Paleoclimatology

Paleoclimatology

- Read Read Ahrens (*Meteorology Today*, 6th Edition) pp. 505 -520 (up until *Carbon Dioxide, Greenhouse Effect and Recent Global Warming*).

Paleoclimatology

- **First 2 Billion Years:**
  - Earth was probably ice-free
  - Weak sun (up to 30% weaker than today)
  - Greenhouse effect was much enhanced over today's standards.
    - » Volcanoes were very active (the interior of the Earth was hotter than today).
    - » Volcanic outgassing of CO_2 and H_20 (i.e., greenhouse gasses) occurred regularly and on much larger scales than today.
  - The greenhouse effect produced by volcanic outgassing provided a much warmer mean Earth temperature than today. This enhanced greenhouse effect offset the influence of a weak sun.

Paleoclimatology

- **The Most Recent 2 Billion Years:**
  - Long-term climate change was influenced by:
    - » High-latitude continents
    - » Continents over the poles
    - » Ocean circulation changes
    - » Sea level changes
    - » Mountain building
    - » Reduced volcanic activity
    - » Increased solar intensity
  - Short-term climate change was influenced by:
    - » Orbital changes
      - Eccentricity
      - Obliquity
      - Precession
    - » Sunspot Activity
    - » Humans

- Reference: Crowley, T.J., and North, G.R. (1991). *Paleoclimatology*. Oxford. ISBN 0195105338

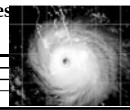
Paleoclimatology

- **How Do We Know About Past Climates?**
  - (Credits: Hugh Anderson and Bernard Walter, NASA http://vathena.arc.nasa.gov/curric/land/global/climchng.html).
- Ancient records of global temperature conditions can be extracted from seabed rock cores in ancient ocean floors. This temperature indicator is related to the O_{16} to O_{18} ratio found in seabed rock cores.
  - The ratio varies as a function of surface ice volume conditions which existed when that sea floor sediment was created.
- The geological record of carved mountain valleys, scratched bedrock, and glacial debris and moraines gives evidence of the past several million years.
- Recently, cores have been removed from the ice at Vostok Station in Antarctica. The longest cores are about 2000 meters, sampling layers of ice deposited as early as 160,000 years ago. The ice trapped bubbles of air when it froze. The ra[illegible] oxygen isotopes in this air indicates the average air temperature at the time the bubble was trapped in ice. The bubbles also trap atmospheric greenhouse gases that can be measured.

- Fossil plants and the distribution of pollen show that vegetation has changed, consistent with changing climate. Ancient Earth's geological history has been re-created from ice cores and deep sea cores taken from ancient seabeds. Pollen from plants, buried in shallow deposits of earth, indicate the distribution of vegetation since the last glaciation, about 20,000 years ago.
- Tree rings provide a record of the weather back 3,000 years in some cases, and hundreds of years in many areas.
- The historical record speaks to us for some 2,000 years and there have been real quantitative measurements since about 1850.

Paleoclimatology

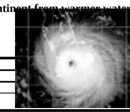
- **Only 5% of the Earth's history is dominated by the existence of significant ice-sheets. Thus, 5% of Earth's history is dominated by *Ice Epochs***
  - **Ice Epoch: Long-term periods when the Earth is preconditioned for ice ages.**
  - **Ice Age: Short-term period when extensive glaciation is observed over the earth.**
    - » **http://www.homepage.montana.edu/~geol445/hyperglac/time1/time.htm**
- **Presently, Earth is in an Ice Epoch, but the present climate is representative of an inter-glacial (i.e., climatic optimum) period between ice ages**



Applied Climatology

Continental Drift and the Impact of Ice-Epoch Formation

- **Continental drift factors favoring glaciation**
  - **Majority of Earth's continental land areas are found in middle and high latitudes.**
    - » **Continents have a low specific heat capacity**
    - » **Continents provide a *platform* for glaciation**
    - » **Glaciation would start first in high elevations.**
      - **The more mountains, the larger the extent of initial glaciation**
    - » **Once continental ice forms, it increases the Earth's albedo (i.e., feedback process).**
  - **Pole covered by a small, isolated continent.**
    - » **Continent must be confined to high latitudes.**
      - **This position promotes extreme cold in high latitudes**
    - » **Deep ocean must be directly adjacent to continental shorelines.**
      - **Vigorous circumpolar current insulates the polar contin... in lower latitudes.**



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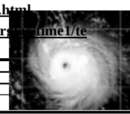
Continental Drift Impact on Ice-Epoch Formation

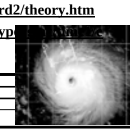
- » **Allows for the formation of cold bottom water in oceans.**
  - **Cold bottom water becomes a CO_2 sink.**
  - **Bottom water has a residence time of thousands of years.**
  - **Major ocean basins of the world must have an unobstructed deep connection to the region where this bottom water forms. (Allows this bottom water to spread world-wide.)**
- – **Mountain building exposes more rock to chemical weathering.**
  - » **Increased weathering reduces amount of CO_2 in atmosphere.**
- **Plate Tectonics Animations:**
  - **http://www.scotese.com/newpage13.htm**
- **Other references:**
  - **http://www.pbs.org/wgbh/nova/ice/continents/**
  - **http://www.pbs.org/wgbh/nova/everest/earth/birth.h**
  - **http://www.homepage.montana.edu/~geol445/hypers... ime1/tectonics.htm**



Applied Climatology

Variation of the Earth-Sun Orbital Parameters (Milankovitch Cycle)

- **Who is Milankovitch?**
  - **http://www.emporia.edu/earthsci/student/howard2/man.htm**
- **Eccentricity:**
  - **Changes in the elliptical shape of the Earth's orbit around the sun.**
  - **100,000 year periodicity.**
  - **With large eccentricity, the Earth will be farther from the sun at various times of the year.**
  - **Currently, the Earth's orbit is nearly circular and becoming more so (ie., less eccentricity)**
    - » **http://www.emporia.edu/earthsci/student/howard2/theory.htm**
    - » **http://www.homepage.montana.edu/~geol445/hyp... ccentric.JPG**



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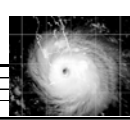
Variation of the Earth-Sun Orbital Parameters (Milankovitch Cycle)

- **Obiliquity:**
  - **The angle between the Earth-Sun orbital plane and the Earth's equatorial plane.**
  - **41,000 year periodicity**
  - **Angle varies between 21.8 and 24.4 degrees.**
  - **Angle is currently at 23.5 degrees and is decreasing (ie., less seasonality).**
  - **Either Uranus or Neptune has an obliquity of close to 90 degrees (ie., massive seasonality)**
    - » **http://www.emporia.edu/earthsci/student/howard2/theory.htm**
    - » **http://www.homepage.montana.edu/~geol445/hyperglac/time1/axial.JPG**



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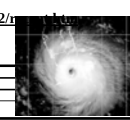
Variation of the Earth-Sun Orbital Parameters (Milankovitch Cycle)

- **Precession:**
  - **A slow change in the time of year that the Earth is closest and farthest from the sun.**
  - **23,000 year periodicity**
  - **Presently, the Earth is closest to the Sun (perihelion) in January and farthest from the Sun (aphelion) in July.**
    - » **http://www.emporia.edu/earthsci/student/howard2/theory.htm**
    - » **http://www.homepage.montana.edu/~geol445/hyperglac/time1/precess.JPG**
- **Recent Work:**
  - **http://www.emporia.edu/earthsci/student/howard2/r...**



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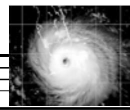
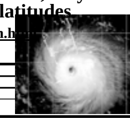
Milankovich-Forced Ice Ages

- At times when Northern Hemisphere summers are coolest (farthest from the Sun due to precession and greatest orbital eccentricity) and winters are warmest (minimum tilt), snow can accumulate on and cover broad areas of North America and Europe. At present, only precession is in the glacial mode, with tilt and eccentricity not favorable to glaciation
  - (From NOAA's National Geophysical Data Center)

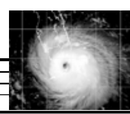


Ice Ages (continued)

- Even when all of the orbital parameters favor glaciation, the increase in winter snowfall and decrease in summer melt would barely be enough to trigger glaciation, and would not grow large ice sheets.
- Ice sheet growth requires the support of positive feedback loops, the most obvious of which is that snow and ice have a much higher albedo than ground and vegetation, thus ice masses tend to reflect more radiation back into space, thus cooling the climate and allowing glaciers to expand.
- In order for ice sheets to grow to massive size, they must form on continents located at high latitudes.
  - http://www.pbs.org/wgbh/nova/everest/earth/birth.h



- http://www.hartwick.edu/geology/work/VFT-so-far/glaciers/glacier1.html
- http://www.mnh.si.edu/museum/VirtualTour/Tour/First/IceAge/
- http://www.sciencenews.org/sn_arc98/8_22_98/fob8.htm
- http://jrscience.wcp.muohio.edu/html/globalchange.html#anchor4241663



General Paleoclimate References

- http://vathena.arc.nasa.gov/curric/land/global/climchng.html