The Smithsonian Associates
Resident Associates Program

Water, Ice, Land and Life: The Earth from Above
Part II
"Where's The Missing Carbon?"

Jim Collatz, Hydrospheric and Biospheric Sciences Laboratory
NASA's Goddard Space Flight Center

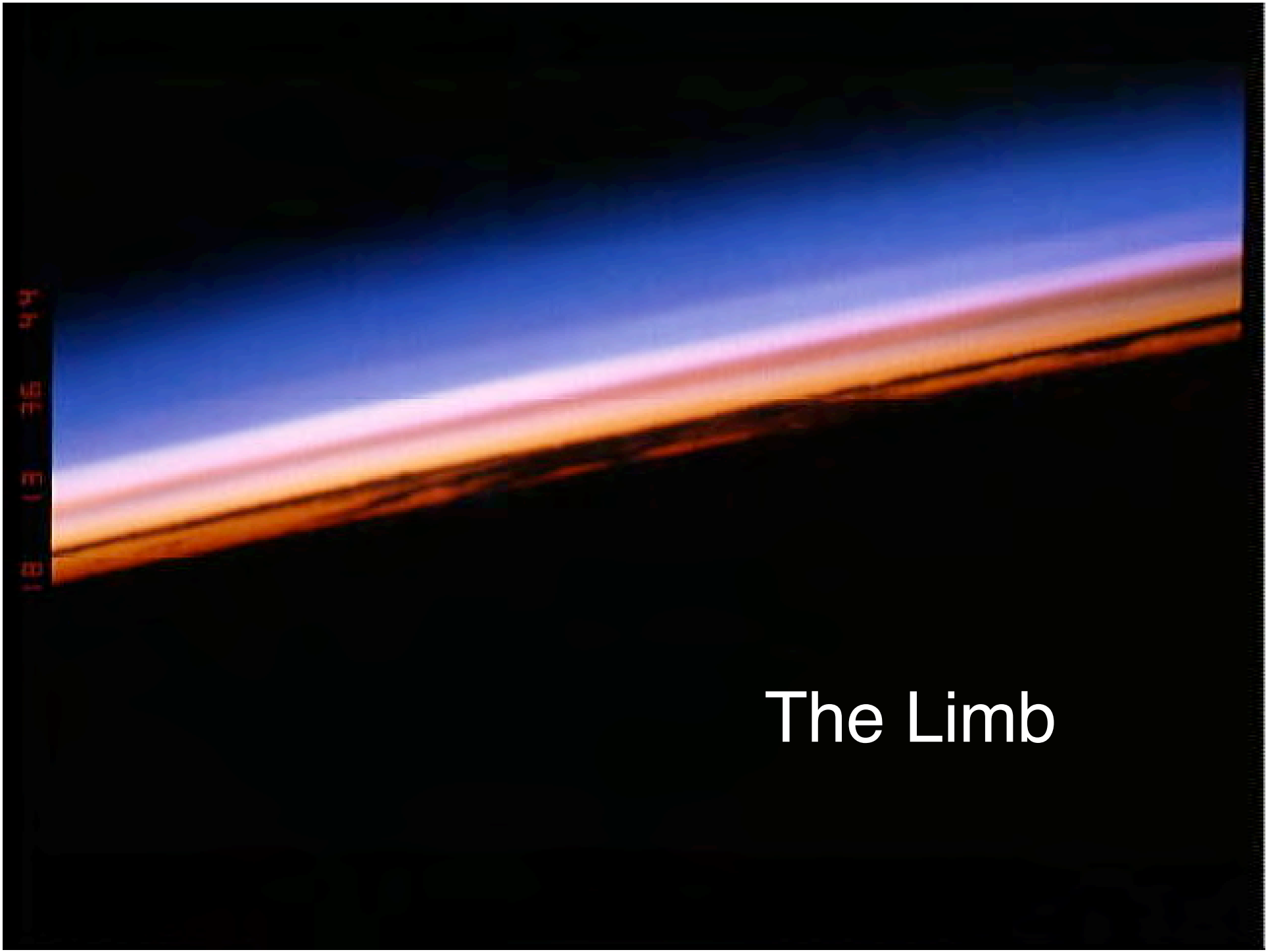
Special Guest
Piers Sellers, Astronaut
NASA's Johnson Space Center

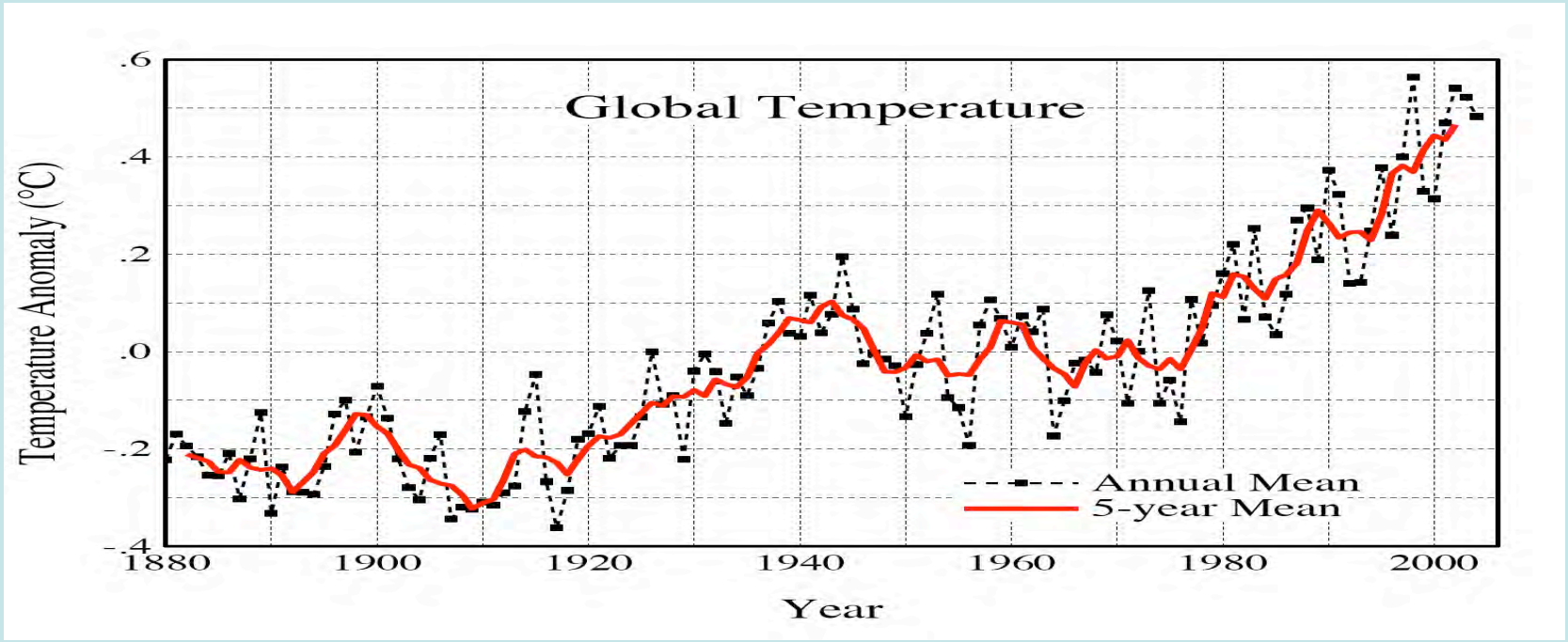
The Earth From Space

Piers Sellers, Ph.D
Astronaut
NASA's Johnson Space Center

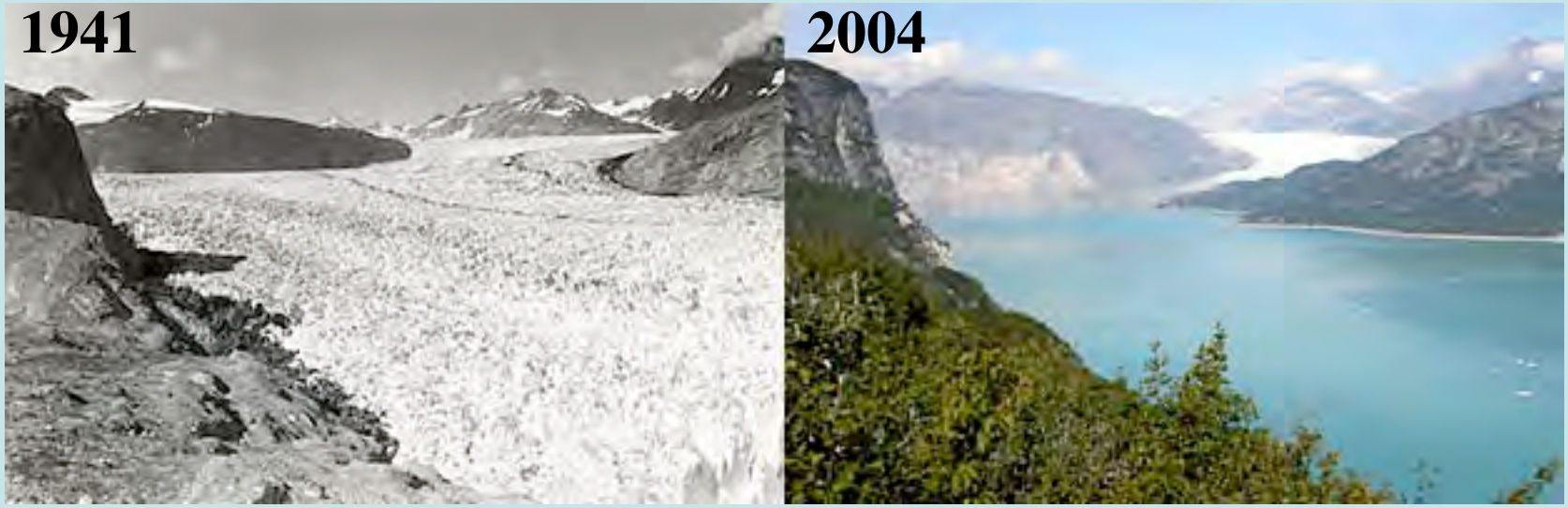

The International
Space Station

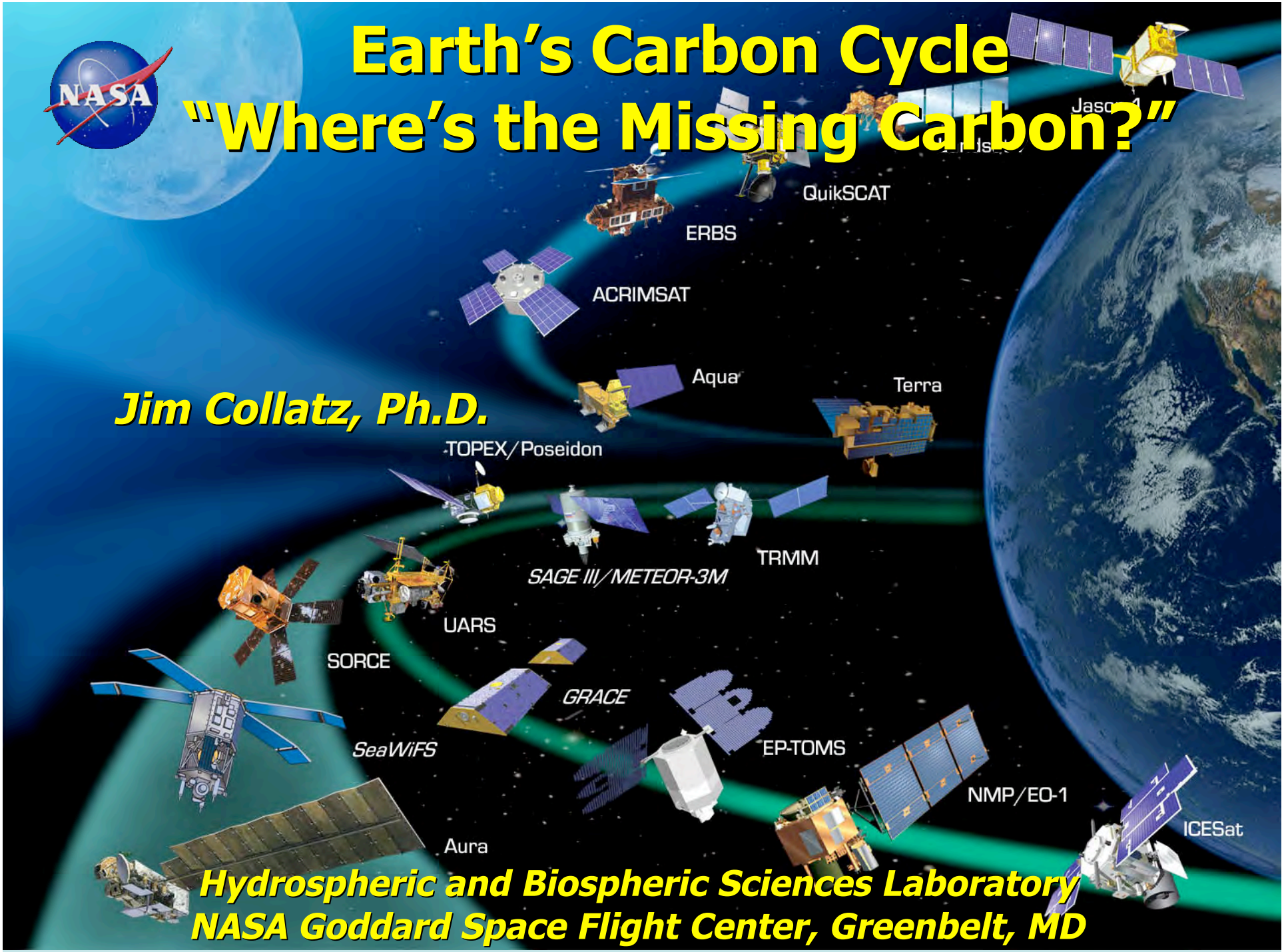
S112E05111


The Limb

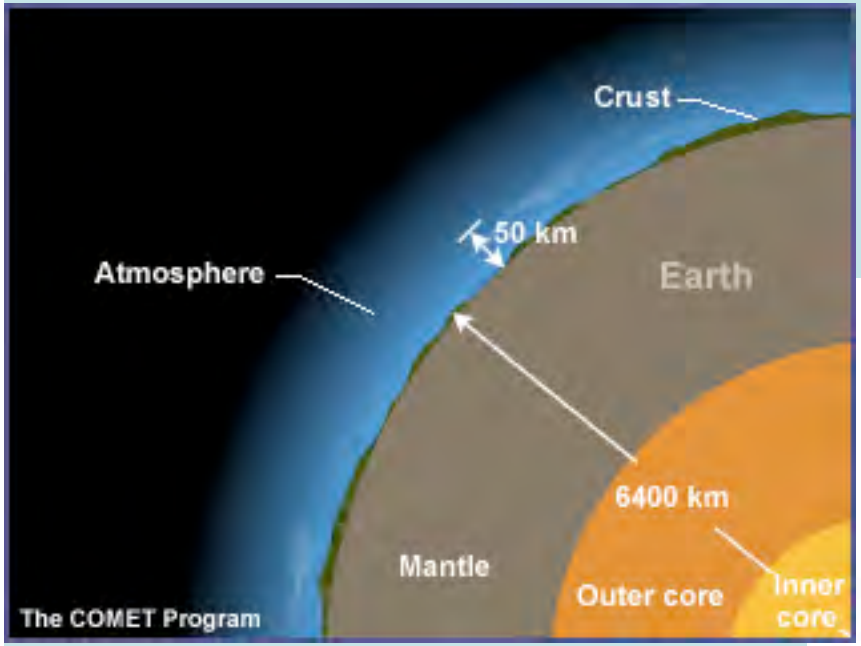


Muir Glacier, Alaska

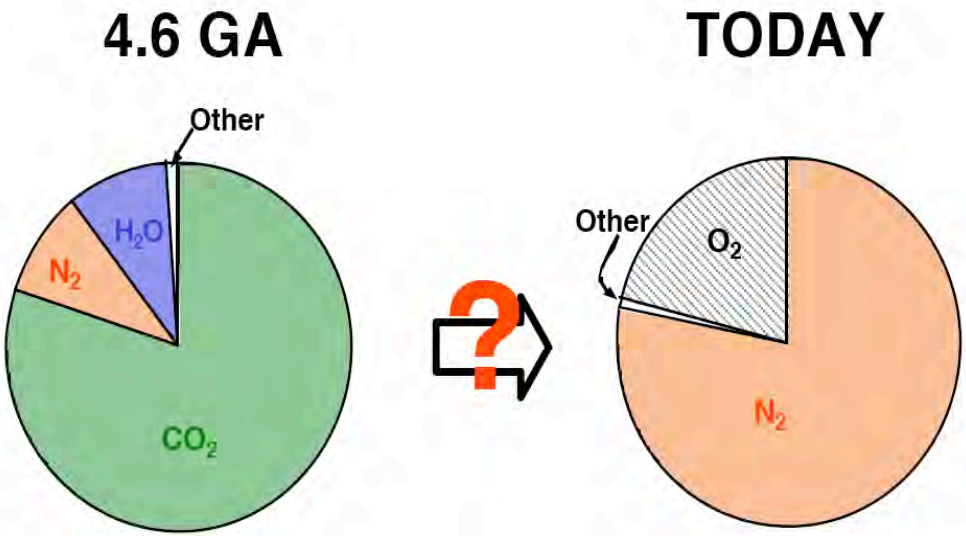



Earth's Carbon Cycle
"Where's the Missing Carbon?"
QuikSCAT
ERBS
ACRIMSAT
Aqua
Terra
Jim Collatz, Ph.D.
TOPEX/Poseidon
TRMM
SAGE III/METEOR-3M
UARS
SORCE
GRACE
SeaWiFS
EP-TOMS
NMP/EO-1
ICESat
Aura
Hydrospheric and Biospheric Sciences Laboratory
NASA Goddard Space Flight Center, Greenbelt, MD

The Earth's Atmosphere

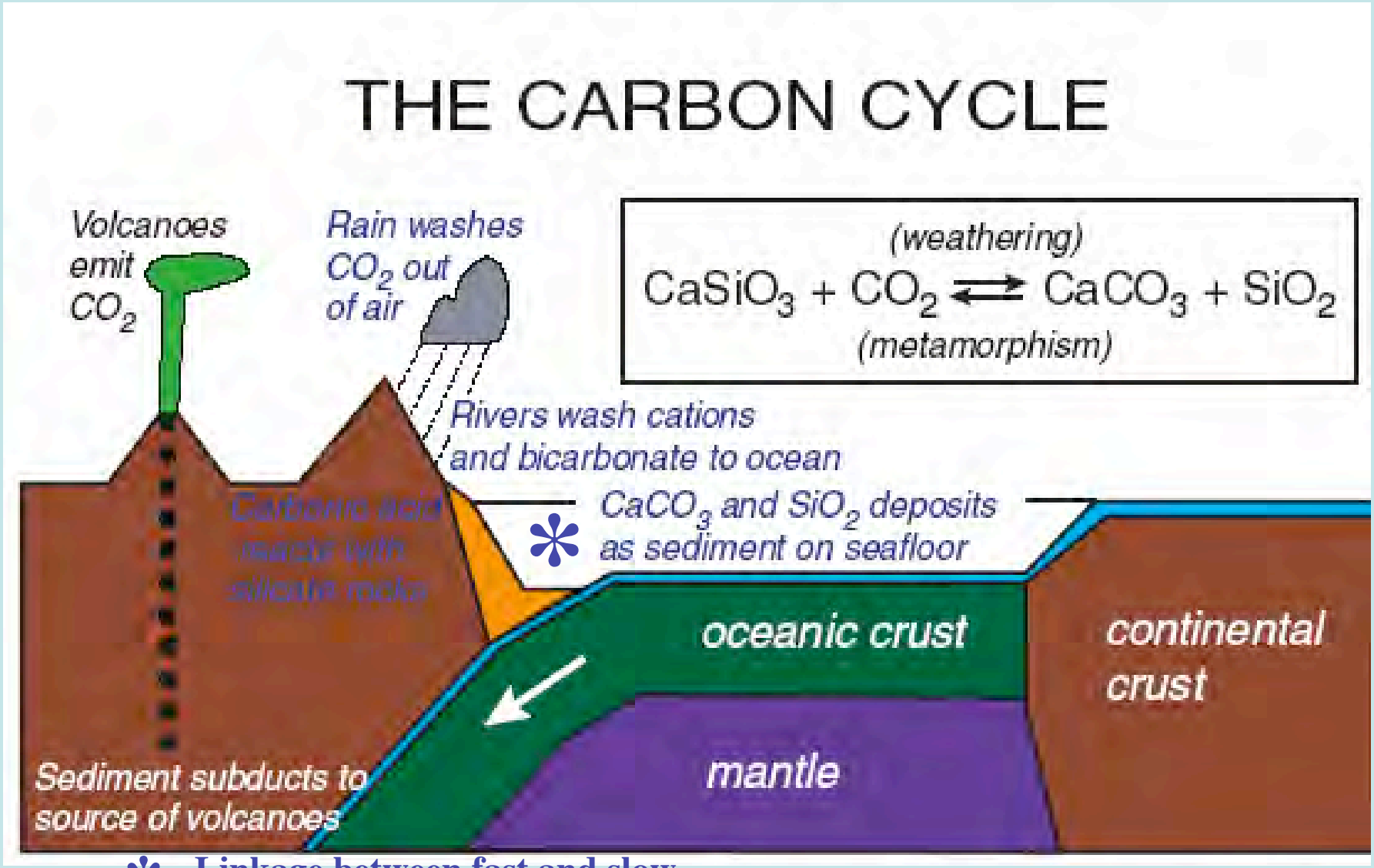


How has its composition changed since its beginnings?



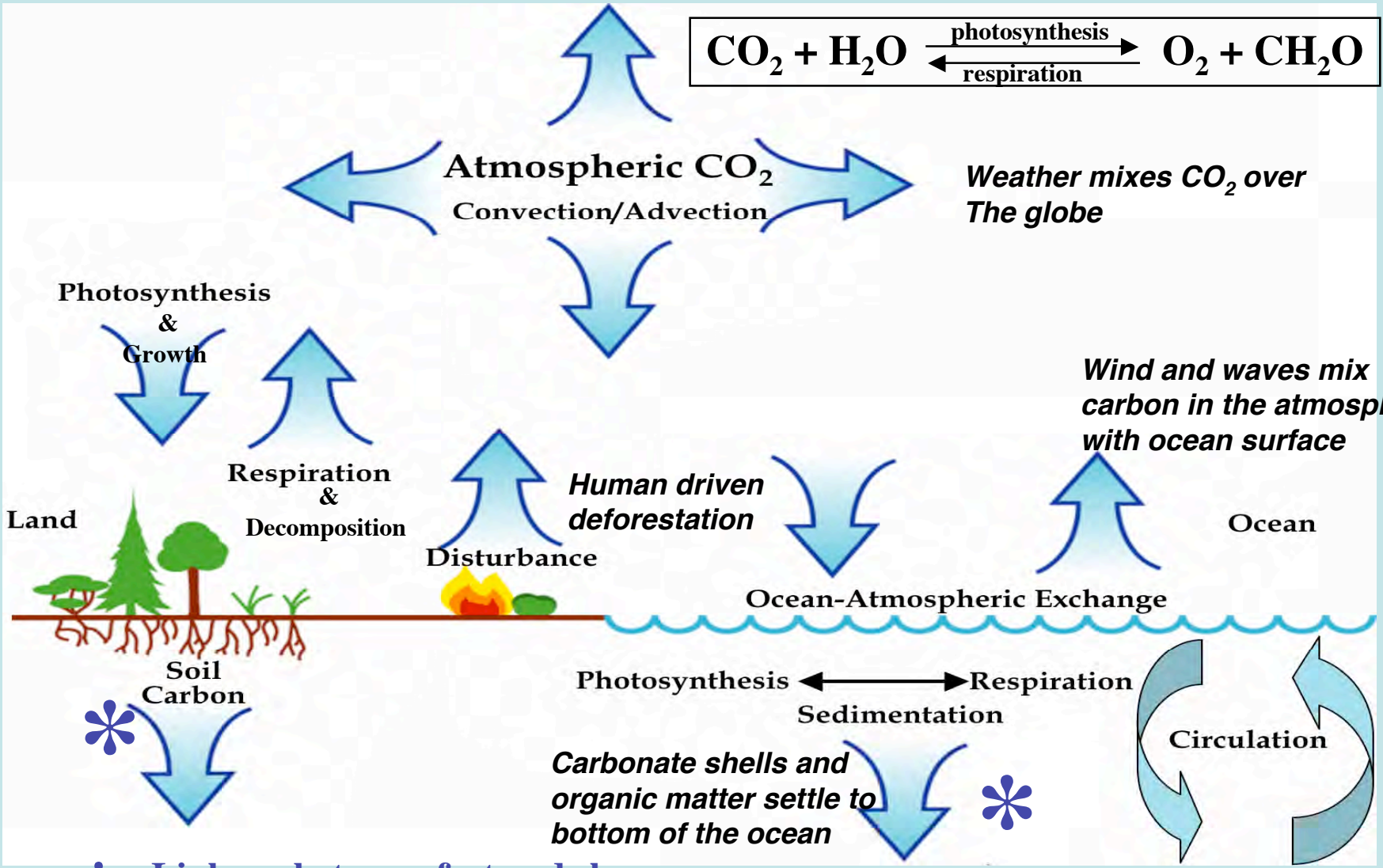
Pressure	**10 atm**		**1 atm**
N_2	**20%**		**79%**
CO_2	**80%**	**"missing carbon"**	**0.04%**
O_2	**0%**		**21%**

The Geologic Carbon Cycle (Slow ~10^{13}-10^{14} gC/yr)



✻ **Linkage between fast and slow processes**

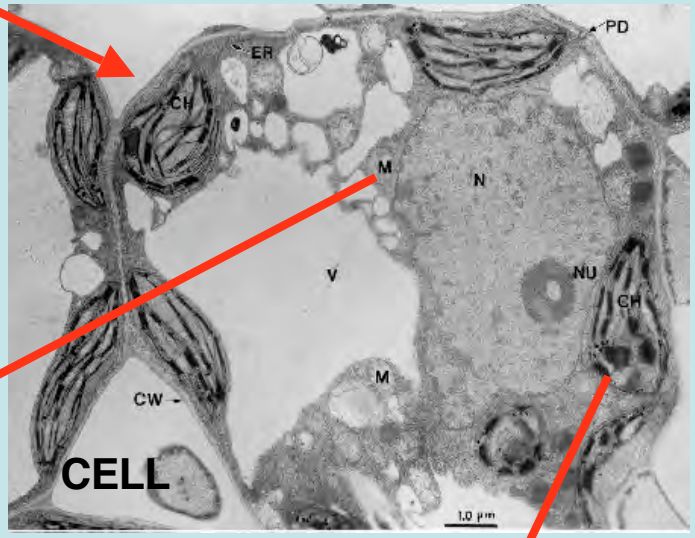
The Fast Part of the Carbon Cycle (~10^{15}-10^{17} gC/yr)



* Linkage between fast and slow processes

The Biologic Carbon Cycle

$$CO_2 + H_2O \underset{\text{respiration}}{\overset{\text{photosynthesis}}{\rightleftharpoons}} O_2 + CH_2O$$



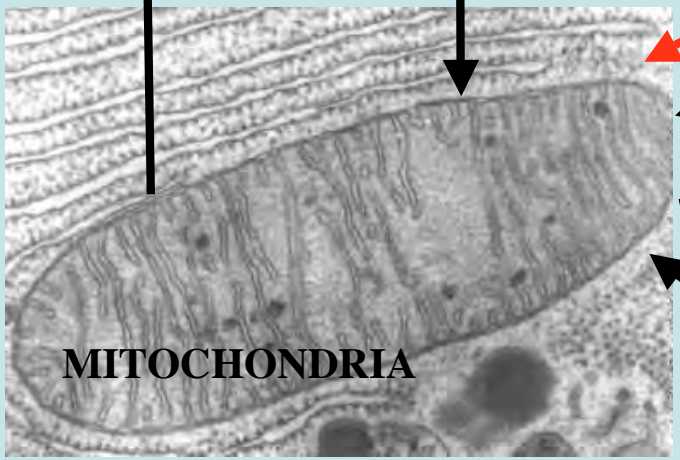
Chemical Energy (ATP)

Sun Light

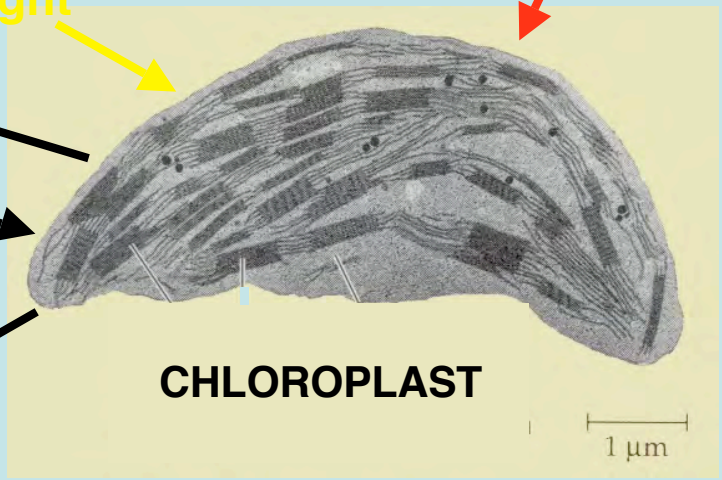
O_2

CO_2

Atmosphere



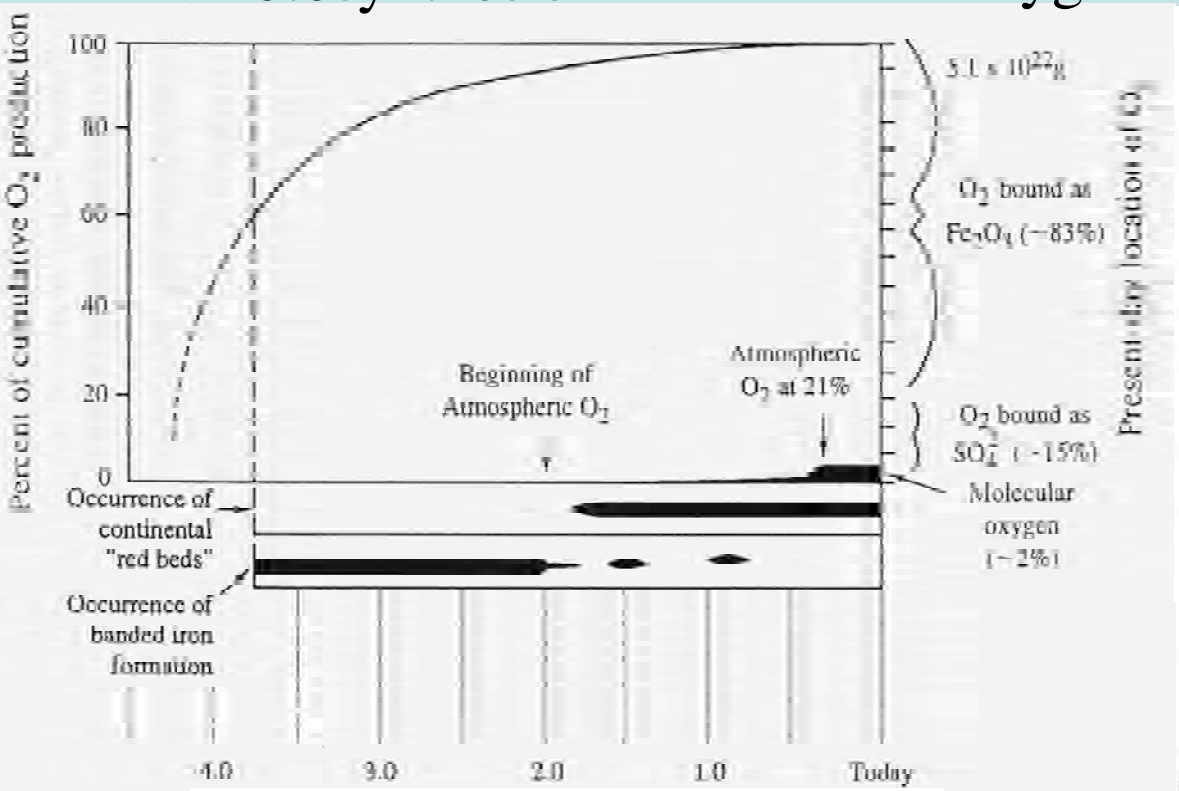
Sugars



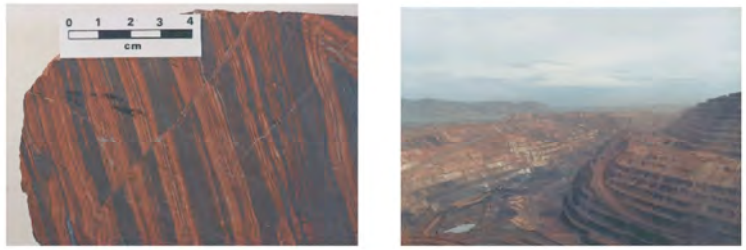
Evolution of Life Altered the Earth's Atmospheric and Geologic Composition

Life on Land

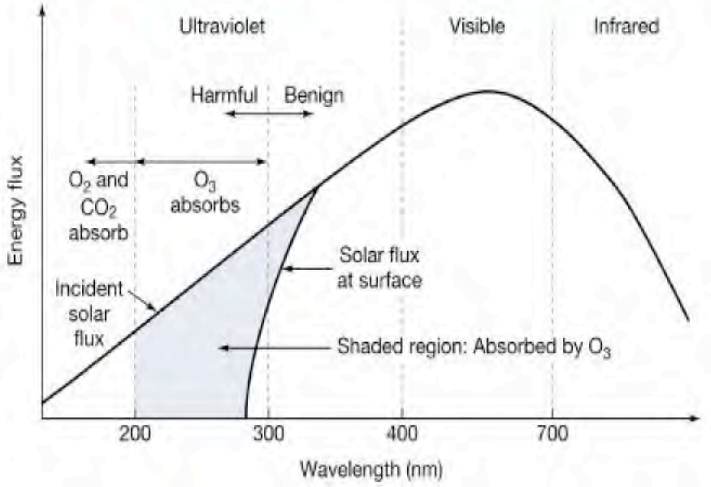
Photosynthesis → Oxygen → Ozone

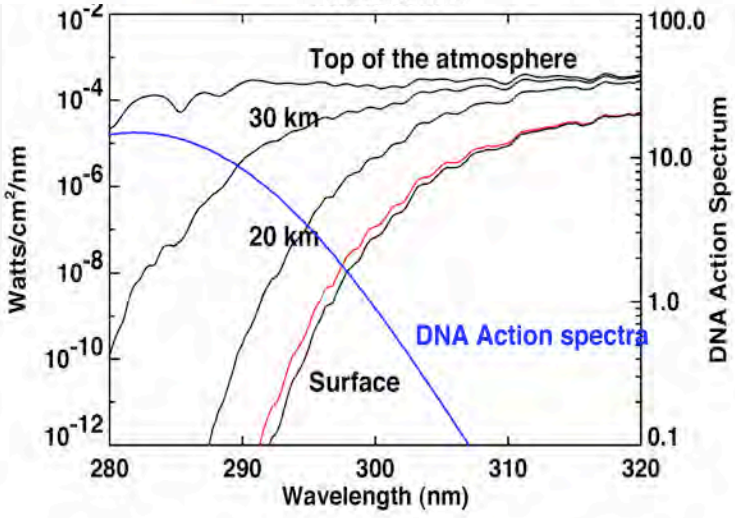


Banded Iron Formations

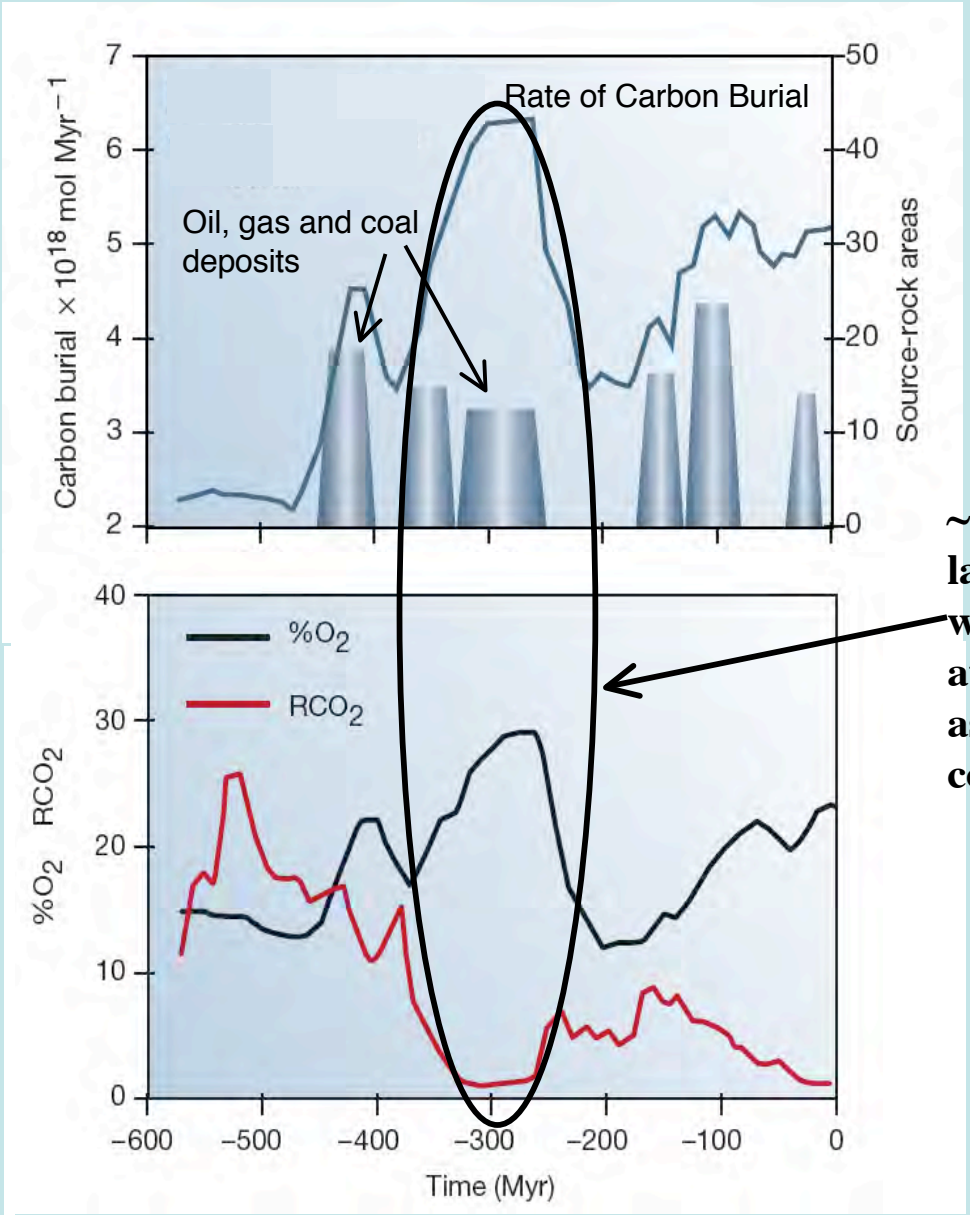


Ozone and UV Radiation





Impacts of Biology on Atmospheric Composition Over the Last 600 Million years (missing carbon during ancient times)



~ 300 million years ago large amounts of carbon were removed from the atmosphere and stored as coal causing the oxygen concentration to go up

Note: current fossil fuel burning rate is ~6x10^{20} mol Myr^{-1}

From: Berner, Nature, 2003

Carbon in the Earth System:

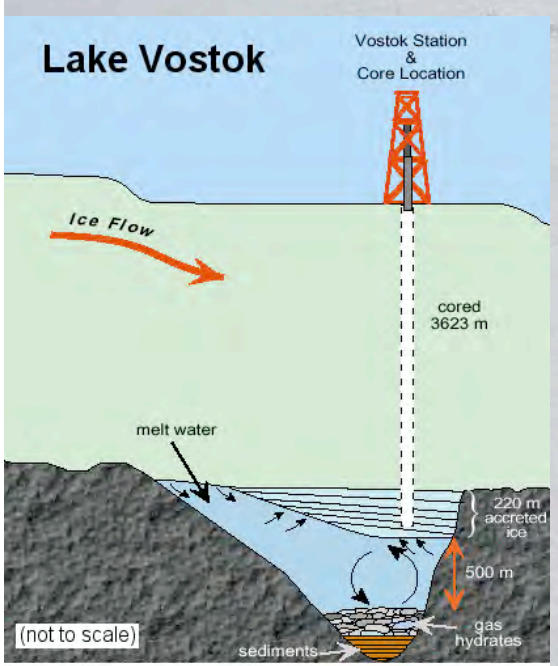
Total Carbon on Earth ~10^{23} grams (a million trillion tons)
80% Carbonates (e.g. limestone),
20% Organic (e.g. fossil fuels, biomass)
0.04% in active pools (Ocean, Soil, Biomass, Atmosphere)

Carbon Cycle: Other Interesting Facts

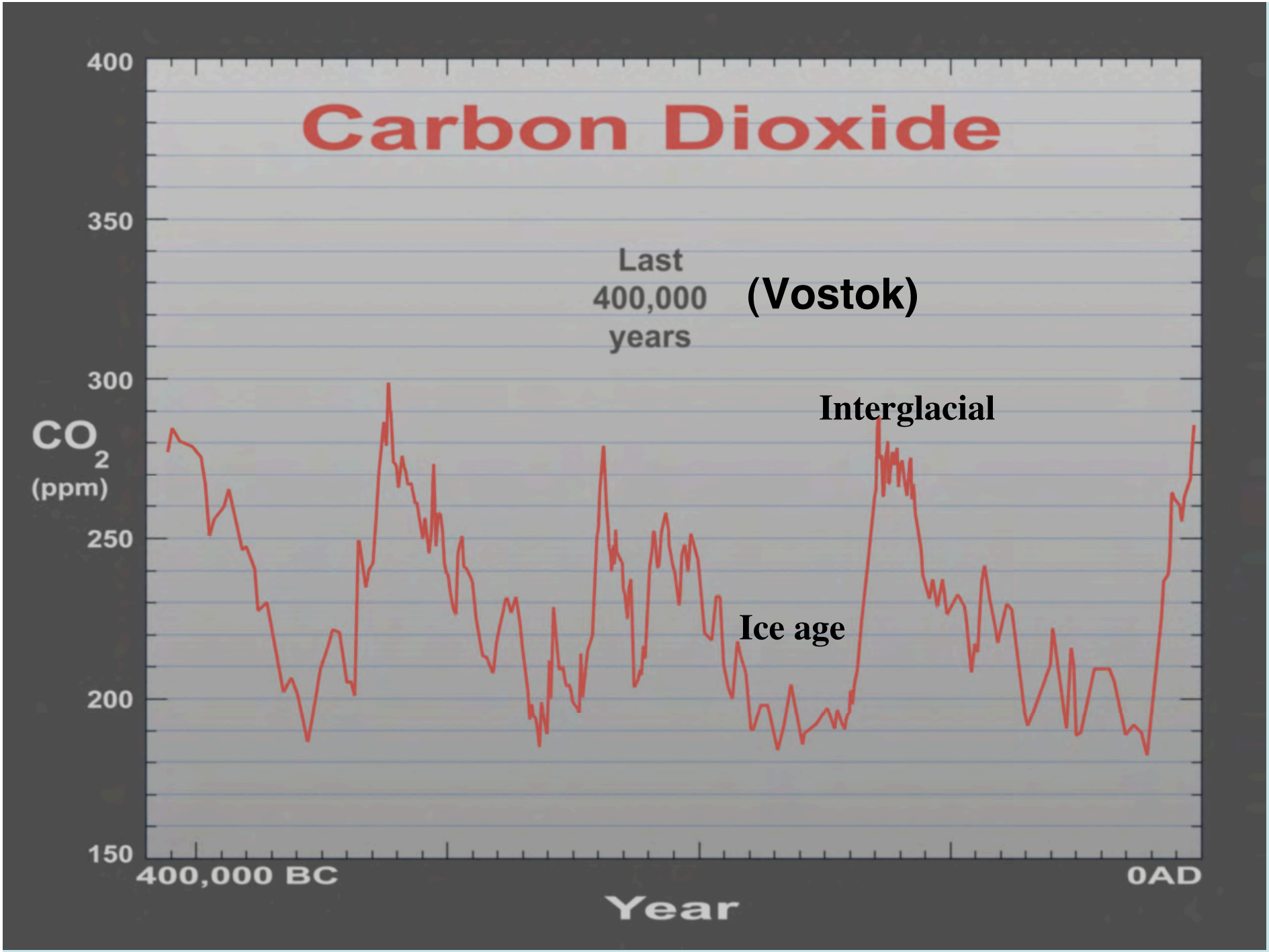
Geologic Fluxes of Carbon are ~ 10^{13}-10^{14} gC/yr
Active pool fluxes are ~10^{15}-10^{17} gC/yr

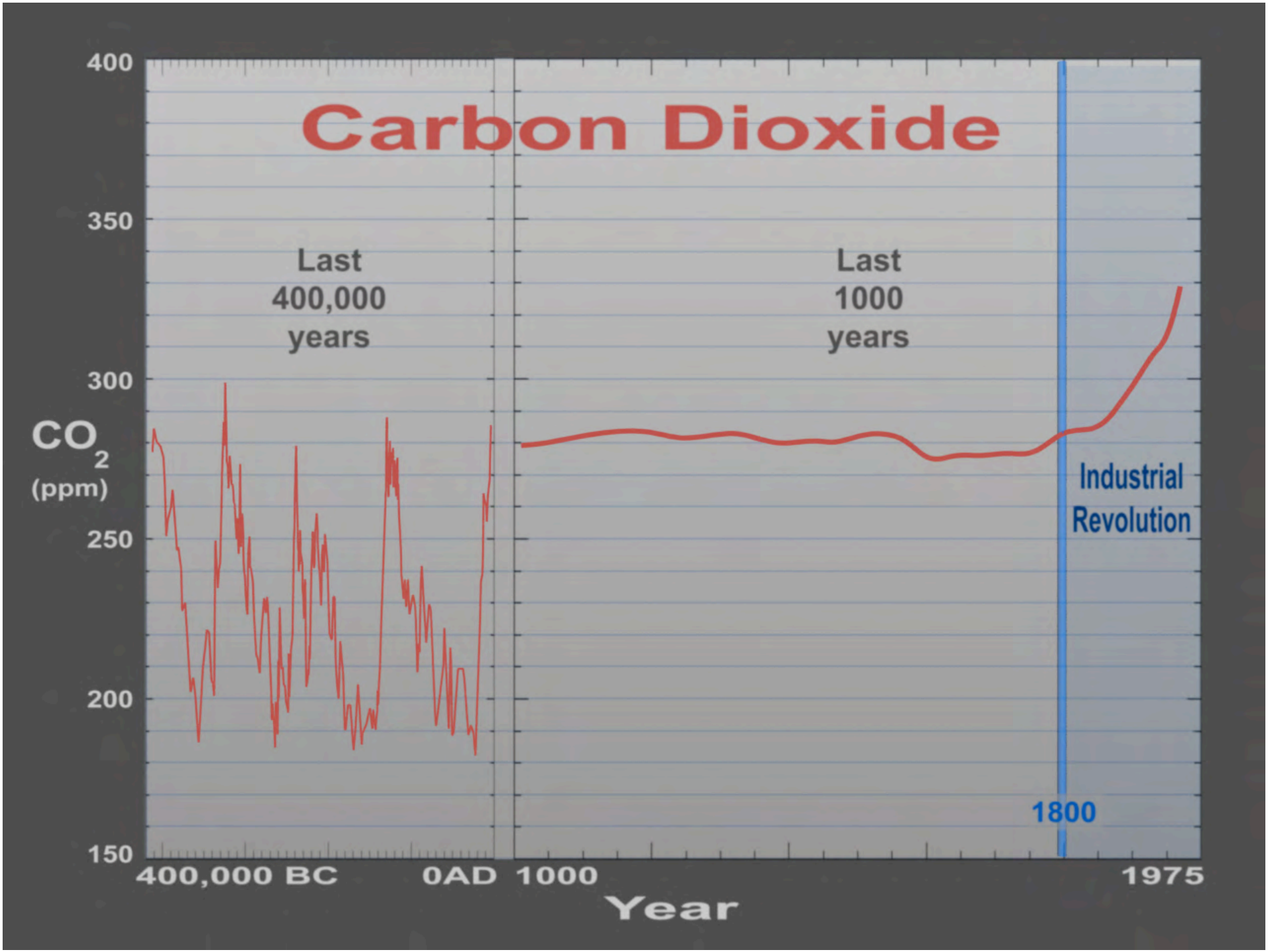
We currently burn fossil fuels at ~70 x the current burial rate.

DOME C, Antarctica
Temperature Low= -129°F
Precipitation= 1”/yr

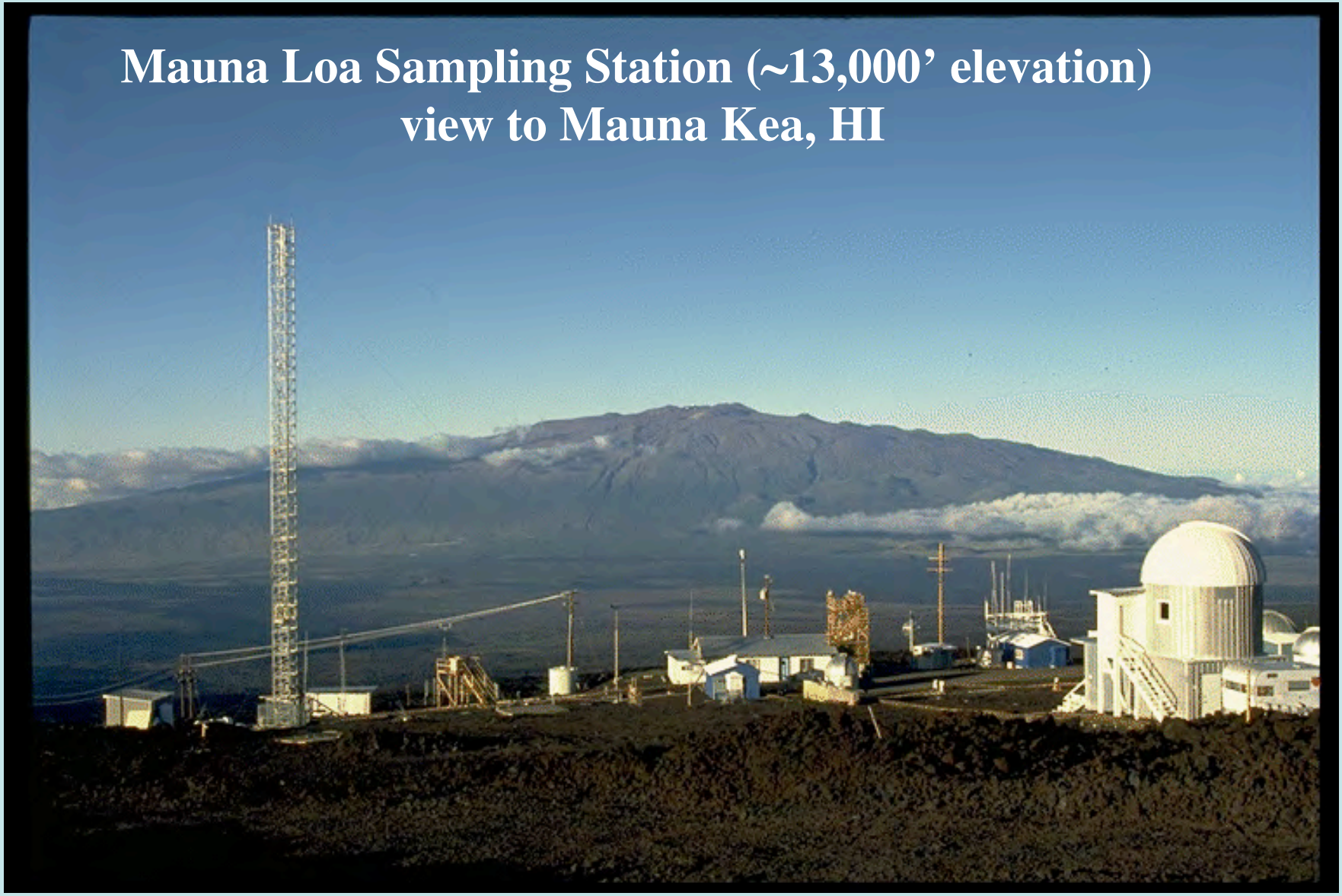


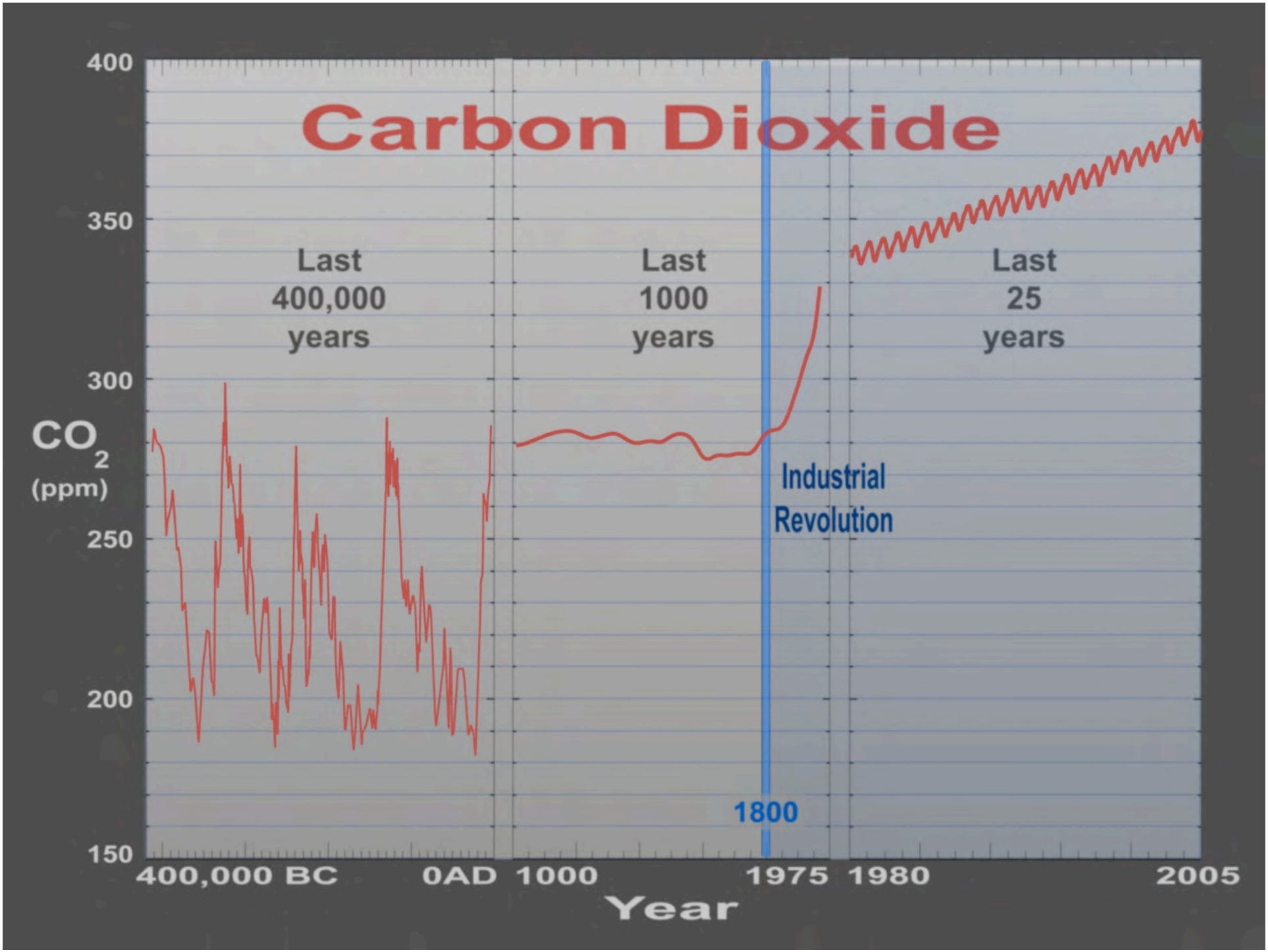
http://www.ldeo.columbia.edu/vostok/Report.pdf


Carbon Dioxide
400
350
300
250
200
150
CO_2
(ppm)
Last
400,000
years
(Vostok)
Interglacial
Ice age
400,000 BC
0AD
Year

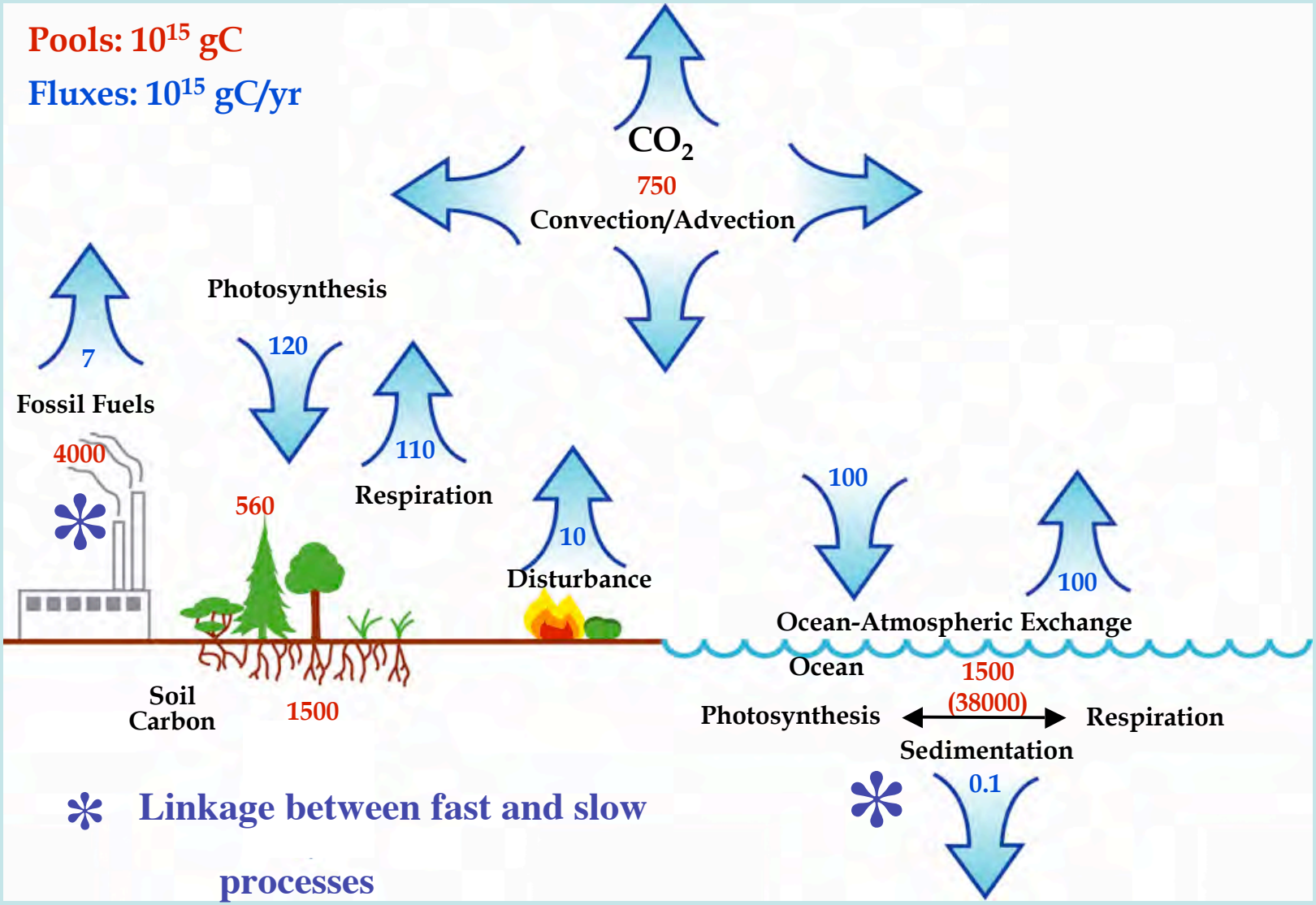

Carbon Dioxide
Last 400,000 years
Last 1000 years
Industrial Revolution
1800
400
350
300
250
200
150
CO2 (ppm)
400,000 BC
0AD
1000
1975
Year

Mauna Loa Sampling Station (~13,000’ elevation)
view to Mauna Kea, HI

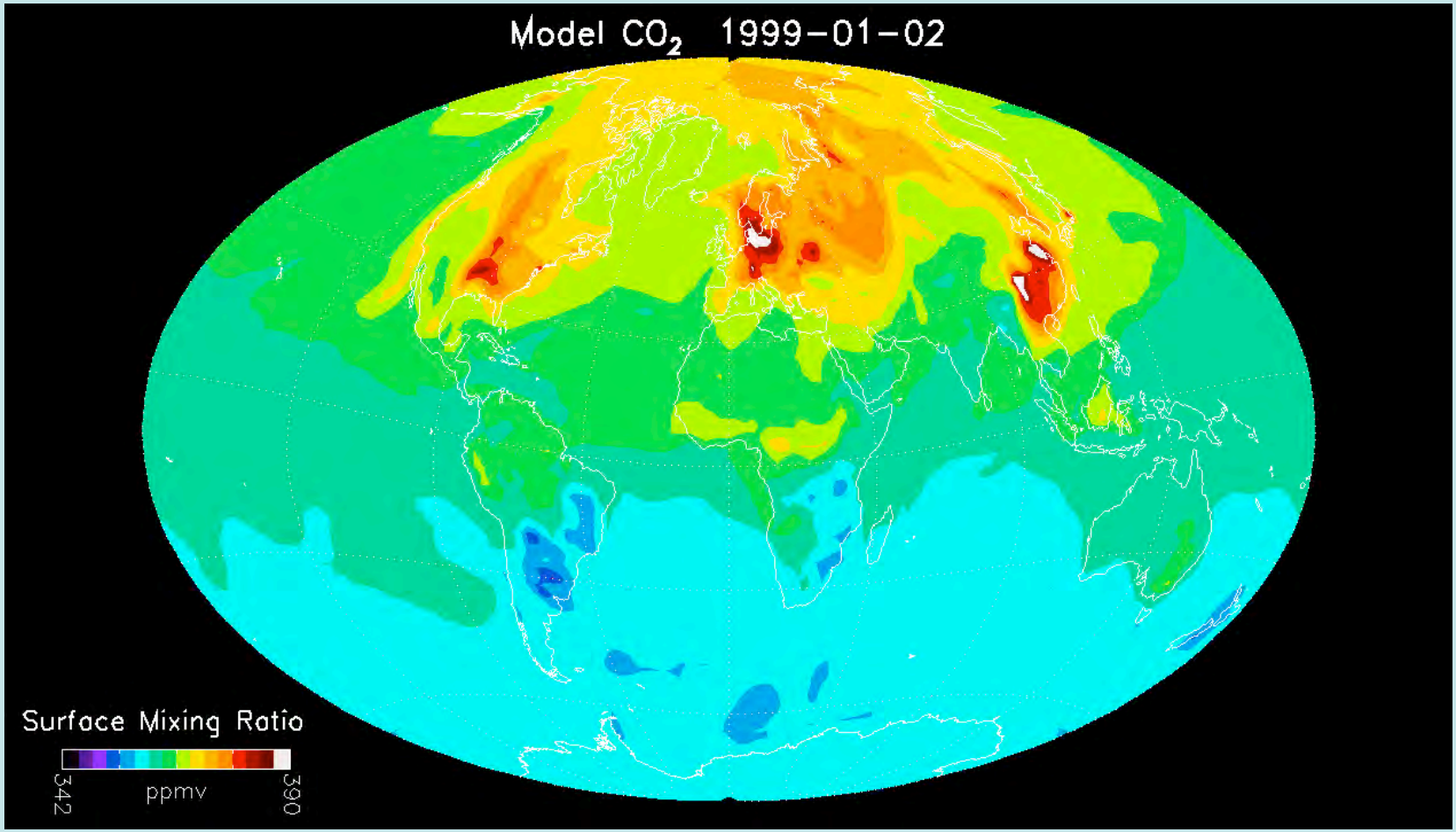



Carbon Dioxide
400
350
300
250
200
150
CO2
(ppm)
Last
400,000
years
Last
1000
years
Last
25
years
Industrial
Revolution
1800
400,000 BC
0AD
1000
1975
1980
2005
Year

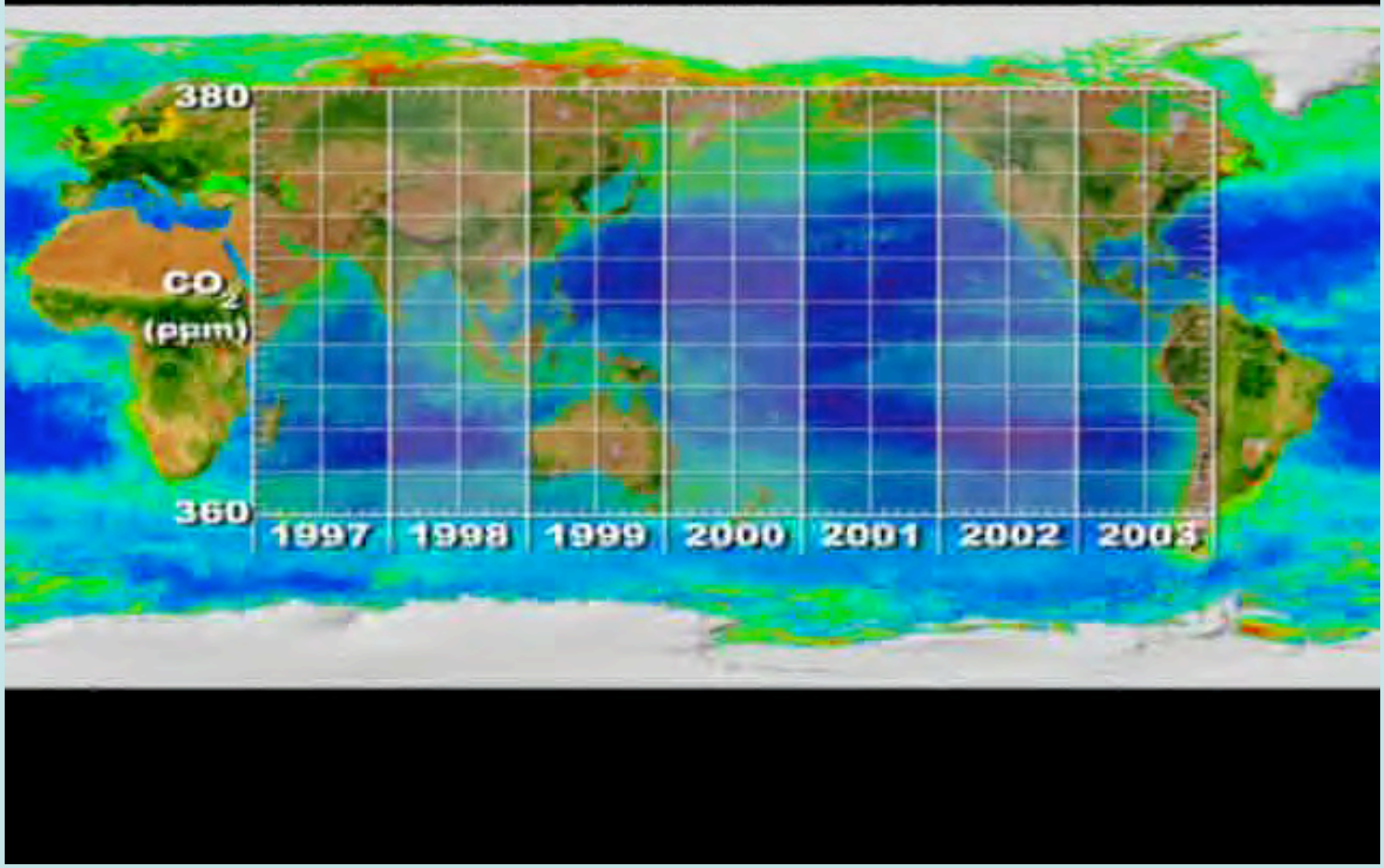
Global Carbon Cycle: The Present

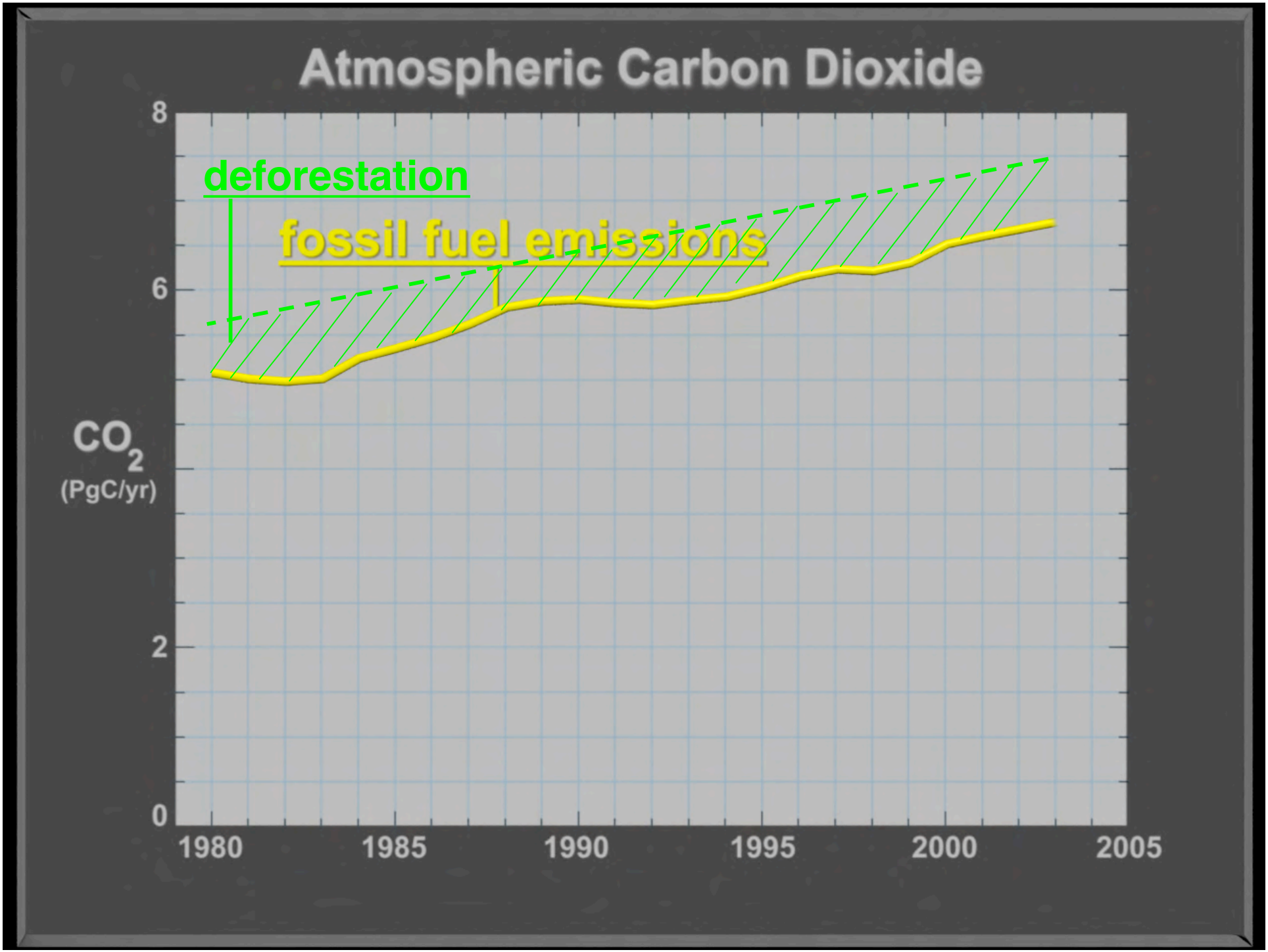


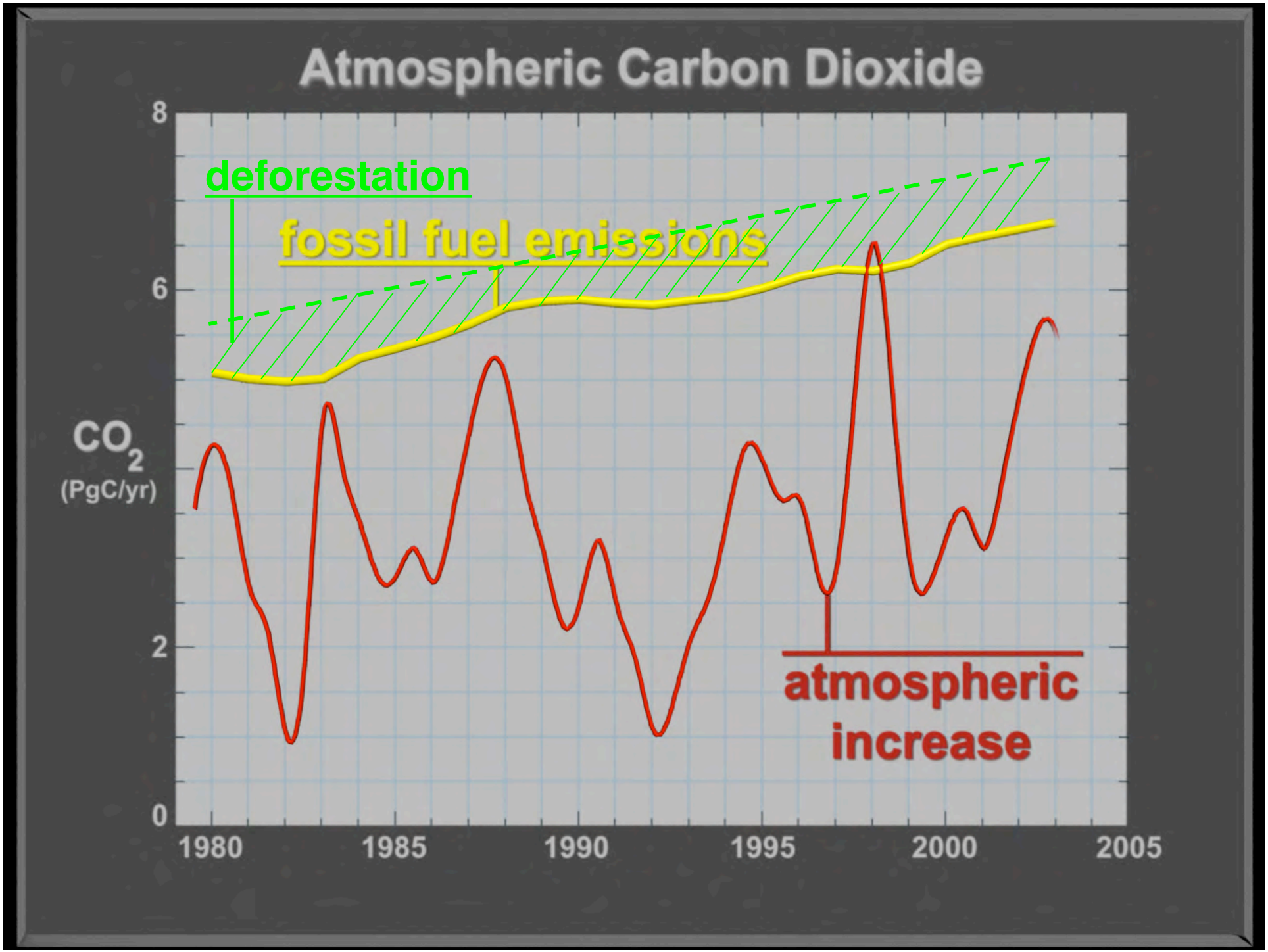
Annual Cycle in Atmospheric CO_2 Concentrations

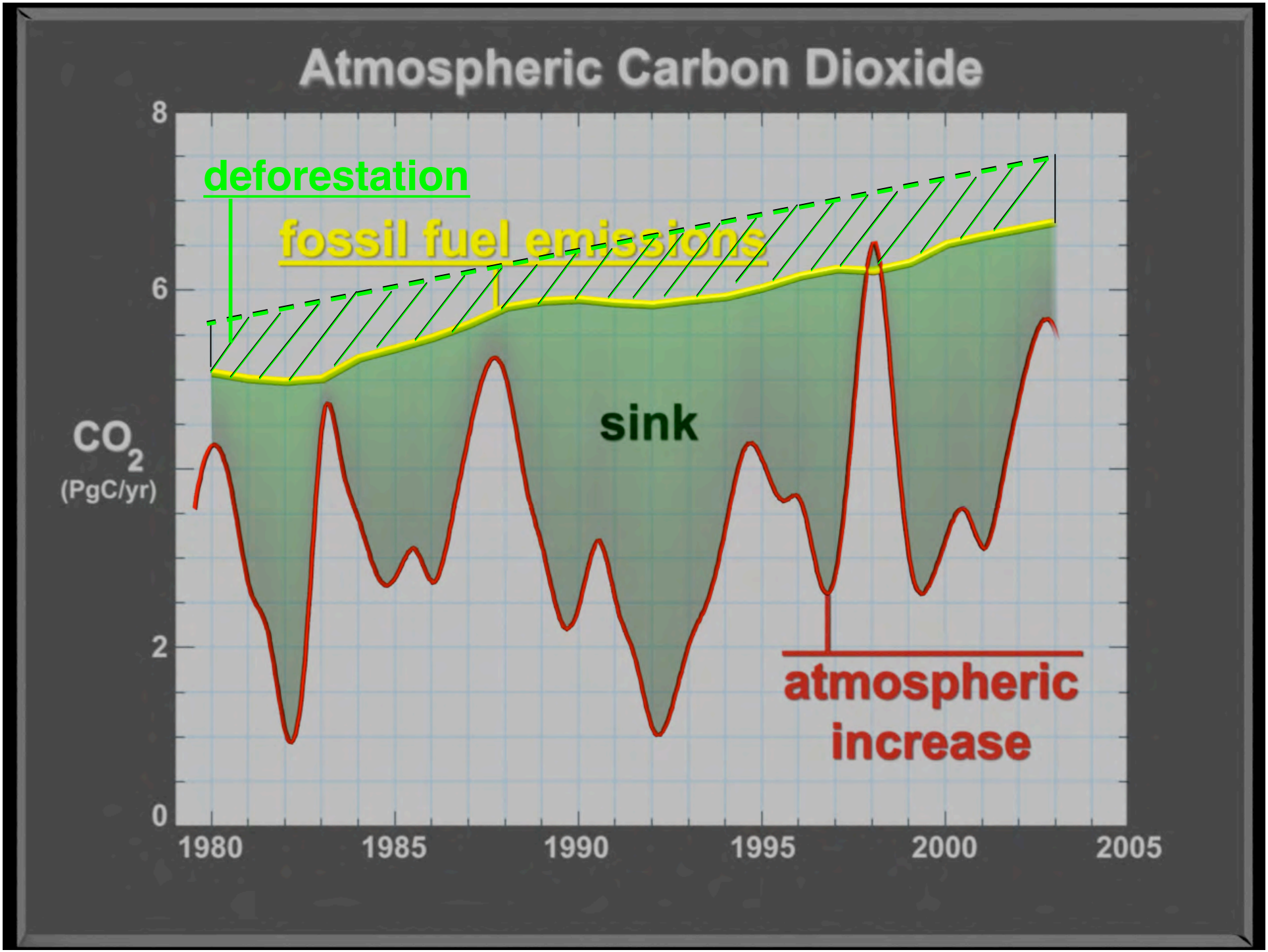


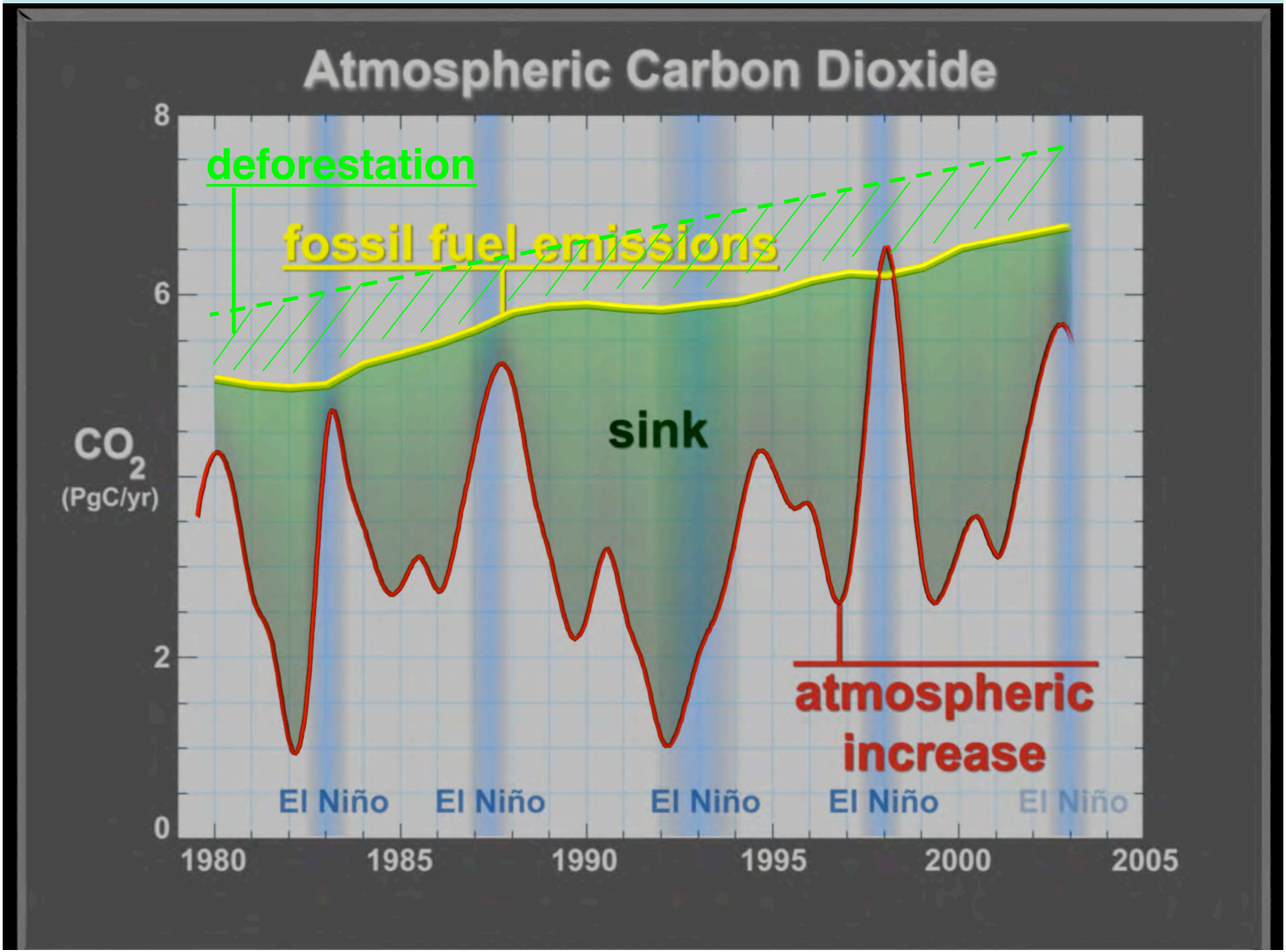
Seasonal Cycles in CO_2 and Vegetation



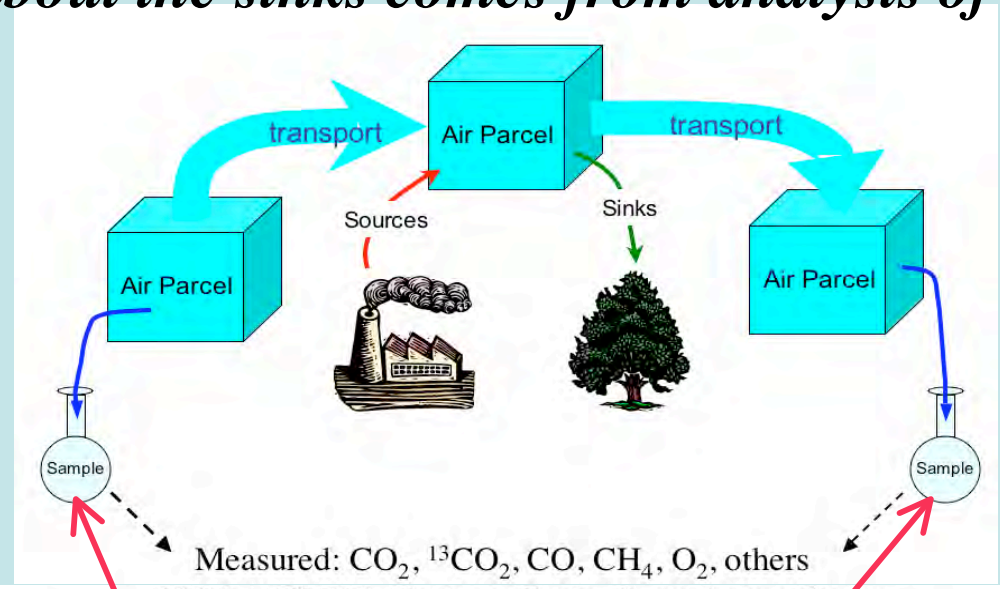

Atmospheric Carbon Dioxide
deforestation
fossil fuel emissions
CO_2
(PgC/yr)
8
6
2
0
1980
1985
1990
1995
2000
2005

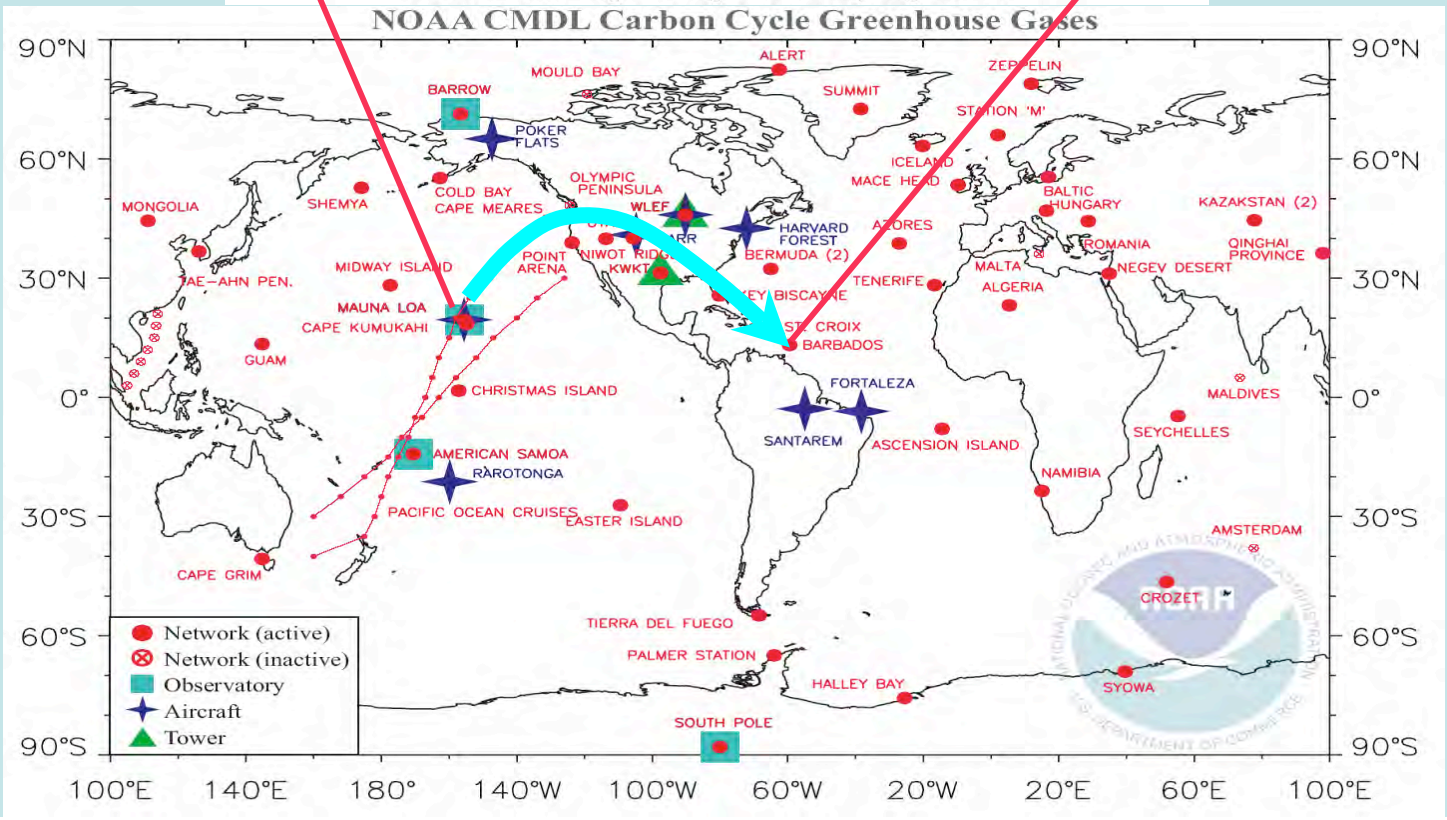

Atmospheric Carbon Dioxide
deforestation
fossil fuel emissions
atmospheric increase
CO_2 (PgC/yr)
8
6
2
0
1980
1985
1990
1995
2000
2005


Atmospheric Carbon Dioxide
deforestation
fossil fuel emissions
sink
atmospheric increase
CO_2 (PgC/yr)
8
6
2
0
1980
1985
1990
1995
2000
2005


Atmospheric Carbon Dioxide
deforestation
fossil fuel emissions
sink
atmospheric increase
CO_2 (PgC/yr)
8
6
2
0
El Niño
El Niño
El Niño
El Niño
El Niño
1980
1985
1990
1995
2000
2005

What we know about the sinks comes from analysis of atmospheric CO_2

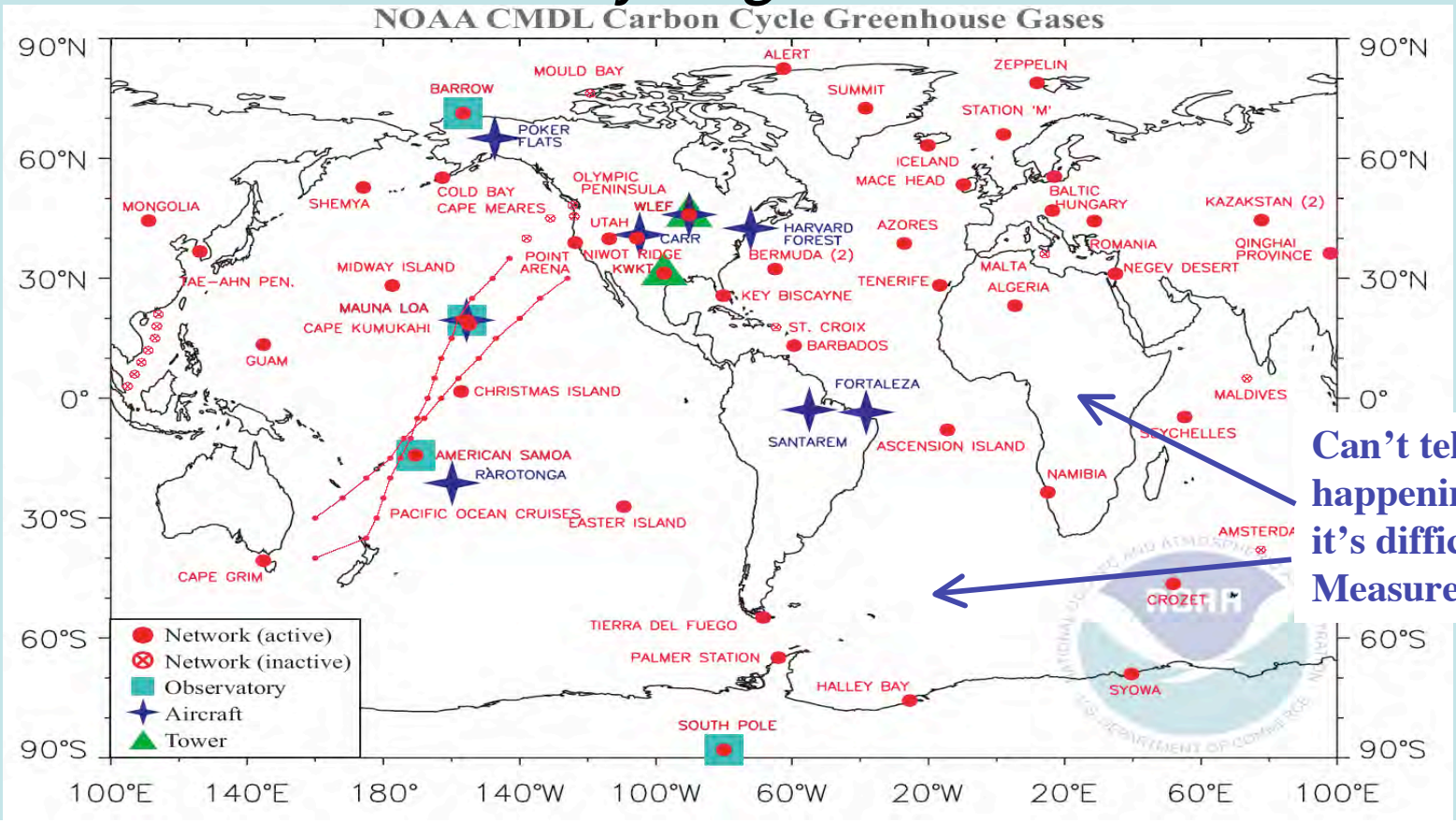




Measurement of Atmospheric CO_2 Concentrations

What we have learned from measuring the changes in atmospheric CO_2

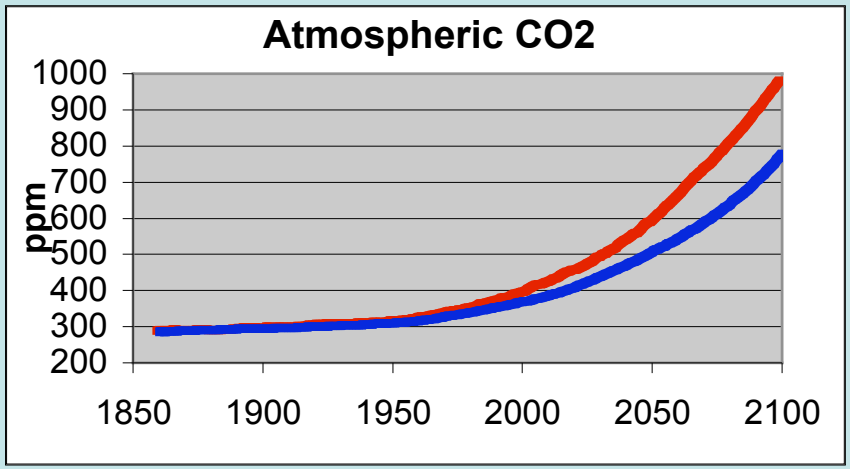
- *Proof that CO_2 is increasing*
- *Breathing Terrestrial Biosphere*
- *Ocean/Land CO_2 sinks (N versus S Hemisphere)*
- *Interannual variability in global sources and sinks*

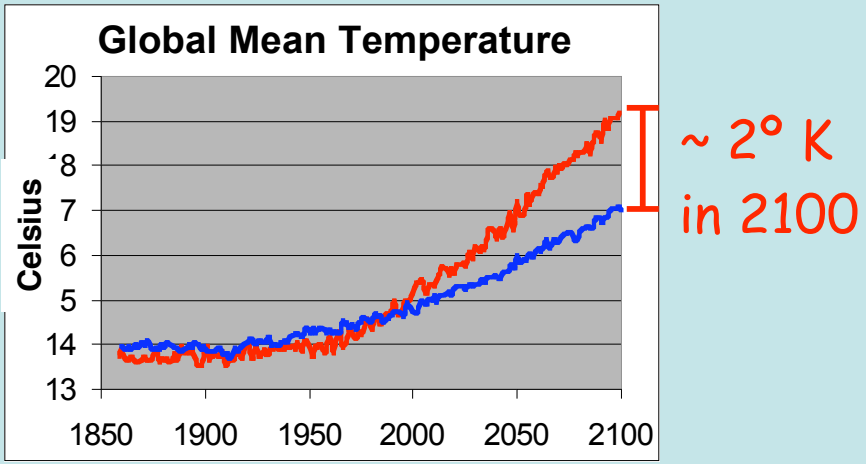


Can't tell what's happening where it's difficult to Measure CO_2

Why must we solve the 'mystery of the missing carbon'?

Simulations of two possibilities for future source/sink behaviors





There are approximately 4000 PgC in fossil fuel reserves or nearly **2000 ppm**

Possibilities for the Future:

sinks could increase in strength, CO_2 max <1400 ppm

sinks could continue at present rates, CO_2 max ~1400 ppm

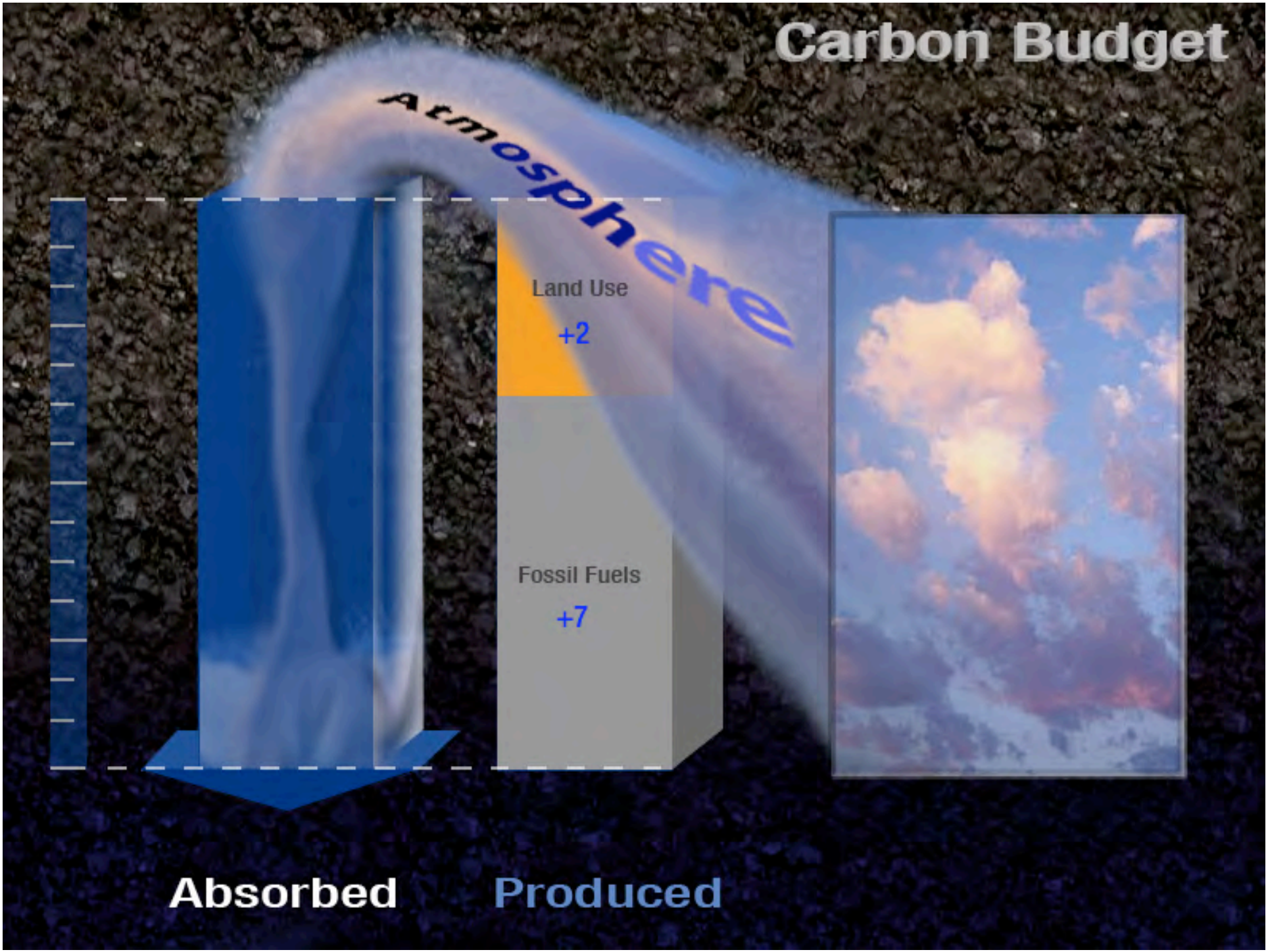
sinks slow, CO_2 max ~1400-2500 ppm

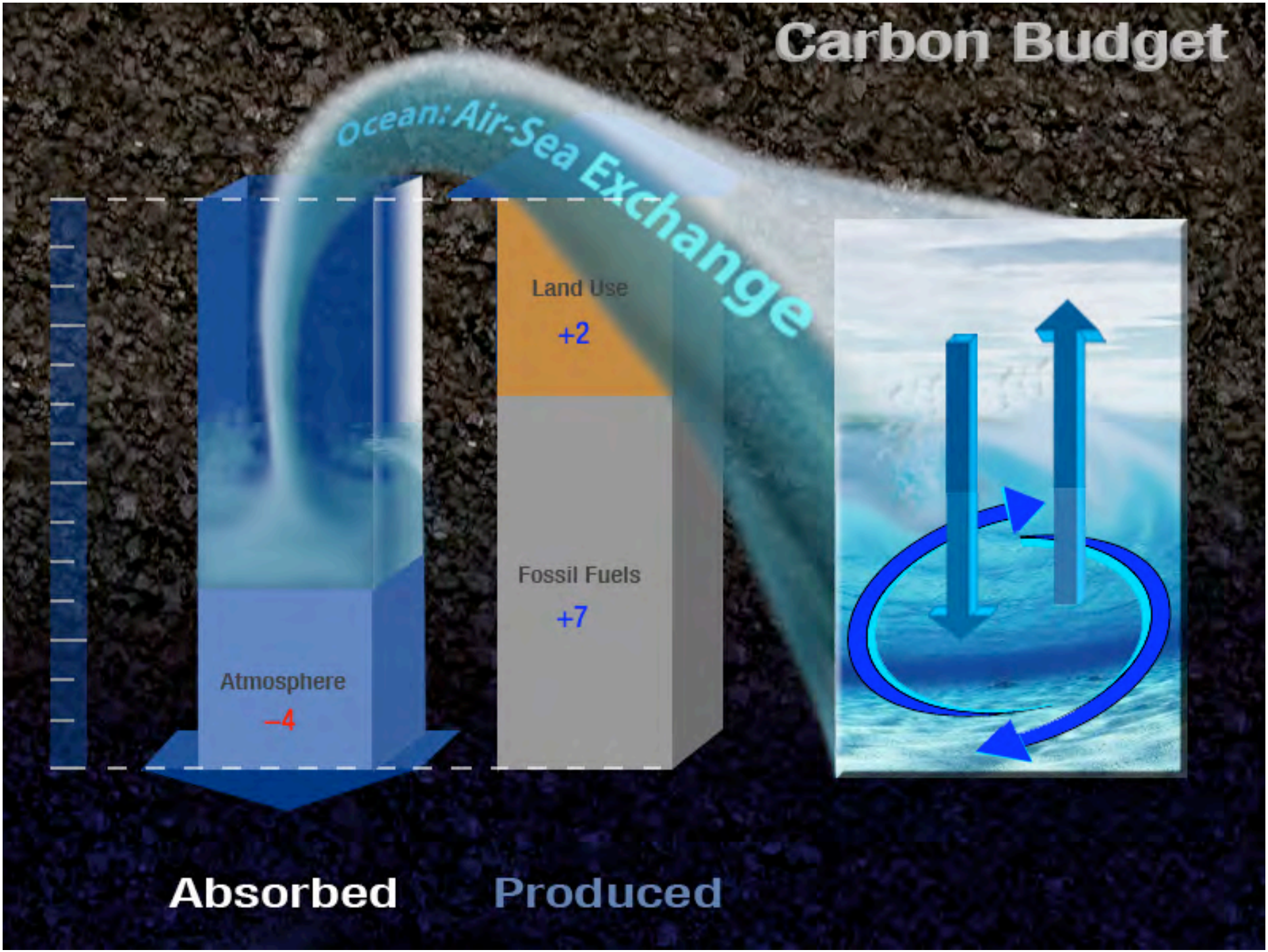
sinks reverse and return previously sequestered carbon, CO_2 max >2500 ppm

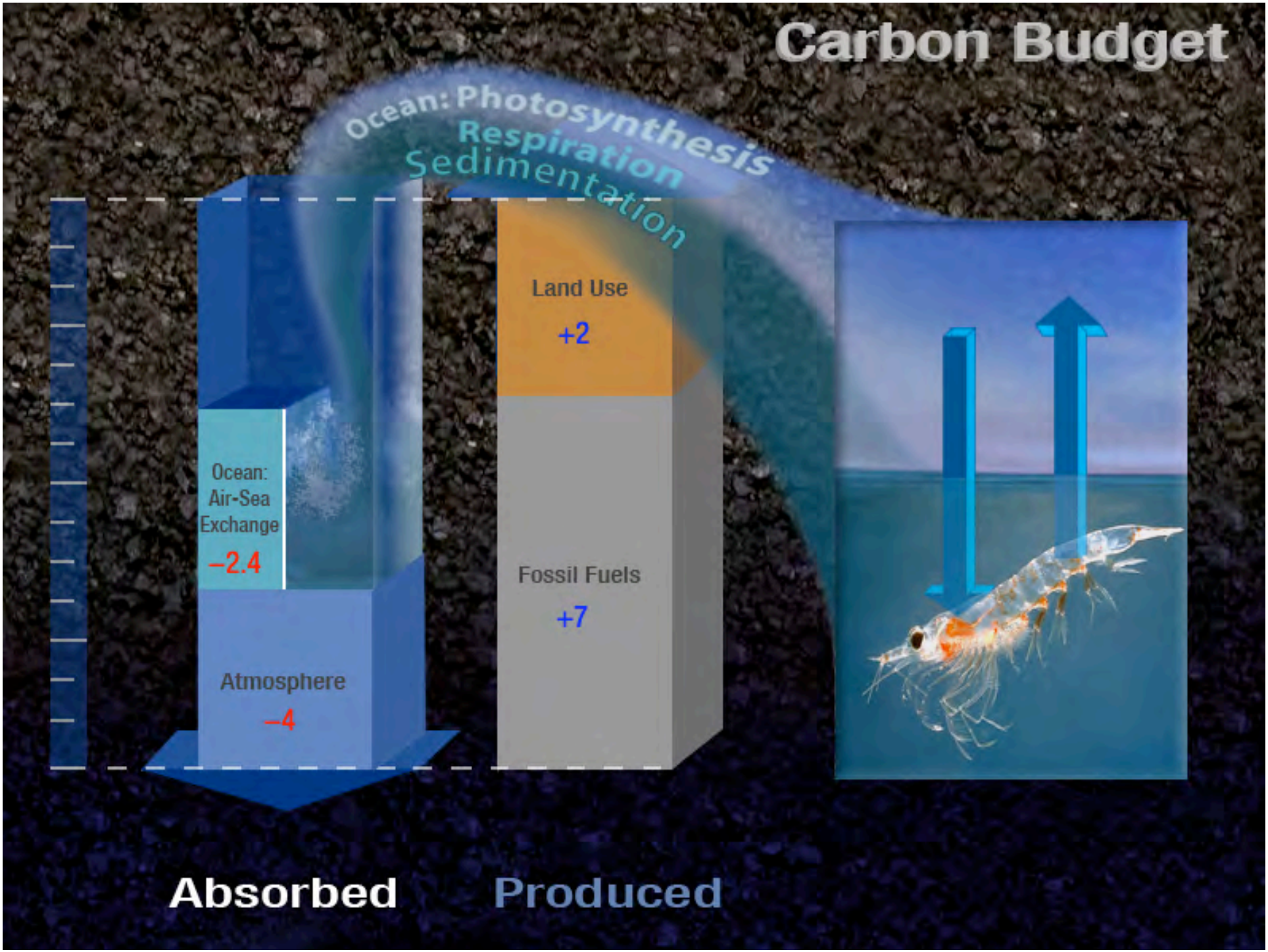
sinks reverse plus release of old carbon from soil and ocean CO_2 max >3000ppm

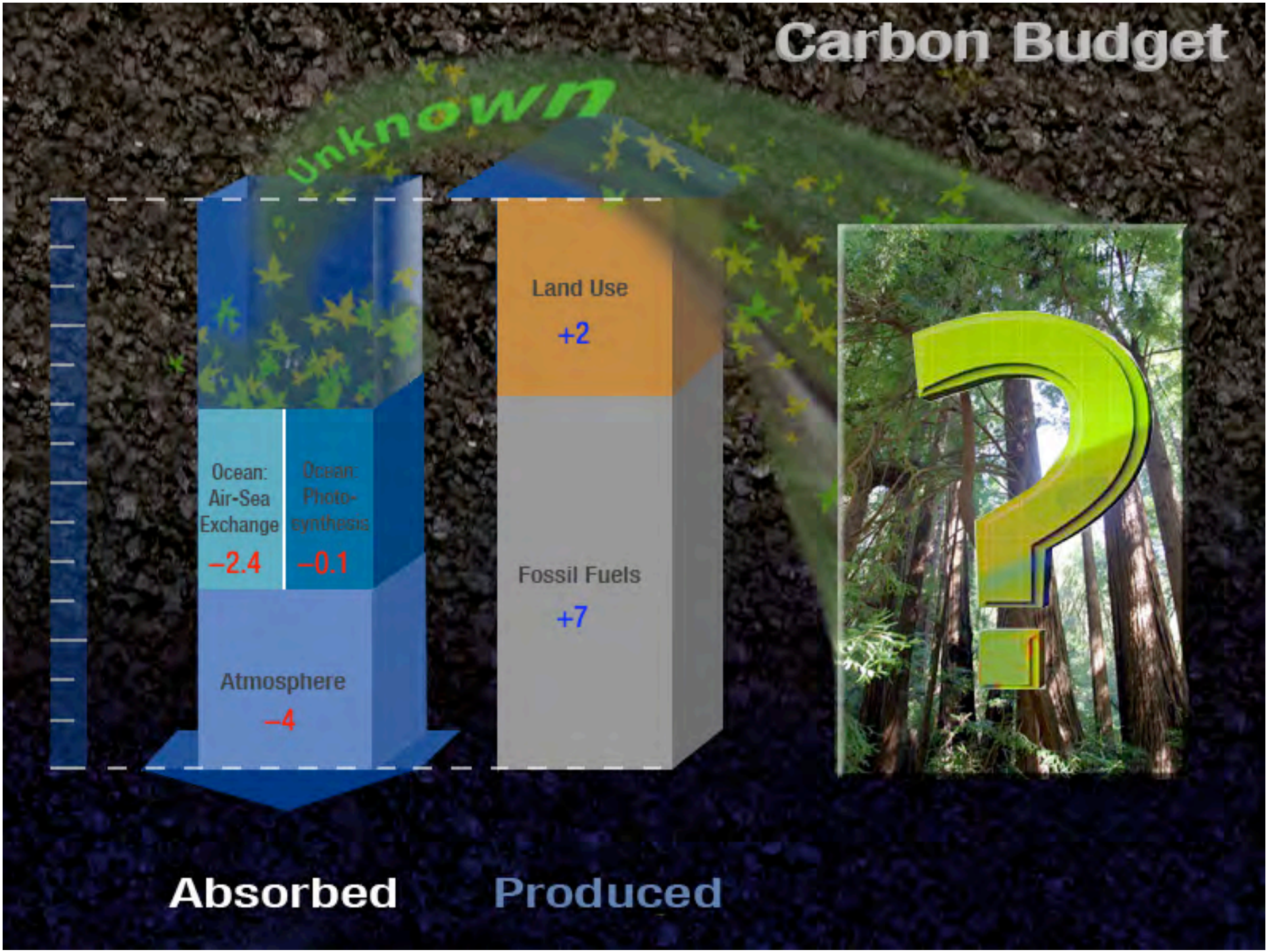

Carbon Budget
Fossil Fuels
Absorbed
Produced

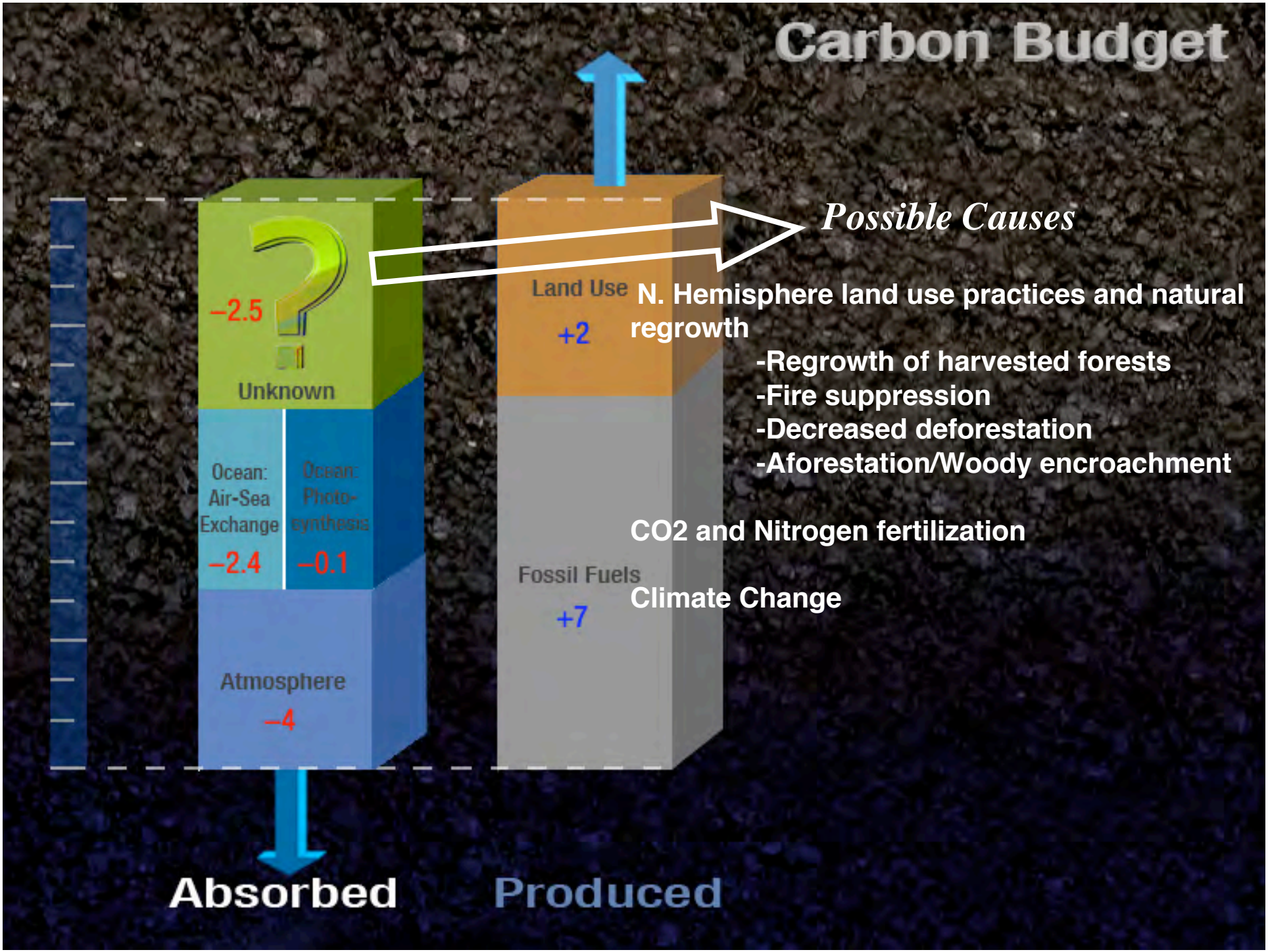

Carbon Budget
Land Use
Fossil Fuels
+7
Absorbed
Produced


Carbon Budget
Atmosphere
Land Use
+2
Fossil Fuels
+7
Absorbed
Produced

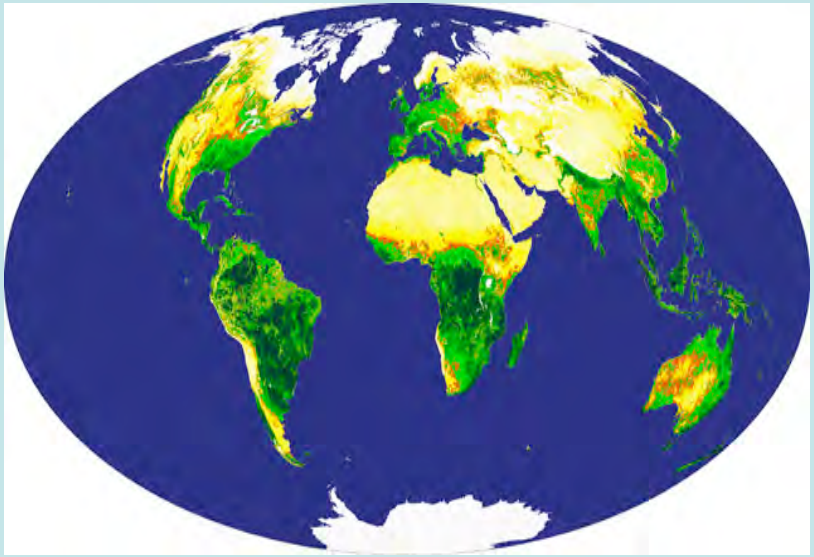

Carbon Budget
Ocean: Air-Sea Exchange
Land Use
+2
Fossil Fuels
+7
Atmosphere
−4
Absorbed
Produced

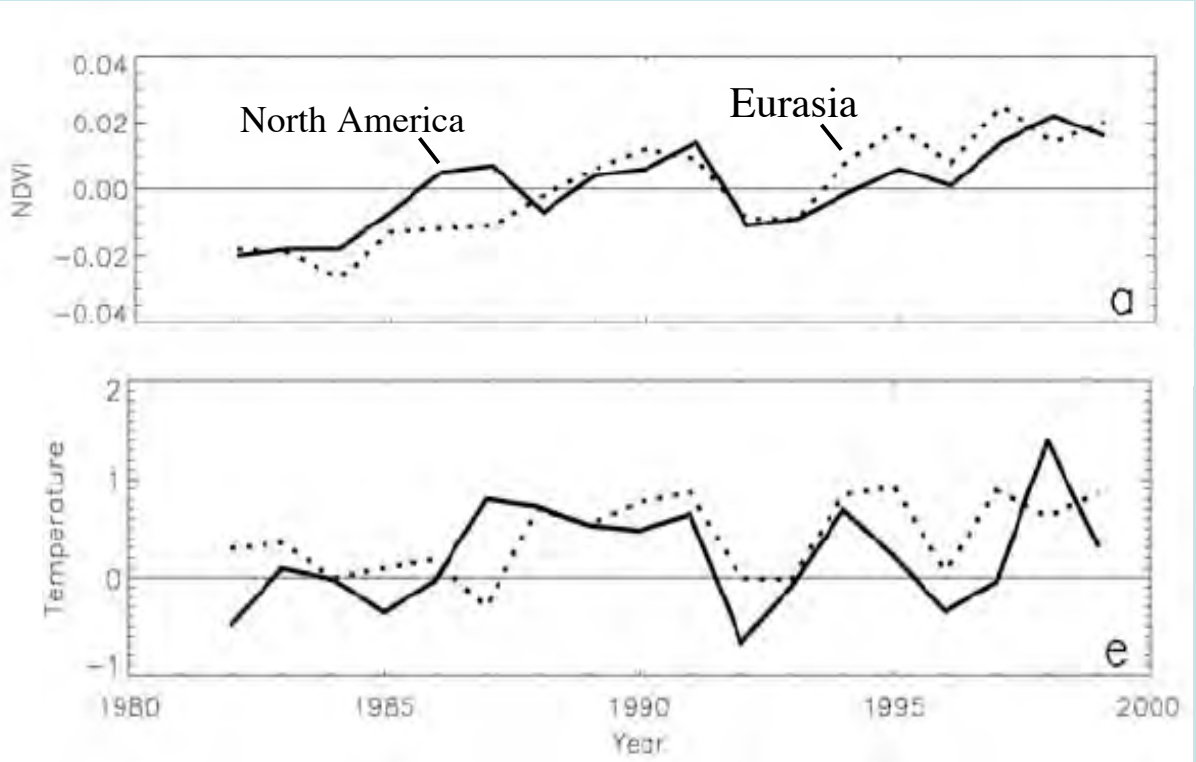

Carbon Budget
Ocean: Photosynthesis
Respiration
Sedimentation
Land Use
+2
Ocean:
Air-Sea
Exchange
–2.4
Fossil Fuels
+7
Atmosphere
–4
Absorbed
Produced

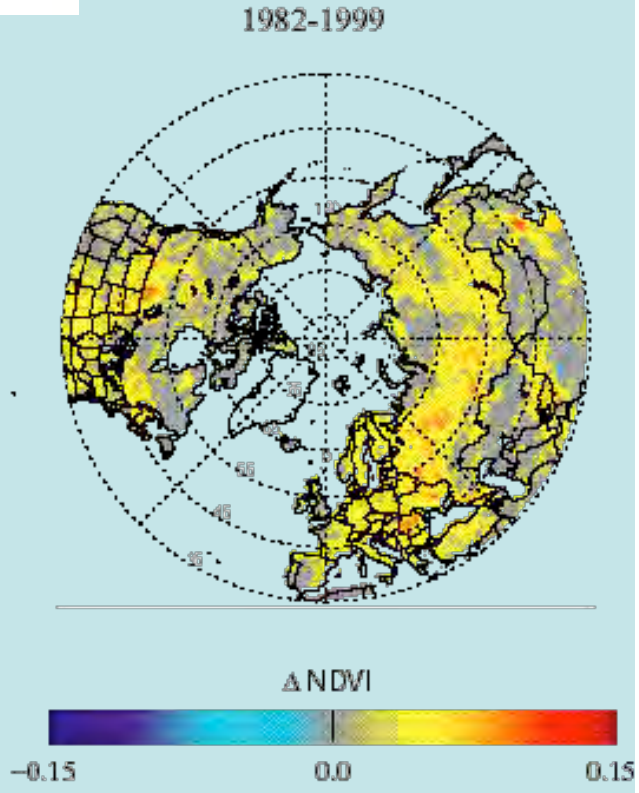

Carbon Budget
Unknown
Land Use
+2
Ocean:
Air-Sea
Exchange
−2.4
Ocean:
Photo-
synthesis
−0.1
Fossil Fuels
+7
Atmosphere
−4
Absorbed
Produced


Carbon Budget
Possible Causes
N. Hemisphere land use practices and natural regrowth
-Regrowth of harvested forests
-Fire suppression
-Decreased deforestation
-Aforestation/Woody encroachment
CO2 and Nitrogen fertilization
Climate Change
Land Use
+2
Fossil Fuels
+7
−2.5
Unknown
Ocean: Air-Sea Exchange
−2.4
Ocean: Photo-synthesis
−0.1
Atmosphere
−4
Absorbed
Produced

Greening of the Northern Hemisphere: Climate Change?

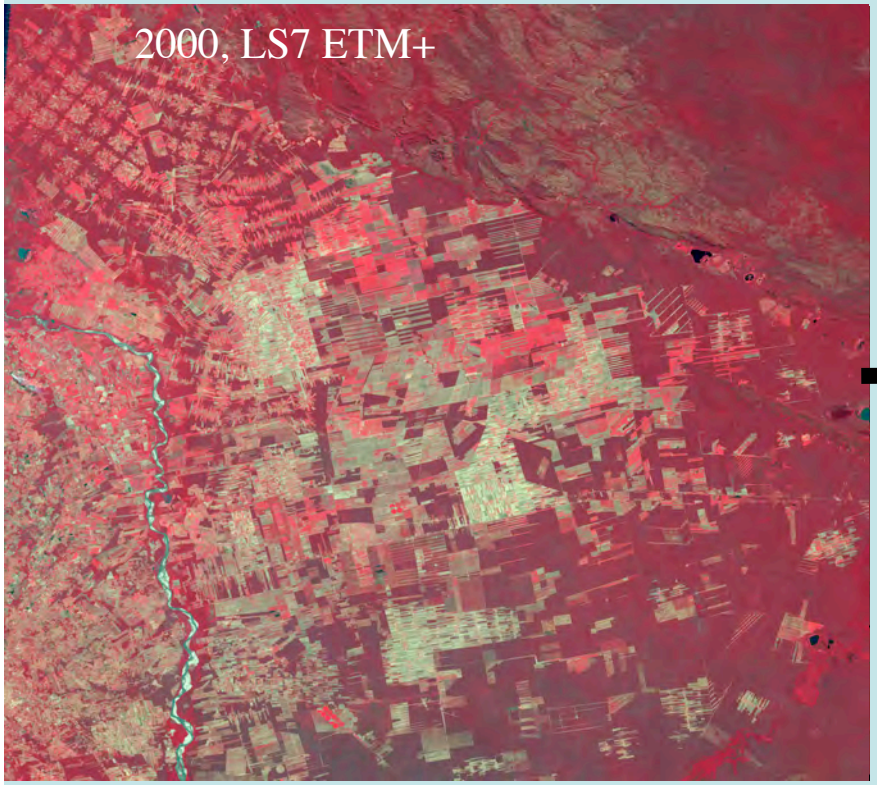


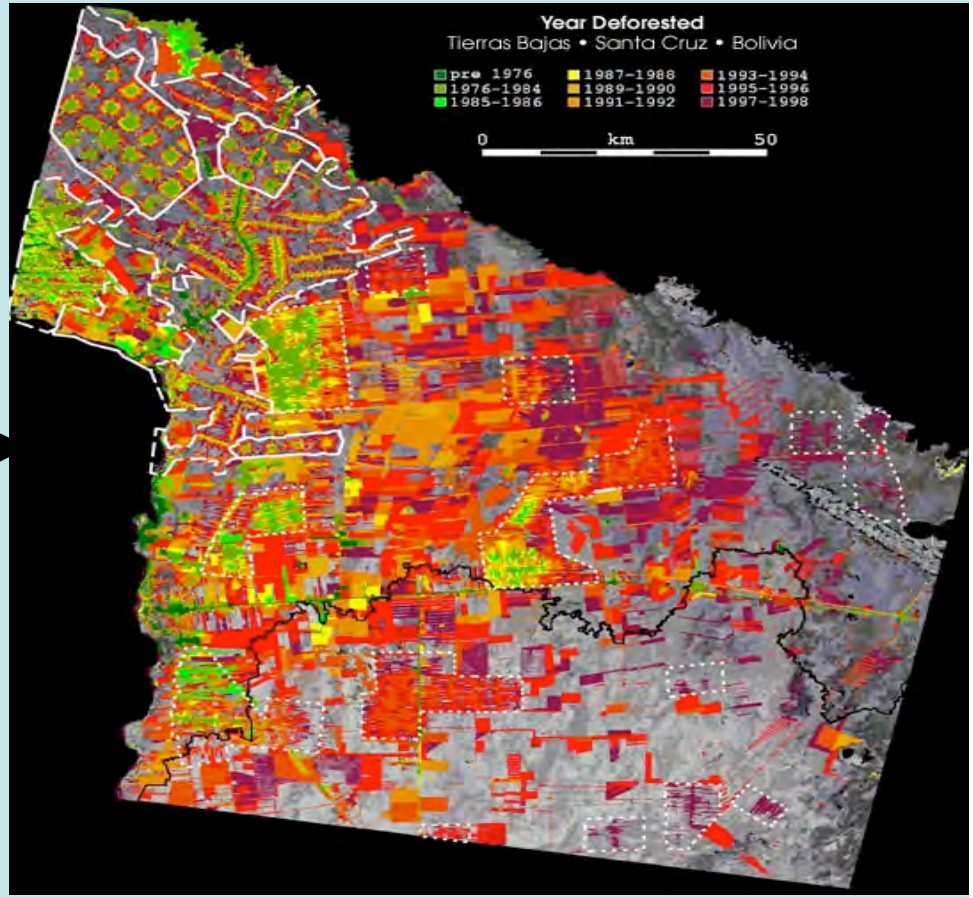




Deforestation and Regrowth

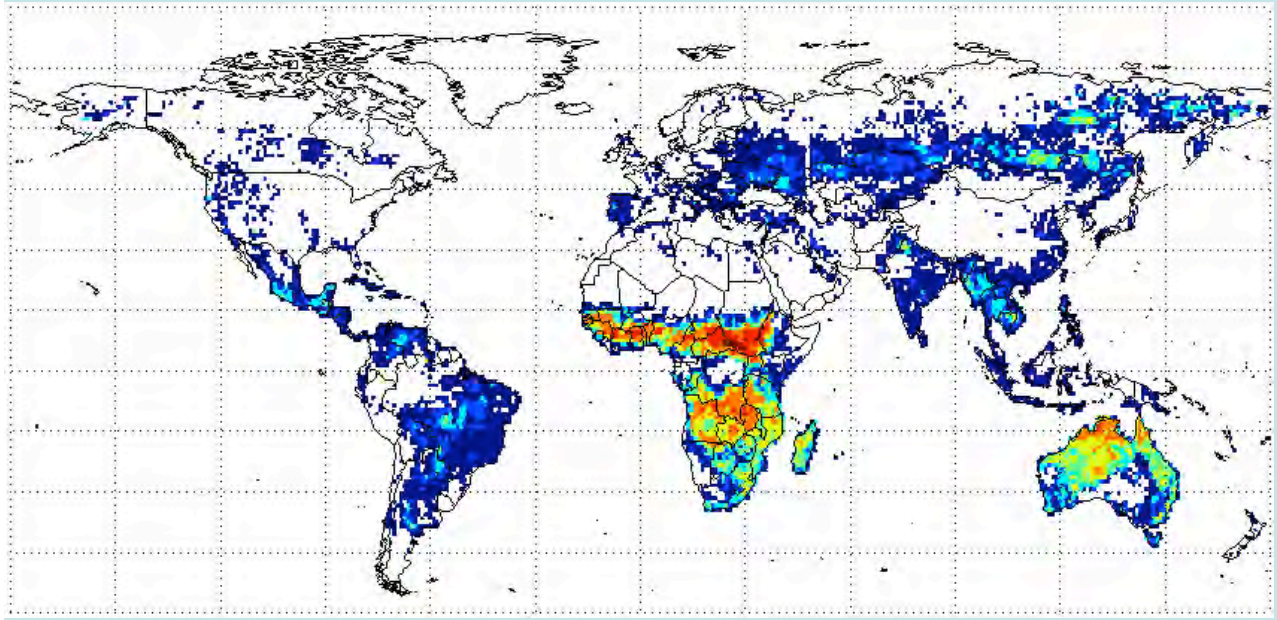
Satellite Observations of Deforestation in Bolivia





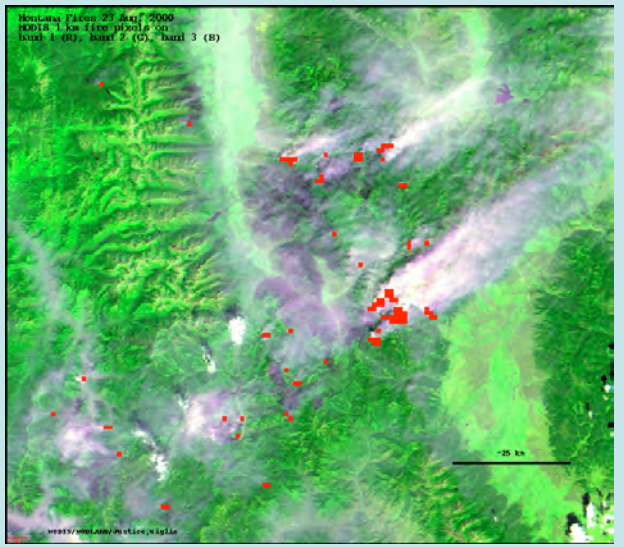
Fires and The Global Carbon Cycle

Satellite Observations of Fires

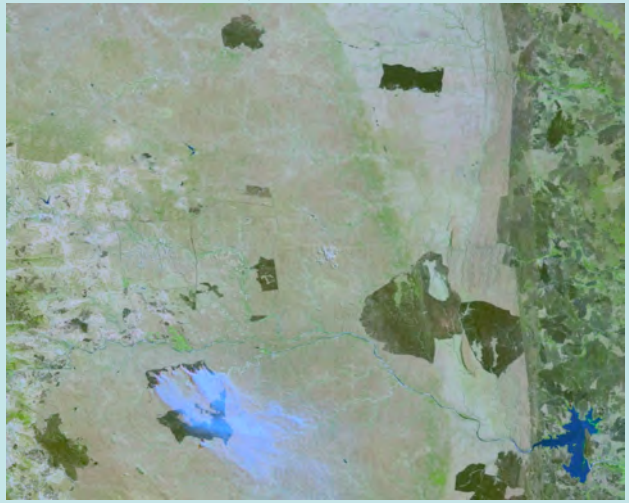


Annual burned fraction(%) of the gridcells, averaged 1997-2001.

MODIS, **Montana '00**



LandSat, **South Africa '00**



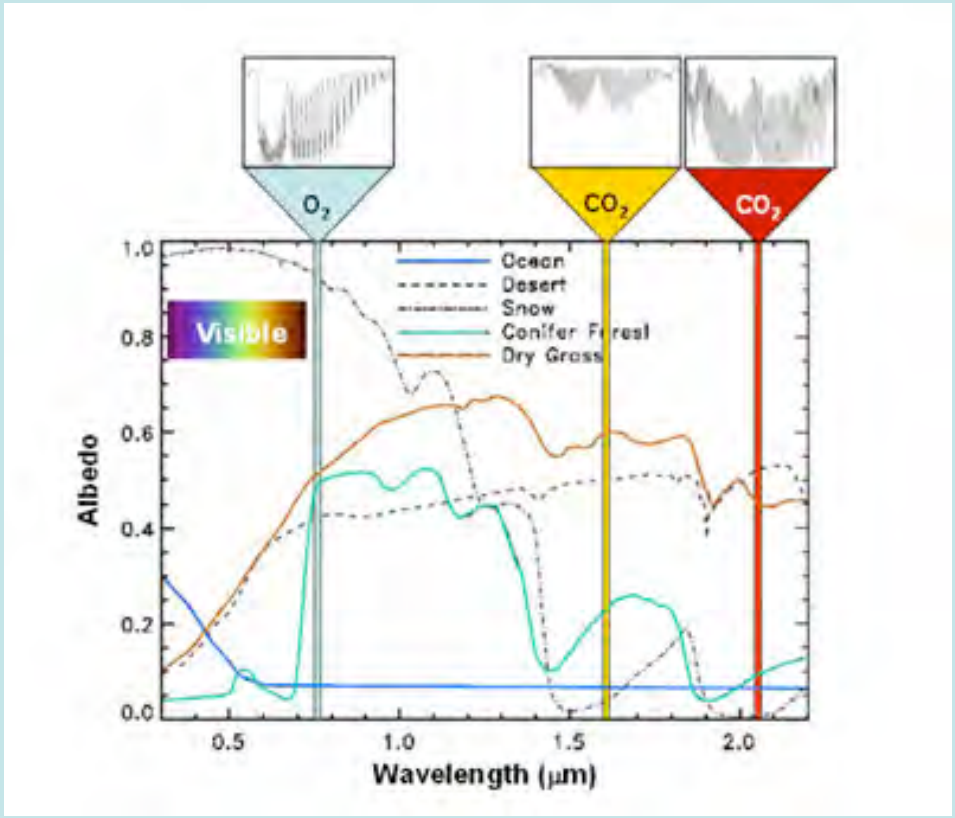
Examples of Potential New Satellite Missions/Observation That Could Bring Us Closer to Understanding:

- **Where The Missing Carbon Is Going,**
- **What Processes Are Responsible For It and,**
- **What May Happen To It In The Future.**

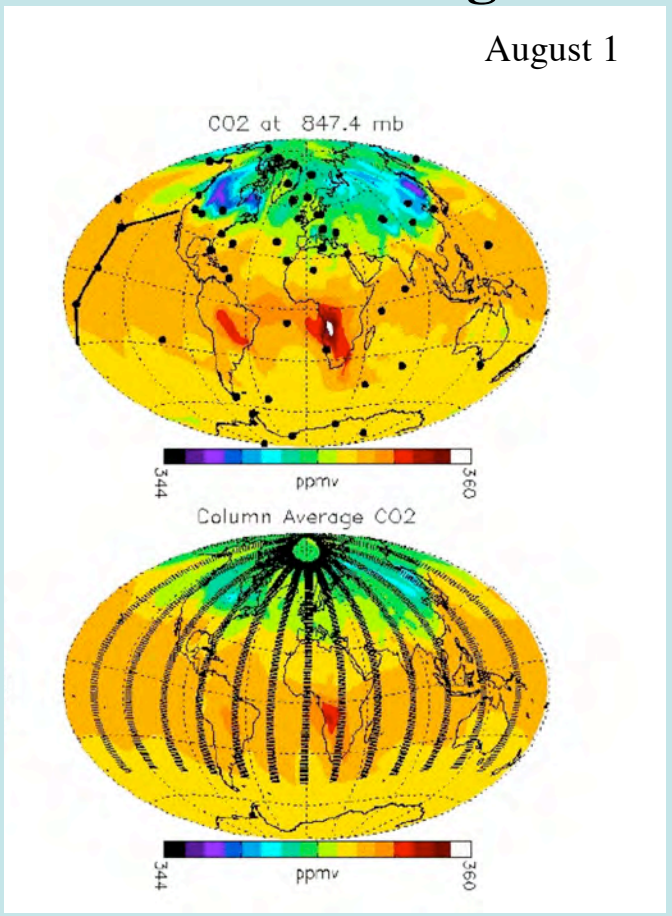
Planned future satellite mission to answer the question: Where is the Missing Carbon?

Orbiting Carbon Observatory (OCO)
Launch scheduled in 2008

The Principle

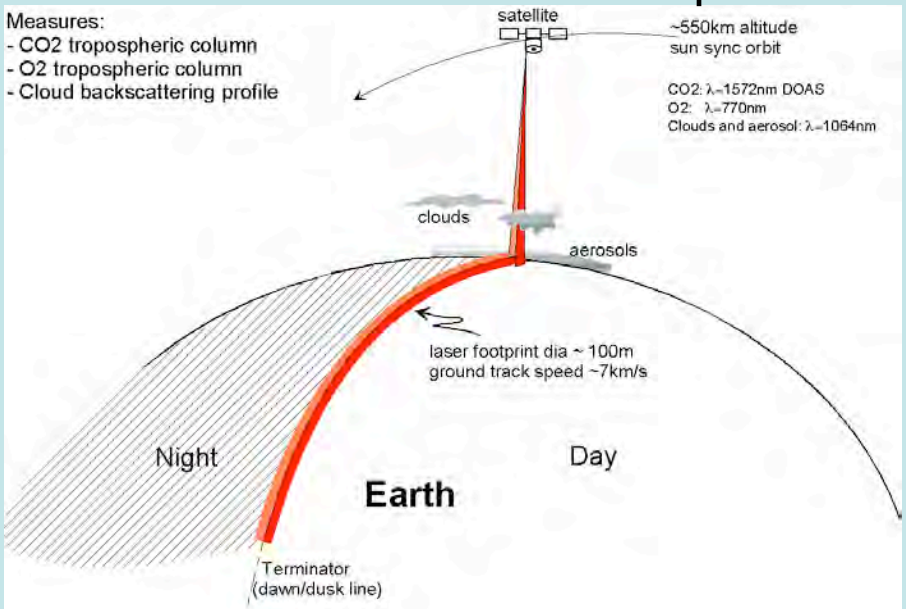


The Coverage

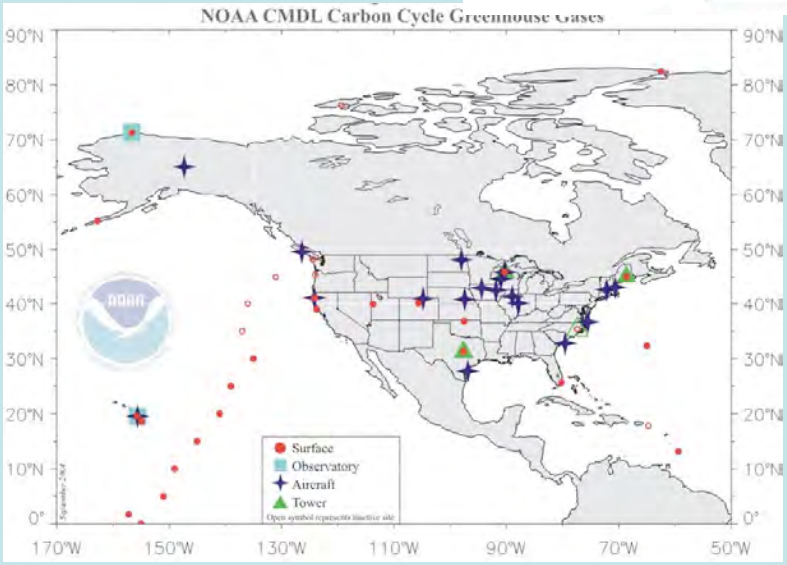


Possible future satellite missions to answer the question: Where is the Missing Carbon?

LIDAR measurements of atmospheric CO_2

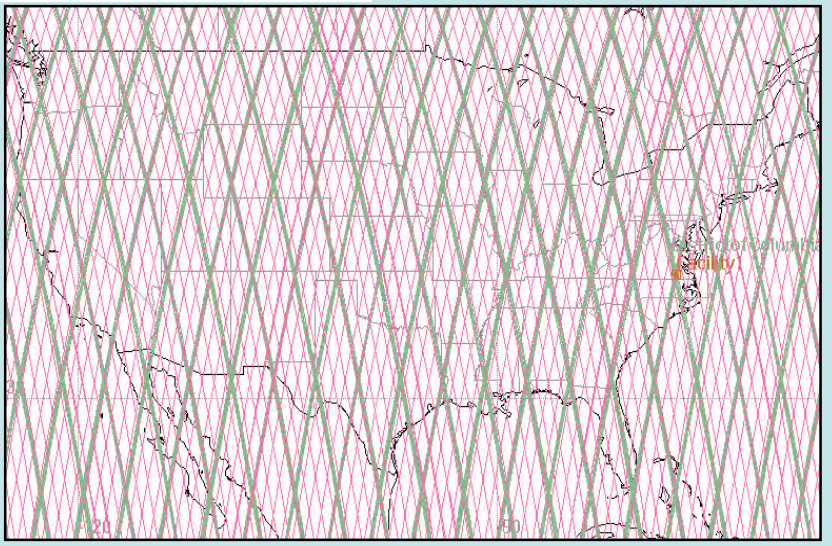


Current coverage



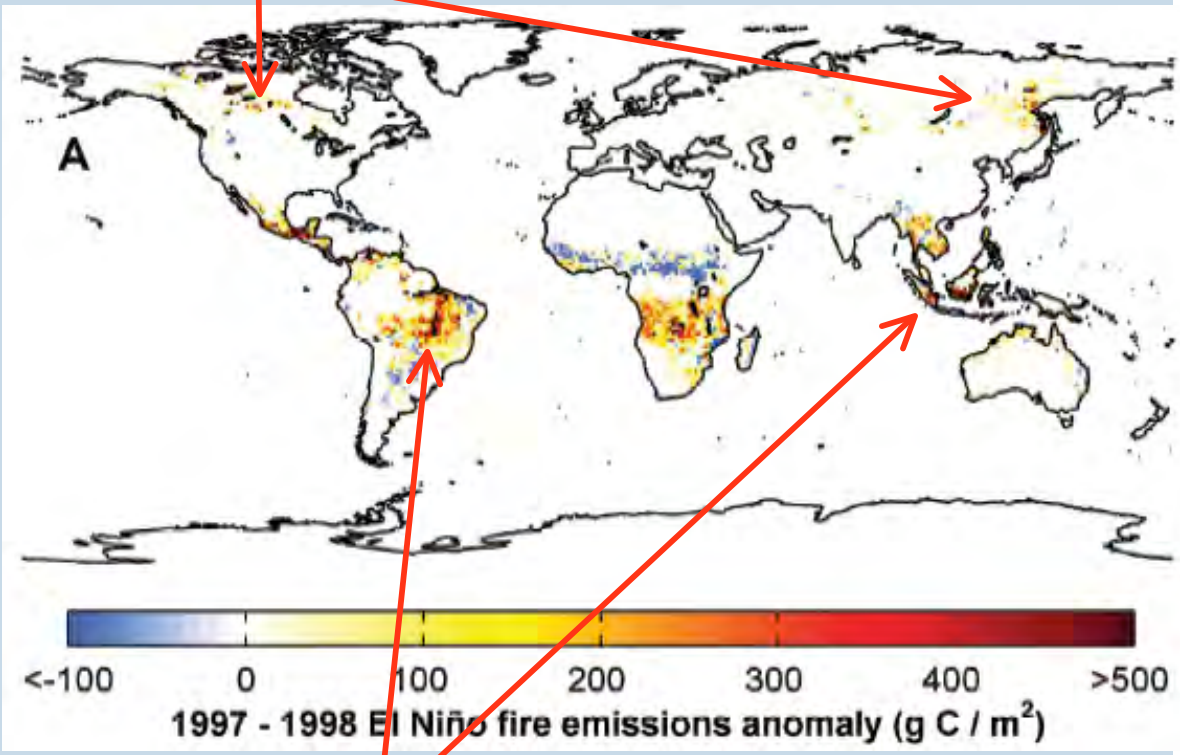
vs.

Possible coverage

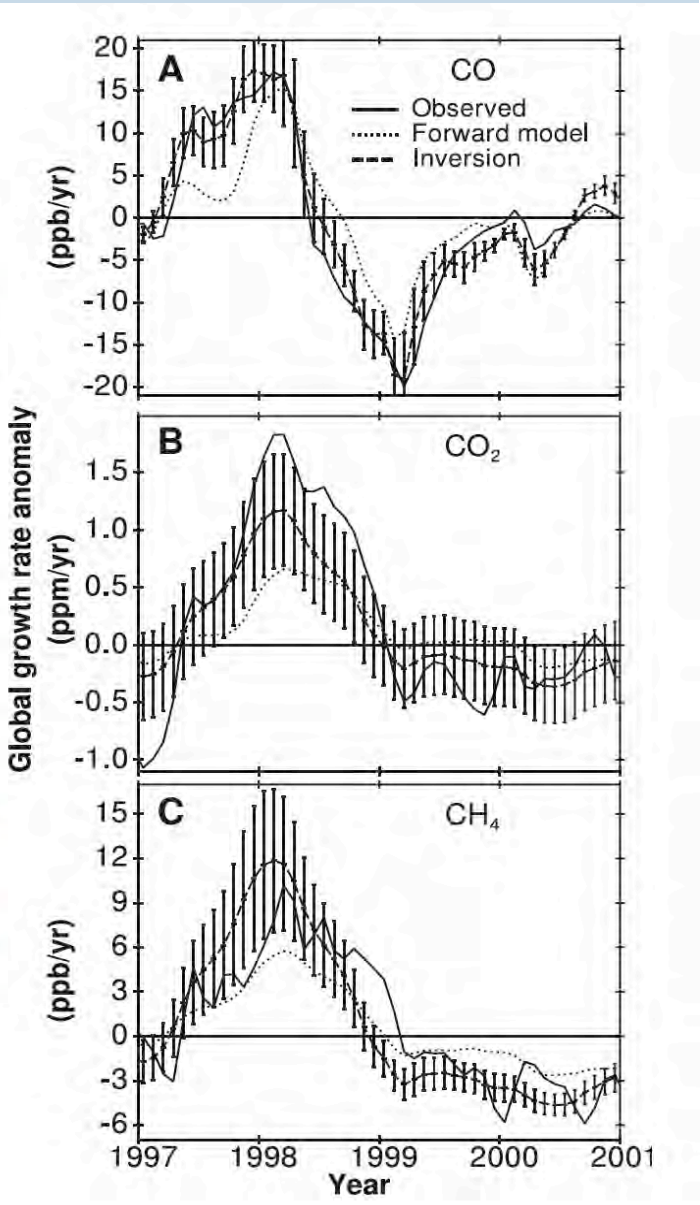


New Results: Fires play a major role in year to year variability in atmospheric CO_2

Dry, warm conditions favor wild fire spread in boreal forests.



Dry conditions favor the use of fire by humans for deforestation in the tropics.

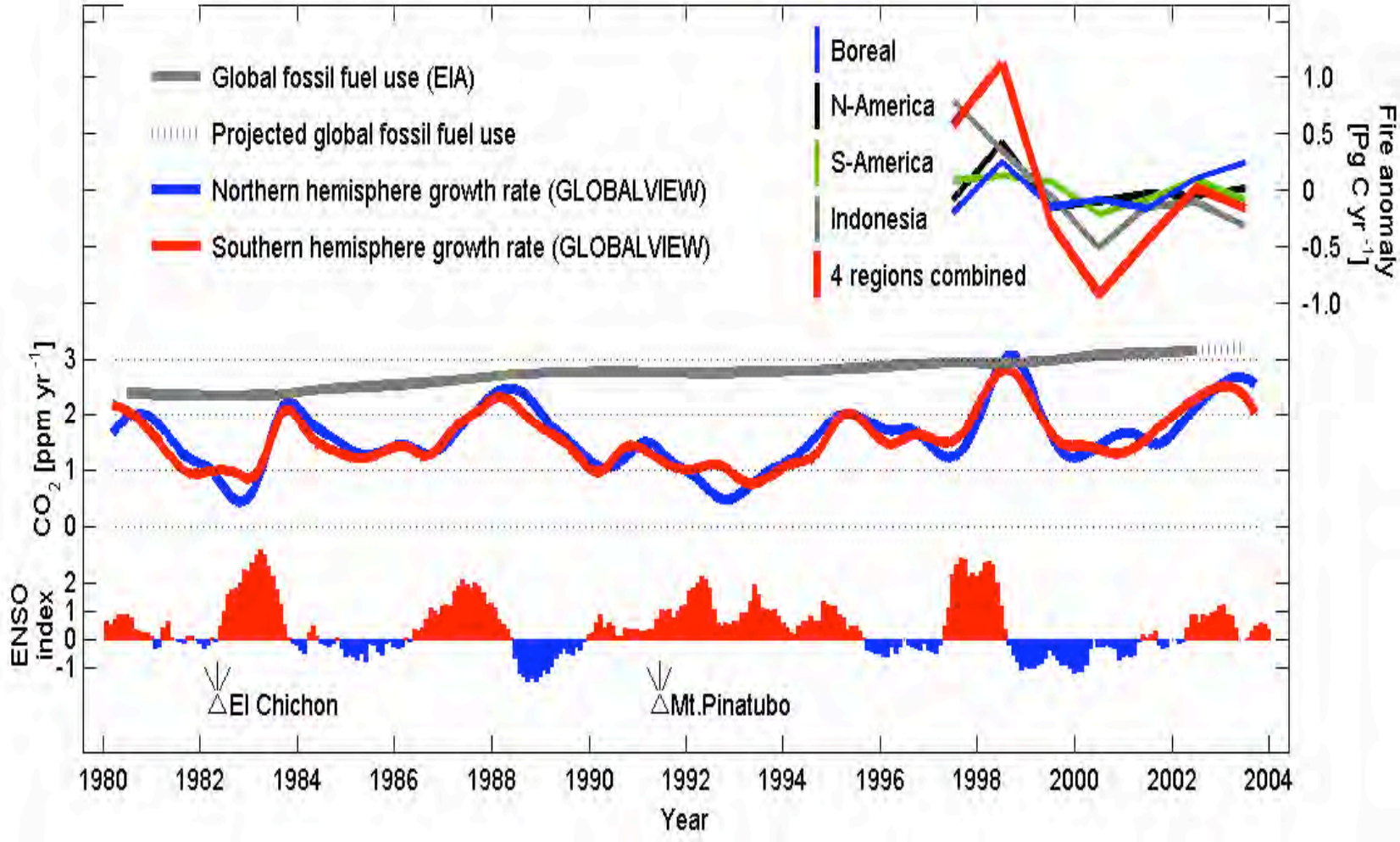


New Results: Atmospheric CO_2 growth rate increased Substantially in 2002 and 2003. *Why?*

-Fires in Siberia in 2003

-Fires in Indonesia and South America in 2002

-Temperate Northern Hemisphere Droughts in 2003



Earth's Carbon Cycle

-Climate

-Food

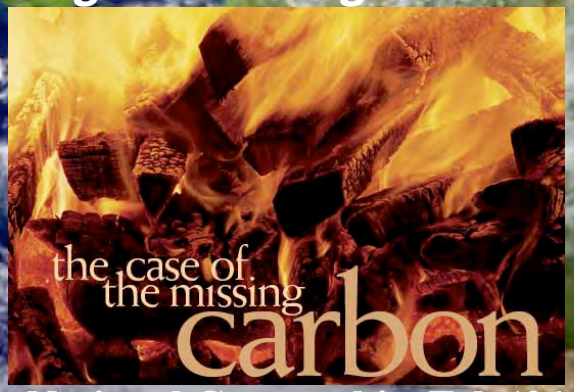
-Ecosystems

Resources:

http://earthobservatory.nasa.gov

http://realclimate.org

BOOK: *Biogeochemistry: An analysis of global change*. WH Schlesinger, AP, 1997



National Geographic, Feb '04