Astr 2310 Tues. April 29, 2016
Today's Topics

- **Chapter 9: Dynamics of the Earth**
  - **Physical Properties of Earth**
  - **Interior, Surface, Magnetic Field, and Atmosphere**
  - **Evidence for Global Warming**
  - **Physical Properties of the Moon**
  - **Surface Features, Interior, Origin**

Chapter 9: Homework

Chapter 9: #1, #2, #5, #7, #8, #9

- Due Tues. April 26

Chapter 9: Physical Properties of the Earth

Basic Properties:

Radius = 6378 km
Mass = 5.97 x 10^{24} kg
$\langle\rho\rangle$ = 5.52 gm/cc

Surface Characteristics:

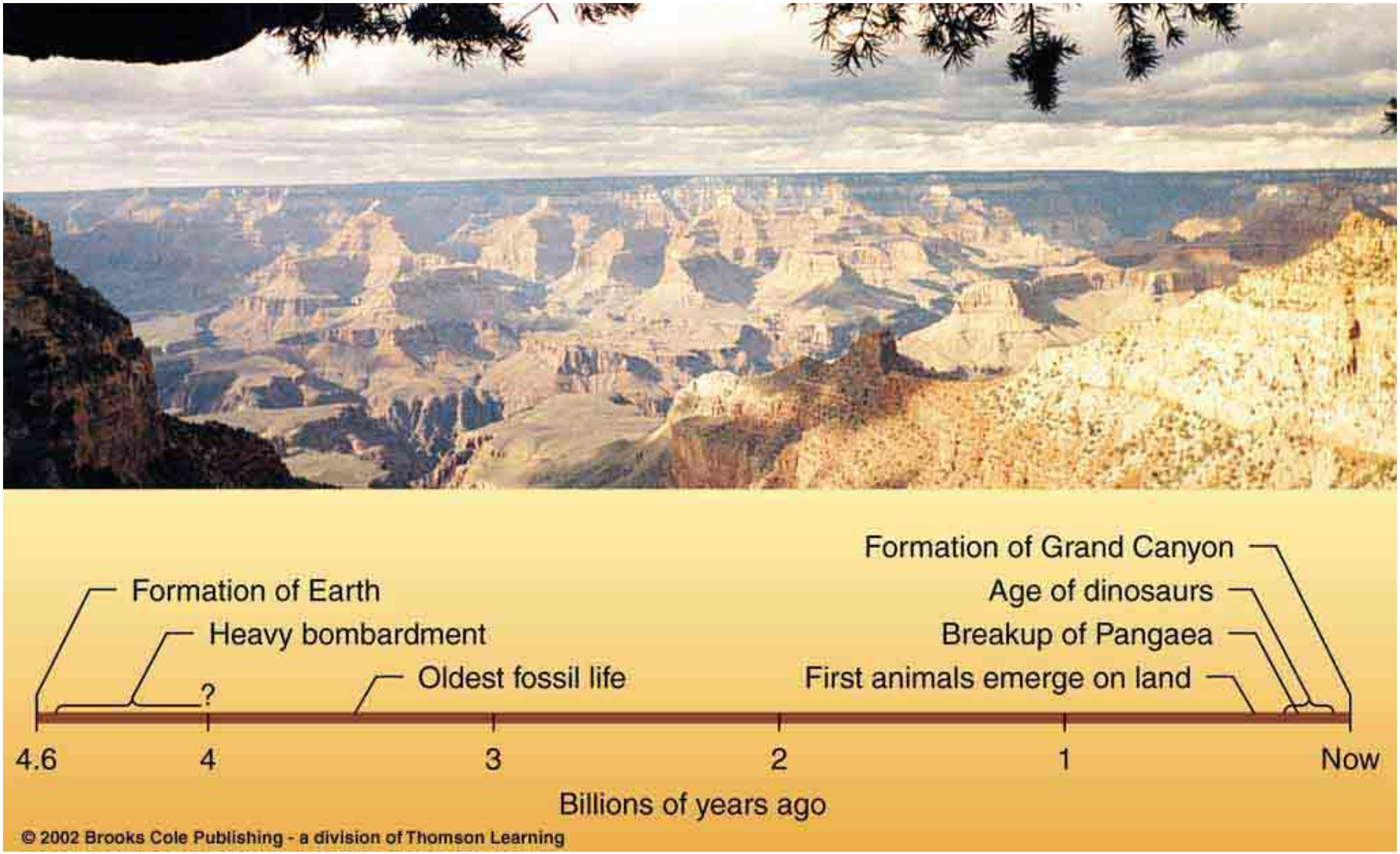
Large Continental Land Masses with Large H_2O Oceans

Mountain Ranges
uplifting of crust

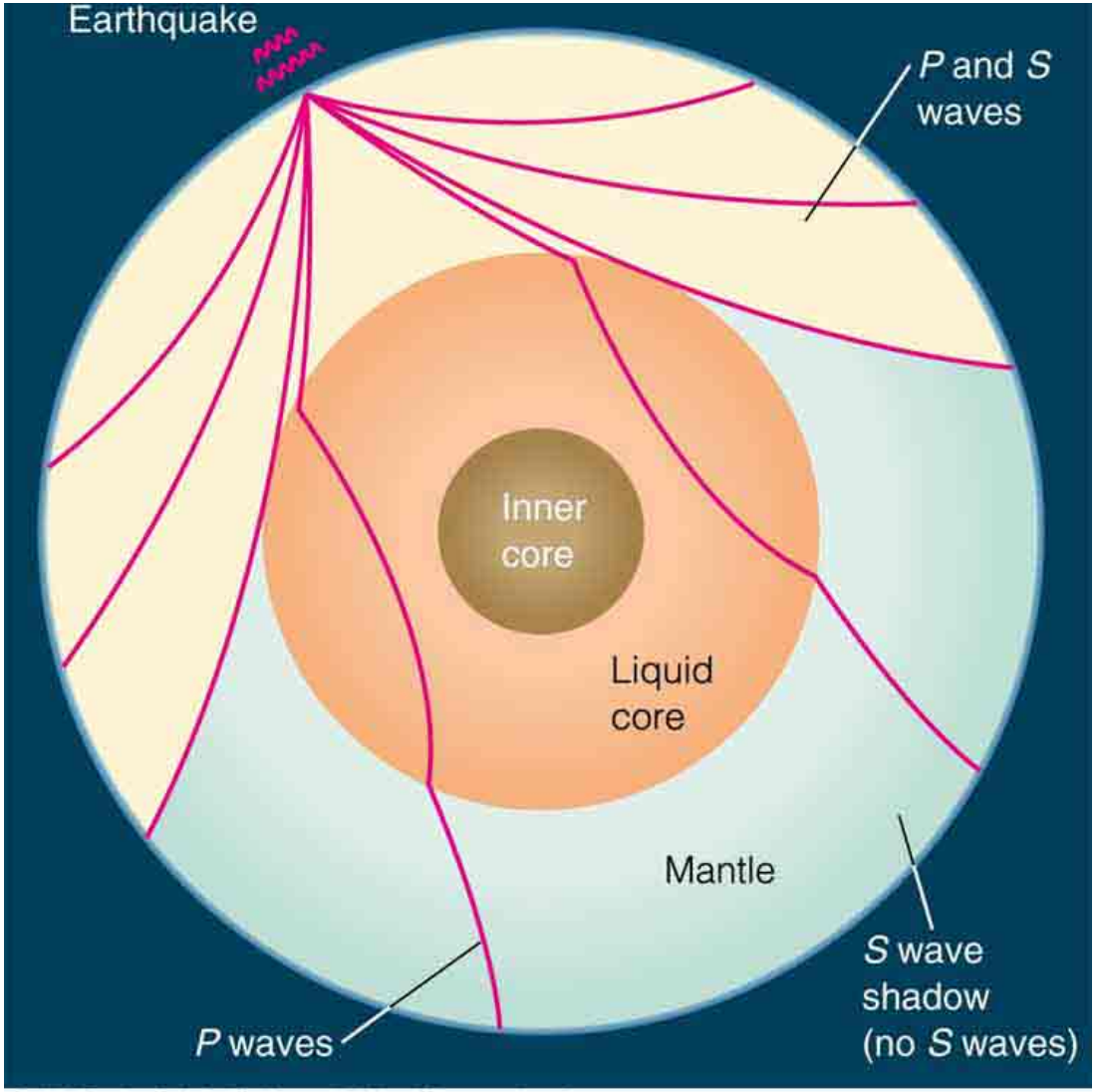
Thick N_2 + O_2 Atmosphere

Severe Weathering of Surface

Timeline



Earth's Interior Probed via Sesmic Waves



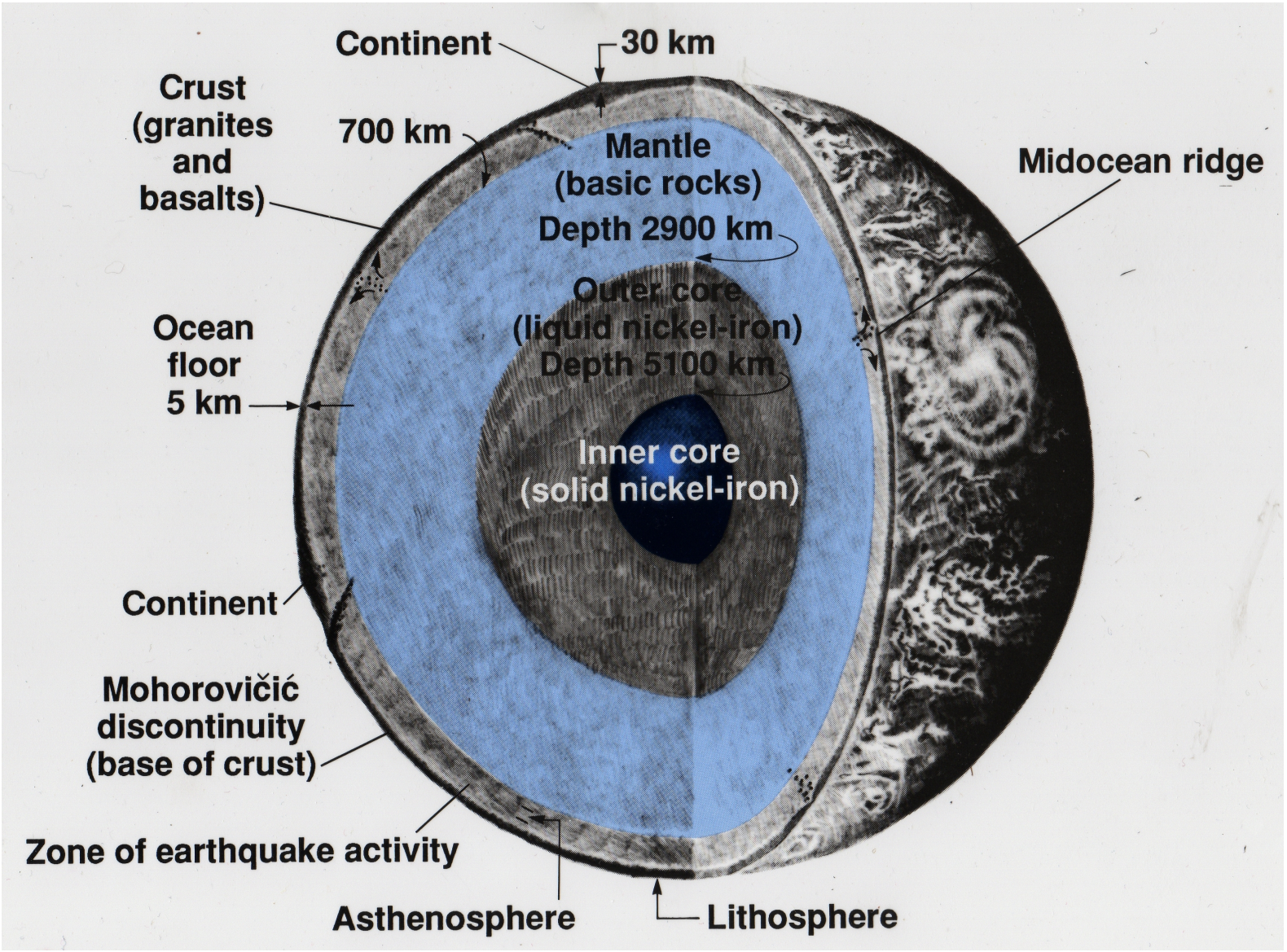
P-Waves travel like sound waves, including through liquid.

S-waves travel side to side and do not propagate through liquid.

Inner Core is dense, molten Fe and Ni at 6000 K.

Mantle is "plastic" – dense rock that can flow, exists under the crust that is a thin surface layer.

Interior Structure of Earth



Internal pressure rises with depth due to compression of overlying layers. (Hydrostatic Equilibrium). Consider a shell of mass and thickness dr:

$F_g(r) = \rho(r)\, 4\pi r^2\, dr\, GM/r^2$ but the shell is in equilibrium with the internal pressure ($4\pi r^2\, dP$). So:

$4\pi r^2\, dP = -\rho(r)\, 4\pi r^2\, dr\, GM/r^2$ and so:

$dP = -\rho(r)\, GM/r^2\, dr$

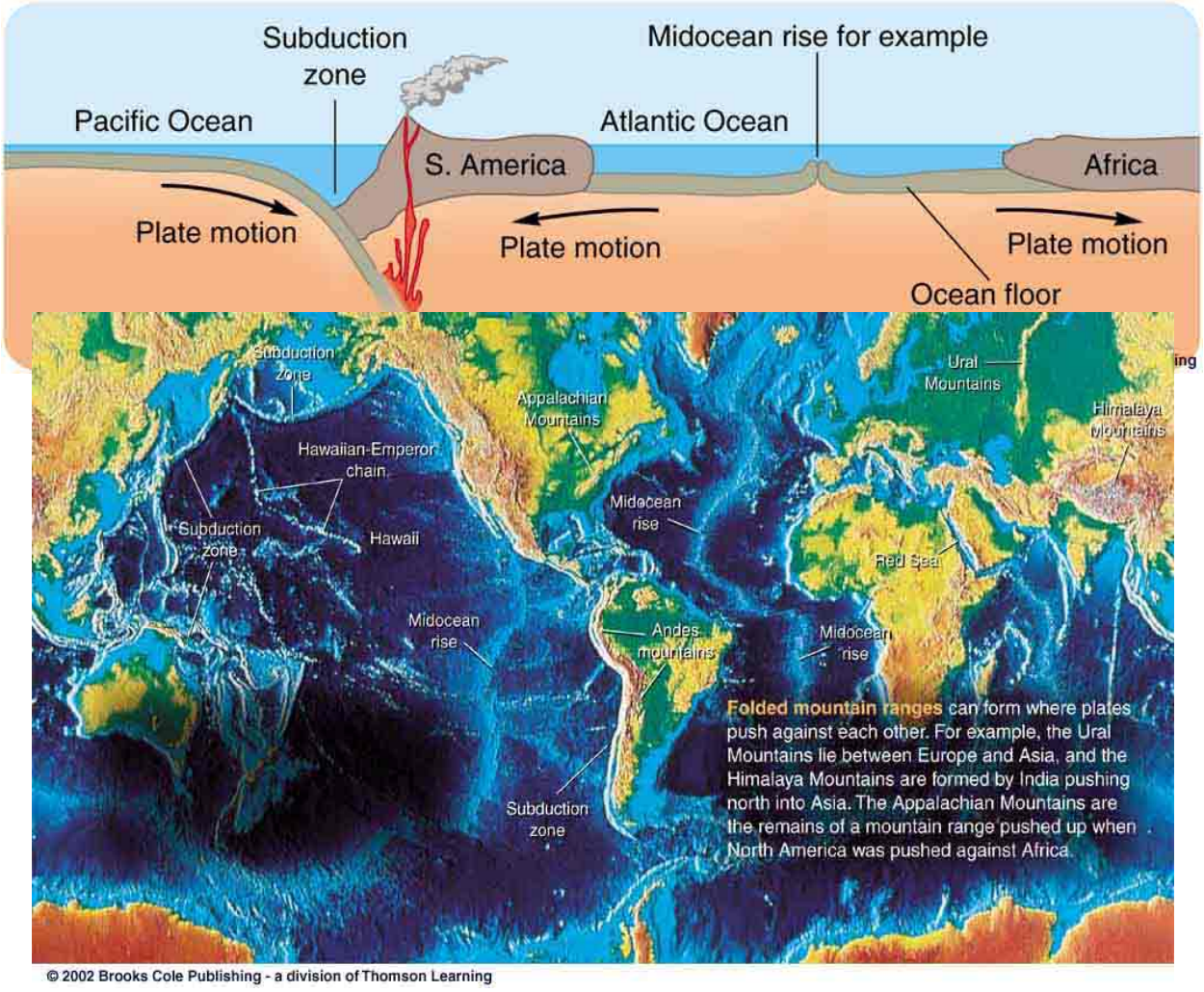
If we let $\langle\rho\rangle = M/(4/3\pi r^3)$ then we have:

$dP = -\langle\rho\rangle G(4/3)\langle\rho\rangle\pi r\, dr$ and if we integrate from 0 to R we find a central pressure of:

$P_c = (2/3)\, \pi G \langle\rho\rangle^2 R^2 = (1.4 \times 10^{-10})(5500\ \text{kg/m}^3)(6.4 \times 10^6\ \text{m})^2$
$= 1.7 \times 10^{11}$ Pa or 1.7×10^6 atm

The Active Earth

- **Plate tectonics, volcanoes, etc., a lot of <u>action!</u>**



Note: Oceans and Subduction can REMOVE CO_2 from Atmosphere

Volcanoes can ADD CO_2 to the Atmosphere

Earth's Atmosphere - I

The pressure of the Earth's atmosphere fall exponentially with height.

Ideal gas law:
P = nkT but n=ρ/m so:
P = ρkT/m o r ρ = mP/kT

Combining withl Hydrostatic Equilibrium:

$dP = -P(m/kT)(GM/r^2)$ or:

$dP/P = -(m/kT)(GM/r^2)dr$

Recall that $g(r) = GM/r^2$ so we have:

dP/P = -g(r)(m/kT)dr and if we assume that g, T and m are ~ constant we can integrate. If we let H = kT/gm:

$$P(h) = P_0 e^{-h/H}$$

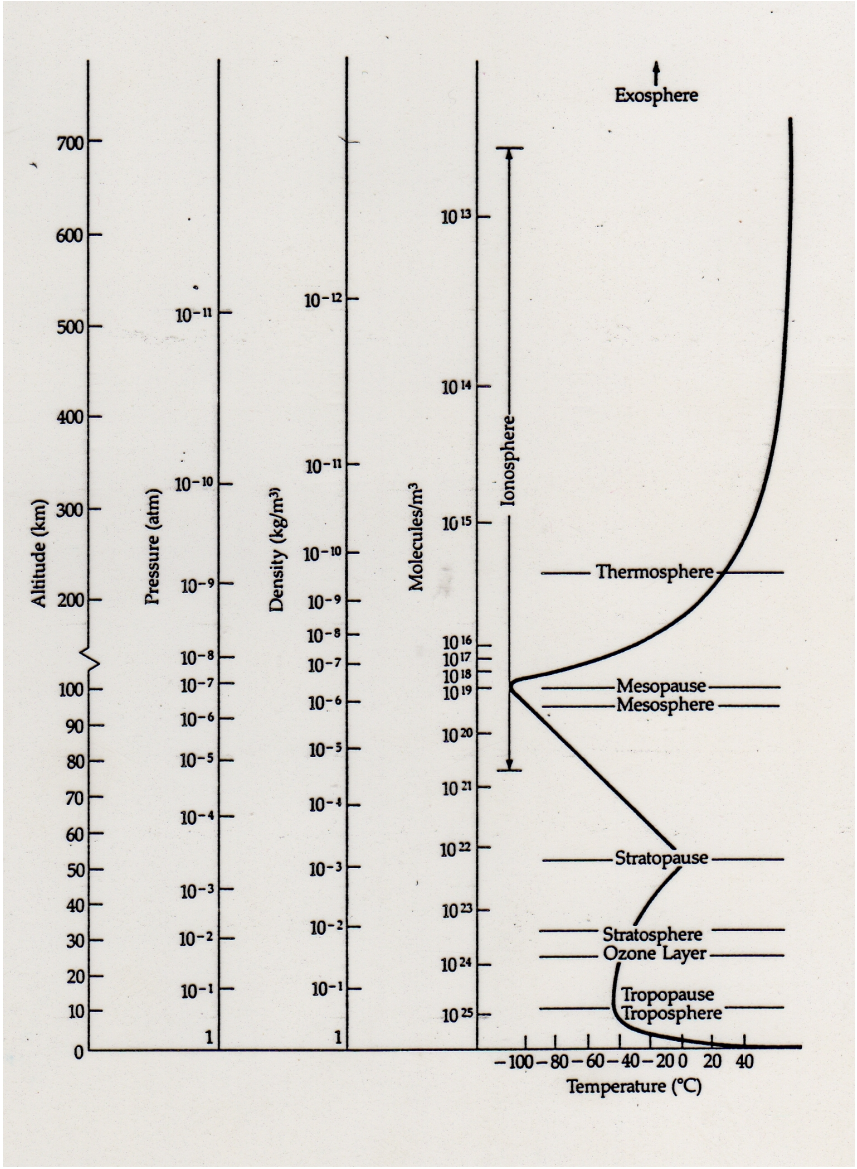
where H is the "scale height"

The thermal profile reveals distinctive regions:

Troposphere: lower region where we live (temp. reversal due to UV absorption from Ozone)

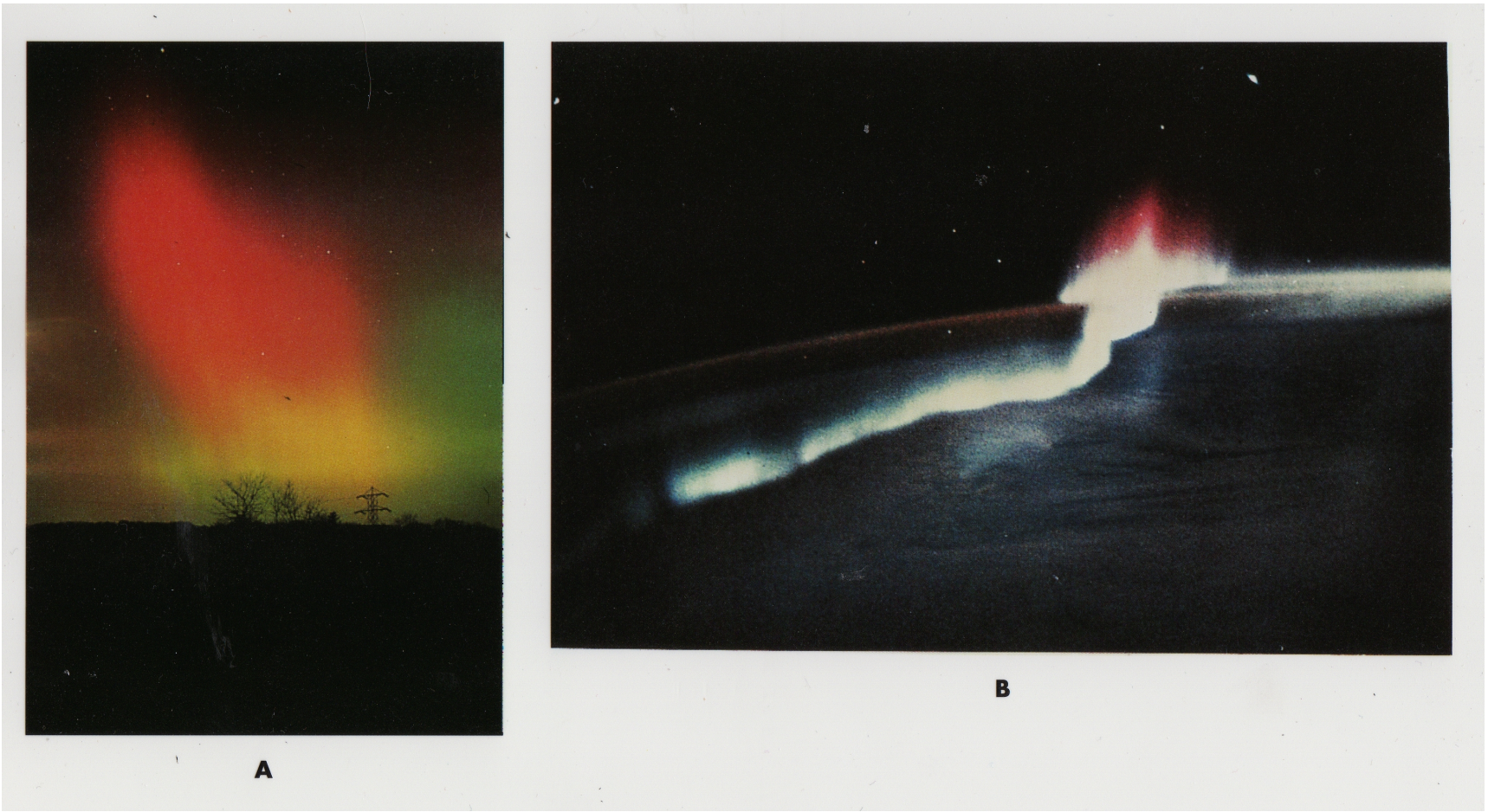
Stratosphere: temp drops with height

Thermosphere: charged particle absorption



Earth's Atmosphere - II

Charged particles from Sun and space impact near magnetic poles
(energy deposited into Thermosphere)



Charged Particles in the Van Allen Belts

Earth's Magnetic Field Creates a "Magnetosphere" Protecting it from Charged Particles from the Sun

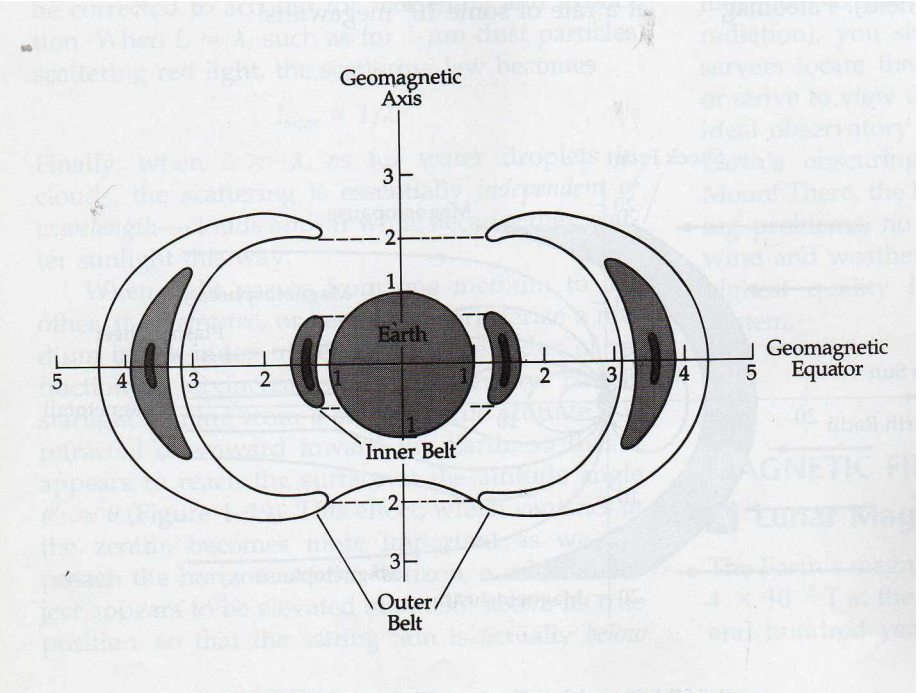
Some are trapped in toroidal belts around the Earth (Van Allen Belts)

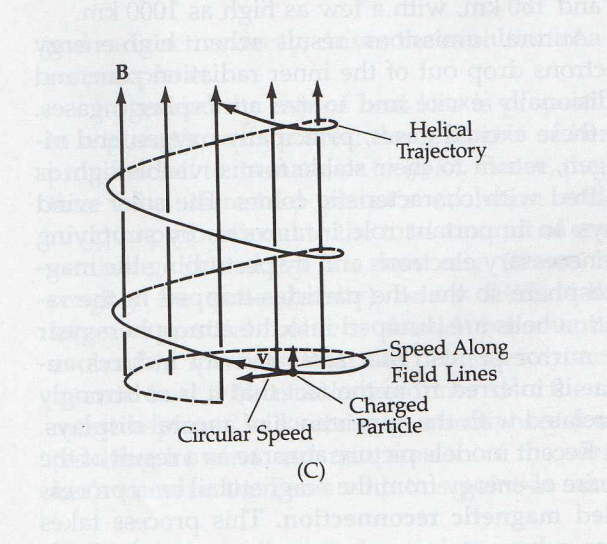
Particles spiral around field lines via Lorentz force:

F = q(**V** X **B**) and spiral with a gyroradius (r):

$mv^2/r = qvB$

$r = mv/qB$

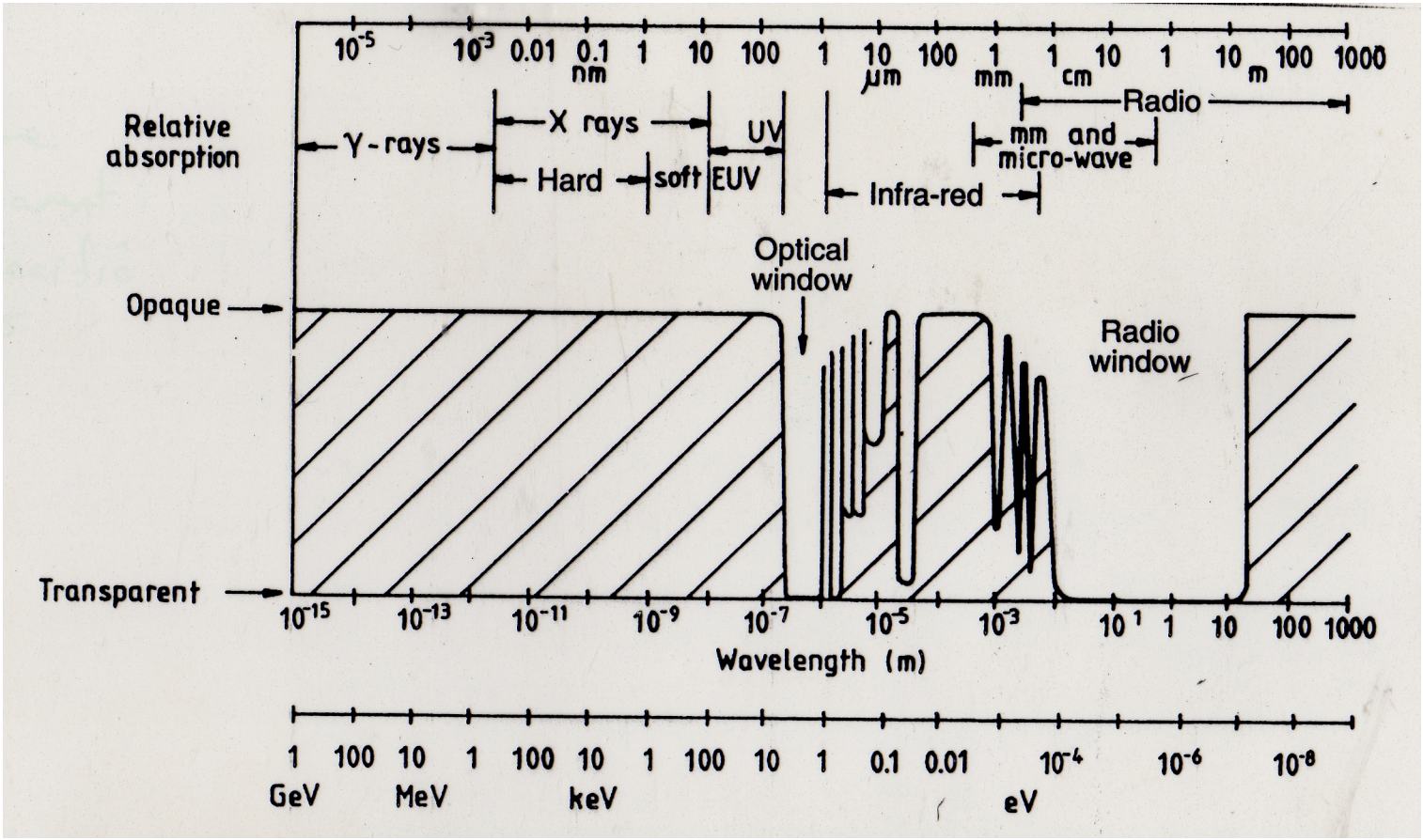




Earth's Atmosphere - III

Transparency of Atmosphere Varies Strongly with Wavelength

- **UV radiation absorbed by Ozone**
- **Radio waves absorbed by trapped charged particles (Van Allen Belts)**
- **H2O and CO2 absorb strongly in Infrared (Greenhouse Effect)**



Earth's Atmosphere - IV

Earth's atmosphere is transparent at visible wavelengths.

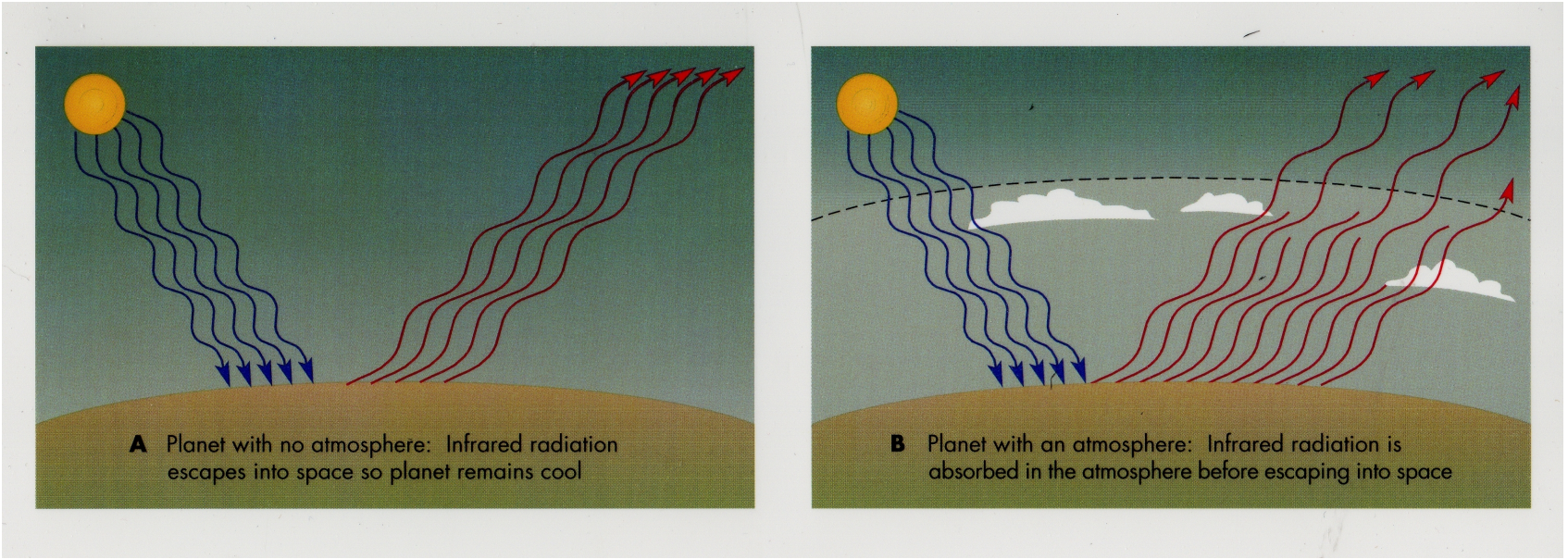
some portion is absorbed (1-A) and heats surface

surface radiates thermally in infrared

H_2O and CO_2 absorb and trap energy (Greenhouse effect)

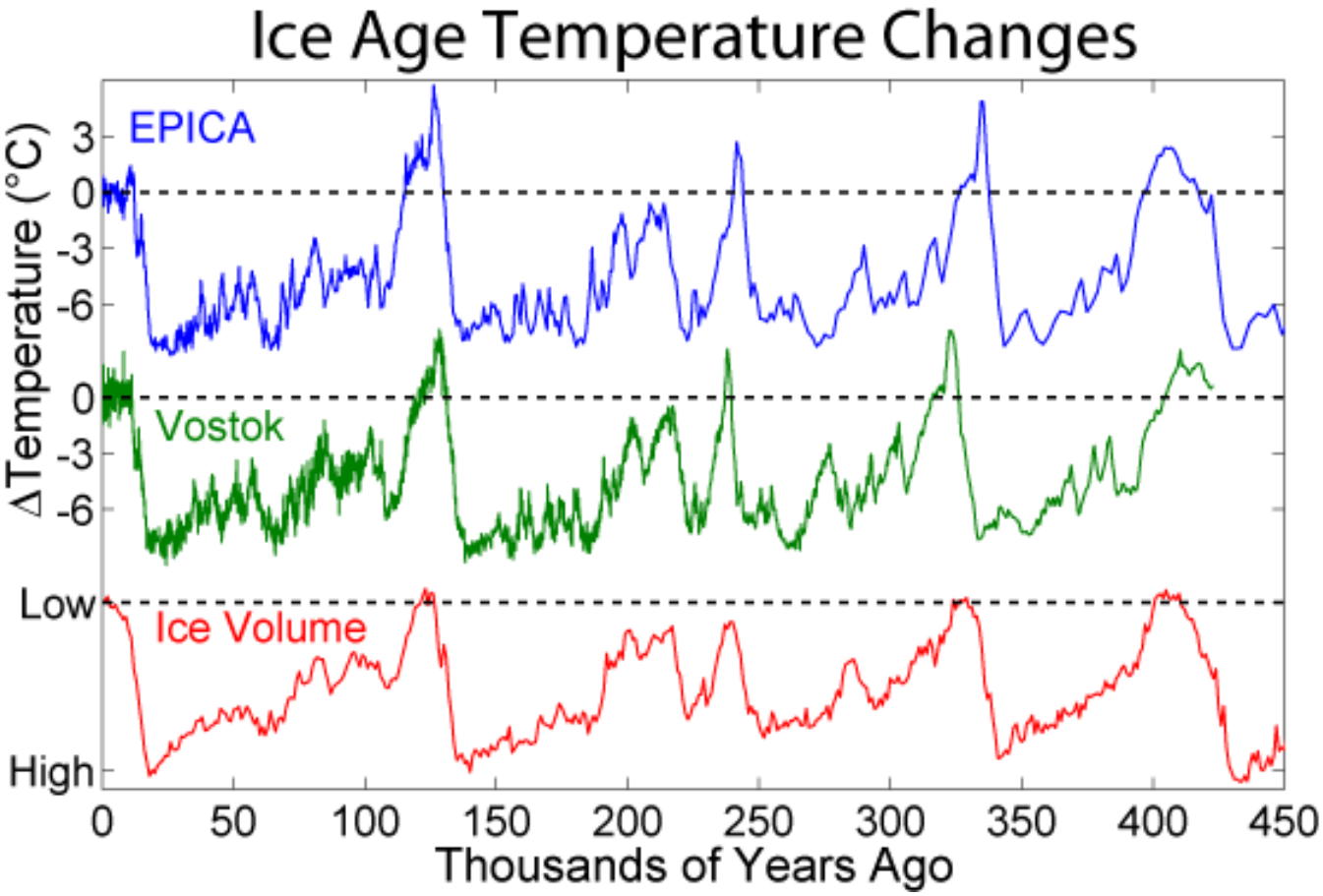
H_2O ~ 36% - 70%, CO_2 ~ 9% - 26%, CH_4 ~ 4% - 9%

CO_2 has shown a significant increase since industrial revolution



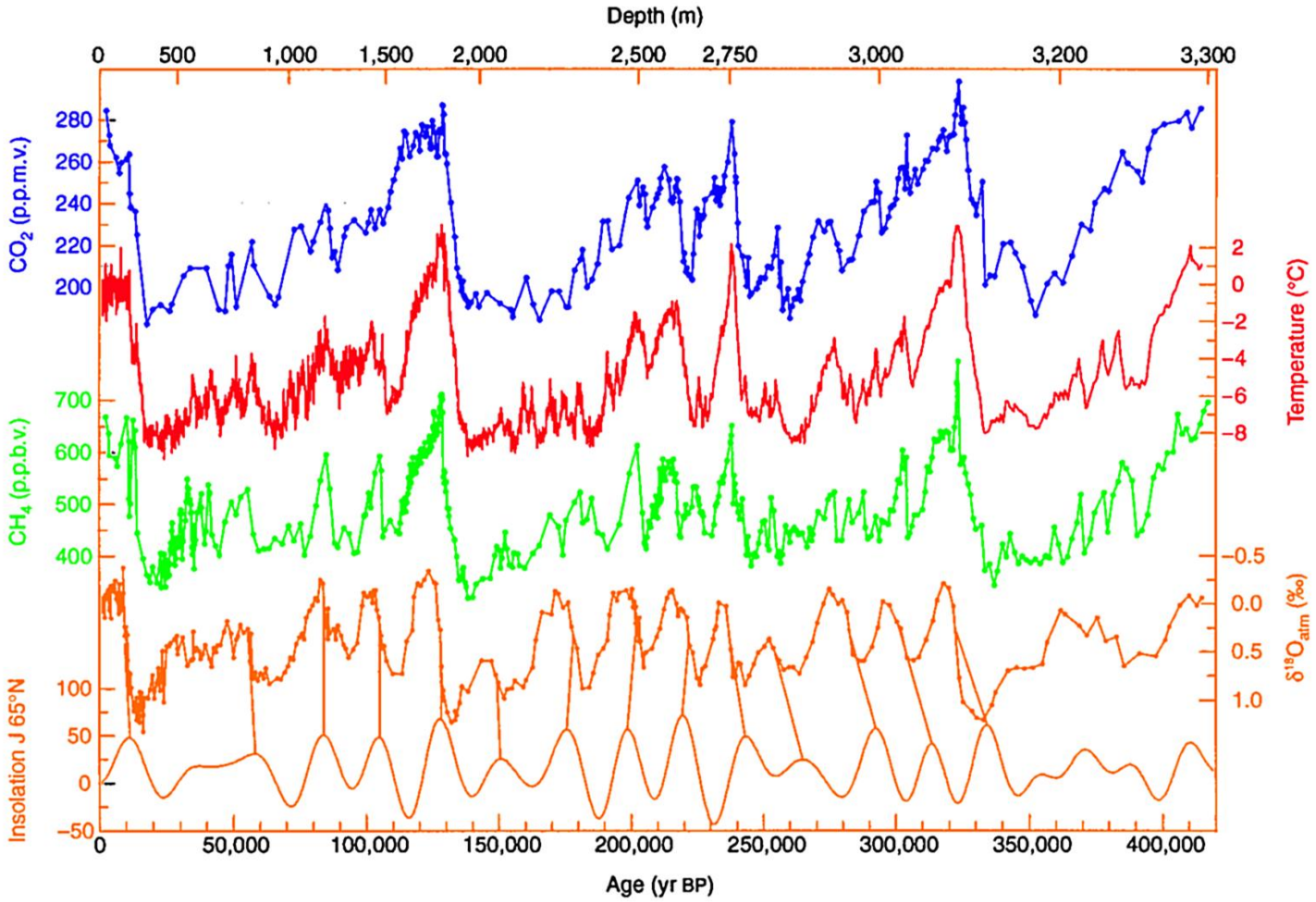
Earth's Long Term Temperature Changes - I

Long-term changes in $^{18}O/^{16}O$ isotopes trapped in ice are used to infer the long-term temperature cycles known to be present in fossil record (Ice Ages). Earth is currently in a warm period between Ice Ages.



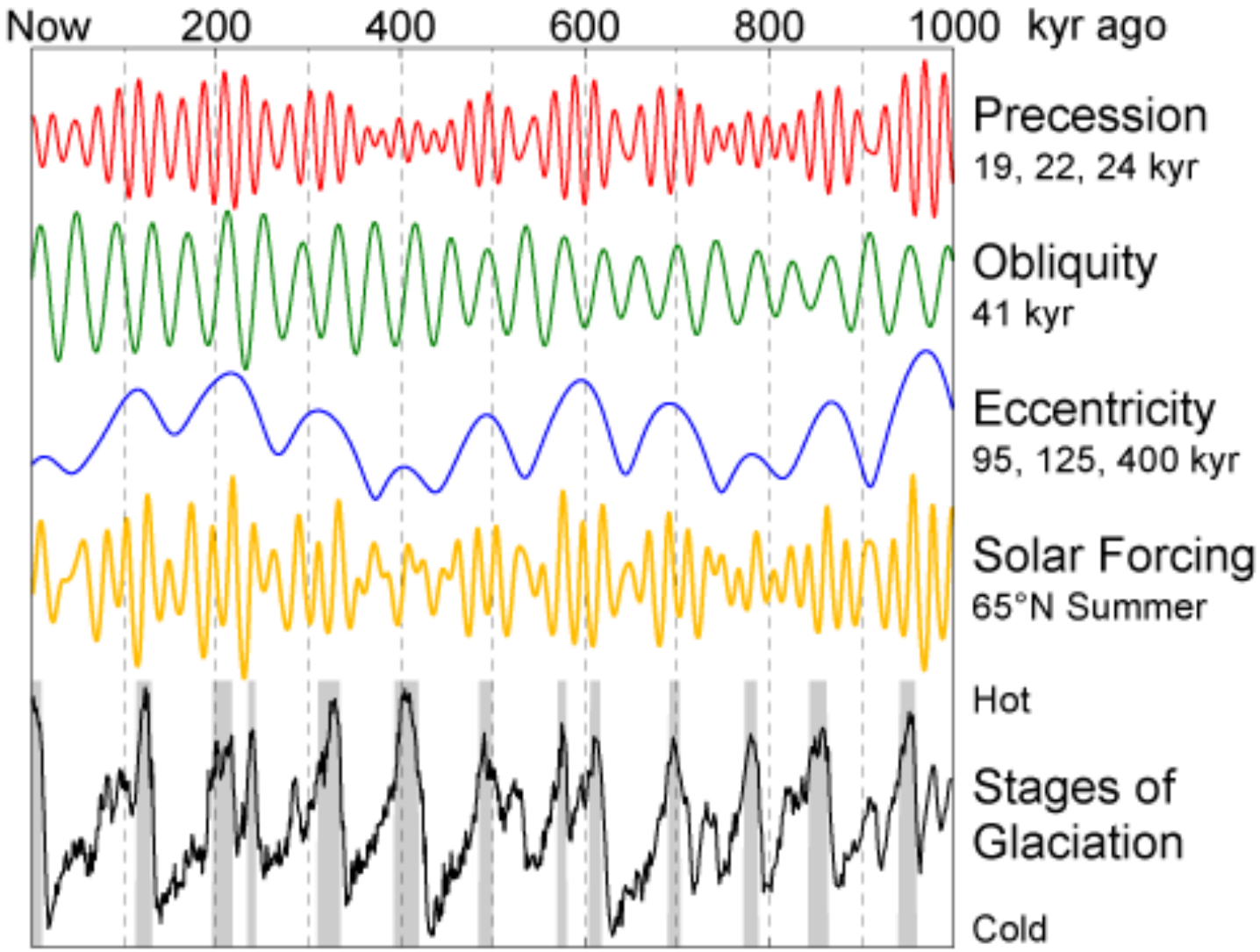
Earth's Long Term Temperature Changes - II

Long-term temp. changes measured via $^{18}O/^{16}O$ isotopes correlates with CO_2 and CH_4 trapped in ice. Appears to be result of small and regular changes in shape of Earth's orbit (Milankovitch cycles). Well Maybe …

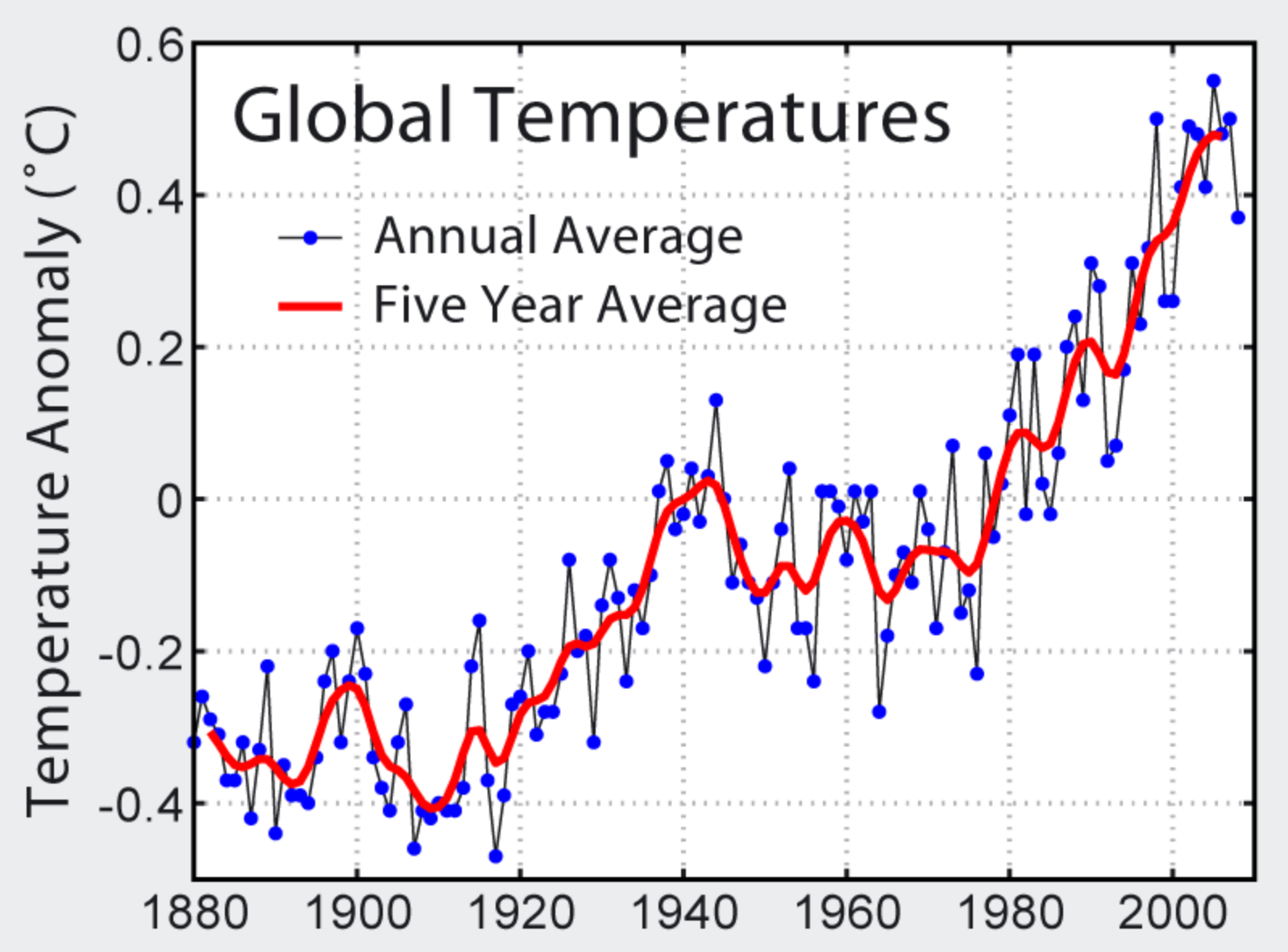


Milankovitch Cycles

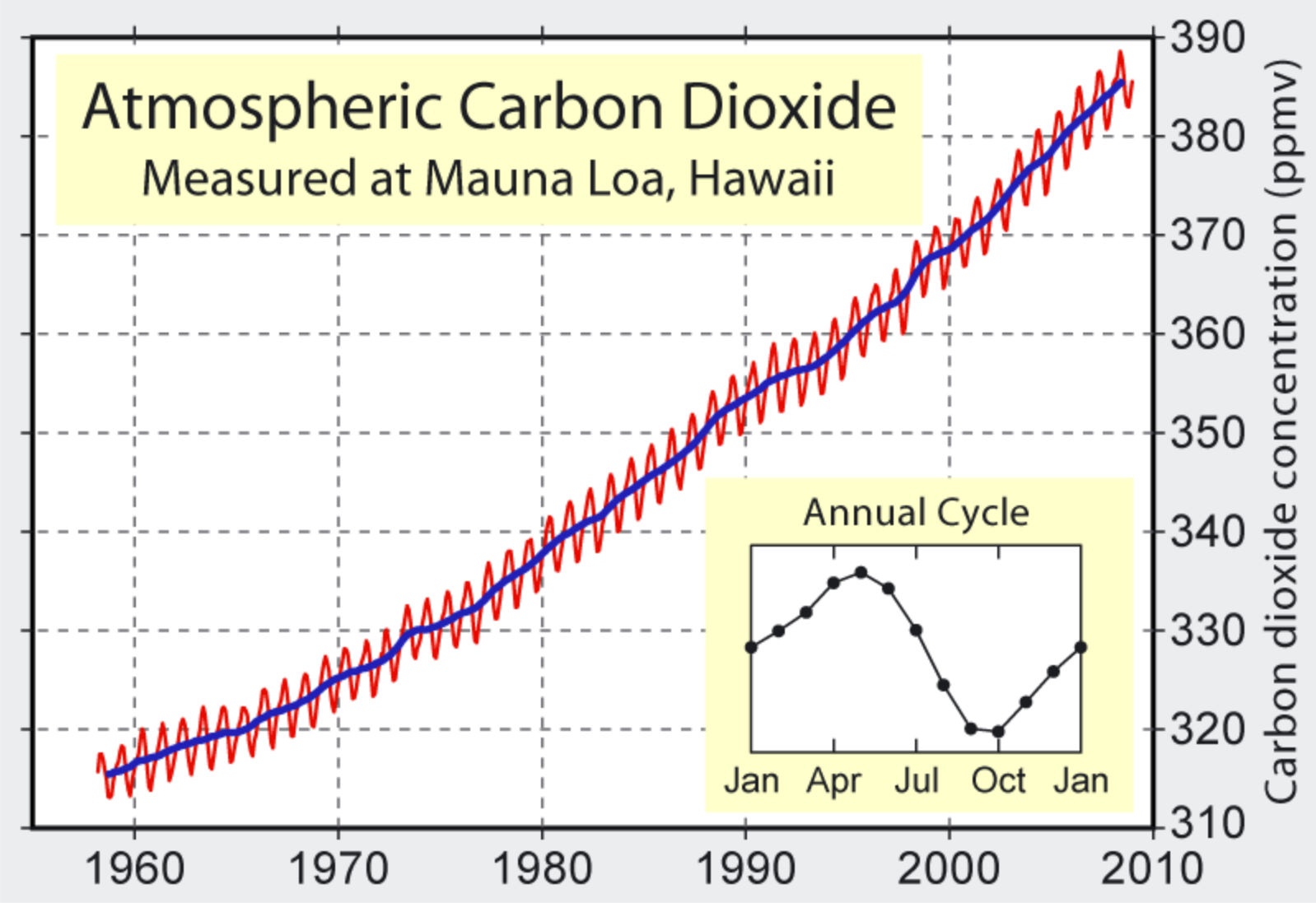
Effects are complicated and not fully worked through but suggest a connection with Earth's long-term climate changes.



Evidence for Recent Global Warming



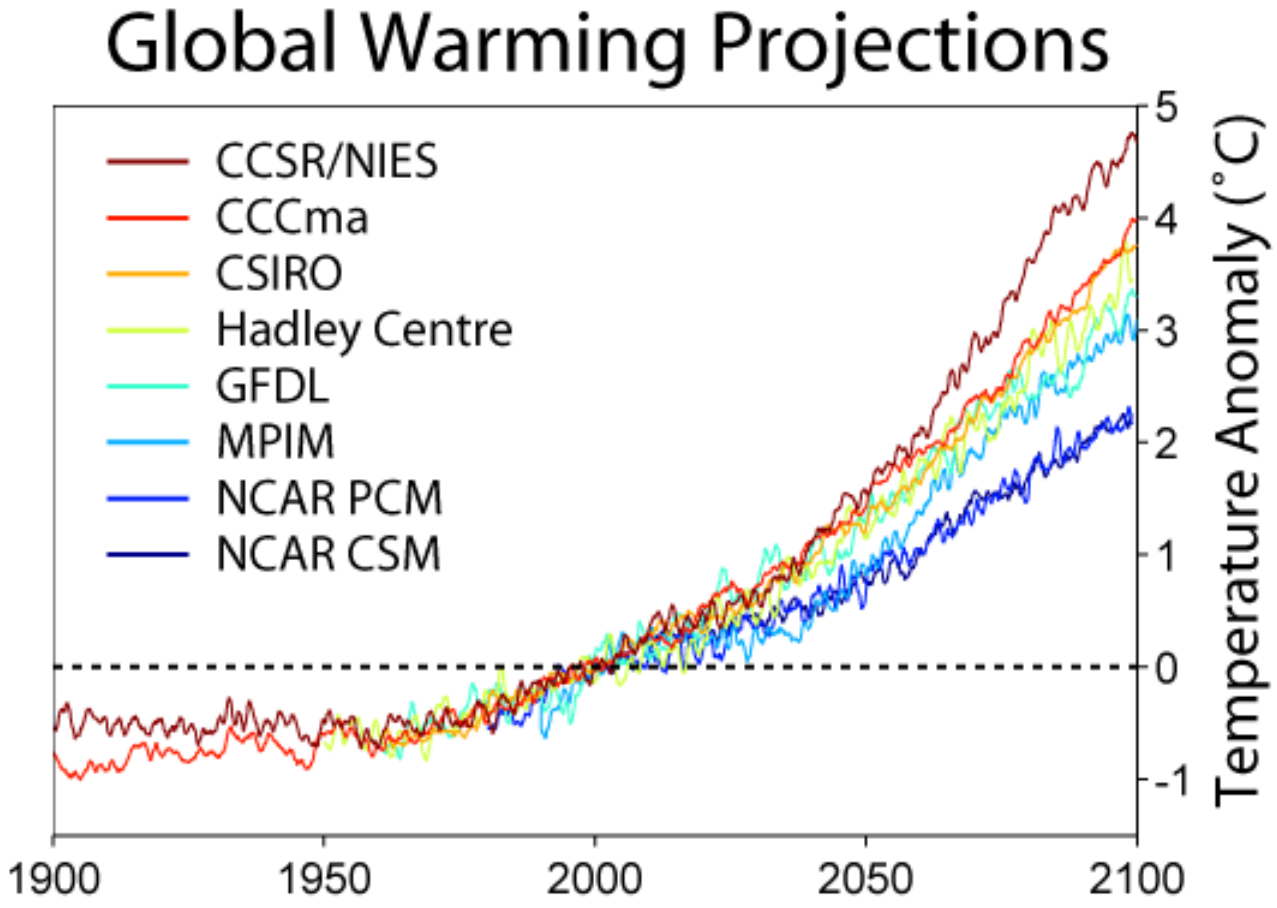
Increasing Atmospheric CO_2



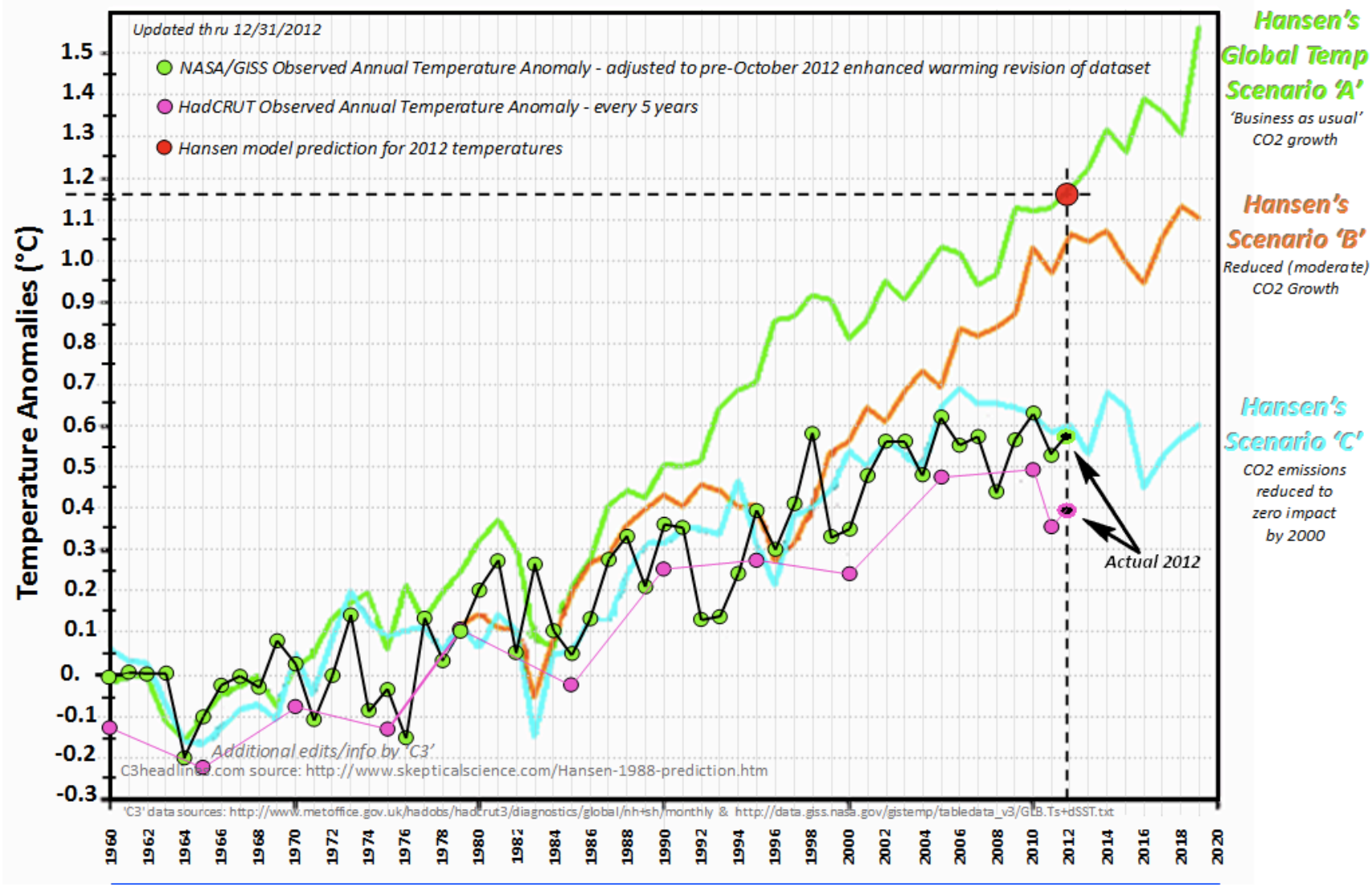
"Obviously" CO2 Must Cause the Rise in Temperature

Atmospheric Model Predictions

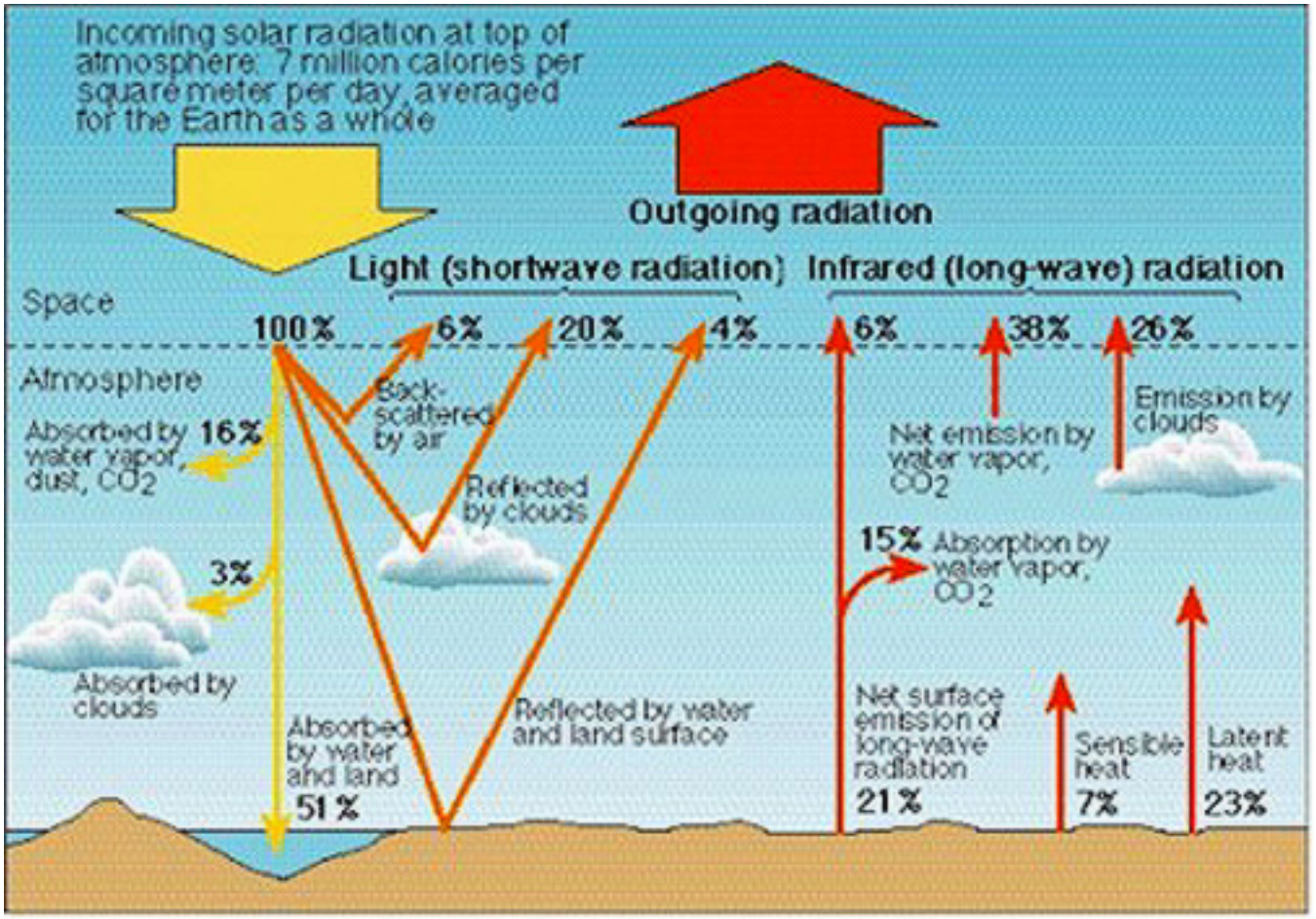
Most models predict ~ 3 ^{o}C over the next century. Effects will be considerable, even catastrophic.



But Here's What's Happened



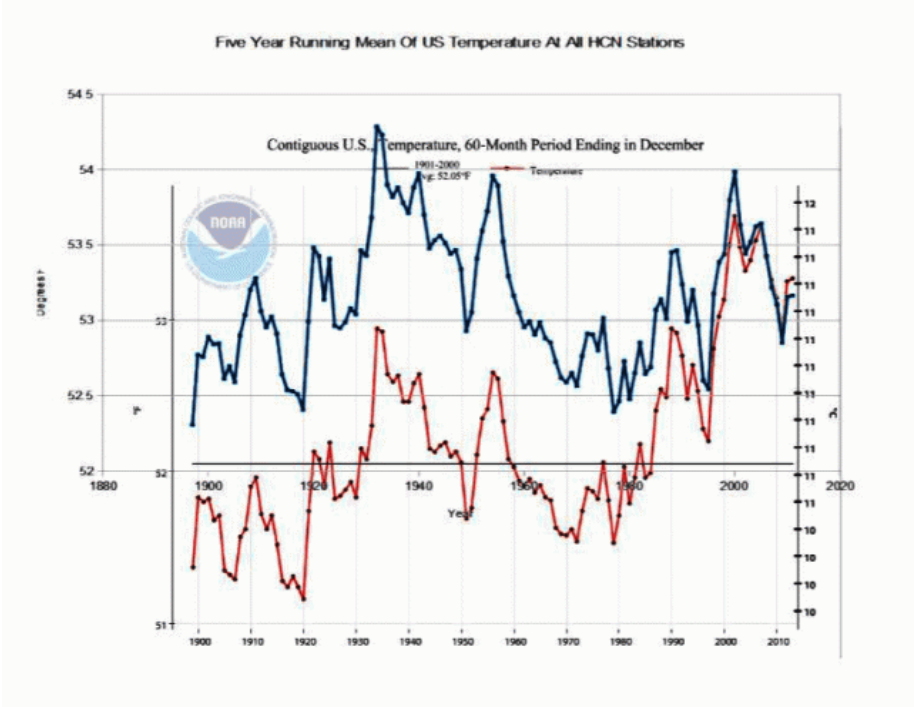
Temperature Equilibrium of Earth

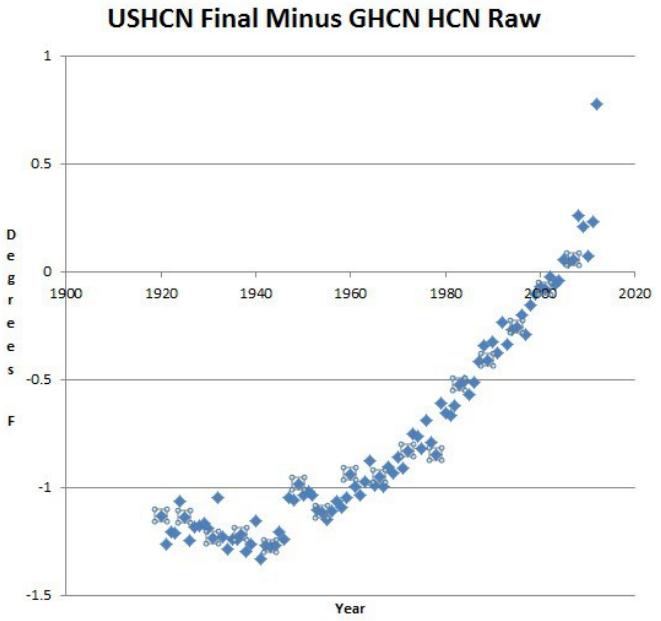


Global Warming: Hypothesis that CO2 Forces Temperature Higher

What About the Temperature Data?

- Most of the Evidence Due to Recent Systematic Adjustments of the Data
- This is Where the Debate Centers Today
- Justification is Urban Expansion Has Distorted Temps (Evidence?)
- What Happened to the Dust Bowl (1930s)?

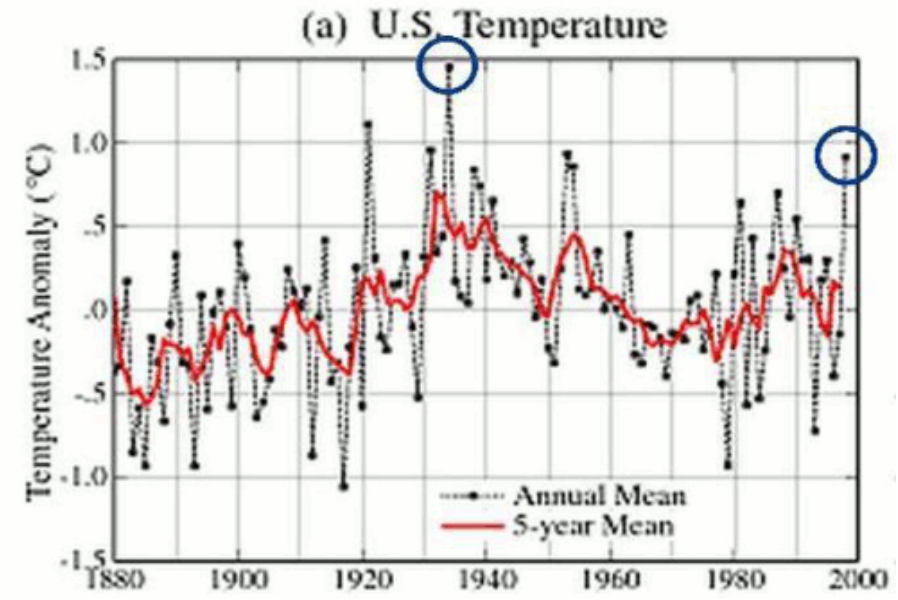


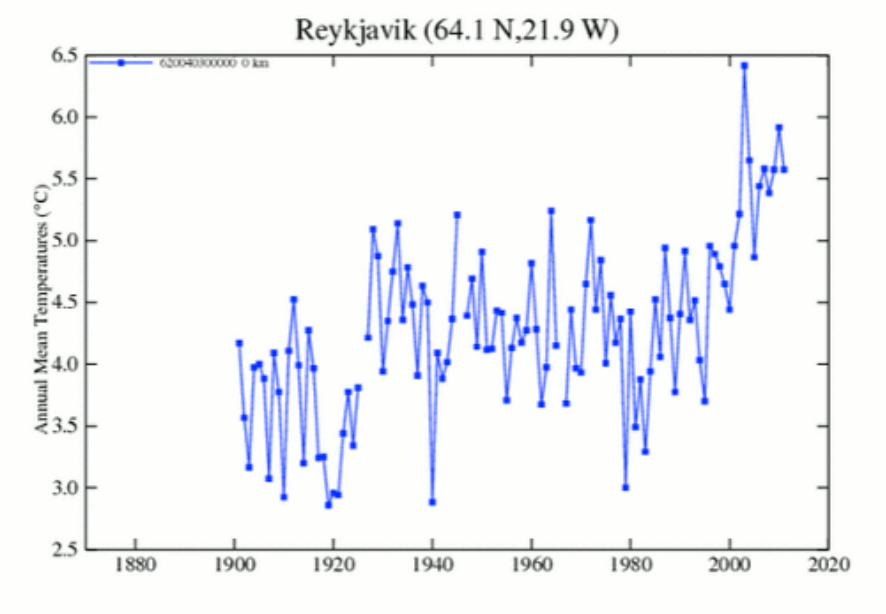


Data from Iceland Show Same Correction but No Justification

Temperature Data Adjustment Looks Awkward

- **AGW Advocates Claim Adjustments Perfectly Reasonable**
- **Critics Cry Foul (even Scientific Fraud)**

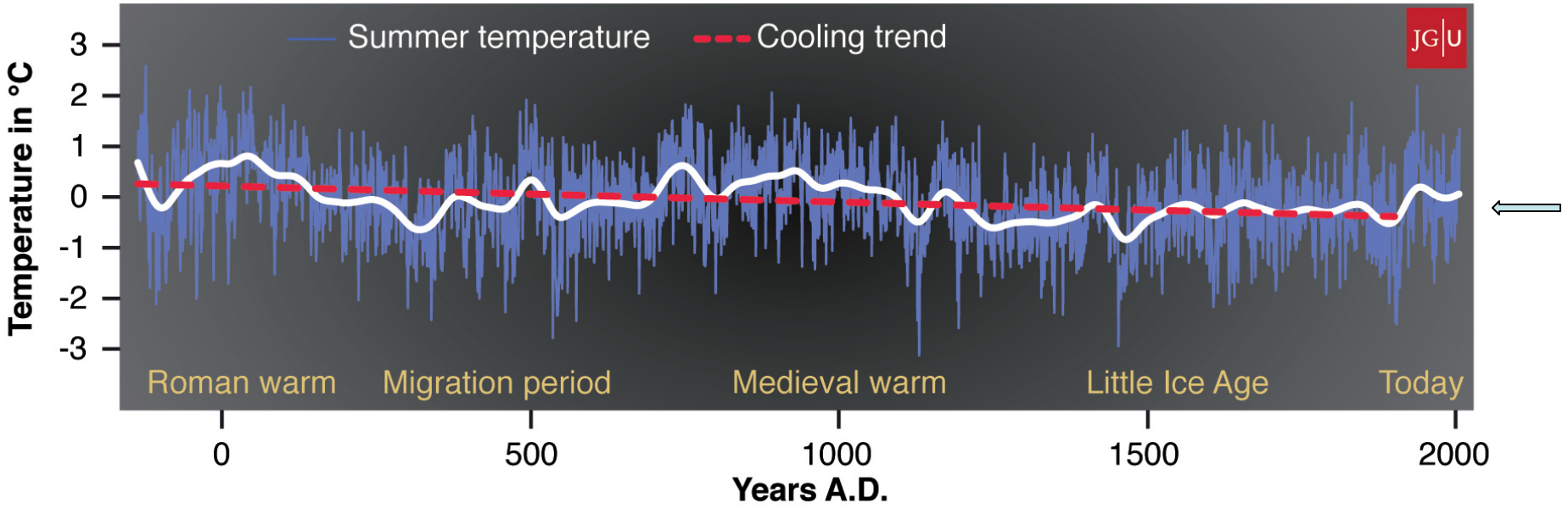




Are the Modesl Incomplete?

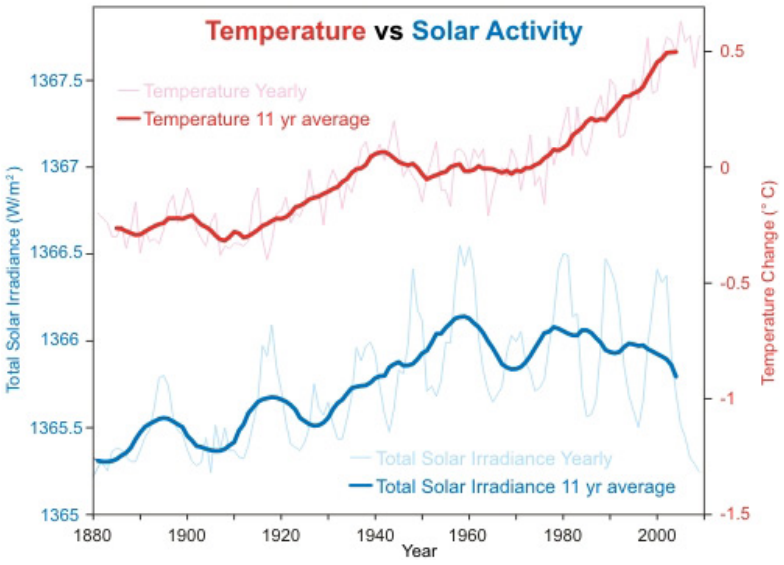
- H_2O Far More Important to Climate Than CO_2
- Cloud Formation Poorly Understood and Poorly Modeled

- Long Term Temperature Data from Tree Rings Suggest Temperature Variations are Common
- Modern CO_2 Rise Cannot Explain Long-term Variations
- Recent Rise then Flattening Consistent with "Natural Variations"
- It Turns Out Models Were "Adjusted" to Fit the Short-term Rise!
- Scientists Now Questioning Role of H_20 in Cloud-Induced Cooling

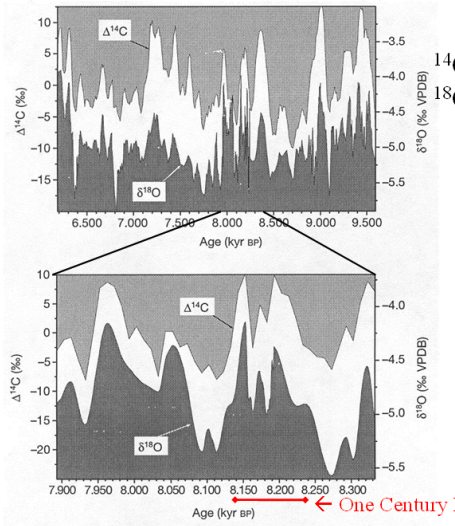


Then what Causes the Temp. Variations?

- **Short Answer: We Don't Really Know but the Sun Has at Least Some Effect**
- **Sun's Irradiance Clearly Varies Over its Activity Cycle (more later)**
- **Correlation with Earth's Temperature not Obvious but its Output of Charged Particles Does Appear to Correlate**
- **Problem is That We Just Don't Know**



Stalagmite Records in Oman



^{14}C – a Proxy for Solar Activity
^{18}O – a Proxy for Temperature

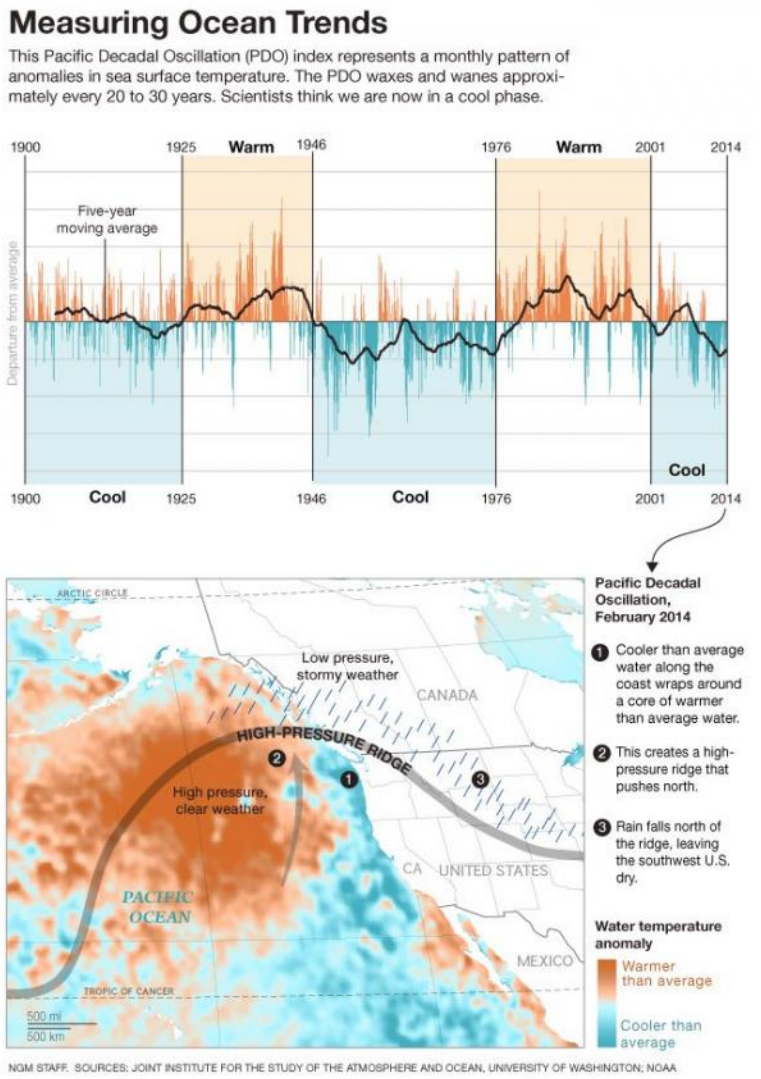
The stalagmite record shows a remarkably close correlation between ^{14}C and ^{18}O over a period of more than 3,000 years.

Thus, a strong association exists between solar activity and temperature.

Neff *et al.* (2001)

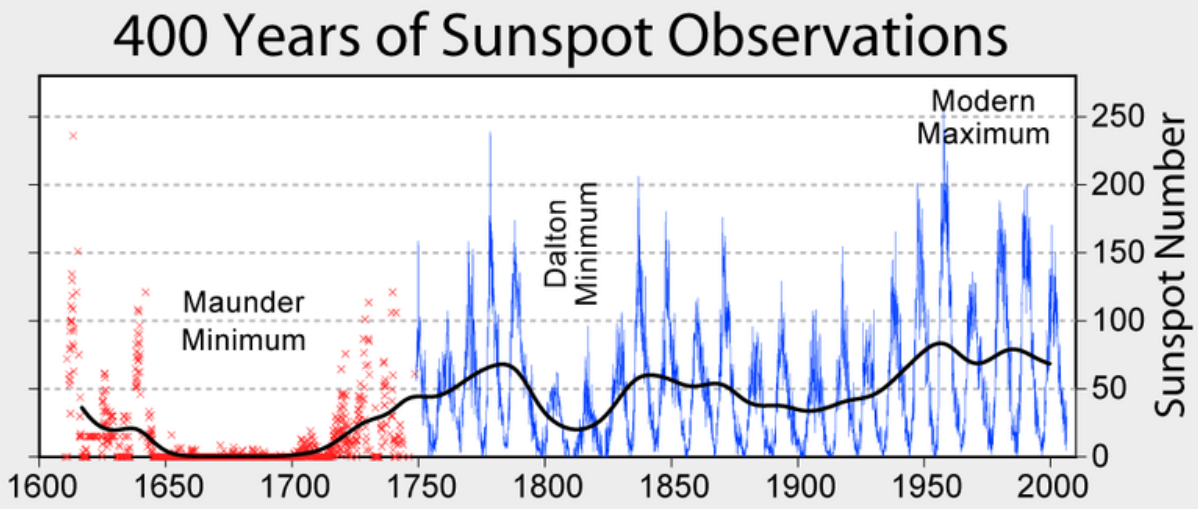
Then what Causes the Temp. Variations?

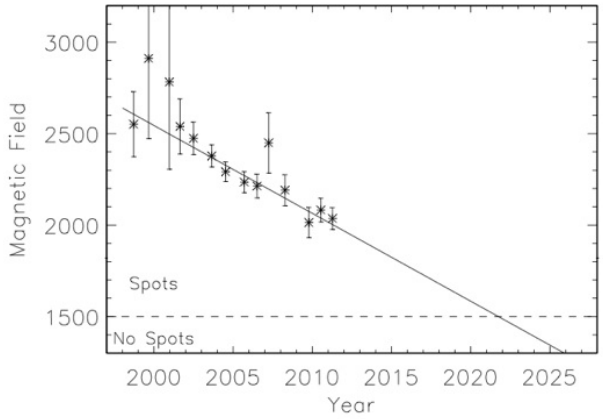
- Other Origins are Possible too
- Volcanoes (year without a summer)
- Pacific Decadal Oscillations are Real
- Warm/Cool Regions of Ocean Affect Weather and Droughts
- Is this a Cause or Effect?
- Note the Correlation with Dust Bowl and Recent Temperature Increase (then drop)
- It may be AGW (Anthropomorphic Global Warming) but Who Can Say?
- <u>Opinion:</u> We Just Don't Have the Capability to Fully Model the Earth's Atmosphere (including clouds), the Ocean, etc.



Troubling Long-term Trends in Sun?

- **Accurate Measurements of the Sun's Magnetic Field Strength Show Decline**
- **Historical Record of "Little Ice Age" (Big Chill) is Clear: No Sunspots were Present During That Period so Sun Might Be Related (Proof??)**
- **This Could be Real Trouble if it Continues. Unfortunately Only Time Will Tell**





Zeeman Splitting Averages Within Sunspots(Livingston & Penn). If Trend Continues Sun's Activity Might "Turn-off" Again (~ 2020).

The Moon - I

Basic Properties:

Radius = 1738 km
Mass = 0.07 x 10^{24} kg
$<\rho>$ = 3.34 gm/cc

Surface Characteristics:

Solid Interior

Heavily Cratered with Lava Basins on Near Side

Very Thin Atmosphere:
Nobel Gasses (Xe)

$\rho_m \sim 10^{-14} \rho_E$

The Moon - II

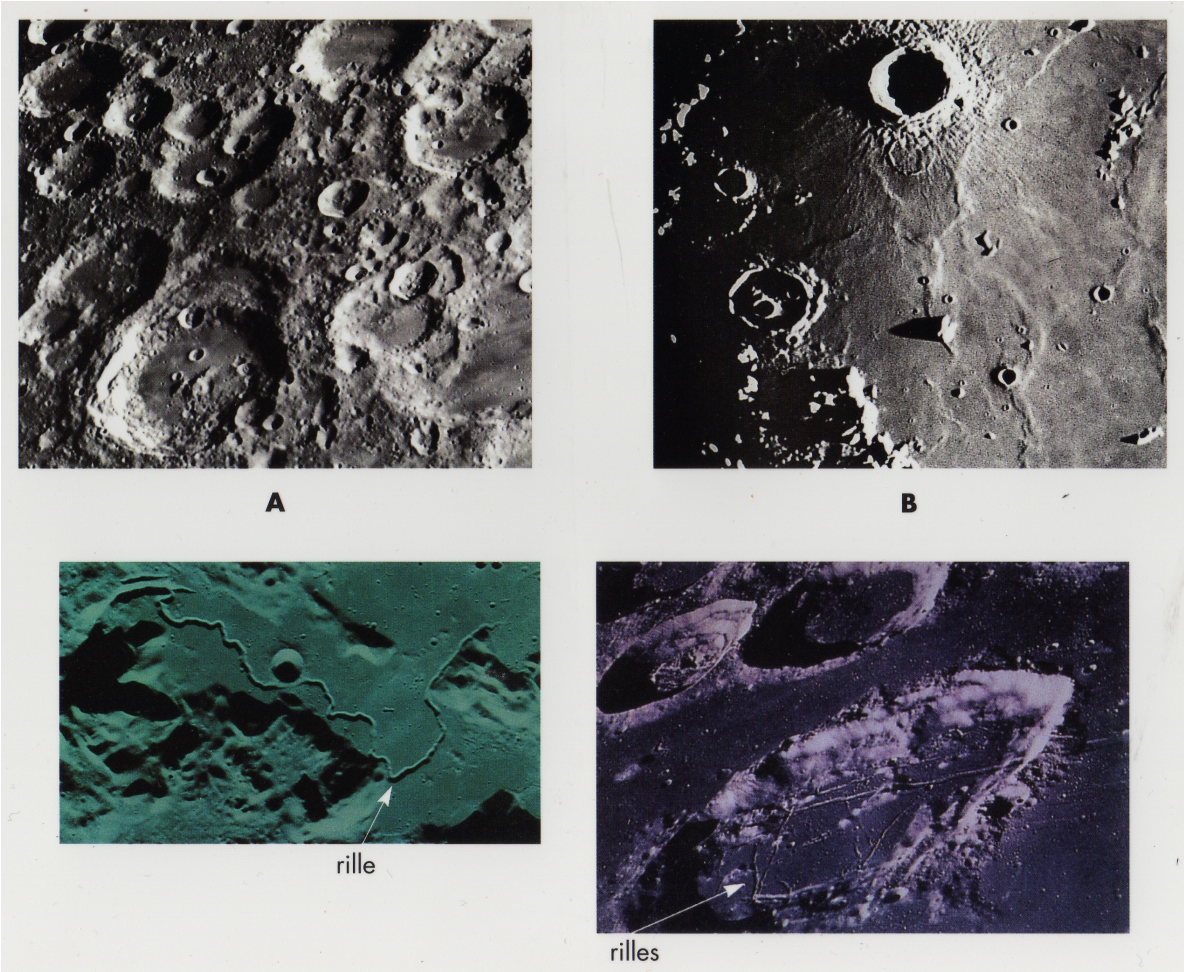
Lunar Maria: Impact Basins Filled with Lava

Lunar Highlands: Heavily Cratered Regions

Lunar Mountains: Mostly Associated with Ejecta or Deformation of Crust but Some Volcanic Domes are Evident

Lunar Farside: Dominated by Highlands, No Large Lava Basins

Ages Indicate Maria are 1 Billion Years Younger than Highlands (3.5 vs. 4.5 Billion Years Old)



The Moon - III

Seismic equipment left on the moon recorded "moon quakes", both natural and from rockets crashing into the moon. Data revealed:

Moon has a hot, solid core displaced toward the Earth. Core is denser than average (ρ ~ 3.5 gm/cc).

A warm "mantle" surrounds the core and has a lower density (ρ ~ 3.2 gm/cc)

The crust is very thick and cold with a low density (ρ ~ 2.9 gm/cc).

Sound speeds can be modeled to constrain interior composition

Core is Iron-rich but still relatively Iron-poor. That is, the Moon doesn't have an Iron core but was clearly melted and differentiated.

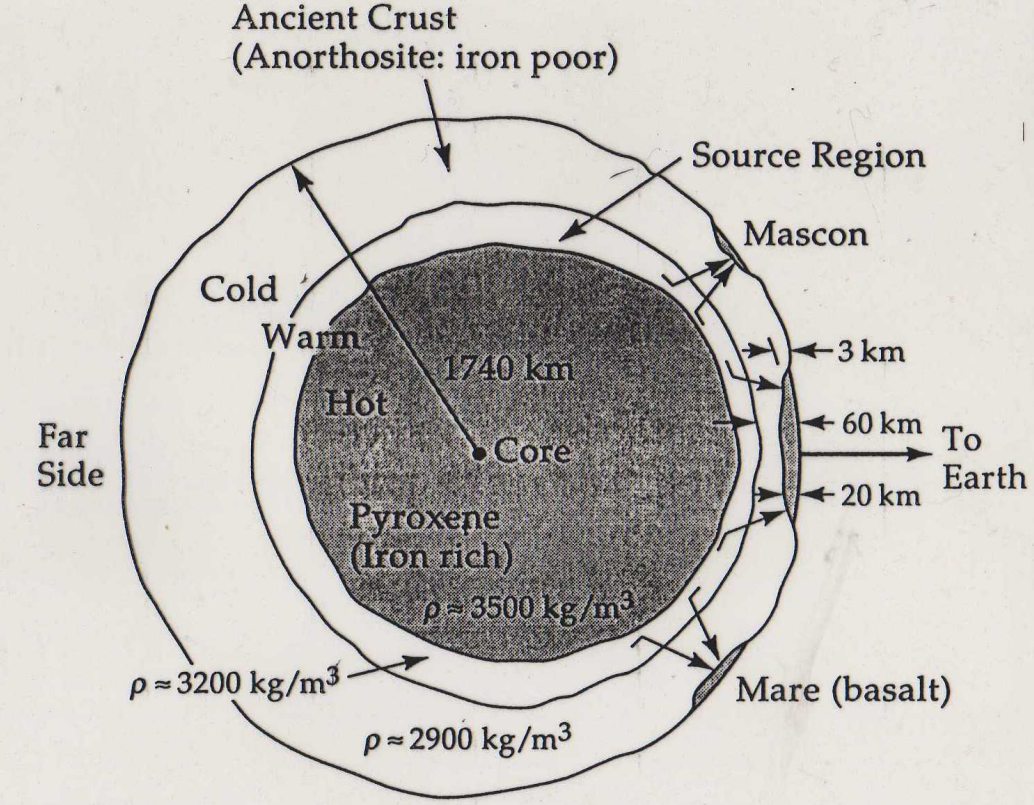


Figure 4–9 The Moon's interior. This model is based on *Apollo* measurements of seismic waves and heat flow; it shows typical values for sizes and densities for each region. The "source region" marks the location of moon-quakes. Note the asymmetry of the interior along the line to the Earth.

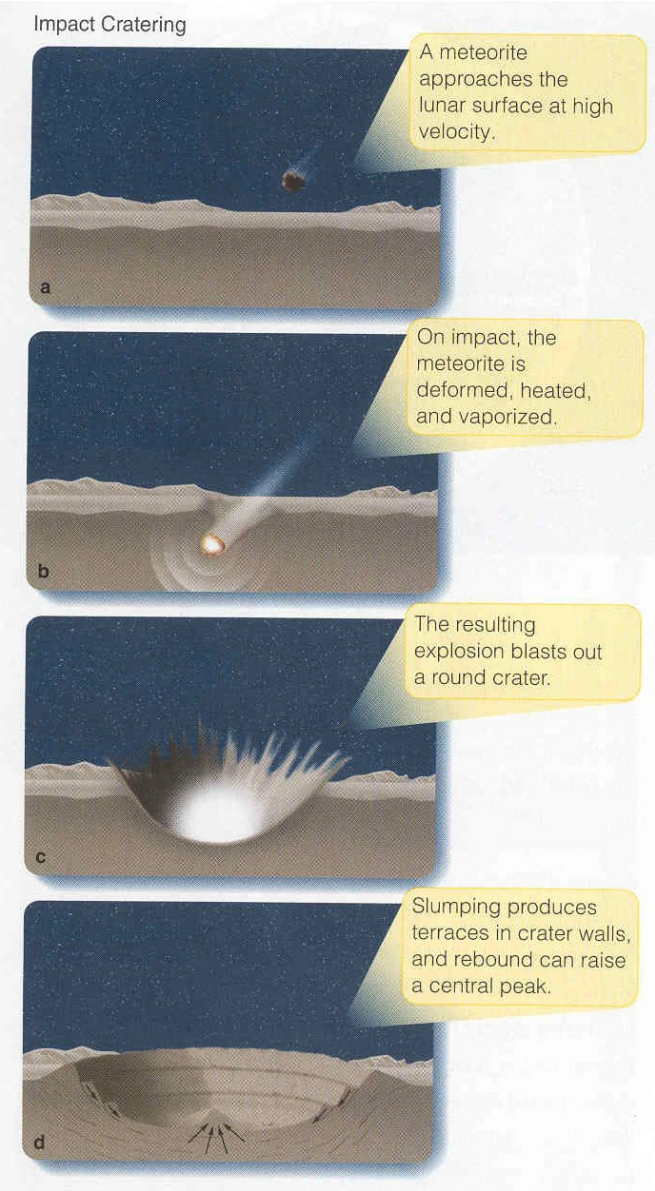
What is a crater?

- **Must think of them as caused by very large explosions from release of kinetic energy of impactor**
  - **Like a mortar shell – it isn't the size of the shell which matters, its how much energy you get out of the explosion**
  - **DO NOT think of them as just holes drilled into surface – think EXPLOSION**
  - **Kinetic Energy $E = \frac{1}{2} m v^2$**
  - ***v* is roughly escape speed of ea** $v_{\text{Escape}} = \sqrt{\frac{2GM}{R}} = 11\,\text{km/s}\ (= 25{,}000\,\text{MPH})$
  - ***m* = mass = volume * density (Consider a 1 km asteroid)**

$$= \tfrac{4}{3}\pi R^3 \rho = \tfrac{4}{3}\pi (1000\,\text{m})^3\ 3500\,\text{kg/m}^3 = 1.5\times10^{13}\,\text{kg}$$

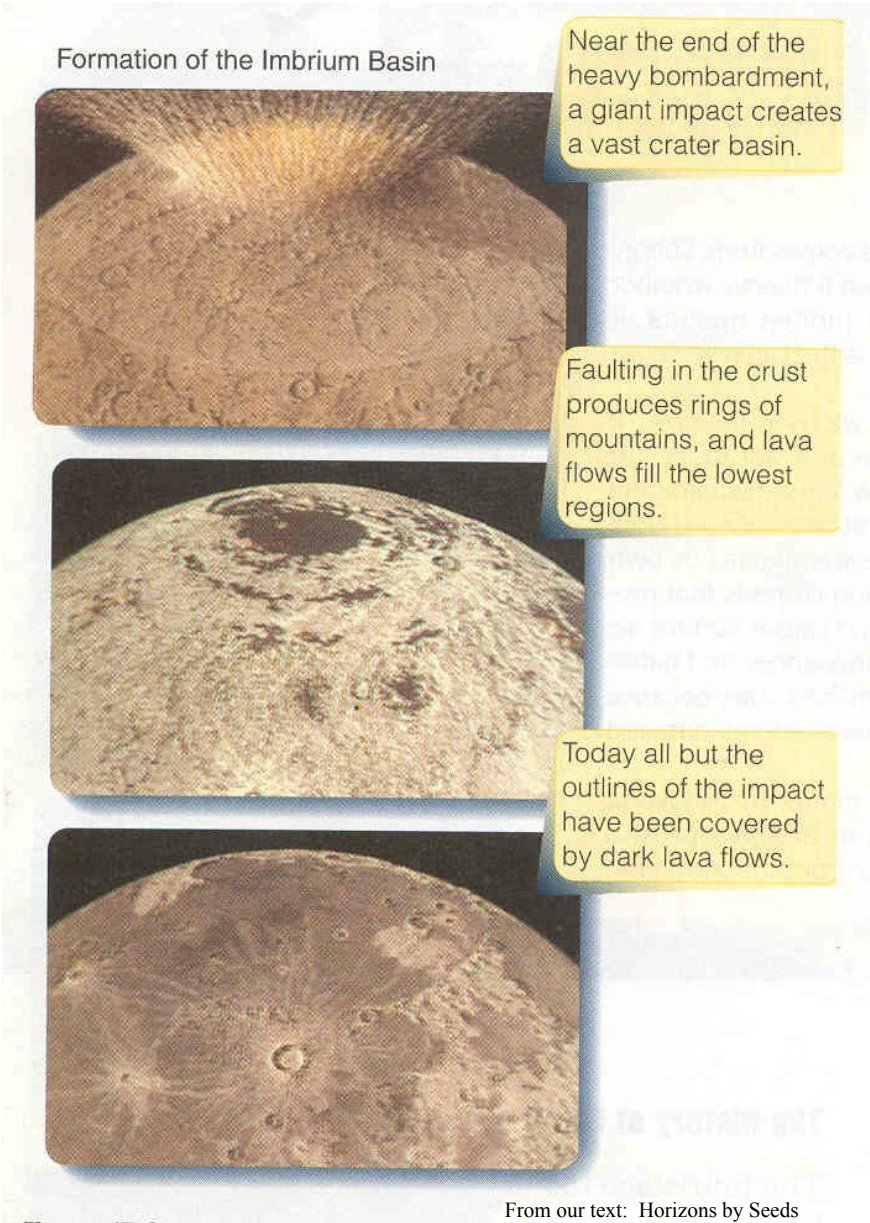
  - ***E*** $= \frac{1}{2} m v^2 = 9\times10^{20}\,\text{kg m}^2/\text{s}^2 = 9\times10^{20}\ \text{joules}$
    $= 9\times10^{20}\ \text{joules} \ /\ (4\times10^{15}\ \text{joules/Megaton})$
    $= 230{,}000\,\text{Megatons}$
  - **This is ~4500 × the size of the largest (~50 Mt) hydrogen bombs ever built and this is for a relatively small size asteroid**

Formation of an impact crater



From our text: Horizons by Seeds

- **Crater caused by the explosion**
  - **Impactor is melted, perhaps vaporized by the kinetic energy released**
- **Temporary "transient" crater is round**
- **Gravity causes walls to slump inward forming "terraces"**
- **Movement of material inward from all sides (trying to fill in the hole) may push up central peak in the middle.**
- **Final crater is typically ~10 times the size of the impactor**



From our text: Horizons by Seeds

Figure 17-6
Mare Imbrium on the moon has a generally round outline, the consequence of its formation by a giant impact 4 billion years ago. *(Courtesy Don Davis)*

Superposition (way to get relative ages)

- **Newer features are <u>superposed</u> on top of older ones**

- **Large impact forms basin**
- **Basin floods with lava**
- **Additional impacts occur in mare lava**

- **Over time both crater rate and volcanic activity are declining**
  - **Craters less because debris swept up**
  - **Volcanism less because moon cooling**

Problems with the Condensation Model:

Why is the moon so different than the earth?

Planet	$\rho_{Compressed}$	$\rho_{Uncompressed}$
Mercury	5.43	5.3
Venus	5.24	4.0
Earth	5.515	4.1
Moon	3.36	3.3
Mars	3.94	3.7

Moon has too low a density: Is missing large iron core
Moon is also missing volatile elements
Moon otherwise looks chemically like the earth

Effects of late impacts

Most recent impacts show “Rays” originating from impact.

Lighter interior material ejected onto the darker surface

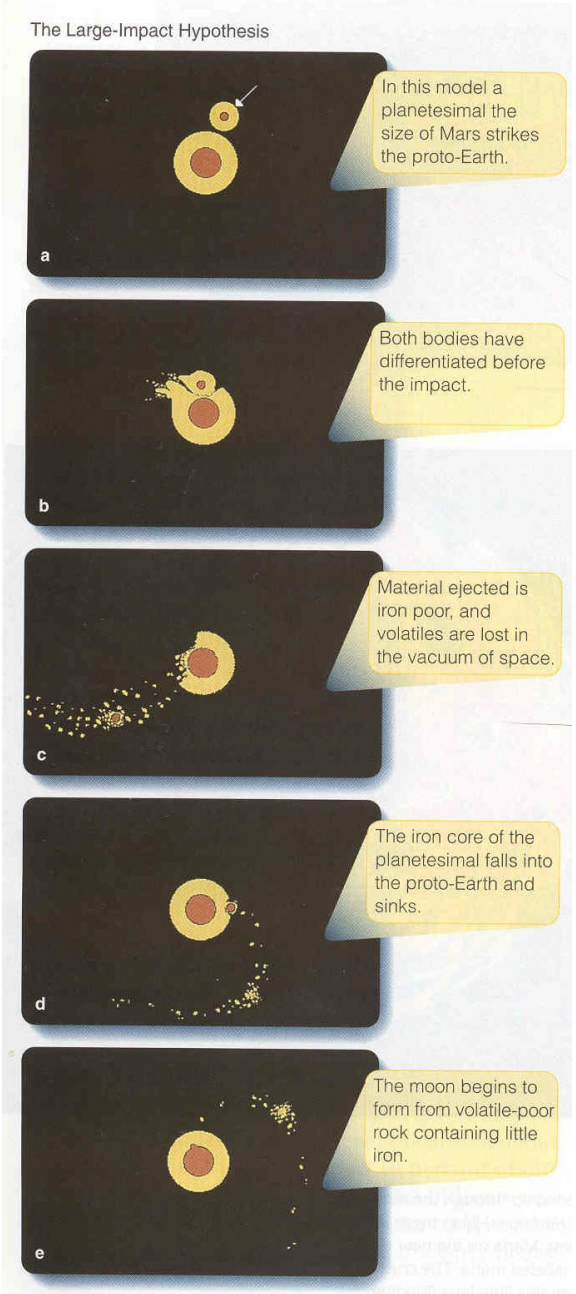


Figure 17-8
Computer simulations of impacts between differentiated bodies suggest Earth's low-density, iron-poor moon might have formed from such an event.

Moon: Giant Impact Hypothesis

- **Explains lack of large iron core**
- **Explains lack of "volatile" elements**

- **Explains why moon looks a lot like earth's mantle, minus the volatiles**

- **Explains large angular momentum in the earth-moon system**

From our text: Horizons by Seeds

Chapter 9: Homework

Chapter 9: #1, #2, #5, #7, #8, #9

- Due Tues. April 26