Mitigation and Adaptation Studies

Class 3: The Syndrome of Modern Global Change: Baseline, Syndrome, Diagnosis

Contents:

- Baseline (continued)
- Syndrome
- Diagnosis
- *Prognosis*
- *Therapy*

Climate is determined by:

- incoming radiation (sun)
- reflected radiation (albedo)
- retained heat (Greenhouse gases)

Earth's energy imbalance is the difference between the amount of solar energy absorbed by Earth and the amount of energy the planet radiates to space as heat.

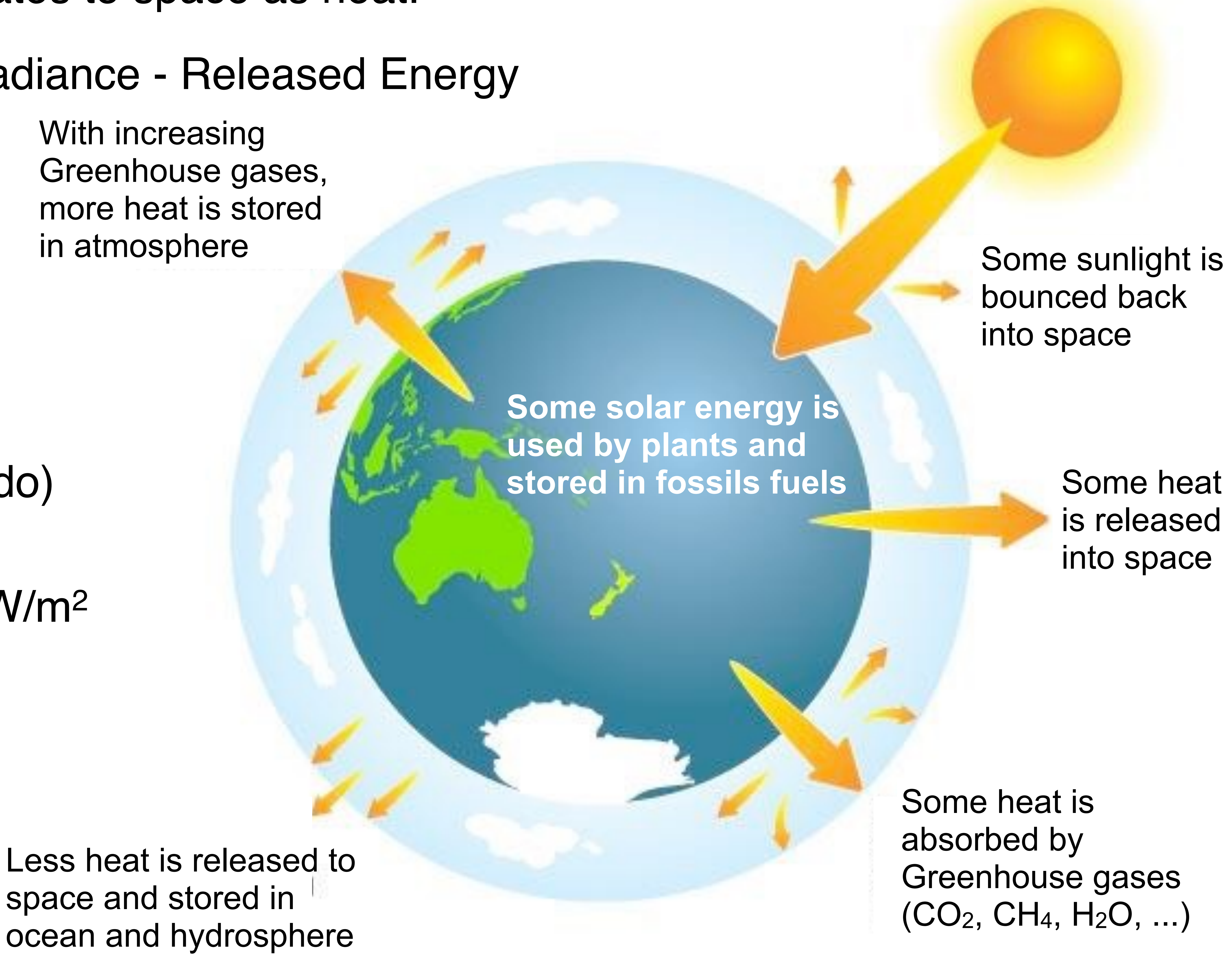
Earth's Energy Imbalance: EI = Solar irradiance - Released Energy

EI > 0: Global Warming
EI < 0: Global Cooling

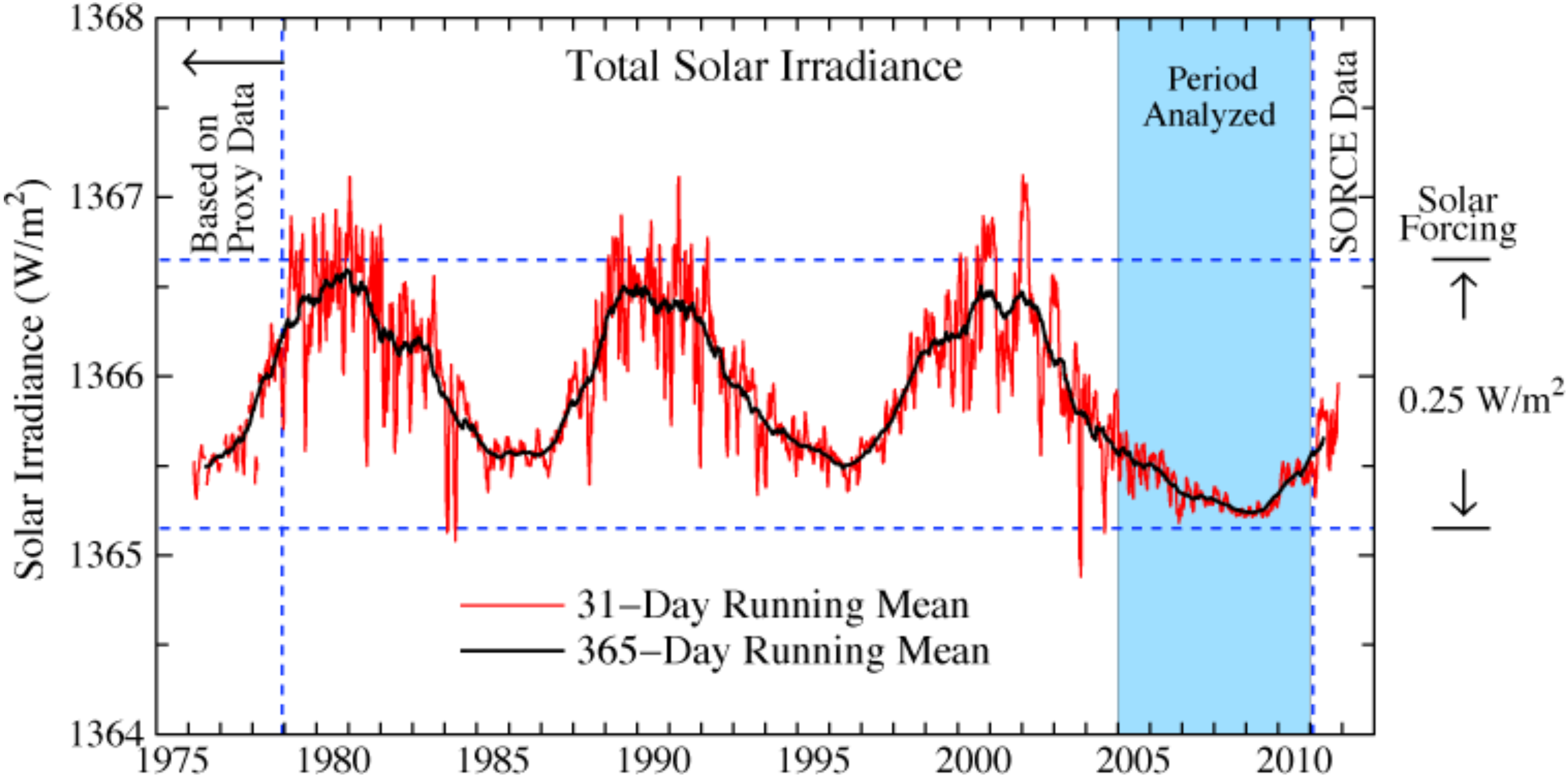
What can change?

- Solar irradiance can change
  Currently: 1366±1 W/m^2 (~240 W/m^2)
- Reflected radiation can change (albedo)
- Absorbed energy can change

- Longterm EI: 0.0000001-0.0000003 W/m^2
- 10,000 years EI: ±0.01 W/m^2
- Current EI: ~0.6 W/m^2

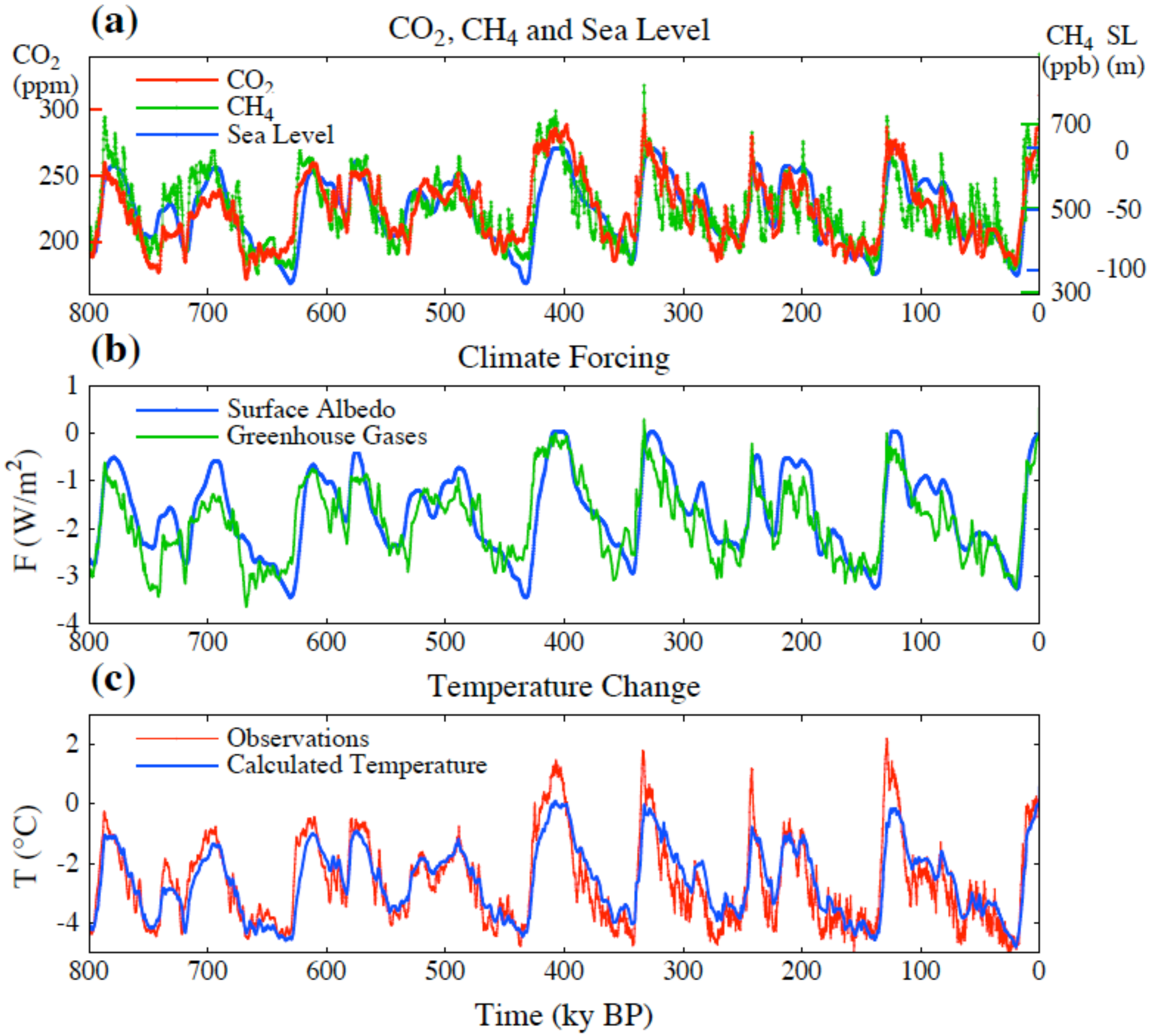


The Baseline: Past Climate and Global Change

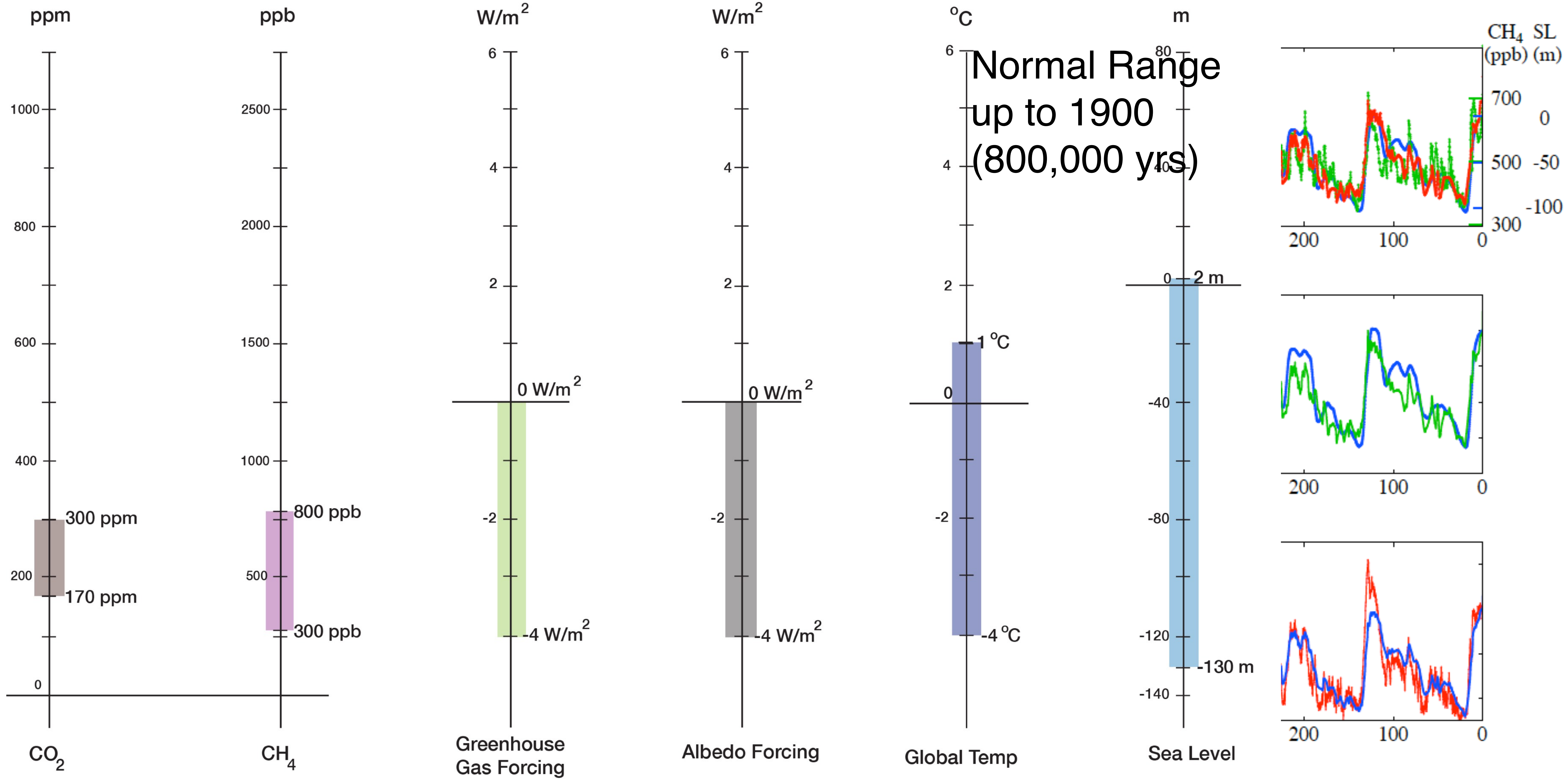


Solar irradiance in the era of accurate satellite data. Left scale is the energy passing through an area perpendicular to Sun-Earth line. Averaged over Earth's surface the absorbed solar energy is ~240 W/m², so the amplitude of solar variability is a forcing of ~0.25 W/m². (Credit: NASA/GISS)

The Baseline: Past Climate and Global Change



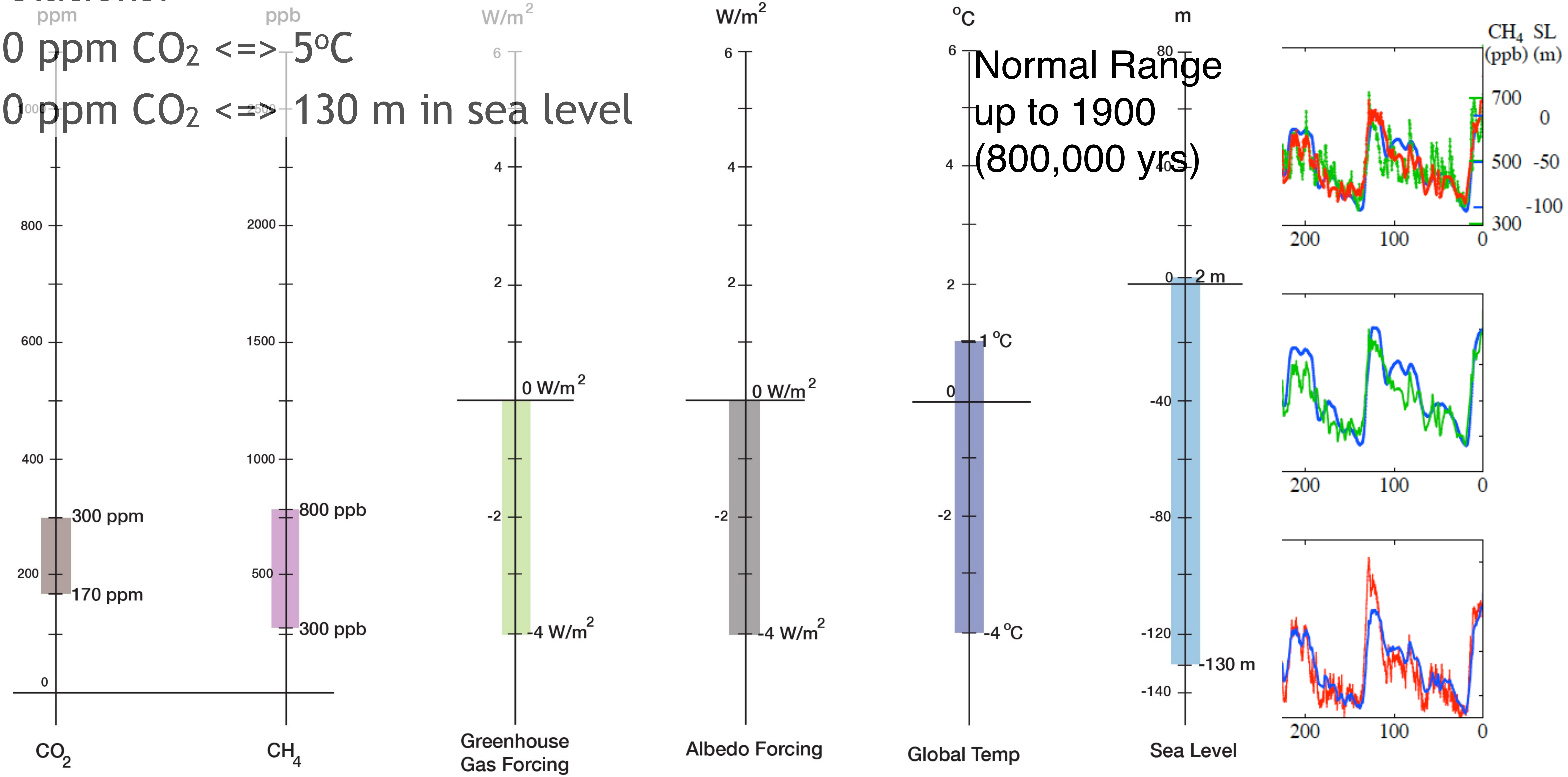
The Baseline: Past Climate and Global Change



The Baseline: Past Climate and Global Change

Long-term (centuries to millennia) correlations:

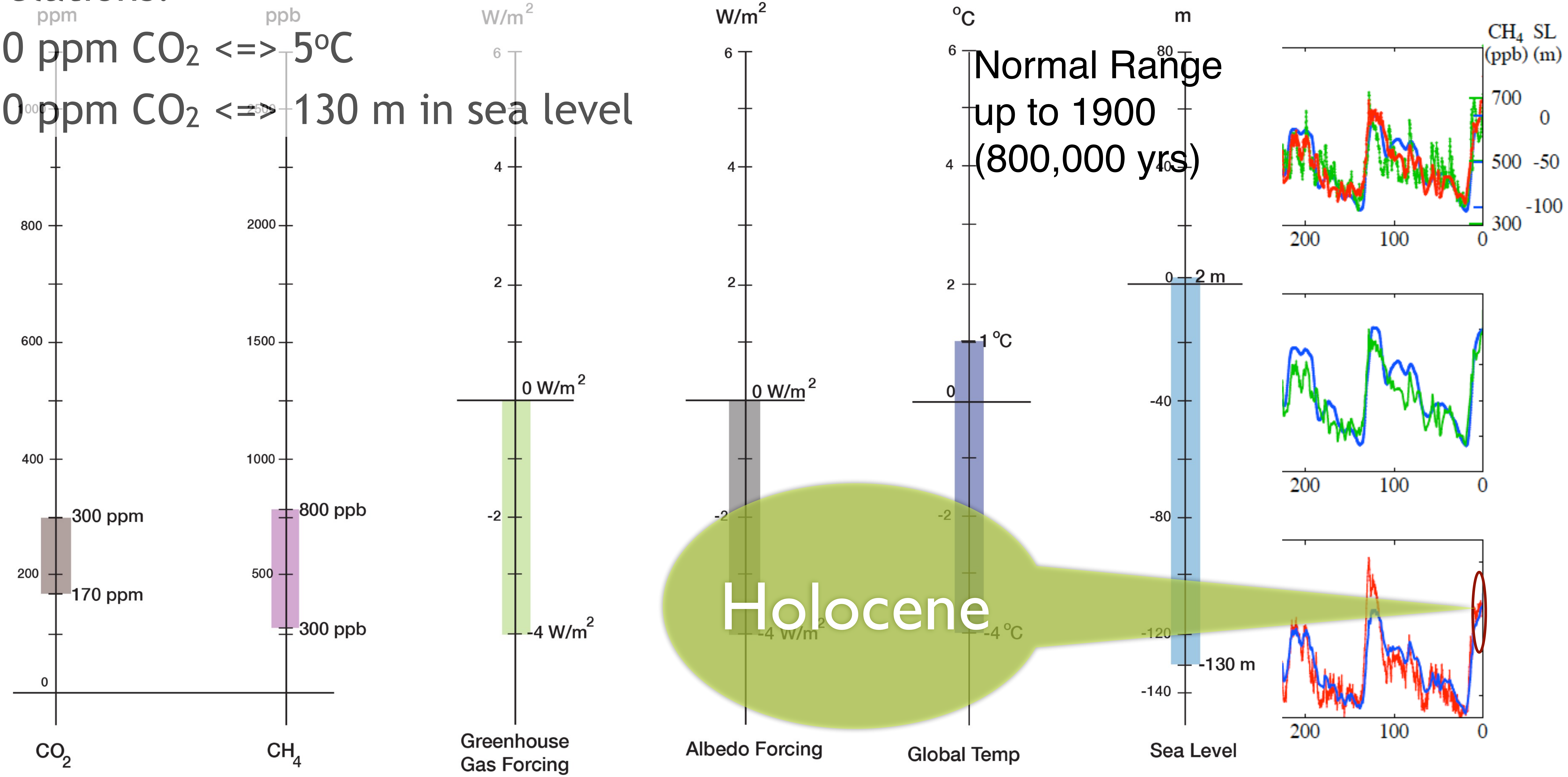
- 130 ppm CO_2 <=> 5°C
- 130 ppm CO_2 <=> 130 m in sea level



The Baseline: Past Climate and Global Change

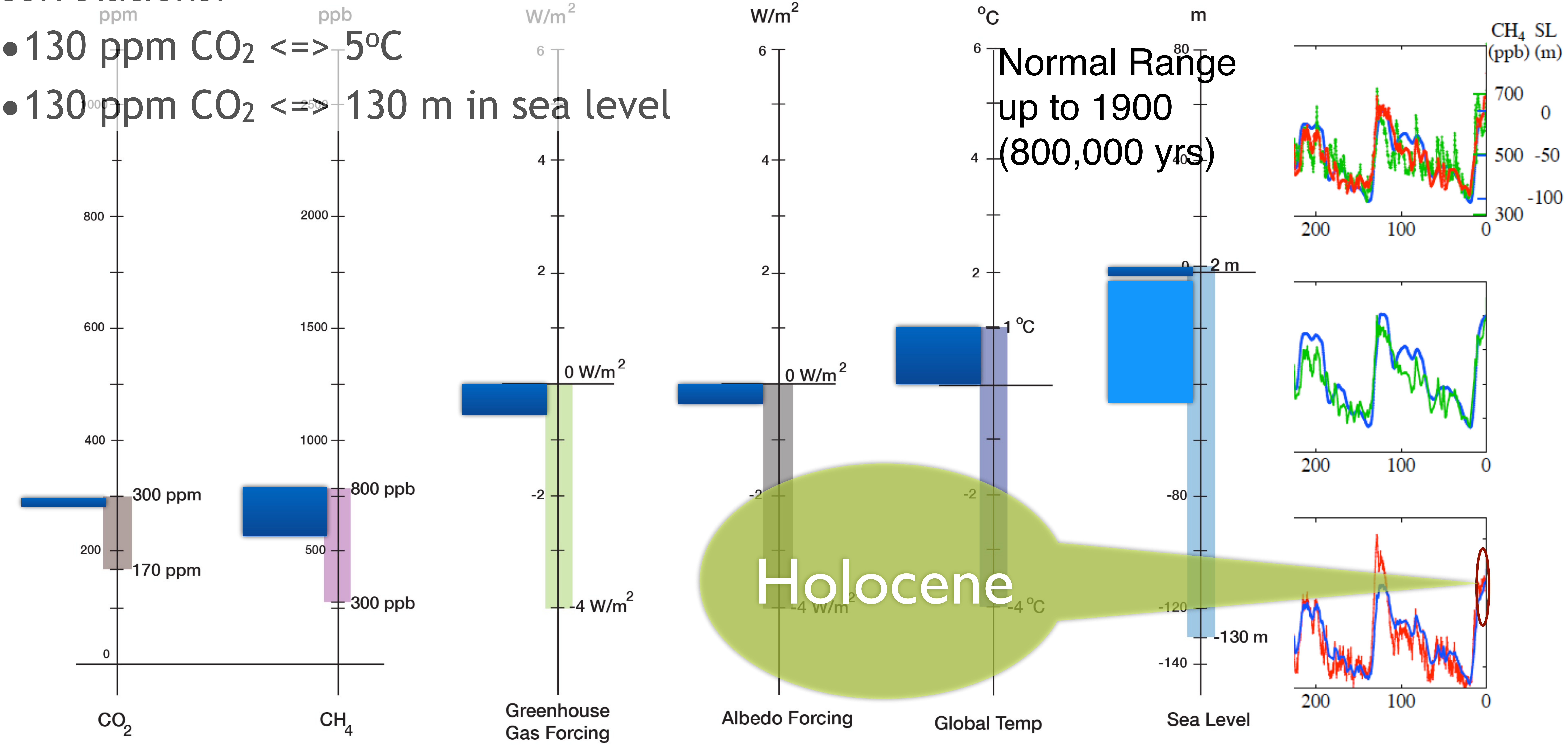
Long-term (centuries to millennia) correlations:

- 130 ppm CO_2 <=> 5ºC
- 130 ppm CO_2 <=> 130 m in sea level



Long-term (centuries to millennia) correlations:

- 130 ppm CO_2 <=> 5°C
- 130 ppm CO_2 <=> 130 m in sea level

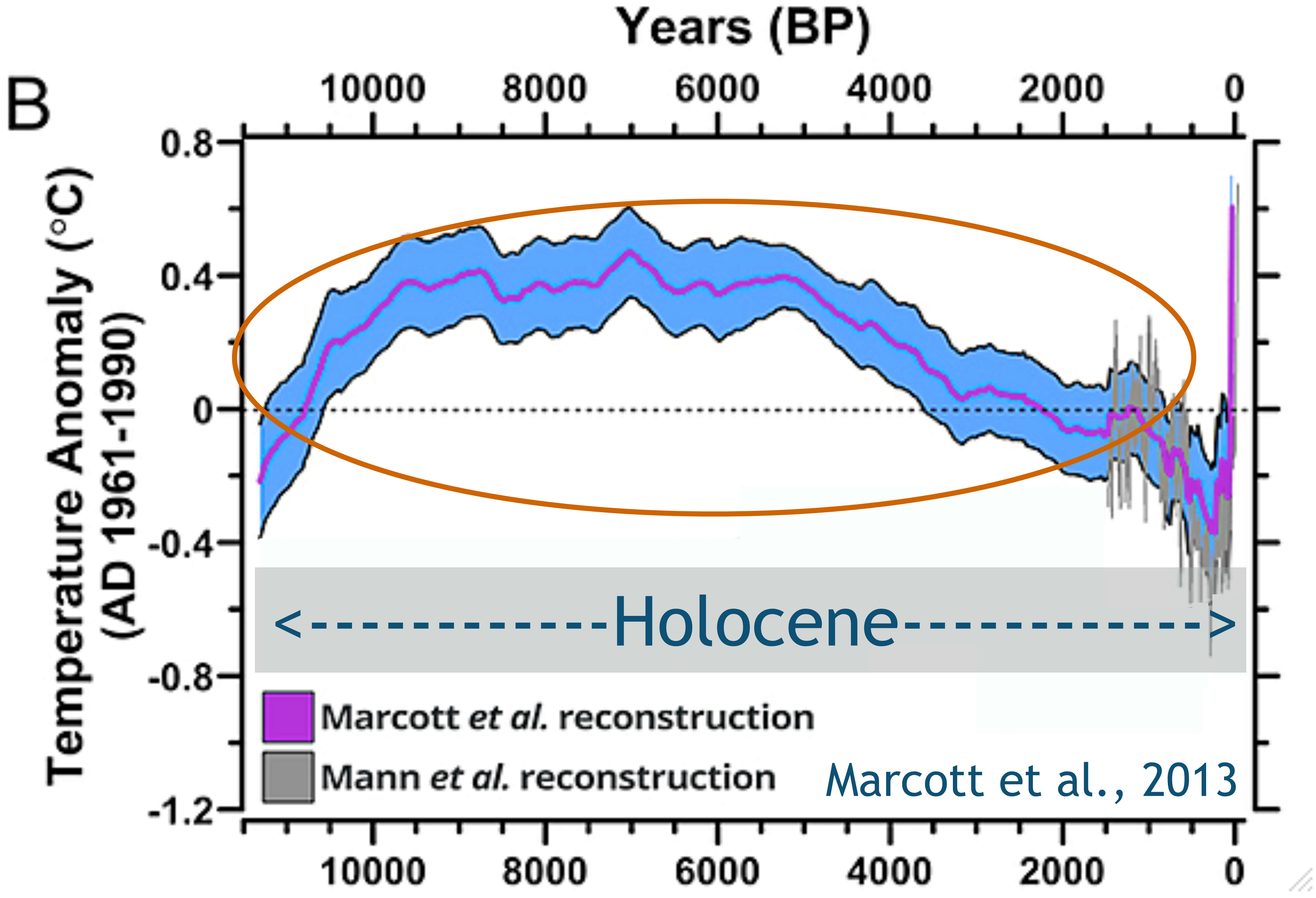


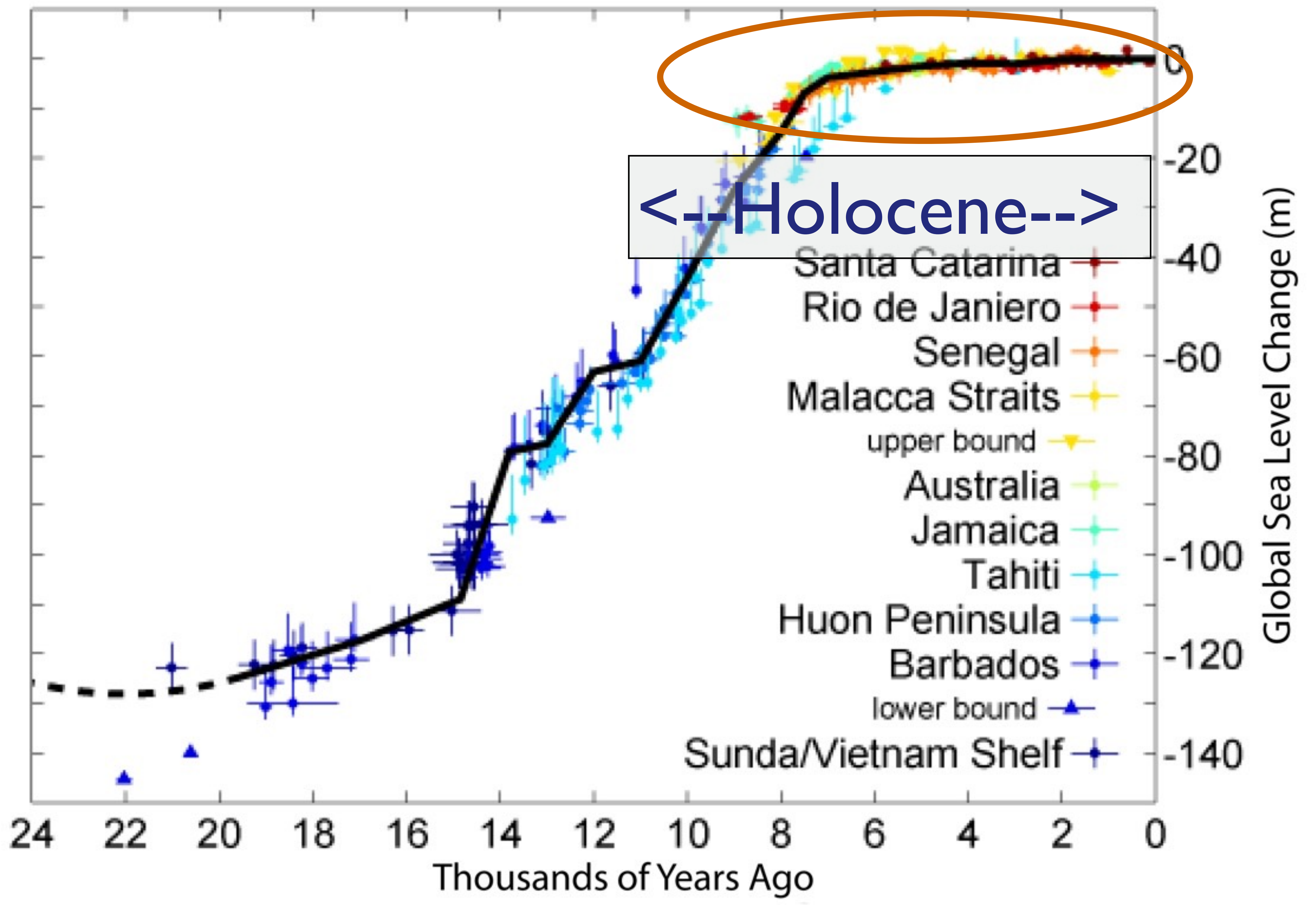
Normalcy Bias: Climate variations are small and sea level is stable

The Baseline: Past Climate and Global Change

Normalcy Bias: Climate variations are small and sea level is stable

Global Temperature Changes	Global Sea Level Changes



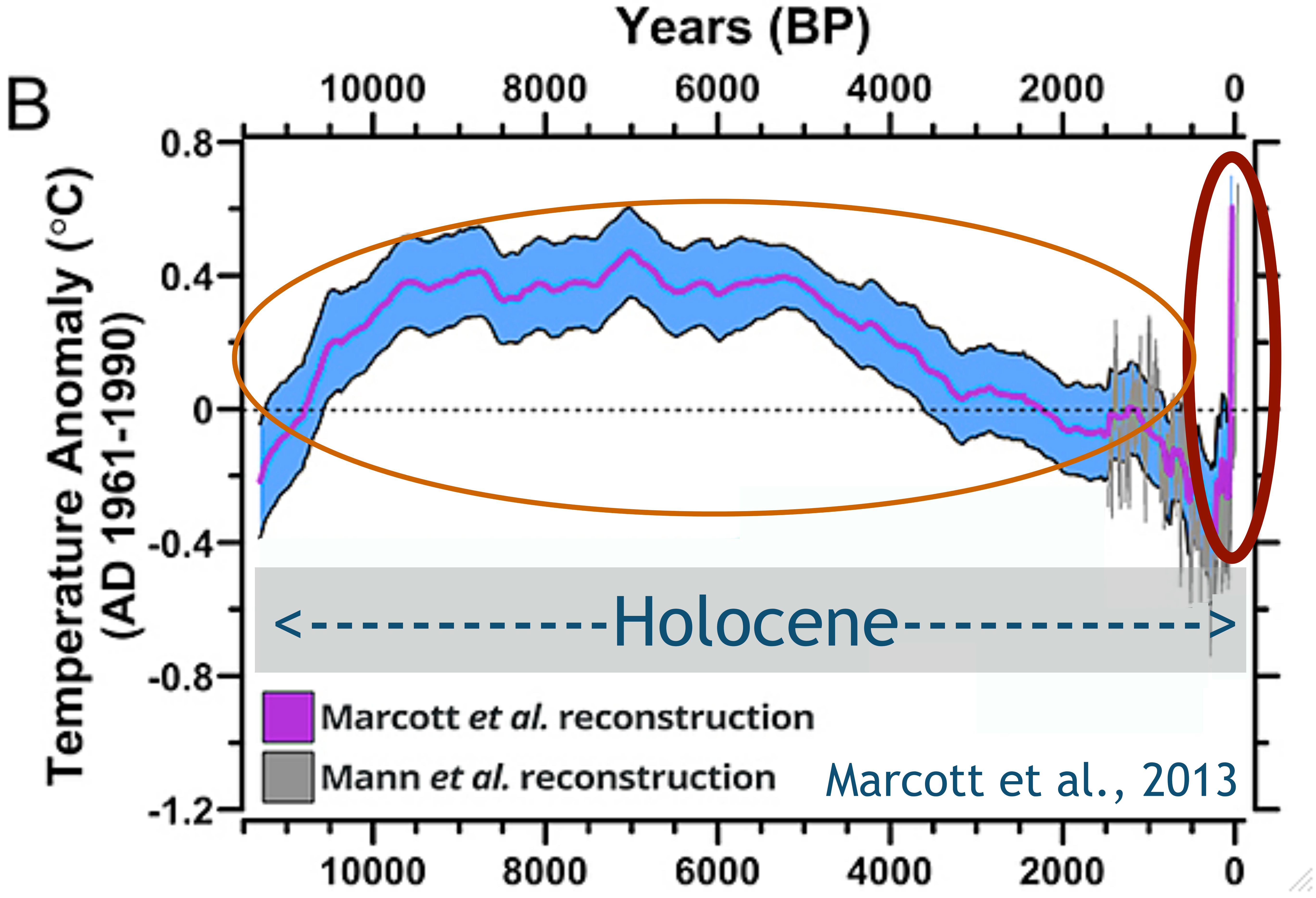


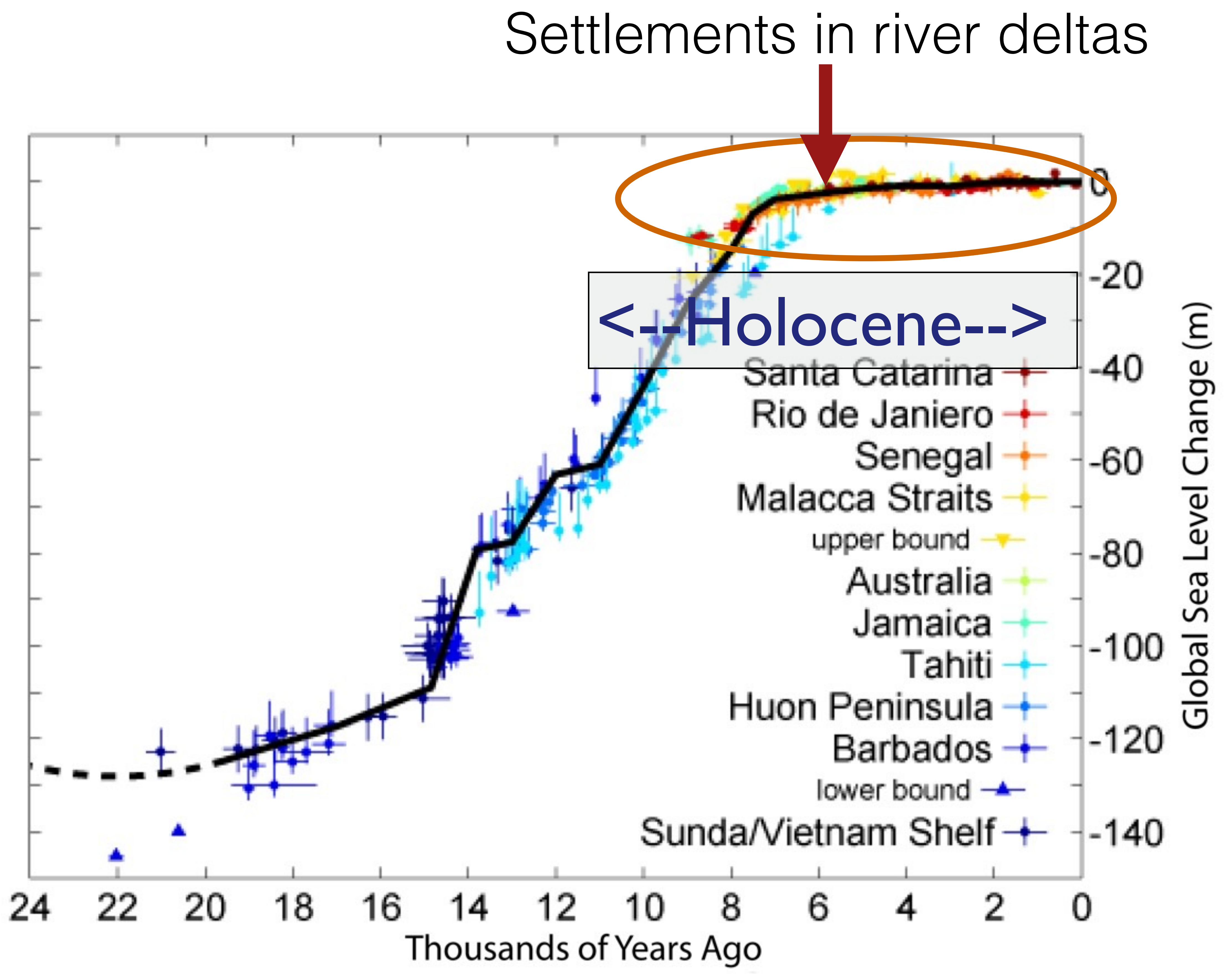
With stable climate and sea level, the Holocene was a safe operating space for humanity.

The Baseline: Past Climate and Global Change

Normalcy Bias: Climate variations are small and sea level is stable

Global Temperature Changes	Global Sea Level Changes

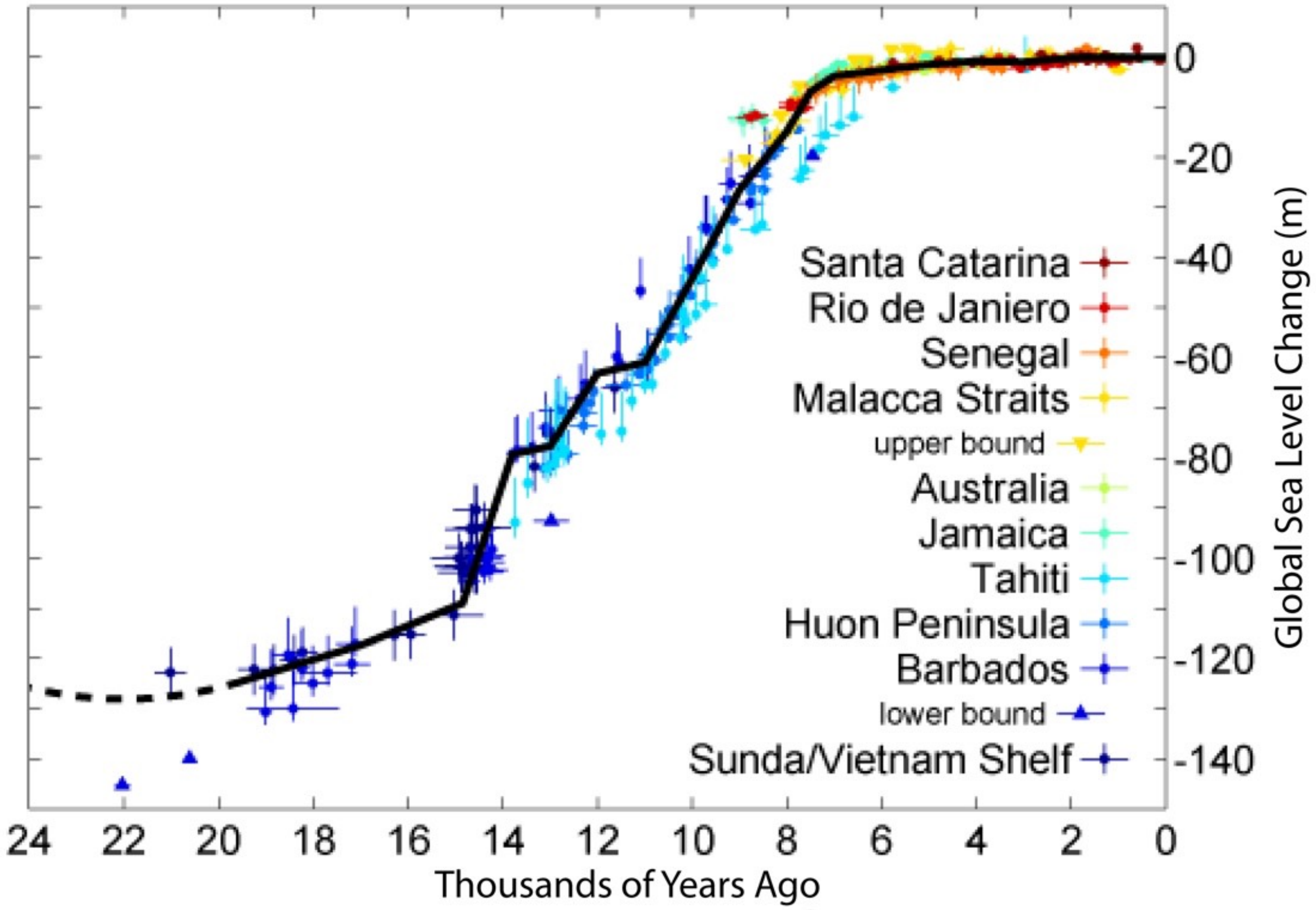




With stable climate and sea level, the Holocene was a safe operating space for humanity.

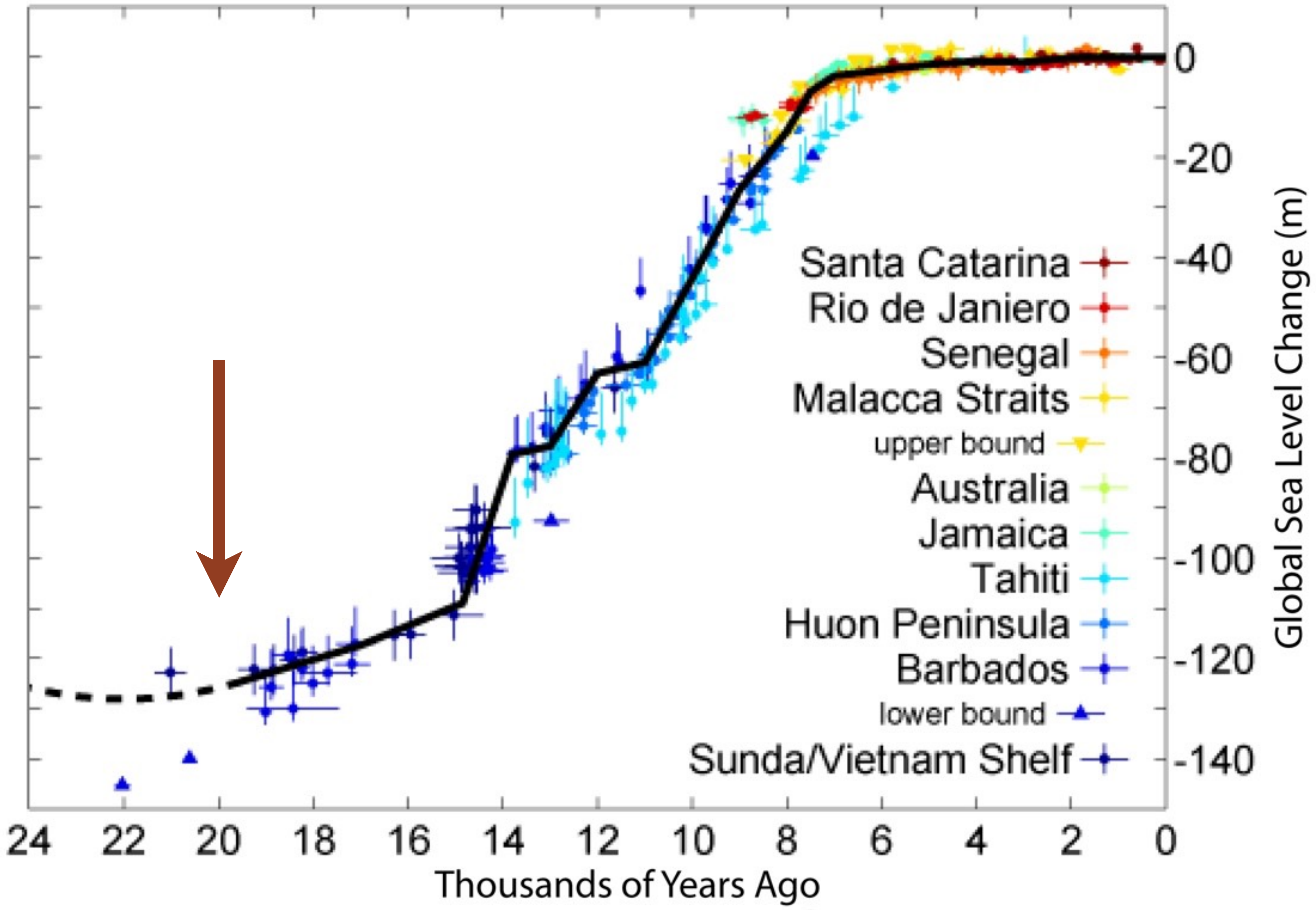
Global and Local Sea Level Changes

Global and Local Sea Level Changes



The Baseline: Past Climate and Global Change

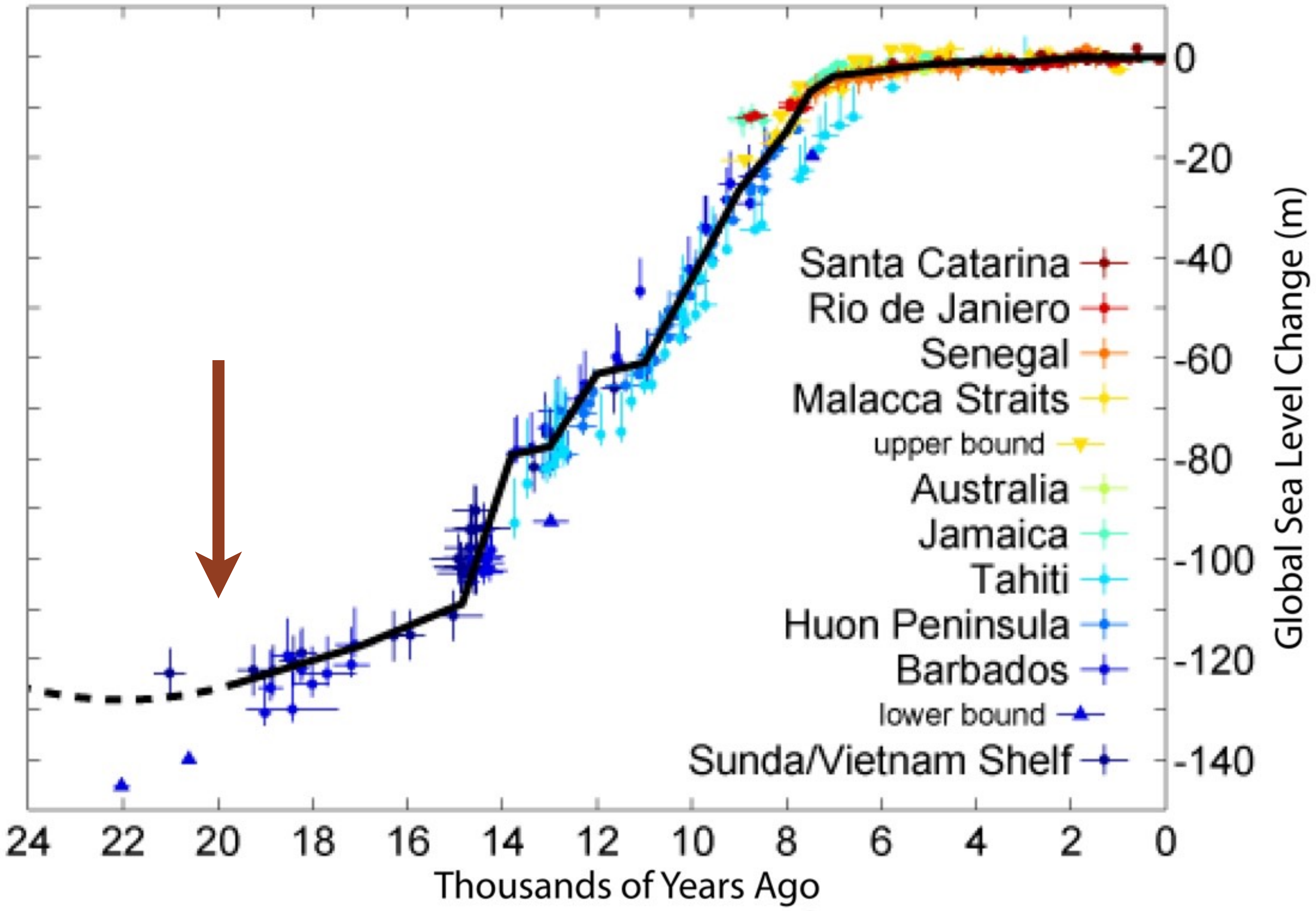
Global and Local Sea Level Changes



20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

The Baseline: Past Climate and Global Change

Global and Local Sea Level Changes

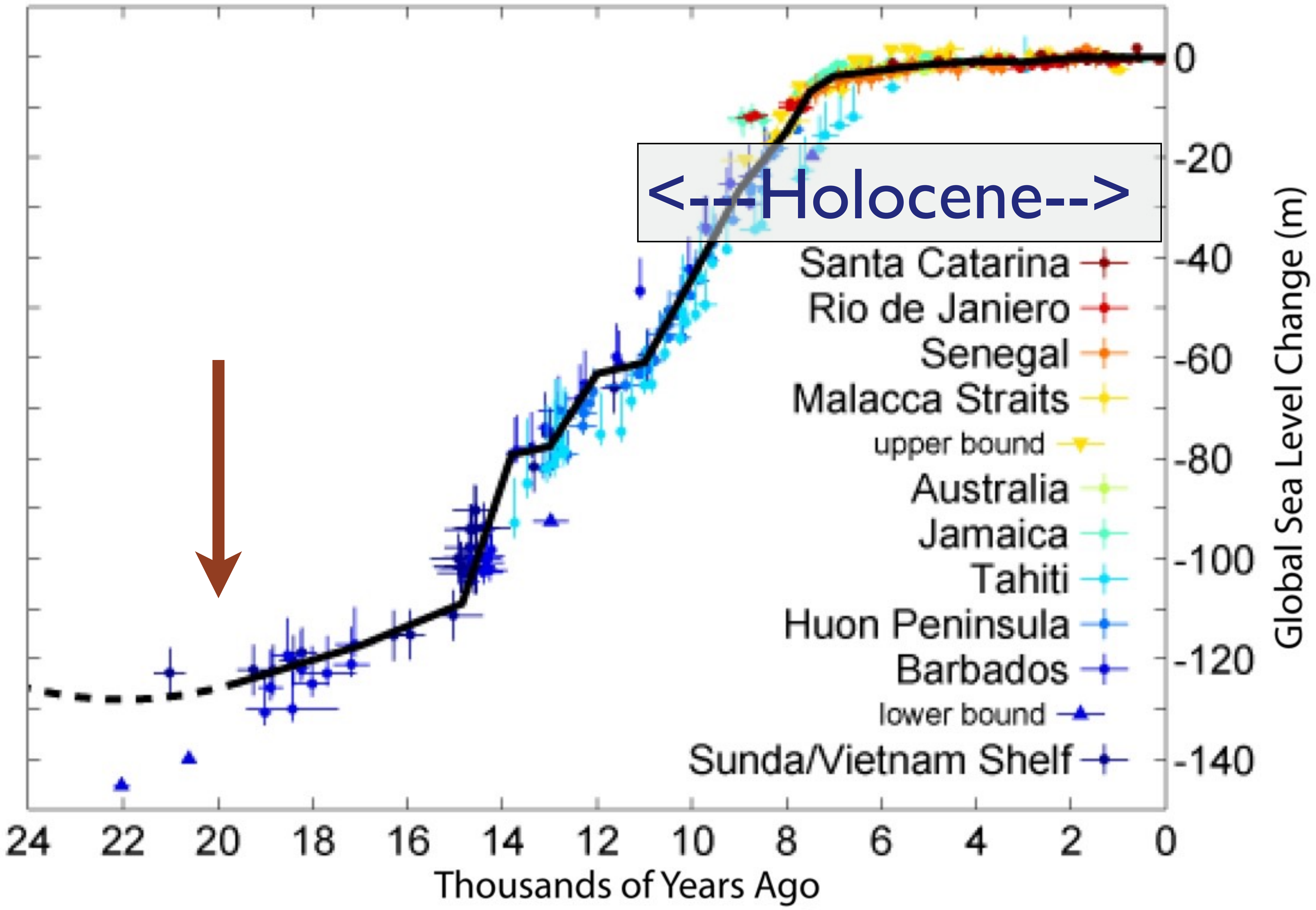


20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

Local Sea Level changes can be much larger than the global average changes.

The Baseline: Past Climate and Global Change

Global and Local Sea Level Changes

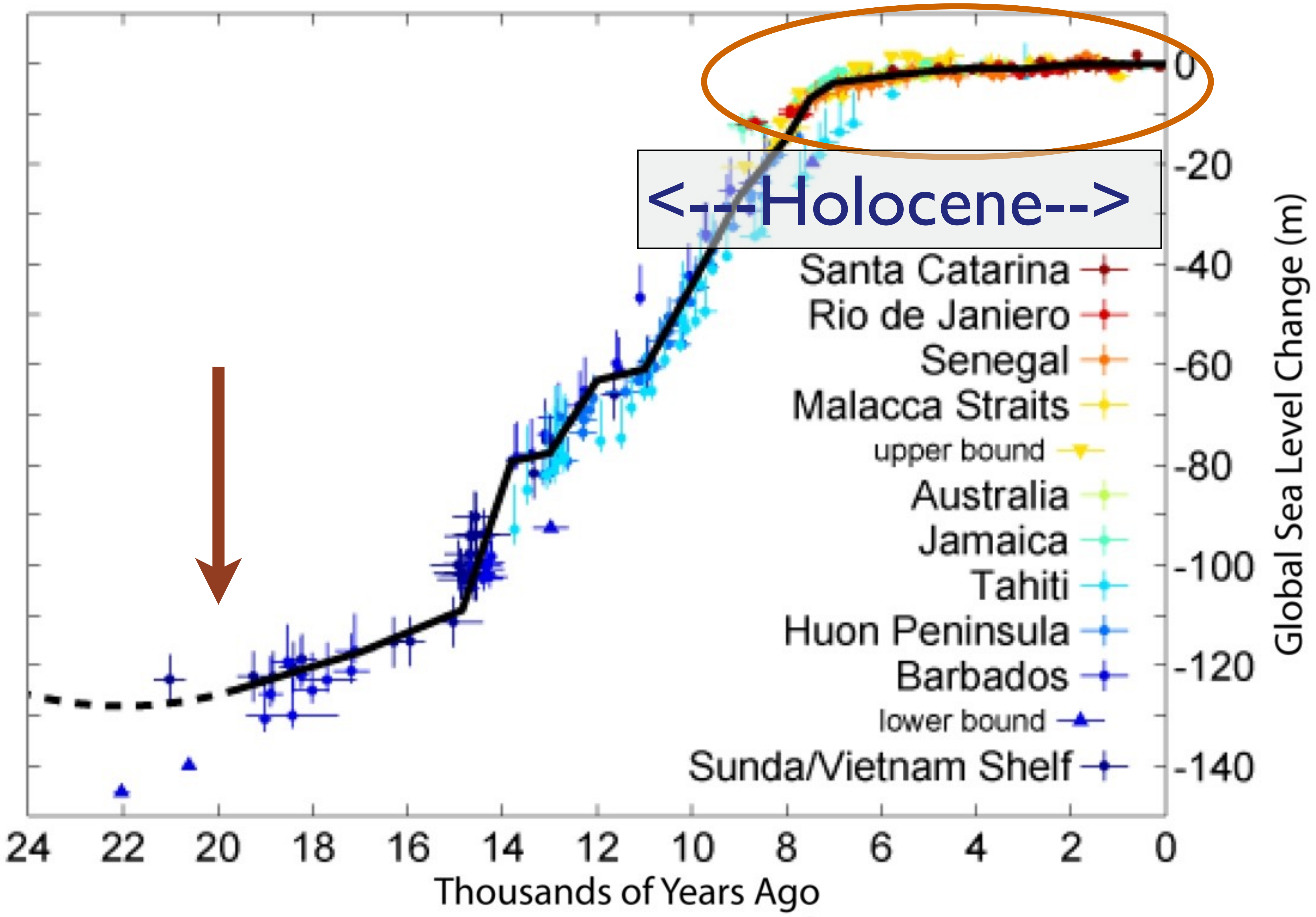


20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

Local Sea Level changes can be much larger than the global average changes.

The Baseline: Past Climate and Global Change

Global and Local Sea Level Changes

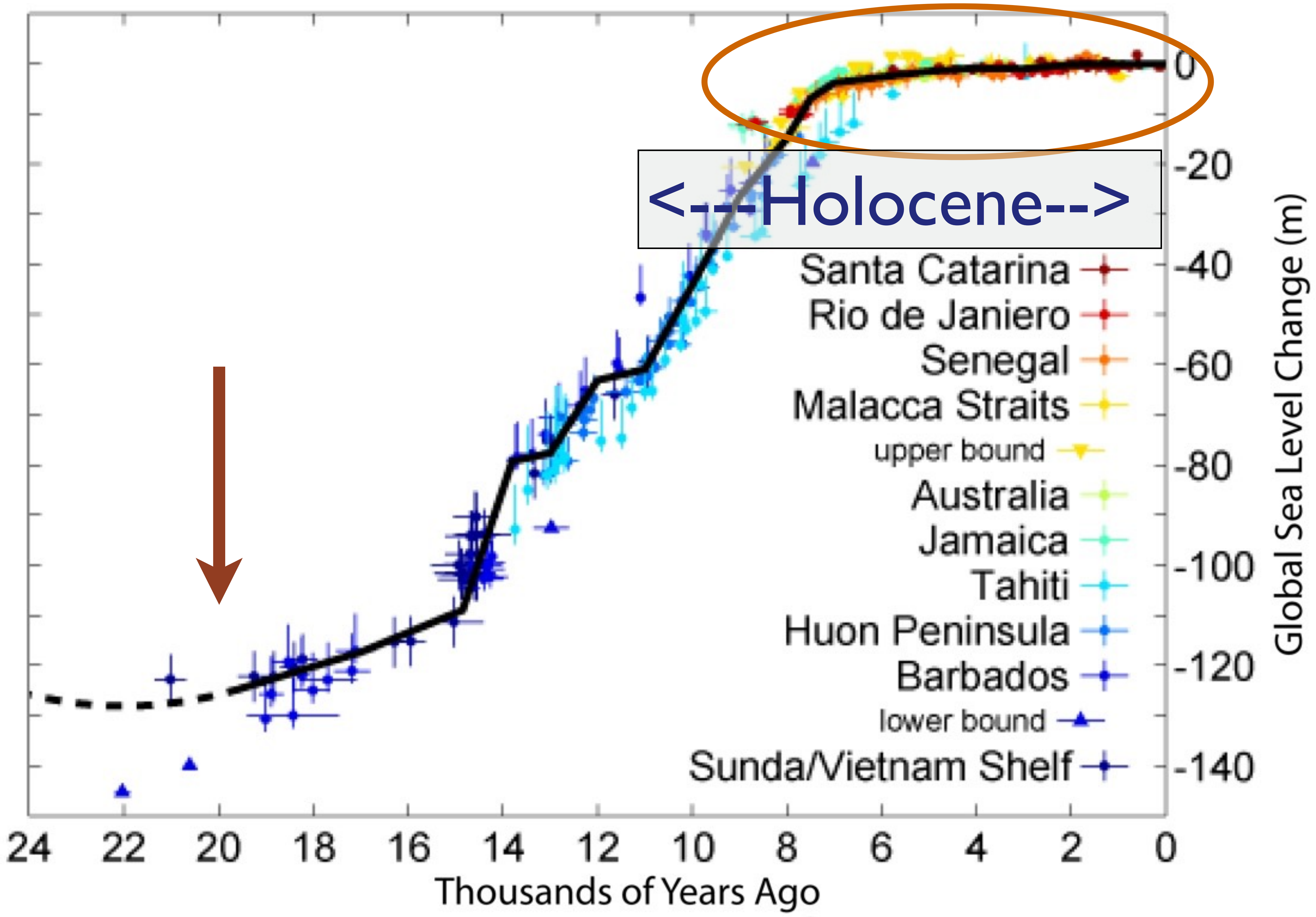


20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

Local Sea Level changes can be much larger than the global average changes.

During the last 7,000 years, global (and local) sea level was exceptionally stable

Global and Local Sea Level Changes



20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

Local Sea Level changes can be much larger than the global average changes.

During the last 7,000 years, global (and local) sea level was exceptionally stable

Sea Level changes can be much larger than what we know from recent history.

Key Points

Baseline

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

Mitigation and Adaptation Studies

Class 3: The Syndrome of Modern Global Change: Baseline, Syndrome, Diagnosis

Contents:

- Baseline (continued)
- Syndrome
- Diagnosis
- *Prognosis*
- *Therapy*

The Syndrome of Modern Global Change

The Syndrome of Modern Global Change

Human Activities and Greenhouse Gases

Our human ancestors invented agriculture about 11,000 years ago—around the same time that atmospheric concentrations of methane and CO_2 peaked in the wake of the last ice age. Had the gas trends subsequently mimicked older interglacial intervals, as expected, they would have fallen right up through the start of the industrial era. Instead the declining trends of both gases reversed direction several thousand years ago and have risen steadily ever since. The timing of key agricultural innovations—namely, deforestation and rice irrigation—may explain these surprising reversals. —*W.F.R.*

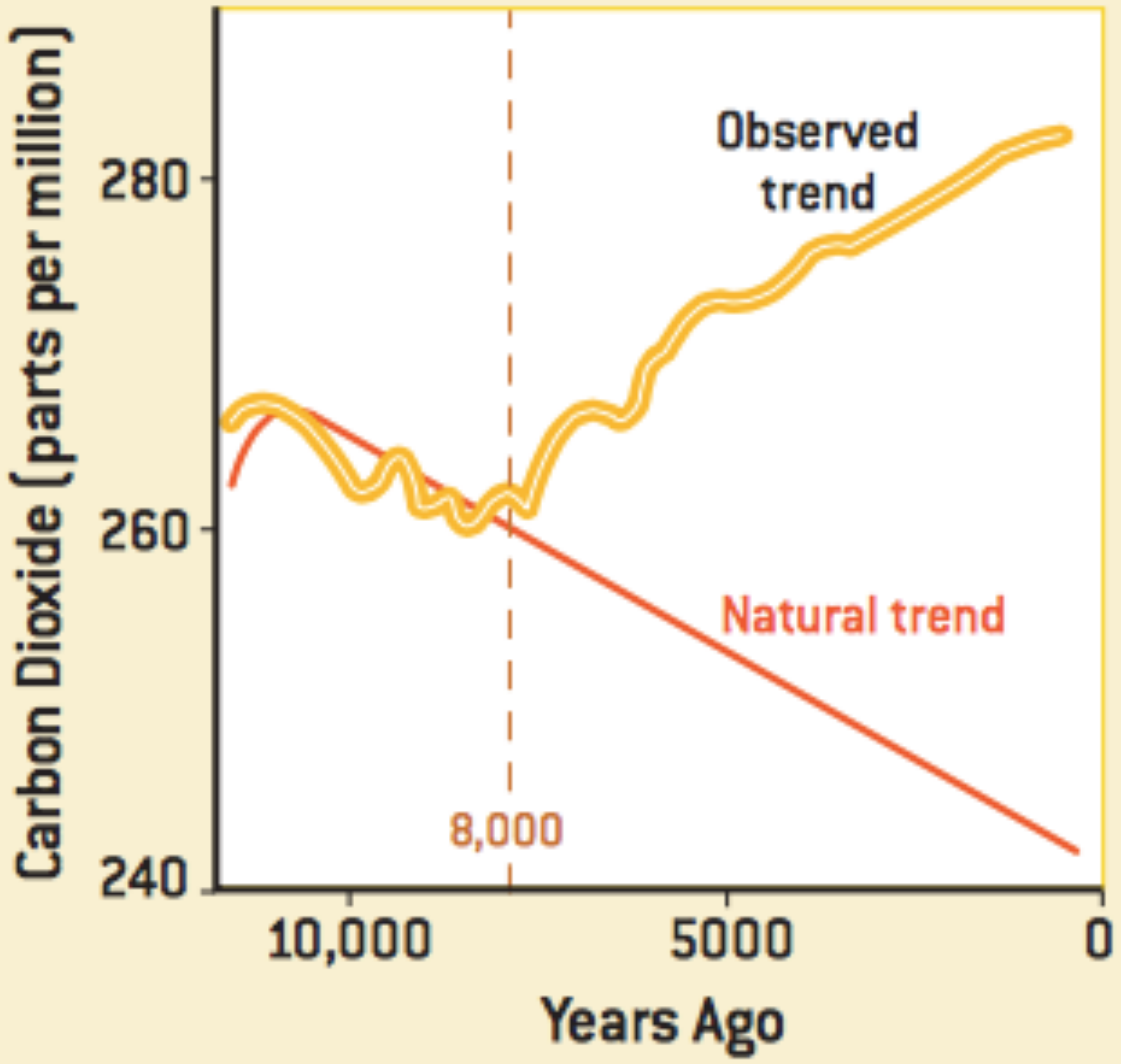
11,000 years ago: Early peoples invent agriculture in Mesopotamia and China

Paleolithic sickle blade

Carbonized wheat

8,000 years ago: Late Stone Age Europeans begin clearing forests to grow wheat, barley, peas and other nonindigenous crop plants

10,000 YEARS AGO — **8,000 YEARS AGO**



8,000 years ago: CO_2 trend, which has been falling for 2,500 years, bottoms out and suddenly reverses direction

7,500 years ago: Humans adapt wild rice for cultivation

PETRIE MUSEUM OF EGYPTIAN ARCHAEOLOGY, UNIVERSITY COLLEGE LONDON (*sickle blade* and *carbonized wheat*); JONATHAN BLAIR *Corbis* (*rice*)

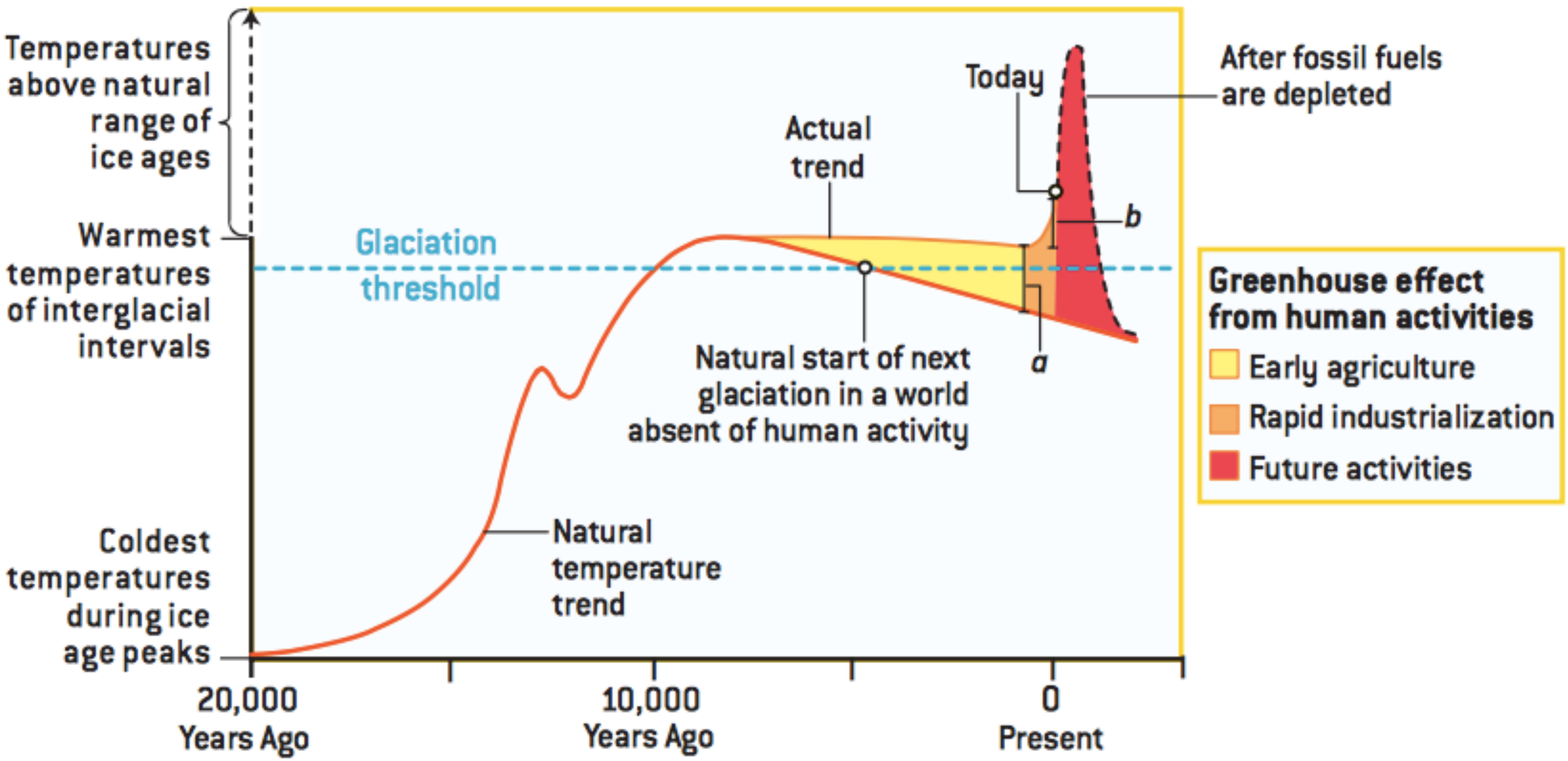
Ruddiman, 2005

The Syndrome of Modern Global Change

JULIA WATERLOW *Eye Ubiquitous/Corbis* (*irrigation*); THE IMAGE BANK (*deforestation*); VINCE STREANO *Corbis* (*wheat field*); DAVID GREEDY *Getty Images* (*rice terraces*); SCIENCE LIBRARY/SSPL (*combustion engine*); LUCY READING-IKKANDA (*graphs*)

Ruddiman, 2005

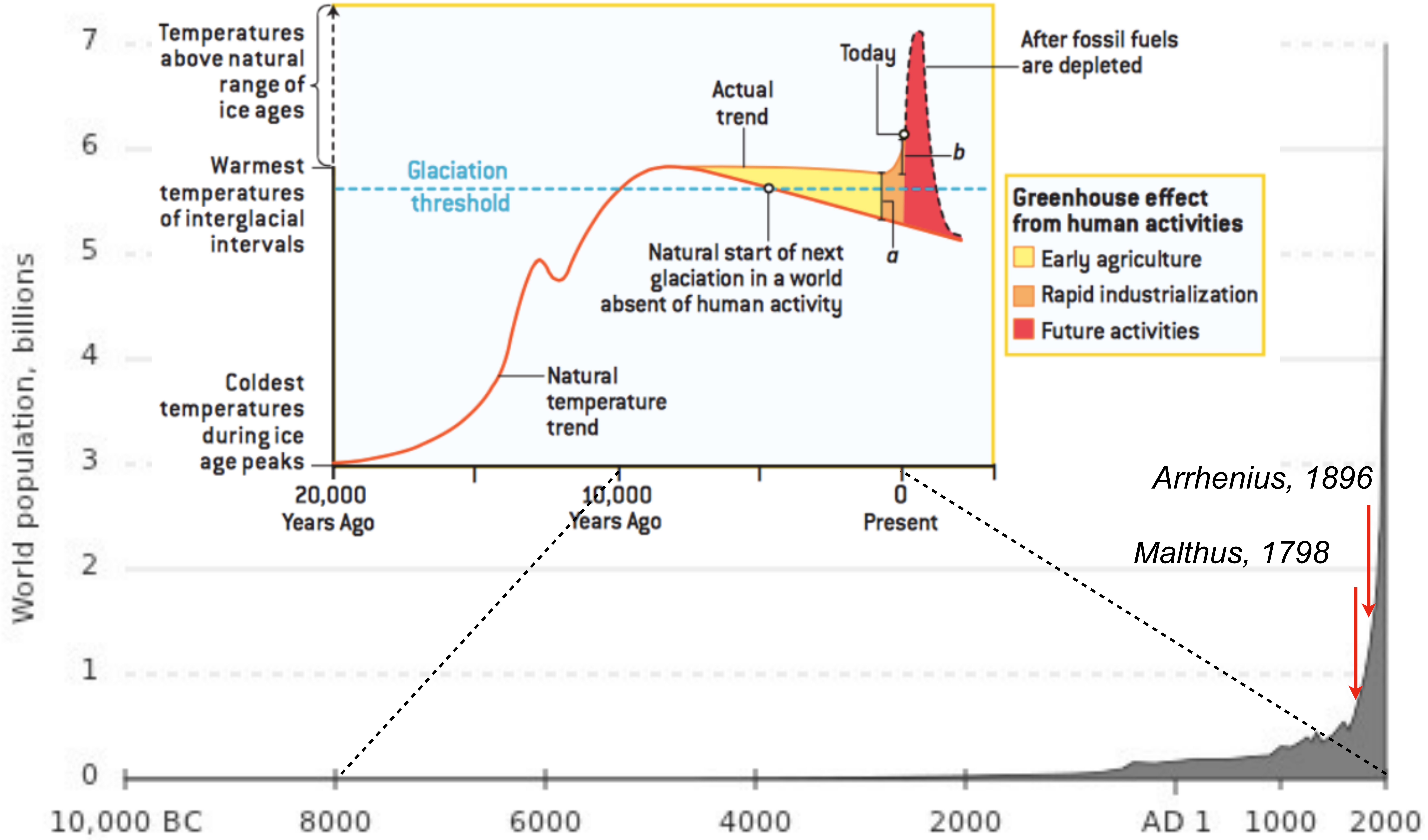
The Syndrome of Modern Global Change



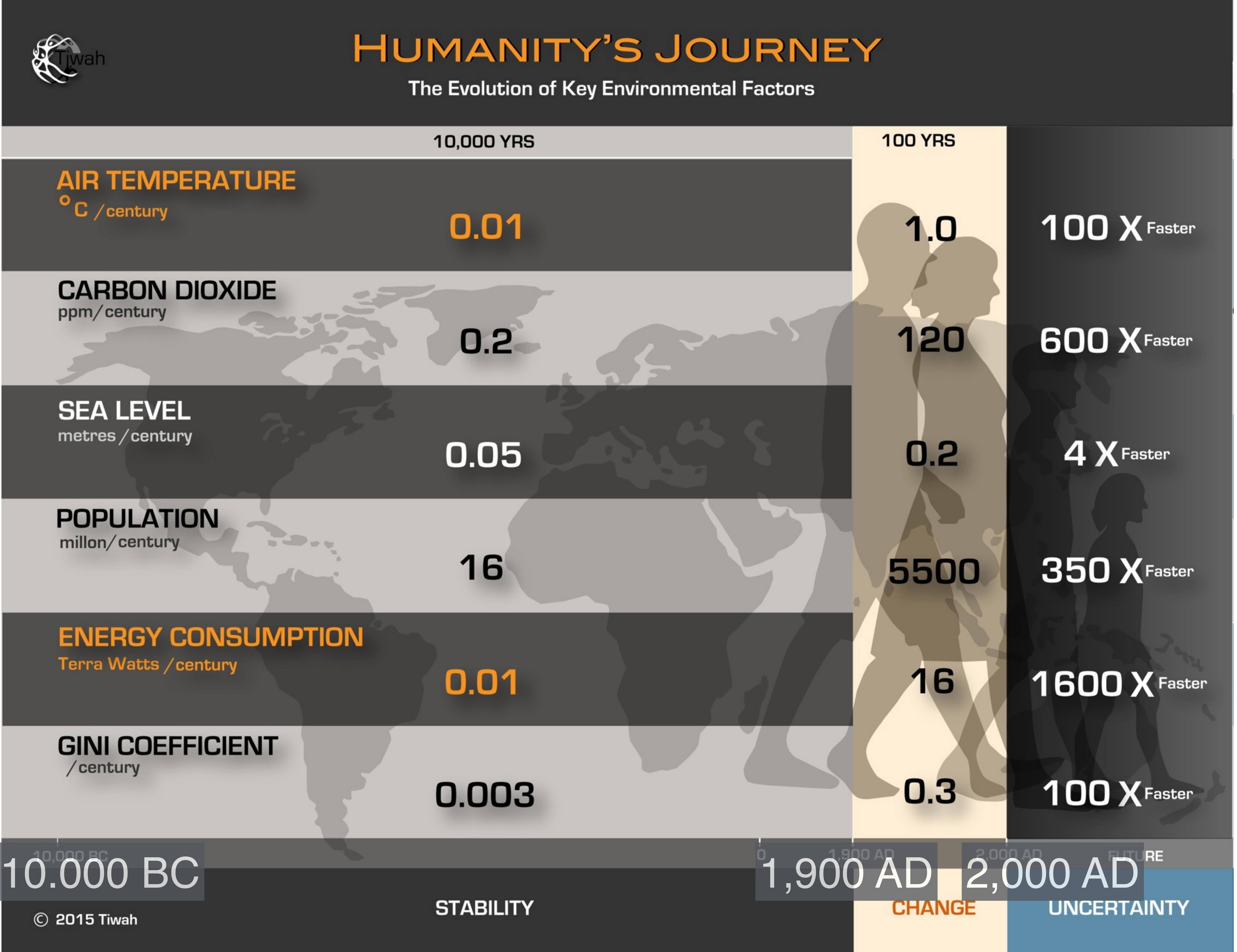
GREENHOUSE EFFECT from human activities has warded off a glaciation that otherwise would have begun about 5,000 years ago. Early human agricultural activities produced enough greenhouse gases to offset most of the natural cooling trend during preindustrial times (*yellow*), warming the planet by an average of almost 0.8 degree Celsius. That early warming effect (*a*) rivals the 0.6 degree Celsius (*b*) warming measured in the past century of rapid industrialization (*orange*). Once most fossil fuels are depleted and the temperature rise caused by greenhouse gases peaks, the earth will cool toward the next glaciation—now thousands of years overdue.

Ruddiman, 2005

The Syndrome of Modern Global Change



Plag, 2016


Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
100 YRS
AIR TEMPERATURE
°C / century
0.01
1.0
100 X Faster
CARBON DIOXIDE
ppm/ century
0.2
120
600 X Faster
SEA LEVEL
metres / century
0.05
0.2
4 X Faster
POPULATION
millon/ century
16
5500
350 X Faster
ENERGY CONSUMPTION
Terra Watts / century
0.01
16
1600 X Faster
GINI COEFFICIENT
/ century
0.003
0.3
100 X Faster
10.000 BC
1,900 AD
2,000 AD
STABILITY
CHANGE
UNCERTAINTY
© 2015 Tiwah

Plag, 2016

The Syndrome of Modern Global Change

Syvitski, 2012

The Syndrome of Modern Global Change

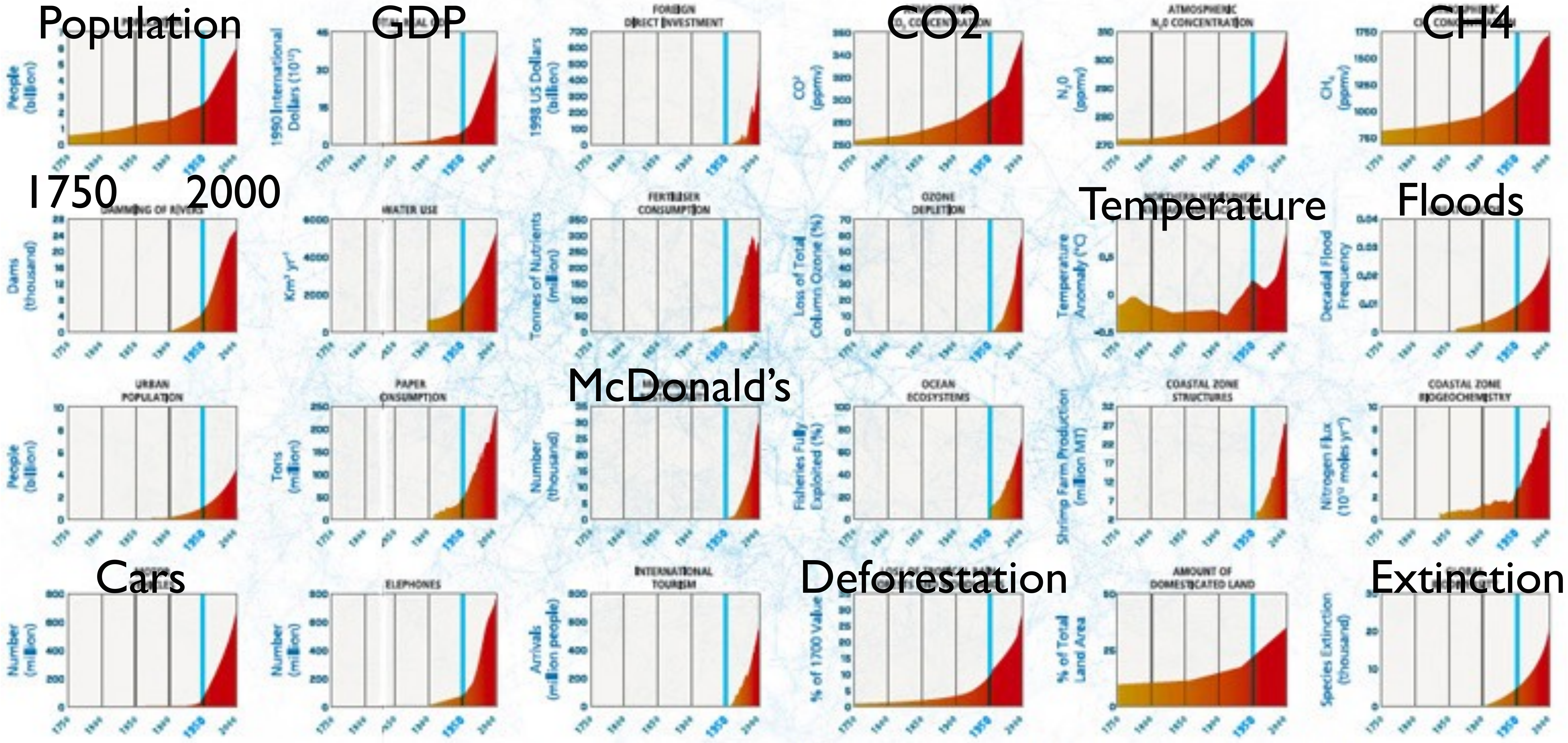


Figure 1. An enterprise to reckon with. Human manipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP's Great Acceleration graphs show. Modified after Steffen W et al. (2004).

Syvitski, 2012

The Syndrome of Modern Global Change

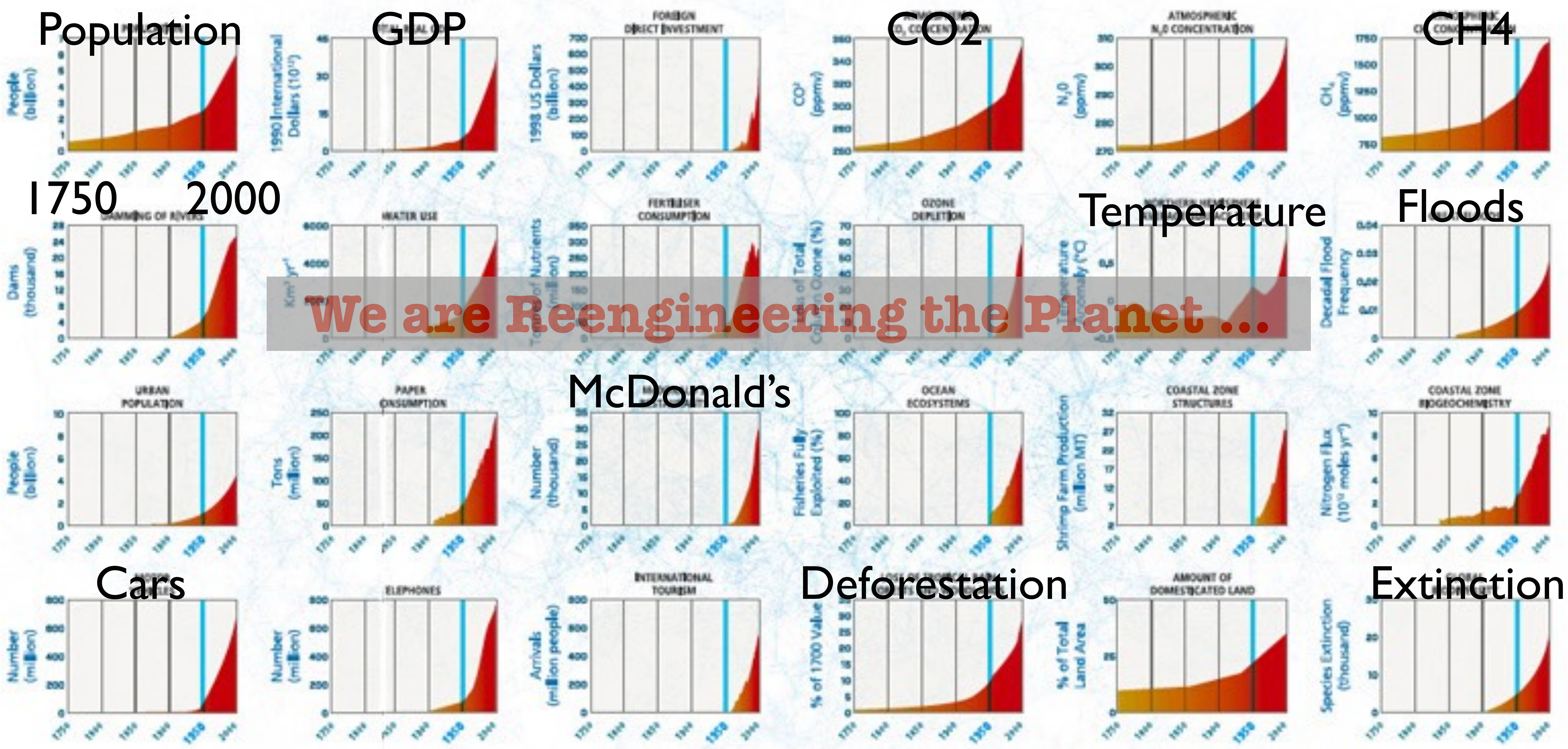


Figure 1. An enterprise to reckon with. Human manipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP's Great Acceleration graphs show. Modified after Steffen W et al. (2004).

Syvitski, 2012

The Syndrome of Modern Global Change

Andrew Freedman Jan 10

SAVE

Just 5% of Earth's landscape is untouched

Illustration: Rebecca Zisser/Axios

Humans have a greater influence on the world's landscape than previously thought, according to a comprehensive new high-resolution analysis of human modification of the planet. The map, published in the journal *Global Change Biology*, is meant to guide conservation strategy in the coming years.

https://www.axios.com/earth-surface-human-activity-landscape-1547164584-48a7c526-b959-4f13-9a2e-c263a341d7f4.html

Global Change Biology

PRIMARY RESEARCH ARTICLE | Free Access

Managing the middle: A shift in conservation priorities based on the global human modification gradient

Christina M. Kennedy, James R. Oakleaf, David M. Theobald, Sharon Baruch-Mordo, Joseph Kiesecker

First published: 10 January 2019 | https://doi.org/10.1111/gcb.14549

SECTIONS PDF TOOLS SHARE

Abstract

An increasing number of international initiatives aim to reconcile development with conservation. Crucial to successful implementation of these initiatives is a comprehensive understanding of the current ecological condition of landscapes and their spatial distributions. Here, we provide a cumulative measure of human modification of terrestrial lands based on modeling the physical extents of 13 anthropogenic stressors and their estimated impacts using spatially explicit global datasets with a median year of 2016. We quantified the degree of land modification and the amount and spatial configuration of low modified lands (i.e., natural areas relatively free from human alteration) across all ecoregions and biomes. We identified that fewer

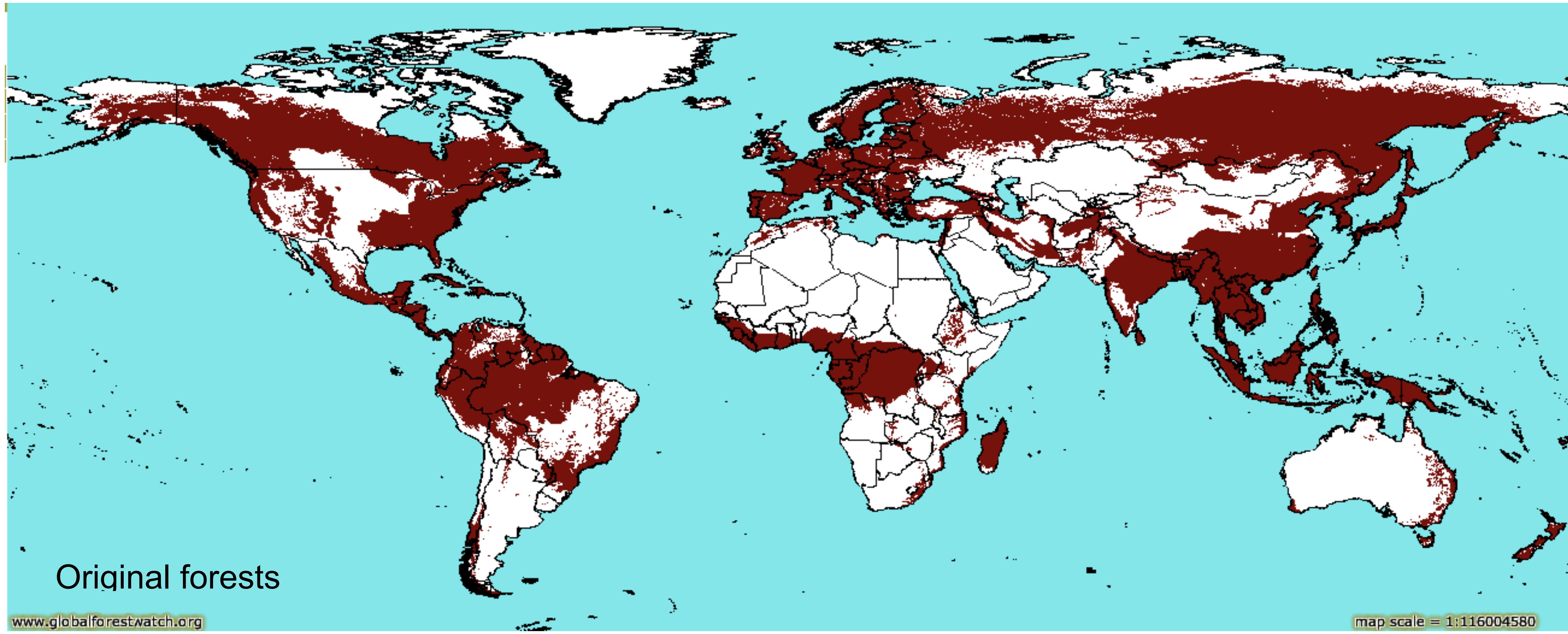
https://doi.org/10.1111/gcb.14549

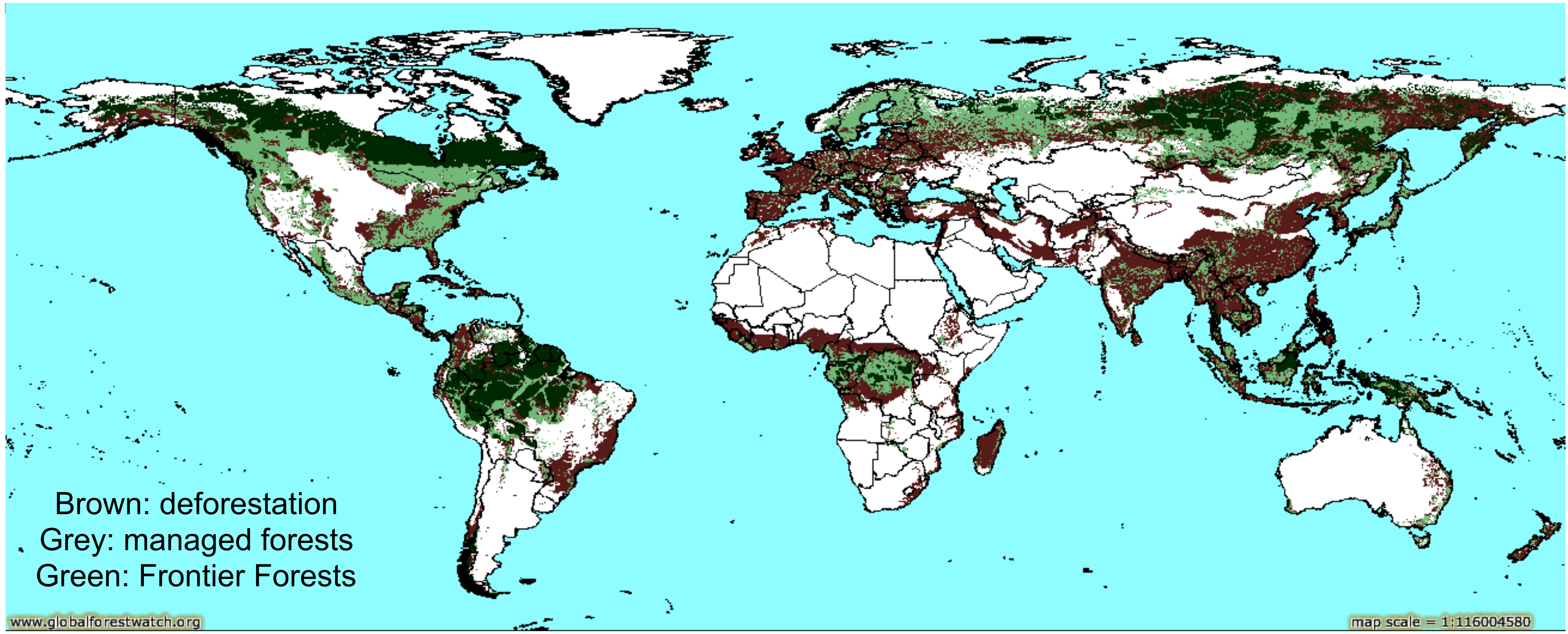
81% of Earth's surface have been changed significantly by humans

The Syndrome of Modern Global Change

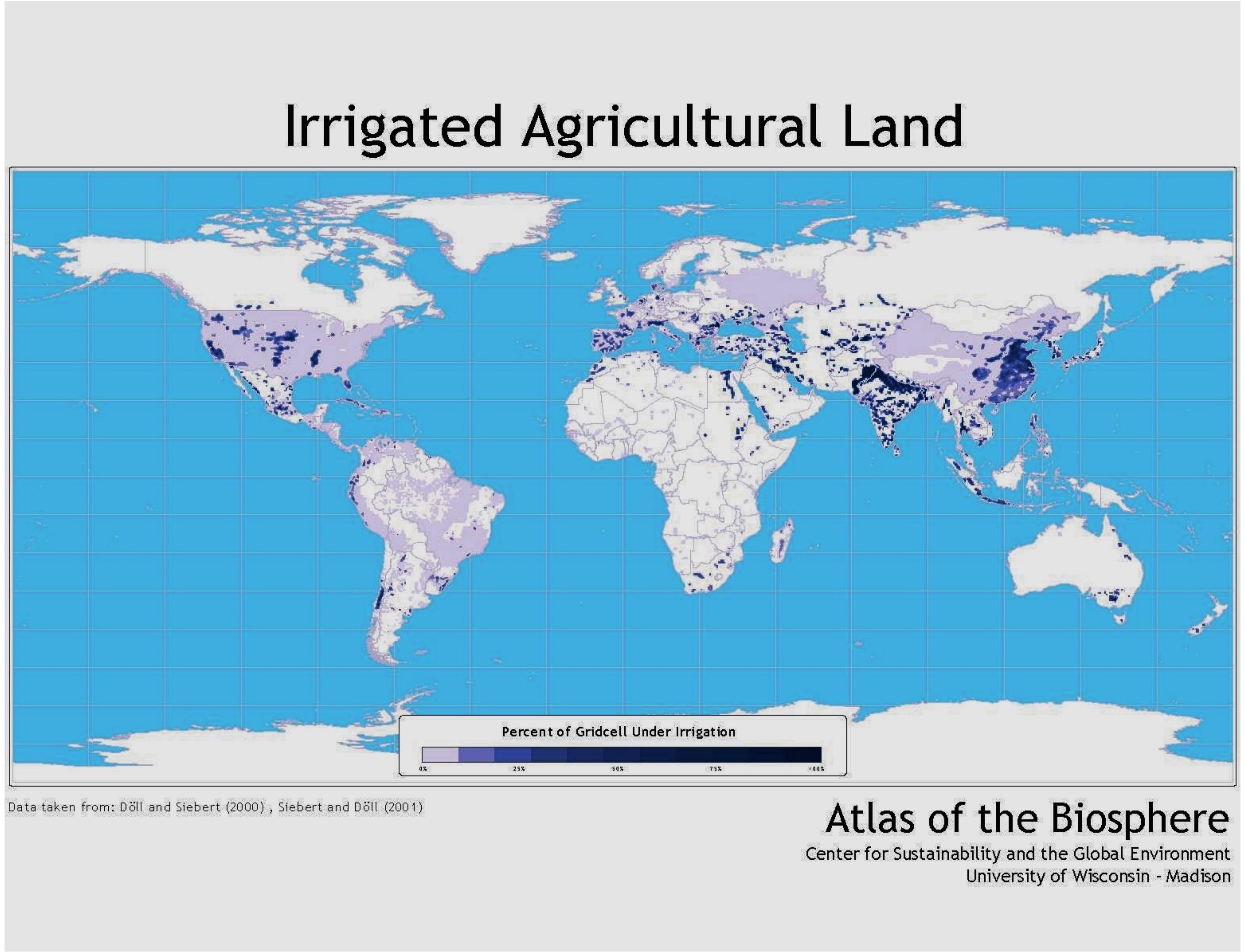
Deforestation

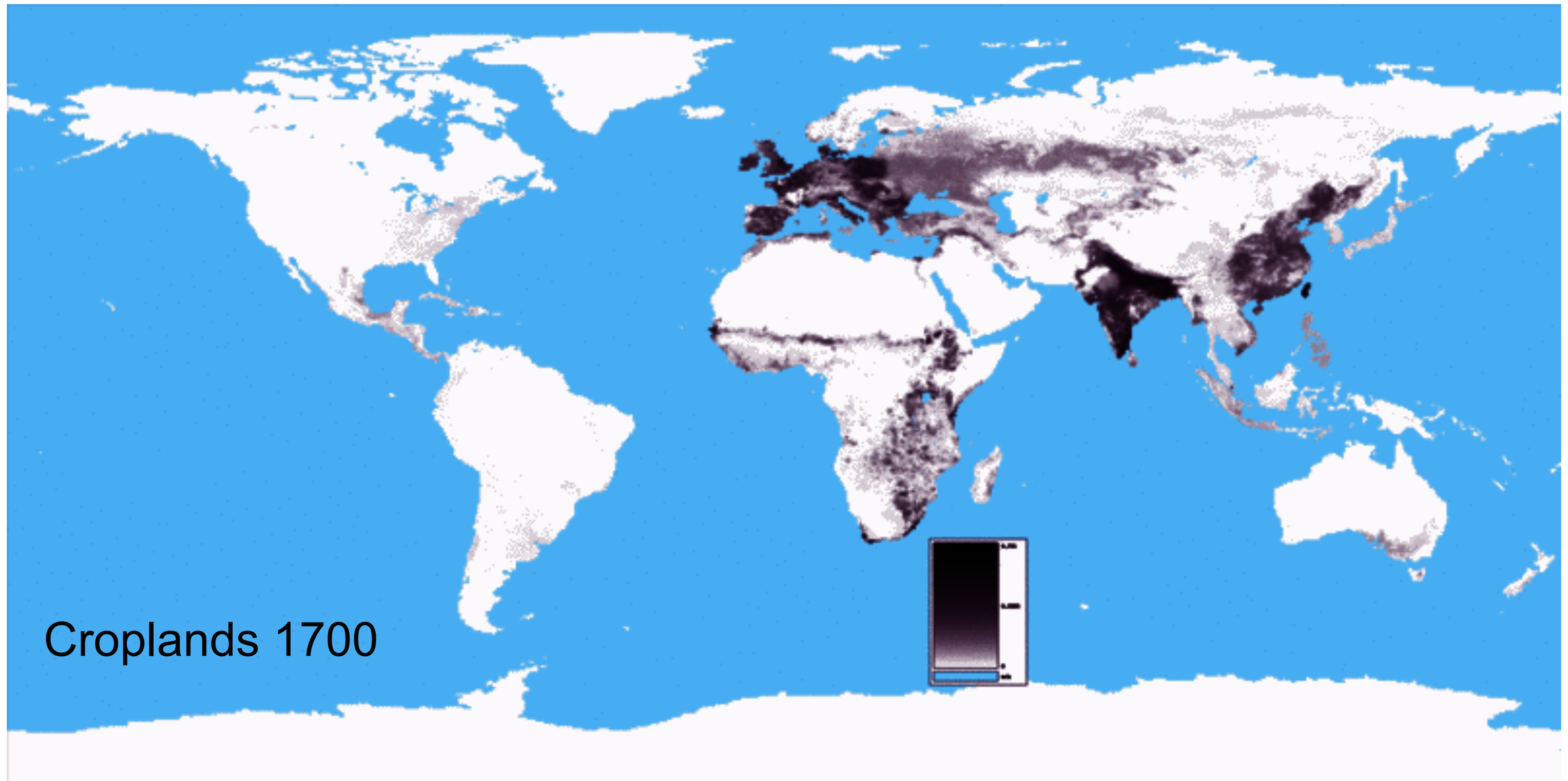
- About 50% of the original forests are gone;
- Only 20% of frontier forests remain
- 75% of forests are less than 1 km away from a forest edge

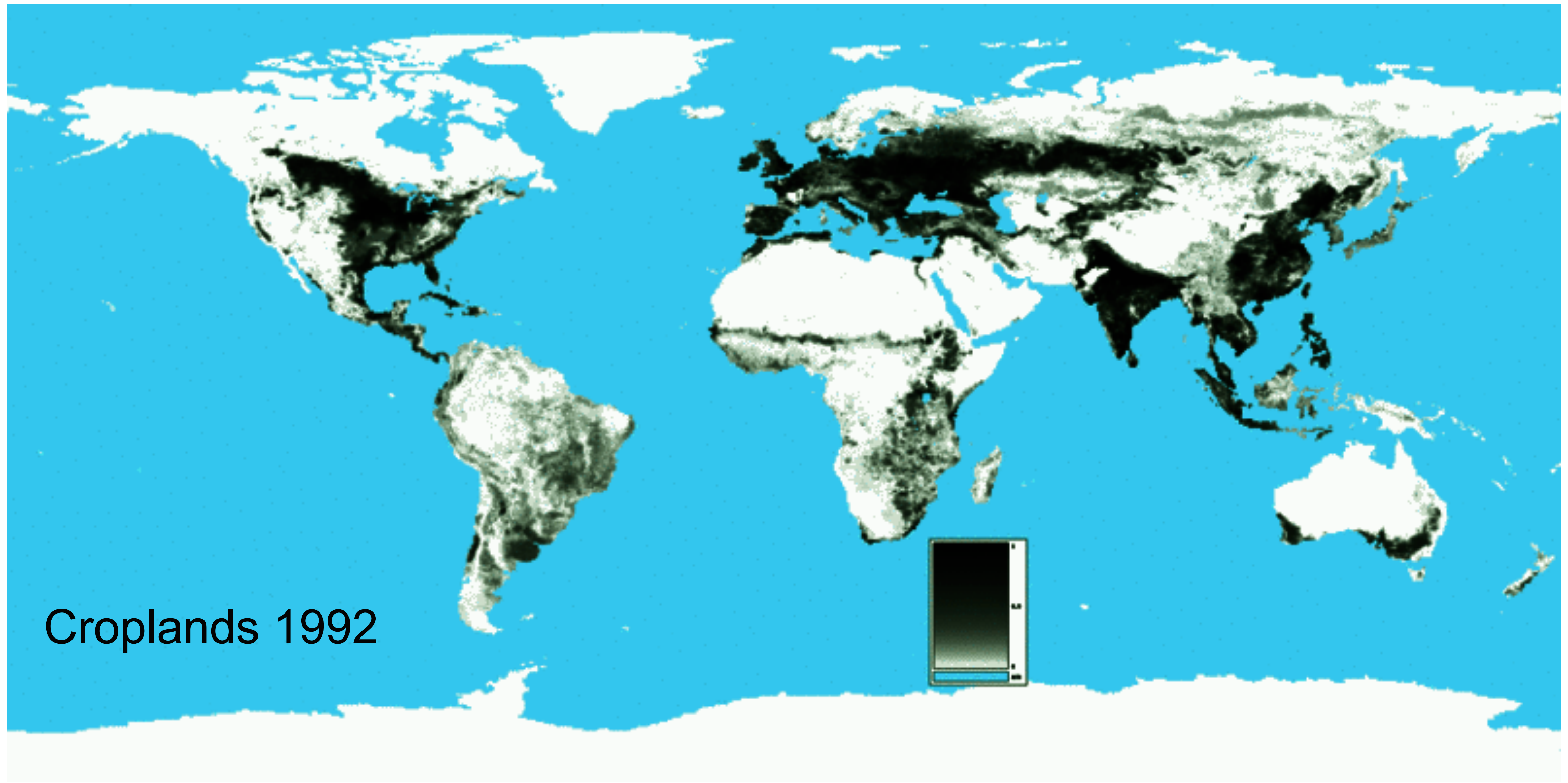




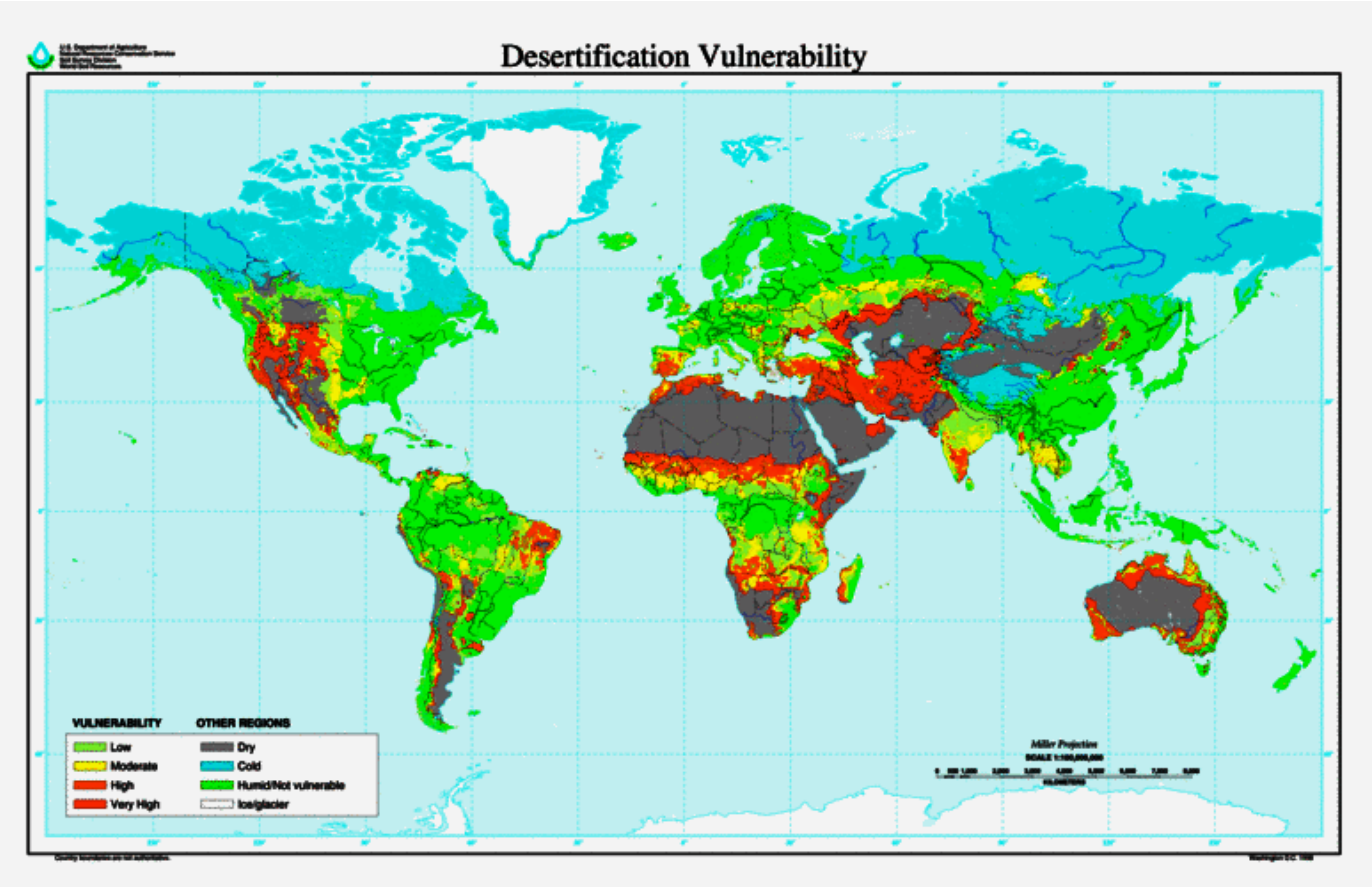
Croplands and Irrigation



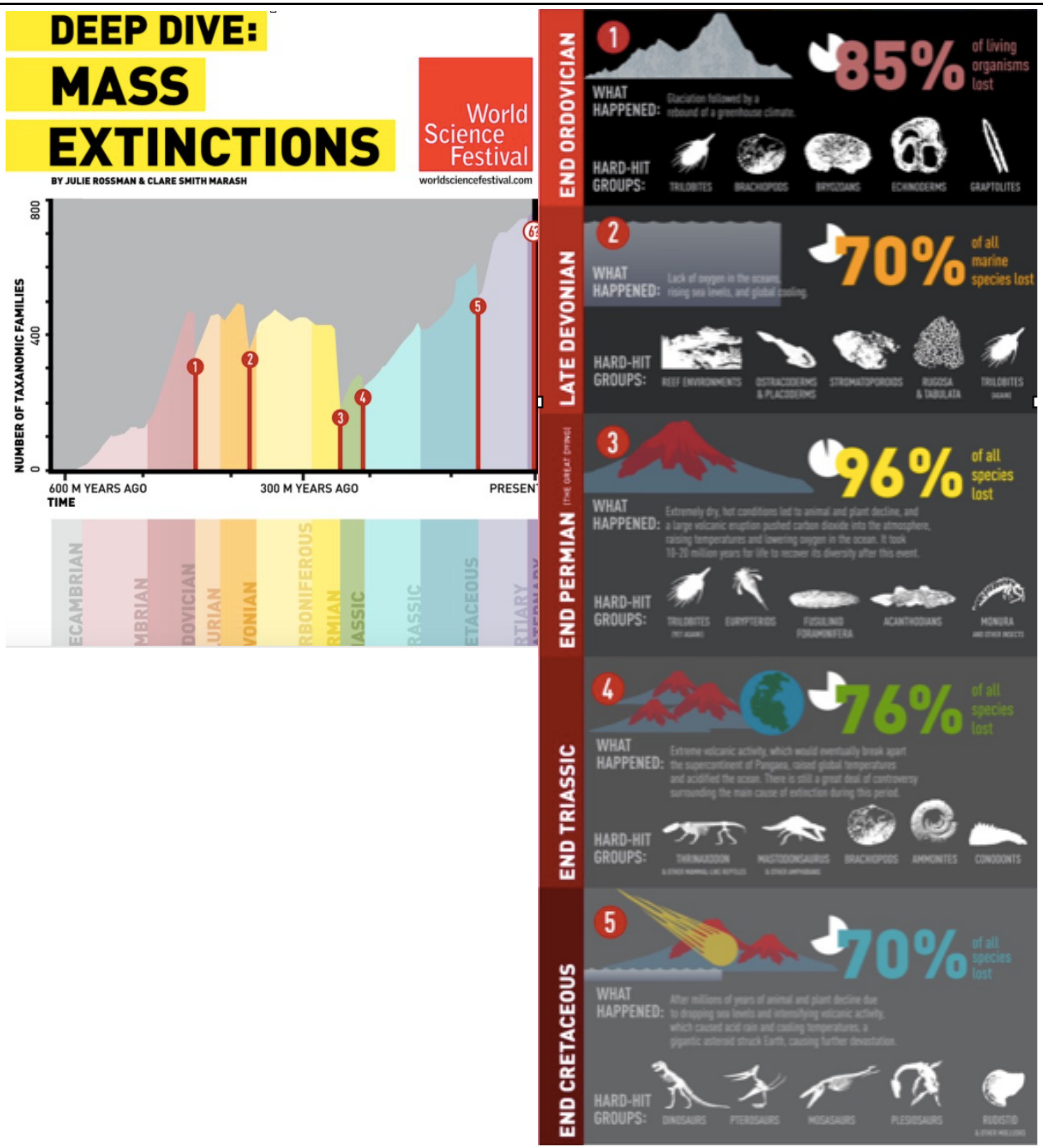




The Syndrome of Modern Global Change

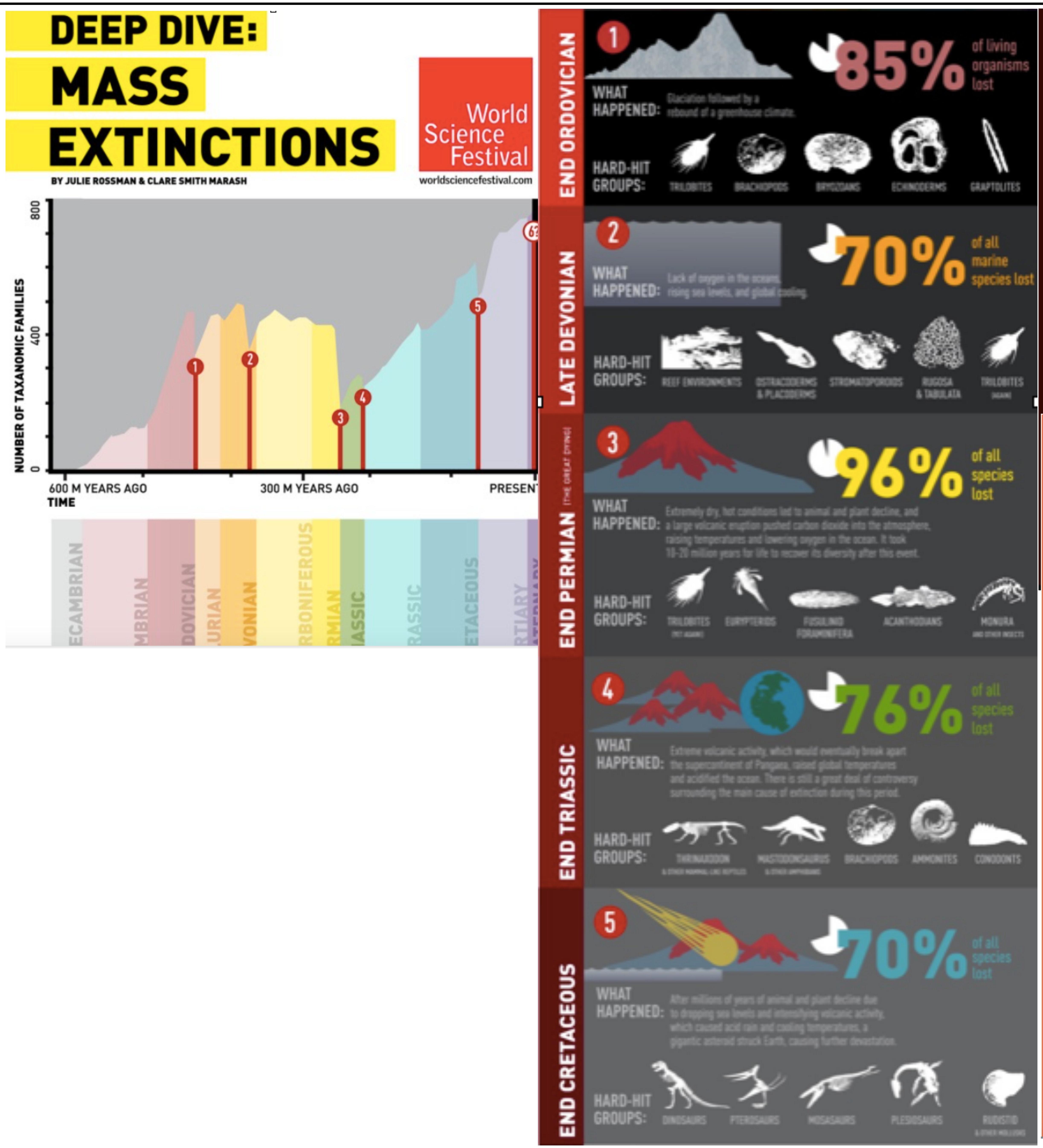


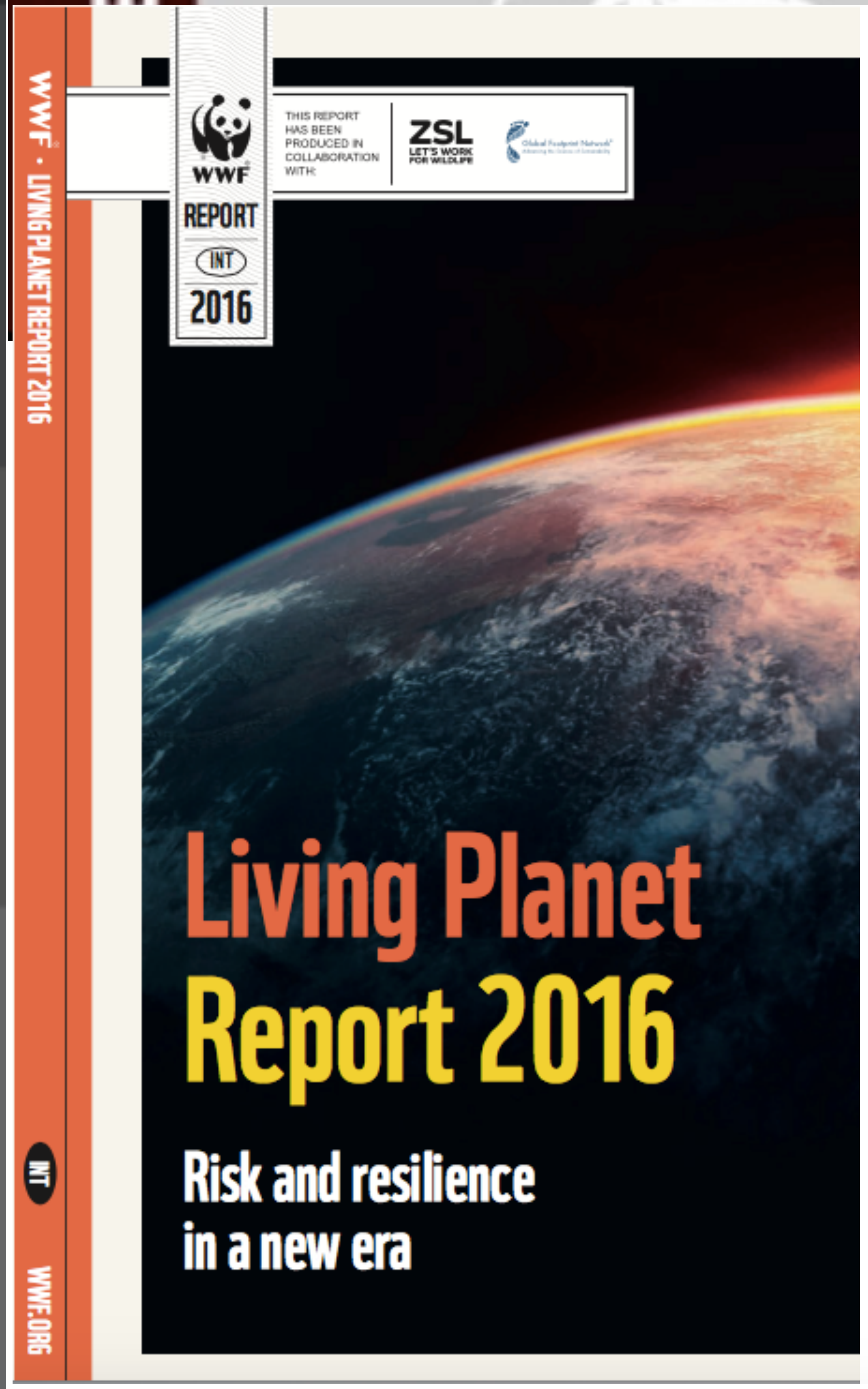
The Syndrome of Modern Global Change



The Syndrome of Modern Global Change

The Syndrome of Modern Global Change





Science & Environment

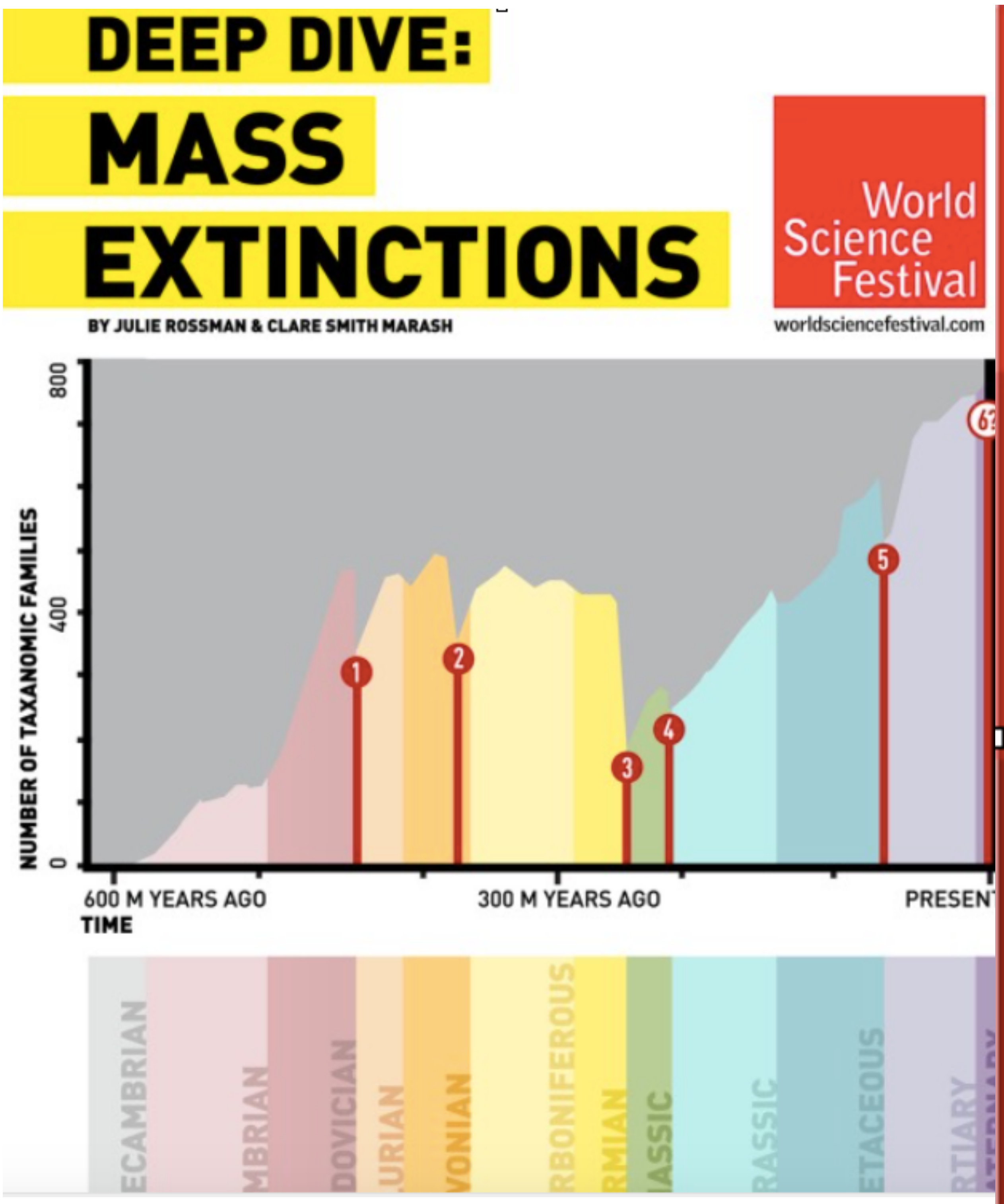
World wildlife 'falls by 58% in 40 years'

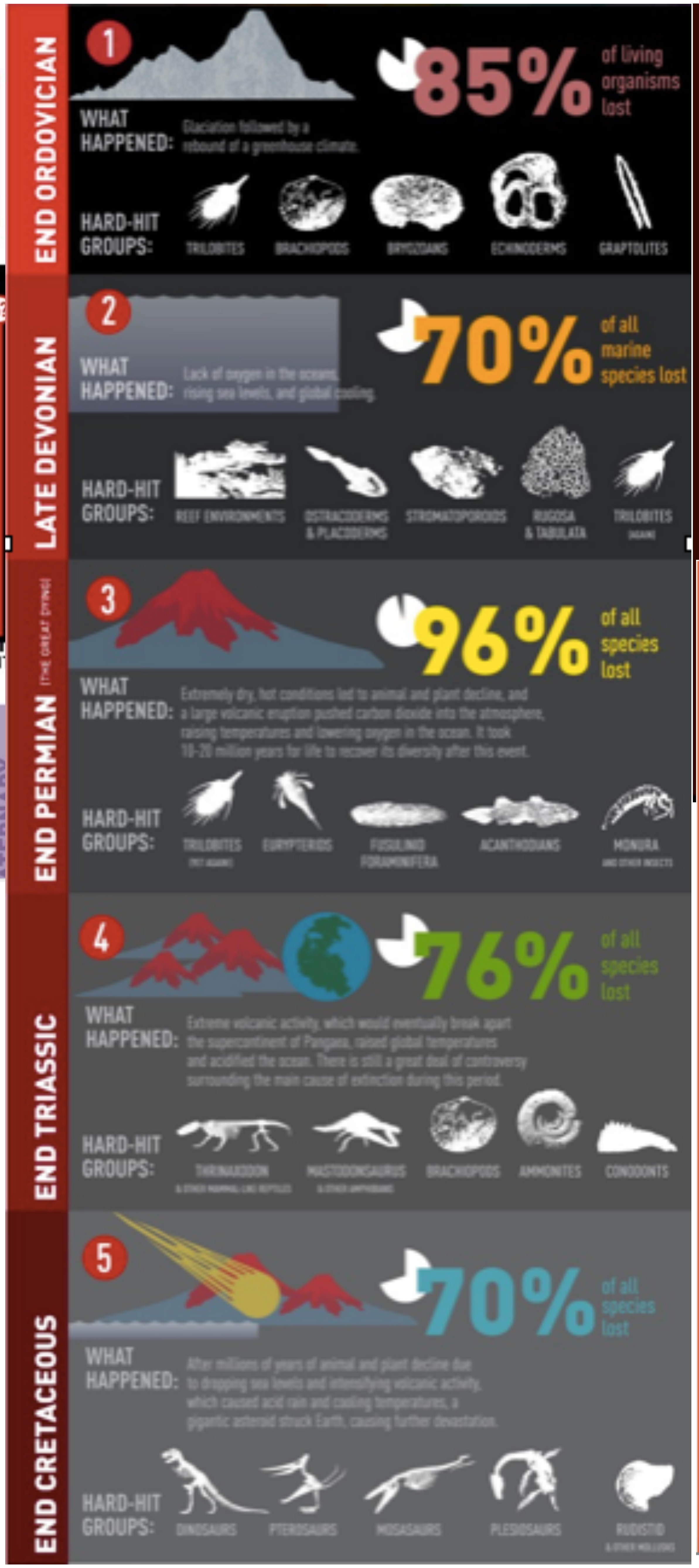
By Rebecca Morelle
Science Correspondent, BBC News

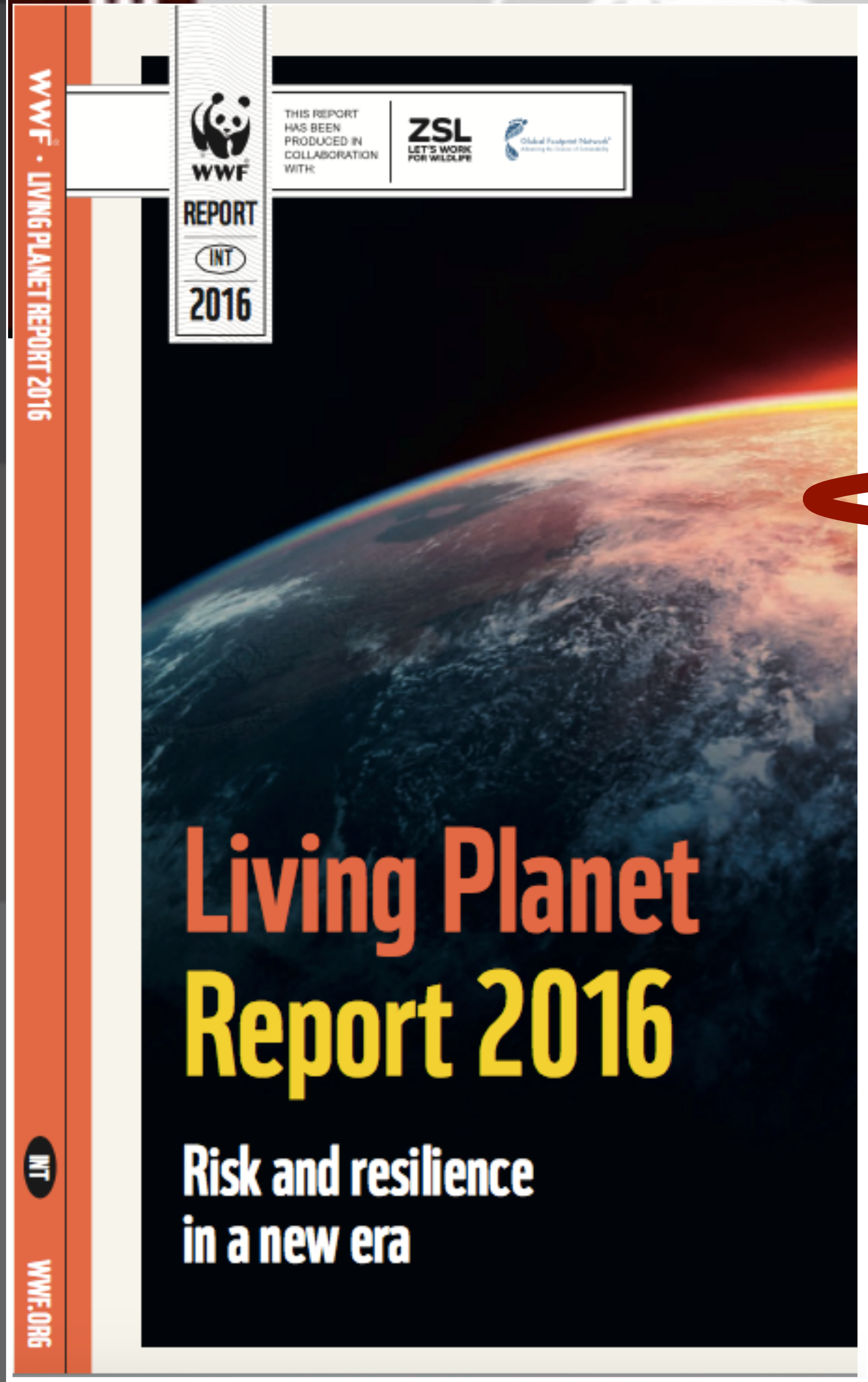
27 October 2016 | Science & Environment | Share

"We do see particularly strong declines in the freshwater environment - for freshwater species alone, the decline stands at 81% since 1970. This is related to the way water is used and taken out of fresh water systems, and also the fragmentation of freshwater systems through dam building, for example."

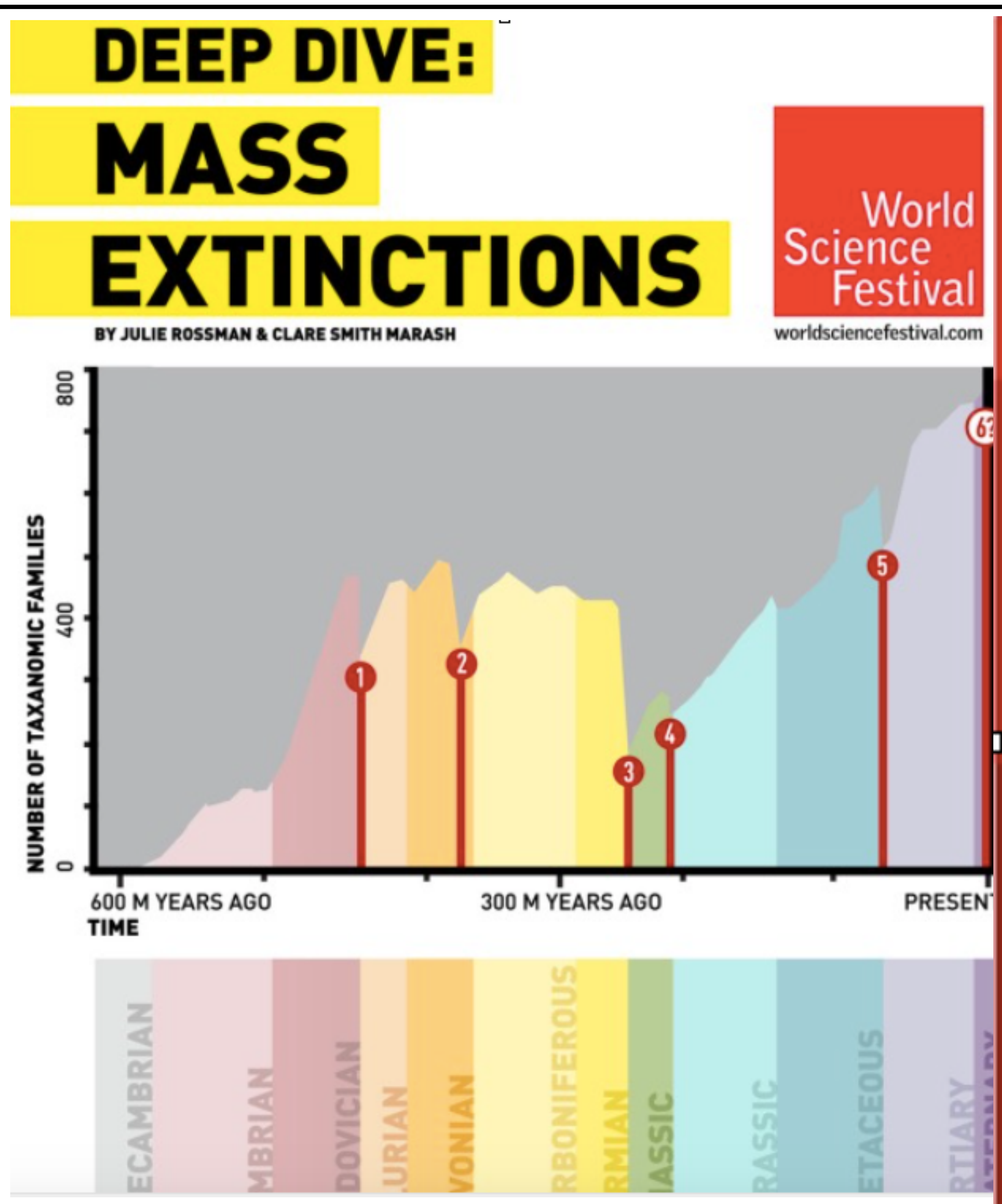
The Syndrome of Modern Global Change

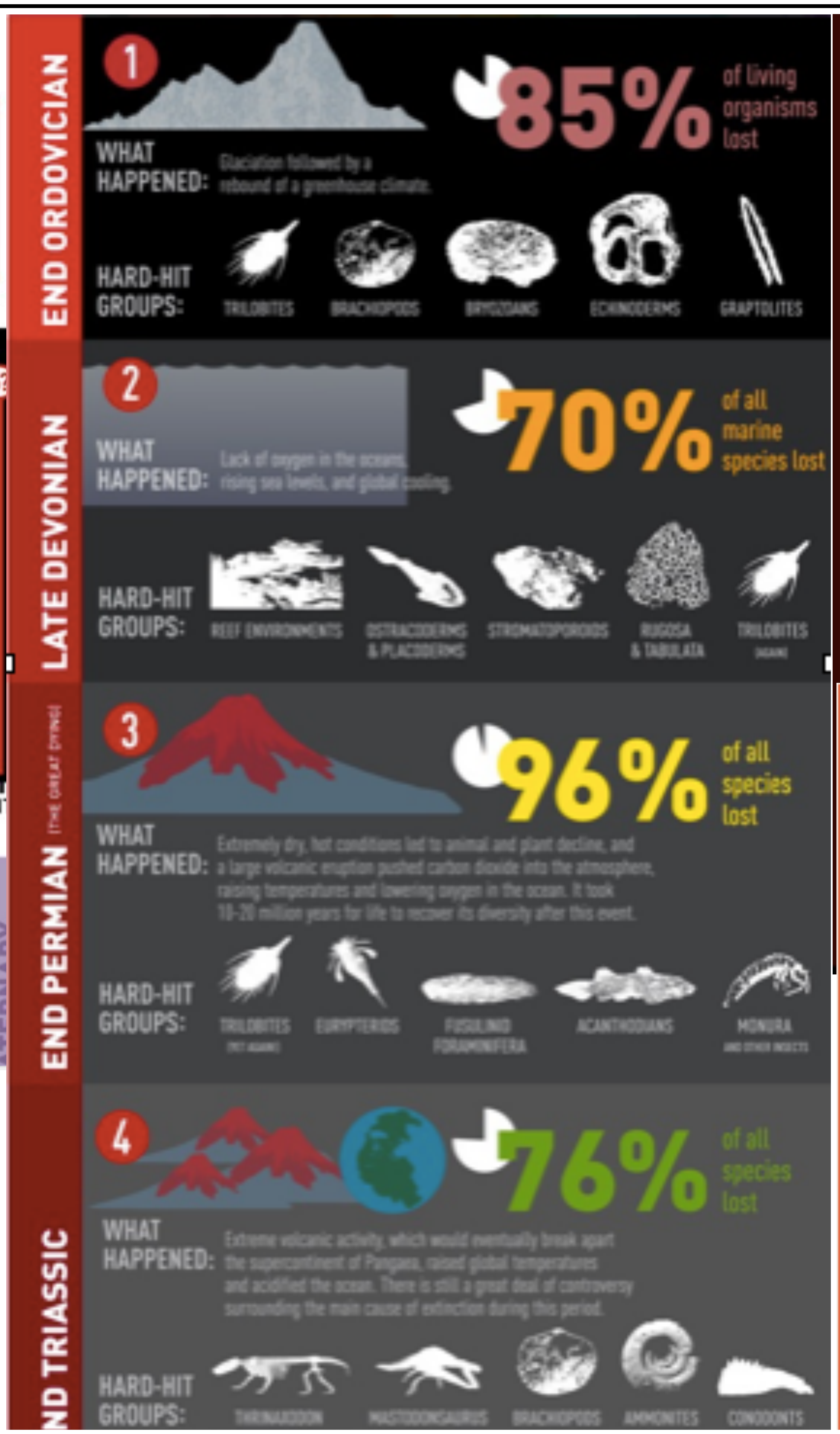






The Syndrome of Modern Global Change



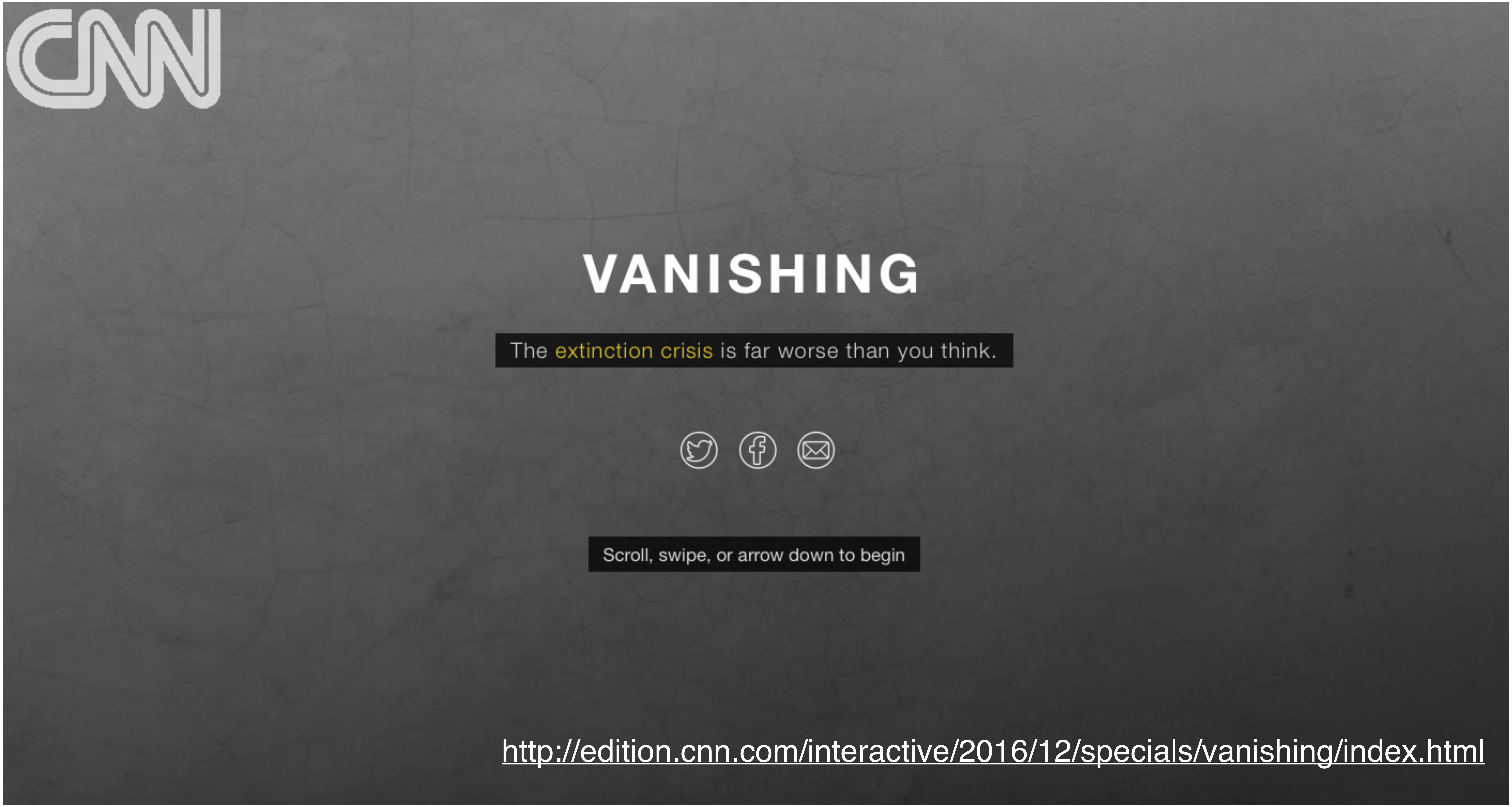


Current extinction rates:

300 times background rate for birds

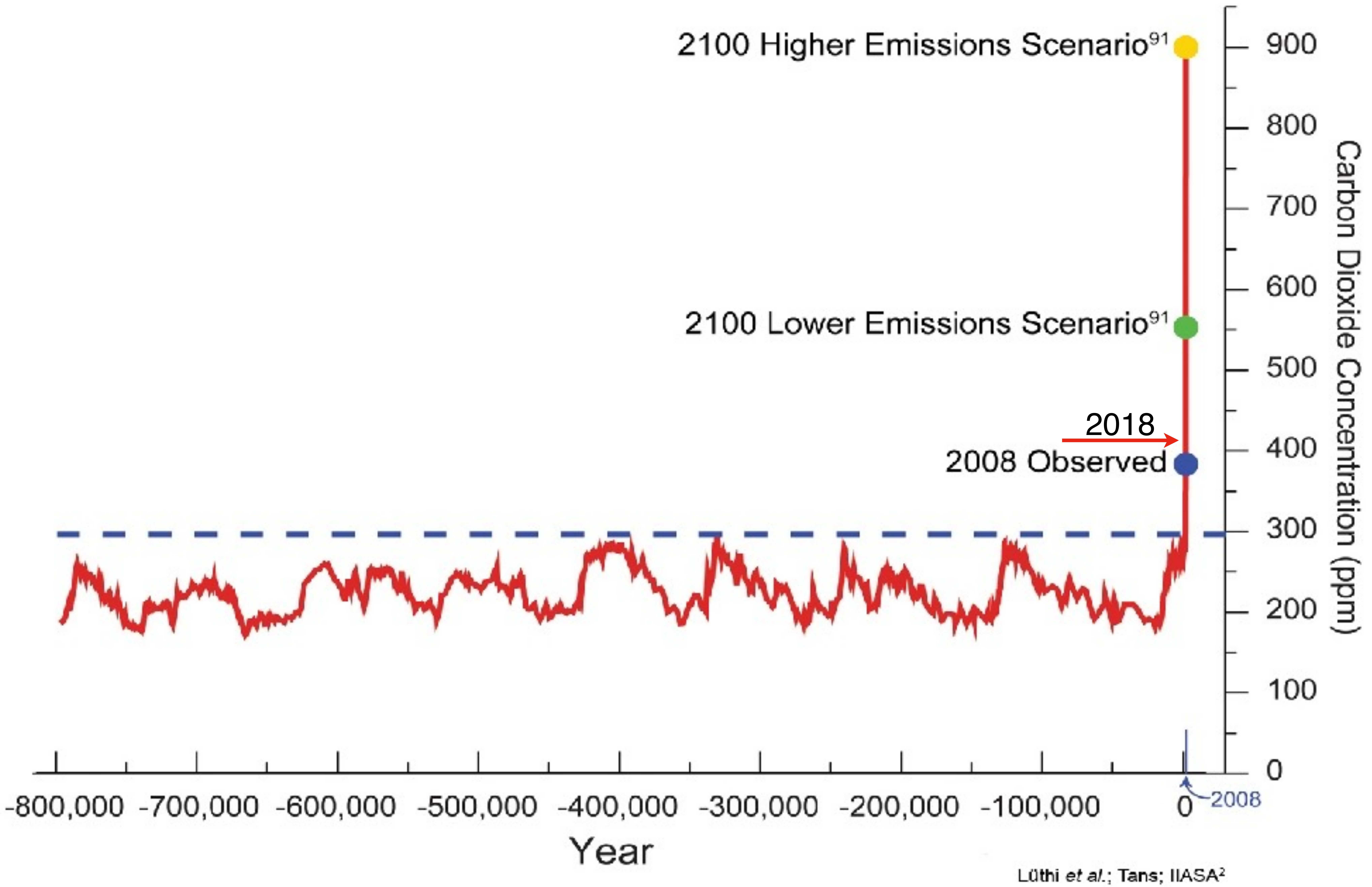
80,000 times background rate for mammals

The Syndrome: Recent Climate and Global Change



http://edition.cnn.com/interactive/2016/12/specials/vanishing/index.html

The Syndrome of Modern Global Change



The Syndrome of Modern Global Change

The Syndrome of Modern Global Change

Anthropogenic Degradation of the Earth's Life-Support System:

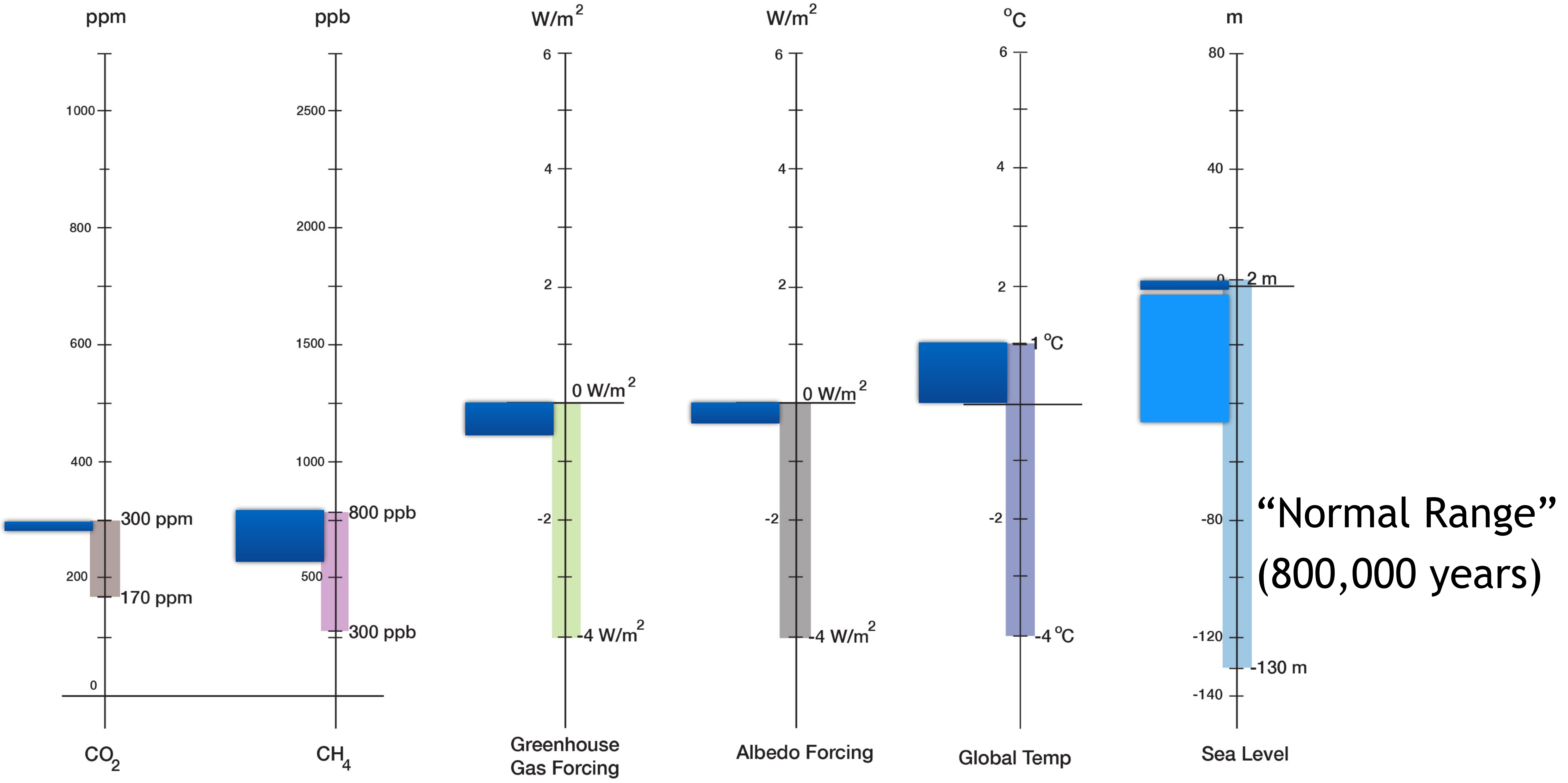
- >80% of the Earth's surface have been modified significantly.
- Human-mobilized material and energy flows are exceeding non-human flows.
- Major mass cycles have been changed, including C, N, P, H_2O, …
- Pollutants have been introduced that did not exists in free from or were not abundant (mercury, aluminum, PCBs, plastics, …).
- Ecosystems have been segmented or eliminated, and innumerable species are in decline or already extinct.
- The biosphere has been changed significantly over of the last 300 years, and a mass extinction is in progress.
- These extinctions are irreversible and threaten the stability of the planetary life-support system.
- The magnitude of human-induced environmental changes at global scale is cataclysmic.
- And then there is modern climate change …

Modern climate change is a symptom in the syndrome of Modern Global Change, not the cause.

Modern climate change is a symptom in the syndrome of Modern Global Change, not the cause.

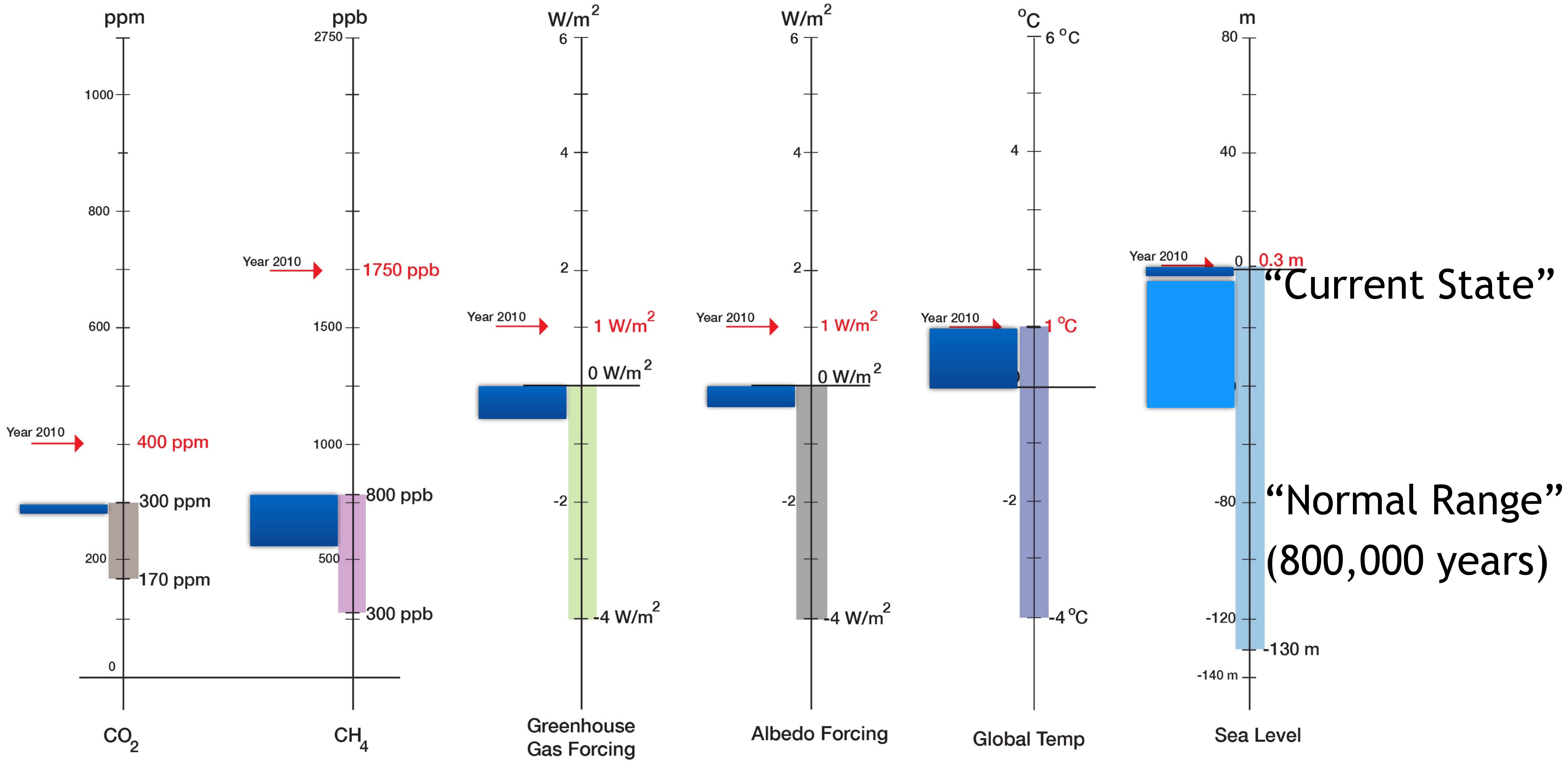
However, modern climate change is increasingly causing cascading changes, thus extending the syndrome of modern global change

The Syndrome of Modern Global Change

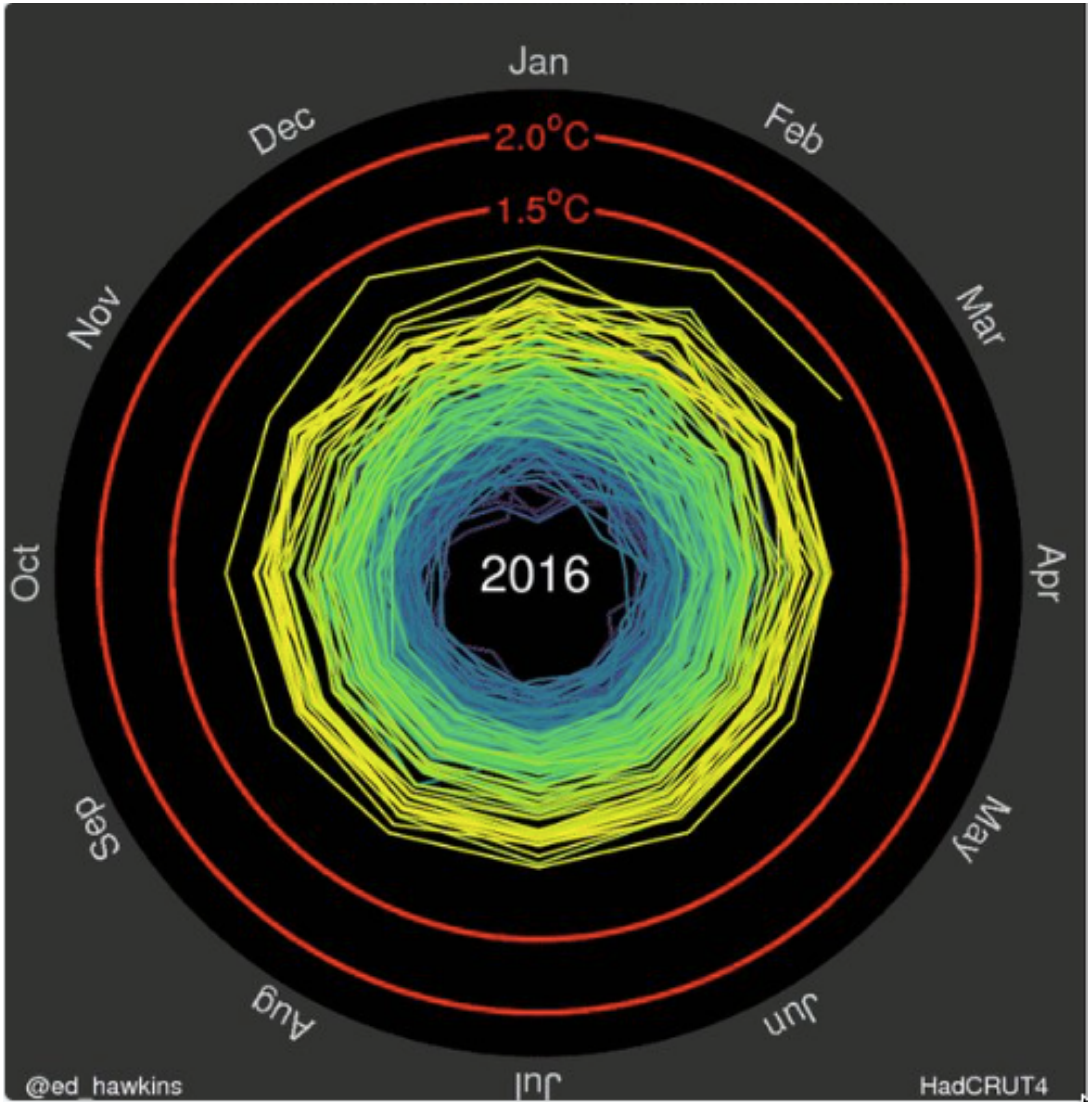


The Syndrome of Modern Global Change

The Lab Results for "Patient Earth"

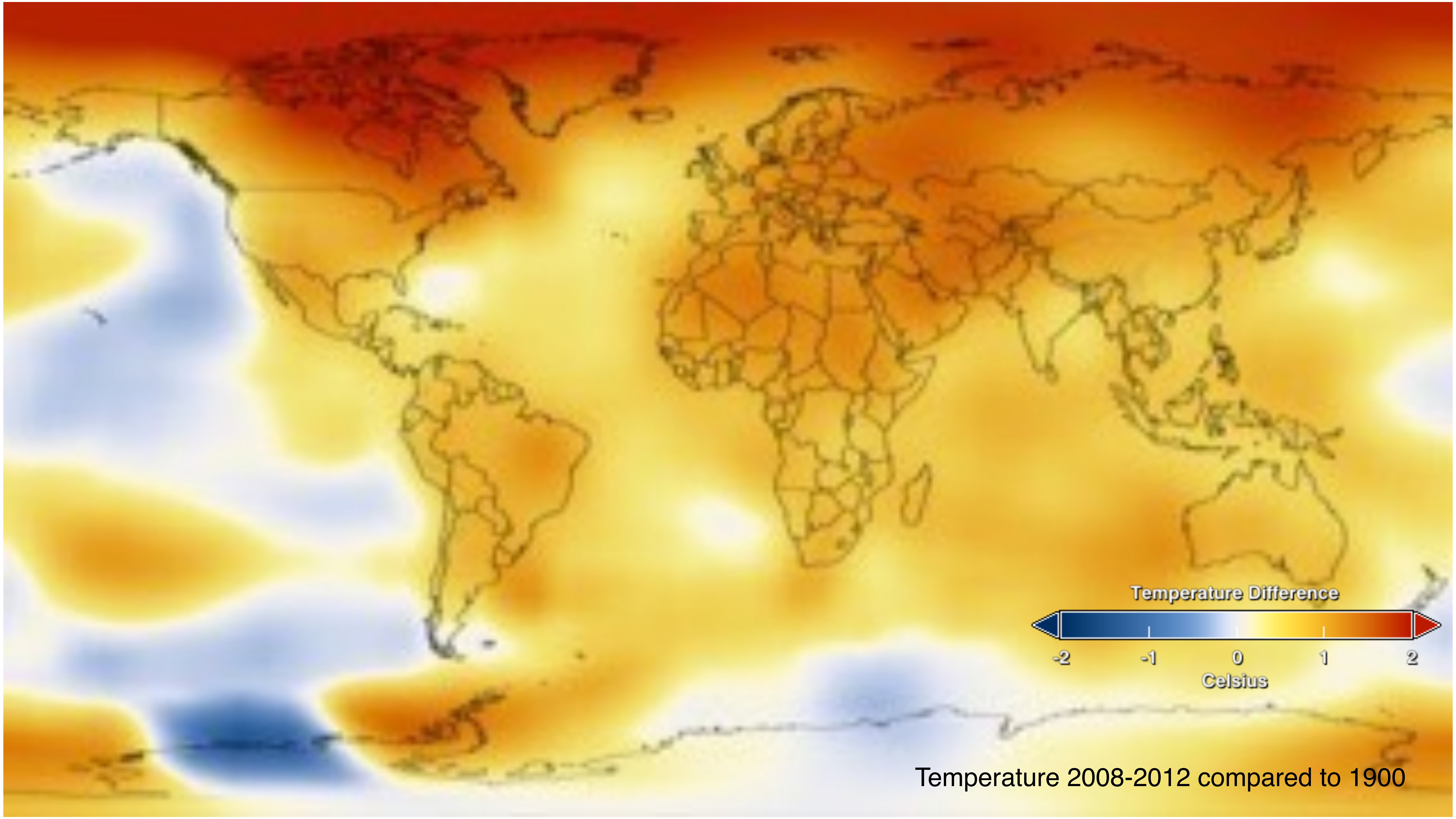


The Syndrome of Modern Global Change



The Syndrome of Modern Global Change

The Syndrome of Modern Global Change



Permafrost Is Warming Around the Globe, Study Shows. That's a Problem for Climate Change.

Rapid changes in the long-frozen soil are raising concerns about a surge of planet-warming greenhouse gases as the permafrost thaws.

BY BOB BERWYN, INSIDECLIMATE NEWS

JAN 16, 2019

Lake and ponds like these at the foothills of the Brooks Range in Alaska form when permafrost thaws. Thawing also releases methane and carbon dioxide. Copyright: Josefine Lenz/Alfred Wegener Institute

Greenland's Melting Ice Nears a 'Tipping Point,' Scientists Say

Greenland's ice is melting so fast that it could become a major factor in sea-level rise around the world within two decades, scientists said in a new study. Lucas Jackson/Reuters

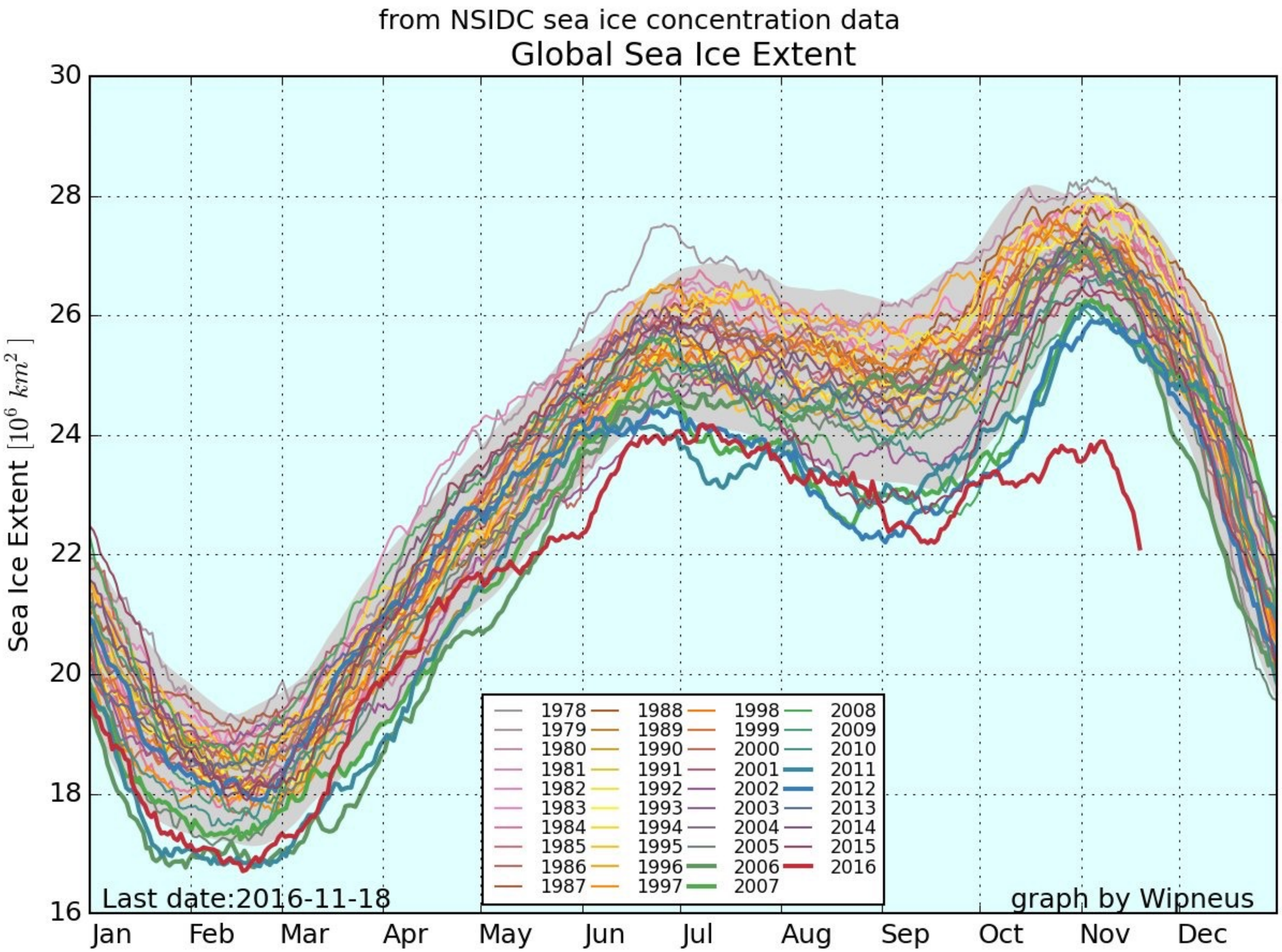
By John Schwartz

A new study shows the East Antarctic Ice Sheet, once thought to be stable, may be melting faster than expected.
TORSTEN BLACKWOOD/POOL/GETTY IMAGES

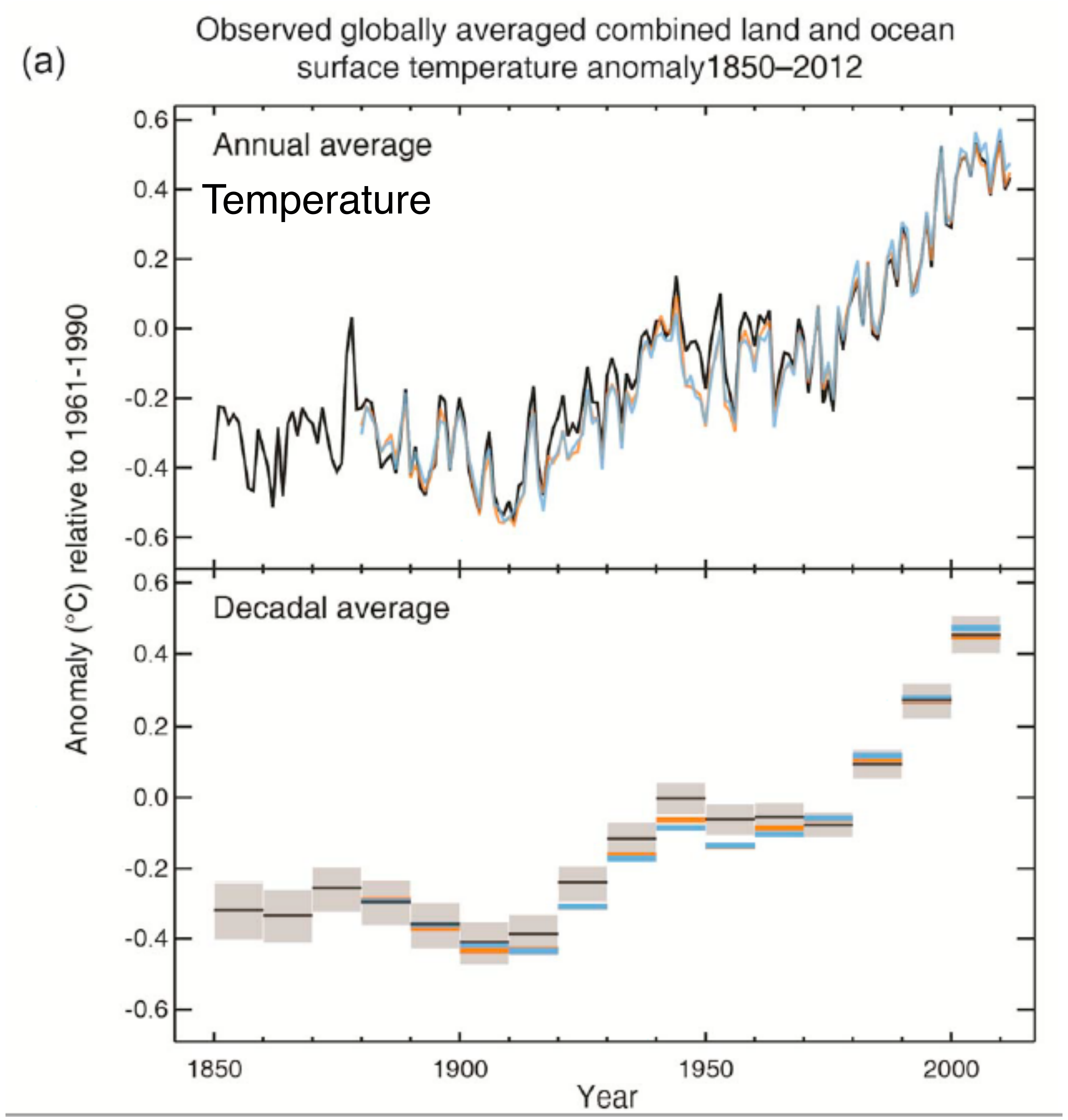
East Antarctica's ice is melting at an unexpectedly rapid clip, new study suggests

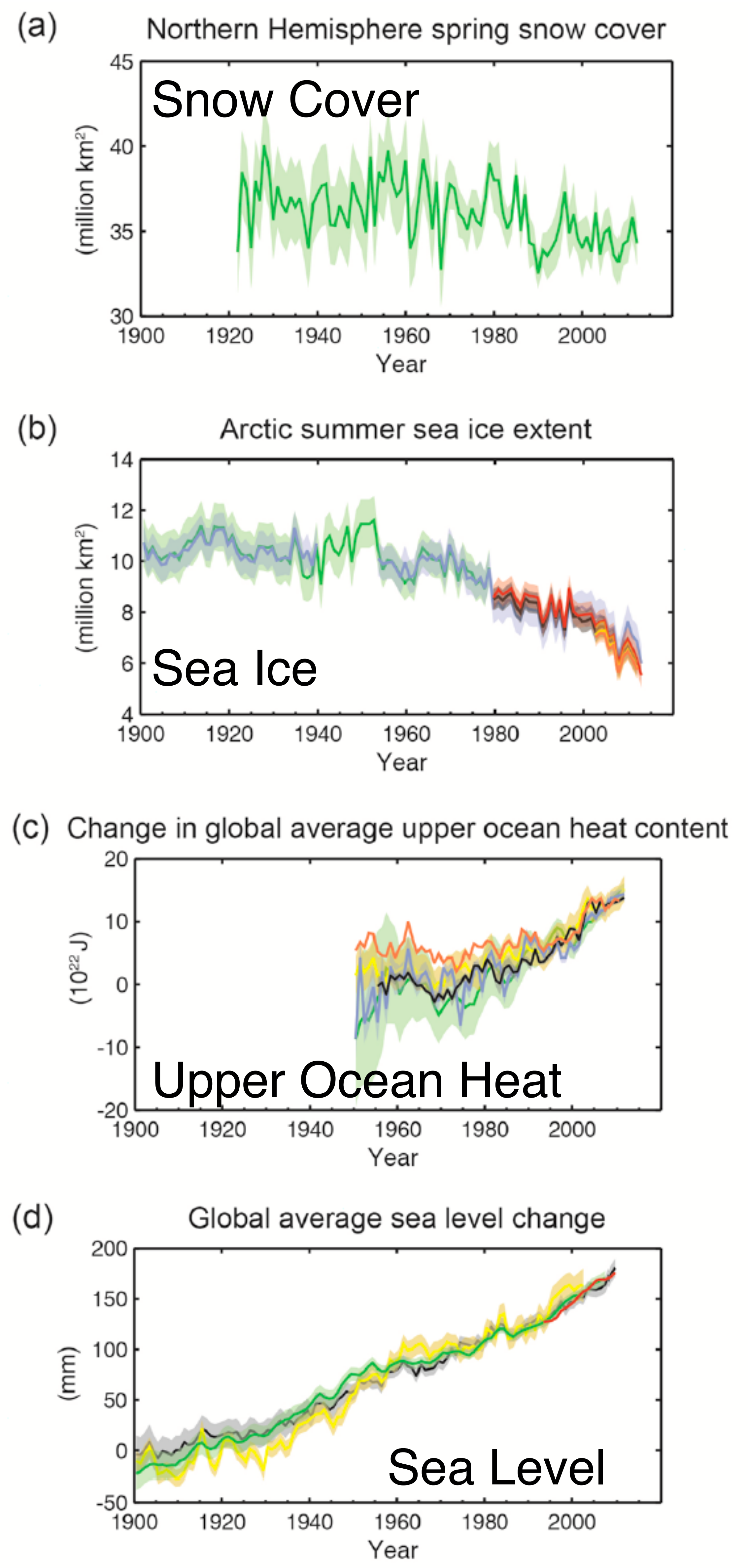
By Alex Fox | Jan. 14, 2019 , 3:30 PM

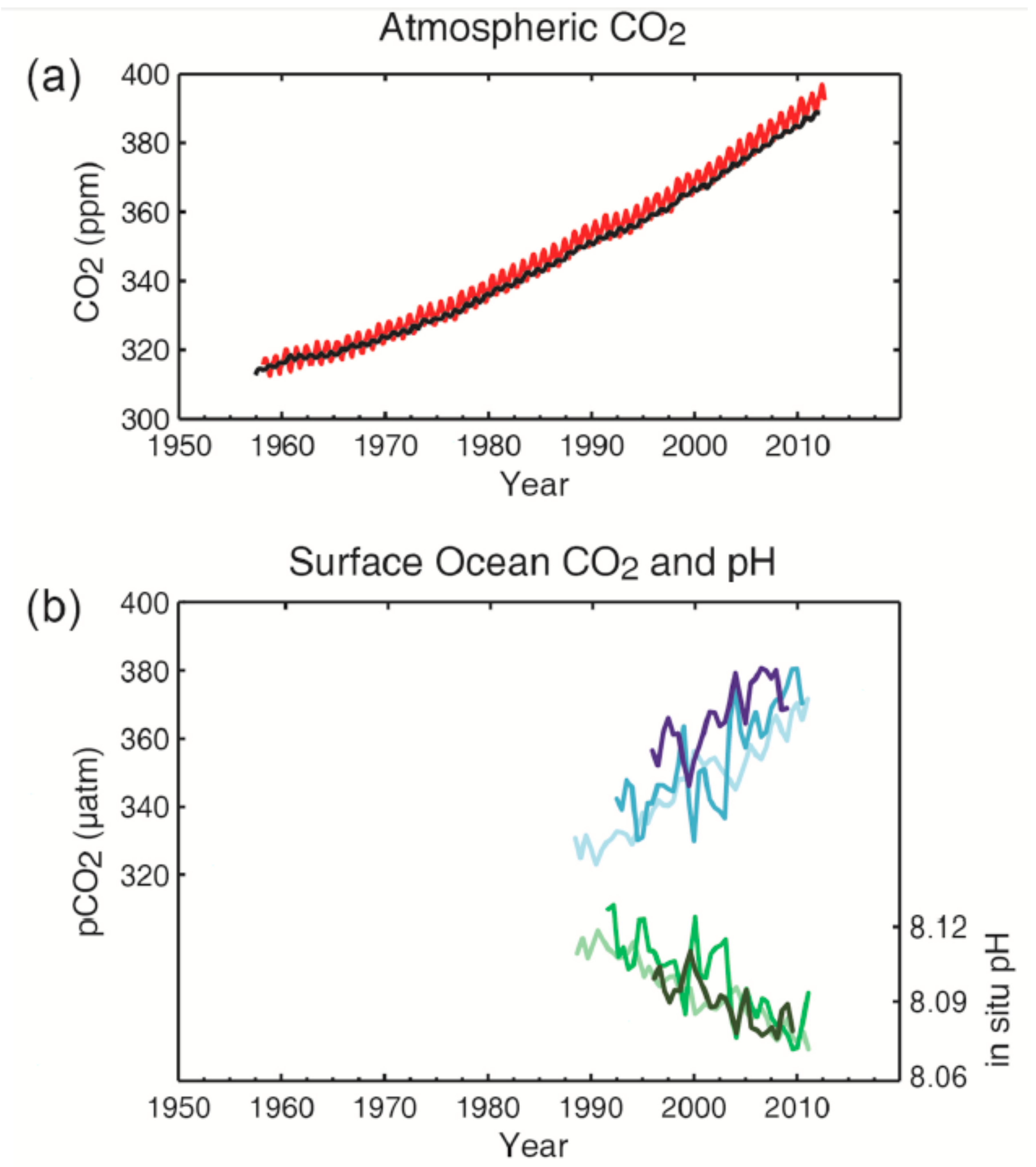
The Syndrome of Modern Global Change



The Syndrome of Modern Global Change

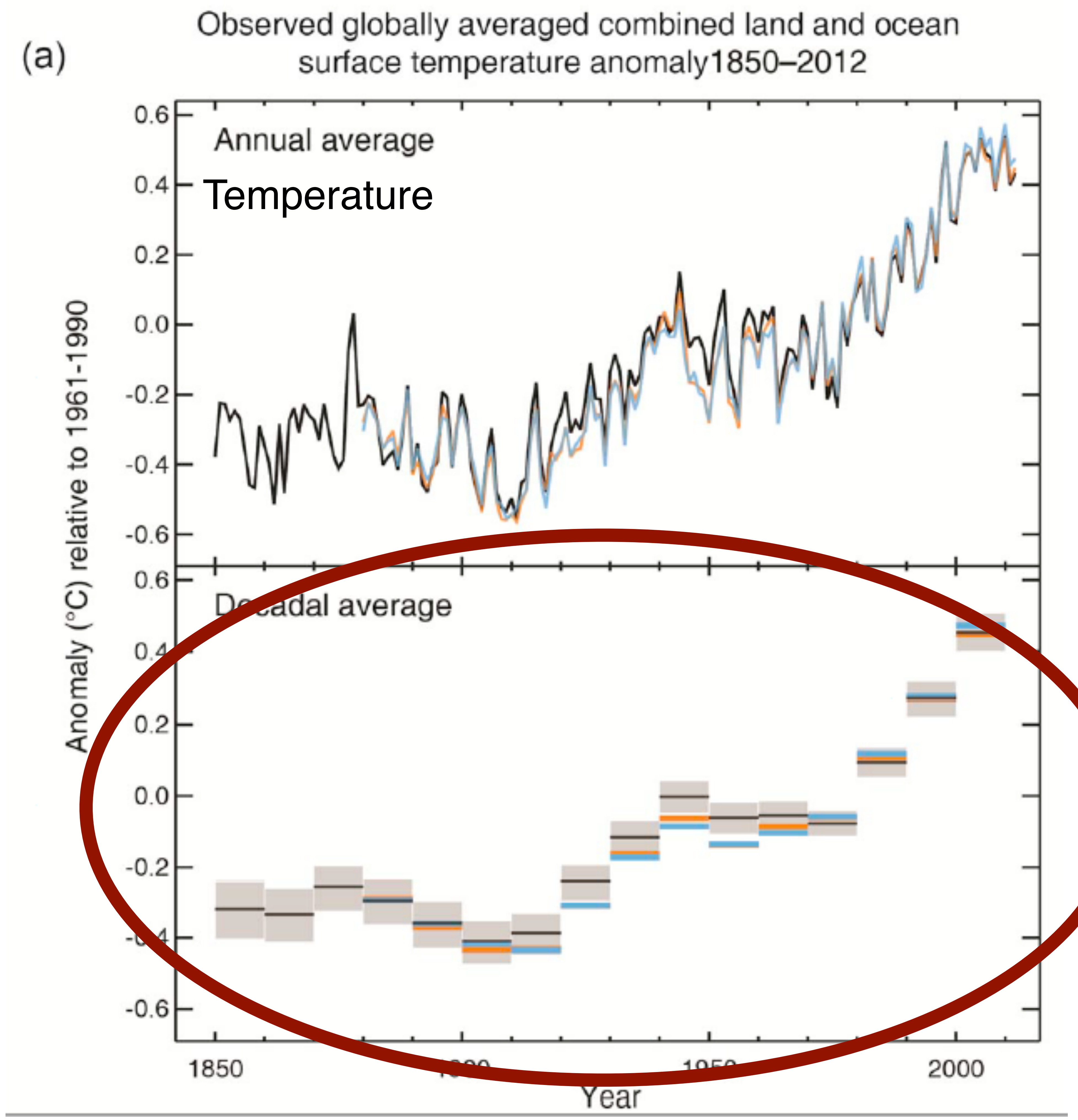


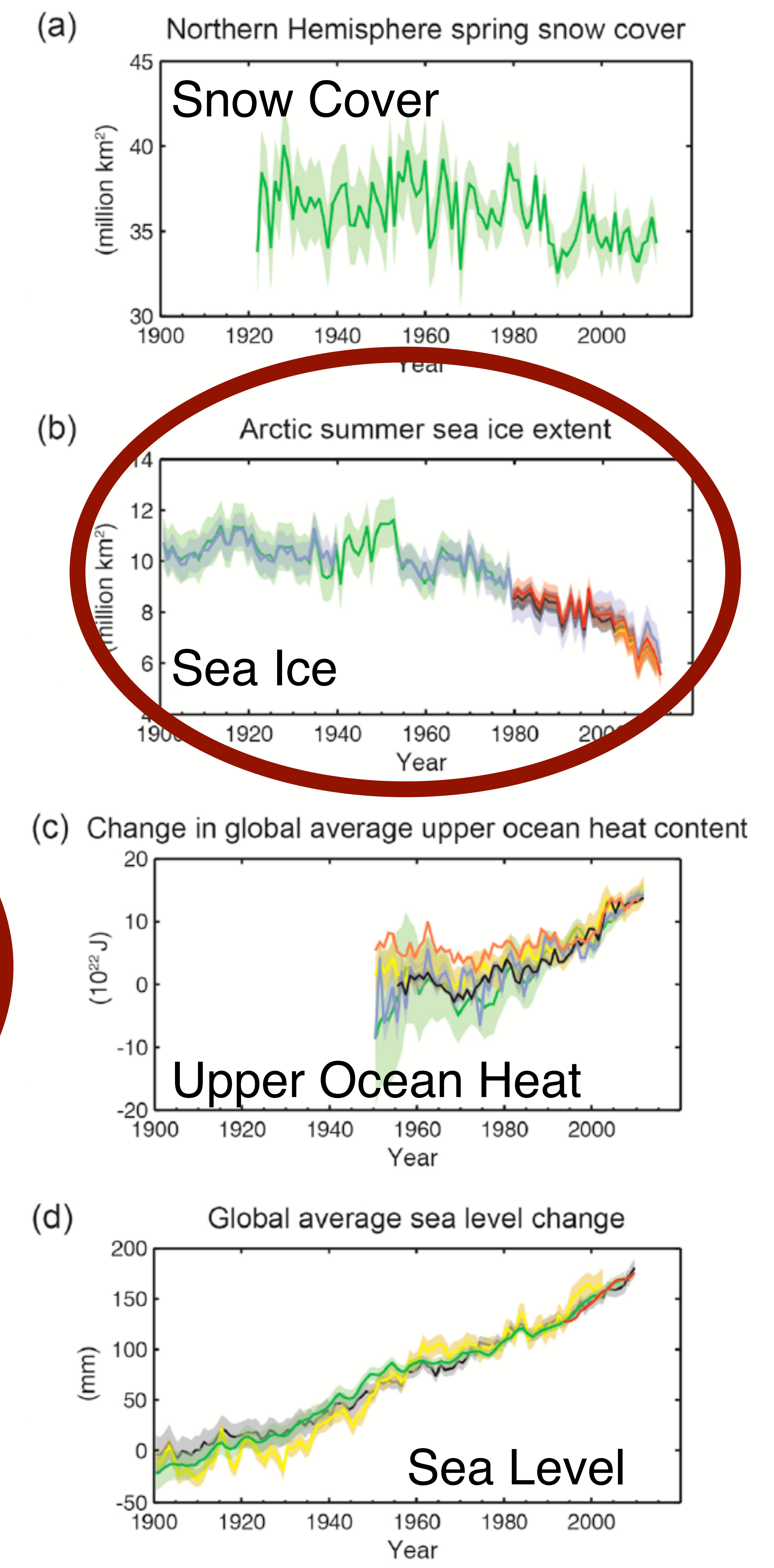


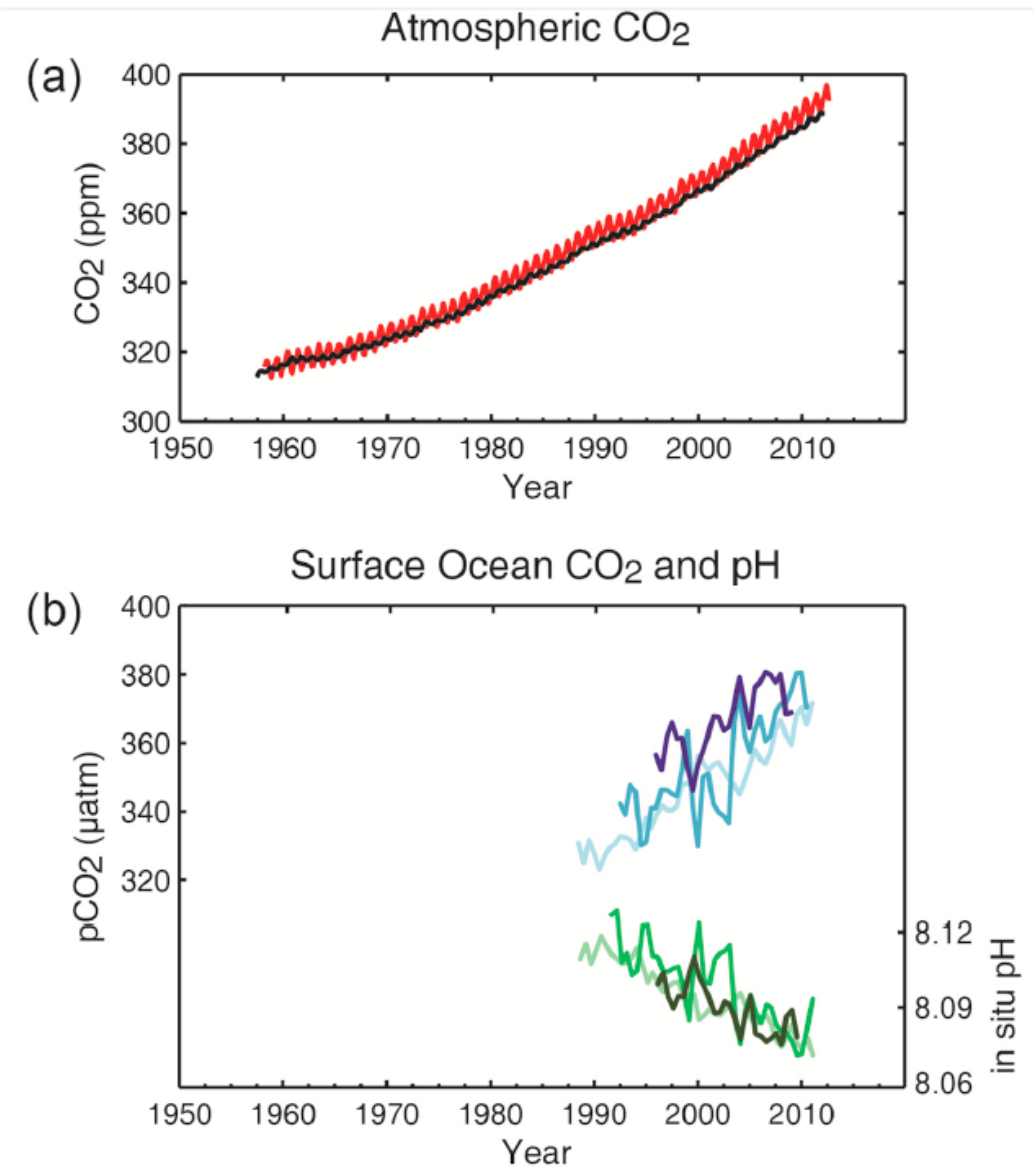


IPCC, 2013

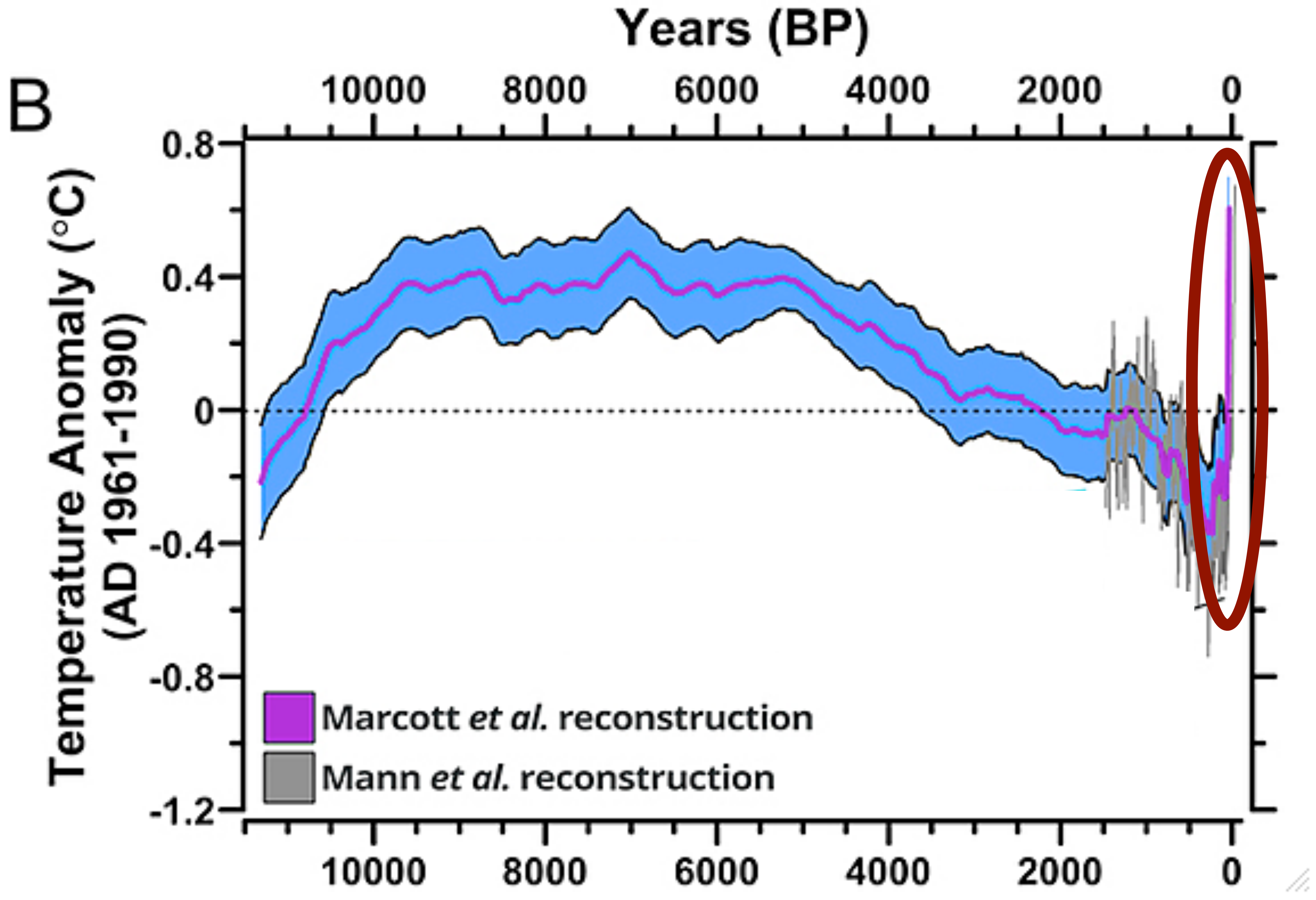
The Syndrome of Modern Global Change



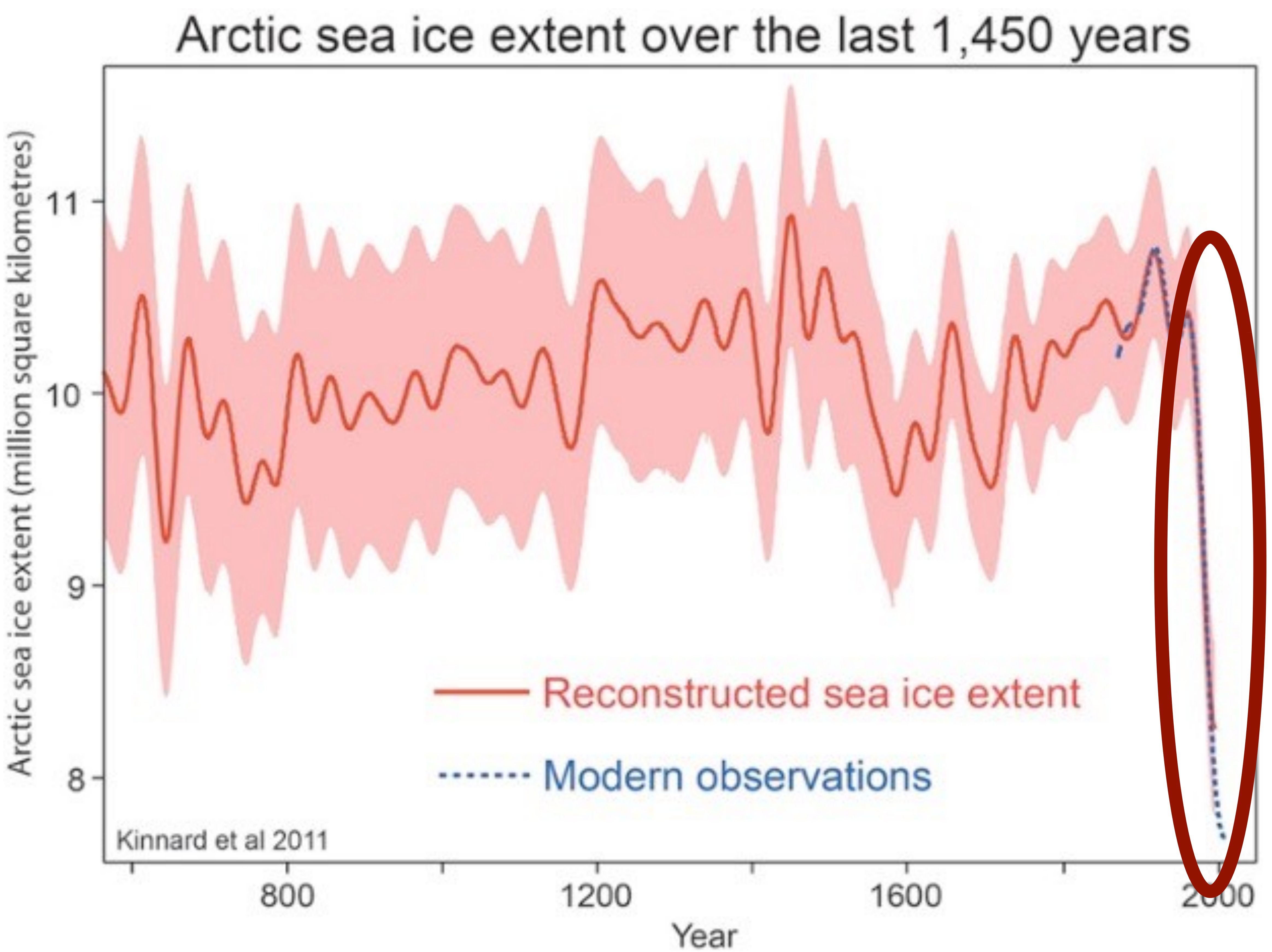




IPCC, 2013



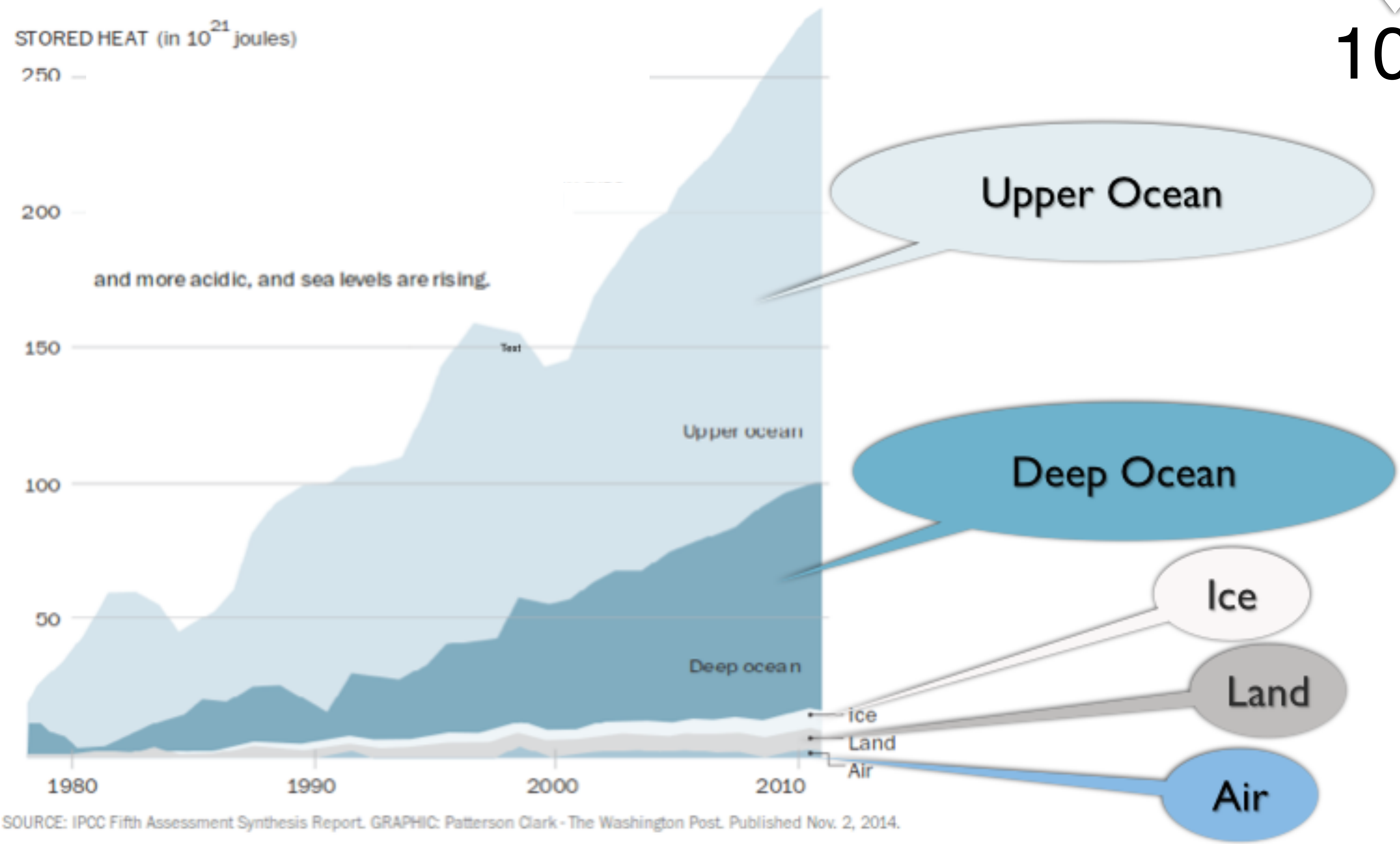
Marcott et al., 2013



Kinnart et al., 2011

Earth's Energy Imbalance

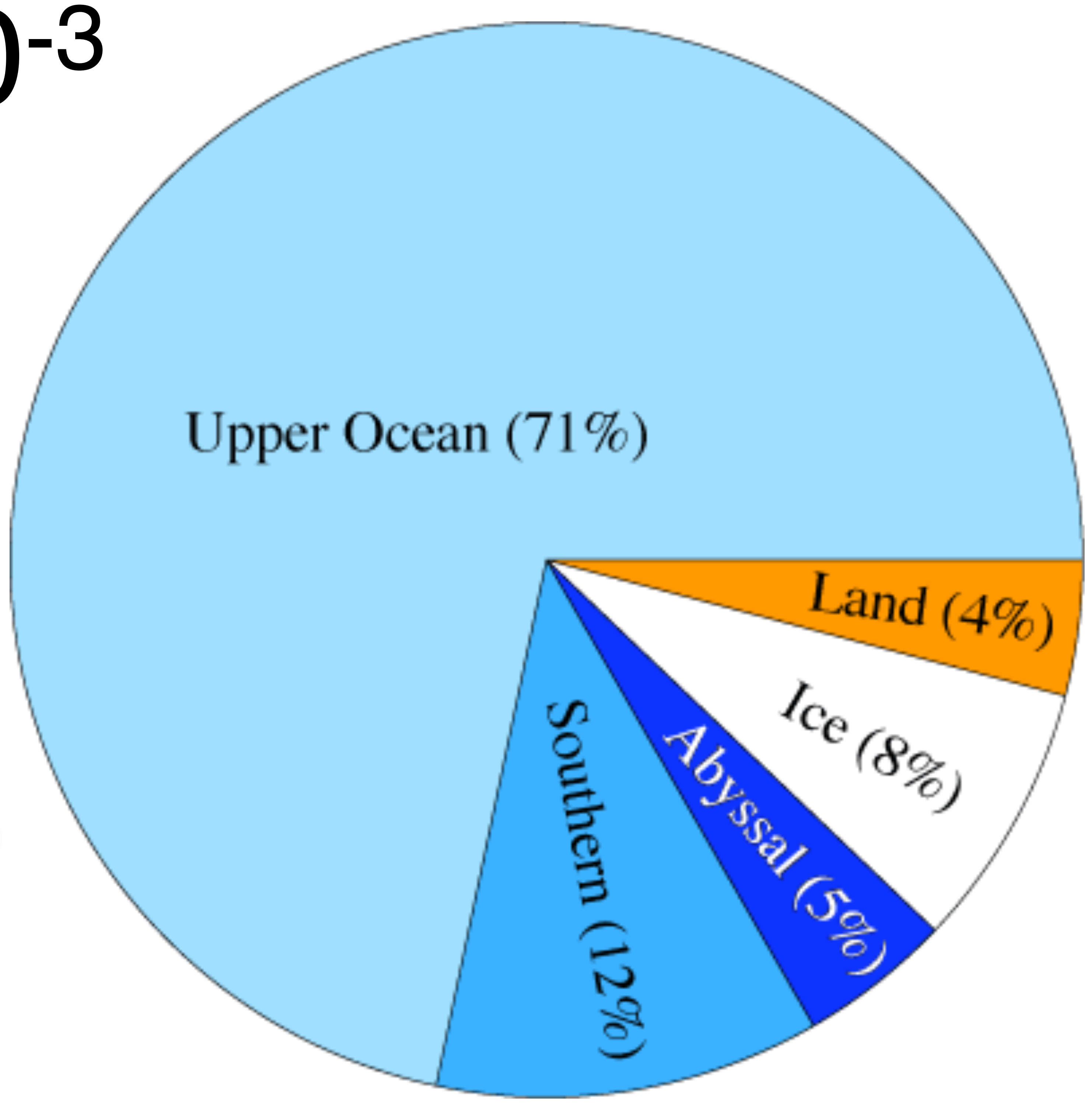
- Long-term due to photosynthesis: 10-100 MegaWatt
- Today: 300-320 TeraWatt



SOURCE: IPCC Fifth Assessment Synthesis Report. GRAPHIC: Patterson Clark - The Washington Post. Published Nov. 2, 2014.

10^{-10} to 10^{-9}

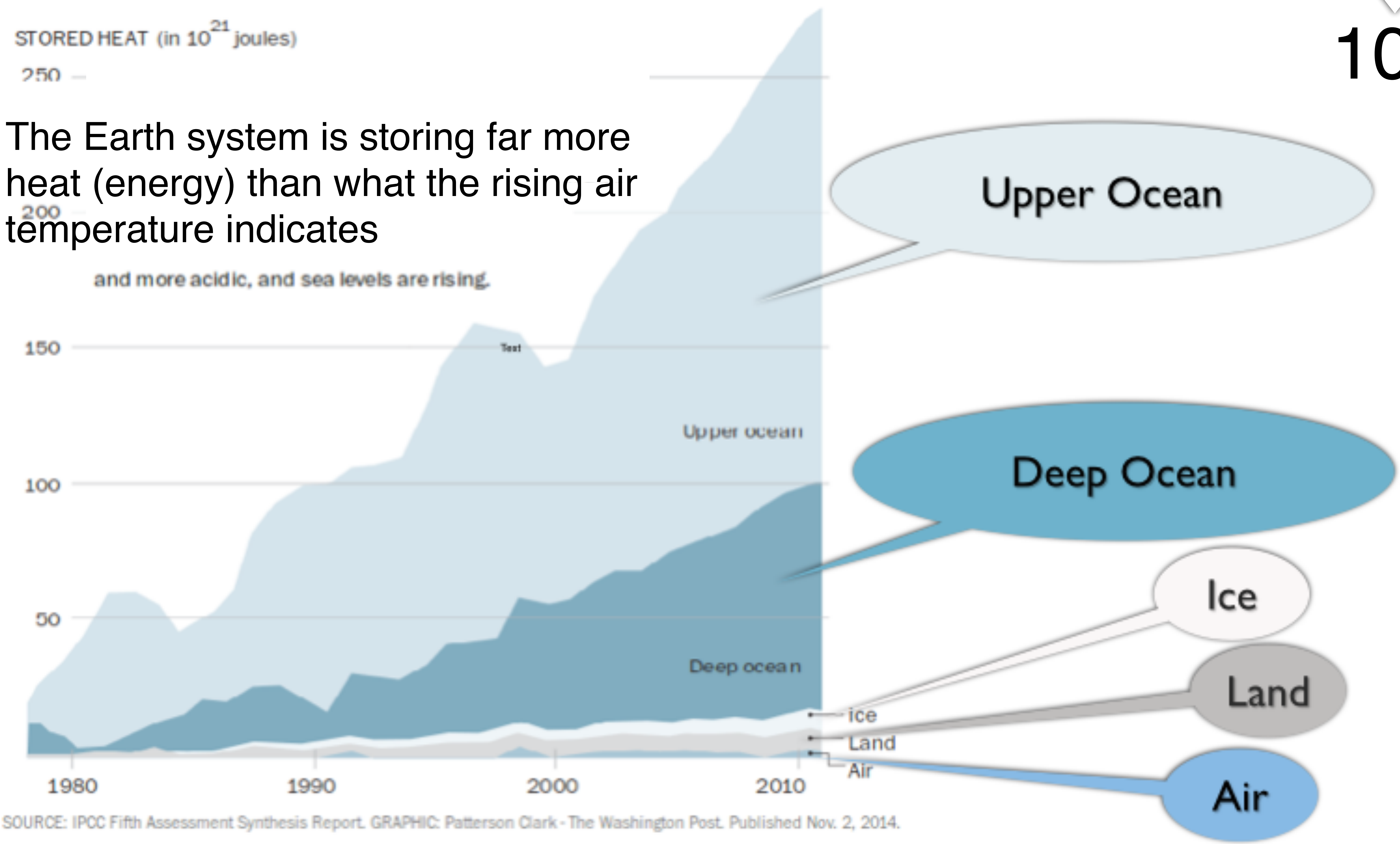
10^{-3}



Earth's Energy Imbalance

- Long-term due to photosynthesis: 10-100 MegaWatt
- Today: 300-320 TeraWatt

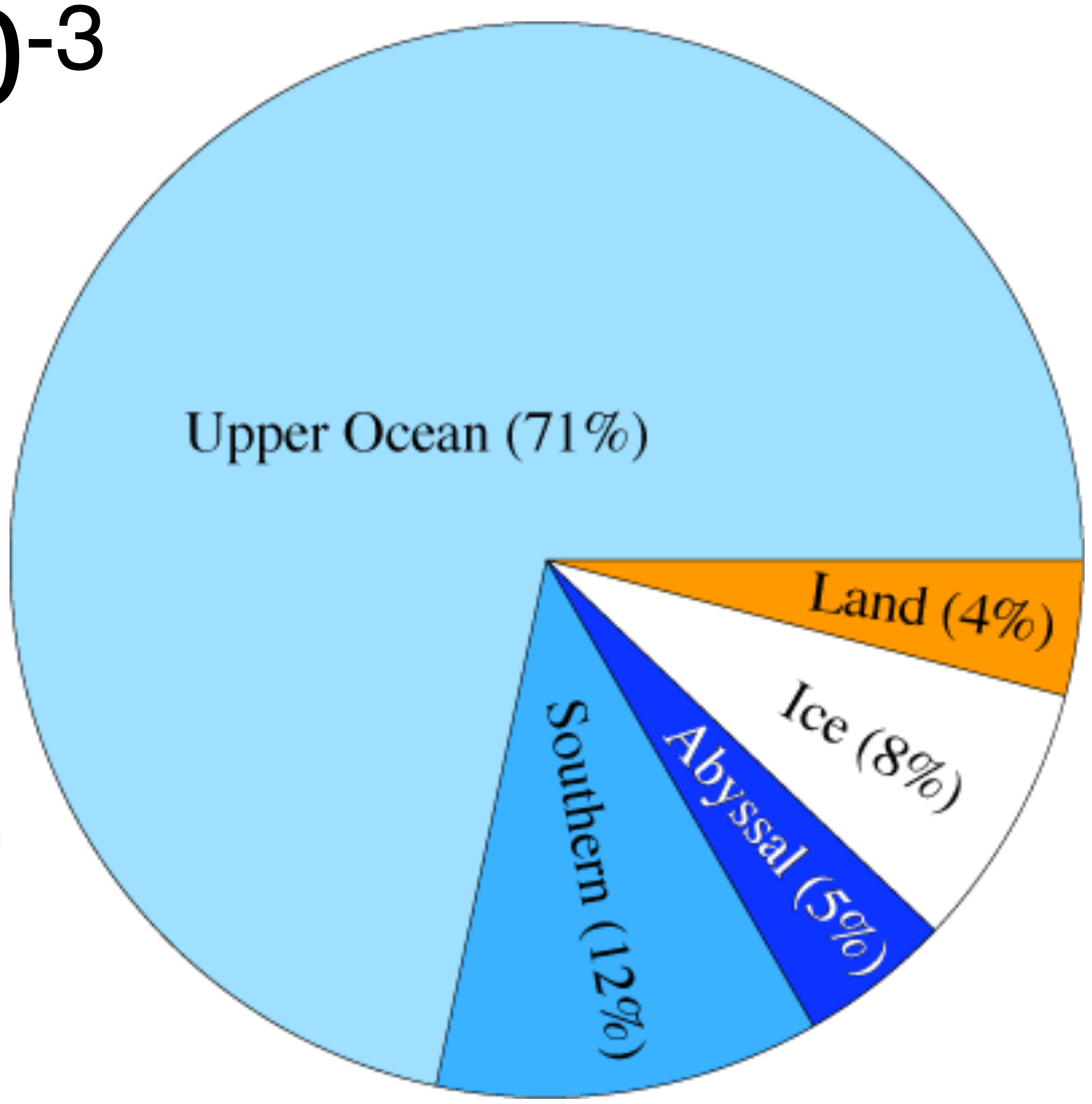
The Earth system is storing far more heat (energy) than what the rising air temperature indicates



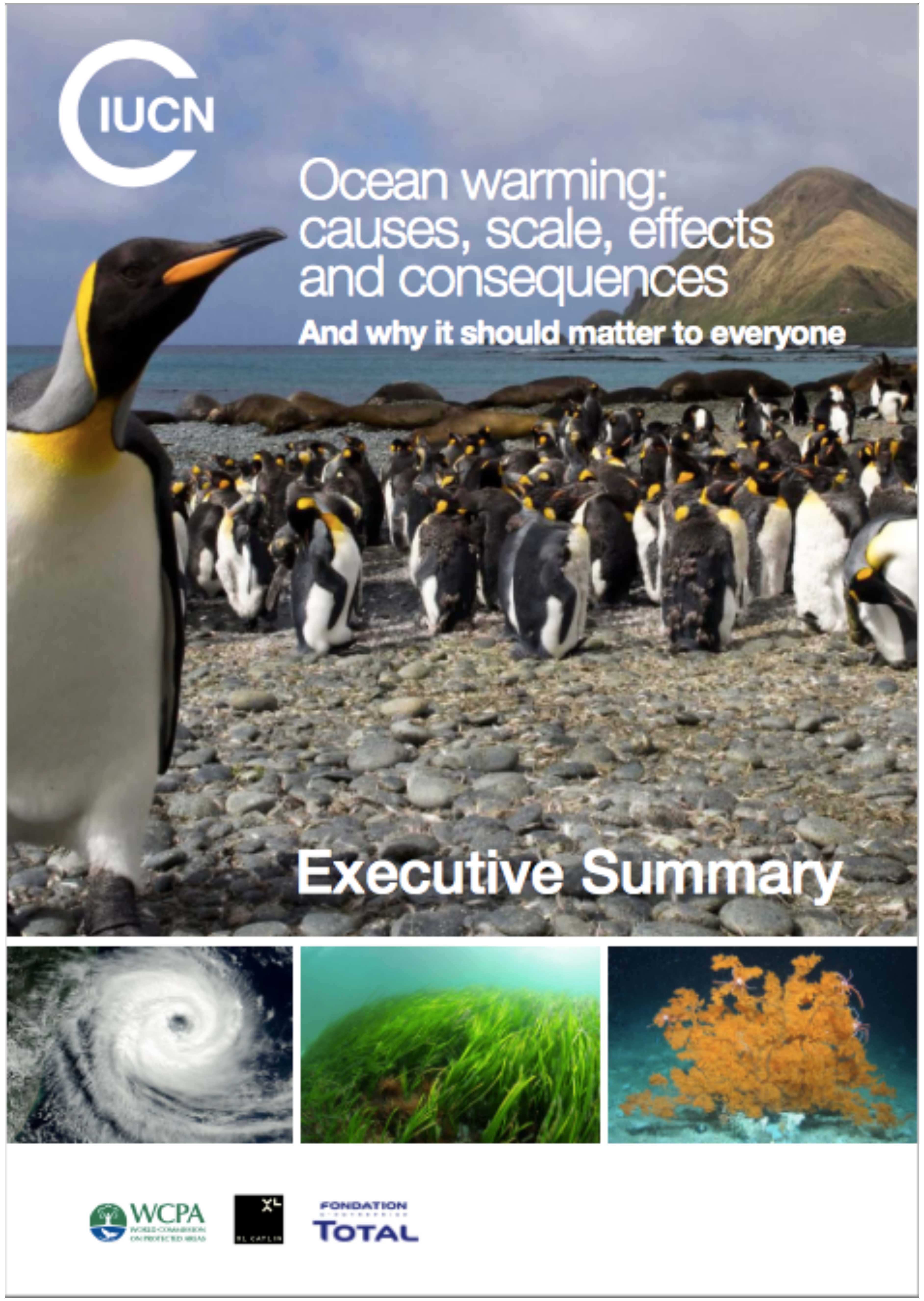
SOURCE: IPCC Fifth Assessment Synthesis Report. GRAPHIC: Patterson Clark - The Washington Post. Published Nov. 2, 2014.

10^{-10} to 10^{-9}

10^{-3}



The Pool-House Effect



The scale of ocean warming is truly staggering with the numbers so large that it is difficult for most people to comprehend. If the same amount of heat that has gone into the top 2000 m of the ocean between 1955-2010 had gone into the lower 10 km of the atmosphere, then the Earth would have seen a warming of 36°C.

IUCN, 2016

Key Points

Baseline

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

Syndrome

During the last few hundred years, humanity has introduced rapid and large changes

The system is outside the “normal range” and in the dynamic transition into the Post-Holocene; we have increasing disequilibrium

Key Points

<u>Baseline</u>

During the Hol

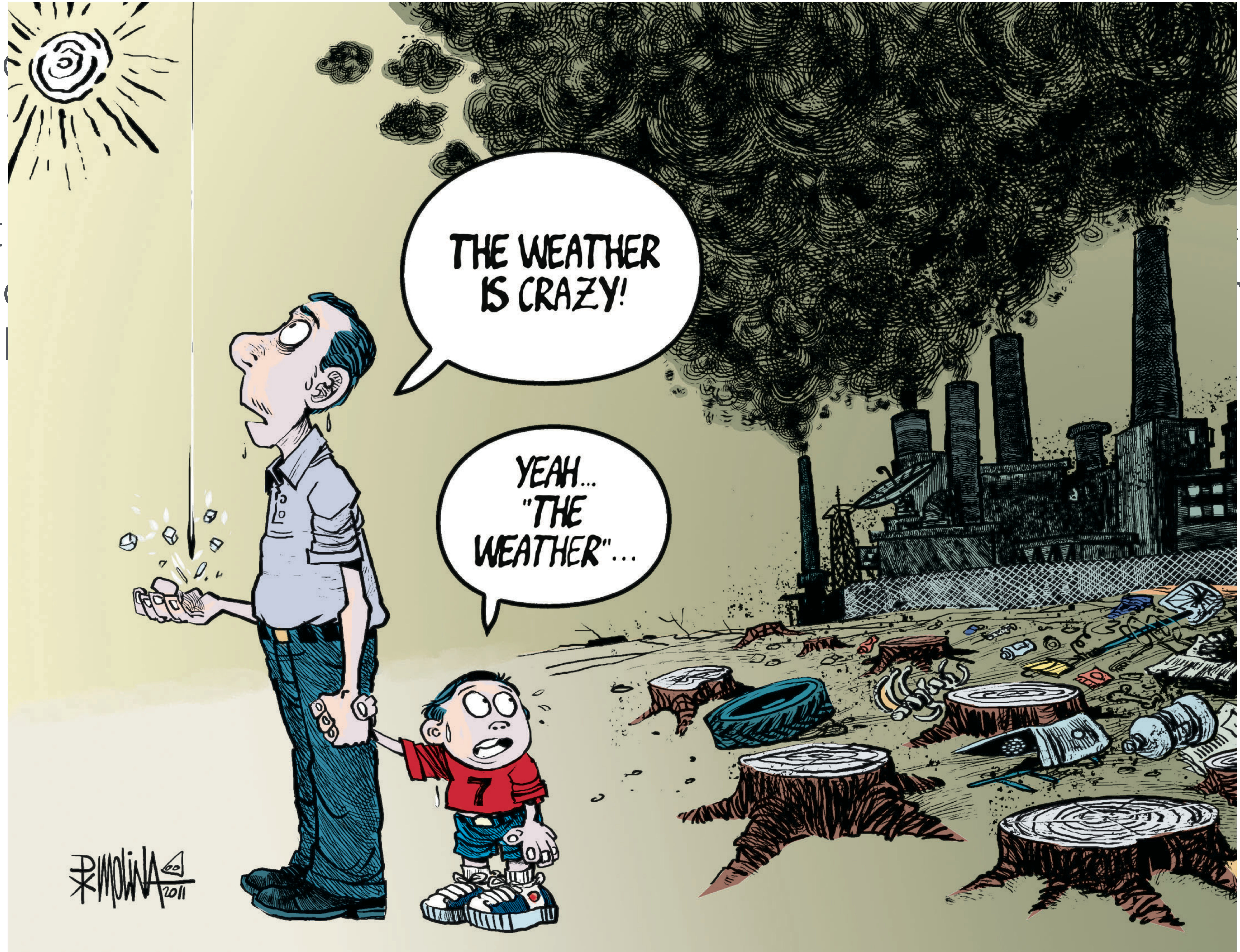
The Holocene

<u>Syndrome</u>

During the last   hanges

The system is   e Post-

Holocene; we l



Mitigation and Adaptation Studies

Class 3: The Syndrome of Modern Global Change: Baseline, Syndrome, Diagnosis

Contents:

- Baseline (continued)
- Syndrome
- Diagnosis
- *Prognosis*
- *Therapy*

Diagnosis

The Anthropocene Review

Home | Browse | Submit Paper | About | Subscribe

The Anthropocene equation

Owen Gaffney, Will Steffen

First Published February 10, 2017 | research-article

Abstract

The dominant external forces influencing the rate of change of the Earth System have been astronomical and geophysical during the planet's 4.5-billion-year existence. In the last six decades, anthropogenic forcings have driven exceptionally rapid rates of change in the Earth System. This new regime can be represented by an 'Anthropocene equation', where other forcings tend to zero, and the rate of change under human influence can be estimated. Reducing the risk of leaving the glacial–interglacial limit cycle of the late Quaternary for an uncertain future will require, in the first instance, the rate of change of the Earth System to become approximately zero.

Diagnosis

The Anthropocene Review

Home | Browse | Submit Paper | About | Subscribe

The Anthropocene equation

Owen Gaffney, Will Steffen

First Published February 10, 2017 | research-article

Abstract

The dominant external forces influencing the rate of change of the Earth
astronomical and geophysical during the planet's 4.5-billion-year existen
decades, anthropogenic forcings have driven exceptionally rapid rates o
System. This new regime can be represented by an 'Anthropocene equa
forcings tend to zero, and the rate of change under human influence can
the risk of leaving the glacial–interglacial limit cycle of the late Quaternar
will require, in the first instance, the rate of change of the Earth System t
zero

Humans causing climate to change 170 times faster than natural forces

Researchers behind 'Anthropocene equation' say impact of people's intense activity on Earth far exceeds that of natural events spread across millennia

Greenhouse gas emissions caused by humans over the past 45 years have increased the rate of temperature rise to 1.7 degrees celsius per century. Photograph: ISS/NASA

https://www.theguardian.com/environment/2017/feb/12/humans-causing-climate-to-change-170-times-faster-than-natural-forces?CMP=share_btn_tw

Diagnosis

Table 1. Rates of change of the Earth System.

	Holocene baseline rate of change	Current rate of change	Magnitude/scale of change	References
Earth System parameter-climate				
Atmospheric CO_2 concentration	~0.17 ppm/century decrease between c. 11k and 7k BP; ~0.30 ppm/century increase between c. 7k BP and 1750	166 ppm/century (average 1970–2015)	~550 times faster than Holocene baseline rate ~100 times faster than the most rapid rise during the last glacial termination. ~10 times faster than the maximum rate of carbon outgassing during the Paleocene-Eocene Thermal Maximum	Ciais et al. (2013) Wolff (2011) Zeebe et al. (2016)
Atmospheric CH_4 concentration	2 ppb/century	575 ppb/century (1984–2015 average)	~285 times faster than Holocene baseline rate. From 1750 to 2012 CH_4 increased by 150% from 722 ppb to 1810 ppb	http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/#global_data Saunois et al. (2016) Singarayer et al. (2011)
Global average surface temperature	−0.01°C/century	1.7°C/ century (average 1970–2015)	170 times faster than the Holocene baseline rate	Marcott et al. (2013) NOAA (2016)
Sea-level rise	~0 mm/yr from c. 3000 BP to pre-industrial	3.2±0.4 mm/yr (1993–2010)	Average global sea level is currently higher than at any other time within the past ~115,000 years	Church et al. (2013) IPCC (2013)
ES parameter-biosphere				
Extinction rate	0.1 extinctions per million species years	1–10 extinctions per million-species years	10–100 times background rate	Ceballos et al. (2015) De Vos et al. (2015)
Terrestrial biosphere modification	Up to 1700, ~50% of global ice-free land cover was wild; ~5% was intensively used	By 2000, only 25% was wild and 55% was intensively used by humans		Ellis et al. (2010)
Climate-triggered species range shifts	Small compared with range shift during Pleistocene –Holocene transition	Similar or greater than range shifts at beginning and end of the Pleistocene	Future range shifts may be ~10 times greater than during Pleistocene –Holocene transition	Diffenbaugh and Field (2013)
ES parameter-biogeochemical cycles				
Ocean acidity	~0 pH unit/year	−0.0014–0.0024 pH unit/year in surface waters	pH of seawater has decreased by ~0.1 since beginning of industrial era, equivalent to a 26% increase in H^+ ion concentration. Surface-ocean chemistry changes during the Anthropocene are projected to be three to seven times larger and 70 times faster than during a deglaciation. Current OA rate of change is highest in possibly 300 million years	Elsig et al. (2009) Hönisch et al. (2012) Rhein et al. (2013) Zeebe (2012)
N cycle	Biological nitrogen fixation on land: 58 Tg/yr, in the ocean: 140 Tg/hr, and fixation by lightning: 5 Tg/yr	~180 Tg N per year from industrial and intended biological fixation, and 30 Tg N per year from human combustion processes.	Humans now fix as much N as all natural processes combined. This is possibly the largest and most rapid change to the global N cycle in 2.5 billion years.	Fowler et al. (2013) Gruber and Galloway (2008)
P cycle	10–15 Tg P/yr input to soil (pre-industrial weathering)	28–33 Tg P/yr input to soil (from enhanced weather and mining of P for fertilizers)	Up to 3 times more P per year released to environment from human activities compared with Holocene baseline	Carpenter and Bennett (2011)
Sedimentary fluxes		~57,000 Tg/yr of sediments displaced by mineral extraction	Sediment displacement by mineral extraction nearly 3 times greater than global river sediment transport. Human processes have increased sediment flow by erosive processes and reduced sediment flow by dam building	Douglas and Lawson (2000) Steffen et al. (2007, 2015) Syvitski et al. (2009) Zalasiewicz et al. (2014b)

Notes: Current rates of change of key Earth System processes (climate, biosphere and biogeochemical cycles) relative to various time intervals in the geological and historical past. Ranges are included where significant uncertainty exists, for example, extinction rates.

Gaffney and Steffen, 2017

Diagnosis

Table 1. Rates of change of the Earth System.

	Holocene baseline rate of change	Current rate of change	Magnitude/scale of change	References
Earth System parameter-climate				
Atmospheric CO_2 concentration	~0.17 ppm/century decrease between c. 11k and 7k BP; ~0.30 ppm/century increase between c. 7k BP and 1750	166 ppm/century (average 1970–2015)	~550 times faster than Holocene baseline rate ~100 times faster than the most rapid rise during the last glacial termination. ~10 times faster than the maximum rate of carbon outgassing during the Paleocene-Eocene Thermal Maximum	Ciais et al. (2013) Wolff (2011) Zeebe et al. (2016)
Atmospheric CH_4 concentration	2 ppb/century	575 ppb/century (1984–2015 average)	~285 times faster than Holocene baseline rate. From 1750 to 2012 CH_4 increased by 150% from 722 ppb to 1810 ppb	http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/#global_data Saunois et al. (2016) Singarayer et al. (2011)
Global average surface temperature	−0.01°C/century	1.7°C/ century (average 1970–2015)	170 times faster than the Holocene baseline rate	Marcott et al. (2013) NOAA (201…
Sea-level rise	~0 mm/yr from c. 3000 BP to pre-industrial	3.2±0.4 mm/yr (1993–201…	Average global sea level is currently higher than at any other time within the past ~115,000 years	C…
ES parameter-biosphere				
Extinction rate	0.1 extinctions per million species years	1–10 extinctions per million-species years	10–100 times background rate	
Terrestrial biosphere modification	Up to 1700, ~50% of global ice-free land cover was wild; ~5% was intensively used	By 2000, only 25% was wild and 55% was intensively used by humans		
Climate-triggered species range shifts	Small compared with range shift during Pleistocene –Holocene transition	Similar or greater than range shifts at beginning and end of the Pleistocene	Future range shifts may be ~10 times greater than Pleistocene –Holocene transition	
ES parameter-biogeochemical cycles				
Ocean acidity	~0 pH unit/year	−0.0014–0.0024 pH unit/year in surface waters	pH of seawater has decreased by ~0.1 since beginning of industrial era, equivalent to a 26% increase in H^+ ion concentration. Surface-ocean chemistry changes during the Anthropo… times larger	Rhein et al… Zeebe (2012)
N cycle	Biological nitrogen fixation on land: 58 Tg/yr, in the ocean: 140 Tg/hr, and fixation by lightning… 5 Tg/yr			
P cycle	10–15 Tg P/yr input to soil (pre-industrial weathering)	… mining…		
Sedimentary fluxes		~57,000 Tg/yr o… displaced by mineral extraction	… have increased sediment flow by erosive processes and reduced sediment flow by dam building	…and Lawson (2000) Steffen et al. (2007, 2015) Syvitski et al. (2009) Zalasiewicz et al. (2014b)

Notes: Current rates of change of key Earth System processes (climate, biosphere and biogeochemical cycles) relative to various time intervals in the geological and historical past. Ranges are included where significant uncertainty exists, for example, extinction rates.

Current rate of change

Global average surface temperature: ~1.7°C/century

Holocene baseline rate of change

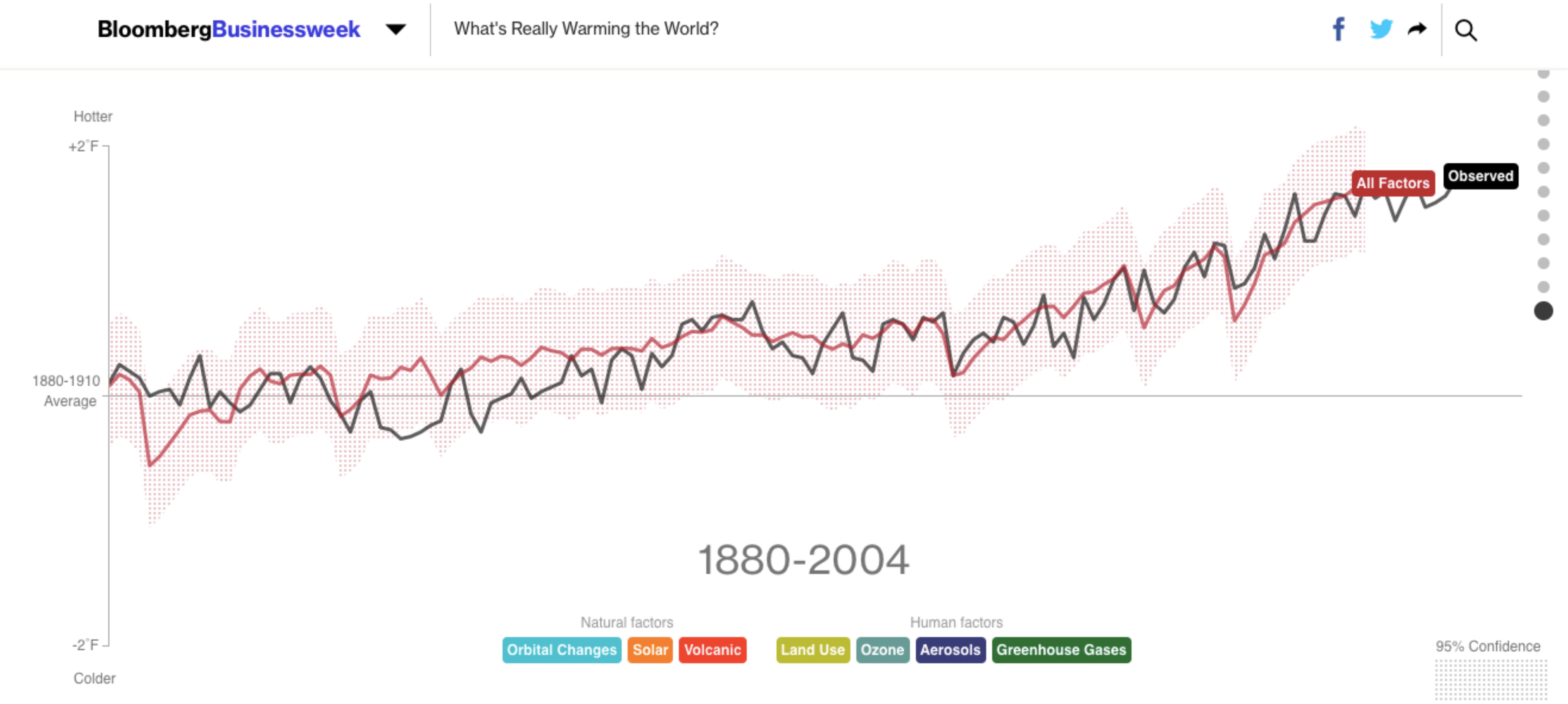
Global average surface temperature: ~0.01°C/century

Gaffney and Steffen, 2017

Diagnosis

Compare and Contrast

Putting the possible natural and human causes of climate change alongside one another makes the dominant role of greenhouse gases even more plainly visible. The only real question is: What are we going to do about it?



Diagnosis

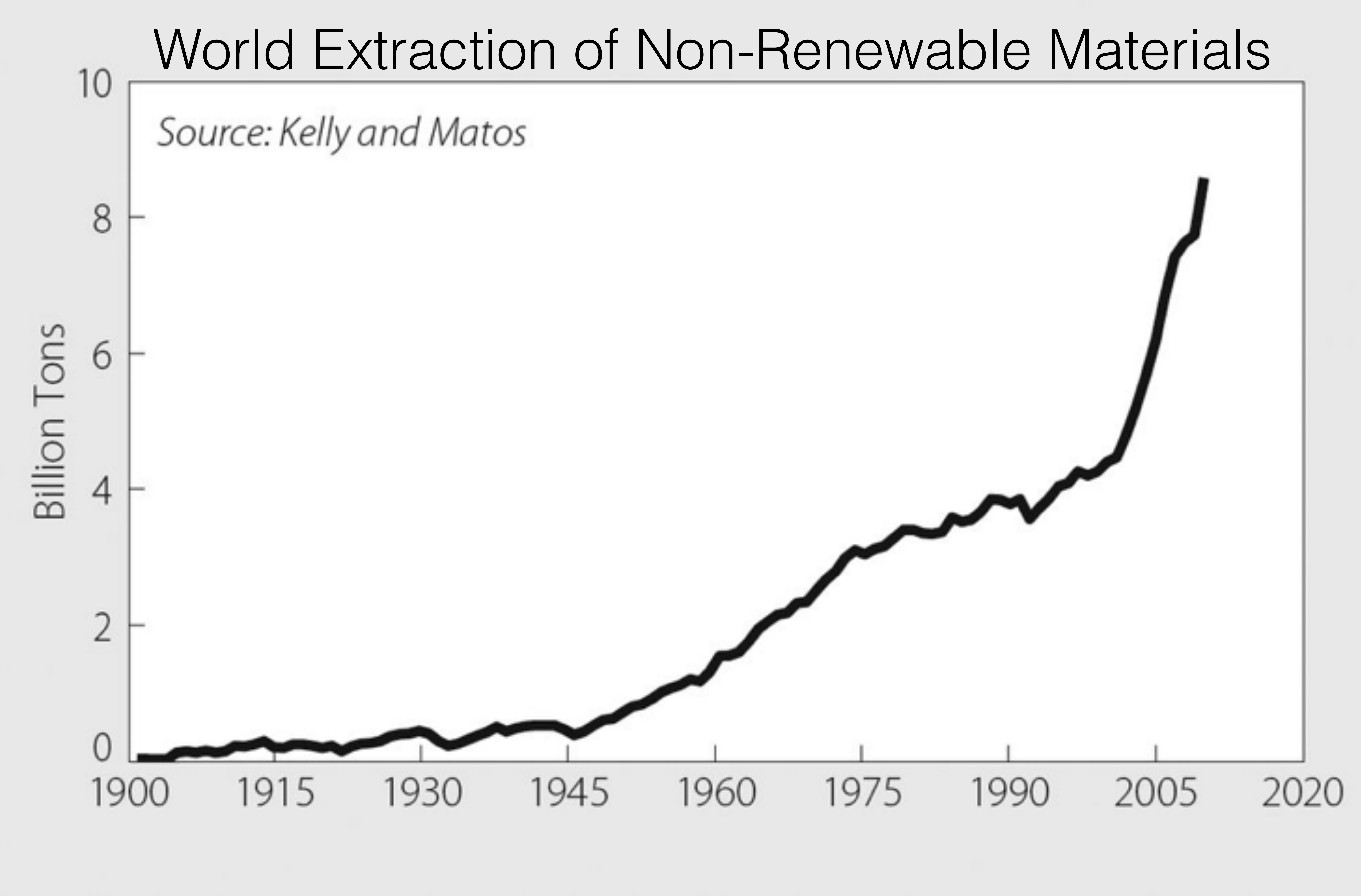
Compare and Contrast

Putting the possible natural and human causes of climate change alongside one another makes the dominant role of greenhouse gases even more plainly visible. The only real question is: What are we going to do about it?

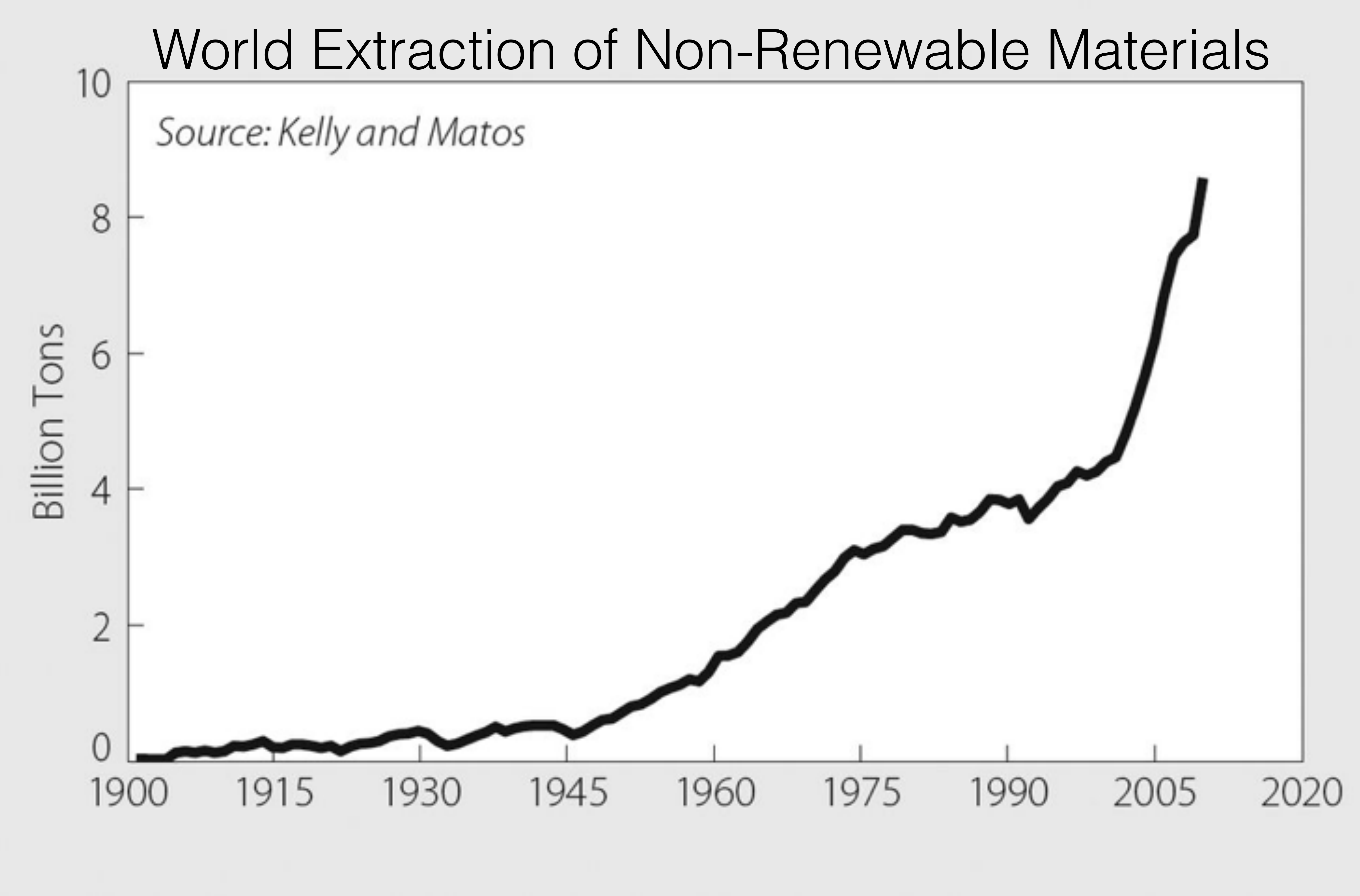
Diagnosis

Role of Economy

Role of Economy



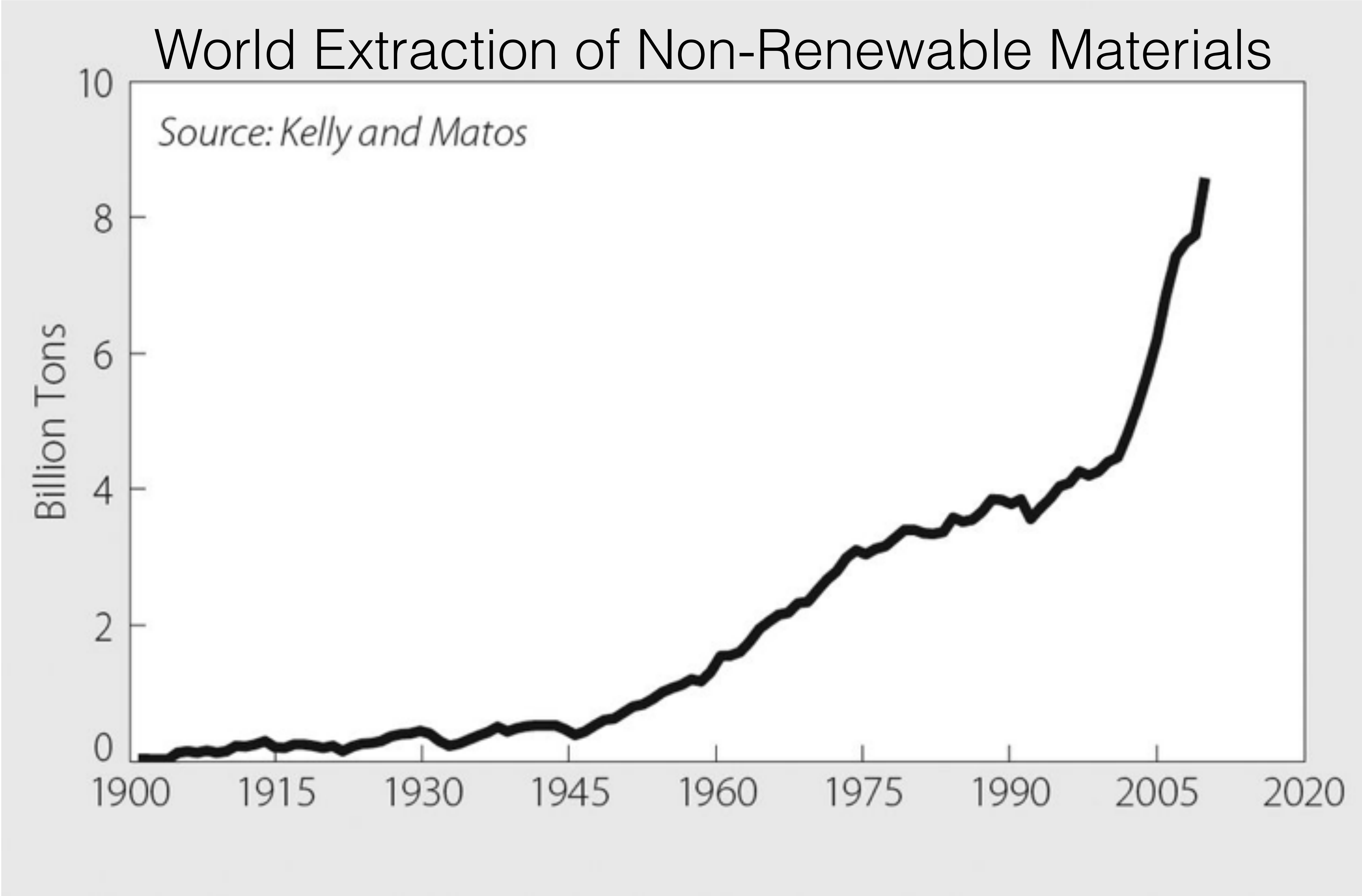
Role of Economy



In 2008, people around the world used 68 billion tons of materials, including metals and minerals, fossil fuels, and biomass. That is an average of 10 tons per person— or 27 kilograms each and every day. That same year, humanity used the biocapacity of 1.5 planets, consuming far beyond what the Earth can sustainably provide.

Assadourian, 2013

Role of Economy

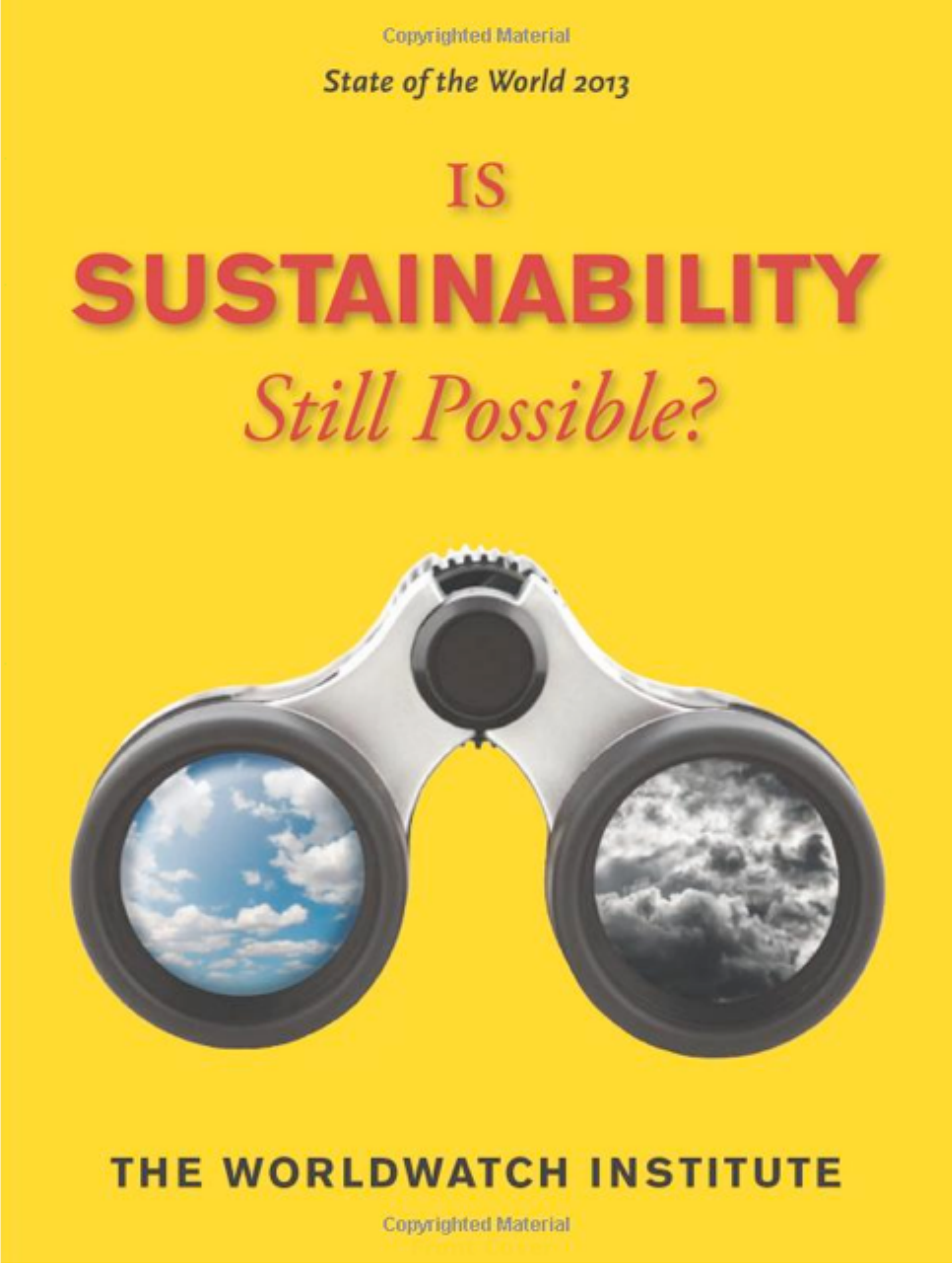


In 2008, people around the world used 68 billion tons of materials, including metals and minerals, fossil fuels, and biomass. That is an average of 10 tons per person— or 27 kilograms each and every day. That same year, humanity used the biocapacity of 1.5 planets, consuming far beyond what the Earth can sustainably provide.

Assadourian, 2013

The urban population in the developing world will double by 2030. The implications are staggering. One is that we have 20 years to build as much urban housing as was built in the past 6,000.
Reinhard Goethert, School of Architecture and Planning, MIT, 2010.

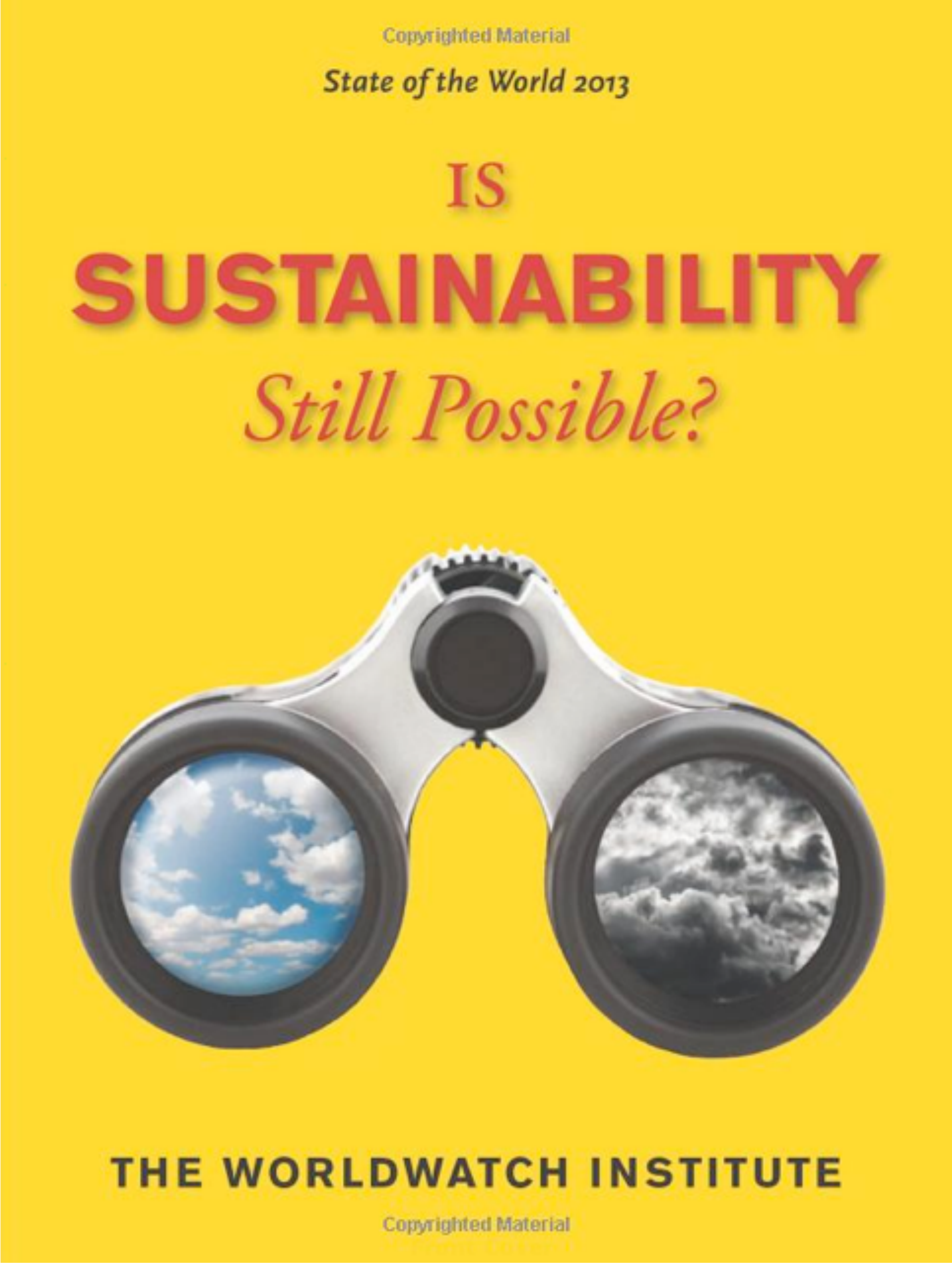
Role of Economy



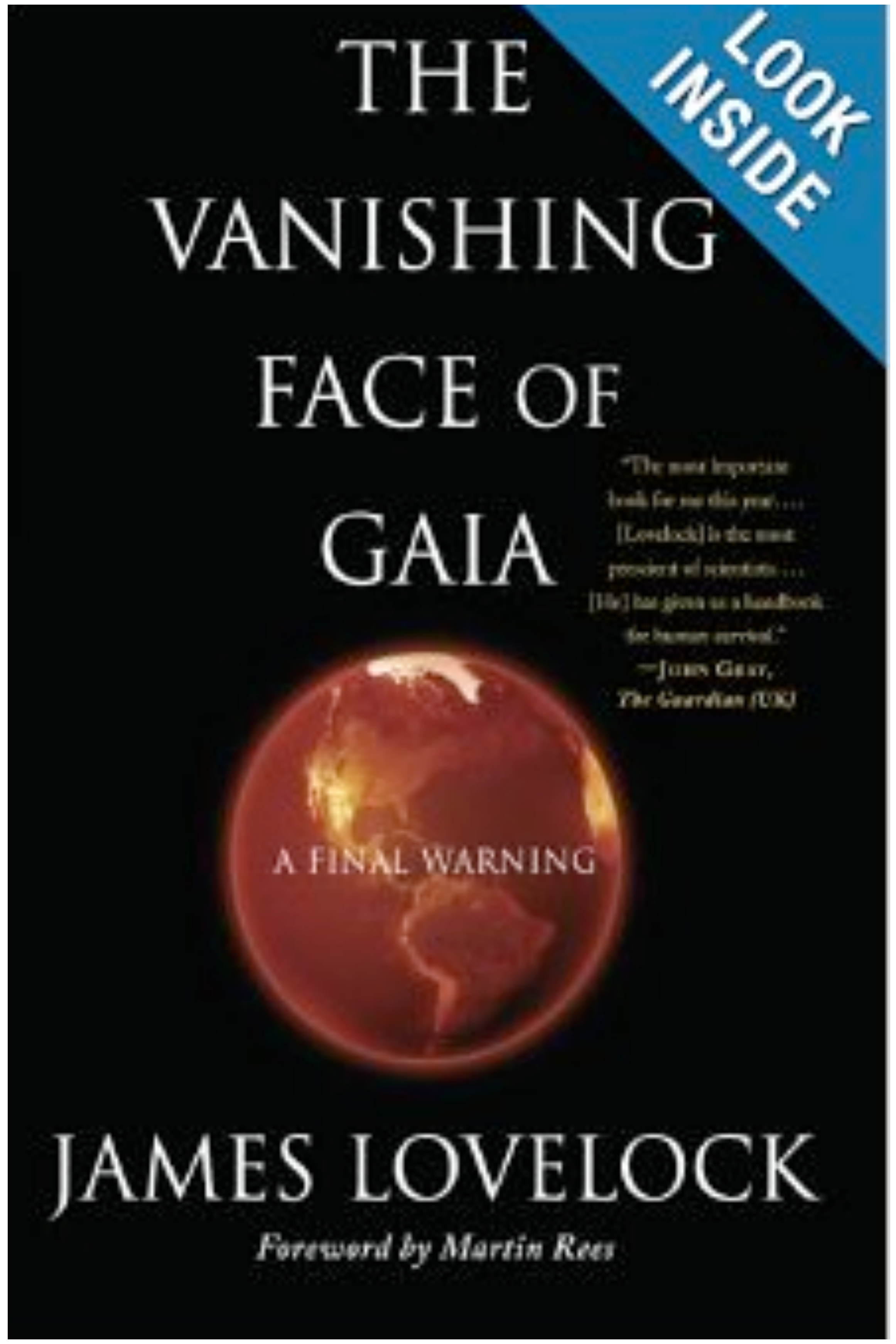
If Ecological Footprint calculations are even roughly accurate, humanity is currently consuming the ecological capacity of 1.5 Earths. That suggests that no more than 4.7 billion people could live within the planet's ecological boundaries without substantially reducing average individual consumption.

Diagnosis

Role of Economy



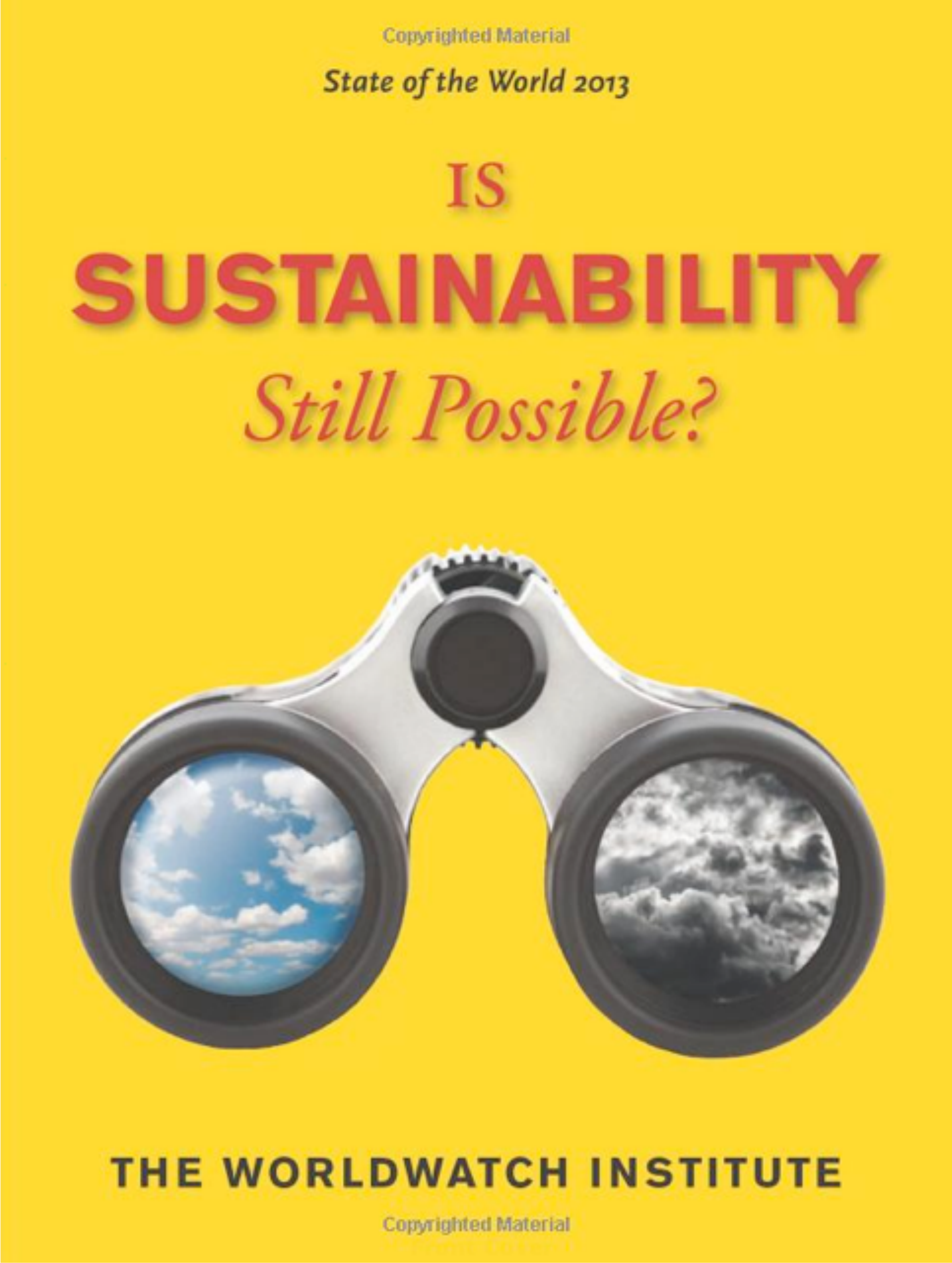
If Ecological Footprint calculations are even roughly accurate, humanity is currently consuming the ecological capacity of 1.5 Earths. That suggests that no more than 4.7 billion people could live within the planet's ecological boundaries without substantially reducing average individual consumption.



Lovelock (and many others):

- Planet is on a run-away path; could reach a warm state (5^{o}C warmer) already in 2050
- Carrying capacity of the planet would be reduced to 1 Billion
- Recommendation: look for the lifeboats

Role of Economy

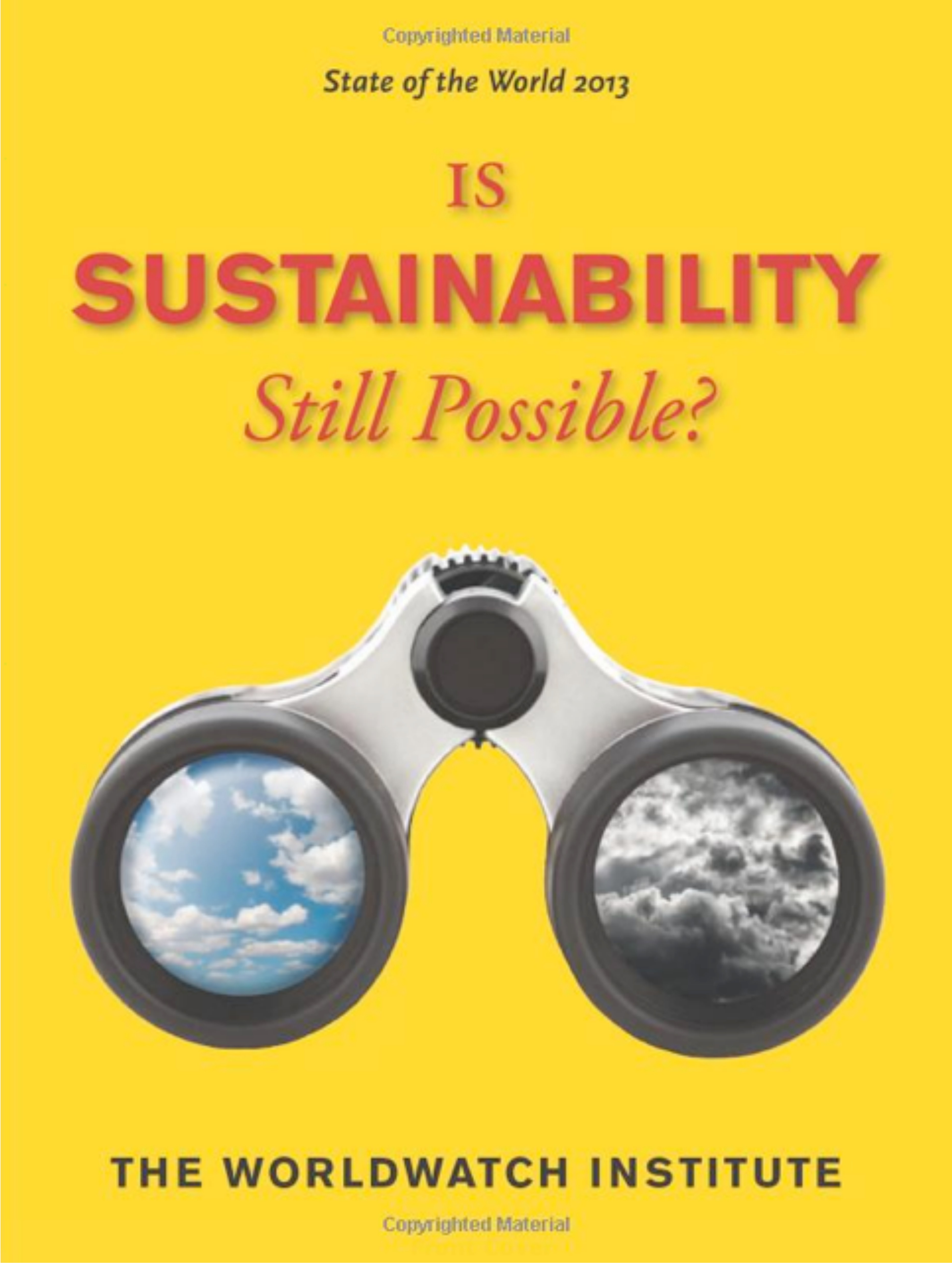


If Ecological Footprint calculations are even roughly accurate, humanity is currently consuming the ecological capacity of 1.5 Earths. That suggests that no more than 4.7 billion people could live within the planet's ecological boundaries without substantially reducing average individual consumption.

Engelman, 2013

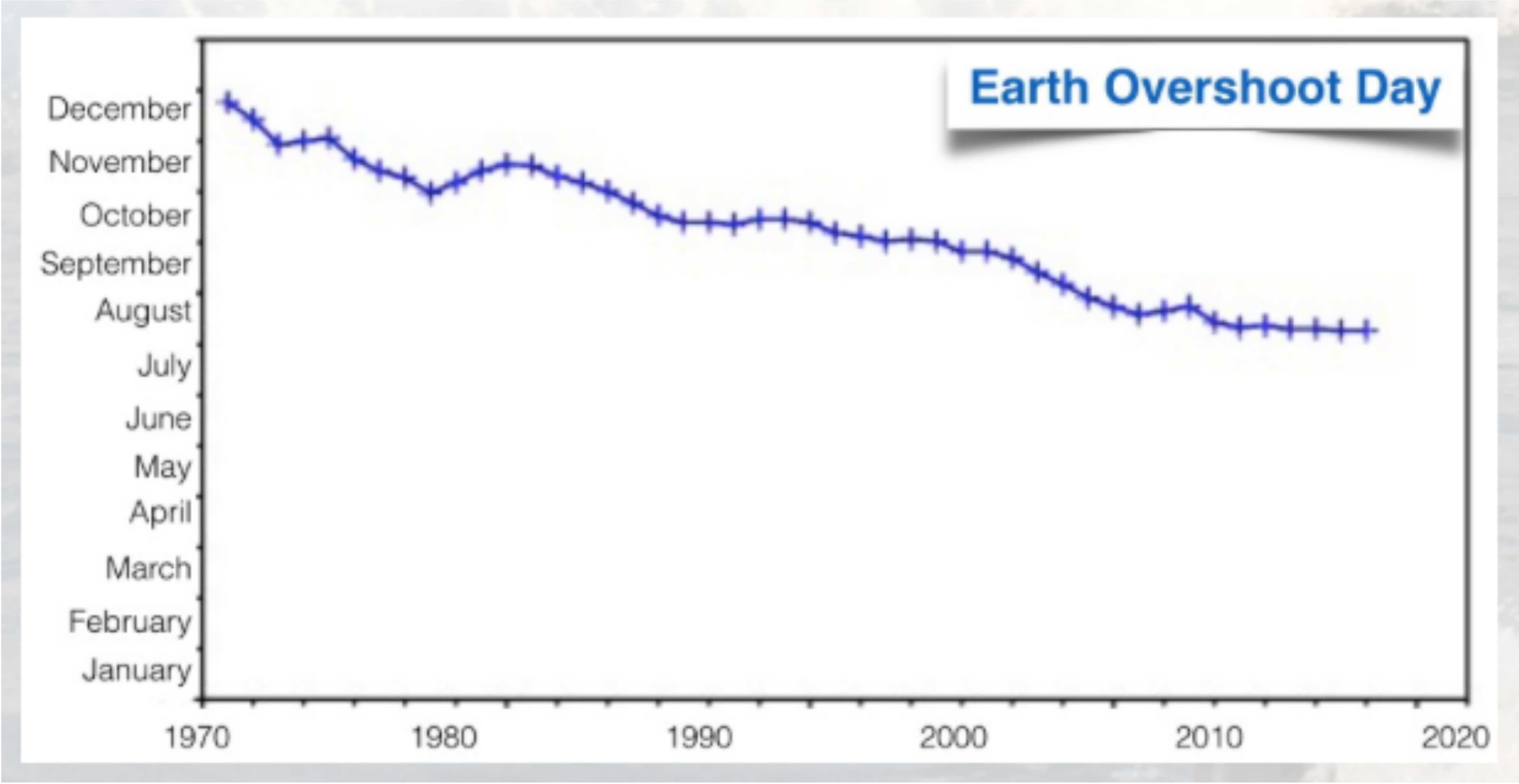
Diagnosis

Role of Economy

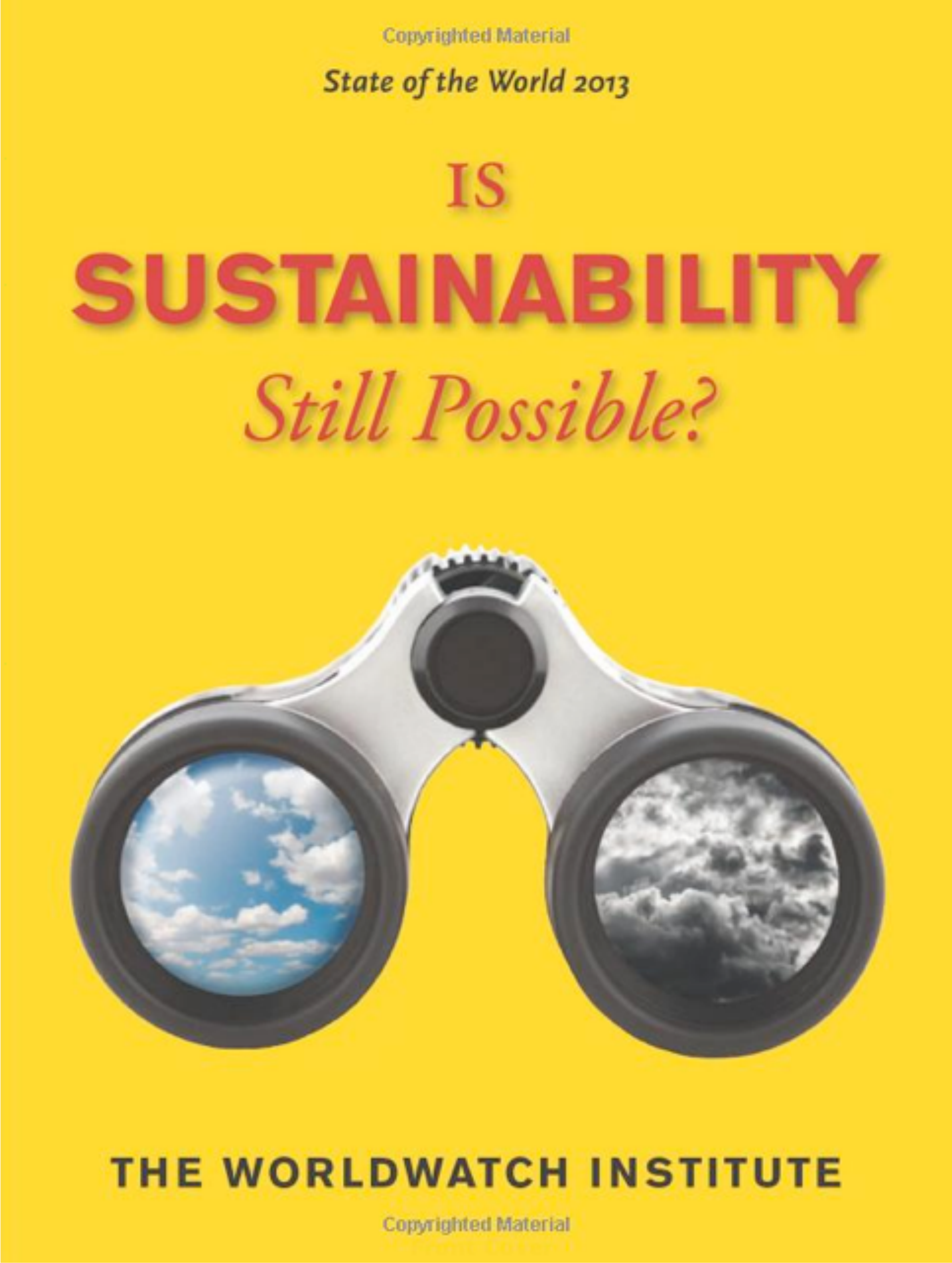


If Ecological Footprint calculations are even roughly accurate, humanity is currently consuming the ecological capacity of 1.5 Earths. That suggests that no more than 4.7 billion people could live within the planet's ecological boundaries without substantially reducing average individual consumption.

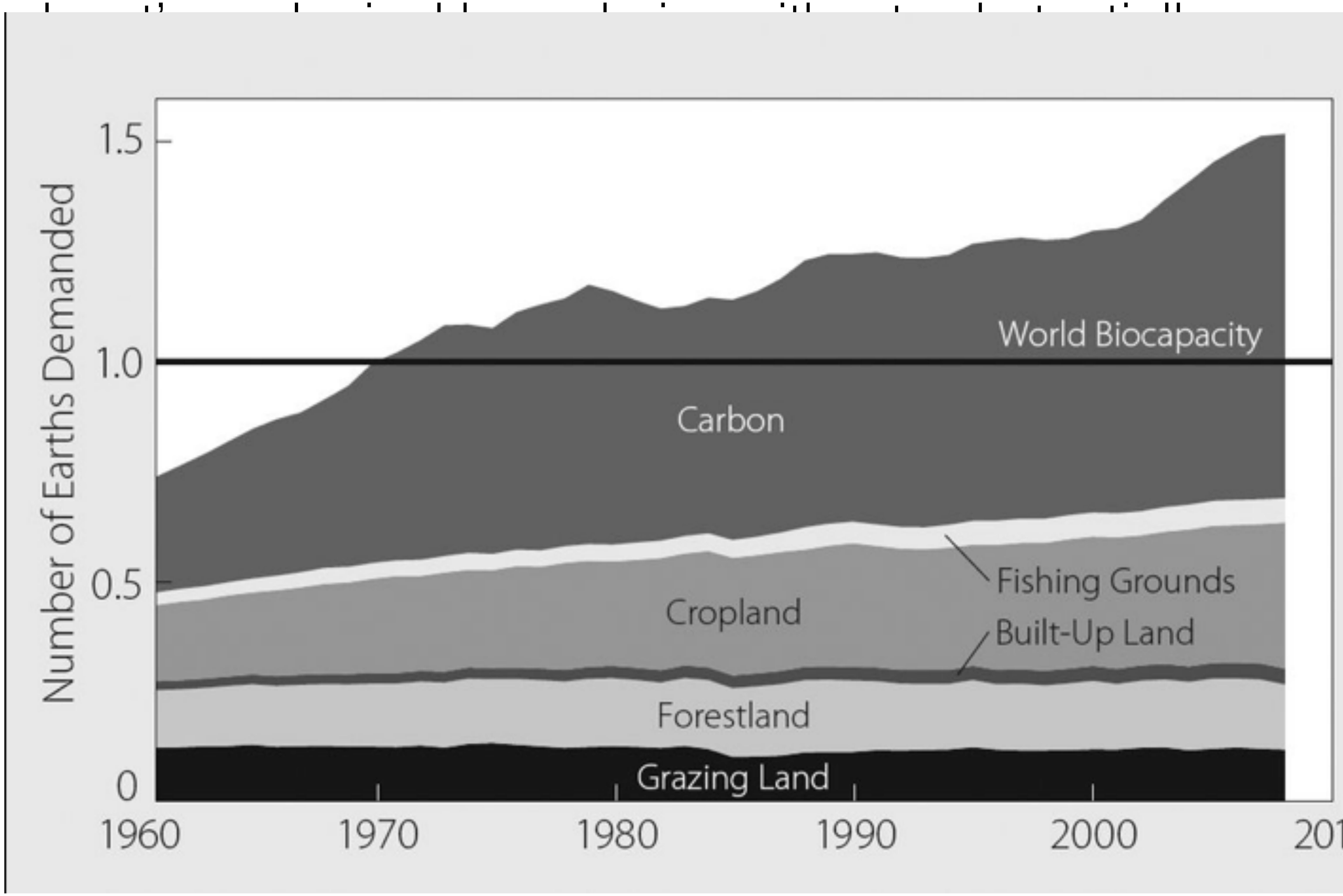
Engelman, 2013



Role of Economy



If Ecological Footprint calculations are even roughly accurate, humanity is currently consuming the ecological capacity of 1.5 Earths. That suggests that no more than 4.7 billion people could live within the



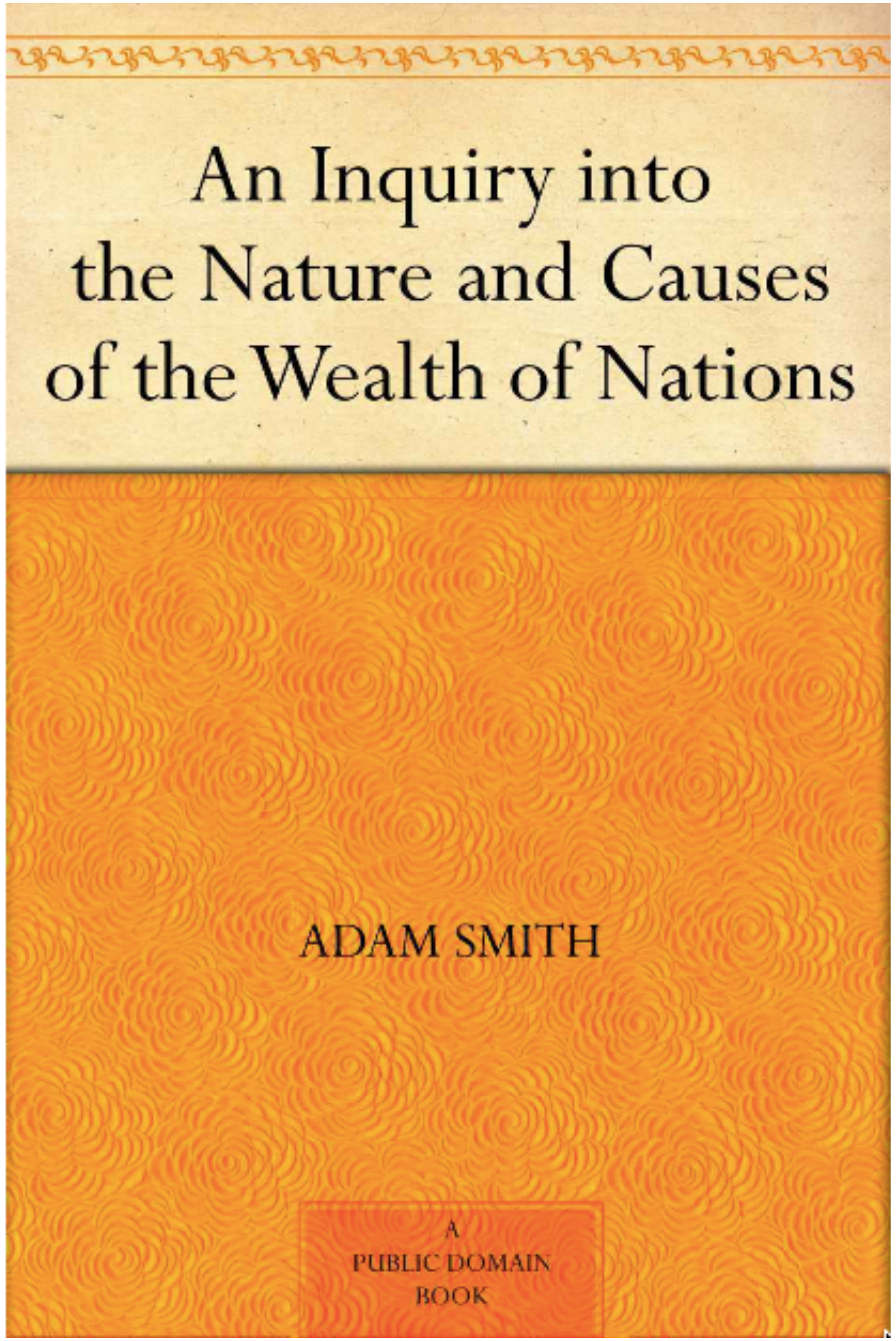
Diagnosis


Homo sapiens
1800
Colonizers
Netherlands
United States
Russian Empire
Ottoman Empire
Holocene
Single-Species Dominance
Post-Holocene
Global energy use since 1850
Exajoules
Biomass
Coal
Oil
Hydro
Nuclear
1/2
Adam Smith
of the Wealth of Nations
1875
1900
1925
1950
1975
2000
10^6
10^5
10^4
10^3
Years BP
10^2
10^1
10^0
2000
10^1
10^2
Years
10^3
Population
4 M
50 M
1.6 B
5.3 B
6.0 B
6.9 B
12 B?
?
Total energy use
$<10^{-6}$ TW
$<10^{-3}$ TW
0.5 TW
10.0 TW
12.8 TW
16.5 TW
>100.0 TW?

Diagnosis

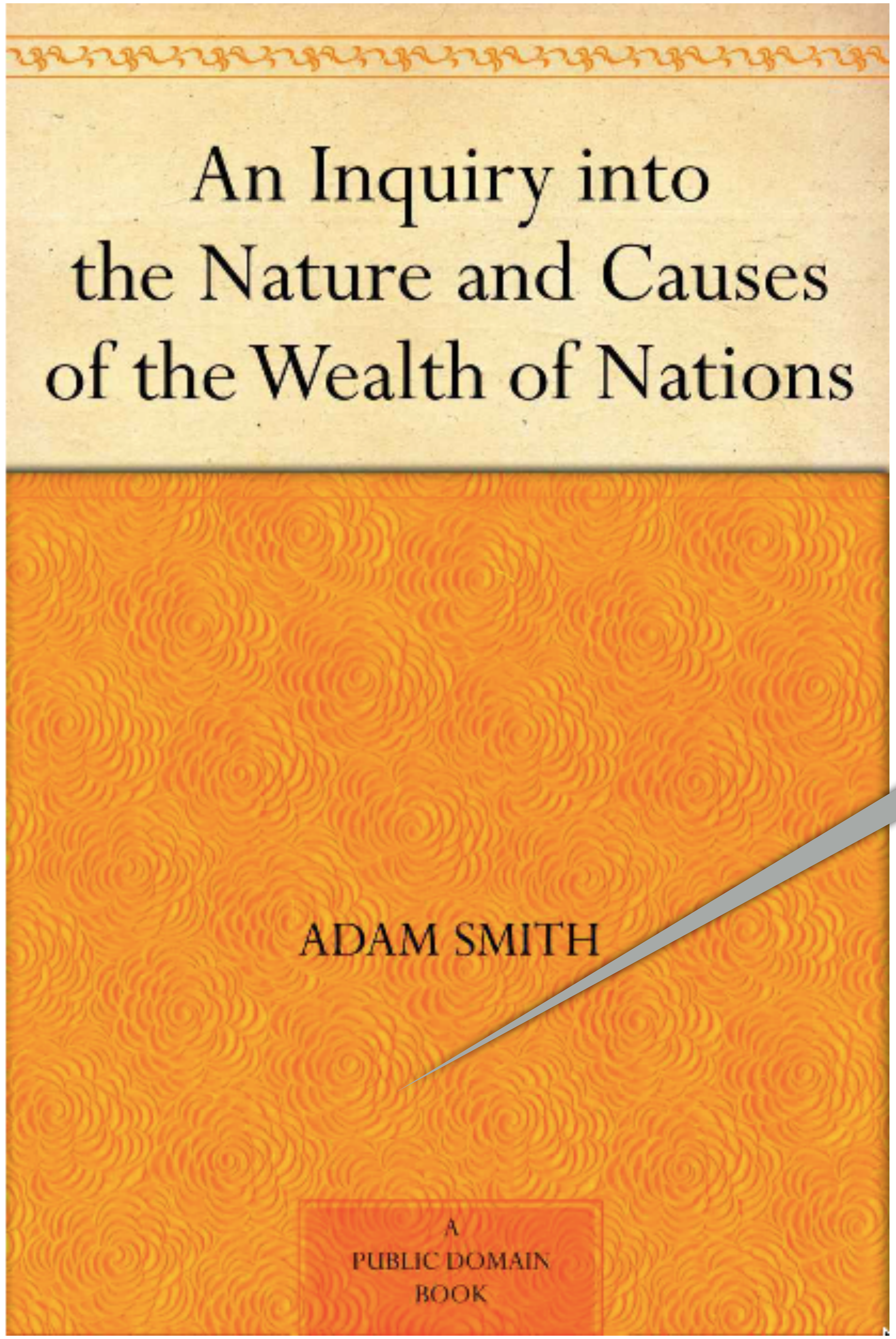

Homo sapiens
1800
Colonizers
Holocene
Single-Species Dominance
Post-Holocene
Netherlands
United States
Russian Empire
Ottoman Empire
Global energy use since 1850
Biomass
Oil
Hydro
Nuclear
Exajoules
1/2
of the Wealth of Nations
Adam Smith
1900
1925
1950
1975
2000
10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^1 10^2 10^3
Years BP
2000
Years
Population
4 M
50 M
1.6 B
5.3 B
6.0 B
6.9 B
12 B?
?
Total energy use
$<10^{-6}$ TW
$<10^{-3}$ TW
0.5 TW
10.0 TW
12.8 TW
16.5 TW
>100.0 TW?

Role of Economy



Published in 1776

Role of Economy

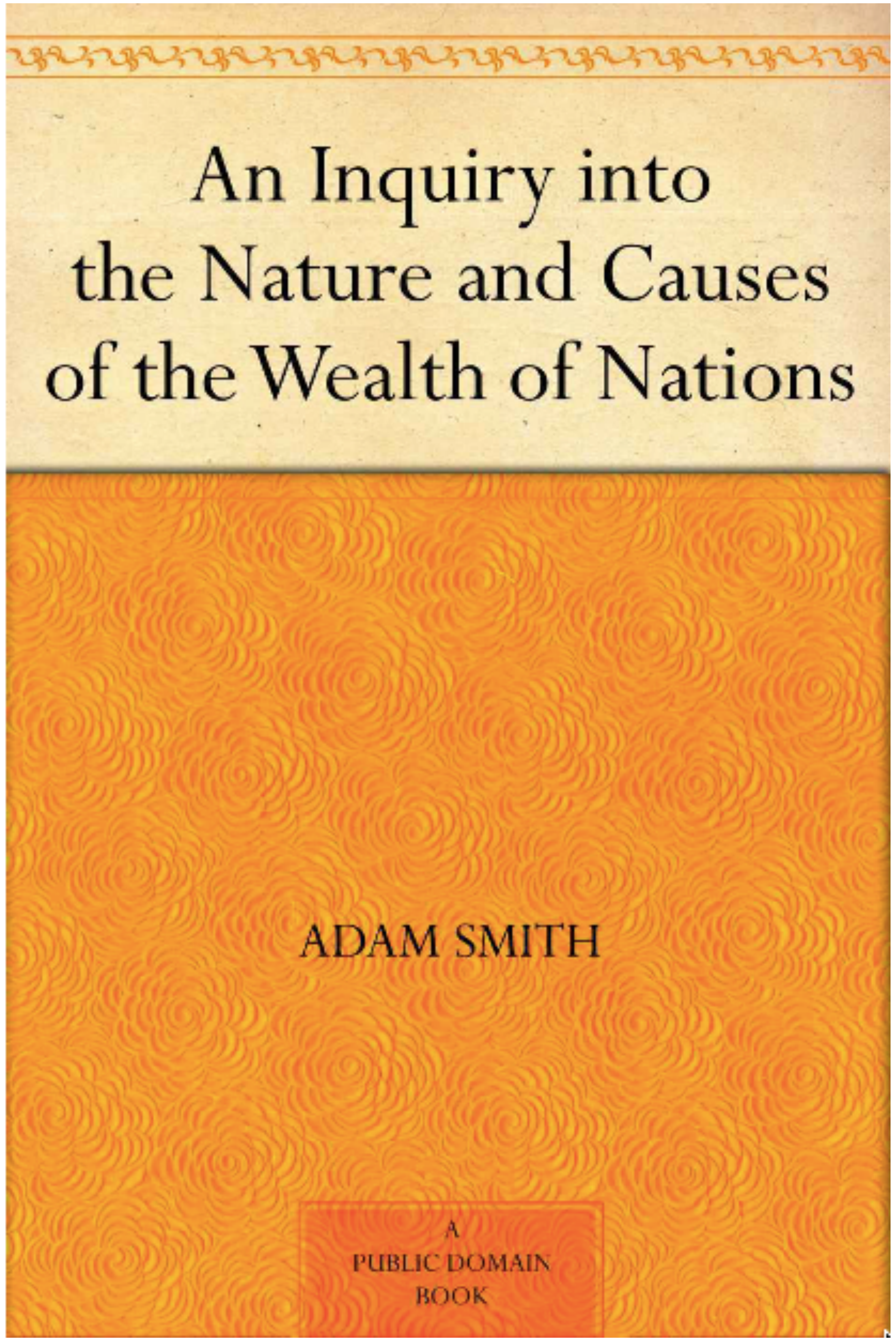


Published in 1776

Economy: the “invisible hand”

Assumption:
Agents independently seeking their own gain will produce the overall best result for society

Role of Economy

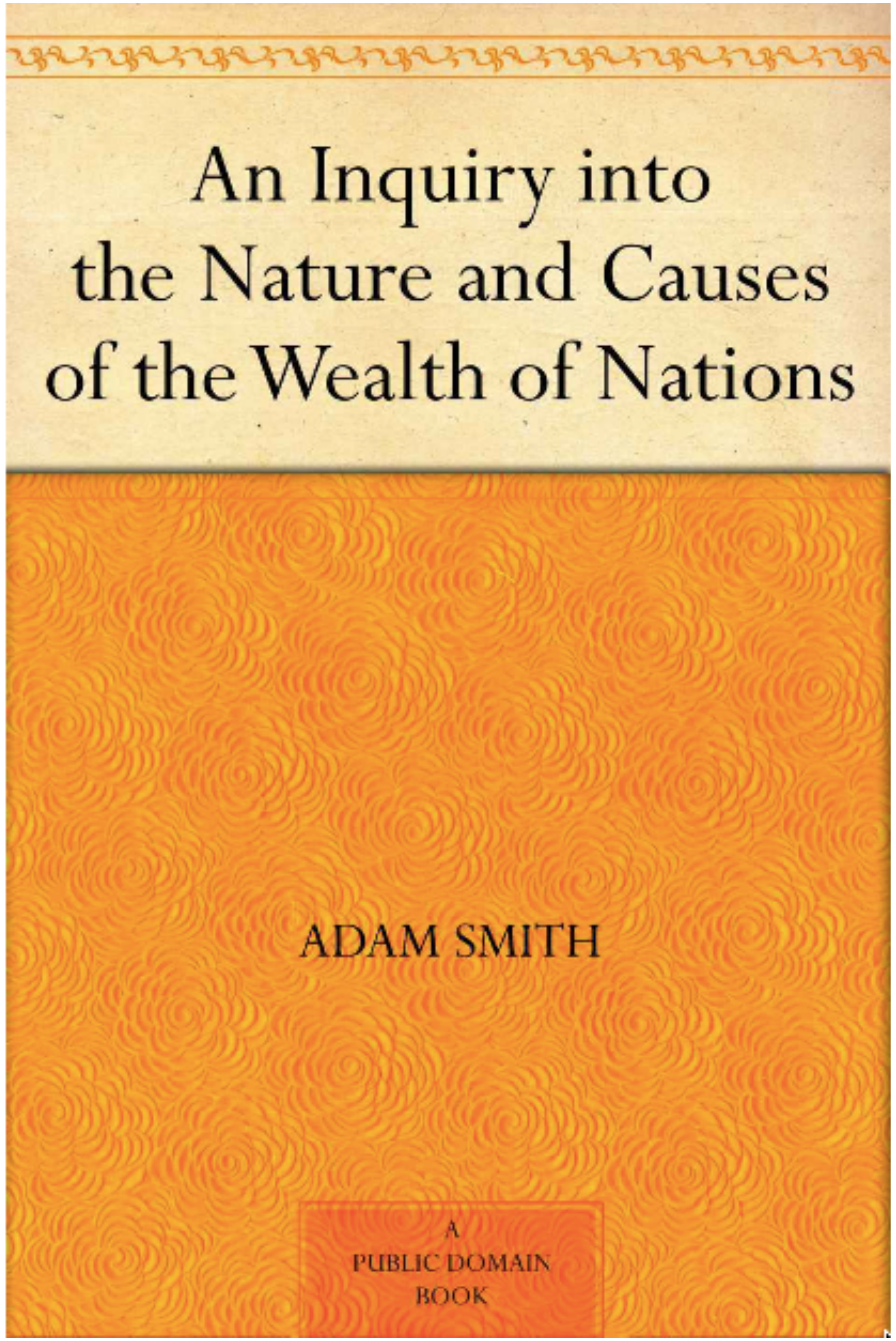


Published in 1776

The current mainstream model of the global **economy is based on a number of assumptions** about the way the world works, what the economy is, and what the economy is for. **These assumptions arose in an earlier period, when the world was relatively empty of humans and their artifacts.** Built capital was the limiting factor, while natural capital was abundant. It made sense not to worry too much about environmental "externalities," since they could be assumed to be relatively small and ultimately solvable. It also made sense to focus on the growth of the market economy, as measured by gross domestic product (GDP), as a primary means to improve human welfare. And it made sense to think of the economy as only marketed goods and services and to think of the goal as increasing the amount of these that were produced and consumed.

The Worldwatch Institute. State of the World 2013: Is Sustainability Still Possible? (Kindle Locations 2921-2927). Island Press. Kindle Edition.

Role of Economy



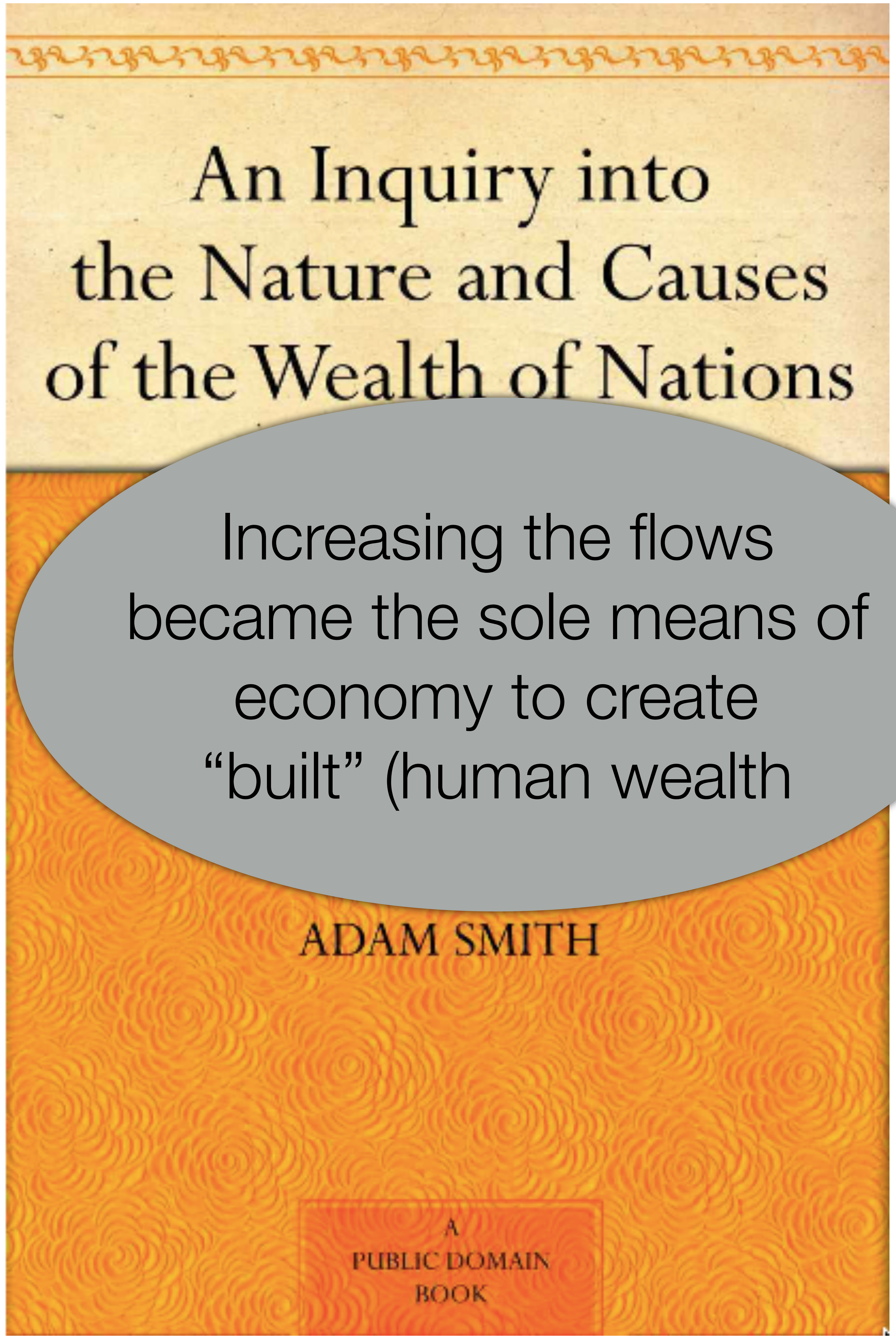
Published in 1776

The current mainstream model of the global **economy is based on a number of assumptions** about the way the world works, what the economy is, and what the economy is for. These assumptions arose in an earlier period, when the world was relatively empty of humans and their artifacts. Built capital was the limiting factor, while natural capital was abundant. It made sense not to worry too much about environmental "externalities," since they could be assumed to be relatively small and ultimately solvable. It also made sense to focus on the growth of the market economy, as measured by gross domestic product (GDP), as a primary means to improve human welfare. And it made sense to think of the economy as only marketed goods and services and to think of the goal as increasing the amount of these that were produced and consumed.

The Worldwatch Institute. State of the World 2013: Is Sustainability Still Possible? (Kindle Locations 2921-2927). Island Press. Kindle Edition.

Diagnosis

Role of Economy



Increasing the flows became the sole means of economy to create “built” (human wealth

Published in 1776

The current mainstream model of the global **economy is based on a number of assumptions** about the way the world works, what the economy is, and what the economy is for. **These assumptions arose in an earlier period, when the world was relatively empty of humans and their artifacts.** Built capital was the limiting factor, while natural capital was abundant. It made sense not to worry too much about environmental “externalities,” since they could be assumed to be relatively small and ultimately solvable. It also made sense to focus on the growth of the market economy, as measured by gross domestic product (GDP), as a primary means to improve human welfare. And it made sense to think of the economy as only marketed goods and services and to think of the goal as increasing the amount of these that were produced and consumed.

The Worldwatch Institute. State of the World 2013: Is Sustainability Still Possible? (Kindle Locations 2921-2927). Island Press. Kindle Edition.

Role of Economy

For almost a century, the **consumption of products has been the dominant paradigm and mindset**.

John Maynard Keynes (*"The General Theory of Employment, Interest and Money"*, 1936):*"I should support at the same time all sorts of policies for increasing the propensity to consume. For it is unlikely that full employment can be maintained, whatever we may do about investment, with the existing propensity to consume."*

Victor Lebow (1955): *"Our enormously productive economy … demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we* ***seek our spiritual satisfaction, our ego satisfaction, in consumption*** *… we need* ***things consumed, burned up, replaced and discarded at an ever-accelerating rate****."*

Role of Economy

In 1970, Milton Friedman argued that businesses' sole purpose is to generate profit for shareholders.

This led to globalization …