EOSC 114 FINAL EXAM REVIEW SHEET

FRAGILE SYSTEMS

1. **List the top 3 most common elements in the ocean, atmosphere, and earth**

- Ocean: oxygen, hydrogen, chlorine
- Crust: oxygen, silicon, aluminum
- Core: iron, nickel, oxygen
- Atmosphere: nitrogen, oxygen, argon

2. **How does density relate to stratification?**

- Less dense materials float on top of more dense materials
- Density measured in kg/m^3

3. **Metric prefixes and scientific notation**

- K = Kilo = 1000 = 1 x 10^3
- M = Mega = million = 1,000,000 = 1 x 10^6
- G = Giga = billion = 1 x 10^9
- T = Tera = trilion = 1 x 10^12
- C = centi = hundredth = 1 x 10^-2
- m = milli = thousandth = 1 x 10^-3
- u = micro = millionth = 1 x 10^-6
- N = nano = billionth = 1 x 10^-9
- p = pico = trillionth = 1 x 10^-12

4. **List the 4 types of energy important to disasters**

- **Potential Energy=** gravity x mass x distance (the work needed to raise an object a distance against the pull of gravity
- **Kinetic Energy=** 0.5 x mass x velocity^2 (moving objects)
- **Sensible Heat:** heat energy we can sense/feel/measure (i.e. temperature), stored as latent heat during melting, boiling, or sublimation
- **Latent Heat:** potential heat energy in chemical bonds between atoms, released as sensible heat during condensation, freezing, crystallization, or deposition

*when gas-liquid, heat is transferred to surroundings

** when liquid-gas, heat is taken from surroundings

5. **Define force and work**

- **Force=** mass x gravity, measured in Newtons, push or pull
- **Work=** force x distance, measured in Joules, effort

6. **Compare risk, perception of risk, hazard, and vulnerability**

- **Risk:** probability that any given hazardous event may occur, = hazard x vulnerability
- **Hazard:** any event or situation that could cause human or economic harm
- **Vulnerability:** A weakness that could be affected by a disaster
- **Perception of Risk:** human perception is extremely flawed

7. **Relate risk and intensity to return period and frequency**

- Intensity and frequency are inverse
- **Return Period:** time span of data/# of cases of mag. M

8. **Population growth and carrying capacity**

- **Carrying Capacity:** population that can be sustainable supported within a given domain. Growth rate will decrease as population approaches carrying capacity
- Population growth is slowing and now linear

EARTHQUAKES

1. **Describe the composition and strength of earths layers and relate it to plate tectonics**

- Tectonic plates are made up of solid crust and the lithosphere (upper mantle)
- Plate tectonic controlled by composition, density, temperature, and gravity, and are responsible for topographic features like mountain belts, ocean trenches, and island chains
- Plate tectonics not possible without density-stratification
- Density increases as you move closer to core
- As temperature increases, density decreases
- **Oceanic Crust:** uniform composition, more dense
- **Continental Crust:** wide composition range, less dense

2. **Crust, mantle, lithosphere, and asthenosphere**

- **Crust:** makes up continental plates, 0-100km thick
- **Mantle:** asthenosphere, lithosphere, mesosphere
- **Lithosphere:** crust and uppermost mantle, brittle, cool, solid
- **Asthenosphere:** very ductile and hot lower mantle,

3. **Describe ridge crest spreading rate and therefore the convergence or subduction rate**

- **Basal Drag:** friction between rigid lithosphere and ductile asthenosphere creates convection cycle that moves plates along

- **Slab Pull:** cold, descending plate is denser than mantle, gravity pulls denser plate down
- **Ridge Push:** heating at rift raises ridge crest, gravity pulls elevated plates down and apart

4. Global distribution of earthquakes and the frequency-magnitude relationship

- Found at plate boundaries

5. Brittle, elastic, and plastic rocks and their connection to deformation and where earthquakes occur

- When a material is put under stress, it will undergo strain (deformation)
- **Brittle Deformation:** rocks break, irreversible
- **Elastic Deformation:** rocks spring back, reversible
- **Ductile Deformation:** viscous plastic flow, irreversible
- A solid can be brittle, ductile, and elastic; controlled by temperature, speed, and duration of deformation

6. 3 types of plate boundaries and their subtypes

- **Convergent:** plates move towards each other, force is compression (hanging wall thrust up over footwall), strong/cool rocks, longest deformation time, and biggest earthquakes [8.5-9.7]. Can occur on the plate interface, in the overriding plate, or within the downgoing plate, and these are the causes of the depth

- Subduction:
    A) oceanic-continental: oceanic plate is always subducted
    B) oceanic-oceanic: oldest plate subducts
- Collision:
    A) continental-continental: plates fuse, mountains occur, i.e. Himalayas

- **Divergent:** plates move away from each other, force is tension (hanging wall is dragged down over the footwall), weak/hot rock, fastest deformation time, smallest and shallowest earthquakes [6.5-7.0]

- Oceanic-Oceanic: underwater, i.e. Mid-Atlantic Ridge
- Continental-Continental: plates spread, usually volcanoes, i.e. East African rift zone

- **Transform:** plates slide past one another, force is shear (vertical fault plane, no extension or shortening), medium strength/warm rock, medium deformation time, medium earthquakes that are mostly in upper 50km [8.0-8.5]

- Oceanic-oceanic:
- Oceanic-continental: i.e. San-Andreas

- Continental-continental:

7. **3 types of faults and the stresses that cause them**

- **Fault:** break in the rocks where deformation has occurred (brittle fracture), can only occur in lithosphere
- **Thrust/Reverse:** convergent boundaries, compression
- **Normal:** divergent boundaries, tension
- **Strike-slip:** transform boundaries, shear

8. **Describe what an earthquake is**

- Occurs during brittle failure after elastic deformation as waves propagate away from hypocentre
- **Hypocentre:** spot underground where brittle failure occurs
- **Epicentre:** spot on surface above hypocentre

9. **Elastic rebound**

- Occurs after brittle failure as plates rebound back together in different position, we feel the waves/vibrations produced by it

10. **Motion, speed, and propagation of seismic waves**

- **Surface Waves:** travel along boundaries between materials, slower than body waves
- require an interface i.e. ground-air, water-air
- **Rayleigh Waves:** vertical/horizontal motion parallel to wave,
- **Love Waves:** horizontal motion perpendicular to wave
- **Body Waves:** travel inside materials (the earth)
- **P-Waves:** fastest type of wave, propagates in same direction as wave within continental crust, compression/extension
- **S-Waves:** slower than P-wave, propagates perpendicular to wave within continental crust, cannot pass through fluids

11. **Seismograms and earthquake locations**

- Can use time delay between p-waves and s-waves to determine earthquake distance, but need at least 3 seismometers

12. **Magnitude v. Intensity and measuring earthquakes**

- **Magnitude:** how much energy is released, quantitative measure based on wave amplitudes, as magnitude increases so does rupture area, duration of shaking, and damage. Each increase in magnitude means the energy increases by E x 32 x 10^1.5
- **Richter:** based on ground motion
- **Moment:** based on rupture area and slip on fault
- **Intensity:** how strong ground motion is at the felt location, qualitative measured based on damage and perception

- **Mercalli:** 1-12, measures damage and ground shaking perception

13. Earthquake hazards & building construction

- People die from buildings, not earthquakes
- Other hazards include fires, tsunami, liquefaction, landslides
- Surface waves are most damaging to buildings, followed by S-waves and P-waves
- Brick & concrete = bad, wood, steel, & reinforced concrete = better
- Flexible wood, low and squat geometry, and strong foundation is best

14. Liquefaction and resonance

- **Resonance:** all objects vibrate at characteristic frequencies , if earthquake vibrations are same as an objects, destruction is amplified
  - Short, squat, low mass buildings (stiffer) resonate at high frequencies, fast vibrations, and low amplitude
  - Tall, skinny, higher mass (flexible) buildings resonate at lower frequencies, slow vibrations, and high amplitude
- **Ground Properties:** shaking amplified by weaker sediment, resisted by harder bedrock
  - soft sediment: lower frequencies, longer shaking, and higher amplitudes
  - Hard rock: higher frequencies, shorter shaking, and lower amplitudes
- **Liquefaction:** shaking of weak, moist sediments can cause soil to lose cohesion, making heavy objects sink and forming sand volcanoes
- Highest risk of liquefaction is in Delta, least is in North Vancouver

15. Local earthquake risks and hazards & the CSZ

- **Prediction:** specific, can only be validly used by using historical data and creating LT imprecise predictions. Precursors include animal behaviour, seismic activity, radon emissions etc., but these are not reliable
- **Forecast:** probability statement, done through land-level change (GPS), historical seismic gaps, groundwater levels, temperature, and chemistry
- **CSZ:** Juan de Fuca & N. American plate, S. Vancouver Island at greatest risk, 20-25% chance it happens during our lifetime. If earthquake occurs, hide under desk and fill bathtub with water

VOLCANOES

1. 4 regions of a volcano

- **Source Region**: hot mantle
- **Transport Region:** cracks in the crust, transported through vertical dikes and horizontal sills

- **Storage Region:** crust, magma chamber
- **Eruption Region:** surface

2. **Given effusive/explosive eruption predict the 5 magma properties**

- **Magma:** below surface
- **Lava:** above surface

Magma Properties

- **Temperature:** colder magma associated with more explosive eruptions, hotter magma with less explosive eruptions
- **Viscosity:** controls eruption style and flow, depends on temperature, gas content, and silica content. High viscosity associated with more explosive eruptions
- **Silica Content:** controls eruption style and flow. High silica in felsic rocks, low silica in mafic rocks
- **Gas Content:** higher gas content associated with felsic rocks and more explosive eruptions, lower w/ mafic and less explosive
- **Density:** controls magma flow
- Igneous rocks are extrusive when cooled at surface and intrusive when cooled below

3. **4 types of magma and resulting rock types**

- **Basaltic:** mafic, less silica, hotter, less viscous, less explosive
- **Andesitic:** mafic-intermediate
- **Dacitic:** intermediate-felsic
- **Rhyolitic:** felsic, more silica, colder, more viscous, more explosive

4. **Pahoehoe vs. Aa**

- Smooth vs. Crumbly

5. **Global volcano distribution**

- Occur at plate boundaries (convergent or divergent) and hotspots

6. **Types of volcanoes, where they occur, and their morphology, rock type, and eruption style, and what they look like**

- **Divergent Boundary Volcanoes:** underwater i.e. mid-Atlantic ridge w/ mafic rocks, and on ground I.e. E. African rift zone w/ mafic-int-felsic rocks. Mantle material rises in dike causing pressure decrease, mafic magma may melt overlying crust
- **Convergent Boundary Volcanoes:** oceanic-oceanic i.e. Aleutian Islands w/ mafic rocks, oceanic-continental I.e. Cascades w/ mafic-int-felsic rocks. Hydration of mantle by subducting plate, mafic magma melts overlying crust.

- **Hot Spots:** under continental crust i.e. Yellowstone w/ mafic-int-felsic rocks, under oceanic crust i.e. Hawaii w/ mafic rocks. Mantle material rises in cylindrical plume and melts overlying crust

Types of Volcanoes

- **Cinder Cones:** mafic (basalt), explosive, are layers of pyroclastic ejecta from fire fountaining, small volcanoes that usually only erupt once and can occur on the side of larger volcanoes
- **Shield Volcanoes:** mafic, non-explosive, are formed through multiple eruptions as long, fluid lava layers to form largest volcanoes, erupts often, flows of pahoehoe followed by aa, I.e. Mauna Loa
- **Stratovolcanoes:** int-felsic, mixed, interbedded lava flows, pyroclastic flows, and lahars from steep slopes, frequently explosive and viscous magma, may erupt many times and stay dormant for thousands of years, i.e. Mt. St. Helens and Mt. Baker, common around ring of fire
- **Calderas:** felsic, explosive, created by large explosive eruptions of felsic, pyroclastic material that cause roof of magma chamber to collapse, produce most devastating eruptions, i.e. crater lake

7. **Lava flows, pyroclastic flows, lahars, fire fountains, fire bombs, volcanic ash, and pyroclastic falls (materials, behaviour, formation)**

- **Effusive Volcanic Processes:** lava flows (mafic-int.), lava domes (int.-felsic), pyroclastic flows due to gravitational collapse
- **Explosive Volcanic Processes:** buoyant eruption columns of ash, pyroclastic air-fall (widespread distribution of ash in downwind direction), pyroclastic flows (gas-pyroclast gravity-driven flows of high velocity and temperature that channels into valleys), blocks and bombs proximal to vent

8. **Which magma properties determine explosivity and why?**

- **Viscosity**: because viscosity fights bubble growth and increases pressure
- **Gas Content:** more gas content = more bubbles and more pressure

9. **Types of Eruptions**

- **Hawaiian:** low viscosity basaltic magma, effusive eruptions involves lava flows and fire fountains
- **Strombolian:** mildly explosive basaltic/andesitic magma, involves lava bombs and lava flows
- **Vulcanian:** viscous highly explosive andesitic/rhyolitic magma, sustained ash explosions, involves ash fallout and ash rain
- **Plinian:** viscous, extremely explosive andesitic/rhyolitic magma, sustained columns of ash, involves pyroclastic flows (Mt st. helens)

- **Phreatomagmatic**: contact between water and magma causes violently explosive flash to steam

10. VEI scale

- Logarithmic 1-8, determined by volume of ash produced, height of eruption cloud, and duration of eruption

11. Volcanic hazards and mediation techniques

- **Lava Flows:** slow, usually not dangerous, mafic low-viscosity magma, only really hazardous to buildings
- **Fire Fountaining:** occurs if basaltic magma is gas-rich, cause small explosive eruptions that may become lava flows later
- **Pyroclastic Falls:** mix of hot ash and gas, hazards include breathing in ash, total darkness, roof collapse, engine malfunction
- **Pyroclastic Flows:** gravity-driven avalanche of pyroclastic material, air, and gas, velocity up to 400km/h, most commonly created from collapse of volcanic column, next most common is explosive collapse of lava domes with highly viscous, silica-rich magma. Usually stays in valleys but if big enough can flow over water and ridges
- **Sector/Dome Collapses:** main cause of pyroclastic flows, adds boulders to flow that are often invisible, essentially a volcanic landslide that leaves a scalloped scar
- **Lahars:** flow made up of water, and loose volcanic debris, prevalent at snow and ice-clad volcanoes like Mt. Baker, very hazardous because they travel far and fast and can occur without an eruption.
- **Toxic Gases:** typically highly toxic and acidic (ph 1) that kills plants and animals. Can be stored in crater lakes and be released while volcano is dormant, i.e. Lake Nyos

12. Mt. St. Helens

- 1980 eruption caused by landslide that led to super fast lateral blast, plinian eruption

13. Volcano monitoring techniques and what they do/how they work + volcanic safety

- Volcanoes have a much longer warning phase and duration than most other disasters
- **Step 1:** Geology-based hazard mapping
- Map volcanic deposits
- Determine deposit type (i.e. lava or pyroclastic flow) and distribution
- Determine age of deposits and eruption frequency
- Consider risk to create risk maps

- **Step 2:** Monitoring
  - **Seismology:** most important tool for monitoring and forecasting, creates baseline
  - **Ground deformation:** done with GPS to measure changes in position, tilt meter to measure changes in slope, InSAR satellites to detect changes in elevation,
  - **Gas emission:** done through fumaroles, can be sampled directly but better done with a COSPEC or FTIR spectrometer
  - **Thermal imaging:** monitors temperature range and change
  - **Lahar flow detection:** monitors flow channels with motion or seismic sensing, provides real time warning
  - **Satellite observation:** allows global coverage, good for remote areas and airline route early warning
- **Step 3:** Prediction and hazard analysis
  - Hazard mitigation is difficult, best option is building away from hazards along with early warning systems and procedures
  - Alert Levels (from least to most danger): normal, advisory, watch (signs of unrest or eruption underway w/o significant hazards), warning (eruption imminent or underway)

14. Mt. Baker

- **Hazards:** lava flows, lahars, tephra (ash fallout), pyroclastic flows
- Dormant but hot, mostly intermediate magma and potential for explosive activity
- Major lahar hazard in Abbotsford, minimal lava/pyroclastic flow hazard due to remoteness

LANDSLIDES

1. Landslides, population preparedness, economic infrastructure, and population density

- Landslide impacts mainly determined by population density, population preparedness, and value of infrastructure
- Landslide fatalities are often understated because they are caused by other disasters

2. Why BC has highest landslide frequency

- Mountainous and moist terrain with lots of development on slopes and near mountains

3. Categorize and identify landslides

- Landslides categorized by **type of material, type of movement,** and **rate of movement**
- Landslide names usually combination of type of movement and type of material (i.e. debris flow)
- Types of materials:
- **Rock**
- **Soil/earth**
- **Mud**
- **Debris (**mixture of whatever is on slope)

4. **Falls, flows, and slides, and how they are influenced by geology**

- **Falls**: usually occur on very steep slopes, material is usually rock, detaches because of weakness (i.e. fracture), falls very fast due to gravity
- **Flows:** very slow to very fast, materials are soil/mud/wet debris, water is usually very important
- **Slides:** vary from slow to fast, usually soil/rock/debris, material moves as a coherent mass along an either curved or straight surface of failure
- **Rotational Slides (Slumps):** occur if surface is curved, intermediate speed, usually weak material (sediment), material rotates on a curved failure plane, characterized by curved scarp above the slide
- **Translational Slides:** occur if surface is flat, slow-fast speed, usually strong material that cohesively moves along a flat plane of weakness
- **Complex Movements:** combinations of mass movements (i.e. a slide that becomes a fall)

5. **Angle of repose**

- Where shear strength is exactly balanced by shear stress
- Steepest angle a slope can maintain without collapse

6. **Assess balance between slope strength and destabilizing forces**

- **Driving Forces:** gravity
- **Resisting Forces:** friction (resistance to sliding) & cohesion (how material holds together).
- **Material Properties:** crystalline rock (mod. friction, v. high cohesion, high Tf if cohesive), sedimentary rock (mod. friction, mod.-high cohesion, moderate Tf), sediment (low, low, low)
- **Shear Stress (T):** effect of gravity
- **Shear Strength (Tf):** friction + cohesion, the slopes ability to resist shearing motion
- If T >Tf, motion can occur

- **Factor of Safety (Fs):** ratio of shear strength to shear stress, or Tf/T, if Fs >1.0 then its a stable slope, if Fs < 1.0 then it is an unstable slope and motion can occur

7. **Landslide Causes vs. Triggers**

- **Causes:** factors leading to instability, often long term, either reduce shear strength or increase shear stress

External

- **Slope Angle:** must have slope to have movement
- **Undercutting:** lower part of slope is removed, caused by roads/logging
- **Overloading:** adding weight like buildings/roads/trees
- **Vegetation:** since roots bind lose material, removal of vegetation can make slopes unstable. Heavy trees can overload
- **Climate:** higher precipitation and avg. temperature increases weathering of rocks and loosening of soil

Internal

- **Water:** adds weight, decreases friction (Tf), increases weathering, acts as medium for flows. In sediment, water can increase cohesion at certain amounts. In solid rock, water reduces shear strength along planes of weakness.
- **Ice:** in cold climates, water can seep into cracks. Once it freezes, it expands and forces cracks/fractures apart. Greatest frequency of rock falls is in winter
- **Inherently Weak Materials:** volcanic rock and quick clay
- **Adverse Geologic Structures:** improperly angled or precarious placed structures

- **Triggers:** factors that translate instability into motion, only one trigger but potentially many causes
- Earthquakes, snow melt, volcanic eruptions, excavation, heavy rainfall, rainfall on snow, vehicles, skiing

8. **Liquefaction (quick clay) landslides**

- Clay is attracted to other clay particles in salt water, percolating groundwater lowers salt content, house-of-cards structure

9. **Oso landslide**

- Heavy rain causes collapse of layers of glacial sediment
- Hit river and caused tsunami

10. **Identify unstable slopes**

- Gun barrel trees
- Cracks in slope/pavement

11. Compare and contrast avoidance, prevention, and protection strategies & determine which mitigation technique is appropriate for a situation

- Geostatistics: historical statistics on frequency/magnitude
- Geologic Mapping: map materials and properties, hazard mapping
- **Avoidance:** usually too expensive
- **Prevention**
- **Removal of material:** cheaper than avoidance, still typically too expensive. Good for some rockfalls
- **Retaining walls/gabions**: used for undercut slopes, apply resisting forces at bottom
- **Rock bolts/anchors:** used for sliding slopes, placed perpendicular to slope and grounded in solid rock beneath lose material
- **Drainage:** used when theres too much water
- **Vegetation:** planting trees/shrubs to hold slope together with roots
- **Protection:** let landslides occur but control destination
- **Rock nets:** good for small crumbling rocks
- **Rock fences:** catches falling/rolling rocks and dissipates kinetic energy
- **Debris flow retention structures:** removes debris from the water and therefore the ability of material to flow

STORMS

1. Types of lightning and sequence of a lightning strike

Types of Lightning

- **Intracloud:** most common type, only occurs in clouds and never strikes
- **Cloud-ground:** can be negative (more numerous, come from cloud base) or positive (less frequent but stronger, comes from anvil, usual cause of wildfires)
- **Cloud-air:** lightning leaps out of clouds into air
- **Anvil Crawler:** random erratic lightning movement within anvil
- **Bead/chain lighting:** after strike, main lightning channel decays into little dots
- **Ribbon:** parallel successive flashes offset from each other, occurs when strong winds blow the flashing channel through the camera frame

Sequence of Strike

- **Stepped Leader:** happens milliseconds before a strike as thundercloud sends negatively charged streams down to the ground where, if they meet an

upward streamer (positively charged stream coming from ground) a strike occurs

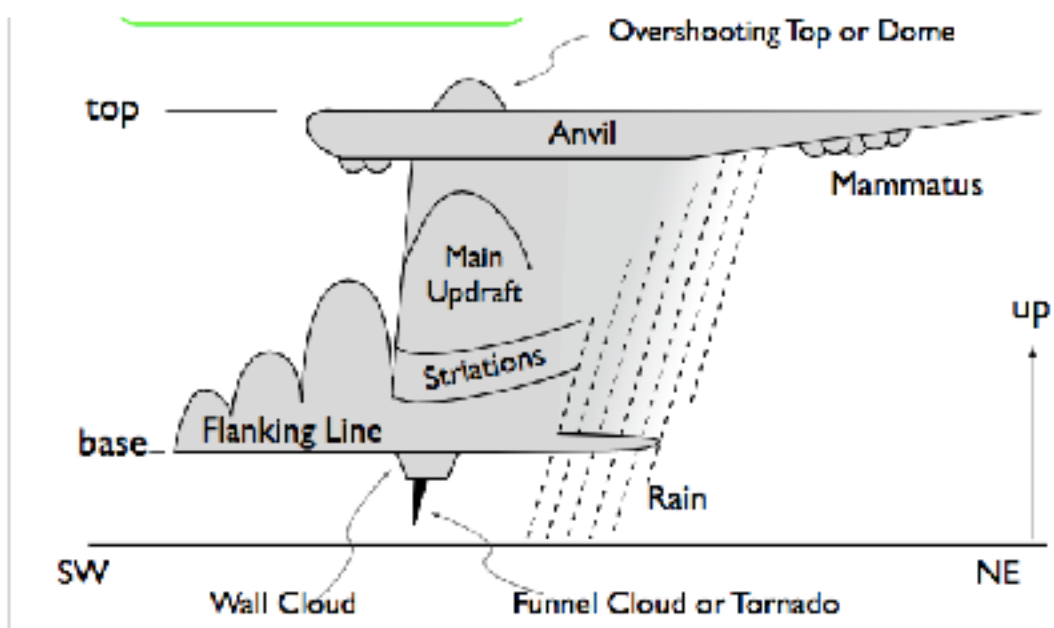
2. Lightning risk in terms of places, people, and safety

- Africa has highest lightning density on earth
- Florida has highest lightning density in NA
- **Direct Hit:** most powerful direct strike of lightning
- **Side Flashes:** lightning curls through tree and strikes out sideways (<2m)
- **Ground Strike**: radial dispersion on ground
- To determine how far lightning is, count number of seconds between when you hear thunder and see the flash, then divide that number by 3 to estimate distance in km of strike

Safety

- If 30 seconds or less between when you see fish and hear bang, move indoors until 30minutes after last lightning or thunder
- Safe places include fully metal vehicles with all windows closed or in a substantial permanent building
- Avoid small structures, nearby metallic objects, open field, and hilltops if stuck outdoors
- If caught in open, do safety crouch with hands over ears and feet together

3. Identify and describe components of thunderstorm clouds and describe nature and evolution of cells within them



- Thunderclouds contain strong updrafts and downdrafts
- Main updraft is the stem of mushroom, overshooting top will occur if updraft strong enough
- Cumulonimbus clouds are made of large cells that evolve during 15-30min
- Most thunderstorms have 2 or more cells and are called **multi-cell thunderstorms**
- **Supercells:** very large, single rotating cell that can cause tornadoes, large hail, lightning, heavy rain, and strong winds
- types include **low precipitation, classic, & high precipitation**

- **Thunderstorm Cell Life Cycle**

- in mature stage, rain begins to fall and creates a downdraft
- Warm air rises and cool air sinks, creating the gust front
- In dissipating stage, downdraft > updraft and cuts it off
- **Ingredients for Thunderstorms**
- moisture
- Instability
- Lift/trigger
- Wind shear (only needed for severe storms)

4. **Relate atmospheric layers to storms**
- Almost all storms occur in the **troposphere**
5. **How solar energy gets into atmosphere and powers storms**
- Solar energy is absorbed at thermosphere, stratopause, and earths surface
- Some solar energy is reflected and some is absorbed
- As the surface warms, it also warms the air and provides fuel for storms
- Warm ground affects **sensible heat** by increasing **temperature**, and **latent heat** by increasing **humidity,** both of which are storm ingredients

Daily Cycle
- solar heating during the day is a heat input like charging a battery
- Infrared cooling occurs during day and night and is a heat loss
- These processes lead to the **greatest accumulation of heat at near sunset**
- **Most likely thunderstorm time:** late afternoon/early evening

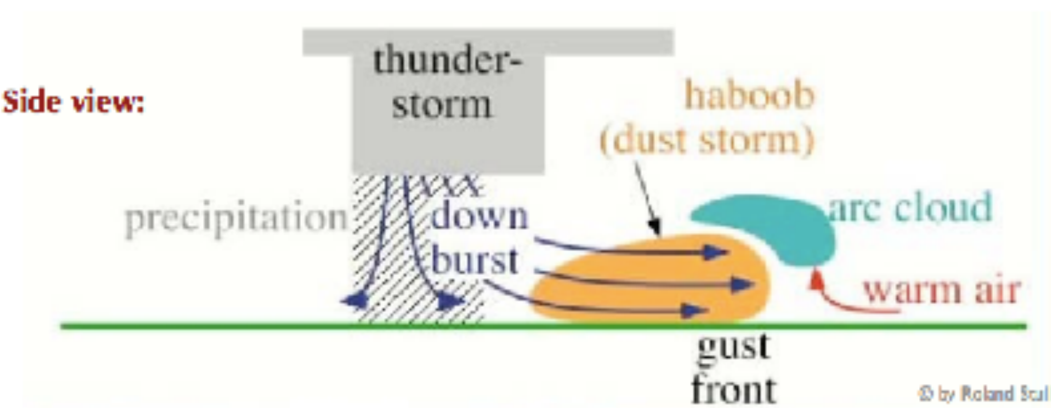
6. **Storm hazards and disaster scales**
- **dBZ:** rainfall intensity scale, measured in decibels from radar

Hazards
- Lightning
- Hail
- Tornado
- Downpours/flash flooding
- Downbursts/gust fronts

7. **Characteristics and hazards of 3 main types of supercell thunderstorms**
- **Low Precipitation:** produces lots of hail
- **Classic:** rainy downdraft & rain-free updraft
- **High Precipitation:** updraft mostly surrounded by rain

8. Weather and satellite to predict and identify storms
- **Radar:** sees precipitation in the storm

9. **Downbursts and gust fronts in terms of their hazards, how they form, and how they look**



- Downdraft speeds of 20-90km/h
- Horizontal ground windspeed up to 250km'h
- **Mesocyclone:** rotating part of severe T-storms
- **Microburst:** small diameter (~1km) downbursts
- **Downbursts:** cold & dense air sinking, created by evaporative cooling as rain falls, pose hazard to aircraft due to invisibility
- **Gust Front:** leading edge of cold, horizontal straight-line winds, created as downburst air hits ground and spreads out in straight lines. Can be visible in the form of **haboobs** (if dry ground), **arc clouds** (if moist air), or **gustnados.** Can blow down trees & small structures, hazard to aircraft during takeoff/landing

10. Humidity, saturation, latent heat, advection, and adiabatic cooling effects on storm energy

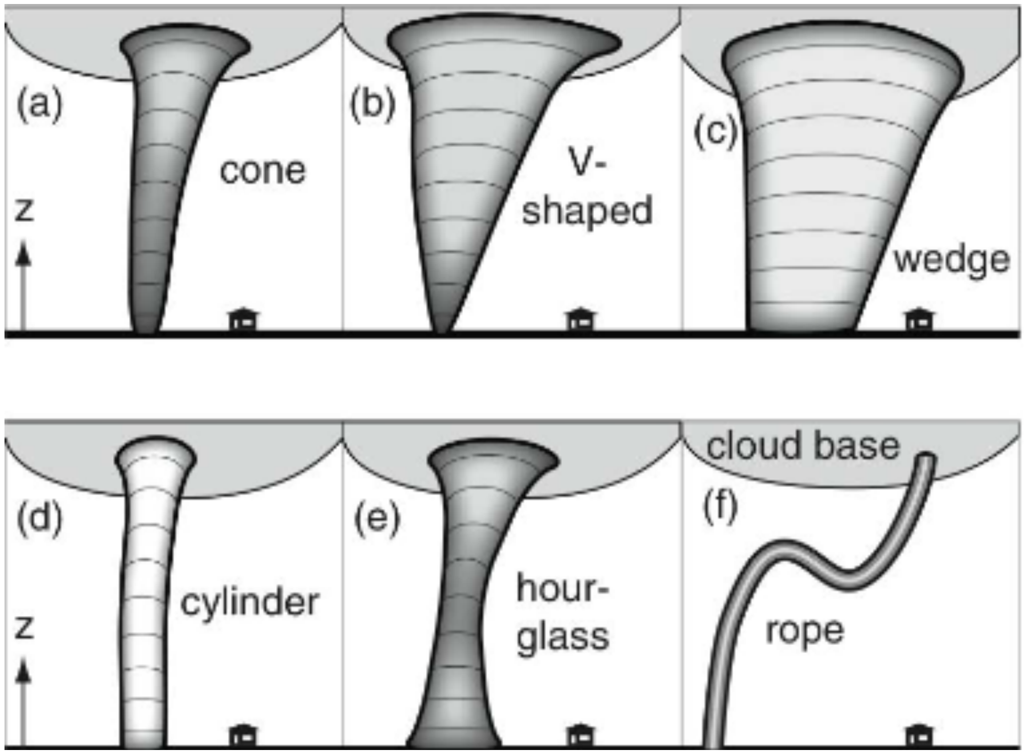
- **Humidity**
- air is a mixture of gases
- Humidity: amount of water vapour in the air
- **Mixing Ratio:** amount of water vapour/all other gases
- Saturation
- equilibrium where evaporation meets condensation
- **Saturation Value:** maximum humidity air can hold
- Saturation mixing ratio increases exponentially with temperature, meaning **warmer air can hold more water vapour at eq than cold air**
- **Adiabatic Cooling**
- as air rises, it cools at **10C/km**
- Occurs because as air cools it can hold less water as vapour, thus some vapour must condense to liquid droplets
- **Latent Heat**
- condensation occurs when saturation humidity value < actual humidity
- Condensation releases stored latent heat into sensible heat, warming storm, reducing humidity down to eq (saturation value), and producing increased liquid cloud drops—rain drops

11. Describe tornado shapes, what makes them visible, and where they form relative to a thunderstorm

- Most violent tornadoes come from supercell thunderstorms
- Most tornadoes are made **visible** by **cloud water droplets** or the **debris cloud.** Some are invisible
- Only 20-30% of supercell thunderstorms produce tornadoes
- In NA, most thunderstorms move from SW-NE

- Tornadoes **attached** to **wall cloud**

Tornado Shapes



- Shape is independent of intensity
- Supercell rotation can be recognized by striations around mesocyclone and a rotating wall cloud
- **Wall Cloud:** isolated lowering of cloud base on SW flank outside of precipitation region, their rotation is where tornadoes come from
- As tornadic thunderstorm approaches, the sequence of events is **anvil, gust front, lightning, downpour, tornado**

12. Enhanced Fujita scale and photo identification

- EF0-EF5, based on damage to buildings caused by rotational winds
- EF1: windows broken, mobile homes overturned/severely damaged
- EF2: roofs torn off, homes shifted off foundation, cars can be tossed
- EF3: trees lose bark, homes w/weak foundations blown away
- EF4: extreme damage, well-constructed homes destroyed, cars blown away
- EF5: massive damage, everything swept super far away, steel-reinforced concrete structures are severely damaged, trees usually completely debarked and stripped of branches

13. Characteristics of tornado evolution, tornado outbreaks, and mesocyclones

- Tornados are usually short lived with narrow damage paths that are rarely more than 1km wide and 100km long
- **Tornado Outbreak:** 6 tornadoes in one day/region or many tornadoes in a week. Occur every year in NA and often associated with squall lines
- Squall Line: line of thunderstorms, often from along cold gust fronts

14. Tornado hazards, safety procedures, locations/times of risk, warnings vs. watches, and safety responses

- If indoors: below ground in a basement/storm cellar
- If outdoors on foot: get into ditch or hole, place body below line of fire
- If in car, do not park under overpass/bridge, drive away perpendicular to storm path
- **Oklahoma** is tornado alley (greatest frequency in NA)
- **S. Tip of Ontario** is greatest tornado frequency in Canada
- Tornado Watch: 6-12 hour forecast, tornado is likely later in day
- Tornado Warning: tornado has occurred and emergency procedures ensue

15. Identify mammatus clouds, haboobs, arc clouds, wall clouds, cloud striations, and flanking lines

- **Mammatus**: cotton ball clouds on underside of anvil that indicate supercell thunderstorms
- **Flanking Lines:** found on west portion of cloud and adds more energy to the storm

16. Forces, acceleration, buoyancy, and PGF relation to winds

Forces

- forces create winds
- If you push on an object with greater force then it accelerates faster in the direction you push it
- **Acceleration:** change of velocity during time interval, where velocity has both speed and direction. Measured in m/s^2
- Combining force and acceleration gives forecast method for determine wind direction, depending on forces acting on air parcel
- **Air Parcel:** hypothetical blob of air about size of city block
- Atmospheric forces include buoyancy and PGF

Buoyancy: vertical, causes up and down drafts

- **warm air rises—updrafts,** and **cold air sinks—downdrafts** because **temperature affects density & density affects buoyancy**

- Buoyancy of air parcel depends on **difference between parcel temperature and temperature of surrounding air**
- Condensation releases latent heat, which warms the thunderstorm air, making it buoyant & rise, leading to violent updrafts

PGF: horizontal or vertical

- temperature alters pressure to drive horizontal winds
- Pressure drives winds
- Difference between opposing pressures is important (tug of war)
- **Pressure Gradient:** pressure difference across a distance

Hurricane Pressure Gradients

- in core of hurricane there are lots of thunderstorms where condensation makes the core warmer and makes the warmer air rise.
- This causes pressure at top of core to be greater than surrounding pressures, leading to horizontal pressure gradient at top of hurricane that creates outward spiralling winds that remove air molecules from the core.
- Fewer molecules in the core causes **lower pressure at the surface** that creates a pressure gradient that sucks in air.
- The air sucked in advects to provide more fuel (humid air), making hurricane stronger

17. How heat released in atmosphere can create vertical and horizontal winds and the continuity effect

- **Continuity Concept**
- air tends to spread evenly
- When buoyant air parcel rises it leaves a partial vacuum that has lower pressure than the surrounding air
- This causes surrounding air to be sucked in
- Air above rising parcel is compressed, has higher pressure, and expands laterally
- Initial vertical motion (due to buoyancy)—horizontal motion in surrounding air—circulation
- **Links vertical & horizontal motions in circulations**

18. Hail hazards, locations/times, and safety procedures

- **Red Deer, Alberta** is highest hail hazard in Canada
- Most common with low precipitation supercell thunderstorms
- Get indoors, park under bridge/roof
- Biggest hazard is to agriculture
- Don’t drive through water of unknown depth

19. Anatomy of a hurricane and how it looks from radar

- Hurricanes are made up of many thunderstorms
- Hurricanes and typhoons are tropical cyclones with winds turning **counterclockwise**
- **Eye:** low pressure at sea level, relatively calm
- **Eye Wall:** ring of thunderstorms

20. How sea surface temperature, winds, waves, condensation, and a warm core relate to hurricanes

- Hurricanes can last for weeks because they manipulate the environment to constantly produce new fuel from the heat stored in the ocean

Fuel-Creation

- low pressure in eye sucks in boundary layer air
- As air approaches air it gets faster and waves get bigger
- This enhances evaporation from ocean surface via the spray from waves, adding moisture to air
- When air finally reaches base of eye wall it is 100% humidity and contains tremendous amounts of sensible and latent-heat fuel
- This method only works if ocean surface temperatures >26C and depth is >60m

21. Evolution and movement of hurricanes and location/time of risk

- Hurricane season in N. Hemisphere is late summer/early fall when waters are warmest and deepest
- Hurricanes form in the **tropics** due to a nonzero **Coriolis effect** and warmest sea temperatures
- Hurricanes can persist if central eye pressure remains low and the hurricane remains over warm ocean, and will decay if they go over cold water or land
- Hurricane paths lead to striking NA at **gulf coast** and **SE Atlantic states**
- Can last for weeks because heavy condensation/precipitation from thunderstorms in eye walls keep core warm relative to its surroundings
- **Warm Core:** creates high pressure at core top and low pressure at core bottom, resulting in vertical circulation with strong updrafts in eye wall thunderstorms and outflow at hurricane top
- **Coriolis Effect:** rotation of earth's poles

22. Main hazards of hurricanes, safety procedures, and forecasting

- **Saffir-Simpson:** hurricane scale that measures wind speed
- **Storm Surges:** strong winds drag ocean water and raise sea level, causing coastal flooding and diseases

- Hurricane prediction is uncertain until it gets close to shore

WAVES

1. Identify key properties of waves

- **Wavelength (L):** crest-crest distance in metres
- **Wave Height (H):** crest-trough vertical distance in metres
- **Amplitude (a):** crest-midpoint vertical distance = H/2
- **Period (T):** time in seconds for two crests to pass a certain point or time for between successive cycles
- **Frequency (f):** number of cycles per one second in Hz
- **Celerity (c):** speed of wave = L/T, wavelength per time period, also known as speed
- **Steepness:** H/L, the shorter the wavelength the greater the steepness

2. How waves move matter and energy

- Waves pass through a medium and transmit energy through them, but the medium itself barely moves

3. Forces that generate and eliminate waves

- Generating Forces: cause disturbance in fluid level/creates crest
  - Wind —wind waves
  - Geologic events (earthquakes, volcanoes, landslides) —tsunami
  - Gravity of Moon/Sun—tides
- Restoring Forces: tries to flatten/balance disturbance but overshoots and creates trough
  - **Surface Tension:** comes from H-bonds in water (for small waves like rippling capillary waves)
  - **Gravity:** weight of water in crest pulls crest back down (for larger waves)

4. Wave classification

- Wind— wind-waves
- Changes in atmospheric pressure/storm surge/tsunami—seiche
- Seafloor faulting/earthquake/volcano—tsunami
- Gravitational attraction/earth rotation—tides
- Surface tension (L <1.7cm)—capillary waves
- Gravity (L>1.7cm)—wind-waves, seiches, tsunamis, tides

5. Wave speed and behaviour in deep and shallow water & as waves shoal

- Water particles move backwards then upwards as trough passes and forward then downwards as crest passes
- This results in orbital motion where energy passes through water but net particle movement is negligible
- In open water, particles move in orbits that decrease with depth
- Particle orbits are largest at surface where orbit diameter = H
- Orbital movements disappear below the **wave base**, or where depth > 1/2L
- **Deep Water Waves:** when water depth > 1/2L, waves don't feel bottom. Speed is determined by wavelength or period only, c = 1.56 x T when units are metres and seconds. Waves with longer wavelengths will be faster than those with shorter wavelengths, and waves tend to travel in groups of similar wavelength
- **Shallow Water Waves:** depth < 1/20L, waves feel bottom and the friction causes orbits to flatten into ellipses. Speed is determined by depth
- As waves approach shore, wavelength decreases, speed decreases, and wave height increases

6. Factors determining roughness of the sea

- **High Wind Speed**
- **Long Fetch:** large uninterrupted distance over which wind blows
- **Sustained Wind:** wind blowing for extended time period
- The stronger the wind, the greater the wave height and the rougher the sea
- **Beaufort Scale:** measures wind speed 1-12, non-logarithmic
- **Maximum Sea State:** every wind speed has a matching practical limit over which time or distance will not produce greater waves, where excess energy into the sea = energy out
- The largest wave heights of wind-driven waves are found around Antarctica

7. Constructive and destructive wave interaction

- When waves collide, height of resulting wave = sum of individual wave heights

8. How rogue waves are generated

- **Rogue Waves:** unusually large waves created by constructive interference, most hazardous to ships at sea but can also hit the coast. Most common around cape of good hope in S. Africa

9. Seiches and natural resonant frequency

- **Seiches:** standing wave oscillating in a closed or semi-enclosed body of water. Properties of standing waves depend on properties of the basin (length, depth, contour). Can be generated by seismic events, meteorological shifts, or tsunamis. Typically have long wavelengths and periods.

- **Natural Resonant Frequency:** period of seiches determined by NRF. When driving forces align with NRF, wave is amplified and can become massive.

10. Describe what a tsunami is and how they are generated

- Tsunamis are rapid displacements of water caused by earthquakes, volcanoes, landslides, icebergs, or meteor impacts

11. How tsunamis differ from wind-driven waves

- Tsunamis have much greater wavelengths (200,000-400,000m), have virtually no wave height or steepness, and travel extremely fast (~720km/h).
- Tsunamis are always shallow water waves

12. Why tsunamis come ashore so violently and how resonance affects them

- Same behaviour as regular wave (H increases & speed decreases) but with far greater speed
- Massive surge of water that can retreat and come back several times causing amplified destruction
- Tsunamis can be exacerbated when they match a multiple of a basins NRF, i.e. Hilo Bay

13. BC coast tsunami risks, warning signs, hazards, and safety procedures

- CSZ poses subduction zone risk
- Tsunami arrival time can be calculated by speed
- Port Alberni greatest risk because of NRF
- **DART:** measures pressure changes on seafloor

Safety Procedures

- Look for animal behaviour, receding water
- Boats out to ocean
- Sturdy upper floors of buildings
- Up and away

14. Determine when a wave will break

- Open ocean waves will break when **H/L >1/7** or 0.14
- Shallow waves will break when **height/depth = ~3/4** or when **H/L > 1/7**, whichever occurs first
- As wave approaches shore, there is a loss of kinetic energy due to friction at the bottom that is converted to potential energy (increased H), potential energy is converted to surf energy

15. Differentiate between breaker types and predict which type will be found on a certain beach

- Slope of ocean floor/surf zone determines type of breakers
- **Spillers:** gentle slope over wide area, gentle waves
- **Plungers:** steep slope, forms pipeline waves that are large and violent
- **Surgers:** very steep slope and very narrow surf zone, waves don't break but surge onto shore

16. Coastline-wave relationship

- Waves refract/bend towards shore when they reach the coast
- Waves converge on headlands and diverge from bays
- **Shore Straightening:** headlands erode and bays fill in
- **Sediment Transport:** caused by waves approaching shore at an angle
- **Longshore Drift:** net movement of sand along shoreline
- **Longshore Current:** moves suspended sand in surf zone

17. Effects of manmade structures on coastal processes and relate these changes to coastal community risks

- Coastline shape is affected by erosion, sediment transport/deposition, storm/hurricane events, uplift and subsidence, and global sea level changes
- **Artificial Structures:** cause unexpected imbalance between sediment erosion and deposition
  - **Groins:** elongated structures installed perpendicular to the shoreline to trap sediments, causes deposition on up current side and erosion on down current side
  - **Jetties:** typically a pair of structures meant to lock an inlet/harbour into place, deposition on up current side and erosion on down current side
  - **Breakwaters:** protect shoreline from wave action and erosion, usually installed at a distance away from coast being protected. Tethered-float breakwaters allow sediment flow and dissipate wave energy
  - **Sea Walls:** reflects wave energy, eventually collapses due to amplified erosion

18. How storm surges are generated, and where in the hurricane they reach their maximum

- Hurricanes and cyclones are found in the N. & S hemispheres respectively
- Hurricanes rotate counterclockwise due to Coriolis effect
- Cyclones rotate clockwise due to Coriolis effect
- **Storm Surges:** caused by low pressure of hurricane pulling up sea level, not an actual wave. Strongest to the right of the eye of hurricanes and to the left of the eye of cyclones. May last a few hours-few days

IMPACTS

1. **Use principles of superposition, lateral continuity, cross-cutting relationships, and original horizontality to determine rock age**

- **Superposition:** in layered strata, whats on top is youngest
- **Lateral Continuity:** if its here, its probably over there too
- **Cross-Cutting:** if it cuts through, its probably younger
- **Original Horizontality:** if its tilted or folded, it was originally flat

2. **Describe faunal succession and the use of fossils in the subdivision of earths history, and the qualities of fossils useful in biostratigraphy**

- **Faunal Succession:** fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances, meaning strata of like age can be dated and correlated by the fossils they contain
- **Fossil Range:** the amount of time a species exists from evolution to extinction
- **Fossil Qualities:** short fossil range, lived in environments where fossilization likely to occur, present in many different environments, and common (i.e. Ammonites)

3. Major subdivisions of geological time scale and appreciate scale between Precambrian and Phanerozoic

- **Precambrian:** 87% of earths history, involves Hadean (4.5-4.0 billion years ago), Archaean (4.0-2.5 billion years ago), and Proterozoic (2.5billion-~550million years ago) eras. From 4.5 billion years ago to 543 million years ago
- **Phanerozoic:** 13% of earths history, involves Paleozoic (543million years ago—251million years ago), Mesozoic (251million years ago—65million years ago), and Cenozoic (6.5million years ago—present) eras
- First life on earth was 4 billion years ago
- Start of photosynthesis was 3.2 billion years ago

4. Explain how continental position is related to species radiation and biodiversity

- Mass extinctions create new opportunities and ecological niches, leading to the radiation of new species
- Towards the end of geological periods, very few new species will evolve
- The more broken up a continent is, the more biodiversity

5. Define characteristics of a mass extinction

- At least ~30% of species lost
- Broad range of ecosystems
- Relatively short duration (1 million year max)

6. 5 big extinctions, when they occurred, and why they occurred

LATE ORDOVICIAN

- 445 million years ago
- Bracketed by Silurian and Cambrian periods
- Caused by global cooling (glaciation), sea-level drop, maybe gamma ray bursts

LATE DEVONIAN

- ~365 million years ago
- Bracketed by Silurian and Carboniferous periods
- Caused by volcanic Siluy trap events

PERMIAN-TRIASSIC

- 250 million years ago
- 95-98% of species went extinct
- Less than 1 million year duration
- Cleared room for dinosaurs
- Separated Mesozoic and Palaeozoic eras
- Bracketed by Jurassic and Carboniferous periods

- Caused by continental configuration (Pangaea) sea level fall, oceanic stagnation (anoxia—polar waters unable to sink—no circulation), possible impacts from extraterrestrial, climate change (volcanic Siberian traps activity leading to high CO2 in atmosphere) & (clastrates: structures containing methane at ocean floor that melted from warming seas)

TRIASSIC-JURASSIC

- 201 million years ago
- Bracketed by Cretaceous and Permian periods
- Caused by central Atlantic magmatic province volcanic event, possible impactor

CRETACEOUS-PALEOGENE

- 66 million years ago
- At least 50% of all species lost, 80-90% of all oceanic species
- Separated Mesozoic and Cenozoic eras
- Caused by Chicxulub impactor and Deccan trap volcanism

7. Distinguish between broad extinction-producing phenomena

- **Biological:** competition, predation, pathogens, biogeology
- **Physical (earth-based):** volcanic events, atmospheric events, changes in climate, sea level, ocean cycles,
- **Extraterrestrial based**
- **Combination of factors**

8. Significance, magnitude, causes and effects of P/T extinction

- Worst day for biosphere as 95-98% of all species extinct
- Caused by continental configuration, sea level fall, anoxia/lack of oceanic circulation, possible extraterrestrial impacts, Siberian traps/CO2, and clastrates/methane
- Led to the evolution of dinosaurs

9. Character, evidence supporting impact theory, location, probable nature, initial/long-term effects, environmental consequences, and other potential causes of the K/G impact

- **EVIDENCE:** impact caused K/Pg extinction, supported by **iridium deposits**, **fern spores, soot layers, tektites common at K/Pg boundary (**natural glass created from impacts), **shocked quartz, tsunami deposits, massive crater**
- **LOCATION:** Gulf of Mexico
- **NATURE:** size of Mt. Everest, concentric ringed structure with central peak

EFFECTS

- **INITIAL:** vaporizes everything close by, global tsunami, global forest fires
- **SHORTER TERM (months)**: nuclear winter, no photosynthesis

- **SHORT TERM (years)**: water vapour remains in atmosphere leading to increased greenhouse effect, limestones vaporized leading to increased CO_2 & temperature,
- **LONGER TERM:** cold house (months)—hot house (years-decades), global volcanic activity increased twofold, nitrogen + oxygen + rain lead to acid rain and oceans/soils are acidified, further sulphates are evaporated also leading to acid rain, base of food chain strongly affected
- **POTENTIAL CAUSES:** formation of Deccan trap flood basalts that caused acid rain, ozone depletion, and climatic greenhouse effects, as well as Pangaea breakup-related environmental degradation

10. Describe type and location of potential impactors and rate of meteoroid influx

- **Asteroids:** very large rocks, come from belts in between Jupiter and mars
- **Meteoroids:** <10m rocks
- **Comets:** rocks mixed with ice and have a tail, come from Oort Cloud
- **Meteoroid Influx:** 100,000 million every 24hours. 10km every 100,000,000 years, 1m diameter every year, 100m diameter every 10,000 years

11. Why impact craters appear to be rare on earth

- 170 large craters have been discovered
- Craters erode over time

12. Raup - Sepkoski hypothesis

- Periodicity of mass extinctions may be related to Oort Cloud
- **Nemesis:** gravitational kicks come from red dwarf, black hole, planet beyond Neptune, and moving through galactic plane
- Potentially dangerous objects every million years

13. List recent impacts, near misses

- Ries crater (germany), 24km diameter
- Manicougan Crater (canada), late triassic, occurred at same time as other craters and lines up with them through latitude
- Tunguska: largest historical impact, no crater because it exploded at 8km in atmosphere
- Near Misses: 1996 would have been size of meteor crater AZ, 2009 DD45 passed earth within 70,000km, comet shoemaker would have wiped out earth but collided in solar system

14. Risk of impacts and effectiveness of mitigation strategies

- **Torino Scale:** assesses risk of near-Earth objects
- **Spaceguard Survey:** tracks potentially disastrous objects

- Impact hazard is unique because it is potentially most devastating, most important factor is time
- **RISK:** 1/20,000, similar to airplane crash

Mitigation Strategies

1. **Fragmentation:** landing on object and drilling into it, risky because of multiple impact risk and difficult prediction
2. **Sudden Orbit Adjustment:** requires warning period, involves exploding nuclear warheads or smashing objects into it
3. **Steady State Orbit Adjustment:** requires warning period but more predictable, use chemical/nuclear/electric propulsion, mass drivers accelerate/excavate materials away from object
4. **Ablation Systems:** irradiate surface with lasers or massive mirror-focused sunlight, requires a satellite orbiting the object
5. **Riding Solar Winds:** install solar sails or coat asteroid with highly reflective material, requires long warning period