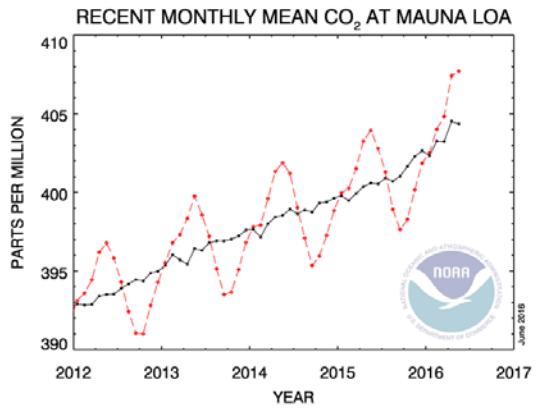
# Carbon Cycle & Budgets

Critical Zone Science
InTeGrate Teaching Team
(Washburne, UA)

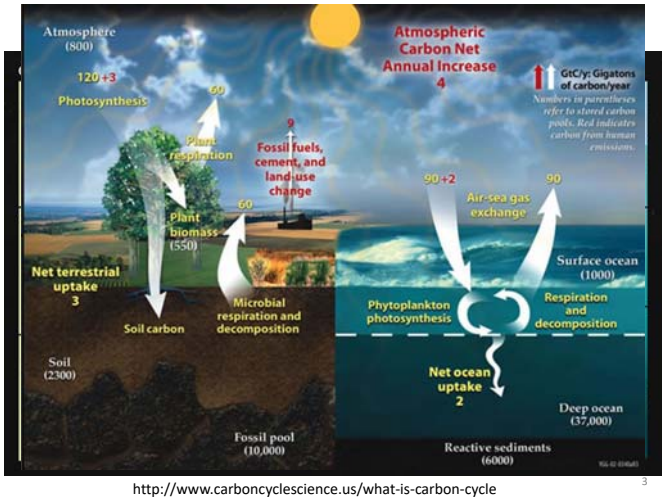


# Why is CO2 Increasing?




Source: NOAA/ESRL/GMD

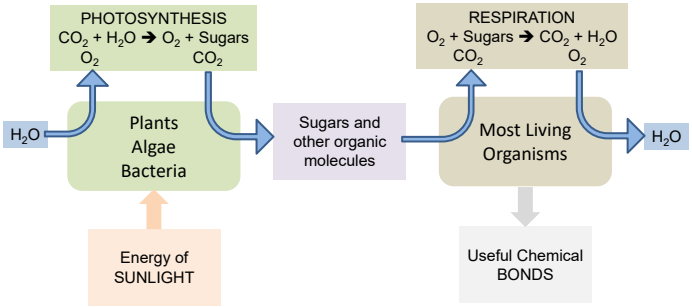





http://www.carboncyclescience.us/what-is-carbon-cycle



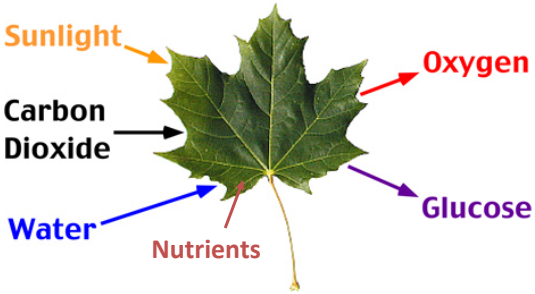
# Mechanisms – How does this work?
## The Plant Carbon Cycle




redrawn from Figure 3-10 Essential Cell Biology 2/e, Garland Science, 2004



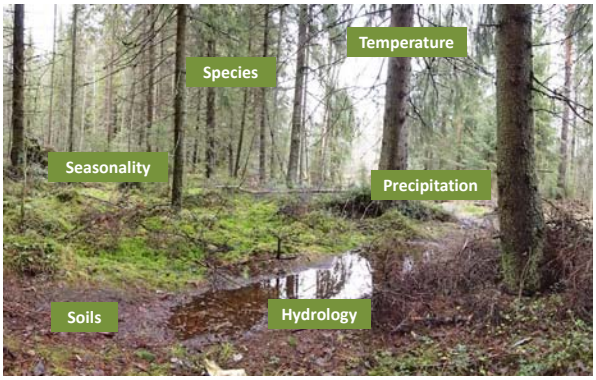
# Controls on Net Primary Productivity




Modified from Brooks, Univ.Utah



# Variables that regulate carbon fluxes & storage




Monto, CC-BY-SA

## Carbon Budget – Conceptual Diagram

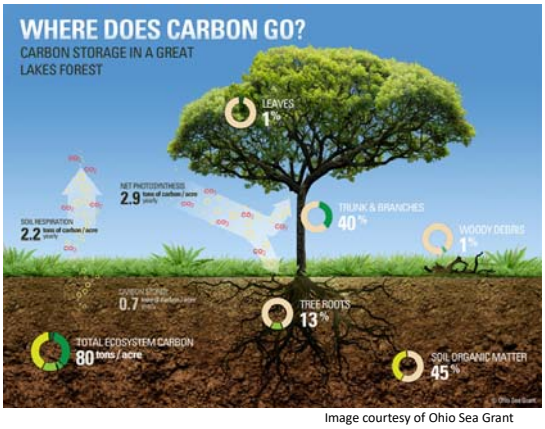


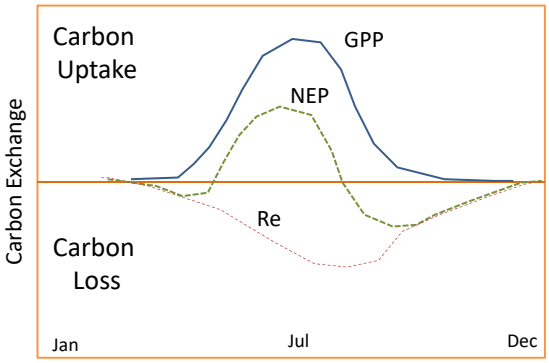

Image courtesy of Ohio Sea Grant



NEE = NEP = GPP – Re

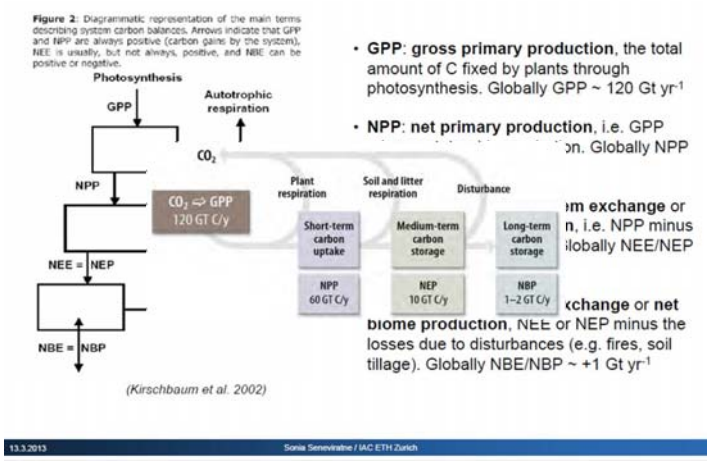
NEP is the balance between 2 large fluxes:

GPP and Ecosystem Respiration




Redrawn from: Chapin






www.iac.ethz.ch/edu/courses/bachelor/vertiefung/climate_systems



NOTATION

GPP = NPP + Ra (always a sink)

NPP = fNPP + wNPP + rNPP + mNPP = biomass

NEP = NPP – Rh

GPP = NEP + Re (eddy covariance)

Re = Ra + Rh; Rs = Ra + Rh (below ground part)

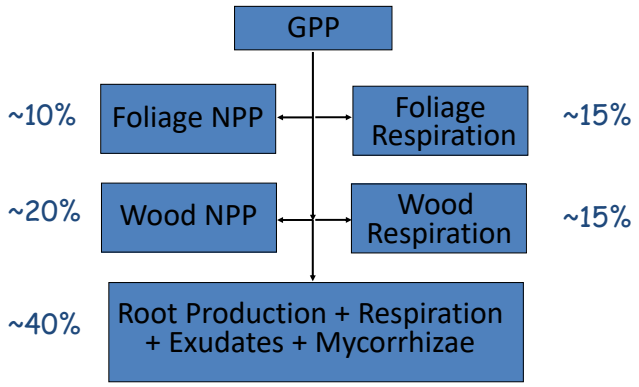
Respiration: autotrophic (plants) or heterotrophic (microbial)

fNPP = foliage component of NPP;
GPP = gross primary production (GPP > 0 denotes photosynthetic uptake);
mNPP = missing component of NPP;
NBP = net biome production (NBP > 0 denotes biome uptake);
NECB = net ecosystem carbon balance (NECB > 0 denotes ecosystem uptake);
NEE = net ecosystem exchange (NEE > 0 denotes ecosystem uptake);
NEP = net ecosystem production (NEP > 0 denotes ecosystem uptake);
NPP = net primary production (NPP > 0 denotes ecosystem uptake);
$R_a$ = autotrophic respiration ($R_a$ > 0 denotes respiratory losses);
$R_e$ = ecosystem respiration ($R_e$ > 0 denotes respiratory losses);
$R_h$ = heterotrophic respiration ($R_h$ > 0 denotes respiratory losses);
rNPP = root component of NPP;
$R_s$ = soil respiration ($R_s$ > 0 denotes respiratory losses);
VOC = volatile organic compounds;
wNPP = wood component of NPP

after Luyssaert, etal, GCB, 2007



## Lets look at the entire budget:

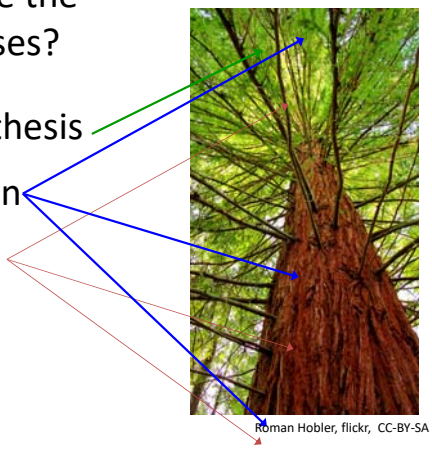



Modified from Brooks, Univ.Utah; after Litton et al., 2007



## What are the Processes?

- Photosynthesis
- Respiration
- Allocation



Roman Hobler, flickr, CC-BY-SA

Modified from Brooks, Univ.Utah

# Photosynthesis

- Nutrients control the amount of leaf area and how well it will work
- Leaf area controls how much light is absorbed
- Humidity controls $CO_2$ uptake during the day
- Soil water controls $CO_2$ uptake seasonally

Jim Stanton, flickr, CC-BY-2.0



# Respiration

- Temperature controls rate
- Nutrient concentration controls amount
- Closely related to photosynthesis and growth

Over a year respiration is about 50% of photosynthesis

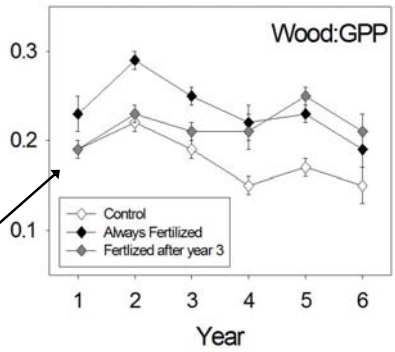
Brooks



# Allocation

- Nutrition can shift allocation from roots
- Environment: dry climate can shift allocation to roots
- Genetics

Fertility can rapidly change allocation to wood

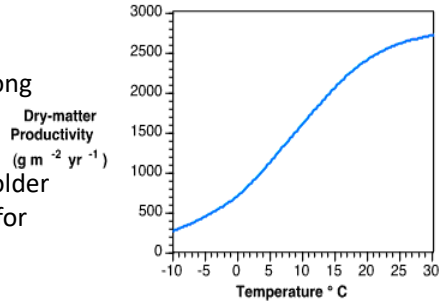





# Controls on NPP - Temperature

Temperature is a strong Limiting factor.

Although plants in colder areas are optimized for Colder conditions




modified from Kling

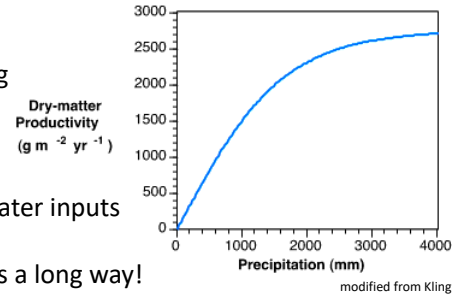


# Controls on NPP - Water

Water also is a strong Limiting factor.

Steeper curve = great sensitivity in water inputs

i.e. a little water goes a long way!



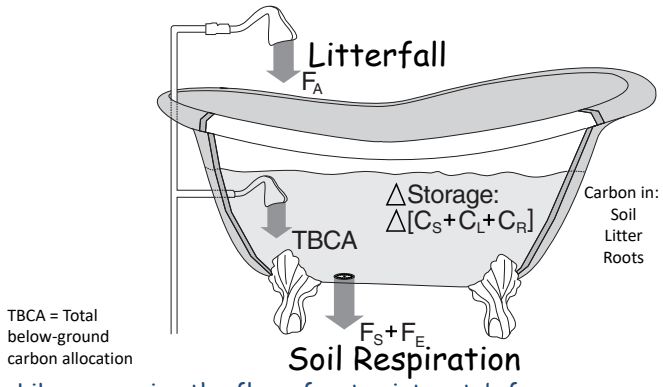

modified from Kling



# How do we measure Photosynthesis and Respiration?

Infrared Gas Analyzer (IRGA), generally to measure response to environment and photo-synthetic capacity. Models used to extrapolate

## How do we Measure? Below ground Allocation




TBCA = Total below-ground carbon allocation

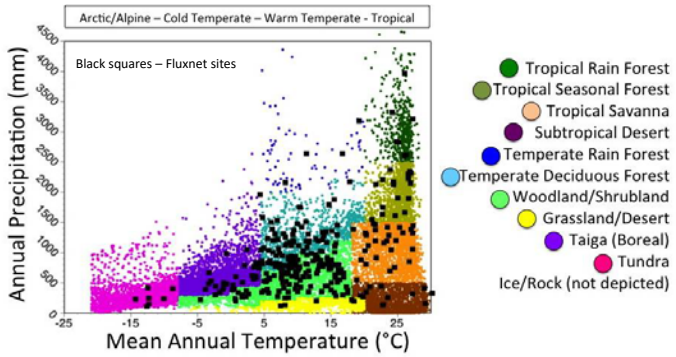
Like measuring the flow of water into a tub from an underwater faucet (= outputs – inputs + storage change)

TBCA = $F_S$ - $F_A$ + storage change

Modified from Brooks, Univ.Utah



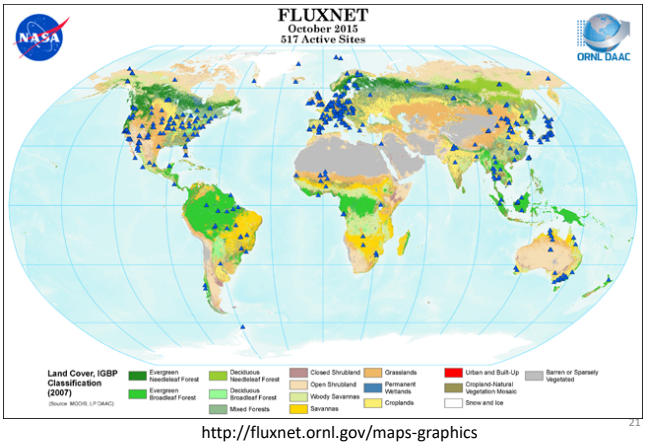
## Classification of Biomes by Ta & Ppt




http://fluxnet.ornl.gov/maps-graphics



## Fluxnet Site Locations & LC Class

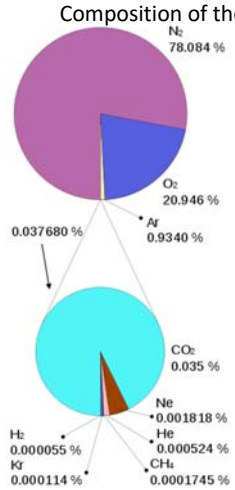



http://fluxnet.ornl.gov/maps-graphics



## Back to Budget: How much is there?

Composition of the Atmosphere by Volume




Molecular Weights:

- Dry Air ~ 29 g/mol
- CO2 ~ 44 g/mol
- Carbon ~ 12 g/mol

1000 Kg = 1 metric ton

Giga = $10^9$

How much Carbon is in the Atmo?

$M_a$ ~ 5.14 x $10^{18}$ Kg

@ 400 ppmV x 44/29 = 607 ppmM

0.000607 x $M_a$ =

~3.12 x $10^{15}$ Kg $CO_2$

x 12/44 = 851 x $10^{12}$ Kg C

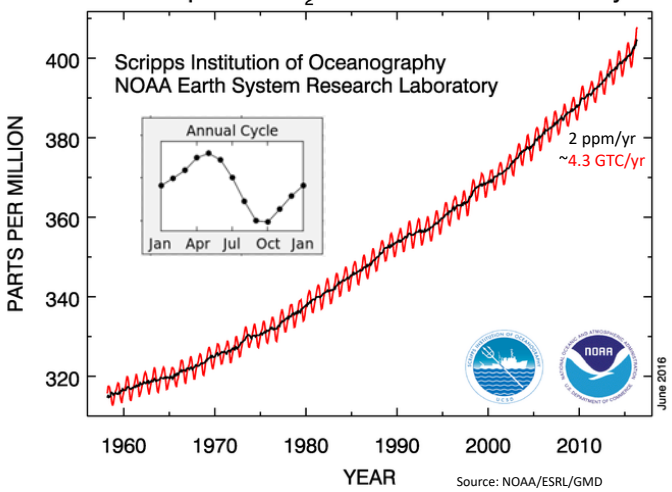
851 x $10^9$ metric tons C

= 851 GTC

Image Source: Wikimedia Commons

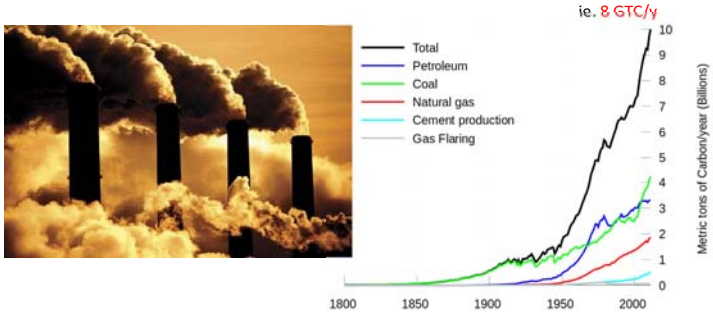


## Atmospheric $CO_2$ at Mauna Loa Observatory




Source: NOAA/ESRL/GMD

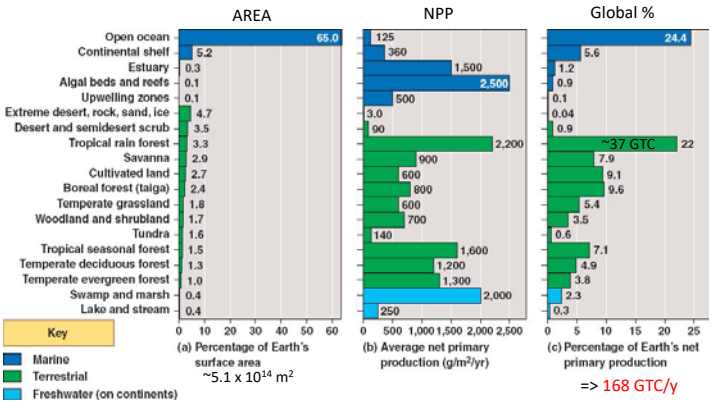
## Anthropogenic Component




**Graph Source:** https://wikimedia.org/wikipedia/commons/..../800px-Global_Carbon_Emissions.svg.png

# How much is there?

## Global Ecosystems – Gross Primary Production




~5.1 x $10^{14}$ $m^2$

=> 168 GTC/y

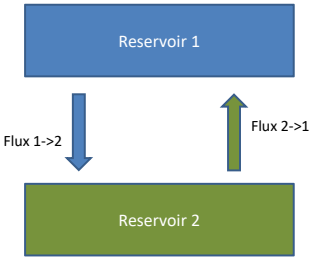
Data after RH Whitaker as found on Wiki/Primary_production



# How to deal with all these numbers?

## Use a Systems Approach

## Develop a Global Balance or Budget





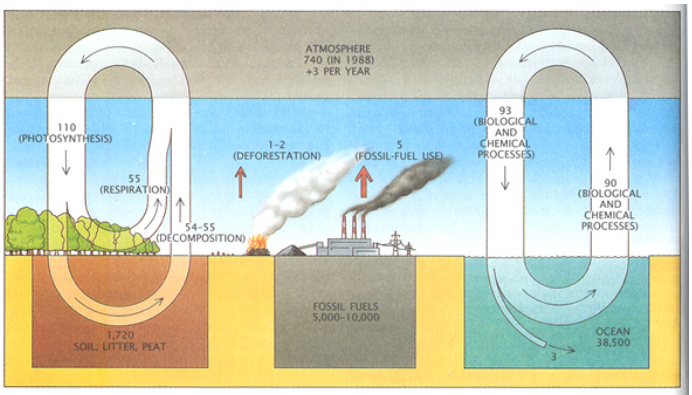




Figure 3.5 CARBON IS EXCHANGED between the atmosphere and reservoirs on the earth. The numbers give the approximate annual fluxes of carbon (in the form of carbon dioxide) and the approximate amount stored in each reservoir in billions of metric tons. The existing cycles—one on land and the other in the oceans—remove about as much carbon from the atmosphere as they add, but human activity (deforestation and fossil-fuel burning) is currently increasing atmospheric carbon by some three billion metric tons yearly. The numbers are based on work by Bert Bolin of the University of Stockholm.

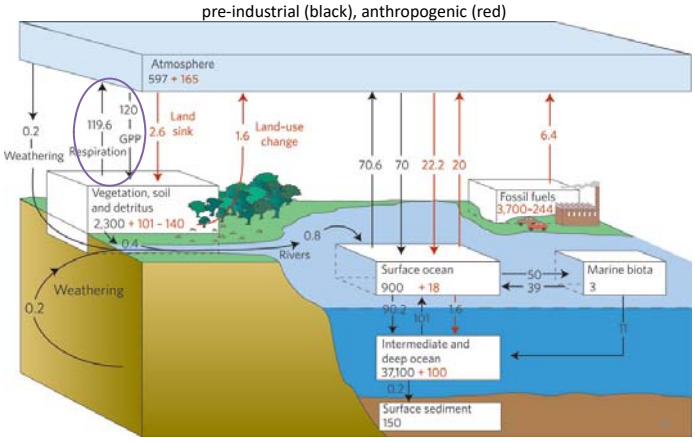
Scientific American, Sept.1989?



# The global carbon cycle for the 1990s (GTC)

## Gent, Nature Climate Change 2, 25–26 (2012)

pre-industrial (black), anthropogenic (red)



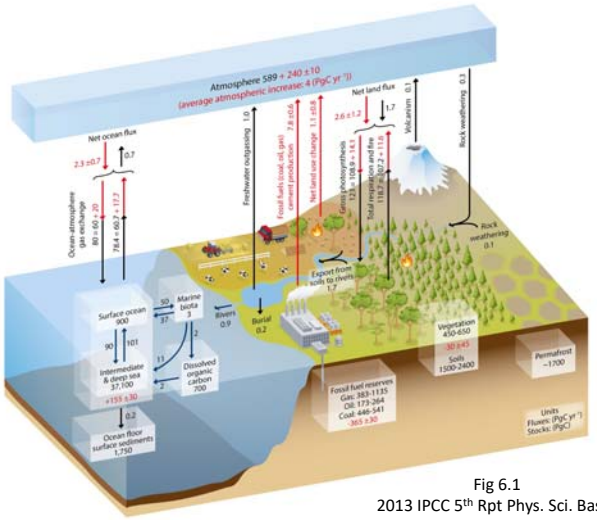




Fig 6.1

2013 IPCC 5th Rpt Phys. Sci. Basis