Natural Climate Forcing
A lead to **Paleoclimate**
### Earth Geological Time Scale

#### Paleo: Greek root means “ancient”

- **Modern age, ice age, last 2 million years**
- **Age of dinosaurs**
- **Animal explosion of diversity**

#### From the formation of earth to the evolution of macroscopic hard-shelled animals

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**Note:** The table shows the geological time scale from the formation of earth to the evolution of macroscopic hard-shelled animals, highlighting key periods and epochs.
Surface Temperature is not uniform in Earth history.
Temperature: the last 400,000 years
From the Vostok ice core (Antarctica)
A Big Argument on Climate Change

- Is the current warming a natural variation caused by natural forcing or a human-induced change related to greenhouse gases?
Determining Past Climates

- How do we know what past climates were like?
  - **Fossil evidence**
    - Fossils of tundra plants in New England suggest a colder climate
  - **Ocean sediment cores**
    - Certain animals must have lived in a range of ocean temperatures
  - **Oxygen isotope ratios**
    - Differing isotope counts mean differing temperatures
Determining Past Climates

- **Ice cores**
  - Sulfuric acid in ice cores
  - Oxygen isotopes (cold the air, more isotopes)
  - Bubbles in the ice contain trapped composition of the past atmospheres

- **Dendrochronology**
  - Examining tree rings to see growth patterns
Climate record distribution from 1000 to 1750
C¹⁴ and O¹⁸ proxy

C¹⁴ dating proxy

- Cosmic rays produce C¹⁴
- C¹⁴ has half-life of 5730 years and constitutes about one percent of the carbon in an organism.
- When an organism dies, its C¹⁴ continues to decay.
- The older the organism, the less C¹⁴

O¹⁸ temperature proxy

- O¹⁸ is heavier, harder to evaporate. As temperature decreases (in an ice age), snow deposits contains less O¹⁸ while ocean water and marine organisms (CaCO₃) contain more O¹⁸
- The O¹⁸/ O¹⁶ ratio or δO18 in ice and marine deposits constitutes a proxy thermometer that indicates ice ages and interglacials.
- Low O¹⁸ in ice indicates it was deposited during cold conditions worldwide, while low O¹⁸ in marine deposits indicates warmth
Climate Through the Ages

- Some of Earth’s history was warmer than today by as much as 15°C
- Ice age
  - Most recently 2.5 m.y.a.
  - Beginning marked by glaciers in North America
  - Interglacial periods (between glacial advances)
  - When glaciers were at their max (18,000 – 22,000 years ago) sea level 395 feet lower than today
  - This is when the sea bridge was exposed

- 20,000 years ago the sea level was so low that the English Channel didn’t even exist.
- [http://www.youtube.com/watch?v=W4gyxUJIGNAs for fu]
Climate Through the Ages

(a) Bering land bridge

© 2007 Thomson Higher Education
Climate Through the Ages

- Temps began to rise 14,000 years ago
- Then temps sank again 12,700 years ago
  - This is known as the Younger-Dryas
HELP!!
HERE COMES THE
YOUNGER DRYAS!
Climate Through the Ages

- Temps rose again to about 5,000 years ago (Holocene Maximum). Good for plants
At 1000, Europe was relatively warm. Vineyards flourished and Vikings settled Iceland and Greenland.
Climate During the Past 1000 Years

- From 1000-1300
- Huge famines due to large variations in weather. Crops suffered.
- Floods and great droughts
Climate During the Past 1000 Years

- From 1400-1800
- Slight cooling causes glaciers to expand
- Long winters, short summers. Vikings died
- Known as the Little Ice Age
Climate During the Past 1000 Years

- Little Ice Age
- 1816 – “Year Without A summer”
- Very cold summer followed by extremely cold winter
Hunters in the Snow by the Flemish painter Pieter Bruegel the Elder (1525–1569). Completed in February 1565, during the first of the many bitter winters of the Little Ice Age. Bruegel painted at least seven such snow scenes, including biblical themes such as Adoration of the Magi (in a snowstorm) and the Census at Bethlehem, and the genre was adopted by other painters of the period. Despite the cold, malaria persisted in northern Europe until the second half of the 20th century. The World Health Organization declared Holland free of the disease in 1970.
Little Ice Age

The Mer de Glace viewed from Montenvers, Mont Blanc region, French Alps. The left-hand picture is an extract from a painting by Birman soon after the Little Ice Age maximum. The right-hand photograph was taken from a similar position in 2000.
Temperature Trend During the Past 100-plus Years

- Warming from 1900 to 1945
- Cooling to 1960, then increasing to today
Temperature Trend During the Past 100-plus Years

- Sources of temperature readings
  - Over land, over ocean, sea surface temps
  - Warming in 20th century is 0.6°C
  - Is global warming natural or manmade?
A Big Argument on Climate Change

- Is the current warming a natural variation caused by natural forcing or a human-induced change related to greenhouse gases?

To answer this question, we have to know the causes/forcing for temperature changes!
Causes of Climate Change

- How can climate change?
  - Emissions of CO₂ and other greenhouse gases are by no means the only way to change the climate.

- Changes in incoming solar radiation
- Changes in Continent drift
- Changes in the composition of the atmosphere
- Changes in the earth’s surface
- etc
Natural Climate Change

- **External Forcing:**
  - The agent of change is outside of the Earth-atmosphere system

- **Internal Forcing:**
  - The agent of change is within the Earth-atmosphere system itself
External Forcing

- Variations in solar output
- Orbital variations
- Meteors
Sunspots are the most familiar type of solar activity. The Sun Spot Number has a clear cycle.
THE SOLAR CYCLE

- Sunspot numbers increase and decrease over an 11-year cycle
- Observed for centuries.
- Individual spots last from a few hours to months.
- Studies show the Sun is in fact about 0.1% brighter when solar activity is high.

More sun spot number, brighter the sun –namely, stronger the solar radiation.
Climate Change and Variations in Solar Output

- **Sunspots** – magnetic storms on the sun that show up as dark region

- **Maximum sunspots**, maximum emission (11 years)

- **Maunder minimum** – 1645 to 1715 when few sunspots happened
THE MAUN德尔 MINIMUM

- An absence of sunspots was well observed
  - from 1645 to 1715.
- The so-called “Maunder minimum” coincided with a cool climatic period in Europe and North America:
  - “Little Ice Age”
- The Maunder Minimum was not unique.
- Increased medieval activity
  - correlated with climate change.
Warm during Cretaceous

High CO₂ may be responsible for the initiation of the warming.

- Higher water vapor concentration leads to increased latent heat transport to high latitudes.

- Decreased sensible heat transport to high latitudes results from decreased meridional temperature gradient.

- Thermal expansion of seawater increased oceanic heat transport to high latitudes.

The Arctic SST was 15°C or higher in mid and last Cretaceous. Global models can only represent this feature by restoring high level of CO₂.
Cretaceous

being the last period of the Mesozoic era characterized by continued dominance of reptiles, emergent dominance of angiosperms, diversification of mammals, and the extinction of many types of organisms at the close of the period
Asteroid impact initializes chain of forcing on climate

**Short-term forcing:** The kinetic energy of the bolide is transferred to the atmosphere sufficient to warm the global mean temperature near the surface by 30 K over the first 30 days. The ejecta that are thrown up by the impact return to Earth over several days to weeks produce radiative heating.

**Long-term forcing:** Over several weeks to months, a global cloud of dust obscures the Sun, cooling the Earth’s surface, effectively eliminating photosynthesis and stabilizing the atmosphere to the degree that the hydrologic cycle is cut off.

The sum of these effects together could kill most flora. The latter results in a large increase in atmospheric CO2, enabling a large warming of the climate in the period after the dust cloud has settled back to Earth.

This **hypothesis** is proposed to 65 Million years ago for one possible reason that kills the dinosaurs.
Temperature: the last 400,000 years
From the Vostok ice core (Antarctica)
Fig 4.5

High summer sunshine, lower ice volume
Climate During the Past 1000 Years

- Little Ice Age
- 1816 – “Year Without A summer”
- Very cold summer followed by extremely cold winter
The Year Without Summer

- The Year Without a Summer (also known as the Poverty Year, Eighteen Hundred and Froze to Death, and the Year There Was No Summer) was 1816, in which severe summer climate abnormalities destroyed crops in Northern Europe, the Northeastern United States and eastern Canada. Historian John D. Post has called this "the last great subsistence crisis in the Western world".

- Most consider the climate anomaly to have been caused by a combination of a historic low in solar activity and a volcanic winter event; the latter caused by a succession of major volcanic eruptions capped off by the Mount Tambora eruption of 1815, the largest known eruption in over 1,600 years.
the 1815 (April 5–15) volcanic eruptions of Mount Tambora on the island of Sumbawa, Indonesia
Climate Change and Atmospheric Particles

- Sulfate aerosols
  - Put into the atmosphere by sulfur fossil fuels and volcanoes

- Mount Pinatubo is an **active stratovolcano** located on the island of **Luzon**, at the intersection of the borders of the **Philippine provinces**.
Coupled orbital variation and snow-albedo feedback to explain and predict ice age

He suggested that when orbital eccentricity is high, then winters will tend to be colder when earth is farther from the sun in that season. During the periods of high orbital eccentricity, ice ages occur on 22,000 year cycles in each hemisphere, and alternate between southern and northern hemispheres, lasting approximately 10,000 years each.
Further development of orbital forcing by Milutin Milankovitch

Mathematically calculated the timing and influence at different latitudes of changes in orbital eccentricity, precession of the equinoxes, and obliquity of the ecliptic.

Deep Sea sediments in late 1970’s strengthen Milankovitch cycles theory.
Orbital changes

- **Milankovitch theory:**
  - Serbian astrophysicist in 1920’s who studied effects of solar radiation on the irregularity of ice ages
  - Variations in the Earth’s orbit
    - Changes in shape of the earth’s orbit around sun:
      - *Eccentricity* (100,000 years)
    - Wobbling of the earth’s axis of rotation:
      - *Precession* (22,000 years)
    - Changes in the tilt of earth’s axis:
      - *Obliquity* (41,000 years)
Climate Change and Variations in the Earth’s Orbit

- **Eccentricity**
  - Change in the shape of the orbit (from circular to elliptical)
  - Cycle is 100,000 years
  - More elliptical, more variation in solar radiation

Presently in Low eccentricity
Eccentricity affects seasons

Small eccentricity $\rightarrow$ 7% energy difference between summer and winter
Large eccentricity $\rightarrow$ 20% energy difference between summer and winter

Large eccentricity also changes the length of the seasons
Climate Change and Variations in the Earth’s Orbit

- **Procession**
  - Wobble of the Earth as it spins
  - The Earth wobbles like a top
  - Currently, closest to the sun in January
  - In 11,000 years, closest to the sun in July
Axis tilt: period ~ 41,000 years

Earth's axial tilt varies from 24.5 degrees to 22.1 degrees at periods of close to 41,000 years.

Axial tilt affects the distribution of solar radiation on Earth's surface. When the tilt is decreased, polar regions receive less sunlight; when it is increased, polar regions receive more sunlight.
Ranges from 21.5 to 24.5 with current value of 23.439281
Small tilt = less seasonal variation
cooler summers (less snow melt),
warmer winters  -> more snowfall because air can hold more moisture

Obliquity of the Nine Planets

Source: http://www.solarviews.com/cap/misc/obliquity.htm
Activity

Consider the fact that today, the perihelion of the Earth’s orbit around the sun occurs in the Northern Hemisphere winter. In 11,000 years, the perihelion will occur during Northern Hemisphere summer.

A) Explain how the climate (i.e. temperature of summer compared to temperature of winter) of the Northern Hemisphere would change in 11,000 years just due to the precession. the summer would warmer!

B) How would this affect the presence of Northern Hemisphere glaciers (growing or decaying)? Assume growth is largely controlled by summer temperature. the glacier would decay
Earth’s orbit: an ellipse

- **Perihelion**: place in the orbit closest to the Sun
- **Aphelion**: place in the orbit farthest from the Sun
Seasonal weather patterns are shaped primarily by the 23.5-degree tilt of our planet's spin axis, not by Earth's elliptical orbit. explains George Lebo, a professor of astronomy at the University of Florida. "During northern winter the north pole is tilted away from the Sun. Days are short and that makes it cold. The fact that we're a little closer to the Sun in January doesn't make much difference. It's still chilly -- even here in Florida!"

http://science.nasa.gov/headlines/y2001/ast04jan_1.htm
If the earth’s tilt was to decrease, how would the summer temperature change at our latitude

1. Warmer summer

2. Cooler summer

3. Summer would stay the same

4. Impossible to tell
A: How would climate change

1. Warmer winters, cooler summers
2. Warmer winters, warmer summers
3. Cooler winters, warmer summers
4. Cooler winter, cooler summer
B: How would glaciers change?

1. Glaciers would grow
2. Glaciers would decay
3. Glaciers would stay about constant
Internal Forcing

- **Plate tectonics/mountain building**
- **Volcanoes**

- **Ocean changes**
  - Earth surface change (snow albedo, land cover change, vegetation change)
    - Urbanization, snow albedo change, etc

- **Chemical changes in the atmosphere (i.e. CO₂)**
  - Natural variations
Internal Forcing

- Continent drift
  see the following 3 ppt
Climate Change, Plate Tectonics, and Mountain-building

- Theory of plate tectonics – moving of plates like boats on a lake
- Evidence of plate tectonics
  - Glacial features in Africa near sea level
  - Fossils of tropical plants in high latitudes
In 1915, German scientist Alfred Wengener first proposed continental drift theory and published book *On the Origin of Continents and Oceans*

Continental drift states:
In the beginning, a supercontinent called Pangaea. During Jurassic, Pangaea breaks up into two smaller supercontinents, Laurasia and Gondwanaland. By the end of the Cretaceous period, the continents were separating into land masses that look like our modern-day continents
Consequences of continental drift on climate

- Polarward drifting of continents provides land area for ice formation → cold climate

- Antarctica separated from South America reduced oceanic heat transport → cold climate

- Joint of North and South America strengthens Gulf Stream and increased oceanic heat transport → warm climate

- Uplift of Tibetan Plateau → Indian monsoon