Science of Global Warming and Climate Change

Part 1 – Science

Dr. David H. Manz, P. Eng.

University of Calgary

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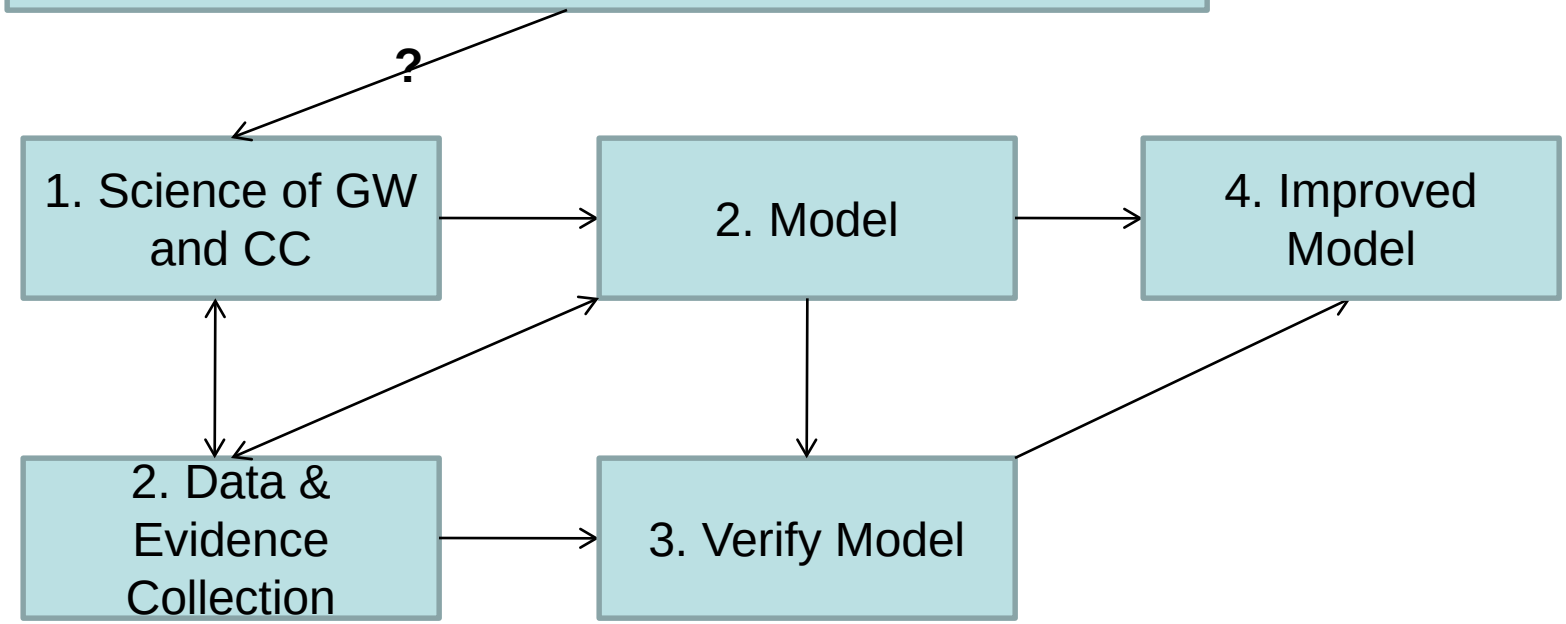
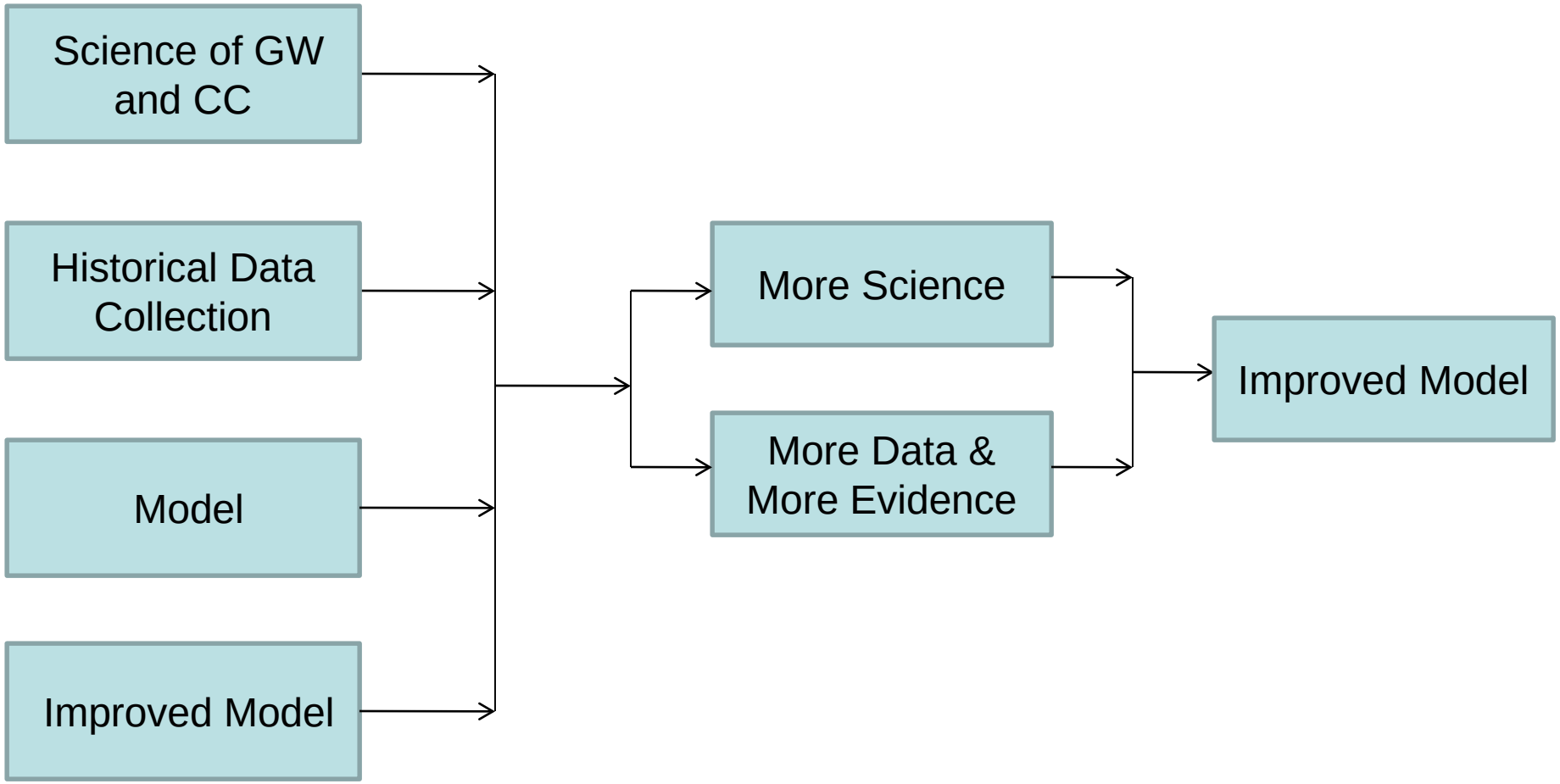
Weather vs. Climate

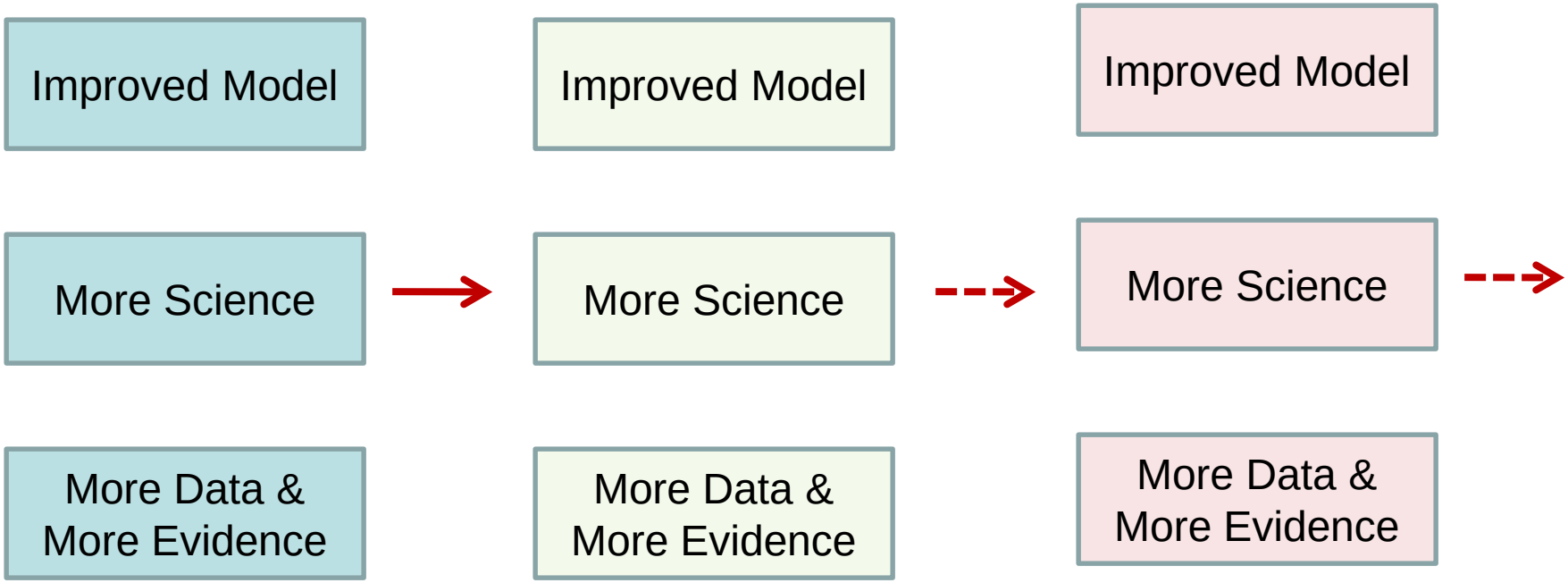
- **Weather happens day to day (moment to moment) – best forecast is no more than 10 days.**
- **Climate is a long term average – parameters averaged over a season, year or longer.**

Both weather and climate include estimates of temperature and precipitation.

Discovery of Climate Change (CC) Based on Evidence of CC




Science of GW and CC
Historical Data Collection
Model
Improved Model
More Science
More Data & More Evidence
Improved Model


Improved Model
More Science
More Data &
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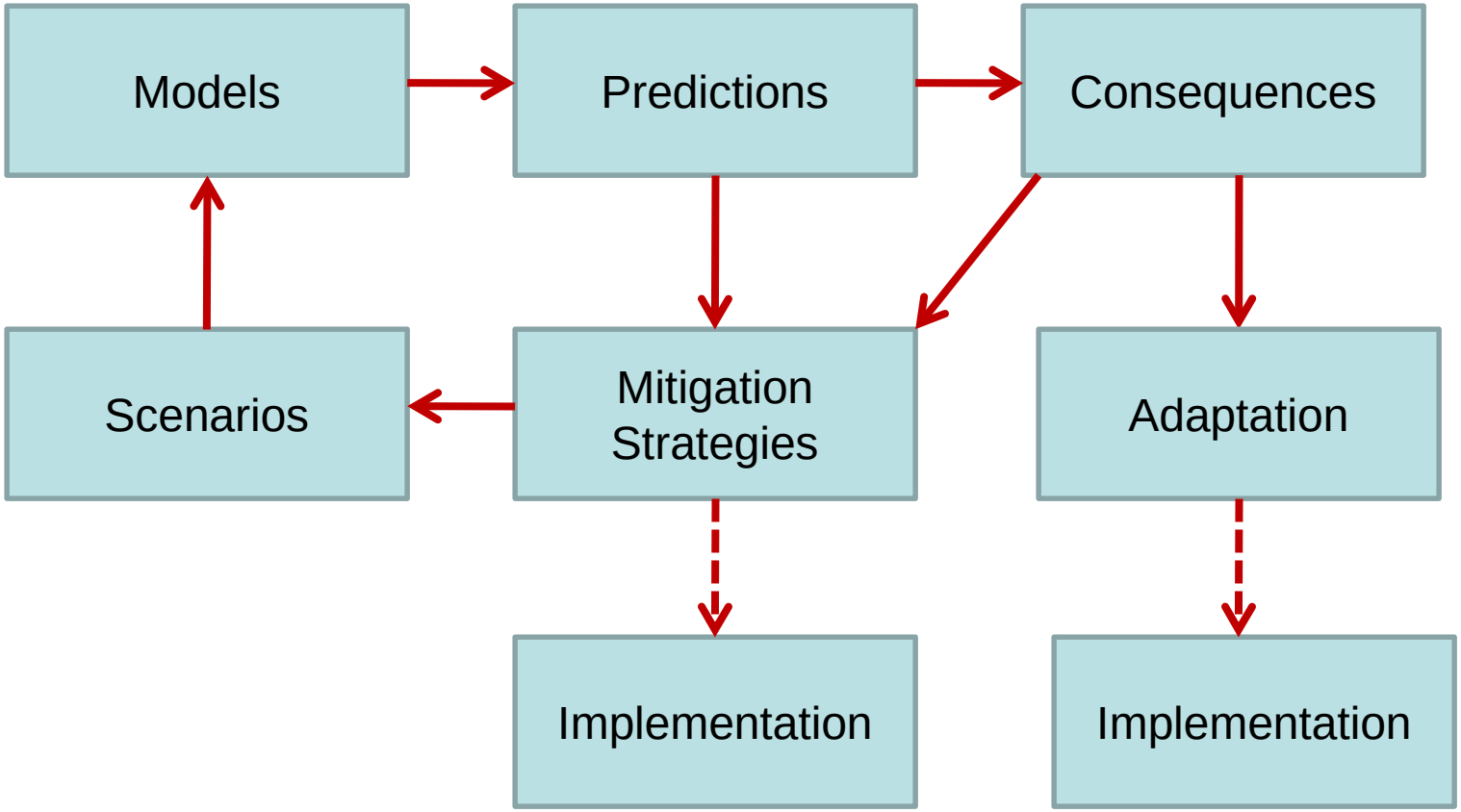
More Evidence



Meanwhile models (science) and data are constantly improving!

See Video #2 – Global warming guy.

http://www.youtube.com/watch?v=mF_anaVcCXg

Discovery of Climate Change

Early Work

1. **Louis Agassiz.**
2. **Tyndall.**
3. **Fourier.**
4. **Arrhenius.**

1. Discovery of global warming
   http://www.aip.org/history/climate/
2. Agassiz the man and contributions
   http://academic.emporia.edu/aberjame/histgeol/agassiz/agassiz.htm

Paleoclimatology

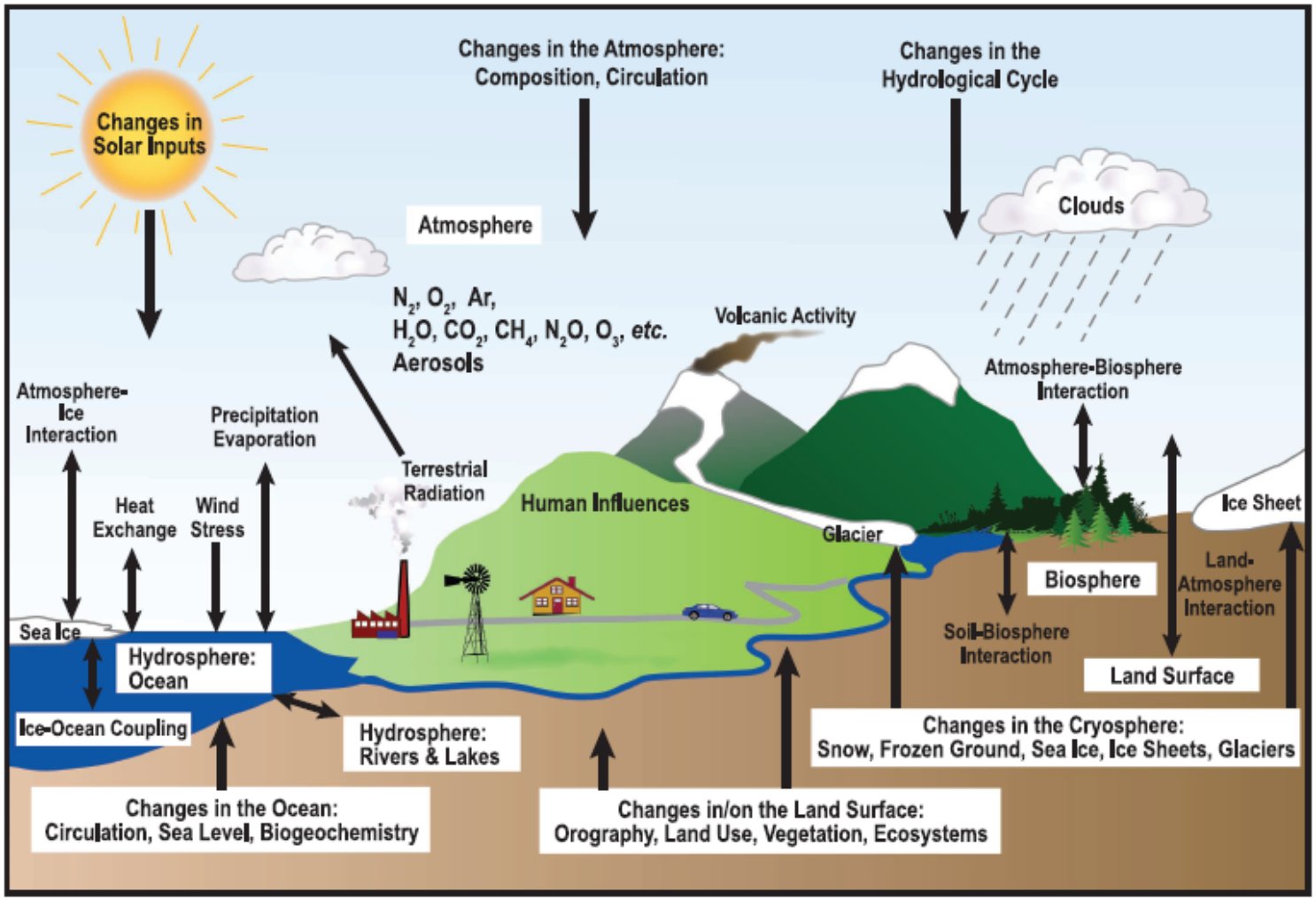
Study of how climate has changed since Earth was formed.

Study of how climate has changed over Earth's existence is only possible if we understand the factors that determine how climate will change – the Science of Climate Change.

Evidence of climate change over Earth's existence confirm the Science of Climate Change.

Apparent but unexplained evidence for changes in climate compel further research and aid in the development of the Science of Climate Change.

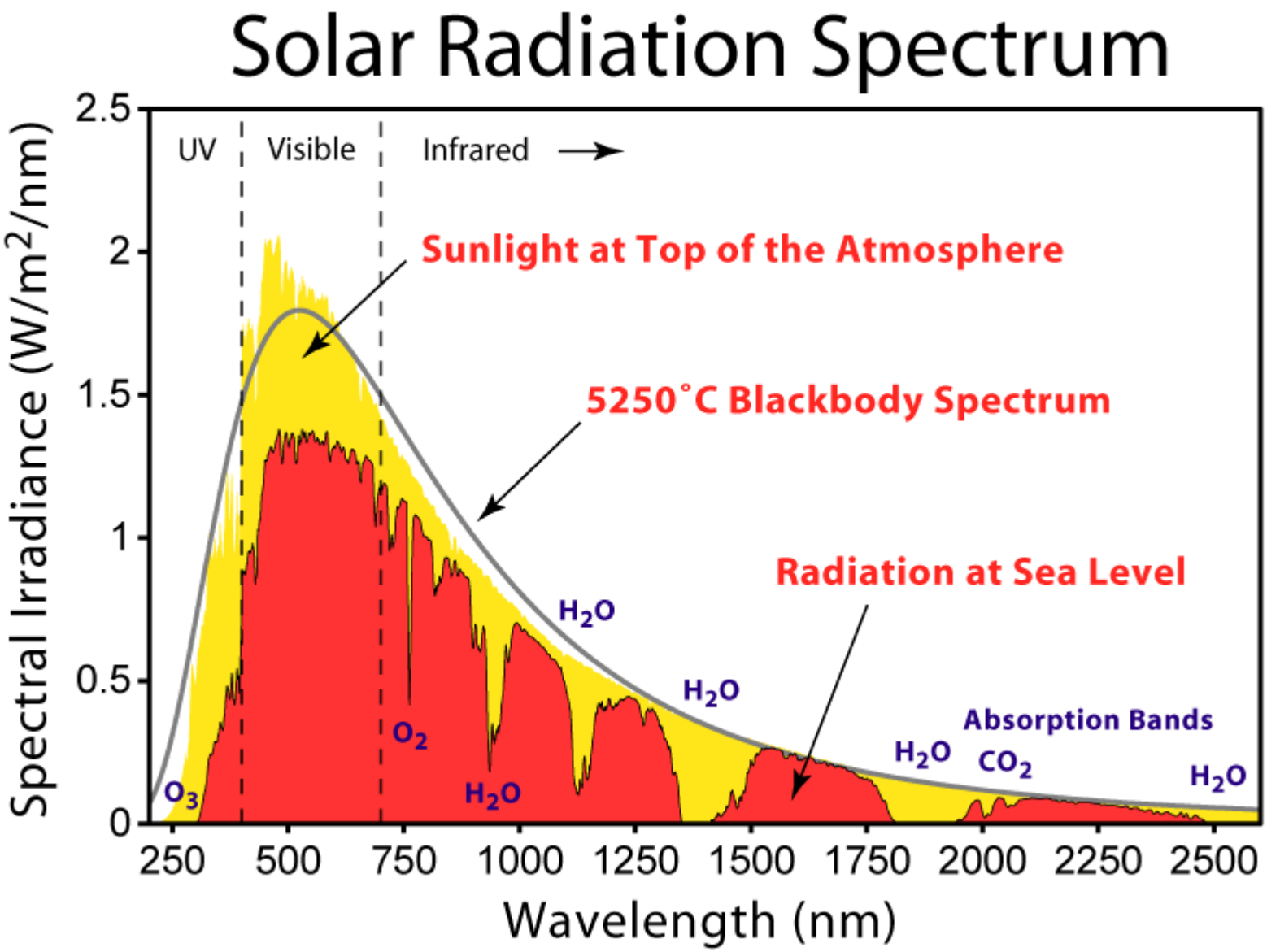
Review of the Major Factors and Their Dynamics which Determine Earth's Weather and Climate.



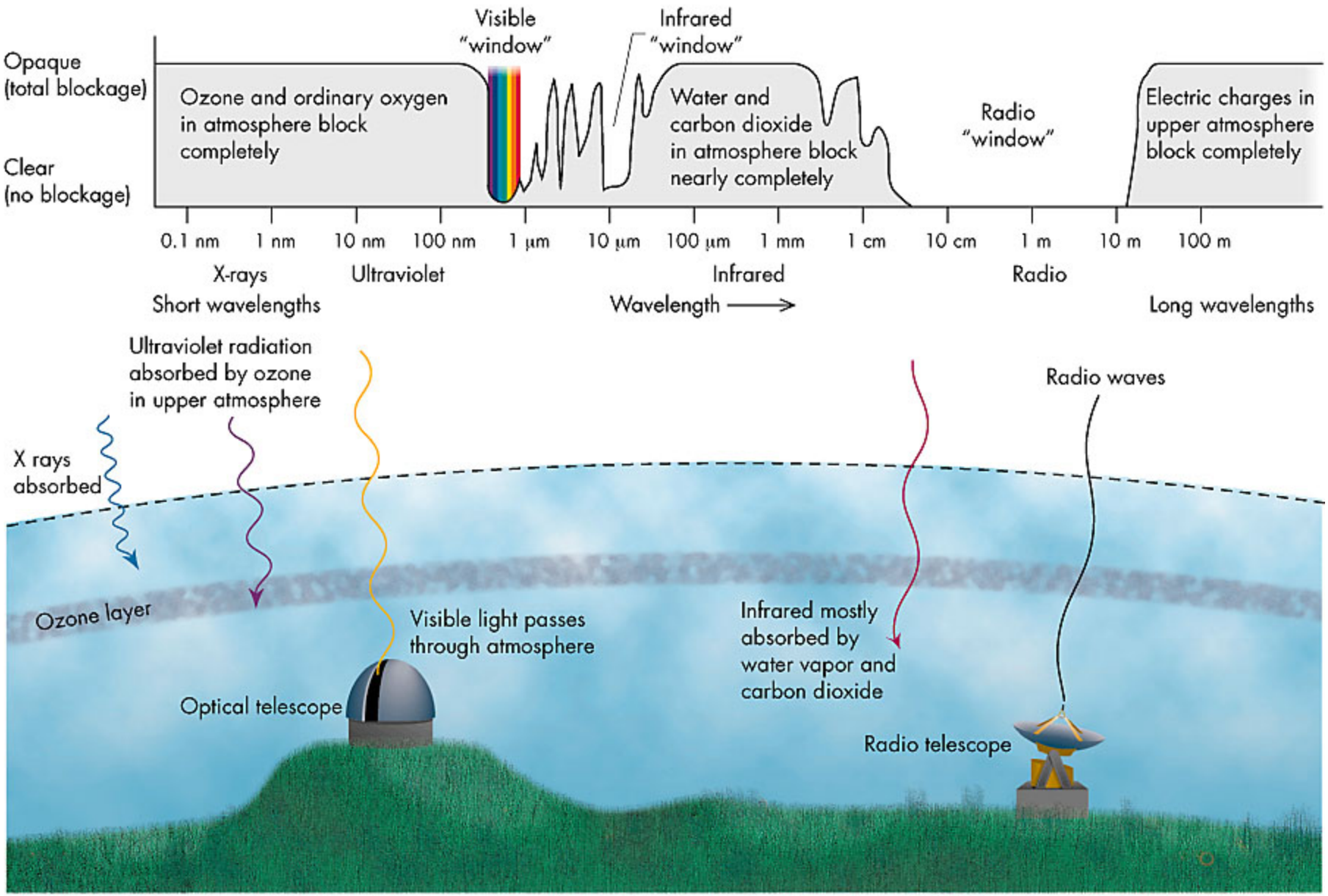
FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

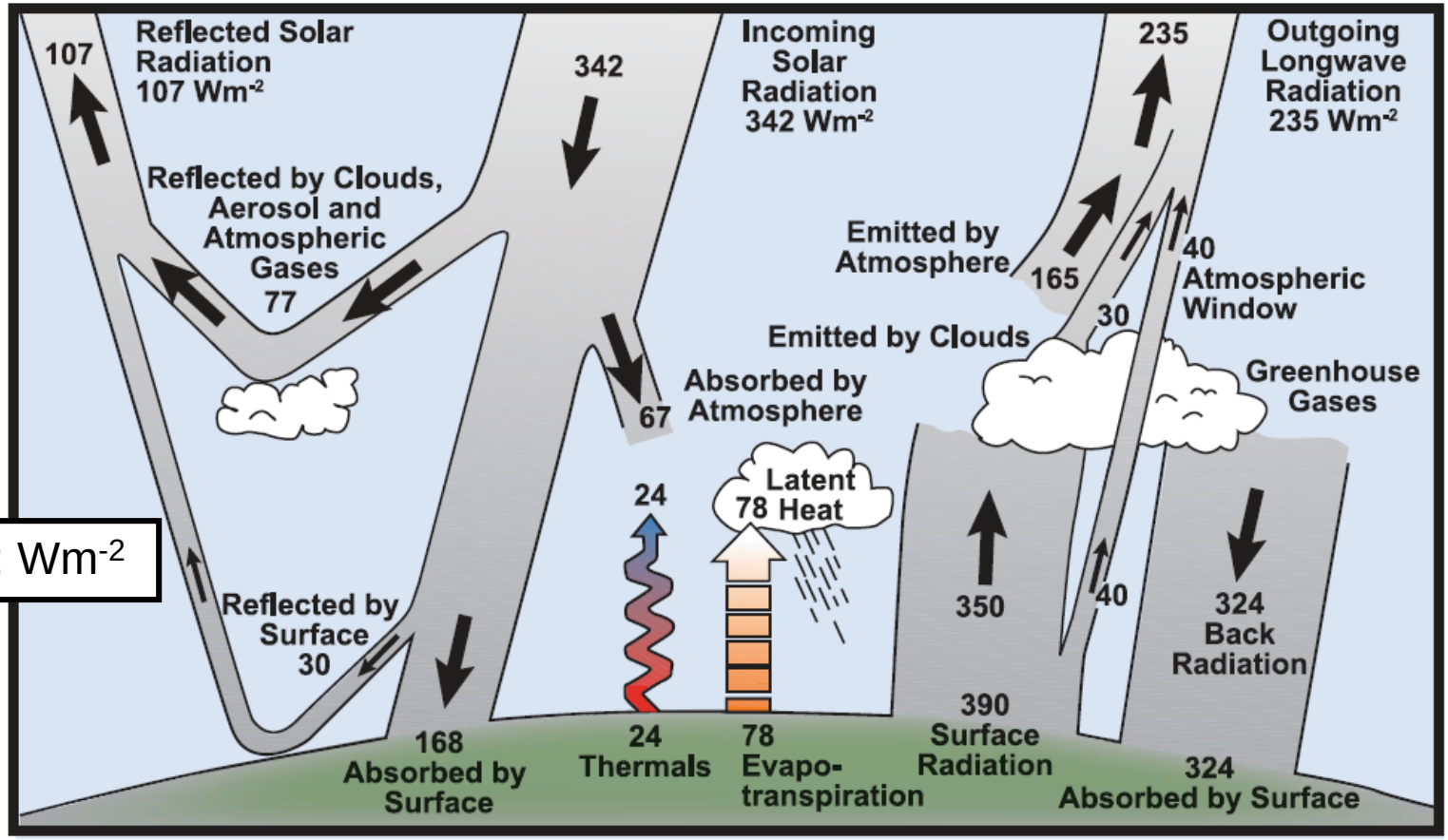
Numerous factors affecting weather and climate. The challenge is to know what their effects are and how they relate to each other to determine weather and climate.

The Sun is the source of all energy reaching the earth.



Solar radiation reaching top of atmosphere compared to solar radiation reaching the earth's surface.

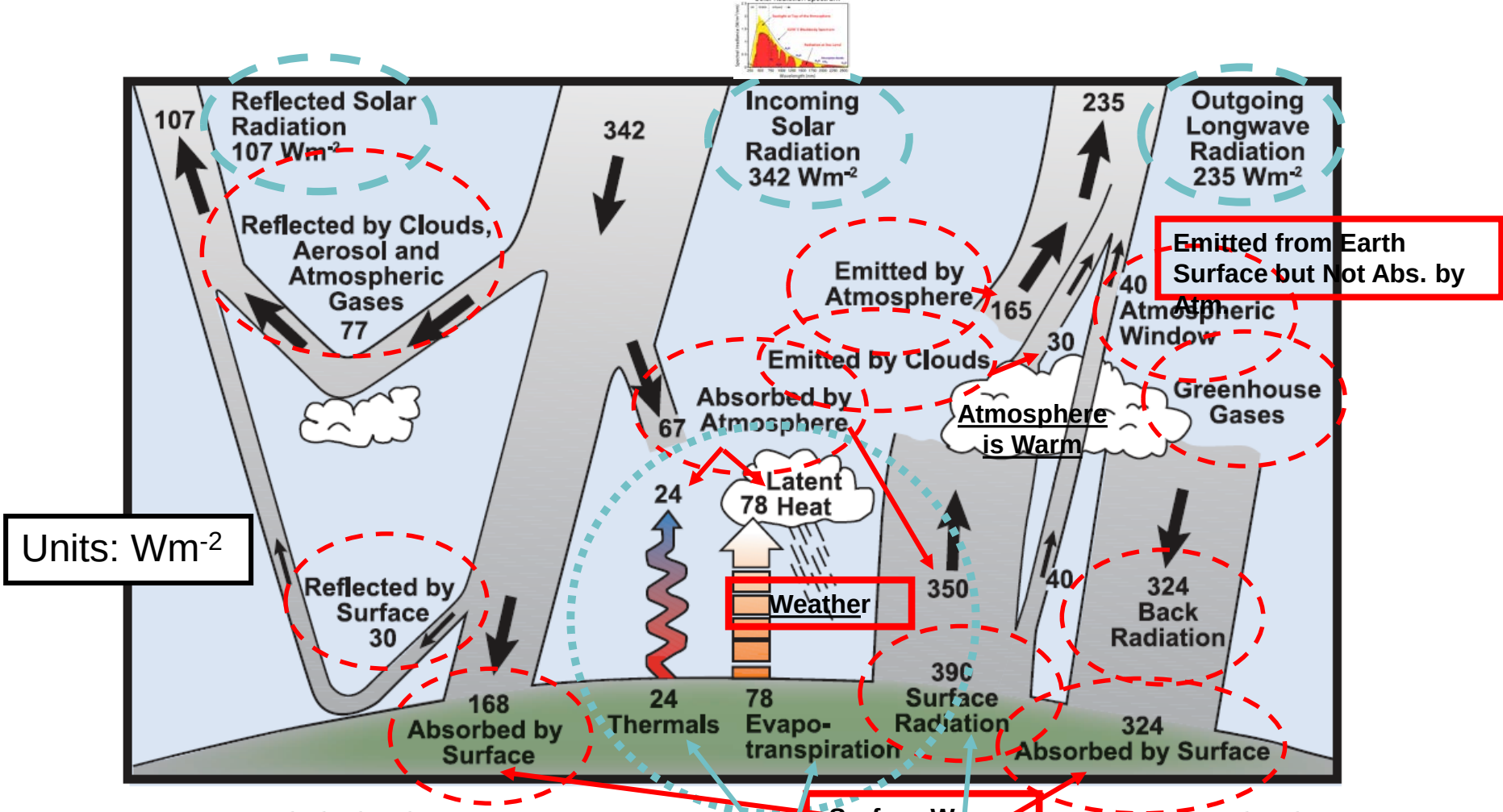




Units: Wm^{-2}

FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Energy budget for <u>entire</u> planet.



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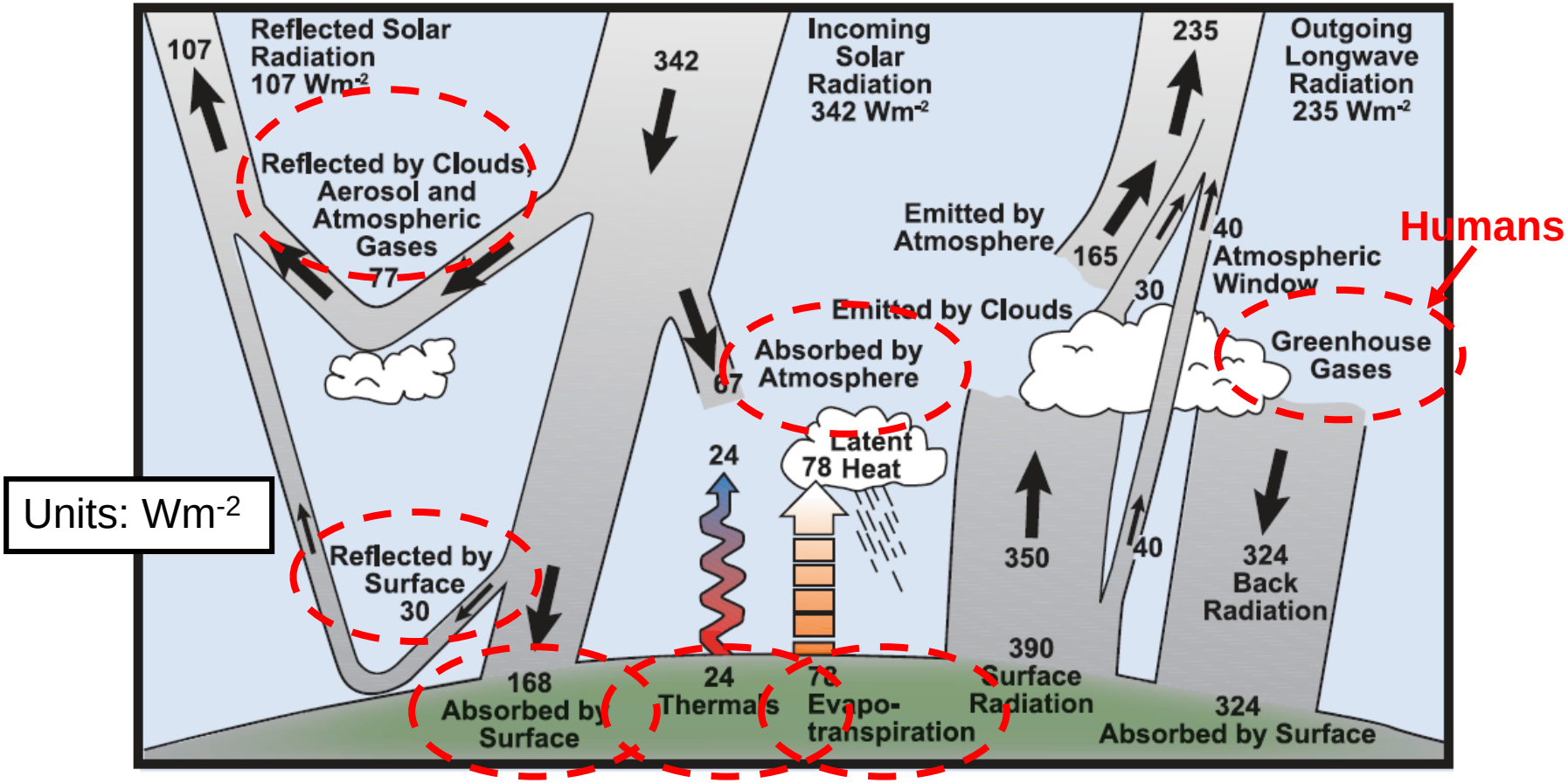

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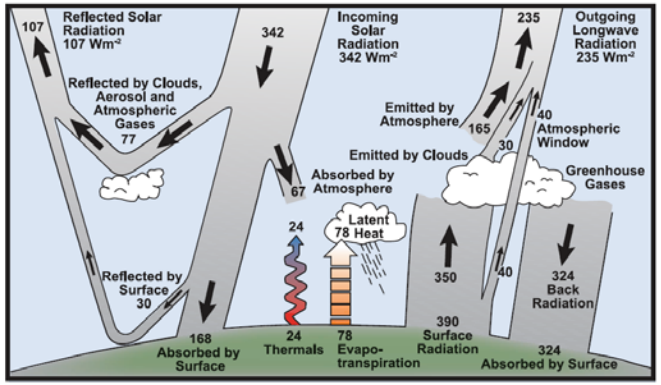

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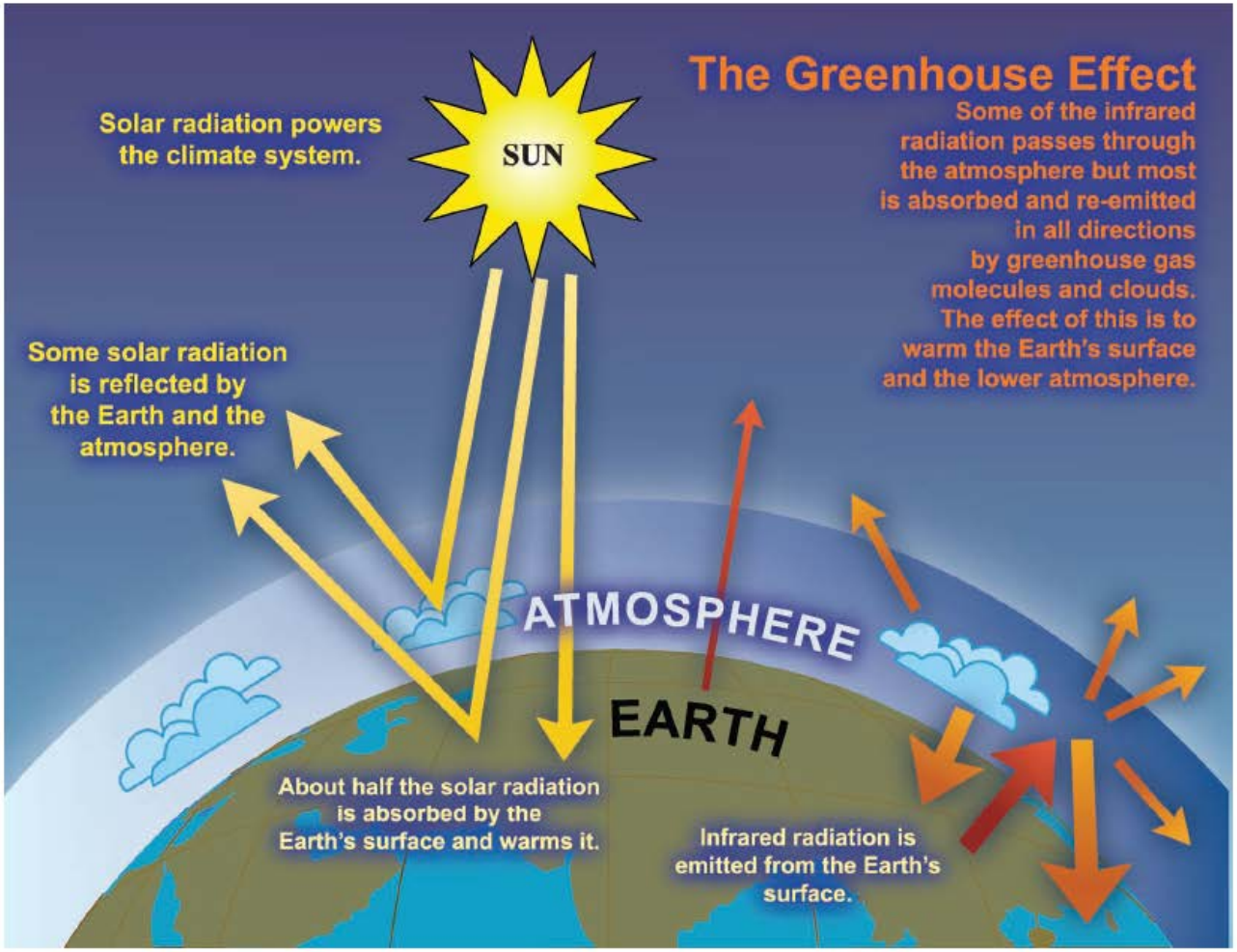
Examine energy balance at:

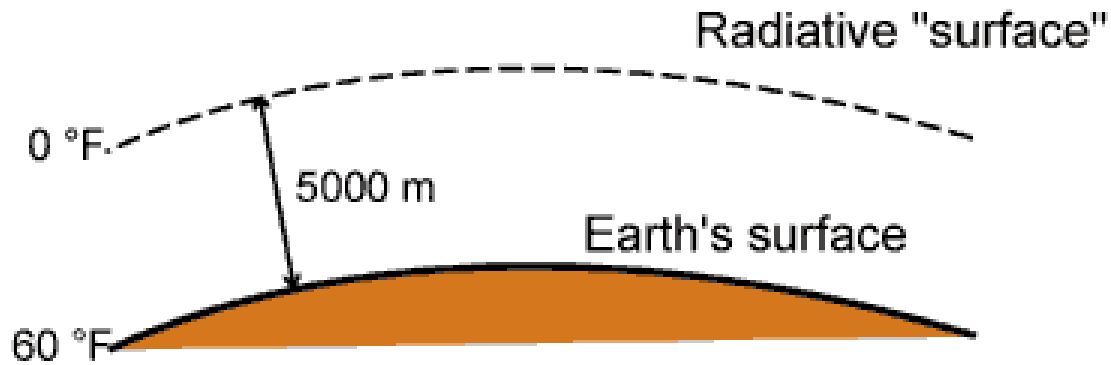
- **edge of atmosphere.** **(342 – 107 – 235 = 0)**
- **earth's surface.** **(168 + 324 – 390 – 24 – 78 = 0)**
- **within atmosphere.** **(350 + 78 + 24 + 67 – 324 – 165 – 30 = 0)**



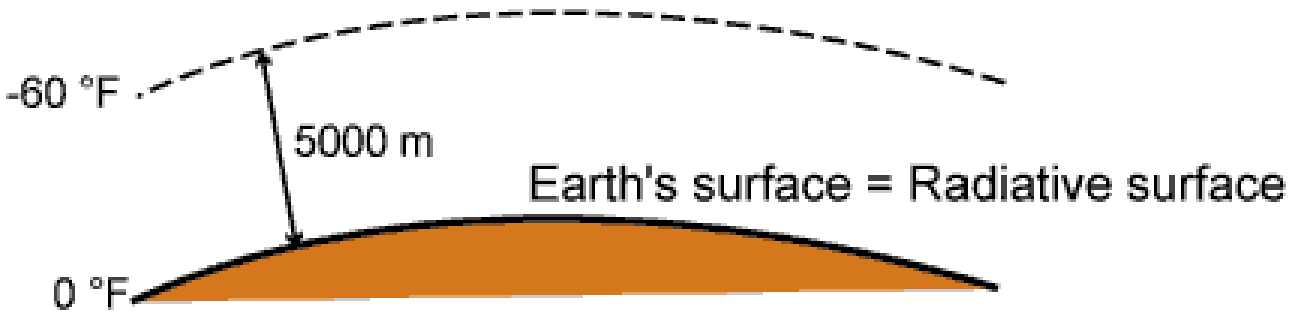
FAQ 1.3, Figure 1. *An idealised model of the natural greenhouse effect. See text for explanation.*

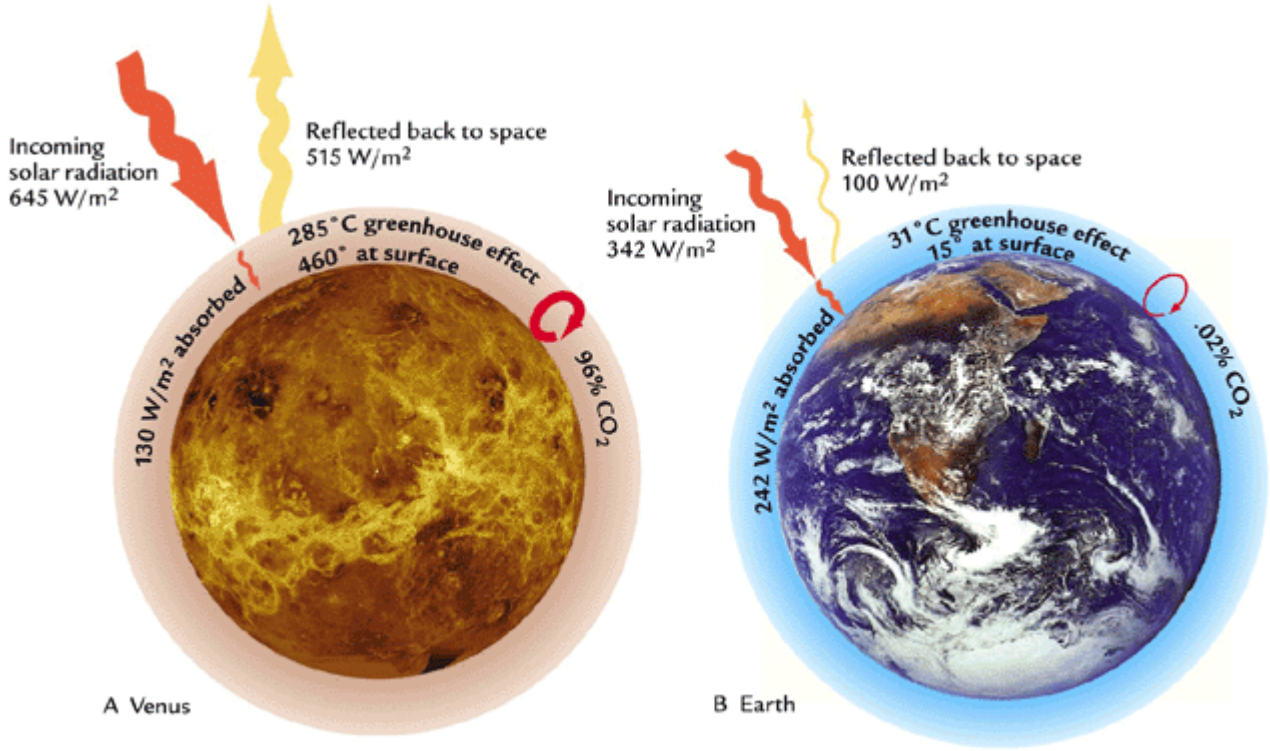
The greenhouse effect for <u>entire</u> planet.

With a Greenhouse Effect



Without a Greenhouse Effect

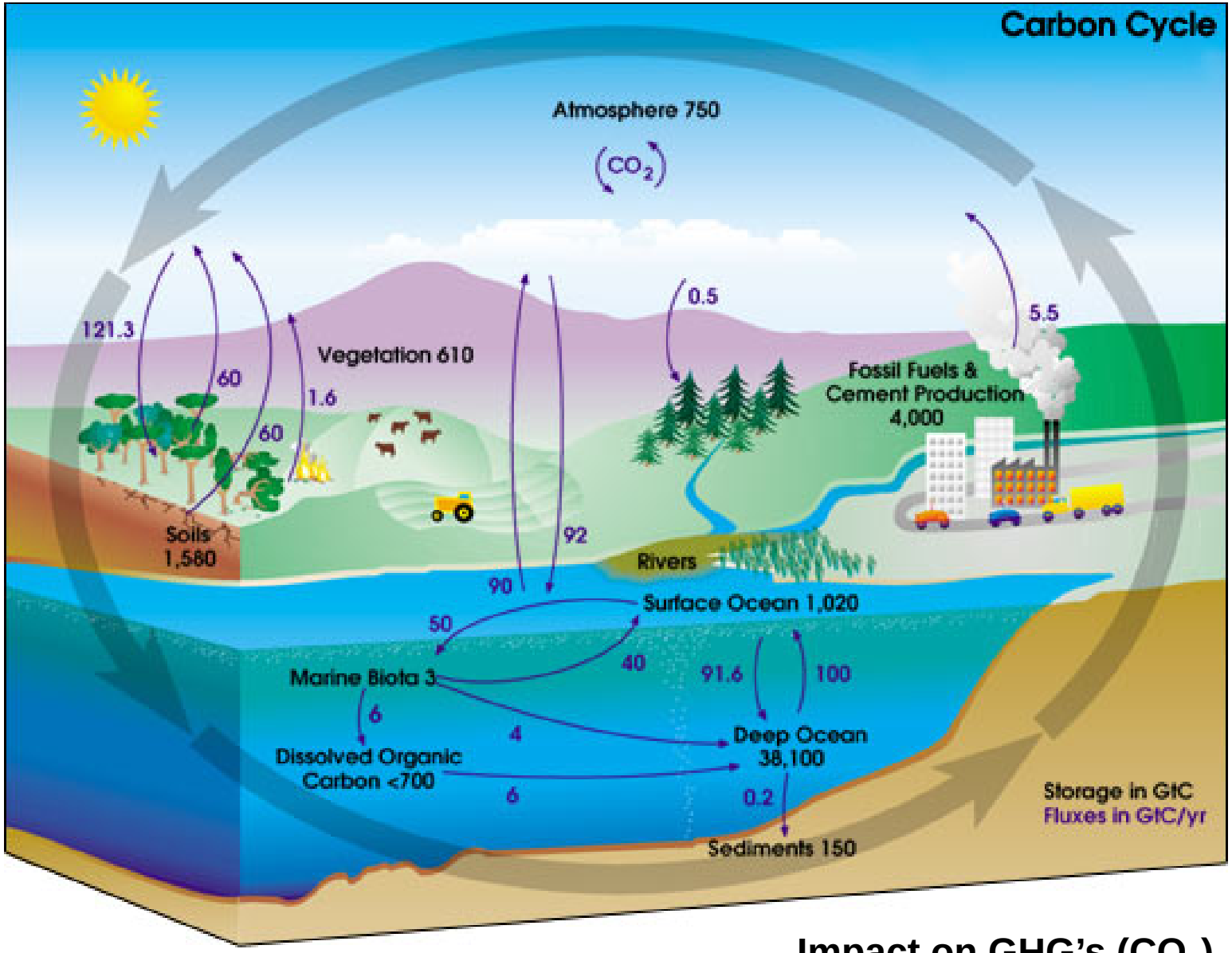




‘Run-away greenhouse effect on Venus.’

Explanation of Greenhouse Effect on White Board

Carbon Cycle.



Impact on GHG's (CO_2).

Definitions for Discussing Global Quantities

Prefixes for large numbers:

kilo-	10^3	=	1,000
mega-	10^6	=	1,000,000
giga-	10^9	=	1,000,000,000
tera-	10^{12}	=	1,000,000,000,000
peta-	10^{15}	=	1,000,000,000,000,000
exa-	10^{18}	=	1,000,000,000,000,000,000

1 gigaton $= 1 \times 10^9 \times 10^3$ kg $= 10^{12}$ kg
$= 10^{12} \times 10^3$ g $= 10^{15}$ g
= 1 petagram

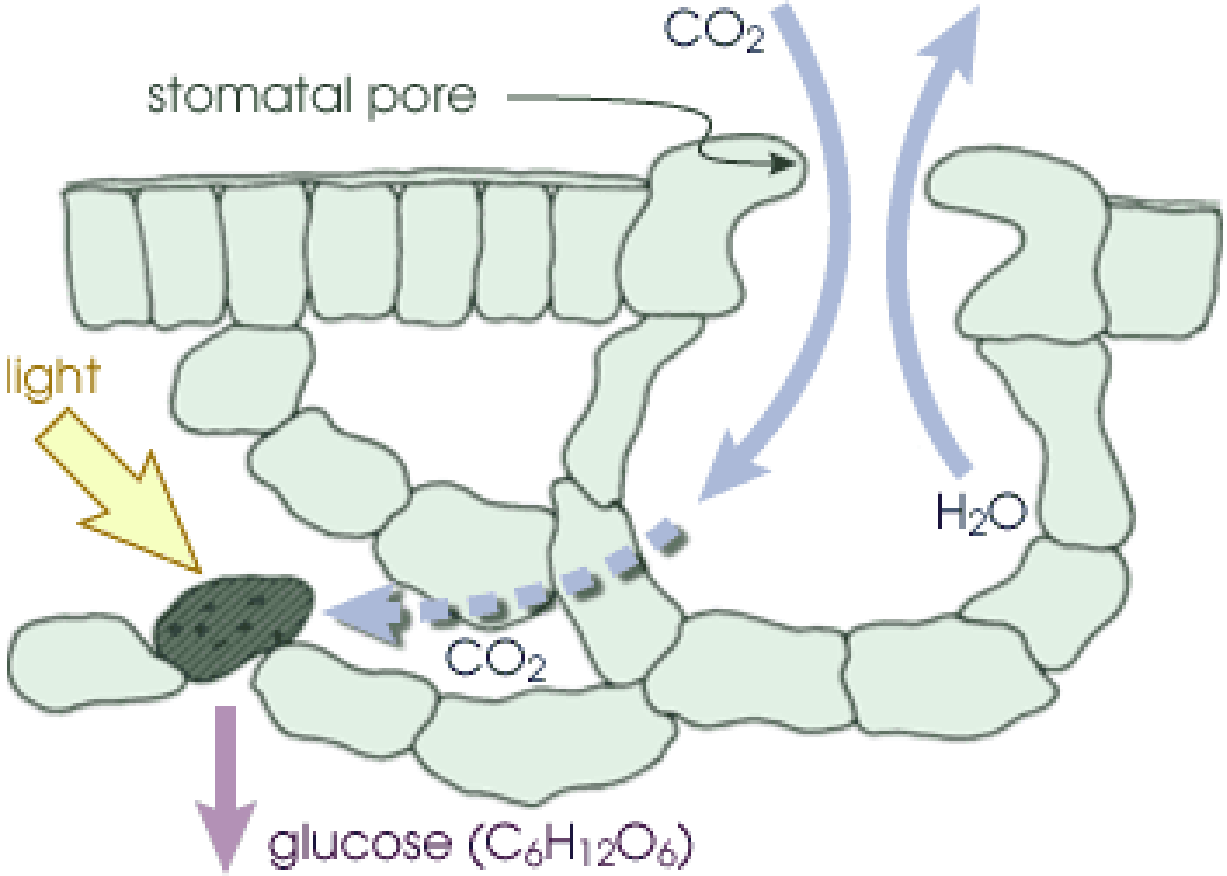
Example:
1 gigaton of water = 1 petagram of water = 10^{15} g

1 g of water has volume 1 cm^3 = 10^{-6} m^3

so 1 gigaton of water = 10^{15} g x 10^{-6} m^3/g
= $10^9 m^3$ = 1 km^3 of water

1 ppmv = 1 part per million by volume (one molecule in a million)
1 ppbv = 1 part per billion by volume
1 pptv = 1 part per trillion by volume

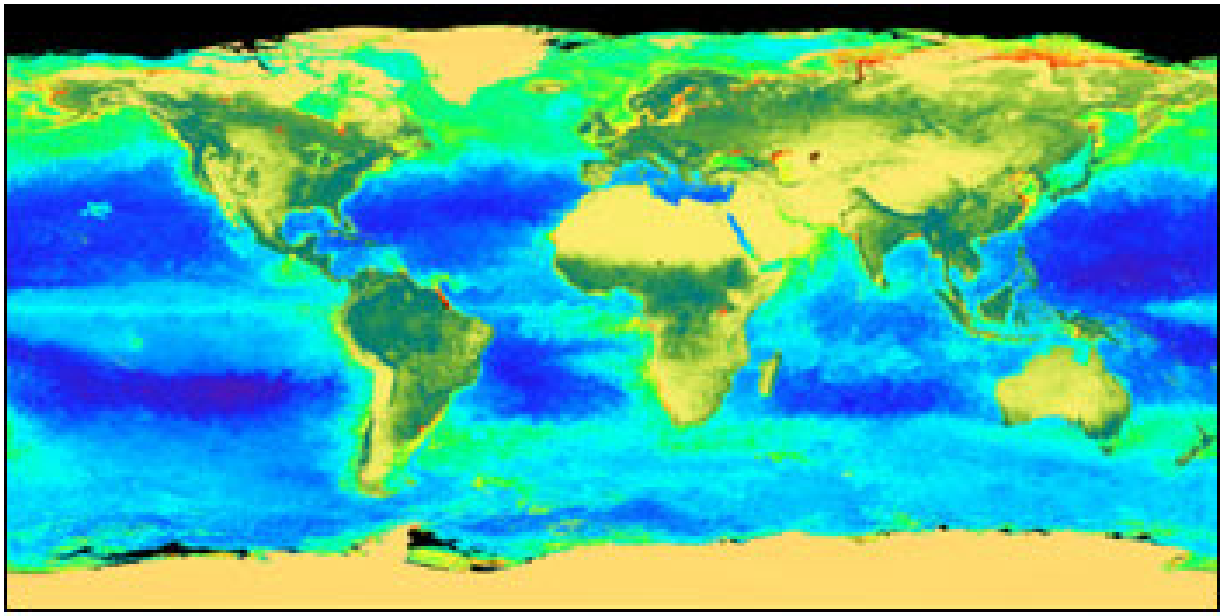
Plant Activity - Biosphere



Plants convert CO2 to glucose and other plant tissue.

Part of carbon cycle that impacts GHG's (CO_2).

Vegetative biomass capable of converting CO2 to plant tissue.



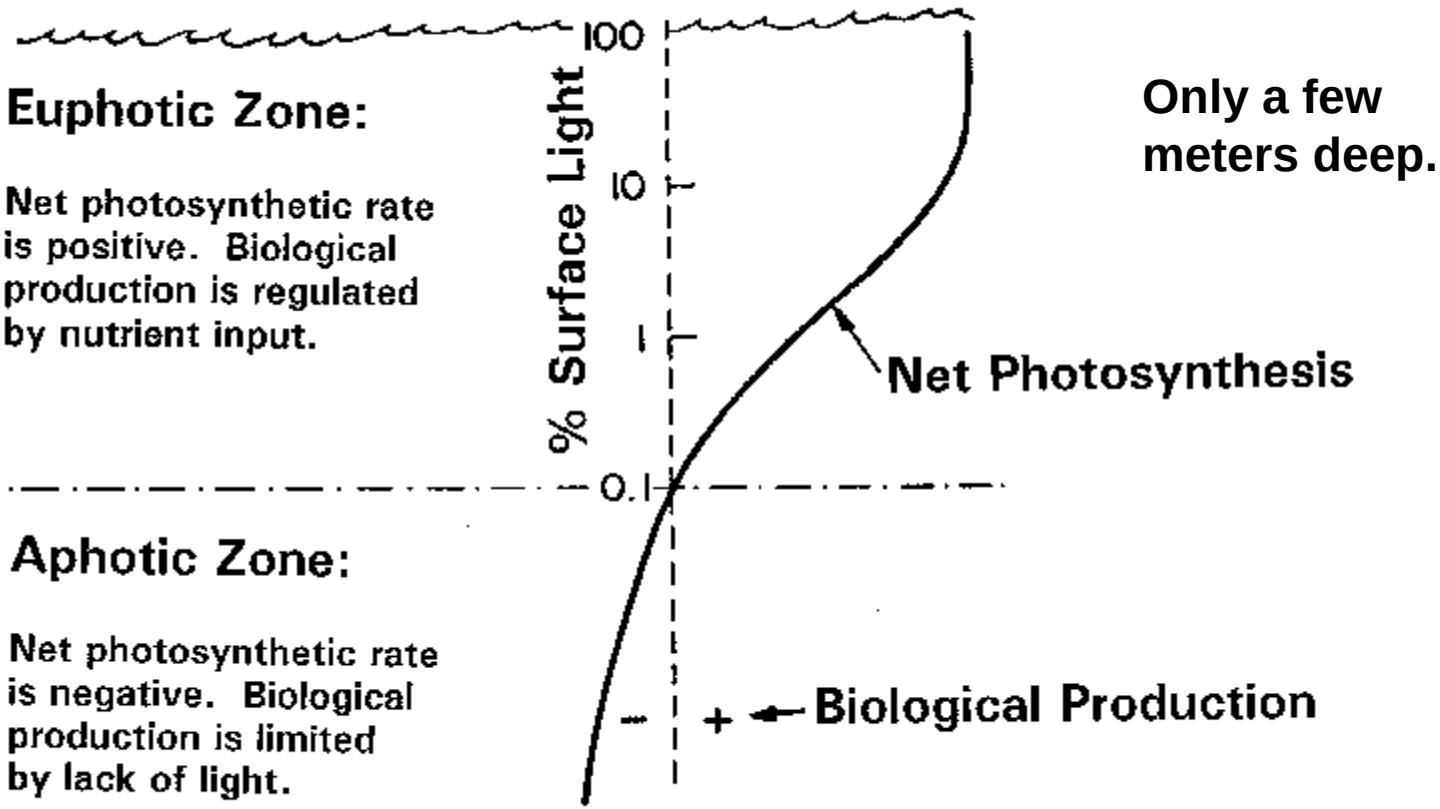
September 2000

Chlorophyll *a* Concentration (mg/m^3)

0.01 0.01 1.0 10 60

Normalized Difference Vegetation Index

minimum maximum



Only a few meters deep.

Part of carbon cycle that impacts GHG's (CO_2).

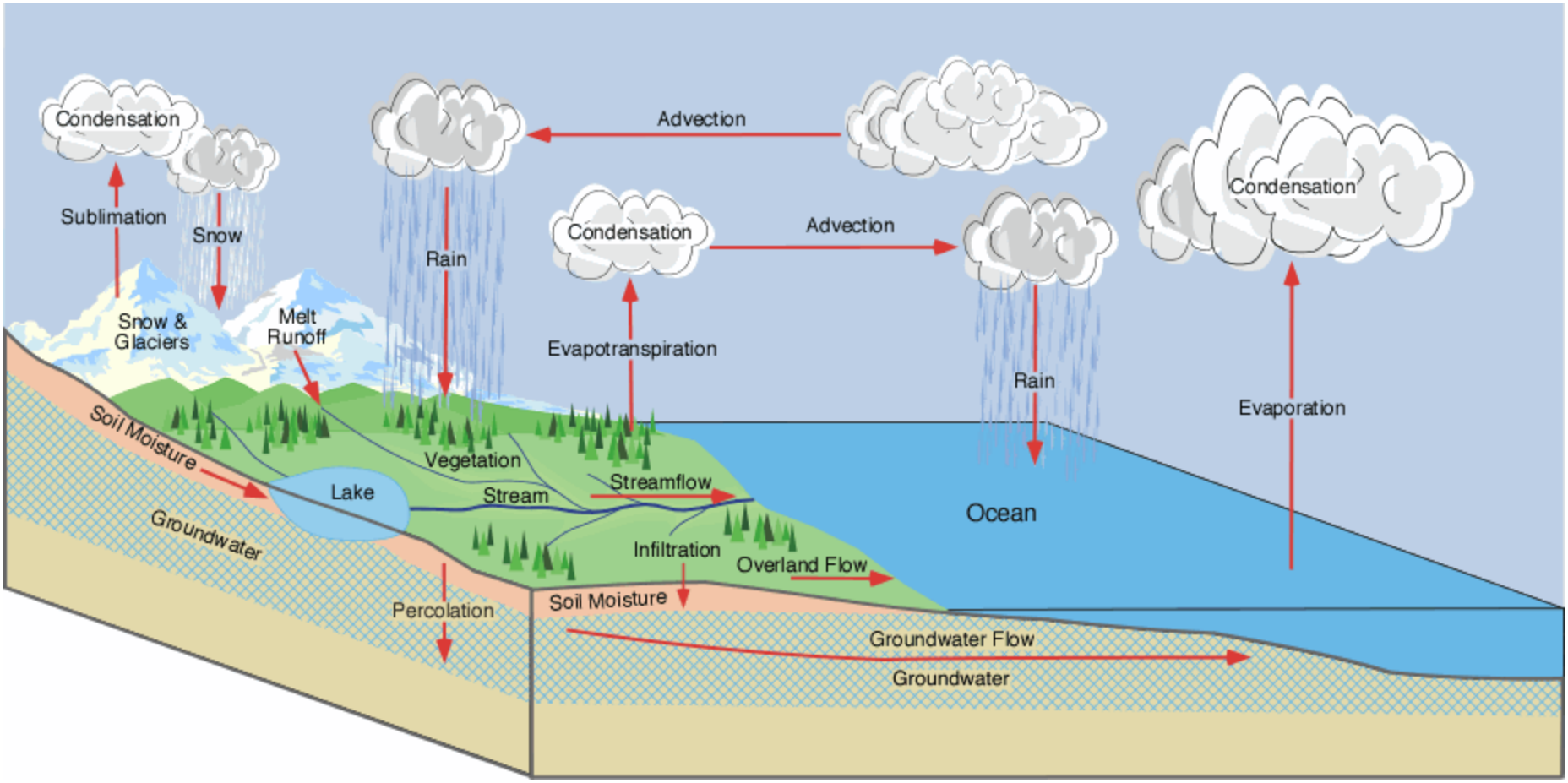
The World's Carbon Reservoirs	Size (Gt C)
Atmosphere	750
Forests	610
Soils	1580
Surface ocean	1020
Deep ocean	38100
Fossil fuels:	
Coal	4000
Oil	500
Natural gas	500
Total fossil fuel	5000

Warmer the water the less dissolved gases (e. g. CO_2) can be dissolved.

Methane hydrates in deep ocean and permafrost 5000 Gt plus?

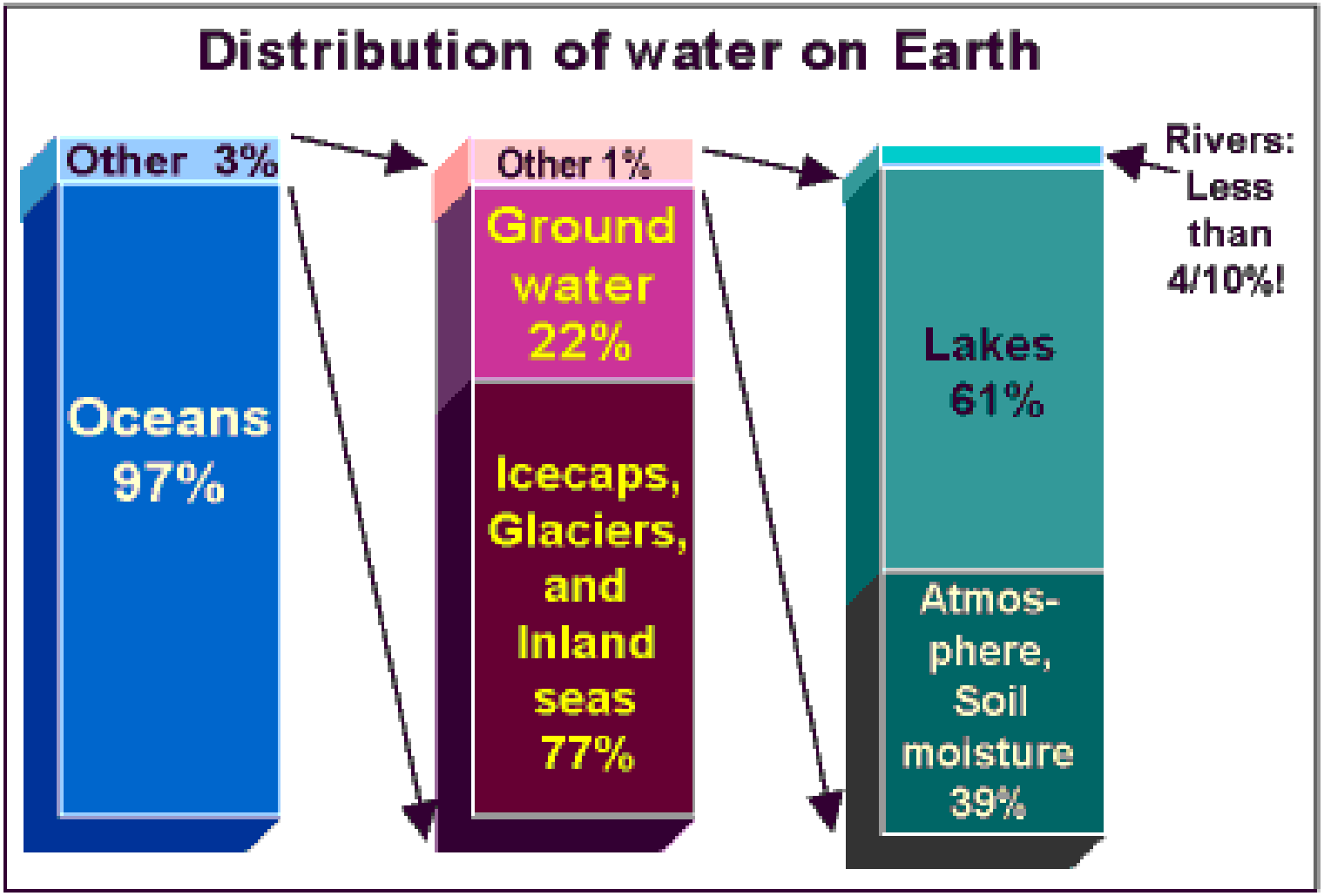
Table 1. Summary of mechanisms by which methane might escape to the atmosphere.

Chronic releases	Inventory	Potential Release	Impacts
Stratigraphic-type hydrate deposits in the ocean	1000–6000	Any release would take millennia	Effects would be most pronounced on geological timescales. Radiative effect of accumulating CO_2 >effect of transient methane.
Arctic Ocean	Hundreds	CH_4 release ongoing today, but time scale for acceleration is probably decades	Released to water column, could reach atmosphere as CH_4
Gulf of Mexico	5–500	Any release would take centuries	Released to water column, small potential impact on atmospheric CH_4
Peat Decomposition	350–450	Say 20% over 100 years	Flux of 0.7 Gton/yr to the atmosphere, triples pCH_4
Permafrost hydrate melting	Hundreds	Comparable to Peat Decomposition	Comparable to Peat Decomposition
Catastrophic releases			
Landslides		5 Gton from Storegga	Some release as hydrate which can reach the atmosphere, but also bubbles which dissolve in the water column



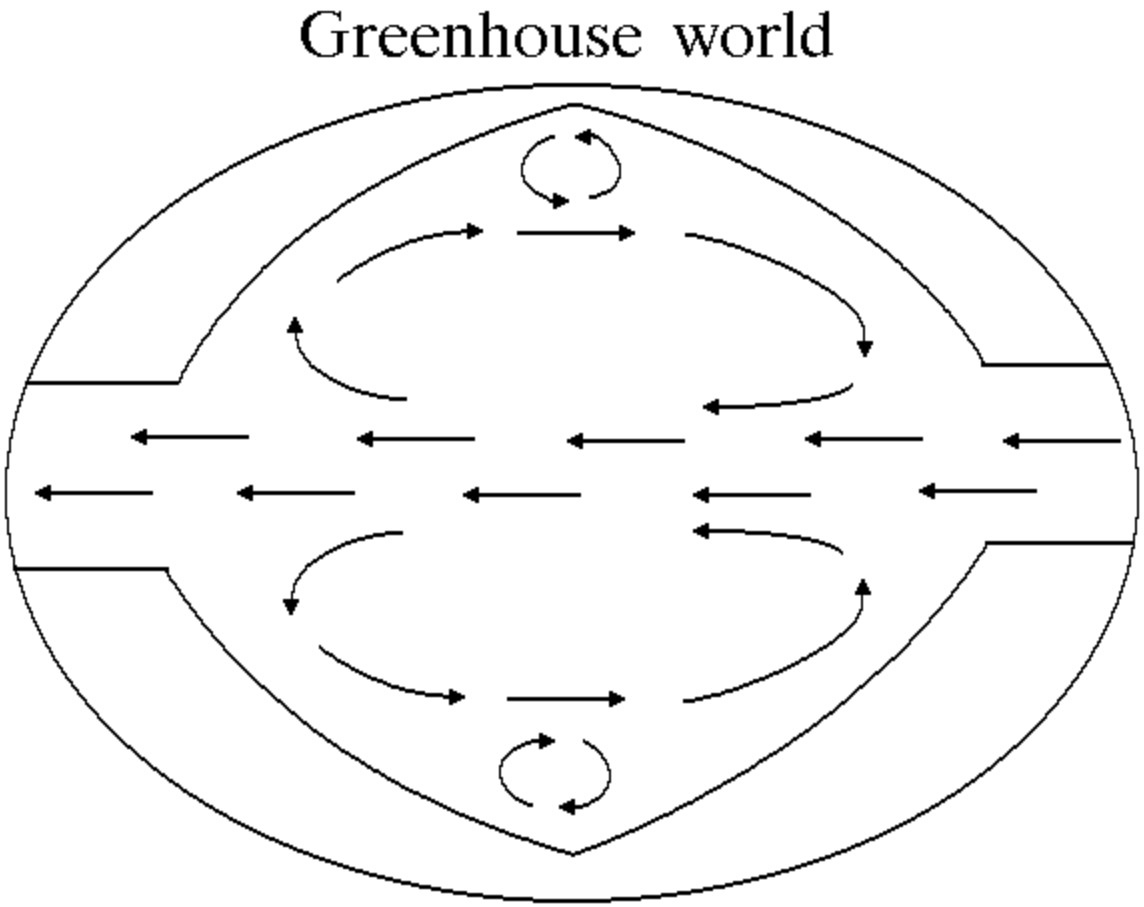
Hydrological Cycle

Water vapour in atmosphere (GHG), cloud cover, volume, location and extent of liquid water and volume, location and extent of frozen water.

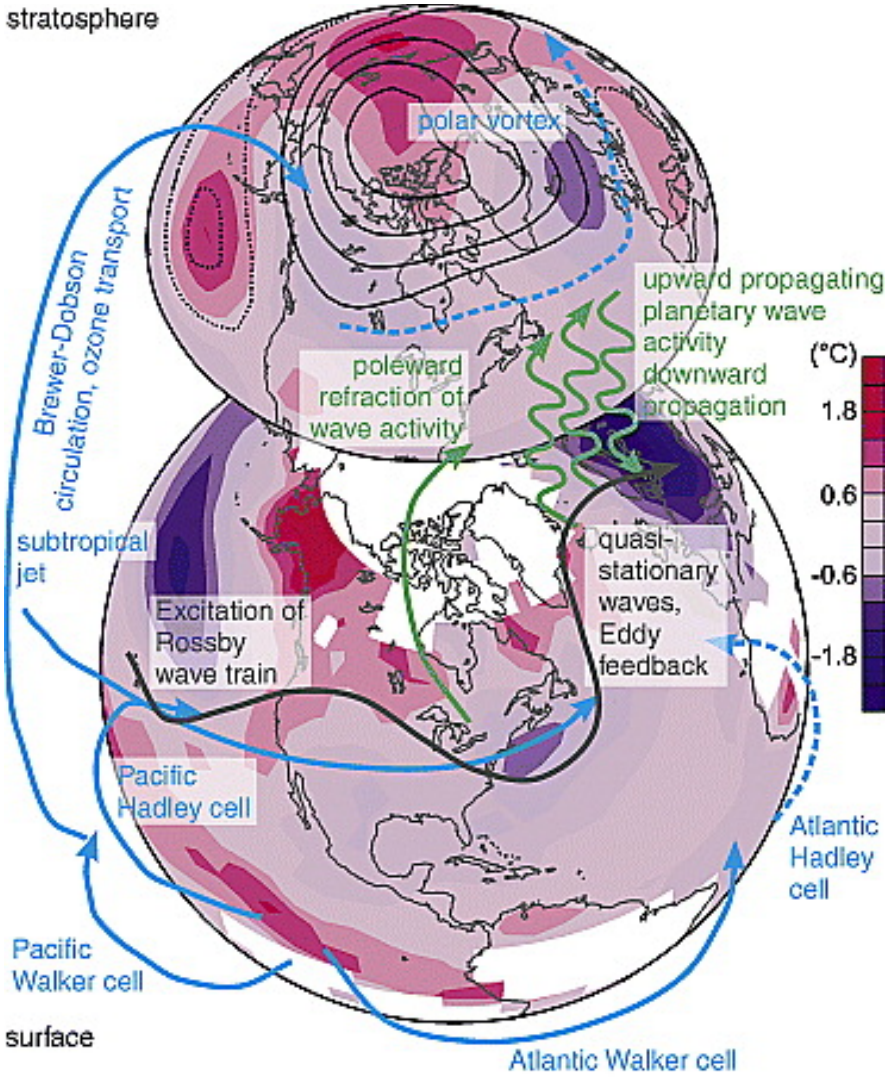

Distribution of water on Earth
Other 3%
Oceans 97%
Other 1%
Ground water 22%
Icecaps, Glaciers, and Inland seas 77%
Lakes 61%
Atmos-phere, Soil moisture 39%
Rivers: Less than 4/10%!

Global circulation of air mass: Convective and advective energy transfer between earth's surface and atmosphere.

Early perception of Global Circulation – Atmosphere

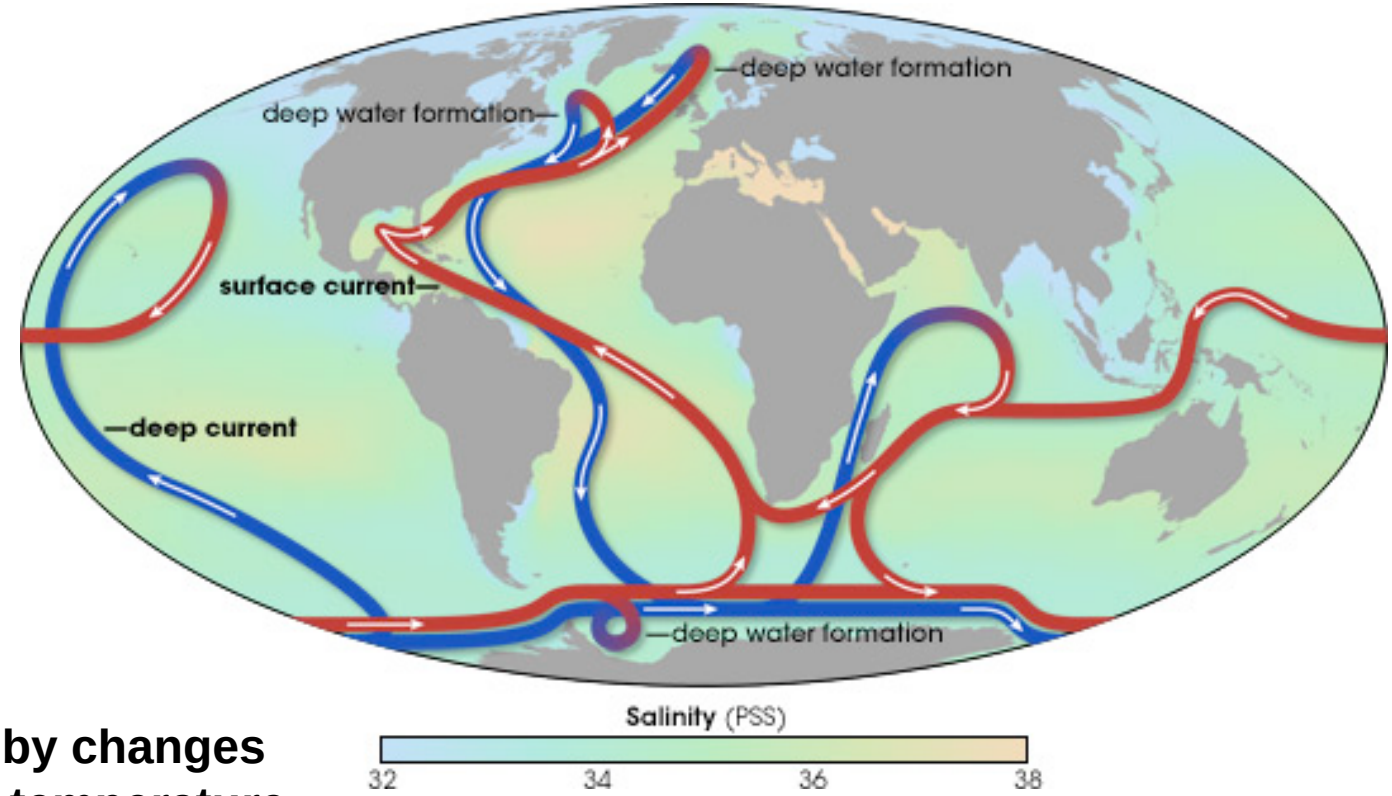


Very little mixing of air masses between North and South Hemispheres.



Current Understanding of Global Circulation - Atmosphere

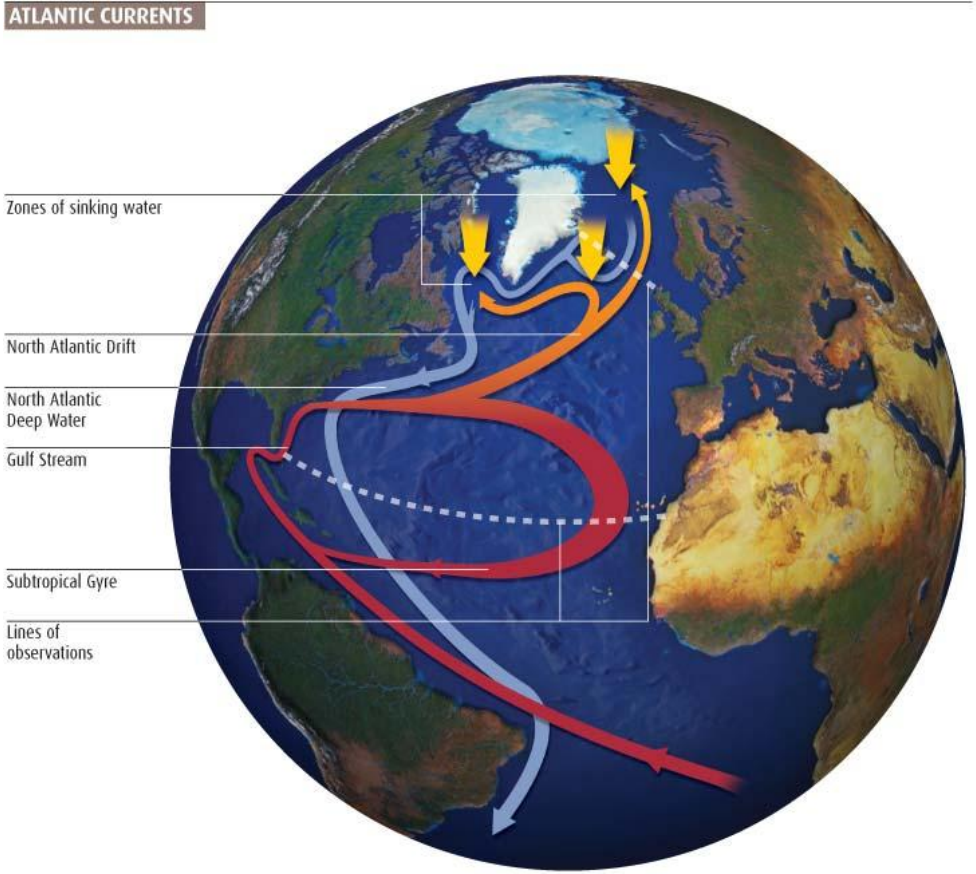
Global Circulation - Ocean Currents

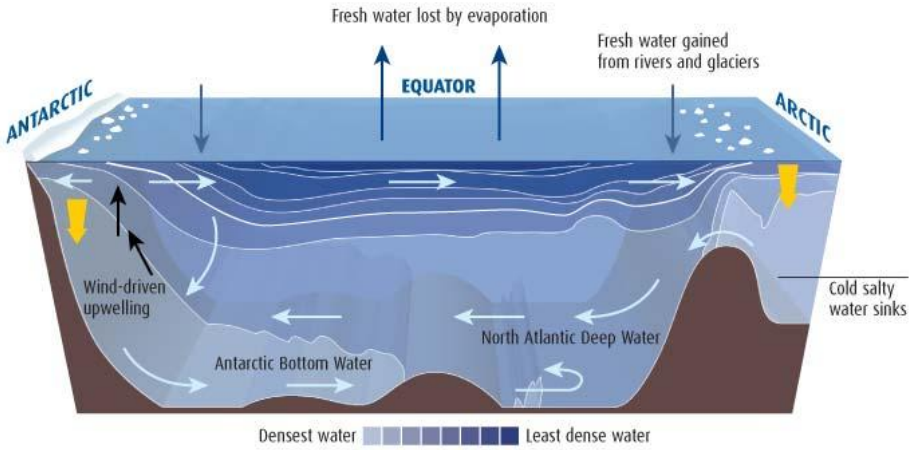


Caused by changes in water temperature and salinity.

General ocean circulation schematic #1

General ocean circulation schematic #2





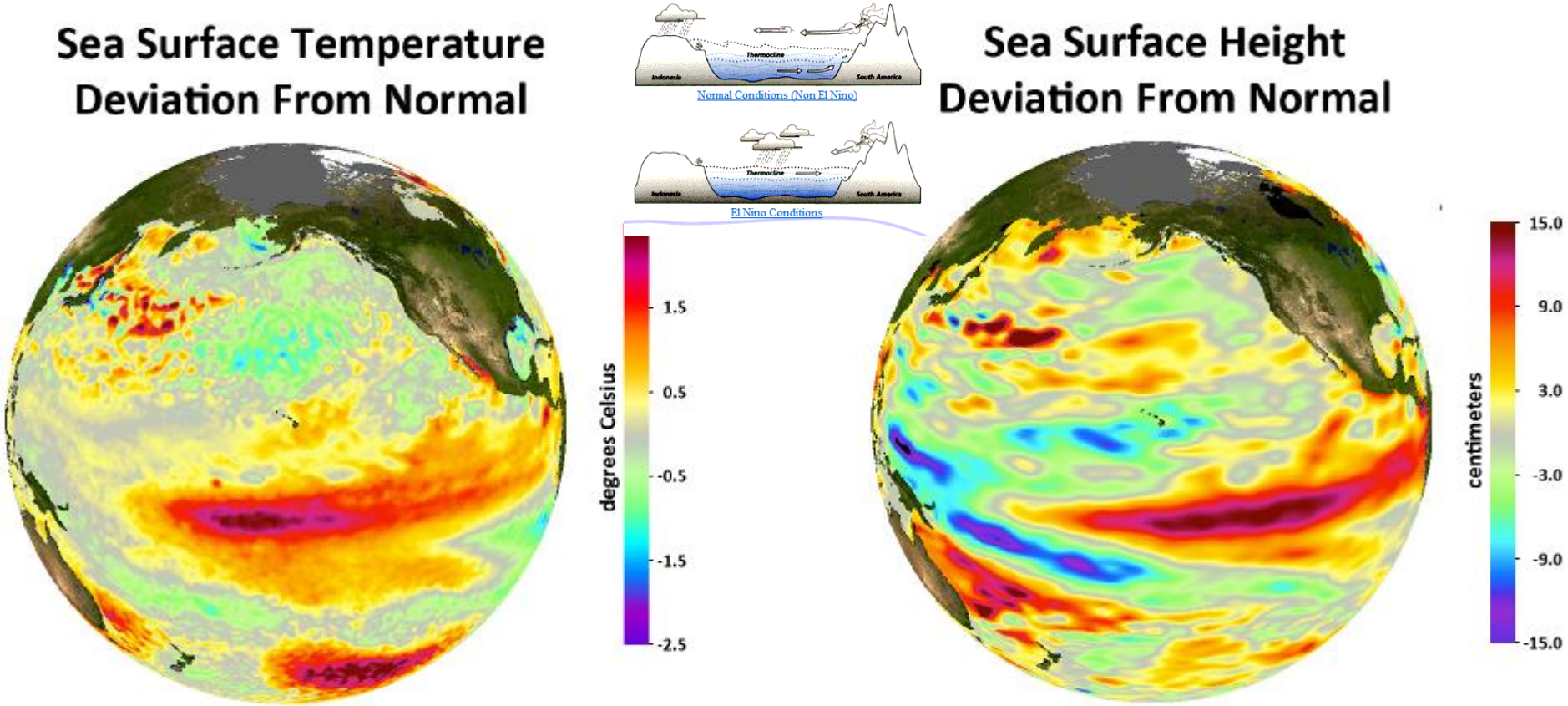
General ocean circulation schematic #3

Eg. El Nino

Effects Result from a Combination of Ocean Circulation and Atmospheric Circulation

See web site: http://sealevel.jpl.nasa.gov/science/elninopdo/learnmoreninonina/

During an El Nino westerly flowing trade winds weaken resulting in changes in weather and ocean circulation.

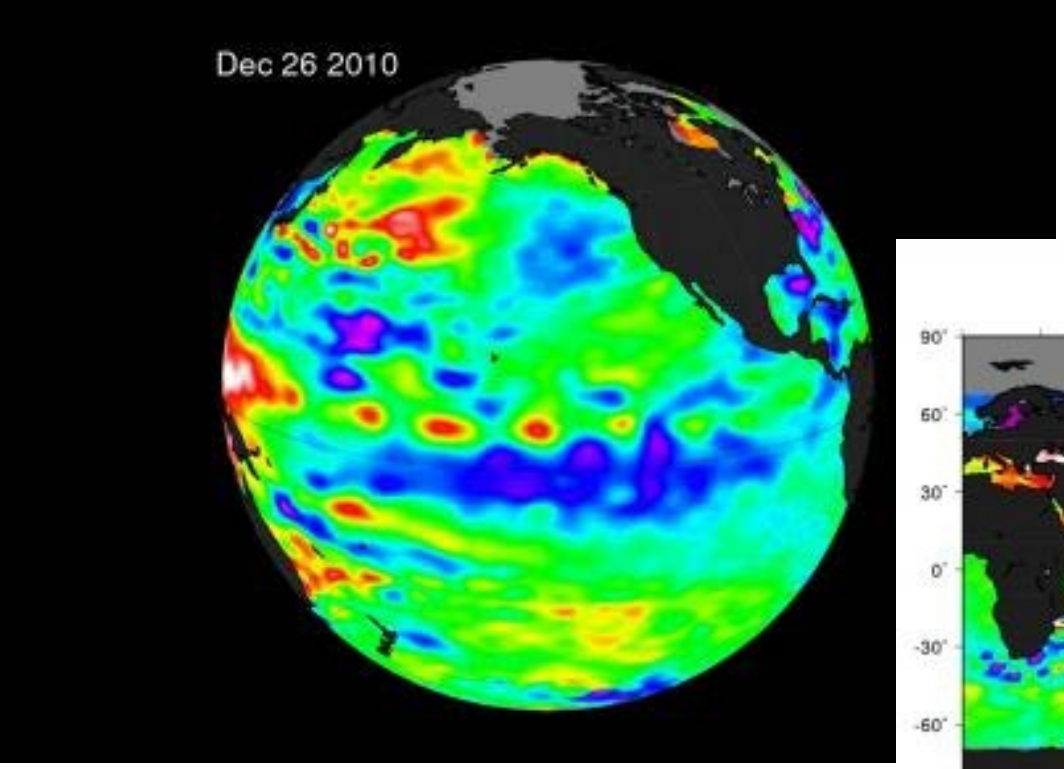


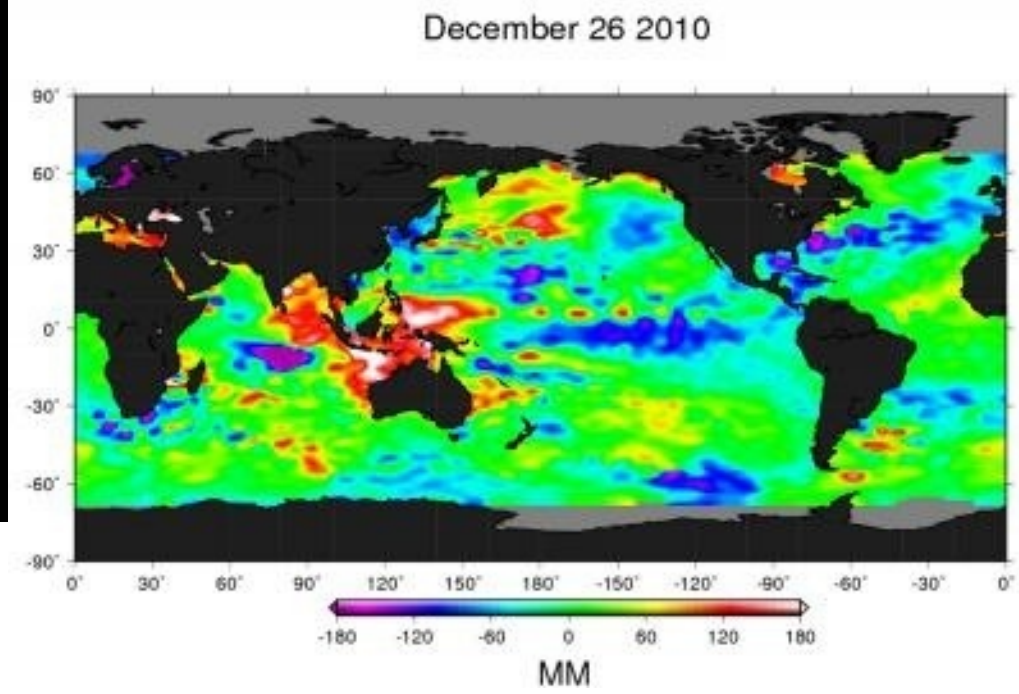
El Niños Are Growing Stronger

Deviations from normal sea surface temperatures (left) and sea surface heights (right) at the peak of the 2009-2010 central Pacific El Niños, as measured by NOAA polar orbiting satellites and NASA's Jason-1 spacecraft, respectively. The warmest temperatures and highest sea levels were located in the central equatorial Pacific.

Image credit: NASA/JPL-NOAA

Eg. La Nina





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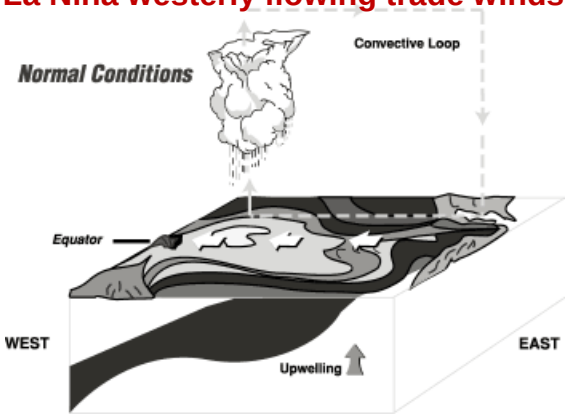
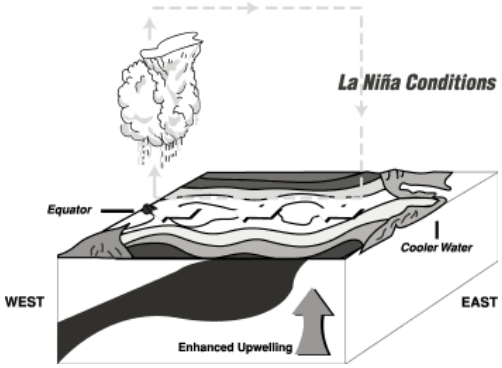
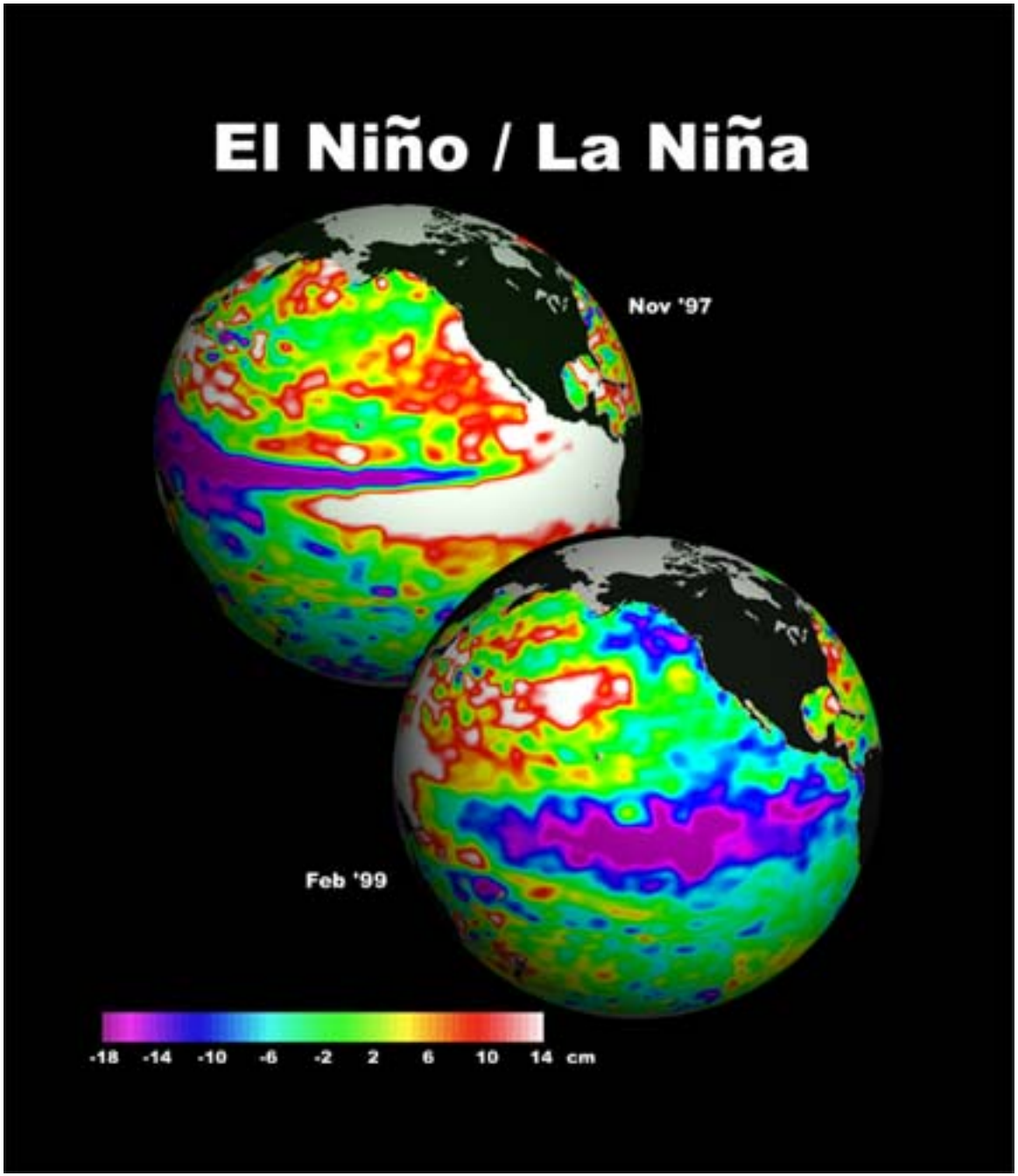
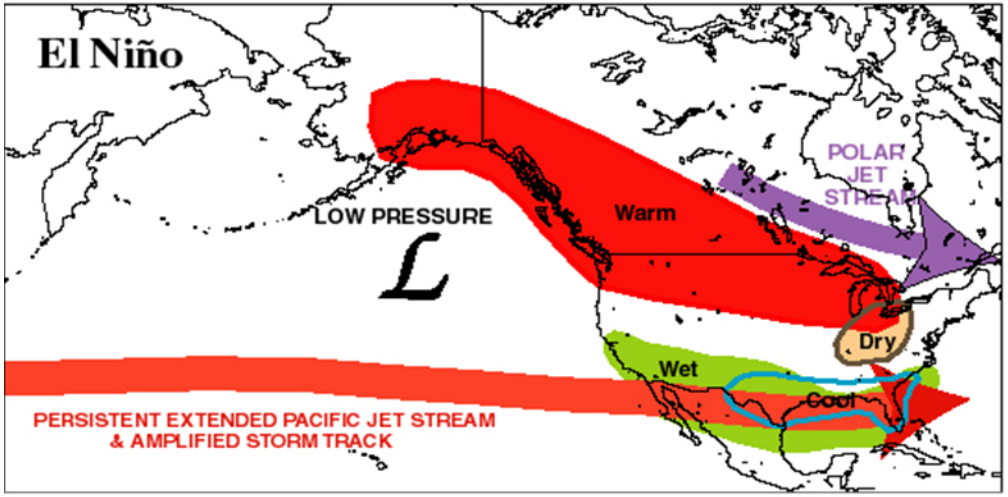


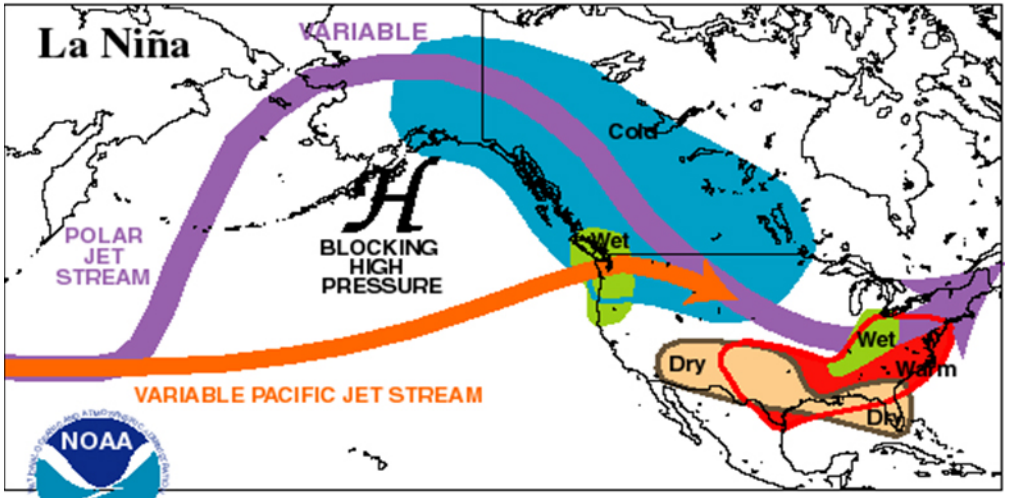


Effect on sea level.



Temperature rainfall effects of El Nino and La Nina





Climate Prediction Center/NCEP/NWS

Weather and climate vary widely with location on the planet.

Changing Climate of Planet Earth

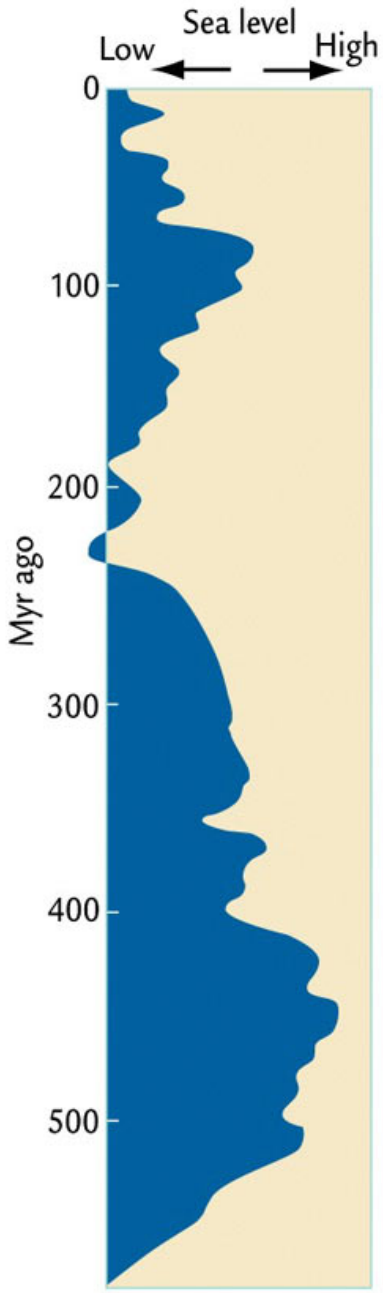
Earth's climate is constantly being *forced* to change by a variety of natural occurring phenomena that directly affect the energy budget.

Even short term local variation of any of these phenomena may cause dramatic short term climate changes.

Short term local variations in climate and associated environmental and physical changes may result in amplification of the original forcing phenomena, an effect known as *positive feedback*.

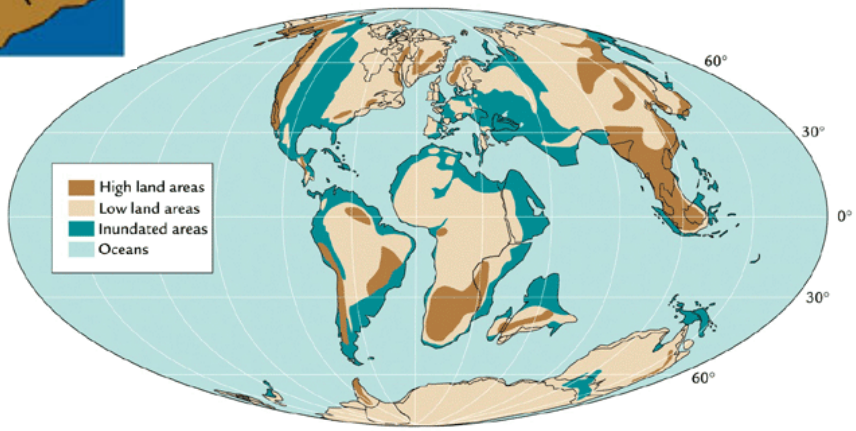
The resulting impact on climate change may be much more significant than that which would have resulted were the original forcing acting without positive feedback.

What characteristics of the planet or the energy budget vary in such a way that they could affect the earth’s climate?



Tectonic processes that influence climate system variability include plate motion, changes in continental geography, mountain building and erosion, the production and subduction of seafloor crust, and related changes in bio-geo-chemical cycles, particularly the carbon cycle.

Earth 100 Million Years Ago



Solar Radiation

<u>Increase or decrease in intensity of incoming solar radiation from the sun.</u>

- **Variations do occur but are not large.**

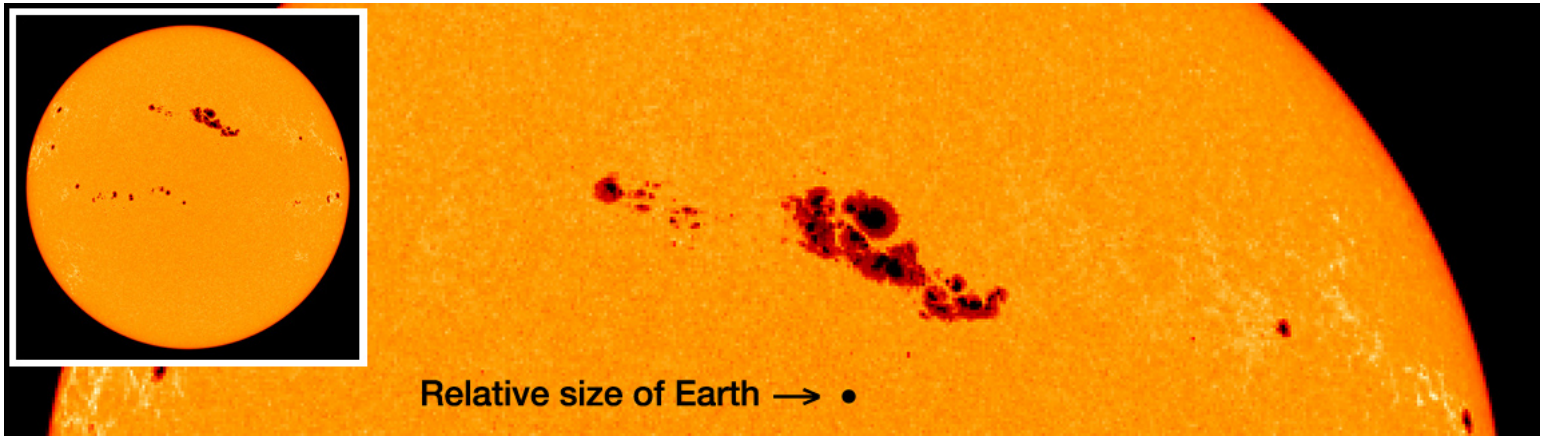
Sunspots

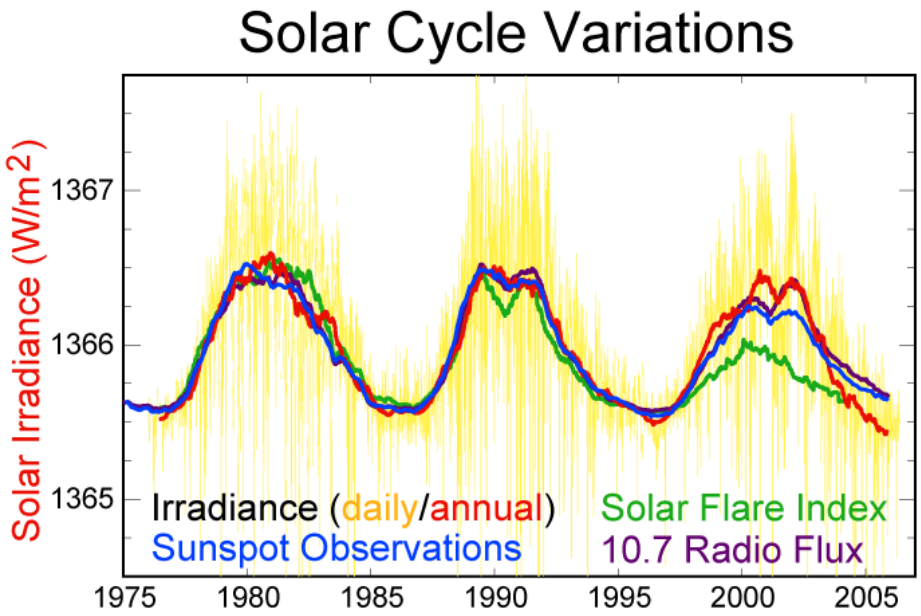
•Reduction or increase in the intensity of incoming solar radiation.

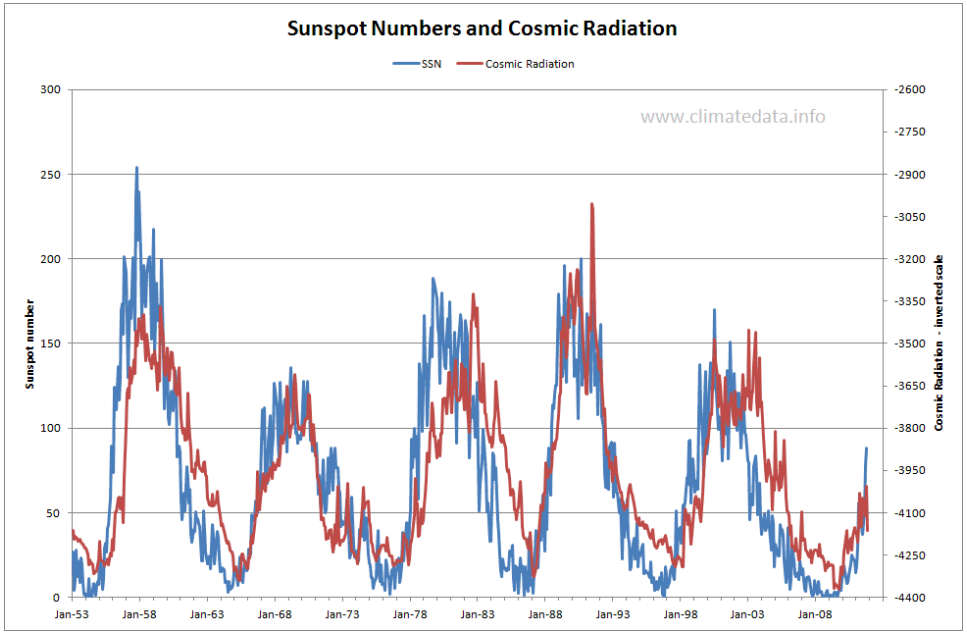
•Well understood cyclical behavior.

•Considered very minor but included in all evaluations.

•No demonstrated connection between sunspots, cosmic rays and cloud cover has been demonstrated or proven. However, there is evidence linking cosmic ray activity with climate change – possibly through increases in cloud cover. Research is in progress at CERN facilities.

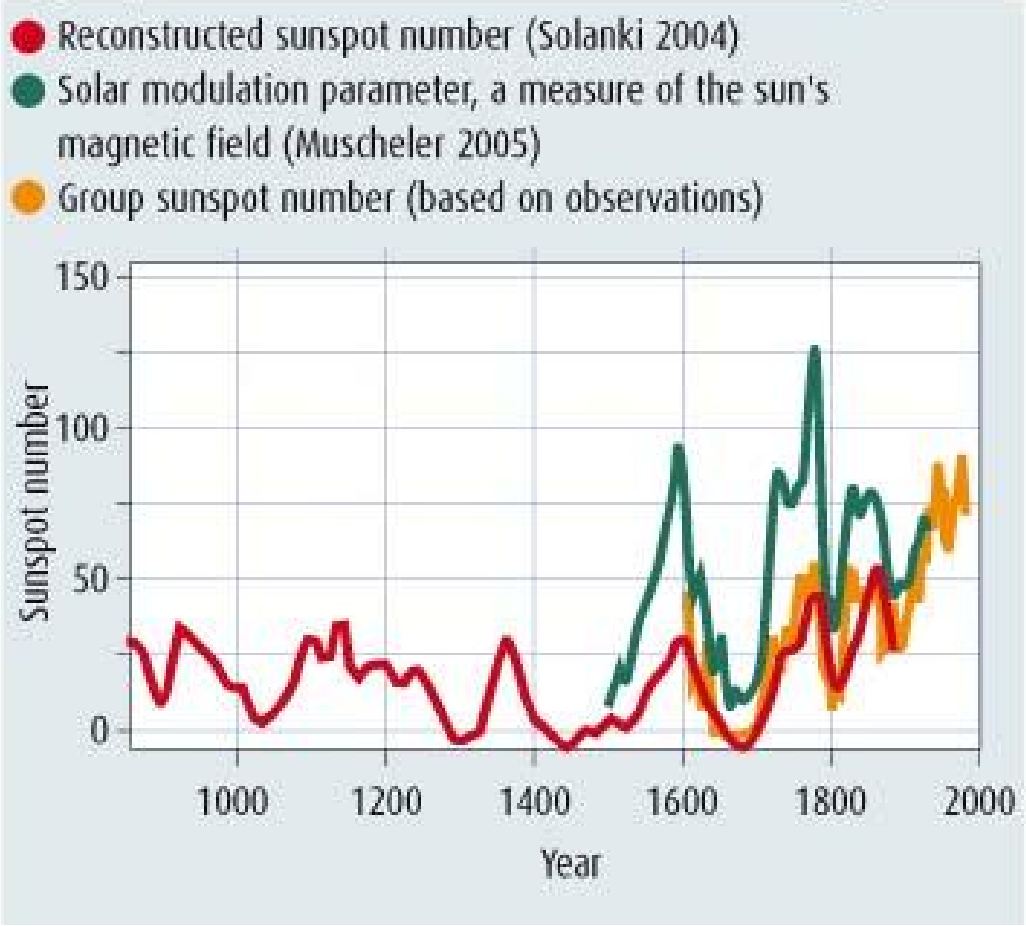



Solar Cycle Variations
Solar Irradiance (W/m2)
1367
1366
1365
Irradiance (daily/annual)
Sunspot Observations
Solar Flare Index
10.7 Radio Flux
1975
1980
1985
1990
1995
2000
2005


Sunspot Numbers and Cosmic Radiation
SSN
Cosmic Radiation
www.climatedata.info
Sunspot number
Cosmic Radiation - inverted scale
300
250
200
150
100
50
0
-2600
-2750
-2900
-3050
-3200
-3350
-3500
-3650
-3800
-3950
-4100
-4250
-4400
Jan-53
Jan-58
Jan-63
Jan-68
Jan-73
Jan-78
Jan-83
Jan-88
Jan-93
Jan-98
Jan-03
Jan-08

PAST SOLAR ACTIVITY

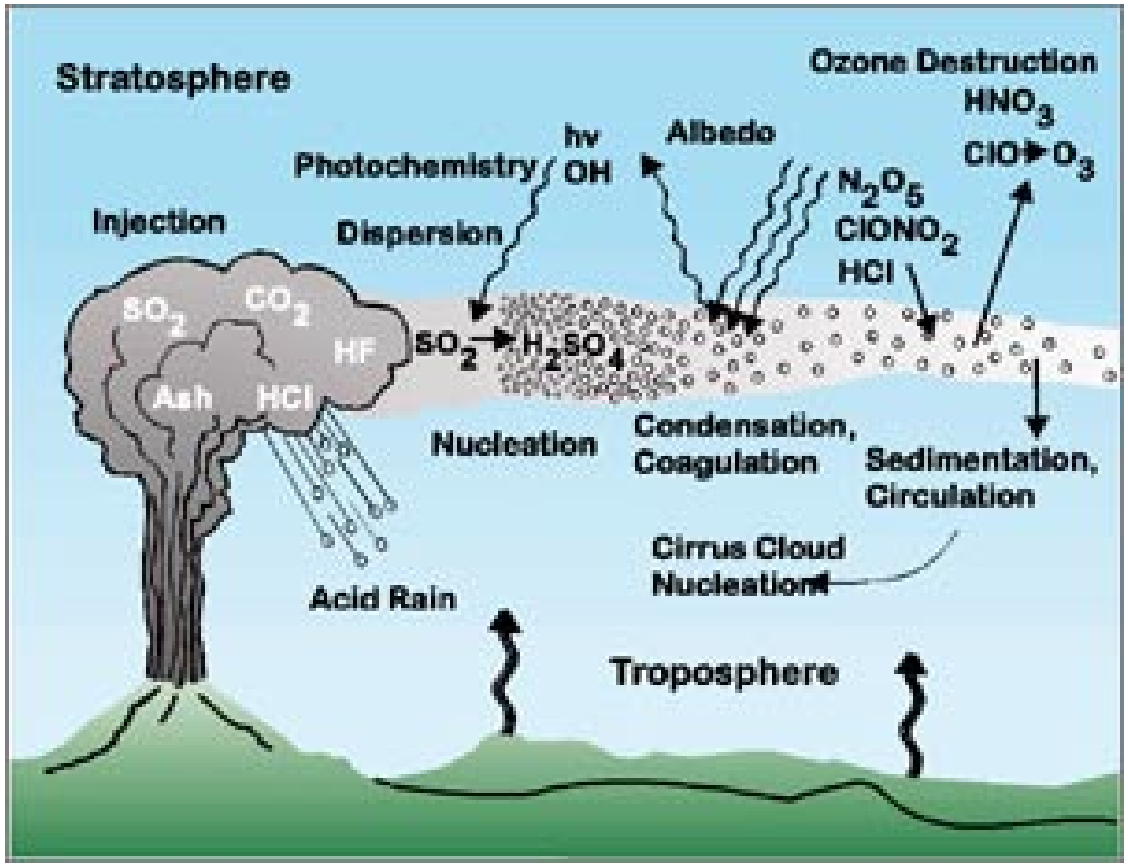
Two recent estimates of past solar activity based on carbon-14 levels in tree rings. Carbon-14 is formed when cosmic rays hit the atmosphere and its levels are approximately inversely proportional to solar activity. Even if solar activity has been exceptionally high over the past century, as the reconstructed sunspot number suggests, this still cannot account for the recent warming



Solar Radiation

Aersols

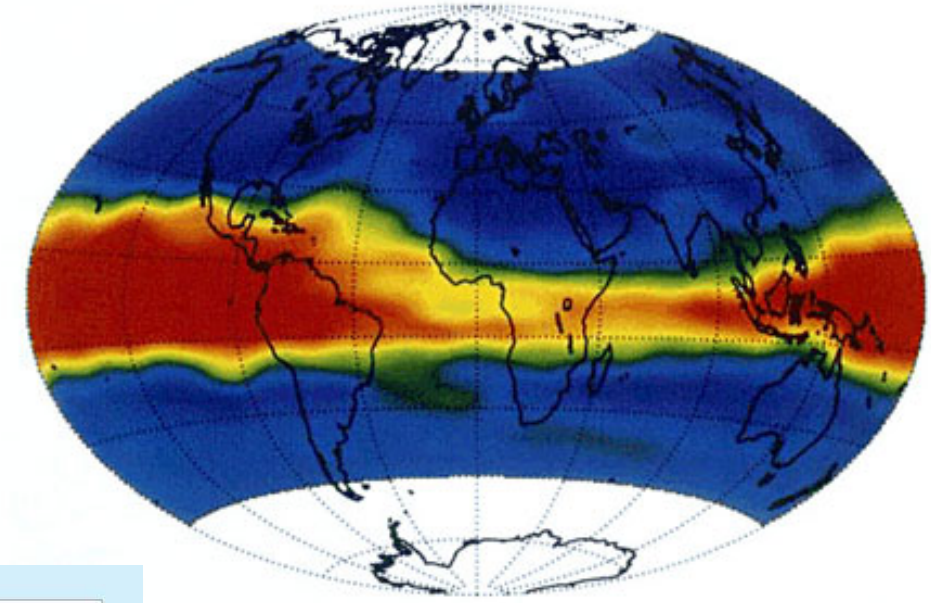
Volcanoes

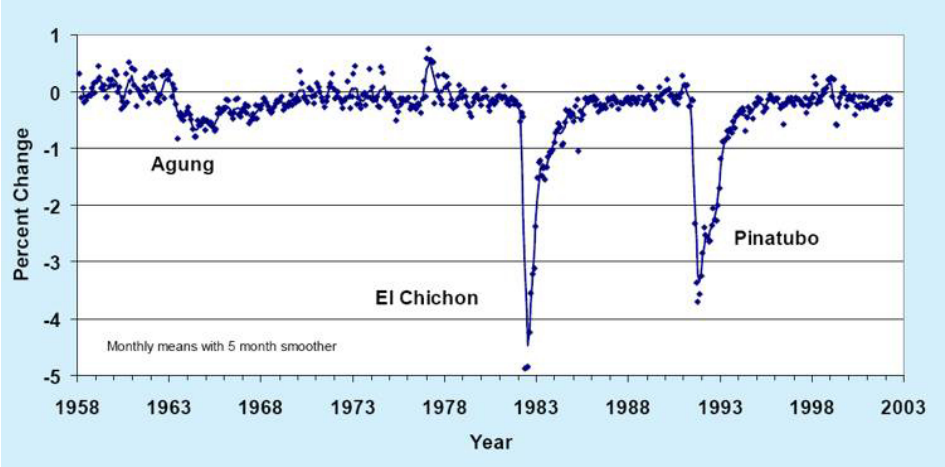


Effects due to aerosols including SO2, CO2 and HCl.

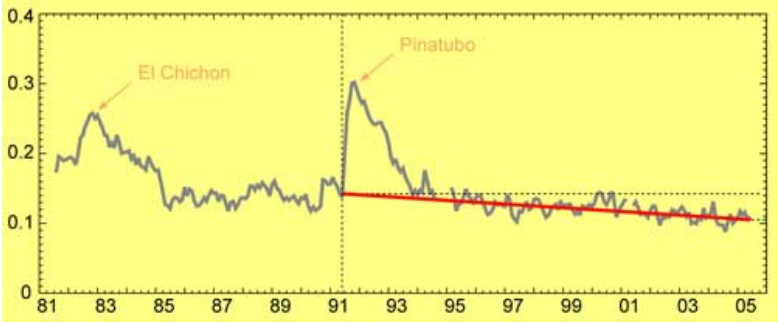
Today, the effects of volcanoes are short termed.

Mt. Pinatubo and global circulation of ash.





Effect is to Decrease Temperature

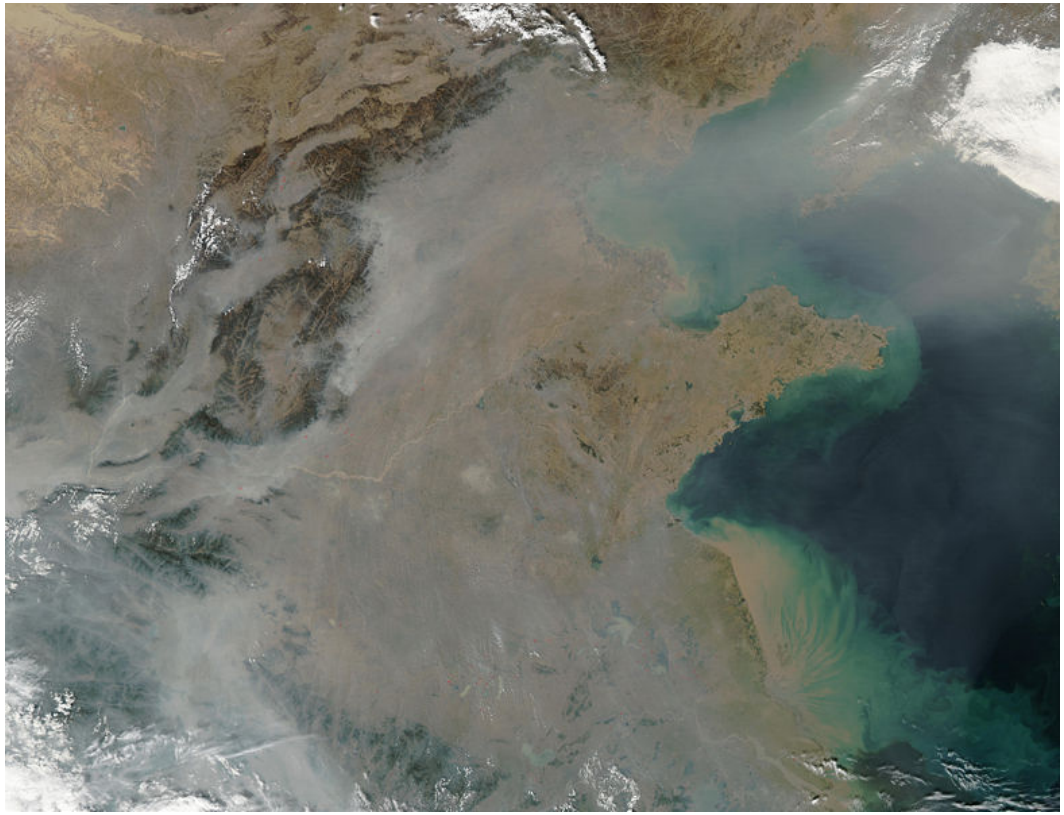


Aerosol Concentration

Global Dimming

Effect of global dimming due to man-made aerosol pollutants in atmosphere is to decrease amount of solar radiation reaching the earth's surface, decrease evaporation, seed clouds and alter local precipitation patterns and regional hydrology.

Forest Fires – Eastern China.



Contrails

Pollution - Golden Gate Bridge – San Francisco

Concentration of aerosols in atmosphere, once was steadily increasing and now is actually decreasing – worry is that global warming will be accelerated.

Solar Radiation

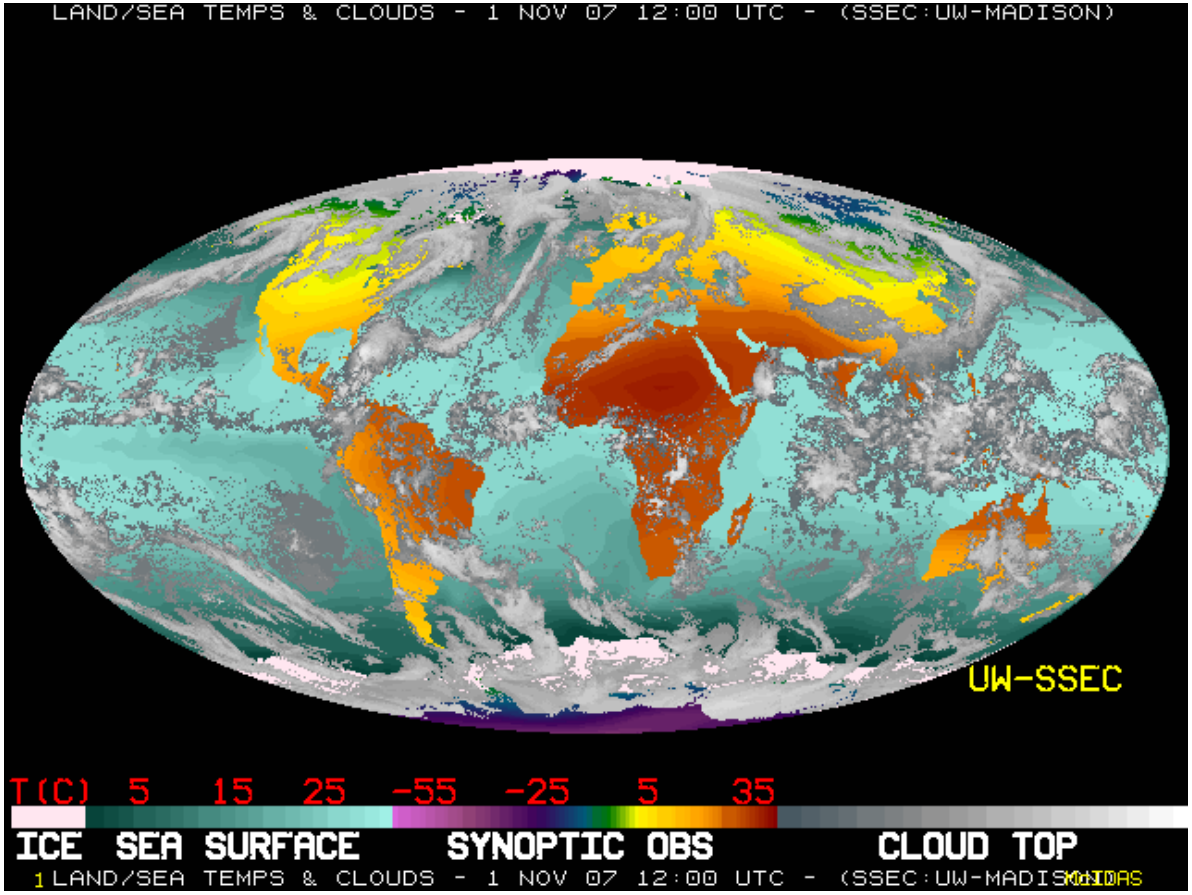
<u>Reflections off Ice cover, and Clouds</u>

- **Considered a consequence of global warming/cooling that may in fact provide a <u>positive feedback</u> to other natural forcing processes.**

- **Maybe a connection to intensity of influx of cosmic rays and associated increase in cloud cover – an hypothesis as yet unproven.**

Solar Radiation

Clouds and Reflection



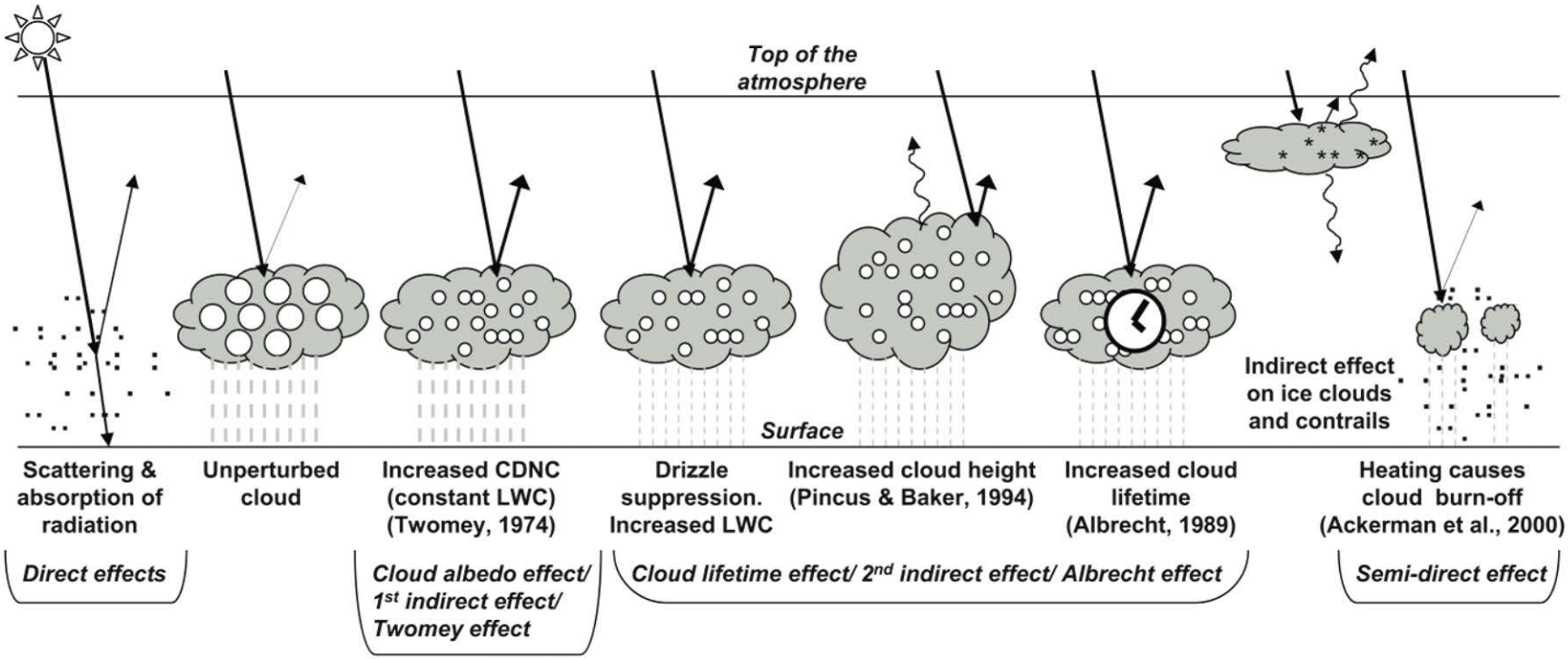


Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

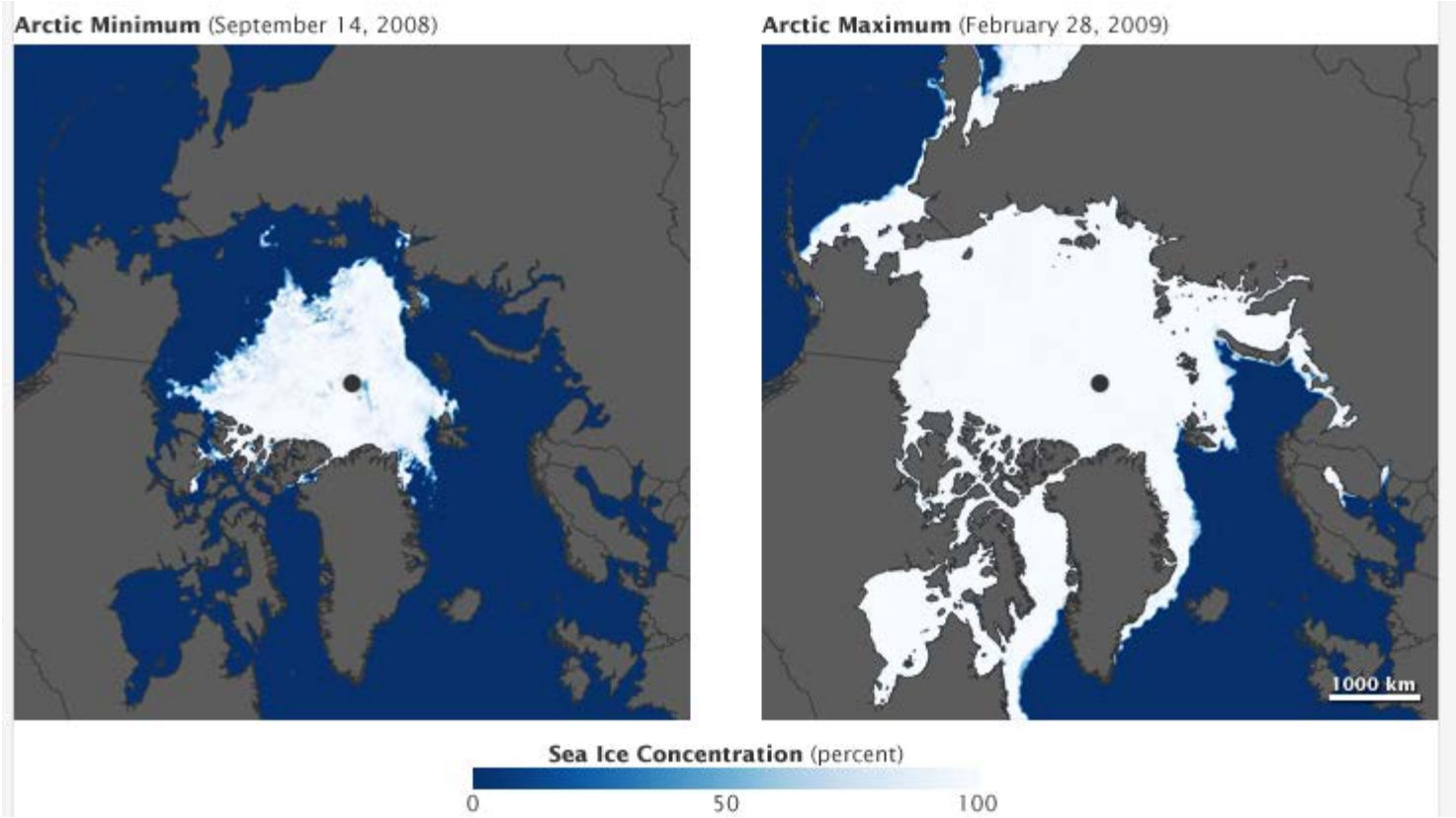
Figure 2.10

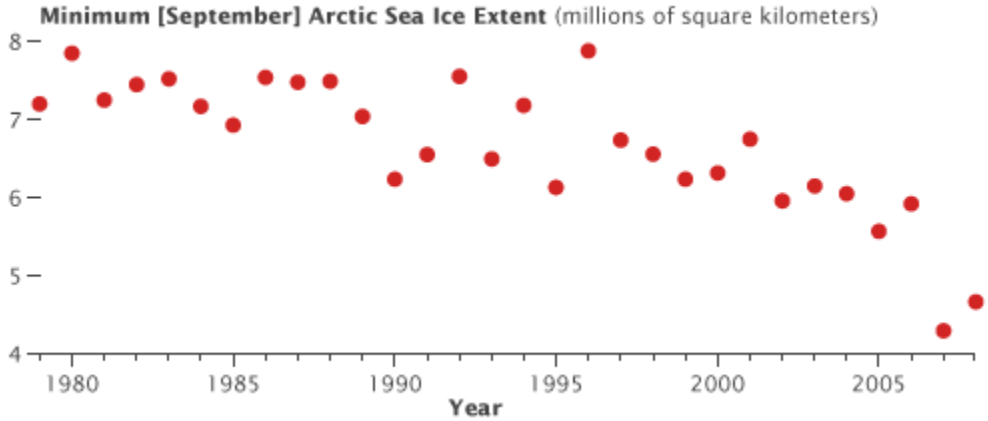
Solar Radiation

Ice and snow

Effect of growth and shrinkage of Arctic, Antarctic and Greenland ice sheets and glaciers on mass of ice and albedo.

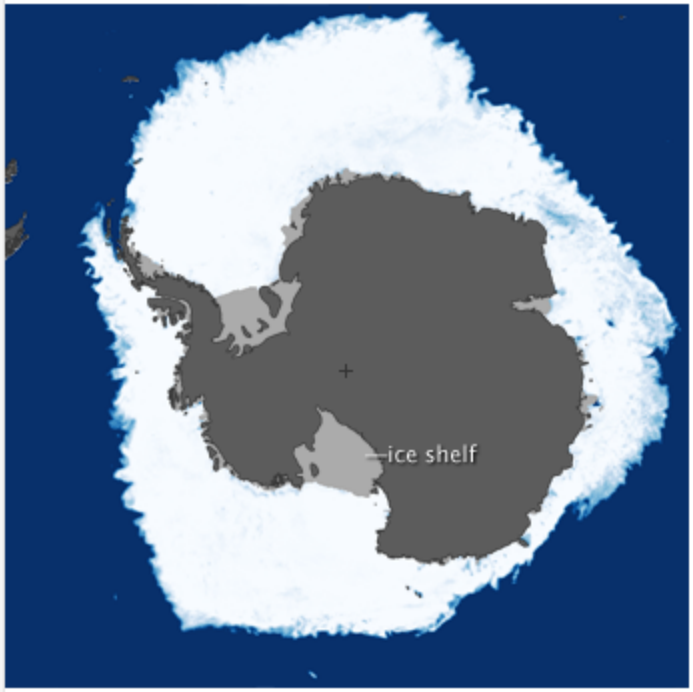
(Aerial extent, volume and timing of seasonal snow accumulation and melt might change.)


Arctic Minimum (September 14, 2008)
Arctic Maximum (February 28, 2009)
1000 km
Sea Ice Concentration (percent)
0
50
100

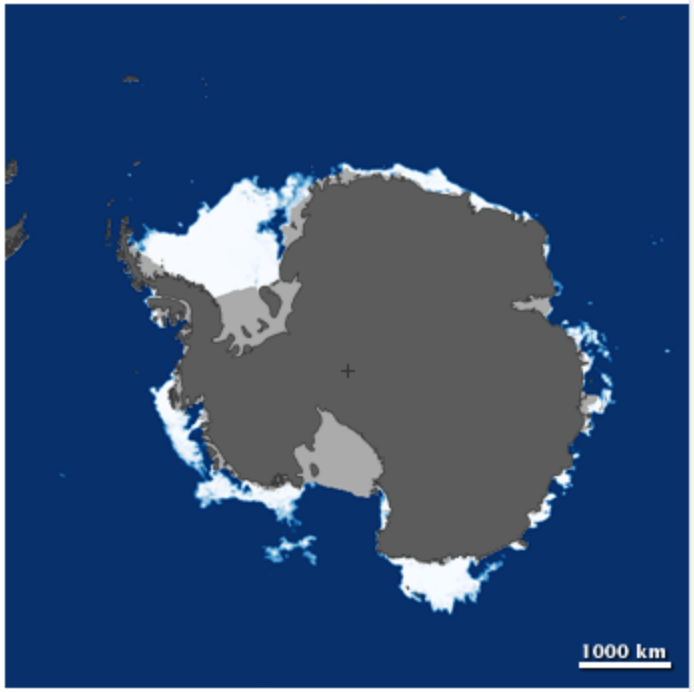

Minimum [September] Arctic Sea Ice Extent (millions of square kilometers)
8
7
6
5
4
1980
1985
1990
1995
2000
2005
Year


Greenland Ice Sheet Melt 1992 to 2002
1992
2002
©2004, Clifford Grabhorn
©2004, Clifford Grabhorn

Antarctic Maximum (September 4, 2008)

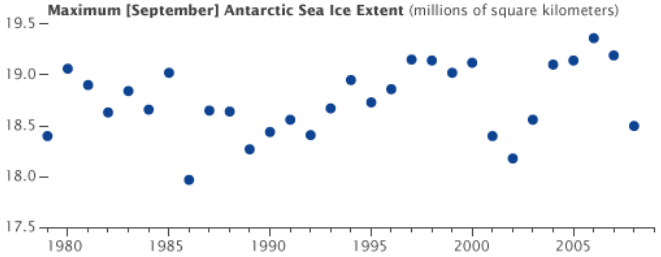


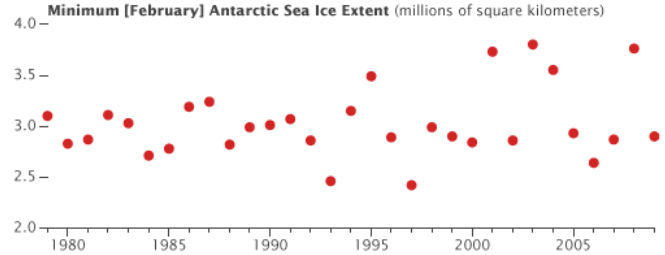
Antarctic Minimum (February 20, 2009)



Sea Ice Concentration (percent)

0 50 100





ON ATHABASCA GLACIER AT THE COLUMBI

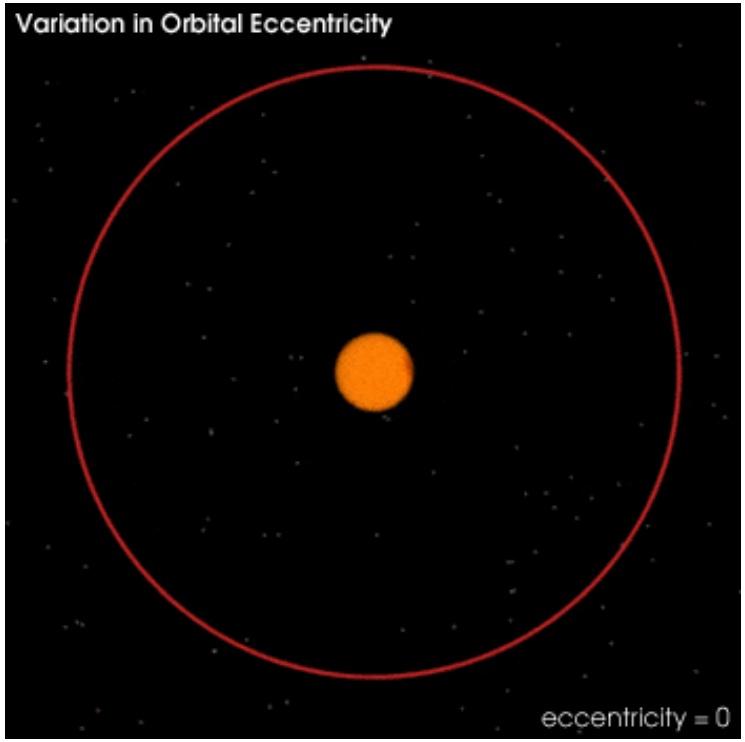
Glaciers

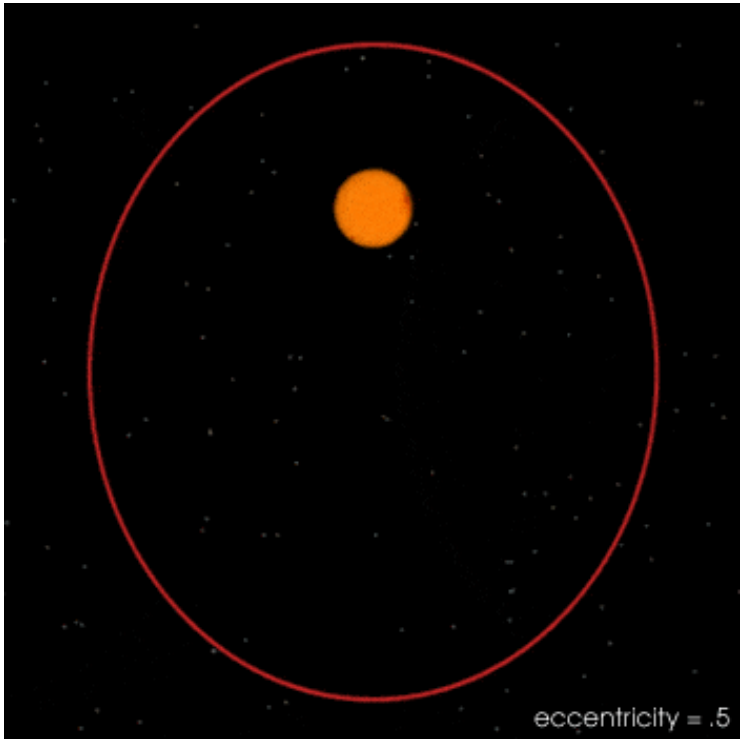
Milankovitch Cycles

Serbian Geophysicist and Civil Engineer

http://www.sciencecourseware.org/eec/GlobalWarming/Tutorials/Milankovitch/
http://en.wikipedia.org/wiki/Milankovitch_cycles
http://www.wwnorton.com/college/geo/egeo2/content/animations/18_2.htm

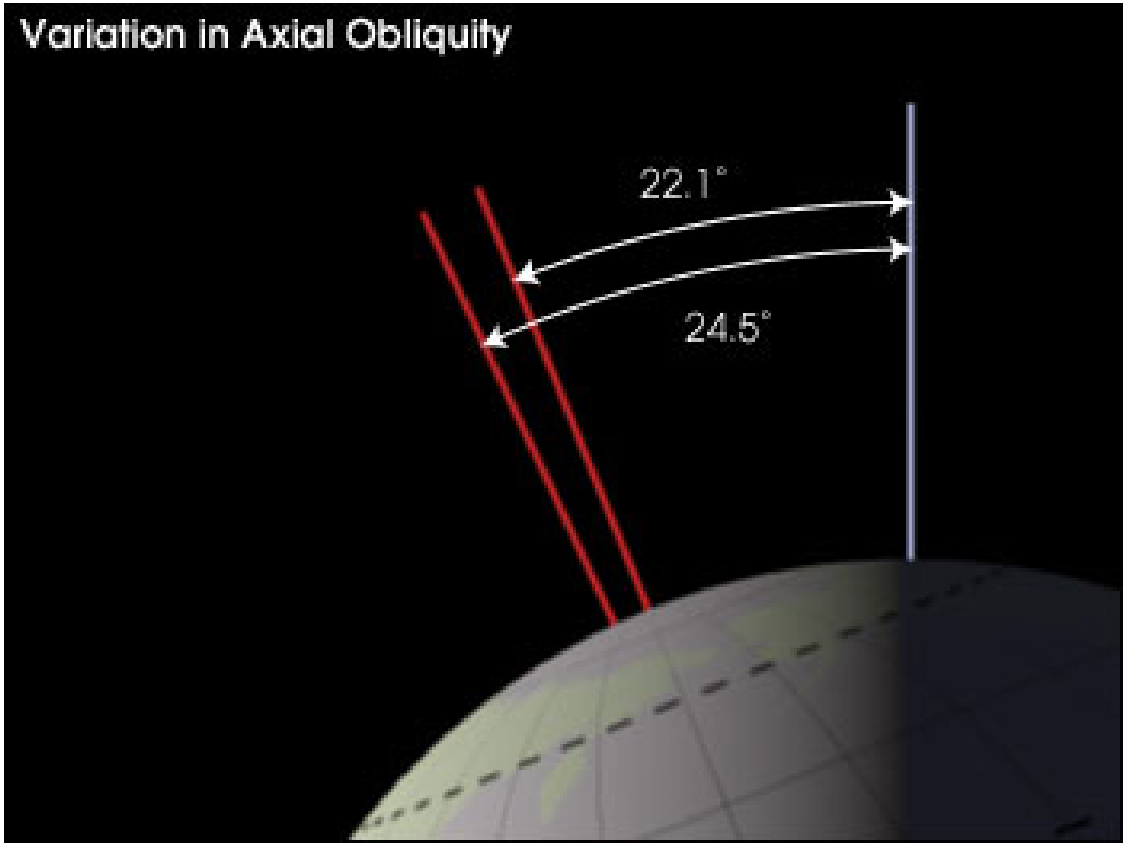
Explain the variations in Earth's climate during 'Ice Age' or Pleistocene.

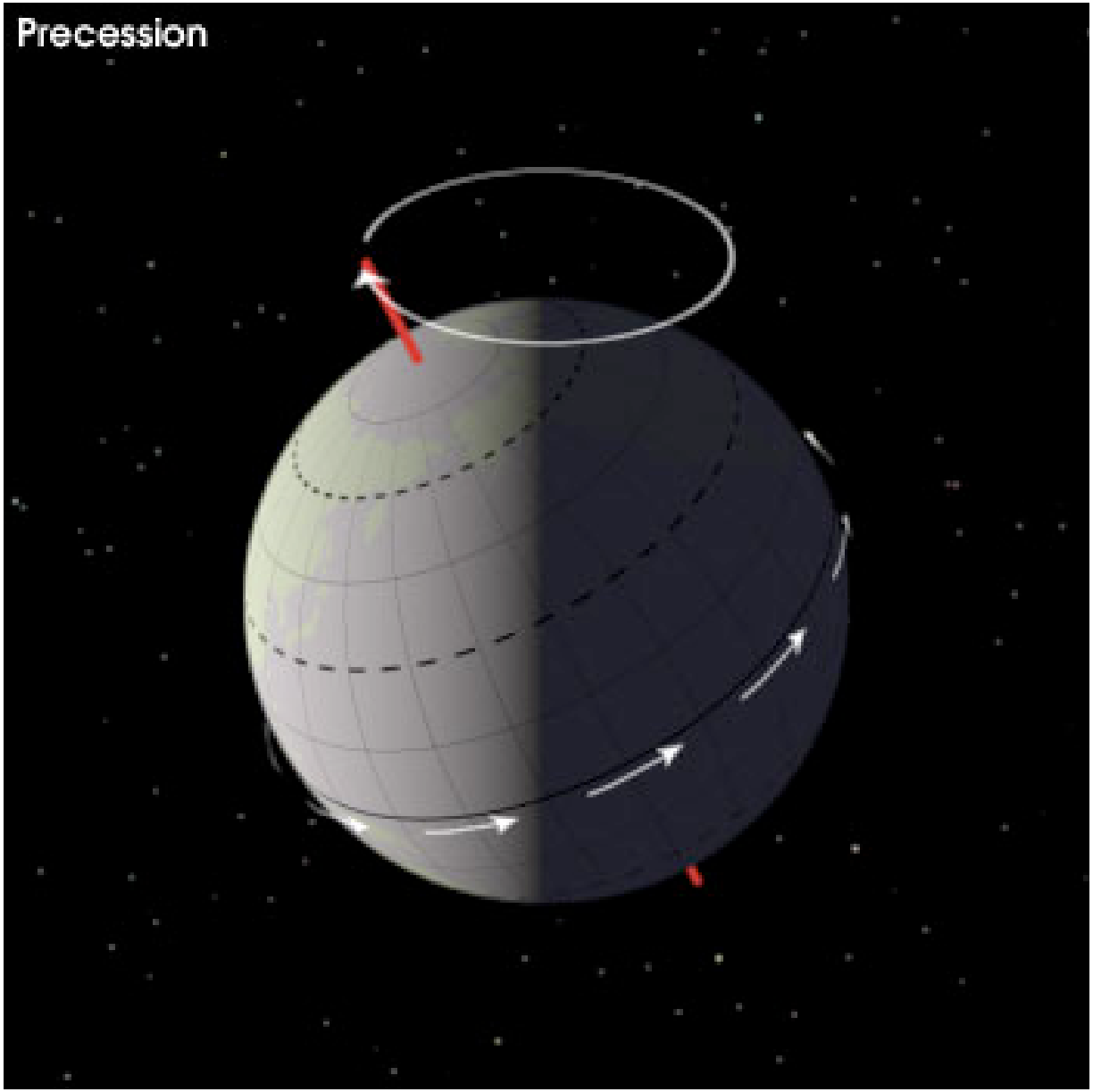


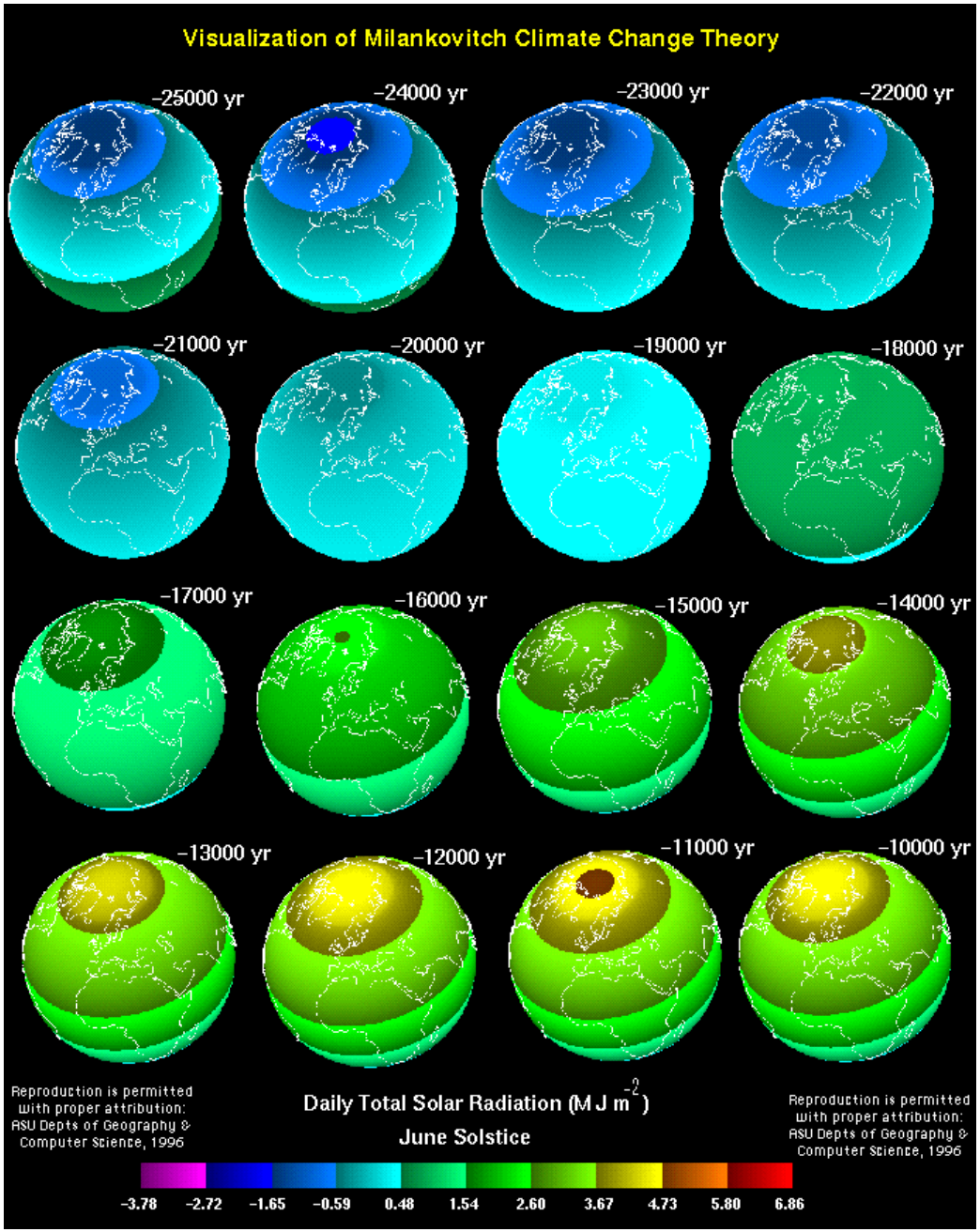


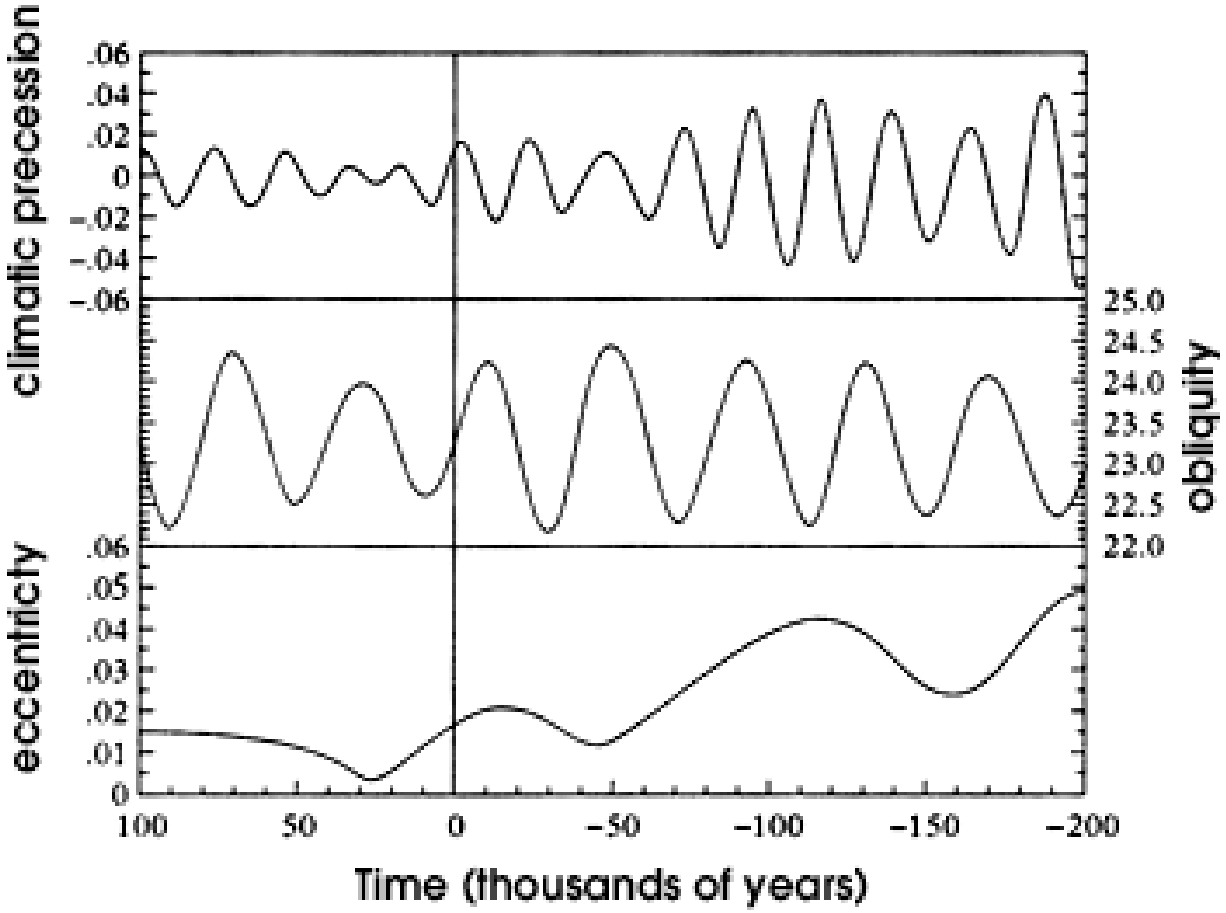
Variations in the Earth's orbit and how it affects the amount of radiation different parts of the Earth receive at any time.

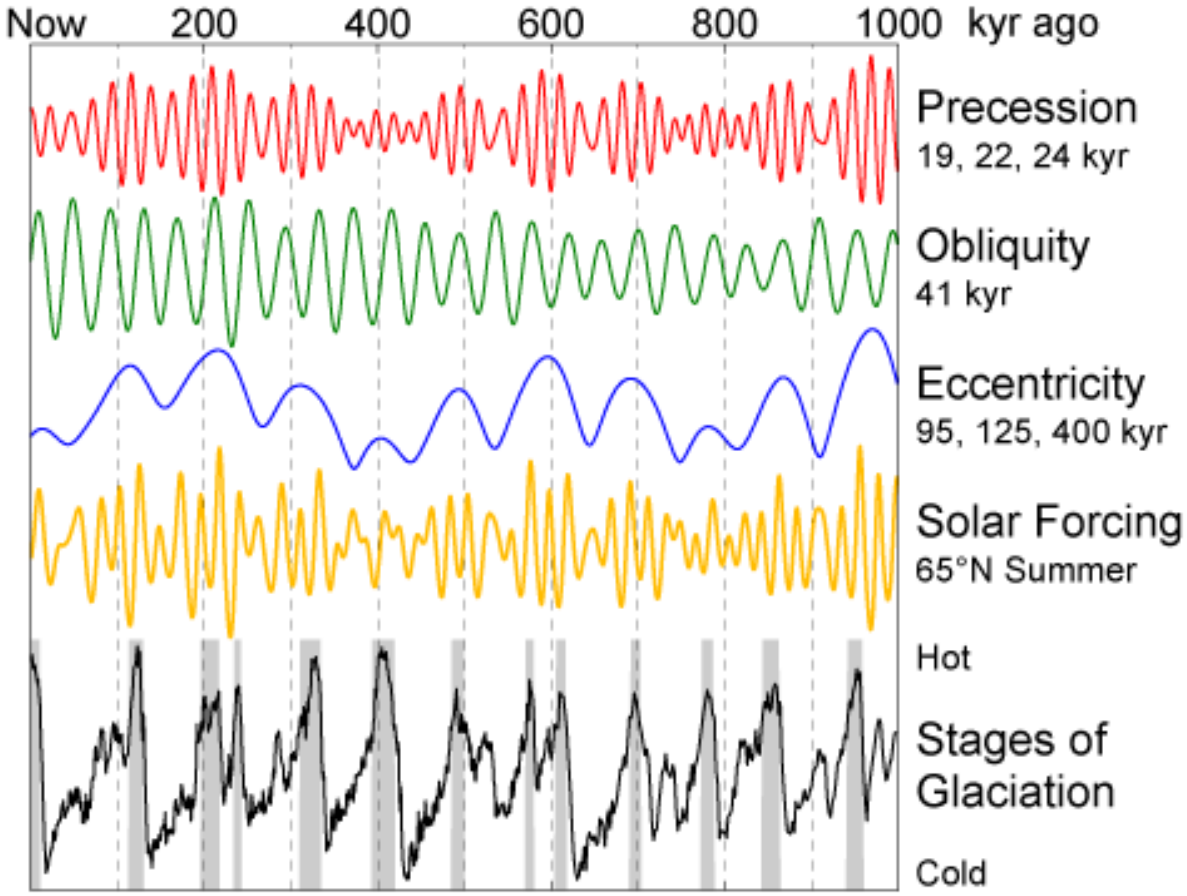
The yearly amount of radiation, for the entire globe, is the same.


Variation in Axial Obliquity
22.1°
24.5°


Precession

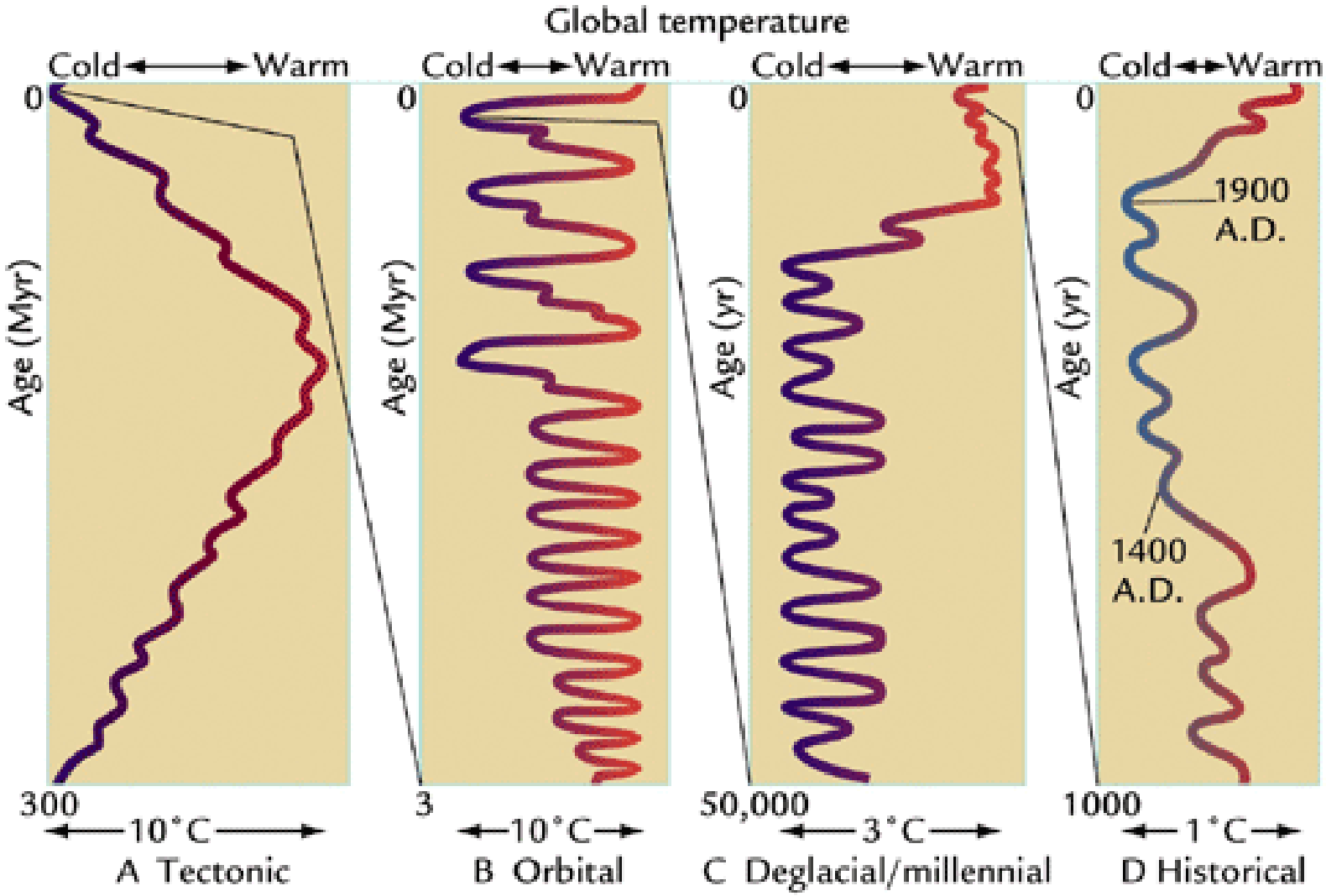

Visualization of Milankovitch Climate Change Theory
-25000 yr
-24000 yr
-23000 yr
-22000 yr
-21000 yr
-20000 yr
-19000 yr
-18000 yr
-17000 yr
-16000 yr
-15000 yr
-14000 yr
-13000 yr
-12000 yr
-11000 yr
-10000 yr
Reproduction is permitted with proper attribution: ASU Depts of Geography & Computer Science, 1996
Daily Total Solar Radiation (M J m-2)
June Solstice
Reproduction is permitted with proper attribution: ASU Depts of Geography & Computer Science, 1996
-3.78
-2.72
-1.65
-0.59
0.48
1.54
2.60
3.67
4.73
5.80
6.86


climatic precession
.06
.04
.02
0
-.02
-.04
-.06
obliquity
25.0
24.5
24.0
23.5
23.0
22.5
22.0
eccentricity
.06
.05
.04
.03
.02
.01
0
100
50
0
-50
-100
-150
-200
Time (thousands of years)

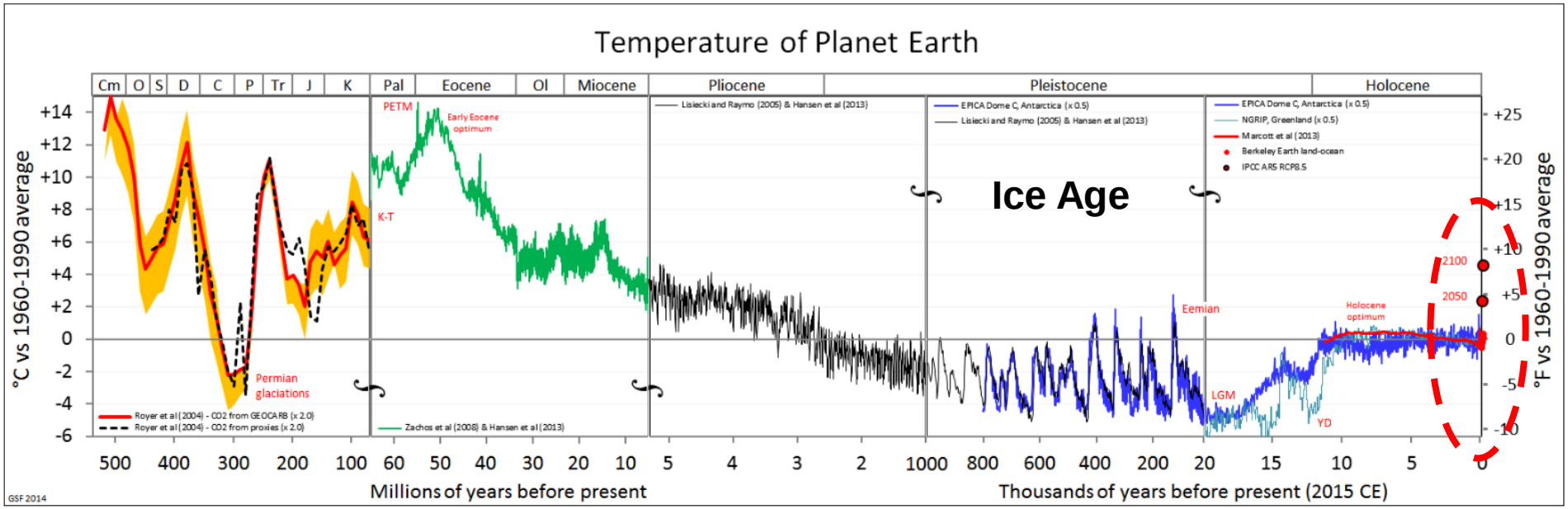


Changing how the Earth receives the sun's radiation determines the occurrence of glaciations.

Information on stages of glaciation gathered from sediment cores.


Global temperature
Cold
Warm
Age (Myr)
Age (yr)
0
300
3
50,000
1000
1900 A.D.
1400 A.D.
10°C
3°C
1°C
A Tectonic
B Orbital
C Deglacial/millennial
D Historical

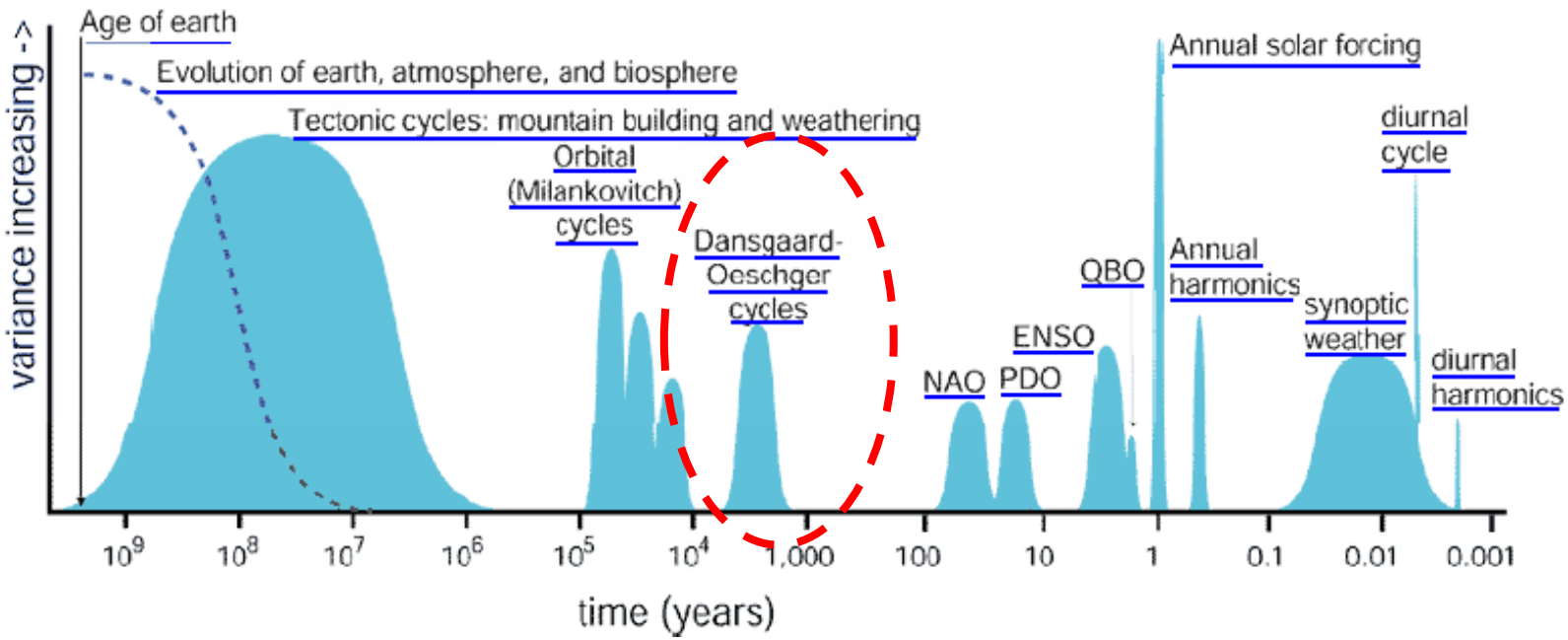
Variation of Earth's Temperature Over Last 500 Million Years



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

There is considerable discussion that the climate has changed continuously over geologic time, for various reasons, and this is undeniably true.

We are interested in knowing why is the climate changing now.



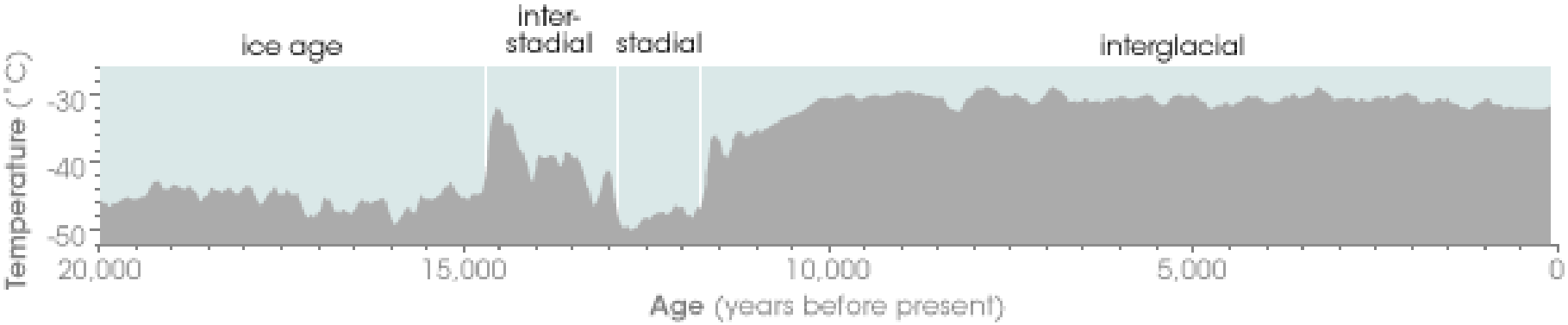
NOAA – Climate Change Cycles

See web site: http://www.ngdc.noaa.gov/paleo/ctl/about1.html

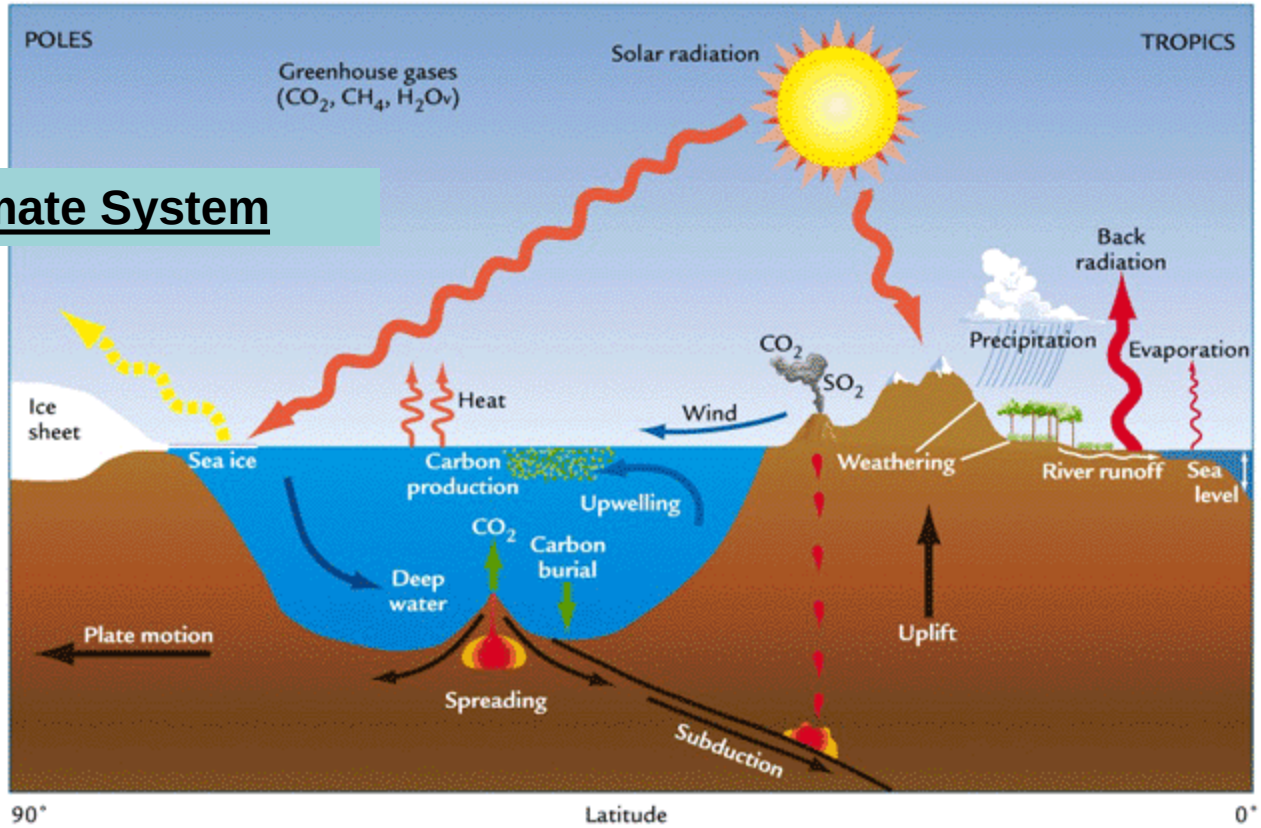
The ice core studies determined that there were frequent rapid changes in climate such as the Dansgaard-Oeschger Cycles that occurred during an ice-age or those such as the Younger Dryas that a resulted from the draining of Lake Agassiz at the end of the ice age http://www.nature.com/nature/journal/v464/n7289/full/nature08954.html and https://en.wikipedia.org/wiki/Younger_Dryas.

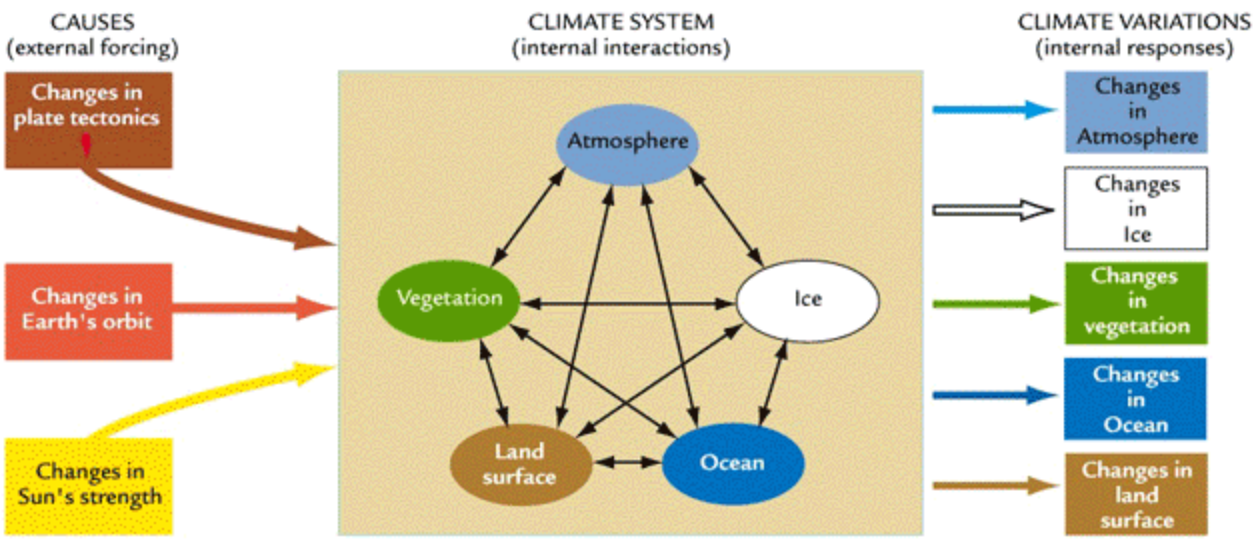
Rapidity of Climate Change

Climate change has occurred very quickly in the past – instantly in geological terms.



Climate System





End Part 1