Chapter 21 – Global Climate Change

Climate and Geology

- The climate system is a multidimensional system of many interacting parts, which includes:
  - Atmosphere
  - Hydrosphere
  - Geosphere
  - Biosphere
  - Cryosphere (snow, glaciers, ice, and frozen ground)
- When one part of the climate system changes, other components react

Earth's Climate System

- Climate–Geology Connections
  - The climate has a profound impact on many geologic processes
    - Weathering
    - Flooding
    - Mass wasting
  - Geologic processes also affect the climate
    - Volcanism
    - Mountain building

Detecting Climate Change

- Using fossils and many other geologic clues, scientists have reconstructed Earth's climate going back hundreds of millions of years.
- Earth's climate can be broadly characterized as being a warm "greenhouse" or a cold "icehouse".

- Instrumental records only go back a couple of centuries
- Reconstructing past climate change is the field of *paleoclimatology*
  - Scientists use *proxy data* (indirect evidence of climate change)

Ancient Bristlecone

- *Seafloor Sediments*—A Storehouse of Climate Data
  - Abundance and types of organic remains are indicative of past sea-surface temperatures
    - Example: foraminifera.

Foraminifera

- Oxygen Isotope Analysis
  - *Oxygen isotope analysis* is the precise measurement of the ratio of $^{18}O/^{16}O$.
    - Ratios are trapped in calcium carbonate shells of marine organisms.
    - Ratio varies with amount of sea ice and water temperature.

- Climate Change *Recorded in Glacial Ice*
  - Some ice cores represent over 200,000 years of climate history
    - Ice can be analyzed for:
      - Oxygen isotope analysis.
      - Carbon dioxide and methane (air bubbles trapped in the ice).
      - Dust, volcanic ash, pollen.

Ice Cores

- *Tree Rings*—Archives of Environmental History
  - Growth rings are added each year

- Thickness and density of rings reflect environmental conditions
- In certain regions, ring chronologies extend back thousands of years.

16 **Tree Rings**

17

- Other Types of Proxy Data
  - Fossil pollen
    - Pollen can provide high-resolution records of vegetation changes in a region
      - Type of regional vegetation is climate dependent.
  - Corals
    - Through oxygen isotope analysis, corals are used as *paleothermometers* and precipitation proxies
  - Historical data
    - Harvest dates
    - Floods
    - Human migration

18 **Other Proxies**

19

20

21 **Some Atmospheric Basics**

- Composition of the Atmosphere
  - Air is a mixture of many discrete gases
  - Clean dry air
    - Air is mostly nitrogen (78%) and oxygen (21%).
    - Carbon dioxide is a minute component (0.04%) of air but can absorb heat and affect global climate.

22 **Composition of the Atmosphere**

23

- Composition of the Atmosphere
  - *Water vapor*
    - Amount varies from 0 percent to 4 percent of air.
    - Source of clouds and precipitation.
    - Can absorb heat and affect global climate.
  - *Ozone*
    - A combination of three oxygen atoms (O_3) in one molecule.
    - Thin layer of gas concentrated in the stratosphere.
    - Absorbs harmful ultraviolet radiation.

24

- Composition of the Atmosphere
  - Aerosols
    - Tiny solid and liquid particles found in the air are called *aerosols*.
      - Sea salts
      - Fine soil
      - Smoke and soot from fire
      - Pollen and microorganisms
      - Ash and dust from volcanoes
    - Can attract moisture for cloud formation
    - Can block sunlight from reaching Earth

25 **Aerosols**

26

- Extent and Structure of the Atmosphere
  - Pressure changes with height
    - Pressure is the weight of the air above.

  - Pressure at higher altitudes is less.
  - Average sea level pressure is 1 kg/cm^2 (14.7 psi).
- Temperature changes with height
  - Earth's atmosphere is divided into four layers based on temperature.
  - Troposphere.
  - Stratosphere.
  - Mesosphere.
  - Thermosphere.

27 **Vertical Changes in Air Pressure**

28 **Thermal Structure of the Atmosphere**

29

- Temperature changes
  - Troposphere
    - The bottom layer of the atmosphere.
    - We live in the troposphere.
    - Temperature decreases with an increase in altitude.
    - Weather occurs in the troposphere.
    - Bounded on the top by the tropopause.
  - Stratosphere
    - Temperature remains constant until 20 kilometers, then it increases.
    - Ozone is concentrated in the stratosphere.
    - Bounded on the top by the stratopause.

30

- Temperature changes
  - Mesosphere
    - Temperatures decrease with height to the mesopause.
    - Coldest temperatures in the atmosphere are found in the mesosphere.
  - Thermosphere
    - Contains only a tiny fraction of the atmosphere.
    - Temperatures increase due to the absorption of solar radiation.
    - No defined upper limit.

31 **Thermal Structure of the Atmosphere**

32 **Radiosonde**

33 **Heating the Atmosphere**

- Energy from the Sun
  - The Sun emits *electromagnetic radiation* in the form of rays, or waves.
    - As an object absorbs radiation, molecule movement increases, causing temperatures to increase
    - Key difference among electromagnetic radiation is the wavelengths

34 **The Electromagnetic Spectrum**

35

- Energy from the Sun
  - Basic laws governing radiation
    - All objects emit radiant energy.
    - Hotter objects radiate more total energy than do colder objects.
    - The hotter the radiating body, the shorter the wavelengths of maximum radiation.
    - Objects that are good absorbers of radiation are good emitters as well.

36

- Paths of Incoming Solar Energy
  - 50 percent of solar energy passes through atmosphere and is absorbed on Earth's surface.
  - 20 percent is absorbed by clouds and atmospheric gases.

- Including oxygen and ozone
- 30 percent is reflected back to space.
  - By clouds, atmosphere, snow, and ice
  - Called *albedo*

37 **Paths Taken by Solar Radiation**

38 **Albedo**

39

- The Greenhouse Effect
  - Shortwave solar radiation passes through the atmosphere and heats Earth.
  - Longwave radiation emitted by Earth is absorbed by gases in the atmosphere.
    - Such as carbon dioxide and water vapor
  - The longwave radiation heats the atmosphere, which radiates heat both out into space and back to Earth.
  - This selective absorption and reheating of Earth is called the *greenhouse effect* and results in warming of the atmosphere.

40 **The Greenhouse Effect**

41 **Natural Causes of Climate Change**

- Plate Movements and Orbital Variations
  - Moving landmasses
    - Landmasses move closer or further from the equator
    - Moving landmasses can affect ocean circulation
  - Variations in Earth's orbit
    - Changes in *eccentricity*, *obliquity*, and *precession* cause fluctuations in distribution of solar radiation

42

- Volcanic Activity and Climate Change
  - The effect of volcanic aerosols on climate
    - 1815 was "*the year without summer*" due to the Mt. Tambora eruption
  - Volcanic ash and dust
    - Ash from Mount St. Helens 1980 eruption settled out of the atmosphere relatively quickly
      - Had a negligible effect on global temperatures
  - Sulfuric acid droplets
    - 1982 eruption of El Chichón released large amount of sulfur dioxide gas; combined with water vapor in the stratosphere to produce sulfuric acid particles
      - Remains in the stratosphere for up to several years
      - Sulfuric acid droplets reflect solar radiation back into space
      - *Lowered global temperatures* by 0.5ºC

43 **Mount Etna**

44 **Volcanic Haze Reduces Sunlight at Earth's Surface**

45 **Natural Causes of Climate Change**

- Volcanic Activity and Climate Change
  - Volcanism and Global Warming
    - Cretaceous period was one of the warmest in Earth's history
      - Extensive volcanism
        - »Lava plateaus
      - Increase atmospheric CO_2

46

- Solar Variability and Climate
  - No long-term variations in solar intensity have been measured outside the atmosphere.
  - Sunspot cycles
    - *Sunspots* are huge magnetic storms on the Sun

- Appear as dark spots on the Sun
- Sunspots reach a maximum every 11 years
  - Cycle is too short to have an effect on global temperatures

47 **Sunspots**

48 **Mean annual sunspot numbers**

49 **Human Impact on Global Climate**

- Humans have been modifying the environment for thousands of years.
  - *Ground cover* has been altered by:
    - Fire
    - Overgrazing
  - Results in modification of reflectivity, evaporation rates, and surface winds.

50

- Rising CO_2 Levels
  - Carbon dioxide is a greenhouse gas.
    - Lets short-wavelength solar radiation pass through to Earth but traps long-wavelength Earth radiation from passing back into space
  - Humans add carbon dioxide to the atmosphere.
    - Burning fossil fuels
    - Deforestation
  - CO_2 levels are highest in the past 600,000 years.

51 **Monthly CO_2 concentrations**

52 **Tropical Deforestation**

53 **CO_2 Concentrations over the Past 400,000 years**

54

- The Atmosphere's Response
  - Global temperatures have increased in response to increased atmospheric carbon dioxide.
    - Global temperatures have increased 0.8°C in the past century
      - The warmest 16 years (since 1850) have occurred since 1995
  - Temperatures are expected to continue to increase in the future.
    - Amount of increase depends on amount of emitted greenhouse gases

55 **Global Temperatures 1800–2014**

56 **Decade by Decade Temperature Trend**

57 **Temperature Projections to 2100**

58

- The Role of Trace Gases
  - *Methane*
    - Less abundant than carbon dioxide, but more effective at absorbing outgoing radiation.
  - *Nitrous Oxide*
    - Greenhouse gas that lasts for 150 years in the atmosphere.
  - *CFCs*
    - Commercially produced chemical that depletes the ozone.
  - A combined effect!
    - CO_2 is not the only contributor to global warming, but it is the single most important cause.

59 **Methane and Nitrous Oxide**

60 **How Aerosols Influence Climate**

- Aerosols are tiny particles and drops of liquid
  - Produce a cooling effect by reflecting sunlight back to space
    - The effect on today's climate is determined by the amount emitted over the course of a few weeks.

- By contrast, carbon dioxide remains for much longer spans and influences climate for many decades.
- Most human-generated aerosols come from the sulfur dioxide emitted during the combustion of fossil fuels
  - *Black carbon* is soot generated by combustion processes and fires.
  - Black carbon warms the atmosphere because it is an effective absorber of solar radiation.

61 **Human Generated Aerosols**

62 **Climate-Feedback Mechanisms**

- The climate is a very complex system
  - When any component is altered, scientists must consider many possible outcomes
  - The different possible outcomes are called Climate-Feedback Mechanisms.
    - Complicate climate modeling
    - Positive feedback mechanisms
    - Negative feedback mechanisms

63

- Types of Feedback Mechanisms
  - Changes that reinforce the initial change are called Positive-Feedback Mechanisms.
    - Example: Warmer temperatures at high latitudes cause sea ice to melt, which is replaced with a lower-albedo ocean, which increases solar radiation absorbed at Earth's surface, which increases temperature.

64 **Sea Ice as a Feedback Mechanism**

65

- Types of Feedback Mechanisms
  - Negative-Feedback Mechanisms produce results that are the opposite of the initial change and tend to offset it.
    - Example: An increase in global temperatures would increase evaporation, which increases cloud cover, which would reflect more solar radiation back into space, lowering global temperatures.

66

- *Computer Models of Climate*: Important Yet Imperfect Tools
  - General circulation models (GCMs) are based on the fundamental laws of physics and chemistry
    - Incorporate human and biological interactions
    - Can predict climate-change scenarios

67 **Separating human and natural influences**

68 **Some Consequences of Global Warming**

- Because the climate system is so complex, predicting specific regional changes related to increased levels of CO_2 is speculative
  - Magnitude of temperature increase is not globally uniform.
  - Precipitation changes will also vary across the globe.

69

- Sea Level Rise
  - Sea level has risen 25 centimeters since 1870.
  - Will affect low-lying countries and regions with a *gently sloping shoreline*
    - Atlantic coast of the U.S.
  - Sea level rise driven by:
    - Melting glaciers
    - Thermal expansion

70 **Changing Sea-Level**

71 **Slope of the Shoreline**

72

- The Changing Arctic
  - Arctic Sea Ice
    - Amount of sea ice has declined by 13 percent since 1979.
  - Permafrost
    - *Thawing permafrost* is a positive feedback mechanism.
      - Organic material stored in the permafrost will start to decay and release carbon dioxide and methane

73 **Arctic Sea Ice**

74 **Tracking Sea Ice**

75 **Siberian Lakes**

76 **Some Consequences of Global Warming**

- Increasing Ocean Acidity
  - When atmospheric carbon dioxide dissolves in seawater, the oceans become acidic
    - Makes it harder for calcite-secreting marine organisms to grow hard parts

77 **Oceans becoming more acidic**

78

- The Potential for "Surprises"
  - Due to the complexity of Earth's climate system, we might experience relatively sudden, unexpected changes or see some aspects of climate shift in an unexpected manner
  - A constant state of change is very likely

79