Climate Change:
A Defining Challenge for the 21st Century?

Svante Arrhenius

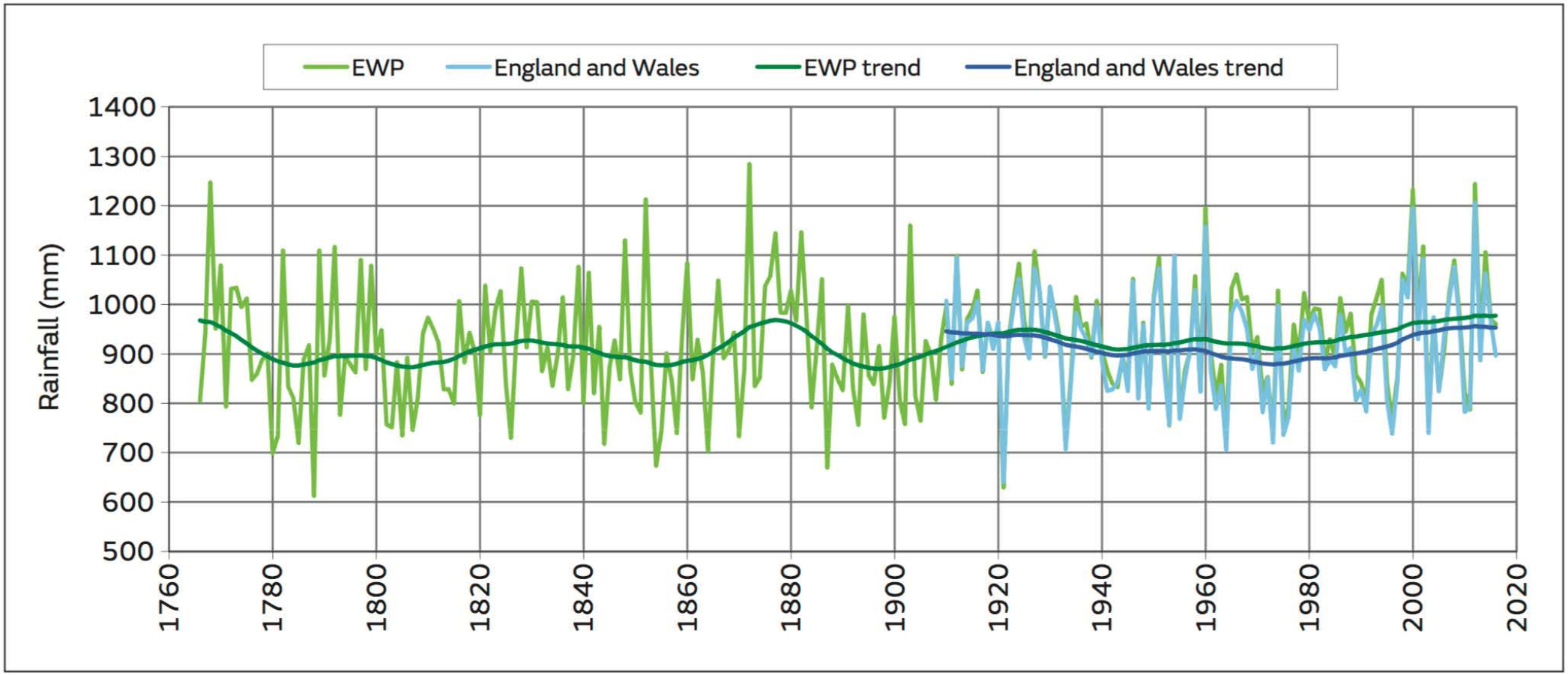
1859 – 1927

In his book on '*Worlds in the Making*' published in 1908 Arrhenius wrote: *" The enormous combustion of coal by our industrial establishments suffices to increase the percentage of carbon dioxide in the air to a perceptible degree.....any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4°C; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°C."*

"By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind."

What is Climate?

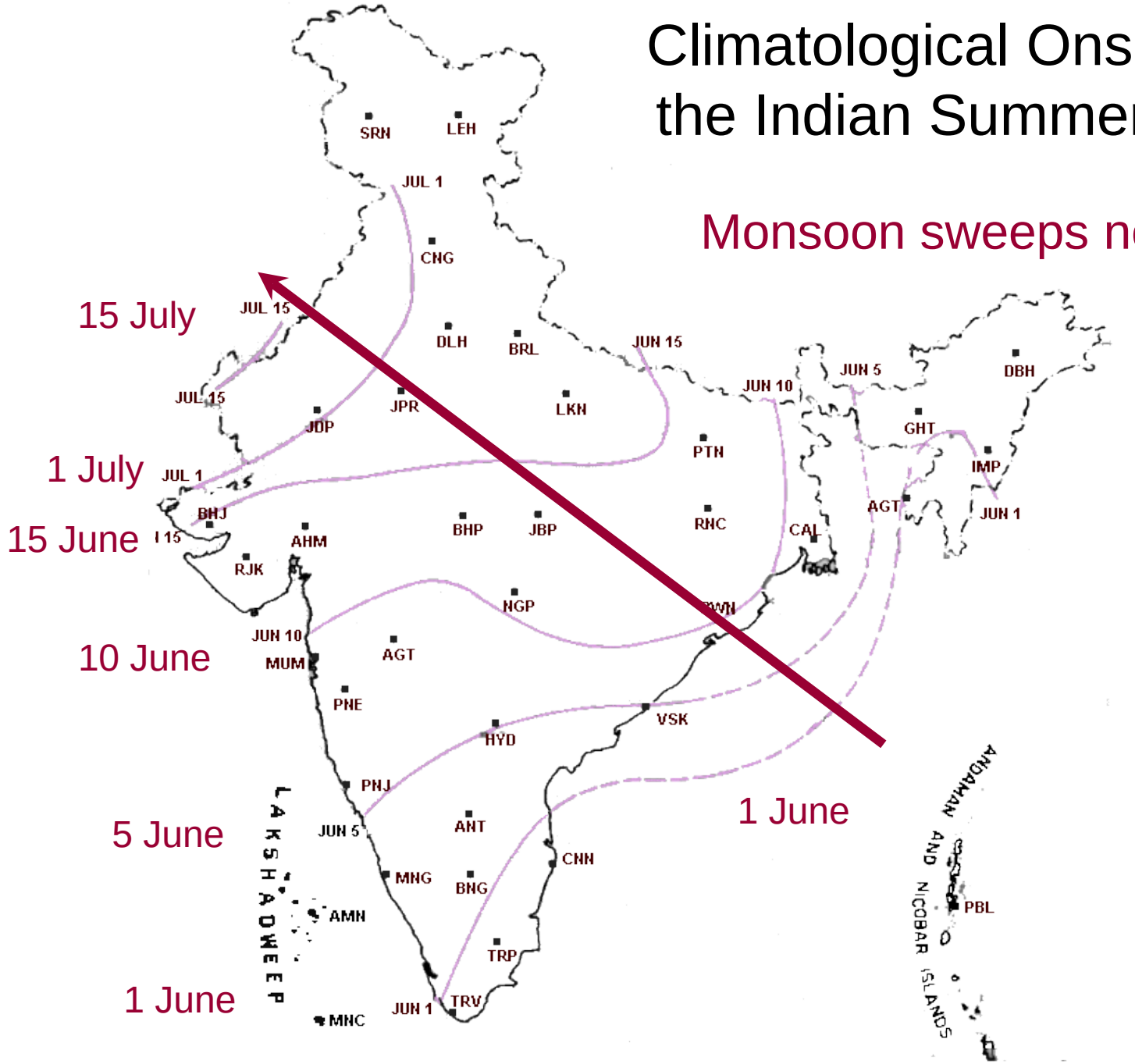
England/Wales Annual Rainfall (mm/day)



Climate is the long-term average of the weather and its variability, season by season and year by year.

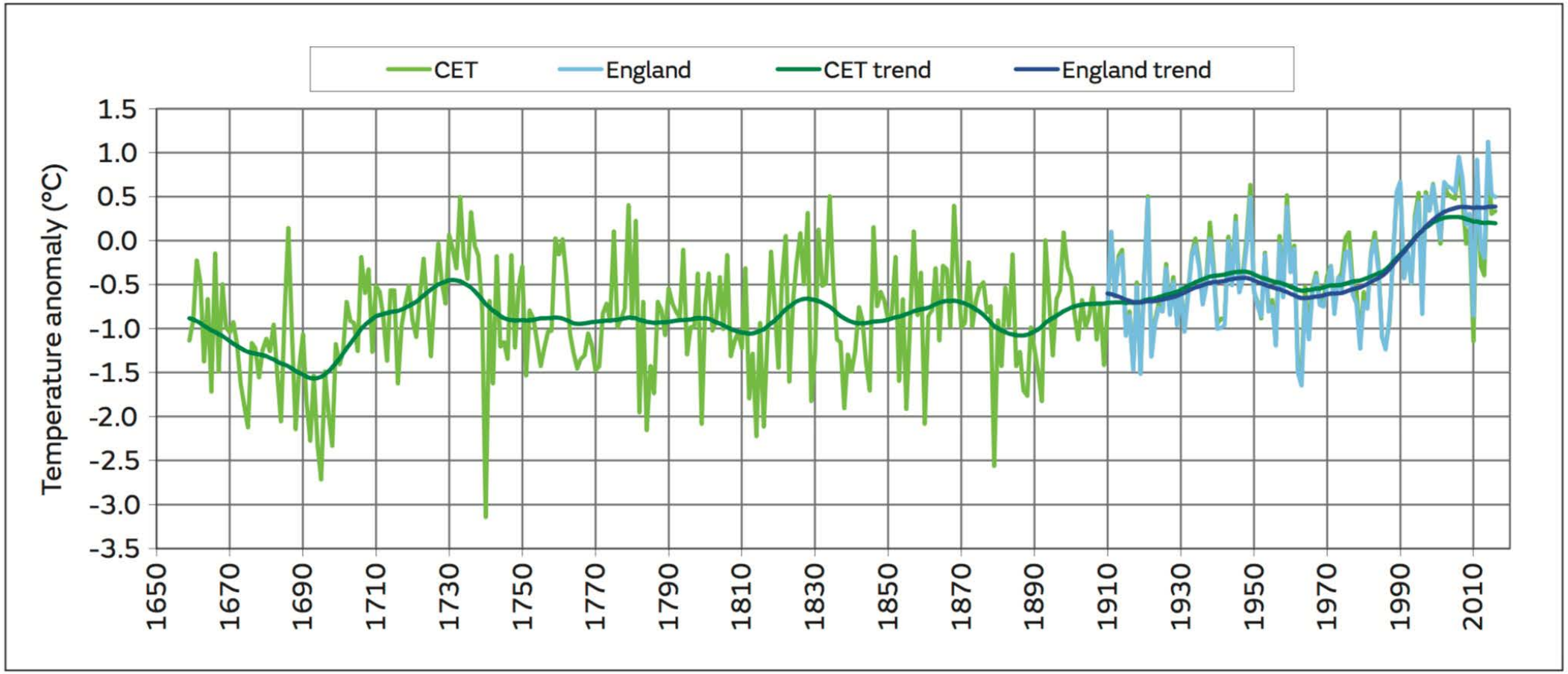
Climatological Onset Dates of the Indian Summer Monsoon

Monsoon sweeps north and west

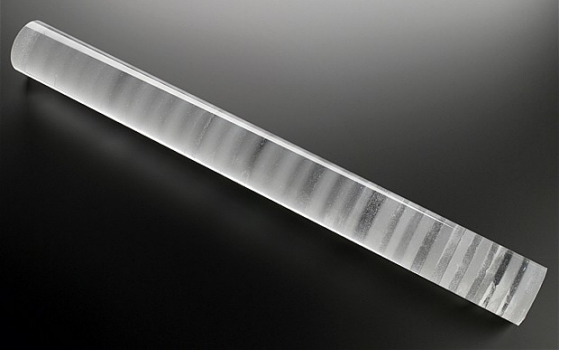


What is Change?

England Annual Temperature Anomaly (°C)

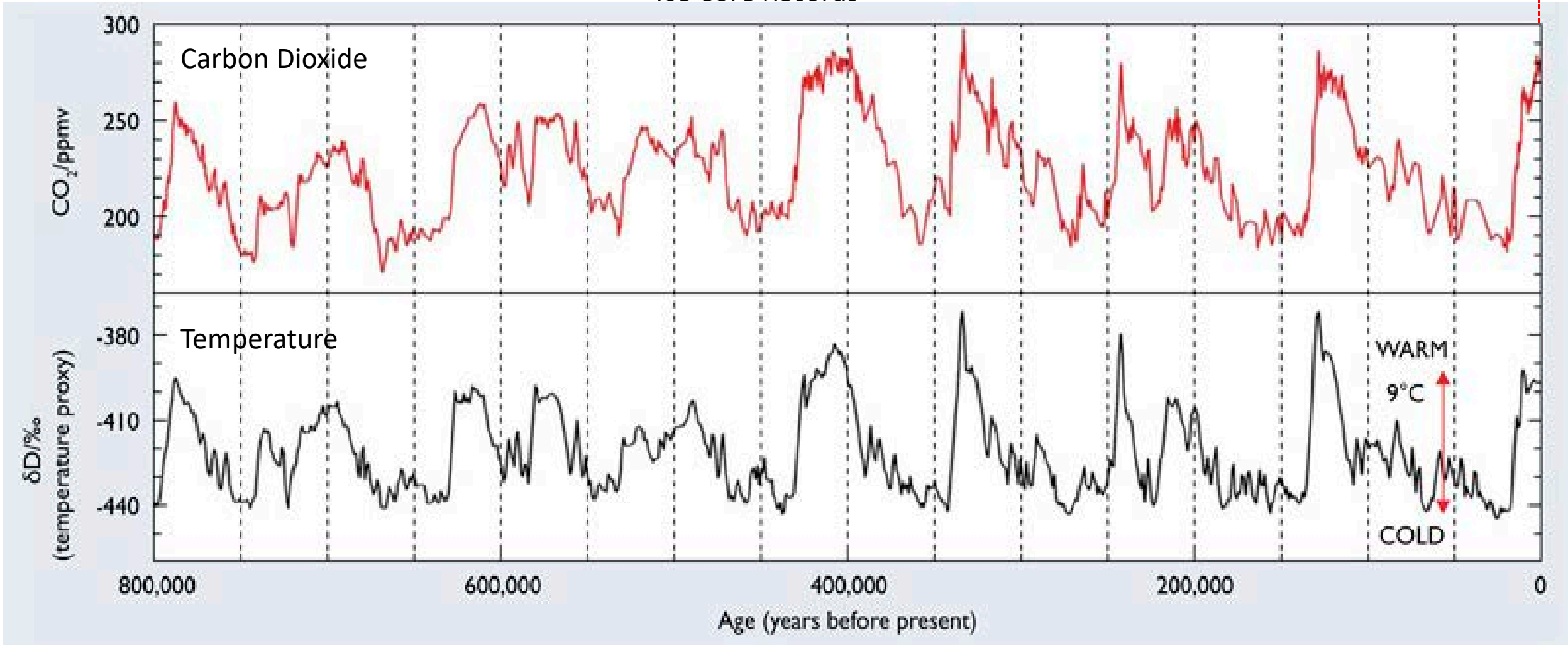


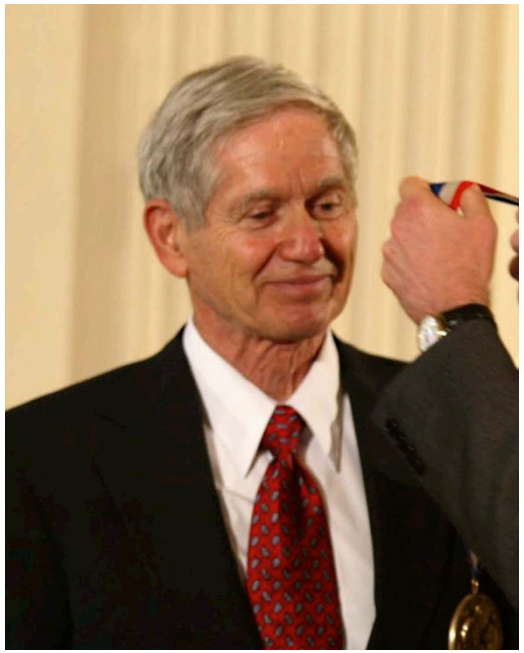
Change is when the climate falls outside the margins that we, as a modern civilization, have experienced and adjusted to.



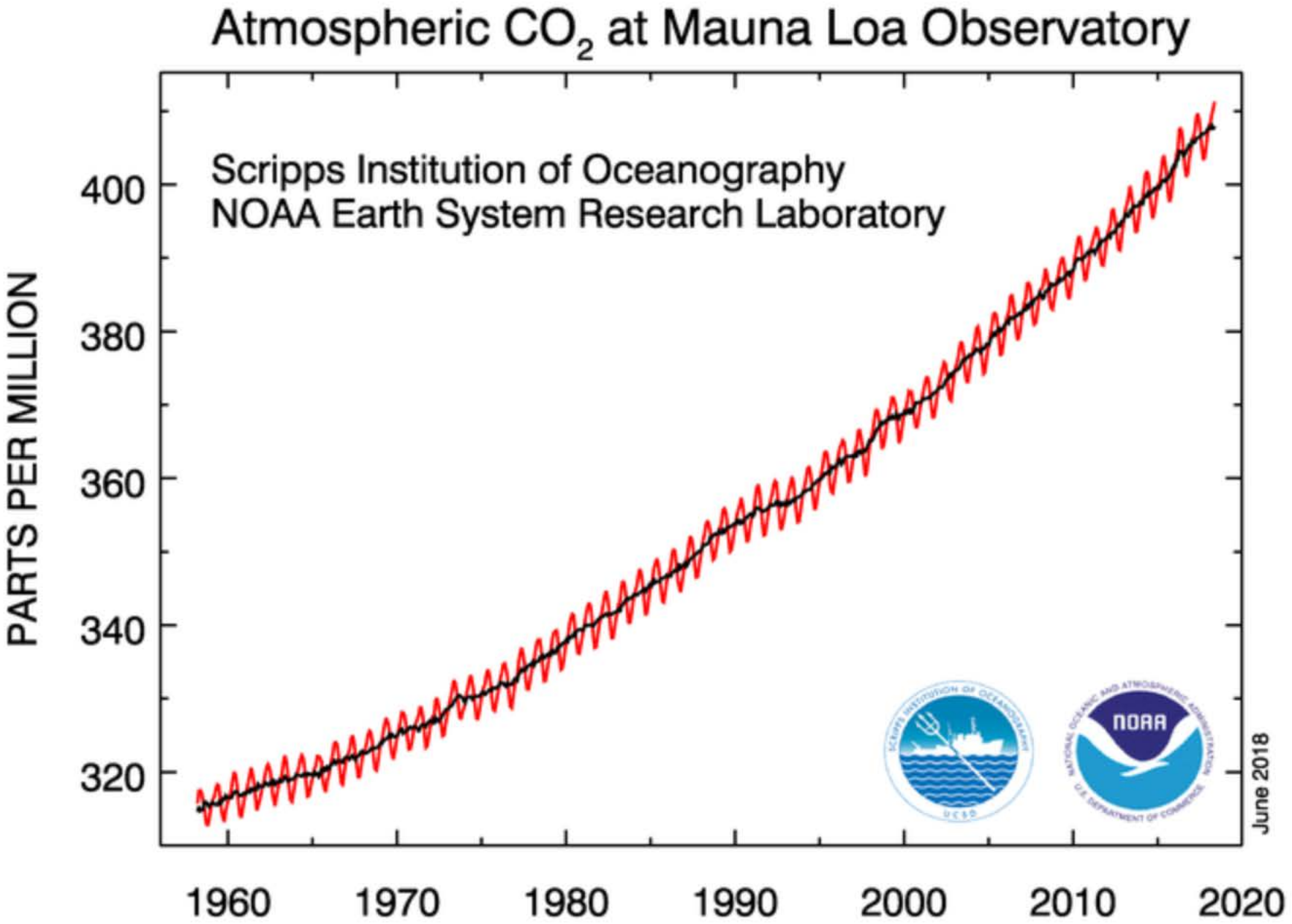
Climate has always changed: 800,000 years of climate trapped in gas bubbles in ice cores from Antarctica

Ice Core Records

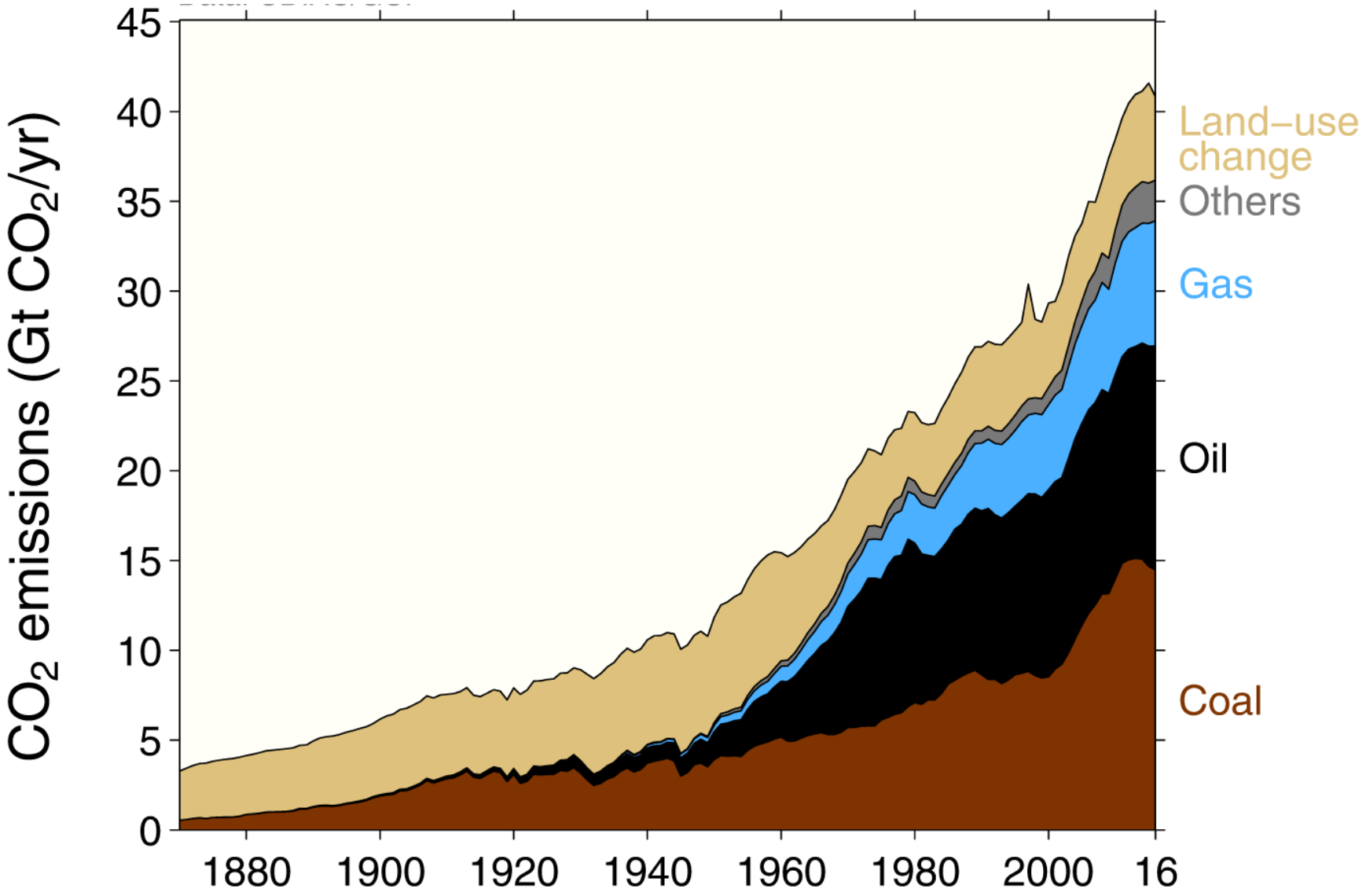




Charles David Keeling,
1928 – 2005



Total global emissions by source



Land-use change was the dominant source of annual CO_2 emissions until around 1950

Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017

Fate of anthropogenic CO_2 emissions (2007–2016)

Sources

34.3 $GtCO_2$/yr

88%

12%

4.9 $GtCO_2$/yr

= Sinks

17.3 $GtCO_2$/yr

47%

30%

11.2 $GtCO_2$/yr

23%

8.7 $GtCO_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

6%

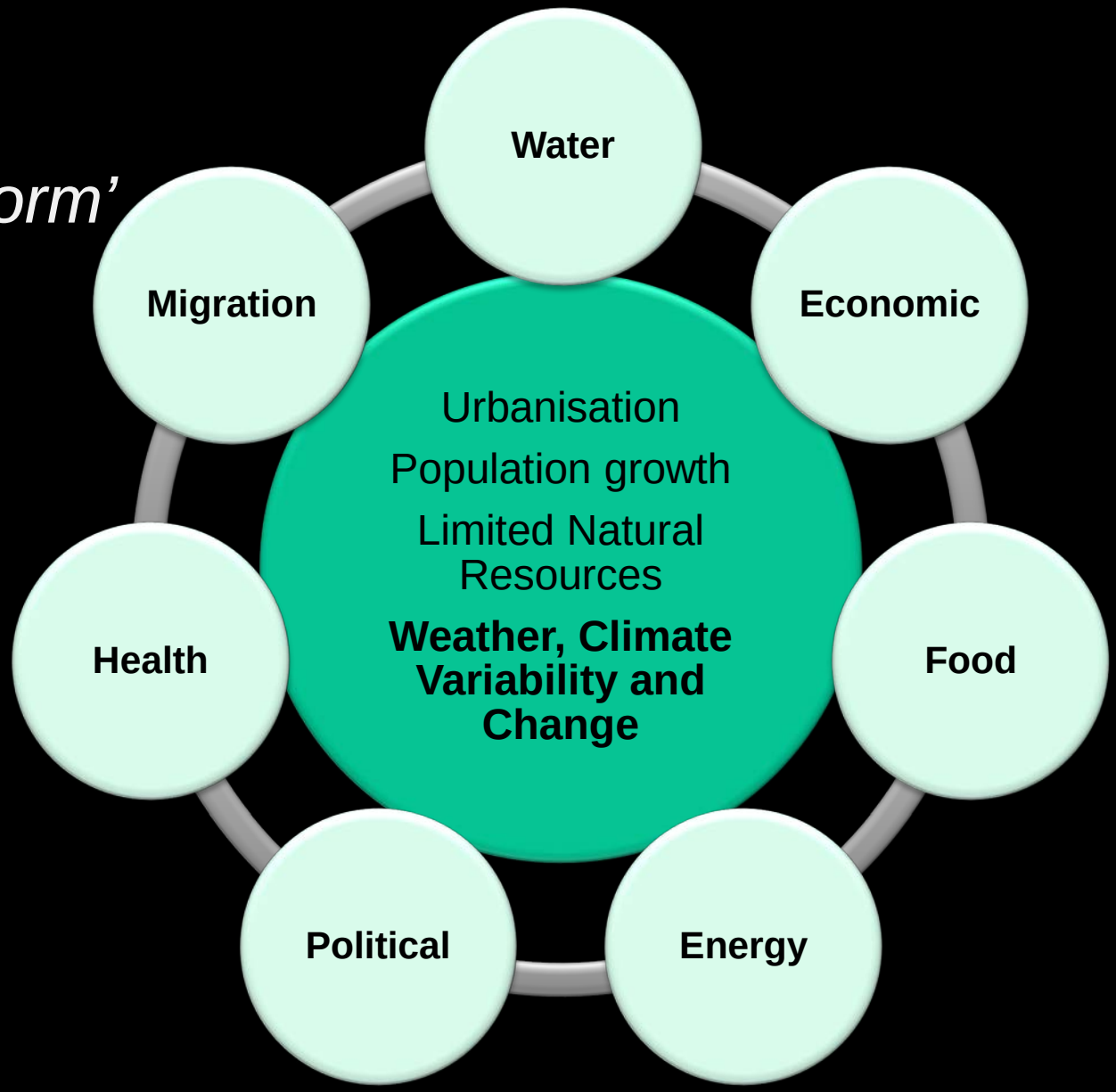
2.1 $GtCO_2$/yr

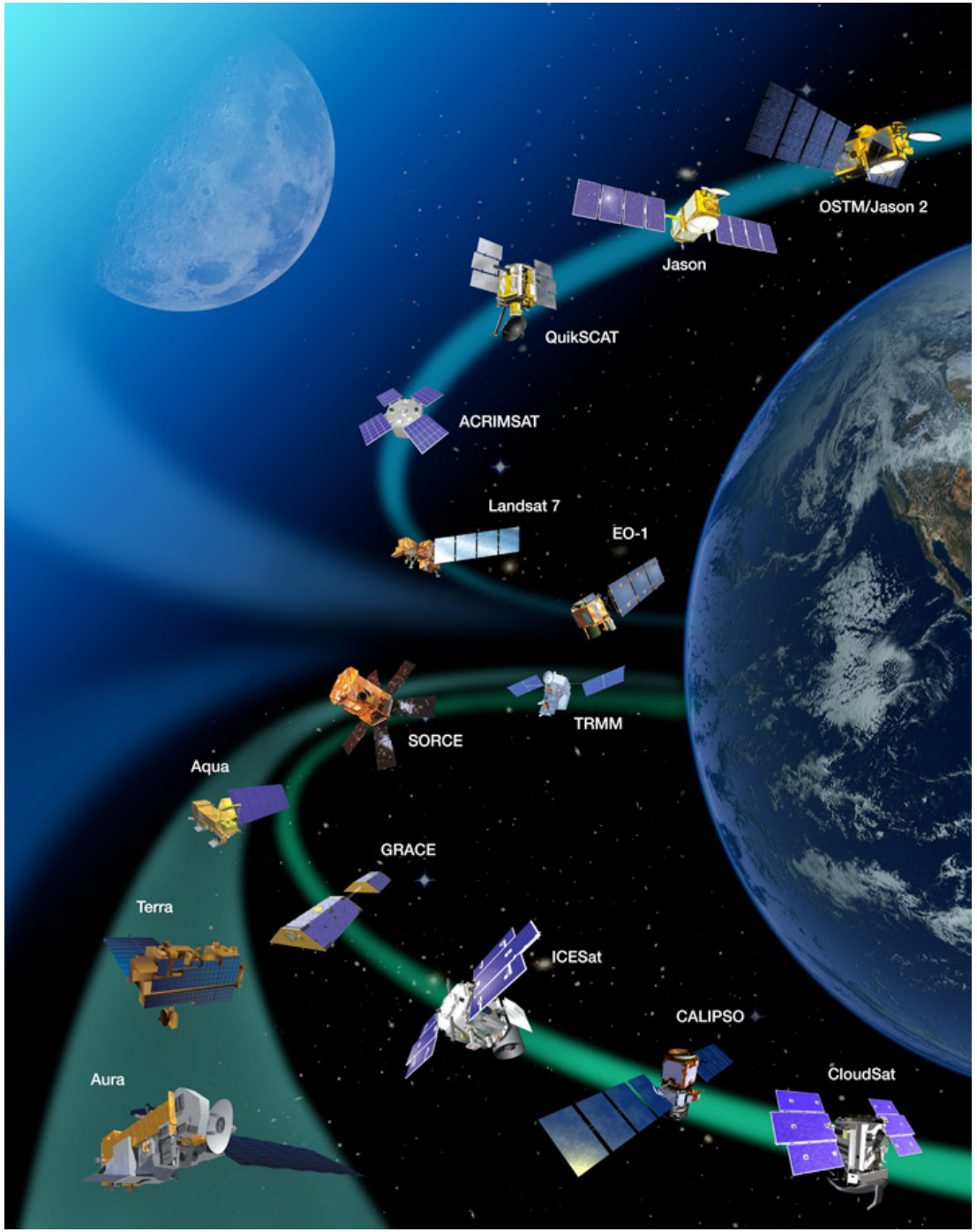
Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017

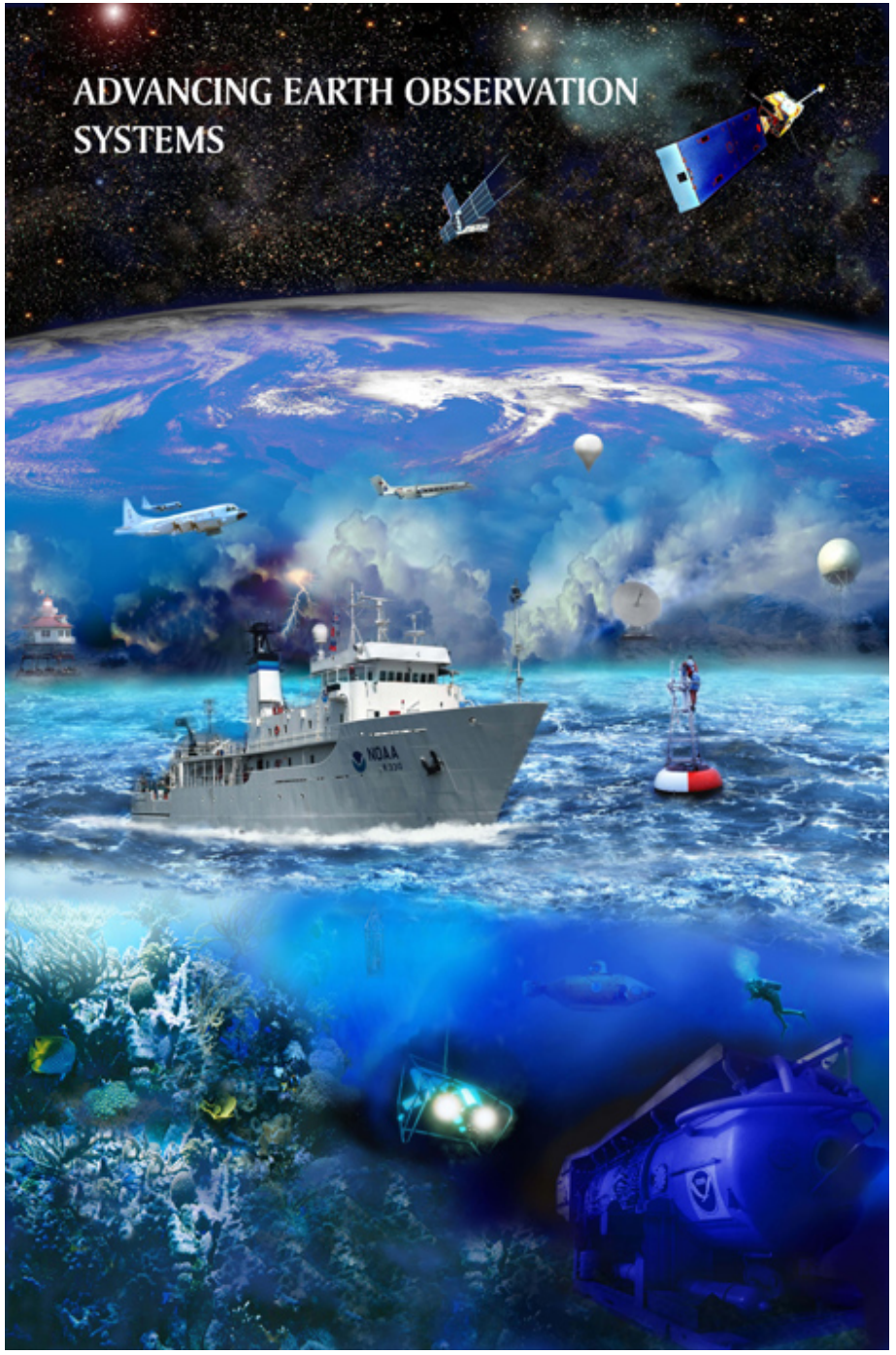
The Scale of the Human Enterprise in a Globally Interdependent World

Sir John Beddington – 'The Perfect Storm'

- Can 9 billion people be fed equitably, healthily and sustainably?
- Can we cope with the future demands on water?
- Can we provide enough energy to supply the growing population coming out of poverty?
- Can we do all this whilst mitigating and adapting to climate change?

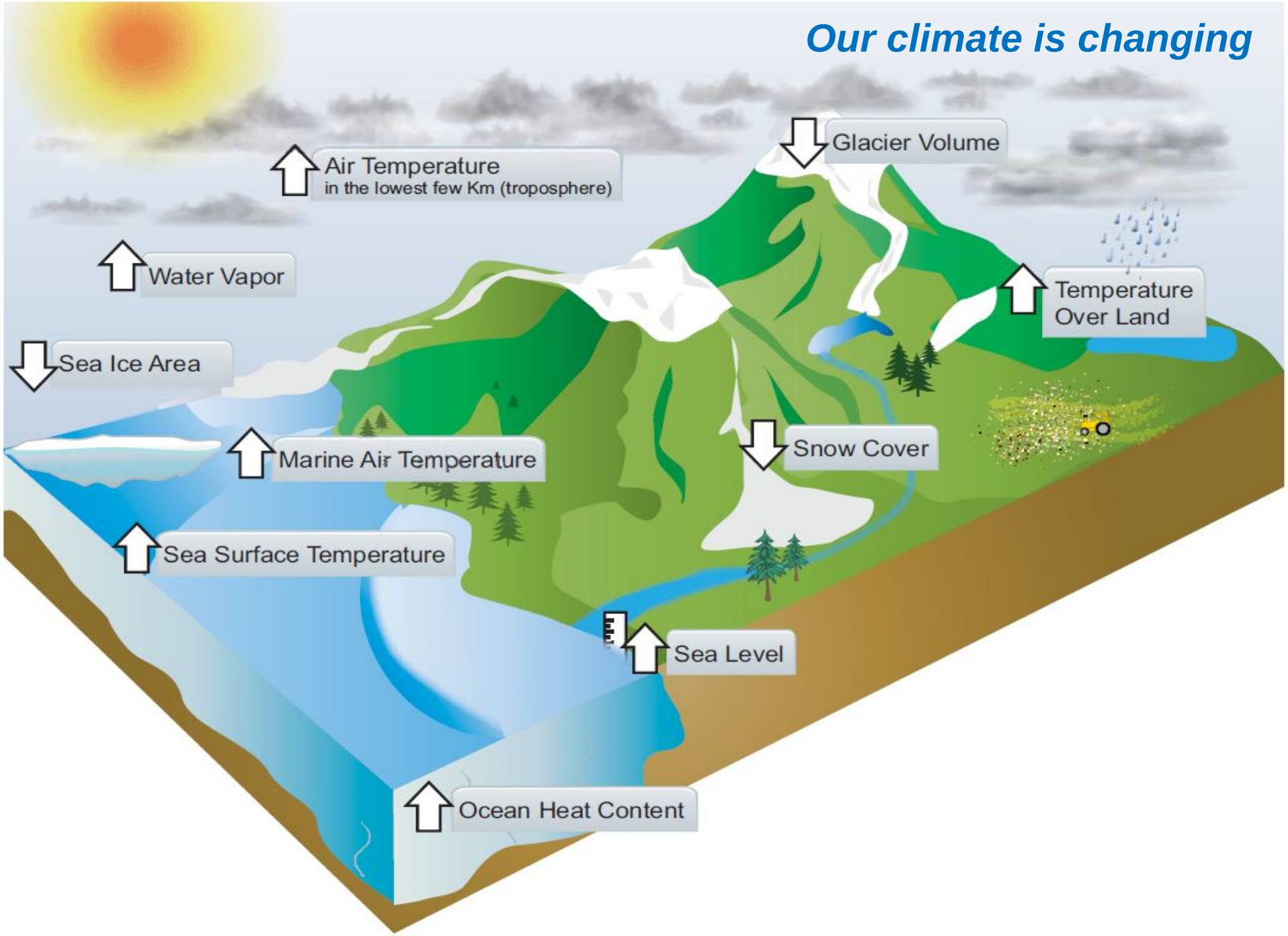



OSTM/Jason 2
Jason
QuikSCAT
ACRIMSAT
Landsat 7
EO-1
SORCE
TRMM
Aqua
GRACE
Terra
ICESat
CALIPSO
CloudSat
Aura

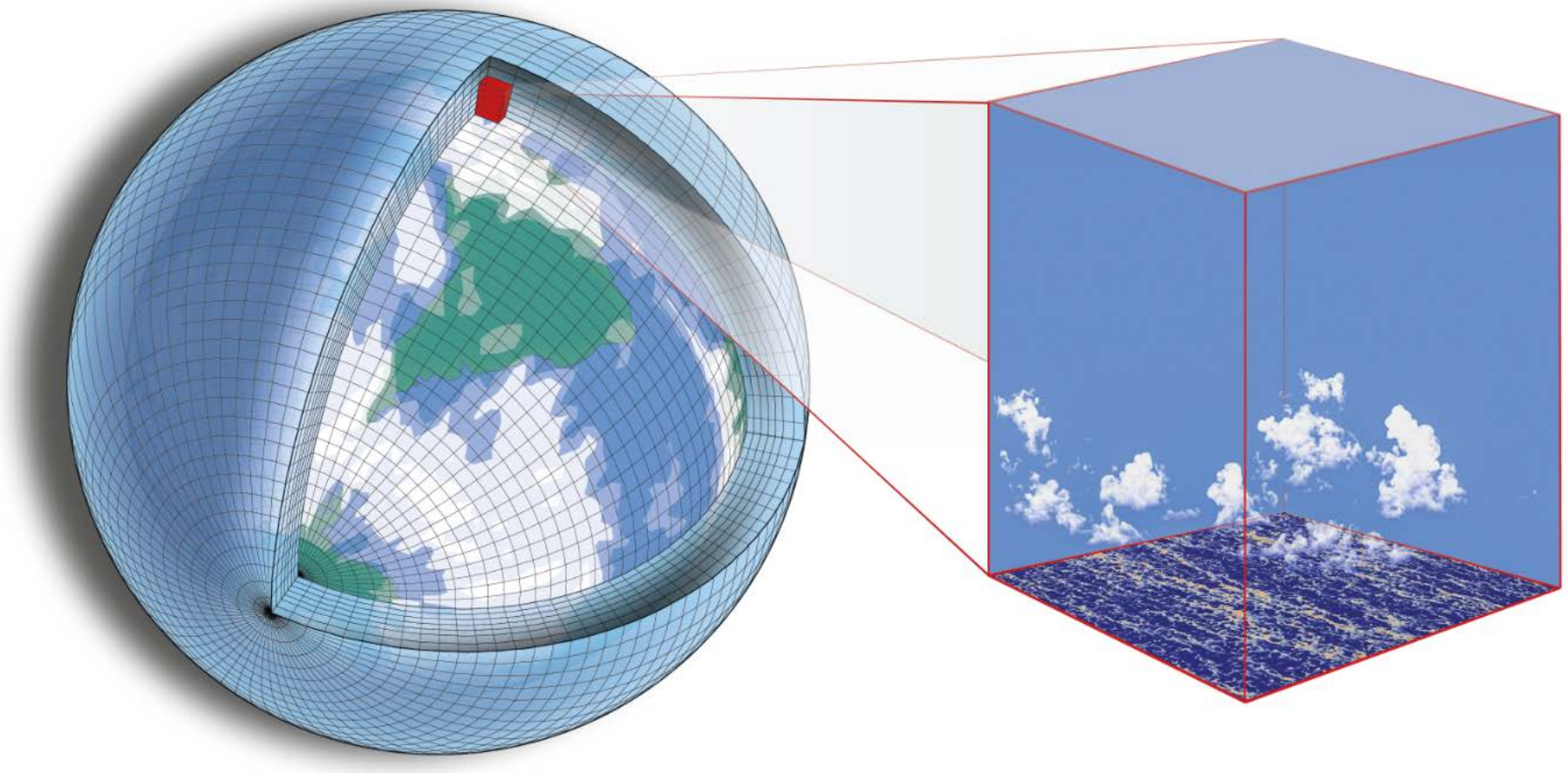

ADVANCING EARTH OBSERVATION SYSTEMS

Our climate is changing

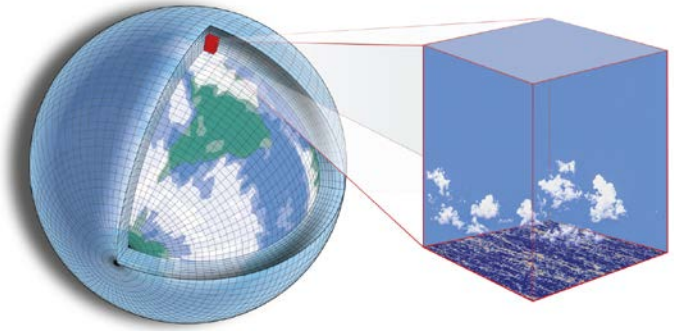
Observations tell us an immense amount about our climate and how it is changing – but not necessarily how it works and why it is changing



Climate Models simulate the climate system based on fundamental laws of physics



Climate Models help us to explain how the climate system works, why it is changing, and what our future climate might be like.



Weather and Climate Models

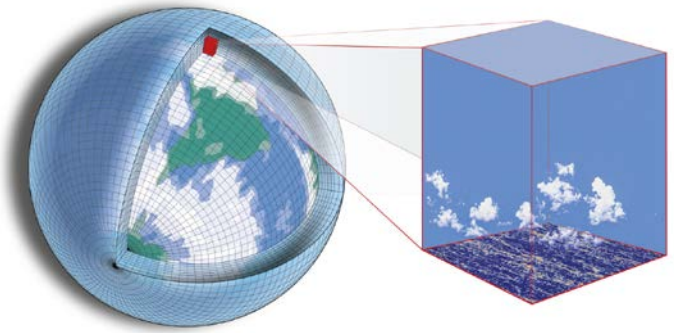
Back to basics: Classical physics

Newton's Second Law of Motion: Force = Mass x Acceleration – how atmospheric winds and ocean currents evolve.

Hydrostatic approximation: Balances vertical pressure gradient force with the pull of gravity – describes how pressure decreases with height.

Mass Continuity equation: Relates vertical motions to the convergence of the wind.

Ideal Gas Equation: Relates temperature with density - warm air rises.



Weather and Climate Models

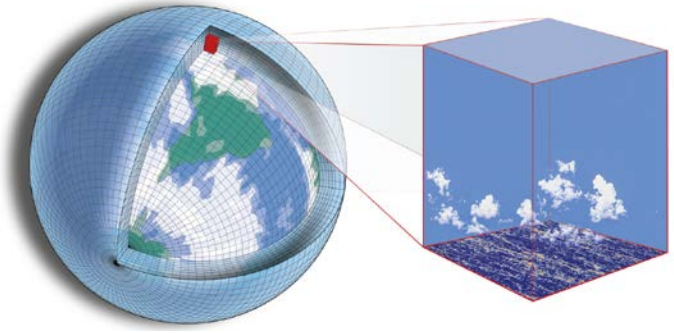
Back to basics: Classical physics

First Law of Thermodynamics: Links heating to changes in the winds – 'heat is work and work is heat'. Latent heat release as clouds and rain/snow form, dominates the Earth's 'heat engine'

Clausius-Clapeyron Equation: Relates saturated water vapour pressure to temperature – warmer air holds more moisture

Planck and Stefan-Boltzmann Laws: Link thermal radiation emitted by a 'black body' (e.g. Earth's surface, most clouds) to temperature

Kirchoff's Law: Links absorption and emission of radiation by atmospheric gases.



Weather and Climate Models
Back to basics: Classical physics

These physics equations are integrated forward in time to simulate:

- Flow of air and water - winds in the atmosphere, currents in the ocean.
- Exchange of heat (sensible and latent) and momentum between the atmosphere and the earth's surface
- Release of latent heat by condensation during the formation of clouds and raindrops
- Absorption of solar radiation and emission of thermal (infra-red) radiation

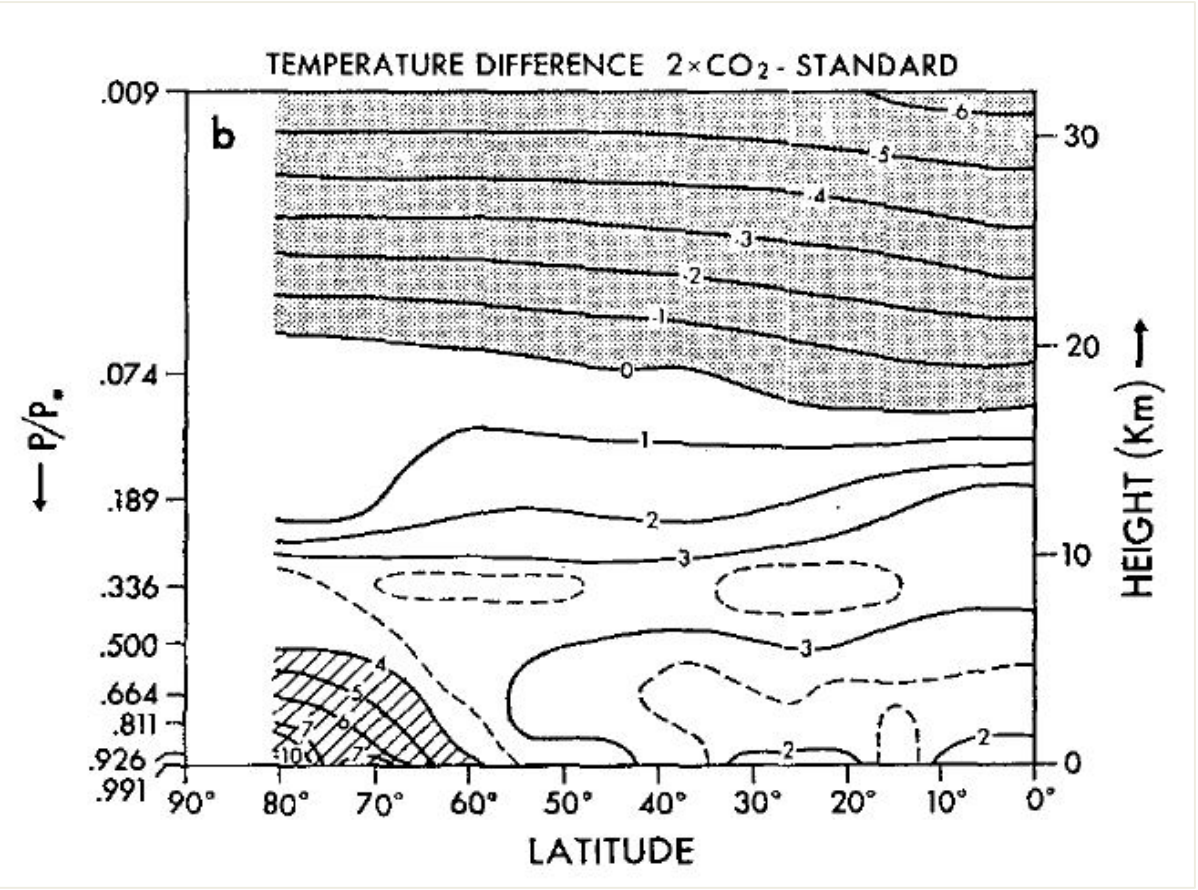
The output is a simulation of the 3-dimensional evolution, over years to centuries, of the world's weather and climate

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

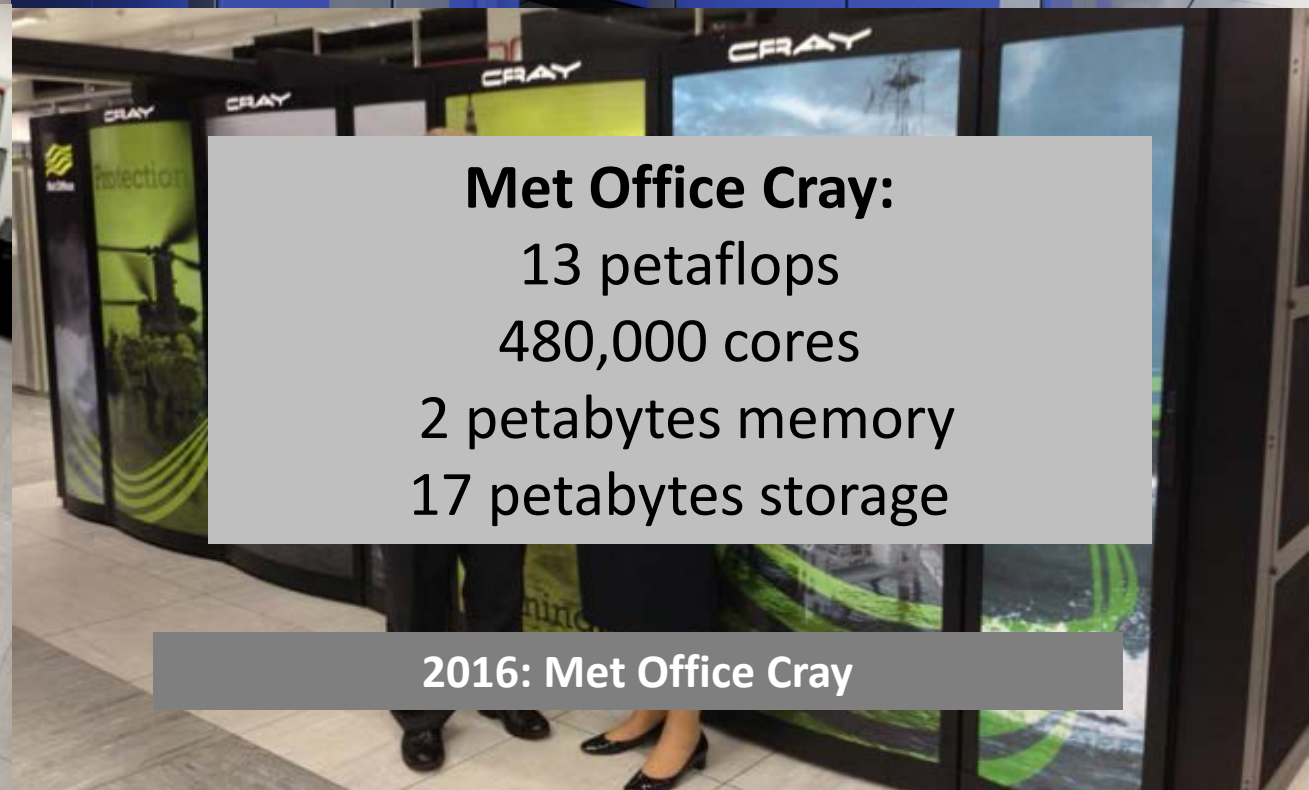
(Manuscript received 6 June 1974, in revised form 8 August 1974)



- Global warming of 2.93K
- Greater warming in the tropical upper troposphere – water vapour feedback
- Stratospheric cooling – increased CO_2 radiating to space
- Enhanced warming at the poles due to loss of snow

1980s: NCAR Cray 1

2000s: Japanese Earth Simulator



Met Office Cray:

13 petaflops

480,000 cores

2 petabytes memory

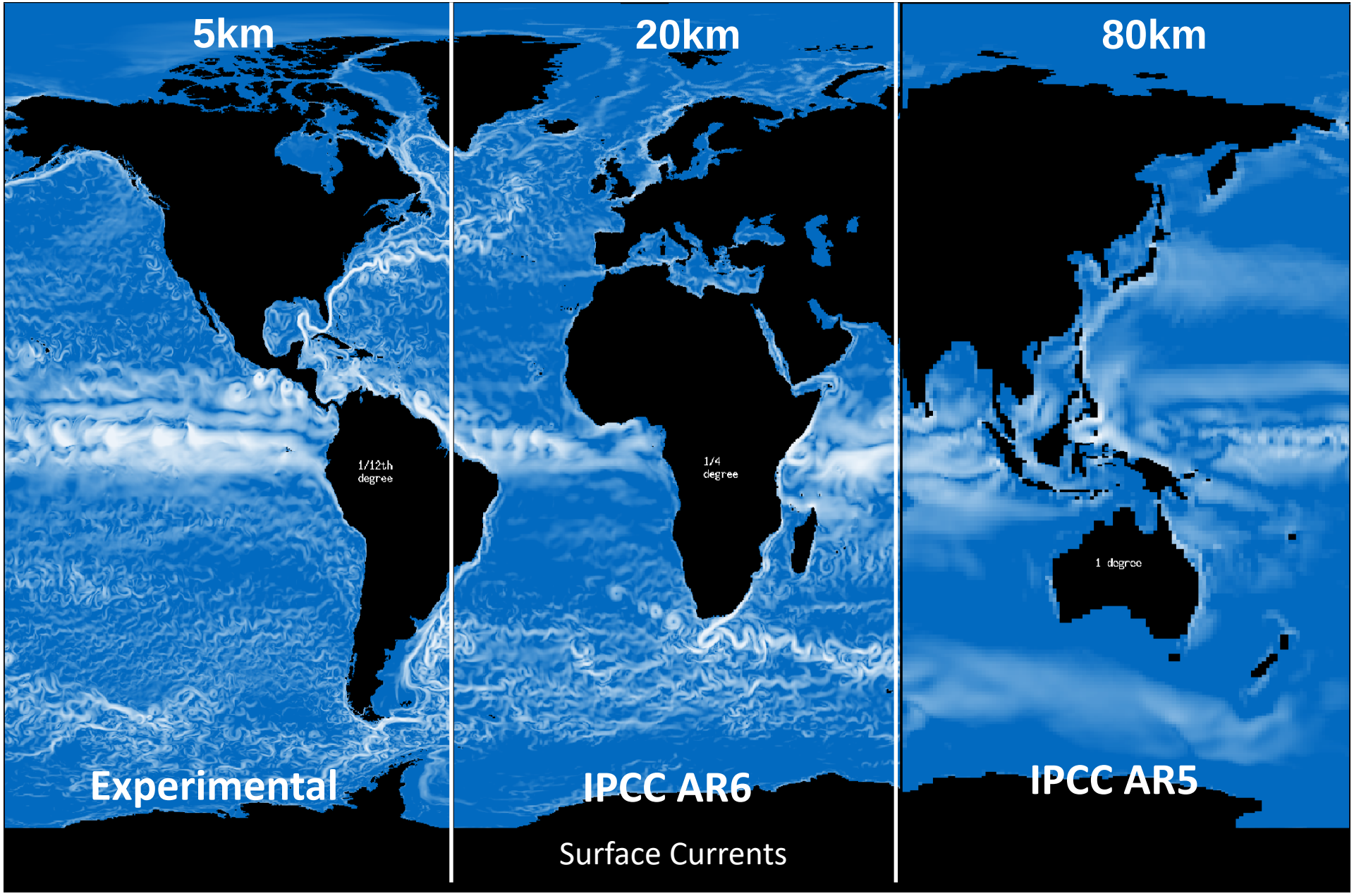
17 petabytes storage

2016: Met Office Cray

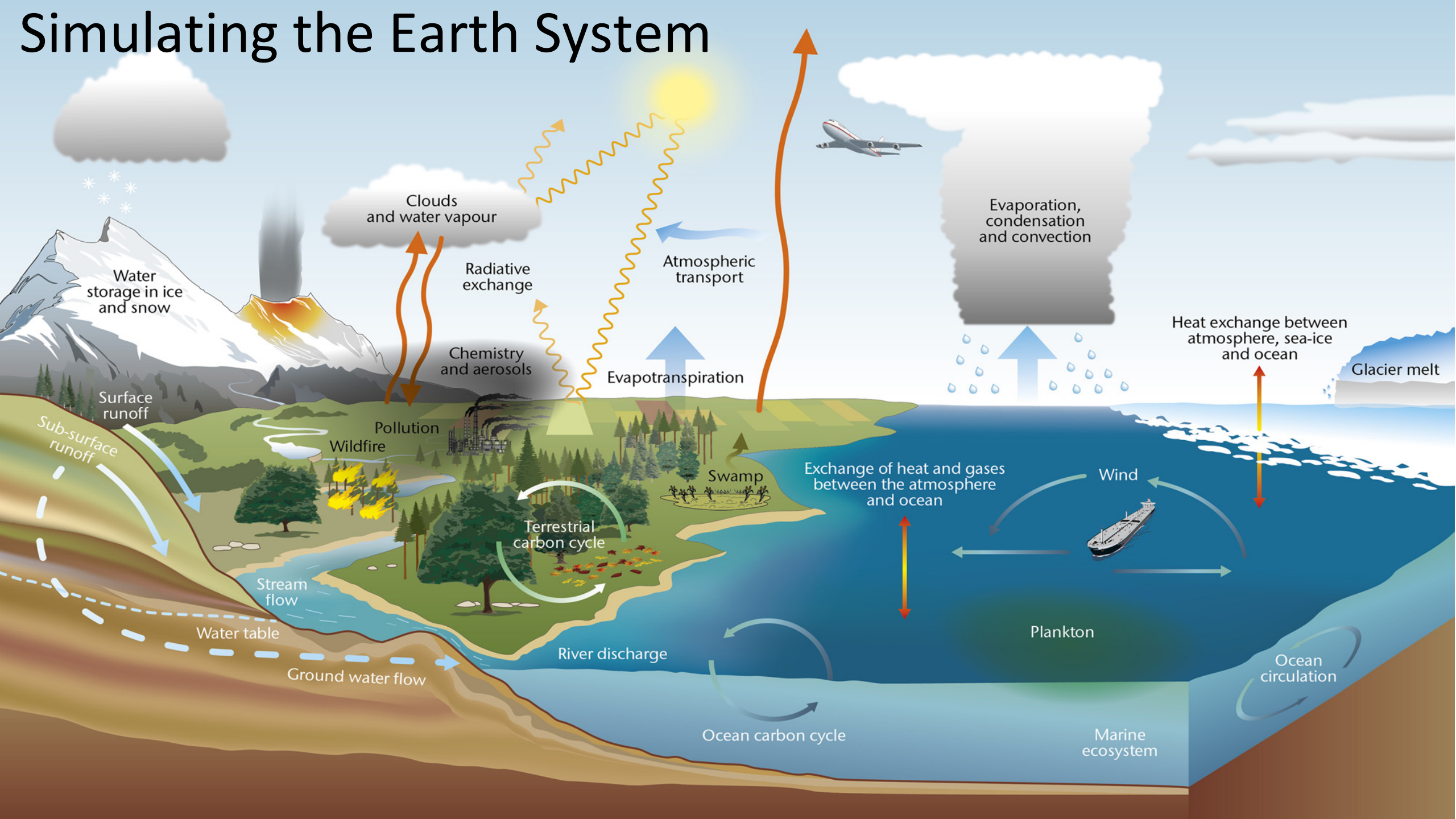
Met Office

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

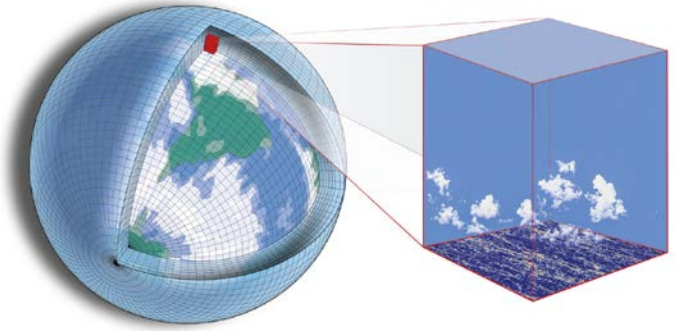
Resolving the ocean



Simulating the Earth System



Simulated Seasonal Cycle in Ocean Biological Production



Climate Models as the '*Laboratories*' of Climate Science

We can't perform experiments on the real world so we use models as our laboratory:

- Test hypotheses about how the climate system varies and changes
- Understand climate responses to forcing agents, such as greenhouses gases, volcanic eruptions, solar variability.
- Pick apart feedbacks and interactions within the climate system
- Perform 'what if' experiments

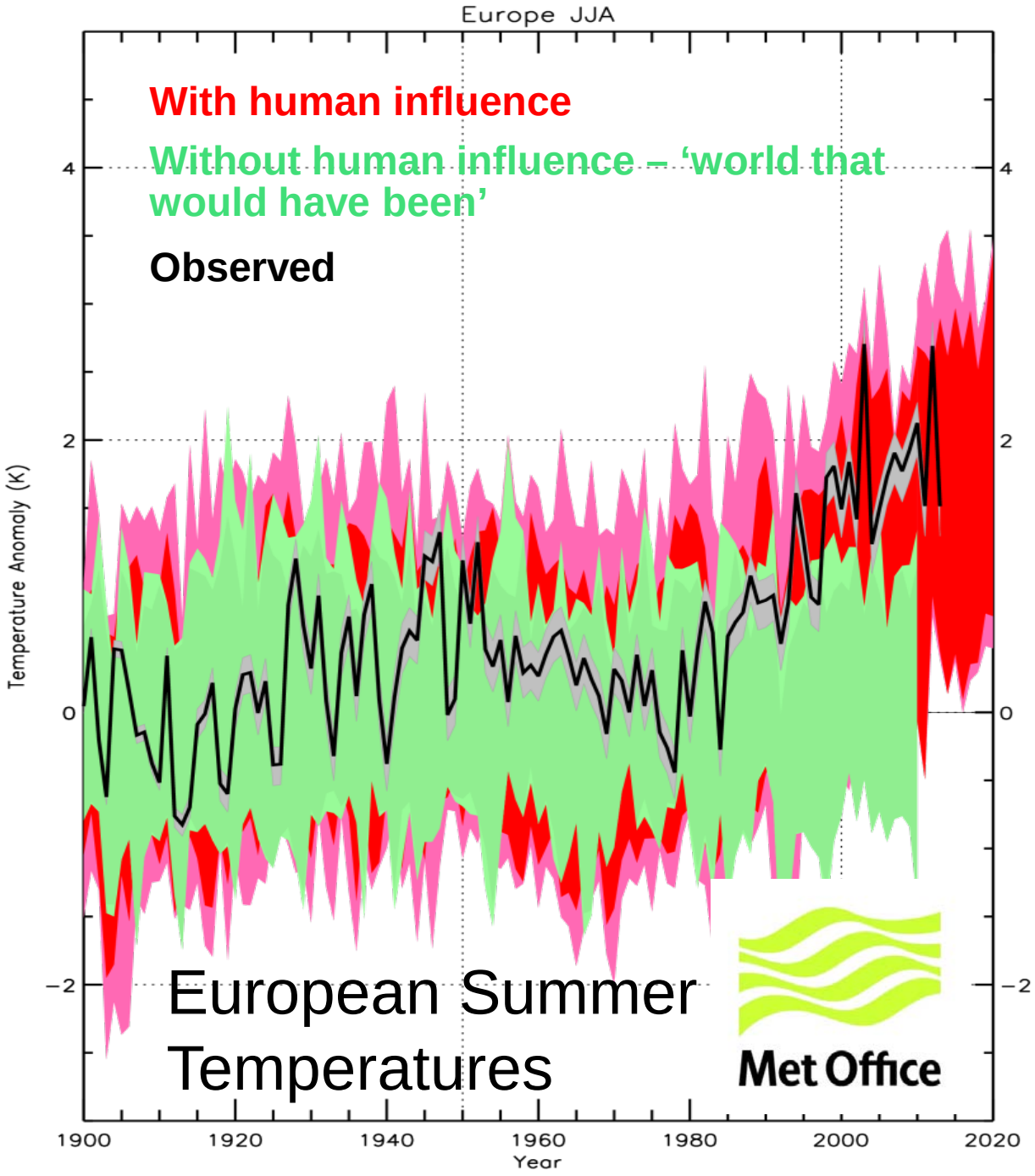
A ‘what if’ experiment……

Multiple simulations of:

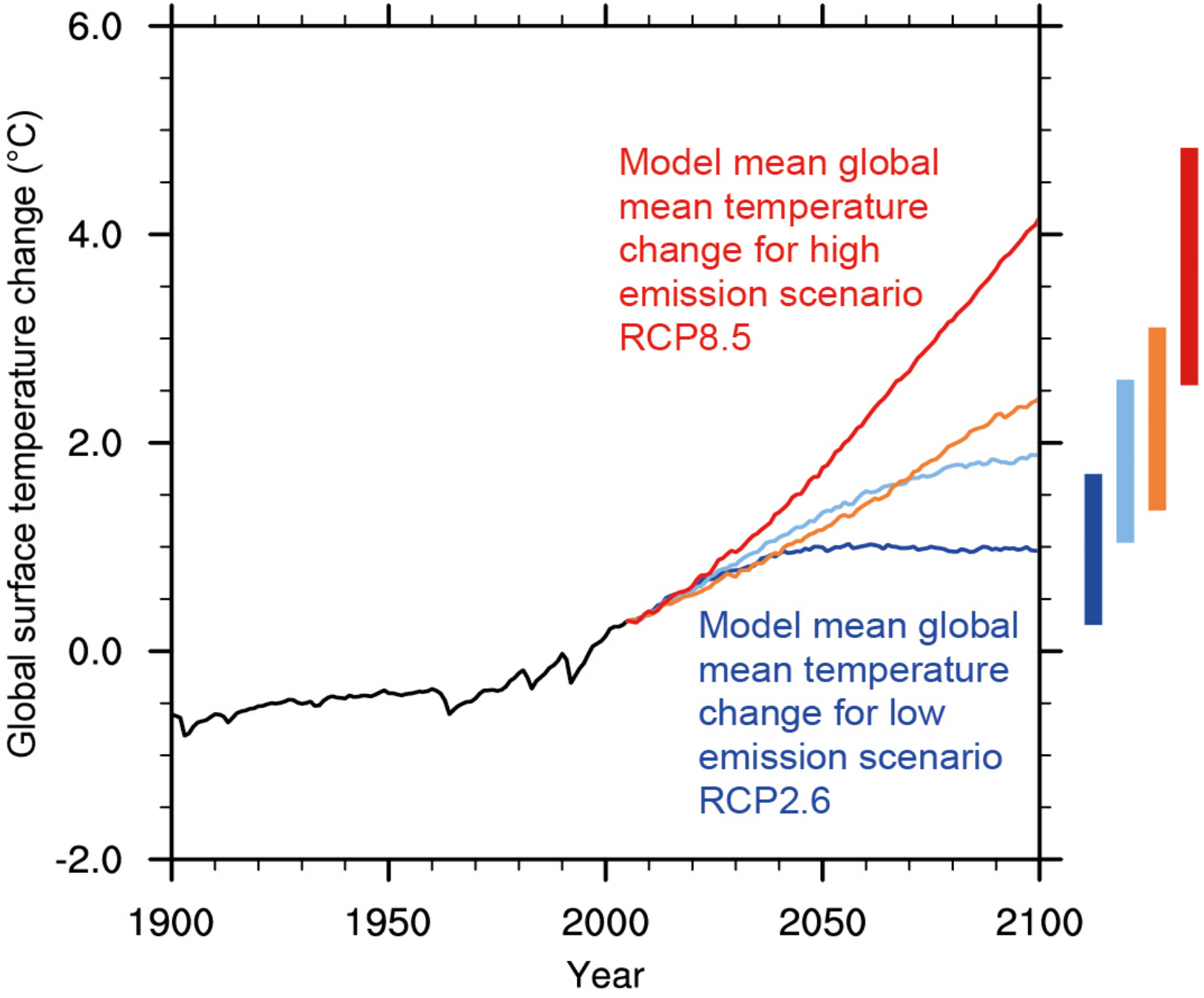
‘The world that is, with greenhouse gas emissions

‘The world that would have been, without greenhouse gas emissions’

Attribution of climate change t human activities.



Using climate models to ‘look into the future’: How much warmer will it get?

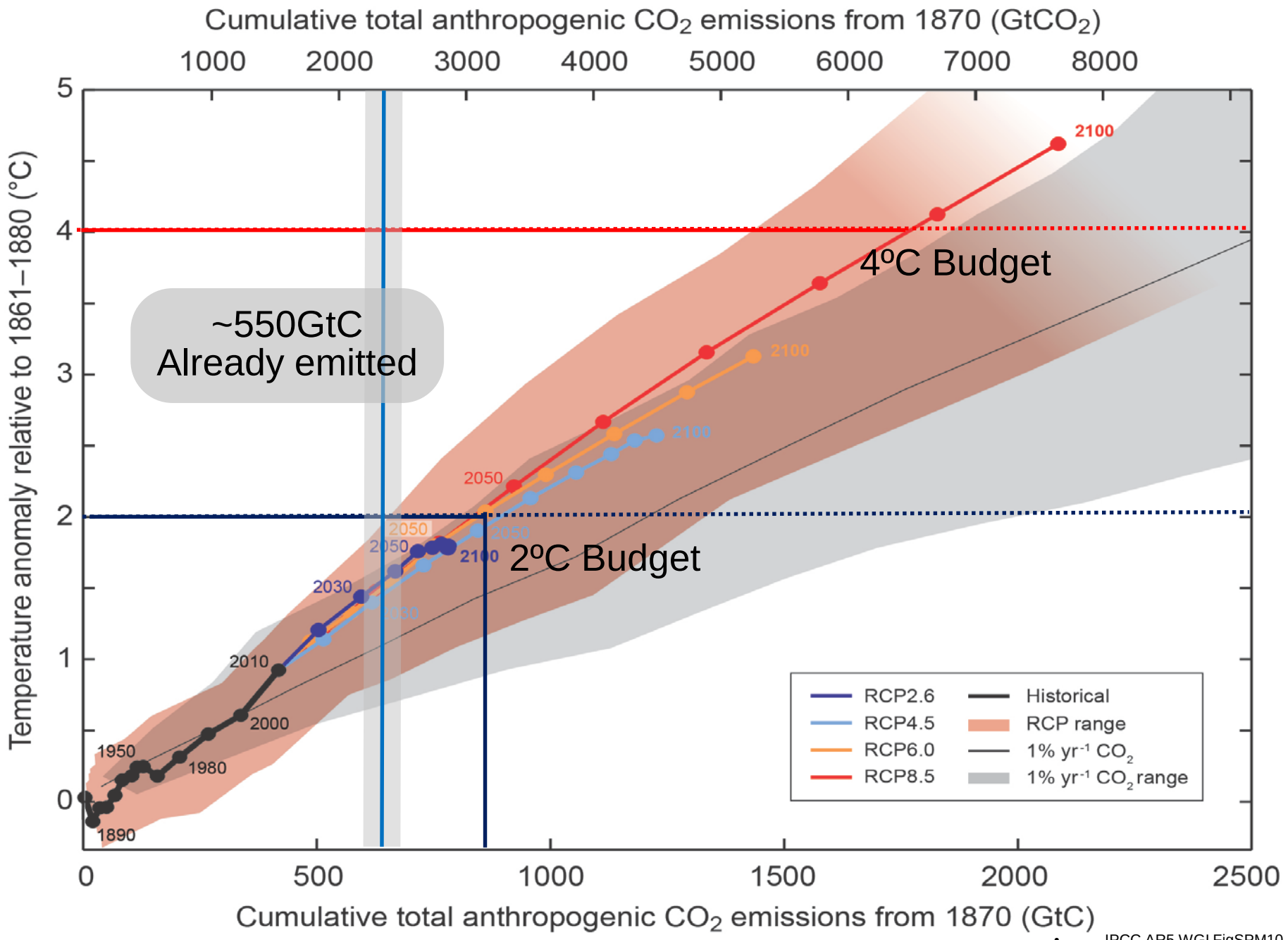



UNDER

WATER – EARTH'S MOST PRECIOUS COMMODITY

'Climate change affects many human rights, undercutting the rights to health, to food, to water, ……. it may even affect the right to self-determination'.

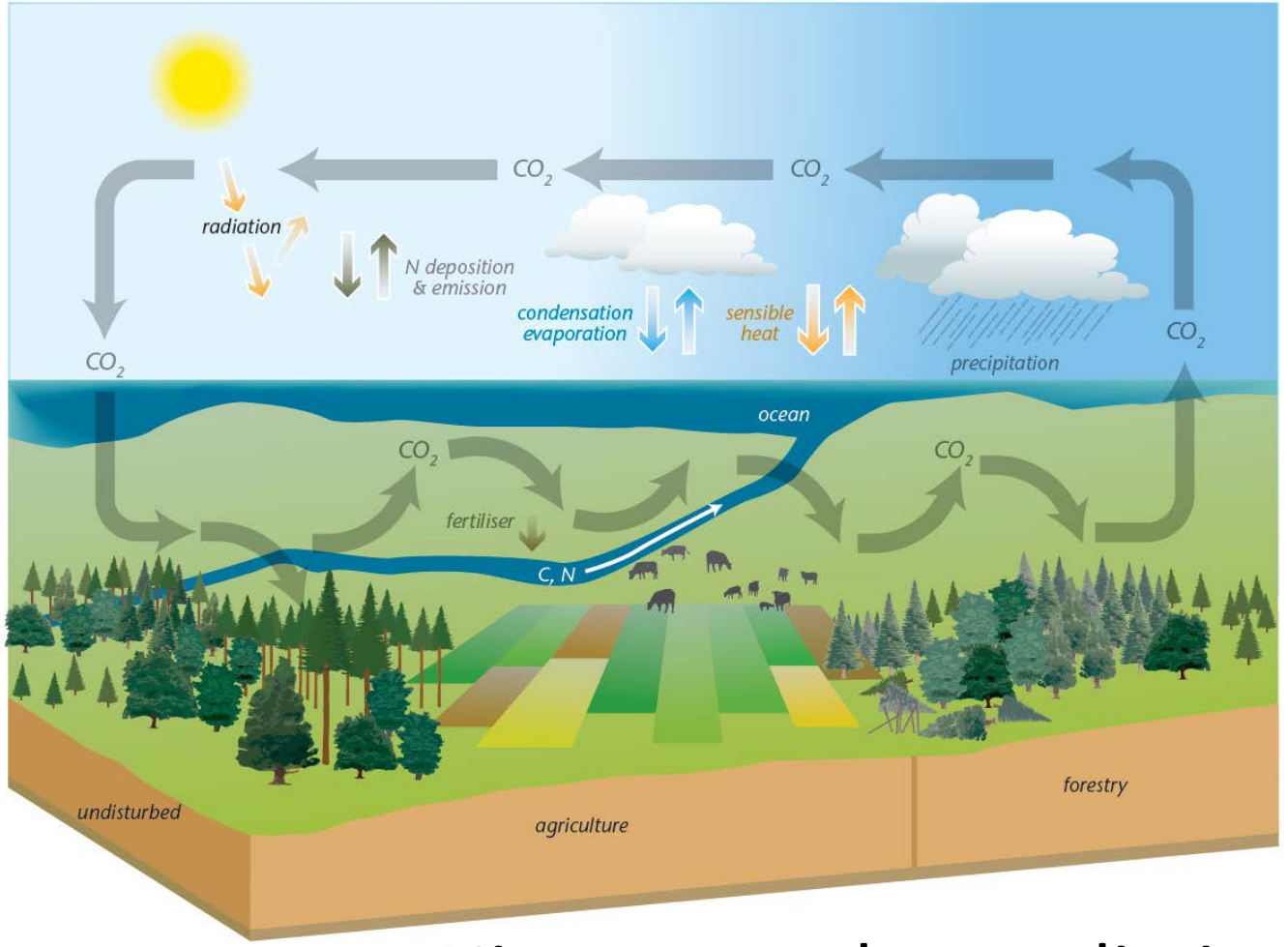
HUMAN RIGHTS AND JUSTICE



- IPCC AR5 WGI FigSPM10

New Insights: Additional Earth System feedbacks may limit our allowable carbon budget

Carbon emissions from permafrost



Nitrogen cycle may limit the efficacy of the carbon cycle.

2015: A Landmark Year

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

- Over 190 countries signed up to reduce emissions, with the target to stay within a 2ºC world.

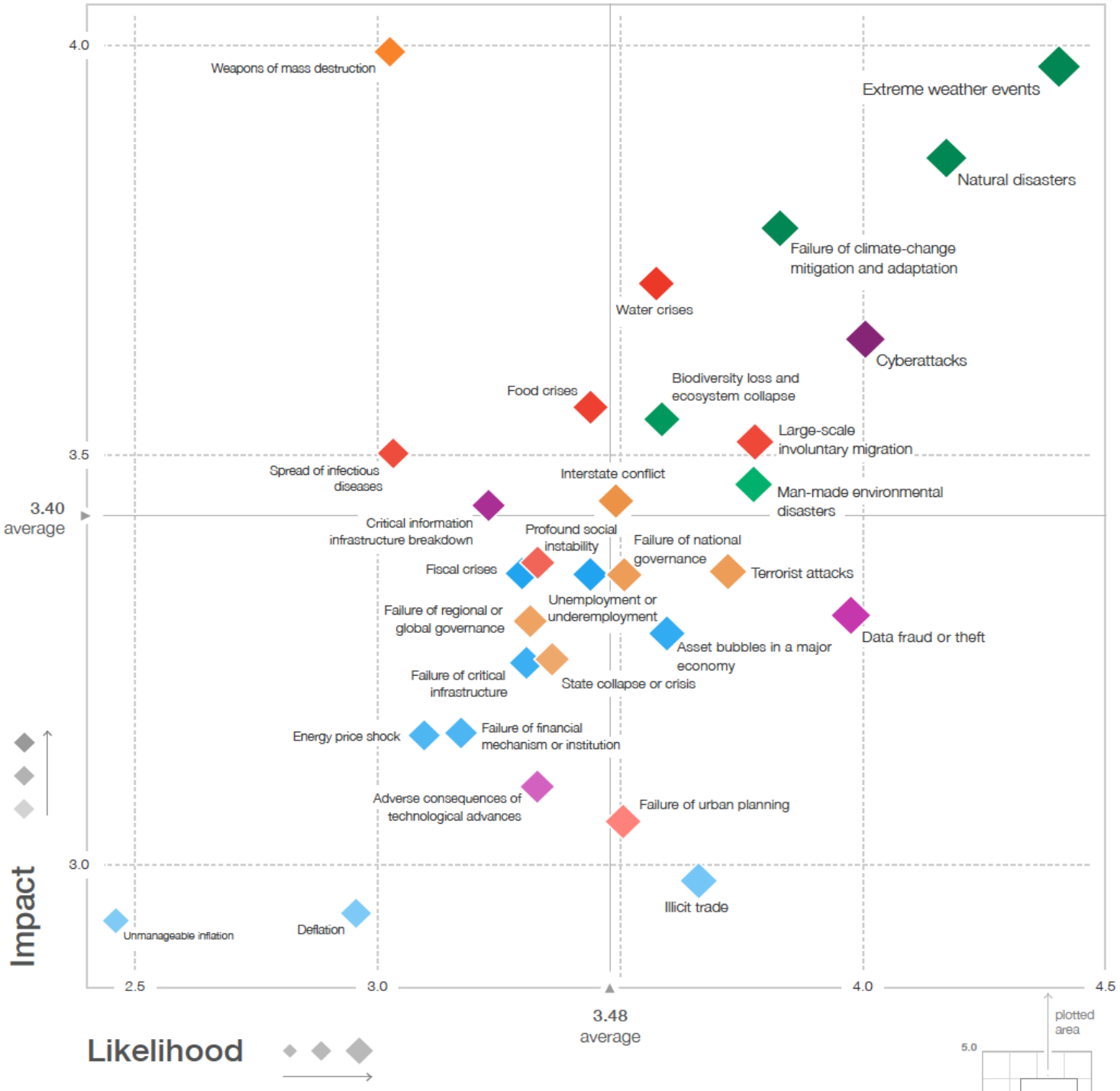
UN World Conference on Disaster Risk Reduction
2015 Sendai Japan

- 15-year agreement for the substantial reduction of disaster risk and losses in lives, livelihoods and health.

- 2030 agenda with 17 goals to end poverty and hunger, improve health and education, making cities more sustainable, combating climate change, and protecting oceans and forests.

Understanding and Quantifying Weather and Climate Risk are at the Core of these Actions

Global Risks Landscape 2018



Categories

- Economic
- Environmental
- Geopolitical
- Societal
- Technological

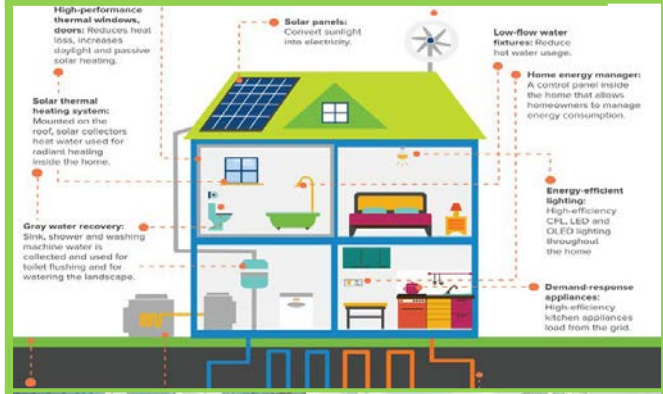
World Economic Forum 2018


Losses from natural catastrophes 2017
US$ 330bn
Less than half of the losses insured
US$ 135bn (41%)
Costliest hurricane season on record
US$ 215bn
Floods in South Asia: a humanitarian disaster
2,700 people killed
© Munich Re NatCatSERVICE

1. CHANGE HOW WE PRODUCE AND STORE ENERGY

2. CHANGE HOW WE USE ENERGY

3. CHANGE HOW AND WHERE WE LIVE



LIVING SUSTAINABLY ON OUR PLANET