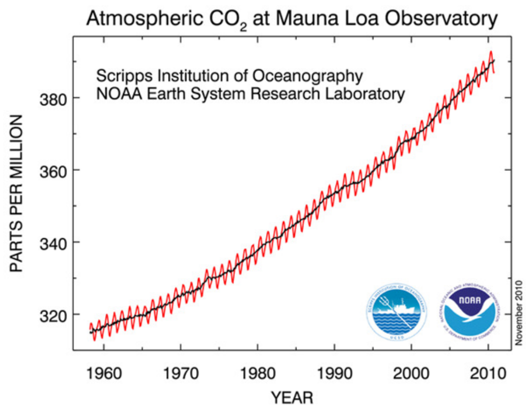
Modern global carbon cycle and terrestrial/oceanic subsidies to anthropogenic emissions

C. David Keeling, 1928-2005

Dave Keeling (Scripps Institution of Oceanography, La Jolla, California) provided the longest continuous record of atmospheric CO_2 measurements.

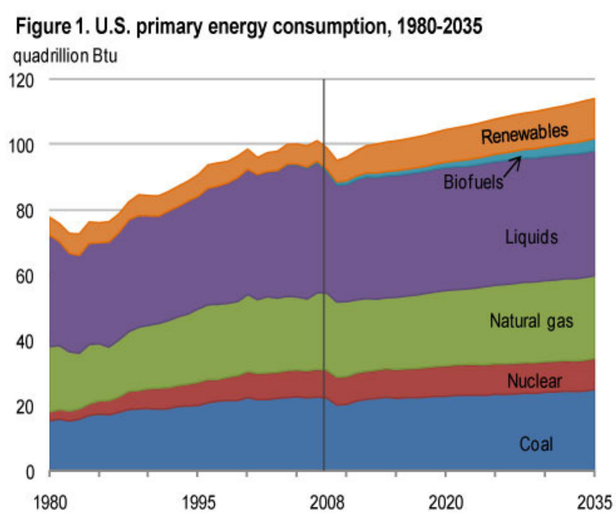


http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full

$$CH_2O + O_2 \longrightarrow \text{energy} + H_2O + CO_2$$

In recognition of this work, Dr. Keeling was awarded the Medal of Science, the highest honor the U.S. awards a scientist.

Fossil fuels are the dominant source of energy in the United States, and in the industrialized world

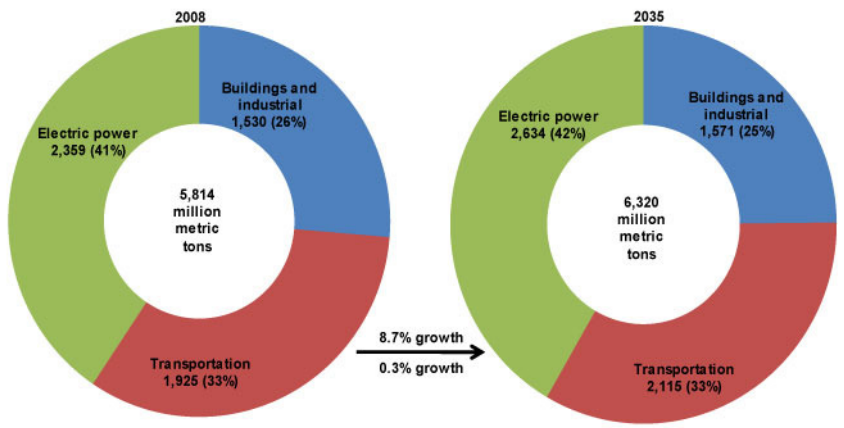


http://www.eia.doe.gov/oiaf/aeo/execsummary.html

No significant changes in energy sources are expected in the next 25 years.

Three uses of energy dominate carbon dioxide emissions

Figure 4. U.S. energy-related carbon dioxide emissions, 2008 and 2035

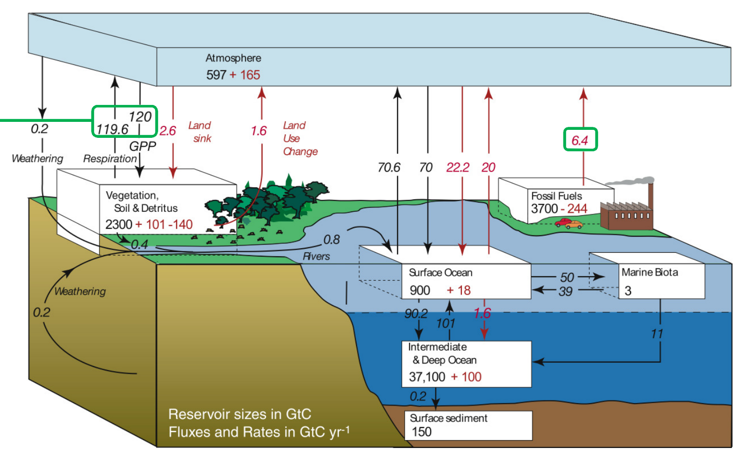


http://www.eia.doe.gov/oiaf/aeo/execsummary.html

CO_2 emissions from energy use are estimated to increase by approximately 9 % between 2008 and 2035, which is an annual increase of 0.3 %.

Global carbon cycle for 1990s

20 times greater than fossil fuel flux.



(IPCC, 2007, *Climate Change 2007: The Physical Science Basis*)
(boxes are reservoirs, arrows are fluxes, human-caused changes in red)

- Gross CO_2 fluxes between land surface and atmosphere, and ocean and atmosphere, are much greater than fossil fuel flux.
- Net CO_2 fluxes between land surface and atmosphere, and ocean and atmosphere, are smaller than fossil fuel flux.

Magnitude of carbon pools

Reservoir	Carbon Stored [Pg]
Sediments and rocks	60,000,000
Intermediate/deep ocean	38,000
Soils	1,500-2,350
Surface ocean	1,000
Atmosphere	760
Vegetation	650
Fossil fuels	3400

Terrestrial ecosystems are large carbon pools:
can potentially store a lot more.

Magnitude of carbon pool turnover times

Mean turnover time = pool size / input flux

Reservoir	Carbon Stored [Pg]
Soils	25-40
Surface ocean	11
Atmosphere	3-4
Vegetation	11
Fossil fuels	No input flux

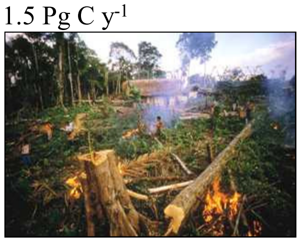
Fossil fuels are not being created.

Net uptake of CO_2 by terrestrial ecosystems and the ocean

7.5 Pg C y^{-1}

+

1.5 Pg C y^{-1}



4.2 Pg y^{-1}

Atmosphere

2.6 Pg y^{-1}

Land

2.3 Pg y^{-1}

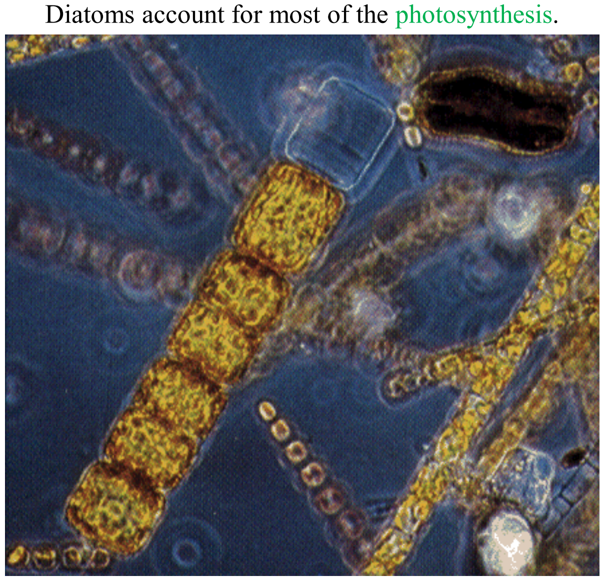
Oceans

(Canadell et al., 2007, *Proceedings of the National Academy of Science*)

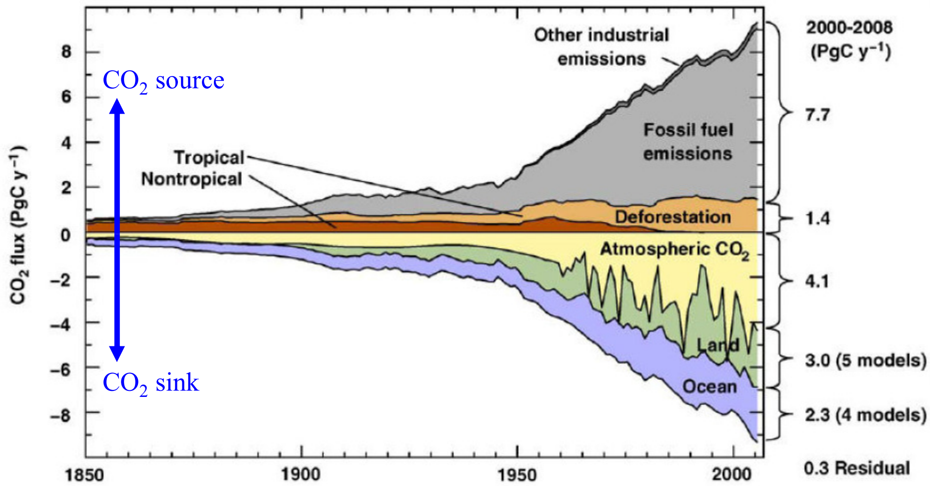
Physical and biological process account for oceanic carbon uptake

CO_2 is soluble in water.

Diatoms account for most of the photosynthesis.

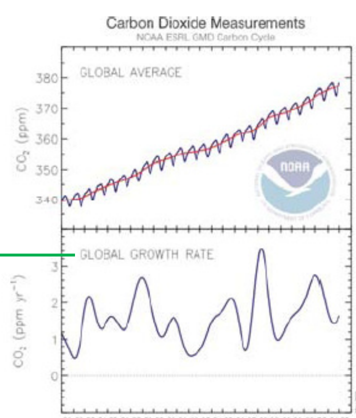


The biosphere removes about half of anthropogenic CO_2 emissions each year

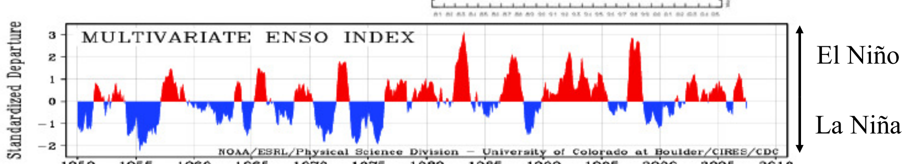


(Raupach and Canadell, 2007, *Current Opinion in Environmental Sustainability*)

Biosphere CO_2 uptake is variable from year to year, and related to climate

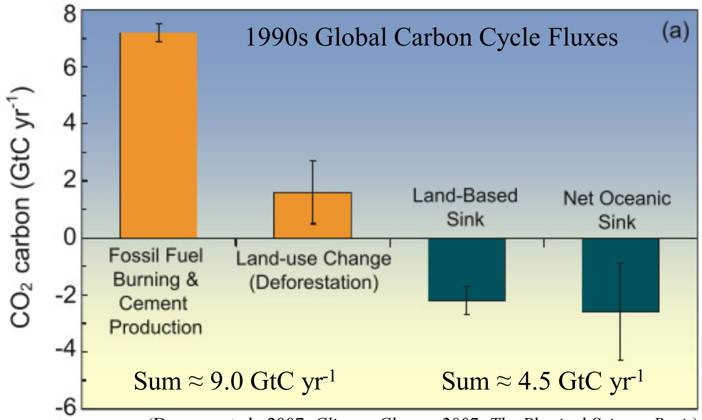


Growth rate of CO_2 in the atmosphere is the increase of CO_2 over a single year; calculated from the slope of CO_2 concentration in the atmosphere.



During El Niño years, precipitation in South America and Southeast Asia is lower than normal.

Net uptake of CO_2 by terrestrial ecosystems and the ocean

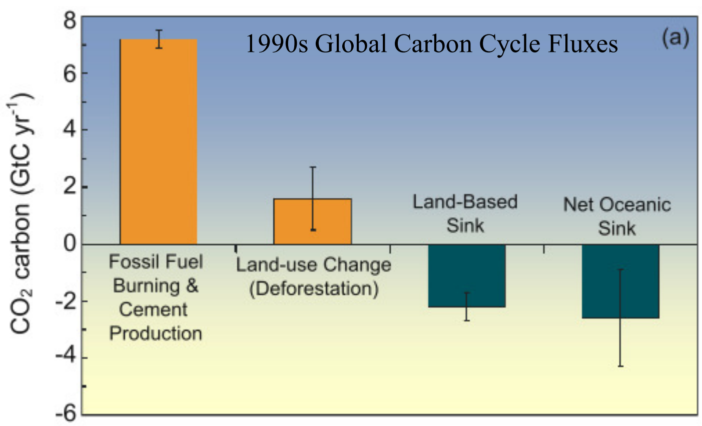


(Denman et al., 2007, *Climate Change 2007: The Physical Science Basis*)

Atmospheric increase ≈ 4.5 GtC yr^{-1} (4.5 x 10^{15} g C yr^{-1})

- Land surface and ocean C sinks: difference between large opposing biological fluxes.
- At current, CO_2 uptake (photosynthesis) is greater than release (respiration).
- Changes in photosynthesis and respiration will likely have an impact on atmospheric CO_2.
- Responses of photosynthesis and respiration to future changes is uncertain.

Net uptake of CO_2 by terrestrial ecosystems and the ocean



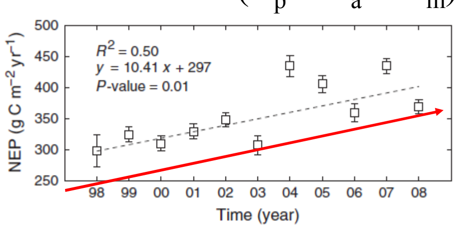
Can terrestrial ecosystems and oceans continue to provide a subsidy by continuing to absorb half of the fossil fuel emissions?

- Increasing atmospheric CO_2 influences plant growth.
- Plant growth is highly dependent on availability of water and nutrients.
- Plant growth and decomposition is dependent on changing temperatures.

FACE experiments suggest plant growth can become nutrient limited at high CO_2 levels

Northern hemisphere terrestrial ecosystems are a major component of the current terrestrial ecosystem carbon sink

$$NEP = GPP - (R_p + R_a + R_m)$$



(Dragoni et al., 2011, *Global Change Biology*)

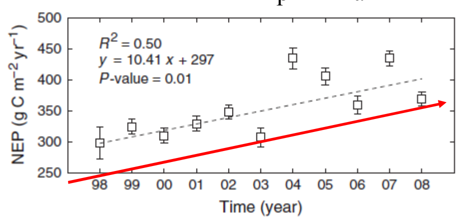
How much longer will terrestrial ecosystems in the Northern hemisphere act as carbon sinks?

This data comes from direct measurements of ecosystem/atmosphere CO_2 exchange from eddy covariance, but there are multiple other lines of evidence that Northern hemisphere terrestrial ecosystems are major carbon sink (Tans and White, 1998, *Science*).

- ^{13}C / ^{12}C ratio in atmosphere.
- O_2 / N_2 ratio in atmosphere.
- Increase in CO_2 seasonal cycle amplitude.
- Climate variability and CO_2 increase rate.
- Forest inventories.
- Ocean inventories (especially ^{14}C).

Northern hemisphere terrestrial ecosystems are a major component of the current terrestrial ecosystem carbon sink

$NEP = GPP - (R_p + R_a + R_m)$



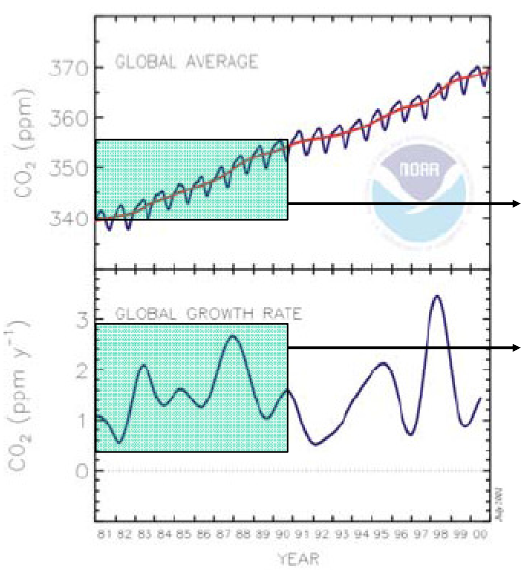
(Dragoni et al., 2011, *Global Change Biology*)

Why are terrestrial ecosystems in the Northern hemisphere acting as carbon sinks?

Possible causes of the Northern hemisphere carbon sink:

- Land use change (forest regrowth, woody encroachment, fire suppression).
- CO_2 fertilization (with no resource limitations, rising CO_2 stimulates photosynthesis).
- N fertilization (N deposition from pollution can enhance photosynthesis).
- Temperature (warming influences growing seasons and decomposition in soil).
- Water (if water is limiting, increased precipitation enhances photosynthesis).

Kyoto Protocol: Reduce greenhouse gas emissions to 5 % below the 1990 emission level

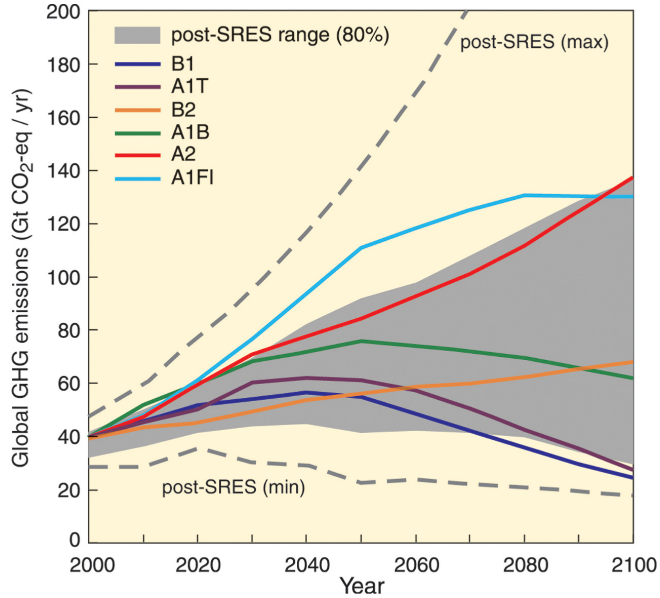


International agreement was adopted on December 11, 1997 and entered into force on February 16, 2005.

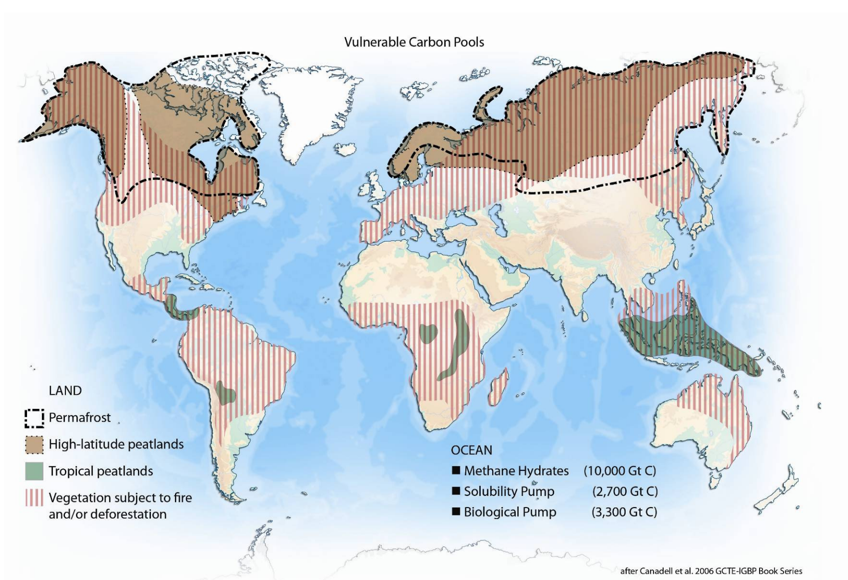
Atmospheric CO_2 increased by approximately 15 ppm during the 1980s.

Previous to 1990, CO_2 in the atmosphere was increasing by 1-2 ppm per year on average.

Projected changes in the global carbon cycle are highly dependent on future population growth and energy sources; high uncertainty



Consider the vulnerability of carbon pools in the 21st Century to temperature change: stored peats, increased fires, CH_4 hydrates



Global carbon cycle has been altered by “modern” CO_2 emissions

- Humans emit 2-3 times more CO_2 (from combustion of fossil fuel energy) in a year than the global terrestrial biosphere can store in a year.
- Is this energy consumption sustainable?
- Do we really need to use all this energy?
- Can the current level of fossil fuel energy usage be replaced with solar, wind, hydroelectric, and biofuel sources?