Avoid the Unmanageable, Manage the Unavoidable

What can we expect from the climate in the coming decades, and what can we do?

J. H. Plumb Auditorium, Christ's College, Thursdays, 5:30 to 7 pm

Charles F. Kennel

Director, Vice-Chancellor, and Distinguished Professor Emeritus,
Scripps Institution of Oceanography,
University of California, San Diego

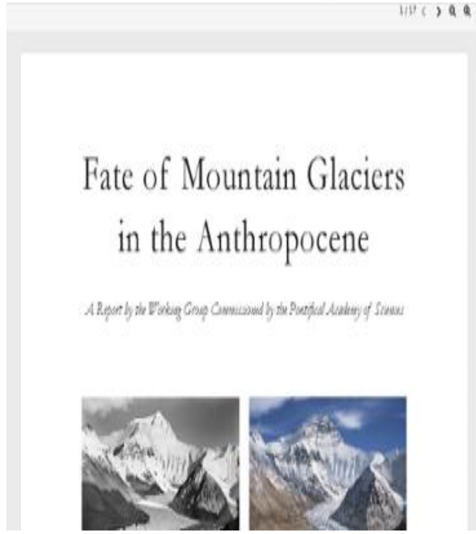
Distinguished Visiting Fellow,
Christ's College, Cambridge

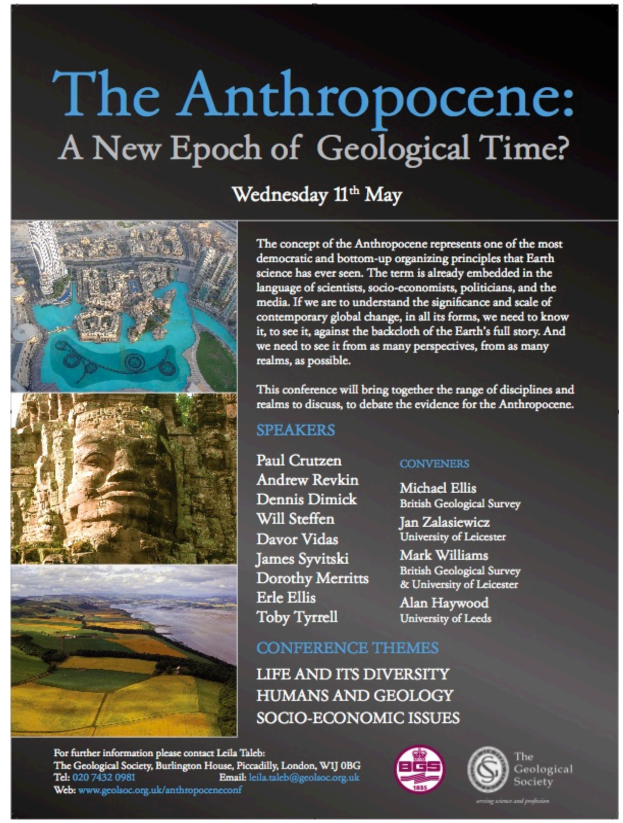
Visiting Research Fellow,
Centre for Science and Policy
University of Cambridge

Jan 16: Introduction

Brief history of climate research, focusing on the relationship between atmospheric abundance of CO_2 and global temperature over time, and fundamental truths about the long-term future

The Anthropocene





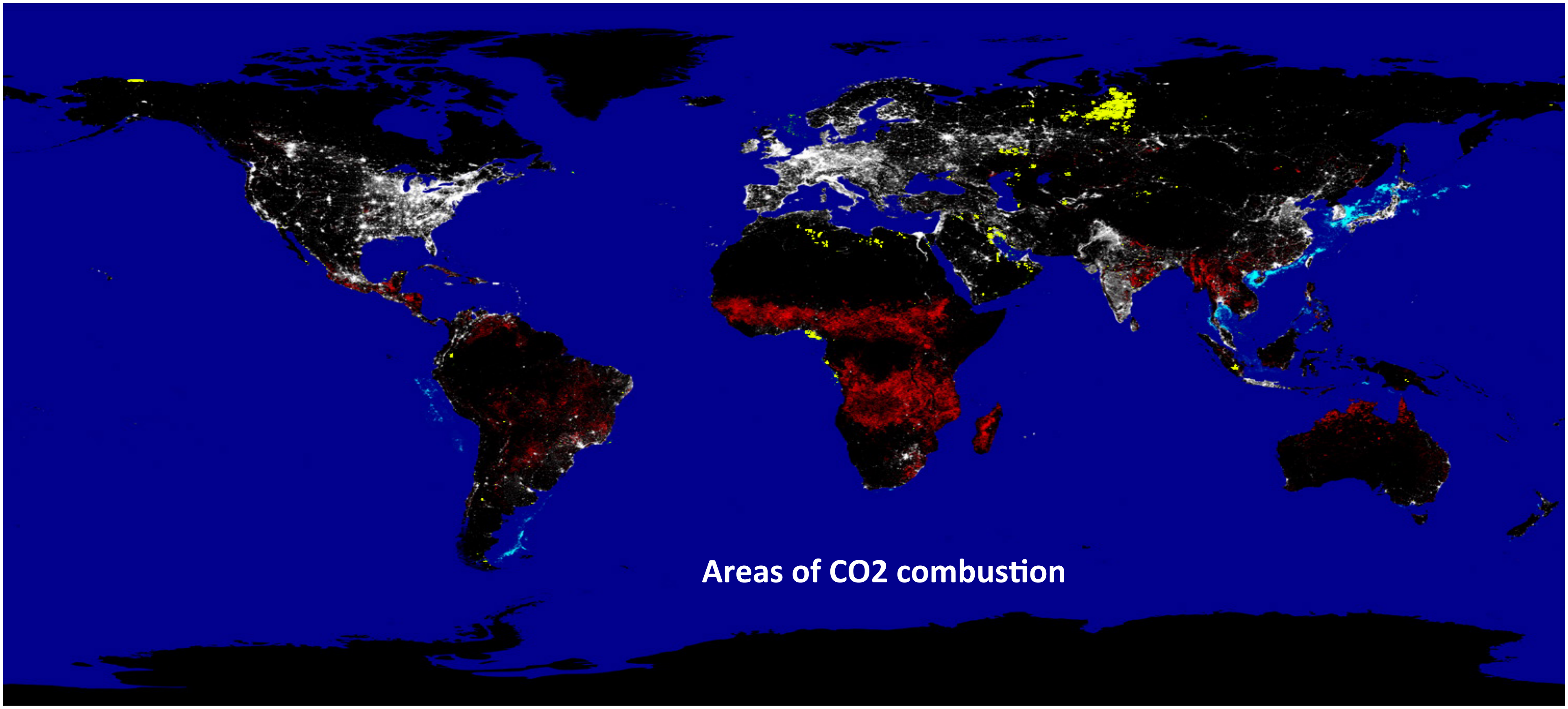
P. Crutzen and E. Stoermer, *Global Change Newsletter*, 41, 1, pp. 17-18, 2000

P. Crutzen, Anthropocene Man, *Nature,* 467, S10, October 14, 2010

Our Civilization Faces An Entirely New Circumstance

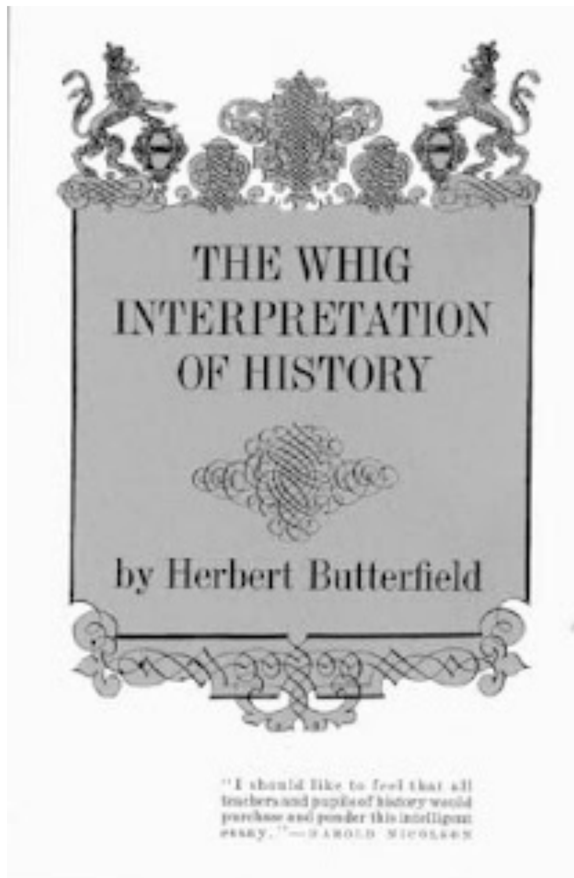
The human environmental impact became global in the last 50 years

Global Climate Change a Symptom and a Cause



Biodiversity collapse, habitat fragmentation, droughts, floods, wildfires, air pollution, deforestation, desertification, melting glaciers, disappearing polar ice, sea level rise…

Historical Highlights



Standard Narrative

A standard narrative may not relate exactly how things happened, but helps to understand why things are happening as they are

An "origins myth" legitimizes what scientists choose to do

Vice-Admiral Robert Fitzroy RN, 1805-1865

Founder of the UK Met Office

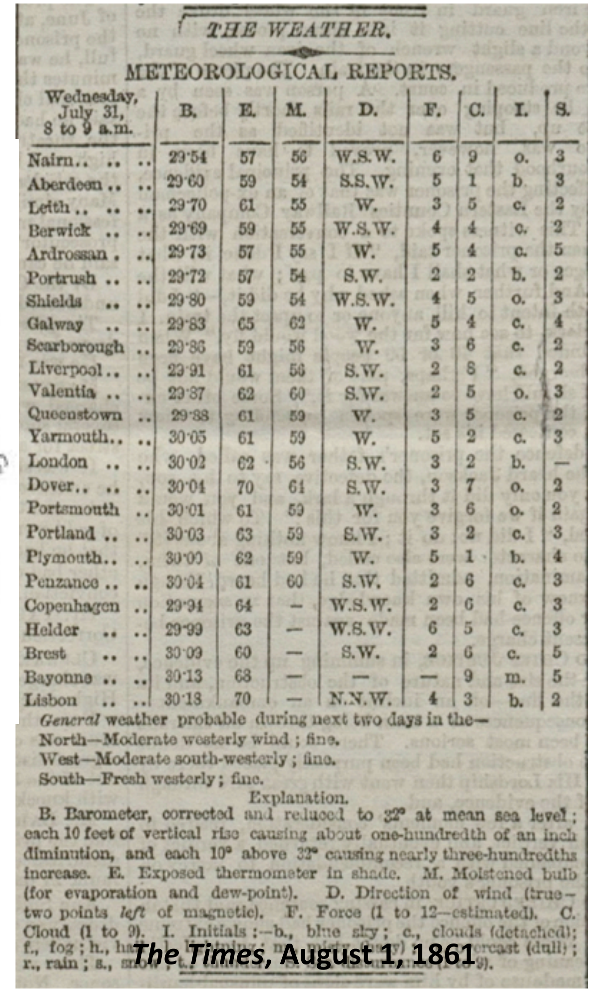
BRITISH

ELECTRIC TELEGRAPH

COMPANY,

CENTRAL OFFICES, ROYAL EXCHANGE,

LONDON.



THE WEATHER.

METEOROLOGICAL REPORTS.

Wednesday, July 31, 8 to 9 a.m.	B.	E.	M.	D.	F.	C.	I.	S.
Nairn..	29·54	57	56	W.S.W.	6	9	o.	3
Aberdeen	29·60	59	54	S.S.W.	5	1	b.	3
Leith	29·70	61	55	W.	3	5	c.	2
Berwick	29·69	59	55	W.S.W.	4	4	c.	2
Ardrossan . ..	29·73	57	55	W.	5	4	c.	5
Portrush	29·72	57	54	S.W.	2	2	b.	2
Shields	29·80	59	54	W.S.W.	4	5	o.	3
Galway	29·83	65	62	W.	5	4	c.	4
Scarborough ..	29·86	59	56	W.	3	6	c.	2
Liverpool.. ..	29·91	61	56	S.W.	2	8	c.	2
Valentia	29·87	62	60	S.W.	2	5	o.	3
Queenstown ..	29·88	61	59	W.	3	5	c.	2
Yarmouth.. ..	30·05	61	59	W.	5	2	c.	3
London	30·02	62	56	S.W.	3	2	b.	—
Dover..	30·04	70	61	S.W.	3	7	o.	2
Portsmouth ..	30·01	61	59	W.	3	6	o.	2
Portland	30·03	63	59	S.W.	3	2	c.	3
Plymouth.. ..	30·00	62	59	W.	5	1	b.	4
Penzance	30·04	61	60	S.W.	2	6	c.	3
Copenhagen ..	29·94	64	—	W.S.W.	2	6	c.	3
Helder	29·99	63	—	W.S.W.	6	5	c.	3
Brest	30·09	60	—	S.W.	2	6	c.	5
Bayonne	30·13	68	—	—	—	9	m.	5
Lisbon	30·18	70	—	N.N.W.	4	3	b.	2

General weather probable during next two days in the—

North—Moderate westerly wind ; fine.

West—Moderate south-westerly ; fine.

South—Fresh westerly ; fine.

Explanation.

B. Barometer, corrected and reduced to 32° at mean sea level ; each 10 feet of vertical rise causing about one-hundredth of an inch diminution, and each 10° above 32° causing nearly three-hundredths increase. E. Exposed thermometer in shade. M. Moistened bulb (for evaporation and dew-point). D. Direction of wind (true—two points *left* of magnetic). F. Force (1 to 12—estimated). C. Cloud (1 to 9). I. Initials :—b., blue sky ; c., clouds (detached) ; f., fog ; h., ha[illegible] overcast (dull) ; r., rain ; s., snow ; [illegible] 9).

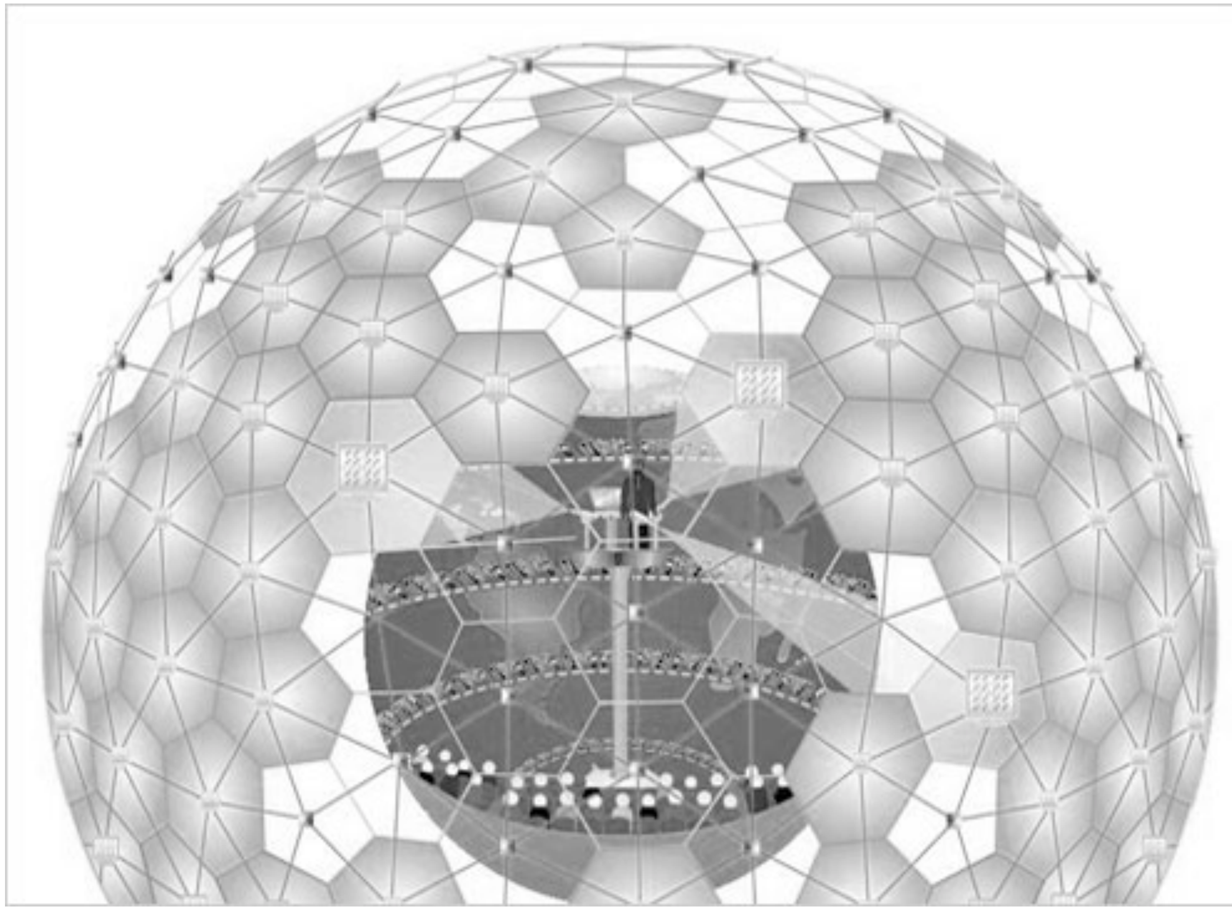
The Times, August 1, 1861

Fitzroy's technology-driven empiricism was not popular among the savants of the Royal Society who, with some justification, complained there was no theoretical basis for the weather forecast. But, no-one then could solve the Navier-Stokes equations, either. In fact, today's forecasting fuses theory-based computations with empirical data.

Richardson's Forecast Factory

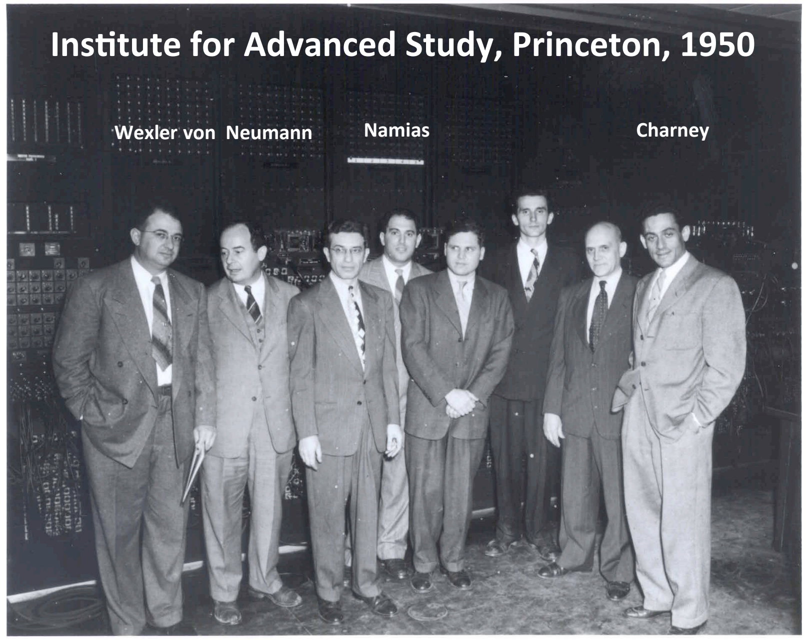
1922

Lewis Fry Richardson
(1881-1953)

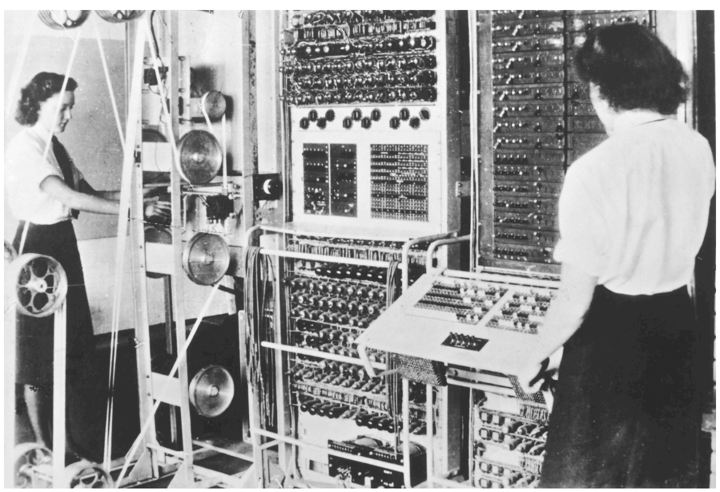


64,000 *Human* "Computers"

The First Electronic Weather Calculations

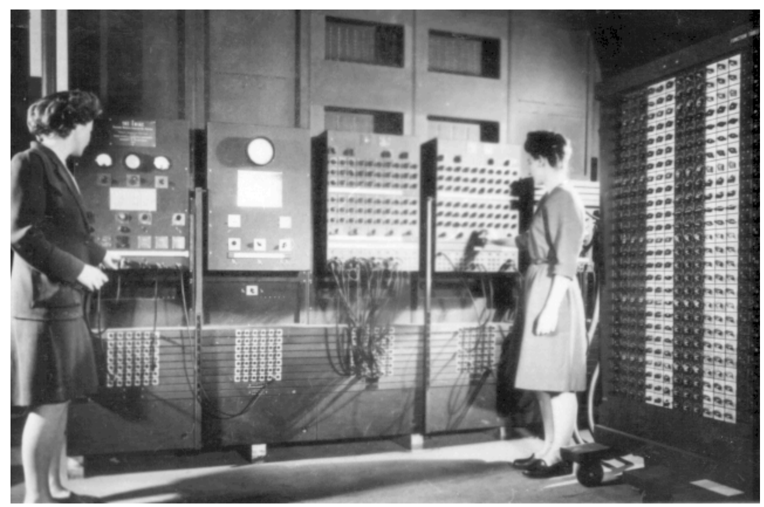


Colossus

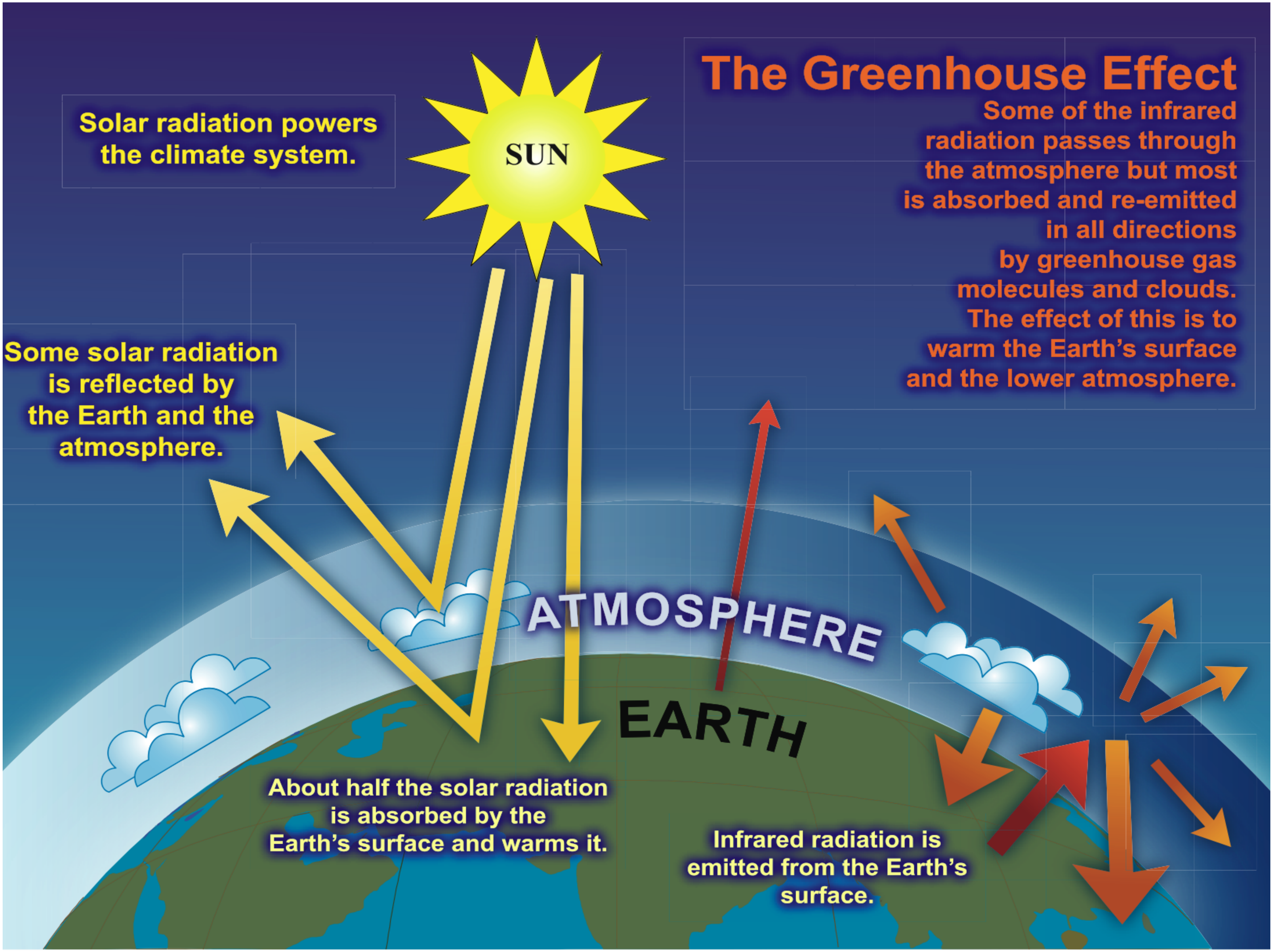


Bletchley Park, 1943

ENIAC



Los Alamos/U. Pennsylvania, 1946



The Greenhouse Effect
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation powers the climate system.
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

A Brief History of Scientists Studying the Human Influence on Climate

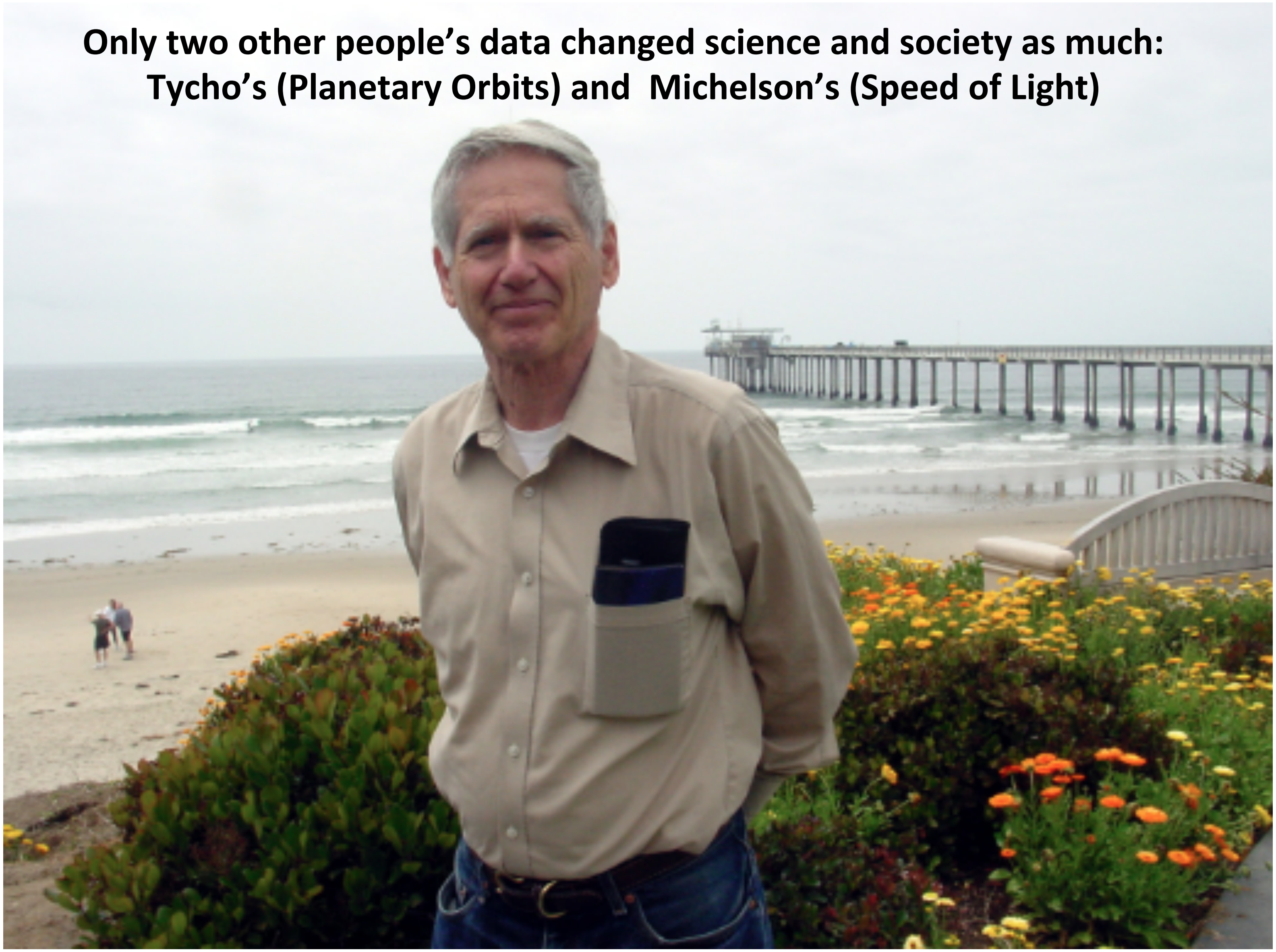
Herschel (1800): Discovery of infrared heat radiation
Fourier (1825-27): Greenhouse effect keeps the earth warmer than expected from visible solar radiation energy flux alone
Tyndall (1850s): Atmospheric H_2O, CO_2 are GHGs: they can scatter infrared radiation
Arrhenius (1896): Fossil fuel CO_2 could cause warming
Callendar (1938): Global land temperatures had increased in previous 50 years
Keeling (1957-2005)): Atmospheric CO_2 is increasing

“A Great One-Time Geophysical Experiment”

Roger Revelle, 1909-1991

In those pre-Anthropocene days, people thought that the vast oceans would easily absorb the atmospheric carbon dioxide produced by human industrial activity. In a landmark paper, Revelle and Hans Suess (1957) ascertained the rate of CO2 exchange between the atmosphere and sea water. They estimated the CO2 lifetime to be 20 years. A fair fraction of the CO2 humans are producing would therefore accumulate in the atmosphere. The next question was, is it increasing? This needed to be measured, not calculated, and Revelle brought Dave Keeling to Scripps from CalTech.

Charles David Keeling, 1928-2005



Mauna Loa Carbon Dioxide Observatory

Because of CO2s long lifetime in the atmosphere, it would be well-mixed and evenly distributed globally. A measurement at a single location would suffice.

The Keeling Curve

A DAILY RECORD OF ATMOSPHERIC CARBON DIOXIDE FROM SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

What Does This Number Mean? How are CO2 Data Processed? Support the Keeling Curve The State of Climate: Other Indicators Search

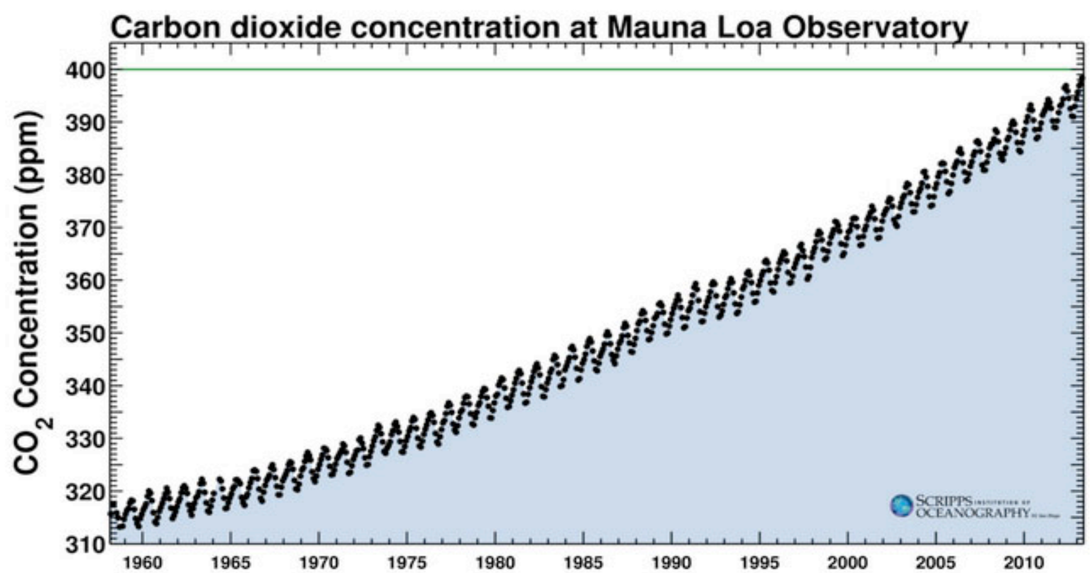
Latest reading: 400.27 ppm

CO2 concentration on May 16, 2013

May 17 instrument status: Operational

Historical Charts

- 1 week
- 1 month
- 6 months
- 1 year
- 2 years
- Keeling Curve (1958-present)
- 300 years
- 800,000 years



Keeling was the first to measure atmospheric CO2 with sufficient precision to resolve seasonal cycle

Charney Report (1979)

Substantiating the reliability and importance of Keeling's results triggered an avalanche of scientific initiative

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate
Woods Hole, Massachusetts
July 23–27, 1979
to the
Climate Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

"The primary effect of increased atmospheric CO2 on climate… is to cause more absorption of thermal radiation from the earth's surface and thus to increase the air temperature….

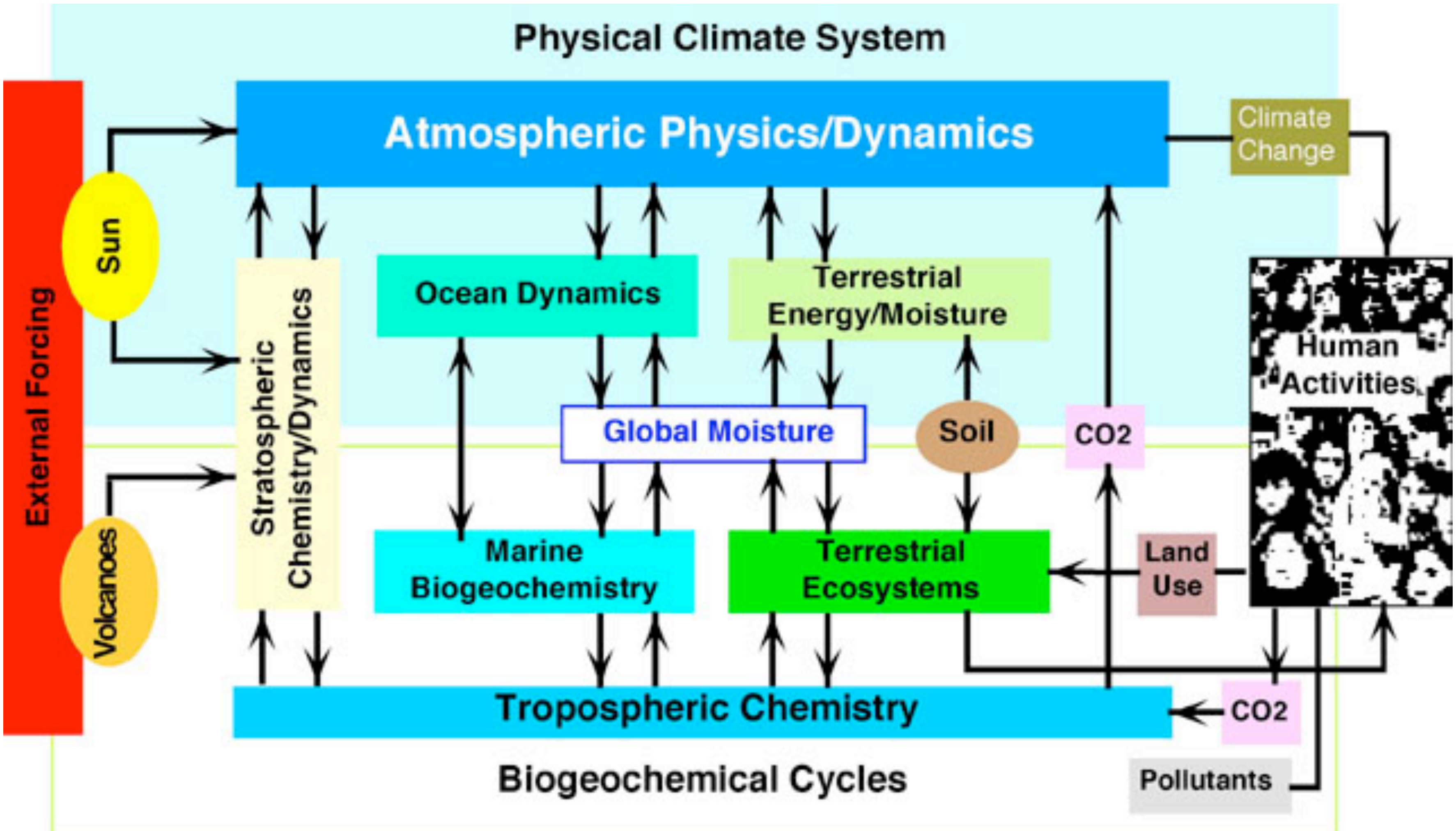
When…the CO2 content of the atmosphere is doubled and … equilibrium is achieved,… modeling efforts predict a global surface warming of between 2°C and 3.5°C, with greater increases at high latitudes…

….the warming will eventually occur, and the associated regional climatic changes (will be) so important (that) socioeconomic consequences may… be significant"

A New Scientific Discipline

Earth System Science

Science for the Anthropocene



(from Earth System Science: An Overview, NASA, 1988)

Centuries, not Eons

Francis Bretherton, 1982 ff.

Earth System Science Partnership

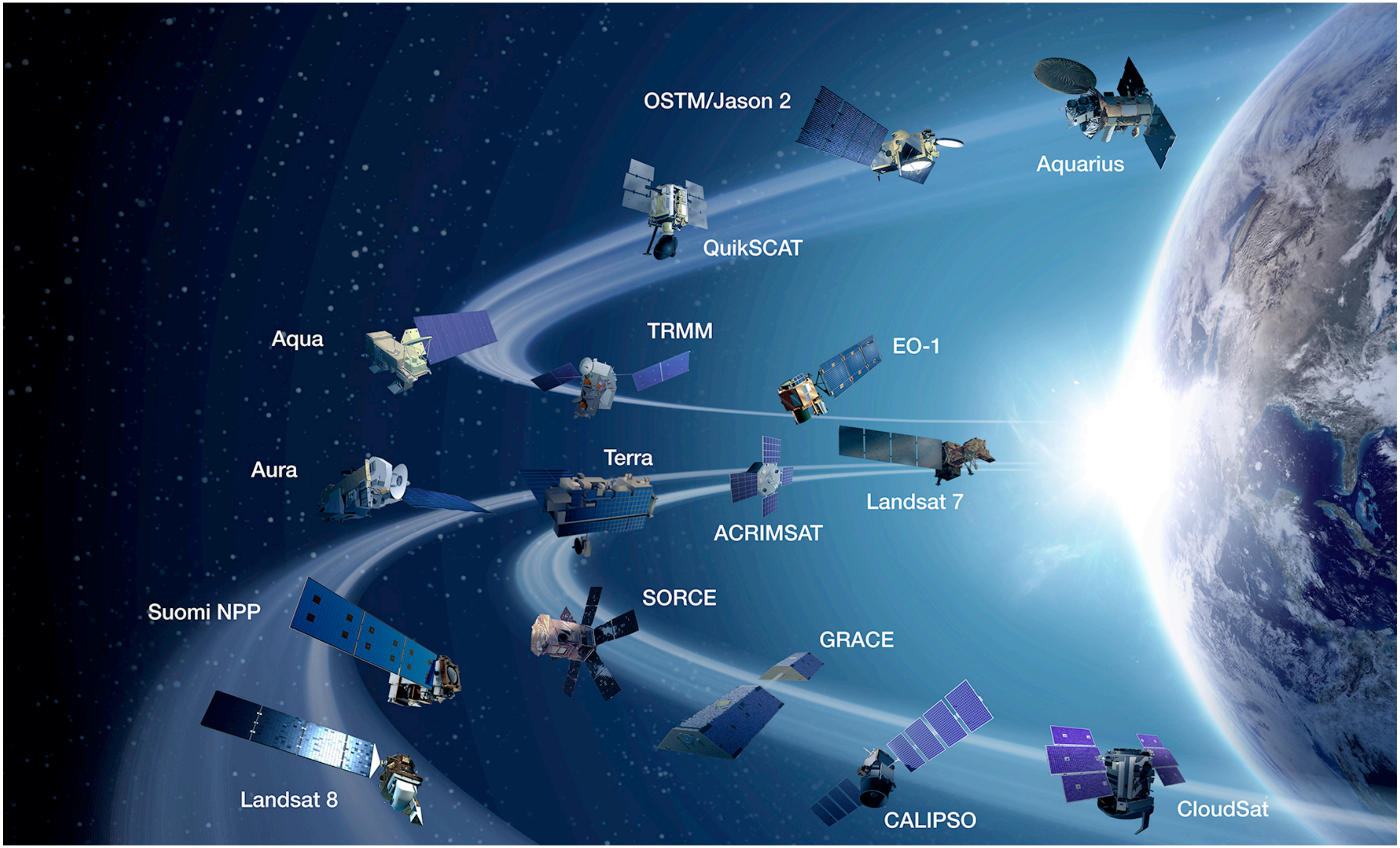
Climate Change in its Larger Sustainability Context

World Climate Research Programme (1980)
International Geosphere-Biosphere Programme (1987)
DIVERSITAS (1991)
International Human Dimensions Programme (1996)

A Vast Scientific Infrastructure

Earth Observing System, 1990-

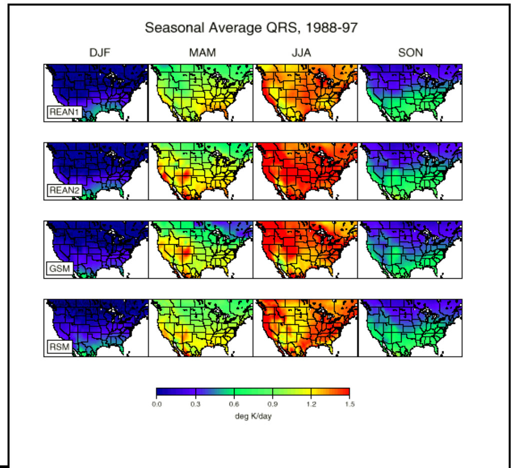
Multi-Disciplinary Observations for Earth System Science



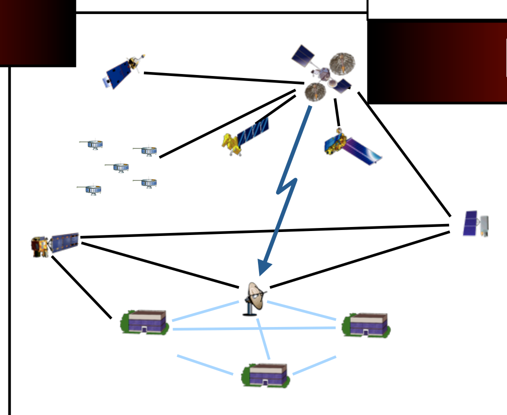
Cyber-Infrastructure

The Earth Observing System's Data and Information System (EOSDIS) pioneered collection, integration, analysis, and distribution of "big data"

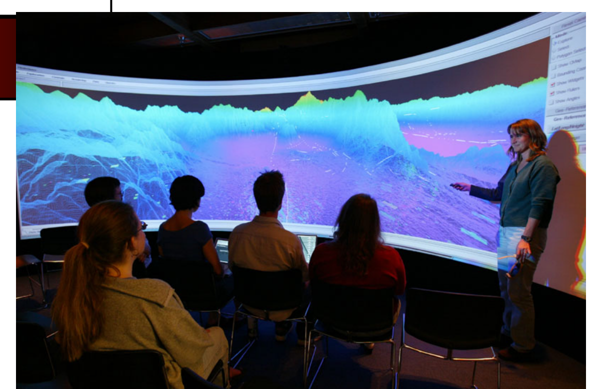
Computing



Modeling

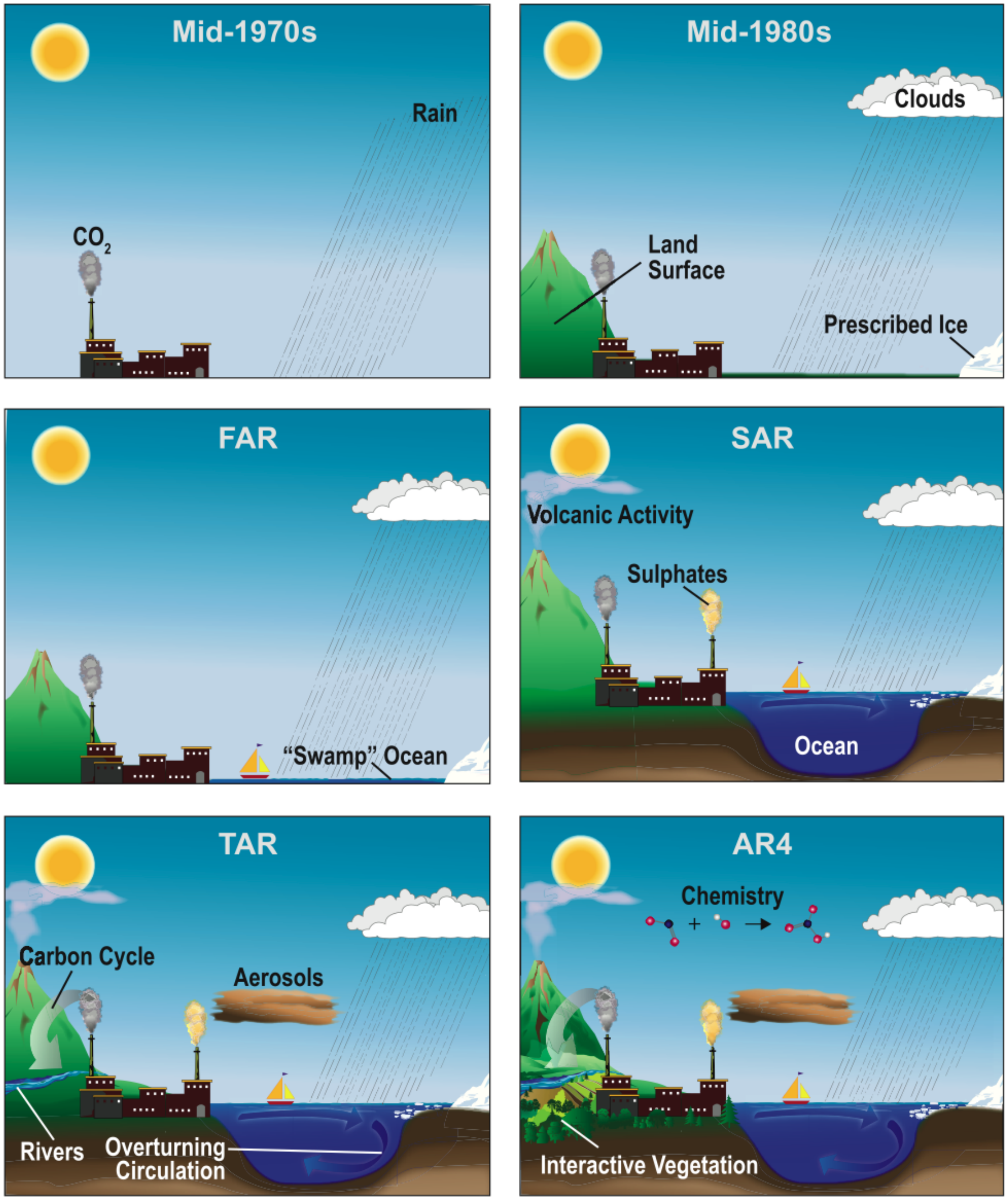


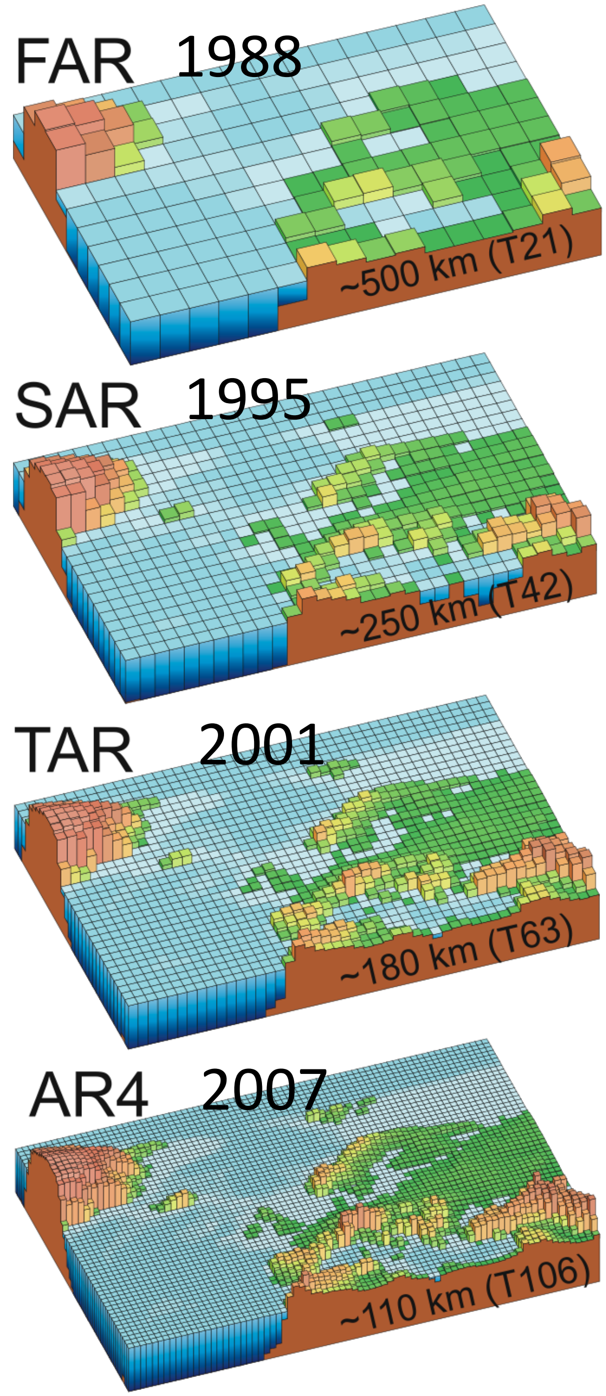
Communications



Visualization

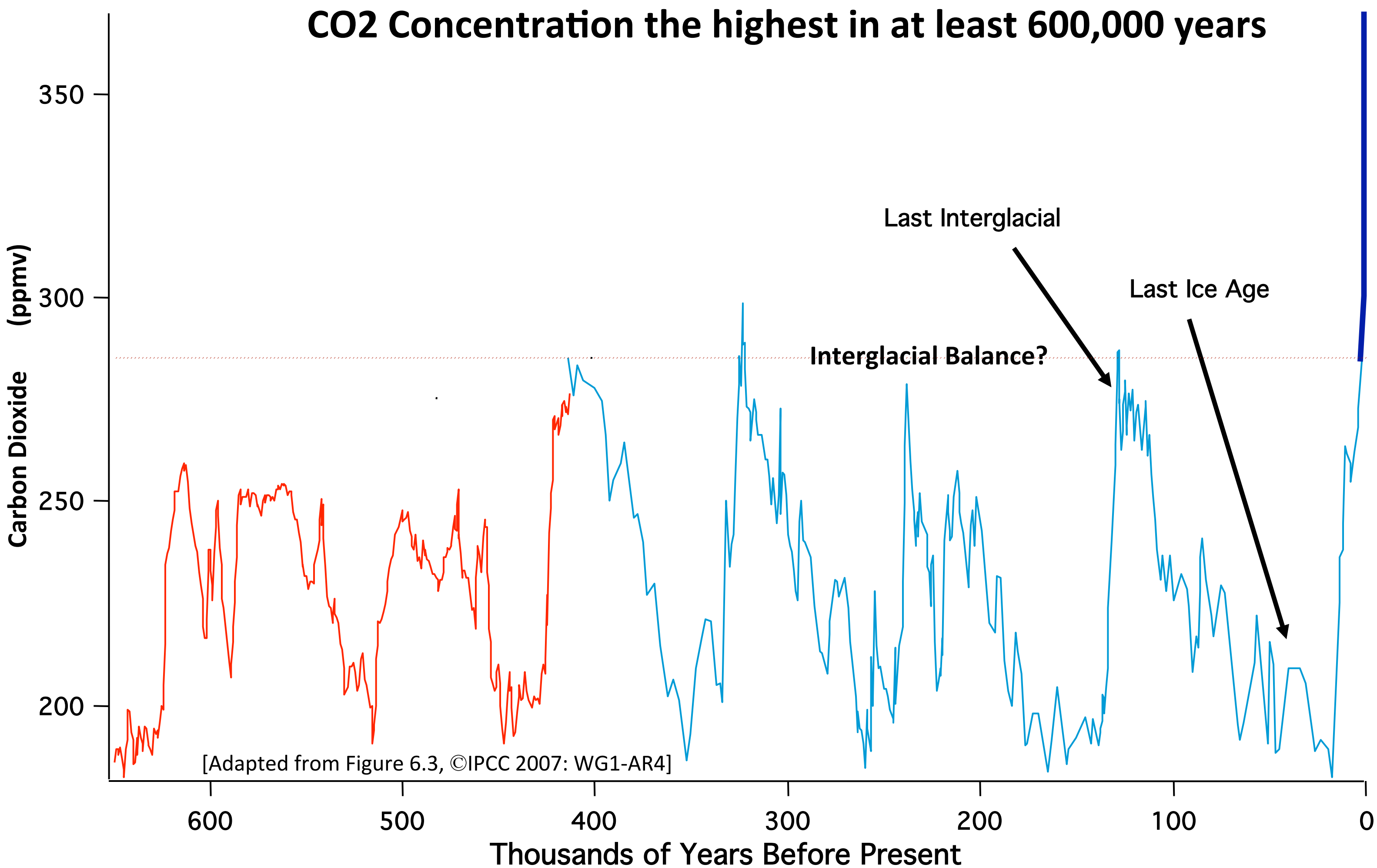
The World in Global Climate Models





Some Achievements of Earth System Science

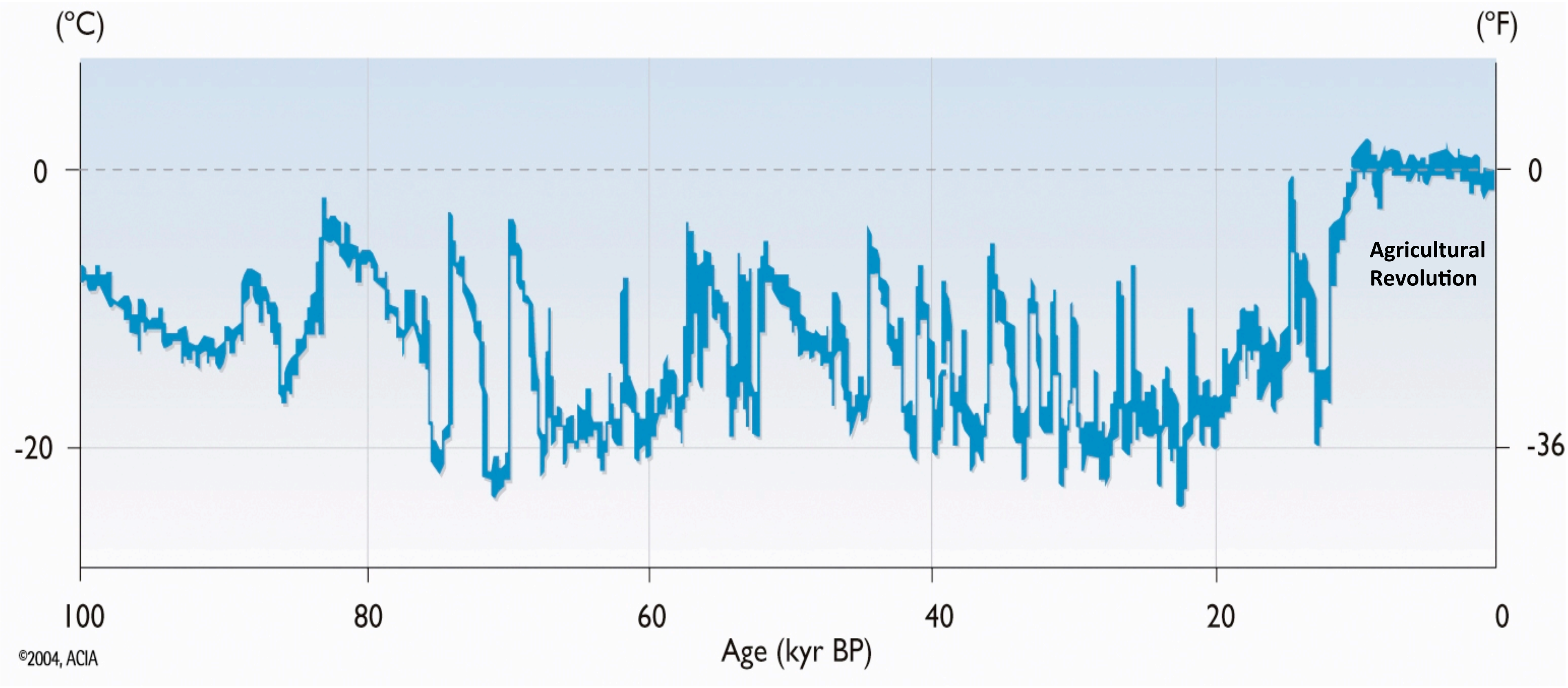
Paleoclimate



Time History of Atmospheric CO_2 Concentrations Inferred From Air Bubbles Trapped In Greenland and Antarctic Ice

The Last Ice Age

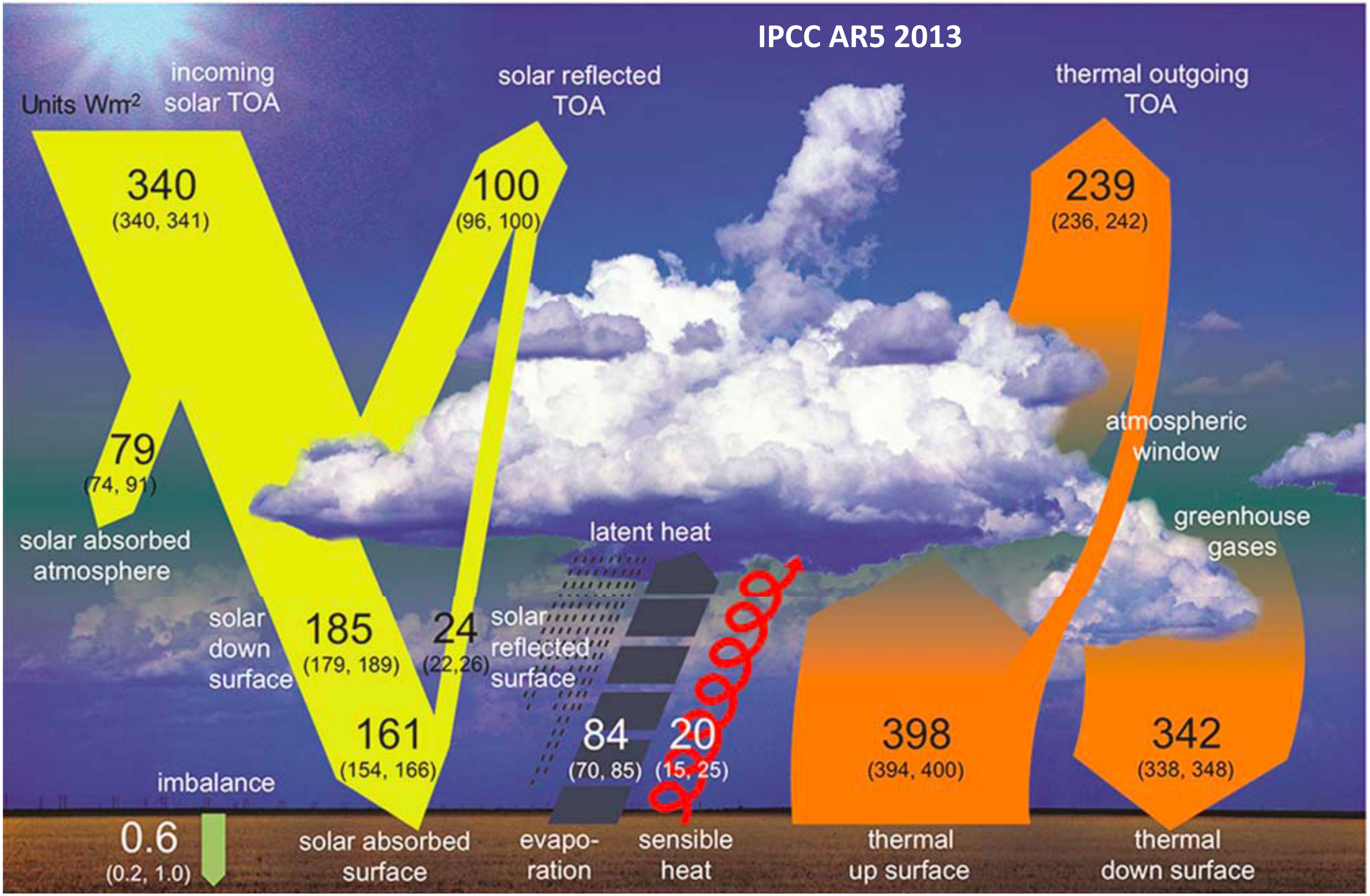
Difference between Ice Age and Interglacial is of order 5 degC



Temperature Inferred from O18/O16 ratio in air bubbles occluded in Greenland Ice Sheet

Arctic Council, Impacts of a Warming Climate: Arctic Climate Impact Assessment, Cambridge U. Press, Cambridge, 2004.

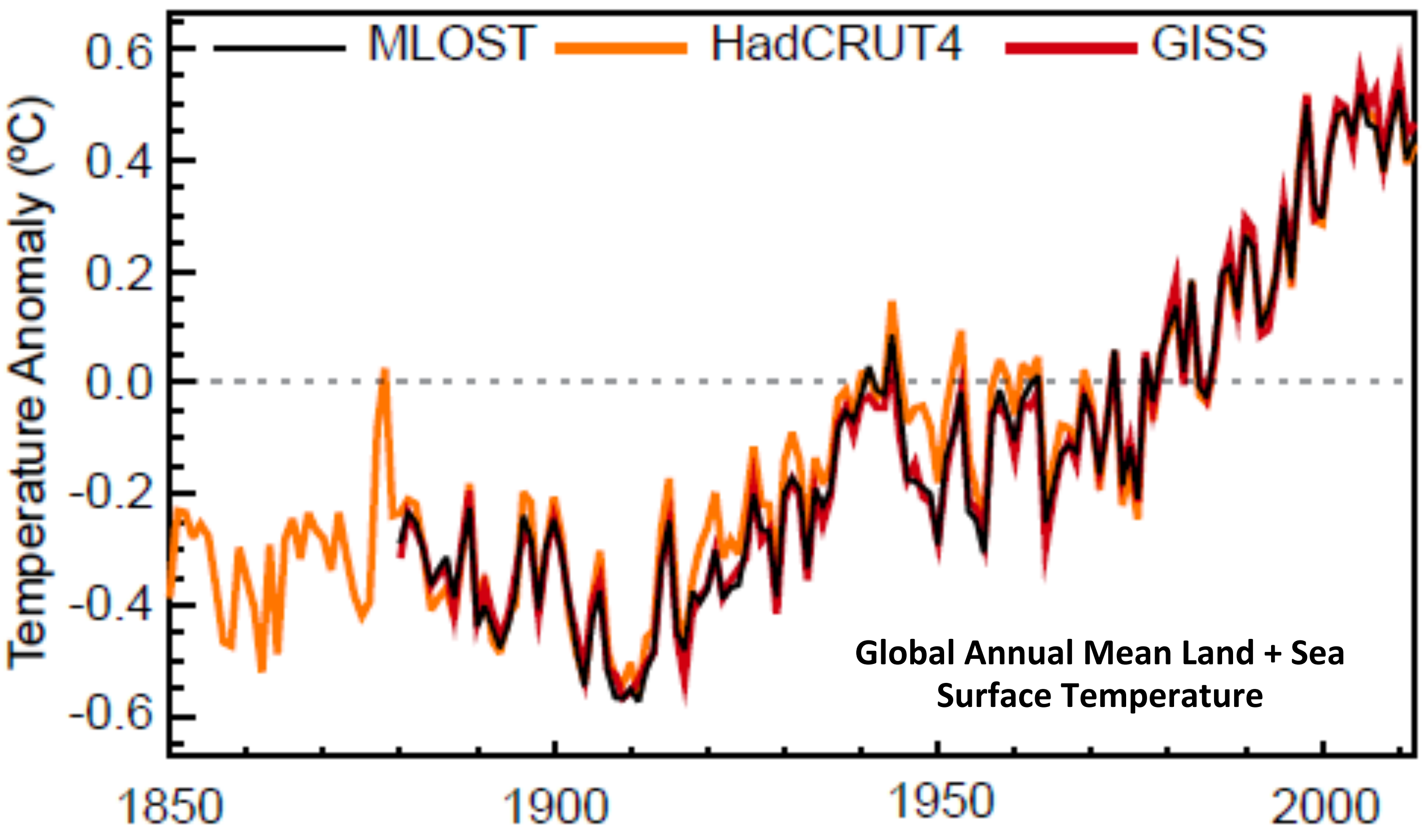
Contemporary Solar Radiation Balance



Global Mean Temperature

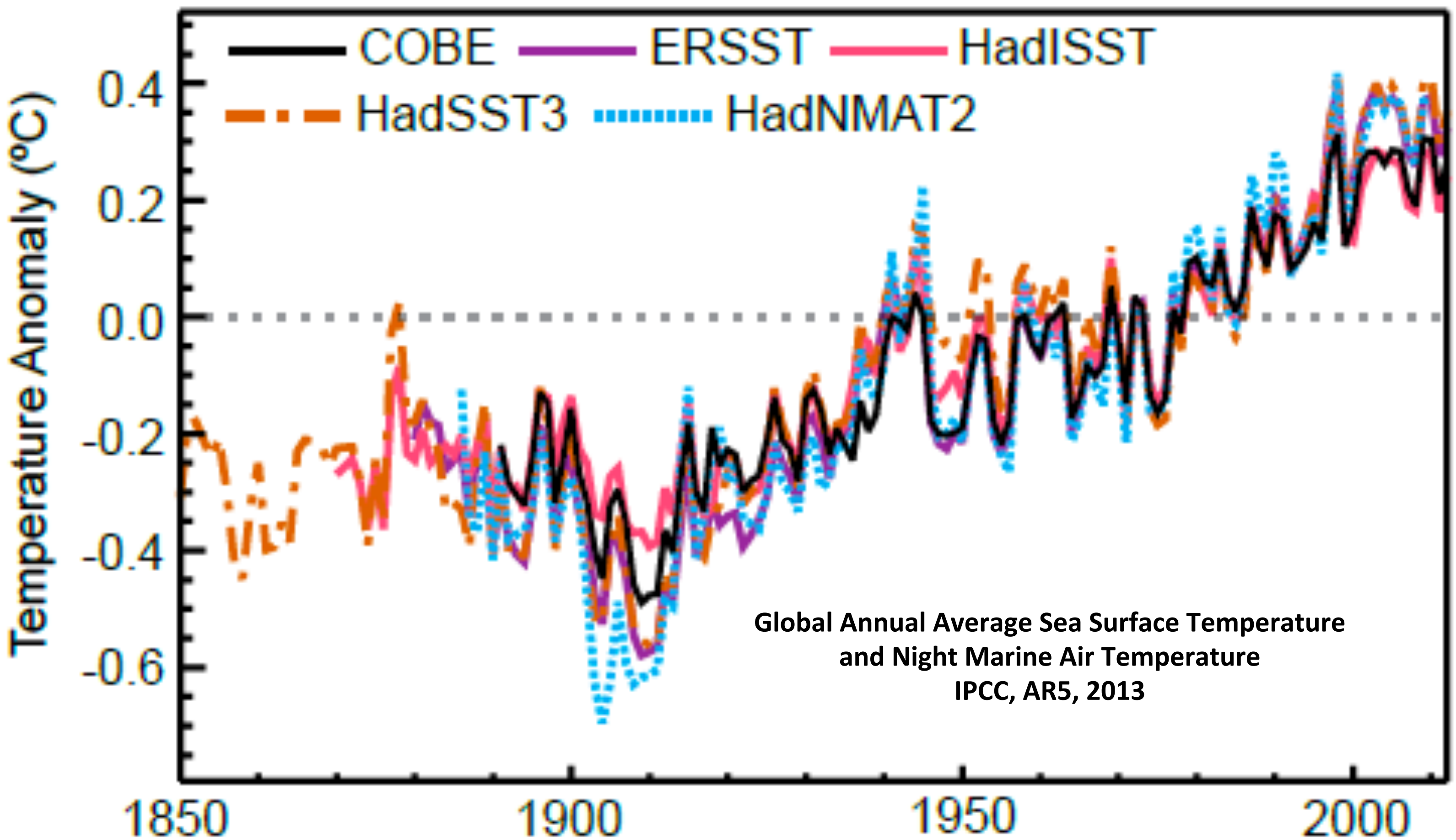
"It is certain that Global Mean Surface Temperature has increased since the late 19th century. Each of the past three decades has been significantly warmer than all the previous decades in the instrumental record, and the first decade of the 21st century has been the warmest"

IPCC AR5, Chapter 2, 2013



N.B. Global temperature does not slavishly follow CO2 atmospheric abundance
Two intervals of arrested temperature rise: 1940-1970, and last 10-15 years

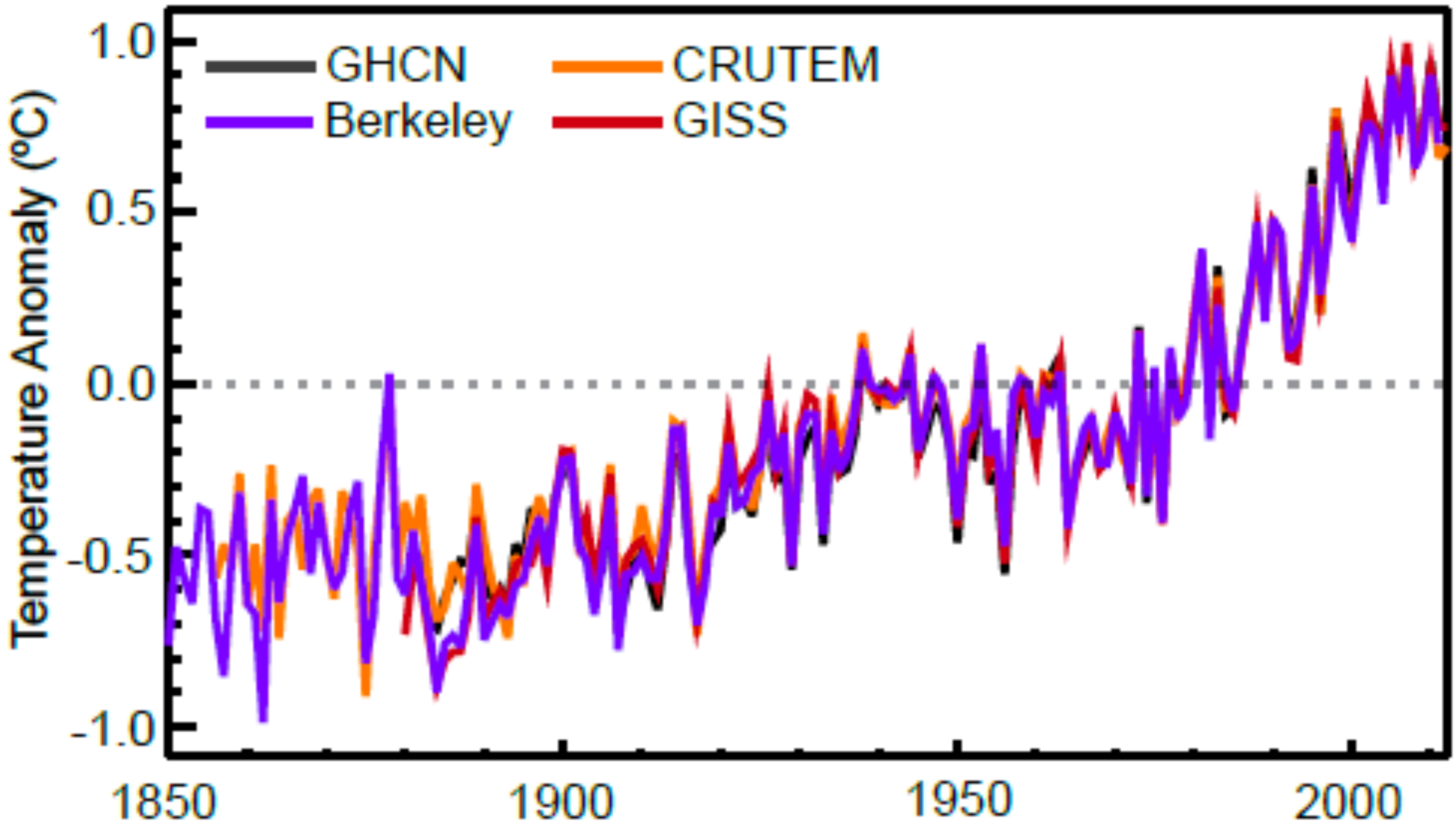
Oceans absorb 90% of the energy added to the climate system by humans



Ocean temperature rise has been small, because of huge heat capacity of ocean water. It required Project ARGO, a global fleet of more than 3000 robotic floats, to measure it

Land-Surface Air Temperature

Global Average Temperature Underestimates Potential Impacts on Humans

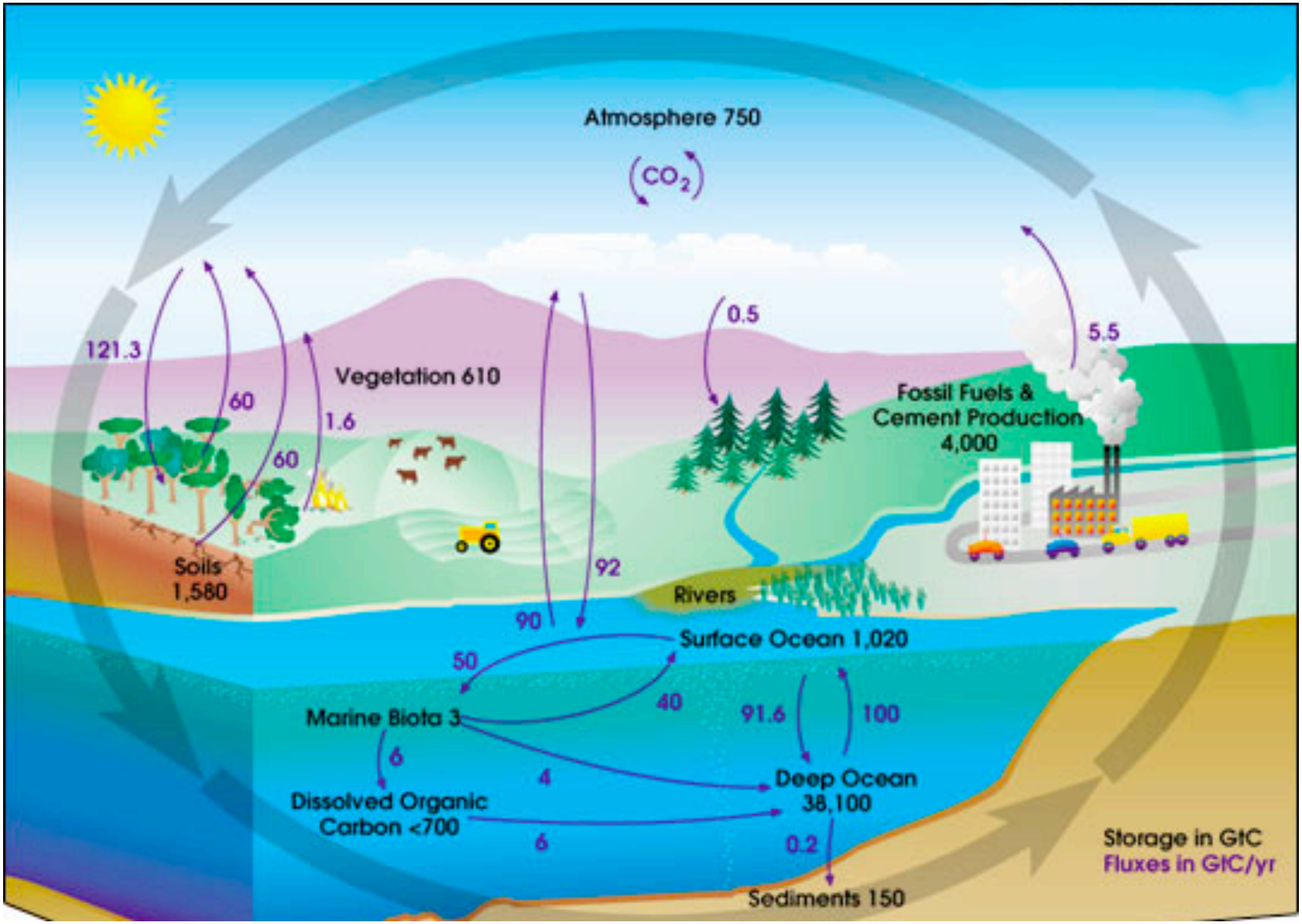


Global annual average Land-Surface Air Temperature (LSAT) anomalies relative to a 1961–1990 climatology from the latest versions of four different datasets (Berkeley, CRUTEM, GHCN and GISS).

The Global Carbon Cycle

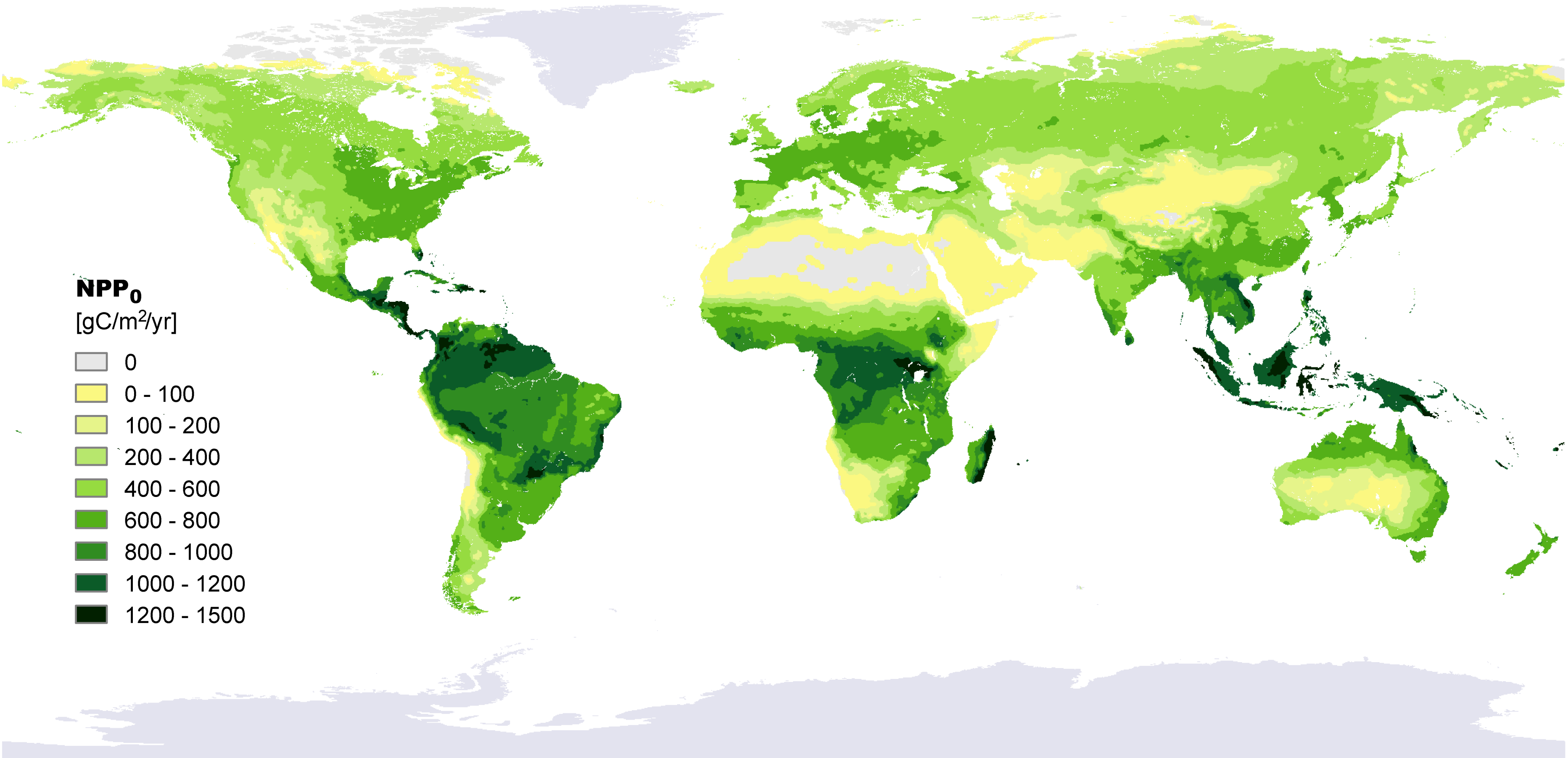
Terrestrial and oceanic Inventories

Rates of exchange with the atmosphere



Net Primary Productivity

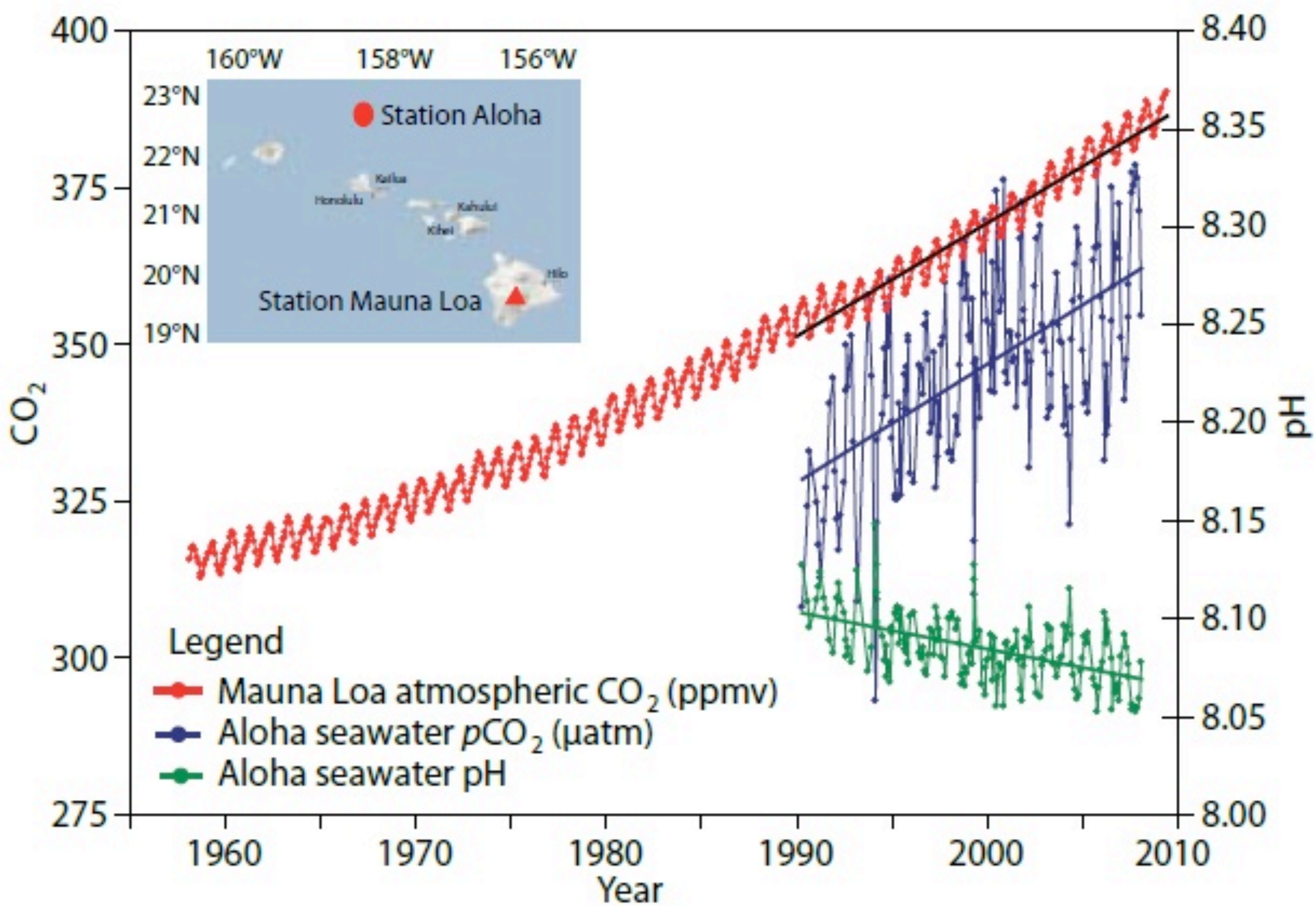
Rate of Carbon Takeup by Photosynthetic Growth of Vegetation on Land
About 25% of anthropogenic CO2 taken up by terrestrial biosphere



Plant growth in northern hemisphere spring and summer draws down CO2, accounting for Keeling's seasonal cycle. The global growing season has lengthened by several weeks since Keeling started taking data. The Northern Hemisphere has been "greening"

Oceans Absorb About 25% of Anthropogenic CO2

Resulting acidification has profound implications for shelled marine life



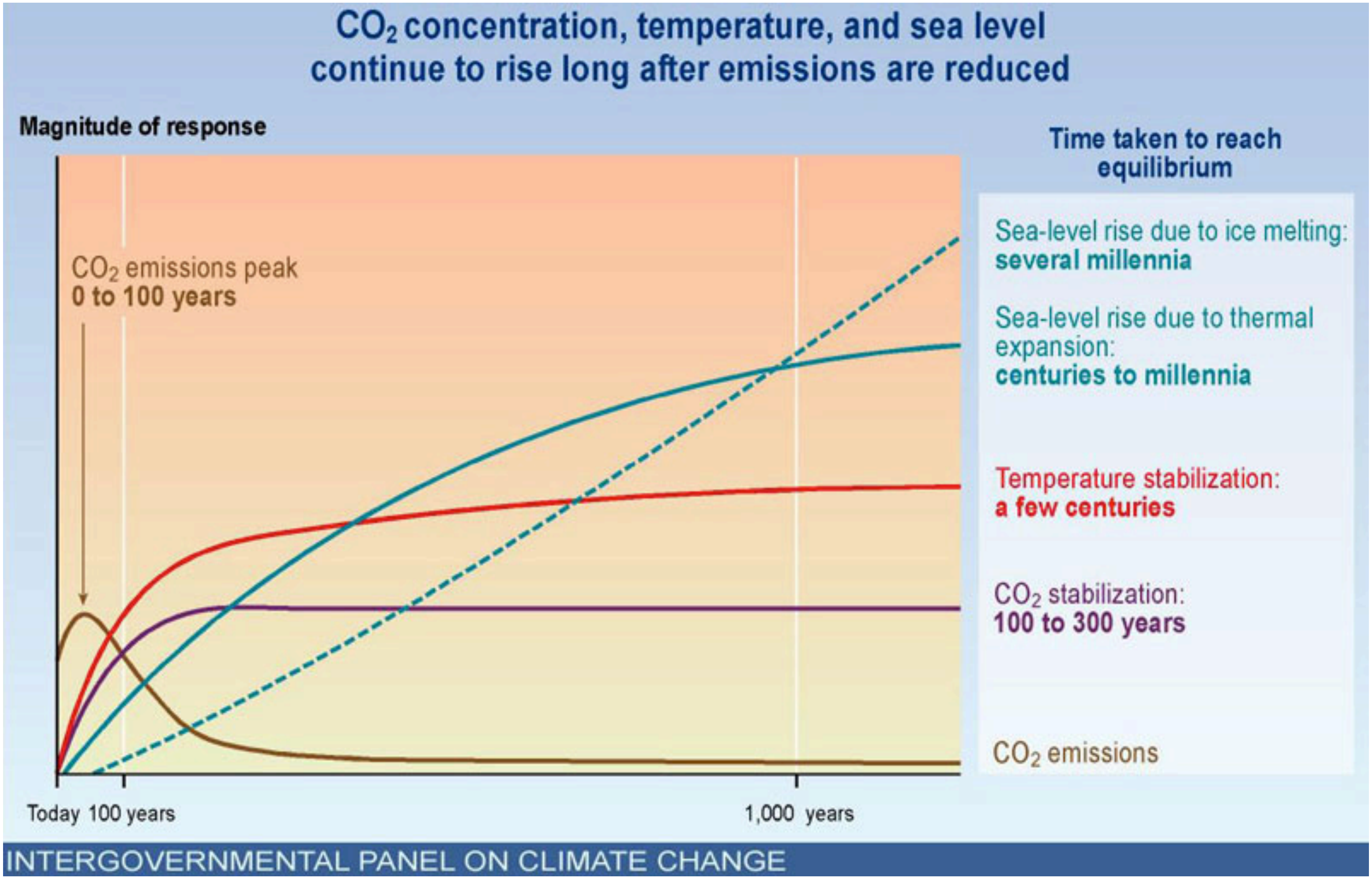
Scott C. Doney *et al,* Ocean Acidification-a critical emerging problem for the ocean sciences, Oceanography, vol 22, no 4, 2009

The oceans, right now our friend, are storing up problems

The oceans are helping us by taking up 50% of the CO_2 and 90% of the energy added to the climate system by humans. If and when we reduce CO_2 emissions, dissolved CO_2 and embedded ocean heat will be released to the atmosphere until the entire ocean has equilibrated with the atmosphere. This will take about 1000 years. Climate change will be a problem for at least that long.

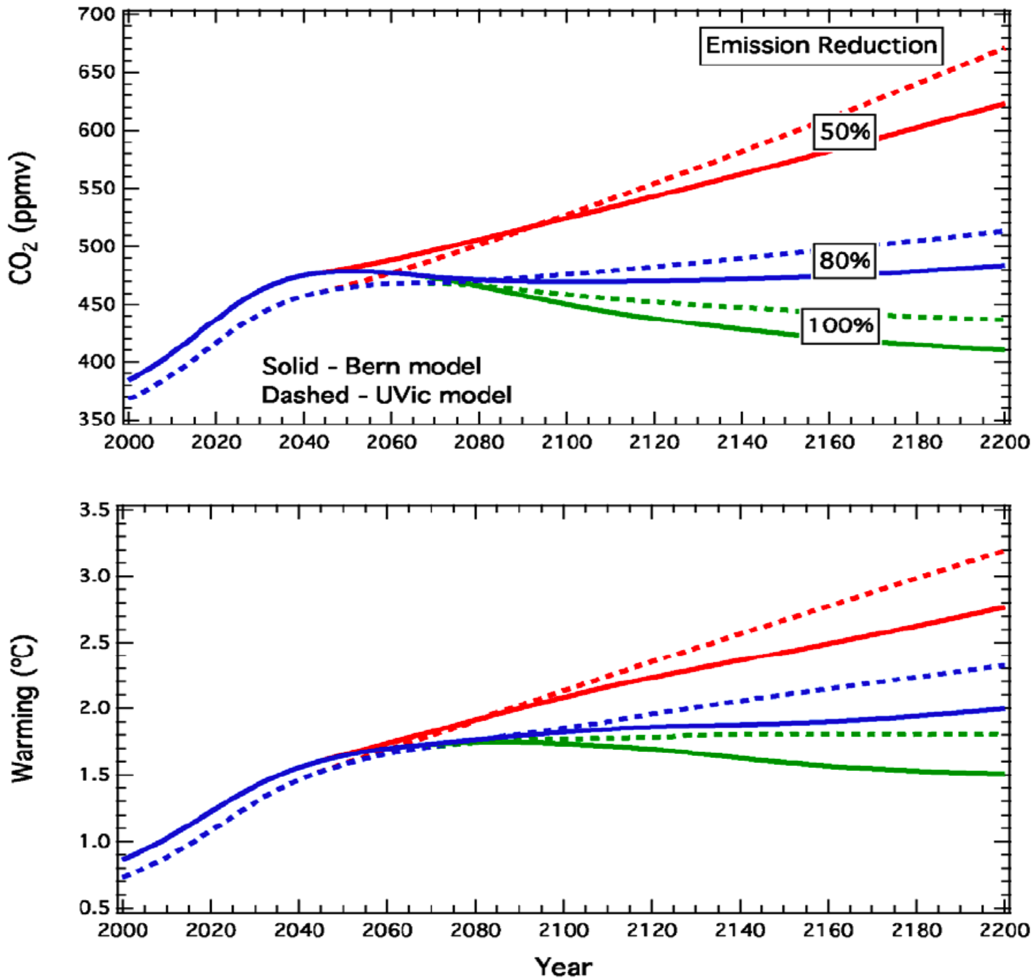
Hard Truths About Carbon Dioxide

Implications of Oceanic and Carbon Cycle Inertia



We cannot avoid significant climate change because of what we have already done, much less what we are about to do

Achieving CO2 Stabilization



Deep emissions reductions (>80%) would be required for long-term stabilization of carbon dioxide at any chosen target (450, 550, 650 ppm….).

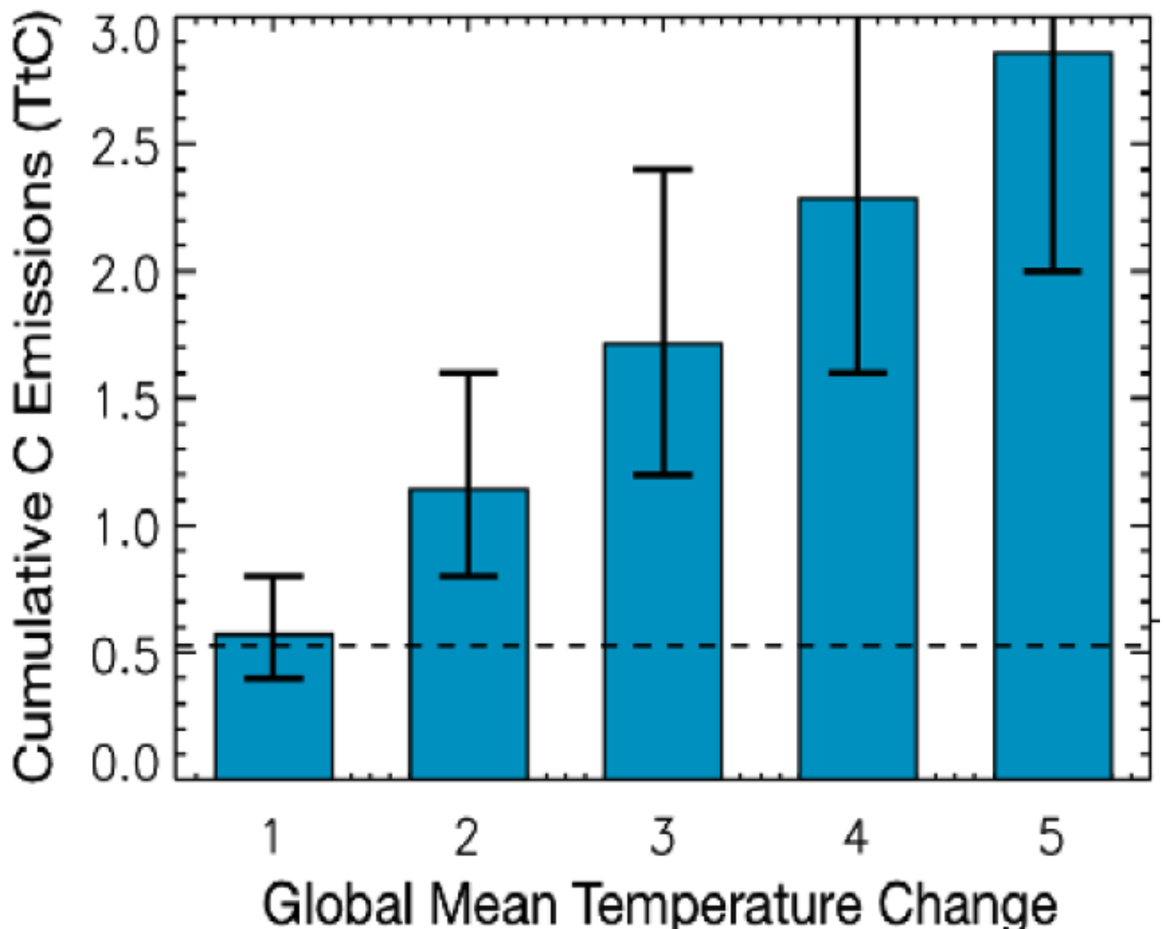
AND

Emission reductions near 100% would be required for manmade CO_2 to decline from any peak it reaches.

Illustrative calculations showing CO2 concentrations and related warming in two models for a test case in which emissions first increase, followed by a decrease in emission rate of 3% per year to a value 50%, 80%, or 100% below the peak. The test case with 100% emission reduction has 1 trillion tonnes of total emission.

Equilibrium Global Temperature Increase is Almost Linearly Related to Cumulative Carbon Emission

Best estimates and likely range of cumulative carbon emissions that would result in global warming of 1, 2, 3, 4, or 5°C.



It does not matter when the emissions occur. Given a maximum tolerable temperature increase, ongoing emissions draw down a finite "carbon account"

The Grand Ethical Dilemma

The global distribution and long lifetime of carbon dioxide give rise to major intergenerational ethical issues

Things humans are doing today will change the climate and conditions for all life in unknown ways for thousands of years.

The CO2 emissions each of us causes today do not affect us directly but change the climate for every human on earth in the next generation

Present generations pass on climate risk to future generations as well as assets such as knowledge and infrastructure. The intergenerational challenge is to strike a balance between incurring future climate debt and present investment for that future

The Grand Political Dilemma

The global distribution and long lifetime of carbon dioxide shape the configuration of political issues in climate change

Everyone causes climate change and everyone is affected by it. The climate negotiations therefore seek inclusive global consensus, but this may be impossible to achieve

Actions to reduce CO2 emissions affect the climate decades later. Those who make the effort do not reap the benefits in their lifetimes.

The free-rider problem: those who did *not* make the effort will reap benefit from the actions of those who did

CO2 emissions are a fundamental byproduct of the contemporary industrial system, which is bringing prosperity and social advancement around the world. The centrality of fossil fuels in today's global economy is pitting those who value the free market system and present prosperity against those who believe that dealing with climate change is an absolute moral imperative.

Climate change is similar to slavery and colonialism. All three are global issues in which economic benefits for some contest with moral views of others. Colonialism and slavery took a century to solve, not without great conflict

Climate Governance

United Nations Framework Convention on Climate Change

New York, 9 May 1992

The long-term objective of the Convention and its related legal instruments is "to achieve […] the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"

UNFCCC Conference of Parties Meetings

Previously held Conference of Parties (COP)

COP	Year	Venue
COP 1	1995	The Berlin Mandate
COP 2	1996	Geneva, Switzerland
COP 3	1997	Kyoto, Japan
COP 4	1998	Buenos Aires, Argentina
COP 5	1998	Bonn, Germany
COP 6	2000	The Hague, Netherlands
COP 7	2001	Marrakech, Morocco
COP 8	2002	New Delhi, India
COP 9	2003	Milan, Italy
COP 10	2004	Buenos Aires, Argentina
COP 11	2005	Montreal, Canada
COP 12	2006	Nairobi, Kenya
COP 13	2007	Bali, Indonesia
COP 14	2008	Poznań, Poland
COP 15	2009	Copenhagen, Denmark
COP 16	2010	Cancún, Mexico
COP 17	2011	Durban, South Africa
COP 18	**2012**	**Qatar**

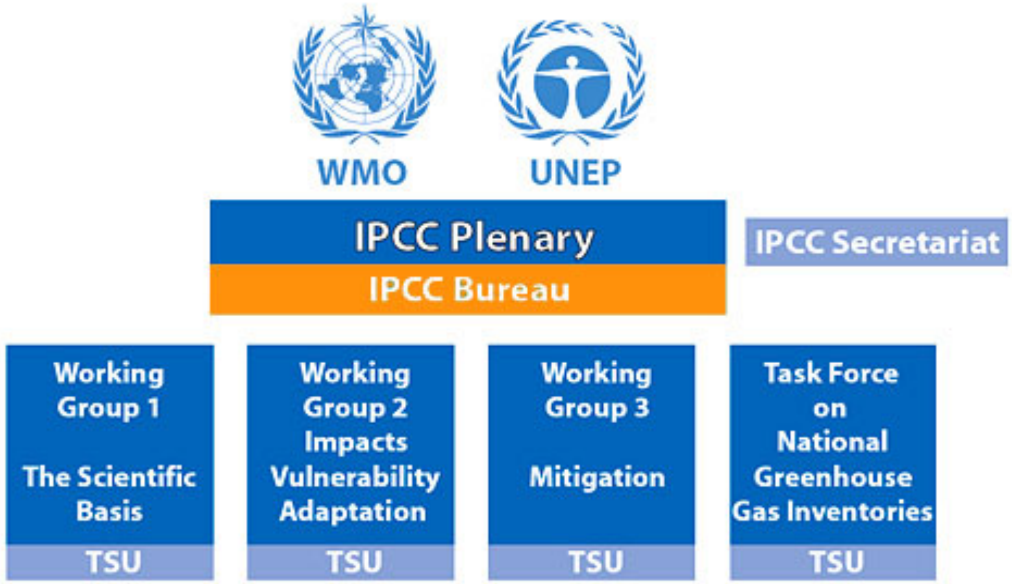
Kyoto, 1997

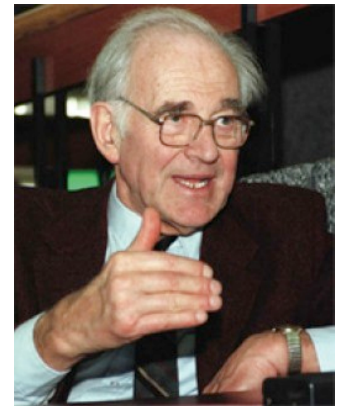
Warsaw, 2013

The Intergovernmental Panel on Climate Change

The most rigorous reviews of a state of scientific knowledge ever attempted.

John Houghton



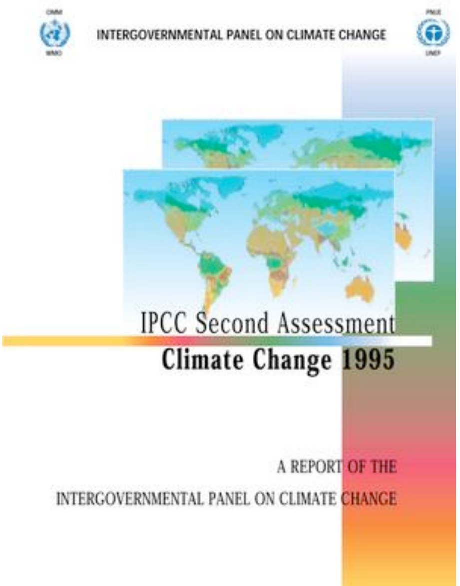


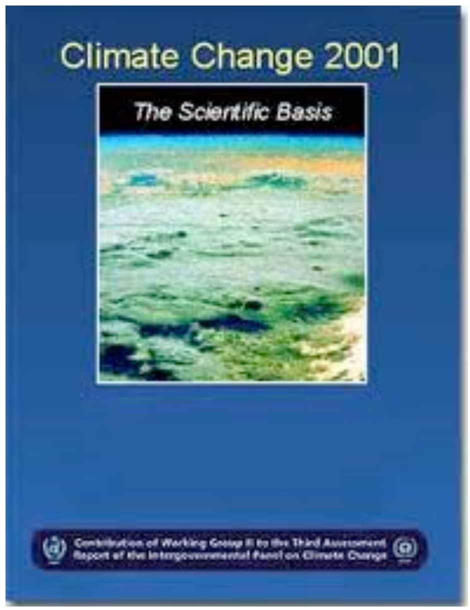
Bert Bolin

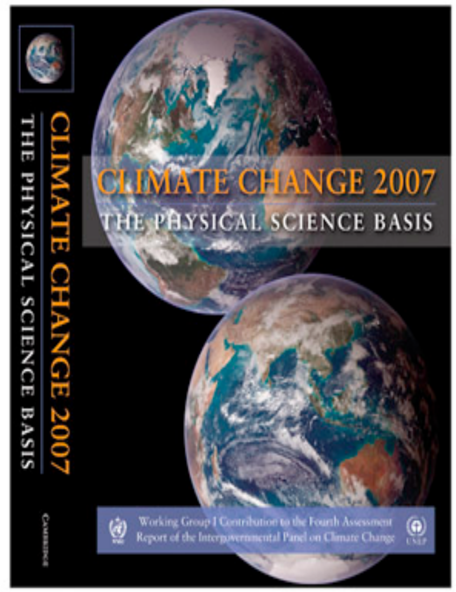
The IPCC was established by WMO and UNEP in 1988 to "assess on a comprehensive objective, open, and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio-economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage"

IPCC Assessments

The IPCC's policy influence grew as succeeding reports communicated a consistently evolving understanding of climate change. At the same time, the return to the same themes created a "standard narrative" that shapes the public dialog







The IPCC devised transparent processes intended to promote trust. Its summarized only the peer-reviewed literature. Review panels were chosen with attention to balance among countries, points of view, and economic and institutional interests. Successive panels recruited a majority of new participants to avoid an institutionalized IPCC point of view. Its most important innovation was to separate assessment of science from discussion of policy. After the scientific assessment is complete, the IPCC engages in a separate process to develop summaries for policy makers. Together, scientists and policy-makers compose, line-by-line, the statements pertinent to policy, with explicit attention to the uniform characterization of uncertainty.

Where Attention Goes, Energy Flows

IPCC assessments energized the global public debate about climate. Not a day passes without media discussion of climate change. This is the most important outcome, since public awareness of the risks of climate change encourages governments to pay attention and motivates public and private initiatives. They have been unsuccessful in promoting concrete actions by governments.

Kennel, C.F., Speaking Scientific Truth to Power, *Cambridge Anthropology,* 2013

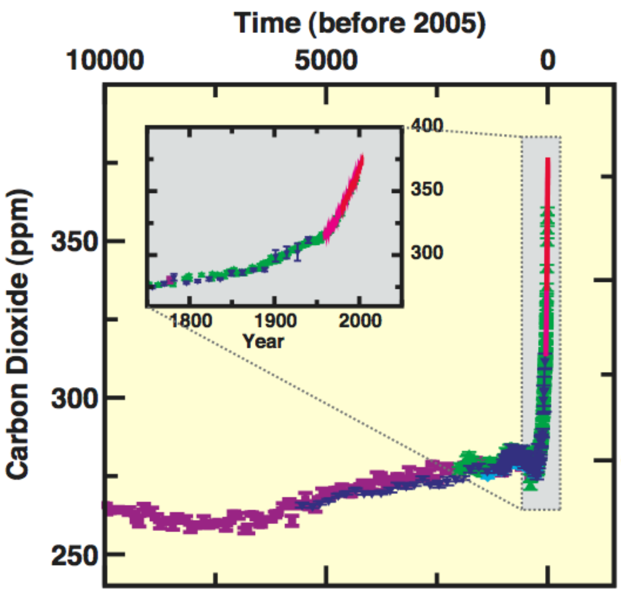
The Standard Narrative

Narrow Focus: CO_2 emissions, abundance, global temperature

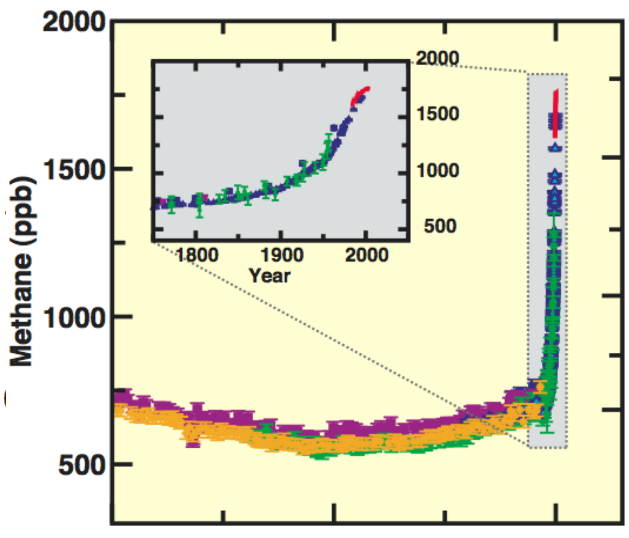
Moses receiving the tablets of the law, João Zeferino da Costa, 1868

Obscures as it clarifies

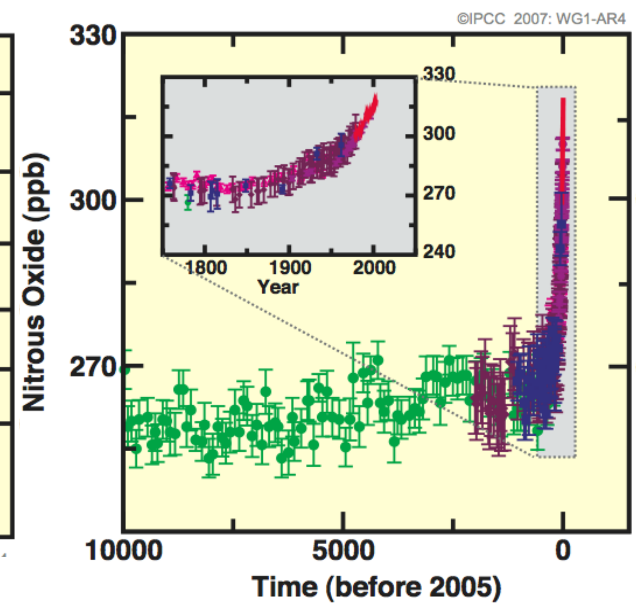
CO2 is not the only driver of climate change



Carbon Dioxide



Methane



Nitrous Oxide

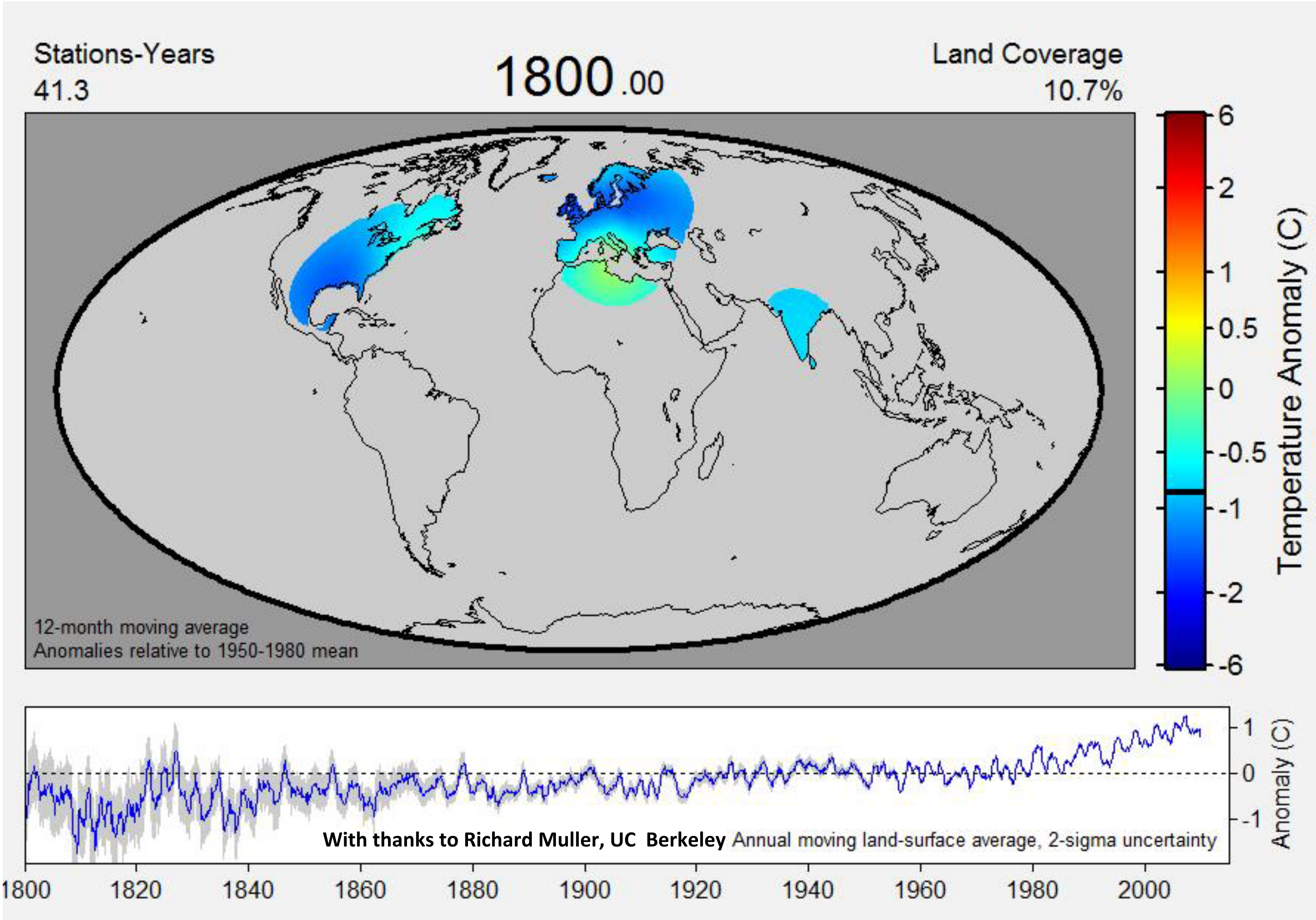
Changes in greenhouse gas compositions since the end of the last Ice Age

IPCC AR4, 2007

Global Temperature

Designed to simplify, the concept obscures to clarify.

We use a vast modeling infrastructure to compute a number that only a physicist could love, one that conveys a misleading impression that the world warms up uniformly. It really is an index of the rate humans are adding energy to the climate system, which will distribute it in complex ways.



Stations-Years
41.3
1800.00
Land Coverage
10.7%
Temperature Anomaly (C)
6
2
1
0.5
0
-0.5
-1
-2
-6
12-month moving average
Anomalies relative to 1950-1980 mean
With thanks to Richard Muller, UC Berkeley
Annual moving land-surface average, 2-sigma uncertainty
Anomaly (C)
1
0
-1
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000

"That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every 'superstar,' every 'supreme leader,' every saint and sinner in the history of our species lived there - on a mote of dust suspended in a sunbeam."

- Carl Sagan, from a lecture delivered at Cornell University: 10/13/94