

# **Biogeochemical, Human and Ecosystem Interactions with Climate and the Complexity of the Earth System**



**Guy P. Brasseur, Carlos A. Nobre, Sybil Seitzinger, Owen Gaffney**

**International Geosphere-Biosphere Programme- IGBP**

# THE FIRST GRAND CHALLENGE: NUMERICAL WEATHER PREDICTION

- The deterministic laws of fluid mechanics should apply to the atmosphere: **weather can be predicted** (V. Bjerknes)
- The **first numerical attempt** was unsuccessful (Richardson)
- With the development of computers, the first **successful numerical weather predictions** are made (Charney and von Neumann, Smagorinsky)
- Weather predictions are greatly improved through the use of **satellite observations** and the development of **data assimilation** techniques.

Bjerknes



Richardson



Smagorinsky

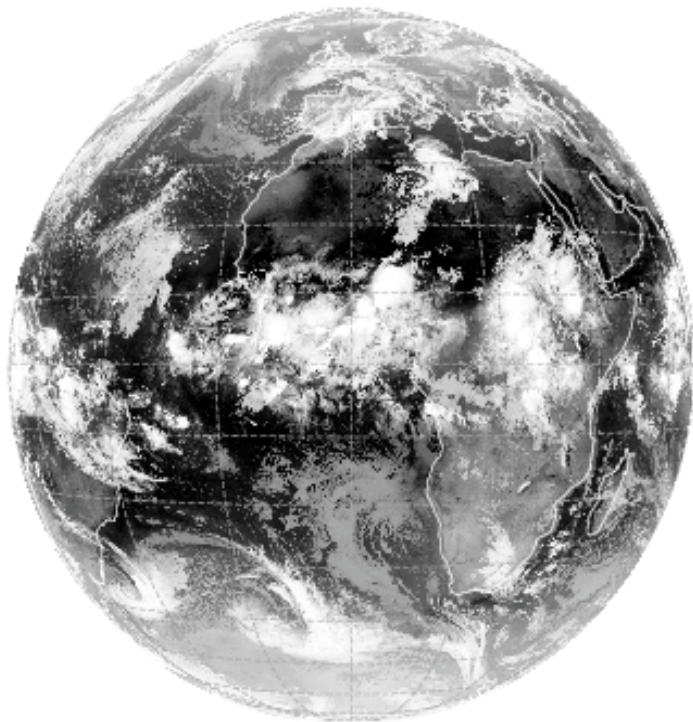


# **WEATHER PREDICTION COMPARED WITH SATELLITE OBSERVATIONS**

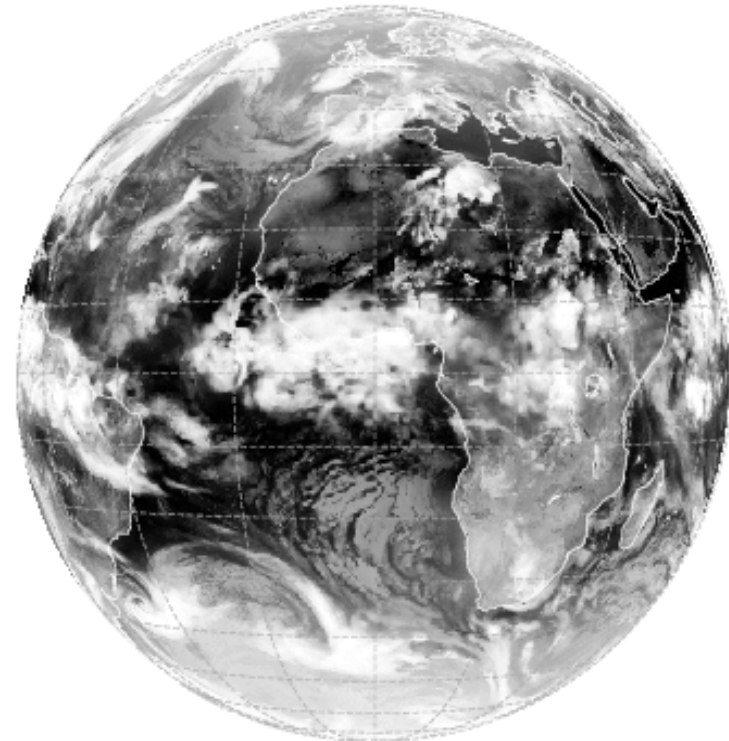
## **ECMWF PREDICTIONS AND METEOSAT OBSERVATIONS**

Meteosat 9 IR10.8 20080525 0 UTC

ECMWF Fc 20080525 00 UTC+0h:



**Meteosat**



**ECMWF**



Fourier

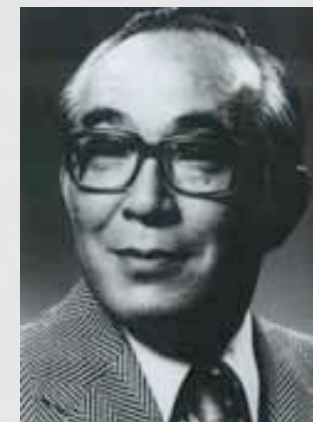
## THE SECOND GRAND CHALLENGE: PREDICTING CLIMATE CHANGE

- **Arrhenius** quantifies in 1896 the changes in surface temperature (approx. 5 C) to be expected from a doubling in CO<sub>2</sub>, based on the concept of "glass bowl" effect introduced in 1824 by Joseph **Fourier**.
- Norman **Phillips** develops the first global atmospheric GCM, and early climate models are being developed by many (Rossby, Manabe, Mintz and Arakawa, Washington, etc.)

Arrhenius



Manabe

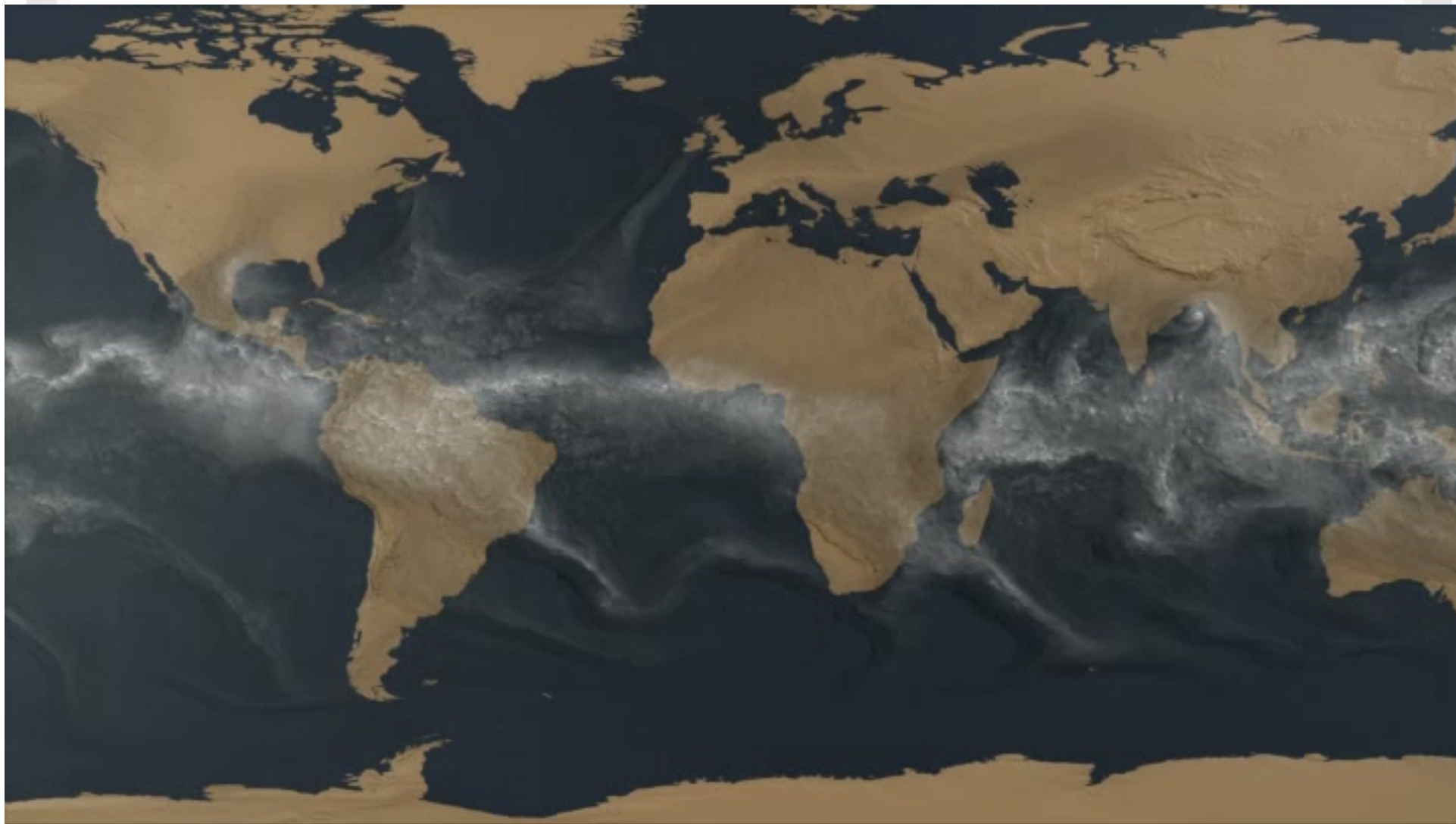


Arakawa



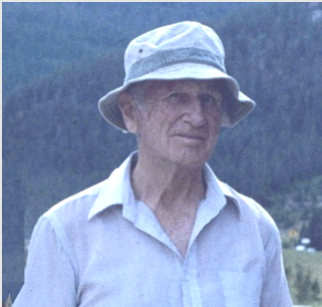
Washington

## GLOBAL WATER VAPOR (14 KM RESOLUTION)



HOMME Model. M.Taylor, Sandia

# THE THIRD GRAND CHALLENGE: UNDERSTANDING THE EARTH AS A COMPLEX NONLINEAR INTERACTIVE SYSTEM

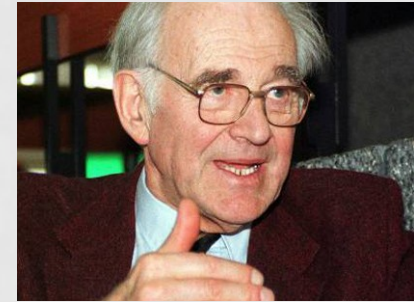


Ed Lorenz

- The Lorenz attractors: the story of predictability.
- The Vostock Ice core and glacial/interglacial transitions (Oeschger, Lorius)
- The Dansgaard/Oeschger cycles
- The CLAW hypothesis (R. Charlson, M. Andreae, et al.)
- The realization of the importance of the carbon cycle and the carbon/climate feedbacks (B. Bolin, R. Revelle)
- Gaia hypothesis (J. Lovelock)



Jim Lovelock



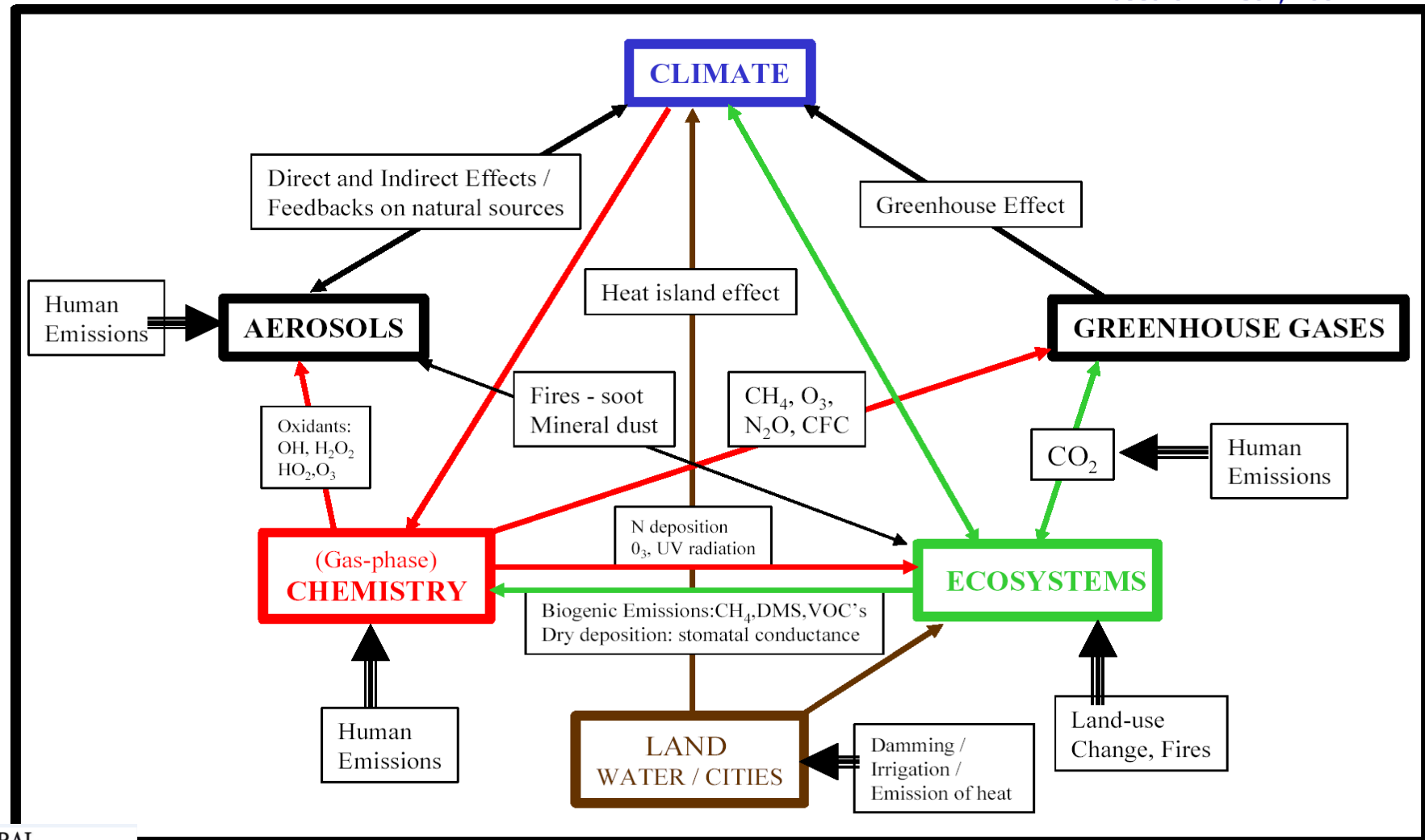
Bert Bolin

Roger. Revelle



# INTERACTIONS BETWEEN THE PHYSICAL CLIMATE, GREENHOUSE GASES, AEROSOLS, GAS-PHASE ATMOSPHERIC CHEMISTRY, ECOSYSTEM DYNAMICS, LAND USE, AND THE WATER SYSTEM

Based on P. Cox, 2004



# Planetary Questions for the Future Life: Prosperity and Sustainability

- Health
- Energy
- Food
- Water
- Population
- Urbanization
- Poverty
- Education
- Species extinction



“Our foot is stuck  
on the accelerator and  
we are heading towards  
an abyss.”

Ban Ki-Moo



# THE ANTHROPOCENE

naturenews

nature news home news archive specials opinion features news blog

NATURE, 2002  
 Geology of Mankind  
 IGBP Vice Chair,  
 Paul Crutzen,



GLOBAL  
**IGBP** International  
 Geosphere-Biosphere  
 Programme  
 CHANGE

Welcome to naturenews

**concepts**

## The Anthropocene

The Anthropocene could be said to have started in the late eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane.

### Geology of mankind

**Paul J. Crutzen**

For the past three centuries, the effects of humans on the global environment have escalated. Because of these anthropogenic emissions of carbon dioxide, global climate may depart significantly from natural behaviour for many millennia to come. It seems appropriate to assign the term Anthropocene to the present, in many ways human-dominated, geological epoch, supplementing the Holocene — the warm period of the past 10–12 millennia. The Anthropocene could be said to have started in the latter part of the eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane. This date also happens to coincide with James Watt's design of the steam engine.

Mankind's growing influence on the environment was recognized as long ago as 1873, when the Italian geologist Antonio Stoppani spoke about a 'new volcanic force' in power and universality may be compared to the greater forces of earth, referring to the 'anthropogenic era'. And in 1926, V. I. Vernadsky acknowledged the increasing impact of mankind: 'The direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings.' Teilhard de Chardin and Vernadsky used the term 'noosphere' — the 'world of thought' — to mark the growing role of human brain-power in shaping its own future and environment.

The rapid expansion of mankind in numbers and per capita exploitation of Earth's resources has continued apace. During the past three centuries, the human population has increased tenfold to more than 6 billion and is expected to reach 10 billion in this century. The methane-producing cattle population has risen to 1.4 billion. About 30–50% of the planet's land surface is exploited by humans. Tropical rainforests disappear at a fast pace, releasing carbon dioxide and strongly increasing species extinction. Dam building and river diversion have become commonplace. More than half of all accessible fresh water is used by mankind. Fisheries remove more than 25% of the primary production in upwelling oceanic regions and the twentieth century continental shelf. Oceanic emissions of 16-fold during the twentieth century, causing 160 million tonnes of sulphur dioxide emissions per year, more than twice the sum of its natural emissions. More nitrogen fertilizer is applied in all terrestrial ecosystems; nitric oxide production by the burning of fossil fuel and fossil-fuel burning and agriculture have caused substantial increases in the concentrations of 'greenhouse' gases — carbon dioxide by 20% and methane by more than 100% — reaching their highest levels over the past 400 millennia, with more to follow.

So far, these effects have largely been caused by only 25% of the world population. The consequences are, among others, acid precipitation, photochemical smog and climate warming. Hence, according to the latest estimates by the Intergovernmental Panel on Climate Change (IPCC), Earth will warm by 1.4–5.8 °C during this century.

Many toxic substances are released into the environment, even some that are not toxic at all but nevertheless have severely damaging effects, for example the chlorofluorocarbons that caused the Antarctic 'ozone hole' (and which are now regulated). Things could have become much worse: the ozone-destroying properties of the halogens have been studied since the mid-1970s. It had turned out that chlorine behaved chemically like bromine, the ozone hole would by then have been a global, year-round phenomenon, not just an event of the Antarctic spring. More by luck than by wisdom, this catastrophic situation did not develop.

Unless there is a global catastrophe — a meteorite impact, a world war or a pandemic — mankind will remain a major environmental force for many millennia. A daunting task lies ahead for scientists and engineers to guide society towards environmentally sustainable management of the era of the Anthropocene. This will require appropriate human behaviour at all scales, and may well involve interesting projects, for instance to optimize climate. At this stage, however, we are still largely trading on terra incognita.

Paul J. Crutzen is at the Max Planck Institute for Chemistry, PO Box 3060, D-5500 Mainz, Germany, and the Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093-7452, USA.

**FURTHER READING:**  
 Marsh, C. P. Man and Nature (1964). (Reprinted as *Earth as Modified by Human Action* (Balknap Press, Cambridge, Massachusetts, 1965)).  
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THE NEXT GOLDEN STATE: A 16-PAGE SPECIAL REPORT ON AUSTRALIA

# The Economist

MAY 28TH-JUNE 3RD 2011

Economist.com

Obama, Bibi and peace

Britain's privacy mess

The costly war on cancer

How the brain drain reduces poverty

A soft landing for China

## Welcome to the Anthropocene

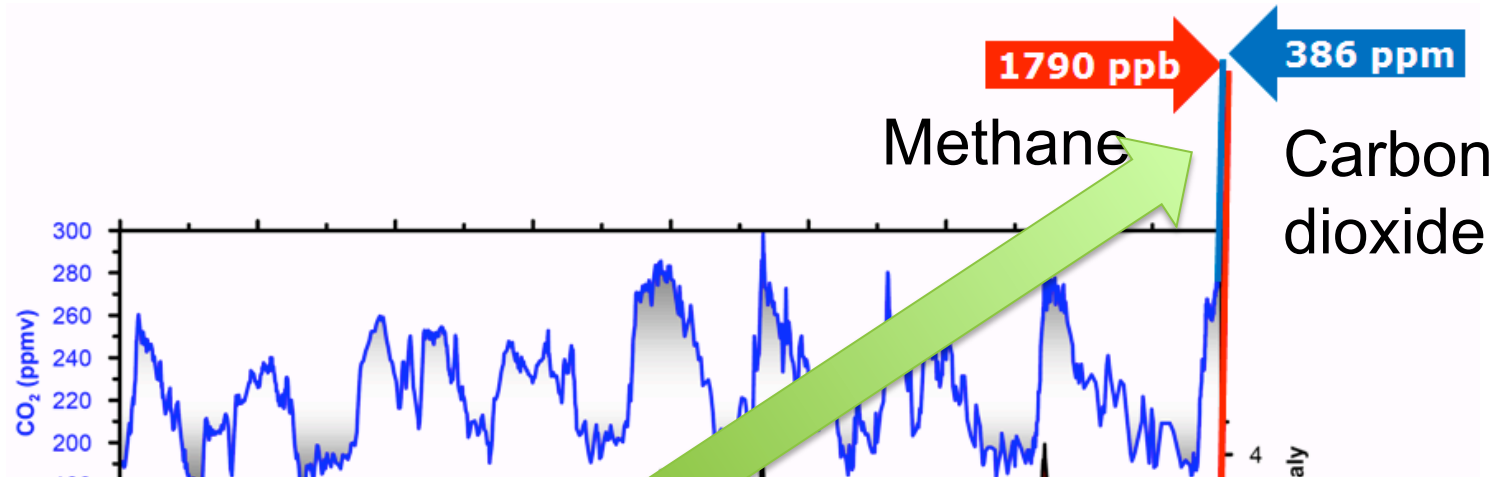


Geology's new age

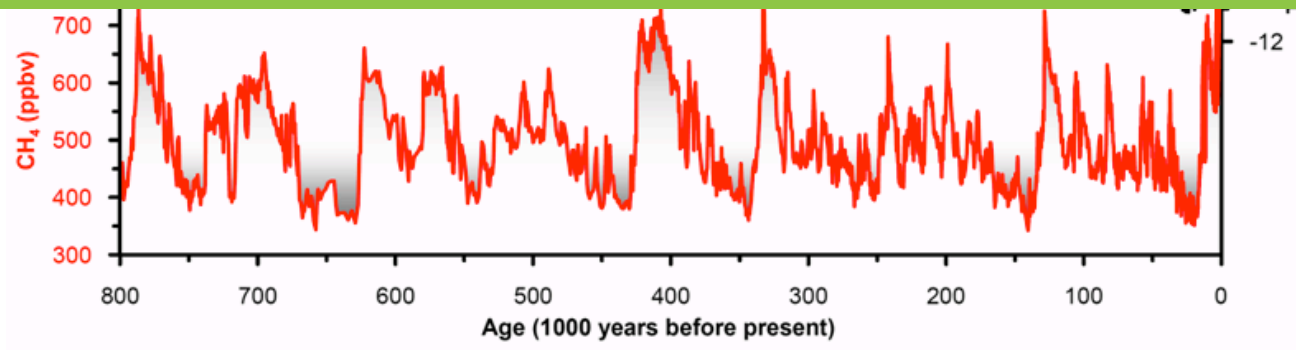
GLOBAL  
IGBP International  
Geosphere-Biosphere  
Programme  
CHANGE

The Economist, 2011

# Antarctic ice core



Beyond natural boundaries



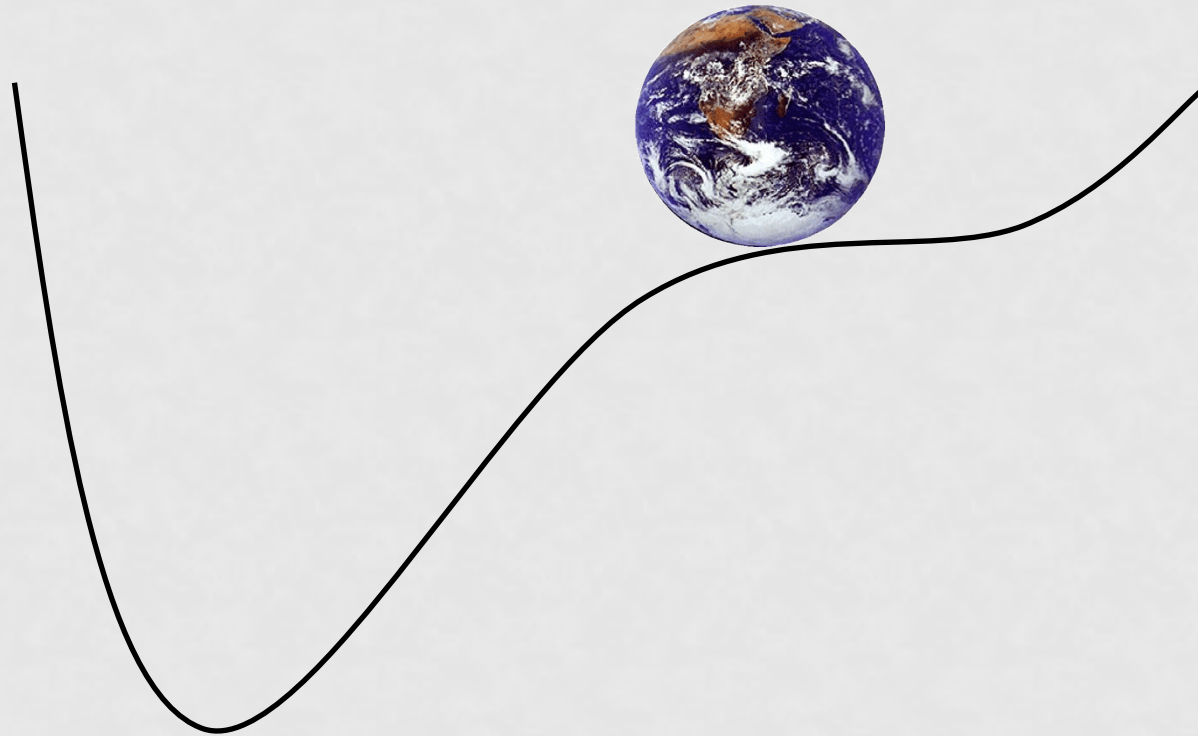
# WHERE ARE THE THRESHOLDS AND TIPPING ELEMENTS IN THE EARTH SYSTEM?



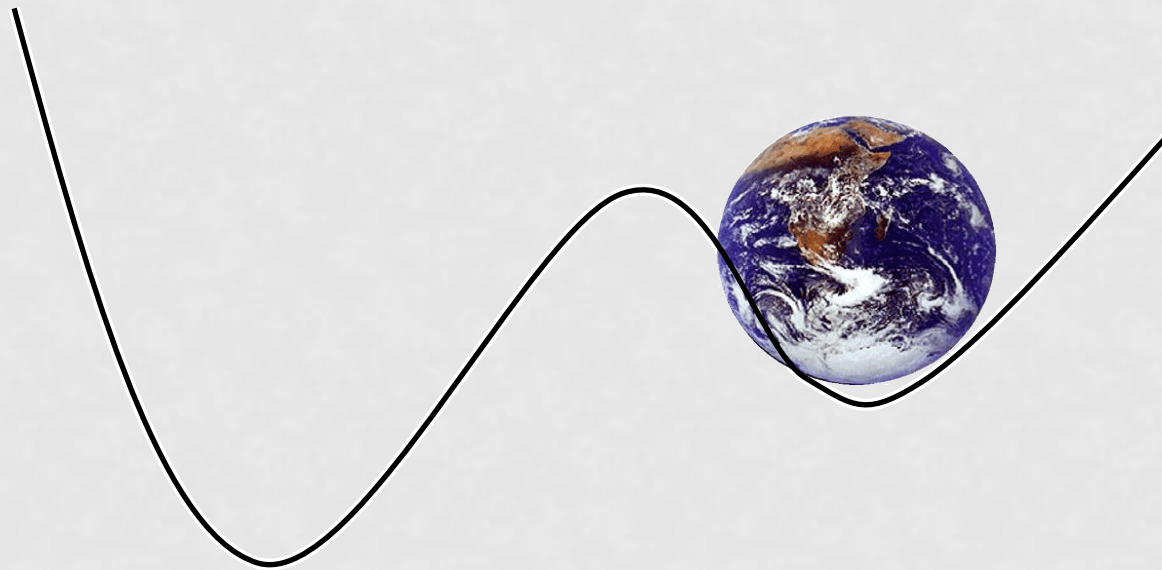
Photograph by Annie Griffiths Belt

National Geographic, February 2008 – © National Geographic Society, All rights reserved.

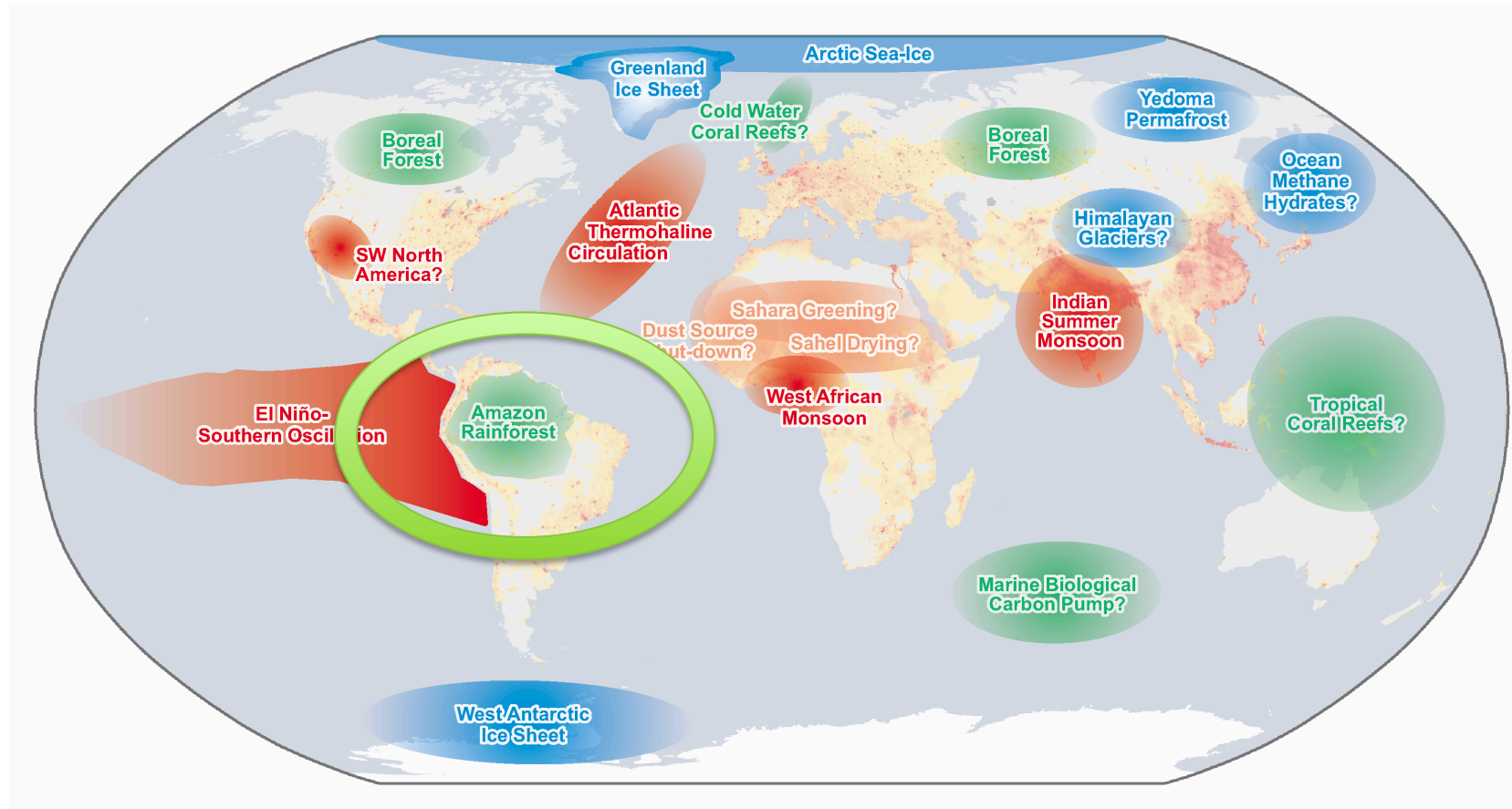
# REDUCED RESILIENCE – OUR PRECARIOUS PREDICAMENT



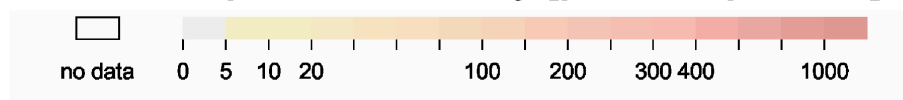
# A RESILIENT EARTH SYSTEM



# Tipping Elements in the Earth System



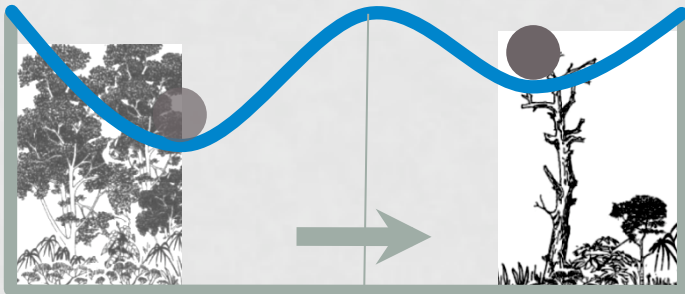
- Melting
- Circulation Change
- Biome Loss



# "Tipping points" for the Amazon Forest

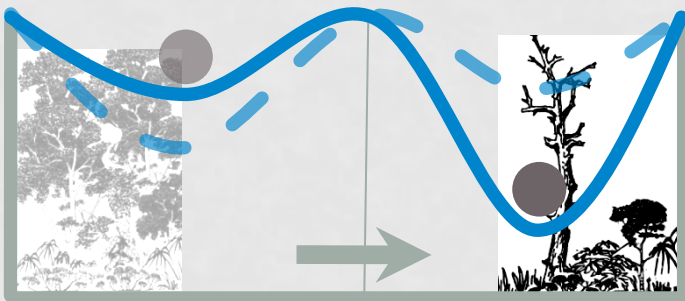


**Tropical Forest**



**Savanna state triggered by climate change or deforestation**

**Tipping points:** temperature  $> 3.5$  C; or deforested area  $> 40\%$



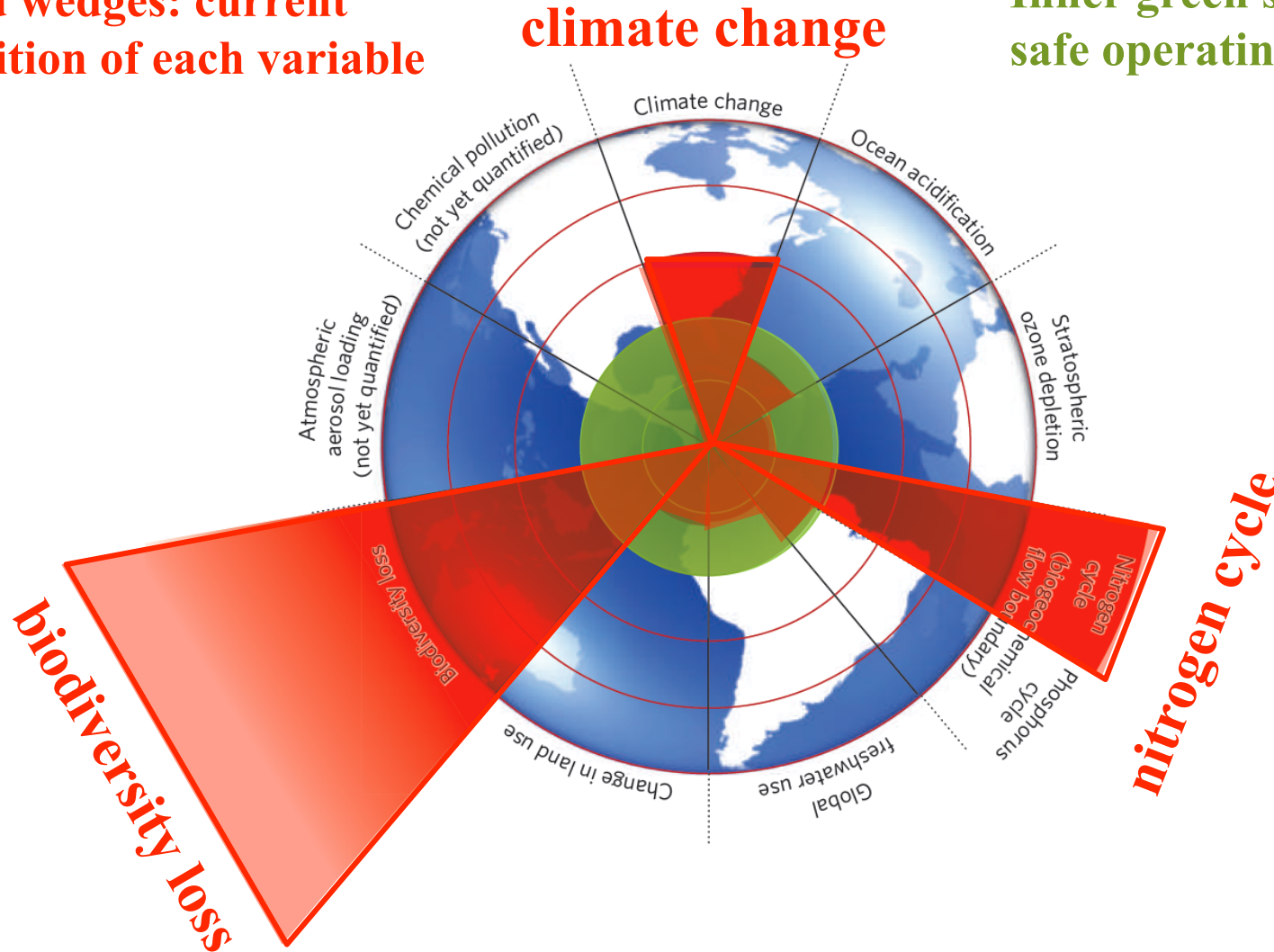
**Stability of savanna enhanced by increased droughts and fires**



# BEYOND THE BOUNDARIES

Red wedges: current position of each variable

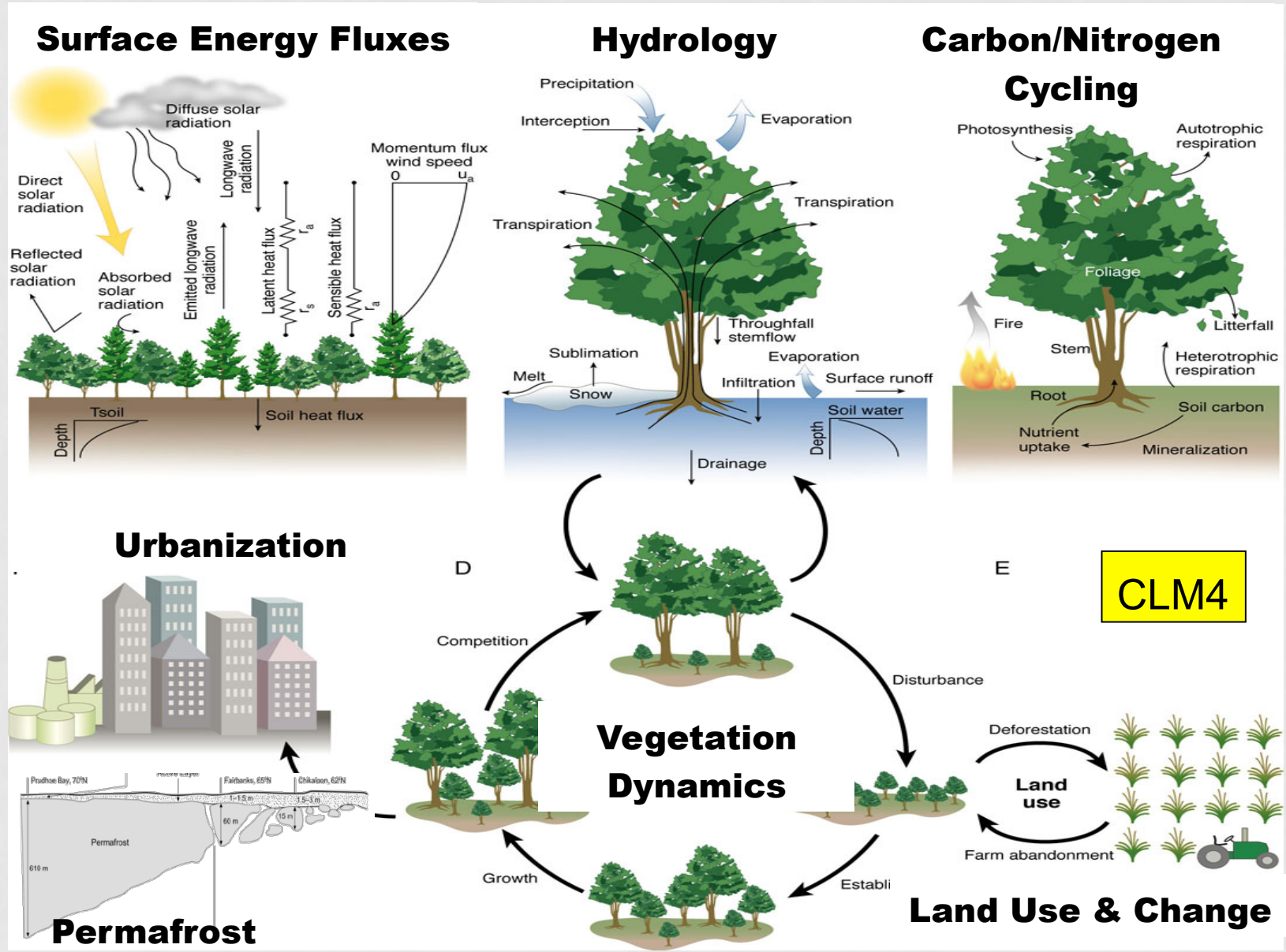
Inner green shading: safe operating space



# IGBP's Second Synthesis Exercise.

- Impacts of land-use-induced land-cover changes on the functioning of the Earth System
- Megacities in the coastal zone
- Nitrogen and climate
- Air pollution and climate
- Earth-system impacts from changes in the cryosphere
- Impacts from changes in the cryosphere on the biota and societies in the arid Central Asia
- Global environmental change and sustainable development: needs of least developed countries
- Geo-engineering impacts

# Introducing Life in Climate Models



Bonan (2009)

# TRY: a global database of plant traits to improve the representation of functional diversity for Earth System Modeling

[www.try-db.org](http://www.try-db.org)

Jens Kattge, Sandra Diaz, Sandra Lavorel, Gerhard Bönisch, Colin Prentice, Paul Leadley, Christian Wirth and all members of the TRY initiative



Credit photos: Christian Wirth (tropical forest) and Serge Aubert (subalpine prairie)



# SUSTAINABILITY IN URBANIZING PLANET

## Urbanization and Built Environments

- If the 3.2 billion additional people by 2100 live mostly in cities of 1 million, it will require 3200 cities of 1 million over 89 years or
- **~ 1 new city of 1 million every 10 days**

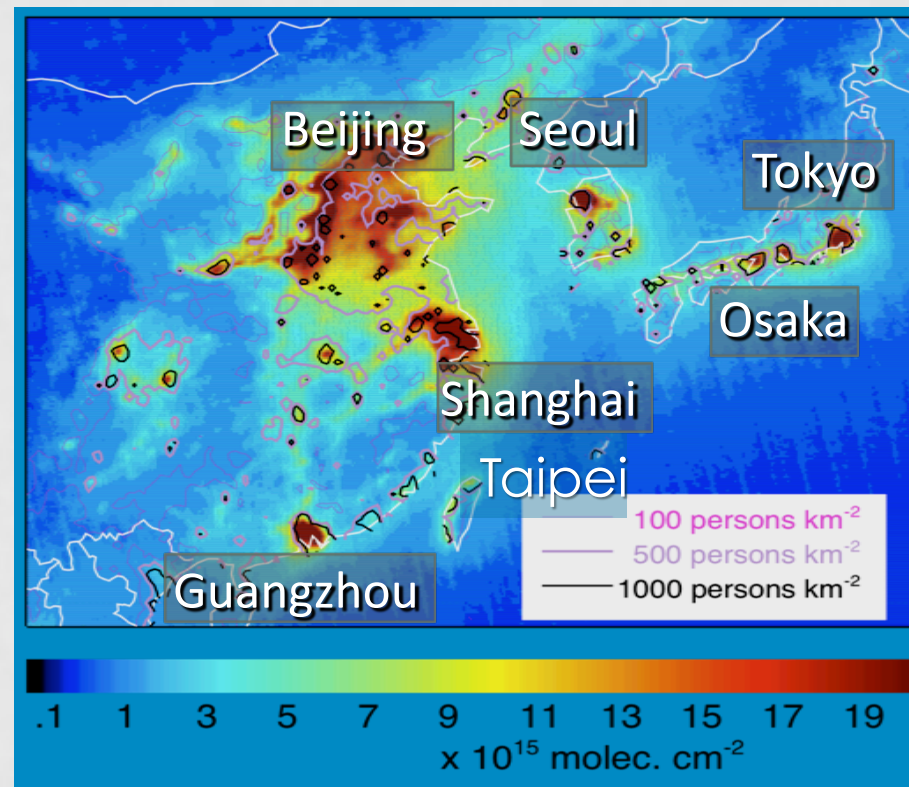


Karen Seto 2011

# URBAN ENVIRONMENTS AND AIR QUALITY MEGACITIES

## Megacities: Asia

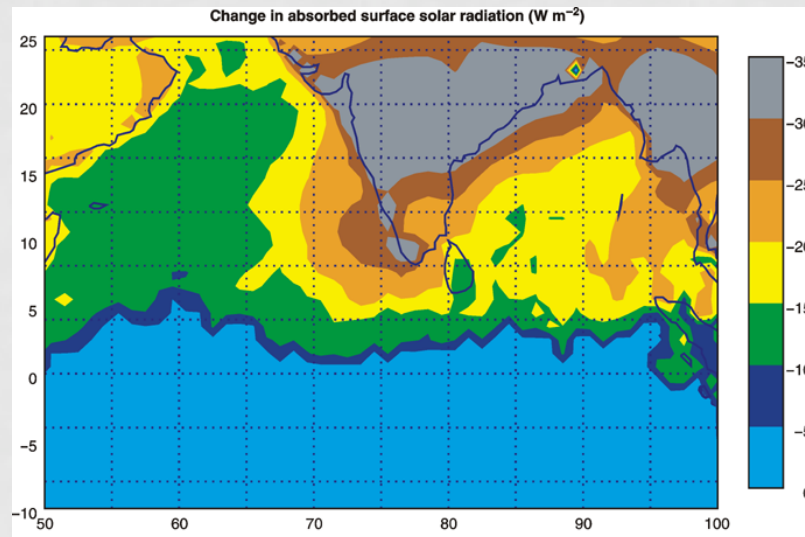
- calibrated, comparable measurements
- capacity enhancement



NO<sub>2</sub> column - Randal Martin

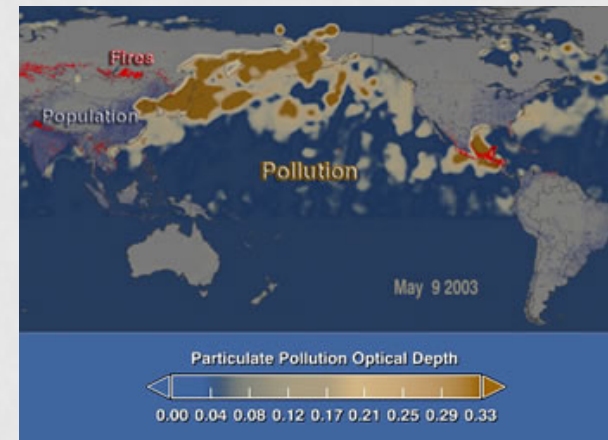
Parrish and Zhu, 2010 Science

# AEROSOLS AND ASIAN POLLUTION AFFECTING THE ENTIRE NORTHERN HEMISPHERE - IGAC

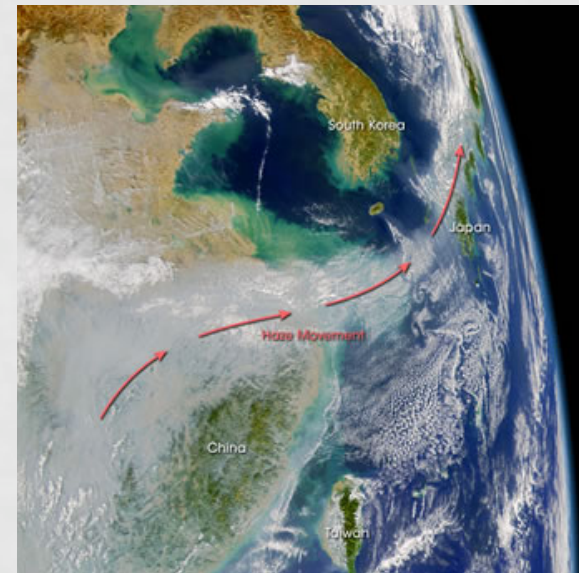


Reduction in surface solar radiation absorption due to the Indo-Asian haze effects (measured January to April from 1996-1999) (Ramanathan et al. 2001a) Steffen et al., 2004

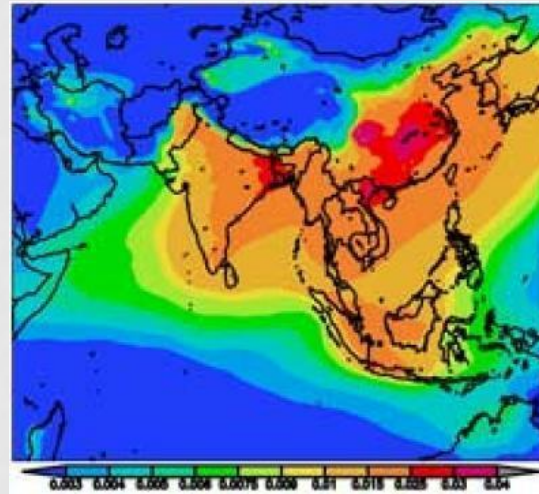
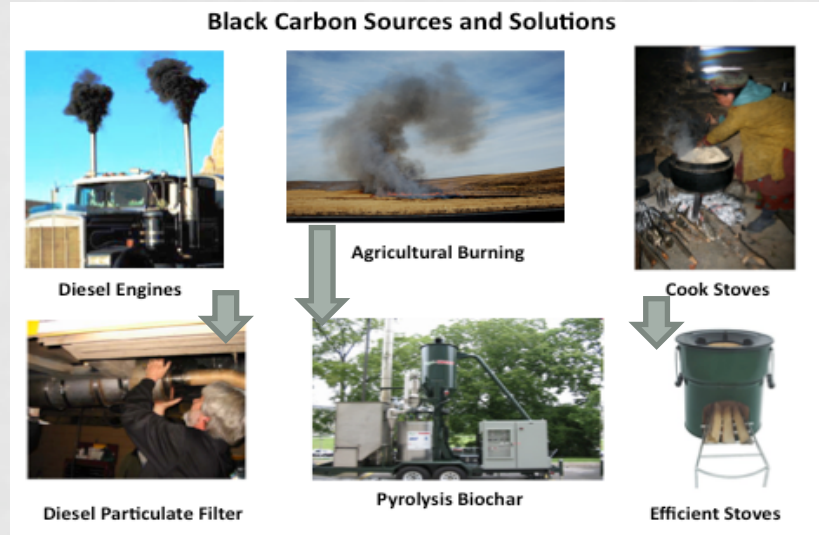
A pool of air pollution has spread out over eastern China and then slipped over the coast like water over a dam. A river of haze flows across the East China Sea past the Korean peninsula and northeastward toward Japan,



Optical depth of particles pollution. Much of this pollution is industrial but some is caused by fires. NASA image.



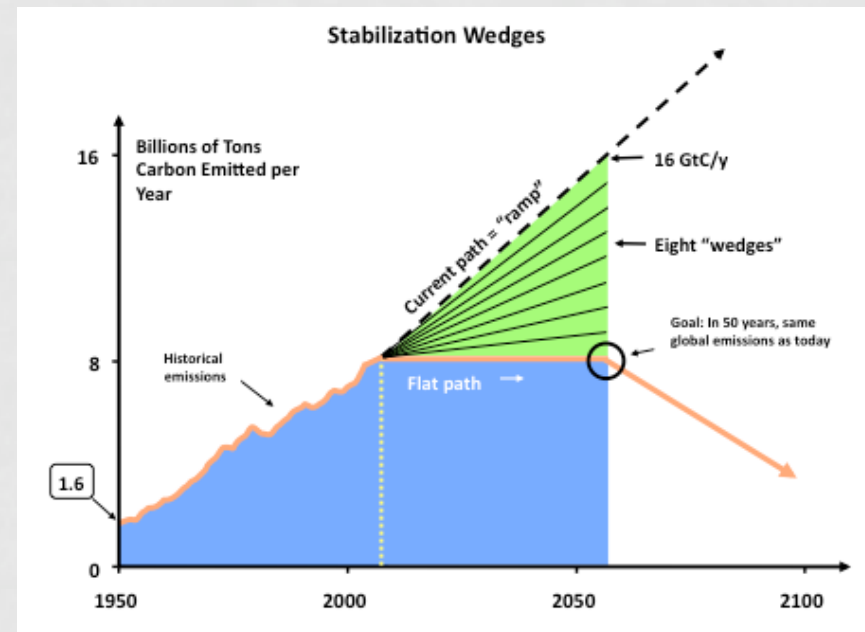
# BLACK CARBON



**Polluting effects of cooking using biomass like wood or cow dung in south Asia: Aerosol optical depth, (Credit: Scripps Institution of Oceanography, UC San Diego)**

Soot and other forms of black carbon could have as much as 60 percent of the current global warming effect of carbon dioxide, more than that of any greenhouse gas besides CO<sub>2</sub> Ramanathan and Carmichael.

See also: UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone 2011



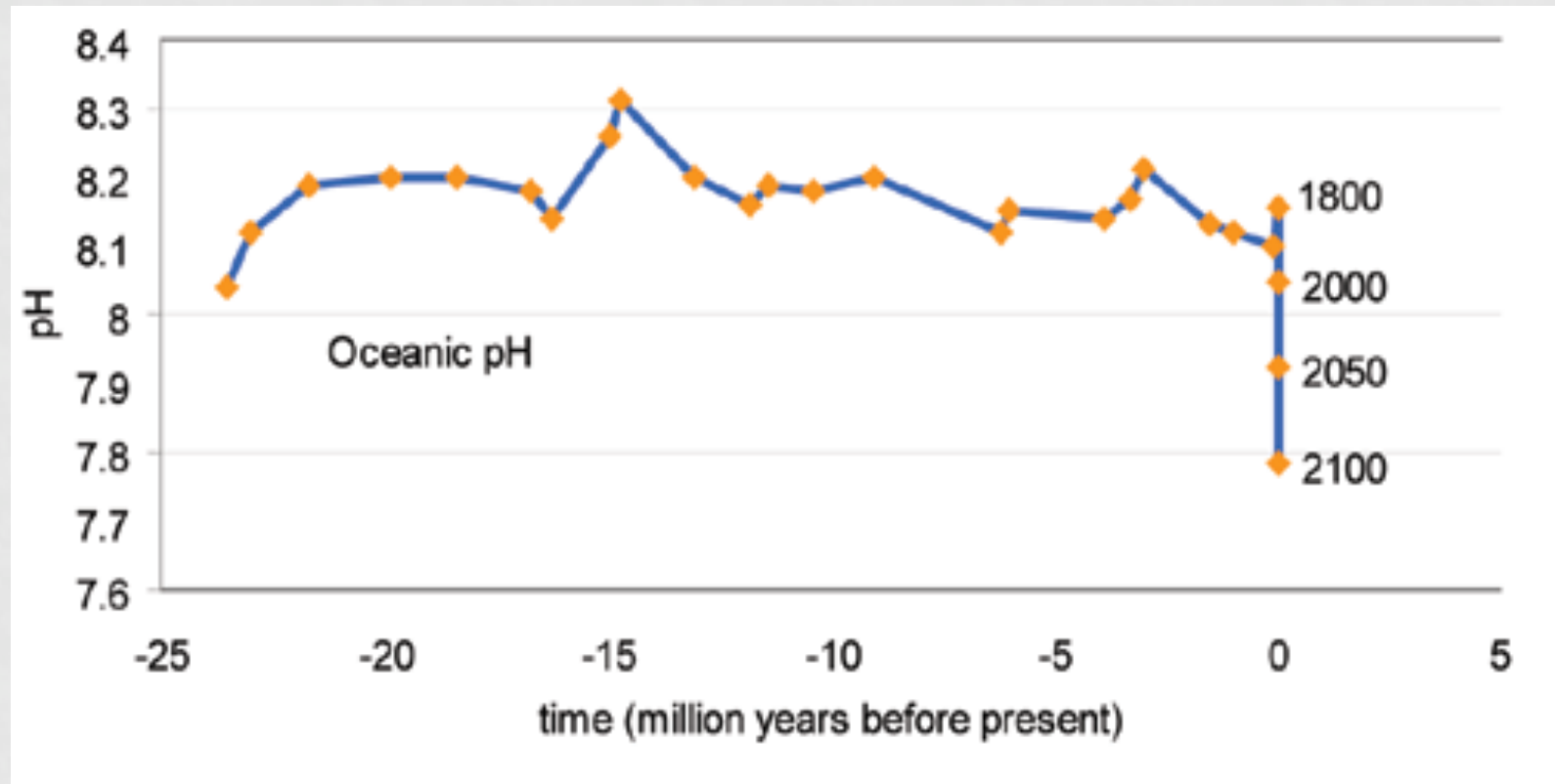
Clean Air Task Force, 2010



# OCEAN ACIDIFICATION

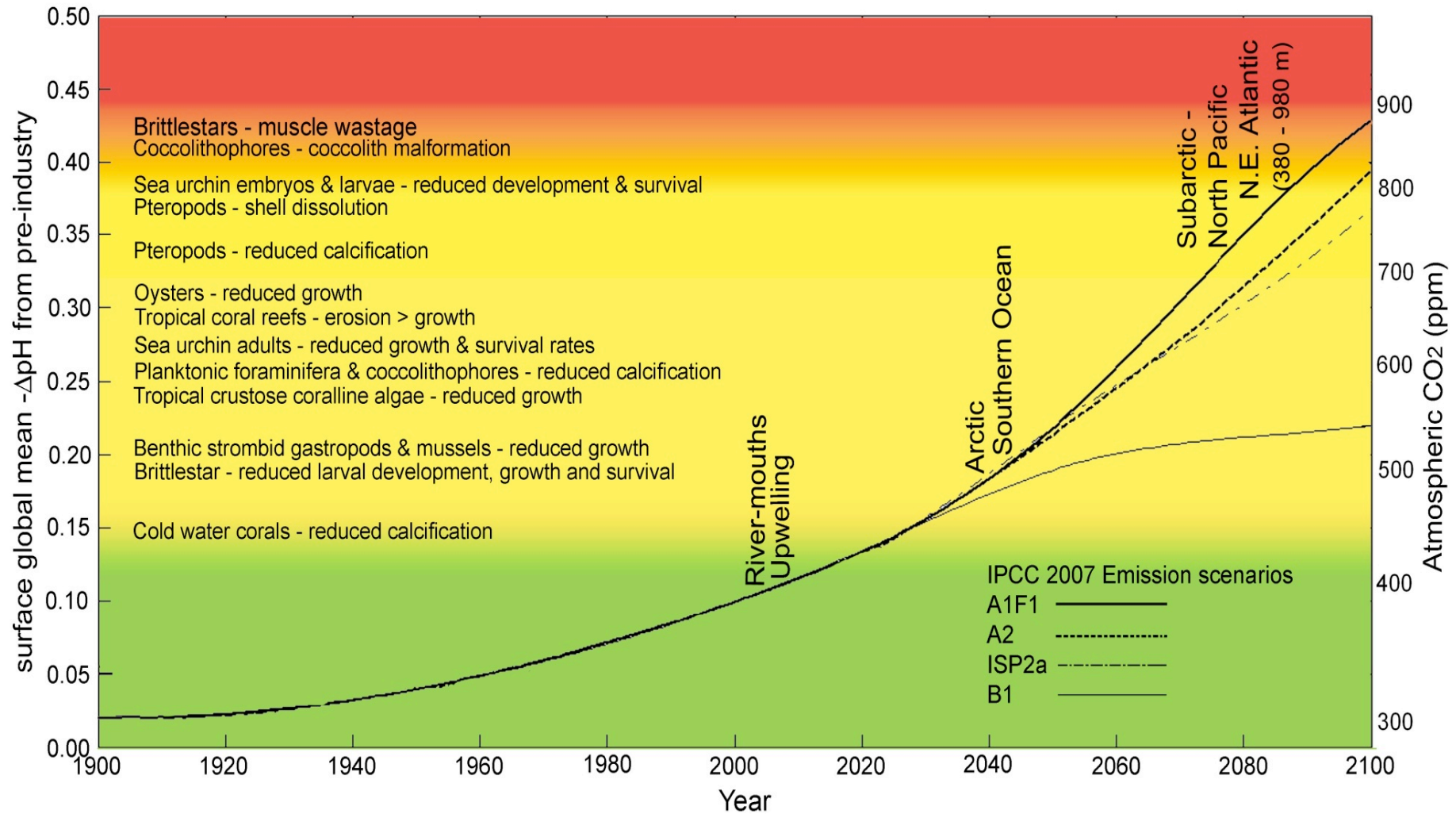
## PAST AND PRESENT VARIABILITY OF MARINE PH

### THE OTHER HALF OF THE CO2 PROBLEM

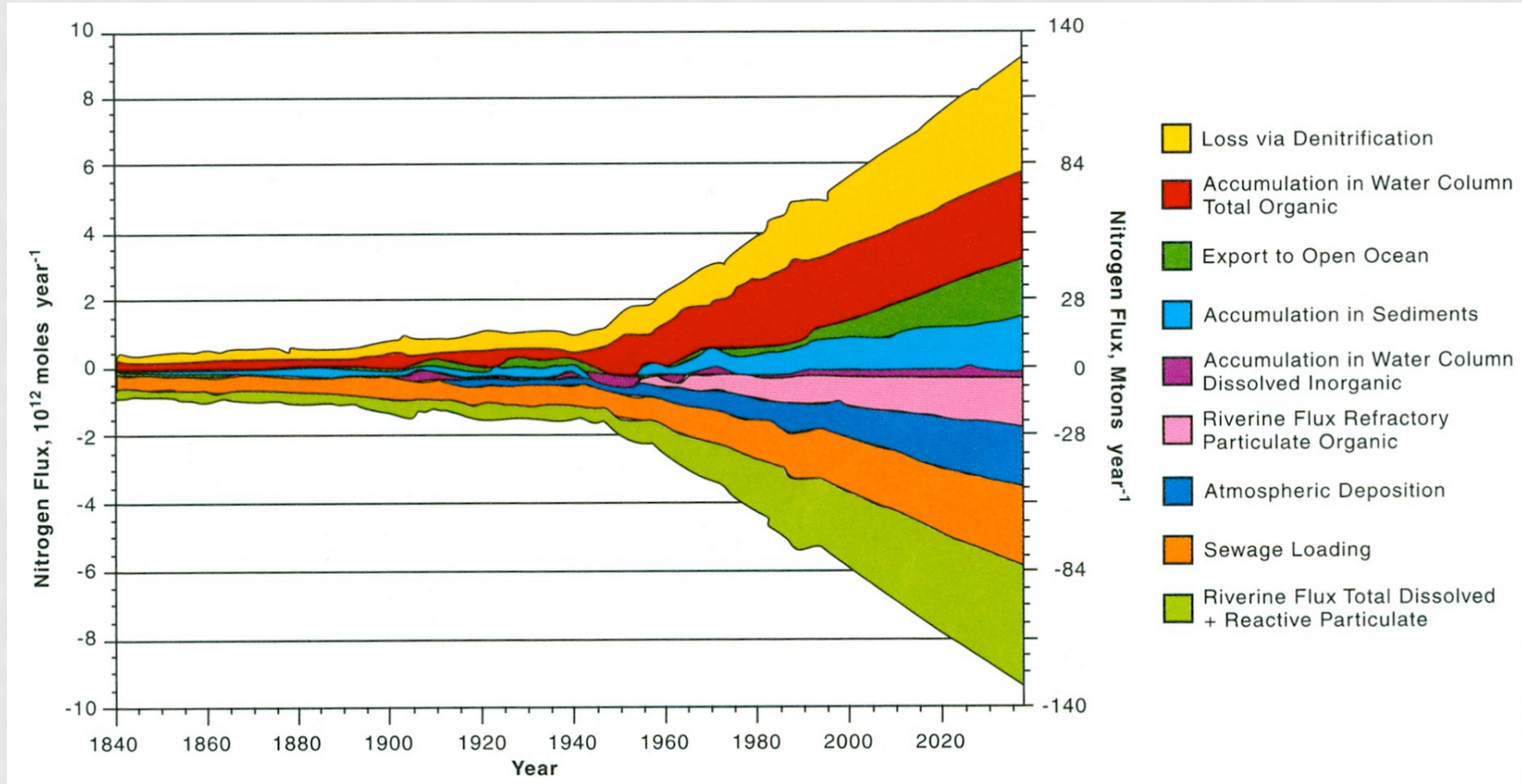


Based on IPCC mean scenarios

# FUTURE CO2 EMISSIONS COULD IMPACT SOME MARINE ORGANISMS AND ECOSYSTEMS THIS CENTURY



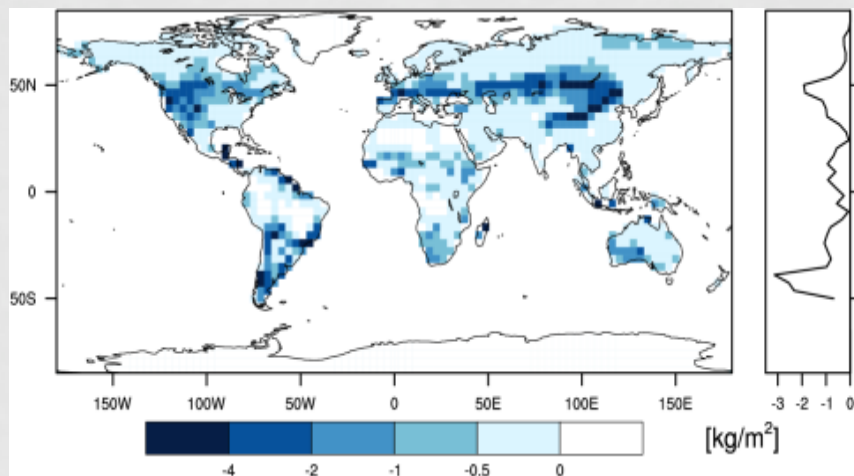
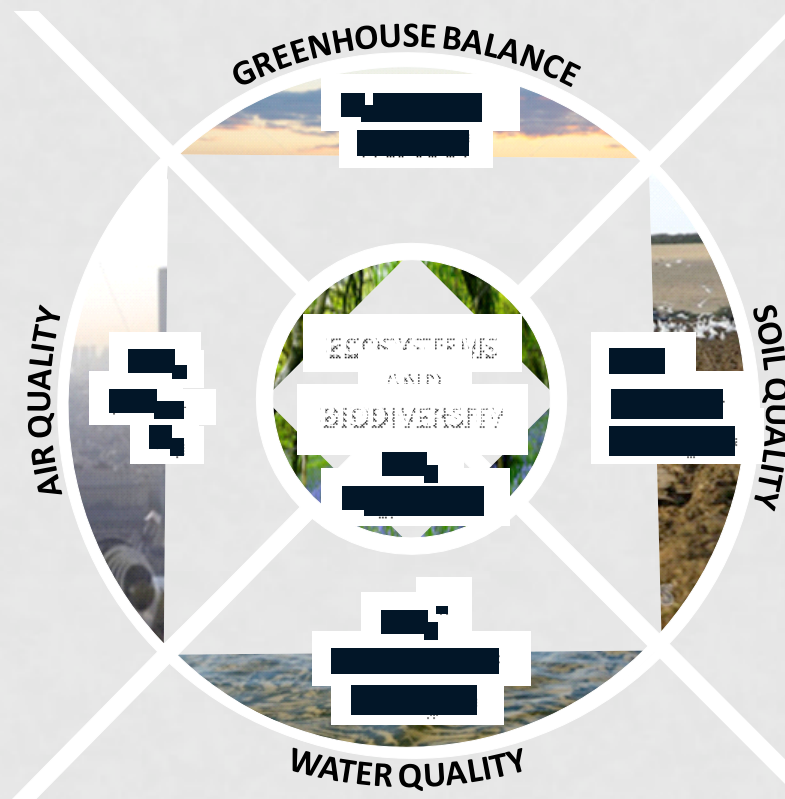
# THE NITROGEN BUDGET IS BEING CONSIDERABLY PERTURBED BY HUMAN ACTIVITIES



Model-calculated partitioning of the human-induced **nitrogen perturbation fluxes in the global coastal margin** for the period since 1850 to the present (2000) and projected to 2035 under a business-as-usual scenario (Steffen et al., 2004 based on Mackenzie et al. 2002)

# THE FIVE KEY THREATS OF EXCESS NITROGEN

Water quality  
Air quality  
Greenhouse balance  
Ecosystems  
Soil quality



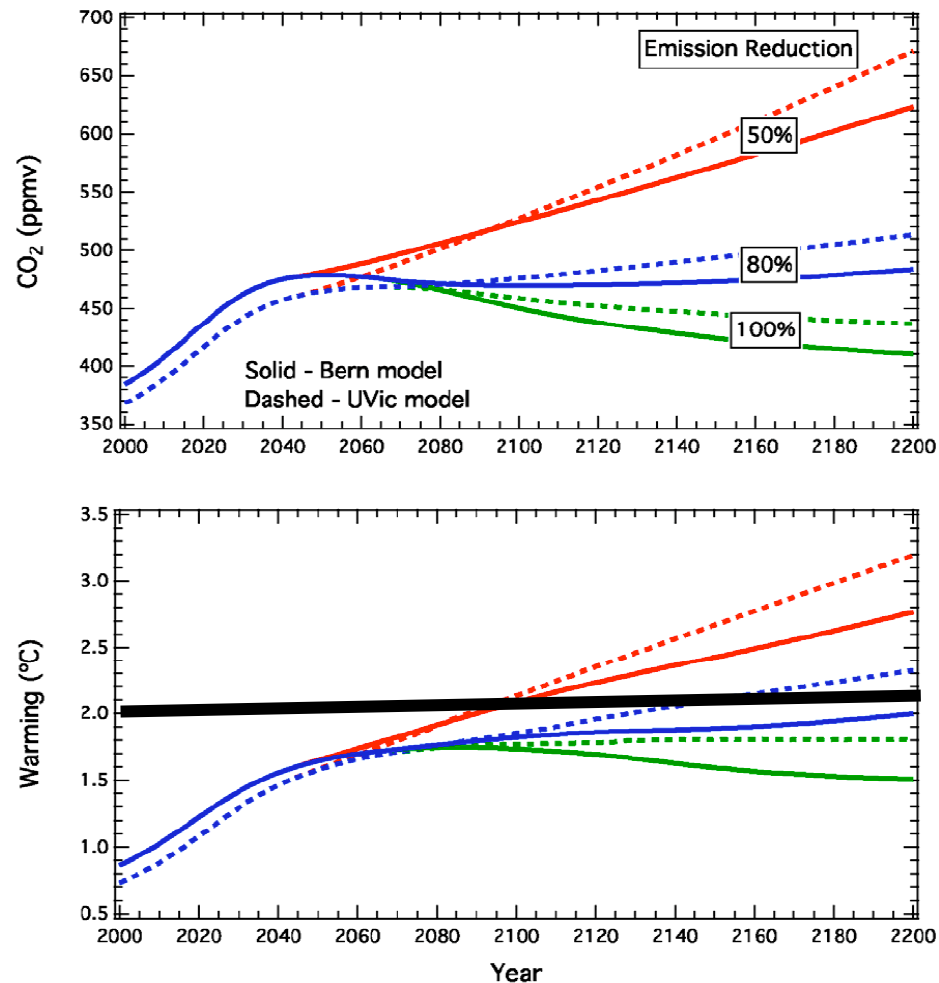
CO<sub>2</sub> induced nitrogen limitation  
in the 21<sup>st</sup> century (JSBACH-CNP)  
Goll et al., 2011

## **THE FOURTH GRAND CHALLENGE: MANAGING THE EARTH SYSTEM**

- Climate has largely evolved from an **environmental** problem to an **economic** problem.
- Private corporations and public services are exploring ways to better manage environmental **risks and opportunities**
- Advances made by the science in the last decades remain, however, **underutilized**.
- Interactions between climate service providers and users will be improved by the UN **Global Framework for Climate Services** and other related initiatives that will facilitate **adaptation** and **climate risk management**.

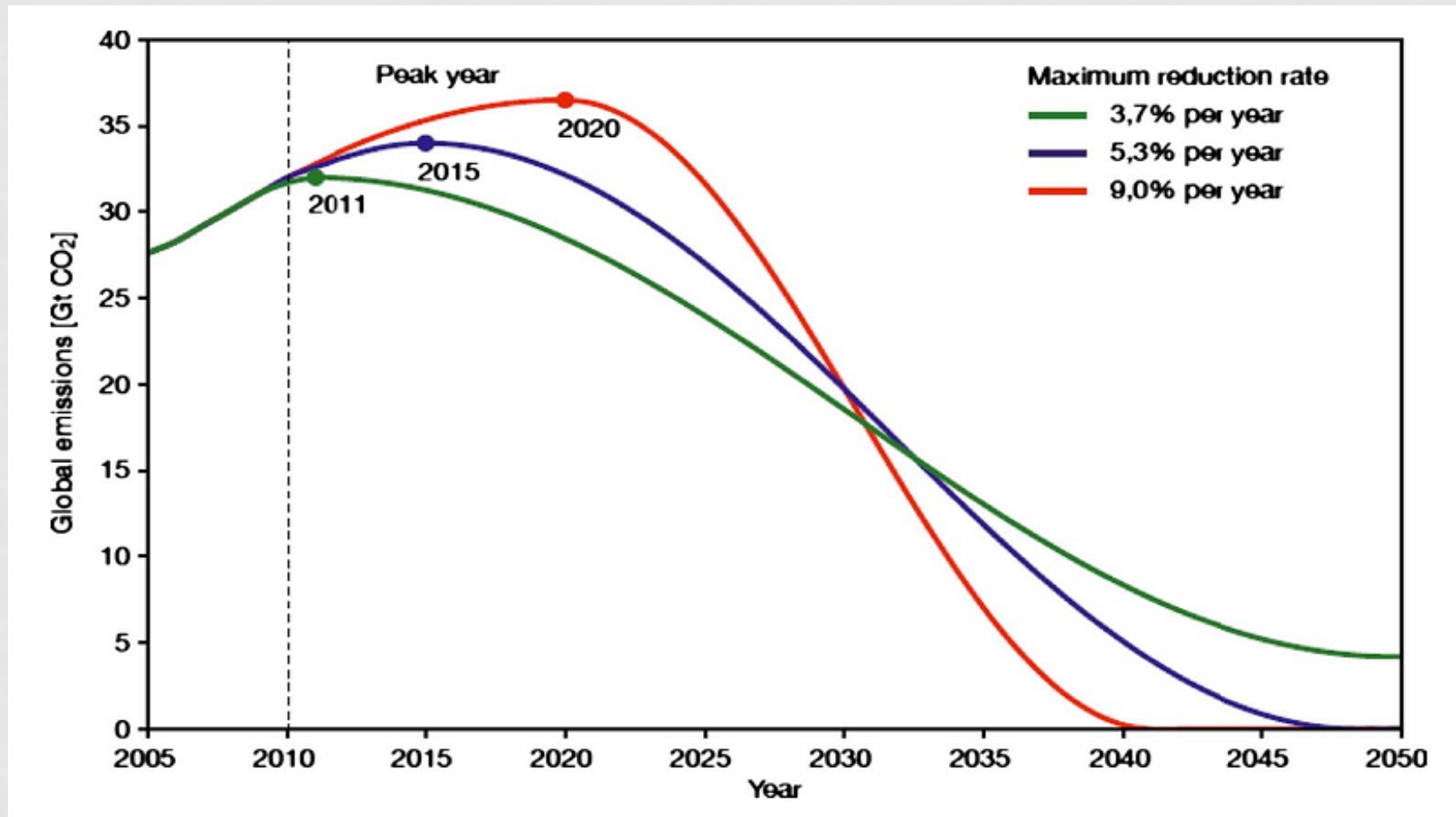
# **Mitigating Climate Change**

# MITIGATION: LIMITING GLOBAL WARMING TO 2°C



National Research  
Council, 2010

**THE WAY TO A DE-CARBONIZED SOCIETY AND LIMITED CLIMATE CHANGE (2 C)**  
**LIMIT THE TOTAL EMISSION OF CO2 TO 750 GT IN THE NEXT 40 YEARS**

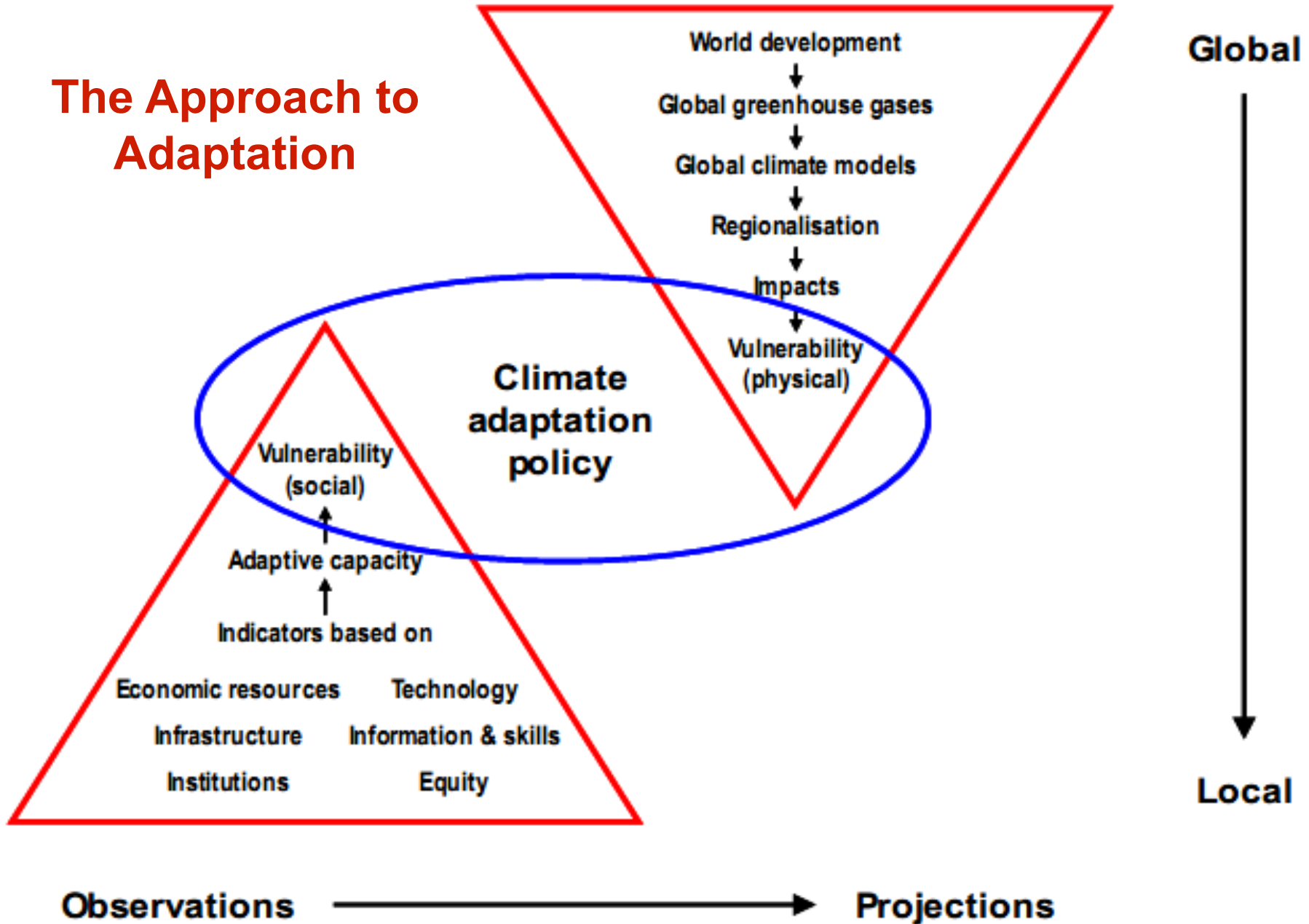


*Messner et al. (2010) and WGBU*

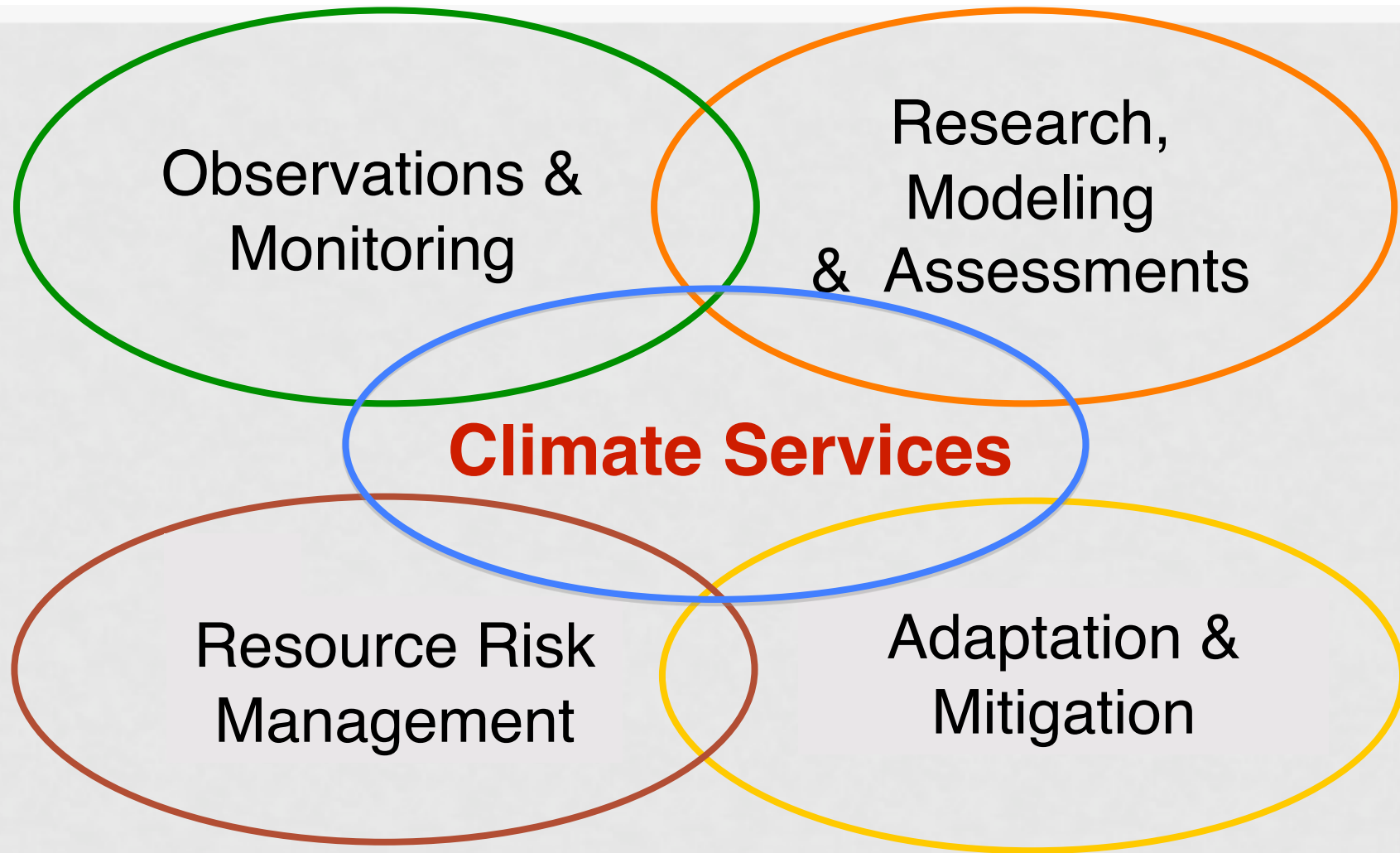


# **Adapting to Unavoidable Climate Change**

# The Approach to Adaptation



# Climate Services will Require an Unprecedented Level of Coordination



# We have some Global Earth Observations

# We don't have:

## Discipline Specific View

## Whole System View

<b>Atmospheric Observations</b>				
<b>Data Systems</b>				
<b>Ocean Observations</b>				
<b>Space Observations</b>				
<b>Technology Development</b>	<p><b>Innovations</b> Breakthrough</p>	<p><b>Efficiencies</b> Cost</p>	<p><b>Mass</b> Productions</p>	<p>Breakthrough <b>Innovations</b> Efficiencies Cost Mass Productions</p>

20<sup>th</sup> Century

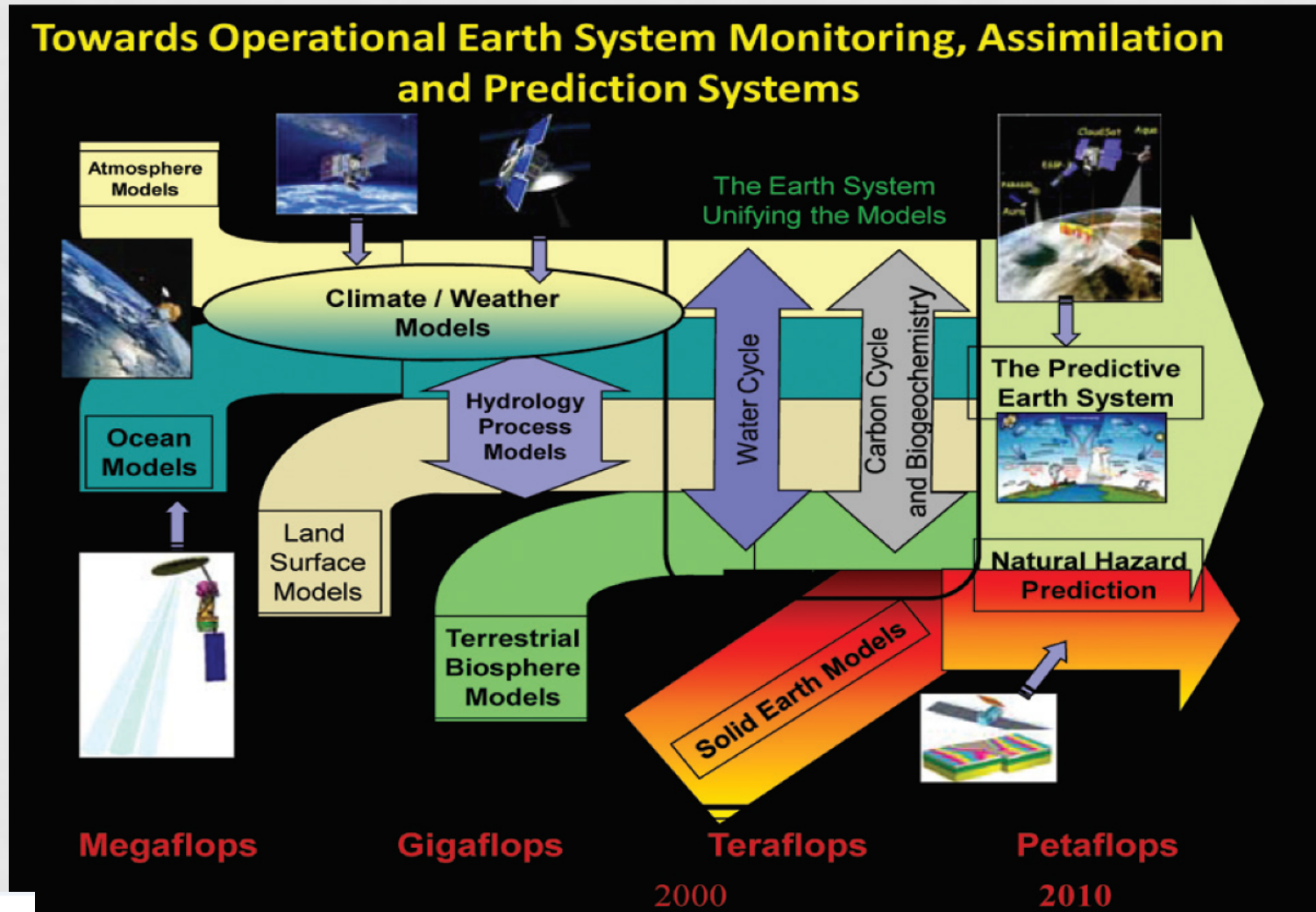
21<sup>st</sup> Century

OBSERVING SYSTEM TIMELINE

From Tom Karl

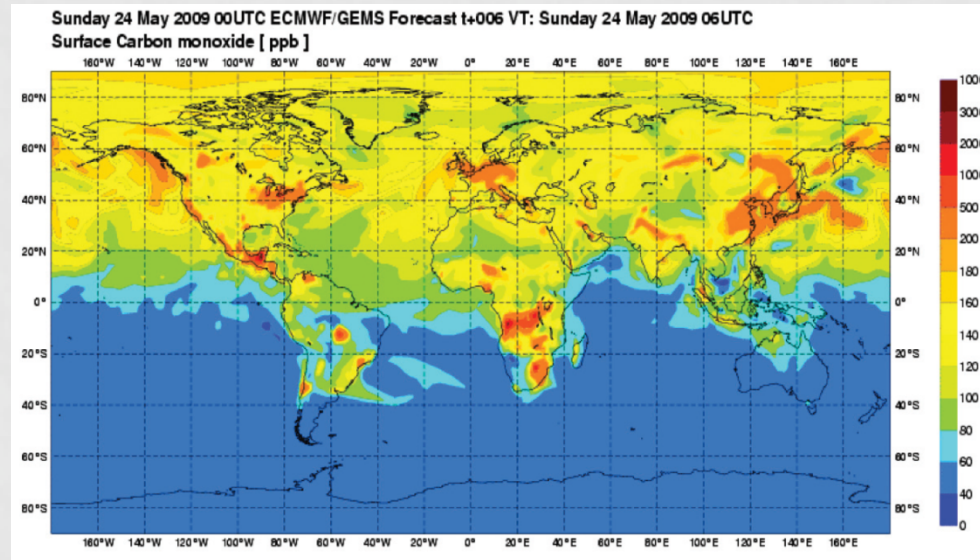


# ELEMENTS OF A COMPLEX EARTH SYSTEM ANALYSIS AND PREDICTION SYSTEM, AND THE COMPUTATIONAL REQUIREMENT

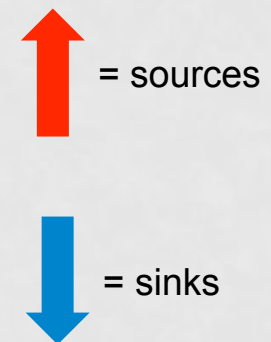
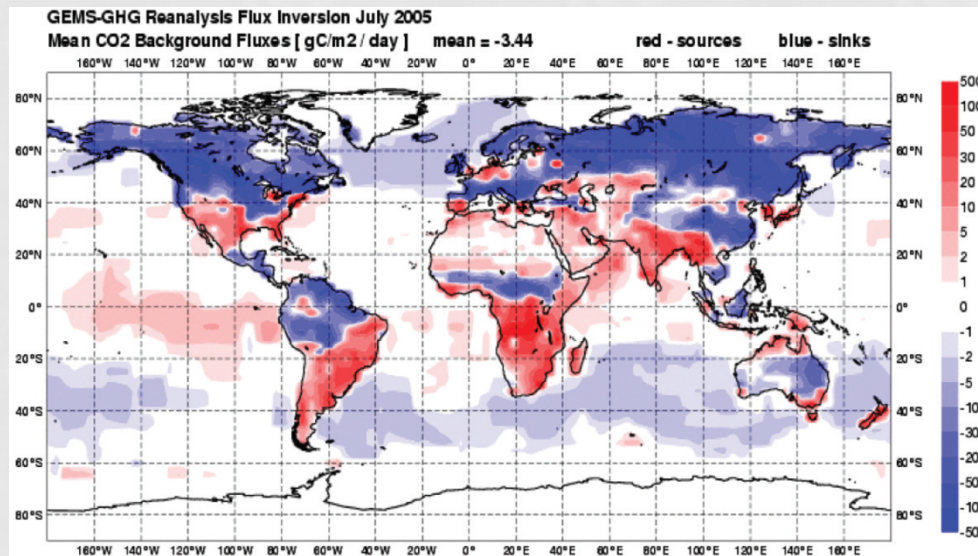


# OPERATIONAL ANALYSIS AND PREDICTIONS OF ATMOSPHERIC COMPOSITION BY THE EU-FUNDED MACC PROJECT

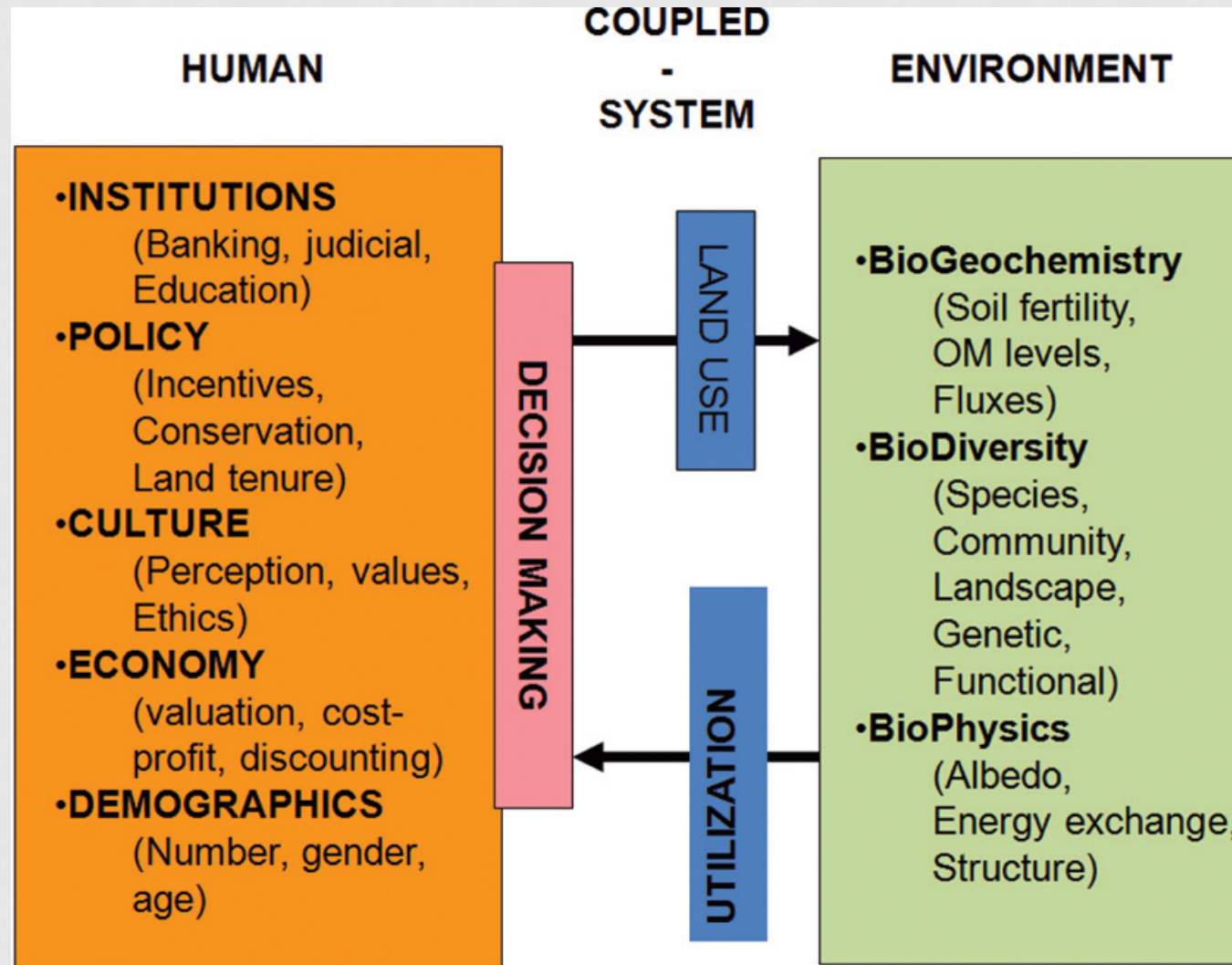
**Predicted global distribution of carbon monoxide surface mixing ratio (ppb) by the ECMWF (EU-funded GEMS Project) with an assimilation of space observations**



**Monthly mean exchange surface flux of carbon ( $\text{gC m}^{-2} \text{day}^{-1}$ ) derived from atmospheric  $\text{CO}_2$  observations by the AIRS and atmospheric transport calculated using winds from the ECMWF reanalysis**



# THE CHALLENGE OF INTRODUCING THE HUMAN DIMENSION IN EARTH SYSTEM MODELS



MODEL OF A COUPLED HUMAN-ENVIRONMENTAL SYSTEM

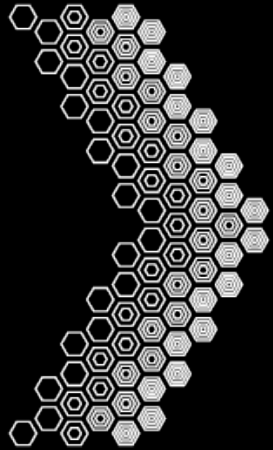
Nobre et al, BAMS, 2010

# CONCLUSIONS

- Climate research has made tremendous **progress** in the last decades
- Today, society is pushing planet's climate and other critical physical processes towards **dangerous thresholds**.
- The world **decision-makers** require therefore **information** on how the Earth's social, ecological and physical systems are linked, how they respond to multiple stressors and what **sustainable solutions** can be applied.
- Knowledge must be properly developed, managed and communicated to **avoid ecological and economic disruptions**, and work towards a sustainable future.



[www.planetunderpressure2012.net](http://www.planetunderpressure2012.net)



# PLANET UNDER PRESSURE

2012 MARCH 26-29  
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NEW  
KNOWLEDGE  
TOWARDS  
SOLUTIONS



GLOBAL  
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Programme



And their Earth System Science Partnership

**Thank you**

