Modeling ecosystems and biogeochemical cycles

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Outline

- Hierarchy in the biosphere
- Distribution and components of life on Earth
- Global biogeochemical cycles
- Modeling ecosystems as components of the Earth System
  - **Dynamic global vegetation models**
- Models of global biogeochemical cycles

How to develop predictive schemes for the **living components** of the **Earth System**?

Why do we need to take **life** into account?

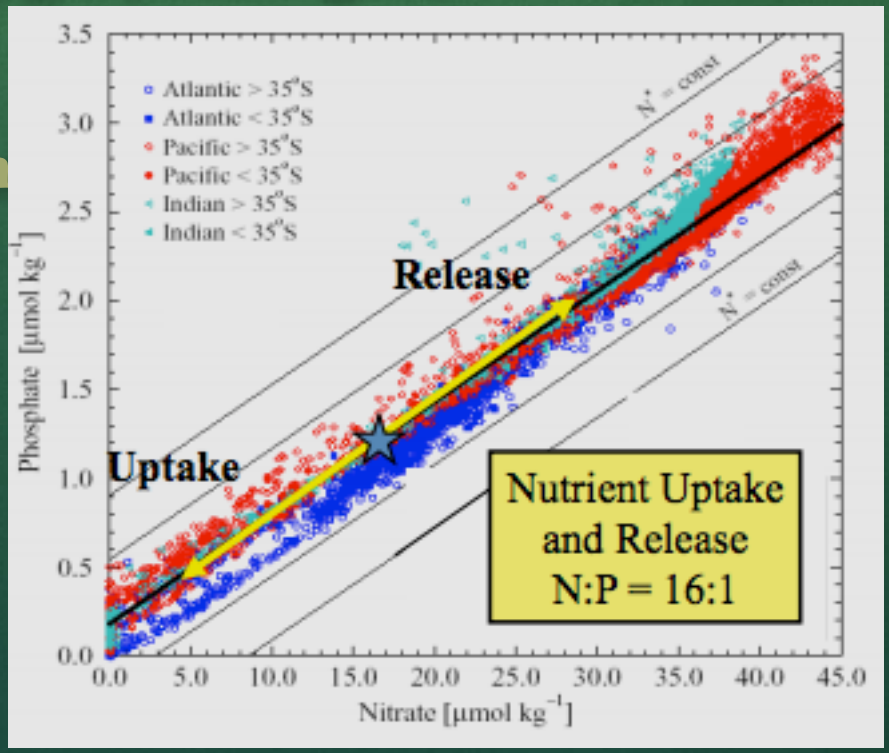
- From a 'climate' point of view:
  - We need to predict the future of the atmospheric composition in GHGs
  - Vegetation controls energy (and moisture) transfer properties of the land surface
- We live in/around ecosystems!
  - Ecosystems are providing us with services!

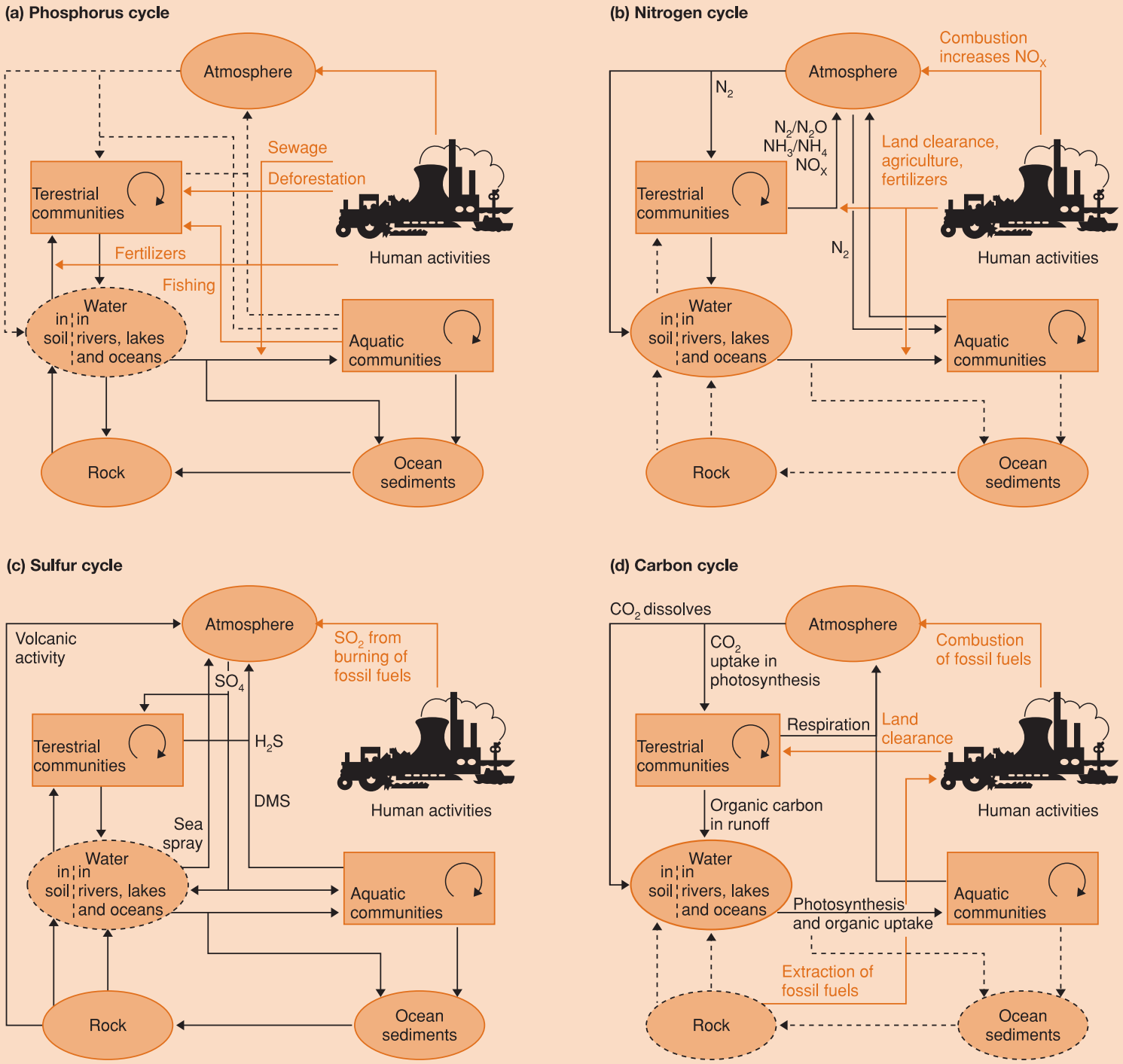
Hierarchy of life…

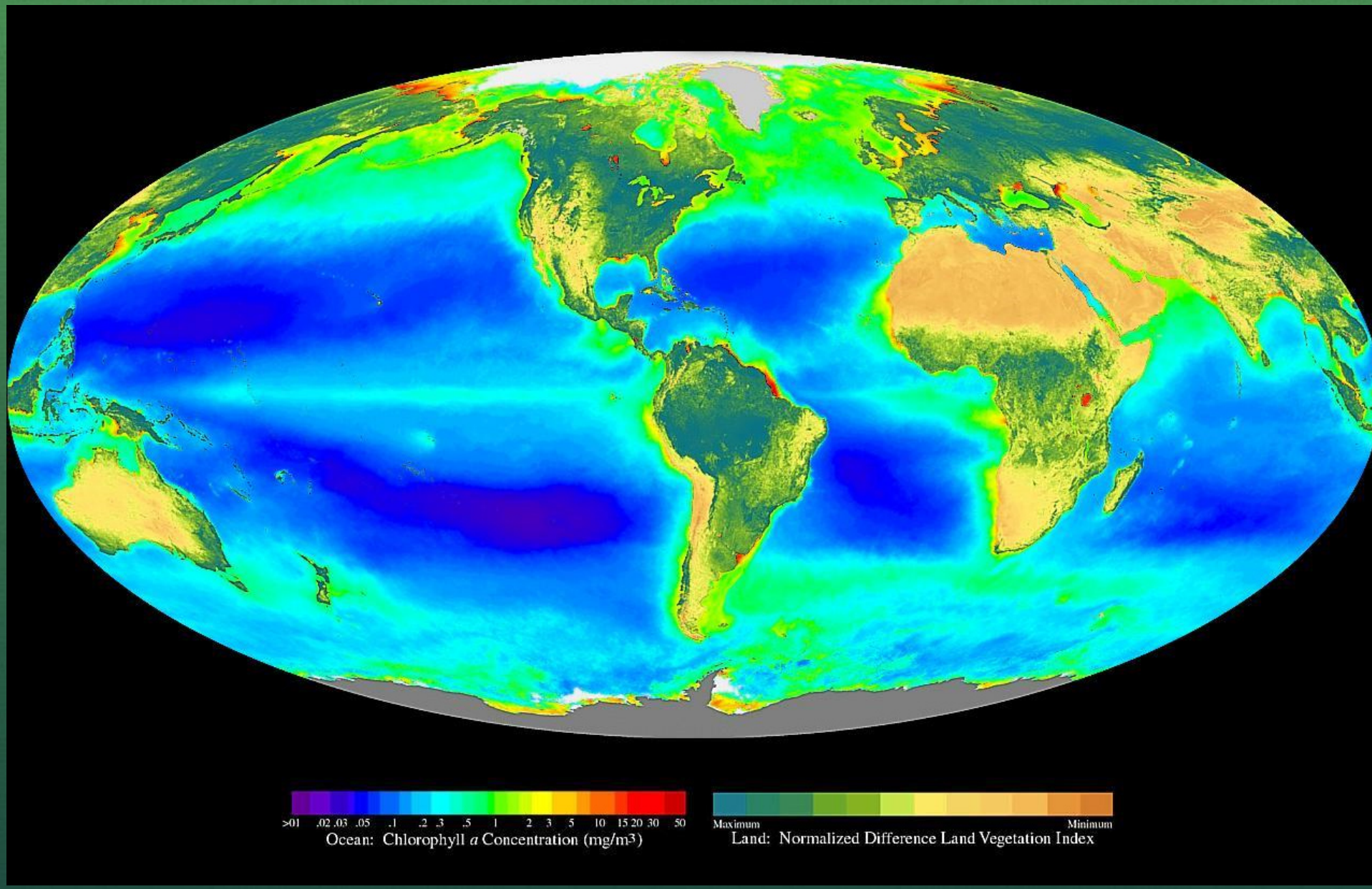
- Individual (of a given species)
- Population
- Community
- Ecosystem = biotic + abiotic
- Biomes
- Biosphere

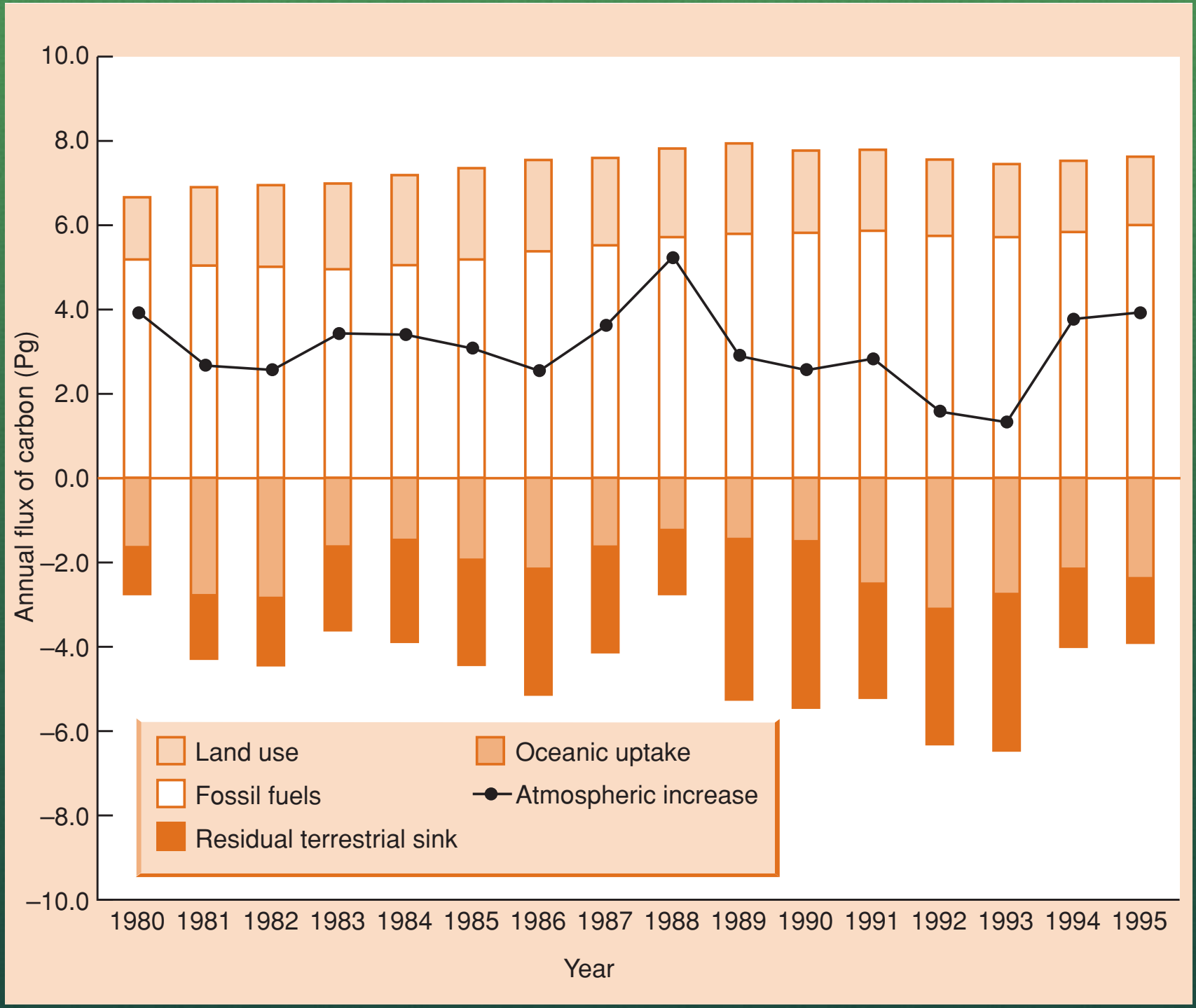
Some numbers…

- ‘Carbon-based’ phenomenon
  - **Carbon**/Hydrogen/Oxygen/**Nitrogen**/ Phosphorus/…
- Stoichiometry of life: **ocean**
  - Redfield ratio:
    - C:N:P —> 106:16:1




(a) Phosphorus cycle
Atmosphere
Sewage
Deforestation
Terestrial communities
Human activities
Fertilizers
Fishing
Water in soil
Water in rivers, lakes and oceans
Aquatic communities
Rock
Ocean sediments
(b) Nitrogen cycle
Combustion increases NO_x
Atmosphere
N_2
N_2/N_2O
NH_3/NH_4
NO_x
Land clearance, agriculture, fertilizers
Terestrial communities
Human activities
N_2
Water in soil
Water in rivers, lakes and oceans
Aquatic communities
Rock
Ocean sediments
(c) Sulfur cycle
Volcanic activity
Atmosphere
SO_2 from burning of fossil fuels
SO_4
Terestrial communities
H_2S
DMS
Human activities
Sea spray
Water in soil
Water in rivers, lakes and oceans
Aquatic communities
Rock
Ocean sediments
(d) Carbon cycle
CO_2 dissolves
Atmosphere
CO_2 uptake in photosynthesis
Combustion of fossil fuels
Respiration
Land clearance
Terestrial communities
Human activities
Organic carbon in runoff
Water in soil
Water in rivers, lakes and oceans
Photosynthesis and organic uptake
Aquatic communities
Extraction of fossil fuels
Rock
Ocean sediments


>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index


10.0
8.0
6.0
4.0
2.0
0.0
–2.0
–4.0
–6.0
–8.0
–10.0
Annual flux of carbon (Pg)
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
Year
Land use
Fossil fuels
Residual terrestrial sink
Oceanic uptake
Atmospheric increase

Some key concepts:
Reservoirs, **residence times, …**

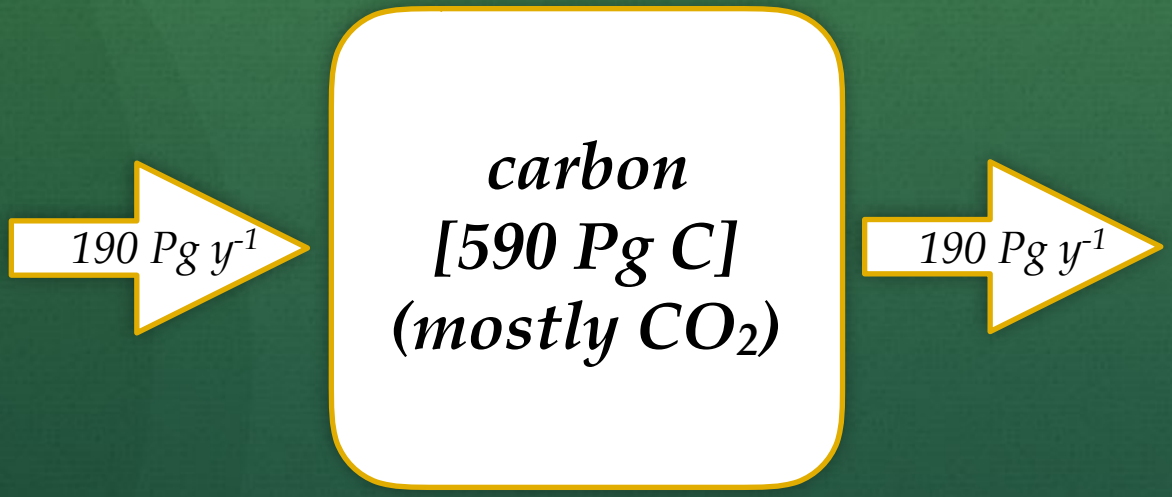
residence time = stock/flow

$[M] / [M\ T^{-1}] = [T]$

flow out = flow in **steady-state**

Carbon in the atmosphere

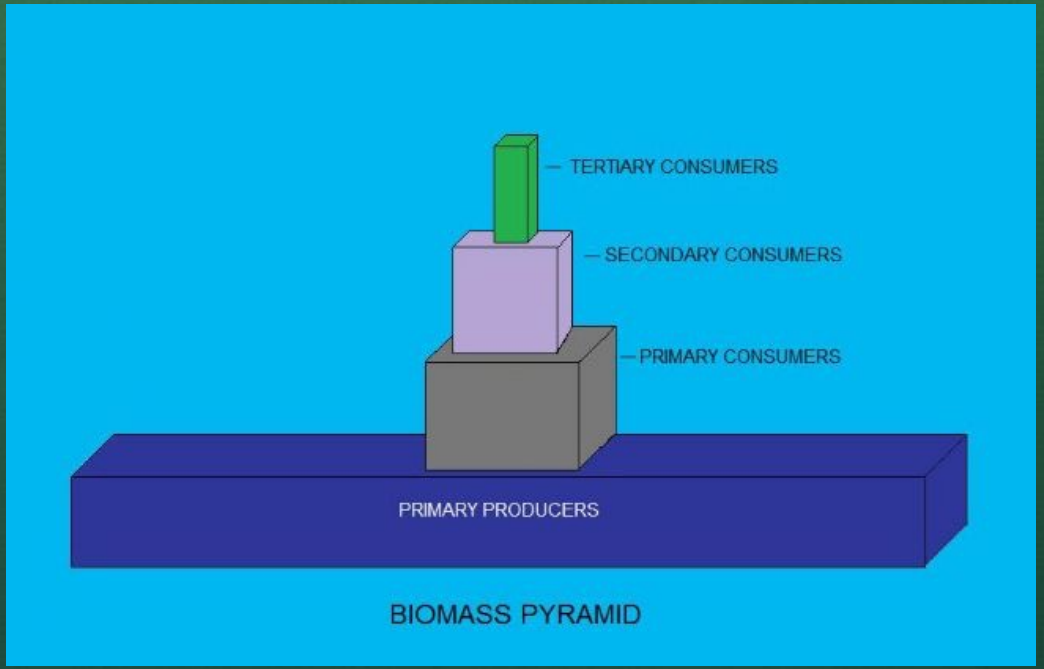
$3{,}1y = 590\ Pg\ C \div 190\ Pg\ C/y^{-1}$



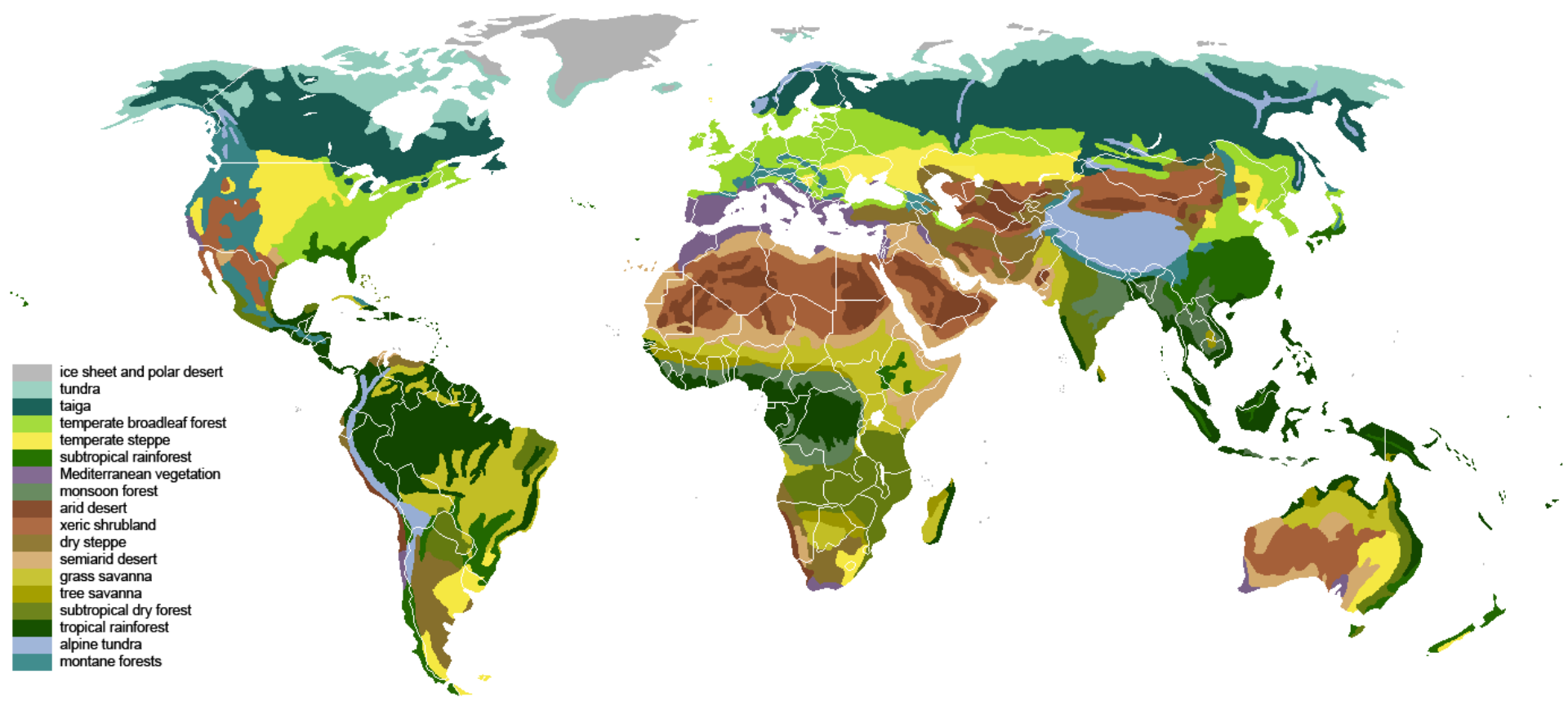
flow out ≠ flow in **not in steady-state!**

Modeling ecosystems…

- Many (too many species) —> $(many)^n$ interactions
- Food webs / trophic levels
- Biomass pyramid



Biomes


ice sheet and polar desert
tundra
taiga
temperate broadleaf forest
temperate steppe
subtropical rainforest
Mediterranean vegetation
monsoon forest
arid desert
xeric shrubland
dry steppe
semiarid desert
grass savanna
tree savanna
subtropical dry forest
tropical rainforest
alpine tundra
montane forests

Dynamic global vegetation models

- Started in ’90s
- DGVMs use time series of climate data and, given constraints of latitude, topography, and soil characteristics, simulate monthly or daily dynamics of ecosystem processes
- generally combine biogeochemistry, biogeography, and disturbance submodels
- spatially distributed mode, geographic points which are assumed to have homogeneous conditions within each cell

Plant functional types

- a system used by ecosystem modelers to classify plants according to their physical, phylogenetic and phenological characteristics
- for each plant functional type, key parameters are defined, such as fecundity, competitiveness, resorption (rate at which plant decays and returns nutrients to the soil after death), etc.

PFTs…

Function	Easily measurable trait
Fecundity Dispersal Recruitment	Seed mass others?
Light interception Competitive ability	Vegetative height others?
Nutrient resorption Litter decomposability	Traits of living leaves NIRS spectrum; others?
Absorption (nutrients, water) Carbon flux (exsudation …)	Density, diameter Specific length

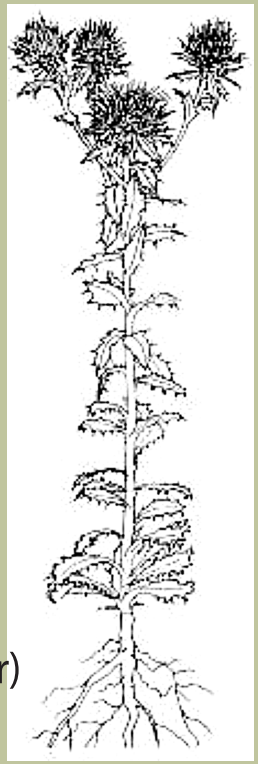


Fig. 13.1. Examples of soft traits and associated functions

IBIS
Integrated Biosphere Simulator

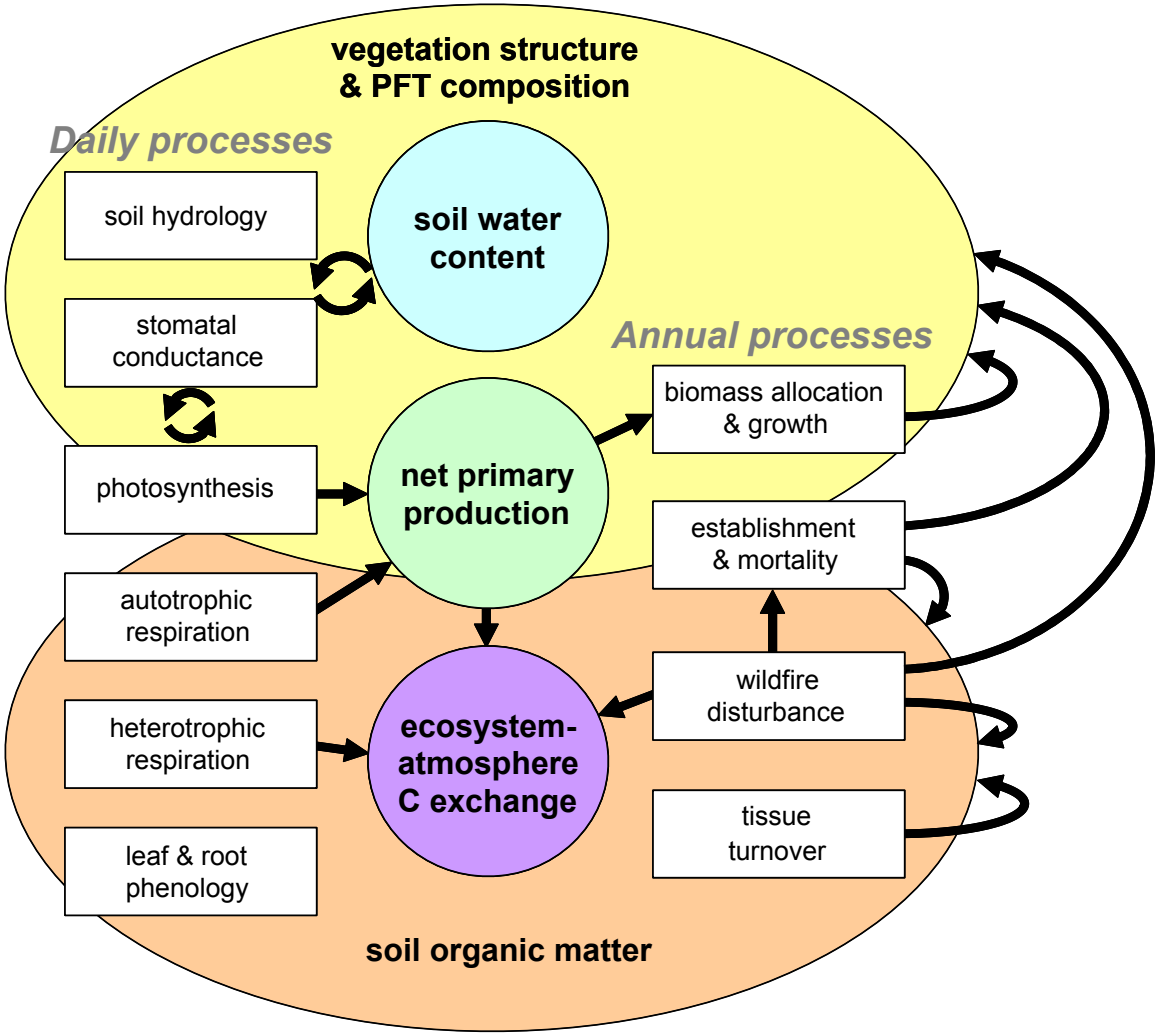
- 1996:
  "was designed to explicitly link land surface and hydrological processes, terrestrial biogeochemical cycles, and vegetation dynamics within a single physically consistent framework"

- 2000: **IBIS2**
  new version of IBIS has improved representations of land surface physics, plant physiology, canopy phenology, plant functional type (PFT) differences, and carbon allocation

LPJ-GUESS

Lund-Potsdam-Jena

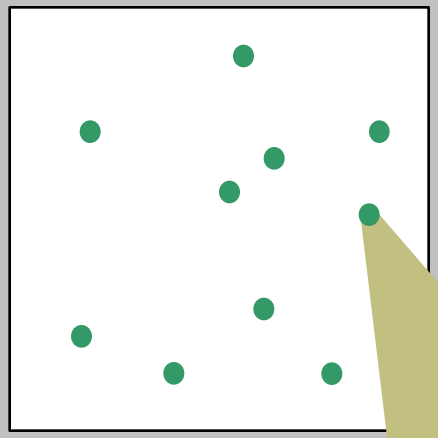
General Ecosystem Simulator

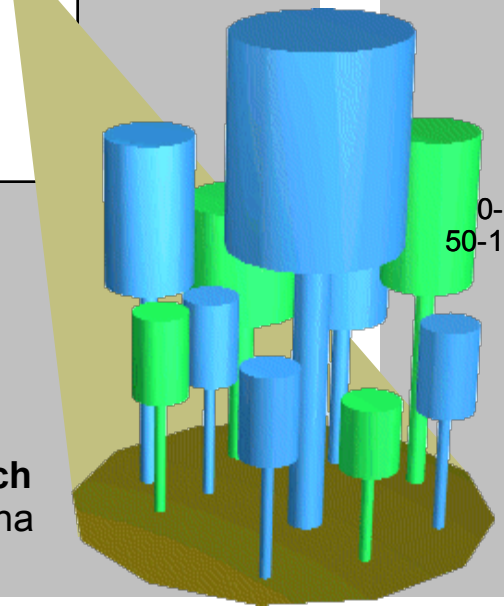

vegetation structure
& PFT composition
Daily processes
soil hydrology
soil water
content
stomatal
conductance
Annual processes
biomass allocation
& growth
photosynthesis
net primary
production
establishment
& mortality
autotrophic
respiration
wildfire
disturbance
heterotrophic
respiration
ecosystem-
atmosphere
C exchange
tissue
turnover
leaf & root
phenology
soil organic matter

Vegetation representation in LPJ-GUESS

Modelled area (stand)
10 ha - 2500 km^2

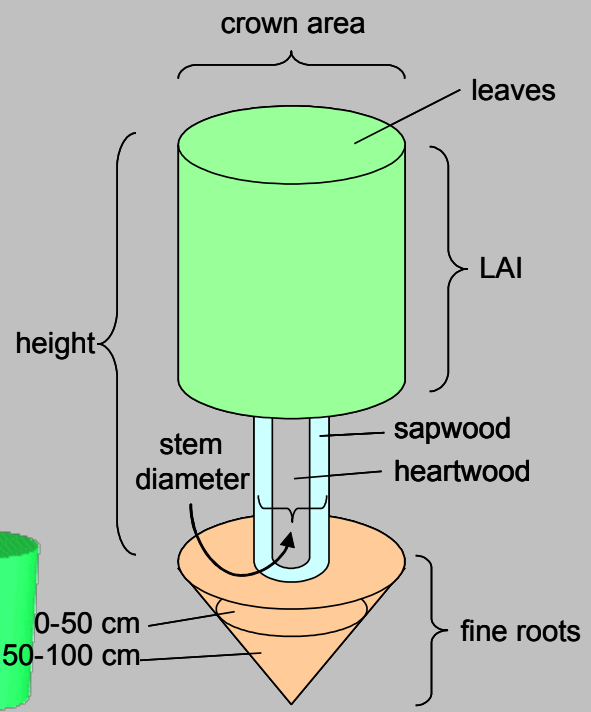
replicate patches in various stages of development



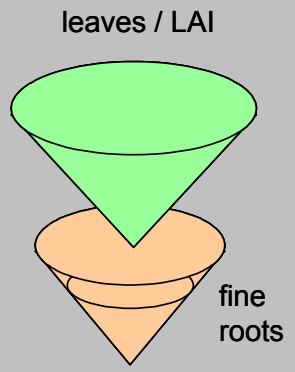


Patch
0.1 ha

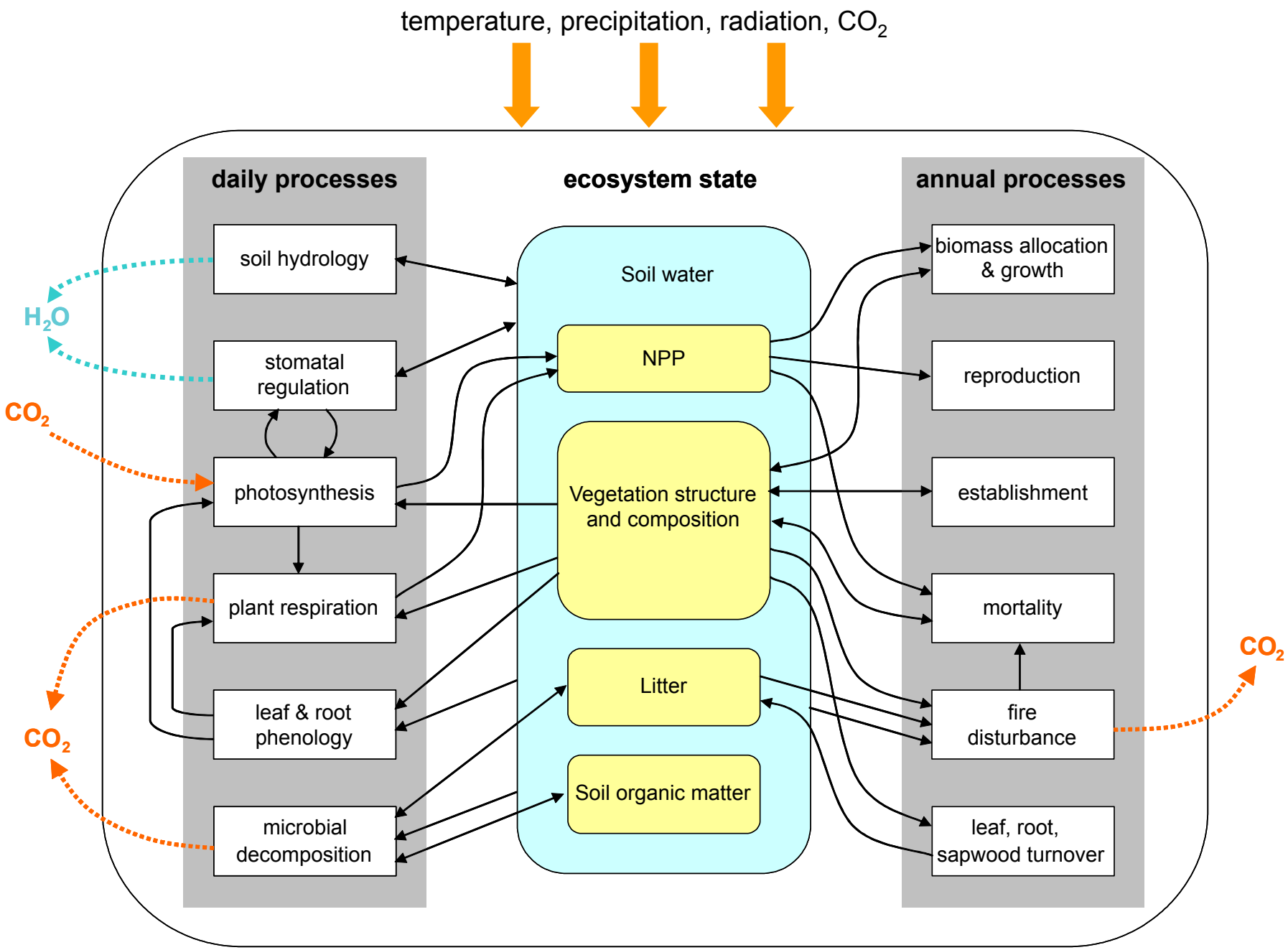
Average individual for PFT or species cohort in patch

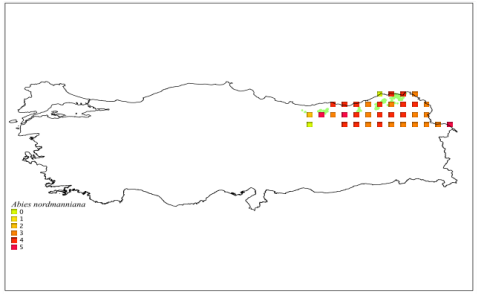


tree

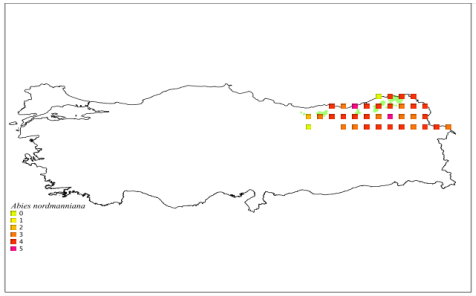


grass

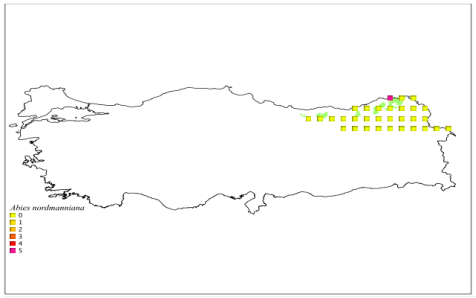

temperature, precipitation, radiation, CO_2
daily processes
ecosystem state
annual processes
soil hydrology
stomatal regulation
photosynthesis
plant respiration
leaf & root phenology
microbial decomposition
Soil water
NPP
Vegetation structure and composition
Litter
Soil organic matter
biomass allocation & growth
reproduction
establishment
mortality
fire disturbance
leaf, root, sapwood turnover
H_2O
CO_2
CO_2
CO_2



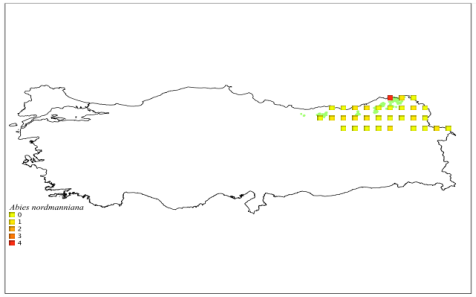
(a) 2000



(b) 2040

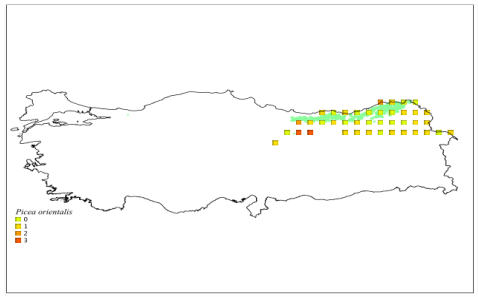


(c) 2070

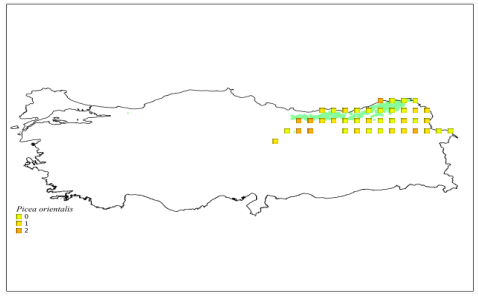


(d) 2100

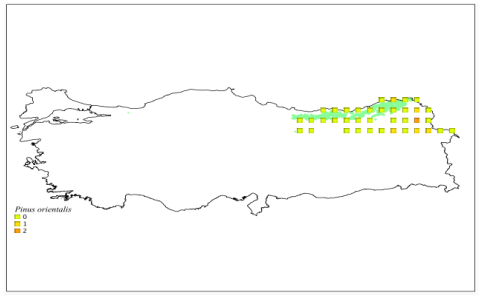
Figure 4.5: *Abies nordmanniana* simulation



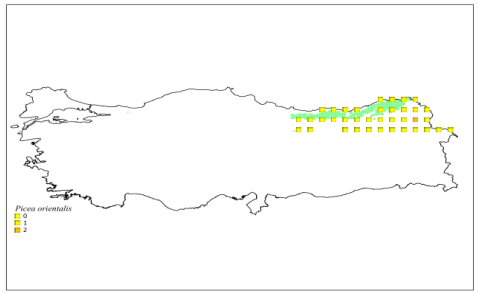
(a) 2000



(b) 2040



(c) 2070



(d) 2100

Figure 4.4: *Picea orientalis* simulation