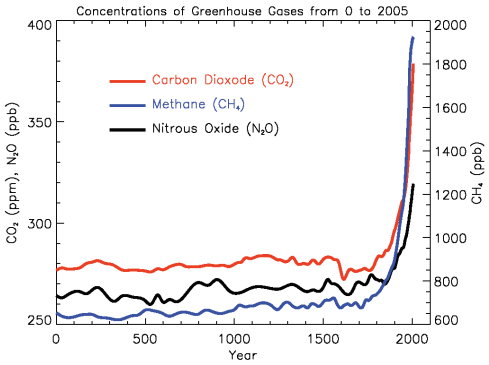
Climate Variability and Climate Change

1. Definitions
   - The Climate System; Natural and Forced Variability
2. Natural Variability
   - North Atlantic Oscillation, El Nino/Southern Oscillation
3. Forced Change (natural)
   - Volcanic Eruptions (scattering particles)
   - Changes in the Solar Luminosity
4. Forced Change (human)
   - Burning of fossil fuels (increasing GH gases)
   - Burning of biomass (scattering particles)

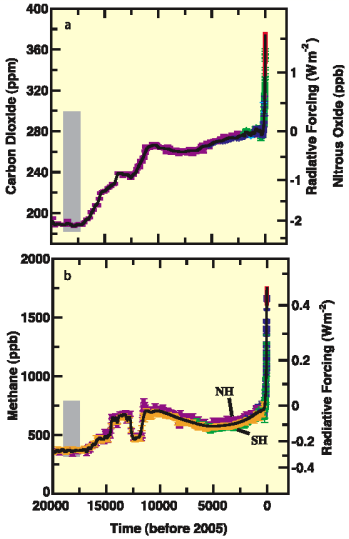
Forced Change: Three Important GH gases influenced by human activity

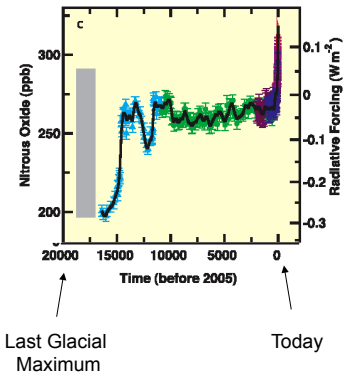


FAQ 2.1, Figure 1. *Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)*

IPCC 2007

Human Forcing: Changes in GH gases



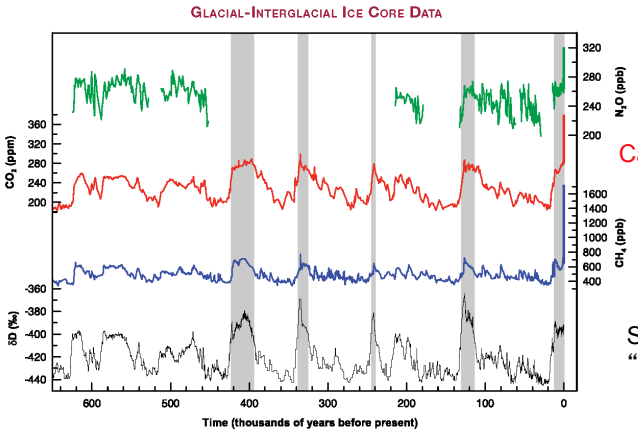


Last Glacial Maximum

Today

Grey bar = maximum range seen over glacial cycles

Forced Change: Three Important GH gases influenced by human activity



Nitrous Oxide N_2O

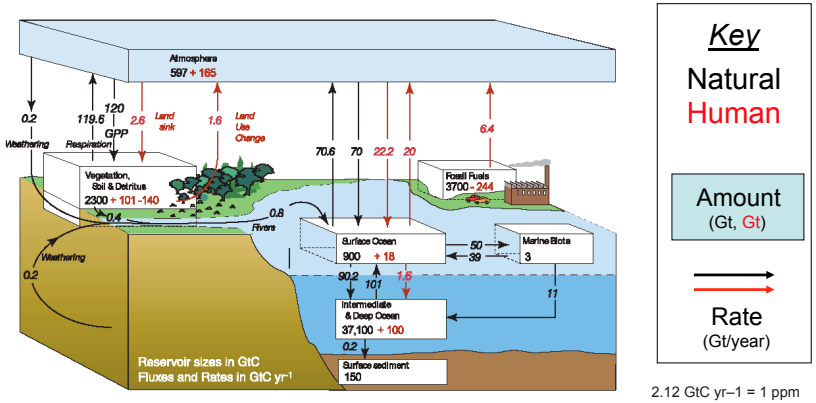
Carbon Dioxide CO_2

Methane CH_4

South Pole "Temperature"

Figure TS.1. *Variations of deuterium (δD) in antarctic ice, which is a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in air trapped within the ice cores and from recent atmospheric measurements. Data cover 650,000 years and the shaded bands indicate current and previous interglacial warm periods. {Adapted from Figure 6.3}*

The Carbon Cycle is complex

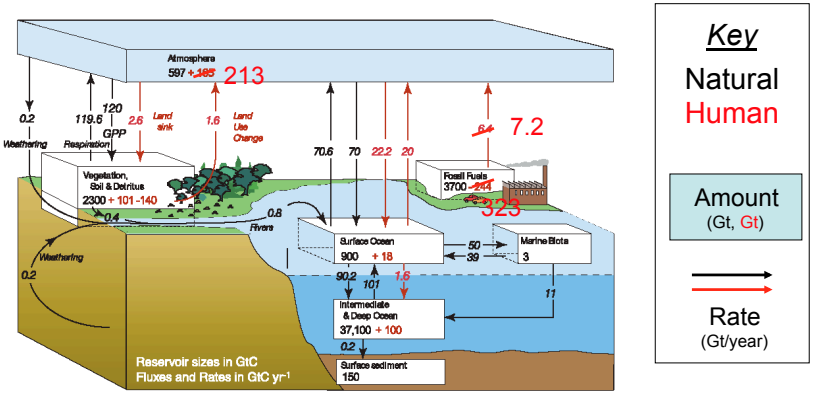


2.12 GtC yr–1 = 1 ppm
1 Gt = billion tonnes

Where is the carbon *circa 1990AD*?

Ocean (non-biota) 38,150 + 118 Gt		Ocean Biota	3
Land Biosphere	2300 - 39	Atmosphere	600 + 165
Fossil Fuels 3700 - 244		Rocks	gobs

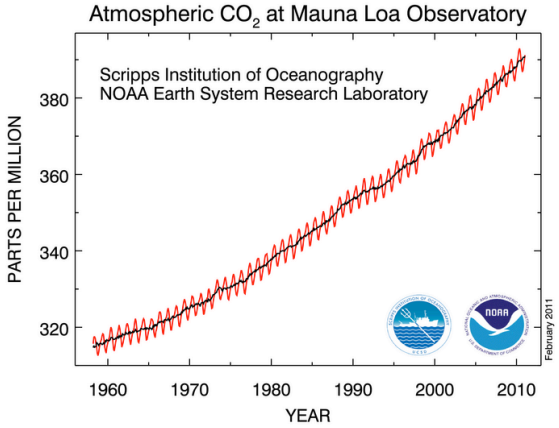
The Carbon Cycle is complex



Where is the carbon *circa ~~1990AD~~ 2005AD*?

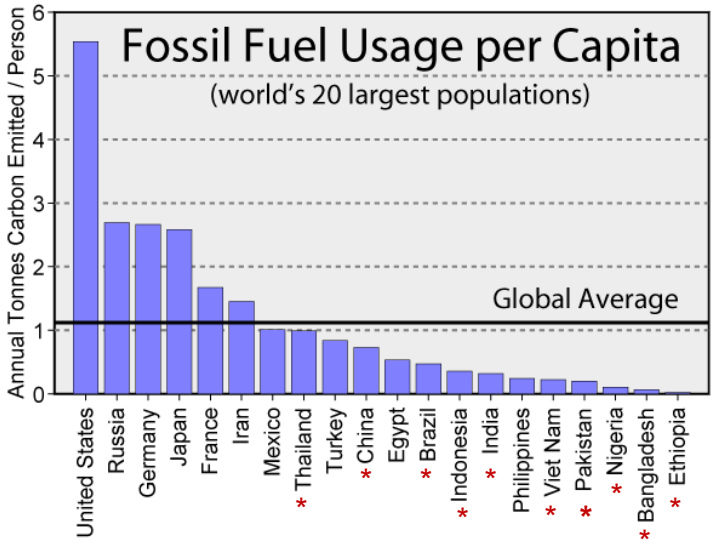
Ocean (non-biota) 38,150 + ~~118~~ + 145		Ocean Biota	3 213
Land Biosphere	2300 - ~~39~~ - 28	Atmosphere	600 + ~~165~~
Fossil Fuels 3700 - ~~244~~ - 323		Rocks	gobs

Atmospheric Carbon Dioxide



•Carbon Dioxide is increasing because of the burning fossil fuels (85%) and deforestation (15%)

– 25% increase in the past 50 years; 10% increase since 1990;



* = Countries most affected by Global Warming

How do we know the increase in CO_2 is due to human activity?

- Inventory industry and government: how much coal and oil is sold each year?
- Look at isotopes of carbon in the atmosphere carbon dioxide
  - Cosmic rays create a little bit of C^{14} in the atmosphere, and plants take this in along with lots of normal carbon (C^{12})
  - Fossil fuels have no C^{14} because it is old (all C^{14} has decayed to C^{12})
  - So adding CO_2 to the atmosphere from burning fossil fuels will cause the atmospheric C^{14}/C^{12} ratio to decrease over time.
- Look at how oxygen in atmosphere has changed in the atmosphere
- Inventory industry: how much cement is produced each year?

Human Forcing: Carbon Dioxide

Sources and Sinks of Carbon to the Atmosphere

	1980s	1990s	2000–2005
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Fossil carbon dioxide emissions	5.4 ± 0.3	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows			
Land use change flux	1.4 (0.4 to 2.3)	1.6 (0.5 to 2.7)	NA
Residual land sink	–1.7 (–3.4 to 0.2)	–2.6 (–4.3 to –0.9)	NA

[3] Fossil CO_2 emissions include those from the production, distribution and consumption of fossil fuels and from cement production. Emission of 1 GtC corresponds to 3.67 $GtCO_2$.
[4] As explained in Section 7.3, uncertainty ranges for land use change emissions, and hence for the full carbon cycle budget, can only be given as 65% confidence intervals.

Units are Giga tonnes of Carbon per year

(1 Gt = 10^9 tonnes; 1 tonne = 2200 lbs)

Human input (burning of fossil fuel) is increasing

Human Forcing: Carbon Dioxide

Sources and Sinks of Carbon to the Atmosphere

	Overall *Gain* (1750-2005)	Overall Rate (1750-2005)	Today's Rate (2000-2005)
Emission (Fossil Fuel & Cement) + Land Use	323 +160 Gt	1.3+0.7 Gt/ year	7.2 FF +1.6 (land use) Gt/year
In Atmosphere	213 Gt	0.8	4.1
In Ocean	145 Gt	0.5	2.2
In Land	125 Gt	0.4	2.5

Amount presently in atmosphere: ~ 833 Gt

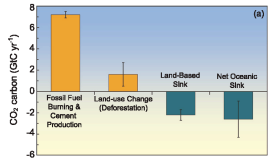
Forced Change: Three Important GH gases influenced by human activity

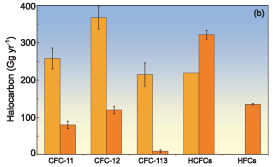
Gas	Human Source	Pre-Indust. Value	2005	RF in 2000 (W/m^2)
Carbon Dioxide CO_2	Burning Fossil Fuel & Cement Production	280 ppm	379 ppm	+1.66
Methane CH_4	Rice agriculture, livestock, landfills	700 ppb	1774 ppb	+0.48
Nitrous Oxide N_2O	Agriculture (fertilizer)	270 ppb	319 ppb	+0.16

Compare to solar (+/- 0.12 W/m^2) or volcanic (~ 2 W/m^2)

For some GH gases, some human sources are comparable to Nature's sources

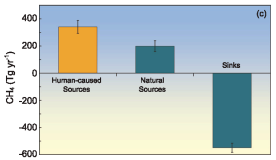
CO_2

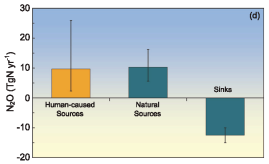




CFCs

CH_4





N_2O

Human

Nature

Human Forcing: Other GH gas changes

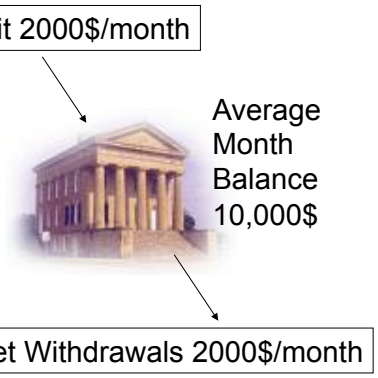
- Tropospheric Ozone (pollution and volatile organic carbon emission from planted forests): RF ~ +0.35 W/ $m^{2)}$
- CFCs and HCFC (industrial) RF ~ + 0.35

Tool: Residence time

- The residence time scale is the typical time it takes something to move through a reservoir when the system is in equilibrium (standard definition)
- It can also be though of as the time it takes to see significant changes in a reservoir, if the inputs or outputs change (non-standard definition)

Tool: Residence time

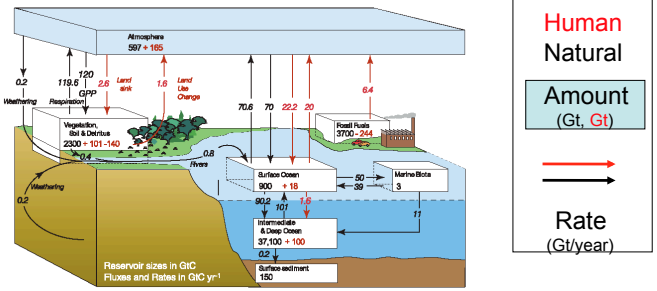
- For example, you have 10,000$ in your bank account. You add 2000$ per month to balance your monthly expenses of 2000$.
- What is the residence time of a typical dollar in your bank account?



Residence time = 10,000$ / (2000$/mo) = 5 months

Tool: Residence time

Residence time is a characteristic time for seeing large changes in some quantity. Another example: What is the residence time fossil fuel reservoir?



Key

Human
Natural

Amount
(Gt, Gt)

Rate
(Gt/year)

Residence time = amount / rate of input
= 3700 Gt / 6.4 Gt per year = 580 yrs

Human Forcing: Aerosols

Human activity puts small particles in the troposphere that greatly affect the Earth's radiation balance

- Sulfates from the burning of coal
  - Direct effect: reflects visible light
  - Indirect effect: increases albedo of clouds
- Soot (organic and black carbon) from the burning of biomass
  - Absorbs visible light (warms atmosphere and cools surface)
- Industrial dust

Human Forcing: Aerosols

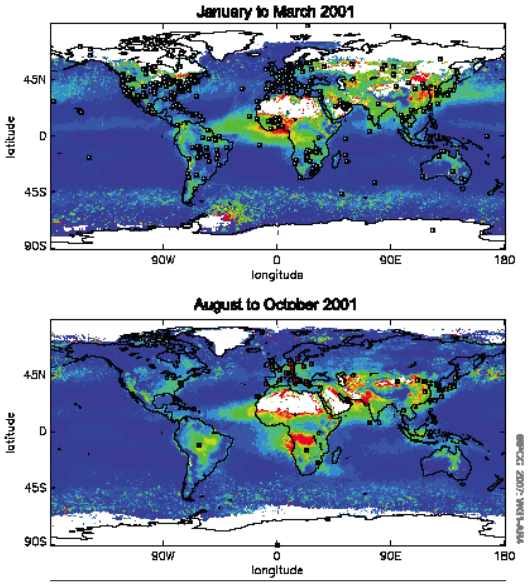
- Aerosols injected into the troposphere settle out quickly (about 2-5 days)
  - Mixing of air that brings it in contact with the ground
  - Scavenged by raindrops
- Hence, aerosols inject into the troposphere don't get far from the source

Distance = wind speed x residence time

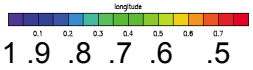
= 15 m/s x (3 x 24 x 60 x 60 s)

= 4×10^6 m = 4000 km

Aerosols in the atmosphere (human and natural)

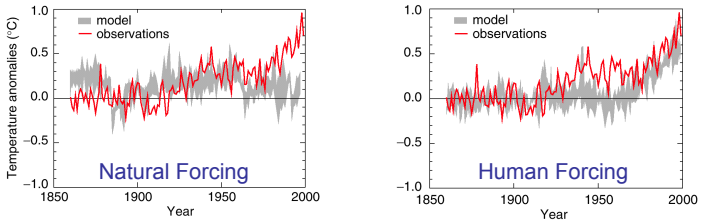


Fraction of solar energy in mid-visible band reaching the surface (when no clouds are present)



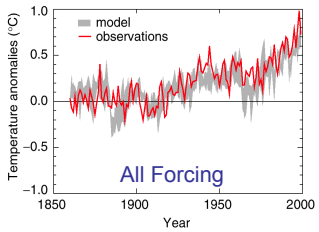
Climate Variability and Climate Change

Modeled and Observed Temperature Change 1850-2000



<u>Natural Forcing</u>
Sun, Volcanic

<u>Human Forcing</u>
Fossil Fuel and Biomass Burning



Next: How we determine which changes are due to *natural variability* and which changes are due to *forcing (natural and human induced)*?