Site level scales

Molecular - Cellular

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).
Earth System model
Land computational units

Gridcell

Landunit
- Vegetated
- Lake
- Urban
- Glacier
- Crop

Column
- Soil
- Roof
- Sun Wall
- Shade Wall
- Pervious
- Impervious

PFT
- PFT1
- PFT2
- PFT3
- PFT4...

V
- PFT1
- PFT2
- PFT3
- PFT4

Ut.H.M
- C1I
- C1U
- C2I
- C2U

Unirrig
- Crop1
- Crop1
- Crop2

Irrig
- Crop2...
Multi-scale model evaluation

**Canopy fluxes**
GPP, latent heat flux

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

**Global vegetation**
GPP, latent heat flux


**Canopy processes**
Theory
Numerical parameterization

*Profiles of light, leaf traits, and photosynthesis*

**Leaf traits**

Global databases of leaf traits and eddy
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)

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 (H₂O, CO₂, 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 CO₂.
• Some of energy goes into warming the ocean.
• How much CO₂ 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 CO₂ 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
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

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

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

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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
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
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 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
Global land-use change emissions are estimated $0.8 \pm 0.5$ 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
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