectonics

- Plate Tectonics Theory: *Lithosphere* is divided into large plates that are constantly moving (1-2 inches annually)
  - History and Evidence
    - Alfred Wegener: Continental Drift
      - Coastlines of several continents seem to fit together
      - supercontinent Pangaea
        - 130 million years ago, Cretaceous Period
      - Rejection of continental drift theory: mantle was believed to be solid, thus the *theory does not seem to work*
    - Dikes created at mid-Oceanic ridge
      - Dramatically *exaggerated topography* along faults
        - Coastline and ridge shape match up
      - Reversal of *magnetic polarities*: symmetrical, alternating parallel bands of magnetised rocks
        - Convection and rotation of liquid outer core creates a self-sustaining magnetic field (Geodynamo)
        - Earth's magnetic field periodically reverses
        - Oceanic spreading causes new crust to form, with each band of rock retaining the polarity at that time
    - *Distribution of seismicity* follow plate boundaries
      - Deep seismicity occur within subducted plate
    - *Tropical species Fossils* in Africa
    - Locations of *glaciations*: matching glacial striations suggest common origin

        - *Rock* type and structural similarities at different continents
        - *Paleoclimates* preserved in rocks
- Structure of earth
    - Chemical layers: separated by composition
        - Crust
            - Mostly rocks and granite, 6-70km thick
                - Oceanic crust thinner & denser
                - Oceanic crust are relatively older and more constant in properties
            - Split into 7 major tectonic plates
            - Most earthquakes happen here
        - Mantle
            - 2900km thick
            - Richer in Mg and Fe
        - Outer core: 2300km, molten metals
        - Inner core: 2400km, solid metal (due to high pressure)
    - Mechanical Layers: separated by movement nature
        - Lithosphere: Crust + Part of upper mantle
        - Asthenosphere: The other part of upper mantle
            - Fluid layer that acts as a lubricant for plate tectonics
            - Rocks close to melting point due to high temperature, rocks are easily deformed
        - Mesosphere
            - Mostly iron and nickel
    - Other divisions
        - Mantle transition zone; Olivine (Fe, Mg silicate) > Spinel (410km) > Perovskite (670km)
        - D'' layer; low and high velocity zone (post-perovskite phase)
- Continental Drift Mechanics: movement cause *compression and tension*
    - Tectonic plates composed of lithosphere topped with crust
    - Fluid mantle moves and pushes plates via *Convection Cells*
        - Mantle material heated by extreme heat from core, rises under the lithosphere
        - Plates pull apart to reduce pressure beneath rising arm
        - Collisions between plates of varying densities causes one to subduct under the other
        - *Melted old crust* recycled and added to the mass of mantle, continuing plate tectonics
            - area of material lost roughly balanced by *formation of new oceanic crust* along Divergent margins by seafloor spreading
    - *Slab-pull force*: Subducting plate pulls the rest of the plate behind
- Plate Boundaries
    - Convergent: largest forces
        - *Subduction*: process of a denser plate sinking under another plate
            - Benioff zones: concentration of deep earthquakes hypocentres that corresponds to a subducting plate

            - crust is consumed in subduction zones, allowing more crust to be created else where
        - Japan & island chains: subduction zones under water, chain of volcanoes
        - India-Eurasia collision: Tibetan plateau pushed up
            - GPS data shows India moves about 5cm towards China annually
        - Seismicity of East Asia
            - Deeper earthquakes occur North east of shallower ones at Java-Sumatra region, and North west at Japan region
            - India plate is converging into the Eurasian plate in the North east direction, and the Pacific plate is colliding in the Northwest directions
            - SE Asia has one of the greatest concentrations of geohazards on earth; Ring of Fires, chain of Volcanoes and the cascades of hazards
    - Divergent
        - Associated with the Oceans
            - Ocean spreading centers: points where plates move apart, new material fills up the space and forms new crust
                - Crust nearest to ridges are the *youngest and lightest*
            - Oldest ocean floors are the deepest; older rocks gets cold and become denser, causing them to slowly sink
        - Divergence on continents produces rift valleys, which eventually become ocean basins
        - Smaller and fewer earthquakes, but volcanoes common
    - Transform
        - Stress build up due to friction, when it exceeds threshold, earthquakes are released
            - Spreading ridges are irregular and jagged, Transform faults are the segments where plates are sliding past
            - Along edges of plates where there is subduction zone at one side: Caribbean-South American collision
        - Coastal California move more NW relative to Eastern California (50mm/year)
    - A single tectonic plate is likely to have all three types of boundaries at different segment
        - Pacific fault: Convergent at Japan and Australia, Transform at Queen Charlotte/Alpine/San Andreas fault, Divergent at East Pacific Rise/East Antarctic Ridge
        - Teeth marks are convergent, double lines are spreading centers, single lines are transform boundaries

Earthquakes

- Each landscapes have its own faults
    - Reverse/Thrust faults: convergent
        - Deepest and most powerful at *Benioff zones*
        - Caucasus and Zagros: most of world's oil
        - Himalaya: Indian-Eurasian subduction, some of the biggest earthquakes here
        - Tibet

    - Sumatran fault;
        - On the west coast of Sumatra, many islands have risen or subsided during large earthquakes because of elastic response to the slip on an underlying megathrust
        - Seismic hazard is relatively low in Singapore, but there are many seismic activity surrounding us and many past events are unknown. Thus we must be adequately prepared.
  - Strike-slip fault: Transform
    - Haiti: 2cm/year left lateral strike-slip, Caribbean-North American
    - *San Andreas fault*: Pacific plate is moving north-westward relative to the North American
    - Tibet
  - Normal faults: divergent
    - Afar triangle: 2.5km sea floor spreading comes on land, creating a valley
    - Tibet: triangular facets, truncated mountain ranges
    - East African Rift Valley
    - Spreading of Western United States
- Earthquake distribution
  - Global: Occurs along all three types of plate boundaries
  - Regional: heavily concentrated around the Pacific Ring of Fire with several converging plate boundaries, extending to Southeast Asia (Indonesia) and New Zealand
    - SEA: in terms of seismic activity, SE Asia is one of the most active regions in the world
  - *Intraplate EQ*: may occur some distance away from plate boundaries
  - highest risk for major earthquakes those in *southern Europe*
- Mechanisms of Earthquakes: *Stress (force) and Strain (deformation & breakage)*
  - Elastic Rebound Theory: when the *stress* exceeds a material's threshold, the material *strains* and releases energy
    - Crust deforms, rocks on opposing sides of a fault subjected to stress, deform until rock strength is exceeded
    - Slip, Sudden movement releases accumulated energy through seismic waves
    - Rock snaps back to original shape
  - Release of these strains causes displacements and ground motion
    - Strike slip fault ruptures
      - determining lateral *direction of strike-slip*; which direction the opposite plate is moving towards when facing them
      - Tarlay fault rapture, Myanmar-Laos border: 12km offset
      - San Francisco rapture: 5m
    - Normal fault ruptures
      - Characteristic exposed fault scarp
      - 1954 Nevada, mountain went up relative to valley
      - Sparta fault, Taygetos mountains went up
    - Reverse fault ruptures

        - Chi-Chi earthquake: 85km rupture, mountains in the east closer over the valleys in the west
        - March 2005: Sunda megathrust rupture produces both uplift (3m) and subsidence (-1.5m)
        - Tohoku 2011: 3m horizontal displacement of Honshu towards Pacific plate
    - seismic gap: part of an active fault that has not had earthquakes in a relatively long period of time
- Seismic signals from earth quake & propagation waves
  - Earthquakes consist of body waves (waves that travel through the earth's interior) and surface waves (waves that travel along or near the earth's surface)
    - P waves (around 6km/s), S waves (around 3km/s, but stronger)
    - Rayleigh waves (less than 3km/s at the surface), Love wave
  - Waves by order of fastest: Body waves > Surface waves
    - Body waves: Primary wave & Shear waves
      - travel outward in all directions from the focus through Earth's interior
    - Surface waves:
      - Rayleigh waves: reverse retrograde ellipse particle motion parallel to direction of propagation
      - Love waves: shearing particle motion only in horizontal plane
  - Wave properties
    - faster waves have higher frequencies
    - amplitude is amount of wave motion; decays exponentially with depth
  - Hypocenter (earthquake origin) vs Epicenter (point on surface above Hypocenter)
  - Wave front: a surface covered by waves that have propagated away from Hypocenter at a point in time
  - Velocity related to bulk or shear moduli of material
- Measuring earthquakes
  - Richter scale is an old measurement
  - *Seismic moment*, $M_o = (Length \bullet width \bullet slip) \cdot \mu$
    - μ is the *shear modulus*: measure of resistance of a material to shear deformation
    - *Area* of fault rupture
      - Width is commonly 10km at Strike-slip faults, and 150 km at megathrust faults (thus deeper earthquakes at subduction zones)
    - Average *slip* distance of fault
  - Moment magnitude: *actual energy* expended by the rupture to move rocks on each side of fault
    - $M_w = 2/3log_{10}M_o - 10.7$
    - some rough estimations between M_w and length (rupture on surface)
      - 6.3-10km, 6.7-25, 7.1-50, 7.4-100, 8.1-400, 8.5-1000
- Earthquake prediction: possible to predict future based on the time and location of previous earthquakes, but not completely accurate
  - however not many earthquakes have reliable recurrence interval
  - Slip rates of active faults for example, we can use

        - GPS data records of past years to decade
        - High resolution topography data that record offsets for past earthquakes
        - Coral data for the historical earthquakes
    - major earthquakes along a fault tend to occur in groups separated by an inactive interval
    - earthquakes do not necessarily occur simultaneously at many locations along a fault
- Earthquake early warning: *NOT a prior warning*
    - fault sends out different types of waves. The fast-moving p-wave is the first to arrive, but damage is caused by the slower s-waves and later arriving surface waves.
    - Sensors detects *p-waves*, *process data* real time and immediately *transmit signal* to an earthquake alert center, where the location and size of the quake are determined and updated as more data becomes available
    - A message from the alert center is immediately transmitted to your computer or your mobile phone which calculates the expected intensity and arrival time of shaking at your location
- Direct consequences of Earthquakes
    1. Ground shaking
        - Characteristics of ground shaking
            - Shaking is greatest near earthquake source
            - Maximum shaking lasts a few seconds to several minutes
            - Maximum shaking may locally exceed 1g and 1m/s
        - Resonant frequency: a specific frequency at which it's easy to get an object to vibrate, where the shaking is at maximum
            - Waves from earthquakes causes buildings to sway. If the swaying is at their natural frequencies, the damage will be amplified.
            - Rule of thumb, *higher frequencies tend to affect smaller buildings*, and lower frequencies tend to affect taller buildings. [Think of boats on ocean waves as an analogy, higher frequencies means smaller choppier waves that dislodges small boats]
            - In a metropolitan area, buildings of different heights are a danger to each other because tall buildings sway slower but with larger amplitude than lower buildings, allowing them to *collide*
        - Doppler Effect: Waves from a source travelling towards an observer get compressed, and cause an increase in frequency
        - Basins can amplify amplitude and duration shaking as they comprise of softer materials that are able to "preserve" the energy [Analogy: when you shake a slime vs a rock, which shakes more and longer]
        - How to mitigate the impact of earthquake ground shaking?
            - Try to understand the consequence before it occurs
            - Do as much as we can after it occurs
    2. Surface Faulting
        - displacement that reaches the earth’s surface during slip along a fault.
        - Commonly occurs with shallow earthquakes, those with an epicenter less than 20km.

- Buildings lying on the fault collapse while the buildings surrounding the fault but not on the fault do not collapse and are still fine.
- California's Alquist-Priolo Fault Zone Act
  - Every active fault zone is restricted w.r.t land use
  - Does not apply to construction of less than 4 single-family dwellings, or to buildings constructed before the law
  - Sellers required to notify buyers, but not renters, of hazard
- Alaska Pipeline
  - oil pipeline was designed to withstand ~8 meters of fault offset. The pipe was put on slides, so the ground could move beneath it without breaking the pipeline. It almost slid off! (5 meters right-lateral slip)

3. Landslides
   - Ground shaking can dislodge large masses of unstable rocks, especially areas that have experienced liquefaction
   - M7.9 Denali fault rupture, Alaska
   - Places are susceptible to landslides
     - An area that has just suffered heavy rainfall
     - Close to the surface expression of the fault
     - On a slope that faces towards the fault
     - On a steep slope near the river
     - On a susceptible rock type
4. Flooding
   - Jian River
     - Flooding of the river due to a landslide caused by EQ led to the creation of Tangjiashan Lake
     - When nearby lakes catastrophically collapsed a month after the earthquake, 4,500 lives were lost downstream.
5. Liquefaction: loosen moist soil acts like quicksand
   - the conversion of unconsolidated *solid sediments* with some initial cohesiveness into a mass of *water-saturated sediment* that flows like a liquid (but no water is added). No longer able to support structures, they sink into the ground.
   - Despite original mixture of different pockets of soils with different moisture content and density, the shaking may have sorted the soils into even layers, where moist softer soil (or water itself) is forced to the surface.
     - The more the *layers of soil*, and the more amount of *ground water*, the higher chance of liquefaction
6. Changes of land level
   - Uplift and Submergence by Elastic Rebound
   - Libuat islets
     - There was ~ 1 m uplift of Libuat islet, Sumatra, during the Mw 8.4 earthquake of September 2007. The coral reef that used to be below the water and alive before the earthquake is now above sea level and dead. Economics make it

difficult to adapt to the changes, and submergence is particularly hard to deal with.

7. Tsunami [Next chapter]

Tsunami

- Habor waves
  - Wind-driven waves have short wavelengths (tens of meters), while Tsunami wavelengths are long (up to more than a hundred kilometers)
- Mechanisms of tsunami
  - Initiation of a tsunami: Sudden vertical motions displace water; waves propagate out both ways. Speed of propagation fronts relates to ocean depth.
  - With reduced water depth (closer to coast), wavelength (distance from peak to peak) gets shorter and period (time for passage of one wave) decreases [due to friction?]. There is a "piling up" effect as the faster waves crash into the slower wave front, amplitude (height of wave) increases.
- Characteristics of **2011 Tohoku Tsunami**
  1. Arrival time 30 minutes after seismic waves hit
  2. Velocity of wave increases over time (3m/s to 20m/s)
  3. Rise of water about 50cm/min
  4. Flow-up river lasted about 16min
  5. Water flows back to ocean after the flow-up river stopped
  6. Fatalities during tsunami quite high...ppl fail to respond urgently even with warning
- Sources of Tsunami
  1. Undersea rupture of normal, thrust and megathrust faults
     - Tsunami mimics the rupture of sub-sea megathrusts. If the rupture is 100km wide, so is the initial tsunami wavelength.
     - A ship at deep sea will not generally notice the passage of a tsunami wave because they have long periods and small wave heights in the deep ocean
     - velocity of a tsunami is controlled by the depth of the sea: $velocity = \sqrt{gravity \times depth}$
     - In the deep ocean, tsunami waves will travel at speeds approaching 250 m/second
     - The waves get steeper and higher as they come into shallower and shallower water. Often, they become a chaotic front.
     - Factors affecting height of tsunami wave: earthquake magnitude, area of rupture zone, rate and volume of water displaced, sense of ocean floor motion, depth of water above rupture
     - As a tsunami enters a bay or fjord, wave height increases because the coastal topography changes gradually
     - P.S subducting plates cannot rise...
     - Tsunami wave can’t be generated by an underwater strike-slip earthquake, since there is no vertical displacement
     - Earthquake induced large tsunami at the subduction zone can reoccur every few hundred years

- The largest vertical displacement of water during the 2004 Sumatran earthquake is about 5-10 m

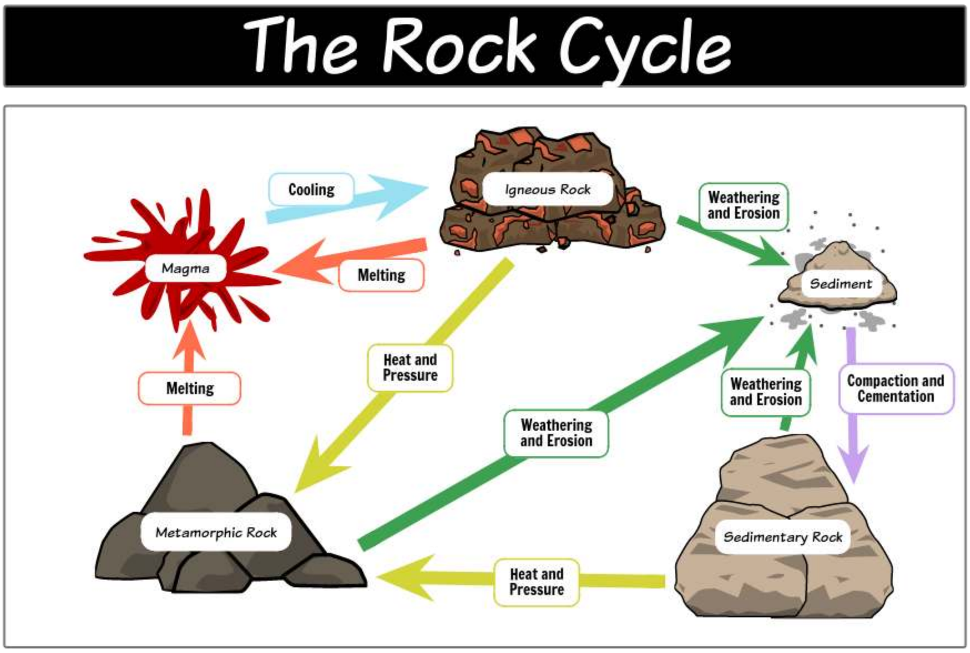
2. Under sea landslides
   - Tsunami from fast moving landslides or rock falls can displace immense amounts of water and generate tsunami
   - The height of fall has more effect than volume of mass that displaces water
   - The strength of a tsunami created by a landslide depends most heavily on the speed and volume of the landslide
3. Undersea volcanic eruptions
   - Volcanic processes can displace large volumes of water and trigger tsunami: fast-moving flows of hot volcanic ash, submarine volcanic explosions, collapse of volcano in giant landslide
   - Tsunami generated by volcanic eruptions are poorly understood; maximum size is unknown
   - 3 causes: An enormous explosion displaces large quantities of sea water, the underwater portions of the volcano subside quickly during the eruption thus greatly disturbing the seafloor, large volumes of volcanic material enter the sea and displace sea water
   - 1883 Krakatau: 35m run up
   - 1628 BC Santorini: Minoan civilization on Crete desecrated
   - **2022 Tonga**
     - *Atmospheric air pressure waves* is the primary (and considered only) source of tsunami
     - Change of topography: sinking of land mass between two islands
4. Meteoroids
   - 65 million years ago K-T extinction
     - A 10-km wide meteorite struck Earth and led to the extinction of about 50% of known species at the time. Clear geological evidence for an immense tsunami on the coasts of the Gulf of Mexico
   - Fortunately, the average frequency of impacts is low (1-kilome per asteroid impact occurs about once every million years)
   - Eltanin Impact simulation: 1-kilometer meteoroid falling into 5-kilometer-deep ocean 20km/s
     - Would generate a 3-kilometer-deep cavity in the sea floor
     - Cavity walls would collapse rapidly and generate tsunami
     - Kilometer-high tsunami waves would cause immense run-up on shore
     - Waves would decrease in size fairly rapidly from impact site

- Tsunami hazard mitigation
  - Better city design and infrastructure
    - Land-use zoning: limit buildings to elevations above those potentially flooded
    - Structures to resist wave erosion and scour
    - Orient streets and buildings perpendicular to wave crest
    - Well-rooted trees can slow wave

- Large ditch or reinforced concrete wall can reduce impact of first wave
- Infrastructural adaptation and emergency planning;
  - Hazard maps
  - Resistant building design, warning signs, vertical evacuation structures
- Awareness and emergency drills
  - your first reaction should be to immediately head for a location as high above sea level as possible
- Tsunami warnings:
  - Warning systems now perfected for far field (far from the source) tsunami
  - **Pacific Ocean tsunami warning network** monitors large earthquakes and ocean waves and transmits warnings to 26 countries. Travel time for tsunami is accurately calculated and ocean surface heights are detected from readings of tidal sensors and ocean bottom sensors
  - Buoys near anticipated sources detect a tsunami in its early stages and transmit to the PTWC in Hawaii (since seismic waves travel faster than tsunami waves)

H2 Volcano

- Lava are molten rock that erupts onto Earth's surface
  - Magma travels to Earth's surface through an upward tunnel



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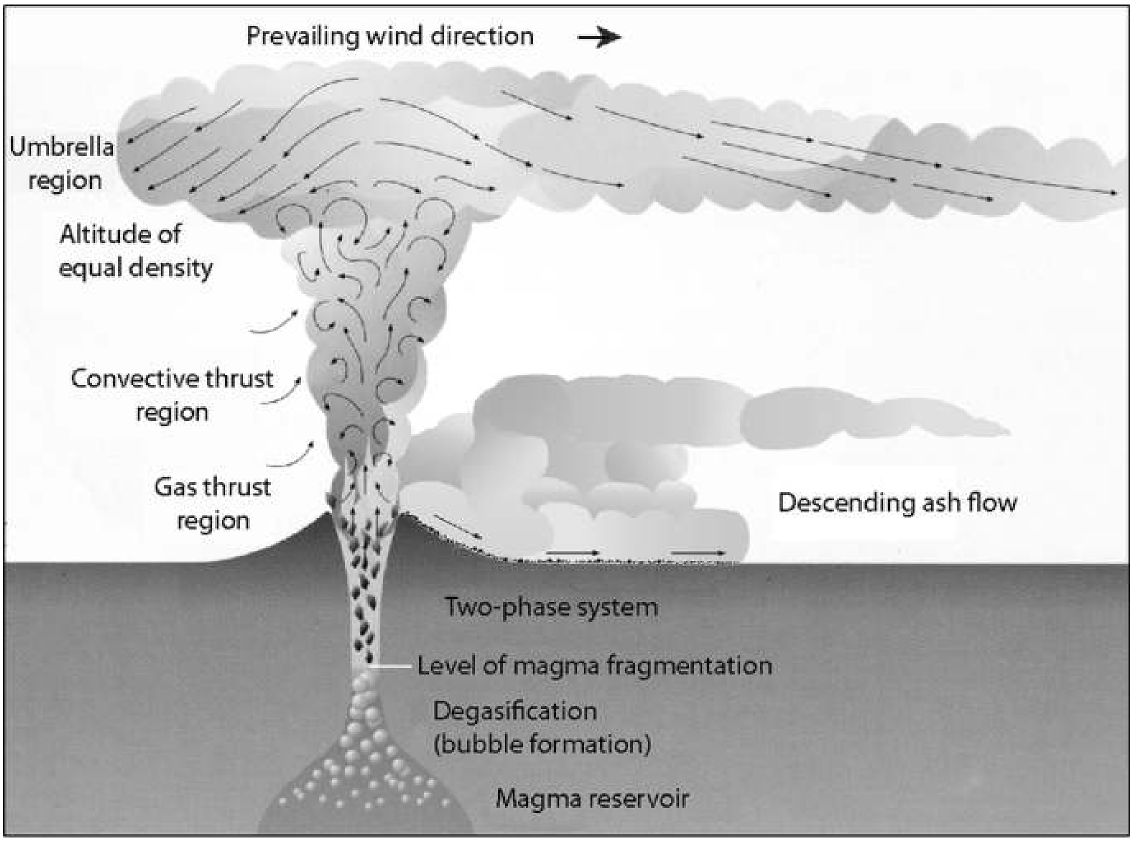
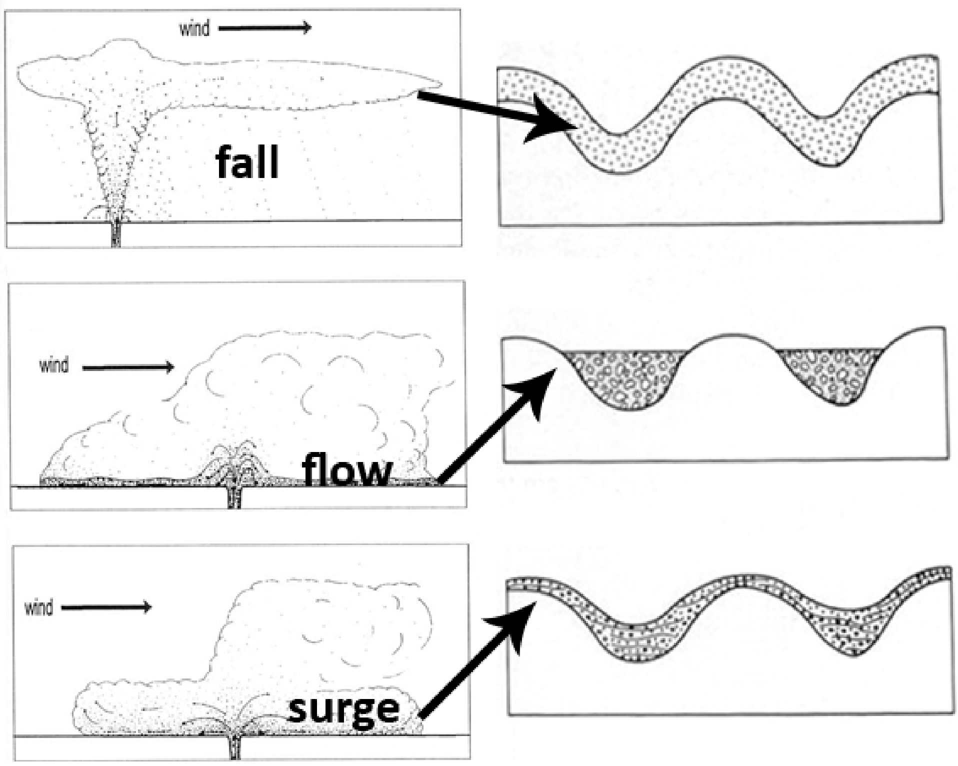
- Rock cycle
  - Metamorphic
    - Rocks start to melt at 800 - 1200 Celsius
  - Igneous: hardened magma
  - Sedimentary
  - Intrusive vs Extrinsic: beneath surface or above
- Magma properties
  - Basaltic Lava: 50% silica
    - Cinder Cones and Shield Volcano
      - Basaltic lava: low viscosity,

- Higher temperature due to low percentage silica
- Andesite Lava: 60% silica
- Rhyolite Lava: 75% silica
  - Stratovolcano
    - Most explosive, high viscosity traps air
    - Stratovolcanoes have relatively steep sides because their magma has moderate to high viscosity so lavas flow a short distance before cooling
  - Caldera: collapse of magma chamber
- Important constituents
  - *SiO_4* tetrahedron anionic group
  - *Water*: lowers stiffness, more explosive

- Eruption categories
  - Eruptions work due to gravity, build up and overflow of lava
  - Hawaiian
    - Properties
      - < a few hundred meters of eruption
    - Mount Kilauea: Hot spot volcano
    - Mount Pu'u 'Ō'ō: Subsidence of lava lakes, due to water getting into high temperature magma, producing high pressure gas bubbles, that cause more explosive eruptions
  - Plinian: Subduction zone volcanos & Stratovolcanoes
    - 

      - Plinian Column reaches Mesosphere
        - Gas thrust (Lower 1-2km) - vertical motion
        - Convection region - vertical motion
        - Umbrella region - horizontal motion with the wind

- Large amount of Pumice
- Powerful gas blasts
  - lighter particles travel further
- Large amounts of magma erupted
- Caldera formation possible
- Rhyolitic magma
- Mount Vesuvius
- Mount St. Helens
- Mount Santorini
- Pyroclastic Deposit



- Ash fall
- Pyroclastic flow
  - Hot gases that glows red
- Pyroclastic surge: a wave of steam associated with pyroclastic flows
- Consequences of Volcanos: The hazard posed by a volcano depends on both the population nearby and the eruption product.
- Hazards without eruption
  1. Ground shaking
  2. Fractures & Fissures
  3. Outgassing: Leakage of dense CO2 into soil or percolate into air near ground level
     - Suffocation of living things
     - High CO2 concentrations in soil interfere with nutrient intake
     - Mammoth Mountain: CO2 makes up to 20-95% of soil content, slowly killing a southern patch of forest
  4. Acid lakes
     - Gases from magma dissolve into crater lakes to form acidic water as low as 0.1 pH

        - Ijen Crater lake, East Java
    5. Lahars & Landslides
        - Lahar: watery volcanic mudslide, grow as they flow and erode anything on the slopes
            - lahars move rapidly down valleys like rivers of concrete
            - lahars and excess sediment cause serious economic and environmental damage to river valleys and flood plains
            - lahars pick up material as they travel, which can cause damage to structures in their path
        - Triggered by eruption or heavy rain soaking fresh volcanic deopsits, quick flows at 10s of m/s
        - Puyallup, Washington: community build on old lahar deposit, unstable
- Direct hazards with eruptions
    1. Lava flows
        - By far the least hazardous one, most lava flow is slow
            - Temperature, silica content, extrusion rate and slope angle
            - Cold & high silica flows do not travel far due to high viscosity
            - Greatest hazard to property though
        - Iceland volcanos are known for beautiful watery lava flows, they form the Icelandic islands
    2. Pyroclastic flow: "broken fire"
        - High density mixtures of hot, dry rock fragments and hot gases
        - You can outrun it, the truck could during Pinatubo 1991...but you may want a head start
        - 80km/h, 200-700°C
        - clog streams, create dams that flood the area (it was very bad for Philippines during Pinatubo
    3. Ash fall
        - Small fragments of rock that rain down from the umbrella of a Plinian Column
        - Travel downwind and cover massive area
        - Visibility, dense enough to collapse roofs, damage engines, power generation, transmission and distribution, clogs water supplies, breathing difficulties, crop damage
    4. Ground shaking
    5. Fissuring
    6. Outgassing
    7. Landslides & Tsunami
        - Collapse of northern sector of Mt. St Helens 1980
            - Outwards bulge due to magma flow into edifice, causing a lateral blast that causes an entire northern sector to collapse
        - **Hawaiian Islands**
            - Some islands such as Alika 1 & 2 are formed from sector collapses with deposits of up to 100-200 km

        - 1500 to 200km^3 of deposits, forming a tsunami that deposits 325 m above sea level
        - A hypothetical collapse of the southern flank of Kilauea: Trans-Pacific tsunami 6 hours out > 10m wave heights that can hit as far as Antarctic Coast
        - An incipient landslide scar indicates that a sector collapse is imminent

- Indirect hazards with eruption
    1. Air travel
        - Damage to jet engine, cockpit window, air conditioning system, electrical hydraulic and fuel systems
        - AVOID at all costs, regardless of ash concentration
        - **Eyjafjallajökull** 2010: largest breakdown of European airspace since WWII
            - Commercial Aircraft unable to pass through ash cloud 20-35k ft in the air
            - US$4,7 billion impact in a week
        - Business and leisure travel delayed or cancelled, perishable goods lost, industry production suspended
        - Kelut 2014: SE Asia affected
    2. Climate change
        - Ash physically blocks sunlight: H_2O, SO_2, CO_2, HCL, OClO, BrO
            - **Pinatubo** 1991: 0.5°C drop in global temperature
                - Optical depth: measure of SO_2 concentration
                - increased global stratospheric optical depth 10-100x pre-eruption levels
            - Tambora 1815: 0.4-0.7°C drop for 3 years, famines, typhus and cholera epidemics
            - Toba 73k BP: up to 15cm ash layer, ash layer at least covered Indian subcontinent, 6–7-year cold snap in ice cores (3-3.5°C temperature drop)
        - Hotter summers: **Tonga** 2022 eruption and China Europe heatwave
            - > *50km column*

- The worst-case scenario: Super volcanos
    - Eruption with ejecta volume > 1000km^3
        - Volcanic Explosivity Index 8 eruptions; the older the more concern, one cycle might be ending soon...
        - Taupo zone NZ, 26500 years ago
        - Toba Sumatra, 74000 years ago
        - Yellow stone 640000 years ago (2-million-year cycle)
        - Cerro Galan Argentina, 2.5 million years ago
        - Pacana Chile, 4 million years
- The idea that gases from magma can dissolve into water and form acid lakes is. True, and the acidity can go as low as pH=0.1 (very strong acid, enough to can serious burns to human skin)
- Volcanic losses to life and property depend on the eruption products and the population density and density of assets located near the volcano

- Historical records of volcanic eruptions are effective in identifying areas at risk for volcanic dangers
  - are difficult to obtain since they depend on written history
  - cannot be used for prediction since volcanoes are inherently unpredictable
  - are difficult to obtain since they depend on written history
  - are easily used to accurately predict the time of an eruption
- Forecasts of the Mt. St. Helens eruption in 1980 were mostly correct, but were not acted on properly by authorities and residents
- How did the 2022 Tonga volcanic eruption produce a tsunami? The atmospheric pressure perturbation from the eruption triggered tsunami.
  - The explosion displaced large amounts of seawater.
  - Volcanic material entered the sea and displaced large amounts of seawater.
  - The top of an underwater volcano collapsed down when the magma beneath it erupted, disturbing the seafloor.
- The last supervolcano eruption at Toba volcano (73,000 years ago) caused what effect on climate? The earth cooled by ~3 degrees C for 6-7 years because ash blocked the sun's rays and altered the albedo.
- One reason why it is difficult to mitigate the hazards from volcanoes is that: Volcanic eruptions can behave in unpredictable ways, such as the landslide that caused the Mt. St. Helens eruption to explode sideways
  - Volcanoes sit above the molten mantle, so they potentially have unlimited eruptible magma
  - Each eruption is sourced from a different pool of magma, so we cannot use erupted material to learn about the volcano's behavior

H2 Landslides

- Landslide: movement of rocks and mud down a slope
  - Rockfall: rocks rolling downhill
    - VERY fast 1-100m/s, but short runout; patchy impact
  - Rotational/translational landslide: large volume of material moving downslope quickly
    - Weak interfaces can transform into debris avalanches when water is squeezed out
    - Rotational: curved slip surface
      - Head moves downward and rotates backwards, Toe moves upward
        - It's like a sinkhole mechanism, just that the hole overflows and flows out
        - Dramatic rotation near the top of landslide, near vertical head scarp
      - Fast (1-10m/s), long distances (shorter than translational)
    - Translational: planar skip surface
      - Either coherent block, or disintegrated debris slide
      - Preserves topography features
      - Long distances and fast
  - Debris flows: wet flow
    - Glacial areas, relatively fast 1-10m/s
    - Long runouts (>50km)

        - Sediment concentration, debris content, velocity and depth
    - Creep: gradual
        - Slow (0.3mm-3.1 cm/yr), short runout
        - Damage to brittle structures through ground movement
- El Salvador 2001: Mw 7.7 earthquake
- Causes of Landslide
    - Driving force: gravity, external forces pull down material
    - Resisting forces: material strength and friction holds material in place
    - Contributing factors: slope angle, material load, moisture content
        - Contributing factors affect frictional resistance, if friction is exceeded by driving force landslides occur
        - Slope angle is the largest factor, but load mass also affects (a right triangular relation)
            - Slope angle cannot exceed Angle of repose (max angle where loose material is stable); Angularity, size of grains, moisture content
                - Internal slopes are the actual slope of the interfaces
                - Sedimentary layers, fractures, layer of rocks of different strength
                - They are a source of weakness. Stress may not overwhelm the daylight beds, but may overwhelm internal slope
            - Natural factors causing slope changes
                - Stream or wave action
                - Construction or human activity; Ulu pandan....
                - Removing vegetation; topography change + uprooting trees
        - Cohesion: how well grains hold together, affected by rain fall
            - Surface tension of thin film of water in partly drained pore spaces between loose grains
            - When pore filled pressure is higher than cohesion, the gains are pulled apart and becomes loose, reducing friction
- **Impacts
    - **Kinabalu 2015**: low probability rockfall, far away from active seismicity (incomplete small cycles), teacher and students killed
    - Nevados Huascaran
    - **St. Helens**
    - Tangjaishan 2008: EQ + Heavy rain
    - Cascading impacts
    - Vajont Dam
    - Lituya bay Alaska 1985; Tsunami
    - **Po Shan Road 1972**; rainfall + dense residence builds on an already steep slope
- Mitigation and monitoring
    - Legal responsibility of mining companies to monitor soil movement
    - Landslide Potential Index of every landslip warning rainstorm
    - Remote sensing; identifying trends from historical data to help predict risk

- Monitoring equipment;
  - Rain gauge, GPS, camera, extensometer (length of string) + tiltmeter (degree of inclination)
- Mitigation
  - Coarse heavy rocks, bridges, water channels, reforestation, barriers and walls
- Which of the following is NOT one of the causes of landslides? fires
  - earthquakes, wind abrasion, volcanic eruptions
- In the earth science, “Mass movements” Refer to materials that can move downslope at a wide range of speeds
- What always plays the main role in a landslide, regardless of the cause? gravity
- What force is responsible for erosion and deposition in landslides? gravity
- Water is a key factor in slope stability.
- A slope will slide if the driving force is greater than the resisting force
- You just inherited a home at a base of a steep hill. What kind of landslide is most likely to happen? Rockfall
- You learned in class that the Hawaiian islands have sustained many large landslides that have slid into the sea, triggering very large tsunamis. Consider the southern edge of the southernmost Hawaiian island breaking off and causing a tsunami. Is it likely that the waves will reach the coast of Antarctica? yes, tsunami waves have long wavelengths that allow them to travel long distances
- The most important factor in creating a translational slide hazard is a pre-existing weak surface parallel to slope
- Translational slides often move faster and farther than rotational slides because there are always more materials involved with translational slides...FALSE
- Which list is correctly ordered from the least to most rapid type of landslide? rotational slide, debris flow, rockfall
- Cohesion is an important force holding soil grains together through surface tension, static attraction or chemical bonds.
- The landslide at Mount Kinabalu in 2015 was a rockfall landslide

Flooding

- Costal risk for SEA: >70% is living in low elevation coastal zones, but there is not enough mitigation plans and large knowledge gaps
  - Global sediment yield (ability of rivers to transport sediments into oceans, usually deltas); Ganges River, Papua New Gene Mountain have larges sedimentary yield
  - Sedimental yield is dependent on precipitation and topography
- Deltas: low-lying landform by deposition of sediment carried by ricer as it enters slower moving water
  - The big deltas are relatively young compared to other land topography
    - Only occur in an era of high global sea level, mm per year is a quick process
  - Dynamic balance between erosion and sedimentary process; as more sediments settle down, erosion hinders the rise

- Sedimentary deposits build into the sea and lengthen river profile, riverbed at mouth has to deposit and rise
  - Ganges-Brahmaputra delta: 400km wide, distributary rivers are mostly inactive (most are not connected to main river) but become active during flooding events
- Sea level rise threatens deltas
  - Global processes dominate long-term sea-level change: tectonics, oceanic, atmospheric
  - Regional and local processes dominate short term changes: glaciers, ground water, sediment compaction, hydrological cycle, human activities
  - Both processes need to be considered for accurate projection

1. Coastal subsidence and Uplift
   - Factors influencing coastal subsidence: extraction of underground water, heavy infrastructure construction, natural compaction of young loose sediments, underground mining, melting permafrost
   - Kaikoura uplift: up to 4m tectonic uplift
   - Singapore: not sinking, thin sedimentary layers and not reliant on extracting underground water, so aquifer layer is safe...but reclaimed lands may not be safe
   - **Jakarta:** located on a water basin
     - Growing from 4.6M to 8.9M in 2005, densely populated coast. Aquifer extracted on industrial scale, heavy infrastructure construction
     - Up to 4.1-meter cumulative subsidence from 1974 to 2010,>20cm/yrs. in some lawyer
     - About 20km inland will be underwater by 2030
2. Melting ice and warming oceans
   - Rising Global temperatures cause thermal expansion of seawater (coefficient 0.0013)
   - Glacial loss and melting ice sheet: 1/3 of the rise in the las 25 years, 40% lost in 21st century alone
   - **A-68** broke off Larsen C Ice Shelf in west Antarctic: 100km long, 500 m thick and >1 T tones
   - Glacial isostatic adjustment and Ocean dynamics
   - CO2 emissions have a correlation with sea levels. The immediate effect of melting ice is clear, but long tern effects are much less certain

- Sea level rise is the baseline for
  1. Storm Surge: coastal rise of water due to low pressure weather systems (wind move towards low pressure points rapidly, literally pushing sea water on shore as the points make landfall)
     - Storm surge can be amplified if it happens during high tide...so rising sea level is dangerous
     - Compound flooding: storm surge + River discharge + heavy precipitation...
       - Combinations of successive/simultaneous extreme events with underlying conditions that amplify the impact of the events
  2. Tsunami
- Mitigation and adaptation
  - New Orleans 2005 Katrina

        - The lower reaches of the Mississippi River, its delta is densely populated
        - Poor land use planning
            - A new sliver of delta started forming right through the city + Bird foot delta has been built since man constructed artificial levees to control the flooding and avulsion
            - Due to compaction of sand and mud and oxidation of organic materials in sediments, older parts of delta have sunken
            - As delta grows seaward, the city gets lower relative to the river
            - Many places in New Orleans are below sea level, and not much is done about it
        - Bad luck: Cat 5 cyclone as it hit landfall at New Orleans
        - Enginering issues: Levee broke...sediments removed for buildings so low elevations...
    - Response strategies to sea level rise: Retreat, Adapt, Defend
        - Planned retreat: minimize losses and maximize cost effectiveness of relocation
        - Accommodation: let the effects occur, live with the rise and minimize human impacts
        - Defend: soft or hard engineering
            - Great Garuda Jakarta seawall
            - Dutch Maeslant Barrier
- What are the main causes of a flood? Heavy consistent rainfall
- Which of the following is true of levees? They protect the people in the area of the levee.
    - They are always strong enough to survive in very large floods
    - They reduce flooding downstream
- Which of the following is NOT the primary delta hazards? landslides caused by flooding
    - over flow of ocean waves into the low elevation area
    - compound flooding due to tide wave and storm surge
    - subsidence of the city due to gravity driven compaction
- Why is New Orleans so vulnerable to the hurricane Katrina? The sedimentary processes were supposed to increase the elevation of the land gradually, but the city cannot be moved up in this way
    - The city was built too late, many places were built at low elevation areas
    - The levees were built with low quality
- The sediments in New Orleans brought by the hurricane Katrina is a common natural phenomenon
- Which of the following about delta is correct? Deltas are important to human activities, fish and wildlife lay in their characteristic highly fertile soil and dense, diverse vegetation
    - Deltas are primarily formed by the slow transportation of large grain size sediments.
    - Ocean is the only place that deltas are formed.
    - The relative sea level of the mouth plays less important role than topography to form a delta.
- Land subsidence occurs in areas underlain by highly-fractured granite, which is readily dissolved by moving groundwater, especially when the water is slightly acidic...FALSE
- What is one famous delta? Mississippi delta
- Which of the following statement about delta is correct? Delta is where the river channels slow down and mostly deposit fine grand size sediments

  - Some deltas belongs to “innies” river mouth and some others belongs to the “outies” river mouth
  - Most of the big deltas in the world formed about 30,000 years ago
  - Deltas flood frequently, so they are not suitable for living and therefore they are not the places that human civilization have been developed
- Which of the following sea level statement about IPCC report is true? Ice melt makes slightly larger contribution to sea level rise nowadays than ocean heat, but their final contribution by the end of the 21st century is not well understood
  - Various models predict that the global sea level will rise more than 1 meter by the end of 21st century
  - Ice melt makes slightly smaller contribution to sea level rise nowadays than ocean heat, and their final contribution by the end of the 21st century is well predicted
  - Sea level rise is so hard to predict, it is meaningless to make prediction, but we have to try our best to slow down global warming

H2 Cyclones and Storms

- Cyclone (Everywhere else), Hurricane (Caribbean, W Atlantic, NE Pacific), Typhoon (NW Pacific)
  - 40-50 per year
  - Regulate climate by moving heat away from equator
- Formation
  - Warm tropical water (>26°C): provide water vapor
    - Strong latitudinal influence (5-20 degrees N & S equator), Western parts of basins are warmer (trade winds blow east to west)
    - Ocean current (cold currents inhibit development of cyclones
  - Atmosphere profile: hot & rising, stable wind shear, cool at the top
    - Warm super saturated air up to 6km above sea level: latent heat from condensation leads to warm air
      - Water has very high latent heat, the amount of energy required to change its phase
    - Low variation in wind speed with height (< 10m/s): otherwise, the rotating rising air is sheared off
    - Cool air at height: to prevent warm air continually rising
  - Coriolis force
    - Equator: no Coriolis force
    - *Things deflect right in NH, and left in SH*
  - Disturbance
    - Tropical disturbance: towering thunderstorms w max sustained winds <40lm/h
    - Tropical depression: inward flowing air starts to rotate under Coriolis effect, max sustained winds <63 km/h
    - Tropical storm: 70-120 km/h
    - Cyclone: air descends into storm center where rotation is weakest, warmest. Thus, vaporizing cloud and forming the 'eye',>120km/h

- Typhoon structures
  - Warm air rises as part of eye wall, cooled and outflow to form outflow cirrus shield
    - Highest winds along eye wall
    - air generally sinks within eyewall, contributing to calm of eye
  - Rain bands (air moving from high low high low pressure under the shield
  - Diameter (300 - >1500km), >1000 hPa near edge & 950 hPa or less in eye as low as 870
  - 30km/h near edge,>240km/h at edge, light and variable in eye
  - Speed of forward motion is <40km/h. Usually faster in temperate climates than tropics.
- Saffir Simpson Scale
- Hazards
  - Strong wind dependent on pressure (lowest recorded is Tip 791012)
  - Storm surge
    - Piling up of water from onshore winds
    - Low pressure elevates ocean surface
    - Bathymetry: shallowing water increases wave height
    - GREATEST hazard: >9m high waves
      - Size of storm: larger wind field, bigger surge
      - Forward speed: slower, bigger inland; faster bigger coastal
      - Angle of approach (geometry): perpendicular to coast, more surge
  - Poorer informal communities are most vulnerable
    - Unsafe property: strong winds and air borne debris
    - Water inundation results in greatest loss of property
    - Drowning (90% death), building collapse, air borne debris, landslides
  - Global trends
    - Costs have drastically increased: rapidly growing population along the coast, more expensive properties
    - Death have decreased: better prediction, better coordination
- Warning and monitoring
  - I GOT DISTRACTED SORRY GET BACK TO THIS LATER SORRY
- Thunderstorm
- Devastating typhoons between 5-30° latitude north or south are the product of: Upward spiralling cyclones from low pressure (converging) centres
- Air spiralling outward around a high-pressure centre is called a Anticlone
- In the northern hemisphere, the wind circulation in a mid-latitude cyclone is Counter clockwise, spiralling inwards
- You are in the northern hemisphere and a hurricane is headed west towards a north-south oriented coastal line. Which area along the storm's path is likely to experience the highest windspeeds? The north side
- What leads to the rapid dissipation of hurricane? collision with cold water, collision with land
- Cyclones get their start as which one of the following rises in the air over tropical ocean water? hot and moist air

- Where do hurricanes that affect the Caribbean and the coast of the USA mostly originate? In the mid-Atlantic
- Which country on Earth gets the most tropical cyclones in an average year? Philippines
- What causes the 'storm surge' that often accompanies a cyclone making landfall? Winds pushing waves onshore
- Evaporated water condenses (cools) and releases heat
- Which of the following is not known to cause damage to coastal communities due to tropical cyclones? lightning
  - rainfall
  - storm surge
  - strong winds
- Which of the following is NOT something affected by the Coriolis effect? a student running from one end of the gym to the other
  - the movement of Hurricane Sandy along the coast of the United States
  - the global wind patterns
  - a plane moving in a curved path from Los Angles to New York City

H2 Climate

- Climate vs Weather
  - weather is all the atmospheric phenomena occurring at a given time
  - Climate is the average weather patterns over a long time period (decades to millions of years)
- Natural changes to the climate
  - Input
    - Amount of solar energy reaching a place is spatially different
      - 23.5° tilt: one hemisphere may get more sun than the other
      - Elliptical orbit: some places are closer to the sun at some points of time than others
      - Angle of inclination: smaller angle, longer distance travelled + larger SA = weaker
    - Earth's orbit is not constant [**Milankovitch Theory**]
      - Milankovitch cycle: irregularities in the motions of the Earth, due to planet-moon-sun geometry and effect of gravity, produces ice age
        - Changing Eccentricity: extent of distortion of circular orbit (longest period)
        - Changing Obliquity: periodical change in tilt angle, larger tilts mean more drastic summer-winter character
        - Precession: wobble (shortest period)
          - Channel of wobble, non-spherical earth (uneven mass distribution)
  - Energy balance
    - Climate systems are affected by and exchanging energy: Atmosphere, hydrosphere, geosphere, biosphere, cryosphere
      - Atmosphere: being the first layer that absorbs energy makes it dynamic

            - Troposphere [0-18] & Stratosphere [18-50], Trade winds, Low-high pressure systems
            - Clouds reflect much of the sun's energy, making the day cooler. They radiate captured IR radiation at night to keep nights warm
                - In absence of clouds, heat from sunlight is less obstructed in the morning, but is radiated more back into space at night
            - Natural greenhouse effect mostly contributed by H20 (l)
            - The thickness of the atmosphere is different at different places
        - Ocean: largest heat pool
        - Land: so little heat capacity that changes are drastic
            - Altitude, coastal effect
        - Ice: ice-albedo feedback
    - Short term natural processes
        - Volcanic eruption: large amounts of ejecta will block sunlight
    - Cycles
        - Carbon cycle
- Establishing past climate
    - Why was the global climate in the past 10k years so stable?
        - Holocene & Pleistocene, Dansgaard-Oeschger events and Heinrich events
        - Younger Dryas: a period where sudden rise in temperature
            - Earth has gone through worse climate change than what we are experiencing now
            - Climate change is a long term process with complicated history
        - The 0.5°C temp change between little ice age is a little smaller as compared with the modern change of temp over instrumental record
    - **O2 isotopes** and paleoclimate: Shackleton's skeletons of foraminifera
        - O18 is heavier than more abundant O16
        - O18 is less likely to evaporate from a water body, cloud water becomes progressively more depleted in H2O_18
        - Snow and ice depleted in O18 wrt O16
        - O18 is higher in the ocean, this is preserved in marine shells [Proxy for temperature record]
    - **Ice cores** in Antarctica and Greenland
        - Greenland ice is a bit more sensitive to changes in the North hemisphere climate
        - *Glacier* length can be used as a proxy for temperature
    - Tree ring
        - In years with favourable rainfall, tree rings are thicker
    - Stalagmites
        - Heavier monsoons are isotopically lighter, because there is more O16 evaporated than O16 evaporated in lighter monsoons. Heavier monsoons correspond to higher temperature
        - Water dripping from ceiling hits the ground, evaporates and leaves behind calcite. Stalagmites grow with rain, thus thicker layers mean heavier monsoon

      - By dating Uranium in the various layers, we can see the level of rainfall at each period
        - Dating accuracy is +- hundreds of years
      - Level of rainfall corresponds to societal events
  - Climate change in short time scale [Atmospheric Ocean connections in Pacific Ocean]
      - Walker Circulation
        - Air pressure higher in Eastern Pacific
        - Strong southeast trade winds
        - Pacific warm pool on western side of ocean, Thermocline deeper on western side
      - **El Nino Southern Oscillation**: years where there is disruption of normal circulations
        - High pressure over Eastern Pacific weakens [even lower than west]
        - Weaker trade winds, west east trade winds, warm pools migrate eastward, down welling
        - Lower biological productivity,
        - Droughts in West Pacific, Floods in East Pacific
- Enhanced Greenhouse effect
  - Gas content and Ice volume of ice cores show alternating warmer periods and ice ages
      - Temperature has stayed abnormally stable in the past thousand years
  - Anthropogenic Forcing agents
      - Pollution
- Temperatures have risen slower in the oceans than on the continents BECAUSE the ocean has a greater heat capacity than land.
- Which of the following is an example of positive feedback? The growth of ice sheets at the poles leads to a greater area of low albedo, causing further growth of ice sheets
  - Ice sheet melting from warm atmospheric conditions causes greater fresh water input into the North Atlantic and reduces the salinity of the water, causing a reduction in downwelling of water and switching off the ocean circulation, leading to cooler temperatures at the poles
  - A colder ocean means less biological activity is occurring and less CO2 uptake into the oceans, leading to greater CO2 in the atmosphere and an enhanced greenhouse effect
  - A colder climate means less evaporation and cloud formation, leading to reduced precipitation to feed glaciers
- If you decrease the axial tilt of the Earth, what will happen to the seasons at latitude 30 degree North? milder summers and milder winters
- Which term refers to the wobble of the earth's axis? precession
- A student was asked the question, "What are the major components of the Milankovitch cycle?" The student answered, "The important components of the Milankovitch cycle are variations in Earth's orbit from nearly circular to elliptical, changes in the tilt of Earth's axis of rotation, and variations in solar output due to sunspots." How would you rate this answer? GOOD: The student's answer was incomplete by one component and included a component that was incorrect
- Greenhouse gases include all of the following except nitrogen

- If both the Greenland and Antarctic ice sheets melted, the following place(s) would still be above sea level: A small patch of NTU and Places above about 67 meters elevation
- The reason that the eccentricity, obliquity and precession of the earth is changing through years: Gravity forces between the earth and other planets/moon/sun
- What type of evidence from ocean core sediments did Shackleton use in 1976 to identify the effects of past global ice volume change? Oxygen isotope ratio from skeletons of foraminifera
- Which best represents the thickness of Earth’s troposphere? A human hair on a basketball
- Back when the ice sheets were greatest, about 21,000 years ago, one could have walked from Singapore to Jakarta without crossing a sea
- Why is it cooler in the southern hemisphere in July than it is in December? The sun’s rays shine less directly on the southern hemisphere in July than in December