

The terrestrial biosphere: biogeochemistry and global change

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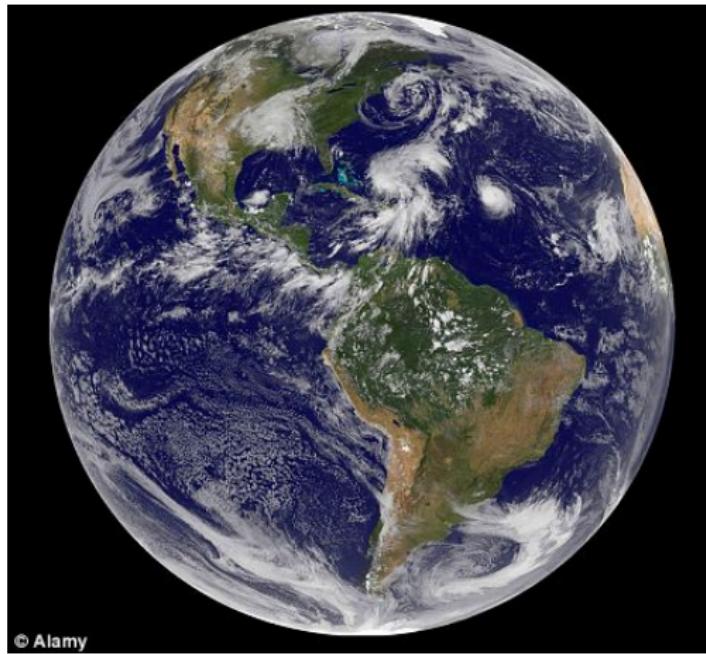


Outline

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



Earth's biosphere



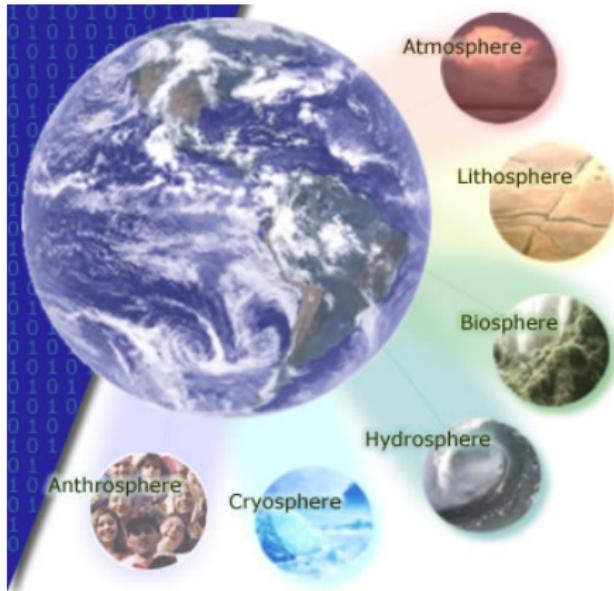
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The biosphere includes all living organisms on earth, together with the dead organic matter produced by them.

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Earth's biosphere



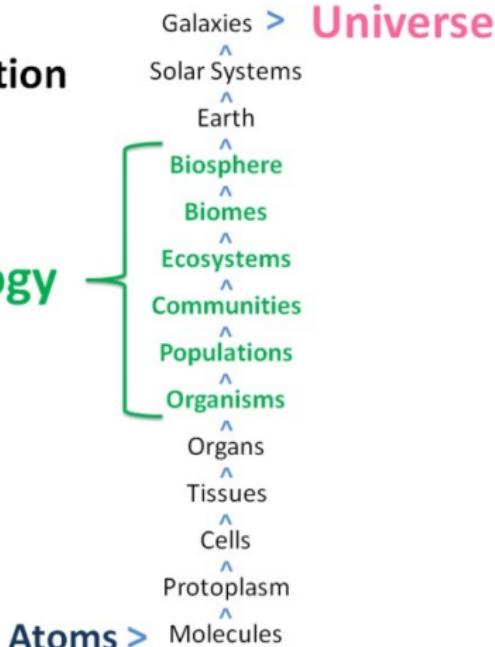
The term “biosphere” originated with the geologist Eduard Suess in 1875, who defined it as “the place on earth’s surface where life dwells”. Vladimir I. Vernadsky first defined the biosphere in a form resembling its current ecological usage in his long-overlooked book of the same title, originally published 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)

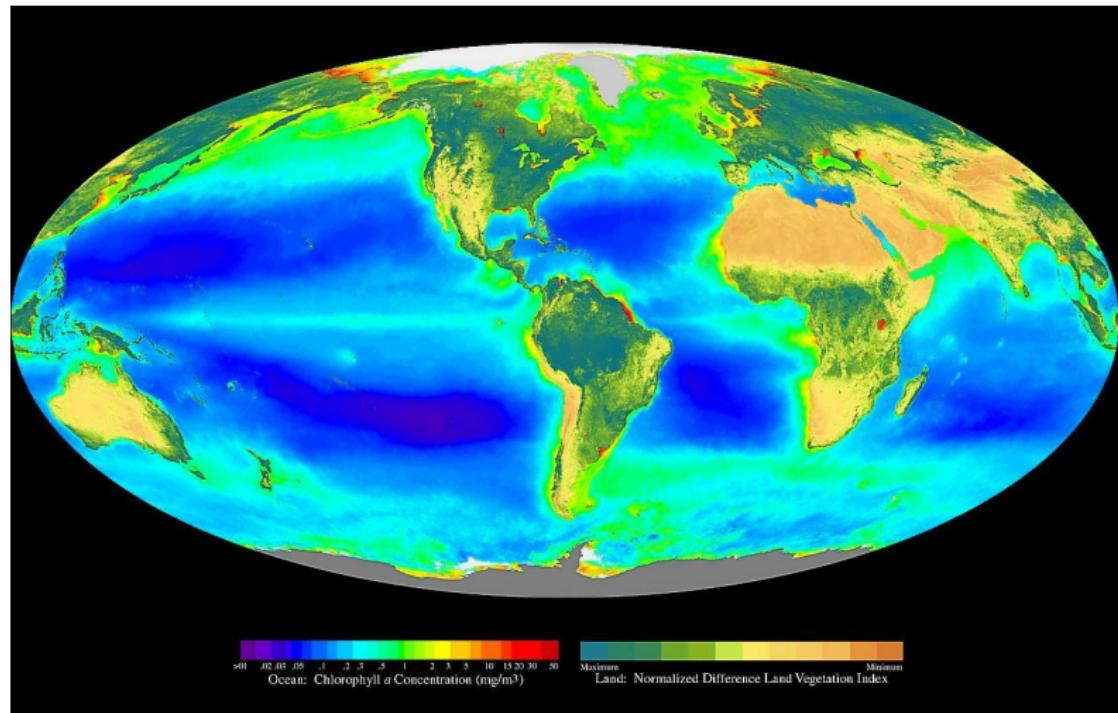
Levels of biological organization in Earth's biosphere

Levels of Organization

Ecology



Earth's biosphere: oceanic and terrestrial components



The terrestrial biosphere within the Earth system

Definition:

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

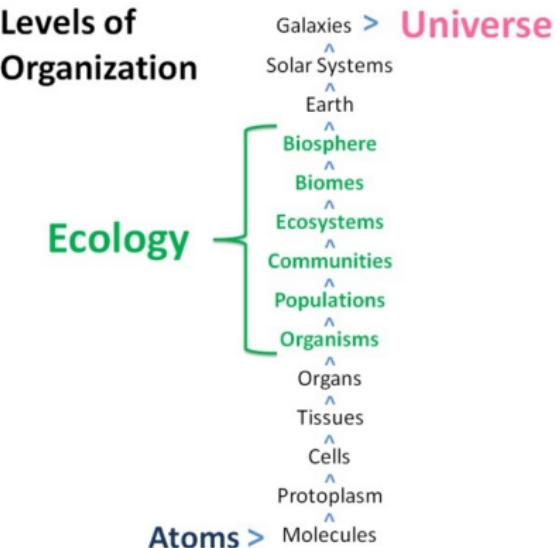


The Ecosystem concept

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.

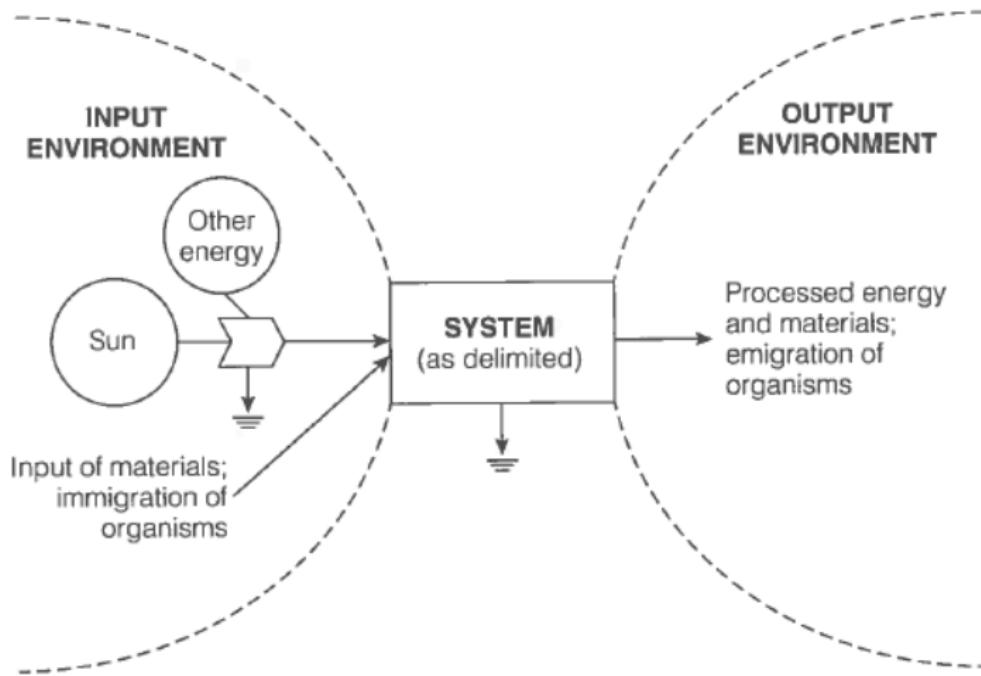
Odum & Barret (2005, Fundamentals of Ecology)

Nested hierarchy and the Ecosystem concept

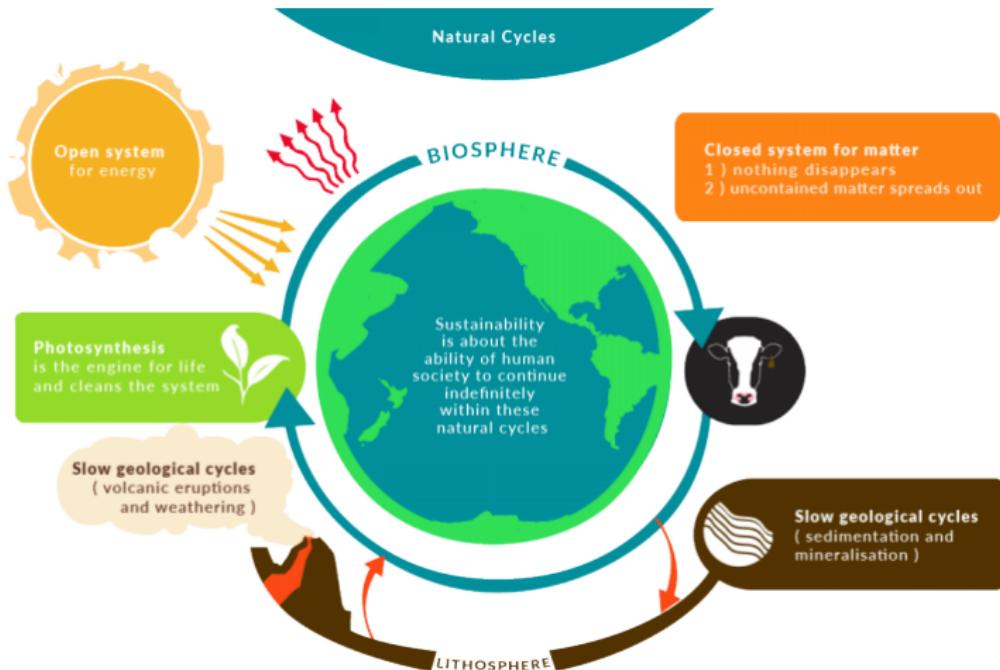


The ecosystem is the first unit of the ecological hierarchy that is complete, has all components necessary for survival.

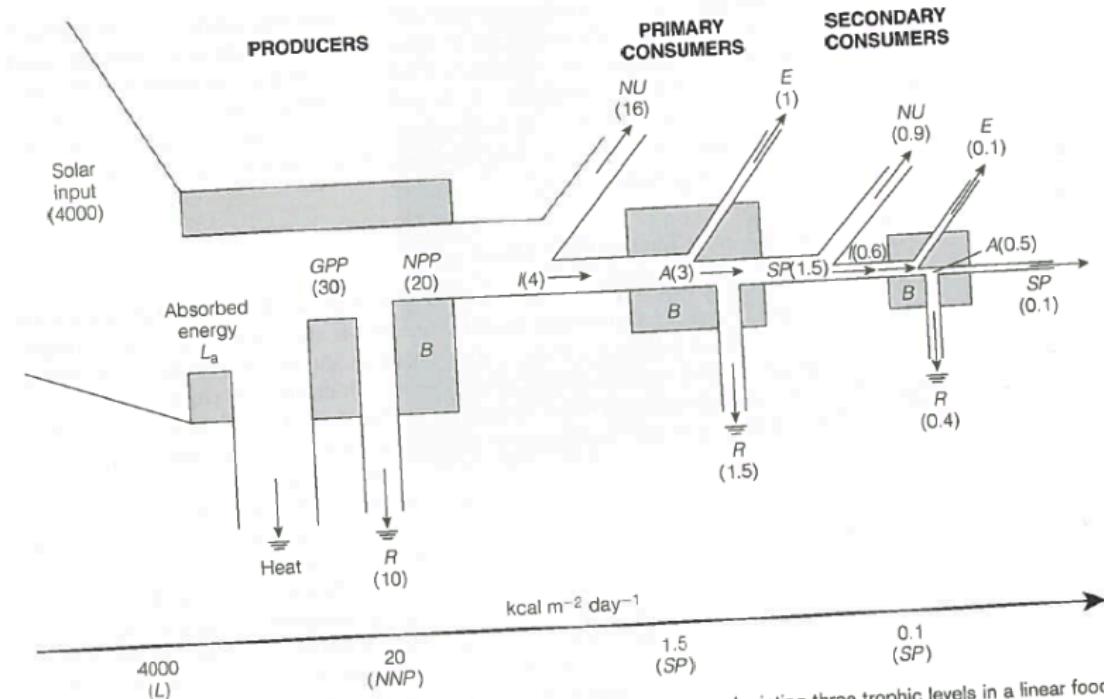
The basic ecosystem concept



Energy and carbon balance in ecosystems



Carbon and energy flow



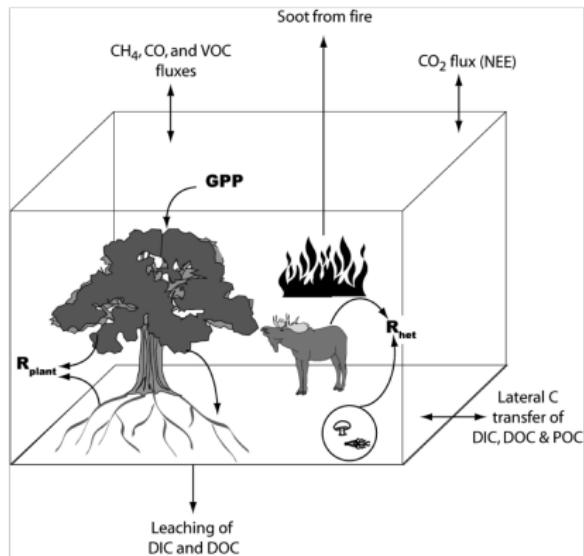
... linking three trophic levels in a linear food

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.



Terrestrial carbon cycle



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

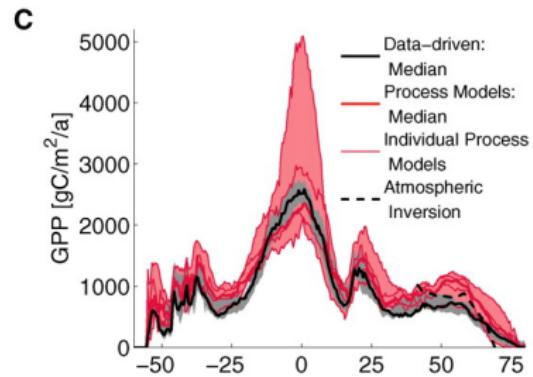
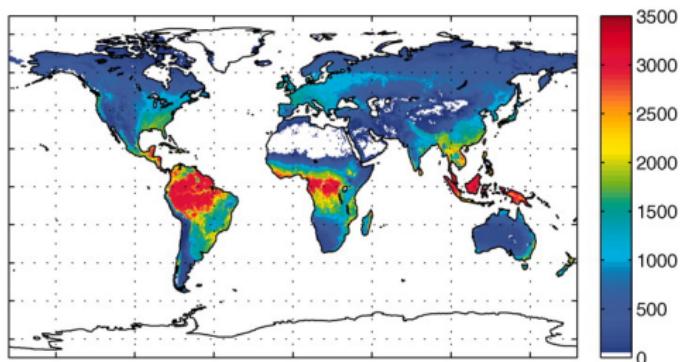
$$NECB = (\text{gas in} - \text{out}) + (\text{dissolved in} - \text{out}) + (\text{solid in} - \text{out})$$

$$\begin{aligned}NEP &= GPP - R_{eco} \\&= NPP - R_{het}\end{aligned}$$

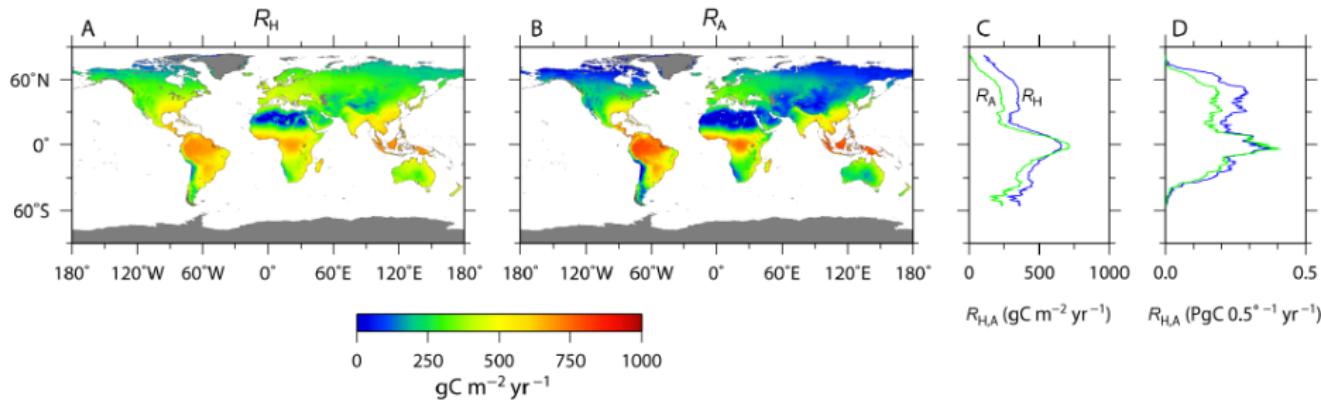
$$NPP = GPP - R_{auto}$$

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

GPP in the terrestrial biosphere

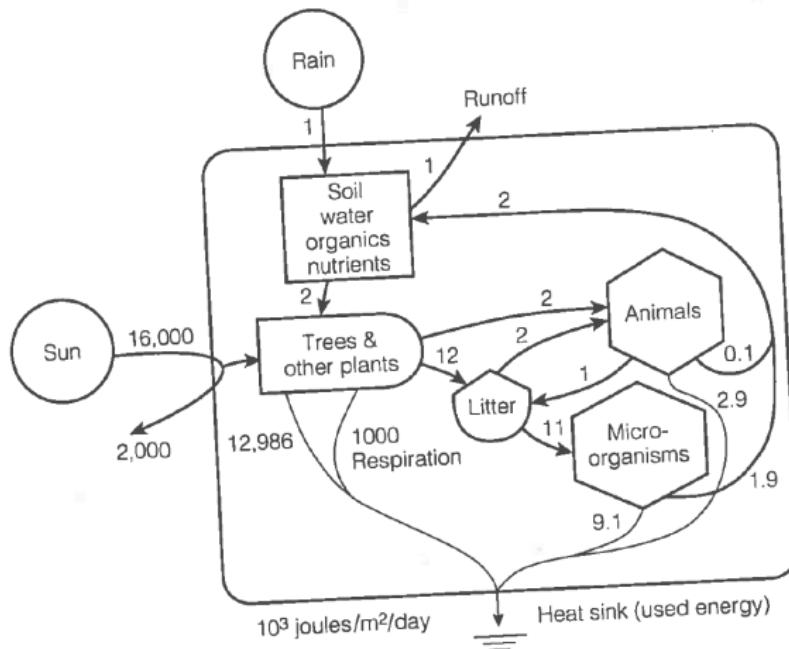


Respiration in the terrestrial biosphere

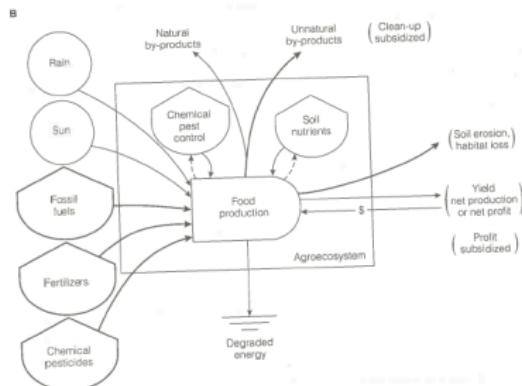
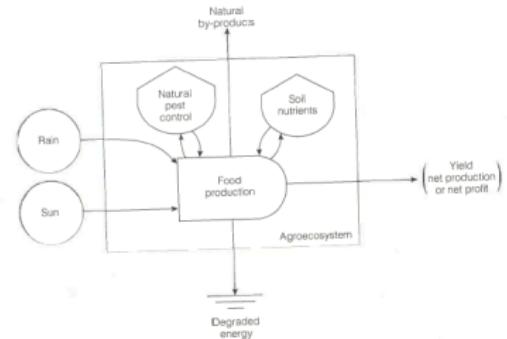


Hashimoto et al. (2015, BGD)

Energy flow in terrestrial ecosystems



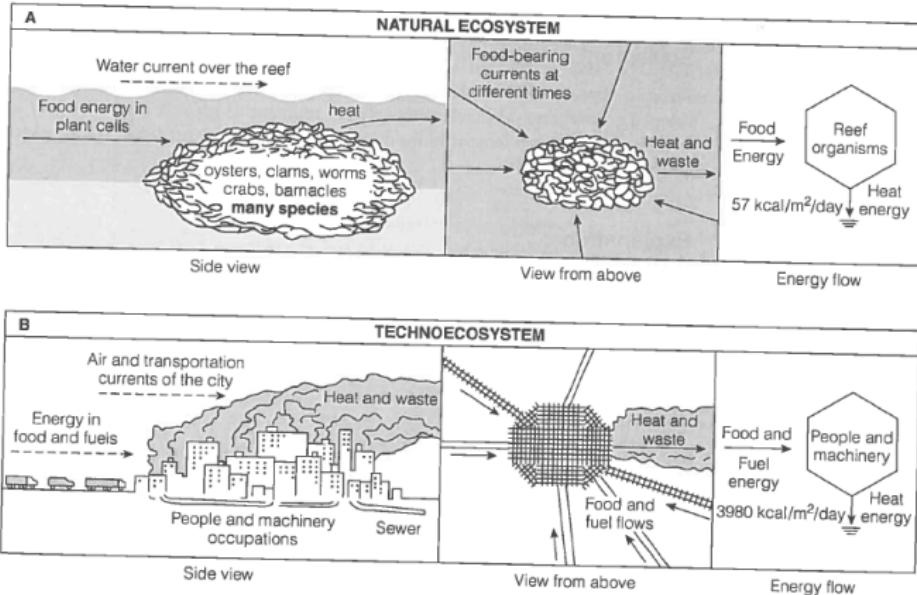
Energy flow in two contrasting agro-ecosystems



<http://www.sciencedirect.com/science/article/pii/S0048969708000390>



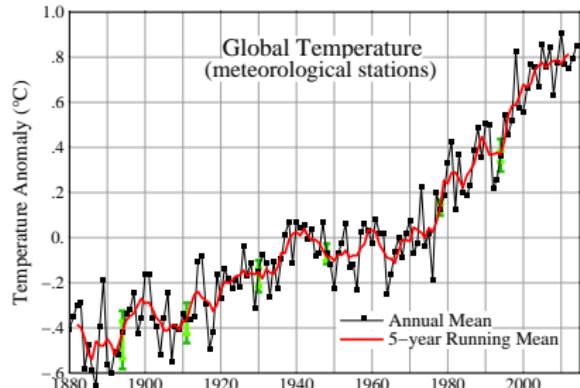
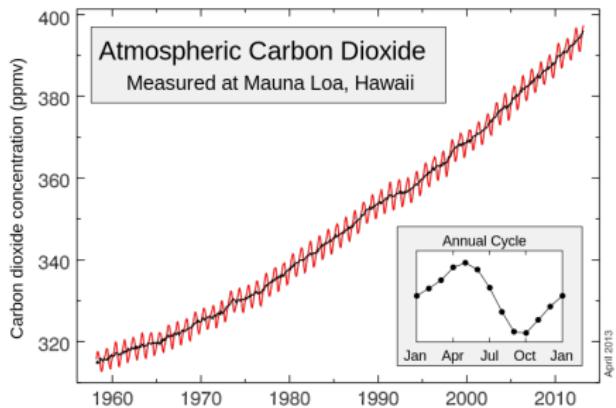
Energy flow in “techno-ecosystems”



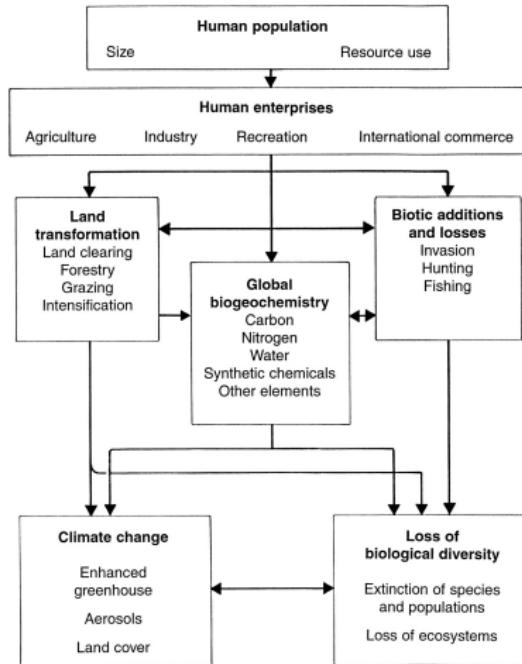
The terrestrial biosphere: take home messages

- 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.

Terrestrial biosphere and global change



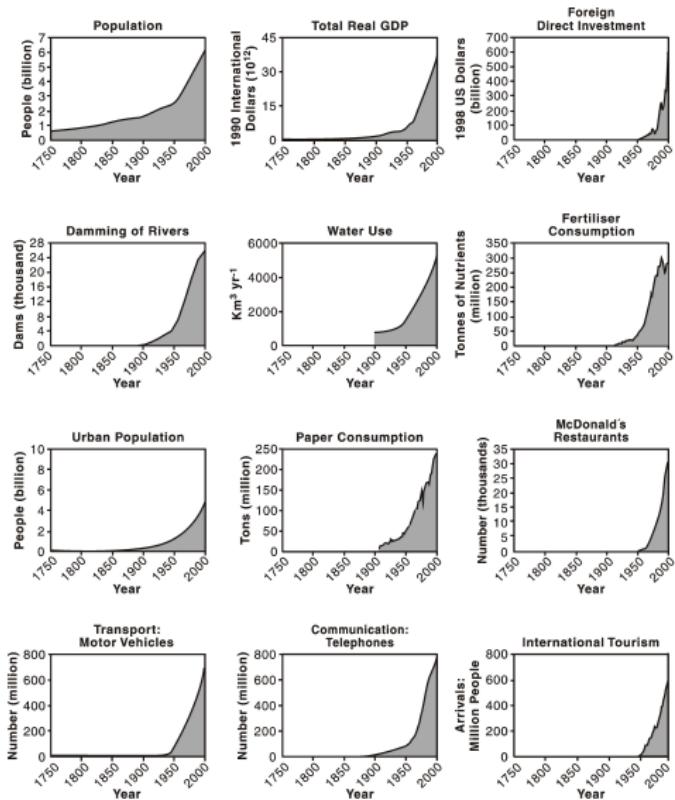
Human modification of the biosphere



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

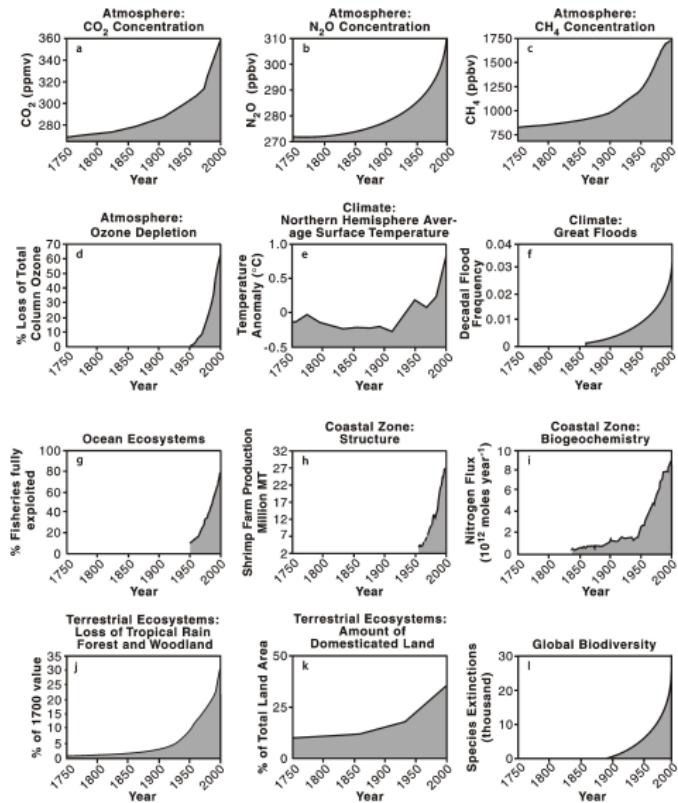


Human modification of the biosphere



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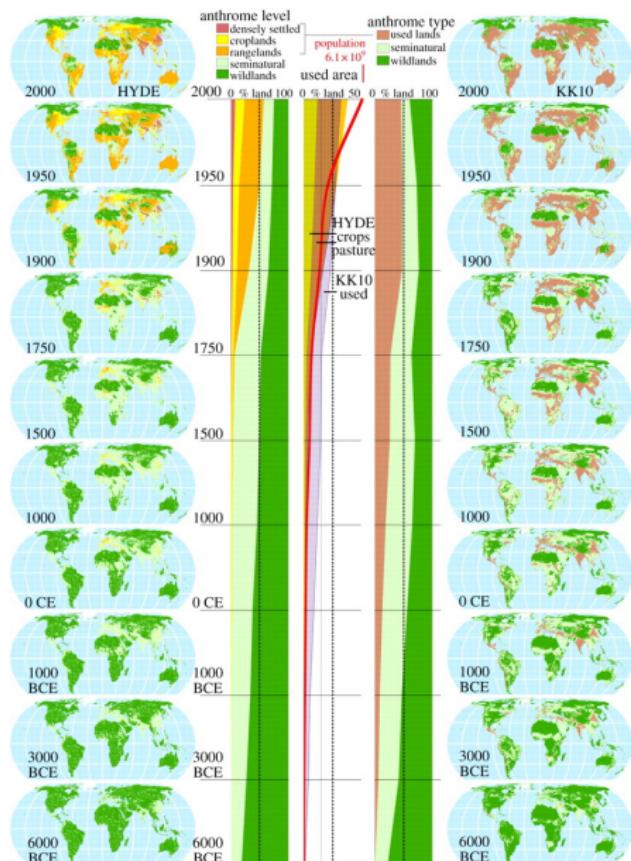
Human modification of the biosphere



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Human modification of the terrestrial biosphere



Terrestrial Biosphere

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

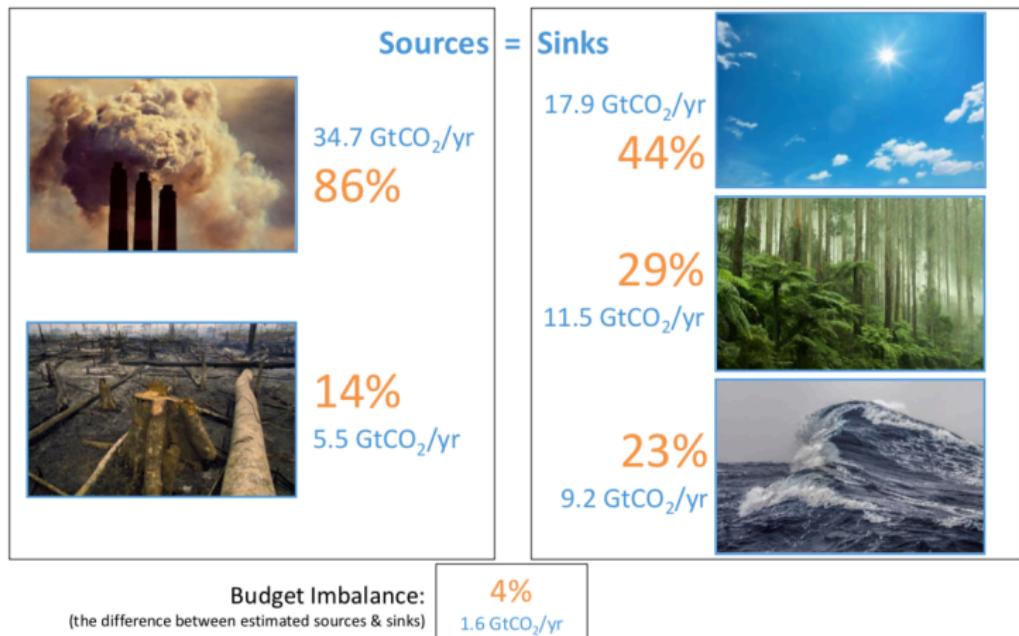
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Modification of the global carbon cycle



Fate of anthropogenic CO₂ emissions (2009–2018)



Budget Imbalance:
(the difference between estimated sources & sinks)

Source: [CDIAC](#); [NOAA-ESRL](#); [Houghton and Nassikas 2017](#); [Hansis et al 2015](#); [Friedlingstein et al 2019](#); [Global Carbon Budget 2019](#)

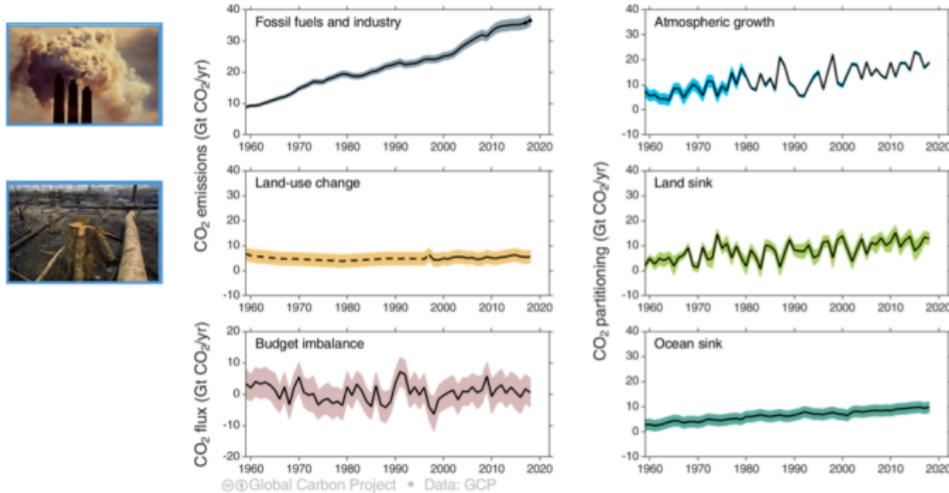
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Modification of the global carbon cycle



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 CO₂ in the atmosphere

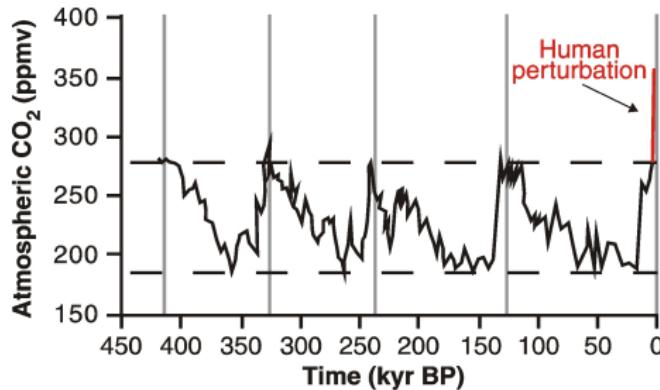


The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean.
It reflects the limits of our understanding of the carbon cycle.

Source: [CDIAC](#); [NOAA-ESRL](#); [Houghton and Nassikas 2017](#); [Hansis et al 2015](#); [Friedlingstein et al 2019](#); [Global Carbon Budget 2019](#)

for Biogeochemistry

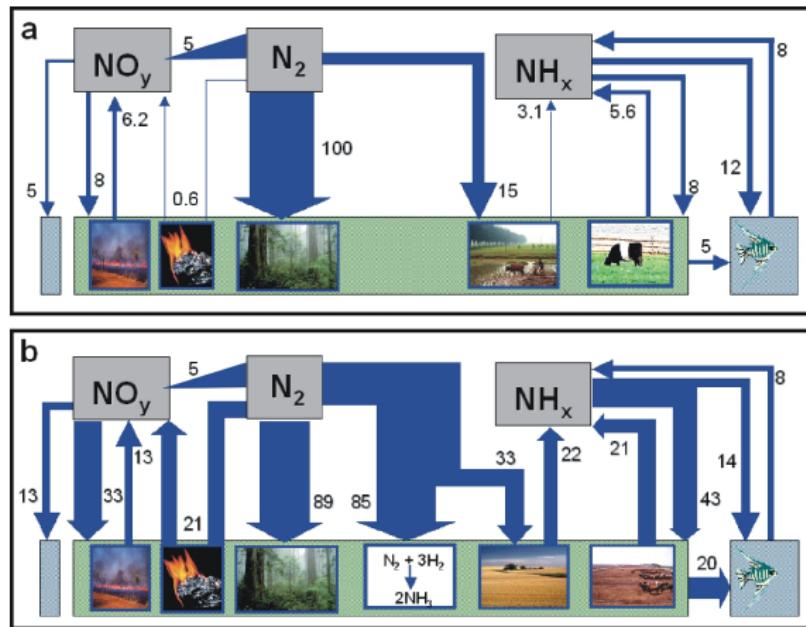
Atmospheric CO₂ over the past 42,000 years



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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.

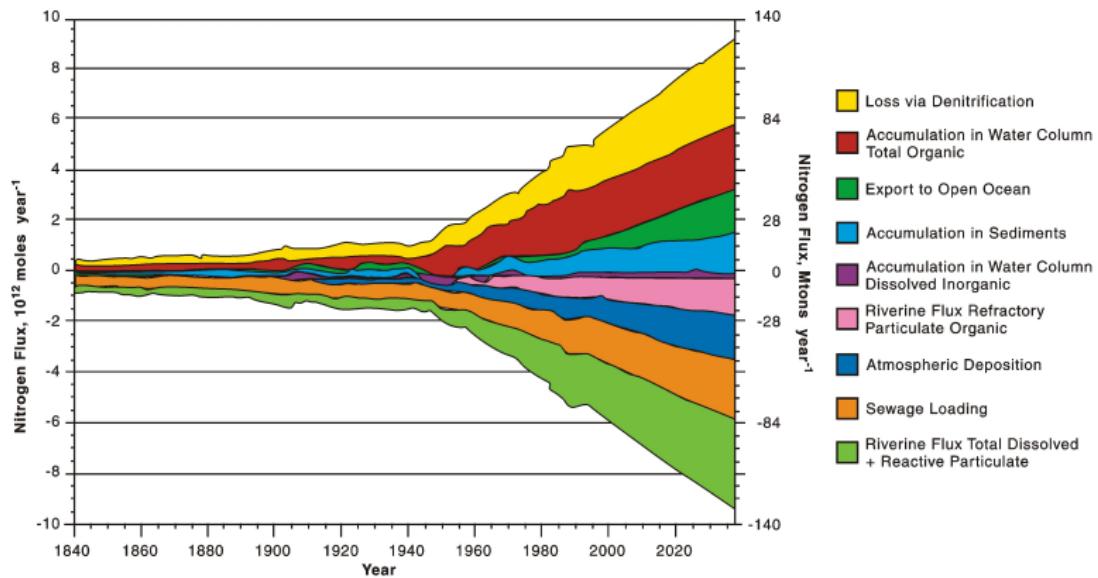
Modification of the N cycle



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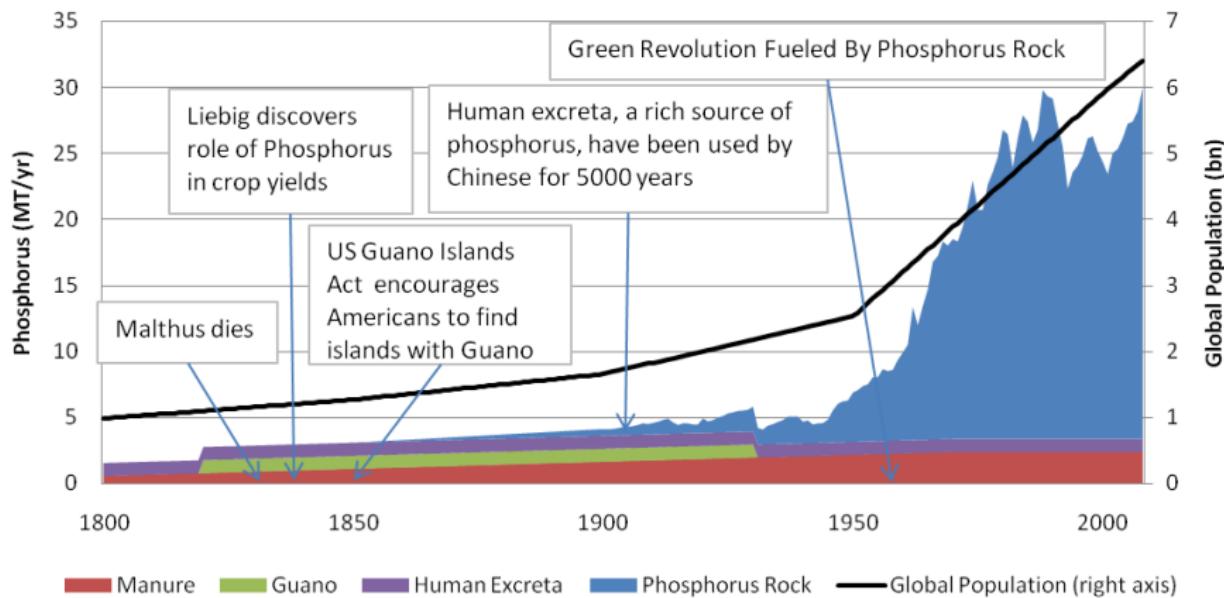
Modification of the N cycle



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Modification of the P cycle

Historical Sources of Phosphorus Fertilizer



Modification of the P cycle

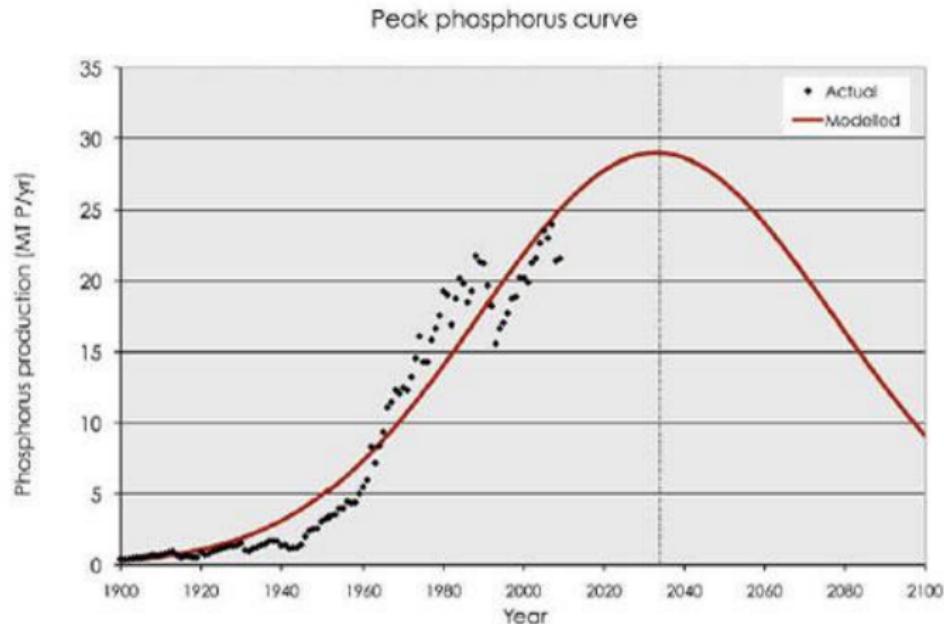


Figure 5-6: Peak phosphorus curve based on industry data, indicating a peak year of global phosphate rock production in 2033. Source: created for this research (Paper I).

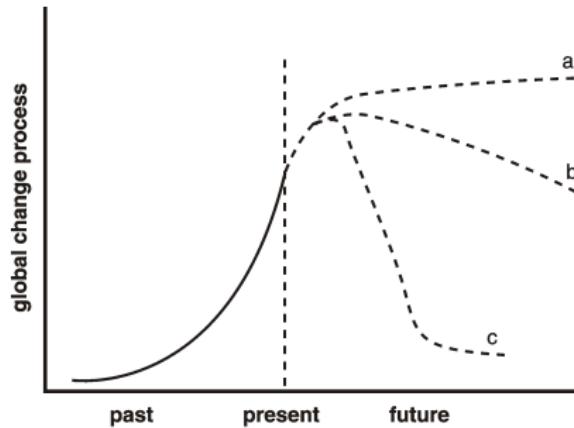


Human impacts on the Earth system

Human impacts on the Earth system

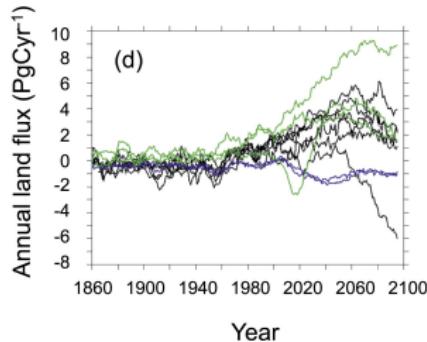
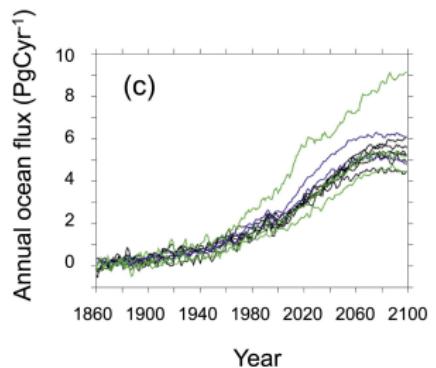
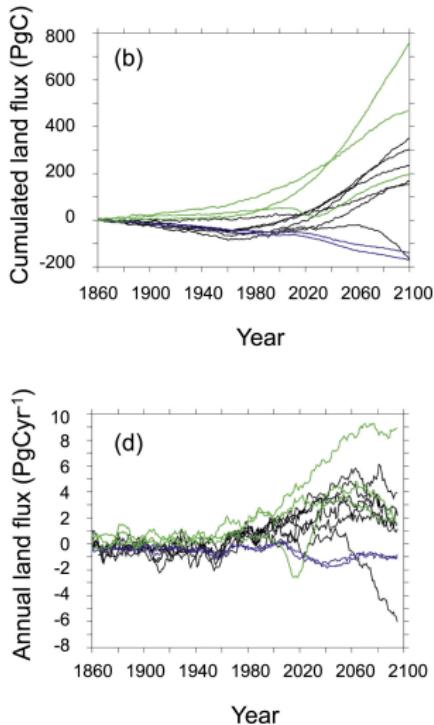
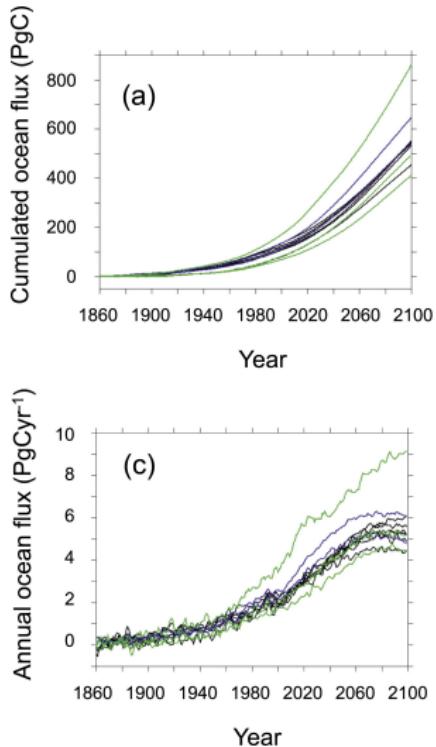
- are approaching or exceeding in *magnitude* some of the great forces of nature
- operate on much faster time scales than *rates* of natural variability, often by an order of magnitude or more
- taken together in terms of extent, magnitude, rate and simultaneity, have produced a *no-analogue* state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

Possible trajectories of ecosystems and global change processes



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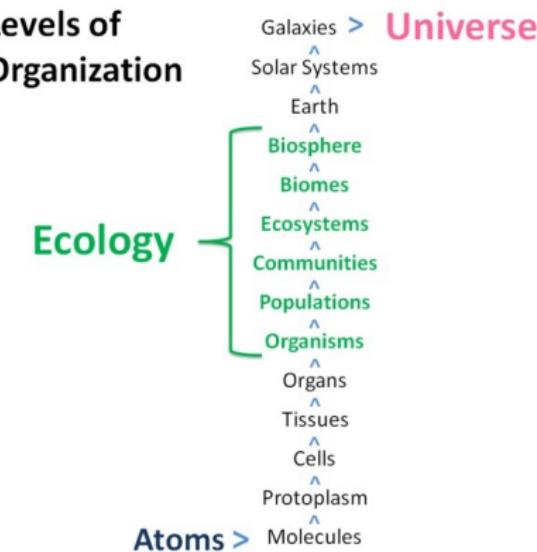
Possible trajectories predicted by Earth system model



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

Hierarchical theory as a tool to integrate information in models



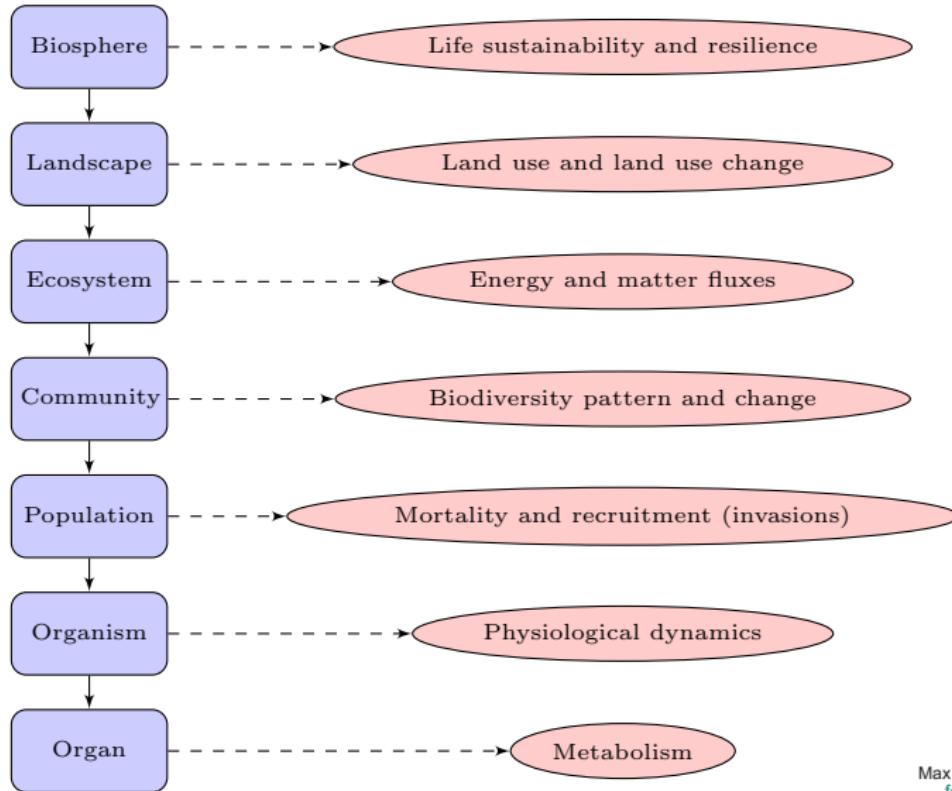
Concepts in hierarchical theory

- **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.

Hierarchies in terrestrial biosphere research

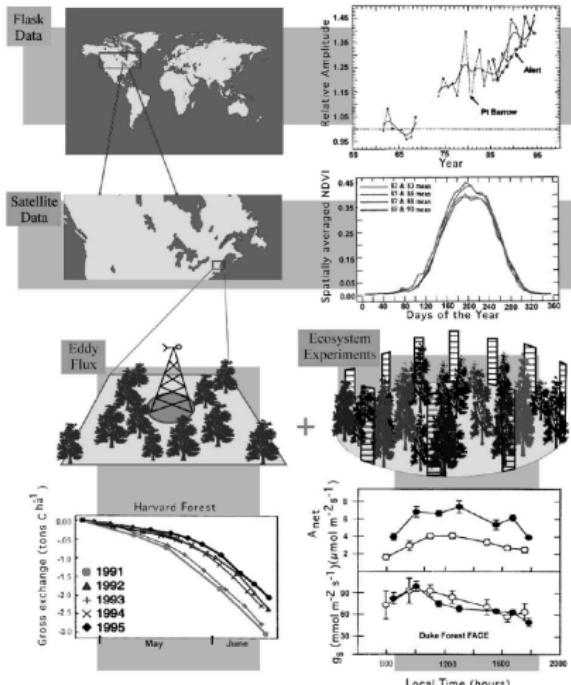


Scaling issues in biosphere research

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

Scaling concept for the C cycle

Measuring the Carbon Metabolism of the Biosphere



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

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 abstraction. 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.

The terrestrial biosphere course

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

Hierarchical organization TB course

