Ablauf

- Stil
  - Biologische, physikalische und chemische Grundlagen
  - Wissensvermittlung Stoffkreisläufe: „key messages" und Hintergründe
  - Interaktive Fallbeispiele
  - Jederzeit Fragen, eigene Themenwünsche möglich!
  - Nachbereitung
    - Fragen am Ende der Vorlesung
    - Antworten am Beginn der nächsten Vorlesung

- Materialien
  - Folien englisch, Vorlesung deutsch
  - Vorlesungsfolien im Netz (am Abend vorher)
  - http://www.bgc-jena.mpg.de/~athuille/VorlesungStoffkreislaeufe.html

Ablauf

- Leistungsnachweise
  - Modulanmeldung: ausgefüllte Formulare an mich bis 2.7.09
  - Anwesenheit in der Vorlesung
  - Aktive Beteiligung bei Fallbeispielen und Diskussion der Fragen
  - Schriftliche Prüfung

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Überblick der Vorlesung

Stoffkreisläufe wichtiger Elemente.

16.04.09	Grundlagen. Kohlenstoffkreislauf: global, Partitionierung in Ökosystemen
23.04.09	Boden: Grundlagen, Humus und Kohlenstoffstabilisierung
30.04.09	Grundlagen: pH und Redoxchemie. Stickstoffkreislauf (1. Teil)
07.05.09	Stickstoffkreislauf (2. Teil). Phosphorkreislauf
14.05.09	Schwefelkreislauf
28.05.09	Makronährelemente

Interaktionen zwischen Stoffkreisläufen, Störungen und Anwendung

04.06.09	Kohlenstoffflüsse in Ökosystemen: Einfluss von Temperatur und Feuchte
11.06.09	Störungen in Ökosystemen
18.06.09	Nährstoffimbalancen: Versauerung, Nährstoffmangel in den Tropen
25.06.09	Nährstoffimbalancen: Eutrophierung
02.07.09	Quellen und Senken biogener Treibhausgase
09.07.09	Landnutzung und Stoffkreisläufe
16.07.09	Einfluss der Biodiversität auf Stoffkreisläufe
23.07.09	Klausur

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Contents Today

- Basics of global element cycles
  - Definitions
  - Global energy balance
  - Global water balance
- Major C stocks
  - location
  - chemical forms
  - ecosystem compartment
- Major C fluxes
  - location
  - time scale

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Basics of global element cycles

- Definitions
- Global energy balance
- Global water balance

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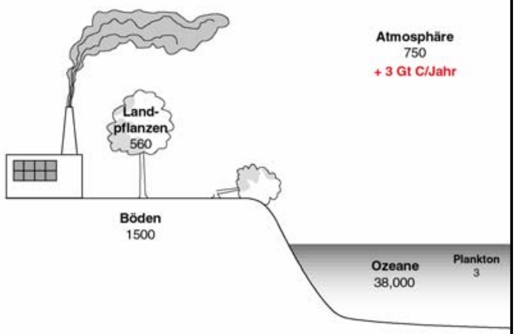
Global reservoirs

- Land
  - Geosphere
  - Soils
  - Biomass
- Oceans
  - Surface layer
  - Deep layer
  - Sediments / Geosphere
- Atmosphere



e.g. Reservoirs of Carbon [Pg]

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Exchange of matter in and between global reservoirs

- Land:
  - main driver of element cycling are biological reactions, which are themselves dependent on energy and water
  - Long and complex food webs and chains
  - Strong small-scale heterogeneity

- Ocean:
  - mainly physical and chemical reactions of elements in water, e.g. solution – precipitation, altered by biota (plankton)
  - Dominant micro-biota
  - Large-scale horizontal gradients (ocean basins), stronger vertical gradients

- Atmosphere
  - Mainly physical transport and chemical reactions
  - Reservoir with fastest dynamics
  - Spatial gradients dependent on reactivity of compounds

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Drivers and media of global element cycles

- Energy
  - Solar!
  - Planetary rotation
- Media
  - Wind / atmospheric transport
  - Water
    - Sea: ocean currents, vertical exchange
    - Sea – land: clouds, precipitation
    - Land: surface water – runoff – rivers – ground water
    - Land – sea
  - Biota, Man

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Global energy balance

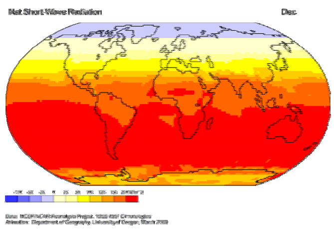
Definition

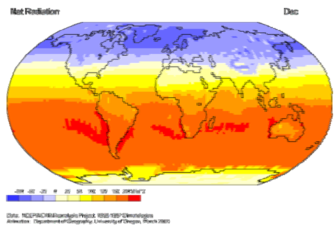
The surface energy balance is the resultant of radiative components such as incoming and outgoing short-wave and long-wave radiation, and also non-radiative components such as sensible heat, latent heat, and the change in energy storage in water or substrate on land.

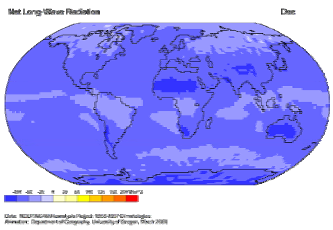
$$EB = R_{in} - R_{out} +/- R_{longwave} + H_{sens} + H_{latent} + \Delta Storage$$

Global energy balance: radiative components

- Net short-wave radiation = shortwave down – shortwave up.
- Net long-wave radiation = long-wave down - long-wave up.
- Net radiation = net short-wave radiation + net long-wave radiation.



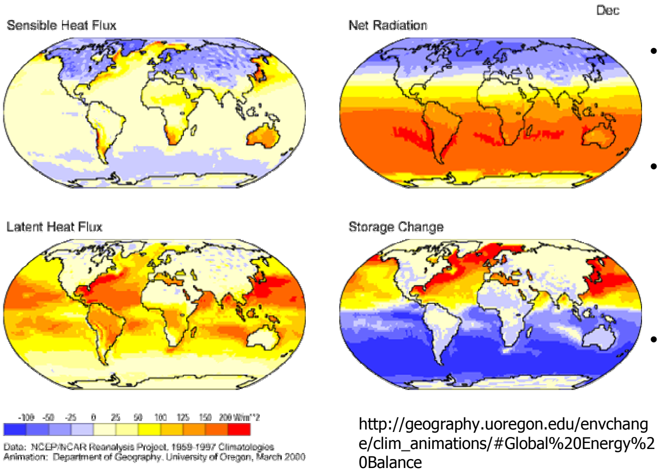




Positive values represent energy moving towards the surface, negative values represent energy moving away from the surface.

http://geography.uoregon.edu/envchange/clim_animations/#Global%20Energy%20Balance

Global energy balance: non-radiative components



http://geography.uoregon.edu/envchange/clim_animations/#Global%20Energy%20Balance

- *Sensible heat flux* = direct heating, a function of surface and air temperature.
- *Latent heat flux* = energy that is stored in water vapor as it evaporates, a function of surface wetness and relative humidity.
- *Change in heat storage* = net radiation - latent heat flux - sensible heat flux.

Positive values for sensible and latent heat flux represent energy moving towards the atmosphere, negative values represent energy moving away from the atmosphere.
Positive values for change in heat storage represent energy moving out of storage, negative values represent energy moving into storage.

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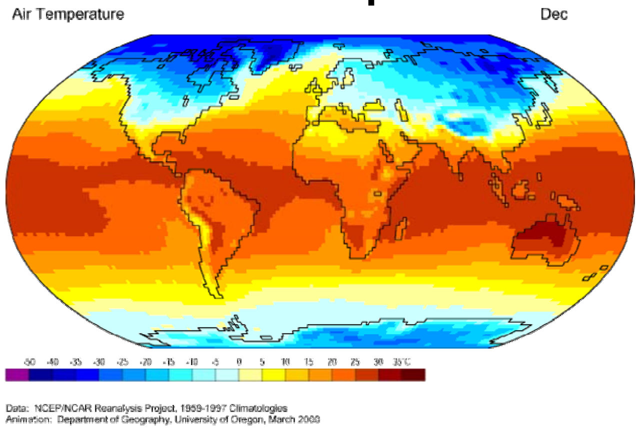
Global energy balance – the consequence: surface temperature



http://geography.uoregon.edu/envchange/clim_animations/#Global%20Energy%20Balance

- Seasonal temperature variations can be explained in terms of the latitudinal and seasonal variations in the surface energy balance. The pattern of temperatures are a function of net short-wave radiation, net long-wave radiation, sensible heat flux, latent heat flux and change in heat storage.
- Seasonal temperature variation larger over land than over ocean.

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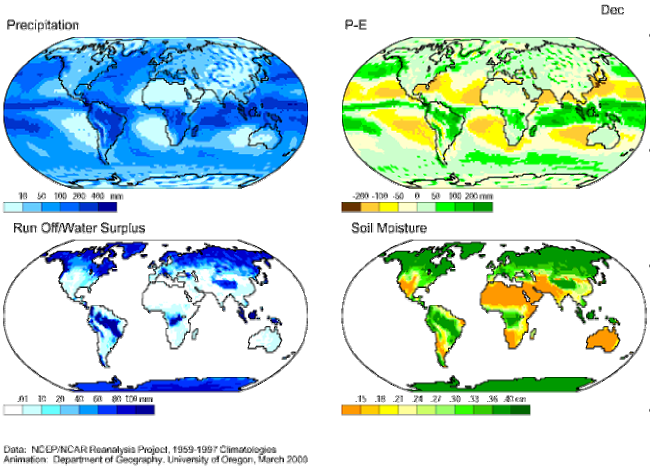
Global water balance

- The water balance is the inflow, outflow, and storage of moisture on the earth's surface.
  The source of inflow is precipitation, outflow is evaporation, transpiration and runoff, and an example of storage is soil moisture.

$WB = W_{in} - W_{out} + \Delta Storage$
$W_{in} = P$
$W_{out} = E + P + R$

http://geography.uoregon.edu/envchange/clim_animations/#Global%20Energy%20Balance

Global water balance



- Precipitable water vapor is a measure of available moisture in the atmosphere.
- *Precipitation* rate is the actual measurement of precipitation at the surface.
- Precipitation-Evaporation *(P-E)* represents the difference between precipitation and evaporation.
- *Runoff/Water surplus* are measurements of outflow of moisture.
- *Soil moisture* represents the pattern of storage of moisture at the surface.

http://geography.uoregon.edu/envchange/clim_animations/#Global%20Energy%20Balance

Questions

- What is latent heat?
- How does the seasonal variation differ between land and ocean:
  - Net radiation
  - Sensible heat
  - Latent heat
- What are storage mechanisms for the regional water balance?
- How does the sun affect global element cycles?
  - Directly
  - Indirectly

Schwerpunkt der Vorlesung: Biogeochemische Stoffkreisläufe

- Wasser, Energie: Teil der Hydrologie und Bodenphysik
- C, N, P, S, ...: Hier v.a. Terrestrische Ökosysteme

Carbon cycle

- Major C stocks
  - location
  - ecosystem compartment
- Major C fluxes
  - location
  - time scale

Key messages: C stocks

- Most of C is stored in lithosphere – inactive
- Focus here: „active" C, which is reactive in <1000 years: atmosphere, biosphere, ocean
- „Active" C reservoirs: ocean >> soil > atmosphere > land vegetation
  - Land biomass: most C in tropical forests
  - Soil C: most in organic soils and boreal regions

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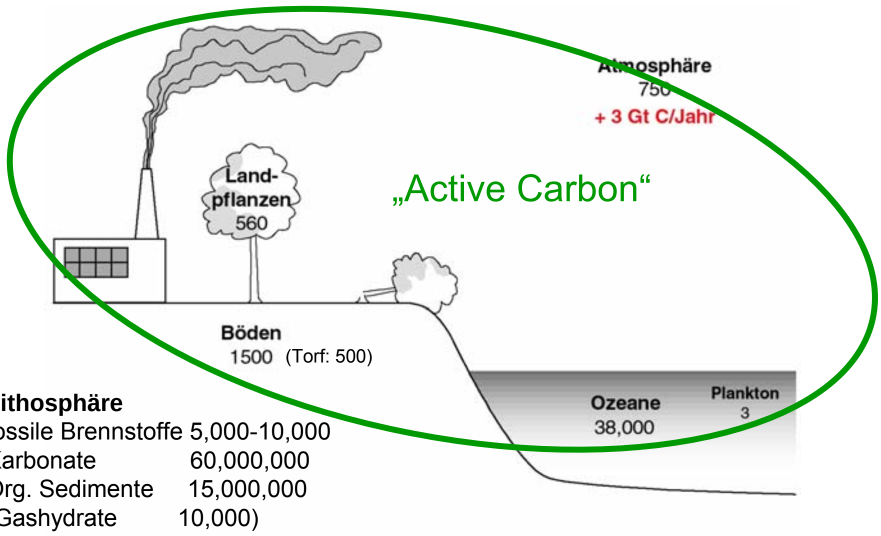
Global carbon stocks [Pg C]



Lithosphäre
fossile Brennstoffe 5,000-10,000
Karbonate 60,000,000
Org. Sedimente 15,000,000
(Gashydrate 10,000)

Schlesinger (1997) Academic Press, S.359
Berner und Lasag (1989), in Haider (1996)

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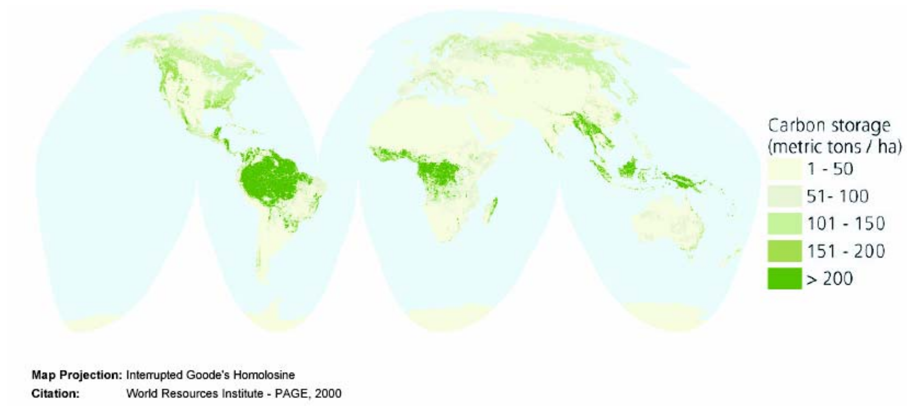
Vegetation carbon distribution



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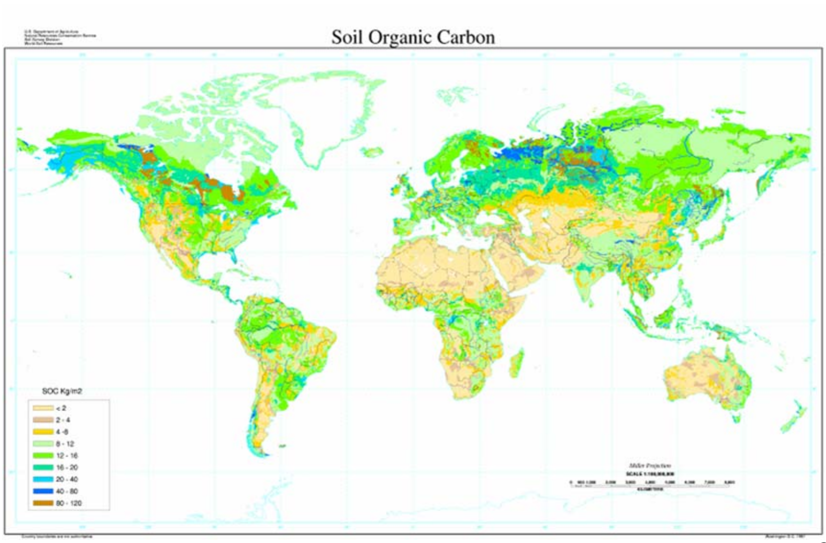
Soil carbon distribution



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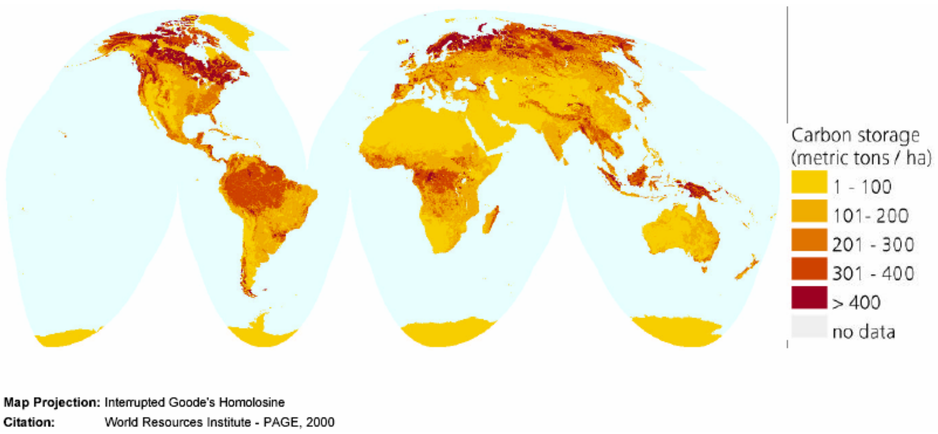
Biosphere carbon distribution



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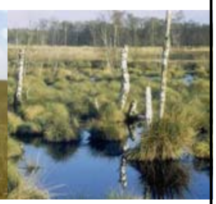
C stocks in world ecosystems

(WBGU 1998)

Vegetation type	Area [mill ha]	Carbon stocks [Gt C]			Carbon per unit area [t C ha-1]			Soil:Veg
		Total	Soil	Vegetation	Total	Soil	Vegetation	
Boreal forest	1372	559	471	88	407	343	64	5-10:1
Temperate forest	1038	159	100	59	153	96	57	1-2:1
Tropical forest	1755	428	216	212	244	123	121	1:1
Average/Total forests	4165	1146	787	359	275	189	86	
Grasslands	3500	634	559	75	181	160	21	6-30:1
Croplands	1600	131	128	3	82	80	2	50:1
Peatlands	350	240	225	15	686	643	43	15:1



Question

- What could be reasons for the differences in C stocks between
  - Ecosystem types?
  - Climatic zones?

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Key messages: C fluxes

- Net C exchange between reservoirs very small against gross C fluxes
- CO_2 increase in atmosphere is 3 GtC/year = 40% of anthropogenic emissions

- C fluxes in biosphere: „Slow-in, fast-out"
- GPP - NPP – NEP – NBP
- C balance in ecosystems: sources/sinks

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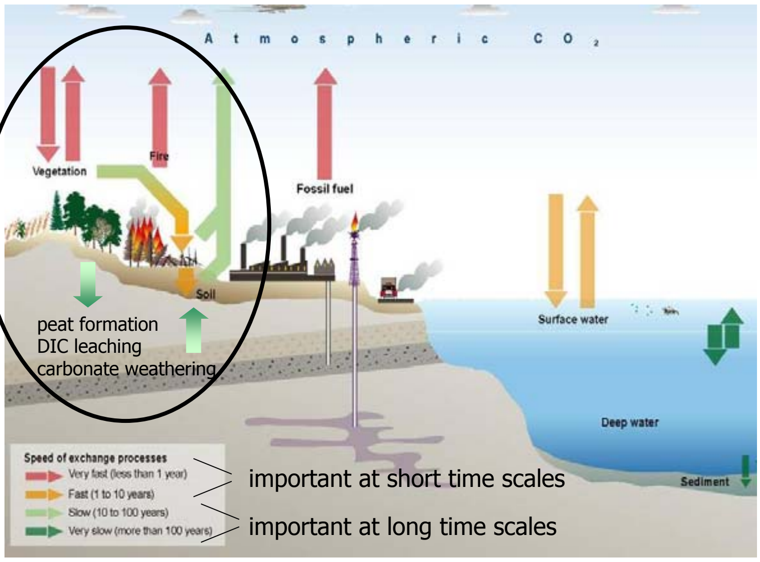
Fast and slow processes in the C Cycle



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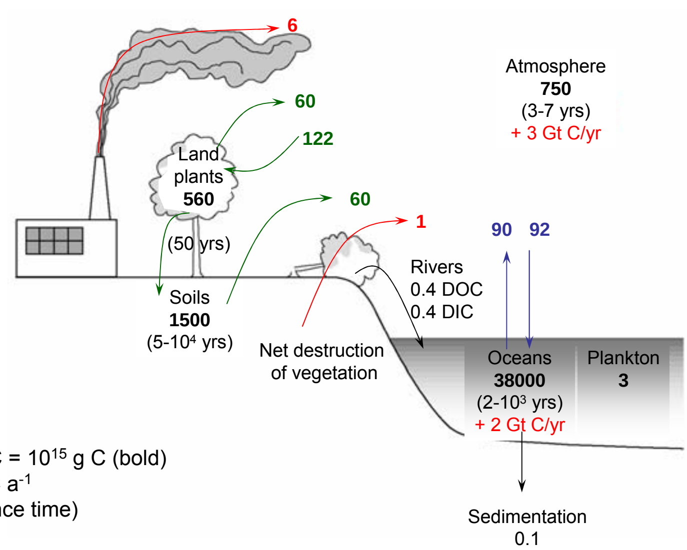
Global carbon stocks and fluxes



Stocks in Gt C = 10^{15} g C (bold)
Fluxes in Gt C a^{-1}
(mean residence time)

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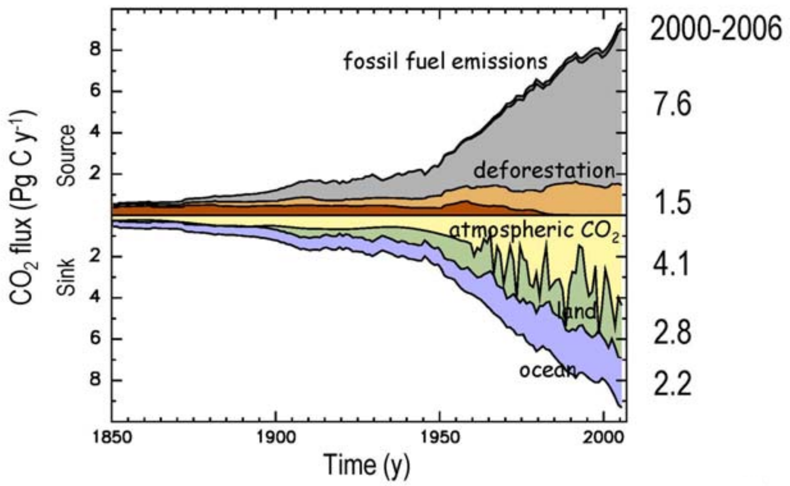
Development of Global Carbon Budget (1850-2006)



Le Quéré, unpublished; Canadell et al. 2007, PNAS

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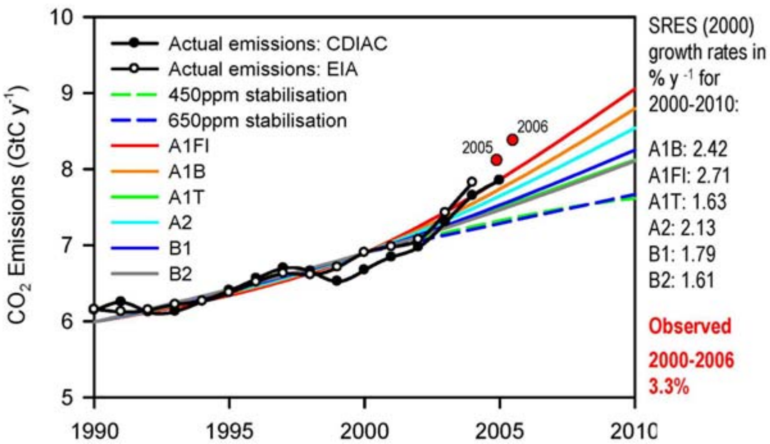
Trajectory of Global Fossil Fuel Emissions



Raupach et al. 2007, PNAS

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Partitioning of Anthropogenic Carbon Emissions into Sinks

(2000-2006)

45% of all CO_2 emissions accumulated in the atmosphere

55% were removed by natural sinks

Land removes 30%

Ocean removes 25%

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Canadell et al. 2007, PNAS

Factors that Influence the Airborne Fraction

1. The rate of CO_2 emissions.

2. The rate of CO_2 uptake and ultimately the total amount of C that can be stored by land and oceans:
   - Land: CO_2 fertilization effect, soil respiration, woody encroachment, …
   - Oceans: CO_2 solubility (temperature, biological activity, acidification, …

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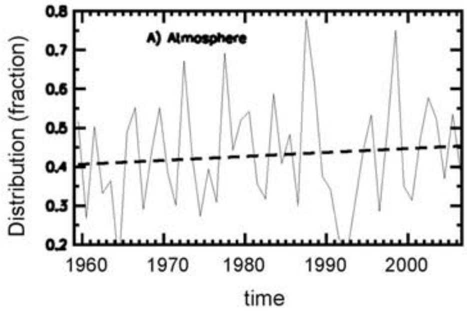
Canadell et al. 2007, Springer; Gruber et al. 2004, Island Press

Time Dynamics of the Airborne Fraction



The observed trend in Airborne Fraction was +0.25% per year (p = 0.89) from 1959- to 2006, implying a decline in the efficiency of natural sinks of 10%

Canadell et al. 2007, PNAS

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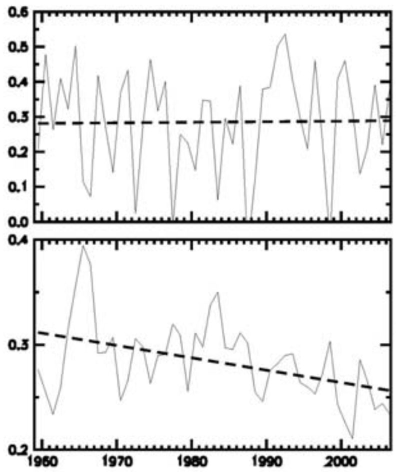
The Efficiency of Natural Sinks: Land and Ocean Fractions



Land

Ocean

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Canadell et al. 2007, PNAS

Causes of the Decline in the Efficiency of the Ocean Sink

- Part of the decline is attributed to up to a 30% decrease in the efficiency of the Southern Ocean sink over the last 20 years.
- This sink removes 0.7 Pg of anthropogenic carbon annually.
- The decline is attributed to the strengthening of the winds around Antarctica which enhances ventilation of natural carbon-rich deep waters.
- The strengthening of the winds is attributed to global warming and the ozone hole.

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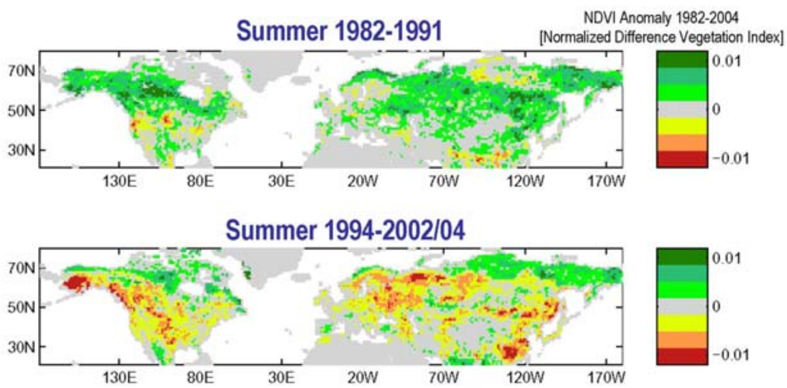
Drought Effects on the Mid-Latitude Carbon Sinks

A number of major droughts in mid-latitudes have contributed to the weakening of the growth rate of terrestrial carbon sinks in these regions.



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Angert et al. 2005, PNAS; Buermann et al. 2007, PNAS; Ciais et al. 2005, Science

Attribution of Recent Acceleration of Atmospheric CO_2 Increase

1970 – 1979: 1.3 ppm yr^{-1}
1980 – 1989: 1.6 ppm yr^{-1}
1990 – 1999: 1.5 ppm yr^{-1}
2000 – 2006: 1.9 ppm yr^{-1}

To:
- Economic growth
- Carbon intensity
- Efficiency of natural sinks

65% - Increased activity of the global economy
17% - Deterioration of the carbon intensity of the global economy
18% - Decreased efficiency of natural sinks

2007: 2.2 ppm yr^{-1}

Canadell et al. 2007, PNAS

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Questions

- What is the mechanism of the ocean CO_2 sink?
- What is the mechanism of the land CO_2 sink?
- What is the mean residence time of carbon in the
  - Atmosphere?
  - Land?
  - Ocean?
- What drives the changes in the C sink strength in
  - Oceans?
  - Land?

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