1 ***Global Climate Change***

***Earth, Chapter 21***

2 ***Chapter 21 – Global Climate Change***

3 **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

4 **Earth's Climate System**

5

- 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

6 **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".

7

8

- 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)

9

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

10 **Foraminifera**

11 **Plankton**

12 ***Aboard JOIDES Resolution***

13

- 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.

14

- Climate Change *Recorded in Glacial Ice*
  - Some ice cores represent over 800,000 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.

15 **Ice Cores**

16 ***National Ice Core Lab***

17

- *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.

18 **Tree Rings**

19 ***Dendrochronology…***

20 **Ancient Bristlecone**

21 ***Extending the range of info:***

22 ***Extending the range of info:***

23 ***Corals***

24 ***Extending the range of info:***

25

- 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

26 **Other Proxies: Pollen**

27

28

29 **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.

30 **Composition of the Atmosphere**

31

- 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.

32

- 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

33 **Aerosols**

34

- 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.

35 **Vertical Changes in Air Pressure**

36 **Thermal Structure of the Atmosphere**

37

- 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.

38

- 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.

39 **Thermal Structure of the Atmosphere**

40 **Radiosonde**

41 **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

42 **The Electromagnetic Spectrum**

43 ***The Electromagnetic Spectrum***

44

- 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.

45

- 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*

46 **Paths Taken by Solar Radiation**

47 **Albedo (Reflectivity)**

48

- 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.

49 **The Greenhouse Effect**

50 ***Figure 21.12 (left)***

51 ***Figure 21.12 (middle)***

52 ***Figure 21.12 (right)***

53 **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

54

- 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

55 **Mount Etna**

56 ***$SO_2$ plume from Mt. Etna***

57 ***Figure 21.13B***

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

59 ***Sulfuric Acid  Haze***

60 **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 $CO_2$

61

- 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

62 **Sunspots**

63 ***Sunspot Close-up:***

64 ***"Geology Guy" Sunspot Image***

65 **Mean annual sunspot numbers**

66 **Mean annual sunspot numbers**

67 **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.

68

- 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.

69 ***$CO_2$ from Ice Core Data:***

70 ***Measuring $CO_2$ : Mauna Loa, Hawaii***

71 ***Charles David Keeling (1928-2005)***

72 ***The Keeling Curve: 1958 to present***
**https://scripps.ucsd.edu/programs/keelingcurve/**

73 ***The Last 10,000 years:***
**https://scripps.ucsd.edu/programs/keelingcurve/**

74 ***The Last 800,000 years:***
**https://scripps.ucsd.edu/programs/keelingcurve/**

75 **Tropical Deforestation**

76 **$CO_2$ Concentrations over the Past**

**400,000 years**

77

- 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

78 **Global Temperatures 1800–2014**

79 **Decade by Decade Temperature Trend**

80 **Temperature Projections to 2100**

81

- 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.

82 **Methane and Nitrous Oxide**

83 ***Methane sources: rice paddies***

84 ***Methane sources: swamps***

85 ***Methane sources: cattle feedlots***

86 **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.

87 **Human Generated Aerosols**

88 ***Human-generated aerosols***

89 **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

90

- 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.

91 **Sea Ice as a Feedback Mechanism**

92

- 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.

93

- *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

94 **Separating human and natural influences**

95 ***Figure 21.23C***

96 **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.

97

- 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

98 **Changing Sea-Level**

99 **Slope of the Shoreline**

100

- 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

101 **Arctic Sea Ice**

102 ***Figure 21.25***

103 **Tracking Sea Ice**

104 **Siberian Lakes**

105 **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

106 **Oceans becoming more acidic**

107

- 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

108 ***Not the end of the story…***