Geologic record of global climate change: Context for modern global warming

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Important Considerations

- Scales of climate change
- Forcing mechanisms
- Feedback systems

Scales of Change

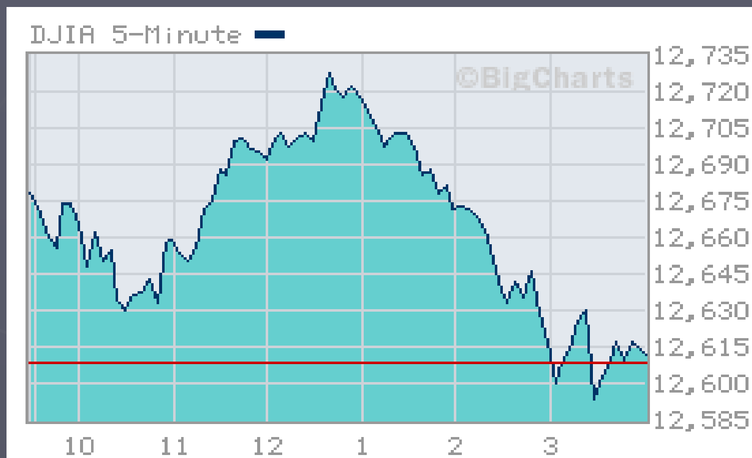
The Importance of Scale

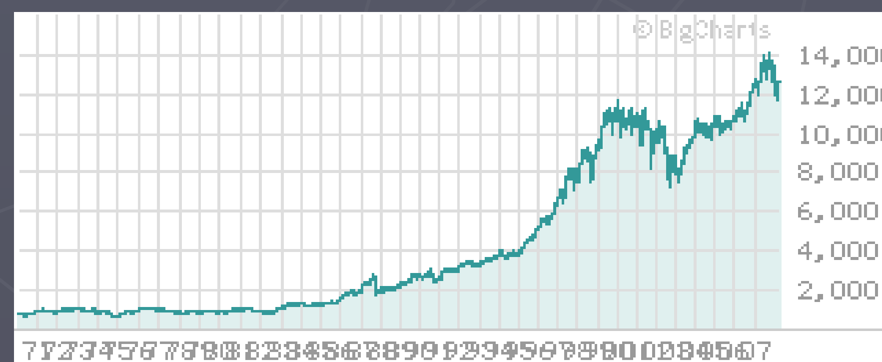
- Trends are always scale-dependent
- The meaning of a trend is tied to the temporal scale being considered.
- Climate trends must always be discussed in the context of a time scale.
- Causal mechanisms vary between time scales

Trends and Time Scales

- The stock market provides an example of how trends change at different time scales

Stock Market Trends





(Figures from cnn.com)

Forcing Mechanisms

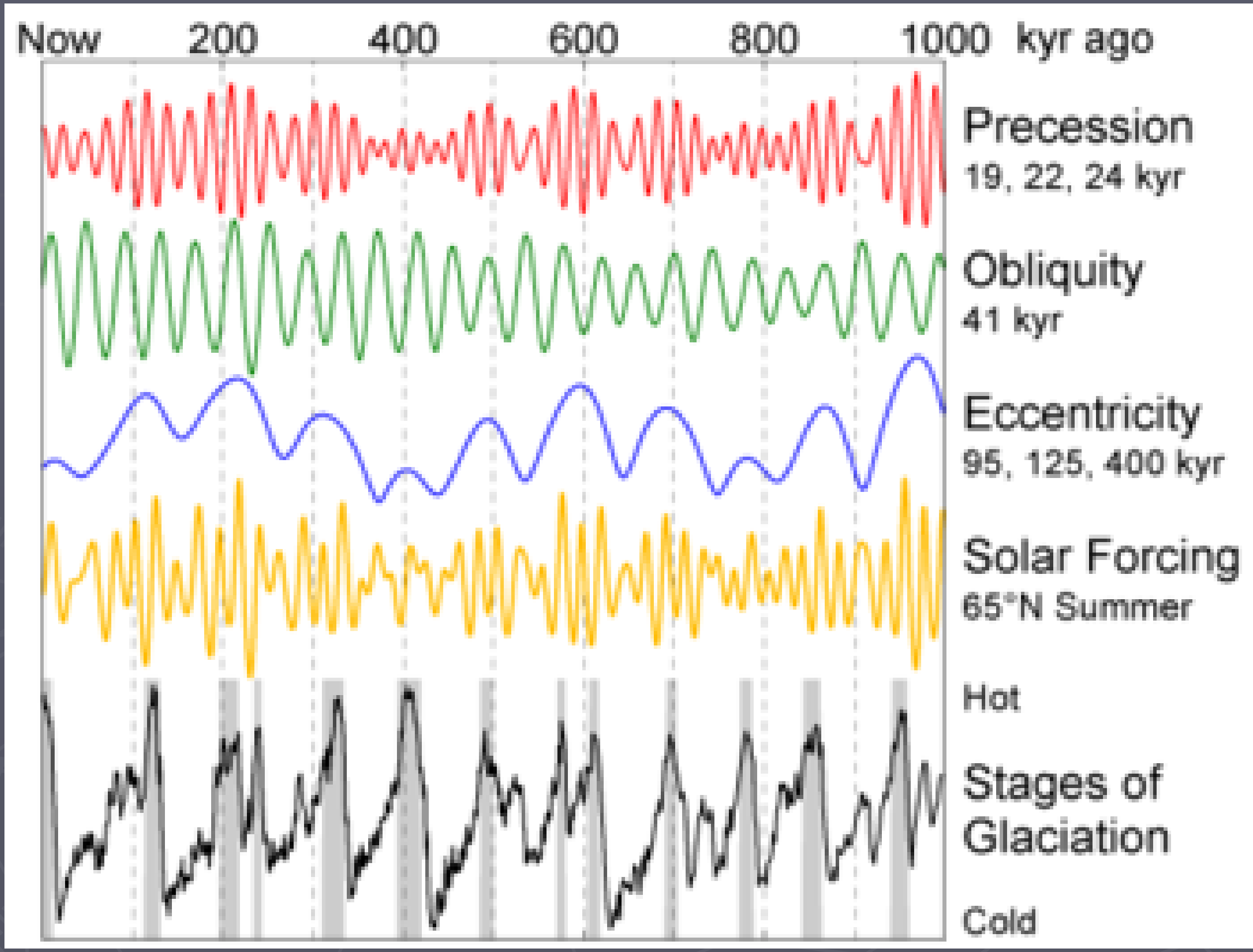
Solar Irradiance

- Long-term change in solar luminosity
- Sun-like stars increase their luminosity through time as the hydrogen in the core is converted to Helium
  - At around 4.6 BYA when the Earth first cooled, the Sun was only 70-75% of its present luminosity

Solar Irradiance

- Changes in solar radiation due to Earth's orbital variations
  - Obliquity of the Earth's axis
  - Precession of the Earth's axis
  - Eccentricity of the Earth's orbit

Milankovitch Cycles



http://en.wikipedia.org/wiki/Milankovitch_cycles

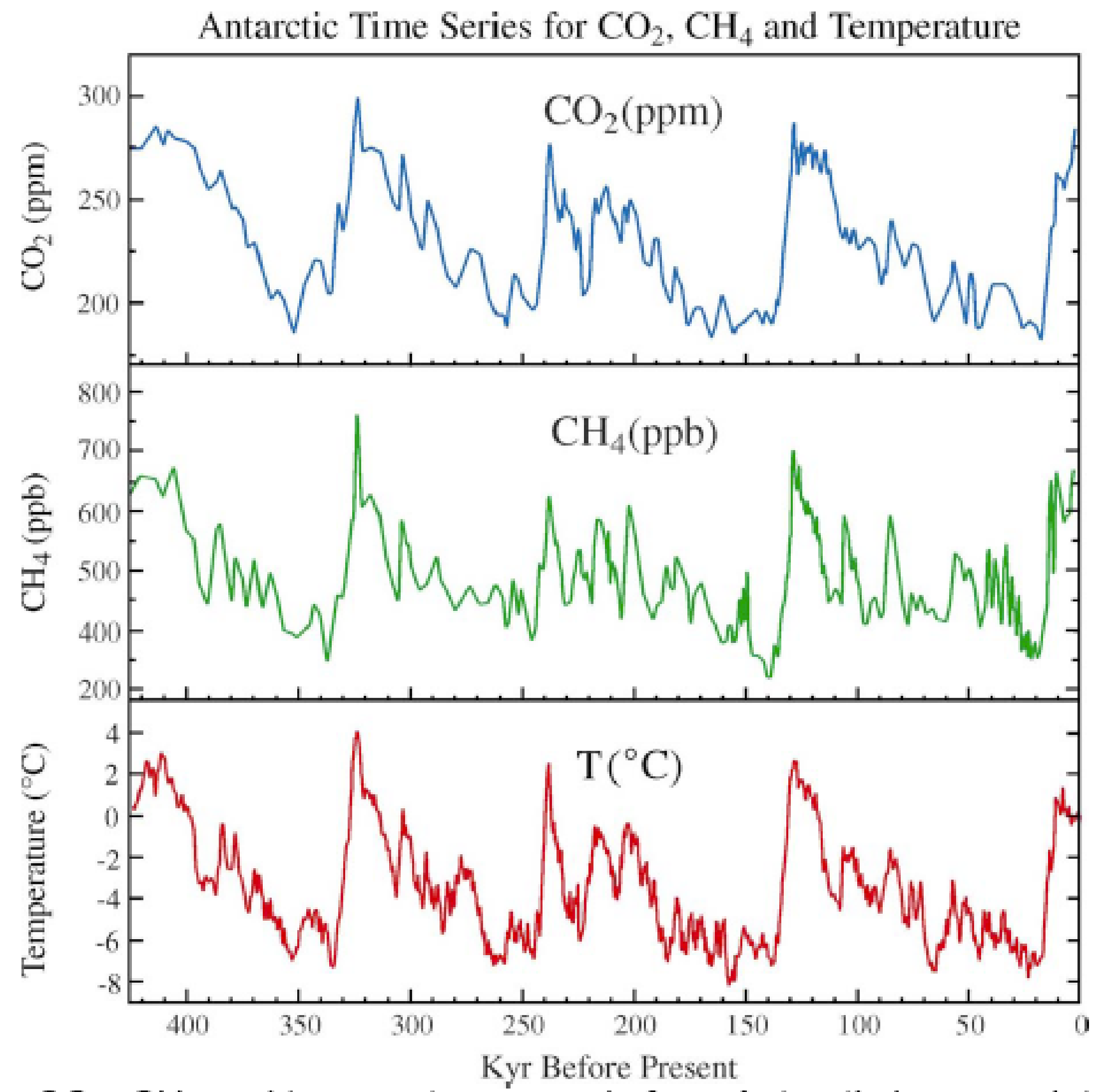
Solar Irradiance

- Short-term changes in Sun’s magnetic field on a 10-11 year cycle
- Variations in luminosity related to sun spot cycles
- Periods of higher irradiance also periods of greater variability

(P. Foukal, et al., 2006, Variations in solar luminosity and their effect on the Earth’s climate, Nature, vol. 443, p.161-166.)

Atmospheric Composition

- Concentration of "greenhouse gases"
  - CO_2 and Methane especially important
- Long-term changes in atmospheric concentrations over Earth history
  - Result of the balance of processes that release and store CO_2 and methane



CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

Sources of CO_2

- Volcanic gases
- Oxidation of organic matter
- Respiration by organisms

Release of Volcanic Gases

Image of Pu’u O’o crater at Kilauea from the Volcano National Observatory website

Removal of CO_2

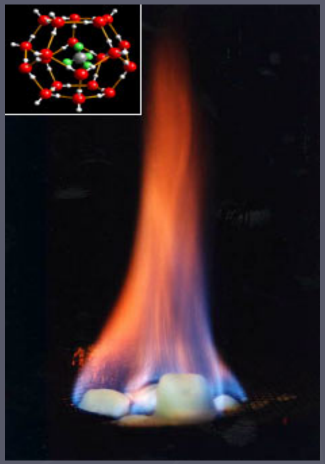
- Chemical weathering of silicate rocks
  - Precipitation of CaCO3 (limestone)
- Photosynthesis
  - Increase in living biomass
- Burial of organic matter
- Burial of carbon in carbonate rocks

Carbon Reservoirs

- Carbonate rocks - Limestone
- Oceans
- Biomass
- Soils and permafrost
- Wetlands and peatlands
- Methane ices (clathrates) on seafloor
- Coal, oil, gas

Carbon Reservoirs

Permafrost



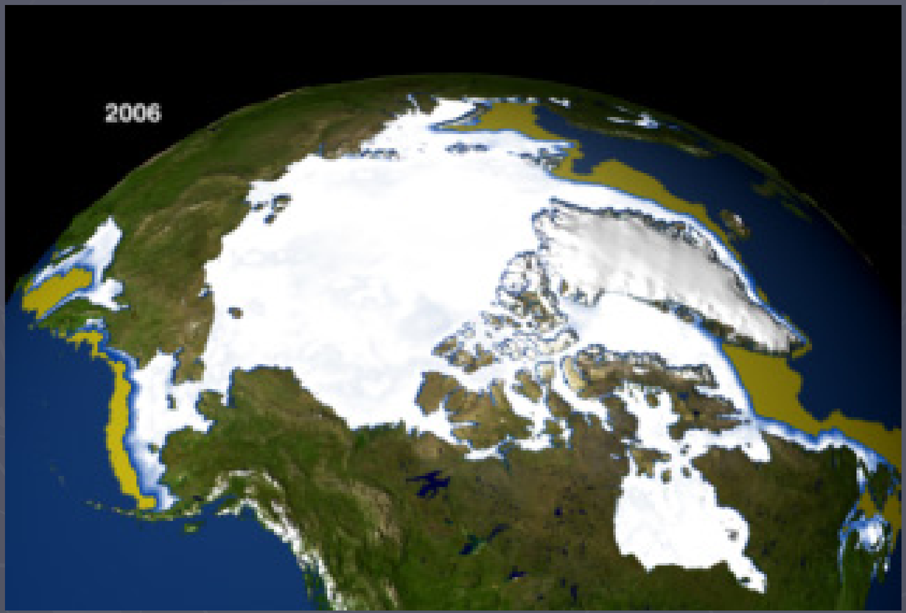
Methane Ice

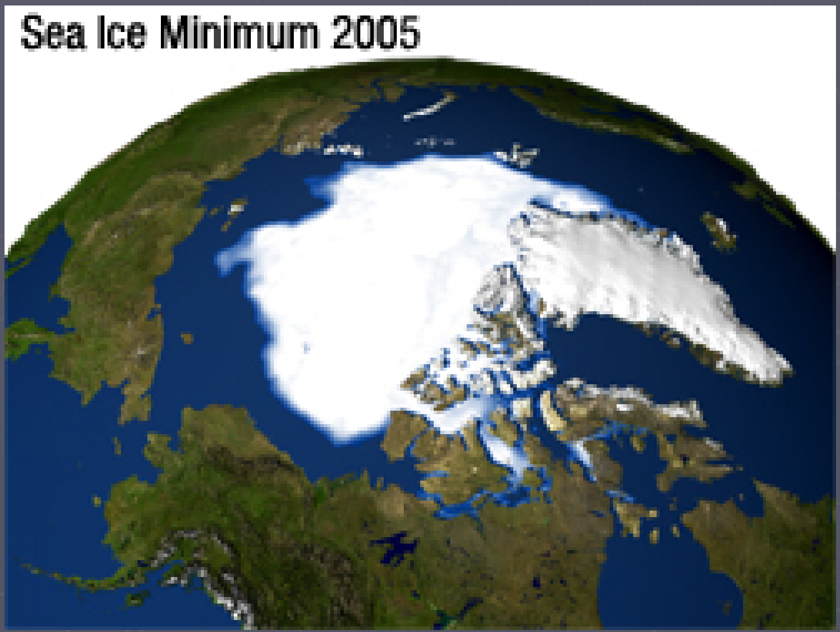
Wetlands, Bogs

Limestone

(Images from Wikipedia.com)

Feedback Systems
Sea Ice and Albedo

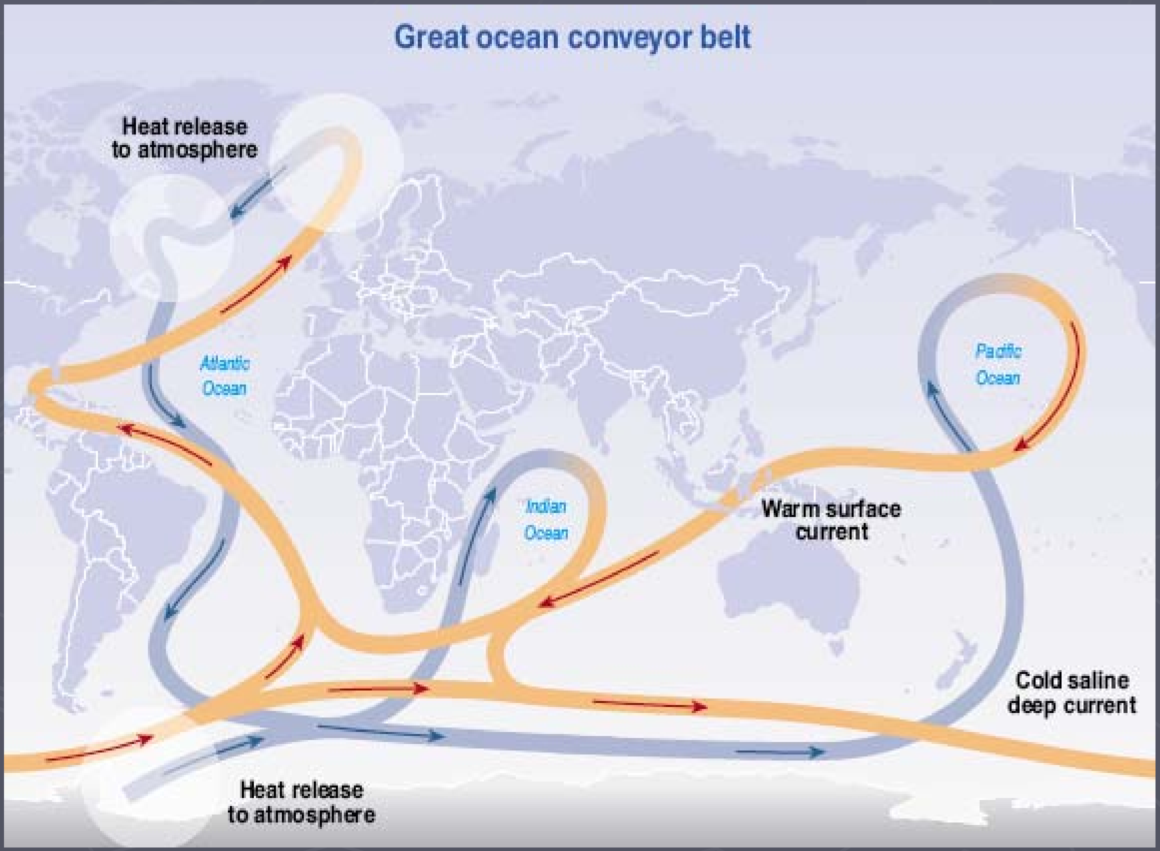




(Images from http://www.nasa.gov)

Feedback Systems
Ocean Circulation

Sinking of cold saline waters with arctic sea ice formation



IPCC Climate change 2001: Synthesis Report

Feedback Systems

- Melting of permafrost
- Melting of methane ices
  - Release of CO_2 and Methane

Icehouse and Greenhouse

Triggers for global Icehouse

- Increased carbon storage
  - Wetlands and peatlands
  - Coal formation
- Increased weathering
  - Large areas of uplifted mountains in low latitudes

Times of Mountain Building and Accelerated Weathering

- Assembly of Pangea - uplift of Appalachian Mountain
  - Late Pennsylvanian and early Permian
- Collision of India with Asia - uplift of Himalayas

Coal Formation over Time

- Huge volume of carbon removed from the atmosphere by extensive wetlands and swamps during the late Carboniferous (Pennsylvanian) and early Permian periods (320-270 million yrs ago).
- This time represents the greatest time of coal formation in Earth history.

(Robert A. Berner, 2004, The Phanerozoic Carbon Cycle: CO_2 and O_2: Oxford University Press.)

Model CO_2 and Temperature

- Atmospheric C0_2 determined by both models and measured proxies were are their lowest values in the late Carboniferous and early Permian, and Pleistocene.
- These periods were both times of global icehouse conditions and extensive continental glaciation.

(Robert A. Berner, 2004, The Phanerozoic Carbon Cycle: CO_2 and O_2: Oxford University Press.)

Runaway Icehouse

- Carbon storage and weathering remove $CO_{2.}$ Increased O_2 destroys methane.
- Increase in ice cover with decline in CO_2 and methane
- Increased albedo reflects more solar radiation causing further cooling

Global Greenhouse

- A runaway greenhouse occurred in the late Permian culminating at the end of the Permian (~248 million yrs ago).

Global Greenhouse

- Trigger - Increase in influx of CO_2 into atmosphere
  - Large scale basaltic volcanism
- Reduced weathering
  - Reduced rates of $C0_2$ removal

Runaway Greenhouse

- Loss of ice cover
  - Reduction of albedo and increased absorption of solar radiation by oceans
- Disruption of ocean circulation
  - Sinking of cold saline arctic water disrupted
  - Warming of deep ocean and decrease in oxygen
  - Stratified ocean

Runaway Greenhouse

- Warming of stratified ocean
  - Anoxic sulfur bacteria increase
  - Release of H_2S
- Melting of methane ices
  - Release of methane

CO_2 and Extinction

- The runaway greenhouse and the end of the Permian coincided with the greatest mass extinction in Earth history.
- Other times in Earth history with evidence of runaway greenhouse conditions also show high extinction rates.

(Peter D. Ward, 2007, Under a Green Sky: Smithsonian Books, p.135.)

A Future Runaway Greenhouse?

- Rapid loss of arctic sea ice
  - Reduced albedo
  - Disruption of thermohaline circulation
- Warming of deep ocean
  - Melting of methane ices
- Thawing of permafrost
  - Release of stored carbon