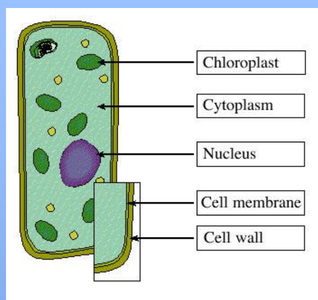
Site level scales



Molecular - Cellular

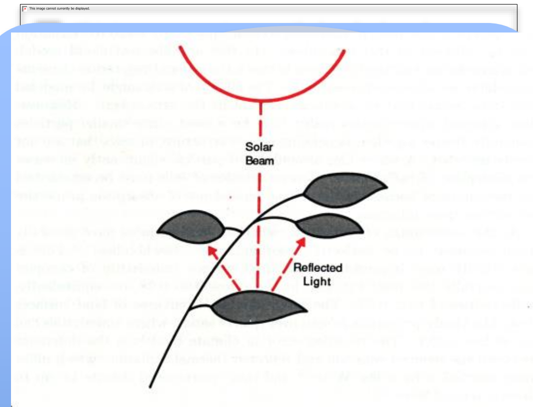


Fig. 5.11 Canopy as a cloud of leaves traps solar radiation, which, incident on leaves, is partially transmitted, partially reflected, and partially absorbed (Dickinson, 1983).

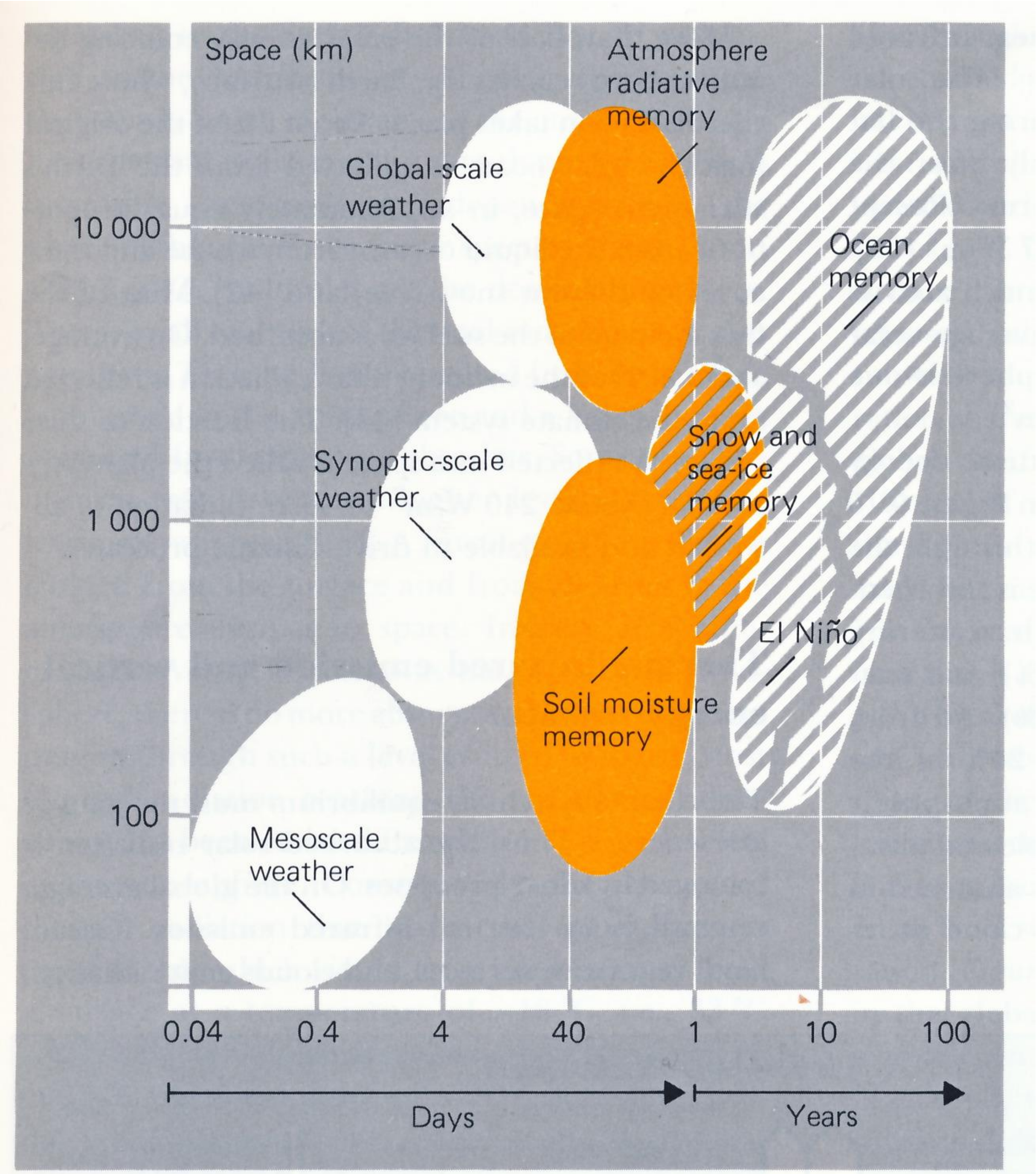
Leaf Level

Canopy level

Microns — 0.1 m — 10m

Landscape Scales

- 0.1-1km (global remote sensing data)
- 10 km (cloud scale, small catchments, thunderstorms)



Climate Scales

Leaf level is a fundamental anchor

- Extensive field and laboratory measurements.
- Controls land intake of CO_2 and loss of water
- Stomates and chloroplasts key ingredients of leaf functioning

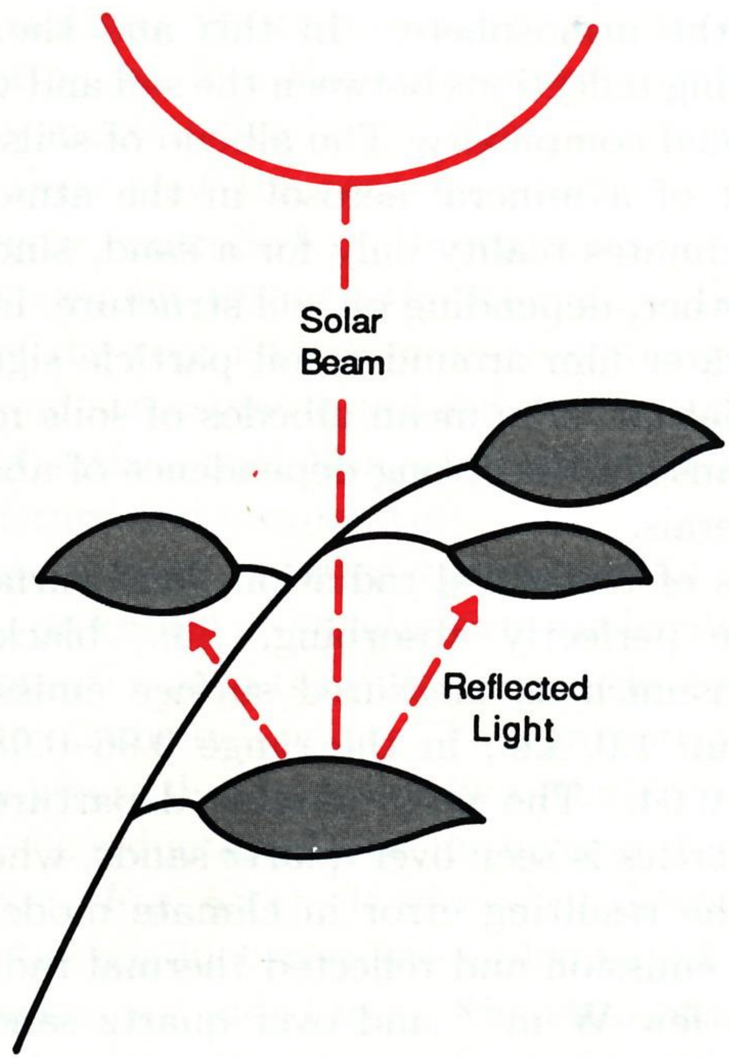
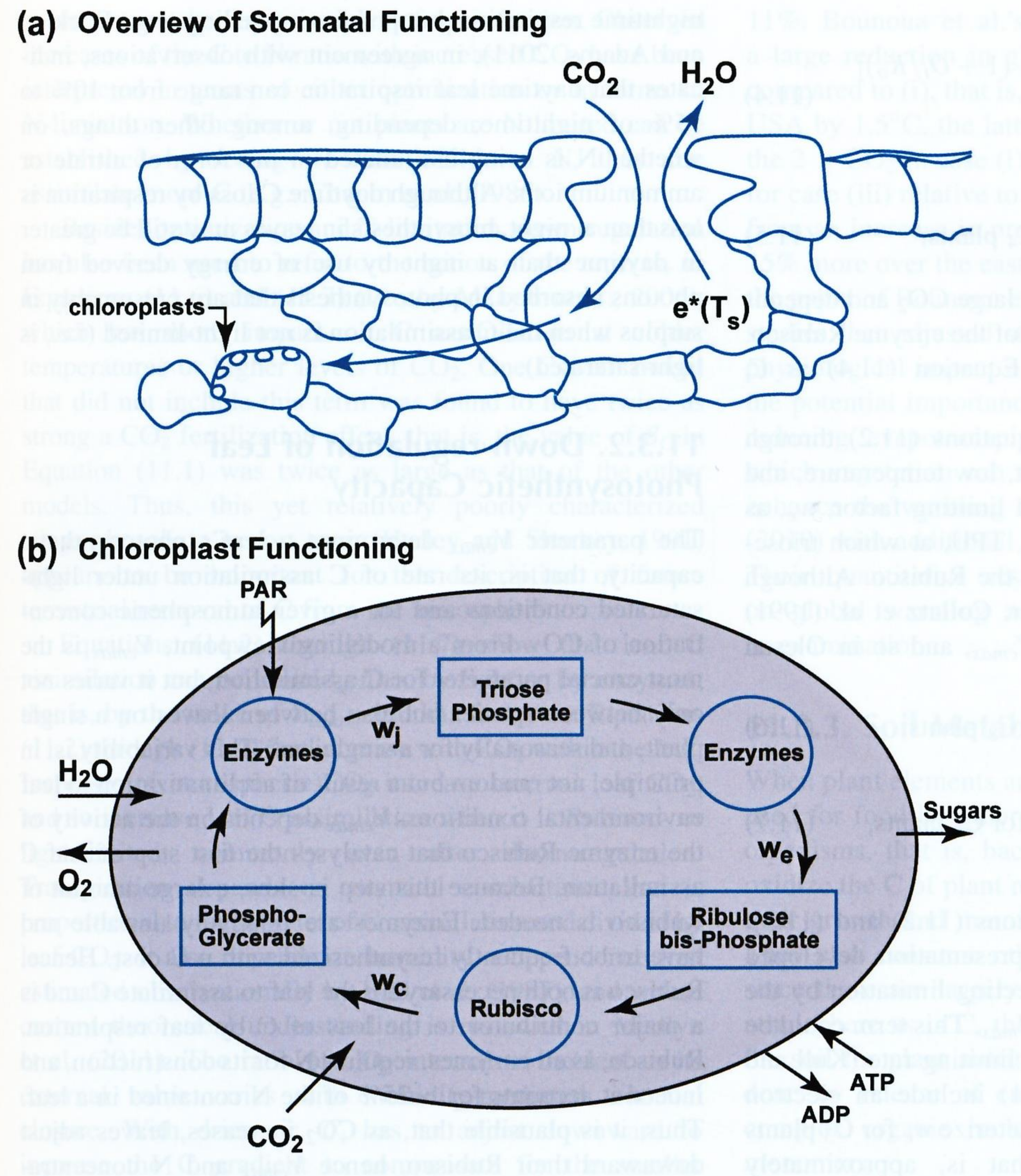
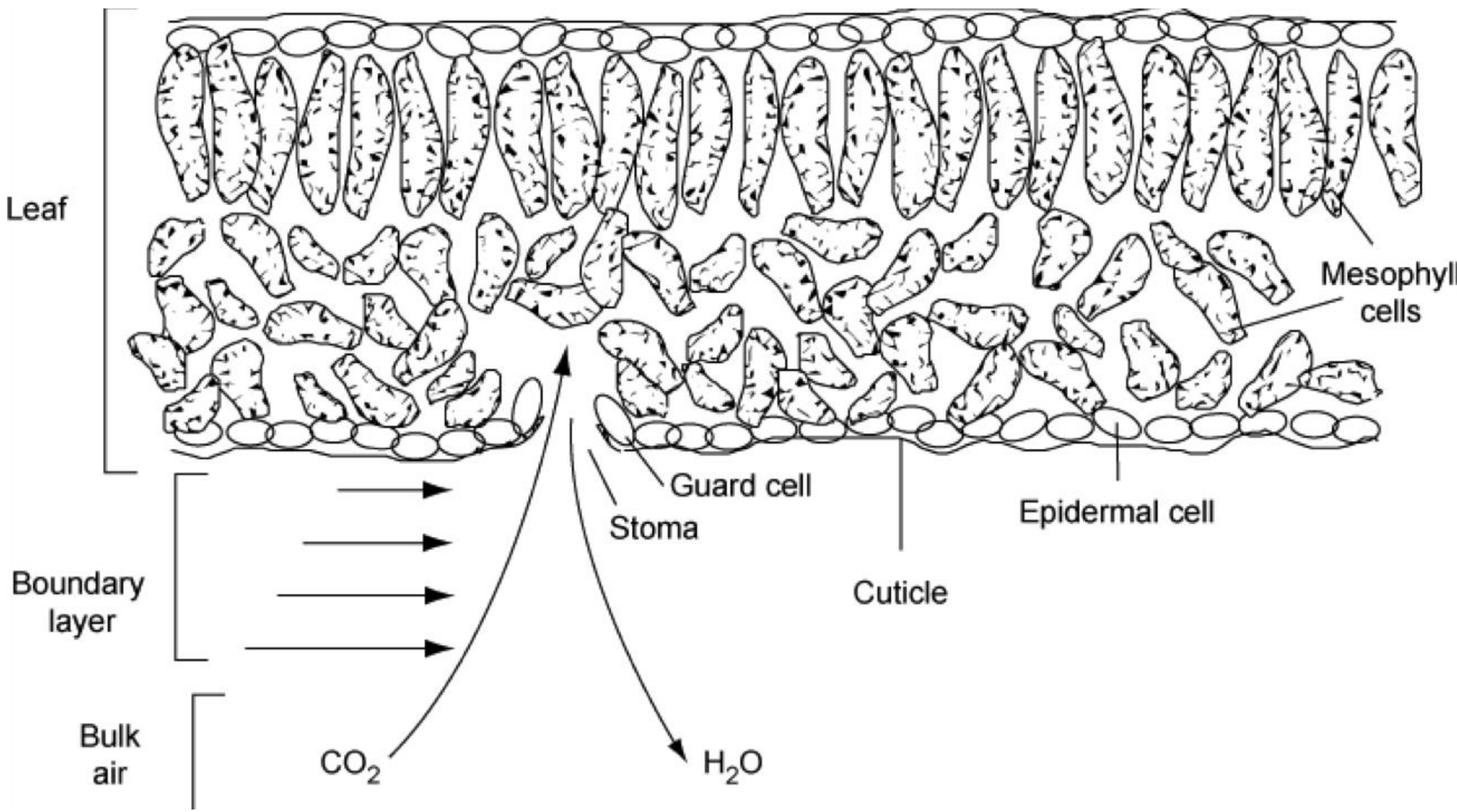


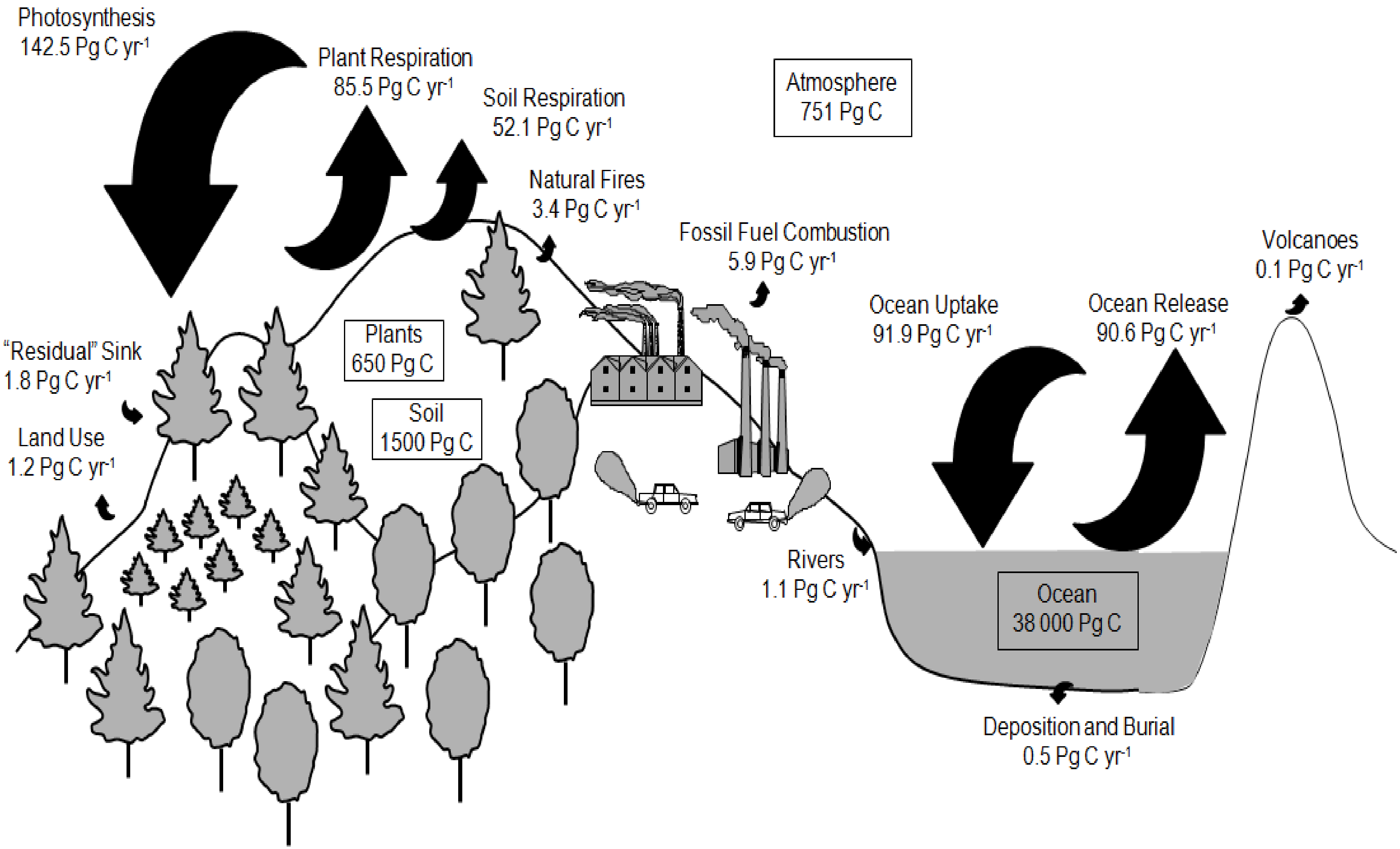
Fig. 5.11 Canopy as a cloud of leaves traps solar radiation, which, incident on leaves, is partially transmitted, partially reflected, and partially absorbed (Dickinson, 1983).

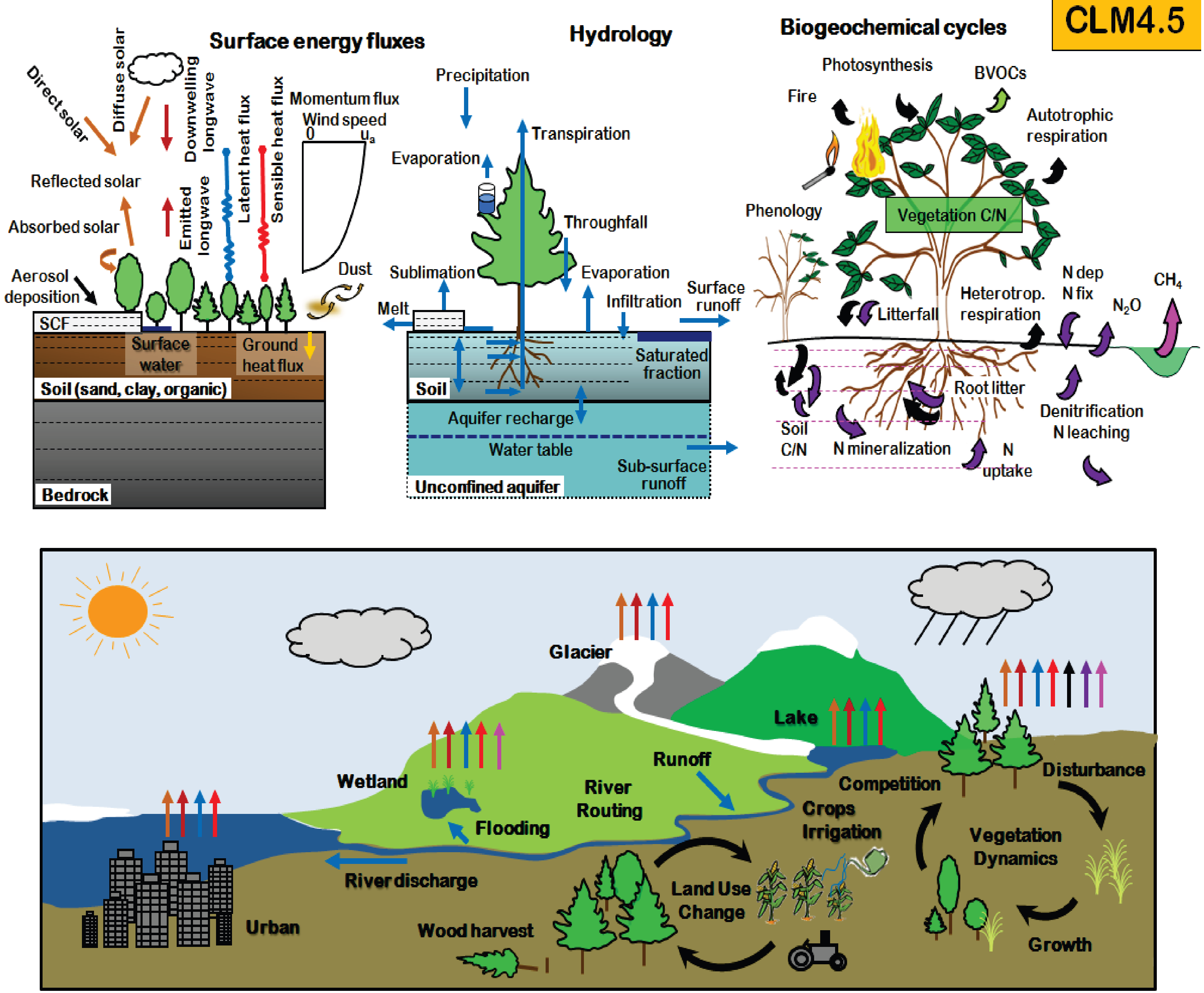

(a) Overview of Stomatal Functioning
CO_2
H_2O
chloroplasts
$e^*(T_s)$
(b) Chloroplast Functioning
PAR
Triose Phosphate
w_j
Enzymes
Enzymes
H_2O
O_2
Sugars
w_e
Phospho-Glycerate
Ribulose bis-Phosphate
w_c
Rubisco
ATP
ADP
CO_2



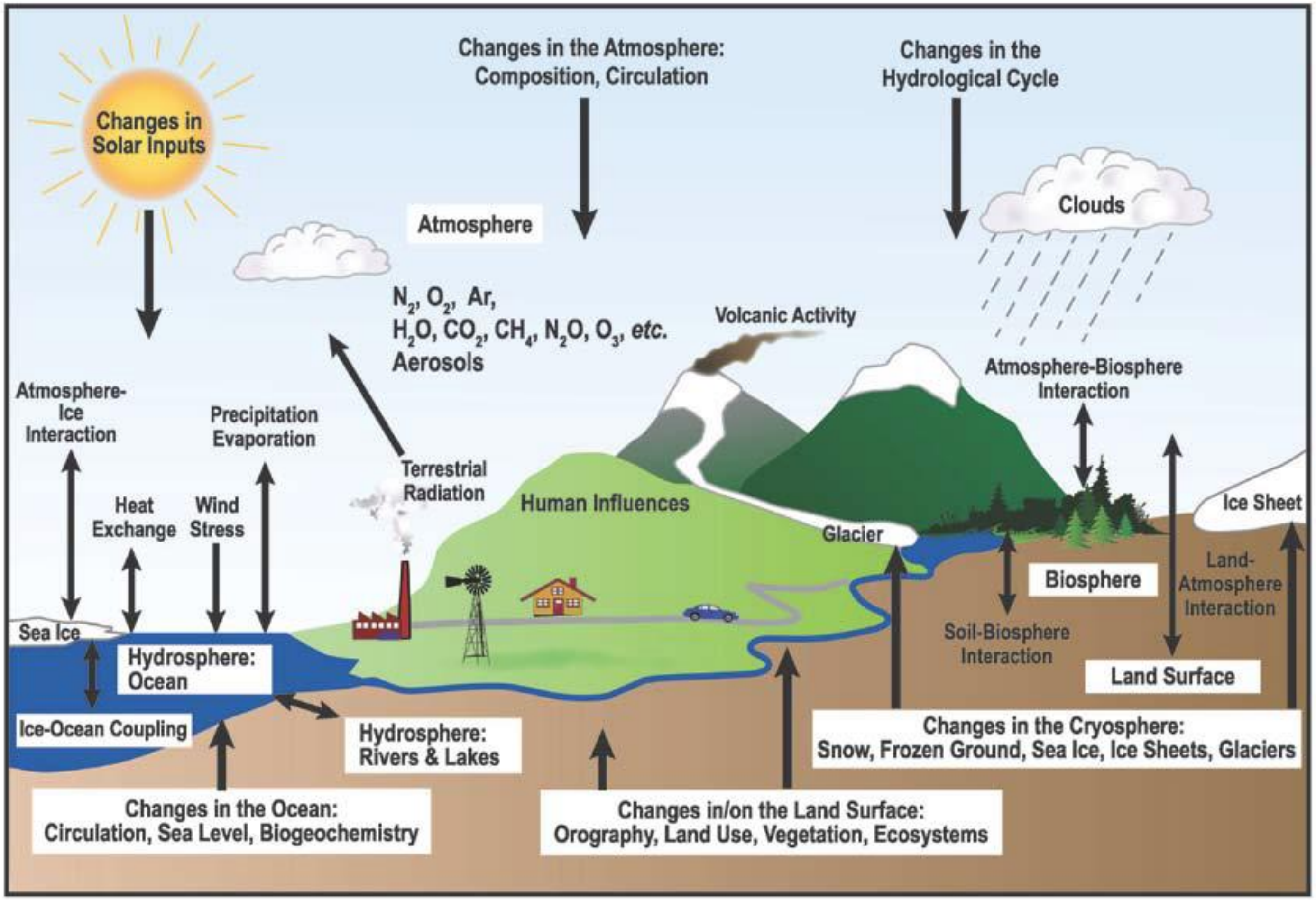
Leaf
Mesophyll cells
Guard cell
Stoma
Epidermal cell
Cuticle
Boundary layer
Bulk air
CO_2
H_2O

Global Carbon Cycle

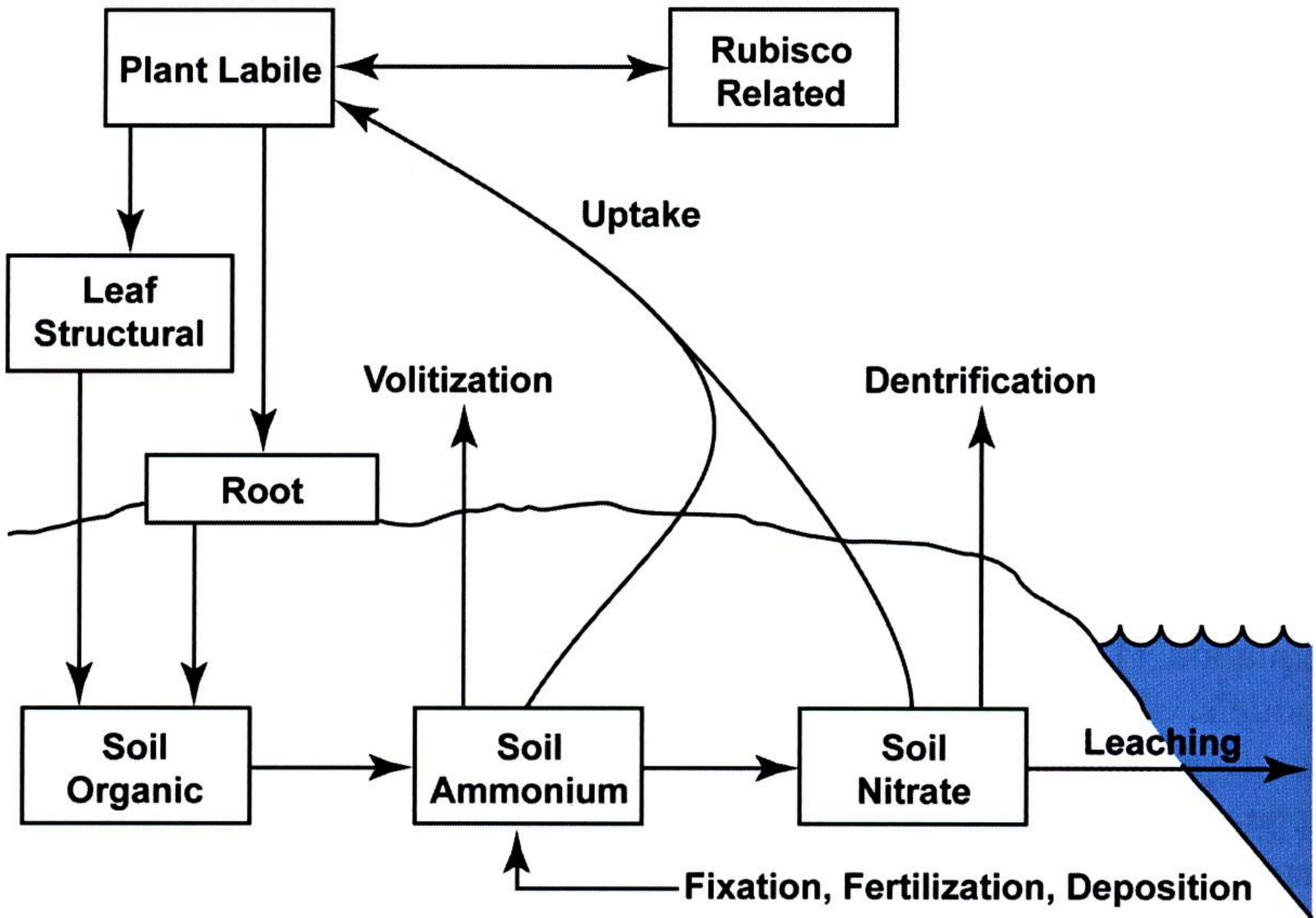



CLM4.5
Surface energy fluxes
Hydrology
Biogeochemical cycles
Direct solar
Diffuse solar
Downwelling longwave
Latent heat flux
Sensible heat flux
Momentum flux
Wind speed
0
u_a
Reflected solar
Absorbed solar
Emitted longwave
Aerosol deposition
Dust
SCF
Surface water
Ground heat flux
Soil (sand, clay, organic)
Bedrock
Precipitation
Transpiration
Evaporation
Throughfall
Sublimation
Evaporation
Melt
Infiltration
Surface runoff
Saturated fraction
Soil
Aquifer recharge
Water table
Sub-surface runoff
Unconfined aquifer
Photosynthesis
BVOCs
Fire
Autotrophic respiration
Vegetation C/N
Phenology
Litterfall
Heterotrop. respiration
N dep
N fix
N_2O
CH_4
Root litter
Soil C/N
N mineralization
N uptake
Denitrification
N leaching
Glacier
Lake
Wetland
River Routing
Runoff
Flooding
River discharge
Urban
Wood harvest
Land Use Change
Crops
Irrigation
Competition
Disturbance
Vegetation Dynamics
Growth

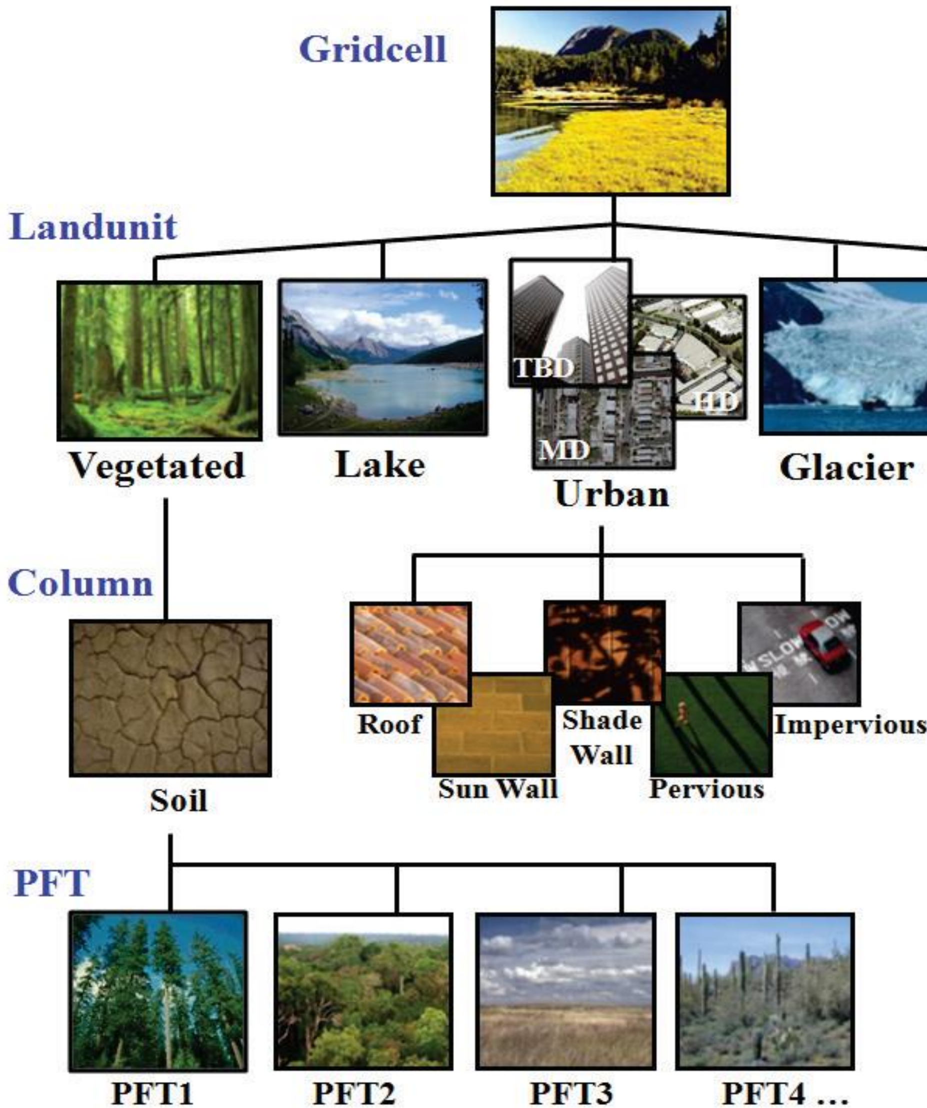
Earth System model

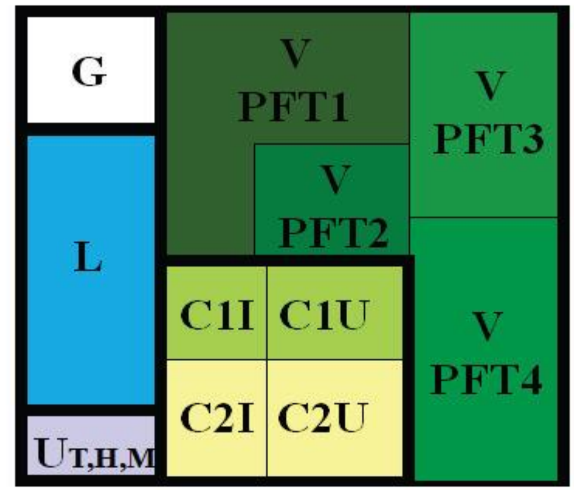


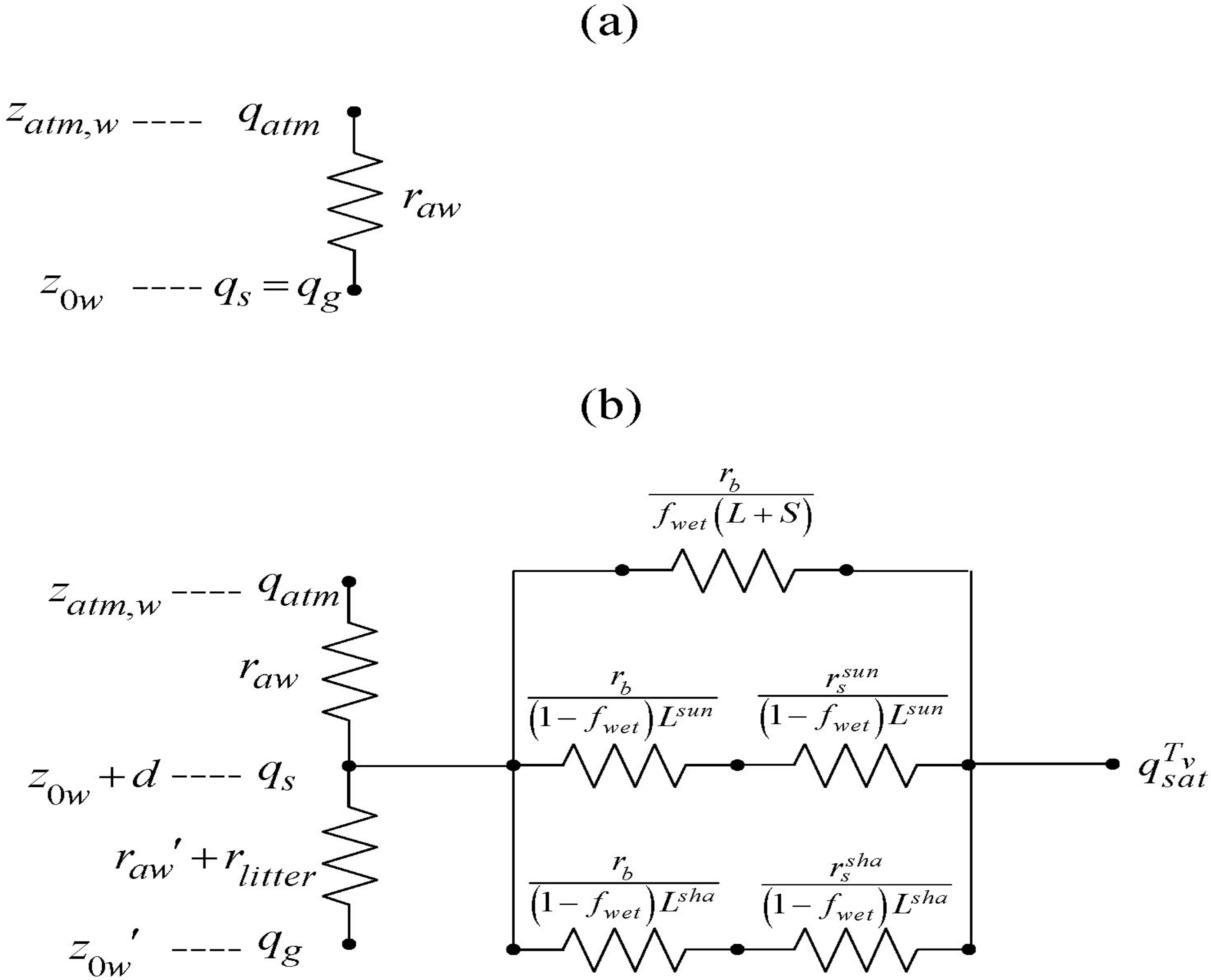
Nitrogen Storage and Fluxes



Land computational units



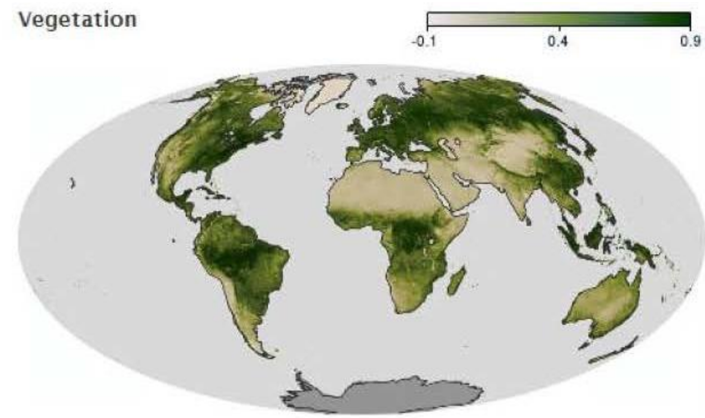



(a)
$z_{atm,w}$ ---- q_{atm}
r_{aw}
z_{0w} ---- $q_s = q_g$
(b)
$\frac{r_b}{f_{wet}(L+S)}$
$z_{atm,w}$ ---- q_{atm}
r_{aw}
$\frac{r_b}{(1-f_{wet})L^{sun}}$
$\frac{r_s^{sun}}{(1-f_{wet})L^{sun}}$
$z_{0w}+d$ ---- q_s
$q_{sat}^{T_v}$
$r_{aw}'+r_{litter}$
$\frac{r_b}{(1-f_{wet})L^{sha}}$
$\frac{r_s^{sha}}{(1-f_{wet})L^{sha}}$
z_{0w}' ---- q_g

Multi-scale model evaluation

Canopy fluxes
GPP, latent heat flux

Lasslop et al. (2010) GCB 16:187-208



Global vegetation
GPP, latent heat flux

Jung et al. (2011) JGR, 116, doi:10.1029/2010JG001566

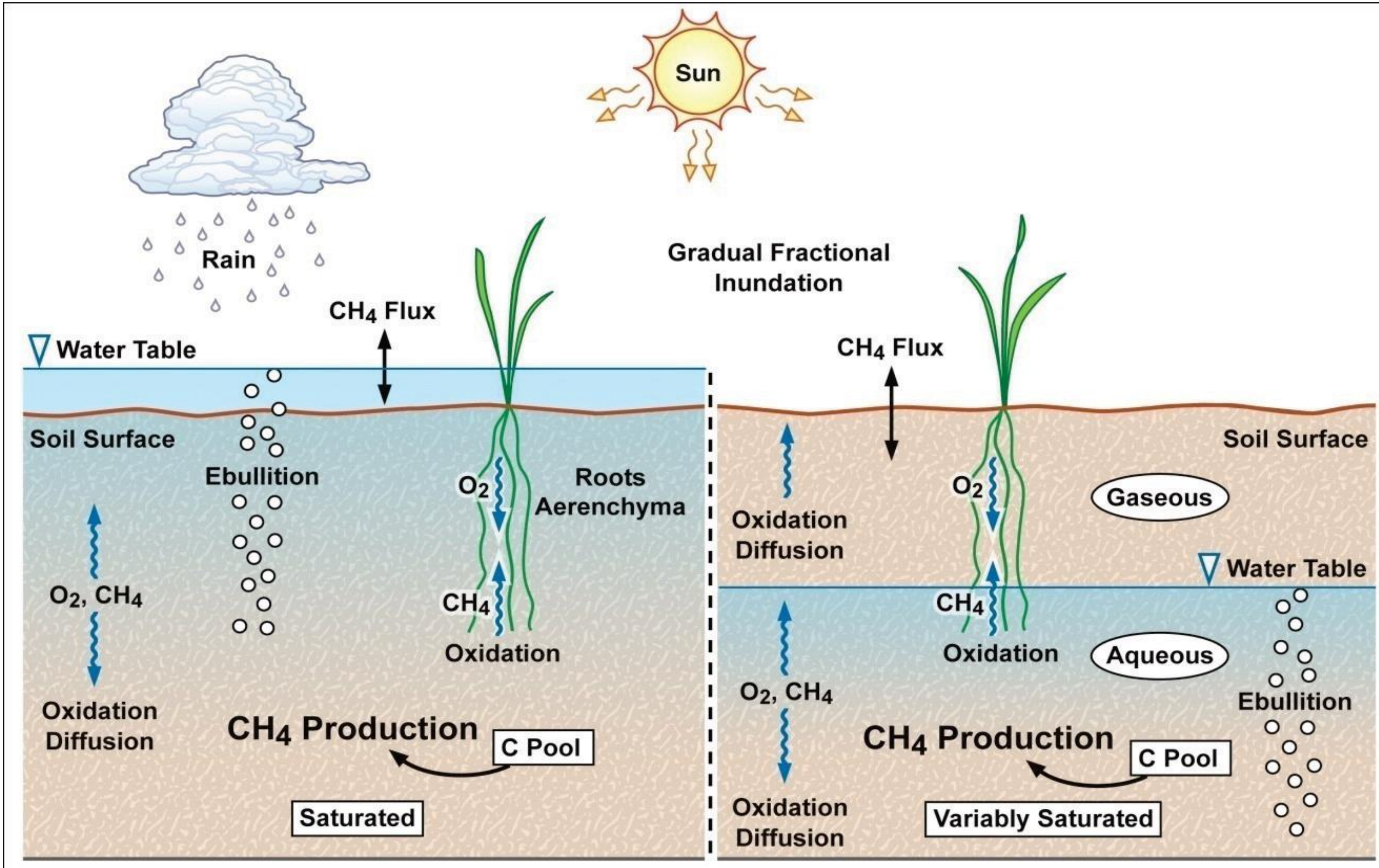
Canopy processes
Theory
Numerical parameterization

Profiles of light, leaf traits, and photosynthesis

Leaf traits

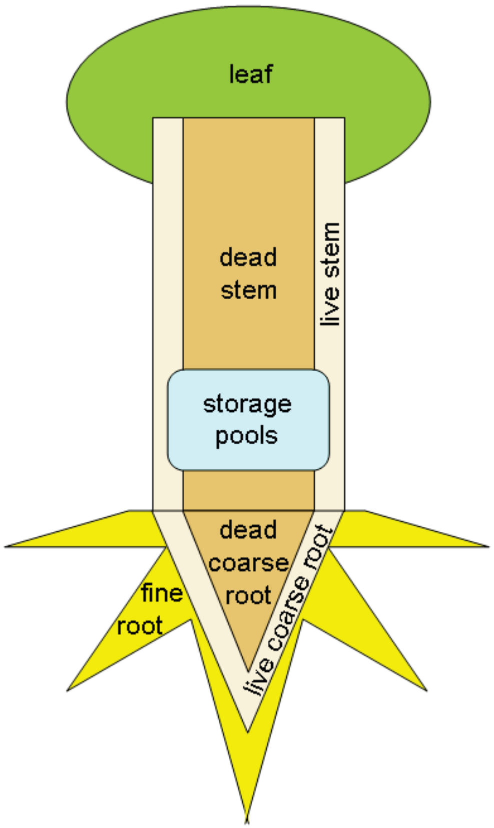
Global databases of leaf traits and eddy

Wetlands



Sun
Rain
Gradual Fractional Inundation
CH4 Flux
Water Table
Soil Surface
Ebullition
O2
Roots Aerenchyma
O2, CH4
CH4
Oxidation
Oxidation Diffusion
CH4 Production
C Pool
Saturated
CH4 Flux
Soil Surface
Oxidation Diffusion
O2
Gaseous
Water Table
CH4
Oxidation
Aqueous
Ebullition
O2, CH4
CH4 Production
C Pool
Oxidation Diffusion
Variably Saturated

Carbon and Nitrogen allocation



CLM vegetation state variables (pools):

C and N pools for each tissue (structural pools):

- Leaf
- Stem (live and dead)
- Coarse root (live and dead)
- Fine root

Each structural pool has two corresponding storage pools:

- Long-term storage (> 1 yr)
- Short-term storage (< 1 yr)

Additional pools:

- Growth respiration storage (C)
- Maintenance respiration reserve (C)
- Retranslocated nitrogen

Total number of pools…

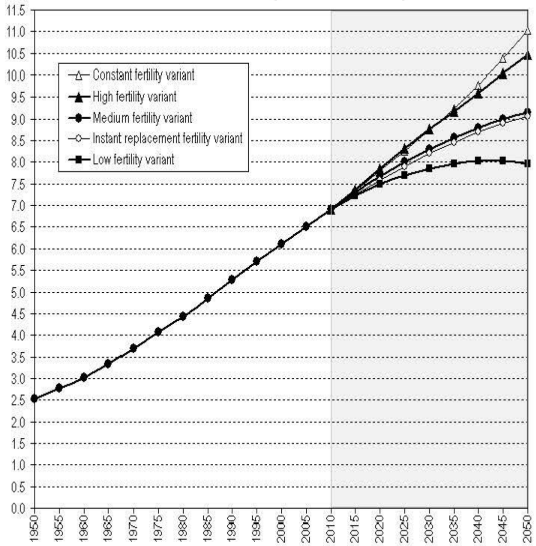
Carbon: 6 + 12 + 2 = 20

Nitrogen: 6 + 12 + 1 = 19

Natural variability-Texas drought

The Anthropocene

Population of the world, 1950-2050, according to different projection variants (in billion)

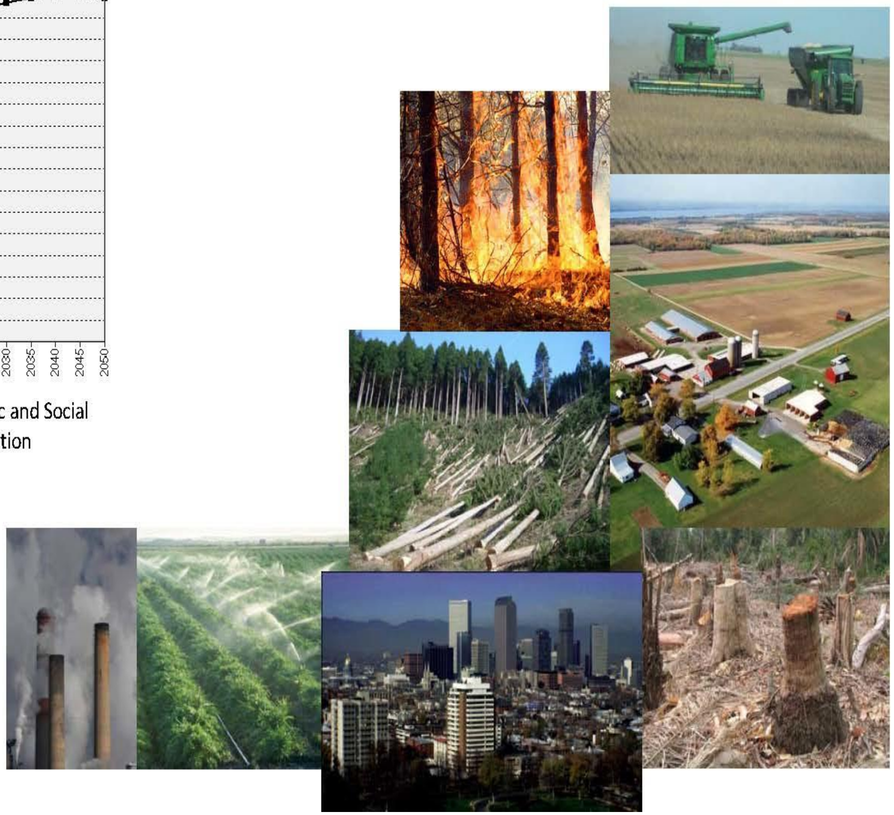


Source: United Nations, Department of Economic and Social Affairs, Population Division (2009): World Population Prospects: The 2008 Revision. New York

Human activities (agriculture, deforestation, urbanization) and their effects on climate, water resources, and biogeochemical cycles

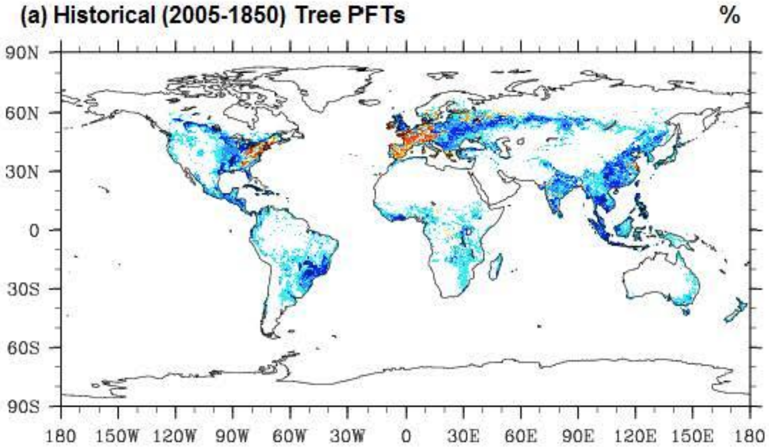
What is our collective future?

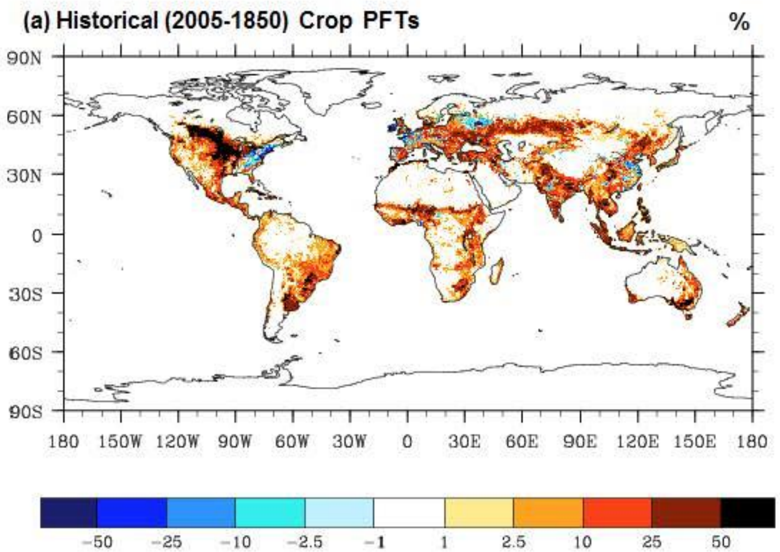
Can we manage the Earth system, especially its ecosystems, to create a sustainable future?



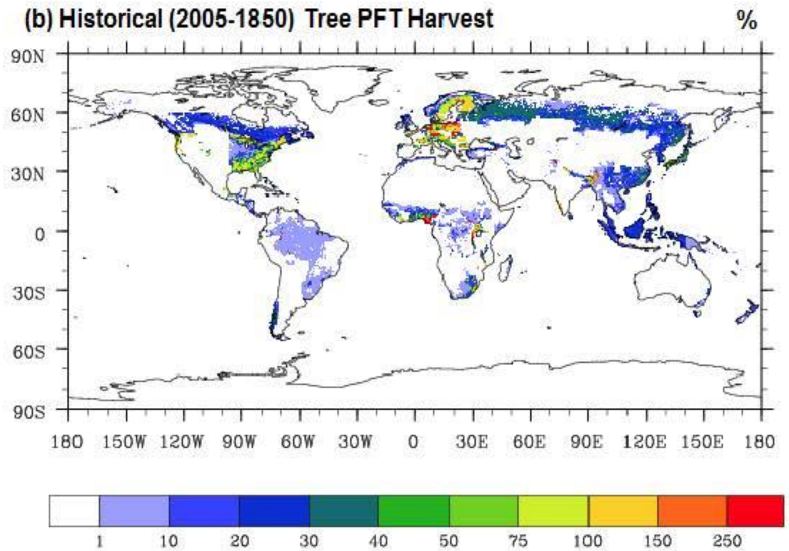
Historical land use and land cover change, 1850 to 2005

Change in tree and crop cover (percent of grid cell)





Cumulative percent of grid cell harvested



Historical LULCC in CLM4

- ❑ Loss of tree cover and increase in cropland
- ❑ Farm abandonment and reforestation in eastern U.S. and Europe
- ❑ Extensive wood harvest

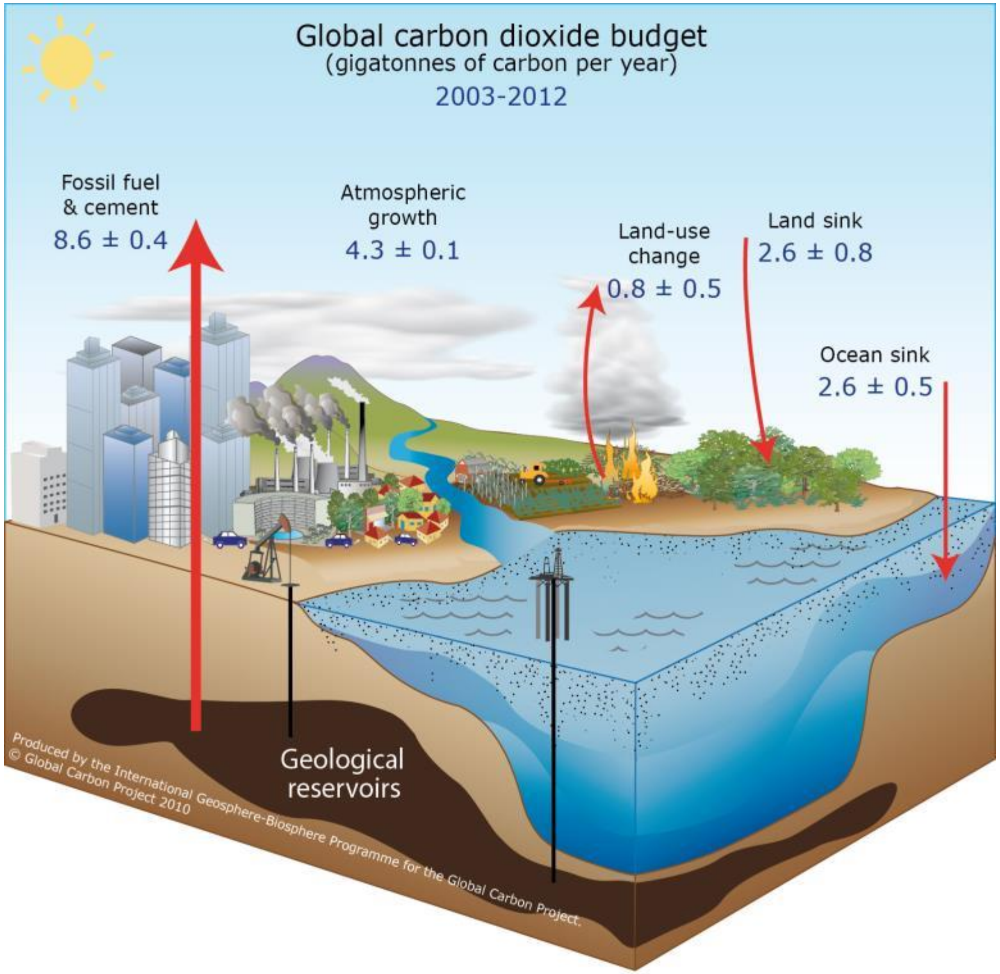
P. Lawrence et al. (2012) J Climate 25:3071-3095

Climate change issue

- Change greenhouse gases (H_20, CO_2, CH4…), change the trapping of escaping thermal infrared (longwave) radiation.
- Get 1-2 K / W m^{-2}, depending on cloud changes and other feedbacks.
- Get 4 W m^{-2} from doubling $CO_{2.}$
- Some of energy goes into warming the ocean.
- How much CO_2 stays in atmosphere depends on how much goes into ocean and land.
- Adds about as much uncertainty as feedbacks

Anthropogenic Perturbation of the Global Carbon Cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2003–2012 (GtC/yr)



Source: Le Quéré et al 2013; CDIAC Data; NOAA/ESRL Data; Global Carbon Project 2013

Fate of Anthropogenic CO_2 Emissions (2003-2012 average)

8.6 ± 0.4 GtC/yr 92%

0.8 ± 0.5 GtC/yr 8%

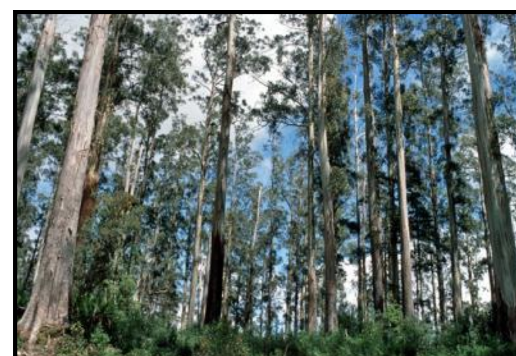
+

4.3±0.1 GtC/yr
45%

2.6 ± 0.5 GtC/yr
27%

2.6 ± 0.8 GtC/yr
27%

Calculated as the residual
of all other flux components

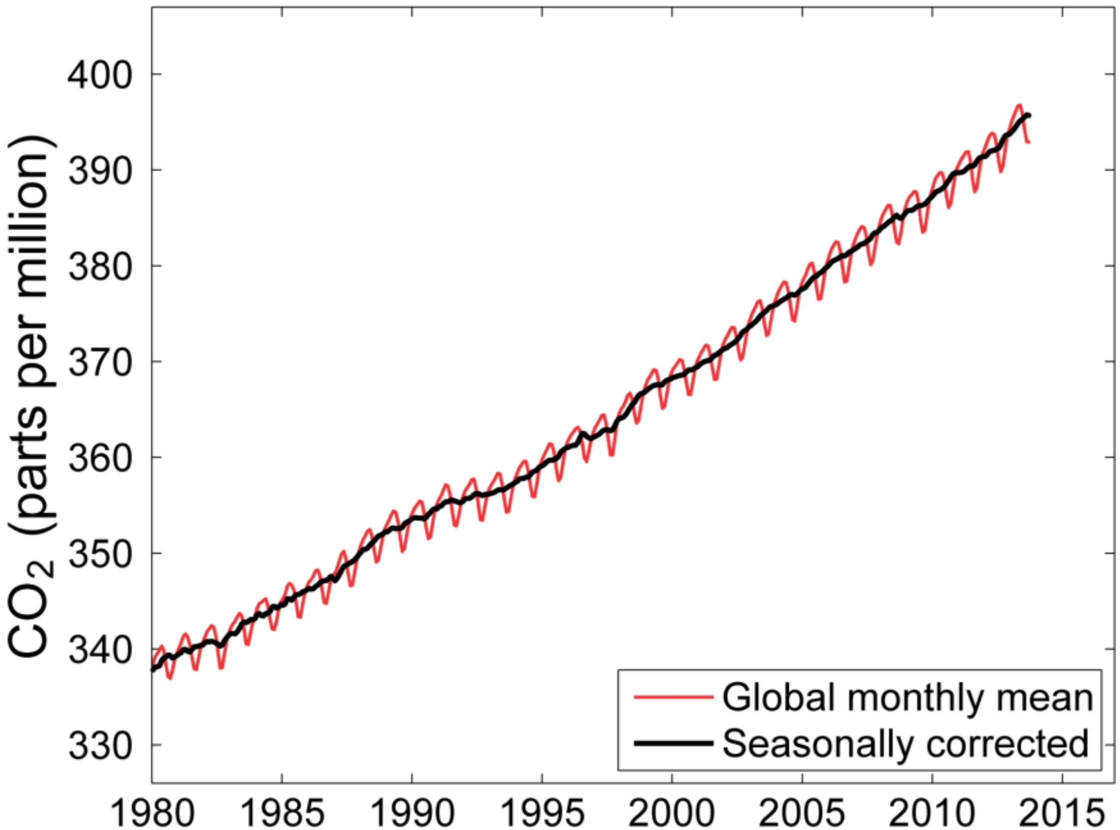


Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

Atmospheric Growth

The pre-industrial (1750) atmospheric concentration was around 277ppm

This increased to 393ppm in 2012, a 42% increase

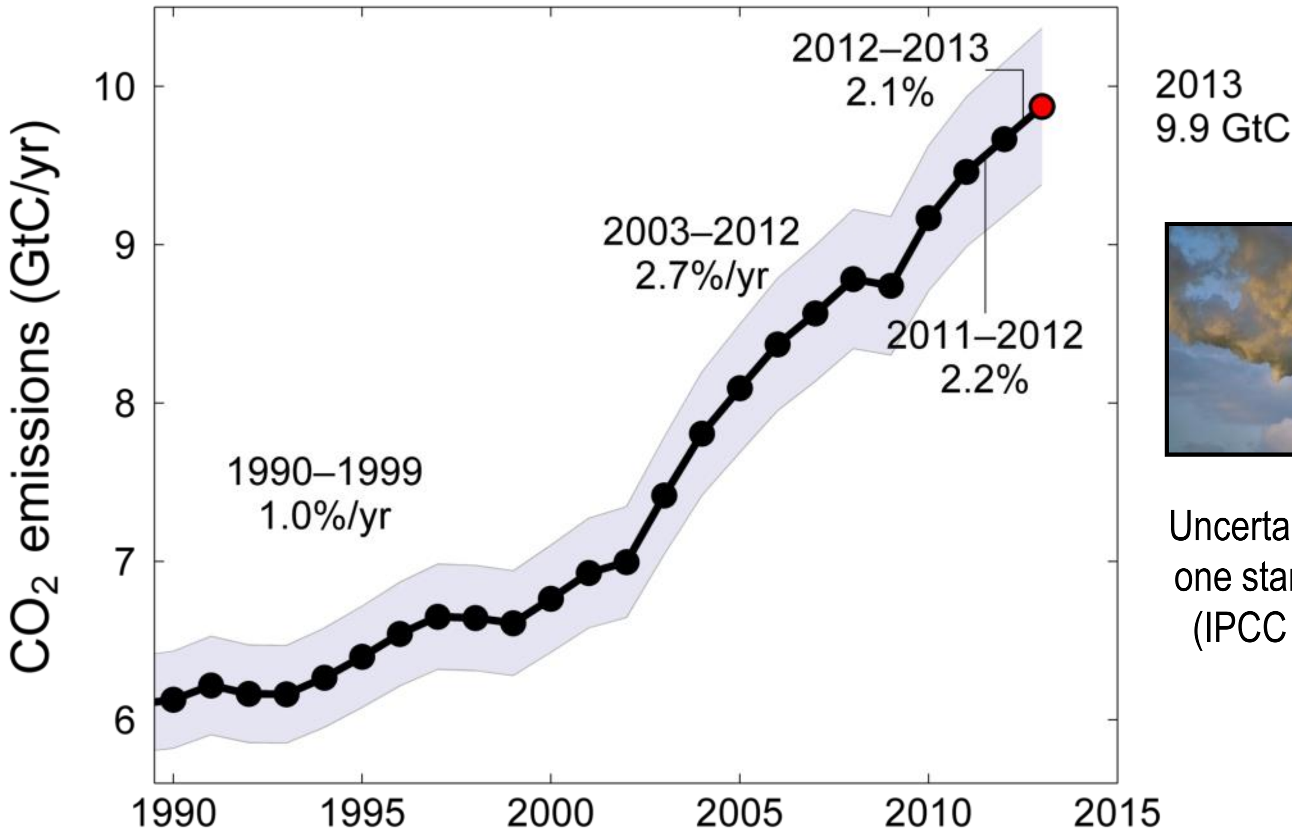


Source: [NOAA/ESRL Data](); [Global Carbon Project 2013]()

Fossil Fuel and Cement Emissions

Global fossil fuel and cement emissions: 9.7 ± 0.5 GtC in 2012, 58% over 1990

Projection for 2013 : 9.9 ± 0.5 GtC, 61% over 1990



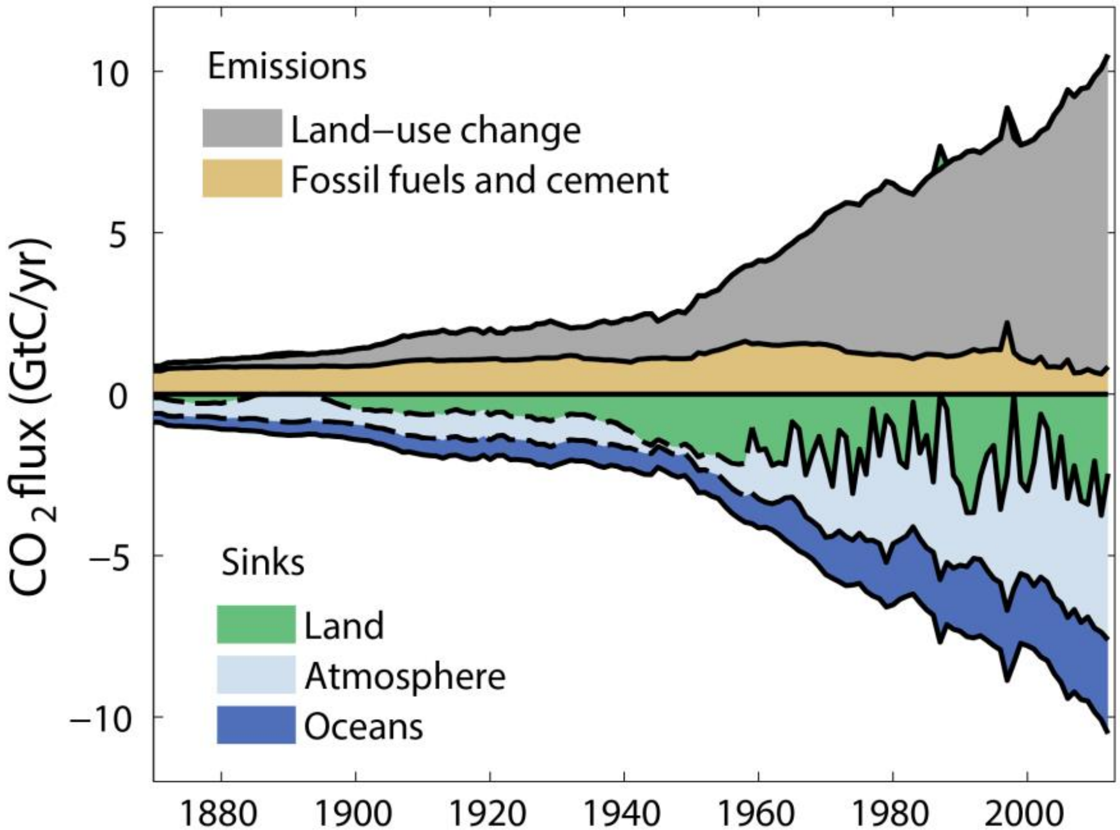
Uncertainty is ±5% for one standard deviation (IPCC “likely” range)

With leap year adjustment: 2012 growth rate is 1.9% and 2013 is 2.4%

Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

Global Carbon Budget

Emissions to the atmosphere are balanced by the sinks
Average sinks since 1870: 41% atmosphere, 31% land, 28% ocean
Average sinks since 1959: 45% atmosphere, 28% land, 27% ocean



Source: CDIAC Data; Houghton & Hackler (in review); NOAA/ESRL Data; Joos et al 2013; Khatiwala et al 2013; Le Quéré et al 2013; Global Carbon Project 2013

Global Carbon Budget

The cumulative contributions to the Global Carbon Budget from 1750
Contributions are shown in parts per million (ppm)

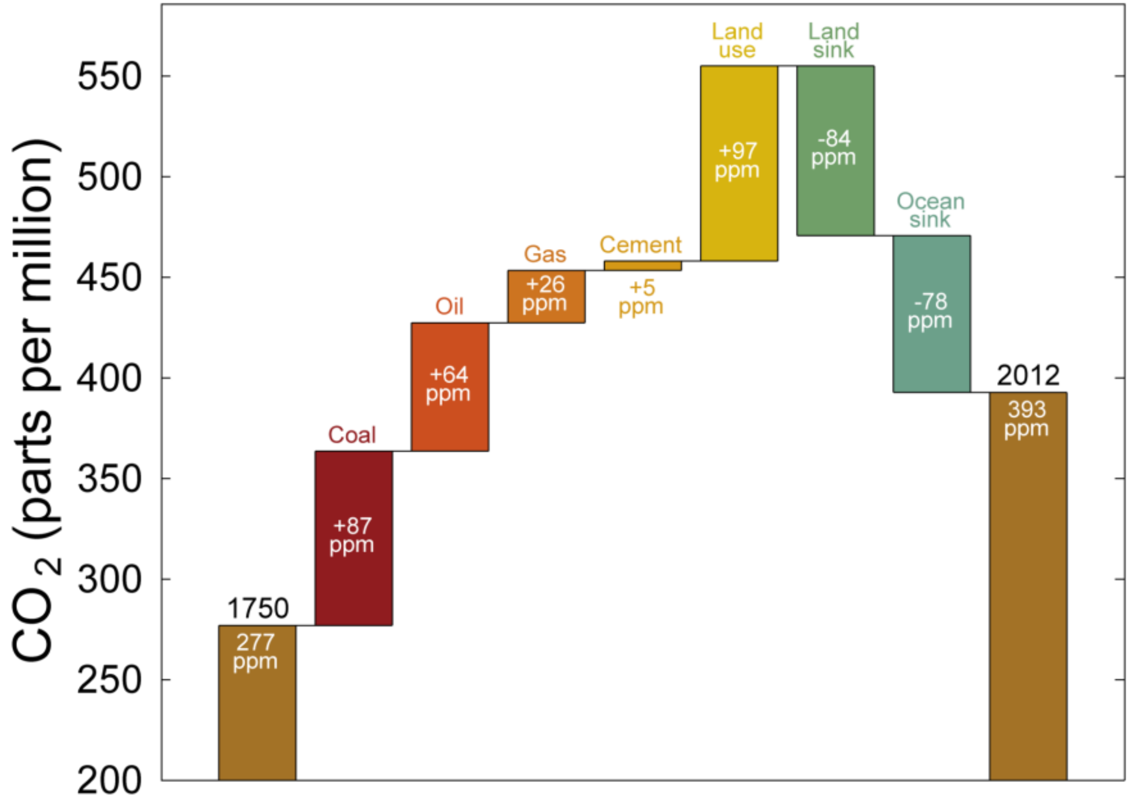
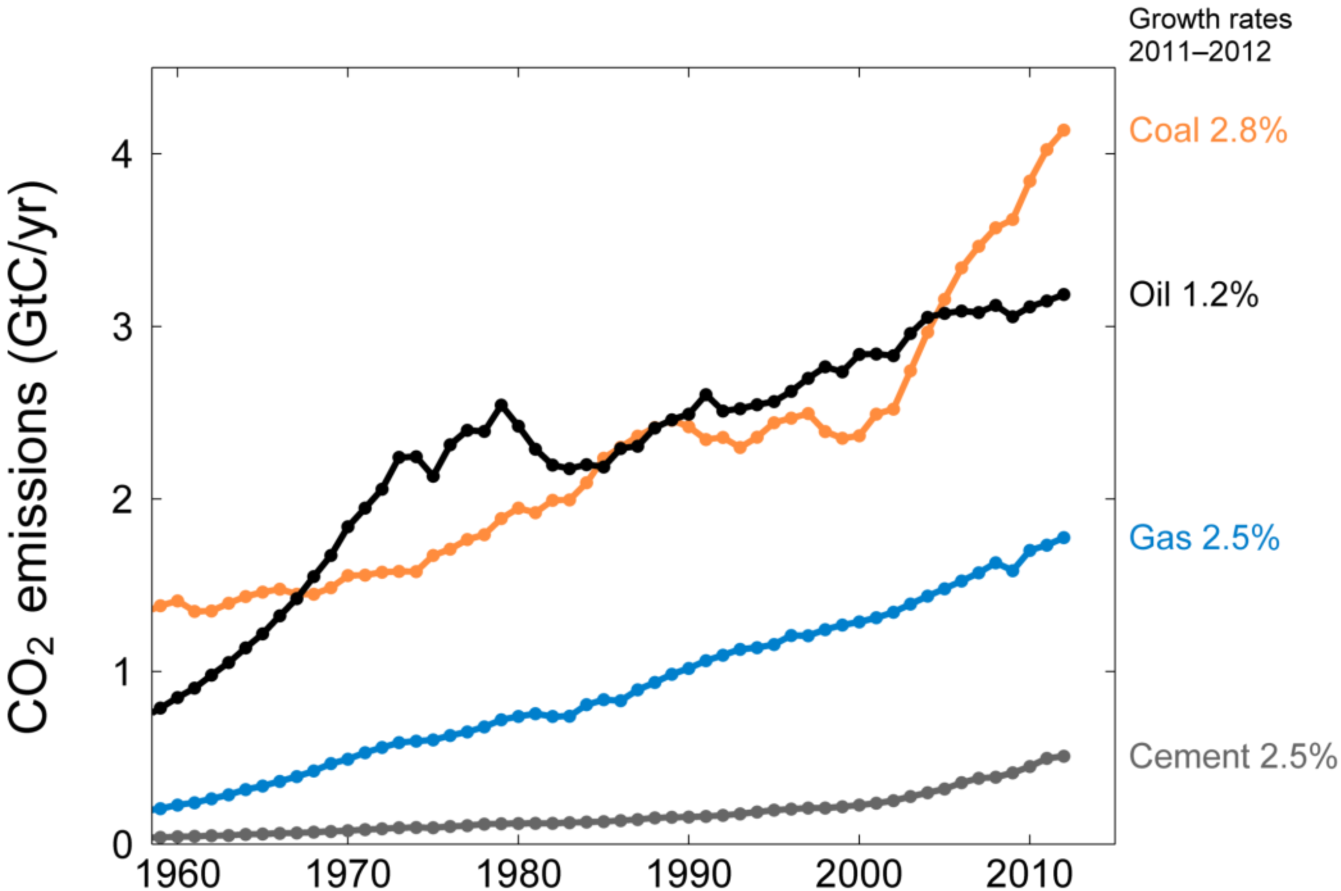


Figure concept from Shrink That Footprint

Source: Le Quéré et al 2013; NOAA/ESRL Data; CDIAC Data; Houghton & Hackler (in review);Global Carbon Project 2013

Emissions from Coal, Oil, Gas, Cement

Share of global emissions in 2012:
coal (43%), oil (33%), gas (18%), cement (5%), flaring (1%, not shown)

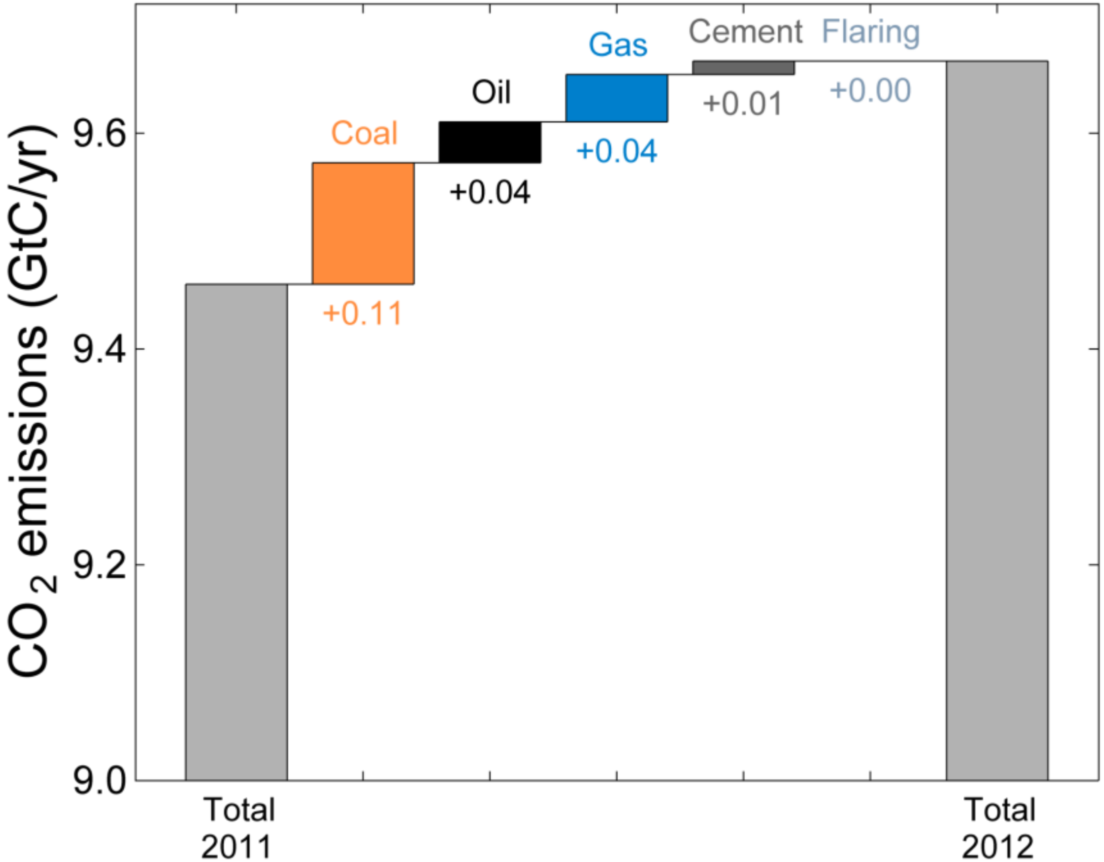


With leap year adjustment in 2012 growth rates are: coal 2.5%, oil 0.9%, gas 2.2%, cement 2.2%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Fossil Fuel and Cement Emissions Growth 2012

Coal accounted for 54% of the growth in global emissions in 2012, oil (18%), gas (21%), and cement 6%.



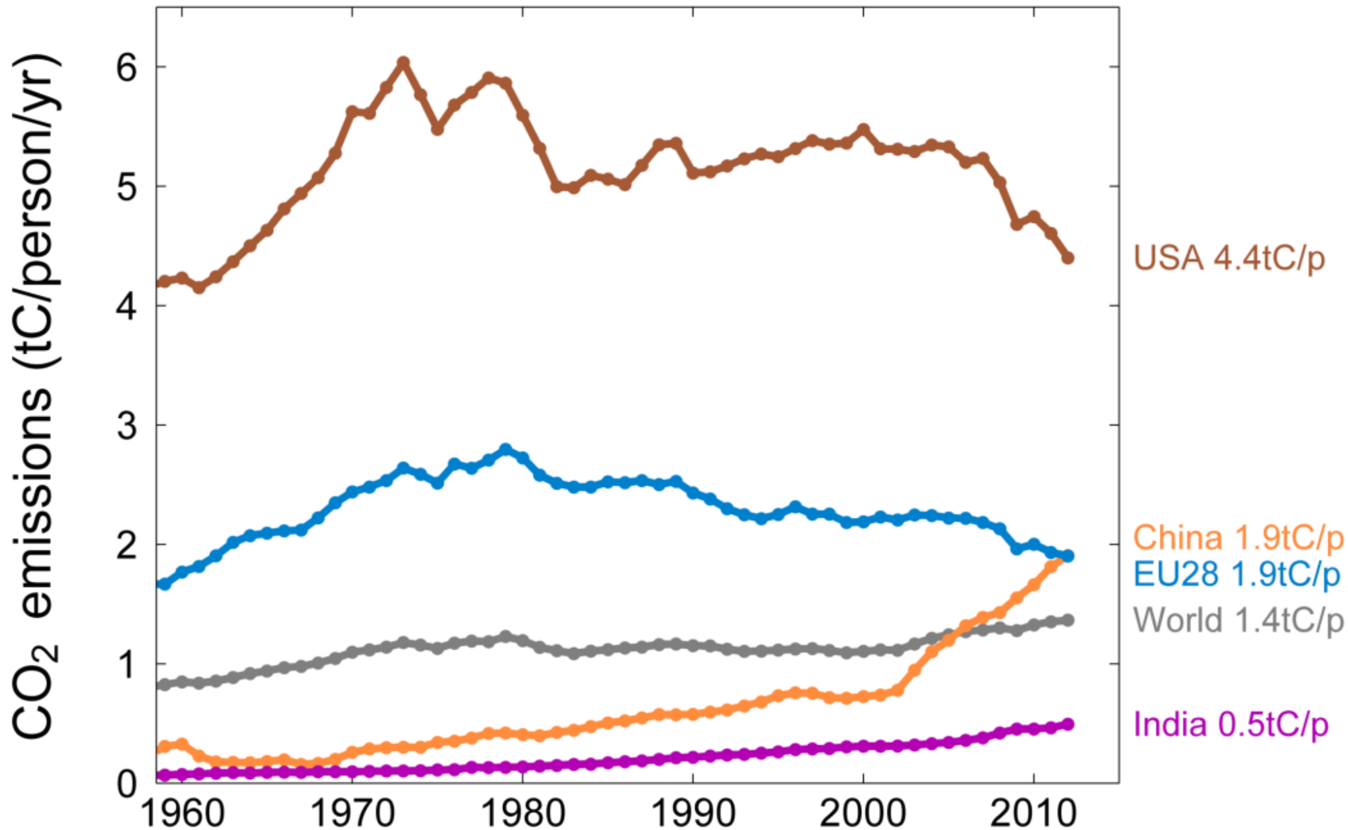
Many countries increased dependence on coal in 2012:

Emissions from coal grew 4.2% in Germany, 5.6% in Japan, 3.0% in the EU28, 10.2% in India.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Top Fossil Fuel Emitters (Per Capita)

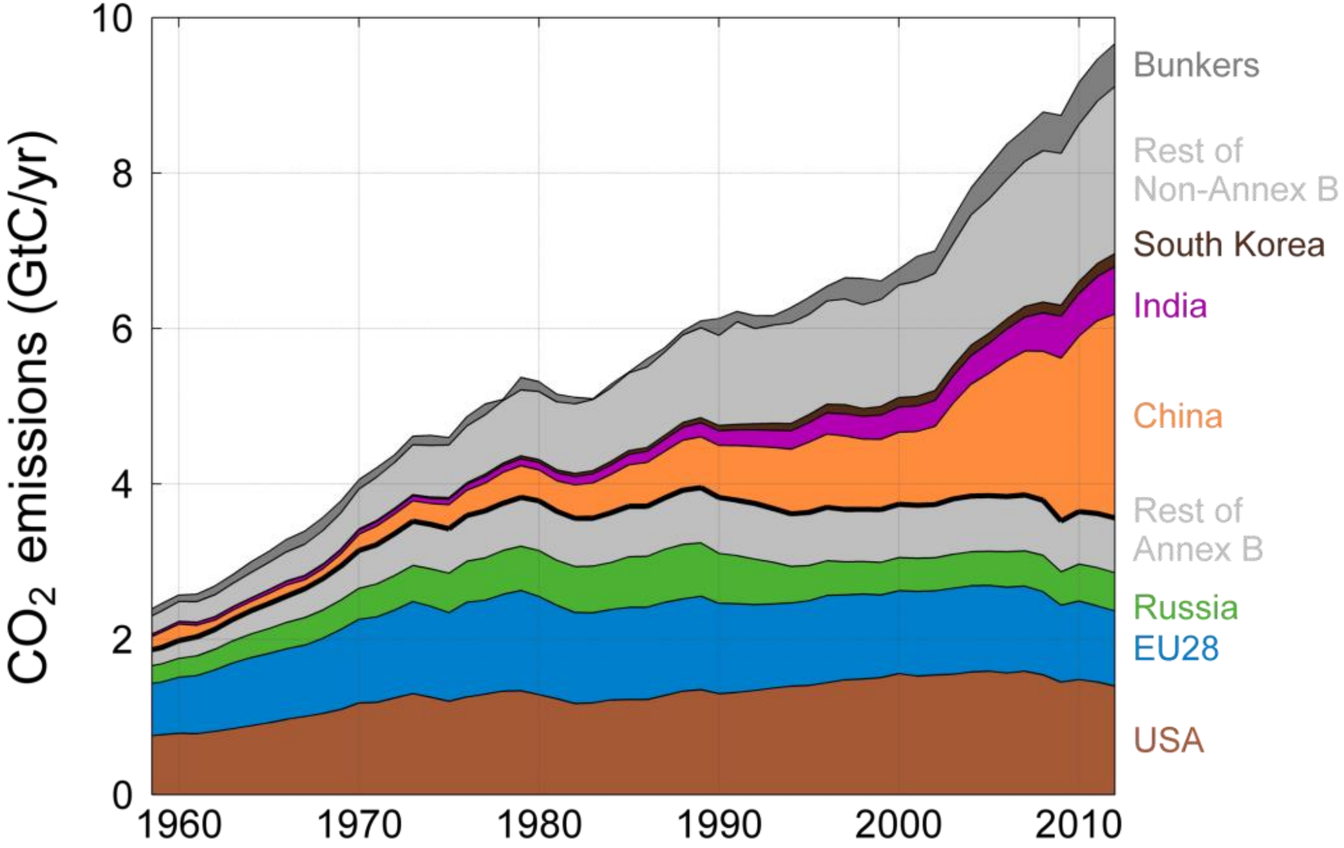
Average per capita emissions in 2012
China is growing rapidly and the US is declining fast



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Breakdown of Global Emissions by Country

Emissions from Annex B countries have slightly declined
Emissions from non-Annex B countries have increased rapidly in recent years

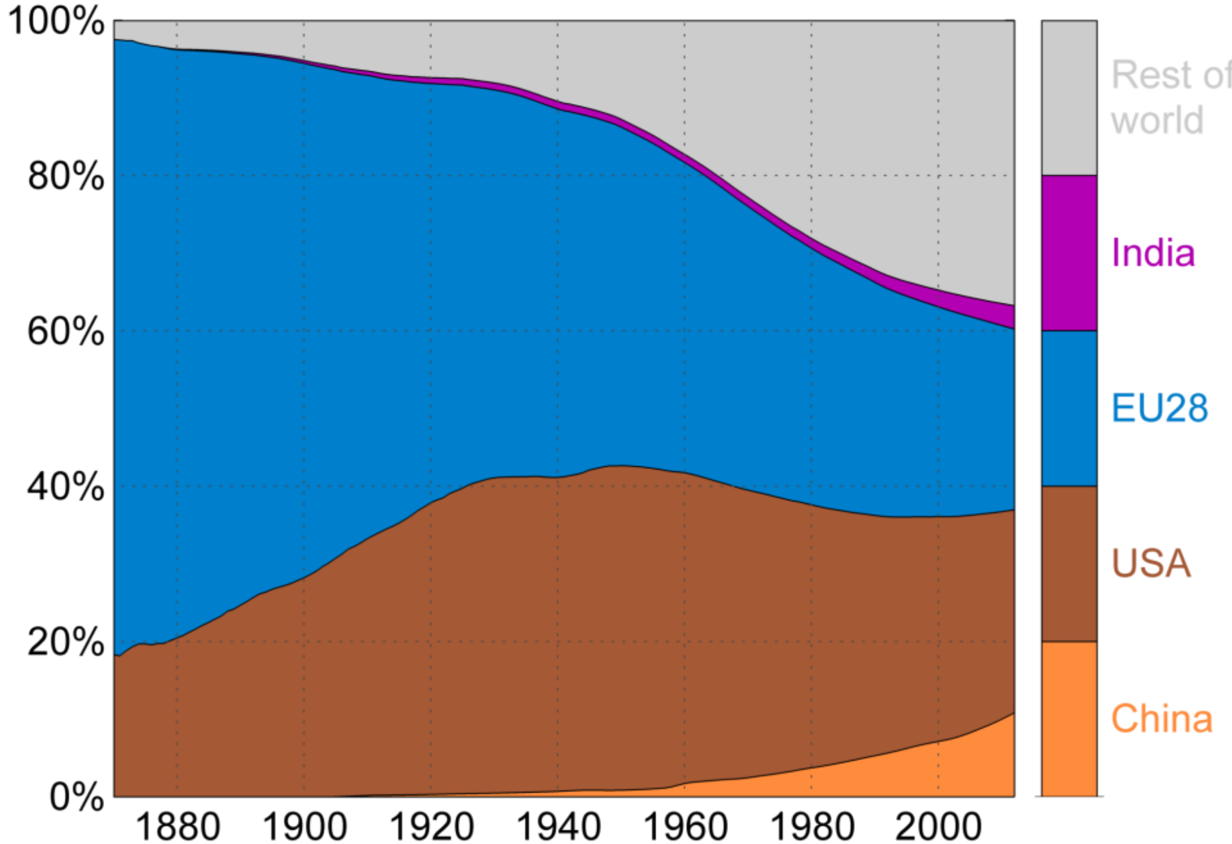


Annex B countries have emission commitments in the Kyoto Protocol

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Historical Cumulative Emissions by Country

Cumulative emissions from fossil-fuel and cement were distributed (1870–2012):
USA (26%), EU28 (23%), China (11%), and India (4%) covering 64% of the total share

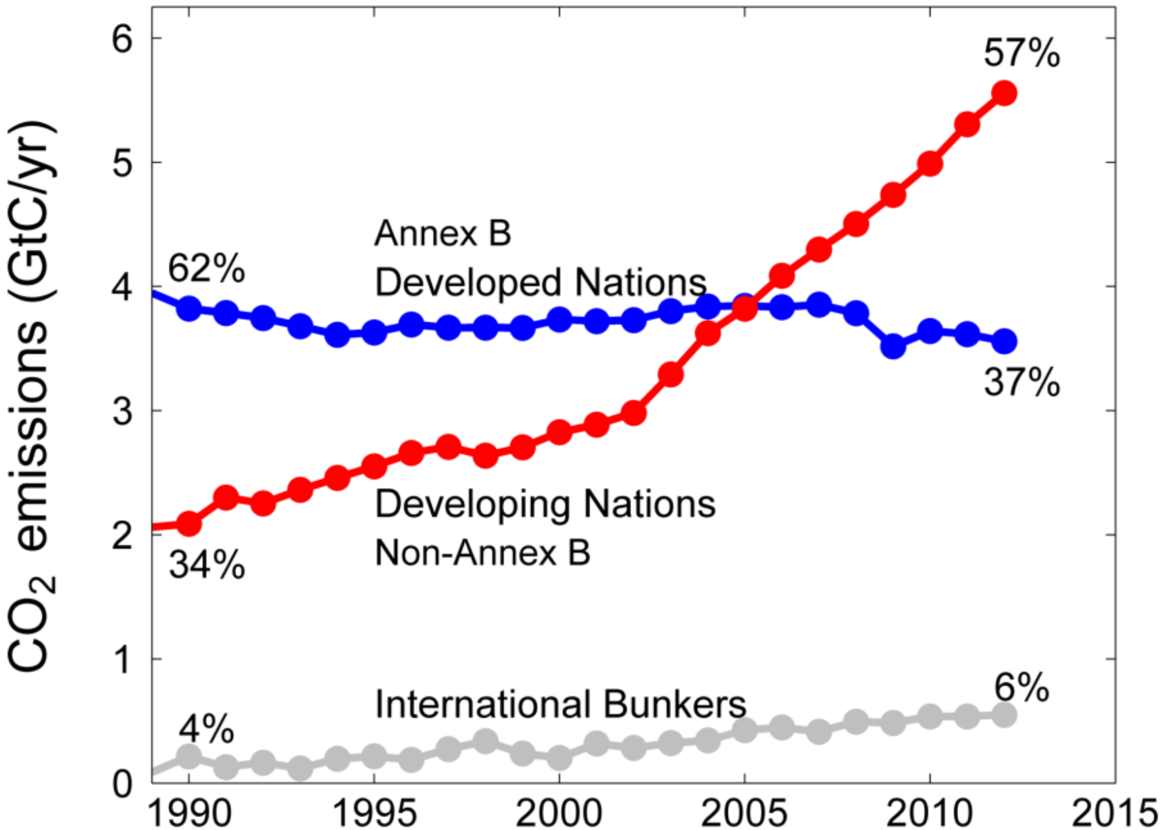


Cumulative emissions (1990–2012) were distributed USA (20%), EU28 (15%), China (18%), India (5%)

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Territorial Emissions as per the Kyoto Protocol

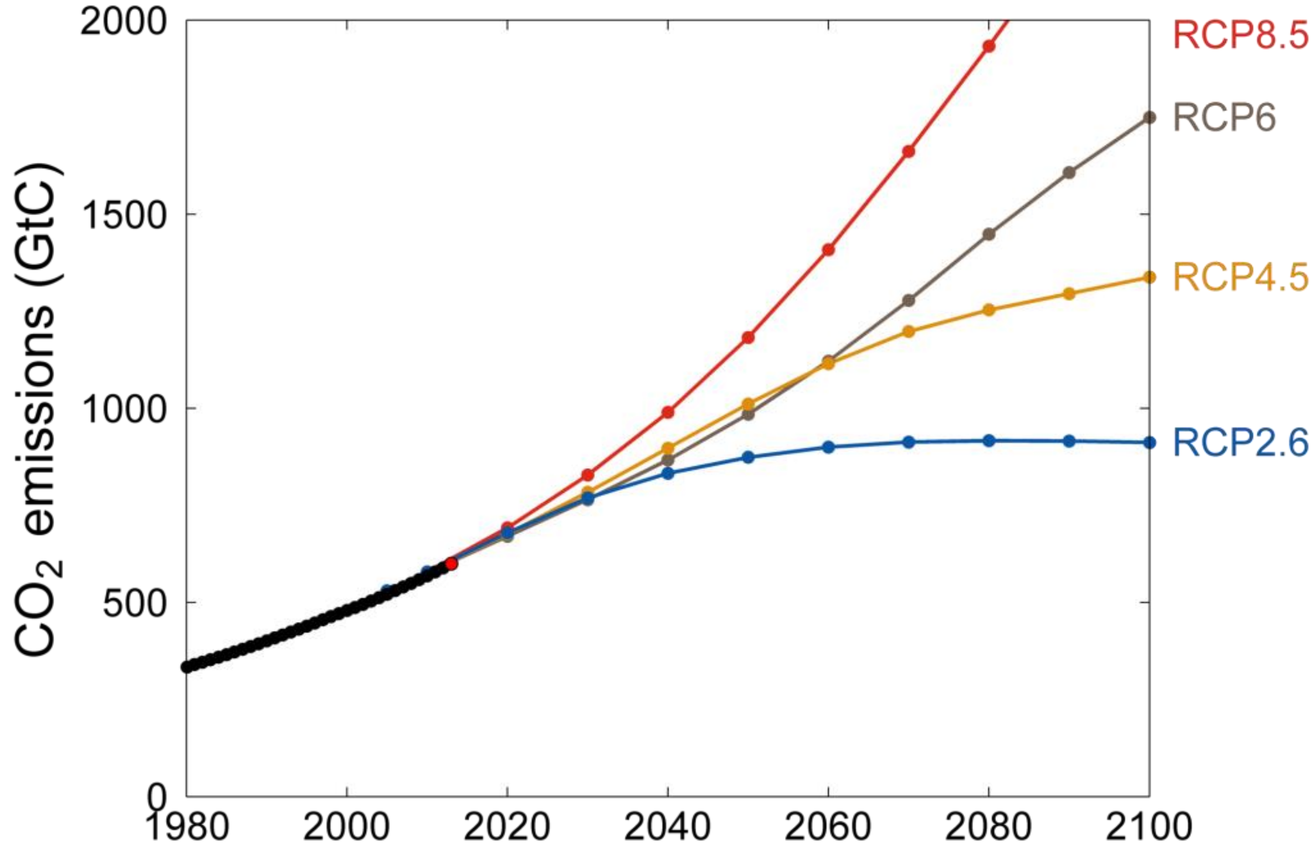
The Kyoto Protocol is based on the global distribution of emissions in 1990
The global distribution of emissions is now starkly different



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Cumulative Emissions and Scenarios

For a "likely" chance to keep warming less than 2ºC since the period 1861–1880, requires cumulative CO_2 emissions to stay below 1000GtC, or 790GtC when allowing for non-CO_2



Cumulative emissions 1870–2013 are 550 ±60 GtC; 70% from fossil fuels and cement, 30% from land-use change

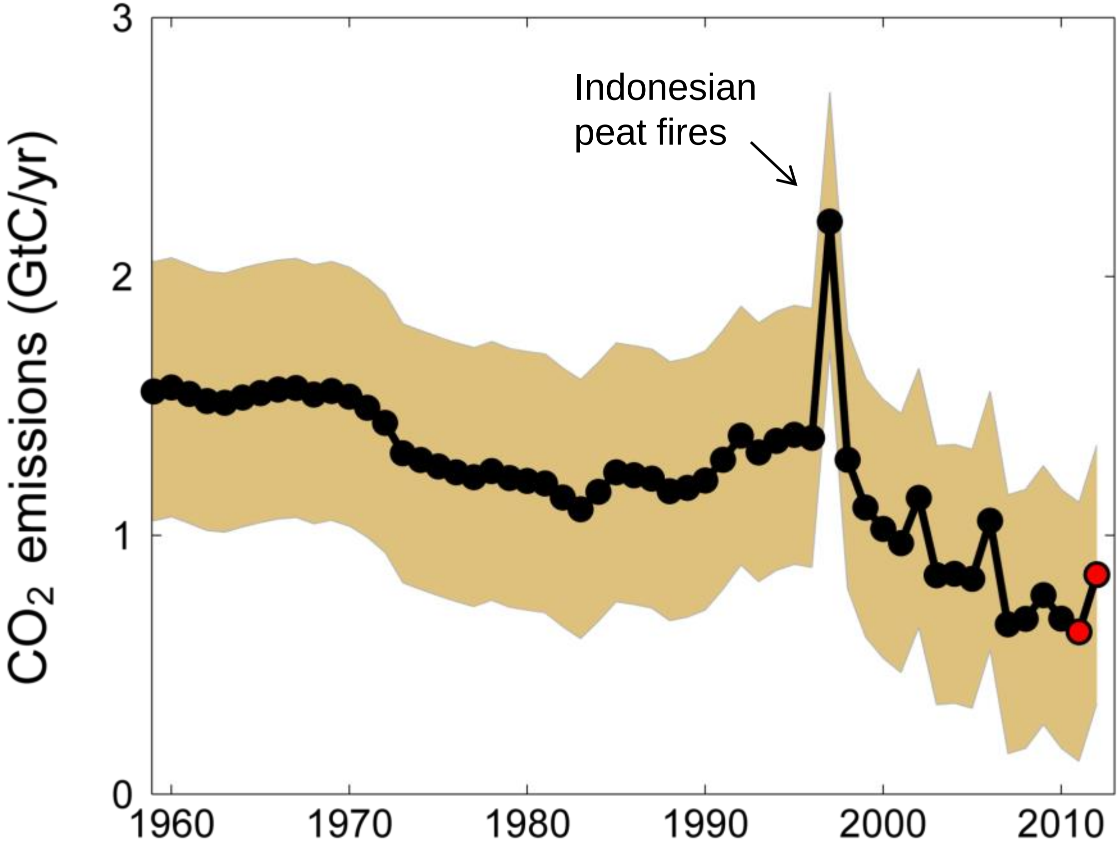
Cumulative emissions from 1750–1870 are highly uncertain, with about 50 GtC with 90% from land-use change

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Land-Use Change Emissions

Global land-use change emissions are estimated 0.8 ± 0.5 GtC during 2003–2012

The data suggests a general decrease in emissions since 1990



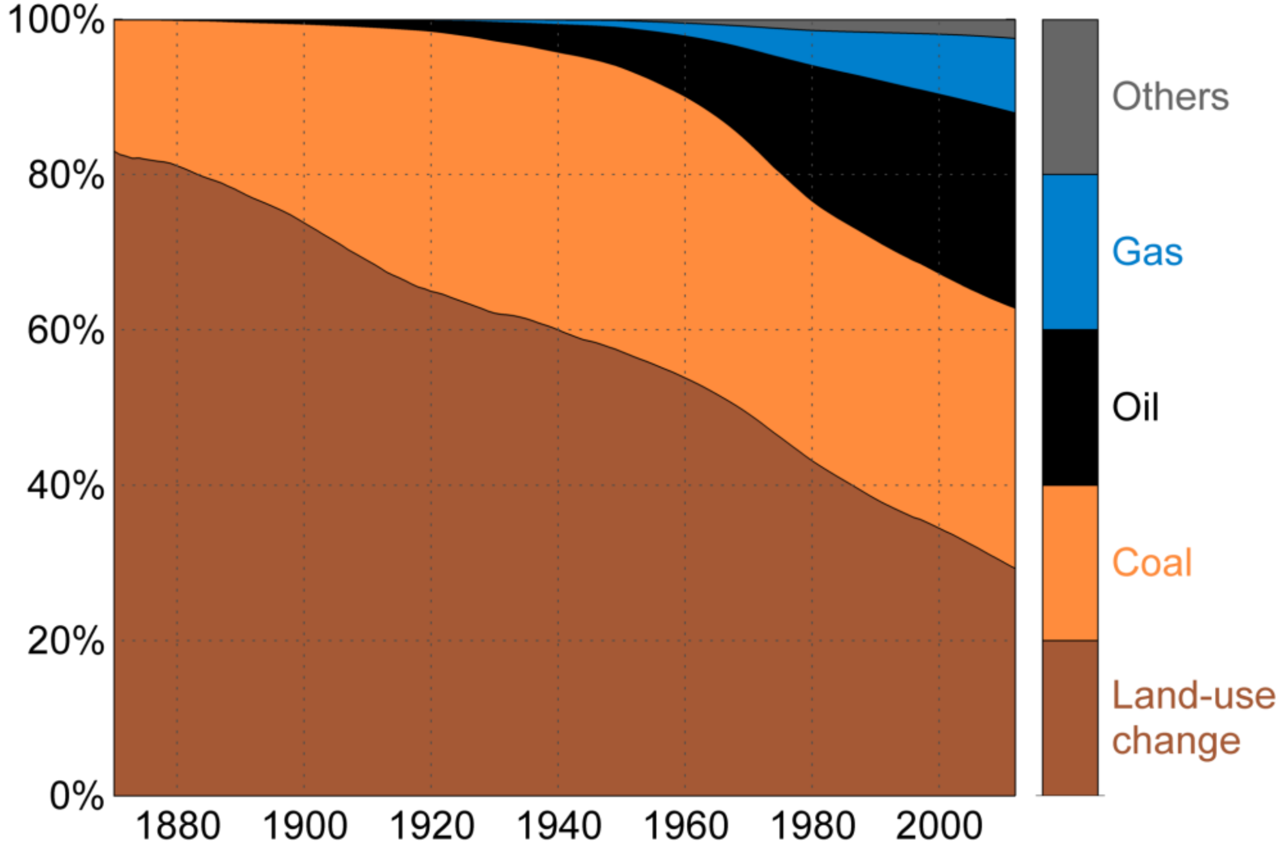
2011 and 2012 are extrapolated estimates

Source: Le Quéré et al 2013; Houghton & Hackler (in review); Global Carbon Project 2013

Historical Cumulative Emissions by Source

Despite reductions in land-use change, it represents about 29% of cumulative emissions in 2012

Coal represents about 34%, oil 25%, gas 10%, and others 2%



Others: Emissions from cement production and gas flaring.

Source: CDIAC Data; Houghton & Hackler (in review); Global Carbon Project 2013