Global Change Research: A Historical Perspective and Future Challenges

Guy P. Brasseur
National Center for Atmospheric Research
Boulder, CO

ACOM NSF NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

The Planet under stress

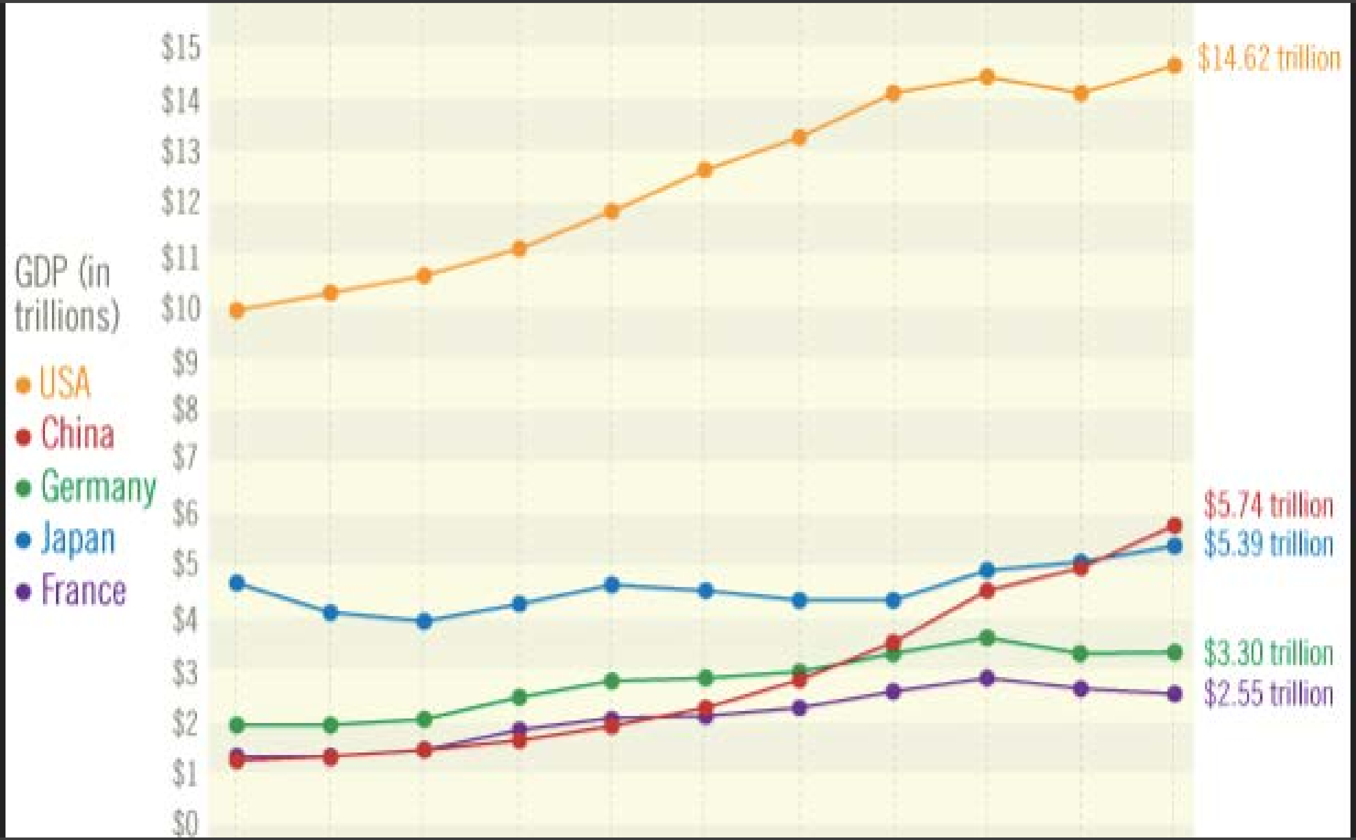
A Profound Transformation of the Earth System is Underway

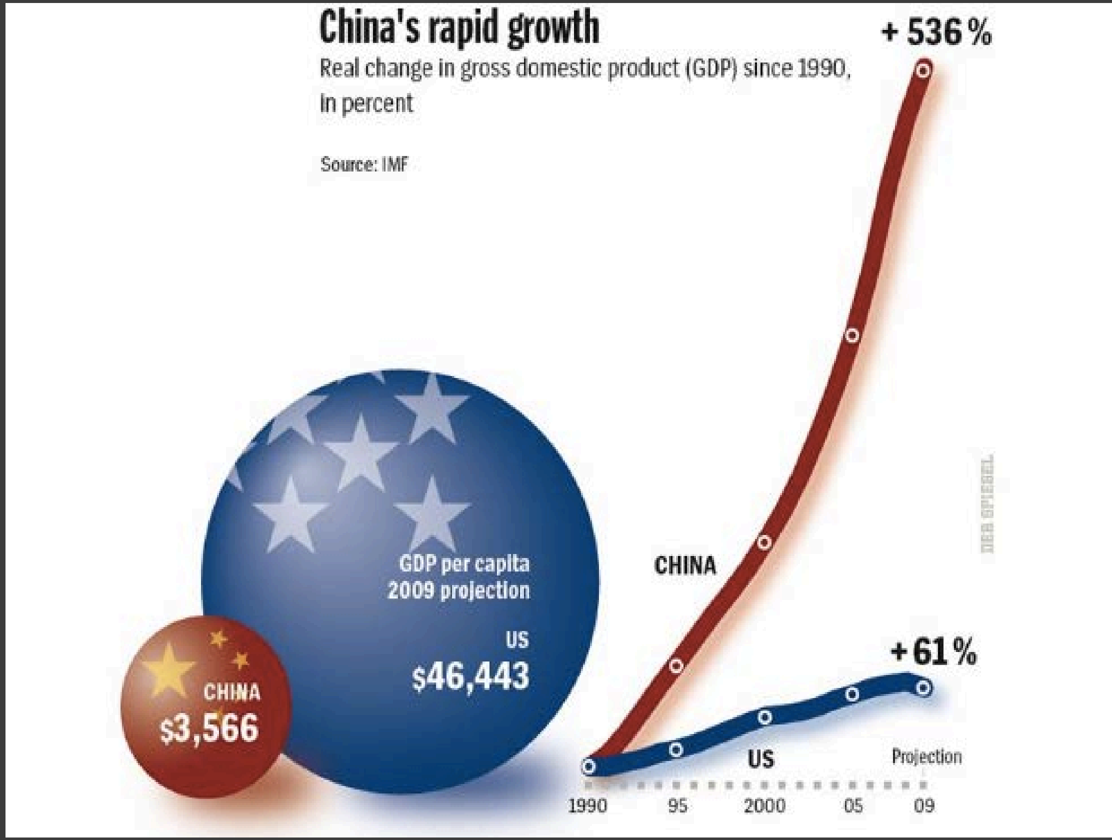
During the last 50 years,

- the human population has risen from 2 to 7 billion,
- economic activity has increased ten-fold,
- the connectivity of the human enterprise has risen dramatically through globalisation of economies and flow of people, information, products and diseases.
- Intensification and diversification of land-use and advances in technology has led to rapid changes in <u>biogeochemical cycles, hydrological processes and landscape dynamics</u>.

Population has been growing rapidly

Gross Domestic Product (trillons $)





Inequalities in the World

The food available to a family in different parts of the world

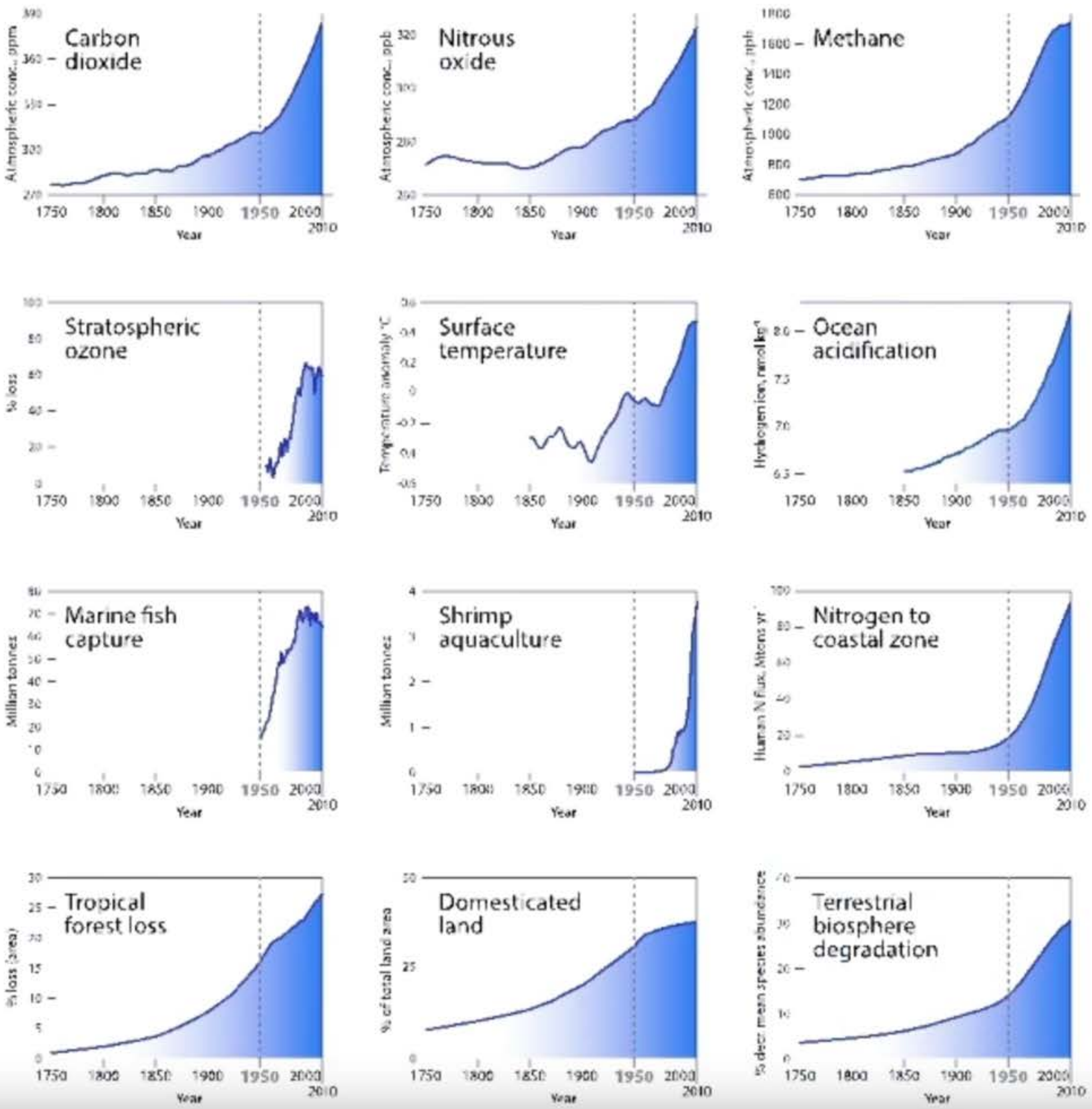
Source: W. Cramer
Chr. Müller,
PIK

The Great Acceleration

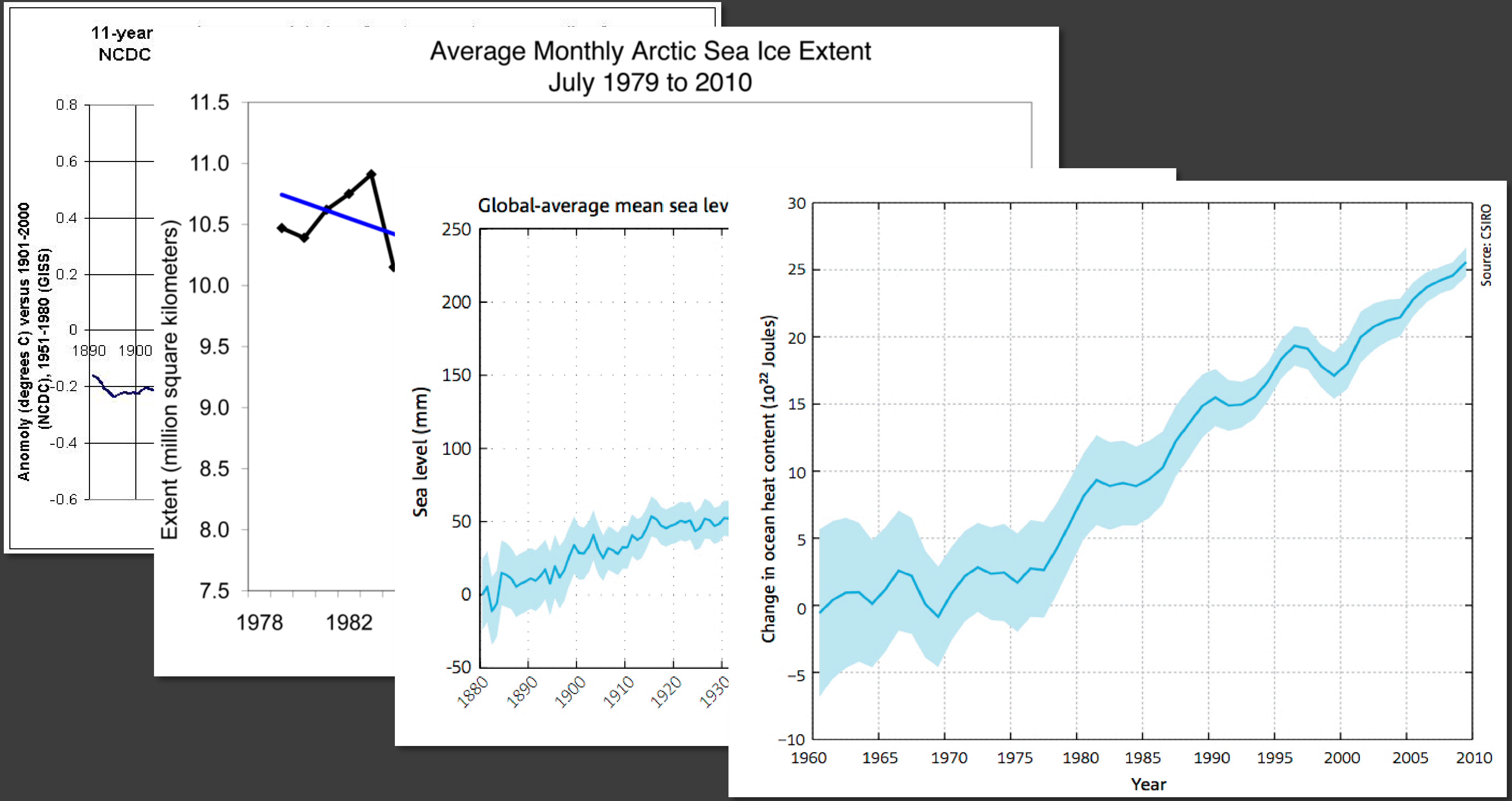
Global Impact

- Greenhouse gases
- Ozone depletion
- Climate
- Marine ecosystems
- Coastal zone
- Nitrogen cycle
- Tropical forests
- Land systems
- Biosphere integrity

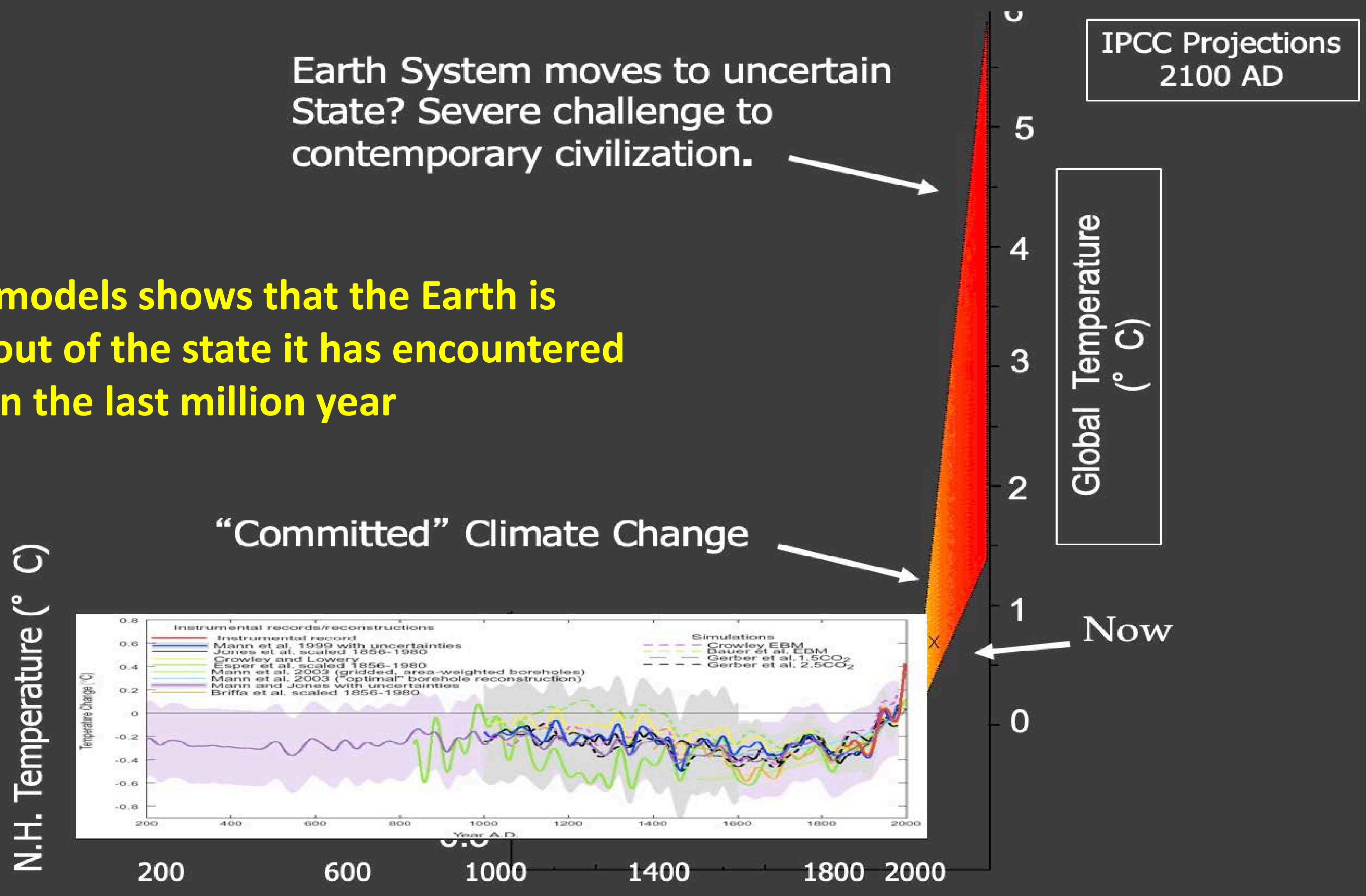
Earth system trends



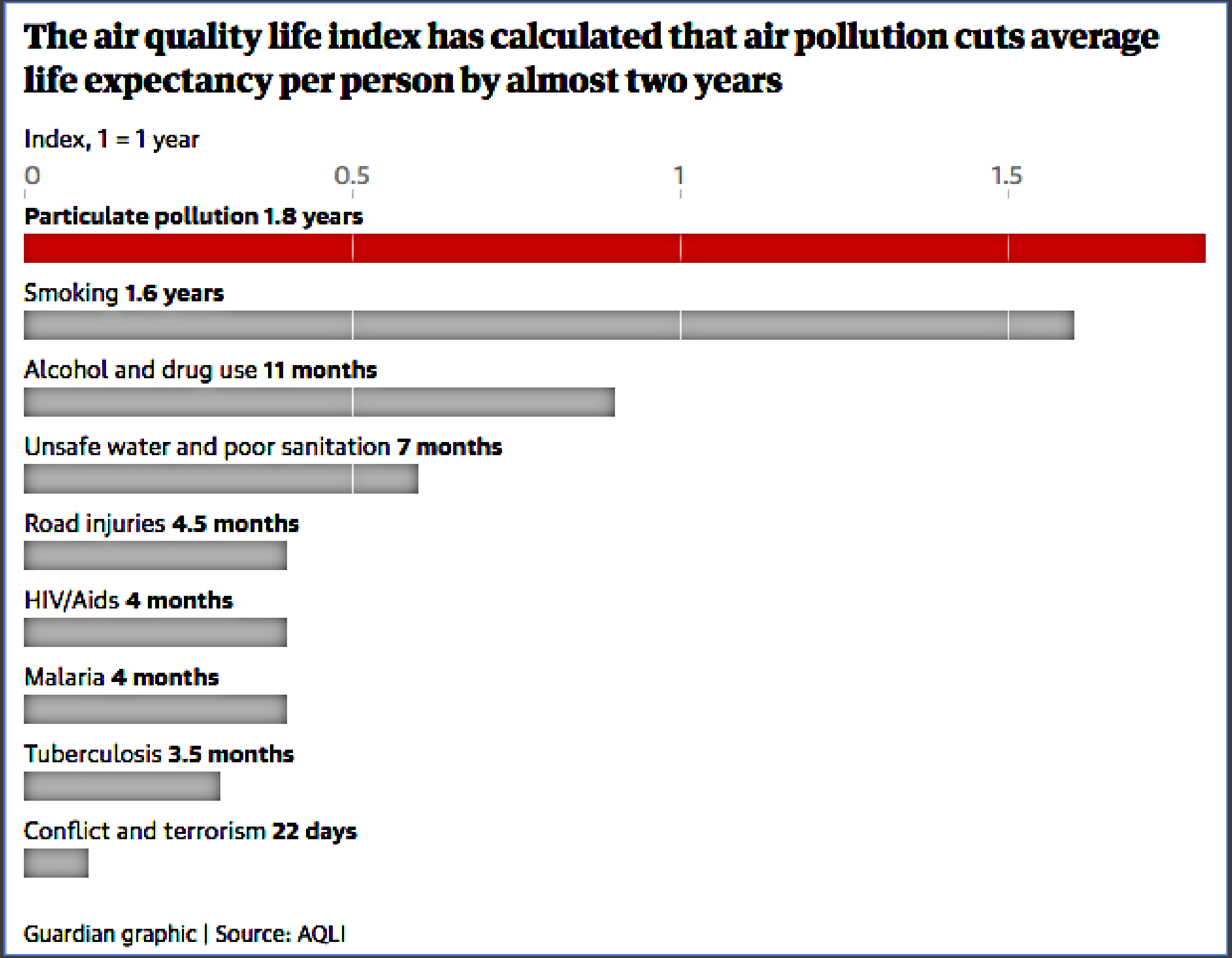
Climate System Trends

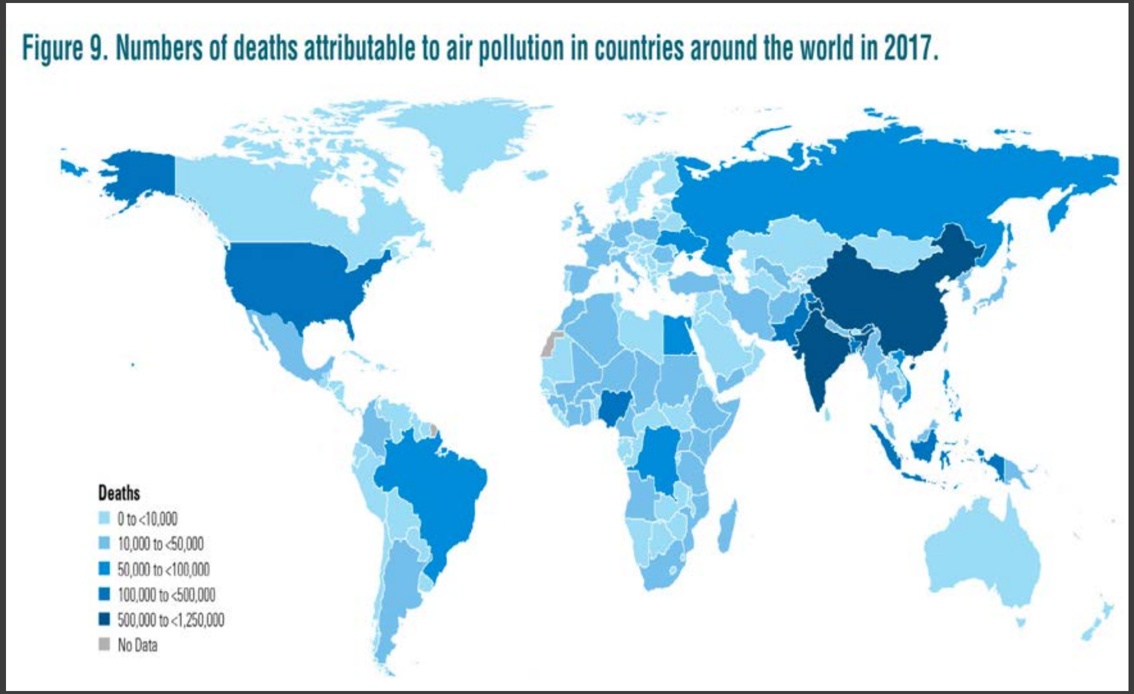


Climate models shows that the Earth is moving out of the state it has encountered at least in the last million year



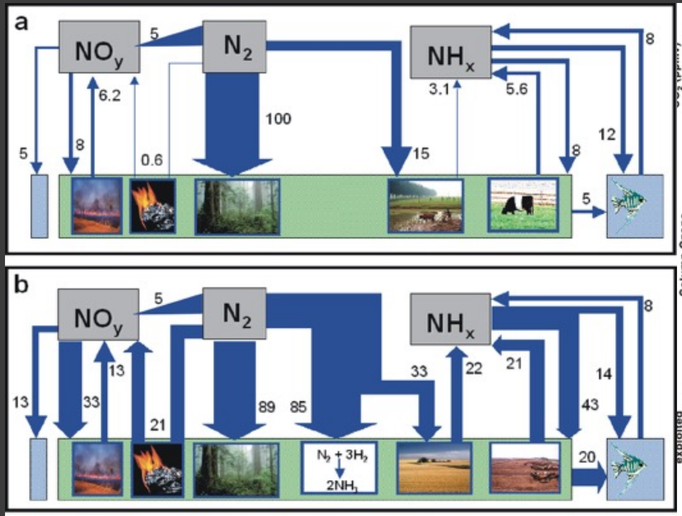
Air pollution is today the first killer in the world

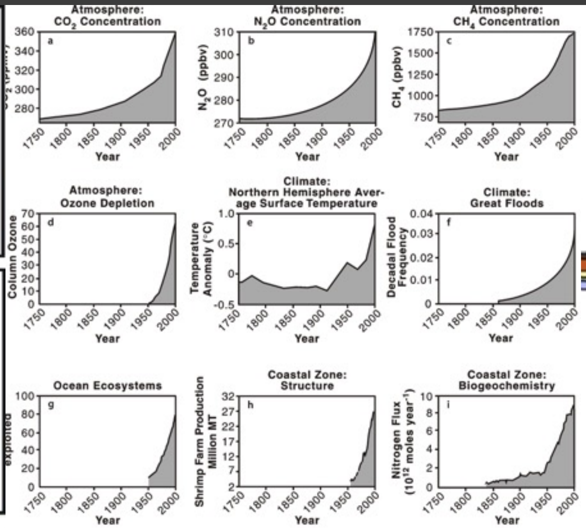


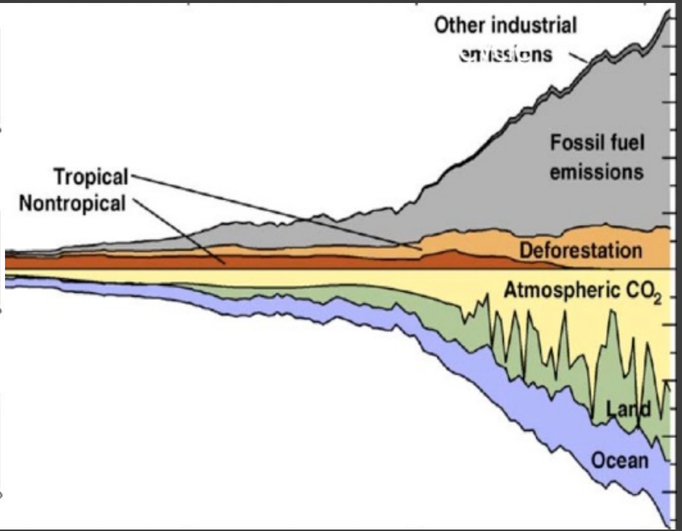


Health Effects Institute, Boston.

The Anthropocene: A New Epoch in Earth History?

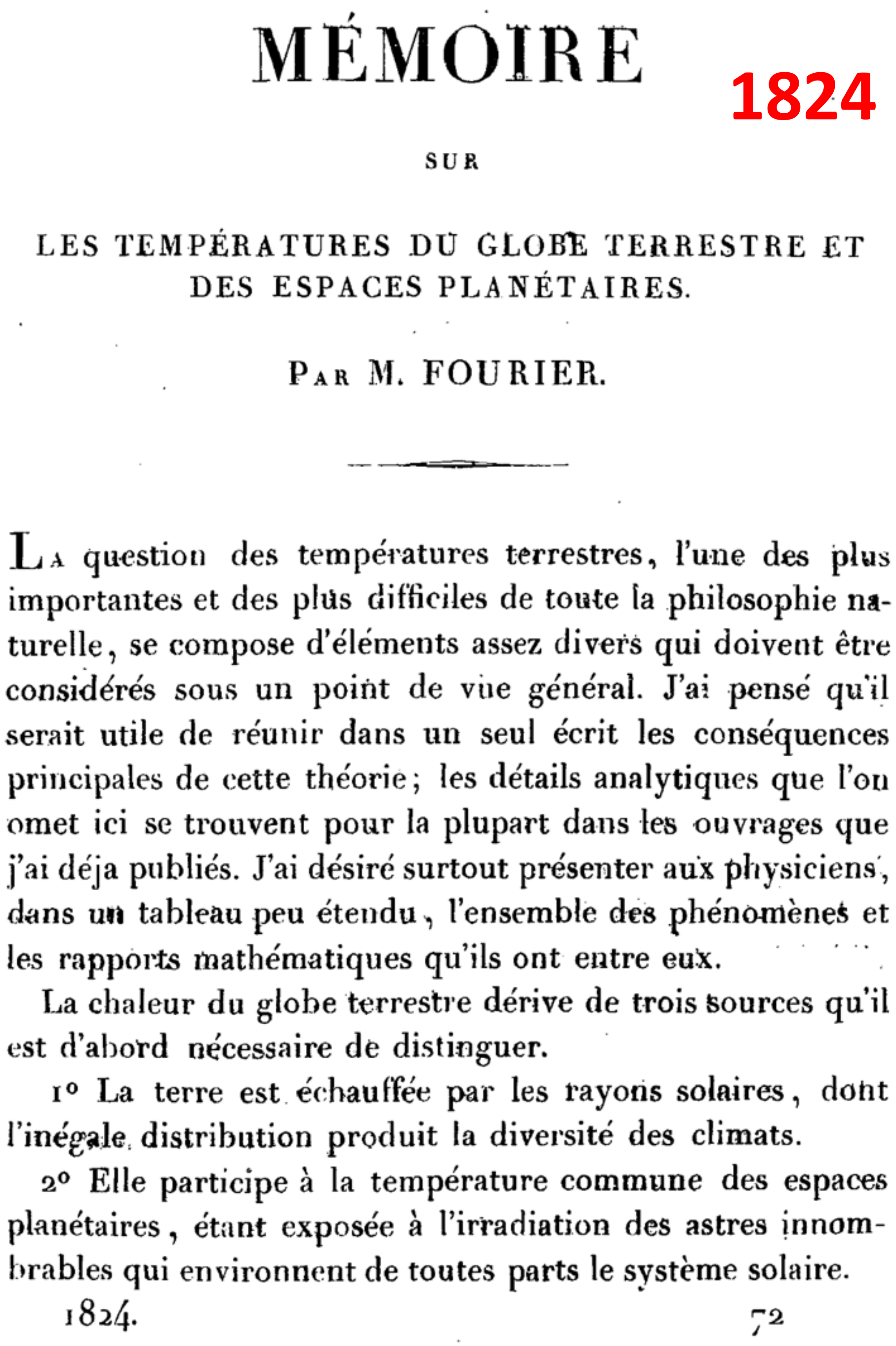






From Will Steffen

A Historical Perspective



MÉMOIRE

SUR

LES TEMPÉRATURES DU GLOBE TERRESTRE ET DES ESPACES PLANÉTAIRES.

PAR M. FOURIER.

LA question des températures terrestres, l'une des plus importantes et des plus difficiles de toute la philosophie naturelle, se compose d'éléments assez divers qui doivent être considérés sous un point de vue général. J'ai pensé qu'il serait utile de réunir dans un seul écrit les conséquences principales de cette théorie; les détails analytiques que l'on omet ici se trouvent pour la plupart dans les ouvrages que j'ai déja publiés. J'ai désiré surtout présenter aux physiciens, dans un tableau peu étendu, l'ensemble des phénomènes et les rapports mathématiques qu'ils ont entre eux.

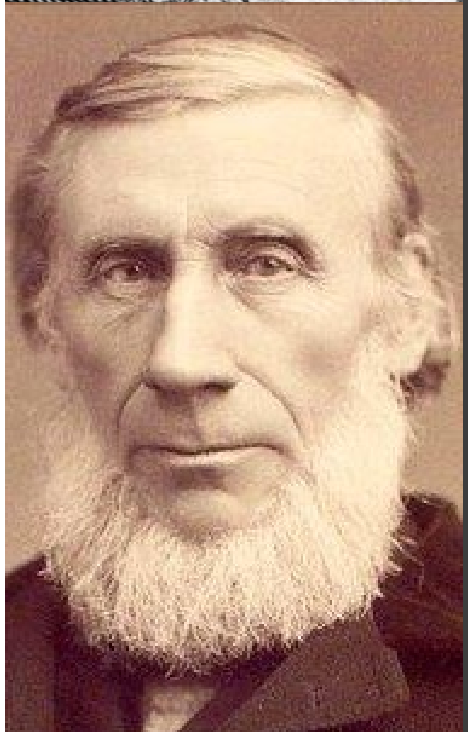
La chaleur du globe terrestre dérive de trois sources qu'il est d'abord nécessaire de distinguer.

1° La terre est échauffée par les rayons solaires, dont l'inégale distribution produit la diversité des climats.

2° Elle participe à la température commune des espaces planétaires, étant exposée à l'irradiation des astres innombrables qui environnent de toutes parts le système solaire.

1824. 72

1824



Fourier and Tyndall

In 1861, Irish physicist John Tyndall showed that gases such as methane and carbon dioxide absorbed infra-red radiation, and could trap heat within the atmosphere. They "would produce great effects on the terrestrial rays and produce corresponding changes of climate".

In 1896, Swedish scientist Svante Arrhenius is the first to calculate the sensitivity (5 ^{0}C) of climate to a doubling of atmospheric CO_2

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.

† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).

‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.

§ *Comptes rendus*, t. vii. p. 41 (1838).

THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE 223

551.510.4 : 551.521.3 : 551.524.34

THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE AND ITS INFLUENCE ON TEMPERATURE

By G. S. CALLENDAR

(Steam technologist to the British Electrical and Allied Industries Research Association.)

(Communicated by Dr. G. M. B. DOBSON, F.R.S.)

[Manuscript received May 19, 1937—read February 16, 1938.]

SUMMARY

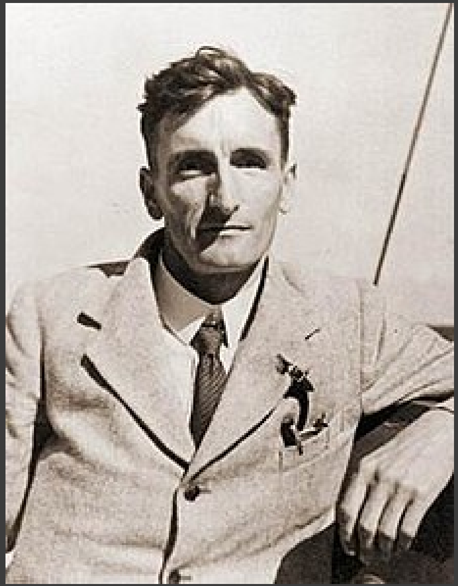
By fuel combustion man has added about 150,000 million tons of carbon dioxide to the air during the past half century. The author estimates from the best available data that approximately three quarters of this has remained in the atmosphere.

The radiation absorption coefficients of carbon dioxide and water vapour are used to show the effect of carbon dioxide on "sky radiation." From this the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0·003°C. per year at the present time.

The temperature observations at 200 meteorological stations are used to show that world temperatures have actually increased at an average rate of 0·005°C. per year during the past half century.

Guy Stewart Callendar (1898-1964)

In 1938, Steam engineer Guy Callendar predicts a temperature increase of 0.3 ^{0}C per century, which should delay the "return of the deadly glaciers".



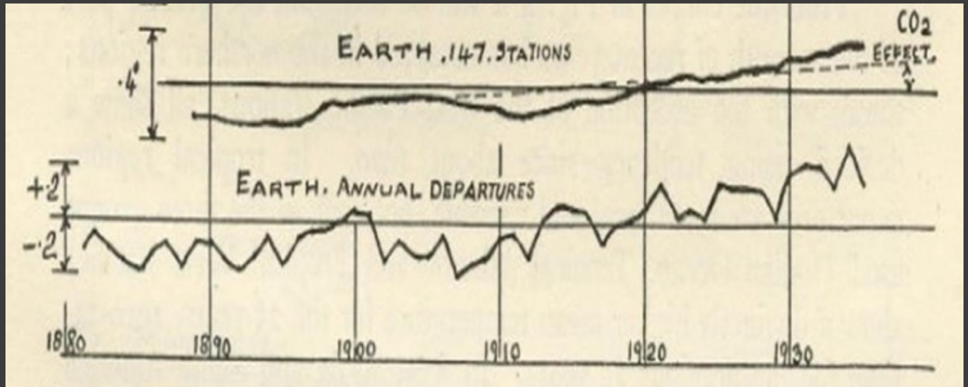


FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930, °C.

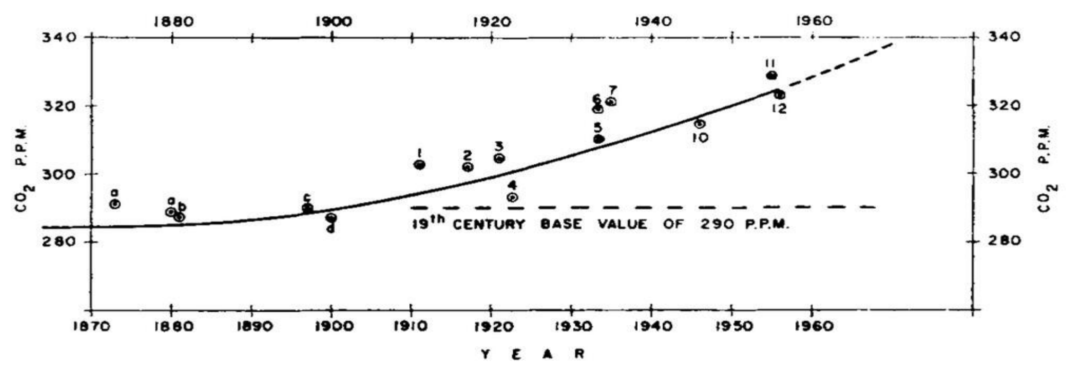
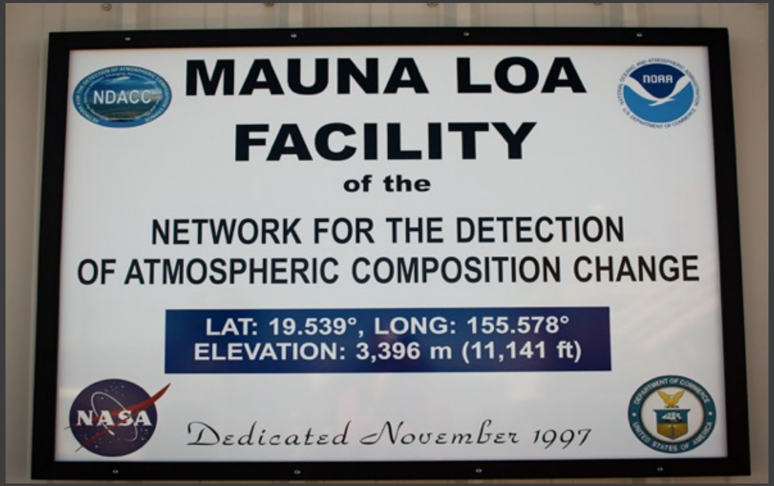
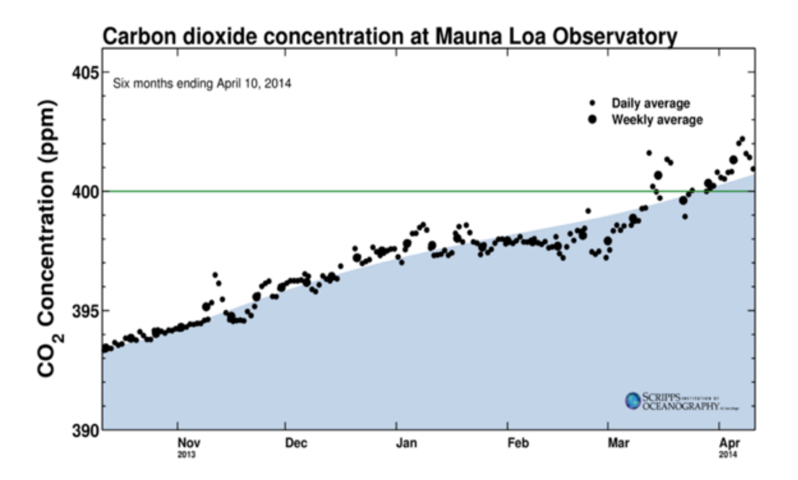


Fig. 1. Amount of CO_2 in the free air of the N. Atlantic region. 1870—1956. Full curve, amount from fossil fuel (See Appx. Table B. for numbered obs. points, and text Table 1 for the 19th century obs. points.)

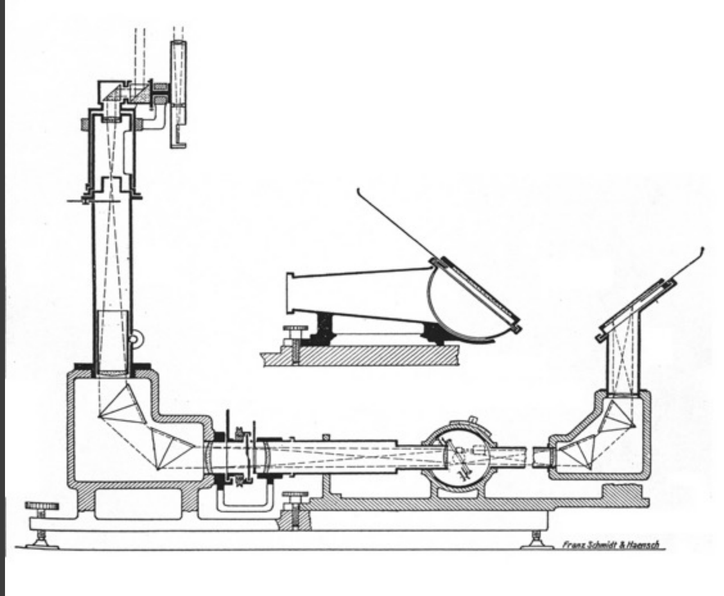
Charles David Keeling

Starting in 1958, monitoring of CO_2 at the Mauna Loa station shows that the level of this greenhouse gas is gradually increasing in the atmosphere even in remote areas: the problem is a global problem.

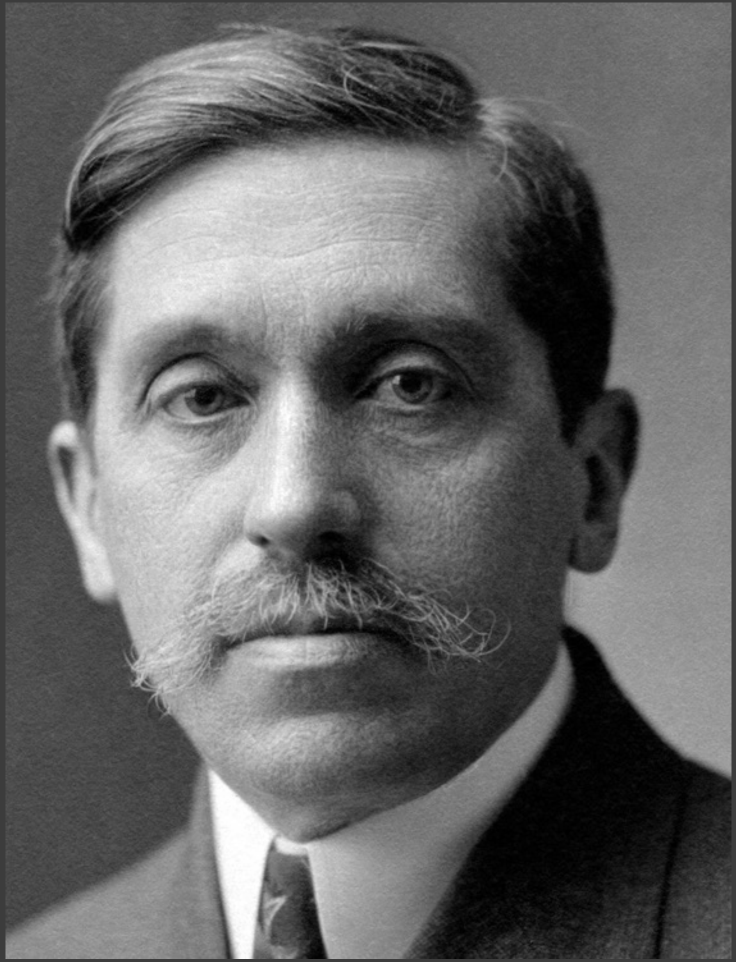




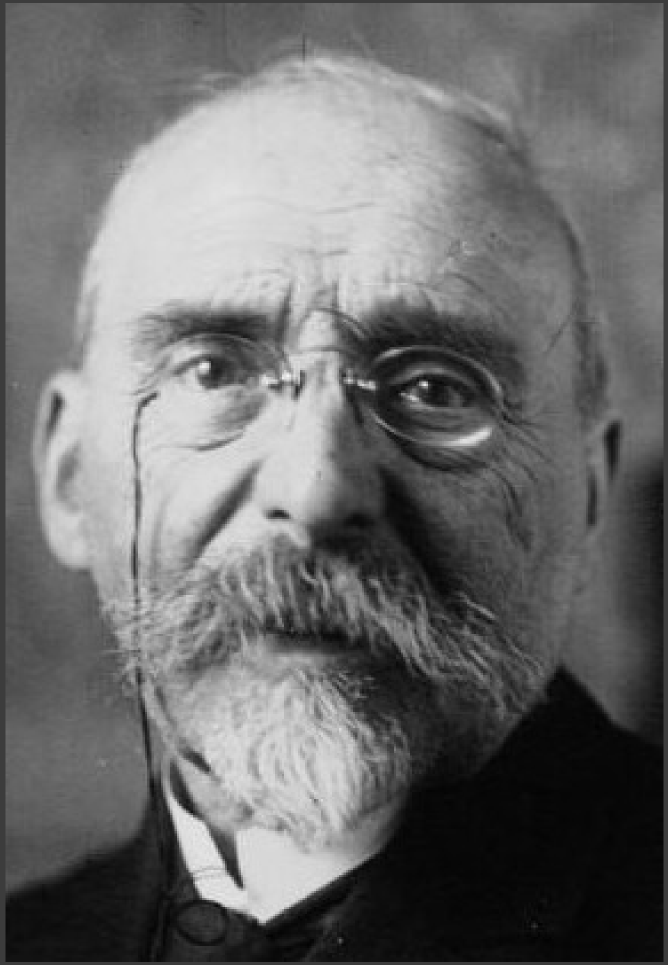
1920: Charles Fabry and Henri Buisson



In 1920, Charles Fabry and Henri Buisson at the University of Marseilles, France, by measuring the absorption of ultraviolet light in the atmosphere discover that the thickness of the ozone column at STP is only of the order of 3 mm.



Charles Fabry



Henri Buisson

The Dobson Ozone Photographic Spectrometer of Gordon Dobson at Oxford, UK.

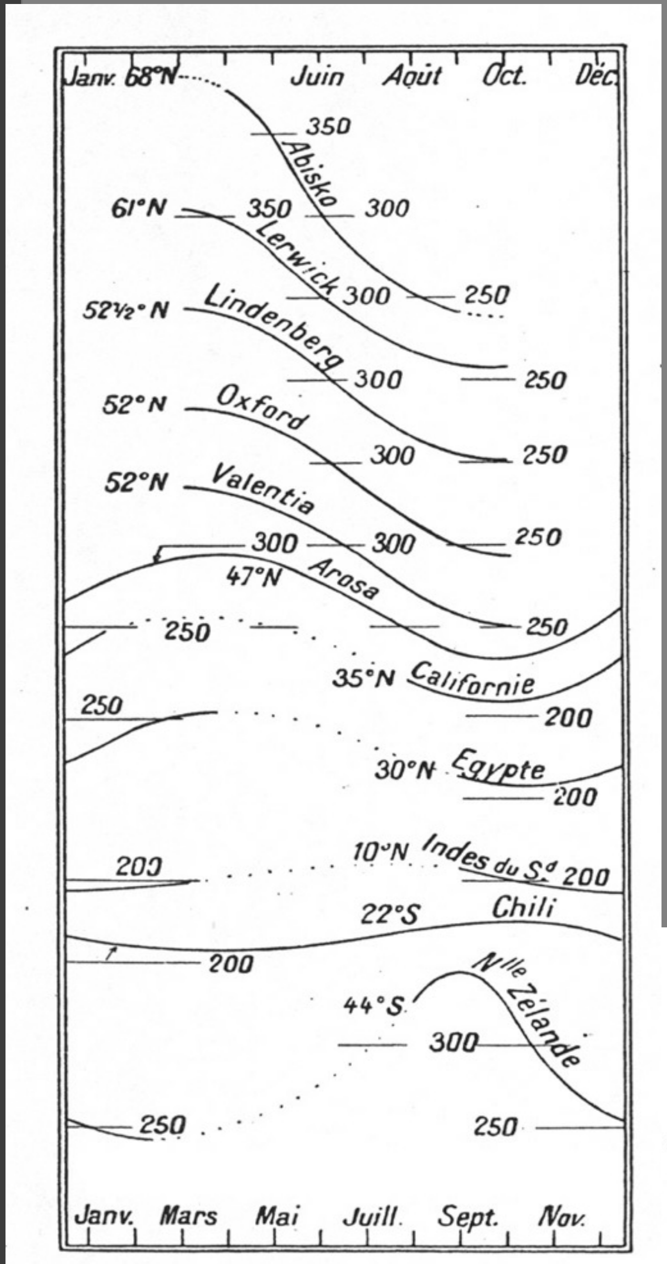
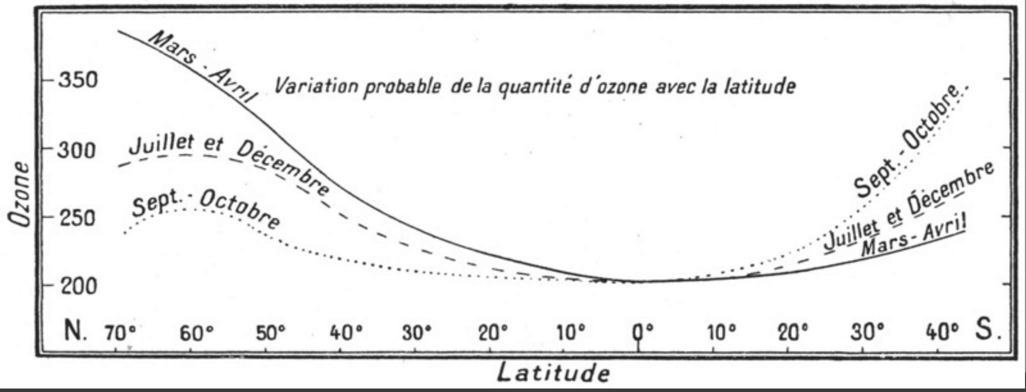


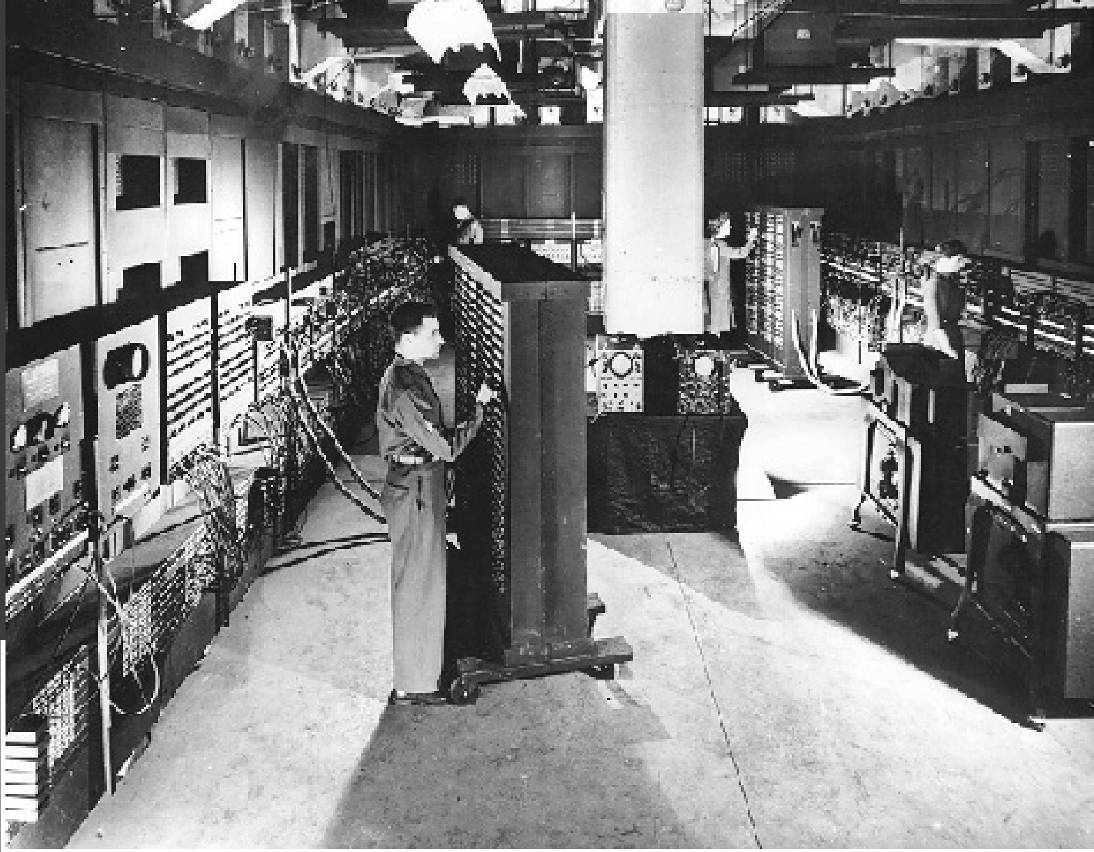
Fig. 3.

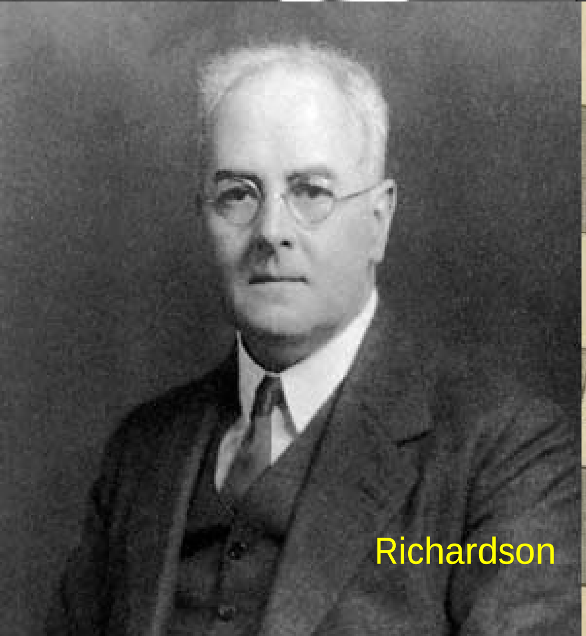


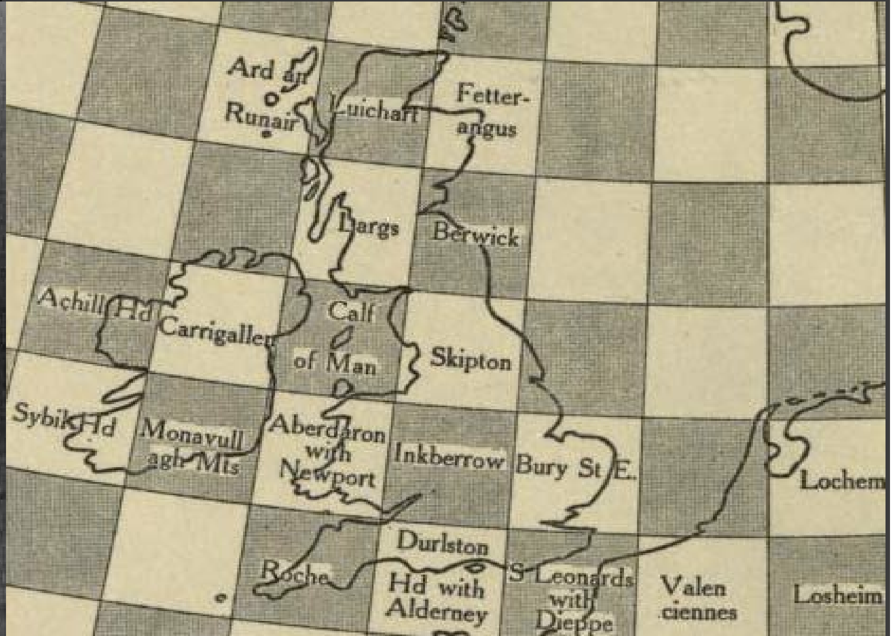
Gordon Dobson

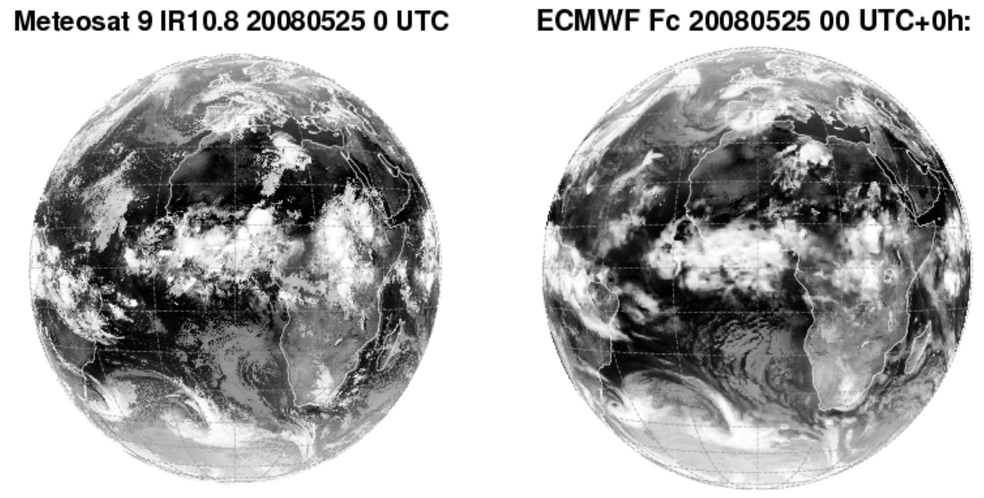
A Century of Tremendous Progress

Numerical Weather Forecast

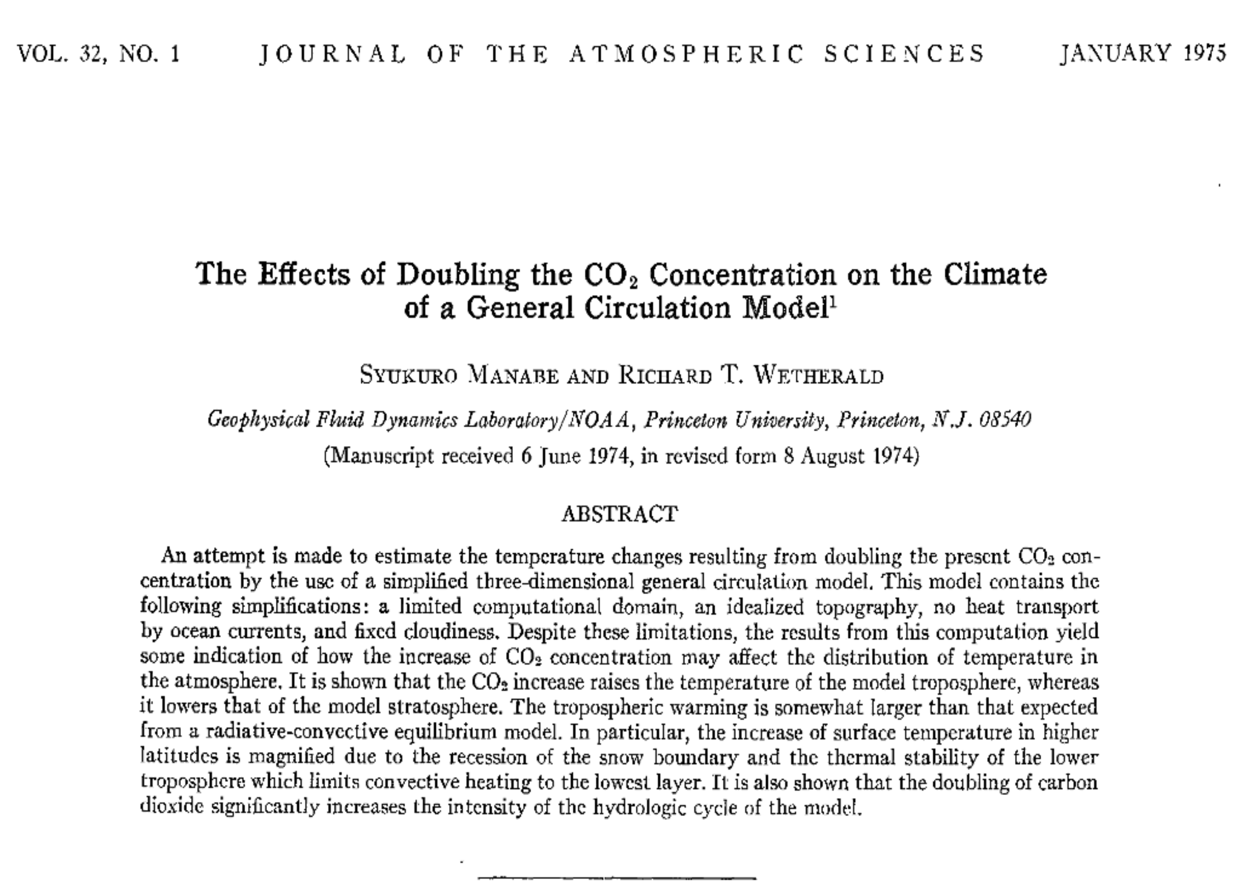








In **1967**, at the NOAA Geophysical Fluid Dynamics Laboratory in Princeton, **Syukuro Manabe et Richard Wetherald** make a first calculation of the effect of greenhouse gases using a 1-D radictive convective model. They derive in **1975** with a general circulation model and derive the effect on climate of a doubling in CO_2.



VOL. 32, NO. 1 JOURNAL OF THE ATMOSPHERIC SCIENCES JANUARY 1975

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)

ABSTRACT

An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

Atmospheric Chemistry as a Dynamic Component of the Earth System

- The photochemical theory of ozone (Chapman, Bates, Nicolet, Crutzen, Cicerone, Solomon)
- Stratospheric ozone depletion and the Antarctic ozone hole (Crutzen, Molina, Rowland)
- The photochemistry of smog (Haagen-Smit)
- The oxidation potential of the atmosphere: the OH radical and tropospheric ozone as a global pollutant (Levy, Weinstock, Crutzen)

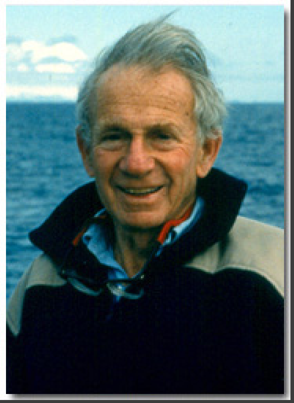
Chapman

Haagen Smith

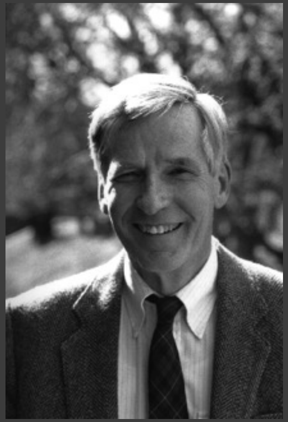
Crutzen

The Ocean as a Dynamical Component of the Earth System

- The conveyor belt (W. Broecker)
- The thermohaline circulation (W. Munk)
- Ventilation of the deep ocean (H. Stommel and P. Rhines)
- The biological pump for carbon (Revelle)
- Development of ocean general circulation models (K. Bryon)



W. Munk



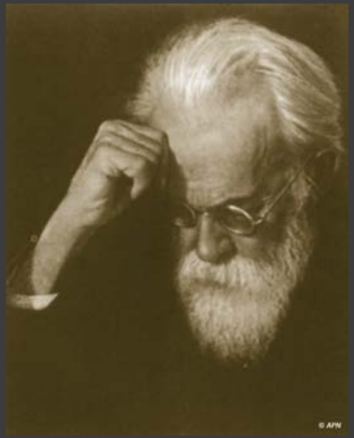
K. Bryon

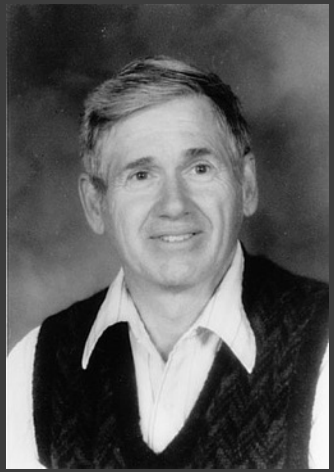
W. Broecker

The Biosphere as a Dynamic component of the Earth System

- The importance of life for the evolution of the Earth (W. Vernadsky)
- Importance of vegetation-albedo feedback (e.g., instability of the Sahara by Charney)
- Increasing atmospheric concentration of CO_2 and the role of the carbon cycle in the Earth System (Keeling, Sr and Jr., Tans)
- The role of the biosphere in controlling the chemical composition of the natural atmosphere.
- The importance of large wildfires (P. Crutzen)

Vernadsky





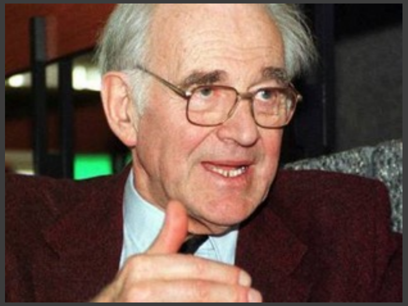
Keeling

The Earth as a Complex Nonlinear Interactive System

Ed Lorenz

- The Lorenz attractors: the limit of predictability.
- The Vostock Ice core and glacial/interglacial transitions (Oeschger, Lorius)
- The Dansgaard/Oeschger cycles
- The CLAW hypothesis (R. Charlson, M. Andreae, et al.)
- The realization of the importance of the carbon cycle (B. Bolin, R. Revelle)
- Gaia hypothesis (J. Lovelock)

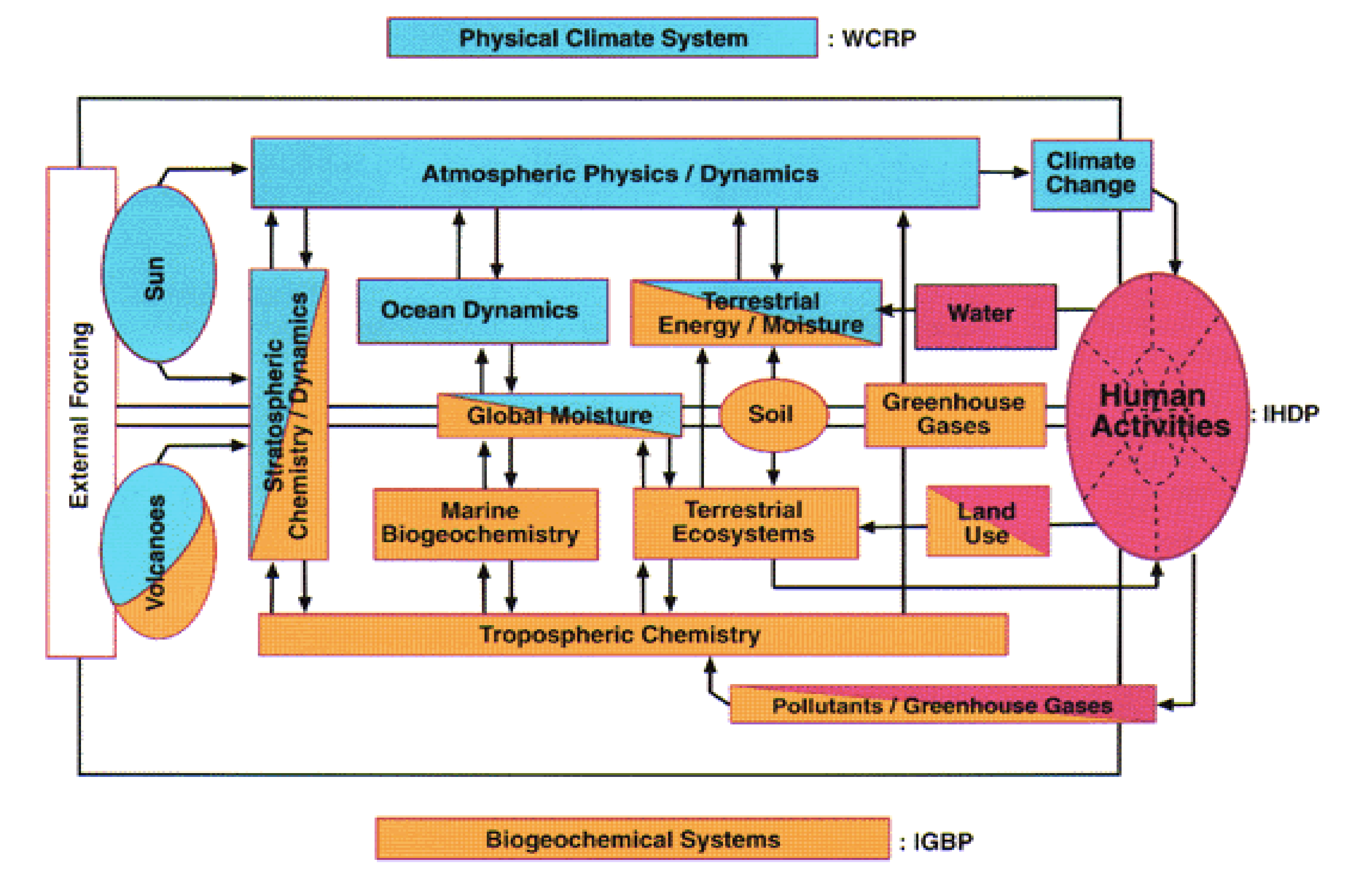
Jim Lovelock



Bert Bolin

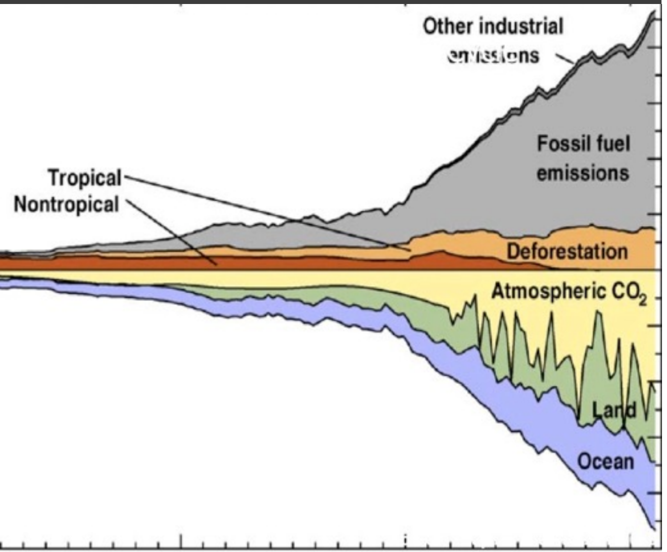
Roger. Revelle

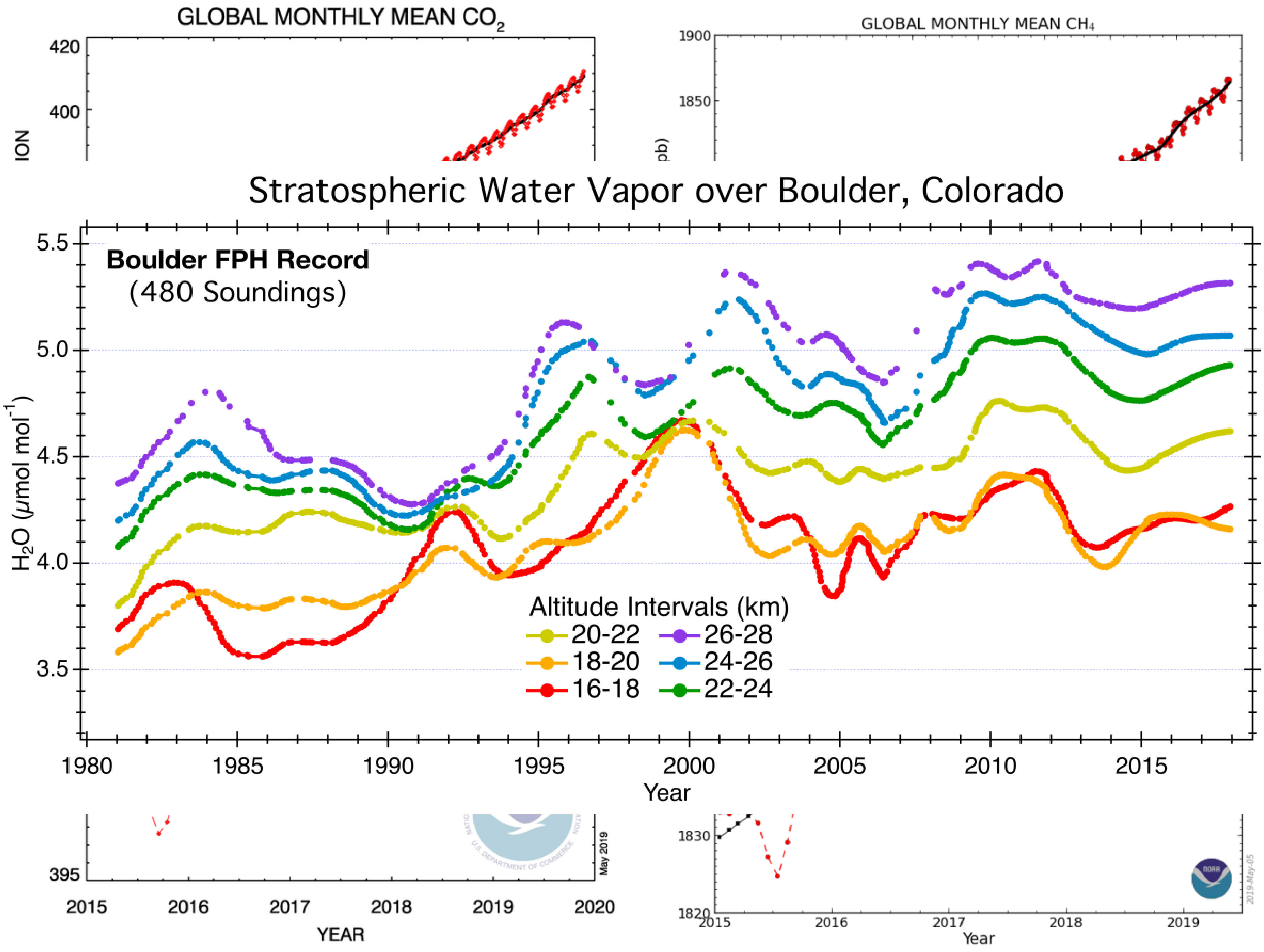
Bretherton's diagram shapes global change research for the decades ahead

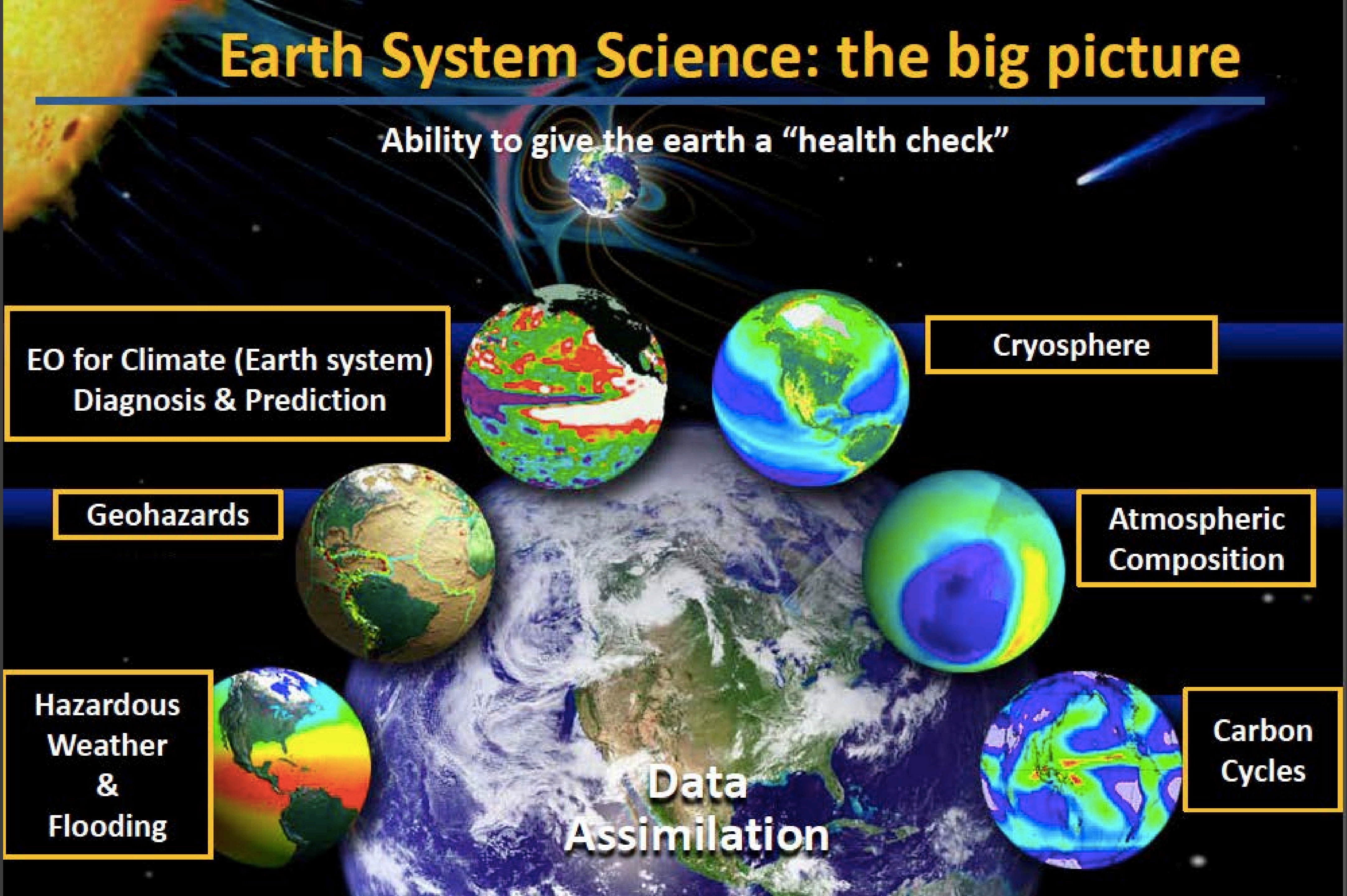


NOAA Boulder

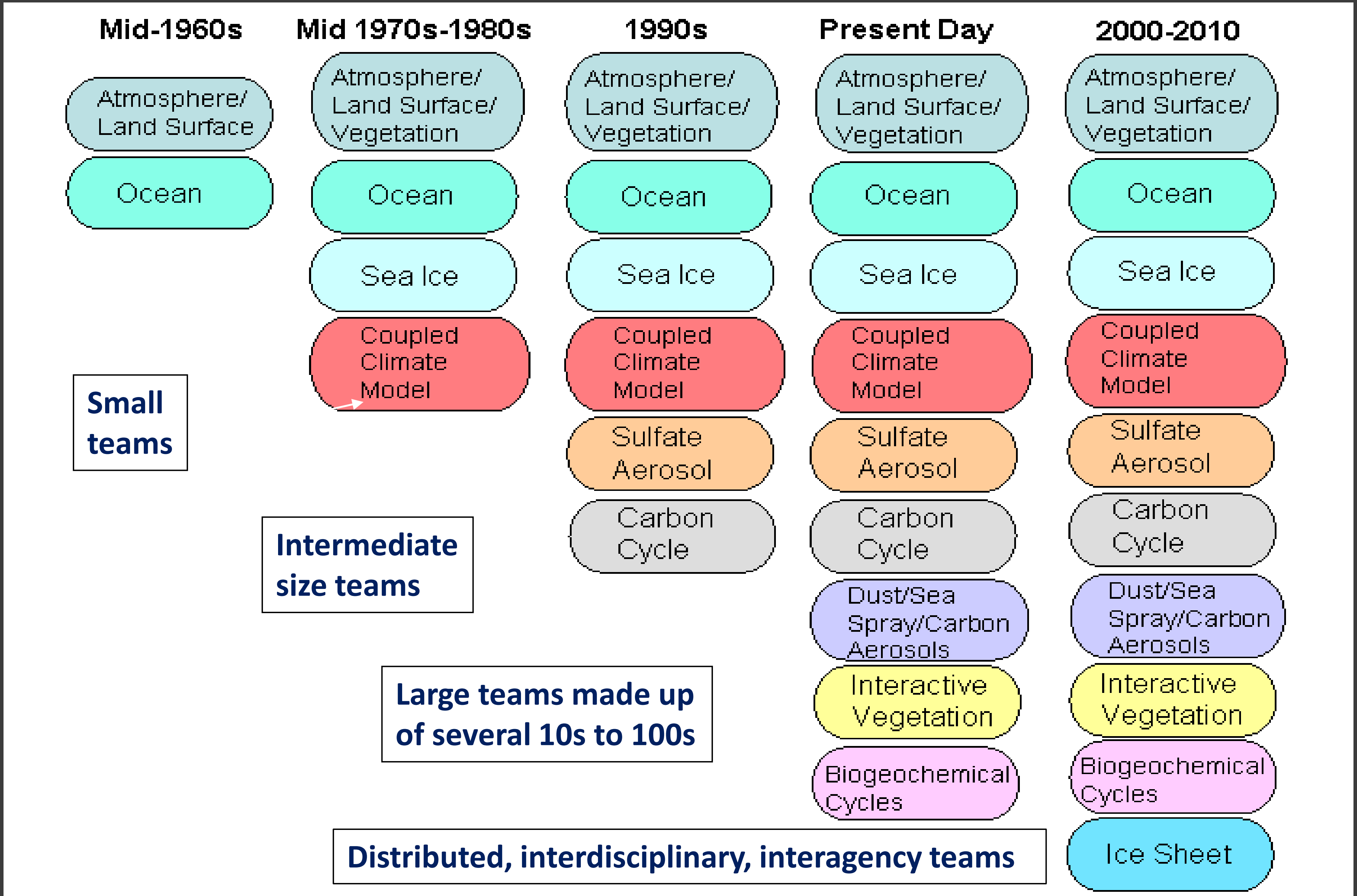
The Importance of Monitoring the State of the Environment






Earth System Science: the big picture
Ability to give the earth a "health check"
EO for Climate (Earth system) Diagnosis & Prediction
Cryosphere
Geohazards
Atmospheric Composition
Hazardous Weather & Flooding
Carbon Cycles
Data Assimilation

Timeline of Climate Model Development



International Programs
and Environmental Diplomacy

An Important Milestone

This conference was followed by other UN conferences in Rio de Janeiro in 1992 and 2012.

- ***The landmark UN Stockholm Conference*** in 1972 recognized that:
- science and technology should be used to improve the environment,
- research and education in environmental sciences should be promoted,
- cooperation on international issues should be regarded as essential.

UNEP

United Nations Environment Programme

environment for development

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"To provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations."

Climate Change

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United Nations Framework Convention on Climate Change

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Building resilience to climate change

Mitigation
Moving towards low carbon societies

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Reducing Emissions from Deforestation and forest Degradation

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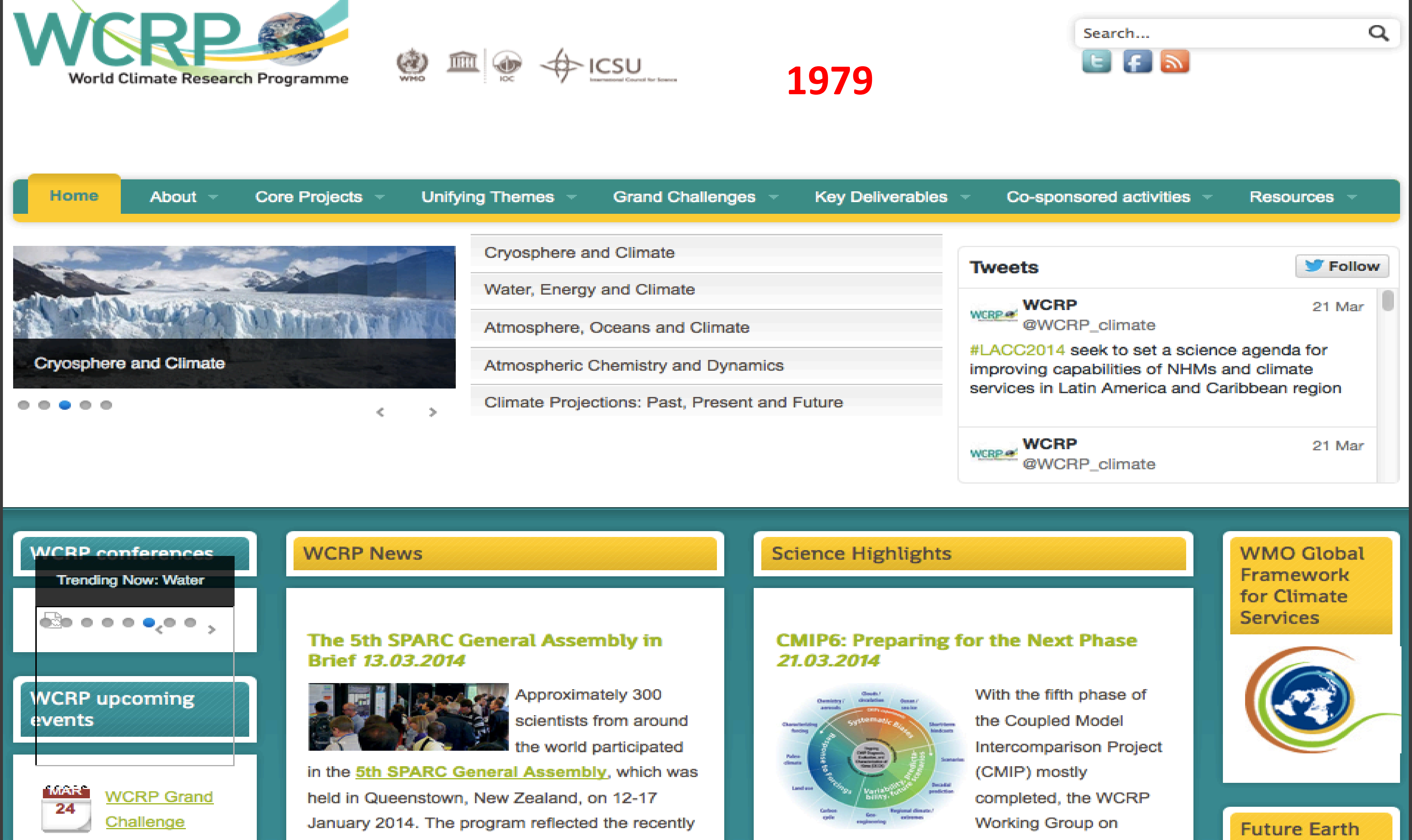
New finance models for the green economy

1979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Approximately 300 scientists from around the world participated in the 5th SPARC General Assembly, which was held in Queenstown, New Zealand, on 12-17 January 2014. The program reflected the recently
Science Highlights
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With the fifth phase of the Coupled Model Intercomparison Project (CMIP) mostly completed, the WCRP Working Group on
WMO Global Framework for Climate Services
Future Earth

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GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

1987

Science for a sustainable planet

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photo: NASA-Visible Earth

About

IGBP was launched in 1987 to coordinate international research on global-scale and regional-scale interactions between Earth's biological, chemical and physical processes and their interactions with human systems. IGBP views the Earth system as the Earth's natural physical, chemical and biological cycles and processes AND the social and economic dimensions.

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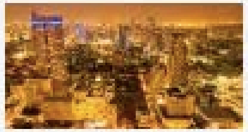

Mar 20, 2014
Conference - Global Challenges: Achieving Sustainability

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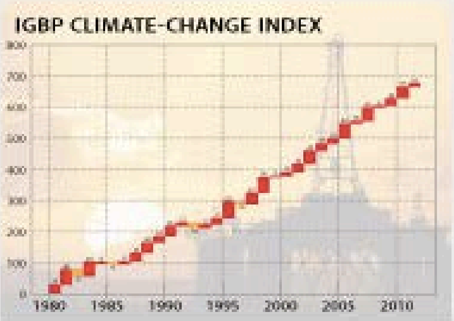

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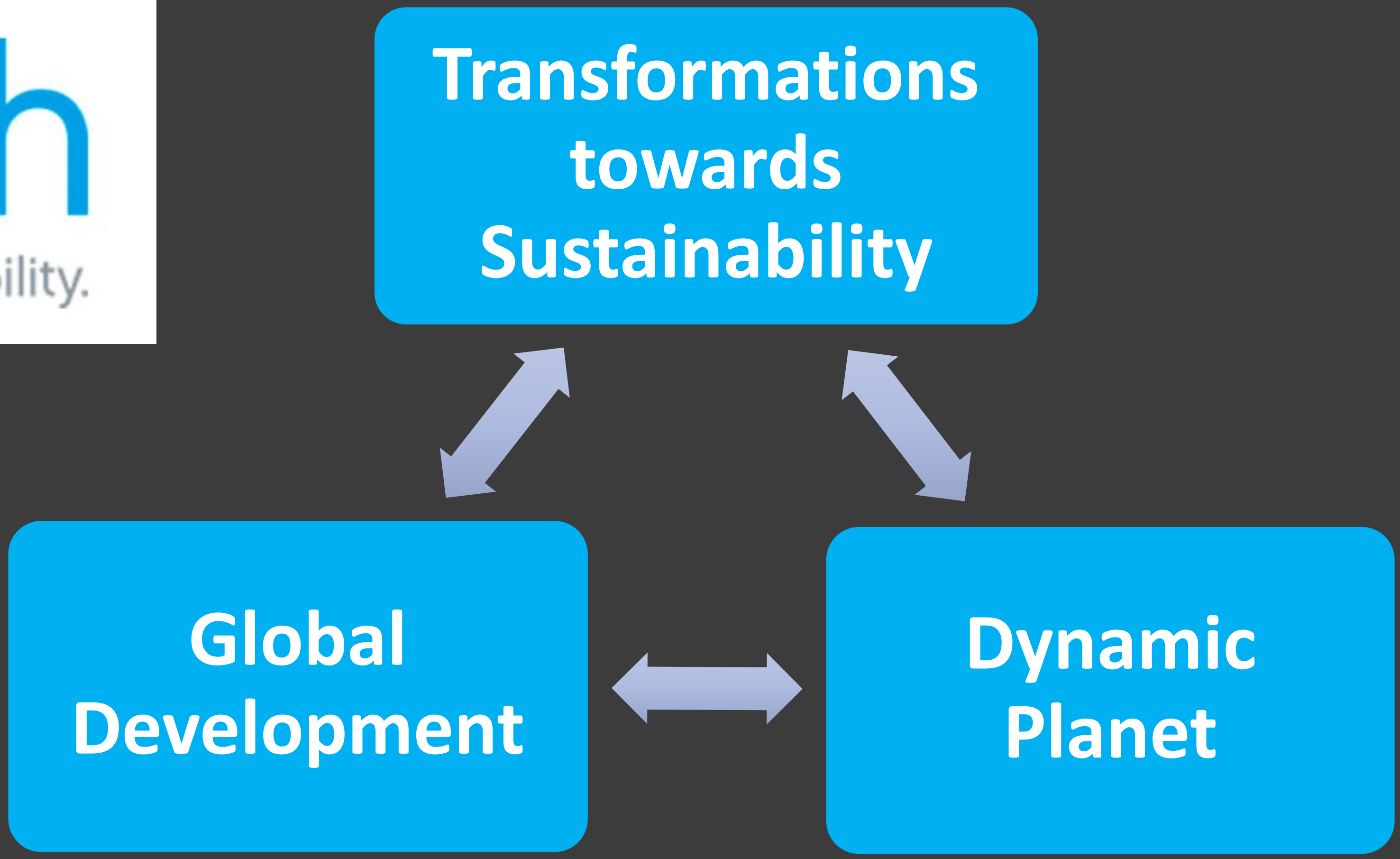
- Emergent Risks and Extreme Events



Observing systems, models, theory development, data management, research infrastructures


SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

The Future

Grand Challenges

Multiple stressors lead to major
planetary problems

Energy and Carbon

Water Scarcity

Food Availability

Air Quality

Human Health

Urbanization and Population Migration

Poverty and Education

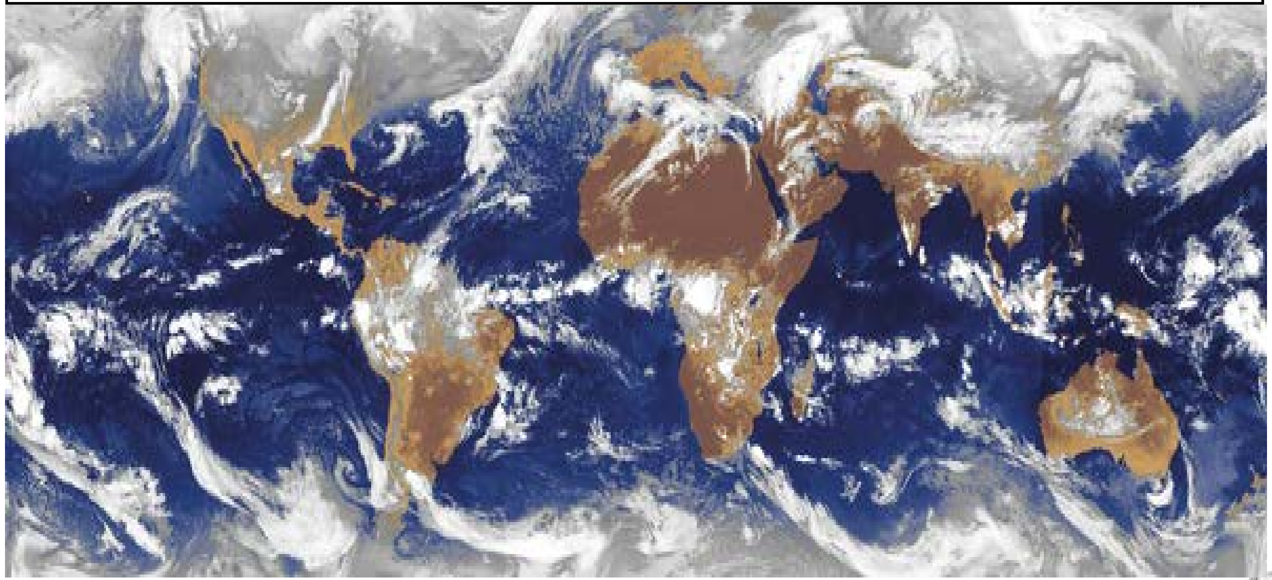
Fundamental research remains key for **addressing these complex questions**

- Understand interactions and feedbacks in the entire Earth System
- Develop integrated regional studies to assess the two-way coupling between the biophysical and social systems
- Improve existing climate tools (observations, models)
- Integrate new approaches, priorities, capabilities
- Cooperate with new partners

Grand challenges addressed by WCRP

WMO IOC ICSU International Council for Science WCRP World Climate Research Programme

Clouds & Circulation



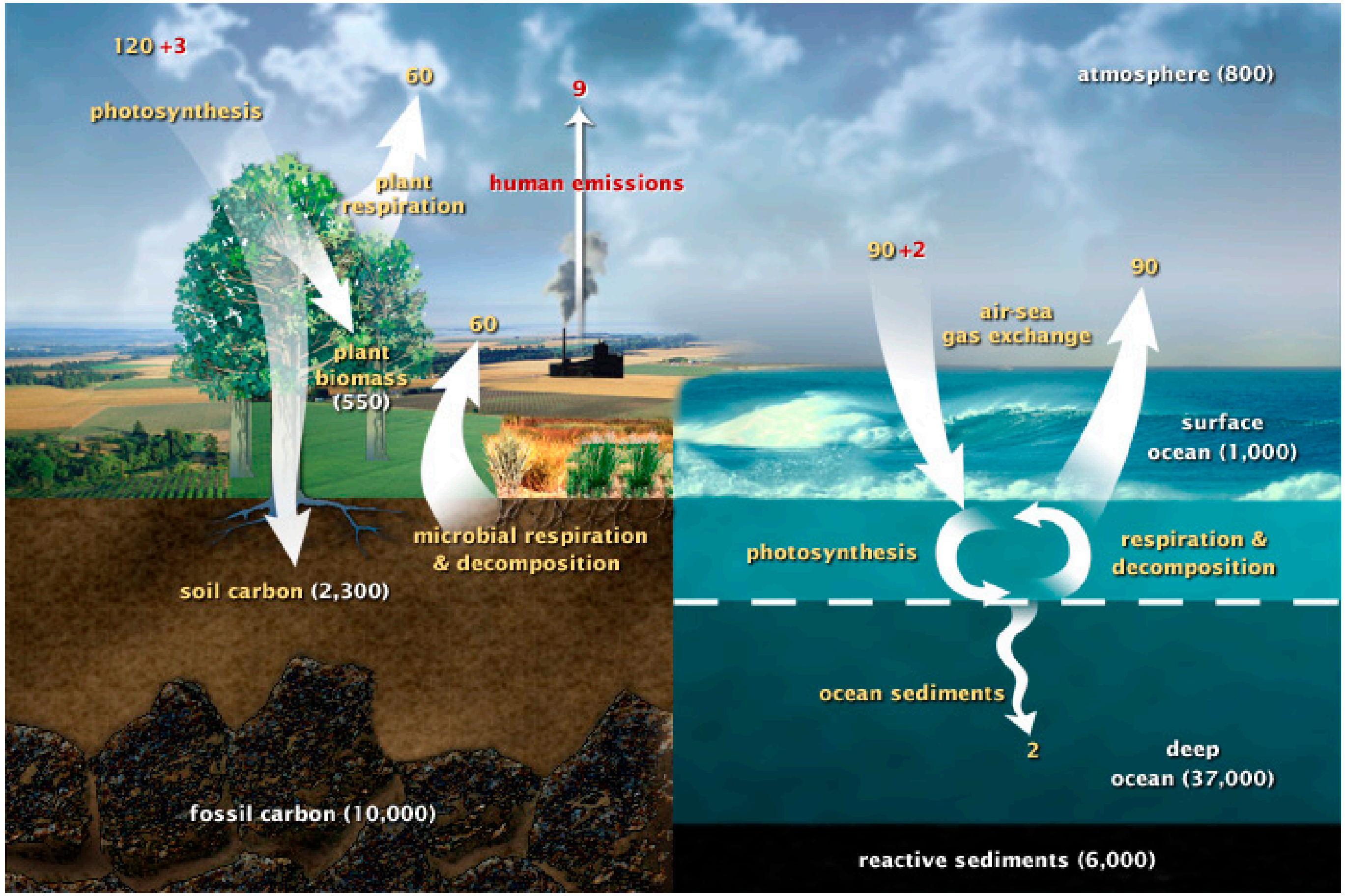
NASA Earth Observatory

How will clouds and circulation respond to global warming or other forcings?

How do clouds couple to circulations in the present climate?

How do these processes determine climate sensitivity to increasing greenhouse gases

Climate & Carbon



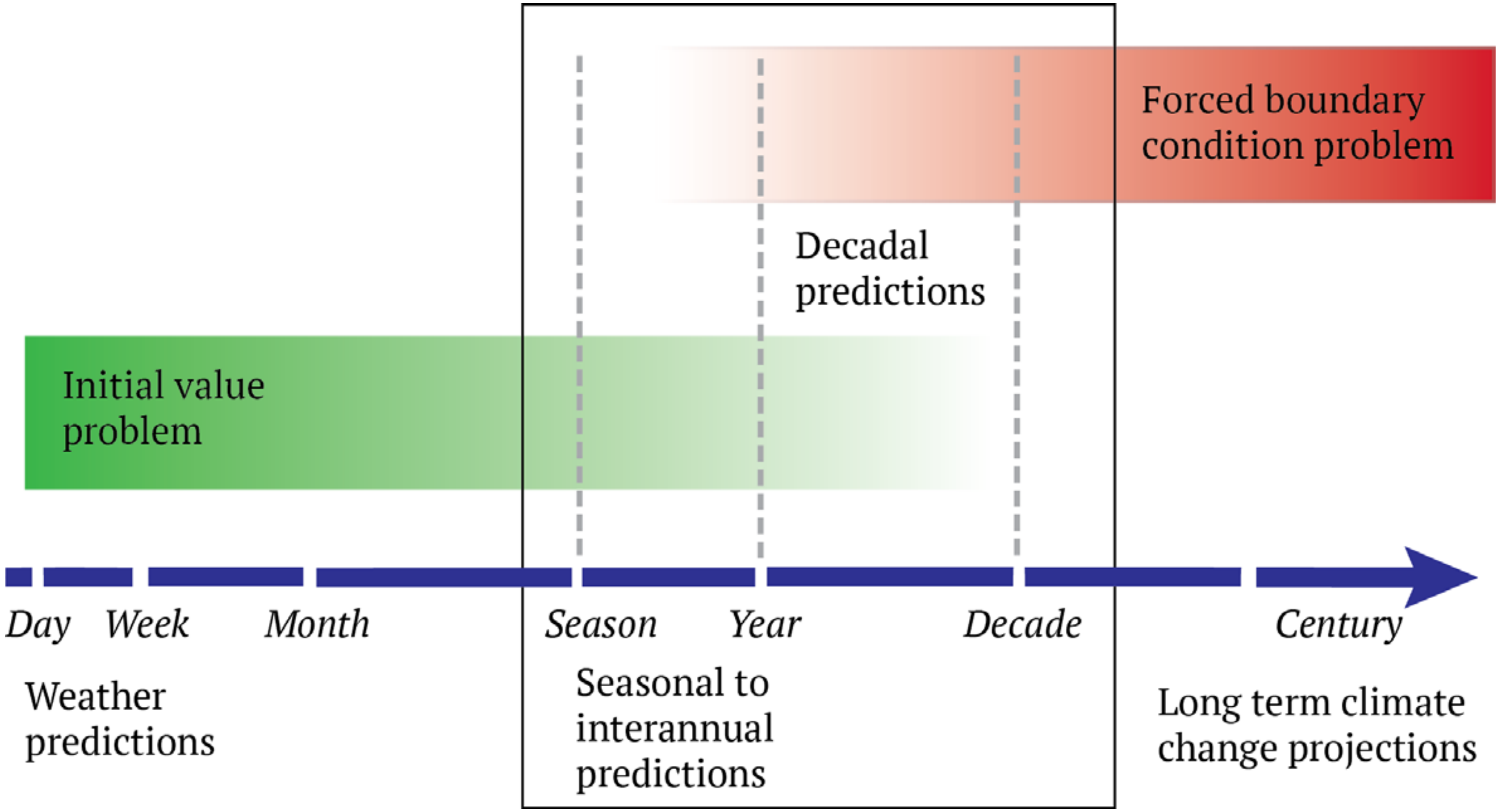
A conceptual illustration of the carbon cycle. NASA Earth Observatory.

What are the drivers of land and ocean carbon sinks?

What is the potential for amplification of climate change over the 21st century via climate-biogeochemical feedbacks?

How do greenhouse gases fluxes from highly vulnerable carbon reservoirs respond to changing climate?

Near-Term Prediction



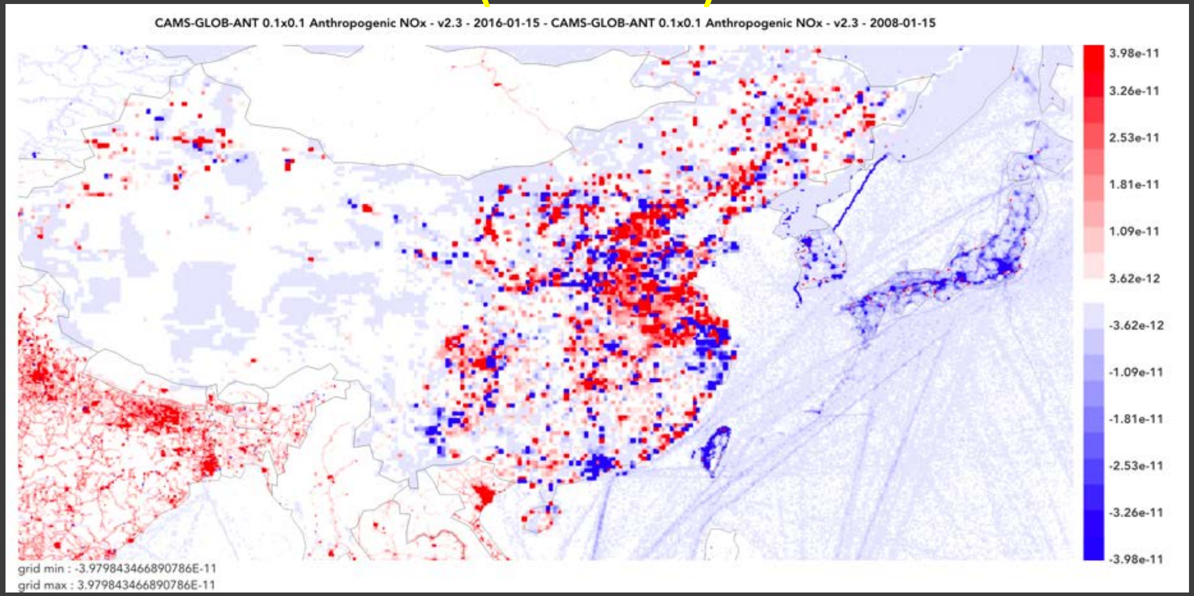
How can we enhance the understanding of sources of decadal predictability?

How can we serve decadal prediction information as is already done for seasonal prediction?

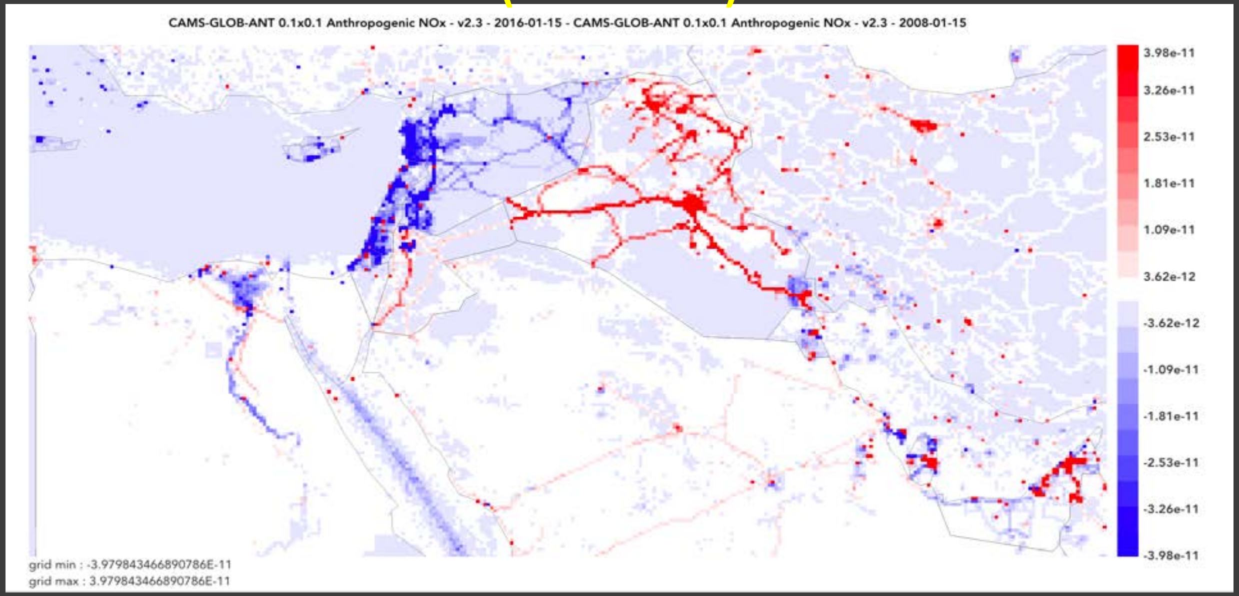
Changing chemical regimes are changing in a dynamical world

Changes in emissions of NO, CO and hydrocarbons (e.g., reduced urban pollution, enhanced wildfires) resulting from mitigation measures and climate change will lead to a revision of policies to combat air pollution.

Changing NO emissions in China, India and Japan (2008-2016)



Changing NO emissions in the Middle East (2008-2016)



Granier et al., NOAA, 2019

A new focus
Environmental Security for Humanity

Security is not only maintaining territorial integrity and domestic peace.

It must value economic prosperity, stability, health and well-being of populations.

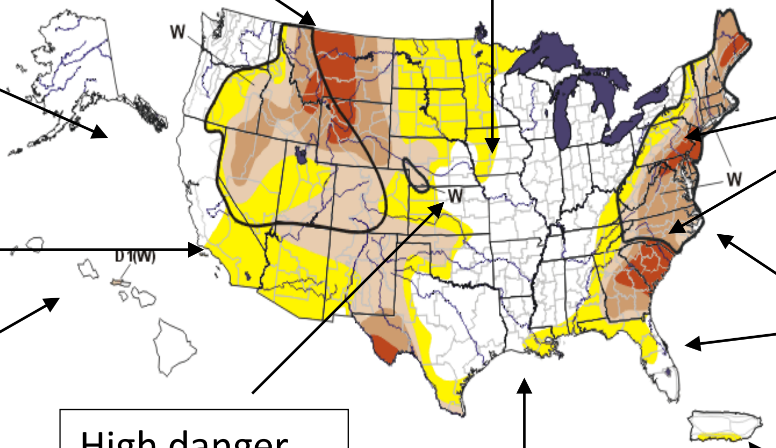
Citizens should have full access to our global commons and the right to be protected from the extreme environmental disruptions:

- Access to clean air
- Access to clean water
- Access to safe food
- Access to natural resources

Environmental prediction of environmental factors is key to address this issue.

What are the prospects for the future?

New **environmental** forecast products will be feasible



Major fires

Agricultural production at 50%, blowing dust

major fisheries regime change likely

Health warning: Limit outdoor activities; expect brownouts

Air quality alerts – 75% of days

Swimming and Fishing prohibited

Frequent floodings and Asian dust threats continue

High danger of toxic CO_2 releases

Expect fisheries downturn; health threats

African bacteria alerts

Possible threats for the summer: hot, dry and unhealthy

Capability to forecast regional air quality within the global context

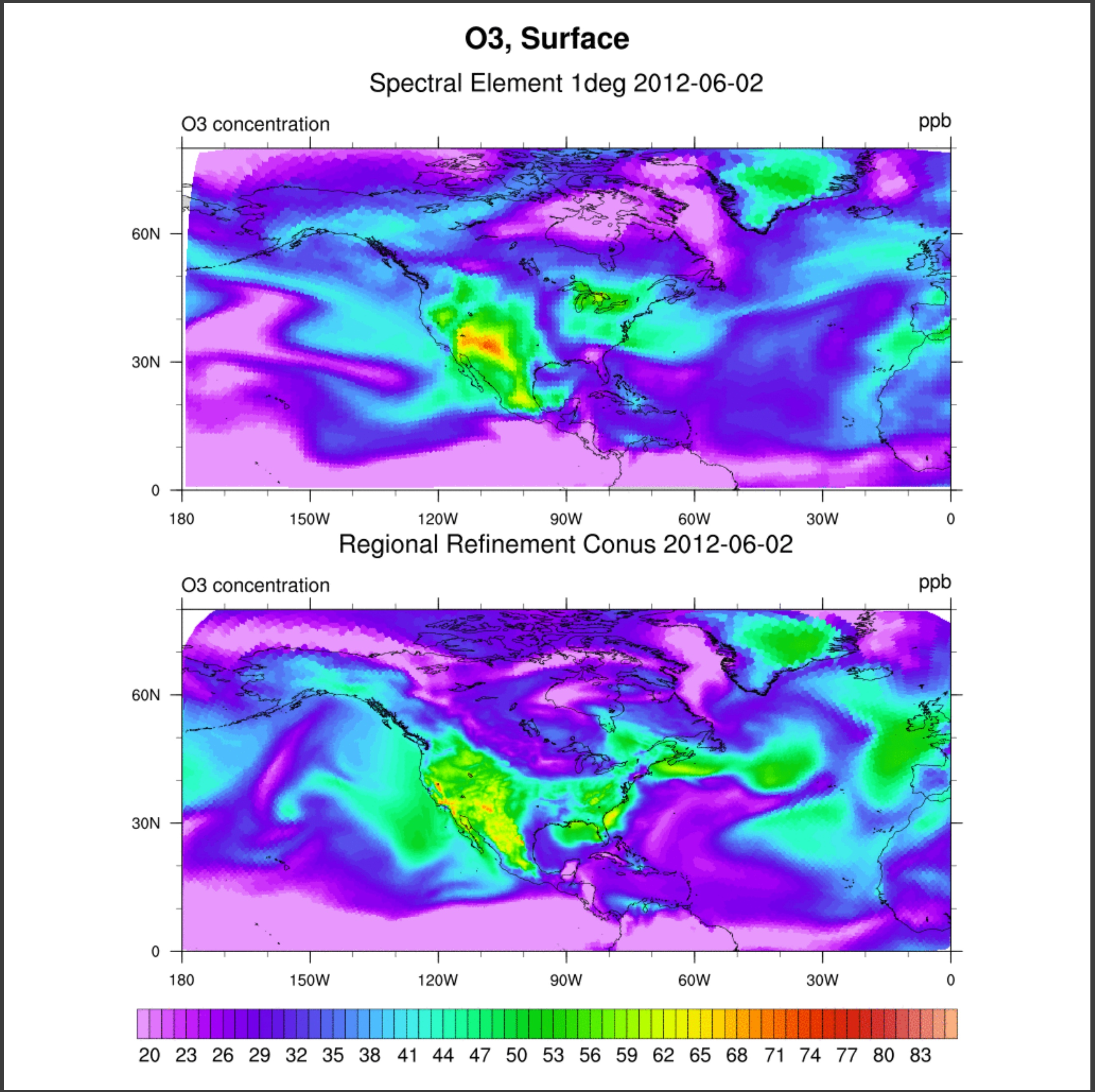
Global model with 100 km resolution

Surface Ozone

Global model with regional refinement.

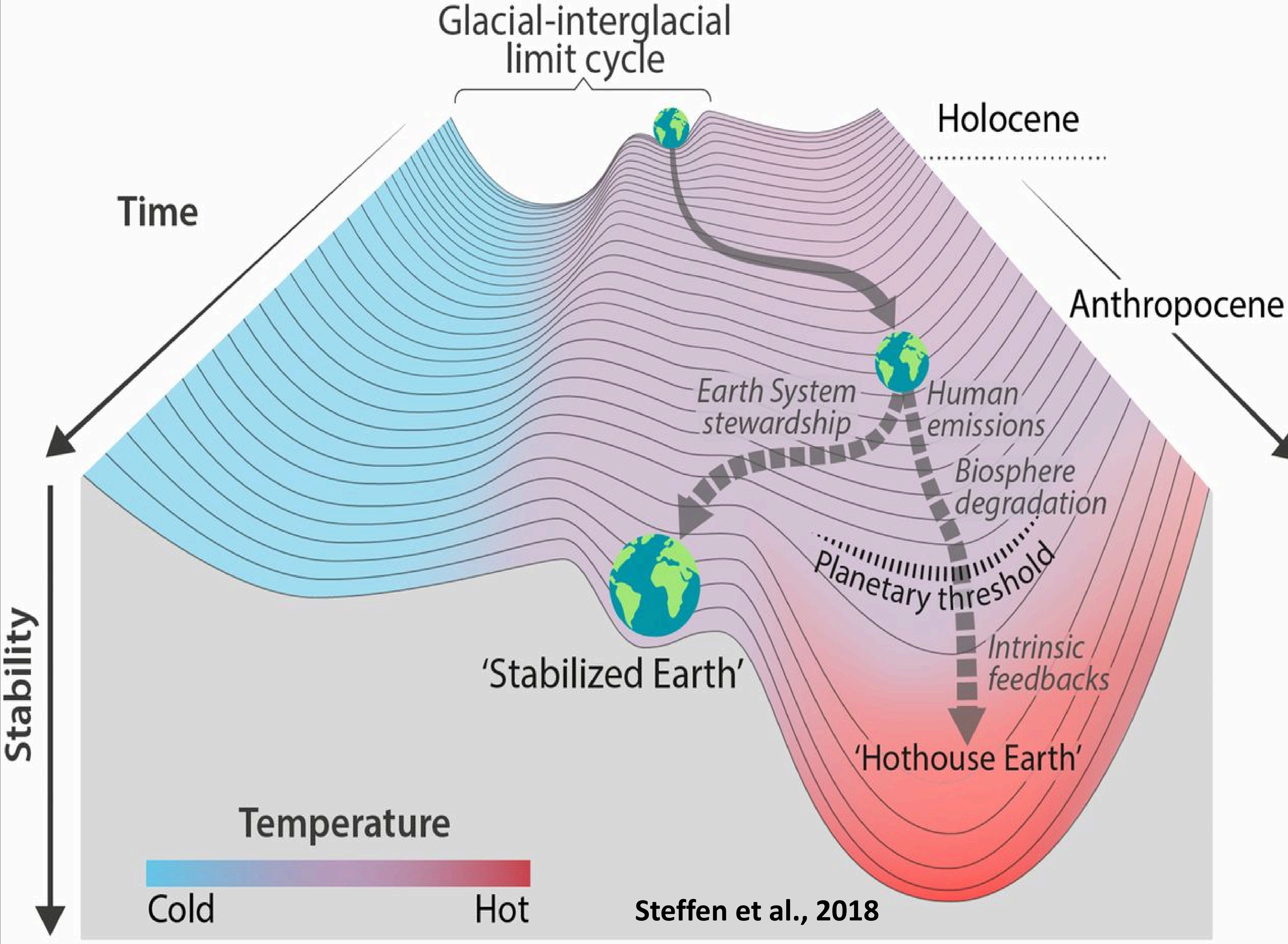
Substantial differences in ozone mixing ratios between coarse grid (~100 km) and regionally-refined grid (~14 km)

Lacey, Schwantes and Tilmes, NCAR



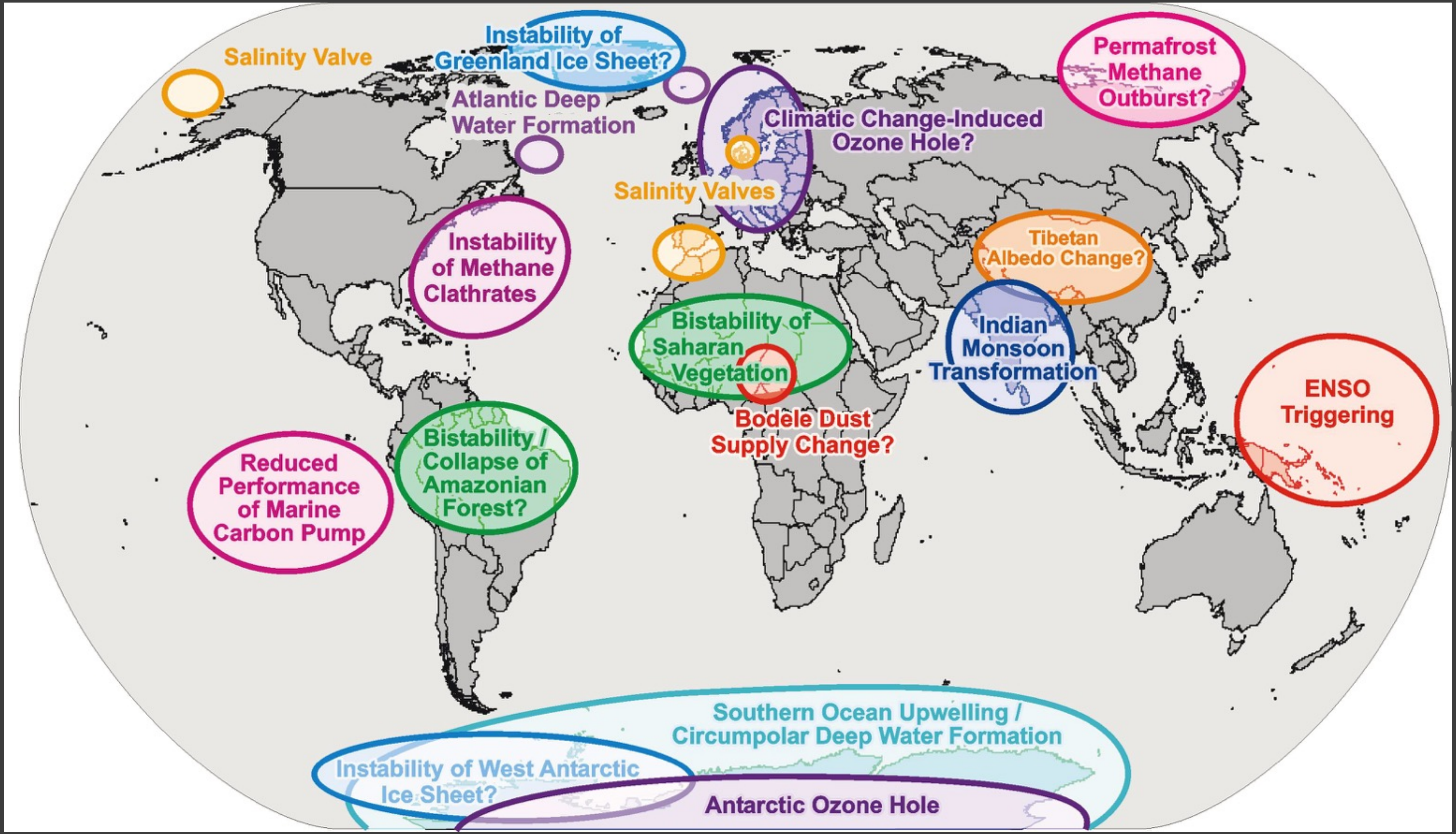
Conclusions

Which trajectory for the Earth System in the Future?



Steffen et al., 2018

Tipping Elements in the Earth System



Source: Schellnhuber, after Lenton et al, PNAS, 2008


An Uncertain Future on a Much Hotter Planet?
A Return to Holocene-like Conditions?
We need to decide which direction we want to take

Thank You

"Science exists to serve human welfare. It's wonderful to have the opportunity given us by society to do basic research, but in return, we have a very important moral responsibility to apply that research to benefiting humanity."

Walter Orr Roberts