Reconstructing Past Climates

• Techniques
  – Glacial landscapes (fossils)
  – CLIMAP (ocean sediment)
  – Ice cores (layering of precipitation)
  – Otoliths (CaCO$_3$ in fish sensory organ)
  – Dendrochronology (tree rings)

• Climate Throughout the Ages
  – Ice Age/Interglacials
  – Younger-Dryas, mid-Holocene maximum
In past 18,000 years

“Ocean Conveyor” and Younger Dryas
- Cold, salty water sinks near Greenland driving warm water north
- Massive freshwater from glacial lake reduced salinity N. Atlantic
- If the conveyor stops much colder over Europe

“Warmed in little as 3 years in Greenland!”
Climate During past 1000 years

- Relatively warm conditions centered around A.D. 1000 (identified by some as the "Medieval Warm Period")
- Little Ice Age from roughly 1500 to 1850 is supported by a wide variety of evidence including
  - ice cores
  - tree rings
  - borehole temperatures
  - glacier length records
  - and historical documents
- Modern warming
Past 1000 Years

This is commonly called the controversial “Hockey Stick” graph

Period in dispute
Reconstructing Past Climate

• Temperature Trend During the Past 100+ Years
  – Instruments only available for past 150 yrs
  – Largest increase in temperature of any century during the past 1000 (400) years
  – Warming of 0.6°C during 20th century is significant when compared to the last 1000 years
  – Scientists point to carbon dioxide and greenhouse gases as the cause
Compared to 1951 to 1980 average

From land, ocean and sea surface temperature measurements
Possible Causes of Climate Change

- **External Causes**
  - Change in incoming radiation
  - Change in composition of the atmosphere
  - Change in Earth’s surface

- **Internal Causes**
  - Change in global circulation patterns

- **Feedback Mechanisms**
  - Water vapor-greenhouse gas feedback (+)
  - Snow-albedo feedback (+)
  - Infrared radiation (-)
Snow Albedo Feedback

(a) • High surface albedo
    • Low absorption of sunlight
    • Gradual surface warming

(b) • Lower surface albedo
    • Higher absorption of sunlight
    • Surface warming increases

(c) • Very low surface albedo
    • Much higher absorption of sunlight
    • Surface warming enhanced

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Possible Causes of Climate Change

• Plate Tectonics and Mountain Building
  – Theory of plate tectonics
  – Ridge and subduction
  – Mountain interaction with airflow and ocean currents
Increased volcanic activity may promote global warming by enriching the CO2 content of the atmosphere.
Possible Causes of Climate Change

- Variation on the Earth’s Orbit
- Milankovitch Theory
  - Eccentricity (100,000 yrs)
  - Precession (23,000 yrs)
  - Obliquity (41,000 yrs)
Precession

(a) Axis now

Axis in approximately 11,000 years

(b) Conditions now

(c) Conditions in about 11,000 years

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Obliquity

• Current tilt angle 23.5 degrees
• Over a period of 41,000 years, tilt angle will change between 22 and 24.5 degrees

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Possible Causes of Climate Change

• Atmospheric Particles
  – Aerosols = natural + anthropogenic
  – Sulfate aerosol derived from SO$_2$ (fossil fuel combustion)
  – Aerosols in the troposphere (sulfate) may cause cooling due to reflection of radiation
  – Volcanic Explosions: ash and dust in the stratosphere reflect light and cool
    • Rich in SO$_2$ (converts to SO$_4$) most effective in cooling
SO₂ Plume from Pinatubo

This satellite image shows the results of the volcanic SO₂ just 3 months after eruption. Height estimated at 25 kilometers.
Pinatubo Effects on Temperature

Global temperature decreased by 0.4°C from the 1981 to 1992 average.
Possible Causes of Climate Change

• Variations in Solar Output
  – Sunspots cause more radiation to be generated by the sun (0.1% more)
  – Maunder minimum (1645-1715) not many sunspots
    • Occurred during little ice age
  – Satellite observations now tracking solar output (Total Solar Irradiance)
    • ACRIM I, II, III
    • VIRGO
So far we have monitored TSI for over 3 complete 11-year solar cycles.

Global Warming

• Recent Global Warming: Perspective
  – Since the beginning of the 20\textsuperscript{th} century average global surface temperature has increased 0.8ºC

• Radiative Forcing
  – Any change in average net radiation that occurs at the top of the atmosphere which is due to some change in the climate system is called radiative forcing
Global Warming

• Radiative Forcing Agents
  – Carbon dioxide and other greenhouse gases disrupt radiative equilibrium, forming an increase in temperature

• Climate Models and Recent Temperature
  – It is difficult to unequivocally prove greenhouse forcing due to the noise in the system
  – Models duplicate past temperatures incorporating sulfate aerosols, greenhouse gases, and change in solar radiation
Is Human activity the cause of present day warming?

Source: IPCC Working Group 1, Summary for Policymakers (2007)
Global Warming

• Future Global Warming: Model Projections
  – Double carbon dioxide levels will cause a surface warming of 2 to 4.5ºC
  – Uncertainties:
    • The effect of water and land on rising levels of carbon dioxide
    • Amount or greenhouse gases
  – Question of Clouds
    • Clouds reflect radiation and emit infrared radiation, positive and negative feedbacks.
Warming compared to the 1980 to 1999 average
Global Warming

• Consequences of Global Warming
  – Land areas warm faster
  – Rise in sea level
  – Fertilize plants

• Land Use Change
  – Desertification
  – Plagues and climate
  – Plants susceptible to insects
  – Fire frequency
  – Native plants replaced by invasive species
Projected Surface Air Temperatures

2090-2099 Compared to 1980 – 1999 average
Projected Changes in Precipitation

For 2090 to 2099 compared to 1980 to 1999 average
Arctic Sea Ice at Minimum in 2005

(a) March 2005

(b) September 2005
Today’s Arctic Sea Ice Extent

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)

Extent (millions of square kilometers)

Jan  Feb  Mar  Apr  May

2009  2007  1979–2000 Average

Sea Ice Extent
04/20/2009

National Snow and Ice Data Center, Boulder, CO
Global Warming

• Efforts to Curb: Kyoto Protocol
• 160 countries, initiated in 1997, put in place 2005
• Work out formal agreements to limit GHG
  – Target emissions, credits, sinks
  – Reduce emissions by 5% below 1990 levels during 2008 to 2012
  – US has yet to sign protocol
  – California implementing protocol