ENVS-1000 Exam #2 Study Guide

Climate Change:

Earth, The Sun, & The Seasons:

- Insolation (incoming solar radiation)
  - Insolation ↑ Temp ↑
    - Temperature ↓ altitude ↑ EXCEPT Thermosphere
  - Highest at equator
- Rate of incoming energy outside the atmosphere: ~1360 W m^{-2}
- Seasonal temperature contrasts due to tilt of Earth's axis + angle of Sun's rays (23.5 degrees)
  - + wind cells shift + large bodies of water
- Earth's axis is always tilted in same direction causing distribution of insolation to change with seasons
  - March – equinox – 12hr daylight, 12 hr darkness
  - June – summer solstice – summer in NH (tilt toward sun), winter in SH
  - September – equinox – 12hr daylight, 12 hr darkness
  - December – winter solstice – summer in SH (tilt toward sun), winter in NH

Net Radiation:

- Difference between incoming and outgoing radiation
- High latitudes = energy deficit
- Poleward heat transfer moves surplus energy from low (equator) to high (poles) latitudes
  - Incoming energy gain between tropics + equator
  - Outgoing energy deficit at poles
- Largely due to wind

Ice Albedo Effect:

- **Cold → more snow → more sunlight reflects**
  - **Less heat retained each cycle = colder**
- **30% reflected = albedo**

Earth's Energy Budget:

- Incoming solar energy (100%) →
    - 16% absorbed by atmosphere
    - 3% absorbed by clouds
      - Although atmosphere = atmosphere + clouds
    - 51% absorbed by surface
    - 6% reflected by atmosphere
      - 6% reflected directly into space
    - 20% reflected by clouds
    - 4% reflected by Earth's surface
  - 20% absorbed by air systems
  - 50% absorbed by earth
    - Absorbed ↑ kinetic energy ↑ temp
  - 30% reflected
    - Not immediately lost, stored for period of time

- Radiation of longwave from ground up to clouds/atmosphere and reflection back down

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  - Incoming:

    $100_{in} - (6+20+4)_{refl} - (16+3)_{abs\ by\ atm} - (51)_{abs\ by\ surf} = \textbf{zero}$

  - Energy gained/lost by surface:

    $+51_{input} - 6_{loss} = \mathbf{45}_{\textbf{emit by surf}}$

  - Energy gained/lost by atmosphere:

    $+(16+3)_{input} + 45_{emit\ by\ surf} - 64_{loss} = \textbf{zero}$

  - Overall planetary net radiation:

    $100_{SWin} - 30_{SWrefl} - 64_{LWatm} - 6_{LWsurf} = \textbf{zero}$

  - Emitted by surface = moved away from the surface
  - 64% lost to space
- Energy received = Energy reemitted
  - Eventually, all of the energy that reaches the Earth's surface is reflected back

Greenhouse Effect:

- Greenhouse effect: barrier causes inflow of energy that outpaces the outflow → interior warms
- Warming effect due to atmospheric GHGs preventing heat emitted from surface from escaping into space
- Water vapor (most abundant), carbon dioxide (most abundant anthropogenic GHG), methane, and nitrous oxide (greatest effect on global warming in future)
- Absorb longwave radiation and reradiate it to surface (counter radiation)

How Do We Measure Global Climate?

- Weather stations recording temperature since 1714
- Instrumental period (1860) = current era, access to temperature readings taken directly with thermometers
- Satellites (1979) measure temperature from space using IR
- Comparing temperatures to fixed base period shows climate changing over time

Proxies:

- Collecting proxy data provides climate change information from ancient climates (paleoclimates) – less precise b/c uncertainty in relation btw proxy and climate
- Proxy: observable + measurable phenomenon, indirect indicator climate change
  - Must overlap with modern instruments to provide calibration
  - Proxy – measurement that stands in for paleoclimate variable when we can't measure it directly because it pre-dates the instrument record. An example is tree rings

    - Archive – material in which the proxy is preserved, not the proxy itself. An example of this is the tree.
- Ratios of heavier to lighter oxygen in air bubbles in ice cores from glaciers tells us how cool past temperatures were
- Heavier oxygen isotopes (^{18}O) condense faster than lighter oxygen isotopes (^{16}O). In colder temperatures, heavier isotope is depleted from air quicker
    - Less ^{18}O = cooler temp

Past Climate Change:

- 1,000 years
    - Medieval warm period: 1000-1300 AD
    - Little ice age: 1400-1800 AD
- Global climate changes naturally, happens over long time scales
- Fossil evidence = polar regions forested during Cretaceous Period
- Glacial sediments near equator suggest Earth was ice during "snowball Earth"

What Caused Climate Change in the Past?

- Climate changes throughout Earth's history can be attributed to variations in:
    - 1) Positions of continents
        - Relative to equator affects amount of solar radiation received
        - Movement of continents influences ocean currents (global heat)
        - Colliding land masses → hills + mountains → affect climate (by ↑ land surface area exposure to acid in rain, created when CO_2 dissolves in water droplets
    - 2) Atmospheric composition
        - Life forms change composition of atmosphere by adding/using CO_2
        - Hot/humid conditions promote swamps + marshes → remove CO_2 from atmosphere
    - 3) Composition of the biosphere (evolution of life)
    - 4) Earth's orbit (Milankovitch cycles)
        - MC: Variations in Earth's orbit that serve as "pacemaker" of glacial-interglacial cycles
            - a) Eccentricity of Orbit: Changes occur over 100,000-year cycle – more elliptical
            - b) Obliquity/tilt of axis: Changes occur over 41,000-year cycle
            - c) Precession: (wobble around axis of rotation) changes occur over 26,000-year cycle – THIS WAS CORRECT
        - Factor for continental glaciation = amnt of summertime insolation at high latitudes (↓ insolation → ↓ melting → ↑ glacier growth)
    - 5) Volcanic eruptions + asteroid strikes
        - 1883 eruption of Krakatoa, reduced sunlight reaching Earth + cooled ave global temperature by 1.2°C
        - Permian-Triassic extinction → volcanic activity in Siberia

AQI Calculations:

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C - C_{low}) + I_{low}$$

- I = the resulting index value,
  C = the pollutant concentration,
  C_{low} = the concentration breakpoint below C,
  C_{high} = the concentration breakpoint above C,
  I_{low} = the index breakpoint corresponding to C_{low}
  I_{high} = the index breakpoint corresponding to C_{high}
    - ALWAYS round AQI up to the nearest whole number
    - AQI is in PPB
    - Publish higher AQI

Ocean Influence

- Surface currents: ocean currents affecting top 400m of water – start from air blowing across surface
    - Distribute heat around planet – moderates global climate by transporting warm water from equator to poles + cold water from poles to equator
- Gyres: large circular ocean currents
- Coriolis effect: force driven by Earth's rotation that deflects objects, winds, and currents on surface of Earth + in ocean or atmosphere

Ocean Currents

- Deep currents: flow of water below surface caused by variations
- in density, temperature, and salinity.
- Salinity: concentration of salt in water (ppt)
- Both contribute to thermohaline conveyor: large-scale ocean circulation driven by ocean currents + changes in water temperature and salinity (density)
    - Halocline - zone of large salinity change
    - Thermocline - zone of large temp change

Countercurrents + El Nino

- Countercurrents: changes in normal ocean currents + cause weather change
- El Nino (ENSO): Countercurrent that weakens/shifts direction of trade winds + ocean currents → upwelling currents (cold water rises)

What's Happening With Our Climate Now?

- Indicators of global warming:
    - ↓ snow cover, ↓ arctic sea ice, ↓ glacier mass, ↑ air temp over land, ↑ humidity, ↑ temp of lower atmosphere, ↑ ocean heat, ↑ sea surface temp
- Earth's climate is currently in a period of global warming
    - Warming attributed to ↑ atmospheric GHG

Concentration of Atmospheric Carbon Dioxide (GHG) Is Increasing:

- Natural processes like photosynthesis and cellular respiration maintain balance by cycling CO_2 between living organisms and the atmosphere
- CO_2 absorbed + released from oceans
- Natural atmospheric life of CO_2 ranges from 50–200 years
- Volcanoes increase CO_2 in atmosphere faster than other processes remove it

- CO2 DOES NOT CONTRIBUTE TO DECREASED AIR QUALITY

Concentration of Other Greenhouse Gasses Are Also Increasing:

- Methane
  - Up 250% since industrial revolution
  - Released from coal mines, natural gas leaks, rice farming, livestock production, and landfills
- Nitrous Oxides
  - Up 20% since industrial revolution
  - Released from processes that produce nylon and from fossil fuel combustion
- Halocarbons
  - Synthesized for use as aerosol spray, refrigerants, solvents, and fire retardants

How Much Do Human-Caused GHG Emissions Affect Climate?

- Current atmospheric CO_2 = 420 ppm highest since before human evolution
- Coal is the biggest producer of fossil CO_2 emissions globally
- Carbon-containing materials have different relative amounts of "light" ^{12}C, "heavy" ^{13}C, and radioactive ^{14}C
  - **Plant matter = ^{12}C** used during photosynthesis b/c lighter weight
  - **Volcanic emissions = ^{13}C**
  - **Since ^{14}C is radioactive, it decays**: young organic matter has more ^{14}C than older organic matter, fossil fuels have no ^{14}C
    - Amount of ^{14}C in atmospheric CO_2 has declined
- Over past 50 years, **troposphere = warming + stratosphere = cooling**
  - If planet was warming due to increasing solar radiation, stratosphere would also be warming
- Hindcasting: computer simulations in support of real-world observations; results show humans are driving global warming
- Anthropogenic cause of current global climate change is supported by:
  - Carbon isotopes, quantification of fossil fuel emissions, computer simulation models

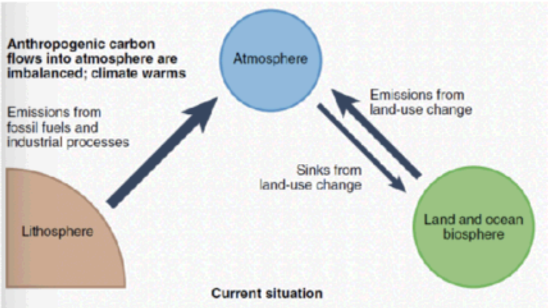
What Are Some Effects of Climate Change?

- 1) Precipitation & The Water Cycle:
  - Changes in precipitation patterns, frequency + intensity of weather events
  - Increase in heavy downpours in US over past 3-5 decades
  - Weather = MORE variable + LESS predictable
  - Southwest and West = increased droughts: prolonged periods of low precipitation + high evaporation → affect agricultural yields + wildfires
  - Increased heat waves
  - East + Midwest will have more rain, SW + Texas will suffer drought
- 2) Hurricanes & Severe Weather:
  - Increase in hurricane intensity will continue, especially in Atlantic Ocean
  - Warming oceans evaporate MORE water + INCREASE amount of energy feeding tropical storm systems that become hurricanes
  - Thunderstorms, tornadoes, + winter storms influenced by climate change
- 3) Sea-Level Rise:

- Global sea levels have risen over 9 inches since late 19th century
  - Due to <u>thermal expansion</u> + <u>melting ice</u> from land and glaciers
    - Thermal expansion contributed to 40% of sea level rise since 1980, remainder due to melting ice from land
- Storm-surge effects are increased within low-lying coastal areas

- <u>4) Ecosystem Effects:</u>
  - Animals incl polar bears depend on sea ice to live
  - INCREASING CO_2 resulted in <u>ocean acidification</u> – DECREASE in pH caused by absorption of CO_2
    - Decrease in pH = 30% increase in acidity + **interferes w/ calcium carbonate shell formation**, base of marine food chain
  - Global warming altering seasonal behavior + geographic range of species
  - <u>Phenology</u>: **seasonal timing of biological activities**, such as breeding, flowering, and migration of various species
    - Affected by climate change – species migrating poleward + breeding earlier
  - <u>Ranges</u> of midlatitude species moving towards poles + to higher/cooler elevations

What About The Future?

- Computer simulation models to forecast:
  - 1) Future economic activity, energy sources, population growth, land-use patterns, + other human factors = estimates for emissions until 2100
  - 2) <u>General Circulation Models (GCMs)</u> use mathematical equations to simulate as many physical/chemical processes in atmosphere as possible
  - 3) Which emissions scenarios needed to achieve climate goals
- From emissions reduction perspective, data are not promising → interest in "negative emissions" and "net zero"
  - 

- <u>Mitigation</u>: **direct actions taken to reduce threat posed by carbon emissions**
- Must avoid emitting ~200 billion tons (Pg) of carbon over next 50 years
- By being more efficient in energy use, emissions could be reduced by 16 Pg
- <u>Four Areas:</u>
  - 1) Transport Efficiency (more efficient planes/cars)

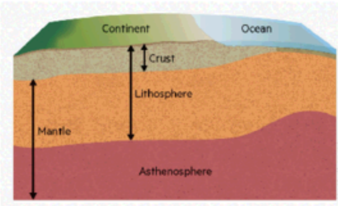
    - 2) Transport Conservation (public transportation)
    - 3) Building Efficiency (heating/cooling)
    - 4) Efficiency in Electricity Production (switch to renewable resources)
- Even if GHG concentrations remained at current levels (ie, emissions cut to zero), warming would NOT reverse
- Concept referred to as committed warming, requires adaptation in agriculture, water management, coastal management, industry, public health

Land:

How Do Mountains Rise & Animals Find Their Way Home?

- How Do We Know Earth's Internal Structure?
    - Direct Evidence:
        - What volcanoes bring up from inside Earth
        - Drilled boreholes and mines
            - "Project Mohole," drilled 600 feet into ocean floor
            - "Kola Superdeep Borehole," drilled 10,000 feet deeper than Mt. Everest rises above sea level
            - One-third of way through Earth's thin outermost layer
    - Indirect Evidence:
        - Infer interior composition from calculations of Earth's density
        - Use energy from earthquakes to construct images of Earth's interior

Earth's Internal Structure:

- Core: iron and nickel metals, solid inner core surrounded by liquid outer core
    - As Earth rotates, liquid outer core generates a magnetic field
        - Aids migration of many animals
        - Establishes magnetosphere: area of space around Earth that shields planet from highly charged particles emitted from Sun
- Mantle: section around Earth's core
    - 84% of Earth's volume
    - Source of volcanic magma
- Crust: Overlays mantle, less dense + more brittle outermost layer, creates the solid surface on which we live
    - Continental vs. Oceanic crust
        - Based on density and chemistry, Oceanic crust is denser
- Earth's layers described by which portions break or bend versus flow
    - 

    - Lithosphere: rigid outer portion of Earth that extends down to roughly 60–90 miles (100–150 km) – **consists of crust and very top of mantle**

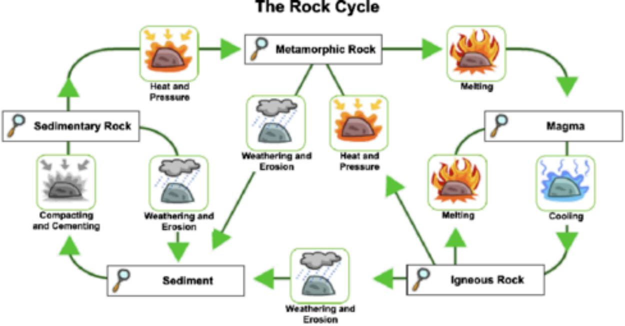
    - Asthenosphere: Earth's mantle, relatively pliable + below rigid lithosphere

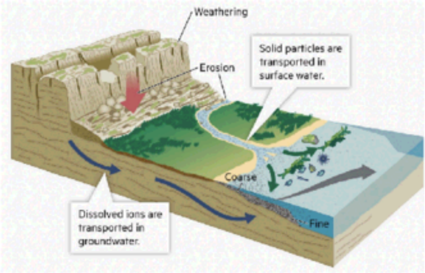
Plate Tectonics:

- Alfred Wegener proposed in 1915 that continents slowly wandered the globe
- Evidence found during the mid 20th century that supported continental drift:
    - Seafloor topography
    - Age of seafloor
    - Distributions of heat flow, volcanoes & earthquakes
    - Paleomagnetism
- Gave rise to theory of plate tectonics – generate minerals resources
    - Divergent
        - Called constructive because new crust is being made
        - Two plates are moving apart. Magma rises to surface + fills gap between the plates. When the magma cools, it forms new crust.
        - In oceans, mid-ocean ridges
    - Convergent – crust is recycled
        - Ocean – Oceanic OR Oceanic – Continental
            - Destructive boundaries, crust is destroyed when it sinks down into mantle
            - Two plates move toward each other. Crust that is more dense will be subducted (drawn under) the plate that is less dense. Oceanic crust always sink under continental crust
            - Volcanoes form at spot where plate that is subducted melts. Volcanoes form at edge of continent (oceanic - continental) OR as a chain in ocean (oceanic - oceanic)
            - OO: The Marianas Trench formed when the Pacific Plate subducted beneath the Philippine Plate
            - OC: Andes Mountains in South America where the Nazca Plate subducts under the South American Plate
        - Continental – Continental
            - Collision boundaries, two plates crash into each other
            - Two continental plates move toward each other, crust between them piles up instead of sinking.
            - High, "folded" mountains form from rock and seabed that is squeezed between the two plates.
            - CC: The Himalayas: Formed by the collision of the India Plate with the Eurasian Plate
    - Transform
        - Conservative boundary, crust is not made or destroyed
        - Plates slide by each other, side-by-side
        - Earthquakes happen when plates get stuck, then break free
        - NO VOLCANOES
        - The Alpine fault in New Zealand

How Does Earth Recycle & Renew Its Surface?

- Plate tectonics → rock cycle: process by which Earth recycles + renews surface



- Rock cycle provides explanations for:
    - Earth's major surface processes
    - Geologic distribution of earthquakes, volcanoes, and mountains
    - Distribution of ancient organisms and mineral deposits
- Erosion: Natural forces such as wind, water, ice, and gravity pick up and move weathered rock particles
- Sediment: Eroded material that gets transported + accumulated elsewhere
- As material erodes, it deposits + accumulates at the foot of mountains, on plains where rivers have flooded, at mouths of rivers and streams, or around reefs
    - 

        - Dissolved ions are transported in groundwater where compaction + cementation occur due to the weight of overlying materials

Why Are Minerals Important & How Do We Get Them?

- Geological processes influence distribution of rocks and minerals in lithosphere
- Rock: Solid aggregation of minerals
- Mineral: Naturally occurring solids from Earth's crust that form rocks + provide materials for products, such as electronics, cell phones, & solar panels
    - Metals:
        - Iron, aluminum, manganese, chopper + chromium, nickel
    - Gemstones + precious metals
    - Sand + gravel

        - Greatest volume and dollar value
        - Brick and concrete construction, paving, sandblasting
        - Glass production
- Child born in 2015 will use >1.4 million kg of minerals during lifetime (fossil fuels + construction material)
- Mining: removal of rock, soil, etc – extracting minerals of economic interest
- Most metals found in ore: mineral/group of minerals from which we extract metals
    - Small proportion of rock, so large amounts of material removed to obtain
        - Mining disturbs large areas of land + severe environmental impacts
- Processing methods very water and energy-intensive
    - Smelting: Heating ore beyond melting point + combining w/ chemicals to extract metal
    - Chemical reactions and heating emit air pollution
    - Tailings (portions of ore left over after extraction) pollutes surrounding area
- Aim of reclamation = restore site to a condition similar to condition before mining
    - Removing buildings and other mining structures
    - Replacing overburden
    - Filling in mine shafts
    - Replanting vegetation
- 1977 Surface Mining Control and Reclamation Act requires U.S. companies to cover costs of mining reclamation before permits are approved
- Magnetic and luminescent properties of rare earth elements (REE) make them essential components of digital and low carbon technologies
- Crustal abundance of light REE same as copper; less abundant heavy REE more abundant than gold
    - China controls Neodymium's global supply

How Do Humans Use The Earth's Surface?

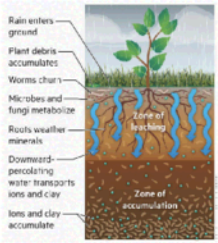
- Land Cover: Physical or biotic nature of a site (e.g., forest, grassland)
- Land Use: Way humans use land
- 50% of Earth's ice-free land surface = transformed, managed or used by humans
- 40% of potential terrestrial plant growth (NPP) of Earth used or dominated by humans, or foregone as a result of land use change
- Grassland, timber production, cropland, recreational/wildlife lands

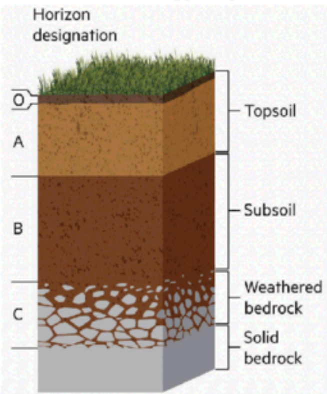
Public lands in the U.S.:

- Of the US's land, 42% is publicly held
- Federal government = largest landowner in U.S., 240 million hectares (25%)
- Government has adopted principle of multiple use in managing public land
- Most of the forested land in the western United States is on public land.

What is Soil, and Where Does it Come From?

- Soil: mixture of weathered rock, mineral particles (sediment), dead/decaying plant + animal matter, and organisms that live within these materials
    - Made by processes at Earth's surface (lithosphere, atmosphere, hydrosphere + biosphere interact) breaking down *parent material* to particles
    - Air spaces around particles (pores) allow water to move into soil via infiltration

- Larger spaces of air promote aeration
- Smaller particles like clay pack together + influence infiltration + nutrient retention
- Mixtures of various particle sizes, types of parent material, soil organisms, and organic matter all determine a soil's structure and texture
- 

- Soil horizons: living (biotic) and nonliving (abiotic) factors in soil creating layers
- Soil profile: collection of soil horizons at a location, is a cutaway view of soil and is composed of up to four major horizons: O, A, B, and C
  - Profiles are typically less than 3 feet deep
- 

  - Topsoil: uppermost 2–6 inches of soil, contains O and A horizons, complex mixture of materials that include organic matter derived from living things
  - B horizon is subsoil composed of mineral matter
    - Clay minerals, iron, aluminum
  - C horizon is composed of weathered parent material + solid (bedrock)

What Makes Soil Alive?

- Soil rich w/ life, supporting animals, microorganisms, insects, and worms
- Earthworms pull material from surface as they burrow up and down through soil + digest/mix soil and organic material → rich excrement known as castings

Soil Organic Matter:

- Complex organic compounds are broken down, resulting in soil organic matter called <u>humus:</u> complex, dark, sticky organic material, stable over time
    - Humus allows soil to feed and reproduce – the "life-force" of the soil
- Carbon in soil organic matter is a sink for atmospheric carbon
- More C in soil than atmosphere and biosphere combined

Factors Affecting Soil Formation & Soil Classification:

- Soil forming factors:
    - Parent material, climate, vegetation, time, relief
- Soil forming processes:
    - Infiltration of water, minerals form + dissolve by weathering, accumulation of organic matter, soil erosion
- Soil properties:
    - Horizons, soil composition & fertility, thickness → soil maturity
- Climate soil (rain increases)
    - Desert soil – humus + minerals, no O
    - Temperate soil – deep A horizon rich in humus
    - Tropical soil – thin topsoil (O)
- Soil classification
    - Pedocal – drier, temperate areas (Middle West)
    - Pedalfer – humid areas, deciduous forests (E, West Coast))
    - Laterite – high temp + moisture, chemical weathering (West)
- Thousands of soil types on Earth, characteristics exert influence on community of life that survives above it
- Scientists developed <u>soil orders</u>: general classification of soil type based on distinct physical, chemical, and environmental characteristics
    - Highest level in the taxonomic organization of soils

Soils & Plant Growth:

- <u>CLORPT:</u> **Cl**imate, **O**rganisms, **R**elief, **P**arent Material, **T**ime
    - Key factors shaping the characteristics of soil
    - Climate – Warm, wet climates form soils more quickly than cold, dry climates
    - Organisms – Vegetation affects weathering and organic matter accumulation
    - Relief/Topography – Slope position affects erosion/sedimentation and water dynamics
    - Parent Material – The original rock that soil is formed from
    - Time – The duration that has along soil forming processes to occur and transform parent materials into soil
- Successful plant growth = balance btw water, pore space, nutrients, + root space
- <u>Tilth:</u> structure and conditions that facilitate plant growth
- When topsoil forms faster than it erodes, it thickens + supports more plant growth, when erosion thins soil = opposite
- Plants consume water by <u>transpiration</u>
- Growth can be inhibited by <u>salinization</u>, when salts build up
- Water can carry nutrients away from plants through <u>leaching</u>: mineral elements moved to deeper soil layers, beyond reach of roots, carried away in groundwater

  - Large amounts of precipitation that moves nutrients downward in the topsoil, potentially below the reach of plant roots

Land Capability Classification:

- System of grouping soils on basis of capability to produce common cultivated crops + pasture plants without deteriorating over long period of time
  - Class Codes: I (1), II (2), III (3), IV (4), V (5), VI(6), VII (7), and VIII (8)
  - Subclass Codes: e, w, s, and c
    - Subclass represents dominant limitation that determines the capability class: erosion, excess water, root zone limitation, climate

How Can Humans Repair & Sustain The Land?

- Human actions degrade land – erosion occurs as side effect of farming practices
- Degraded landscapes can be rehabilitated or restored after human use
- **Ways To Repair & Sustain The Land:**
  - 1) Agriculture & Grazing
    - Farming practices accelerate soil erosion and degrade soil fertility
    - Tillage: preparing soil for planting by breaking it up + turning it over = weed control, but exposes soil to wind and water erosion
    - Overuse of pesticides, overirrigation, + overgrazing damage land
    - Terracing, no-till agriculture (increasing slightly), cover crops, windbreaks + hedgerows
  - 2) Mining
    - Abandoned mine sites can be reclaimed + rehabilitated
      - Import topsoil, planting trees, + sustainable livestock grazing
  - 3) Forestry
    - Deforestation global annual rate of 13 million hectares per year due to logging or burning
      - Removes primary source of organic material + soil-binding ability of tree roots
    - Tree harvesting from steep slopes leaves land susceptible to landslides following rain events
    - Sustainable forest management

Food:

How Did Our Modern Agriculture Develop?

- Agriculture: System of land management used to grow plants and animals for food, fiber, or energy
  - Began as hunter-gatherers
  - 10,000 years ago humans began purposefully growing food
  - Adaptation led to domestication
    - Herding animals
    - Tuber-producing plants
- Domesticated varieties of many crops: wheat, corn, bananas
- Domestication of animals began w/ dogs for hunting, then cattle, chicken, and pigs for consumption

- ~6,000 Years Ago: canals + dams along rivers to irrigate crops + organic matter (decaying plant and animal matter) as fertilizer
- ~2,000 Years Ago: rotating crops btw fields + allowing fields to remain unplanted (fallow) helped restore soils
    - Does not decrease soil erosion and land degradation?
- NA enriched soil w/ fish + companion planting
- Companion planting: growing multiple crops in close proximity to facilitate nutrient uptake, pollination, and pest control
- Agricultural Revolution: Increase in agricultural production mid-17th/late 19th C
    - New agricultural practices such as crop rotation, selective breeding, and a more productive use of arable land
- Columbian exchange brought new foodstuffs from Americas to Eurasia (potato)
- Integration of machines since Industrial Revolution = farming less labor-intensive

Modern Agricultural Practices – The Green Revolution:

- New technologies in twentieth century led to the Green Revolution
    - Pesticides, crop breeding, irrigation, synthetic fertilizers
- After 1960, tripling average grain yields only took 40 years
- **Green Revolution – Genetic manipulation:**
    - Plant geneticists cross-bred crops to create varieties that thrive with intensive irrigation + fertilization while resisting common diseases
    - Genetic engineering developed in 1970s → GMOs
- **Green Revolution – Gasoline or Diesel Powered Farm Equipment:**
    - Replaced human + animal powered tools, reduced time/effort
    - Less employees needed but increased use of fossil fuels
- **Green Revolution – Modern Irrigation:**
    - Large-scale dams and reservoirs, electric aquifer pumps, long-distance canals and pipelines, and automated sprinkler systems
- **Green Revolution – Synthetic Pesticides:**
    - Use of synthetic pesticides has also increased globally
    - Synthetic pesticides: chemicals applied to combat insects and weeds
    - Found to harm pollinators. Top food crops rely on pollinators

Agroecosystems:

- Nitrogen
    - Cycles rapidly between atmosphere and biosphere
    - Plants modify to create essential compounds
        - Amino acids
        - Nucleic acids
    - Nitrogen enters biosphere by nitrogen fixation
        - Bacteria convert N2 to NH3 and then other molecules
        - Small amount by lightning
    - Soil bacteria carry out nitrification
        - Makes nitrogen available to other organisms
    - Denitrification
        - Bacteria transform nitrates to N2 gas

    - Humans: NOx emissions from fossil fuel combustion + N fixation through fertilized production
- Phosphorous
    - Organisms use phosphorus as phosphate (PO4)
    - Must be weathered out of rock (mainly sedimentary)
    - Limiting factor in marine production
    - Humans: mining
- Human impacts
    - Haber–Bosch process (non-biological N fixation)
    - Apatite mining
    - Increased N and P production advanced agricultural production, but…
        - Fossil fuel costs of production
        - Excess N and P often act as pollutants

How Does Modern Agriculture Impact The Environment?

- Agrobiodiversity: Variety + variability of genetic material in lifeforms used by humans for food and other agricultural applications
    - Green Revolution selected crop varieties for production over others → reduced agrobiodiversity
- Loss of crop varieties leads to genetic erosion
    - Resultant crop or livestock monoculture temporarily have higher yields but are more vulnerable to pests and diseases
- In 1940s, synthetic fertilizers + monocultures = agricultural pest infestations
    - Use of pesticides caused toxic bioaccumulation in species above insects in the food chain
- Overuse of pesticides creates chemical resistance and poses risks for humans
- "Roundup-ready" crops: GMOs that allow broadfield spraying to control weeds without affecting crops
- European regulations: new products show they are safe prior to use. United States: new products are safe until shown not to be
- GMOs are creating resistant weeds and insects through natural selection
- When land is intensely cultivated, large areas of bare soil are vulnerable to erosion, where water and wind redistribute soil particles across landscape
- Irrigation systems speed up erosion when application rates exceed abilities of cultivated soil to absorb water
- Intensive irrigation speeds up leaching and salinization
- Agriculture draws on most water resources and uses two-thirds of all freshwater
- Due to drilling and pumping, groundwater supplies 40% of irrigation water
- As an aquifer dries up, subsidence may occur where formerly water-filled places collapse under weight of overlying rock and soil

How Is Meat Production Changing What We Consume?

- Farmers = more specialized and industrialized, crop/animal agriculture decoupled
- Farms use synthetic fertilizers and predominantly raise livestock in Concentrated Animal Feeding Operations (CAFOs)

- CAFOs began with chicken production, where industry bred chickens called "broilers" for meat production
- Broilers enhanced w/ animal protein, amino acids, vitamins, and minerals
- Crowded conditions in CAFOs led antibiotics to prevent diseases and artificial light to stimulate growth
- Results are bigger broilers with less feed and fewer deaths pre-slaughter

- Smithfield Foods propagated a genetic line of pigs on thousands of farms to standardize production
- Producers started designing slaughter/butcher machinery to fit characteristics of developed breeds
- In feedlots calves receive corn-based feed enhanced with soybeans, fats and proteins, vitamins, synthetic estrogen, antibiotics, and roughage
- Growth promoters added to feed to boost muscle growth in the final 3 weeks before slaughter to add 30 pounds of meat
- Cows are <u>ruminants</u>: digestive system that turns plant-based cellulose into protein by fermenting food in different digestive compartments

Catching & Raising Seafood:

- Sonar, GPS, 3-D mapping, and helicopter technologies have enhanced abilities to find and catch large quantities of fish
- Since 1950, global annual oceanic fish catch has quintupled
- Seafood also raised in high concentrations in controlled ponds, tanks, or pens in a practice called <u>commercial aquaculture</u>
    - Fastest growing form of food production, more 1/2 half of US seafood

Is Conventional Meat Production Sustainable?

- CAFOs produce lots of manure each year
- CAFO waste runoff pollutes groundwater, spreading pathogens incl Salmonella
- Organic dust from CAFO feed, bedding, pesticides, waste, dander, and livestock methane cause air pollution
- Antibiotics added to cattle feed in CAFOs caused bacteria to develop resistance
    - Reason many bacteria are now resistant to penicillin and tetracycline
- <u>Overfishing</u>: quantity of fish caught exceeds productive capacity of a species, causes population decline and even collapse
- <u>Bycatch</u>: non-food species are incidentally captured in fishing nets and lines, killing millions of tons of sea turtles, seabirds, marine mammals, and fish
- Aquaculture avoids overfishing + bycatch, weakens genetic traits of wild fish + spreads diseases

How Have Our Food Systems Changed?

- <u>Food system</u>: web of processes merging agricultural production to consumption
- <u>Food security</u>: physical and economic access to nutritious food to maintain dietary needs and food preferences for an active and healthy life

Production:

- Increasing Scale and Shrinking Diversity:
    - Varieties of cultivated food crops declined, more than ½ variety extinct

    - Types of crops we consume has decreased, with ~60% of human plant calories derived from only three crops—rice, maize, and wheat
    - More than ½ food production in US from 10 states in Midwest + California, production of foods (particularly meats) concentrated in monopoly

Consumption:

- Increasing Role of Meat & Processed Foods:
    - Global meat consumption increased
    - Processed foods are produced to optimize ease of preparation, consumption, and storage – remove fiber but add sweeteners, salt, fats, colors, artificial flavors, and preservatives
- Overnourishment & Obesity:
    - Overnourishment: energy use does not match food energy consumed, leads to obesity: overweight due to excessive fat accumulation
    - Linked to diabetes, heart disease, and respiratory problems – primary killers in the developed world
- Shifting Food Culture:
    - Sweet and fatty foods are cheaper + readily available for consumption
    - Supermarkets, with lower-priced processed foods, increased in numbers while public markets with a direct producer-consumer connection declined

Food For The Future – Challenge:

- Food needs to be farmed, harvested or caught, transported, processed, packaged, distributed and cooked, and the residuals disposed of
- Global population will continue to grow
- Increased wealth comes with higher consumption and greater demand for processed food, meat, dairy and fish
- Production needs to double to keep pace with projected demands from population growth, dietary changes, and increasing bioenergy use
- Solution to past food shortages = use more land in agriculture + exploit fish stock
- Croplands cover 12% of Earth's land, pastures cover 26% of Earth's land
- World's croplands + pastures expanding in tropics + limited change in temperates
- 75% of those suffering from hunger live and work in farming communities
- Food systems are responsible for **a third of global anthropogenic GHG**s
- Agriculture must also address tremendous environmental concerns
- Threefold challenge:
    - Match demand for food from larger + affluent populations to its supply
    - Do so in ways that are environmentally and socially sustainable
    - Ensure the world's poorest people are no longer hungry

Food For The Future – Solutions:

- National Geographic: Feeding 9 Billion
    - Freeze Agriculture's Footprint, Grow More on Farms We've Got, Use Resources More Efficiently, Shift Diets, Reduce Waste
- Sustainable Agriculture Is:
    - Farming in sustainable ways meeting society's food + textile needs, w/o compromising ability for current or future generations to meet needs

    - Farming to protect the environment, aid and expand natural resources, and to make the best use of nonrenewable resources
- U.S. Code Title 7, Section 3103: Sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will over the long-term:
    - 1) Satisfy human food and fiber needs
    - 2) Enhance environmental quality + natural resource base upon which agriculture economy depends
    - 3) Make efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls
    - 4) Sustain the economic viability of farm operations
    - 5) Enhance the quality of life for farmers and society as a whole
- **<u>Solutions – Eating Lower On The Food Chain:</u>**
    - In a food chain/web, energy is lost as it is transferred btw trophic levels
    - Eat lower on the food chain = less energy is lost
    - Producing animal-based foods uses more water + causes more GHG emissions, especially CAFO-produced meat
- **<u>Solutions – Reducing Food Waste:</u>**
    - <u>Wasted food</u>: food not used for its intended purpose + managed in a variety of ways (donation, creation of animal feed, composting, anaerobic digestion, or disposal in landfills)
    - <u>Excess (or surplus) food:</u> food that is donated to feed people
    - <u>Food waste:</u> food not consumed by humans that is discarded or recycled, such as plate waste, spoiled food, or peels and rinds considered inedible
        - Occurs at retail, food service, and residential levels and is managed by landfill; controlled combustion; sewer; litter, discards, and refuse
        - Solve by: donate/upcycle feed, animals/leave unharvested, compost/anaerobic digestion, anaerobic digestion/apply to land
    - <u>Food loss:</u> unused product from the agricultural sector
- **How do we recycle and reuse waste:**
    - 40% of food produced in US is uneaten and wasted, which amounts
    - Can be diverted from waste stream by eating leftovers or composting
    - Composting: form of recycling that decomposes and converts food waste into organic material that can be used to grow crops

<u>Waste:</u>

What Is Waste?

- Waste or garbage – what we determine to be unusable or unwanted
- Waste ends up in a <u>waste stream</u>: flow of materials from "upstream" processes such as extraction, production, and distribution to disposal – "downstream"

Municipal Solid Waste (MSW):

- American consumers directly contribute 5 lbs of garbage per person per day
- Produces 1,800+ lbs of garbage per year as <u>municipal solid waste (MSW)</u>
    - Majority of MSW is landfill

- 4 biggest components are paper, paperboard, food scraps, yard trimmings, plastics

Solid Waste:

- MSW does not account for waste generated upstream before products reach us
- Solid waste: all discarded material in solid, liquid, semisolid, or contained gaseous form

Life Cycle Assessment:

- LCA: Accounting for environmental impacts of all steps involved in making, distributing, using, and ultimately disposing of a product
  - Impacts of producing plastic bottles include air pollution, water pollution, and environmental health effects

What happens when waste is dumped:

- Unregulated dumps: garbage heaped in uncovered openly accessible piles
- Decomposing waste attracts vermin, and leaks polluting gases and liquids

Effects of Unregulated Dumps:

- 1) Polluting Gasses:
  - Bacterial Decomposition: Results in the release of CO_2
    - Occurs in the PRESENCE of Oxygen
  - Volatilization: Results in the release of Methane
    - Occurs in the ABSENCE of Oxygen
  - Chemical Reactions: Results in release of VOCs
    - Either on own or w/ CO2, methane, or other compound
- 2) Leachate:
  - Leachate: foul-smelling soupy liquid, forms when rainwater or groundwater mixes with decomposing waste
    - Include harmful substances incl ammonia, heavy metals, + dioxins
    - Can carry pathogens
    - Can form harmful plumes of liquid that can seep into soil and drinking water and harm humans, plants, and wildlife
- 3) Ocean Dumping:
  - Industrial waste, sewage sludge and dredge spoils are dropped into ocean
  - Can cause eutrophication or dead zones
  - Often contain toxic heavy metals like mercury or lead
  - Can accumulate in fish, which may then be consumed by humans

Waste Trade:

- 121 countries (not US) sign Basel Convention: international agreement restricting movement of hazardous waste from developed to non developed countries
  - Many hazardous materials shipped to developing countries incl e-waste

Waste Management Methods:

- 1) Isolation: segregation of waste from significant contact with humans or wider environment
  - Dominant disposal strategy in US
  - Common isolation technology is **sanitary landfill**
    - Daily waste is spread on top, then covered with a layer of clay, and then dirt to prevent blowing away or animal attraction

- Stringent regulations for landfill placement now consider factors such as topography, hydrology, geology, and precipitation levels
- **Geologic Disposal:** Injecting or placing waste beneath Earth's surface
  - Liquid waste from industry, mining, and oil and gas production injected into deep wells
- Waste can be stored in secured concrete **containment buildings**: air-lock doors, liquid collection drains, negative air-pressure and dust control
- No permanent disposal strategy for radioactive waste from nuclear fuel
- Challenges of Isolation:
  - 1) Leachate will escape from sanitary landfills as synthetic liners degrade, releasing hazardous pollutants like heavy metals + VOCs
  - 2) Release significant level of greenhouse gasses, and are largest human-generated source of methane

- 2) Incineration: technology of controlled combustion at high temperatures with pollution controls in place (burning waste)
  - Reduces volume + provides heat, results in uncontrolled fires/air pollution
  - 3/4 of incinerators use mass burn technologies: combust solid waste first then perform secondary combustion of resulting gasses
  - Refuse-derived fuel uses dehydrated waste pellets, where non-combustibles (glass/metal) are removed to increase efficiency
  - Incineration Pollution Control System: NO Removal System → Scrubbers Remove Air Pollutants → Particulate Removal → Pollution Control Tests
- 3) Conversion: disposal strategy where waste is converted into something else useful, most often generating electricity
  - **Waste-to-energy** sites
  - **Bioreactor landfill**: disposal strategy using injected water + air to accelerate decomposition, reduce volume of waste, and reduce methane production due to aeration
  - **Remediation**: converts hazardous waste to less hazardous substances
    - Bioremediation uses microorganisms and enzymes
    - Mycoremediation uses fungi
    - Phytoremediation uses plants to reduce toxic substances like pesticides and polychlorinated biphenyls (PCBs)

Recycling:

- Recycling: Strategy of redefining "waste" as "resources" for new products, diverting materials from waste stream
  - Saves energy and reduces impacts from creating products from scratch but does require processing
- Primary Recycling (closed-loop recycling): converts waste materials into same sort of product from which they came
  - Most efficient
- Secondary Recycling (open-loop recycling): converts waste material from one product into different sort of product

- Downcycling – requires more energy + materials, reduces quality of source material

- % of MSW recycled = recycling rate
- Differences in recycles rates tied to waste management policies + cultural diff

Economics of Recycling:

- Different materials have different processes for recycling due to removal of foreign materials and sorting
- Materials like plastics use a variety of polymers or additives to provide specific characteristics like color and stability
- Extensive processing required for plastics recycling has kept cost of recycled plastic as much as 40% above cost of virgin plastic
- Collection systems, behavior of consumers, + product design play roles
- Feasibility of recycling also depends on market for recyclables
- Design for recovery guidelines establish standards for manufacture of materials and products to facilitate efficient recycling

Advantages & Limitations of Recycling:

- Recycling reduces environmental effects of landfills and incineration and reduces effects of extraction and consumption of raw materials
- Processing recyclables saves energy and reduces contributions to GHG
- Important that recycled products are safe + do not contain hazardous materials
- Market for recyclables fluctuates, some recycled materials end up in landfills

Can We Recycle Human Waste?

- Sewage treatment separates out biosolids from disinfected wastewater
- If biosolids are suitably treated to eliminate disease-causing microbes, they can be converted to fertilizer

Challenge of Handling Biodegradable Plastics:

- Biodegradable plastics are typically made from polylactic acid (PLA) resin
- PLA plastics made from plant material like corn and can be assimilated back into environment but hard to compost because do not degrade as quickly
- PET plastics are petroleum-based + must be removed from food waste recycling
- Difficult to sort PLA from PET which is a problem for recycling systems

How does our culture affect consumption:

- Consumption: ways we use and dispose of material things
  - Plays an important cultural role in our lives
  - Individual consumption patterns have functions beyond survival + comfort
- Conspicuous consumption happens when people purchase goods to project particular identities or images within society
- Businesses that sell material goods strive to raise profits by boosting consumption, since economists use sales as indicators of economic growth

Can We Reduce Our Waste?

- Large-volume purchasers are influencing suppliers to reduce waste by redesigning packaging as a condition of sale

- States have passed producer responsibility laws: require manufacturers of products/packaging to take responsibility for collection, recycling, reuse, or disposal of their products, including e-waste
- Producer responsibility places cost on manufacturer and consumer rather than taxpayers

Waste Management Hierarchy (From Most To Least Preferred):

- Source Reduction & Reuse → Recycling/Composting → Energy Recovery → Treatment & Disposal

Plastics:

What Are Plastics?

- Plastics: range of synthetic or semi-synthetic materials, use polymers as main ingredient
- Classification of plastics = degree to which chemical processes used in formation are reversible or not:
    - Thermoplastics: Do not undergo chemical change when heated, can be molded repeatedly
        - Polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC)
        - PE and PP = most common
    - Thermosets: Irreversible chemical reaction occurs during formation, so can melt and take shape only once. If reheated, they decompose rather than melt
        - Epoxy, melamine
- Plastic is much more difficult to recycle because it consists of a wide range of compounds and materials (PVC, PE, HDPE, etc.), some of which can be melted and reformed (thermoplastics) while others cannot (thermosets). On the other hand, paper in various forms is all made of the same stuff and can be reduced to pulp and reformed into paper.

Where does plastic waste come from?

- Majority from packaging and building/construction

Where Does All The Plastic Go?

- Of global plastic produced from 1950 to 2015:
    - 55% landfill, 30% in use, 8% incinerated, 6-7% recycled
- Of plastic no longer in use, ~9% was recycled
- 3% of global annual plastics waste entered ocean
- >80% of plastic in ocean comes from land sources
- Plastic enters rivers and ocean if poorly managed

Can Plastic Waste Be Managed Sustainably?

- Primary options for handling plastic waste: 1) Recycling, 2) Incineration or 3) Disposal in Landfill
- Impact of different methods can be assessed across multiple factors including GHG emissions, energy use, local pollution, and cost of processing
- Recycling has lowest global warming potential and energy use, usually thought of as best option from environmental perspective
- >95% of plastic in EU and >70% in US was sent to China
- Major global shift in where and how materials are being recycled/processed

- While recycling is preferable to incineration or landfill by displacing new plastic production, most plastic can be recycled only once or twice
    - Means most recycled plastic eventually ends up in landfill or incinerator
- Recycling delays, rather than avoids, final disposal. It reduces future plastic waste generation only if it displaces primary plastic production

Beyond Plastics Recycling:

- >500 US cities and counties have legislation discouraging or banning distribution of disposable plastic bags at checkout counters

Health Risks Associated With Plastics:

- Derived from breakdown of plastic objects, cosmetics, and industrial applications
- Enter body through inhalation and ingestion
- Oxidative stress, organ dysfunction, neurotoxicity, etc

RECITATION MATH:

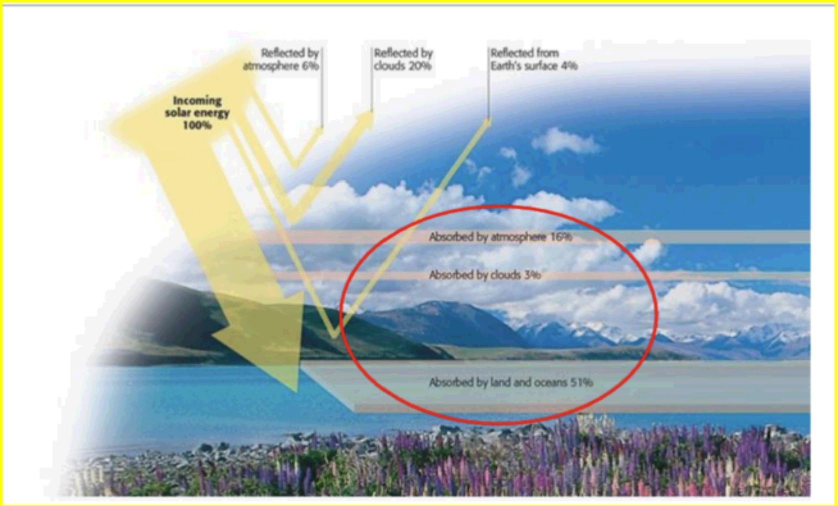
- Higher R-square values indicate a stronger relationship between the two variables
- Probability that the slope equals zero (i.e., significance)
    - A significant or p-value below 0.05 indicates there is less than a 5% chance that the slope is equal to zero

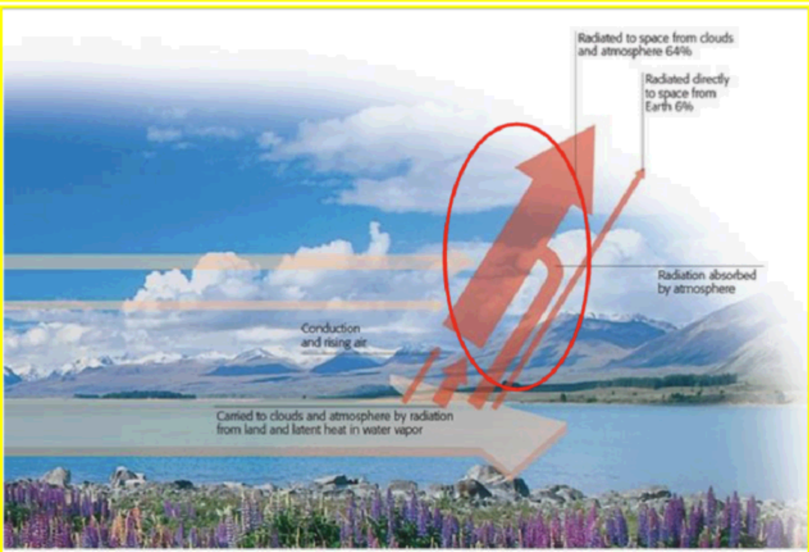
Quantifying Biodiversity:

- • richness (S), evenness (E)
  • Shannon index (H)

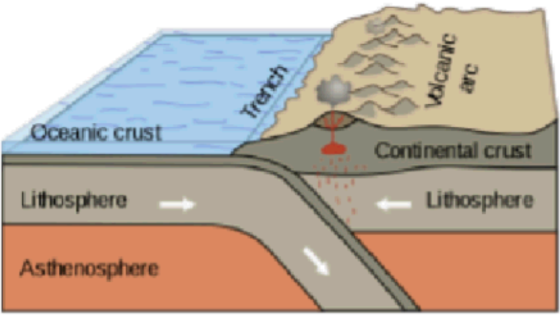
  $$H = -\sum\left[\left(\frac{n_i}{N}\right) \times ln\left(\frac{n_i}{N}\right)\right]$$

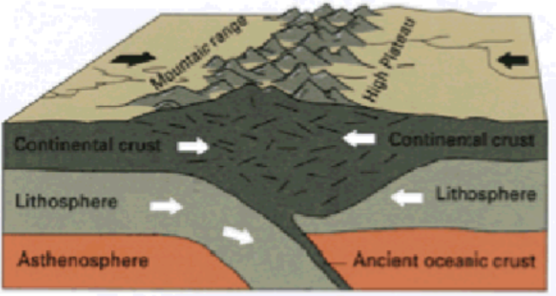
  n_i is number of individuals of ith species
  N is total number of individuals
  $\left(\frac{n_i}{N}\right)$ is relative abundance
  ln is natural log
    - <u>Species Richness:</u> Refers to the number of species in a given area
    - <u>Species Evenness:</u> Refers to the relative abundance (or dominance) of a species in a given area
    - <u>Relative Abundance:</u> # of individuals of a species/total # of individuals
    - <u>Proportional Abundance:</u> A species' rel. abundance/rel. abundance of most dominant species
    - <u>Shannon's Evenness Index</u> = Diversity Index/ln(species richness)
- Rank Abundance Curve (Whittaker Plot)
    - Visually depicts both richness (max x-axis) and evenness (slope)
        - Steep gradient indicates low evenness as the high-ranking species have much higher abundances than the low-ranking species
        - Shallow gradient indicates high evenness as the abundances of different species are similar





Greenhouse effect = radiation of longwave from ground up to clouds/atmosphere and reflection back down





Continental-continental convergence