The terrestrial biosphere: biogeochemistry and global change

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Outline

- The terrestrial biosphere: definitions and useful concepts
- Global change and the terrestrial biosphere
- Scaling and hierarchical theory
- Introduction to the course

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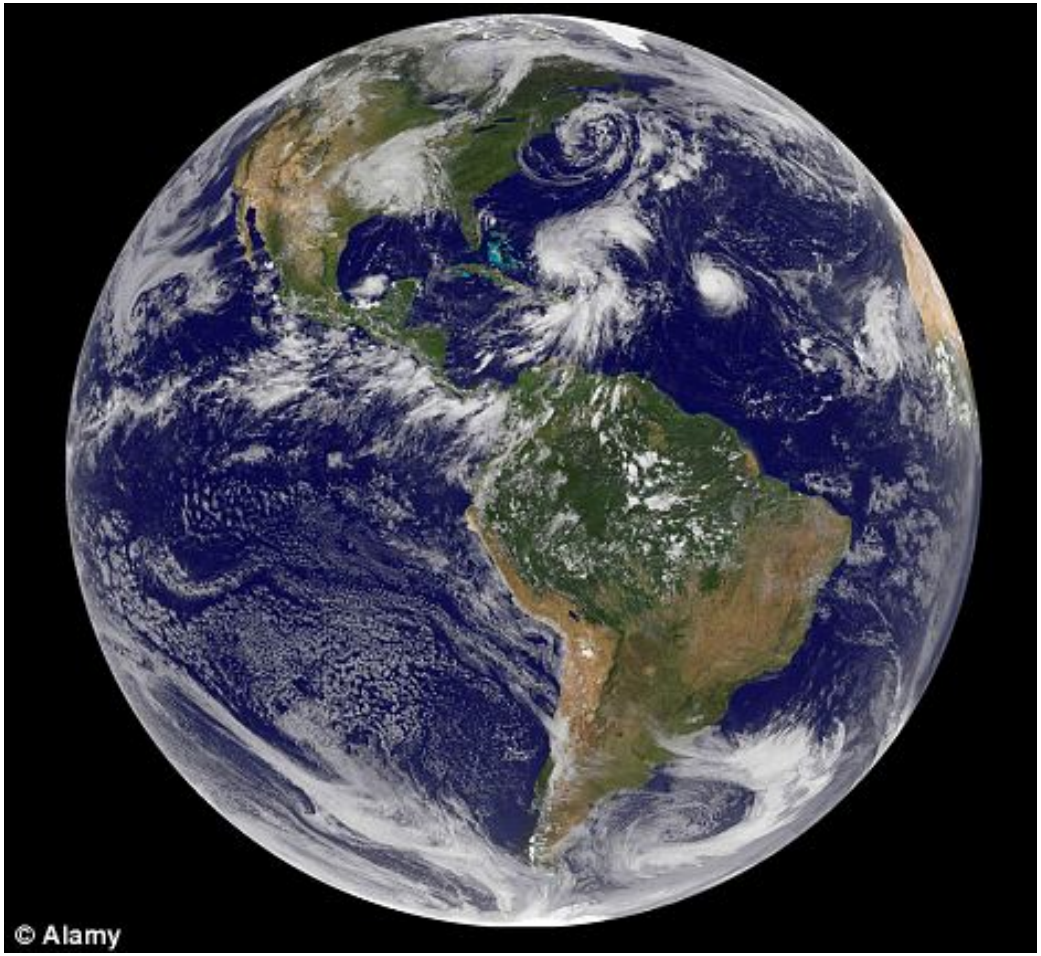
Earth's biosphere



The biosphere includes all living organisms on earth, together with the dead organic matter produced by them.

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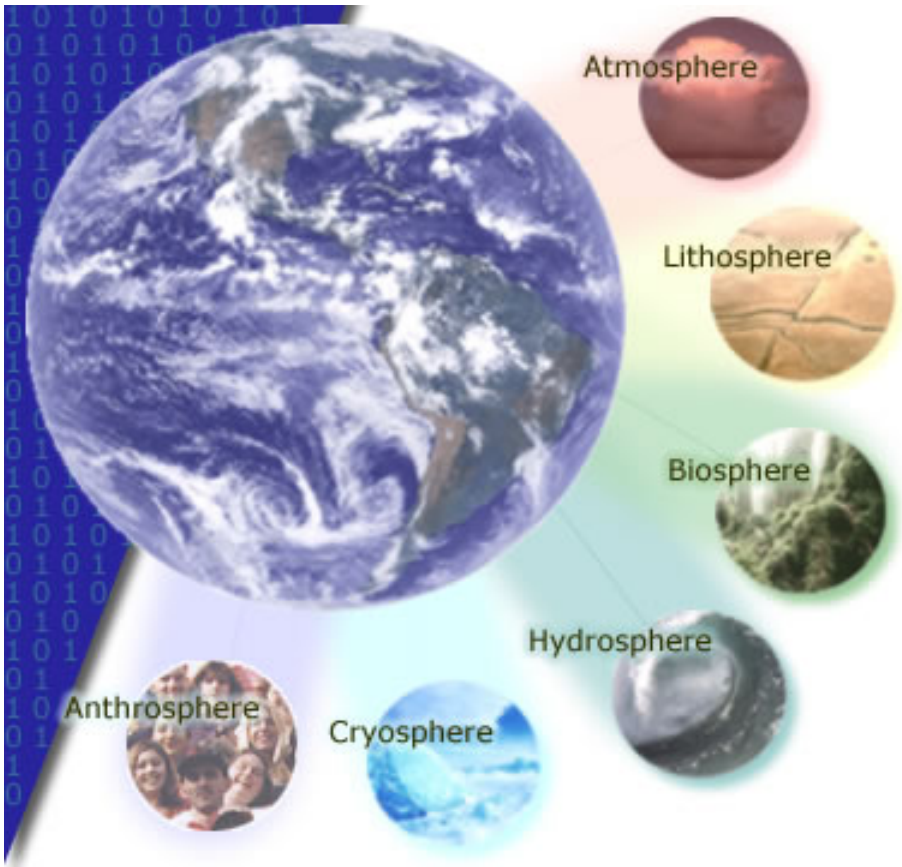
Earth's biosphere



The term "biosphere" originated with the geologist **Eduard Suess** *in 1875, who defined it as "the place on earth's surface where life dwells".* **Vladimir I. Vernadsky** *first defined the biosphere in a form resembling its current ecological usage in his long-overlooked book of the same title, originally published in 1926. It is Vernadsky's work that redefined ecology as the science of the biosphere and placed the biosphere concept in its current central position in earth systems science.*

Ellis (2009, The Encyclopedia of Earth)

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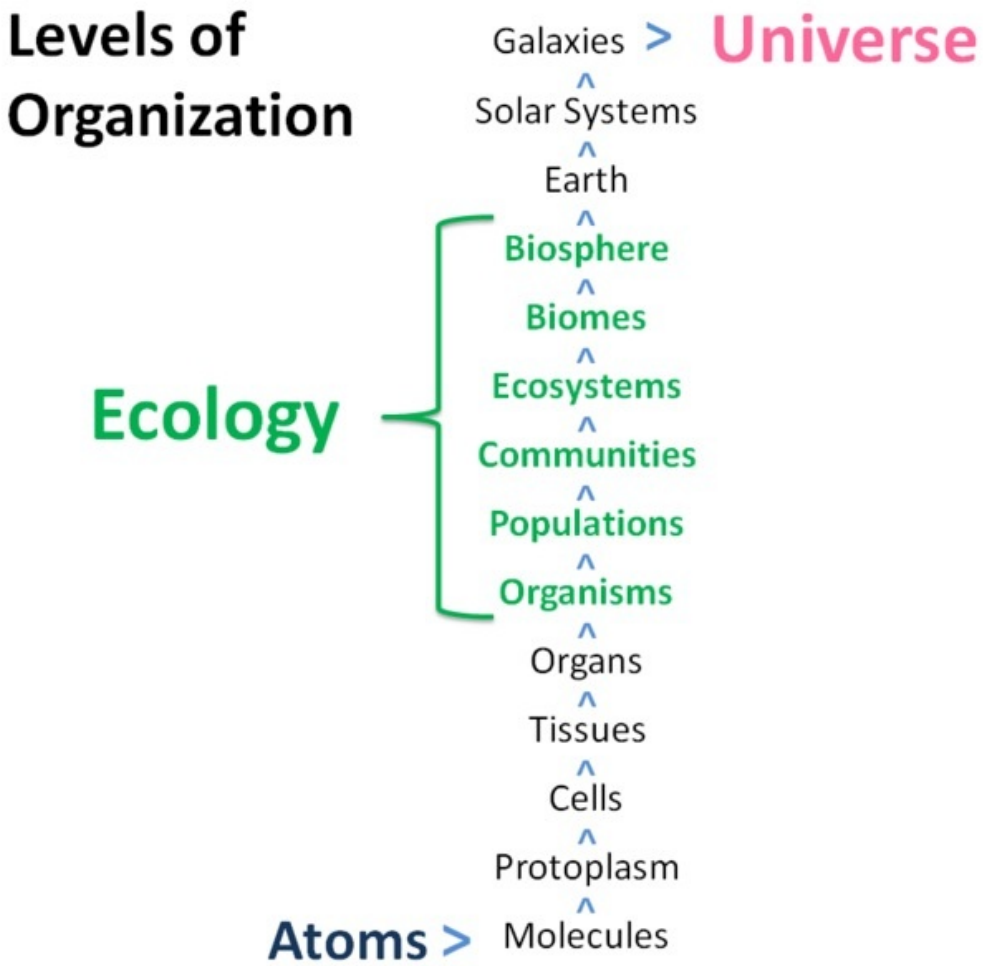
Levels of biological organization in Earth's biosphere



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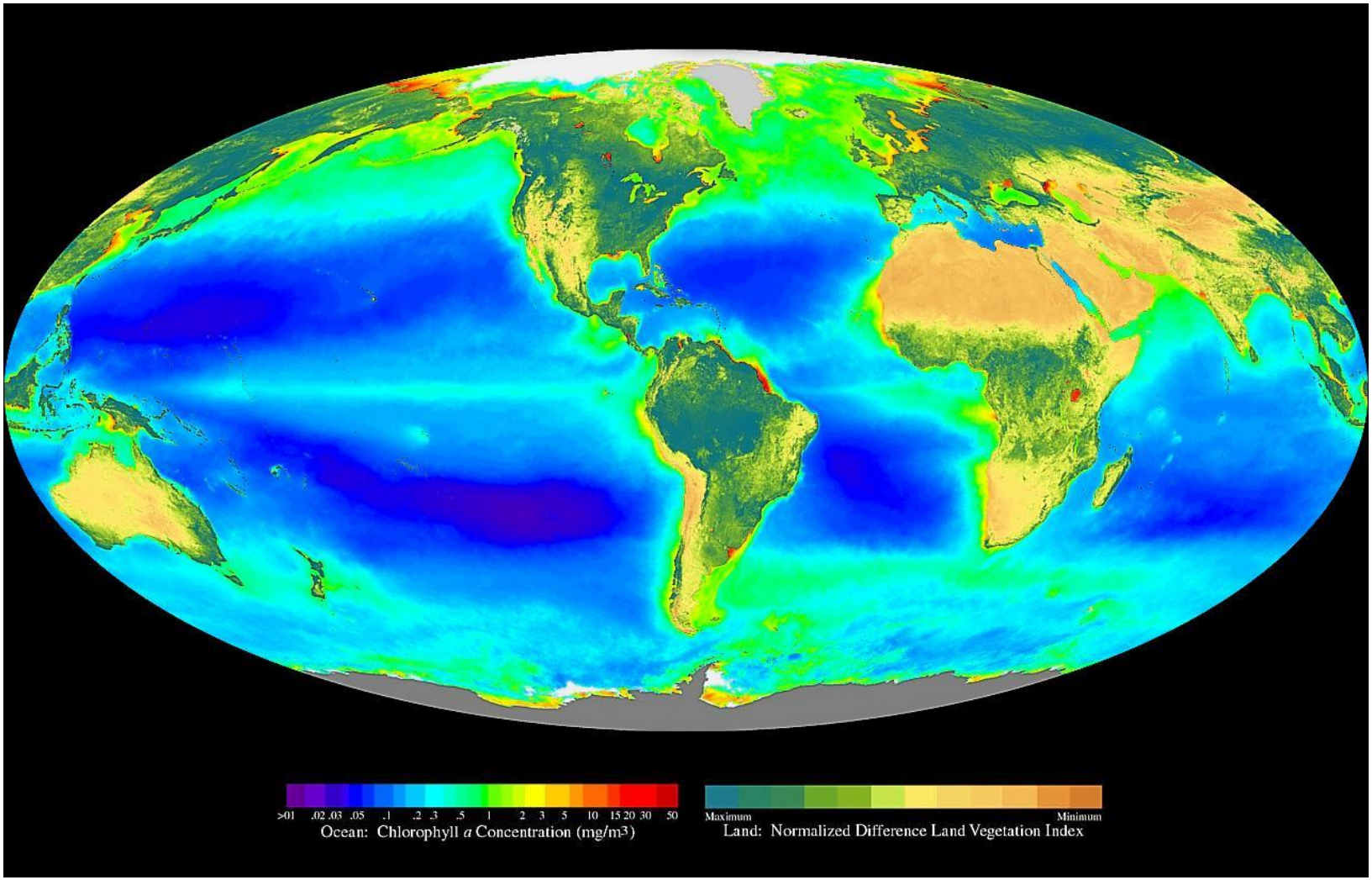
Earth's biosphere: oceanic and terrestrial components



©*SeaWiFS project, NASA*

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The terrestrial biosphere within the Earth system

Definition:
The terrestrial biosphere as the sum of all terrestrial *ecosystems* on Earth

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The Ecosystem concept

Any unit that includes all the organisms in a given area interacting with the physical environment so a flow of energy leads to clearly defined biotic structures and cycling of materials between living and nonliving components is an ecological system or ecosystem.

Odum & Barret (2005, Fundamentals of Ecology)

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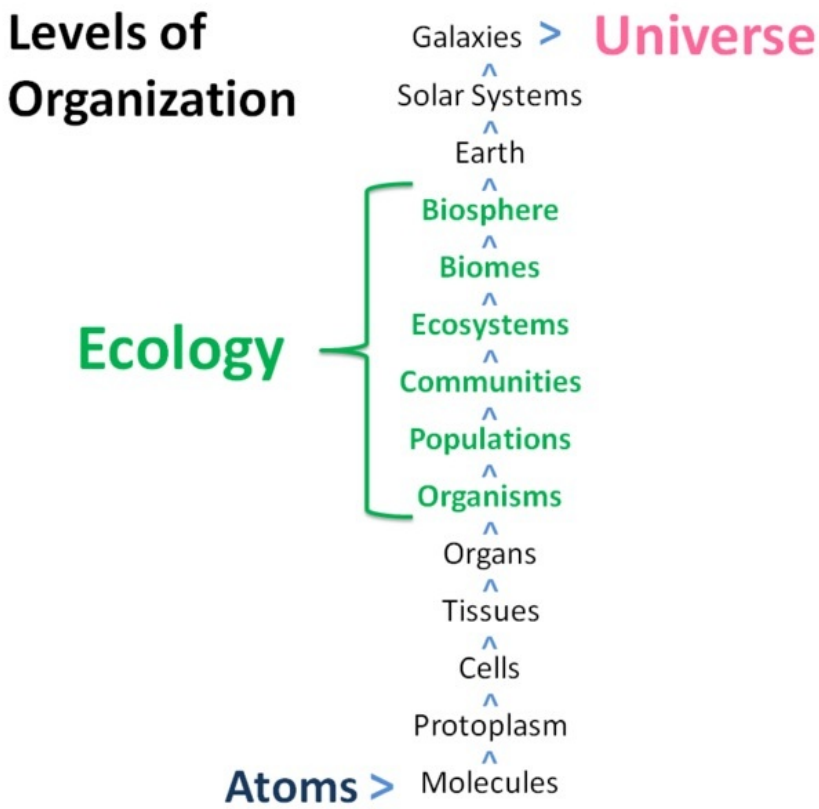
Nested hierarchy and the Ecosystem concept



The ecosystem is the first unit of the ecological hierarchy that is complete, has all components necessary for survival.

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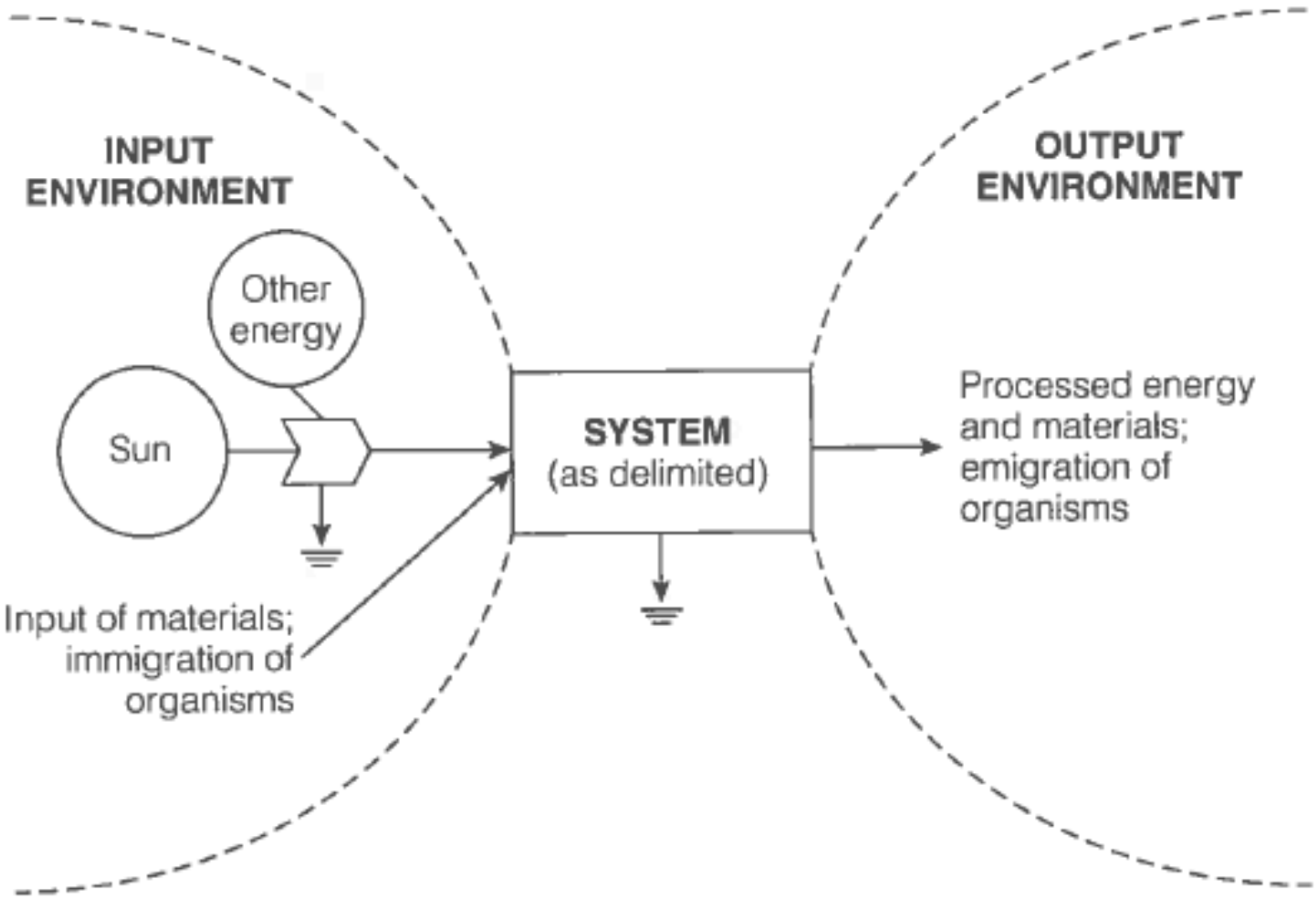
The basic ecosystem concept



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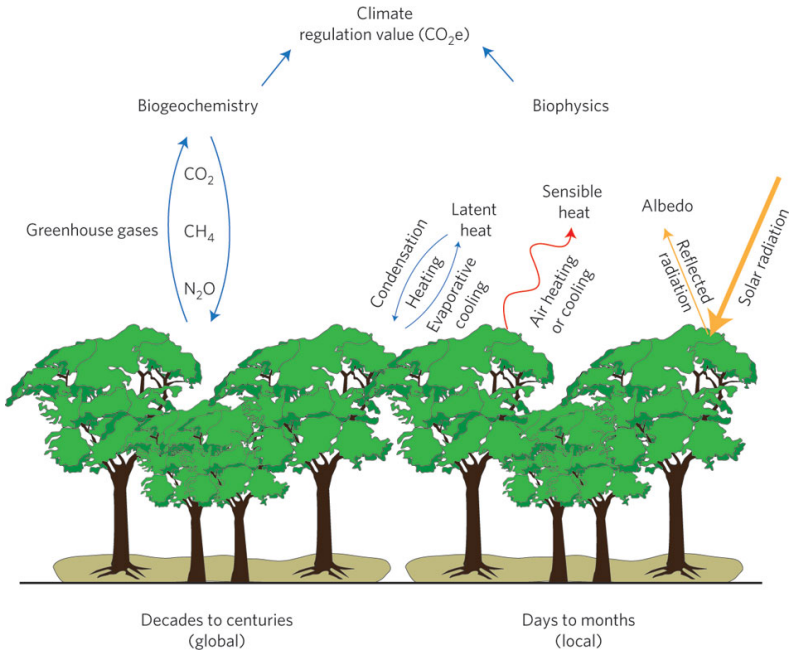
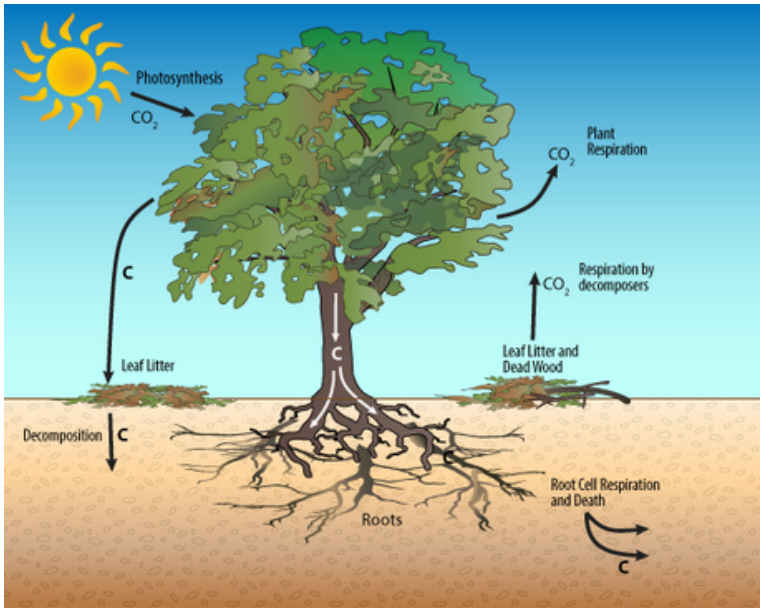
Energy and carbon balance in ecosystems





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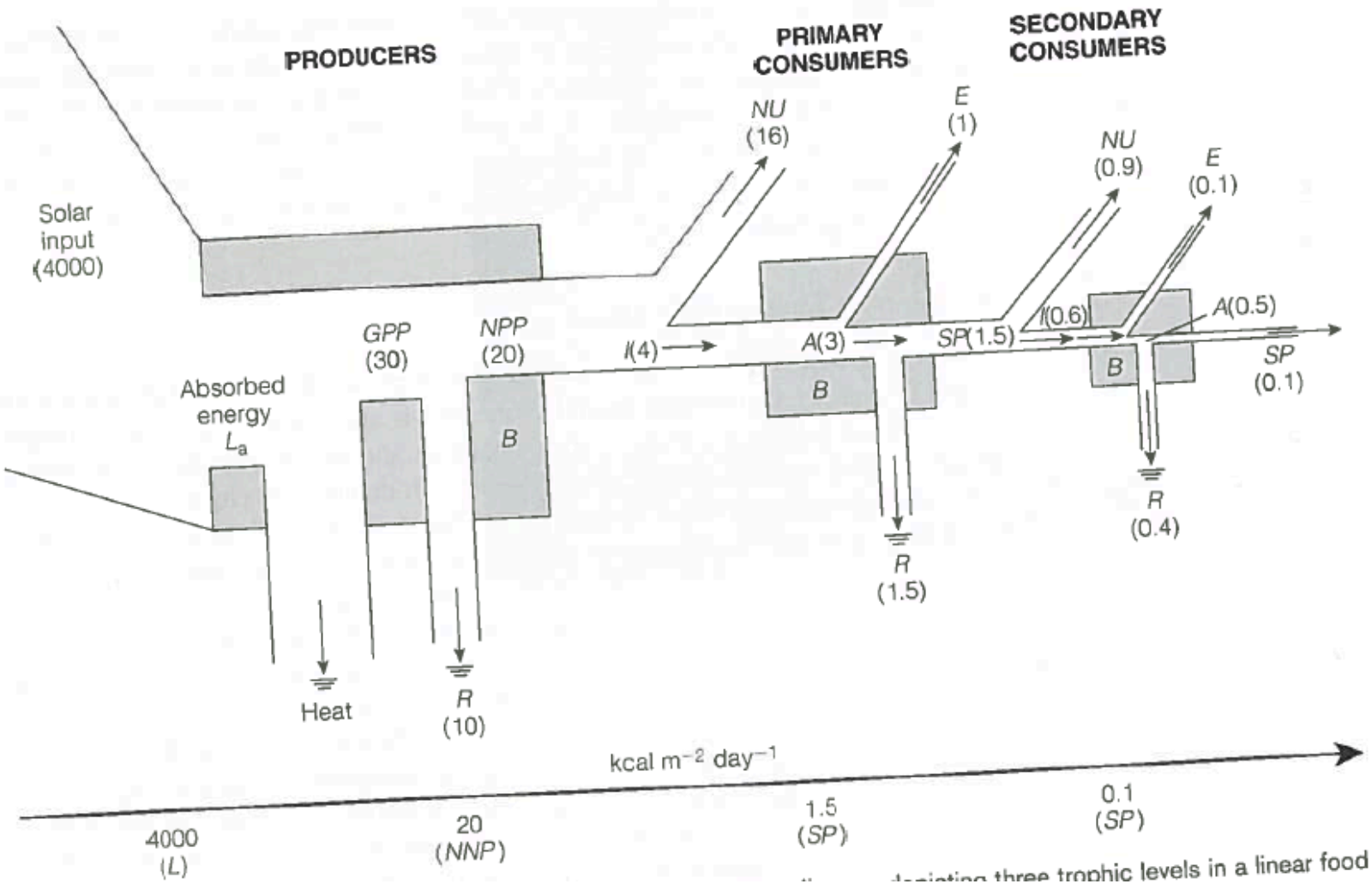
Carbon and energy flow



three trophic levels in a linear food

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Autotrophs and heterotrophs

- Autotrophs: Organisms that produce their own food from inorganic molecules; e.g. photosynthetic plants, algae, many bacteria.
- Heterotrophs: Organisms unable to manufacture its own food from inorganic matter, which therefore consume other organisms to acquire their own energy; e.g. animals, fungi, many bacteria.

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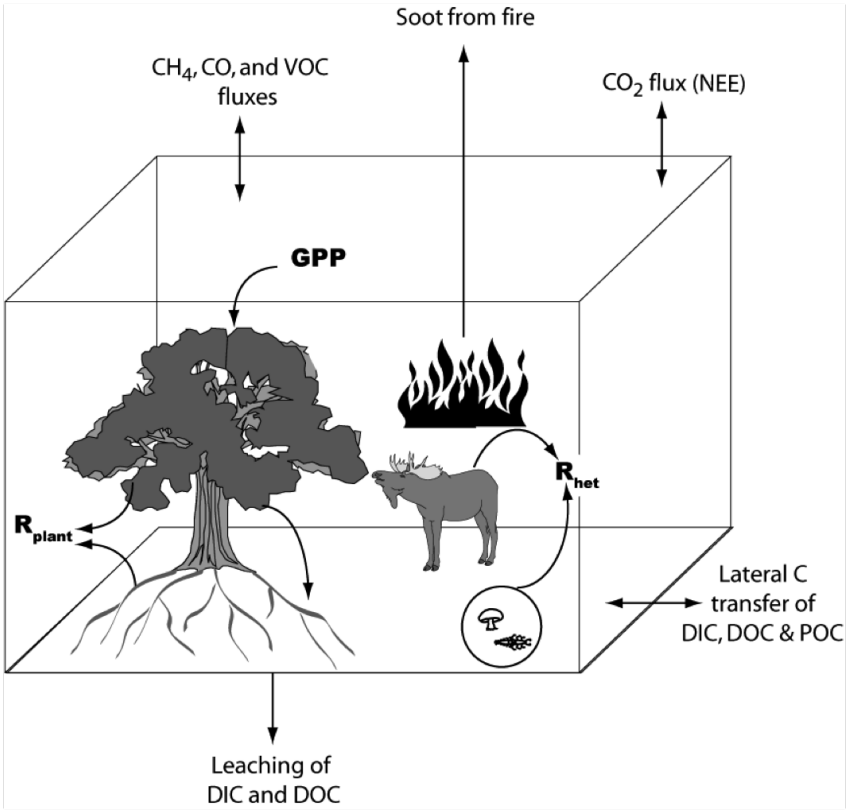
Terrestrial carbon cycle



$$NECB = \frac{dC}{dt}$$

$$NECB = (\text{gas in - out}) + (\text{dissolved in - out}) + (\text{solid in - out})$$

$$NEP = GPP - R_{eco}$$
$$= NPP - R_{het}$$

$$NPP = GPP - R_{auto}$$

$$R_{eco} = R_{auto} + R_{heter}$$

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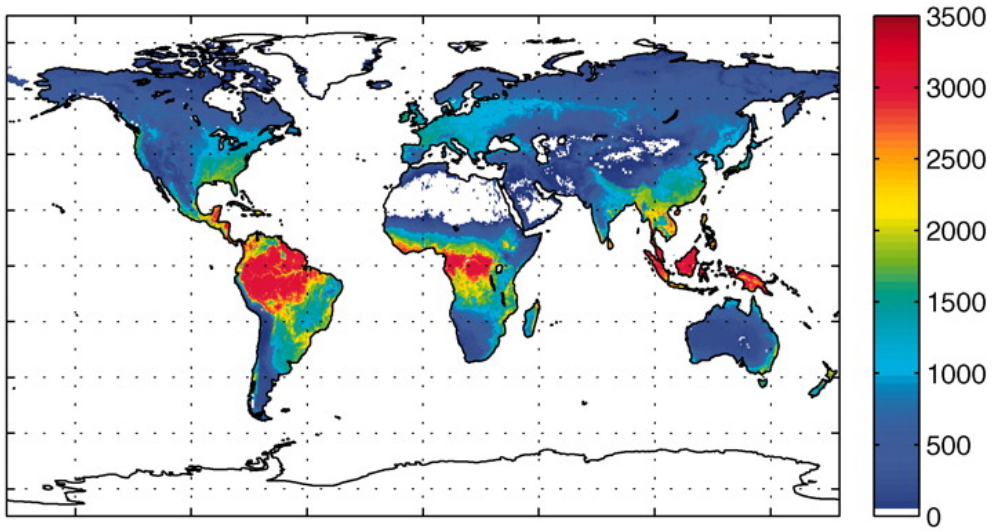
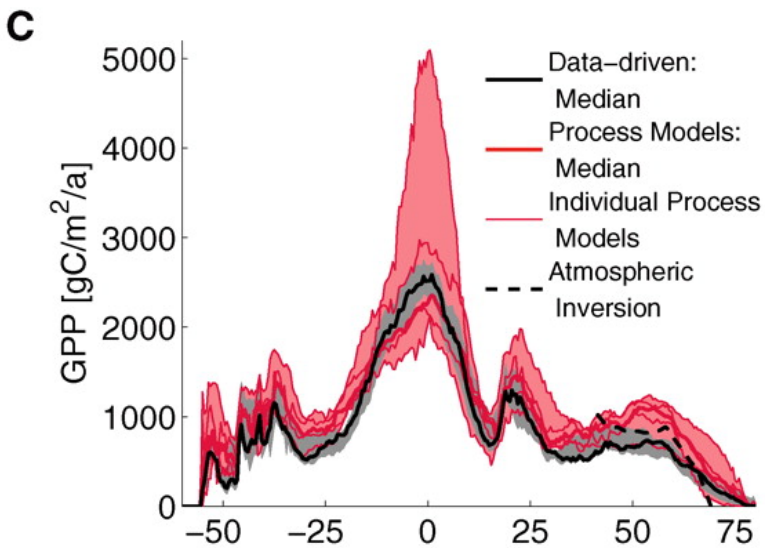
GPP in the terrestrial biosphere





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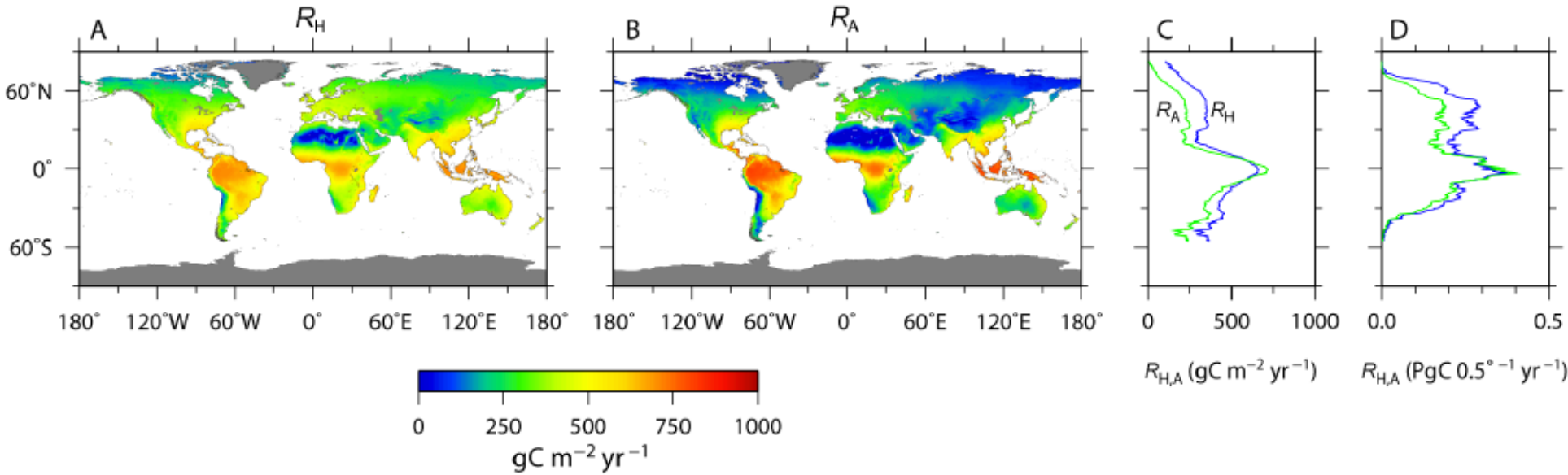
Respiration in the terrestrial biosphere



Hashimoto et al. (2015, BGD)

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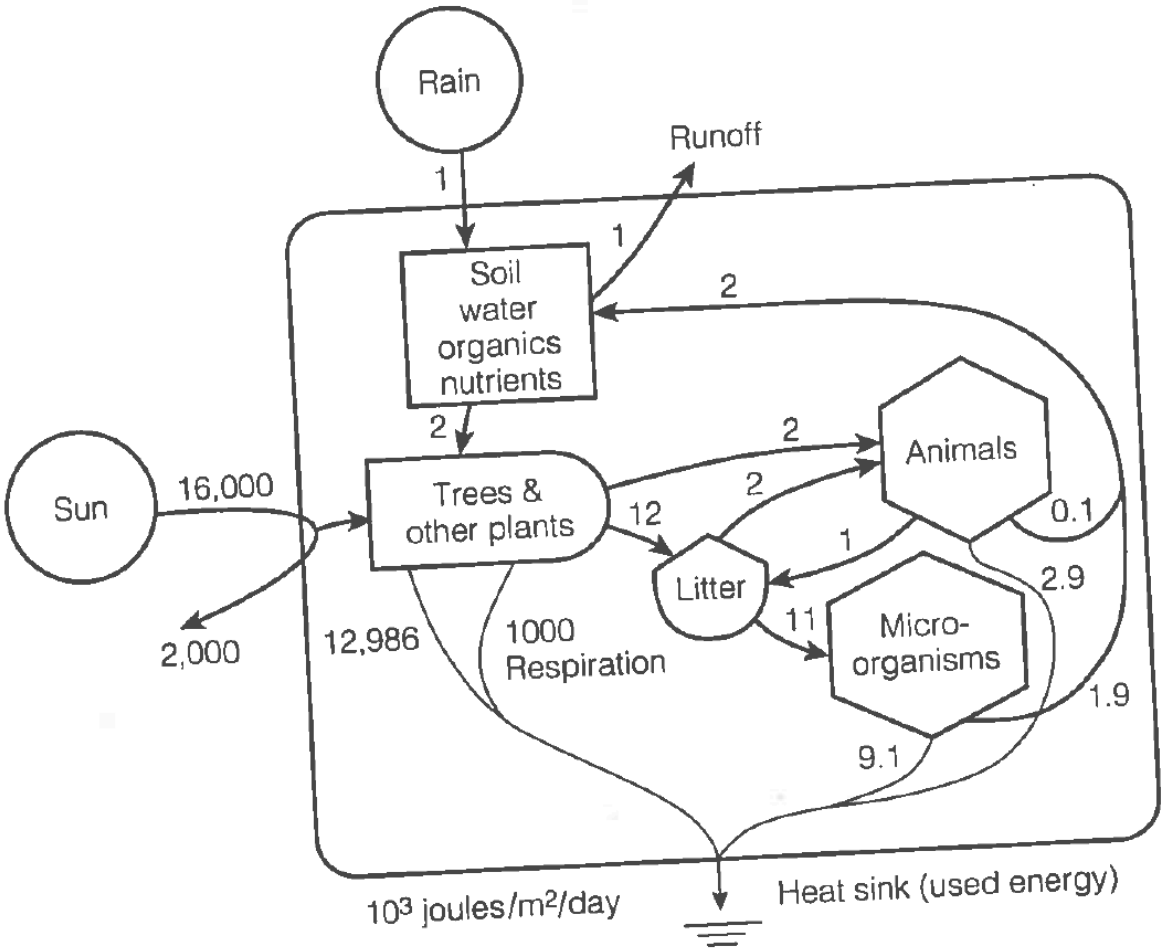
Energy flow in terrestrial ecosystems



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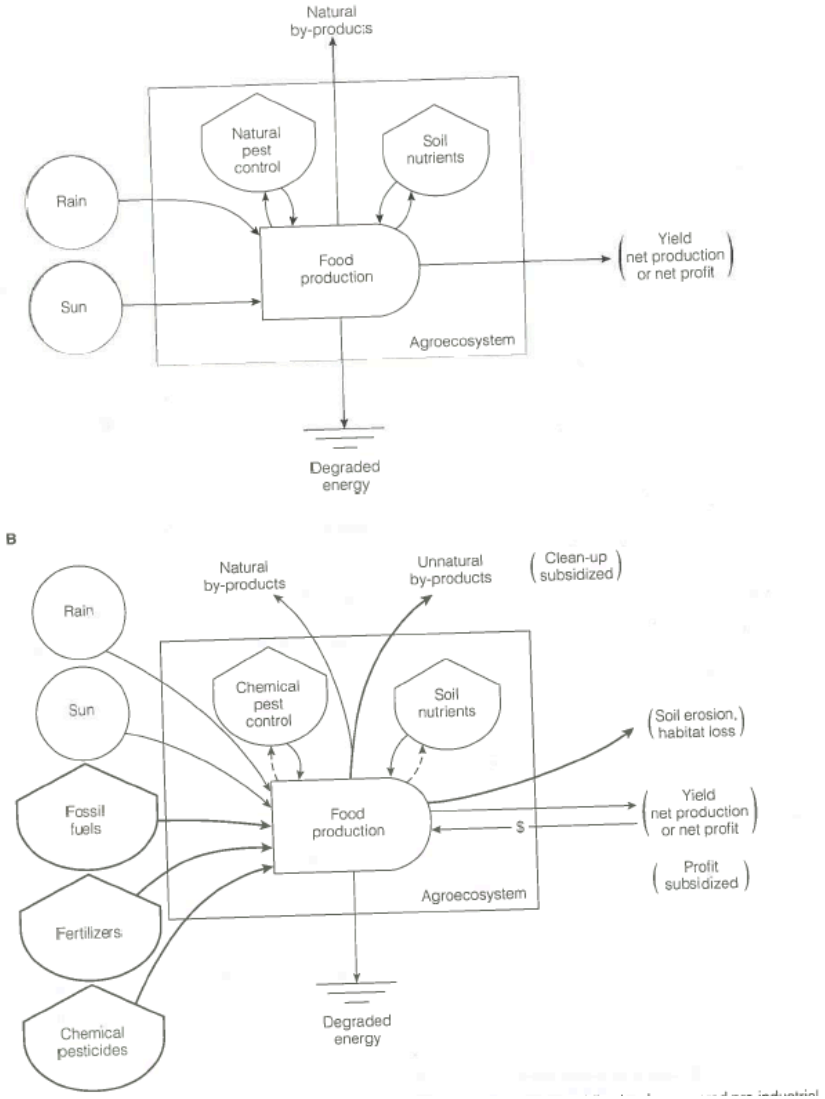
Energy flow in two contrasting agro-ecosystems



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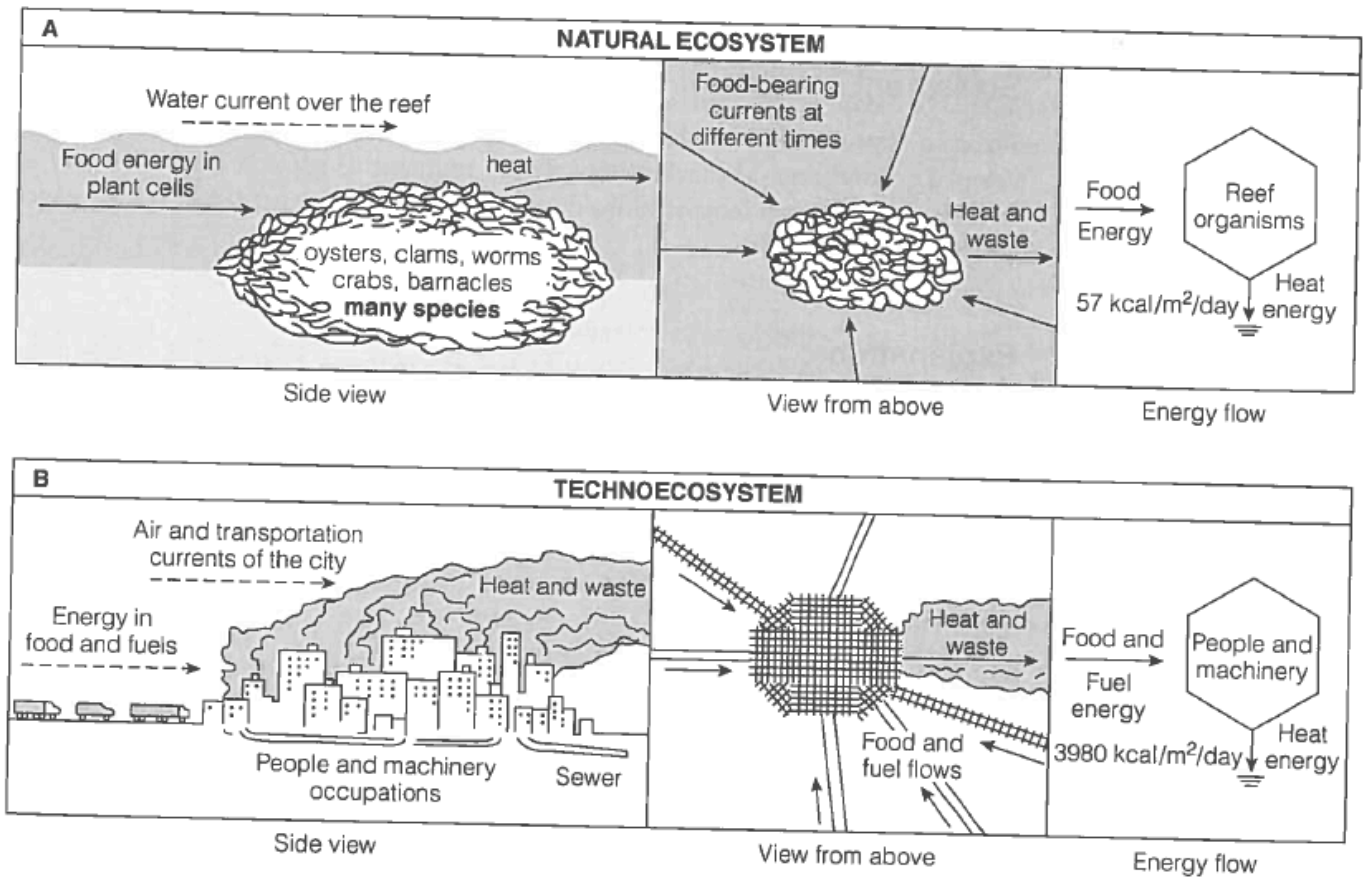
Energy flow in "techno-ecosystems"



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Th terrestrial biosphere: take home messages

- The terrestrial biosphere is an abstraction (level of organization) that help us to understand flows of energy and matter on Earth.
- The terrestrial biosphere is the set of all ecosystems on Earth.
- The ecosystem concept is key to understand biospheric processes.
- Ecosystems dissipate energy but transform matter in different forms.
- Autotrophy and heterotrophy are fundamental components of any ecosystem.

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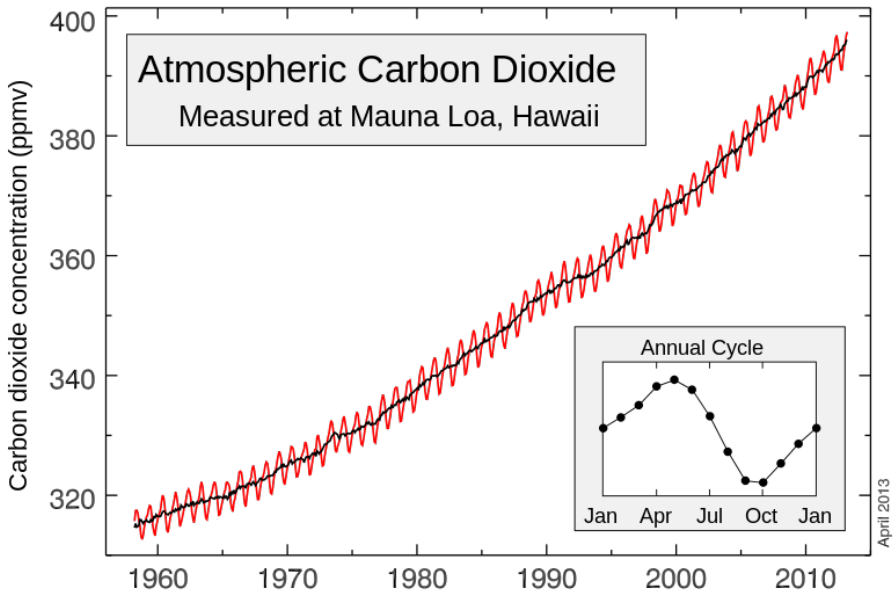
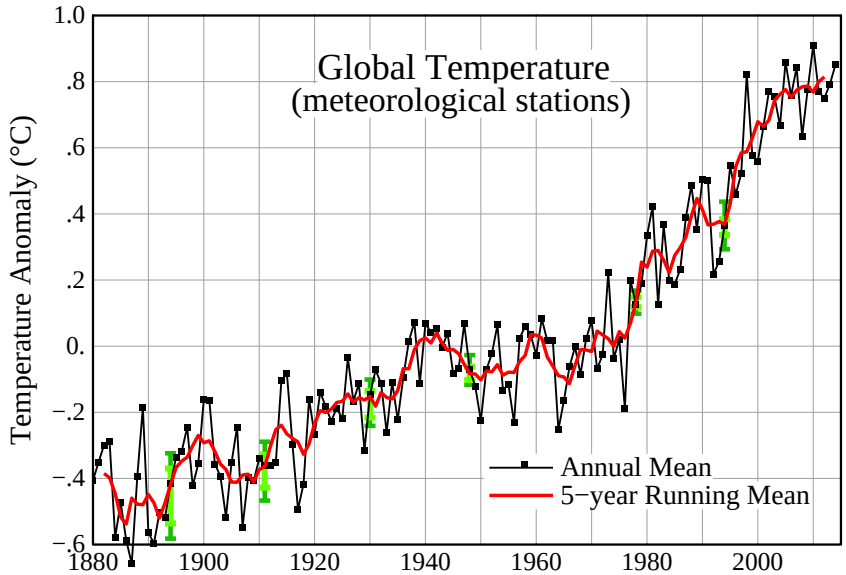
Terrestrial biosphere and global change





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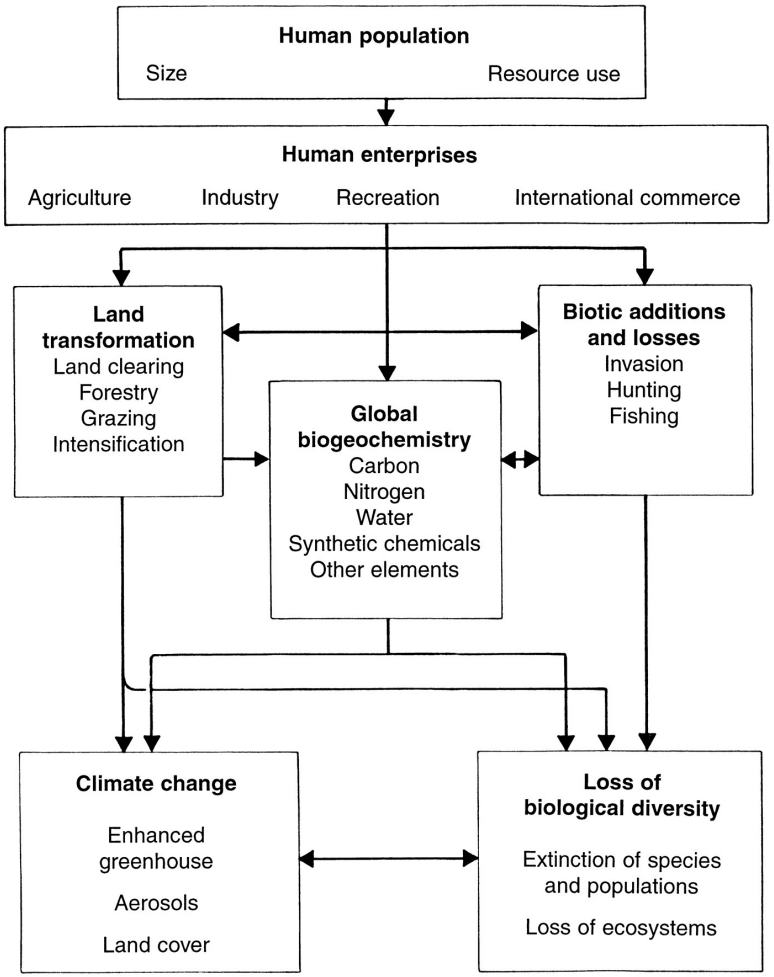
Human modification of the biosphere



Vitousek et al. (1997, Science 277, 494)

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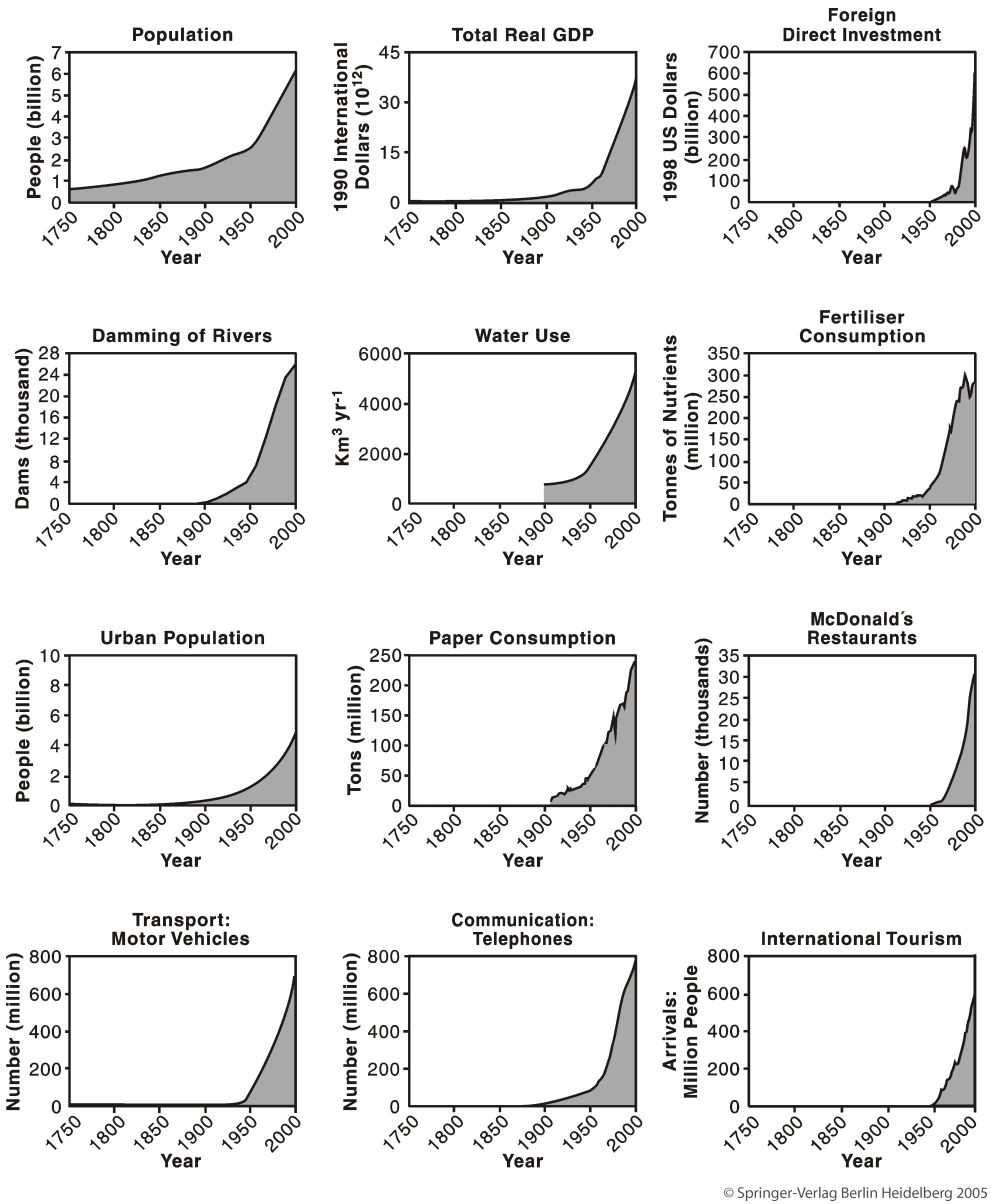
Human modification of the biosphere



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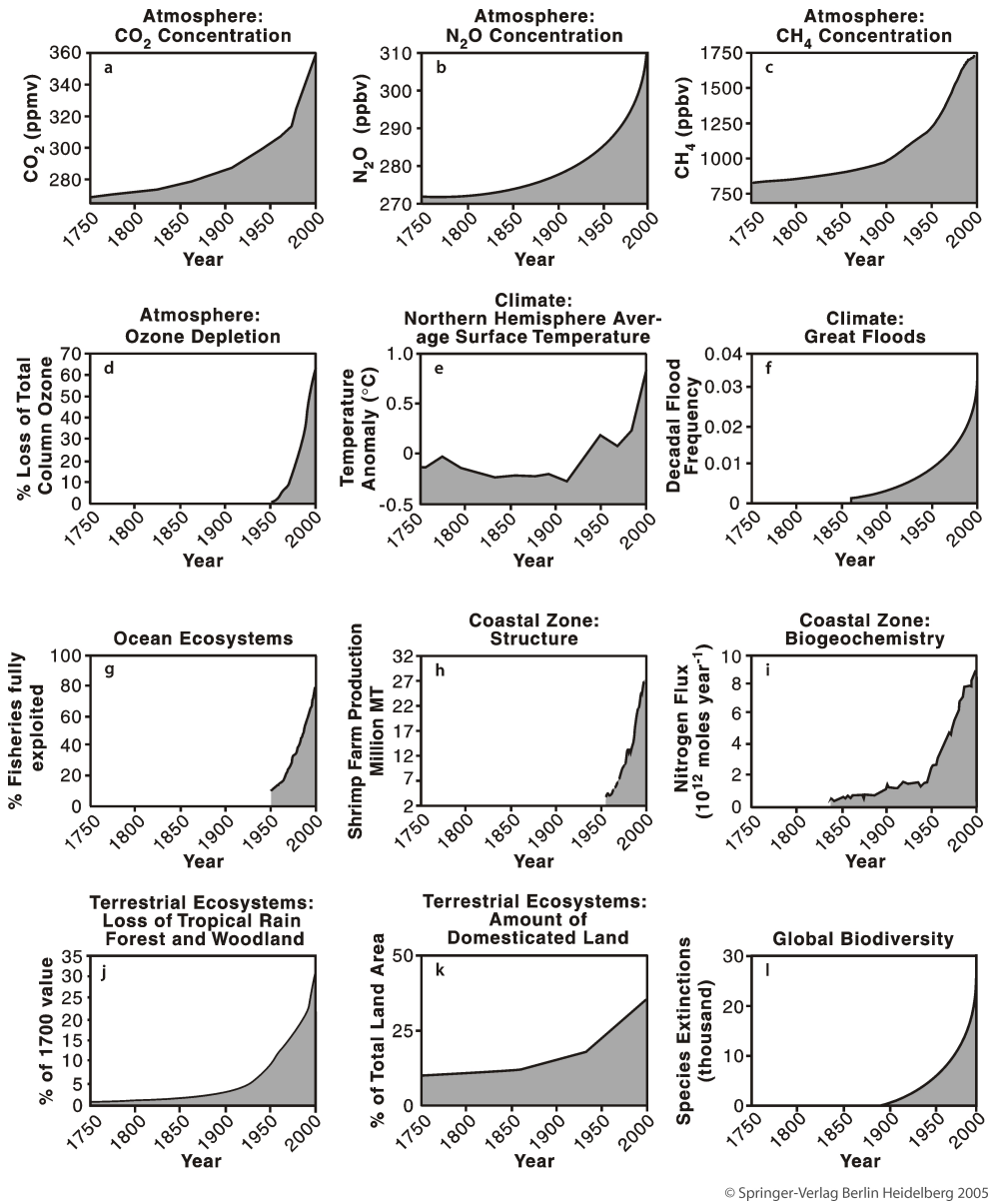

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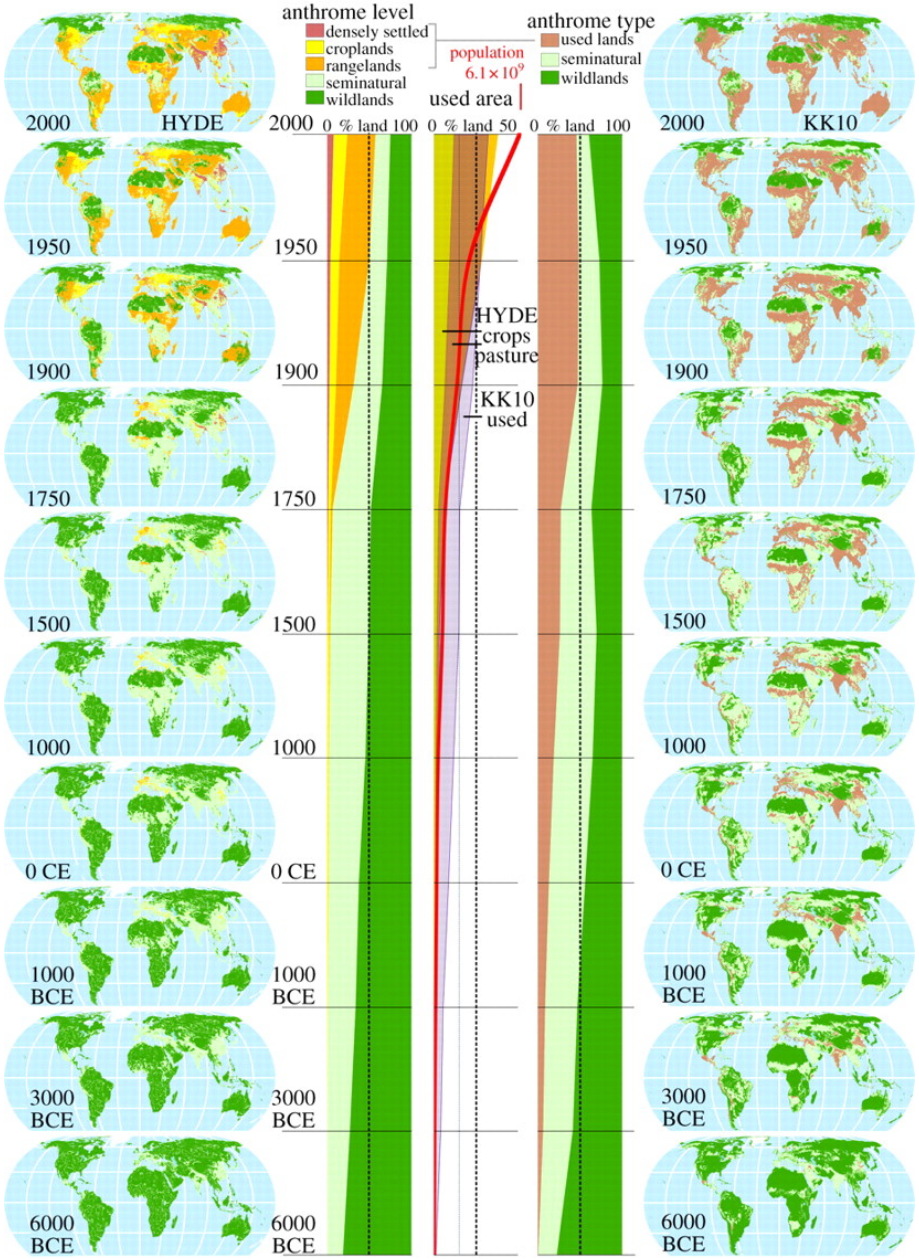

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Ellis (2011, Phil Trans A, 369: 1010)

Modification of the global carbon cycle

GLOBAL CARBON PROJECT

Fate of Anthropogenic CO_2 Emissions (2004-2013 average)

32.4 ± 1.6 $GtCO_2/yr$ 91%

3.3 ± 1.8 $GtCO_2/yr$ 9%

+

15.8 ± 0.4 $GtCO_2/yr$
44%

10.6 ± 2.9 $GtCO_2/yr$
29%

Calculated as the residual of all other flux components

26%
9.4 ± 1.8 $GtCO_2/yr$

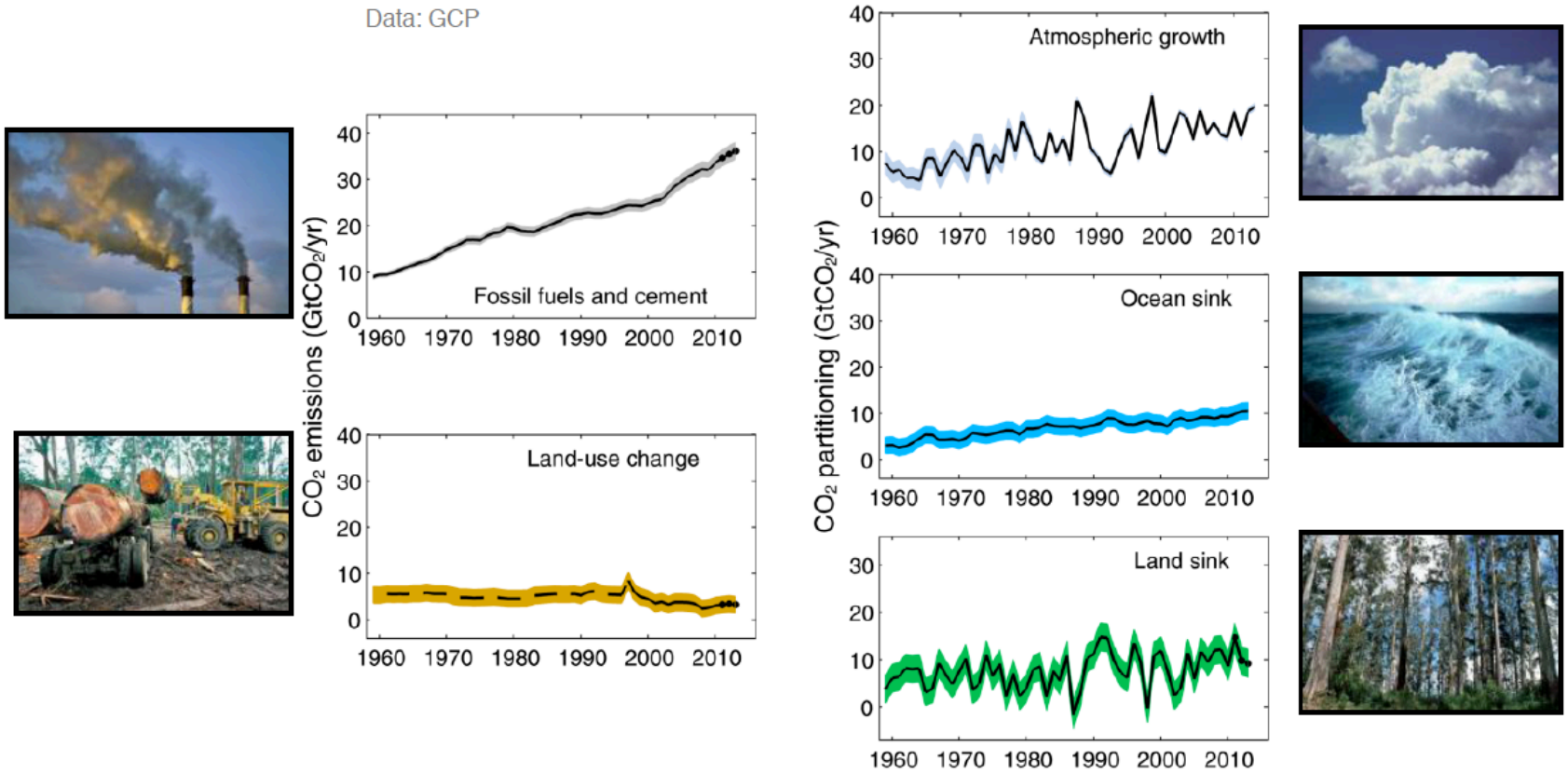
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

Modification of the global carbon cycle

GLOBAL CARBON PROJECT

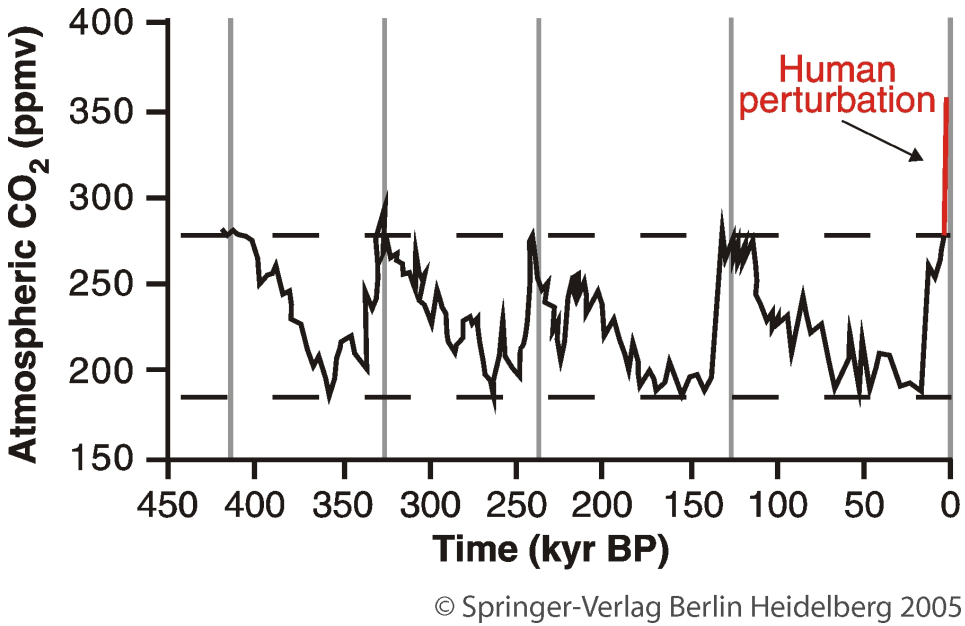
Changes in the Budget over Time

The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

Atmospheric CO_2 over the past 42,000 years



Anatomically modern humans arose in Africa about 200,000 years ago.
Reached behavioral modernity about 50,000 years ago.
The Neolithic Revolution began 12,000 years ago.

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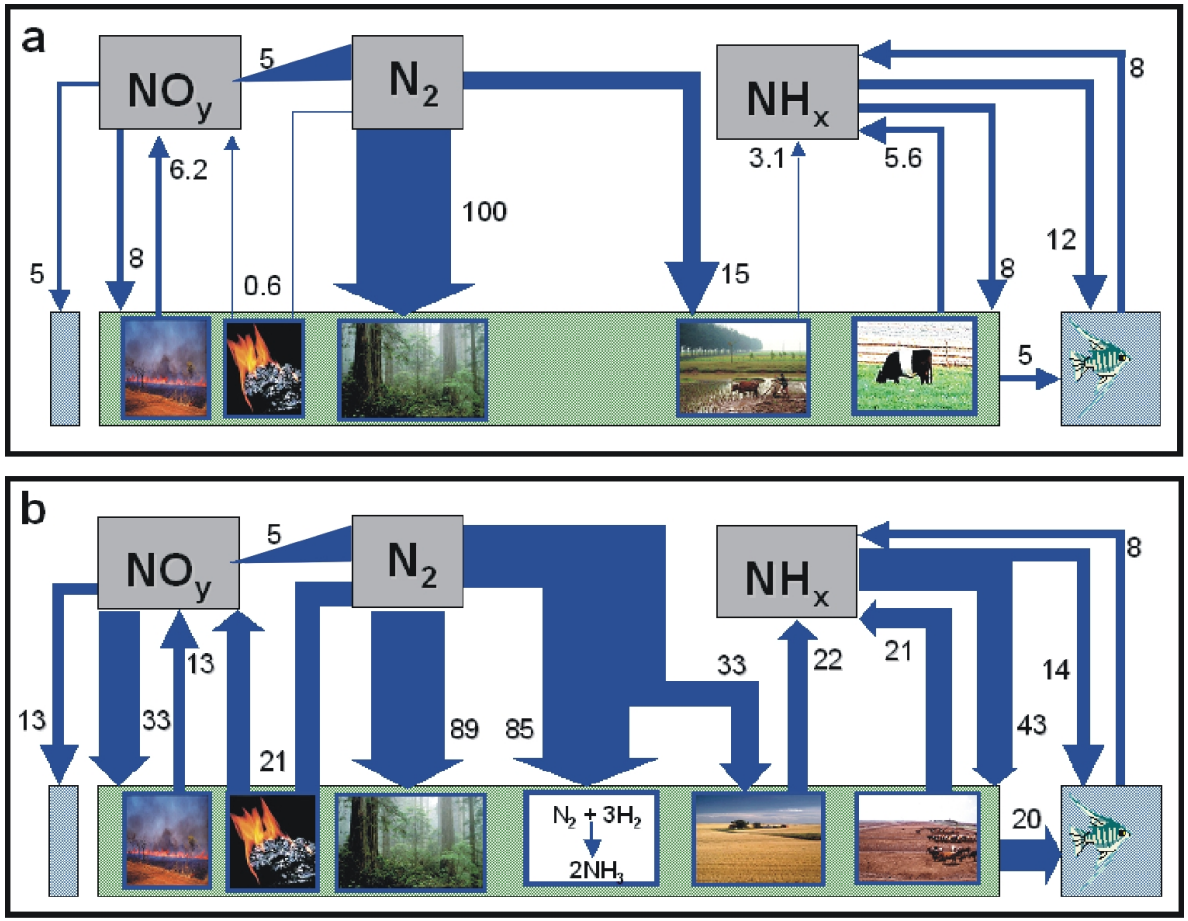
Modification of the N cycle



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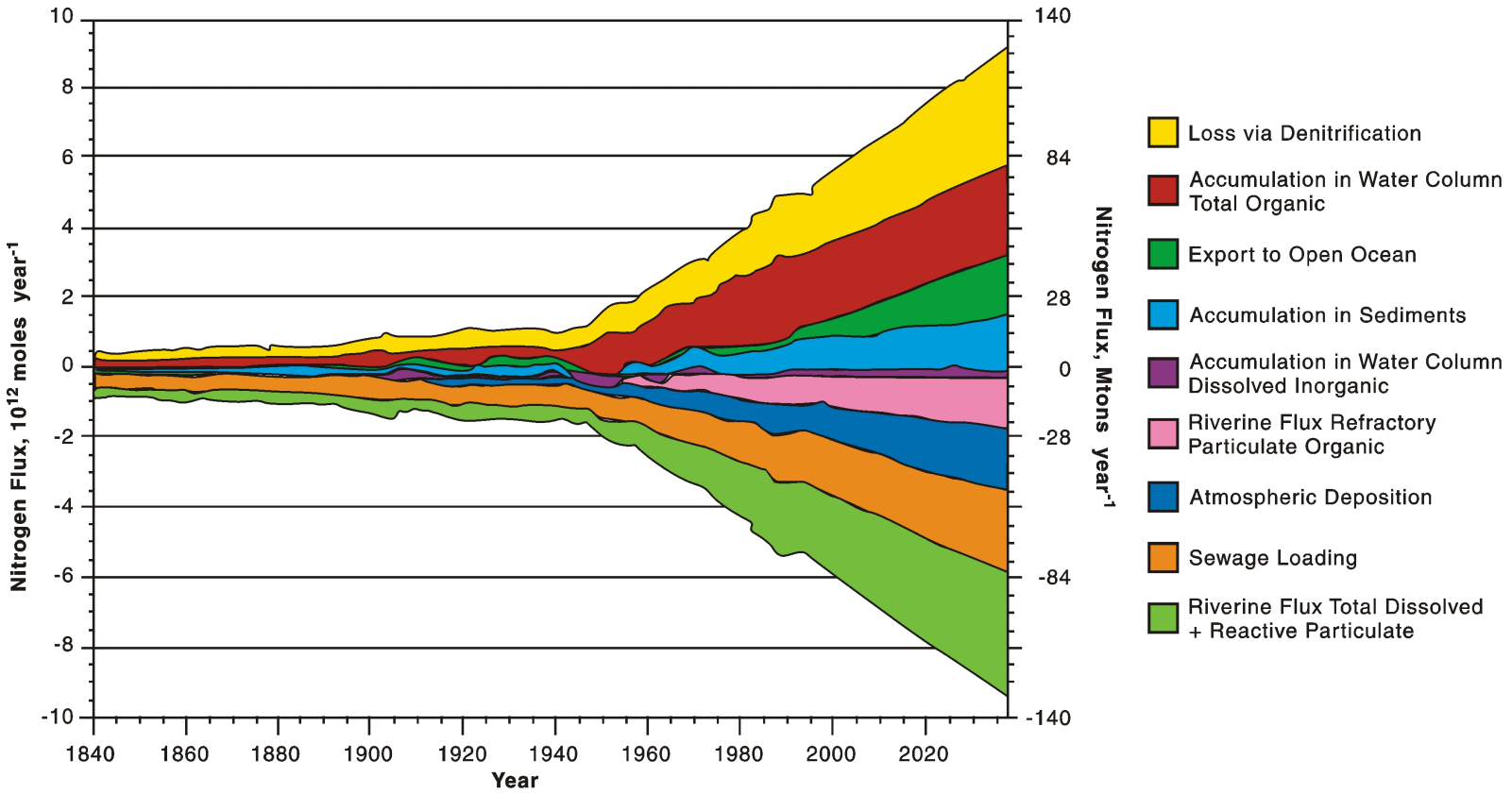
Modification of the N cycle



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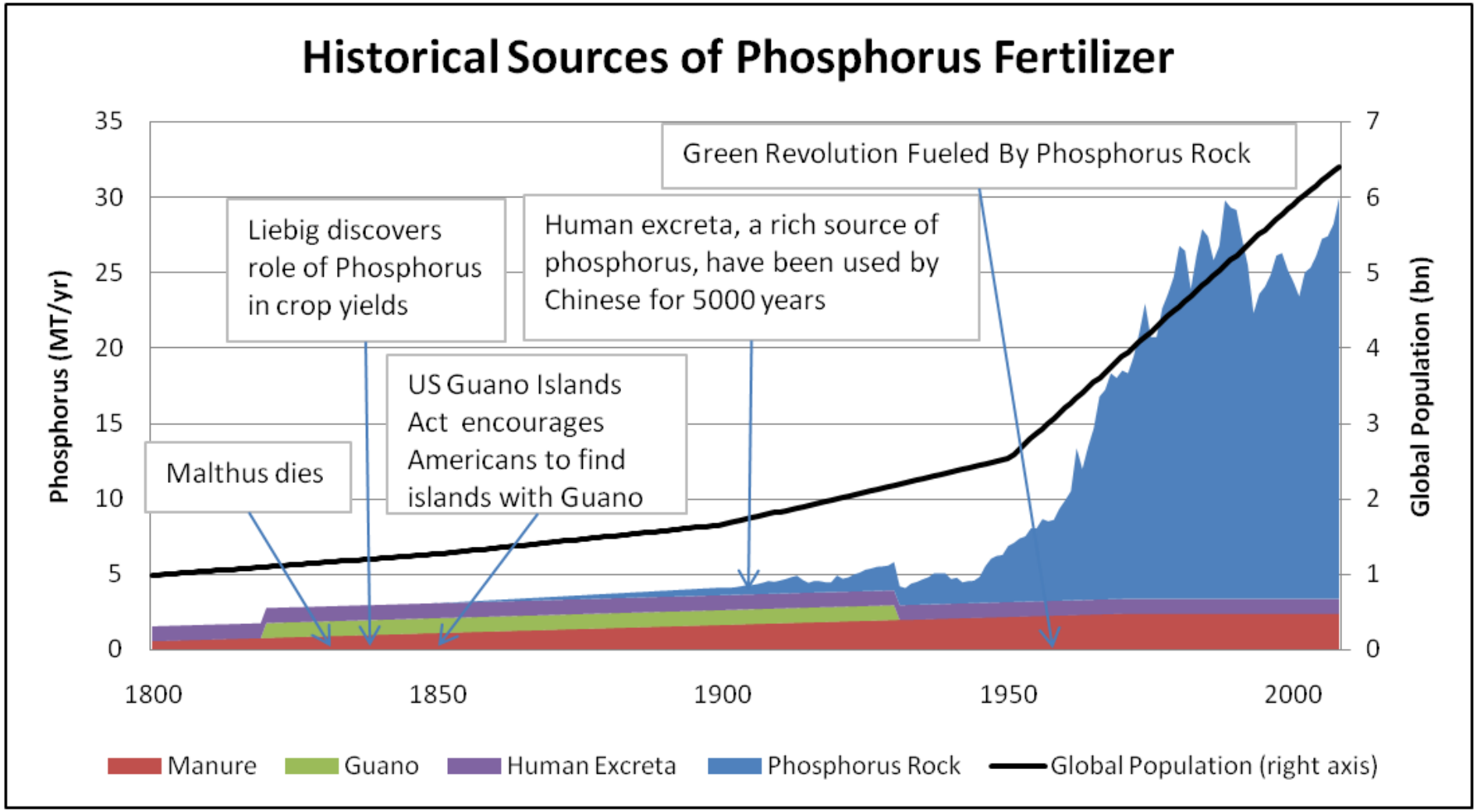
Modification of the P cycle



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Modification of the P cycle

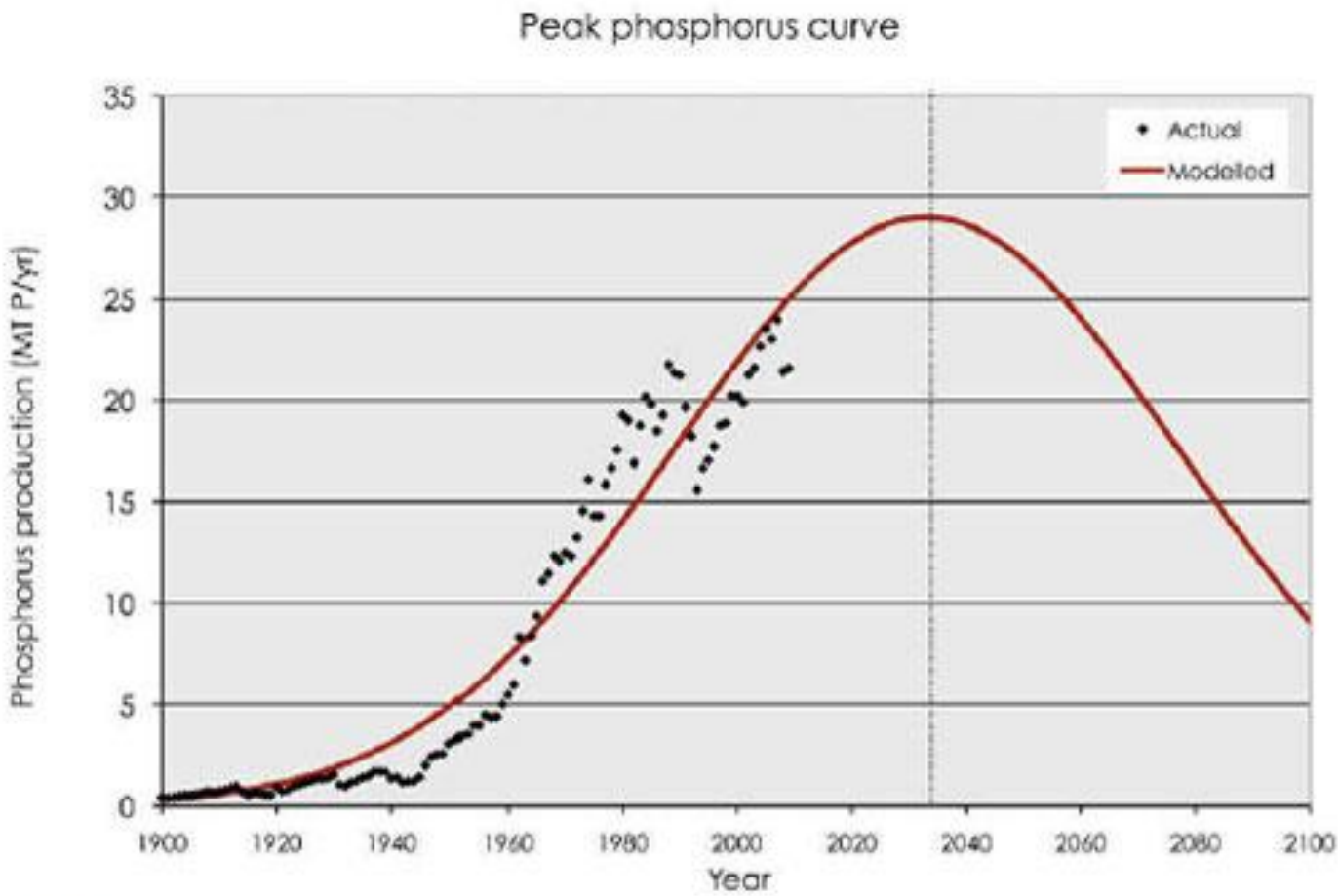

***Figure 5-6**: Peak phosphorus curve based on industry data, indicating a peak year of global phosphate rock production in 2033. Source: created for this research (Paper I).*

Human impacts on the Earth system

Human impacts on the Earth system

- are approaching or exceeding in *magnitude* some of the great forces of nature
- operate on much faster time scales than *rates* of natural variability, often by an order of magnitude or more
- taken together in terms of extent, magnitude, rate and simultaneity, have produced a *no-analogue* state in the dynamics and functioning of the Earth system.

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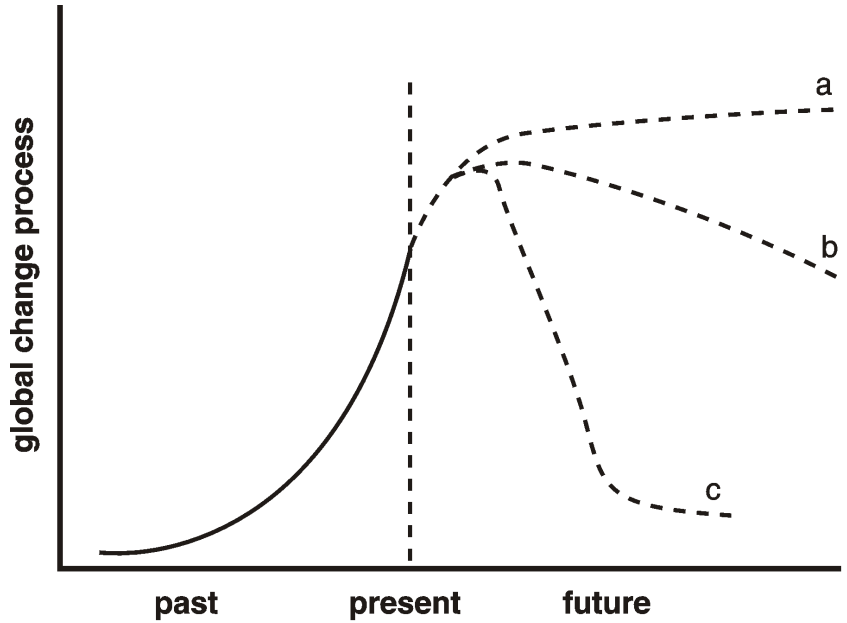
Possible trajectories of ecosystems and global change processes



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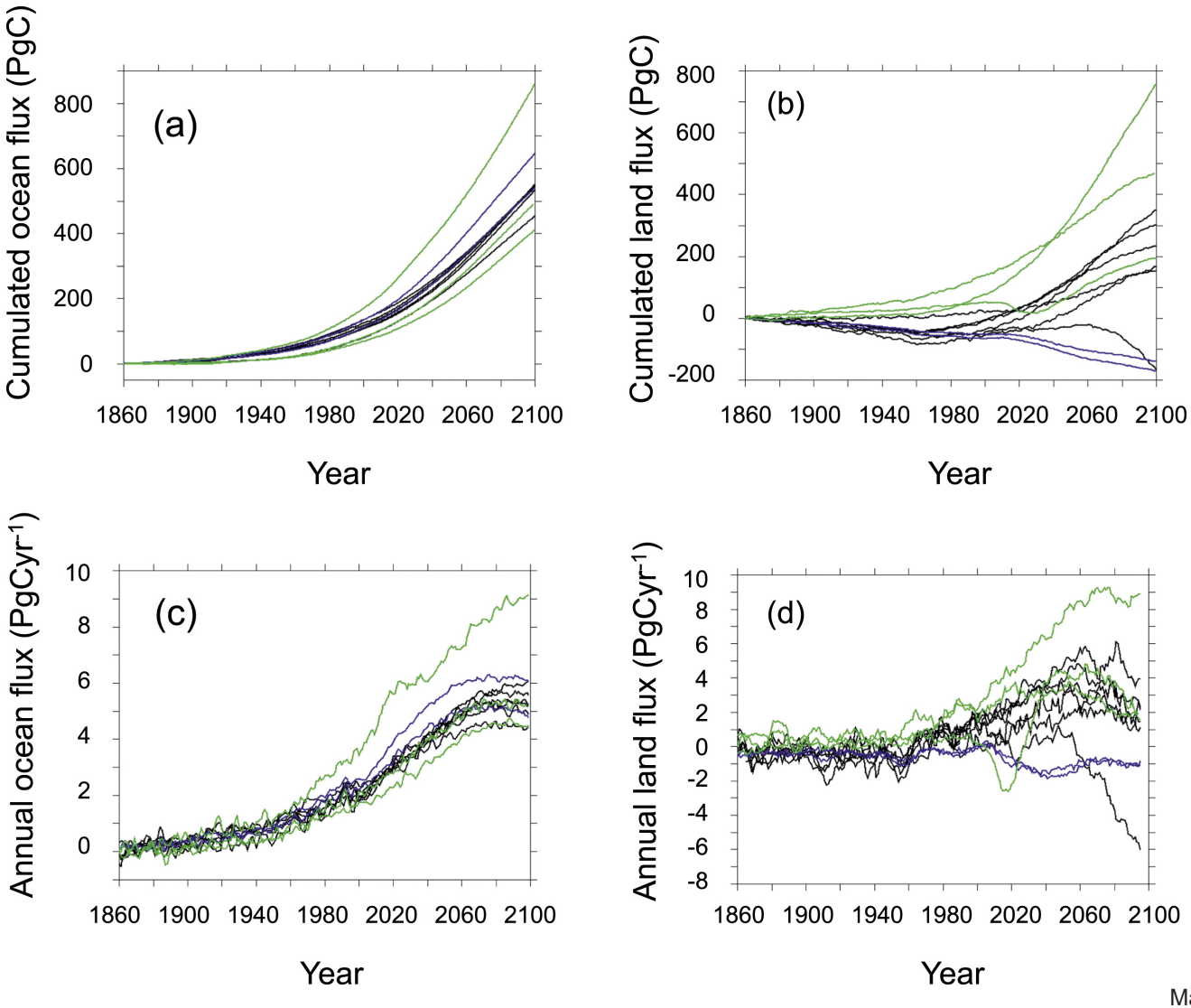
Possible trajectories predicted by Earth system model



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Models and the Earth system

- Models are tools that represent our best understanding of different components of the Earth system and allow us to predict consequences of changes in system components
- However, there are large uncertainties in models that hinder our ability to predict consequences of global change
- Improving models is a major task of the scientific community in the Earth system sciences

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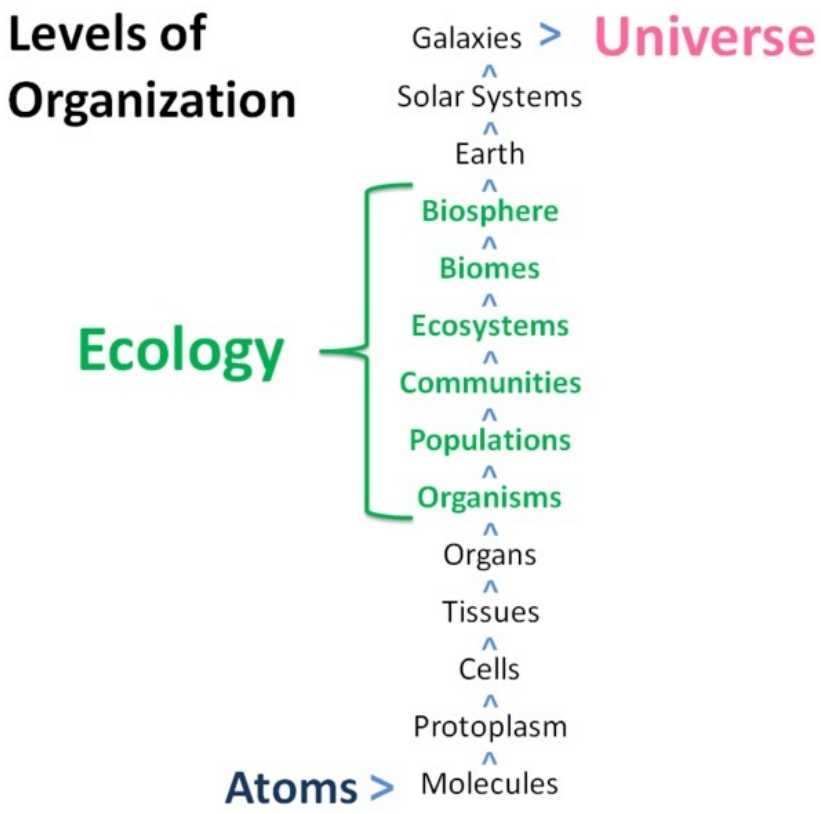
Hierarchical theory as a tool to integrate information in models



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Concepts in hierarchical theory

- **Hierarchy**: a collection of parts with ordered asymmetric relationships inside a whole. That is to say, upper levels are above lower levels, and the relationship upwards is asymmetric with the relationships downwards.

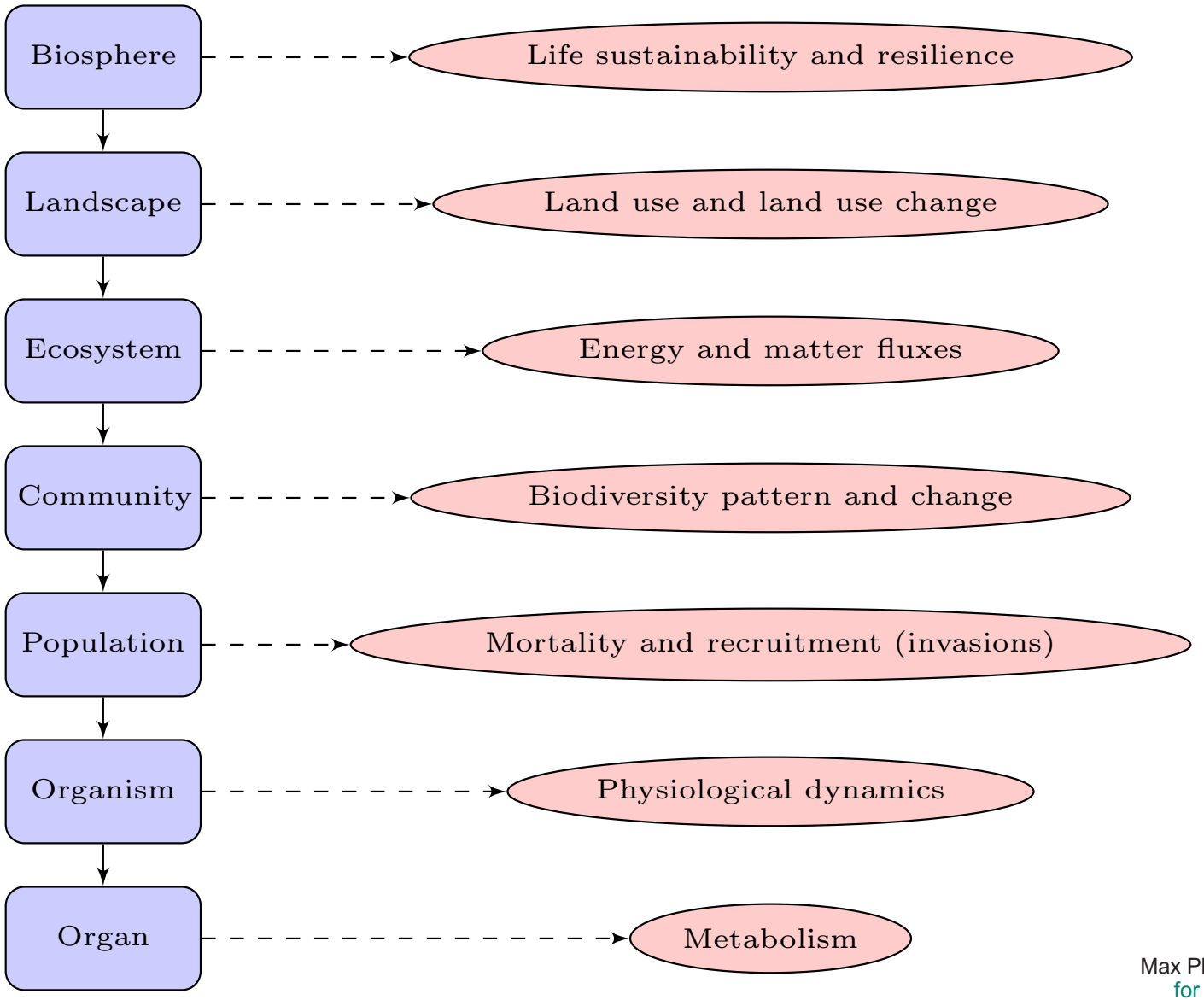
- **Hierarchical levels**: levels are populated by entities whose properties characterize the level in question. A given entity may belong to any number of levels, depending on the criteria used to link levels above and below. For example, an individual human being may be a member of the level i) human, ii) primate, iii) organism or iv) host of a parasite, depending on the relationship of the level in question to those above and below.

Concepts in hierarchical theory

- **Level of organization**: this type of level fits into its hierarchy by virtue of set of definitions that lock the level in question to those above and below. For example, a biological population level is an aggregate of entities from the organism level of organization, but it is only so by definition. There is no particular scale involved in the population level of organization, in that some organisms are larger than some populations, as in the case of skin parasites.

- **Level of observation**: this type of level fits into its hierarchy by virtue of relative scaling considerations. For example, the host of a skin parasite represents the context for the population of parasites; it is a landscape, even though the host may be seen as belonging to a level of organization, organism, that is lower than the collection of parasites, a population.

Hierarchies in terrestrial biosphere research



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Scaling issues in biosphere research

- Explicit scaling is in most cases not feasible or computationally impossible
- Implicit scaling is always possible but often controversial

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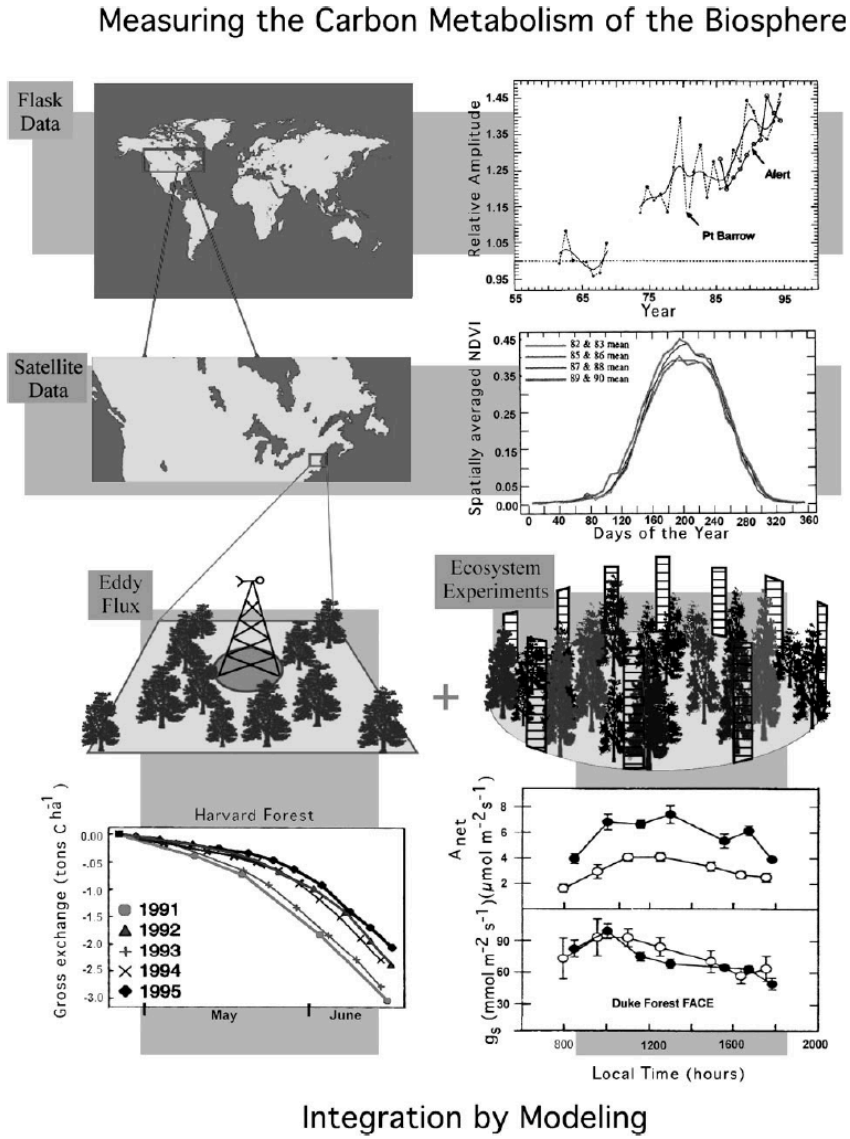
Scaling concept for the C cycle



Canadell et al. (2000, Ecosystem 3: 115).

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Key concepts

- The terrestrial biosphere is a hierarchically nested level of abstraction (biological organization) that integrates many components at lower levels of biological organization.
- The study of the terrestrial biosphere requires the integration of many different processes at different levels of observation. Mathematical/simulation models seem to be the only tool capable of integrating sources of information from different levels.
- However, scaling issues limit the ability of models to produce confident predictions.

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The terrestrial biosphere course

- A selection of topics from different levels of abstraction relevant for biospheric dynamics.
- Introduction to basic concepts and research topics

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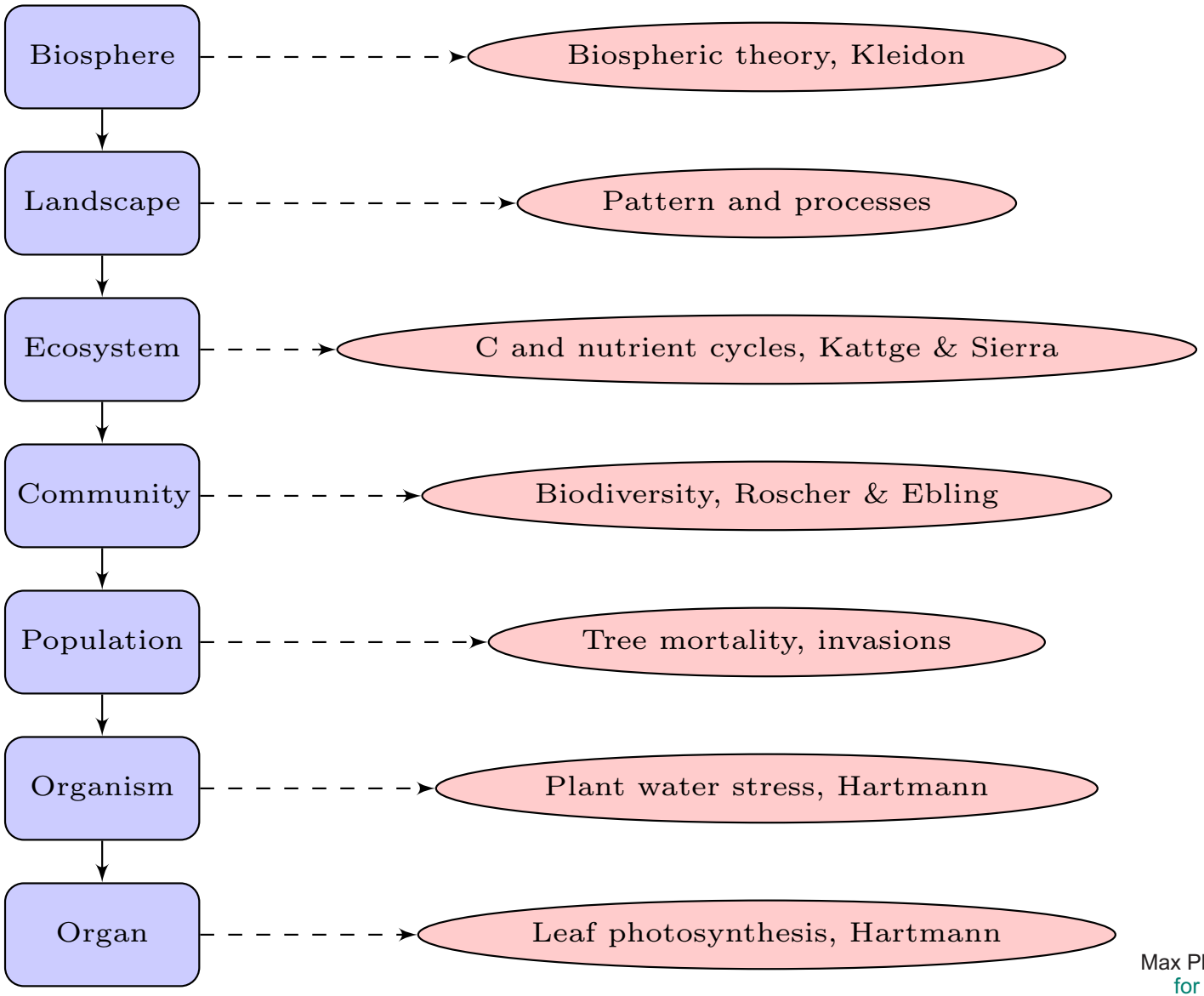
Hierarchical organization TB course



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