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.
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
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.)
GLOBAL WATER VAPOR (14 KM RESOLUTION)

HOMME Model. M. Taylor, Sandia
THE THIRD GRAND CHALLENGE:
UNDERSTANDING THE EARTH AS A COMPLEX
NONLINEAR INTERACTIVE SYSTEM

• 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)
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

NATURE, 2002
Geology of Mankind
IGBP Vice Chair, Paul Crutzen,
Welcome to the Anthropocene
Geology’s new age

The Economist, 2011
Antarctic ice core


WHERE ARE THE THRESHOLDS AND TIPPING ELEMENTS IN THE EARTH SYSTEM?
REDUCED RESILIENCE – OUR PRECARIOUS PREDICAMENT
A RESILIENT EARTH SYSTEM
Tipping Elements in the Earth System

(Source: after Lenton et al. 2008)
"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

Cardoso and Borma, 2010
Red wedges: current position of each variable

Inner green shading: safe operating space

climate change

Boundaries have already been exceeded!

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
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)
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$_2$ 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.
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 Tropospheric Ozone 2011
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
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

CO₂ induced nitrogen limitation in the 21st 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 adaptation policy

- World development
  - Global greenhouse gases
  - Global climate models
    - Regionalisation
      - Impacts
        - Vulnerability (physical)

- Vulnerability (social)
  - Adaptive capacity
    - Indicators based on
      - Economic resources
      - Technology
      - Infrastructure
      - Information & skills
      - Institutions
      - Equity

Observations → Projections

Local

Global
Climate Services will Require an Unprecedented Level of Coordination

Observations & Monitoring

Research, Modeling & Assessments

Climate Services

Resource Risk Management

Adaptation & Mitigation
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<th>Atmospheric Observations</th>
<th>Data Systems</th>
<th>Ocean Observations</th>
<th>Space Observations</th>
<th>Technology Development</th>
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| From Tom Karl

**OBSERVING SYSTEM TIMELINE**

*From Tom Karl*
ELEMENTS OF A COMPLEX EARTH SYSTEM ANALYSIS AND PREDICTION SYSTEM, AND THE COMPUTATIONAL REQUIREMENT

Towards Operational Earth System Monitoring, Assimilation and Prediction Systems

- Atmosphere Models
- Ocean Models
- Land Surface Models
- Terrestrial Biosphere Models
- Hydrology Process Models
- Climate / Weather Models
- Water Cycle
- Carbon Cycle and Biogeochemistry
- The Earth System Unifying the Models
- The Predictive Earth System
- Natural Hazard Prediction
- Solid Earth Models

Megaflops, Gigaflops, Teraflops, Petaflops

2000, 2010

Nobre et al, BAMS, 2010
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.

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
• 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.
Thank you