# Climate Change and the '*Safe Operating Space*' for Humanity in the Anthropocene



**Carlos A. Nobre**
**Ministry of Science, Technology and Innovation of Brazil**

**IAP Conference on Grand Challenges and Integrated Innovations: Science for Poverty Eradication and Sustainable Development**

**Rio de Janeiro, 25 February 2013**











# Earth System, the ways it is changing, and the implications for global and regional sustainability

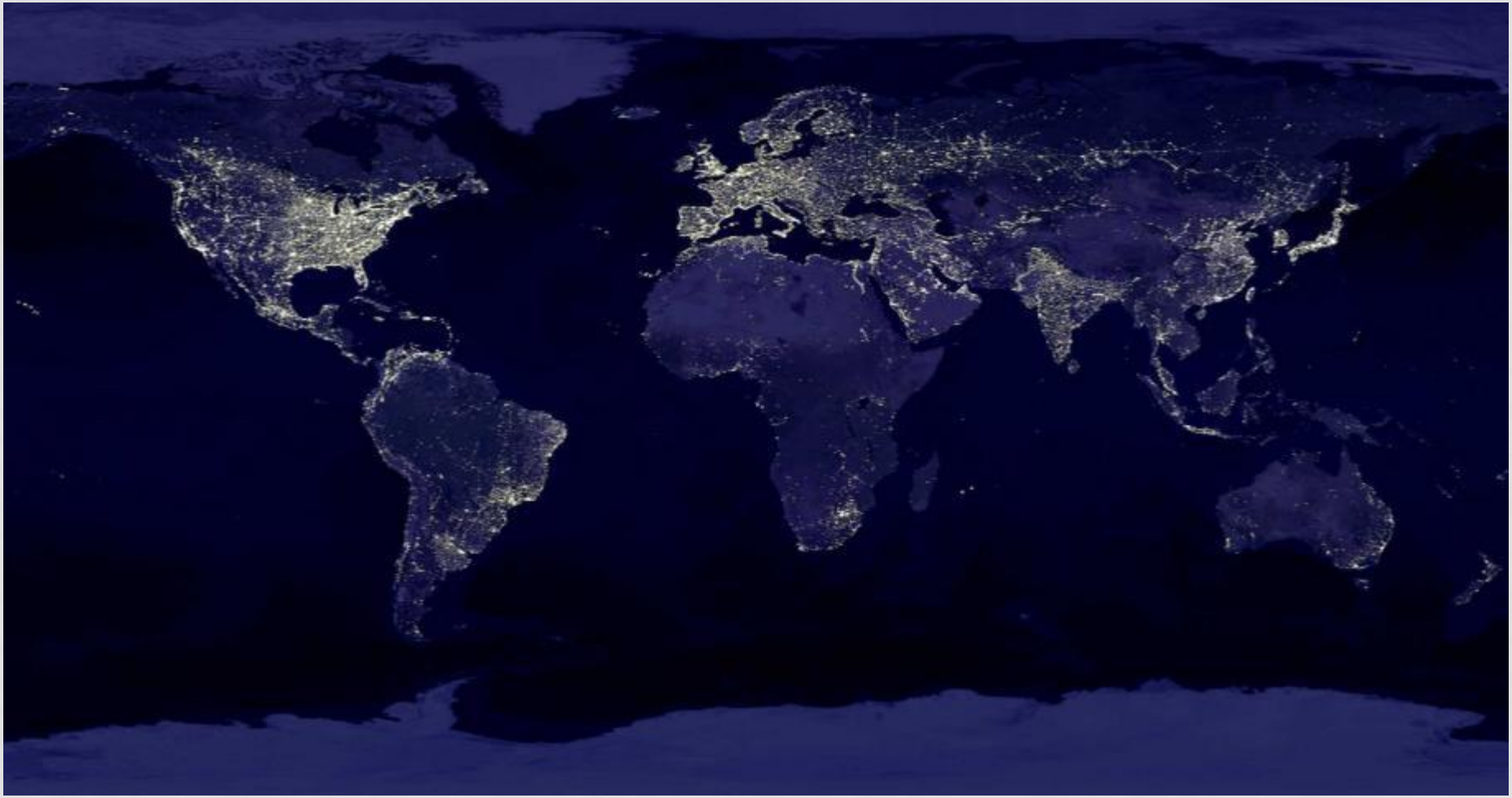




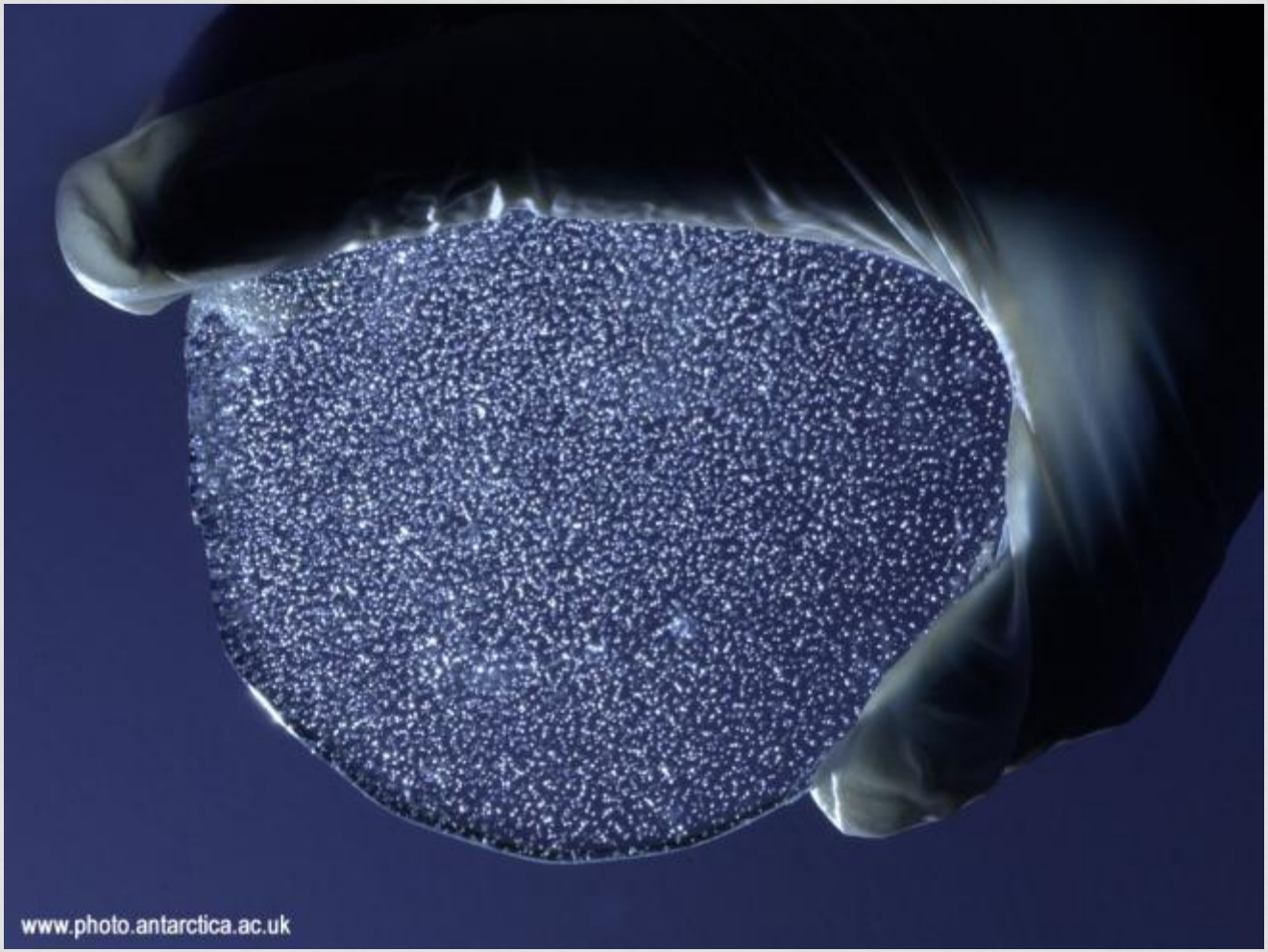

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

# HAVE WE ENTERED A NEW GEOLOGICAL EPOCH?

## *THE ANTHROPOCENE*



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www.photo.antarctica.ac.uk

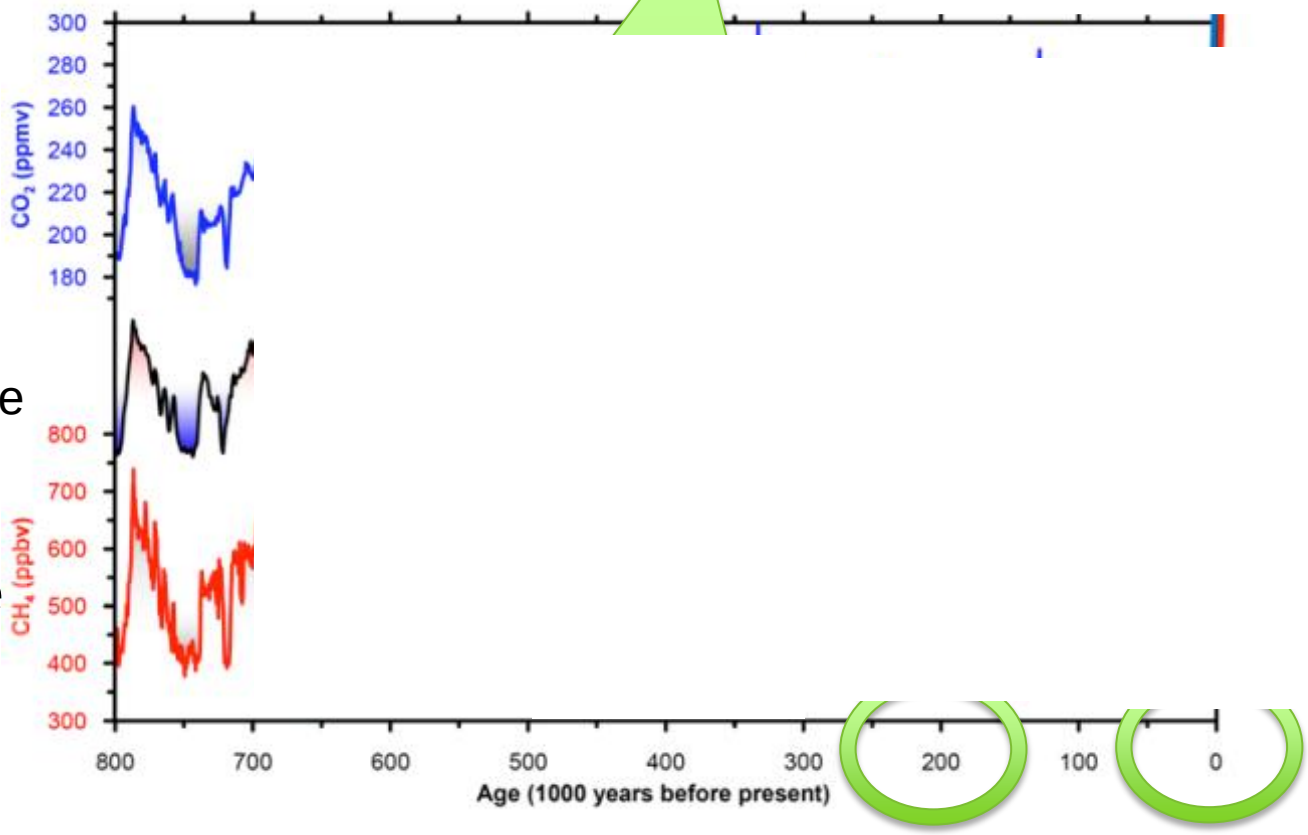
# Antarctic ice core

## Modern humans appear in Africa

Carbon dioxide

Temperature

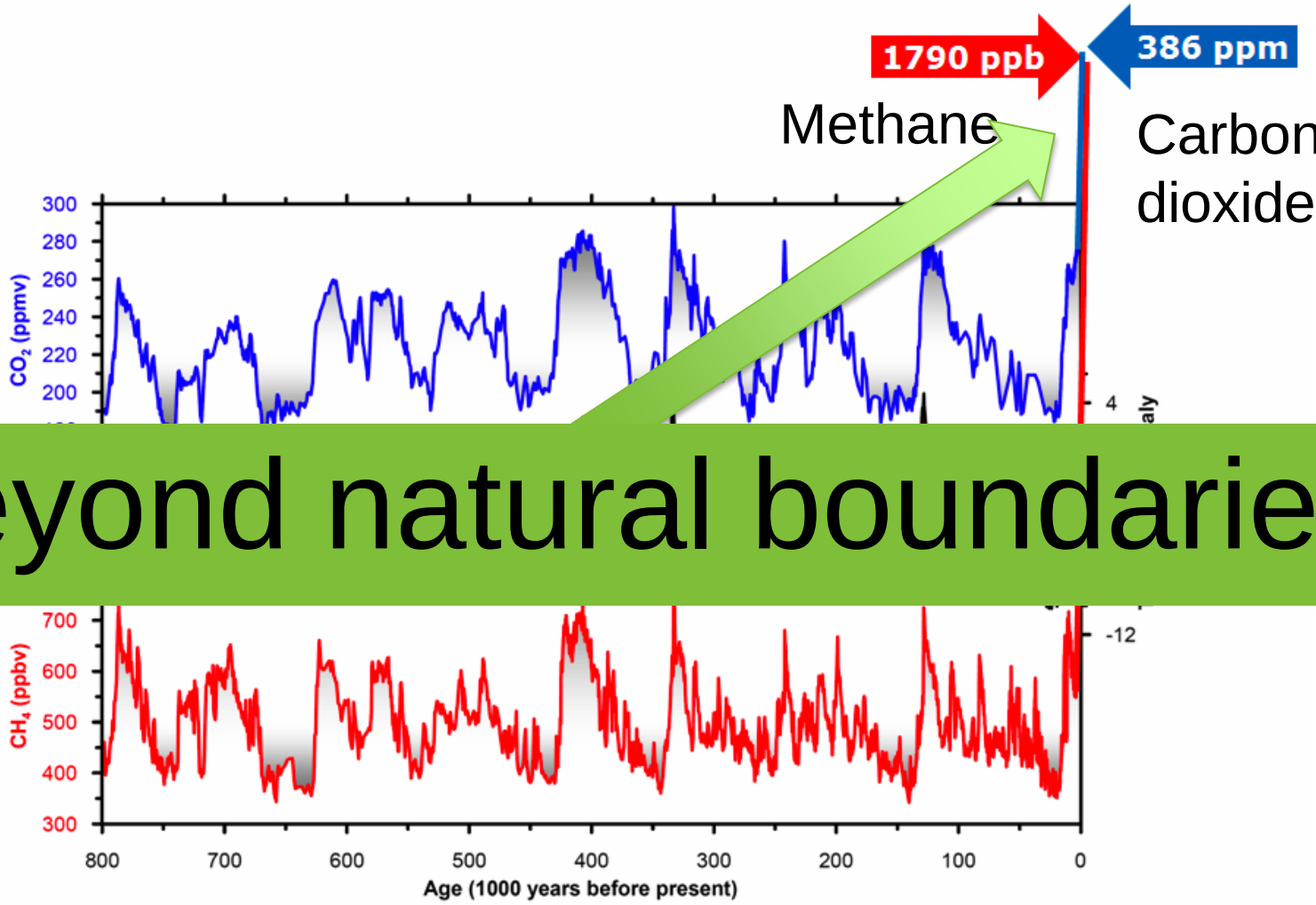
Methane




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.

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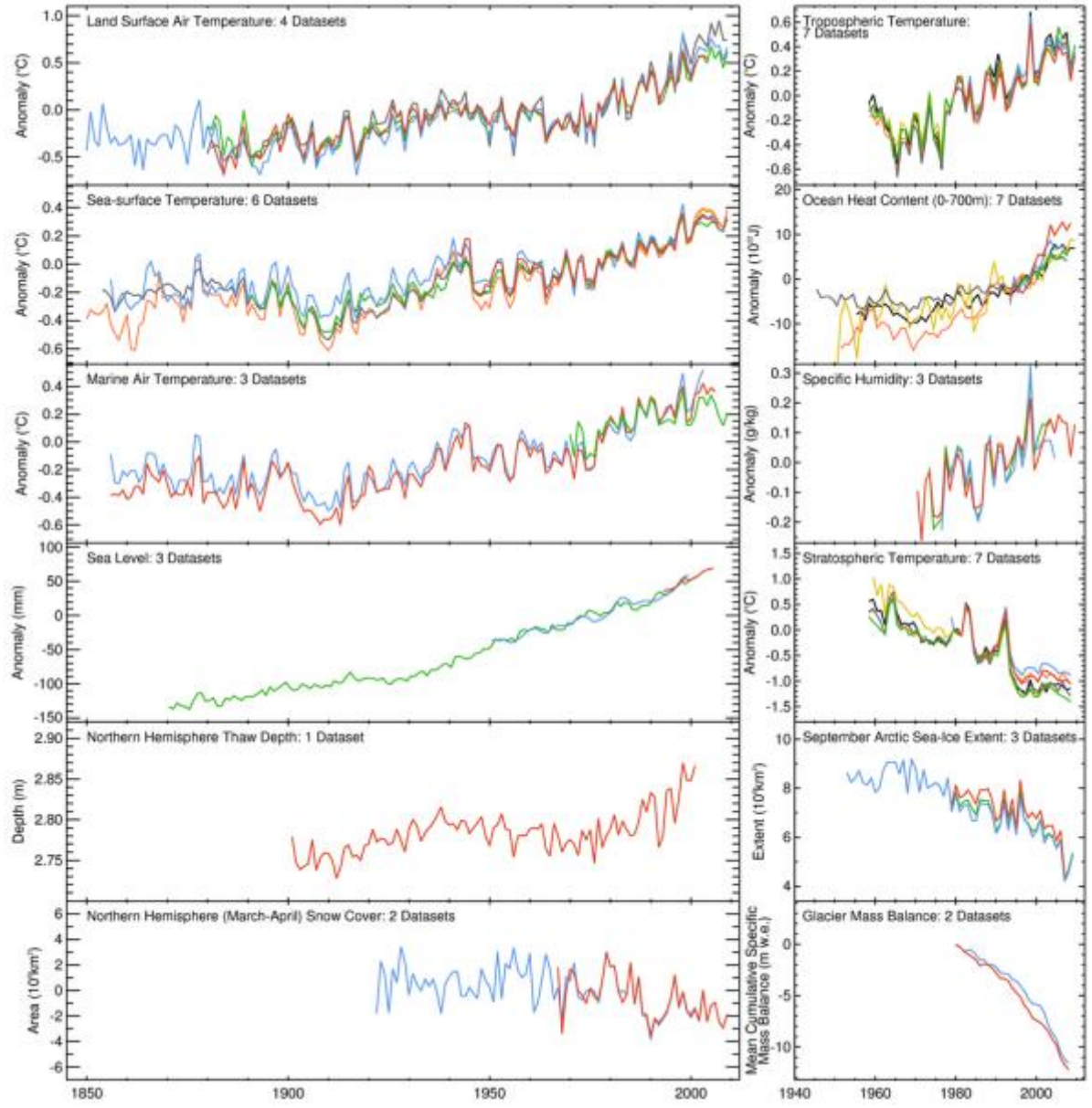
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**Beyond natural boundaries**

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.

GLOBAL IGBP International Geosphere-Biosphere Programme CHANGE



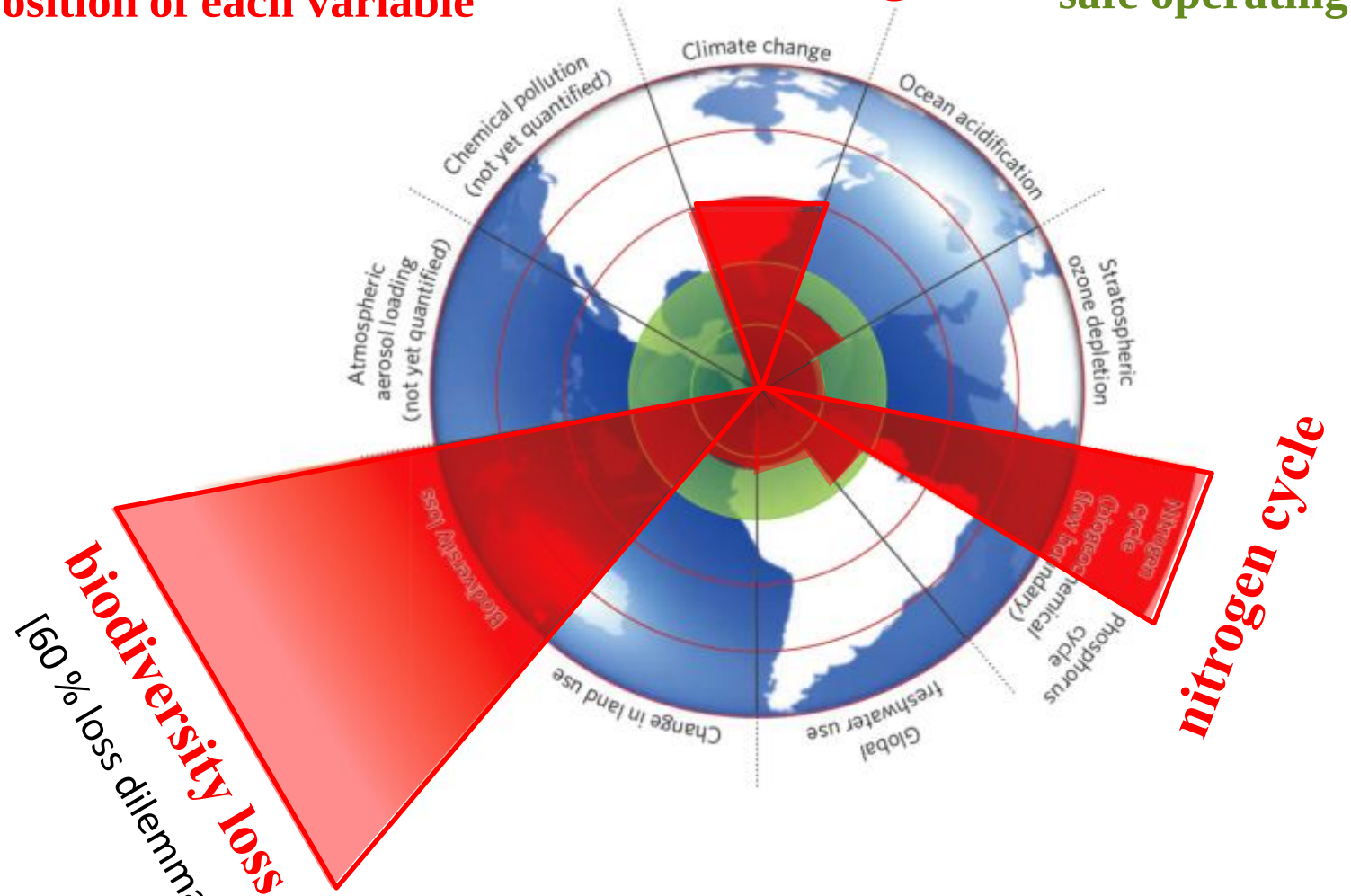

The climate is changing ….

# BEYOND THE BOUNDARY

**Red wedges: current position of each variable**

[560/450/400 dilemma]
**climate change**

**Inner green shading: safe operating space**




**biodiversity loss**
[60 % loss dilemma]

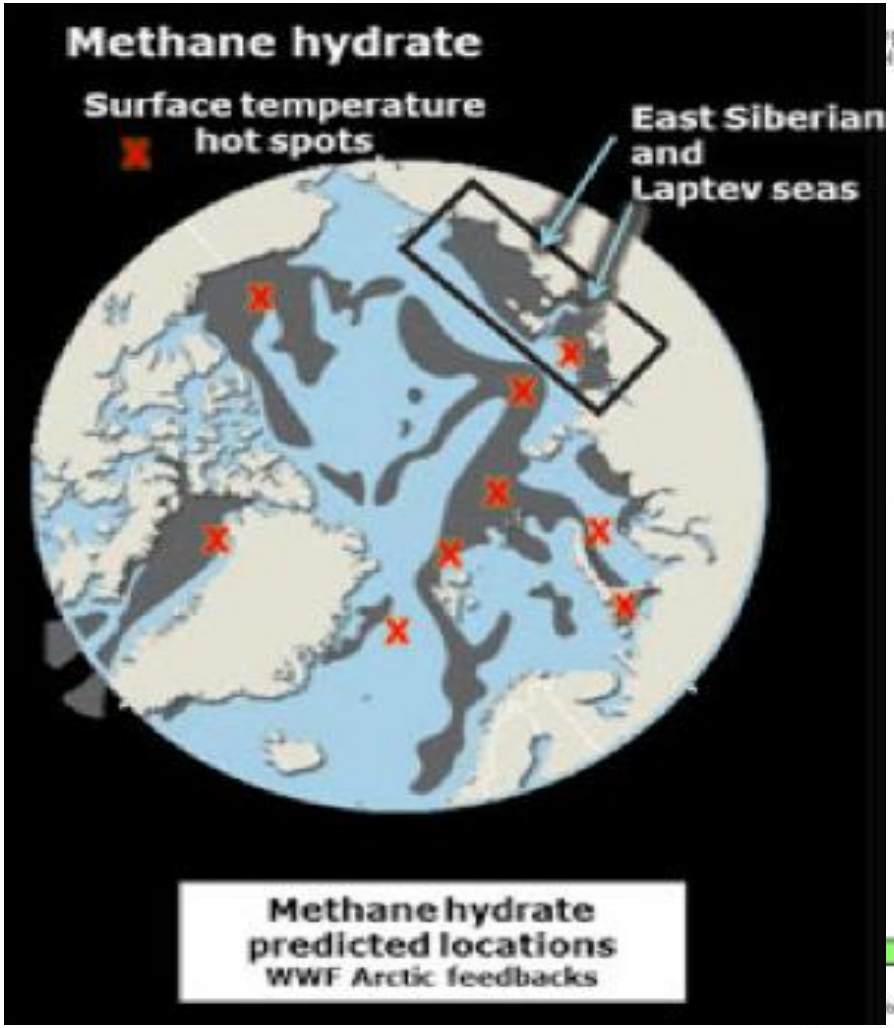
**nitrogen cycle**

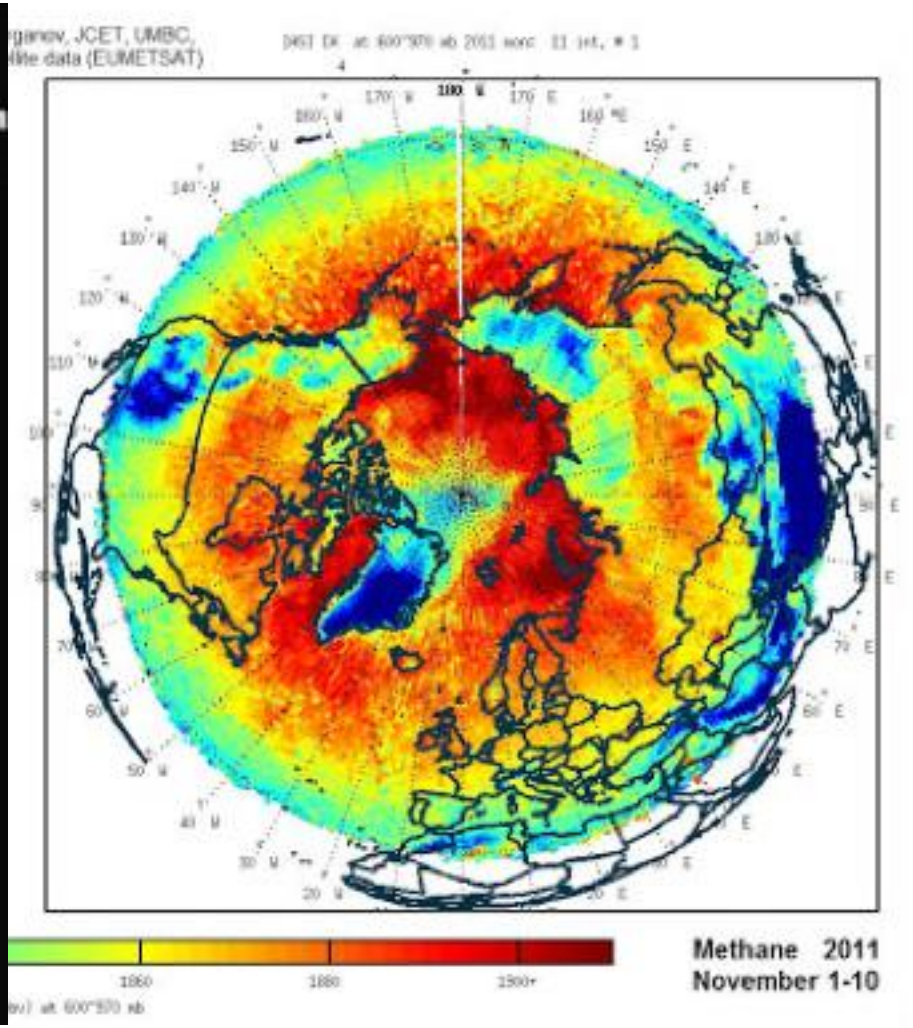
**Boundaries have already been exceeded!**

Rockstrom, 2009

**SURPRISE: [99/1 DILEMMA]**

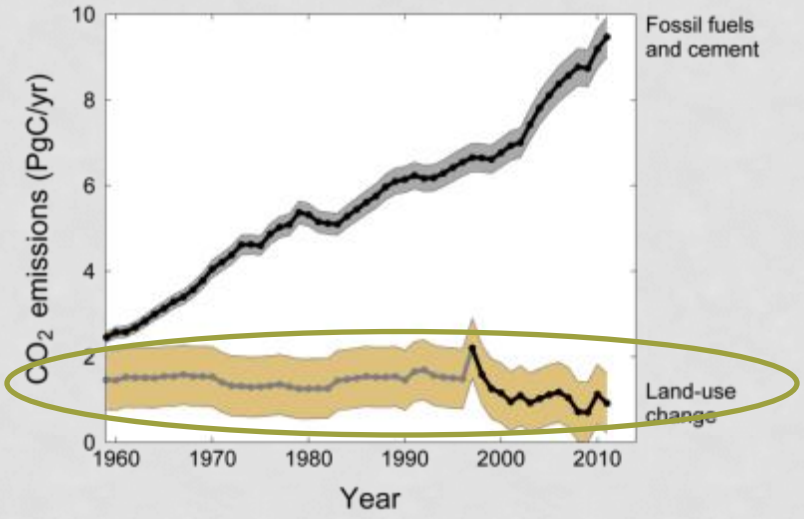
# Striking Increase in Arctic Methane



# GLOBAL CARBON EMISSIONS

- Total global emissions: 10.4±0.7PgC in 2011, 37% over 1990
- Percentage land-use change: 36% in 1960, 18% in 1990, 9% in 2011



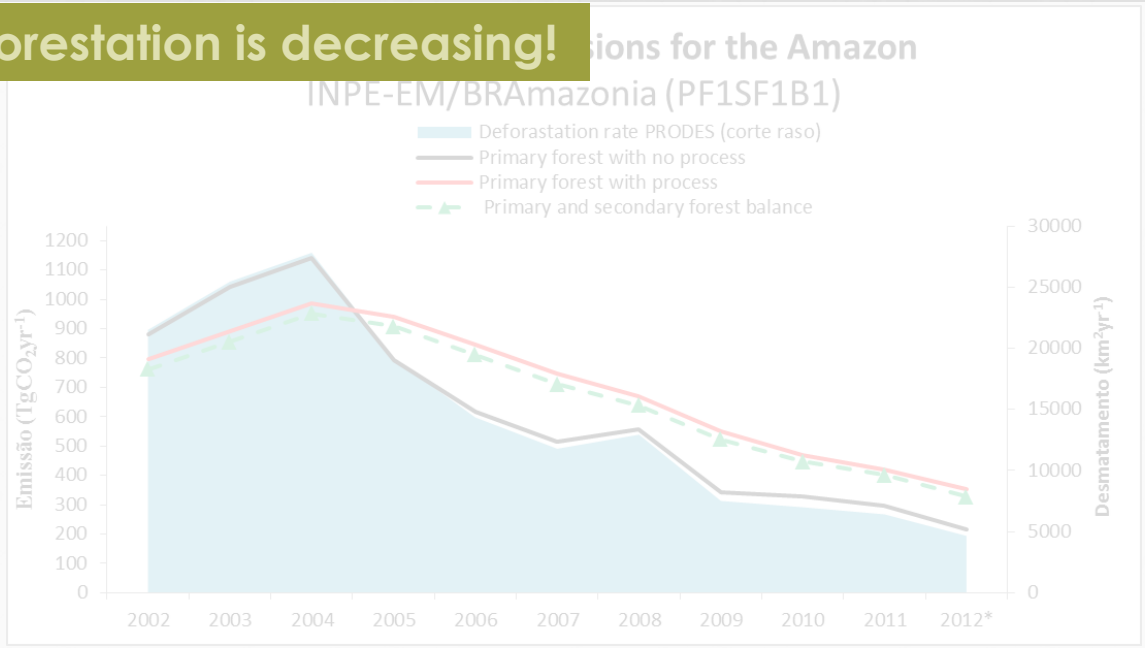





- **Land-use change black line: Includes management-climate interactions**
- **Source: Le Quéré et al. 2012; Global Carbon Project 2012**

## Tropical Deforestation is decreasing!

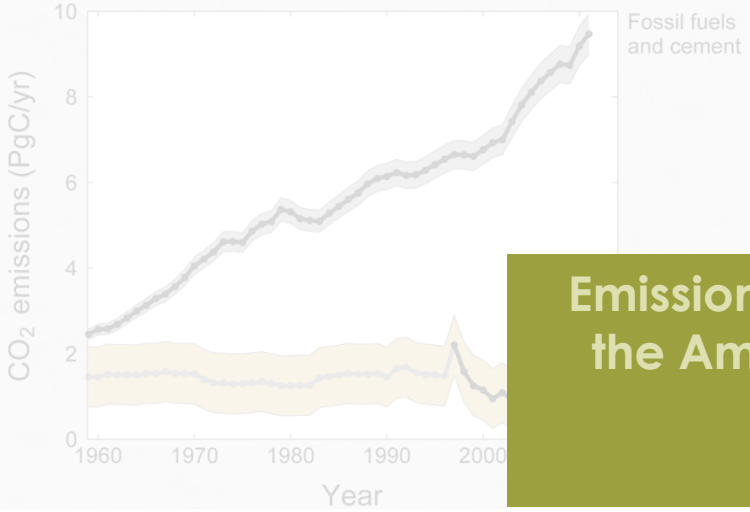





Source: Aguiar et al, 2012 (http://inpe-em.ccst.inpe.br/resultados/amazonia.html)

# TOTAL GLOBAL EMISSIONS AND THE AMAZON

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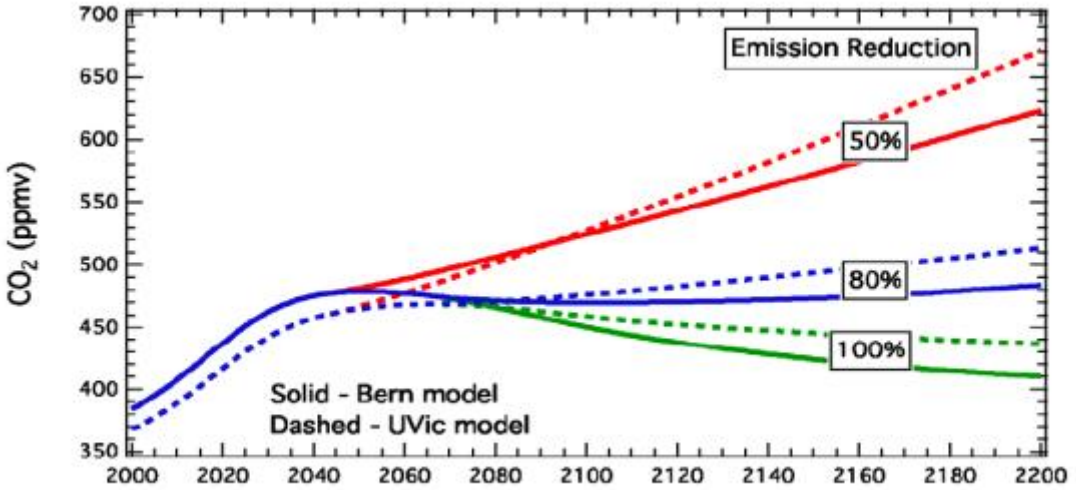
**Emissions declined 75% in the Amazon since 2005!**

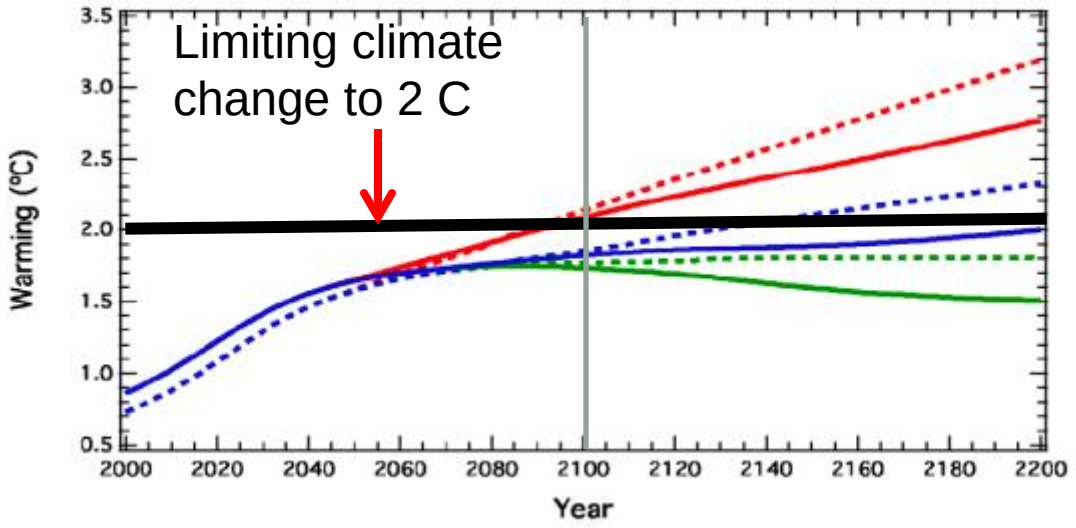





Source: Aguiar et al, 2012 (http://inpe-em.ccst.inpe.br/resultados/amazonia.html)

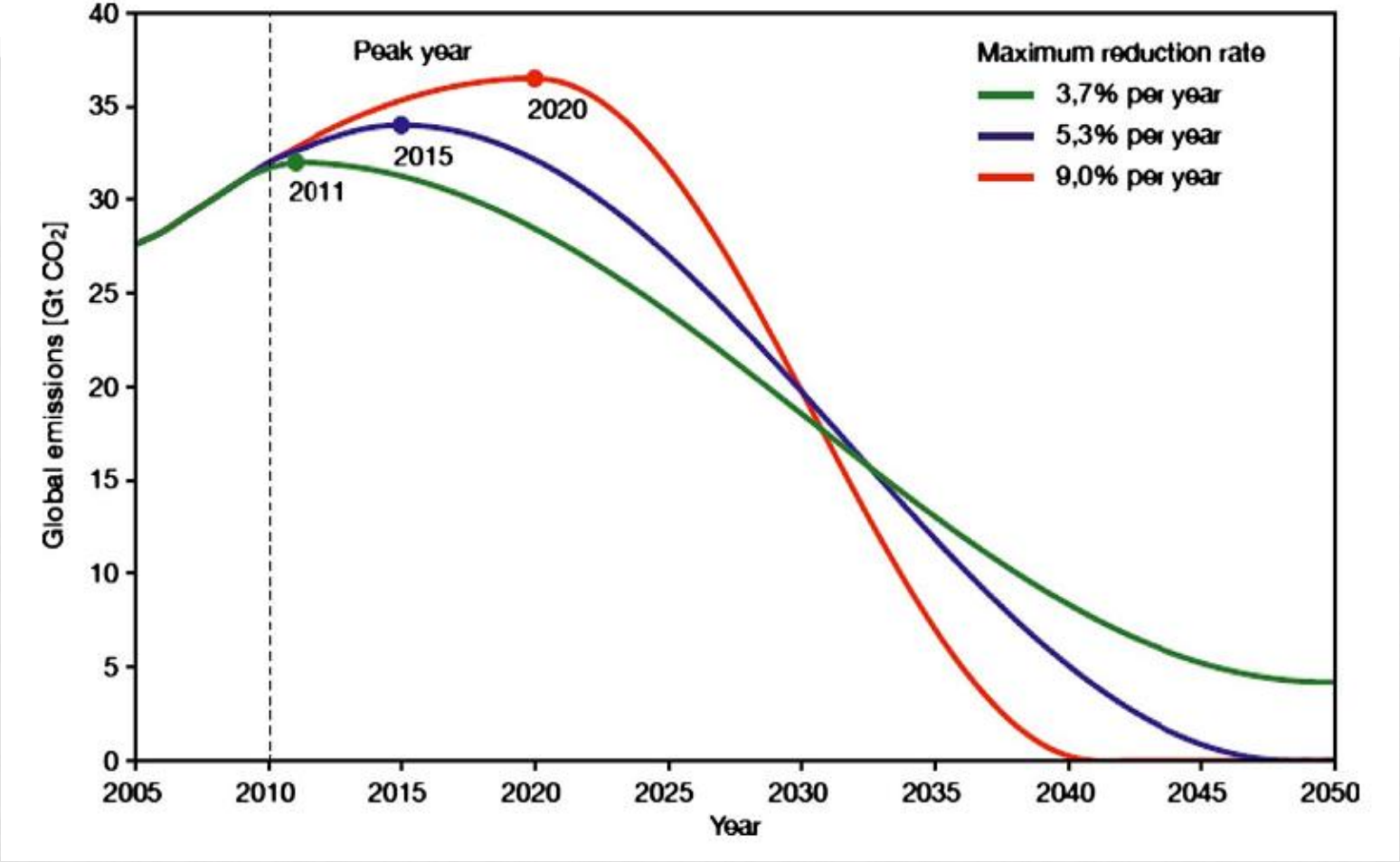
# MITIGATION: LIMITING GLOBAL WARMING




*National Research Council, 2010*

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




*Messner et al. (2010)*

- CONVERT THE WORLD TO RENEWABLE ENERGY

WHAT CAN BE DONE IN 10 YEARS?



# 'PLANET RENEWABLE'

RENEWABLE ENERGY COULD:

- provide nearly 80 percent of the globe's power by 2050

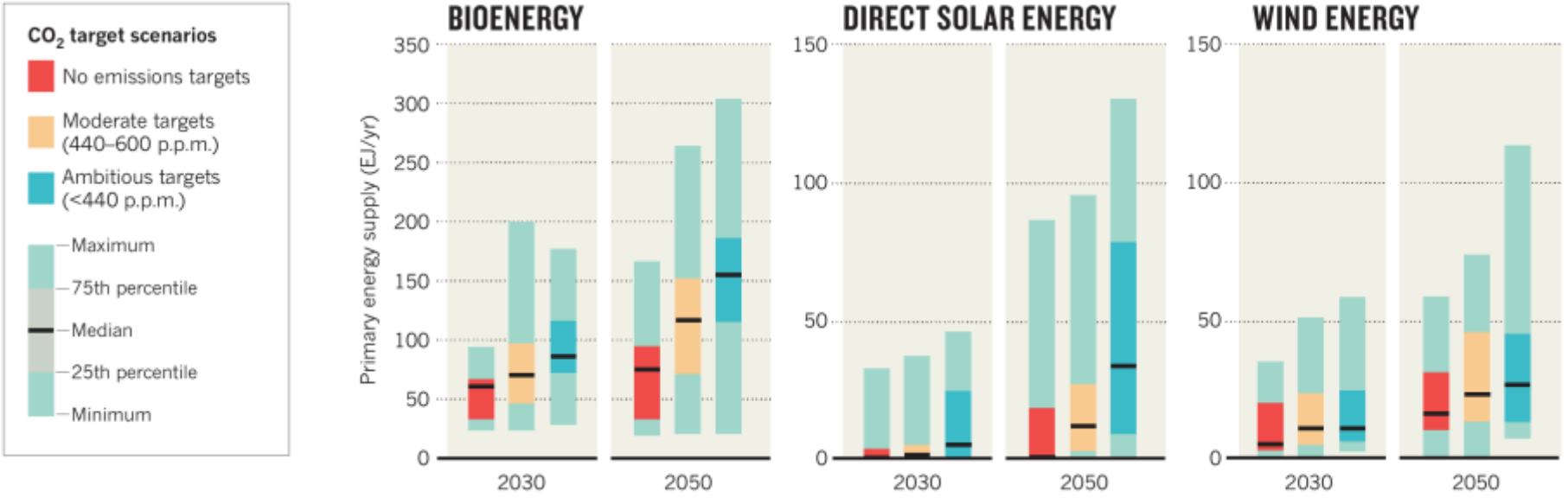
- lead to cumulative greenhouse gas savings equivalent to 220 to 560 Gigatonnes of carbon dioxide (Gt $CO_{2eq}$) between 2010 and 2050.

Tollefson, J. Nature, 473, 2011, reporting results of IPCC's Special Report on Renewable Energy Sources and Climate Change Mitigation, 2011




## THE BIG THREE

Under the emissions scenarios studied by the Intergovernmental Panel on Climate Change, future renewable energy development varies with the level of ambition in halting the rise of atmospheric carbon dioxide concentrations. These rose to more than 390 parts per million (p.p.m.) in 2010. Biomass, solar energy and wind power look to remain the key renewable energy types.




Nature, 2011

Earth System moves to uncertain State? Severe challenge to contemporary civilisation.

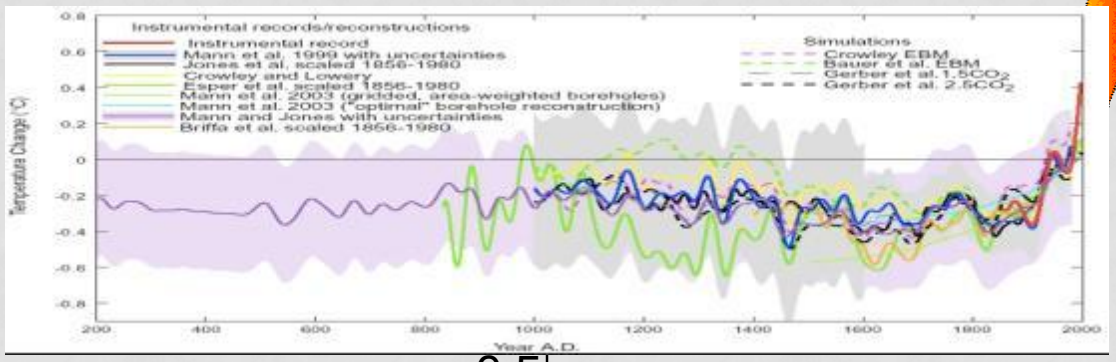
IPCC Projections 2100 AD

"Committed" Climate Change

Now

Global Temperature (° C)

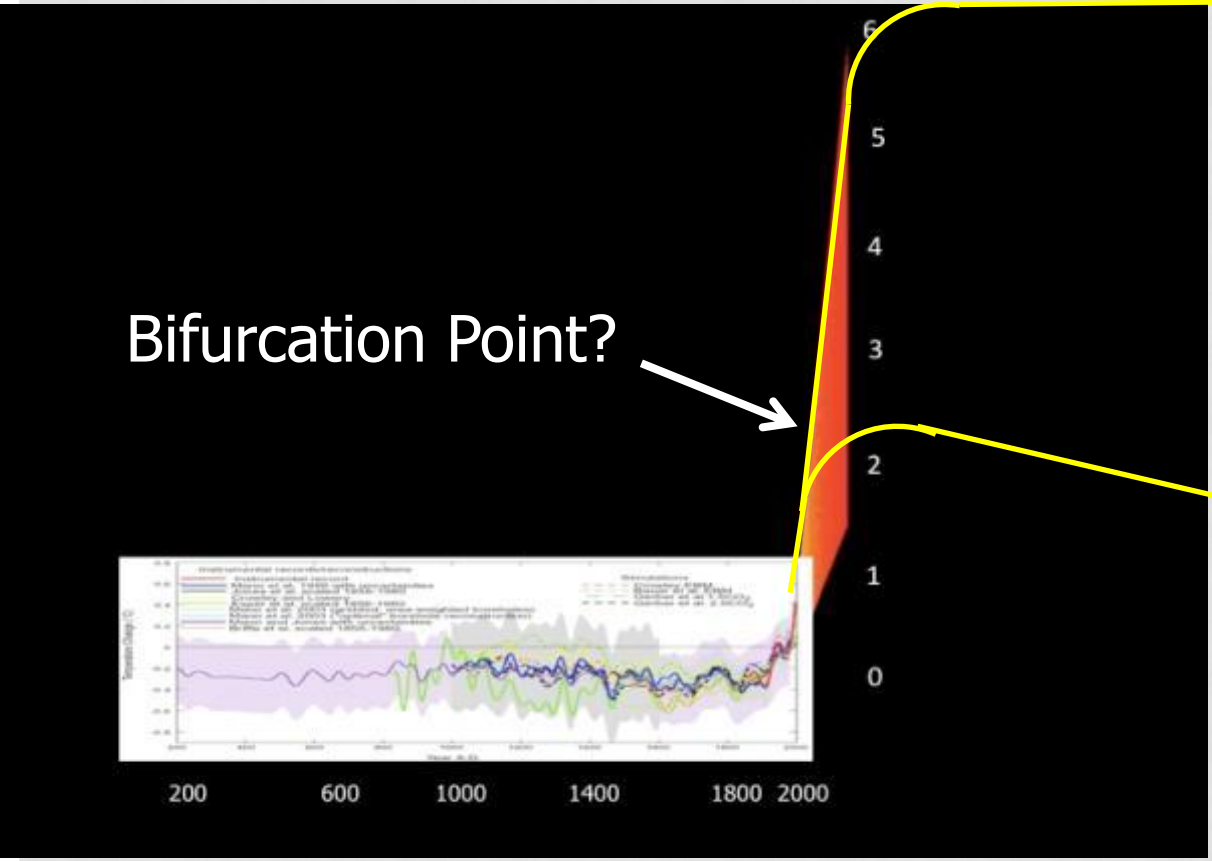
N.H. Temperature (° C)




6
5
4
3
2
1
0
-0.5

200
600
1000
1400
1800
2000

# Implications of the Anthropocene




Transition to a new, much hotter state of the Earth System?

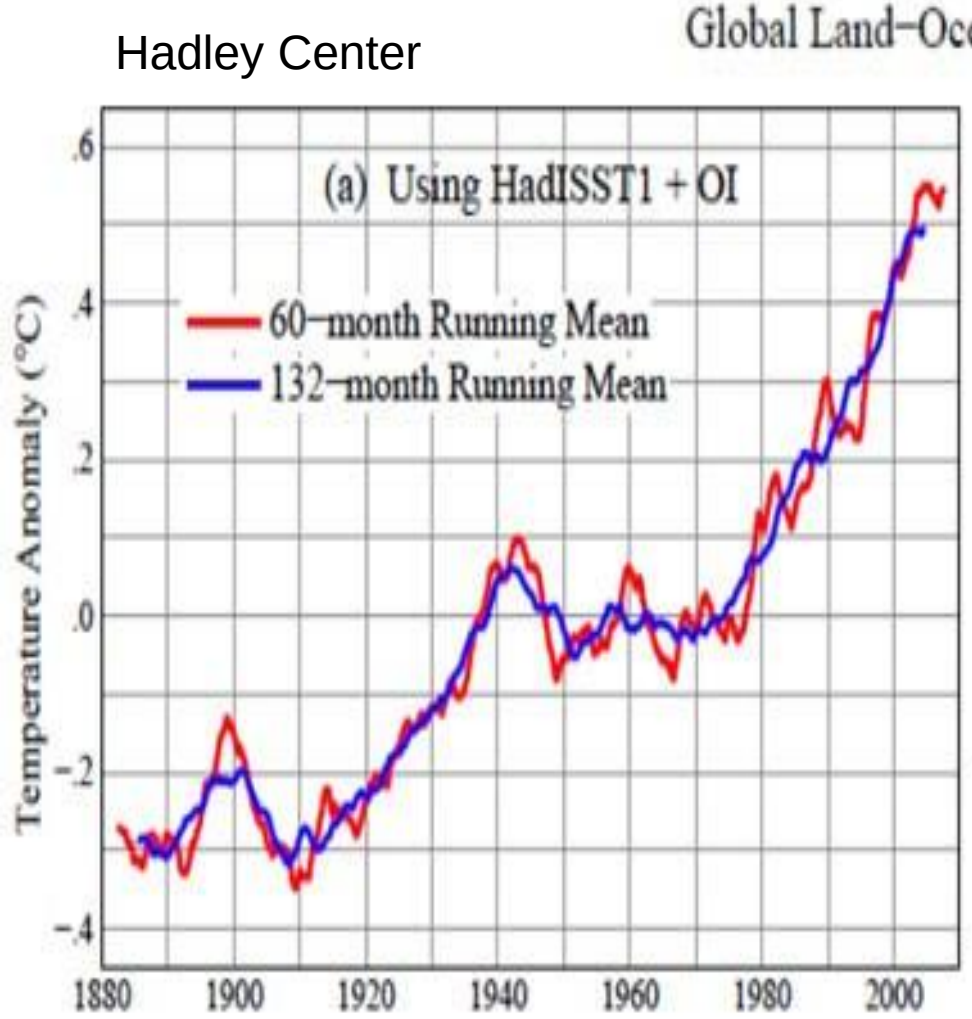
Return towards a Holocene-like state?

# Thank you



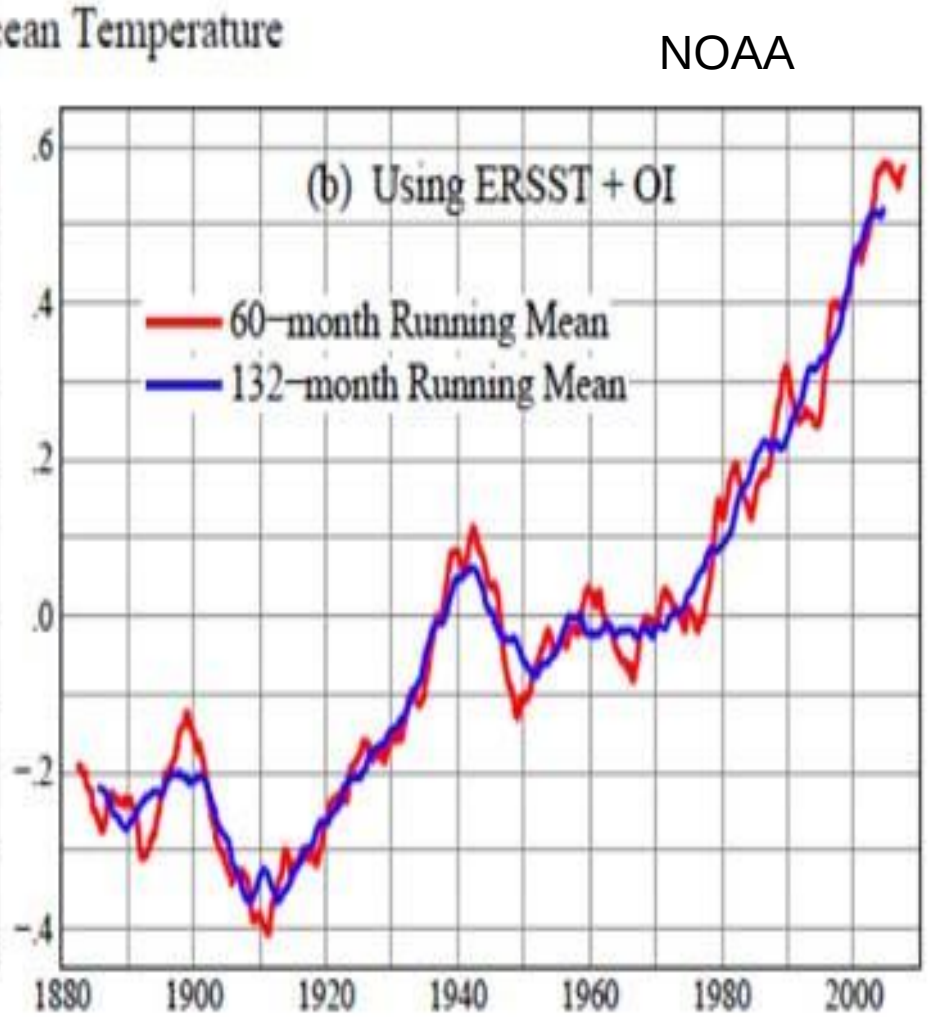
# NEW GLOBAL SEA SURFACE AND LAND TEMPERATURES TRENDS (HANSEN ET AL, 2010)

Hadley Center

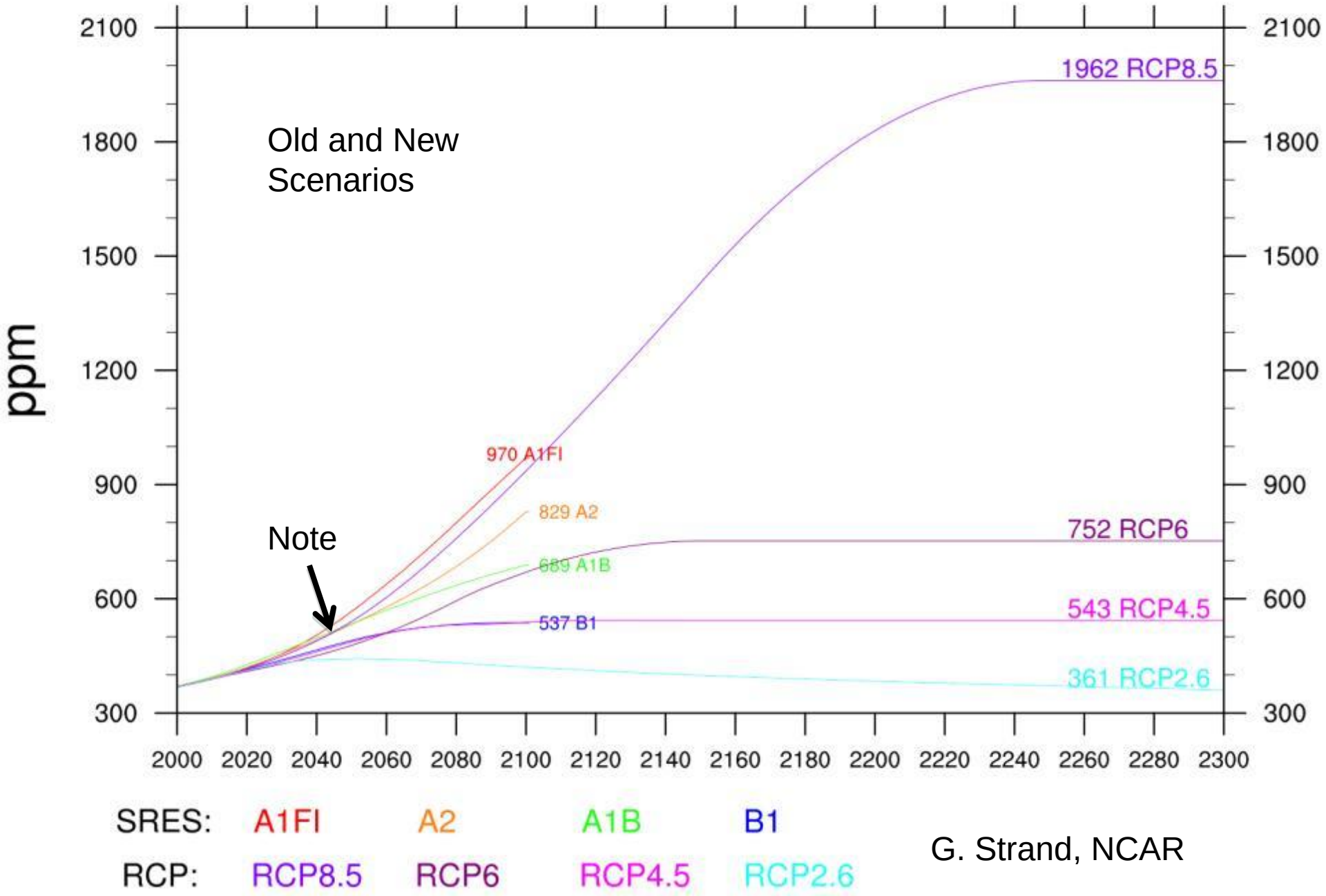



Global Land–Ocean Temperature

NOAA

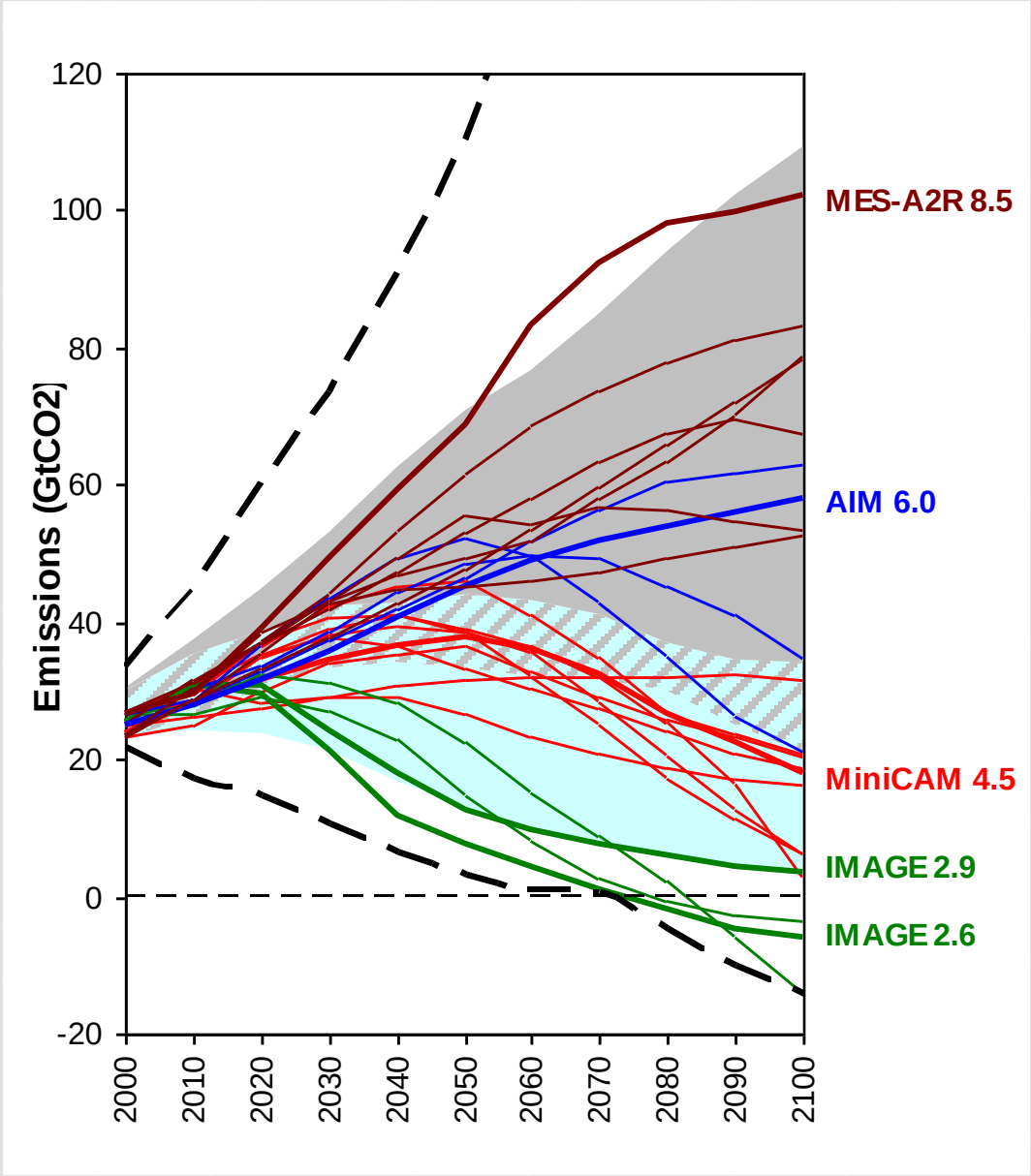


# $CO_2$ concentrations




G. Strand, NCAR

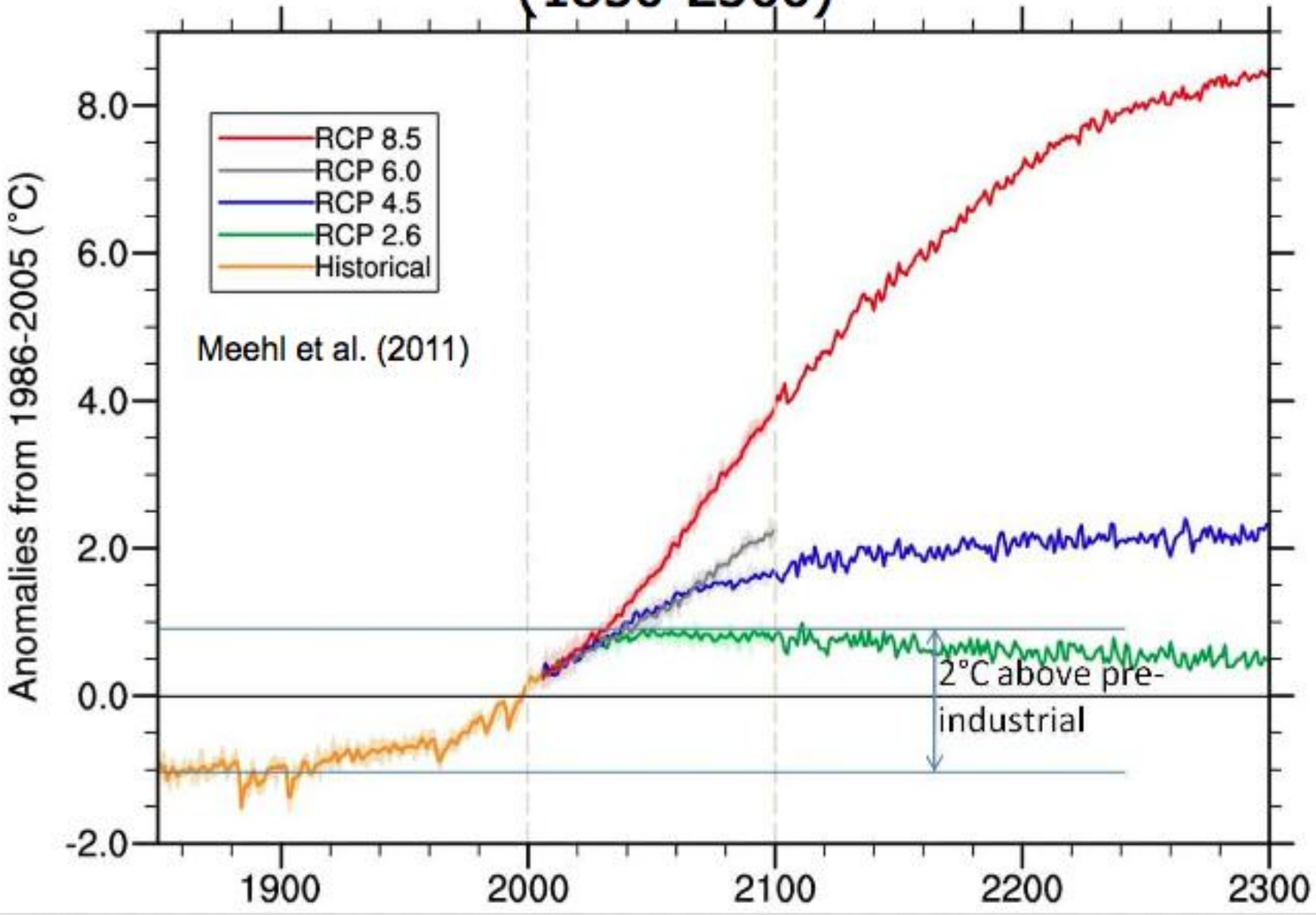
# RCPs in perspective – $CO_2$ emissions




From Moss et al., 2008

# Global Surface Temperature

## (1850-2300)

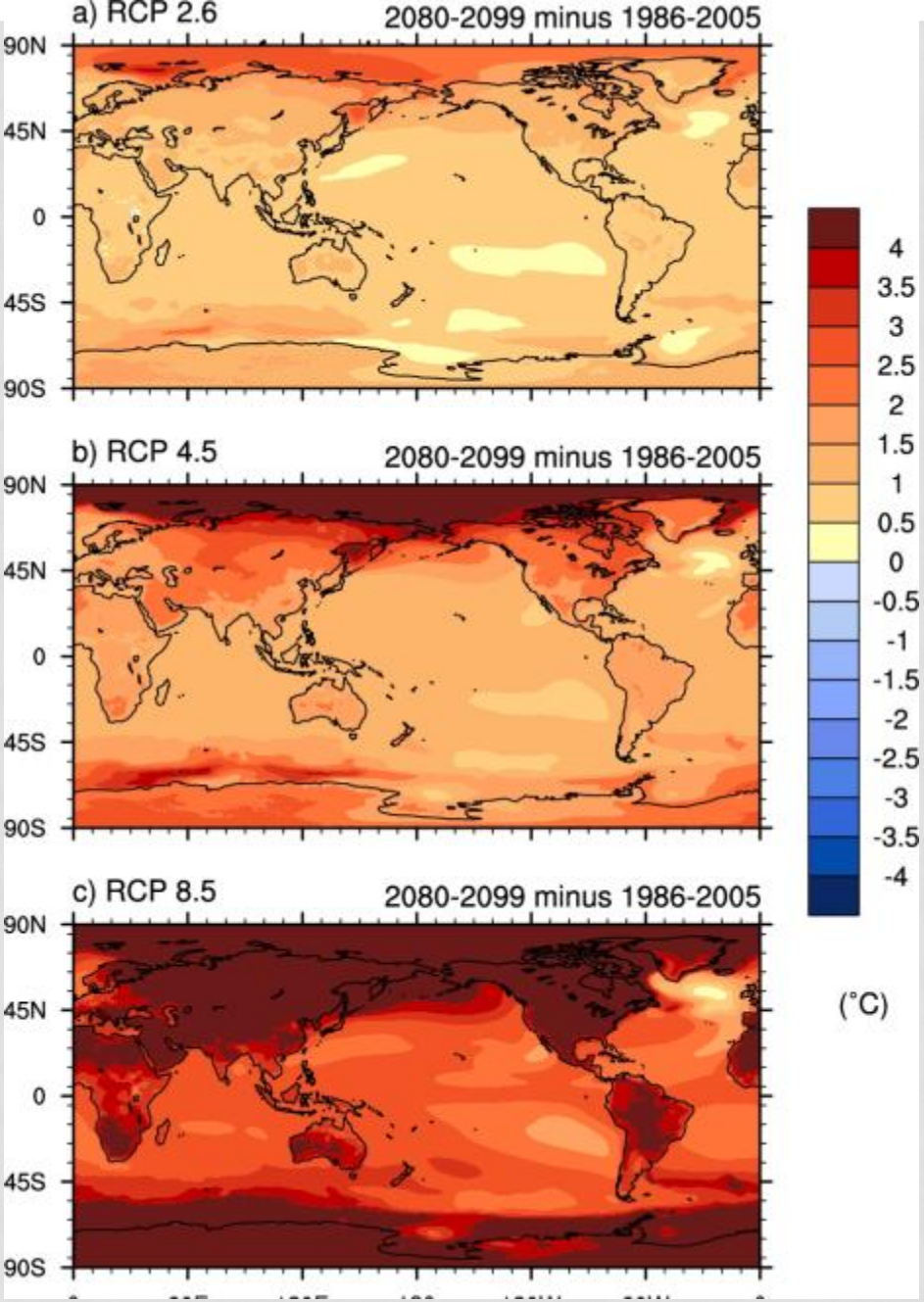


RCP 2.6, 4.5 and 8.5

Changes over 100 years:

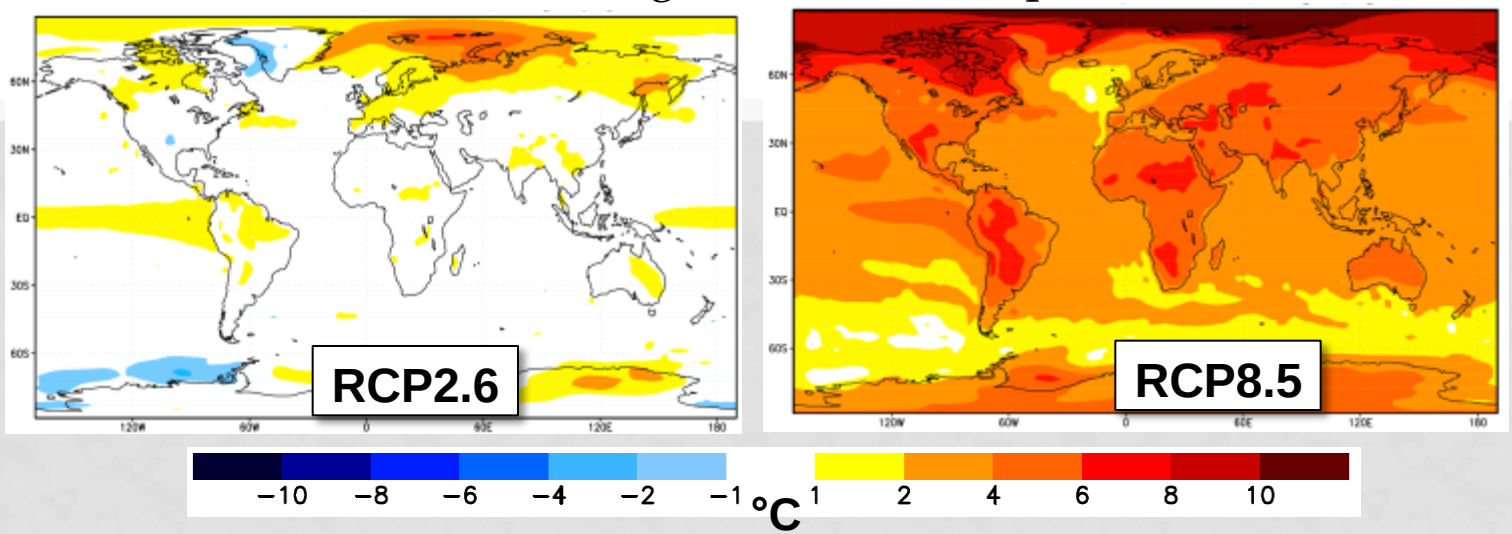
New RCP
simulations
for next
IPCC assessment

NCAR CESM Model

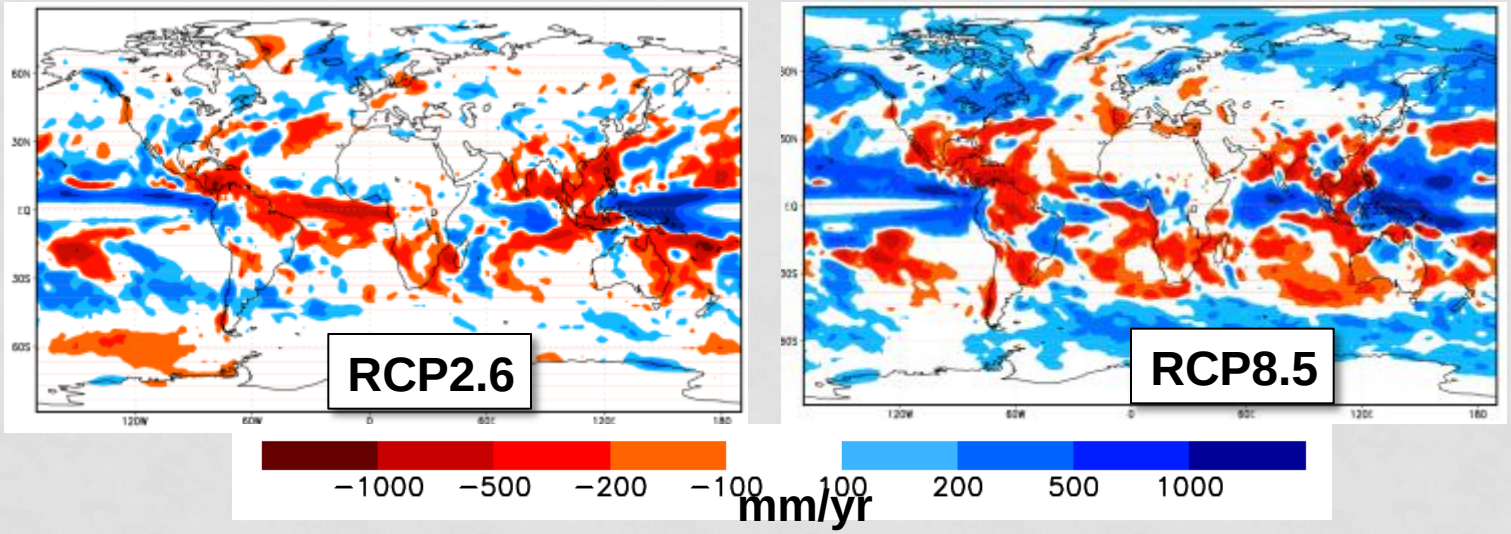


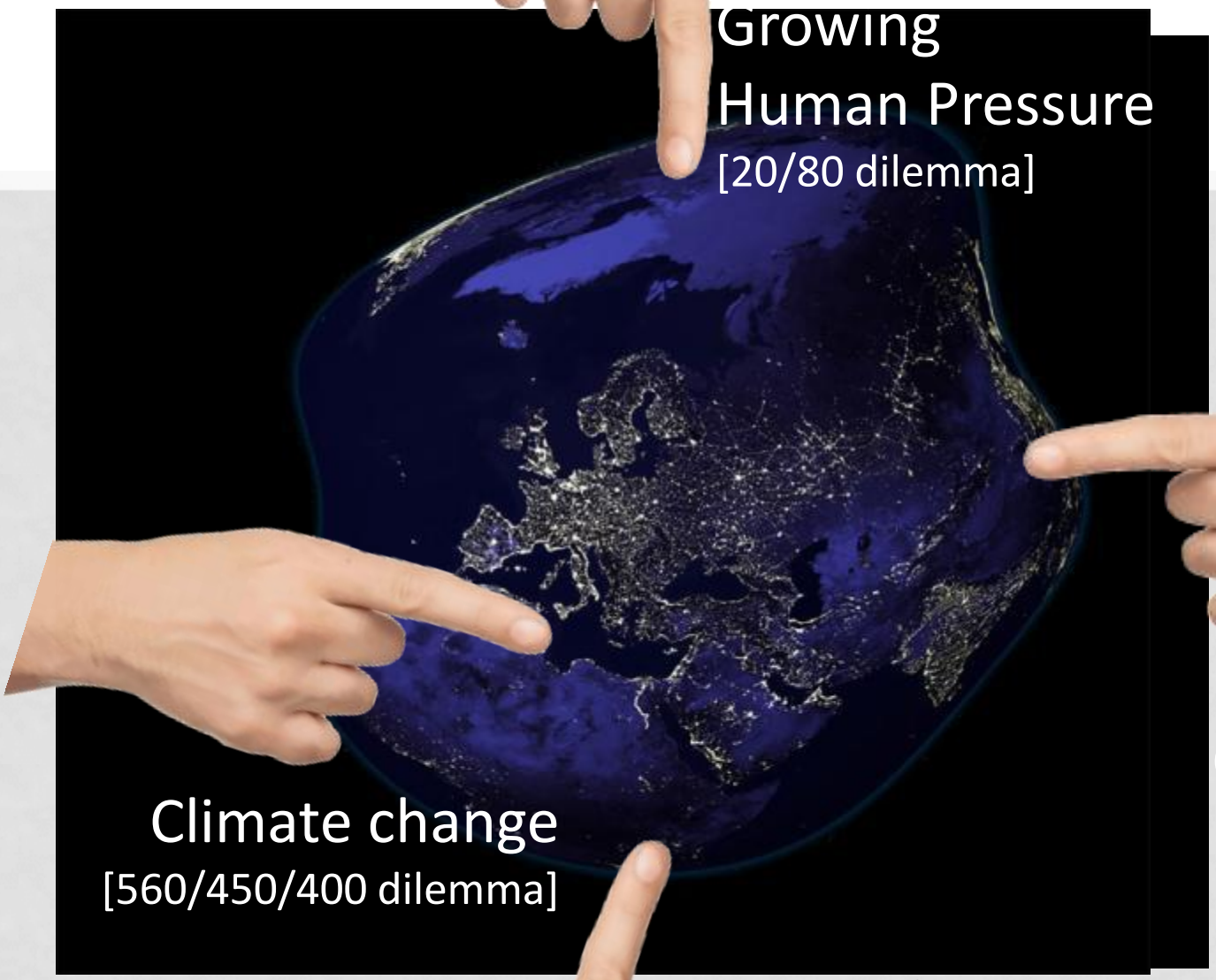
# CLIMATE CHANGE IN MPI-ESM, 2100-2005

changes in annual temperature




changes in annual precipitation

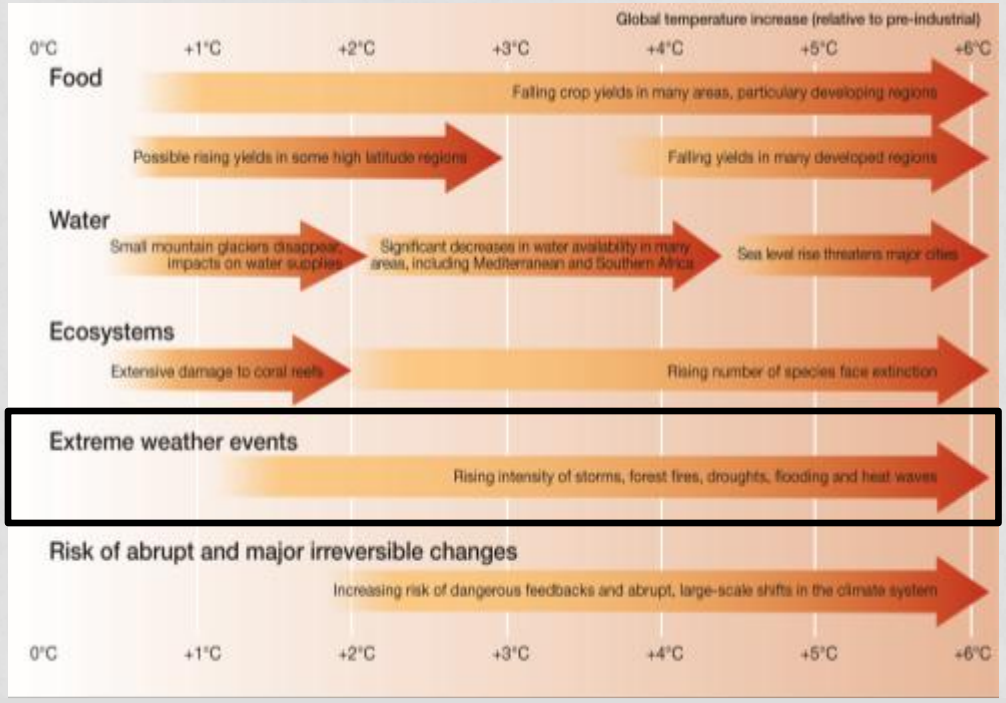





From Johan Rockstrom



# PROJECTED IMPACTS OF CLIMATE CHANGE




UNEP/GRID-Arendal, 2009

NATURAL DISASTERS








EMDAT - The International Emergency Disasters Database (www.emdat.be)

# REGIONAL SOLUTION FOR THE TROPICS
# WHAT CAN BRAZIL DO?

# WILL BRAZIL, AT THIS CENTURY, BECOME A "TROPICAL ENVIRONMENTAL POWER", FULL-FLEDGED DEVELOPED COUNTRY IN THE TROPICS?



**Our biggest challenge is the Amazon!**

# HOW TO DEVELOP A NEW MODEL FOR THE TROPICS ?

## A new paradigm for the Amazon



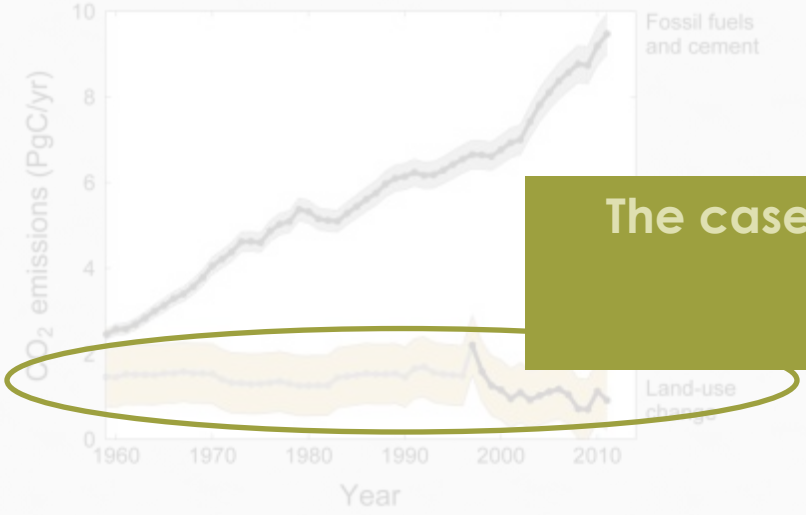

Regional Plan






# TOTAL GLOBAL EMISSIONS AND THE AMAZON

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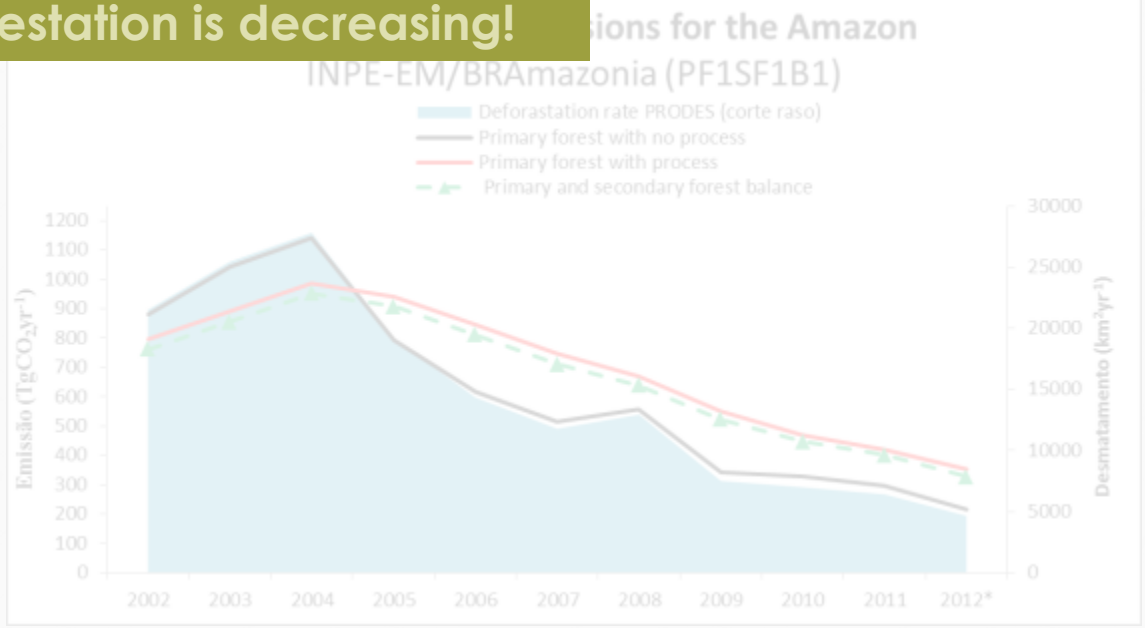

- Land-use change black line: Includes management-climate interactions

Source: Le Quéré et al. 12; Global Carbon oject 2012

**The case of the Amazon**

**Deforestation is decreasing!**






Source: Aguiar et al, 2012 (http://inpe-em.ccst.inpe.br/resultados/amazonia.html)

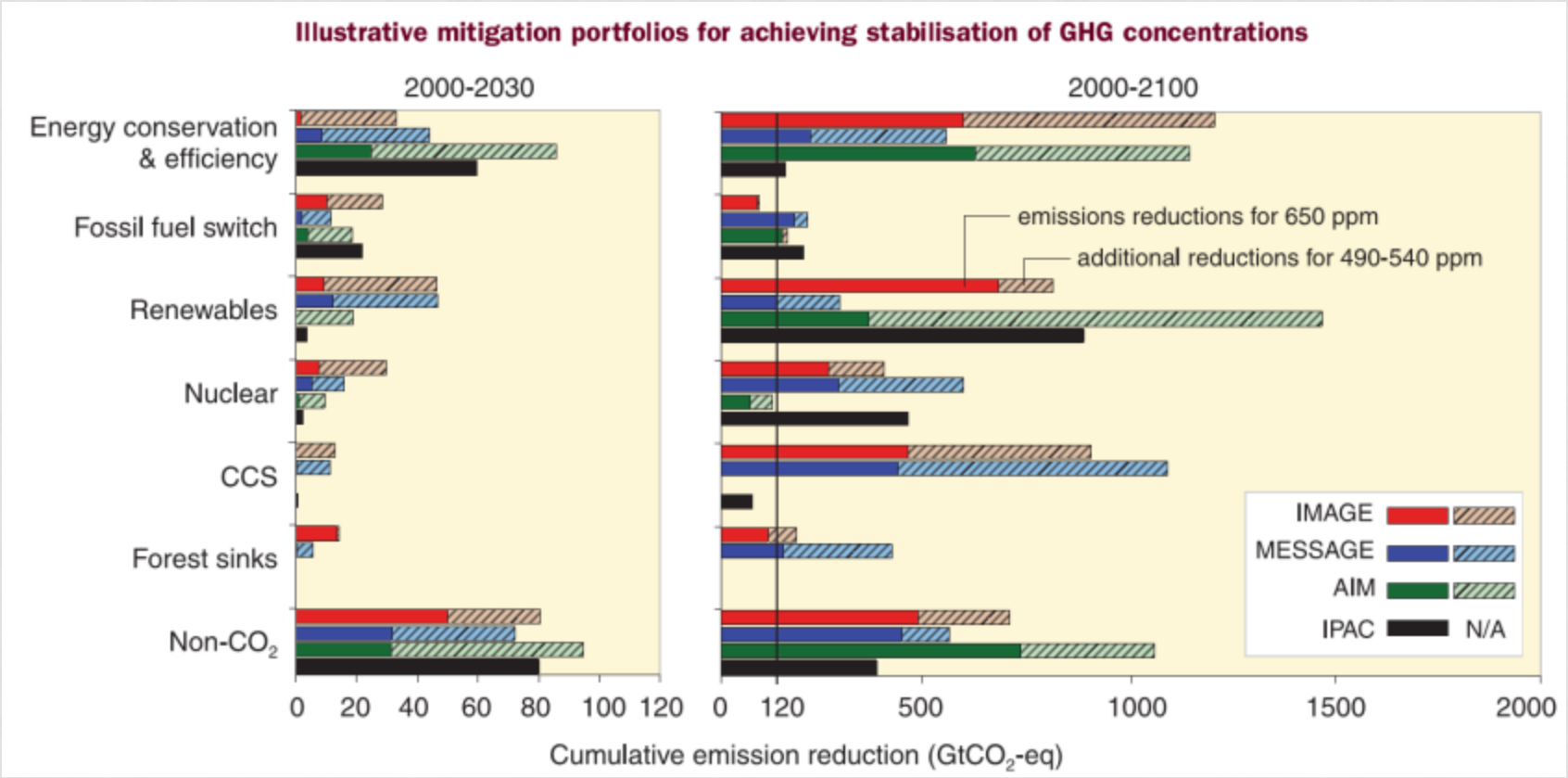
*WHAT CAN BE DONE?*

*CAN RENEWABLE ENERGY MEET GLOBAL DEMAND?*

RENEWABLE ENERGY:

- COULD PROVIDE NEARLY 80 PERCENT OF THE GLOBE'S POWER BY 2050

- COULD LEAD TO CUMULATIVE GREENHOUSE GAS SAVINGS EQUIVALENT TO 220 TO 560 GIGATONNES OF CARBON DIOXIDE (GTC02EQ) BETWEEN 2010 AND 2050.




IPCC, AR4, 2007

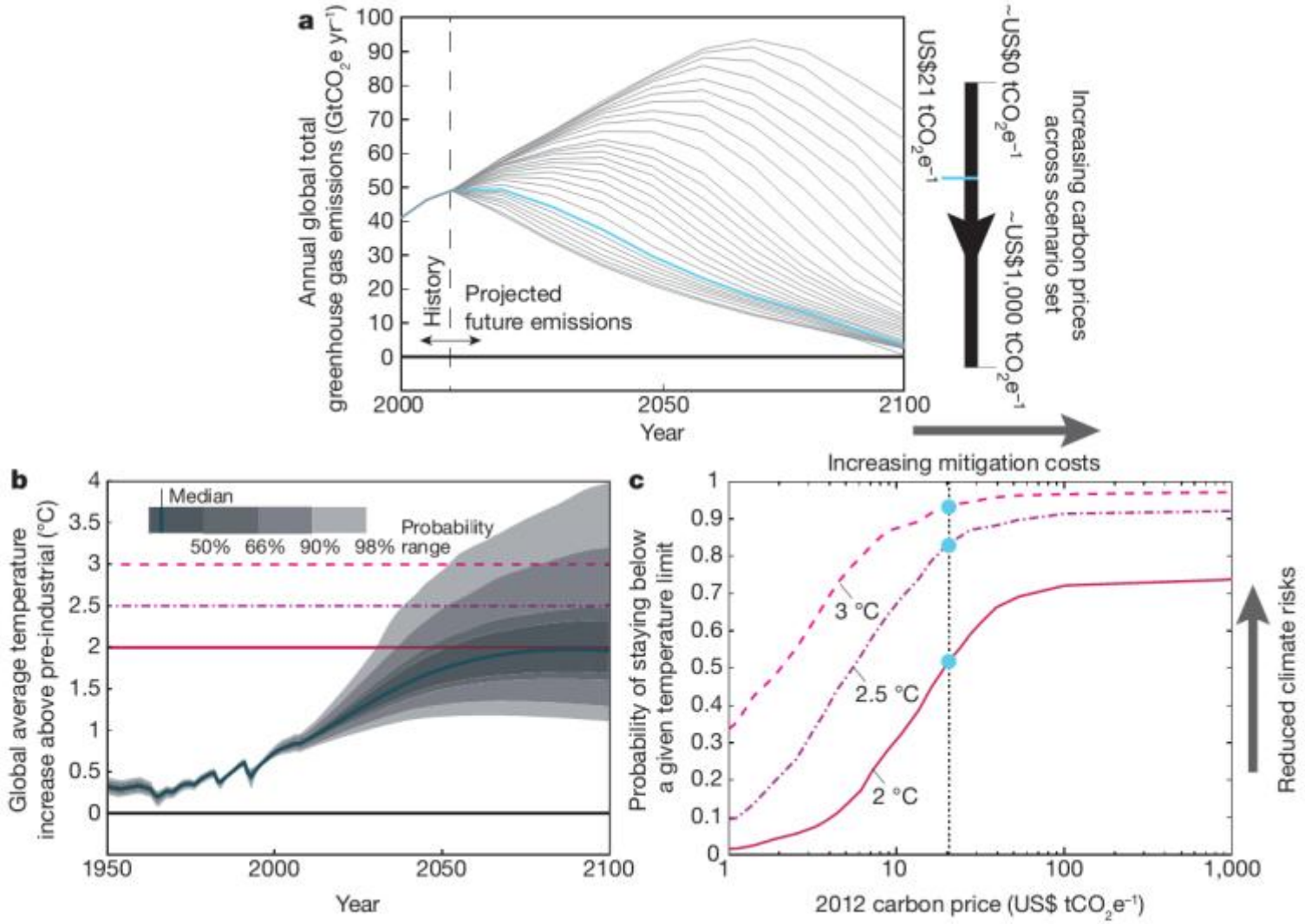



**Figure 1 | Methodology for creating cost–risk relationships for a given temperature limit.** **a**, Illustrative set of emissions scenarios with carbon prices increasing from zero to US$1,000 $tCO_2e^{-1}$. The arrow at right indicates the direction of increasing carbon prices across the illustrative set. The blue-highlighted scenario has a global carbon price discounted back to 2012 of US$21 $tCO_2e^{-1}$. **b**, Probabilistic temperature projections for the blue trajectory in **a**. Horizontal lines at 2, 2.5 and 3 °C show possible target temperature limits. In this illustrative scenario, median (50% probability) warming is 2.0 °C. There is a slim chance (<5%) that temperatures remain below 1.3 °C and a large chance (>90%) that they remain below 3.0 °C. **c**, Cumulative distributions of carbon prices consistent with limiting warming to below 2, 2.5 and 3 °C, as indicated. Blue dots indicate points defined by the cost information of the scenario highlighted in **a** and the probabilistic temperature projection in **b**.

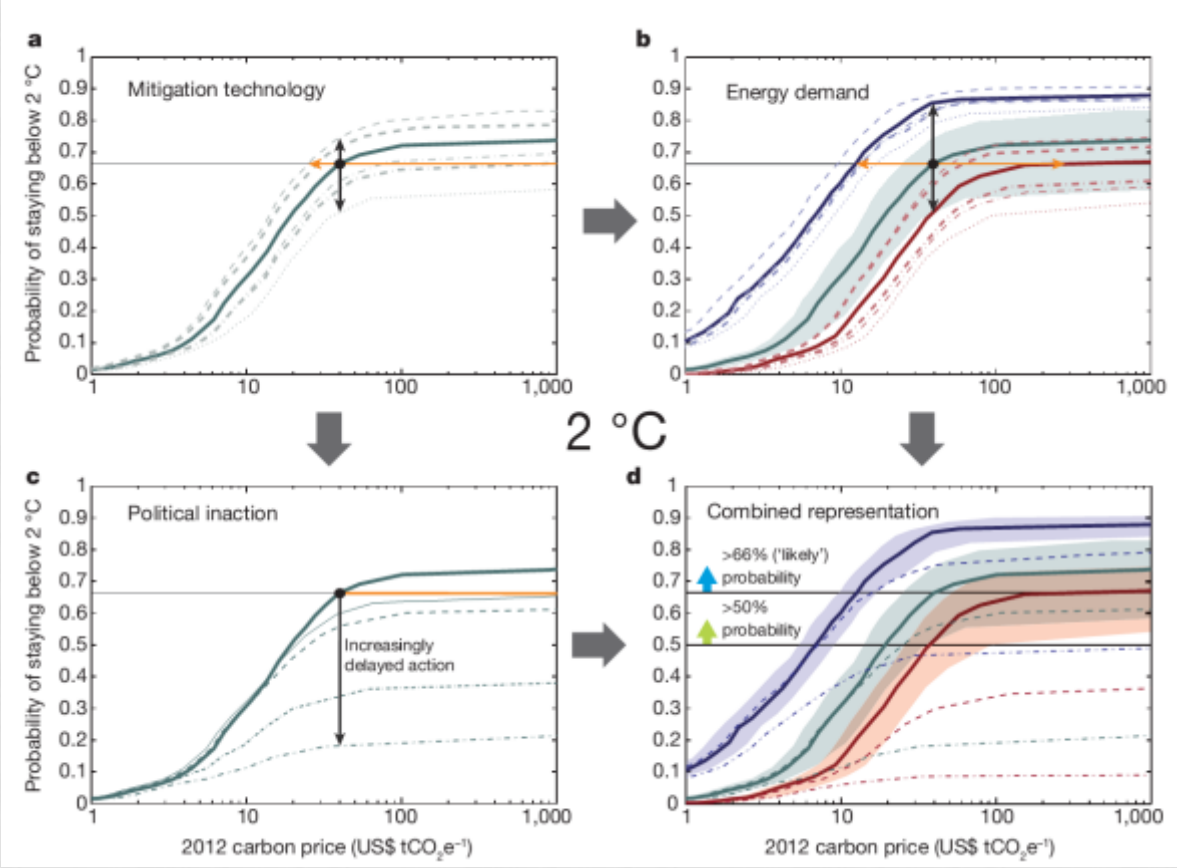



**Figure 2 | Influence of mitigation technology, energy demand and political inaction on the cost–risk distributions for staying below 2 °C.** Cost distributions for six cases with varying future availability of specific mitigation technologies (**a**) and three sensitivity cases for future energy demand (**b**, thick solid lines). Shaded areas and dashed lines in **b** represent technology-sensitivity cases comparable to those shown in **a**. Shaded areas and dashed lines in **d** represent technology- and politics-sensitivity cases comparable to those in **b** and **c**, respectively. **c**, Impact of delayed global mitigation action. **d**, Overview figure combining all sensitivity cases. The horizontal line in **a**–**c** is the 66% line. Similar figures for 2.5 and 3 °C are provided in Supplementary Figs 4 and 5. A comparison with 91 scenarios from the literature[2] is provided in Supplementary Fig. 7.

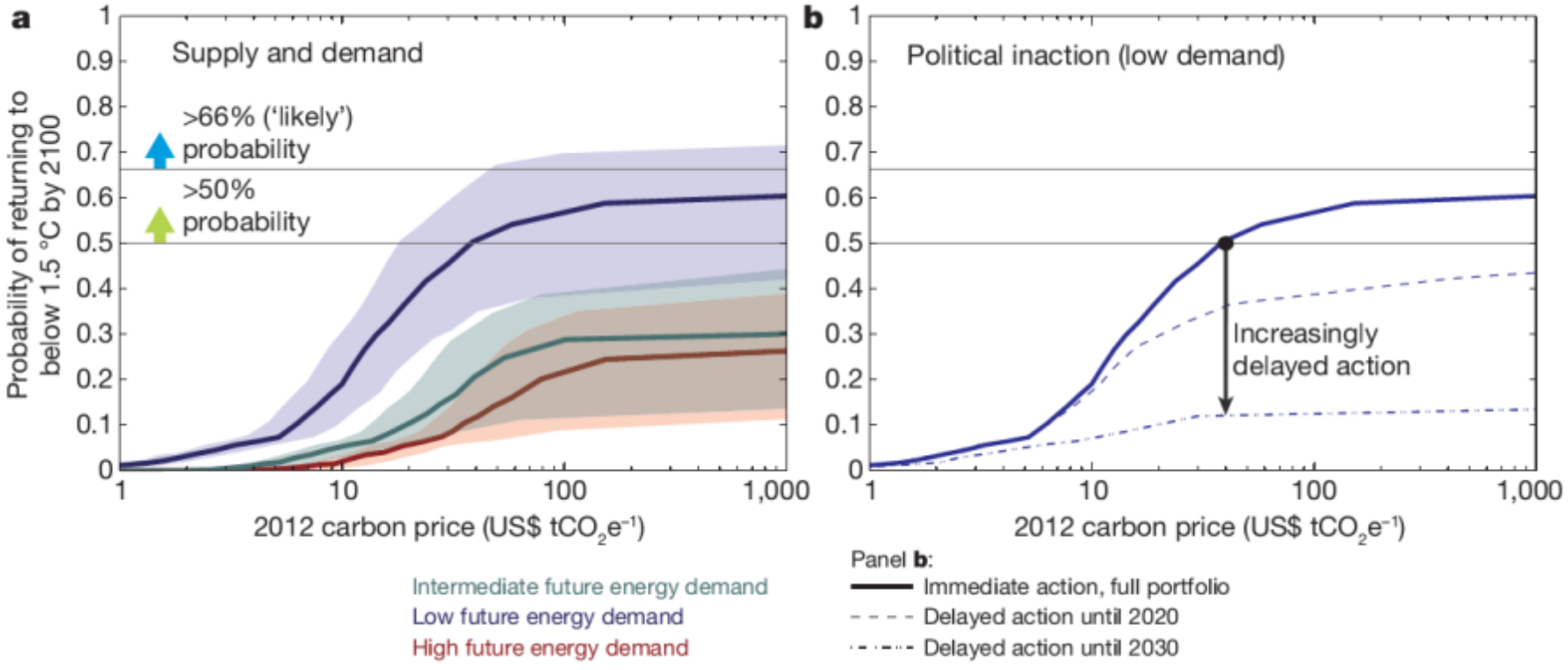
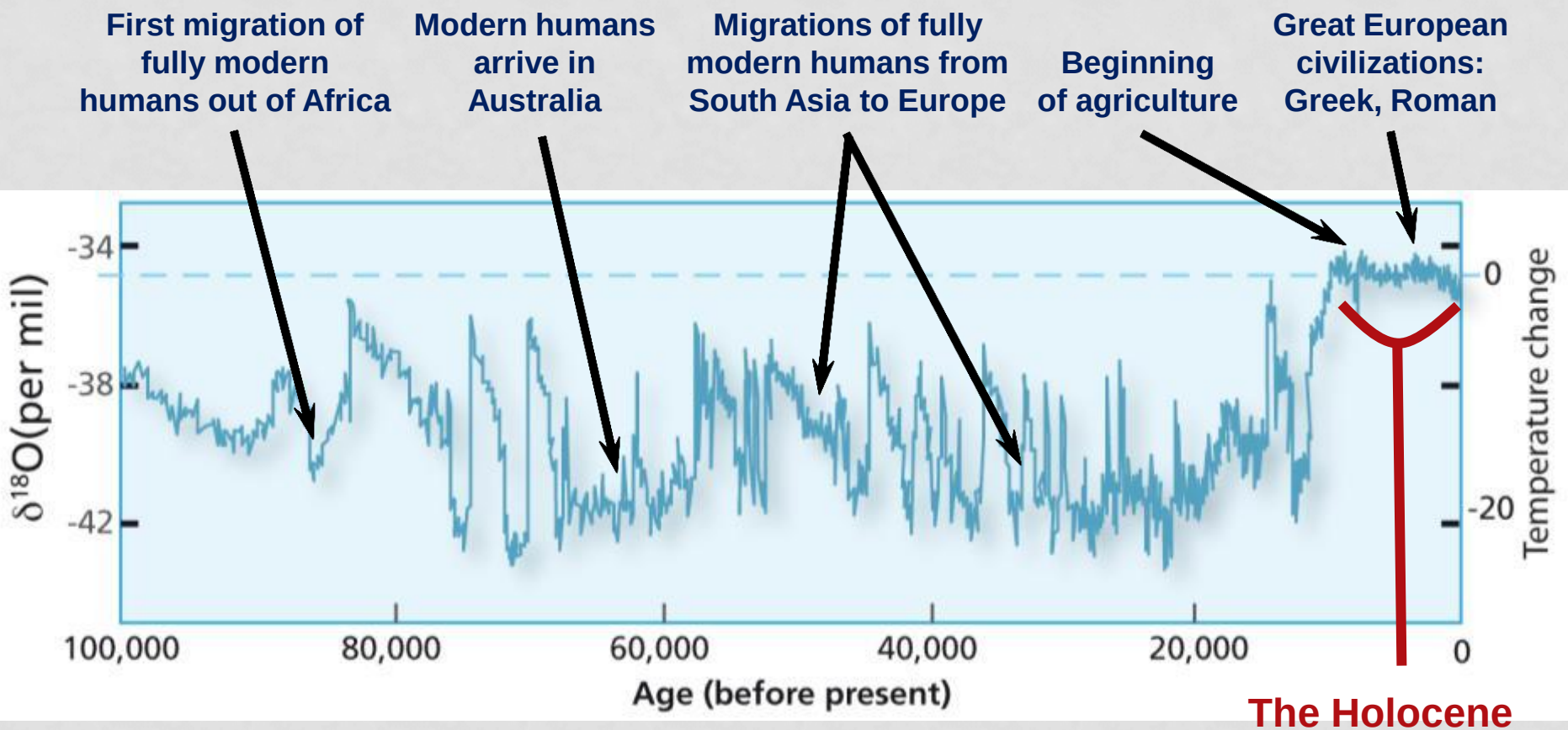



**Figure 3 | Cost–risk distributions for returning global temperature increase to below 1.5 °C by 2100.** **a**, Cost distributions for three cases of varying future energy demand (solid red, green, and blue lines) and varying future availability of specific mitigation technologies (shaded ranges around solid lines). Ranges show the variation over all assessed technology-sensitivity cases. **b**, Influence of global mitigation action delayed from now until 2030. The vertical axis shows the probability of returning global average temperature increase to below 1.5°C by 2100.

# HUMAN DEVELOPMENT AND GLACIAL-INTERGLACIAL CYCLING




Source: GRIP ice core data (Greenland)
And S. Oppenheimer, "Out of Eden", 2004

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

Source: GRIP ice core data (Greenland) and S. Oppenheimer, "Out of Eden", 2004

# PROPOSED PLANETARY BOUNDARIES

**PLANETARY BOUNDARIES**

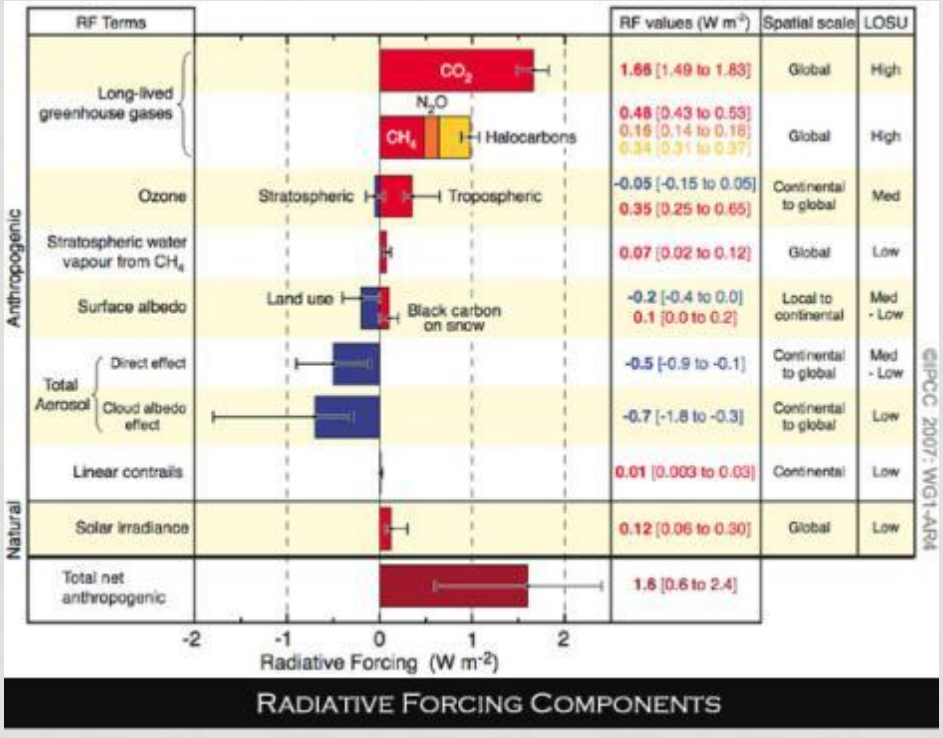
| Earth-system process | Parameters | Proposed boundary | Current status | Pre-industrial value |
|---|---|---|---|---|
| Climate change | (i) Atmospheric carbon dioxide concentration (parts per million by volume) | 350 | 387 | 280 |
| | (ii) Change in radiative forcing (watts per metre squared) | 1 | 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 | | |

Nature, 2009

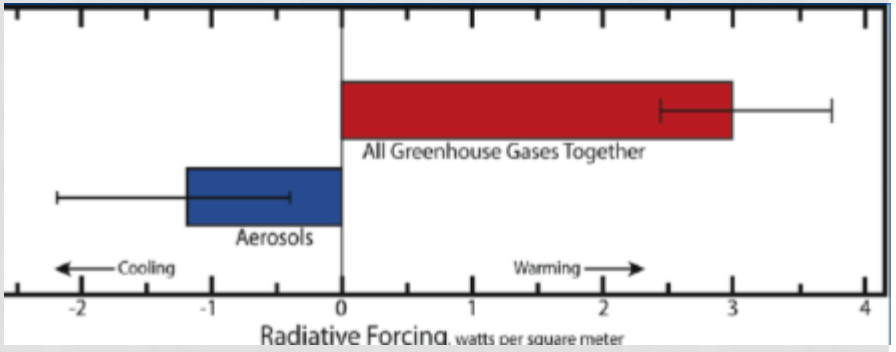
# INTERACTIONS

- BIOGEOCHEMISTRY-CLIMATE INTERACTIONS
  - TRACE GASES/AEROSOLS CONTRIBUTIONS TO RADIATIVE FORCING
  - AEROSOLS AND POLLUTION
  - CHEMICAL POLLUTION AND MEGACITIES
  - PALEOCLIMATE RECONSTRUCTIONS
  - DMS ATLAS
  - LAND USE AND LAND COVER CHANGE
  - IGBP CLIMATE CHANGE INDEX
- OCEAN ACIDIFICATION
- HUMAN APPROPRIATION OF NPP
- PLANT FUNCTIONAL TYPES
- NITROGEN/PHOSPHORUS
- OZONE
- WATER
- COASTAL VULNERABILITY

# AEROSOLS AND OTHER AQ AGENTS ON CLIMATE



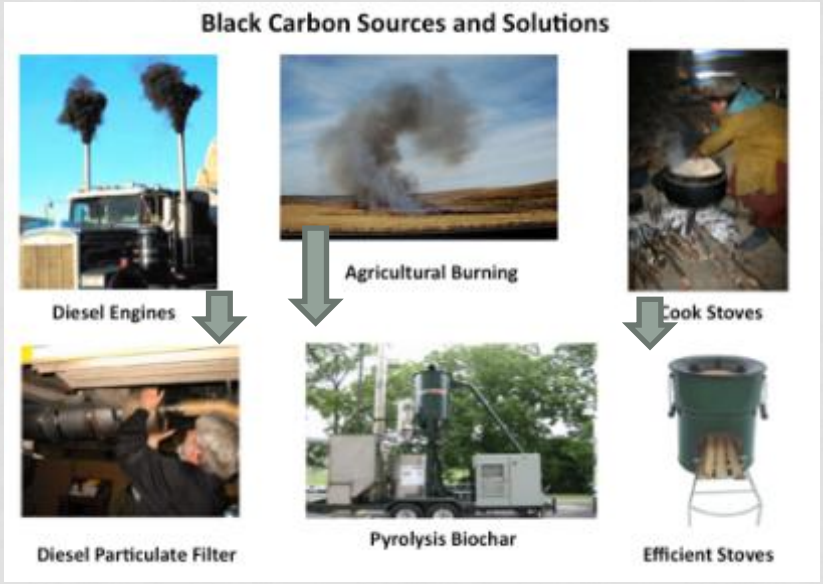

RADIATIVE FORCING COMPONENTS

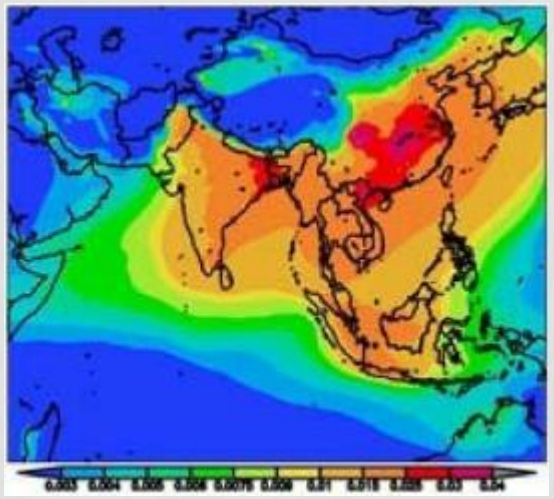



Air Quality "regulated"? aerosols are the largest factors offsetting greenhouse gas forcing!

Source: Paul S. Monks –IGAC

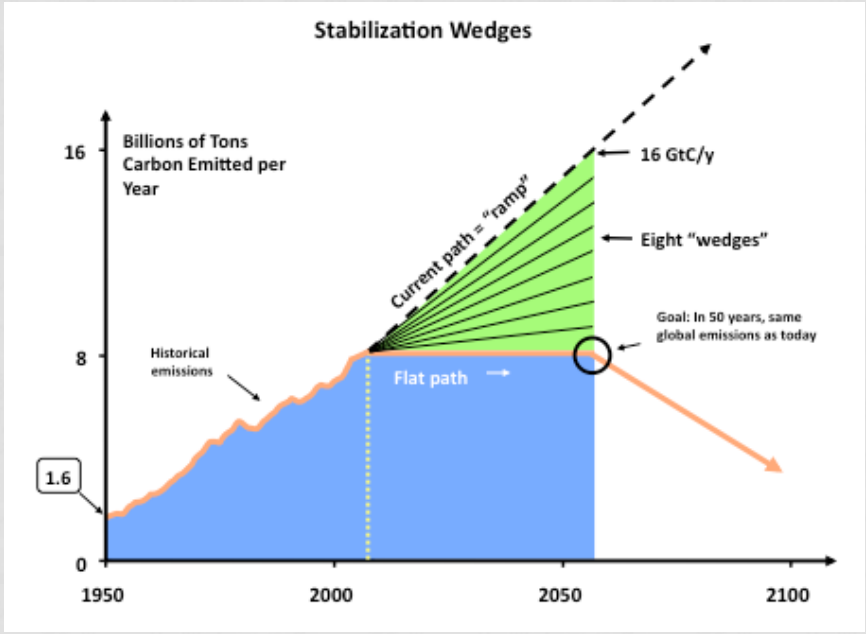
# BLACK CARBON



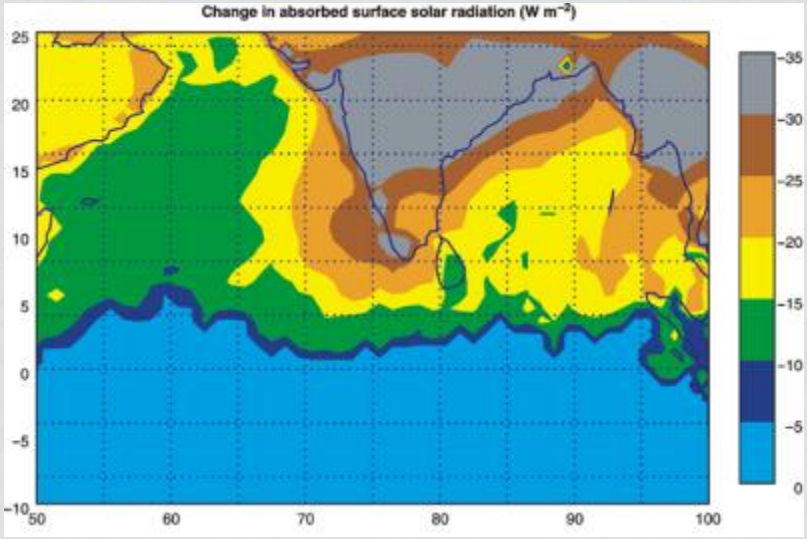
***The polluting effects of cooking using biomass like wood or cow dung in south Asia*** *are illustrated through a measurement of aerosol optical depth, a way of measuring the quantity of pollutants in the air by the relative ability of light to penetrate through them. This representation shows reconstructed levels of pollution from 2004 and 2005. (Credit: Scripps Institution of Oceanography, UC San Diego)*

Scripps Institution of Oceanography at UC San Diego atmospheric scientist V. Ramanathan and University of Iowa chemical engineer Greg Carmichael, said that 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 $CO_2$

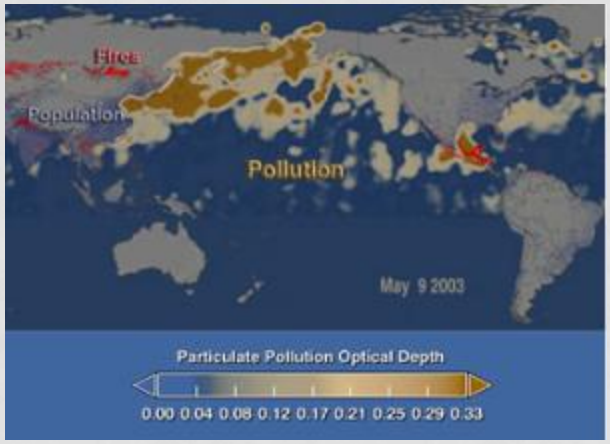



Clean Air Task Force, 2010

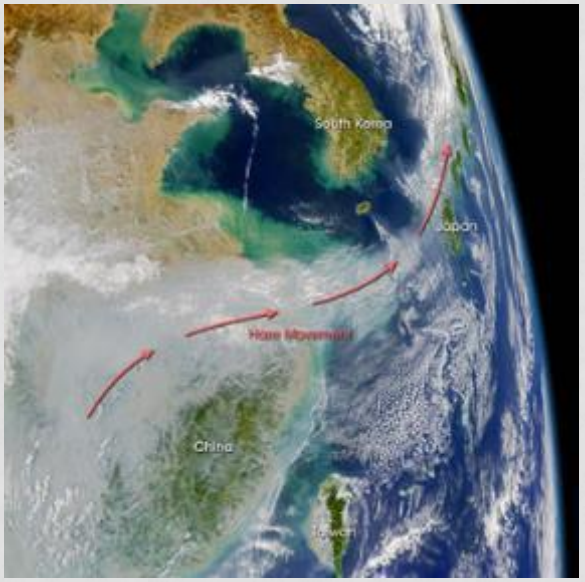
# AEROSOLS AND ASIAN POLLUTION HITTING US - IGAC




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, where it arcs along the western coastline of the island chain before disappearing out of the scene at upper right.

# ARCTIC HAZE



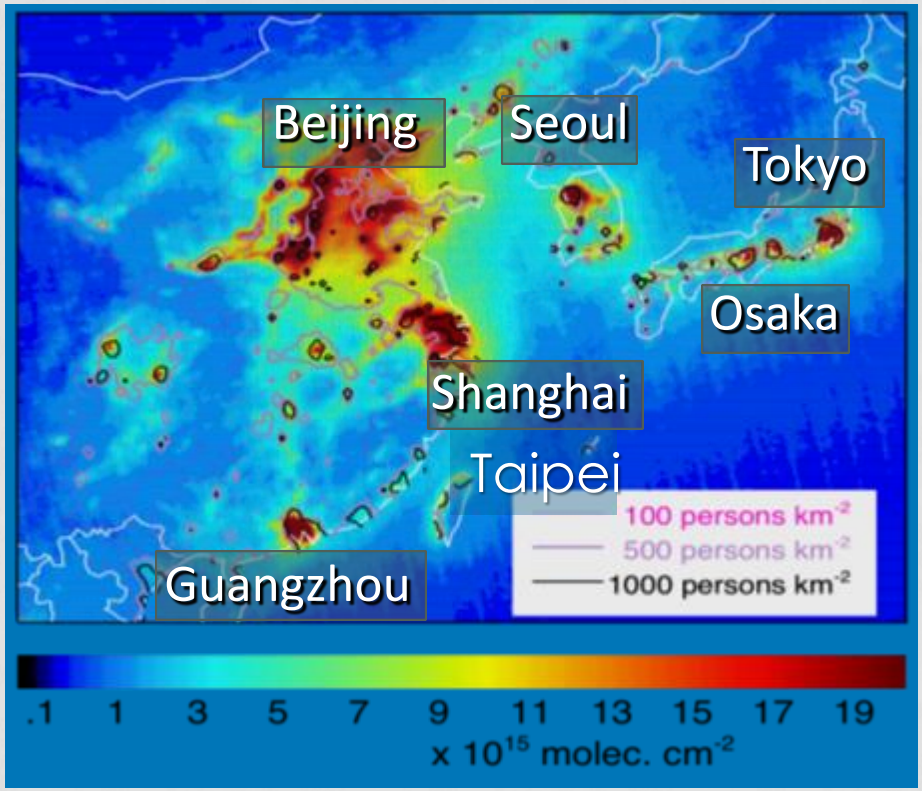
Fire and Ice: MODIS image of smoke from forest fires burning in Alaska and the Yukon, travelling into the Arctic over ice-covered areas, in July 2004

IGAC

# URBAN ENVIRONMENTS AND AIR QUALITY MEGACITIES

Megacities: Asia

- calibrated, comparable measurements
- capacity enhancement



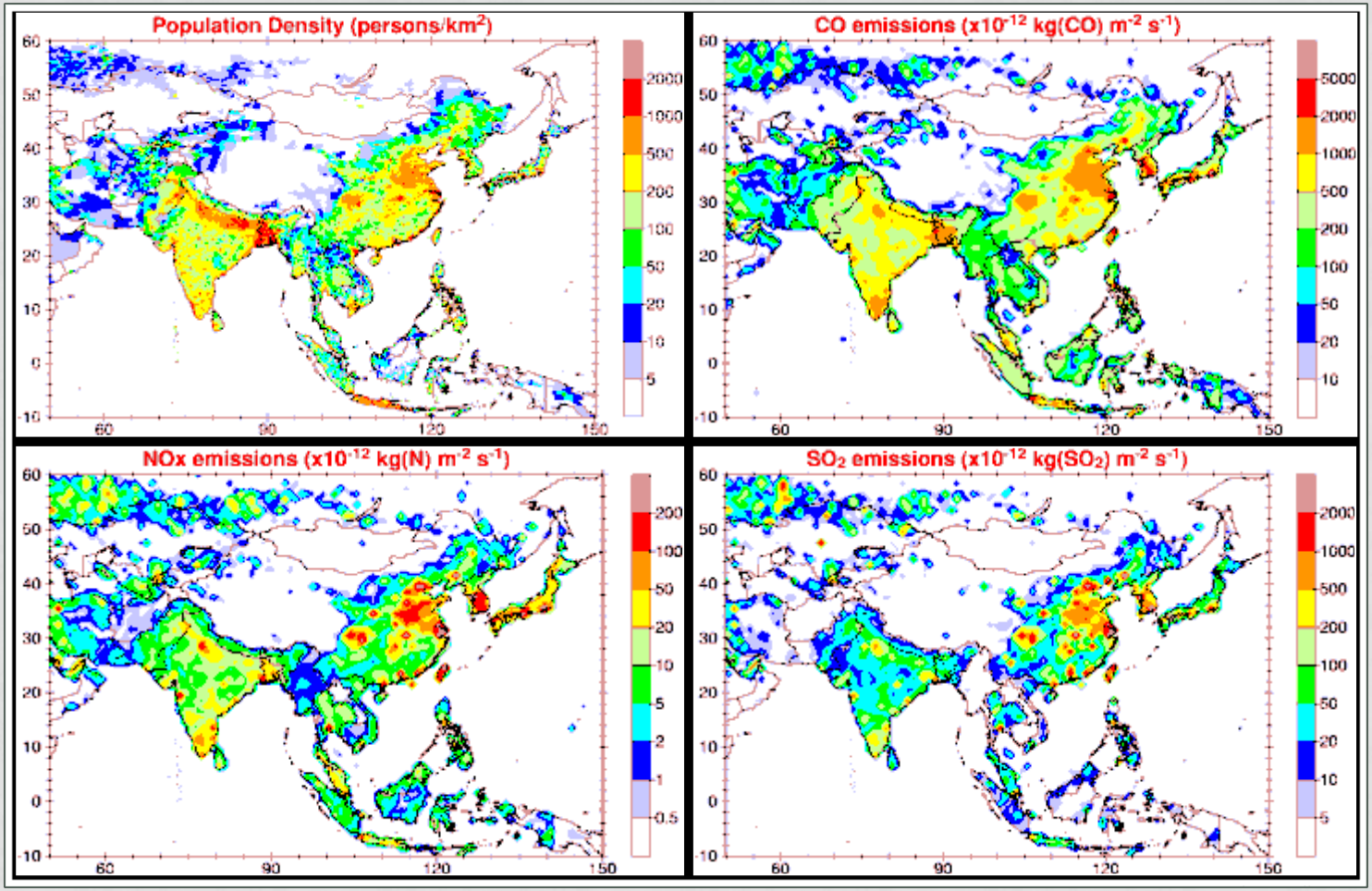

$NO_2$ column - Randal Martin

Parrish and Zhu, 2010 Science

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

IGAC International Global Atmospheric Chemistry

# REPORT ON ATMOSPHERIC CHEMISTRY IN MEGACITIES: ASIA CHAPTER



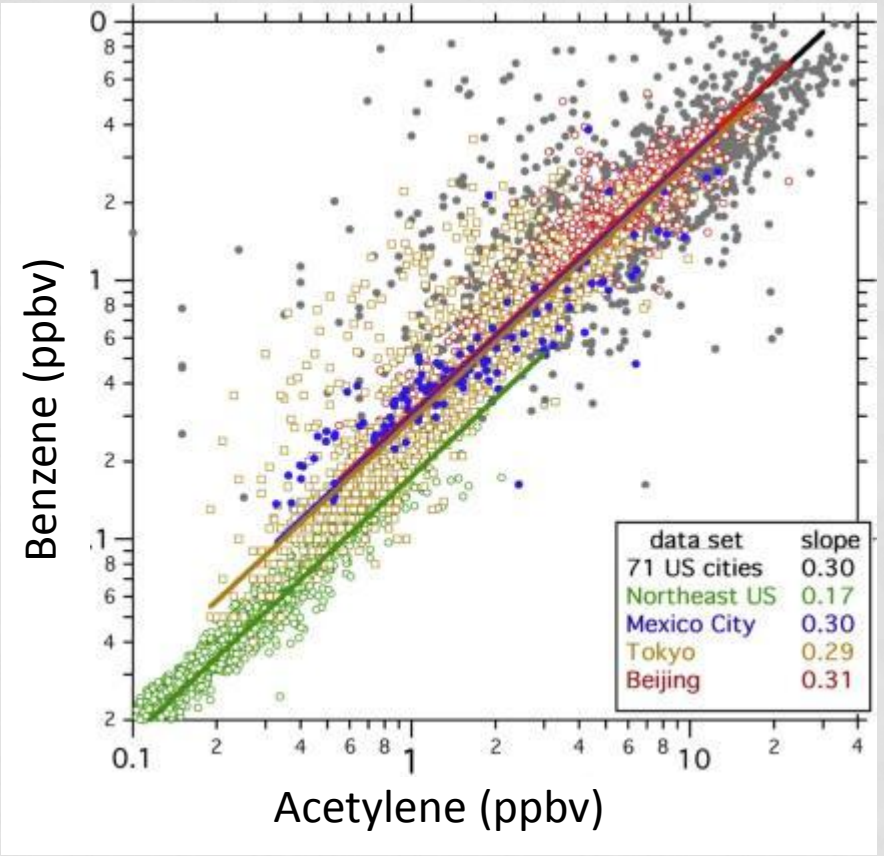

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WMO

IGAC INTERNATIONAL GLOBAL ATMOSPHERIC CHEMISTRY

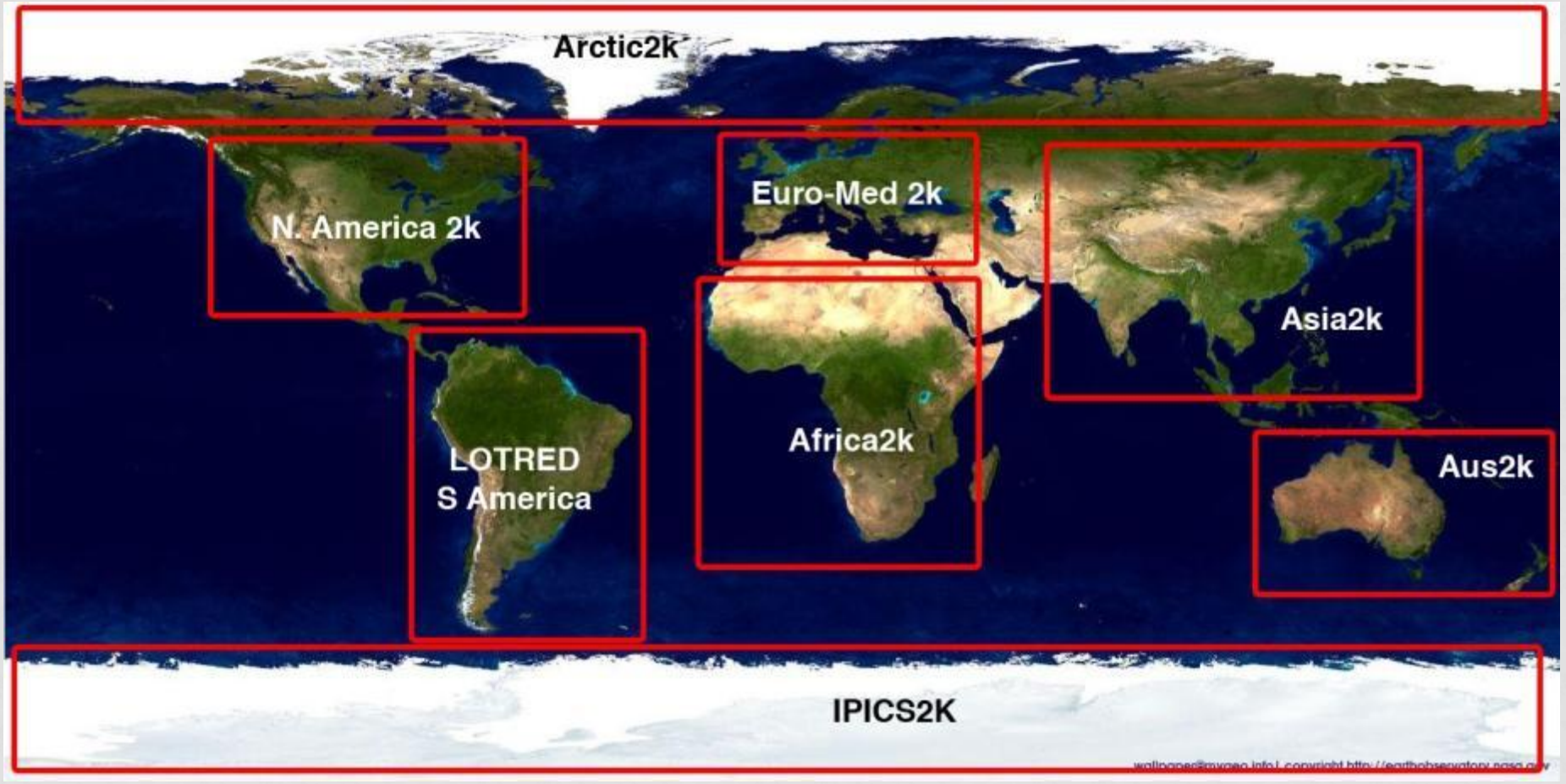
# URBAN ENVIRONMENTS AND AIR QUALITY MEGACITIES

- Asia, Africa, US, Latin America,…
- comparison diverse regions




Parish et al. 2009 Atmos. Envir.

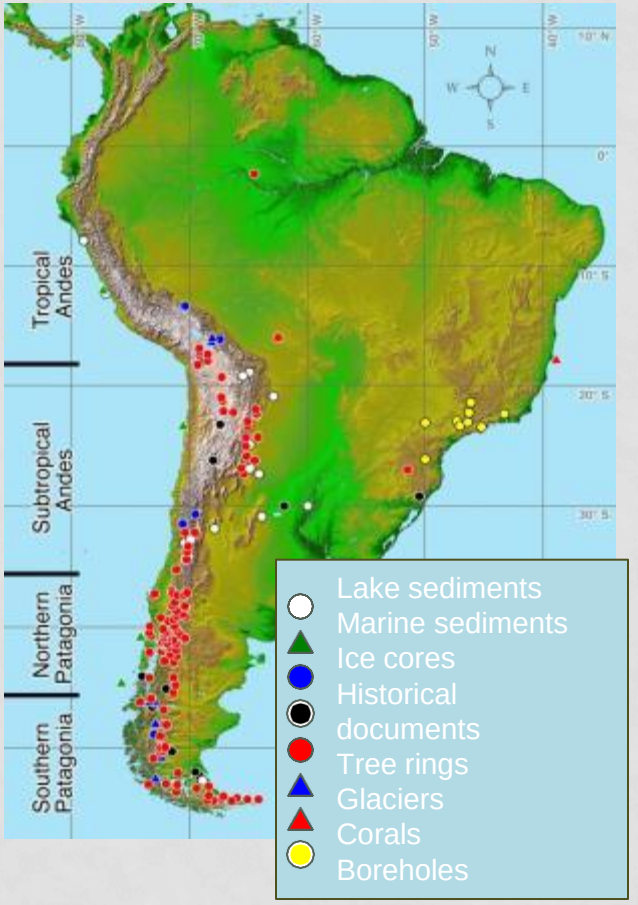
# 2000 YEAR REGIONAL CLIMATE RECONSTRUCTION




GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

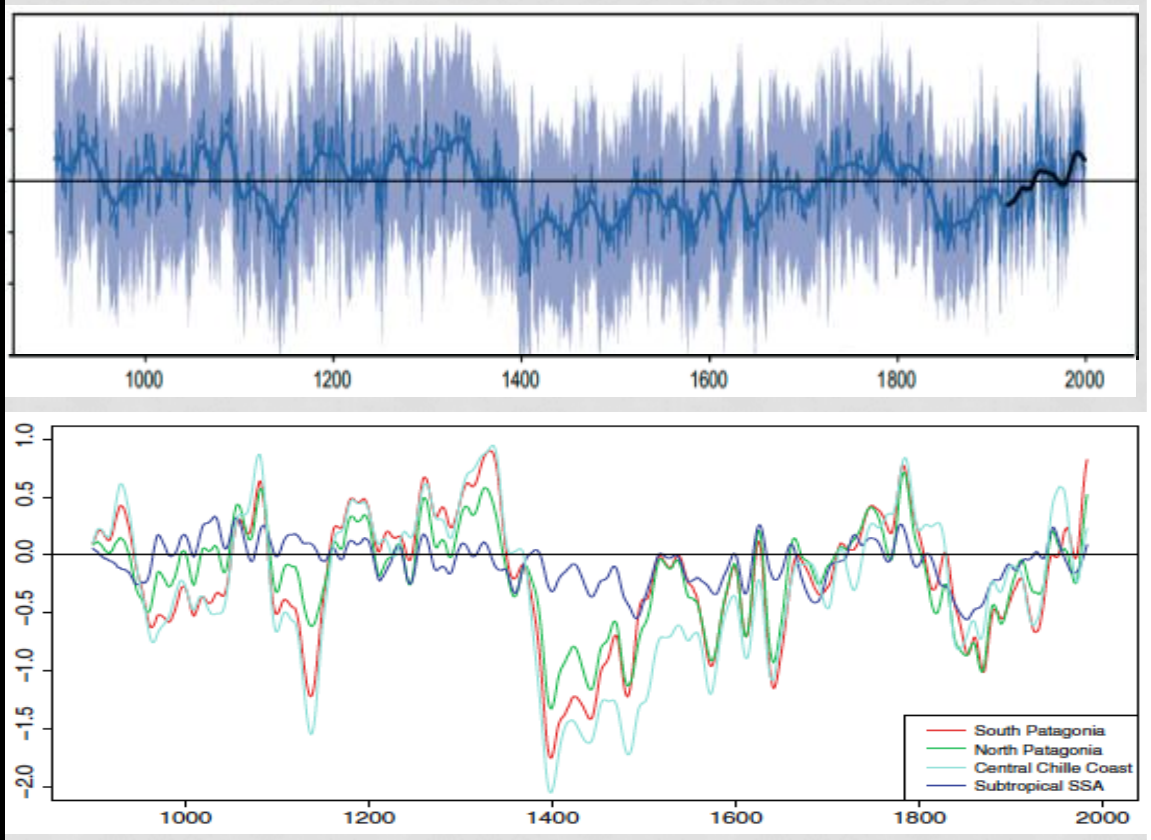
PAGES PAST GLOBAL CHANGES

# PAST CLIMATE IN SOUTH AMERICA




Villalba et al. 2009 Palaeo-3 (special issue)

**TT-Anomaly wrt 1901-1995, °C**



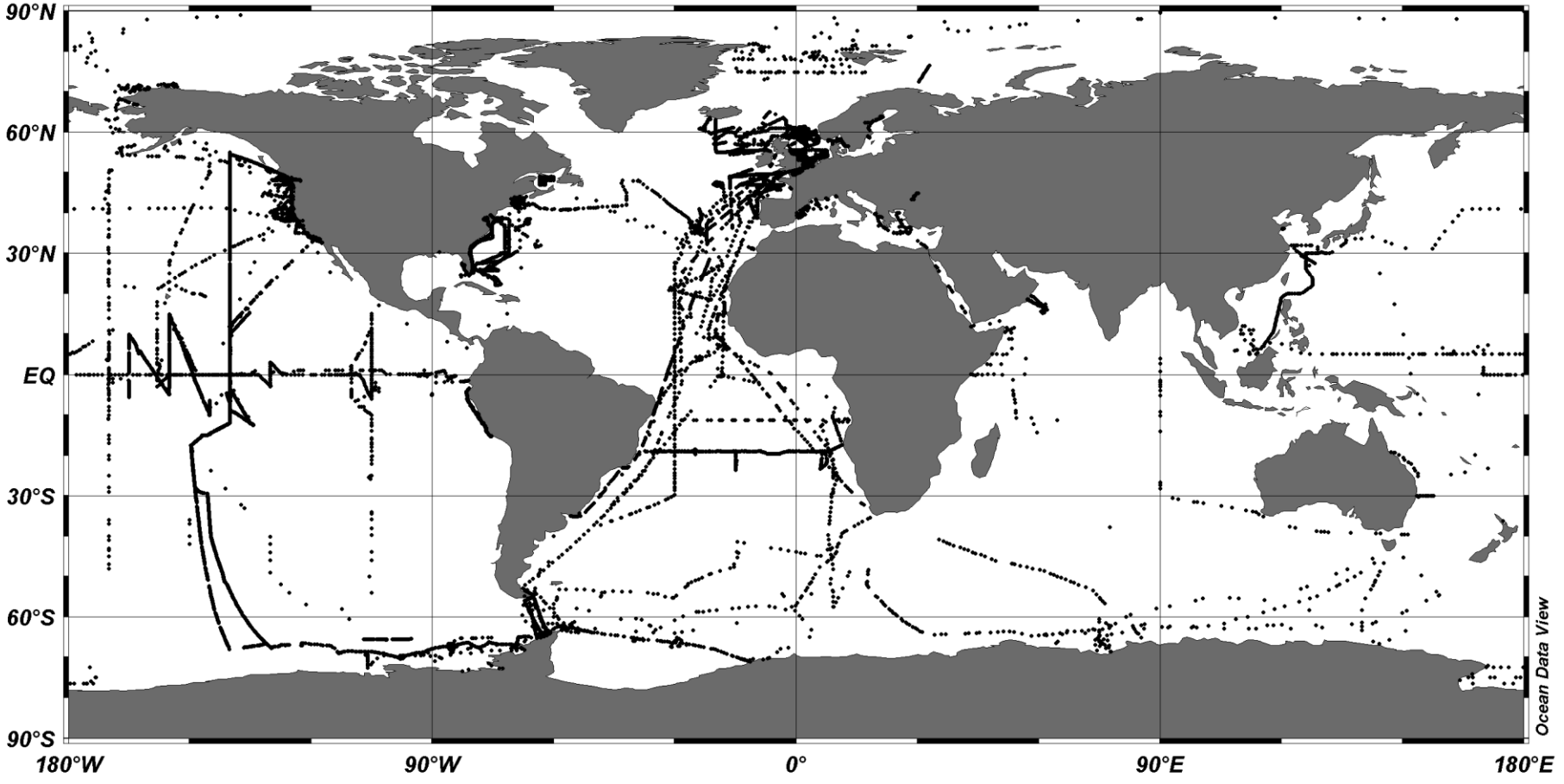

Neukom et al., 2010, Climate Dynamics

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PAGES PAST GLOBAL CHANGES

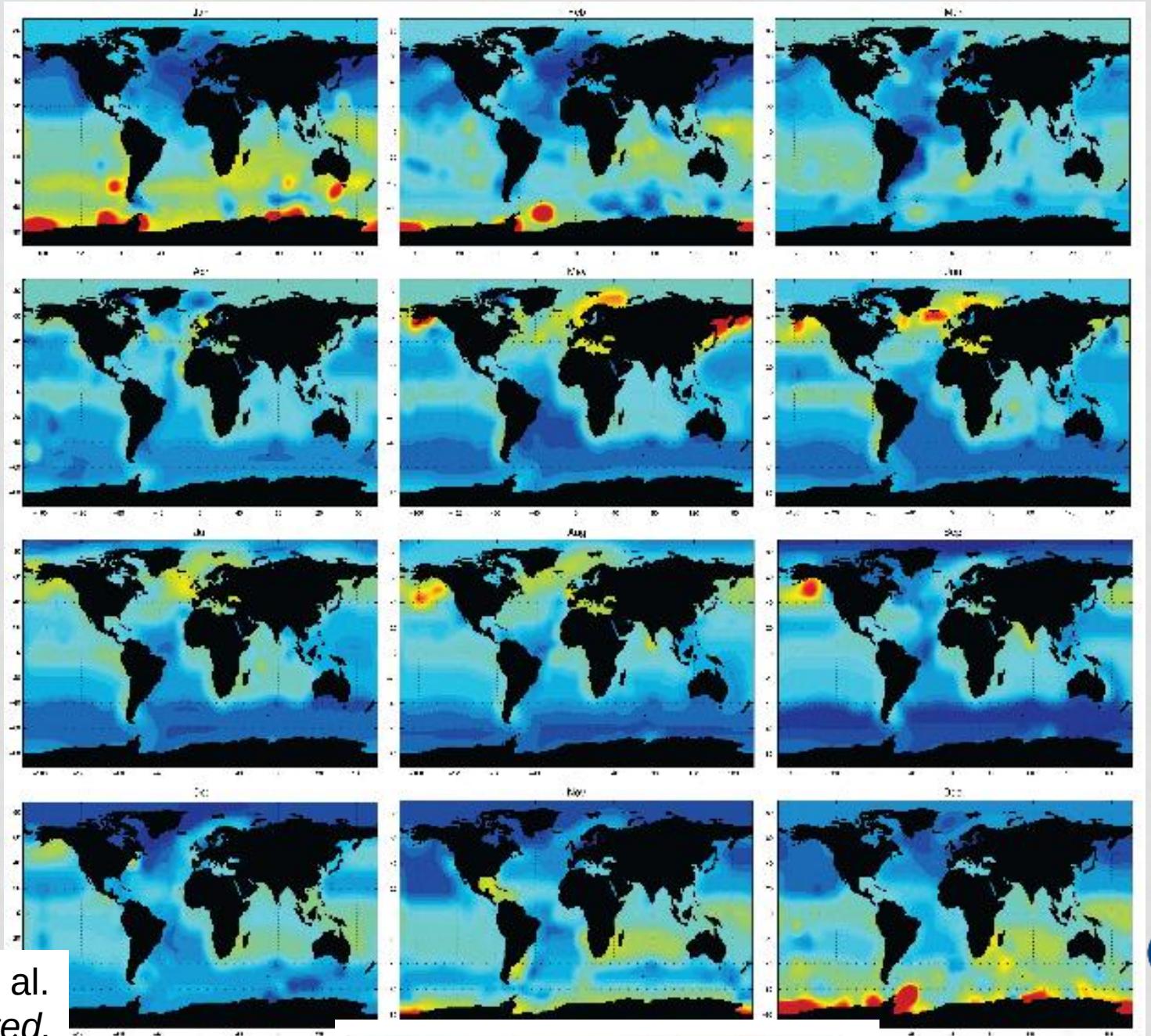
# UPDATED SEAWATER DMS DATABASE

Jim Johnson, Tim Bates (NOAA PMEL) http://saga.pmel.noaa.gov/dms/



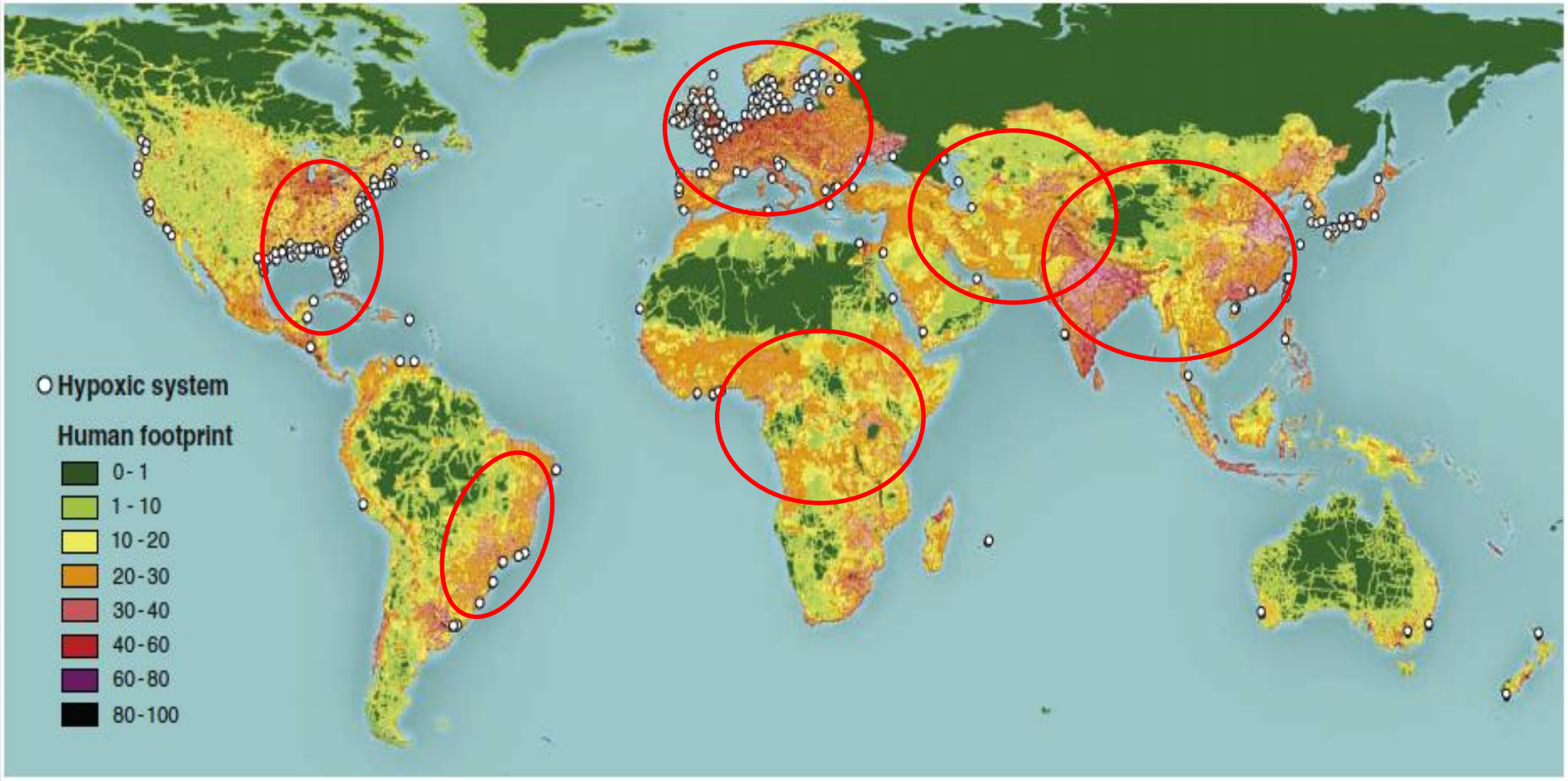

- Kettle et al. (2000) = approx. 15,000 data points
- Now, approx. 47,000 data points.

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Lana et al.
*Submitted, GBC*

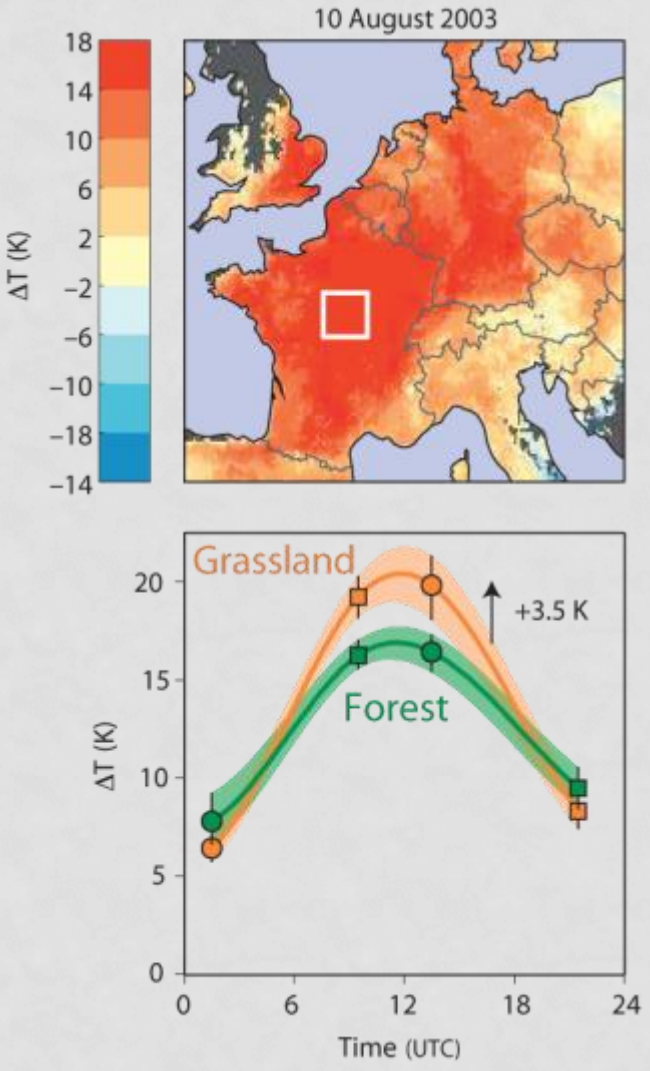
# HUMAN FOOTPRINT: NOT SO MUCH PRISTINE ENVIRONMENT LEFT




*Diaz and Rosenberg, Science, 321, 2008.*

# LAND COVER AFFECTS CLIMATE

- Europe heat waves 2003-2006
  - dry, warm conditions
- Grasslands contribute extreme heating
  - soil-moisture depletion
- Implications future
  - forests help ammeliorate
  - prolonged/severe heat waves

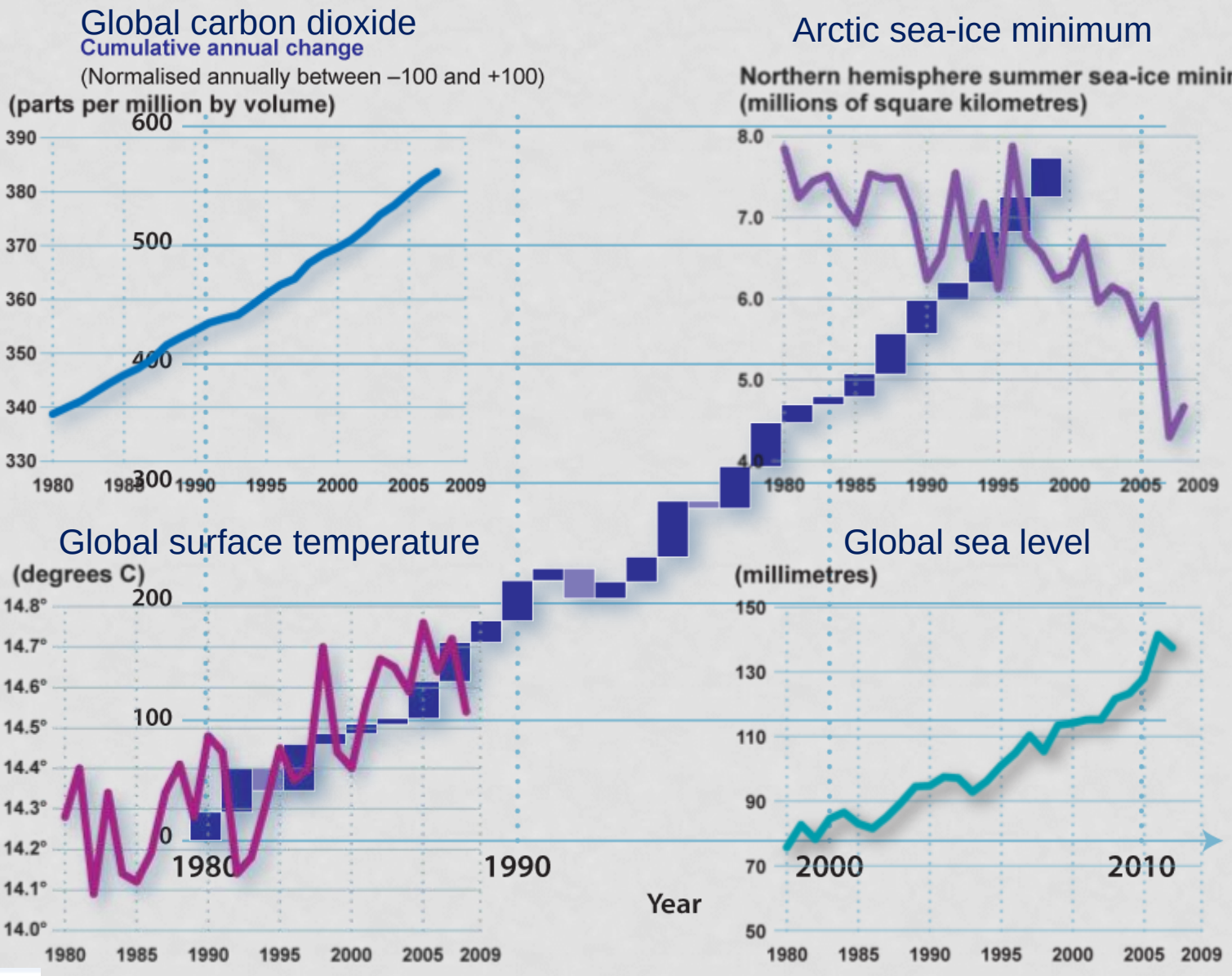



Teuling et al. 2010 Nature Geoscience

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iLEAPS

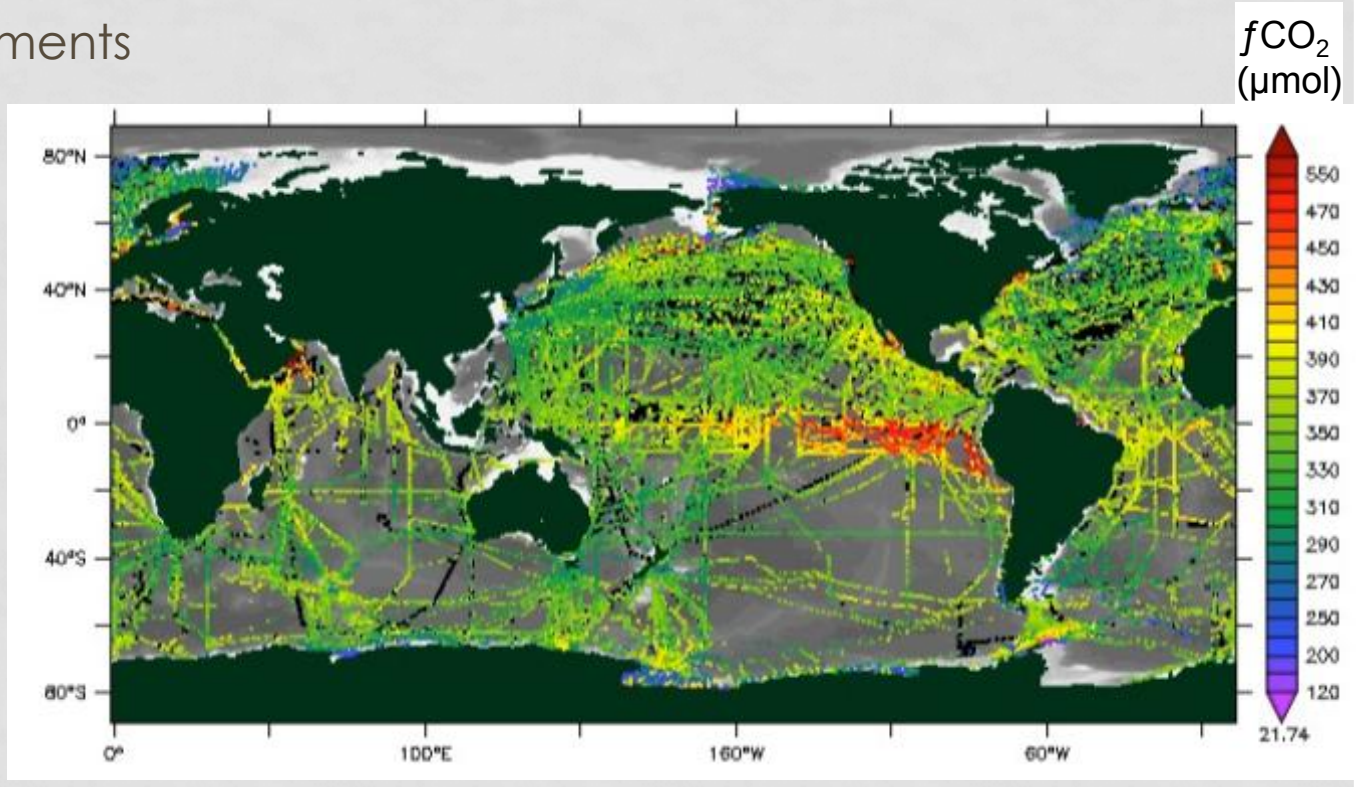
# IGBP CLIMATE-CHANGE INDEX




GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

# SURFACE OCEAN $CO_2$

- 4.5 million measurements
  - 10+ countries
  - +1250 cruises
  - 1968 – 2007
- Publically available
- Quality controlled
- Updated

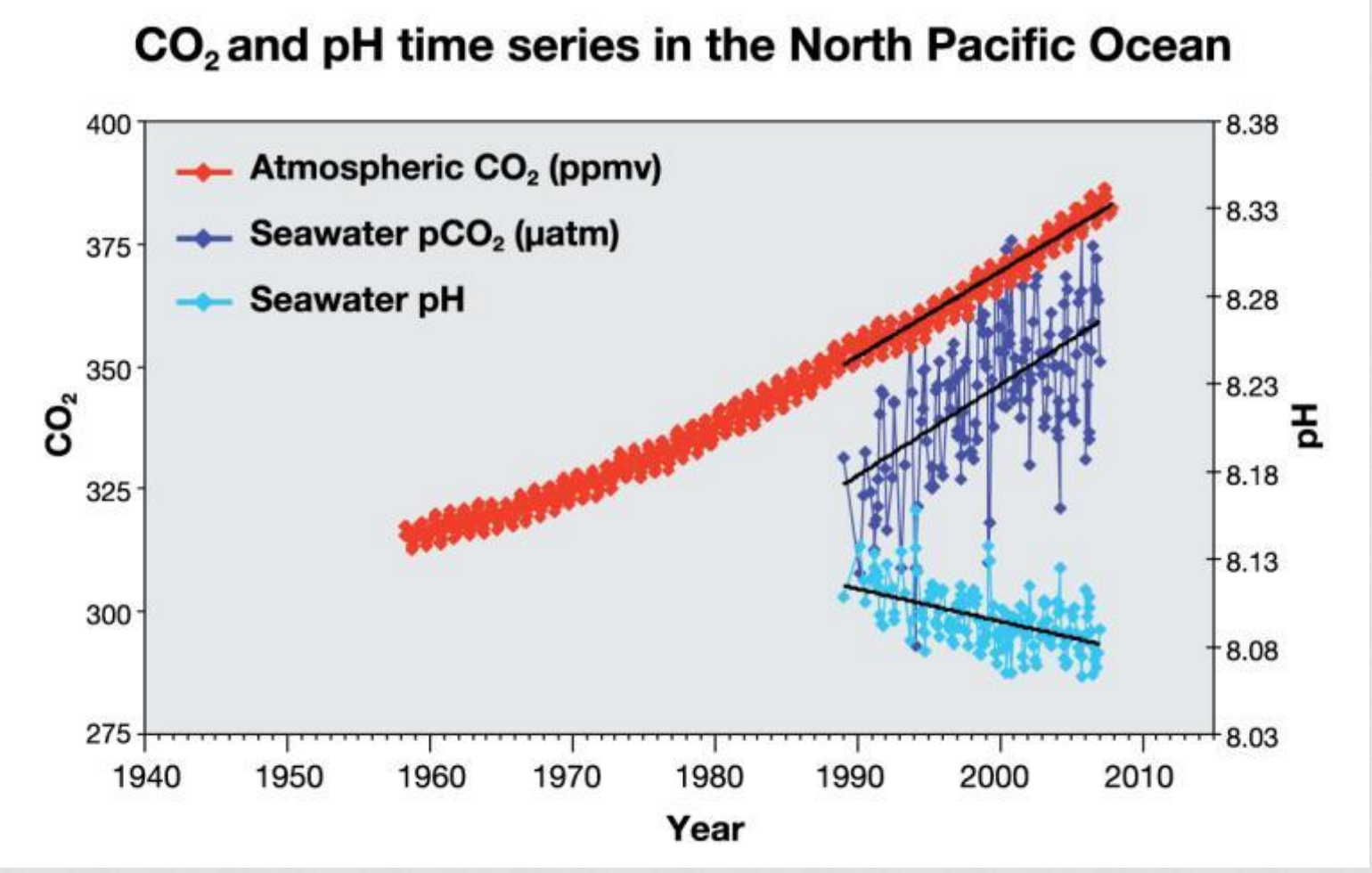



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IMBER

solas

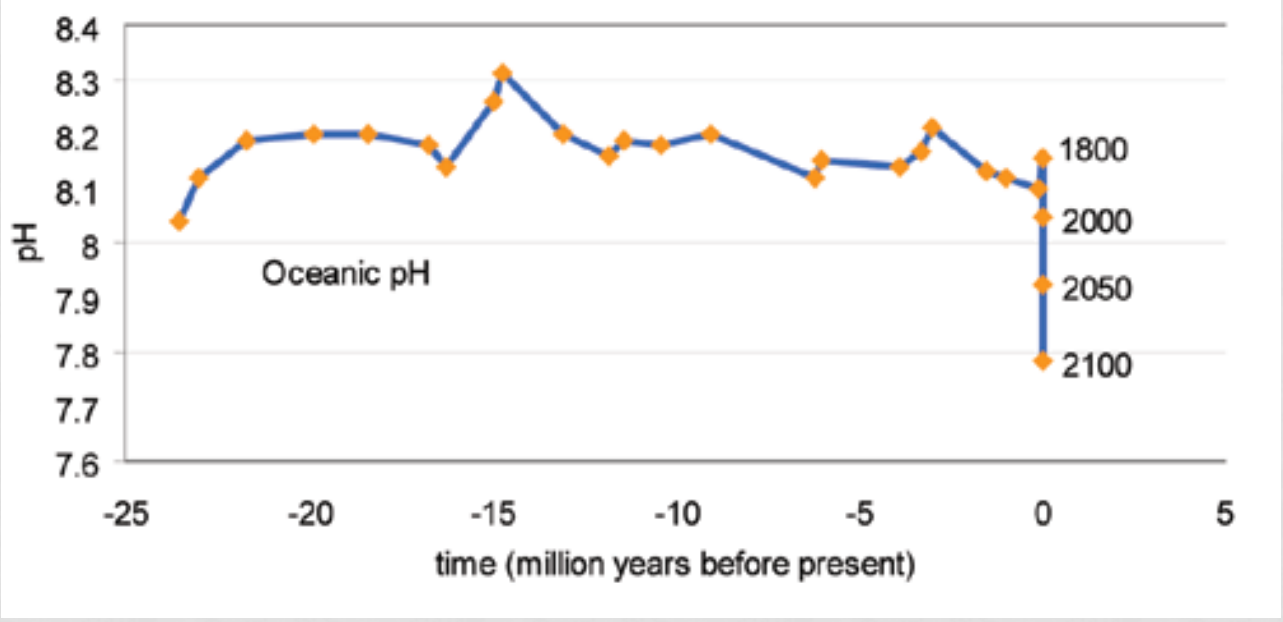
# OCEAN ACIDIFICATION




Modified after R.A. Feely, Bulleting of the American Meteorological Society, July 2008

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# OCEAN ACIDIFICATION
## PAST AND PRESENT VARIABILITY OF MARINE PH

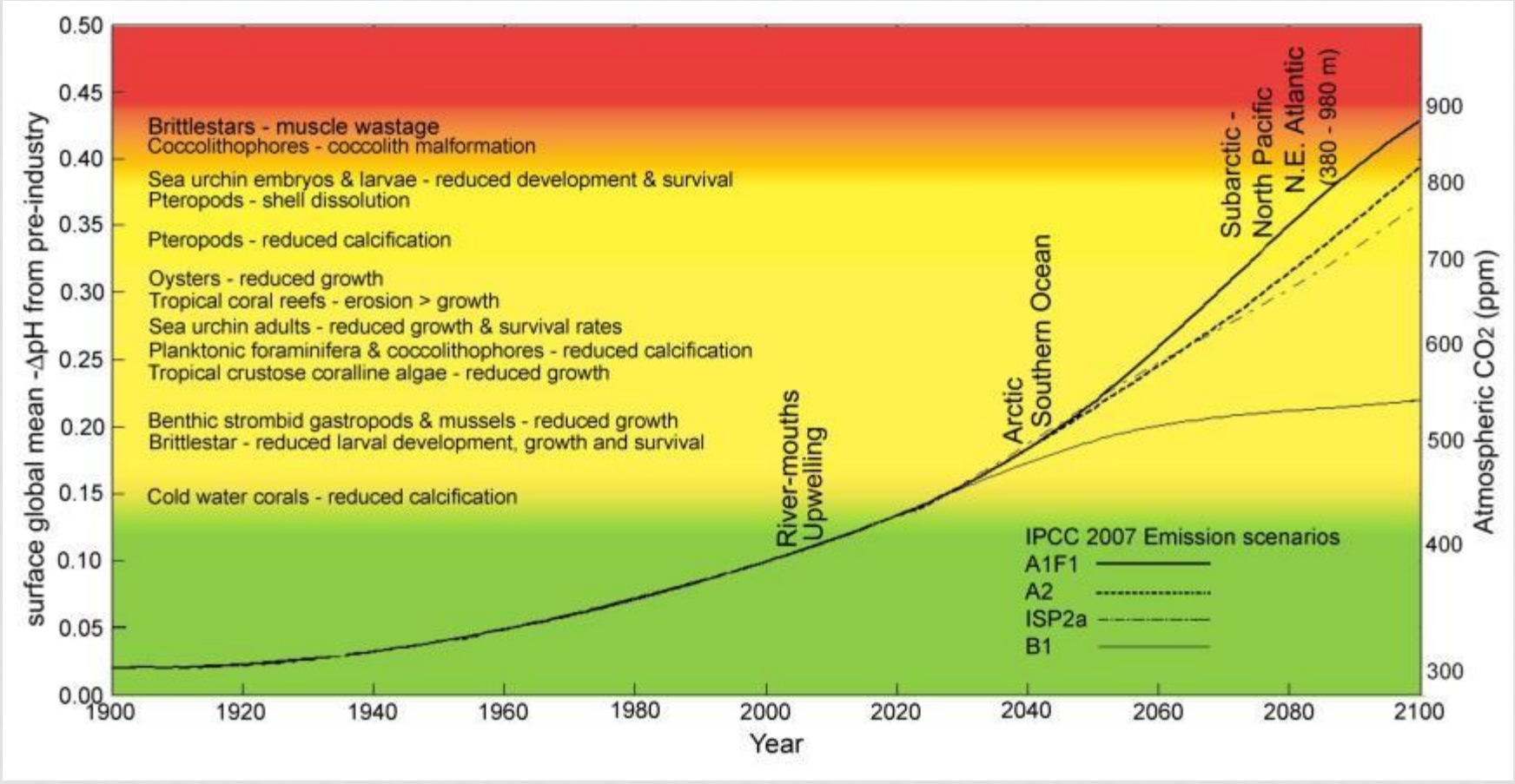



Based on IPCC mean scenarios

Turley et al. 2006

GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

# MOUNTING EVIDENCE: THAT FUTURE CO2 EMISSIONS COULD IMPACT SOME MARINE ORGANISMS AND ECOSYSTEMS THIS CENTURY




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

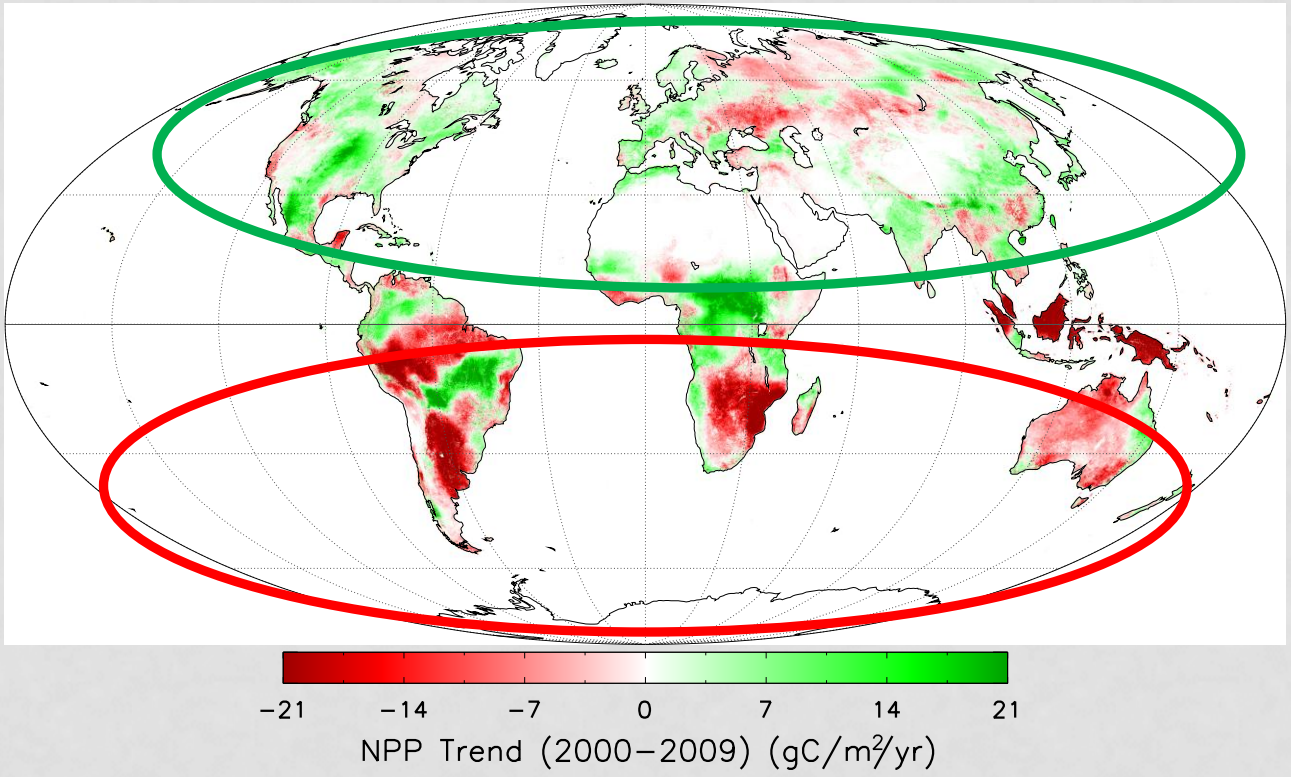
GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

# LAND USE: NET PRIMARY PRODUCTIVITY

- Global NPP decrease
- SH decrease – drought
- Implications terrestrial C sink
- Space-based and *in situ* observations

**NPP increased over large areas in the (NH)**
(65% of vegetated land area had increased NPP)

**NPP decreased over in the (NH)**
(70% of vegetated land areas had decreased NPP)




Zhao and Running 2010

GLOBAL IGBP International Geosphere-Biosphere Programme CHANGE

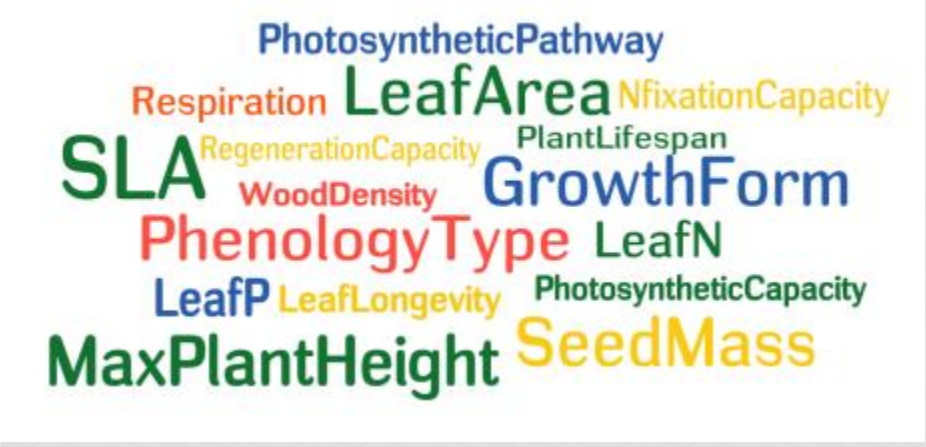
# PLANT FUNCTIONAL TYPES

## FAST TRACK INITIATIVE

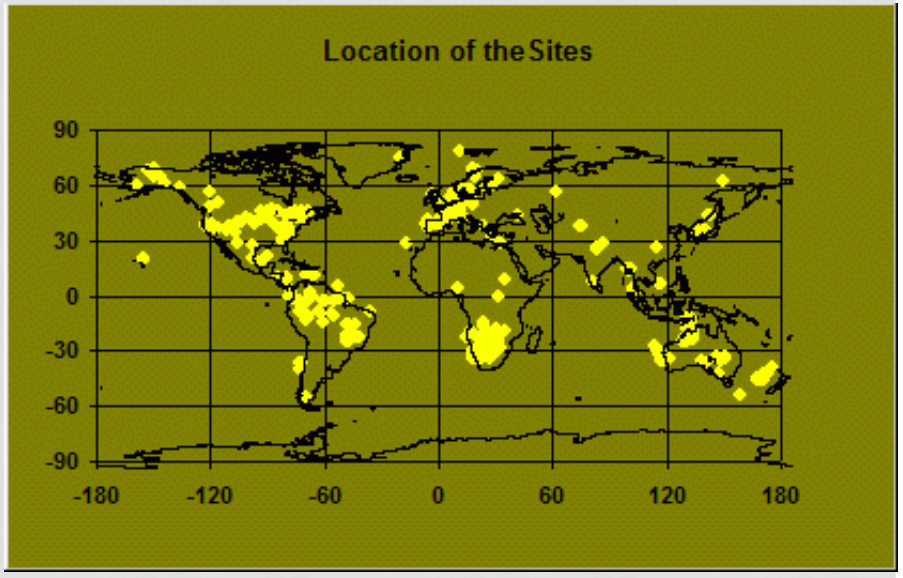
Leaders: Sandra Lavorel (IGBP), Colin Prentice (AIMES), Sandra Díaz (GLP), and Paul Leadley (DIVERSITAS)

**Objectives**

- Construction of a global database of plant functional traits
- Design of a new generation of global dynamic vegetation models




**Nitrogen fixation capacity**




www.try-db.org

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# THE FIVE KEY THREATS OF EXCESS NITROGEN

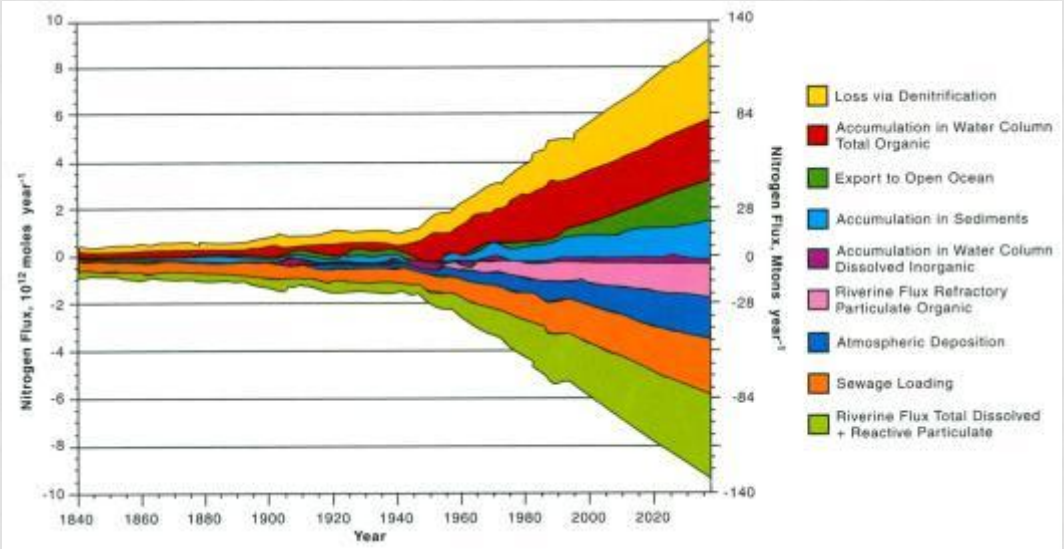
The WAGES of too much nitrogen

Water quality
Air quality
Greenhouse balance
Ecosystems
Soil quality

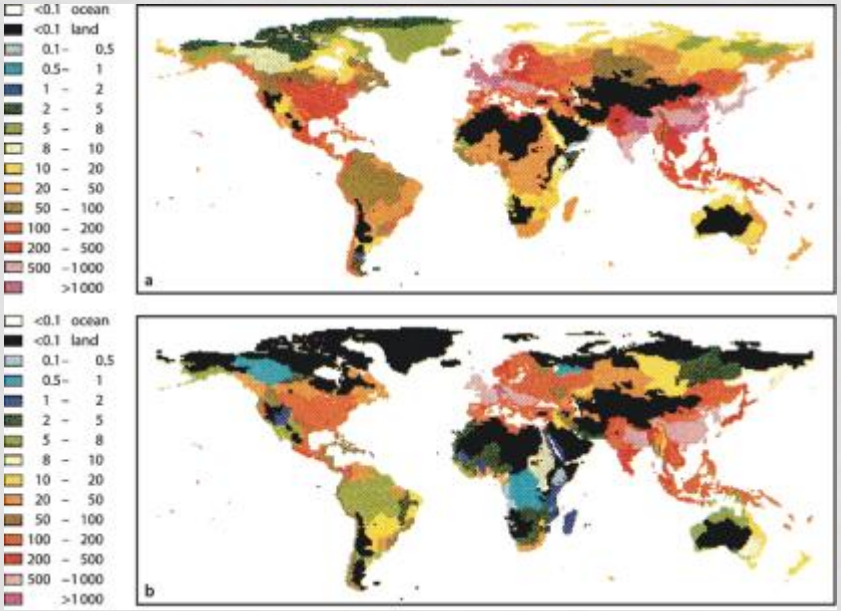



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# NITROGEN



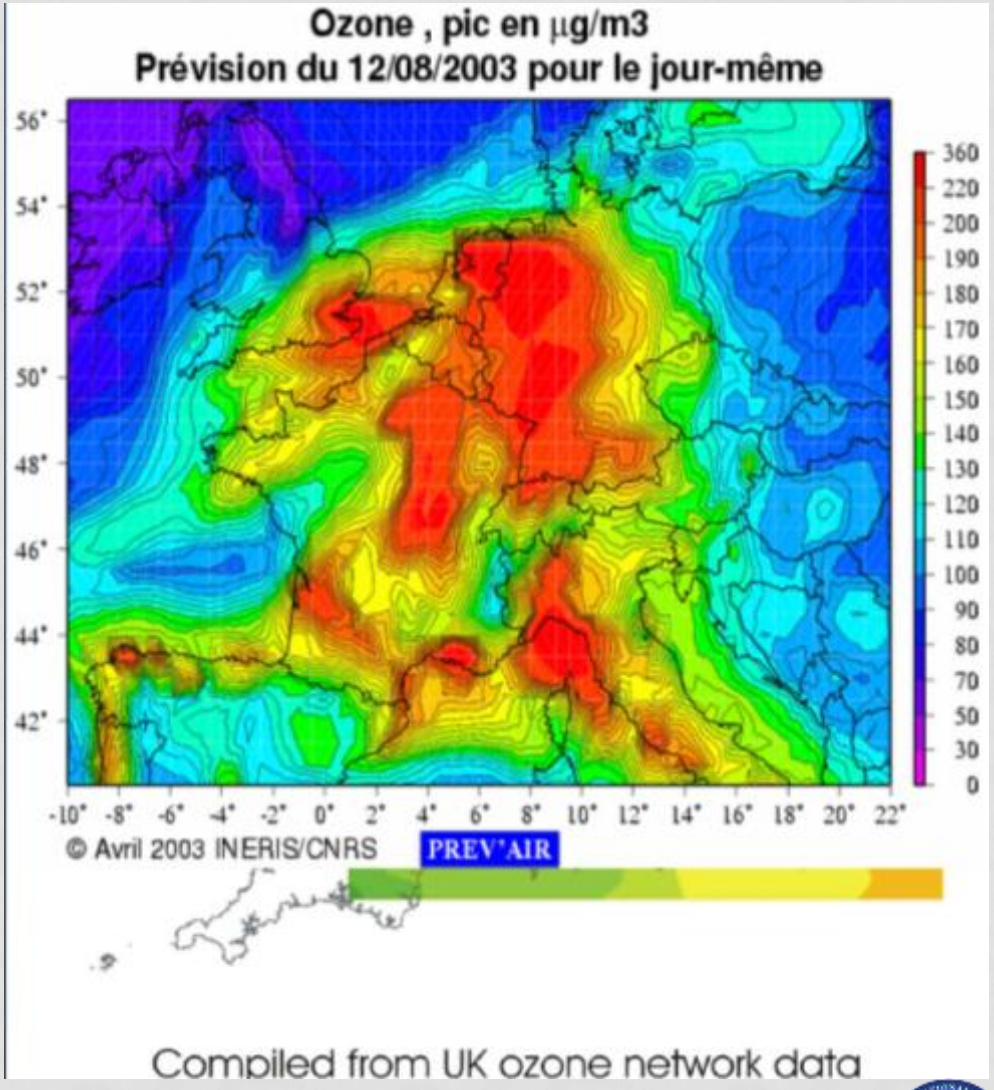

Model-calculated partitioning of the human-induced nitrogen perturbation fluxes in the global coastal margin for the period since 1850 to the present (2000) and projected to 2035 under a business-as-usual scenario (Steffen at al., 2004 based on Mackenzie et al. 2002)




Multiple regression modelling of contemporary dissolved inorganic nitrogen fluxes (kg N km-$^2$year) from some rivers (Steffen at al., 2004 based on Seitzinger and Kroeze 1998): a total dissolved inorganic nitrogen export; and b export attributed to fertiliser use .

# UK OZONE BUBBLE – 2PM 6TH AUGUST 2003

- In the UK, 2000 excess deaths during heat waves
- 700 may have been attributable to high levels of ozone and PM10

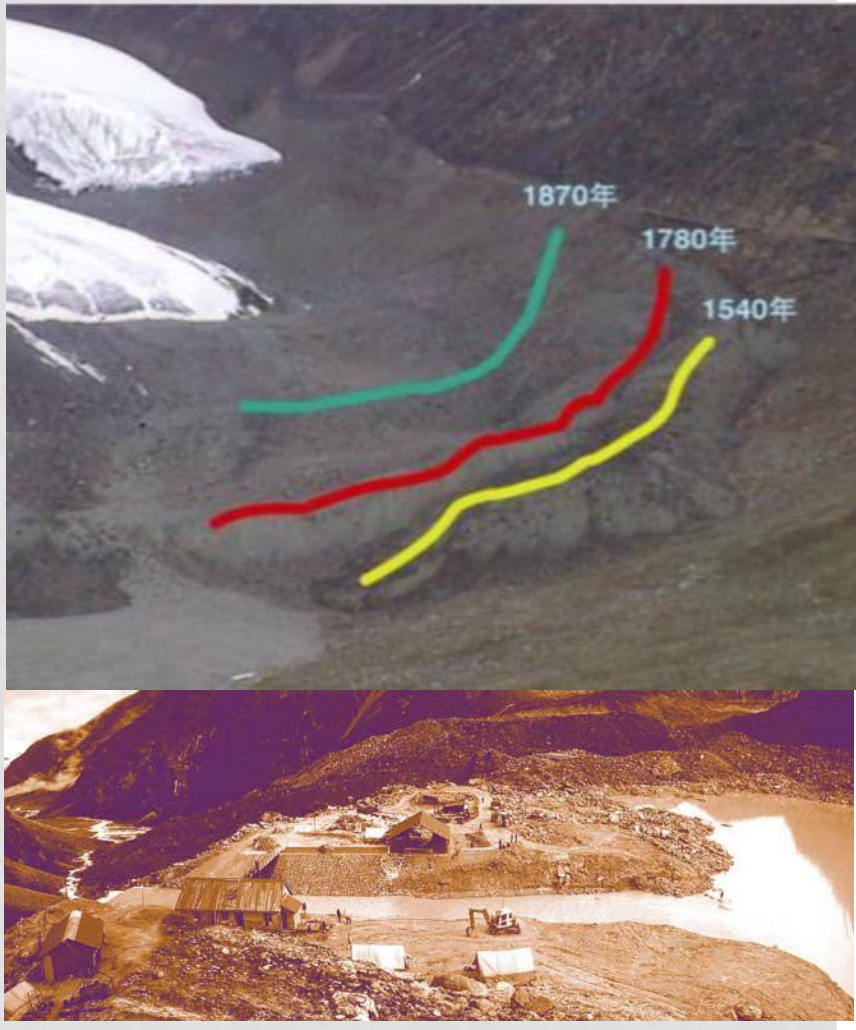



Source: Paul S. Monks –IGAC

# FRESHWATER SECURITY

## Changes in the cryosphere of arid Central Asia

- Water availability, management
- Hazards
- Vulnerability, adaptation strategy
- Peer-reviewed publications
- Reports for policy-makers

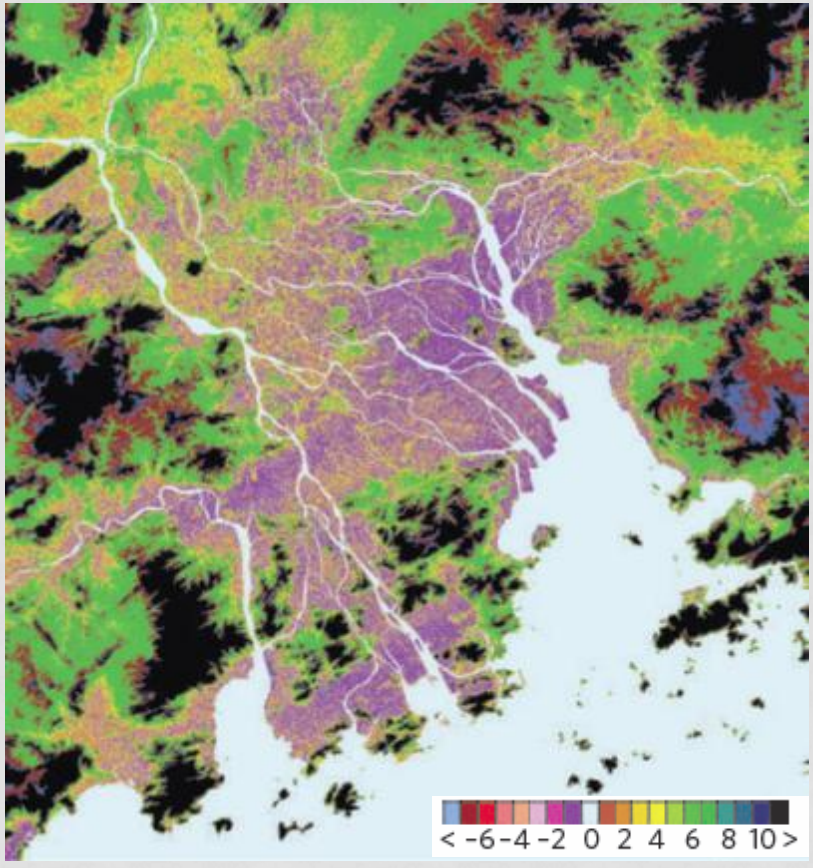



Qin Dahe, Lead

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# COASTAL VULNERABILITY, FRESHWATER SECURITY

- 24 of 33 deltas sinking
- multiple stresses
  - urbanization
  - water, mineral mining
  - land use/hydrology
  - sea level rise
- future  projections




Syvitski et al. 2009
Nature Geoscience

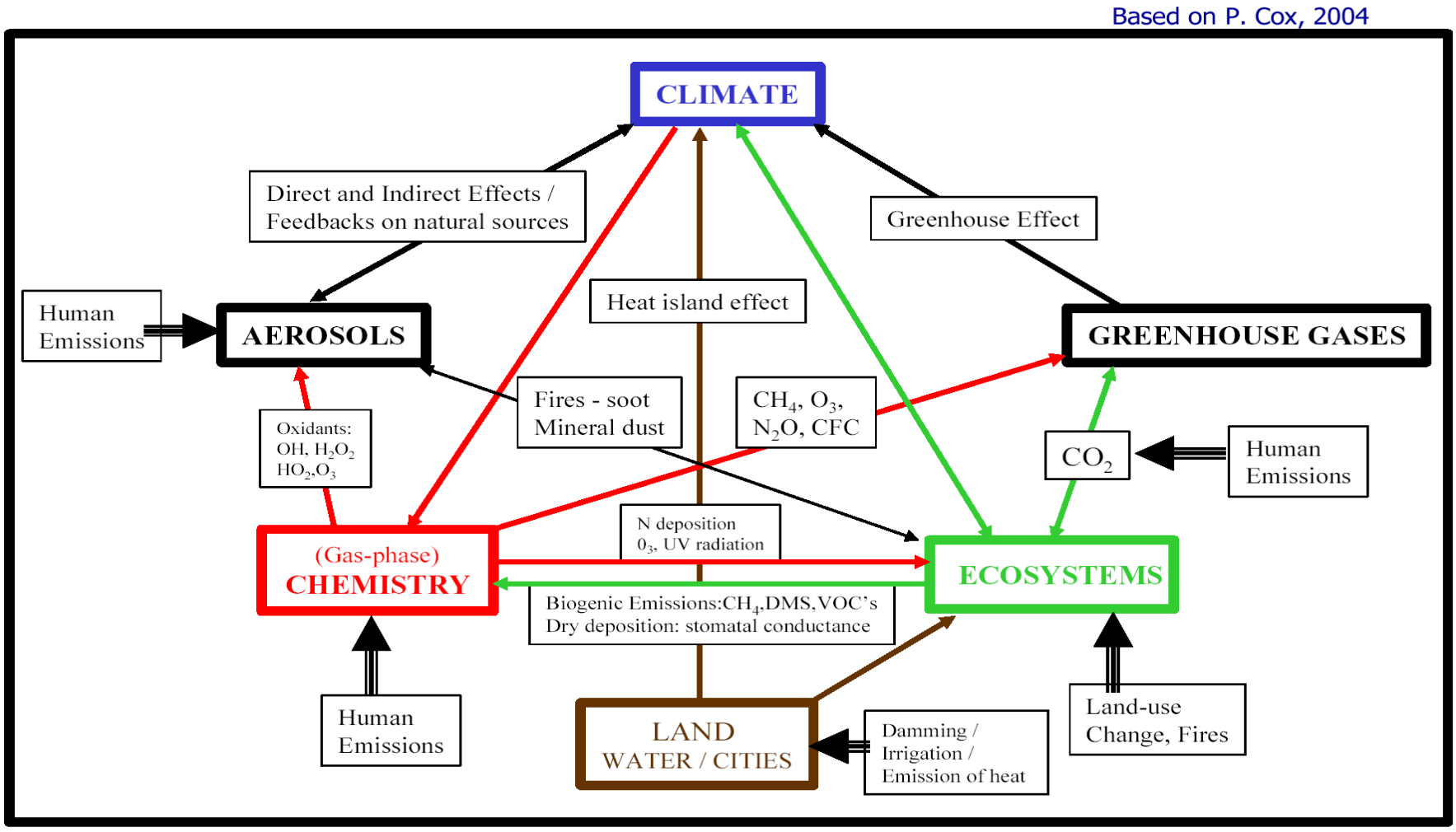
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GWSP

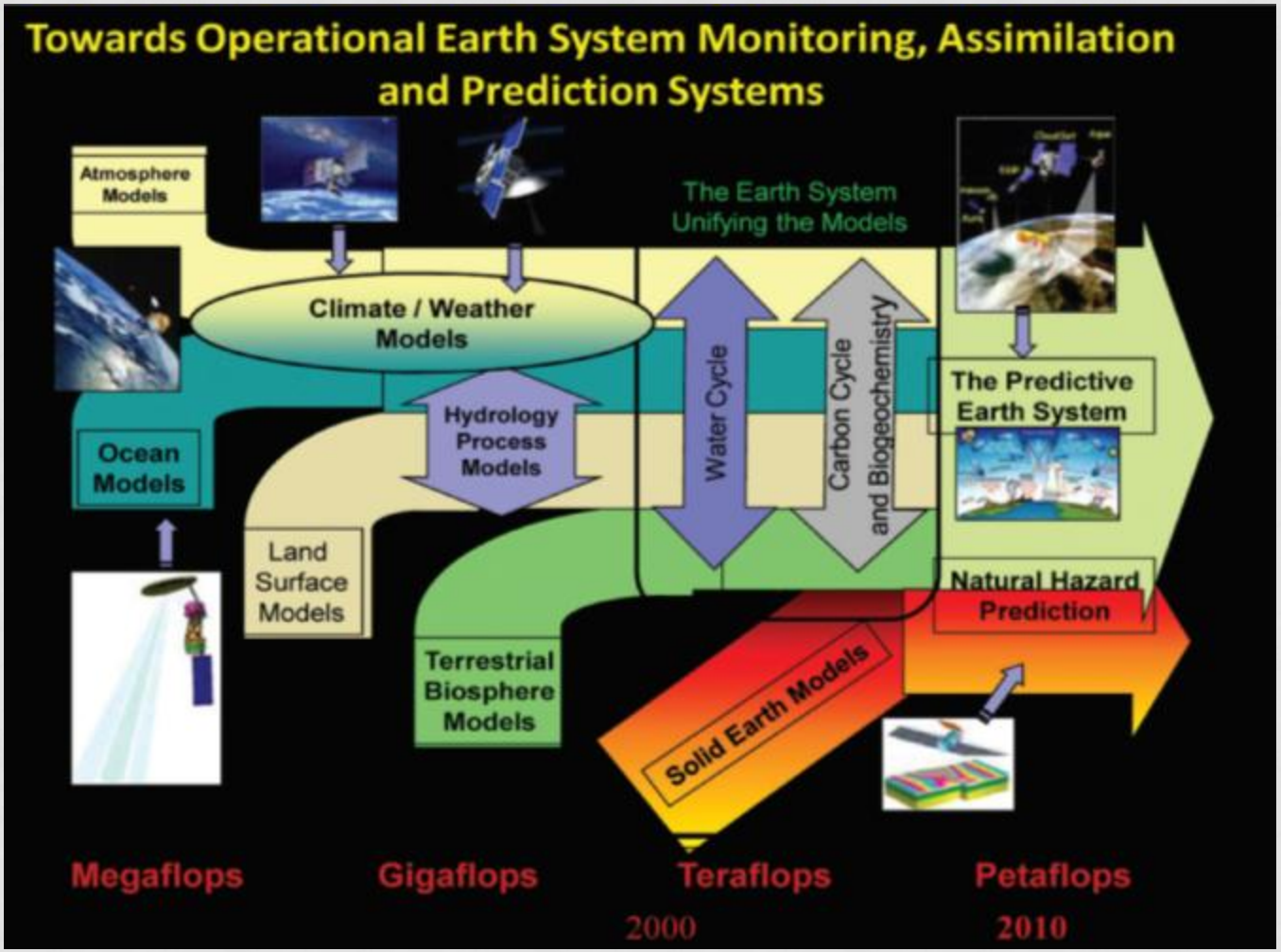
LOICZ

# COMPLEXITY OF THE EARTH SYSTEM

# Interactions between the physical climate, greenhouse gases, aerosols, gas-phase atmospheric chemistry, ecosystem dynamics, land use, and the water system



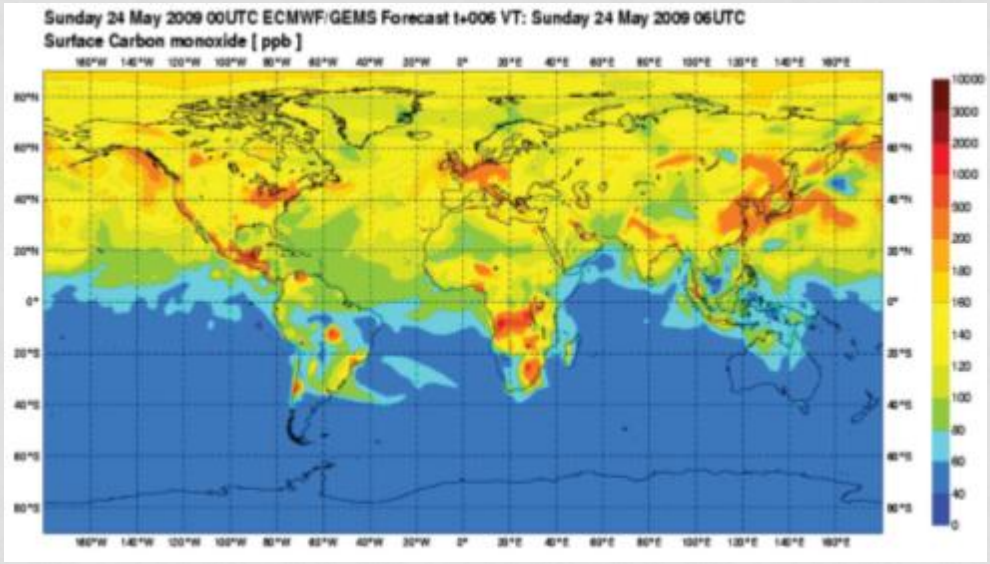
# ELEMENTS OF A COMPLEX EARTH SYSTEM ANALYSIS AND PREDICTION SYSTEM, AND THE COMPUTATIONAL REQUIREMENT



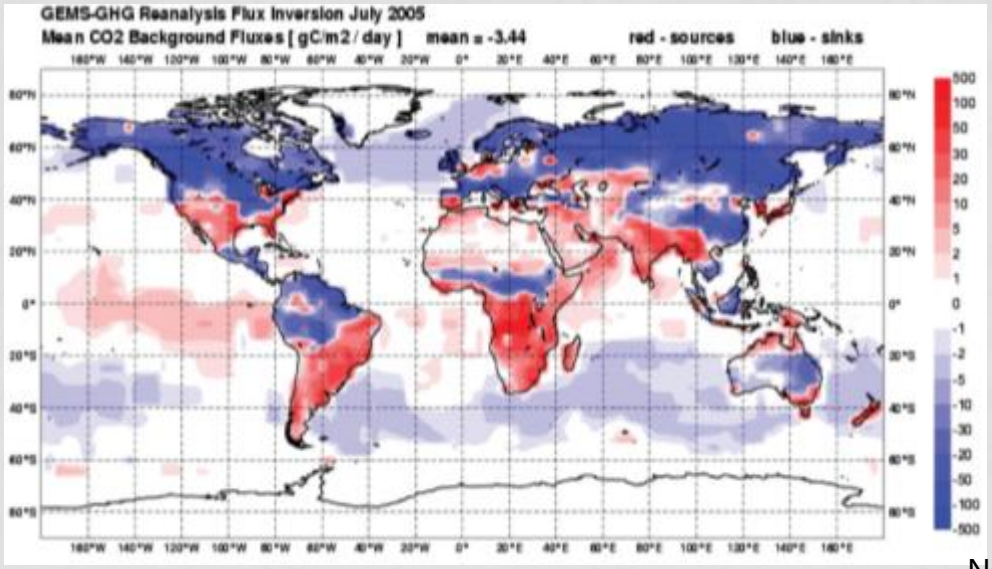

Nobre et al, BAMS, 2010

# PREDICTED GLOBAL DISTRIBUTION OF CARBON MONOXIDE BY ECMWF (EU FUNDED GEMS 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

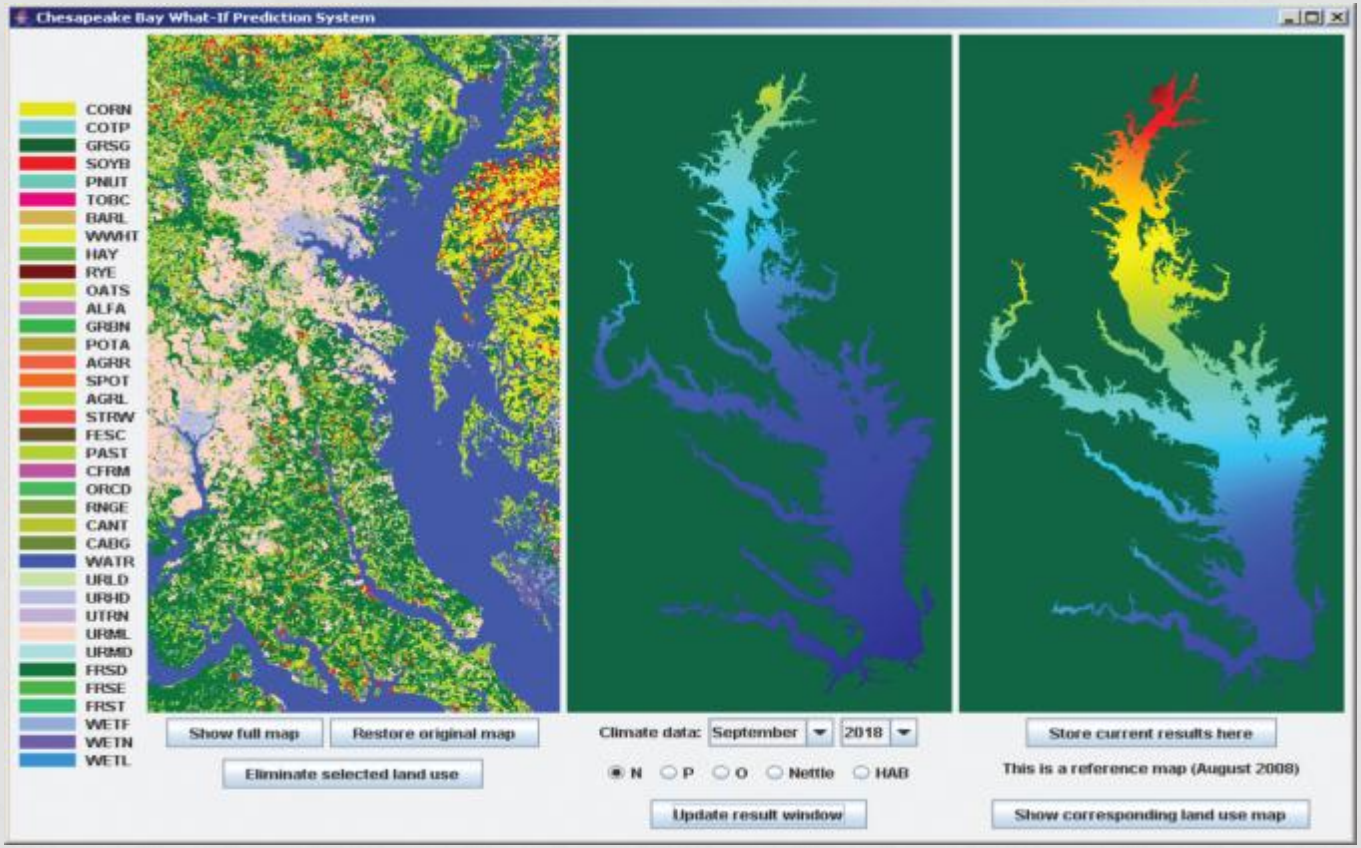



= sources

= sinks

Nobre et al, BAMS 2010

# REGIONAL EARTH SYSTEM MODEL: THE CHESAPEAKE BAY FORECAST SYSTEM DECISION SUPPORT INTERFACE



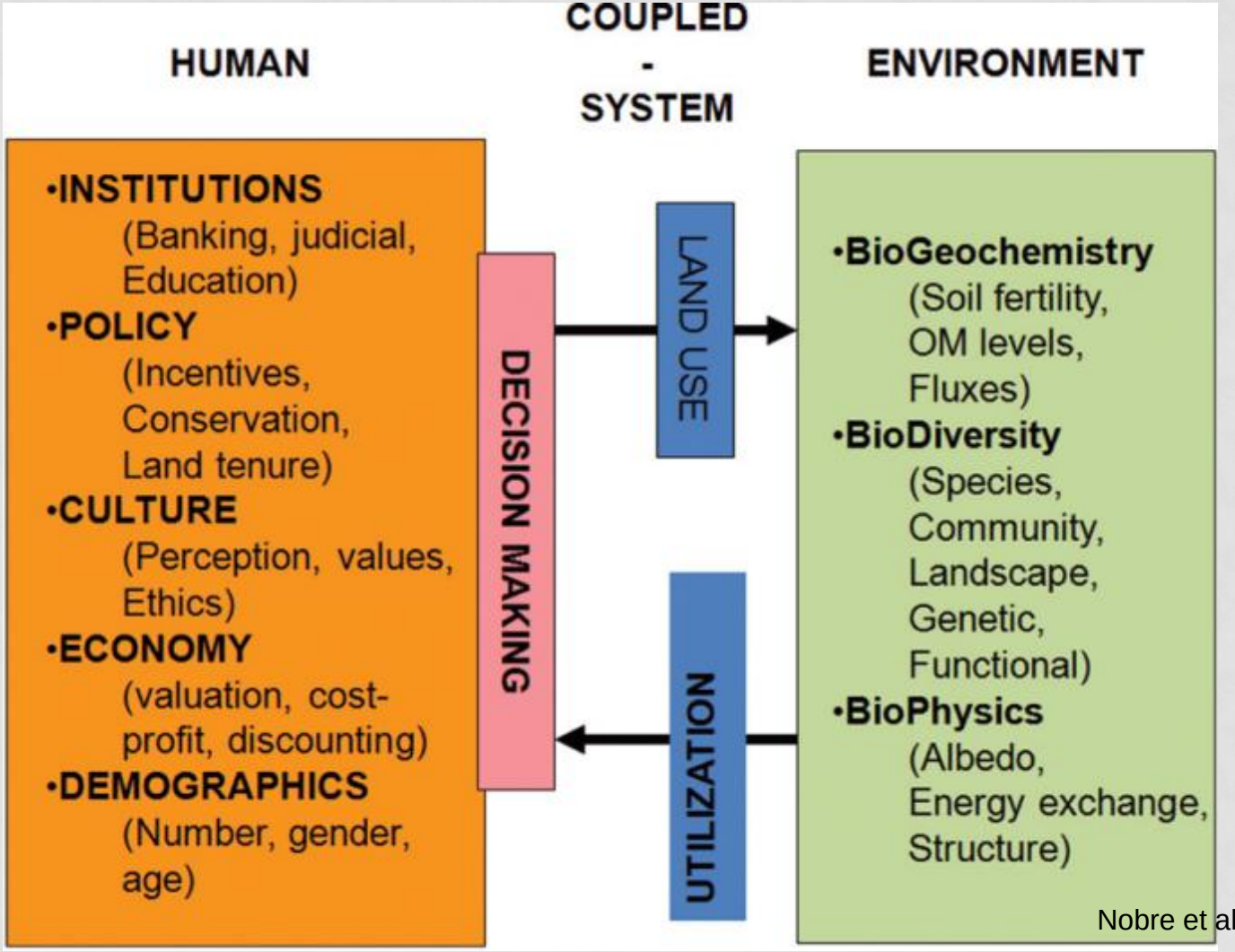

**Land cover/land use types at a 30-m resolution incorporated into the coupled ocean–atmopshere–land–ecosystem model of the watershed**

**Changes to nitrogen loading to the bay if all runoff from poultry farms is remediated by 2018**

**Current nitrogen concentrations in the bay**

Nobre et al, BAMS, 2010 based on Murtugudde 2009)

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




Nobre et al, BAMS, 2010

MODEL OF A COUPLED HUMAN–ENVIRONMENTAL SYSTEM

# EARTH SYSTEM GOVERNANCE: RIO+20

# GOVERNANCE AND RIO+20




**Agenda:**

Green economy

Institutional Frameworks for Sustainable Development

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

PLANET UNDER PRESSURE 2012 MARCH 26-29 LONDON

NEW KNOWLEDGE TOWARDS SOLUTIONS




## The conference

- Focussing on solutions
- 3000+ participants
- 139 countries
- 40% abstracts from developing countries
- Day 4: High-Level Policy
- Demand exceeding expectations

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PLANET UNDER PRESSURE
2012 MARCH 26-29 LONDON

NEW KNOWLEDGE TOWARDS SOLUTIONS

RIO+20
United Nations Conference on Sustainable Development

**The conference will provide a "State of the Planet" assessment for Rio+20**

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

PLANET UNDER PRESSURE 2012 MARCH 26-29 LONDON

NEW KNOWLEDGE TOWARDS SOLUTIONS

# Policy briefs for Rio+20

- Green economy
- International governance
- Water security
- Energy security
- Food security
- Interconnected risks and solutions
- Health
- Wellbeing
- Biodiversity and ecosystems

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IHDP

WCRP World Climate Research Programme

ICSU International Council for Science

And their Earth System Science Partnership

# ECONOMIC IMPACTS OF OCEAN ACIDIFICATION







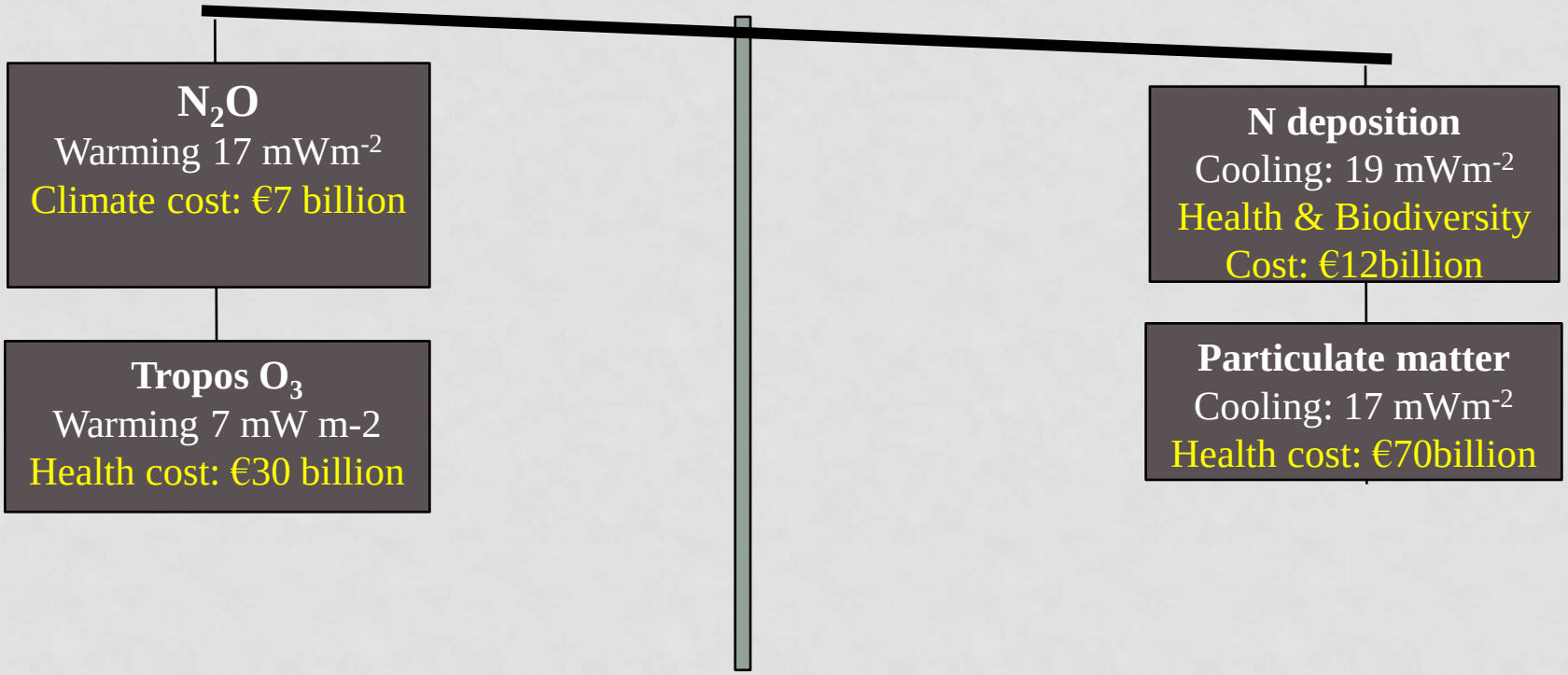


# POLICY SOLUTIONS

- Reduction in atmospheric $CO_2$
- Manage marine areas
  - increase resilience of kelps, mangroves, coral reefs
  - stakeholder engagement
- Adaptation e.g. shellfish aquaculture:
  - identify resilient species
  - monitoring pH of seawater intakes
- Valuing ecosystem services

# WEIGHING UP NITROGEN & CLIMATE

Climate balance for EU27: -16 [-47 to +16] mW $m^{-2}$

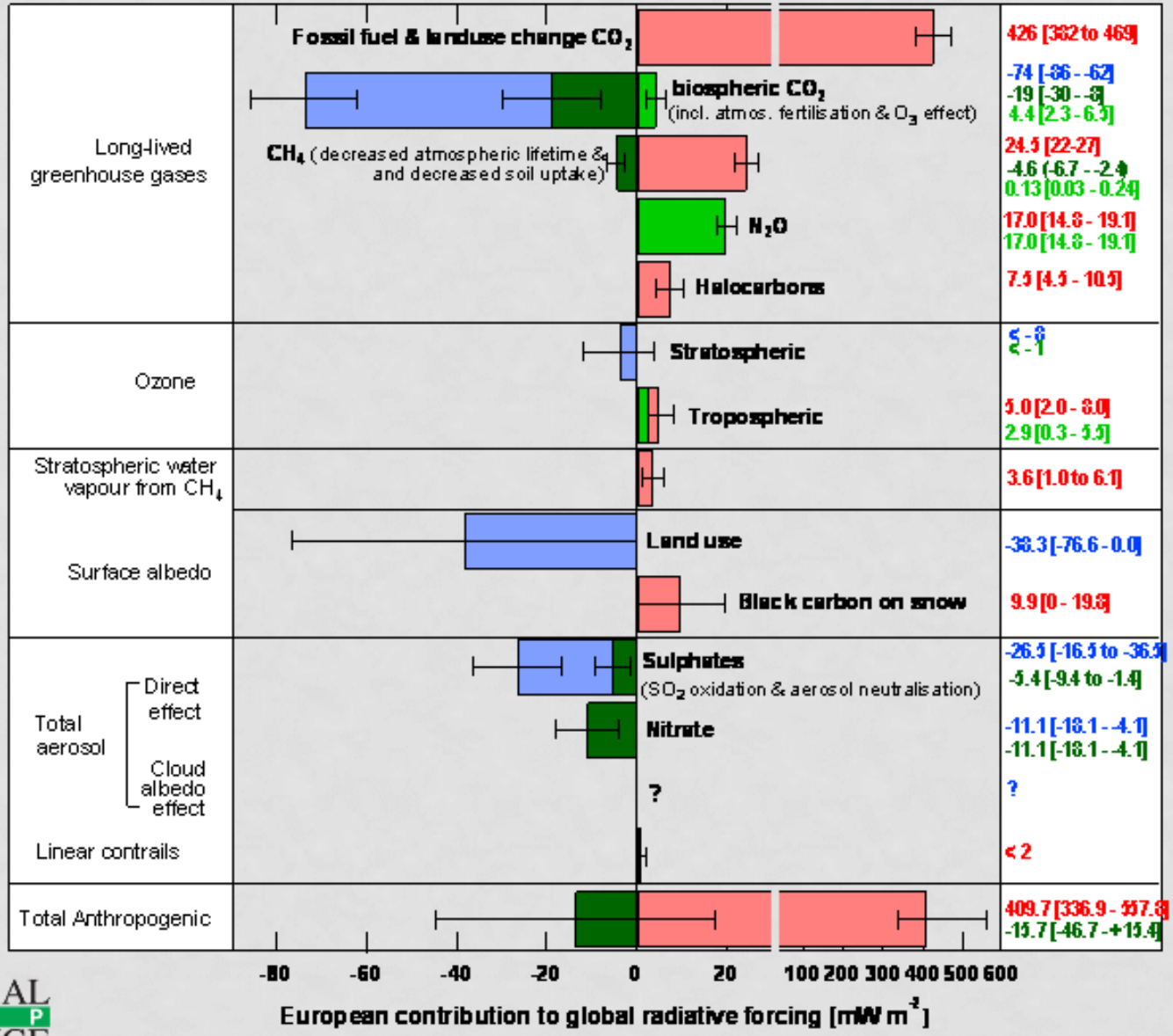



Total economic cost of N emissions:
€70billion – €320 billion per year for EU27

Nitrogen and climate effects roughly balance, but we cannot count on the cooling effects of particulate matter and nitrogen deposition ,which have even larger societal costs for human health and ecosystems.

GLOBAL IGBP International Geosphere-Biosphere Programme CHANGE

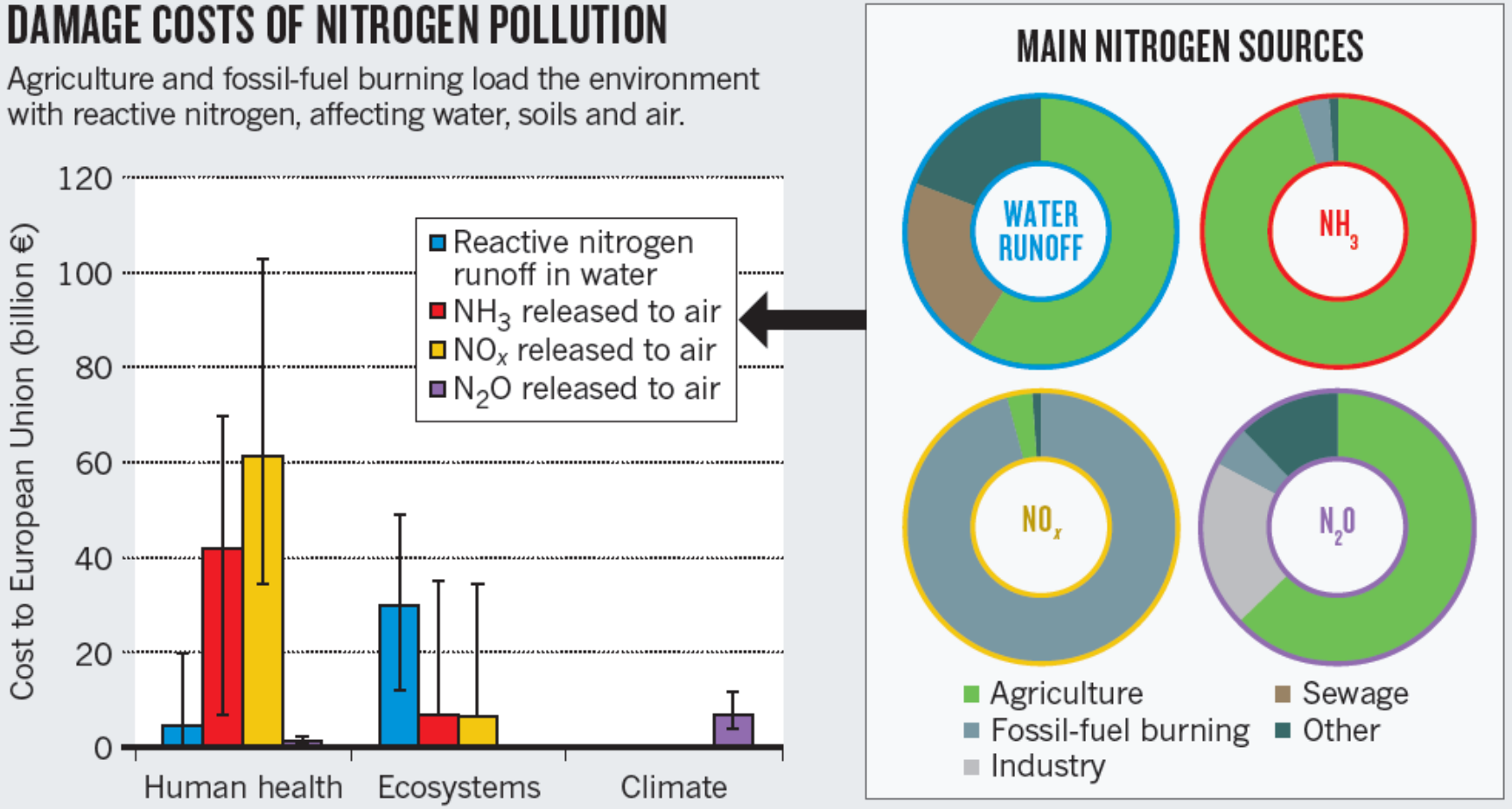
# NITROGEN & EUROPEAN RADIATIVE FORCING




GLOBAL IGBP CHANGE

European Nitrogen Assessment 2011

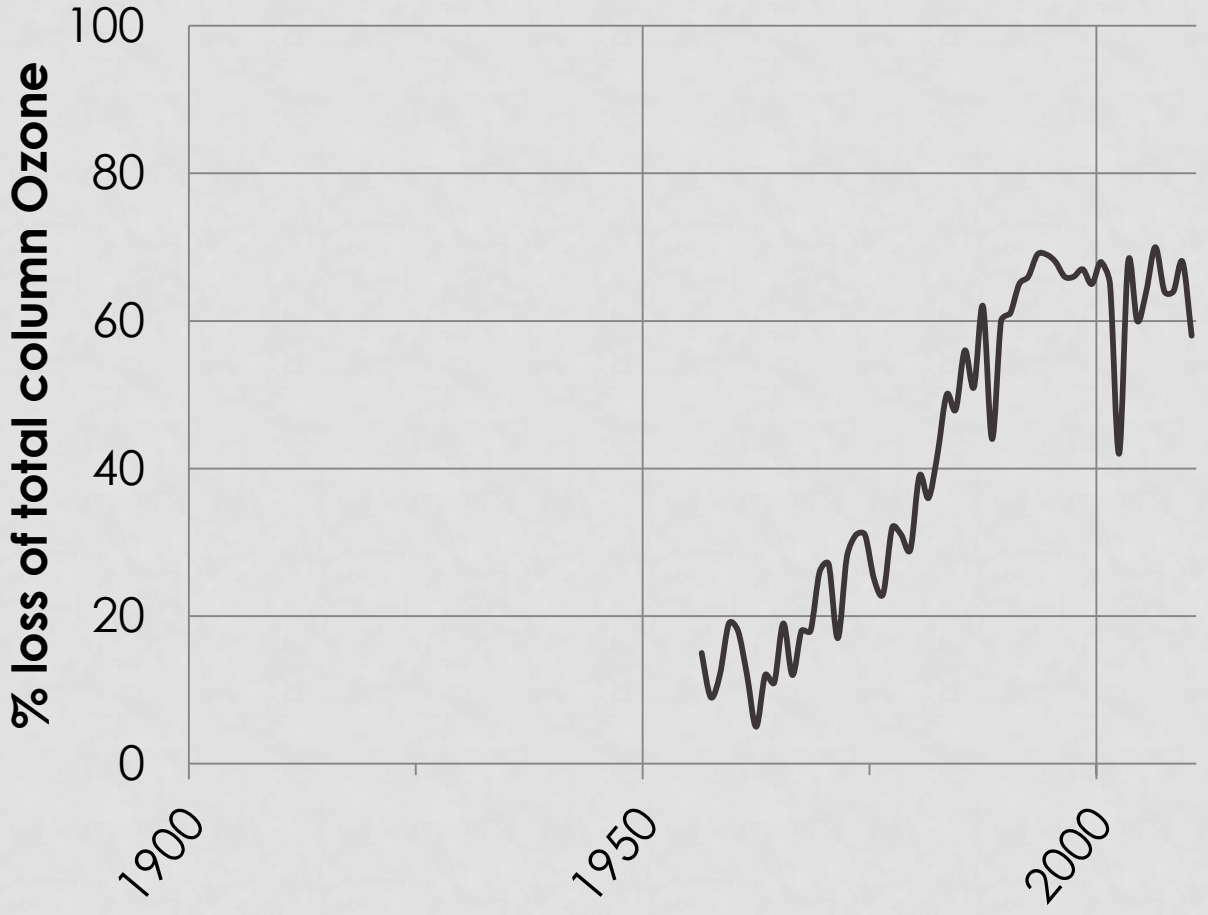
# NITROGEN DAMAGE COSTS & SOURCES




GLOBAL CHANGE IGBP International Geosphere-Biosphere Programme

*Nature* 14 April 2011

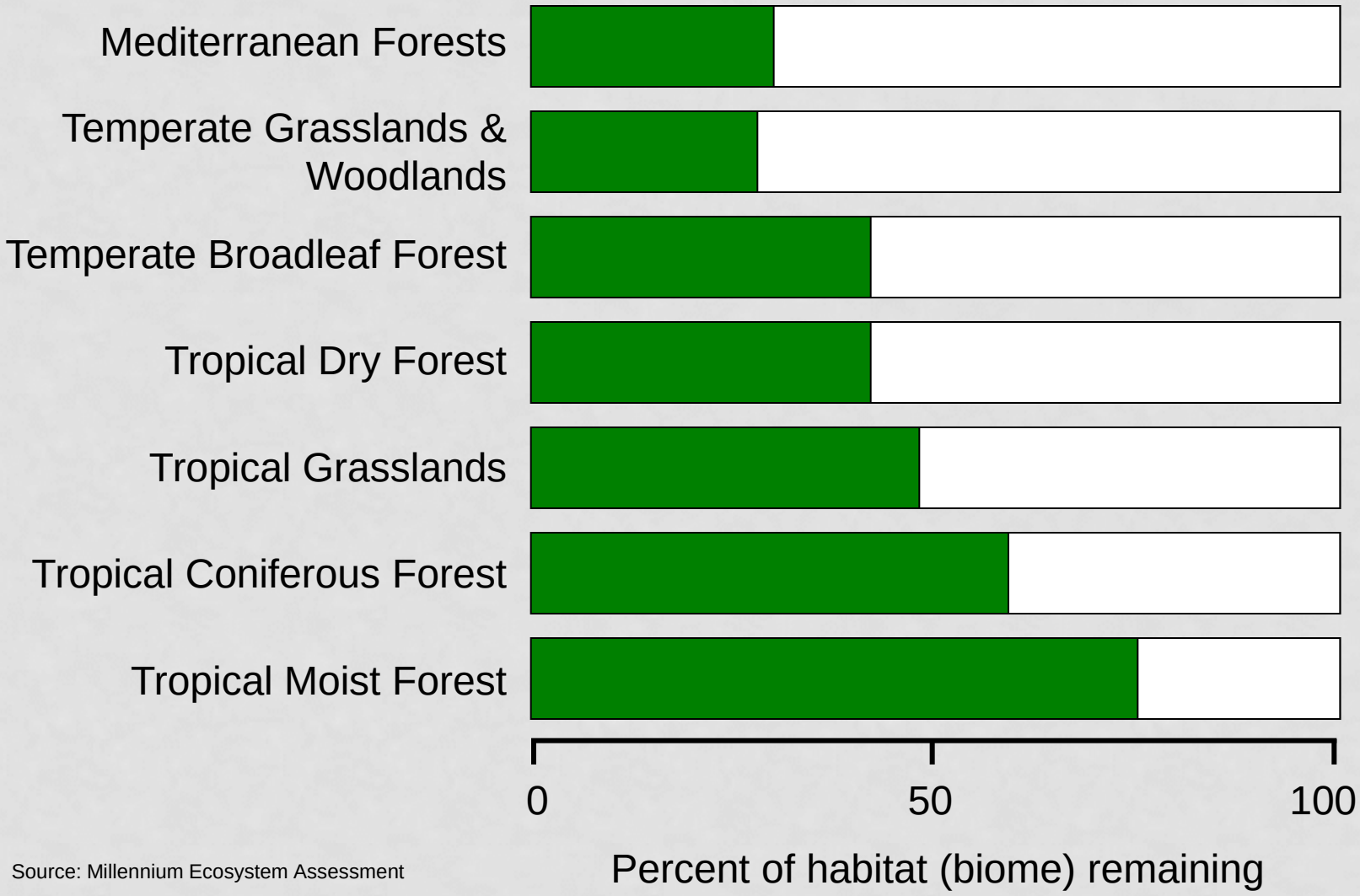
# ANTARCTIC OZONE LOSS




Data from J. Shanklin, British Antarctic Survey

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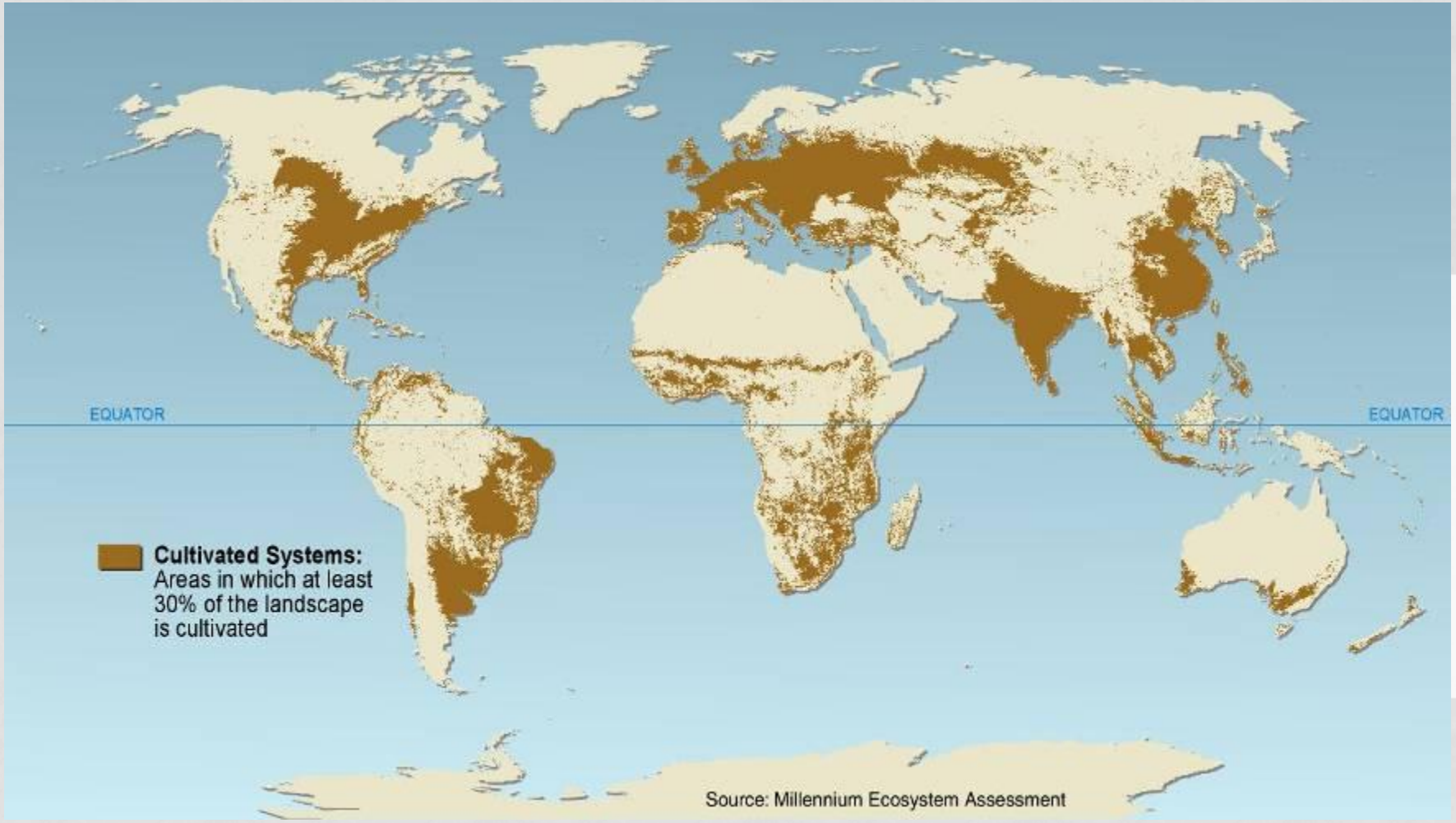
# HABITAT LOSS TO 1990




Source: Millennium Ecosystem Assessment

# EXTENT OF CULTIVATED SYSTEMS, 2000.

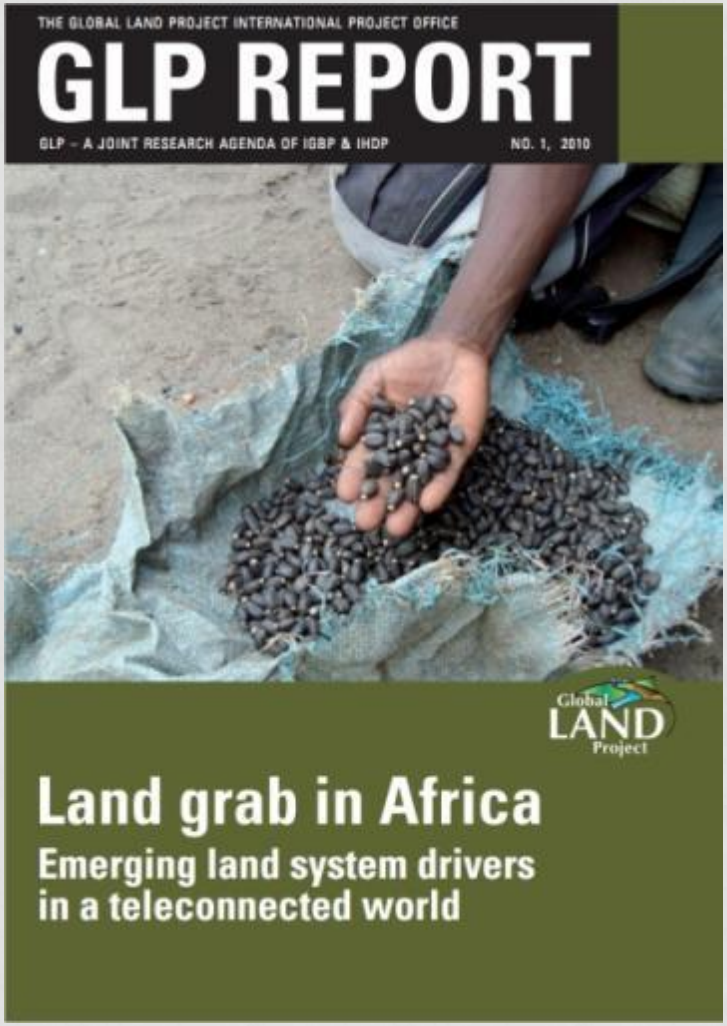
## CULTIVATED SYSTEMS COVER 24% OF THE TERRESTRIAL SURFACE



# GEOPOLITICAL IMPACTS OF CLIMATE

## Land Grab in Africa

- Magnitude of land deals
- Throughout Africa
- Teleconnections and land-scarcity




Friis and Reenberg, 2010

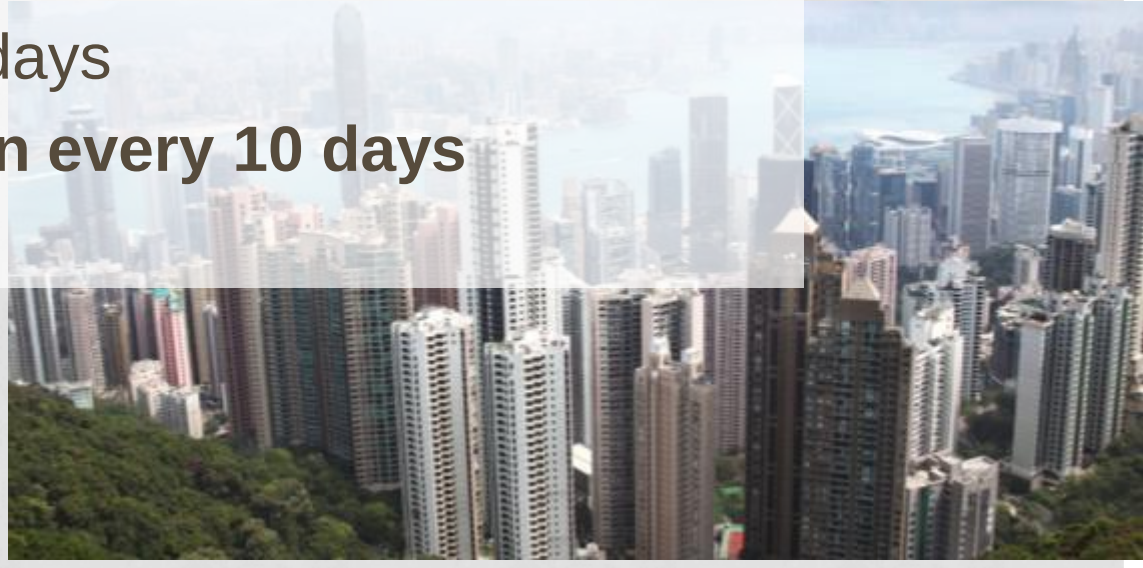
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Global LAND Project

# SUSTAINABILITY IN URBANIZING PLANET

**Urbanization and Built Environments**

- If 3.2 billion additional people by 2100
- Mostly in cities of 1 million
- Require 3200 cities of 1 million over 89 years
- 89 years = 32485 days
- 3200 cities over 32485 days
- **~ 1 new city of 1 million every 10 days**



Karen Seto 2011

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# INCREASED POPULATION -URBANIZATION

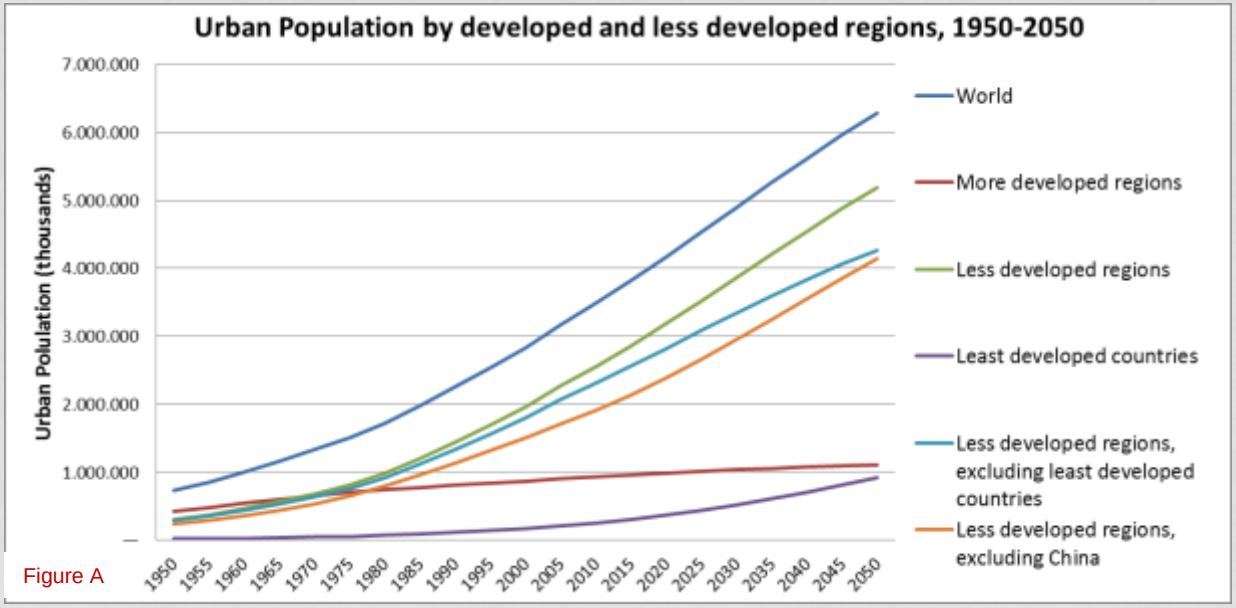
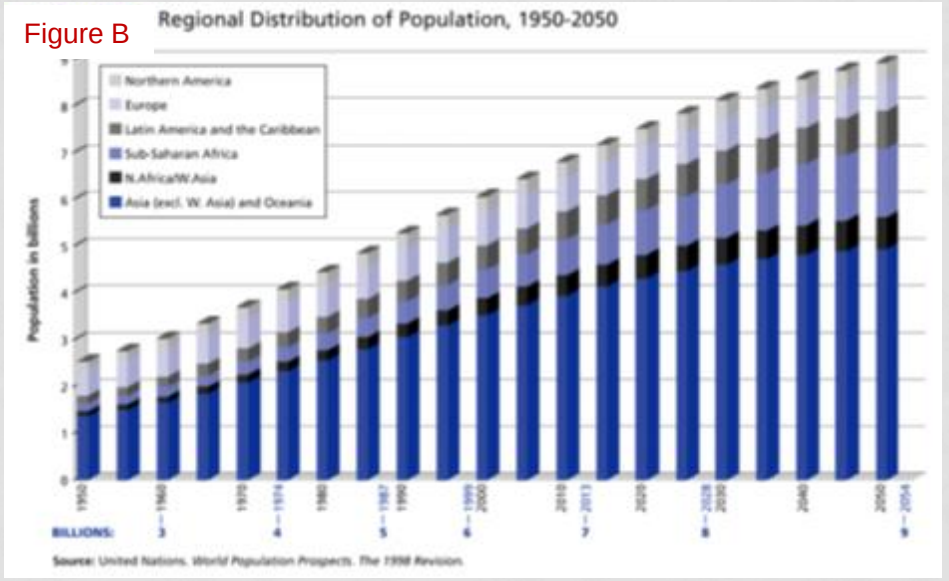



Figure A

Data Source: United Nations, Department of Economic and Social Affairs, Population Division (2010). World Urbanization Prospects : The 2009 Revision.

Figure B




UNFPA, based on United Nations

# THE ANTHROPOCENE




**NATURE, 2002**

**Geology of Mankind**

IGBP Vice Chair,

Paul Crutzen,

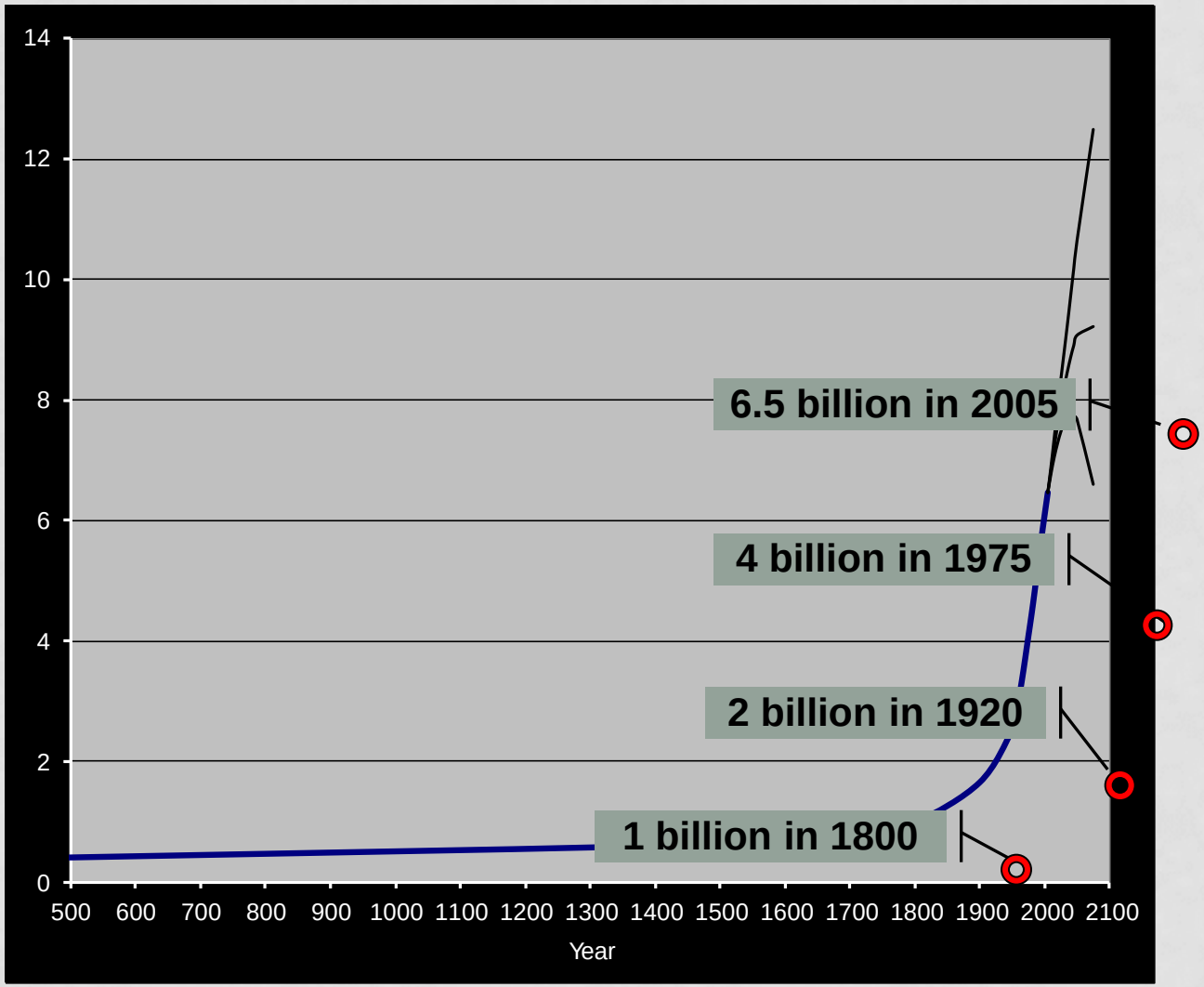
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The Economist, 2011

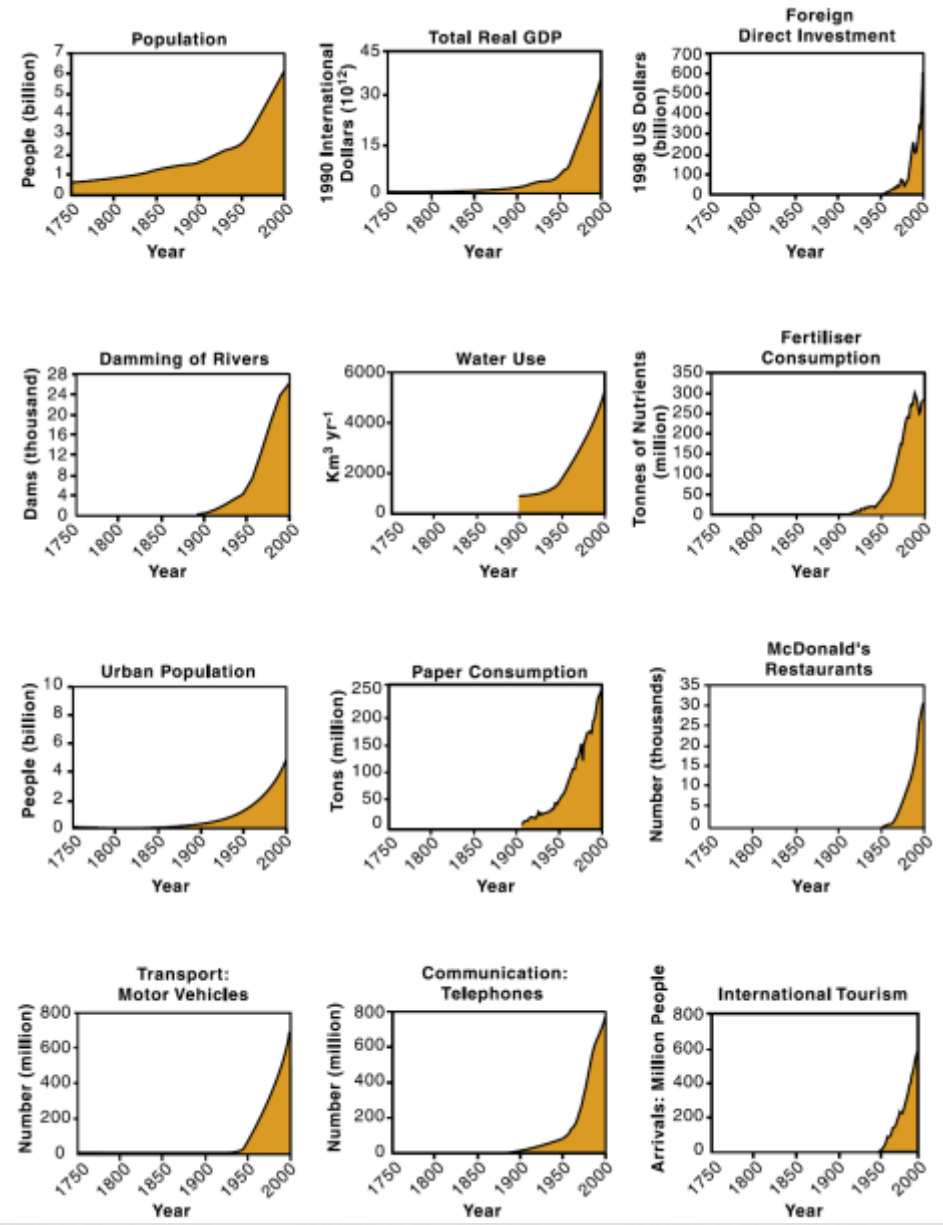
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# WORLD POPULATION (BILLIONS)



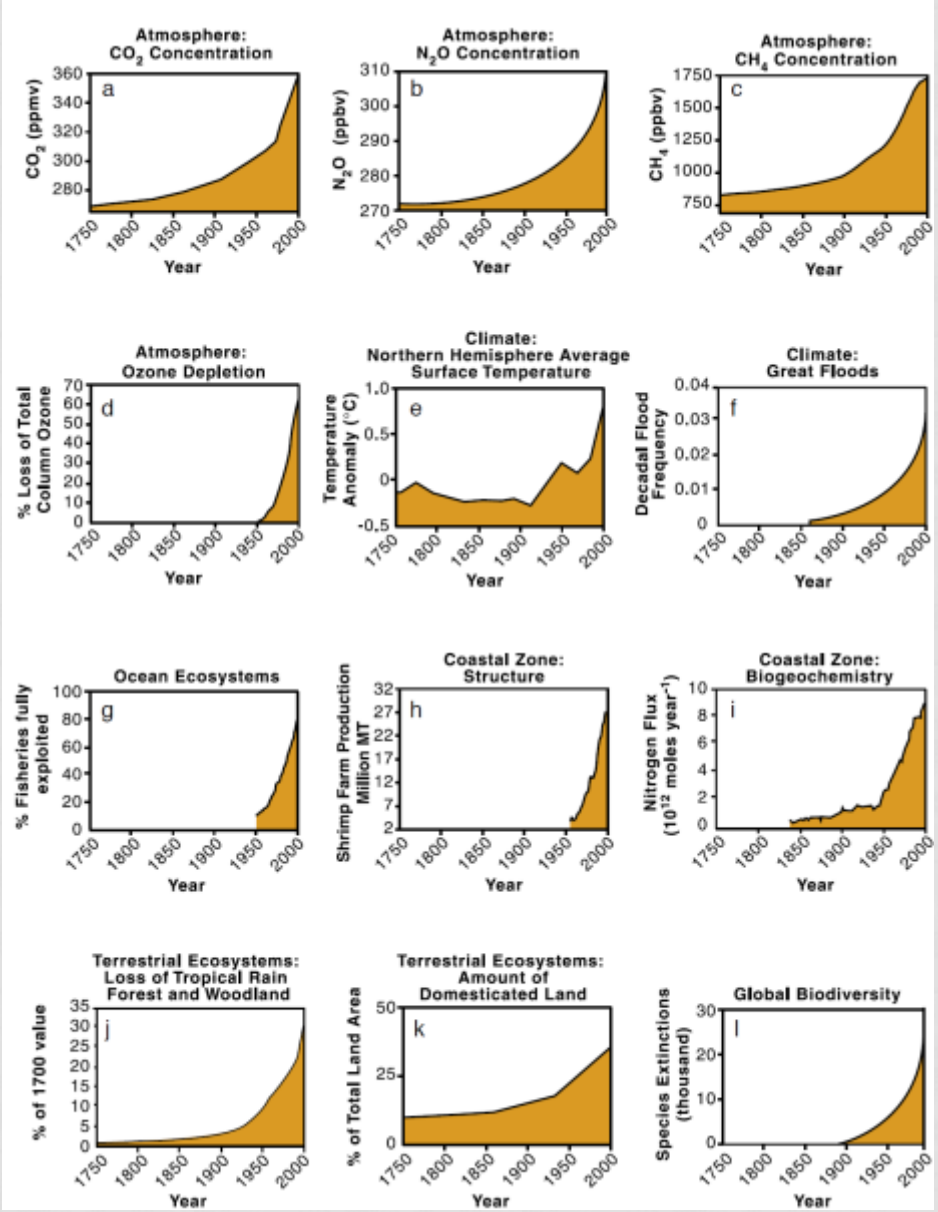

Source: UN Population Division 2004; Lee, 2003; Population Reference Bureau

# The great acceleration – a planet under pressure




Steffen et al, 2004

# Planetary response




Steffen et al, 2004




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# HUMAN CHANGES/THRESHOLDS TO THE EARTH SYSTEM:

- NITROGEN
- BIODIVERSITY
- FRESHWATER
- OCEAN ACIDIFICATION
- ATMOSPHERIC POLLUTION

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

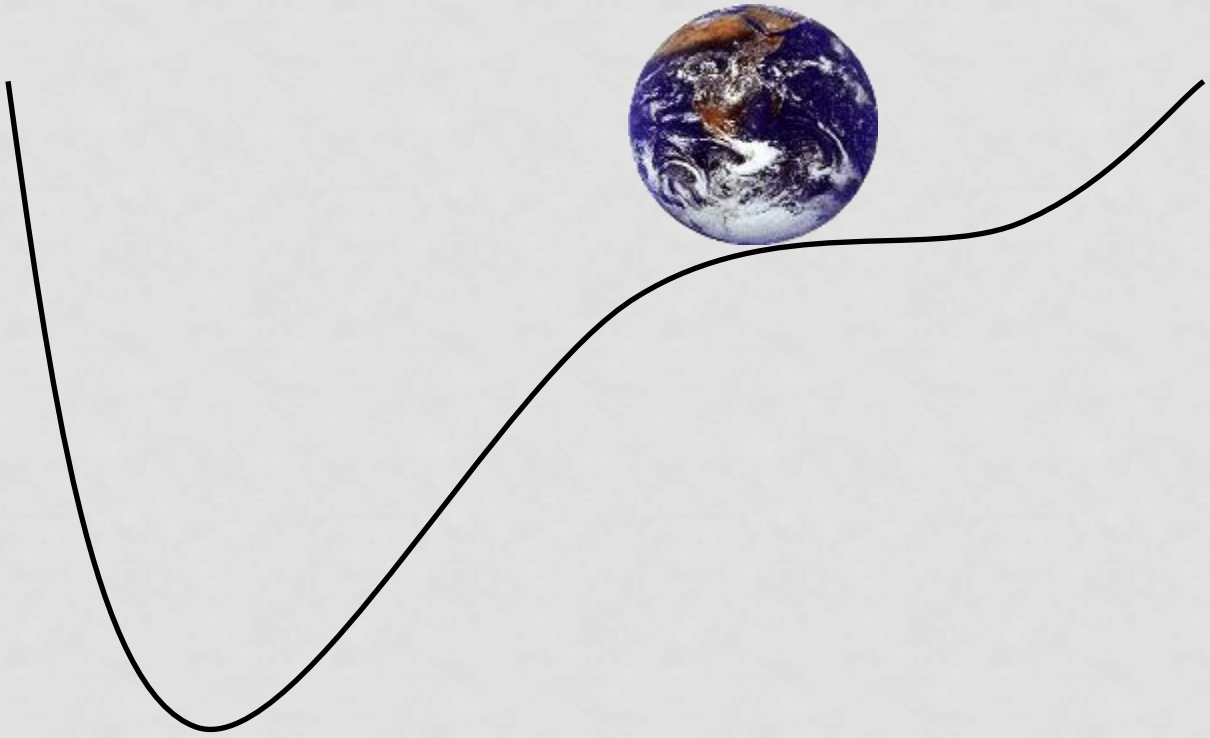


**Photograph by Annie Griffiths Belt**

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

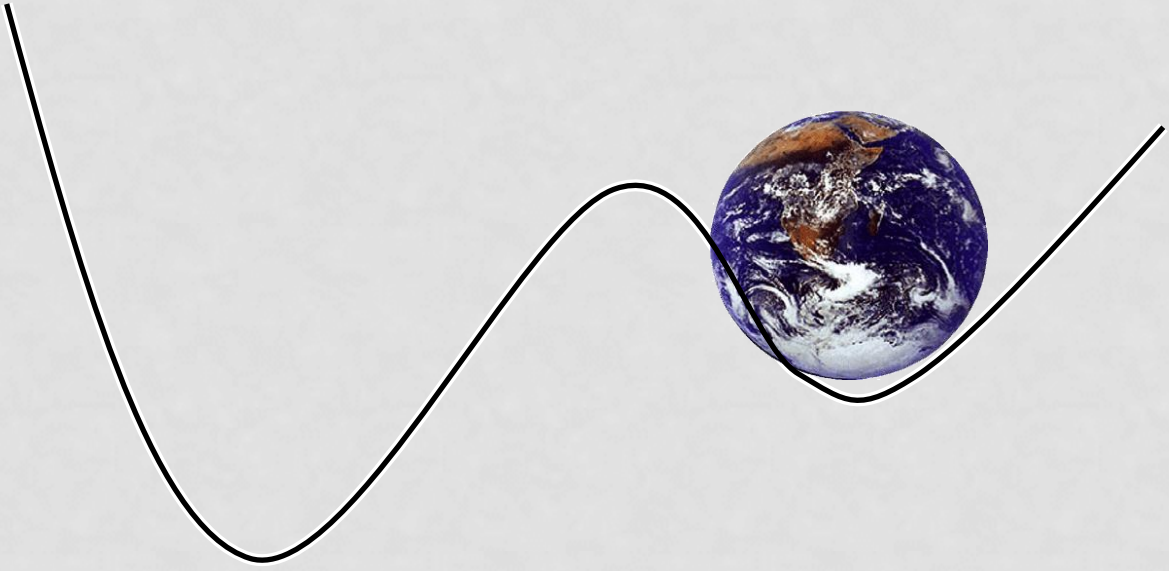
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# REDUCED RESILIENCE – OUR PRECARIOUS PREDICAMENT



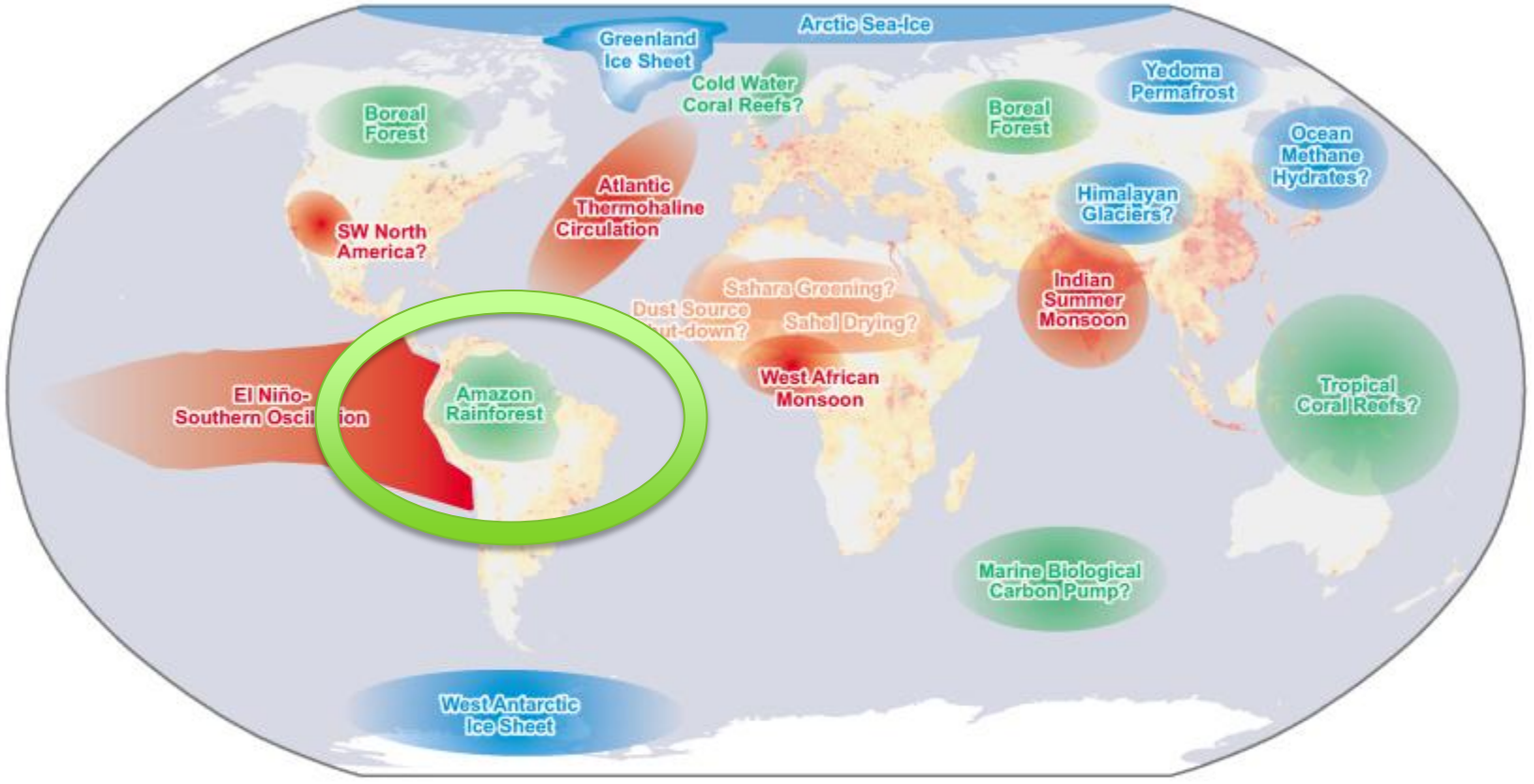
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# A RESILIENT EARTH SYSTEM



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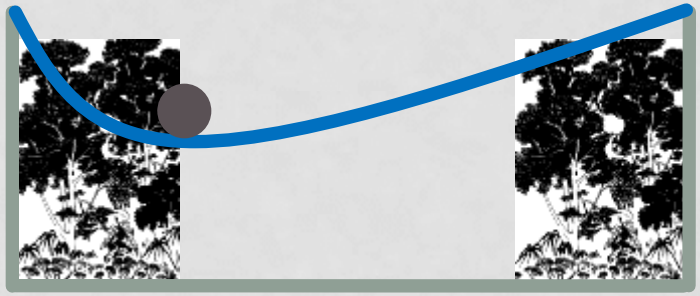
# Tipping elements in the Earth system



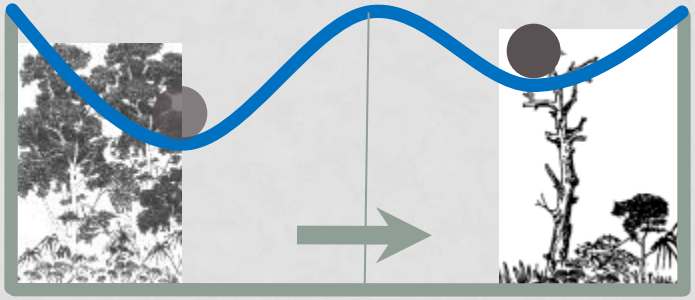

(Source: after Lenton et al. 2008)

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# “Tipping points" for the Amazon Forest

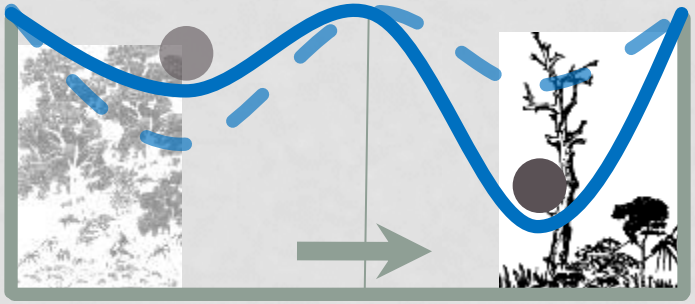


**Tropical Forest**



**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**

Cardoso and Borma, 2010