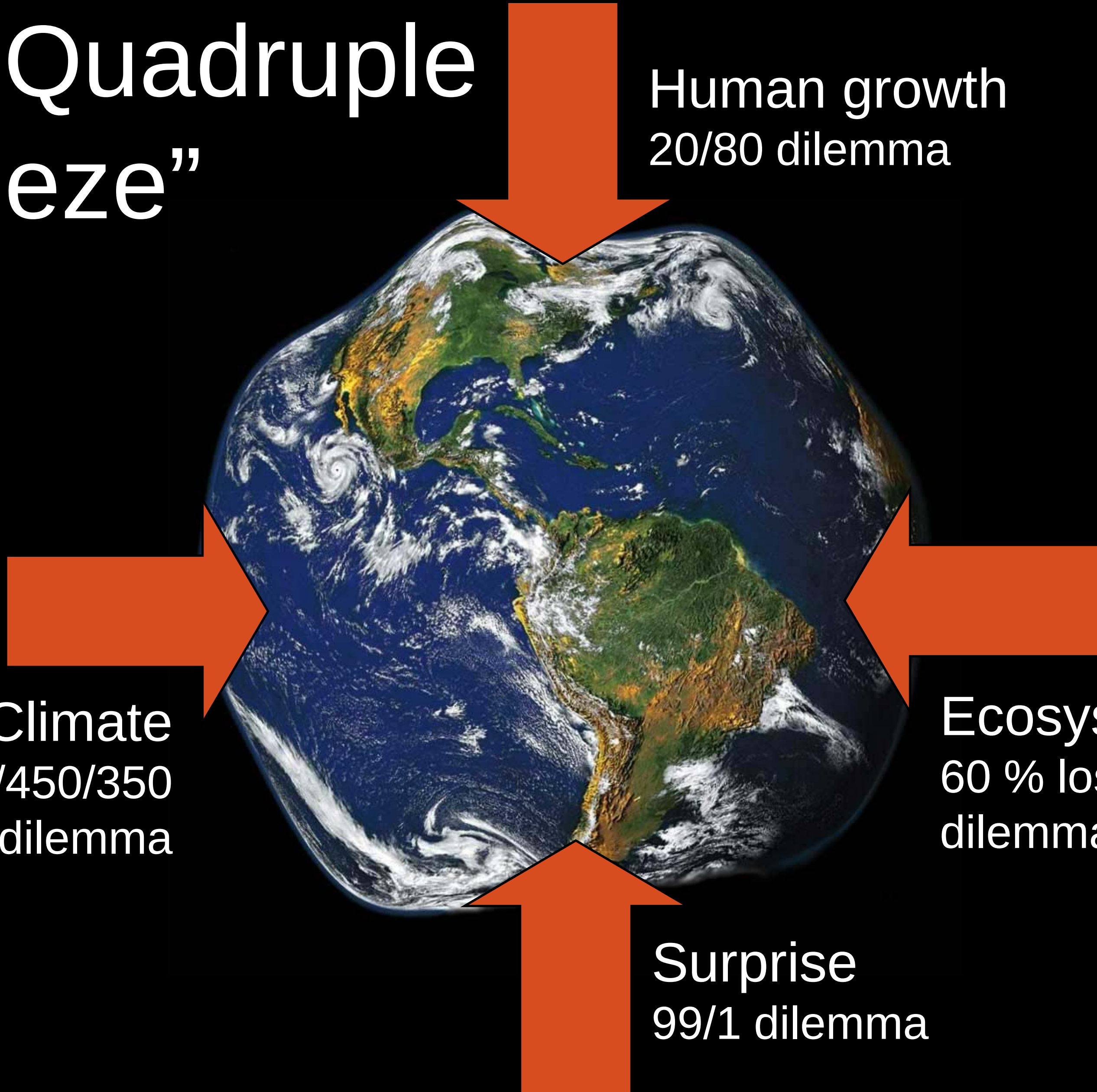
Human Development within the Safe Operating Space of the Planetary Boundaries

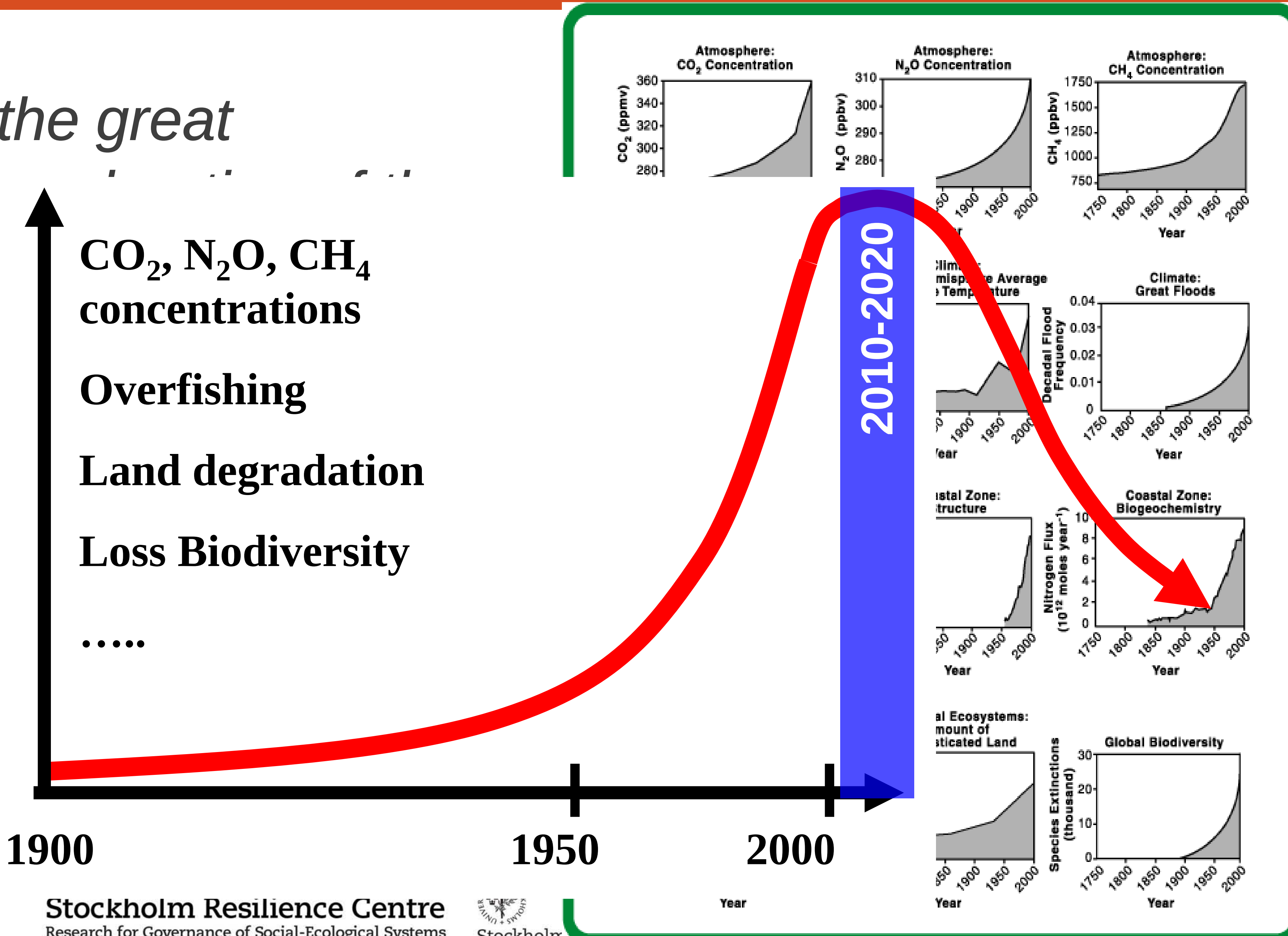
Världens Eko 14e
Sept 2010

Prof. Johan Rockström
Stockholm Resilience Centre
Stockholm Environment Institute

”The Quadruple Squeeze”



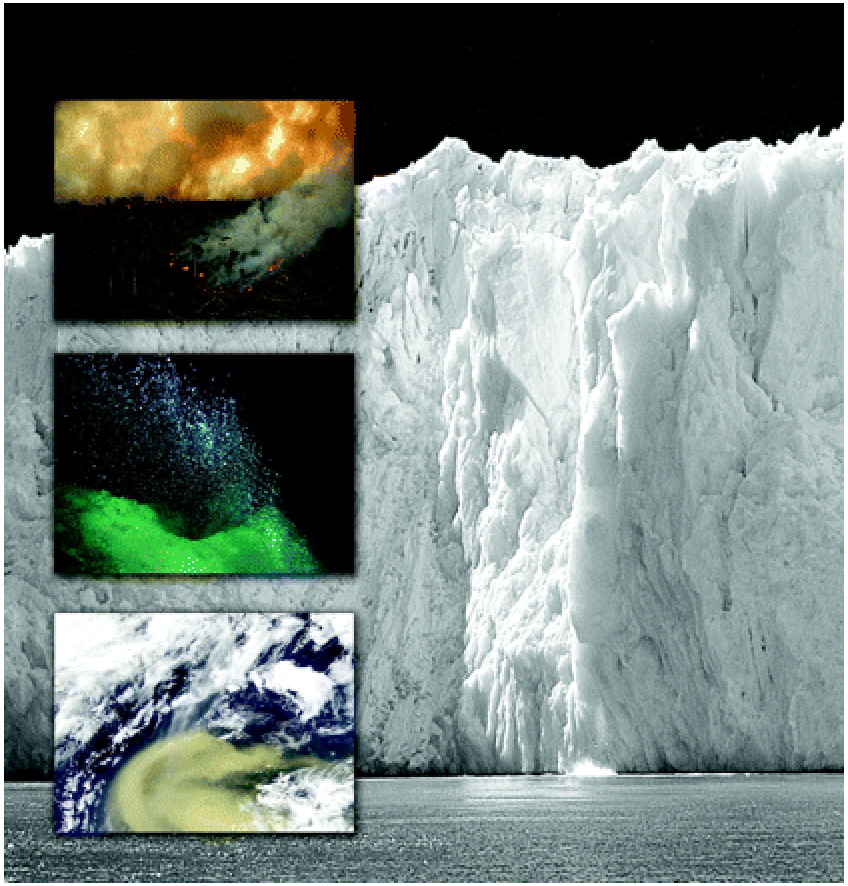
”the great



From: Steffen et al. 2004

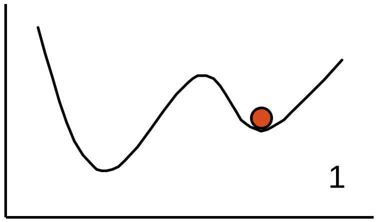
Tipping elements in the Earth system –

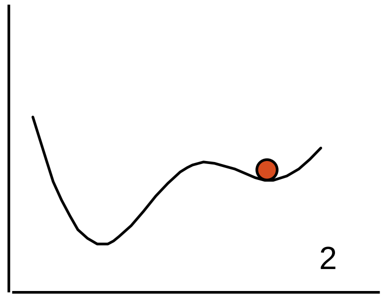
PNAS Special Feature released December 2009

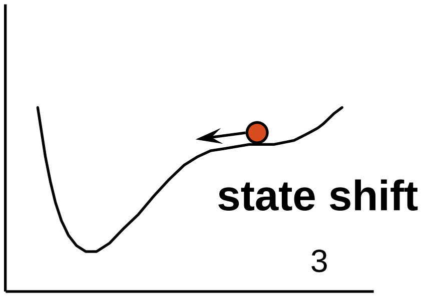


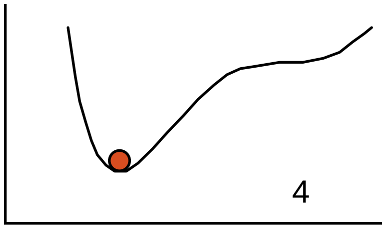
PNAS Special Feature:
Tipping elements in the Earth System, Jan 2010, vol 106 (49)

Valuable Ecosystem Services (Desirable) → **Loss of ecosystem services (Undesirable)**







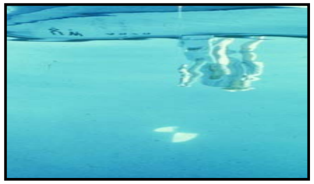


coral dominance

- overfishing, coastal eutrophication
- disease, hurricane

algal dominance

clear water



- phosphorous accumulation in soil and mud
- flooding, warming, overexploitation of predators

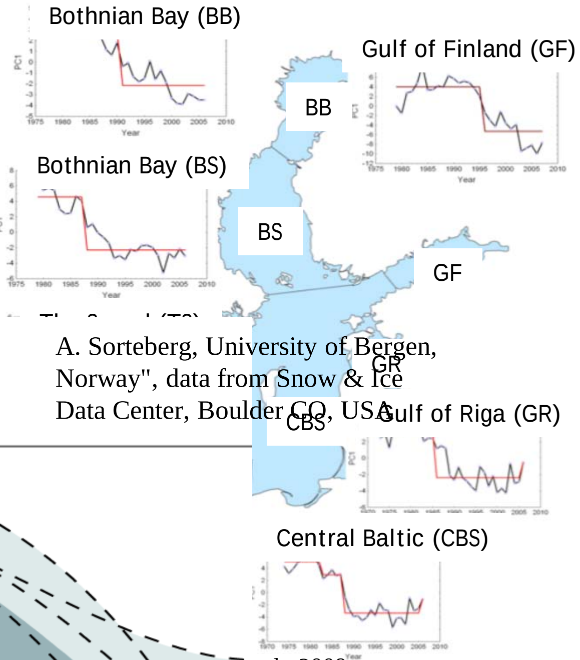
turbid water

grassland

- fire prevention
- good rains, continuous heavy grazing

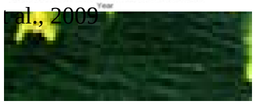
shrub-bushland

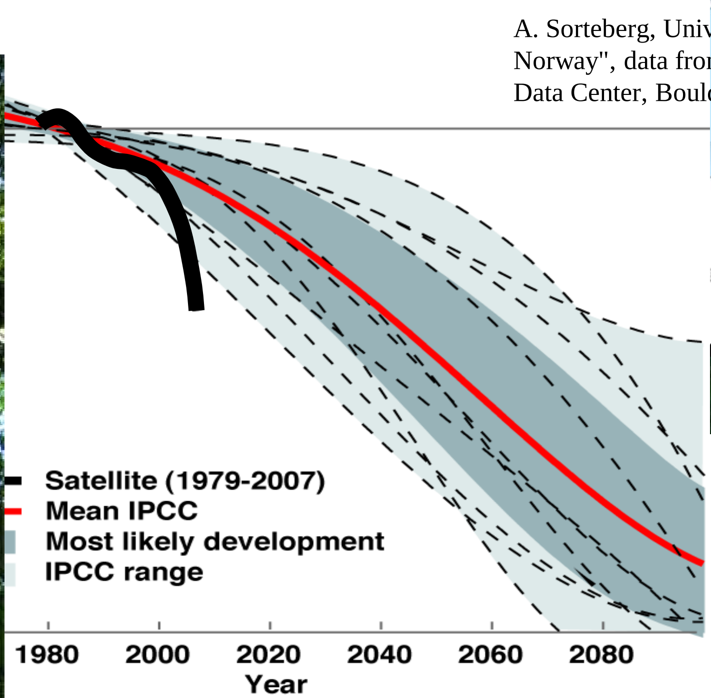
Regime shifts in all systems



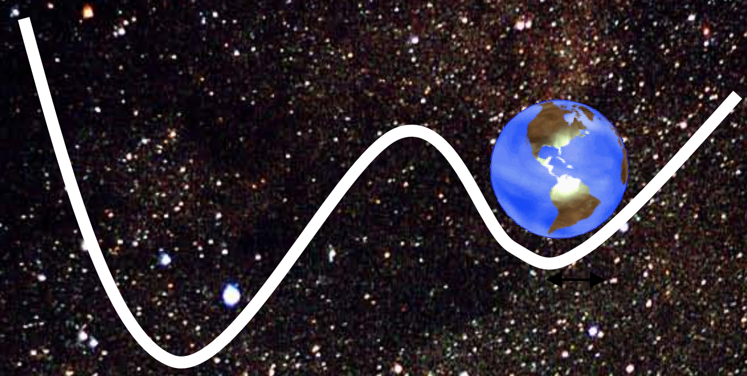
A. Sorteberg, University of Bergen, Norway", data from Snow & Ice Data Center, Boulder CO, USA

al., 2009

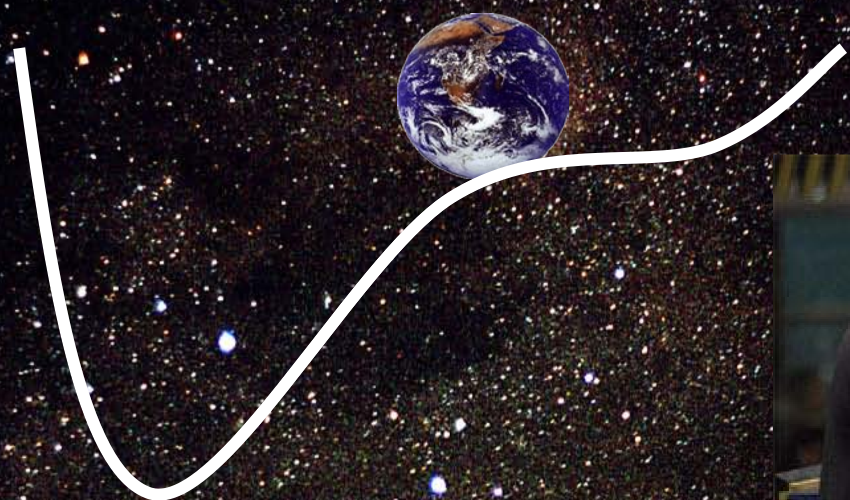




The Resilience of the Earth System

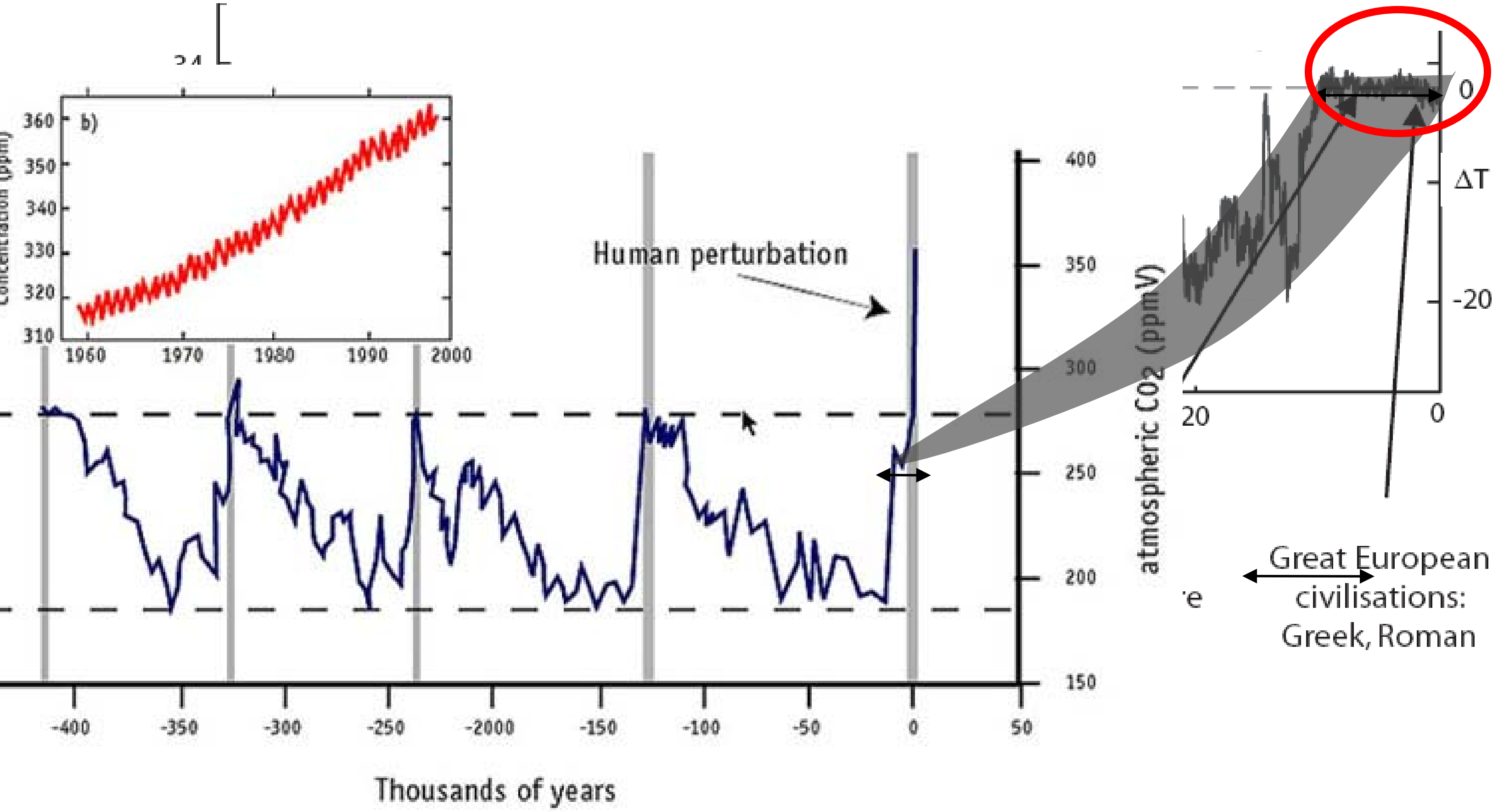


Our precarious predicament



”We have our foot on the accelerator
driving towards the Abyss...”
Ban Ki-moon Secretary General of the UN
Sept 2009

Humanity's period of grace – the last 10000 years



Planetary Boundaries:

Exploring the safe operating space for humanity in the Anthropocene

(*Nature*, 461 : 472 – 475, Sept 24 - 2009)

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.

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1–3]. 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[4], in which human actions have become the main driver of global environmental change[5]. 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 change occurred naturally 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 forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state. The result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development[6]. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[7].

ROAD TO COPENHAGEN

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

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 react in a nonlinear, often abrupt, way, and are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans[8,9].

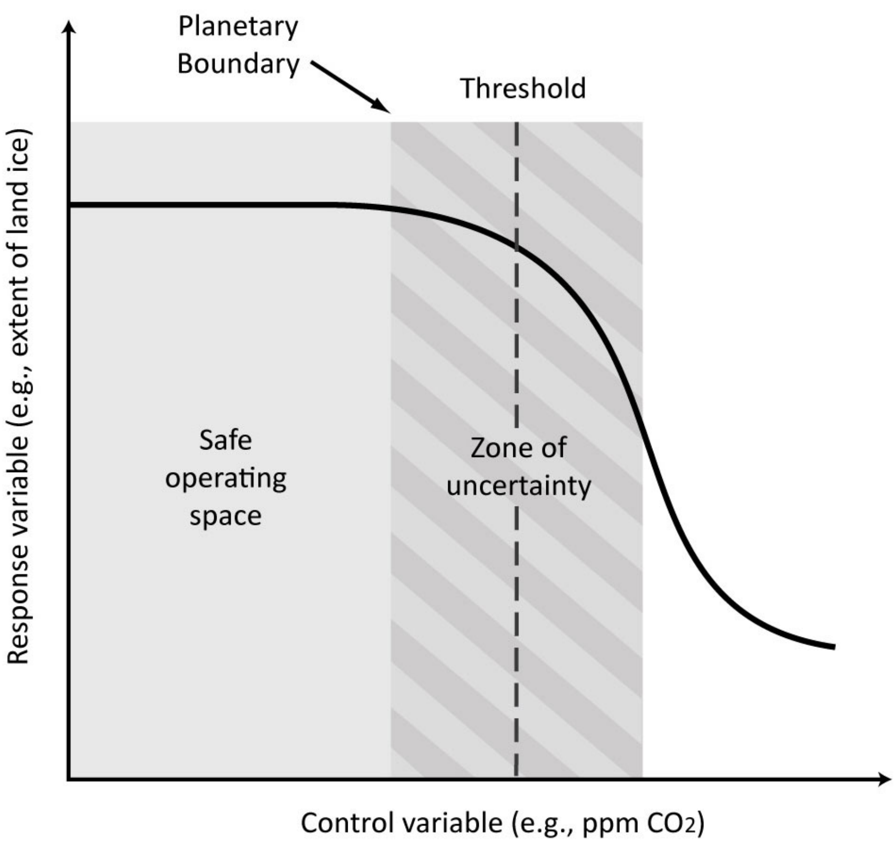
Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example,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

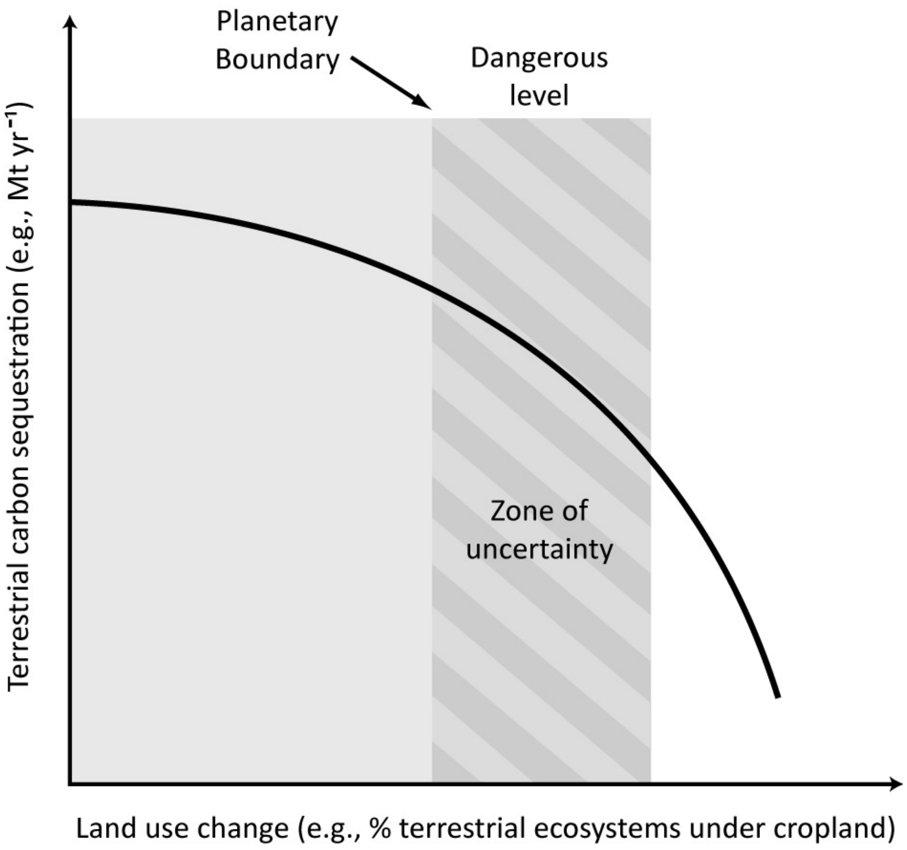
We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial 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

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

Two different types of planetary boundary processes





1. Critical continental to global threshold **2. No known global threshold effect**

Climate Change

< 350 ppm CO_2 < 1W m^2
(350 – 500 ppm CO_2 ; 1-1.5 W m^2)

Ozone depletion

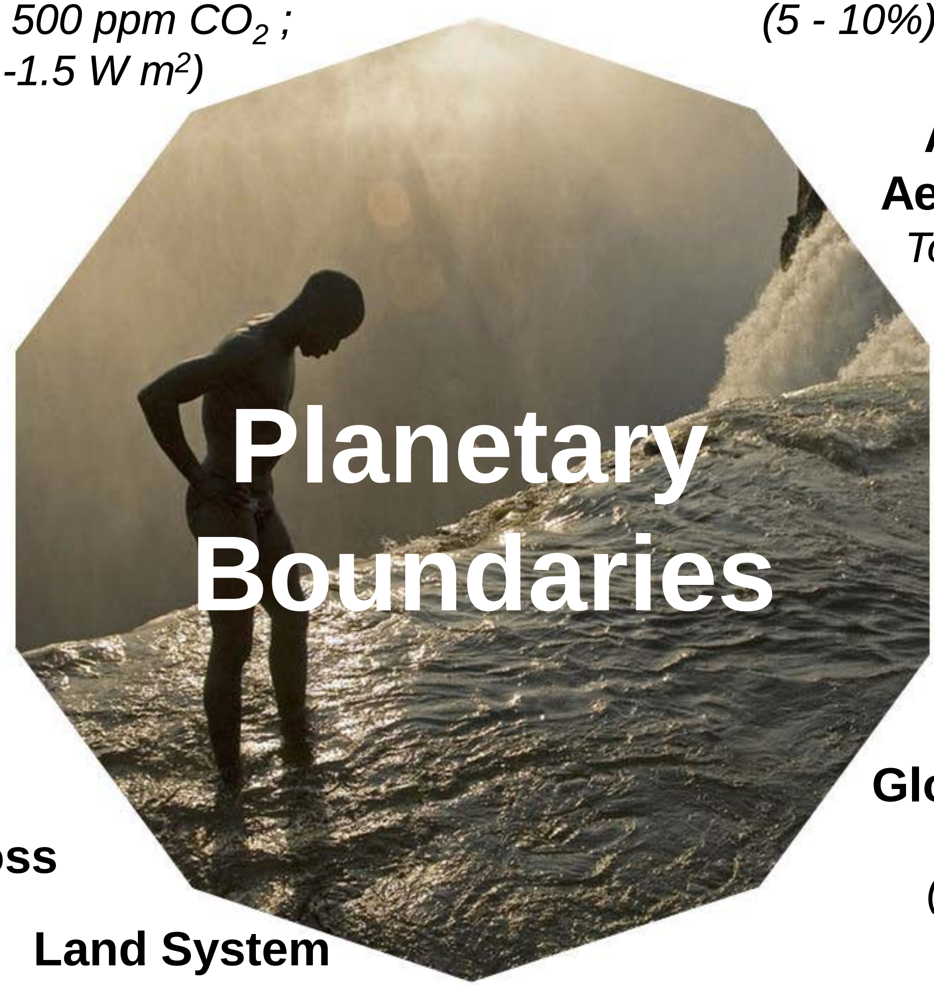
< 5 % of Pre-Industrial 290 DU
(5 - 10%)

Biogeochemical loading: Global N & P Cycles

Limit industrial fixation of N_2 to 35 Tg N yr^{-1}(25 % of natural fixation)
(25%-35%)
P < 10× natural weathering inflow to Oceans
(10× – 100×)

Atmospheric Aerosol Loading

To be determined



Ocean acidification

Aragonite saturation ratio > 80 % above pre-industrial levels
(> 80% - > 70 %)

Global Freshwater Use

<4000 km^3/yr
(4000 – 6000 km^3/yr)

Rate of Biodiversity Loss

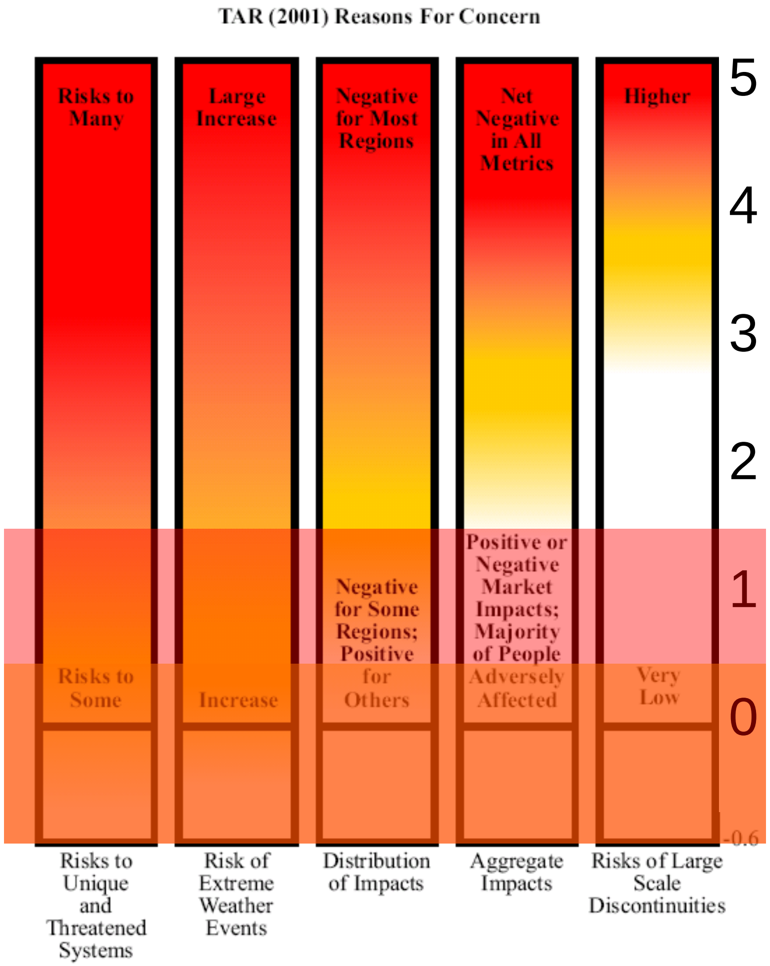
< 10 E/MSY
(< 10 - < 1000 E/MSY)

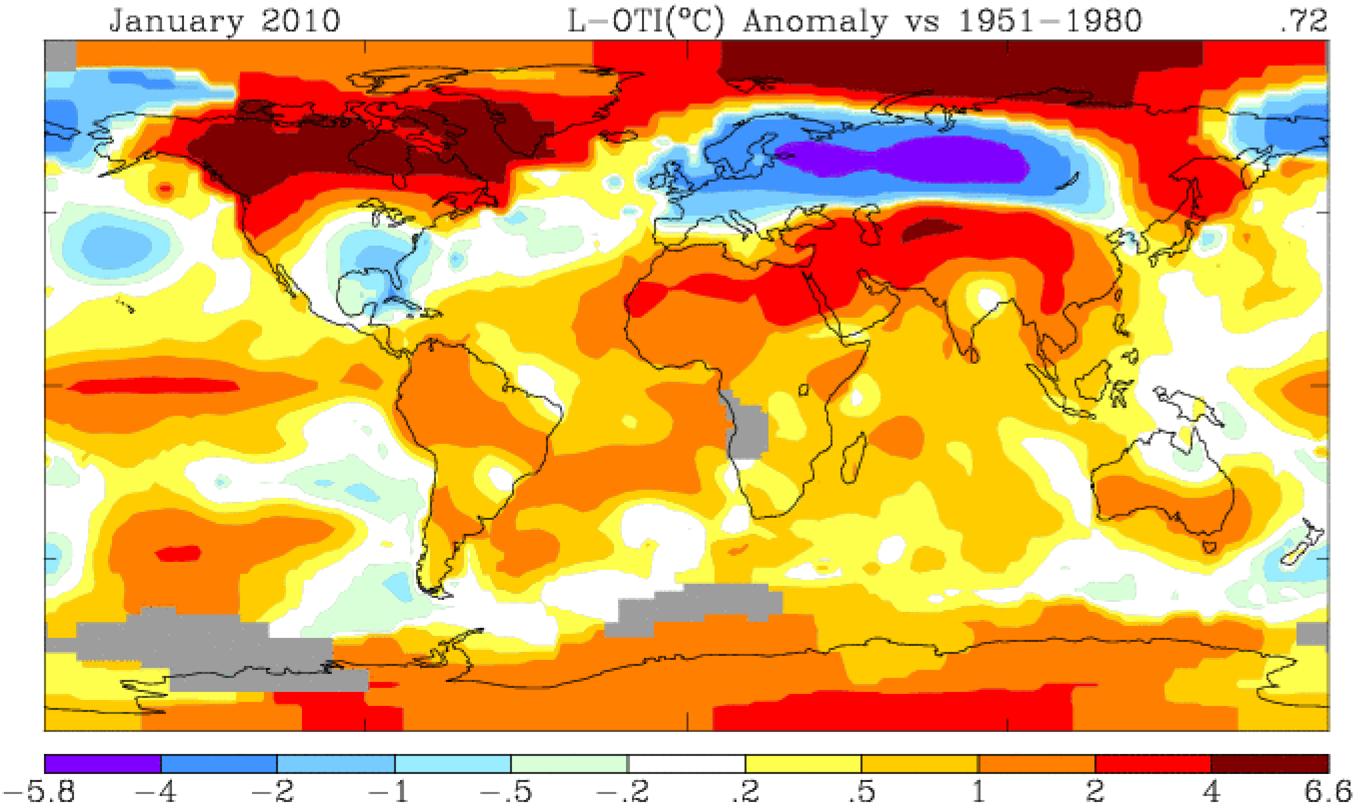
Land System Change

≤15 % of land under crops
(15-20%)

Chemical Pollution

Plastics, Endocrine Desruptors, Nuclear Waste Emitted globally
To be determined


TAR (2001) Reasons For Concern
5
4
3
2
1
0
-0.6
Risks to Many
Large Increase
Negative for Most Regions
Net Negative in All Metrics
Higher
Negative for Some Regions; Positive for Others
Positive or Negative Market Impacts; Majority of People Adversely Affected
Risks to Some
Increase
Very Low
Risks to Unique and Threatened Systems
Risk of Extreme Weather Events
Distribution of Impacts
Aggregate Impacts
Risks of Large Scale Discontinuities


January 2010
L-OTI(°C) Anomaly vs 1951-1980
.72
-5.8 -4 -2 -1 -.5 -.2 .2 .5 1 2 4 6.6

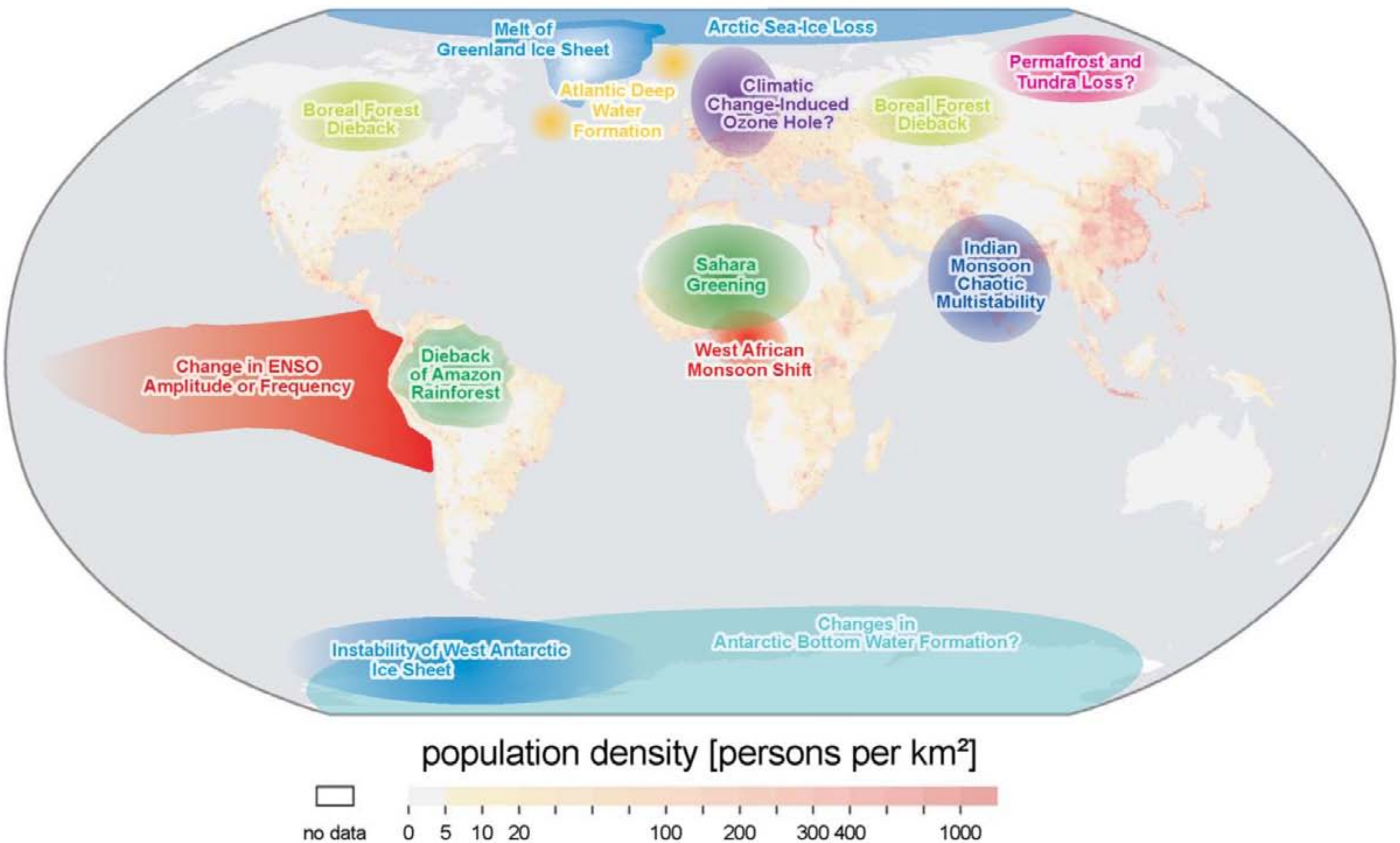
Tipping elements in the Earth's climate system

Timothy M. Lenton*†, Hermann Held‡, Elmar Kriegler‡§, Jim W. Hall¶, Wolfgang Lucht‡, Stefan Rahmstorf‡, and Hans Joachim Schellnhuber†‡‖**

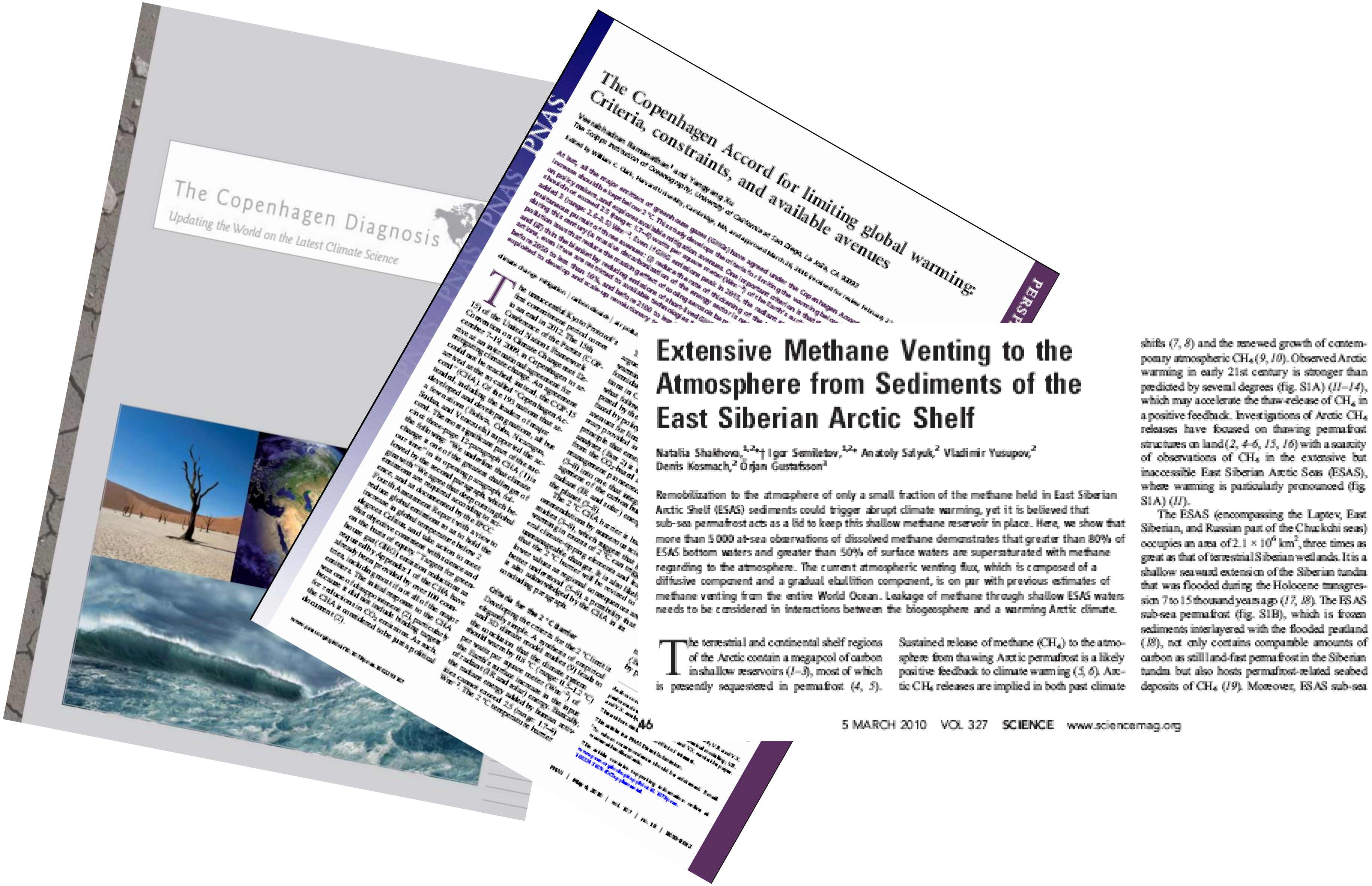
**School of Environmental Sciences, University of East Anglia, and Tyndall Centre for Climate Change Research, Norwich NR4 7TJ, United Kingdom; ‡Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany; §Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213-3890; ¶School of Civil Engineering and Geosciences, Newcastle University, and Tyndall Centre for Climate Change Research, Newcastle NE1 7RU, United Kingdom; and ‖Environmental Change Institute, Oxford University, and Tyndall Centre for Climate Change Research, Oxford OX1 3QY, United Kingdom*

**This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected on May 3, 2005.

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved November 21, 2007 (received for review June 8, 2007)



1786–1793 | PNAS | **February 12, 2008** | vol. 105 | no. 6



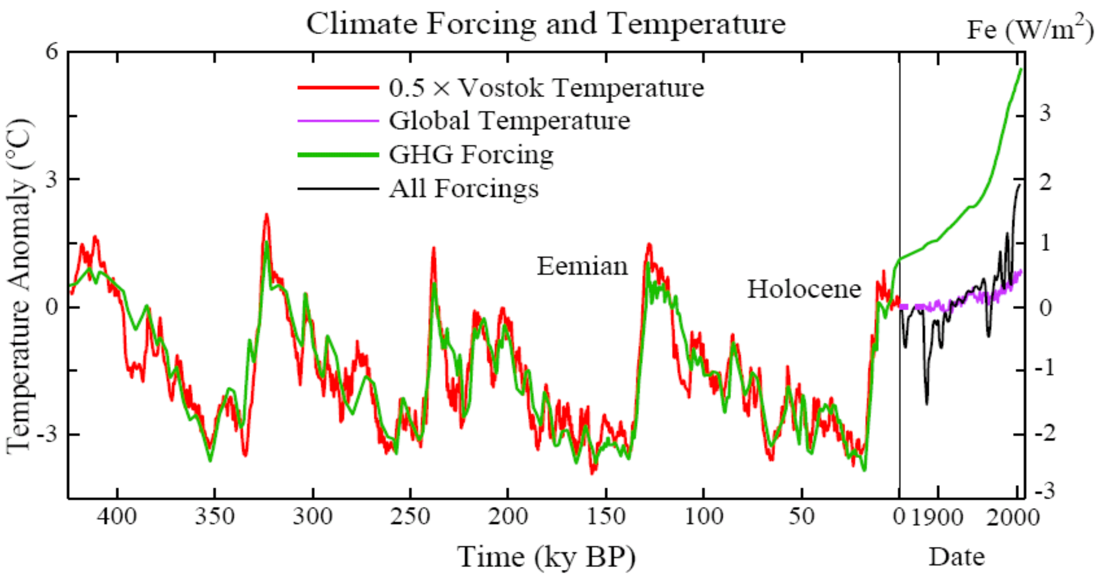
Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems

Stockholm University

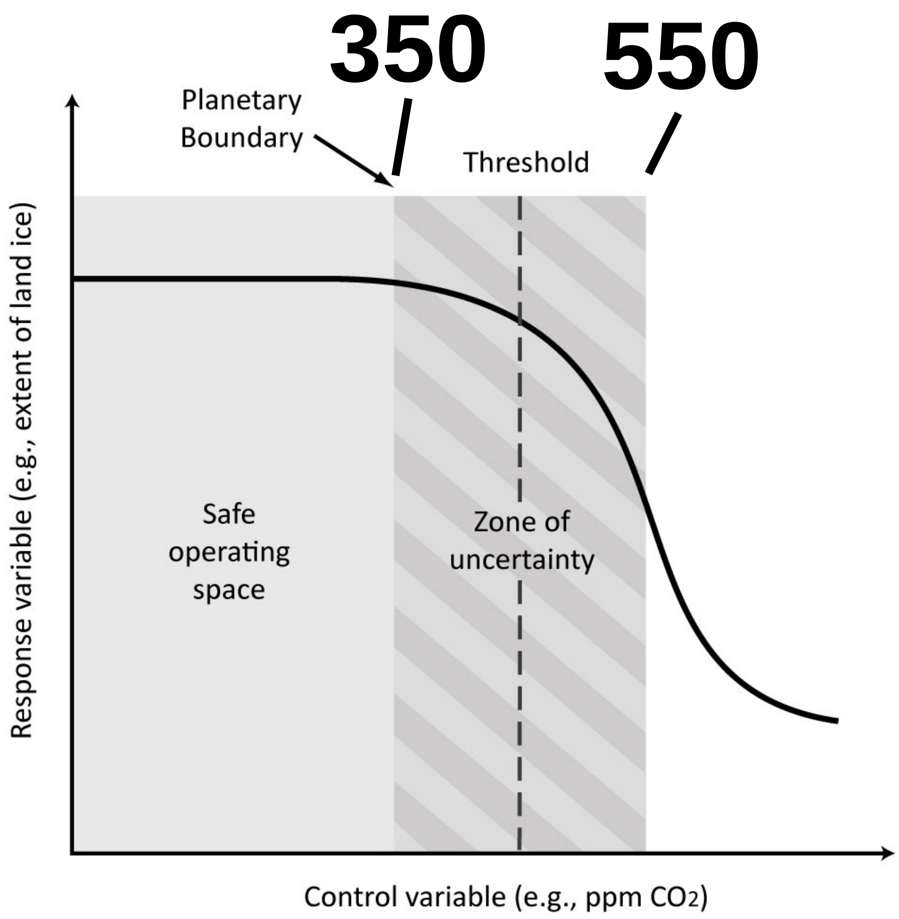
A centre with: SEI Stockholm Environment Institute · The Beijer Institute of Ecological Economics

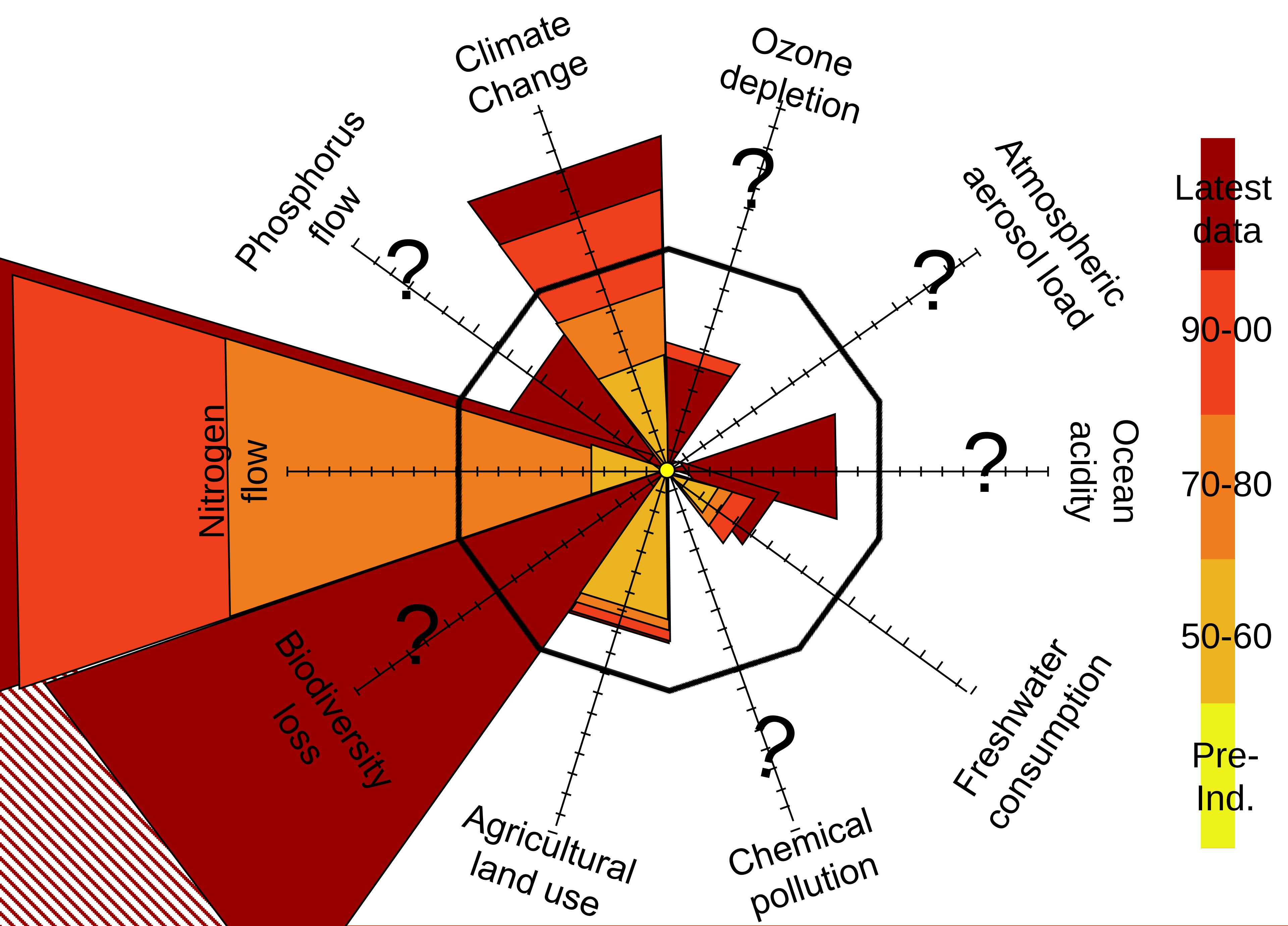
Climate Change

what is required to avoid the crossing of critical thresholds that separate qualitatively different climate system states

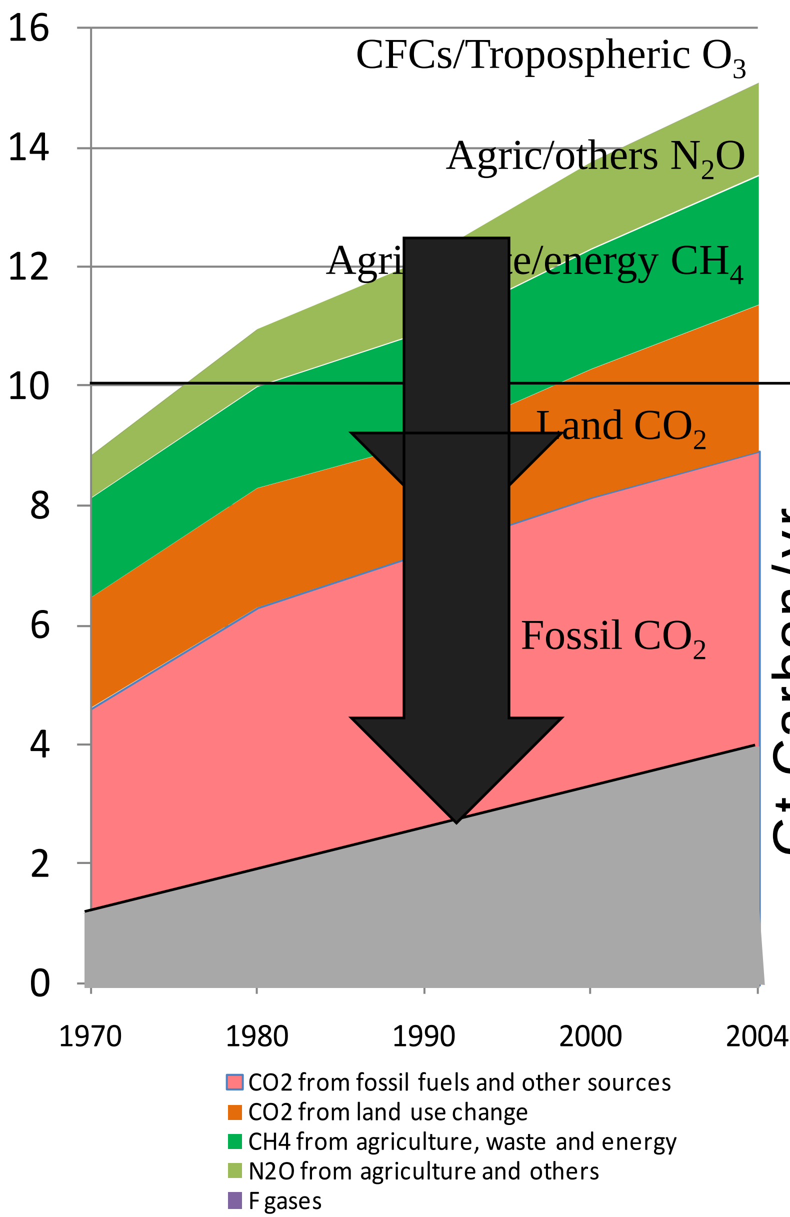


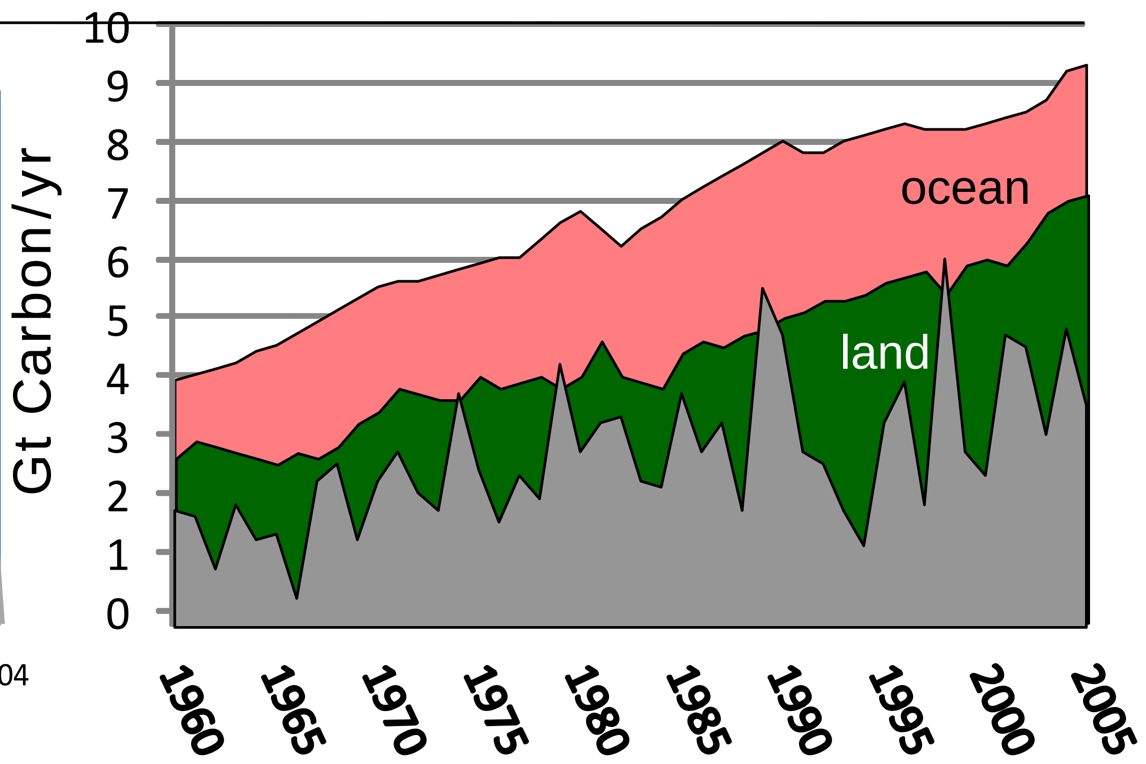
- We suggest boundary values of 350 ppm CO_2 and 1 W m^{-2} above pre-industrial level


350
550
Planetary
Boundary
Threshold
Response variable (e.g., extent of land ice)
Safe
operating
space
Zone of
uncertainty
Control variable (e.g., ppm CO2)


Climate Change
Ozone depletion
Atmospheric aerosol load
Ocean acidity
Freshwater consumption
Chemical pollution
Agricultural land use
Biodiversity loss
Nitrogen flow
Phosphorus flow
?
?
?
?
?
?
Latest data
90-00
70-80
50-60
Pre-Ind.

Terrestrial and Marine Carbon sinks

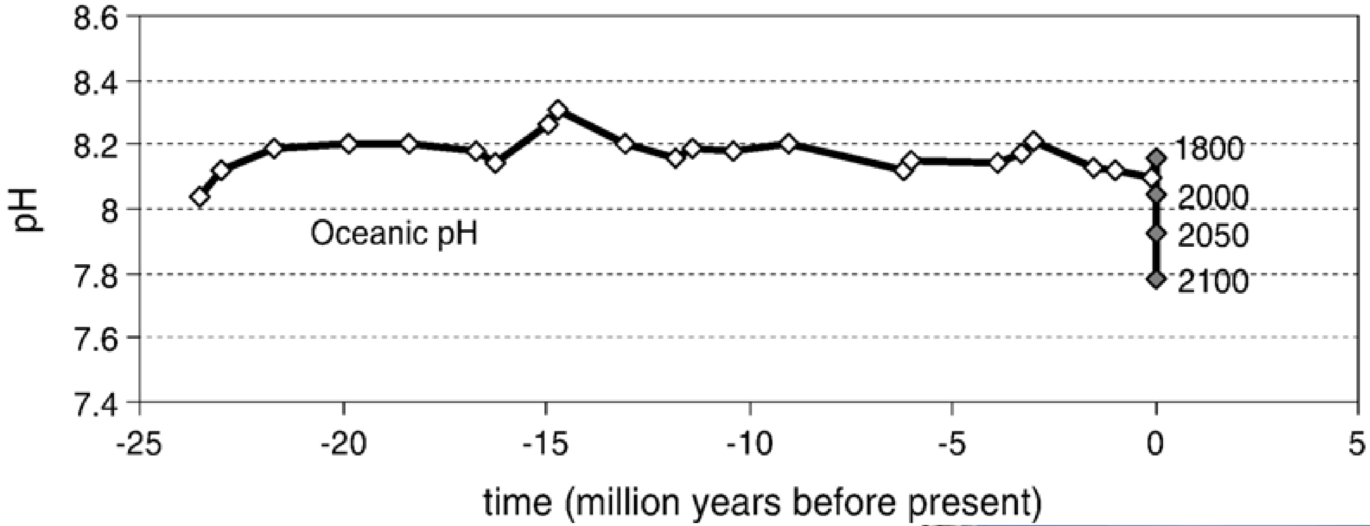




Adapted from Canadell et al., 2007

Ocean acidification

Challenge to marine biodiversity and ability of oceans to function as sink of CO_2



Turley et al 2006

- Southern Ocean and Arctic ocean projected to become corrosive to aragonite by 2030-2060

Predicted Future (~2065) Surface Ocean Aragonite Saturation State

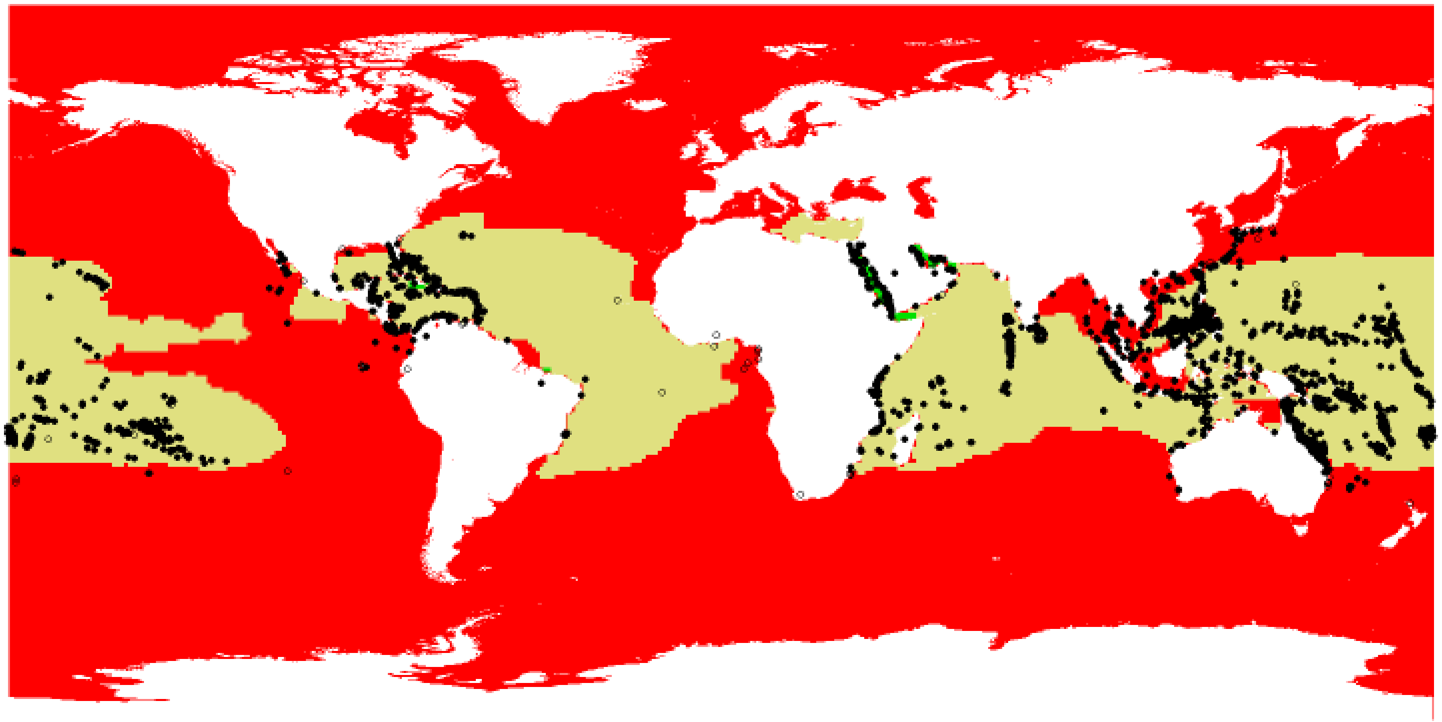
References: 5, 7

ReefBbase.shp
- Coral Reef
- Reef Community

Country.shp

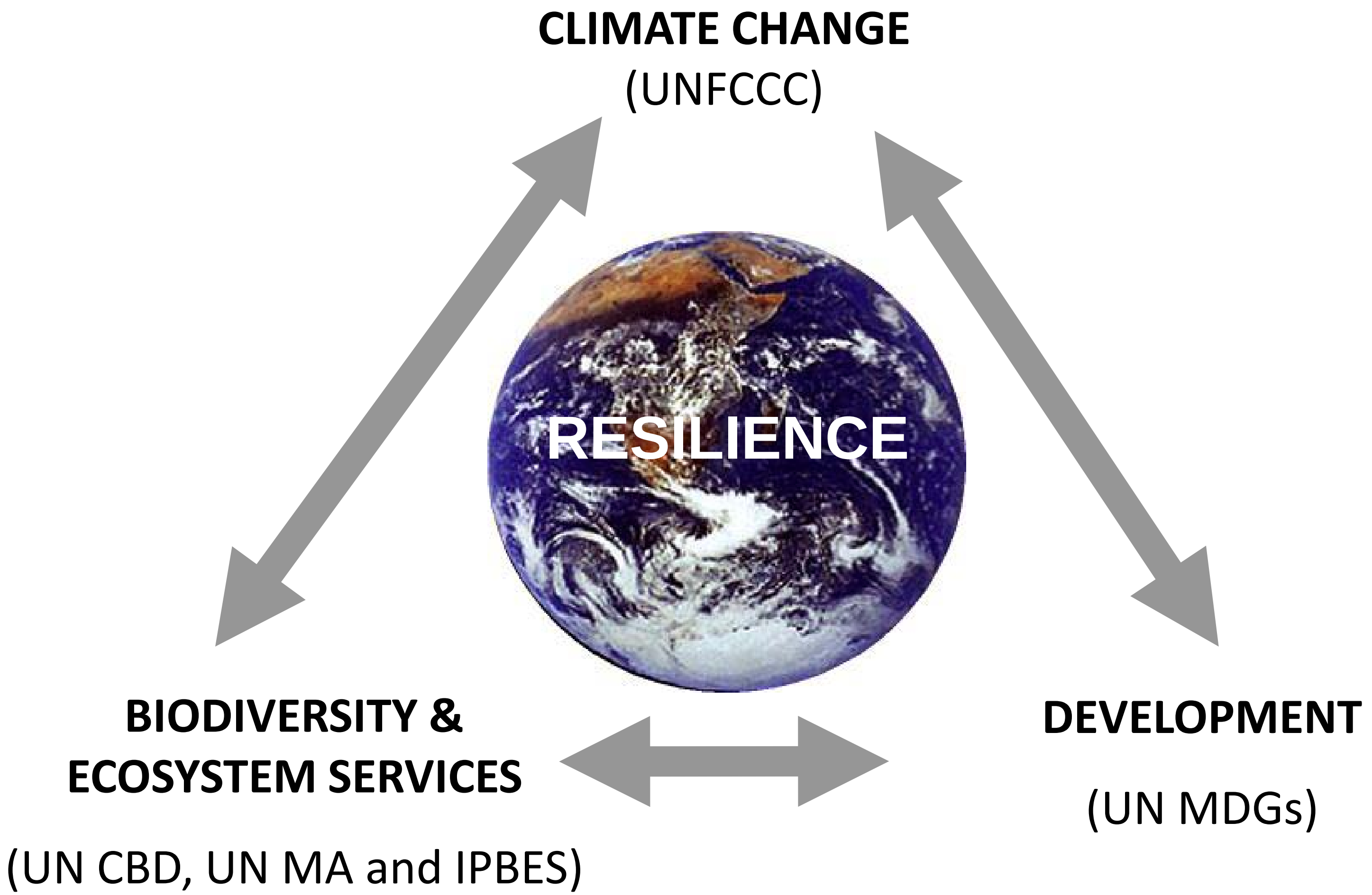
Saturation State Future

> 4.0	Optimal
3.5 - 4	Adequate
3 - 3.5	Marginal
< 3.0	Extremely Low
No Data	



A new "global spec" for world food production

1. Stay within 350 ppm, an agricultural system that goes from being a source to a global sink
2. Essentially a green revolution on current cropland (expansion from 12 % to 15 %)
3. Keep global consumptive use of blue water < 4000 km^3/yr, we are at 2,600 km^3/yr today and rushing fast towards 4000 km^3/yr
4. Reduce to 25 % of current N extraction from atmosphere
5. Not increase P inflow to oceans
6. Reduce loss of biodiversity to < 10 E/MSY from current 100-1000 E/MSY


CLIMATE CHANGE
(UNFCCC)
RESILIENCE
BIODIVERSITY &
ECOSYSTEM SERVICES
(UN CBD, UN MA and IPBES)
DEVELOPMENT
(UN MDGs)

Rate of Biodiversity Loss

Avoid large scale irreversible loss of functional diversity and ecological resilience

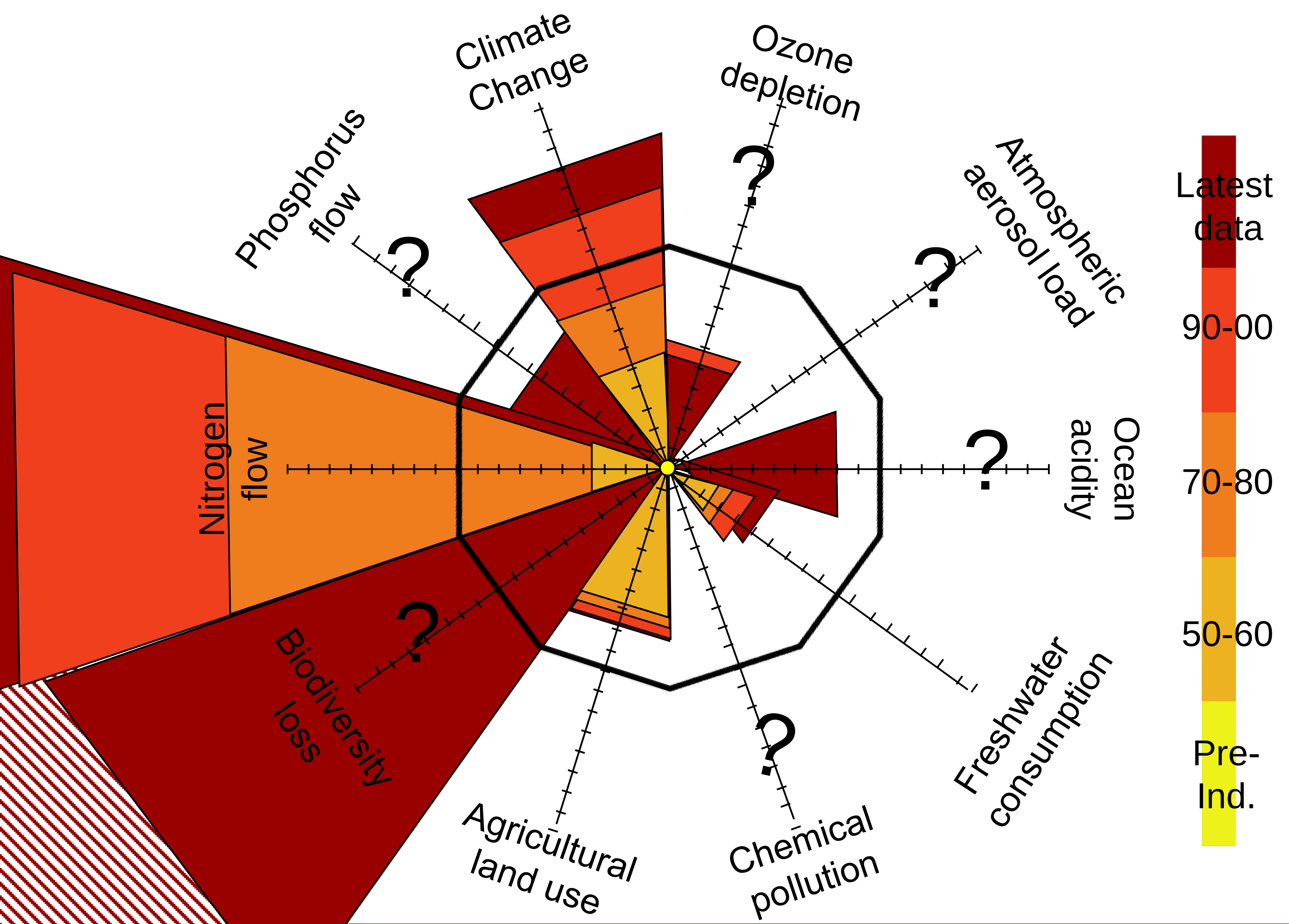
- The current and projected rate of biodiversity loss constitutes the sixth major extinction event in the history of life on Earth – the first to be driven by human activities on the planet
- Biodiversity plays a key role for functional diversity and thereby ecosystem resilience
- Humans have increased the rate of species extinction by 100-1,000 times the background rates that were typical over Earth's history
- Average global extinction rate projected to increase another 10-fold, to 1,000-10,000 E/MSY during the current century

Biodiversity Loss

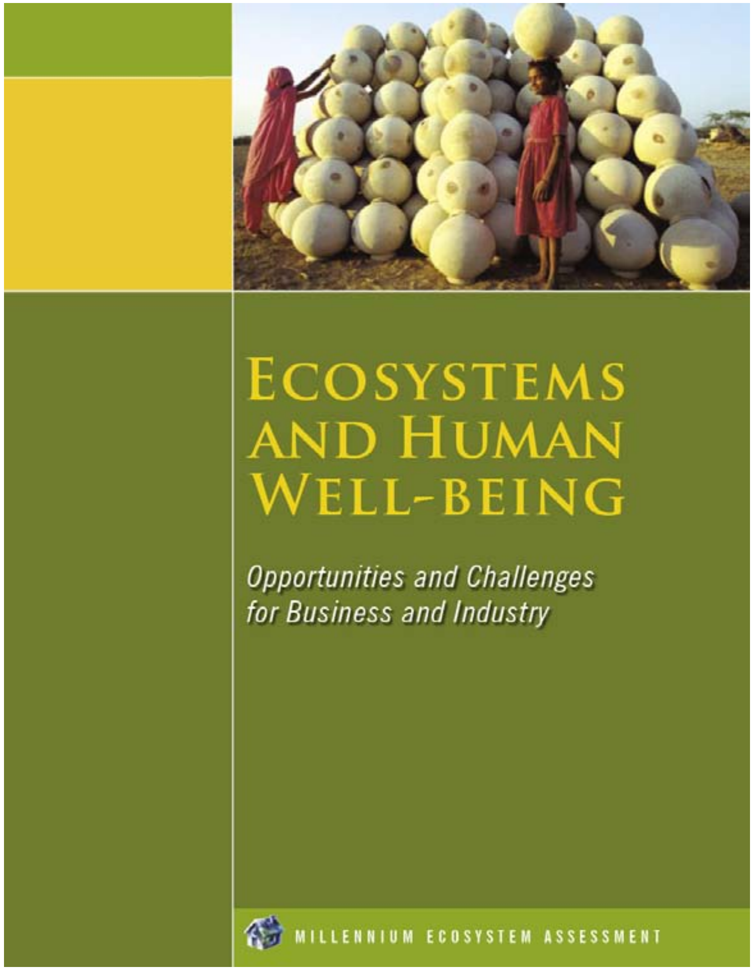
Setting the boundary:

- Suggesting a safe planetary boundary (here placed at 10 E/MSY)
- within an order of magnitude of the natural background rate

Biodiversity provides resilience for humanity in an era of rapid global change


Climate Change
Ozone depletion
Atmospheric aerosol load
Ocean acidity
Freshwater consumption
Chemical pollution
Agricultural land use
Biodiversity loss
Nitrogen flow
Phosphorus flow
?
?
?
?
?
?
Latest data
90-00
70-80
50-60
Pre-Ind.

The institutional capacities to manage the earth's ecosystems are evolving more slowly than man's overuse of the same systems.



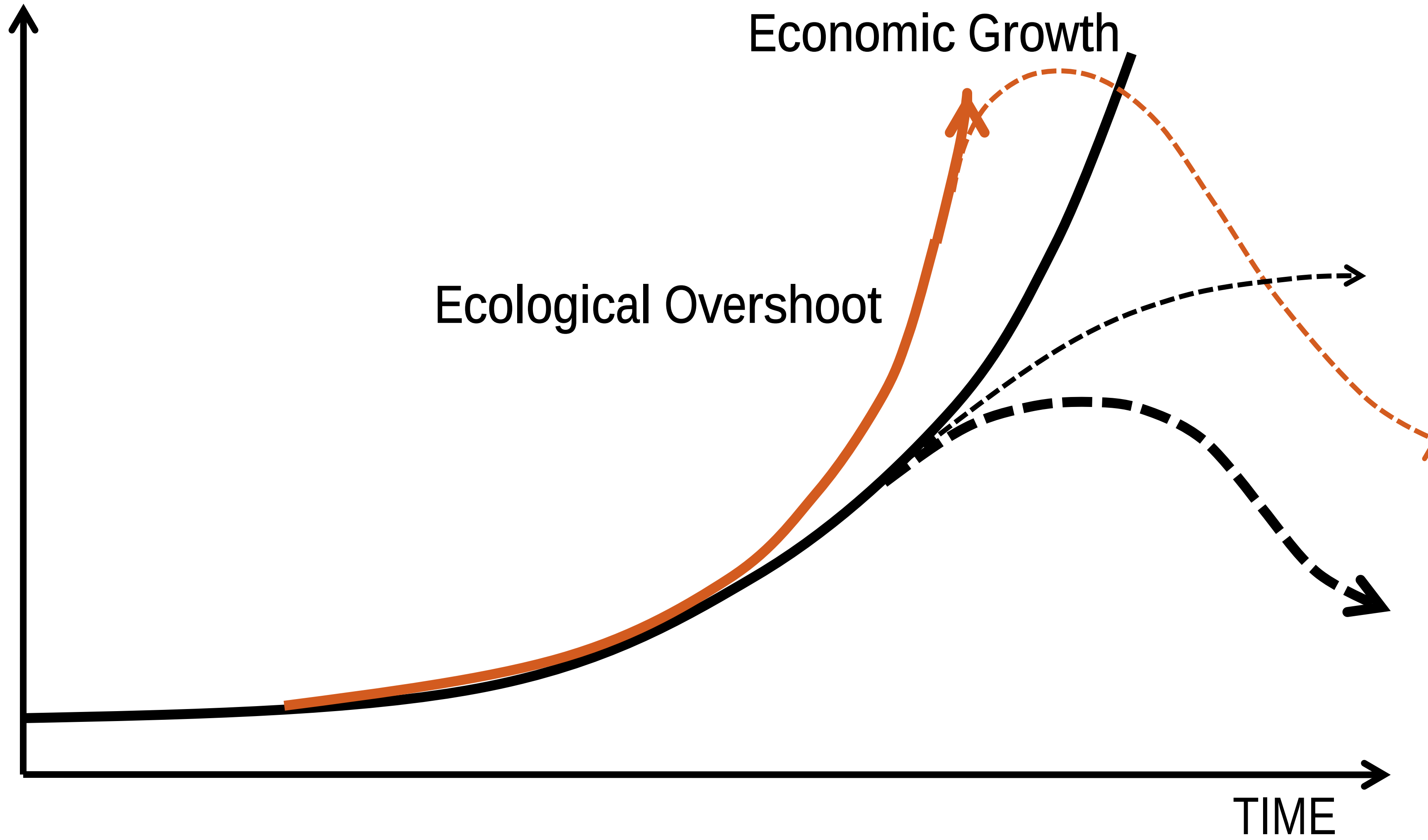
Accelerated biodiversity loss during the Anthropocene

– The 6th Major extinction event in the History of Planet Earth

THE GLOBAL DRAMA OF BIODIVERSITY LOSS

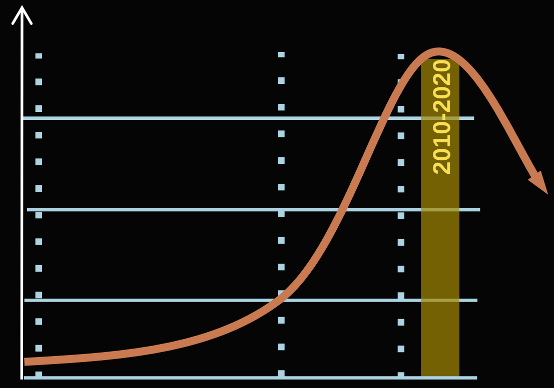
Growing evidence of importance of biodiversity

- to sustaining ecosystem functioning and services
- to prevent ecosystems from tipping into undesired states
- to prevent other Earth system processes from flipping



Economic Growth
Ecological Overshoot
TIME

A shift in mindset: Sustainable development in the Anthropocene is not Utopia!



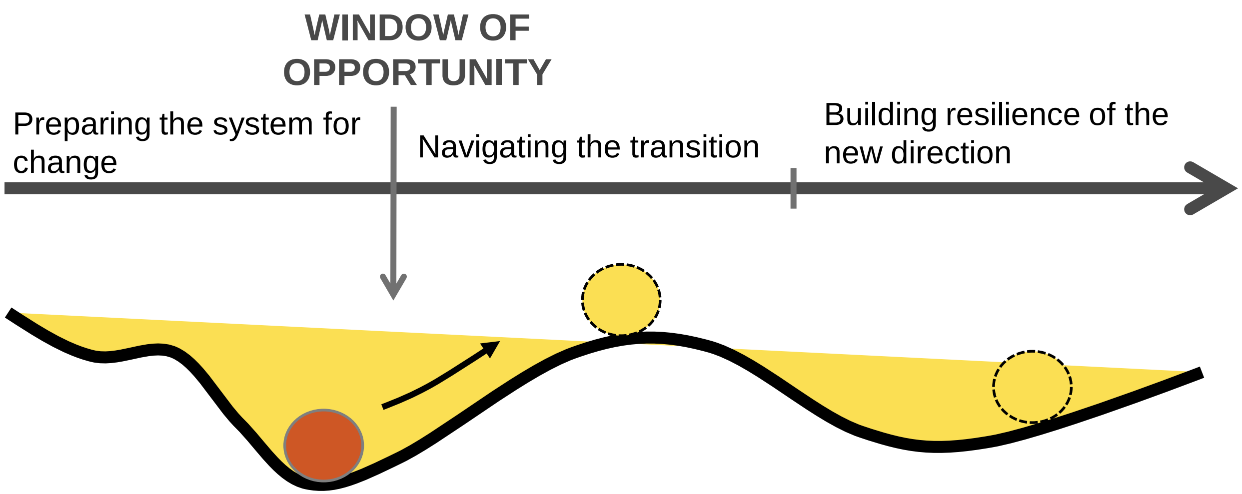
Persistence

Transformability

Adaptability

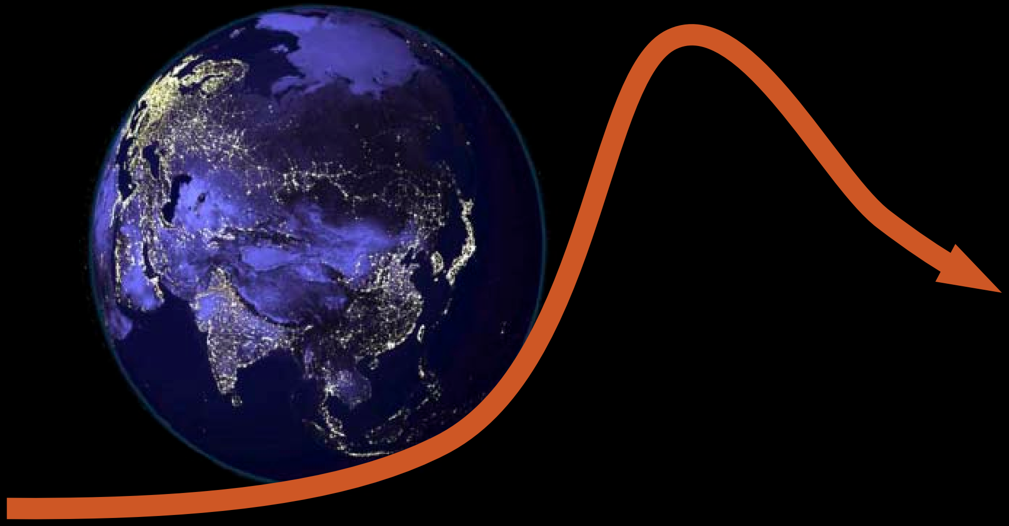
Turning crisis into opportunity

A shift in mindset for transformation



R
D
E
T
D
ELINOR OSTROM
2009 Nobel Laureate
in Economic Sciences
FEED-IN TARIFFS
Accelerating the Deployment
of Renewable Energy
MIGUEL MENDONÇA
WORLD FUTURE COUNCIL

The largest and fastest transformation in the history of Humanity



For a more prosperous future within the safe operating space of the Planetary Boundaries

1. Recognise the fundamental role of biological diversity for ecosystem functions, services and resilience
2. Urgent need to establish an IPBES with close links to the IPCC and UNFCCC process
3. Internalise the Biodiversity agenda with the MDG agenda – ecosystem management for poverty alleviation
4. Investments in biological diversity and ecosystem management for climate adaptation and mitigation
5. Time is running out. To stay within the Planetary Boundaries for human development the irriversible mass extinction of our biological life support base must come to an end

Conclusions

- In the Anthropocene Humanity is, for the first time, influencing hard-wired processes at the Earth System scale
- We define the **Holocene as the desired stable state** providing necessary environmental pre-conditions for human development
- **We need a new approach to global sustainability and development that builds on conceptual and knowledge advancements such as the ”limits to growth” work, tipping elements, guardrails, carrying capacities.** Scientific insights from research on resilience and complex systems, and Earth System Science, on the risks of human induced tipping points in a multitude of Earth system processes and sub-systems
- We propose that a **Planetary Boundary framework** may provide one step towards this necessary redefinition

- The Planetary Boundaries analysis presented in Nature is **a "proof-of-concept" analysis**, with many of the proposed boundaries being first best guesses. Many uncertainties remain, and will continue to remain.
- What we suggest is a **challenge to the Earth System Science community** to advance further research on Earth system interactions and non-linear dynamics
- **Large Knowledge gaps remain**
  - Understanding of threshold dynamics
  - Boundary interactions and feedbacks
  - Spatial variability and patchiness may require global and regional boundaries
  - Allowed overshoot time unclear

- No doubt, a Planetary Boundaries approach to sustainable development would have **profound implications for governance and policy across scales**. Large scientific challenges to address the human dimensions and governance implications of development within Planetary Boundaries

- Despite uncertainties on allowed overshoot before large discontinuities, we have **enough evidence to act now**. Time is running out on several of the Planetary Boundaries, and the momentum of driving forces tremendous. This is a first attempt to define the safe space for human development, which may prove critical in turbulent times ahead.

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Land System Change

Avoid unsustainable land system change predominantly from intensive agricultural use

- Threat to biodiversity and undermining of regulatory capacity of ecosystems

- Setting the boundary: No more than 15 % of the global ice-free land surface should be converted to cropland (12% today)

Global Freshwater Use

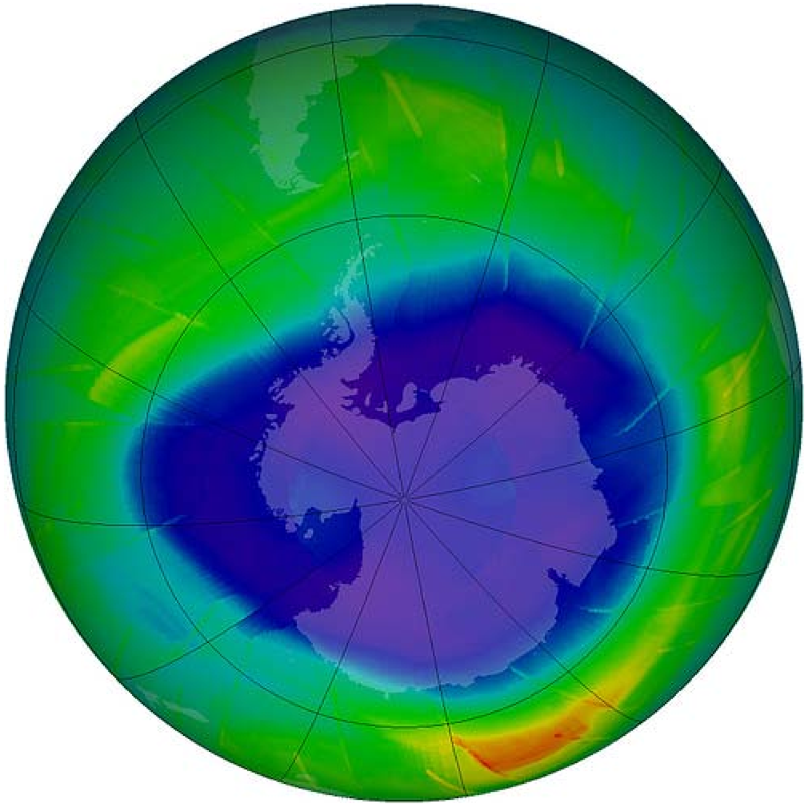
Avoid water induced environmental change at regional scale

- Humans now alter global runoff flows, through withdrawals of blue water, and changes in green water flows, affecting water partitioning and moisture feedback
- Physical water scarcity when withdrawals exceed 5000 – 6000 $km^3\ yr^{-1}$
- Final availability of runoff determined by consumptive use of green and blue water flows
- Consumptive use of blue water an aggregate control variable with boundary set at < 4000 $km^3\ yr^{-1}$

Ozone depletion

Avoiding the risk of large impacts for humans and ecosystem from thinning of extra-polar ozone layer

- Antarctic ozone depletion a classic example of an unexpected crossing of a threshold
- Our framing on extra-polar ozone layer depletion
- Identifying a threshold remains uncertain
- a less than 5% decrease in column ozone levels for any particular latitude

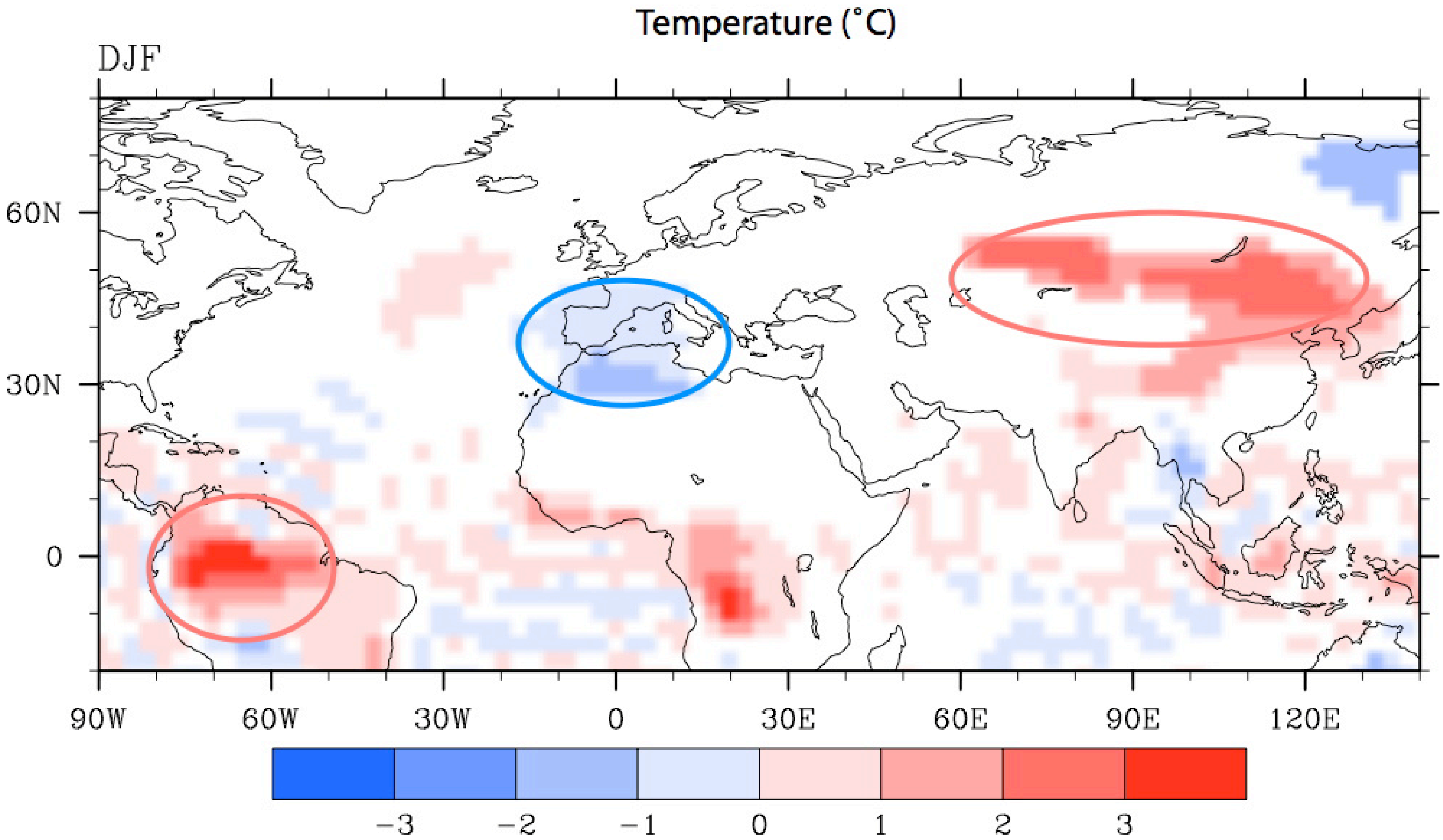


Chemical Pollution

Steer away from irreversible impacts on living organisms

- Global, ubiquitous impact on the physiological development and demography of humans and other organisms with ultimate impacts on ecosystem functioning and structure
- By acting as a slow variable that affects other planetary boundaries (e.g., rate of biodiversity loss)
- 2 complementary approaches: amounts of persistent pollutants with global distribution (e.g., mercury); Effects of chemical pollution on living organisms
- Difficult to find an appropriate aggregate control variable. Close interactions with Aerosol loading; may require sub-boundaries based on sub-impacts/categories of chemicals

Planetary Inter-connections



Peter Snyder et al. 2004

Atmospheric Aerosol Loading

Avoid major influence on climate system and human health at regional to global scales

- Human activities have doubled the global concentration of most aerosols since the pre-industrial era
- Influence on the Earth's radiative balance
- May have substantial implications on hydrological cycle and, e.g., Asian monsoon circulation
- Fine particle ($PM_{2.5}$) air pollution
- Processes and mechanisms behind these correlations remain to be fully explained