MET 200 Lecture 27 Climate Change

- What is climate?
- What controls our climate?
- Past climates

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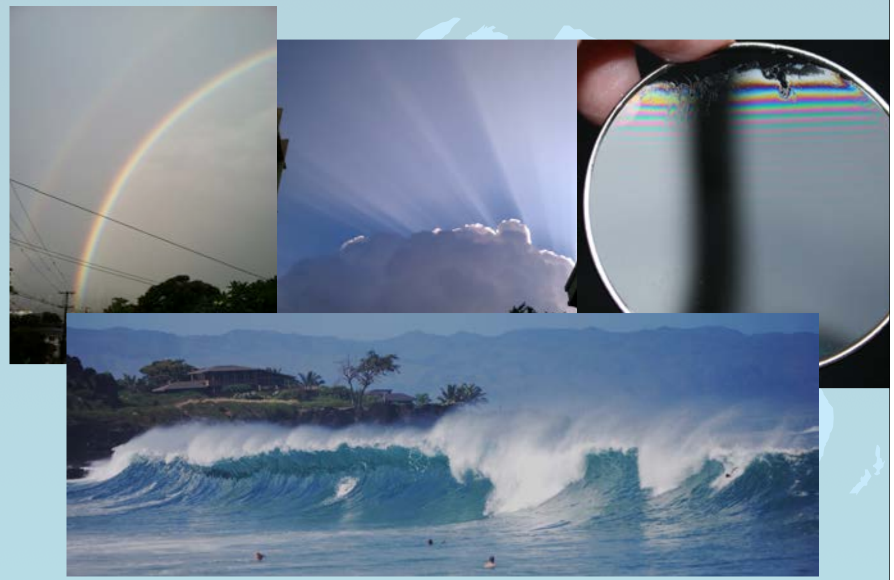
Observation Assignment



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Observation Assignment Due

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Previous Lecture

Air Pollution – Elevated levels of aerosols and harmful gases

- Air pollution episodes
- Acid Rain
- Ozone hole
- Vog

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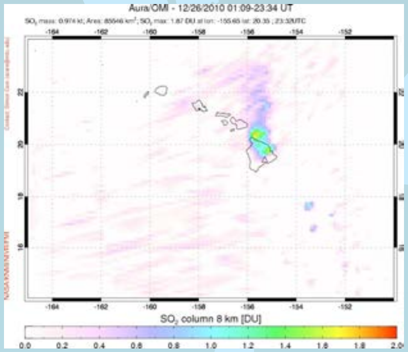
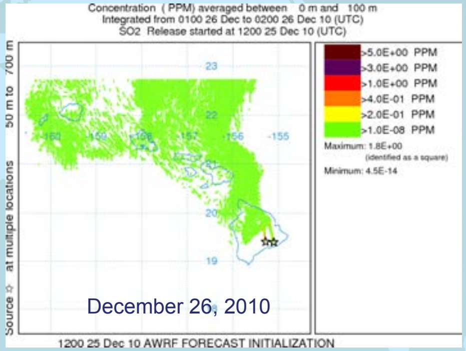
Satellite Validation of Vog Model





Vog model predictions can help those who are sensitive to vog to plan their activities.

MET 200 Lecture 27 Climate Change

The climate of the Earth as a whole is controlled by the balance between incoming and outgoing radiation.

Climate can be defined as the accumulation of daily and seasonal weather events over a long period of time.

Local Climate

Is controlled by

- local radiation balance
- altitude
- location - latitude and longitude - length of day/night
- geography - near coast or not - sea breeze
- biology - evapotranspiration, forested or deforested
- surface - ice, snow, water
- proximity to ocean currents - Gulf Stream
- Mean location of polar front - jet stream

Radiation Concepts

Solar constant - Amount of solar radiation passing through a unit area at the top of the earth's atmosphere perpendicular to the direction of the radiation at the mean Earth-sun distance.

Solar Constant = $S = E_s*(R_s / R_{sE})^2$

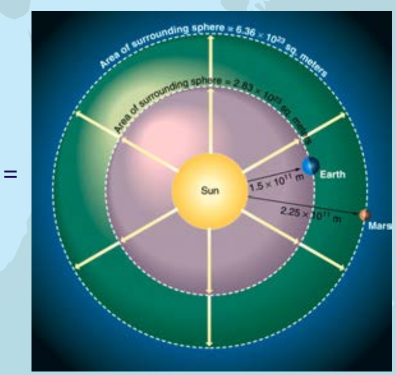
At the sun's surface:

$E_s = \sigma T^4 = 5.67*10^{-8}$ W/(m^2*K^4)*(5800K)^4 = 6.416X10^6 W/m^2

The radius of the sun $R_s = 6.955x10^8$ m

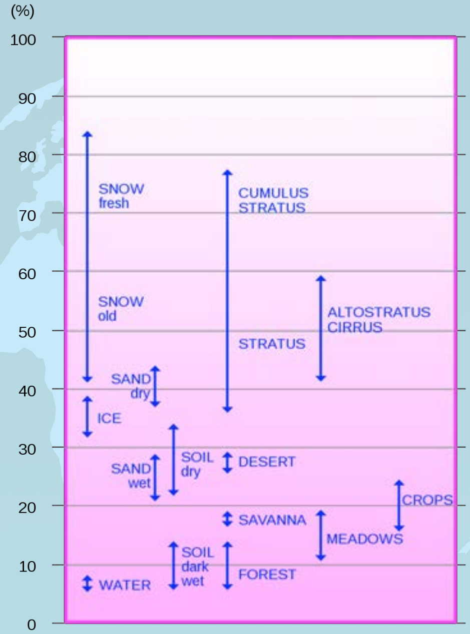
Distance of sun to Earth $R_{sE} = 1.5x10^{11}$ m

$S = E_S(R_s / R_{sE})^2 = 1379$ W/m^2



Reflection and Scattering of Incoming Sunlight

- Albedo: the ratio of reflected radiation to incident radiation
- Surface albedo varies geographically and in time.



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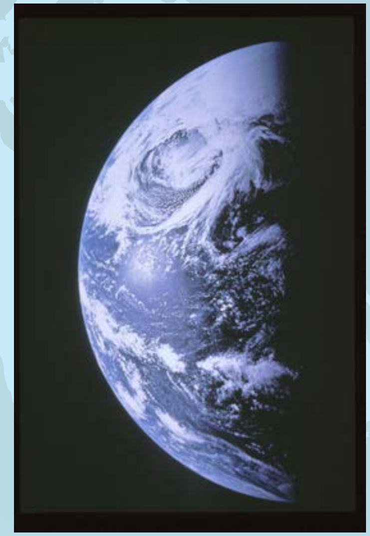
Impact of Reflection (Albedo)

More clouds and ice at higher latitudes means higher albedo.



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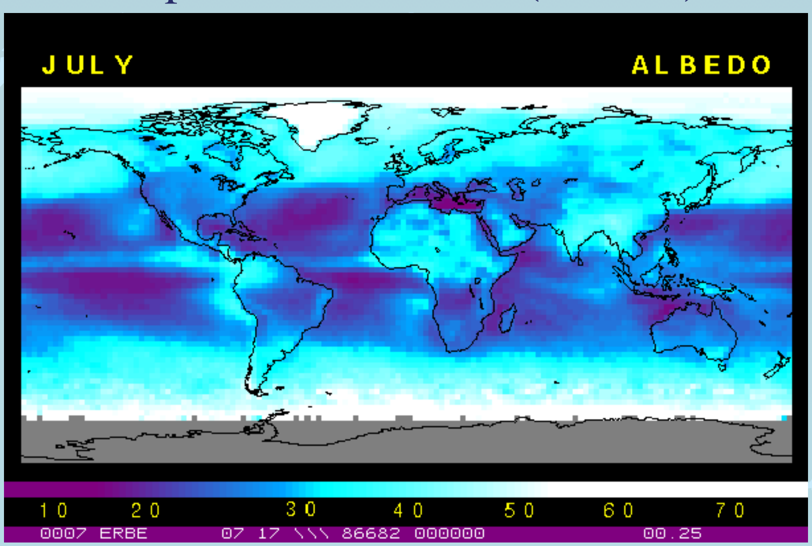
Impact of Reflection (Albedo)



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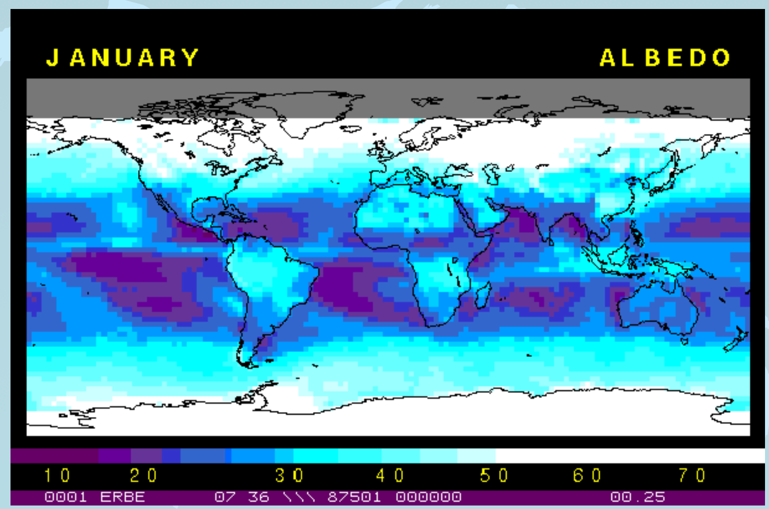
Impact of Reflection (Albedo)



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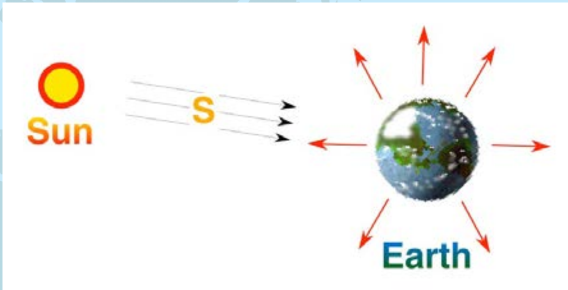
Earth Radiation Balance

Without an atmosphere: radiative equilibrium temperature = -18°C



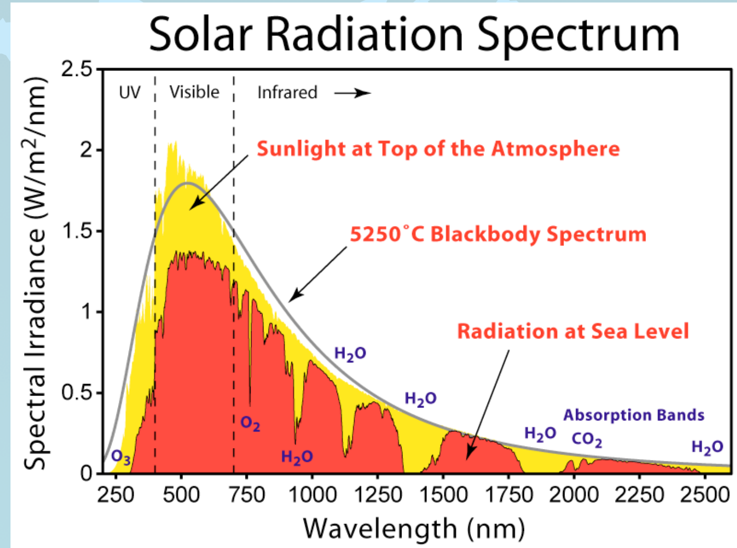
Incoming Energy (visible) = Outgoing Energy (IR)

$S(1-a)\ \pi r^2 = \sigma T_E^4\ (4\pi r^2)$

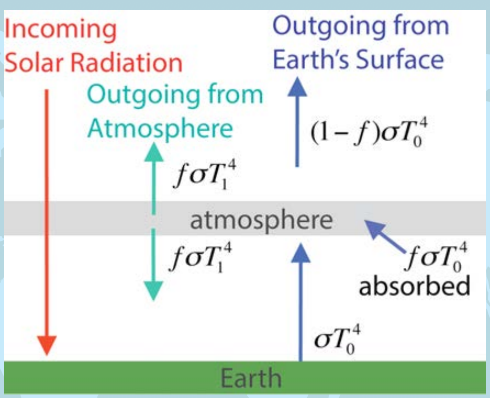
$T_E = [S(1-a)/4\sigma]^{1/4} = 255K = -18^{\circ}C$

Where S = solar constant, a = albedo, and σ = constant.

Atmospheric Absorption of Solar Radiation

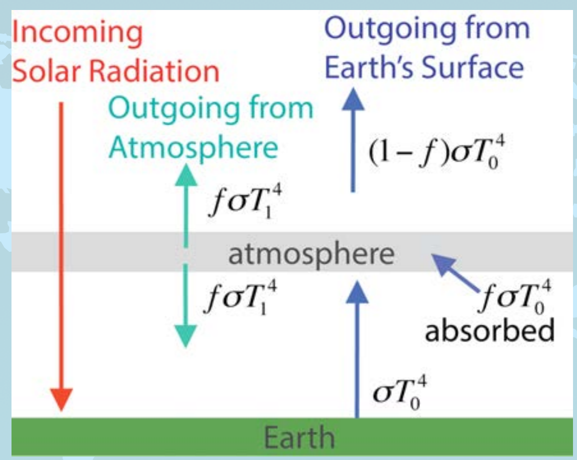


A Simple Greenhouse Model



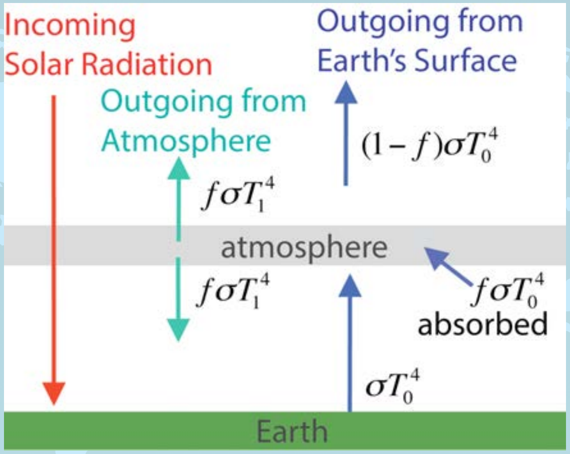
- Incoming solar radiation = (0.7*1379)/4 W m^{-2} = 241 W m^{-2}
- IR flux from surface = σT_o^4
- Assume atmospheric layer has an absorption efficiency = *f ~0.77*
- Kirchhoff's law: absorptivity = emissivity
- IR flux from atmospheric layer = $f\sigma T_1^4$ (up and down)

A Simple Greenhouse Model



- Balance at top of atmosphere $f\sigma T_1^4 + (1-f)\sigma T_o^4 = 241$
- Balance for atmospheric layer $f\sigma T_1^4 + f\sigma T_1^4 = f\sigma T_o^4$
- Balance at the surface $\sigma T_o^4 = 241 + f\sigma T_1^4$

A Simple Greenhouse Model

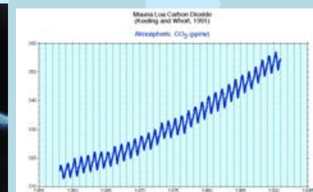


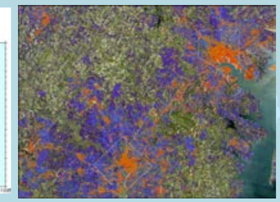
- We have two equations and two unknowns, can solve.
- T_o = 288 K ; T_1 = 241 K
- Greenhouse gases affect *f*; as *f* increases, T_o and T_1

Climate Change = Changes to the Earth's Radiation Balance

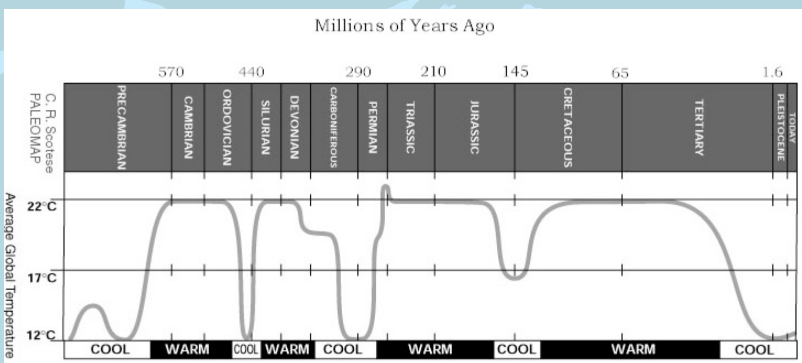
External Forcing
- Astronomical
- Solar Output
- Orbital Changes
- Interplanetary dust
- Collision with comet/asteroid

Internal Forcing
- Atmospheric composition
- Surface Characteristics
- Ocean Currents
- Volcanic Activity
- Continental Drift



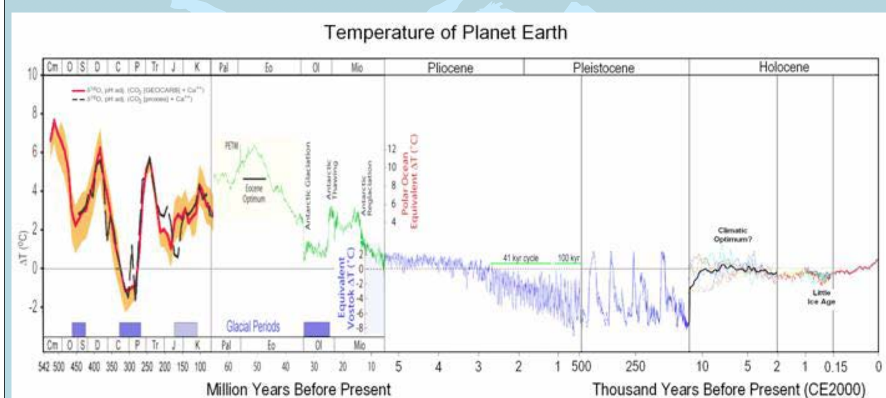


700 Million Years of Past Climate



Throughout most of earth's history the temperature was warmer and wetter than today

Warm periods of hundreds of millions of years (think dinosaurs) interrupted by glacial periods.

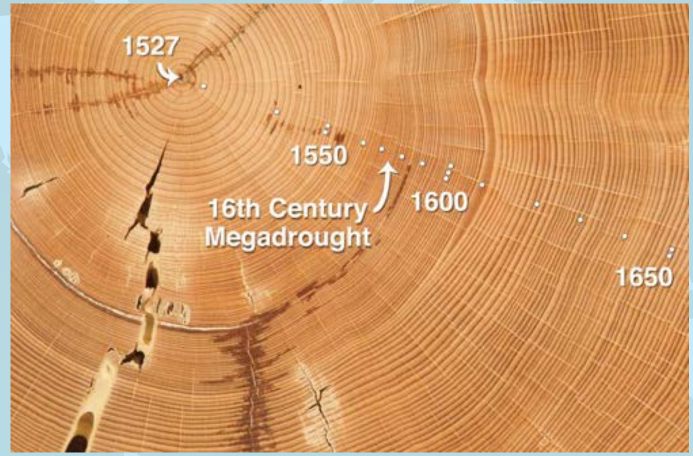


Paleoclimatology

The study of past climates using non-instrumental records, including:

- Oral and written histories of extreme weather, crop failure, famine, floods, droughts, commodity price fluctuations, etc.,
- Biological evidence, including live tree rings, fossil tree rings, fossil pollen, coral layers, marine sediments
- Ice cores, glacial ice deposited as annual layers which trap bubbles of air (atmospheric samples), organisms, and other material; stable water isotopes used to estimate temperature
- Geological evidence, including evidence of glaciation, evidence of inundation, sediments
- Isotopic evidence, radioisotopes used for dating other evidence; ratios of stable water isotopes indicate temperature; other isotope ratios used for a variety of purposes

Paleoclimatology



Dendrochronology

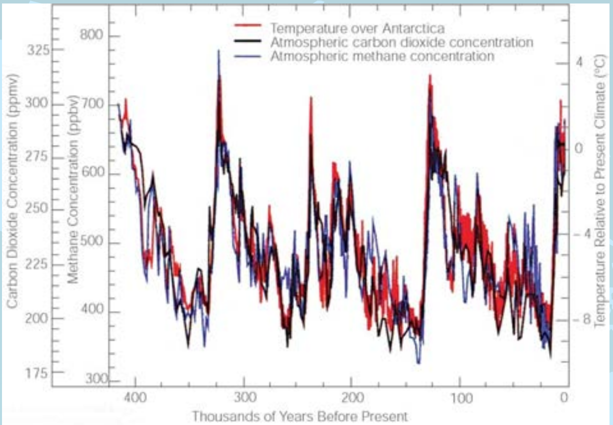
Hard Core

Glaciologists Victor Zagorodnov, left, and Patrick Ginot extract a section of a 550-foot (170-meter) core from the summit of Peru's Quelccaya ice cap, at an elevation of about 18,600 feet (5,670 meters). The ratio of oxygen isotopes (O_{18}/O_{16}) in the ice varies with temperature, enabling scientists to distinguish cold periods from warm periods dating back 2,200 years.

Climate History from Ice Cores

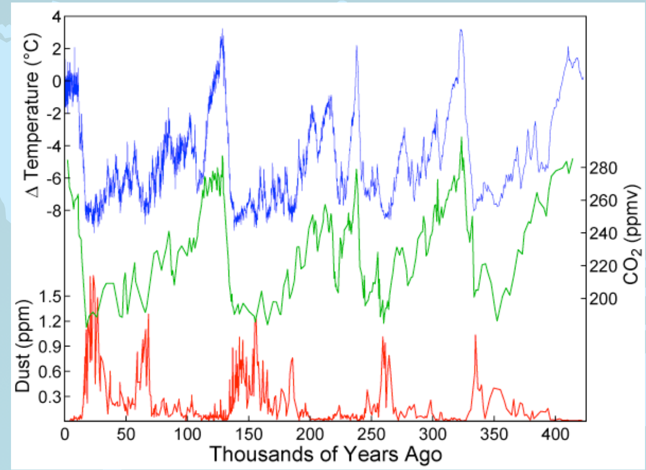
Left: The gloved hand of Tracy Mashiotta, a researcher at Ohio State's Byrd Polar Research Center, points to an annual dust band in an ice core from Peru's Quelccaya ice cap. Right: Vostok team photo with unprocessed ice cores.

Ice-Core Temp and Trapped Gas Data



Data from Vostok, Antarctica ice cores show that the most recent series of ice ages began about 2 million years ago.

Observations Show Recent Ice Ages



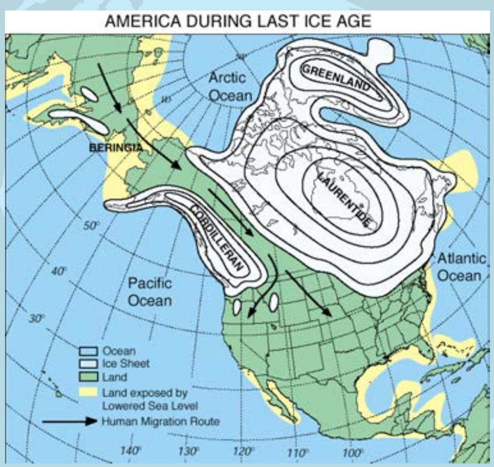
Graph of CO_2 (Green graph), temperature (Blue graph), and dust concentration (Red graph) measured from the Vostok, Antarctica ice core as reported by Petit et al., 1999. Higher dust levels are believed to be caused by cold, dry periods.

Last Ice Age Allowed Migration

Most recent North American glaciers at maximum ~ 18,000 years ago

Sea level 125-m lower

Bering land bridge allowed Asia – N. America migration.



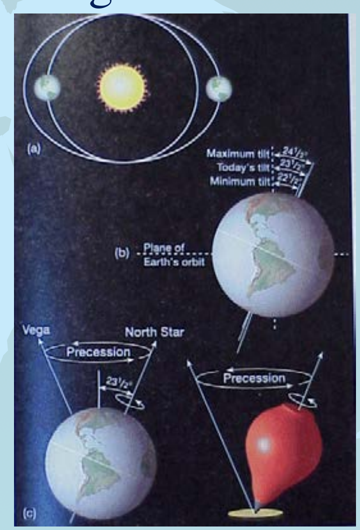
Orbital Changes Correlate with Recent Ice Ages

Cool periods associated with:

- more circular earth orbit – period 100,000 years
- smaller tilt of earth's axis – period 41,000 years

Warm periods associated with:

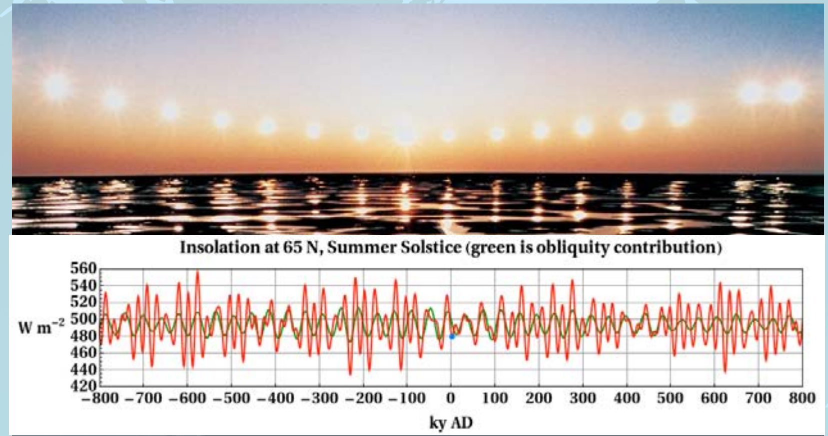
- more eccentric earth orbit – period 100,000 years
- Tilt closer to maximum 24.5˚ – period 41,000 years



Tilt of Earth’s Axis Defines Height of Polar Midnight Sun in Summer

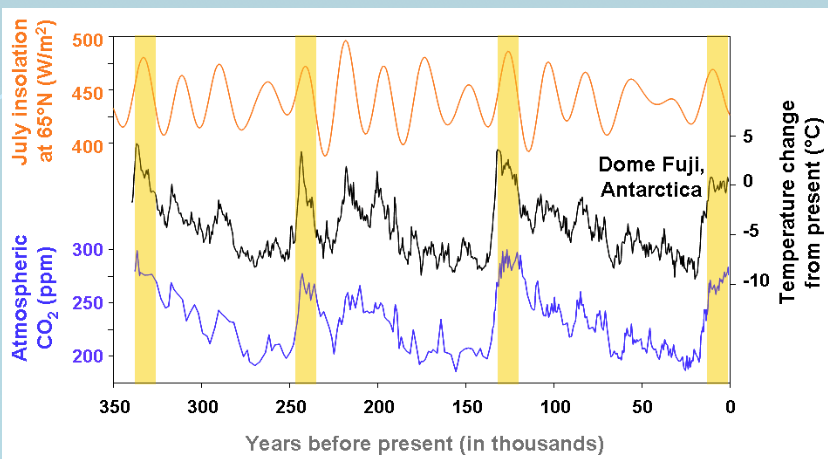
More tilt equals more summer snow/ice melt.

Tilt of Earth’s Axis Defines Height of Polar Midnight Sun in Summer



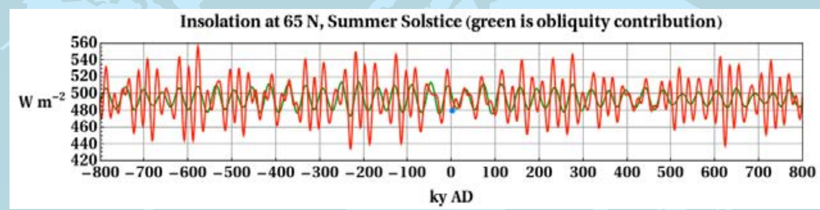
Past and future of daily average insolation at top of the atmosphere on the day of the summer solstice, at 65 N latitude shown in red.

Orbital Changes and Future Climate



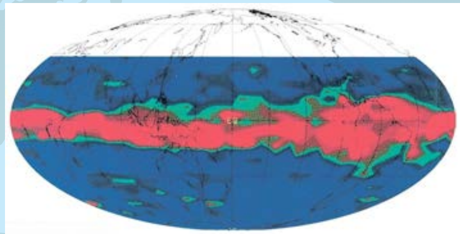
The amount of solar radiation (insolation) in the Northern Hemisphere at 65° N seems to be related to occurrence of past ice ages.

Orbital Changes and Future Climate



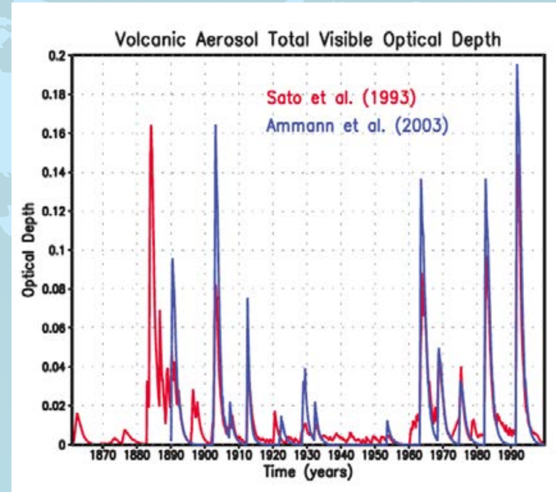
Astronomical calculations show that 65° N summer insolation should increase gradually over the next 25,000 years. A regime of eccentricity lower than the current value will last for about the next 100,000 years. Changes in Northern Hemisphere summer insolation will be dominated by changes in obliquity ε. No declines in 65° N summer insolation, sufficient to cause an ice age, are expected in the next 50,000 years.

Aerosol Forcing from Volcanoes Cools Surface



Aerosol loading tends to cool the troposphere & warm stratosphere

Aerosol Forcing from Volcanoes



Climate Feed-Back Mechanisms

- When any component of the climate system is changed, climate-feedback mechanisms can come into play.
- Changes that reinforce the initial change are called positive-feedback mechanisms.
- For example, warmer surface temperatures cause ice to melt, reducing the albedo and making more solar radiation available to warm the planet.

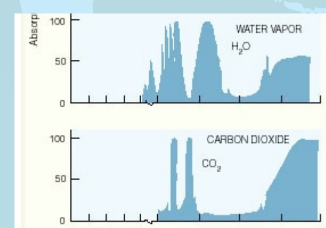
Water Vapor Feedback Loop

Water vapor feedback

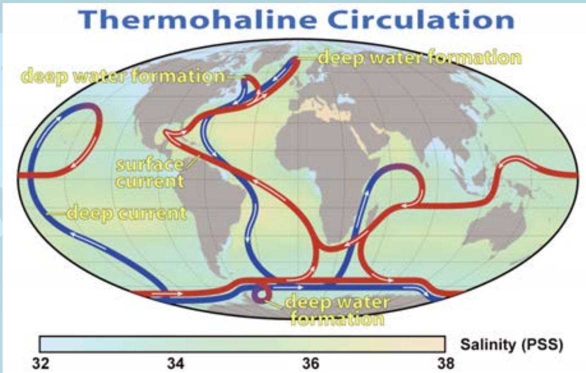
Adding CO2

Increased greenhouse effect

Increased temperature and water vapor



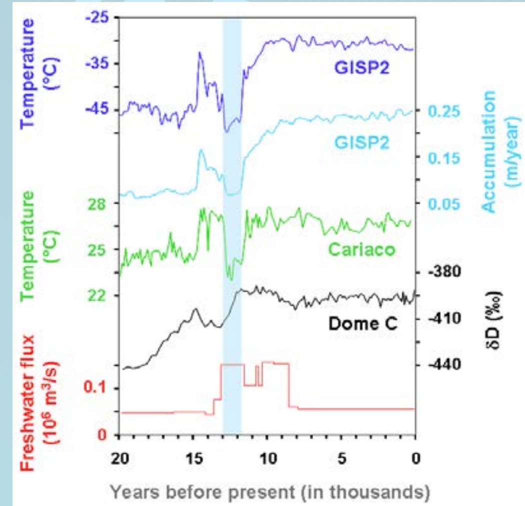
Negative Feed-Back Mechanisms



- On the other hand, negative-feedback mechanisms produce results that are the opposite of the initial change and tend to offset it.
- For example , additional fresh water flowing into the North Atlantic during a warming cycle may also reduce the global ocean water circulation. A reduction of the northward flow of warm water would then have a cooling effect on high latitudes, where snow retention increases during summer.

Recent Climate

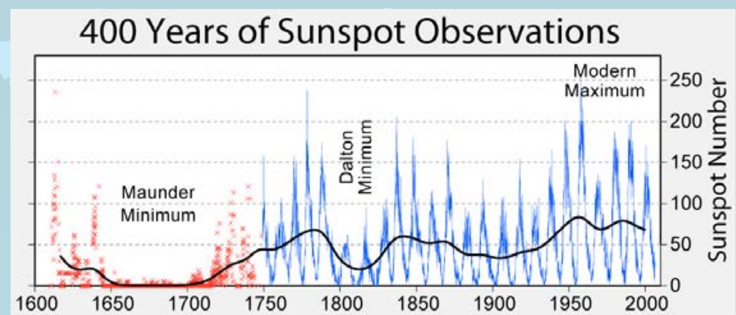
Warming since last ice age 18,000 years ago was punctuated by shorter cold periods. The sudden cooling during the Younger-Dryas is thought to be related to ocean circulation changes caused by a sudden influx of fresh water from Lake Agassiz into the Atlantic Ocean.



Negative Feed-Back Mechanism

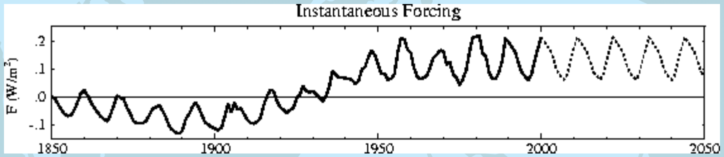
Warming since last ice age 18,000 years ago was punctuated by the sudden cooling during the Younger-Dryas, which is thought to be related to ocean circulation changes caused by a sudden influx of fresh water from Lake Agassiz into the Atlantic Ocean.

Solar Forcing – Sun's Output



- Output of the sun is modulated by sunspot cycle.
- Some climate scientists attribute the little ice age to the minimum in solar output associated with the Maunder minimum in sunspot activity.

Solar Forcing – Sun's Output



- Output of the sun is modulated by sunspot cycle.
- However, these changes are too small to explain recent warming

Summary: Past Climate Change

- Earth's climate was warmer than now during most of its history (e.g., last billion years).
- Ice ages and cooler average temperature occurred during past 2 million years, with changes correlating to Earth's orbital mechanics.
- Forcing for climate change includes astronomical and internal factors.
- Climate change research is complex due to many components of climate system and feedback mechanisms.

Questions?

On Thin Ice