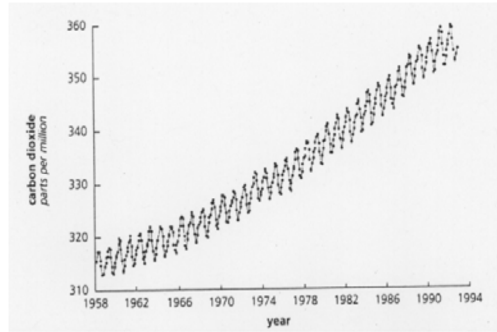
The Carbon Cycle

I. Introduction: Changes to Global C Cycle (Ch. 15)
II. C-cycle overview: pools & fluxes (Ch. 6)
III. Controls on GPP (Ch. 5)
IV. Controls on NPP (Ch. 6)
V. Controls on NEP (Ch. 6)

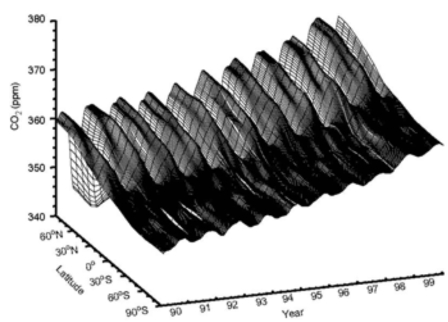
Powerpoint modified from Harte & Hungate (http://www2.for.nau.edu/courses/hart/for479/notes.htm) and Chapin (http://www.faculty.uaf.edu/fffsc/)

Rising atmospheric CO_2

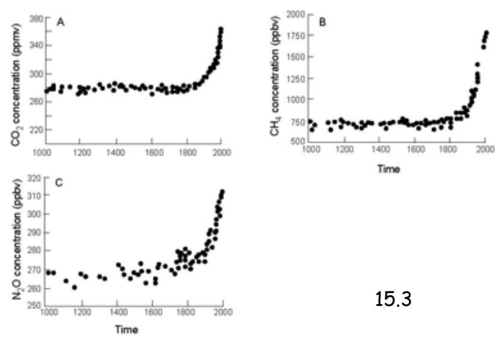


Schlesinger 1997

-Atmospheric CO2 concentration is rising
-Significant effects of biospheric uptake/release

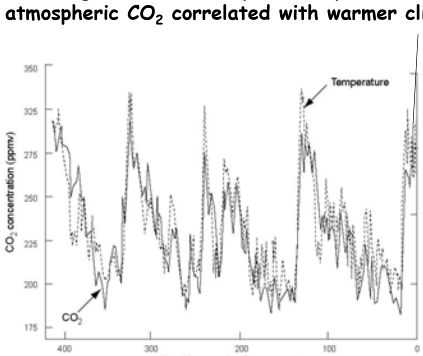


Most major greenhouse gases are increasing in atmospheric concentrations



15.3

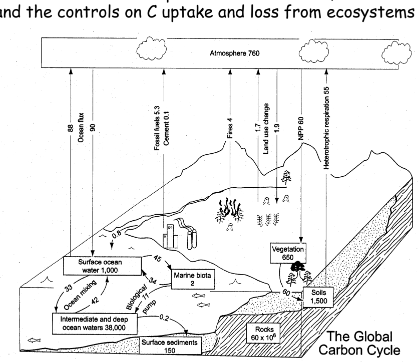
-CO_2 at highest level in past 650,000 yrs.
-CO_2 increasing faster than any time in past 650,000 yrs
-High atmospheric CO_2 correlated with warmer climates



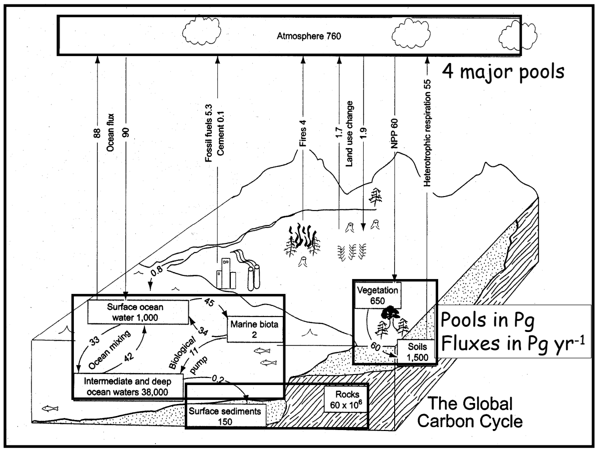
15.2

Global C Cycle

To understand fates of C and potential remediation, we need to understand the controls on C uptake and loss from ecosystems

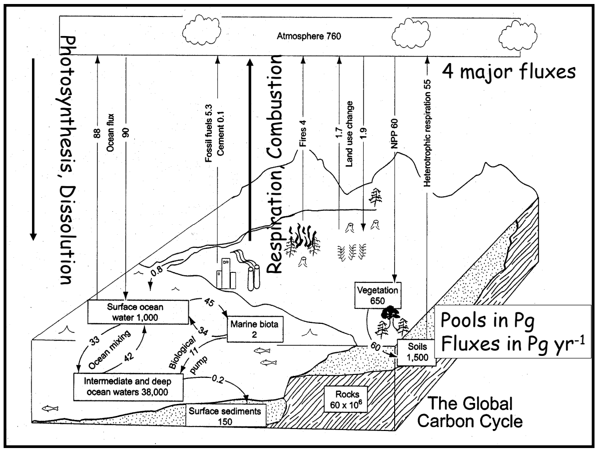


15.1



Major Global C pools

- **Atmosphere, land & oceans contribute to cycling over decades-centuries.**
- **Rocks have the largest pool of C, but changes are small on these time scales**
- **Main pools on land are organic C (terrestrial biota & SOM) (~3x atmosphere)**
- **Main pool in oceans is dissolved inorganic C. Aquatic biota are a relatively small pool.**



Major global C fluxes

- **Terrestrial systems: fires, het resp roughly balance NPP**
- **Oceans take up ~2 Pg more than they release→deep storage (biol & solubility pumps)**
- **Humans adding C to atmosphere through fossil fuels & land use change.**

Global Carbon Budgeting
How much have we released in fossil fuel burning?
Where is it all going?

	$\underline{\text{Pg C yr}^{-1}}$
Sources:	***7.1 ± 1.1***
Fossil Fuel Burning	5.5 ± 0.5
Land use change	1.6 ± 1.0
Sinks:	***7.1***
Atmospheric accumulation	3.2 ± 0.2
Oceanic Uptake	1.6 ± 1.0

The "Missing Sink" 2.3
Oceanic? Terrestrial? Why?

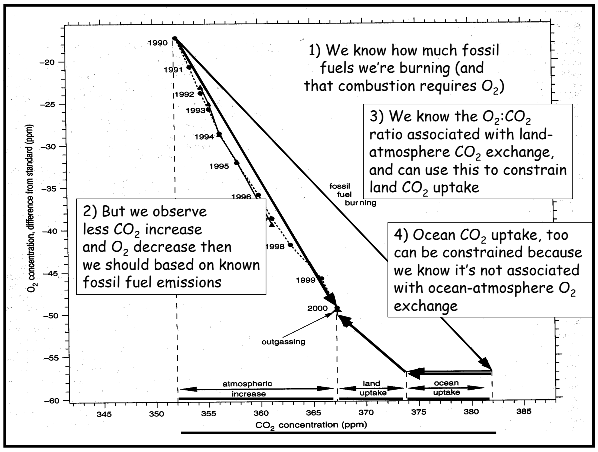
How do we figure this out?

Partitioning terrestrial and oceanic carbon exchange:
a multiple tracer approach

1) Oxygen
   A) Land-atmosphere CO_2 exchange is immediately coupled with O_2 exchange: photosynthesis produces O_2, respiration consumes it

   B) Ocean-atmosphere CO_2 exchange is physical dissolution, so oceanic CO_2 uptake does not influence atmospheric O_2

   C) Thus, the relationship between the CO_2 and O_2 content of the atmosphere provides a fingerprint of terrestrial and oceanic CO_2 exchanges



Partitioning terrestrial and oceanic carbon exchange: a multiple tracer approach

2) Carbon Isotopes

A) Terrestrial photosynthesis fractionates against ^{13}C

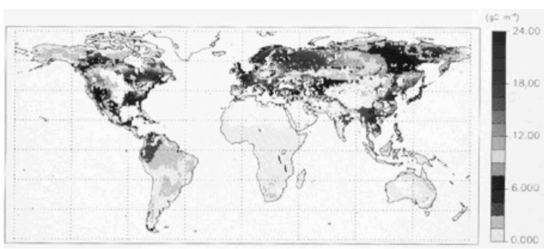
Overall average fractionation currently estimated at about 18 per mil (‰) – so far, this is a rough global estimate of the combined influences of C3 vs. C4 vs. CAM, water stress, etc.

B) Oceanic CO_2 uptake involves very small fractionation effects

C) Thus, changes in the ^{13}C content of the atmosphere indicate the extent to which concurrent CO_2 variations can be ascribed to terrestrial or oceanic activity

Potential Terrestrial C sinks

Atmospheric N Deposition Fertilizes Ecosystems, Causing A Large Global Carbon Sink (as much as 1.6 Pg C yr^{-1})



Townsend et al. 1996, Holland et al. 1999

Potential Terrestrial C sinks

2. CO_2 fertilization

3. Plant growth from land use change
- Afforestation: Previously cultivated lands have been abandoned throughout the temperate zone and are becoming forests again.
- Woody encroachment into deserts and grasslands
- Suppression of wildfires
- Changing agricultural practices promotes C storage in soils
- Wood products are C sinks…

Global Carbon Budgeting
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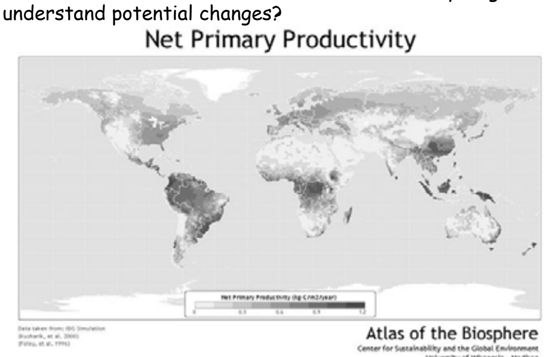
Where is it all going?

	Pg C yr^{-1}	
Sources:	***7.1 ± 1.1***	
Fossil Fuel Burning	5.5 ± 0.5	
Land use change	1.6 ± 1.0	
Sinks:	***7.1***	
Atmospheric accumulation	3.2 ± 0.2	
Oceanic Uptake	1.6 ± 1.0	
Terrestrial Uptake	2.1	
CO_2 fertilization		1.0 ± 0.5
Forest Regrowth		0.5 ± 0.5
Nitrogen Deposition		0.6 ± 0.3
Other	0.2 ± 2.0	

-Long-term behavior of terrestrial sink is unknown
- What do we need to know about terrestrial C cycling to understand potential changes?

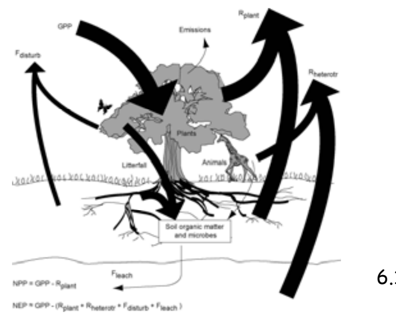


II. C-cycle overview (within-ecosystem C pools and fluxes)

- **A. Terms**
  1. Biomass vs. productivity
  2. GPP vs. NPP vs. NEP
  3. Secondary production
- **B. C-cycle schematic**
  1. Simple
  2. Complete

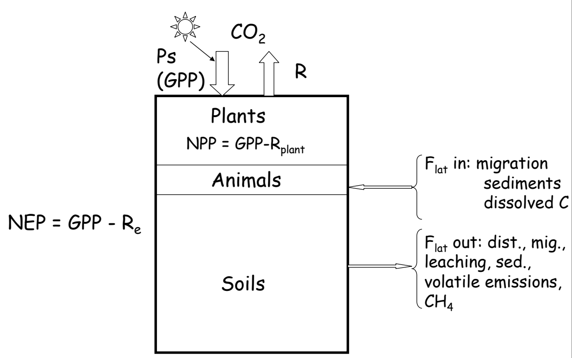
Overview of ecosystem carbon cycle

Inputs: plant photosynthesis (GPP)
Internal cycling: litterfall, herbivory, consumption, mortality
Outputs: plant, animal, microbial respiration; volatile emissions (small); leaching (~small); disturbance (fire, harvest)



6.1

Carbon Cycle – The Simple Version



Primary production

- **Gross primary production (GPP) = plant photosynthesis**
- **Net primary production (NPP)**
  - $NPP = GPP - R_{plant}$
  - $NPP = \Delta Plant/\Delta t + C_{lost}$
  - C_{lost}: exudates, vol. emissions, herbiv., tissue turnover, disturbance (fire, harvest)
- **NPP is total energy available to rest of ecosystem**
- **In practice, NPP is hard to measure**
  - $\Delta Plant/\Delta t$ – misses C_{lost} (~30% of total)
  - Some pathways more important than others
  - Difficulties belowground

Primary production

- **Net ecosystem production (NEP)**
  - $NEP = GPP - R_{ecosyst}$ (note change from book, see Chapin et al. 2006)
  - $R_{ecosyst}$ = Rplant + Rhet
  - $NEP = NPP - R_{het}$
  - $NEP = (\Delta Plant + \Delta Het + \Delta SOM)/\Delta t$
  - $NECB = NEP +/- F_{lat}$ (note change from book, see Chapin et al. 2006
  - NBP = net biome production = NECB at large spatial and temporal scales.(Chapin et al. 2006)
- **Secondary production = $\Delta Het/\Delta t$**
  (see Chap. 11)

See Box 6.1

Which of these (GPP, NPP, NEP) is most relevant to long-term sequestration of CO_2 from atmosphere?

C-cycle: the somewhat more detailed version

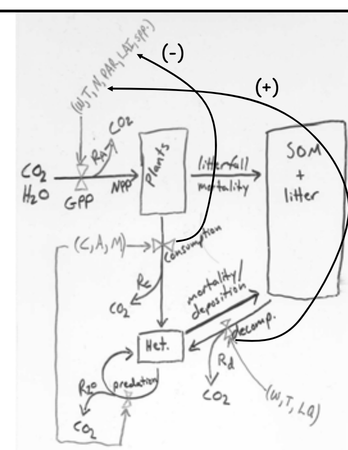
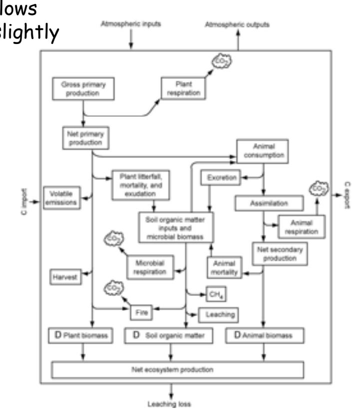


Figure from CMM follows similar pattern with slightly different structure



6.8

Main messages

- C flow is linked to energy flow
- C cycles, energy flow is one-way
- Plant production provides the fuel for the entire ecosystem
- GPP>NPP>NEP
- GPP, NPP determine how fast C taken up by ecosystem
- NEP determines how much C stored by ecosystem per unit time