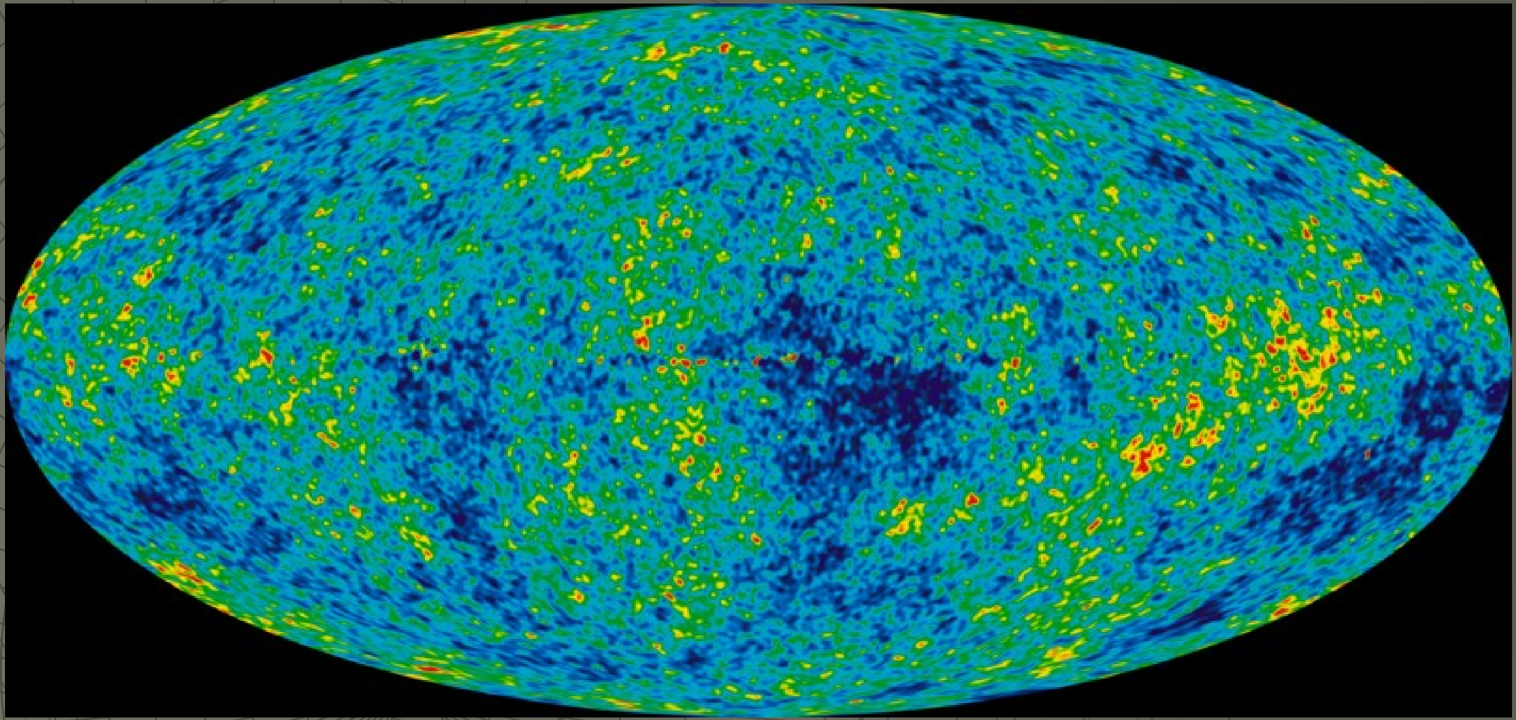
EARTH

A Changing Planet

Original slides provided by Dr. Daniel Holland

The story begins…



The estimated **age of the universe** is 13.75 ± 0.17 billion years. (Estimate is based on fluctuations in cosmic background radiation.)

Audio Link

The story begins…

- The Sun was born from a cloud of interstellar gas approximately 4.6 billion years ago. (The sun is a third generation star.)
- Most of the cloud is Hydrogen and Helium formed just after the start of the Universe.
- Heavier elements are the remnants of older star that have burned out and exploded.

- As the cloud collapses, it heats the gas eventually making the temperature at the center high enough for nuclear fusion to start. (More later. Gravitational potential energy converted into heat energy)
- The newborn sun is only about 70% as bright as today’s sun
- There is enough material for the sun to last about 10 billion years. It will get brighter very slowly.

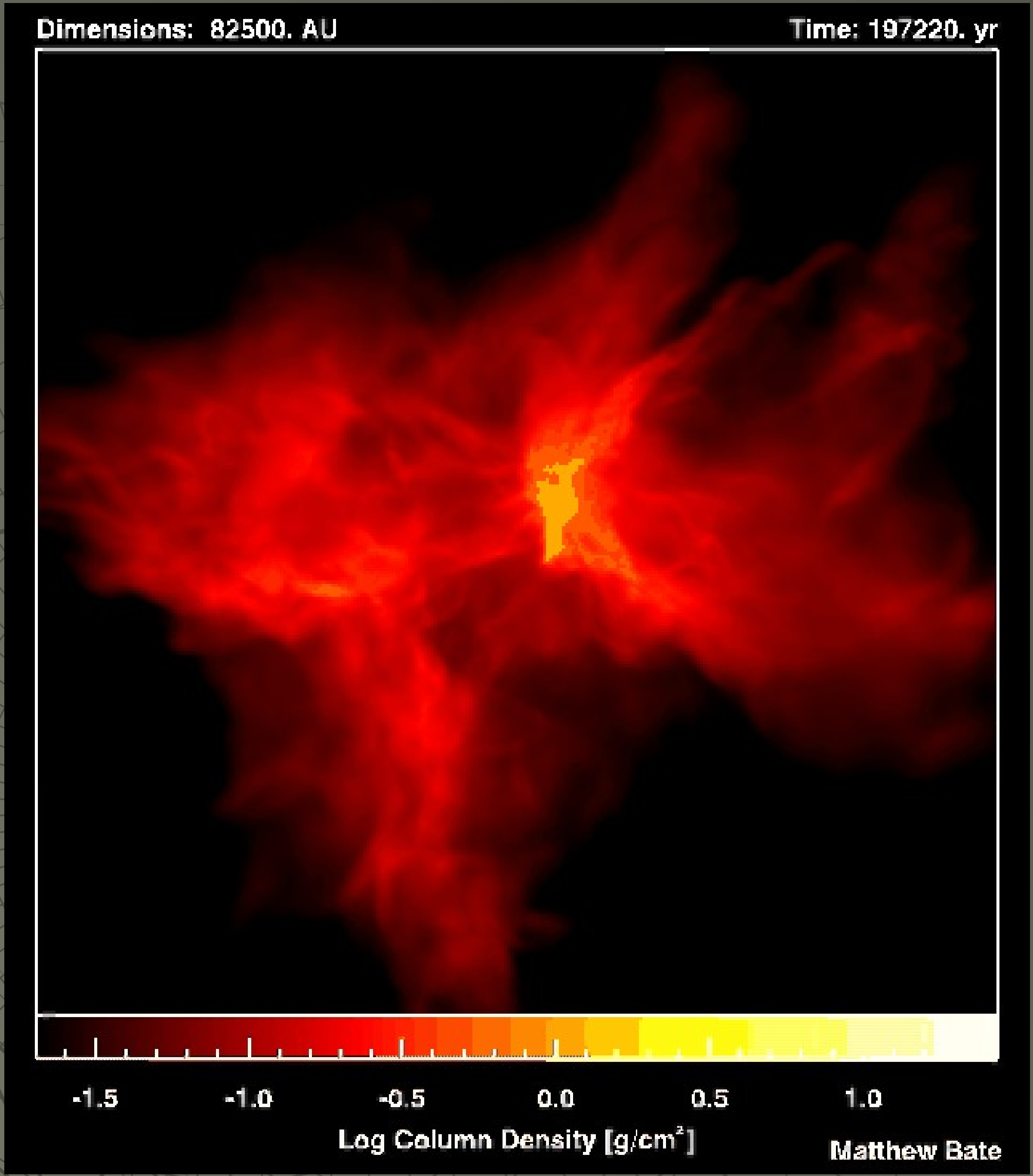
The Formation of Stars and Brown Dwarfs and the Truncation of Protoplanetary Discs in a Star Cluster

Matthew R. Bate, Ian A. Bonnell, and Volker Bromm

The calculation models the collapse and fragmentation of a molecular cloud with a mass 50 times that of our Sun. The cloud is initially 1.2 light-years (9.5 million million kilometres) in diameter, with a temperature of 10 Kelvin (-263 degrees Celsius).

The cloud collapses under its own weight and very soon stars start to form. Surrounding some of these stars are swirling discs of gas which may go on later to form planetary systems like our own Solar System.

The calculation took approximately 100,000 CPU hours running on up to 64 processors on the UKAFF supercomputer. In terms of arithmetic operations, the calculation required approximately 10^{16} FLOPS (i.e. 10 million billion arithmetic operations).



Dimensions: 82500. AU
Time: 197220. yr
-1.5
-1.0
-0.5
0.0
0.5
1.0
Log Column Density [g/cm^2]
Matthew Bate

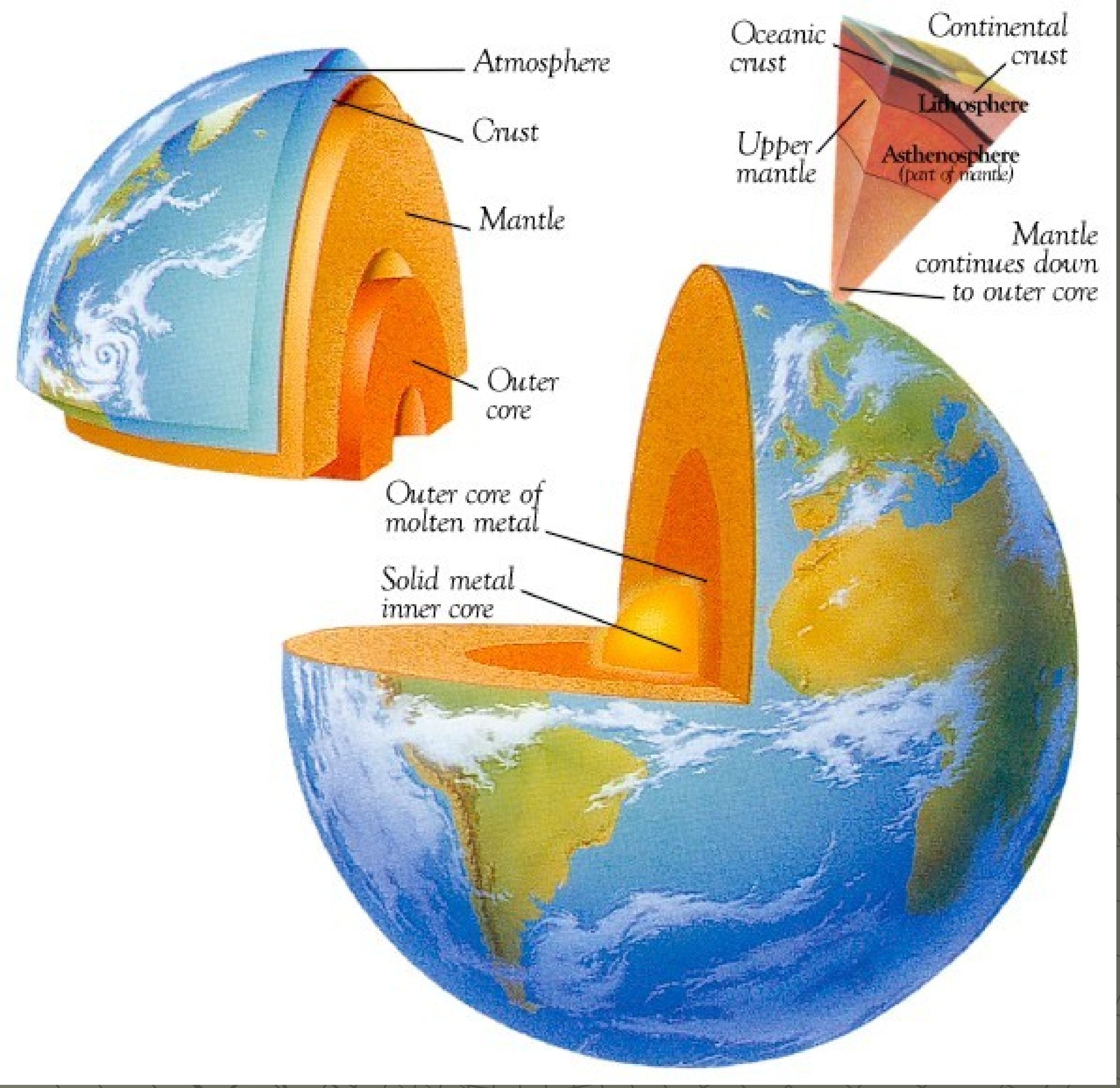
- Further out, the dust grains accumulate into smaller object such as planets and comets. It takes about 100,000,000 years to form planet size objects. (Earth formed ~4.5 billion years ago)
- Early planets are continually bombarded by large and small objects.

When the earth is about 50,000,000 years old it is hit by a Mars size object. The ejected material forms the moon

Evidence for Collision Model

- The Earth has a large iron core, but the moon does not.
- The moon has exactly the same oxygen isotope composition as the Earth, items from other parts of the solar system have different oxygen isotope compositions.

- On young molten earth heavy elements sink to the center and lighter elements rise to surface and form a hard crust
- Gas escapes to form an atmosphere of mostly Carbon Dioxide (CO_2)and Nitrogen (N_2).
- There is essentially no free oxygen in the early atmosphere.
- Water vapor condenses to form primeval oceans about 4,000,000,000 years ago.



Basic structures are still there today

Beginnings of life

- Sometime around 4 billion years ago life begins on earth. Earliest direct fossil evidence (fossil algae) is 3.5 billion years old.

Audio Link

- Earliest life forms didn’t change much for billions of years. (Some fossil bacteria are very similar to modern ones.)
- Early bacteria are “generalists”…they adapt to a wide range of conditions. (Most highly evolved life requires very specialized conditions.)
- Early organisms extracted energy from their chemical surroundings.
- Example: Black Smoker Ecosystem

- At some point (solid evidence is 2.7 billion years ago but probably earlier) primitive organism near the surface developed the ability of photosynthesis.

Sunlight + CO_2 + $H_2O \rightarrow$ Carbohydrates + O_2

- Oxygen is highly reactive and is actually toxic to early life. (Early pollution?)

Evolution of the Atmosphere

- Early: Mostly CO_2 and N_2 with traces of methane, ammonia, sulfur dioxide and Hydrochloric Acid. (and a lot of water before it cooled enough to condense.)
- CO_2 lost by two mechanism: 1) Geochemical and 2) biological. It is not clear which was most significant. (still a hot topic w.r.t. global warming)

- At first, Oxygen in atmosphere rose slowly. It is very reactive so it combined with other substances.
- After whole earth has “rusted”, Oxygen content begins to rise. It reached its present concentration (20%) about 1.5 billion years ago.
- Nitrogen is relatively non-reactive so it hasn’t changed much.

- The presence of free oxygen in an atmosphere is VERY unusual. Only earth has it in our solar system.
- Requires replenishment by some mechanism because it is so reactive.
- The presence of free oxygen on a distant planet is probably a good indicator of life.

The primary gases in the early atmosphere were

1. Nitrogen and Oxygen
2. Carbon Dioxide and Oxygen
3. Carbon Dioxide and Nitrogen
4. Methane and Nitrogen

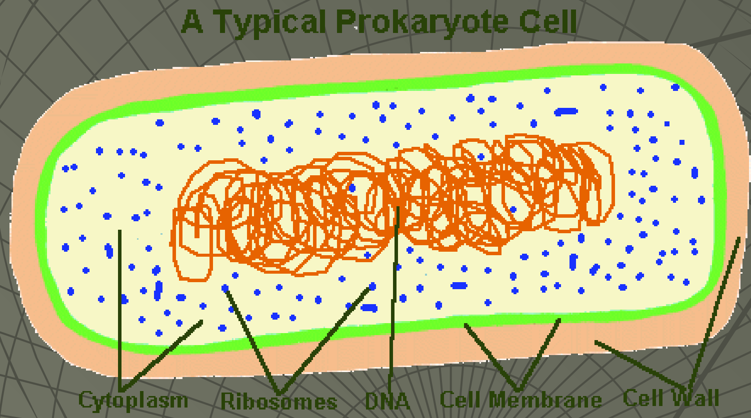
The primary gases in the atmosphere today are

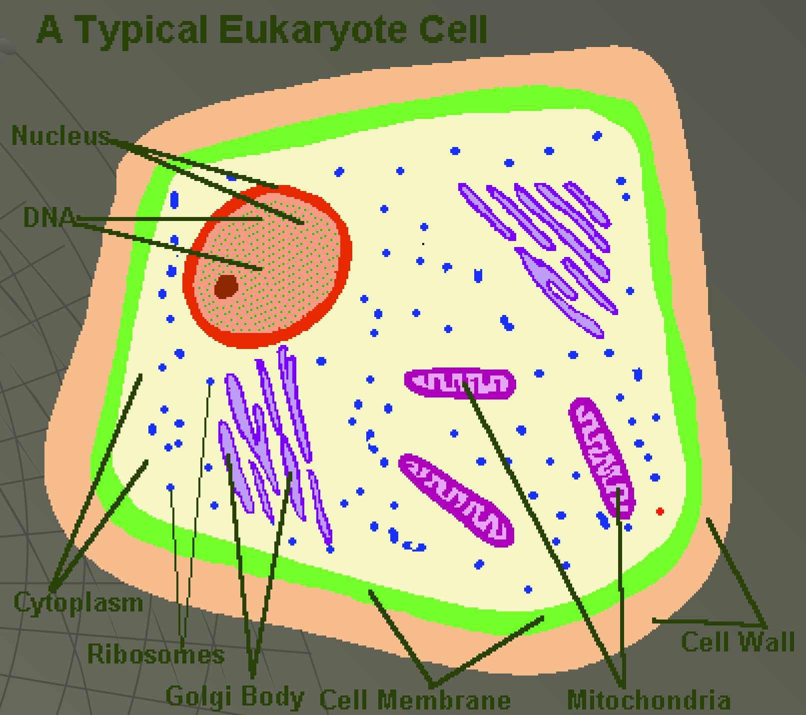
1. Nitrogen and Oxygen
2. Carbon Dioxide and Nitrogen
3. Carbon Dioxide and Oxygen
4. Oxygen and Methane

Life continued:

- Evolution of life and atmosphere are strongly linked.
- The presence of free oxygen allowed for the development of life forms that could use it.
- The rise of oxygen coincides roughly with the development of Eukaryotes, which contain a cell nucleus. (early life was prokaryotic.)

Single Cell Organisms





- Around 1 billion years ago eukaryotes developed sexual reproduction
- Resulting sharing of genetic information lead to the diversification of life and accelerated evolution
- Note “modern” humans have been around less than 2 million years out of the 4.5 billion the earth has been here. (0.044% of history) If we kill ourselves the world will continue to spin.

Climate Change

- Climate: Average conditions that prevail in a region. (Changes slowly… we hope.)

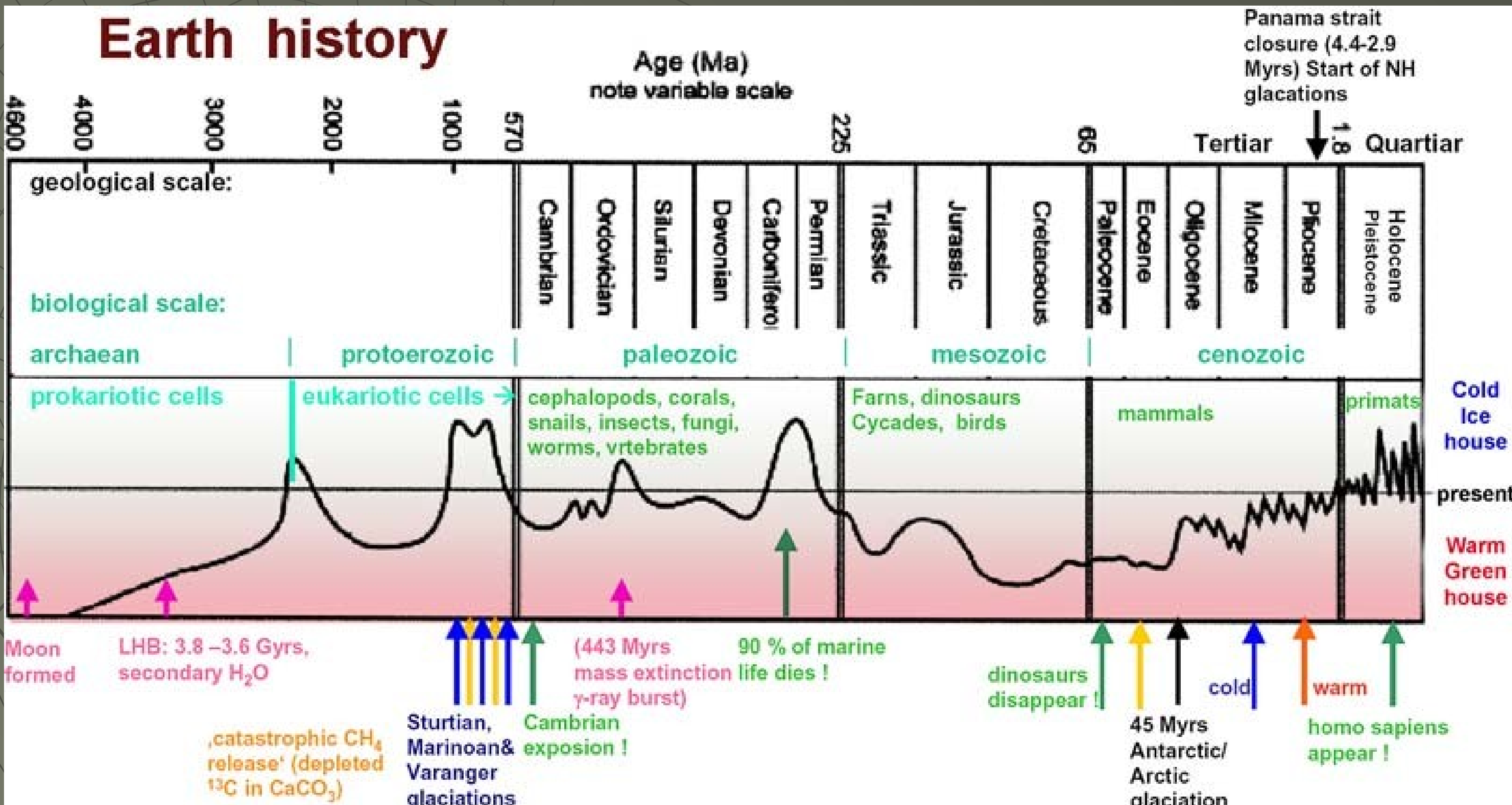
- Weather: What happens in the atmosphere locally and day to day.

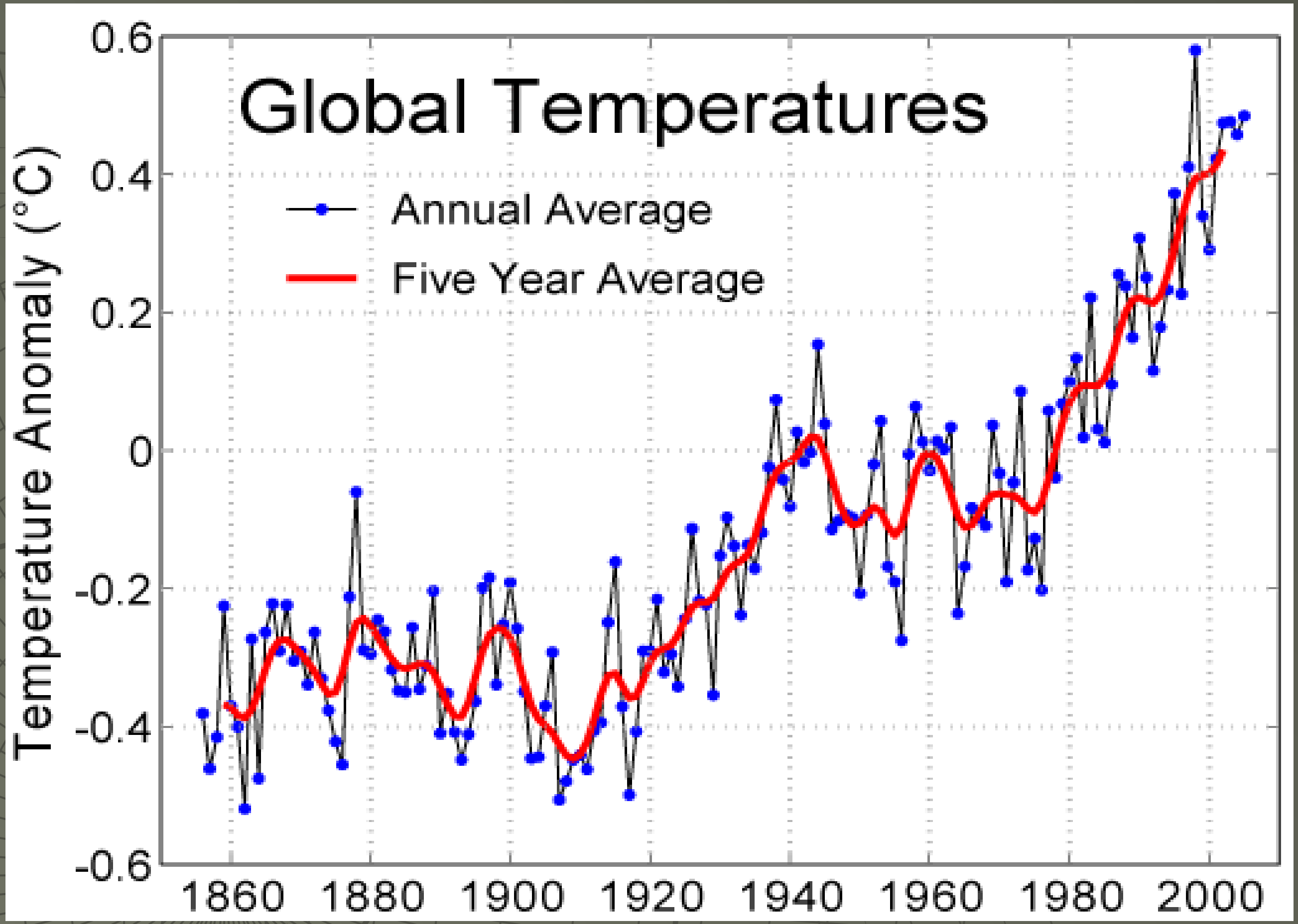
- How many times will we misuse these terms in the class?

Audio Link

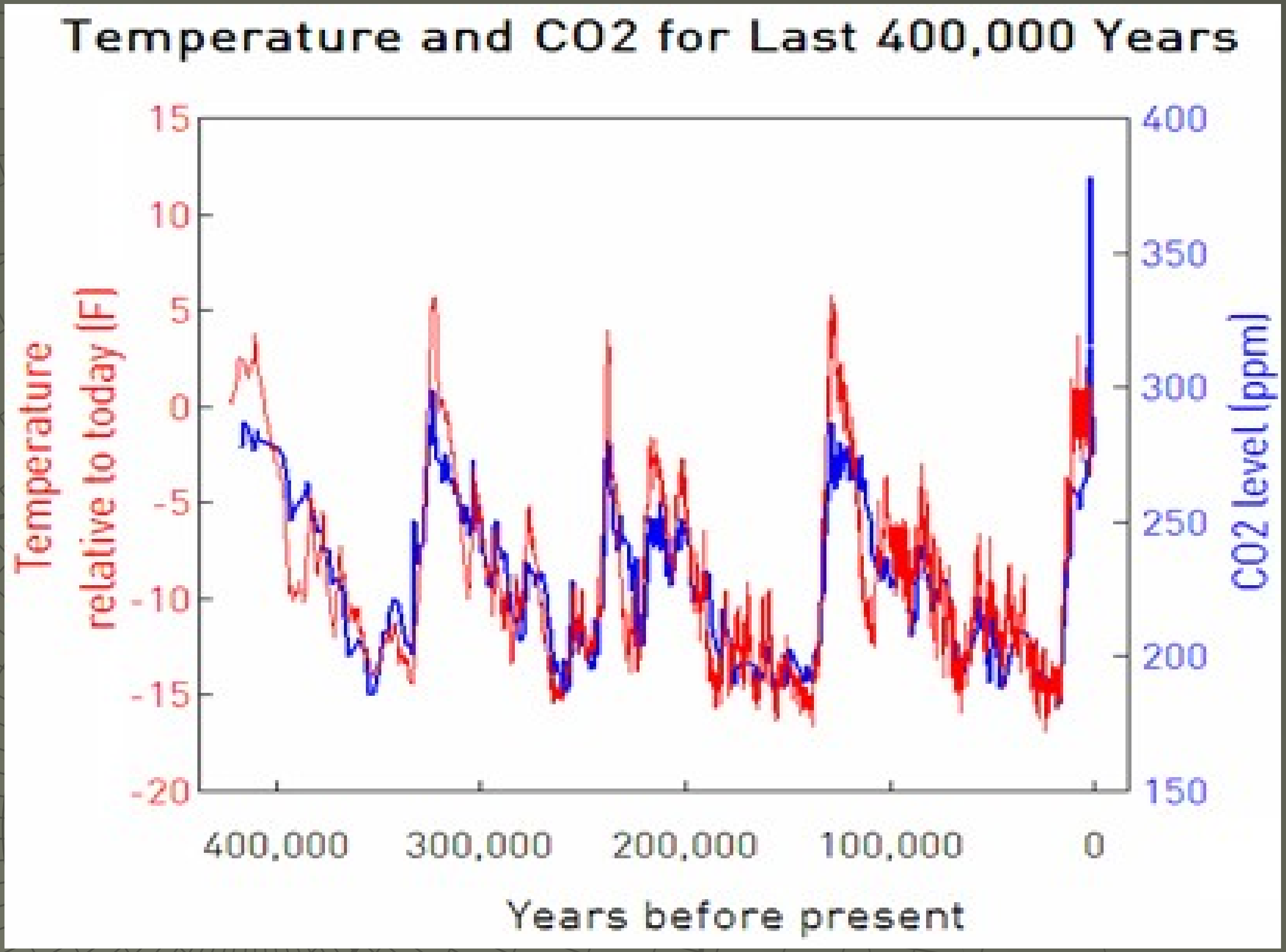
- Two important factors in determining climate are sunlight and atmospheric composition. (We will cover this in more detail later.)
- We know that the sun’s output has increased over the years. (Early sun 30% dimmer than today.)
- We have a rough estimate of climate for the last 3 billion years from geophysical evidence.

Estimates of Earth Temperature

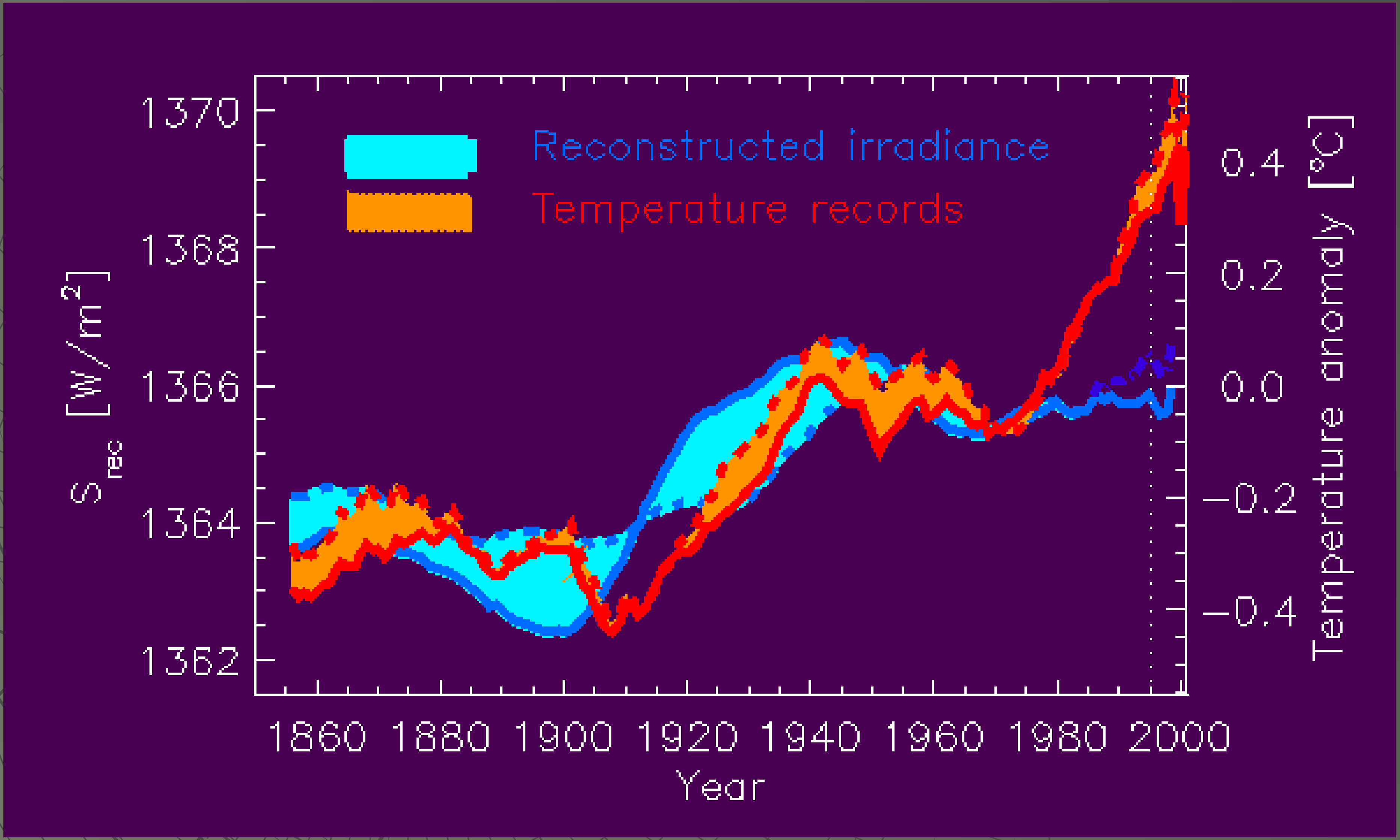



Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000

- THE EARTH’S TEMPERATURE HAS CHANGED, BUT IT HAS NOT TRACKED THE INCREASED OUTPUT OF THE SUN.
- Geophysical processes regulate the concentration of Carbon Dioxide and have established a relatively stable climate.



Temperature and CO2 for Last 400,000 Years
Temperature relative to today (F)
CO2 level (ppm)
15
10
5
0
-5
-10
-15
-20
400
350
300
250
200
150
400,000
300,000
200,000
100,000
0
Years before present



Reconstructed irradiance
Temperature records
1370
1368
1366
1364
1362
S_{rec} [W/m^2]
0.4
0.2
0.0
−0.2
−0.4
Temperature anomaly [°C]
1860 1880 1900 1920 1940 1960 1980 2000
Year

The fact that it is cold today proves that global climate change is not happening

1. True
2. False

- Carbon Dioxide is removed from the atmosphere by weathering and biological processes.
- Carbon Dioxide is added to the atmosphere by volcanoes (and more recently by burning fossil fuels)

Audio Link

SIMPLE MODEL

- When temperature goes up, increased weathering takes CO_2 out of the atmosphere and reduces temperature.
- If temp is low, weathering is slowed and CO_2 increases due to volcanoes, thus temperature rises.

NEGATIVE FEEDBACK

SNOWBALL EARTH

- Recent evidence has shown that at up to four times in the distant past the whole earth froze.

- Continents near equator: Warm rain caused rapid removal of CO_2.
- Loss of CO_2 caused ice sheets to form over northern/southern oceans.
- Increased ice reflected more energy back into space….more cooling.

POSITIVE FEEDBACK

Reversal of snowball

- Volcanoes continue to put out CO_2 but it is no longer removed by precipitation.
- Eventually temperature rose enough to melt equatorial oceans
- Dark water absorbs more light and rapidly increases temperature.

A process that tends to oppose changes in the system is called

1. Negative Feedback
2. Positive Feedback

Earth's Energy Endowment

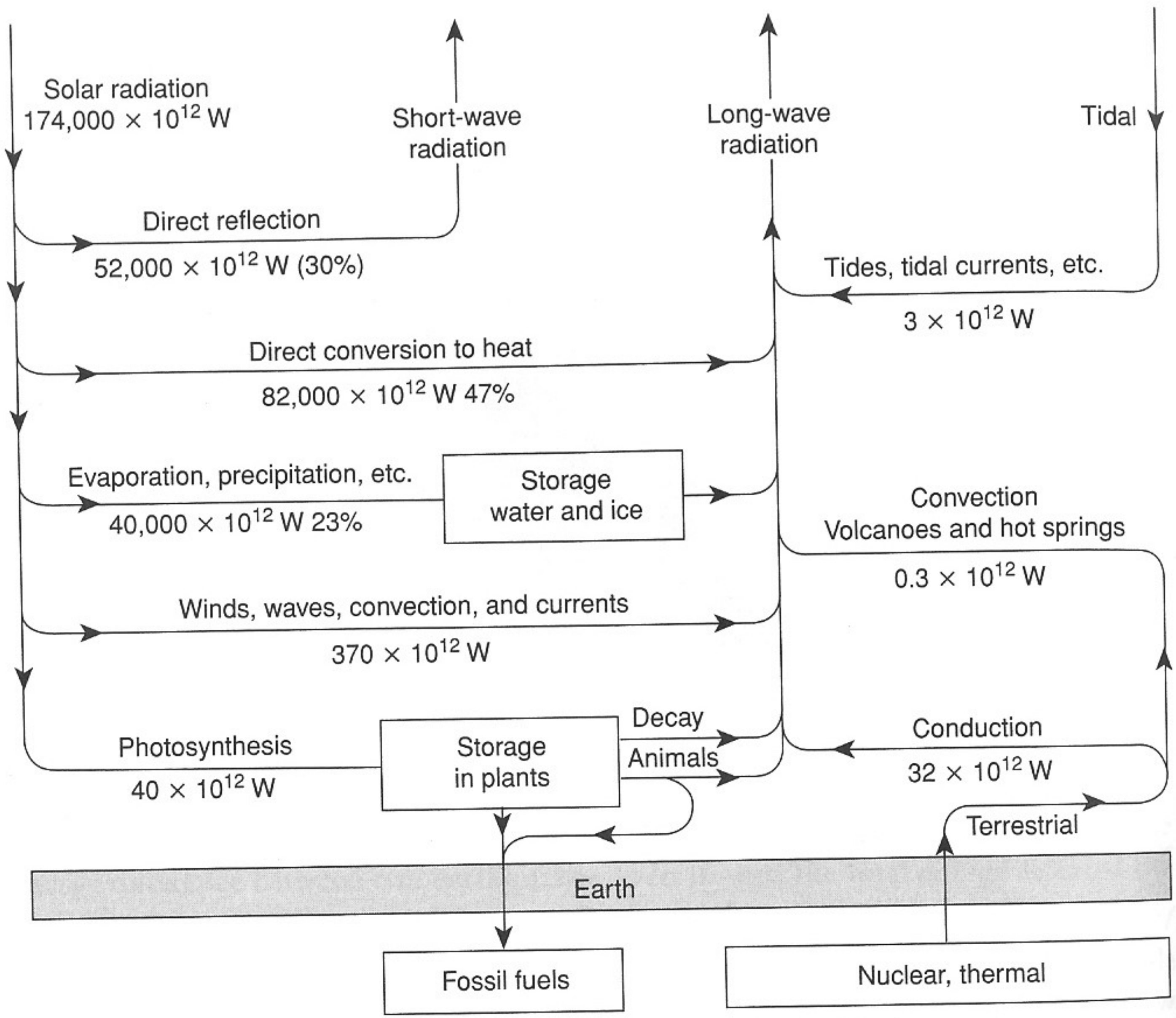
- Processes described above have left the earth with a number of energy resources.
- Basically have two options 1) Energy flows (renewable resources) 2) Fuels (nonrenewable resources.

ENERGY FLOWS

- 99.98% of energy flow comes from sunlight (10^{17} watts)
- Goes into wind, ocean currents, photosynthesis, heat….
- Other potentially useful flows: Geothermal energy, tidal energy

FUELS

- Energy sources the earth acquired long ago in the form of chemical or nuclear energy.
- Major sources are Fossil Fuels (Coal, Oil, Natural Gas) and Nuclear


Solar radiation
174,000 × 10^12 W
Short-wave radiation
Long-wave radiation
Tidal
Direct reflection
52,000 × 10^12 W (30%)
Tides, tidal currents, etc.
3 × 10^12 W
Direct conversion to heat
82,000 × 10^12 W 47%
Evaporation, precipitation, etc.
40,000 × 10^12 W 23%
Storage water and ice
Convection
Volcanoes and hot springs
0.3 × 10^12 W
Winds, waves, convection, and currents
370 × 10^12 W
Photosynthesis
40 × 10^12 W
Storage in plants
Decay
Animals
Conduction
32 × 10^12 W
Terrestrial
Earth
Fossil fuels
Nuclear, thermal

A renewable energy source is obtained from

1. An energy flow
2. A fuel