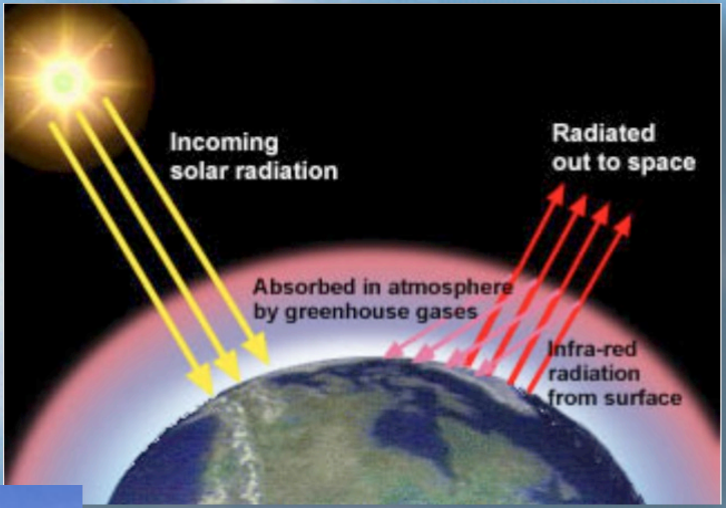
São Paulo School of Advanced Science on Atmospheric Aerosols: properties, measurements, modeling, and effects on climate and health
São Paulo, 22 July 2019

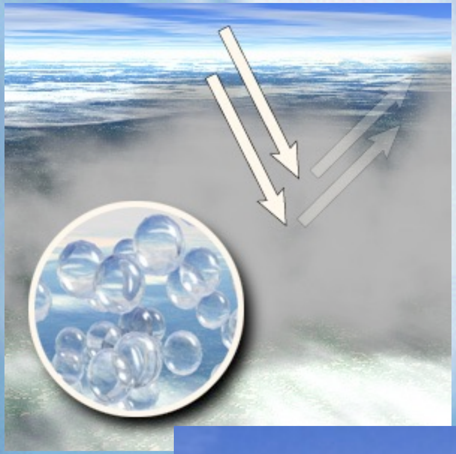
Impacts of atmospheric aerosols on climate and ecosystems

Paulo Artaxo
Laboratório de Física Atmosférica
Instituto de Física
Universidade de São Paulo - USP

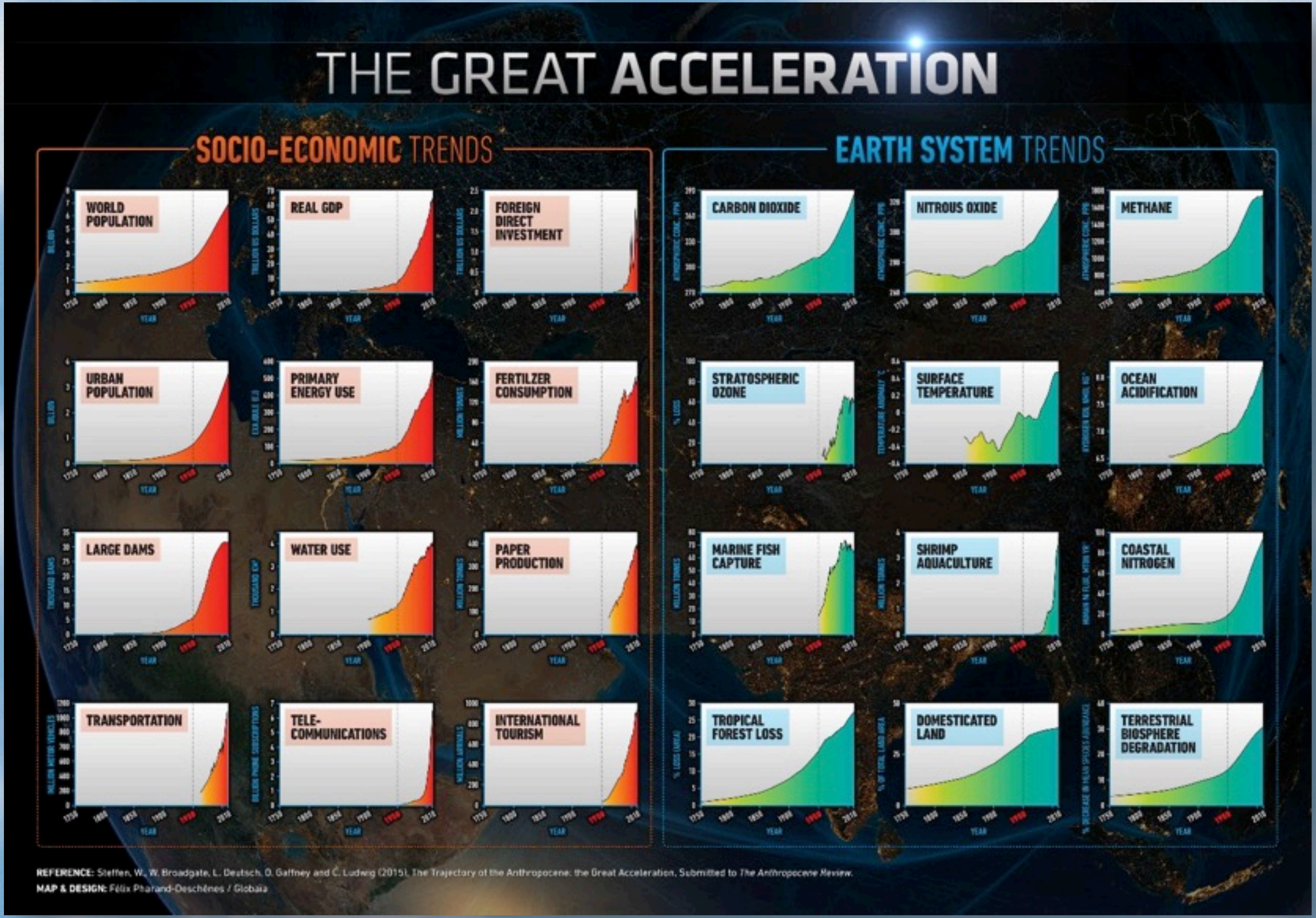
Why we are here?

Aerosol particles are critically important for:
Climate Change
Urban air pollution
Health effects
Ecosystem functioning
Cloud formation and development
Lot´s of other issues!!!





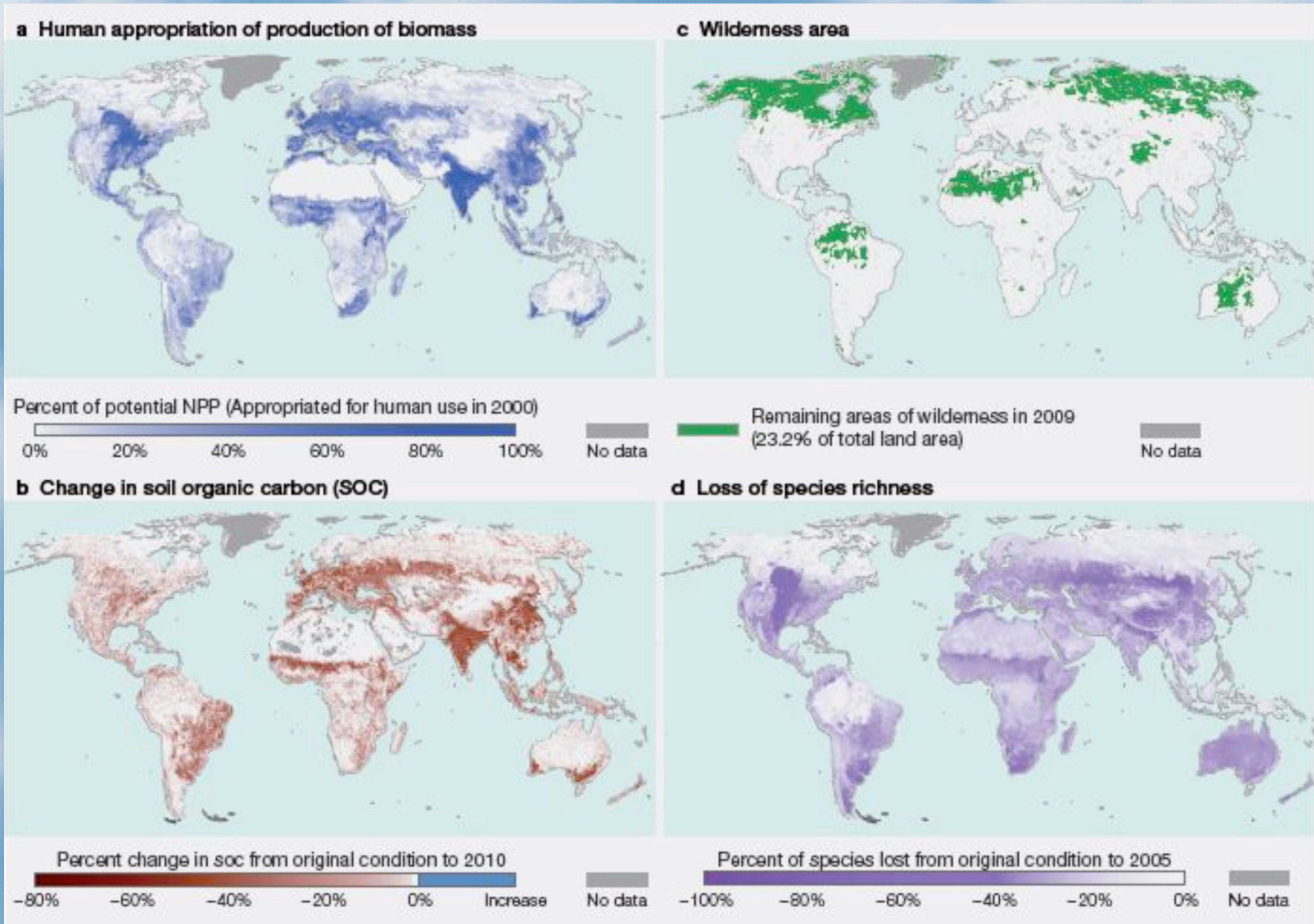
We are changing the face of our world very quickly and in many ways



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

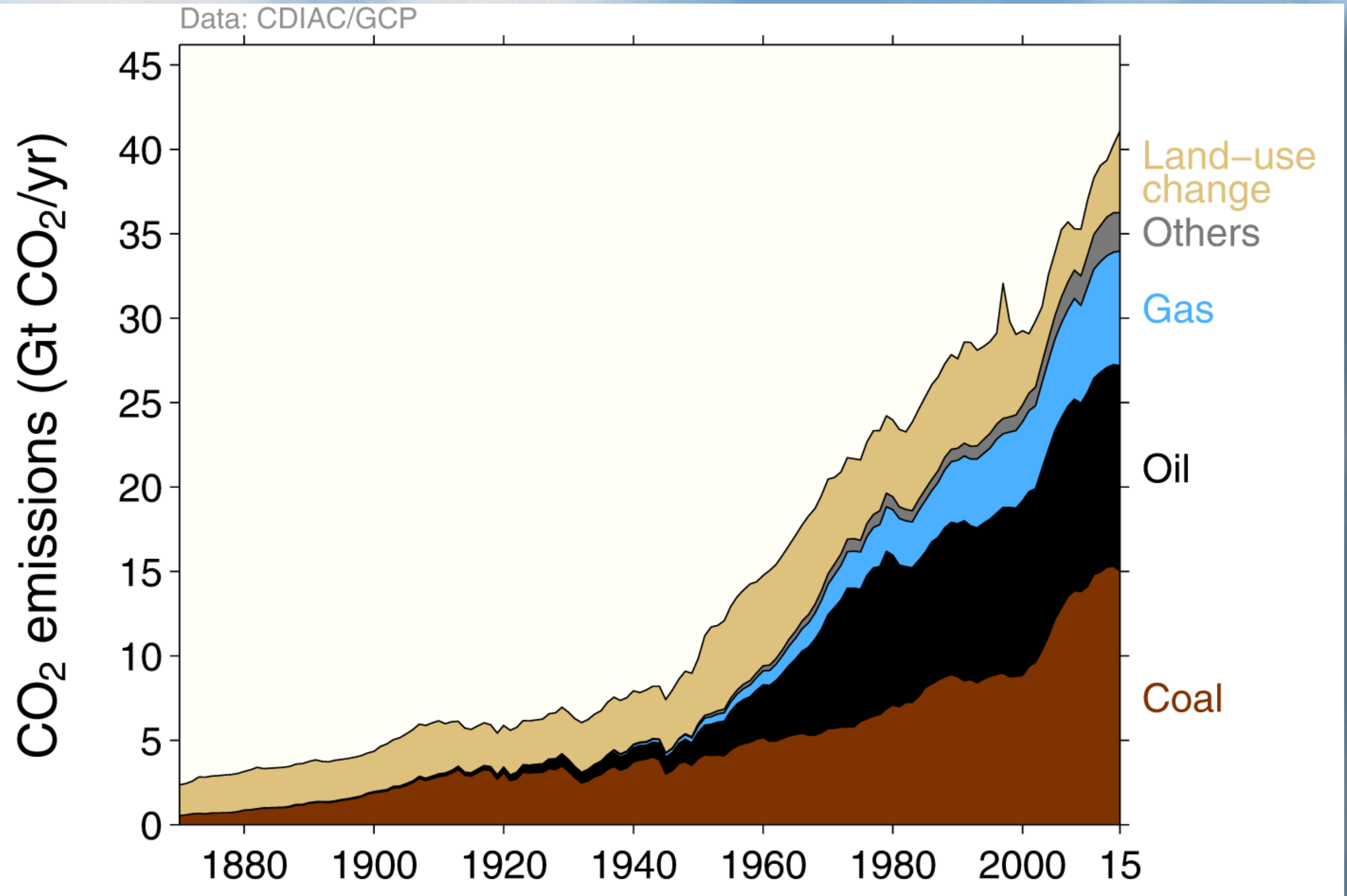
Will Stefan, 2015

Impact of human activity on our planet



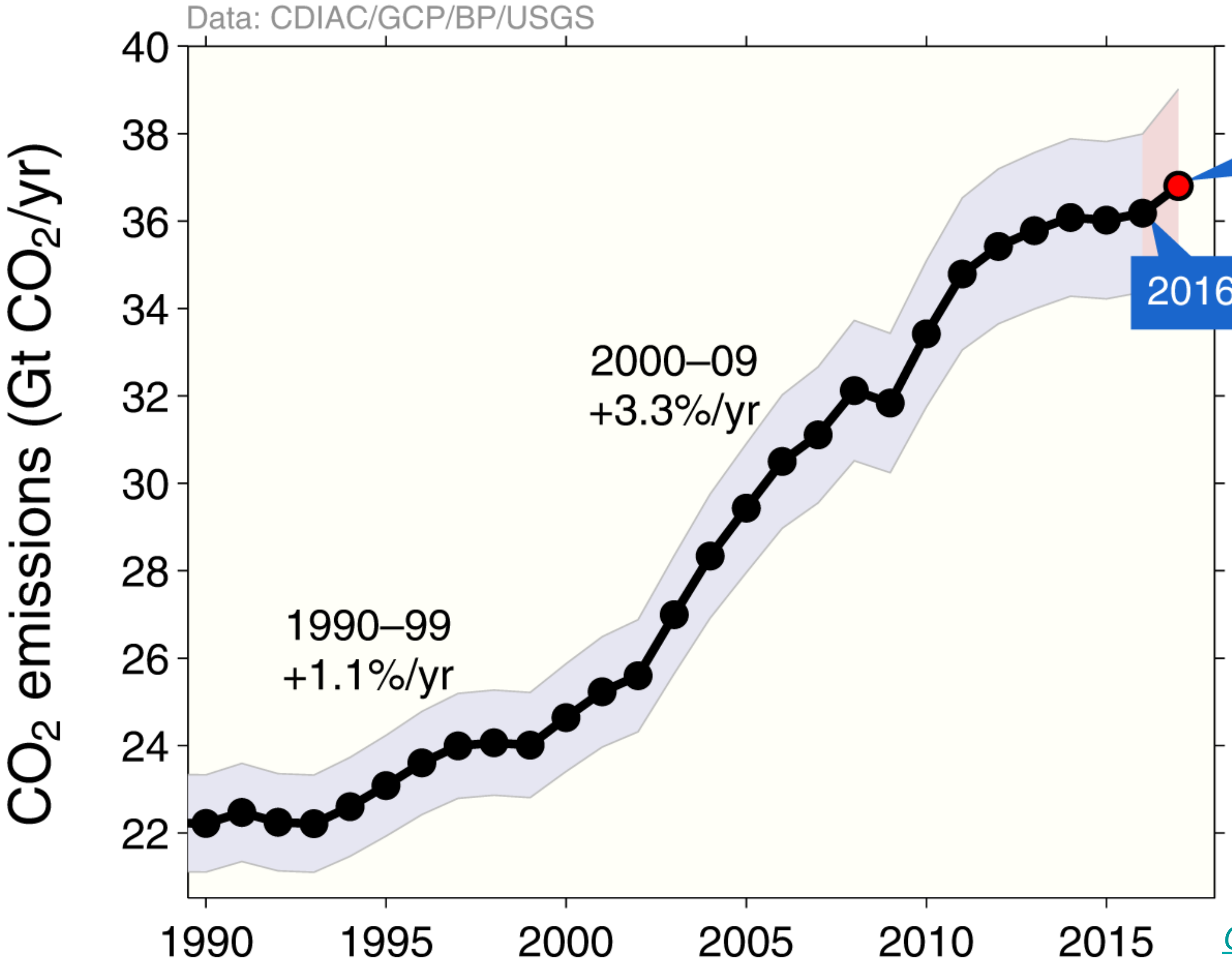
IPBES, 2018

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



Source: Global Carbon Project 201

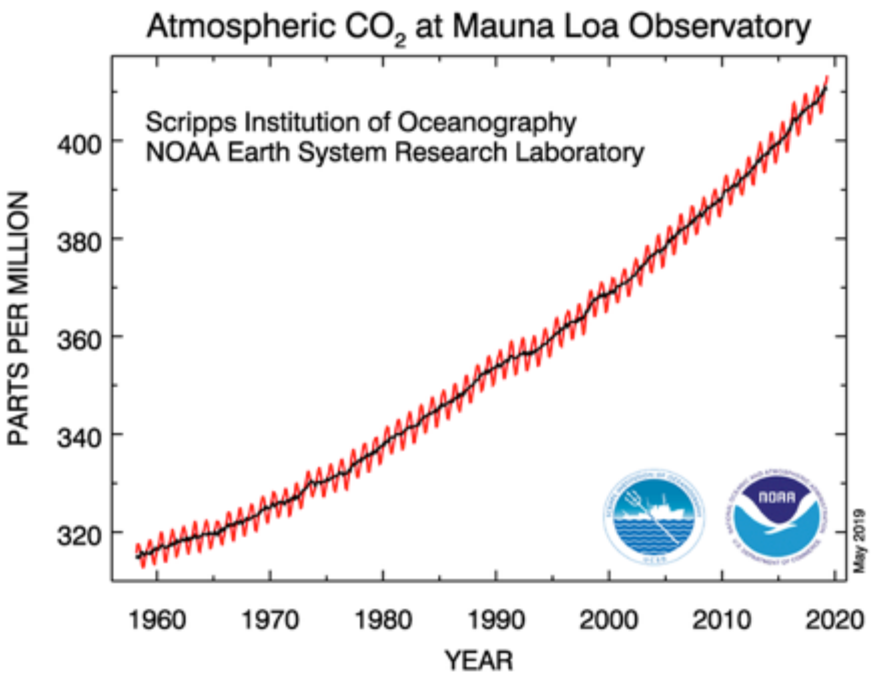
Global emissions from fossil fuel and industry: 36.8 $GtCO_2$ in 2017, 62% over 1990

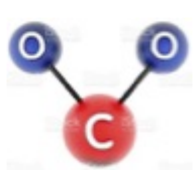


Global Carbon Budget 2017

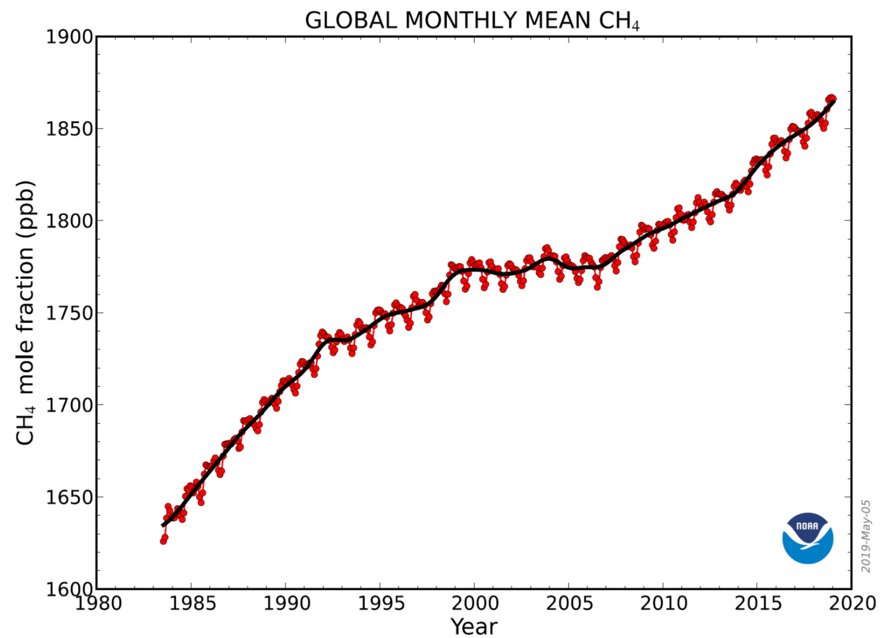
Increase in the concentration of carbon dioxide (CO_2) and methane (CH_4)

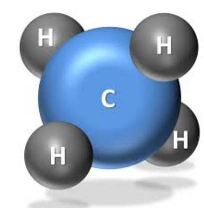
CO2: Increase of 44% since 1850



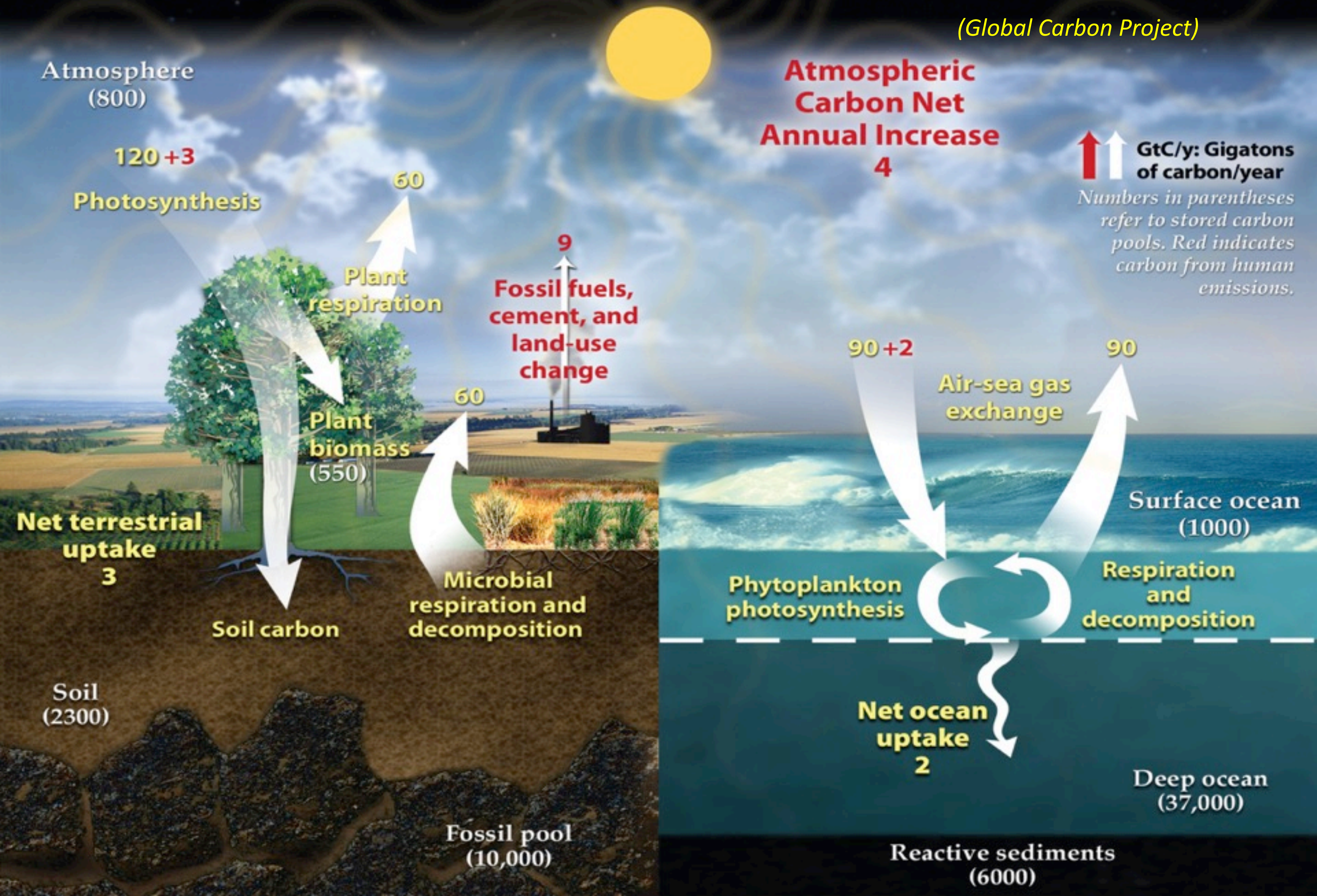


CH4: Increase of 175% since 1850

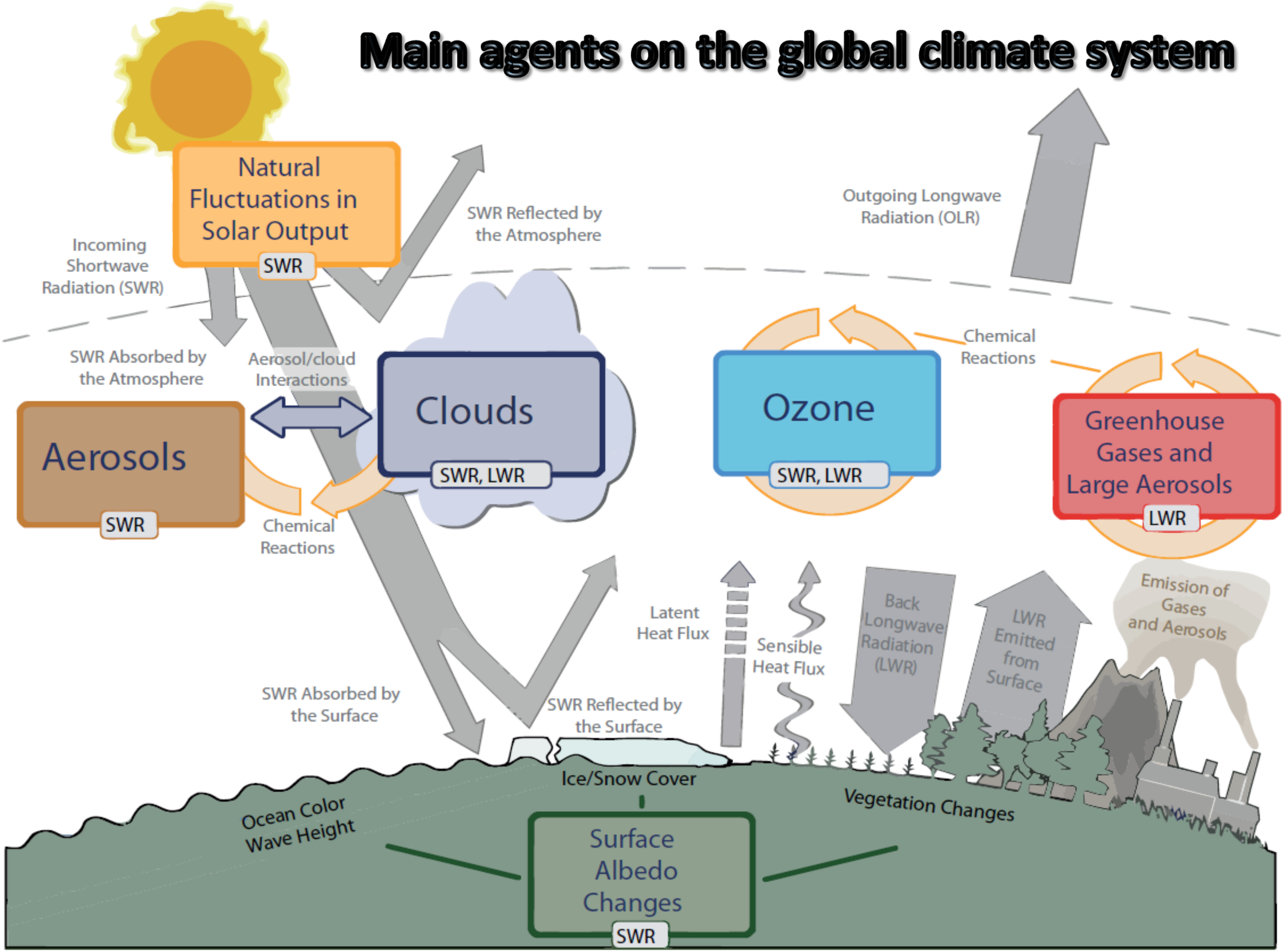




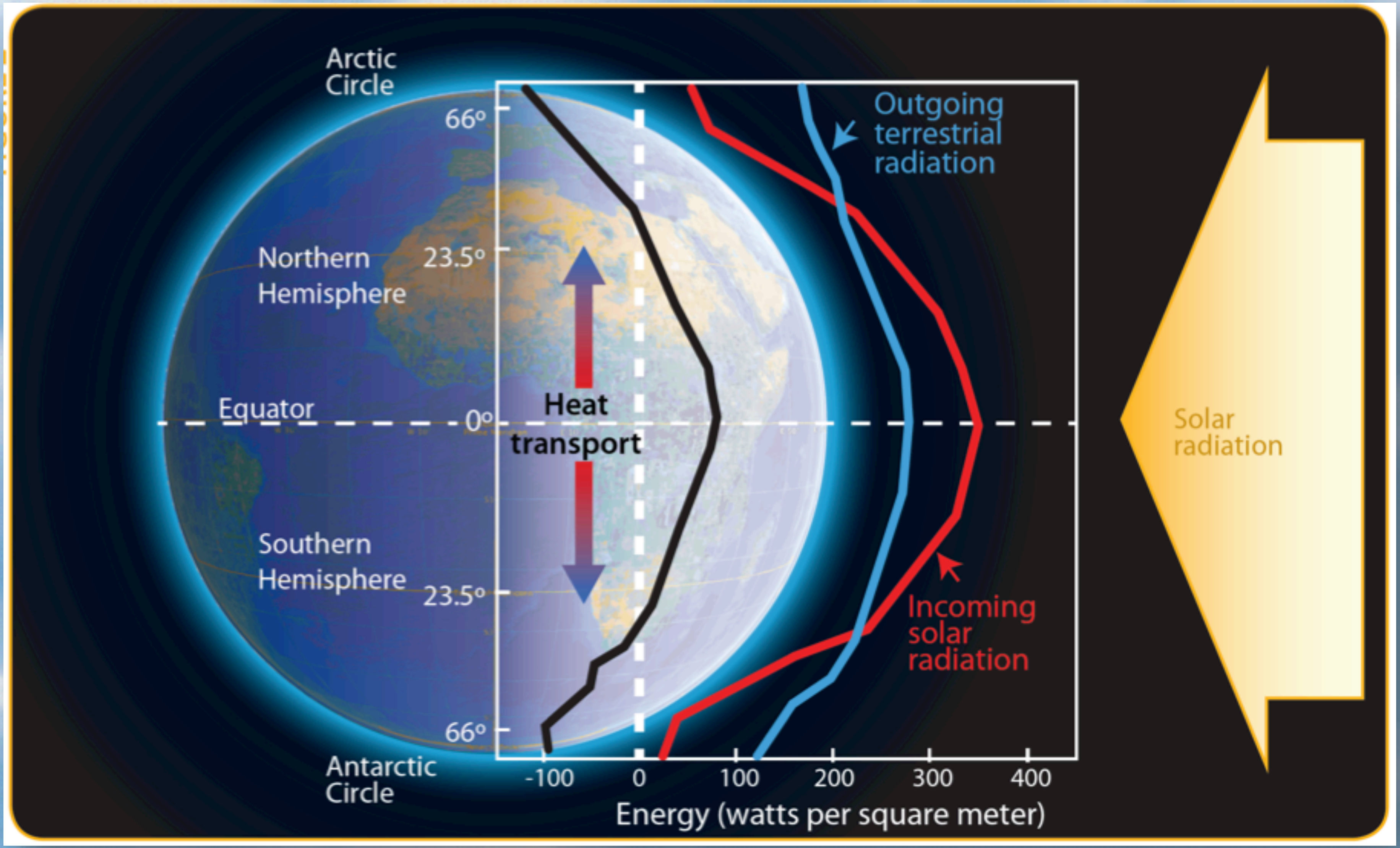
Human perturbations on the global carbon cycle



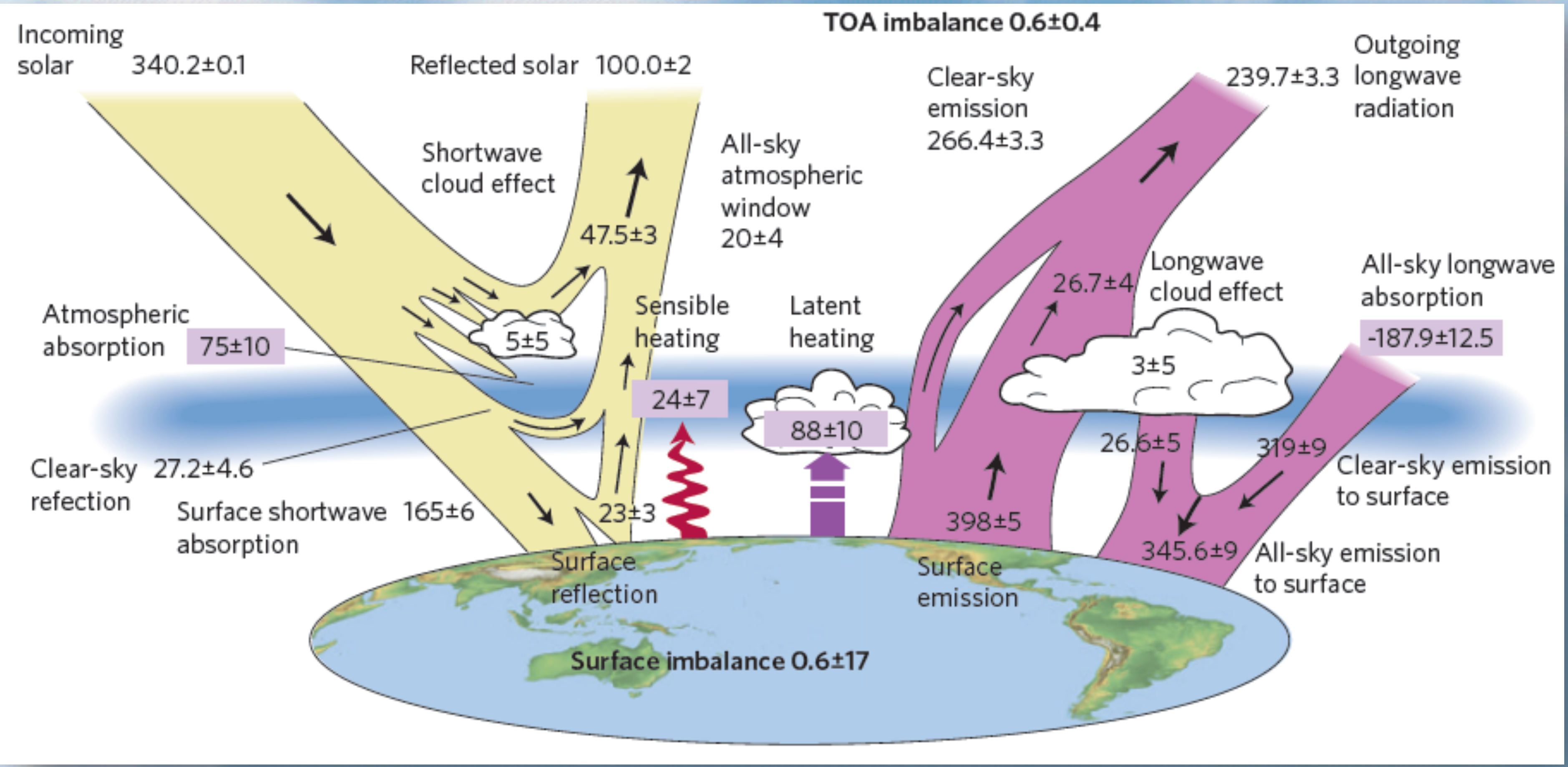
Main agents on the global climate system



Solar Radiation Balance

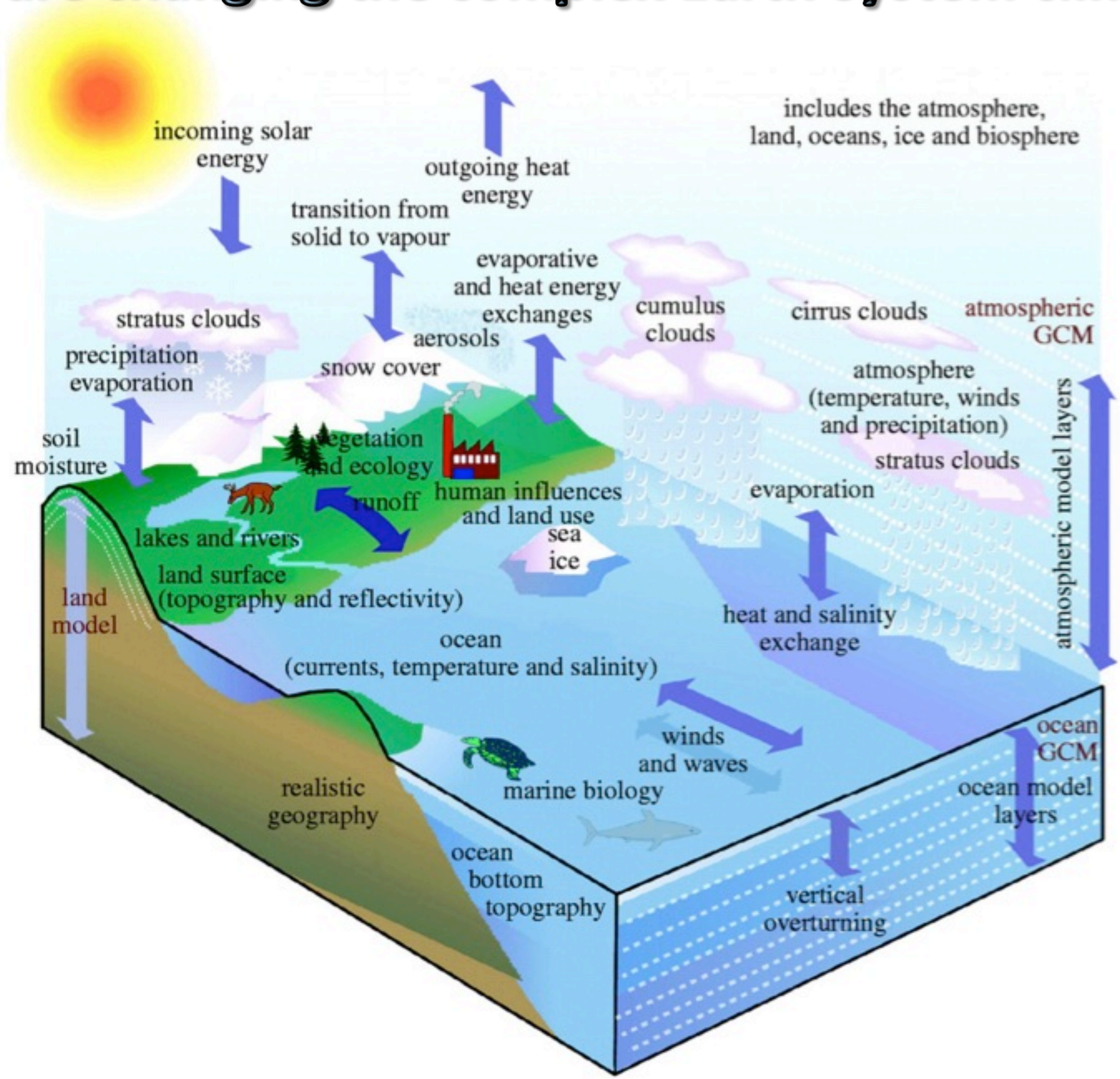


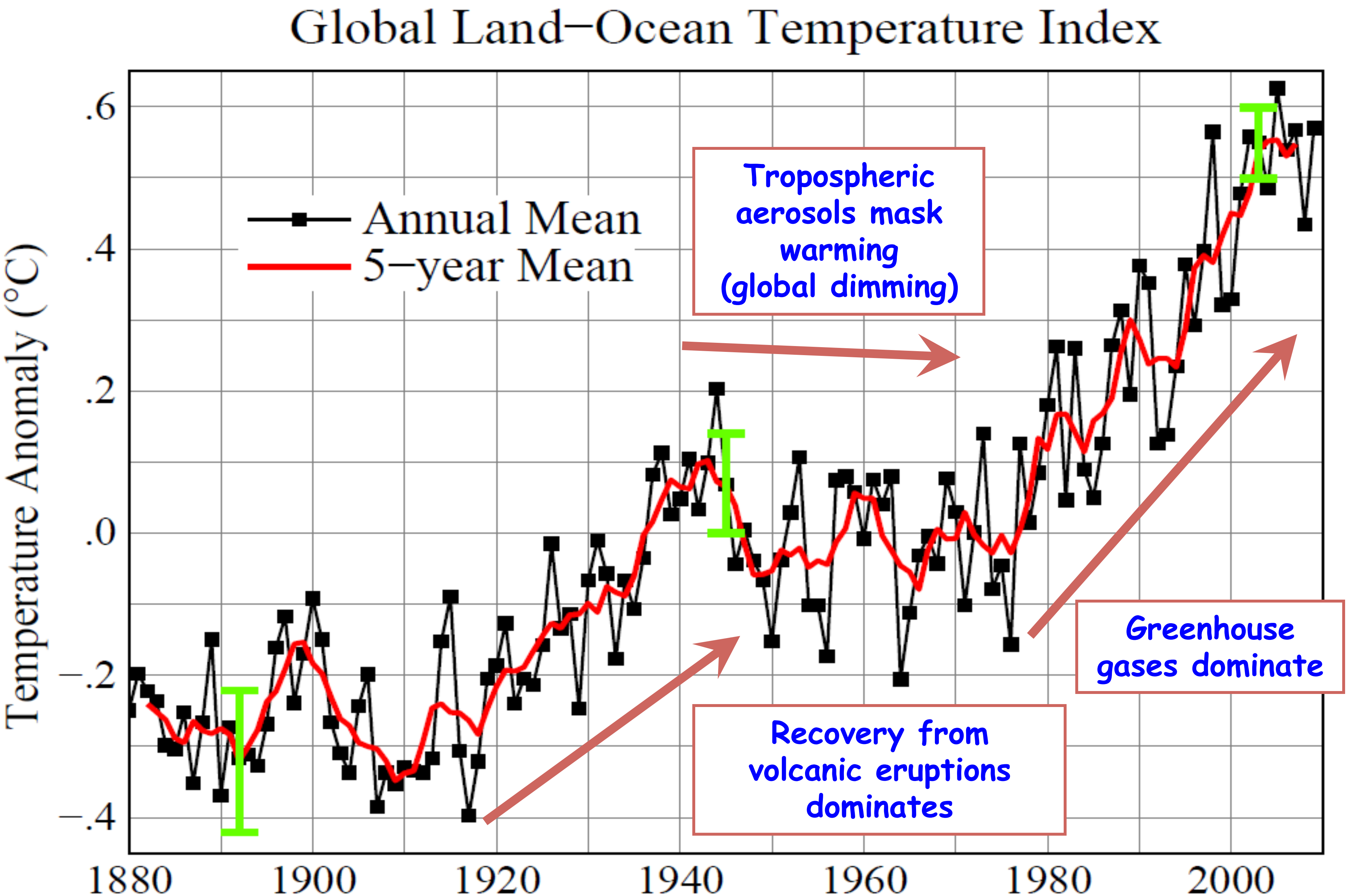
Earth Energy budget (W/m²)



Aerosols influence the incoming visible radiation and also the outgoing flux via cloud interactions

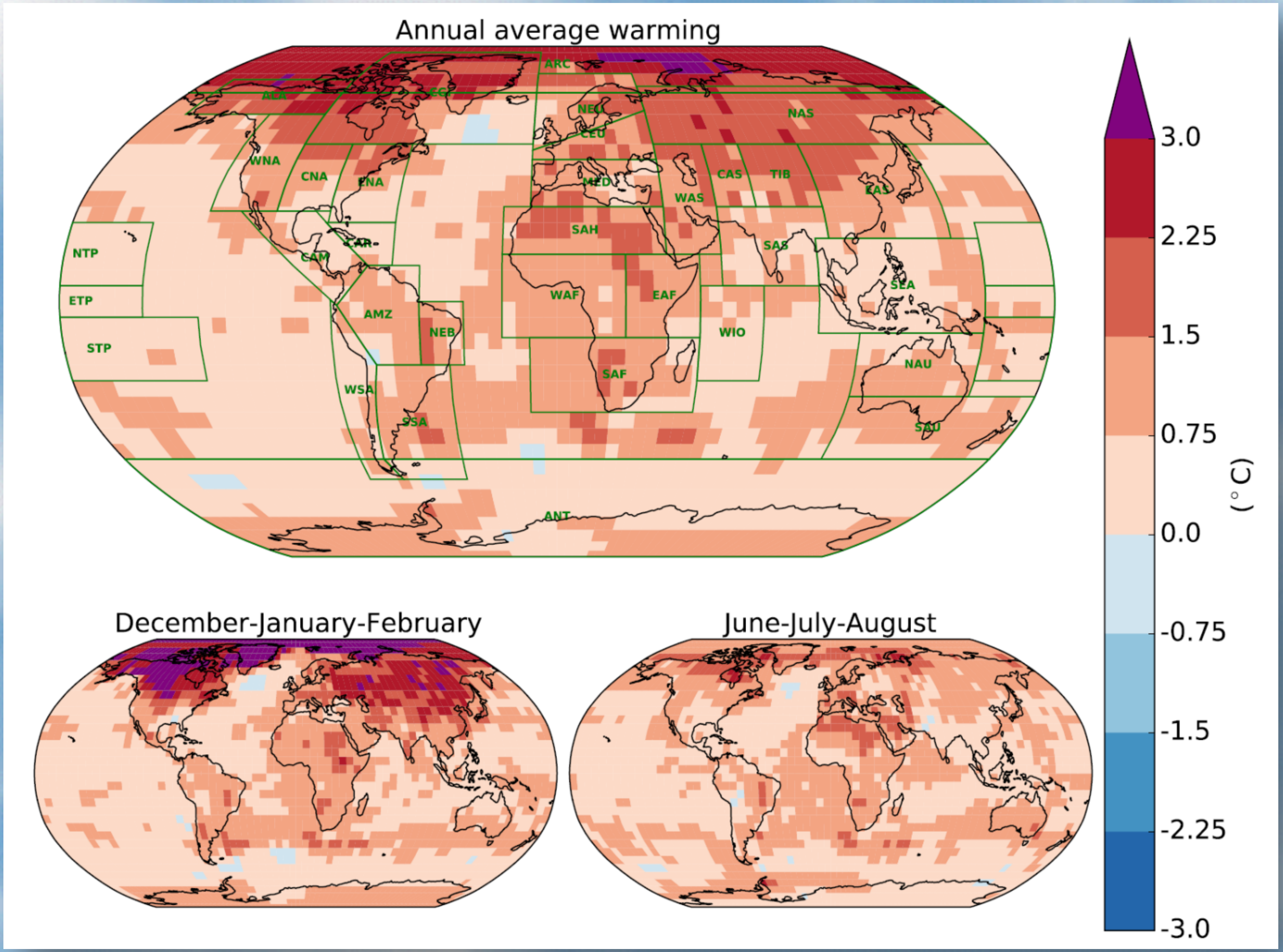
We are changing the complex Earth System climate





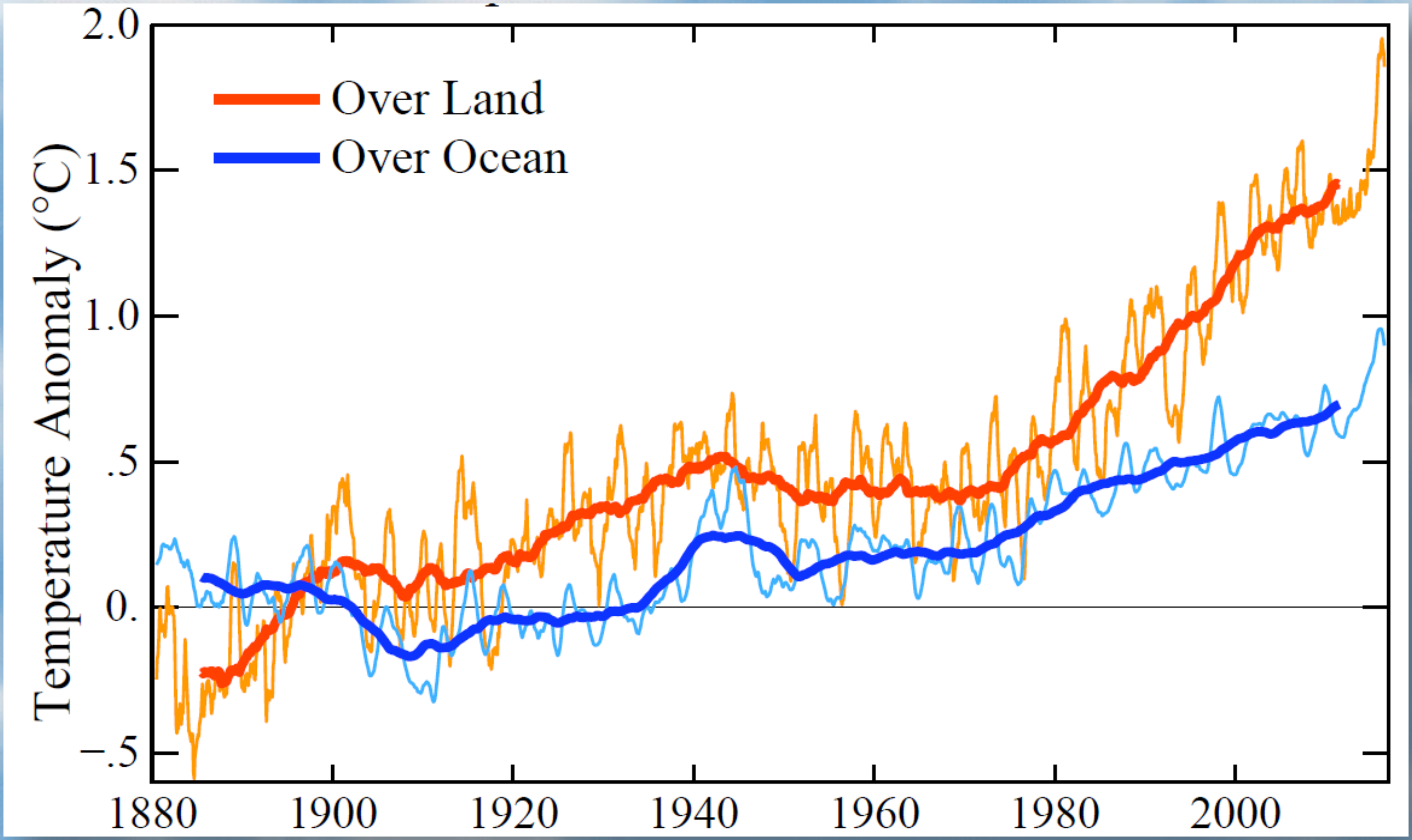
Aerosols (and greenhouse gases) dominate the temperature change

Observed increase in Temperature 1901 to 2012
Spatial distribution not homogeneous



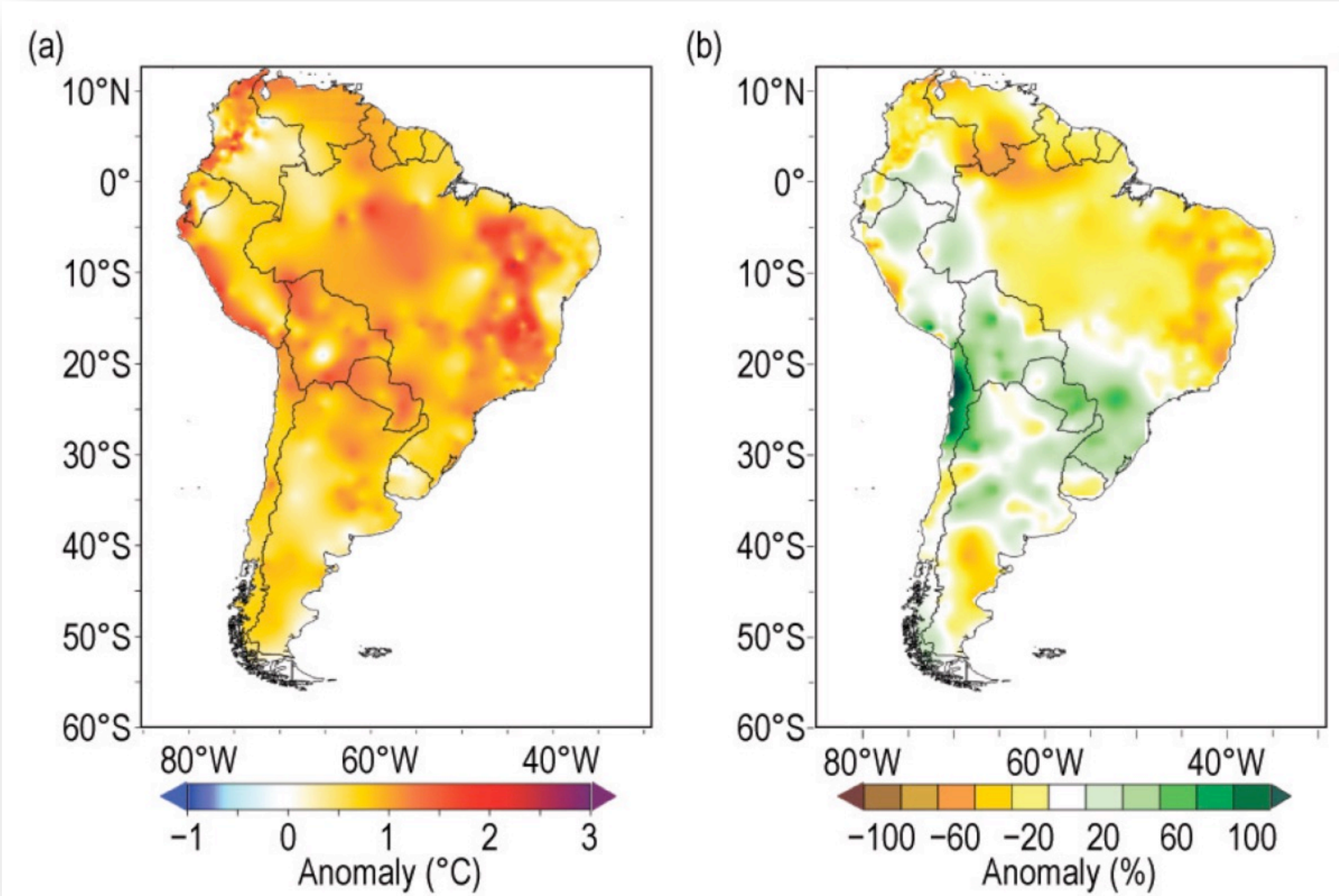
Source: IPCC 2018 Special Report on Global Warming of 1.5°C

Increase in temperature in continental areas: about 1.5 degrees
Surface temperatures relative to 1880-1920 mean



Jim Hansen NASA GISS, 2017

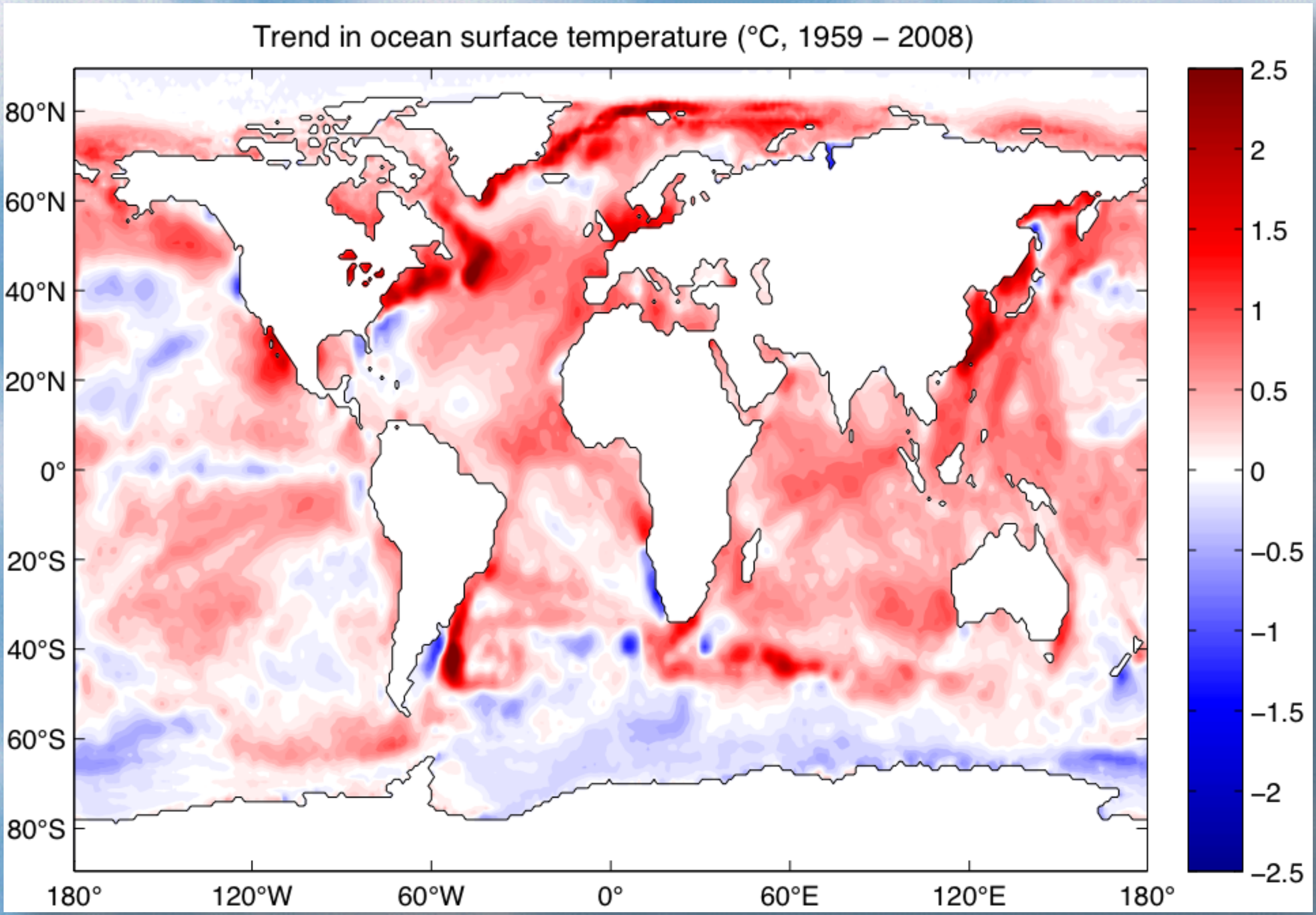
South American (a) temperature anomalies (°C) and (b) precipitation anomalies



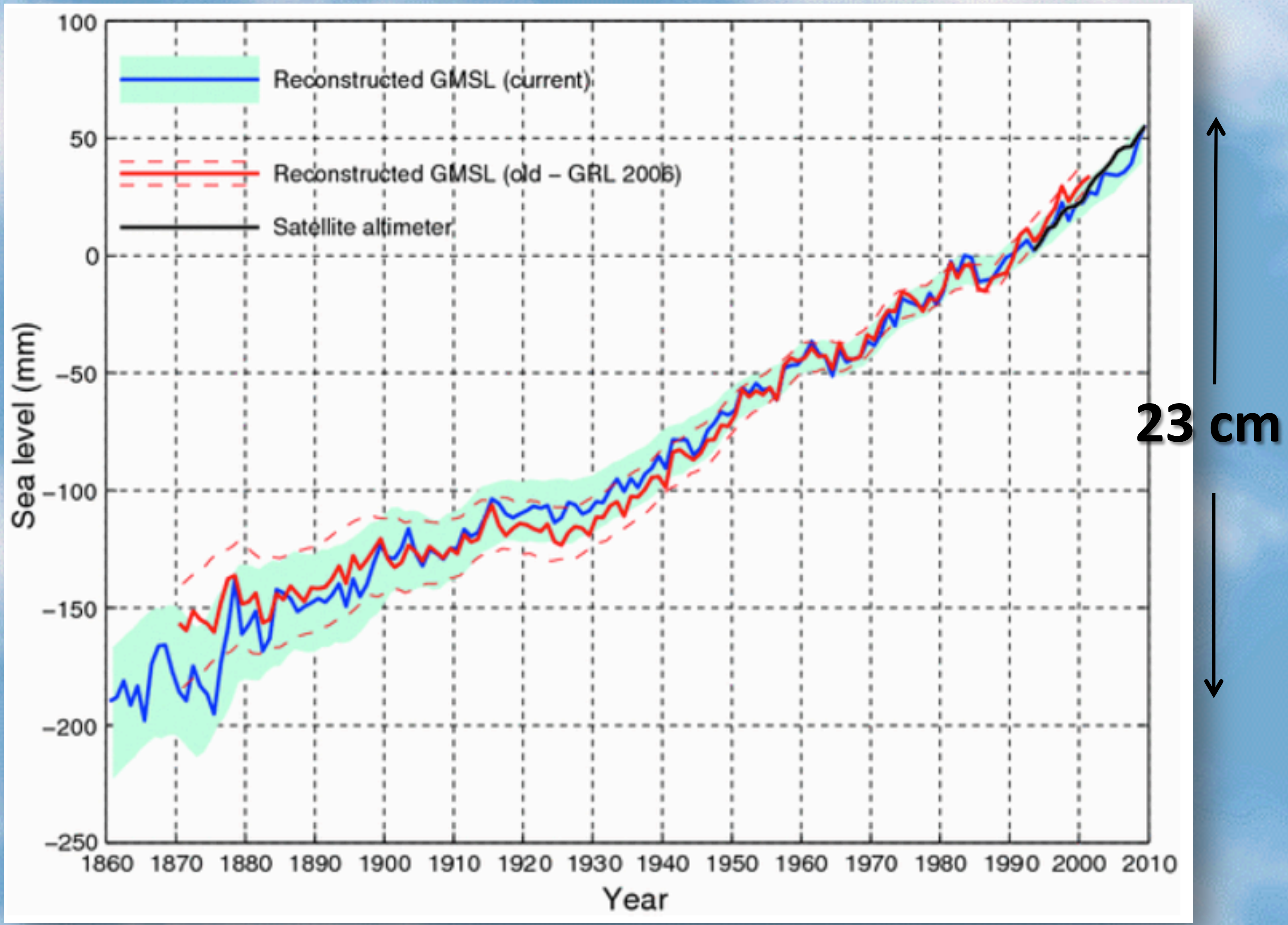
base period: 1981–2010.

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

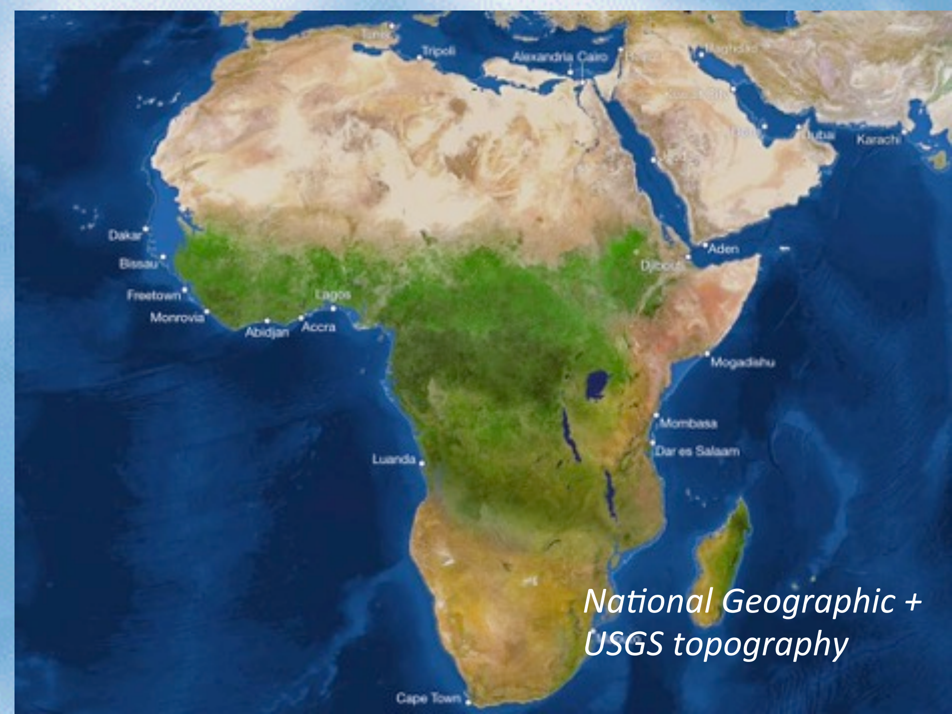


Source: Church and White (2011).

South America in the future?

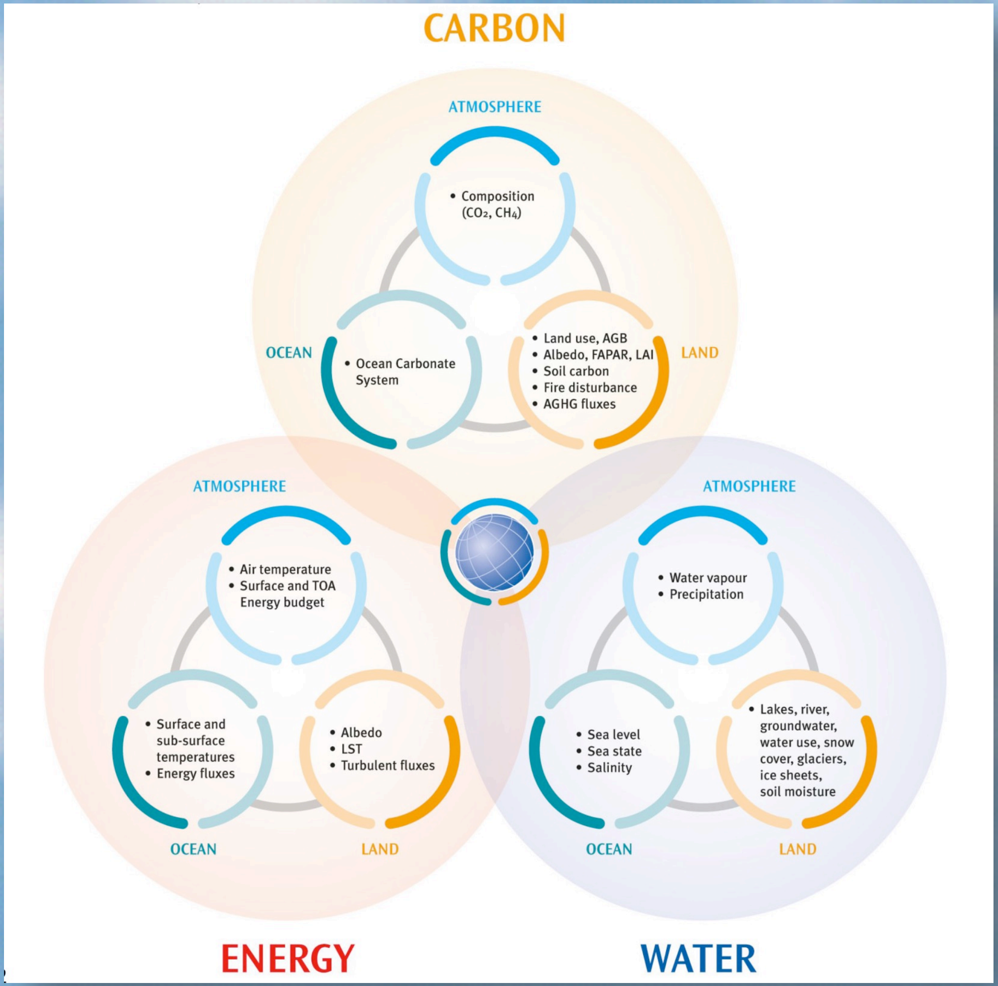
National Geographic + USGS topography

Reshaping the continents



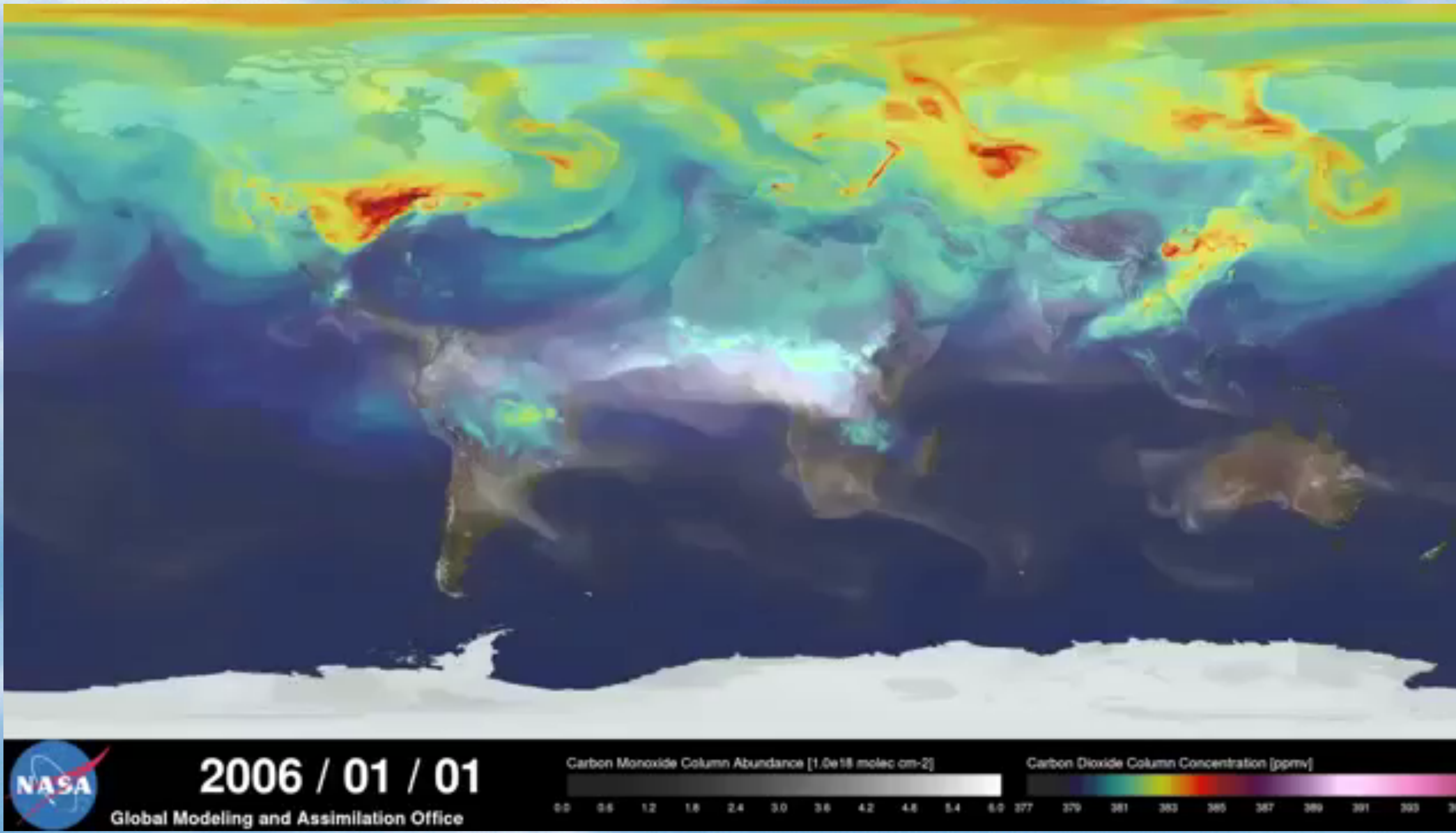
National Geographic + USGS topography

Carbon, energy and water cycles closely coupled in the compartments: Atmosphere, ocean and land



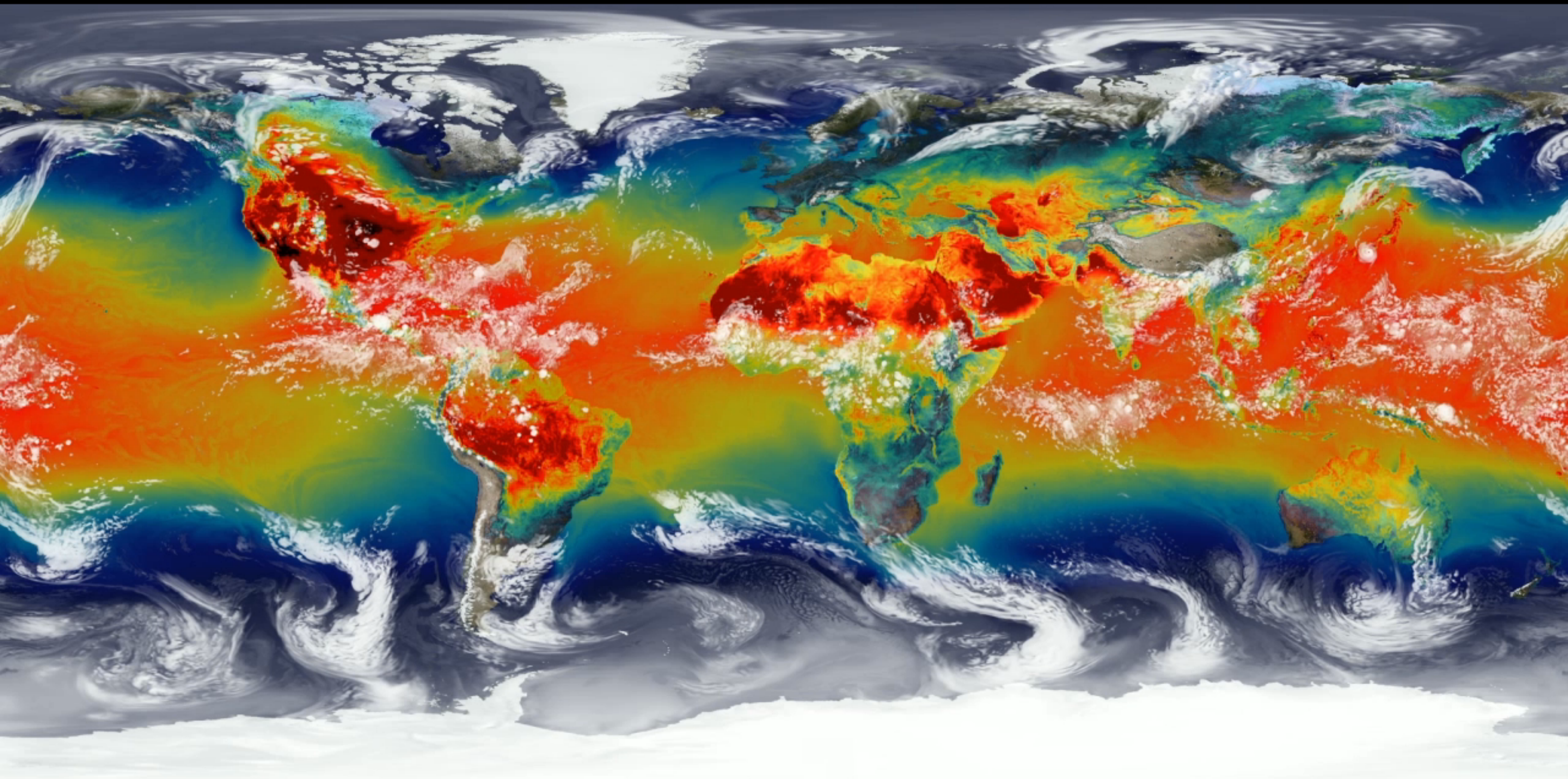
It is essential to look at aerosols integrated with all cycles and compartments

Global distribution of CO_2



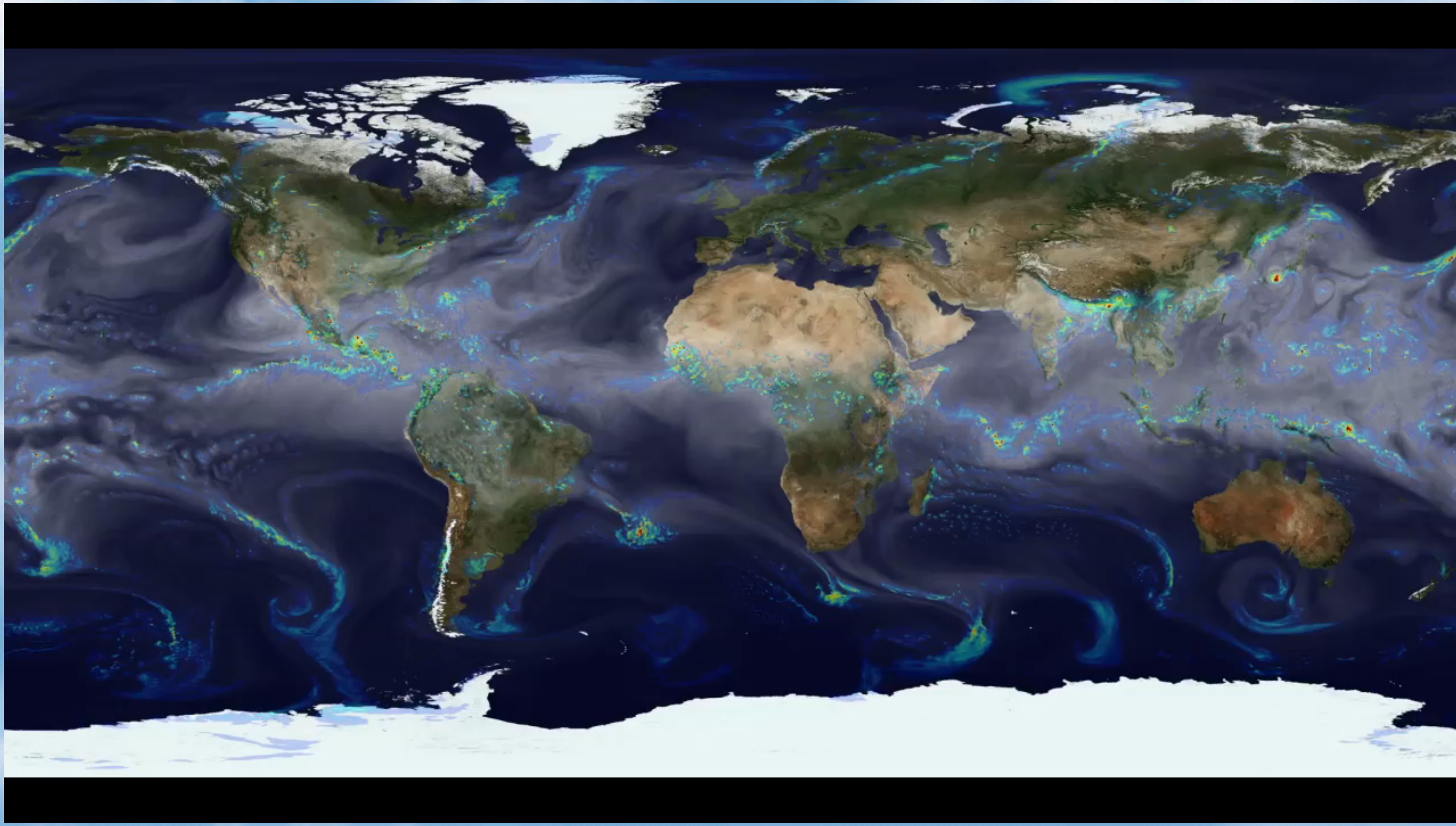
http://svs.gsfc.nasa.gov/goto?11719

Around the World with Energy



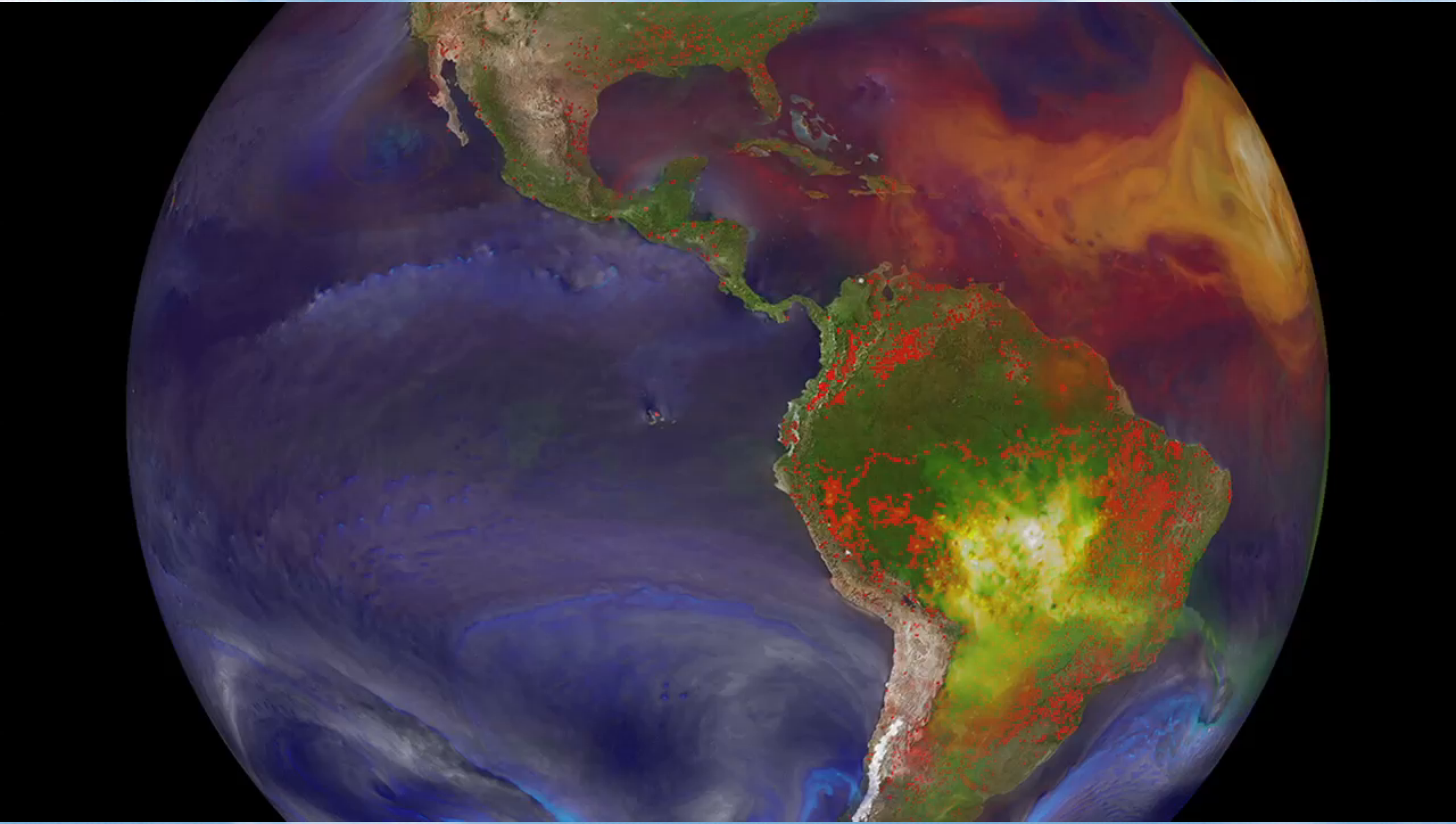
Around the World with Energy
Surface temperature (colors 270-310 Kelvin) and outgoing longwave radiation at the top of the atmosphere (white) representative of clouds in the model.
GEOS-5 simulation of surface temperatures between May 2005 and May 2007. Colors show surface temperatures ranging from 270 to 310 Kelvin. Outgoing longwave radiation at the top of the atmosphere represents clouds (white) in the model. Model: GEOS-5

Moisture and precipitation in the atmosphere

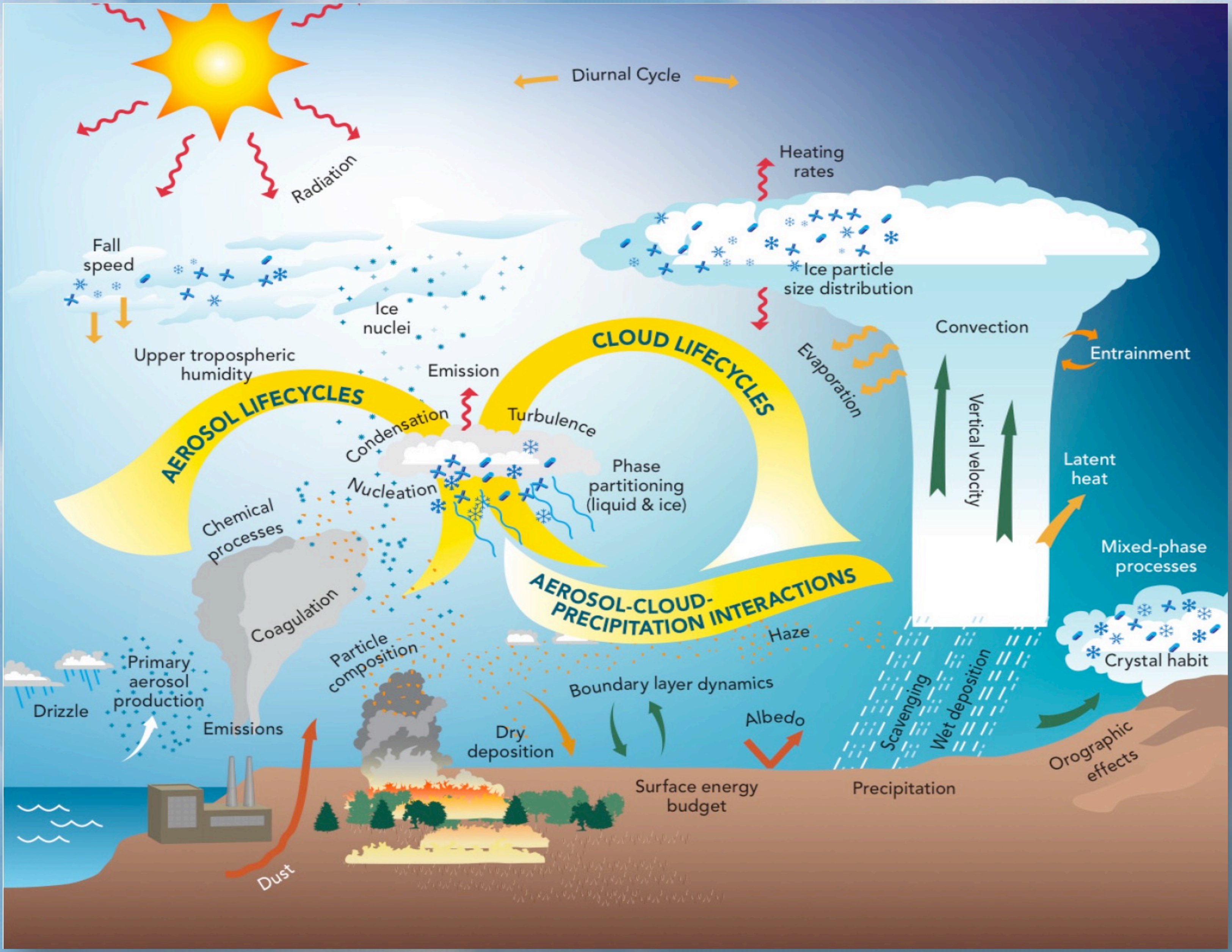


To study the effects of precipitation and how it influences other phenomena, scientists study moisture and precipitation in the atmosphere. Satellite observations cover broad areas and provide more frequent measurements that offer insights into when, where, and how much it rains or snows worldwide. Researchers from NASA's Global Modeling and Assimilation Office ran a 10-kilometer global mesoscale simulation to study the presence of water vapor and precipitation within global weather patterns. In this simulation, from May 2005 to May 2007, colors represent rainfall rates ranging from 0 to 15 millimeters per hour. Total precipitable water, or precipitable water vapor, is depicted in white shades. Such simulations allow scientists to better understand global moisture and precipitation patterns.

Aerosol particles in the atmosphere

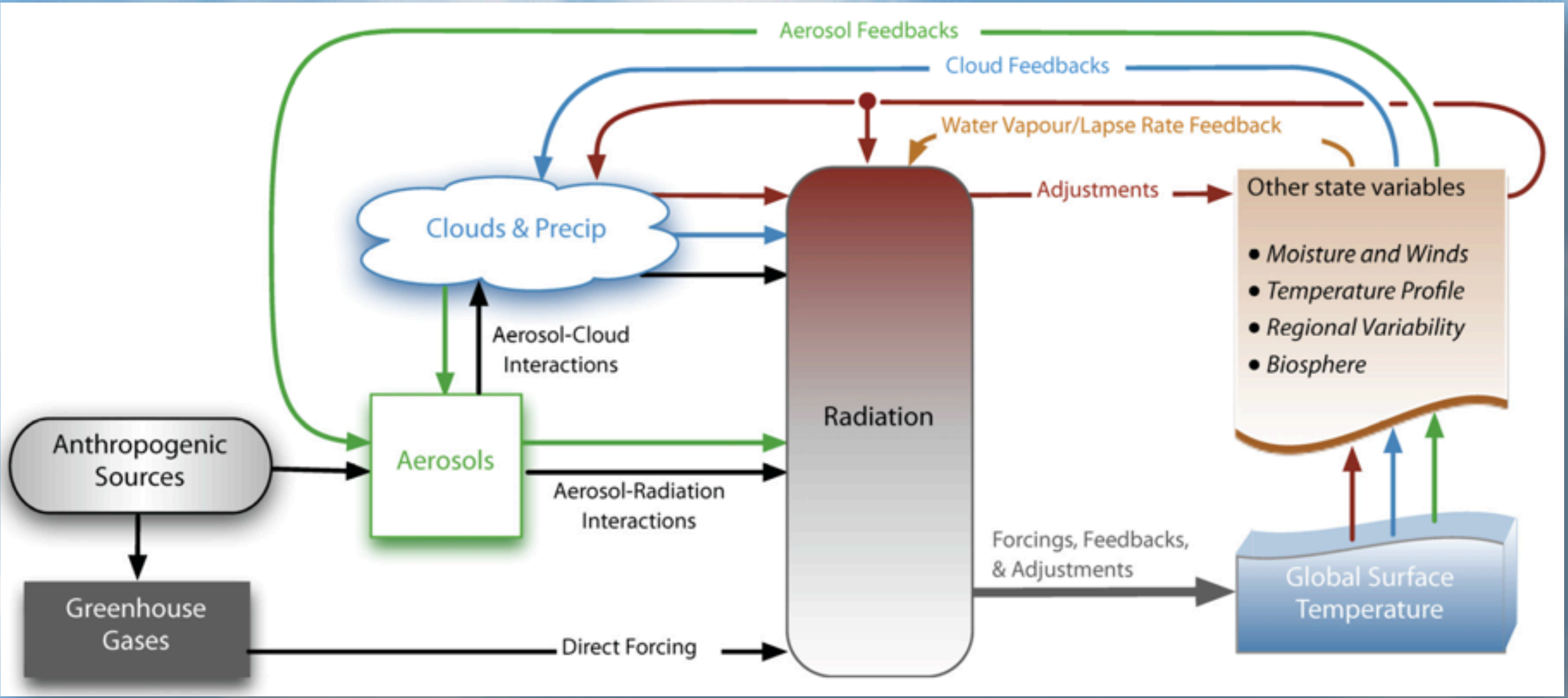


Global aerosol and cloud life cycles

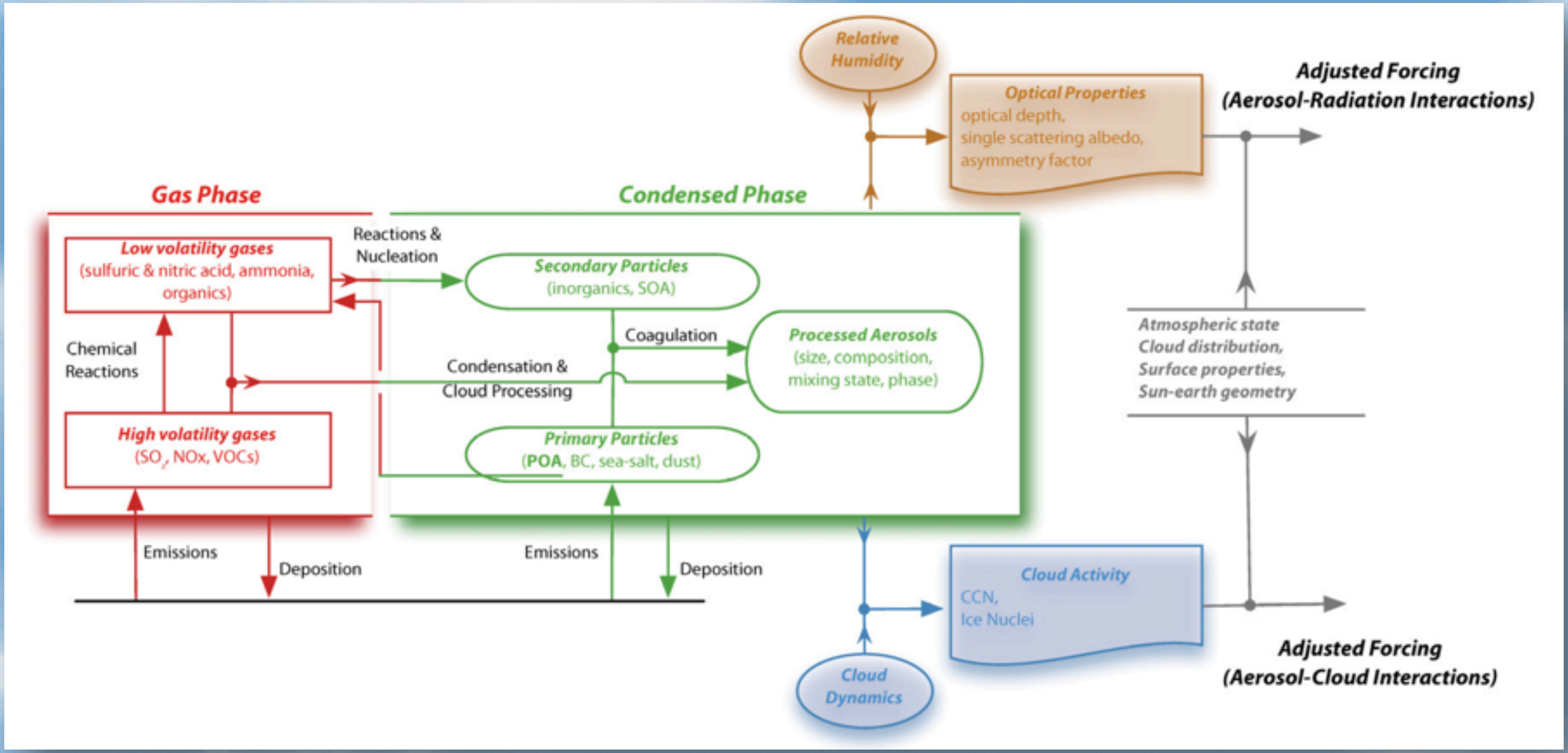


Feedbacks and forcing pathways involving clouds and aerosols

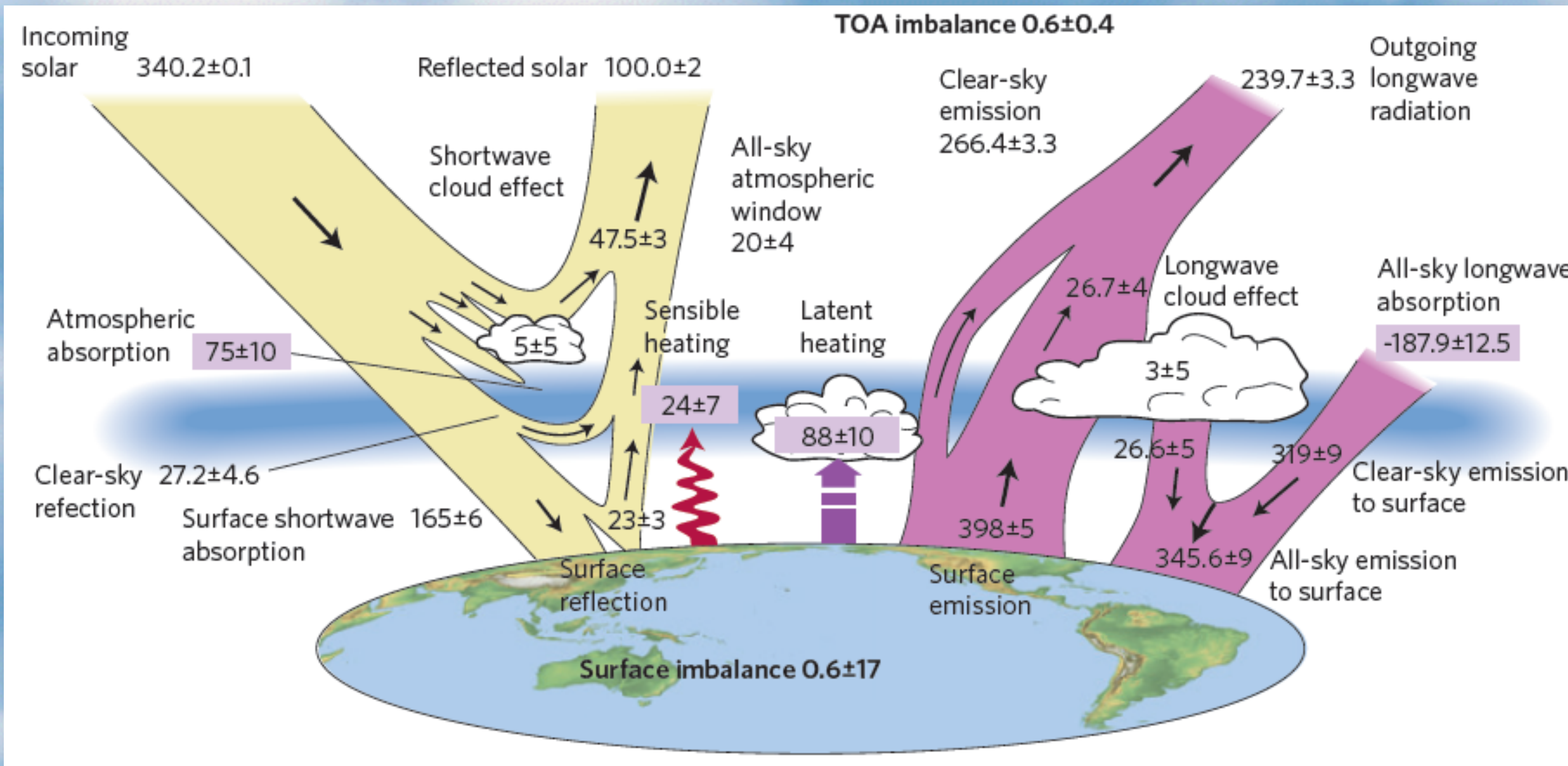
Forcing mechanisms are represented by black arrows; forcing agents are boxes with grey shadows, rapid forcing adjustments (also called rapid responses) are shown with brown arrows and feedbacks are other-coloured arrows.



Trace gases, aerosols, clouds and radiation: An integrated coupled system impossible to deal individually

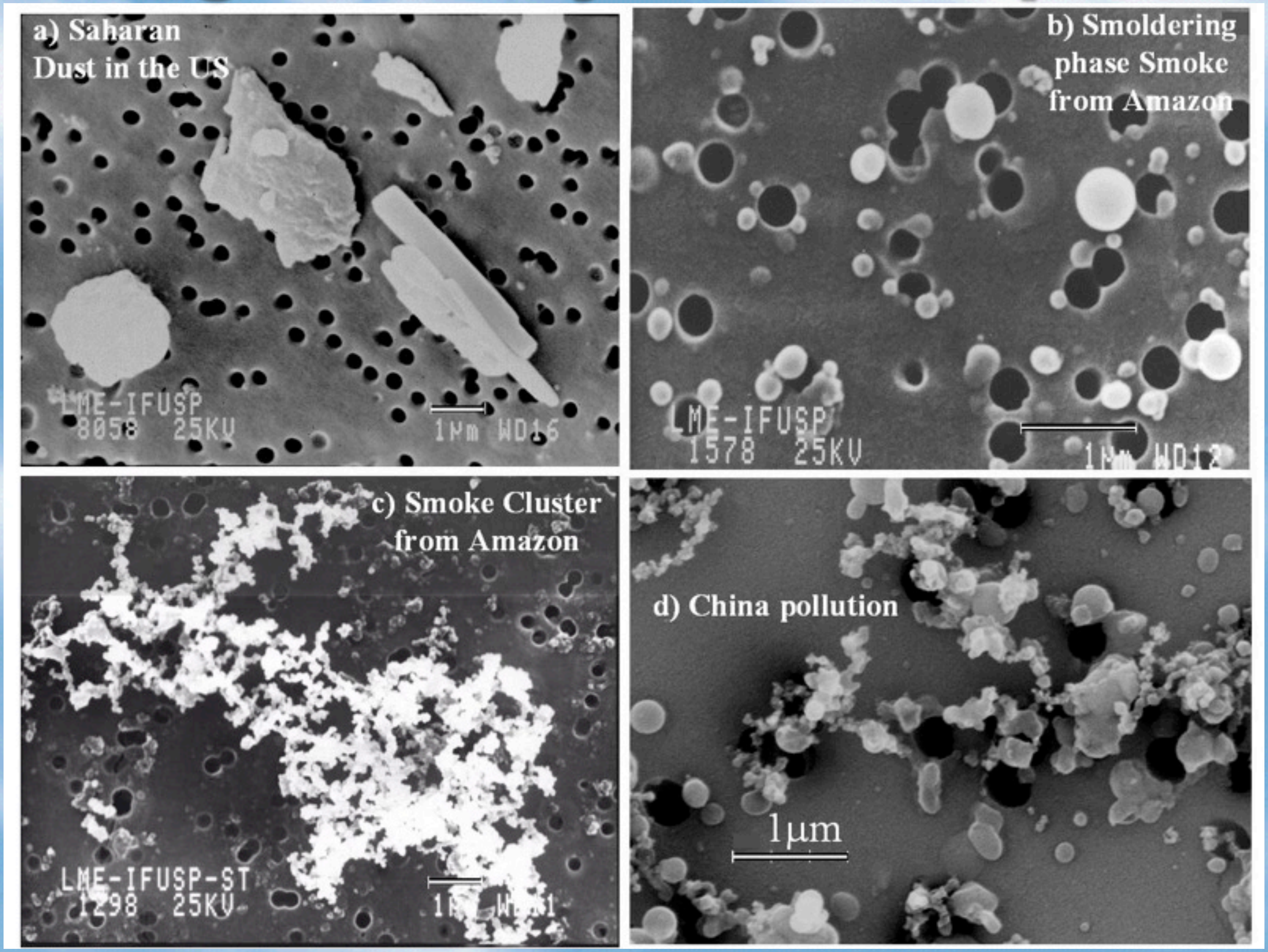


Earth Energy budget (W/m²)

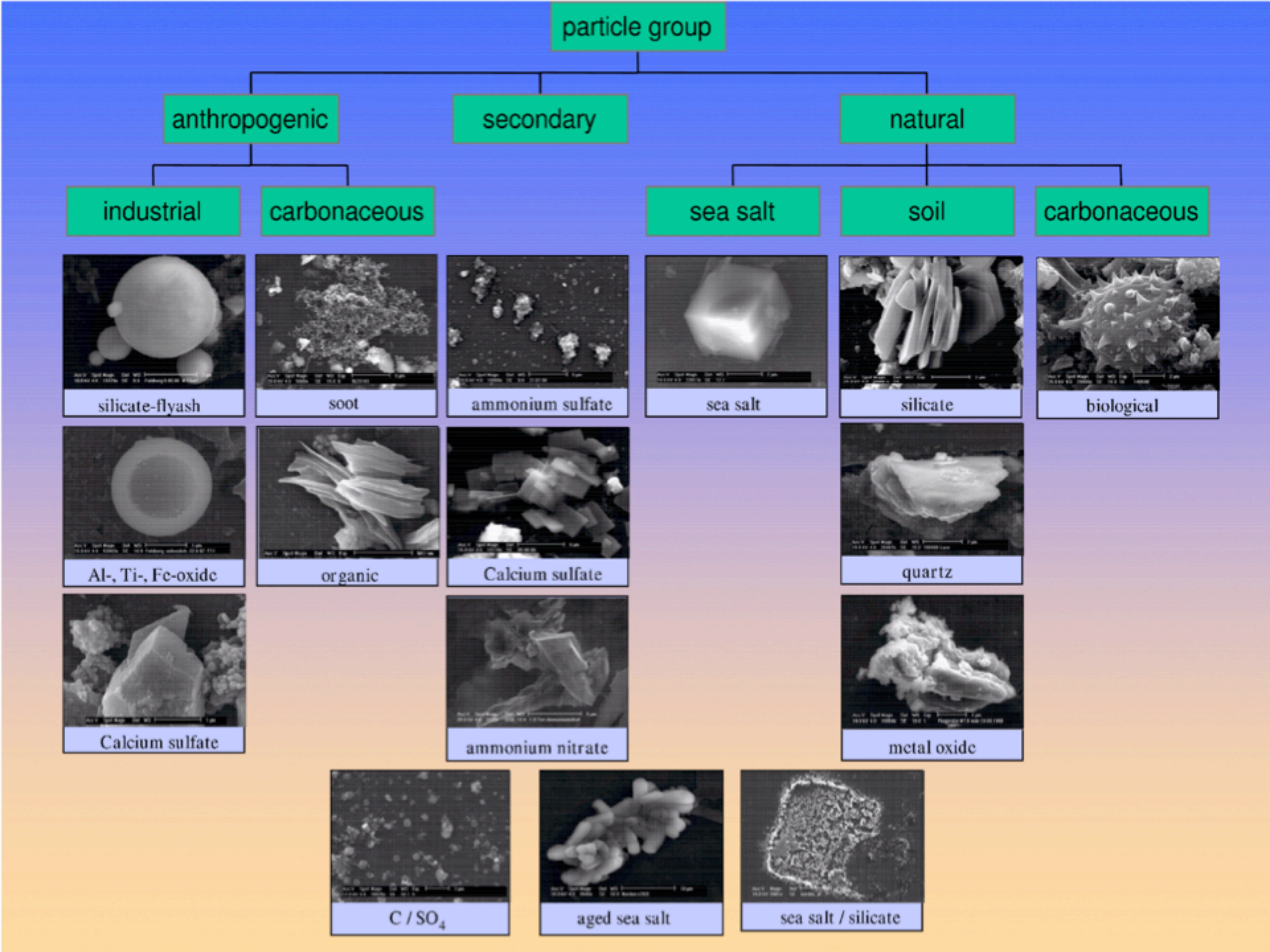


Aerosols influence the incoming visible radiation and the outgoing flux via clouds

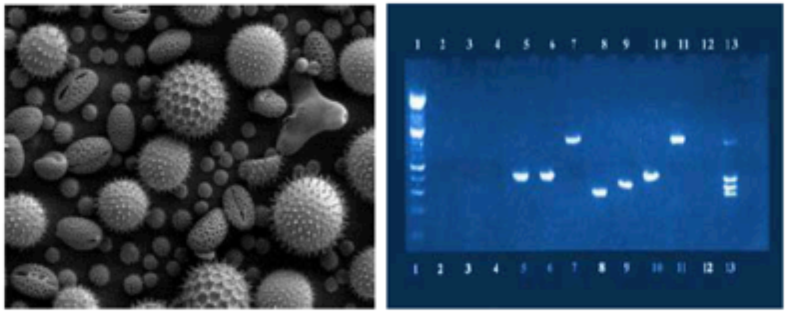
The large diversity of aerosol particles



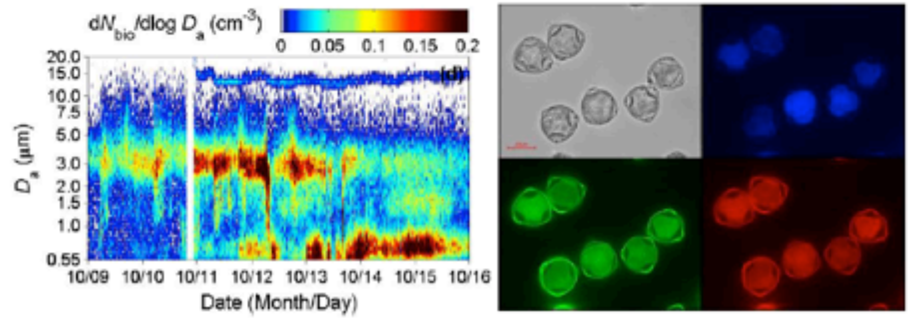
José Vanderlei Martins photos


particle group
anthropogenic
secondary
natural
industrial
carbonaceous
sea salt
soil
carbonaceous
silicate-flyash
soot
ammonium sulfate
sea salt
silicate
biological
Al-, Ti-, Fe-oxide
organic
Calcium sulfate
quartz
Calcium sulfate
ammonium nitrate
metal oxide
C / SO4
aged sea salt
sea salt / silicate

Life is in the air and it does interact with precipitation



DNA & Protein Analysis



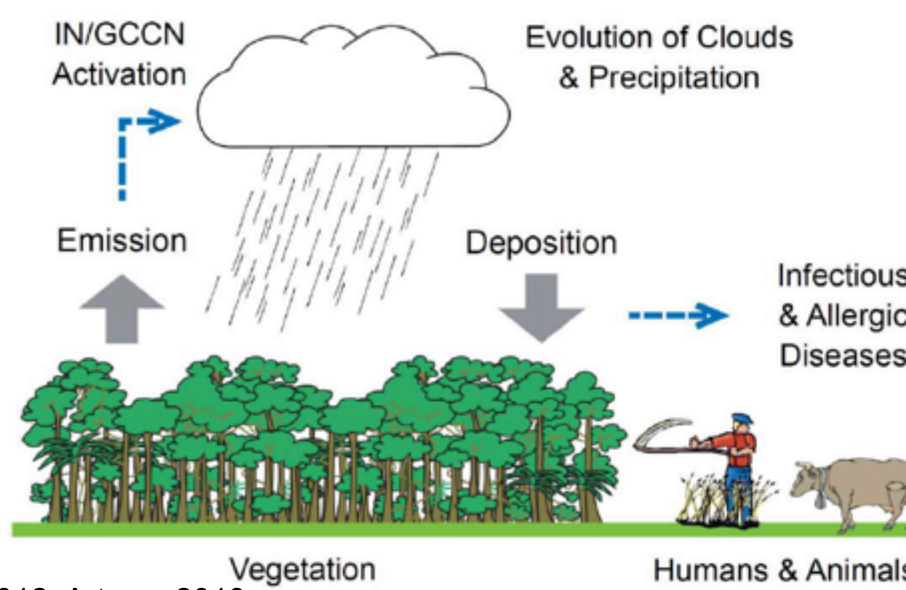
Fluorescence Spectroscopy & Microscopy

High abundance, diversity & emission fluxes of airborne fungi & bacteria:
~1 μg m^{-3}, ~10 L^{-1}, **~10^2 m^{-2} s^{-1}**, >10^3 species (urban PM)
Elbert ACP 2007, Fröhlich-Nowoisky PNAS 2009, Burrows ACP 2009, Huffman ACP 2010

Information: ~10 ng m^{-3} DNA
⇒ inhalation of ~1 μg/day ≡
~10^8 bacterial genomes/day
Despres BG 2007

Pathogens: permanent challenge
⇒ infectious & allergic diseases

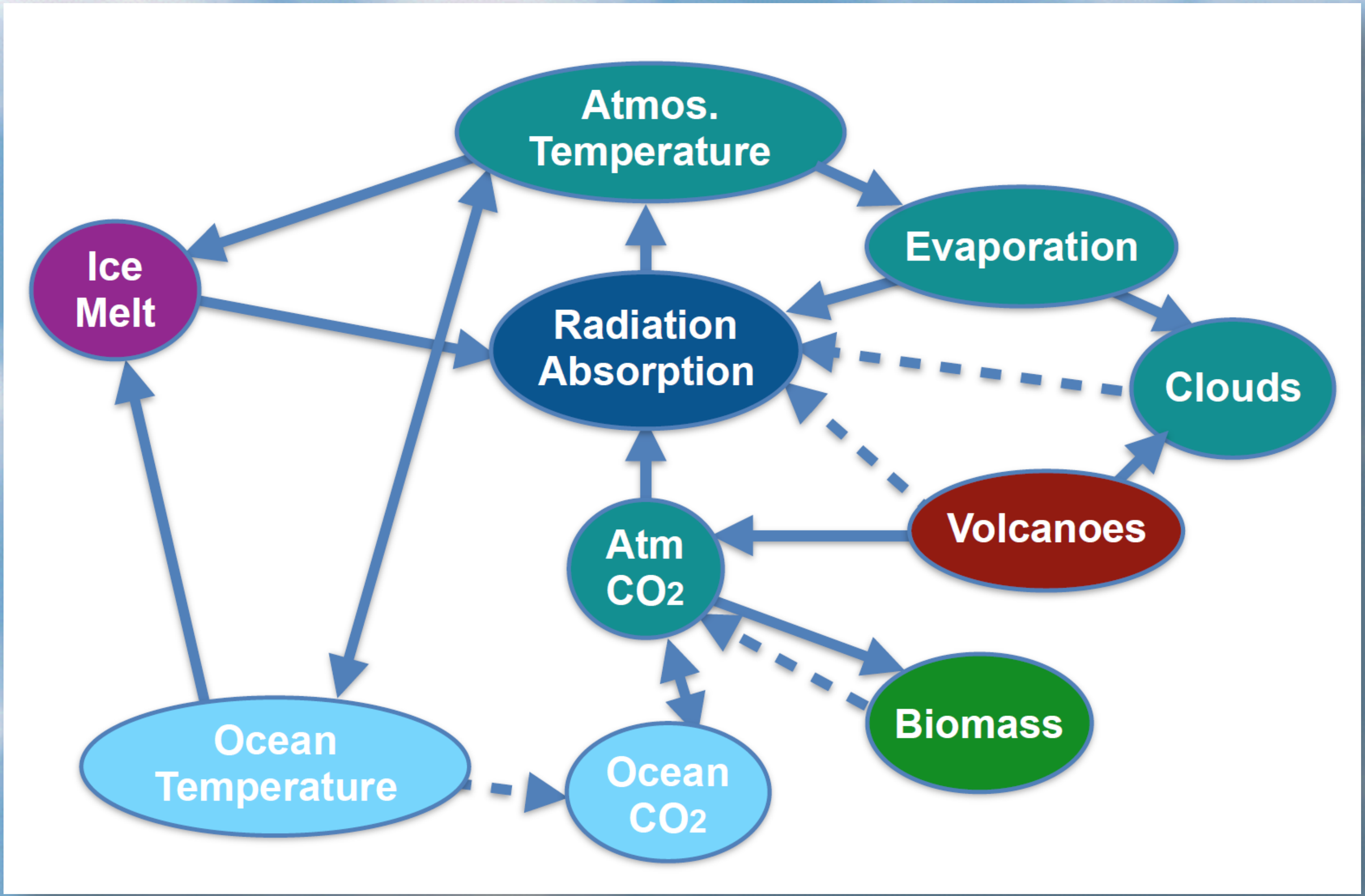
Cloud condensation & ice nuclei:
co-evolution of life & climate
⇒ bioprecipitation cycle
Sands J Hung Met Serv 1982



Poschl et al., 2012, Artaxo, 2013


Aerosol emissions make the high variability visible – it also applies to aerosol composition and the trace gases!

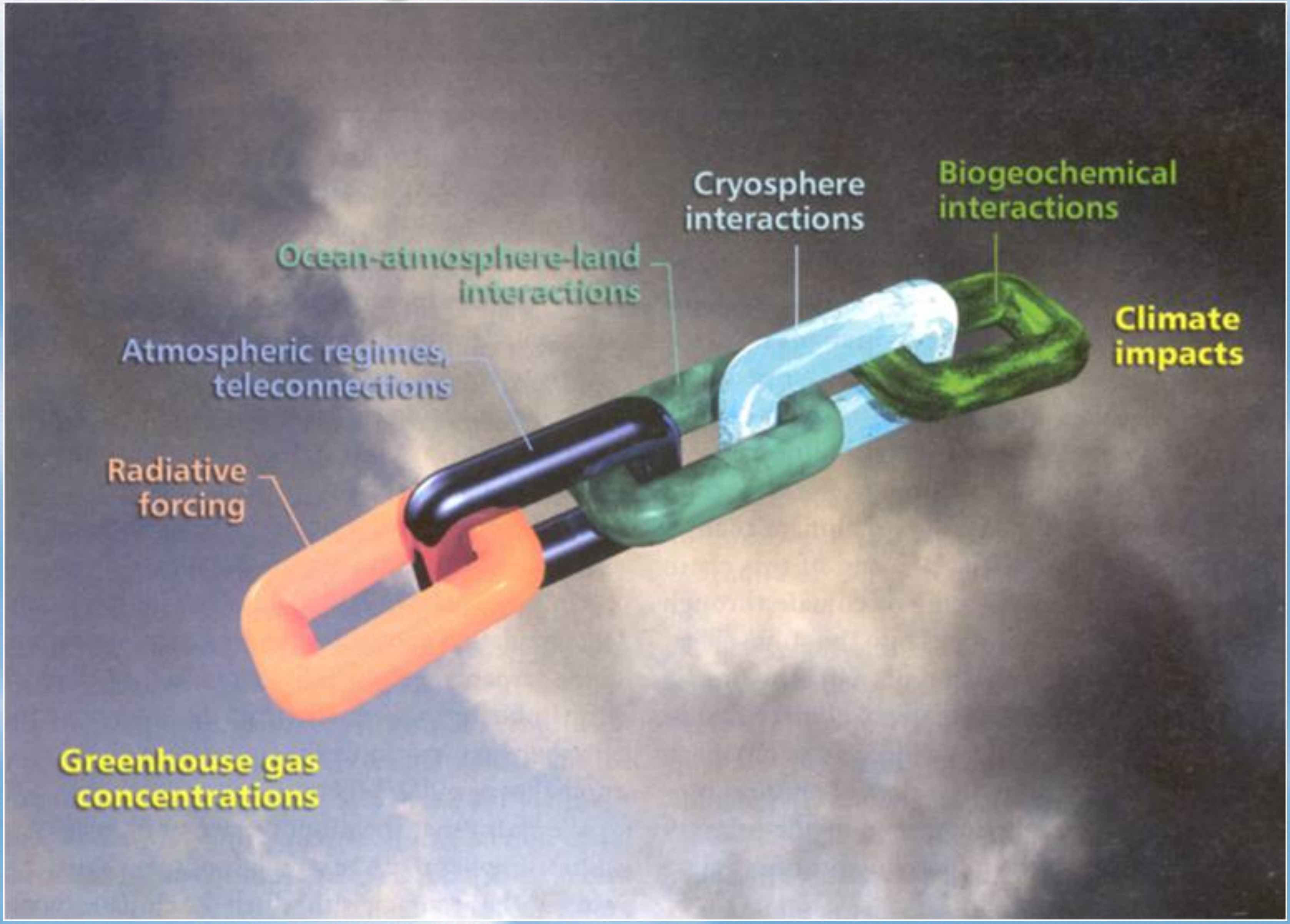
Constructing a physical model of our planet



Our changing planet is an integrated complex system:

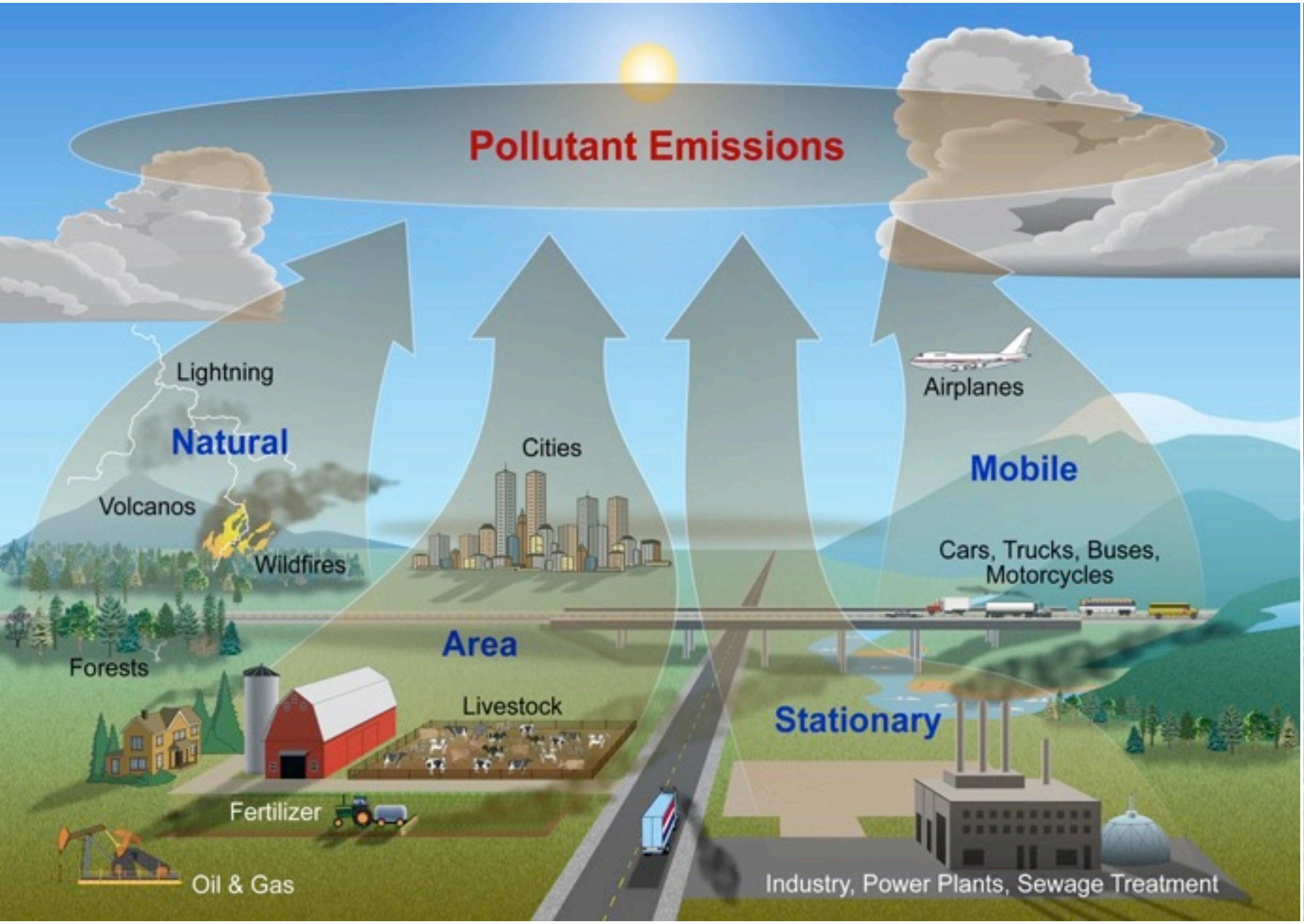
Atmosphere
Cryosphere
Biosphere
Geosphere
Hydrosphere

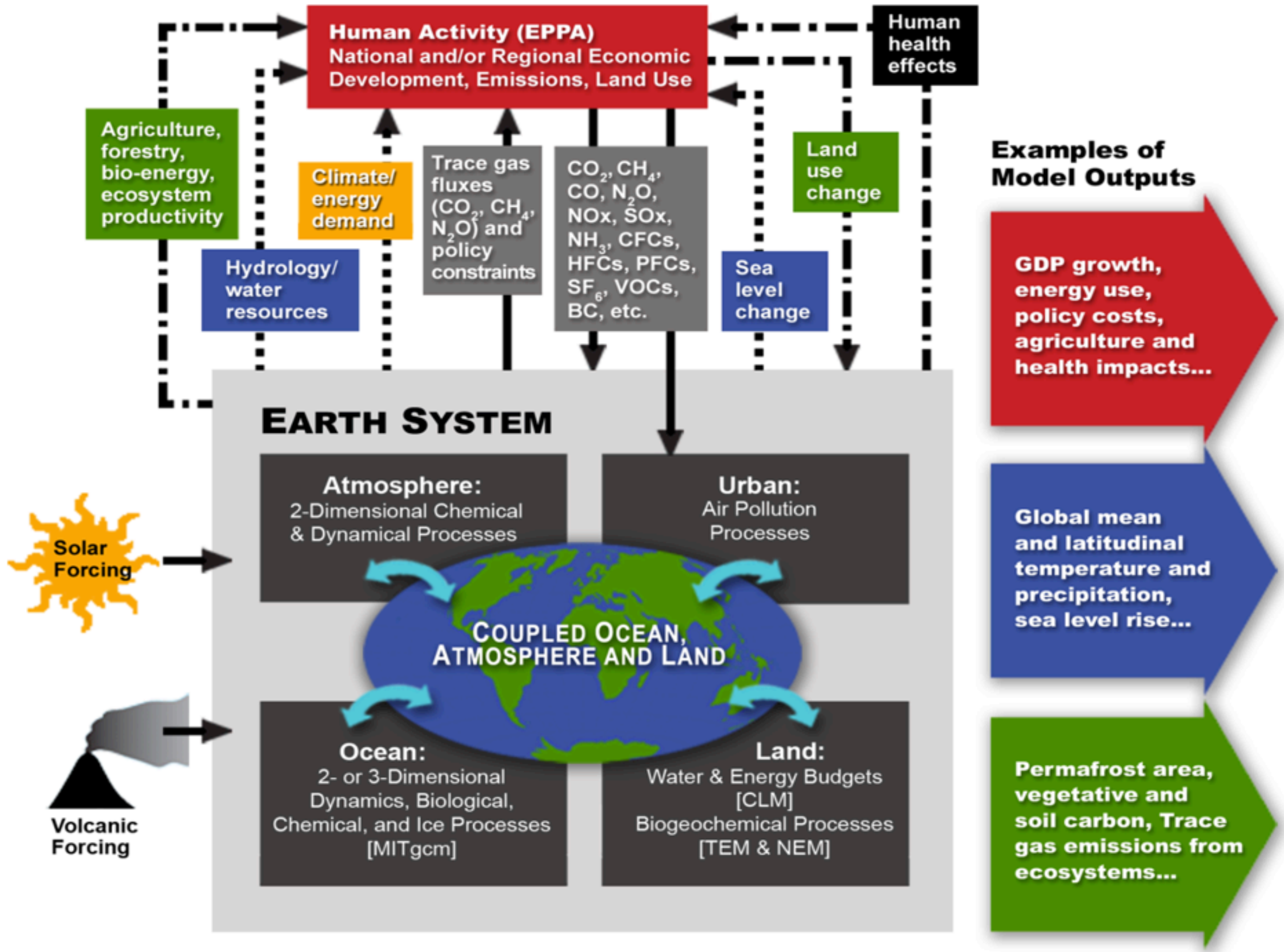
Climate is a complex system: interaction among several components



For climate modelling, we need to go from many scales and components

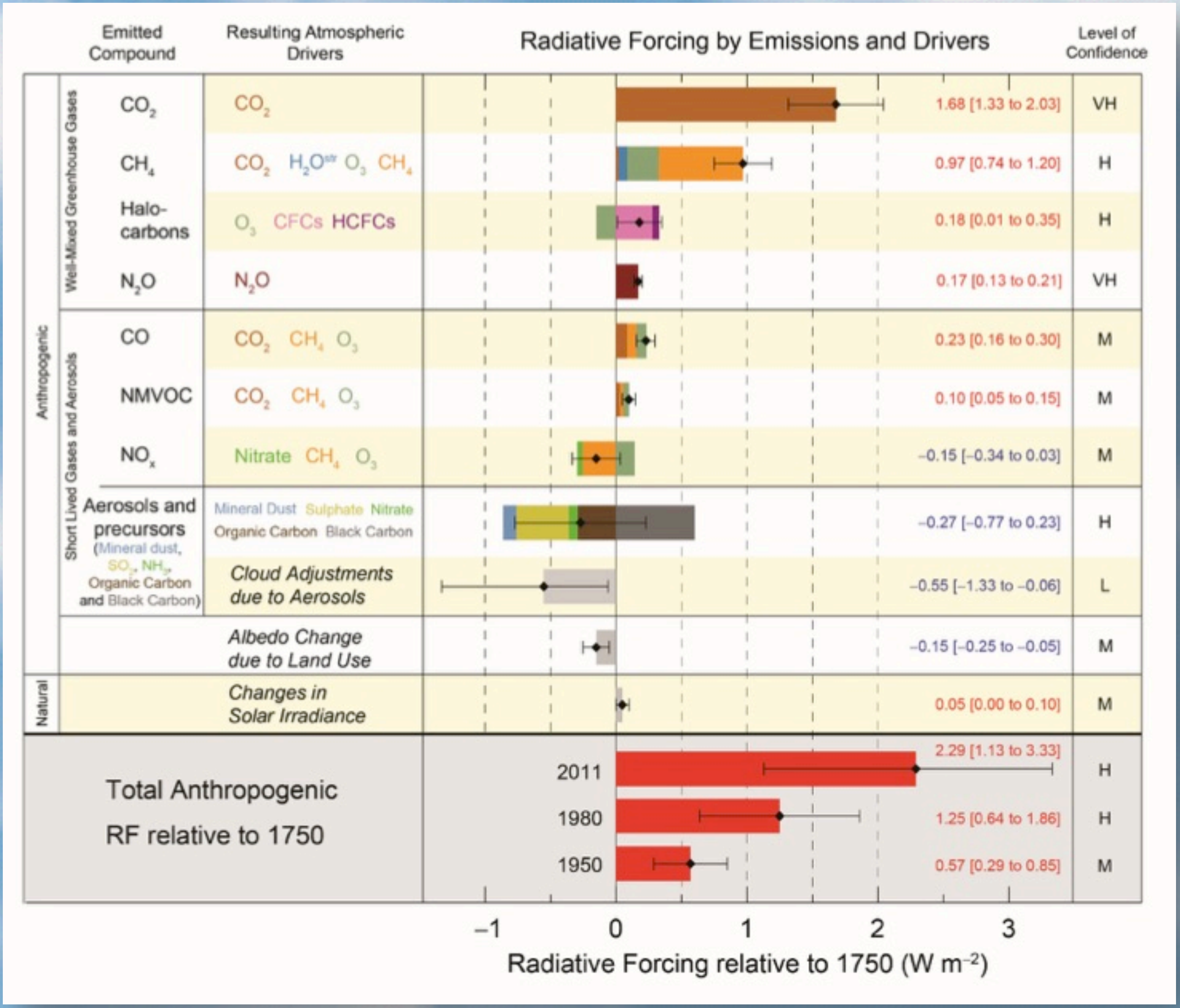
CO_2, N_2O, CH_4, CFC, HFC, NO_x, SO_2, NH_3, VOC, BC, OC



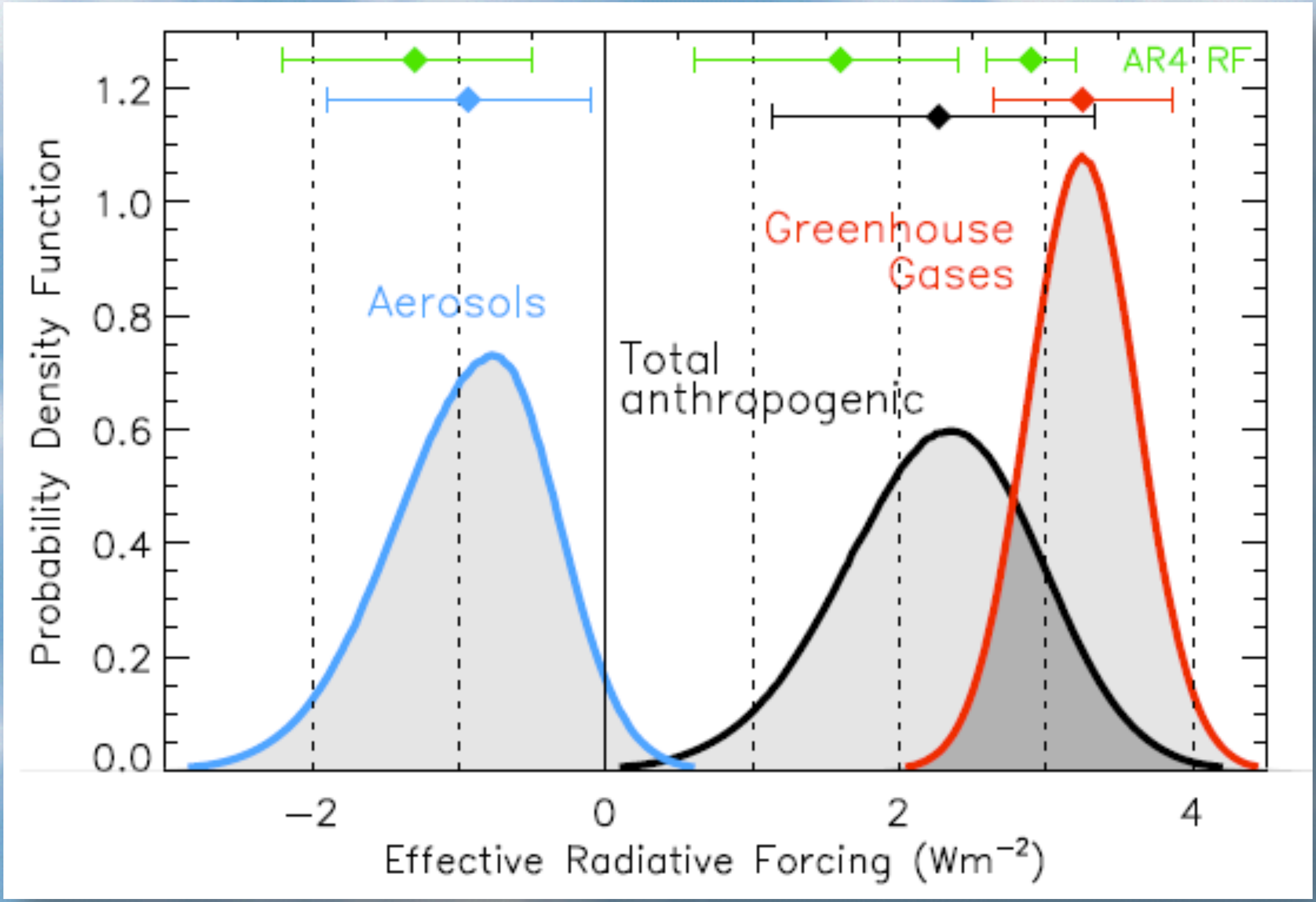


Human Activity (EPPA)
National and/or Regional Economic Development, Emissions, Land Use
Human health effects
Agriculture, forestry, bio-energy, ecosystem productivity
Climate/ energy demand
Trace gas fluxes (CO_2, CH_4, N_2O) and policy constraints
CO_2, CH_4, CO, N_2O, NOx, SOx, NH_3, CFCs, HFCs, PFCs, SF_6, VOCs, BC, etc.
Land use change
Hydrology/ water resources
Sea level change
Examples of Model Outputs
GDP growth, energy use, policy costs, agriculture and health impacts...
Global mean and latitudinal temperature and precipitation, sea level rise...
Permafrost area, vegetative and soil carbon, Trace gas emissions from ecosystems...
EARTH SYSTEM
Atmosphere:
2-Dimensional Chemical & Dynamical Processes
Urban:
Air Pollution Processes
COUPLED OCEAN, ATMOSPHERE AND LAND
Ocean:
2- or 3-Dimensional Dynamics, Biological, Chemical, and Ice Processes [MITgcm]
Land:
Water & Energy Budgets [CLM] Biogeochemical Processes [TEM & NEM]
Solar Forcing
Volcanic Forcing

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

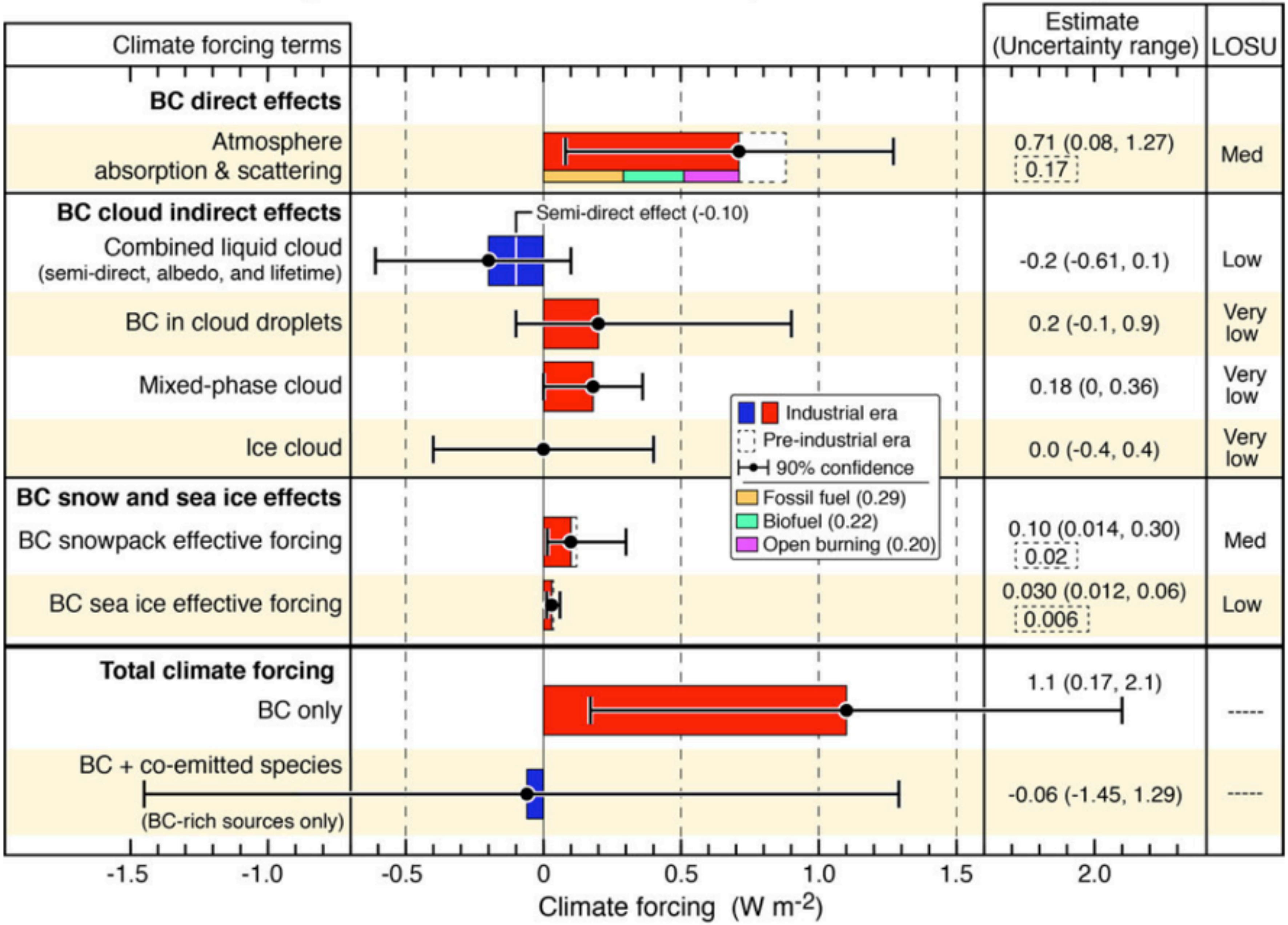


Climate forcing of aerosols and greenhouse gases

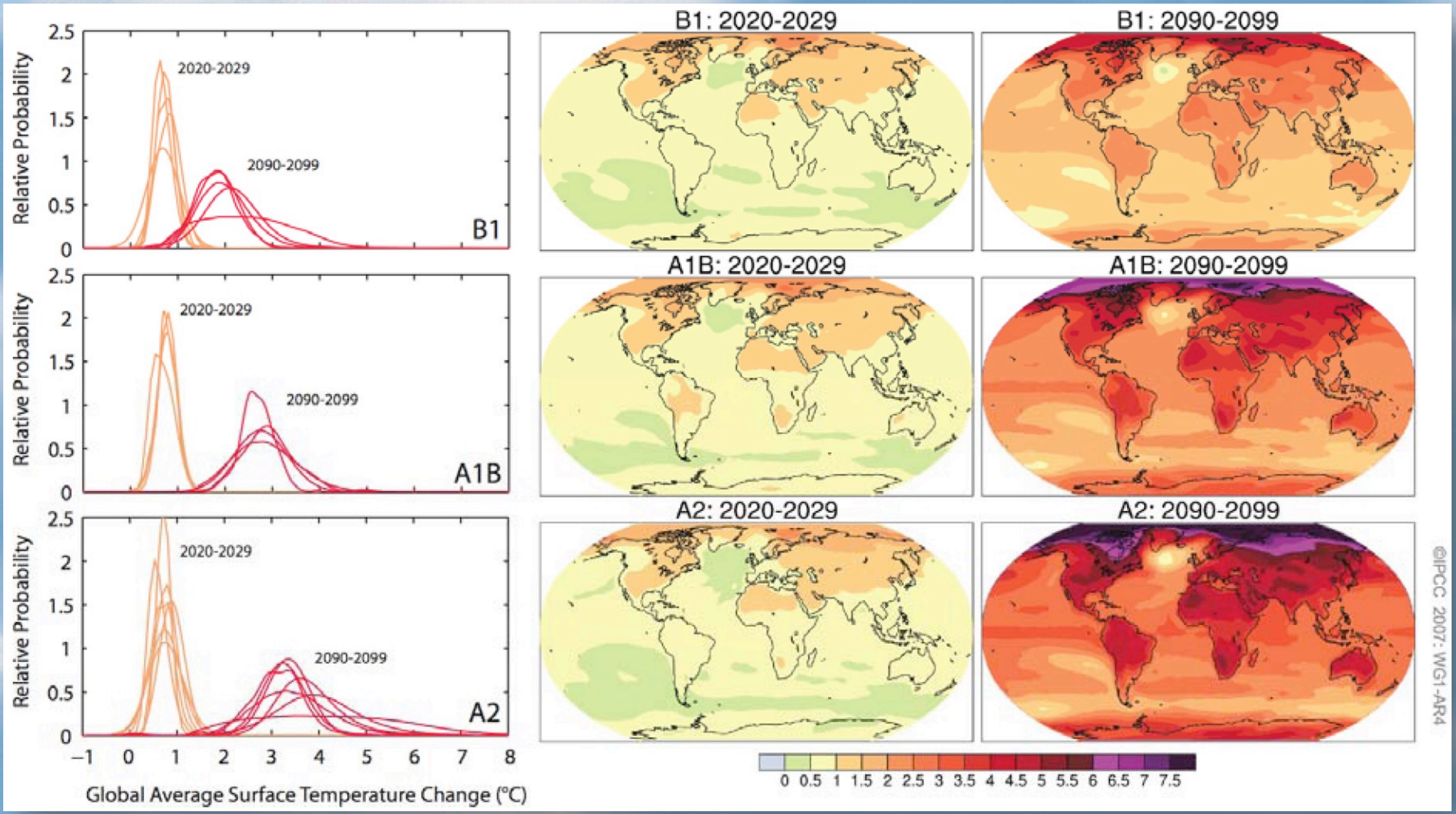


IPCC AR5, Chapter 8, 2013

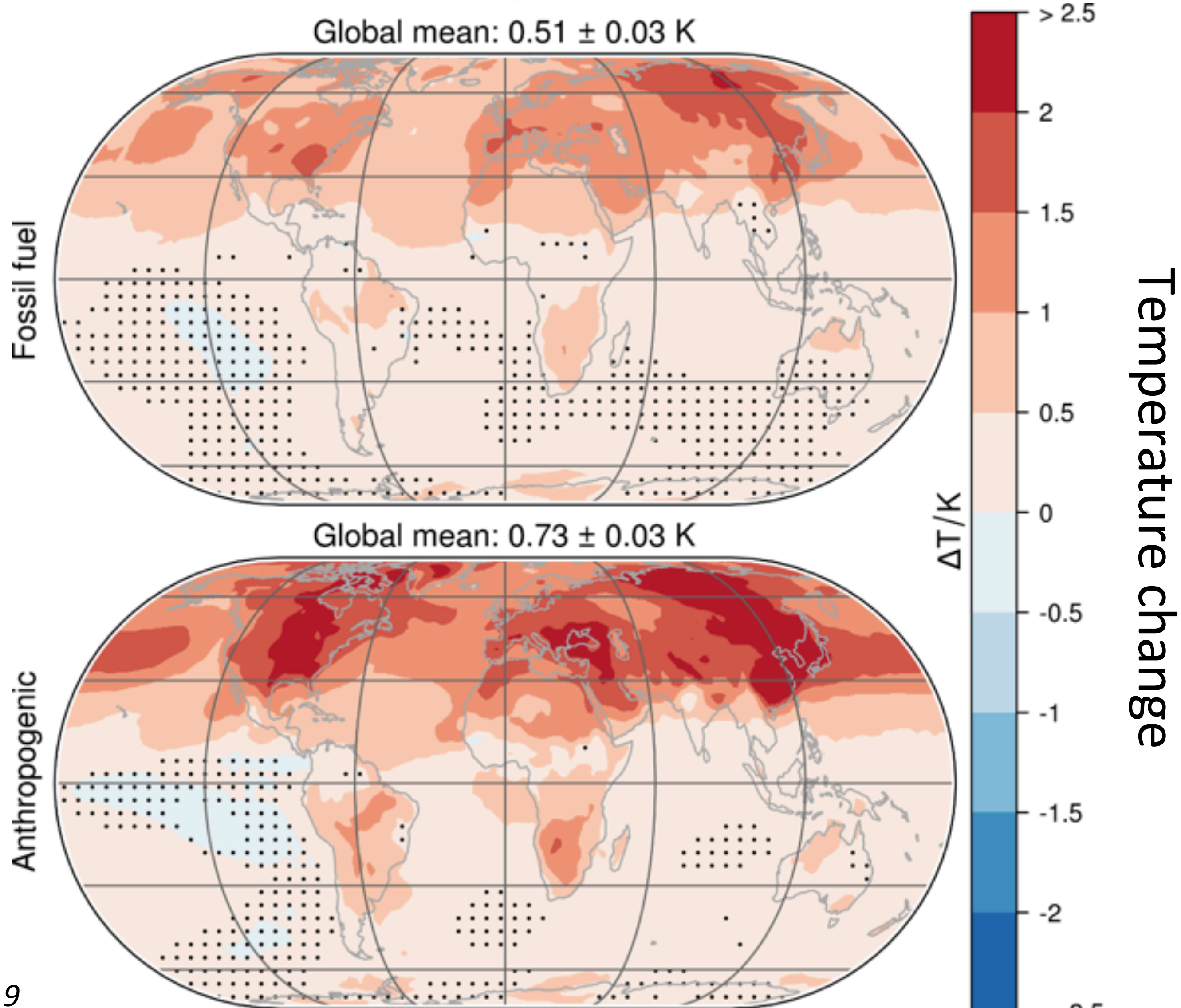
Global climate forcing of black carbon and co-emitted species in the industrial era (1750 - 2005)



Estimates of temperature increase for 2029 and 2099 following 3 emissions scenarios

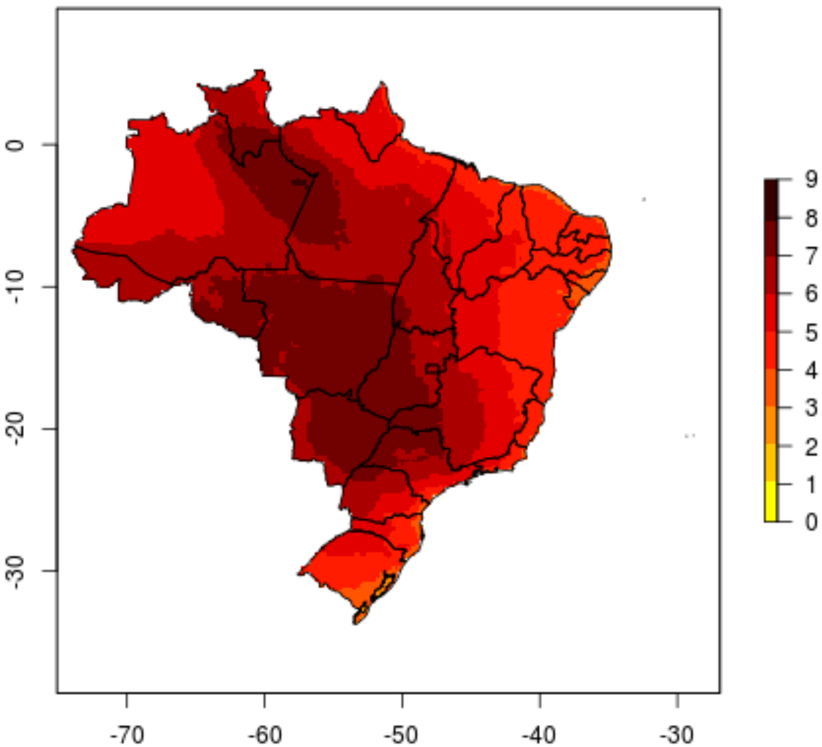


Temperature increase from phase-out of fossil fuel related and all particulate air pollution



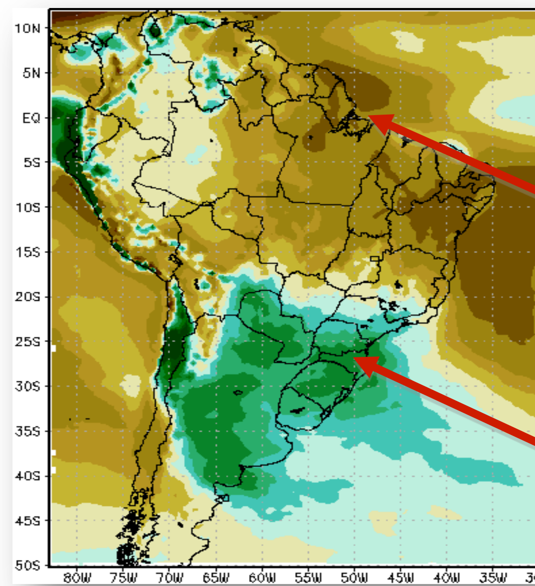
Jos Lelieveld, 2019

Aumento médio de temperatura esperado para o Brasil 2071-2099



Áreas continentais se aquecem mais que áreas oceânicas

Mudança na precipitação esperada para o Brasil 2071-2100



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

<u>Amazonia e Nordeste do Brasil → deficiência de chuvas</u>

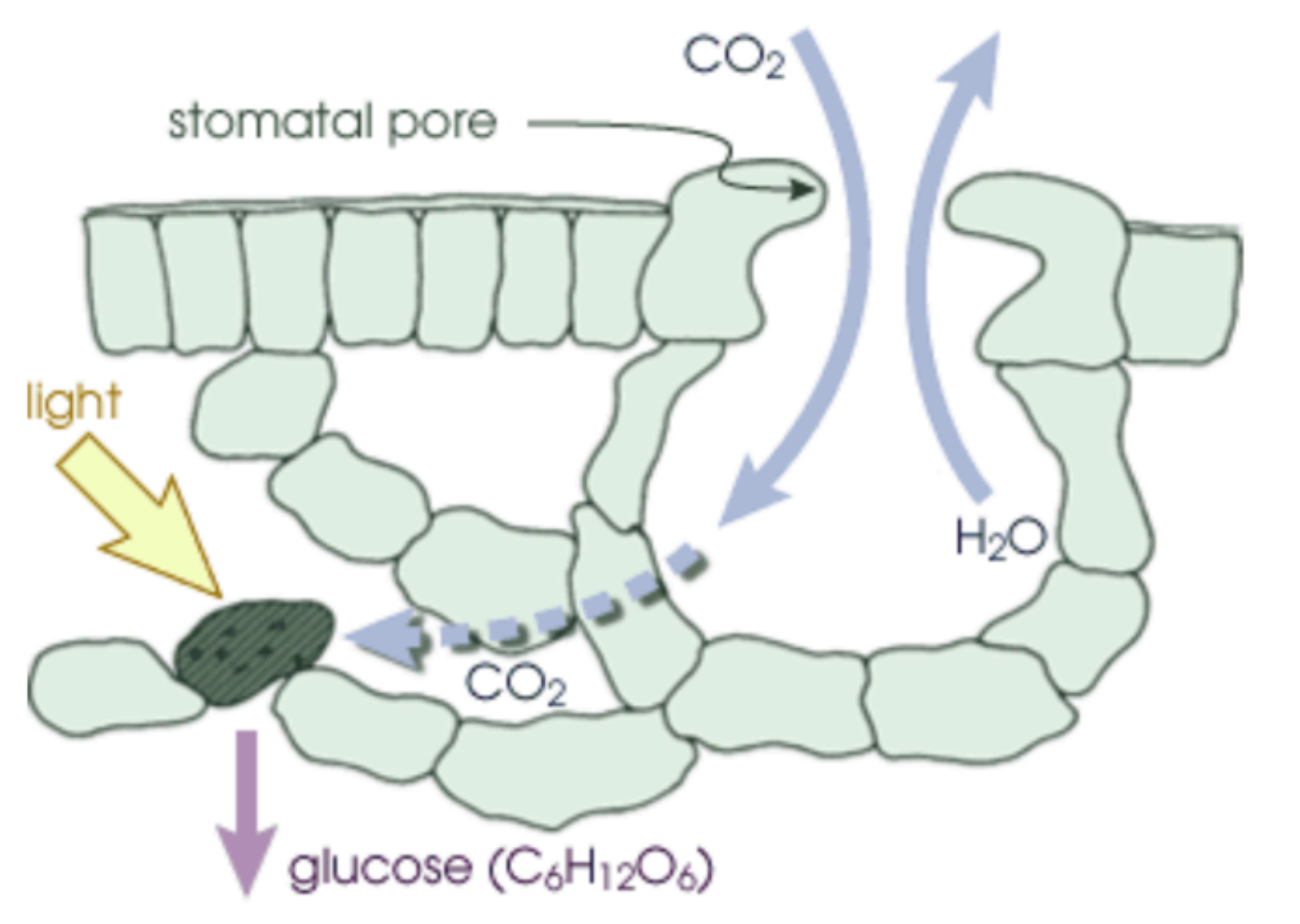
<u>Sudeste da America do Sul → aumento nas chuvas</u>

INPE, (RCP 8.5)

How close to the edge do we dare to get?

The tipping point issue...

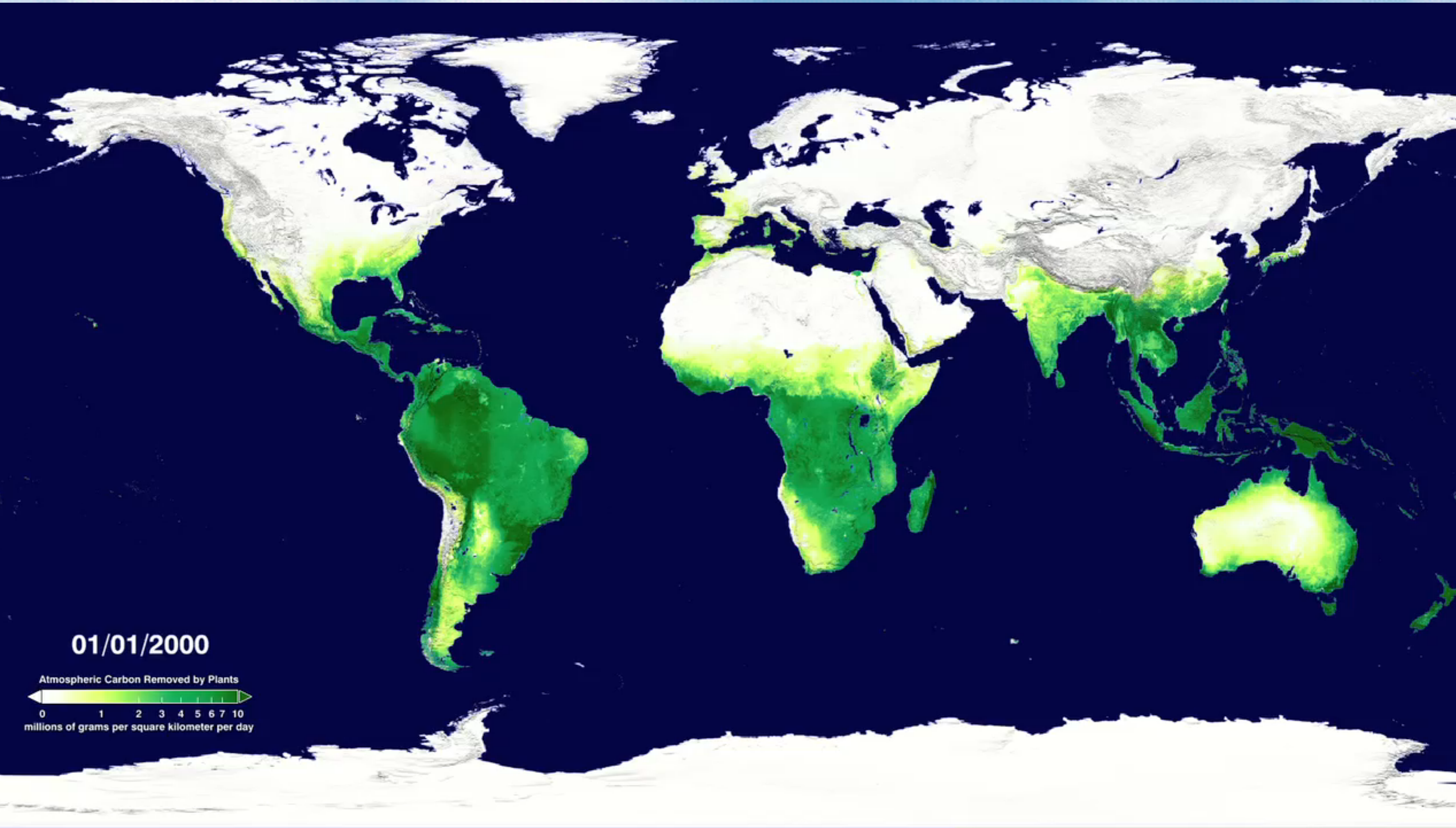
Photosynthesis: where radiation meets life



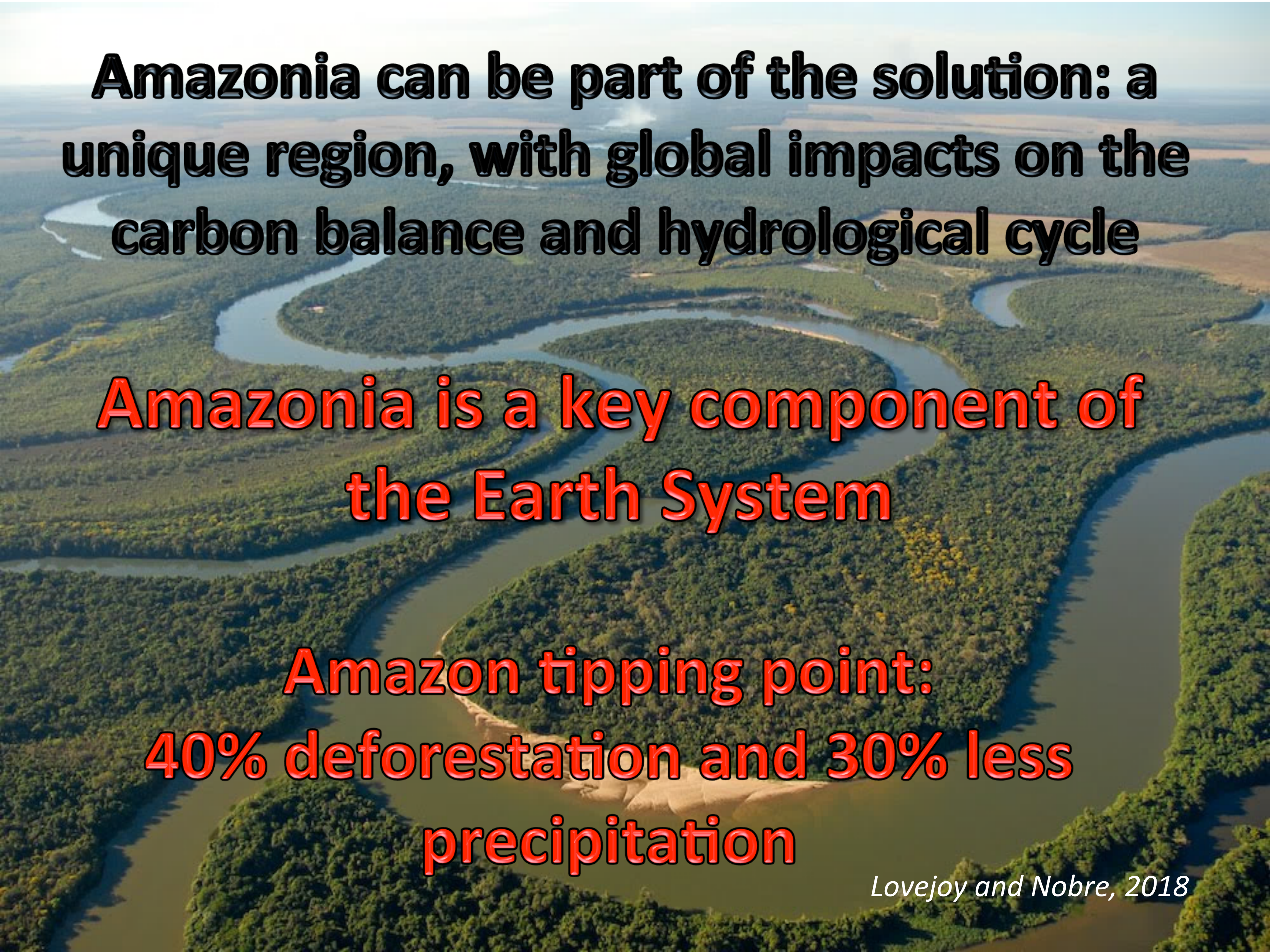
During photosynthesis, plants absorb carbon dioxide and sunlight to create fuel, glucose and other sugars for building plant structures. This process forms the foundation of the biological carbon cycle.

HOW MUCH CARBON DO PLANTS TAKE FROM THE ATMOSPHERE?

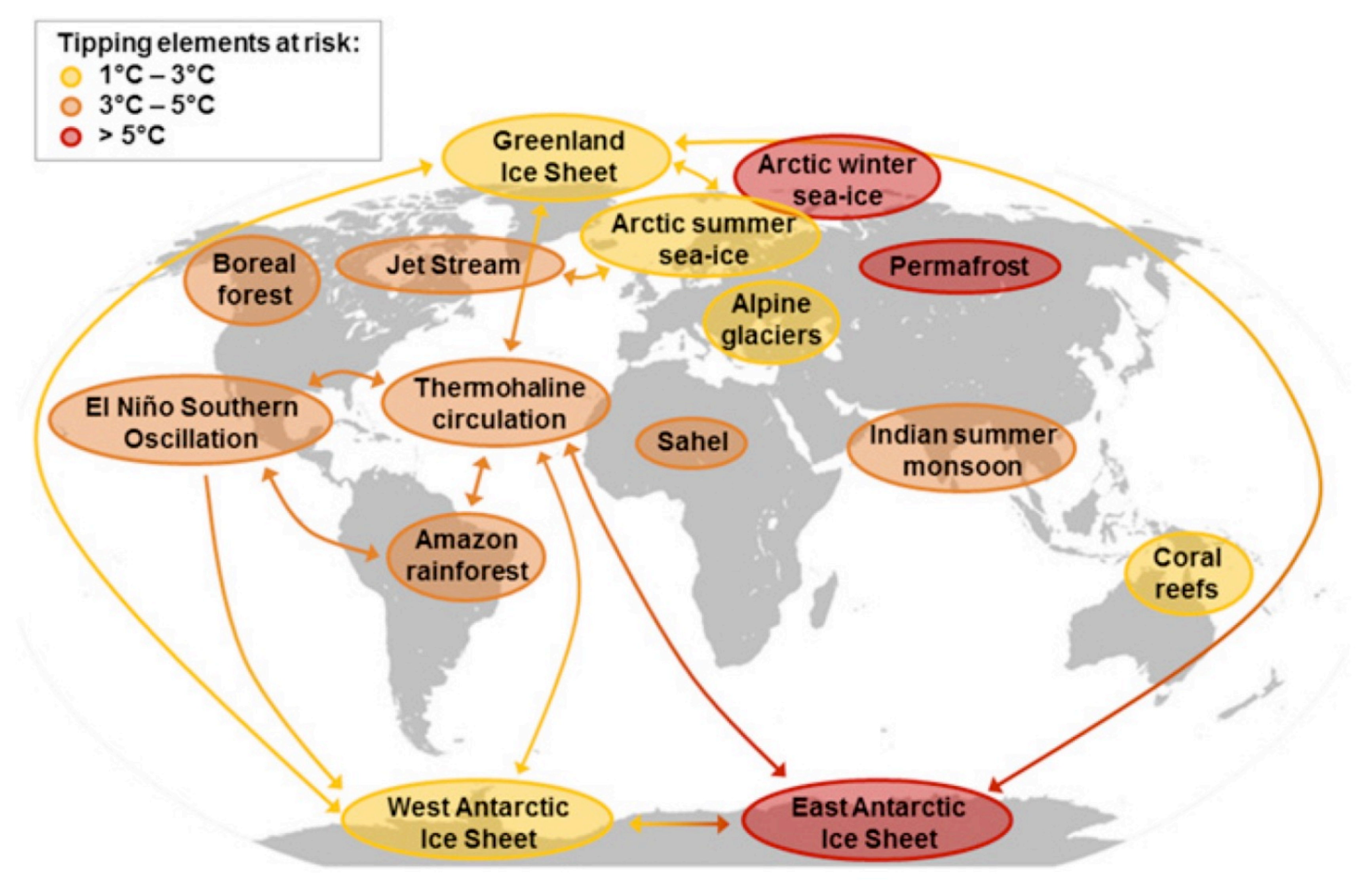
MODIS gross primary productivity (GPP) estimation from NDVI 2000-2010



Amazonia: about 120 billion tons of carbon in the forest

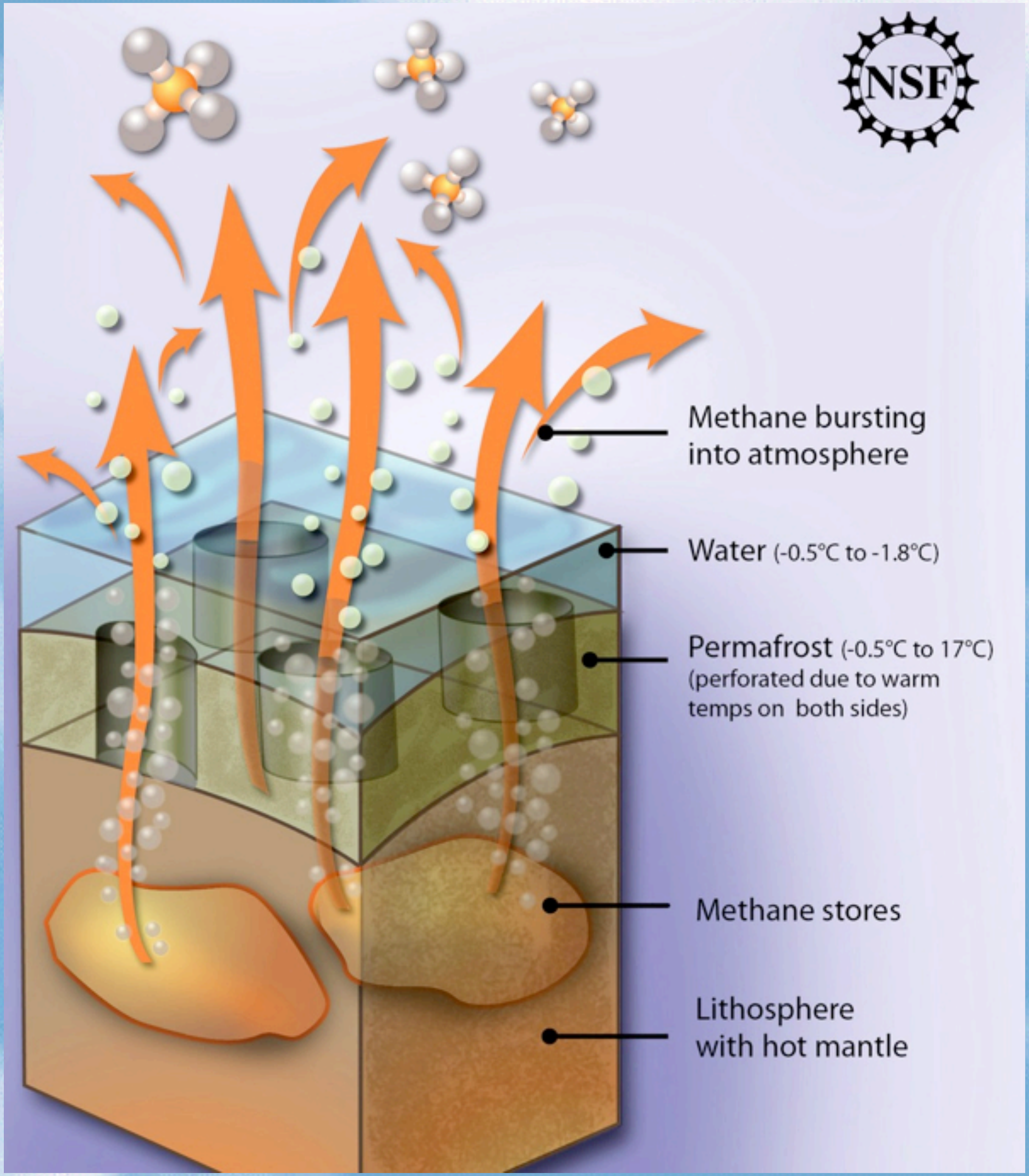

Amazonia can be part of the solution: a unique region, with global impacts on the carbon balance and hydrological cycle
Amazonia is a key component of the Earth System
Amazon tipping point:
40% deforestation and 30% less precipitation
Lovejoy and Nobre, 2018

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

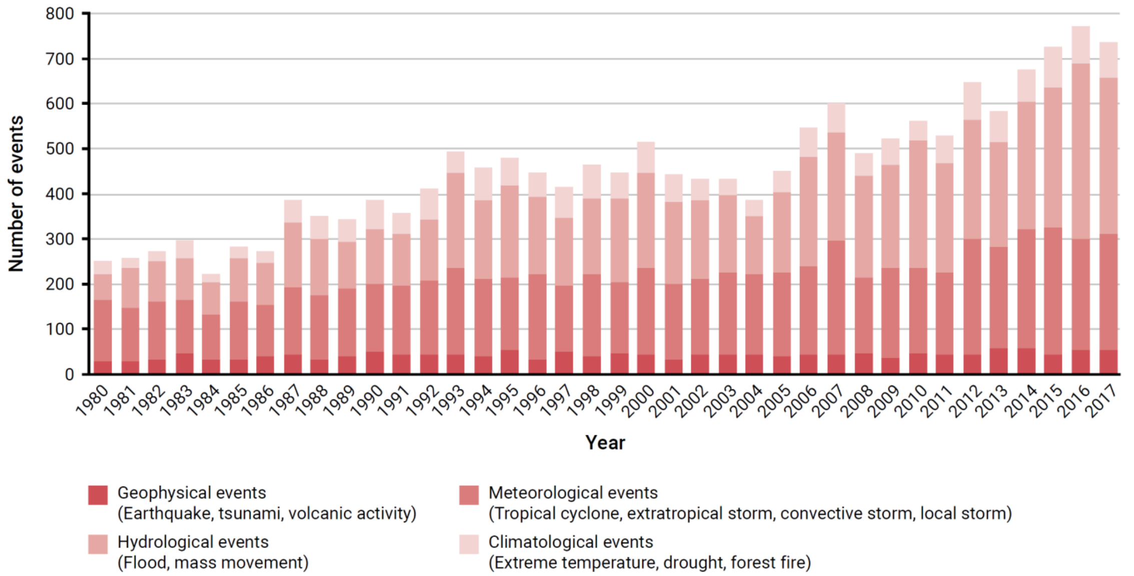
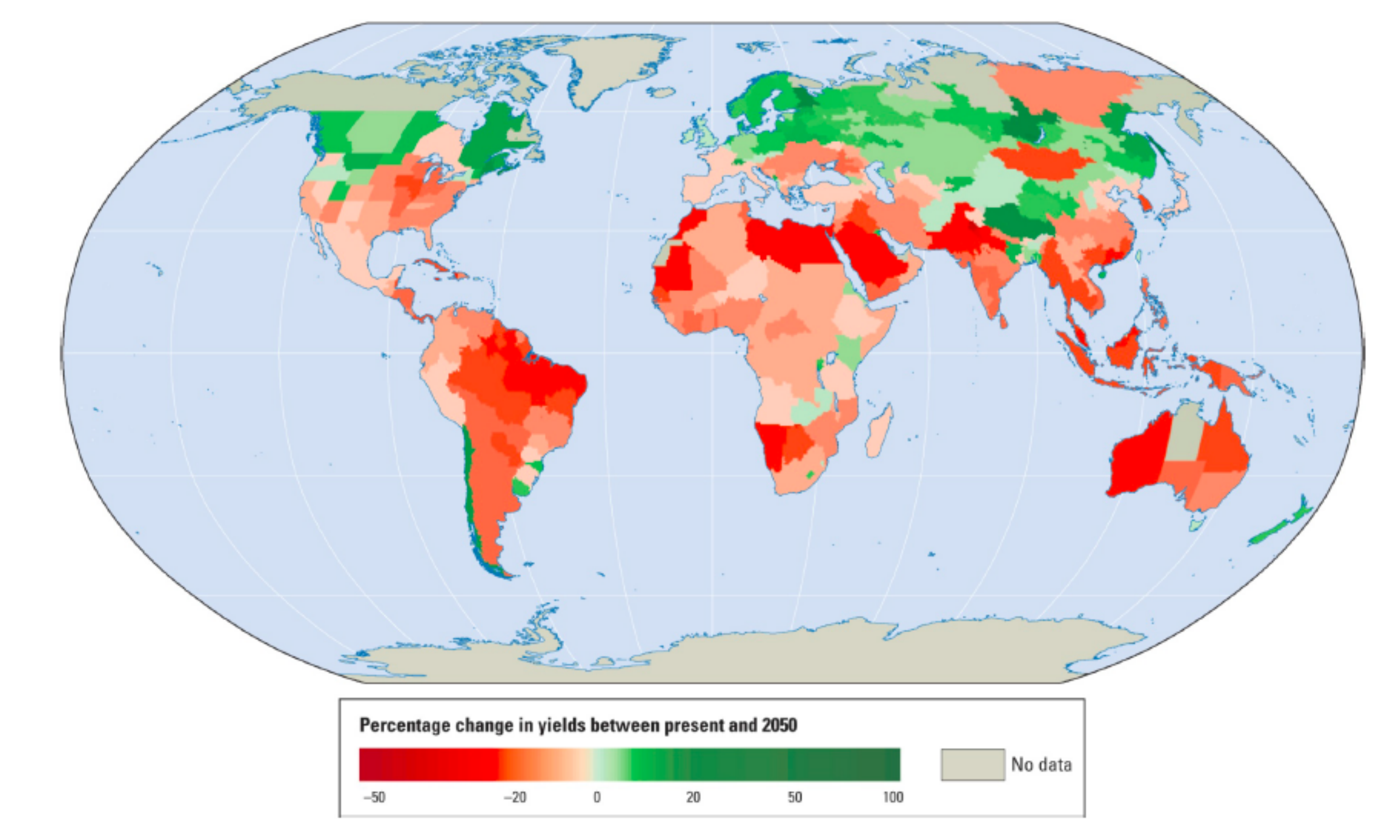


Figure 2.22: Trends in numbers of loss-relevant natural events

Source: Munich Re (2017)

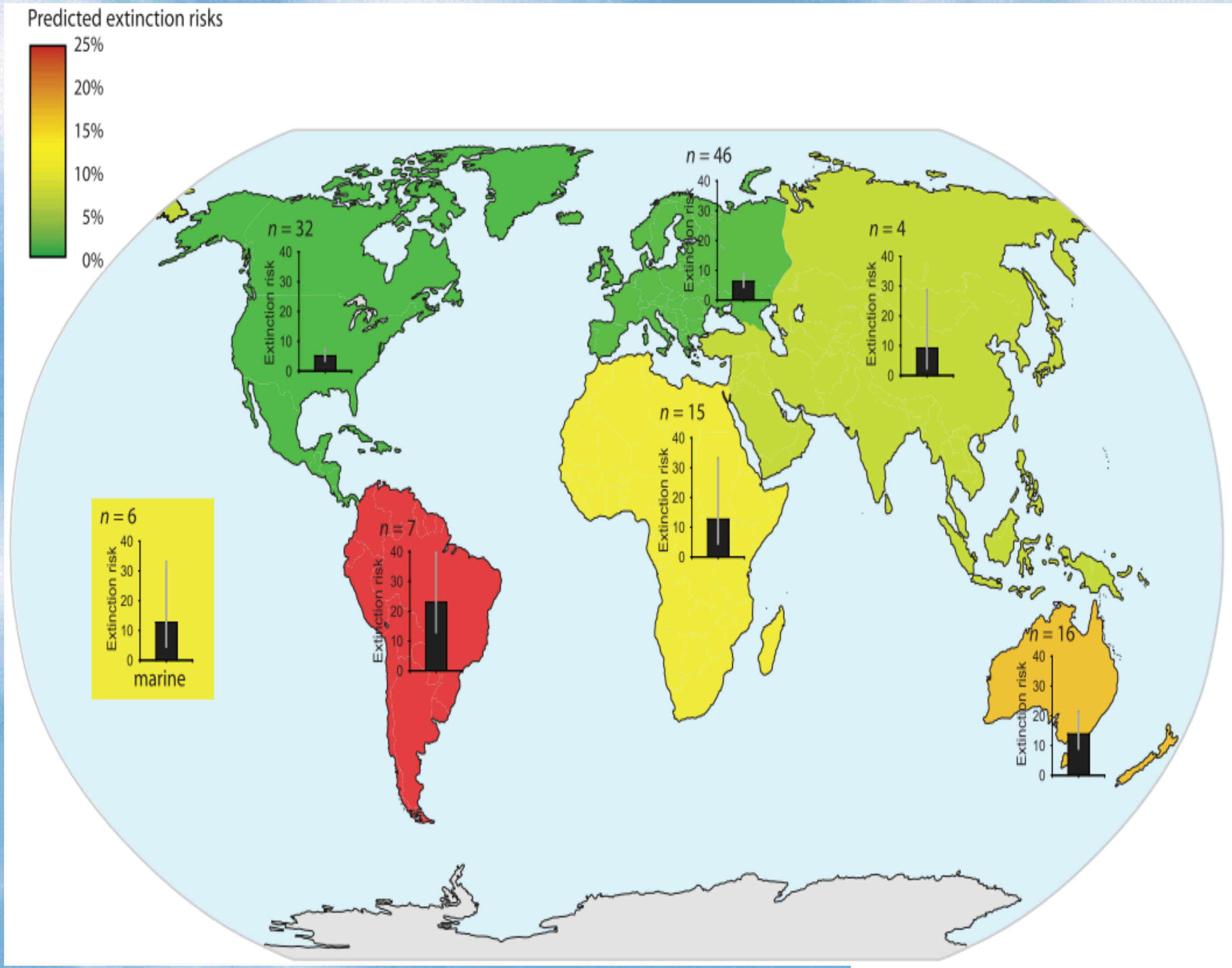
It is already happening since the 80's

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



FAO and World Economic Forum: Global Risks 2016

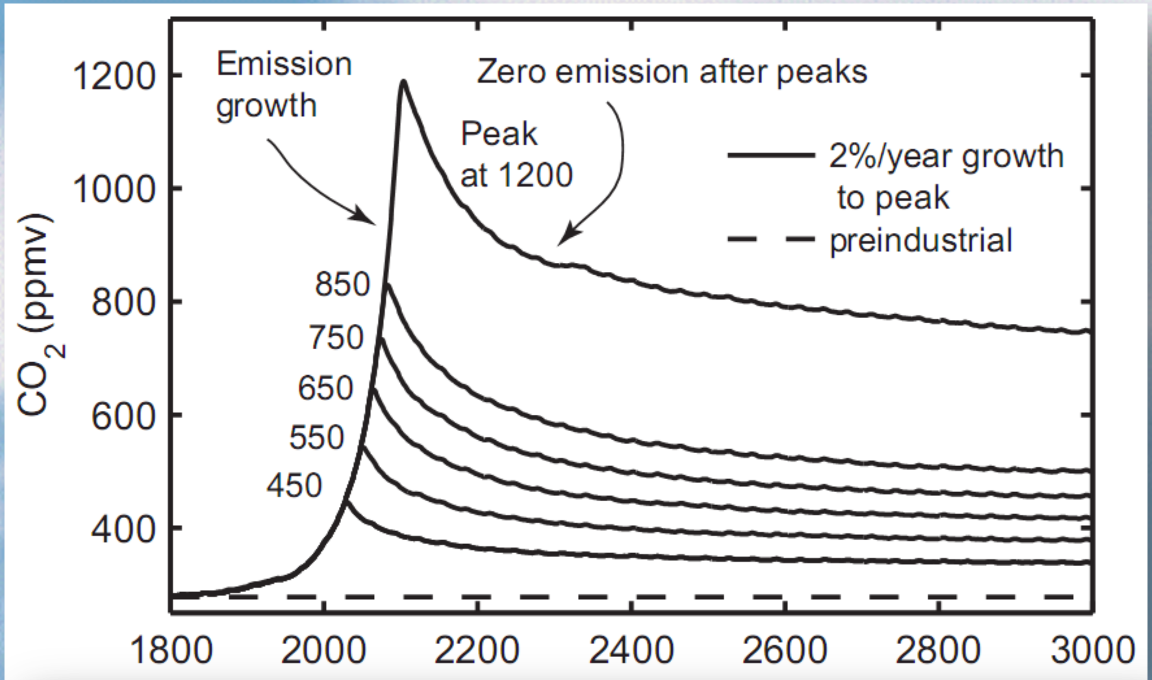
Predicted Extinction Risks of Biological Species

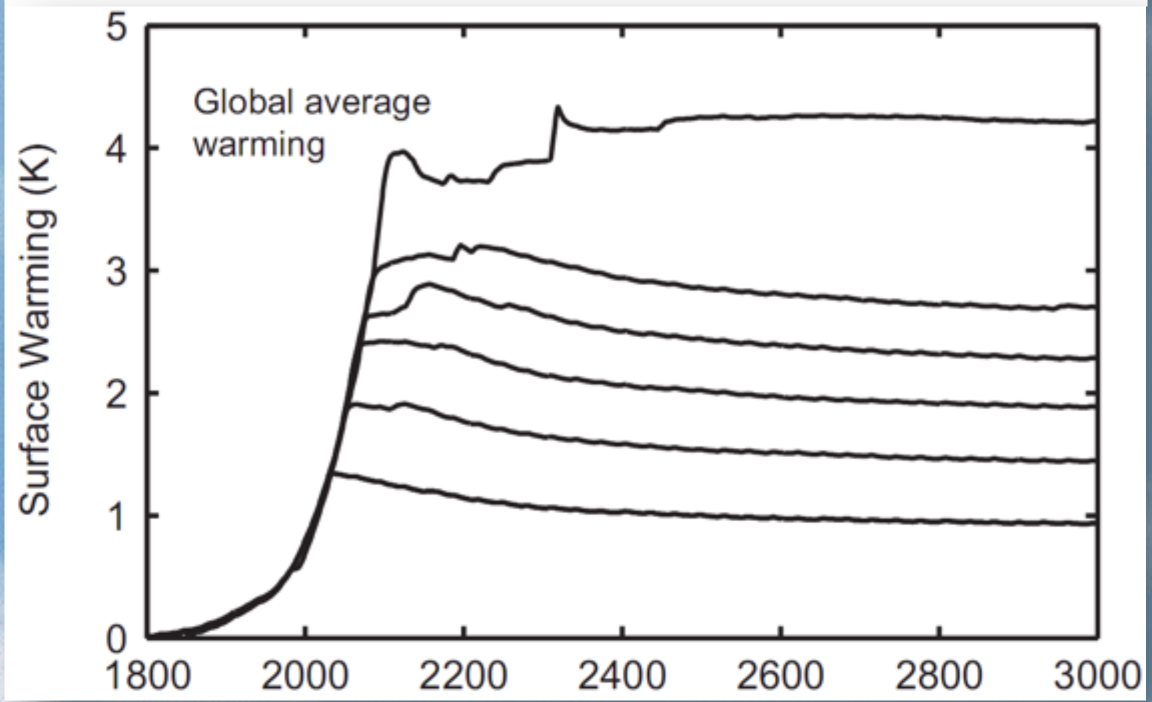


The highest risks: South America, Australia, and New Zealand (14 to 23%)

Source: Urban M.C-Nature, 2015

How much time the CO_2 will affect the climate?

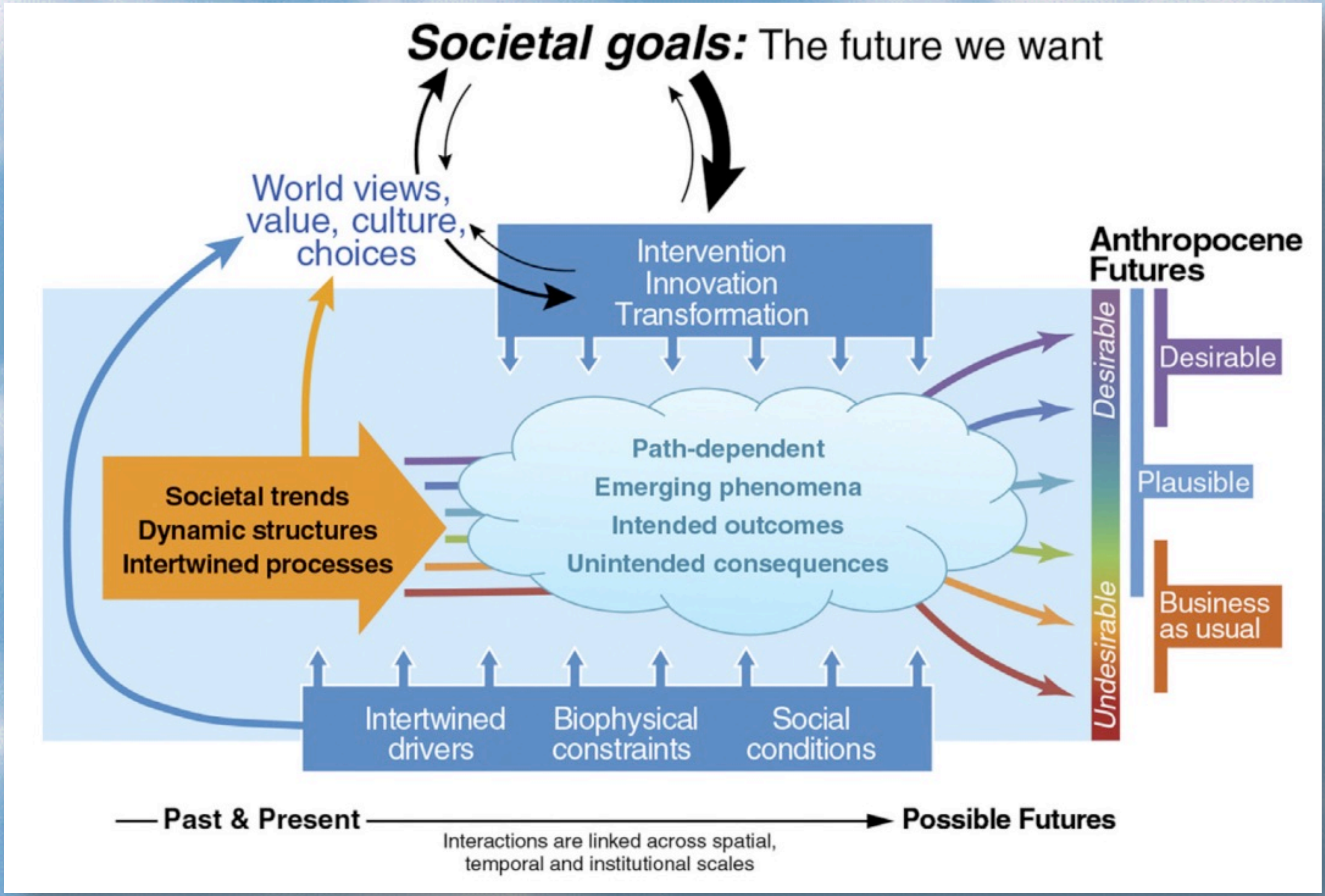




Susan Salomon PNAS Fev 2009

Note the scale: Till year 3000 ⟶

Which future do we want? The future of the Anthropocene



Global Environmental Change 39 (2016) 351–362

Solutions

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

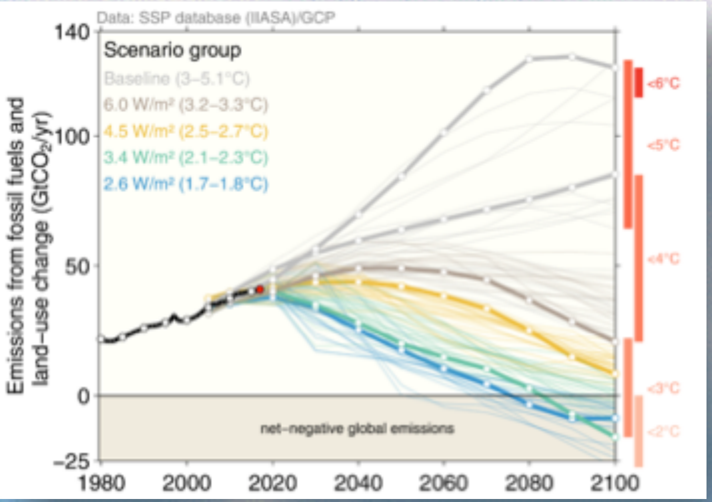
Energy production

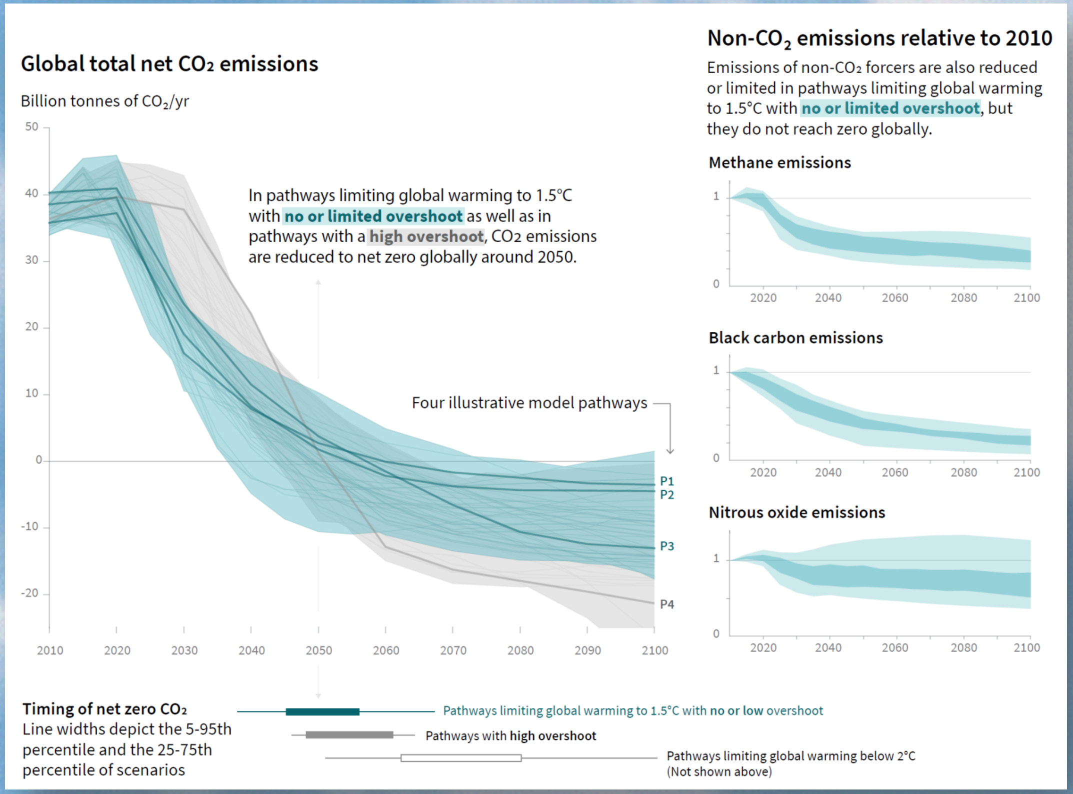
Transportation

Agriculture

Biofuels?

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





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

Black Carbon emissions: 90% reduction

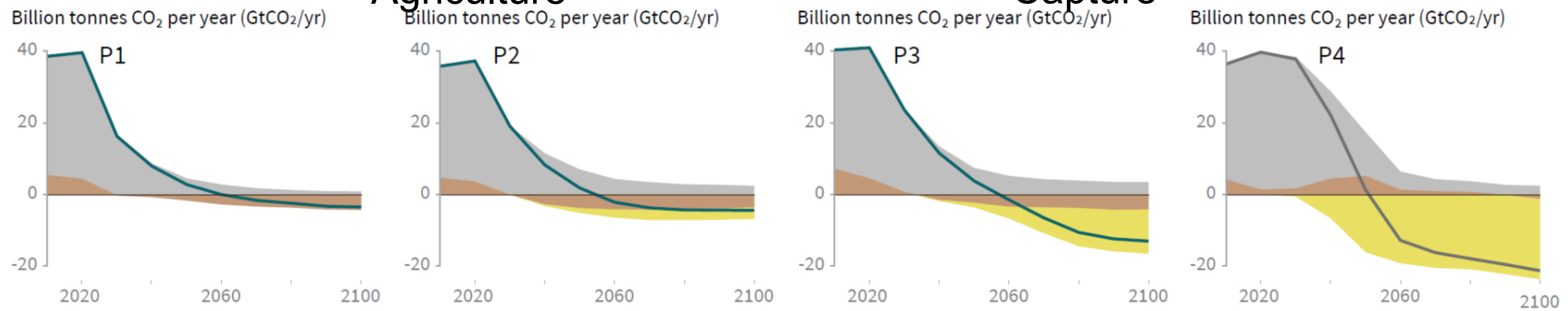
Source: IPCC Special Report on Global Warming of 1.5°C

Net emissions for 4 possible scenarios

Fossil Fuels

AFOLU – Forests and Agriculture

Bioenergy with Carbon Capture



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

AFOLU - Agriculture, Forestry and Other Land Use

CDR - Carbon Dioxide Removal

BECCS - Bioenergy with Carbon Capture and Storage

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

WORLD ECONOMIC FORUM

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

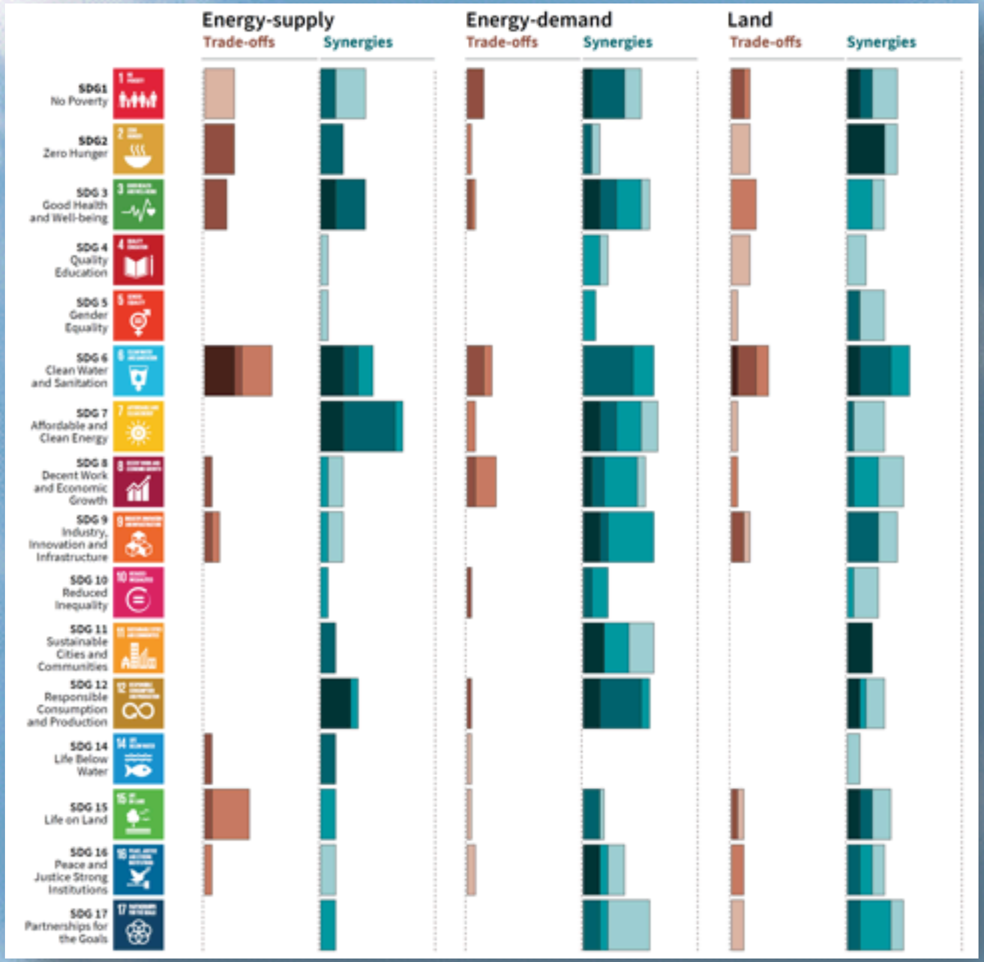
Economic Environmental Geopolitical Societal Technological

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

UN 17 goals to transform our world

SUSTAINABLE DEVELOPMENT GOALS

Mitigation options and sustainable development using SDGs



Potential positive effects (synergies)
Negative effects (trade-offs) with the SDGs

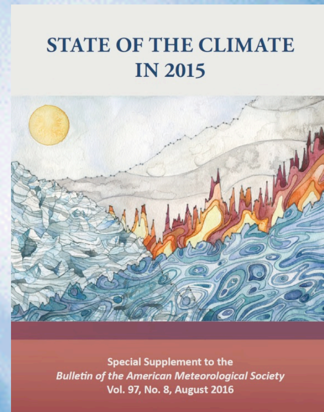
IPCC SR1.5, 2018

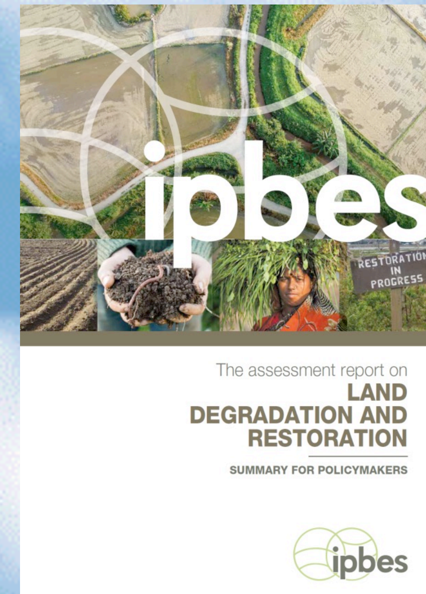
Ethical issues

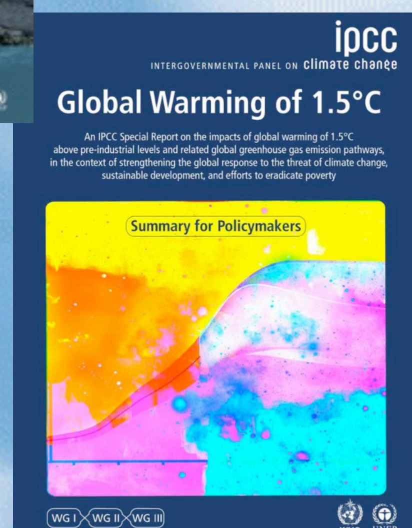
Encyclical Letter *LAUDATO SI' of Pope Francis (2015)*

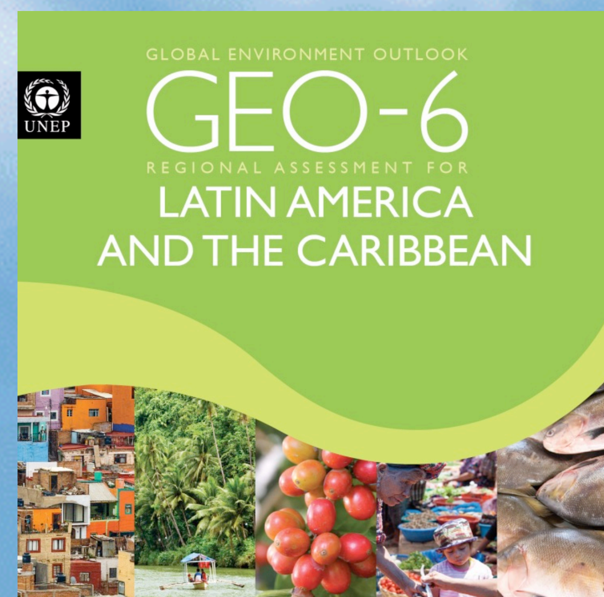
I urgently appeal for a new dialogue about how we are shaping the future of our planet. We need a conversation which includes everyone, since the environmental challenge we are undergoing, and its human roots, concern and affect us all.

Science basically have done his job…

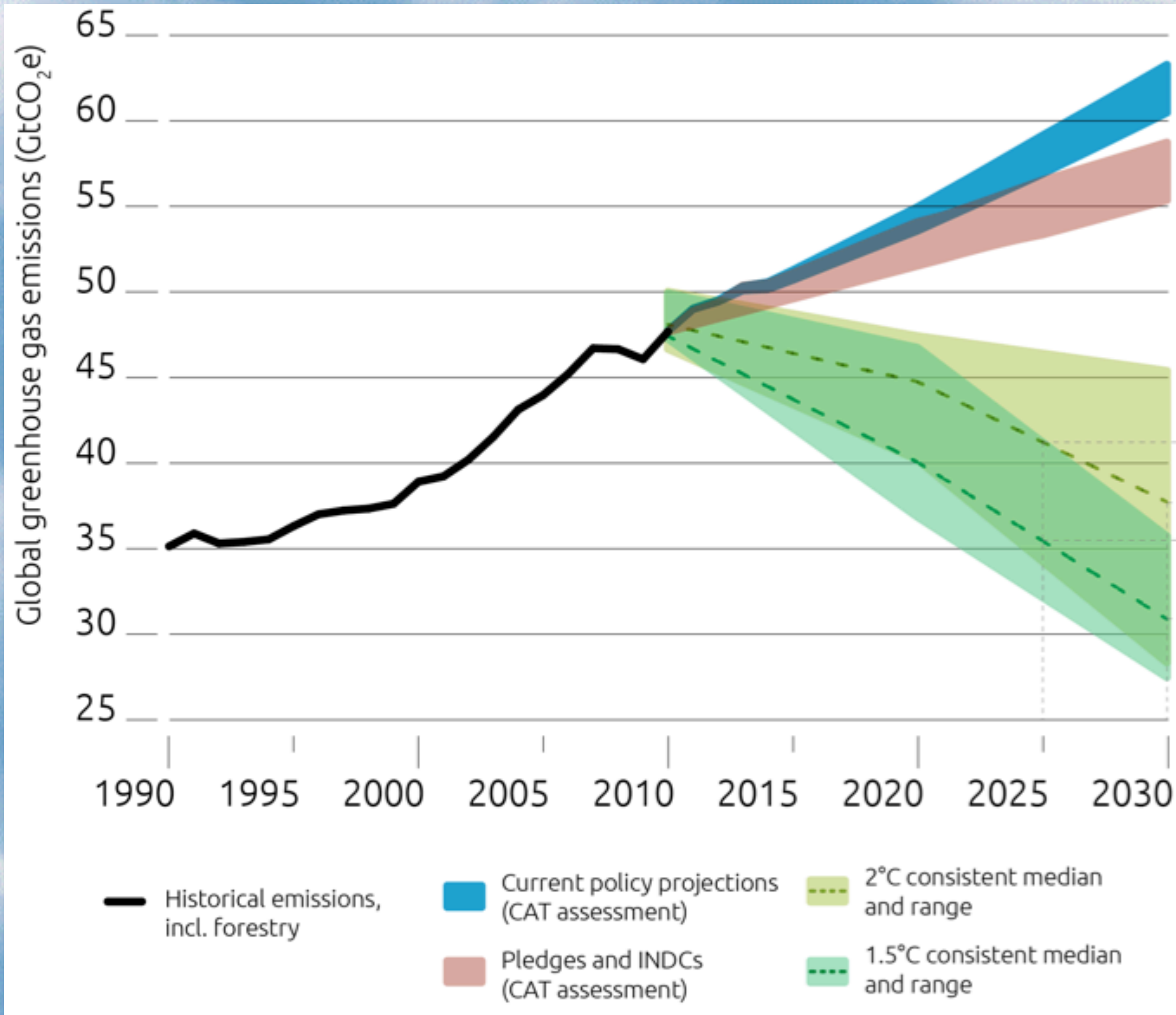


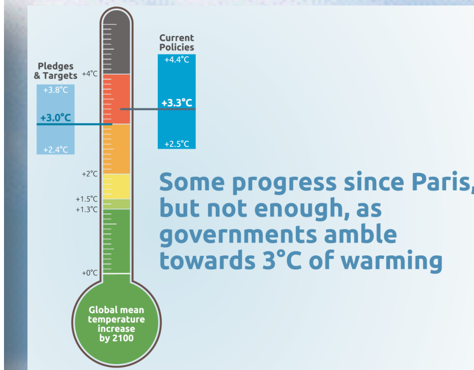






Paris Agreement: IF all iNDC fulfilled: warming of about 3.0 degrees in 2050





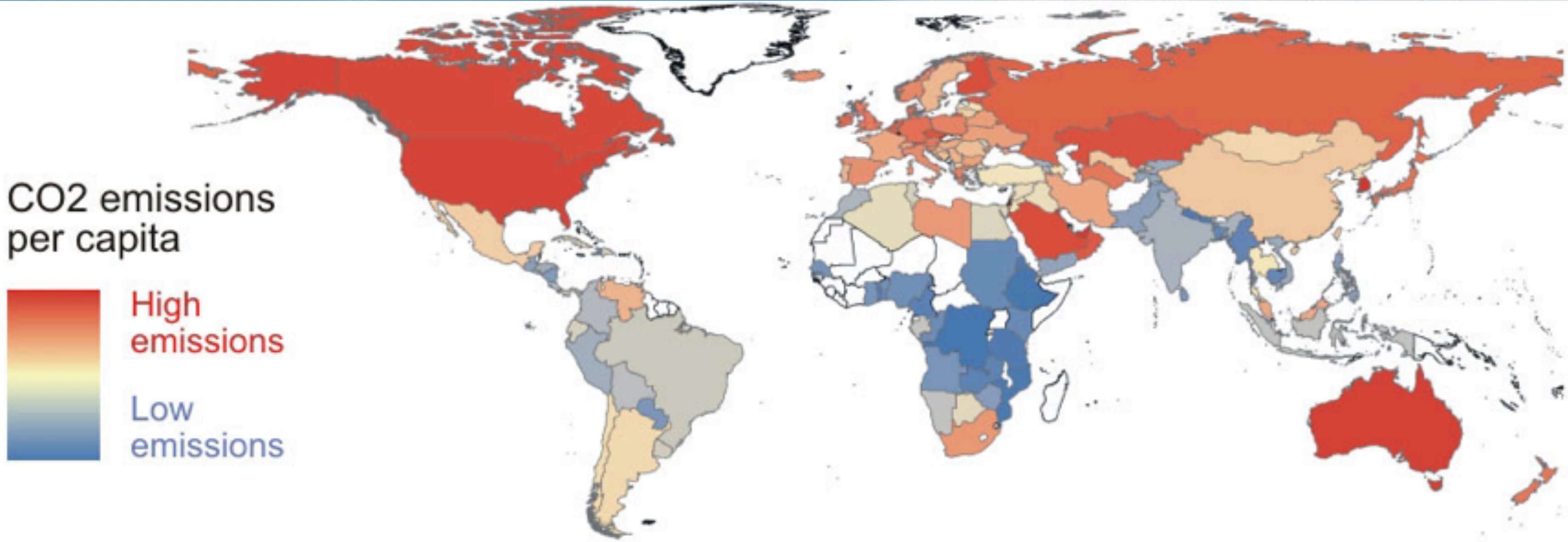
http://climateactiontracker.org

Brazilian iNDC

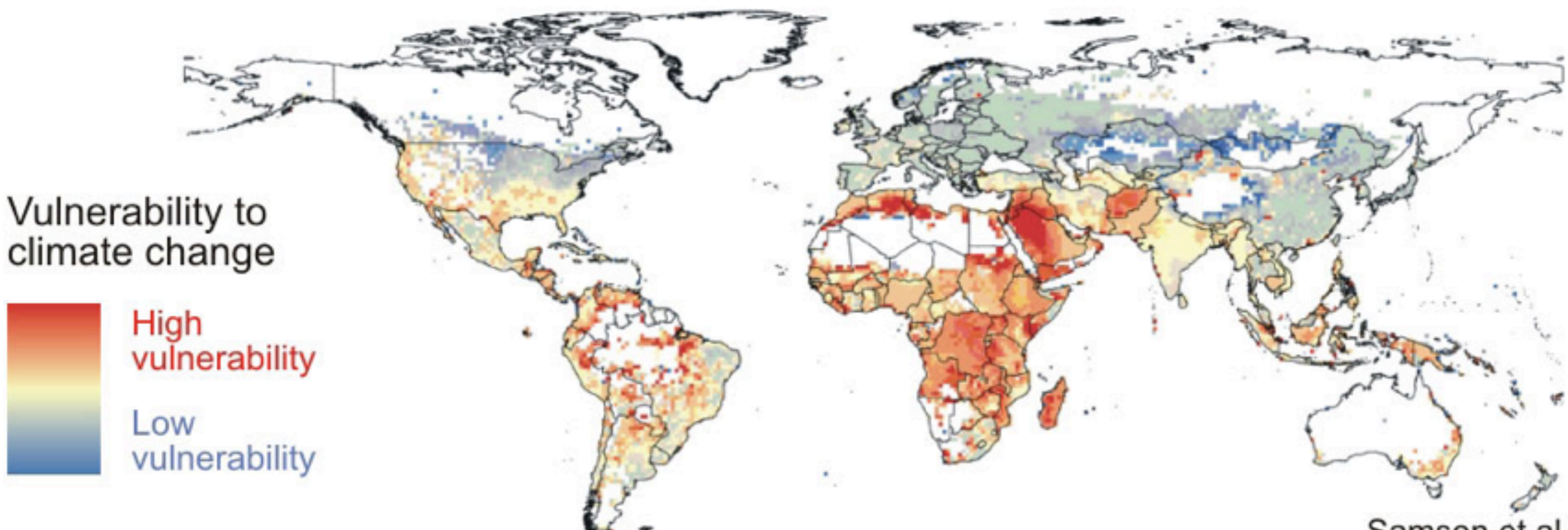
Emissions reductions in 2025	Reduction in 2030
37%	**43%**

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**



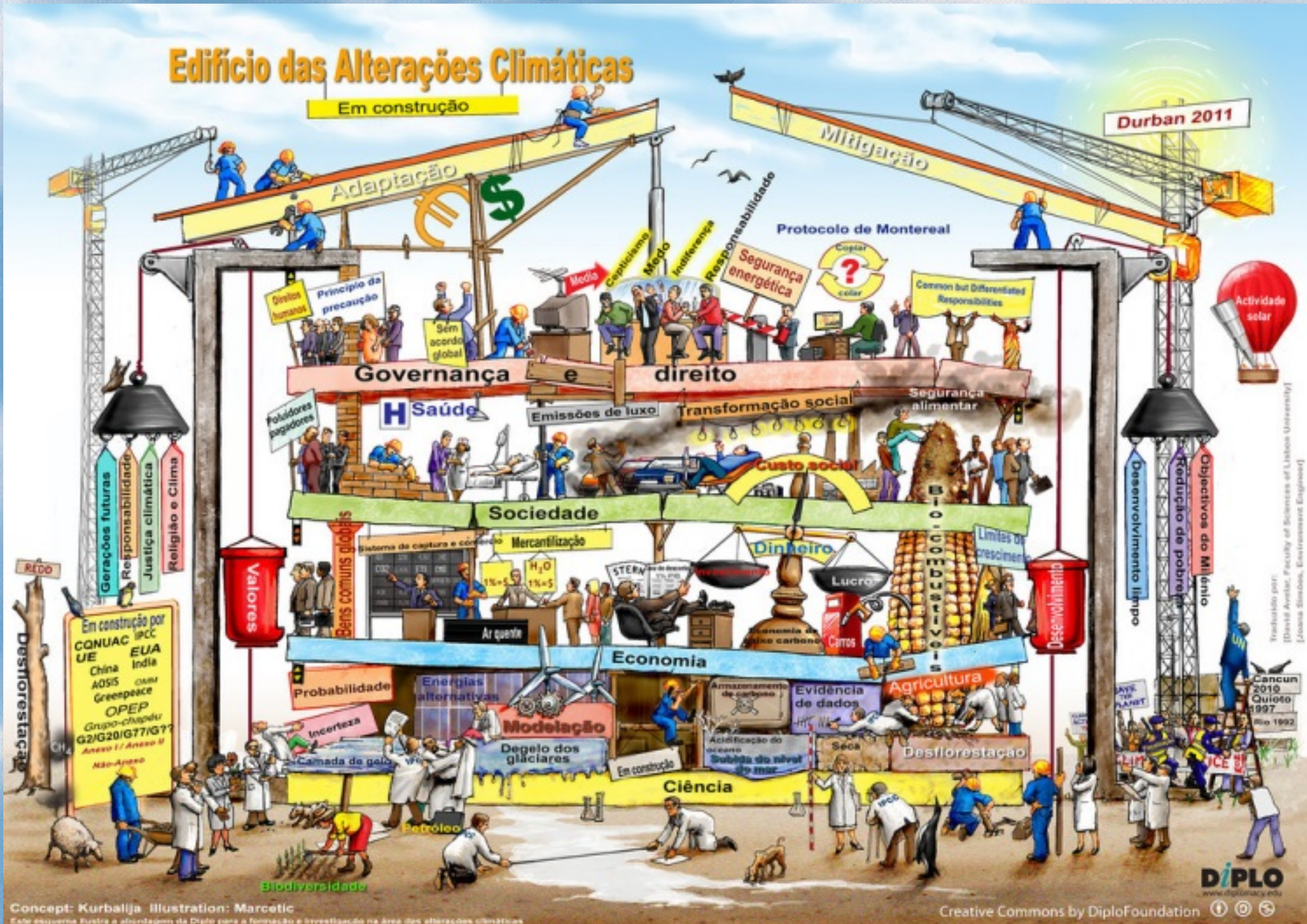
Those who contribute the least greenhouse gases will be most impacted by climate change



Samson et al 2011

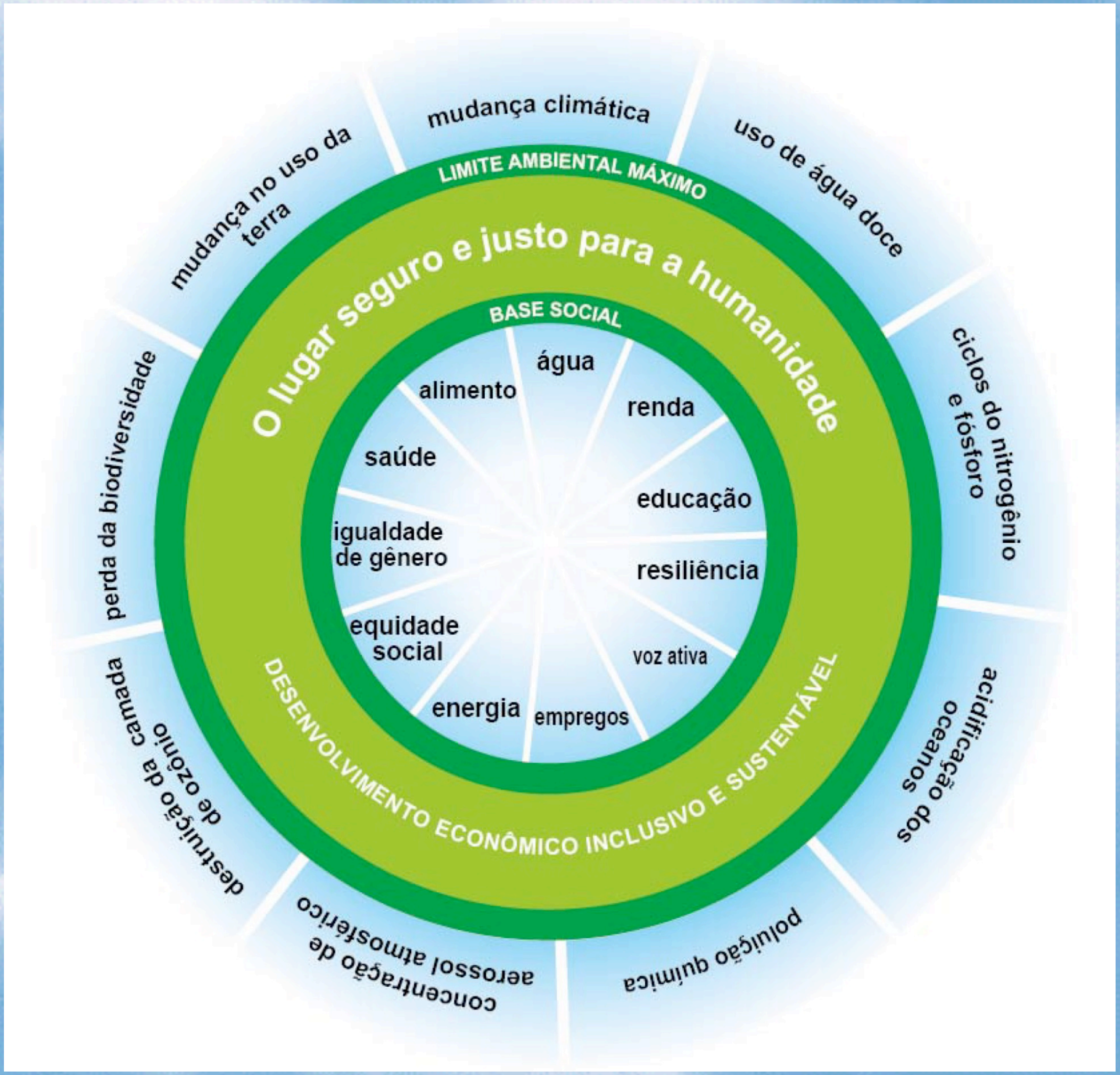
Global inequality is a big issue: consumption in one week…

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

We need solid science and public policies to build this space

SDGs and the six transformations required for The World in 2050

Source: TWI2050

Aerosols are a very critical ingredient of the climate system.

Let´s learn its role in the next 2 weeks!!!

Thanks for the attention!!!