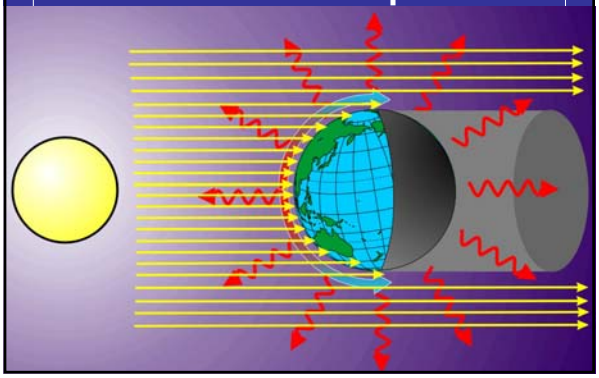
MET3003

Lecture 21: Climate Change 11APR07

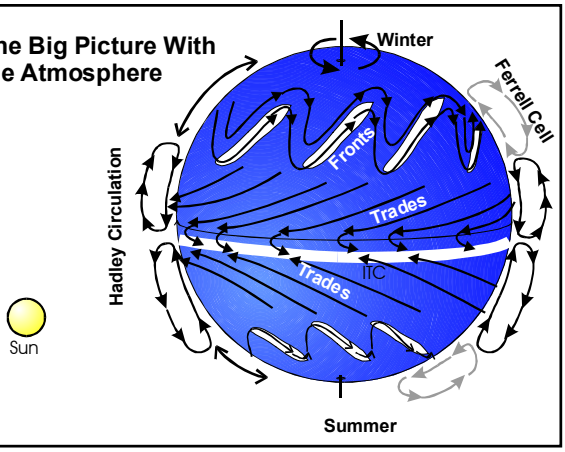
Causes of Climatic Variation

- Changes in solar "constant".
- Plate tectonics
  - Opening of the Southern and North Atlantic Oceans (65-55 MYA)
  - Very warm Eocene climate
  - Gradual cooling to Pleistocene Ice ages
- Orbital cycles (Eccentricity (100 kyr), Tilt (41 kyr), Precession (21 kyr)
  - Force periodic advances and retreats of glaciers (~100 kyr)
  - Greenhouse gasses change in phase
  - Not enough change in solar heating to explain temperature changes
- Changes in albedo and atmospheric IR absorptivity
  - Volcanic dust
  - Changes in surface properties
- Anthropogenic changes
  - Production of Greenhouse gasses
  - Changes in land use and albedo
- **The Climate System in FLAKEY!**

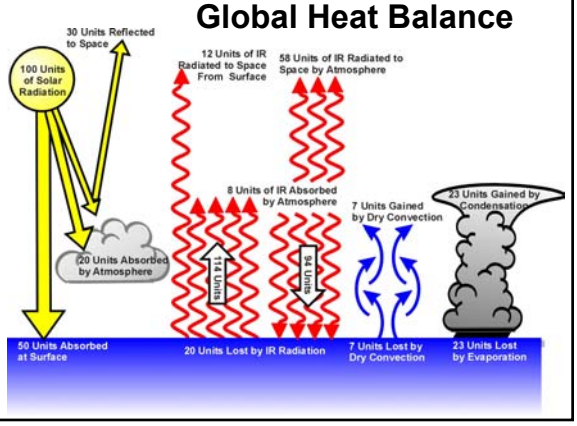
Earth's Radiative Equilibrium



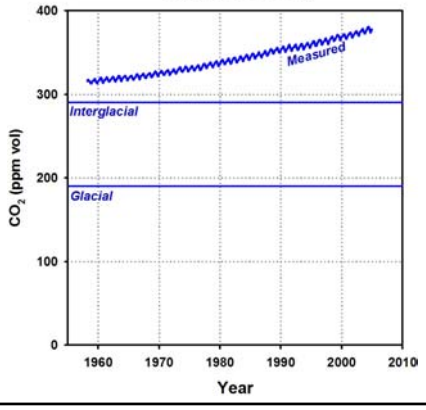
The Big Picture With the Atmosphere



Global Heat Balance

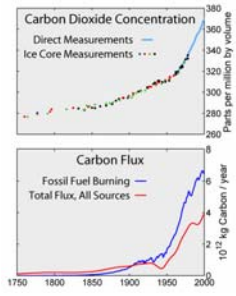


Mauna Loa CO_2

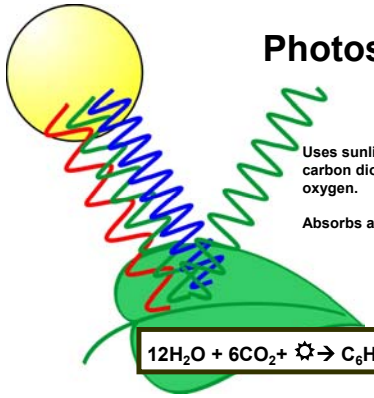


Greenhouse Gasses

- Pre-industrial CO2 concentration was ~280 ppm (v)
- This is a peak interglacial value
- It has risen to ~380 ppm
- Anthropogenic due to burning fossil fuels, deforestation…
- About half of the new CO2 disappears into plants, sea, or solid Earth
- Still, we expect DOUBLING of pre-industrial values by 2100



Photosynthesis

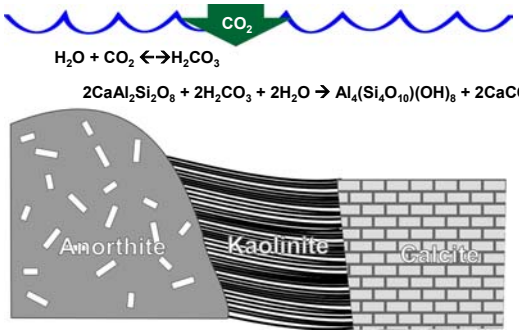


Uses sunlight to combine water and carbon dioxide to make glucose and oxygen.

Absorbs at 0.662 and 0.430 µm.

$$12H_2O + 6CO_2 + \text{☼} \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

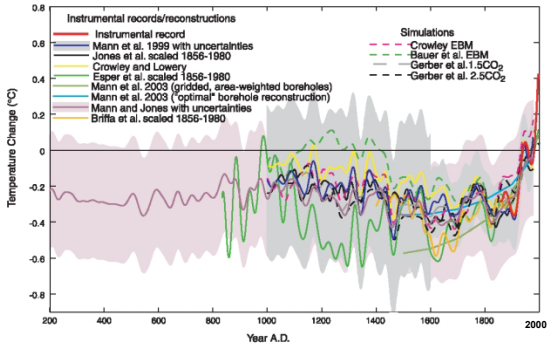
Chemical Weathering of Igneous Rocks Consumes CO_2

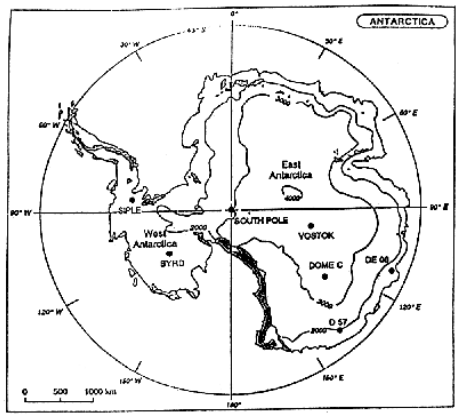


$$H_2O + CO_2 \leftrightarrow H_2CO_3$$

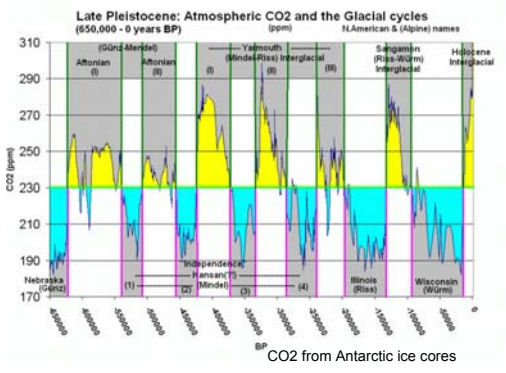
$$2CaAl_2Si_2O_8 + 2H_2CO_3 + 2H_2O \rightarrow Al_4(Si_4O_{10})(OH)_8 + 2CaCO_3$$

The Notorious Hockey-Stick Diagram



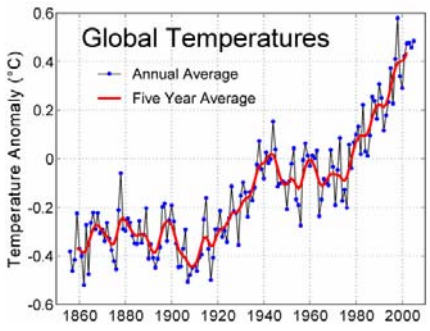


Ice Ages: The Climate is Naturally Unstable

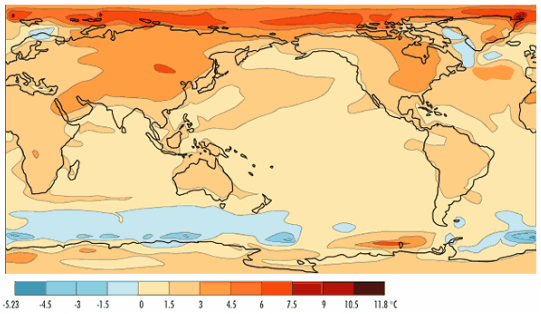


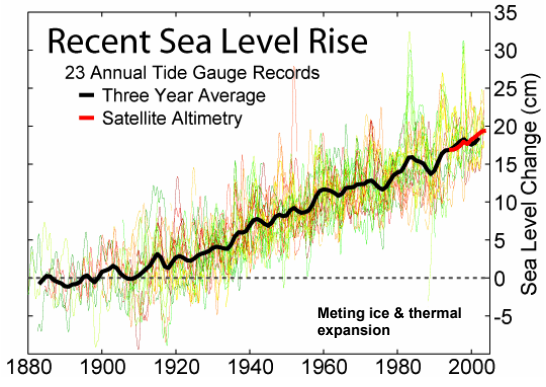
CO2 from Antarctic ice cores

Focus on the Recent Past

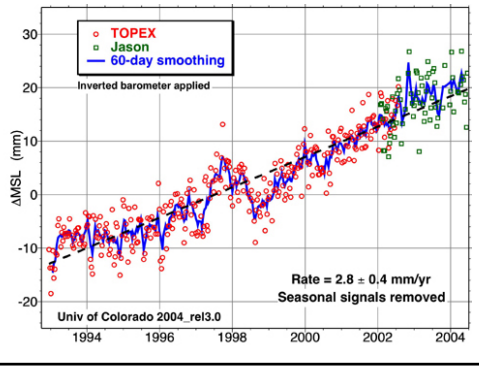


Geographical Distribution of Warming





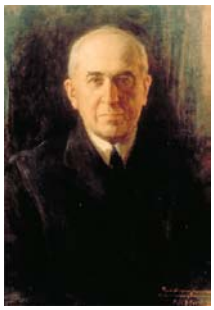
Sea-Level Rise From Satellites



The Future of Our Hometown?

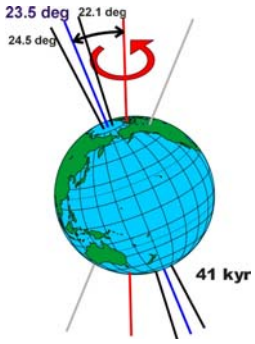
Ice Ages & Milankovitch Forcing

- Agassiz hypothesized Global Ice Ages in 1840, based upon erratics and moraines in Alps
- Milutin Milankovitch (1920 through 1940) related changes in solar heating to slow variations in Earth's orbital elements:
  - Obliquity (Tilt) of axis
  - Precession of equinoxes
  - Eccentricity of orbit
- Theory generally discounted until deep ice cores and ocean sediments brought confirmation of a sort

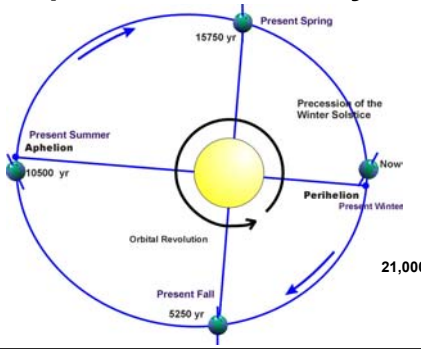


Obliquity (Tilt) of Earth's Axis Causes the Seasons

- Presently 23.5°.
- Stays (nearly) fixed with respect to the stars during the year
  - Tilts toward the Sun in summer
  - And away in winter
- Changes slowly
  - Oscillates from 22.1° to 25.5°
  - With 41 kyr period
- Orientation also rotates with 21 kyr period (***Precession***)

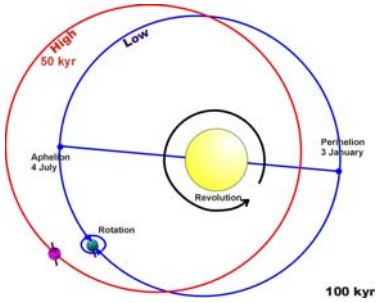


Precession moves the perihelion and aphelion later in the year



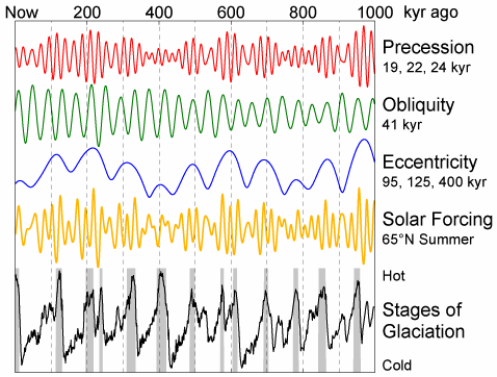
21,000 yr period

The orbital *Eccentricity* oscillates from nearly circular to elongated

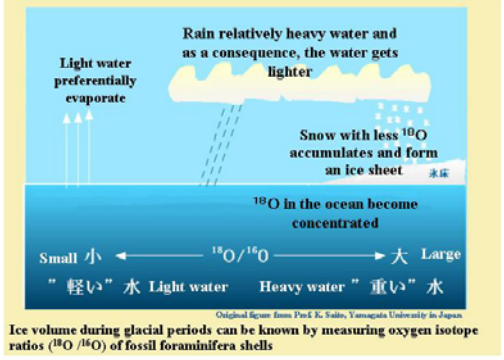


100 kyr

How all the orbital components add up

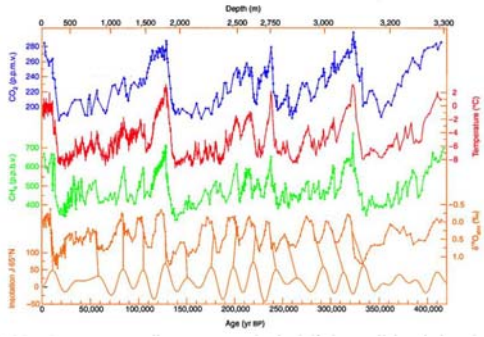


Ice sheet formation and oxygen isotope ratio variation during glacial periods

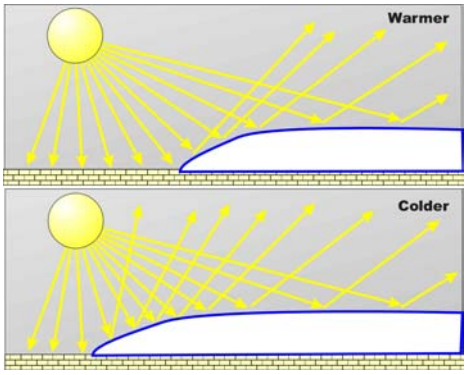


Ice volume during glacial periods can be known by measuring oxygen isotope ratios (^{18}O /^{16}O) of fossil foraminifera shells

Milankovitch forcing, greenhouse gasses. and ^{18}O temperatures

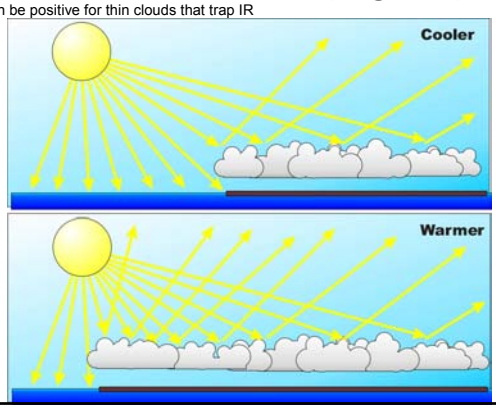


Ice-Albedo Feedback (positive)

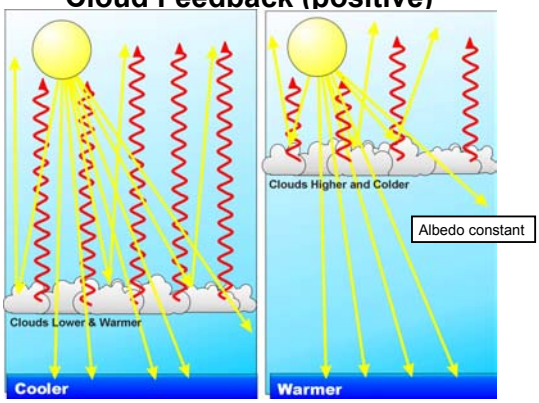


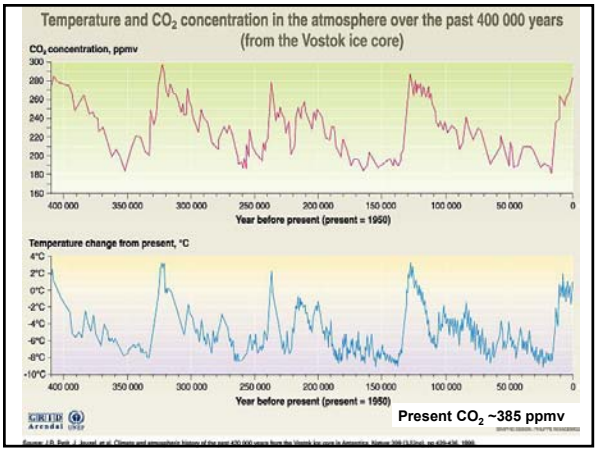
Cloud-Albedo Feedback (negative)

Can be positive for thin clouds that trap IR



Cloud Feedback (positive)

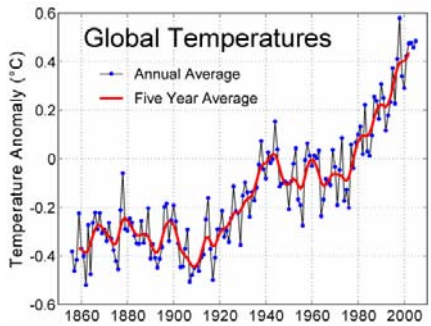


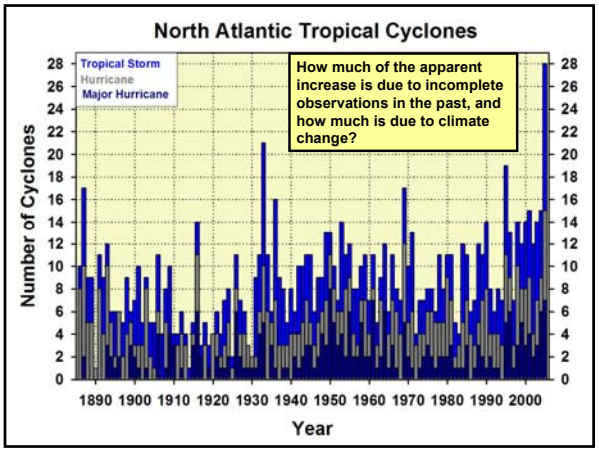


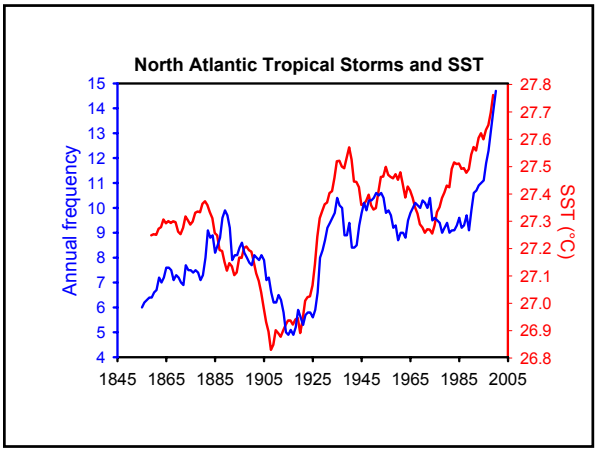
Summary

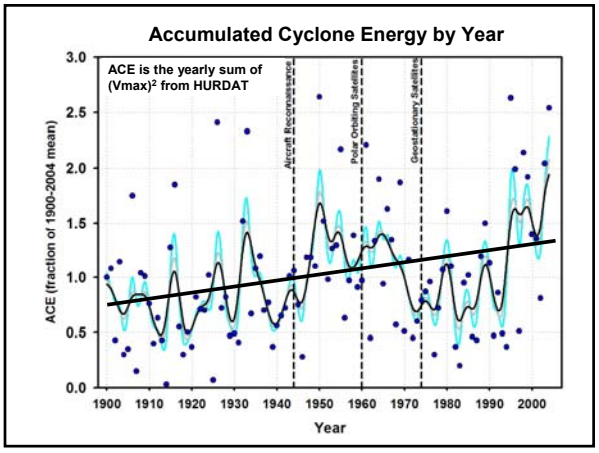
- Understand the review of solar heating and atmospheric poleward heat transport
- Understand the CO_2 budget and the reasons for increasing atmspheric CO_2 since the industrial revolution
- Be able to explain the "Hockey-Stick" diagram and know what the Little Ice age was.
- Know the significance of the Vostok Ice Cores and how ^{18}O can be use to reconstruct past temperatures
- Know that the Earth has warmed ~1ºC since 1900 and that most of the warming has been in high latitudes
- Know that sea-level rose 15-20 cm during the last century and that it is currently rising at a rate of 3 cm per decade
- Be able to explain the components of Milankovitch cycles
  - Obliquity (Tilt) of the axis (41 kyr)
  - Precession of the equinoxes (21 kyr)
  - Changes in orbital eccentricity (~100 kyr)
- Know how temperature, green-house gasses, and orbital elements have evolved through time
- Be able to explain cloud-albedo and ice albedo feedback in the climate system
- **NEXT TIME:** **Climate and hurricanes**

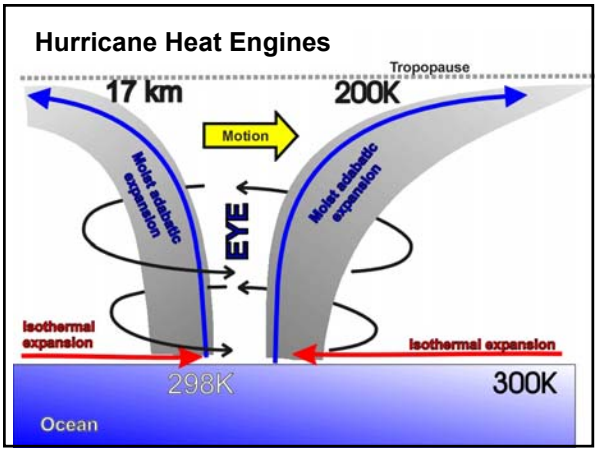
The Recent Past Again

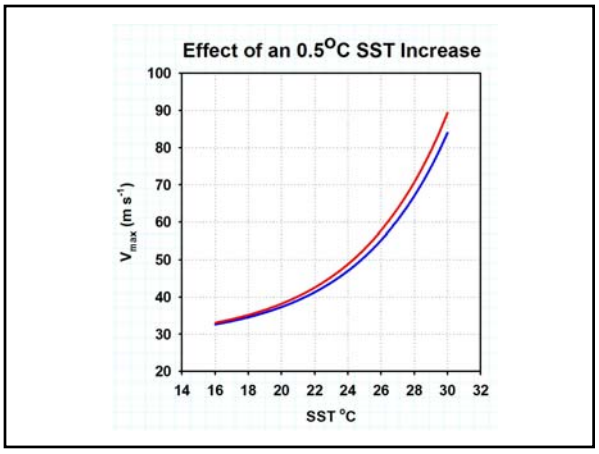


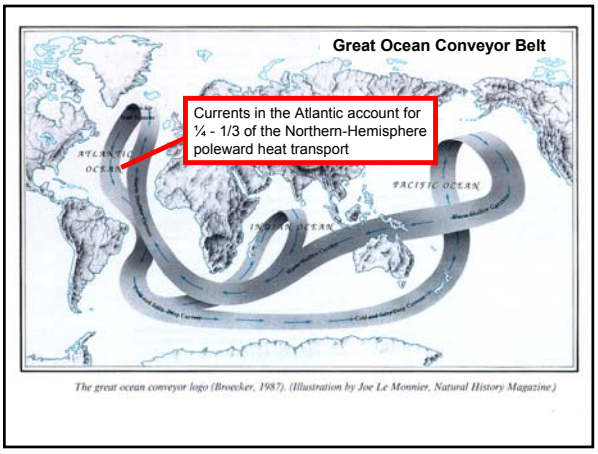




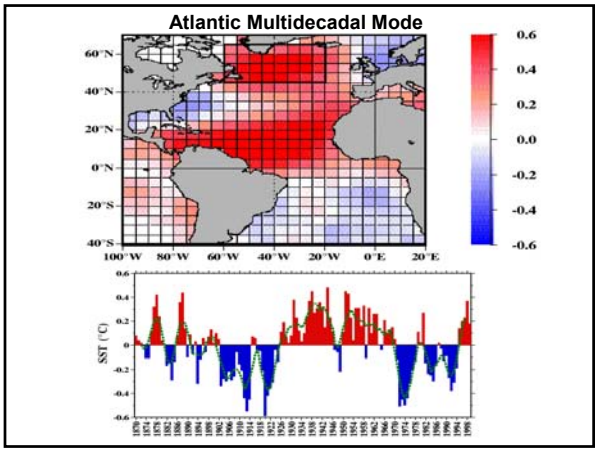


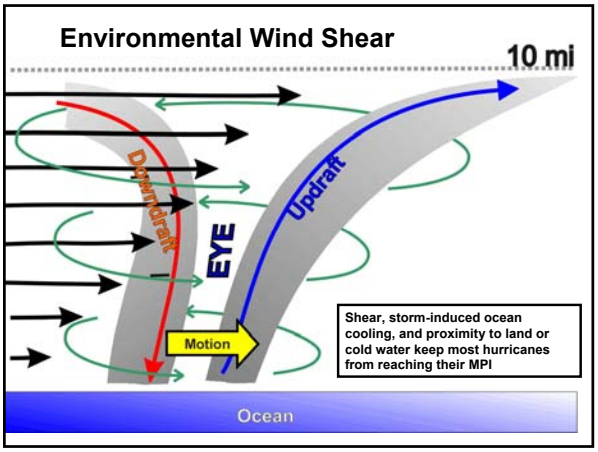


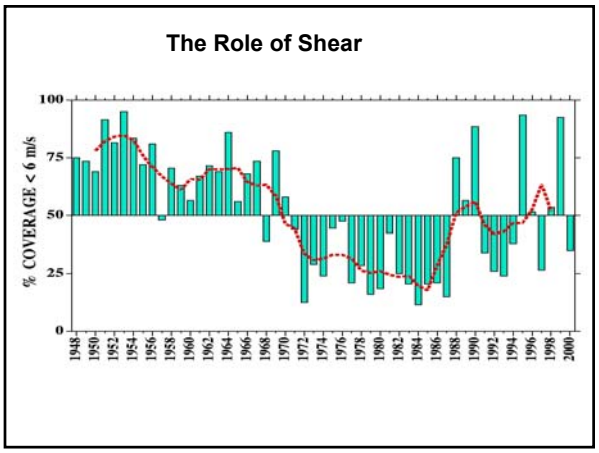


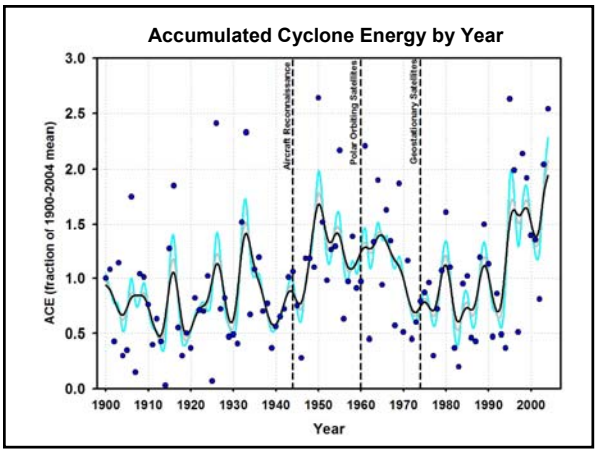


The great ocean conveyor logo (Broecker, 1987). (Illustration by Joe Le Monnier, Natural History Magazine.)



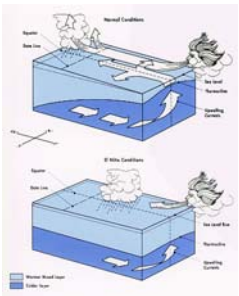


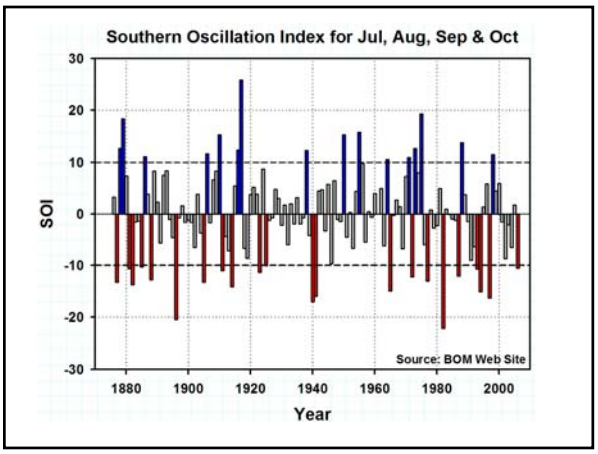


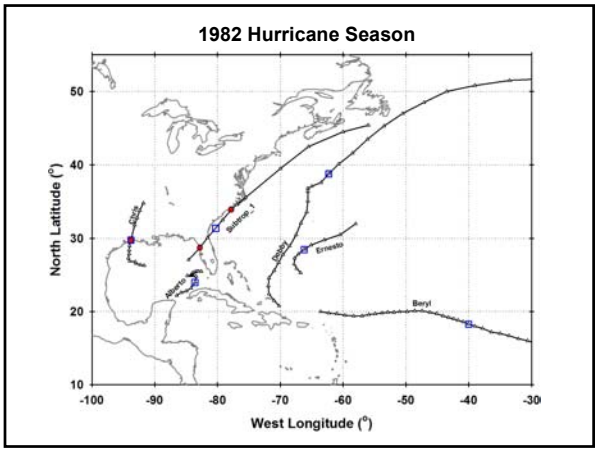


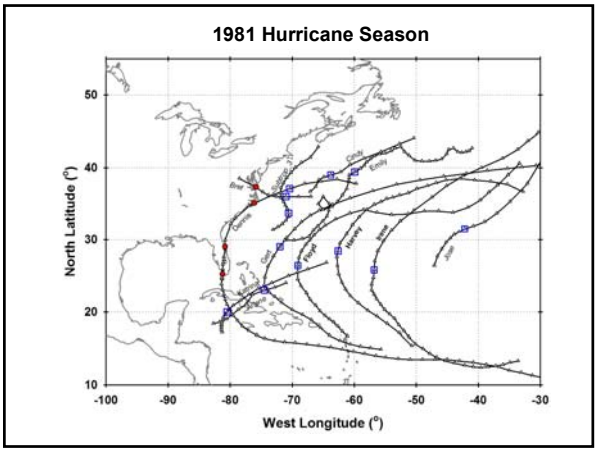
Role of El Niño

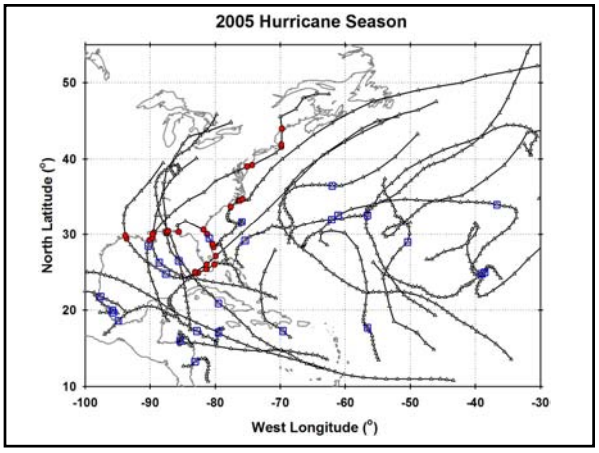
- Periodic warming of the normally cool water near South America
- Cool (normal) phase
  - Strong trades push warm water westward
  - Convection in W. Pacific
  - Positive SOI (Tahiti – Darwin)
- Warm (El Niño) phase
  - Trades weaken
  - Warm water sloshes eastward
  - Convection shifts east of the Dateline
  - Negaive SOI
- El Niño increases shear over the tropical Atlantic MDR

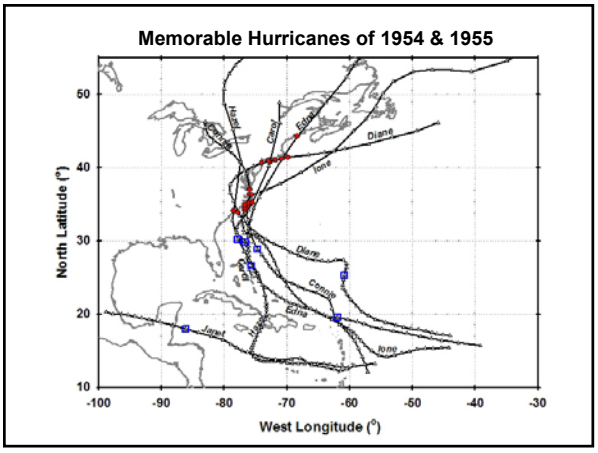


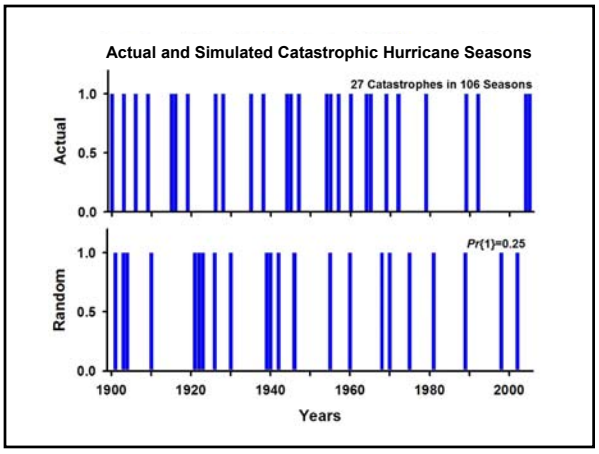


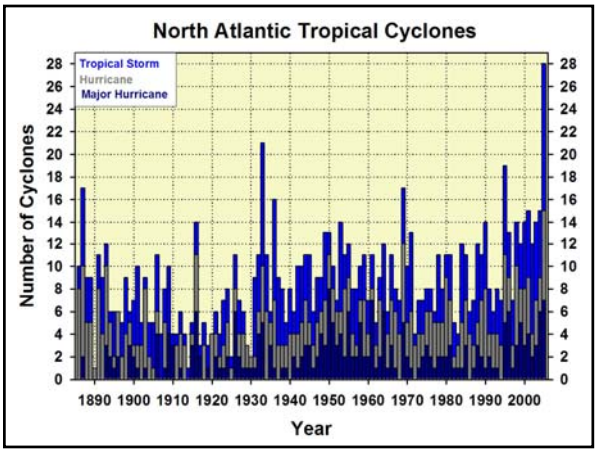

1982 Hurricane Season
North Latitude (°)
West Longitude (°)
Chris
Debby
Alberto
Subtrop. 1
Ernesto
Beryl

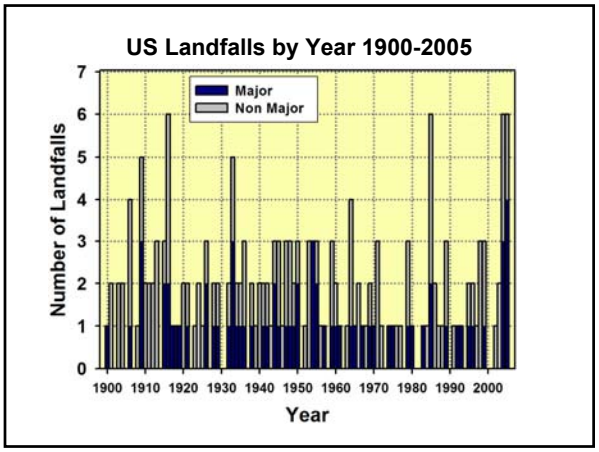

1981 Hurricane Season
North Latitude (°)
West Longitude (°)

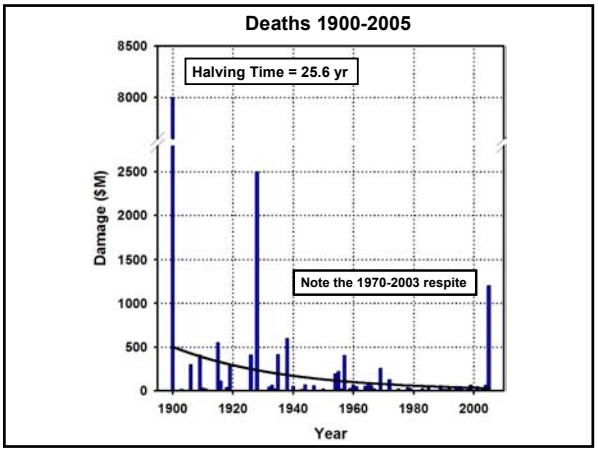

2005 Hurricane Season
North Latitude (°)
West Longitude (°)

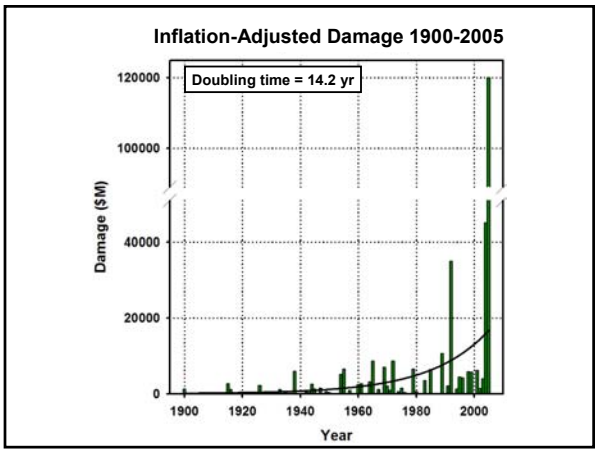

Memorable Hurricanes of 1954 & 1955
North Latitude (°)
West Longitude (°)
Hazel
Carol
Edith
Diane
Ione
Connie
Edna
Janet


Actual and Simulated Catastrophic Hurricane Seasons
27 Catastrophes in 106 Seasons
Actual
Pr{1}=0.25
Random
Years


North Atlantic Tropical Cyclones
Tropical Storm
Hurricane
Major Hurricane
Number of Cyclones
Year

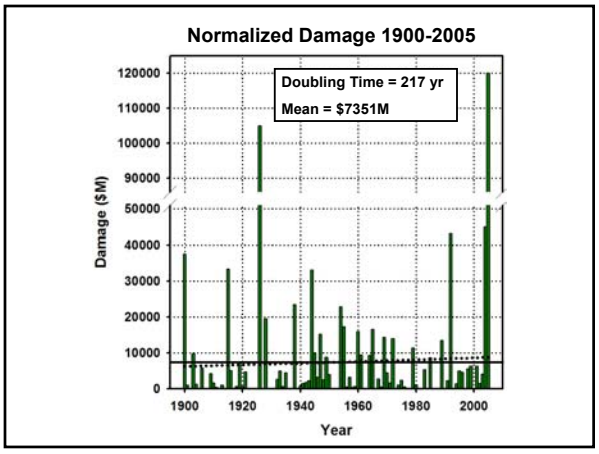


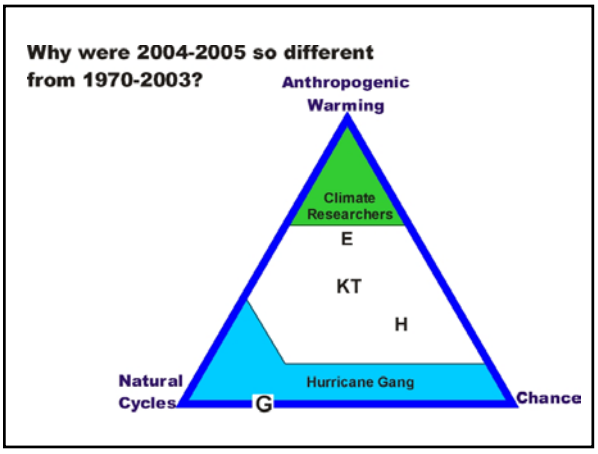


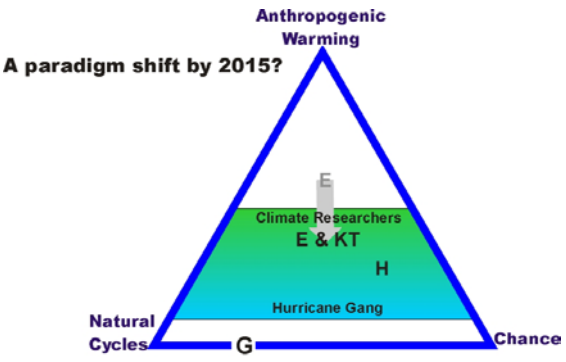


Normalized Hurricane Damage

- Pielke & Landsea (1998, updated in press 2005)
- Corrects for:
  - Inflation
  - Population increase
  - Greater personal wealth
- What would historical hurricanes cost with 2005 population and development?
- Constant at $10B per year, based upon updated 1900-2005 data







Summary

- "Globe" is getting warmer
  - Primarily in high latitudes
  - But does effect tropics (0.5 C since 1970, 0.9ºC since 1900)
  - Almost certainly Anthropogenic
- Sea-level rise
  - Thermal expansion & melting ice
  - 15 cm last century
  - Accelerating, now 30 cm per decade
- Thermodynamic expectation of stronger storms
- El Niño, every 3-5 years, few hurricanes
- Atlantic Multidecadal Oscillation
  - 20-30 years in each phase
  - Thermohaline circulation
  - Warm phase, low shear, many hurricanes
- Chance: Random events produce clusters
- Which explanation is right????
- Landfall is when the vorticity hits the voters
- What if the climate shifts to some completely bizarre new mode?
- For next time **REVIEW FOR FINAL EXAM** (25APR07, 9:30-12:15)