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

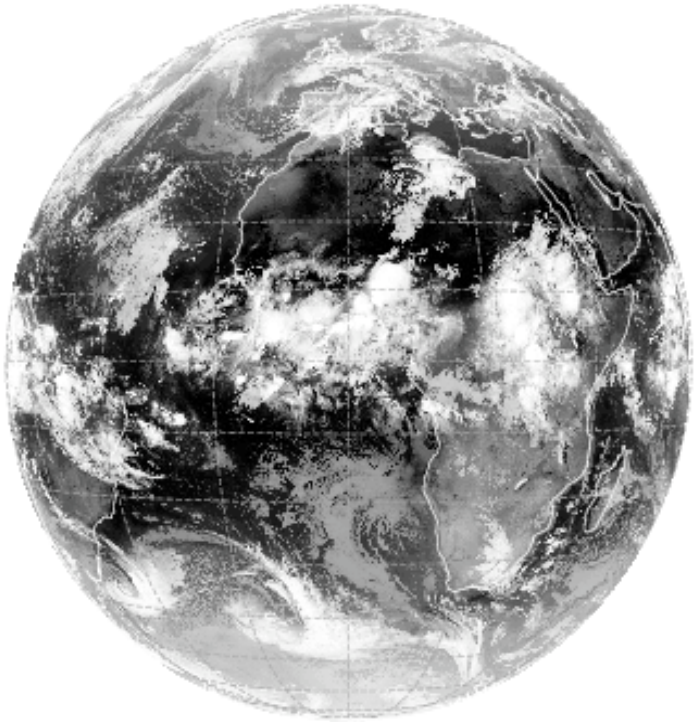
Richardson

Smagorinsky

WEATHER PREDICTION COMPARED WITH SATELLITE OBSERVATIONS

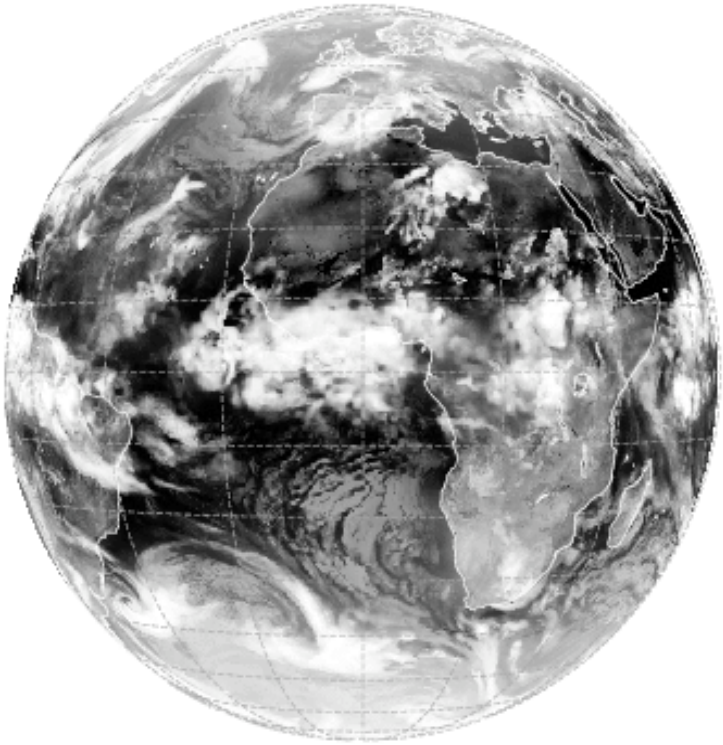
ECMWF PREDICTIONS AND METEOSAT OBSERVATIONS

Meteosat 9 IR10.8 20080525 0 UTC



Meteosat

ECMWF Fc 20080525 00 UTC+0h:



ECMWF

Fourier

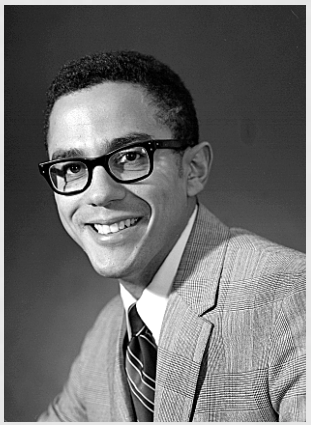
THE SECOND GRAND CHALLENGE:
PREDICTING CLIMATE CHANGE

- **Arrhenius** quantifies in 1896 the changes in surface temperature (approx. 5 C) to be expected from a doubling in CO_2, 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

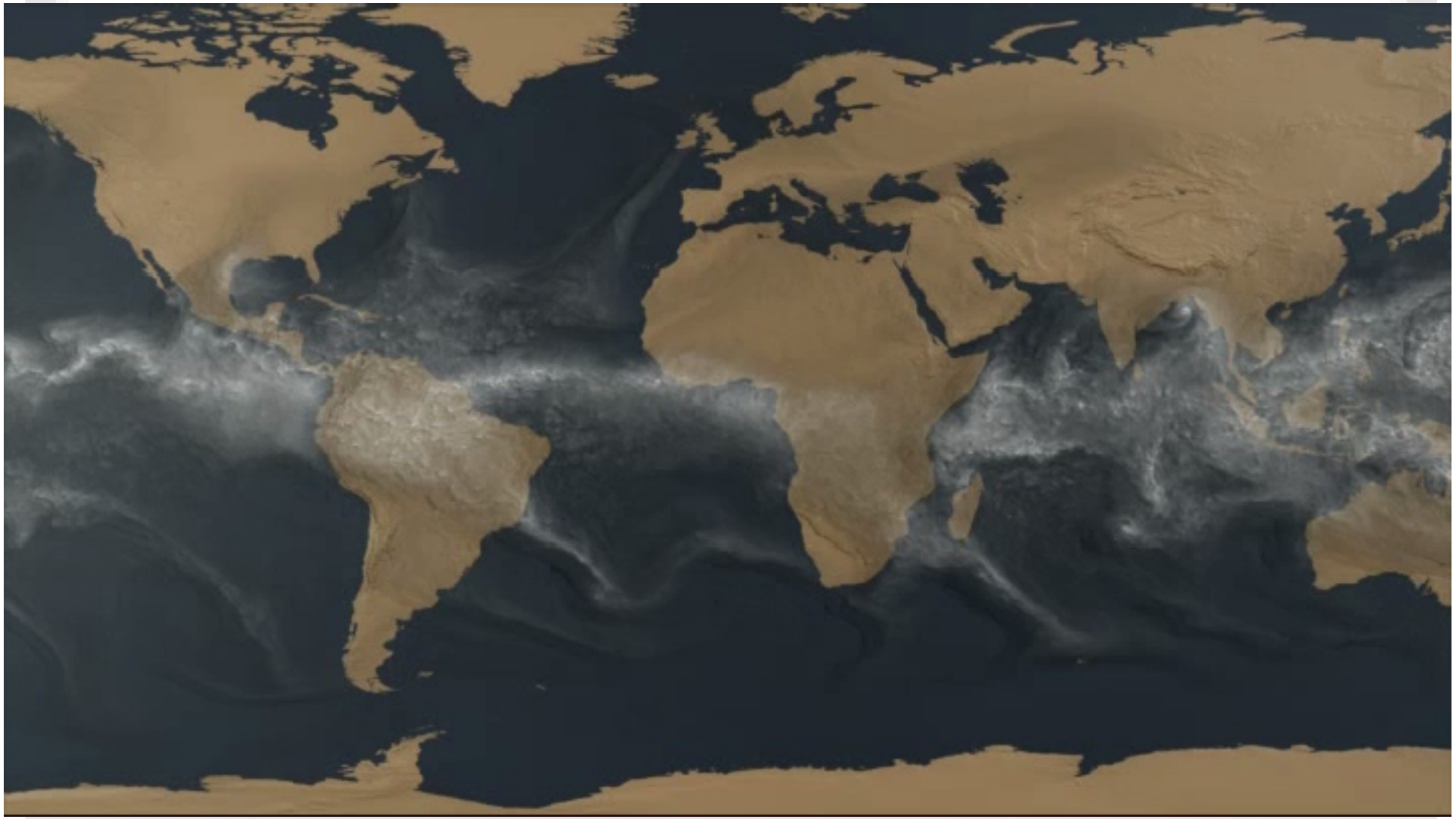
Manabe

Arakawa



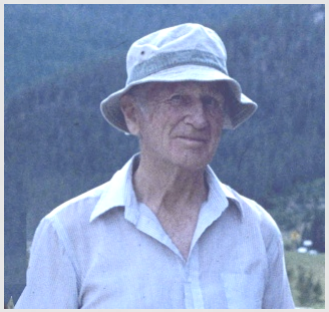
Washington

GLOBAL WATER VAPOR (14 KM RESOLUTION)



HOMME Model. M.Taylor, Sandia

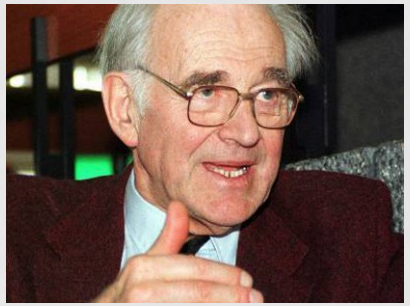
THE THIRD GRAND CHALLENGE:
UNDERSTANDING THE EARTH AS A COMPLEX NONLINEAR INTERACTIVE SYSTEM



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

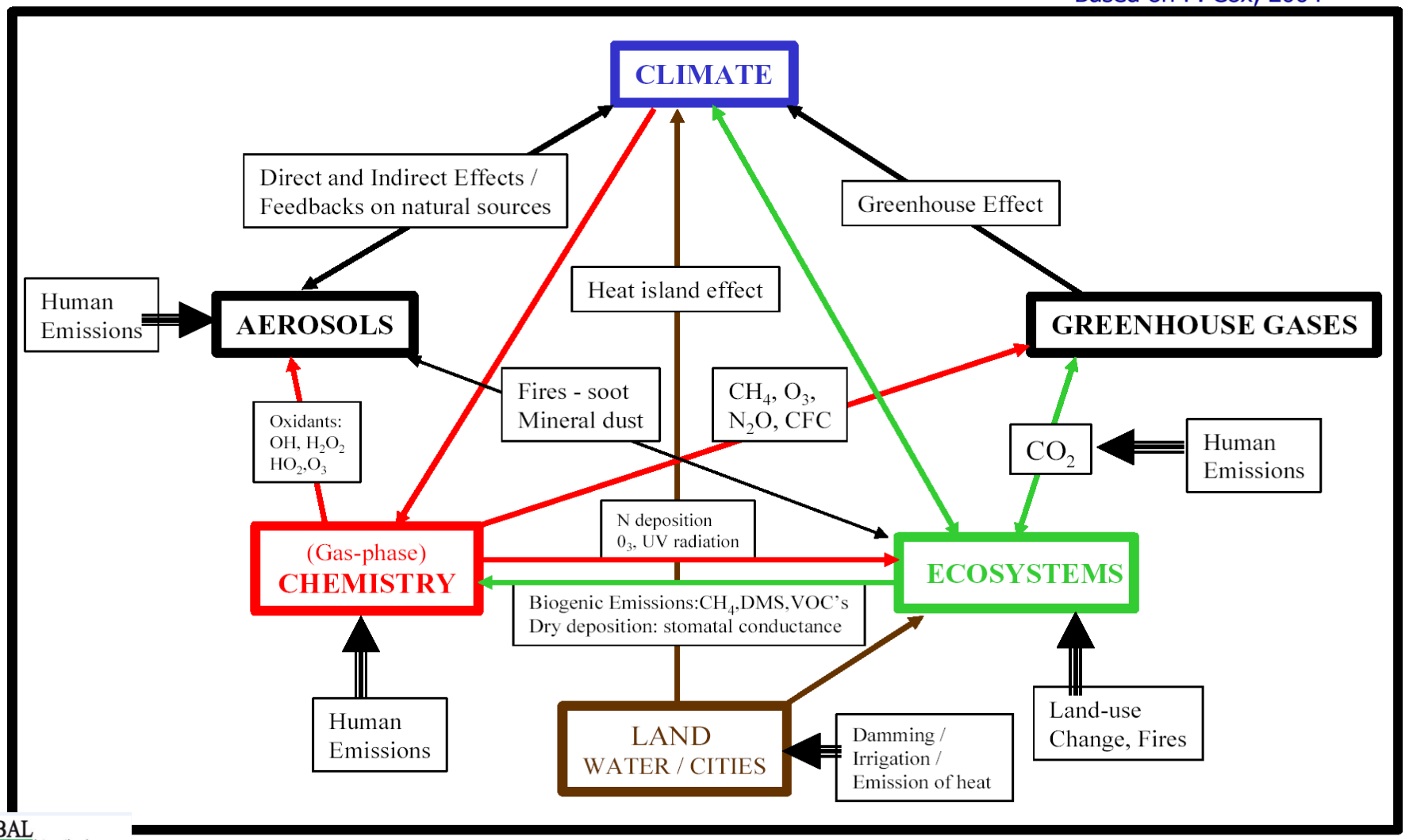


Bert Bolin

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



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Planetary Questions for the Future Life: Prosperity and Sustainability

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

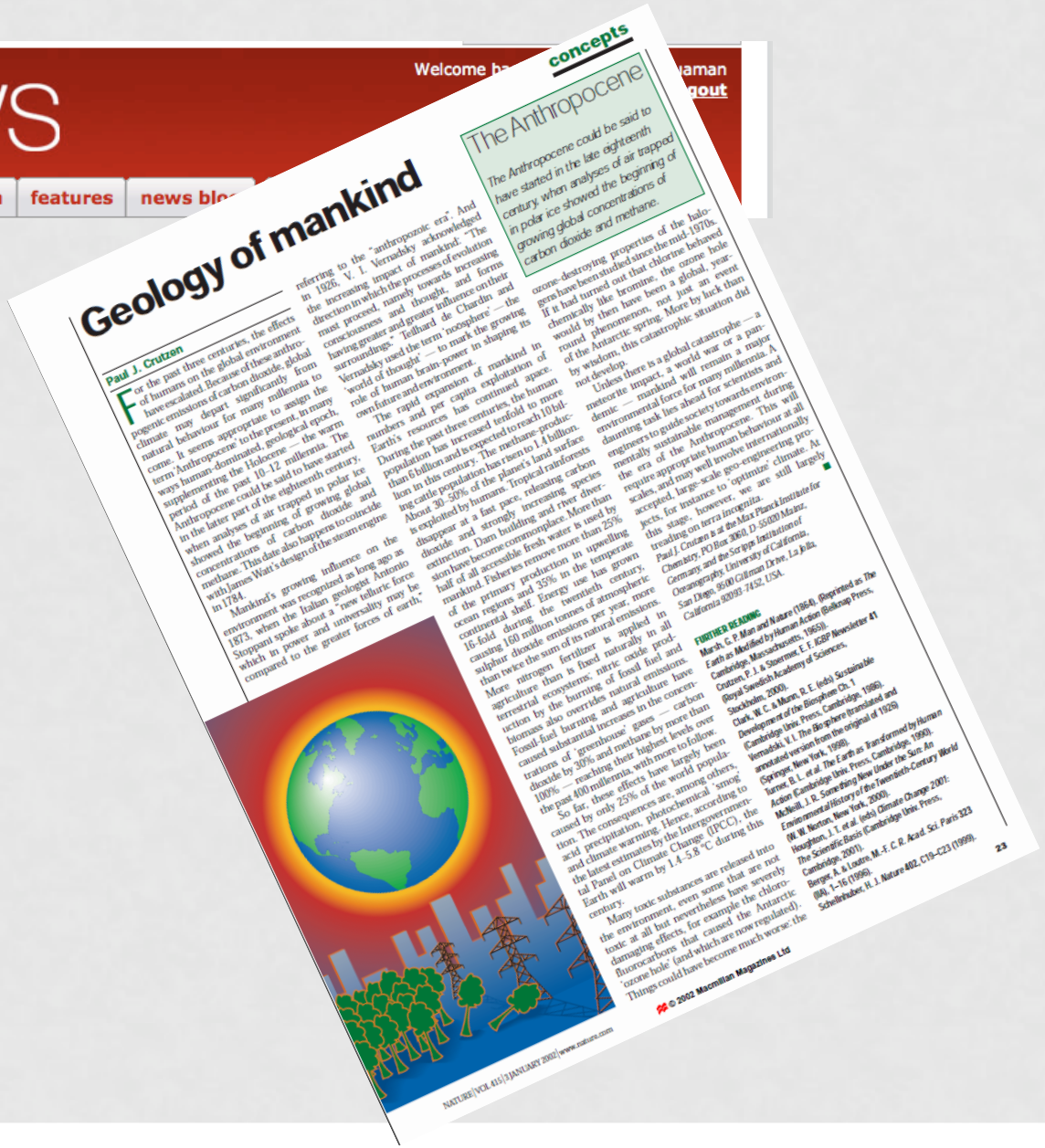
THE ANTHROPOCENE

NATURE, 2002

Geology of Mankind

IGBP Vice Chair,

Paul Crutzen,



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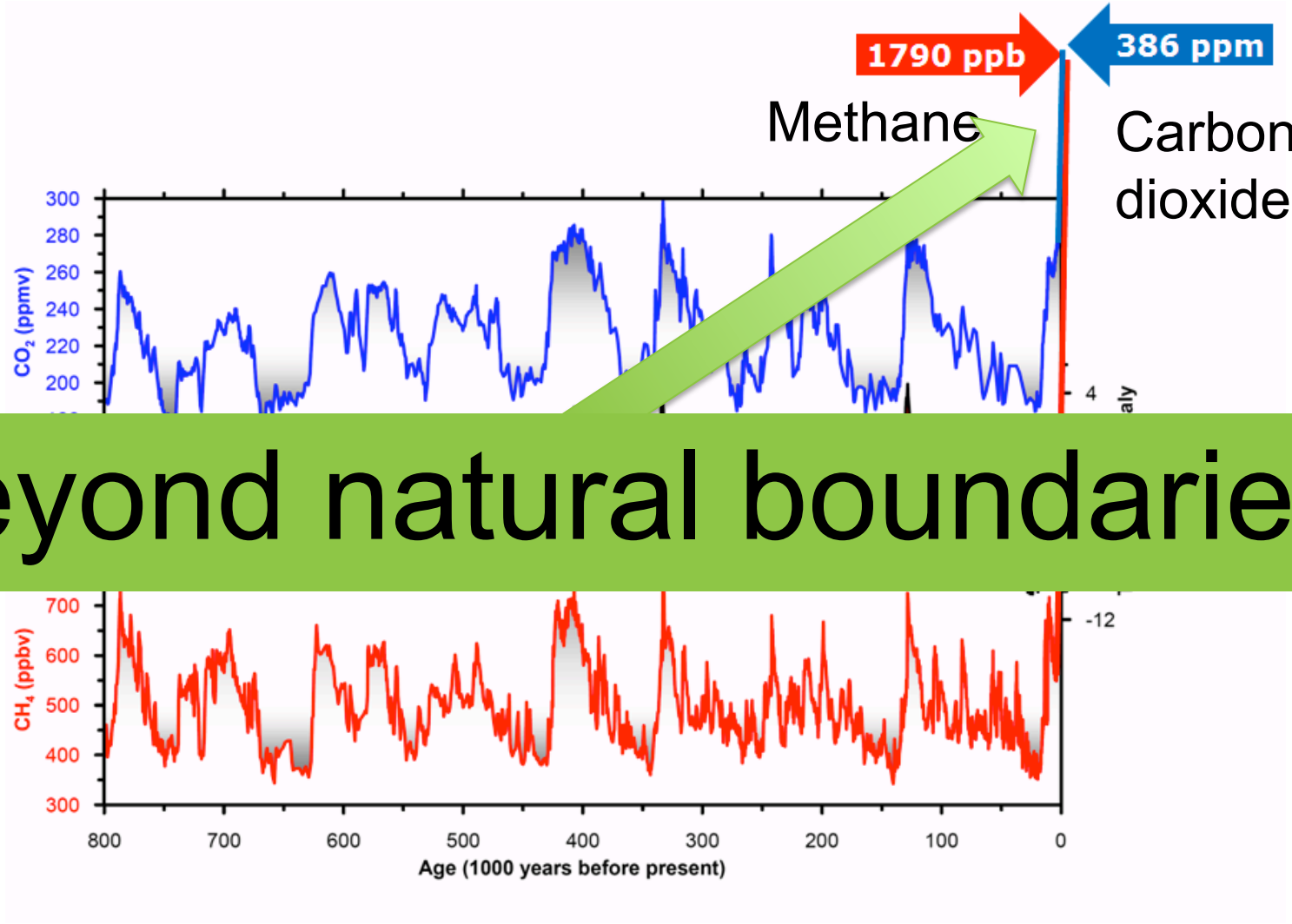
The Economist, 2011

Antarctic ice core



Beyond natural boundaries

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Loulergue, L.,et al Orbittal and millennial-scale features of atmospheric CH4 over the past 800,000 years, Nature, 2008.
Lüthi, D. et al High-resolution carbon dioxide concentration record 650,000-800,000 years before present Nature, 2008.

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

Photograph by Annie Griffiths Belt

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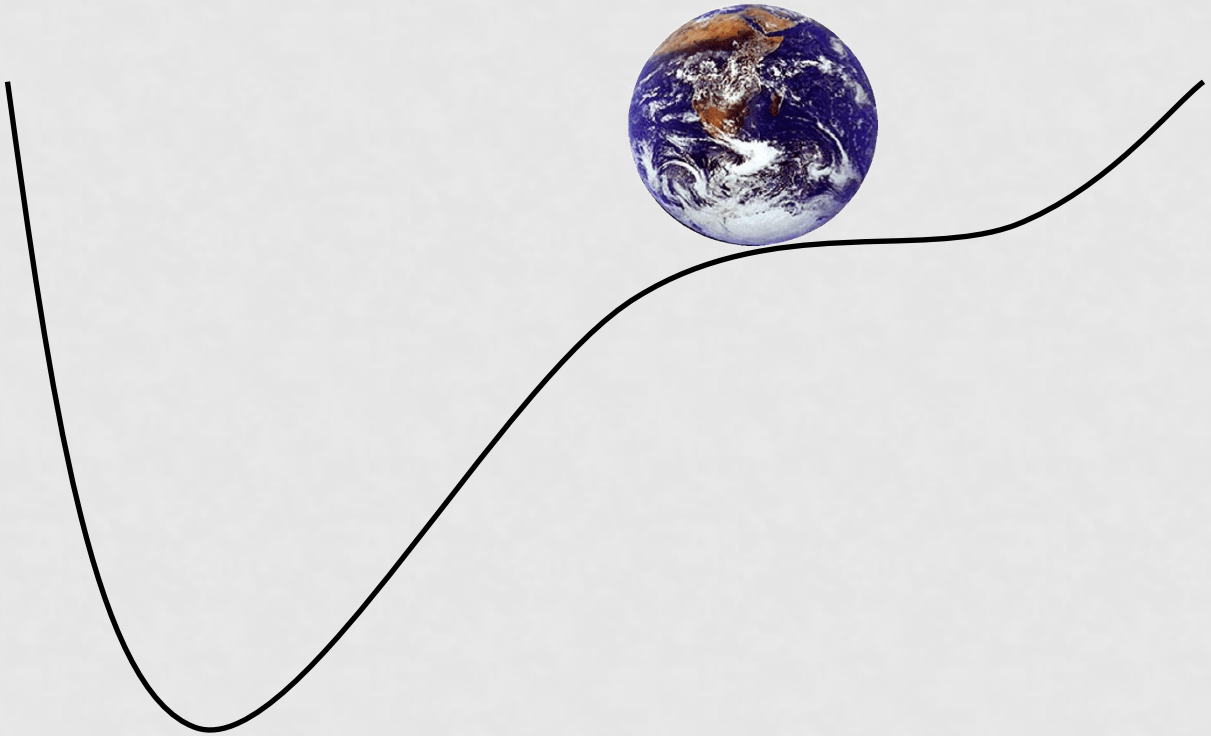
REDUCED RESILIENCE – OUR PRECARIOUS PREDICAMENT



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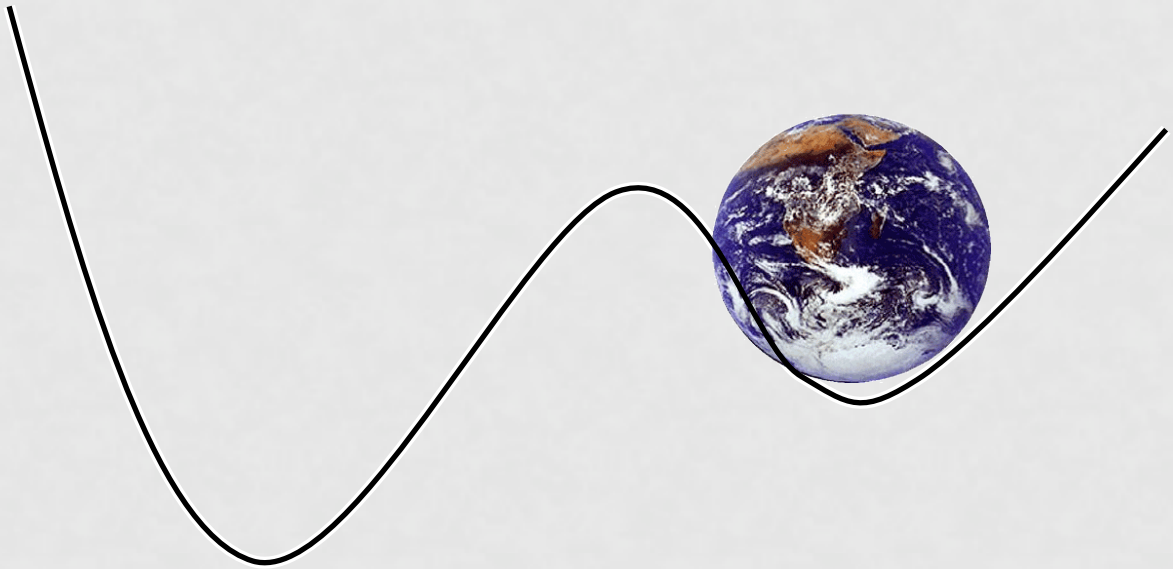
A RESILIENT EARTH SYSTEM



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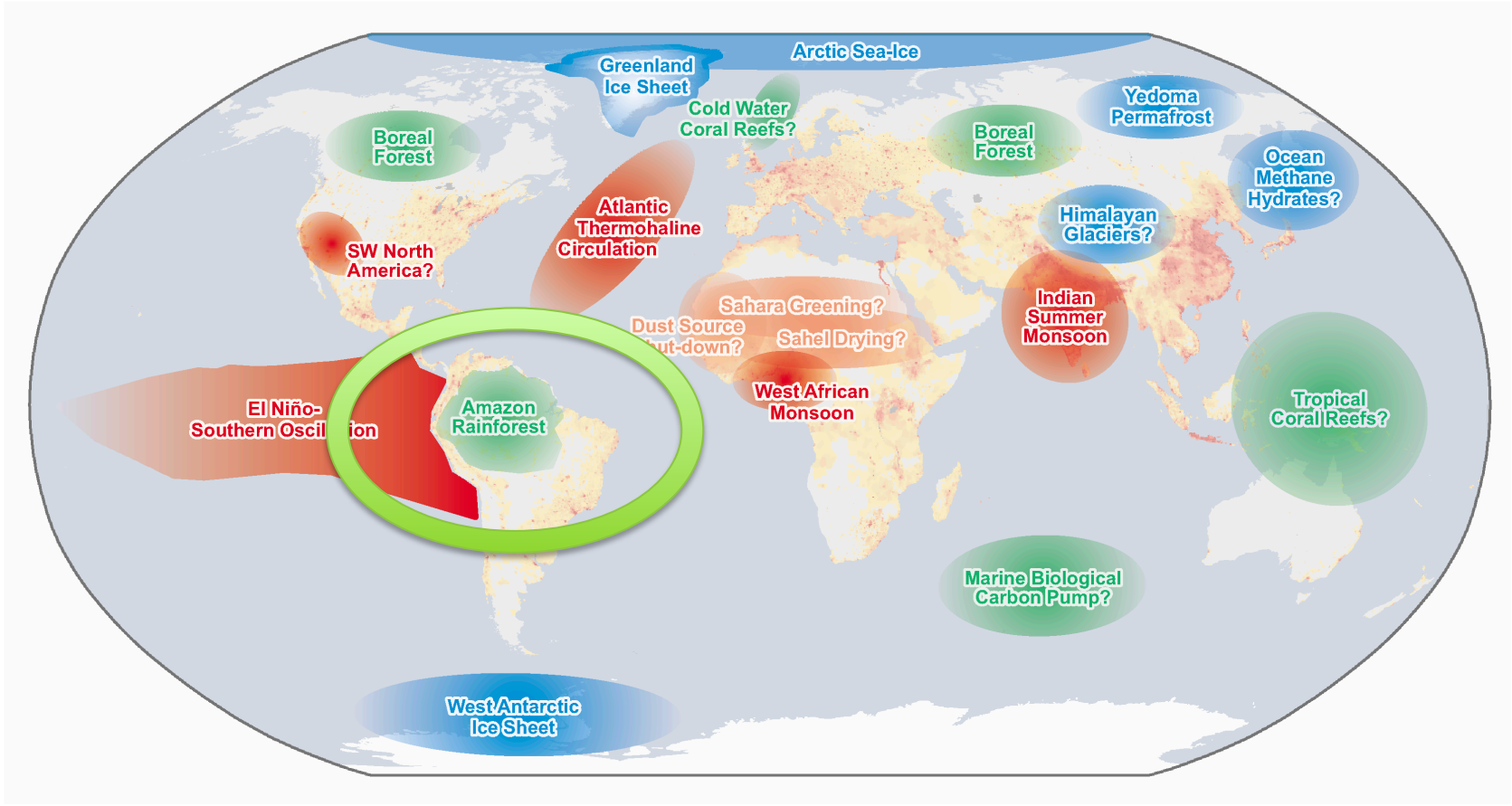
Tipping Elements in the Earth System



Melting

Circulation Change

Biome Loss

Population Density [persons per km²]

no data 0 5 10 20 100 200 300 400 1000

(Source: after Lenton et al. 2008)

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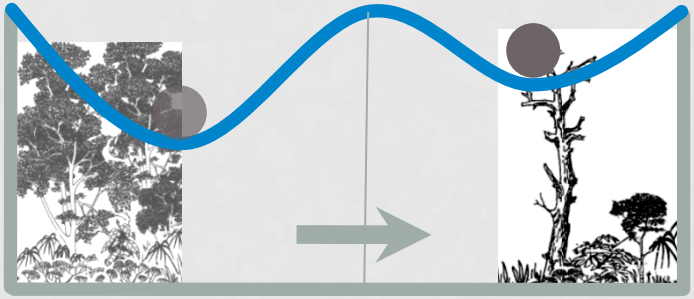
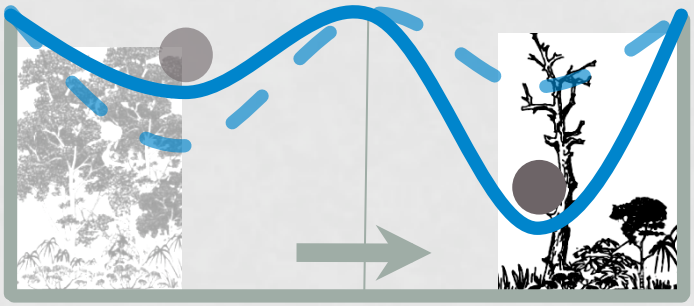
“Tipping points" for the Amazon Forest

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

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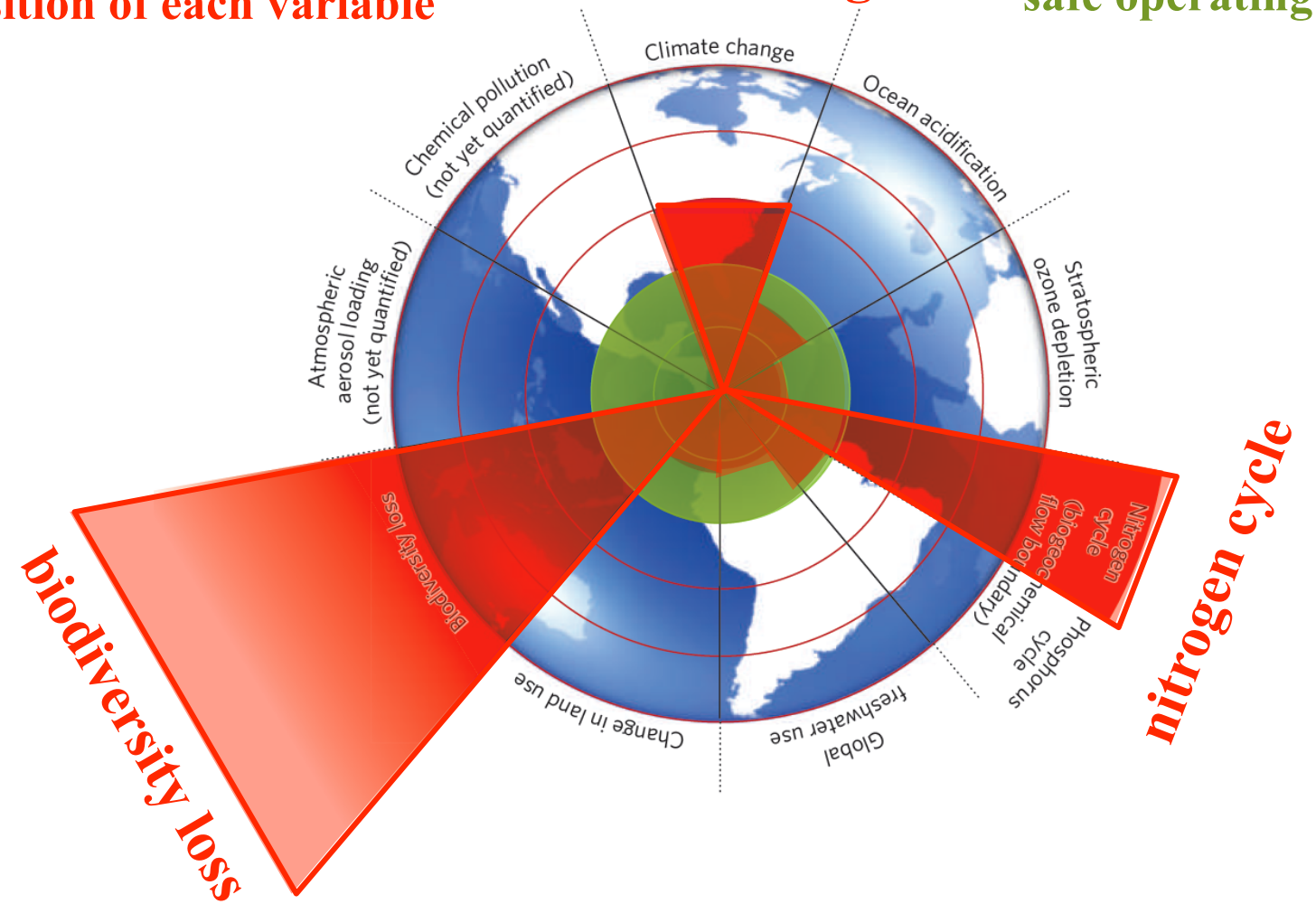
Cardoso and Borma, 2010

BEYOND THE BOUNDARIES

Red wedges: current position of each variable

Inner green shading: safe operating space



Boundaries have already been exceeded!

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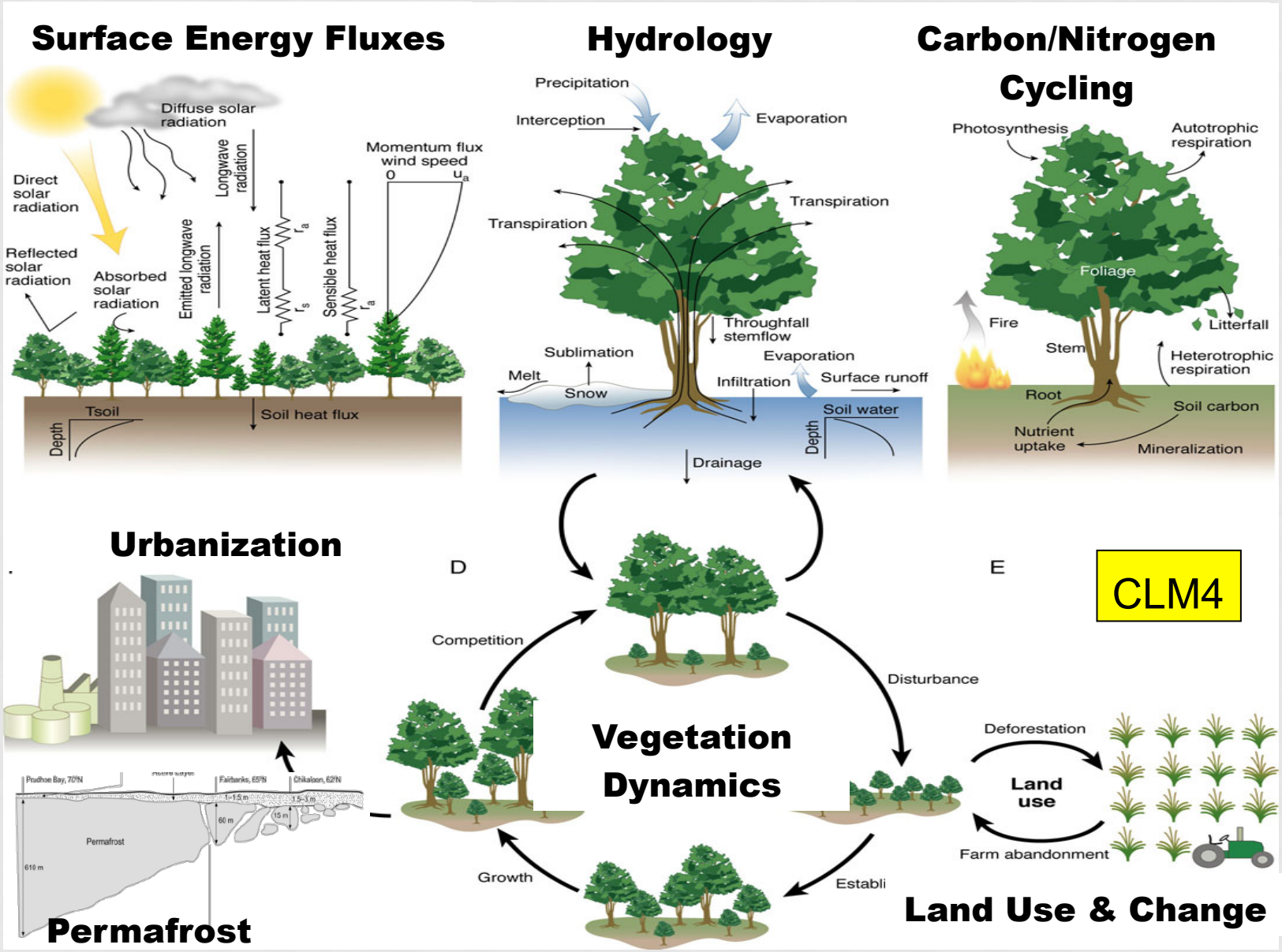
Rockstrom, 2009

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

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)

MPI-BGC Jena

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DIVERSITAS an international programme of biodiversity science

FRB

CLIMAT ENVIRONNEMENT SOCIÉTÉ Groupement d'Intérêt Scientifique

QUEST

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

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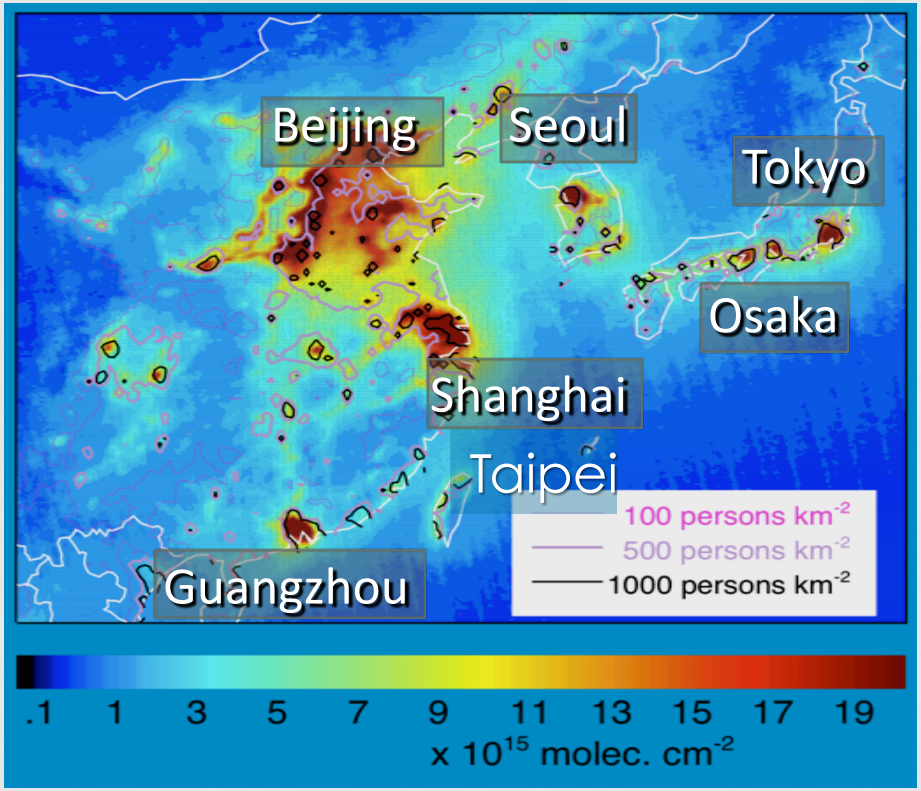
URBAN ENVIRONMENTS AND AIR QUALITY MEGACITIES

Megacities: Asia

- calibrated, comparable measurements
- capacity enhancement



NO_2 column - Randal Martin

Parrish and Zhu, 2010 Science

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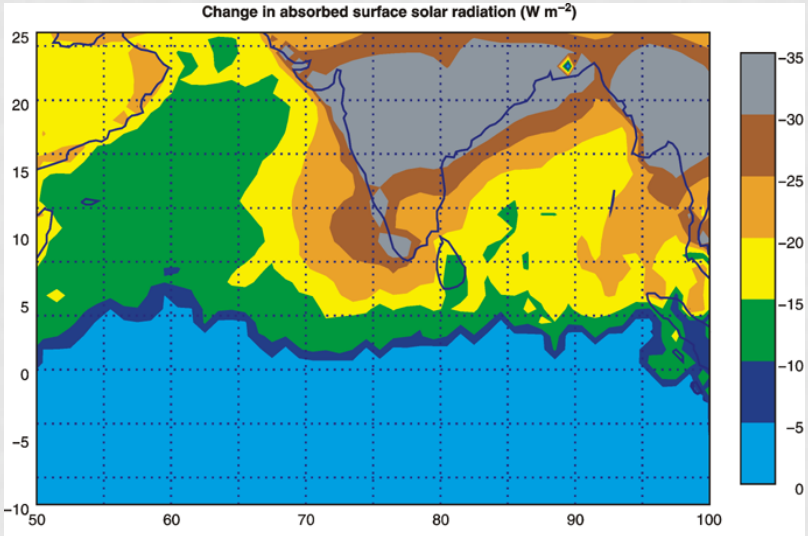
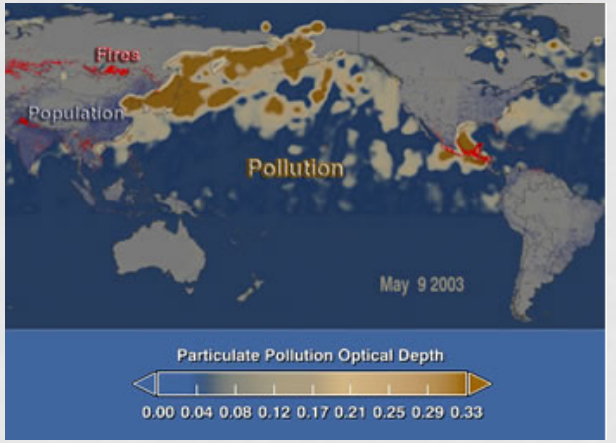
IGAC International Global Atmospheric Chemistry

AEROSOLS AND ASIAN POLLUTION AFFECTING THE ENTIRE NORTHERN HEMISPHERE - IGAC

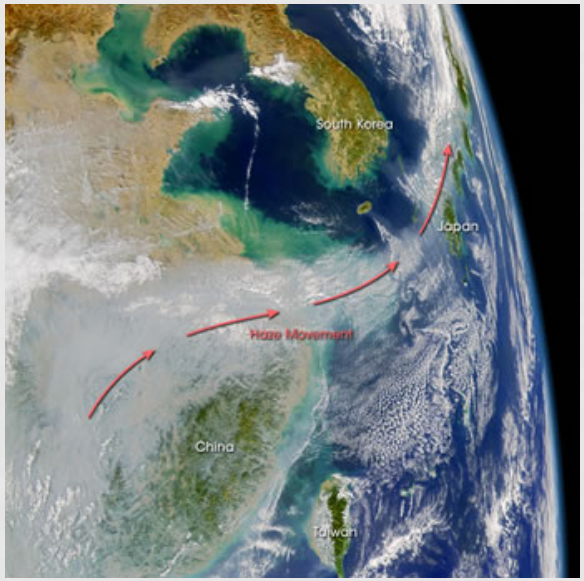


Reduction in surface solar radiation absorption due to the Indo-Asian haze effects (measured January to April from 1996-1999) (Ramanathan et al. 2001a) Steffen at al., 2004



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

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,



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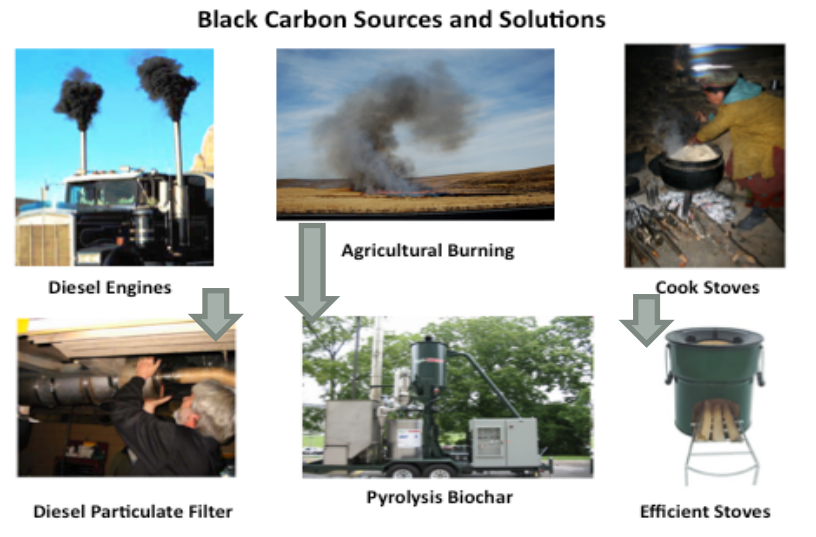
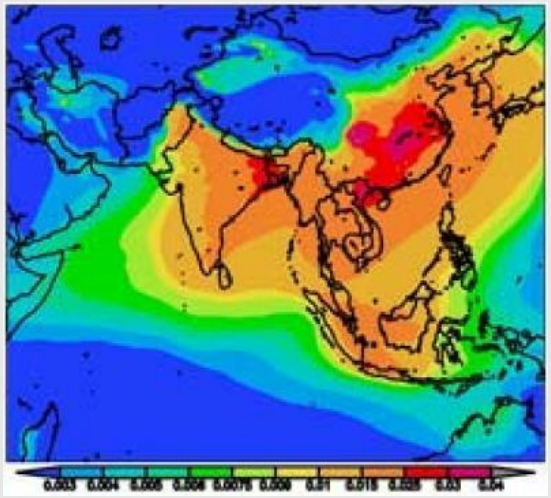
BLACK CARBON

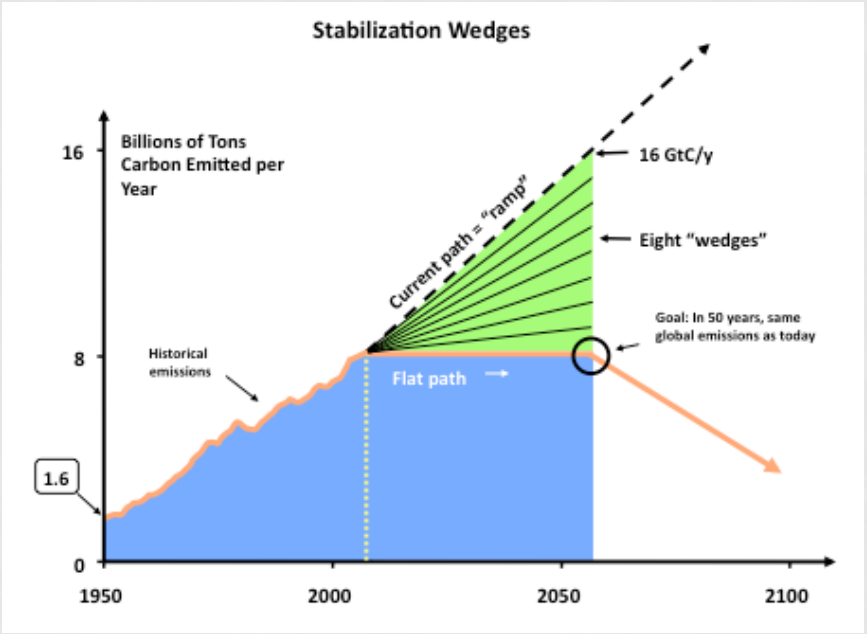




Polluting effects of cooking using biomass like wood or cow dung in south Asia: *Aerosol optical depth, (Credit: Scripps Institution of Oceanography, UC San Diego)*

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_2 Ramanathan and Carmichael.

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



Clean Air Task Force, 2010

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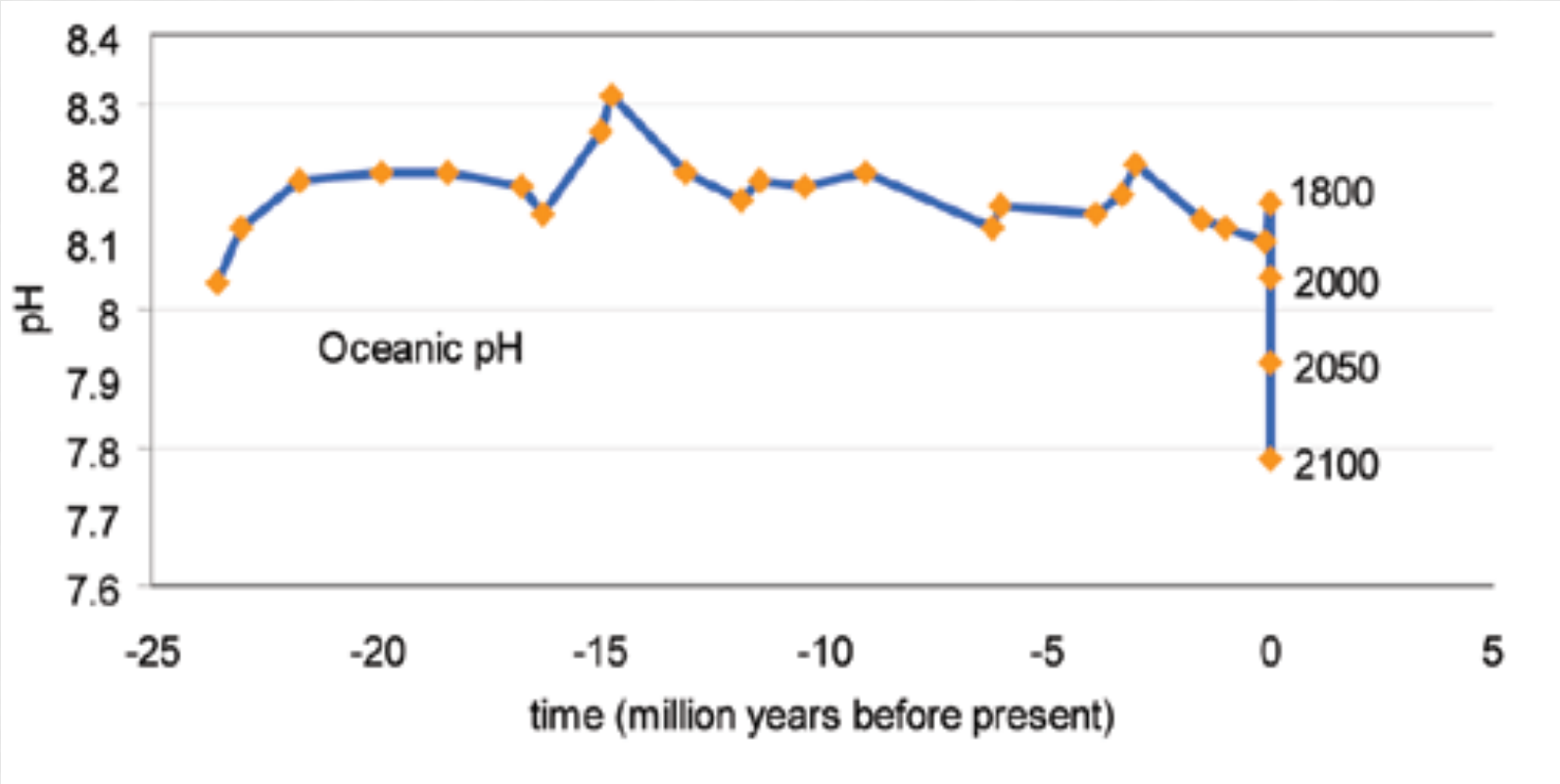
OCEAN ACIDIFICATION

PAST AND PRESENT VARIABILITY OF MARINE PH

THE OTHER HALF OF THE CO2 PROBLEM



Based on IPCC mean scenarios

Turley et al. 2006

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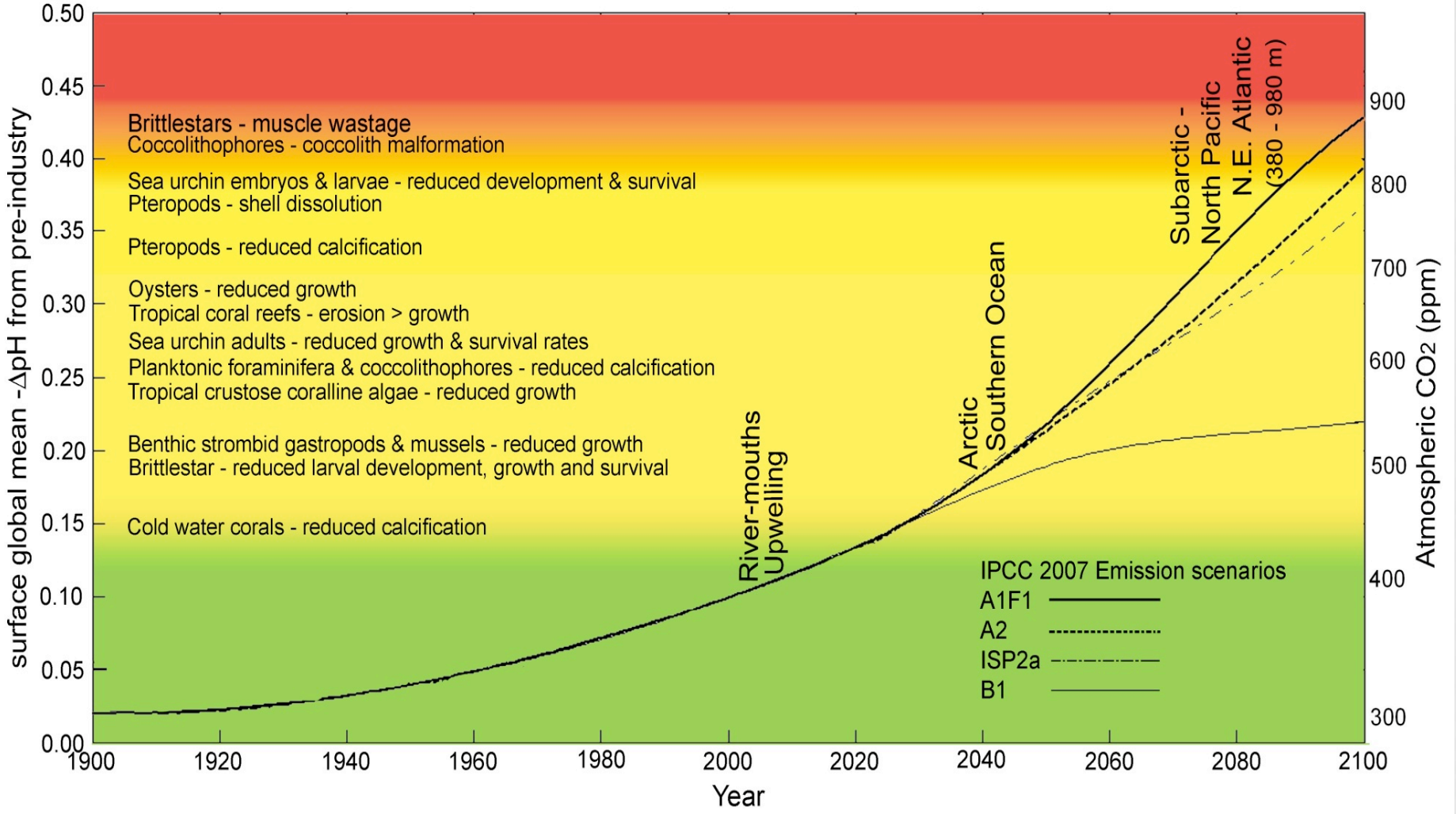
FUTURE CO2 EMISSIONS COULD IMPACT SOME MARINE ORGANISMS AND ECOSYSTEMS THIS CENTURY



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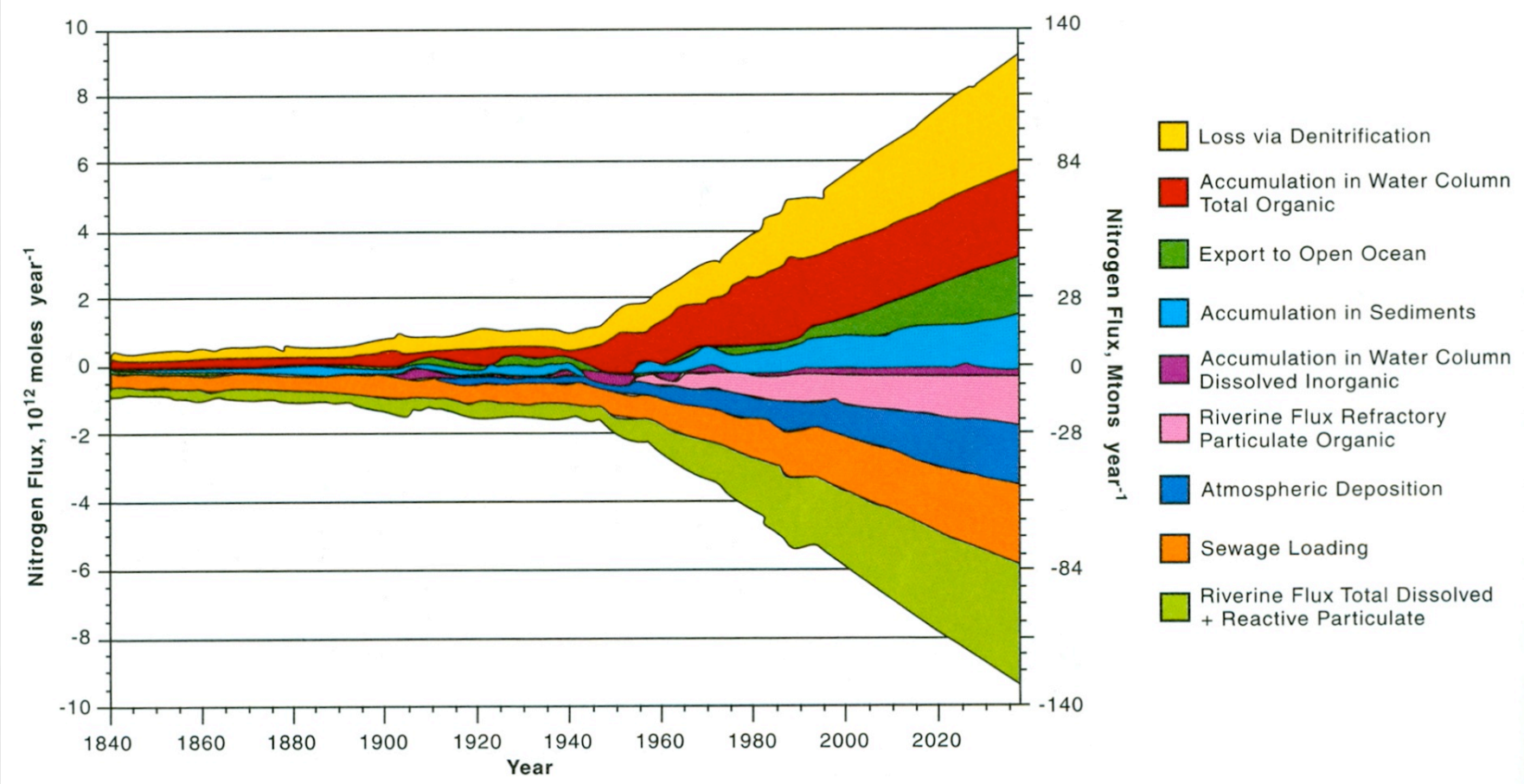
Turley et al. (2010) The societal challenge of ocean acidification Marine Pollution Bulletin

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 at al., 2004 based on Mackenzie et al. 2002)

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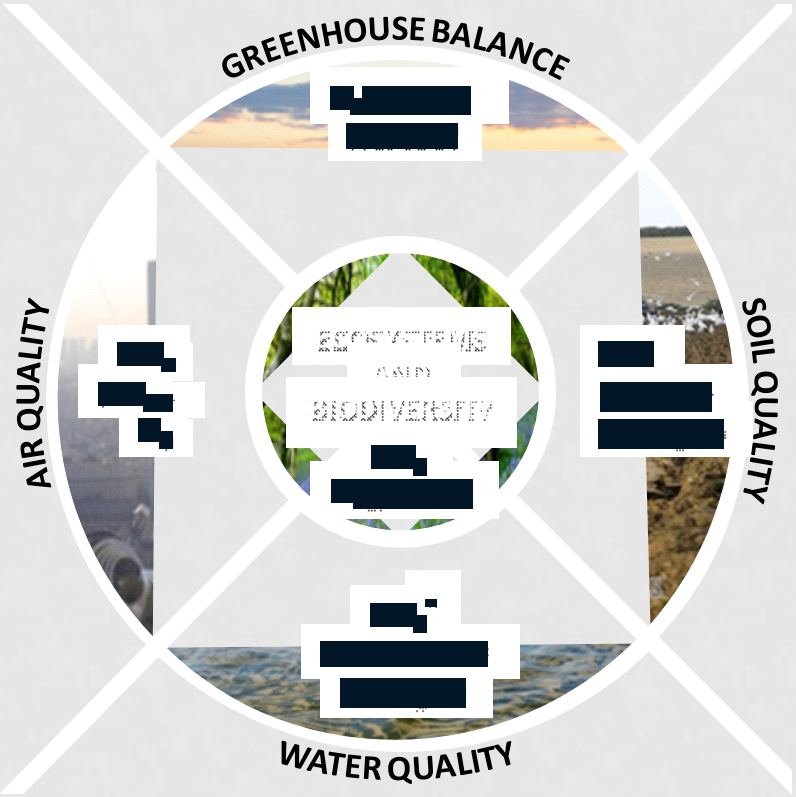
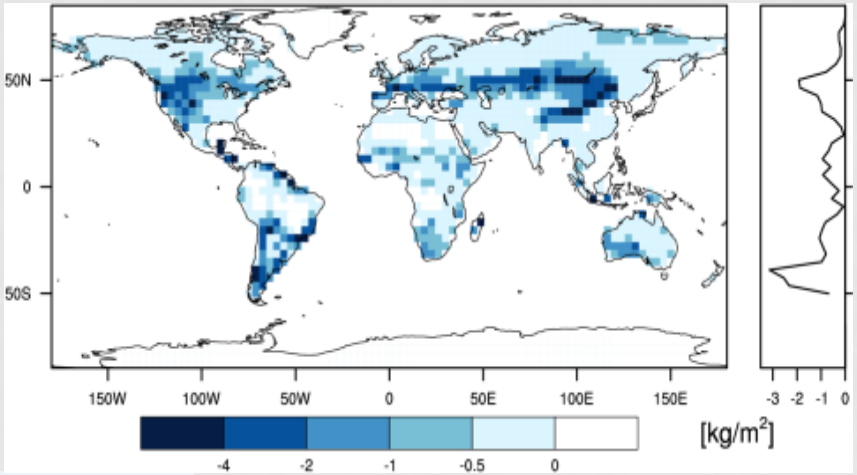
THE FIVE KEY THREATS OF EXCESS NITROGEN

Water quality
Air quality
Greenhouse balance
Ecosystems
Soil quality





CO_2 induced nitrogen limitation in the 21st century (JSBACH-CNP)
Goll et al., 2011

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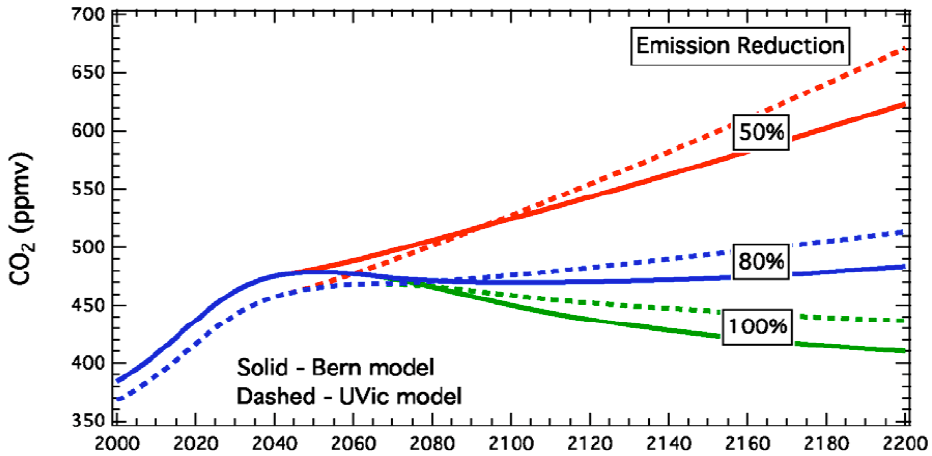
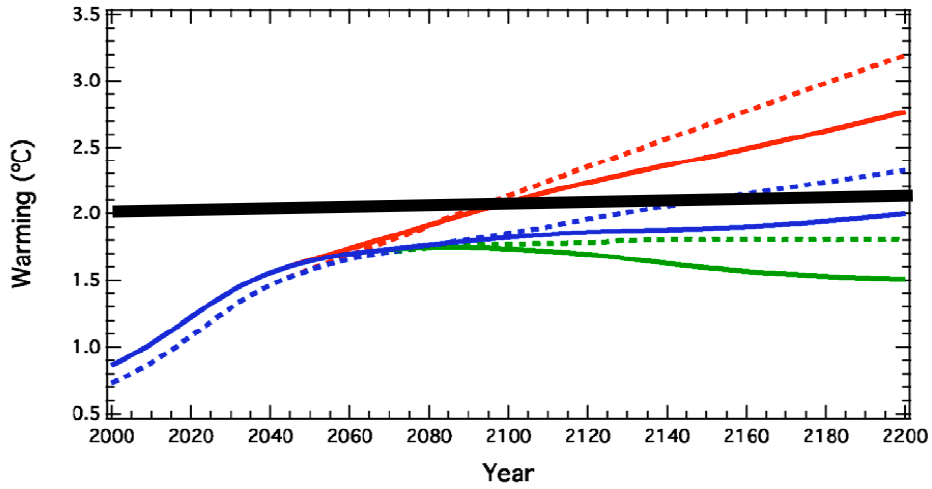
THE FOURTH GRAND CHALLENGE:
MANAGING THE EARTH SYSTEM

- 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^{0}C

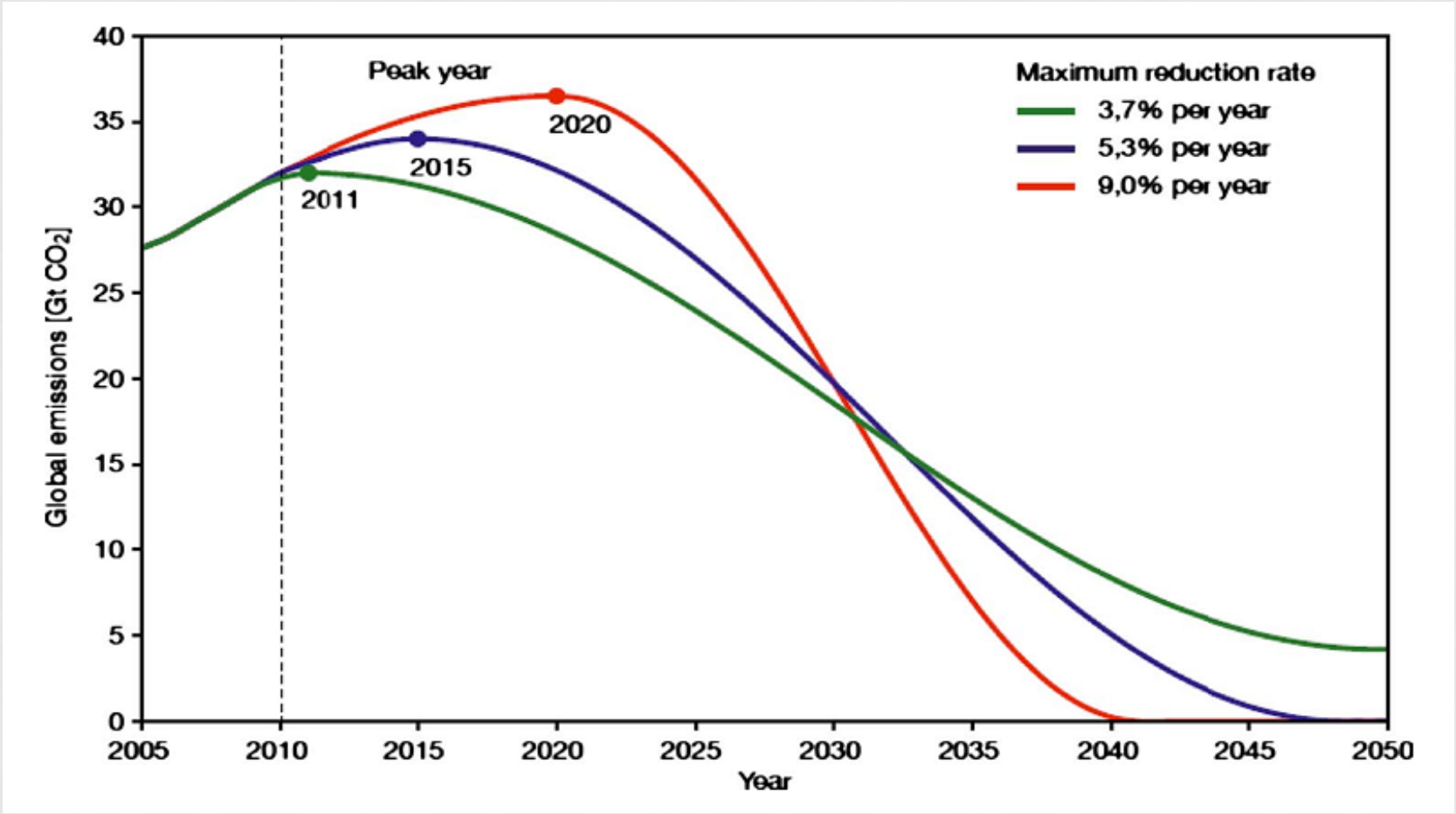




National Research Council, 2010

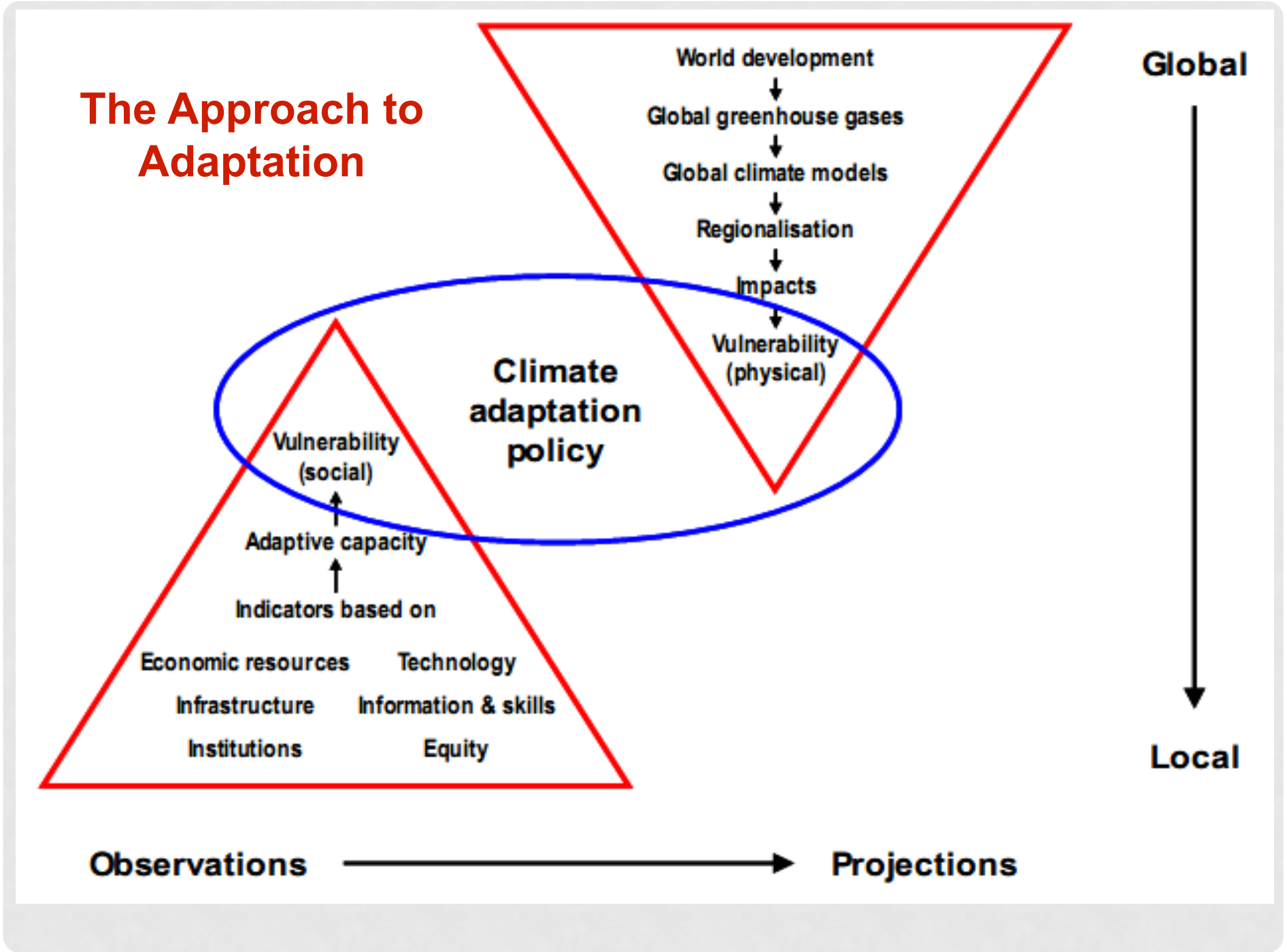
THE WAY TO A DE-CARBONIZED SOCIETY AND LIMITED CLIMATE CHANGE (2 C)

LIMIT THE TOTAL EMISSION OF CO2 TO 750 GT IN THE NEXT 40 YEARS

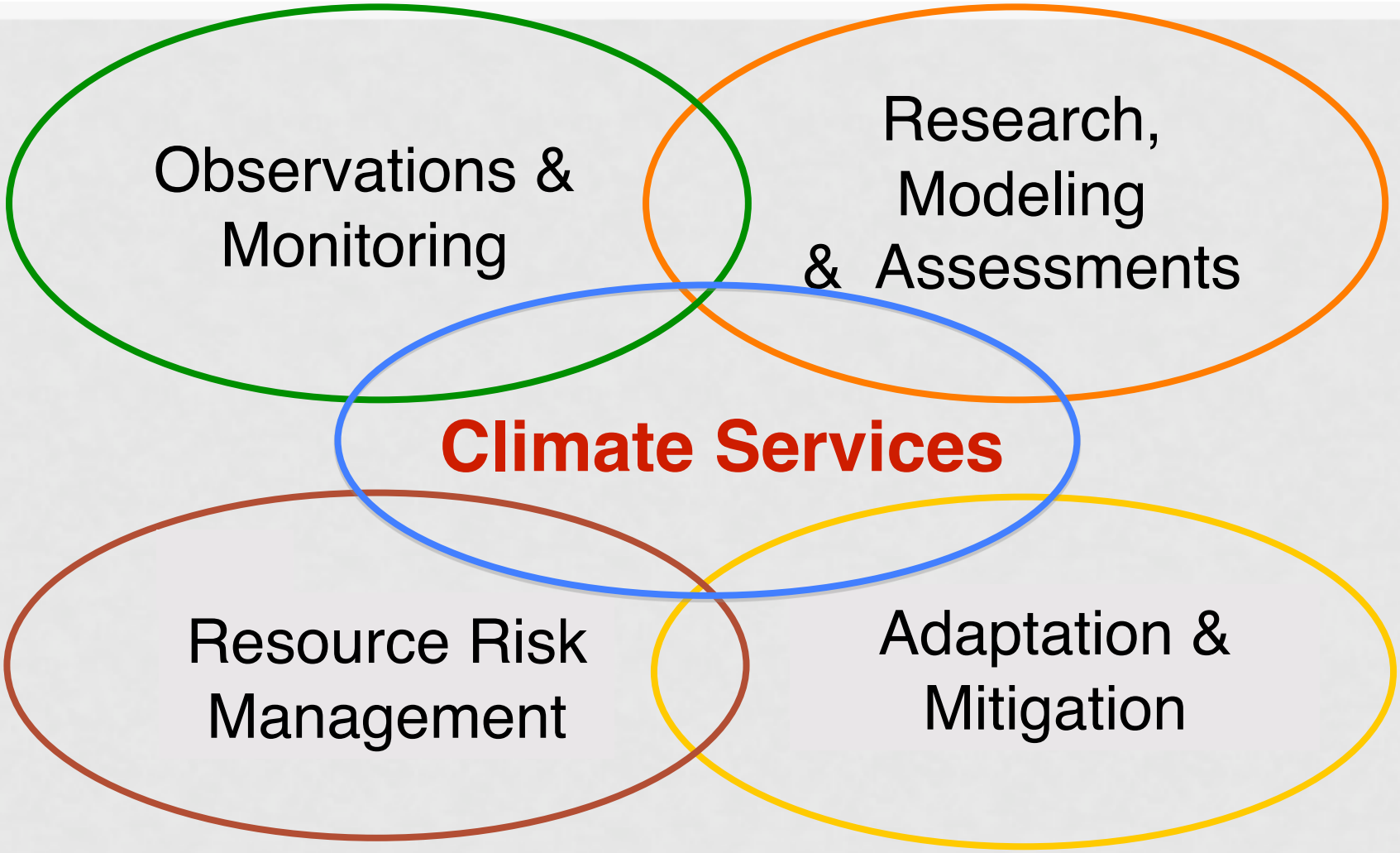


Messner et al. (2010) and WGBU

Adapting to Unavoidable Climate Change


The Approach to Adaptation
World development
Global greenhouse gases
Global climate models
Regionalisation
Impacts
Vulnerability (physical)
Global
Climate adaptation policy
Vulnerability (social)
Adaptive capacity
Indicators based on
Economic resources
Technology
Infrastructure
Information & skills
Institutions
Equity
Local
Observations
Projections

Climate Services will Require an Unprecedented Level of Coordination

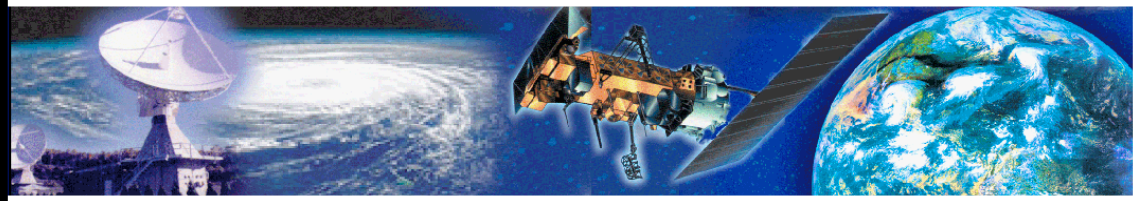


We have some Global Earth Observations

We don't have:

Discipline Specific View

Whole System View

Atmospheric Observations		
Data Systems		
Ocean Observations		
Space Observations		
Technology Development	Innovations Breakthrough Efficiencies Cost Mass Productions	Breakthrough Innovations Efficiencies Cost Mass Productions

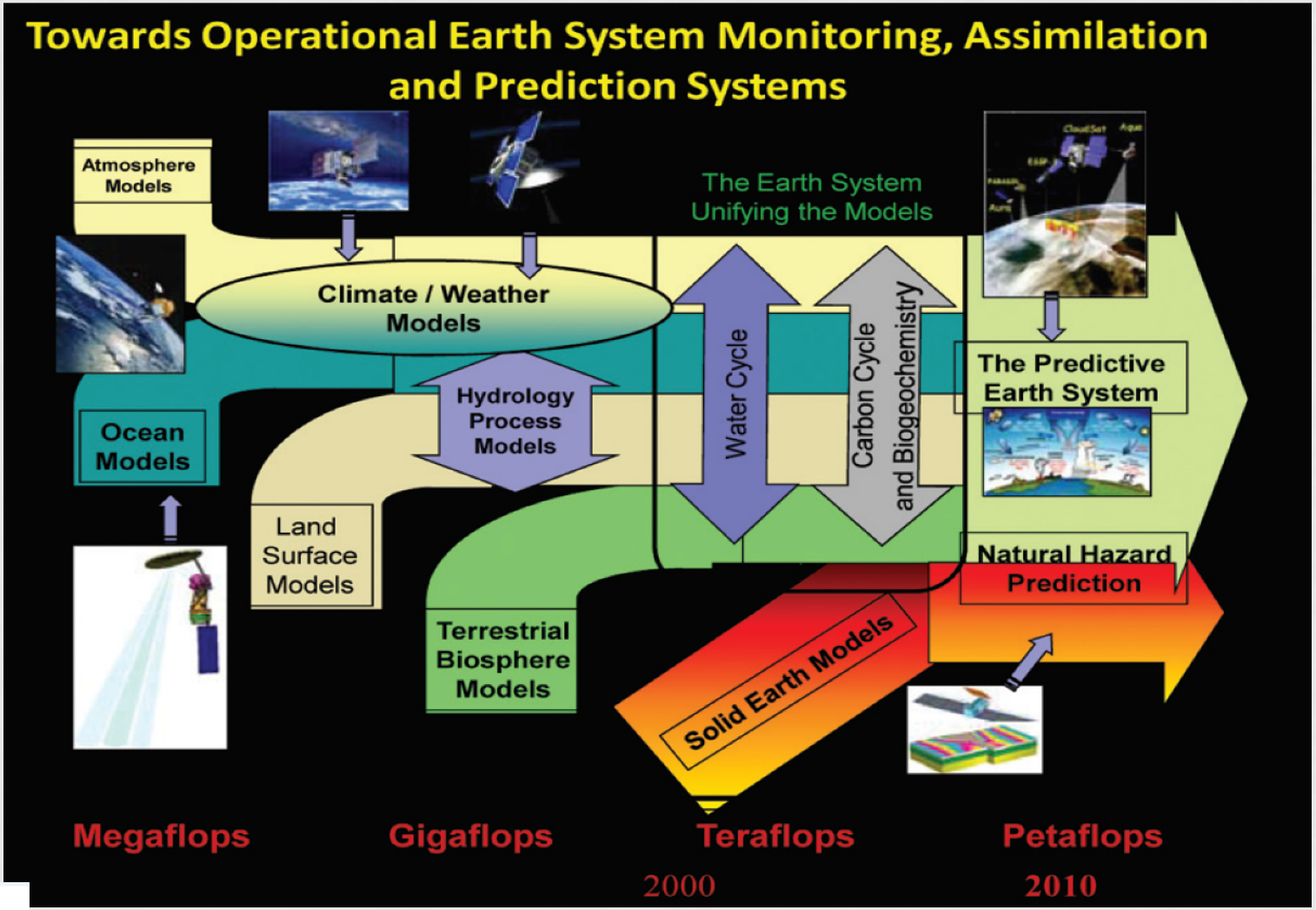
20th Century

21st Century

OBSERVING SYSTEM TIMELINE

From Tom Karl

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



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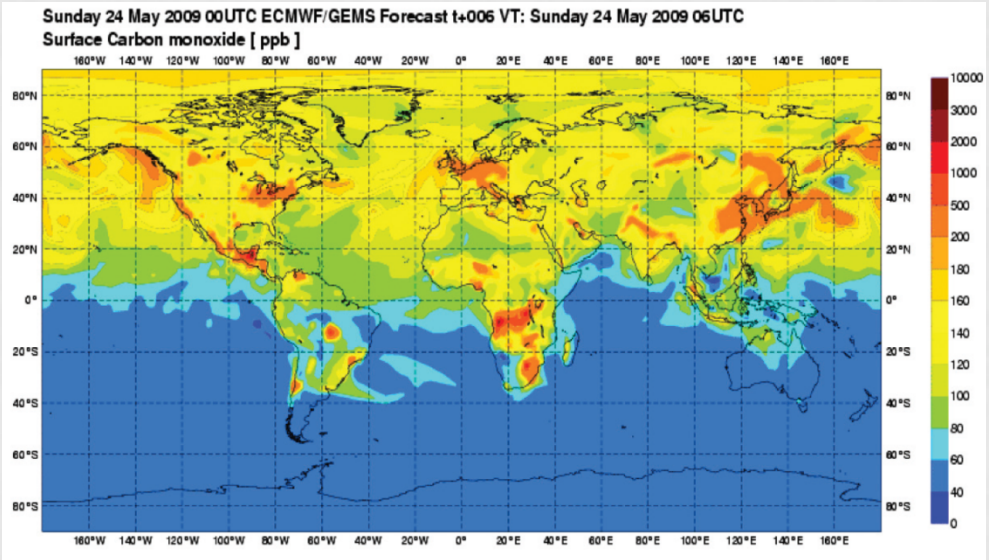
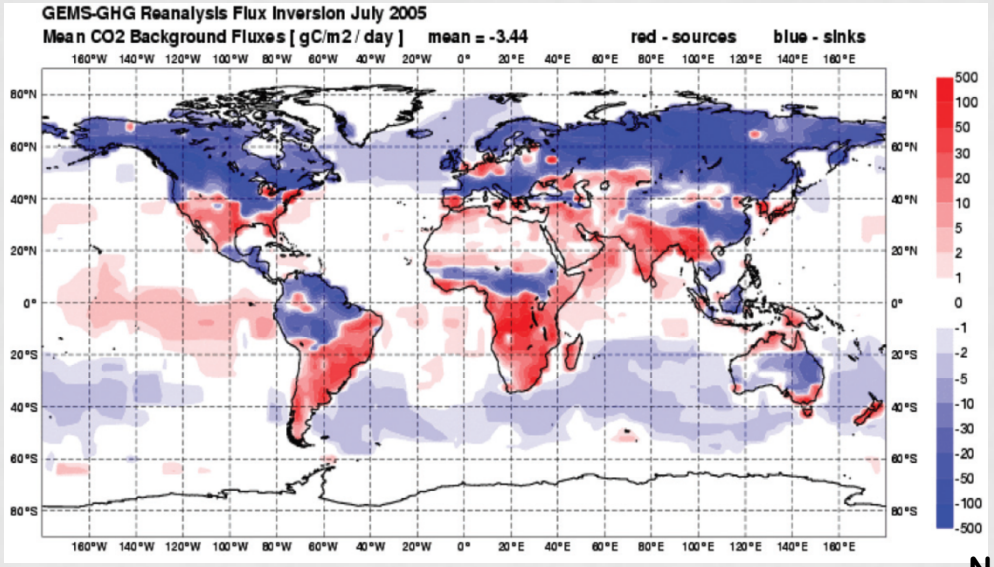
Nobre et al, BAMS, 2010

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 (gC m−2 day−1) derived from atmospheric CO_2 observations by the AIRS and atmospheric transport calculated using winds from the ECMWF reanalysis



= sources

= sinks

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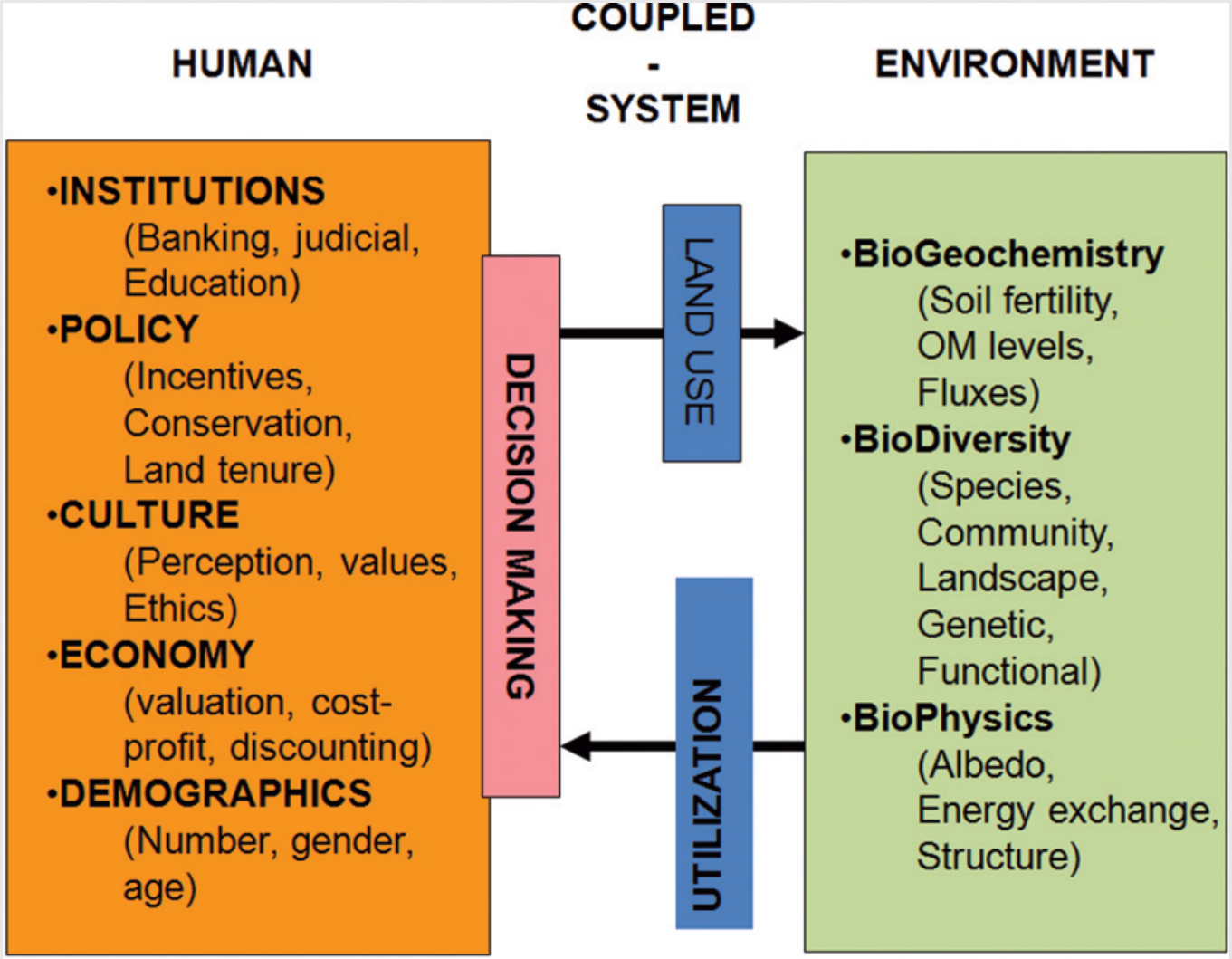
Nobre et al, BAMS 2010

THE CHALLENGE OF INTRODUCING THE HUMAN DIMENSION IN EARTH SYSTEM MODELS



MODEL OF A COUPLED HUMAN–ENVIRONMENTAL SYSTEM

Nobre et al, BAMS, 2010

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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

PLANET UNDER PRESSURE

2012 MARCH 26-29 LONDON

NEW KNOWLEDGE TOWARDS SOLUTIONS

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

DIVERSITAS

IHDP

WCRP World Climate Research Programme

ICSU International Council for Science

And their Earth System Science Partnership

Thank you