Grand Challenges Scholar Program Workshop –
Belo Horizonte, August 5, 2019

The role of science and engineering in climate change and the implementation of the sustainable development goals

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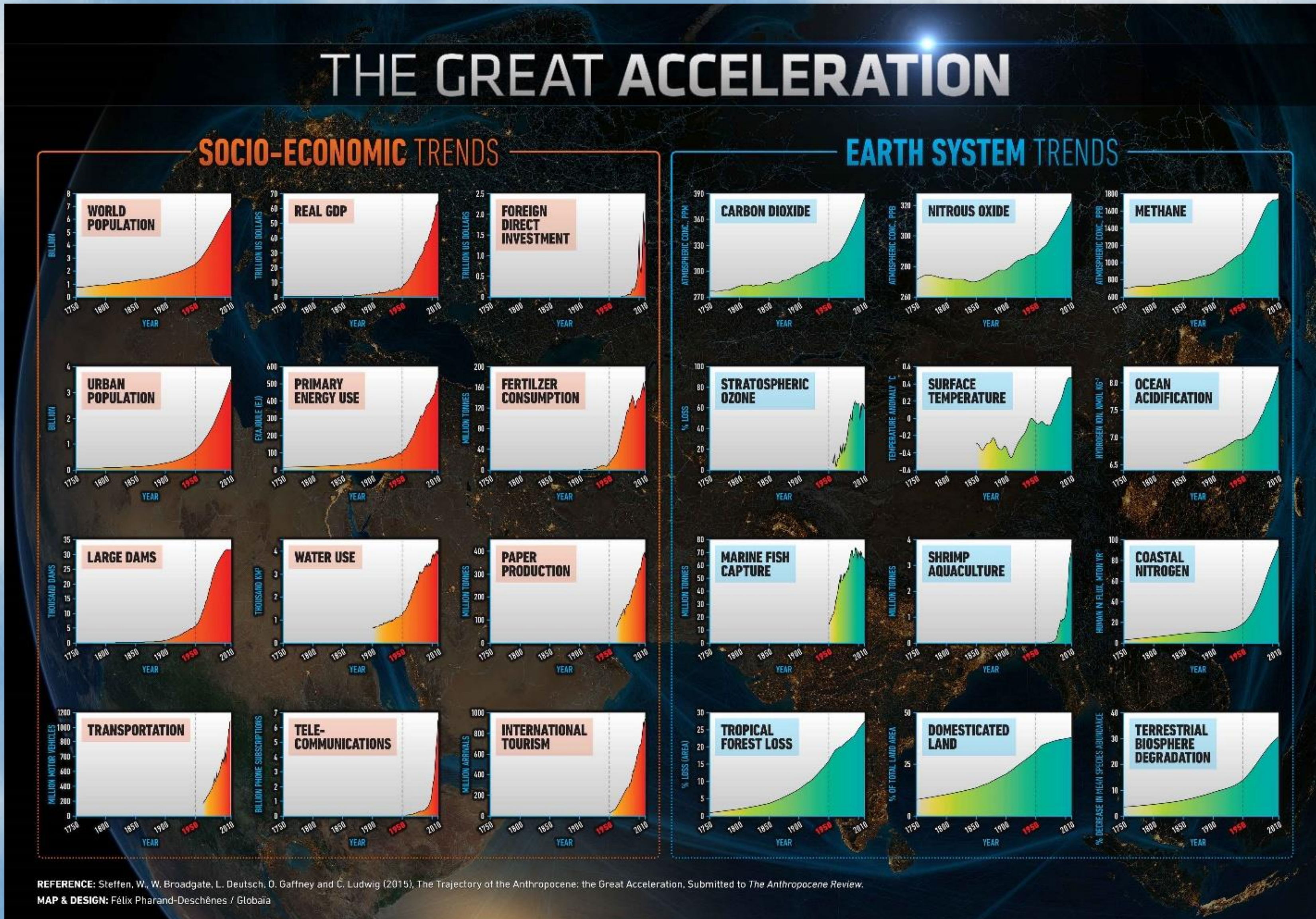
Strong linkages between climate and achievement of the Sustainable Development Goals

There are synergies and trade-offs in terms of climate costs on implementing the Sustainable Development Goals

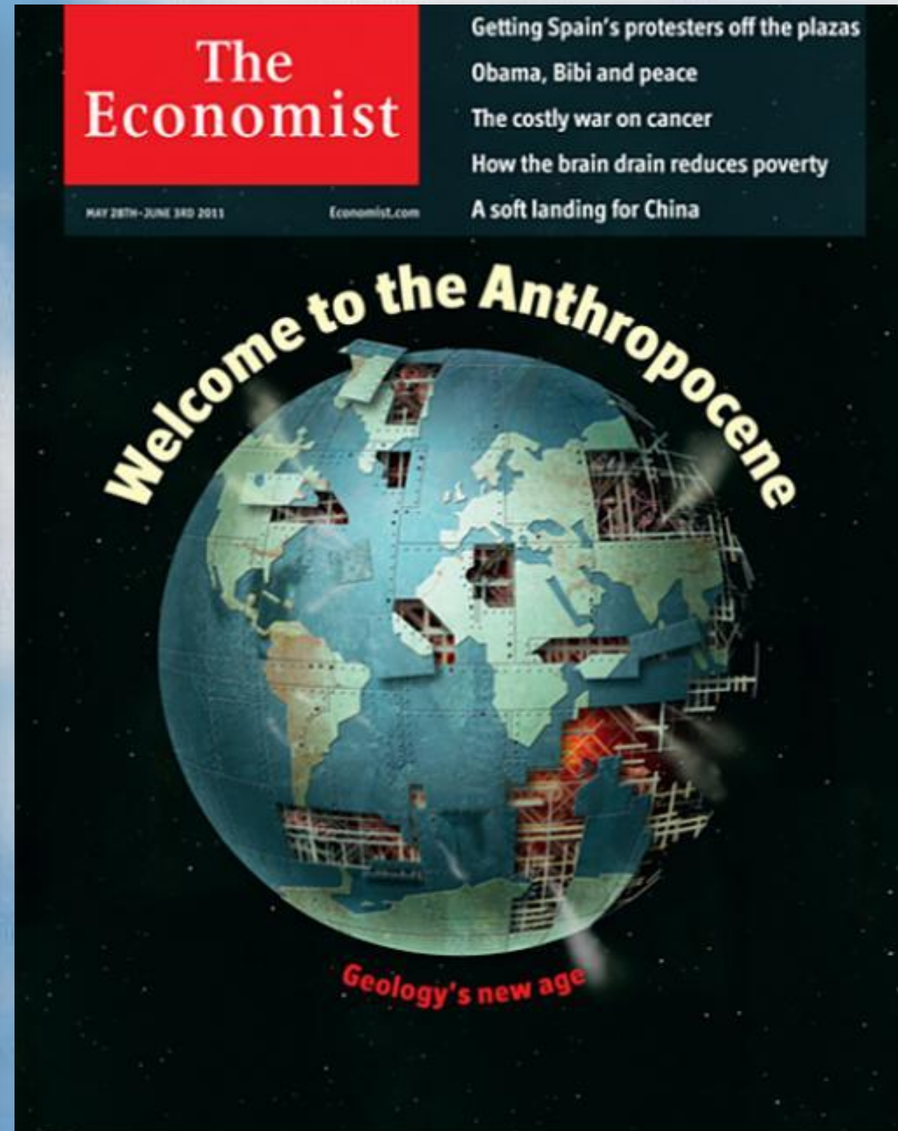
Direct linkages are shown with bold arrows, indirect linkages with light arrows.

We are changing the face of our world very quickly and in many ways



Which will be the impacts in our society of these changes?

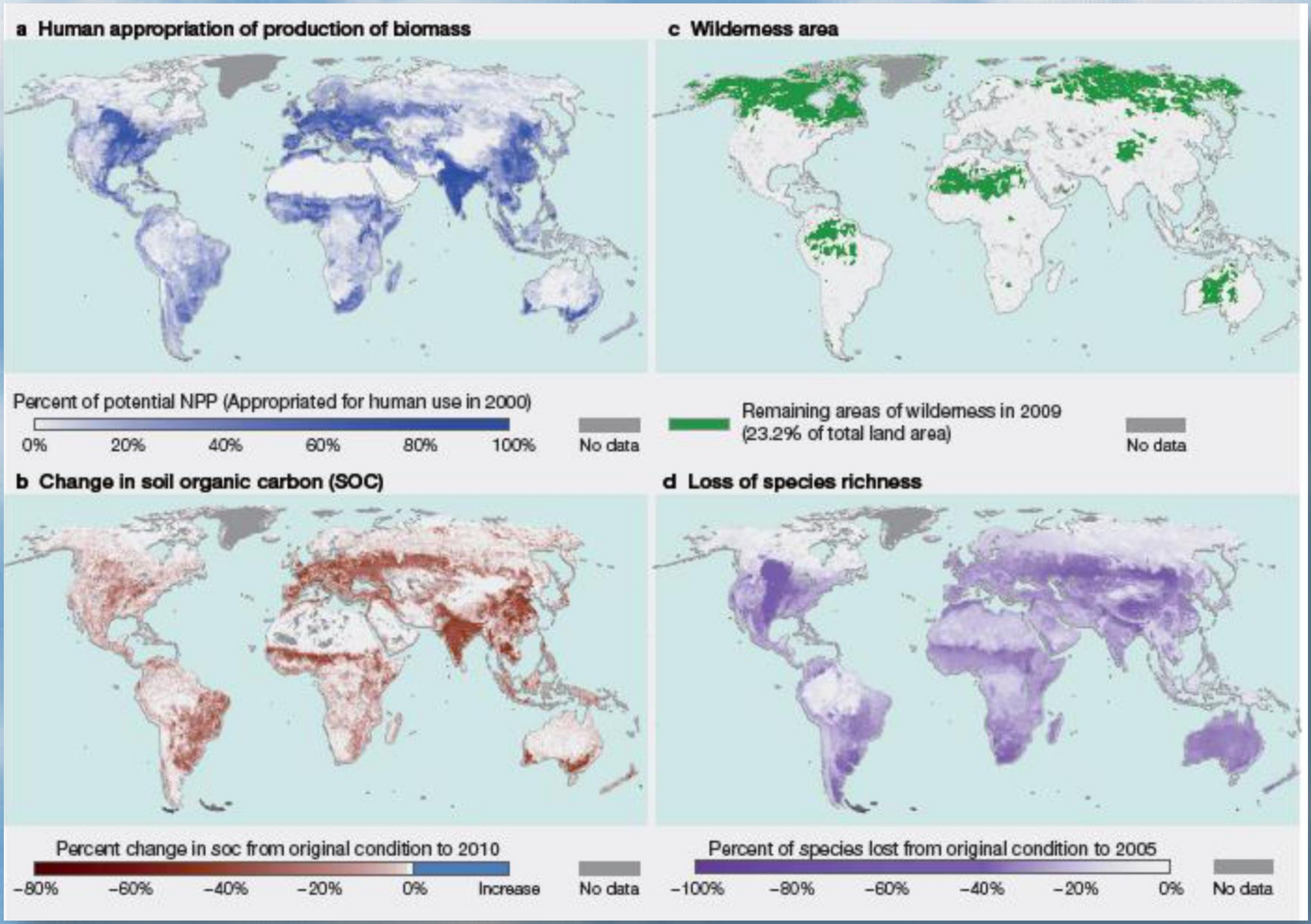
Will Stefan, 2015



The Anthropocene is a time when humans and our civilization became a major geophysical planetary force

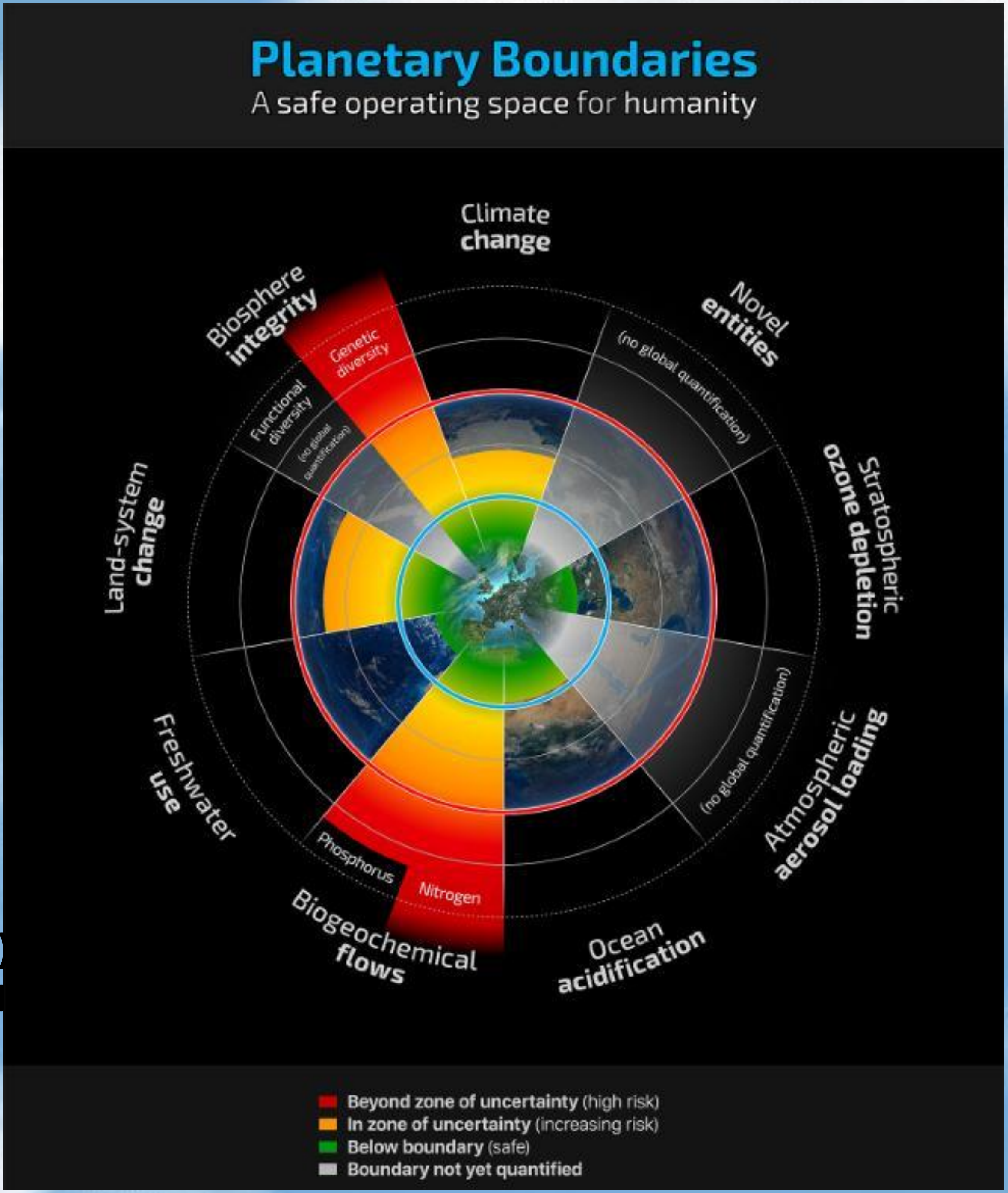
The Economist, 2011

Impact of human activity on our planet



IPBES, 2018

Planetary boundaries: Where is the safe space for humanity?



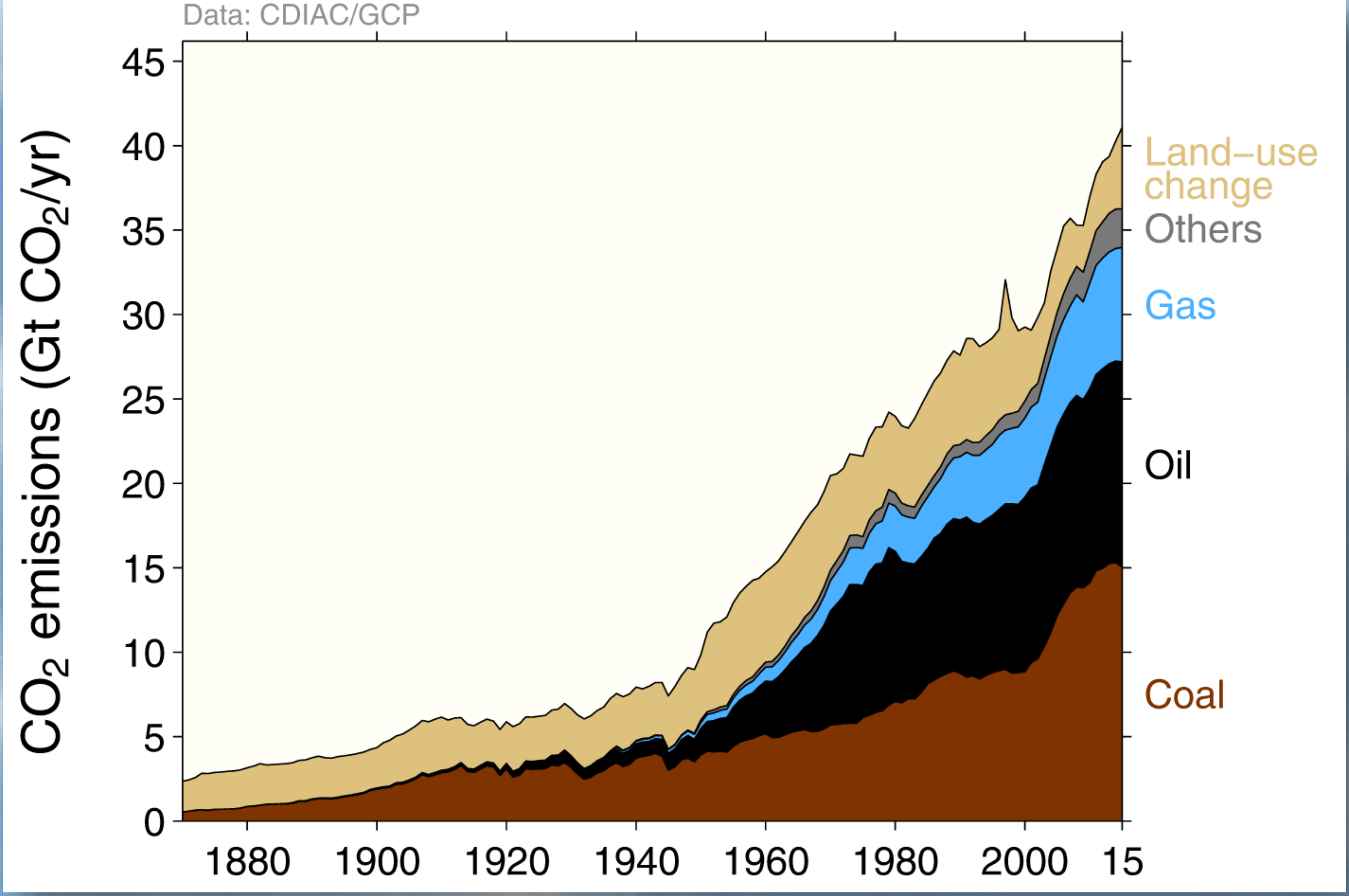
9 Boundaries identified

4 transgressed:

- **Climate**
- **Biosphere integrity**
- **Land use (deforestation)**
- **Biogeochemical flows (N and P fertilizer use)**

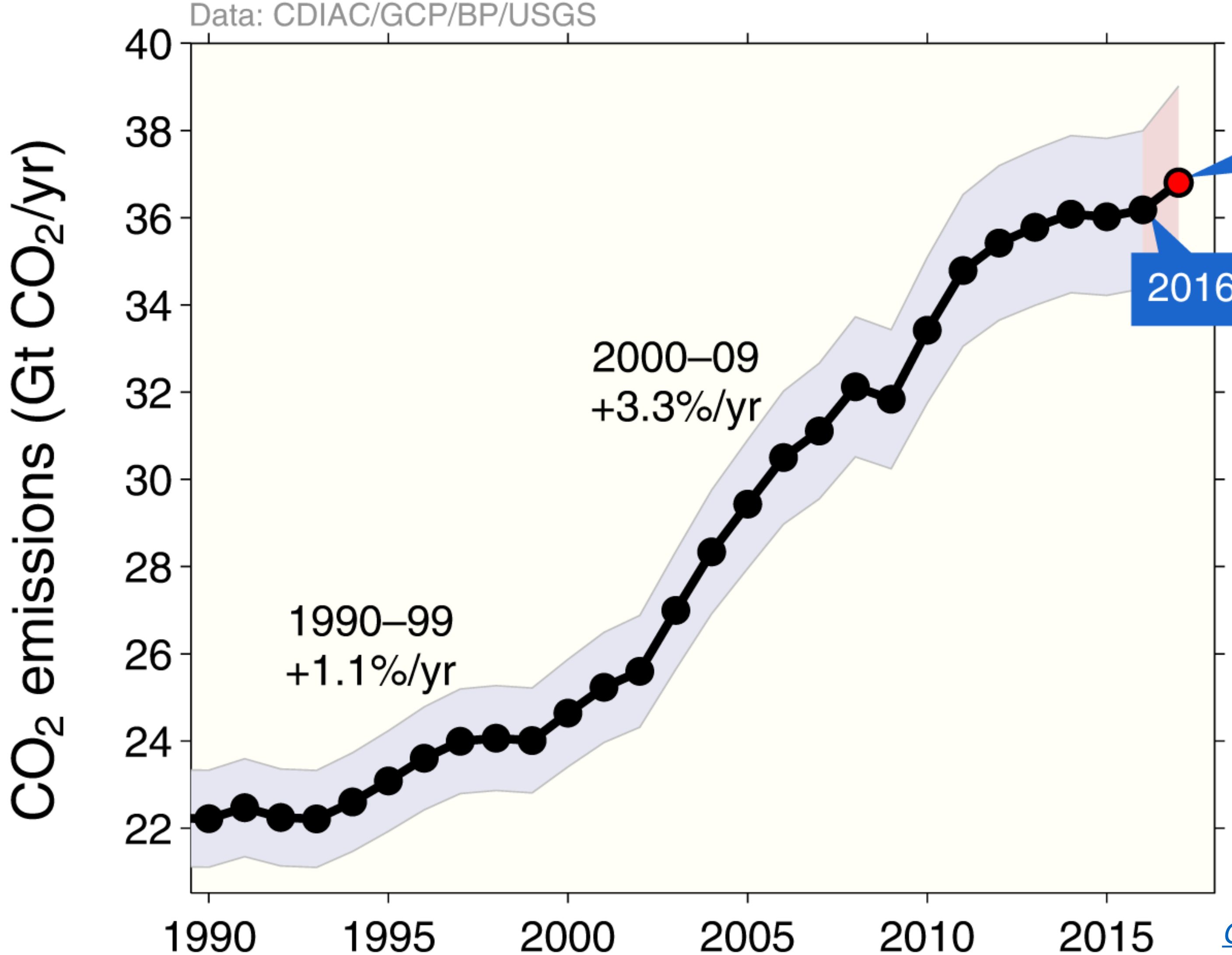
Science Feb 2015

Carbon emissions from 1870 to today: Energy from fossil fuel dominates



Source: Global Carbon Project 2016

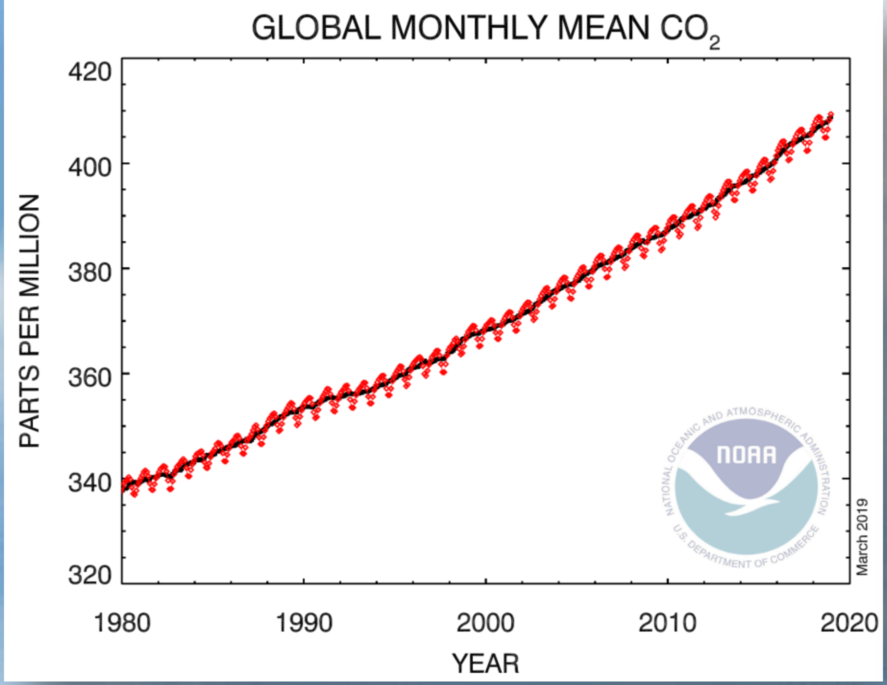
Global emissions from fossil fuel and industry: 36.8 $GtCO_2$ in 2017, 62% over 1990



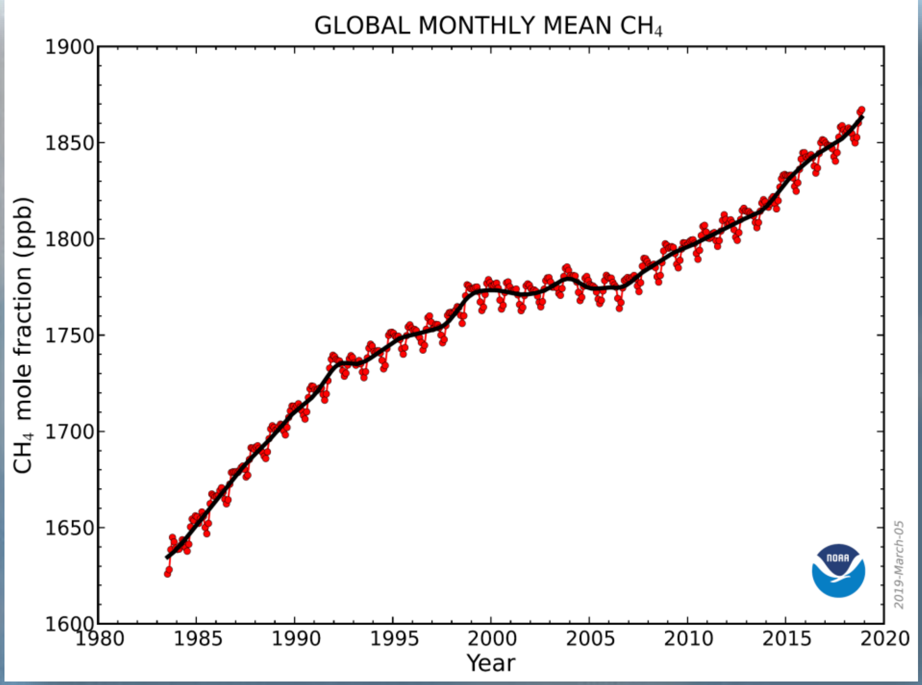
Global Carbon Budget 2017

Increase in the concentration of carbon dioxide (CO_2) and methane (CH_4)

CO_2: increase from 280 ppm to 415 ppm

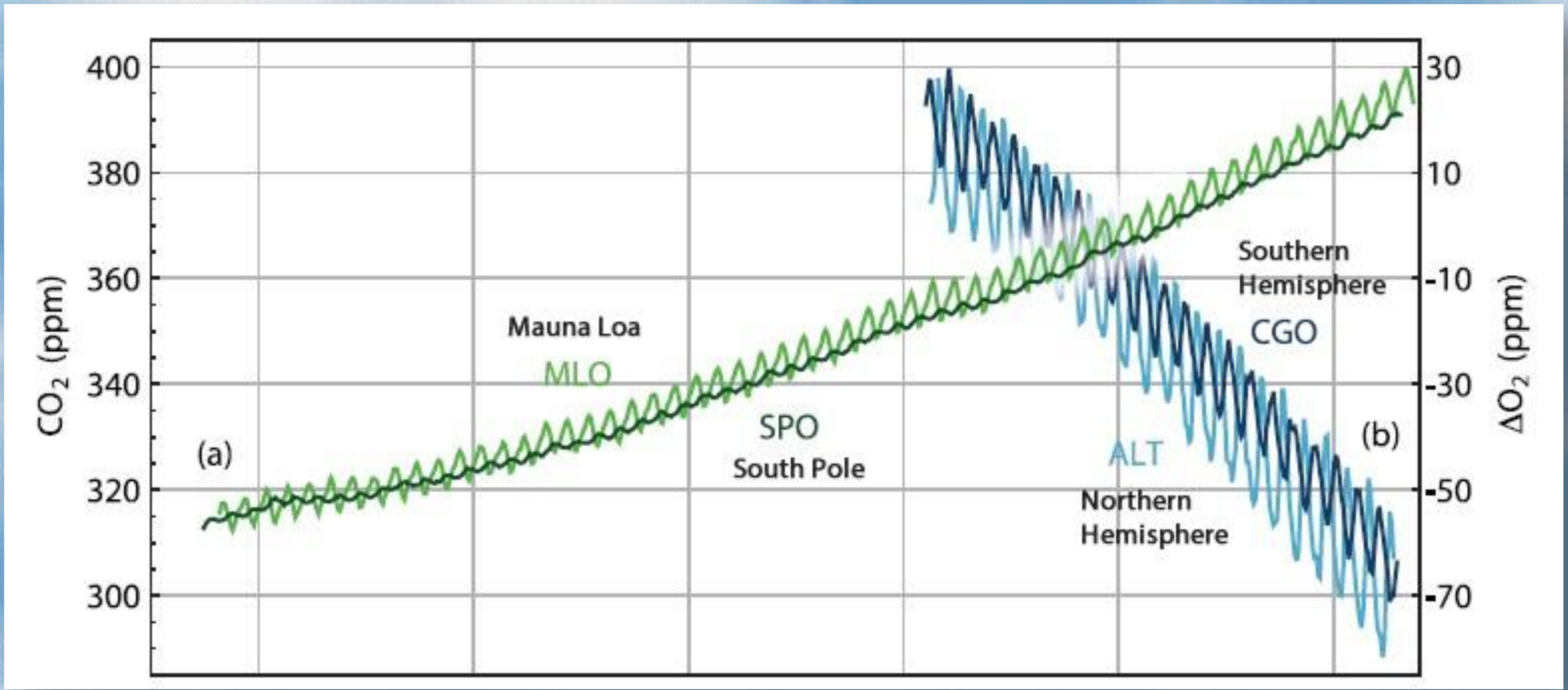


CH_4: increase from 650 ppb to 1865 ppb



Mauna Loa CO_2 reached 415 ppm, the highest value in the last 3 millions years

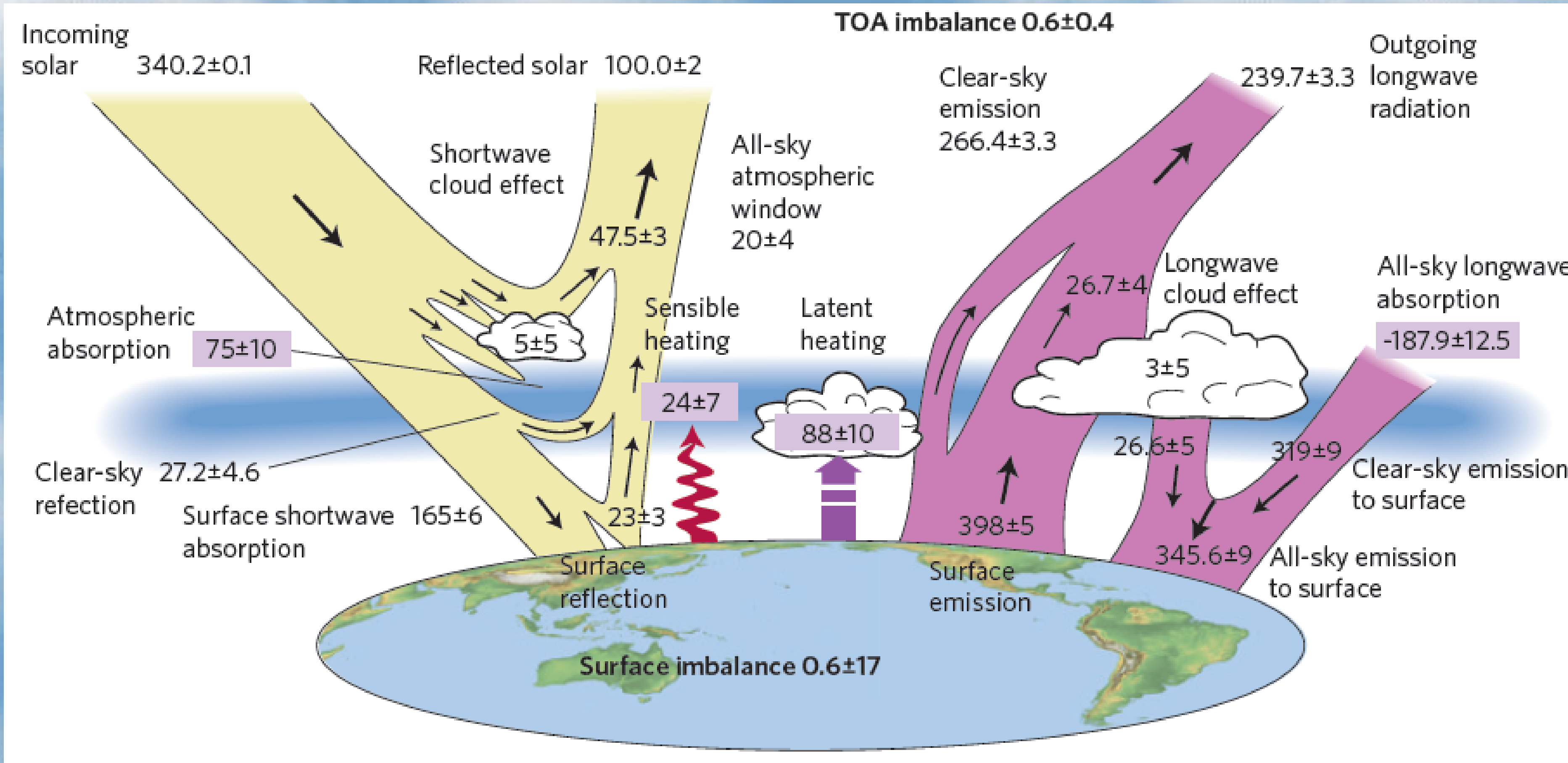
Increase in CO_2 and reduction in O_2



1950

2015

Earth Energy budget (W/m²)



The global annual mean energy budget of Earth for the approximate period 2000–2010. All fluxes are in Wm^{-2}. Solar fluxes are in yellow and infrared fluxes in pink. The four flux quantities in purple-shaded boxes represent the principal components of the atmospheric energy balance. (Stephens, Nature 2012)

Sources and sinks of CO_2 (2006-2016)

34.1 $GtCO_2$/yr

91%

Sources

9%

3.5 $GtCO_2$/yr

16.4 $GtCO_2$/yr

44%

Sinks

31%

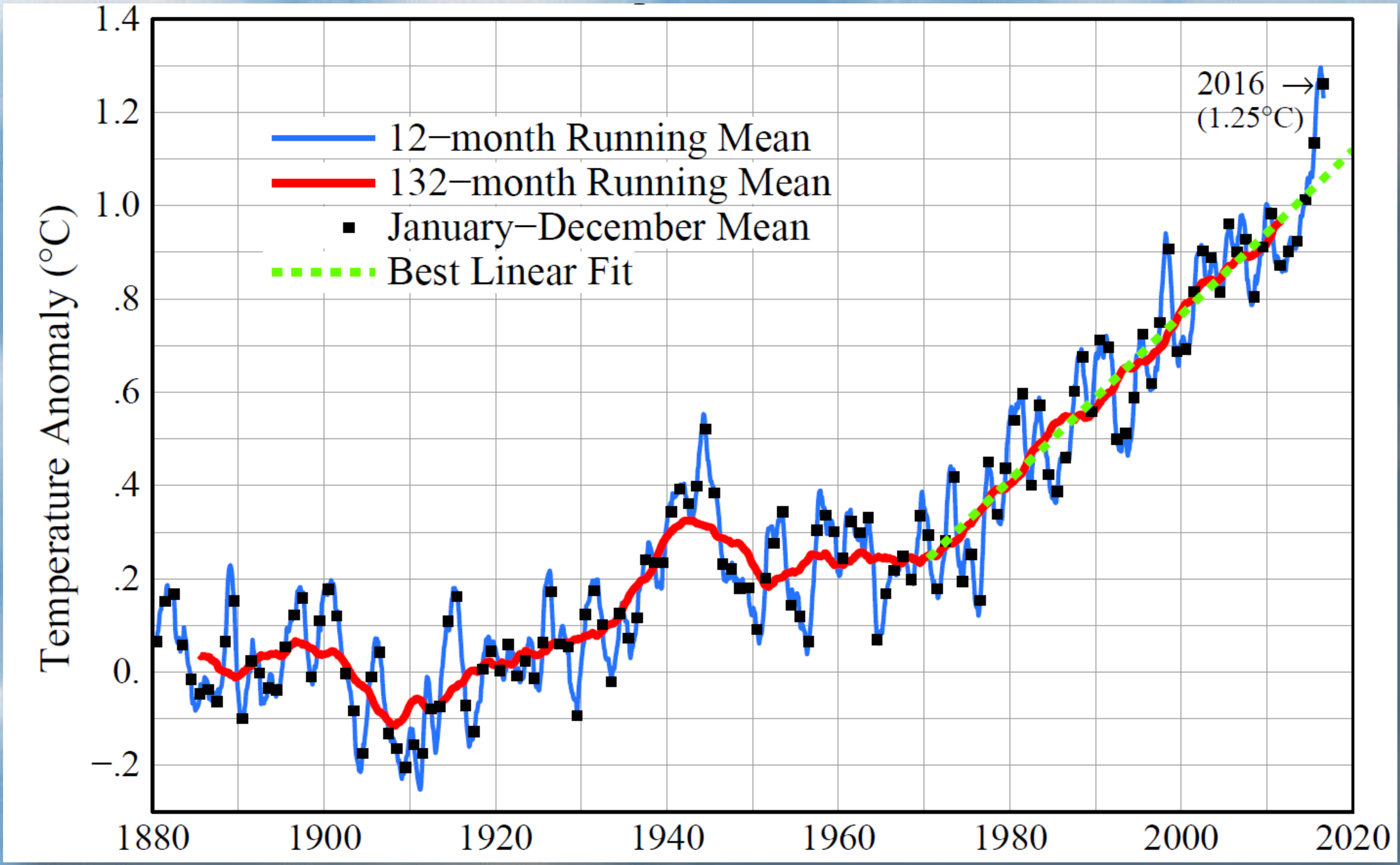
11.6 $GtCO_2$/yr

25%

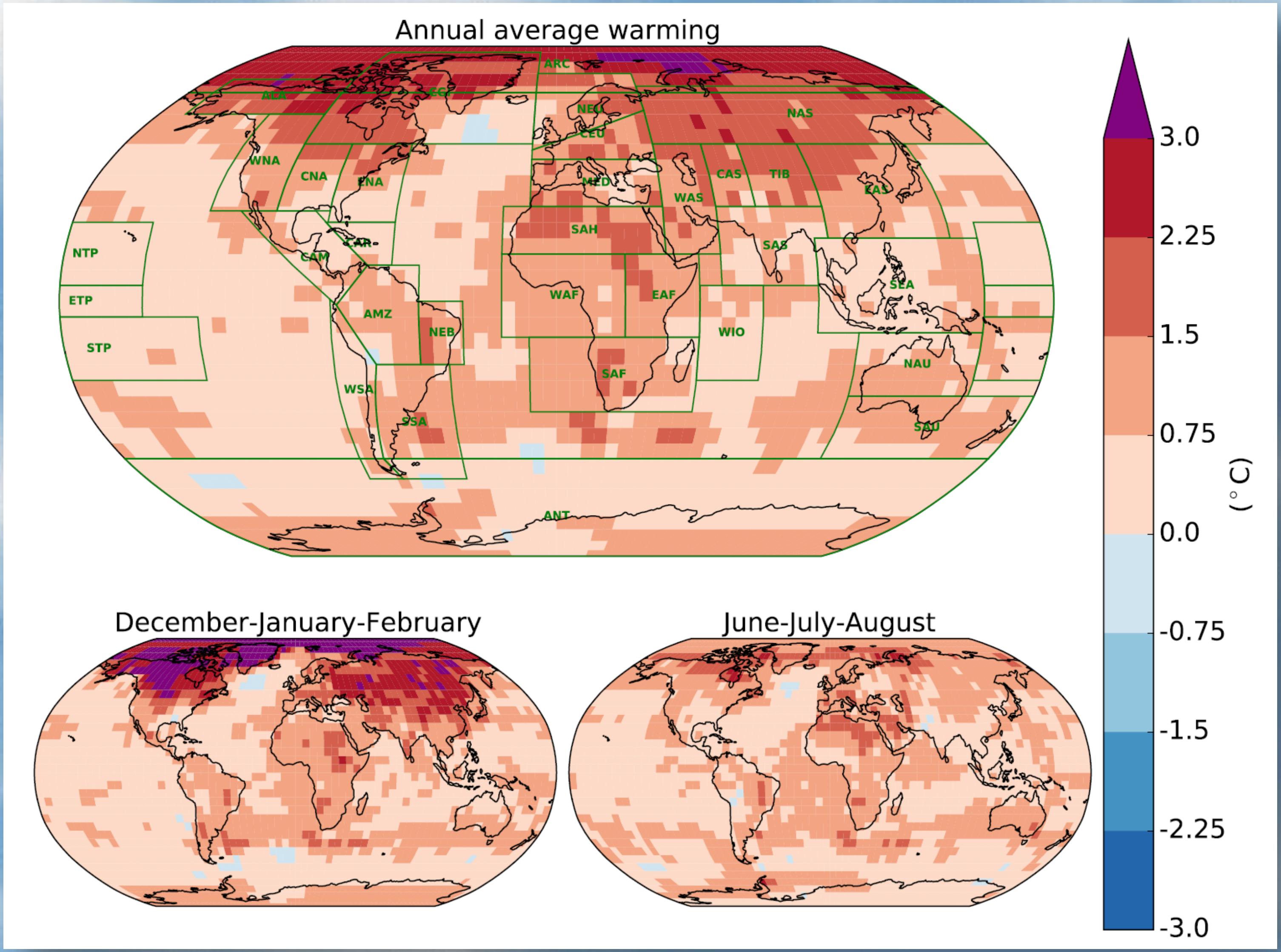
9.7 $GtCO_2$/yr

Source: Le Quéré et al 2016; Global Carbon Budget 2016

Global Surface Temperature 1880-1920 base period

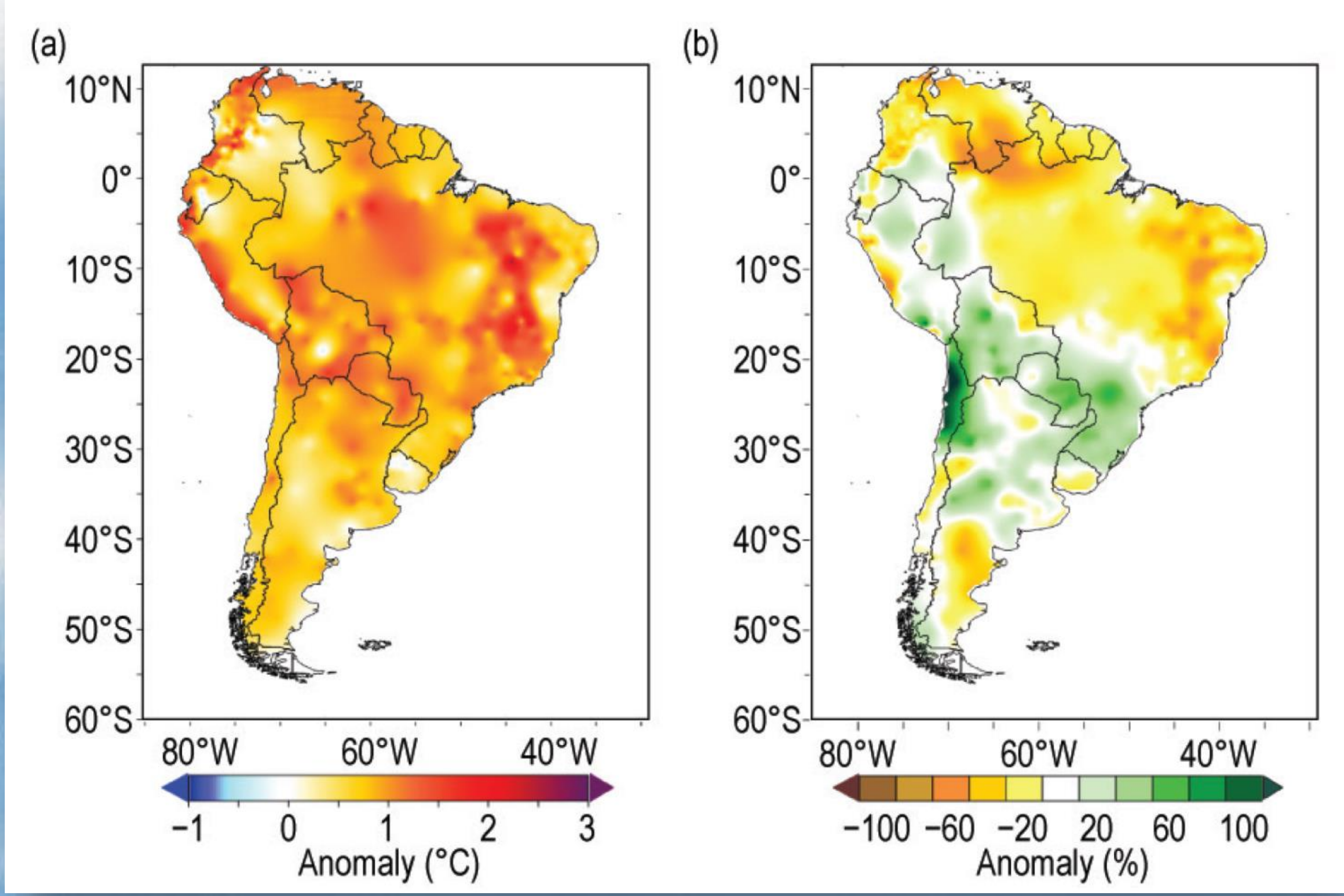


Observed increase in Temperature 1901 to 2012
Spatial distribution not homogeneous



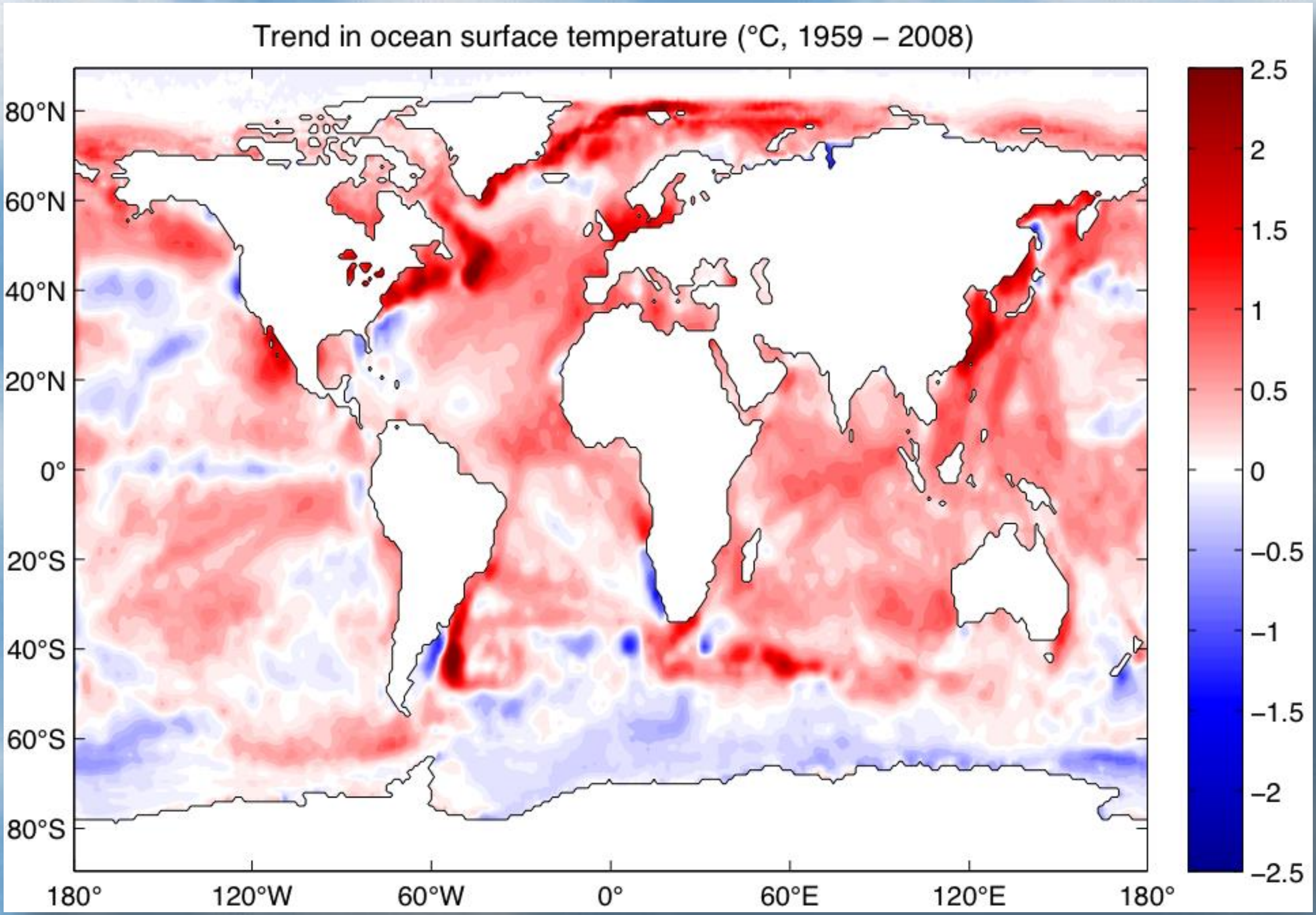
Source: IPCC 2018 Special Report on Global Warming of 1.5°C

South American (a) temperature anomalies (°C) and (b) precipitation anomalies

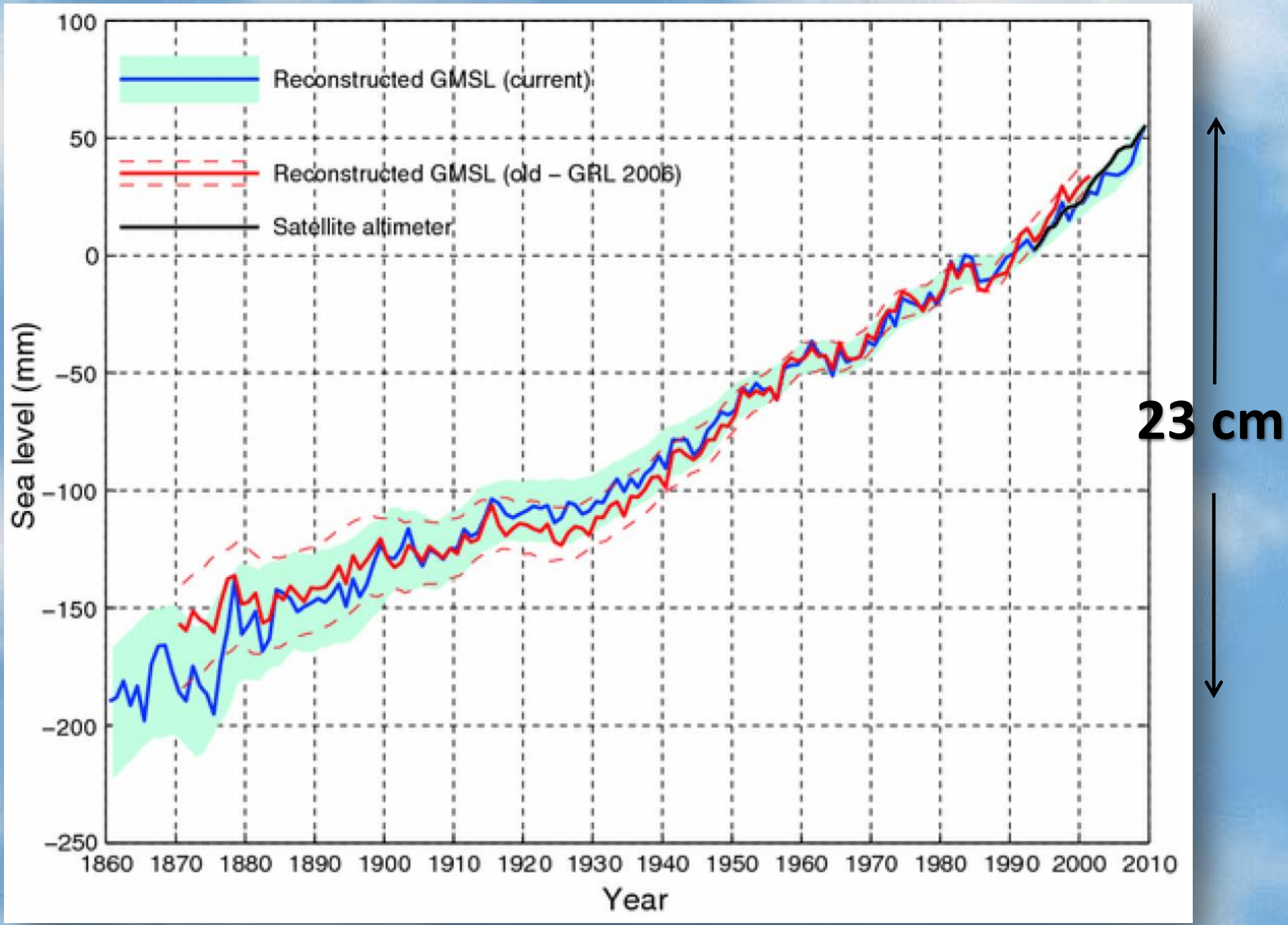


base period: 1981–2010.
Source 2016: State of the Climate in 2015, Bull. Amer. Meteor. Soc., 97 (8), 2016.

Ocean temperatures also increasing - 1959 - 2008



Seal level rise - 1860 to 2010

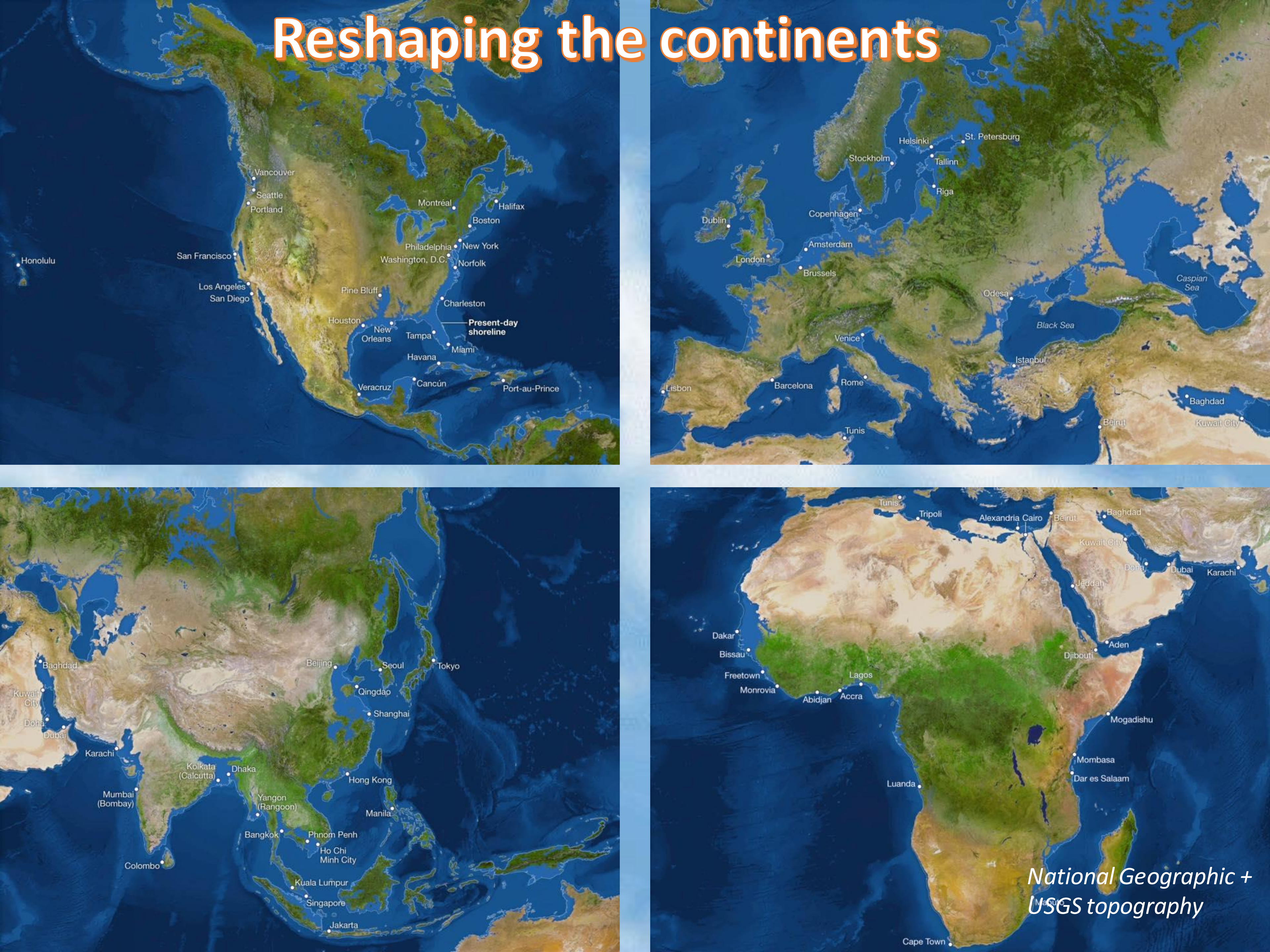


Source: Church and White (2011).

South America in the future?

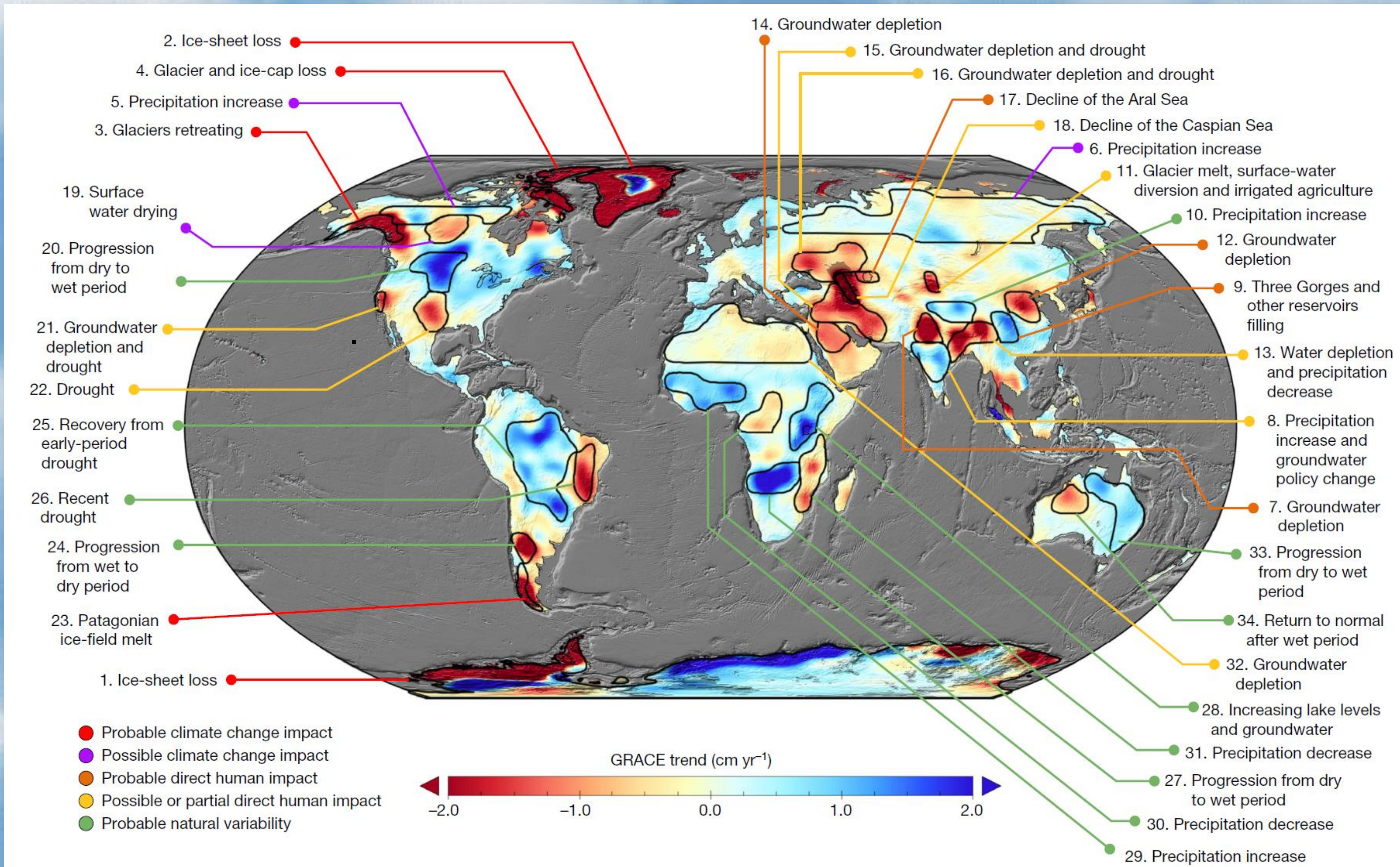
National Geographic + USGS topography

Reshaping the continents



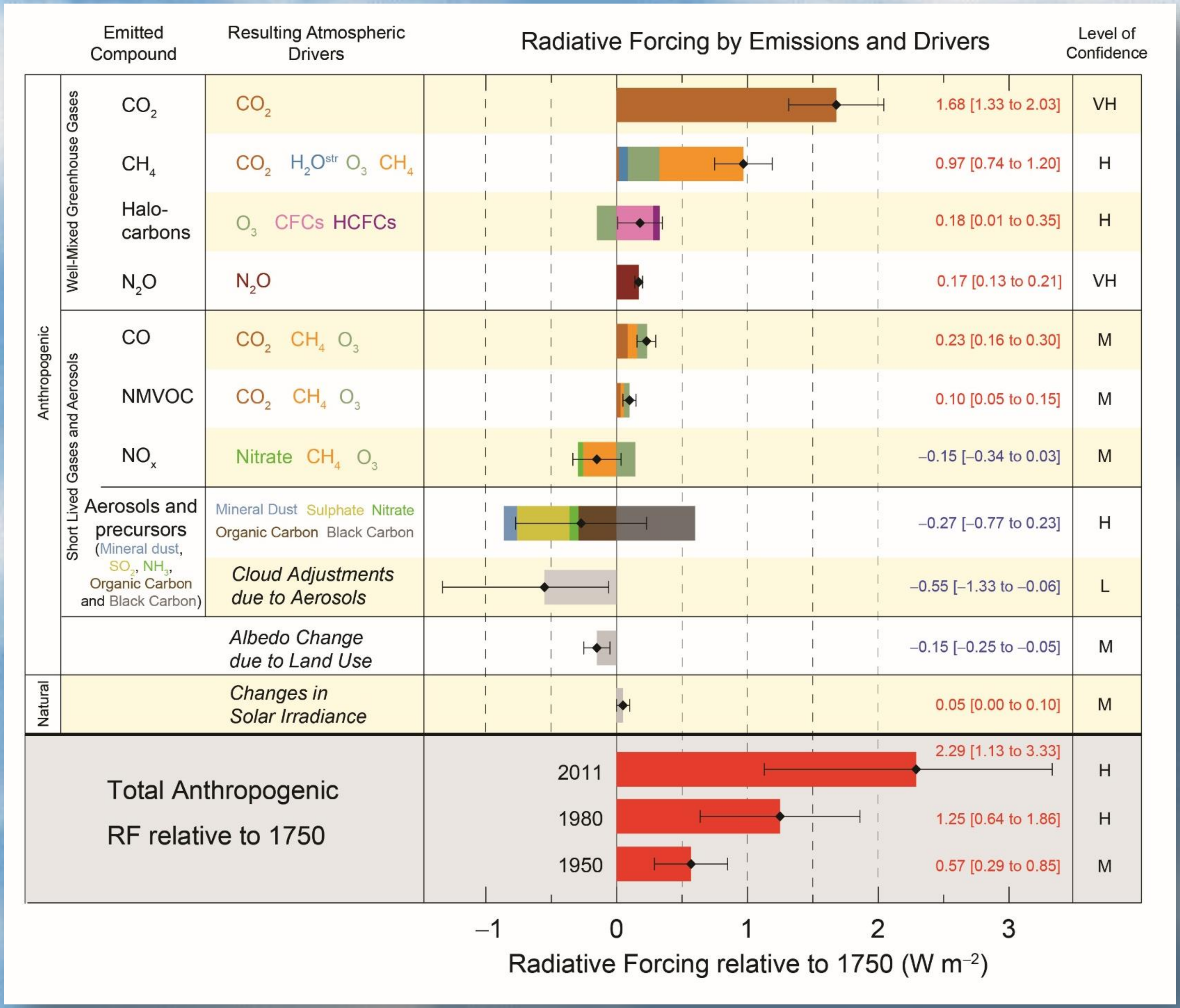
National Geographic + USGS topography

The changing terrestrial water cycle (in cm per year) GRACE satellite from 2002 to 2016

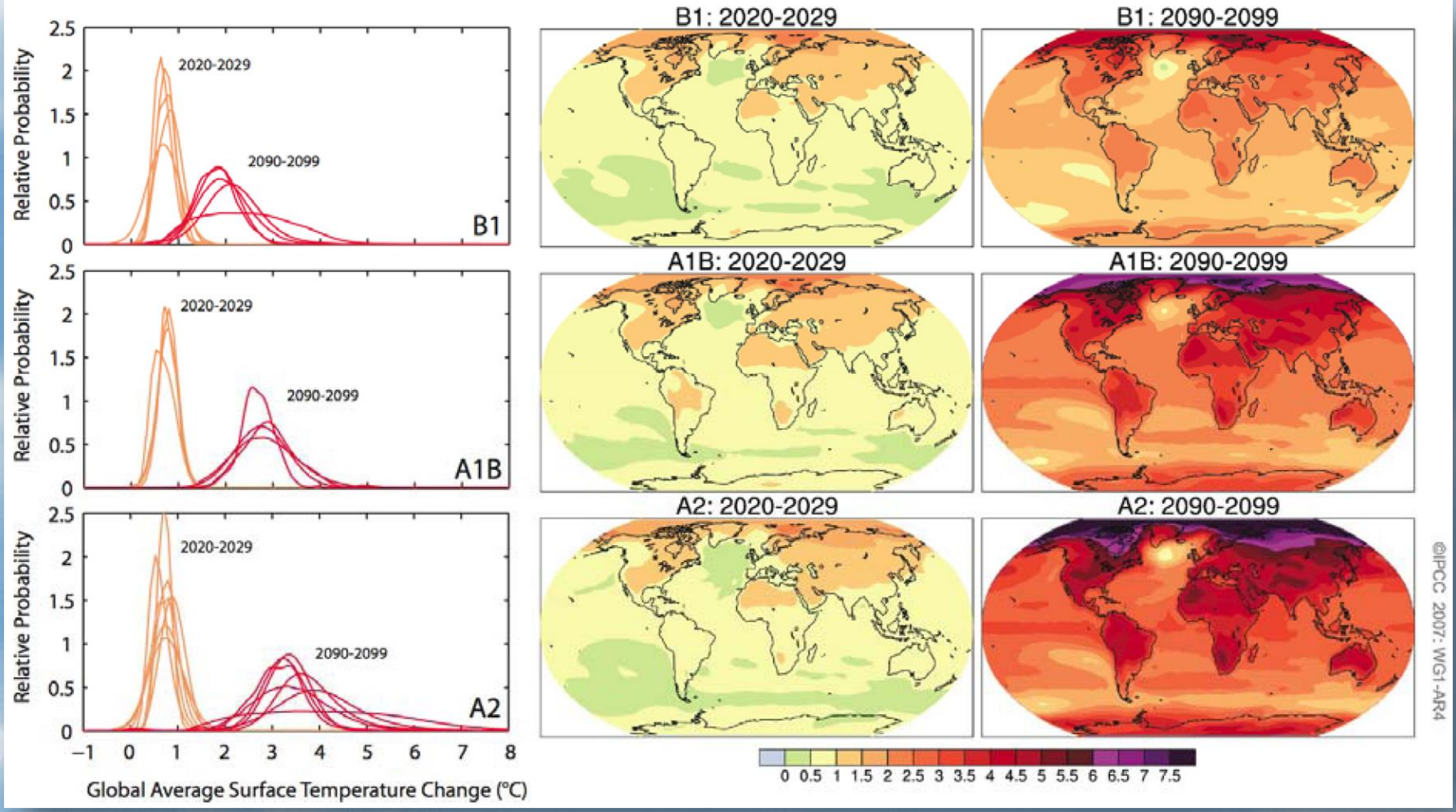


Terrestrial water cycle: sum of groundwater, soil moisture, surface waters, snow and ice

The Radiative Forcing of the global climate system (IPCC 2013)



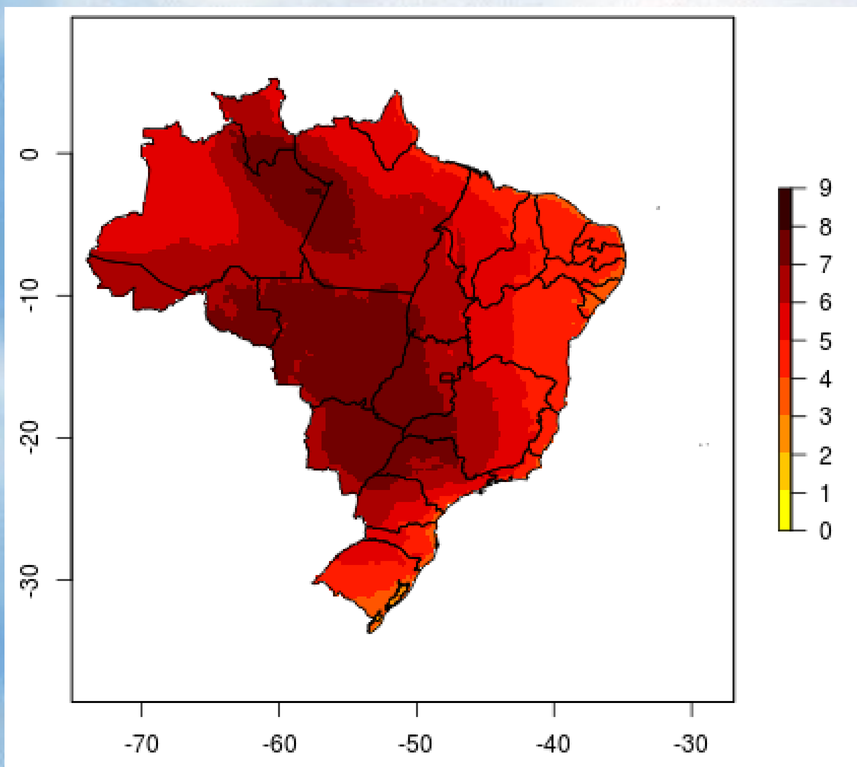
Estimates of temperature increase according to 3 emission pathways

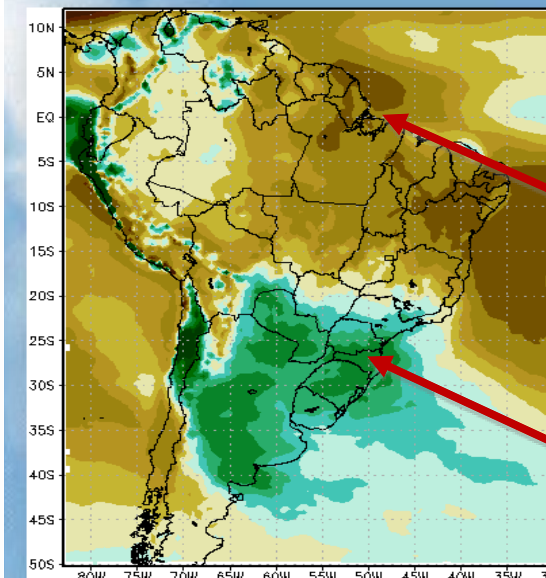


(IPCC 2013)

Aumento médio de temperatura esperado para o Brasil 2071-2099

Mudança na precipitação esperada para o Brasil 2071-2100





Mudanças na chuva (%) em 2071-2100 relativo a 1961-90.

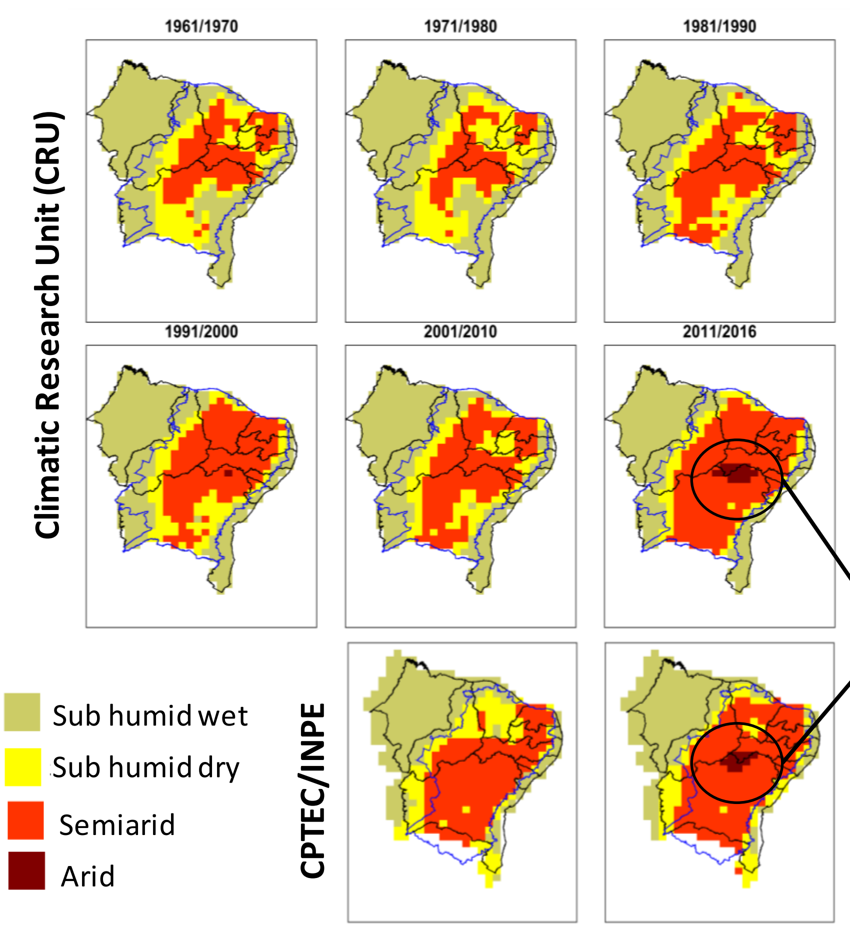
Amazonia e Nordeste do Brasil → deficiência de chuvas

Sudeste da America do Sul→ aumento nas chuvas

Áreas continentais se aquecem mais que áreas oceânicas

INPE, (RCP 8.5)

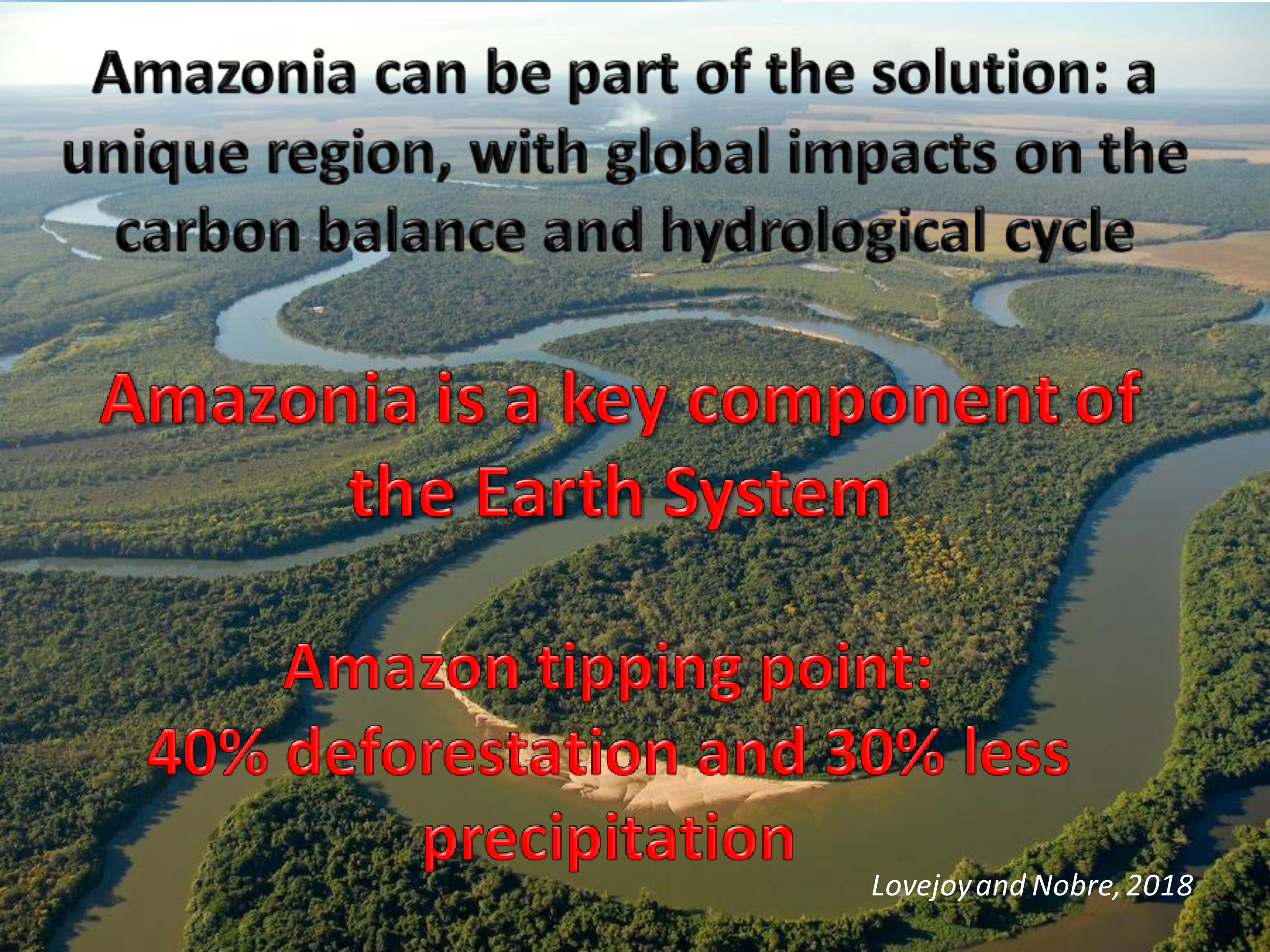
Arid Index evolution from 1970 to 2016



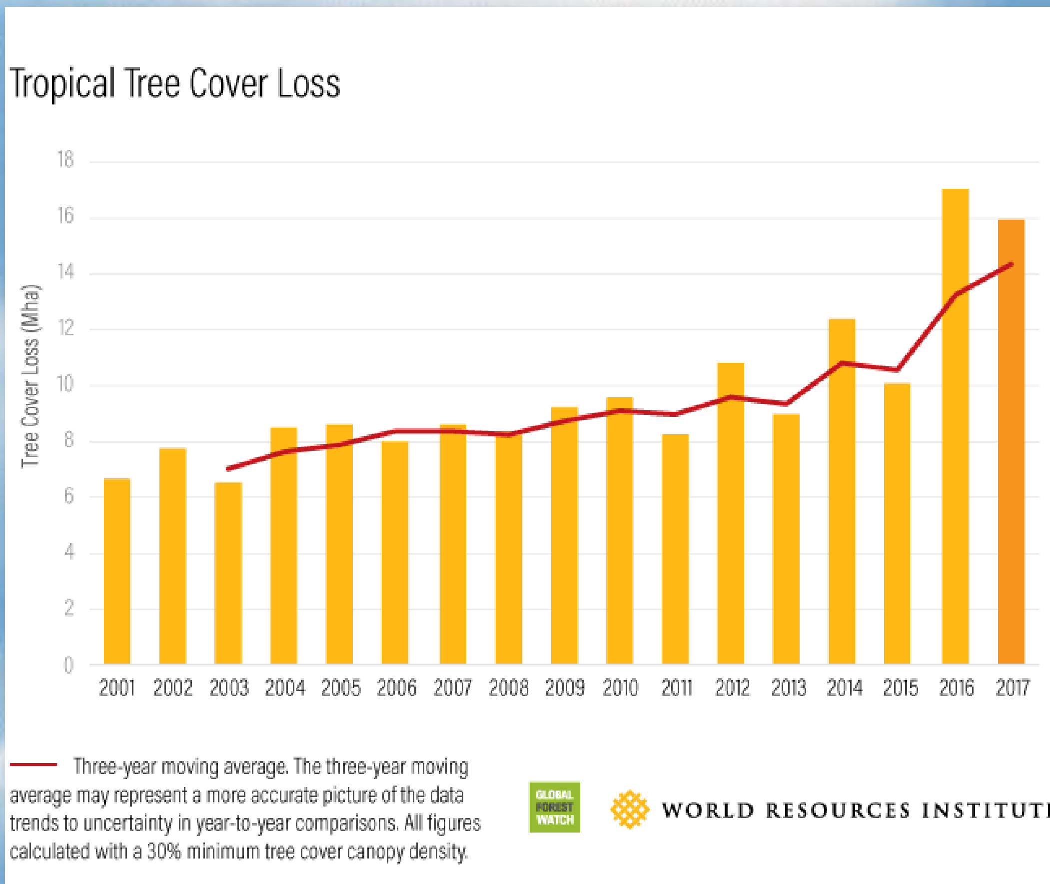
$$\text{Arid Index} = \frac{\text{Annual total precipitation}}{\text{Potential total annual evapotranspiration}}$$

New arid zones are appearing in the last 5 years on Bahia

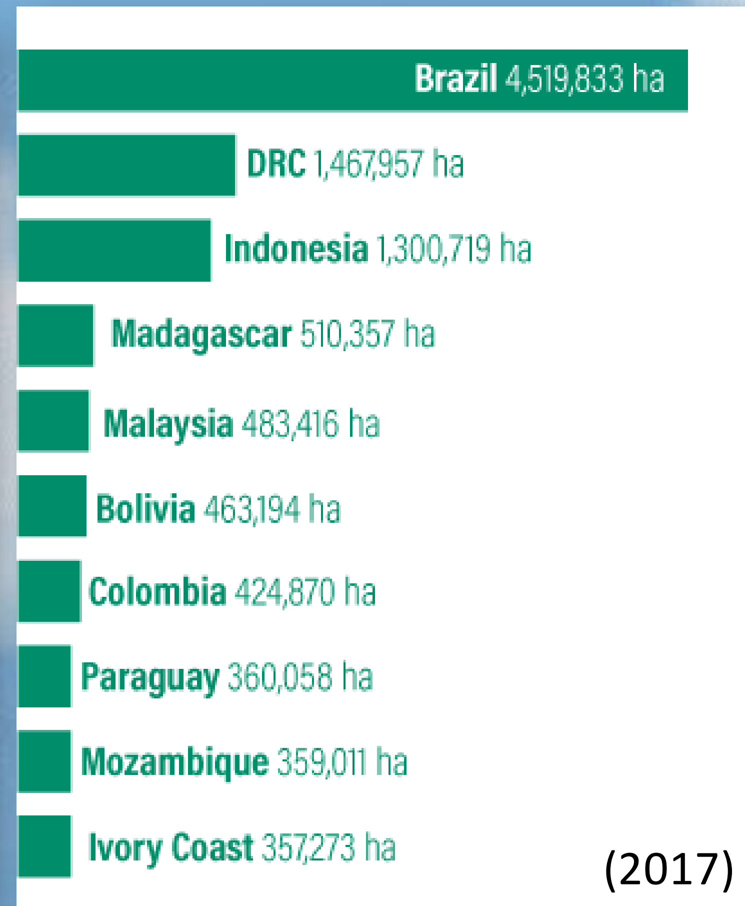
Source: Marengo et al., 2019

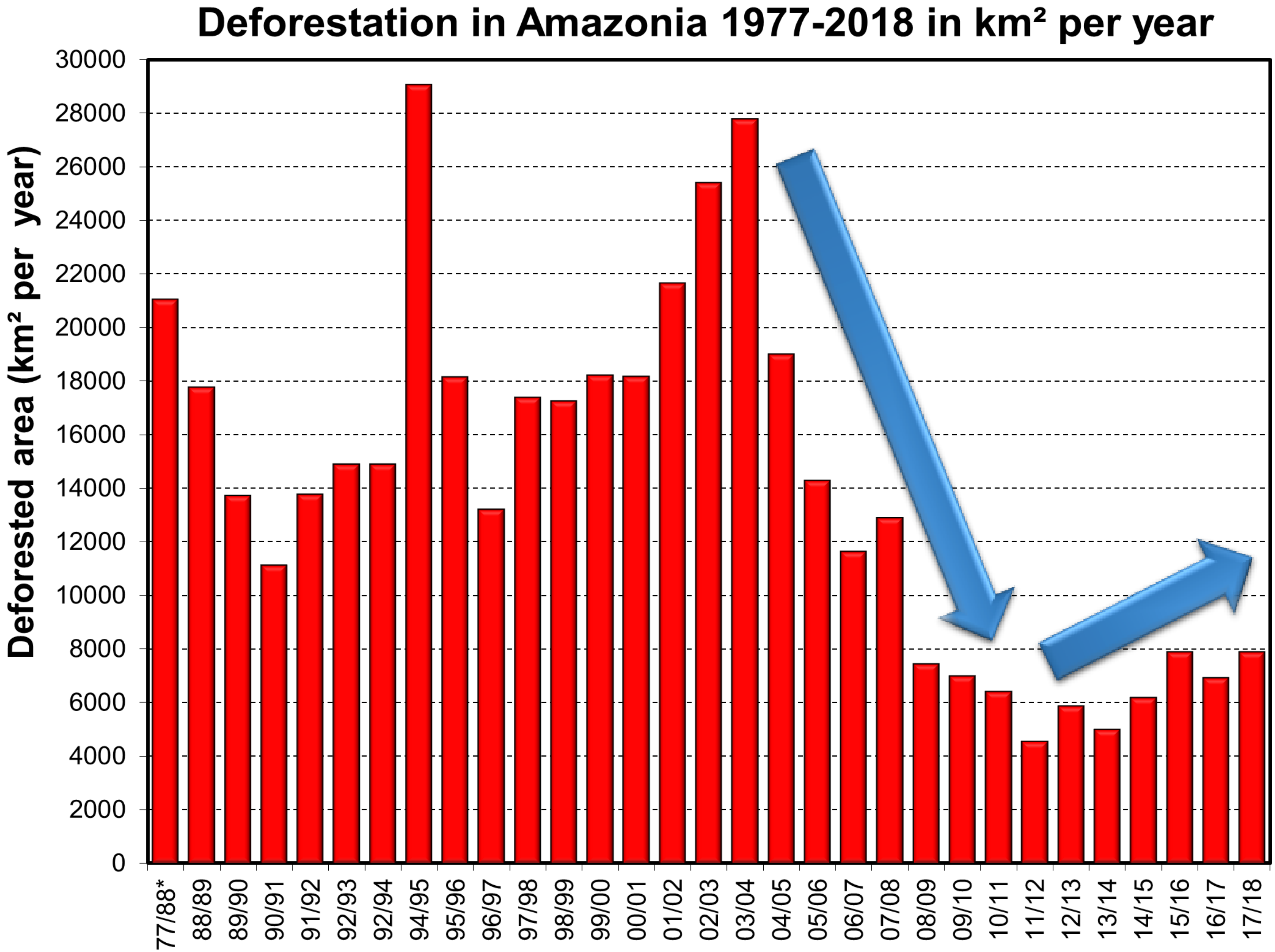

Amazonia can be part of the solution: a unique region, with global impacts on the carbon balance and hydrological cycle
Amazonia is a key component of the Earth System
Amazon tipping point:
40% deforestation and 30% less precipitation
Lovejoy and Nobre, 2018

Tropical Tree Cover Loss



Tropical forest loss: which country?





Deforestation in Amazonia 1977-2018 in km² per year
Deforested area (km² per year)
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
77/88*
88/89
89/90
90/91
91/92
92/93
92/94
94/95
95/96
96/97
97/98
98/99
99/00
00/01
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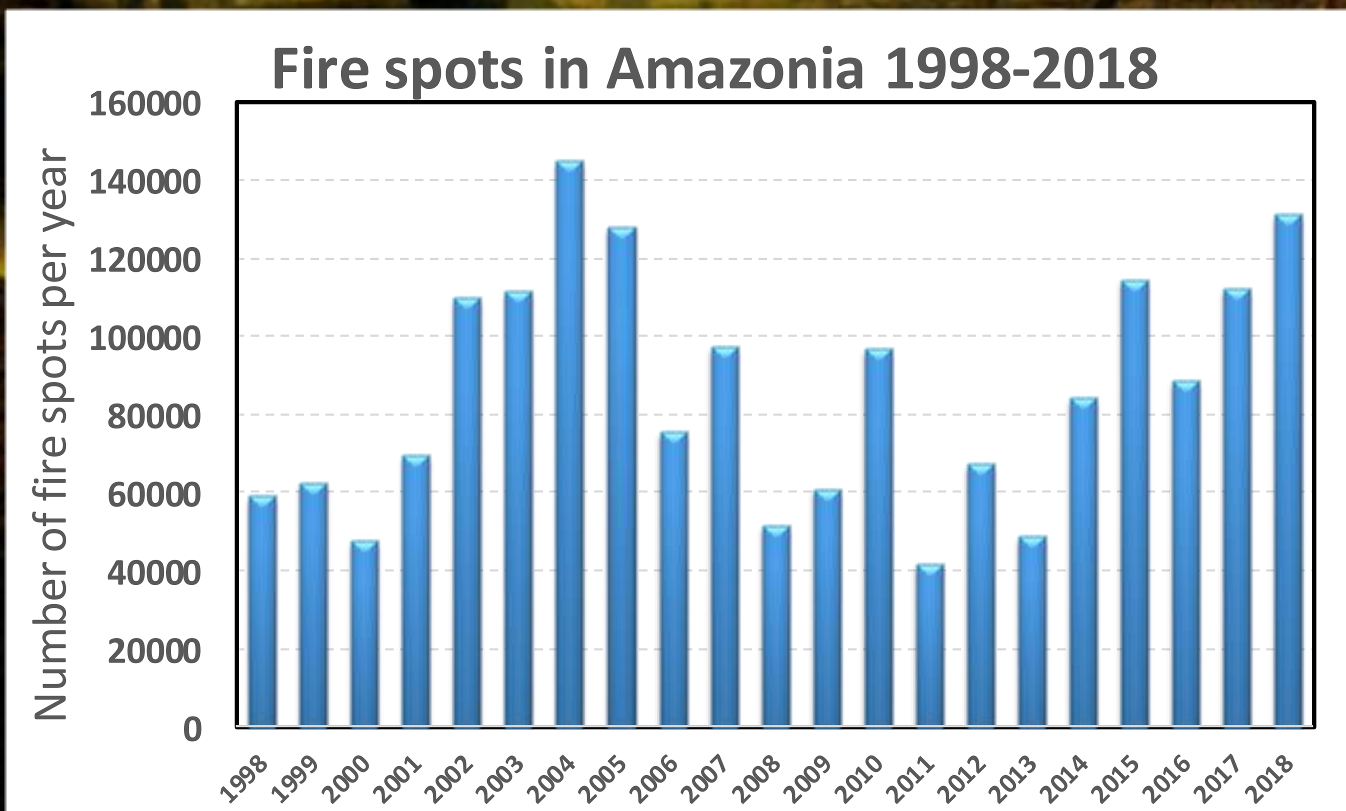
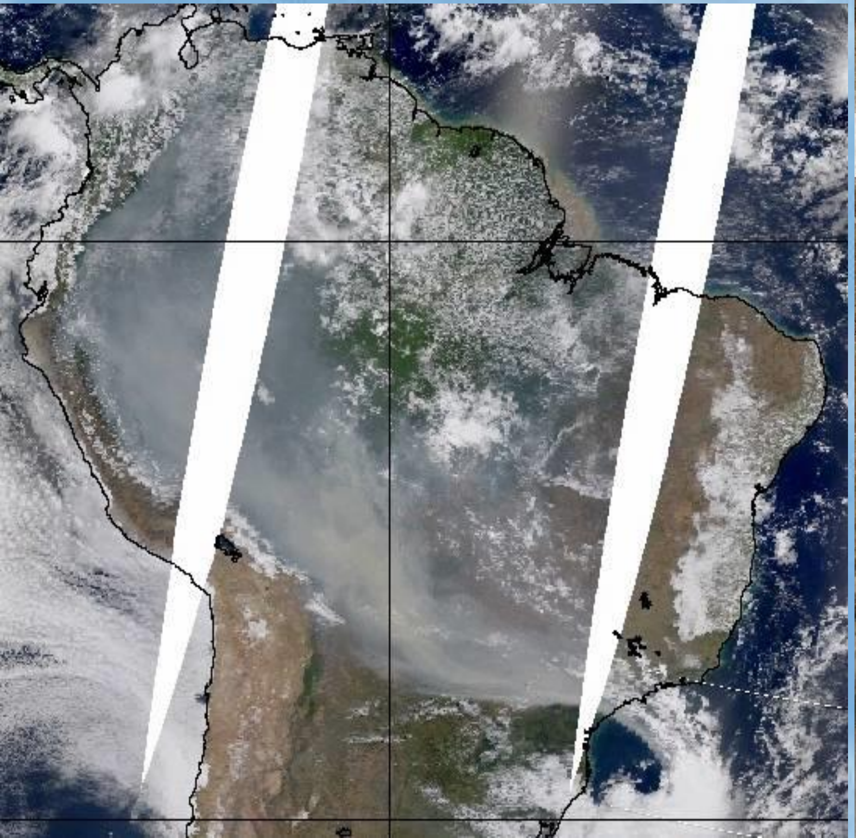
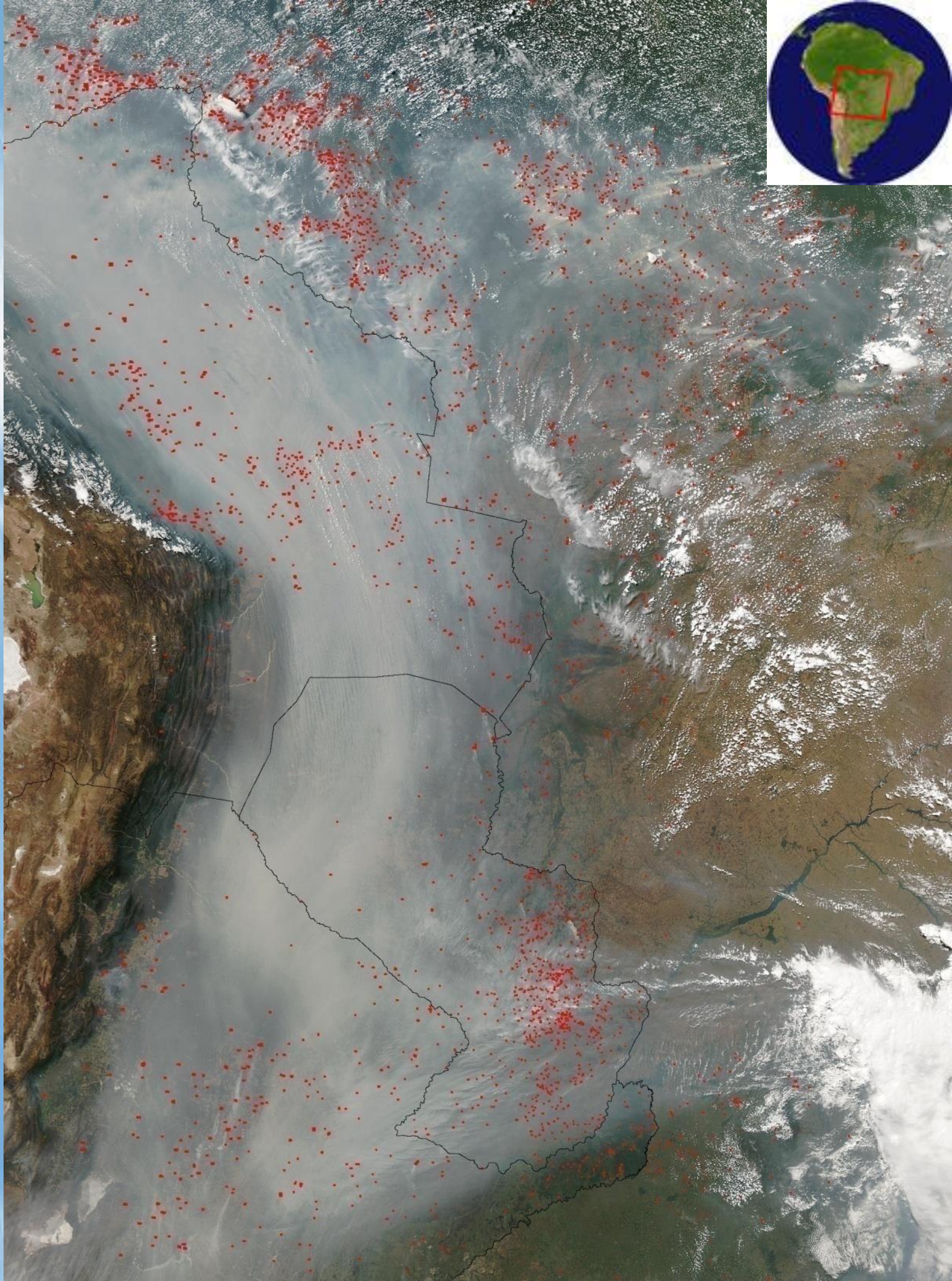
Biomass Burning…



Large scale aerosol distribution in Amazonia

- Severe health effects on the Amazonian population (about 20 million people)
- Climatic effects, with strong effects on cloud physics and radiation balance.
- Changes in carbon uptake and ecosystem functioning

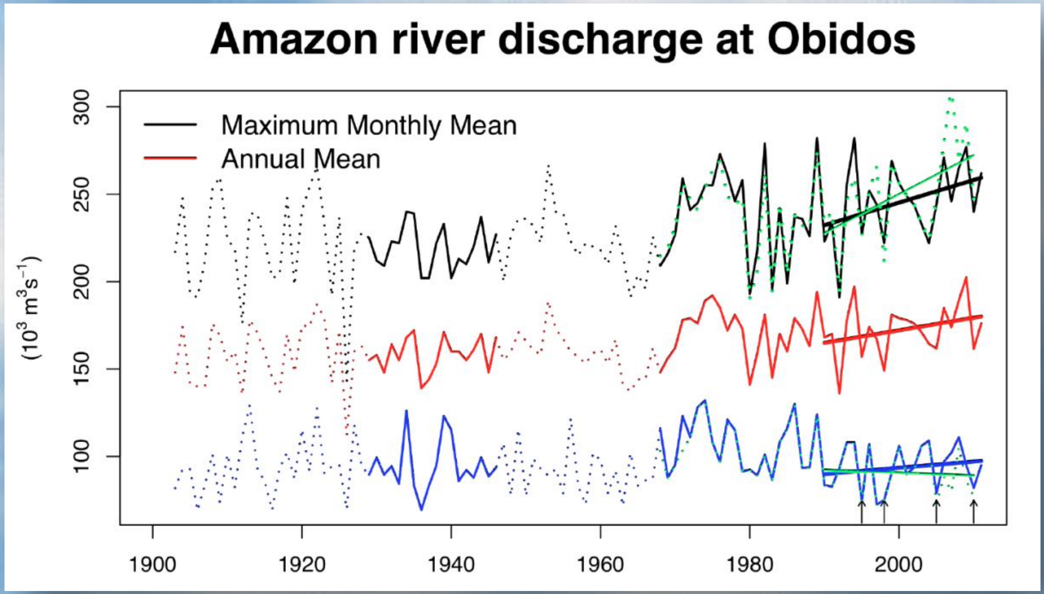




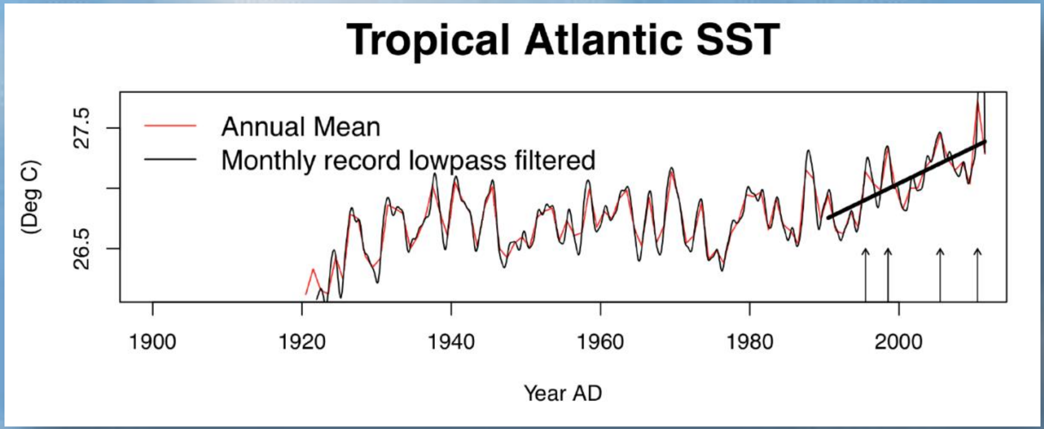
Amazon is critical for water vapor transport over South America

What processes controls these fluxes?

Is the Amazonian hydrological cycle intensifying?



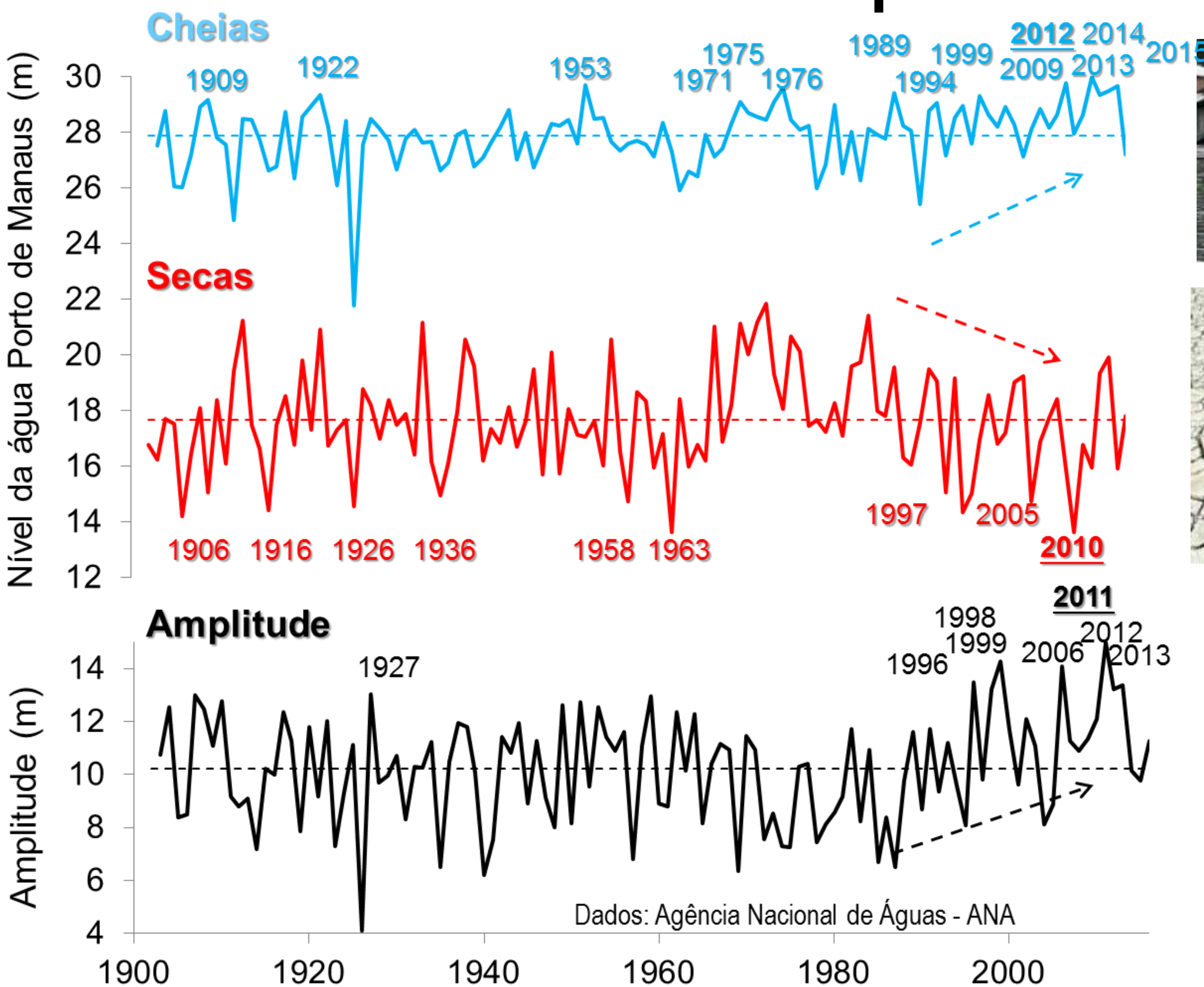
Maximum monthly, annual mean and minimum monthly mean Amazon river discharge at Óbidos and in green maximum and minimum daily mean river discharge.



Tropical Atlantic sea surface temperature from Extended reconstructed sea surface temperature.

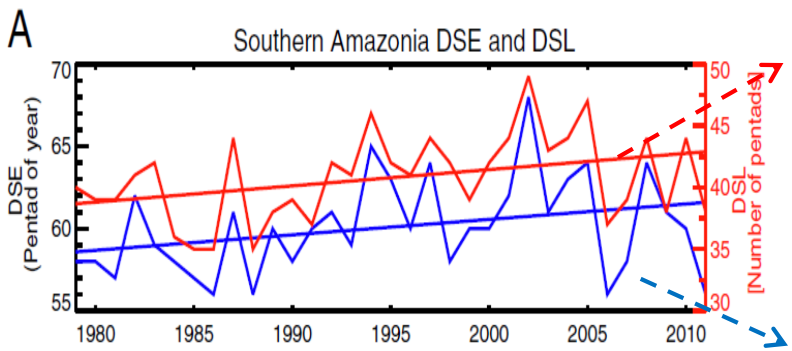
Gloor et al. 2013

Port of Manaus maximum and minimum levels of water and amplitude



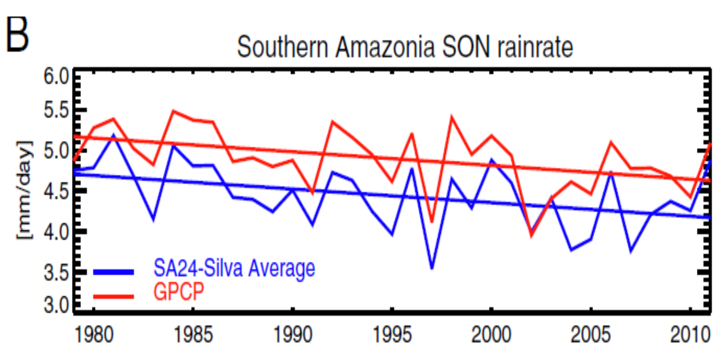
Jochen Schöngart, 2017

Dry season length is increasing in Amazonia



Annual time series of dry season length (DSL)

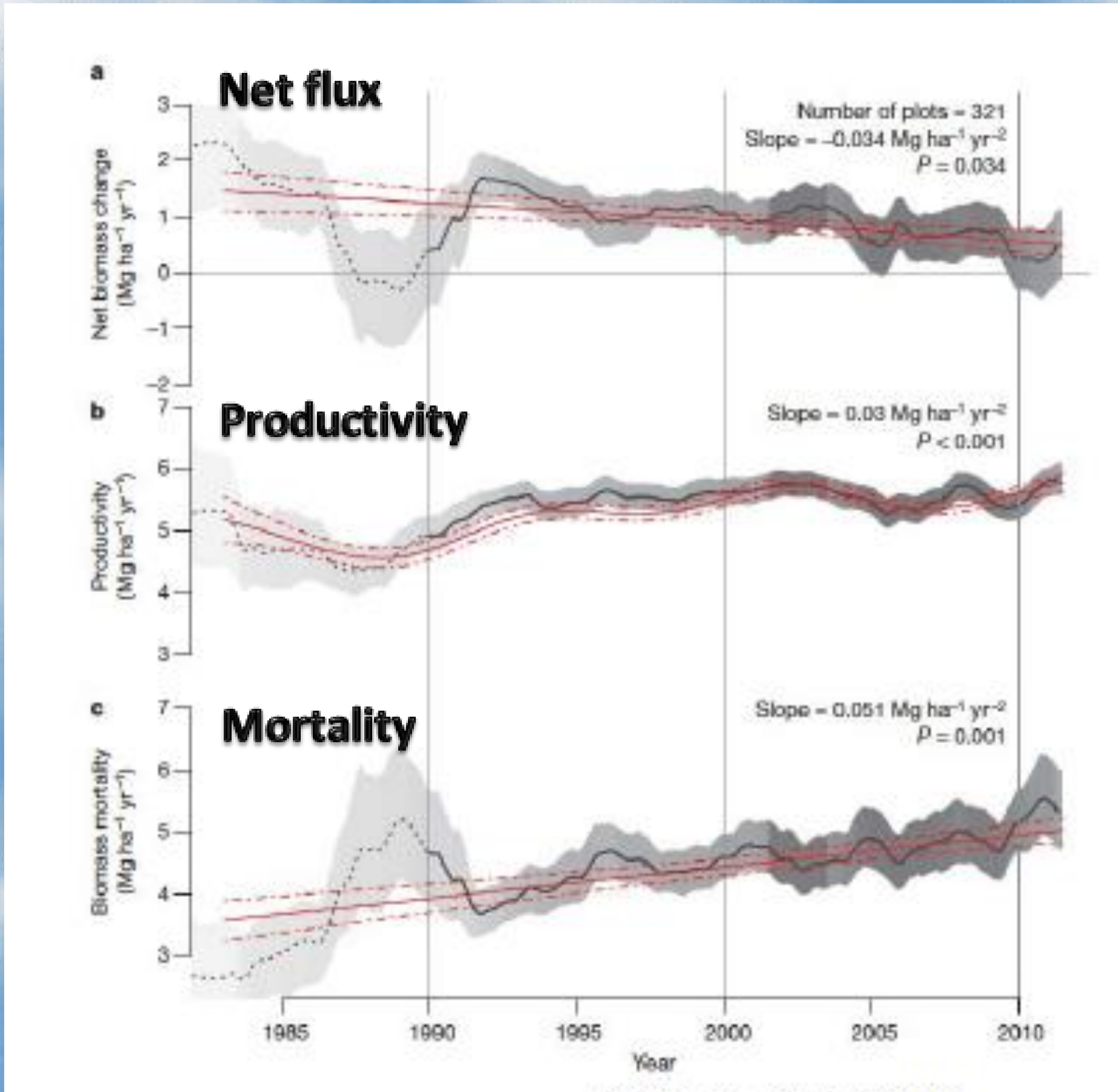
Annual time series of dry season END (DSE)



Dry season length has increased by **6.5±2.5** days/decade;

Fu et al. 2013 (PNAS)

Carbon cycling in Amazonia from 1985 to 2010

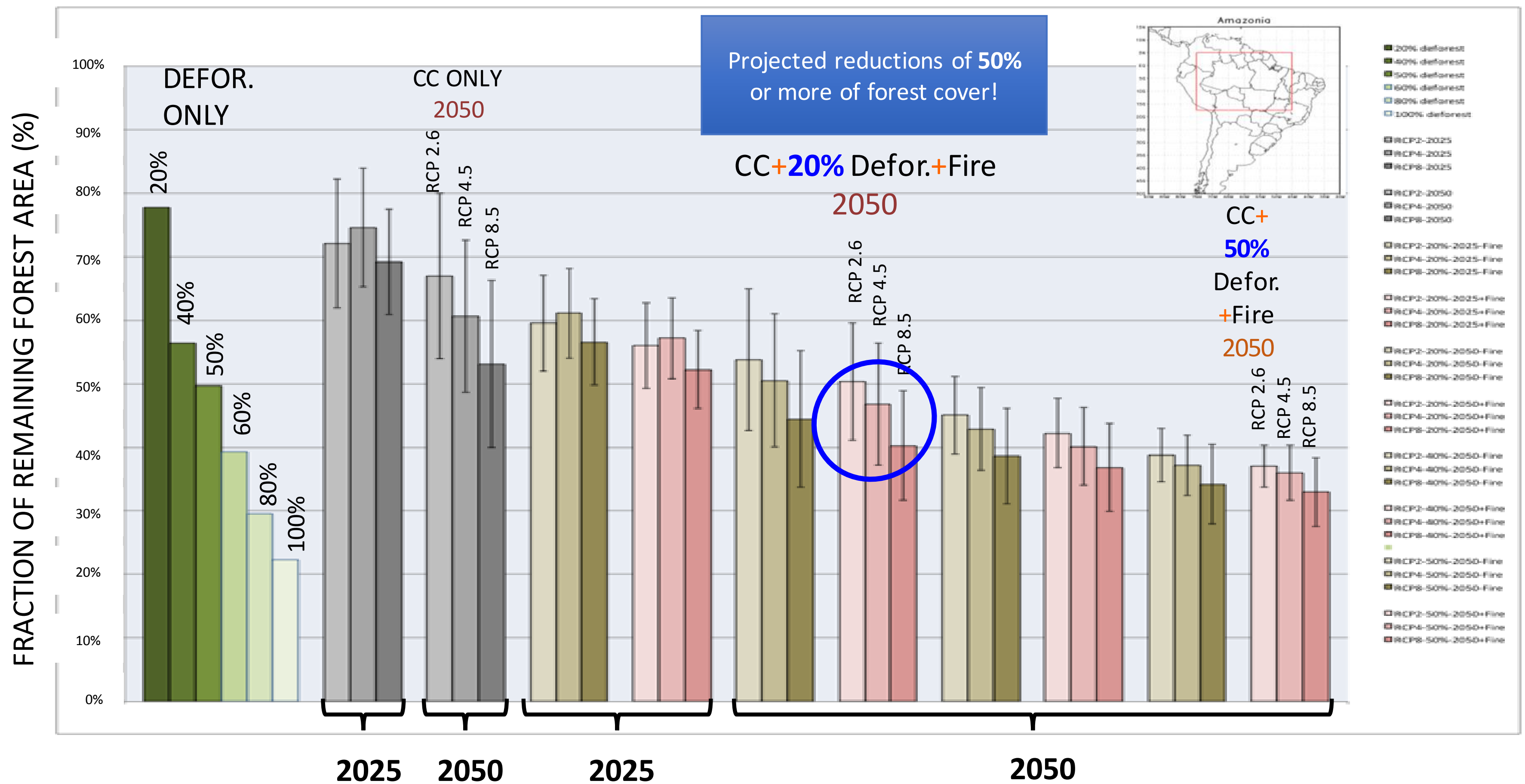


(Brienen et al., 2015)

Net carbon flux:
Today: ZERO

Tree mortality:
significant INCREASE

Fraction of the remaining forest area
9 Earth System Models climate change projections



Nobre et al., 2016 PNAS

‘TIPPING POINTS’ OF FOREST-CLIMATE EQUILIBRIUM IN THE AMAZON

A) Tropical forest in equilibrium with current climate

One stable equilibrium state

Amazon covered mostly by forests

B) Savanna state triggered by climate change and/or deforestation

Two stable equilibrium states

Forests in the West

Savannas in the East-Southeast

C) Stability of second equilibrium state

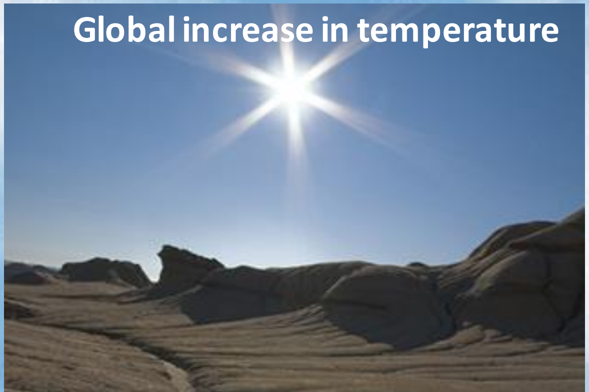
Savanna enhanced by increased /intensity of droughts and forest fires

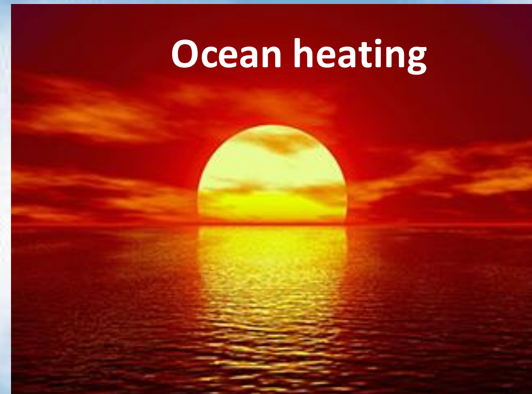
Thresholds for tipping
from state A to state B ≈ 4ºC Amazon warming or
≈ 40% of total deforested area

- **Observations: ΔT ≈ 1.1 to 1.5ºC**
- **Deforestation: ≈ 18%**
- **Forest fire frequency (increasing)**
- **Lengthening of dry season (increasing)**
- **Increasing climate extremes**

Adapted from Nobre et al., 2015, 2016

Evidences for rapid climate changes


Global increase in temperature

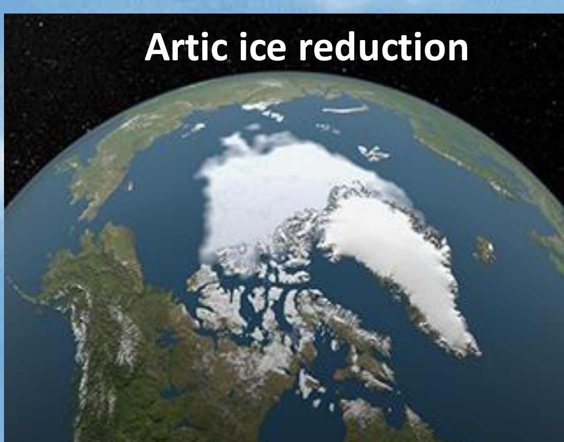

Ocean heating

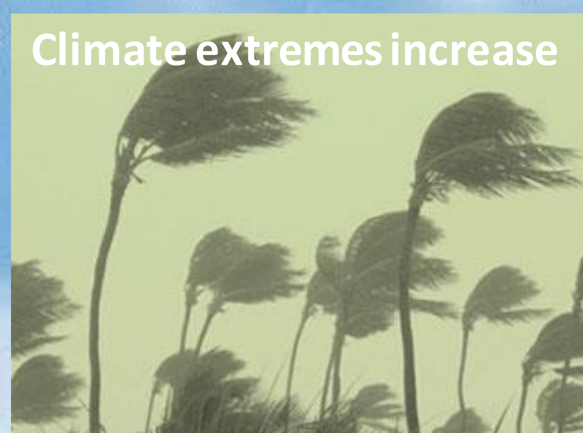

Reduction in ice area


Reduction in ice caps


Snow cover reduction


Sea level rise


Artic ice reduction

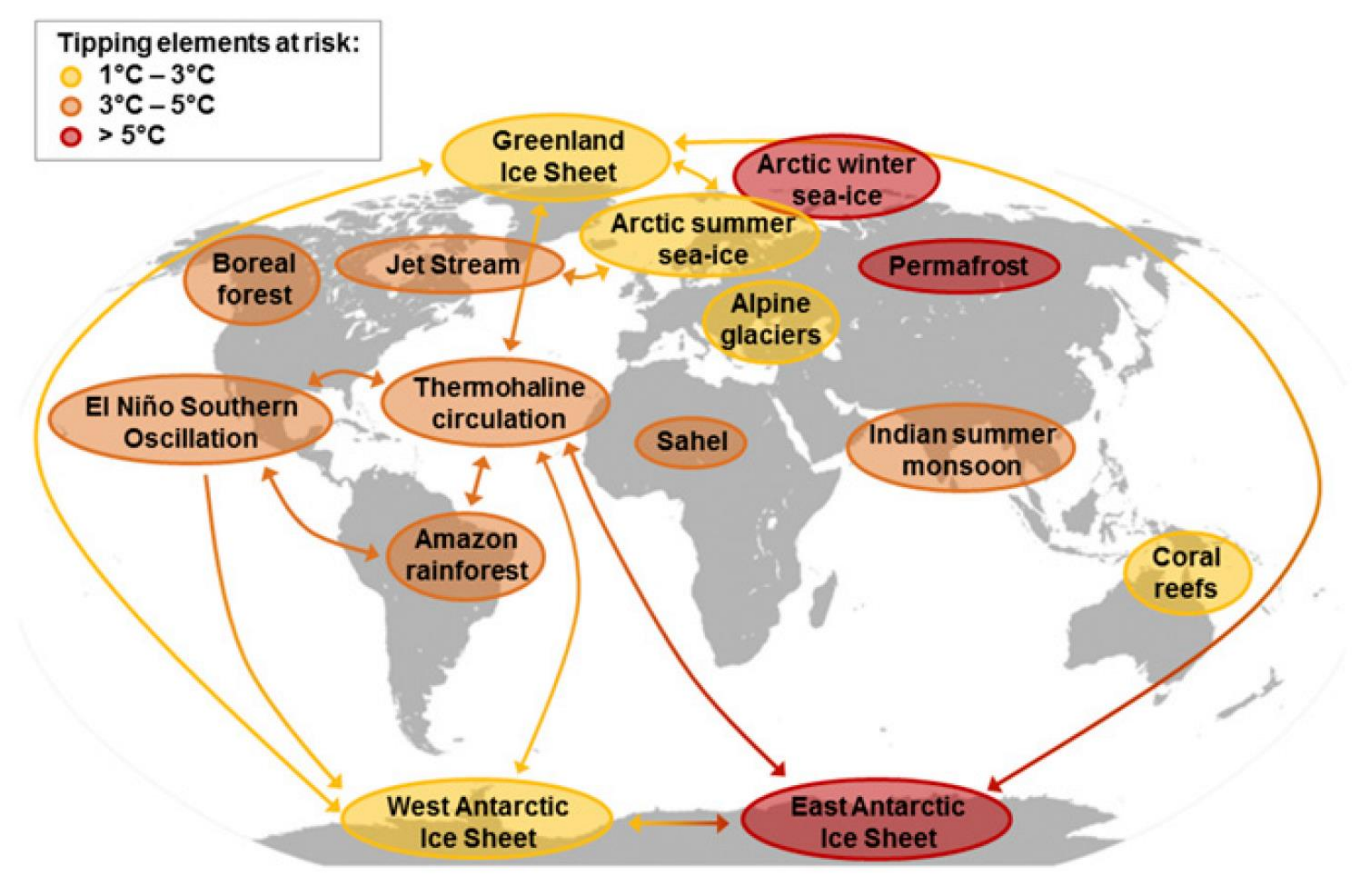

Climate extremes increase


Ocean acidification

How close to the edge do we dare to get?

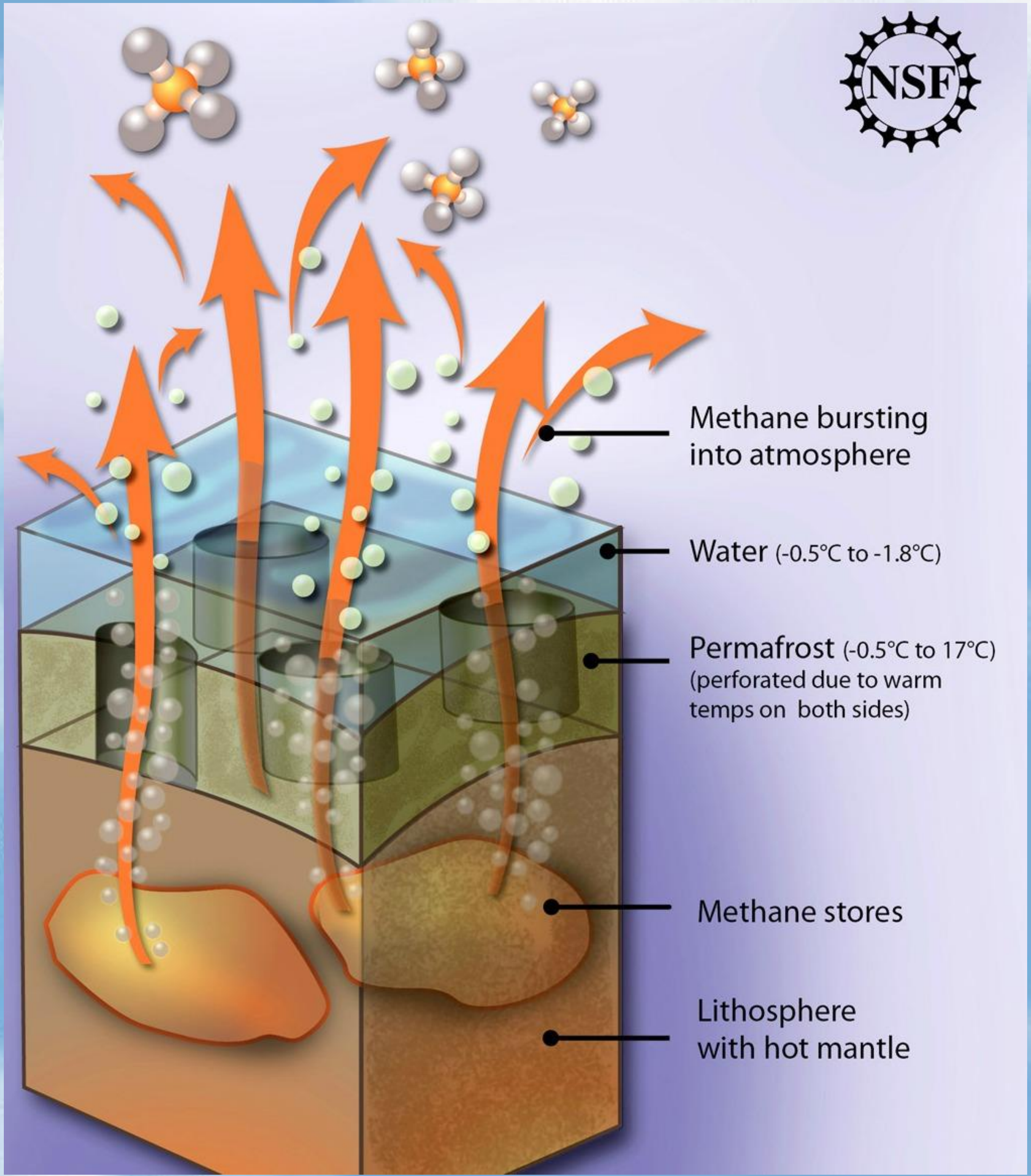
The tipping point issue…

Tipping points of the Earth climate system



UNEP GEO-6 2019

Feedbacks: Arctic permafrost methane leakage to the atmosphere



Risks: Increase in the intensity and frequency of climate extremes

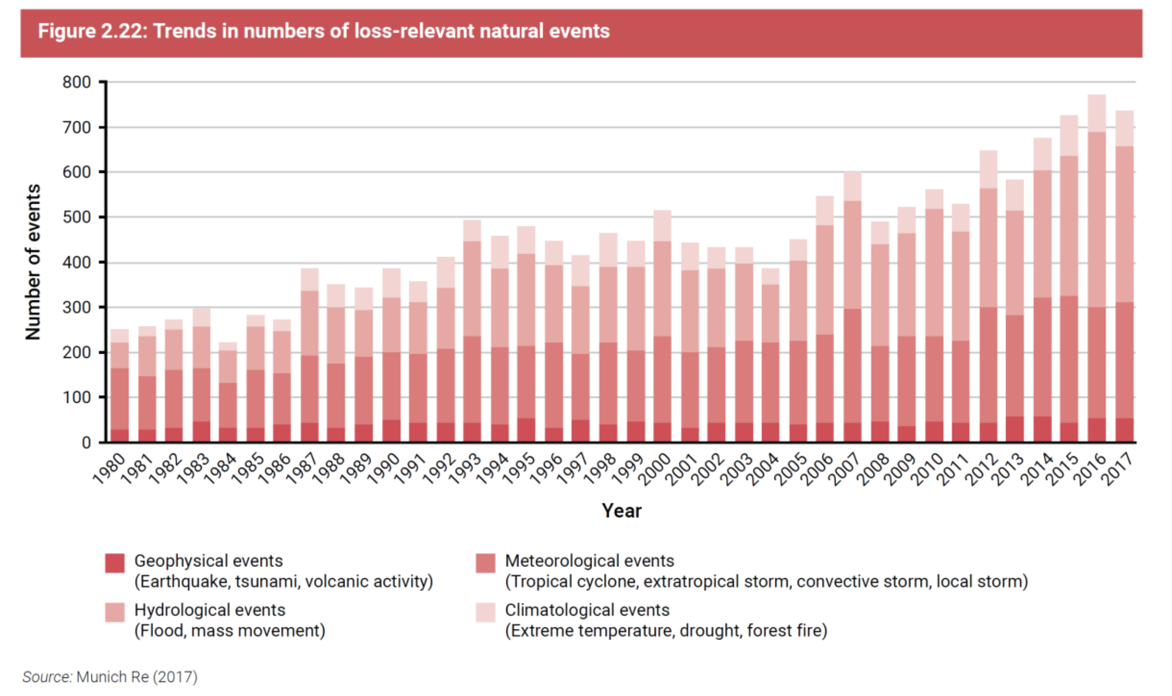
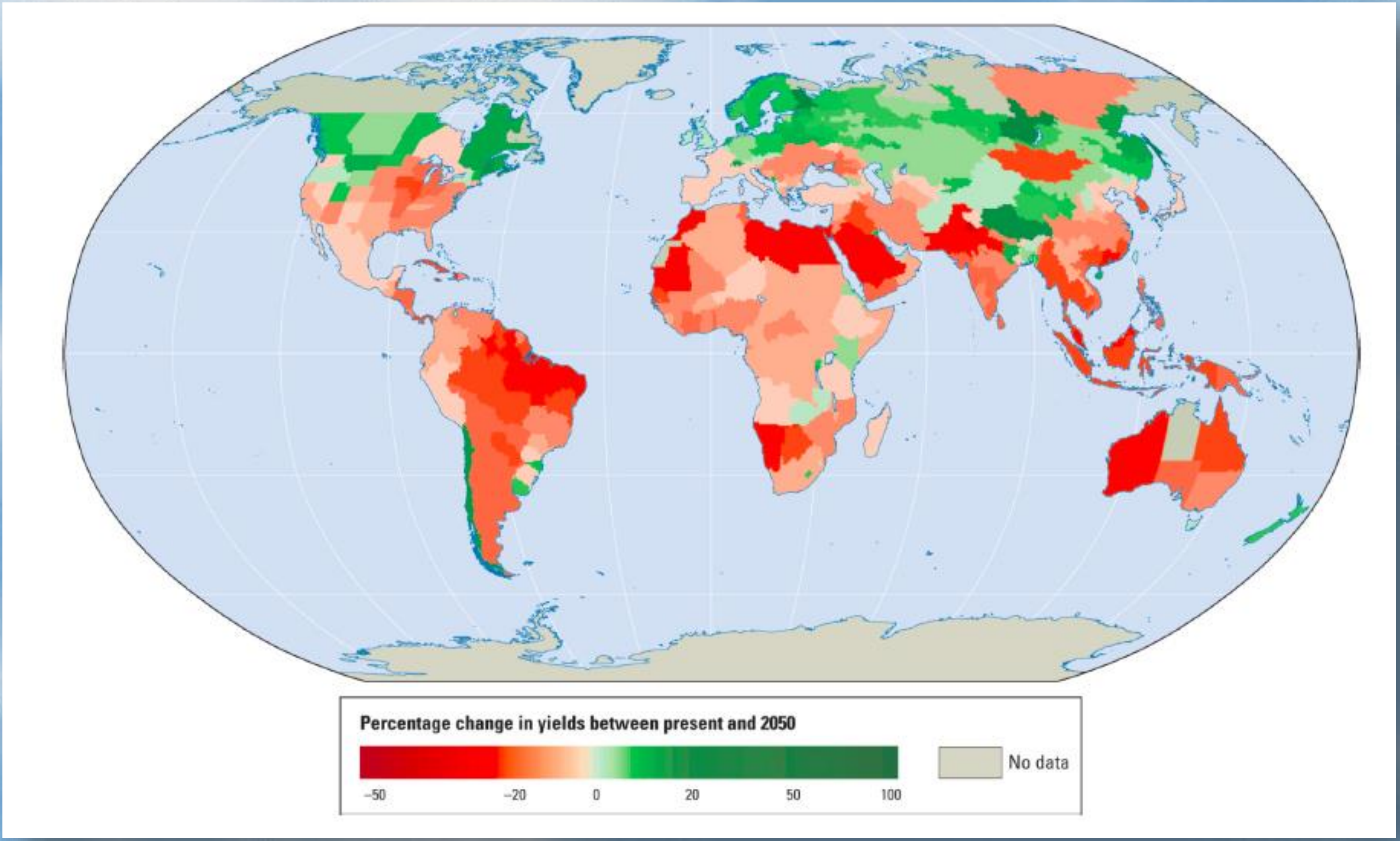


Figure 2.22: Trends in numbers of loss-relevant natural events

Source: Munich Re (2017)

It is already happening since the 80's

Food Security: Potential impacts on food production in a 3°C hotter world



FAO and World Economic Forum: Global Risks 2016

Solutions: Please we need engineering here!!!

More efficient use of energy

Greater use of low-carbon and no-carbon energy
- Many of these technologies exist today
- Nearly a quadrupling of zero- and low-carbon energy supply from renewable energy by 2050

Improved carbon sinks
- Reduced deforestation and improved forest management and planting of new forests
- Bio-energy with carbon capture and storage

Lifestyle and behavioural changes

AR5

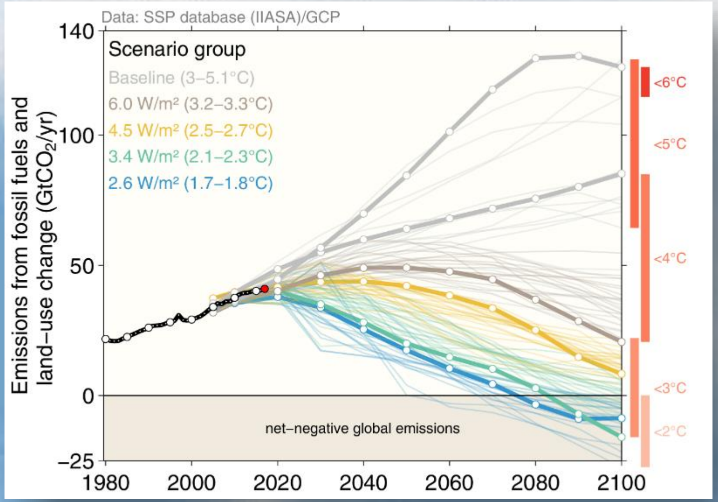
Energy production

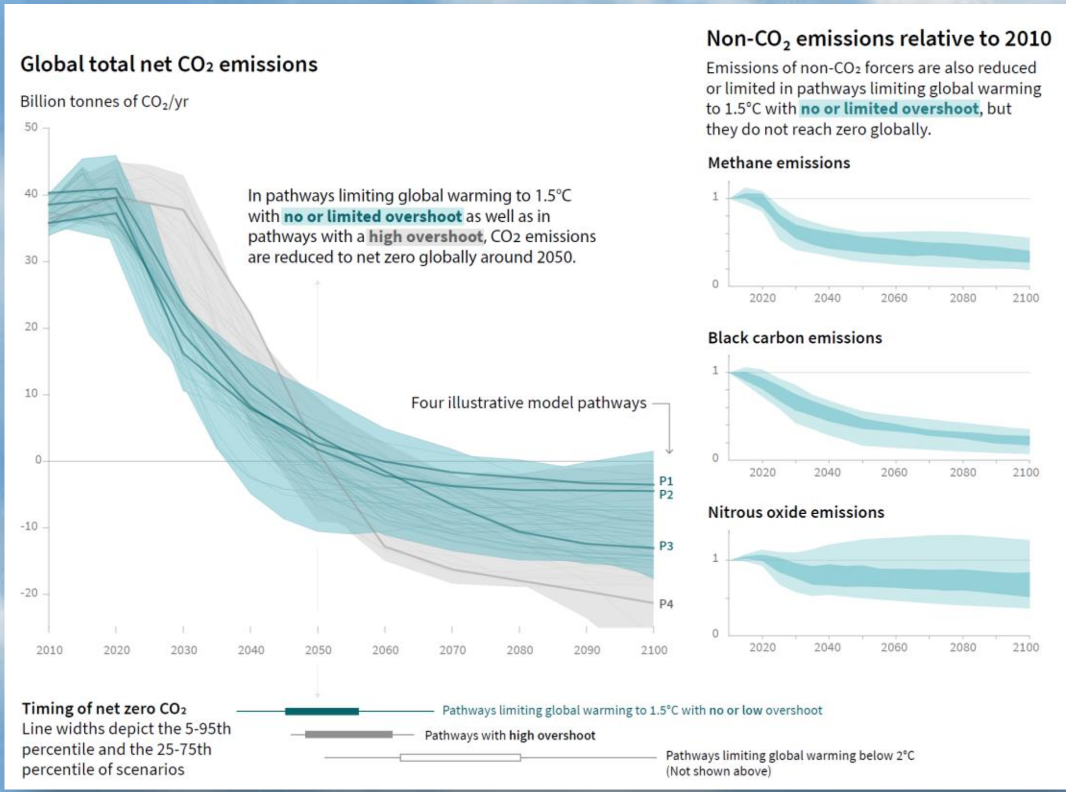
Transportation

Agriculture

Biofuels?

Emissions pathways to limit temperature increase to 1.5 degrees with Short Lived Climate Forcers



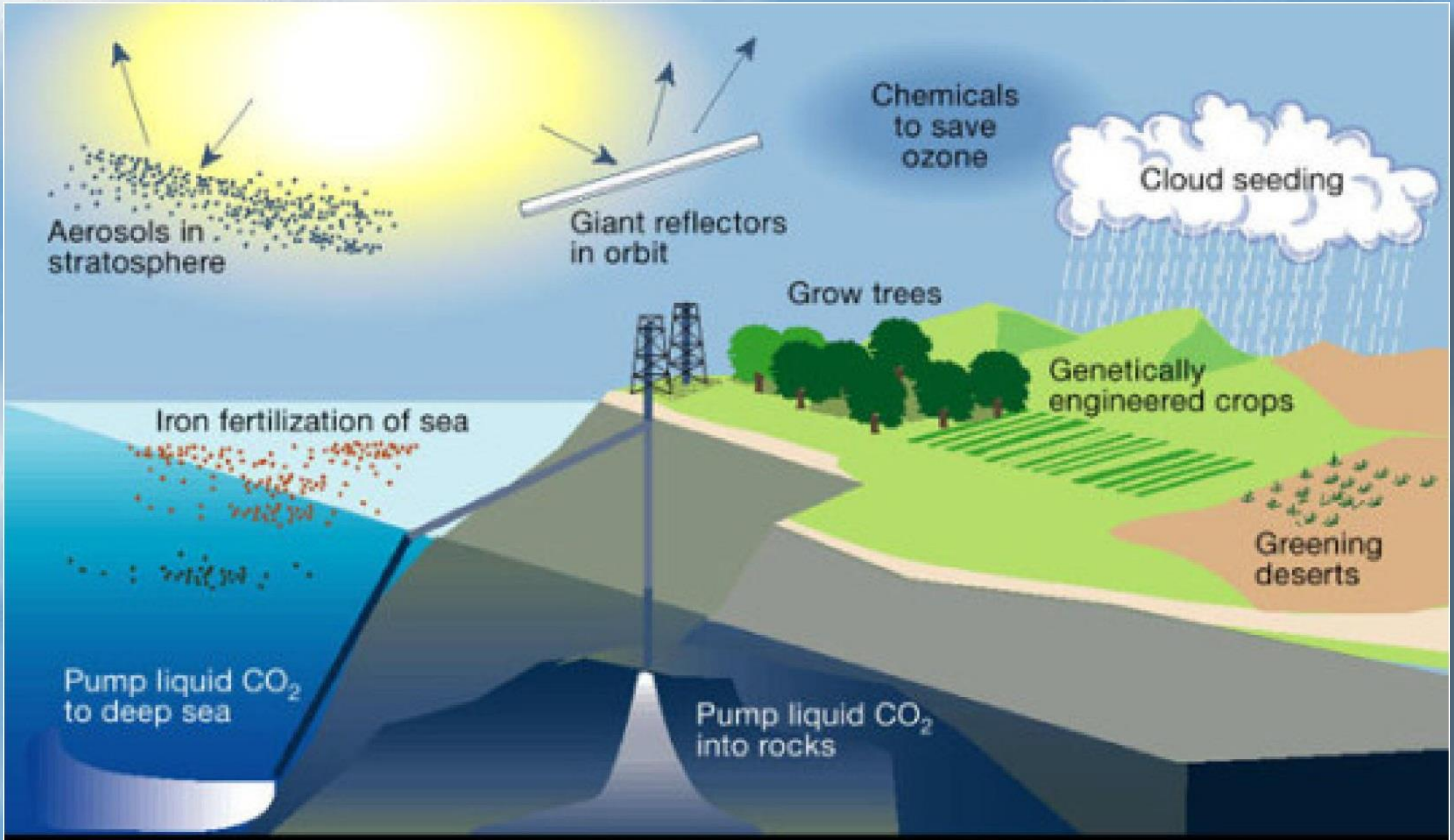


Faster immediate CO2 emission reductions (-5% per year, at 2020)

Maximum temperature rise is determined by cumulative net CO2 emissions and net non-CO2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

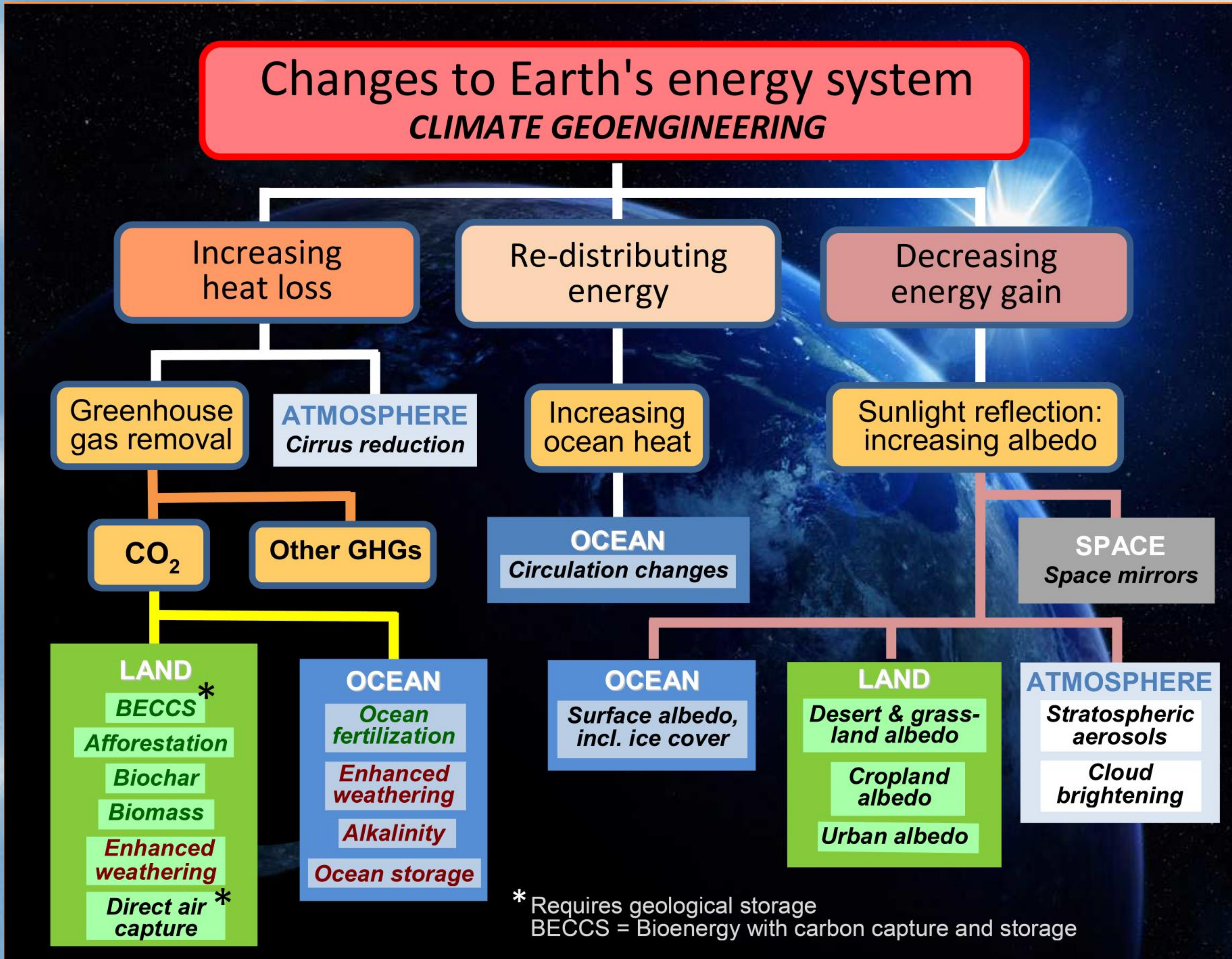
Source: IPCC Special Report on Global Warming of 1.5°C

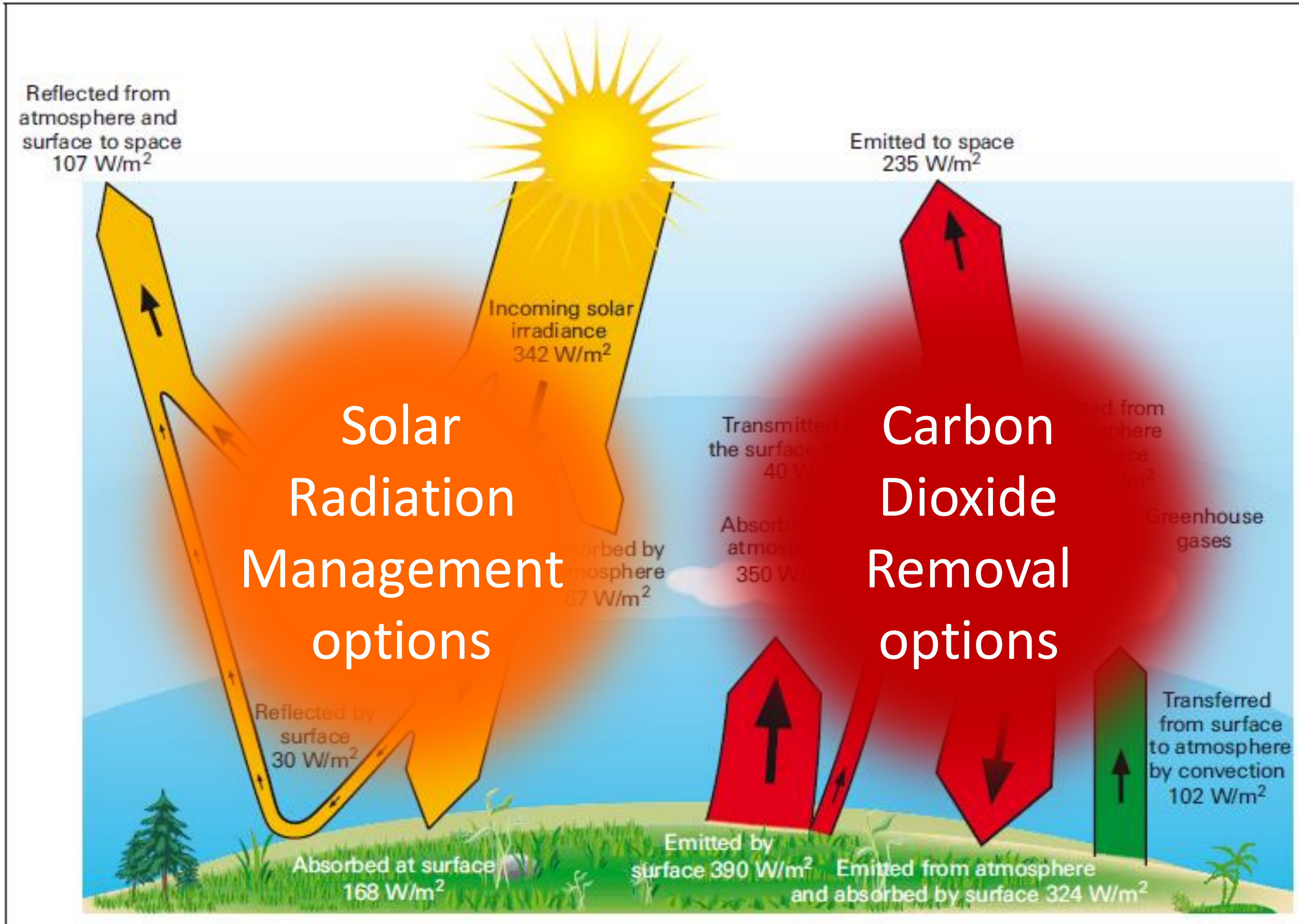
Geoengineering is defined as
"deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."



Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Shepherd, J. G. S. et al., 2009: *Geoengineering the climate: Science, governance and uncertainty*, RS Policy Document 10/09, (London: The Royal Society).

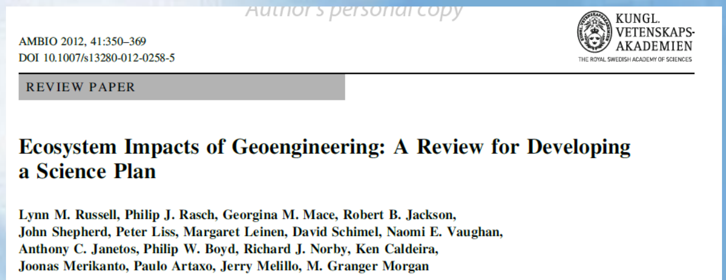

Changes to Earth's energy system
CLIMATE GEOENGINEERING
Increasing heat loss
Re-distributing energy
Decreasing energy gain
Greenhouse gas removal
ATMOSPHERE
Cirrus reduction
Increasing ocean heat
Sunlight reflection: increasing albedo
CO_2
Other GHGs
OCEAN
Circulation changes
SPACE
Space mirrors
LAND
BECCS *
Afforestation
Biochar
Biomass
Enhanced weathering
Direct air capture *
OCEAN
Ocean fertilization
Enhanced weathering
Alkalinity
Ocean storage
OCEAN
Surface albedo, incl. ice cover
LAND
Desert & grass-land albedo
Cropland albedo
Urban albedo
ATMOSPHERE
Stratospheric aerosols
Cloud brightening
* Requires geological storage
BECCS = Bioenergy with carbon capture and storage



Reflected from atmosphere and surface to space 107 W/m^2
Incoming solar irradiance 342 W/m^2
Emitted to space 235 W/m^2
Solar Radiation Management options
Carbon Dioxide Removal options
Greenhouse gases
Reflected by surface 30 W/m^2
Transferred from surface to atmosphere by convection 102 W/m^2
Absorbed at surface 168 W/m^2
Emitted by surface 390 W/m^2
Emitted from atmosphere and absorbed by surface 324 W/m^2

Very extensive literature…

IGBP Ambio task force



Author's personal copy

AMBIO 2012, 41:350–369
DOI 10.1007/s13280-012-0258-5

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THE ROYAL SWEDISH ACADEMY OF SCIENCES

REVIEW PAPER

Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan

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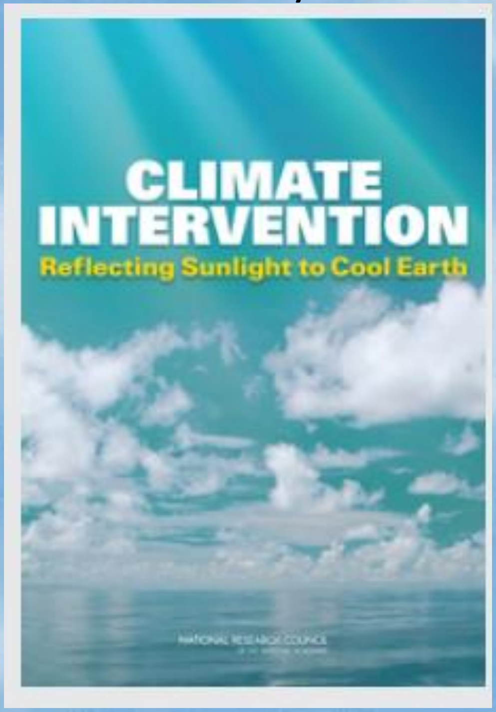
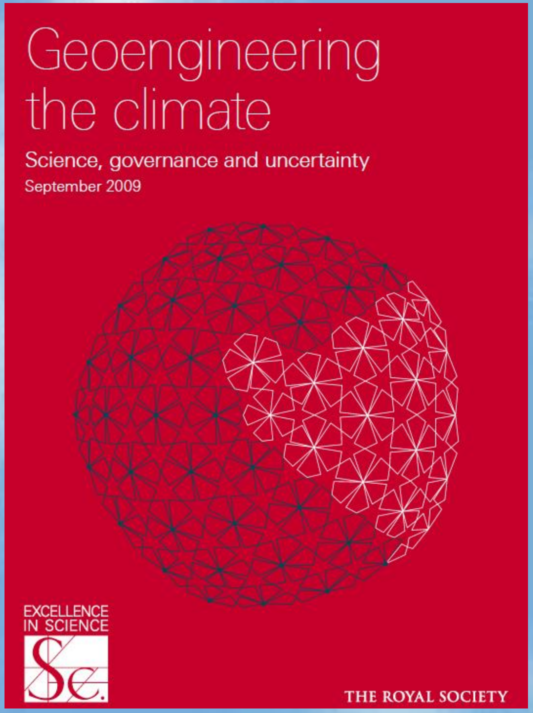
US National Academy of Sciences



UK Royal Society



World Economic Forum: The Global Risks Report 2019

Top 5 Global Risks in **Terms of Likelihood**

2017	2018	2019
Extreme weather events	Extreme weather events	Extreme weather events
Large-scale involuntary migration	Natural disasters	Failure of climate-change mitigation and adaptation
Major natural disasters	Cyber-attacks	Natural disasters
Large-scale terrorist attacks	Data fraud or theft	Data fraud or theft
Massive incident of data fraud/theft	Failure of climate-change mitigation and adaptation	Cyber-attacks

Top 5 Global Risks in **Terms of Impacts**

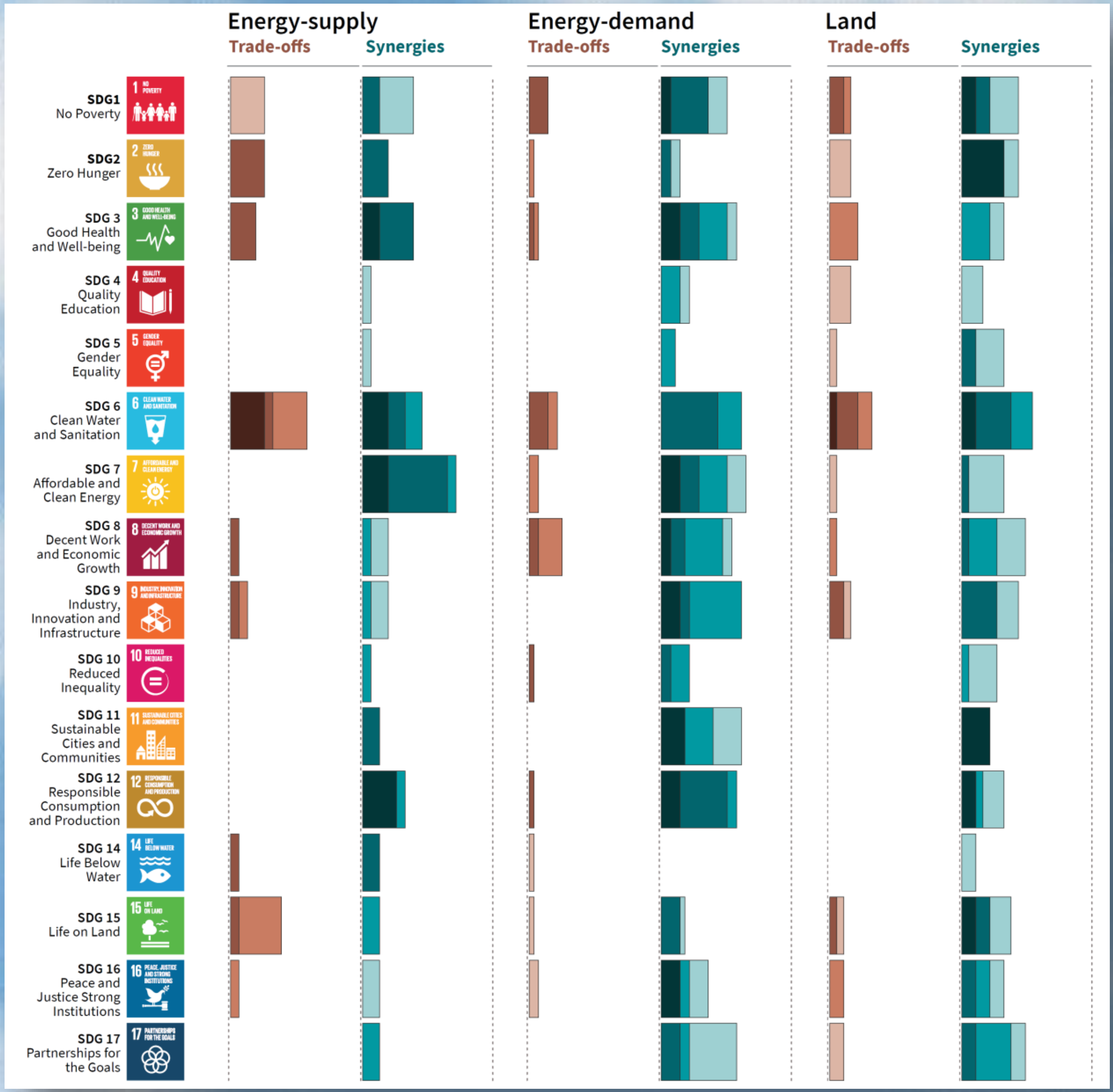
2017	2018	2019
Weapons of mass destruction	Weapons of mass destruction	Weapons of mass destruction
Extreme weather events	Extreme weather events	Failure of climate-change mitigation and adaptation
Water crises	Natural disasters	Extreme weather events
Major natural disasters	Failure of climate-change mitigation and adaptation	Water crises
Failure of climate-change mitigation and adaptation	Water crises	Natural disasters

Economic Environmental Geopolitical Societal Technological

P.S.: These are issues raised by economists, not scientists or NGOs…

UN 17 sustainable goals to transform our world

Mitigation options and sustainable development using SDGs



Potential positive effects (synergies)

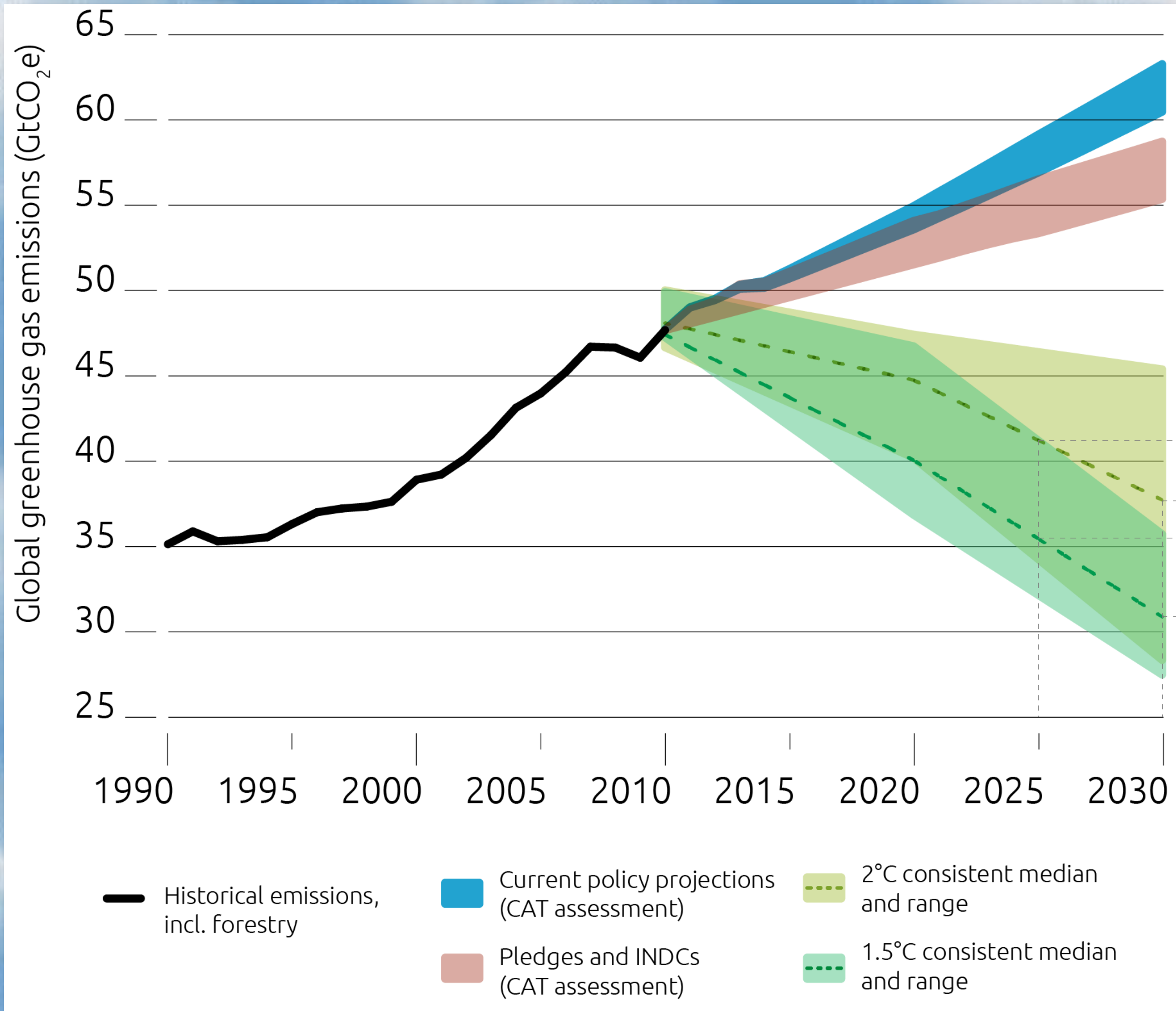
Negative effects (trade-offs)

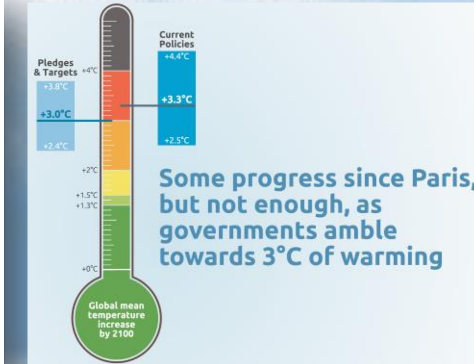
IPCC SR1.5, 2018

Science basically have done his job…

Now it is the time of engineering and policies

Paris Agreement: IF all iNDC fulfilled: warming of about 2.7-3.0 degrees in 2050





http://climateactiontracker.org

Brazilian iNDC

Emissions reductions in 2025	Reduction in 2030
37%	**43%**

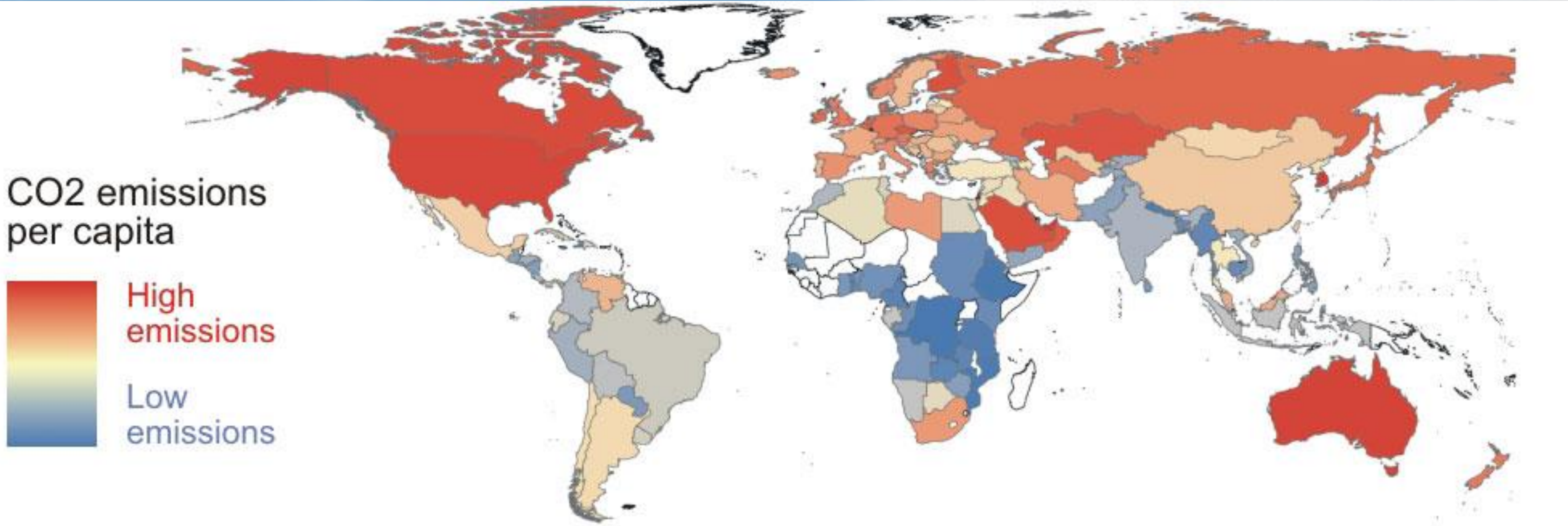
A few of the Brazilian iNDC commitments (*Reference point:* 2005):

- **ZERO illegal deforestation at 2030 and compensation of emissions from legal deforestation at 2030;**
- **Restore and reforest 12 millions hectares of forests till 2030, for multiple uses;**
- **Restoration of 15 millions of hectares in degraded pastures till 2030**
- **Participation of 45% renewable energy in the energy system at 2030**

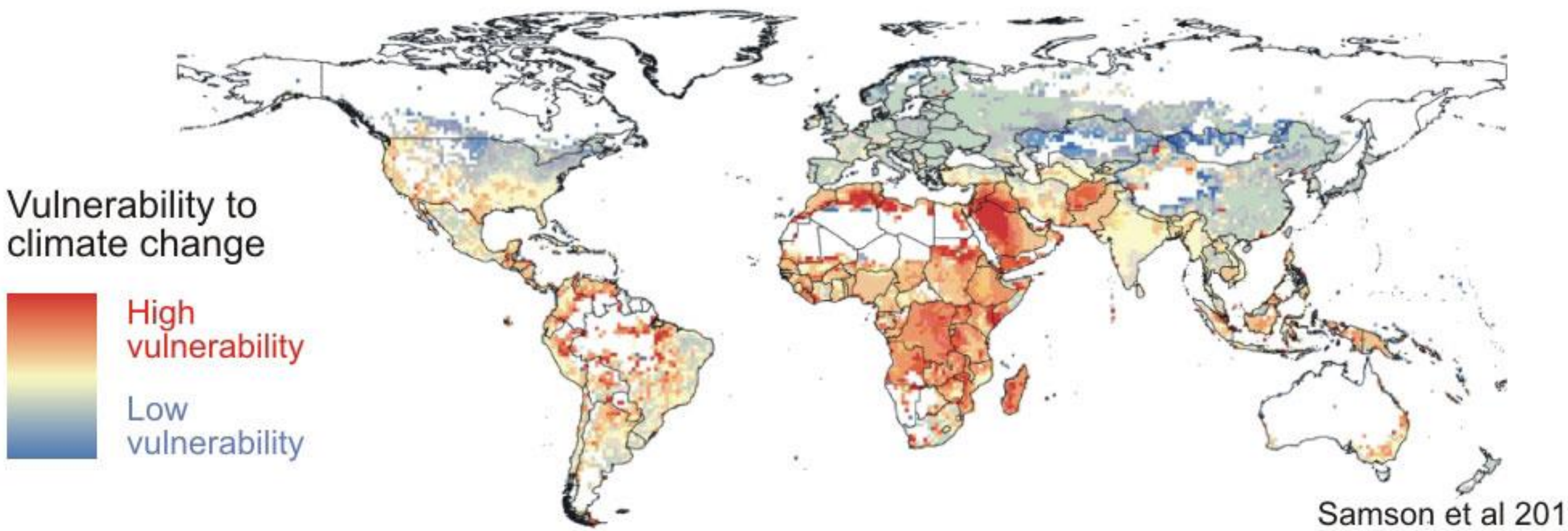
Ethical issues

Encyclical Letter *LAUDATO SI' of Pope Francis (2015)*

I urgently appeal for a new dialogue about how we are shaping the future of our planet. We need a conversation which includes everyone, since the environmental challenge we are undergoing, and its human roots, concern and affect us all.



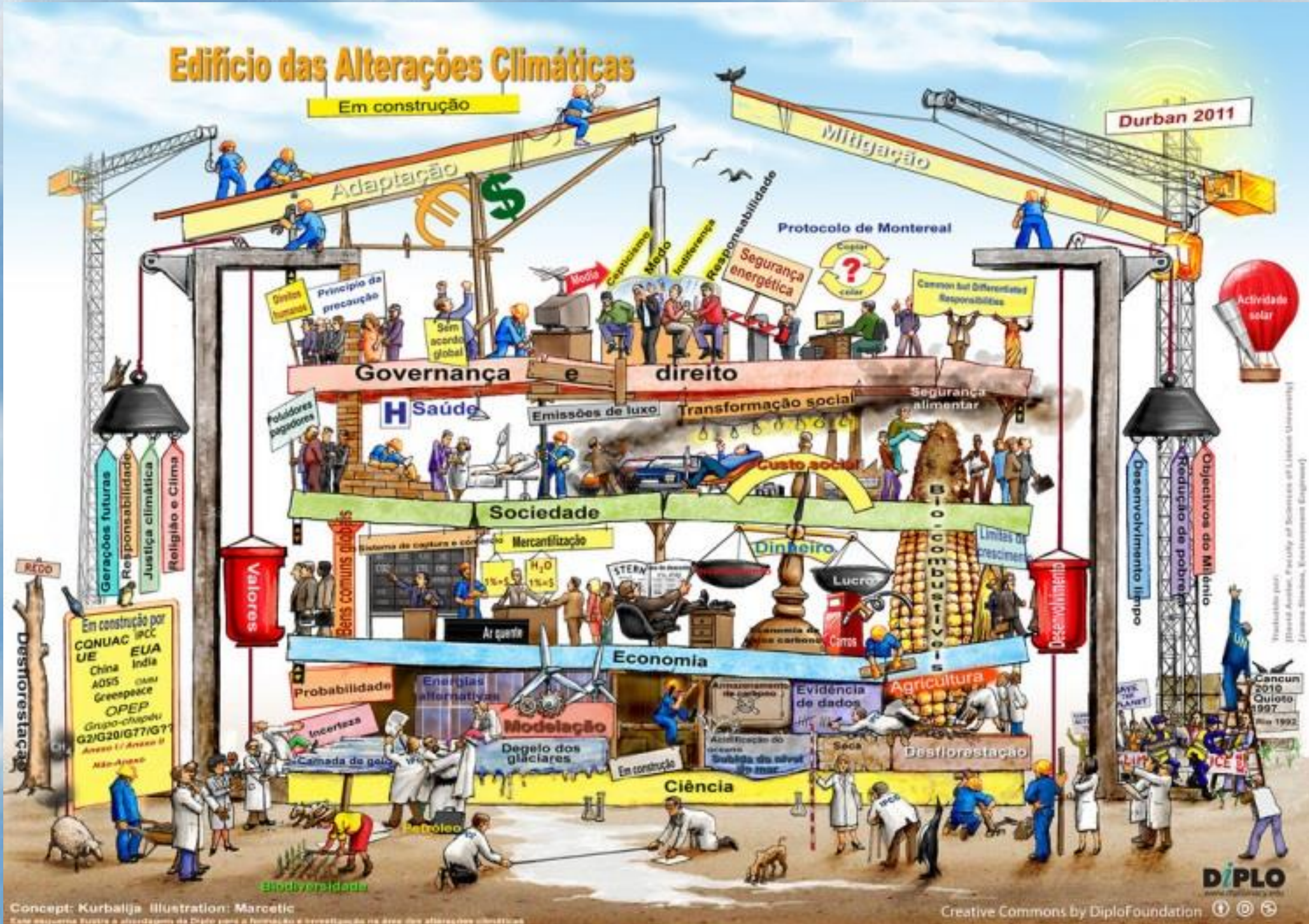
Those who contribute the least greenhouse gases
will be most impacted by climate change



Samson et al 2011

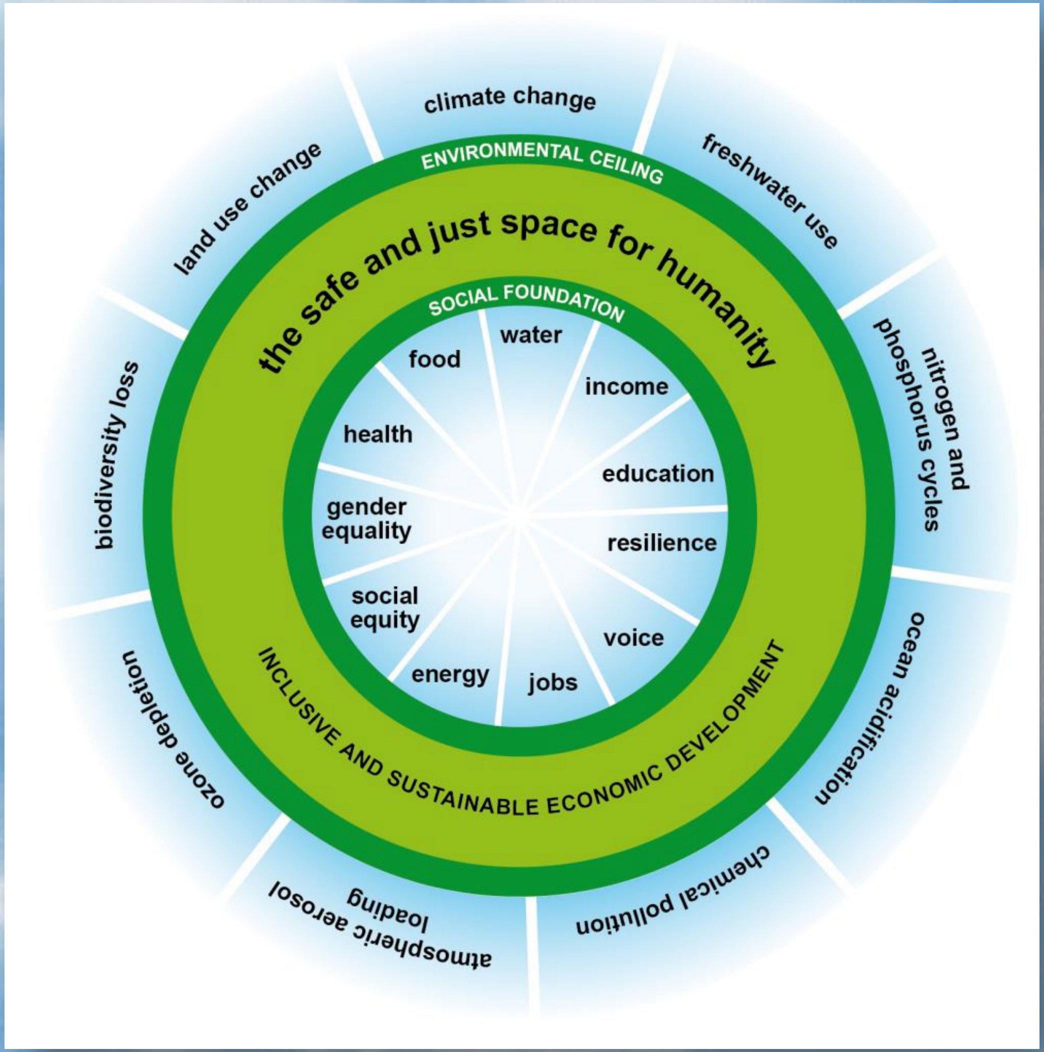
Global inequality is a big issue: consumption in one week...

The role of Science versus economy, society, governance, etc…



How to build a safe space to our humanity?

Combining the Earth System with societal needs



Steffen et al. 2015, Science
A Safe and Just Space for Humanity Oxfam Discussion Paper

We need solid engineering, science and public policies to build this space

SDGs and the six transformations required for The World in 2050

Digital revolution
Artificial intelligence, big data, biotech, nanotech, autonomous systems

Human capacity & demography
Education, health, ageing, labor markets, gender, inequalities

Smart cities
Decent housing, mobility, sustainable infrastructure, pollution

Consumption & production
Resource use, circular economy, sufficiency, pollution

Food, biosphere, & water
Sustainable intensification, biodiversity, forests, oceans, healthy diets, nutrients

Decarbonization & energy
Energy access, efficiency, electrification, decent services

Source: TWI2050

Role of science and engineering: Reaching the SDG must be done together with adaptation and reducing emissions aiming at mitigating climate change

Thanks for the attention!!!