The Abdus Salam International Centre for Theoretical Physics

2490-4

Joint ICTP-IAEA Advancing Modelling of Climate, Land-use, Energy and Water (CLEW) Interactions

7 - 11 October 2013

Characterizing a "safe operating space" for humanity

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Characterizing a "safe operating space" for humanity

Charlotte Sullivan, UK
Winning entry in Paint for the Planet, 2008

Sarah Cornell
Stockholm Resilience Centre

Joint ICTP-IAEA Advancing Modelling of
Climate, Land-use, Energy & Water (CLEW) Interactions
9 October, 2013

Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems
Stockholm University
A centre with: SEI Stockholm Environment Institute, The Beijer Institute of Ecological Economics
FUNDED BY MISTRA The Swedish Foundation for Strategic Environmental Research

James Lovelock

The Gaia Hypothesis –

our planet functions as a single “organism”
that maintains the conditions
necessary for its survival.

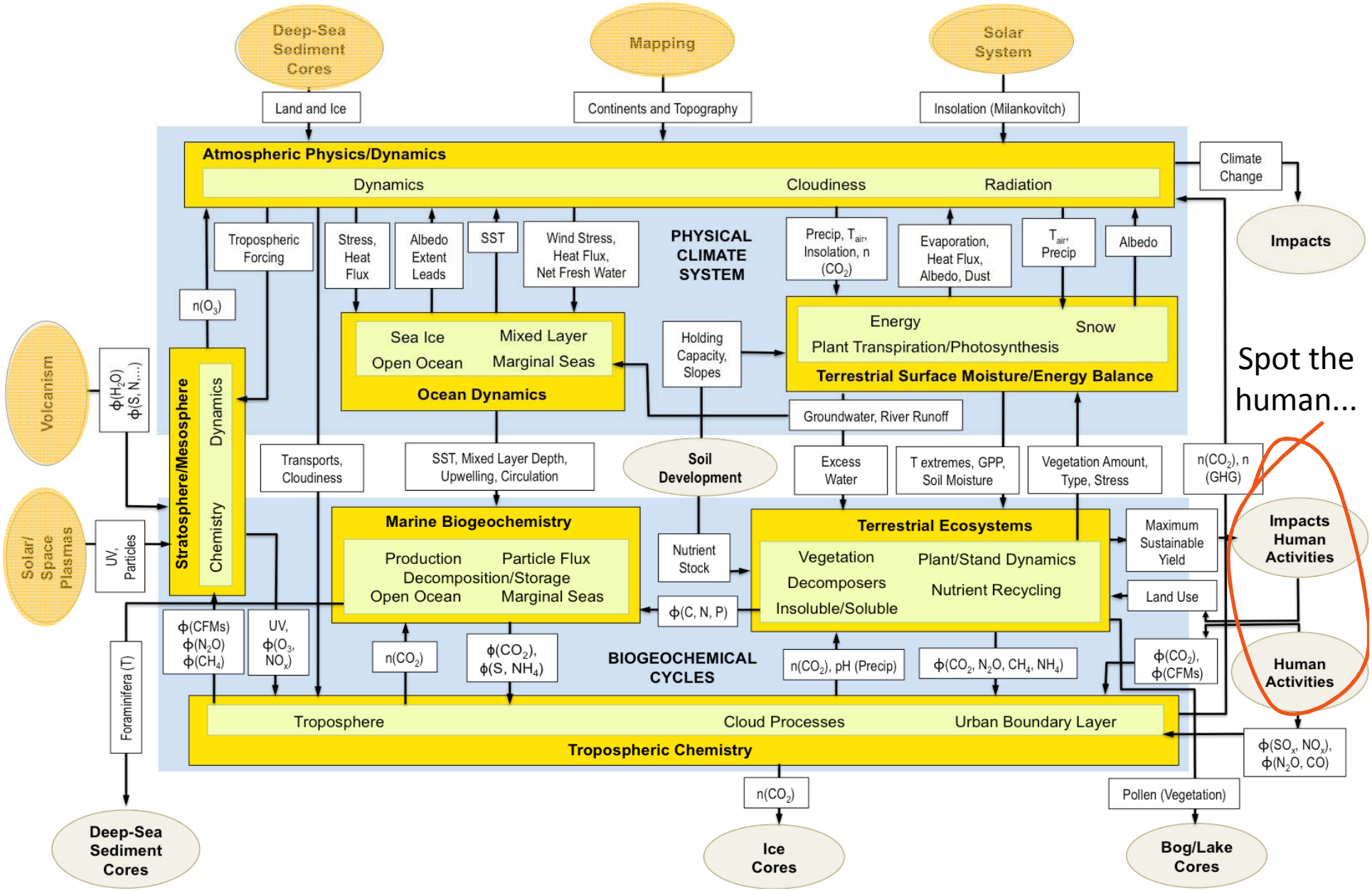
The Earth system science perspective …

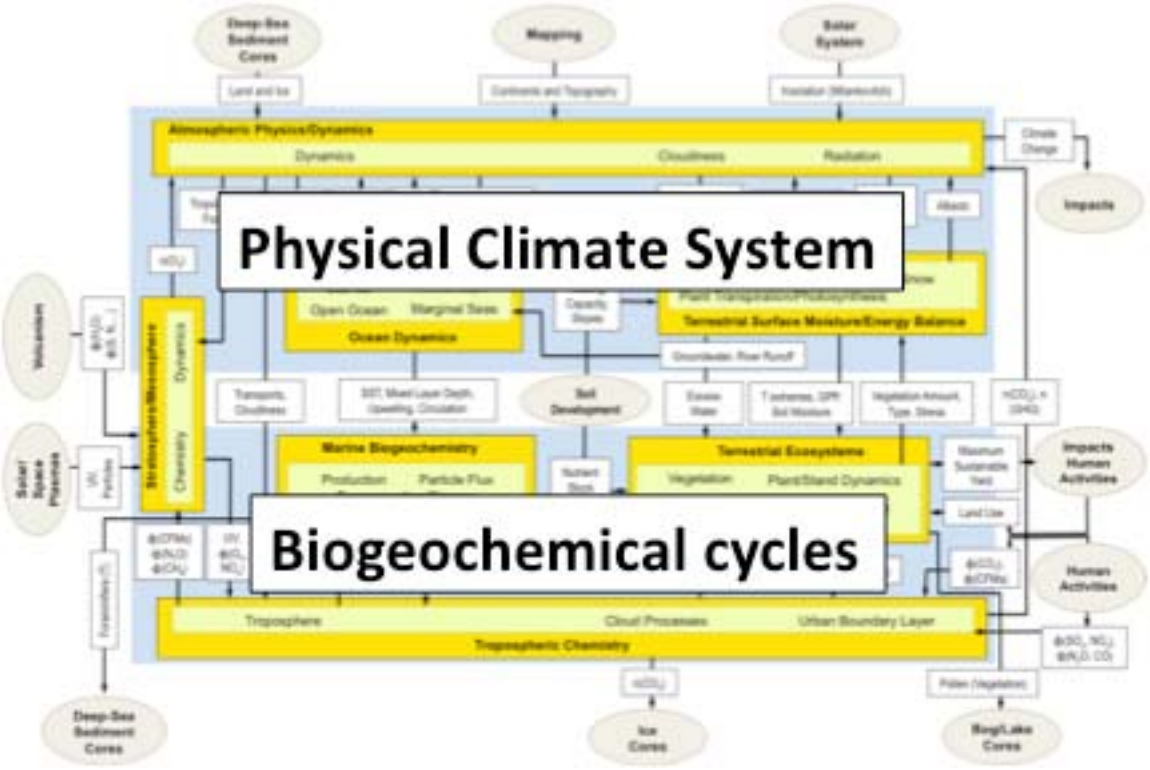
- ***The Co-evolution of Climate and Life***, Schneider and Londer (1984)
- NASA Earth system science overview (1988) – the Bretherton diagram
- International Geosphere-Biosphere Programme (IGBP) founded 1986
- The Amsterdam Declaration on Global Change (2001) and the Earth System Science Partnership
- Future Earth (2013–)

Excerpts from the Amsterdam Declaration on Global Change (2001):

- The Earth System behaves as a self-regulating system comprised of physical, chemical, biological and human components…
- Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change…
- Earth System dynamics are characterised by critical thresholds and abrupt changes…
- The Earth is currently operating in a no-analogue state.

The "Bretherton Diagram" (NASA 1988) set out the observational, conceptual and computational modelling framework for 1-2 decades of global change research.





1960s

Increasing complexity

Present day

Climate modeling

Atmosphere
Land surface
Oceans
Sea-ice
Sulfur cycle (sulfate aerosol)

Carbon cycle
Dynamic vegetation
Cloud & aerosol chemistry
"Green ocean"

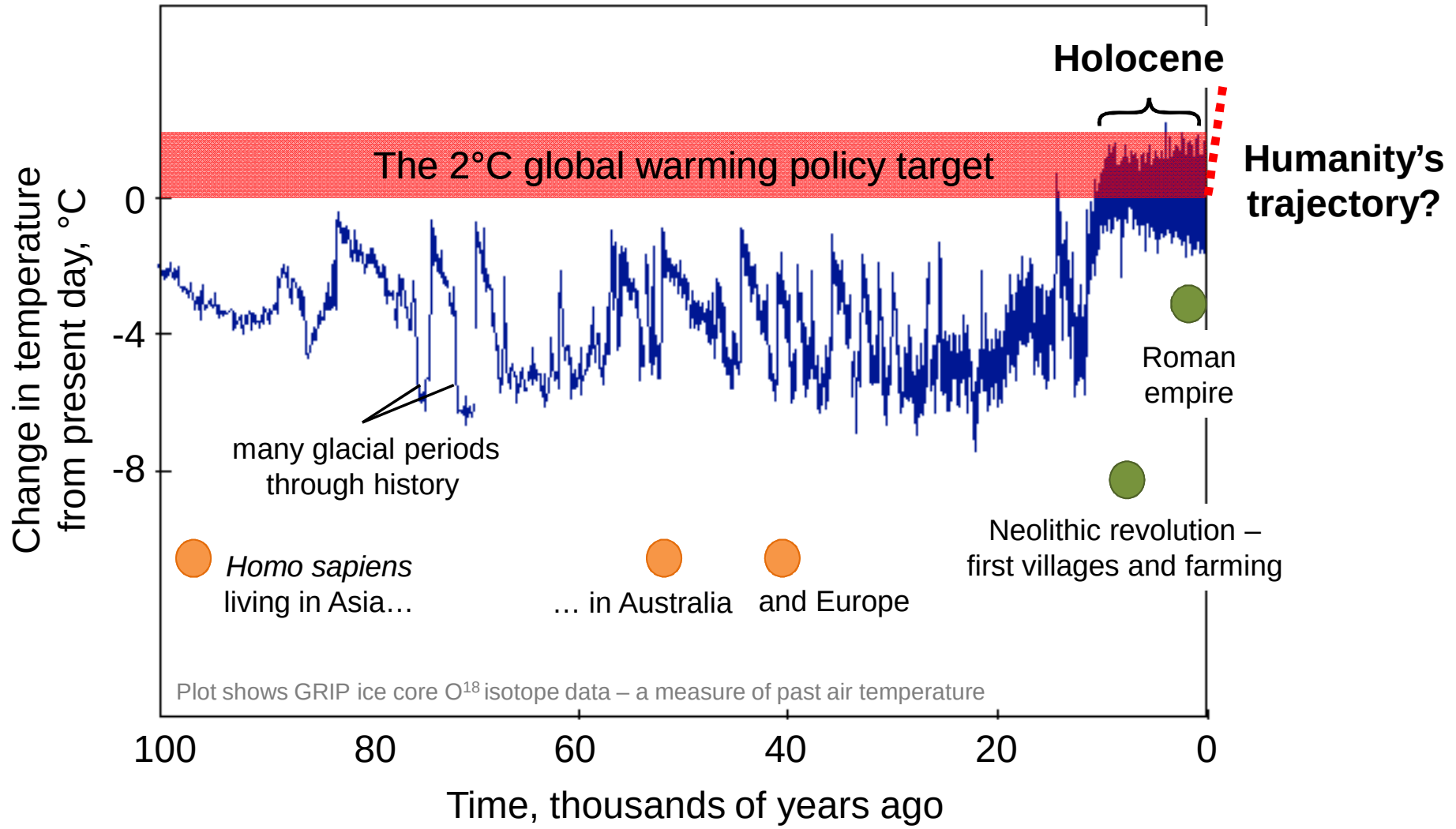
Earth system modeling

D.1 Evaluation of Climate Models

Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*). {9.4, 9.6, 9.8}

IPCC AR5 WG I SPM, 2013

Towards a new geological era:
The Anthropocene

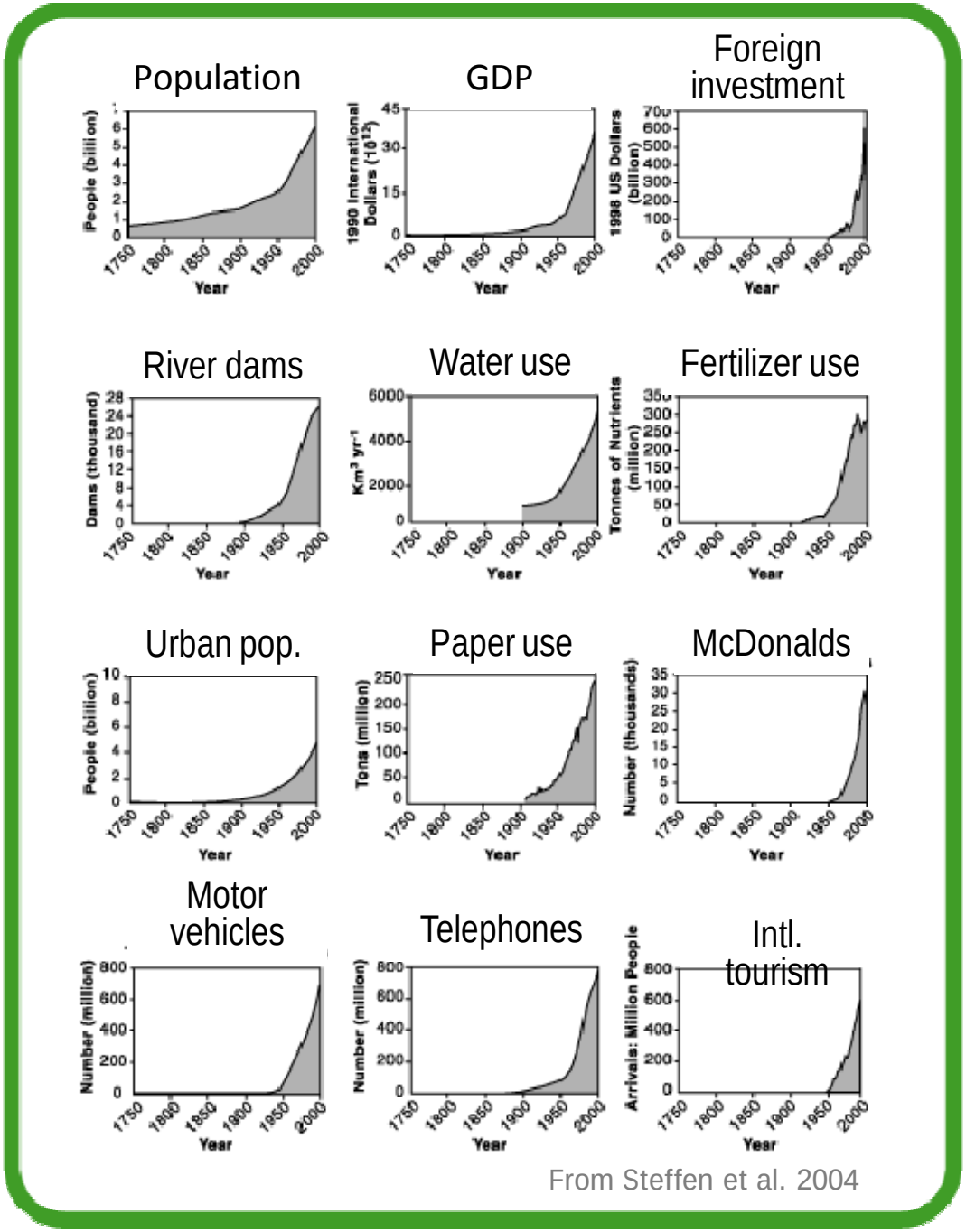


Steffen, Crutzen and McNeill (2007) *The Anthropocene: are humans now overwhelming the great forces of Nature?* Ambio

The Anthropocene

The changing human enterprise, from 1750 to 2000

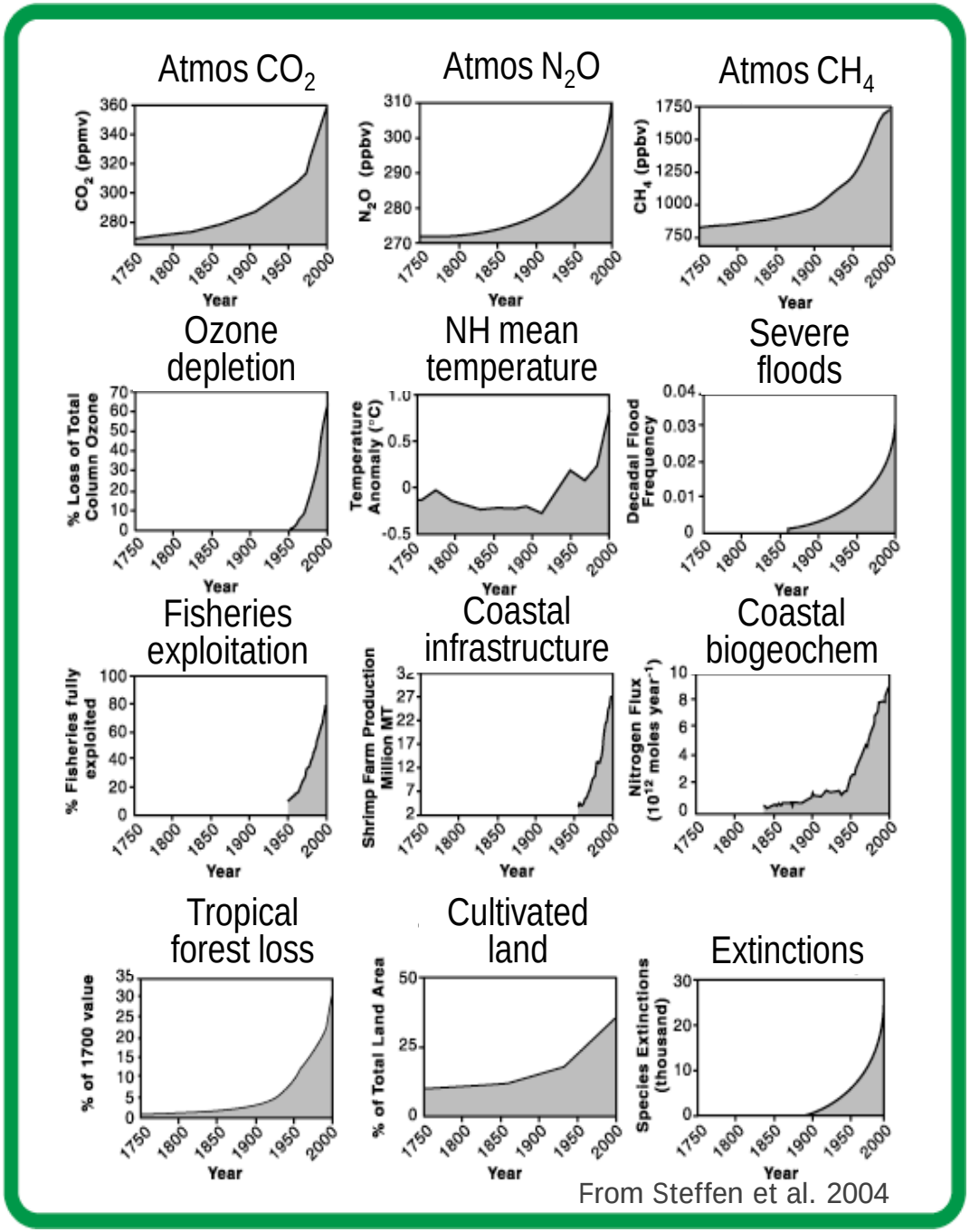
The period from 1950 to 2000 is often called The Great Acceleration



From Steffen et al. 2004

The Anthropocene

The human imprint on the global environment, from 1750 to 2000



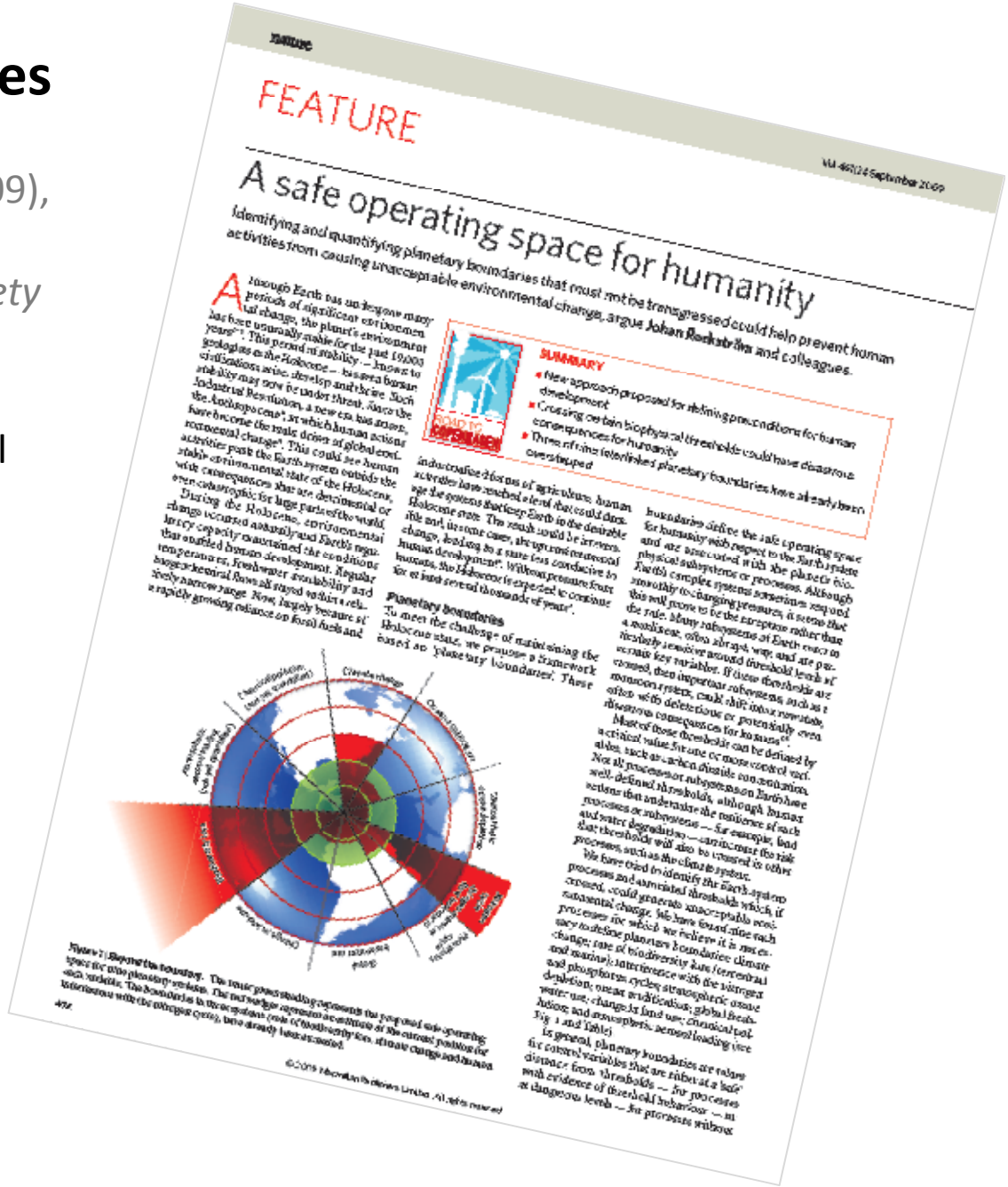
From Steffen et al. 2004

The Planetary Boundaries

J. Rockström and 28 co-authors (2009),
Feature published in *Nature*
Article published in *Ecology & Society*

Concept taken up by UN High-Level Panel on Global Sustainability (Rio + 20), UNEP, EEA, WEF, World Bank, NGOs such as Oxfam, and many other policy arenas.

Method?
Assumptions?
Evidence base?
Issues for debate?



nature

FEATURE

A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue Johan Rockström and colleagues.

SUMMARY

- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

Through Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1]. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene[2], in which human actions have become the main driver of global environmental change[3]. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world.

During the Holocene, environmental changes occurred adequately and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all stayed within a relatively narrow range. Now, largely because of a rapidly growing reliance on fossil fuels and industrialized agriculture, human activities have reached a level that could drive the system that keeps Earth in the desirable Holocene state. The result would be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[4].

Planetary boundaries

To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries'. These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although Earth's complex systems sometimes respond smoothly to changing pressures, it seems that this will prove to be the exception rather than the rule. Many subsystems of Earth exist in a critical state, often abruptly stop, and are particularly sensitive around threshold levels at certain key variables. If these thresholds are crossed, then important subsystems, such as monsoon systems, could shift into new states, often with deleterious or potentially even disastrous consequences for humans[5].

Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such systems or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is urgent to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (see Fig. 1 and Table).

In general, planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds — for processes with evidence of threshold behaviour — or at dangerous levels — for processes without

The Planetary Boundaries

Method?

Expert deliberation

Assumptions?

A well-characterized Holocene

Dynamic system can be represented with static measures

Evidence base?

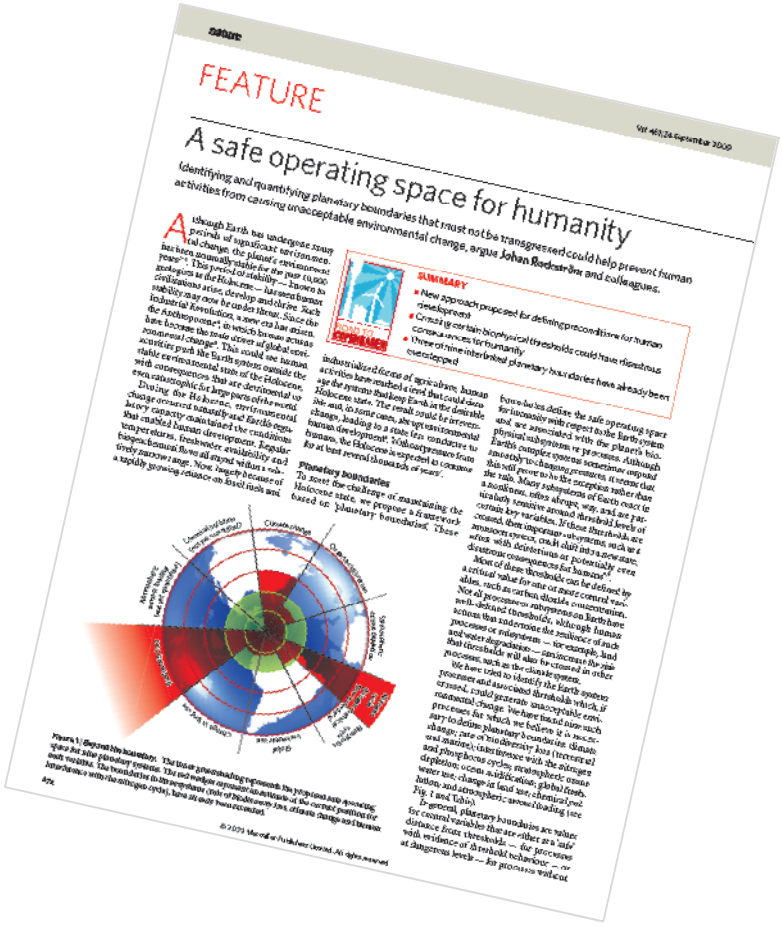
Earth observation, models/theory, palaeo records – but “in silos”

Issues for debate?

Cross-scale interactions, thresholds

Arbitrariness of boundaries → risk/impact

Role of scientific expertise in governance



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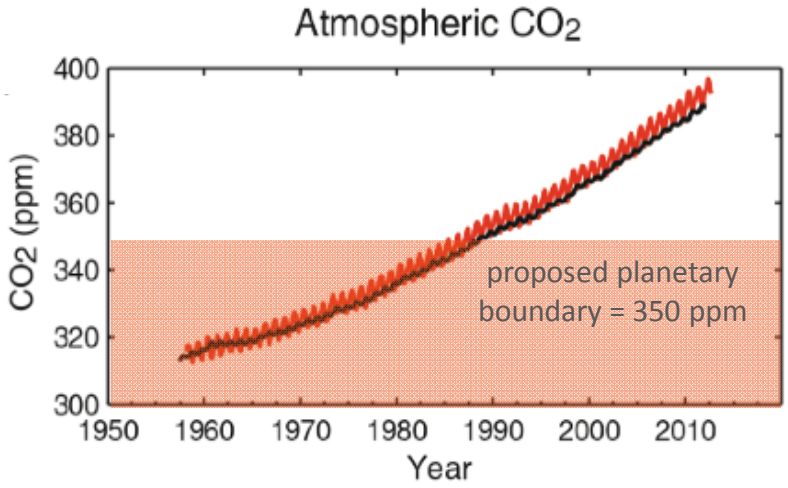
The proposed boundaries and their 'control variables':

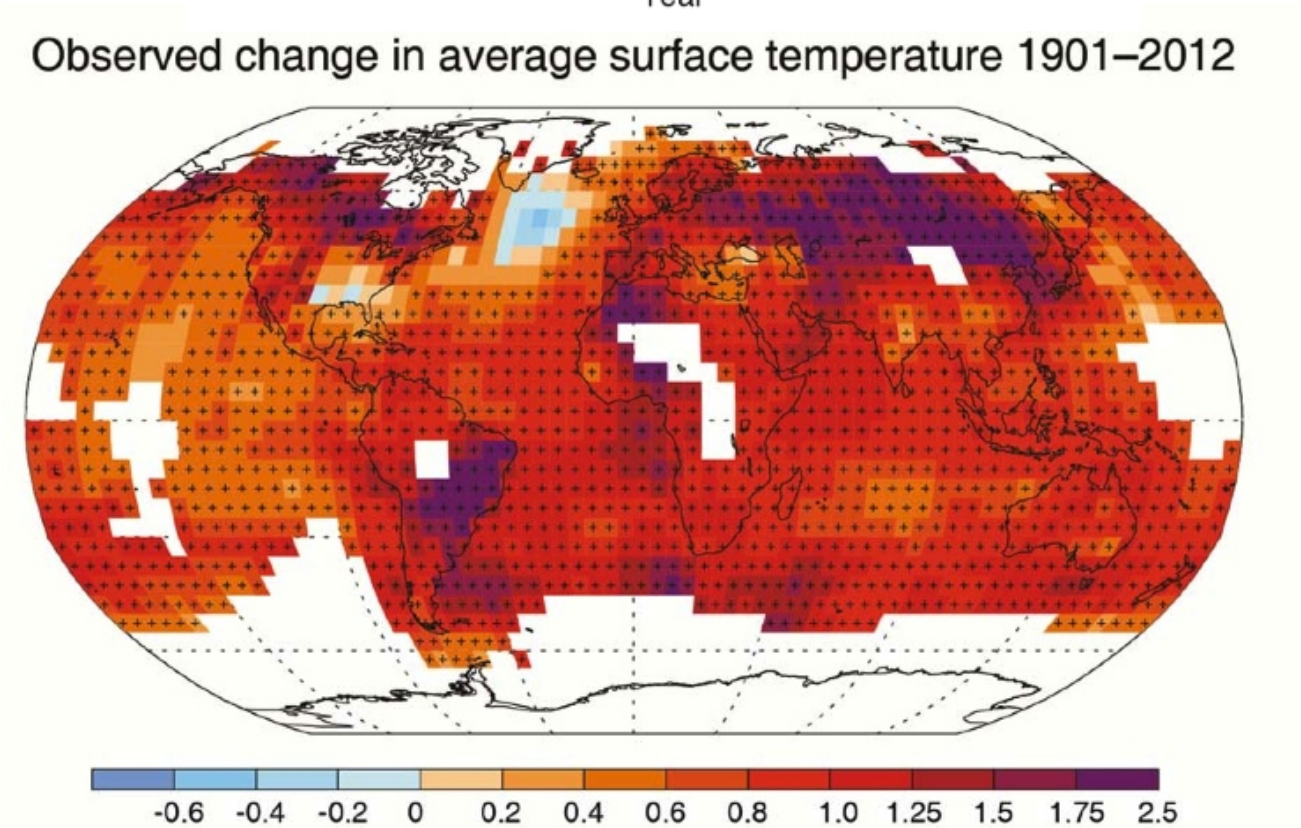
Climate change	CO_2 concentration and radiative forcing
Ocean acidification	Surface ocean CO_3^{2-} saturation state
Stratospheric ozone depletion	Ozone concentration
Perturbed biogeochemical flows (nitrogen and phosphorus)	Human-induced phosphorus inflow to ocean; Human fixation of atmospheric N_2 to bioavailable forms
Global freshwater use	Annual volume of water used in human activities
Land system change	% land converted to cropland
Biodiversity loss	Global species extinction rate
Chemical pollution	Not quantified (concentrations and effects considered)
Atmospheric aerosol loading	Not quantified

Rockström et al. (2009)

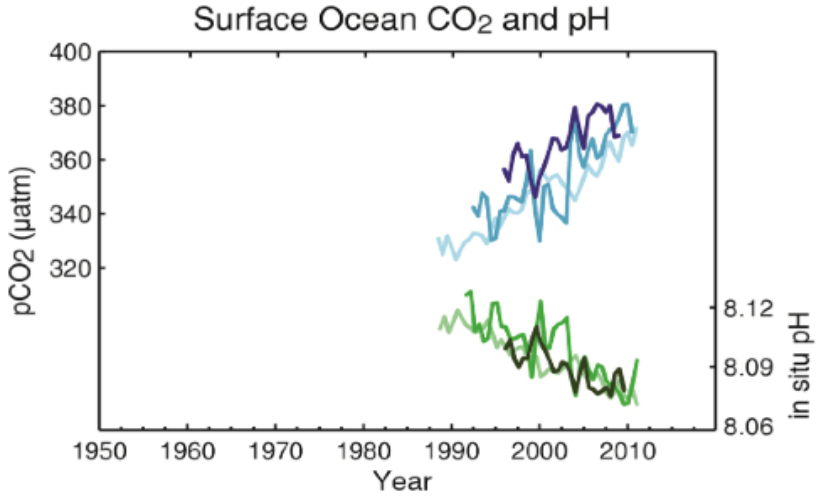
Climate and CO_2

Figures from IPCC AR5 WG I SPM (2013)

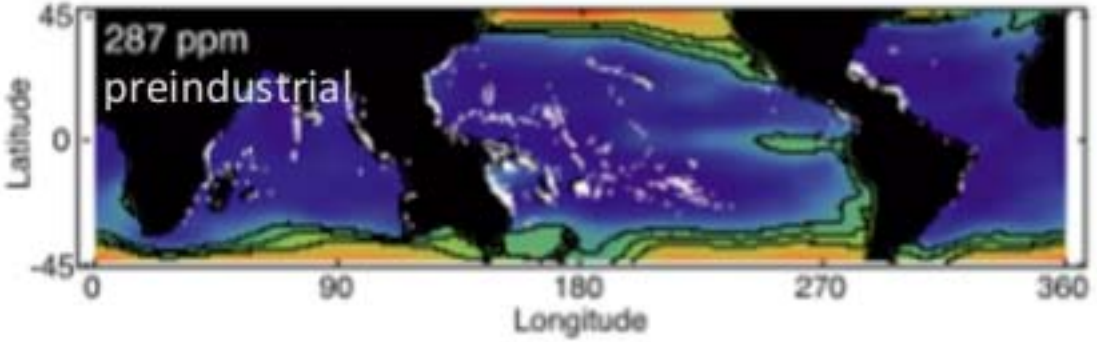


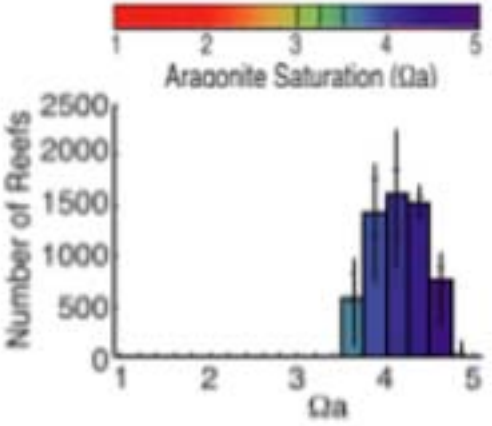


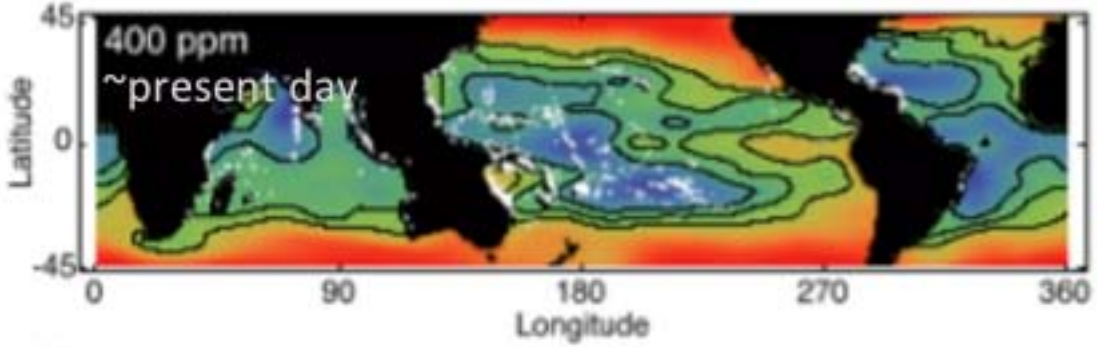
Ocean acidification (the other half of the CO_2/climate problem)



Upper figure from IPCC AR5,
lower figure from Ricke (2013)







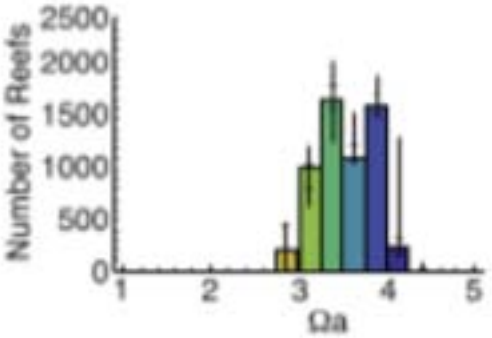
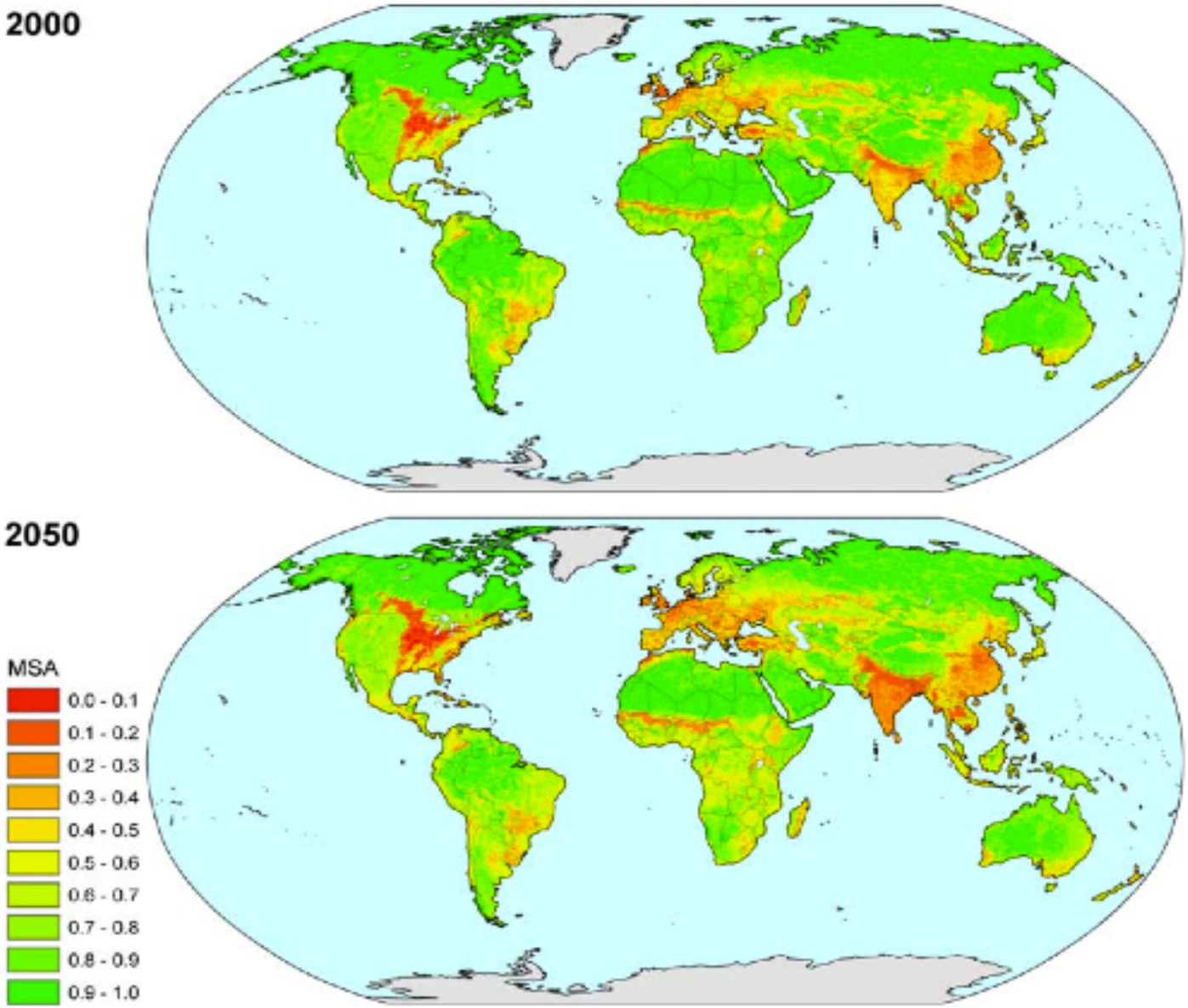


Figure from Alkemade et al. 2009

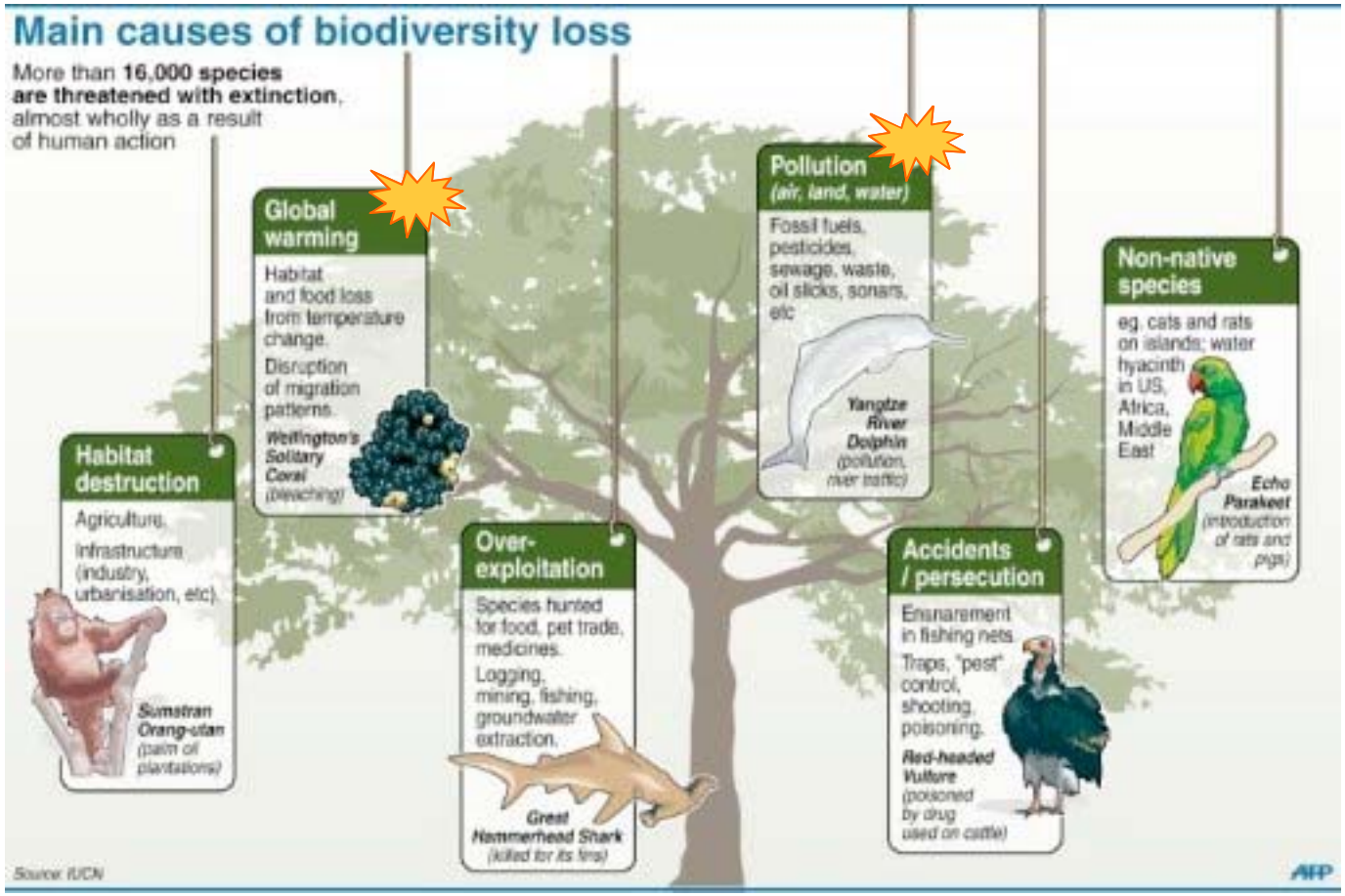
Biodiversity loss (using Mean Species Abundance)



Proposed boundary →

Ecological changes

- are seen to be widespread
- influence biophysical feedbacks ("Gaia")
- are under-monitored and weakly managed

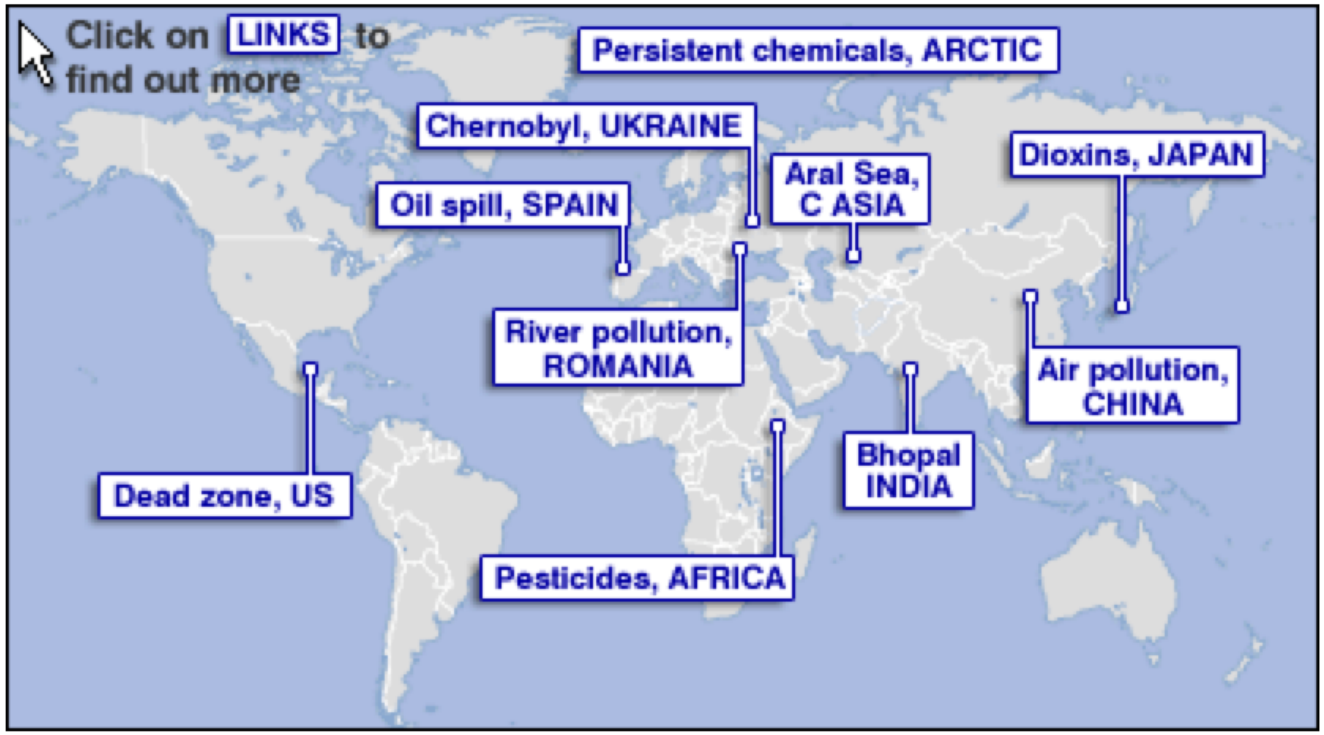


Chemical Pollution

Image/links: http://news.bbc.co.uk/2/hi/science/nature/4083331.stm

Chemical Pollution

Also see Persson et al. 2013, Env Sci Tech



Global problem? Yes (but surprisingly hard to find global data…)

Earth System impacts? Yes (as seen in CFCs/ozone and in "PBT" chemicals)

Holocene baseline? Zero…

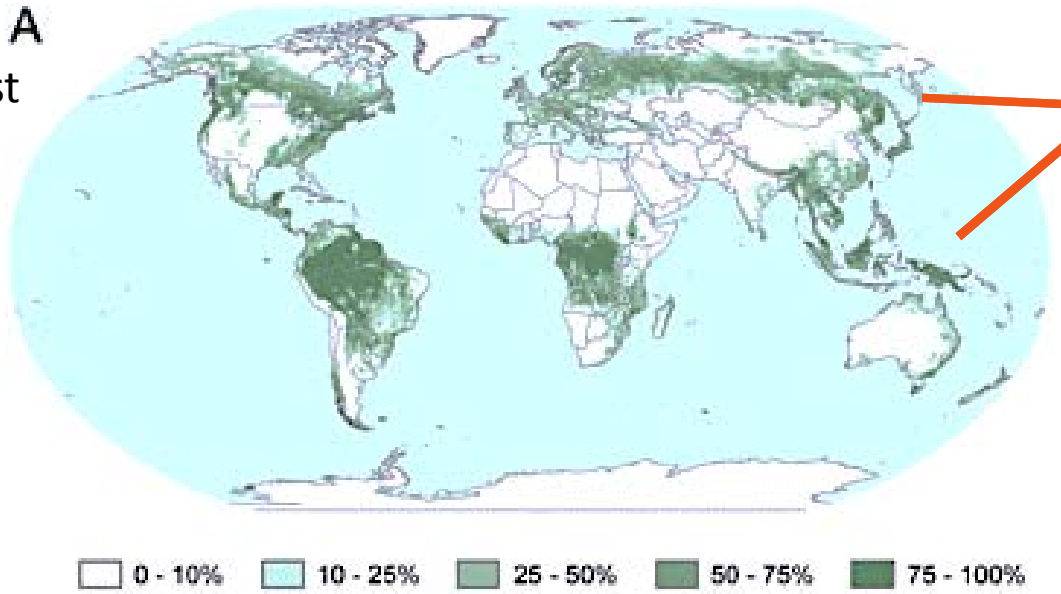
Chemical pollution is a full complexity problem,
in a system with purpose and intentionality.

Figure from Hansen et al. 2010

Land cover change (from forest to other land cover)

A

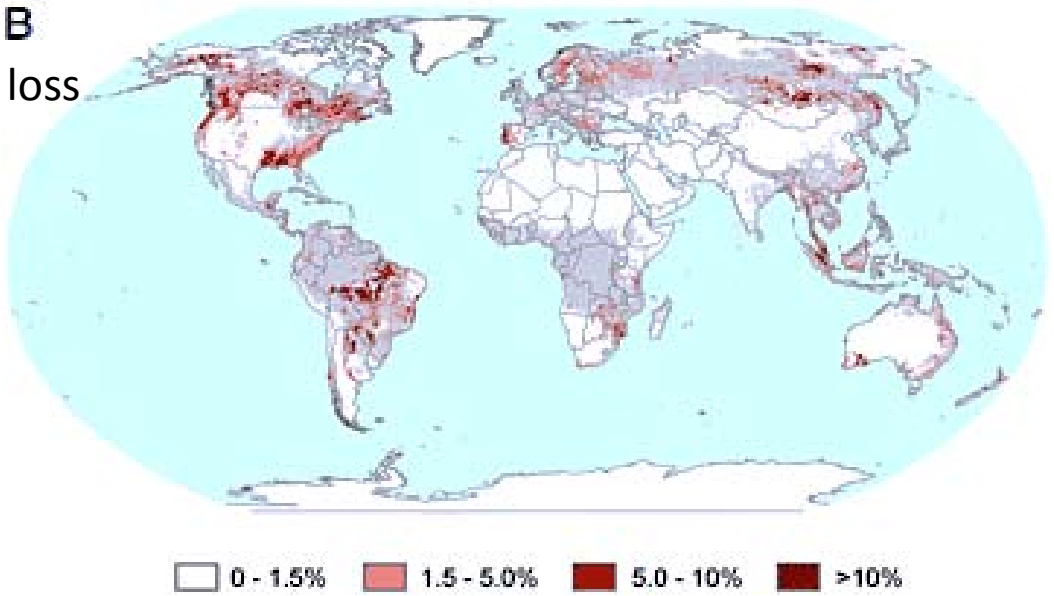
Observed forest cover in 2000



These bands of forest play an important biophysical role in the Earth system (albedo, hydrology, carbon cycling)

B

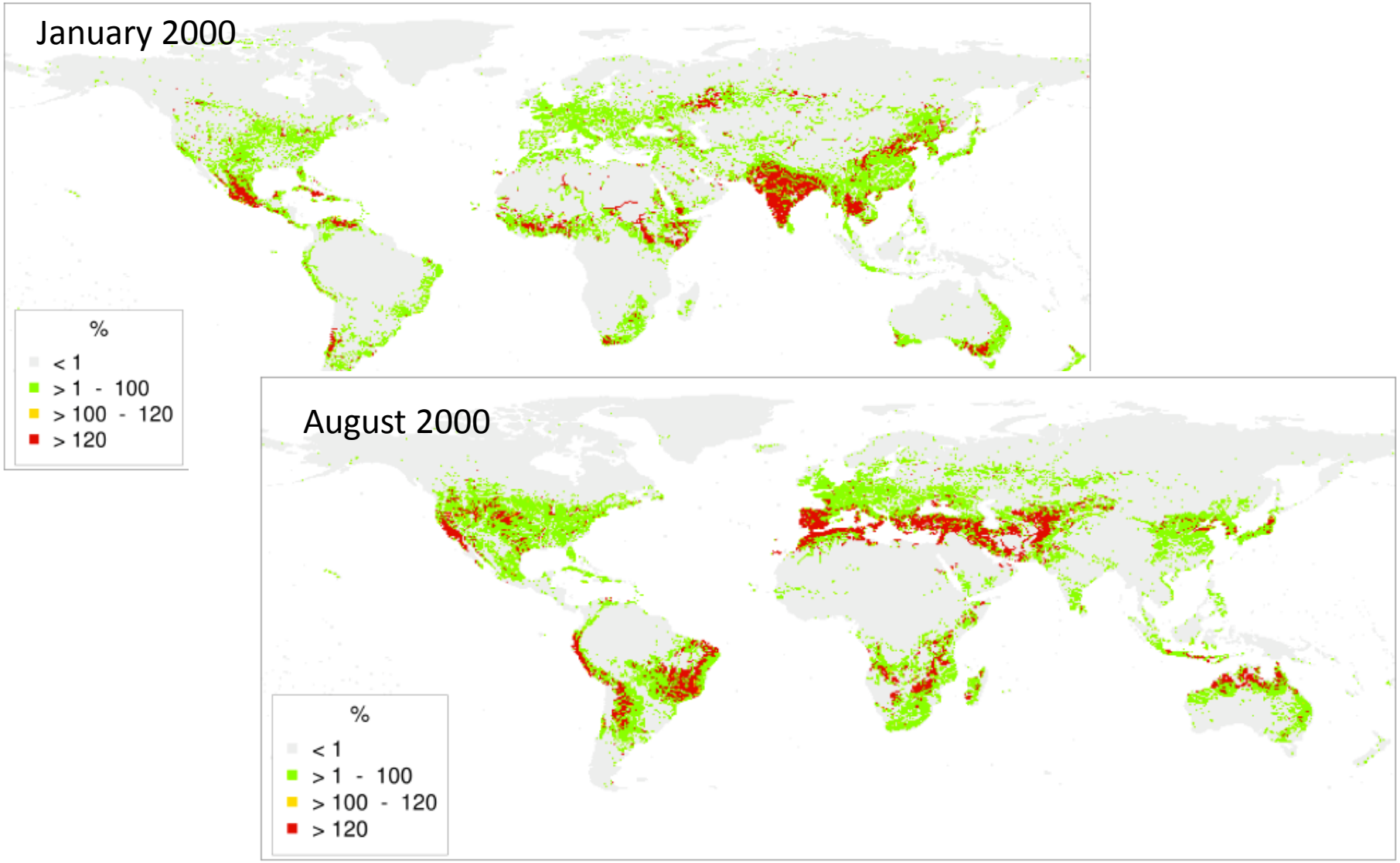
Observed forest loss 2000-2005



Water Use

"Withdrawal Index" – how much is withdrawal tapping into ecological flow resource?

(work in progress, PIK-SRC collaboration – Gerten, Pastor et al.)



Atmospheric aerosol

Complex behaviour –

- Direct and indirect radiative forcing
- Direct and indirect ecosystem effects

Planetary effects?

- Hydrological cycle
- Biome shifts
- Albedo

→Changing weather patterns, e.g., monsoons, convective rains

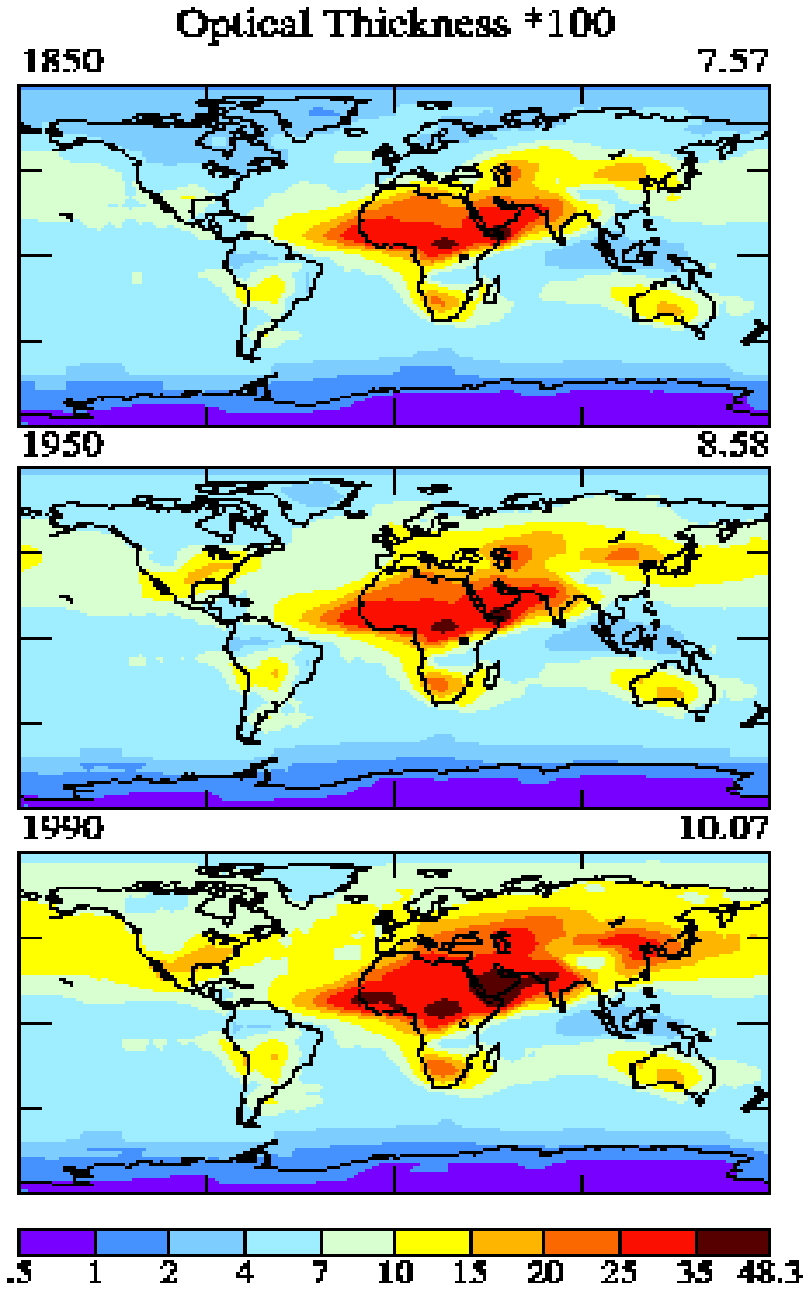
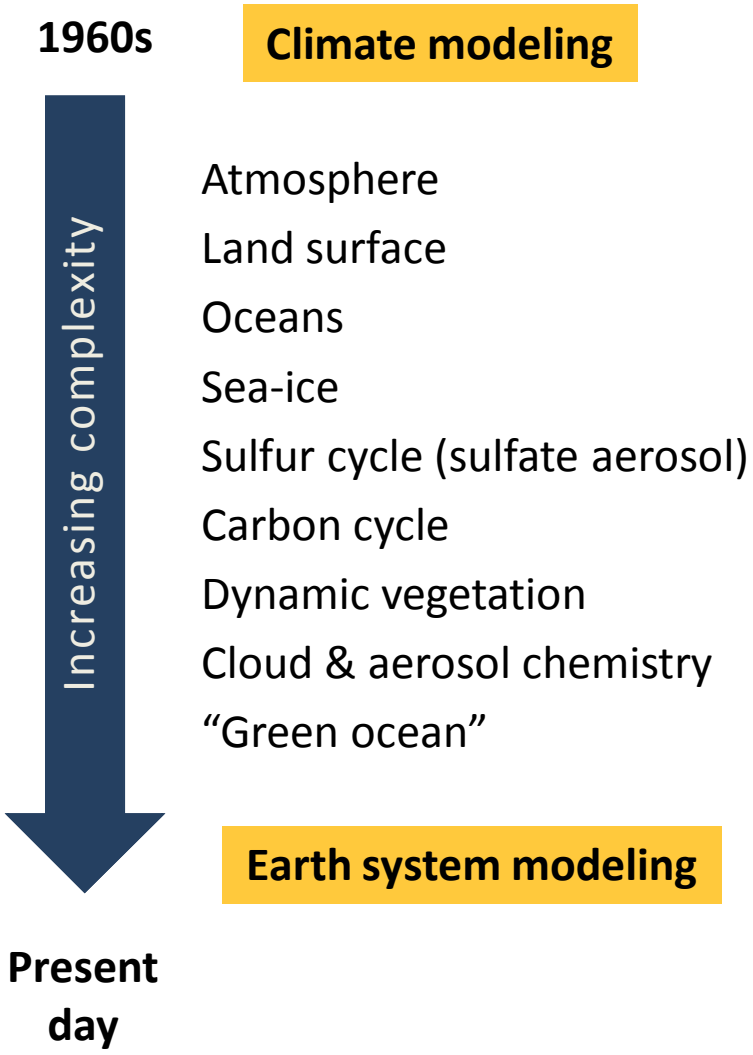


Figure from NASA GISS

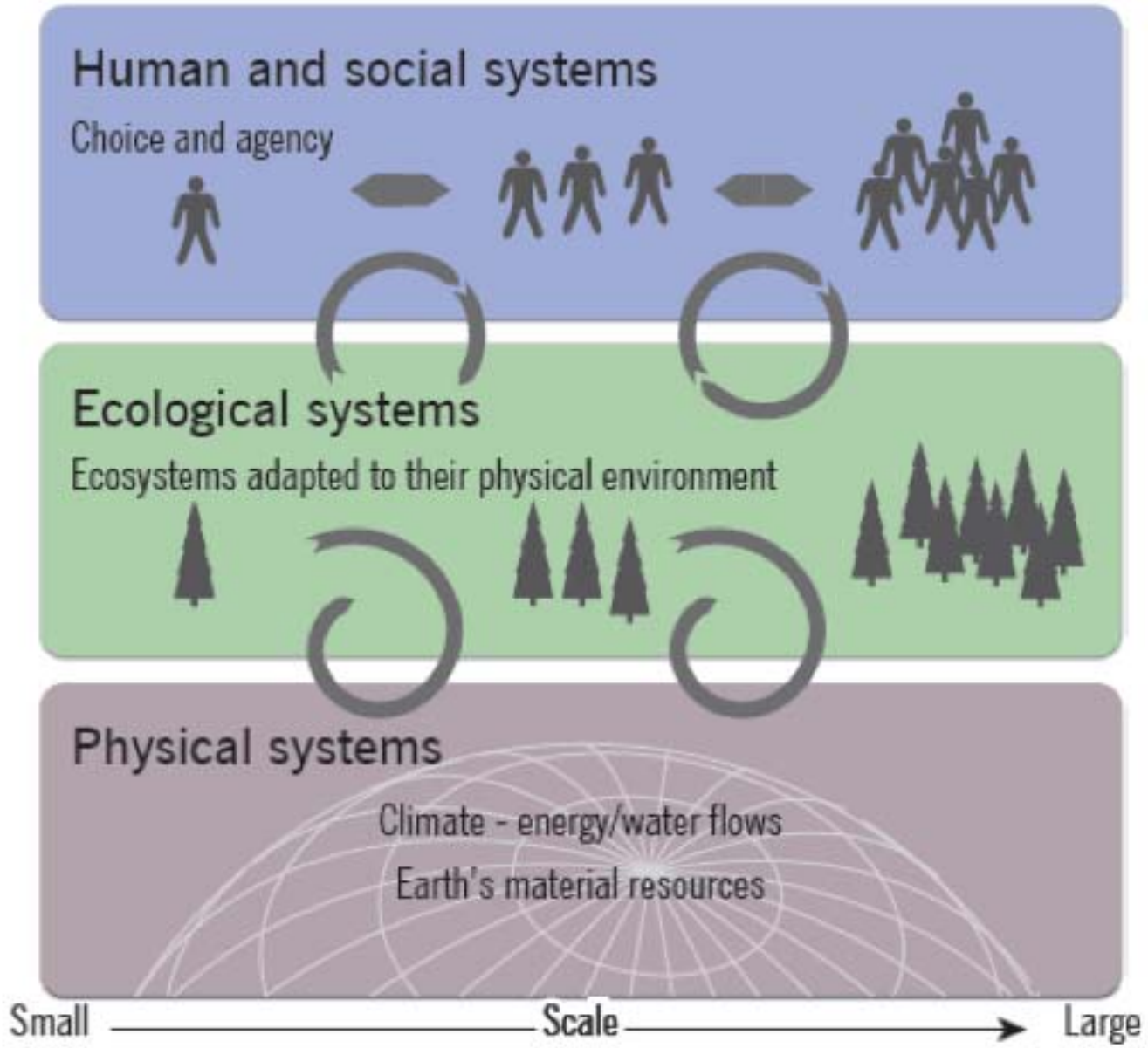
Biogeochemical perturbation from nutrient releases

Figure from WRI, using data from Diaz and Rosenberg 2008

Local problem turned global?
What about human needs?



So what’s missing from these high-complexity models? (and why?)



"Integration" of different types of knowledge remains a challenge.

Earth's mechanisms are not clockwork

Humans are not just observers of the system

Apollo 11 image, July 1969

From: CBD (2013) Aichi Target 19 Quick Guide

Quick guide to the

Aichi Biodiversity Targets

Knowledge improved, shared and applied

By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.

All countries need information to identify threats to biodiversity and determine priorities for conservation and sustainable use. While nearly all Parties report that they are taking actions related to monitoring and research, most also indicate that the absence or difficulty in accessing relevant information is an obstacle to the implementation of the goals of the Convention.

Information and data gaps

Development of effective solutions must link from local to global scales

From: Our Nutrient World (2013)

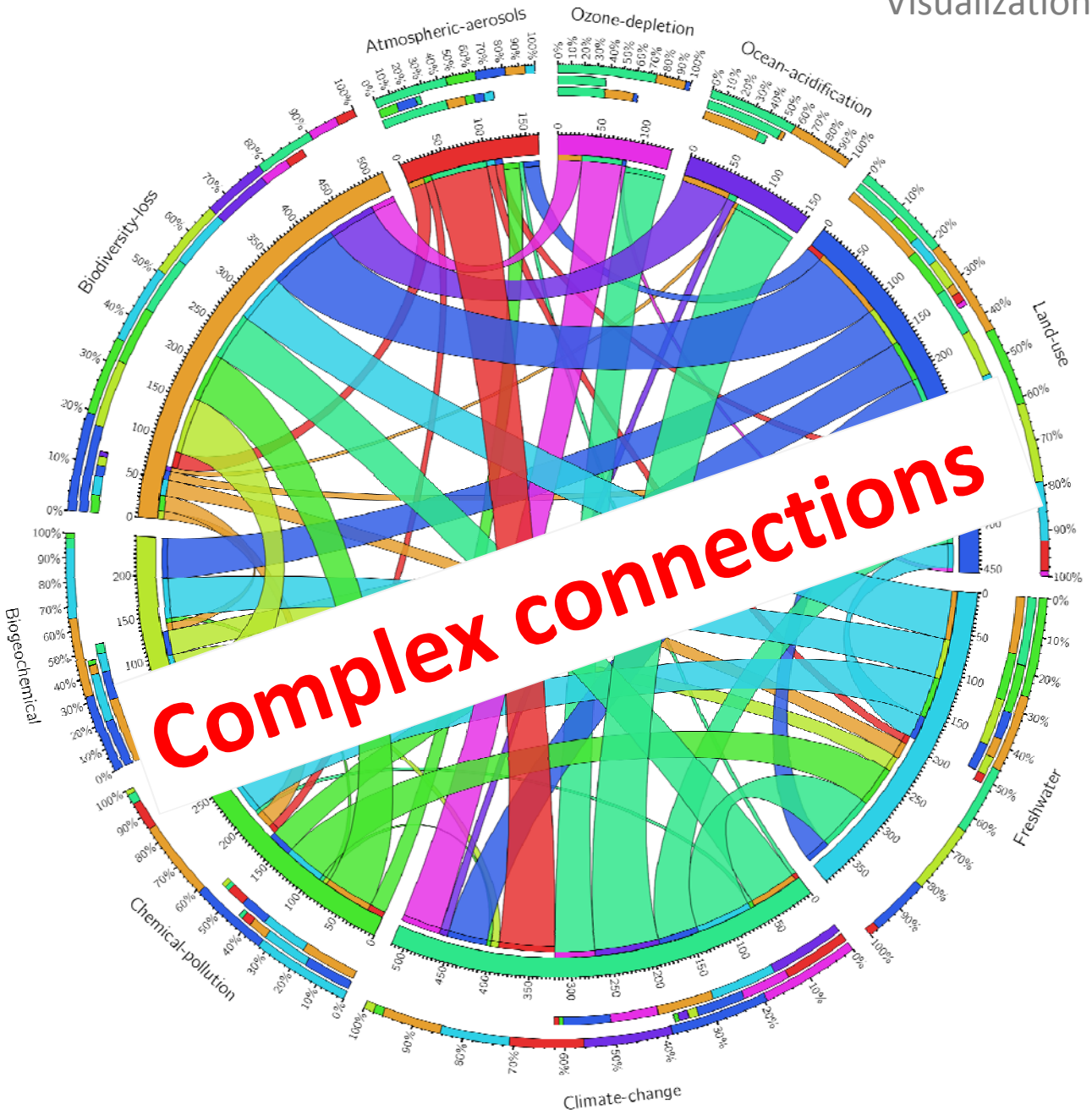
- There is an urgent need to develop joined-up approaches to optimize the planet's nutrient cycles for delivery of our food and energy needs, while reducing threats to climate, ecosystem services and human health.

7.2 Knowledge and Information

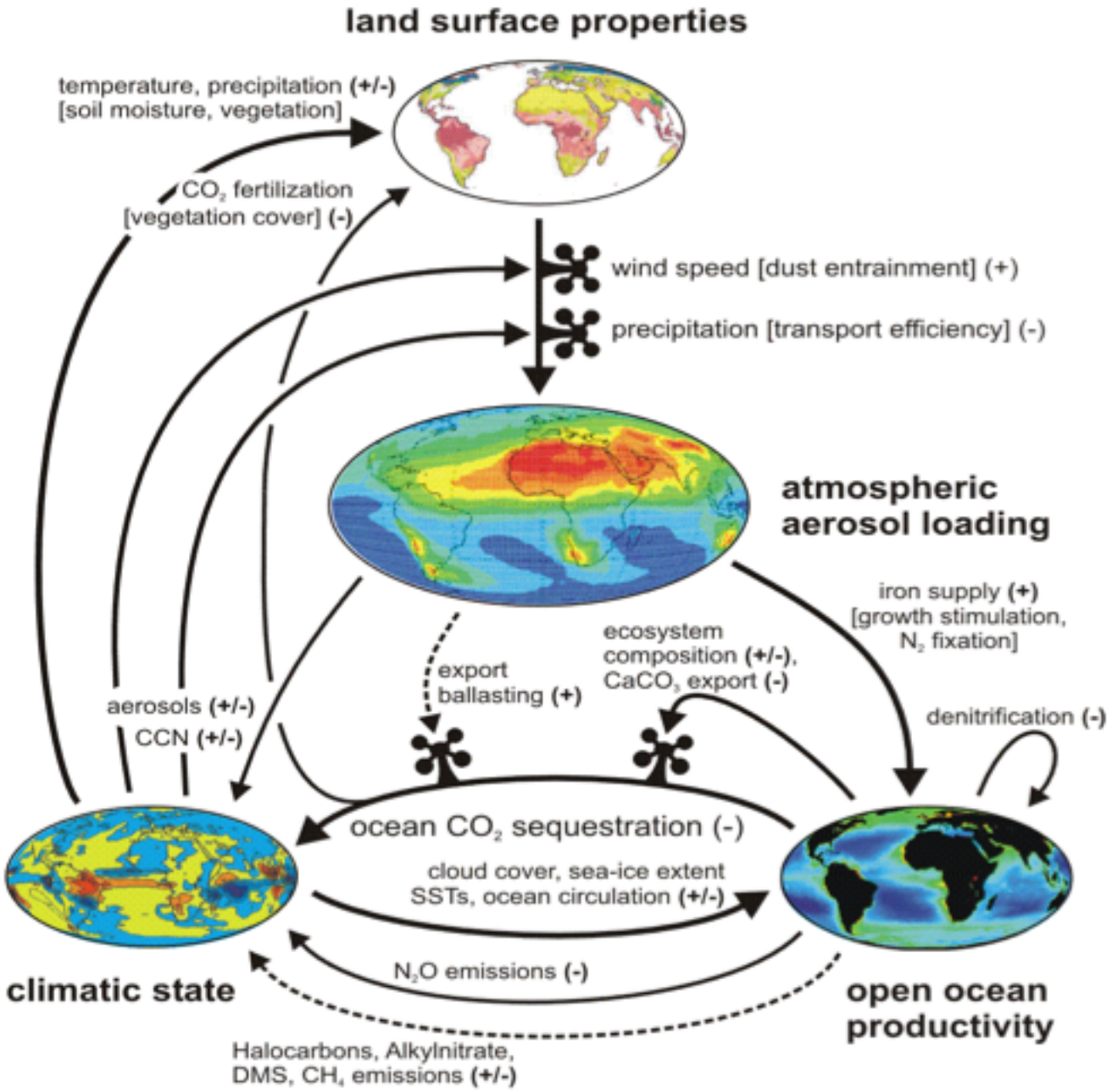
From: UNEP Global Chemical Outlook (2013)

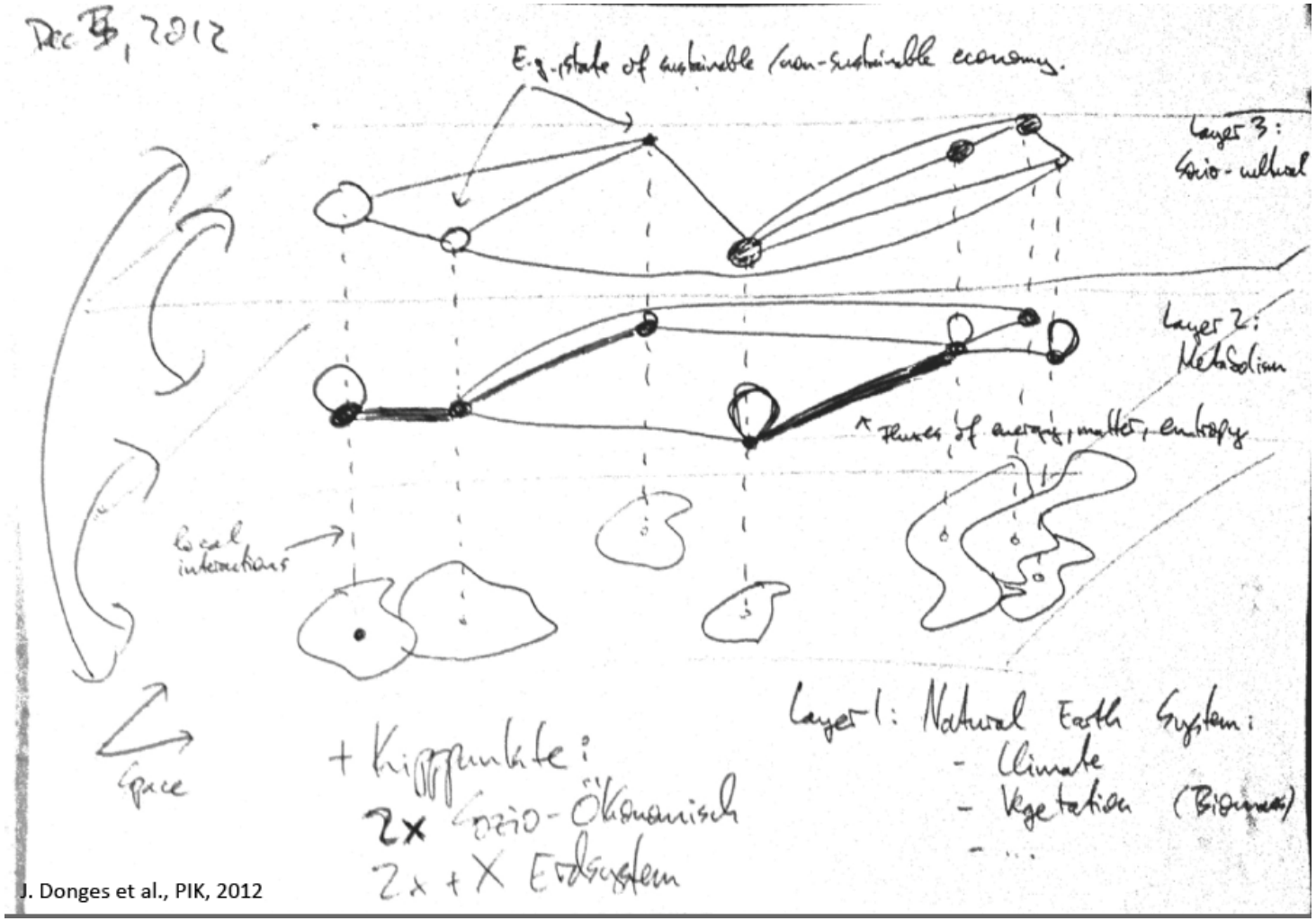
The transition towards sound chemical management requires a significantly expanded base of chemical information not only on the health and environmental effects of chemicals, but also on the production, use, transport and disposal of chemicals. Information is needed through-out the life cycle of products. The burden for this information must fall on those companies that manufacture and use chemicals; however, governments, along with companies and civil society organizations, must make it available, accessible and understandable to the public.

Visualization: J. Friedrich (WRI)



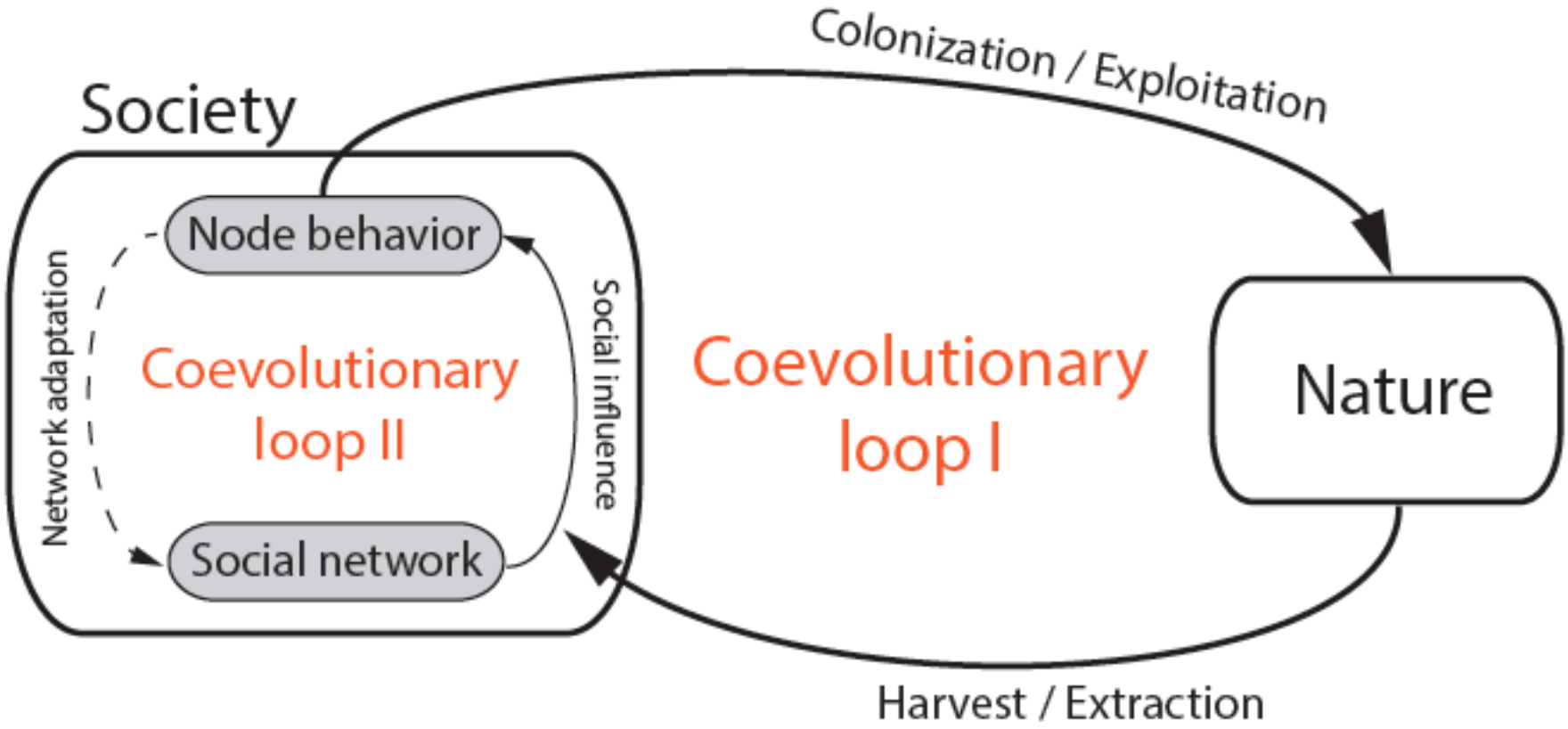
Jickells et al., 2005





J. Donges et al., PIK, 2012

Modeling: J. Donges et al 2013



But what are we doing all this for?

Navigating the global community's Safe Operating Space…

"The problem is the idea that the planet has a cockpit, and in that cockpit, we can change course.

The planet doesn't work like that"

Maarten Hajer, PBL Netherlands

AHDR 2004, 2013
ACIA 2005

Human uses → social structures → global connections

Once upon a time two planets met. One seemed very healthy and the other seemed very sick with its face mutilated by a rash…

So the healthy one asks the sick one, ”Hey - what happened to you since we last met?"

And the sick one answers, "Well, I am really sick… I have a strange disease called *homo sapiens.*"

The healthy planet answers, "Ah, never mind – it's a minor problem. I had it once and it disappeared by itself".

Alexander Likhotal

Macro-Engineering

=

Macro-Mitigation

(including large-scale renewables schemes)

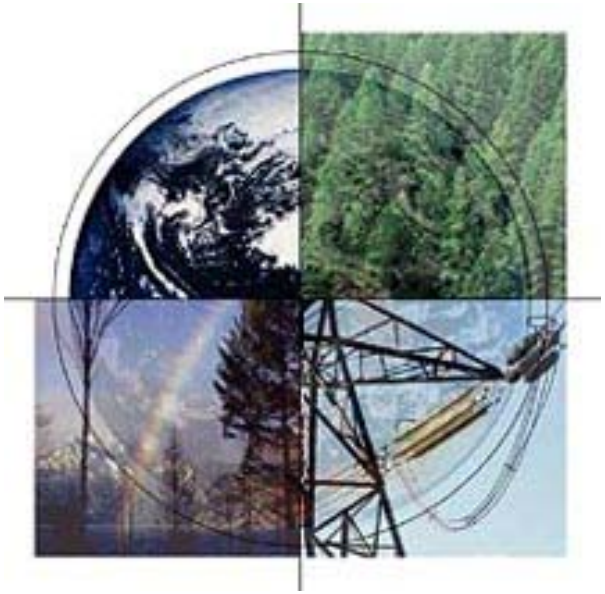
+

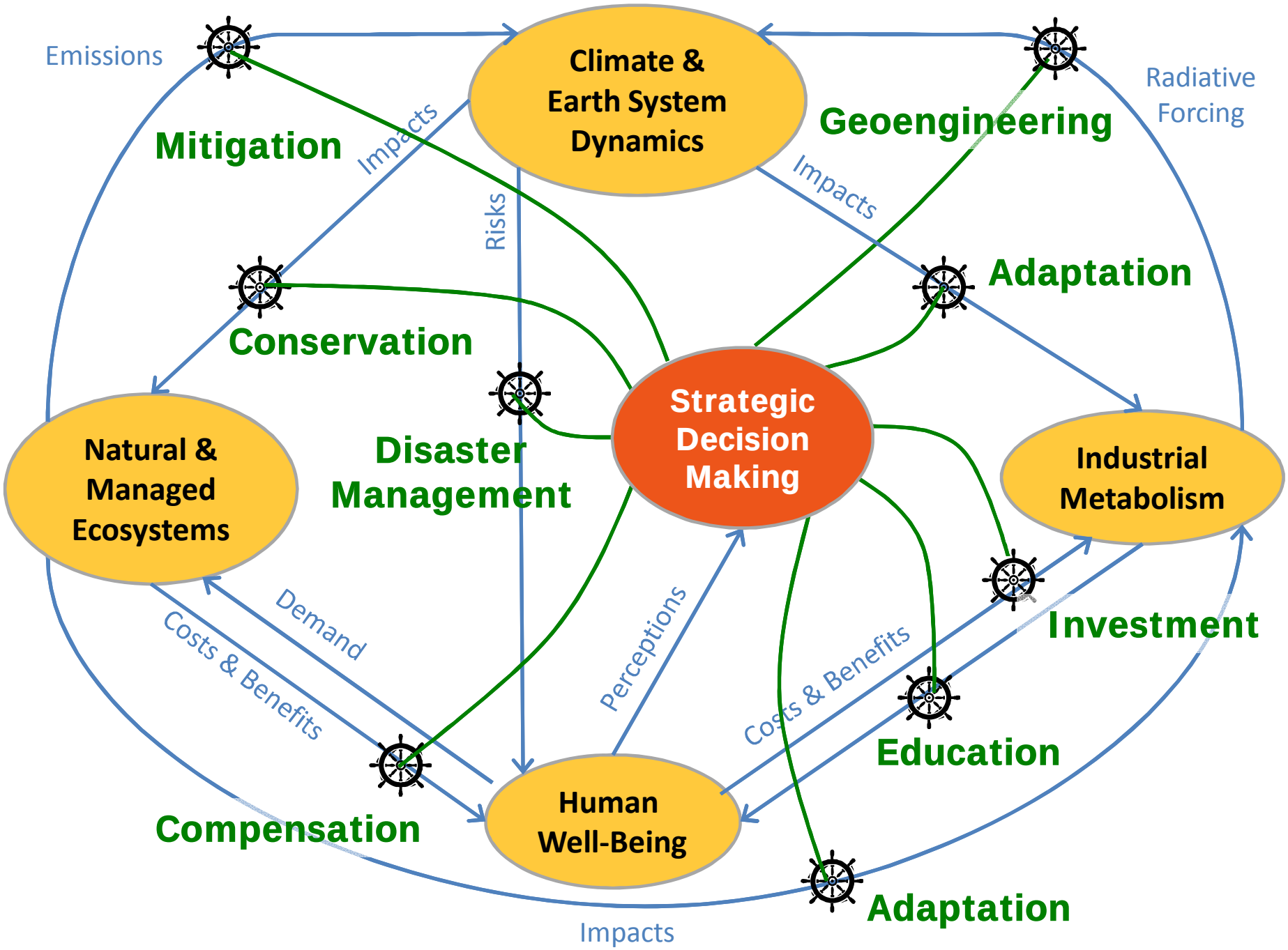
Macro-Adaptation

(landscape redesign, eco-migration corridors, river diversion, coastal reconstruction, sea level management, etc.)

=

Re-Invention of Global Environment




Emissions
Climate & Earth System Dynamics
Radiative Forcing
Mitigation
Impacts
Geoengineering
Impacts
Risks
Adaptation
Conservation
Natural & Managed Ecosystems
Disaster Management
Strategic Decision Making
Industrial Metabolism
Demand
Costs & Benefits
Perceptions
Costs & Benefits
Investment
Education
Compensation
Human Well-Being
Adaptation
Impacts

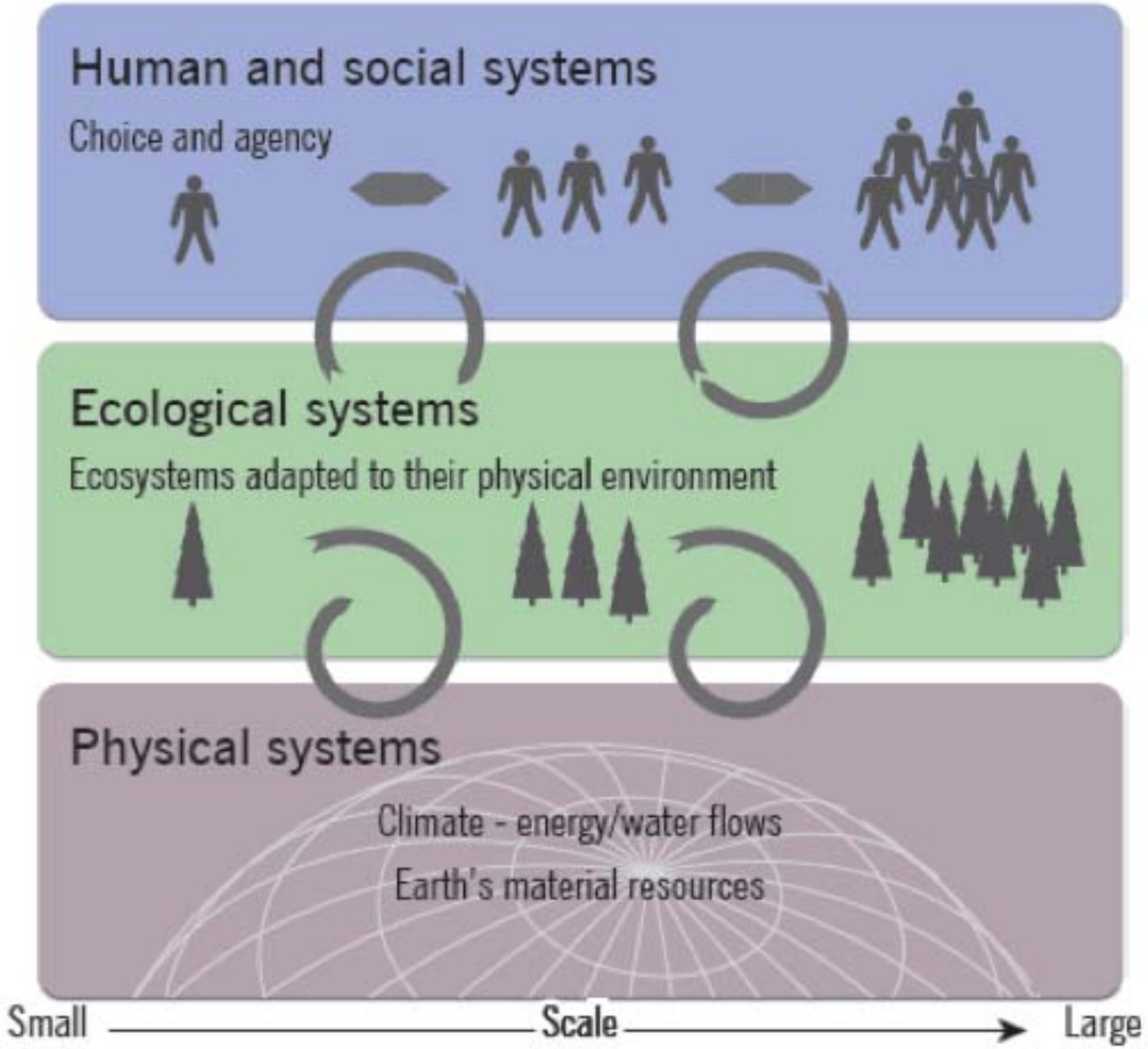
Our models need to provide

information that is

- **Relevant,**
- **Robust,**
- **Rough & ready,**
- **Reproducible**

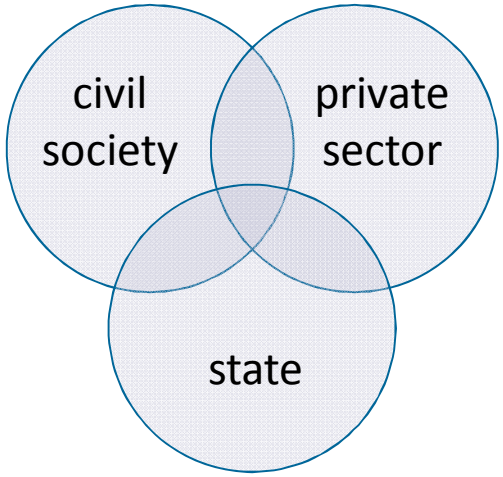
systems-level wisdom
without perfect
subsystem-level knowledge

Integration of knowledge is a challenge



Today's questions -

- When "everything is changing fast", what can we be sure of?
- What is the basis for action in the context of change (especially when we are not sure)?
- Whose knowledge?
  Whose action?
  Whose sustainability?



Governance = the various ways that society steers itself

Good or bad governance?

- **New integrated assessments that link social and ecological change**
- **Avoiding inadvertent 'iatrogenic' risks –**
  ie, safeguards on policies so that the cure is not worse than the disease…
- **Engagement and input from wider interests**
- **Embedding the plurality of values**

Precaution – Provisionality – Participation

Global Responsibility?

- Researchers need to engage in social debates
- Researchers need to be policy-literate
- Polymaths need to reflect on what they do *and* how they do it:
  - Values
  - Practices

Not conclusions
(perhaps discussion points)

- Research challenges: knowledge integration, describing the state of the (whole) world
- Governance challenges: “one vision?”, history, expanding network of actors

+ BIG real-world challenges where these issues meet