



1 2  **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

3 4  **Earth's Climate System**4 

- 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

5 5  **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".

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- 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)

8 9  **Ancient Bristlecone**9 

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

10 11  **Foraminifera**11 

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

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- 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.

13 14  **Ice Cores**14 

- *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.

15 **Tree Rings**

16 

- 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

17 **Other Proxies**

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20 **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.

21 **Composition of the Atmosphere**

22 

- 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 (O₃) in one molecule.
 - Thin layer of gas concentrated in the stratosphere.
 - Absorbs harmful ultraviolet radiation.

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- 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

24 **Aerosols**

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- 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/cm² (14.7 psi).
- Temperature changes with height
 - Earth's atmosphere is divided into four layers based on temperature.
 - Troposphere.
 - Stratosphere.
 - Mesosphere.
 - Thermosphere.

26 **Vertical Changes in Air Pressure**

27 **Thermal Structure of the Atmosphere**

28

- 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.

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- 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.

30 **Thermal Structure of the Atmosphere**

31 **Radiosonde**

32 **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

33 **The Electromagnetic Spectrum**

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- 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.

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- 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*

36 **Paths Taken by Solar Radiation**

37 **Albedo**

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- 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.

39 **The Greenhouse Effect**

40 **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

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- 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 0.5°C

42 **Mount Etna**

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


44 **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 CO₂

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- 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

46  **Sunspots**47  **Mean annual sunspot numbers**48  **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.

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- Rising CO₂ 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
 - CO₂ levels are highest in the past 600,000 years.

50  **Monthly CO₂ concentrations**51  **Tropical Deforestation**52  **CO₂ Concentrations over the Past 400,000 years**53 

- 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

54  **Global Temperatures 1800–2014**55  **Decade by Decade Temperature Trend**56  **Temperature Projections to 2100**57 

- 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!
 - CO₂ is not the only contributor to global warming, but it is the single most important cause.

58  **Methane and Nitrous Oxide**59  **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.

60 **Human Generated Aerosols**

61 **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

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- 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.

63 **Sea Ice as a Feedback Mechanism**

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- 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.

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- *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

66 **Separating human and natural influences**

67 **Some Consequences of Global Warming**

- Because the climate system is so complex, predicting specific regional changes related to increased levels of CO₂ is speculative
 - Magnitude of temperature increase is not globally uniform.
 - Precipitation changes will also vary across the globe.

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- 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

69 **Changing Sea-Level**

70 **Slope of the Shoreline**

71 


- 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

72  **Arctic Sea Ice**

73  **Tracking Sea Ice**

74  **Siberian Lakes**

75  **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

76  **Oceans becoming more acidic**

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- 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

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