Natural Hazards and Disaster

Class 11: Modern Climate Change

Modern Climate Change: A Symptom of Humanity's Evolution into a Growth-Addicted Industrialized Civilization

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Modern Climate Change: A Symptom of Humanity's Evolution into a Growth-Addicted Industrialized Civilization

Modern Climate Change: A Symptom of Single-Species High-Energy Pulse Syndrome


Hans-Peter Plag
Old Dominion University
Norfolk, VA, USA

Ubuntu:

“I am, because of you”

“a person is a person through other persons”

Hans-Peter Plag
Old Dominion University
Norfolk, VA, USA

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“a person is a person through other persons”

Me:
“I know, because of you”

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Modern Climate Change: A Symptom of Single-Species High-Energy Pulse Syndrome

Our perception depends on the distance we have …

Hans-Peter Plag
Old Dominion University
Norfolk, VA, USA

Planetary Life-Support System

Planetary Life-Support System

Physiology: Homeostasis

Planetary Life-Support System

Physiology: Homeostasis

Essential: Earth’s Energy Imbalance: Incoming Energy - Outgoing Energy

Planetary Life-Support System

Physiology: Homeostasis

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“Healthy Life-Support System”: Energy Imbalance is very small, tiny

Planetary Life-Support System

Physiology: Homeostasis

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“Healthy Life-Support System”: Energy Imbalance is very small, tiny

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

Earth’s energy imbalance due to photosynthesis: on the order of 10^{-10} to 10^{-9}

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(e.g., Stephens et al., 2012; Trenberth et al., 2014, Cheng et al., 2016)

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Planetary Life-Support System

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(1) Where is the additional energy stored and what are the impacts?
(2) Why did the imbalance increased?

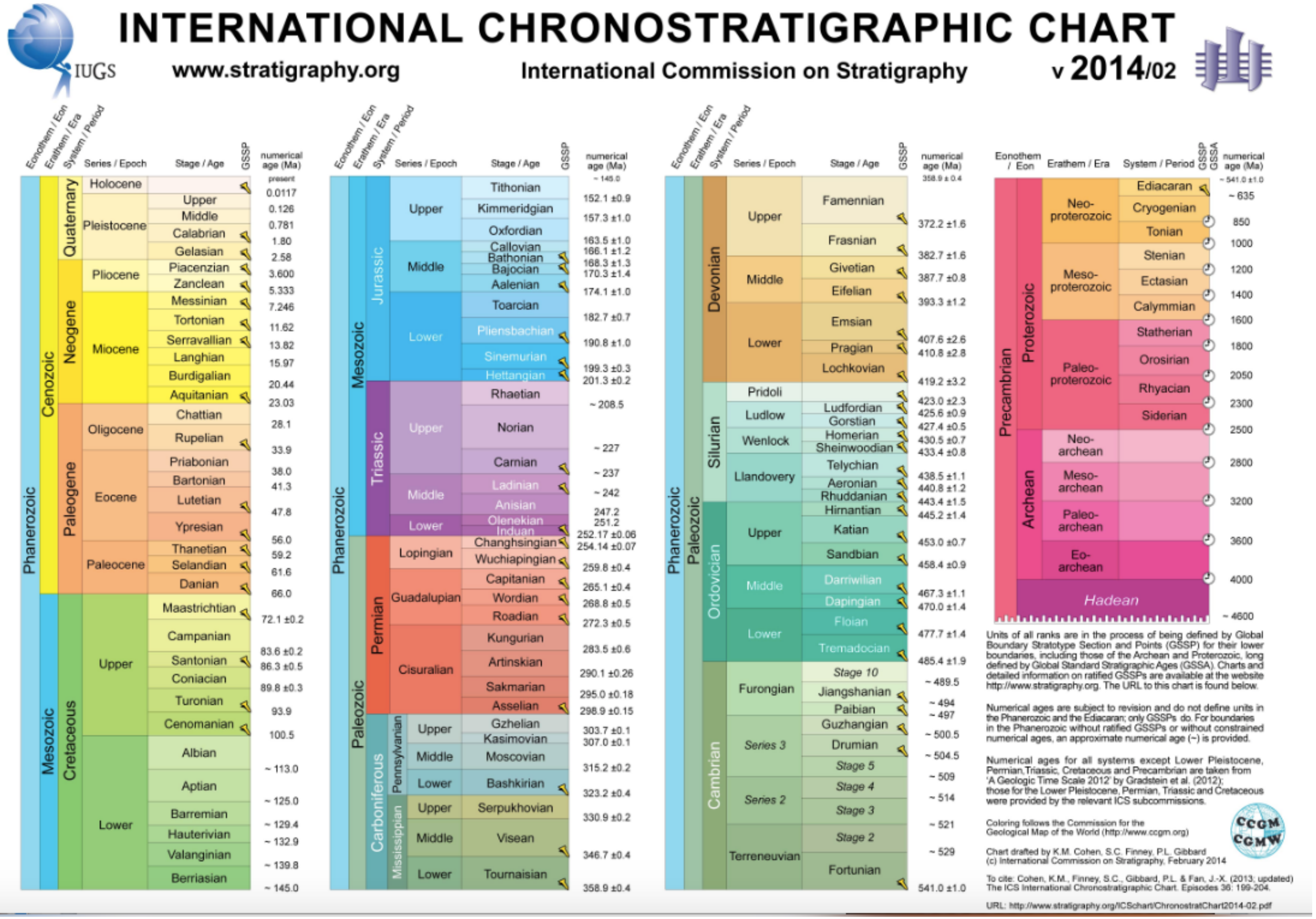
Modern Climate Change: A Symptom of a Single-Species High-Energy Pulse Syndrome

Modern Climate Change: A Symptom of a Single-Species High-Energy Pulse Syndrome

Contents

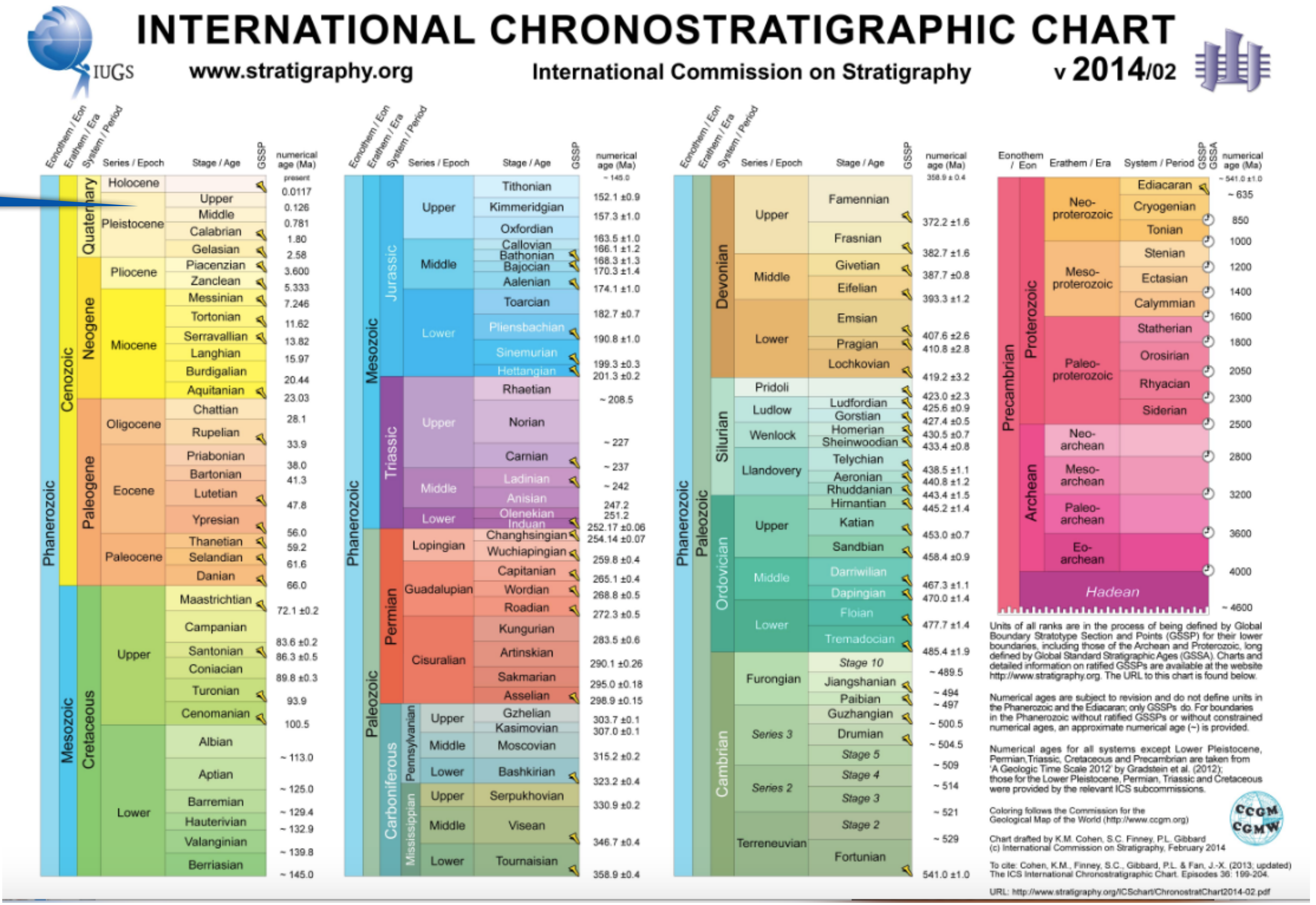
- The Baseline: Past Climate Changes
- The Syndrome: Recent Climate and Global Change
- The Diagnosis: Leaving the “Safe Operating Space”
- The Prognosis: Journey Into the Unknown
- The Therapy: “Lifestyle” changes

The Baseline: Past Climate and Global Change



The Baseline: Past Climate and Global Change

Subdivisions of the Quaternary System			
System/ Period	Series/ Epoch	Stage/ Age	Age (Ma)
Quaternary	Holocene		0.0117–0
	Pleistocene	Tarantian	0.126–0.0117
		Ionian	0.781–0.126
		Calabrian	1.80–0.781
		Gelasian	2.58–1.80
Neogene	Pliocene	Piacenzian	older



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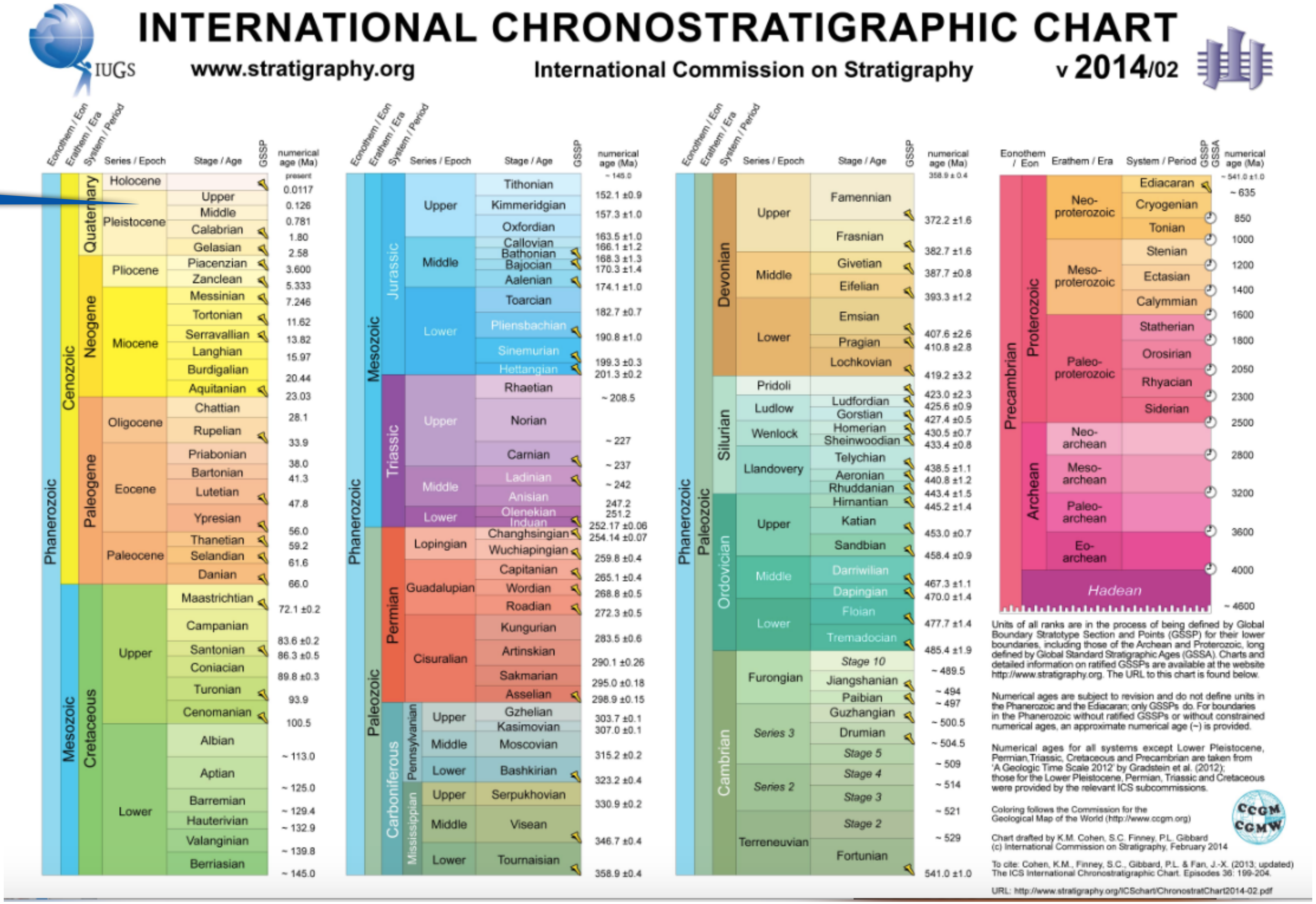

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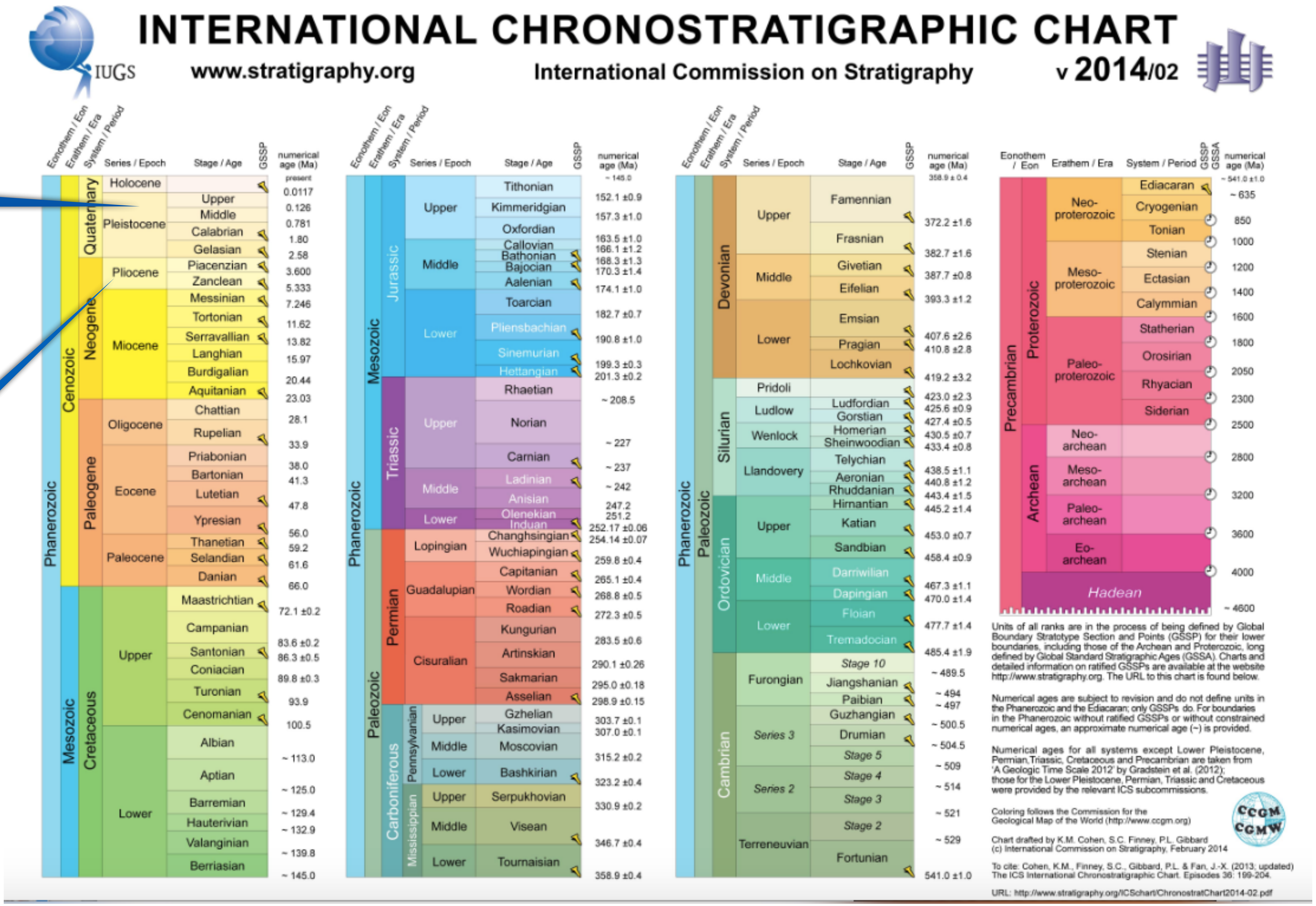
Neogene	Pliocene	Piacenzian	3.600–2.58
		Zanclean	5.333–3.600
	Miocene	Messinian	7.246–5.333
		Tortonian	11.62–7.246
		Serravallian	13.82–11.62
		Langhian	15.97–13.82
		Burdigalian	20.44–15.97
		Aquitanian	23.03–20.44
Paleogene	Oligocene	Chattian	older



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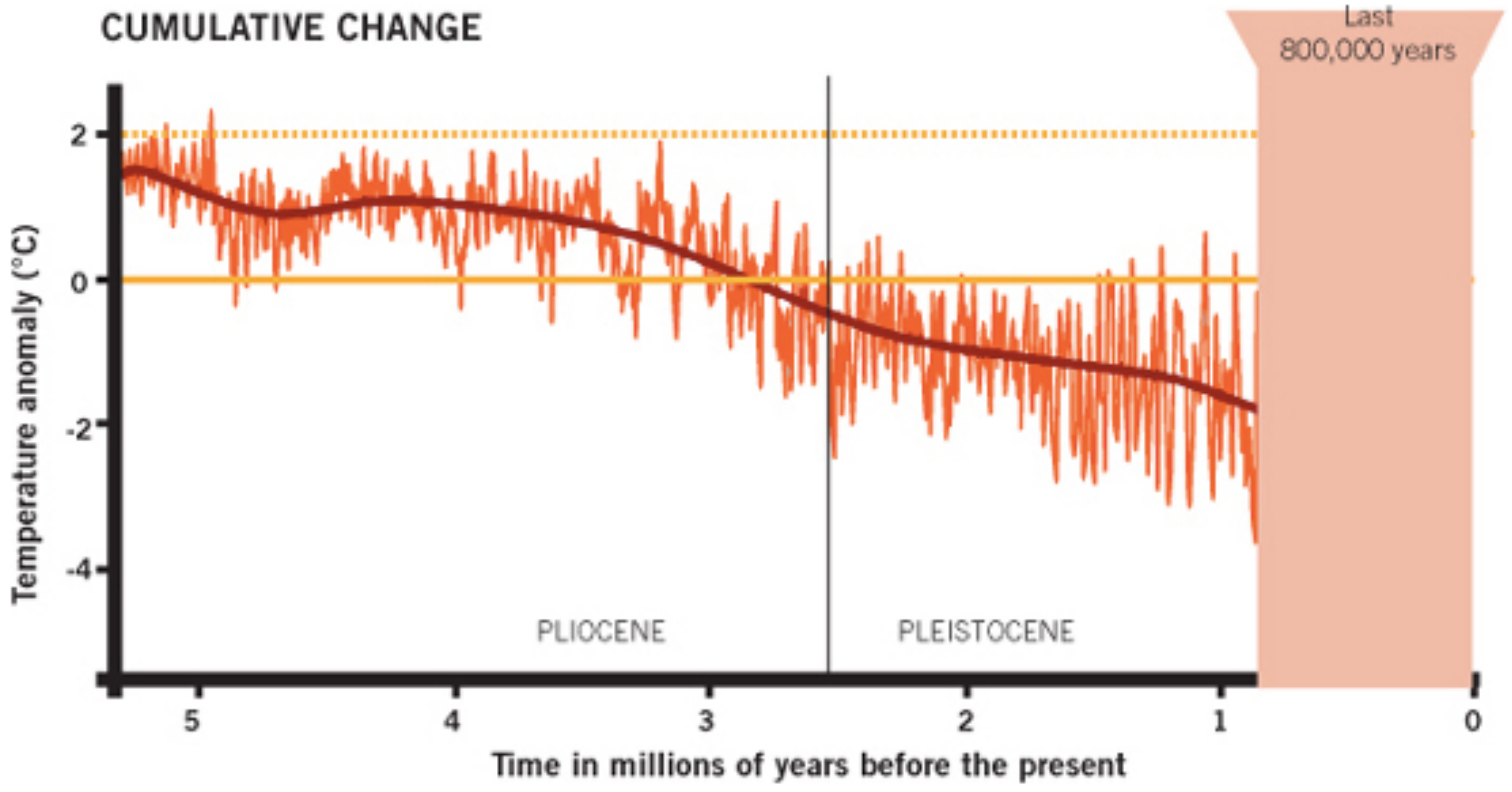
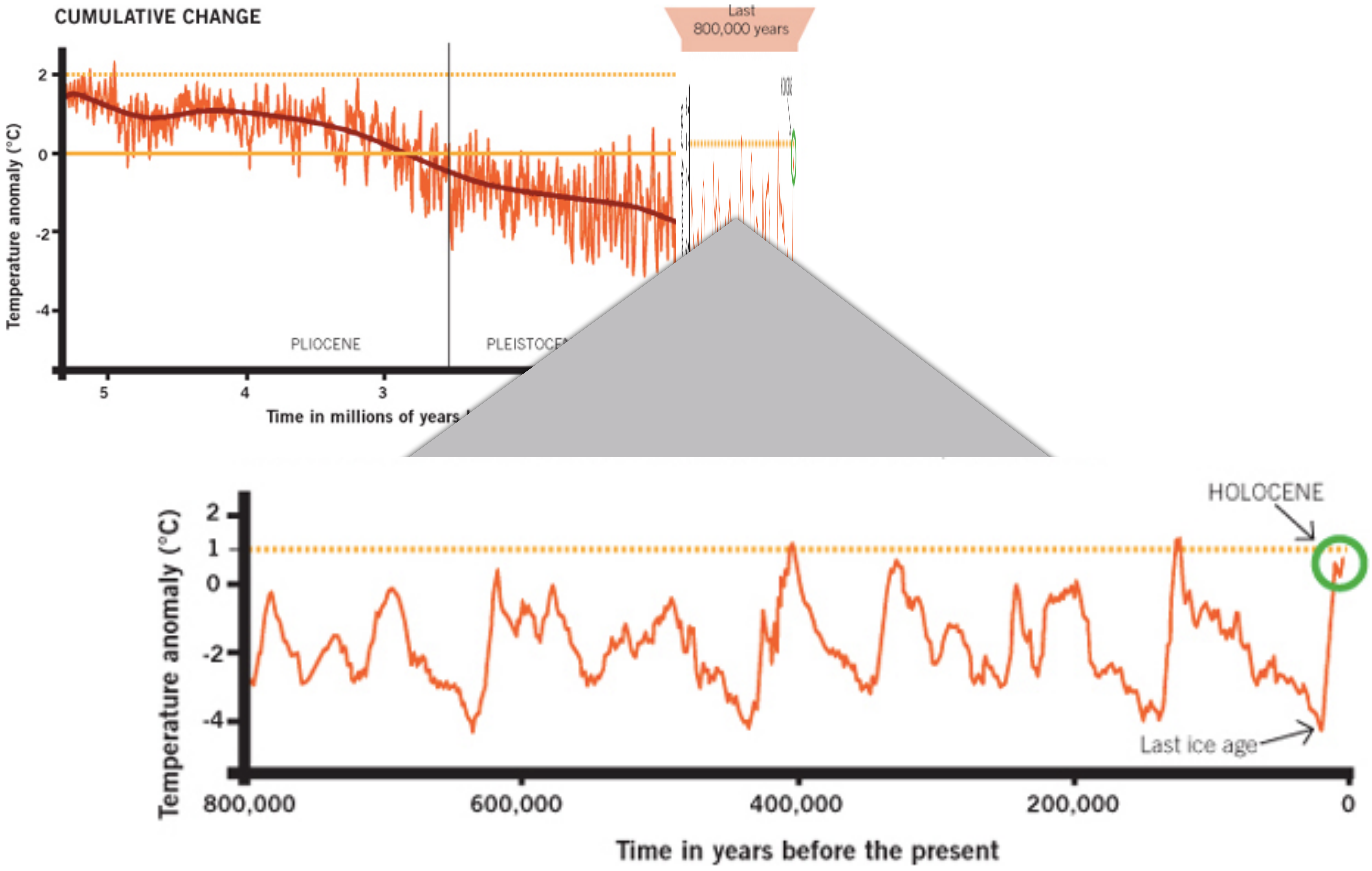


Rockstrom and Klum, 2015

The Baseline: Past Climate and Global Change



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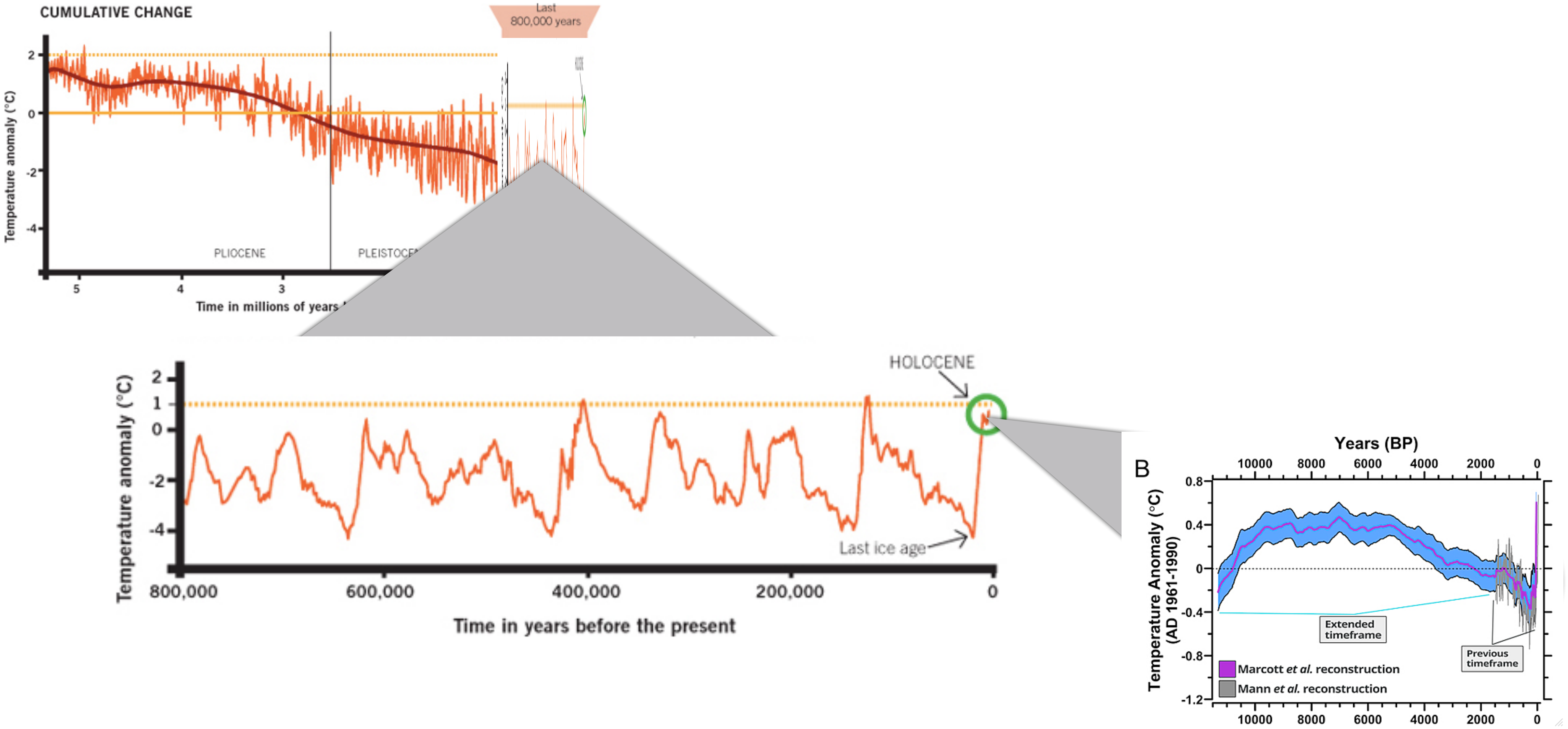

Rockstrom and Klum, 2015

Marcott et al., 2013

The Baseline: Past Climate and Global Change

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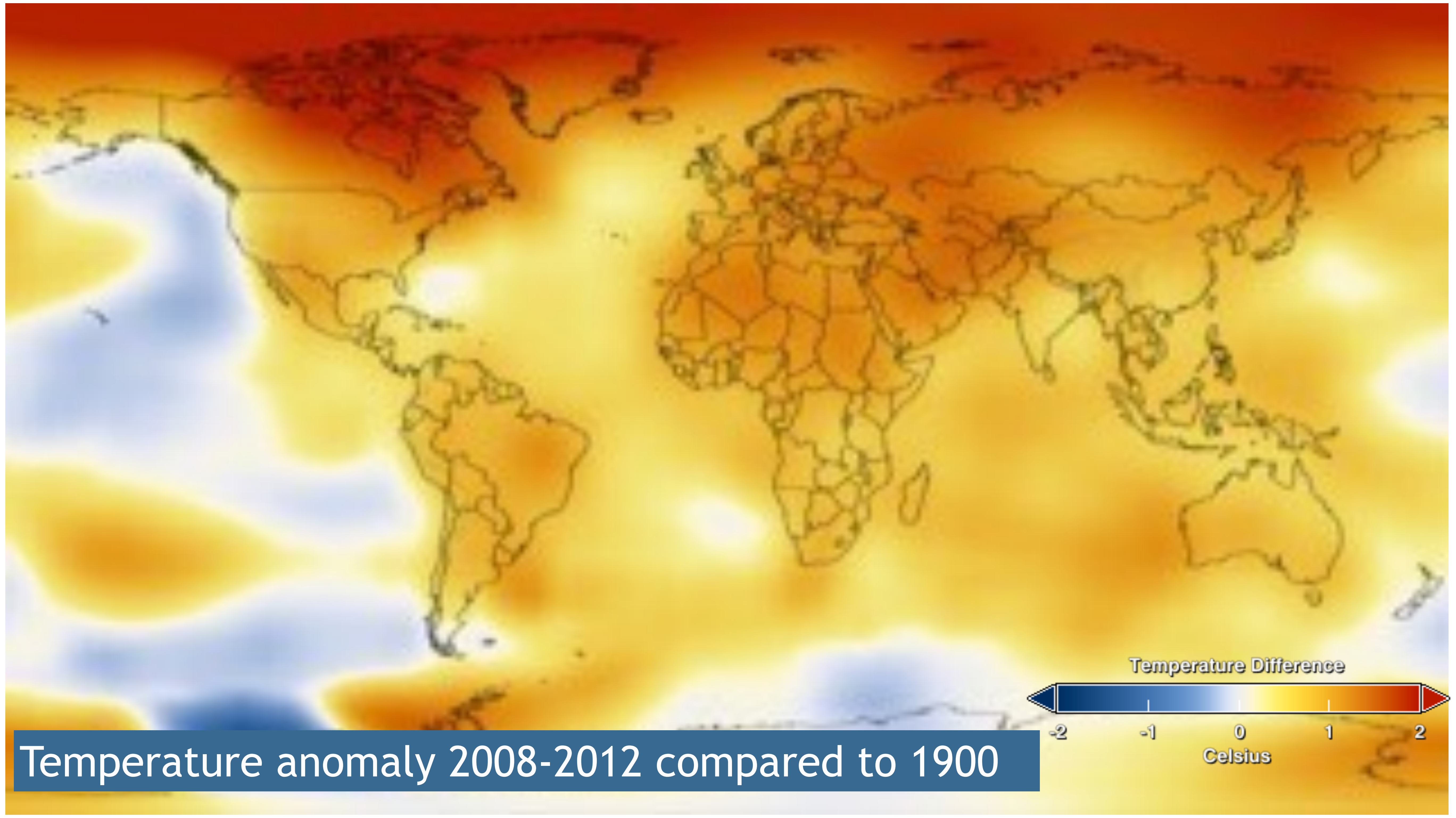

Temperature anomaly 2008-2012 compared to 1900

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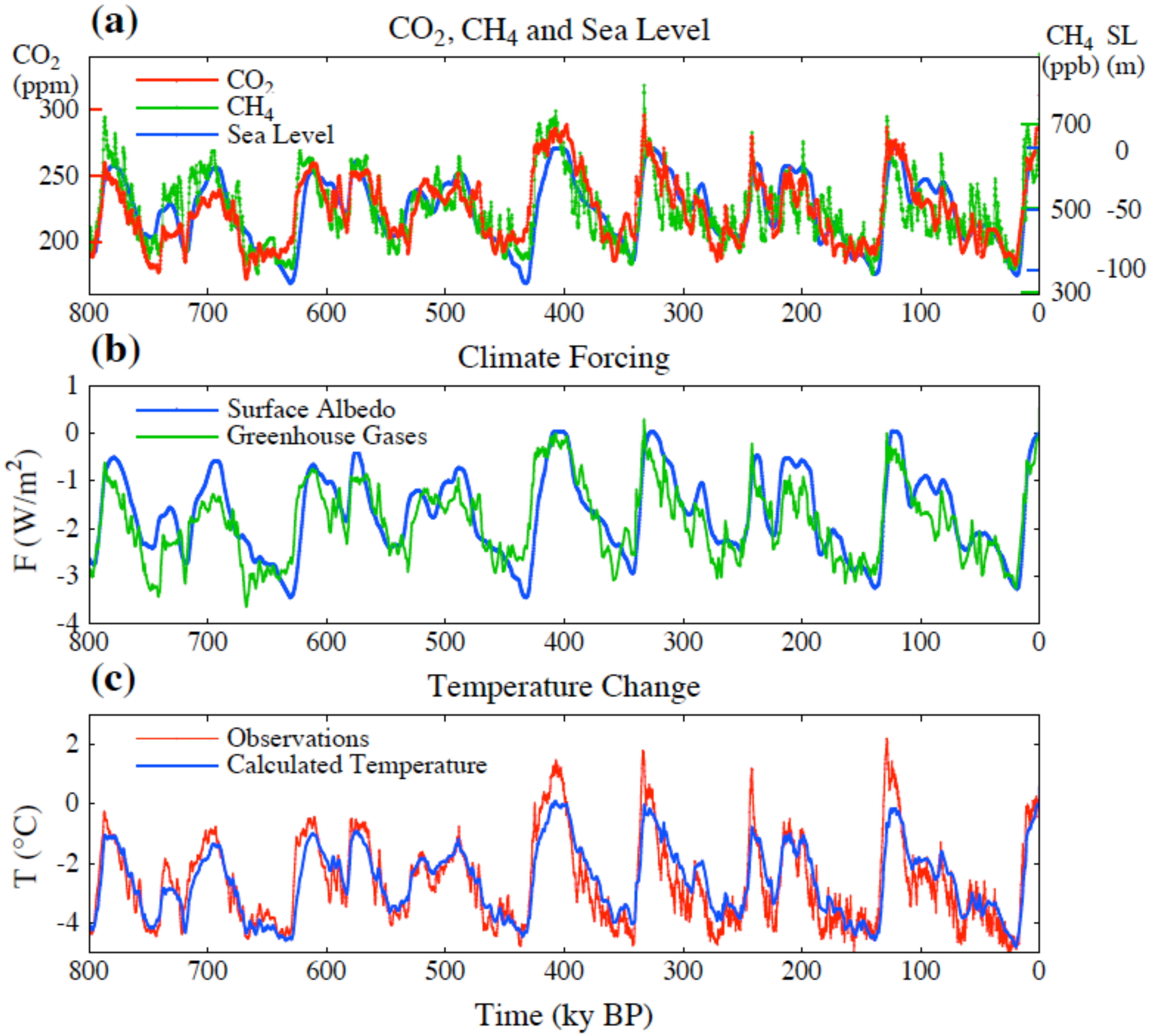
Climate can change a lot over time.



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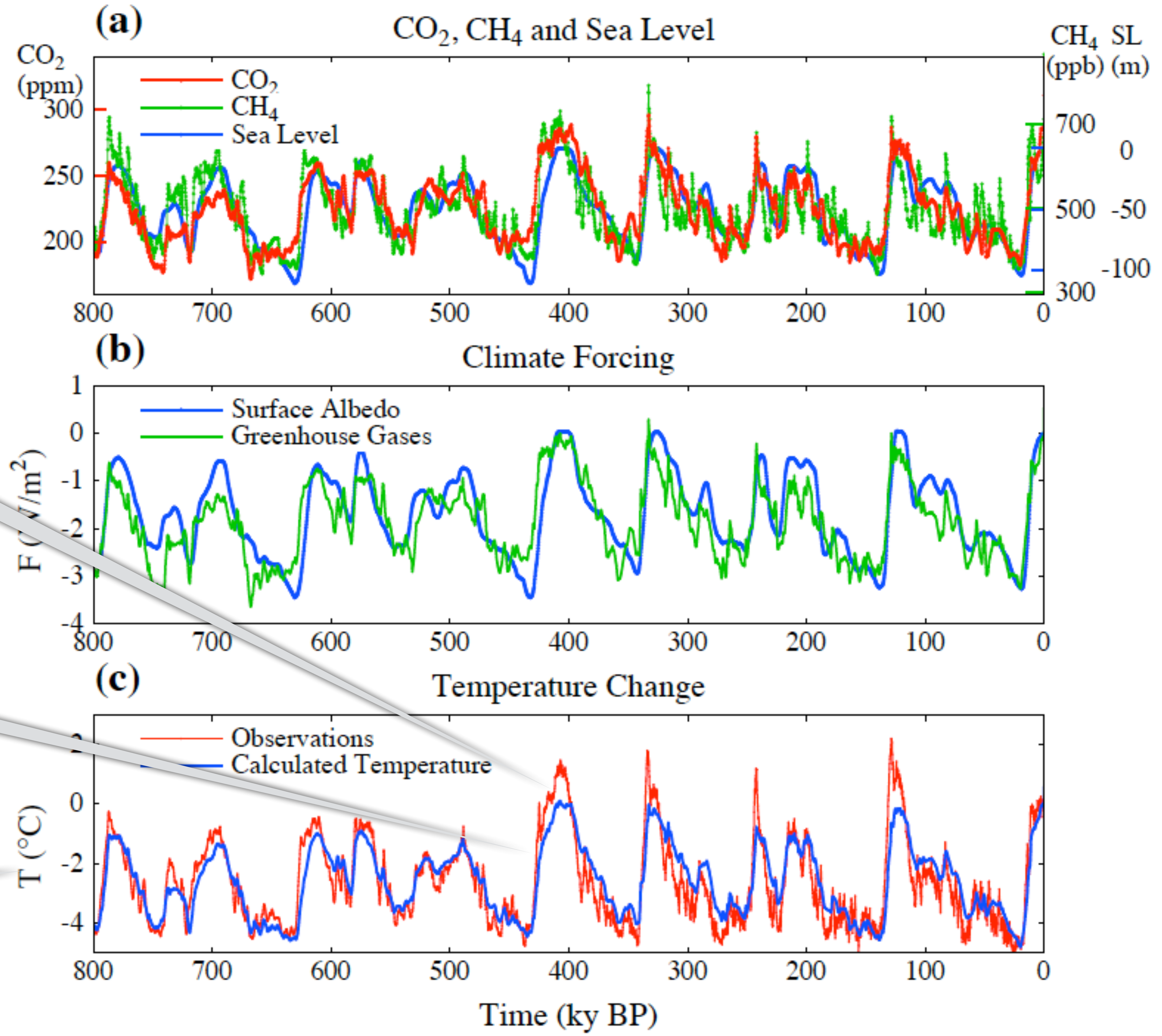
Warm period
“Inter-glacial”

Climate can cha global scales.

Cold period
Ice age
“glacial”

Climate can change a lot over time.

Temperature difference:
4°C - 5°C



The Baseline: Past Climate and Global Change

The Baseline: Past Climate and Global Change

EARTH OBSERVATORY
Where every day is Earth Day

Home Image

SVANTE ARRHENIUS (1859-1927)

Arrhenius did very little research in the fields of climatology and geophysics, and considered any work in these fields a hobby. His basic approach was to apply knowledge of basic scientific principles to make sense of existing observations, while hypothesizing a theory on the cause of the "Ice Age." Later on, his geophysical work would serve as a catalyst for the work of others.

The Baseline: Past Climate and Global Change

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In 1895, Arrhenius presented a paper to the Stockholm Physical Society titled, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground." This article described an energy budget model that considered the radiative effects of carbon dioxide (carbonic acid) and water vapor on the surface temperature of the Earth, and variations in atmospheric carbon dioxide concentrations. In order to proceed with his experiments, Arrhenius relied heavily on the experiments and observations of other scientists, including Josef Stefan, Arvid Gustaf Högbom, Samuel Langley, Leon Teisserenc de Bort, Knut Angstrom, Alexander Buchan, Luigi De Marchi, Joseph Fourier, C.S.M. Pouillet, and John Tyndall.

Arrhenius argued that variations in trace constituents—namely carbon dioxide—of the atmosphere could greatly influence the heat budget of the Earth. Using the best data available to him (and making many assumptions and estimates that were necessary), he performed a series of calculations on the temperature effects of increasing and decreasing amounts of carbon dioxide in the Earth's atmosphere. His calculations showed that the "temperature of the Arctic regions would rise about 8 degrees or 9 degrees Celsius, if the carbonic acid increased 2.5 to 3 times its present value. In order to get the temperature of the ice age between the 40th and 50th parallels, the carbonic acid in the air should sink to 0.62 to 0.55 of present value (lowering the temperature 4 degrees to 5 degrees Celsius)."

The Baseline: Past Climate and Global Change

REMARKABLE WEATHER OF 1911

The Effect of the Combustion of Coal on the Climate — What Scientists Predict for the Future

By FRANCIS MOLENA

THE year 1911 will long be remembered for the violence of its weather. The spring opened mild and

The mean temperature of every month except November was above the average of that of the 40 years covered by

Popular Mechanics, March 1912, 393-342

"It is largely the courageous, enterprising, and ingenious American whose brains are changing the world. Yet even the dull foreigner, who burrows in the earth by the faint gleam of his miner's lamp, not only supports his family and helps to feed the consuming furnaces of modern industry, but by his toil in the dirt and darkness adds to the carbon dioxide in the earth's atmosphere so that men in generations to come shall enjoy milder breezes and live under sunnier skies."

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.

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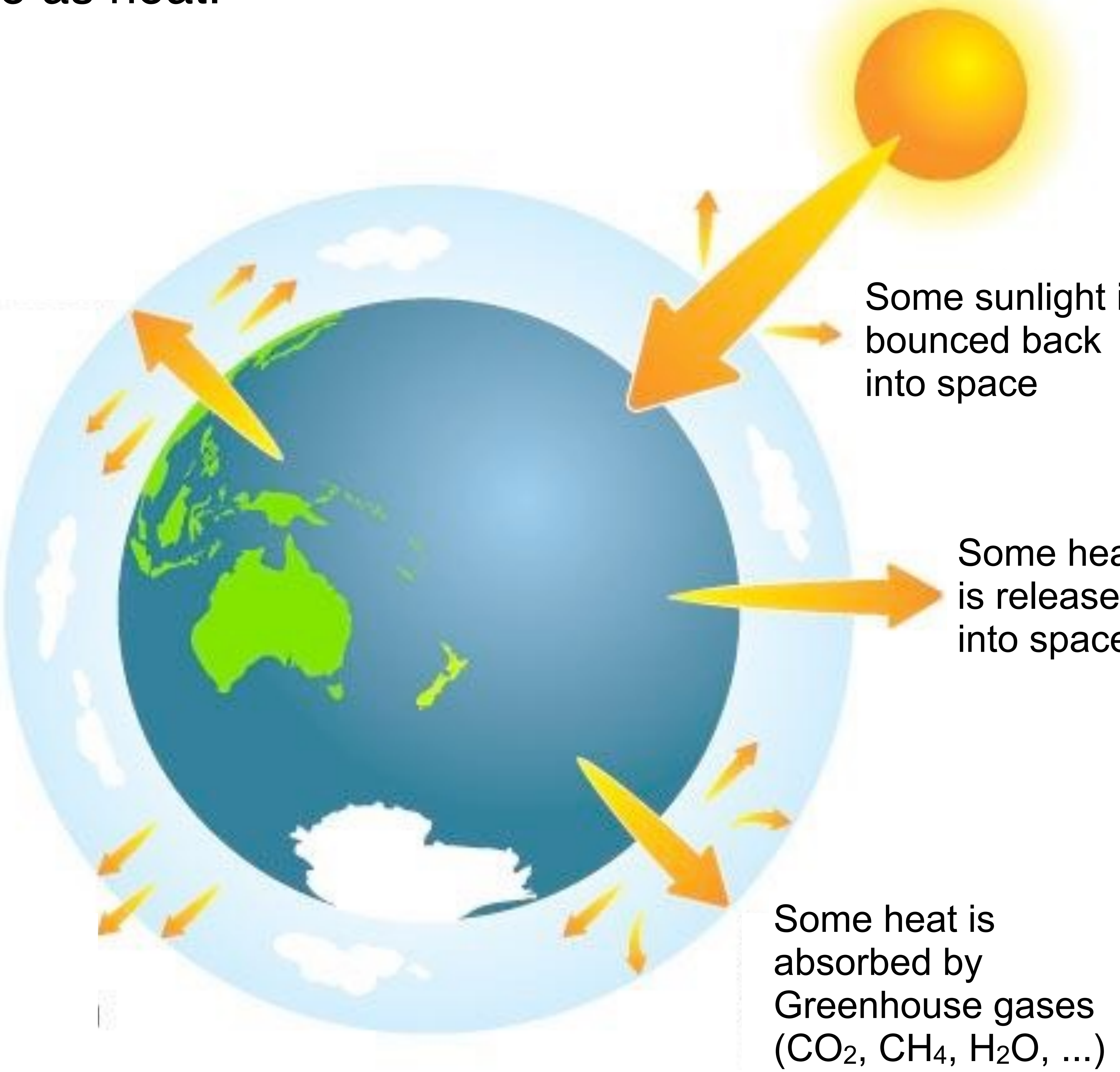

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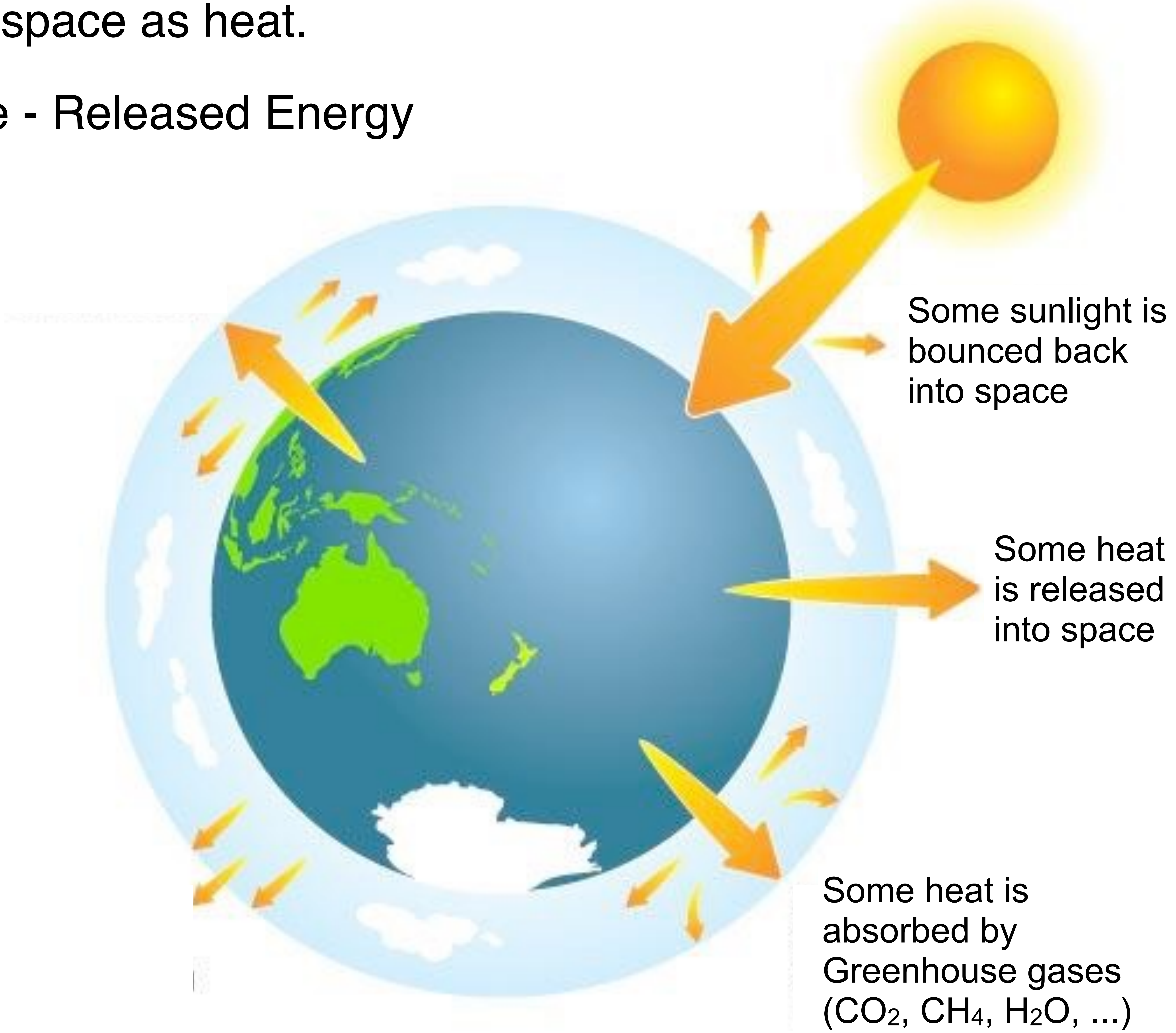
Earth's Energy Imbalance: EI = Solar irradiance - Released Energy



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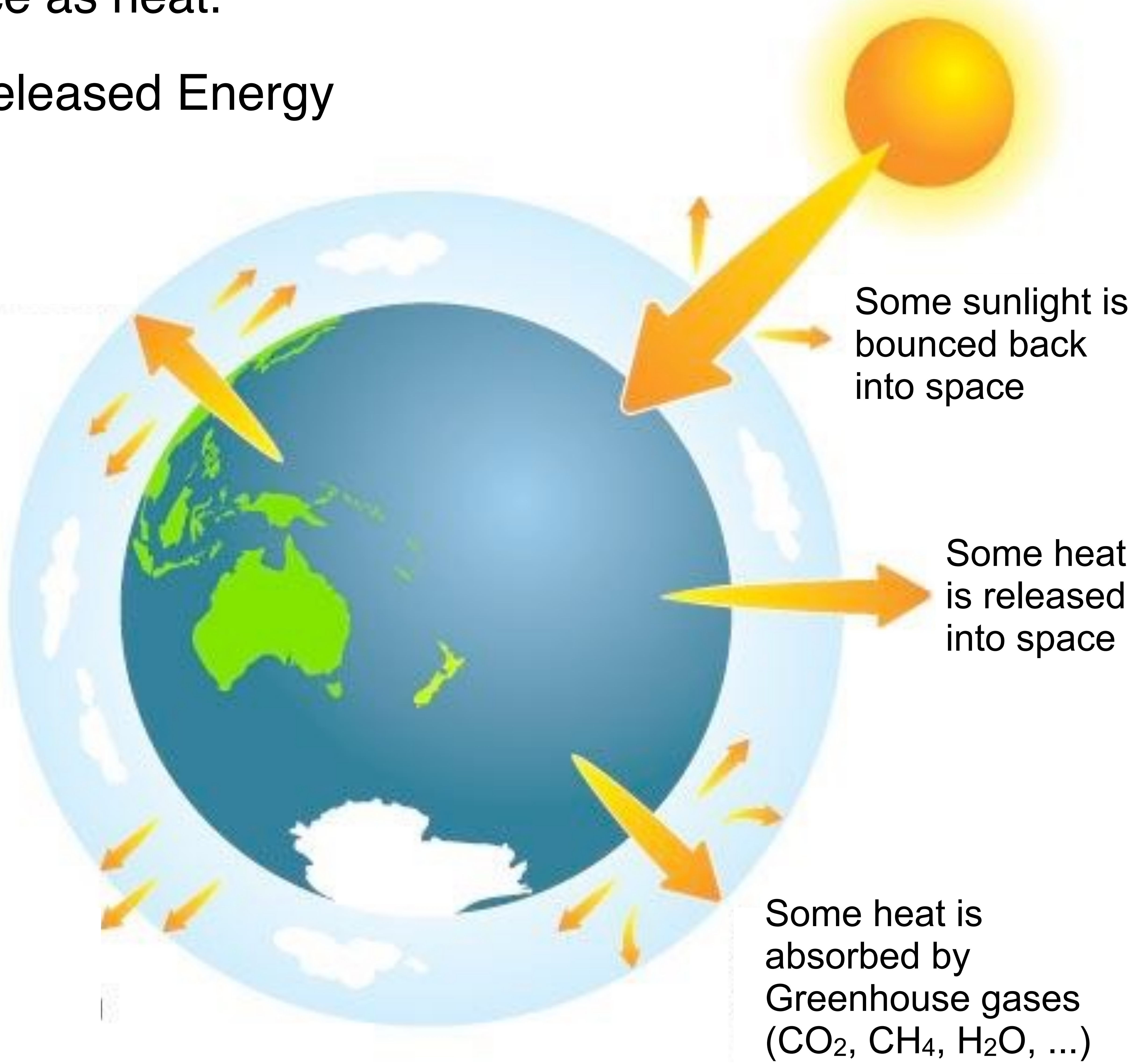
EI < 0: Global Cooling



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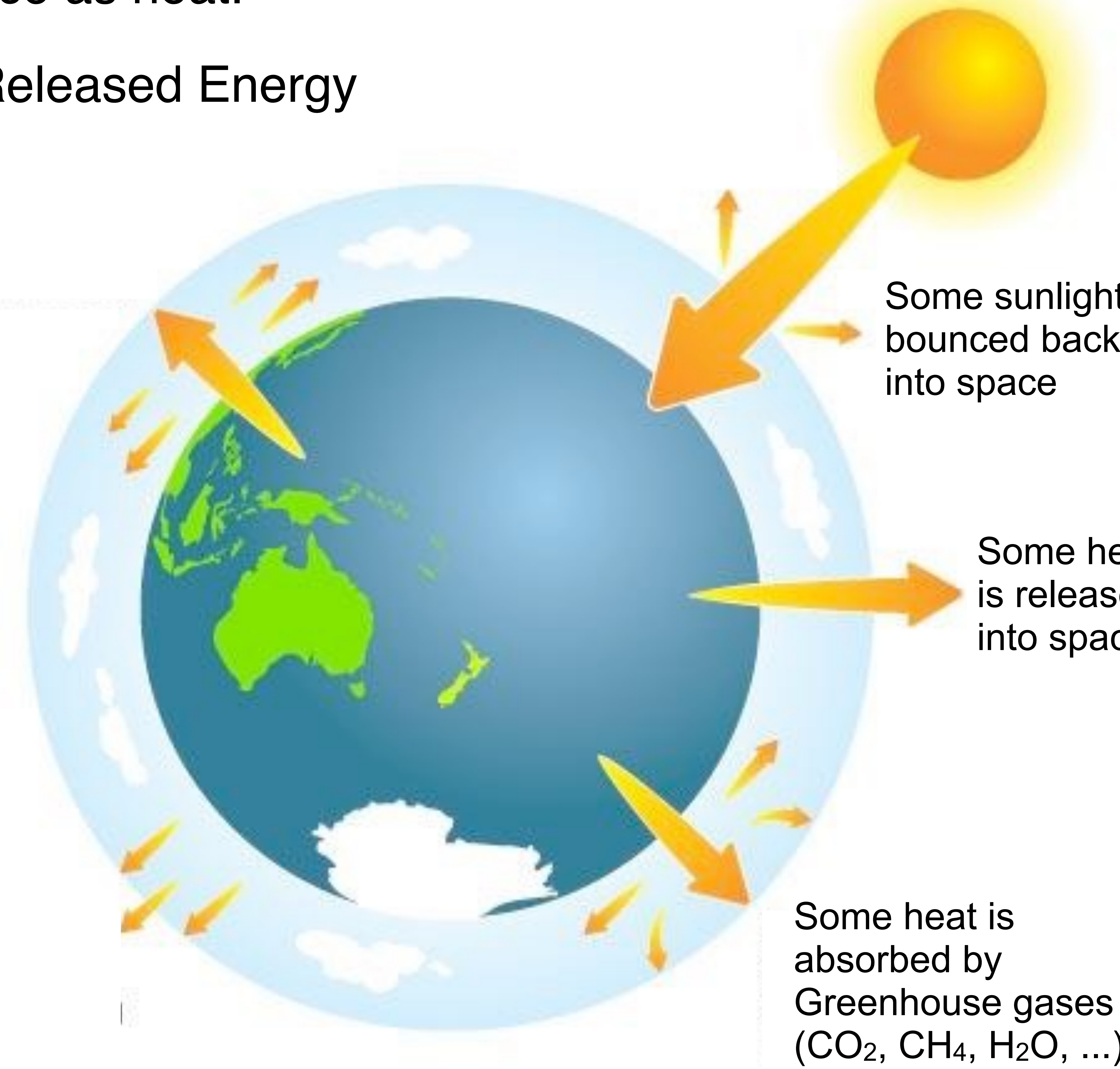
  Currently: 1366±1 W/m^2 (~240 W/m^2)
- Reflected radiation can change (albedo)
- Absorbed energy can change



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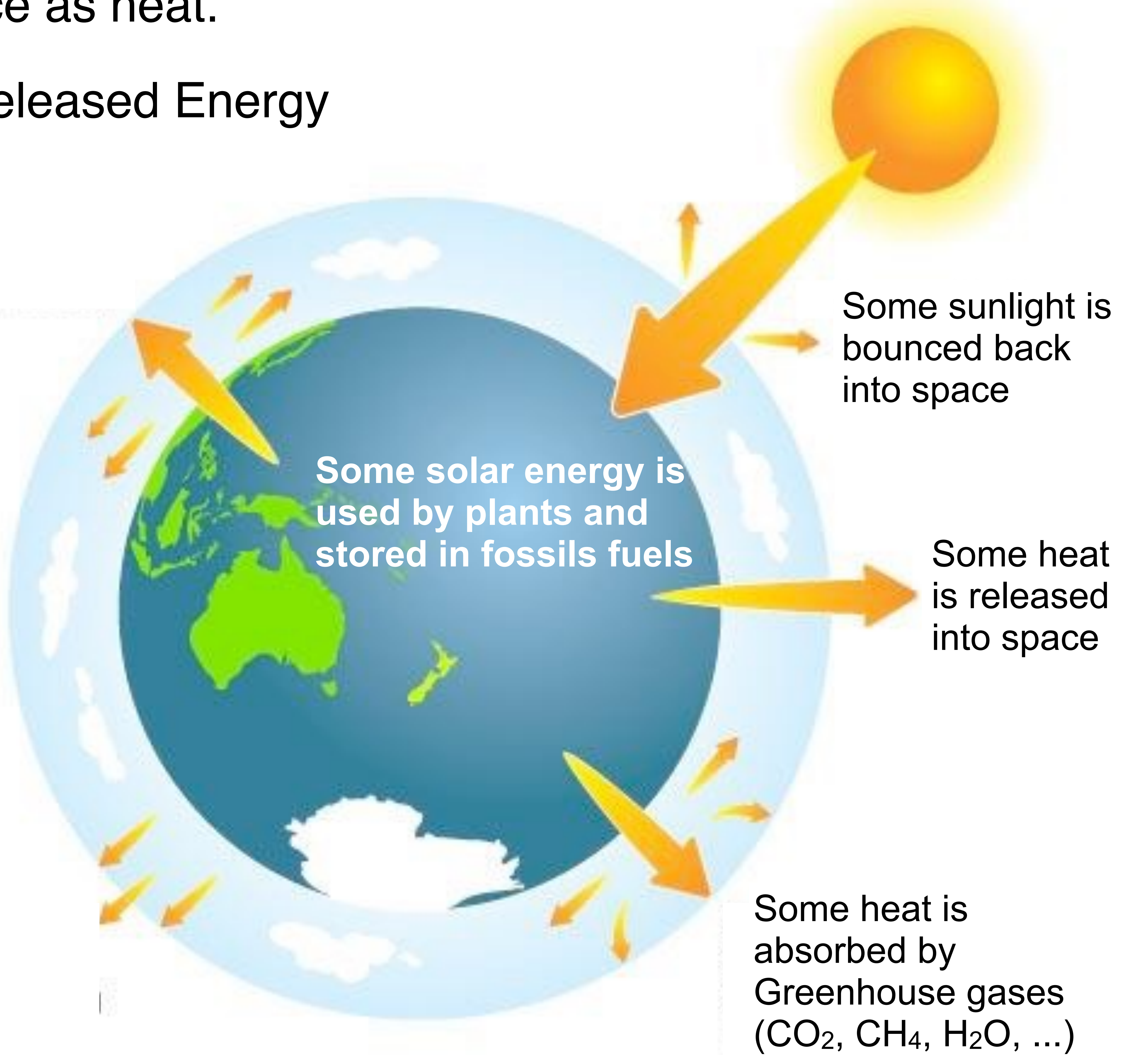

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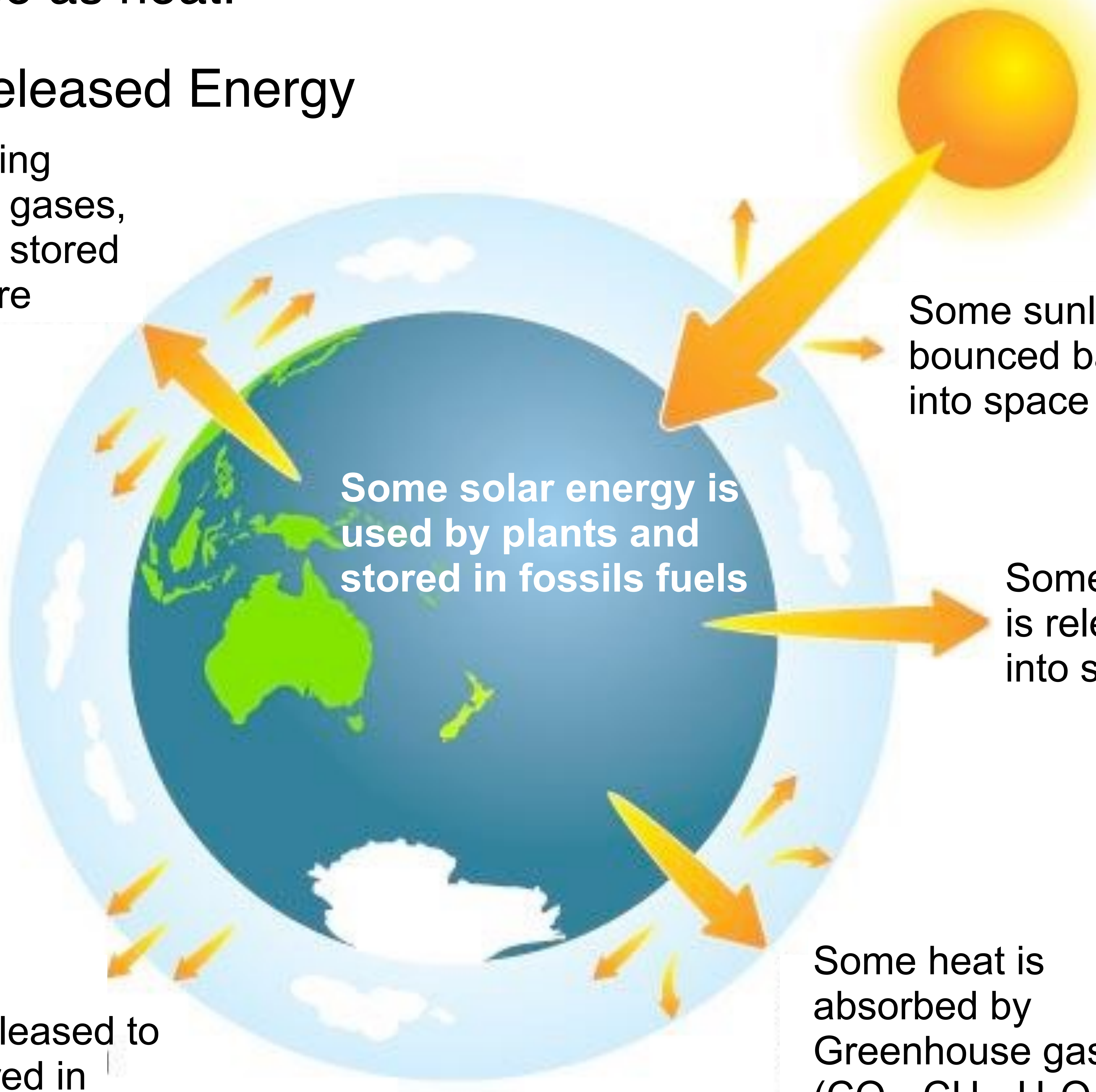

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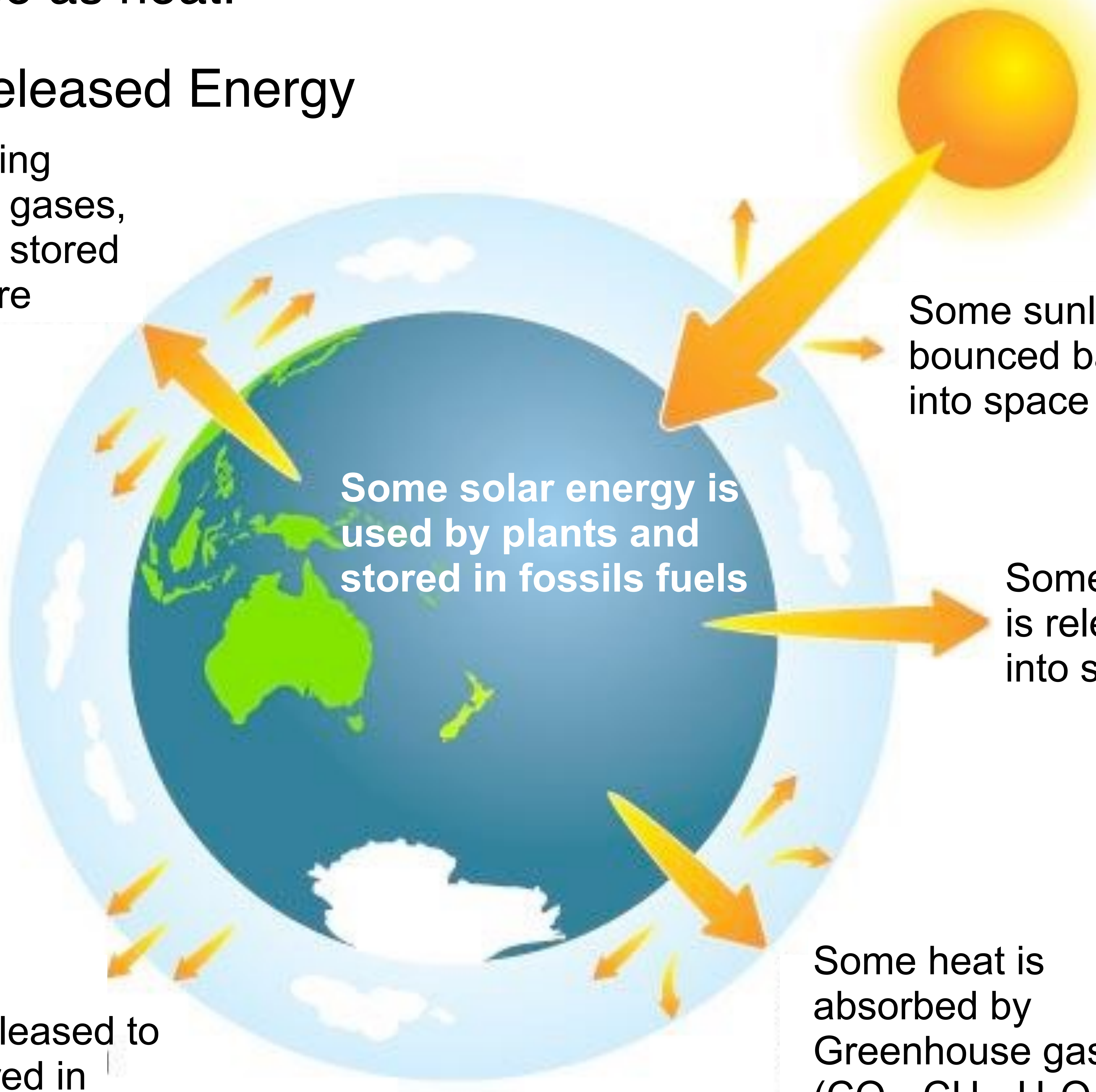
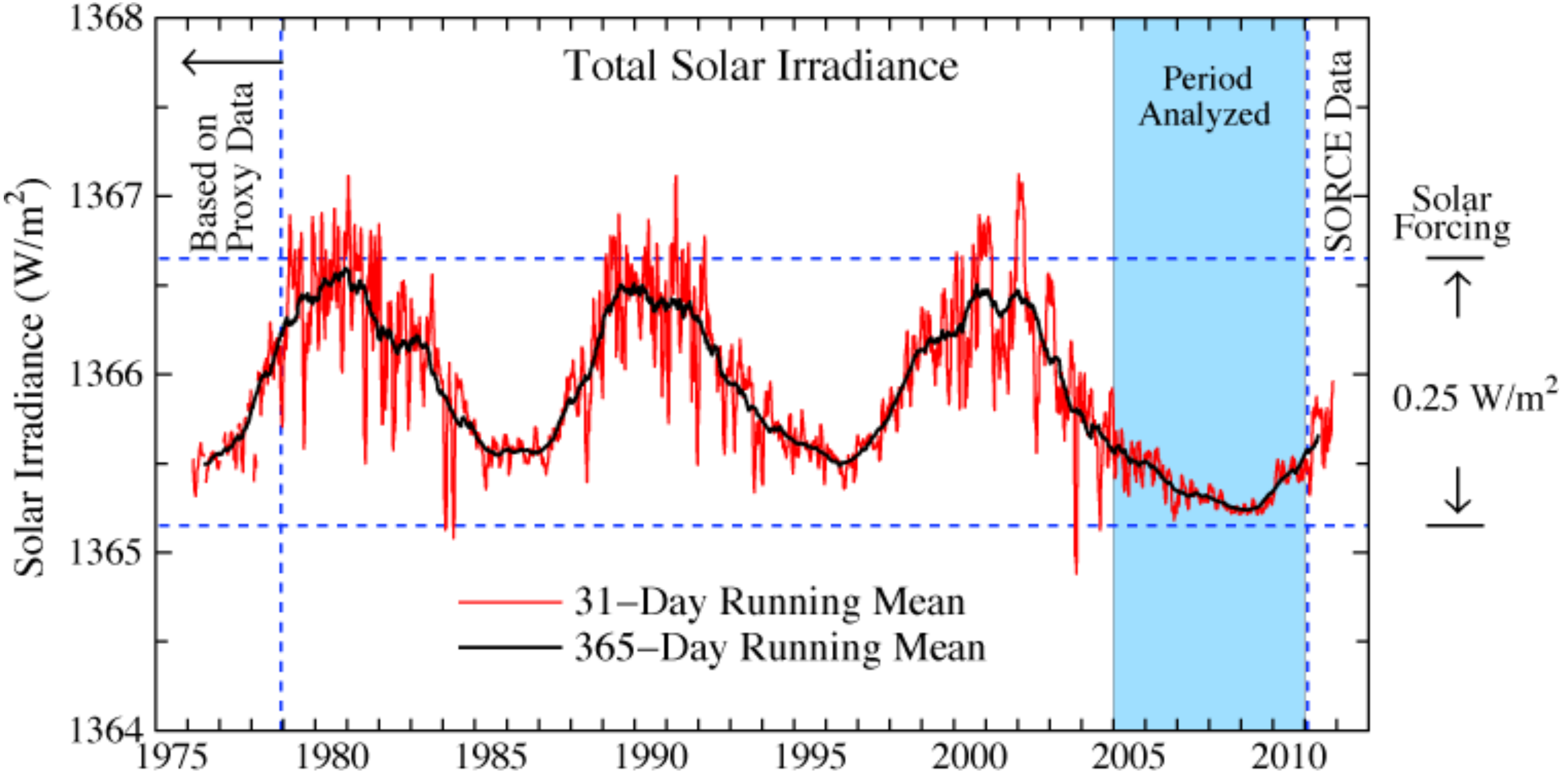
- 10,000 years EI: ±0.01 W/m^2
- Current EI: ~0.6 W/m^2



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/m^2, so the amplitude of solar variability is a forcing of ~0.25 W/m^2. (Credit: NASA/GISS)

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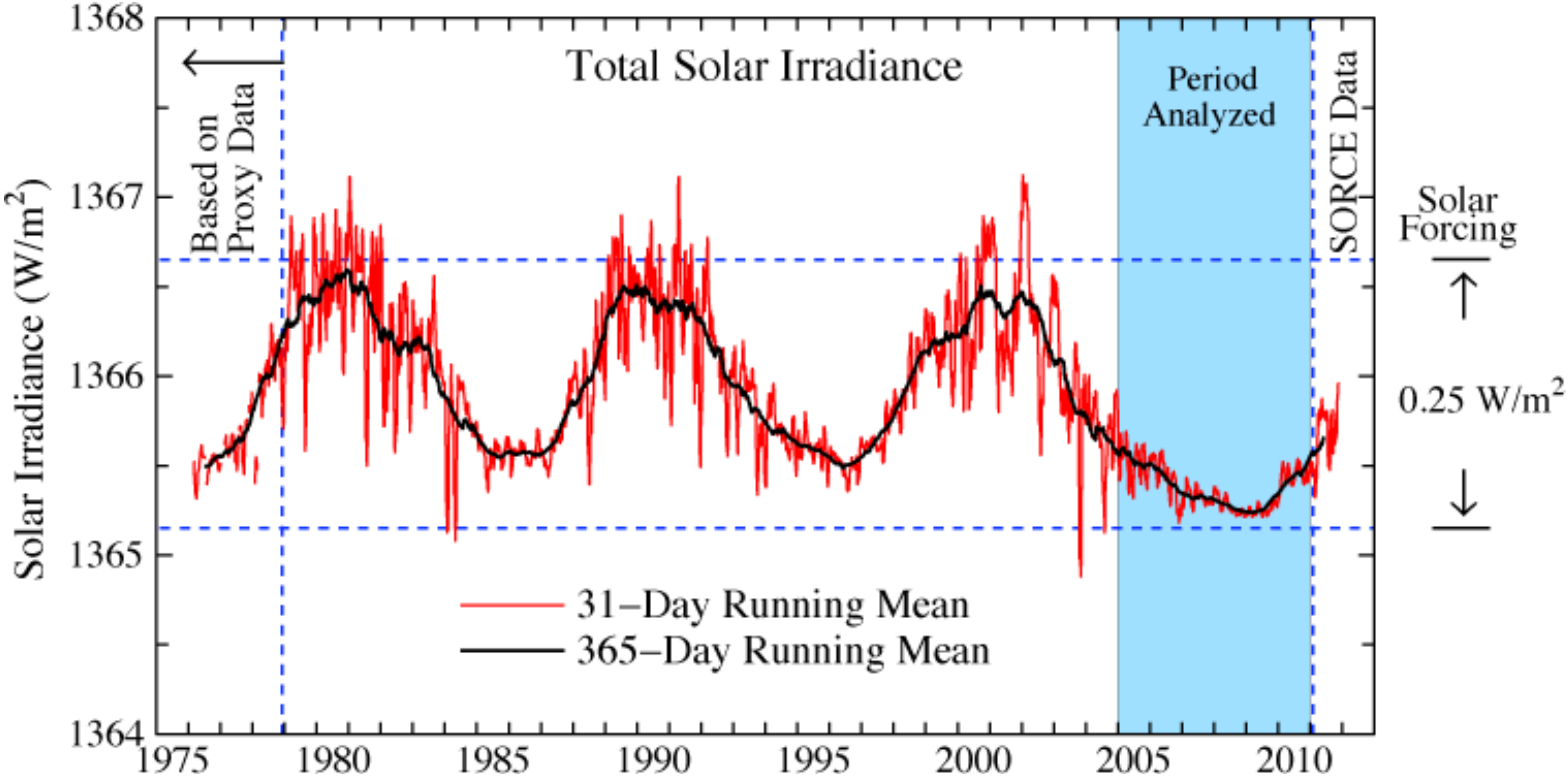

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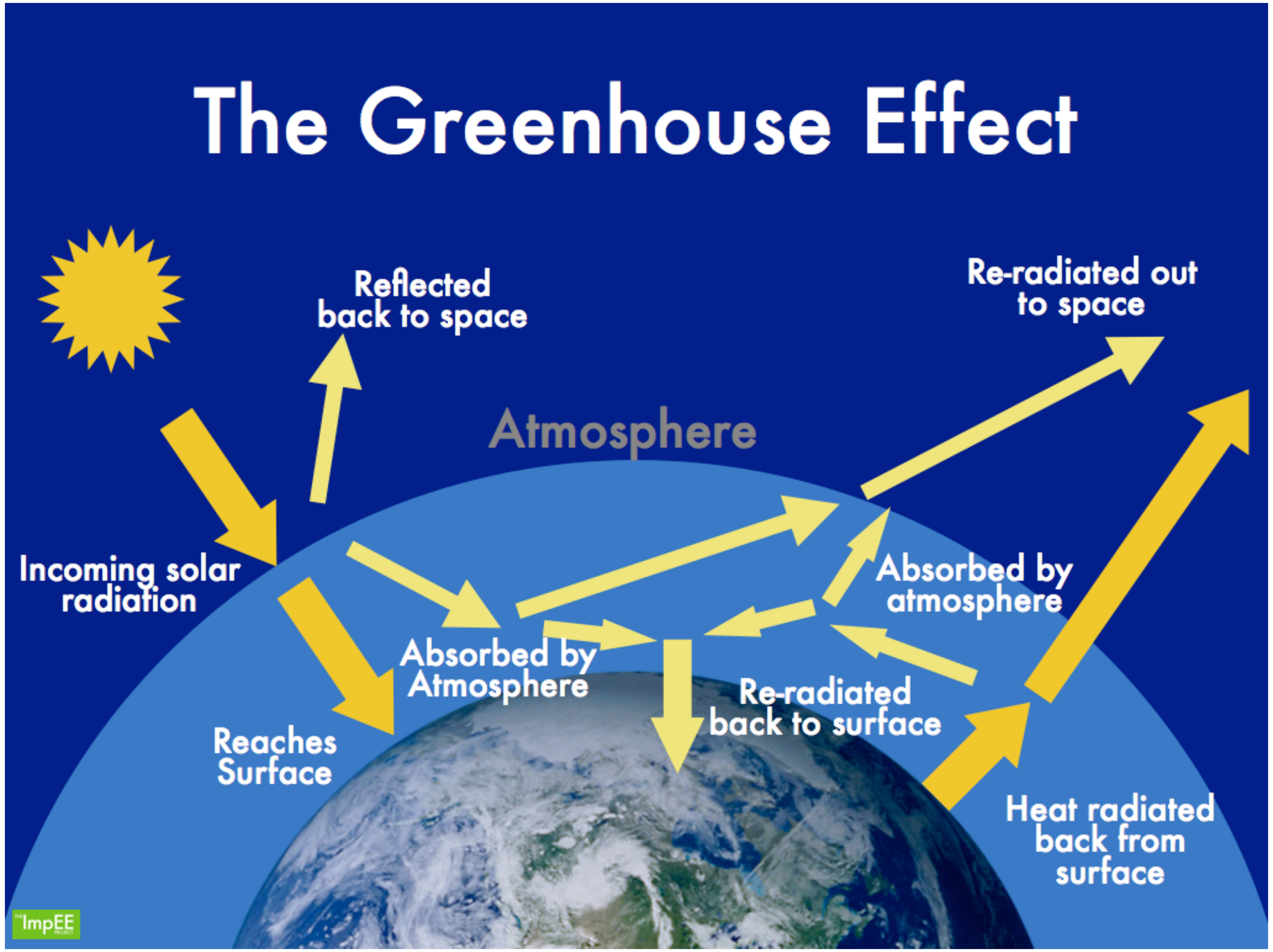
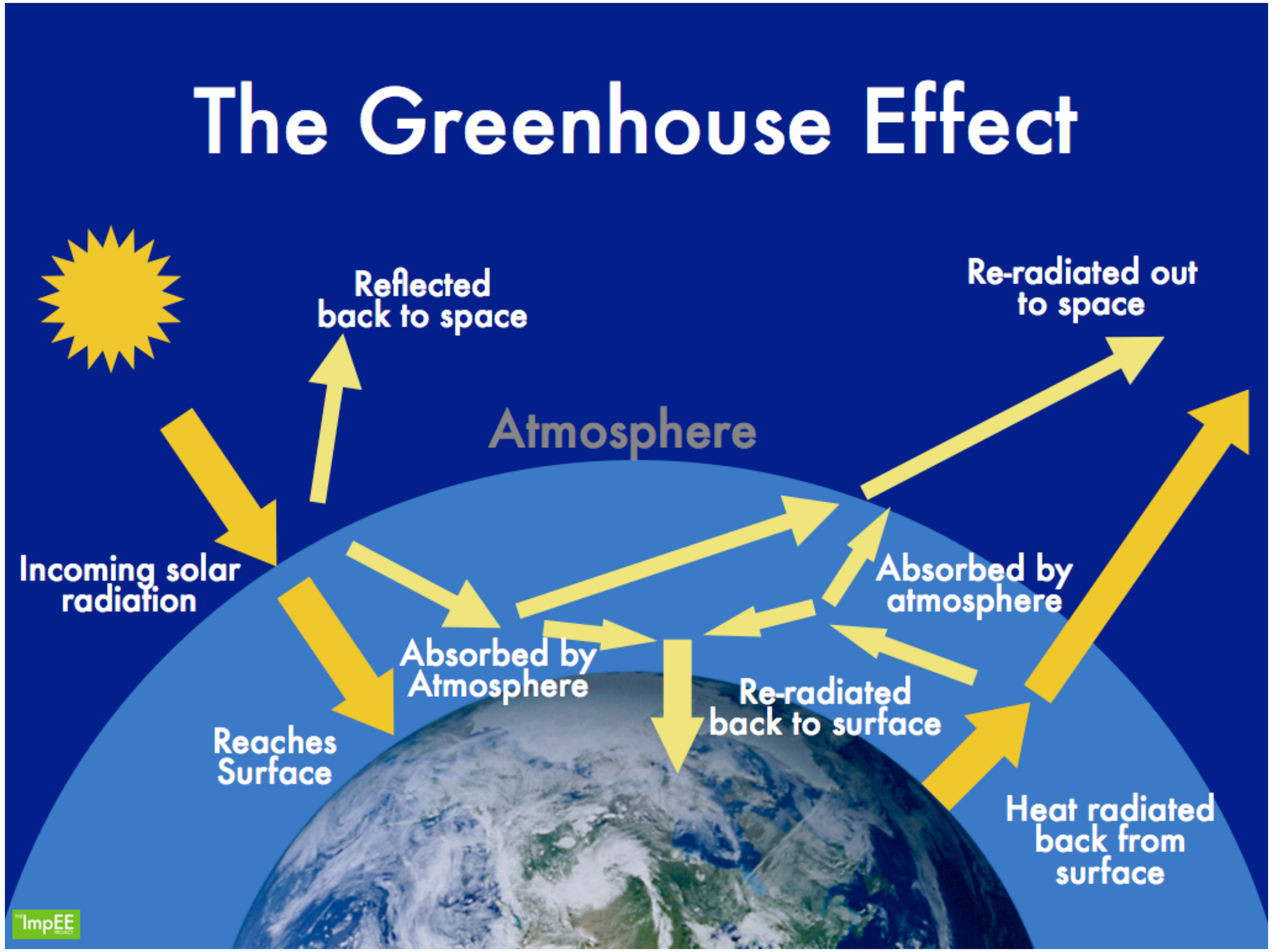
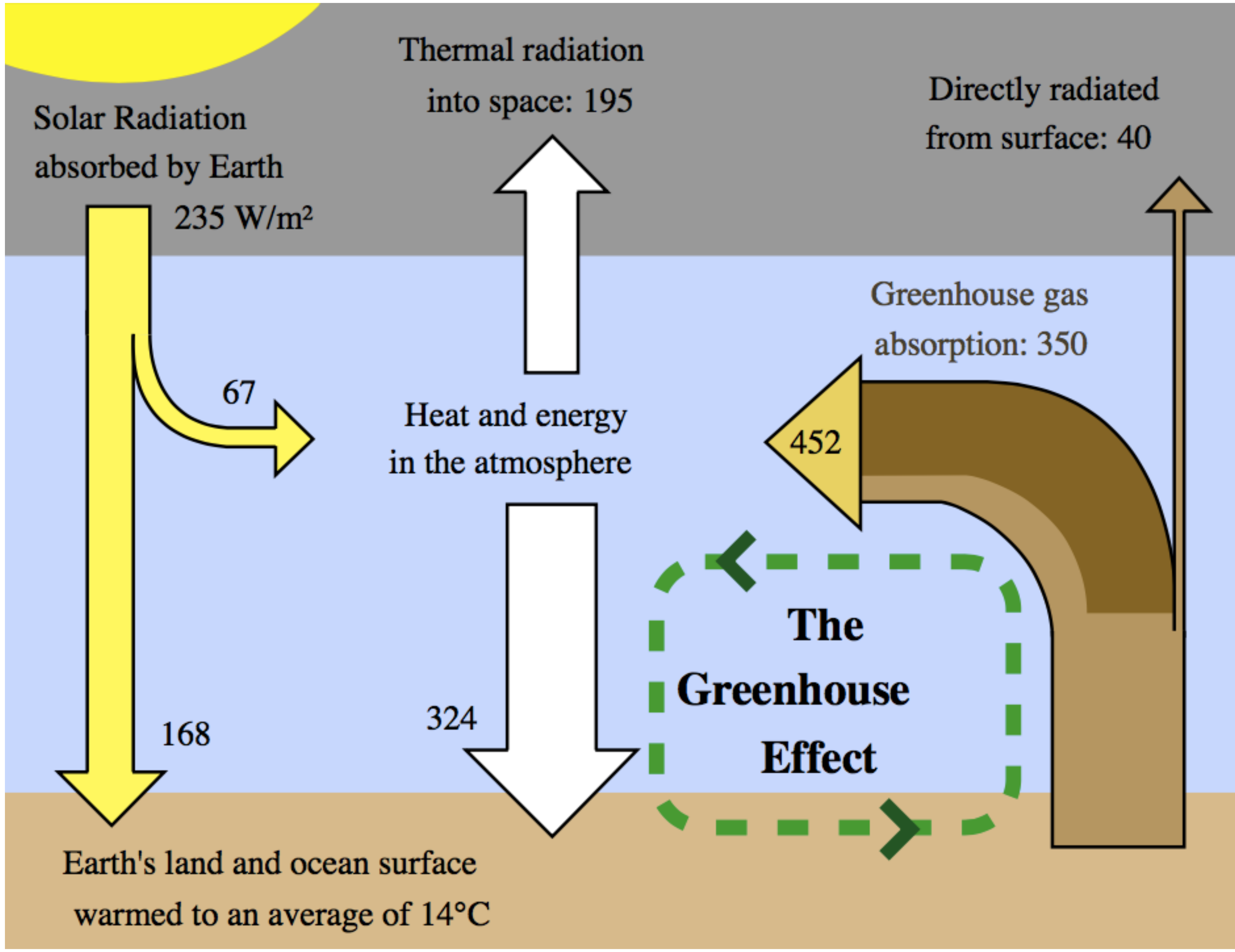



The Greenhouse Effect
Reflected back to space
Re-radiated out to space
Atmosphere
Incoming solar radiation
Absorbed by atmosphere
Absorbed by Atmosphere
Re-radiated back to surface
Reaches Surface
Heat radiated back from surface
ImpEE


Thermal radiation into space: 195
Solar Radiation absorbed by Earth
235 W/m²
Directly radiated from surface: 40
Greenhouse gas absorption: 350
67
Heat and energy in the atmosphere
452
The Greenhouse Effect
168
324
Earth's land and ocean surface warmed to an average of 14°C

The Baseline: Past Climate and Global Change

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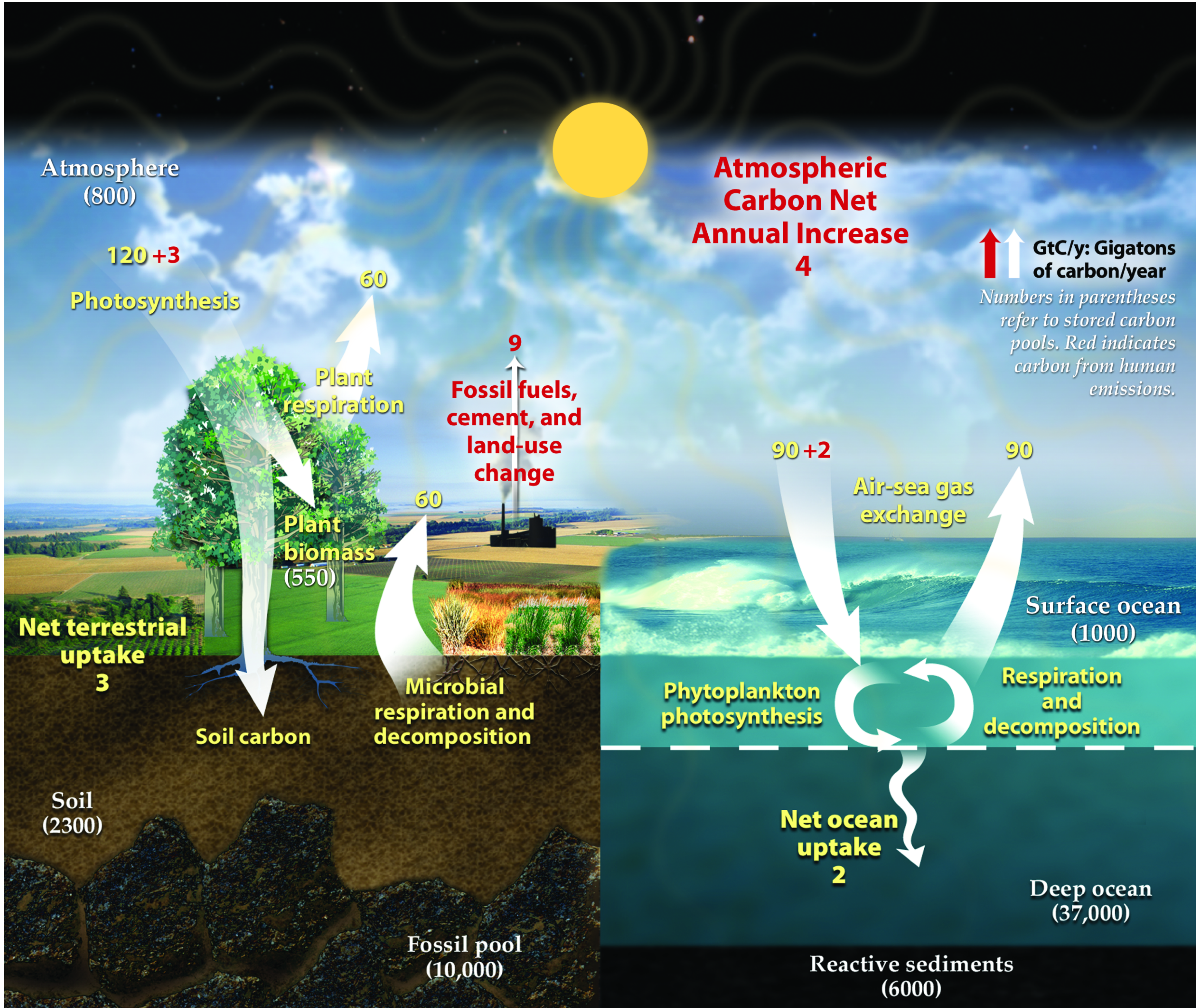
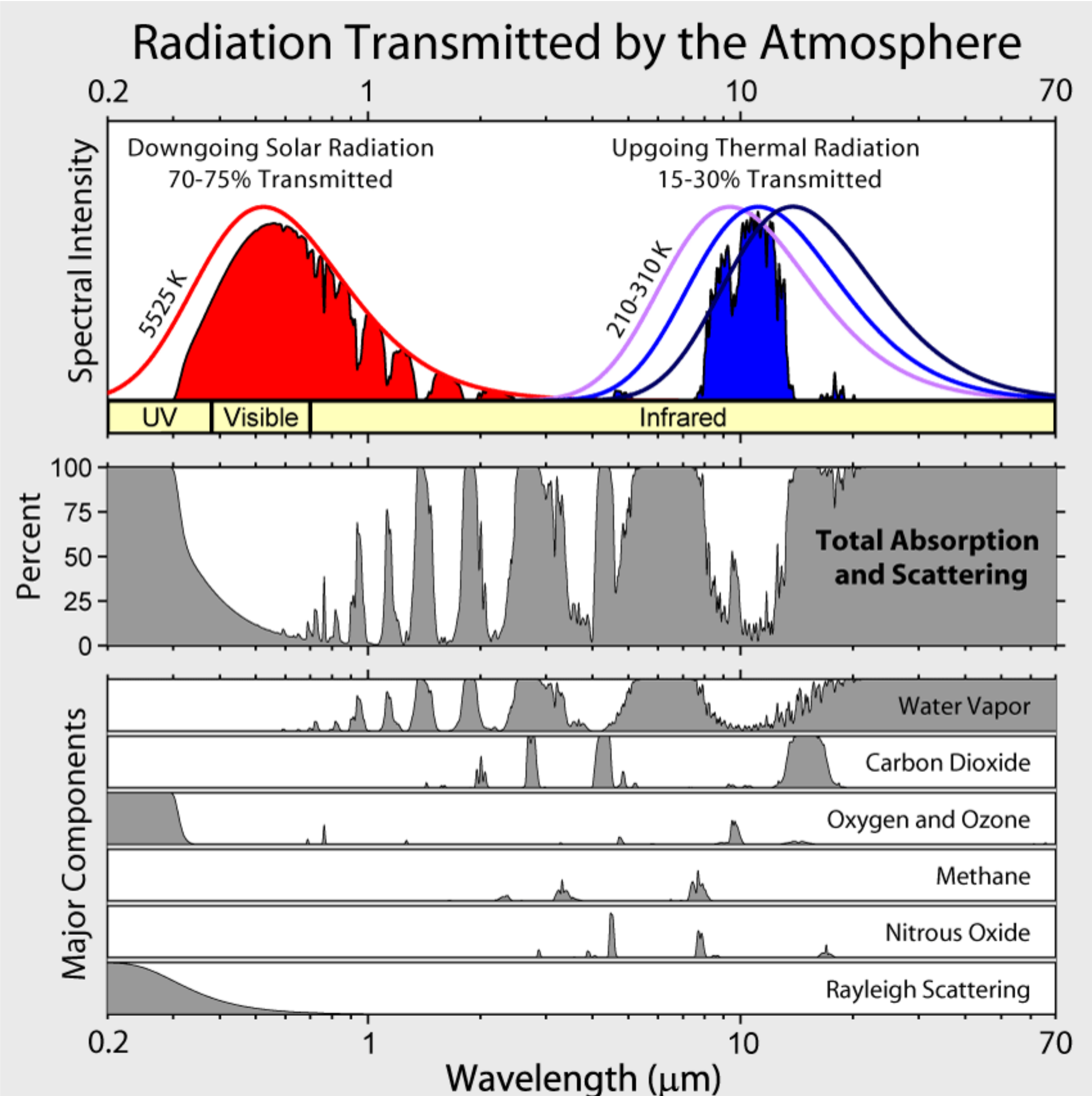




Atmospheric absorption and scattering at different wavelengths of electromagnetic waves. The largest absorption band of carbon dioxide is not far from the maximum in the thermal emission from ground, and it partly closes the window of transparency of water; hence its major effect.

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases

Gas name	Chemical formula	Lifetime (years)[22]	Global warming potential (GWP) for given time horizon		
			20-yr[22]	100-yr[22]	500-yr[39]
Carbon dioxide	CO_2	30–95	1	1	1
Methane	CH_4	12	84	28	7.6
Nitrous oxide	N_2O	121	264	265	153
CFC-12	CCl_2F_2	100	10 800	10 200	5 200
HCFC-22	$CHClF_2$	12	5 280	1 760	549
Tetrafluoromethane	CF_4	50 000	4 880	6 630	11 200
Hexafluoroethane	C_2F_6	10 000	8 210	11 100	18 200
Sulfur hexafluoride	SF_6	3 200	17 500	23 500	32 600
Nitrogen trifluoride	NF_3	500	12 800	16 100	20 700

The Baseline: Past Climate and Global Change

Greenhouse

Greenhouse

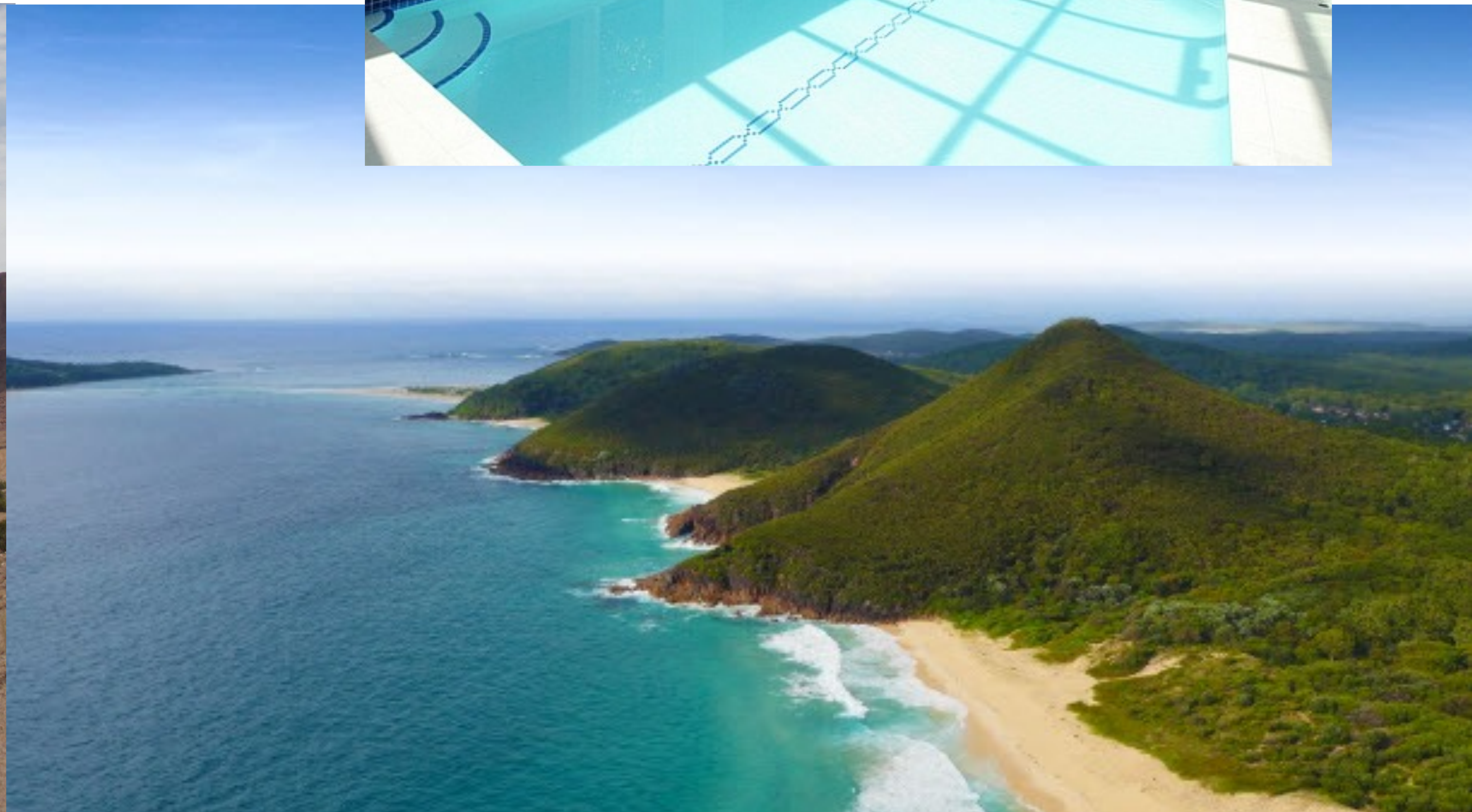
The Baseline: Past Climate and Global Change

Greenhouse

The Baseline: Past Climate and Global Change

Greenhouse

Poolhouse



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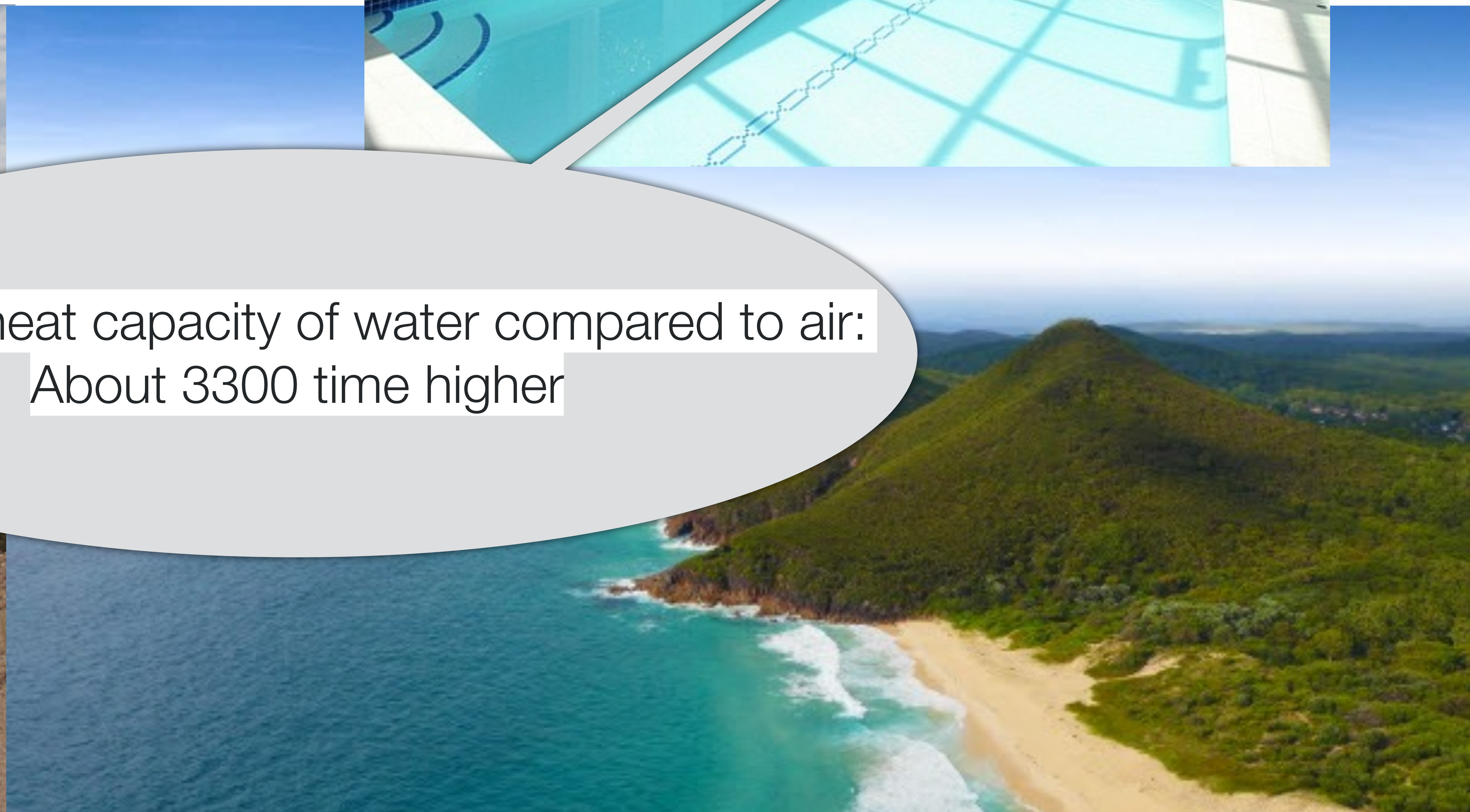
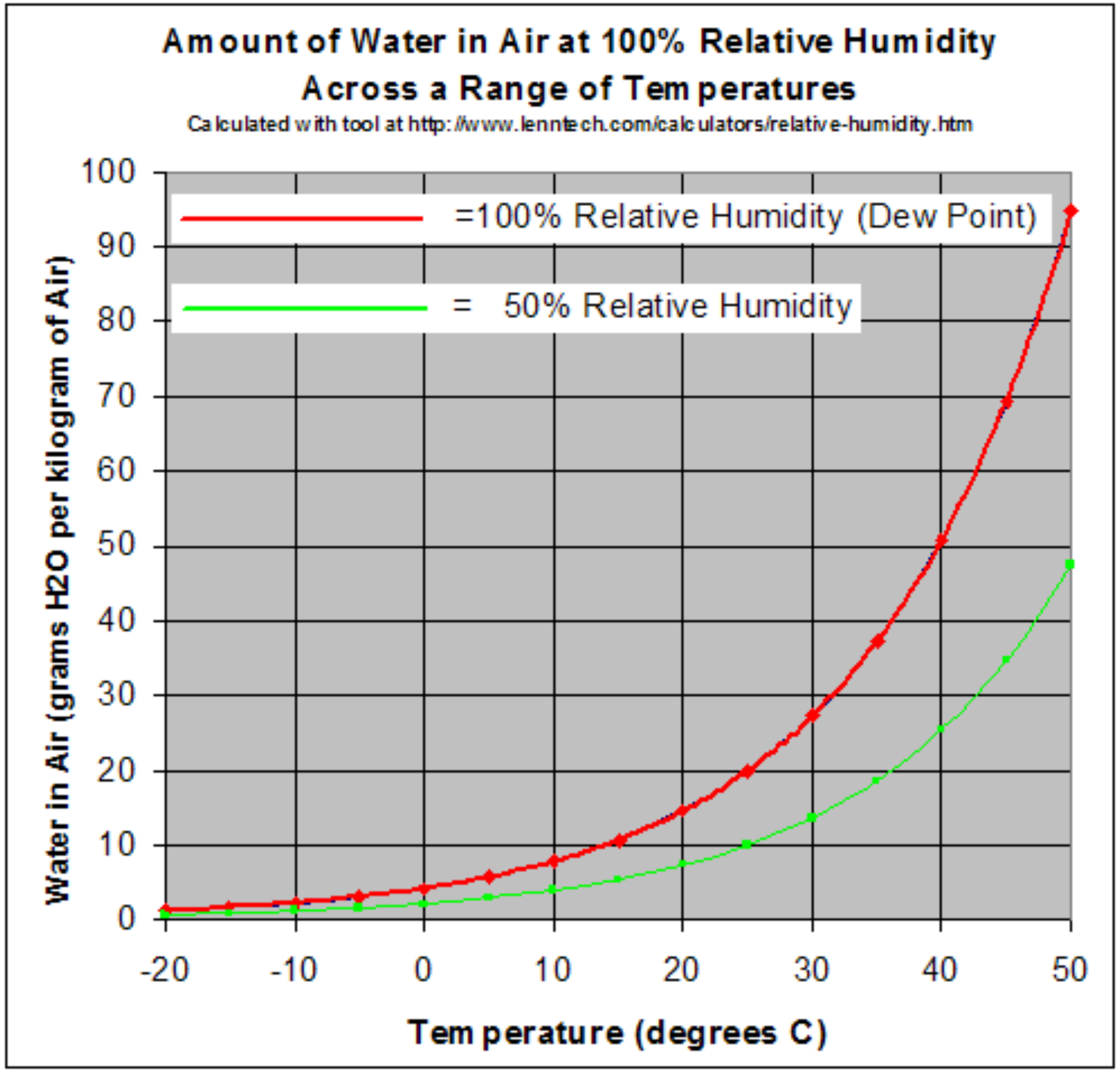
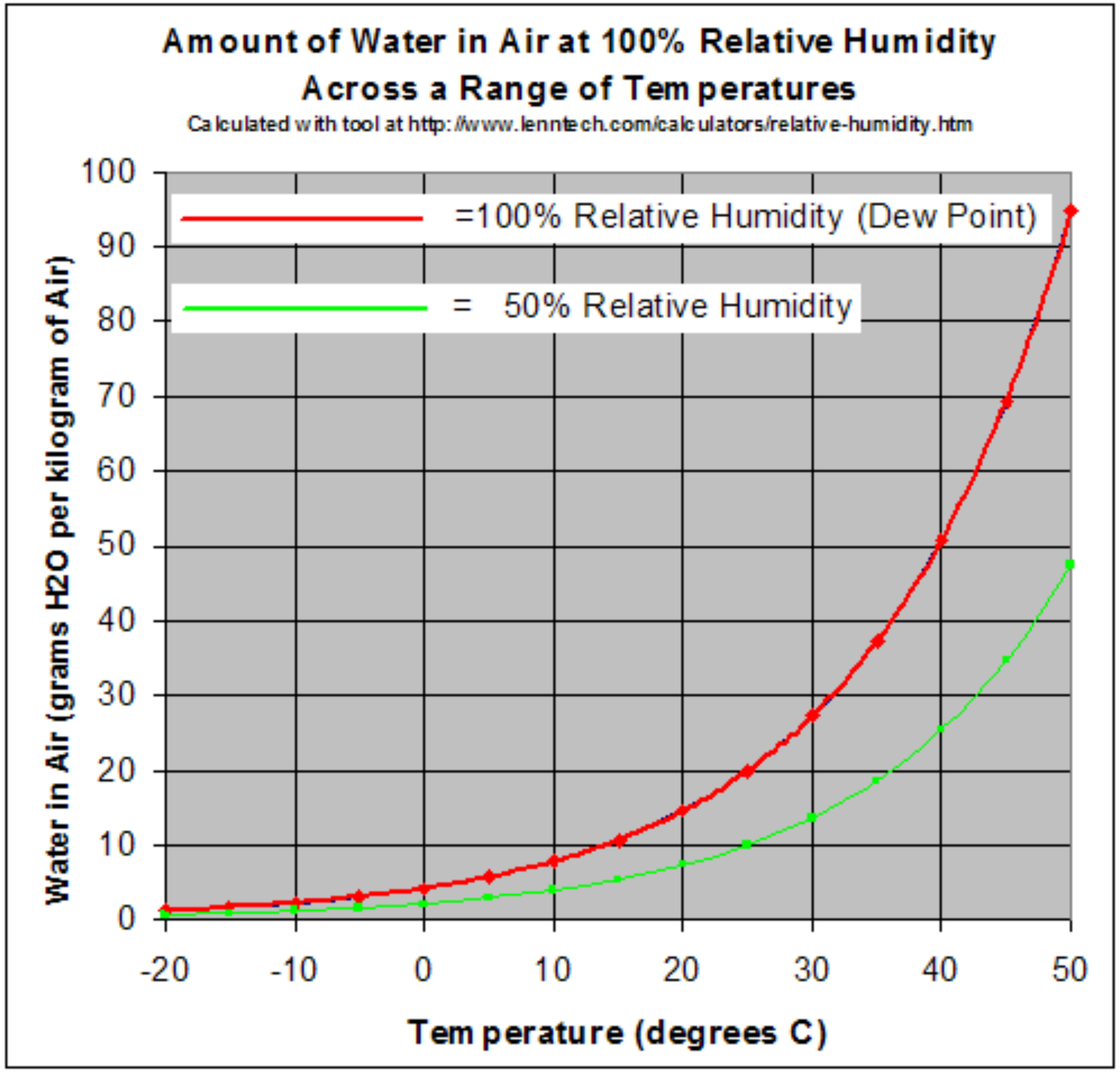


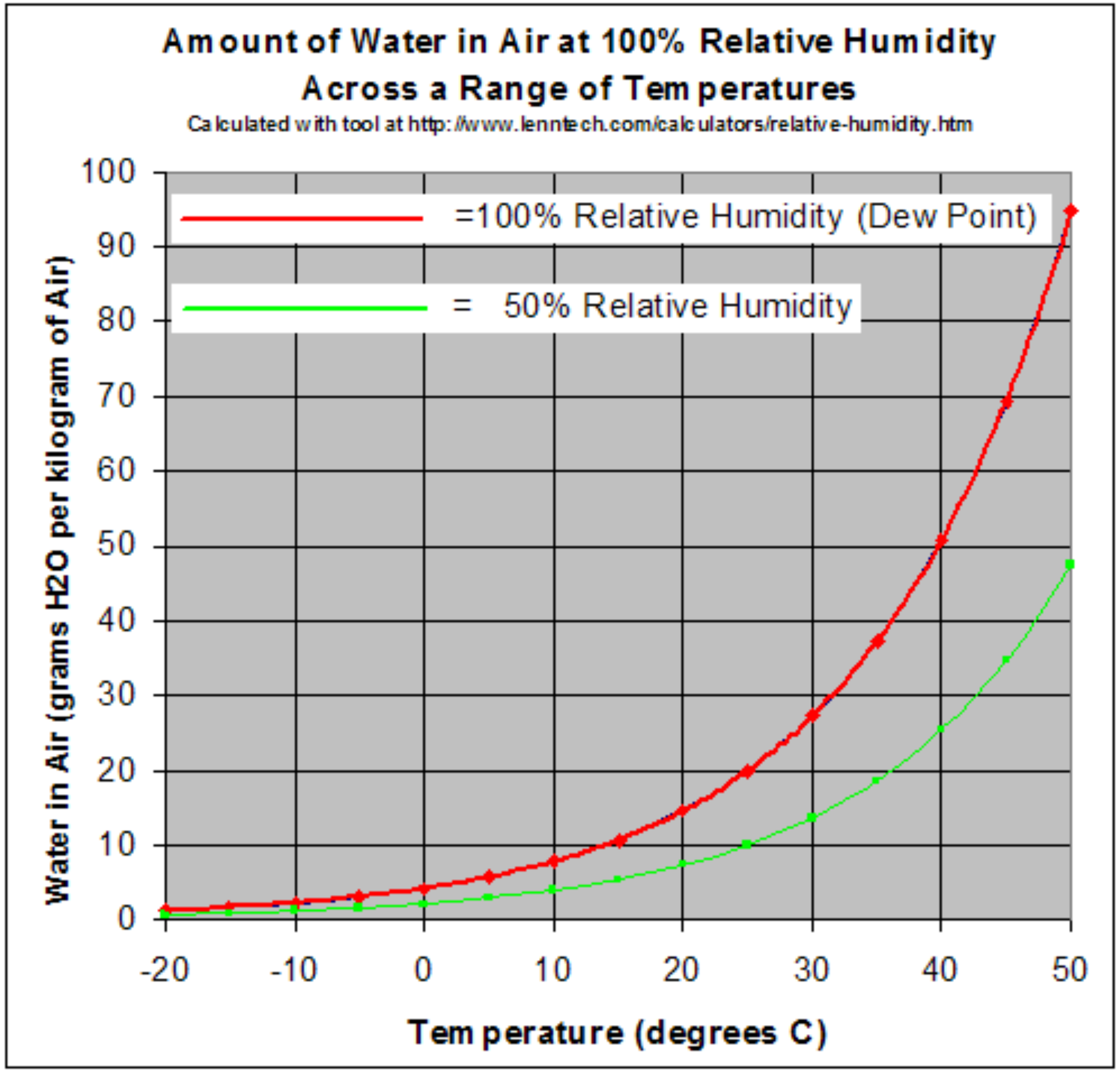
Volumetric heat capacity of water compared to air:
About 3300 time higher


Amount of Water in Air at 100% Relative Humidity
Across a Range of Temperatures
Calculated with tool at http://www.lenntech.com/calculators/relative-humidity.htm
=100% Relative Humidity (Dew Point)
= 50% Relative Humidity
Water in Air (grams H2O per kilogram of Air)
Temperature (degrees C)
100
90
80
70
60
50
40
30
20
10
0
-20
-10
0
10
20
30
40
50



Specific heat capacity:
Water: 4200 $Jkg^{-1}K^{-1}$
Air: 993 $Jkg^{-1}K^{-1}$

Water has 4.23 times higher specific heat capacity.



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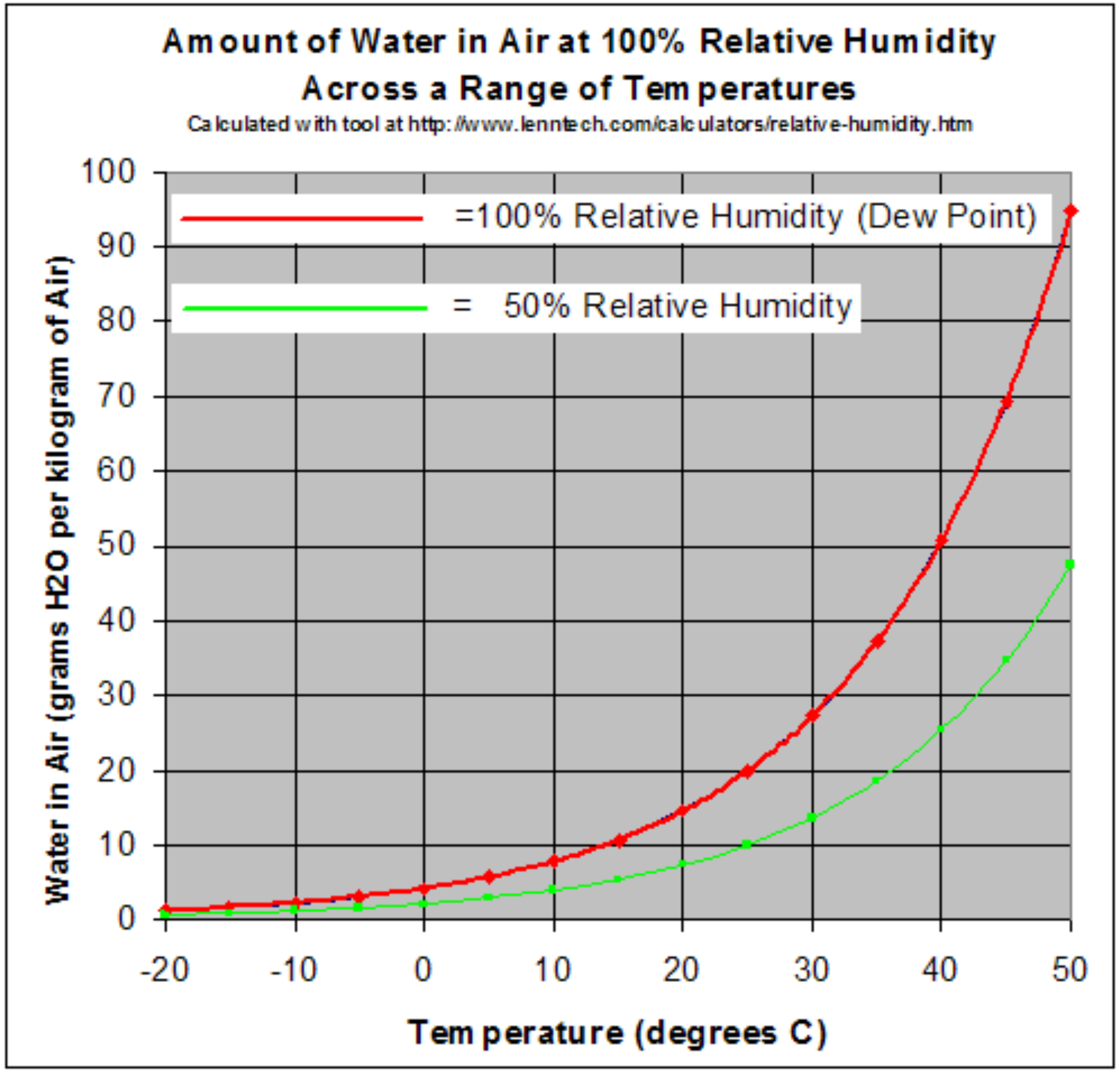
Density:
Water: 1000 kg/m^3
Air: 1.275 kg/m^3

Water is about 785 times denser than air.



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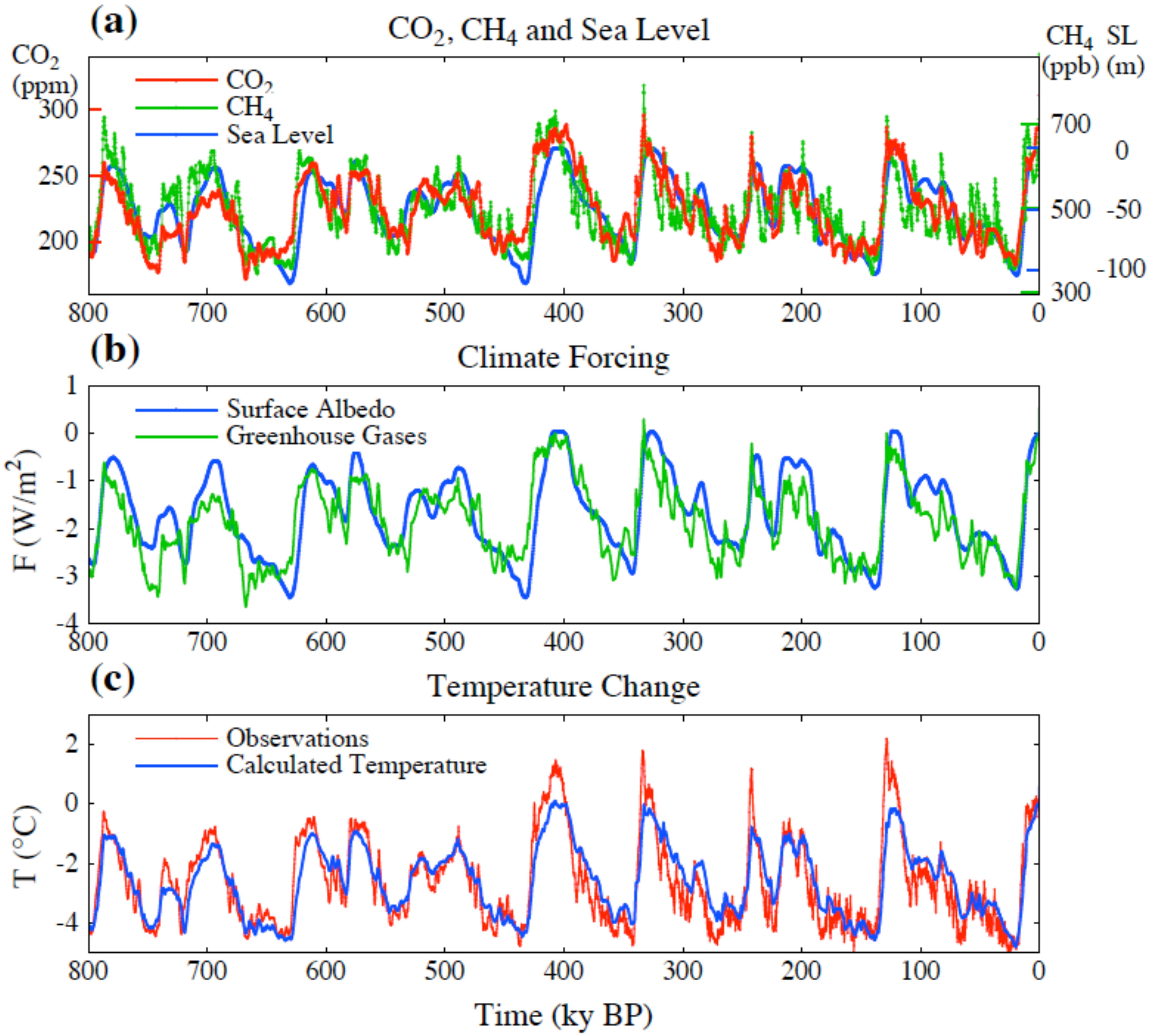
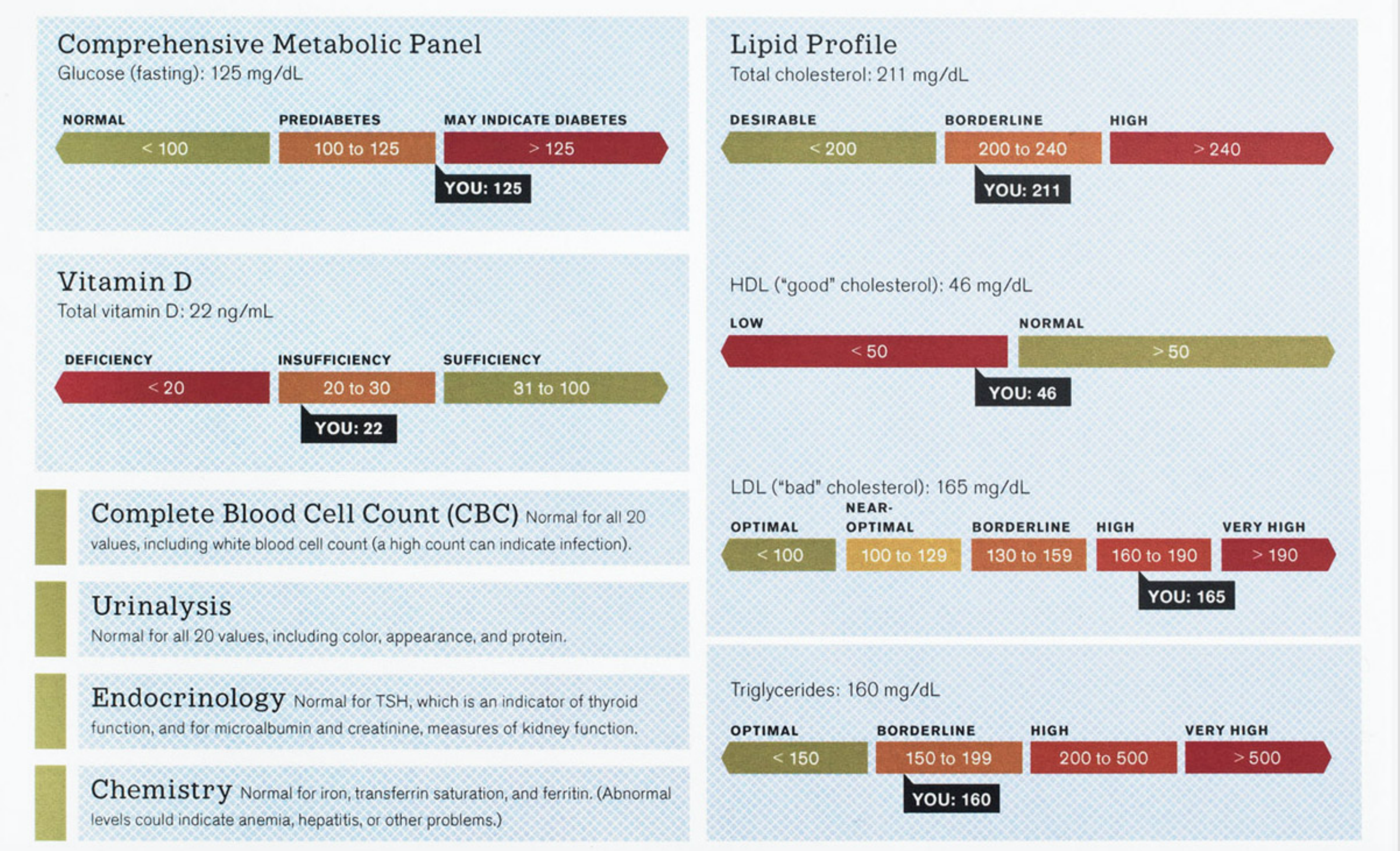
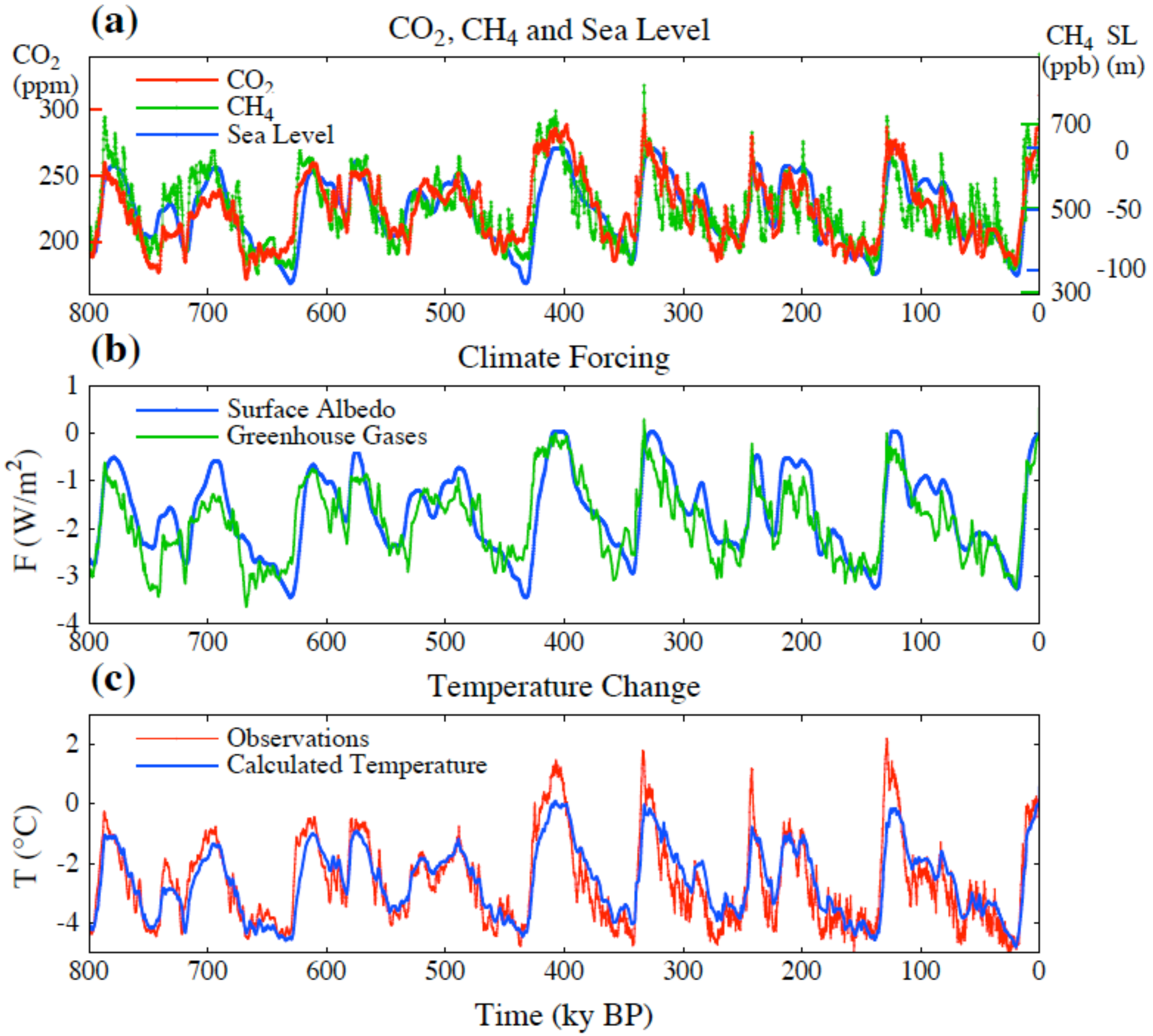


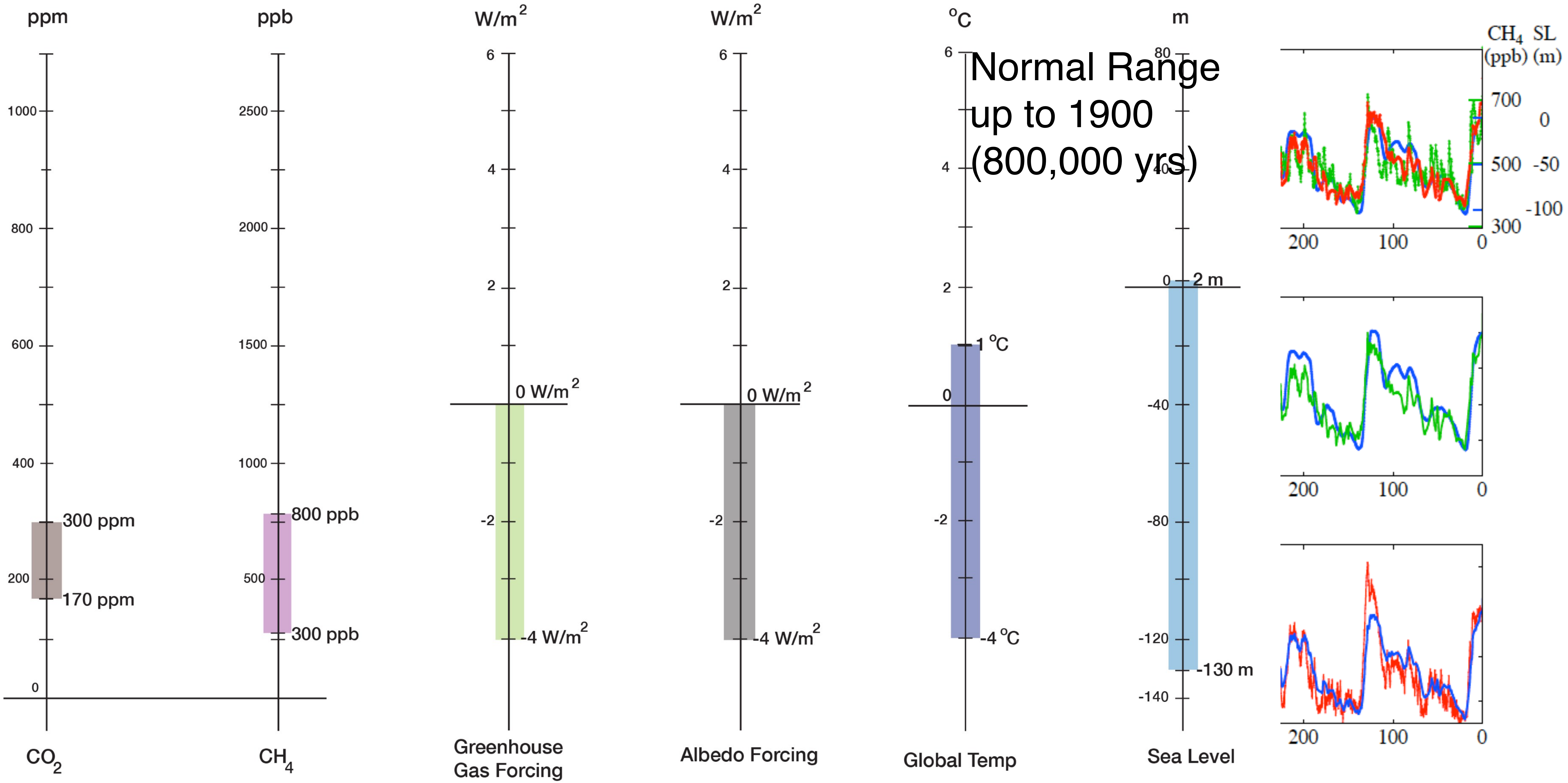
The Baseline: Past Climate and Global Change

Medical Lab Sheet



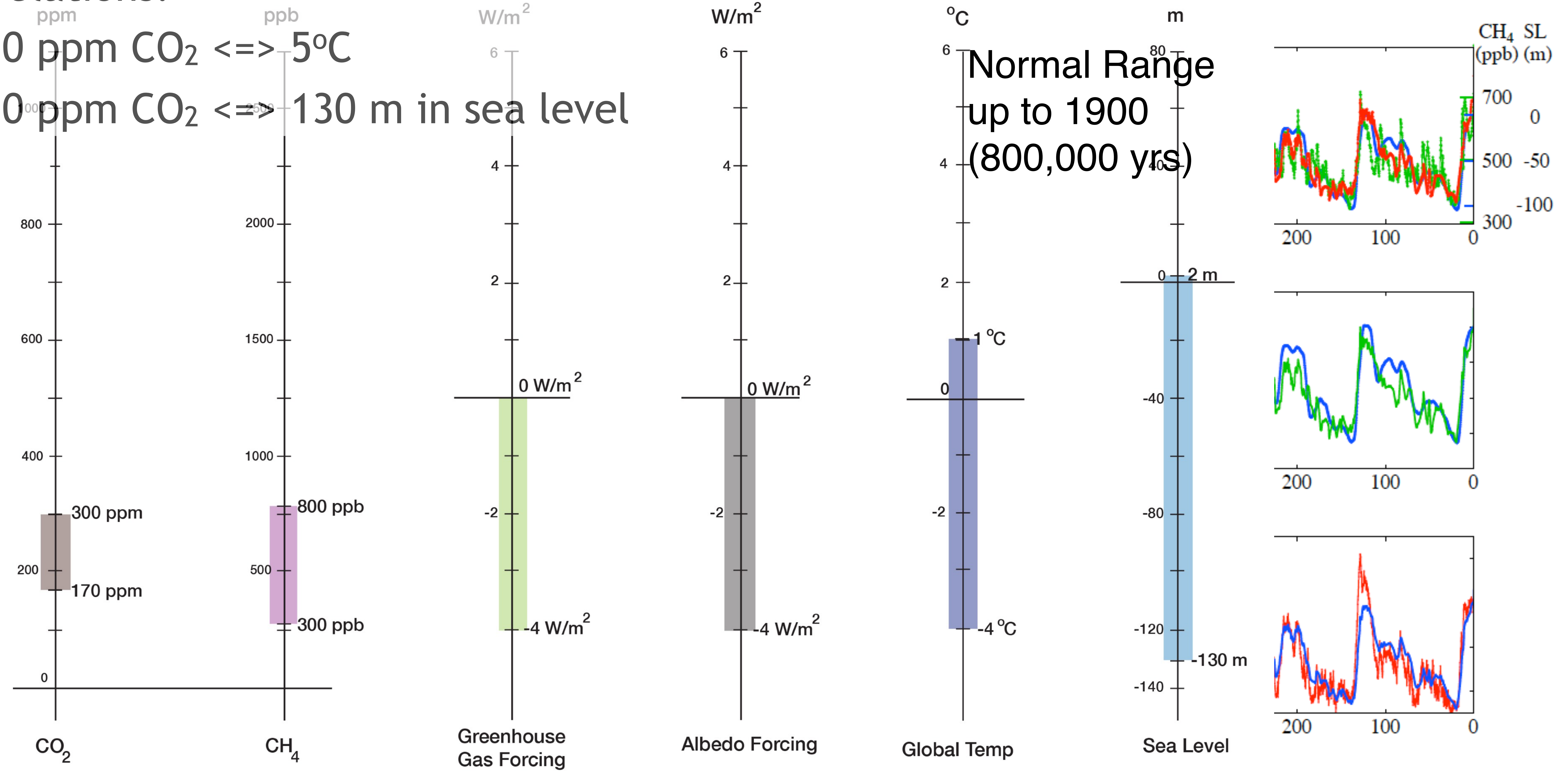


The Baseline: Past Climate and Global Change



Long-term (centuries to millennia) correlations:

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



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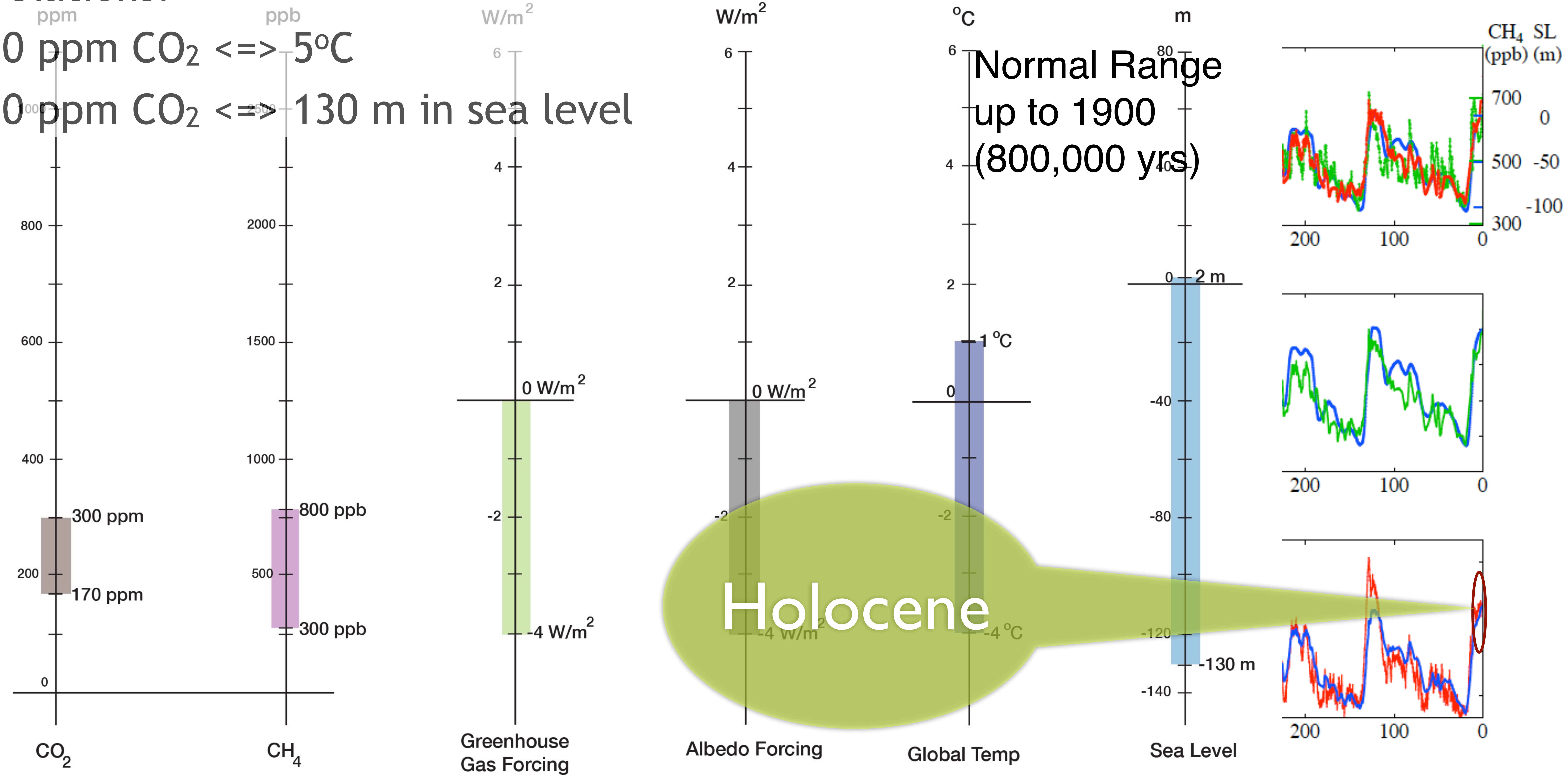

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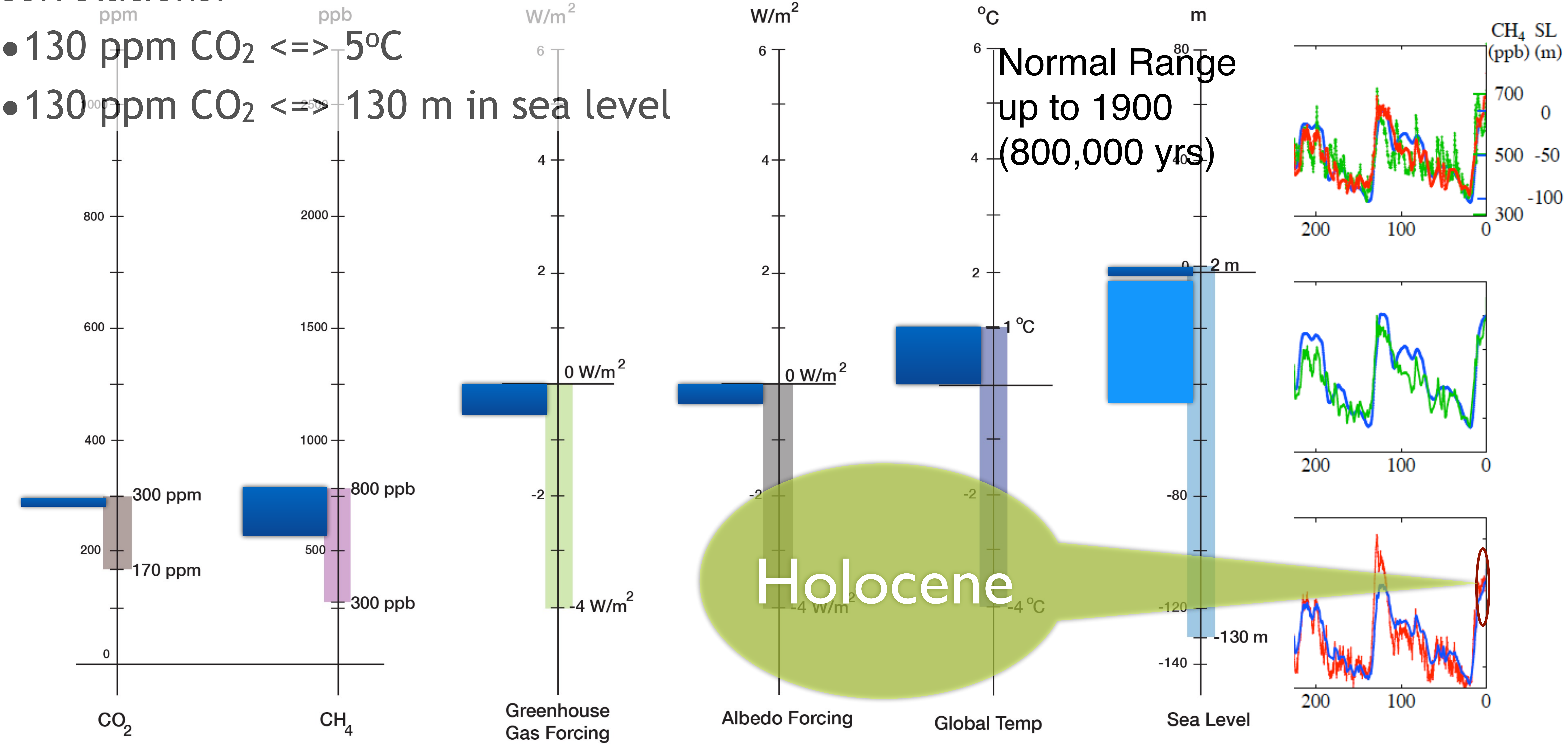

The Baseline: Past Climate and Global Change

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

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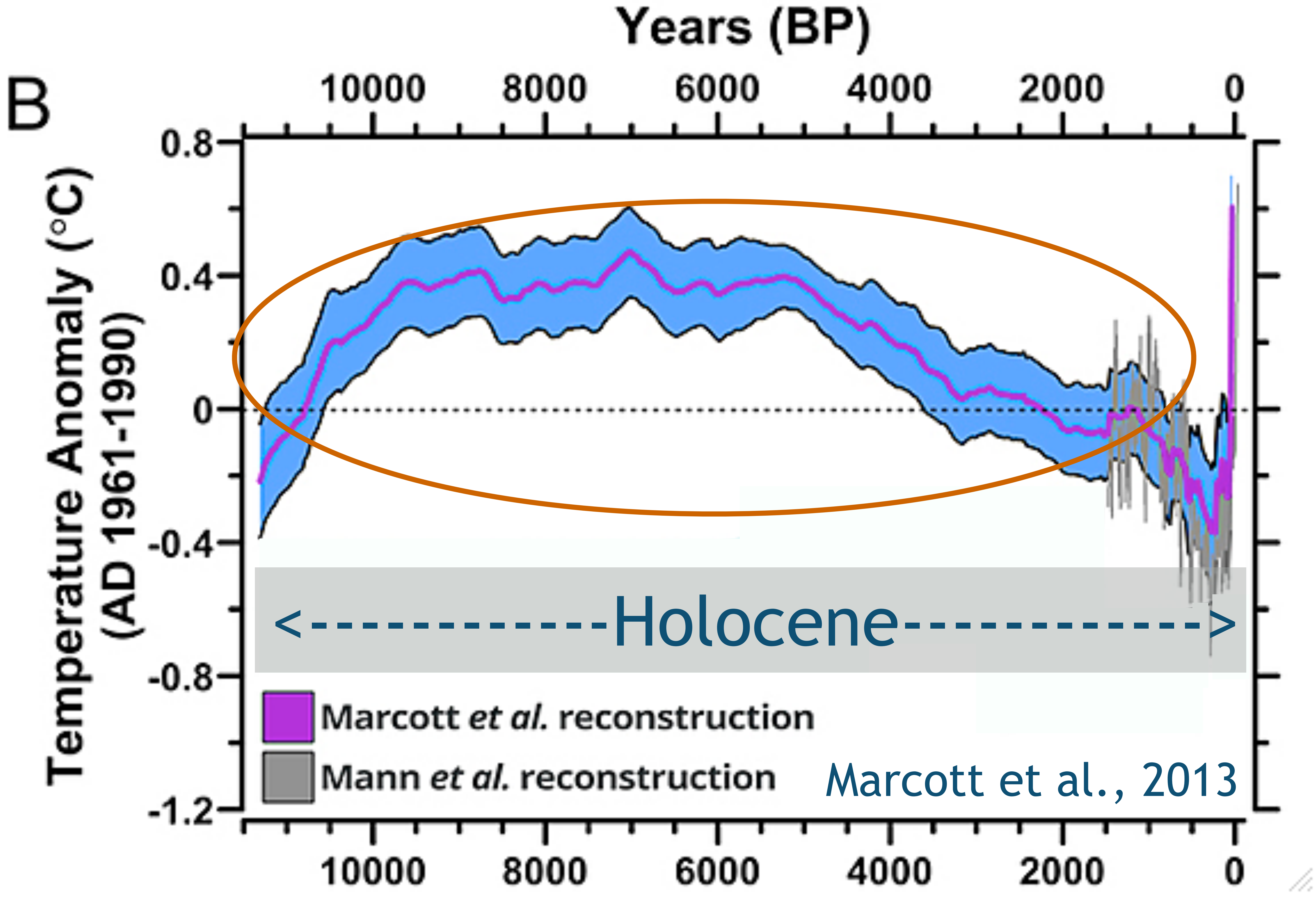
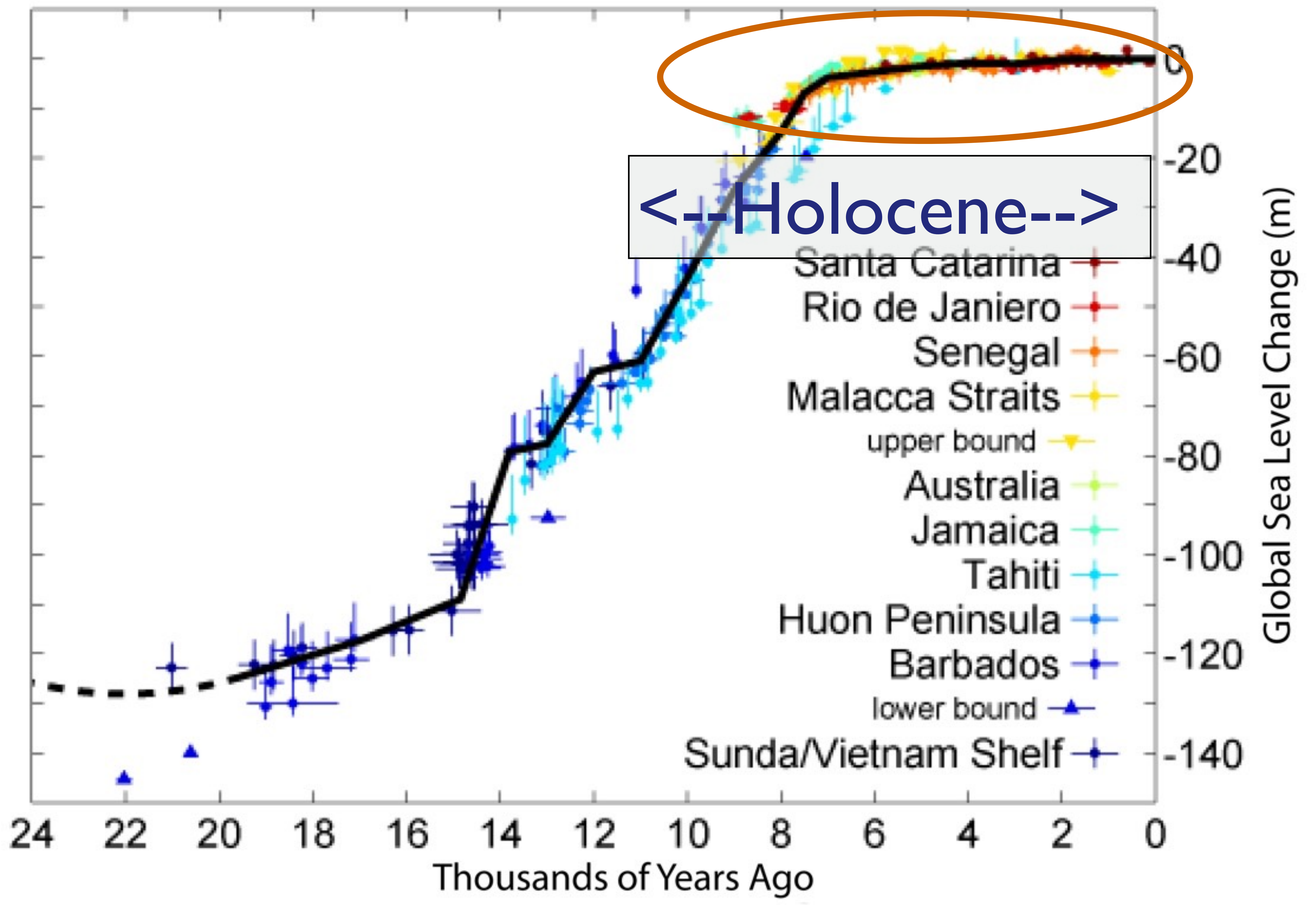
Global Temperature Changes



Global Sea Level Changes



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

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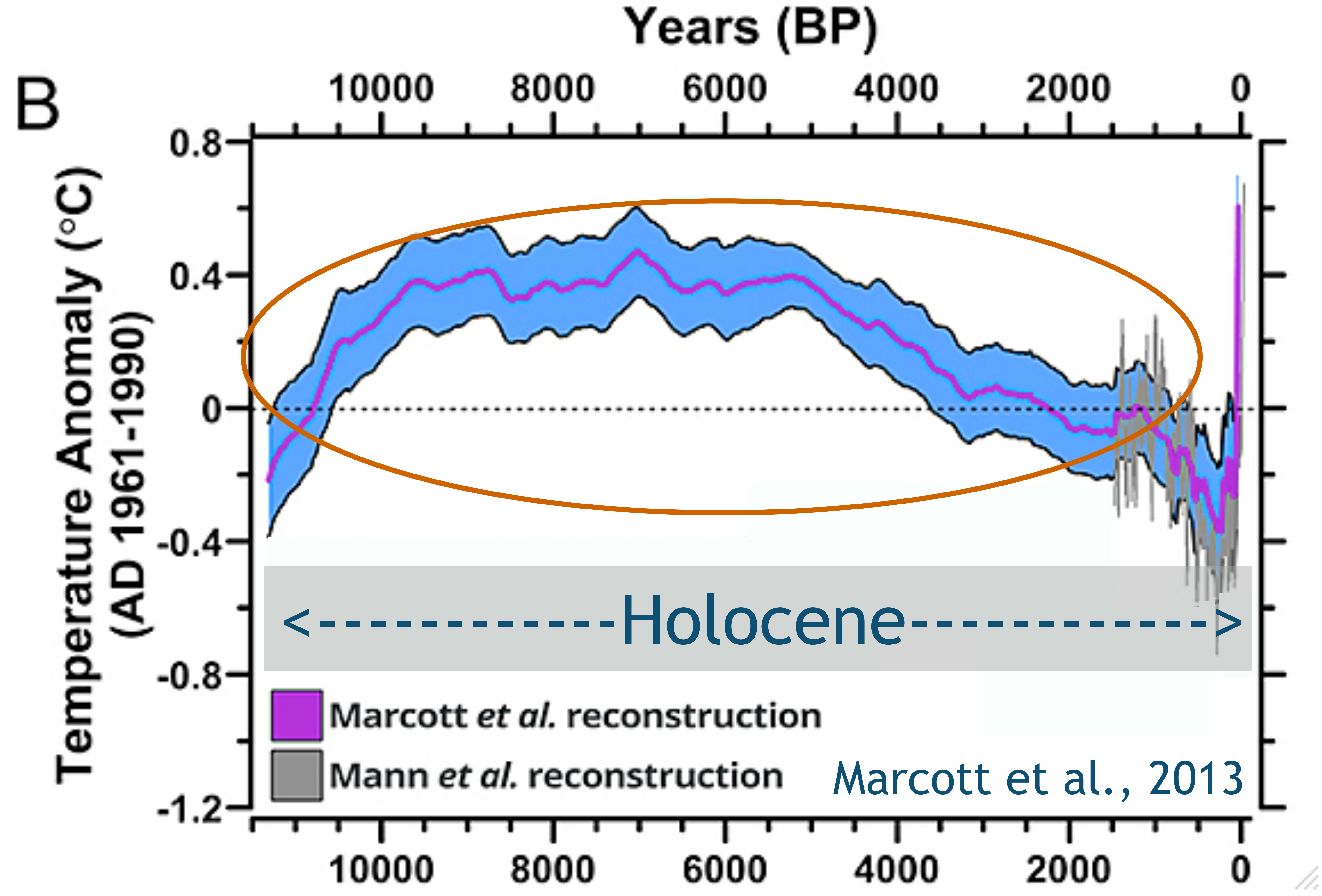
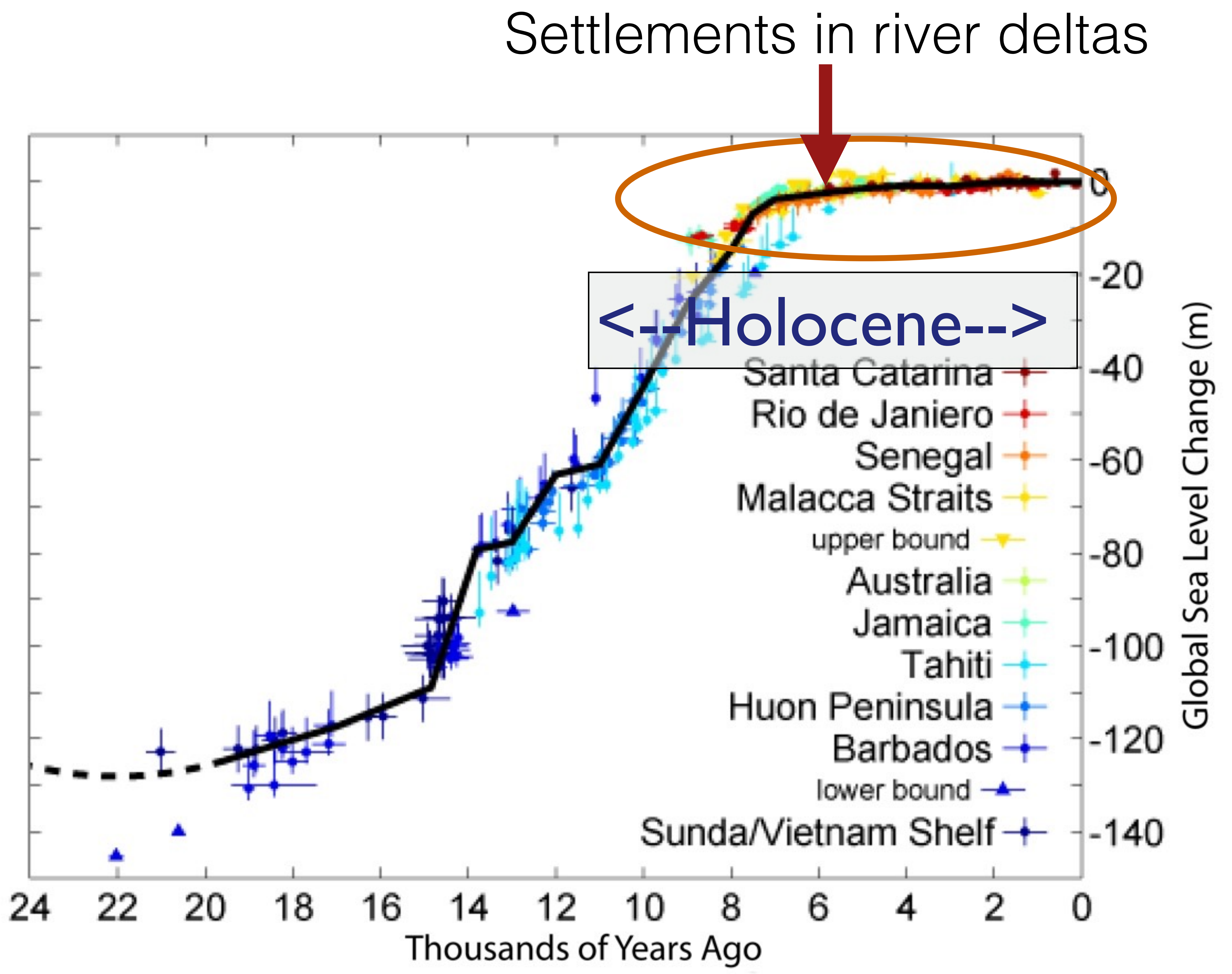
Global Temperature Changes	Global Sea Level Changes





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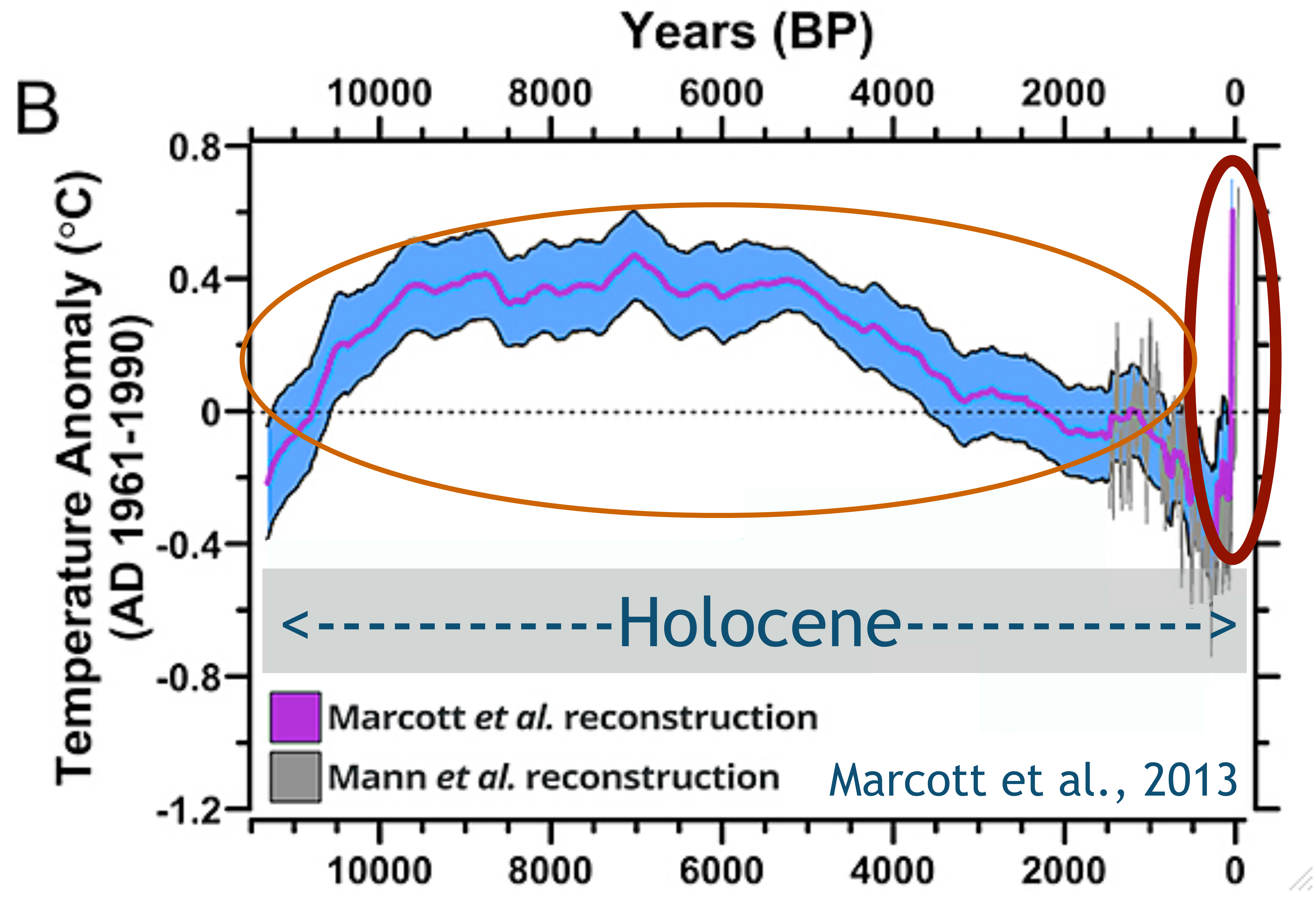

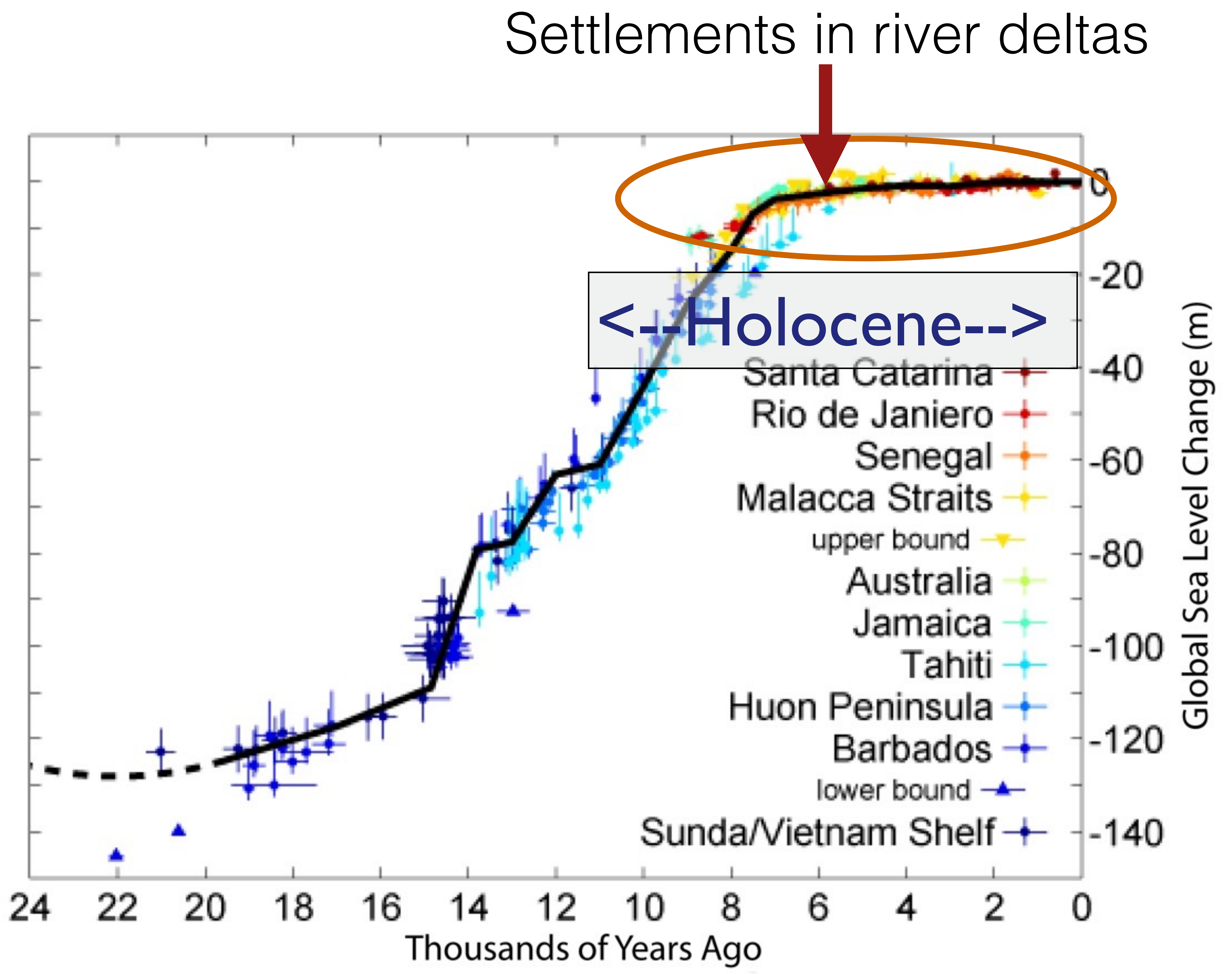

With stable climate and sea level, the Holocene was a safe operating space for humanity.

Key Points

Baseline

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

Modern Climate Change: A Symptom of a Single-Species High-Energy Pulse Syndrome

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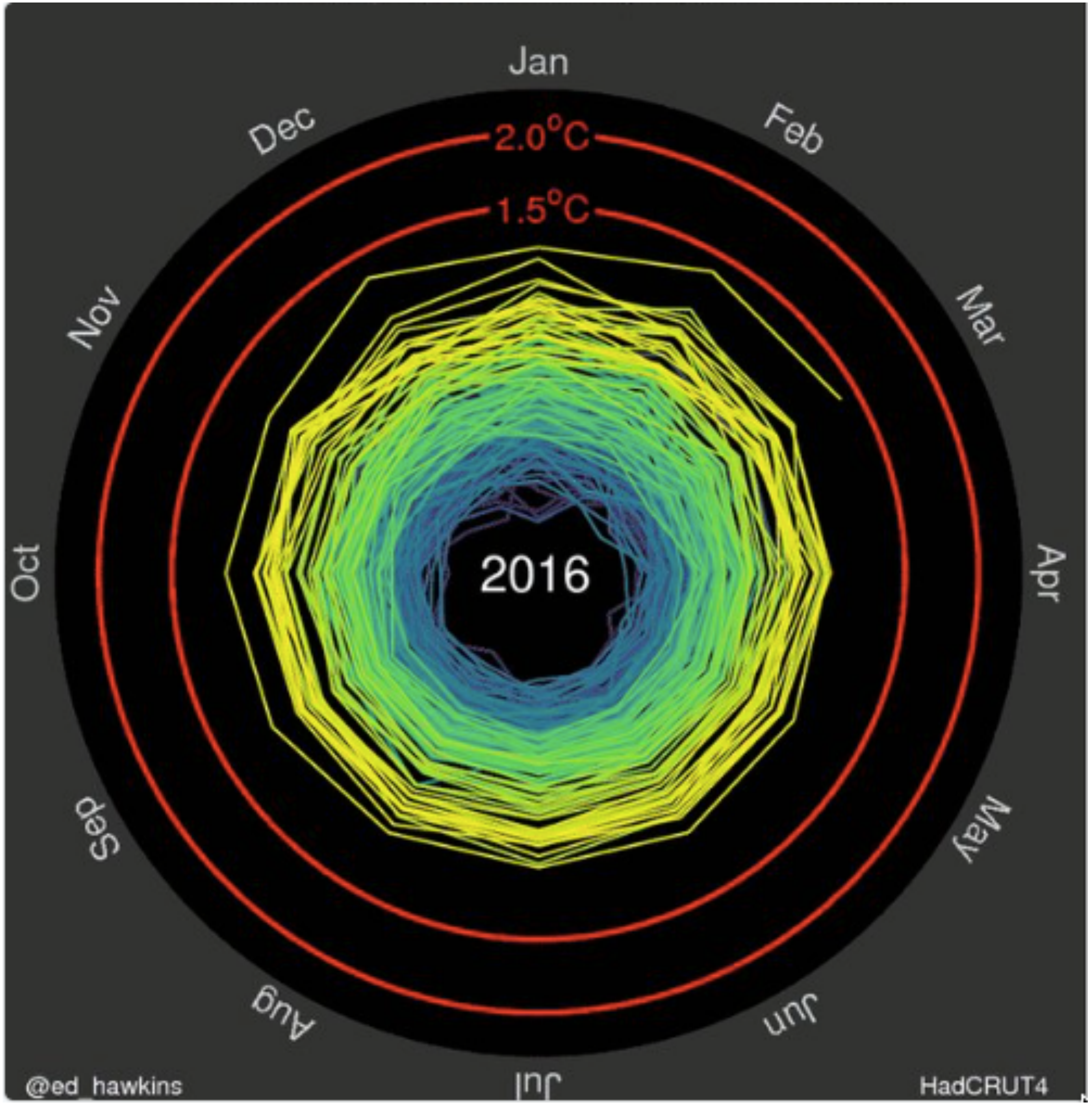
The Syndrome: Recent Climate and Global Change



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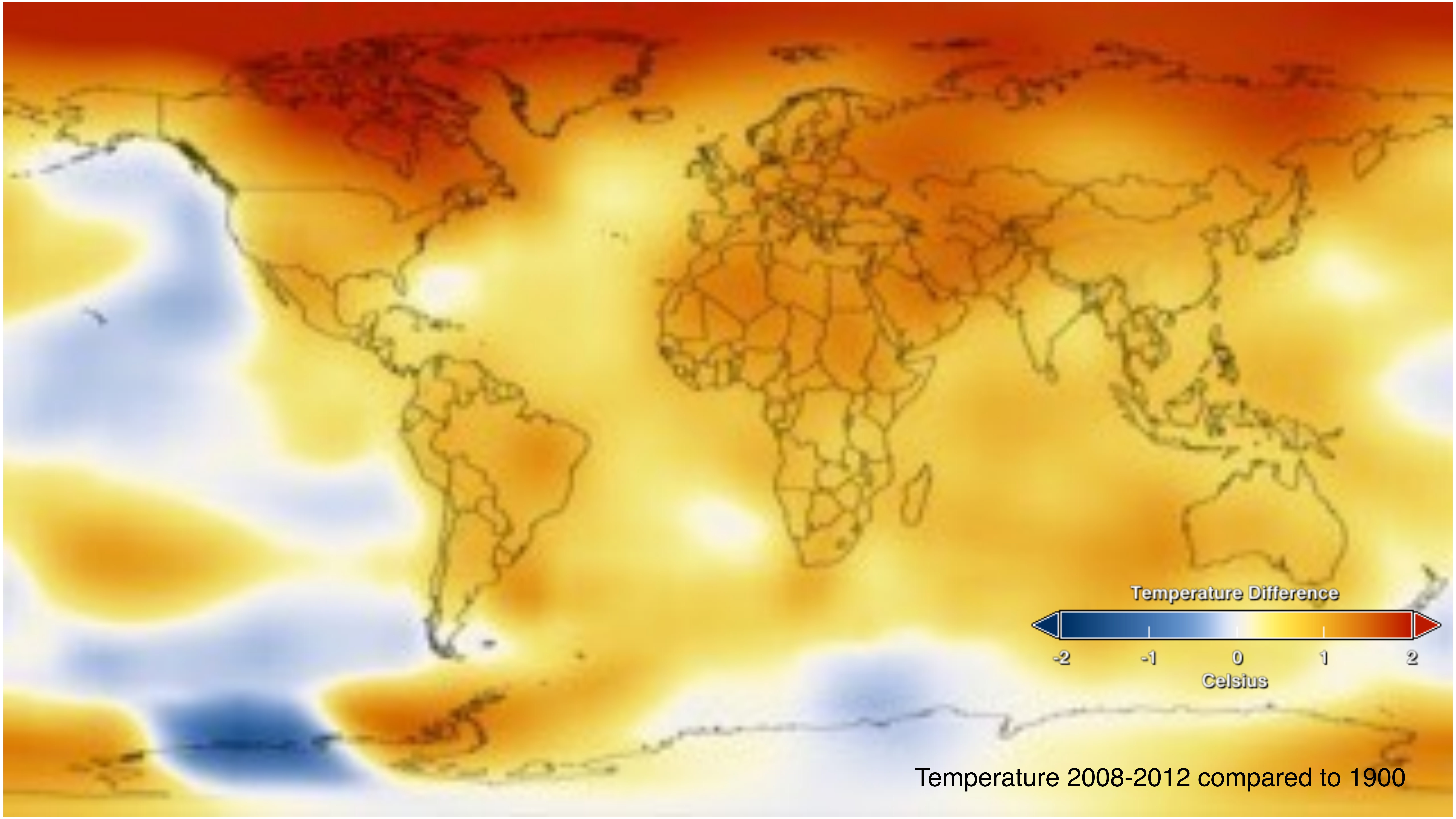
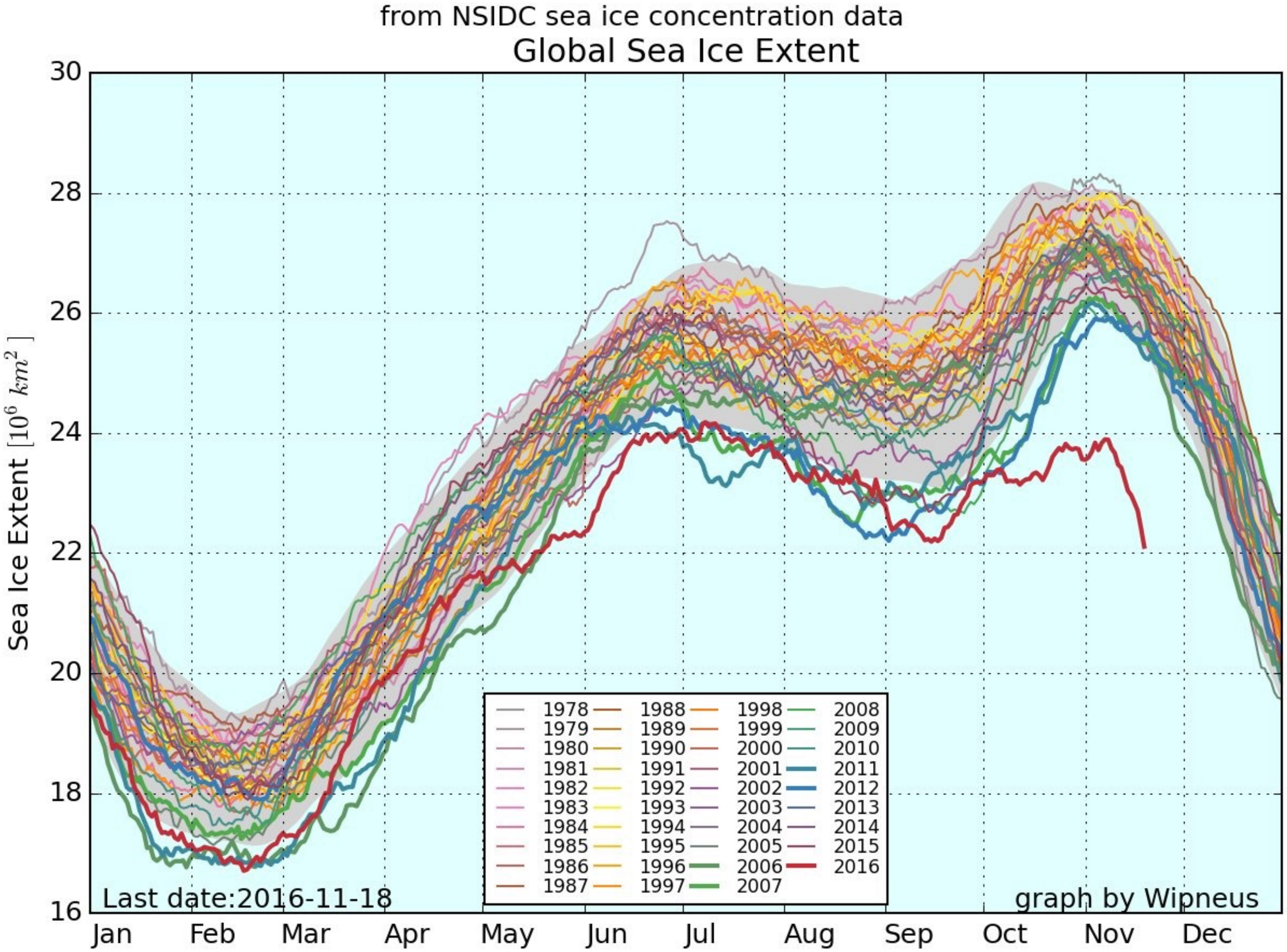


Temperature 2008-2012 compared to 1900

The Syndrome: Recent Climate and Global Change



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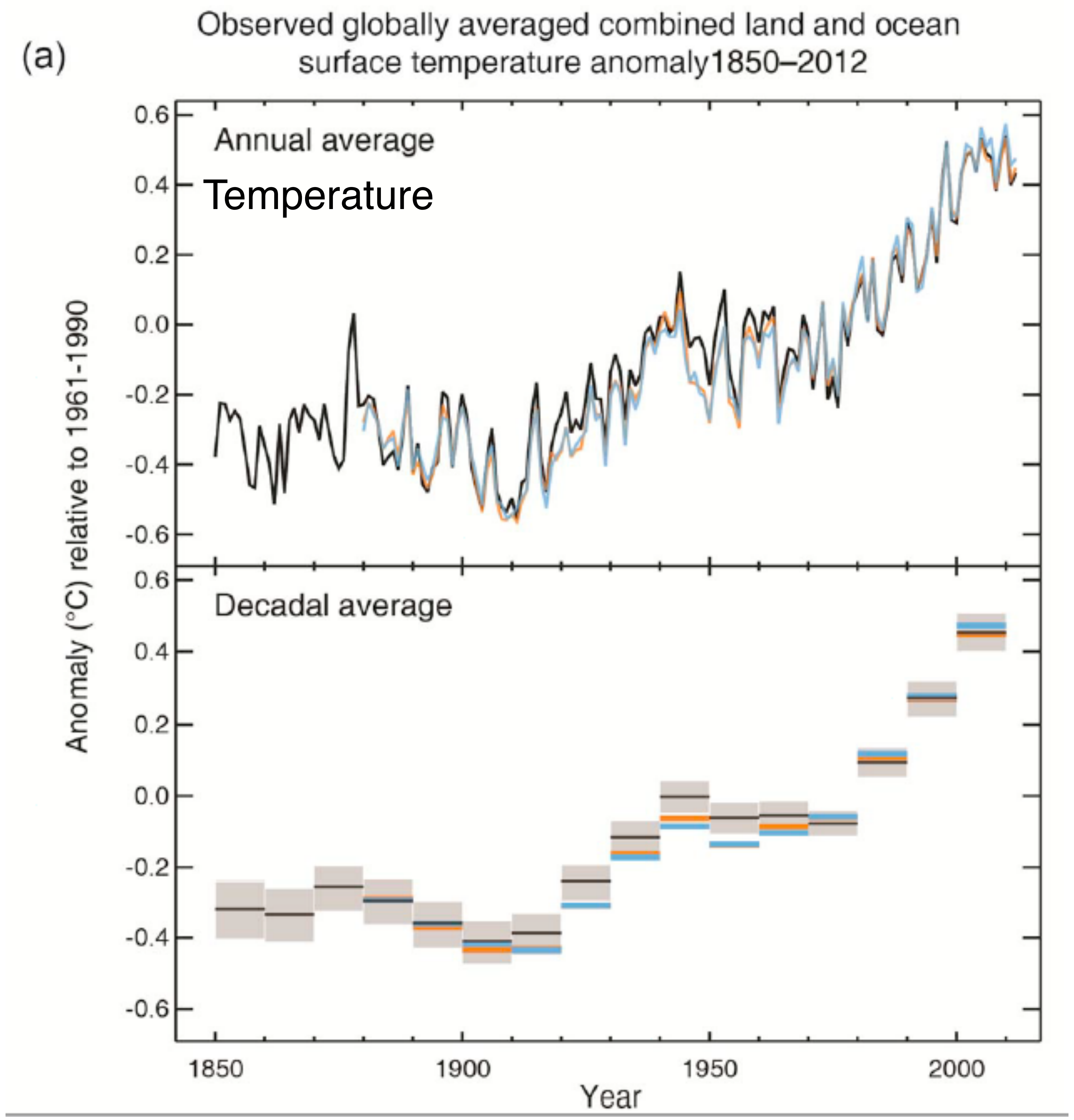
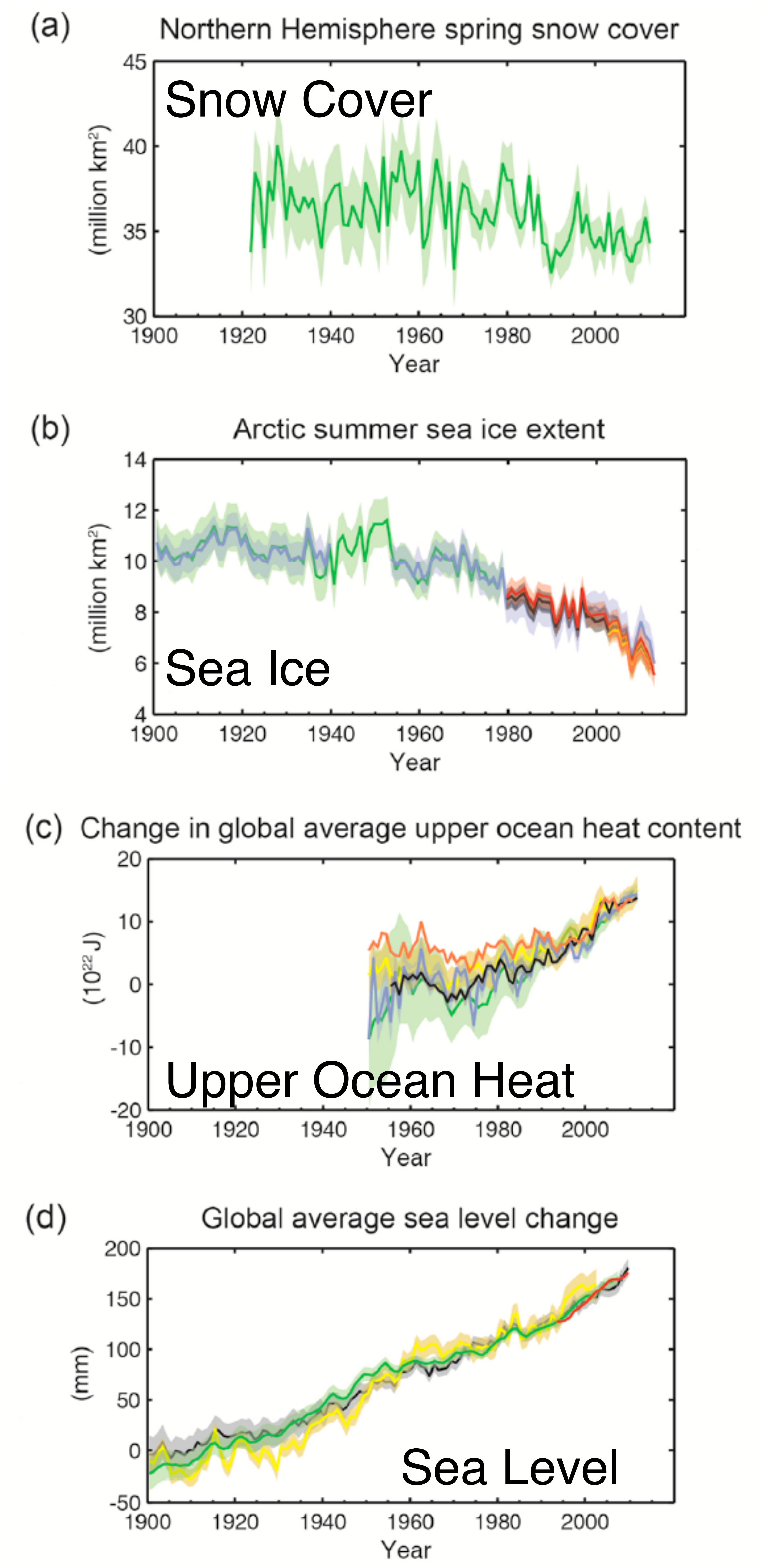
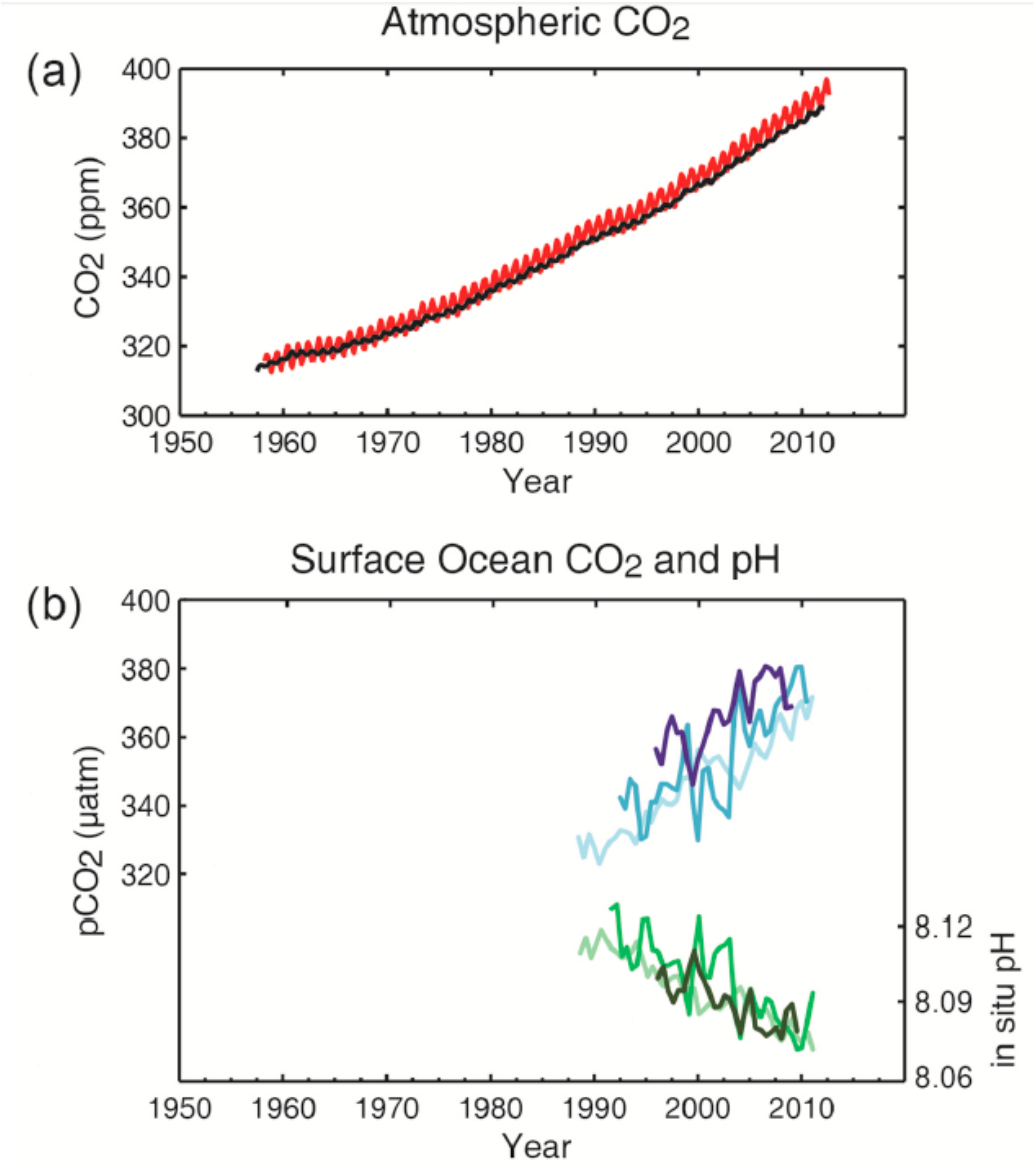
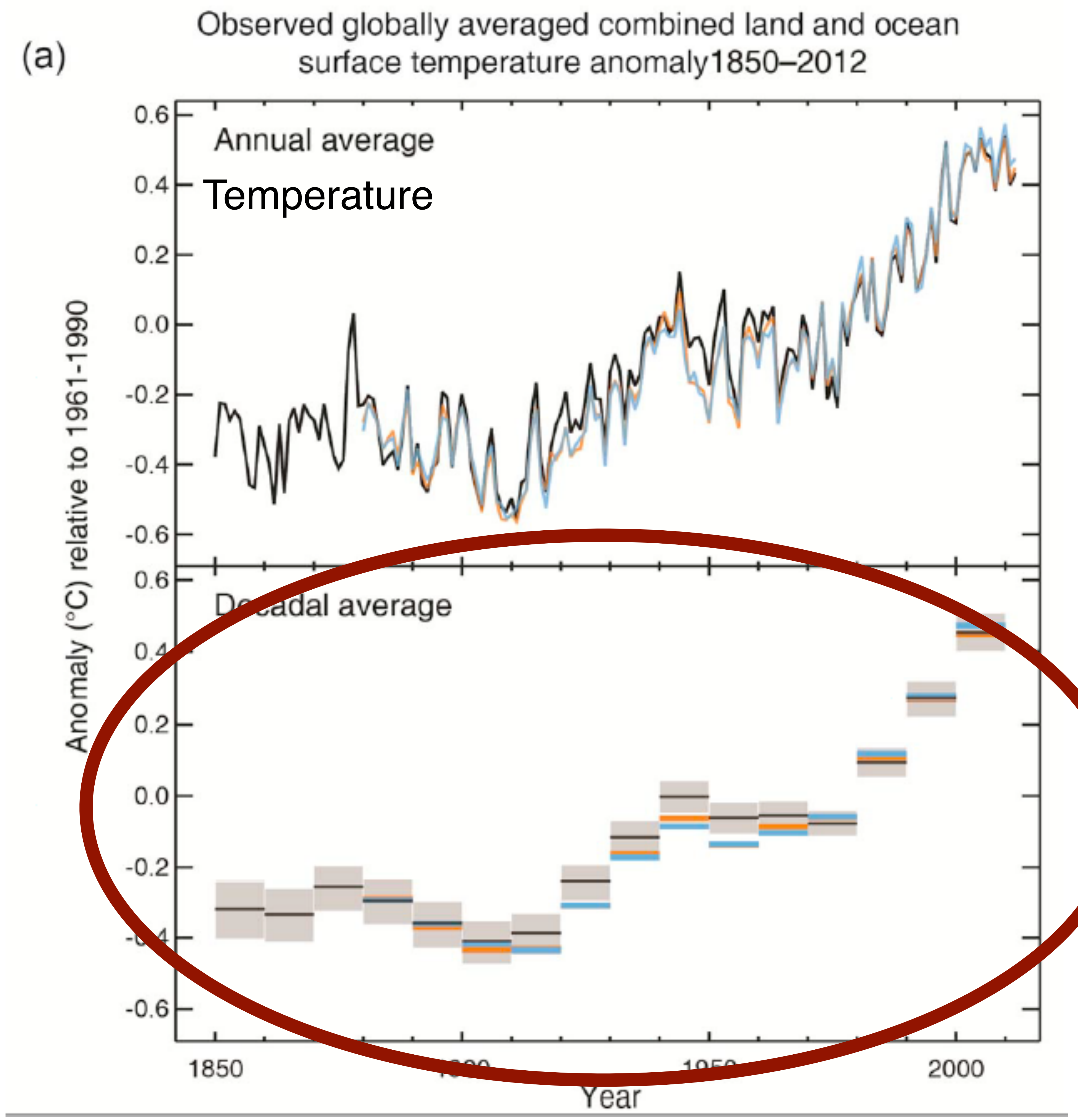


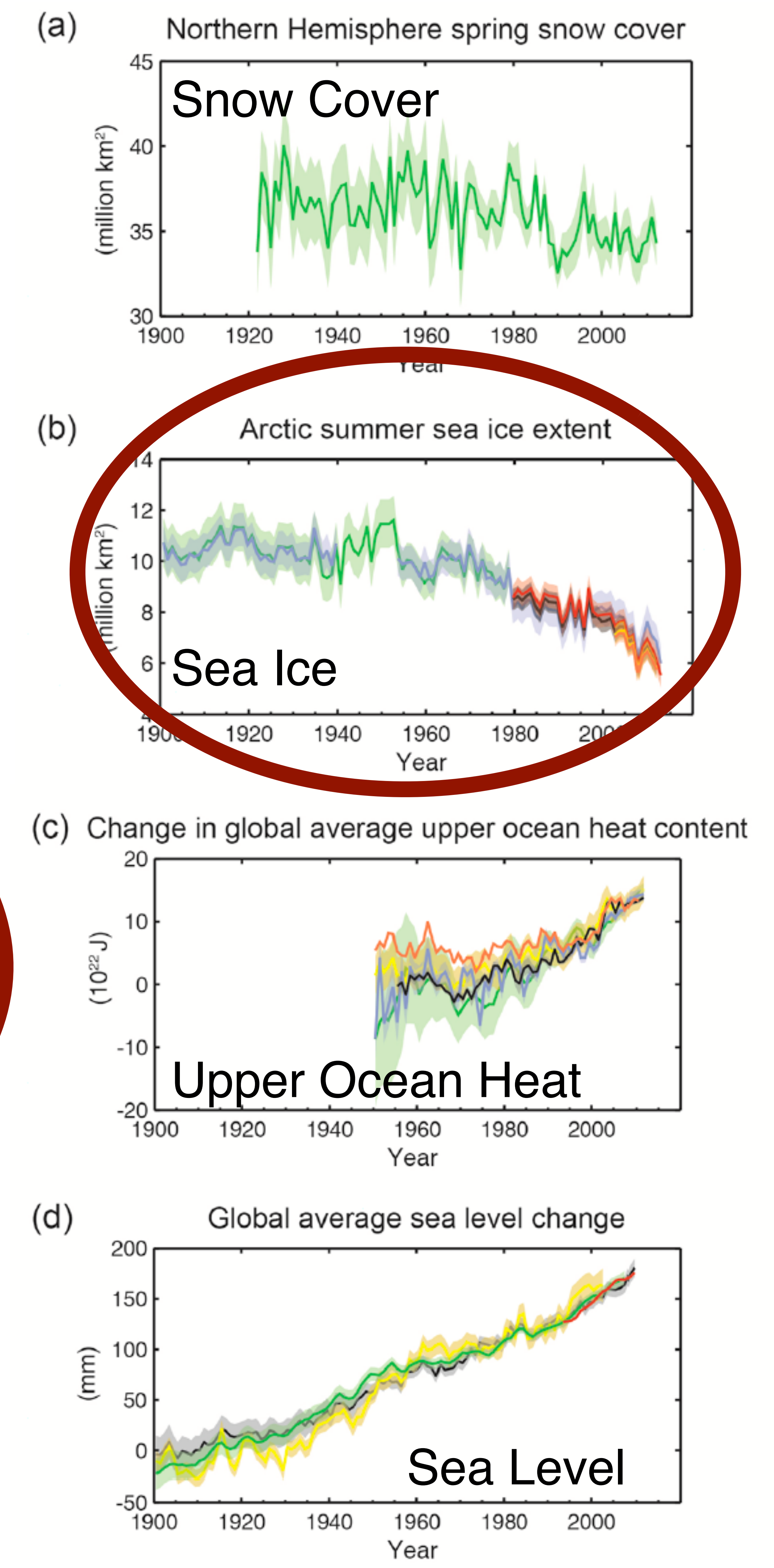


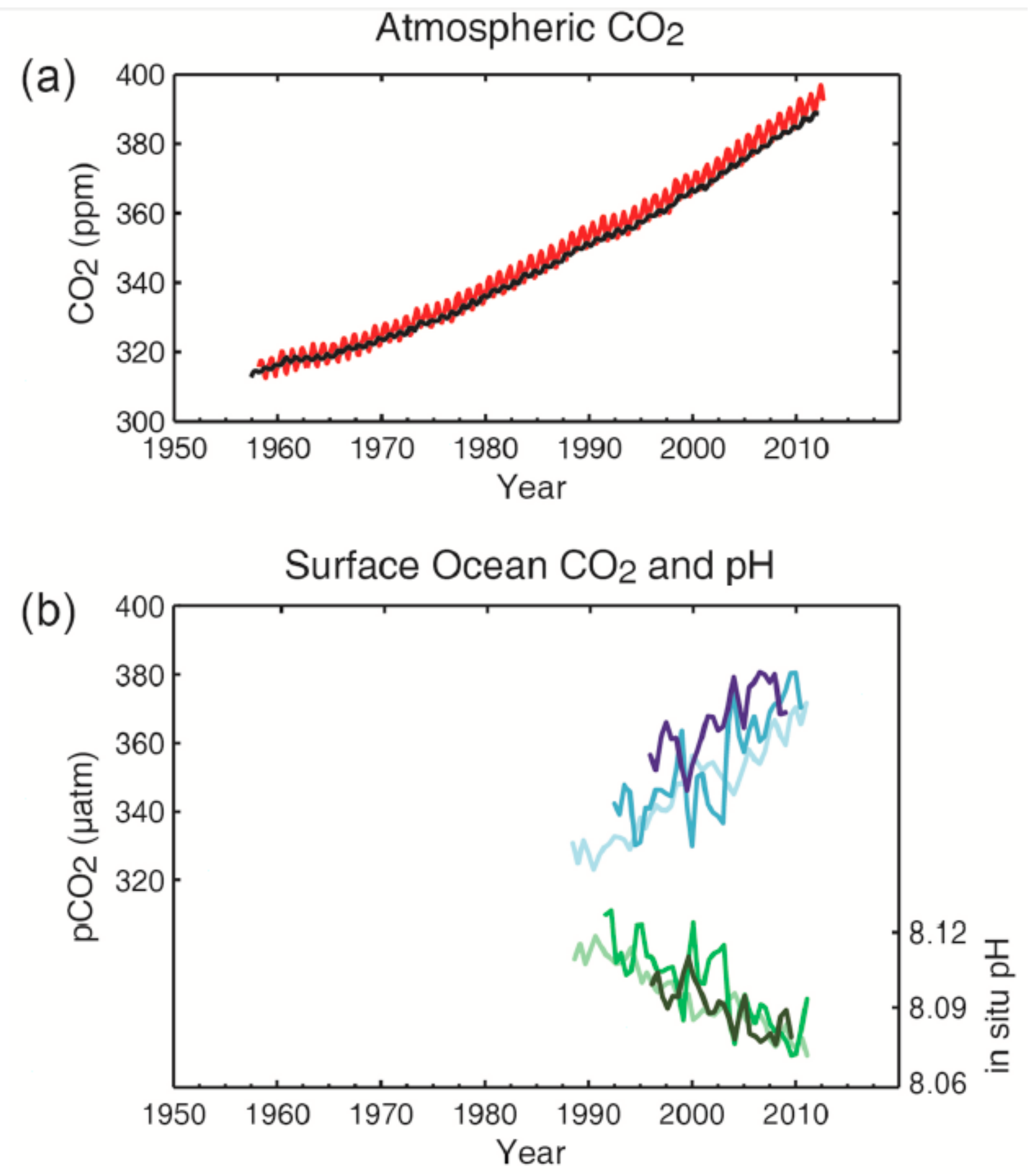


IPCC, 2013

The Syndrome: Recent Climate and Global Change







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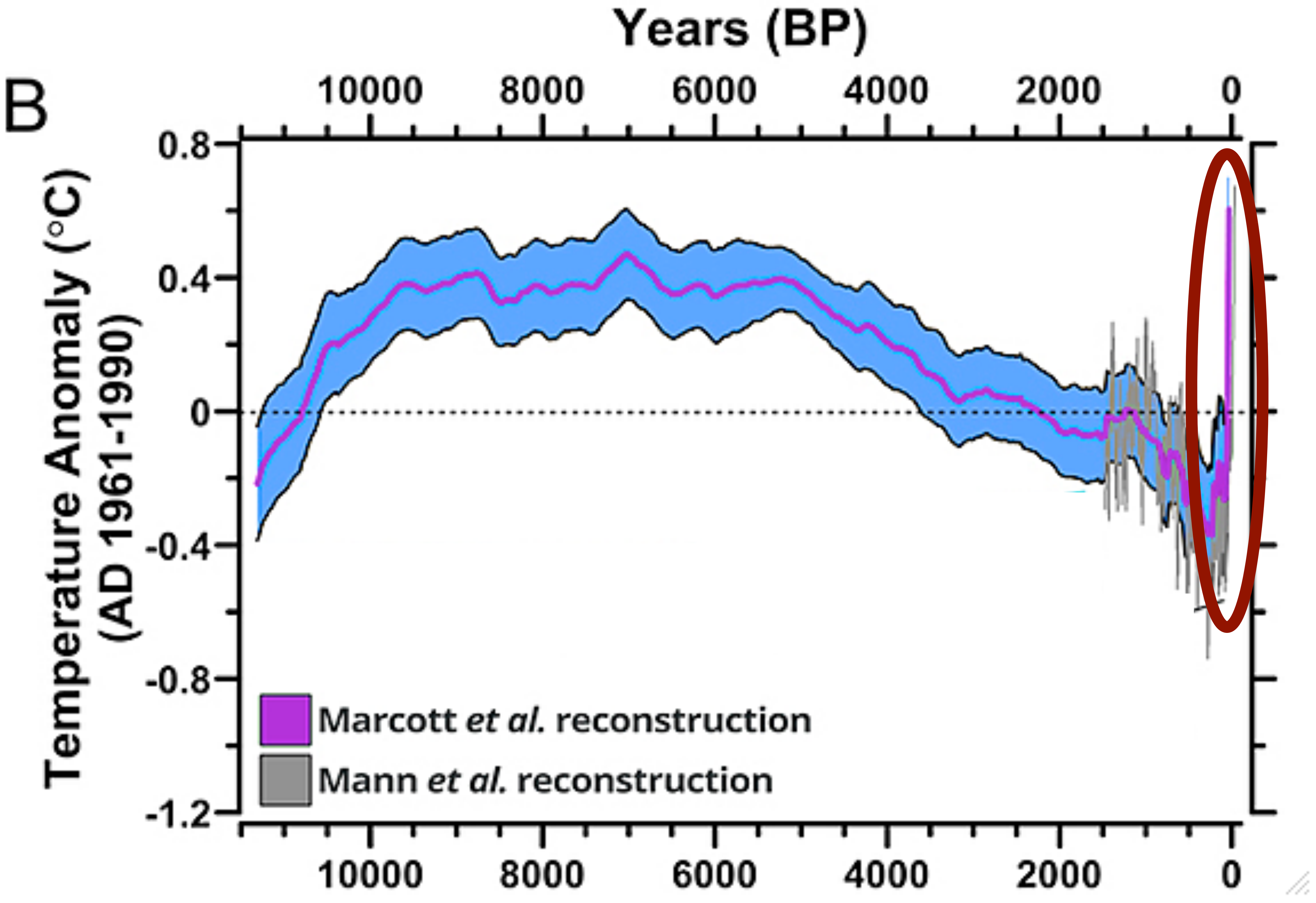
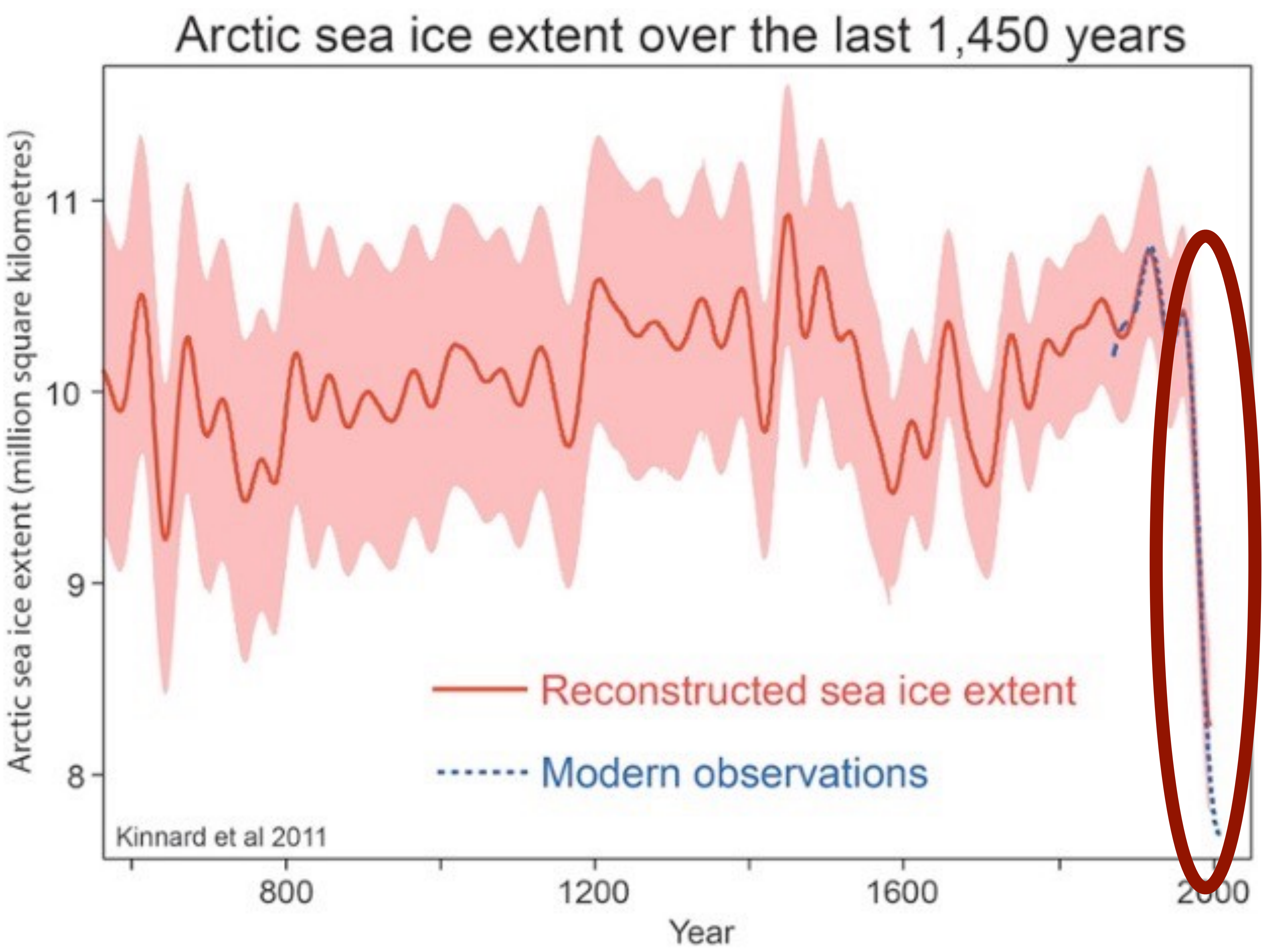


Marcott et al., 2013



Kinnart et al., 2011

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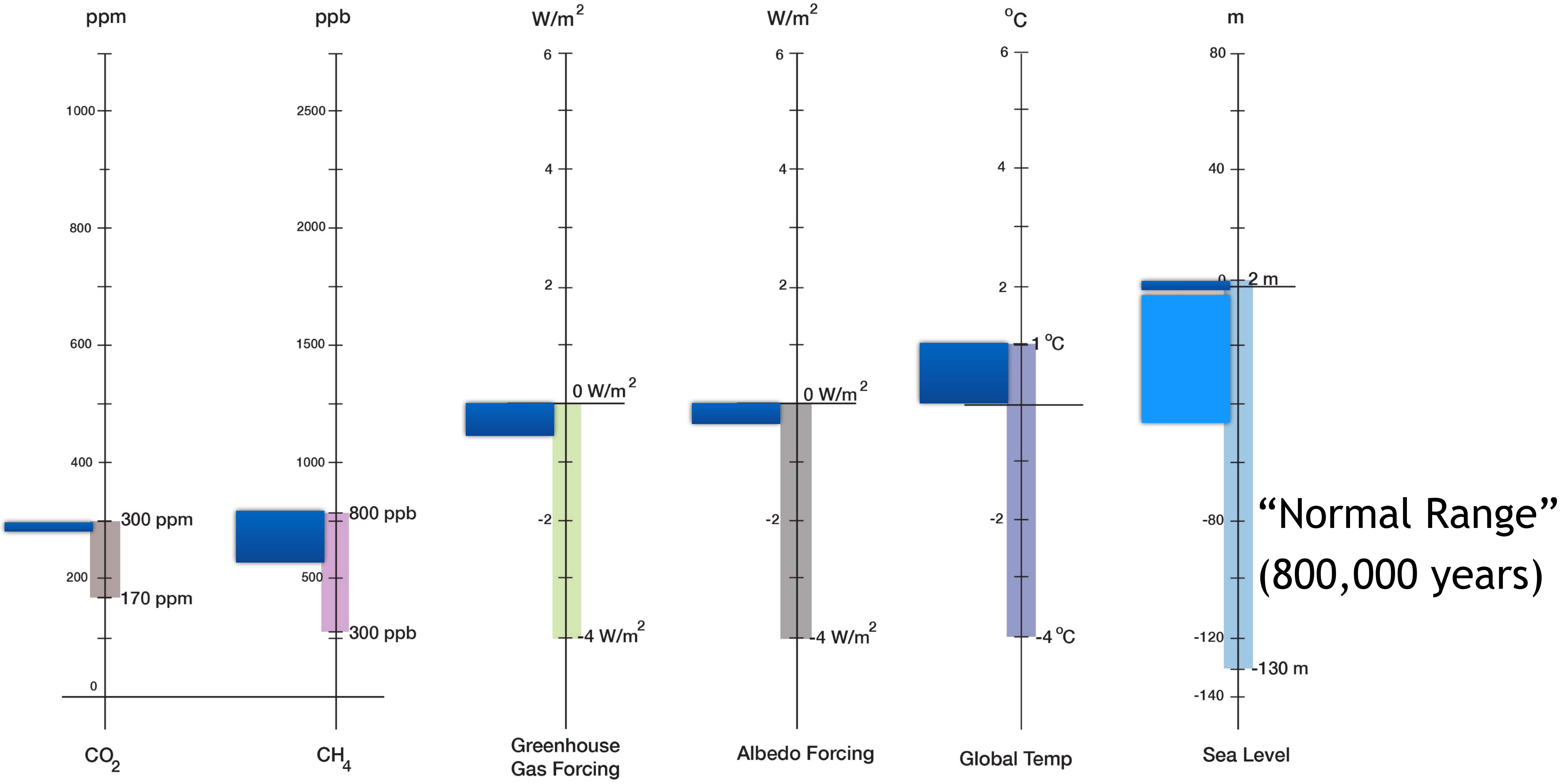
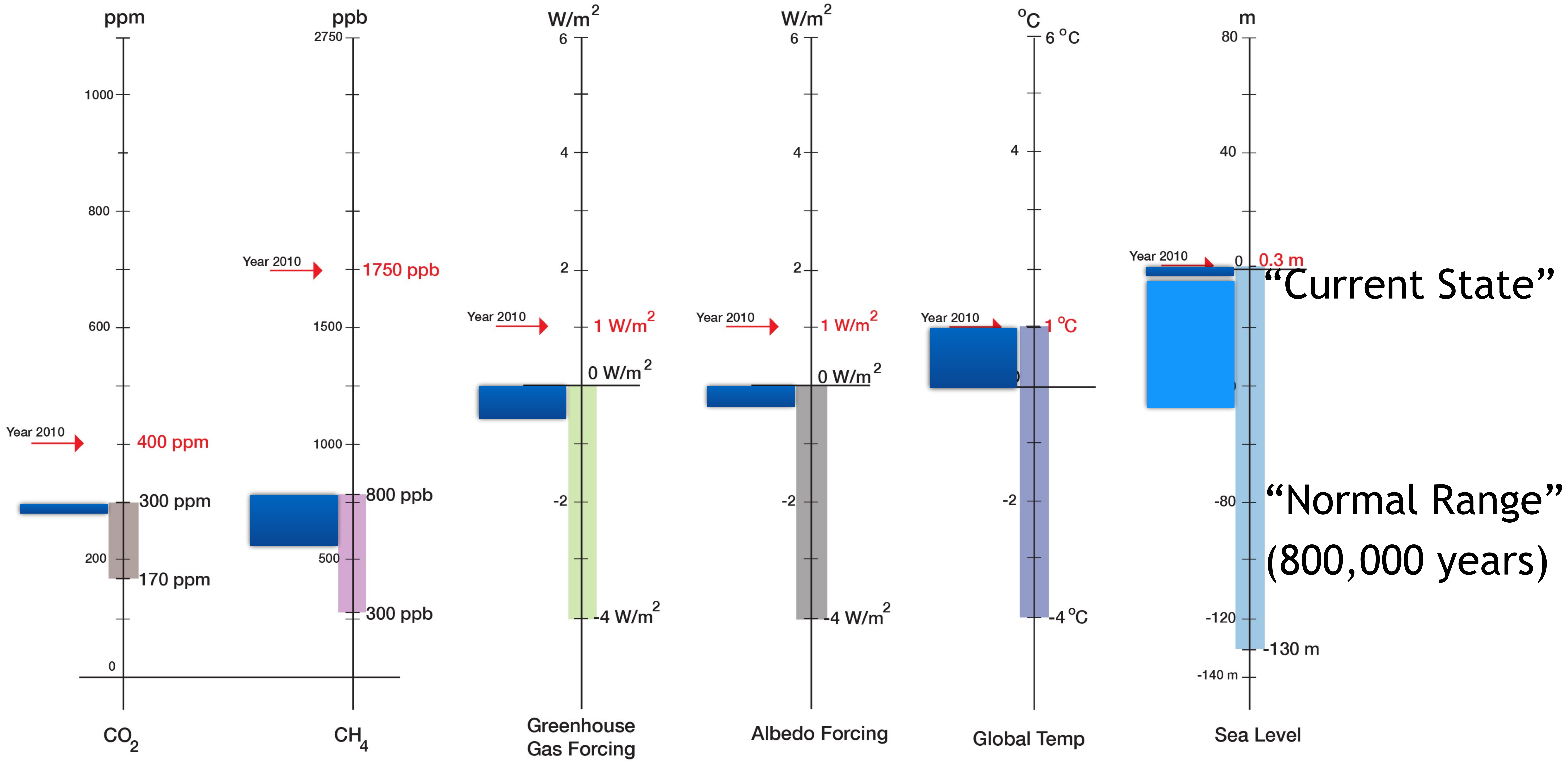


The Syndrome: Recent Climate and Global Change

The Lab Results for “Patient Earth”



Earth's Energy Imbalance

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

The Syndrome: Recent Climate and Global Change

Earth's Energy Imbalance

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↓

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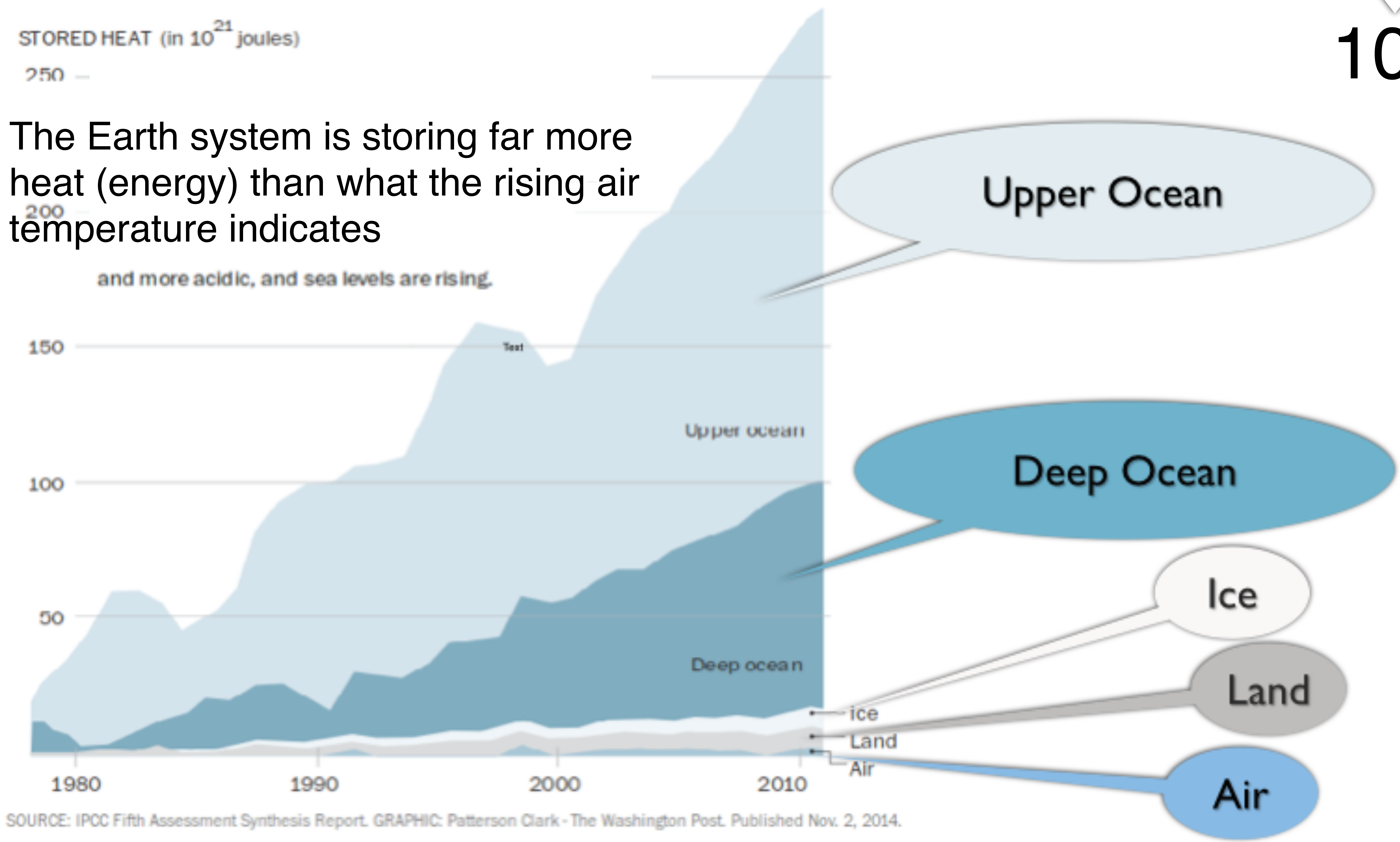
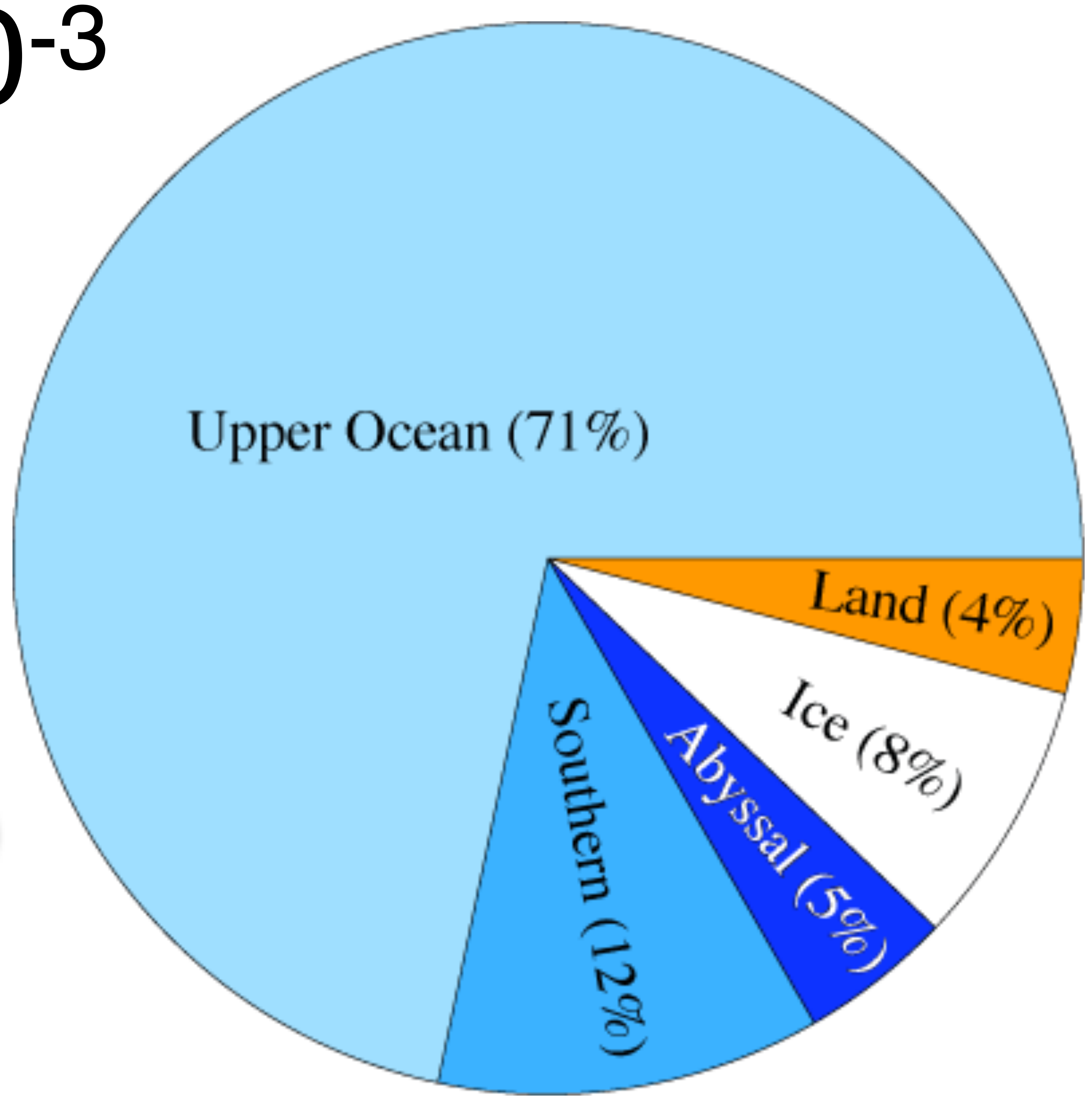
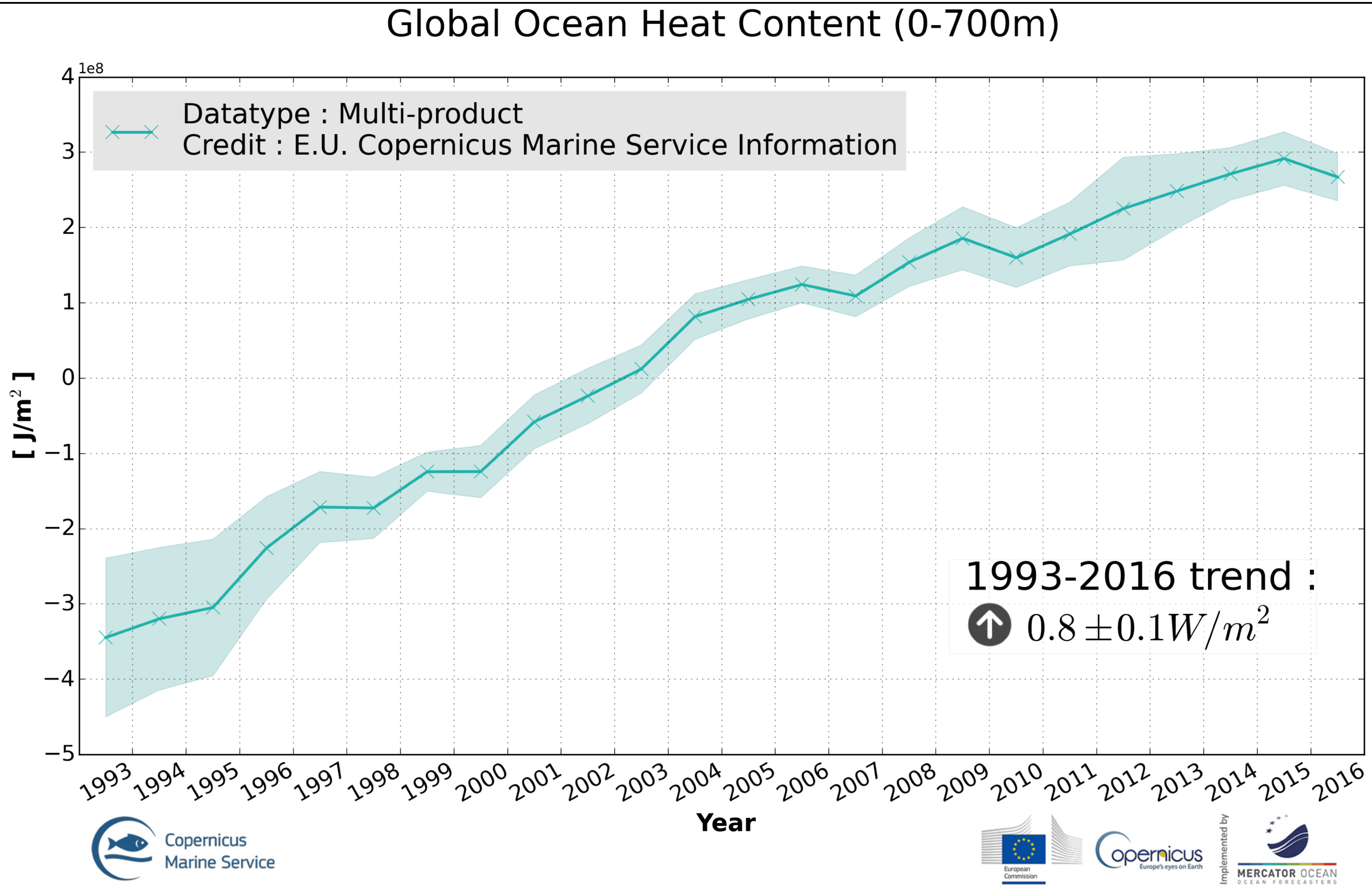




The Pool-House Effect

The Syndrome: Recent Climate and Global Change



Earth’s Energy Imbalance

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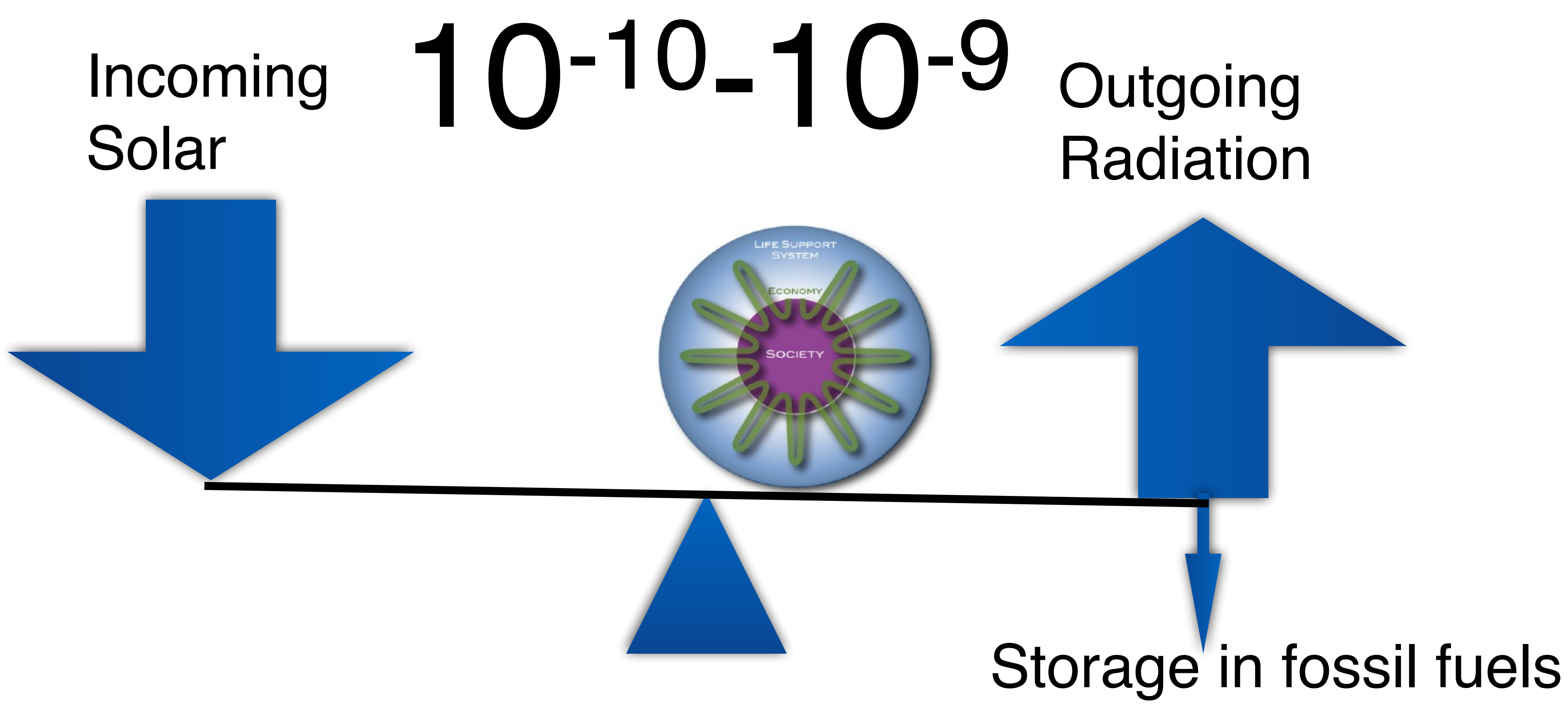
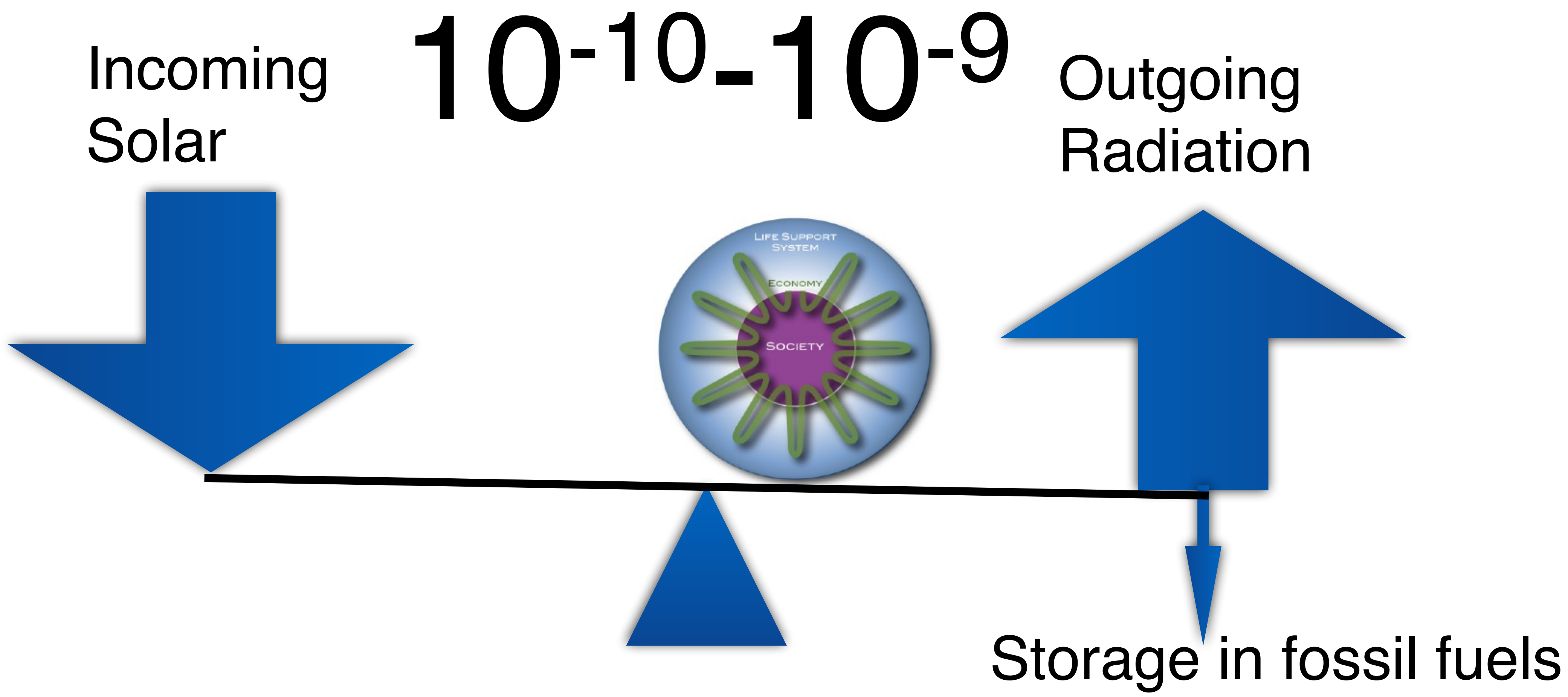


Imbalance on the order of 10^{-10}-10^{-9}

Last 200 Million years

Earth's Energy Imbalance



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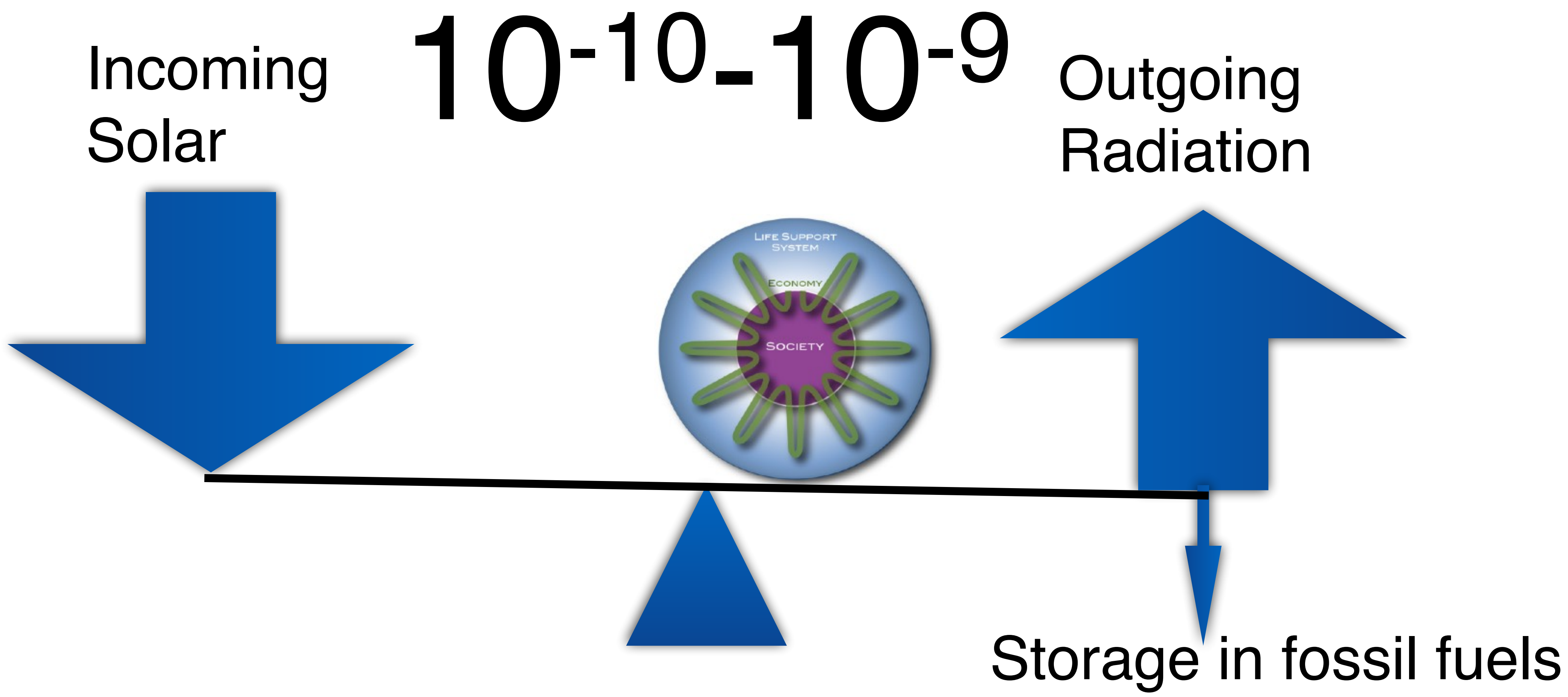

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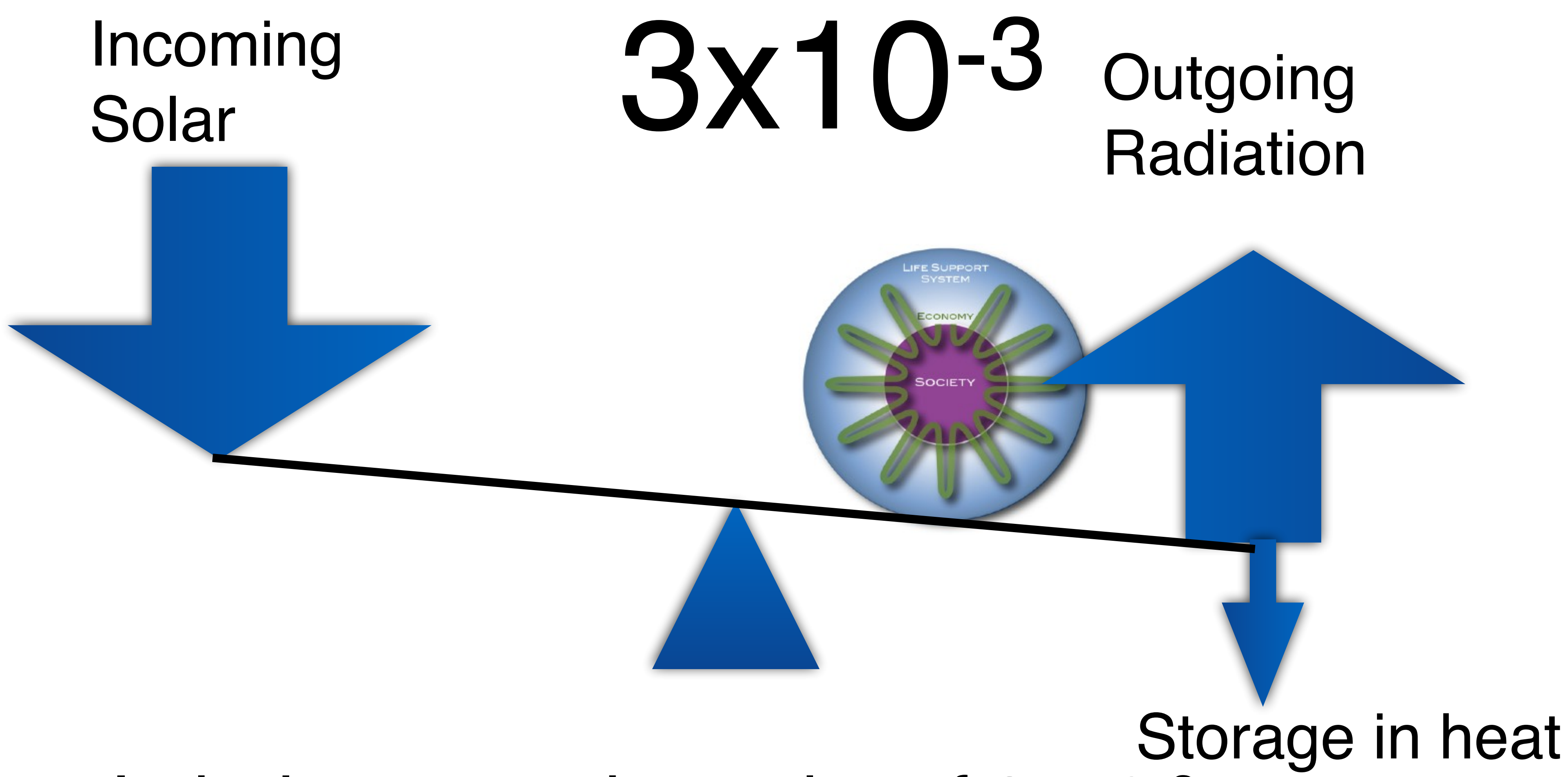

Imbalance on the order of $3x10^{-3}$

Last 70 years

Total energy storage in 200 Myrs:
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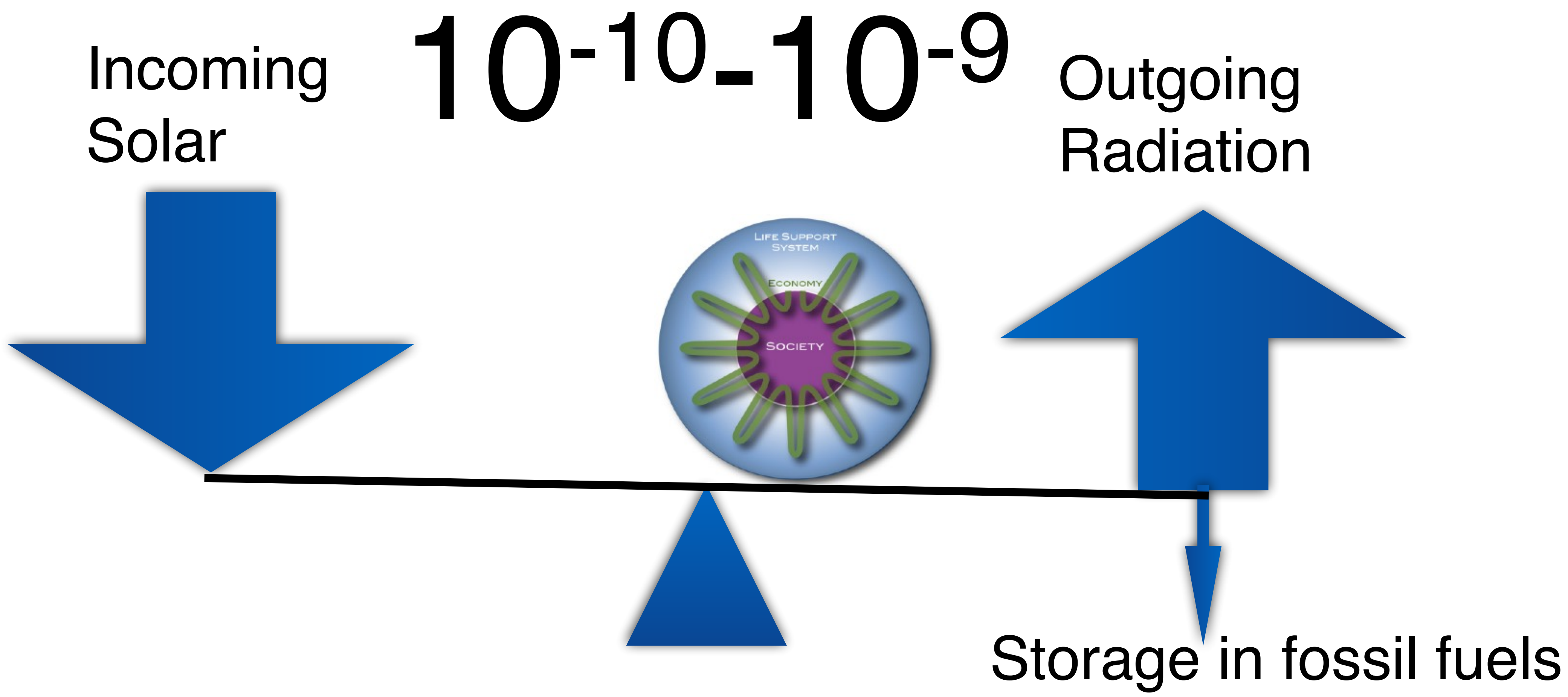
Total energy storage per century:
Order 1000 ZetaJoules

The Syndrome: Recent Climate and Global Change

Earth’s Energy Imbalance

What increased the Earth’s energy imbalance by a factor of 10^6 to 10^7?



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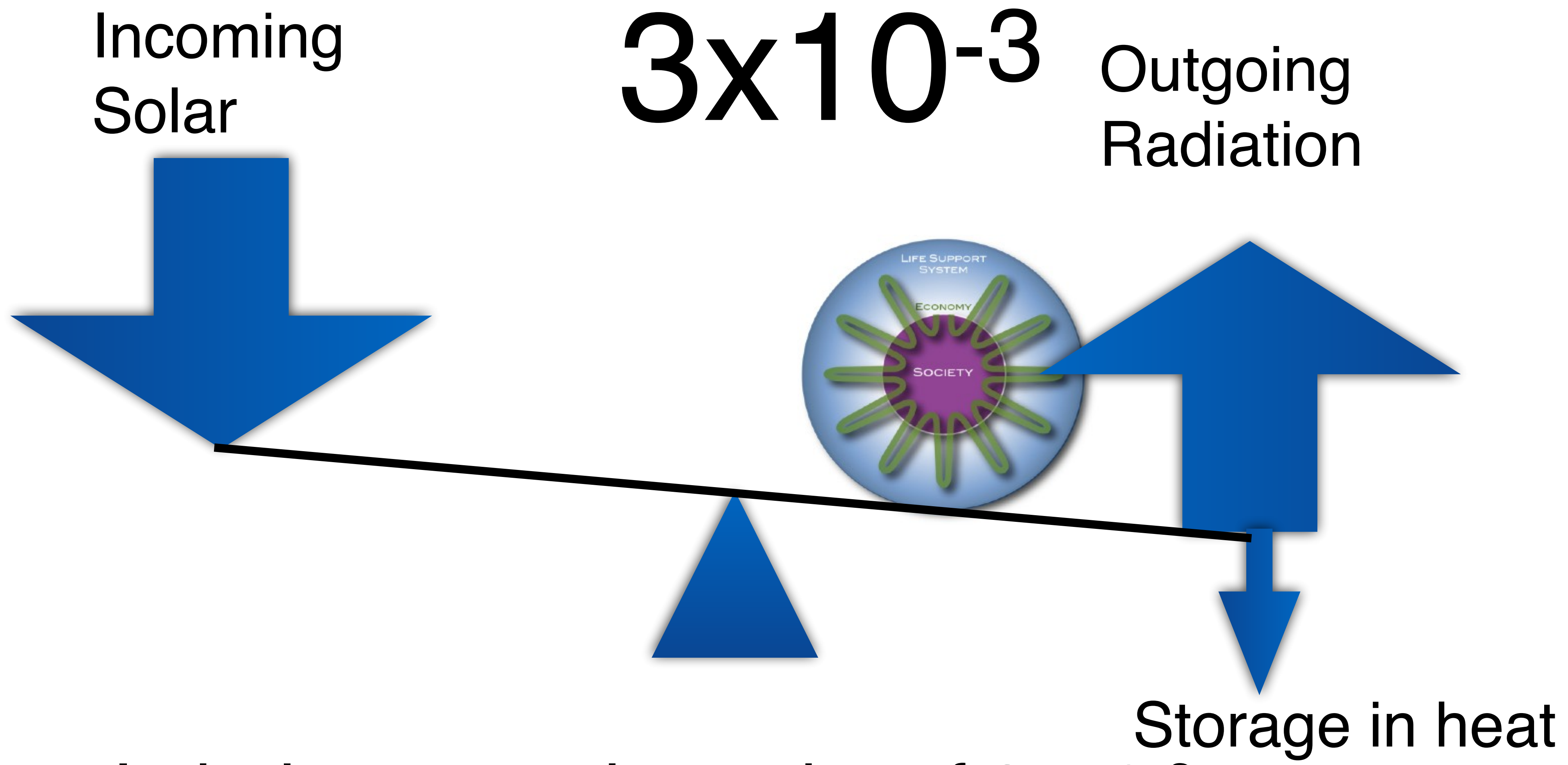

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Earth: Life-Support System for many species

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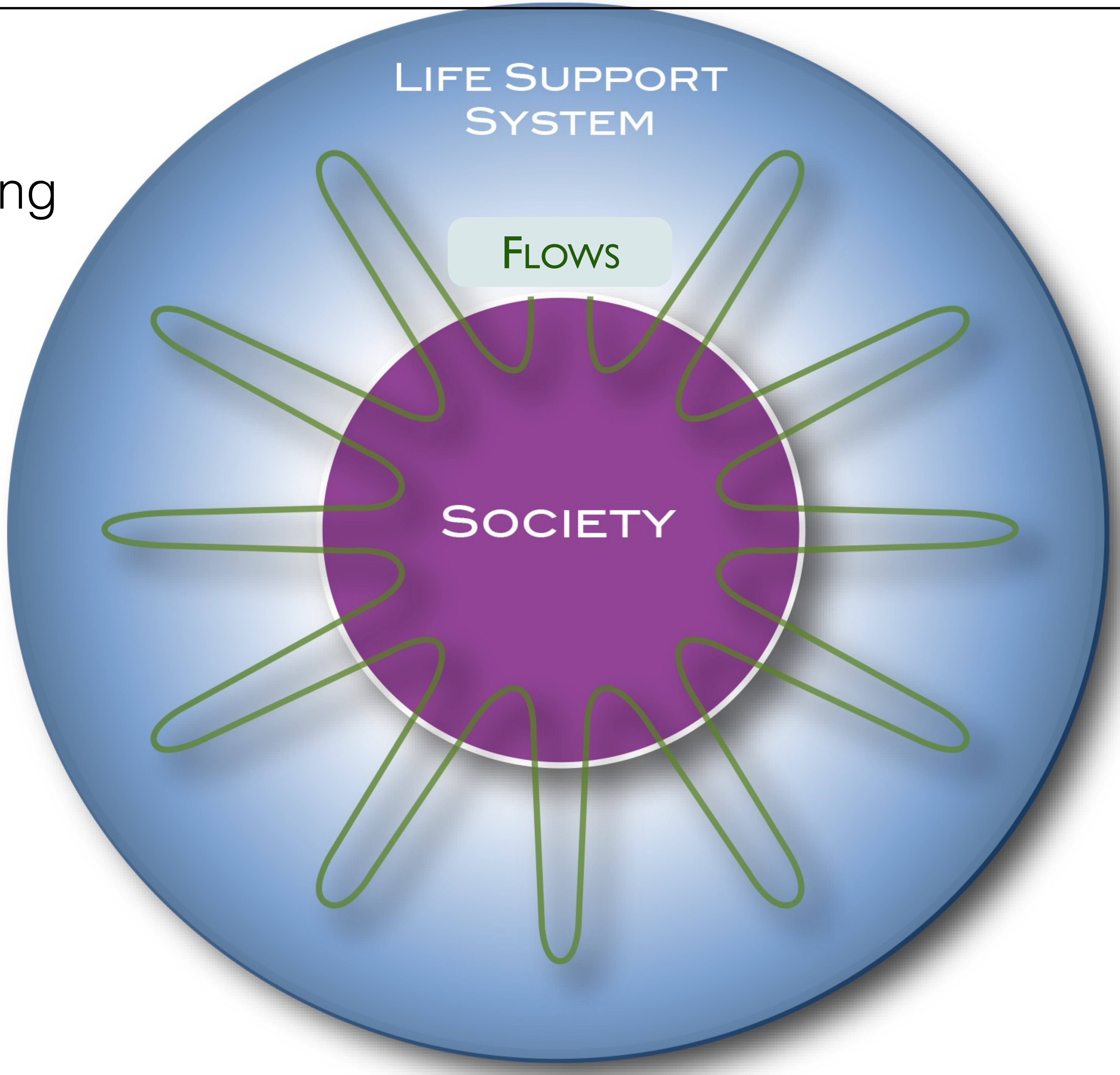
Everything is about Flows



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Earth: Life-Support System for many species

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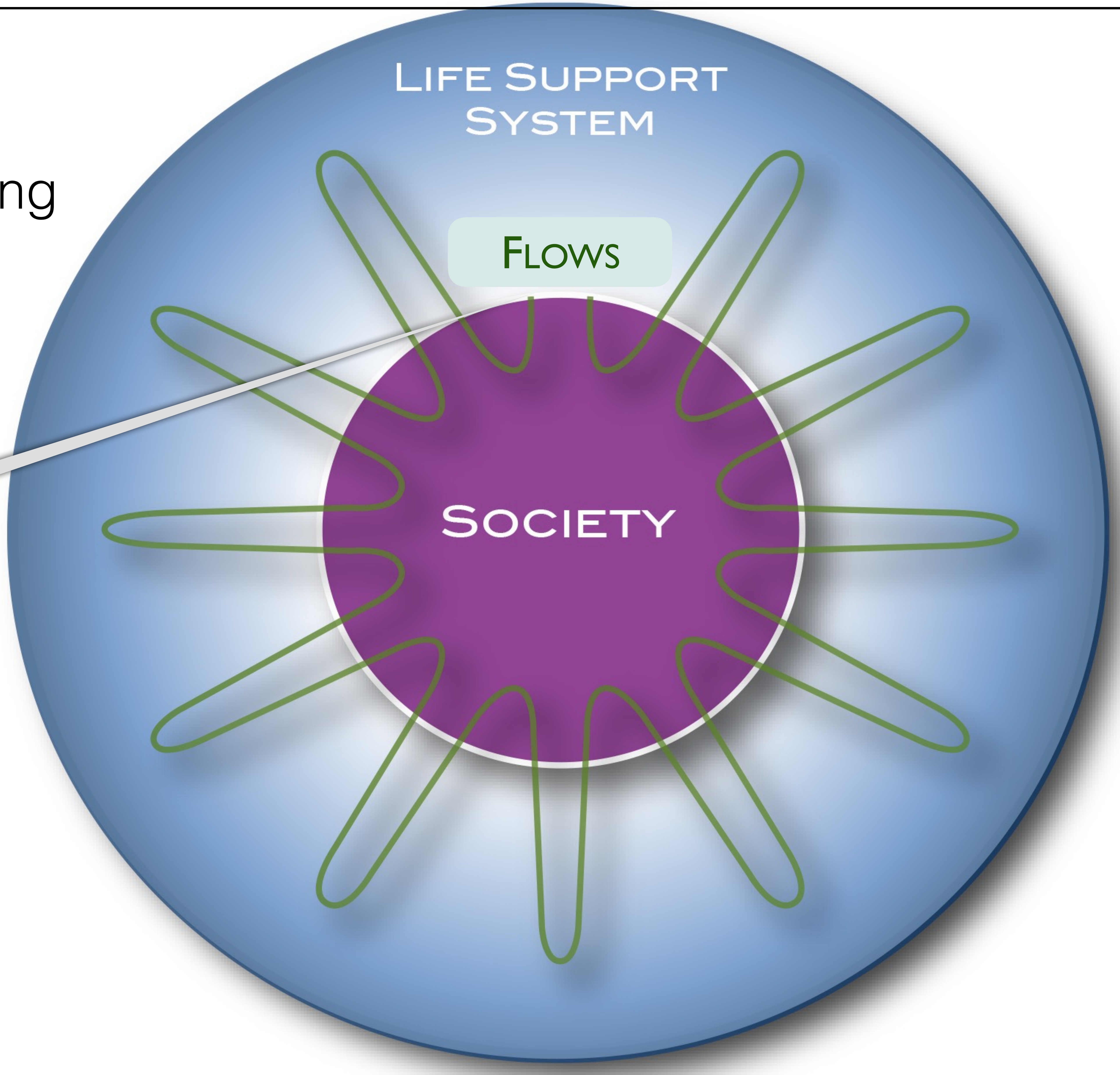
Limitations in the flows between a community and its life-support system limit the growth of the community



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Earth: Life-Support System for many species

Everything is about Flows

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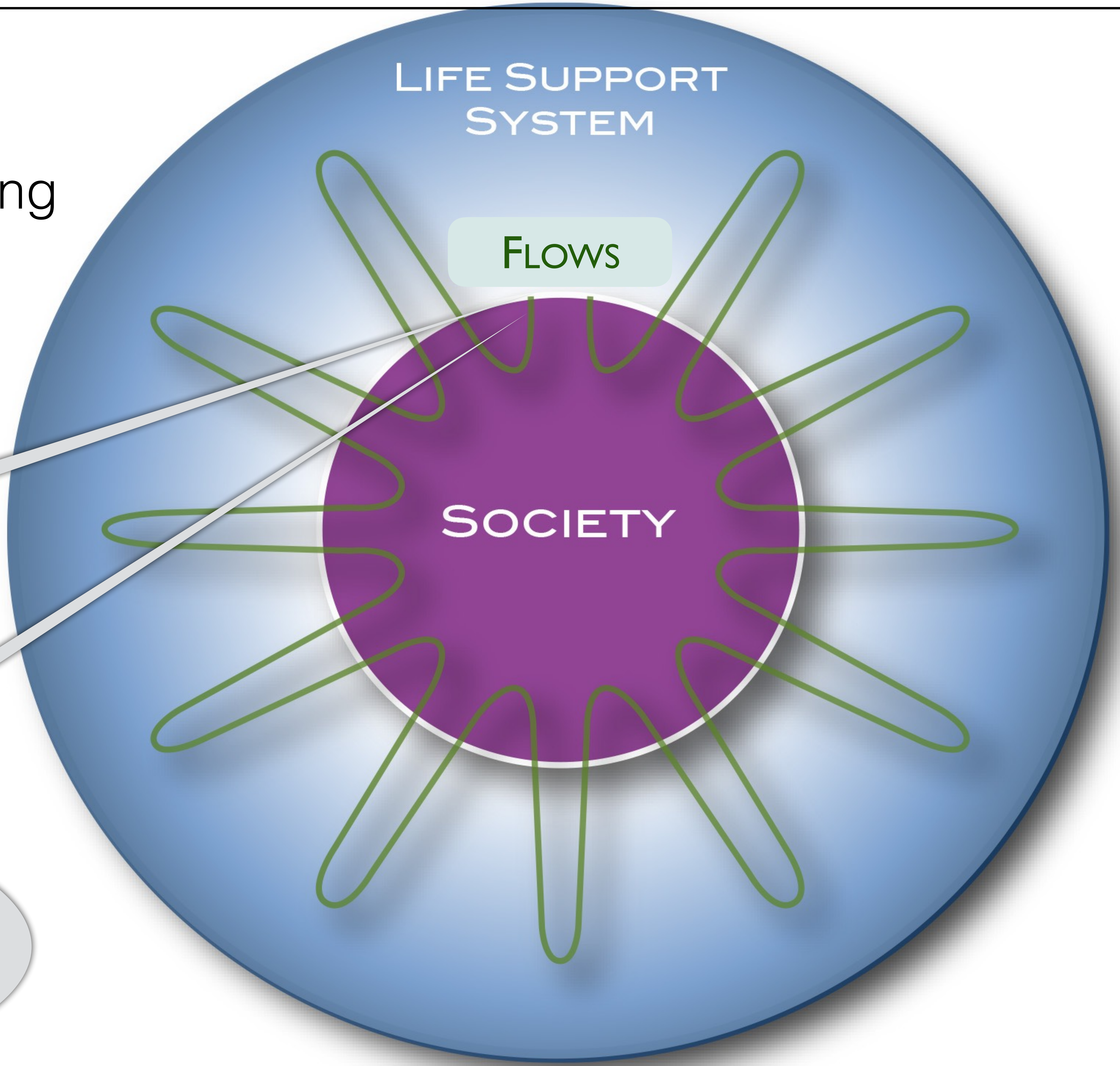
For Home sapiens, the flows are regulated by ethical, social, and - recently - economic rules



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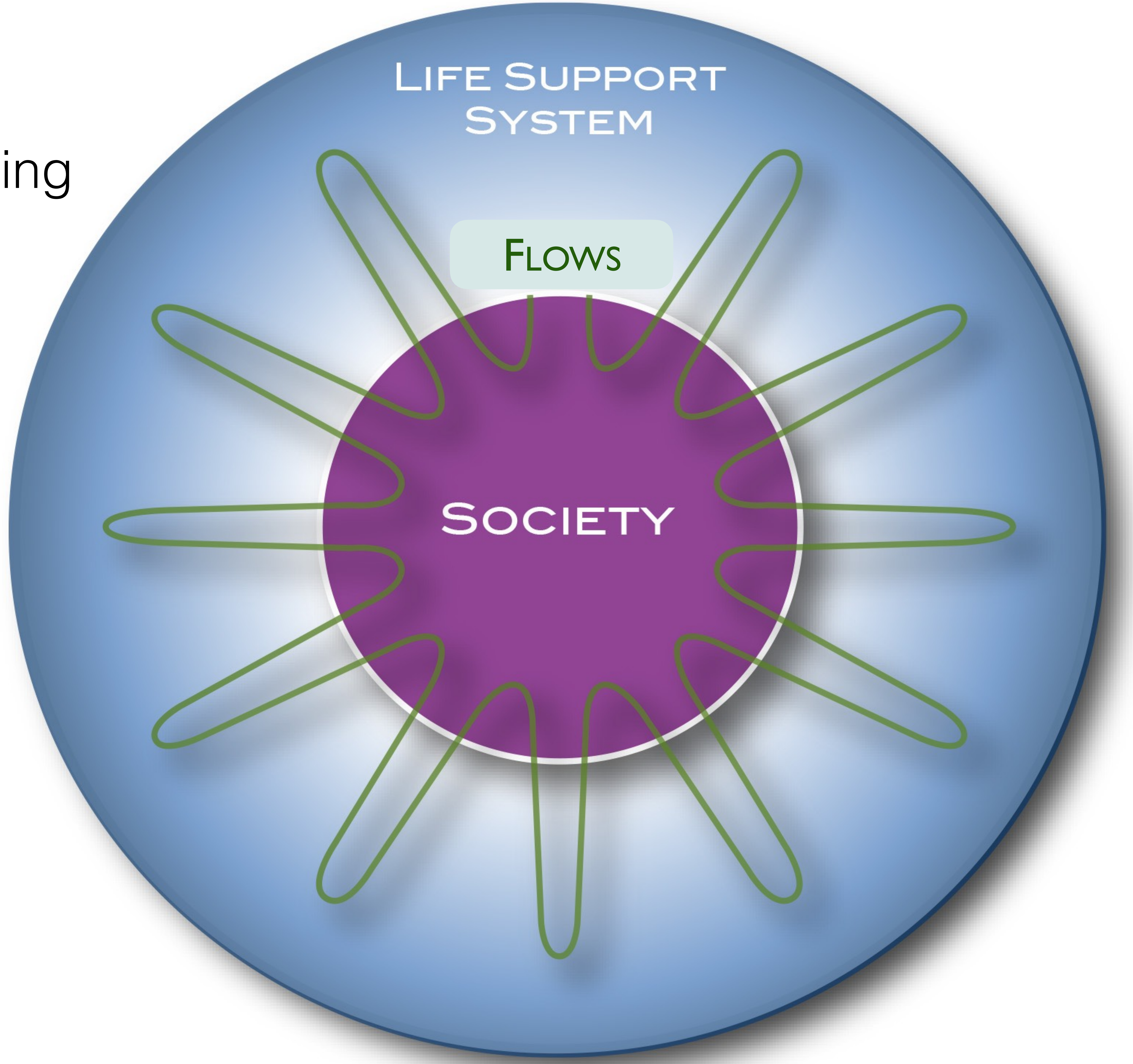

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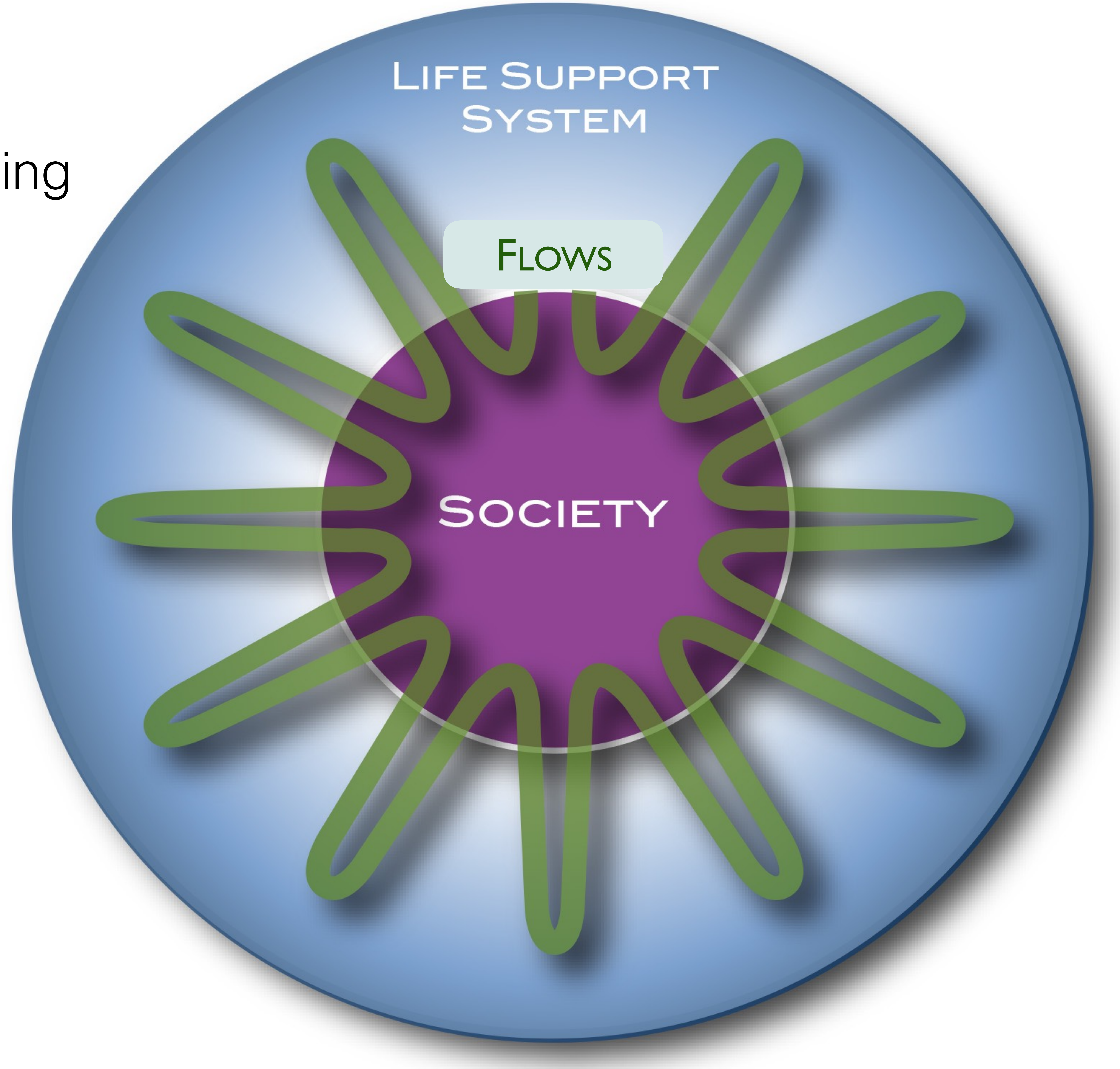
Flows have accelerated in the last 200 years



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

Baseline

During the Hol

The Holocene

Syndrome

During the last   hanges

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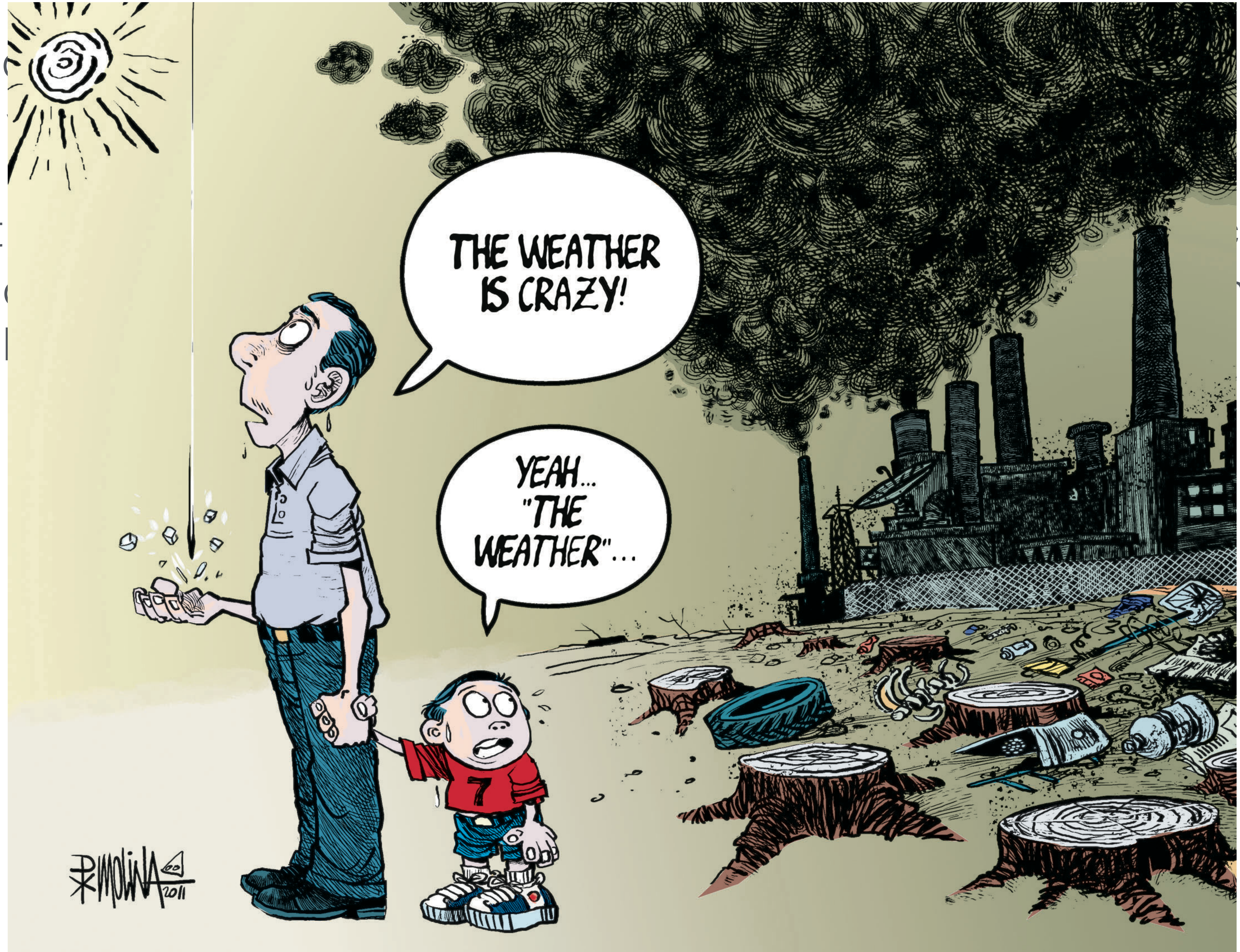

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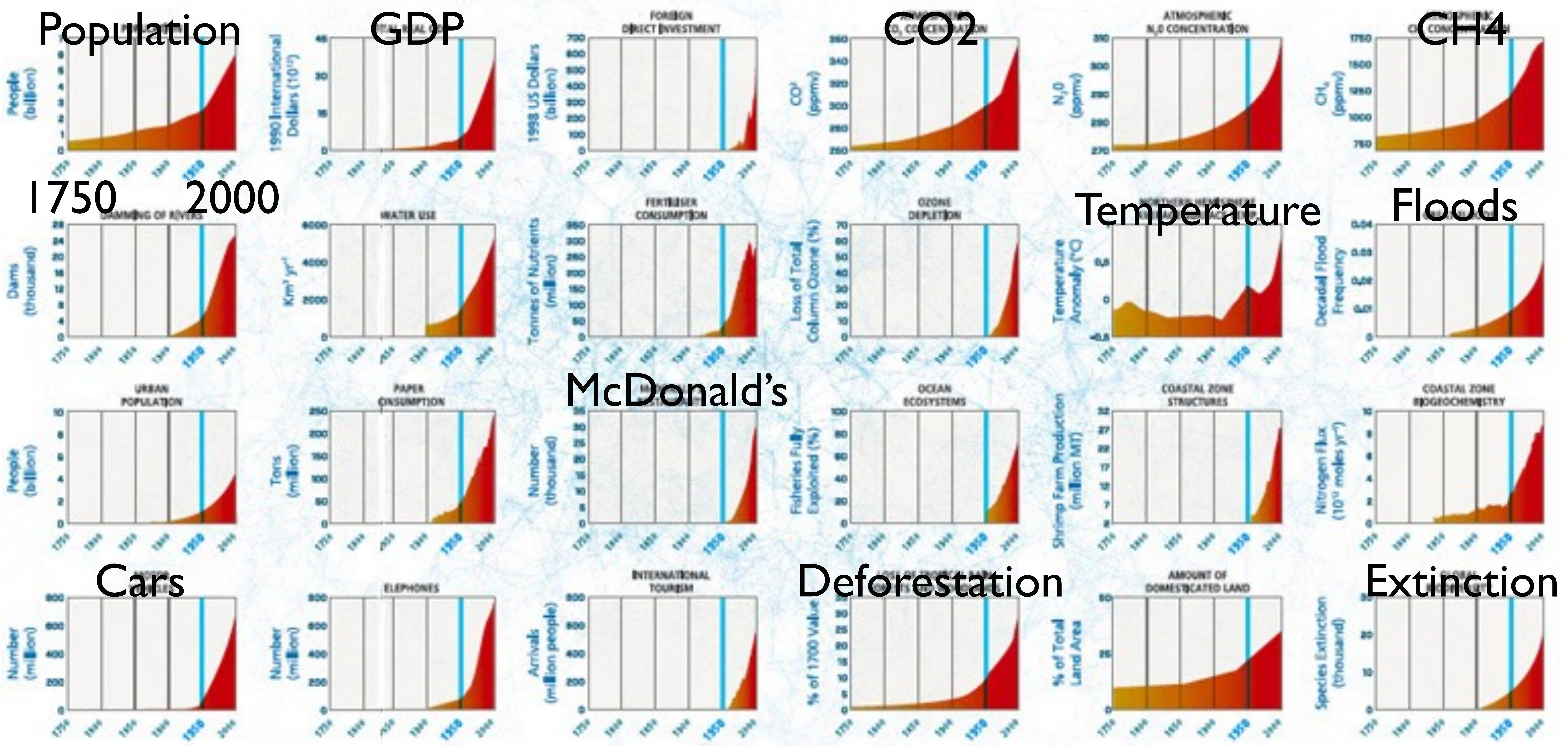

Figure 1. An enterprise to reckon with. Human manipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP's Great Acceleration graphs show. Modified after Steffen W *et al.* (2004).

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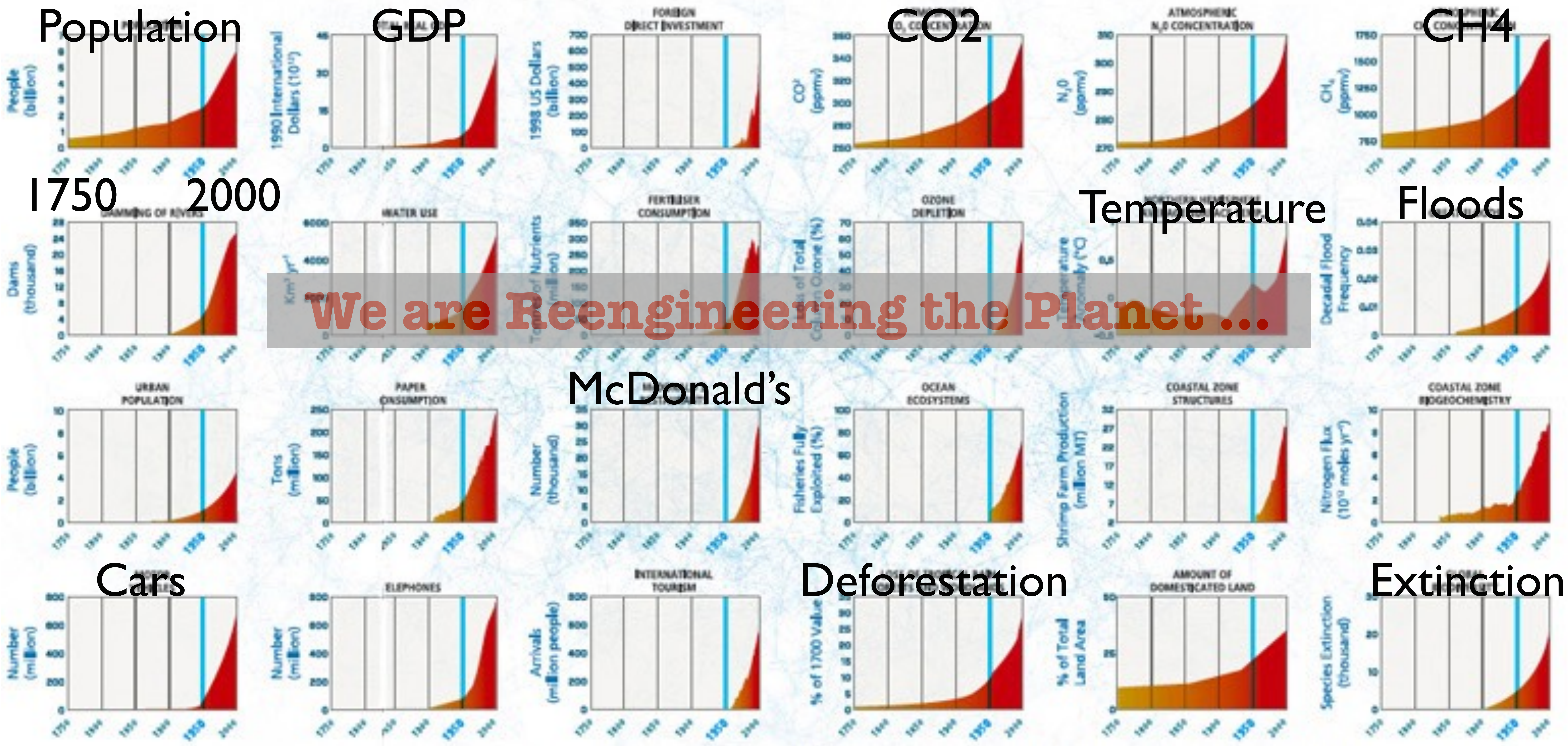

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The Diagnosis: Leaving the “Safe Operating Space”

The Anthropocene Review

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.

The Diagnosis: Leaving the "Safe Operating Space"

The Anthropocene Review

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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

The Diagnosis: Leaving the “Safe Operating Space”

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

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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 15[illegible] 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[illegible]
Sea-level rise	~0 mm/yr from c. 3000 BP to pre-industrial	3.2±0.4 mm/yr (1993–201[illegible])	Average global sea level is currently higher than at any other time within the past ~115,000 years	[illegible]
ES parameter-biosphere				
Extinction rate	0.1 extinctions per million species years	1–10 extinctions per million-species years	10–100 times background rate	[illegible]
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		[illegible]
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	[illegible]
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 Anthro[illegible] times larger [illegible]	[illegible] Rhein et al. [illegible] 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	[illegible]	[illegible]	[illegible]
P cycle	10–15 Tg P/yr input to soil (pre-industrial weathering)	[illegible] mining [illegible]	[illegible]	[illegible]
Sedimentary fluxes		~57,000 Tg/yr of [illegible] displaced by mineral extraction	[illegible] have increased sediment flow by erosive processes and reduced sediment flow by dam building	[illegible] 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

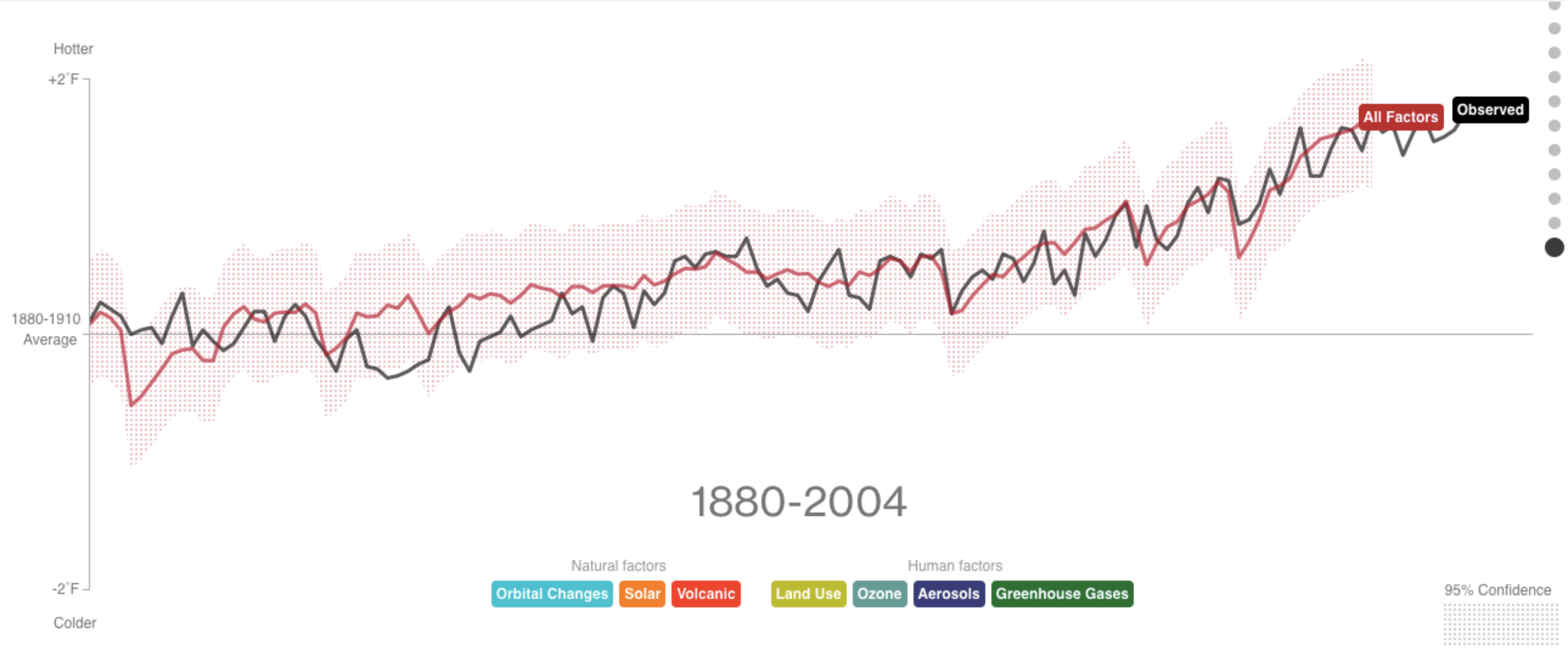
Gaffney and Steffen, 2017

The Diagnosis: Leaving the "Safe Operating Space"

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?

BloombergBusinessweek | What's Really Warming the World?



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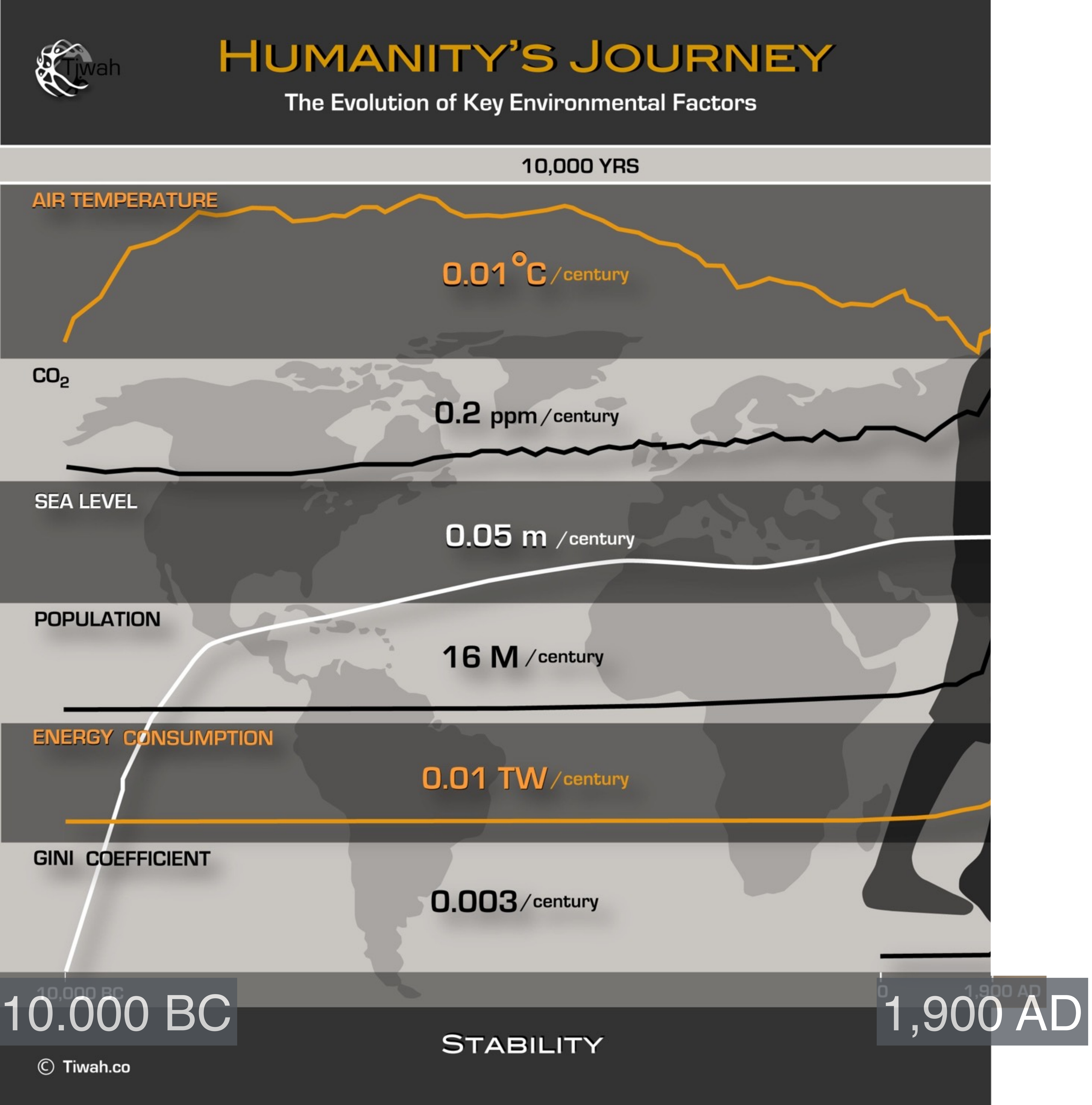
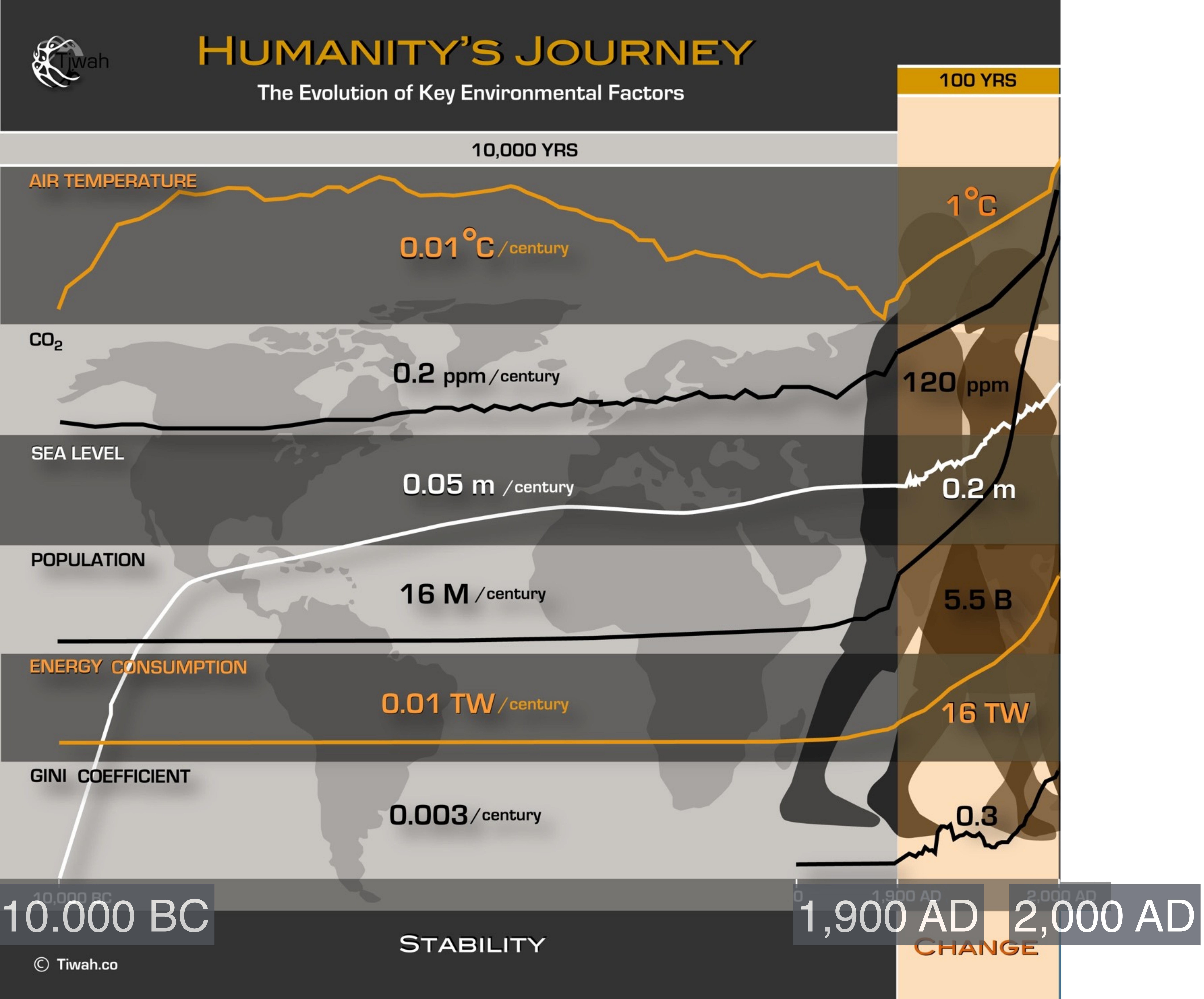
Plag, 2016


Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
AIR TEMPERATURE
0.01 °C / century
CO2
0.2 ppm / century
SEA LEVEL
0.05 m / century
POPULATION
16 M / century
ENERGY CONSUMPTION
0.01 TW / century
GINI COEFFICIENT
0.003 / century
10.000 BC
1,900 AD
STABILITY
© Tiwah.co

Plag, 2016



Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
100 YRS
AIR TEMPERATURE
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1 °C
CO2
0.2 ppm /century
120 ppm
SEA LEVEL
0.05 m /century
0.2 m
POPULATION
16 M /century
5.5 B
ENERGY CONSUMPTION
0.01 TW /century
16 TW
GINI COEFFICIENT
0.003 /century
0.3
10.000 BC
1,900 AD
2,000 AD
STABILITY
CHANGE
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Plag, 2016

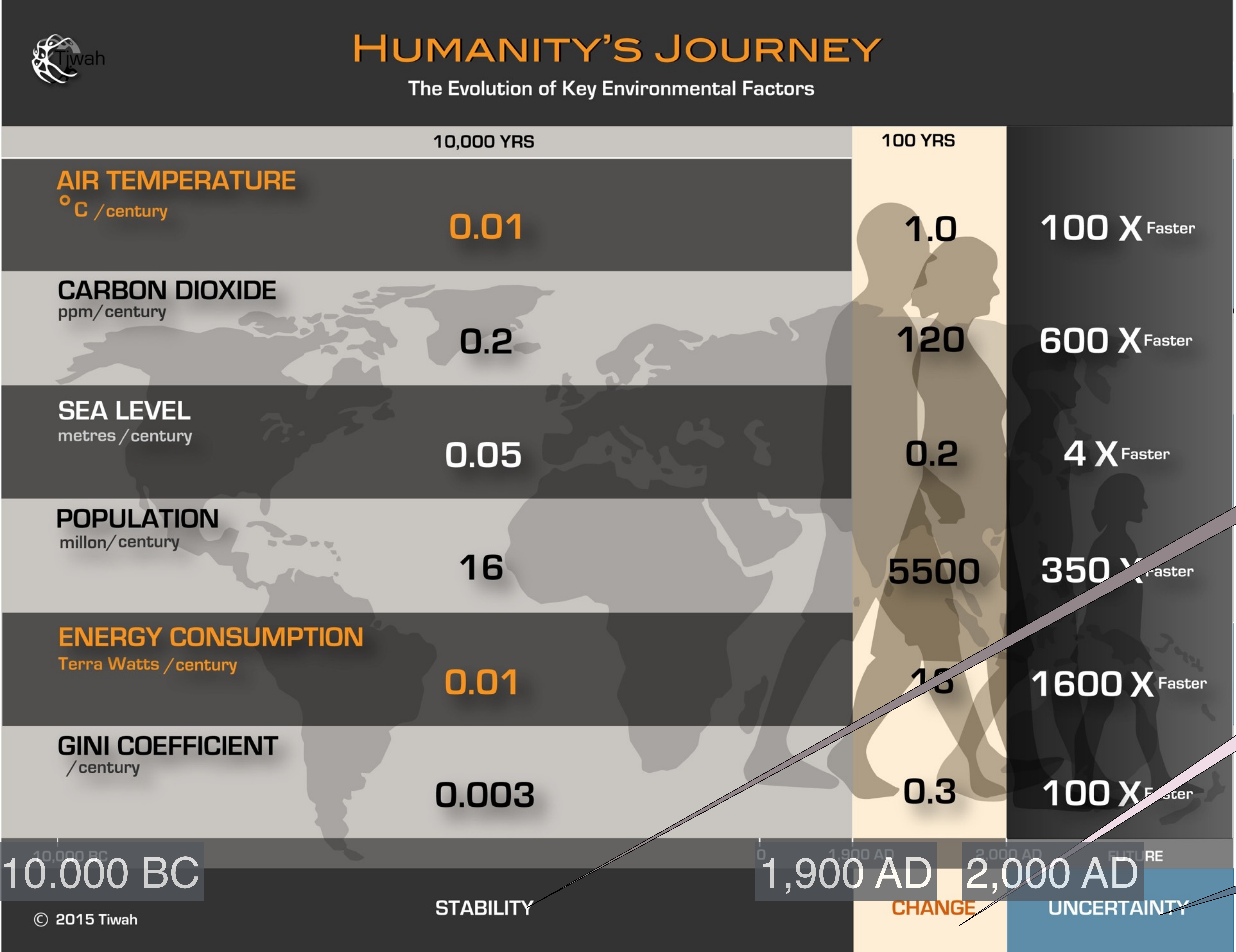
HUMANITY'S JOURNEY

Tiwah

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 — FUTURE
	STABILITY	CHANGE	UNCERTAINTY

Plag, 2016



Holocene: Stability

20th and 21st Century: Change, imbalance

Future: Uncertainty

Plag, 2016

The Diagnosis: Leaving the “Safe Operating Space”

Impacts on the Earth’s Life-Support System

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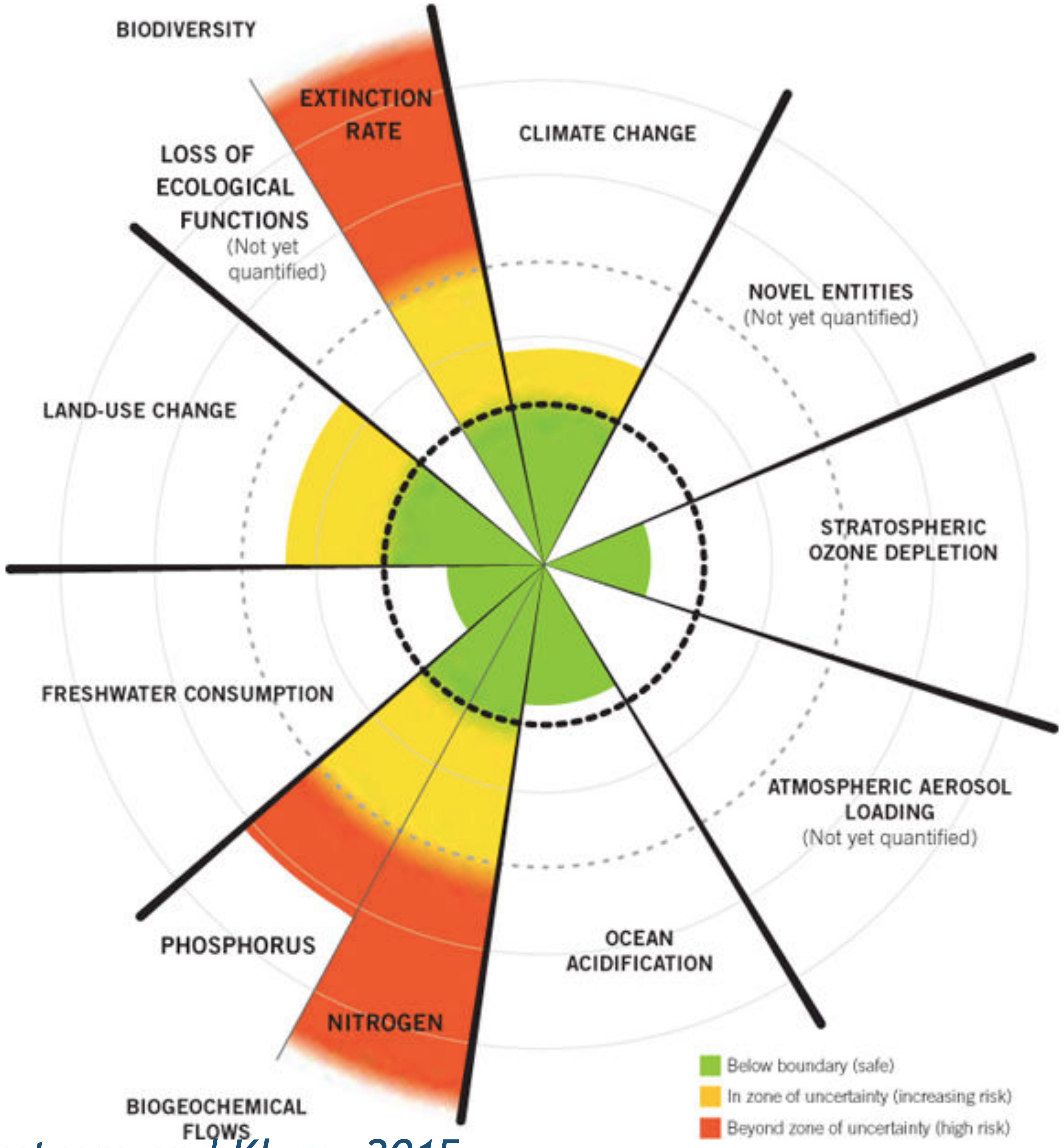

Rockstrom and Klum, 2015

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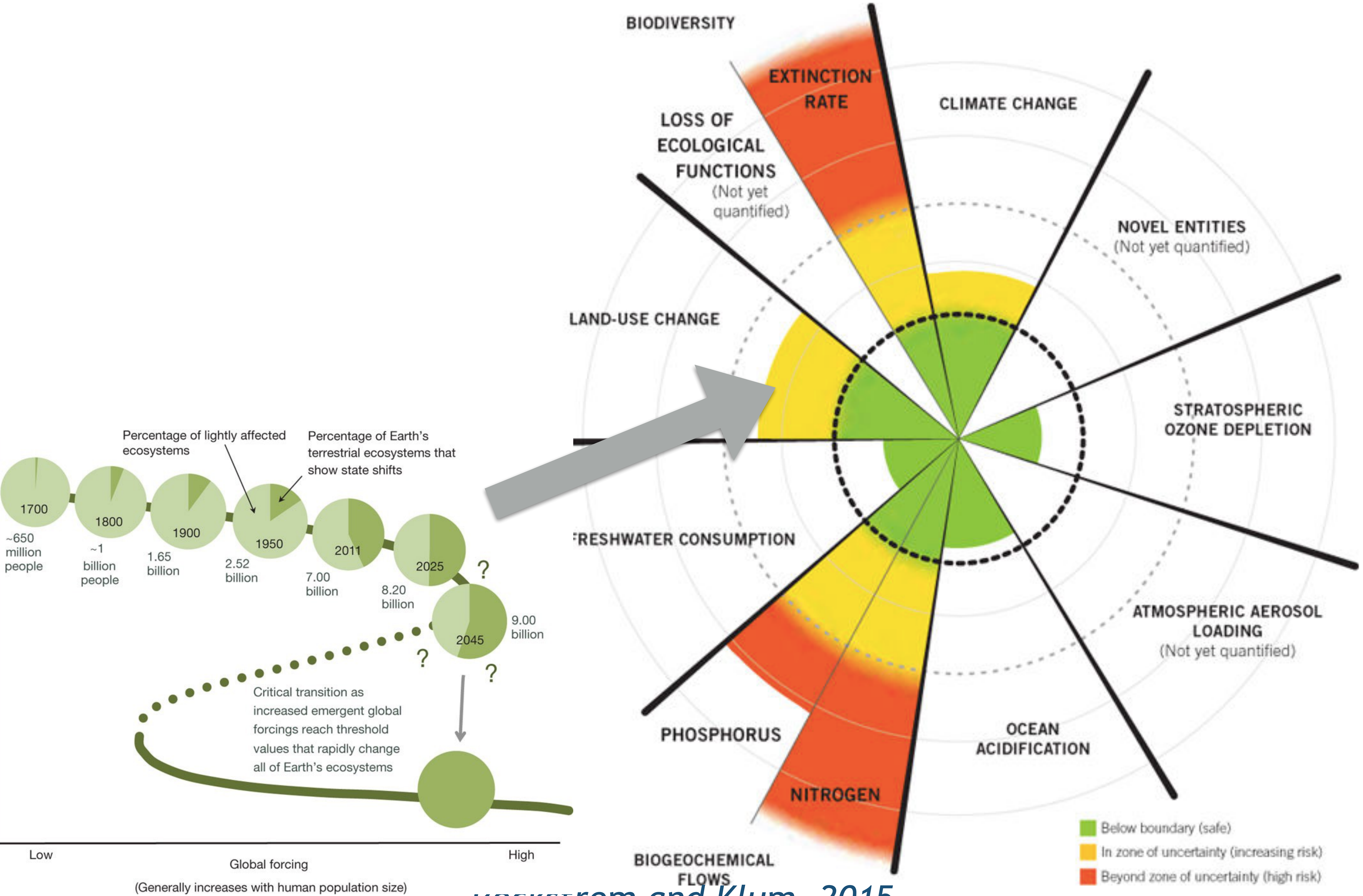

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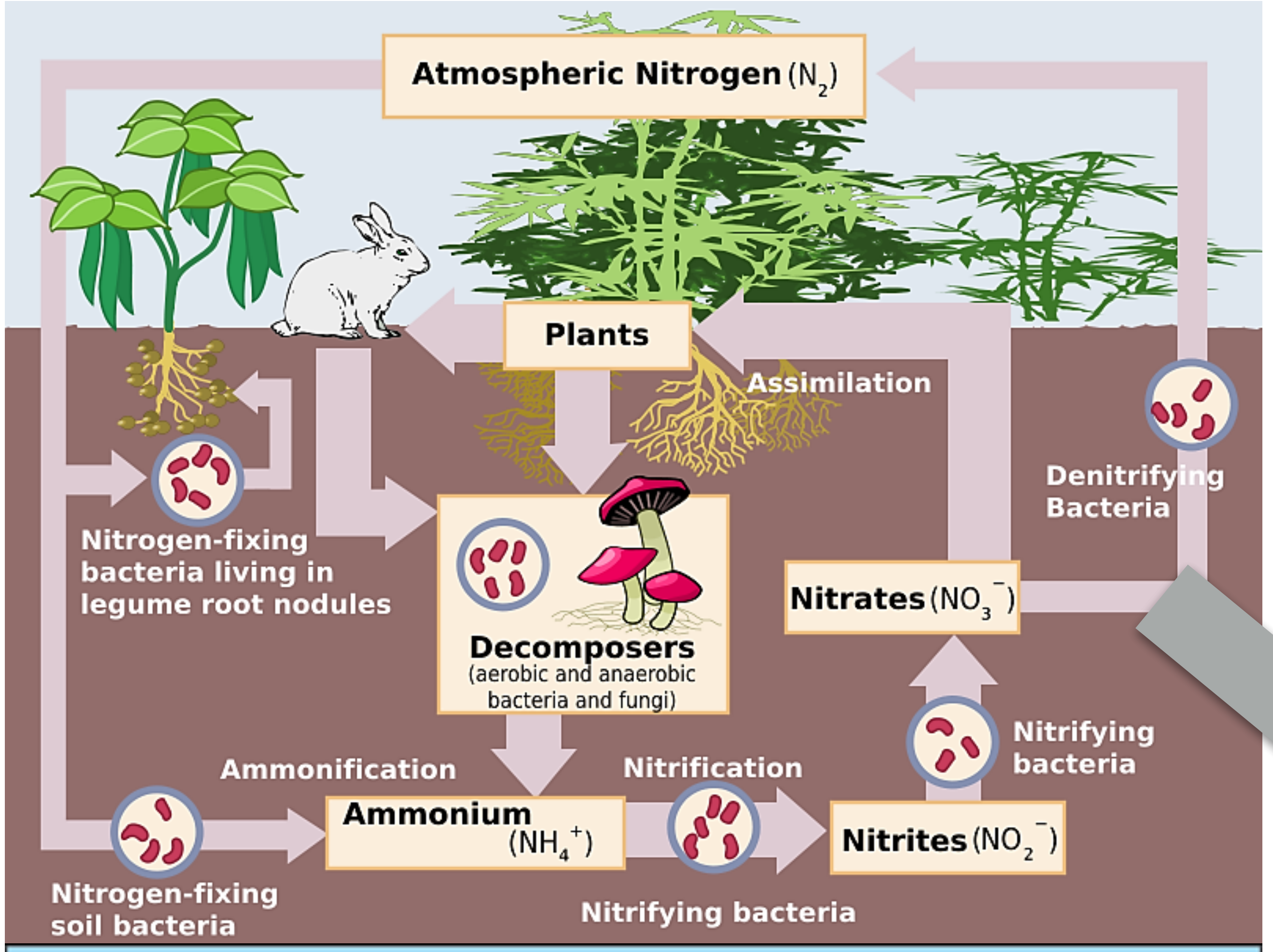

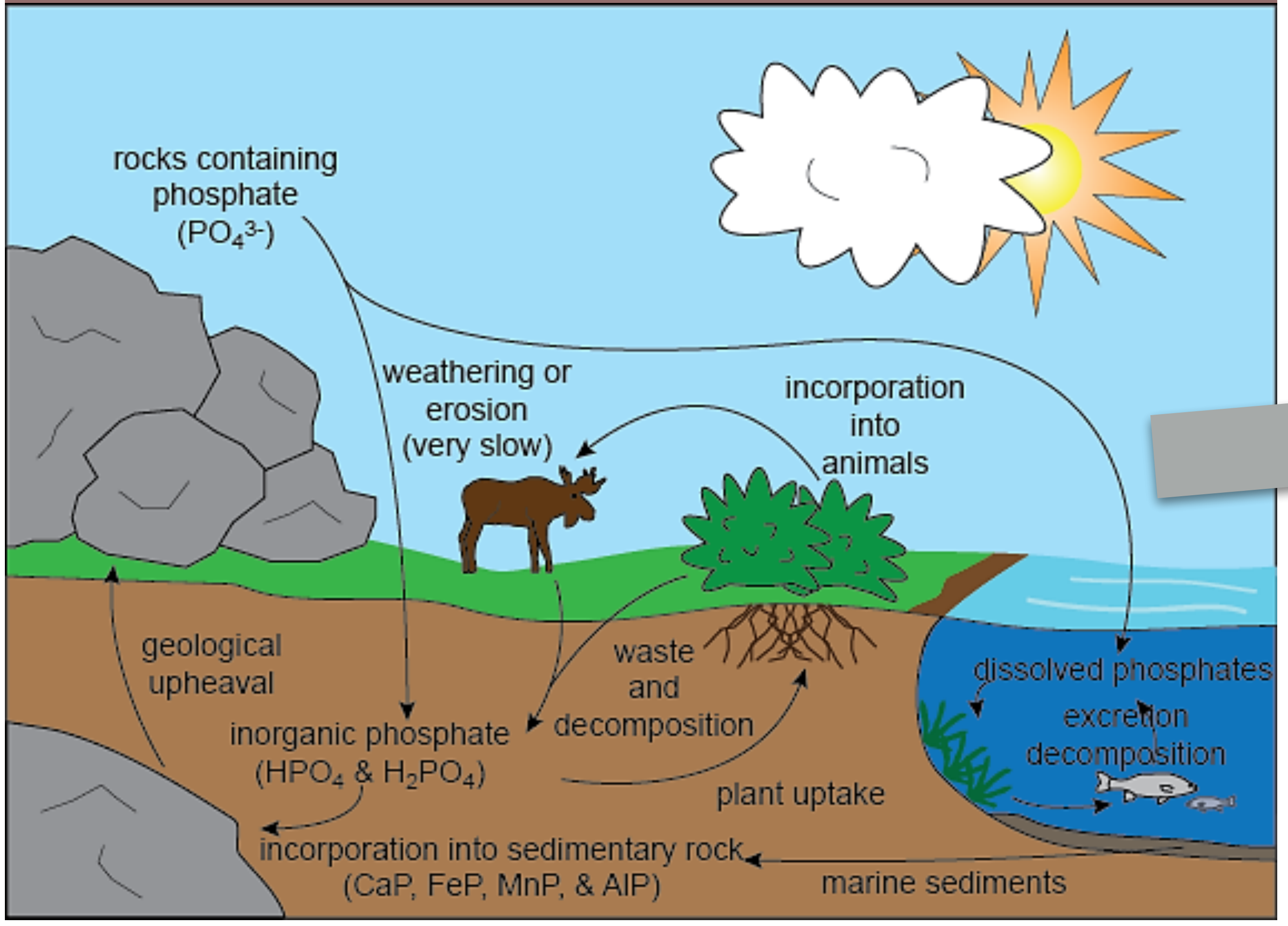

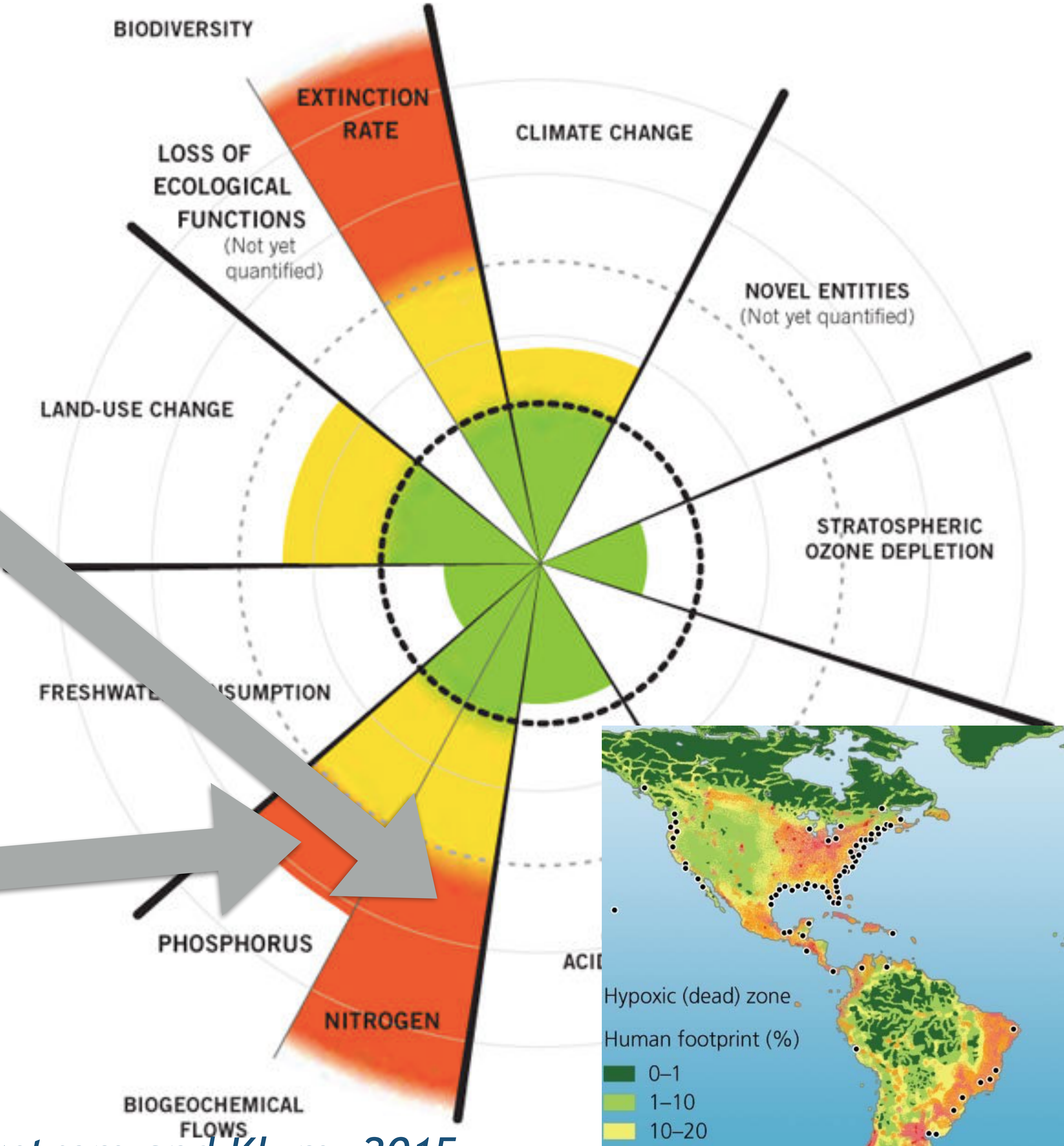

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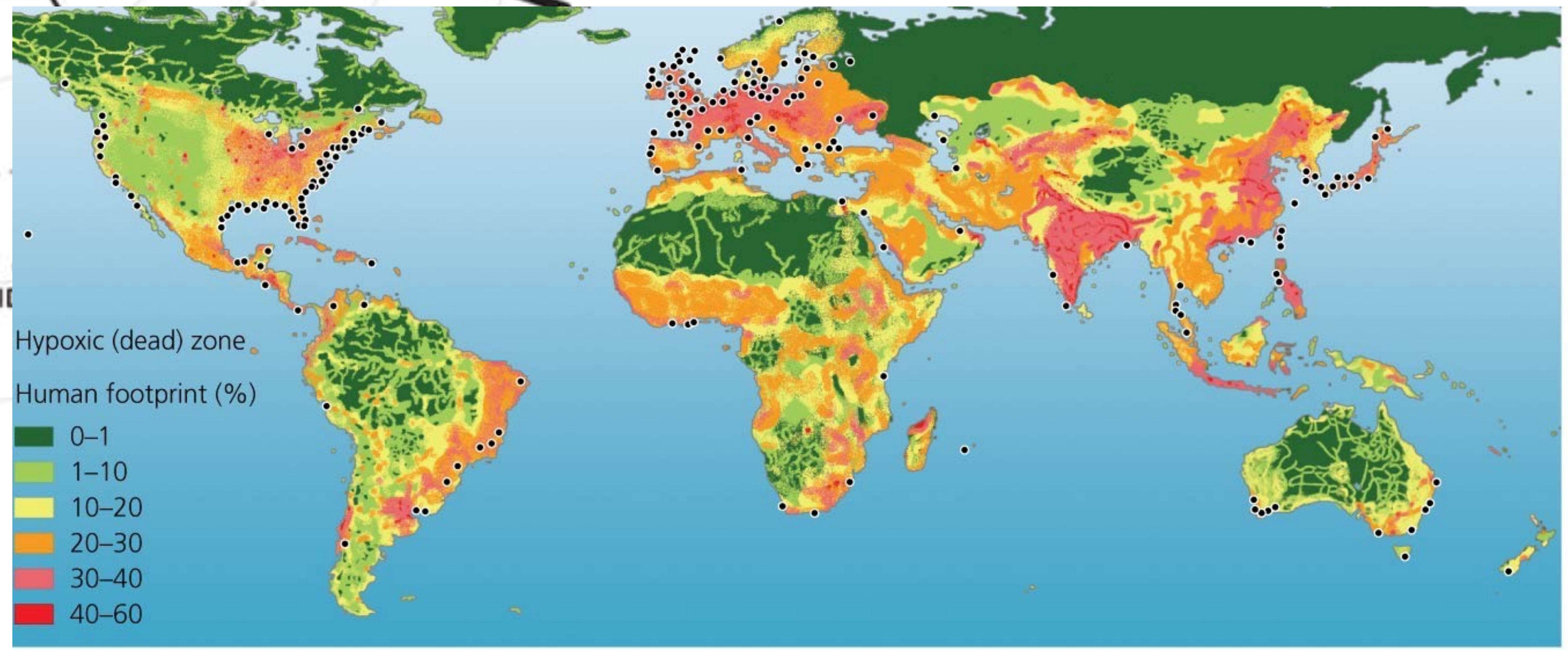

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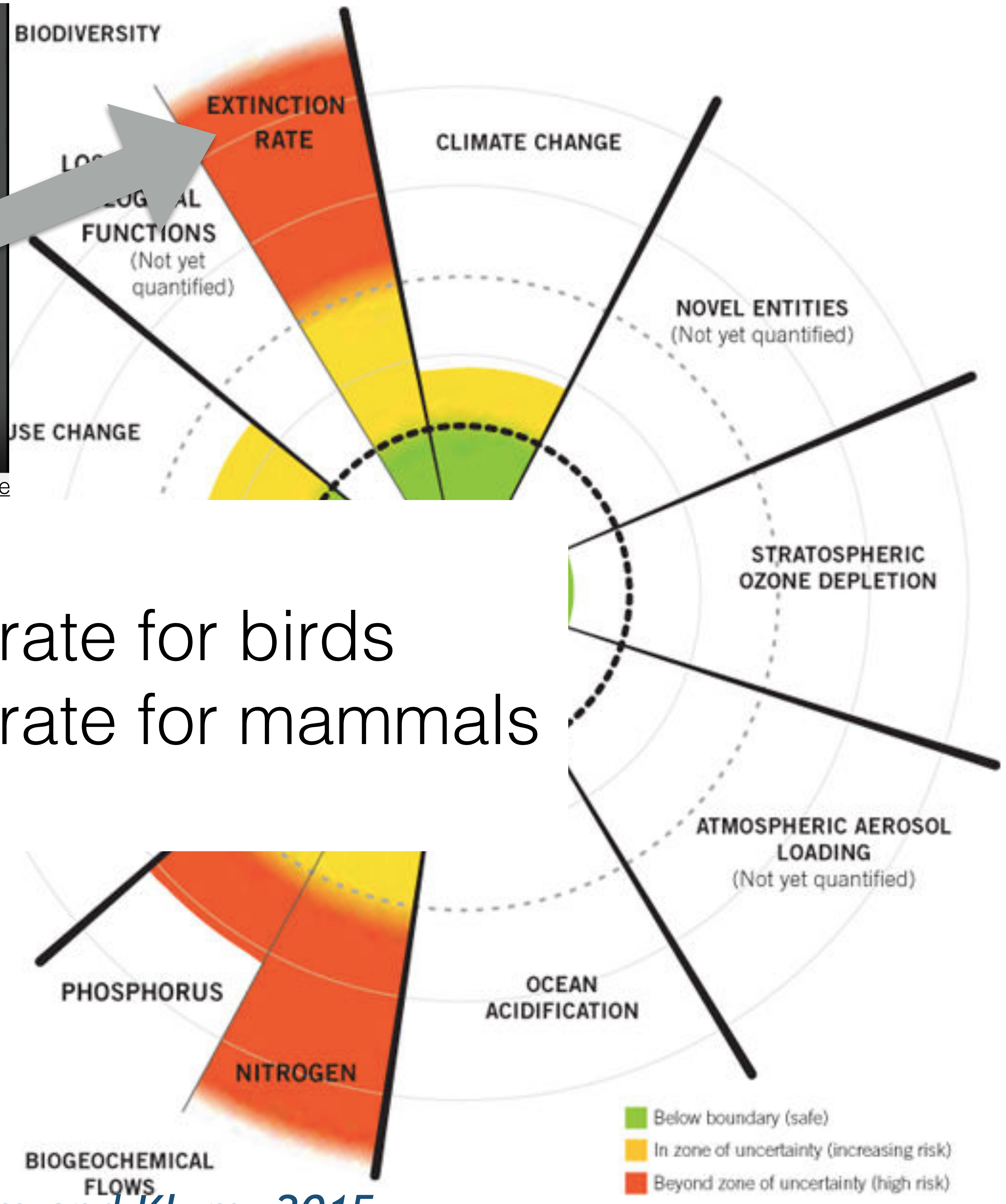
https://www.youtube.com/watch?v=gPq9YAg9mfc&feature=youtu.be



Current extinction rates:

300 times background rate for birds

80,000 times background rate for mammals

Rockstrom and Klum, 2015

The Diagnosis: Leaving the “Safe Operating Space”

Impacts on the Earth’s Life-Support System

https://www.youtube.com/watch?v=gPq9YAg9mfc&feature=youtu.be

“We are the asteroid …”

Current extinction rates:

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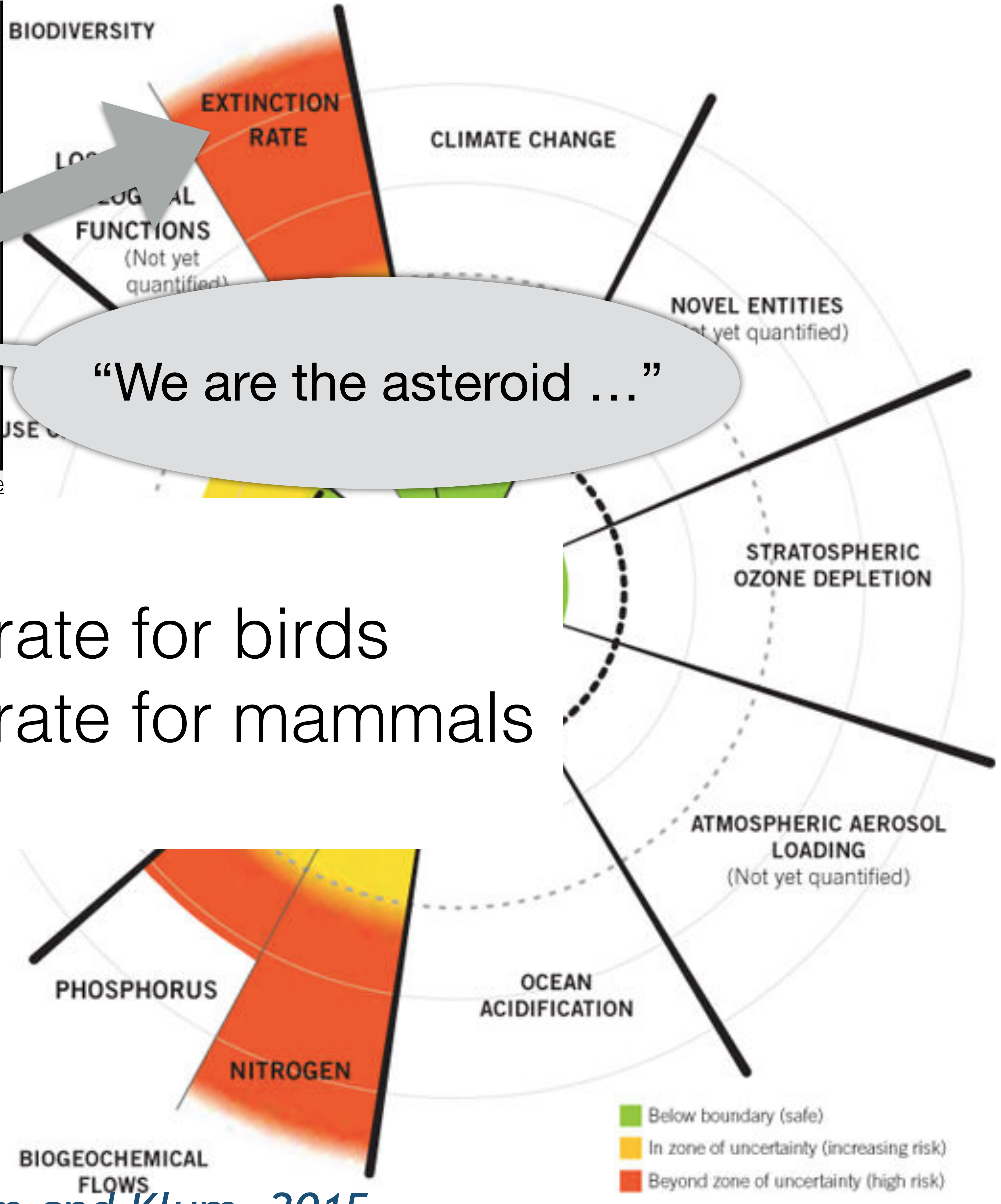

Rockstrom and Klum, 2015

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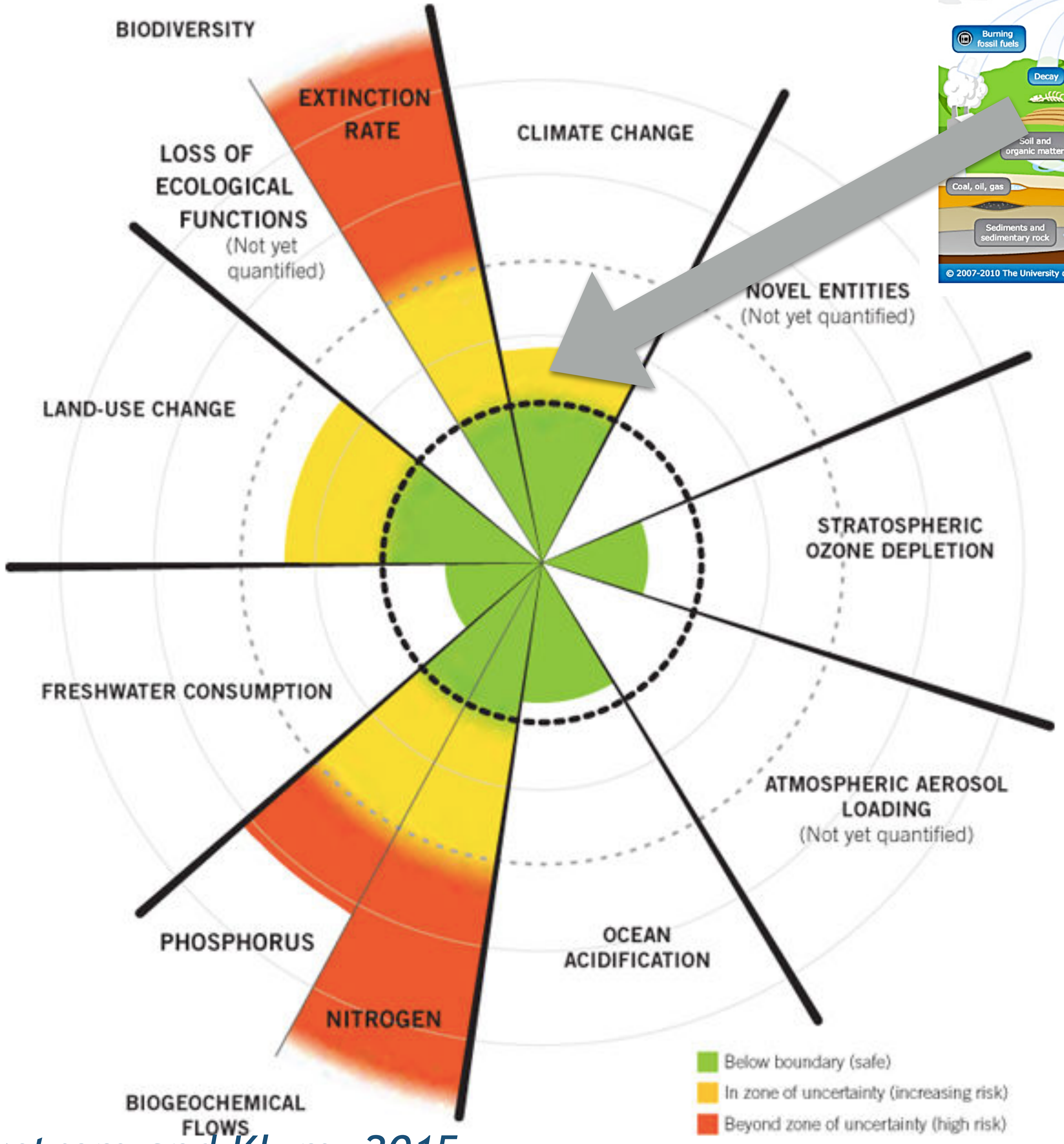

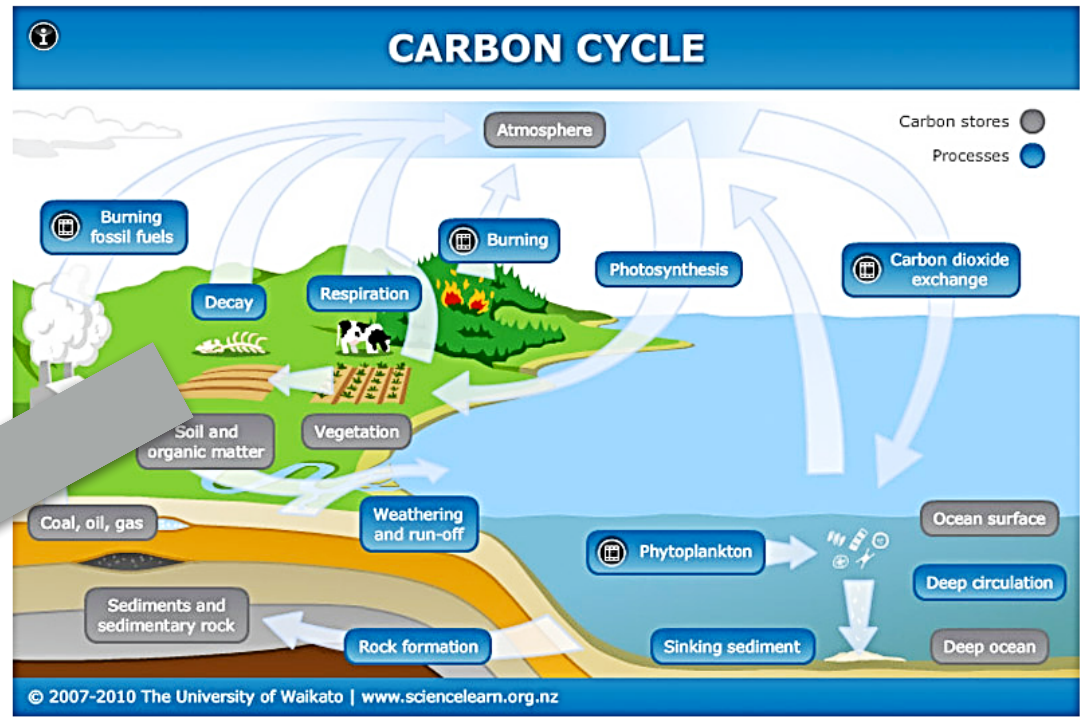

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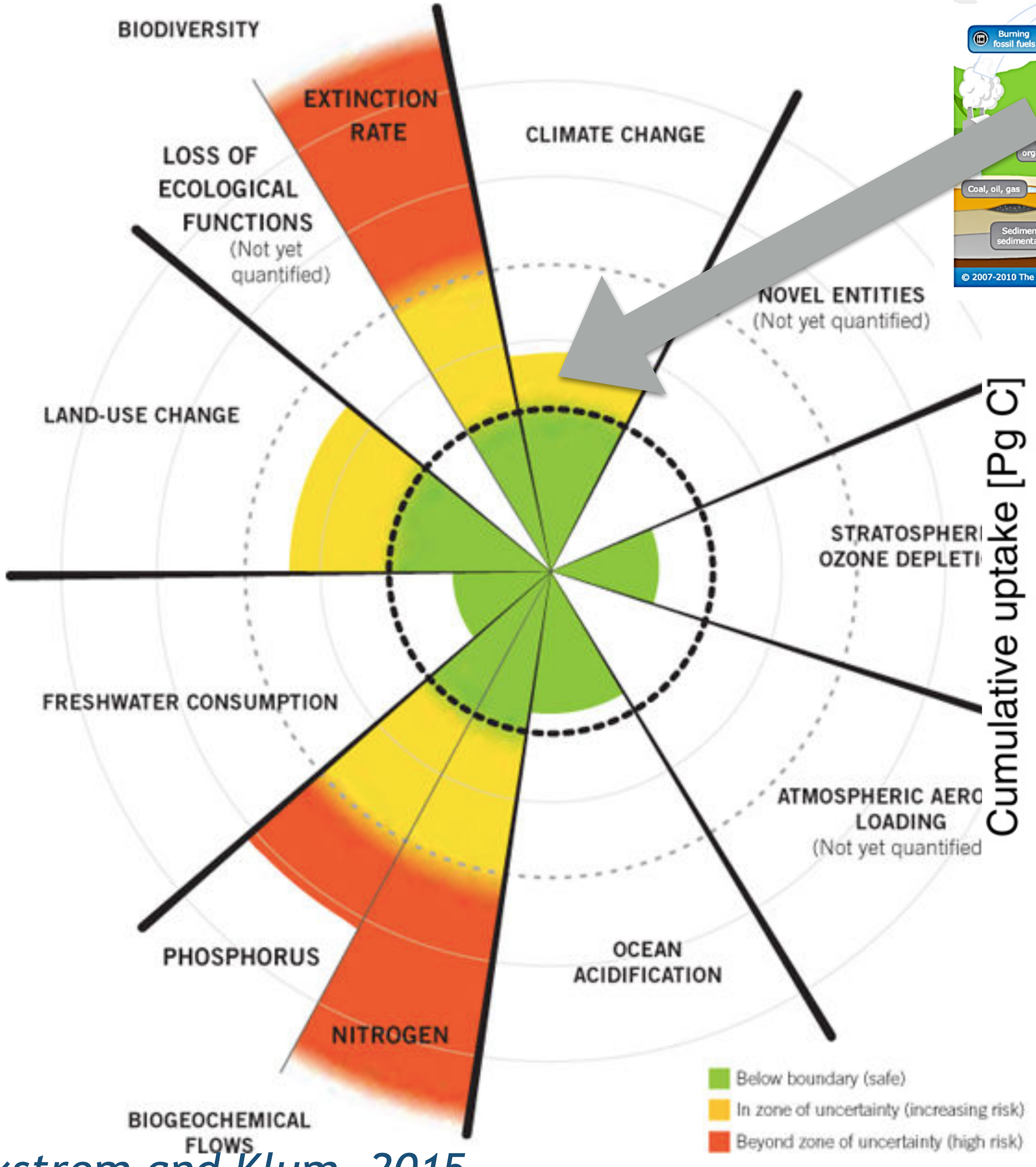

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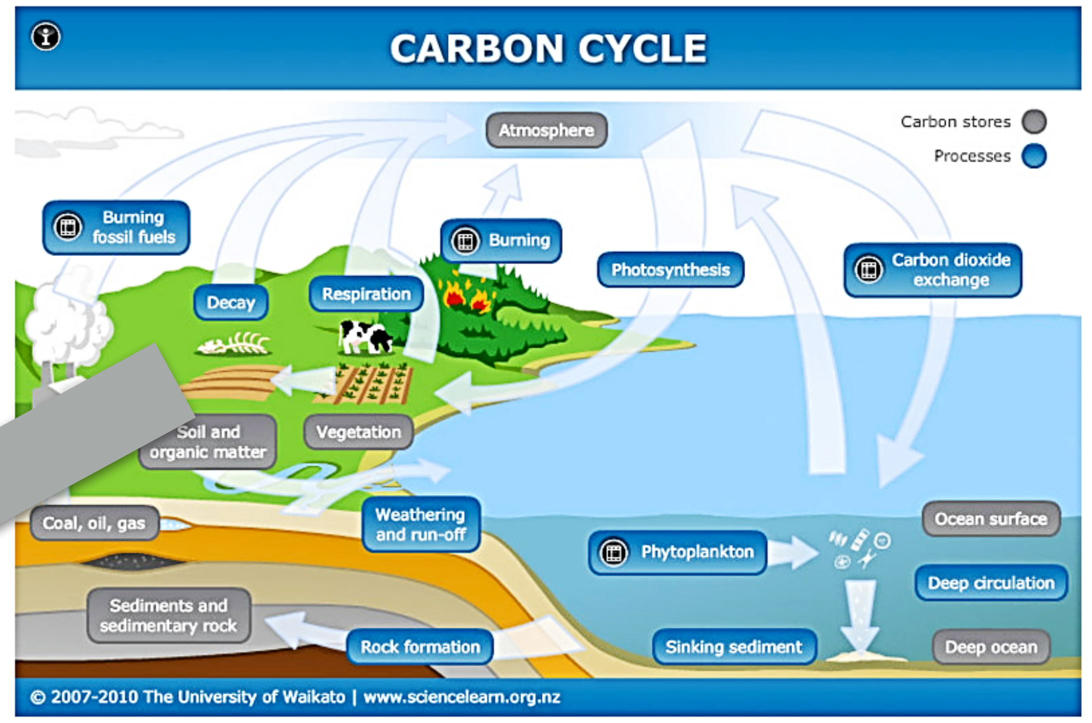

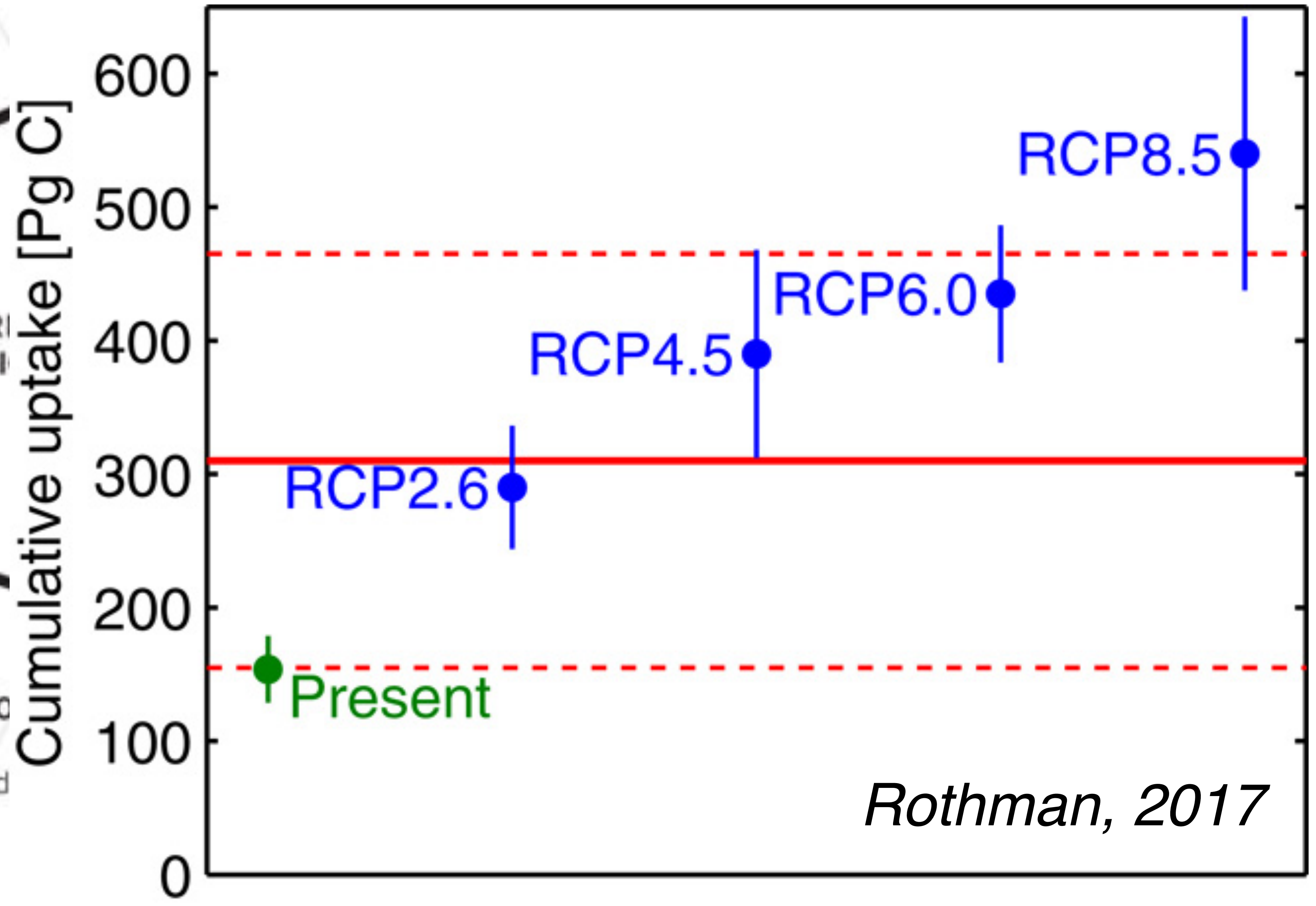

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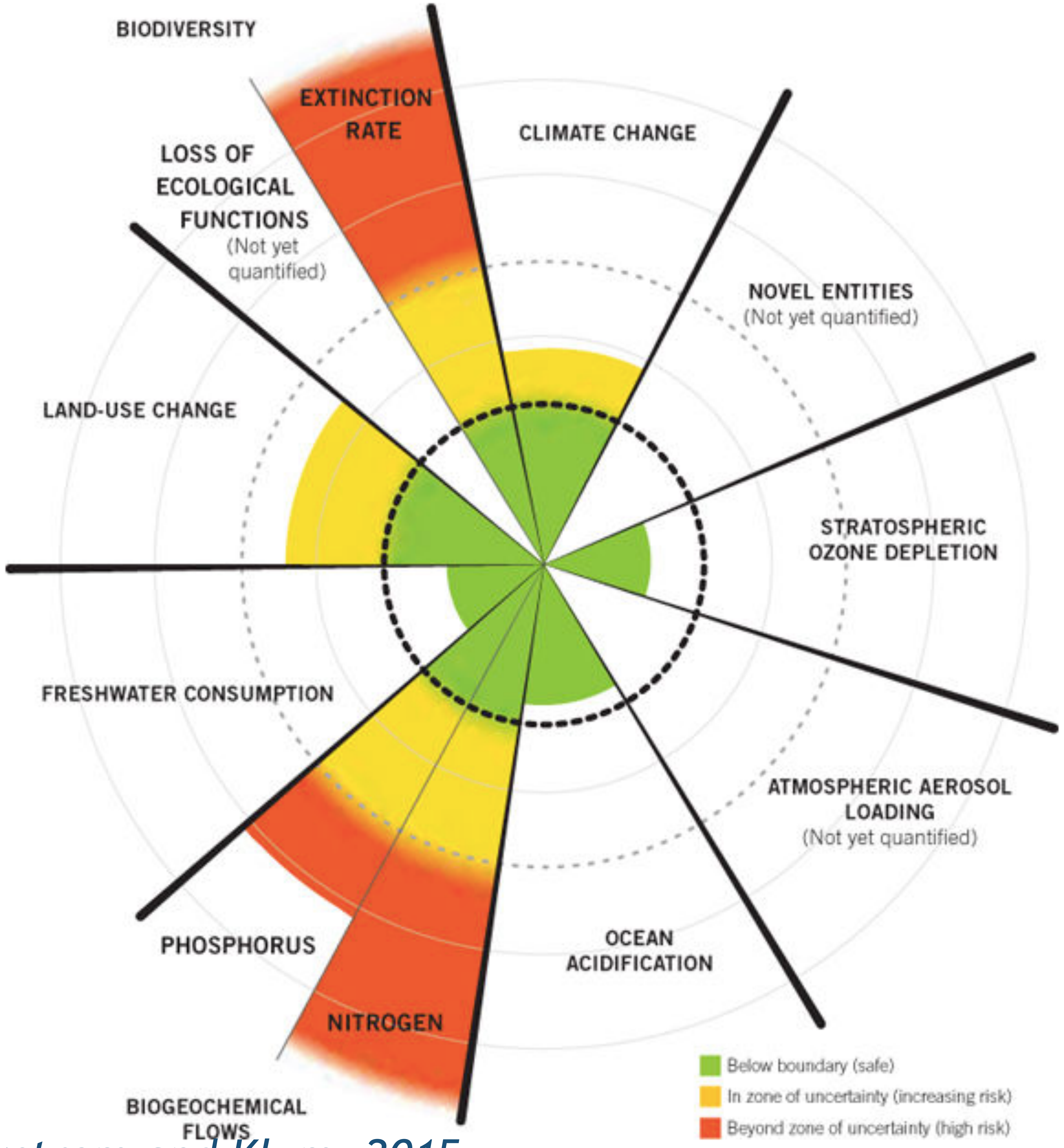


Rockstrom and Klum, 2015

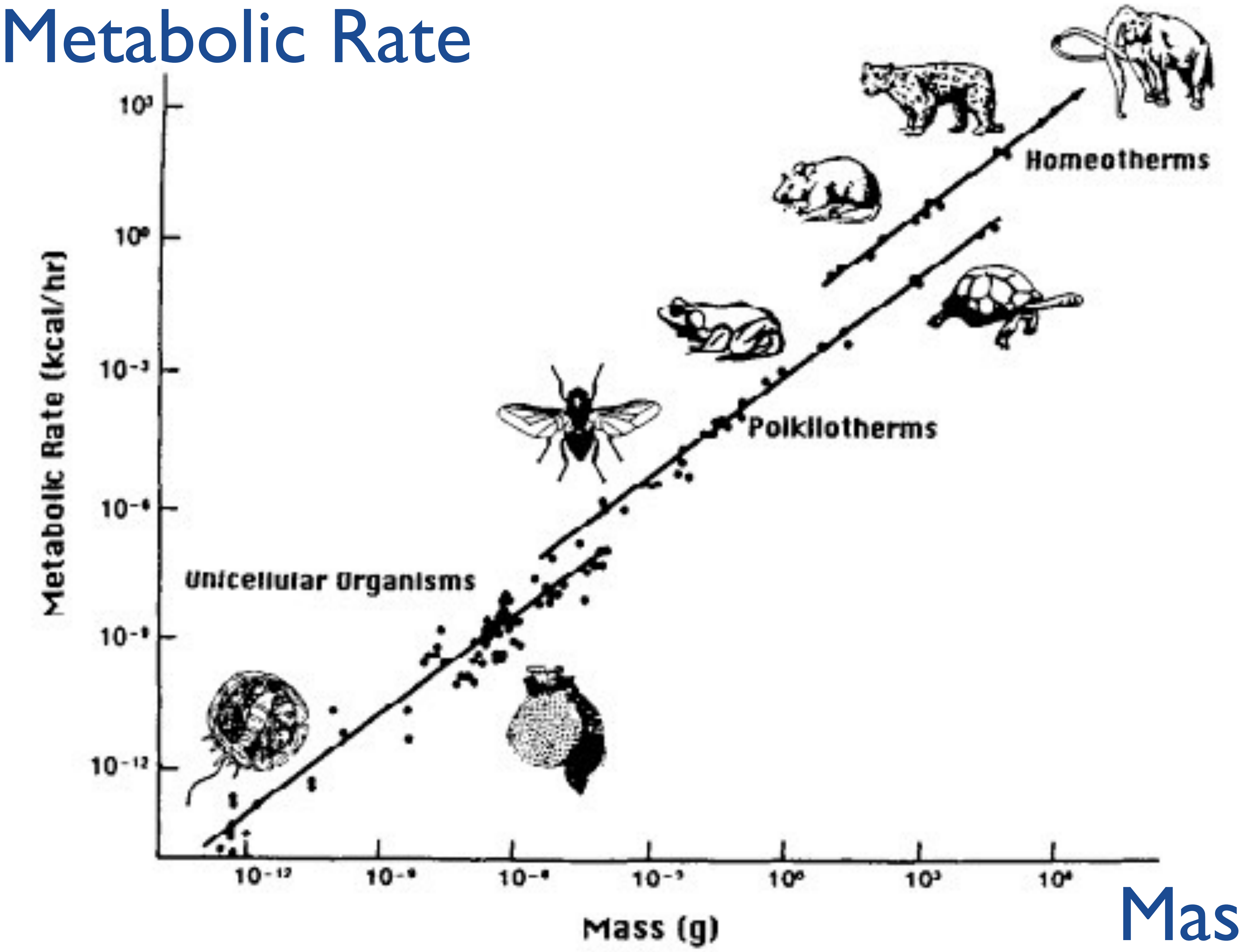
Modern climate change is a symptom, not the cause, not the "sickness."

The Diagnosis: Leaving the “Safe Operating Space”

Out of Scale

Scaling law for metabolic rate:
$Y = Y_0 * M^{(3/4)}$

Metabolic Rate



Mass

The Diagnosis: Leaving the “Safe Operating Space”

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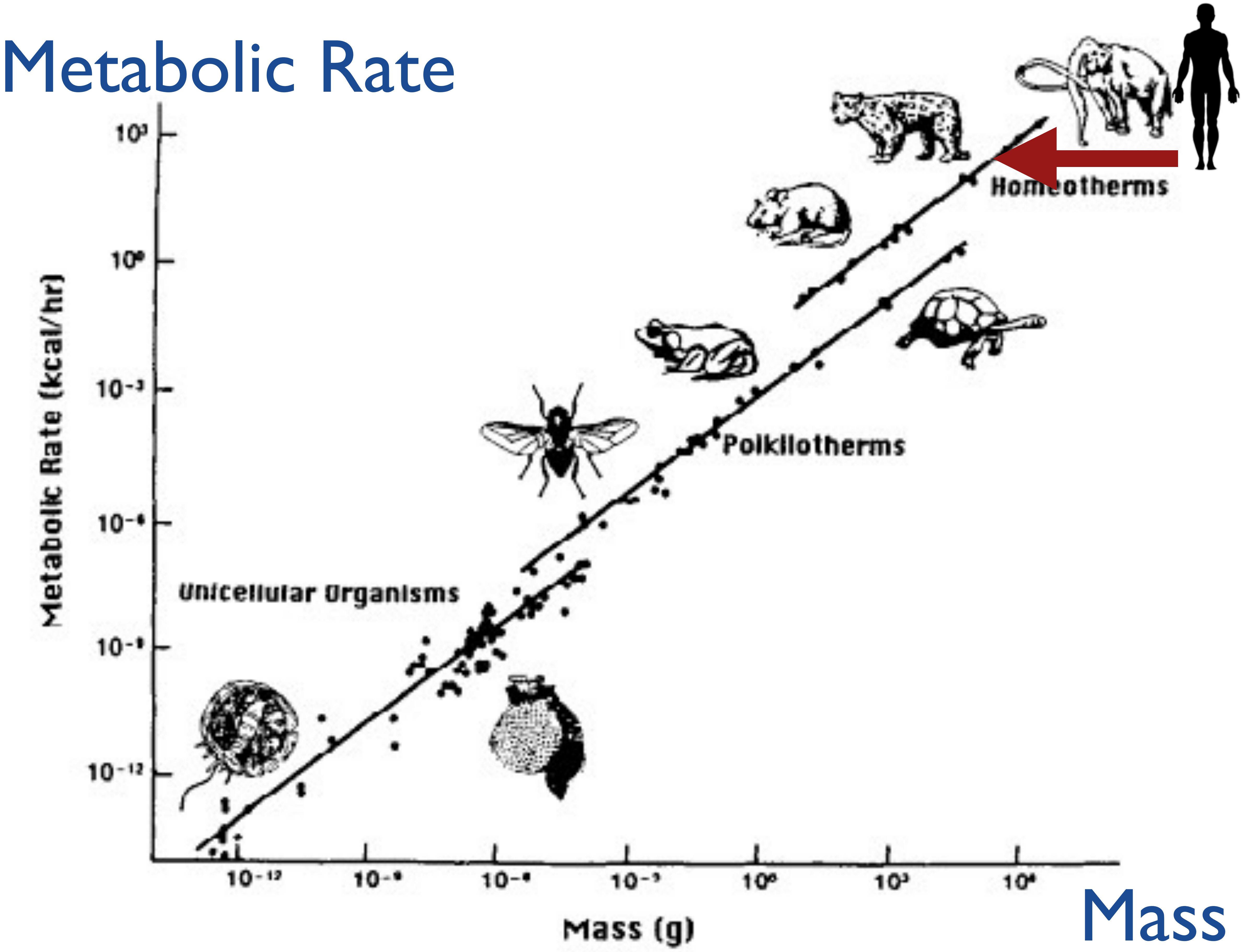
human: Y = 50 -100 Watt

Metabolic Rate

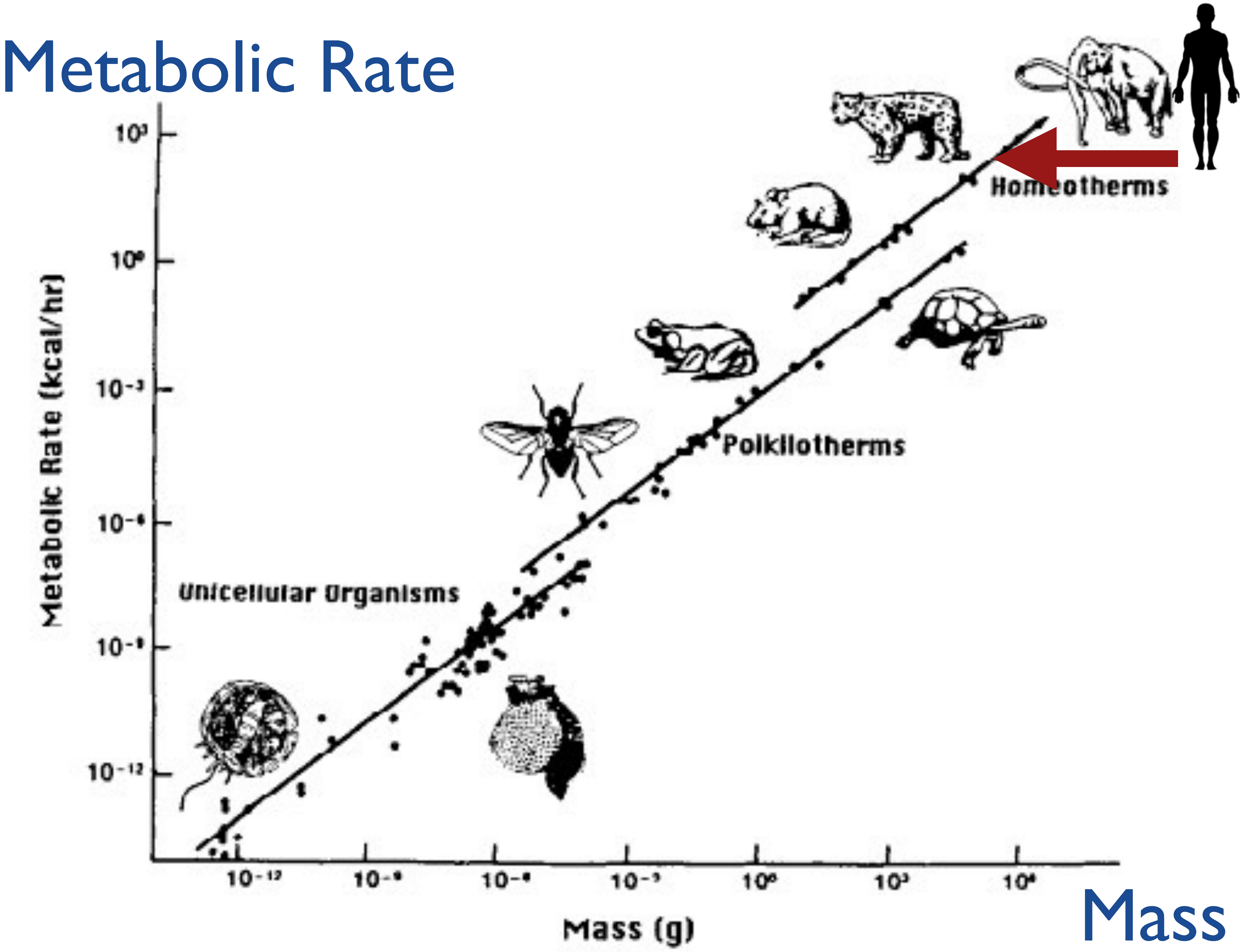


Mass

The Diagnosis: Leaving the “Safe Operating Space”

Out of Scale

Metabolic Rate



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Extended metabolic rate:
$Y_E = Y + C_E$
(C_E: total energy consumption)

The Diagnosis: Leaving the “Safe Operating Space”

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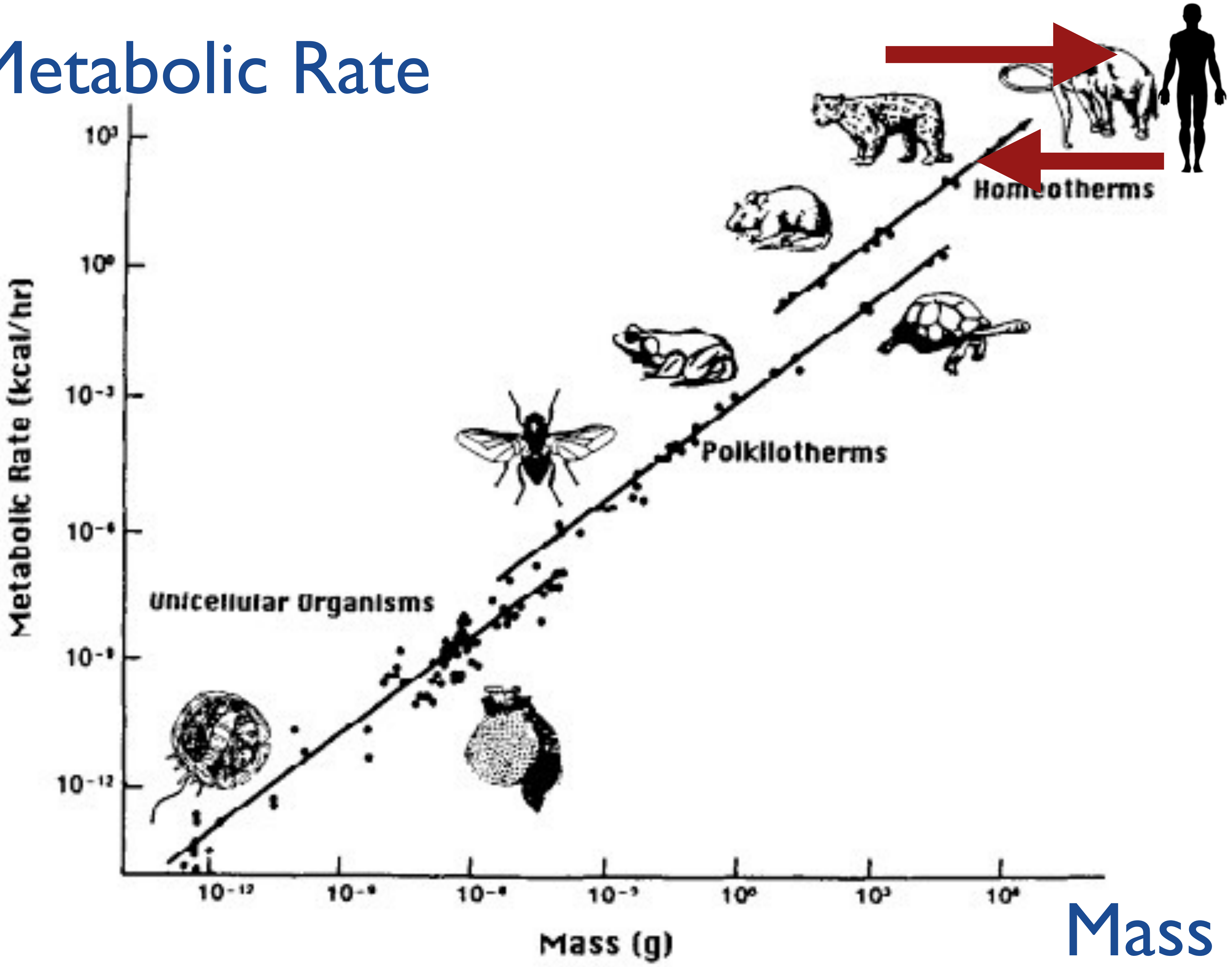

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Global Average: Y_E = 2,835 Watt
M = 10 metric tons

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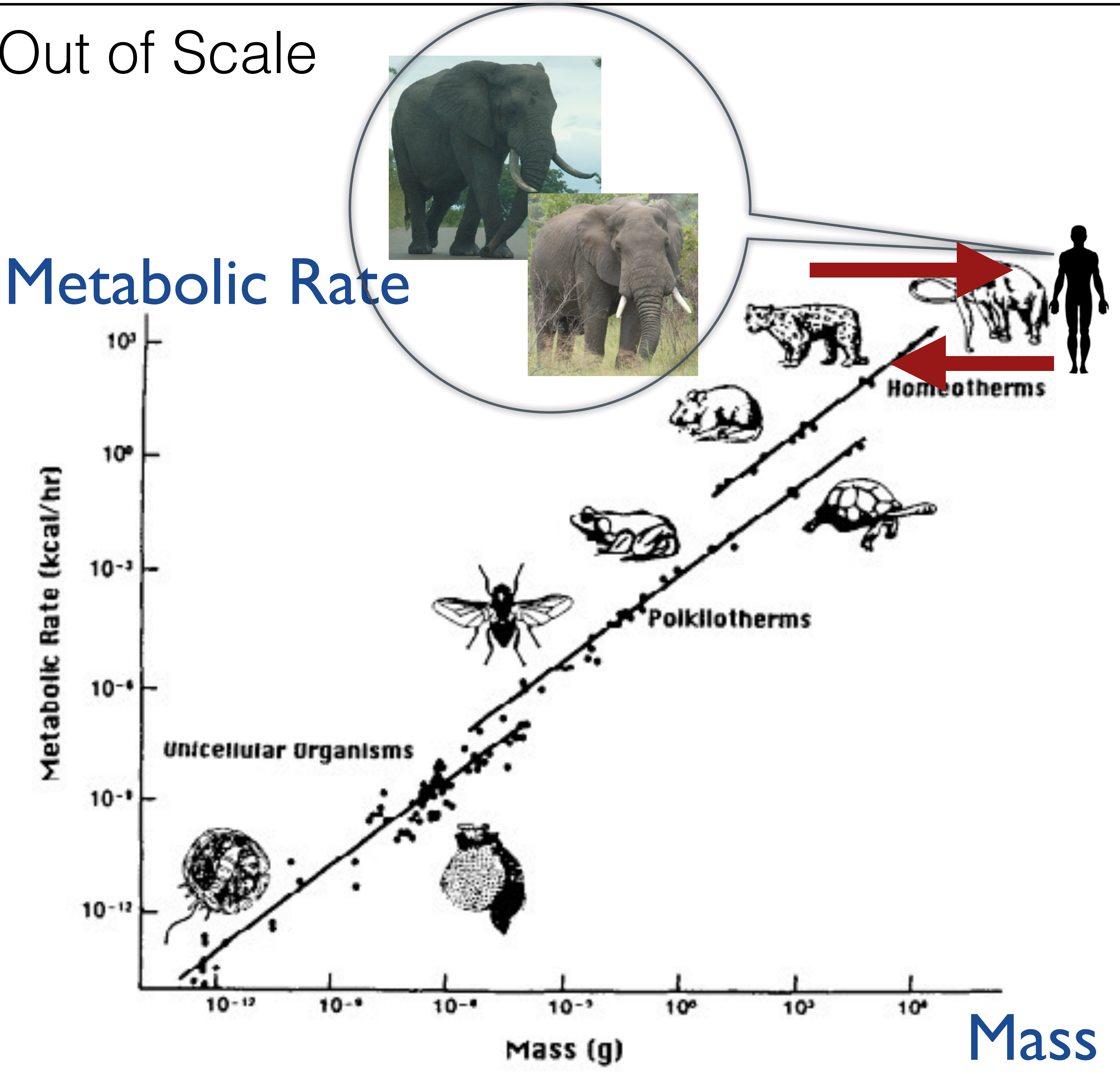

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Humanity has an extended metabolic rate equivalent to 14 Billion elephants (2.7 Billion for the U.S. alone)

The Diagnosis: Leaving the "Safe Operating Space"

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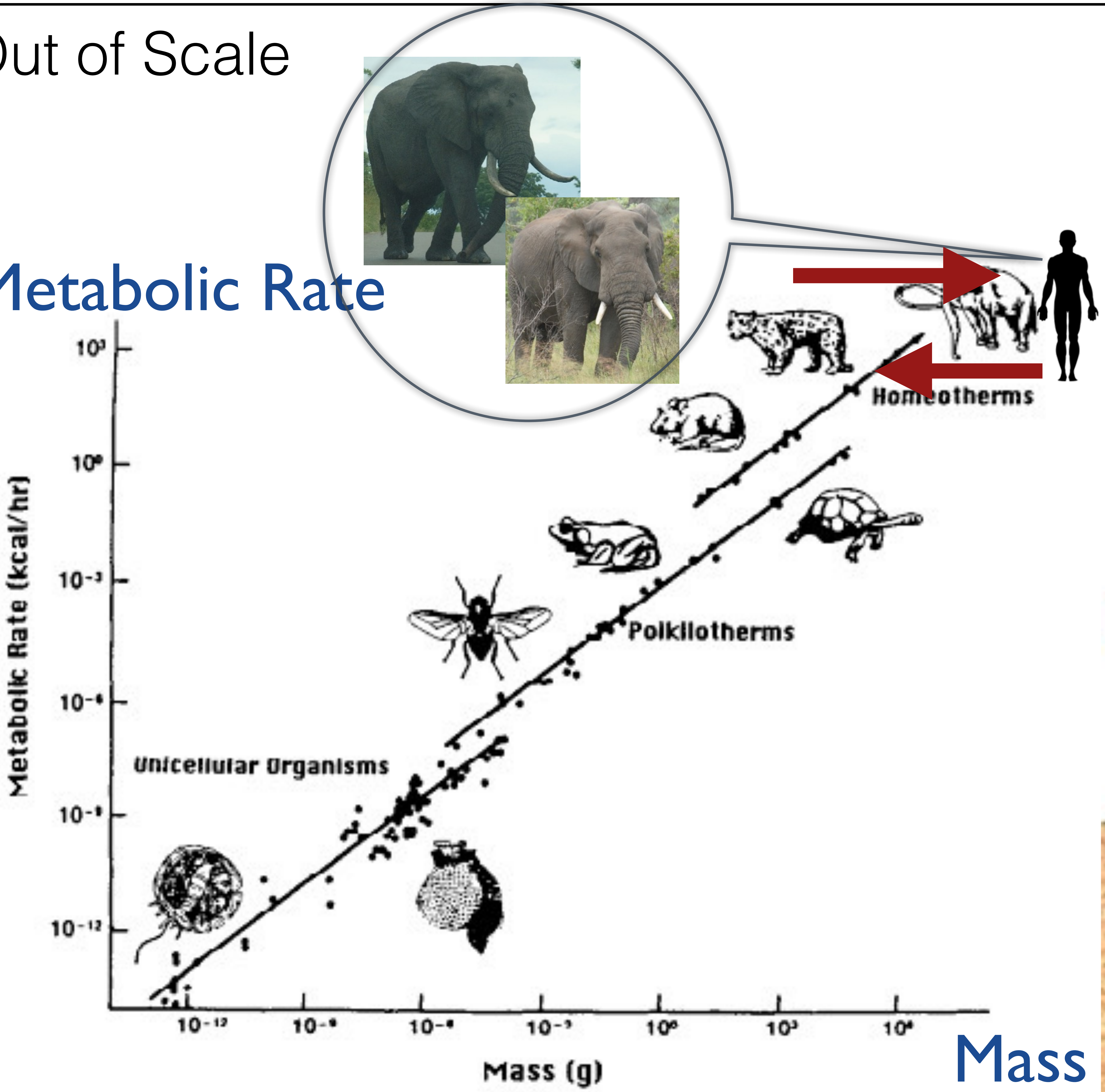
Metabolic Rate



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14 Billion elephants: a heavy "load" for Earth

The Diagnosis: Leaving the “Safe Operating Space”

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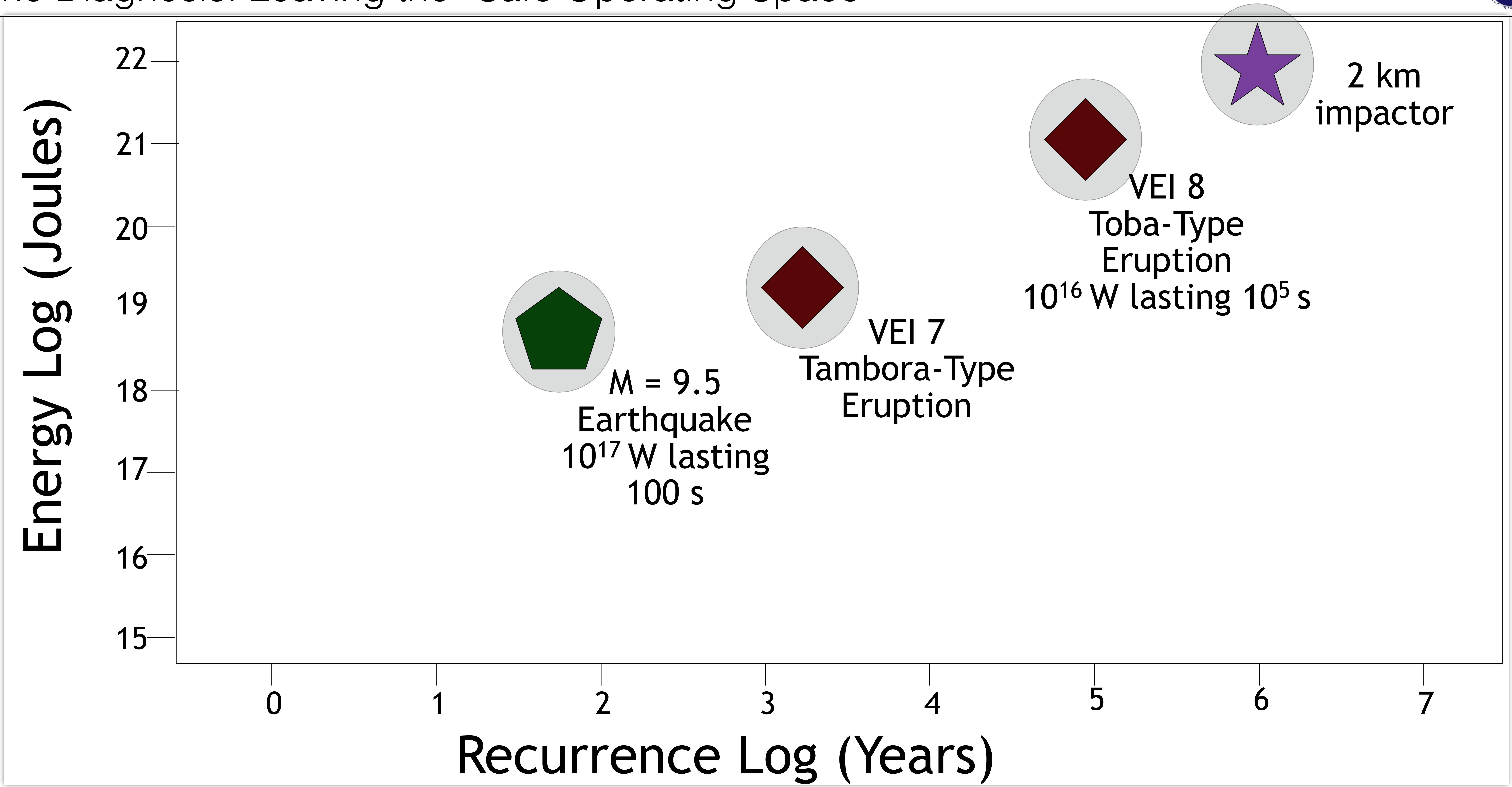

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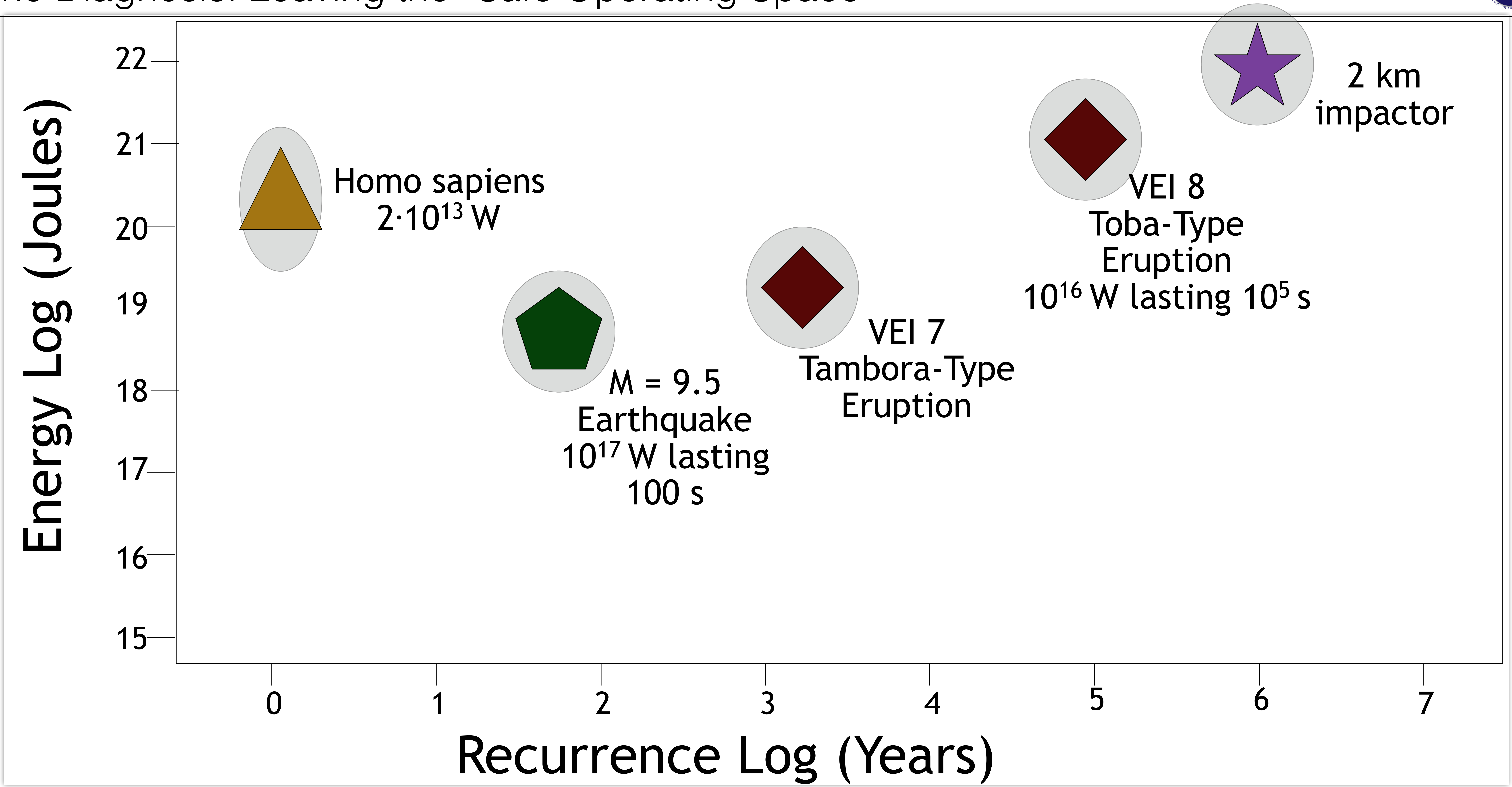

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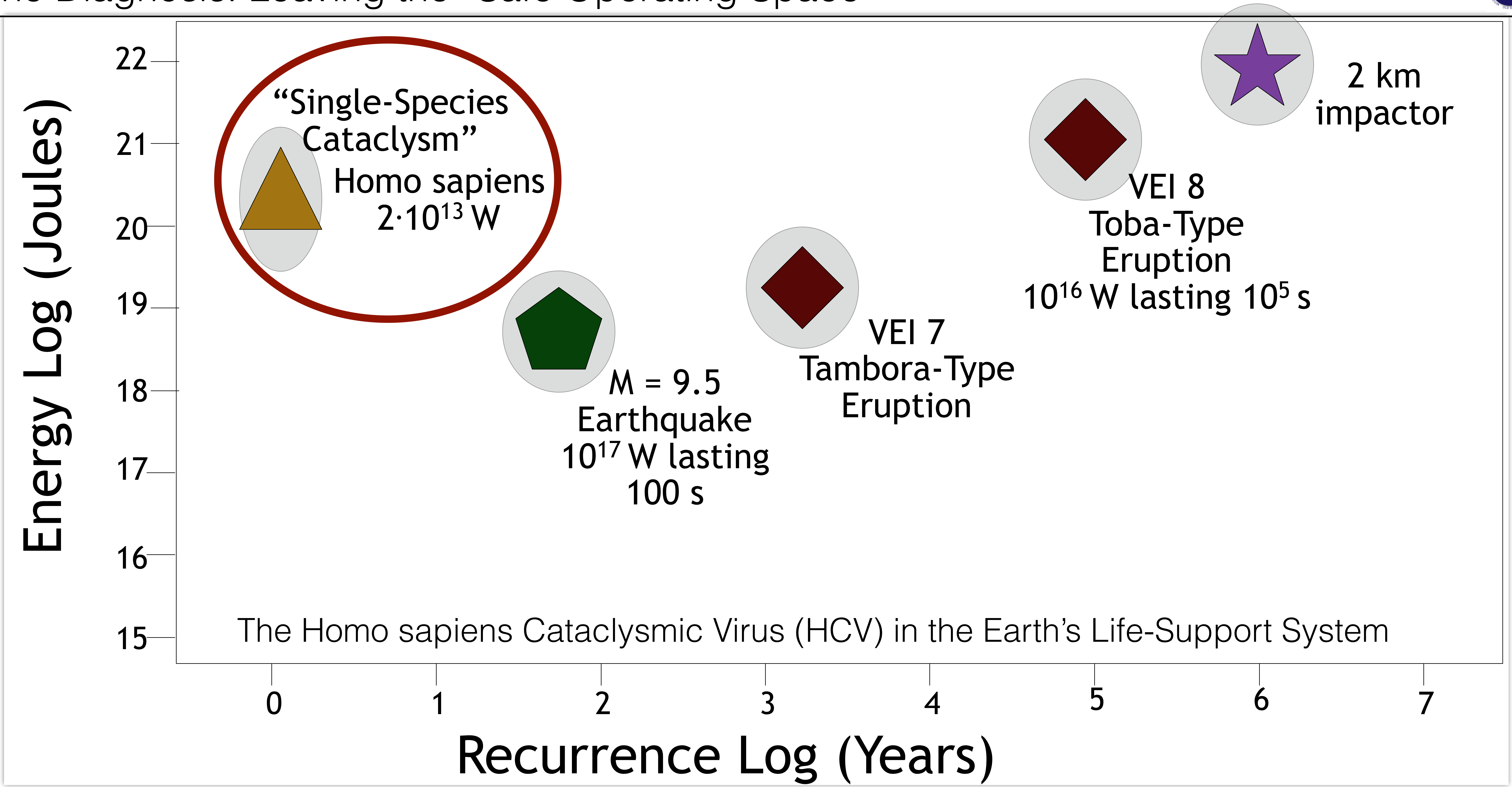


Malignant skin cancer of the planet
Plag, 2010
Anthropogenic Cataclysmic Virus (ACV)
Plag, 2015


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Plag, 2010
Anthropogenic Cataclysmic Virus (ACV)
Plag, 2015
Can the “virus” transform itself into the “healer”?

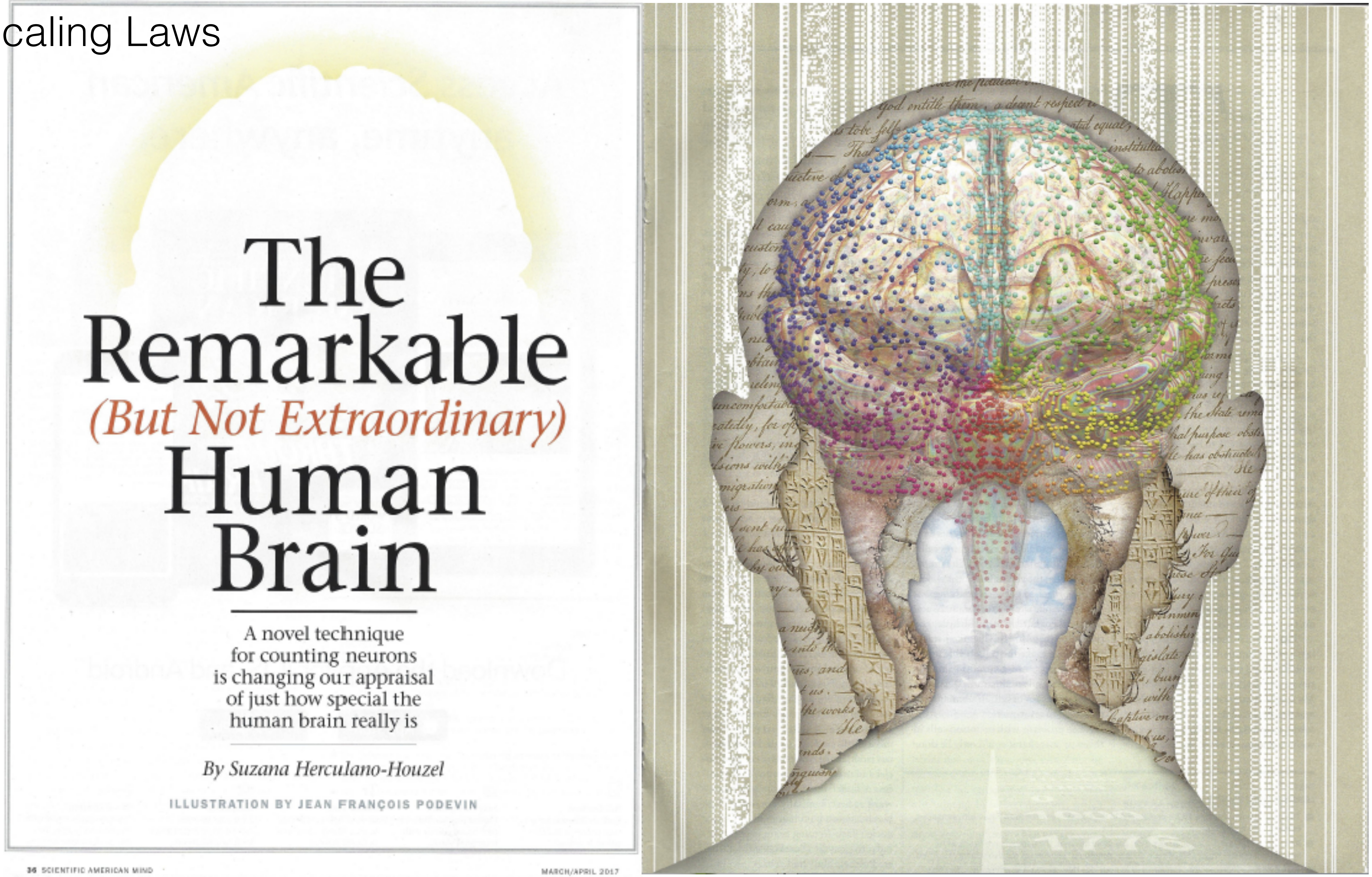
The Diagnosis: Leaving the “Safe Operating Space”

Breaking Scaling Laws

How could Homo sapiens “break” the scaling law?

The Diagnosis: Leaving the “Safe Operating Space”

Breaking Scaling Laws



The Remarkable *(But Not Extraordinary)* Human Brain

A novel technique for counting neurons is changing our appraisal of just how special the human brain really is

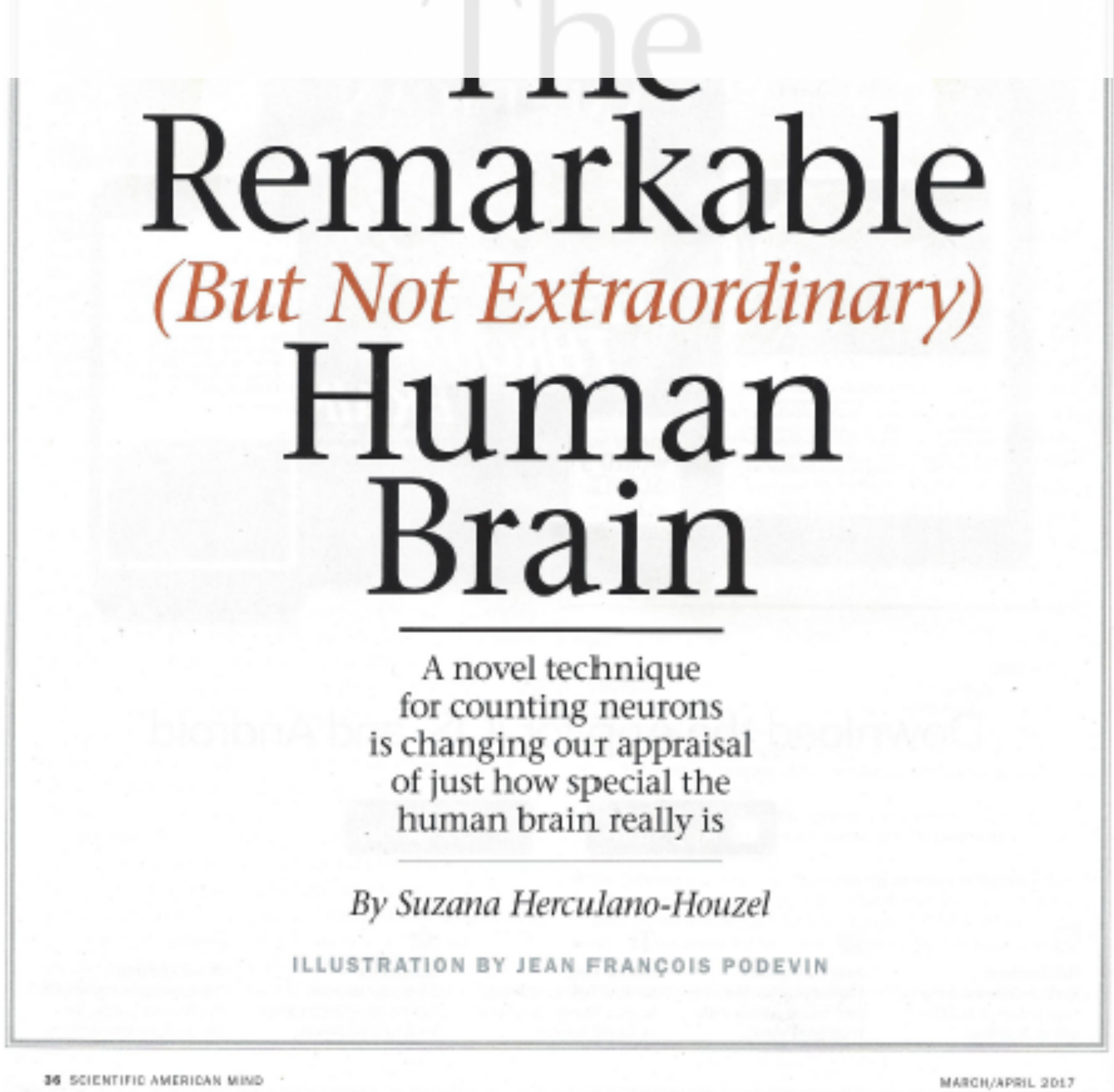
By Suzana Herculano-Houzel

ILLUSTRATION BY JEAN FRANÇOIS PODEVIN

The Diagnosis: Leaving the “Safe Operating Space”

Breaking Scaling Laws

- Brain is the most energy-demanding part in an organism.
- Brain to body ratio is limited by energy available to the organism to sustain the metabolic rate.



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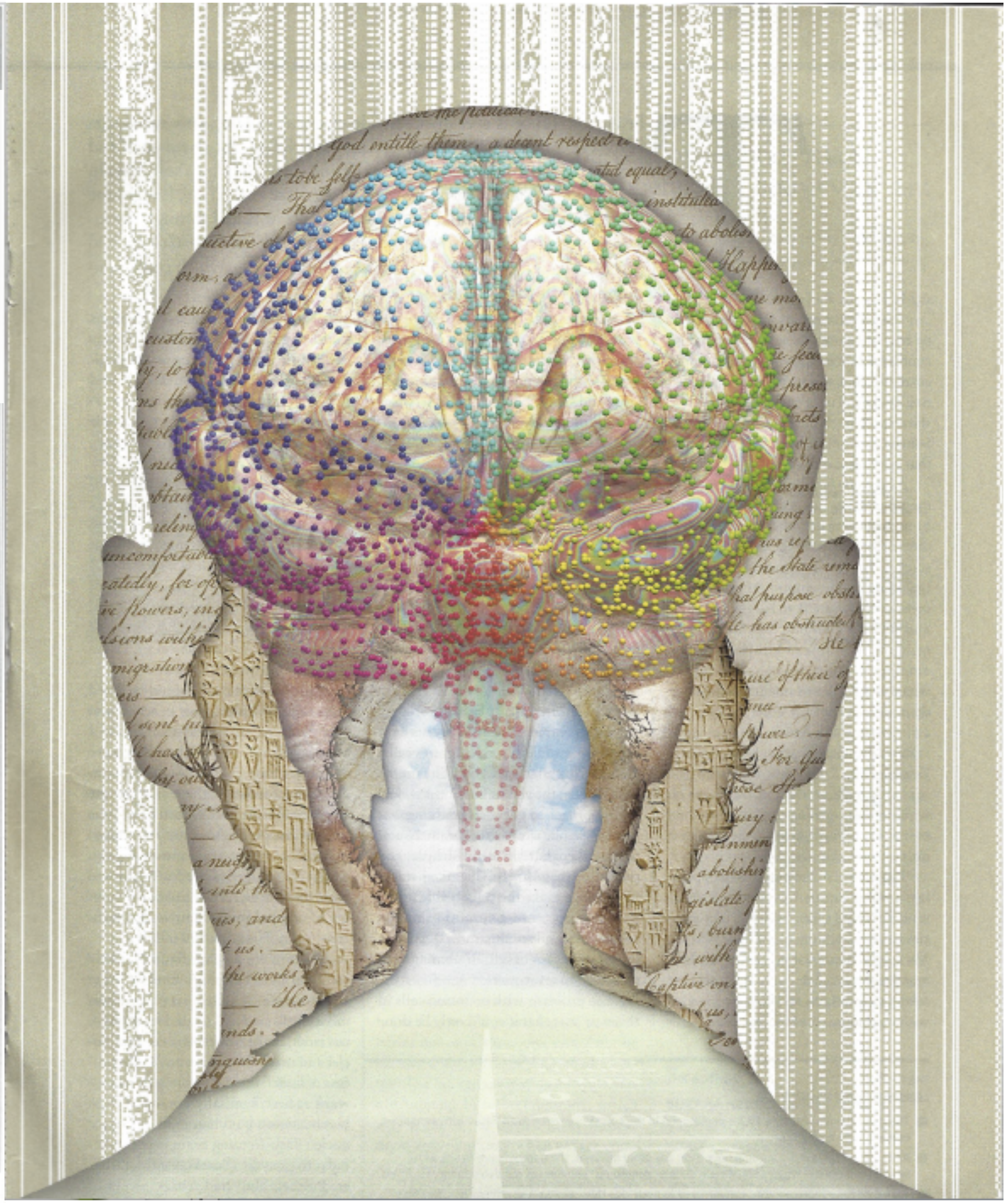
36 SCIENTIFIC AMERICAN MIND

MARCH/APRIL 2017



The Diagnosis: Leaving the “Safe Operating Space”

Breaking Scaling Laws

Brain is the most energy-demanding part in an organism.

Brain to body ratio is limited by energy available to the organism to sustain the metabolic rate.

Great apes such as gorillas and orangutans need to spend hours foraging to have enough energy to sustain the large body frames.

They cannot afford larger brains.

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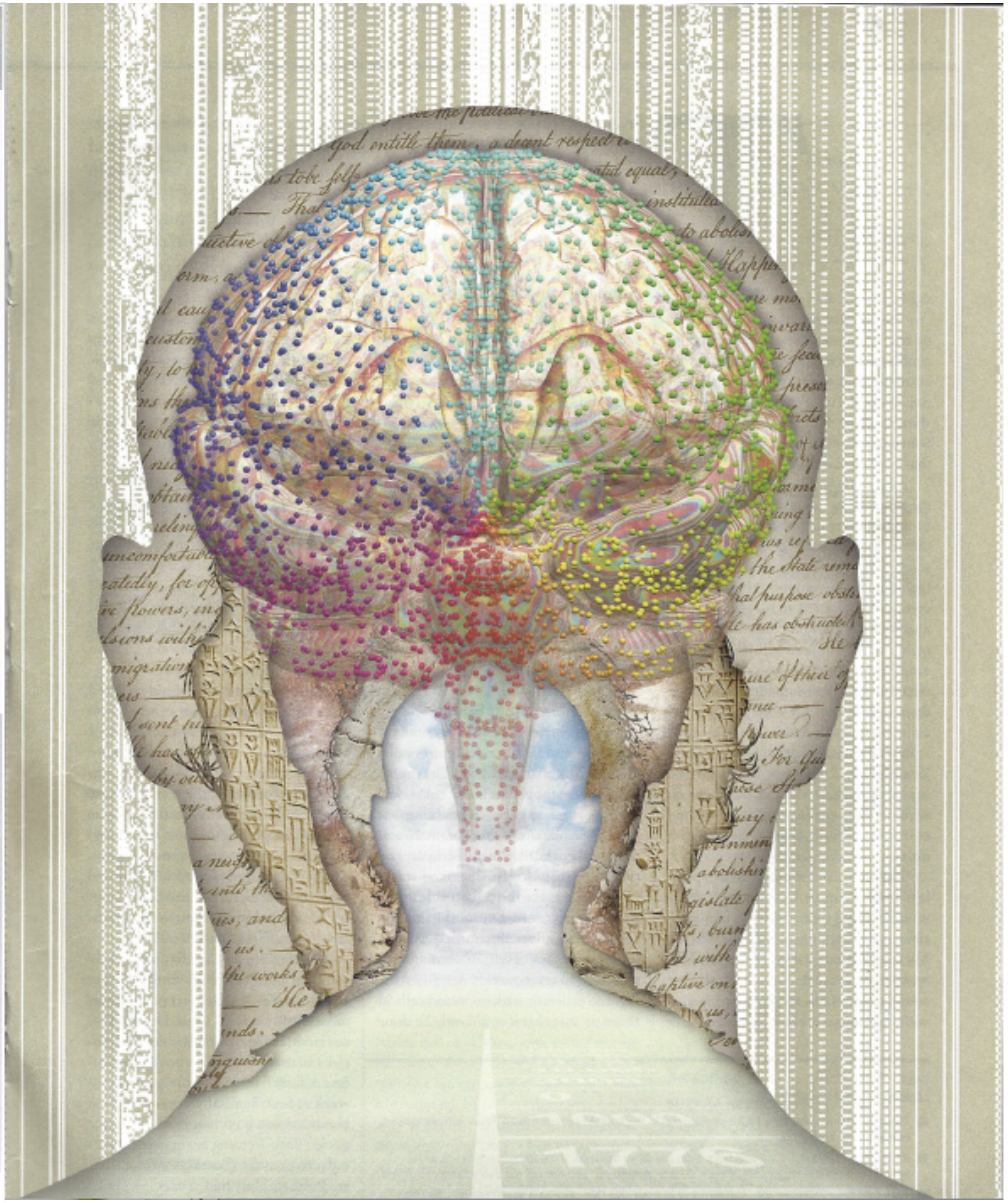

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Supporting a large, more efficient brain requires high-energy, easy to process food:
Homo sapiens achieved this by using fire to process food (particularly meat)

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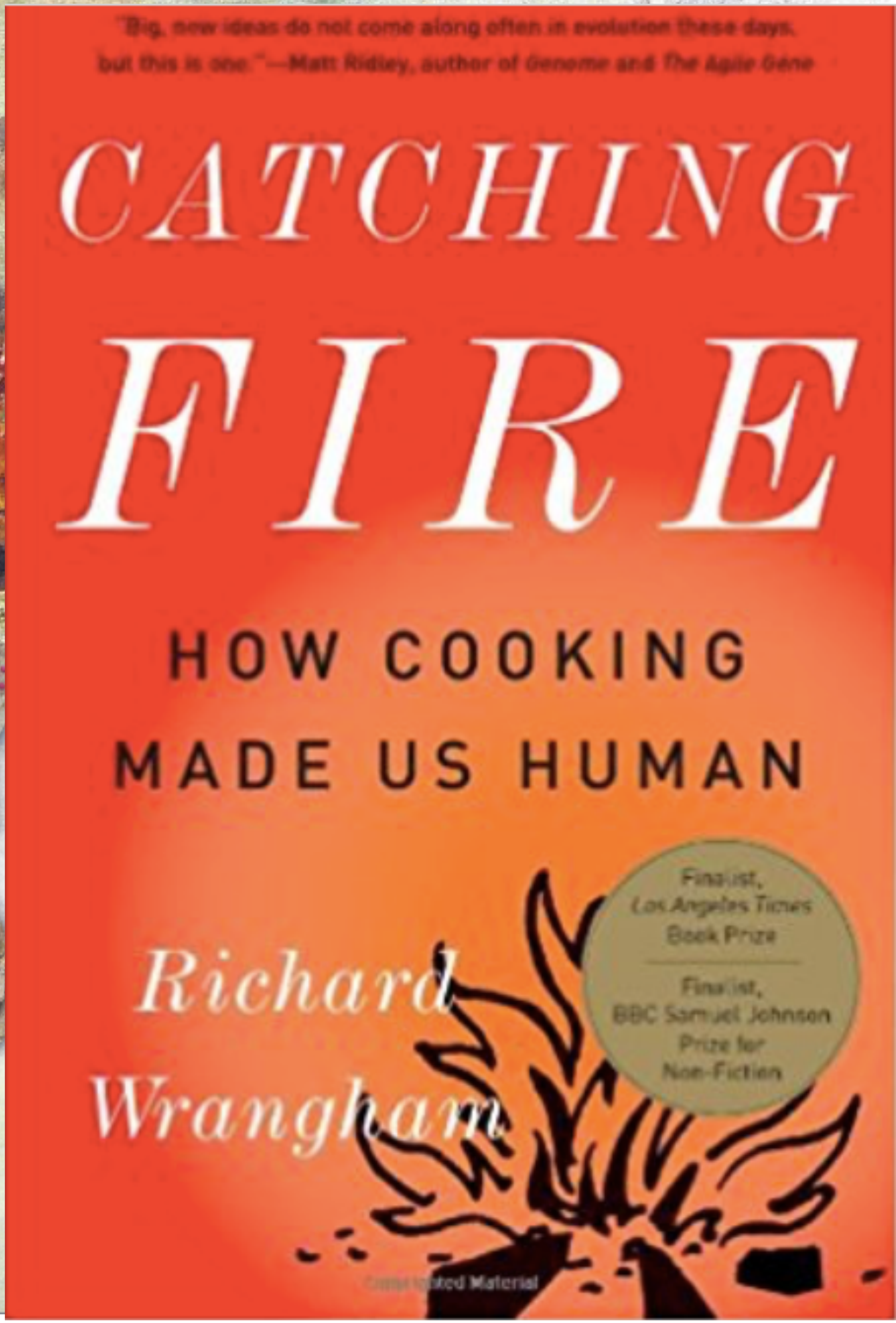

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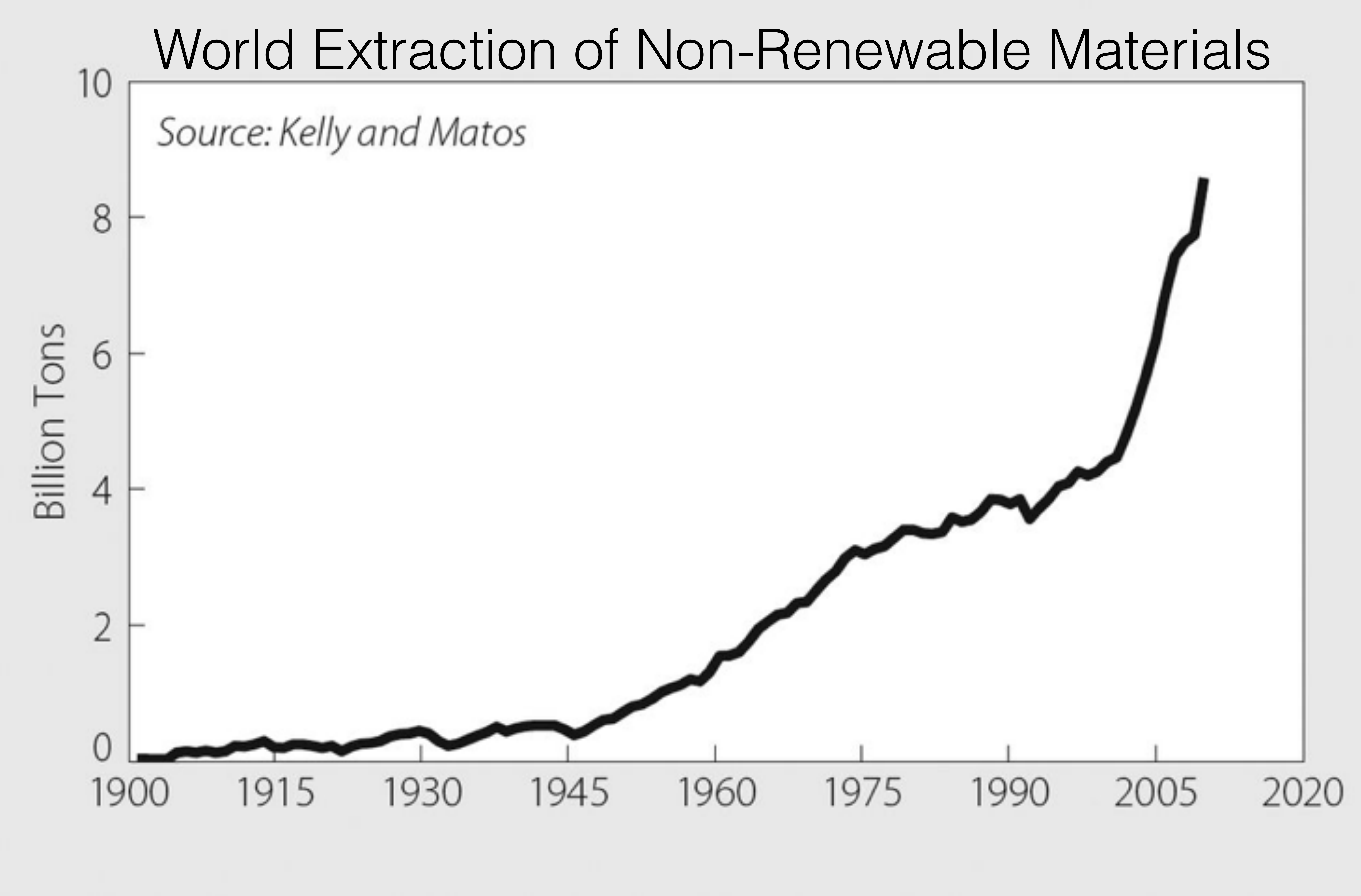
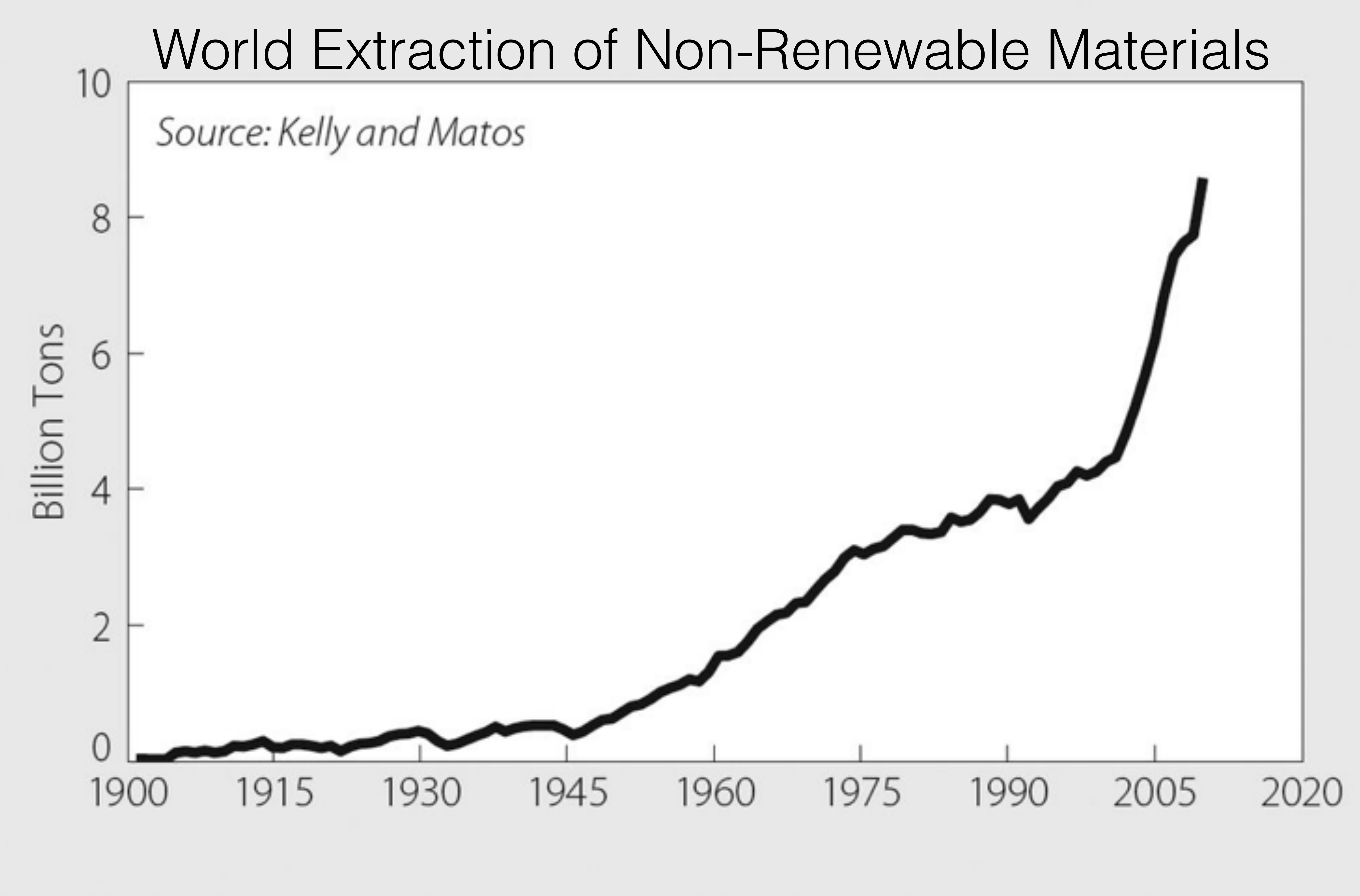
Role of Economy

The Diagnosis: Leaving the “Safe Operating Space”

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

The Diagnosis: Leaving the “Safe Operating Space”

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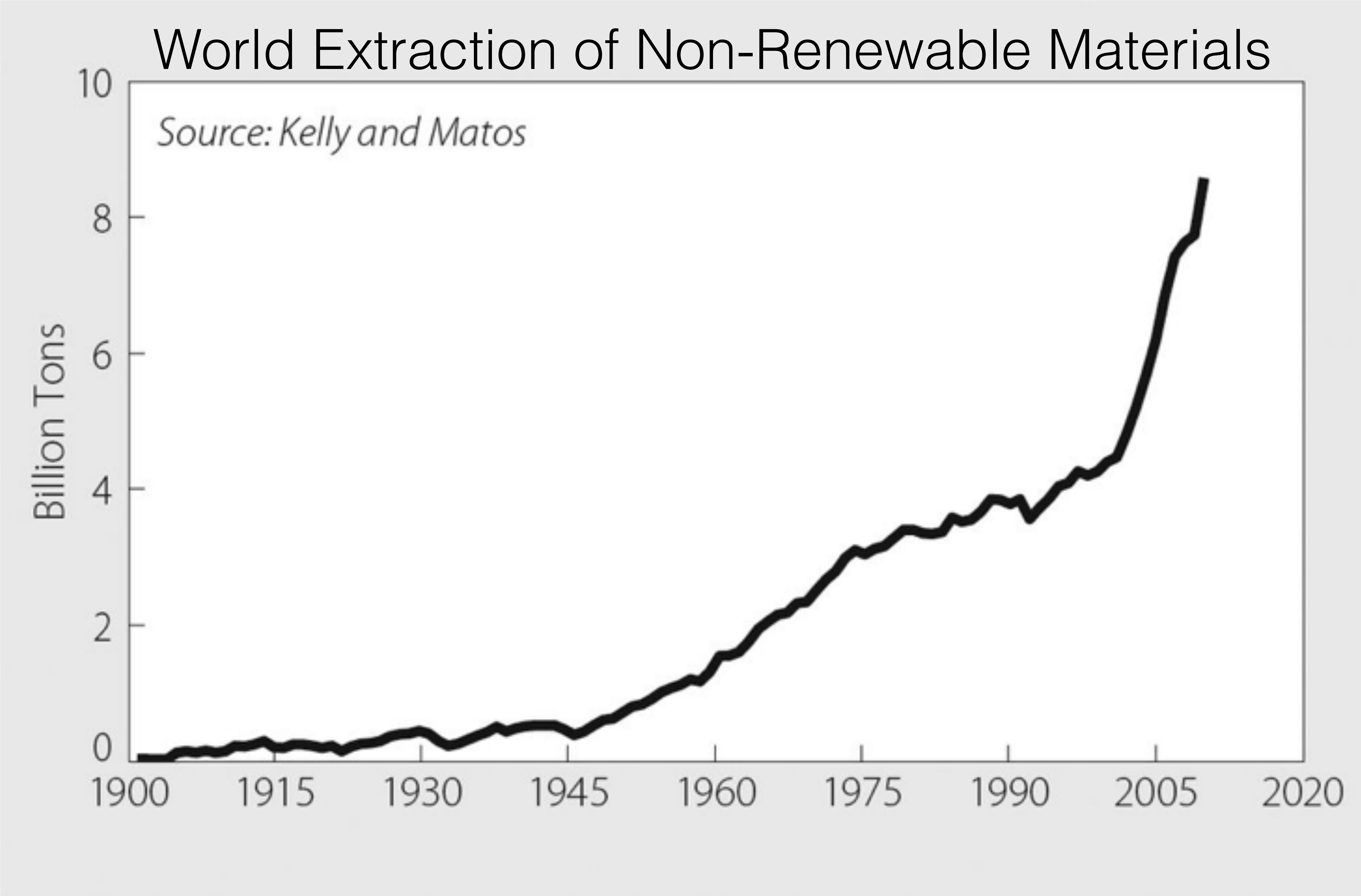

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Assadourian, 2013

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

REVIEW OF THE MONTH

Capitalism and the Curse of Energy Efficiency

The Return of the Jevons Paradox

by John Bellamy Foster, Brett Clark and Richard York
(Nov 01, 2010)

The Jevons Paradox is the product of a capitalist economic system that is unable to conserve on a macro scale, geared, as it is, to maximizing the throughput of energy and materials from resource tap to final waste sink. Energy savings in such a system tend to be used as a means for further development of the economic order, generating what Alfred Lotka called the "maximum energy flux," rather than minimum energy production.

An economic system devoted to profits, accumulation, and economic expansion without end will tend to use any efficiency gains or cost reductions to expand the overall scale of production. Technological innovation will therefore be heavily geared to these same expansive ends. It is no mere coincidence that each of the epoch-making innovations (namely, the steam engine, the railroad, and the automobile) that dominated the eighteenth, nineteenth, and twentieth centuries were characterized by their importance in driving capital accumulation and the positive feedback they generated with respect to economic growth as a whole—so that the scale effects on the economy arising from their development necessarily overshot improvements in technological efficiency.

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

Diagnosis

Easy access to seemingly unlimited energy allowed humans to accelerate flows in the Earth’s life-support system and sustain rapid population growth and increasing demands

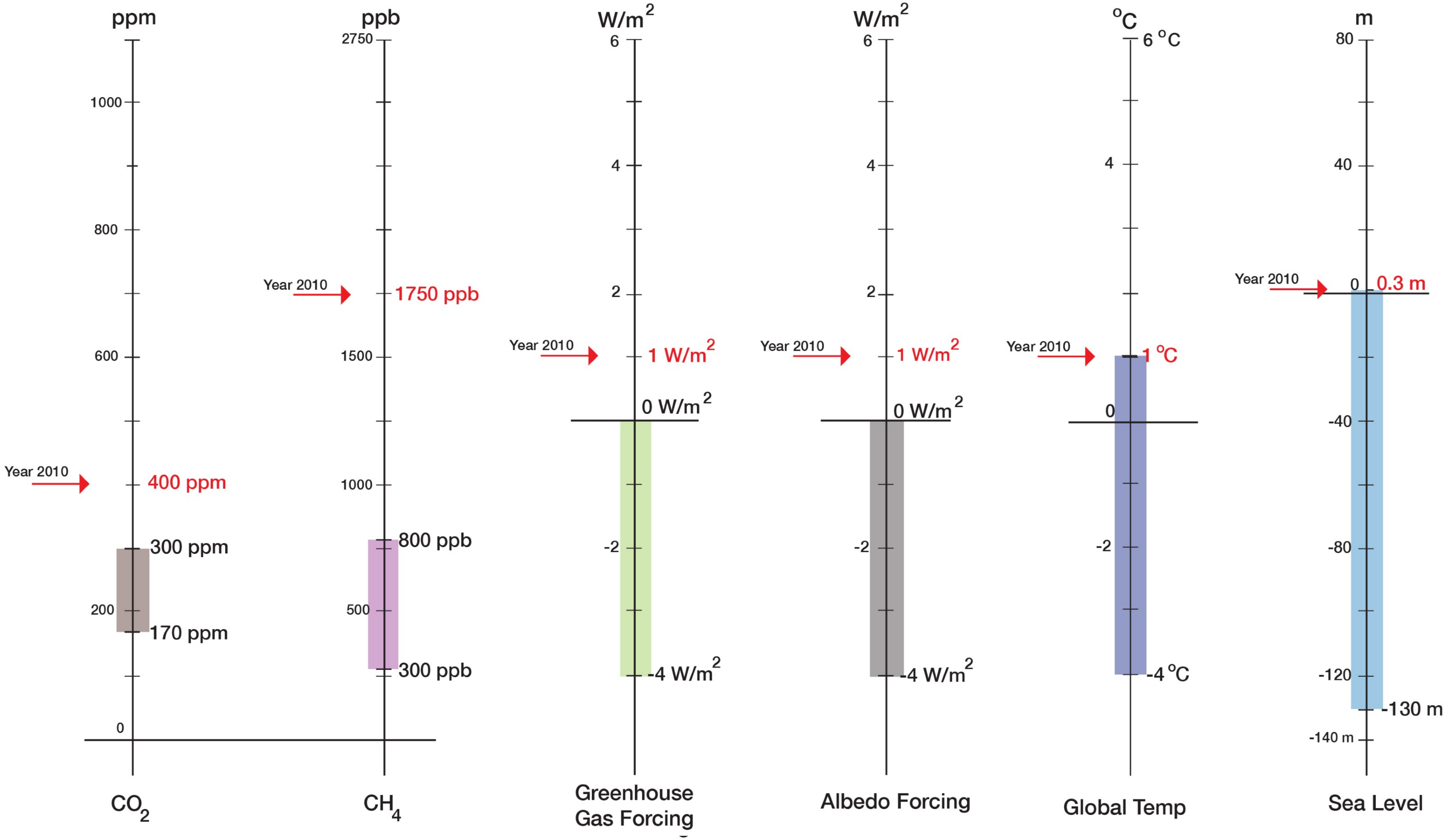
Humans are the “Anthropogenic Cataclysmic Virus” (ACV) in the Earth’s life-support system

Modern Climate Change: A Symptom of a Single-Species High-Energy Pulse Syndrome

Contents

Prognosis: Journey into the Unknown

Baseline and Changes

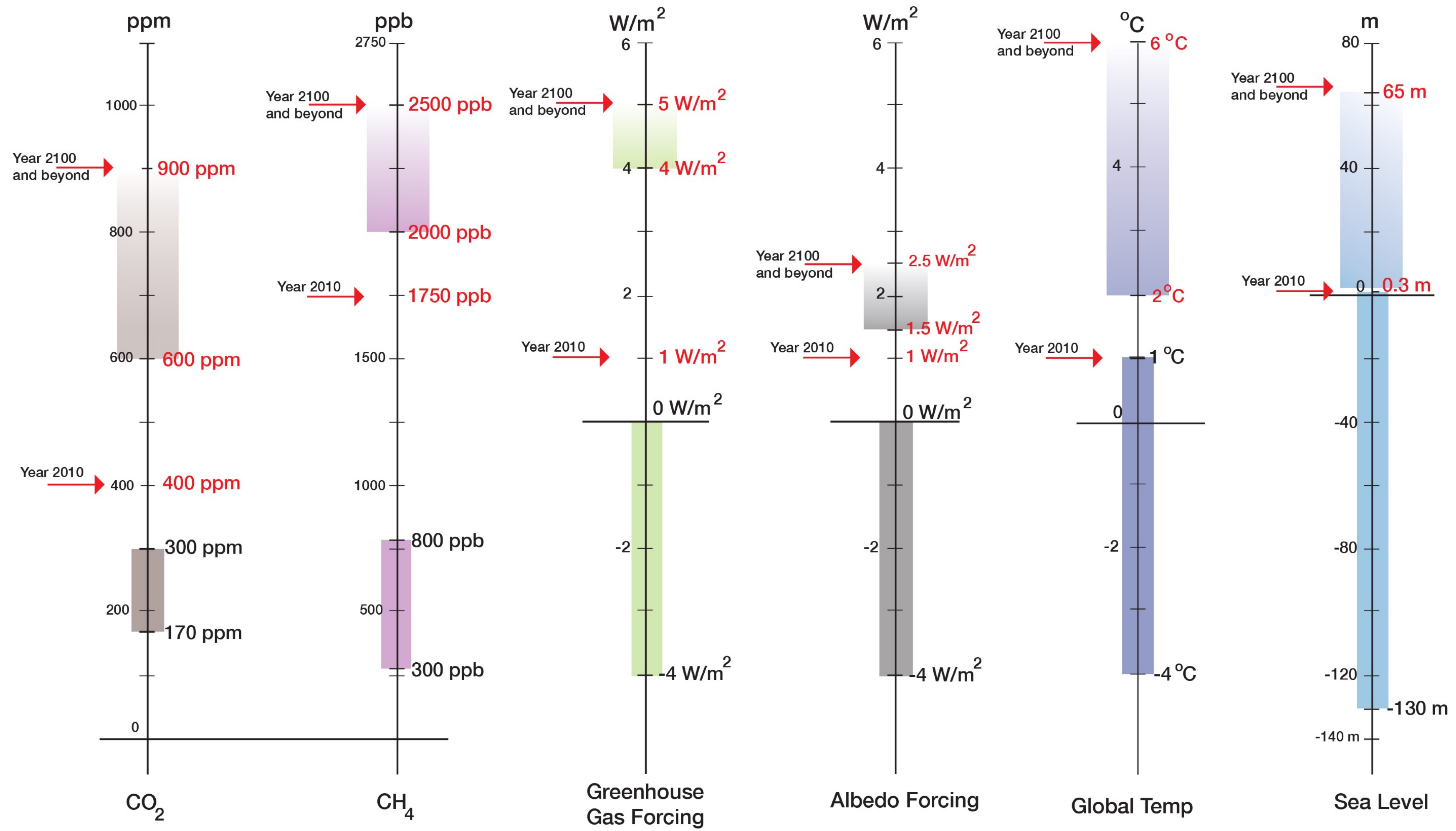


“Current State”

“Normal Range”
(800,000 years)

Prognosis: Journey into the Unknown

Baseline and Changes



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Prognosis: Journey into the Unknown

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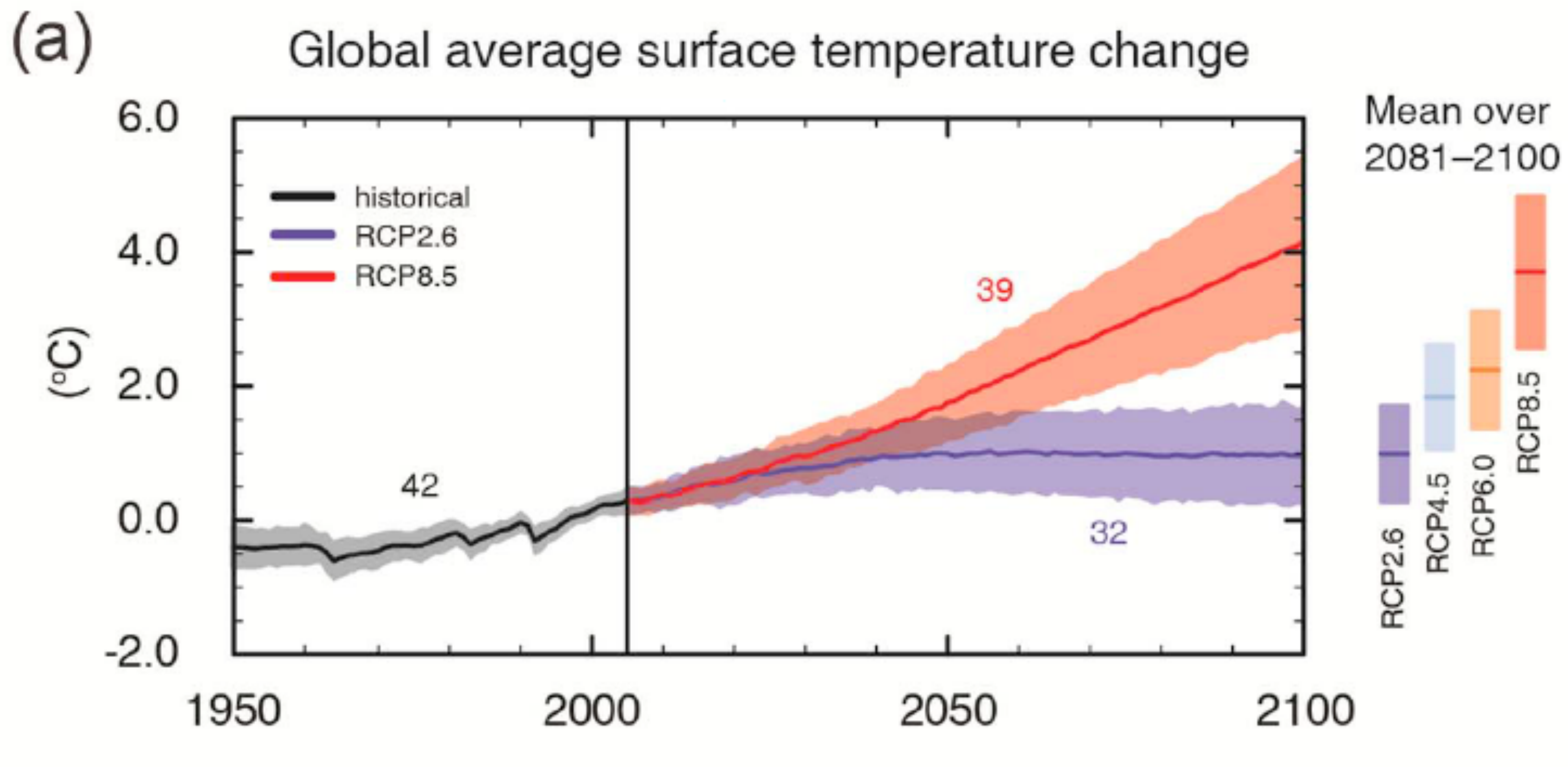
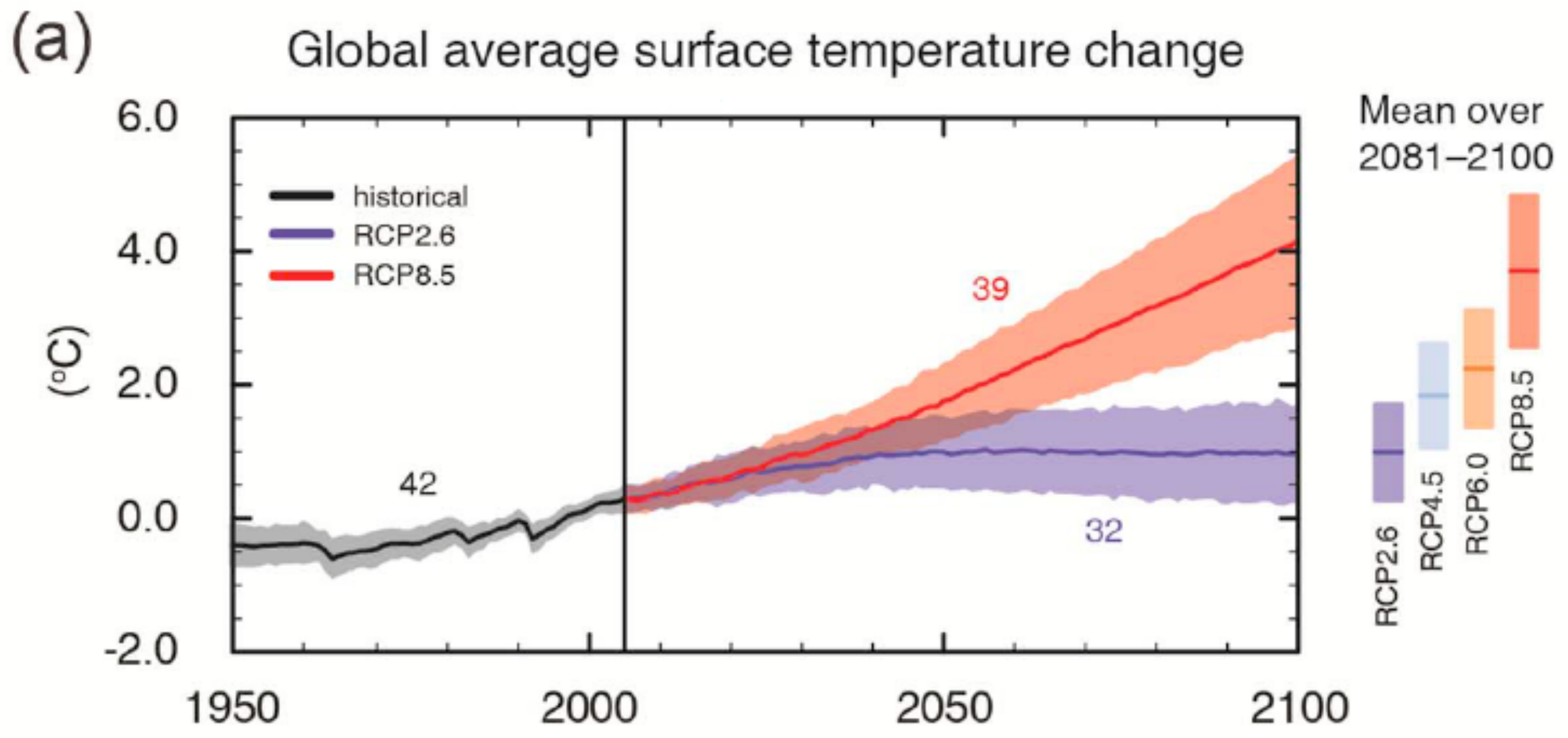
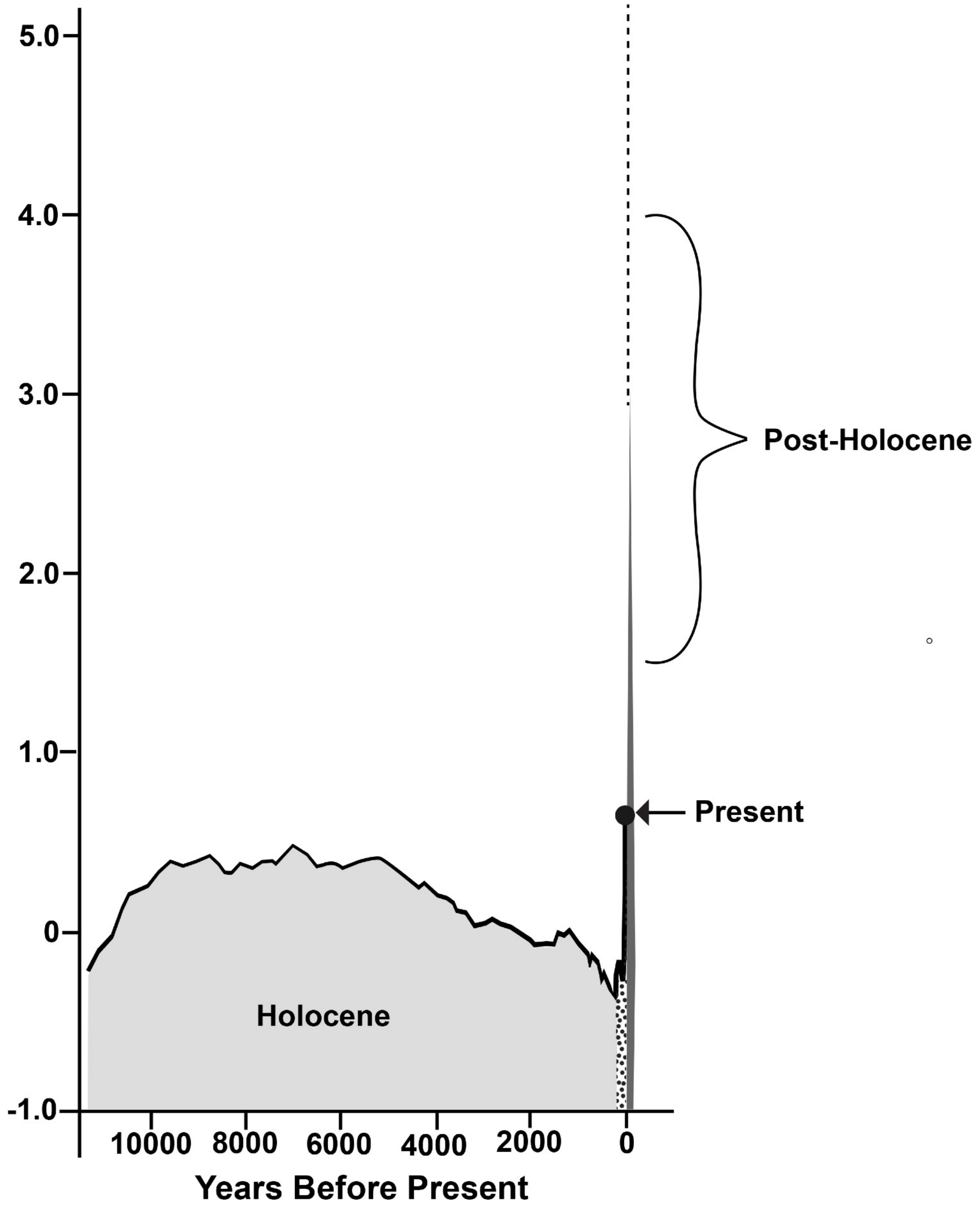


Prognosis: Journey into the Unknown





The Prognosis: Journey Into the Unknown

Longer-term:

- $1^{o}C$ corresponds to about 25 m in sea level
- Expect large sea level rise over several centuries (several meters to >20 m)
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We have committed to an ice-free planet: eventually 65 m (195 ft) of sea level rise (1000 - 5000 years)

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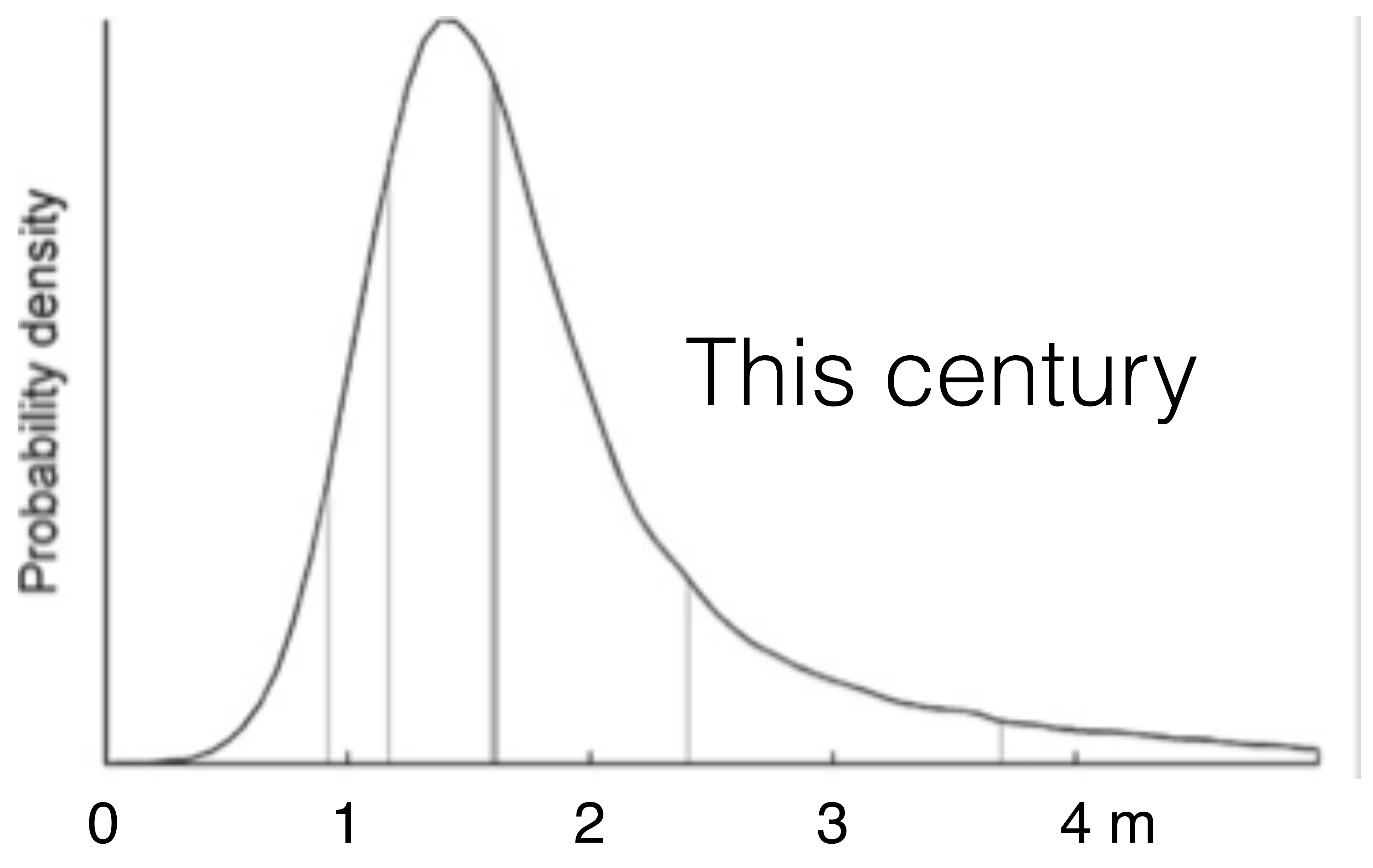

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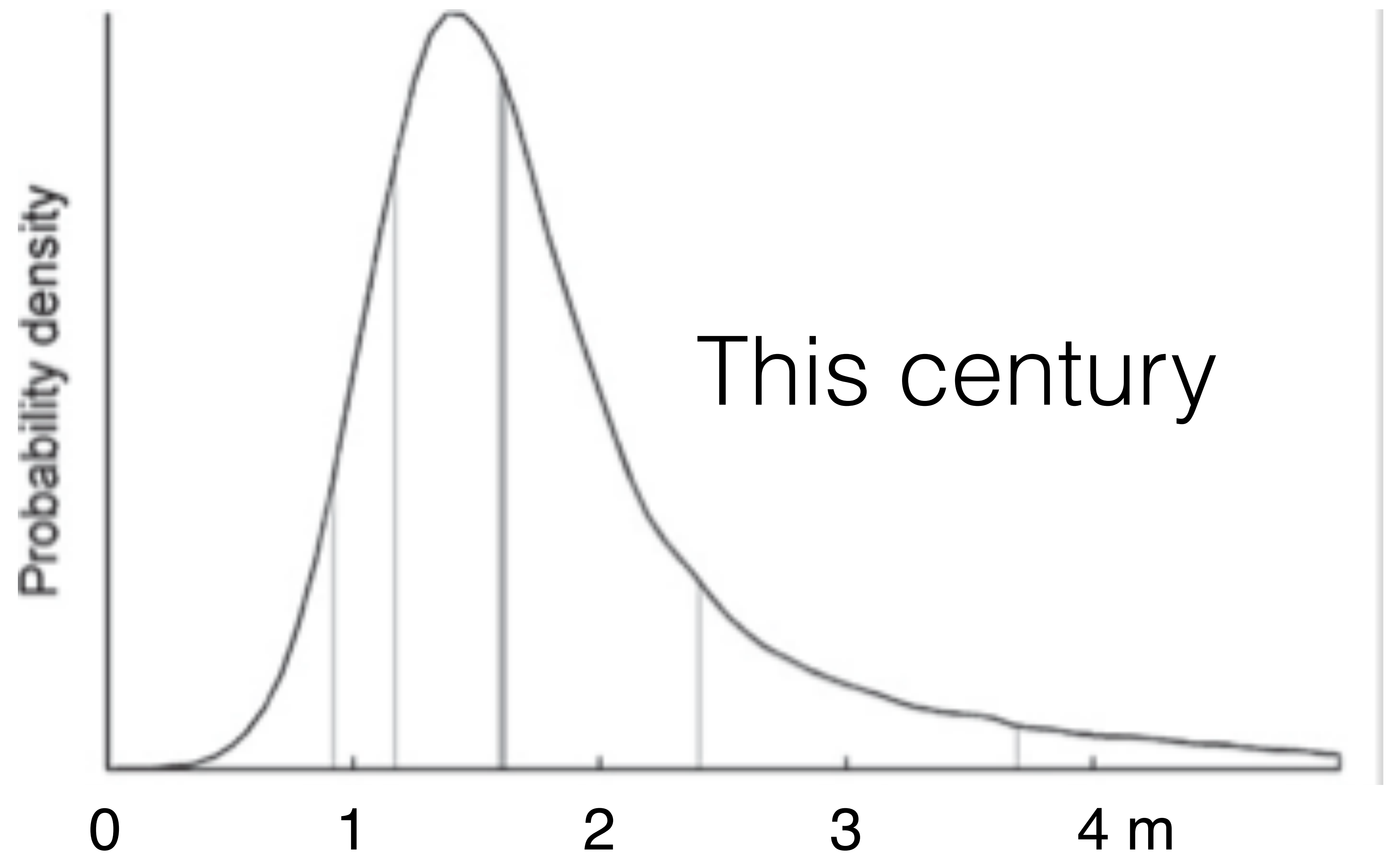
Eventually, protections will fail



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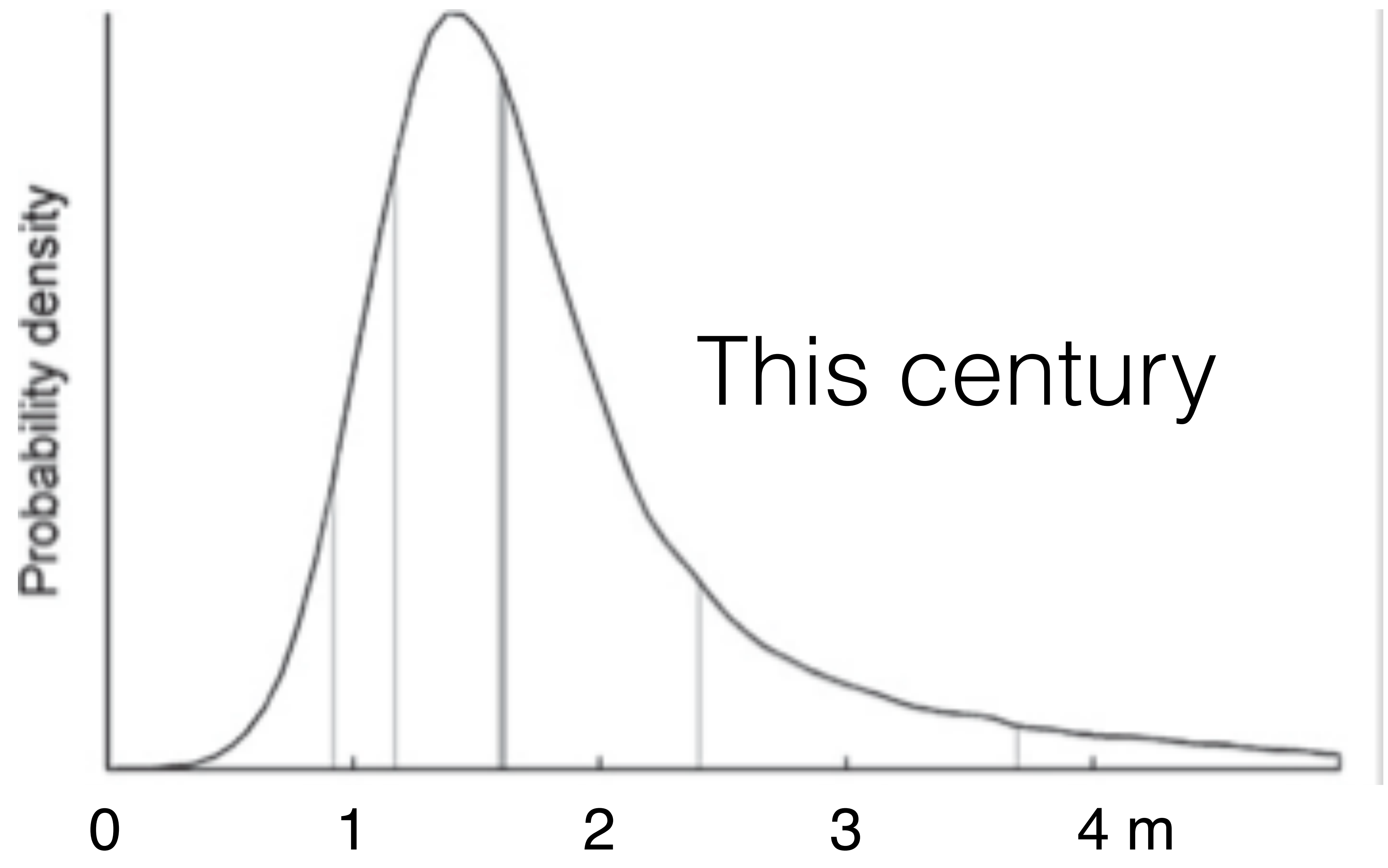
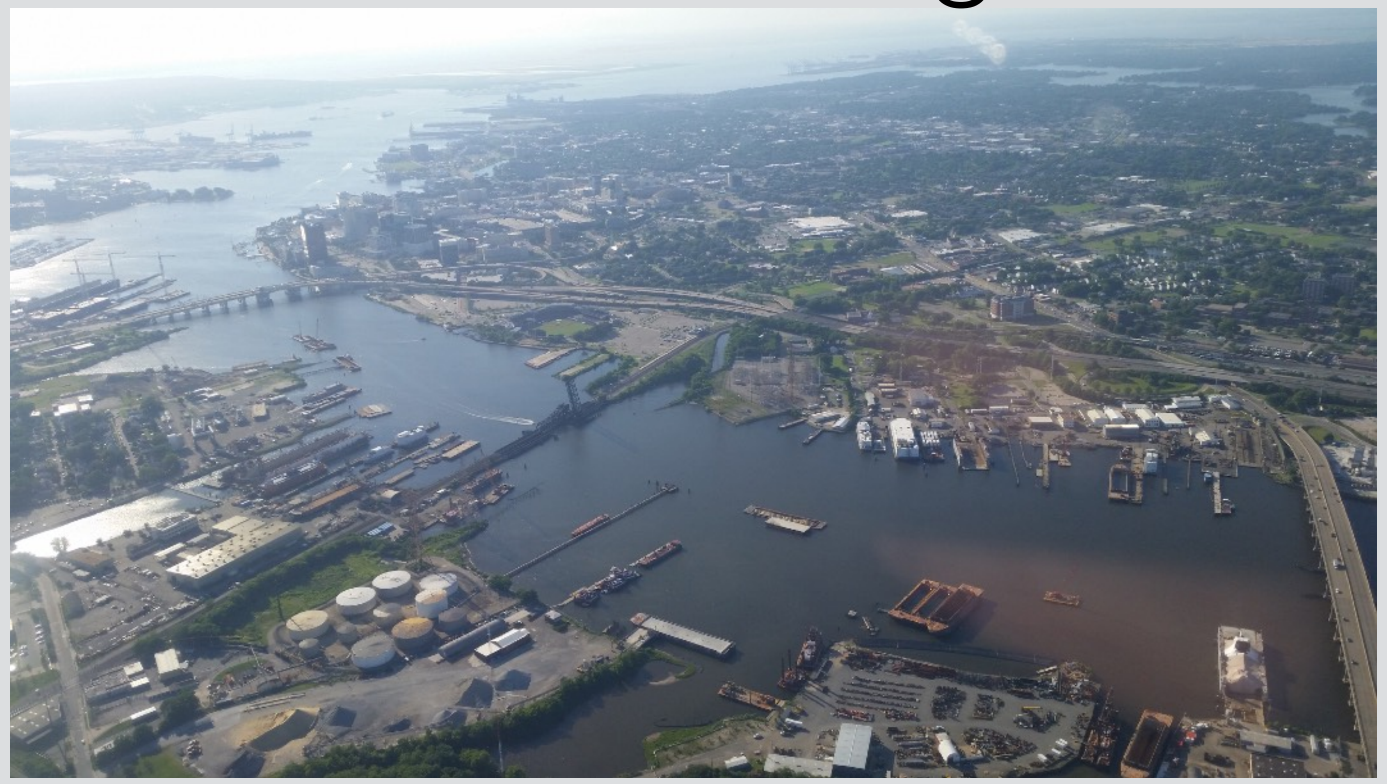
Slowly divest in exposed coastal areas



The Prognosis: Journey Into the Unknown

Build mobile infrastructure and buildings



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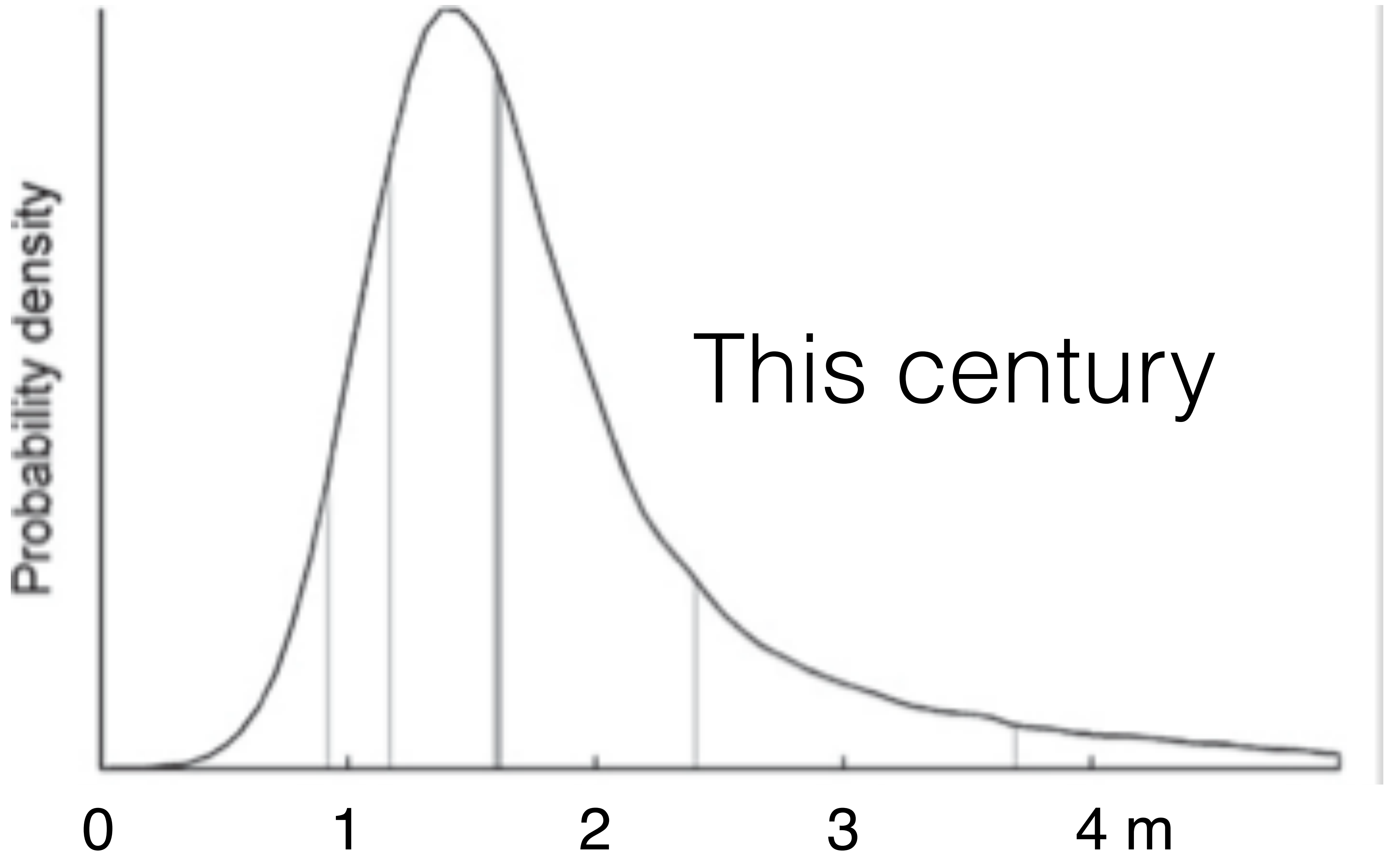

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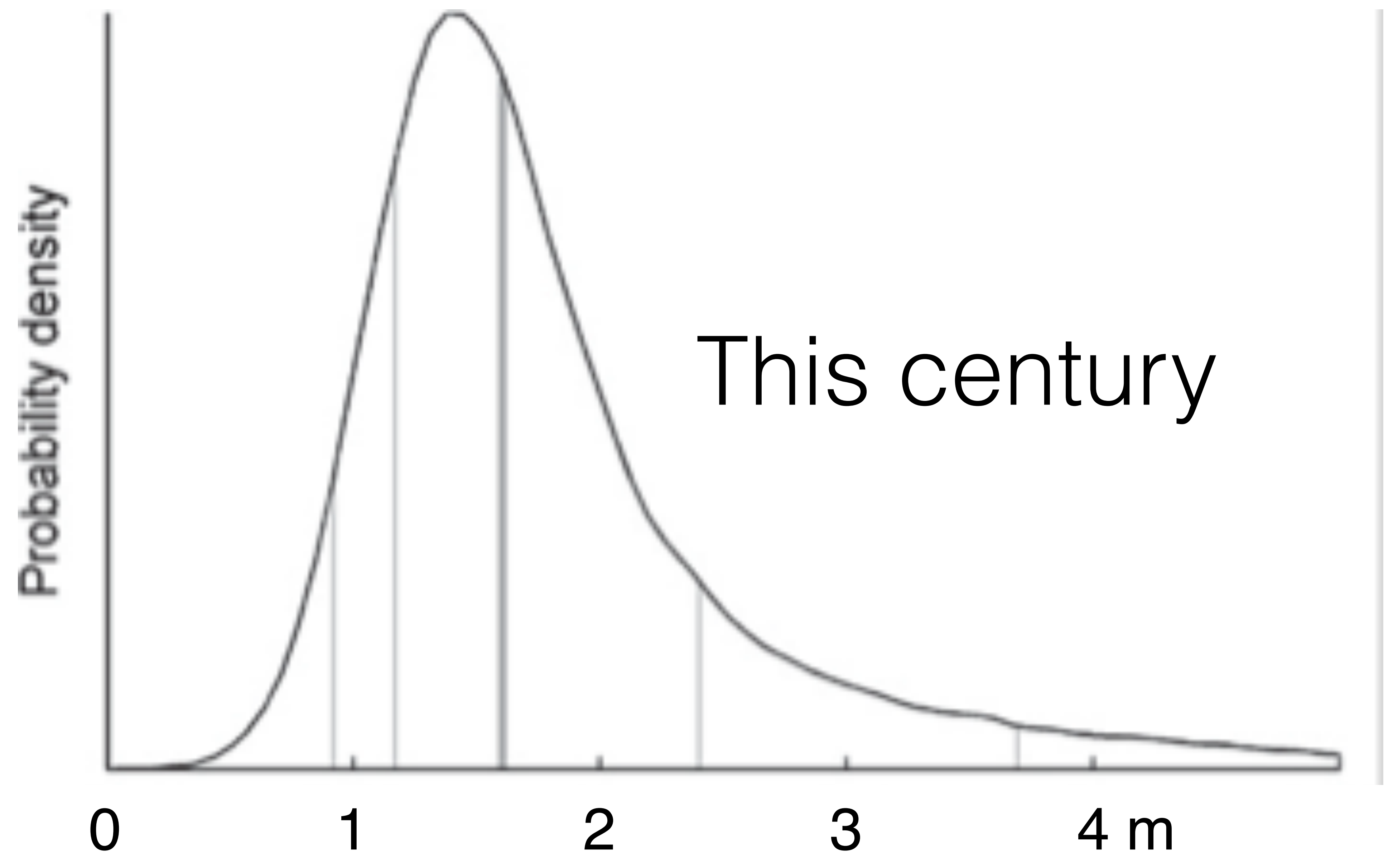

Clean up the coastal zone

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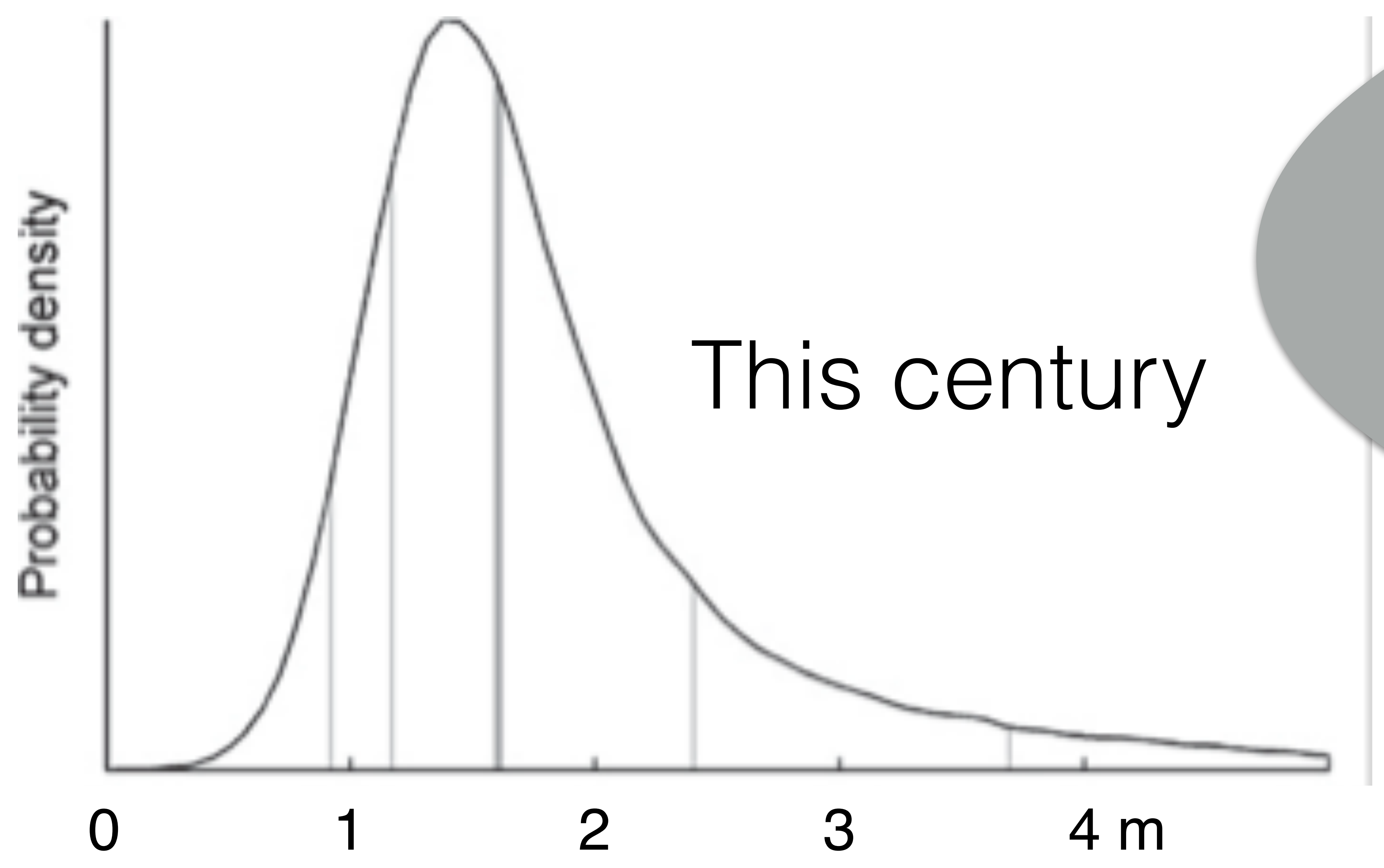

Will a rising tide sink all homes? Zillow

Nationwide, almost 1.9 million homes (or roughly 2 percent of all U.S. homes) worth a combined $882 billion are at risk of being underwater by 2100 if sea levels rise by six feet. Some states will be hit harder than others.

State	Number of Potentially Underwater Properties	Fraction of Total Housing Stock Underwater	Total Value of Potentially Underwater Properties
California	42,353	0.44%	$49.2B
Texas	46,804	0.61%	$12B
New York	96,708	2.10%	$71B
Florida	934,411	12.56%	$413B
Pennsylvania	2,661	0.06%	$730M
Georgia	24,379	0.75%	$10.2B
North Carolina	[illegible]	[illegible]	$20.6B
New [illegible]	[illegible]	[illegible]	[illegible]
Maine	[illegible]	[illegible]	[illegible]
New Hampshire	4,064	0.71%	$1.7B
Rhode Island	4,853	1.47%	$2.9B
Delaware	11,670	3.09%	$3.6B

Source: National Oceanic and Atmospheric Administration (NOAA); Zillow data

Zillow study:

- 1.8 m by 2100
- 36 U.S. Coastal Cities lost;
- more than 50 cities lose at least 50% of residential real estate
- $1 Trillion in loss (2% of residential real estate value)

The Prognosis: Journey Into the Unknown

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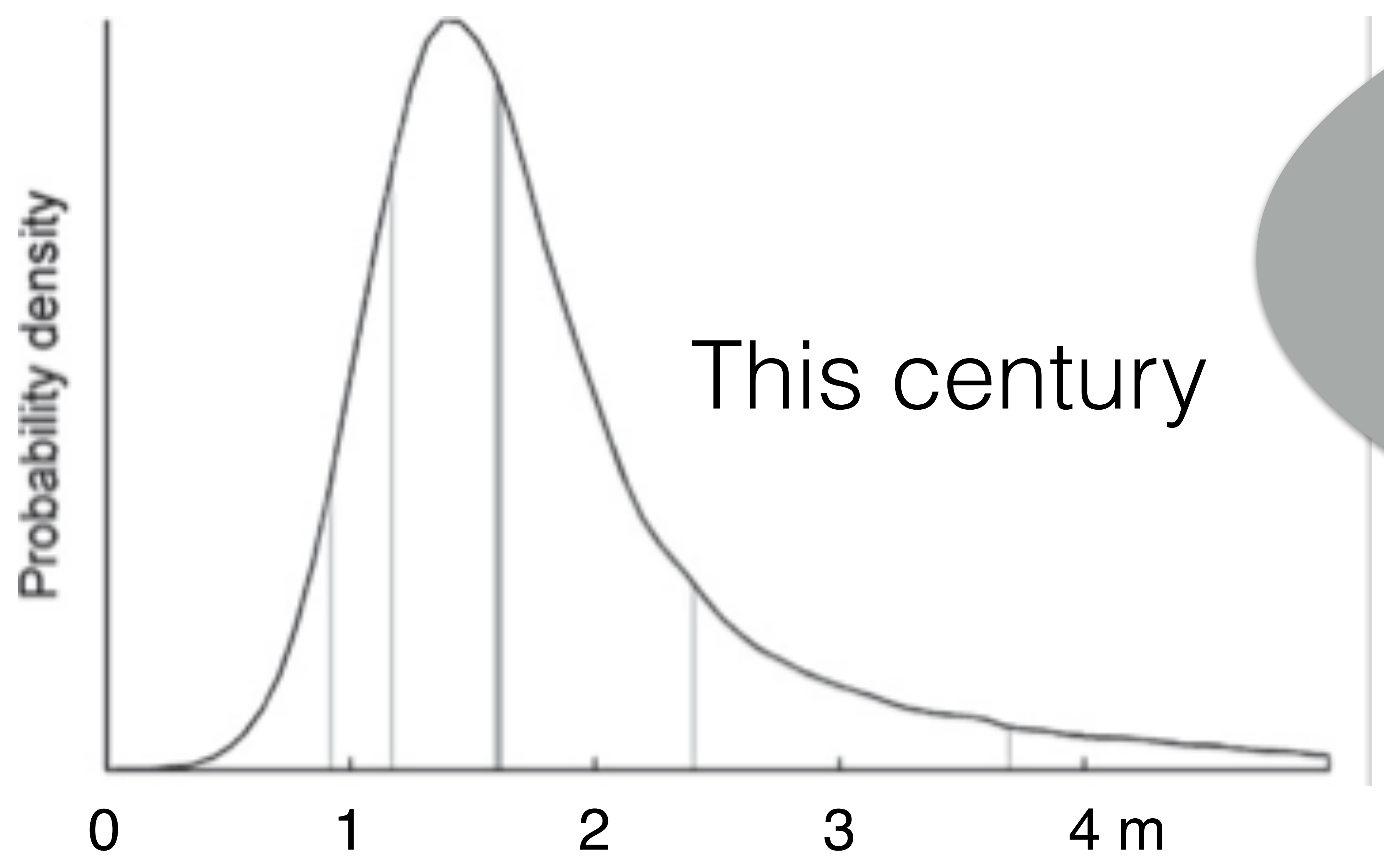

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t 50% of

ential real

Costs might be very high

Rising ocean waters from global warming could cost trillions of dollars

We'll need to mitigate and adapt to global warming to avoid massive costs from sea level rise

Waterfront condo buildings are seen June 3, 2014 in Miami, Florida. Photograph: Joe Raedle/Getty Images

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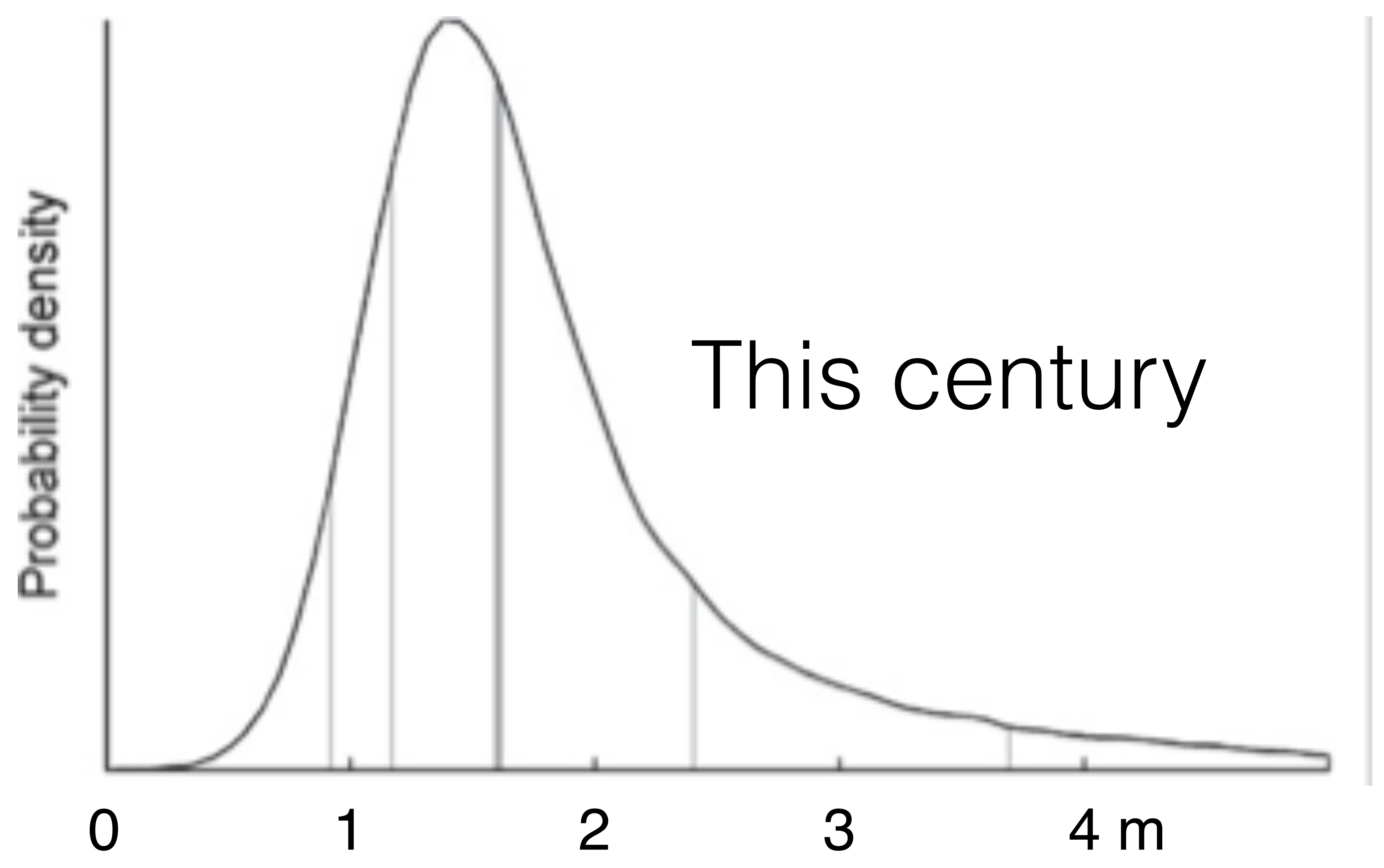

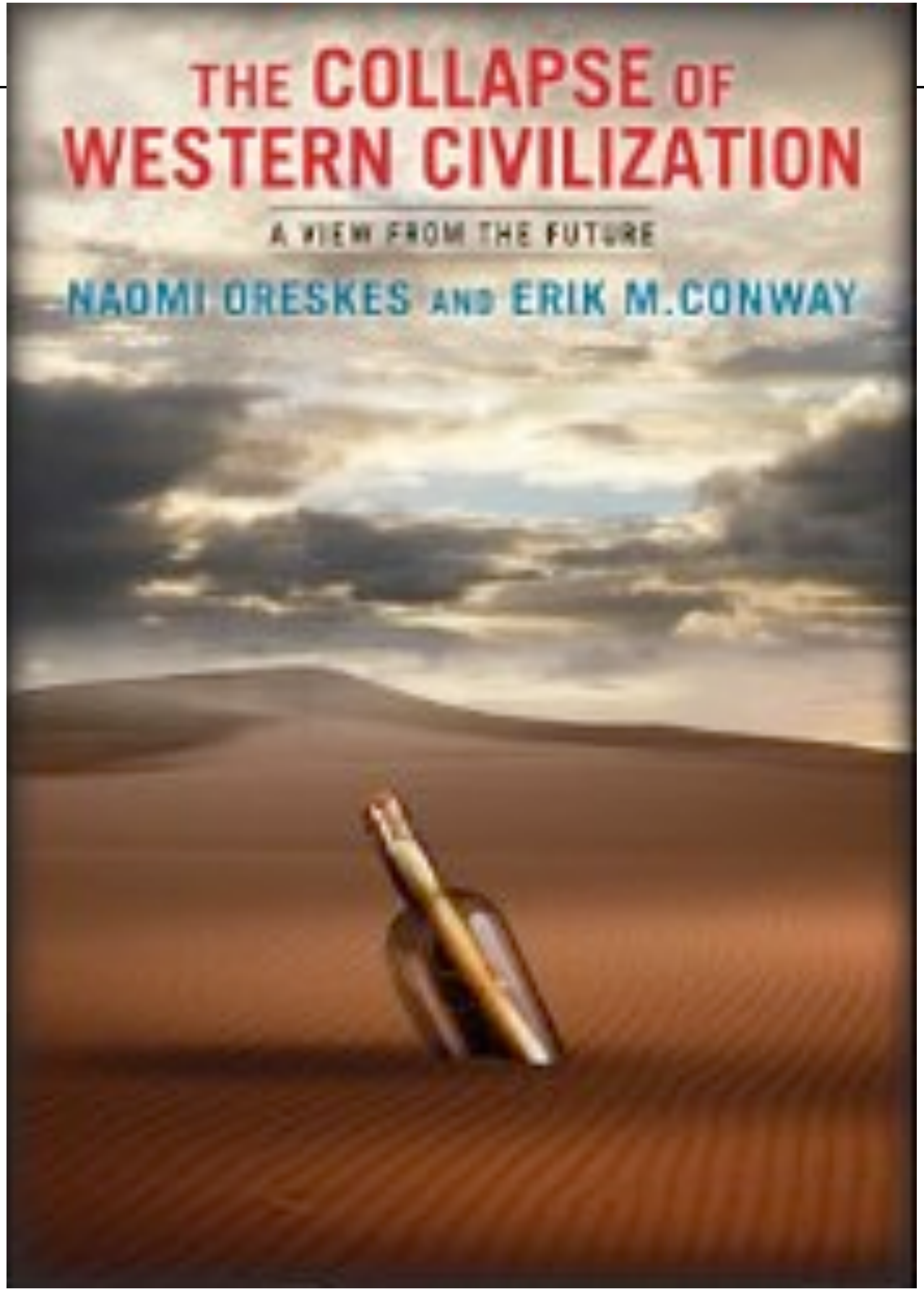

The Prognosis: Journey Into the Unknown

Assessing the risk …

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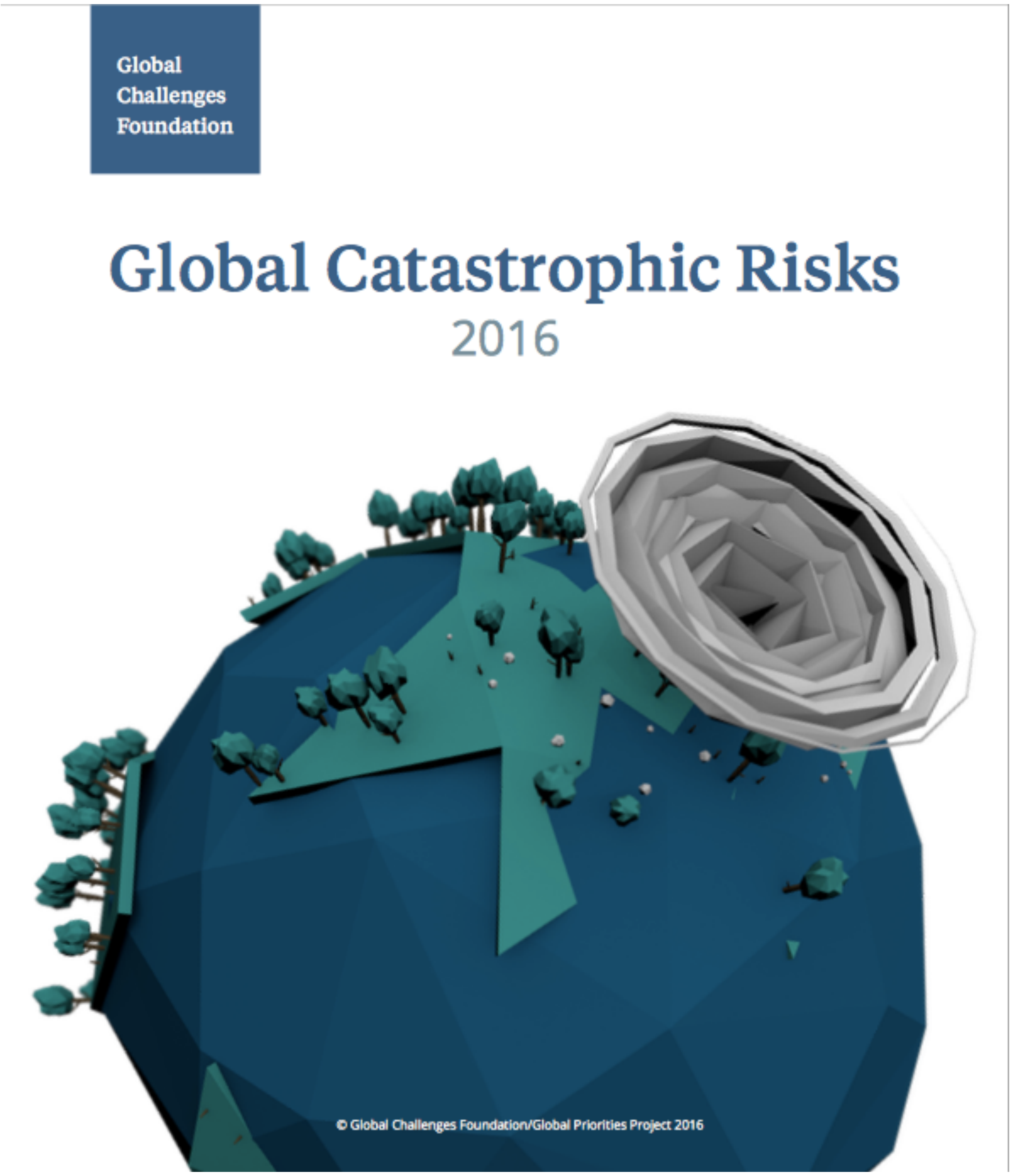

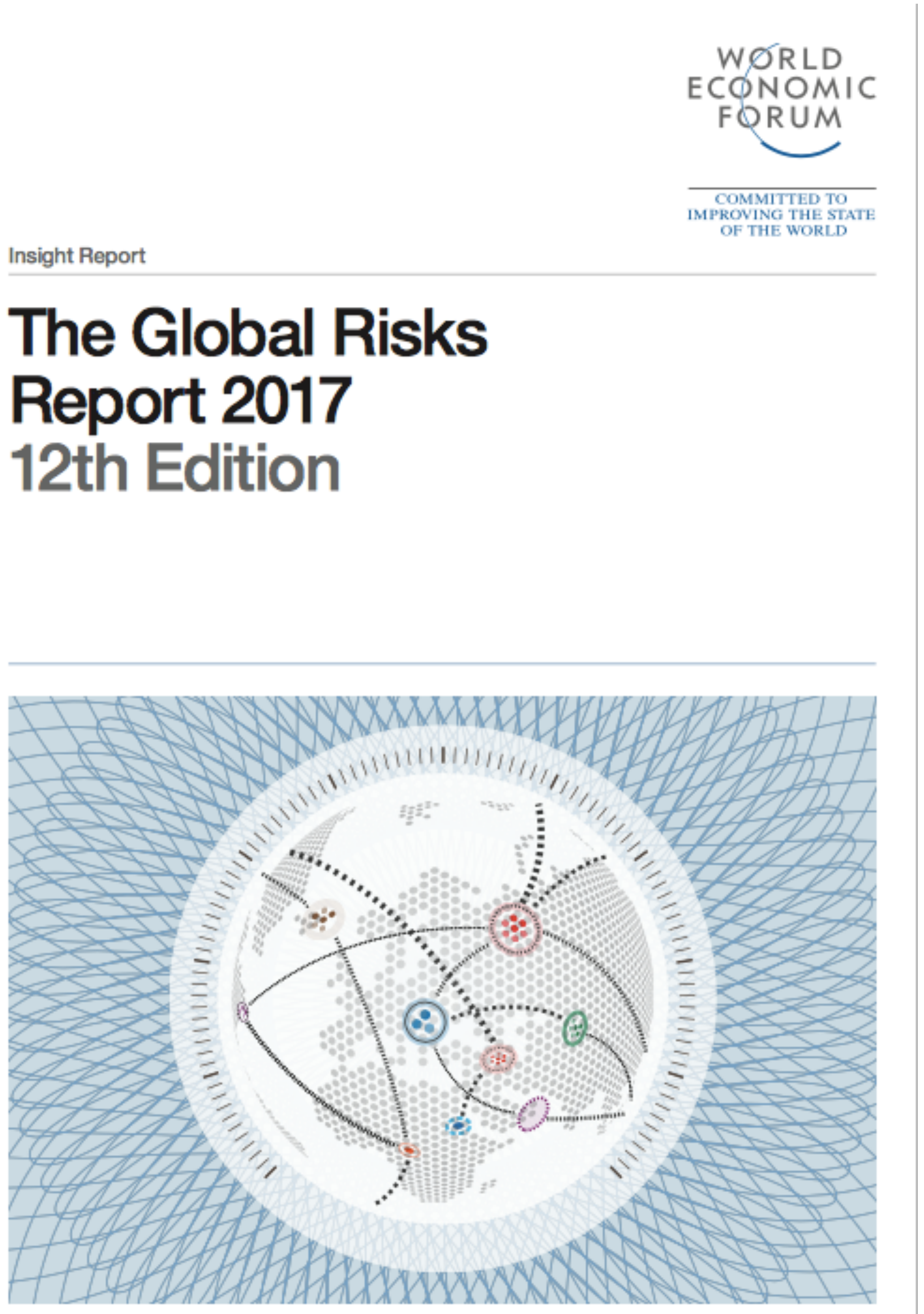

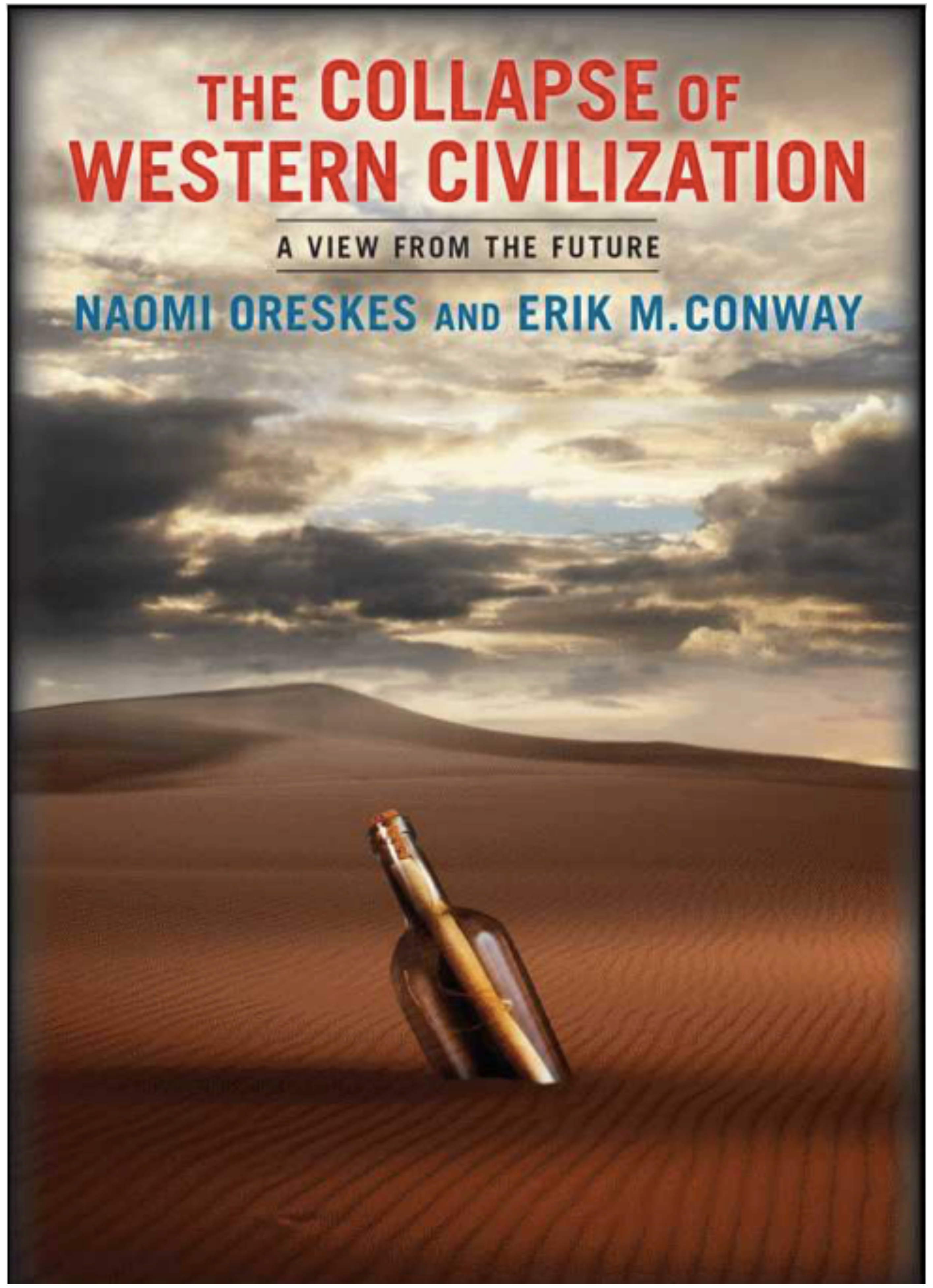

The Prognosis: Journey Into the Unknown

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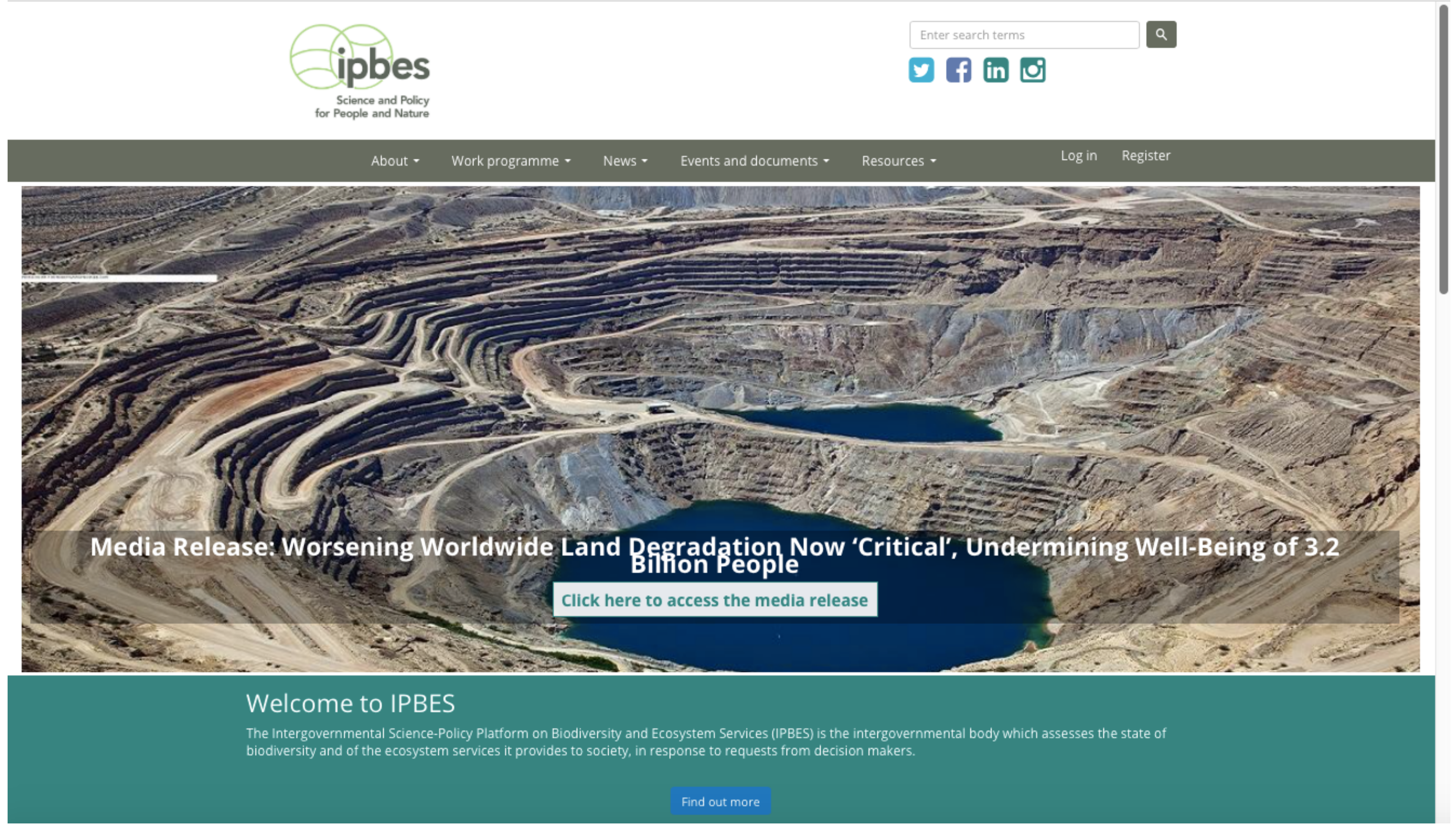
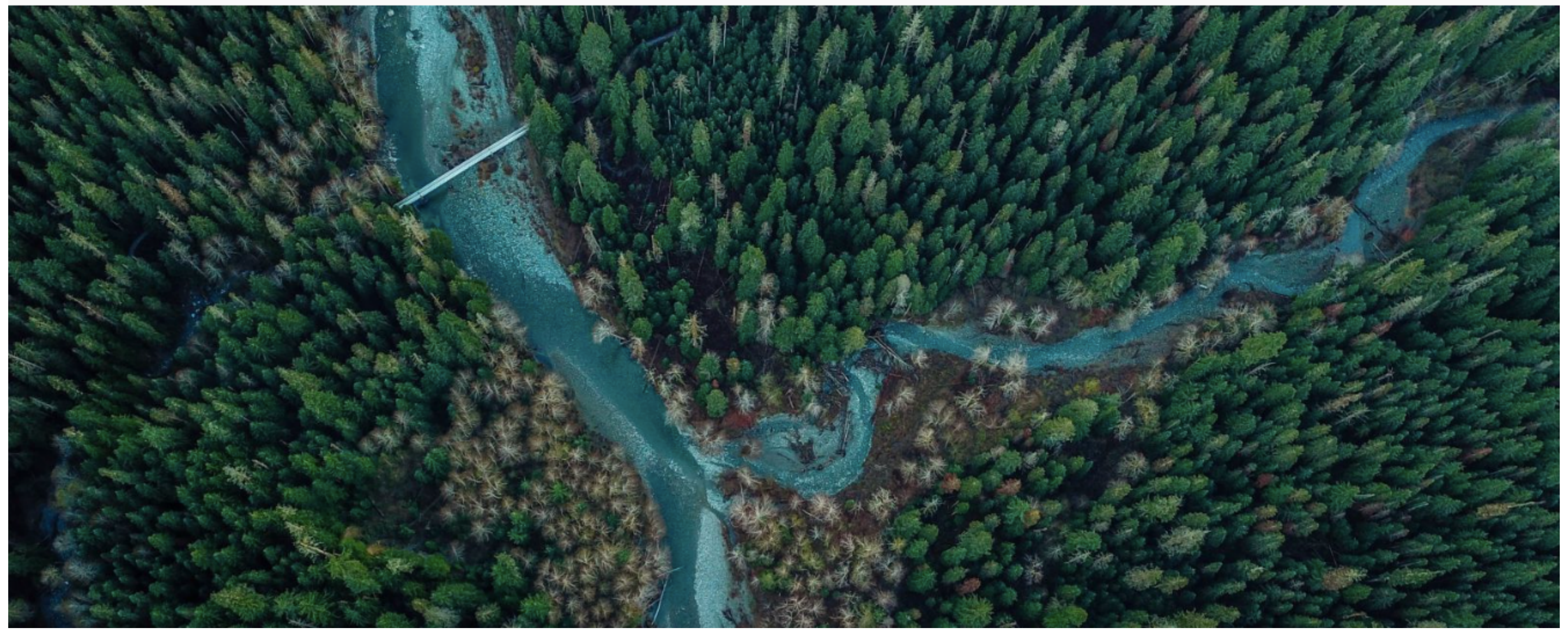


We can't engineer our way out of an impending water scarcity epidemic



Homo sapiens have a huge amount of data and knowledge

ipcc
INTERGOVERNMENTAL PANEL ON climate change

GLOBAL WARMING OF 1.5 °C

an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

Summary for Policymakers

This Summary for Policymakers was formally approved at the First Joint Session of Working Groups I, II and III of the IPCC and accepted by the 48th Session of the IPCC, Incheon, Republic of Korea, 6 October 2018.

Mammal diversity will take millions of years to recover from the current biodiversity crisis

Matt Davis, Søren Faurby, and Jens-Christian Svenning

PNAS published ahead of print October 15, 2018 https://doi.org/10.1073/pnas.1804906115

Climate-driven declines in arthropod abundance restructure a rainforest food web

Bradford C. Lister and Andres Garcia

PNAS published ahead of print October 15, 2018 https://doi.org/10.1073/pnas.1722477115

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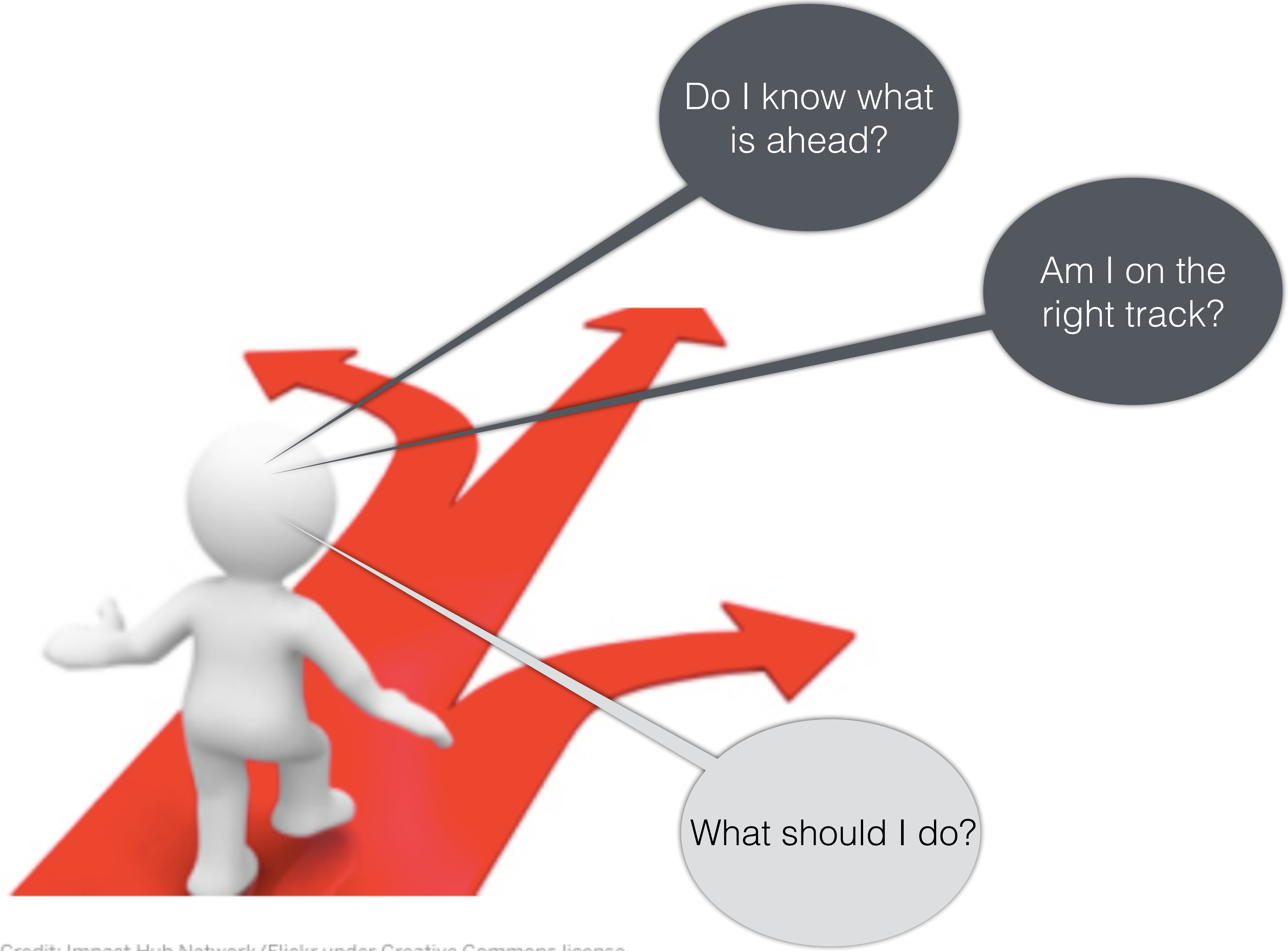


Credit: Impact Hub Network/Flickr under Creative Commons license

Prognosis: Journey into the Unknown

What do I need to know?

Do I understand the challenge?

Who can help me?

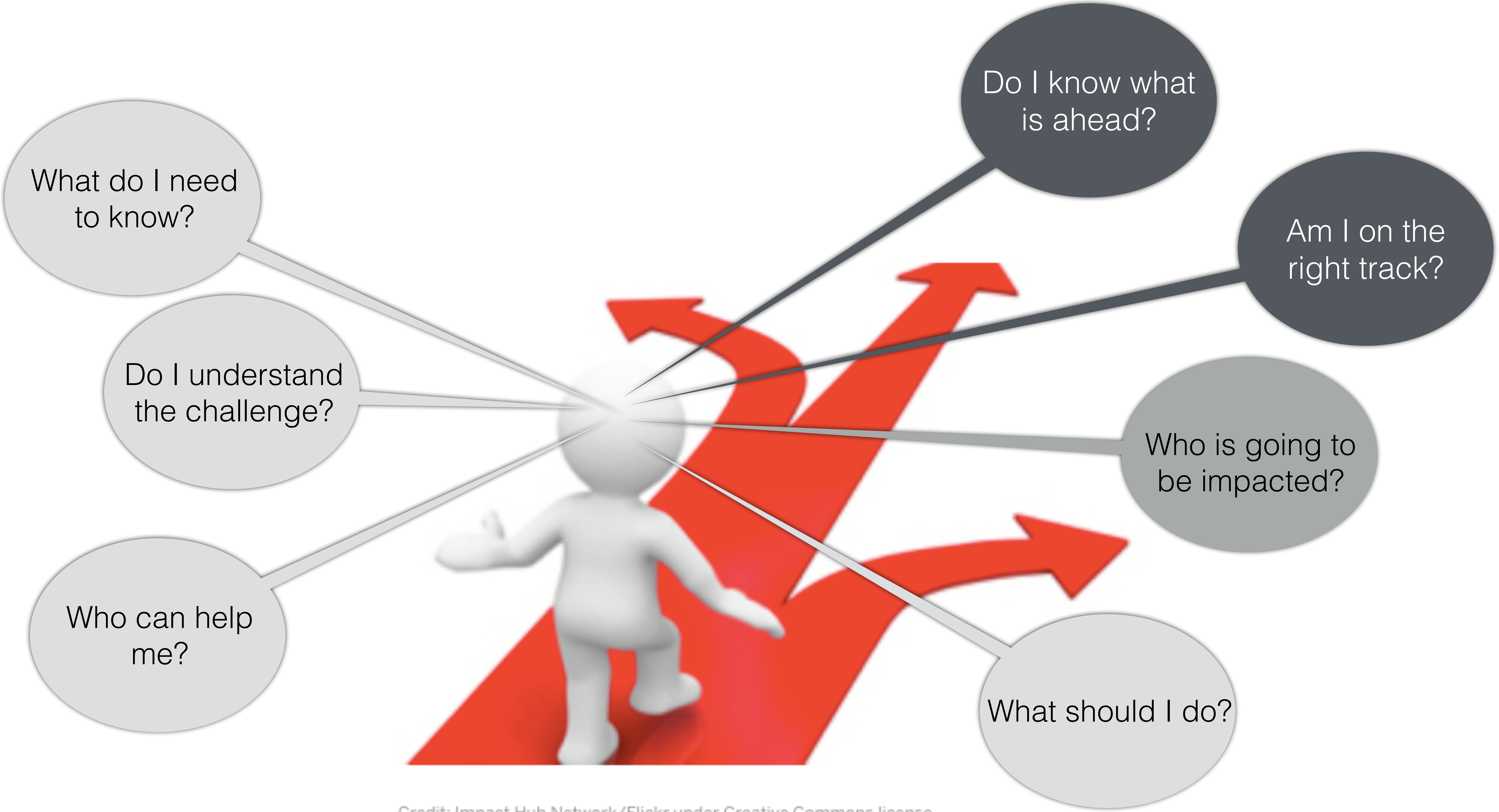
Do I know what is ahead?

Am I on the right track?

What should I do?

Credit: Impact Hub Network/Flickr under Creative Commons license

Prognosis: Journey into the Unknown



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Prognosis: Journey into the Unknown

Trajectories of the Earth System in the Anthropocene

Will Steffen, Johan Rockström, Katherine Richardson, Timothy M. Lenton, Carl Folke, Diana Liverman, Colin P. Summerhayes, Anthony D. Barnosky, Sarah E. Cornell, Michel Crucifix, Jonathan F. Donges, Ingo Fetzer, Steven J. Lade, Marten Scheffer, Ricarda Winkelmann, and Hans Joachim Schellnhuber

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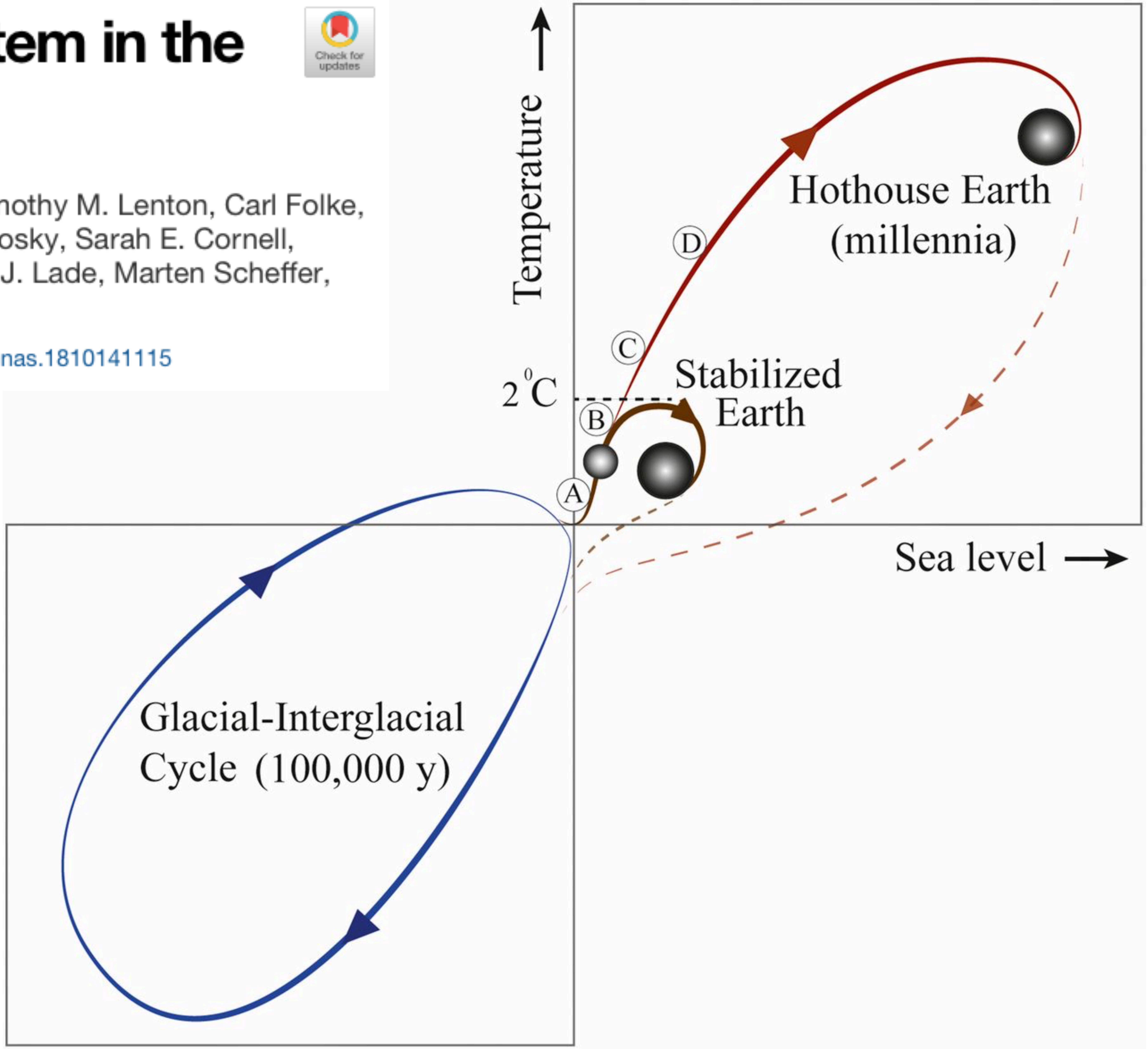

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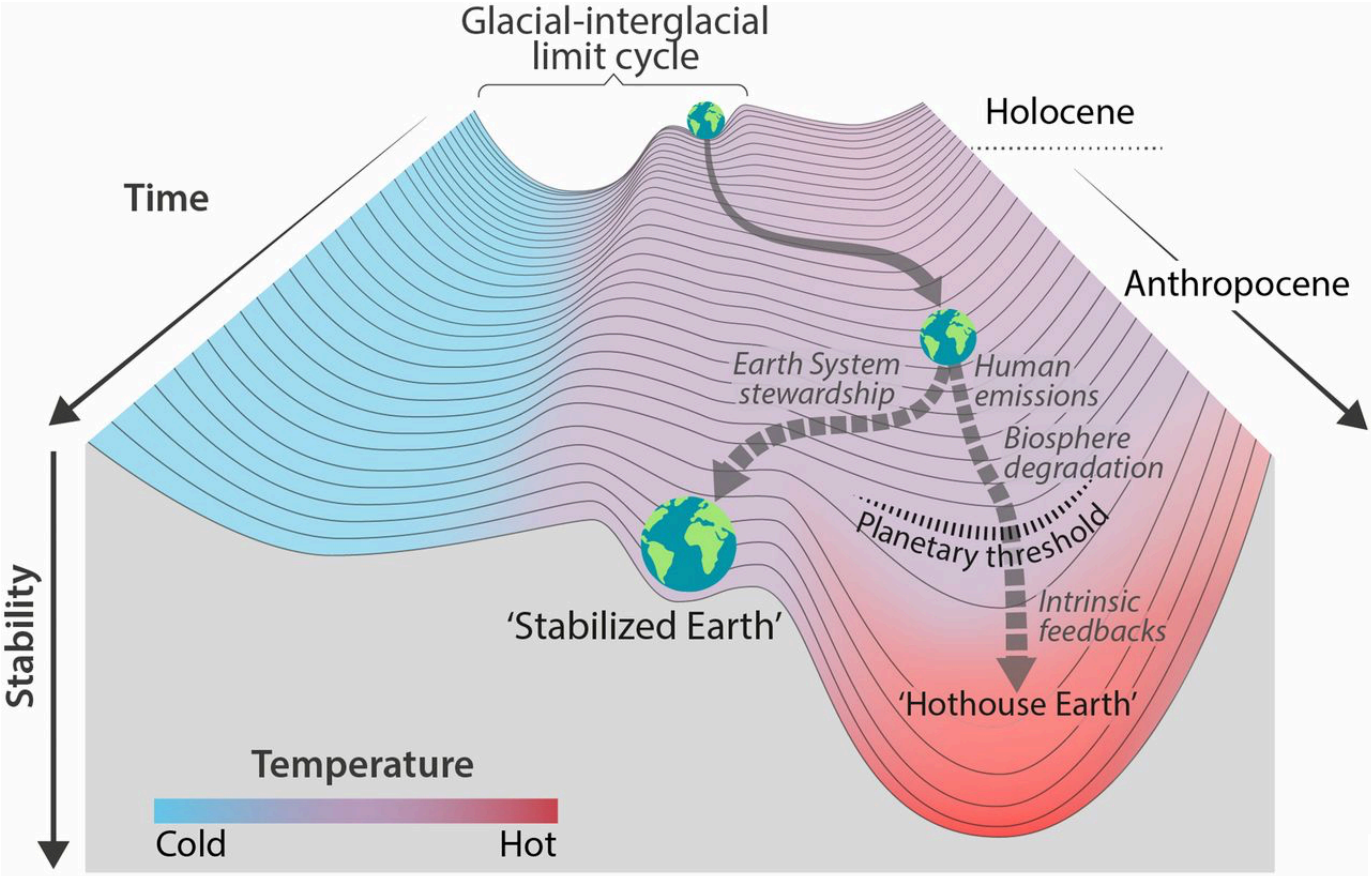

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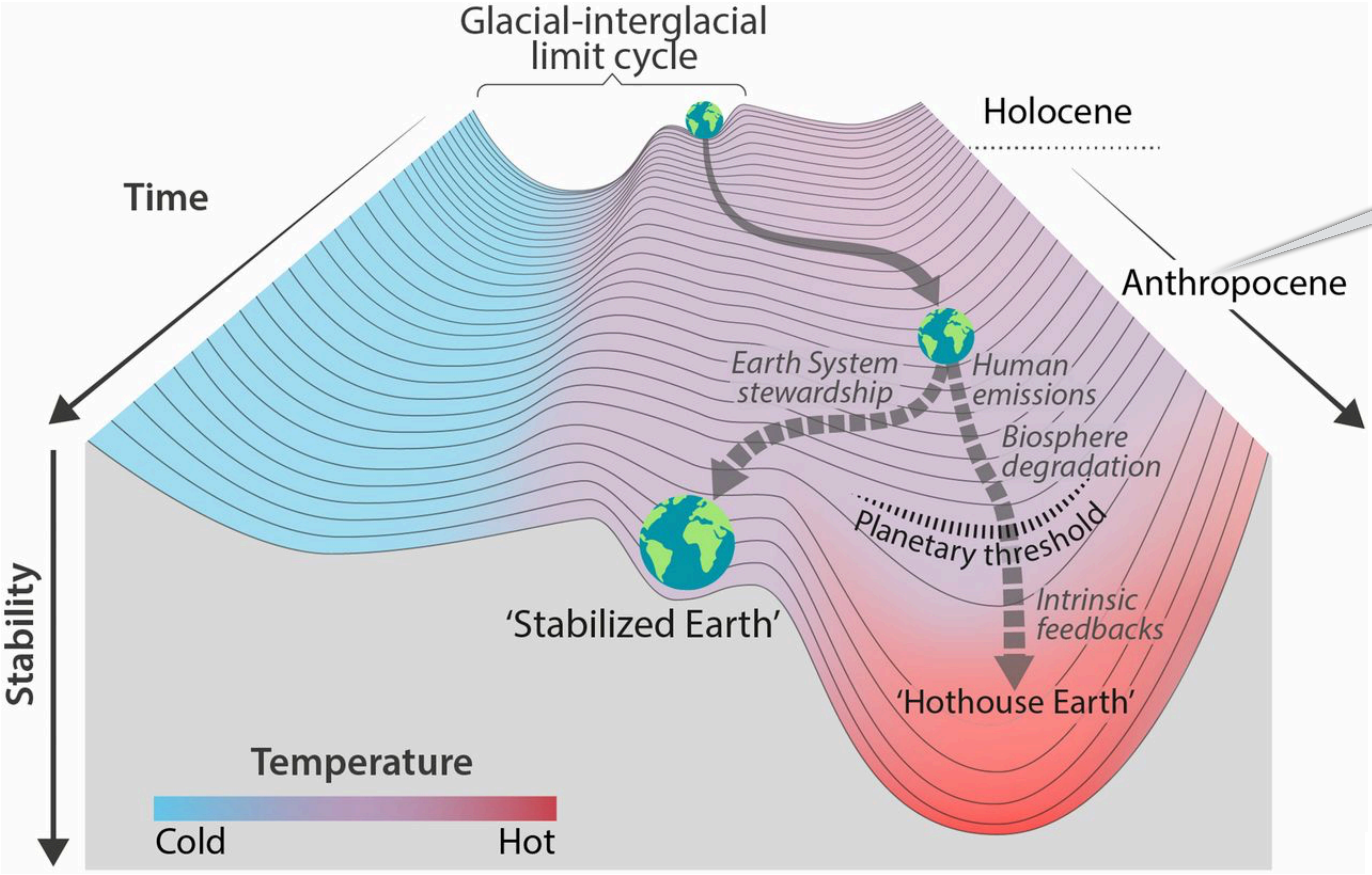

Anthropocene or Post-Holocene?

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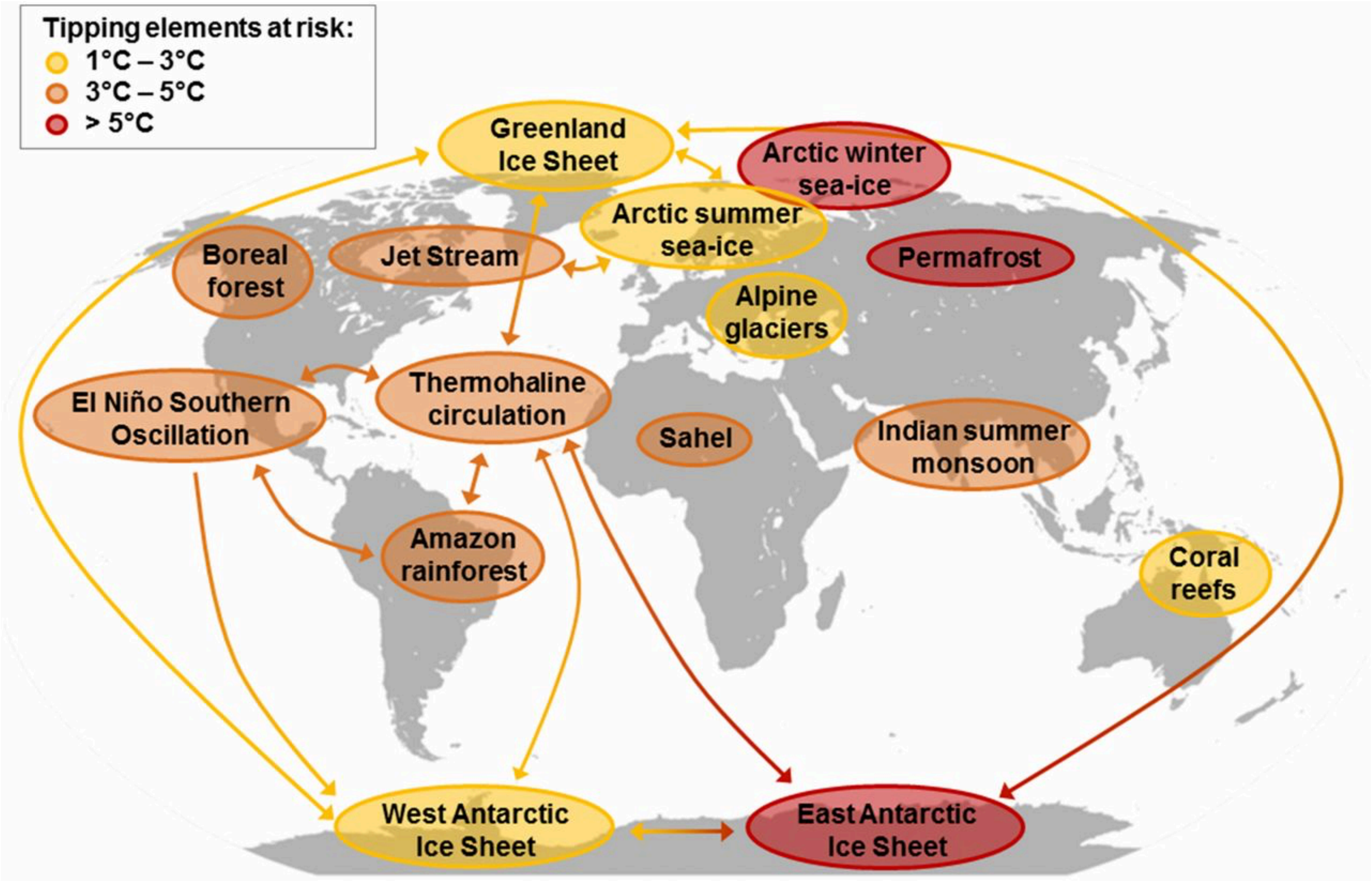

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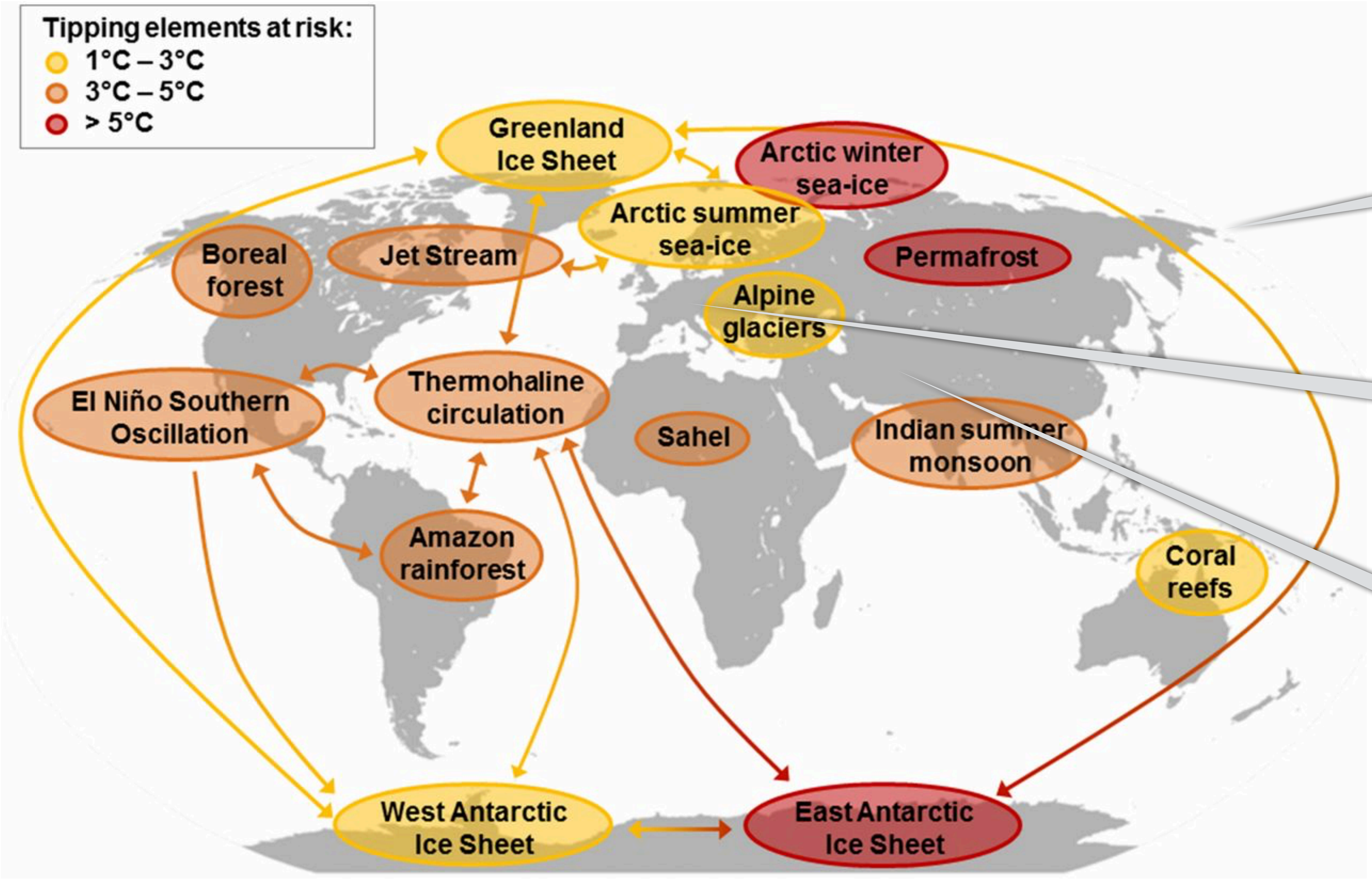

Extinction of mammals and birds

Extinction of insects

Loss of soil

Trajectories of the Earth System in the Anthropocene

Will Steffen, Johan Rockström, Katherine Richardson, Timothy M. Lenton, Carl Folke, Diana Liverman, Colin P. Summerhayes, Anthony D. Barnosky, Sarah E. Cornell, Michel Crucifix, Jonathan F. Donges, Ingo Fetzer, Steven J. Lade, Marten Scheffer, Ricarda Winkelmann, and Hans Joachim Schellnhuber

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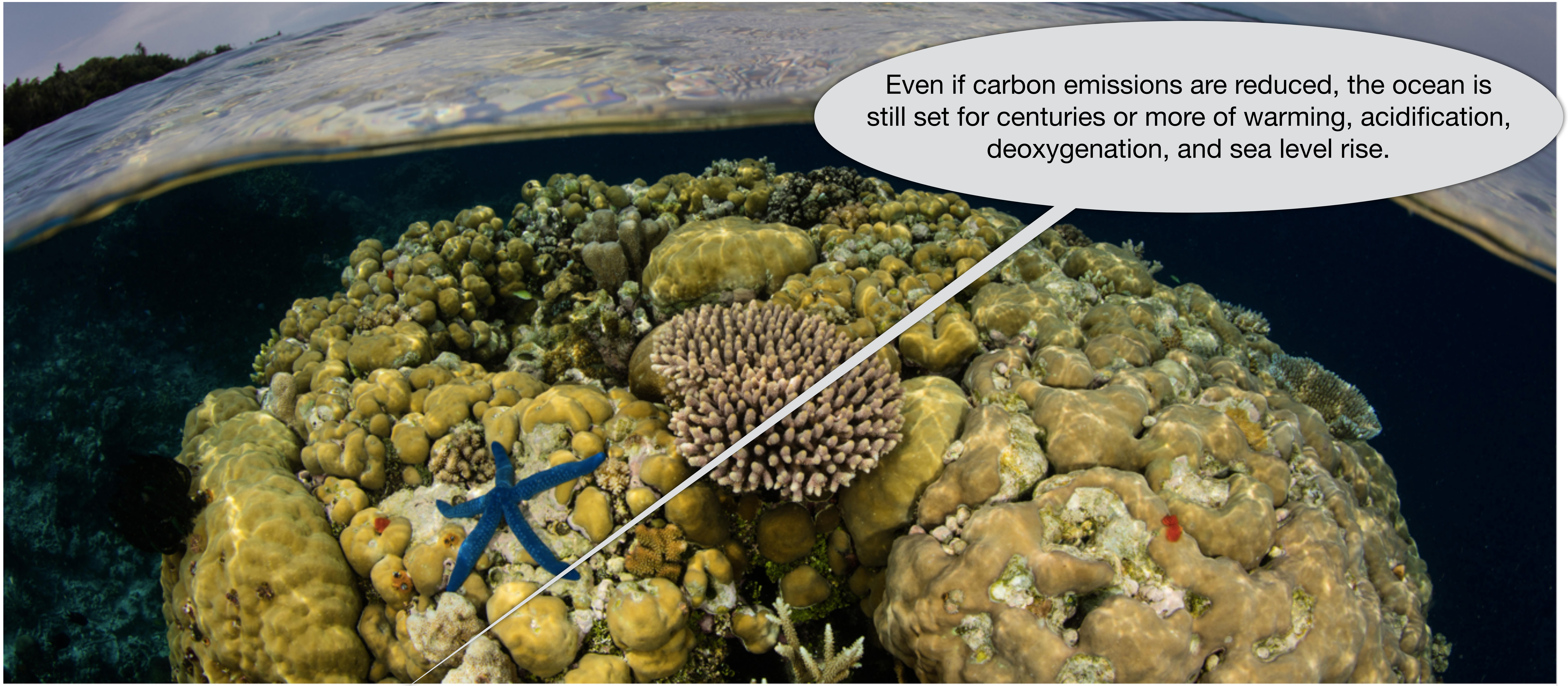
Prognosis: Journey into the Unknown

Even if carbon emissions are reduced, the ocean is still set for centuries or more of warming, acidification, deoxygenation, and sea level rise. Photo by Ethan Daniels/Alamy Stock Photo

When It Comes to Climate Change, the Ocean Never Forgets

Prognosis: Journey into the Unknown



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When It Comes to Climate Change, the Ocean Never Forgets

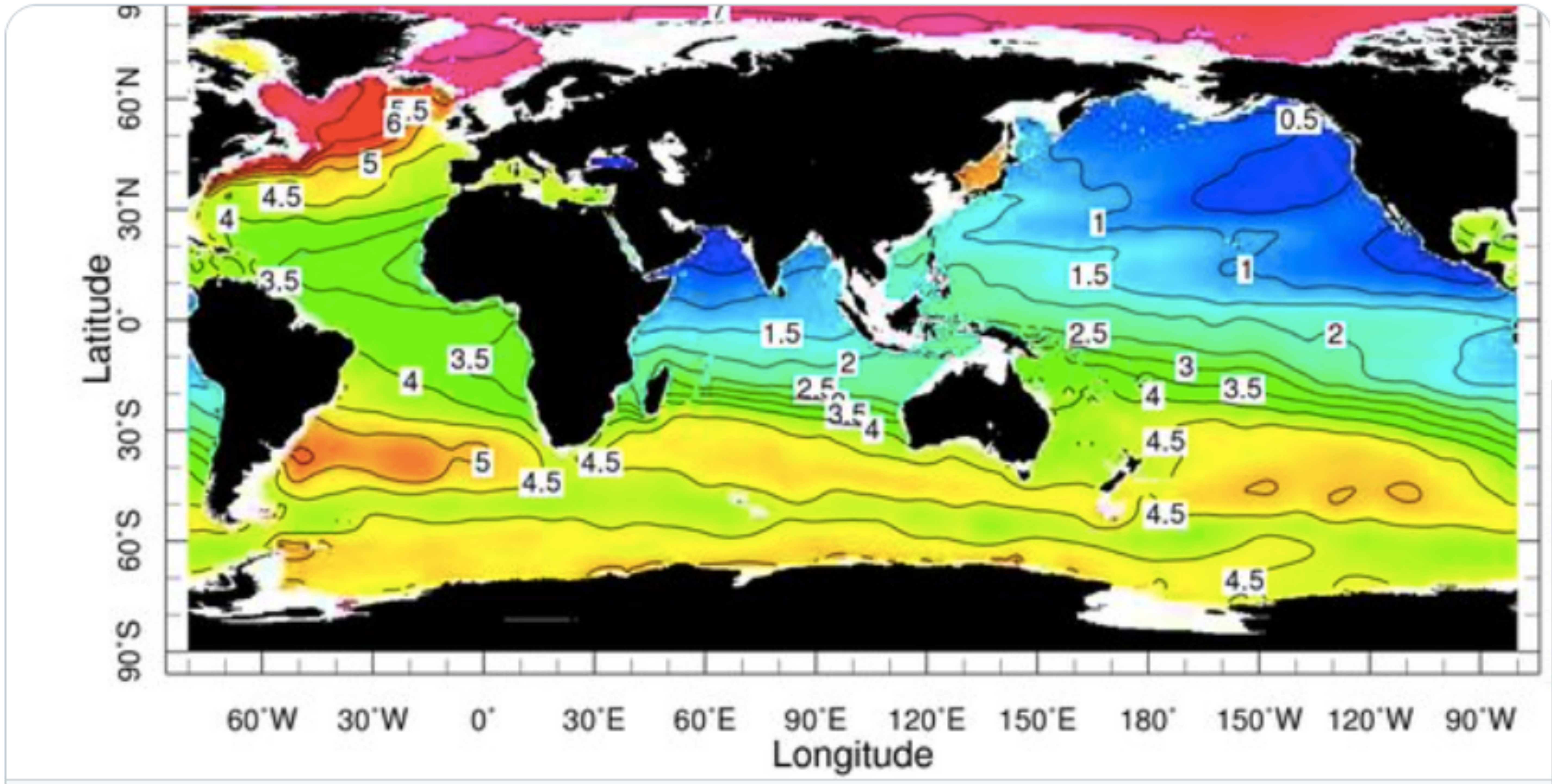
Prognosis: Journey into the Unknown

REPORT

Large-scale ocean deoxygenation during the Paleocene-Eocene Thermal Maximum

Weiqi Yao[1,*], Adina Paytan[2], Ulrich G. Wortmann[1]
+ See all authors and affiliations

Science 24 Aug 2018:
Vol. 361, Issue 6404, pp. 804-806
DOI: 10.1126/science.aar8658



Fishin' gone?

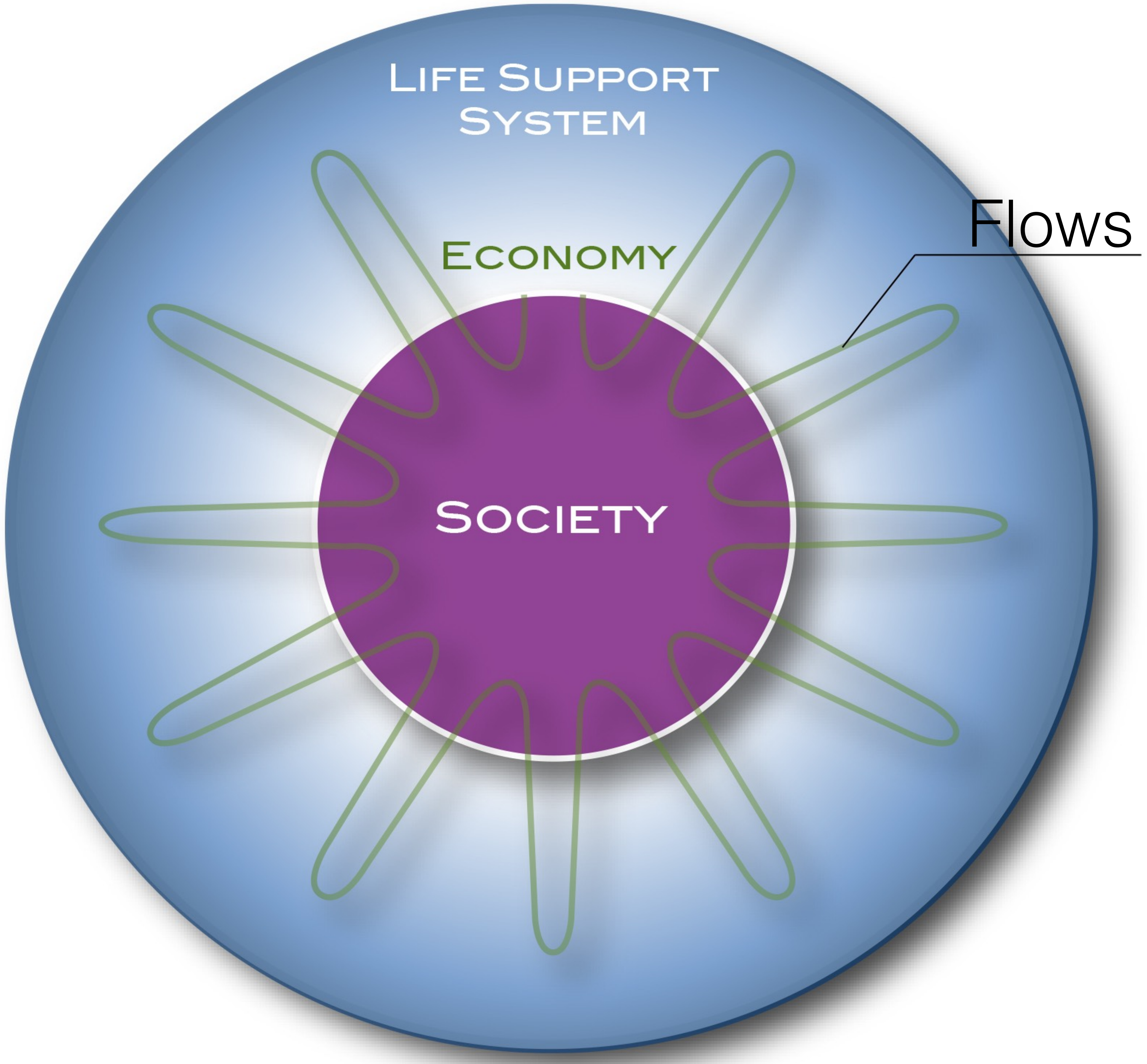
Because gas solubility decreases as temperatures increase, global warming is likely to cause oxygen loss from the oceans. This could have a detrimental impact on fish populations, the fishing industry, and global food availability. Have such impacts occurred before? Yao *et al.* report sulfur isotopic data from the Paleocene-Eocene Thermal Maximum, an interval around 55 million years ago when atmospheric carbon dioxide concentrations and global temperatures were also high. They found widespread anoxia and resulting high concentrations of hydrogen sulfide, which is toxic to marine organisms. Similar effects could have severe negative effects on ocean ecosystems.

Science, this issue p. 804

Abstract

The consequences of global warming for fisheries are not well understood, but the geological record demonstrates that carbon cycle perturbations are frequently associated with ocean deoxygenation. Of particular interest is the Paleocene-Eocene Thermal Maximum (PETM), where the carbon dioxide input into the atmosphere was similar to the IPCC RCP8.5 emission scenario. Here we present sulfur-isotope data that record a positive 1 per mil excursion during the PETM. Modeling suggests that large parts of the ocean must have become sulfidic. The toxicity of hydrogen sulfide will render two of the largest and least explored ecosystems on Earth, the mesopelagic and bathypelagic zones, uninhabitable by multicellular organisms. This will affect many marine species whose ecozones stretch into the deep ocean.

Physiology of the Life-Support System: Flow



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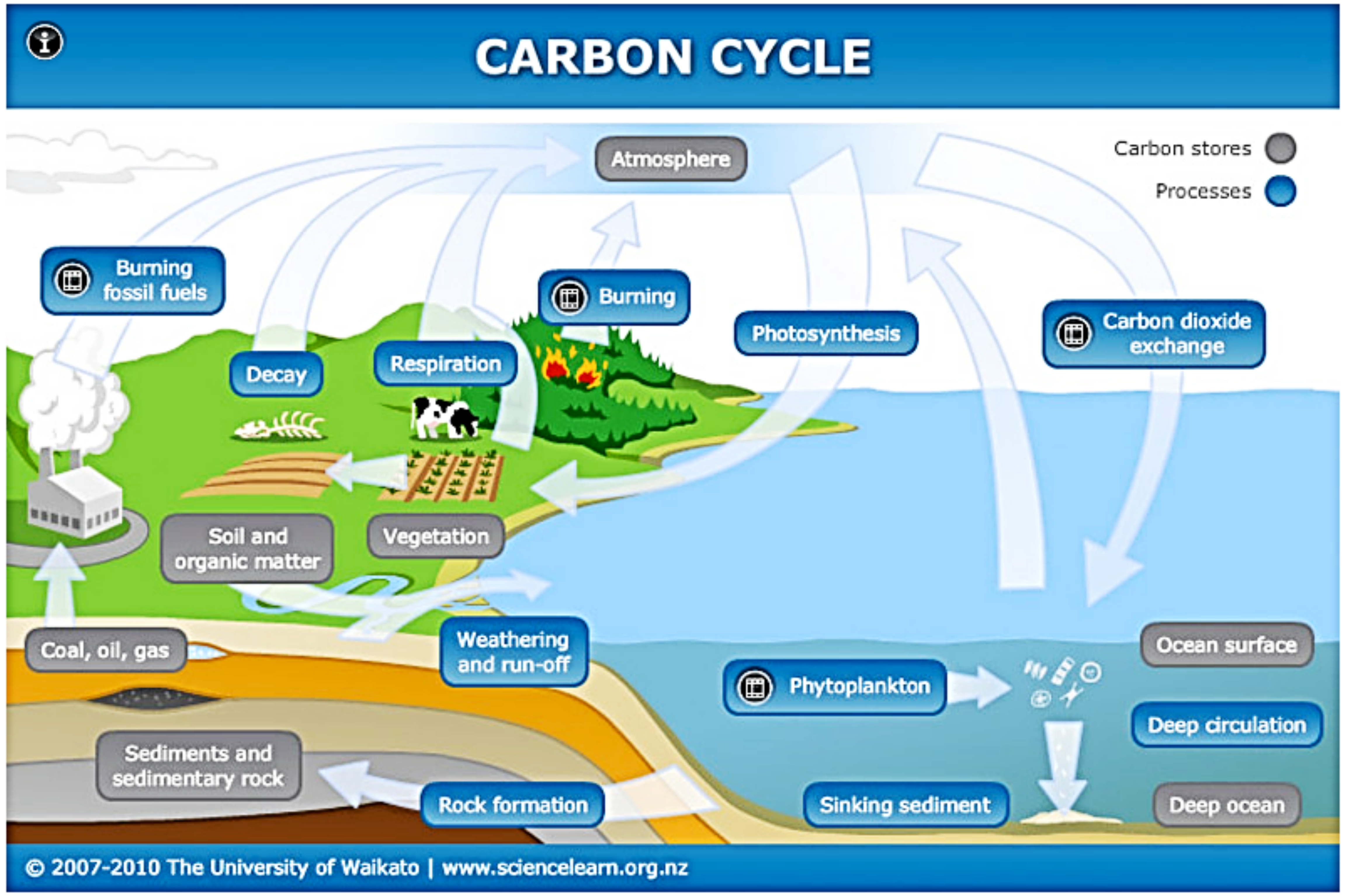

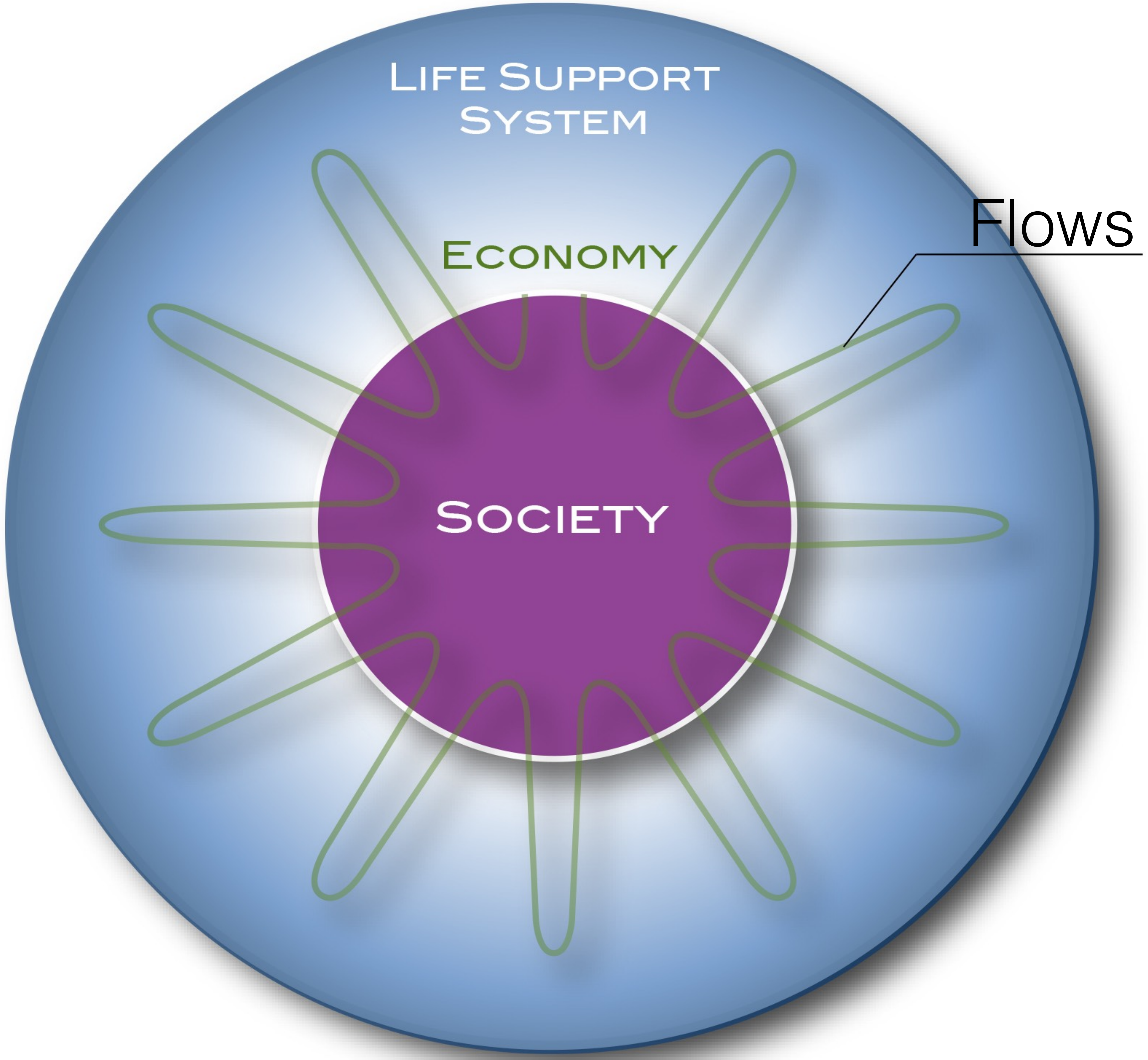

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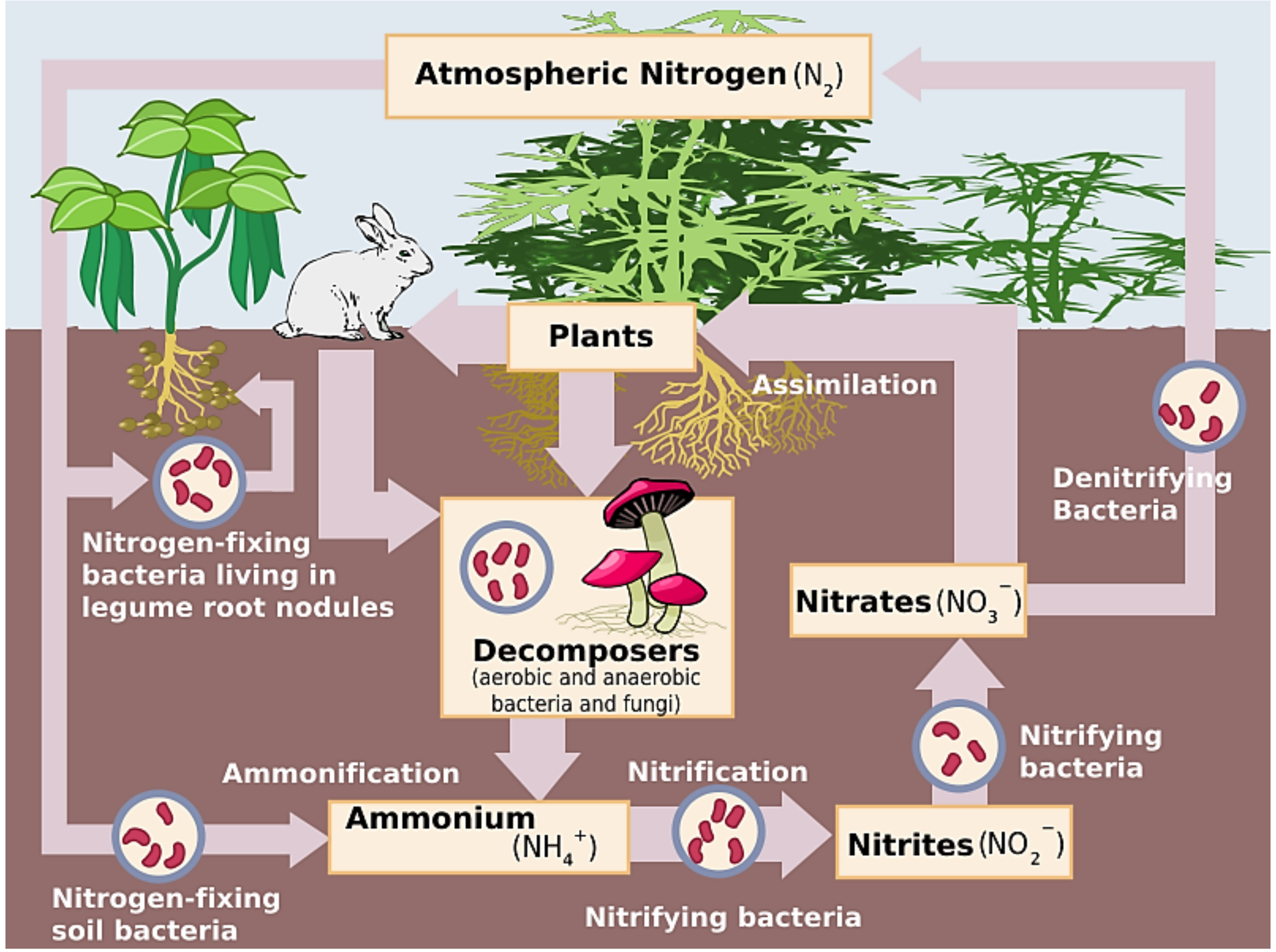

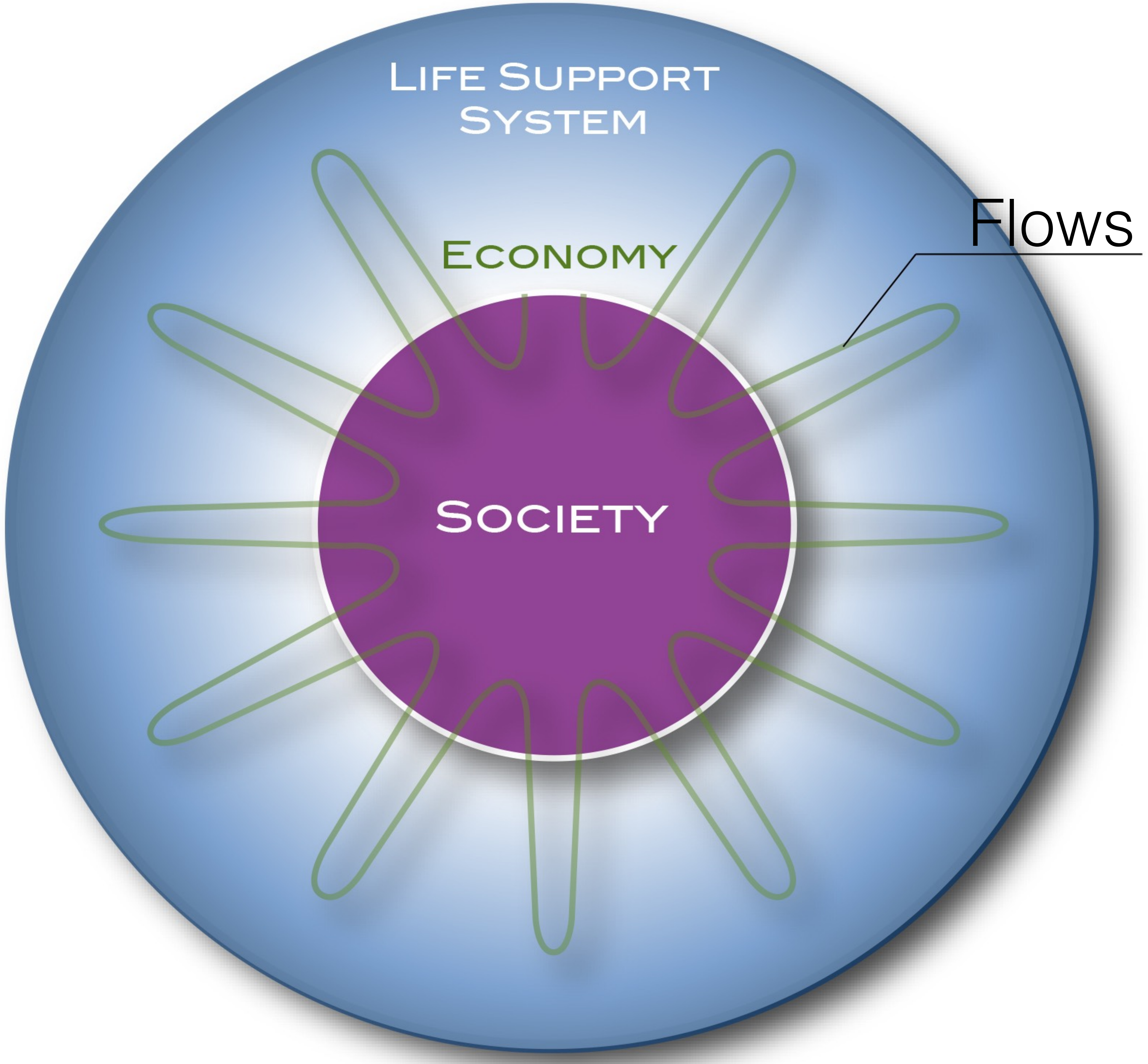

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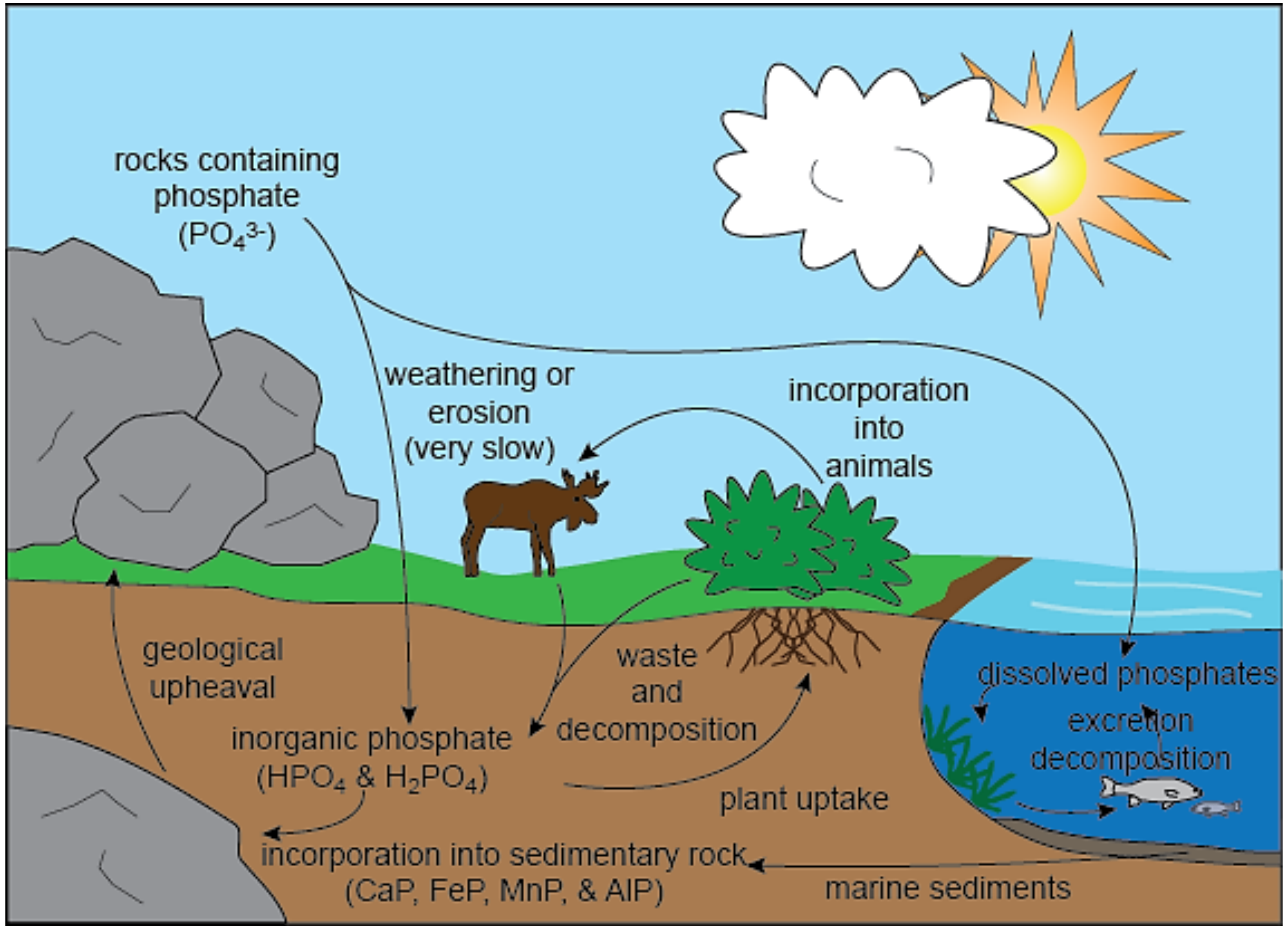
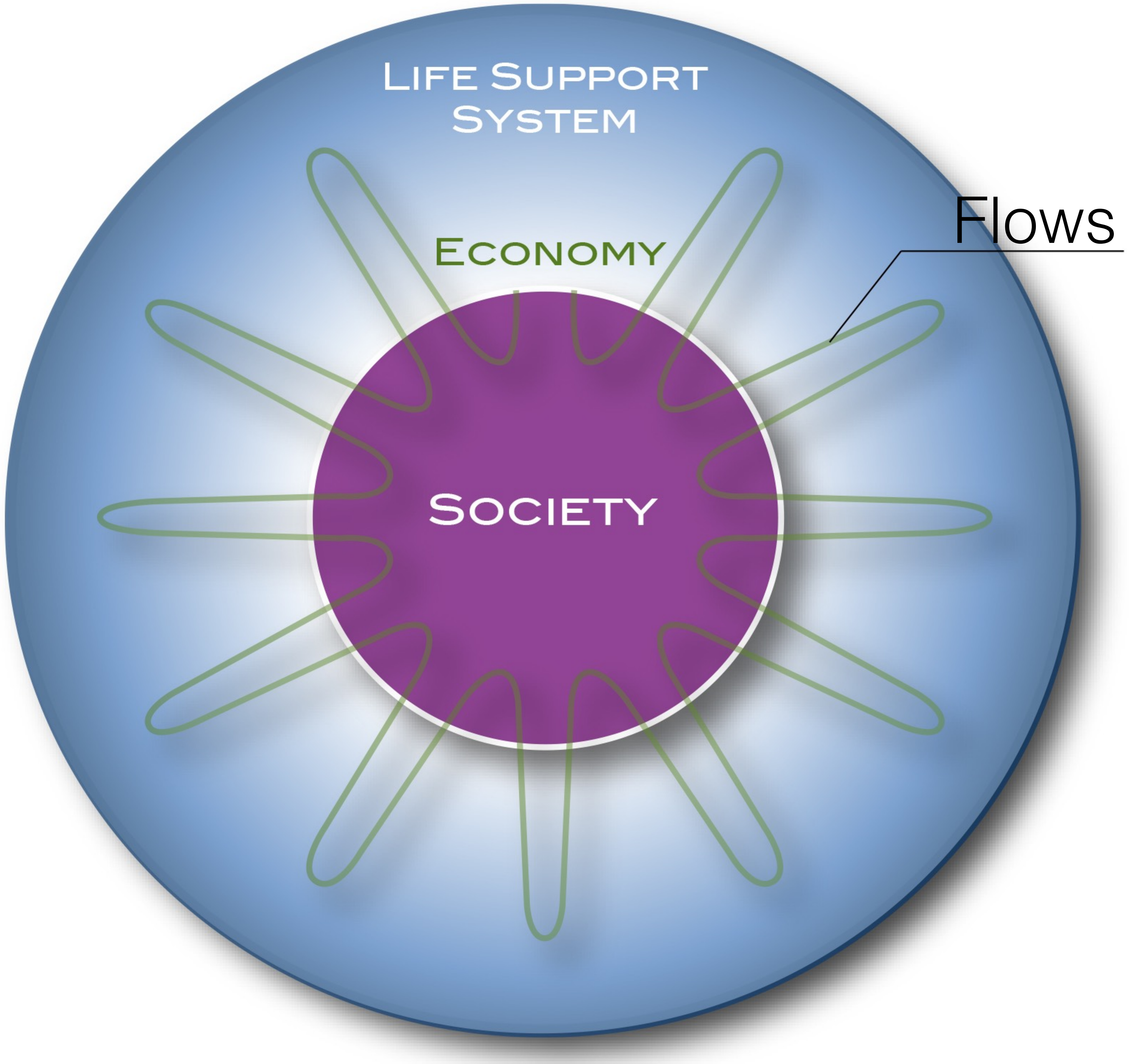
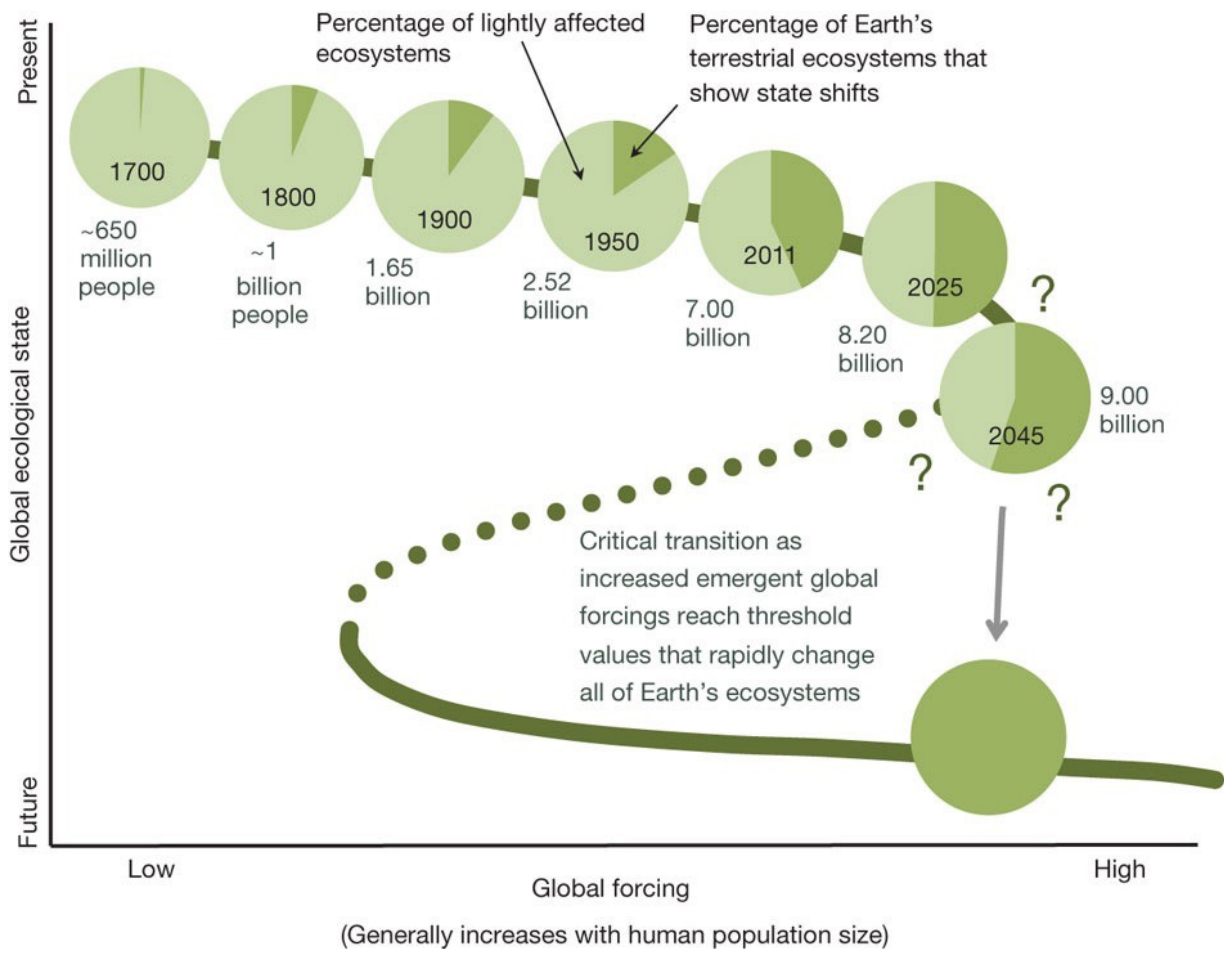
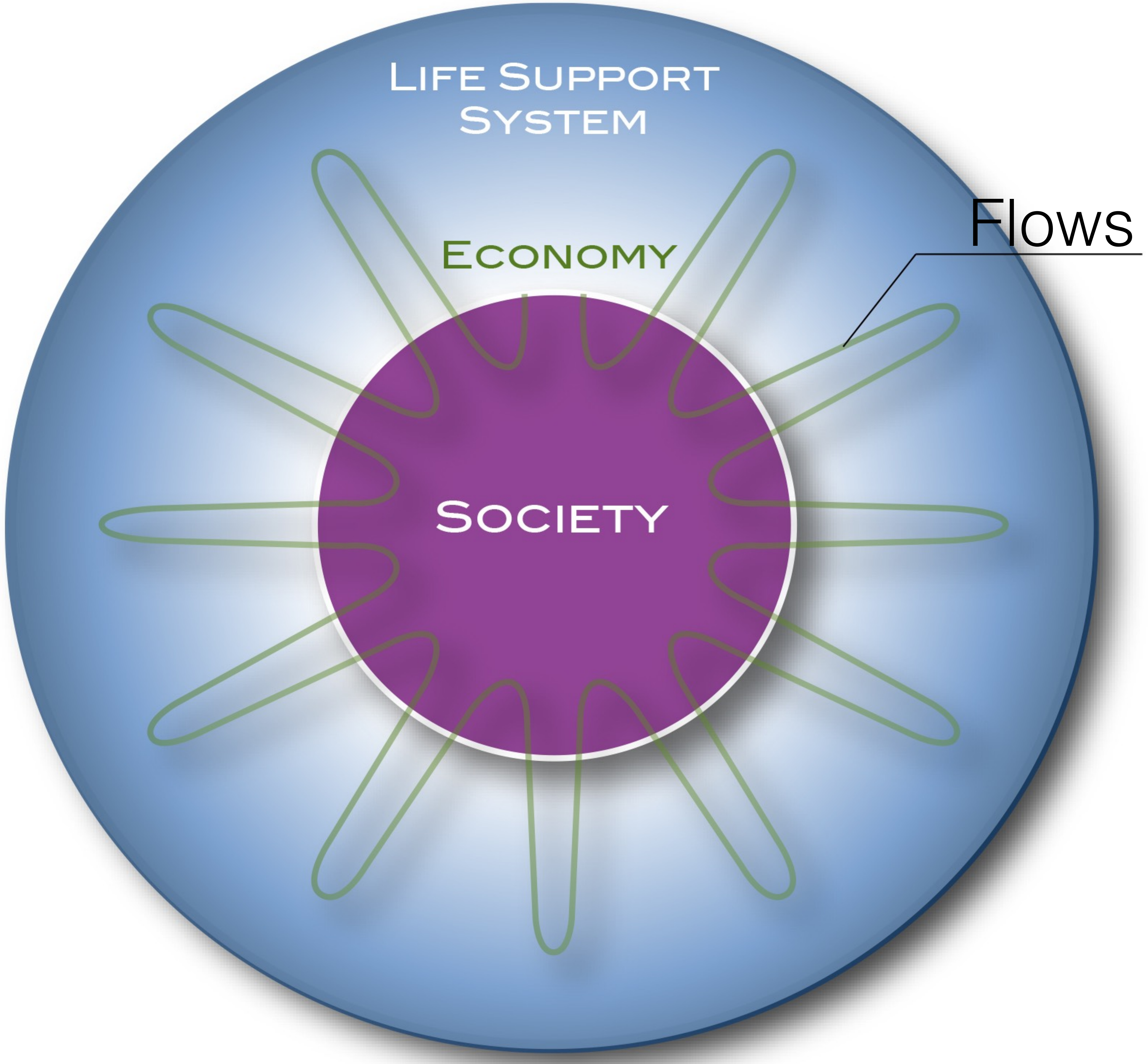




Prognosis: Journey into the Unknown

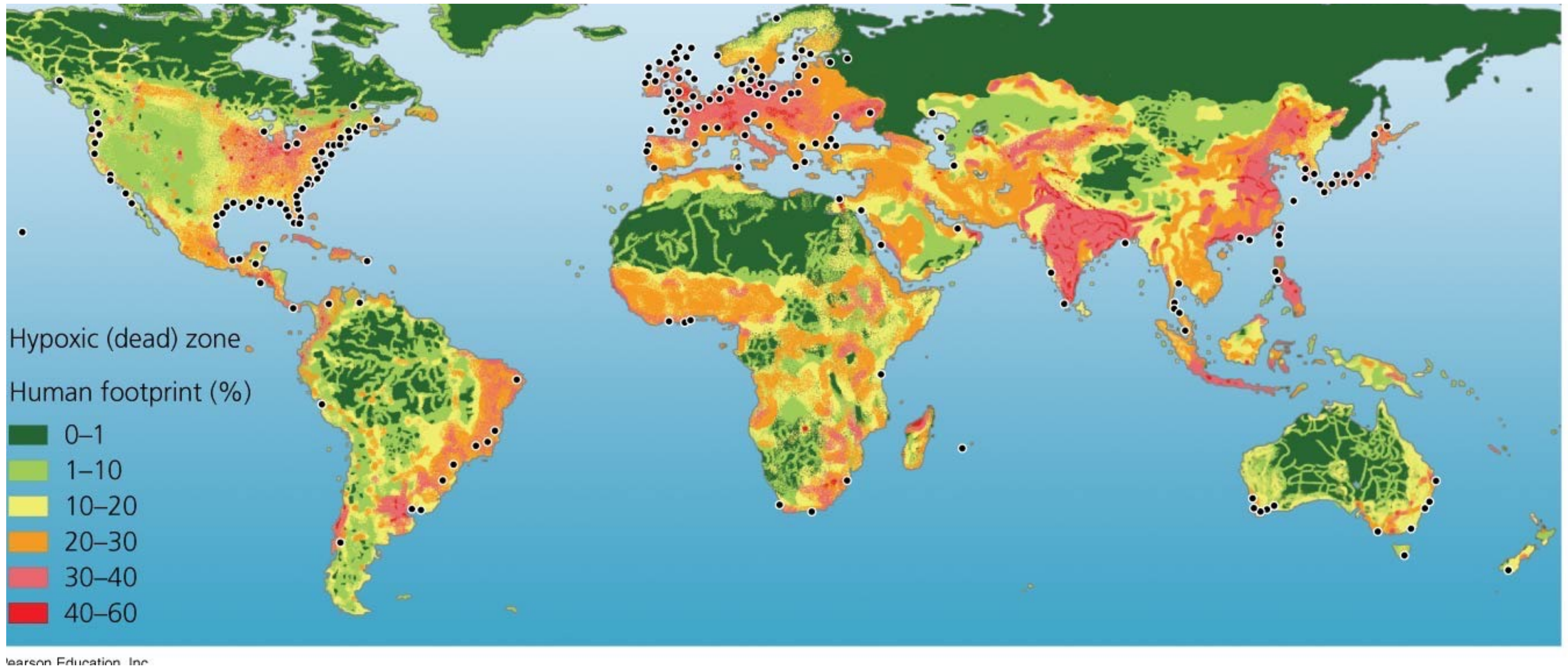
Physiology of the Life-Support System: Flow

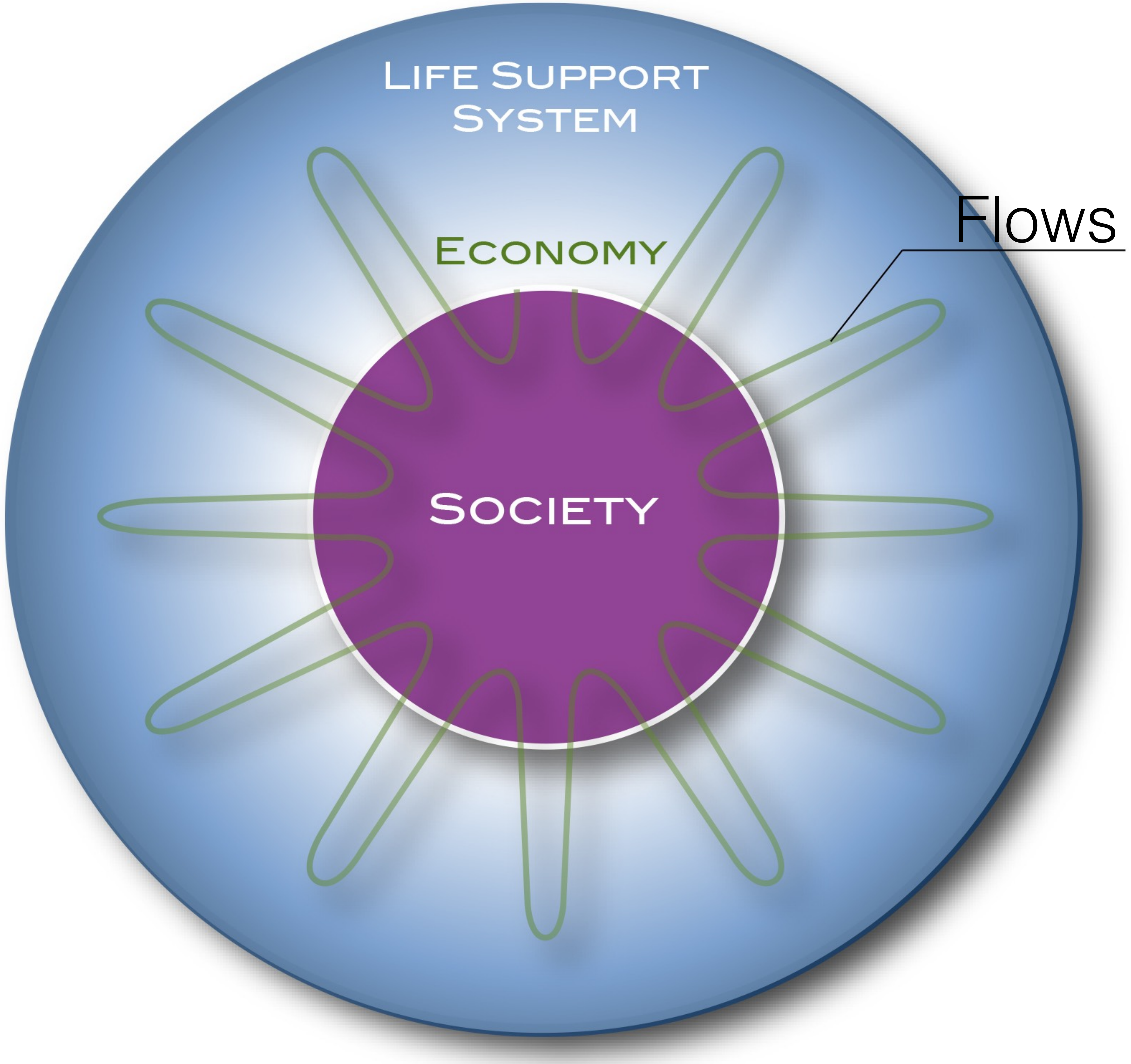




Physiology of the Life-Support System: Flow

Hypoxic (dead) zones





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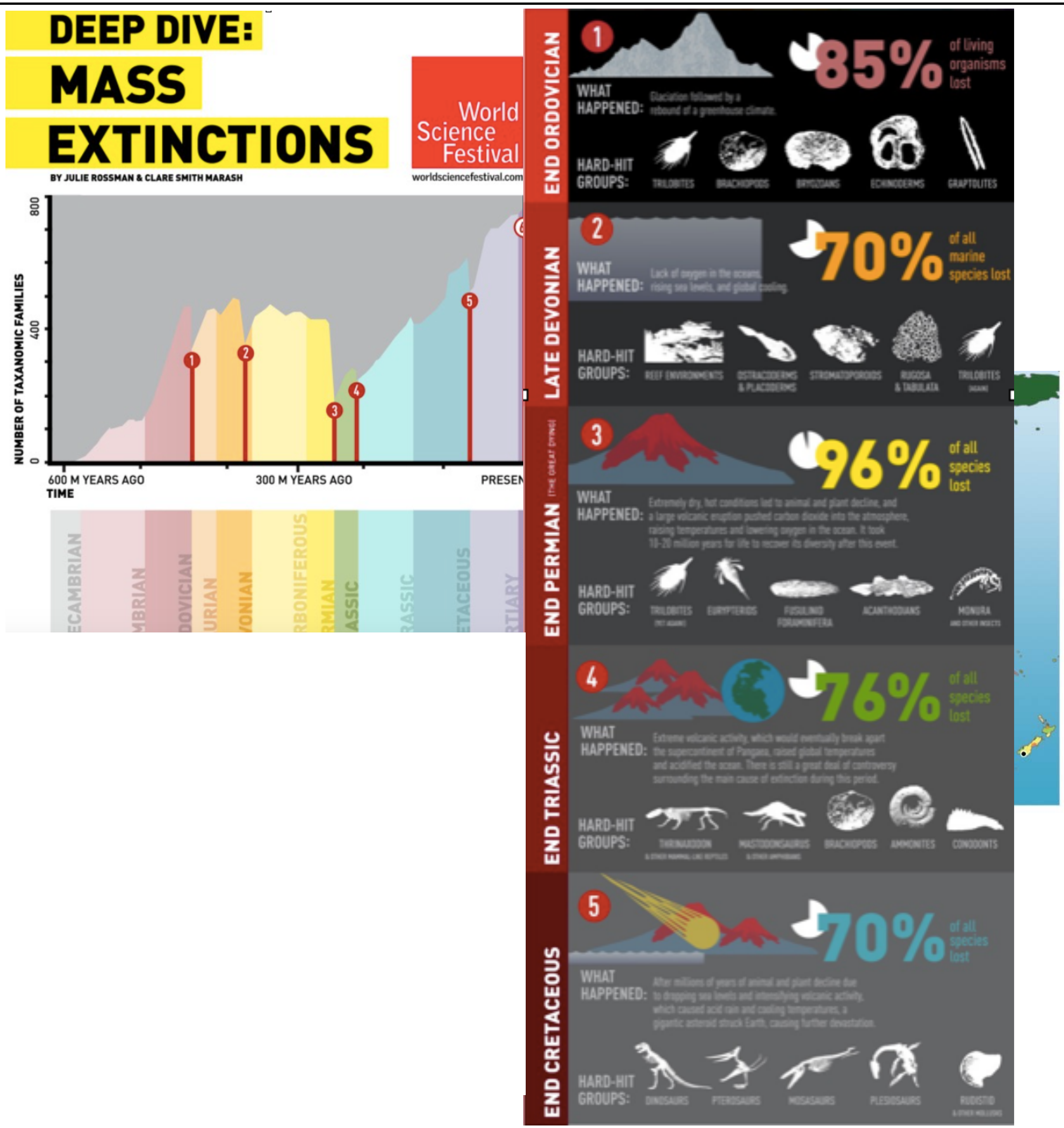

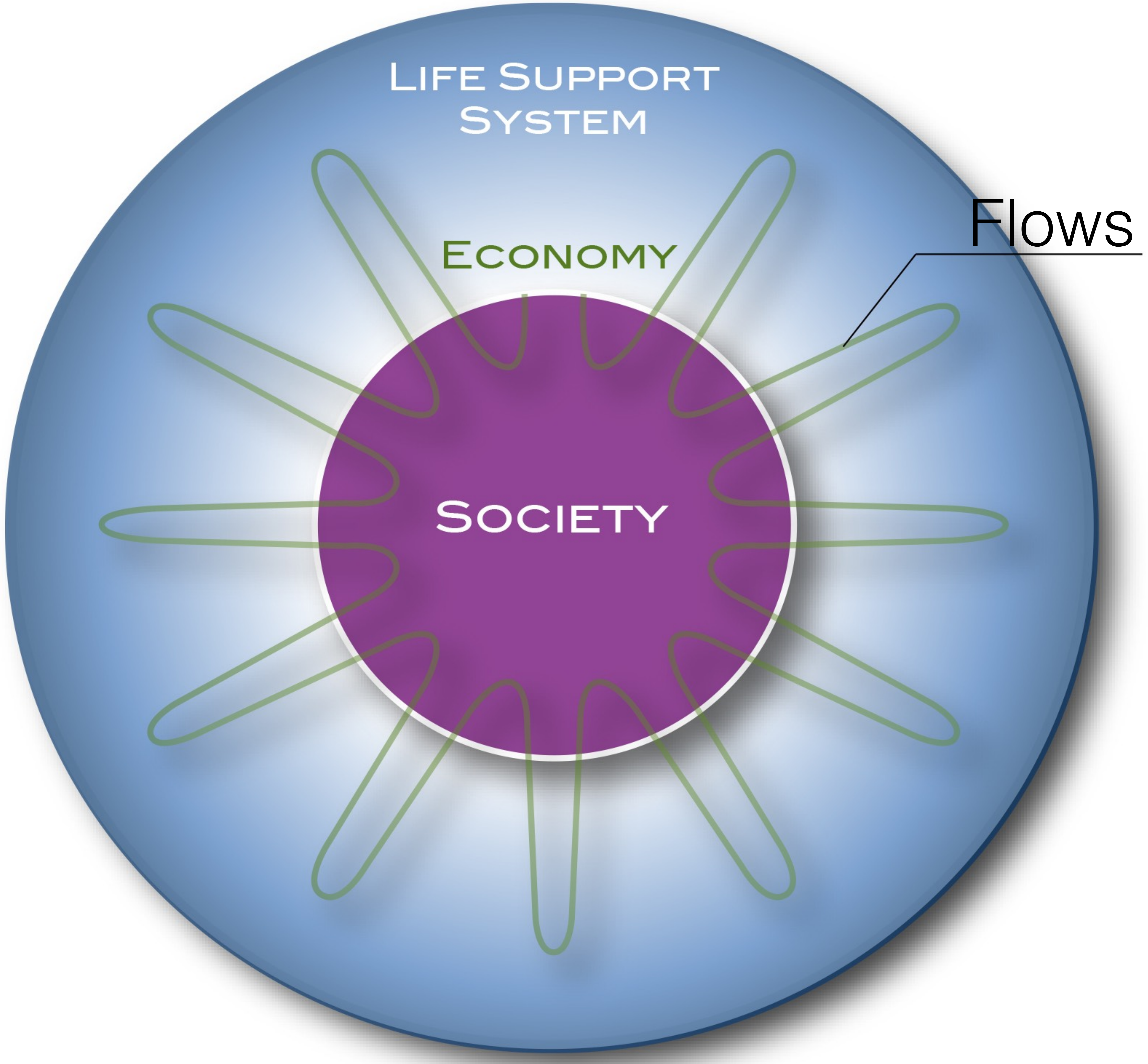

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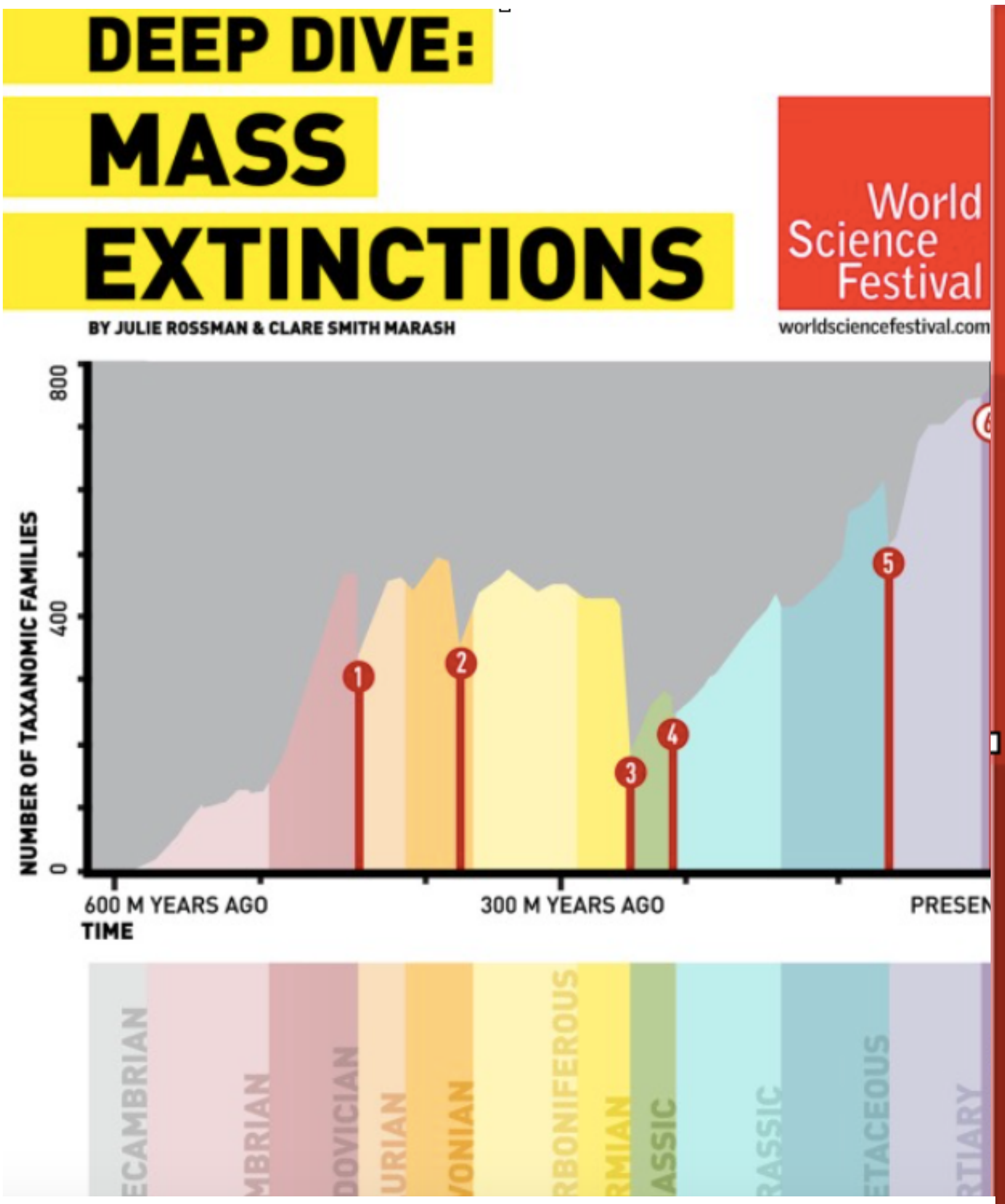
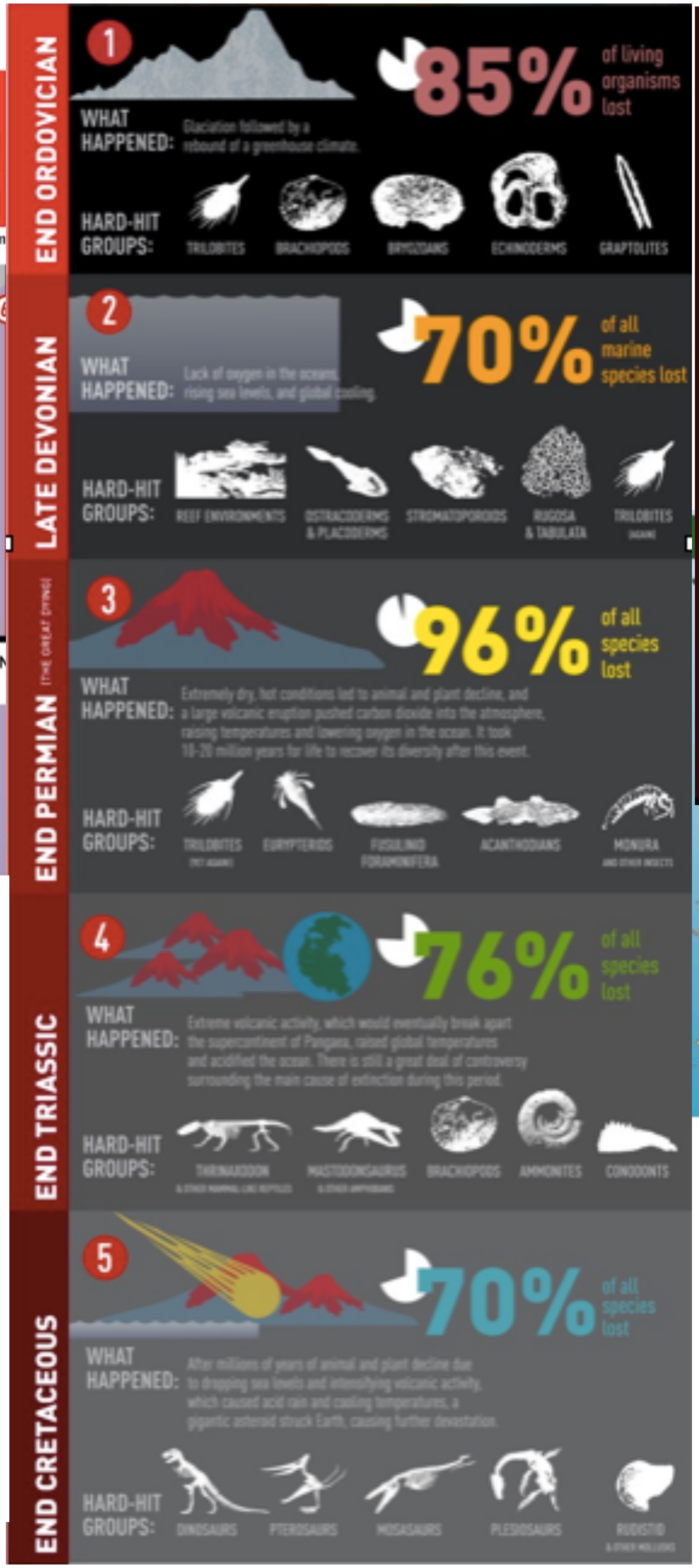
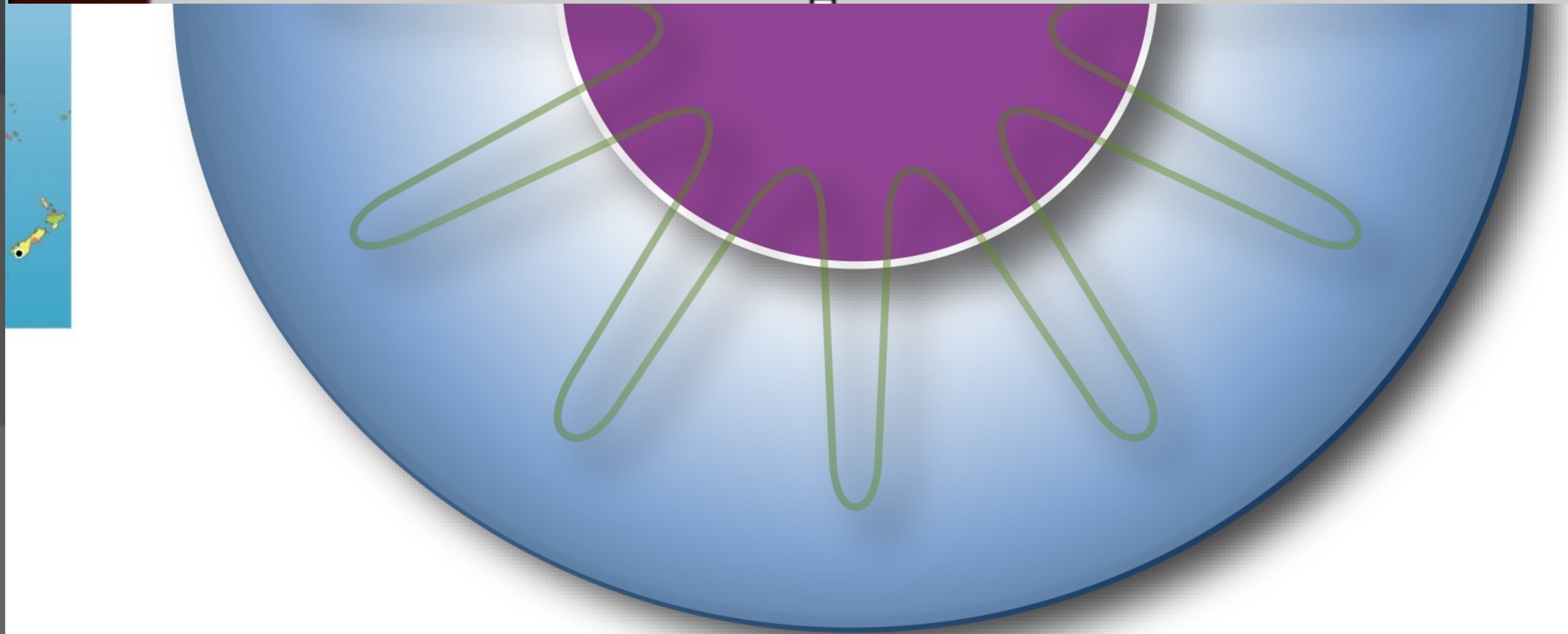
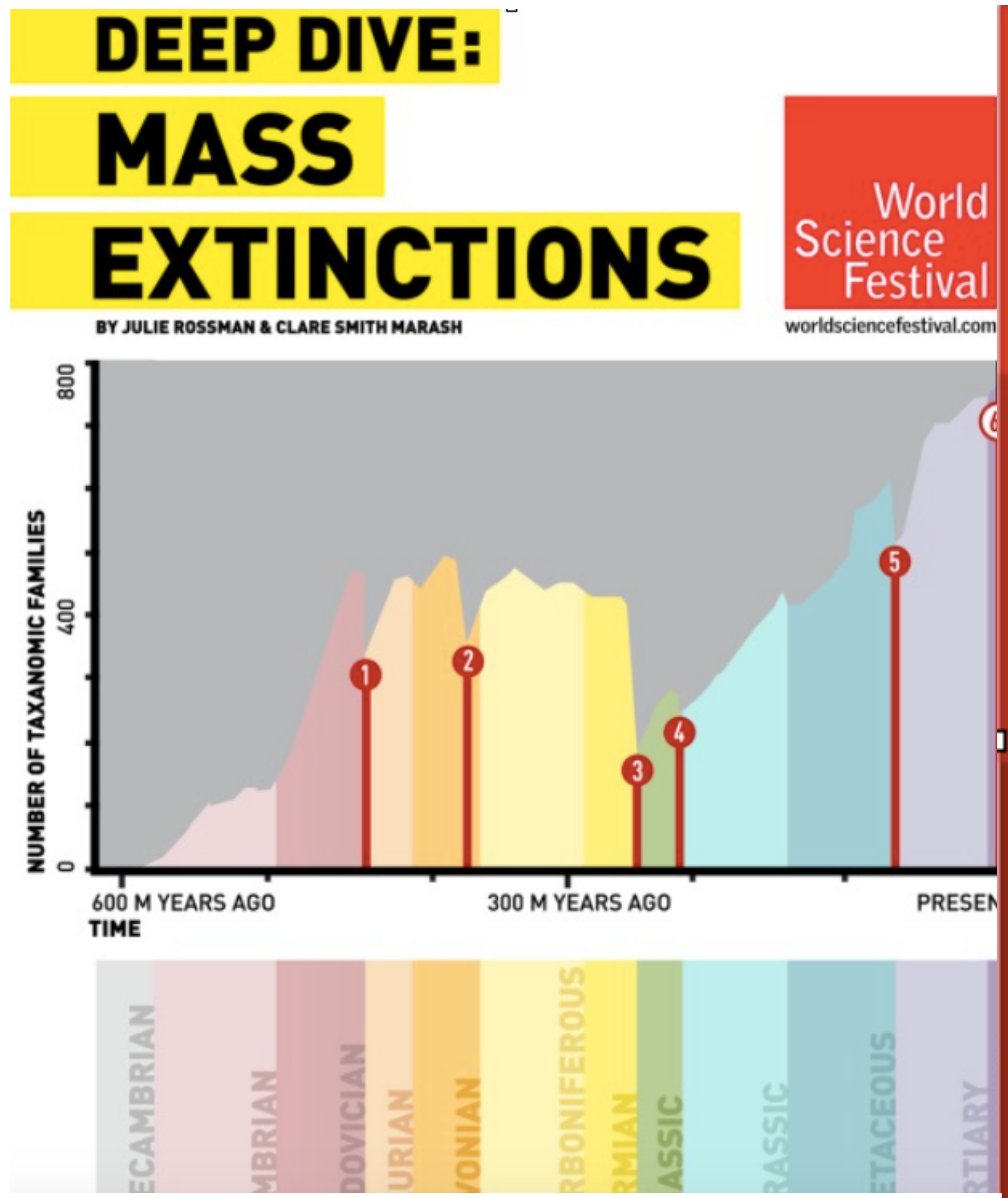
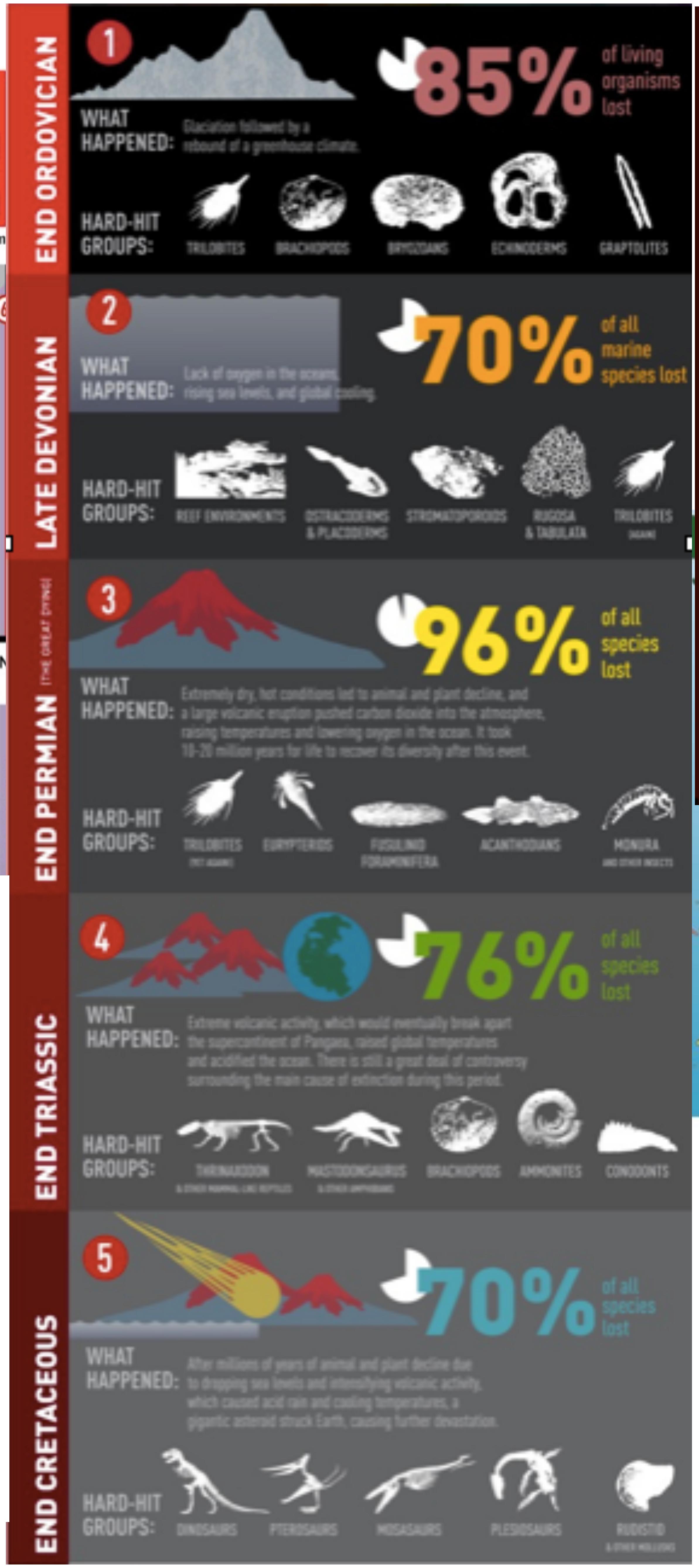


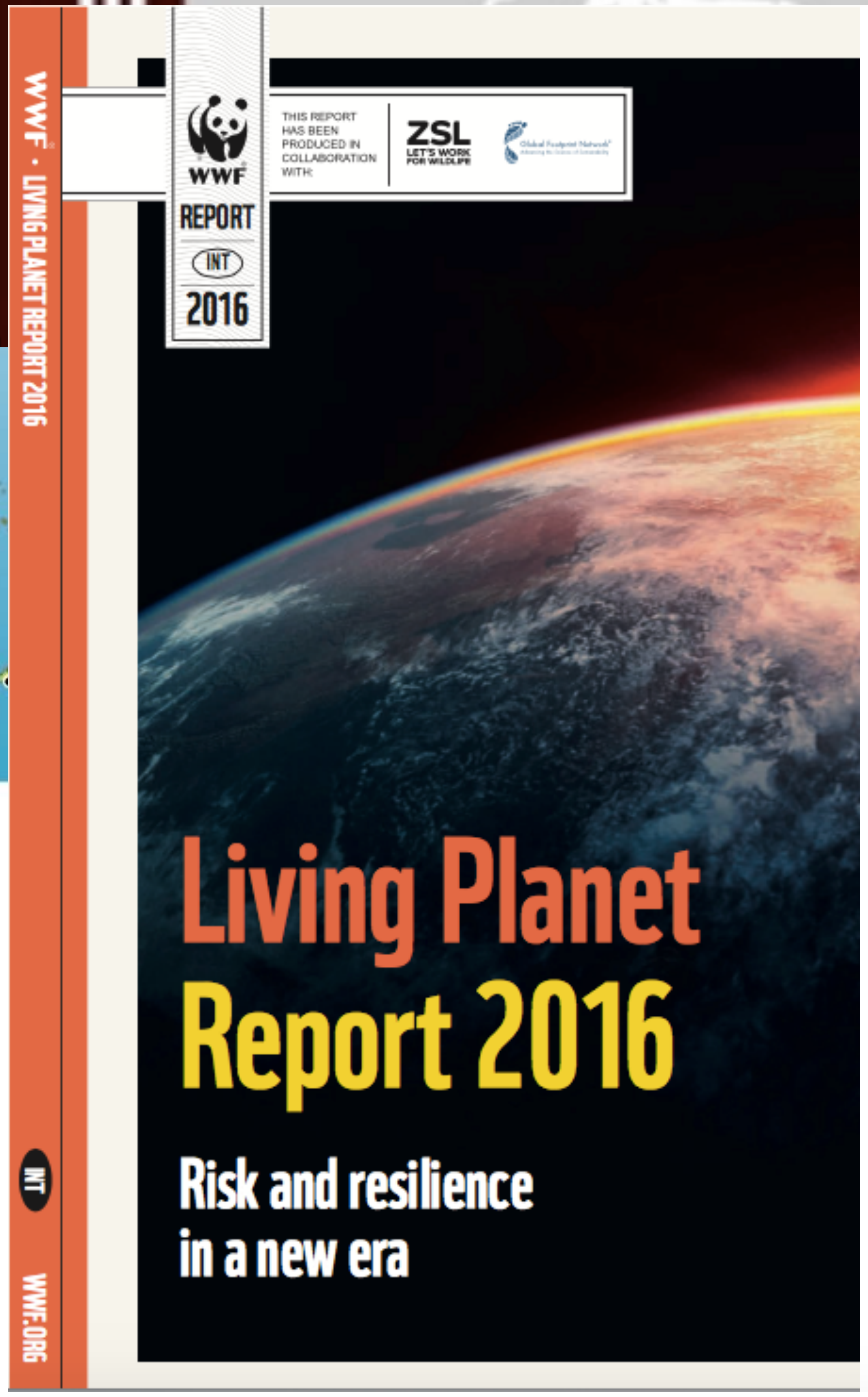




Prognosis: Journey into the Unknown







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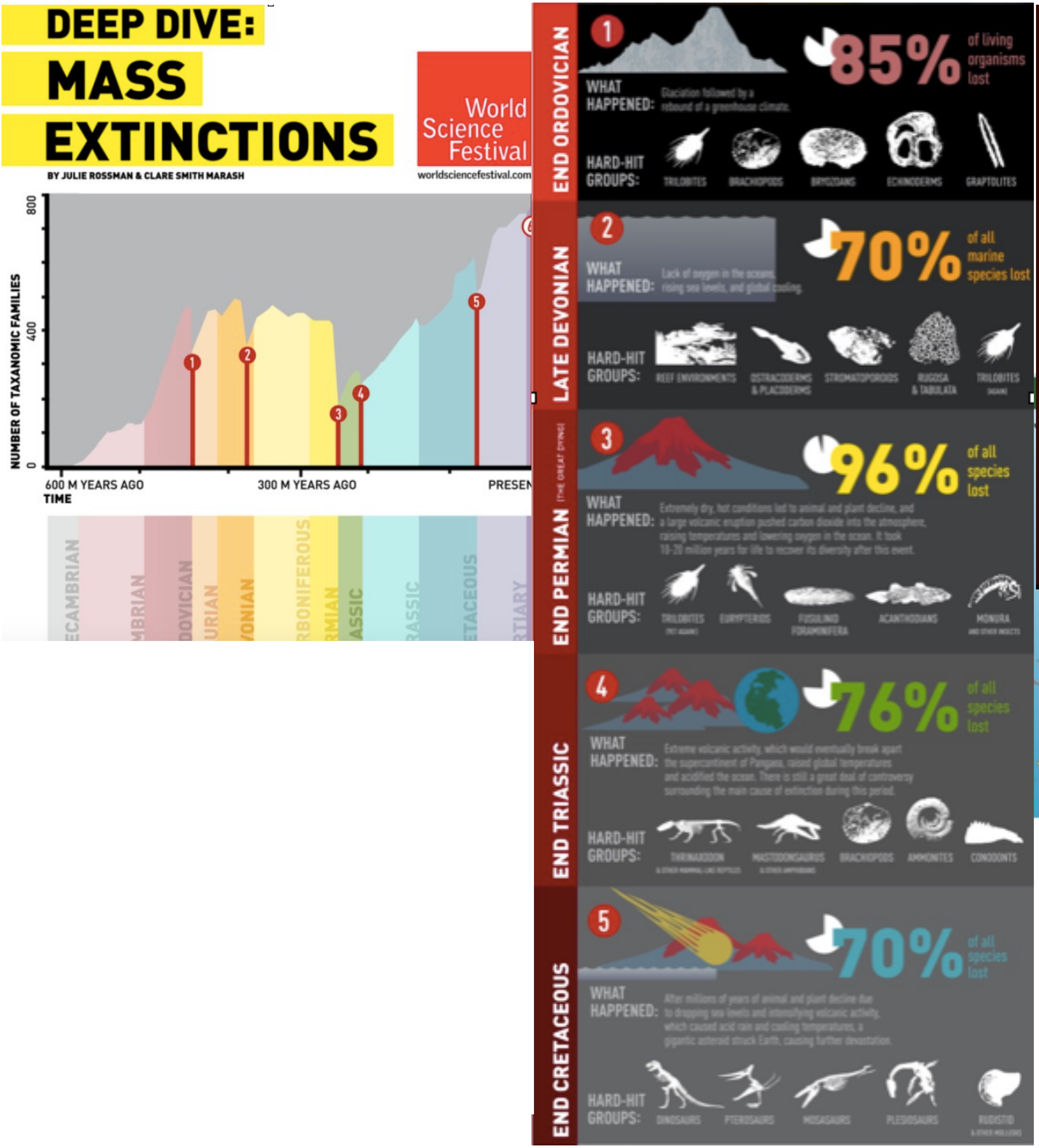

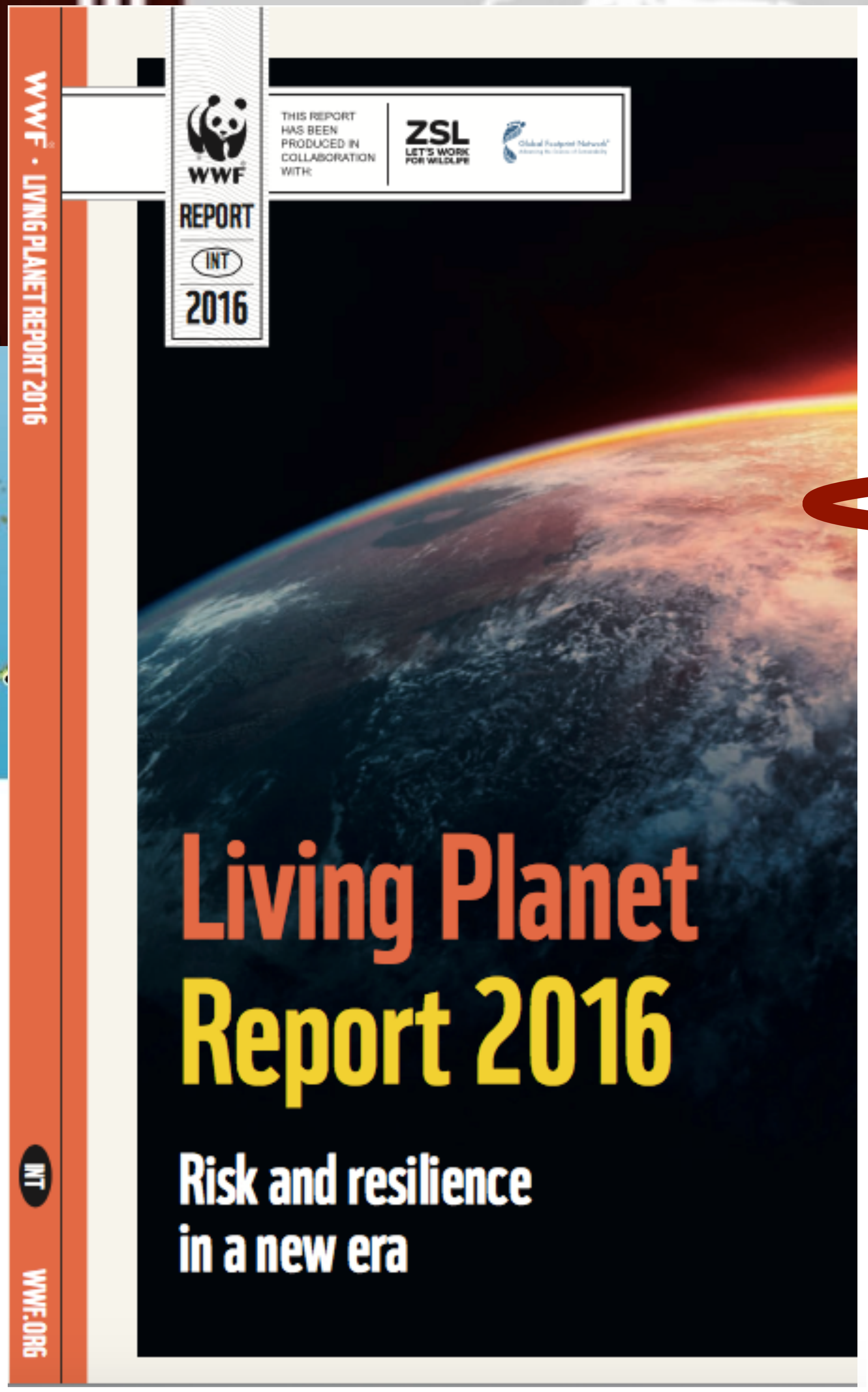

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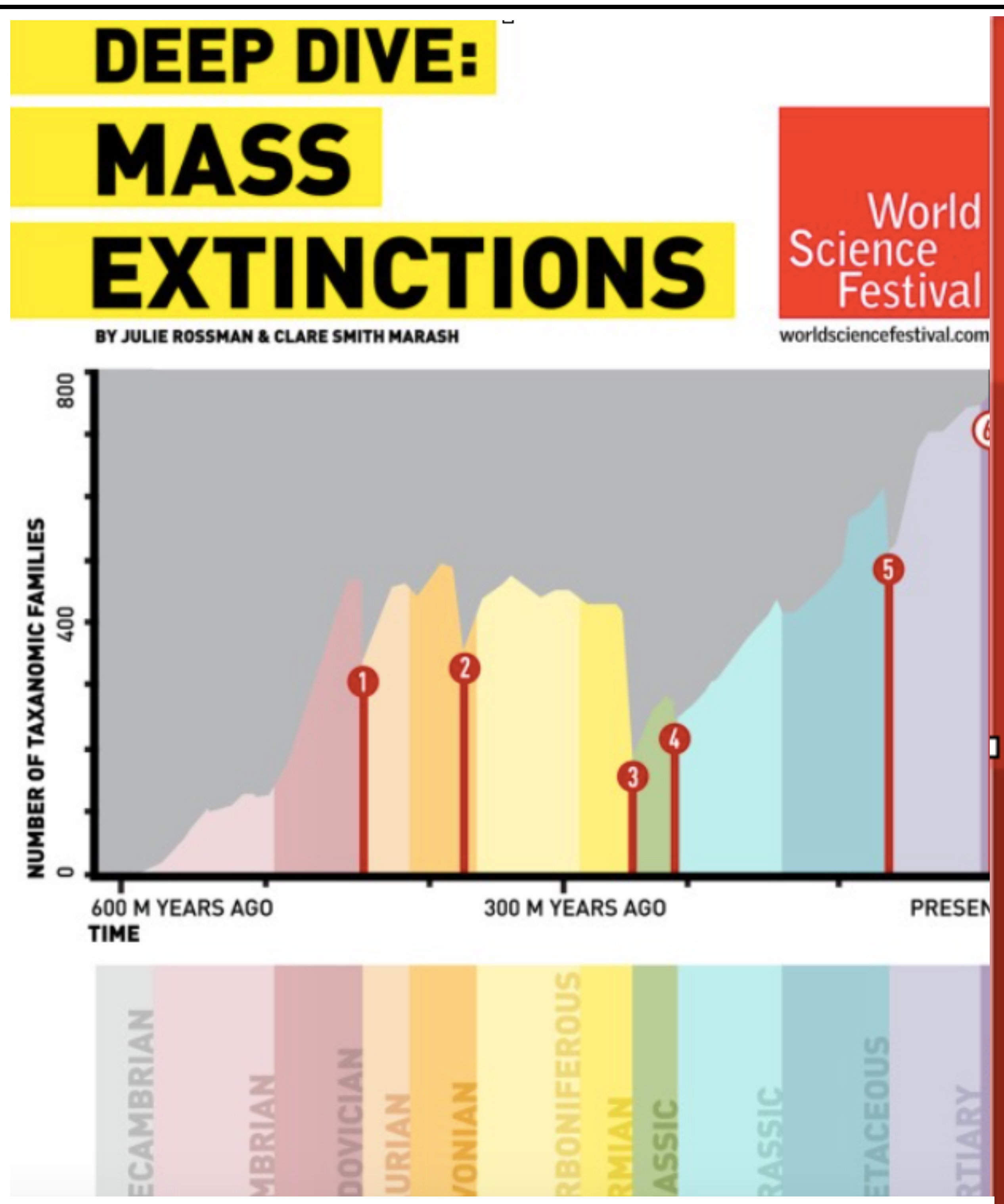
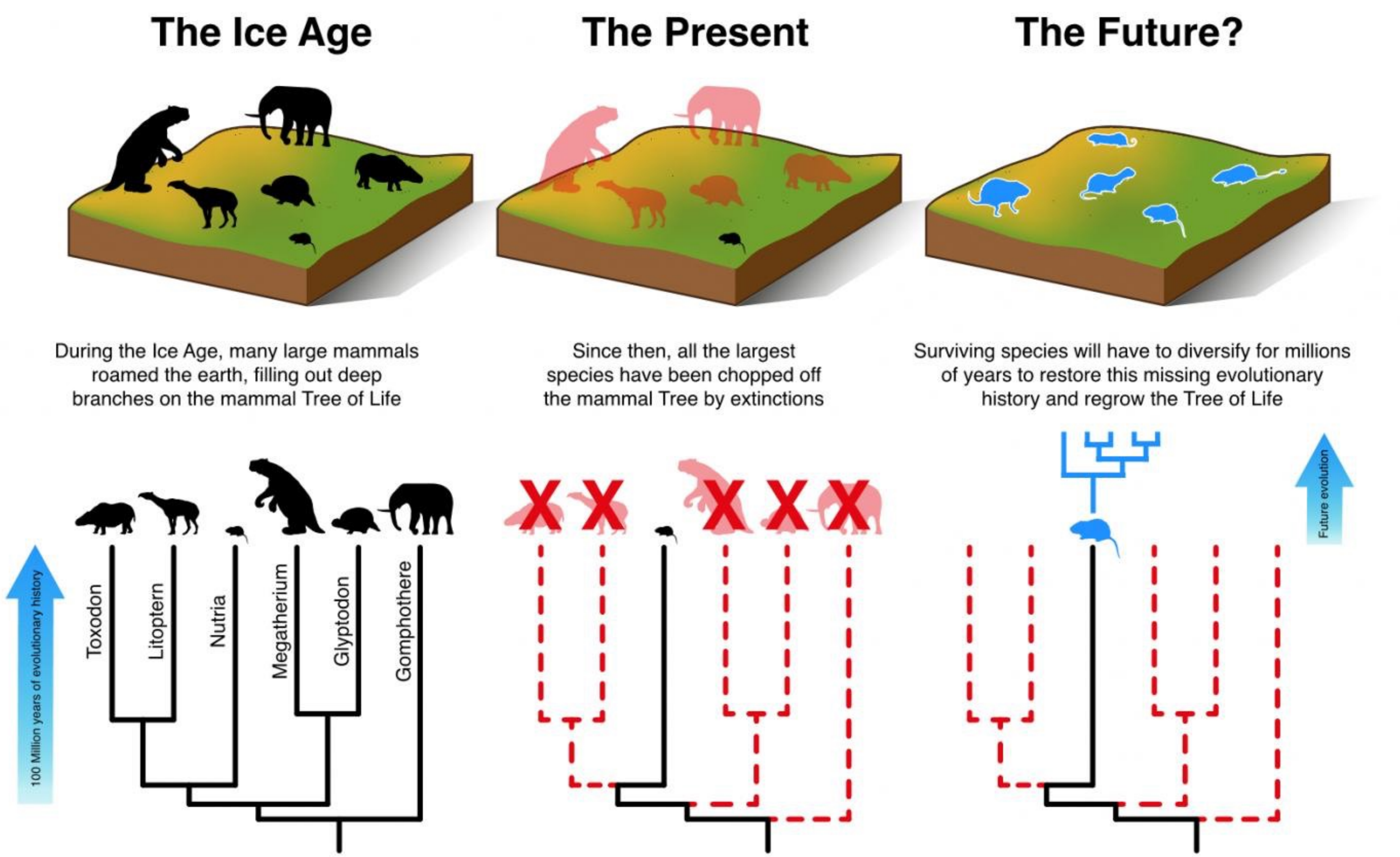


Current extinction rates:

300 times background rate for birds

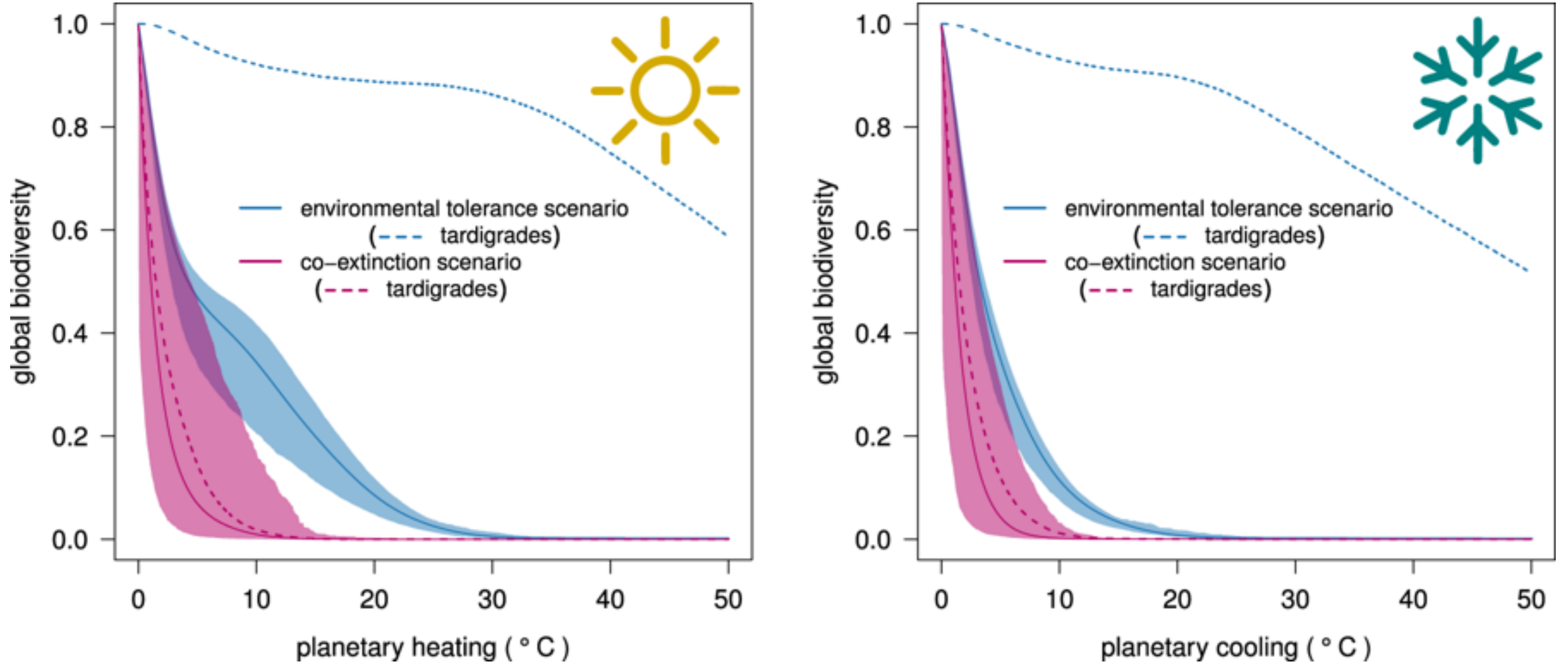
80,000 times background rate for mammals

Prognosis: Journey into the Unknown



Davis et al., 2018

Prognosis: Journey into the Unknown

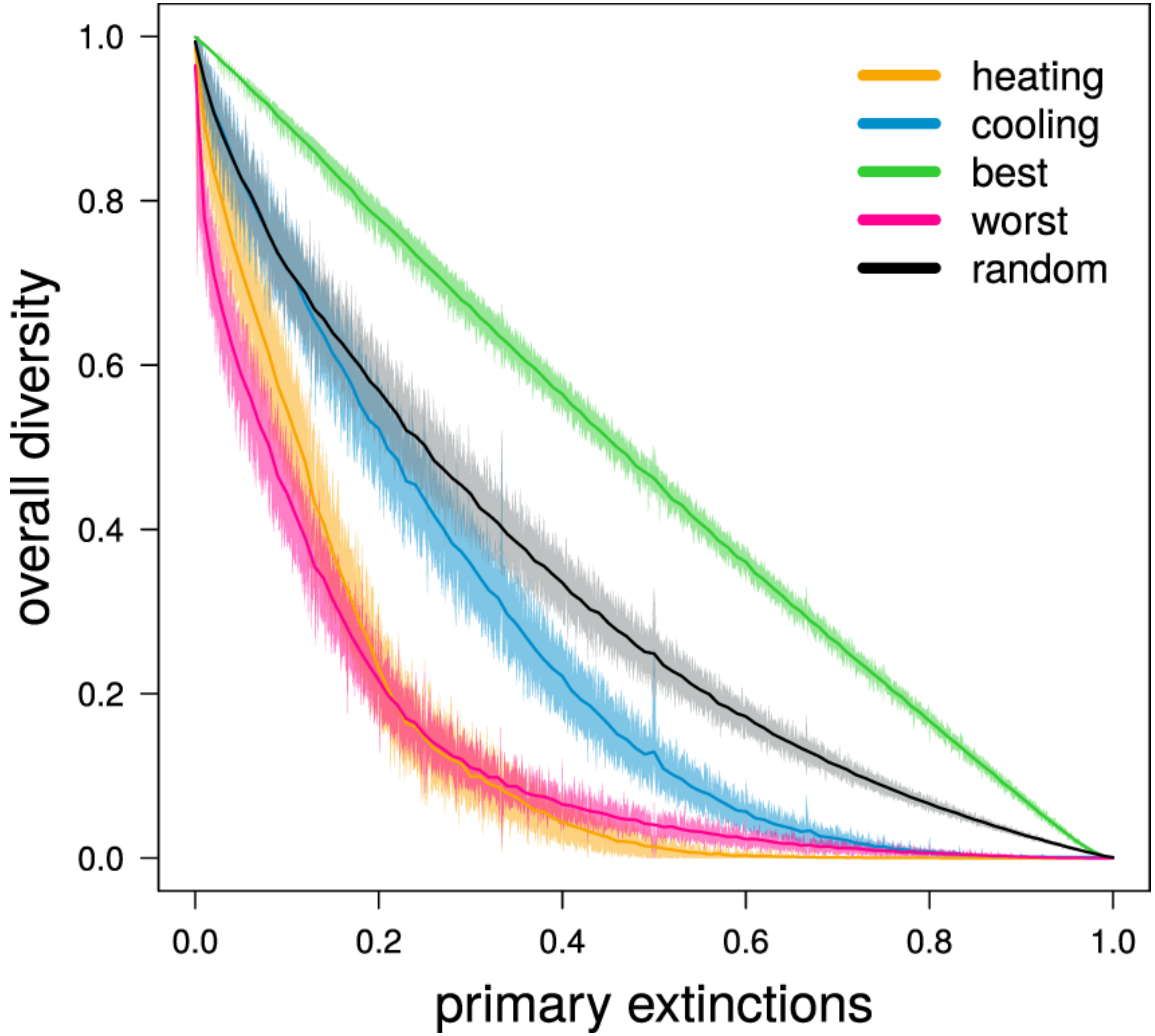


Co-extinctions reduce the robustness of planetary life to catastrophe. Response of global diversity to environmental change: progressive, monotonic increase ('planetary heating'; left panel) or decrease ('planetary cooling'; right panel) trajectories in local temperature. Species either go extinct based only on their tolerance to environmental conditions ('environmental tolerance' scenarios = blue curves), or where species go extinct not only when unable to cope with changed environmental conditions, but also following the depletion of their essential resources ('co-extinction' scenarios = magenta curves). Solid lines represent mean values, and shaded areas indicate the system boundaries (minimum-maximum) arising from 1000 randomly parametrized models (see Methods for details). Dotted lines show the decline in 'tardigrade' (extremophile) species richness in the environmental tolerance (blue) and in the co-extinction scenario (magenta) for both temperature trajectories.

Strona and Bradshaw, 2018

https://www.nature.com/articles/s41598-018-35068-1

Prognosis: Journey into the Unknown



Co-extinctions reduce the robustness of planetary life to catastrophe. Response of global diversity to environmental change: progressive, monotonic increase ('planetary heating'; left panel) or decrease ('planetary cooling'; right panel) Simulated food webs are more robust to global cooling than to heating. We evaluated robustness by 'disassembling' a random sample of 1000 food webs. Disassembly consisted of removing species progressively from the least to the most tolerant to warm ('heating') or cold ('cooling') temperatures. We simulated co-extinctions after each species removal, and then plotted the curves depicting the (co-extinction driven) decline of local diversity following direct species removal. To obtain approximate upper and lower boundaries of robustness, we did two additional disassembly simulations for each food web by removing species in increasing ('best') or decreasing ('worst') order of their expected contribution to network persistence (measured as the number of associated resources per species). For each food web, we also obtained a reference curve by removing species in random order ('random'). Solid lines represent mean values, while shaded areas indicate 99% confidence intervals.

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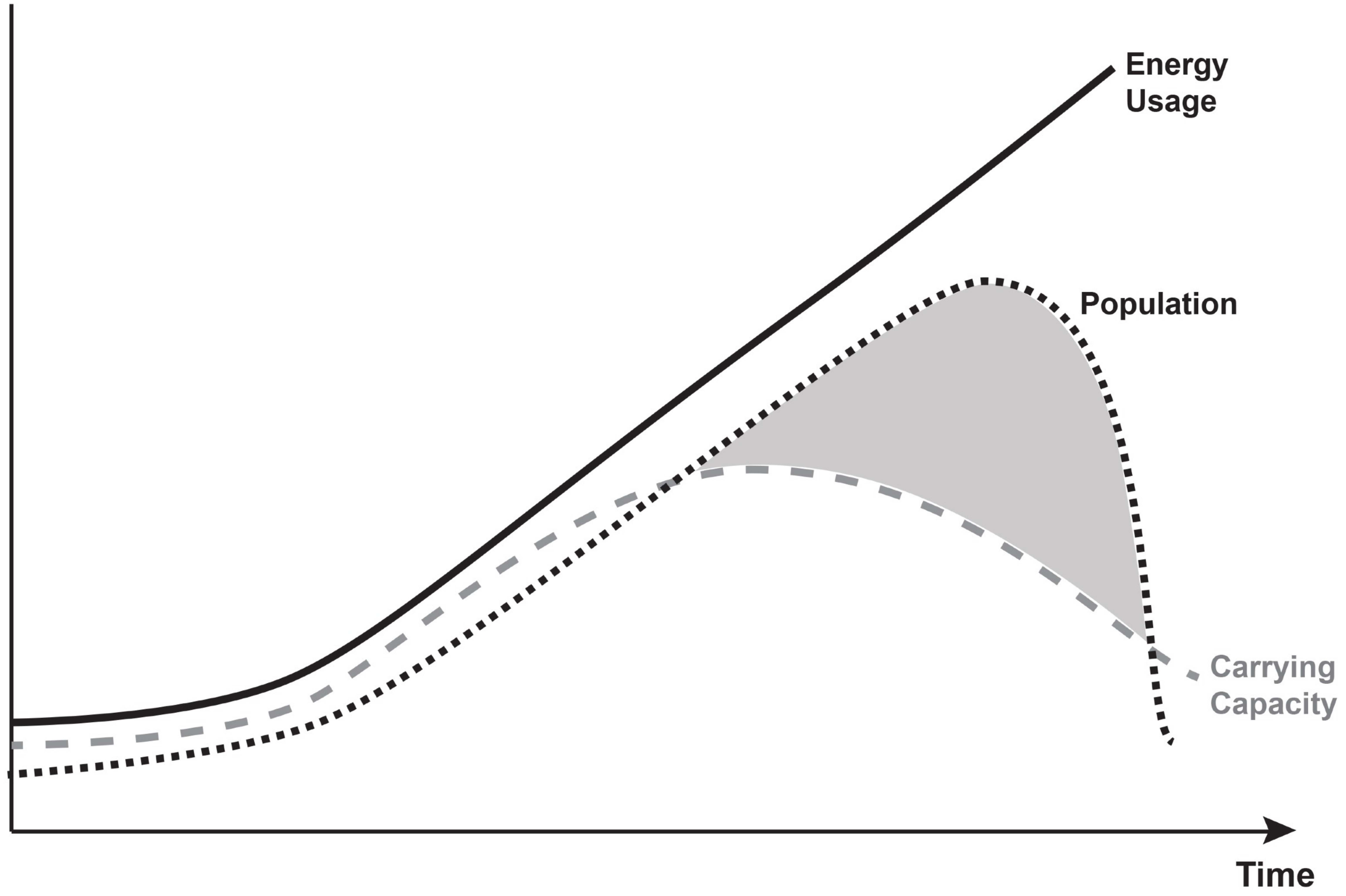

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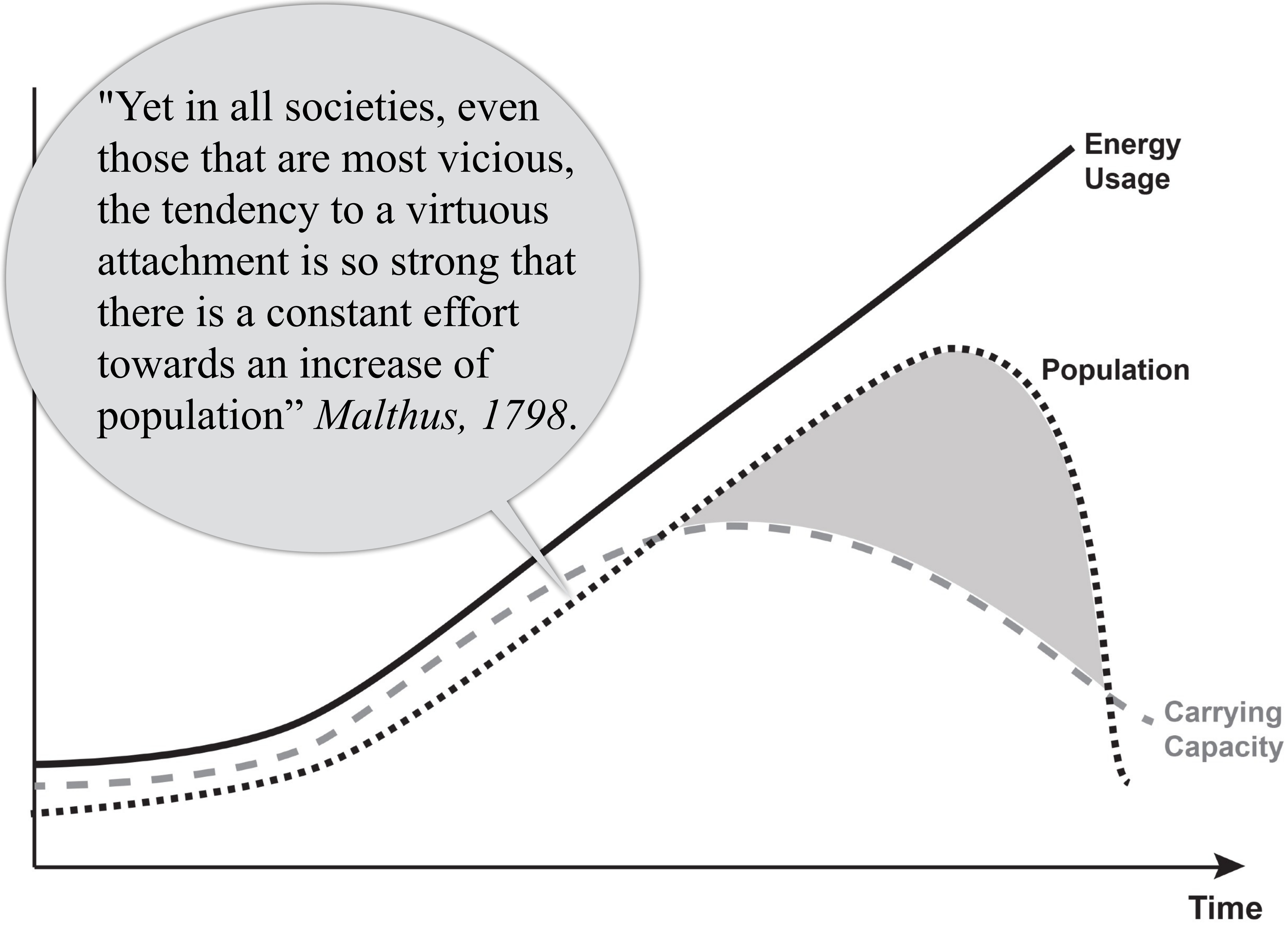

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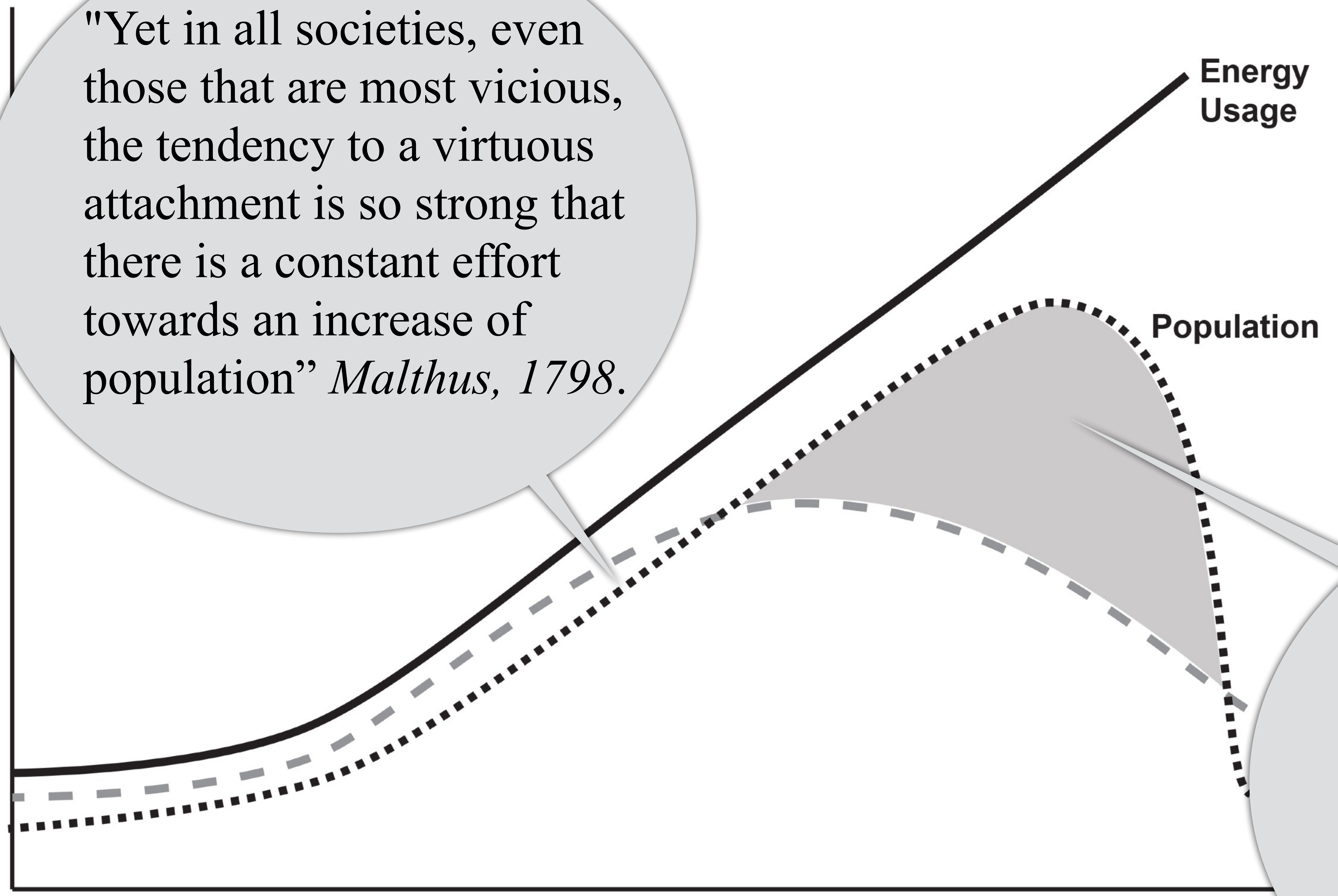

"Yet in all societies, even those that are most vicious, the tendency to a virtuous attachment is so strong that there is a constant effort towards an increase of population" *Malthus, 1798*.

"That the increase of population is necessarily limited by the means of subsistence, That population does invariably increase when the means of subsistence increase, and, That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, **by misery and vice**."

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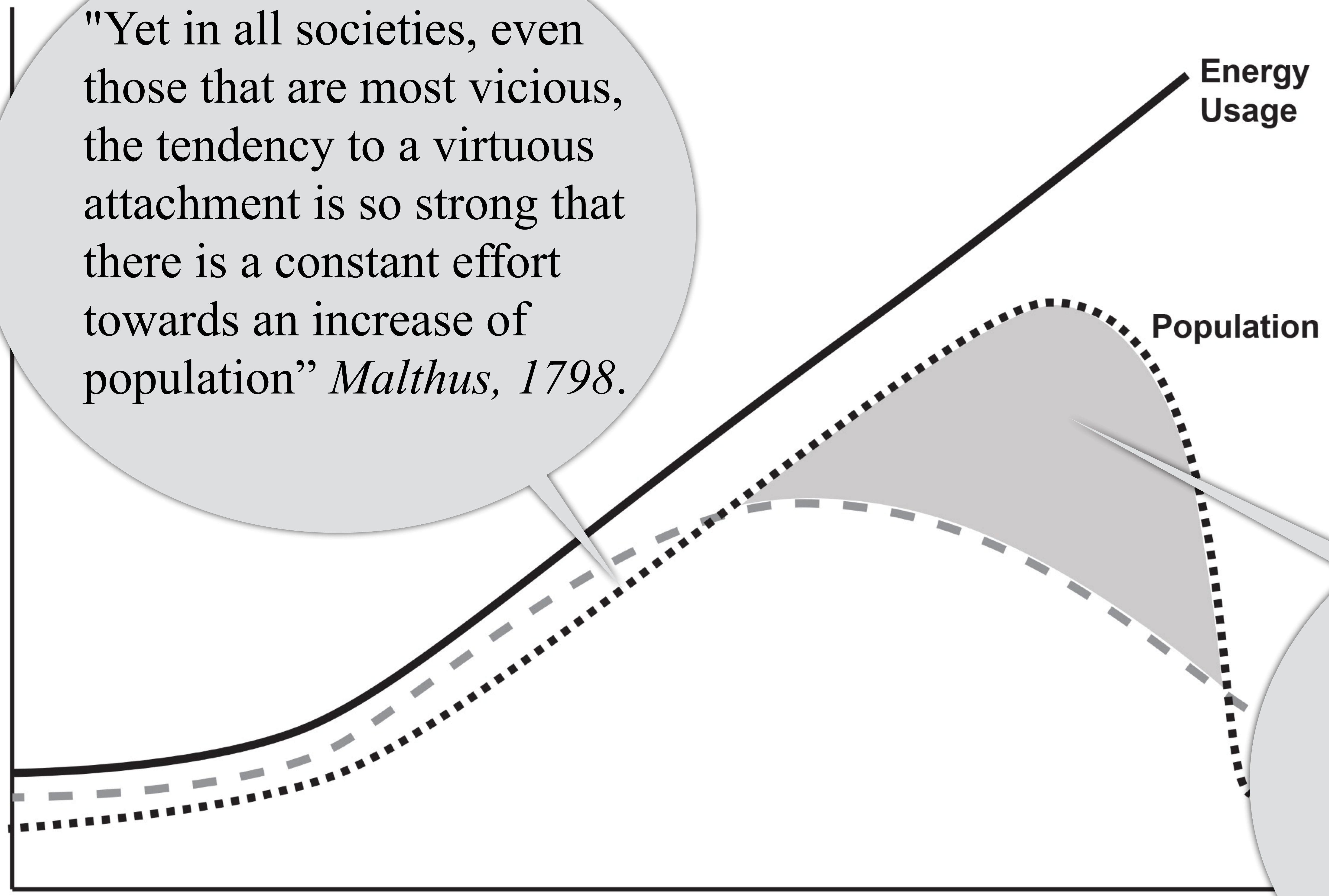

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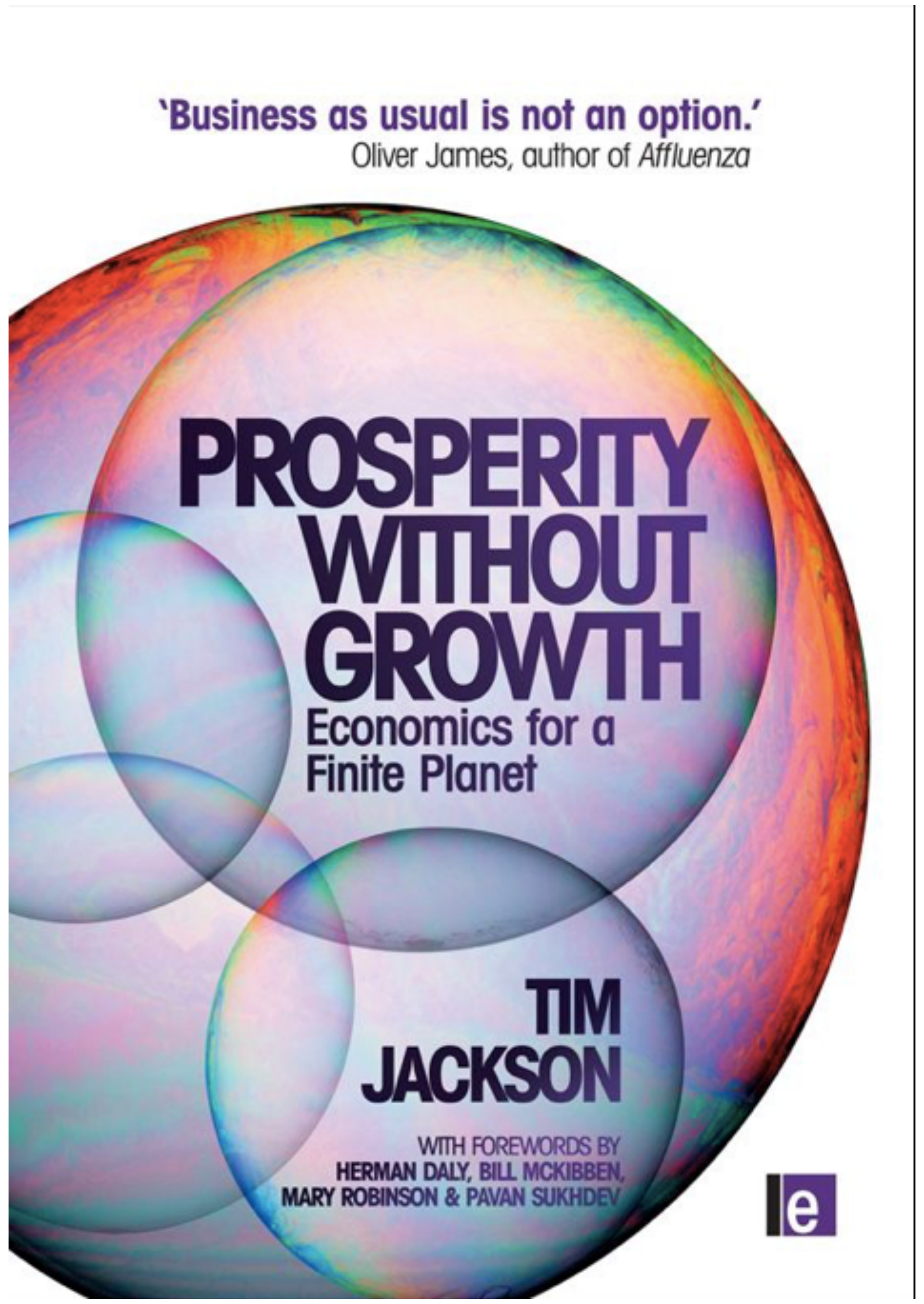
Lovelock: Carrying Capacity will be down to 1 Billion in 2050

Humans have all the Knowledge …

Homo sapiens have a huge amount of data and knowledge

Humans have all the Knowledge …

Published in 1987



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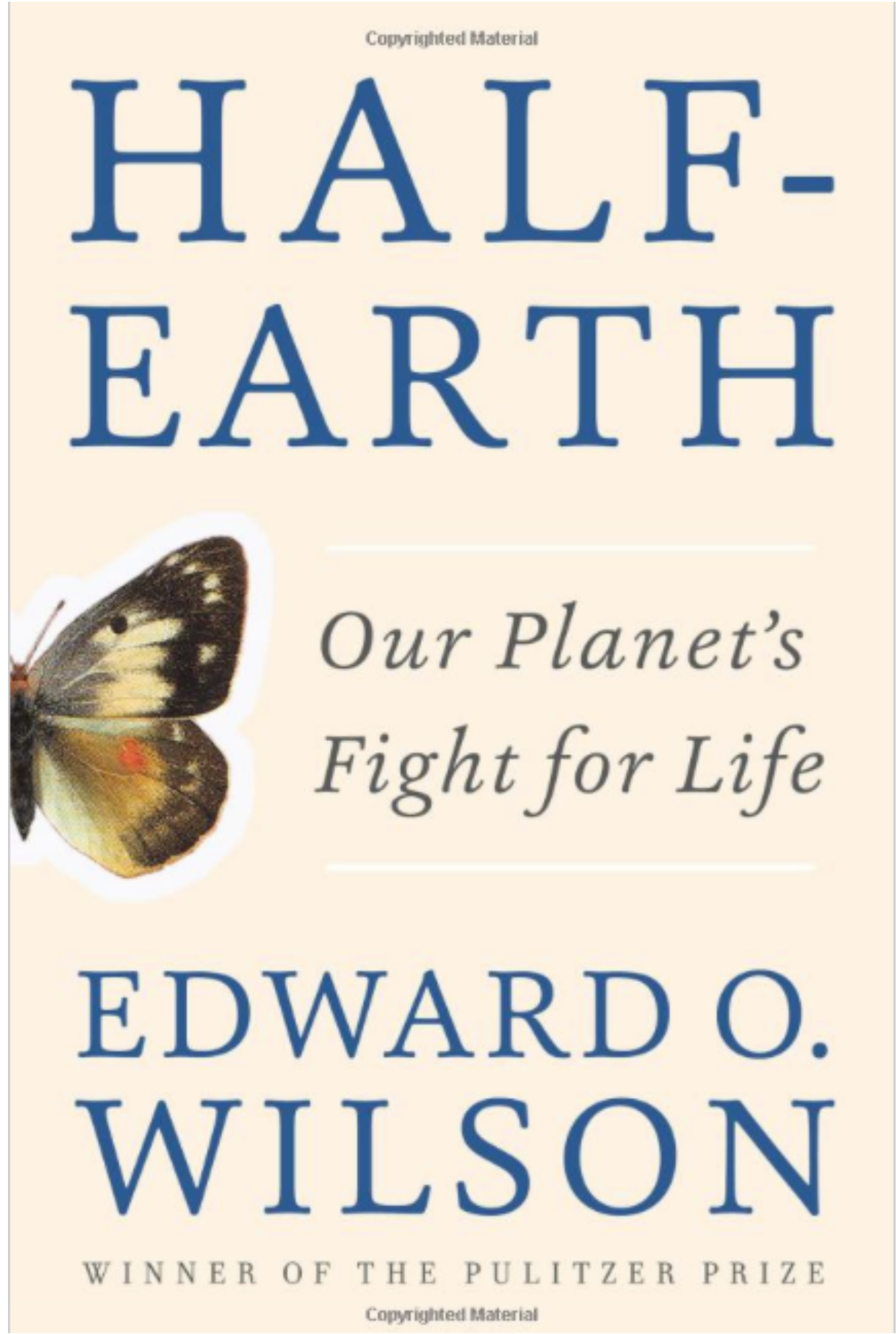

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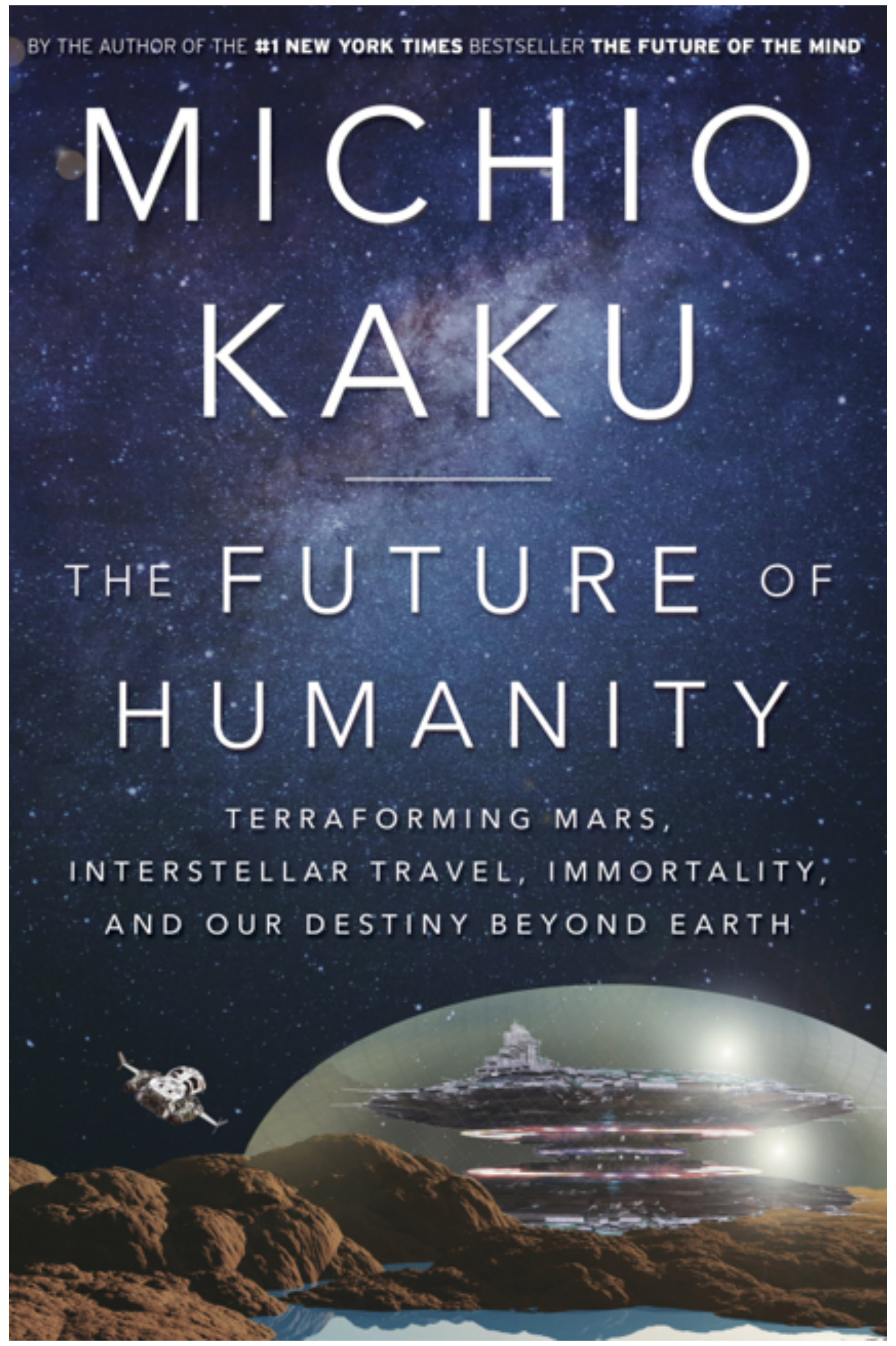

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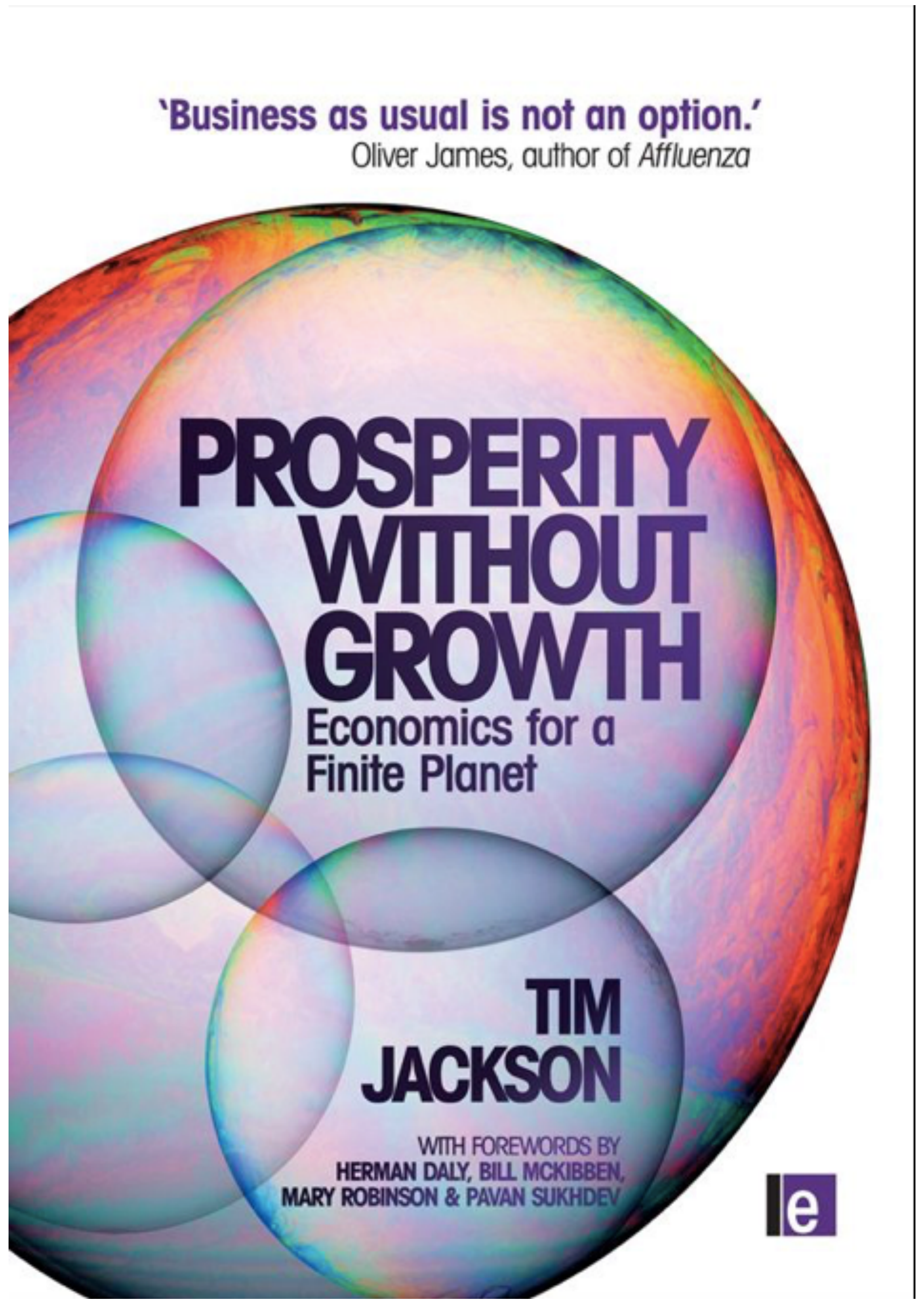

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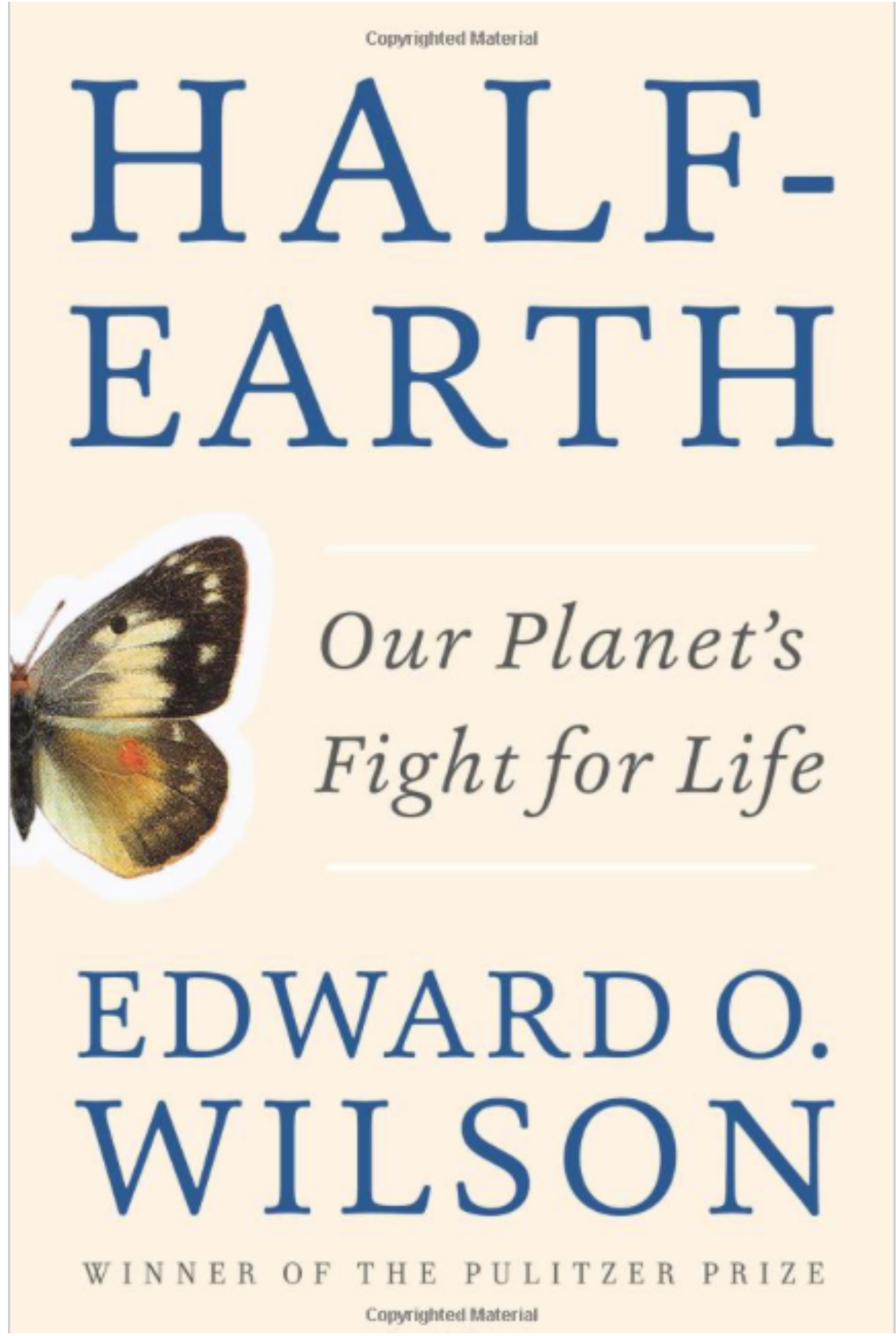
Homo sapiens have (controversial) ideas about how to fix the problems

But they use reason more to find fault in others' thoughts than to agree on a common future



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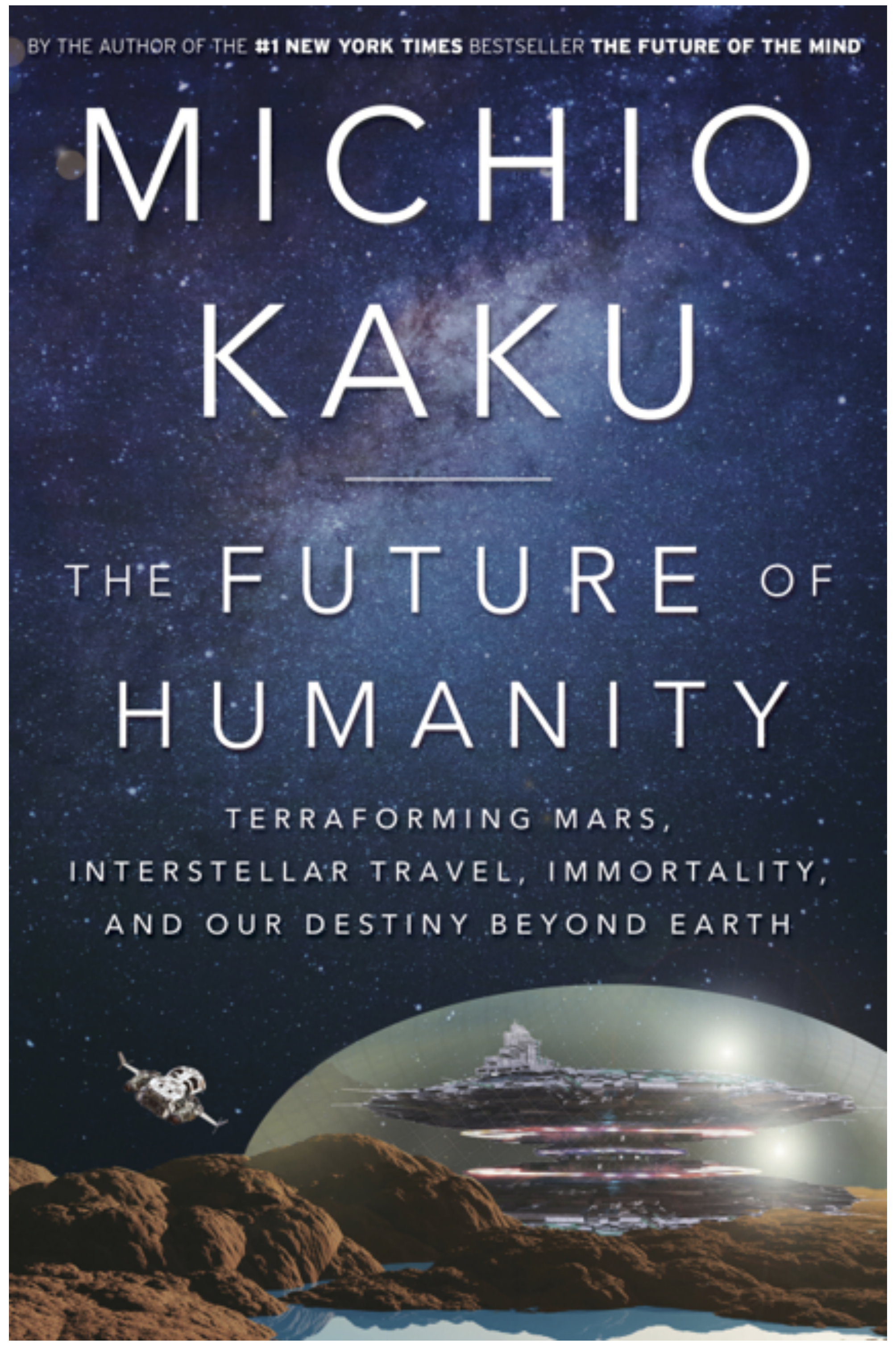

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Key Points

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

Diagnosis

Easy access to seemingly unlimited energy allowed humans to accelerate flows in the Earth's life-support system and sustain rapid population growth and increasing demands

Humans are the "Anthropogenic Cataclysmic Virus" (ACV) in the Earth's life-support system

Prognosis

We are heading rapidly into a very different system state (tippingpoints; Post-Holocene)

Our knowledge is changing rapidly; there is room for surprises; Foresight is needed

Modern Climate Change: A Symptom of a Single-Species High-Energy Pulse Syndrome

Contents

The planetary life-support system is rapidly degrading and overheating; ;
They are heading for a mono-species system

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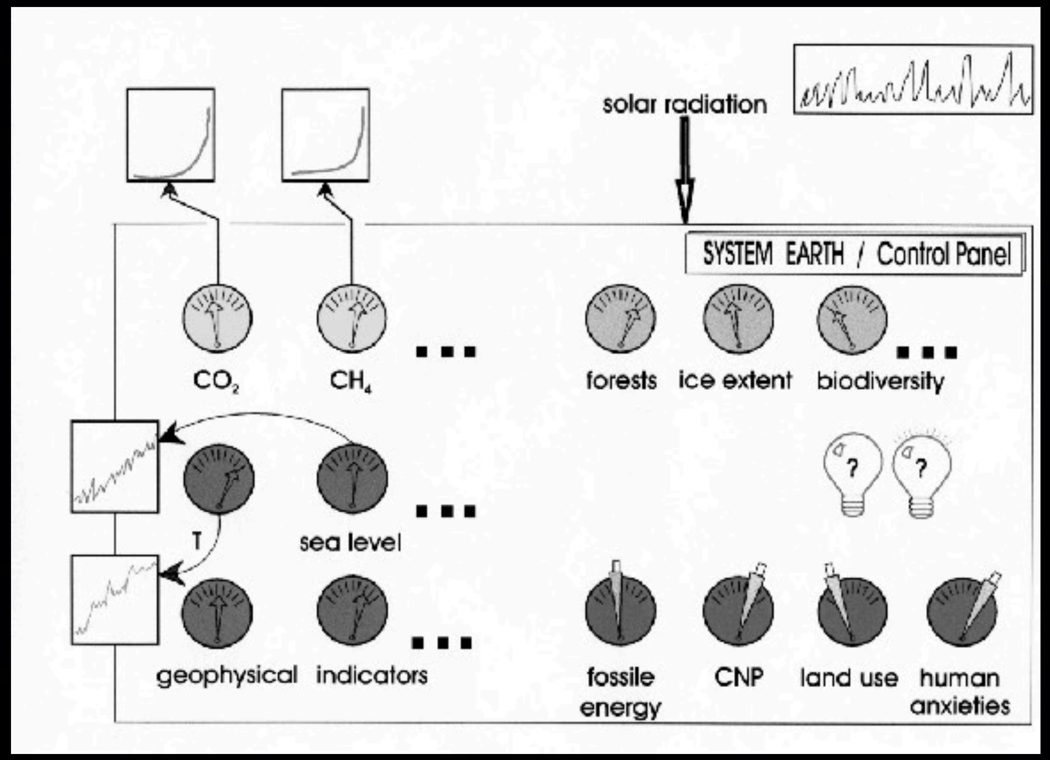

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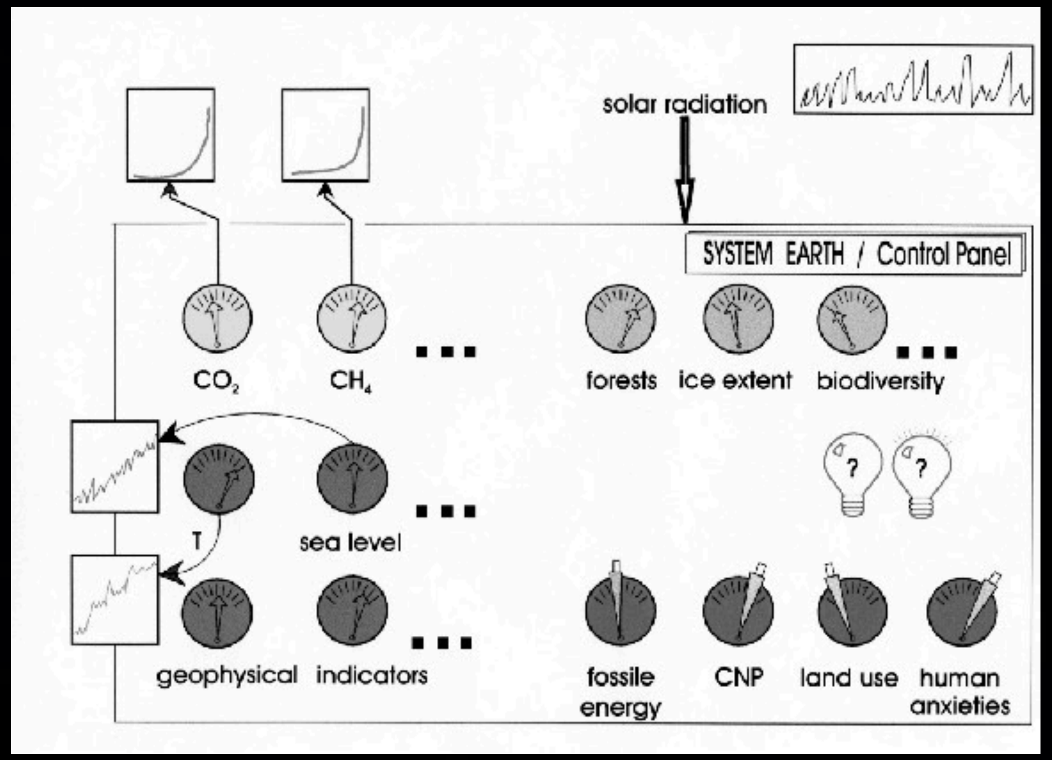

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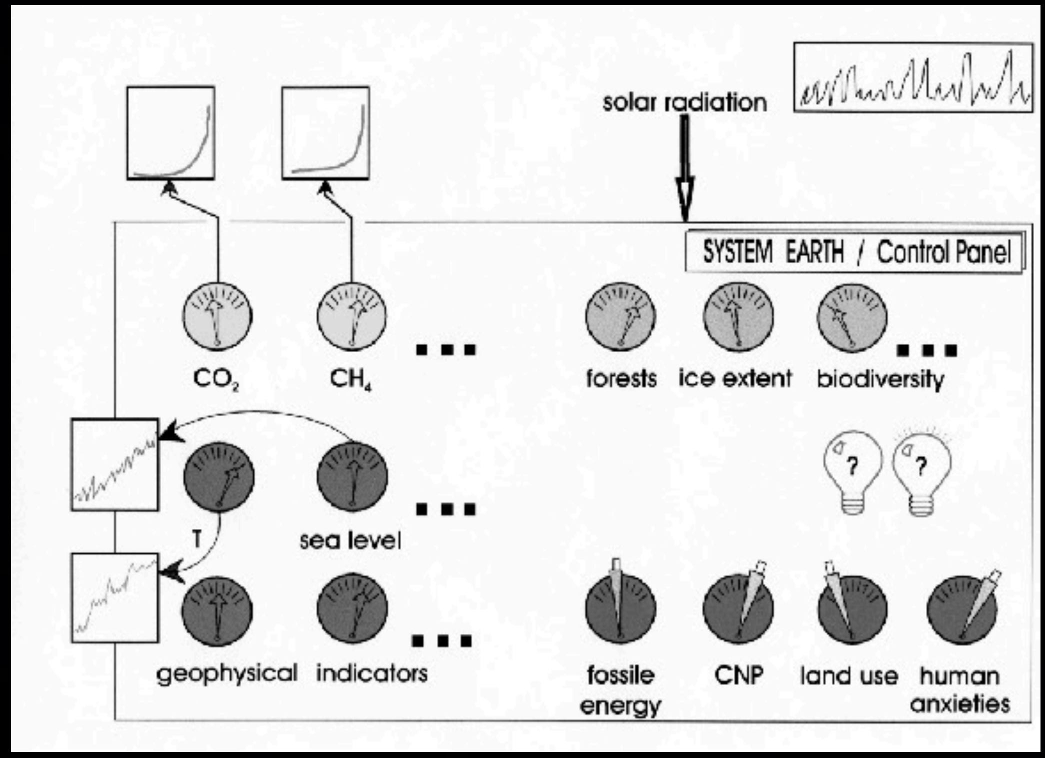

Plaq, 2000

Before we leave, a recommendation for humanity …

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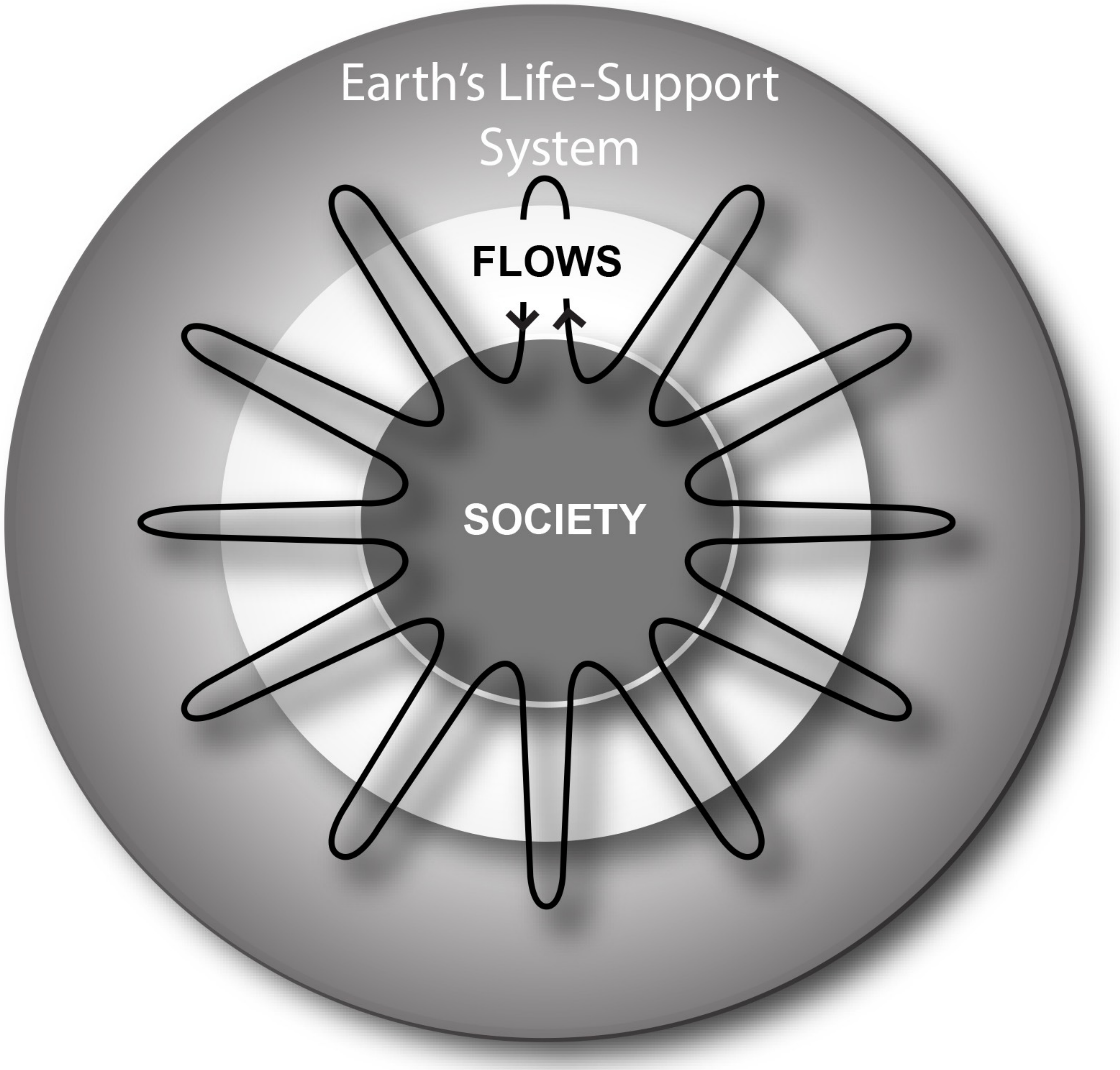
Homo Sapiens' Economy and Earth's Life-Support System



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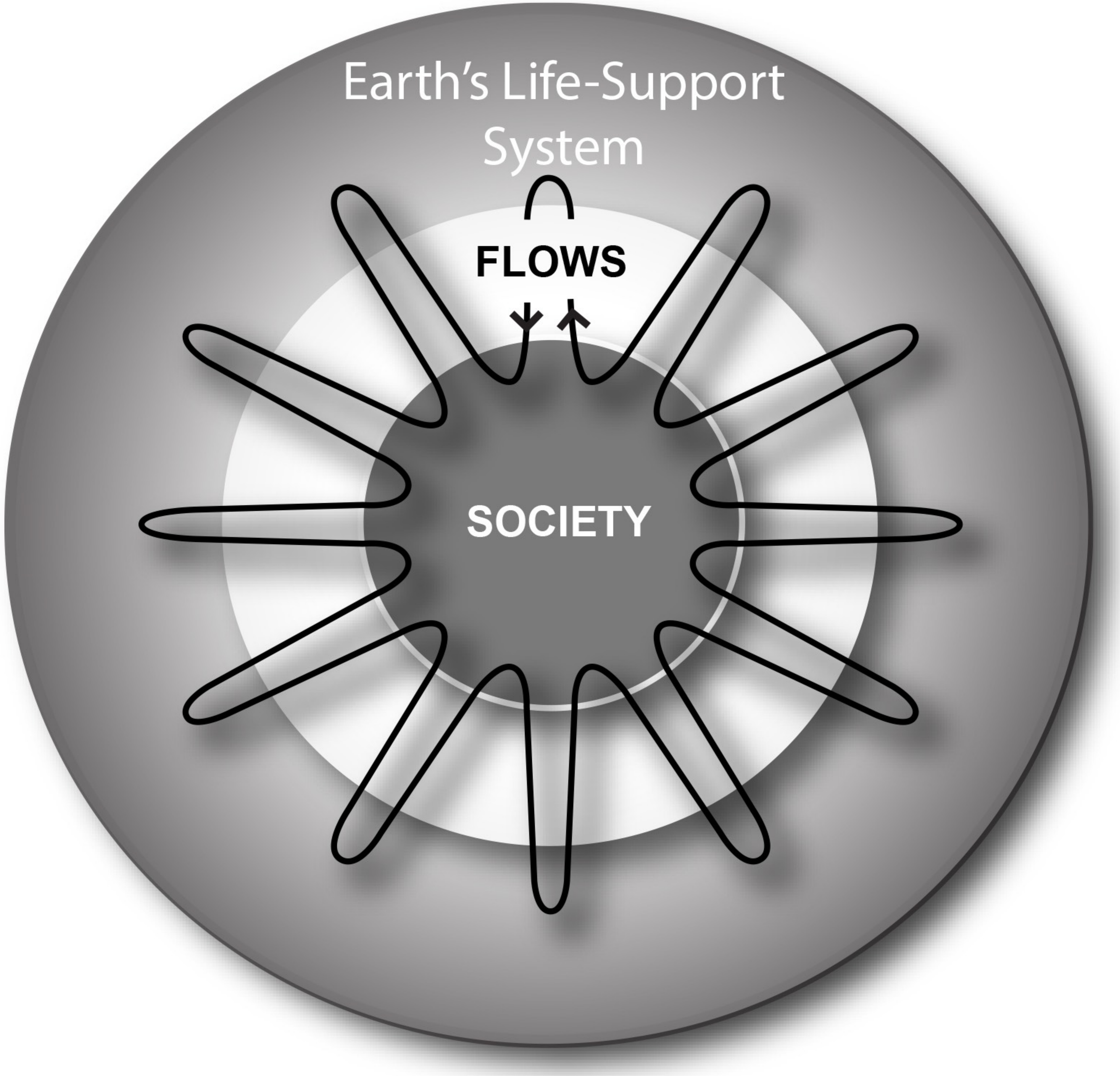

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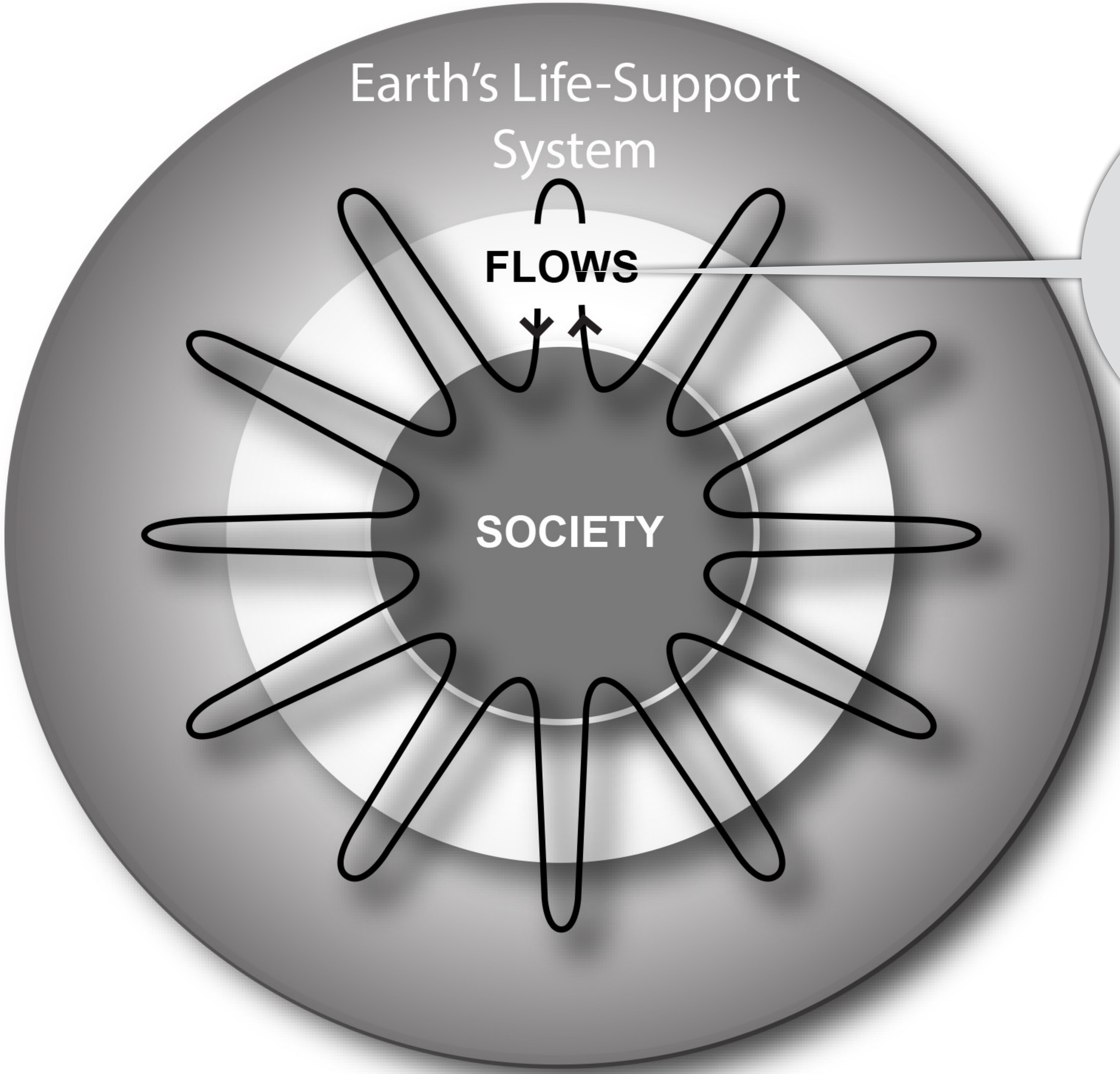
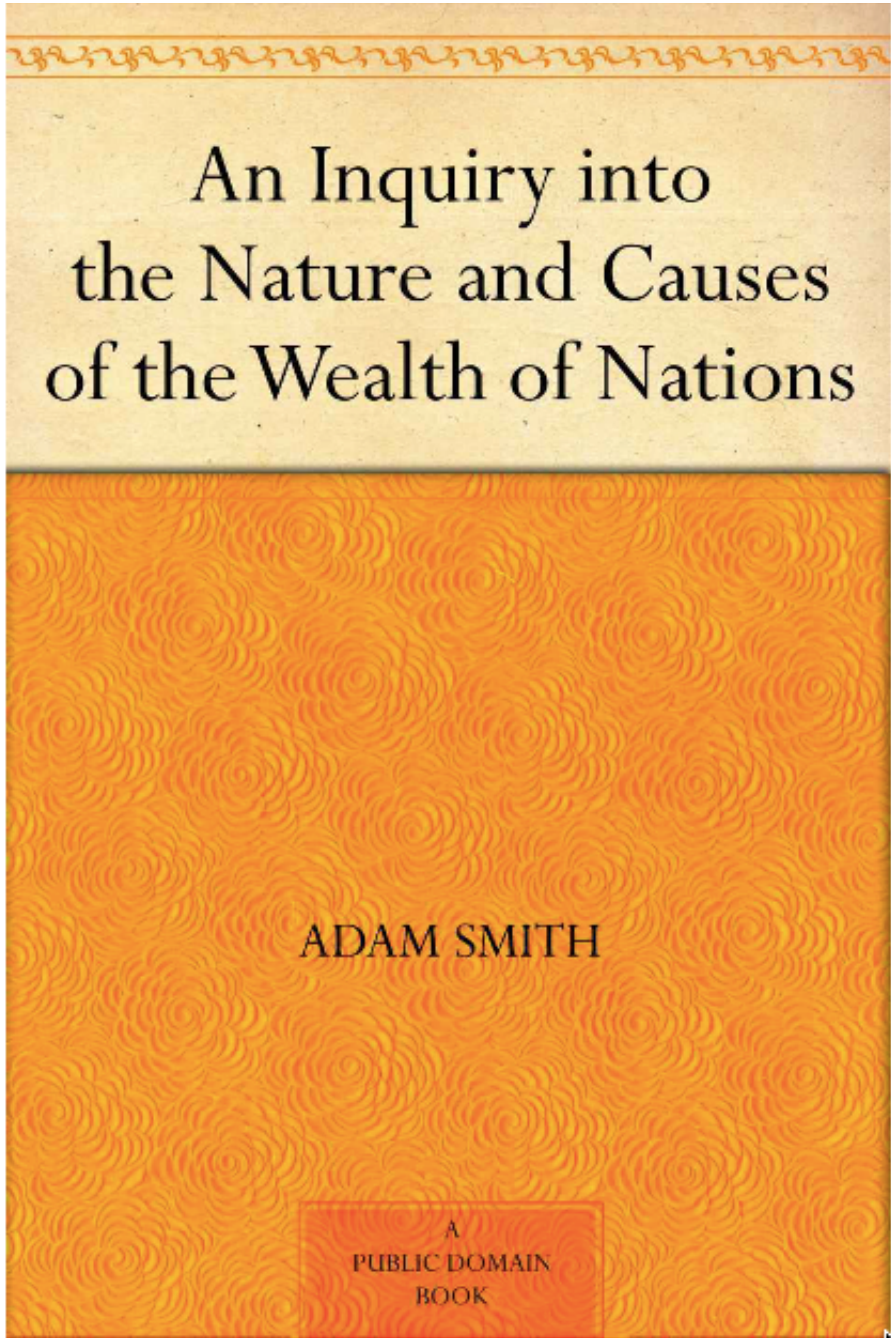


For Homo sapiens, flows are regulated by

- ethics,
- social norms,
- economic rules



Published in 1776

- Purpose of economy is to increase human wealth;
- Earth and its natural wealth is basically infinite.

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WCED (1987)

Homo Sapiens' Economy and Earth's Life-Support System

COMMENT

ENVIRONMENT Conservationists call for a global zoning exercise for roads p.308

HISTORY Ripping yarn of the ape-man of Victorian England p.310

EVOLUTION First biography of W. D. Hamilton, the gentle giant of genetics p.313

FUNDING Australia's grant system wastes centuries of researchers' time p.314

Sustainable development goals for people and planet

Planetary stability must be integrated with United Nations targets to fight poverty and secure human well-being, argue **David Griggs** and colleagues.

The United Nations Rio+20 summit in Brazil in 2012 committed governments to create a set of sustainable development goals (SDGs) that would be integrated into the follow-up to the Millennium Development Goals (MDGs) after their 2015 deadline. Discussions on how to formulate these continue this week at UN headquarters in New York.

We argue that the protection of Earth's life-support system and poverty reduction must be the twin priorities for SDGs. It is not enough simply to extend MDGs, as some are suggesting, because humans are transforming the planet in ways that could undermine development gains.

As mounting research shows, the stable functioning of Earth systems — including the atmosphere, oceans, forests, waterways, biodiversity and biogeochemical cycles — is a prerequisite for a thriving global society. With the human population set to rise to 9 billion by 2050, definitions of sustainable development must be revised to include the security of people and the planet.

Defining a unified set of SDGs is challenging, especially when there can be conflict between individual goals, such as energy provision and climate-change prevention. But we show here that it is possible. By ▶

21 MARCH 2013 | VOL 495 | NATURE | 305

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Griggs et al. (2013)

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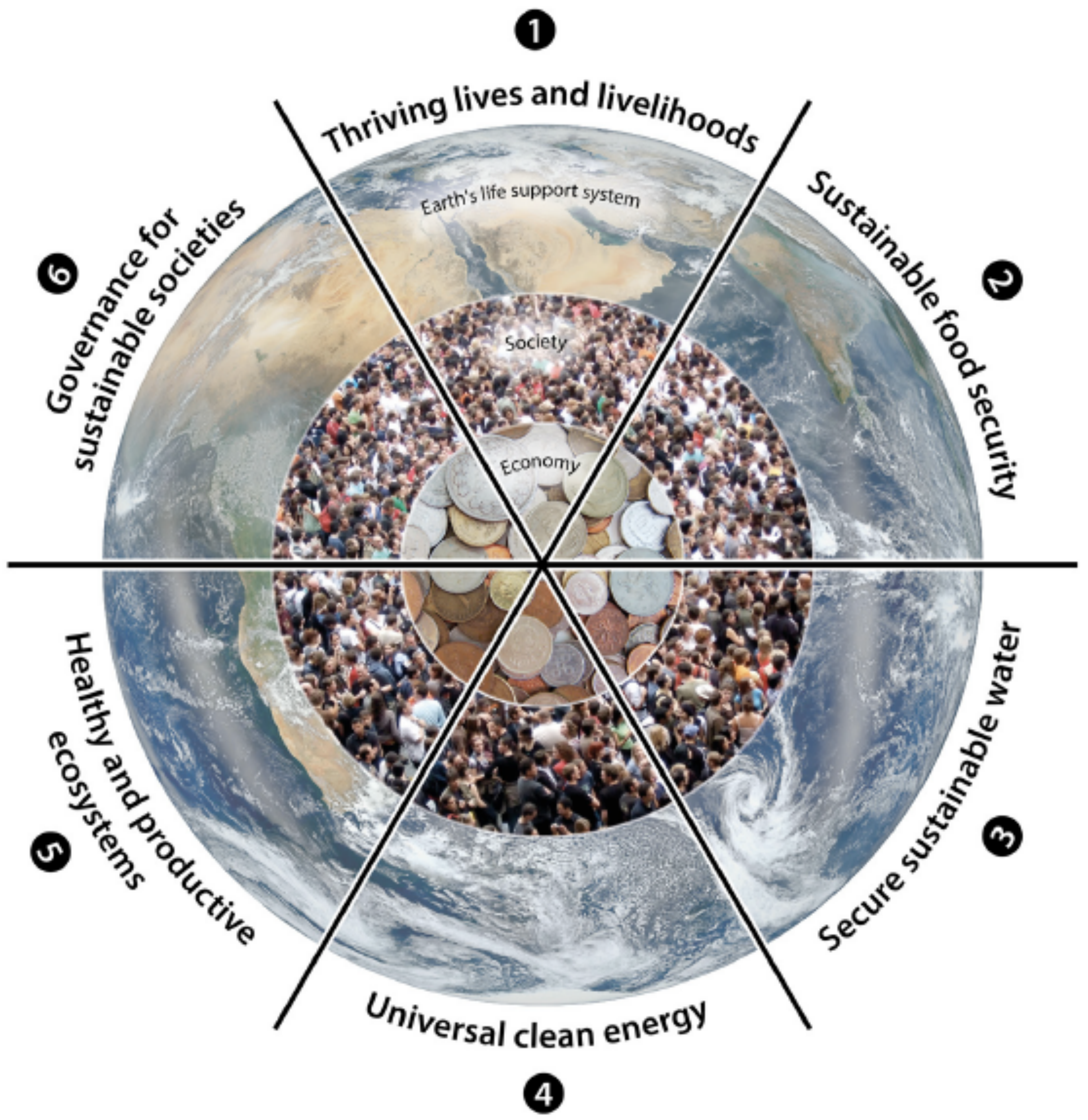

Figure 1 | Six universal Sustainable Development Goals cutting across economic, social and environmental domains.

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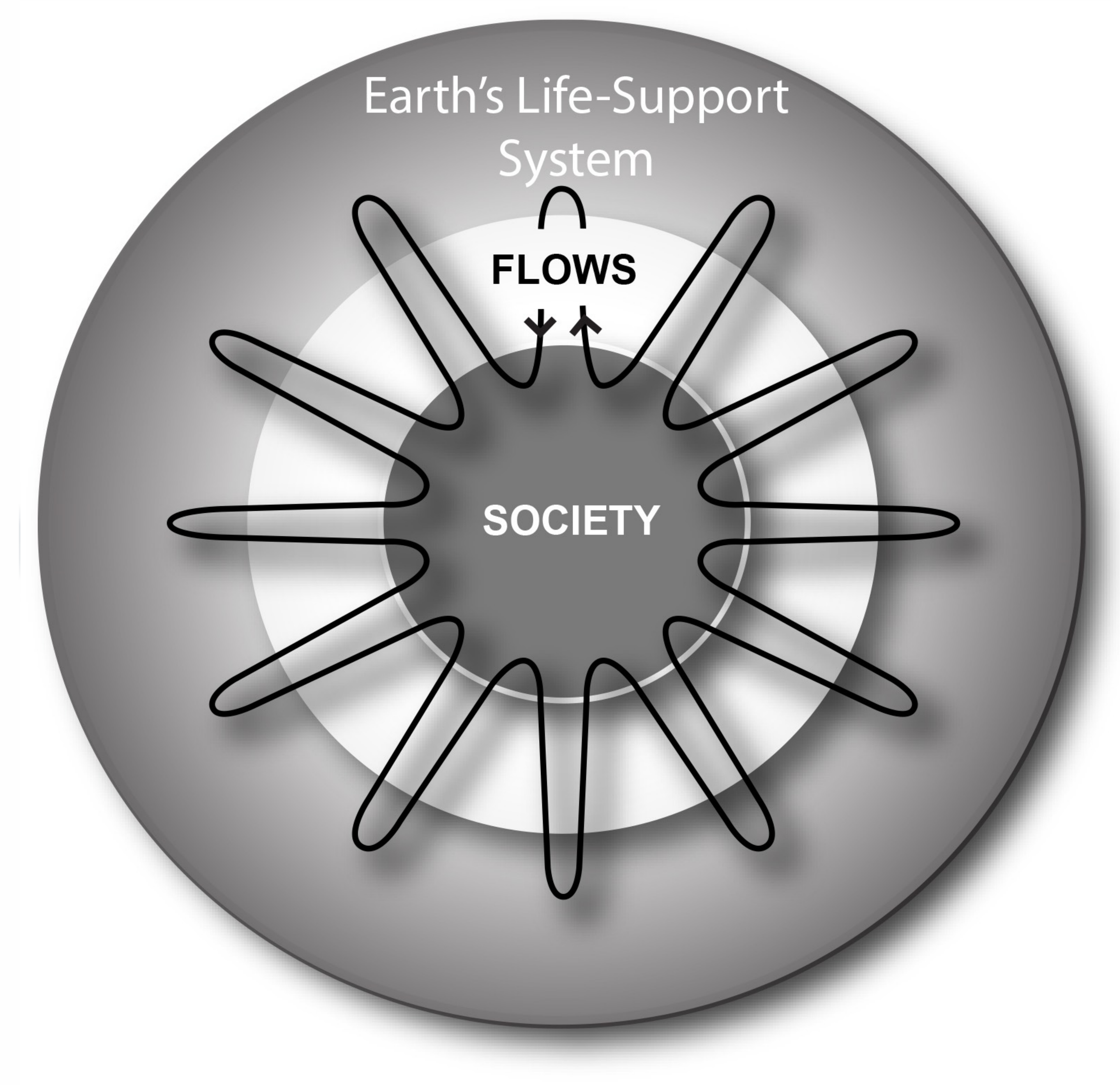

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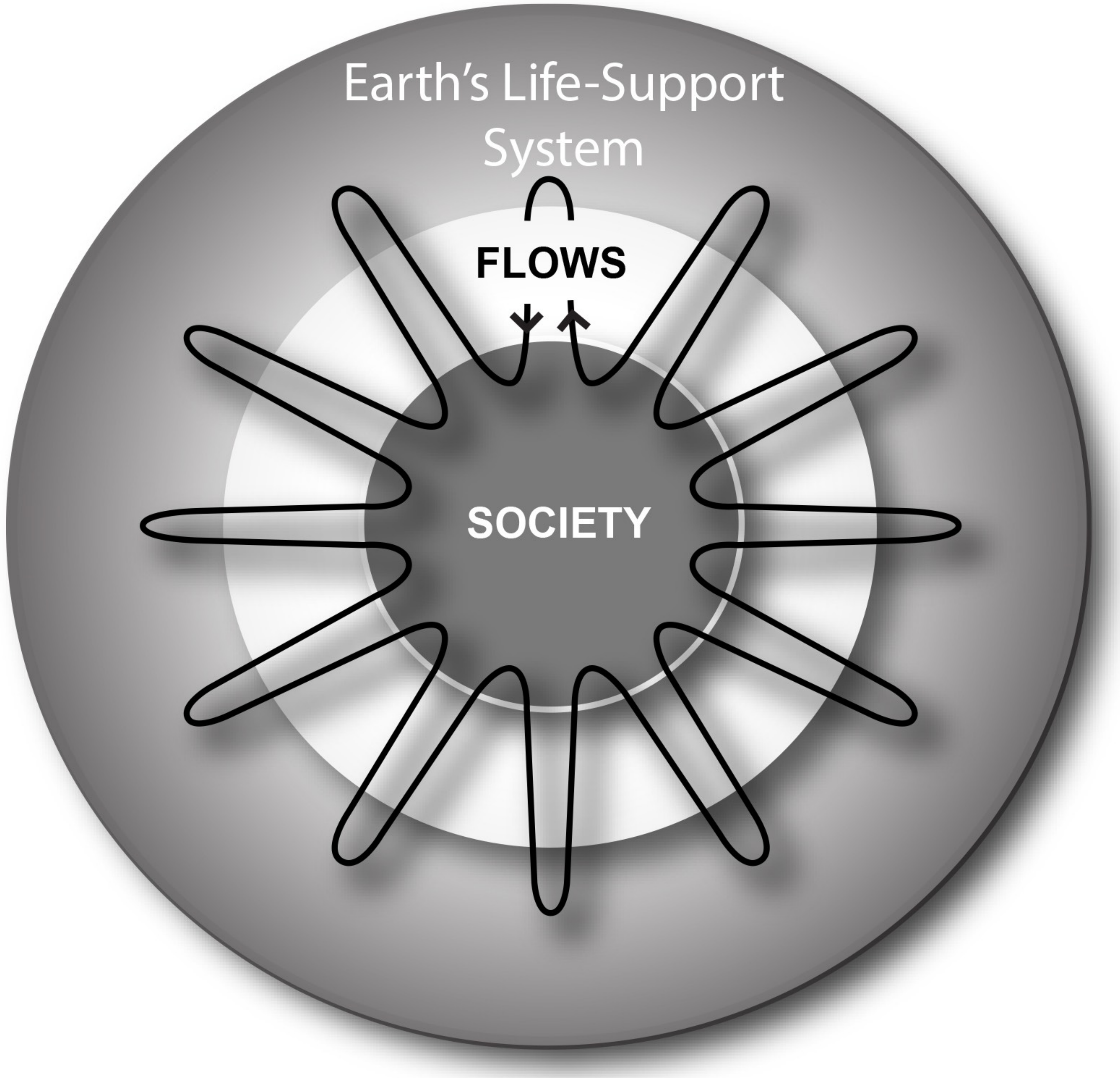

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Our Message to Humanity: You need an economy that meets the needs of the present while safeguarding Earth's life support systems, on which the welfare of current and future generations depends.

ON THE EDGE°

Safeguarding Our Life Support System

OVERCOMING THE "IMMUTABLE TRUTH" OF GROWTH BEING NECESSARY FOR A THRIVING ECONOMY

Prof. Hans-Peter Plag, PhD
Mitigation and Adaptation Research Institute
Old Dominion University
Norfolk, Va.
www.mari.odu.edu

IN EARLIER COLUMNS, I MADE REFERENCE TO a new definition for sustainable development: a development that meets our needs while safeguarding the Earth's life support system on which we and all future generations depend. Safeguarding our life support system (LSS) seems logical and to be something we all should be eager and able to agree upon.

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Prognosis

We are heading rapidly into a very different system state (thresholds; Post-Holocene)

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Therapy

Change in the purpose of economy from growing human wealth (growth addiction) to meeting our needs while safe-guarding the life-support system