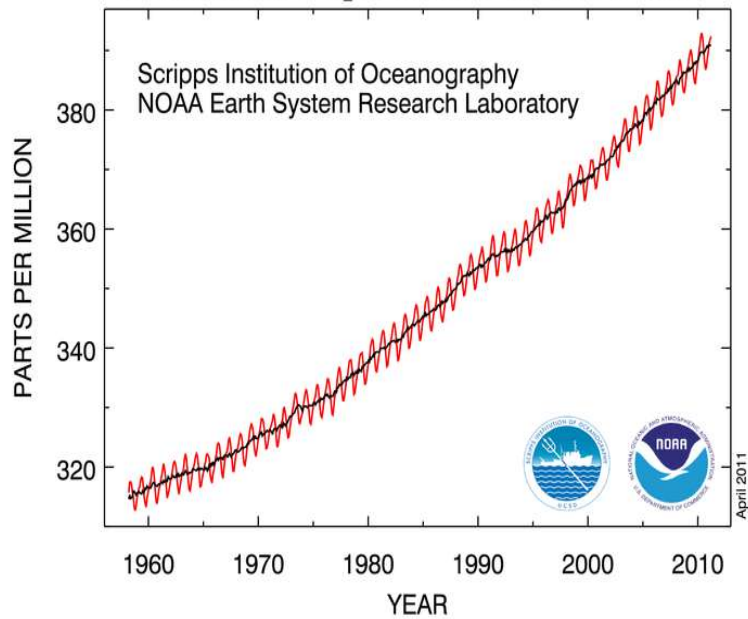
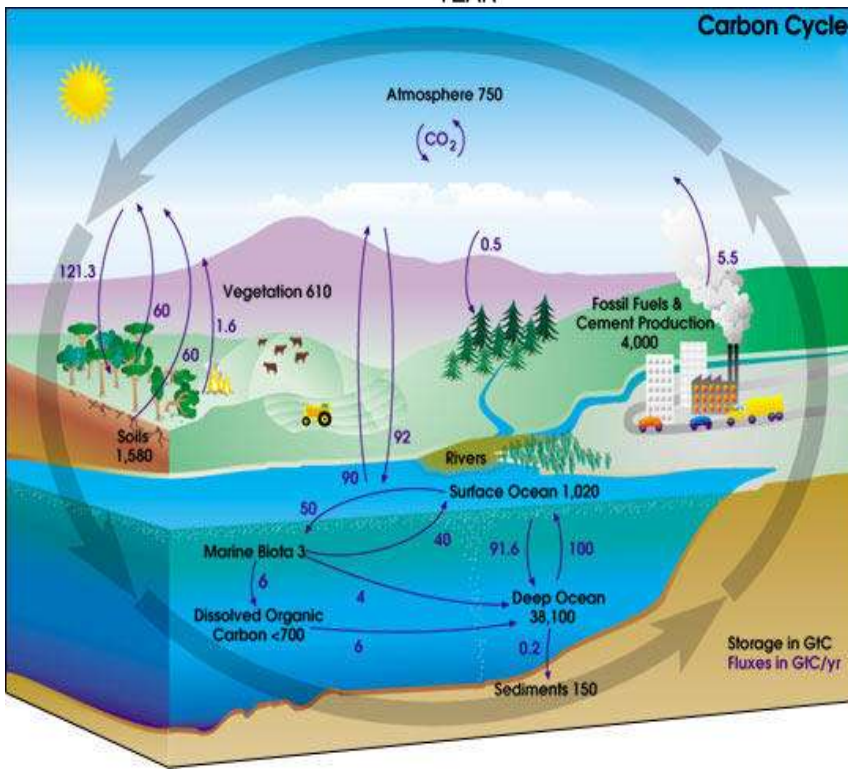


Atmospheric CO₂ at Mauna Loa Observatory

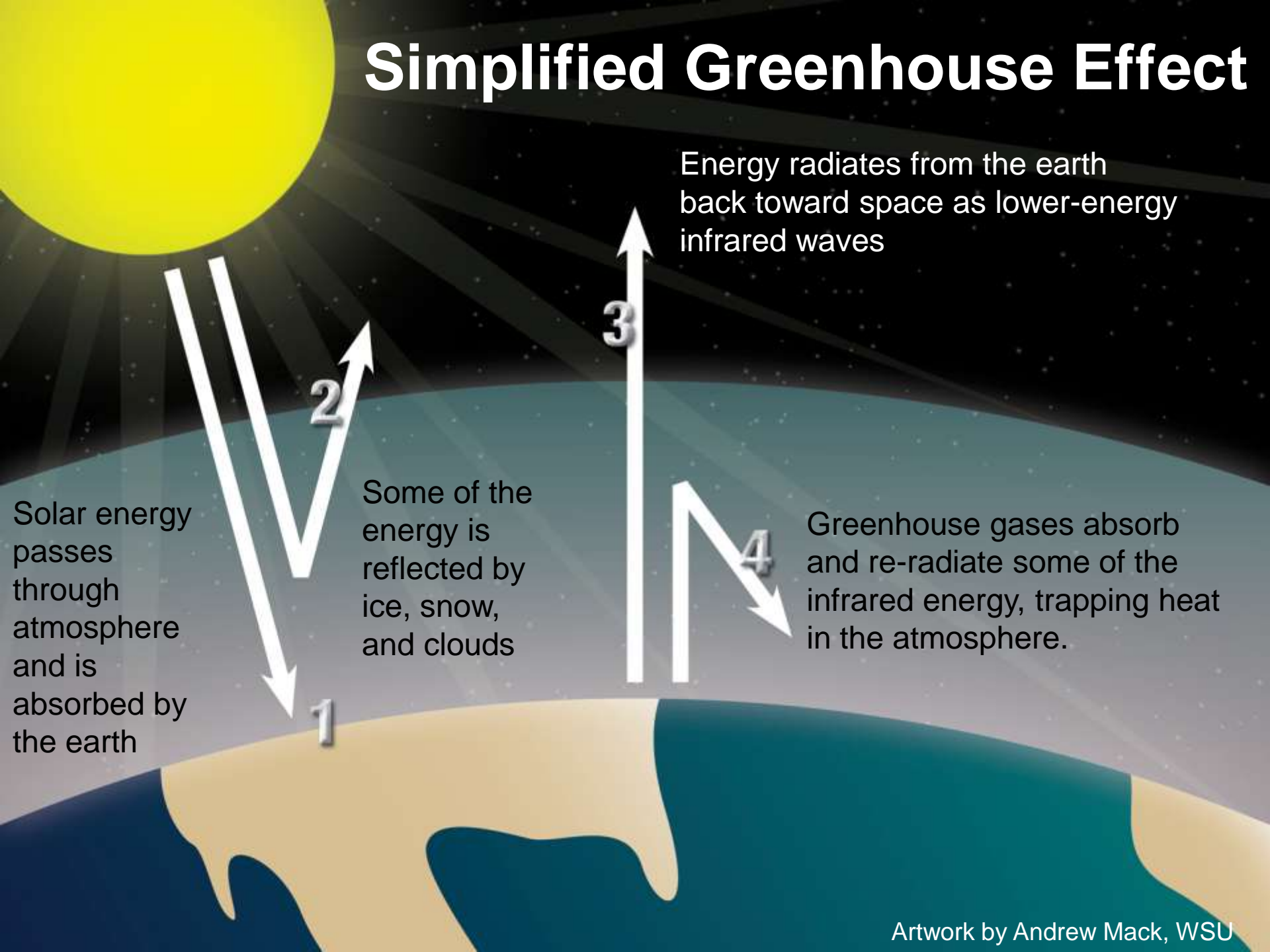


The Carbon Cycle and Climate Change



- 1. Review of climate science;
physical laws and evidence**
- 2. Fast carbon cycle**
- 3. Slow carbon cycle**
- 4. Human inputs**
- 5. Carbon sequestration;
potential, challenges, and limitations**
- 6. C sequestration in the city**

Simplified Greenhouse Effect



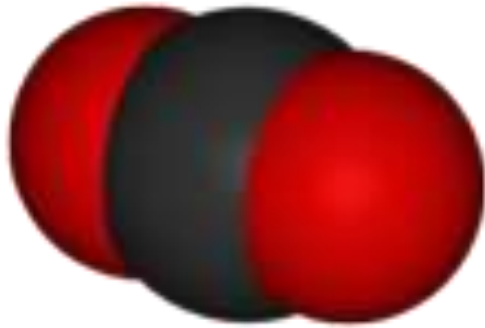
Energy radiates from the earth back toward space as lower-energy infrared waves

Solar energy passes through atmosphere and is absorbed by the earth

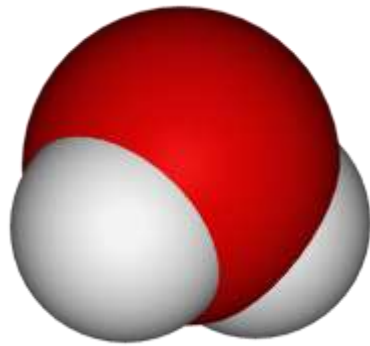
Some of the energy is reflected by ice, snow, and clouds

Greenhouse gases absorb and re-radiate some of the infrared energy, trapping heat in the atmosphere.

Greenhouse gases include carbon dioxide, water vapor, nitrous oxide, methane, and ozone.



Carbon Dioxide

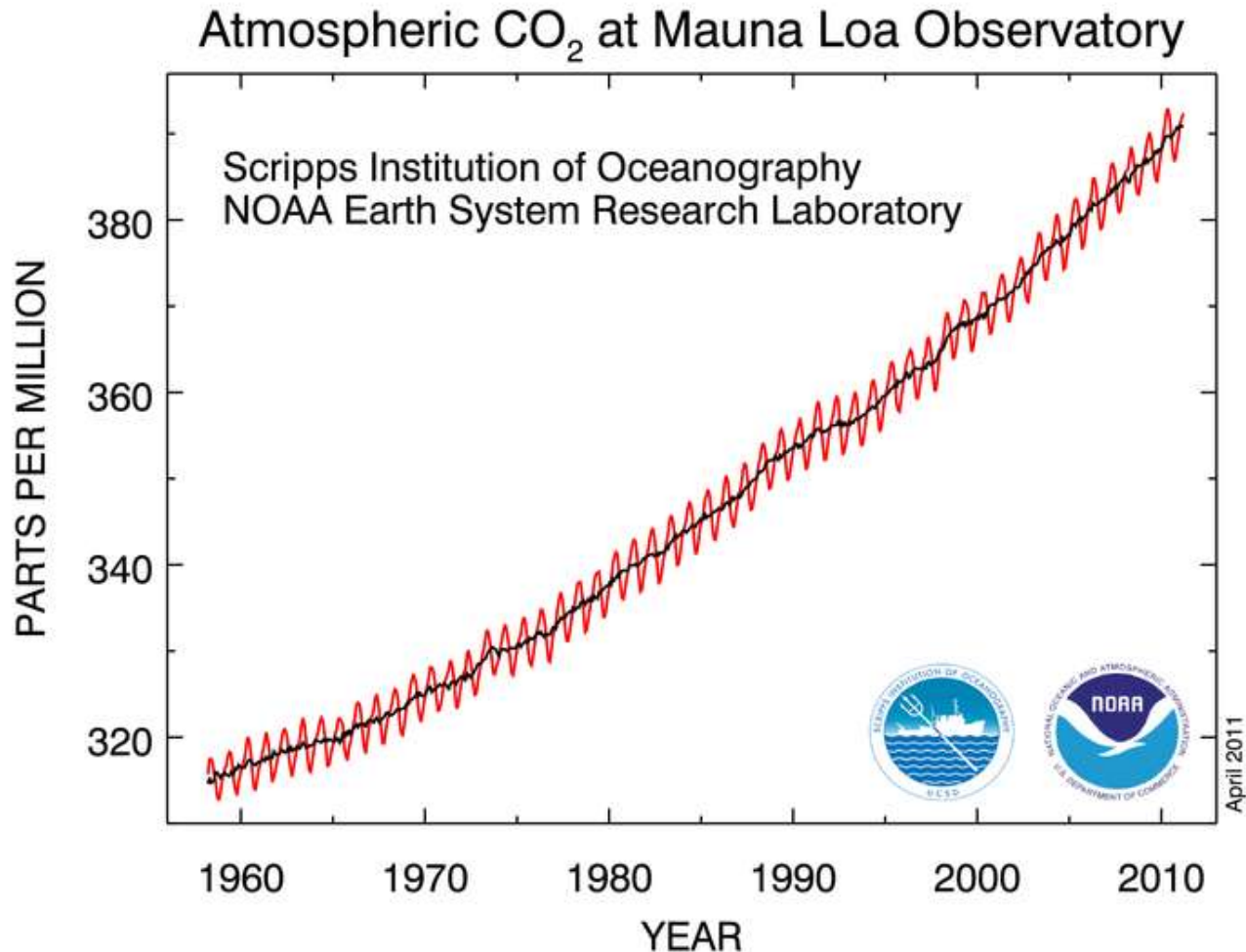


Water

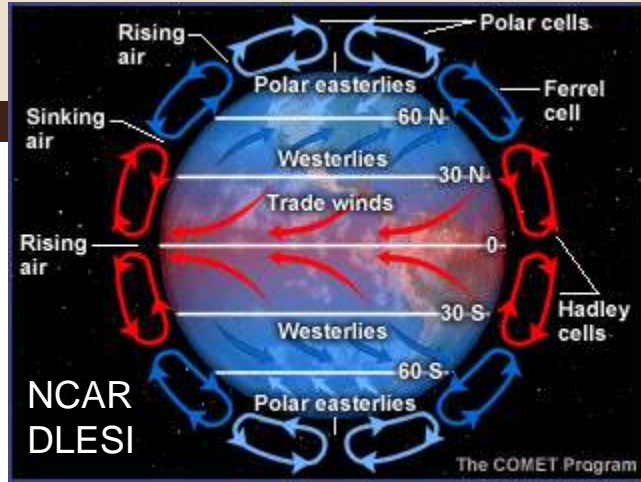
- Absorb infrared energy and act like a blanket
- Without the greenhouse effect, earth's mean temperature would be **0° F**, nearly 60° lower than it is now

The Problem:

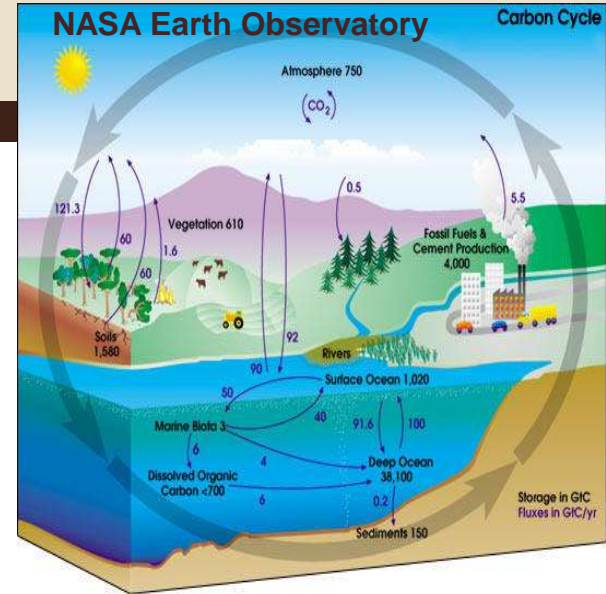
We are increasing atmospheric CO₂, adding to the greenhouse effect, and warming the planet.



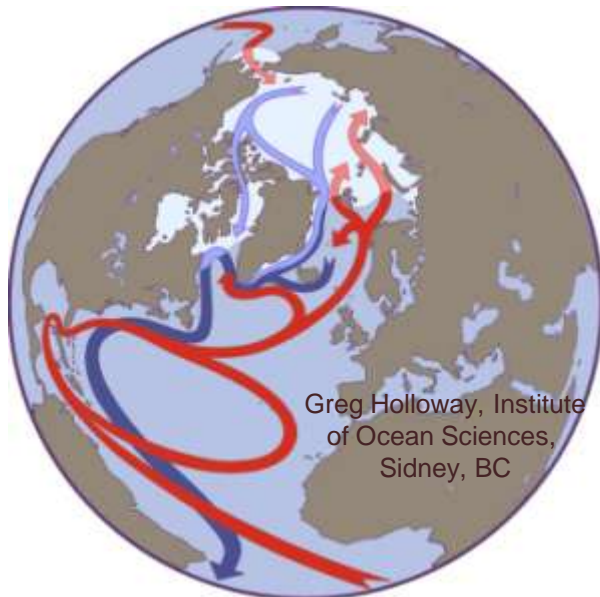
The greenhouse effect is part of a complex climate system.



Atmospheric Circulation moves heat

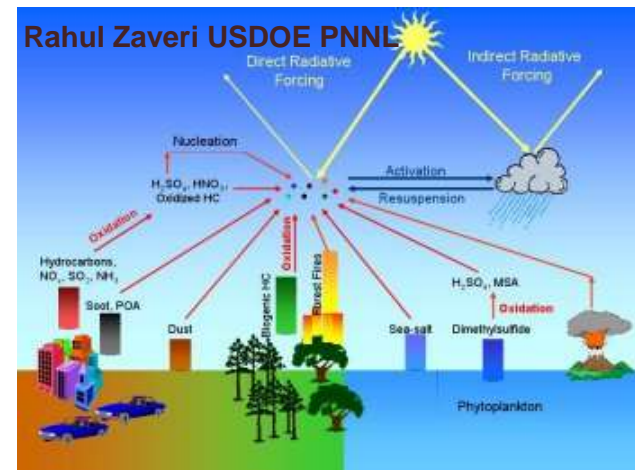


Carbon Cycle moves, transforms, and stores CO₂



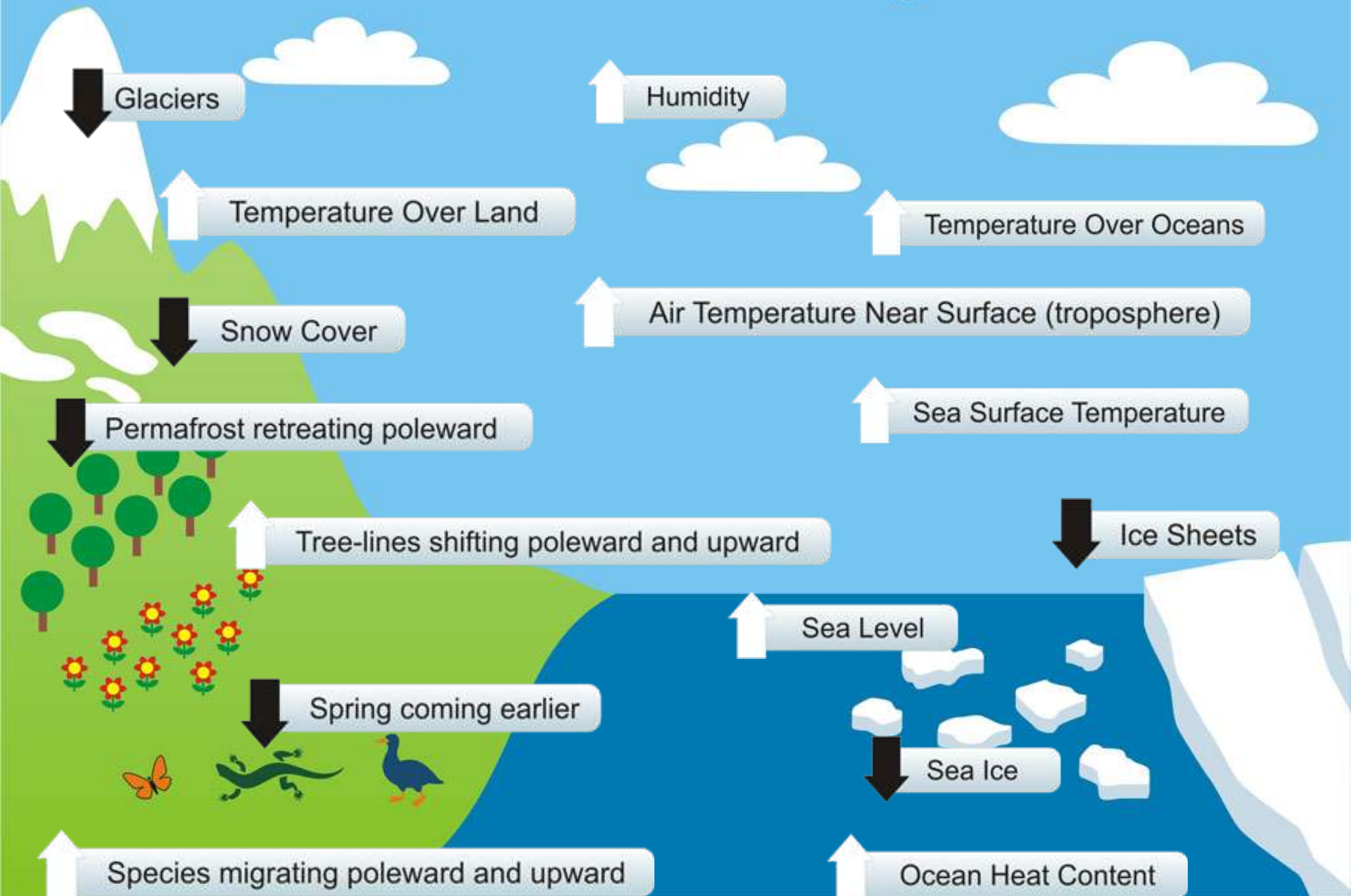
Greg Holloway, Institute of Ocean Sciences, Sidney, BC

Ocean Circulation moves and stores heat and CO₂



Aerosols interact with solar energy

Indicators of a Warming World



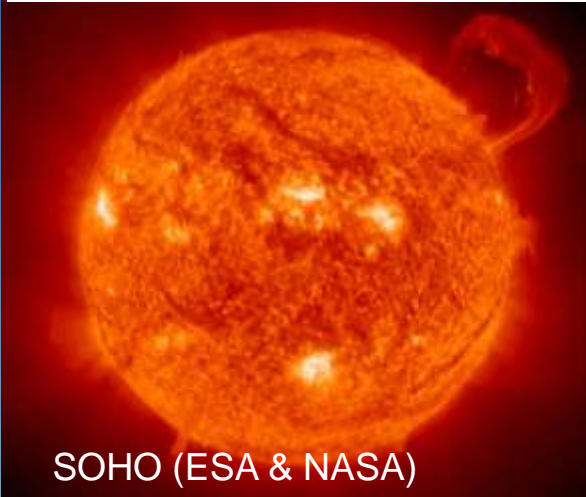
Climate forcing affects global energy balance, forcing a change in climate.

Coal-fired power plant emitting CO₂



J.C. Willett U.S. Geological Survey

SOHO (ESA & NASA)



Credit: NOAA

Climate feedback amplifies or dampens climate forcing.



NASA Johnson Space Center

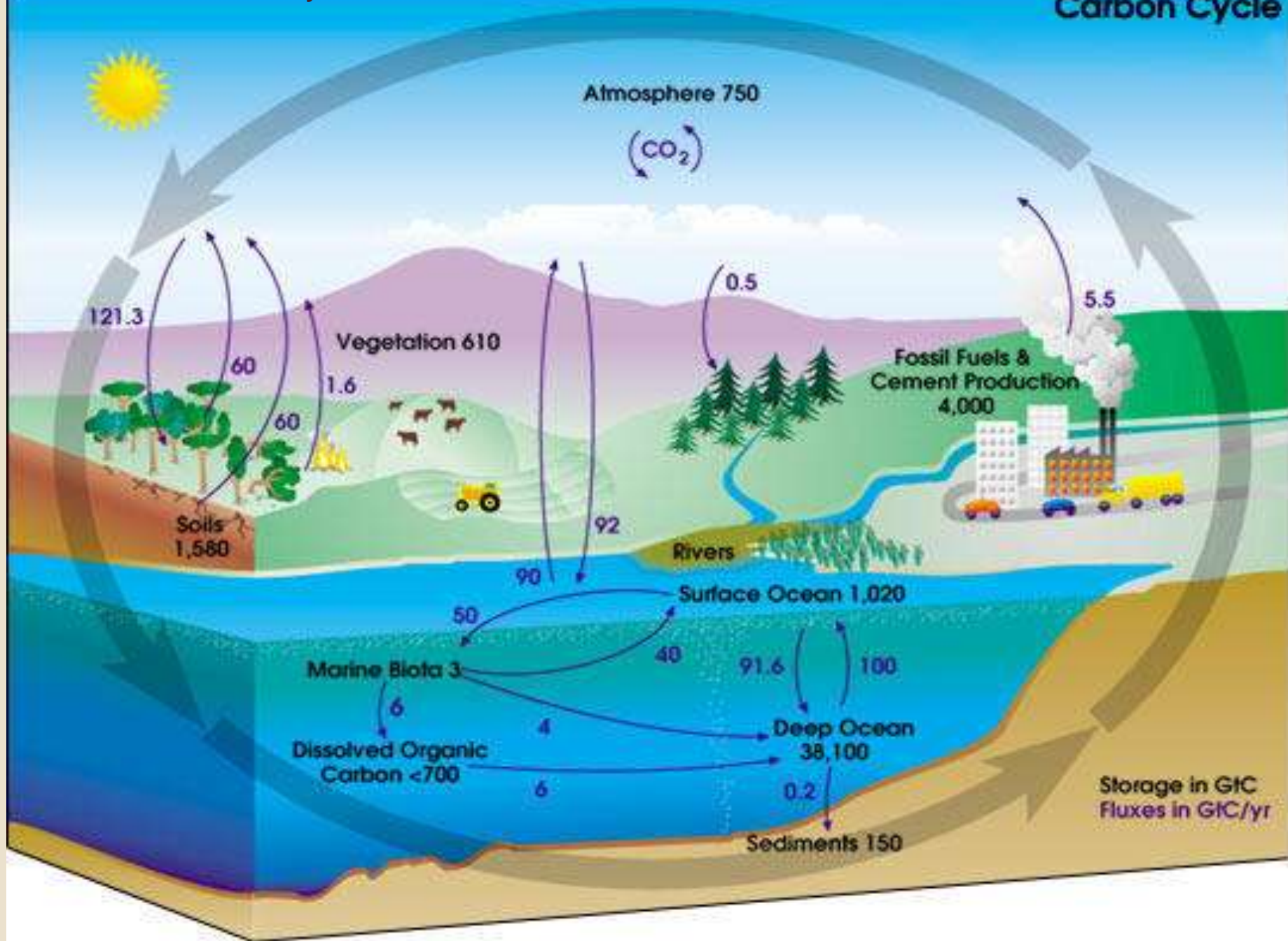
Photo by Gifford Miller, Univ. Colorado



Katey Walter Anthony, U Alaska-Fairbanks



Credit: NOAA



We'll be talking about some big numbers!

Here are some units to keep in mind.

1 kg = kilogram = 1×10^3 g = 2.2 lb

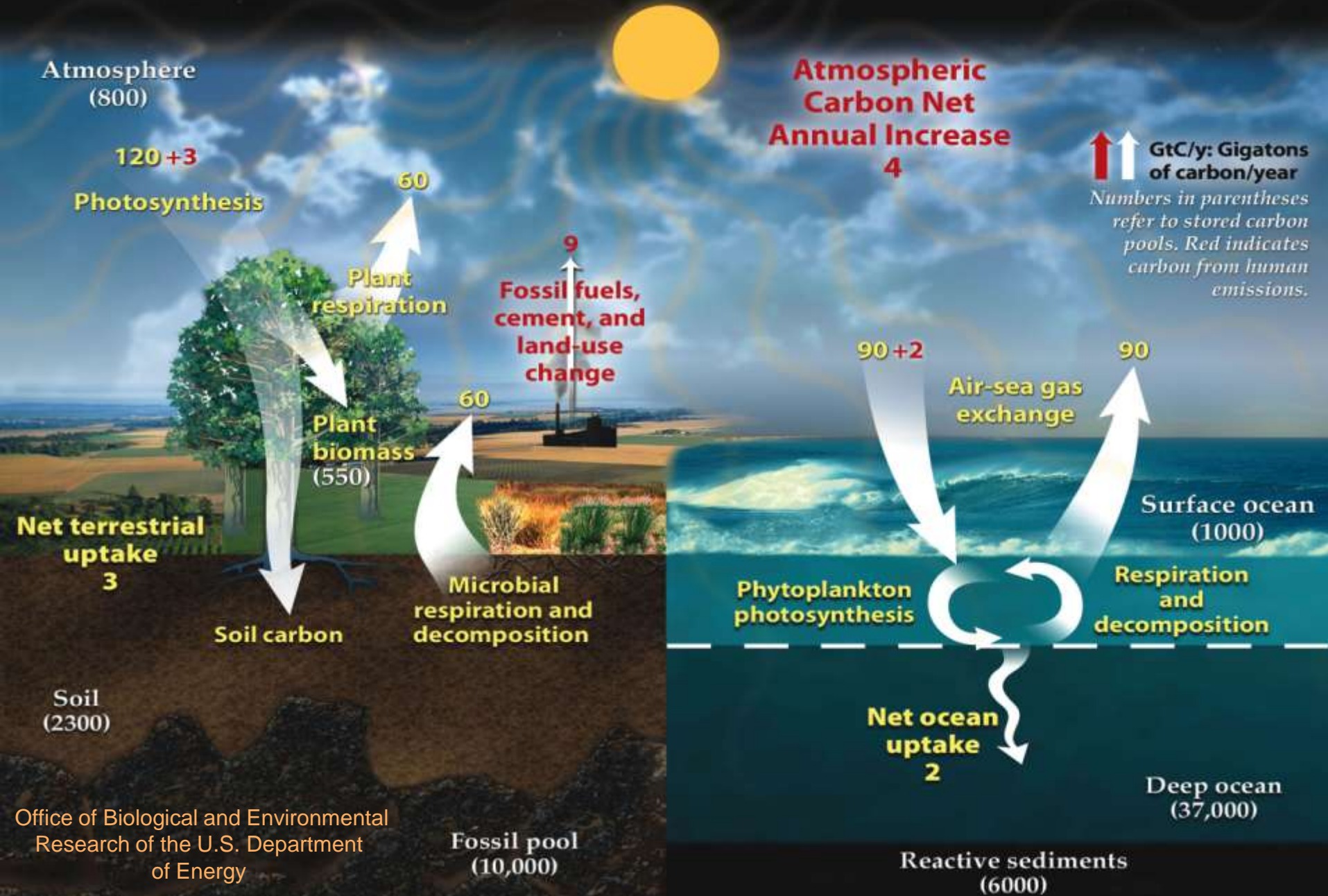
1 Mg = Megagram = 1×10^6 g = 2240 lb = 1 metric ton

1 Tg = 1 Teragram = 1×10^{12} g = 1 Million metric tons

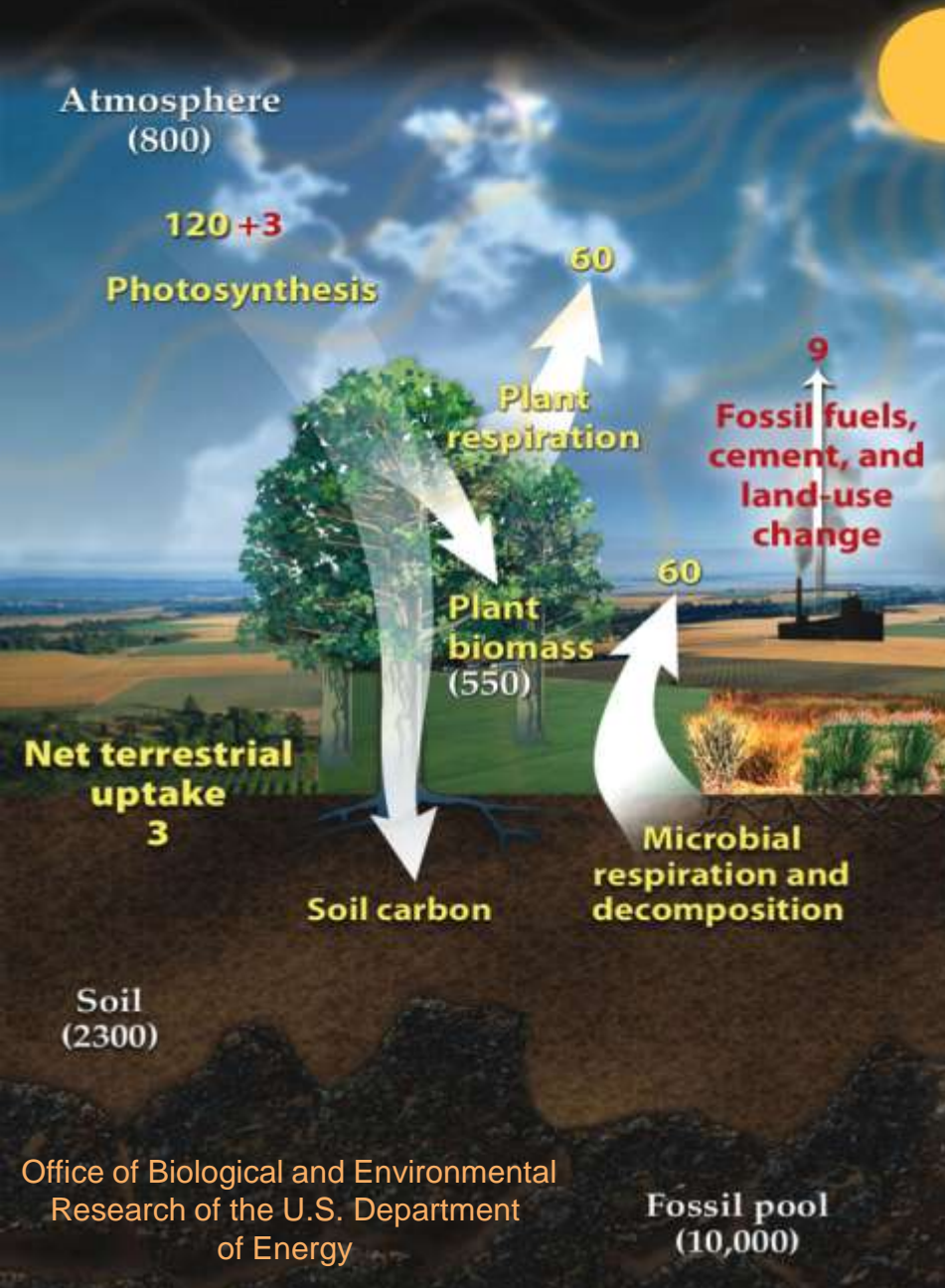
1 Pg = 1 Petagram = 1×10^{15} g = 1 Billion metric tons = 1 Gigaton

1 Kg Carbon (C) = 3.67 Kg Carbon Dioxide (CO₂)

Fast Carbon Cycle



Fast Carbon Cycle



Terrestrial

Active

Photosynthesis -- Energy Capture

Respiration/
Decomposition -- Energy Use

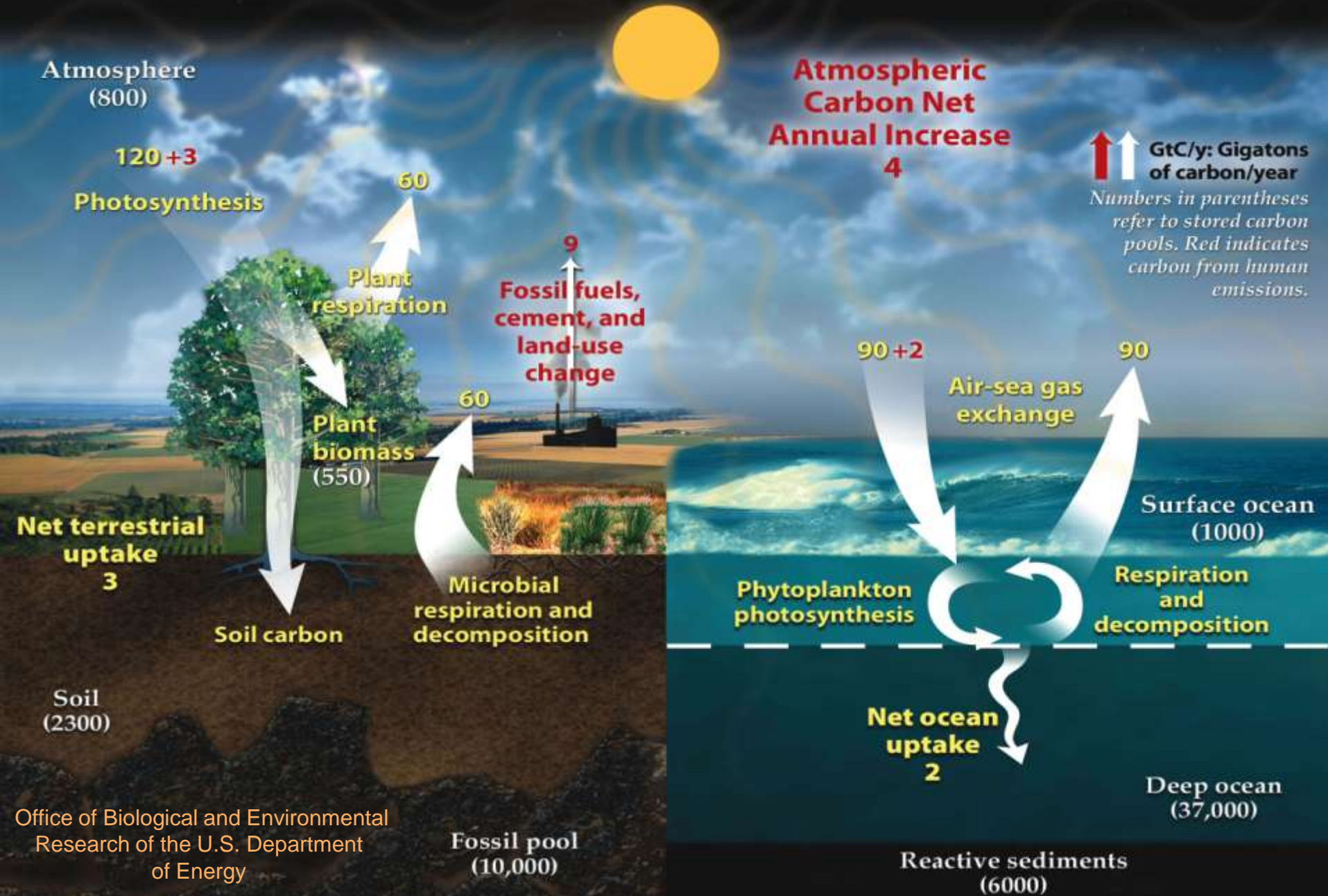
Daily and Annual Cycles

Storage

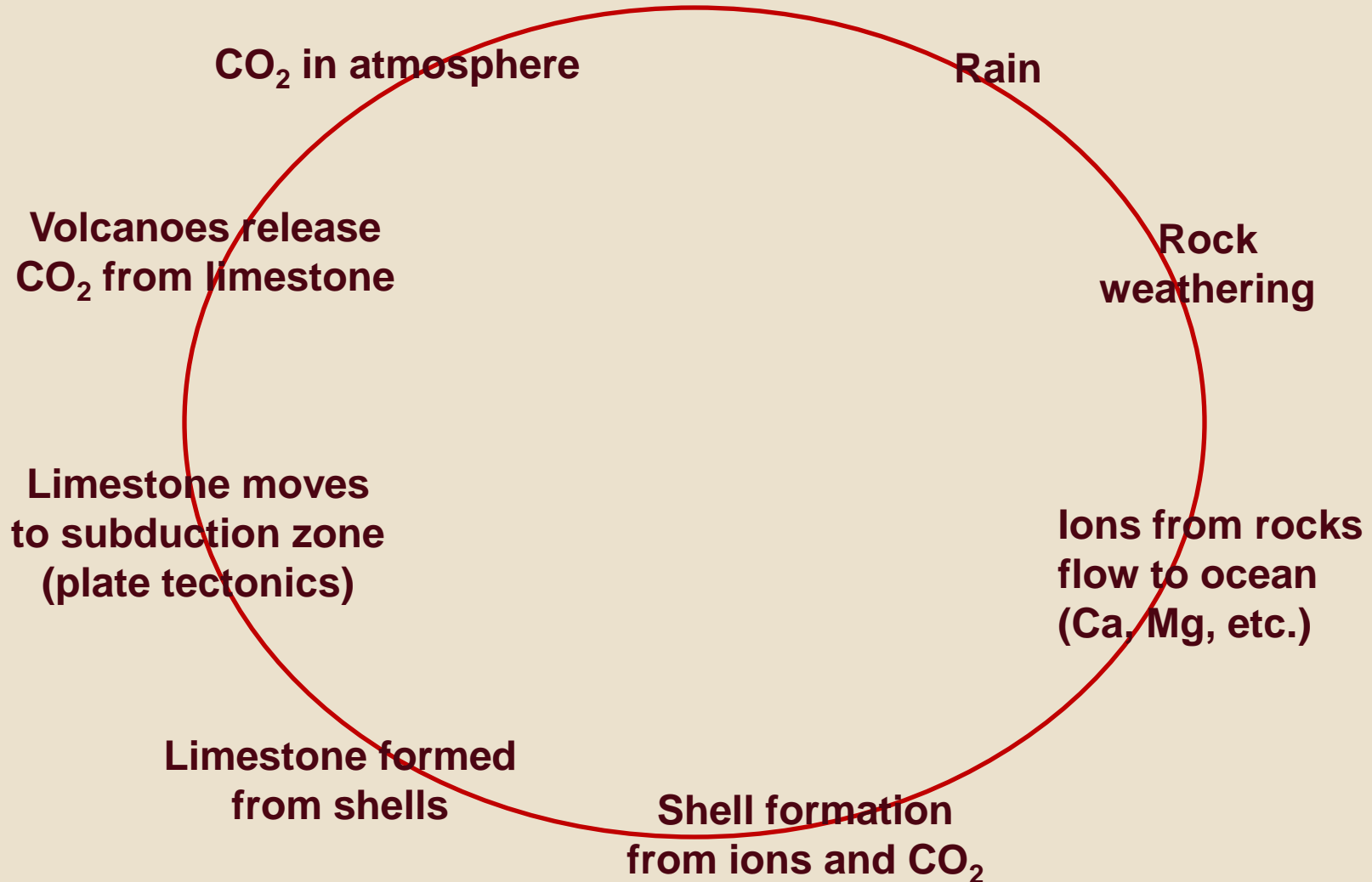
Trees and Soil -- Long lived and resistant to decay

Decades to centuries

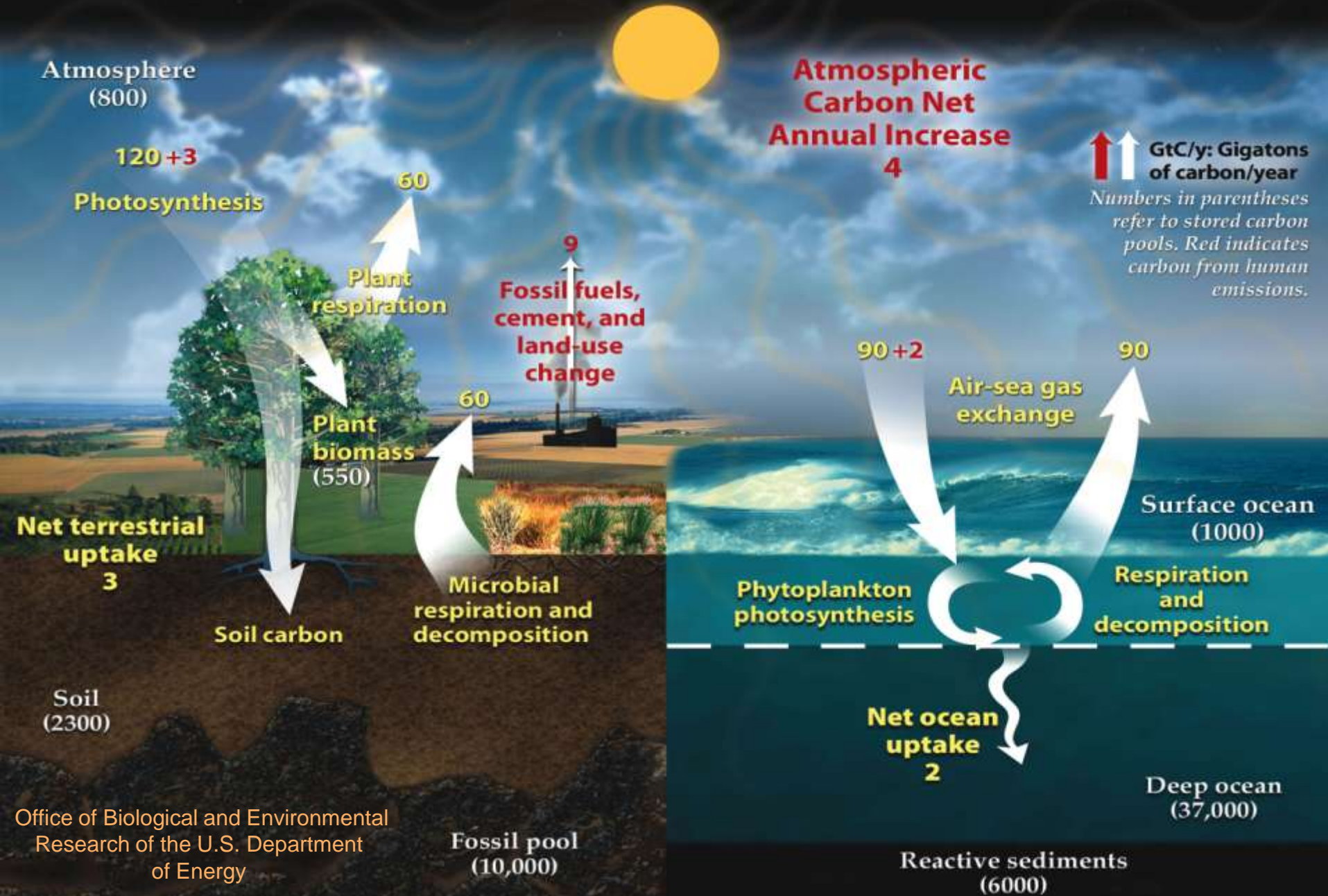
Fast Carbon Cycle



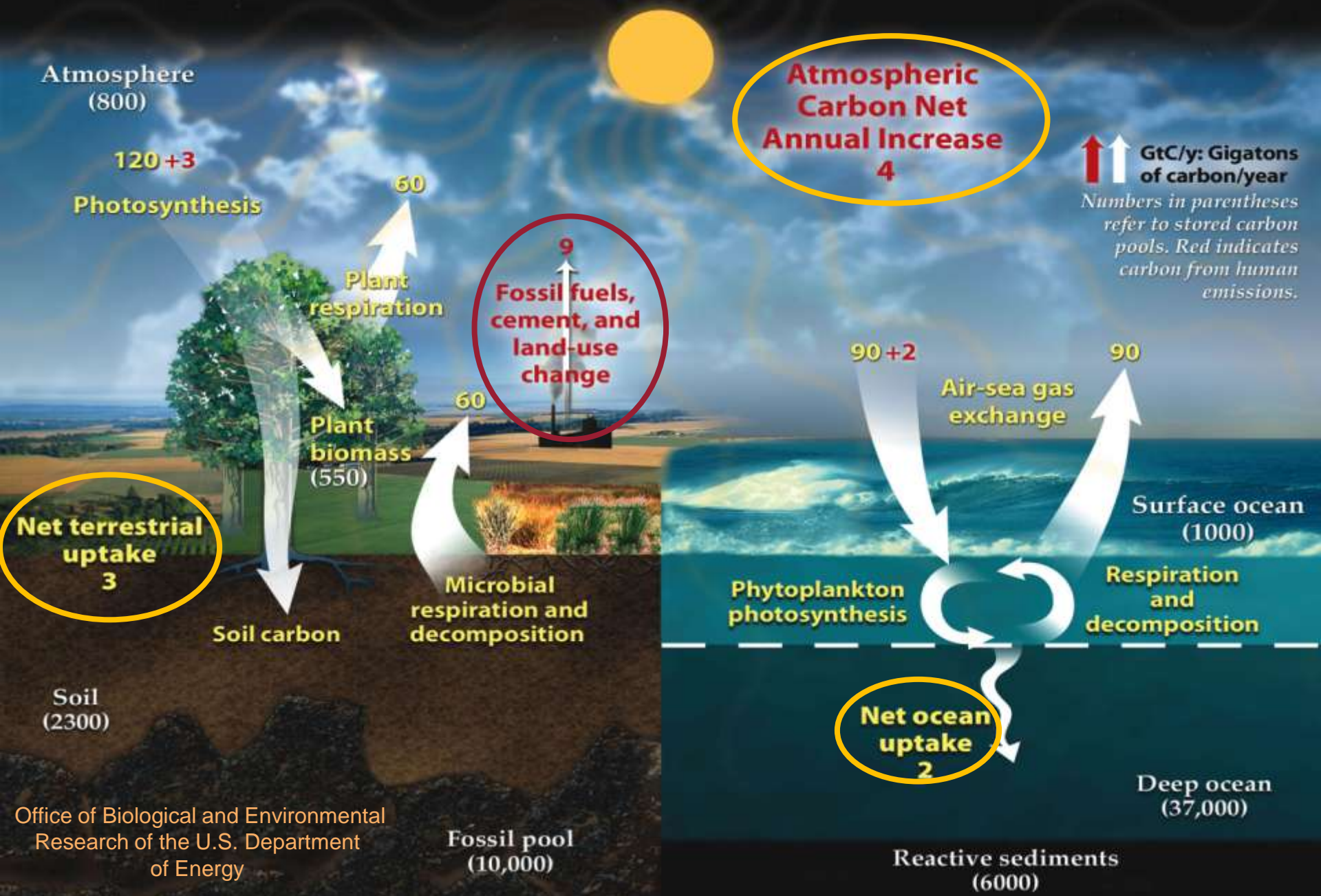
Slow (geologic) carbon cycle



Fast Carbon Cycle



What happens to human C emissions?



Fate of Anthropogenic CO₂ Emissions (2000-2009)

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS
<http://www.globalcarbonproject.org/carbonbudget>

1.1 ± 0.7 PgC y⁻¹



7.7 ± 0.5 PgC y⁻¹ +



4.1 ± 0.1 PgC y⁻¹
47%



2.4 PgC y⁻¹
27%

Calculated as the residual of
all other flux components



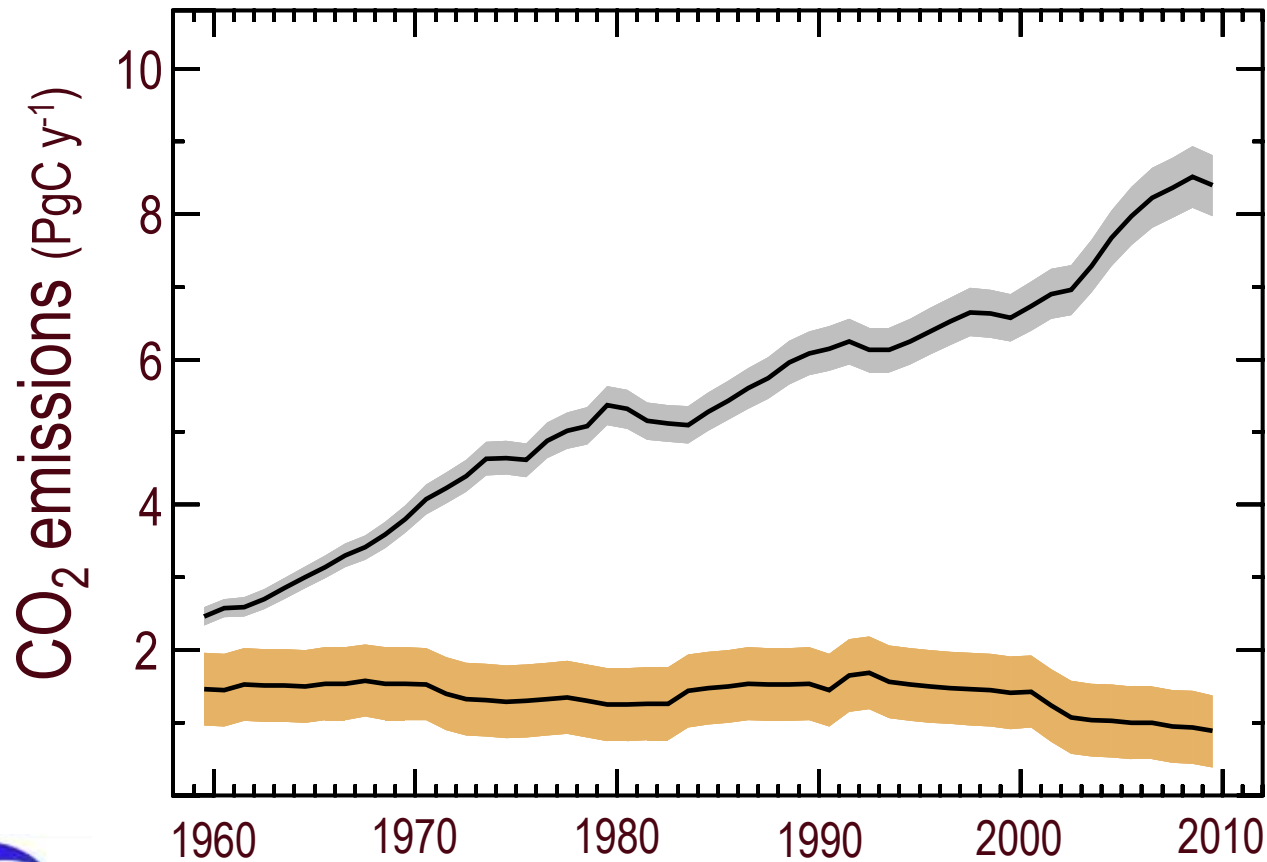
26%

2.3 ± 0.4 PgC y⁻¹

Average of 5 models



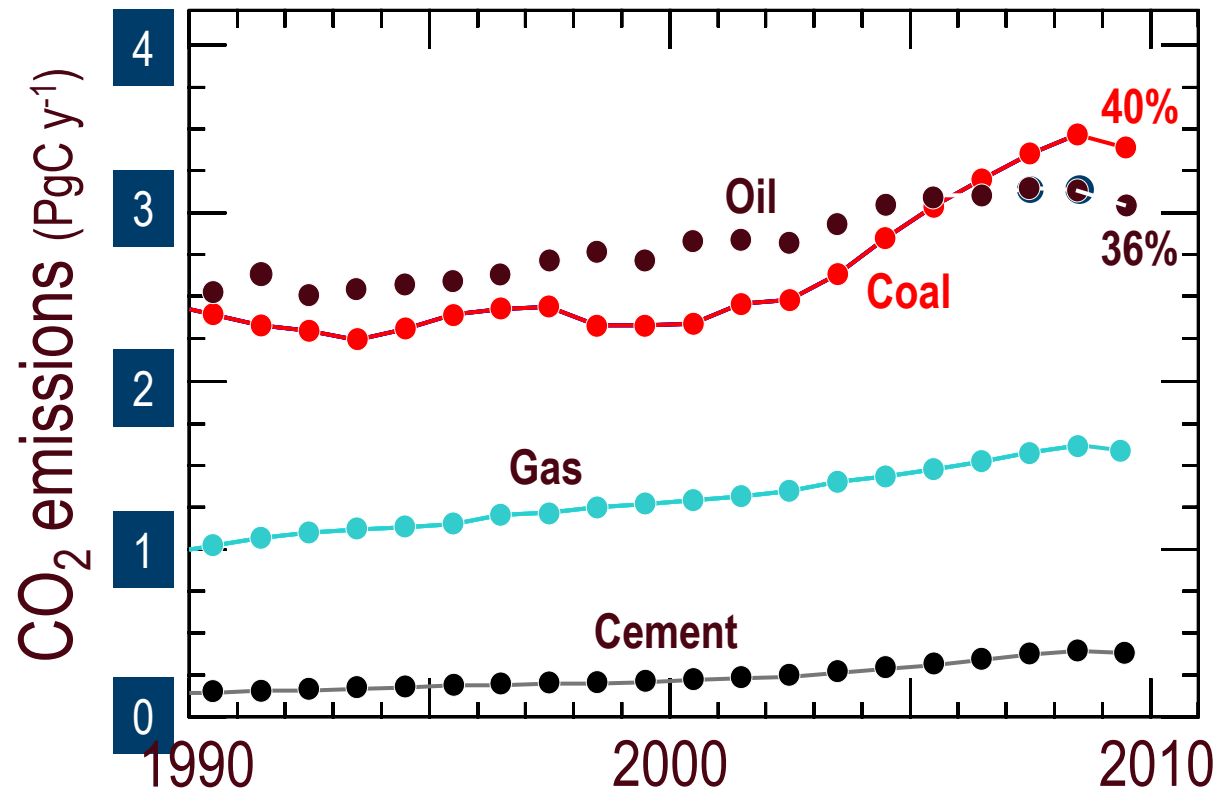
CO₂ emissions from fossil fuels and land use changes (1960-2009)



**LUC emissions now
~10% of total CO₂ emissions**



CO₂ Emissions by Fossil Fuel Type



Updated from Le Quéré et al. 2009, Nature Geoscience; Data: Gregg Marland, Thomas Boden-CDIAC 2010
<http://www.globalcarbonproject.org/carbonbudget>

Carbon Sequestration Practices for Forests

- Forestation:
 - Aforestation of agricultural land
 - Reforestation of harvested/burned timberland
- Practice changes to emphasize C storage
 - Low-input harvest methods
 - Longer rotation cycles
 - Agroforestry
- Preserve forestland from conversion
- Urban forest management

Forest Carbon Sequestration Potential

Amount of sequestration ranges depending on region, species, economic assumptions, etc.

Typical estimate for United States:

300 Tg/yr (0.3 GT/yr) at a cost of \$8.2 billion/yr

About 10 to 15 GT carbon over 50 years

Source: Stavins and Richards, 2005. The cost of US forest-based carbon sequestration. Pew Center on the Environment

Carbon Sequestration Potential Soil

Potential sequestration

- Replenish historical depletion of soil organic matter
- Agricultural soils typically have lost 30 to 40 Mg/ha of soil through decomposition and erosion
- Greatest potential to sequester C is in the most degraded soils
- Multiple benefits to replenishing organic matter – sequesters C and improves soil productivity

Carbon Sequestration Potential Soil

Agriculture (0.1 to 1.5 Mg/ha/yr)

- Conservation tillage/no-till
- Crop rotations, including agroforestry
- Improved pastures
- Manure/biosolids/biochar amendments
- Aforestation
- Technical global potential = 2 to 3 GT/yr
- Economic potential = 1.2 GT to 2 GT/yr



Chris Benedict, WSU

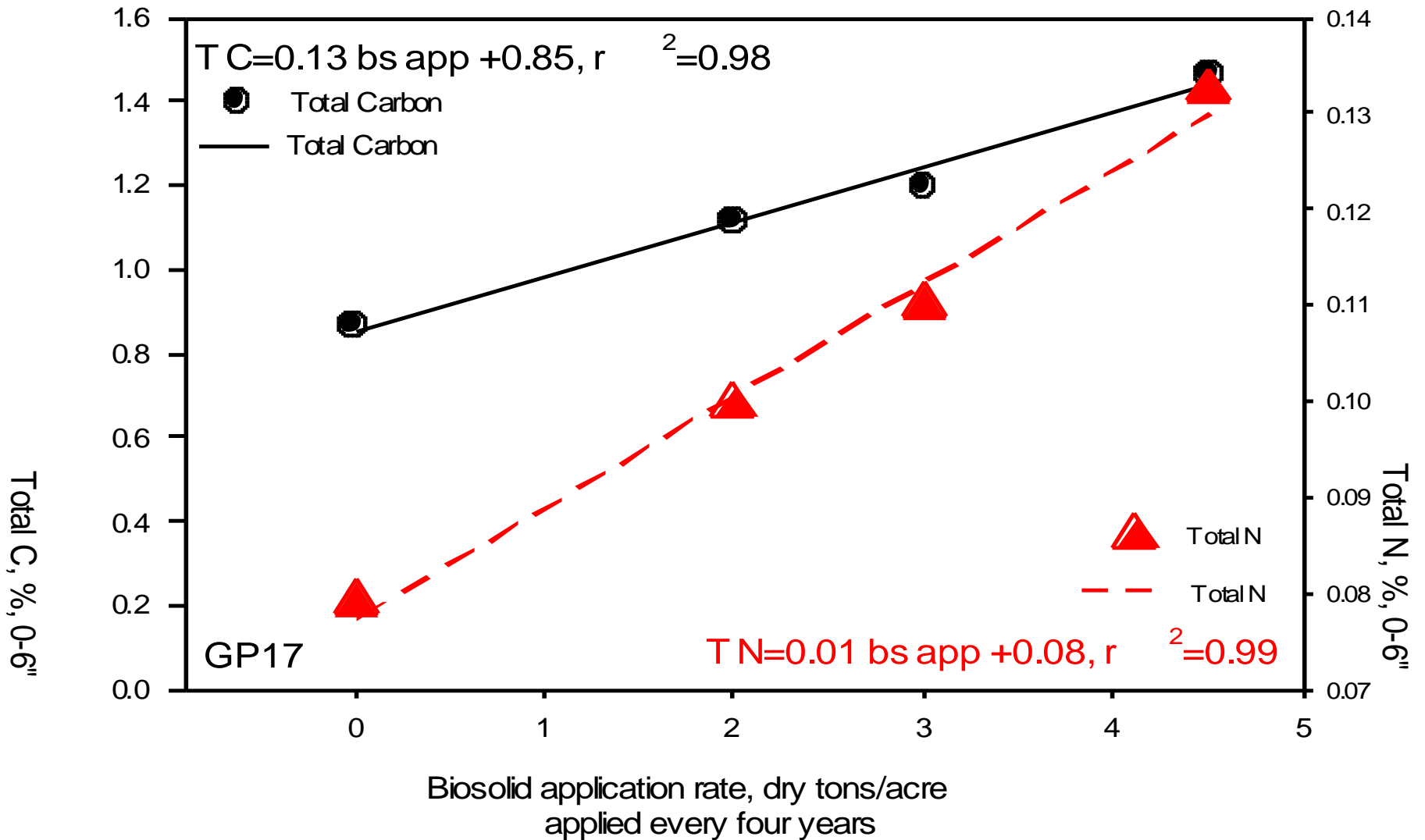
Source: Lal, 2009. Agriculture and climate change: An agenda for Copenhagen
www.ifpri.org

Carbon Sequestration Potential Soil

Urban

- Turf
- Compost and biosolids





Biosolids applied at an agronomic rate every fourth year since 1994 have increased soil C by 50% over plots receiving inorganic N.

Climate change is likely to lead to negative feedbacks in carbon cycle

- **Faster decomposition of organic matter**
- **Permafrost thawing**
- **Increased wildfire risk**
- **Will photosynthesis increase or decrease?**



Photo by Chris Figenshau, BLM Alaska Fire Service

As permafrost thaws, decomposition increases, releasing stored C as CO₂ and methane.

Katey Walter Anthony, U Alaska-Fairbanks



Climate change-related pest damage weakens and kills trees, resulting in loss of stored C through fires and decomposition





**Is there a
trade-off
between
carbon
sequestration
and N₂O
emissions?**

Carbon sequestration is not forever, but it is an important interim tool.

Part of fast cycle
Finite capacity
Reversible

Soil carbon sequestration is a win–win strategy. It mitigates climate change by offsetting anthropogenic emissions; improves the environment, especially the quality of natural waters; enhances soil quality; improves agronomic productivity; and advances food security. It is a low-hanging fruit and a bridge to the future, until carbon-neutral fuel sources and low-carbon economy take effect.

Rattan Lal