Oluwakemi Izomo

Adaptation to Sea Level Rise: Protecting the Coastal Zone Against, or Preparing it for, Inundation?

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Hans-Peter Plag

October 19, 2015

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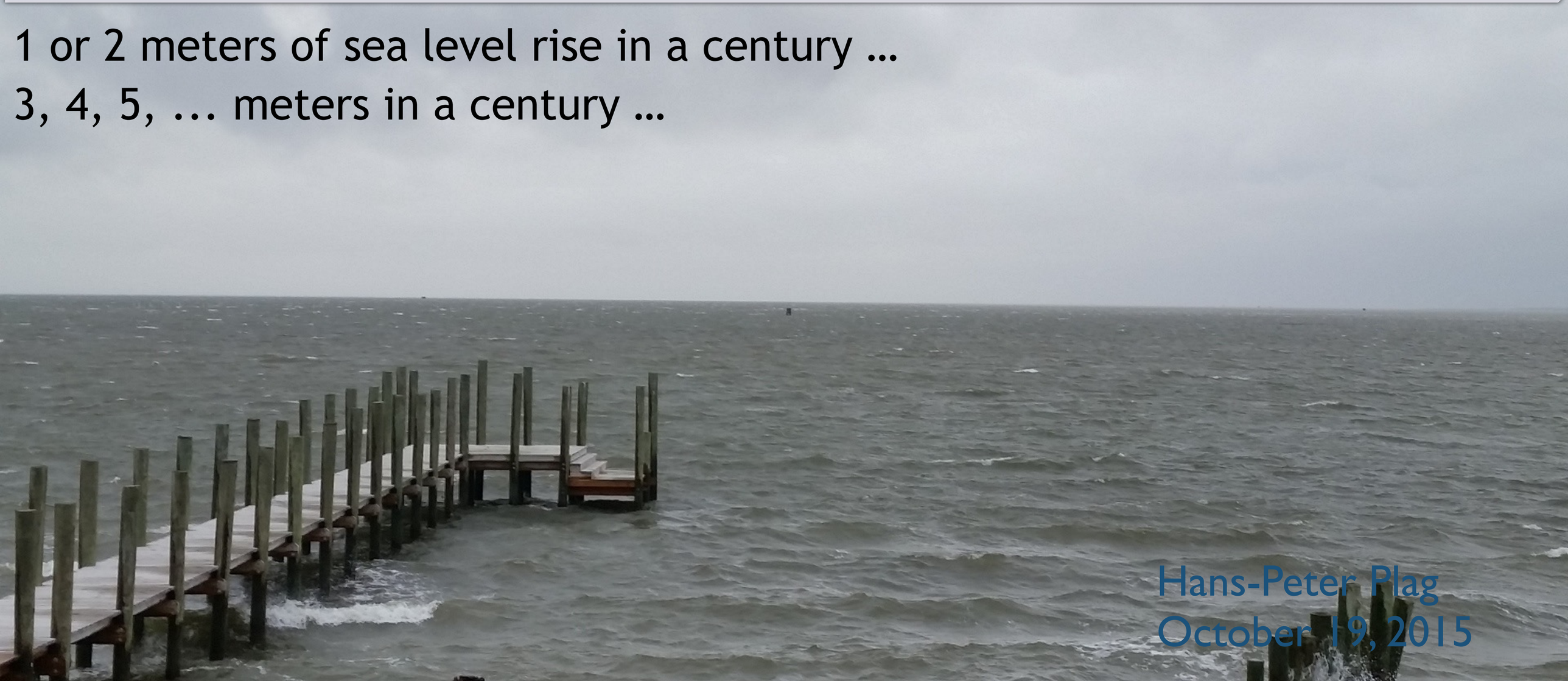

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The Baseline: Past Climate and Sea Level Changes

Hans-Peter Plag

October 19, 2015

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OLD DOMINION UNIVERSITY

The Baseline: Past Climate and Sea Level Changes
The Syndrome: Recent Climate and Global Changes

Hans-Peter Plag
October 19, 2015

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The Baseline: Past Climate and Sea Level Changes
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Hans-Peter Plag
October 19, 2015

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Hans-Peter Plag
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The Diagnosis: Leaving the “safe operating space”

The Prognosis: Anticipating Surprises
The Therapy: “Lifestyle” changes

Hans-Peter Plag
October 19, 2015

The Baseline: Past Climate Variability

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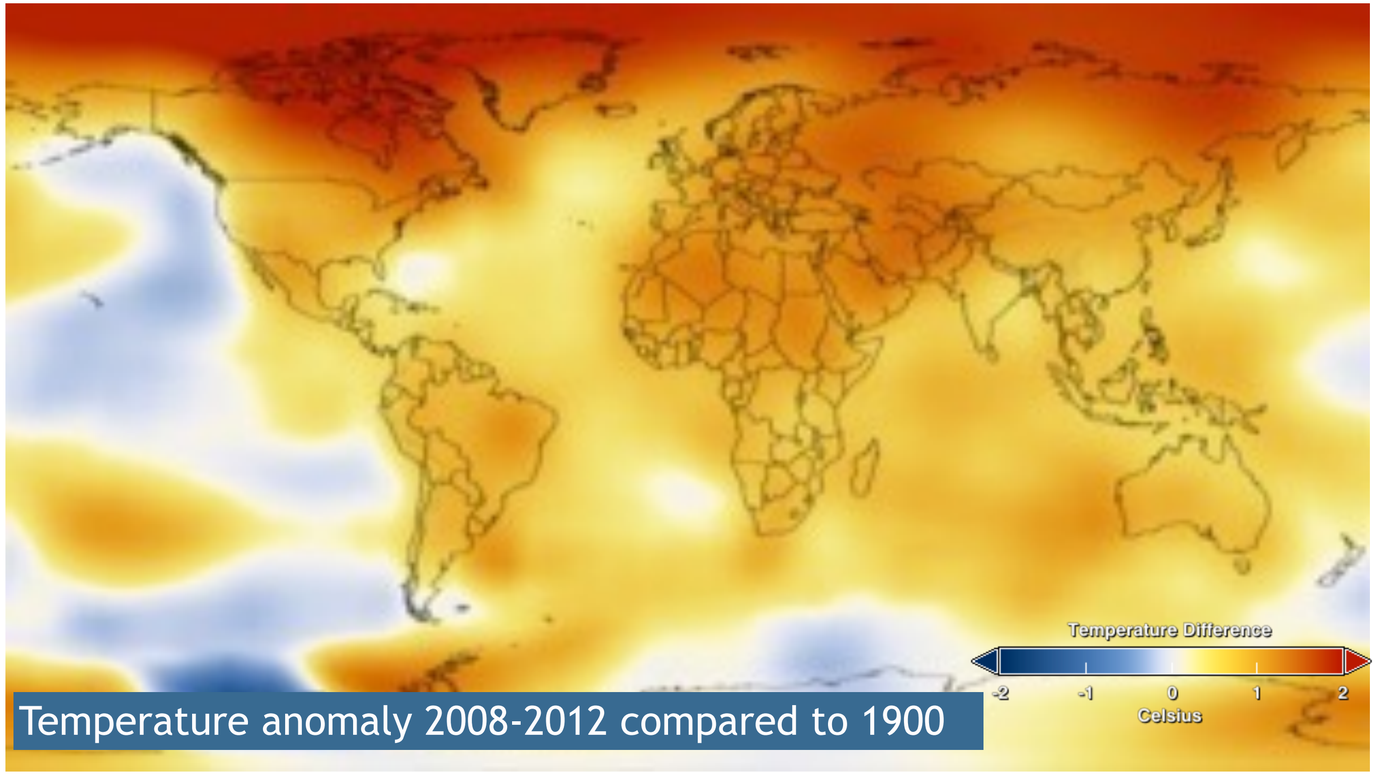

Temperature anomaly 2008-2012 compared to 1900

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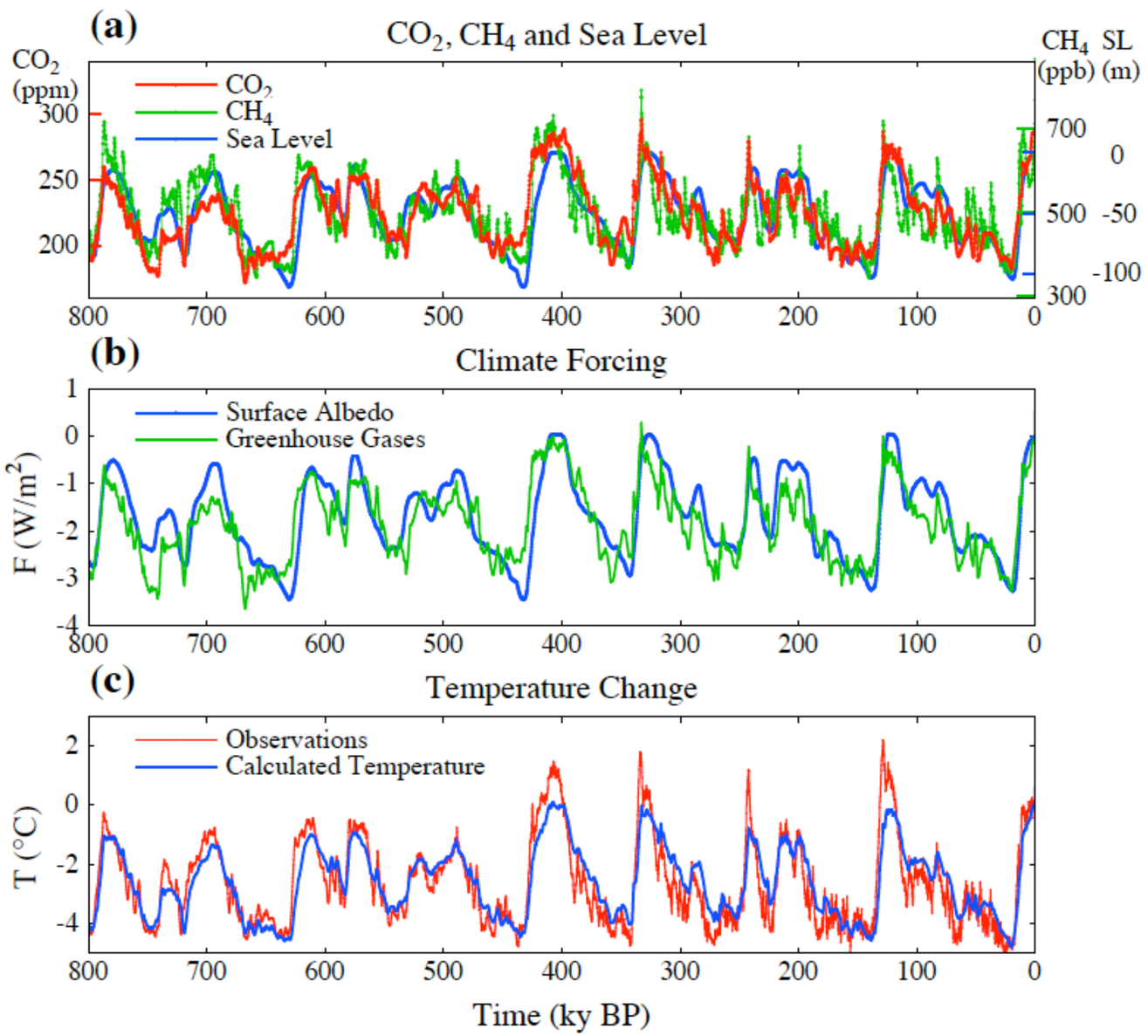

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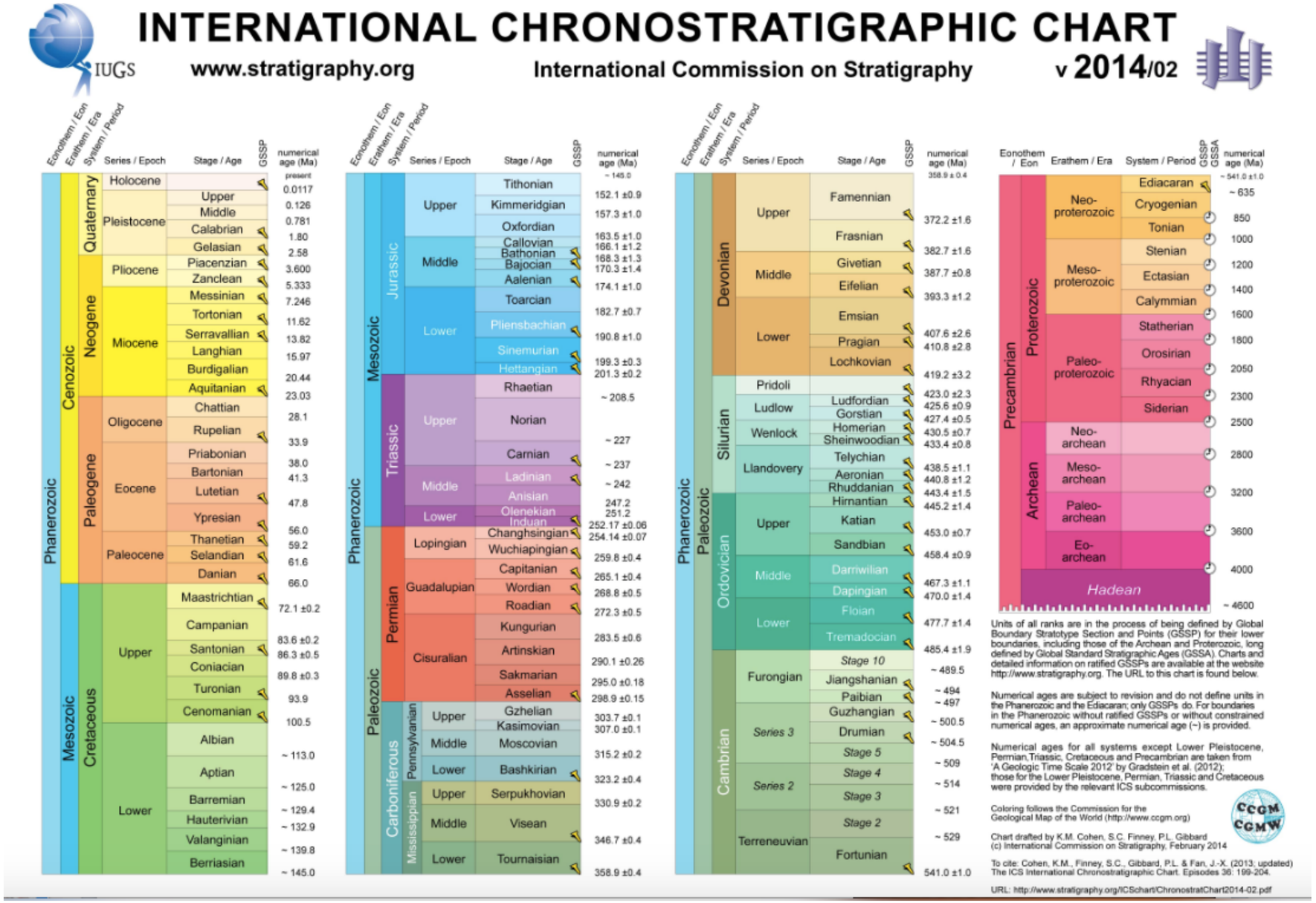
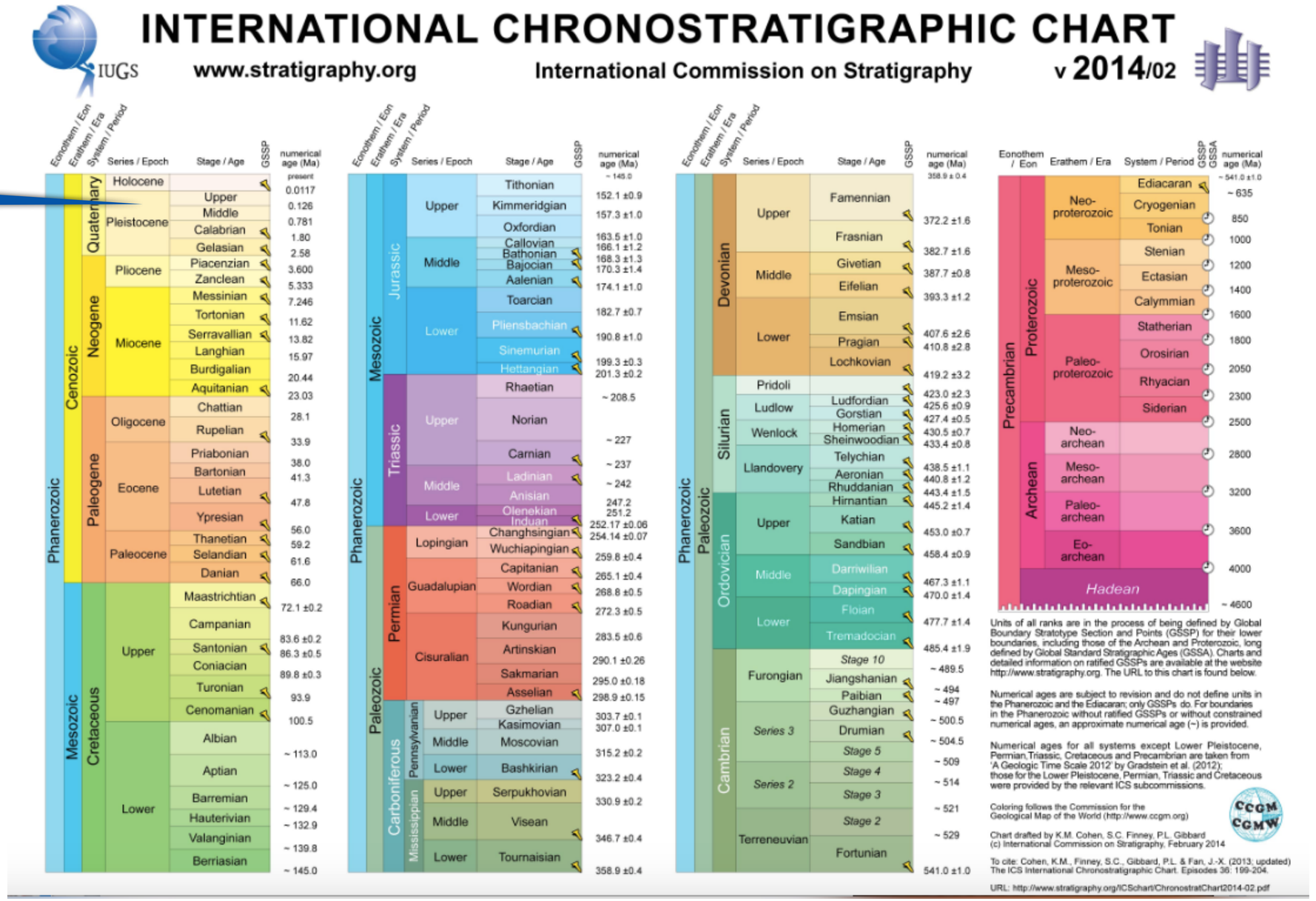


The Baseline: Past Climate Variability

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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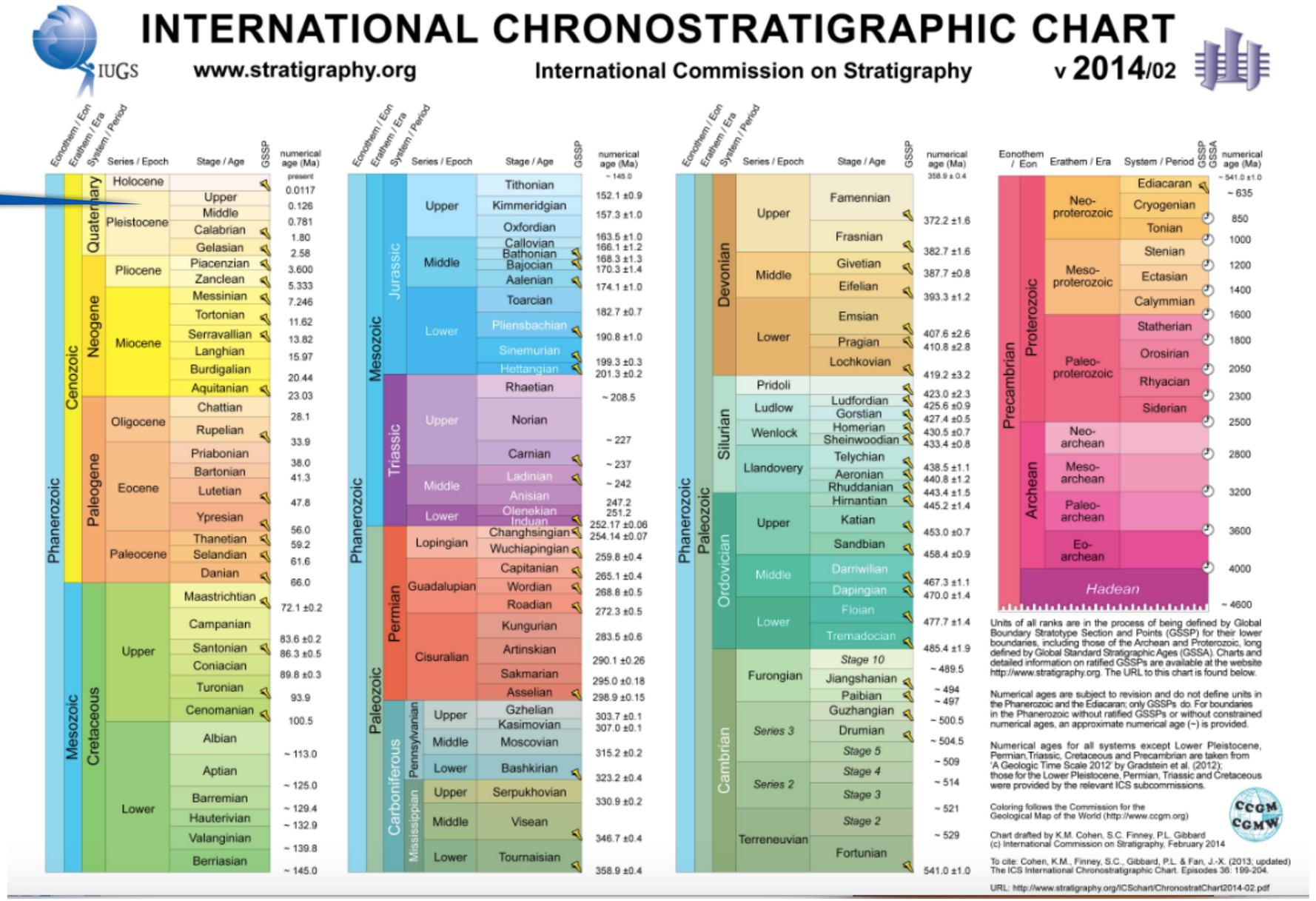

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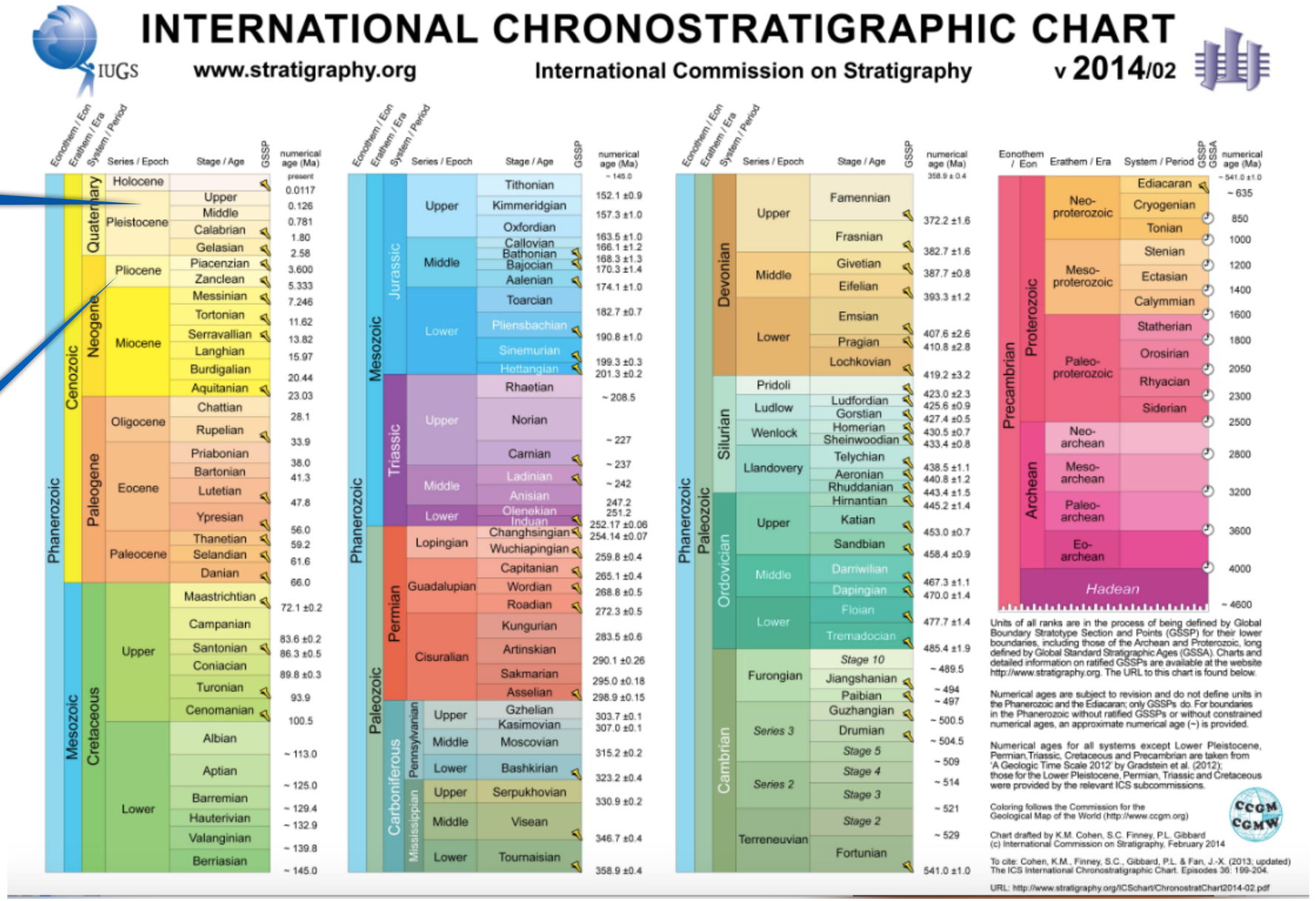
Neogene	Pliocene	Piacenzian	3.600–2.58
		Zanclean	5.333–3.600
	Miocene	Messinian	7.246–5.333
		Tortonian	11.62–7.246
		Serravallian	13.82–11.62
		Langhian	15.97–13.82
		Burdigalian	20.44–15.97
		Aquitanian	23.03–20.44
Paleogene	Oligocene	Chattian	older



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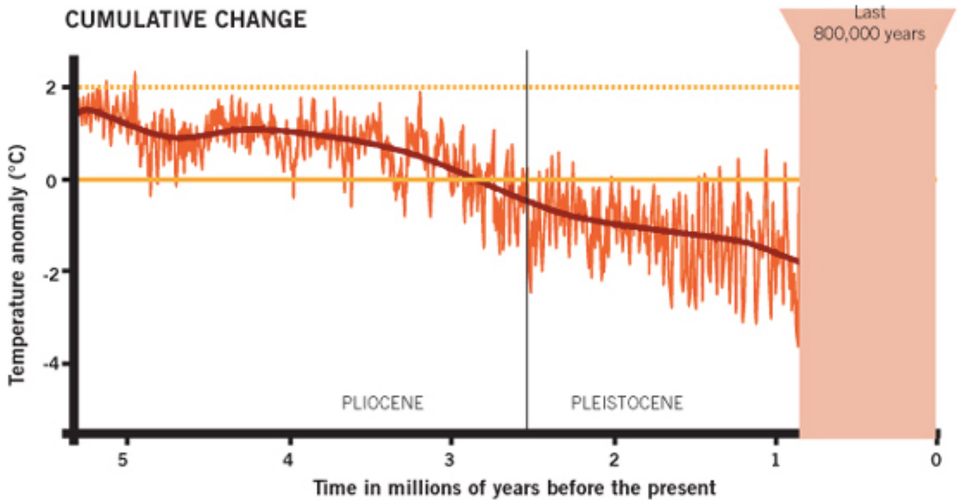

Rockstrom and Klum, 2015

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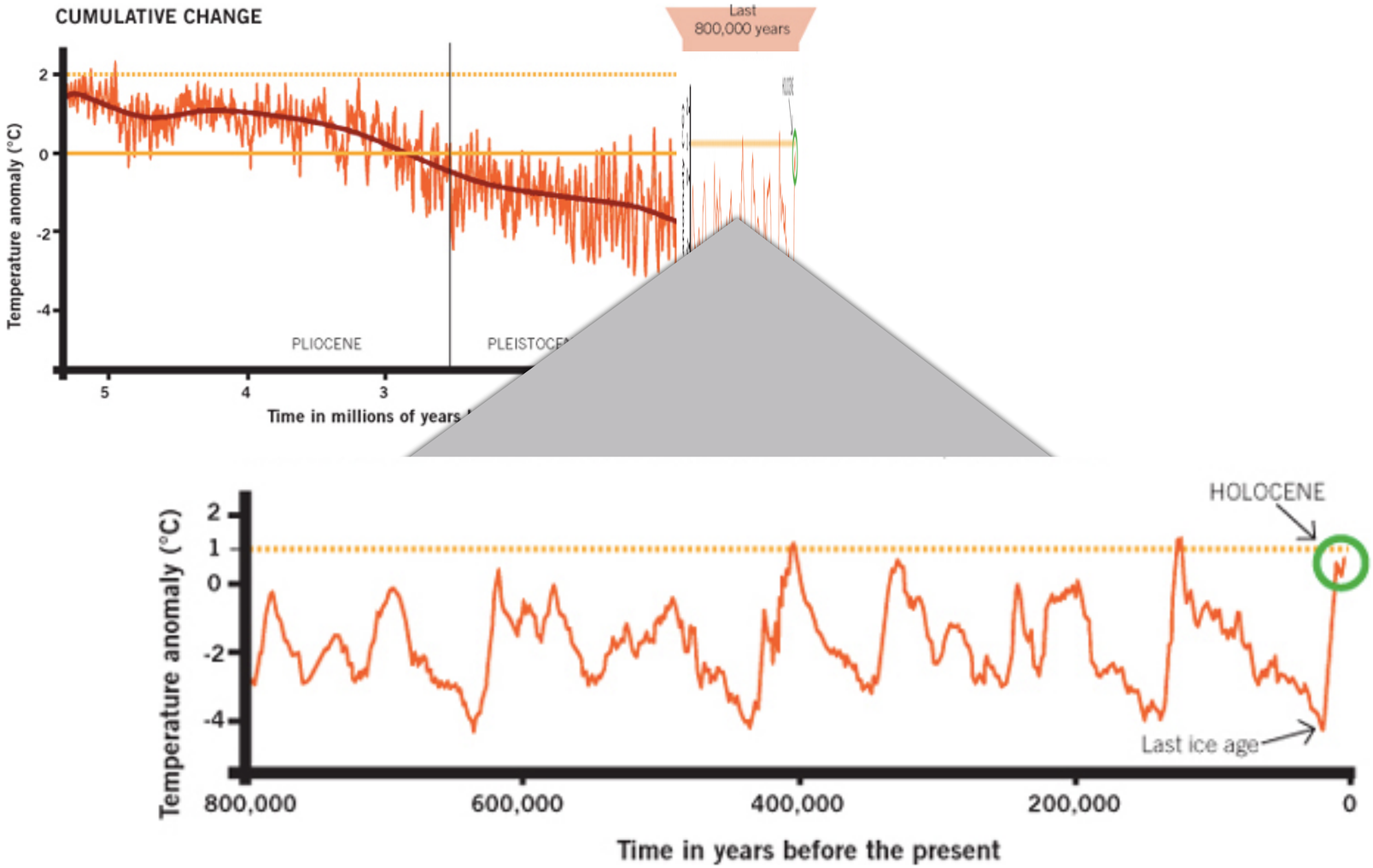

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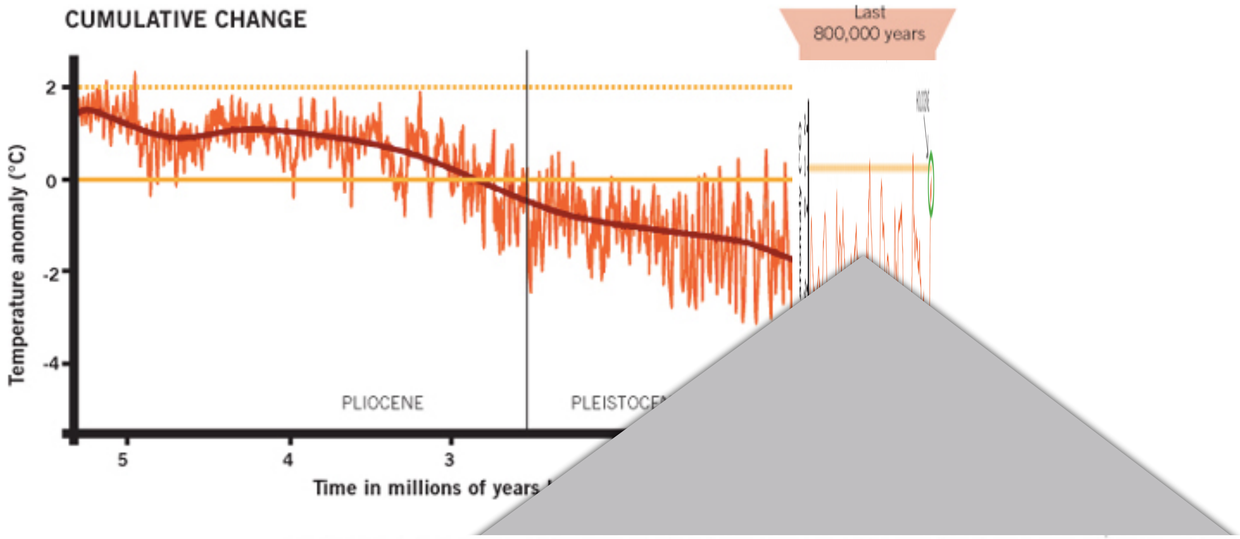

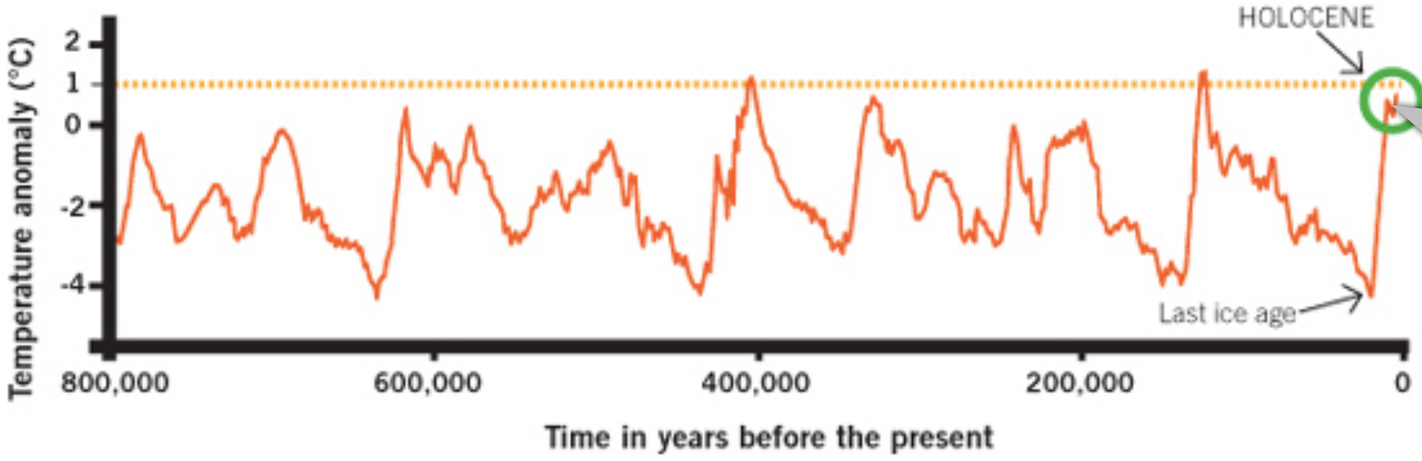

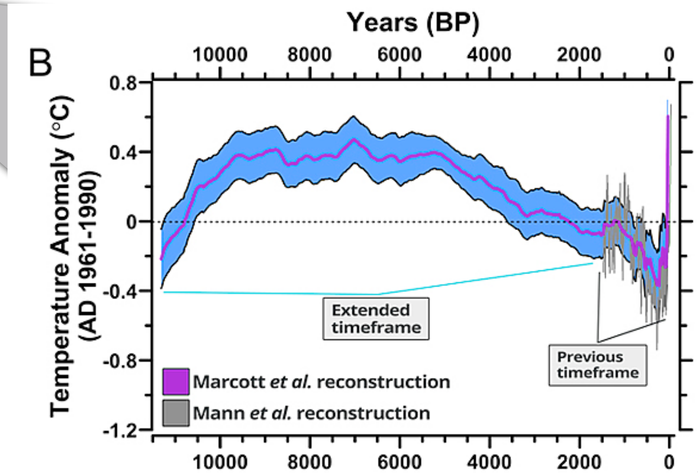

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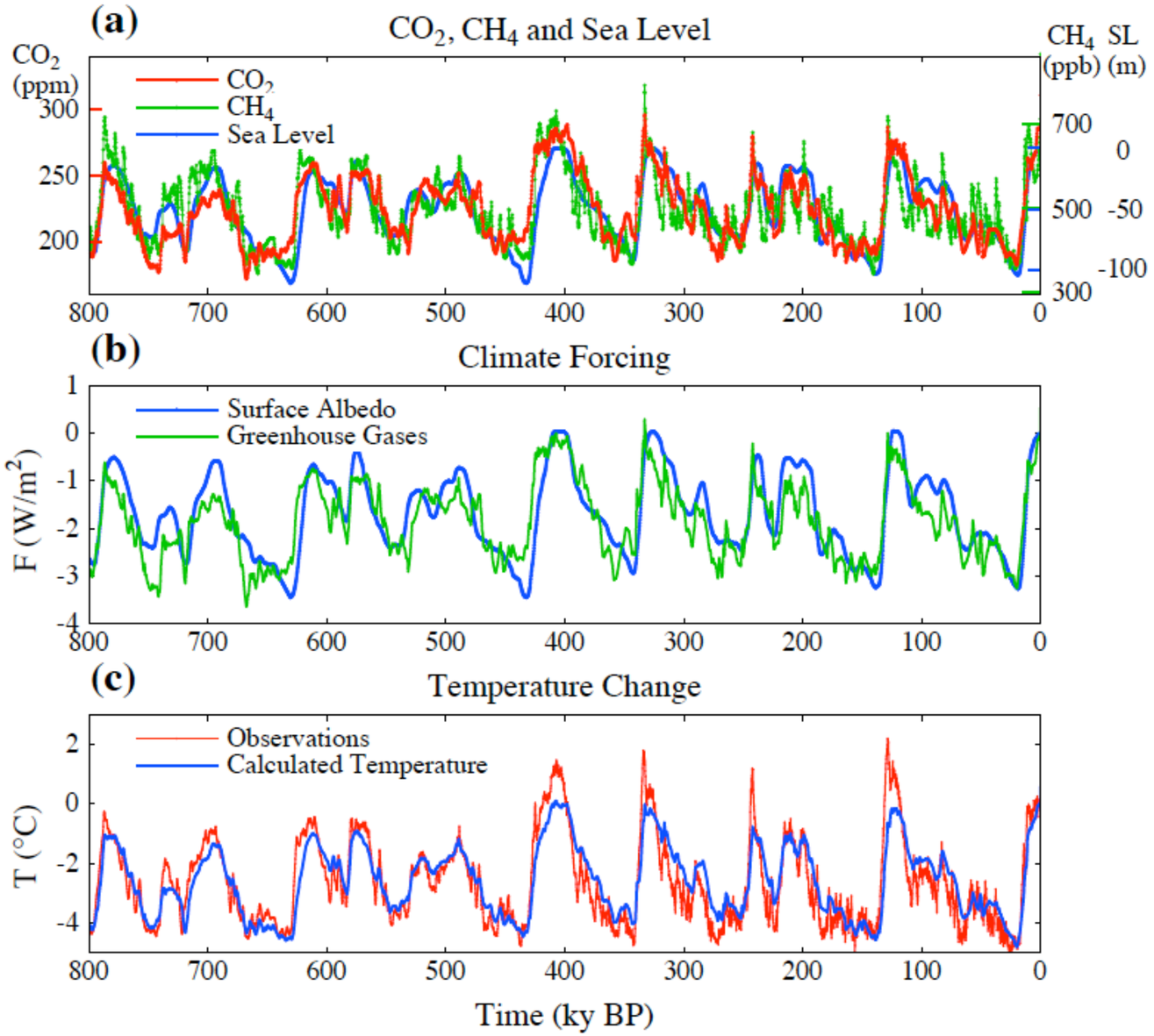
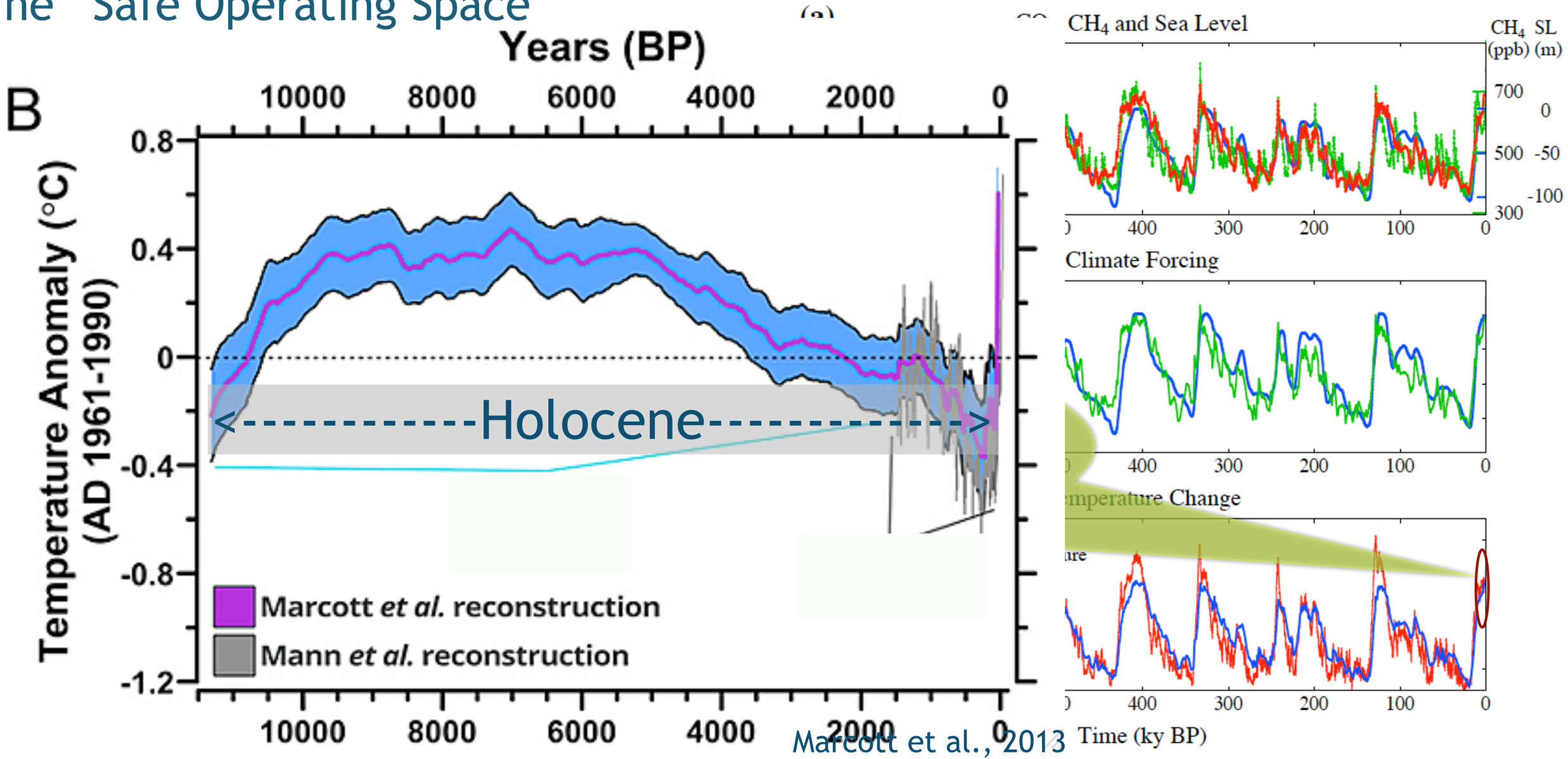
Marcott et al., 2013

The Baseline: Past Climate Variability



The Baseline: Past Climate Variability

The "Safe Operating Space"



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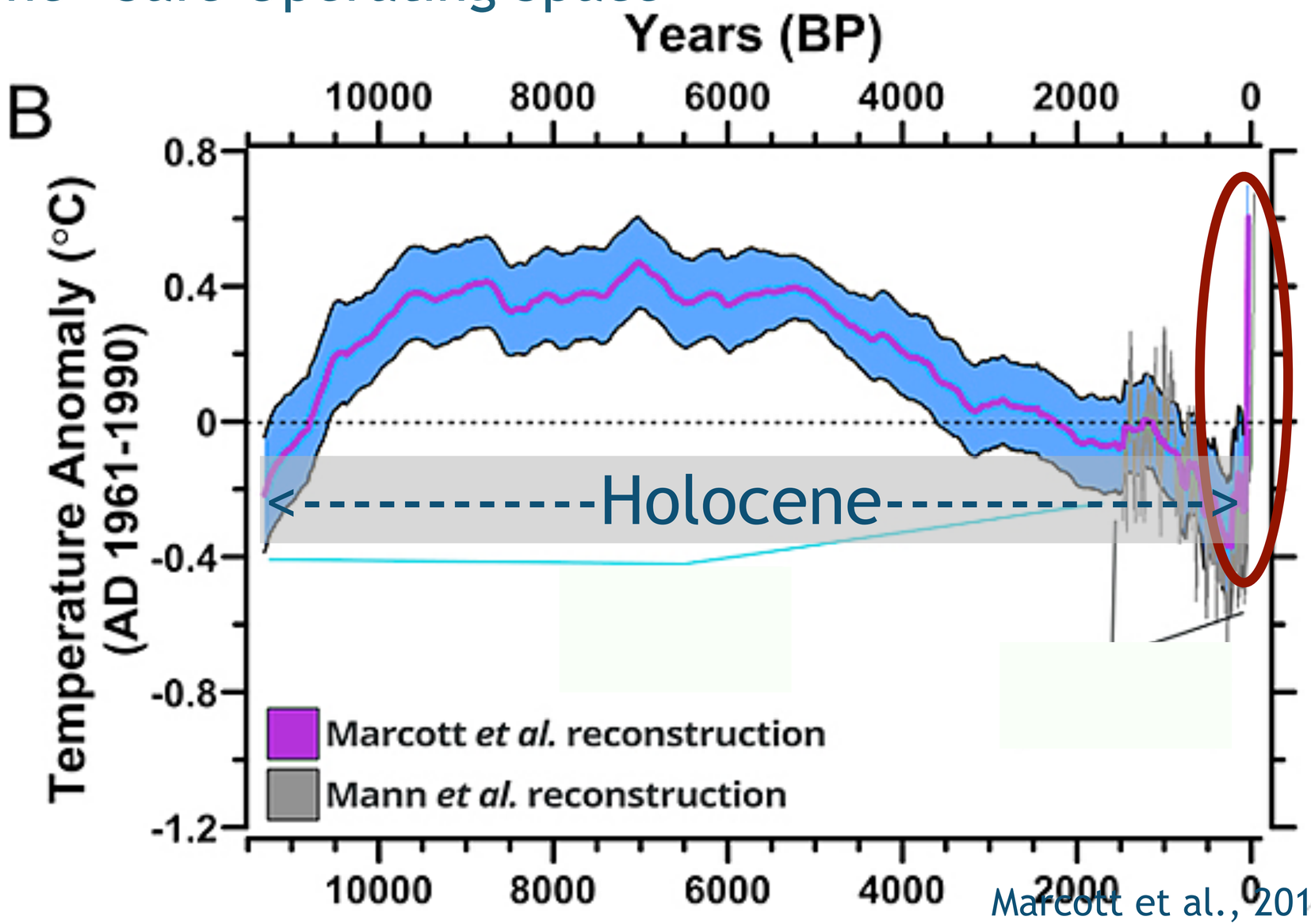

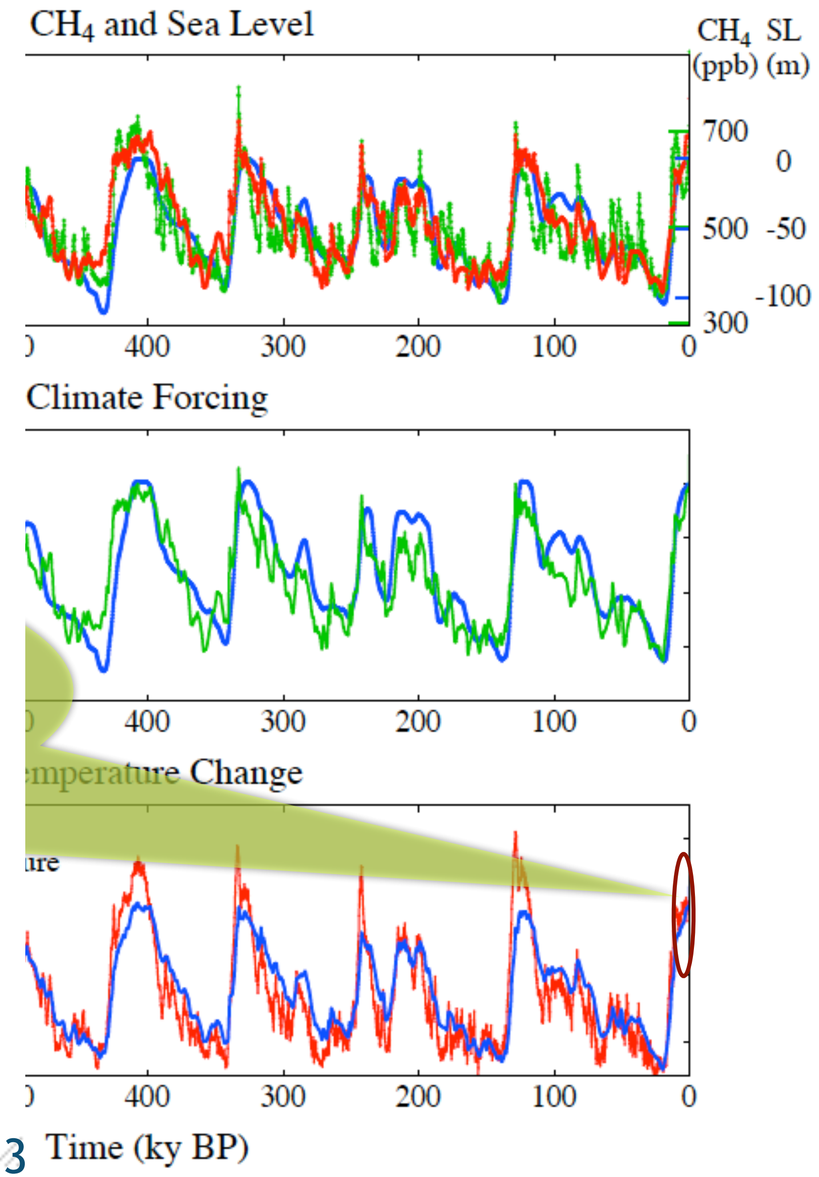

Marcott et al., 2013

The Baseline: Past Climate Variability

Global and Local Sea Level Changes

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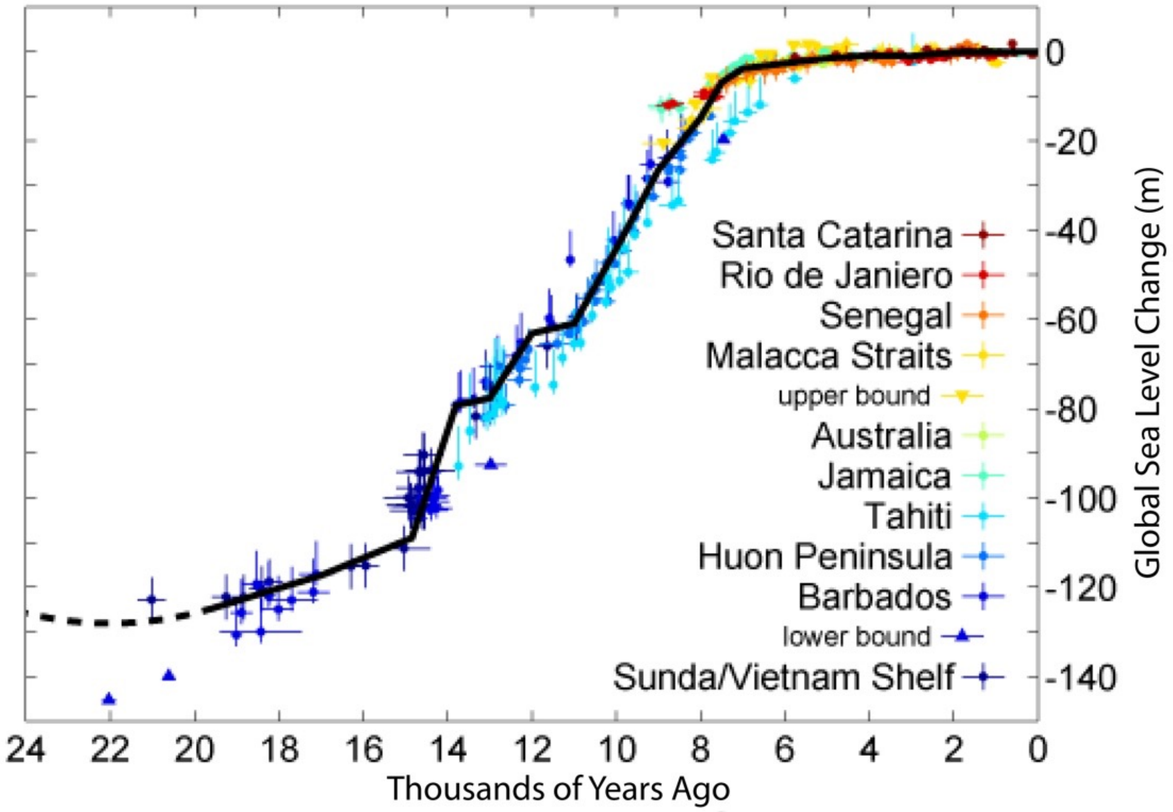

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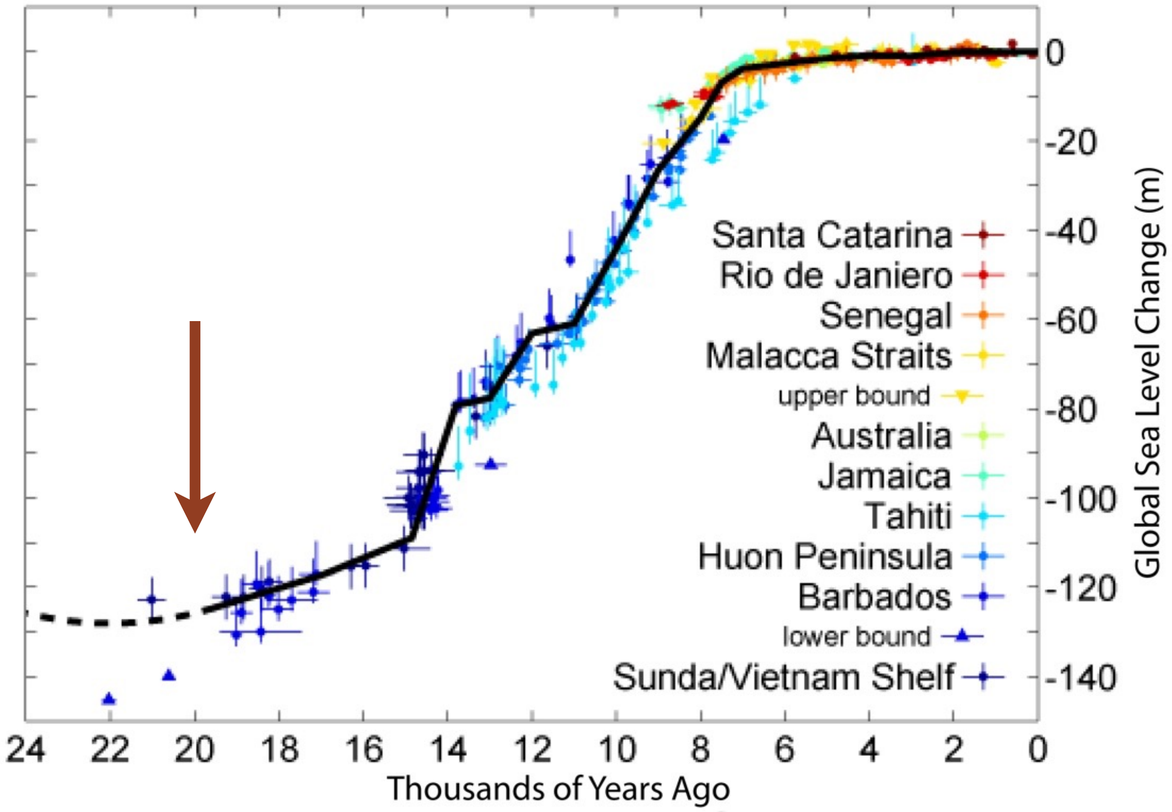
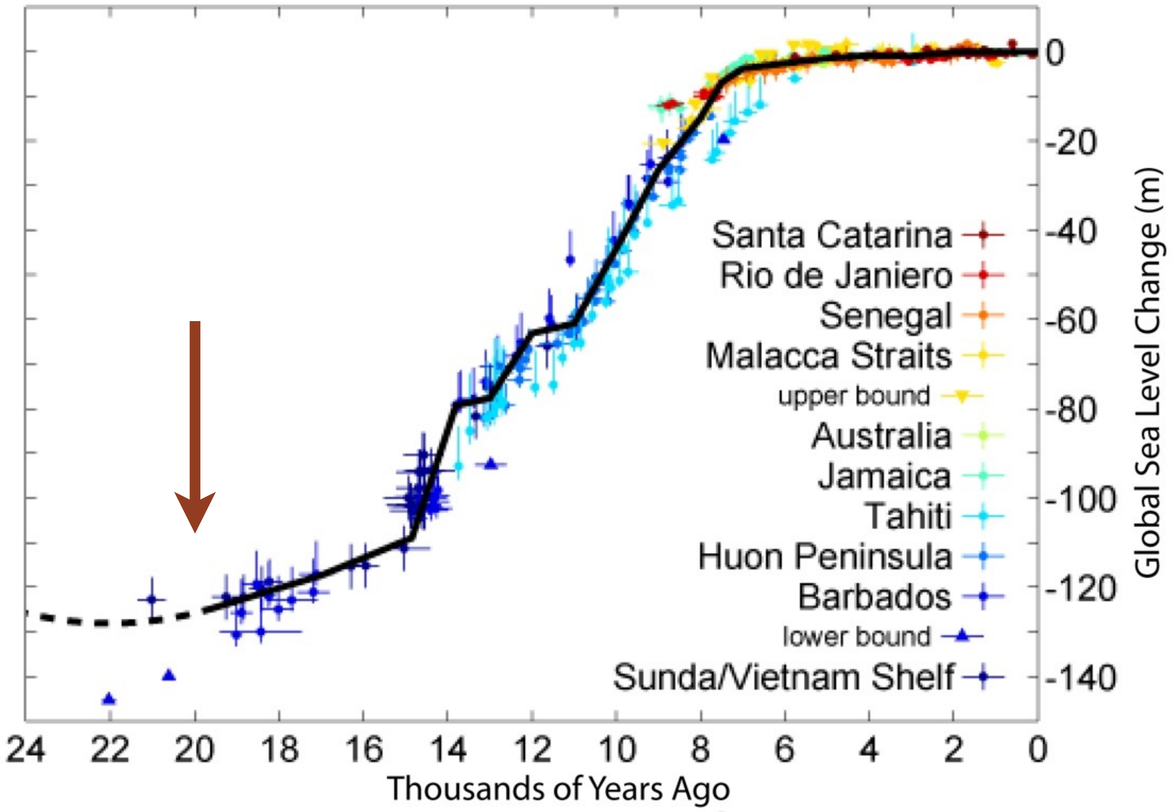


20,000 years ago, sea level in Northern America and Scandinavia was up to 600 m higher than today, and in some other location 200 m lower

The Baseline: Past Climate Variability

Global and Local Sea Level Changes



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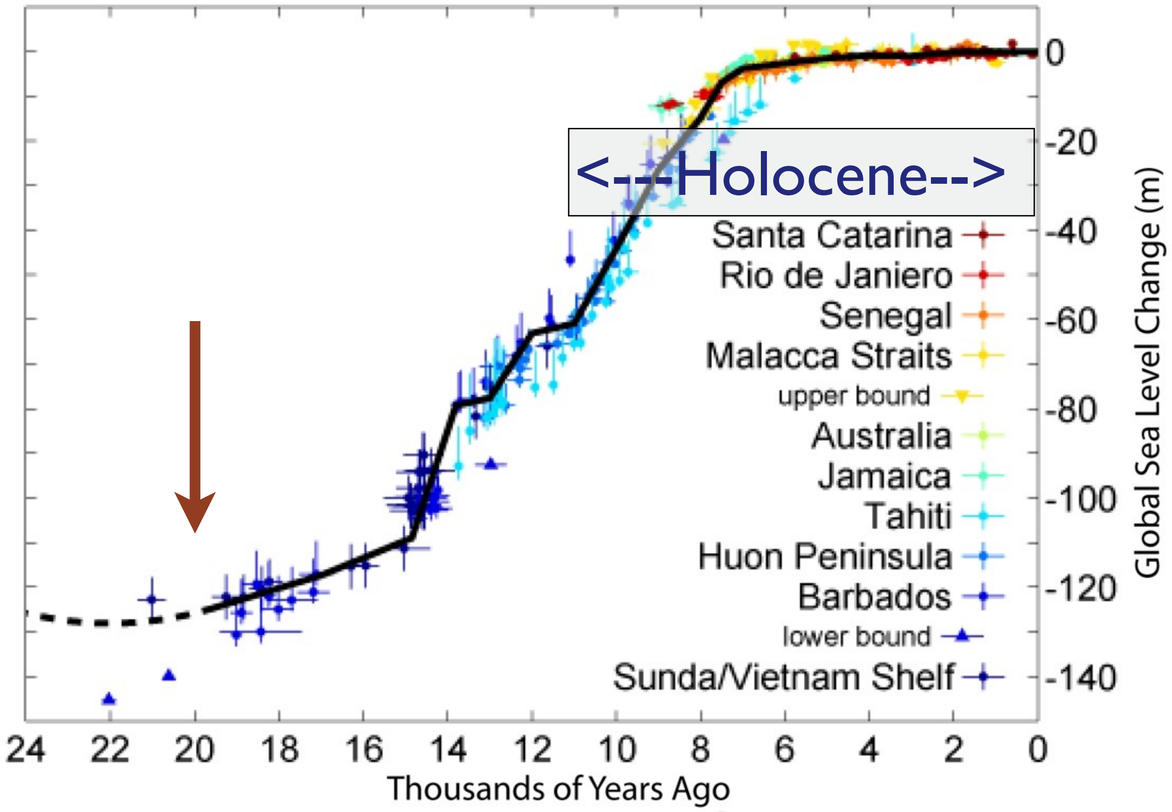

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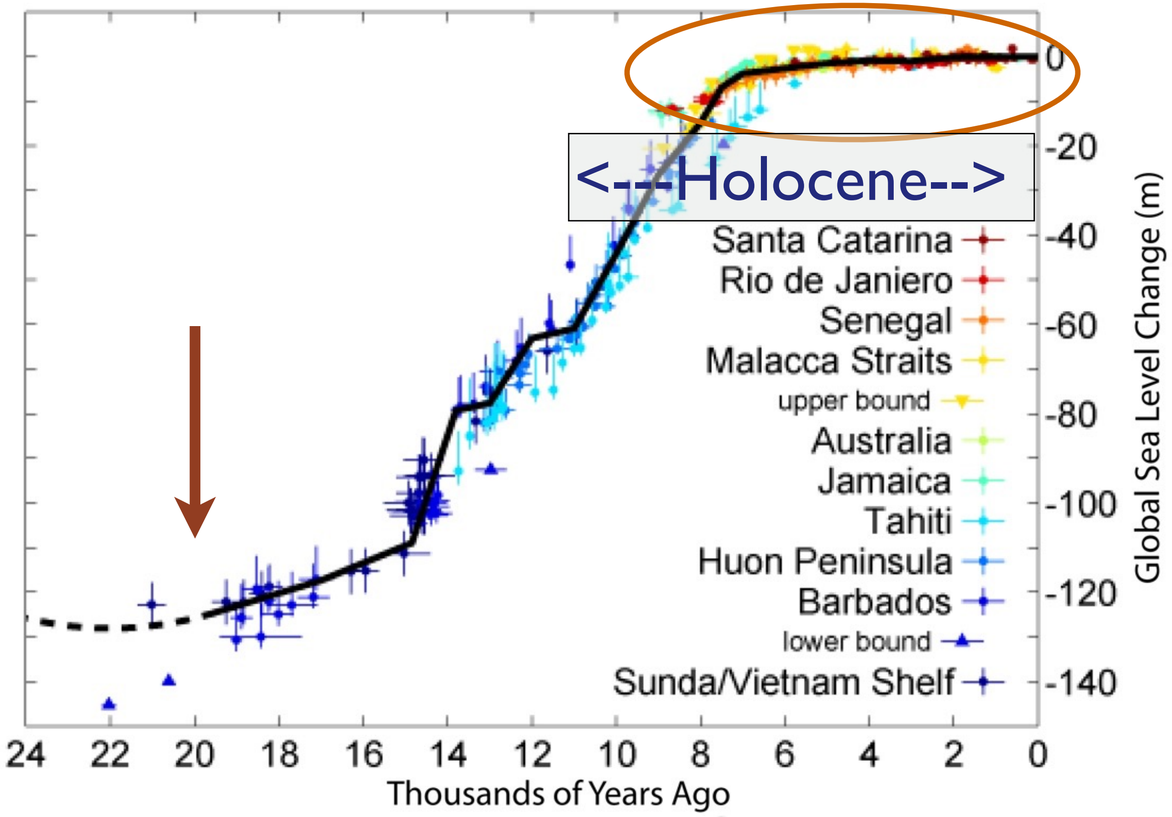

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The Baseline: Past Climate Variability

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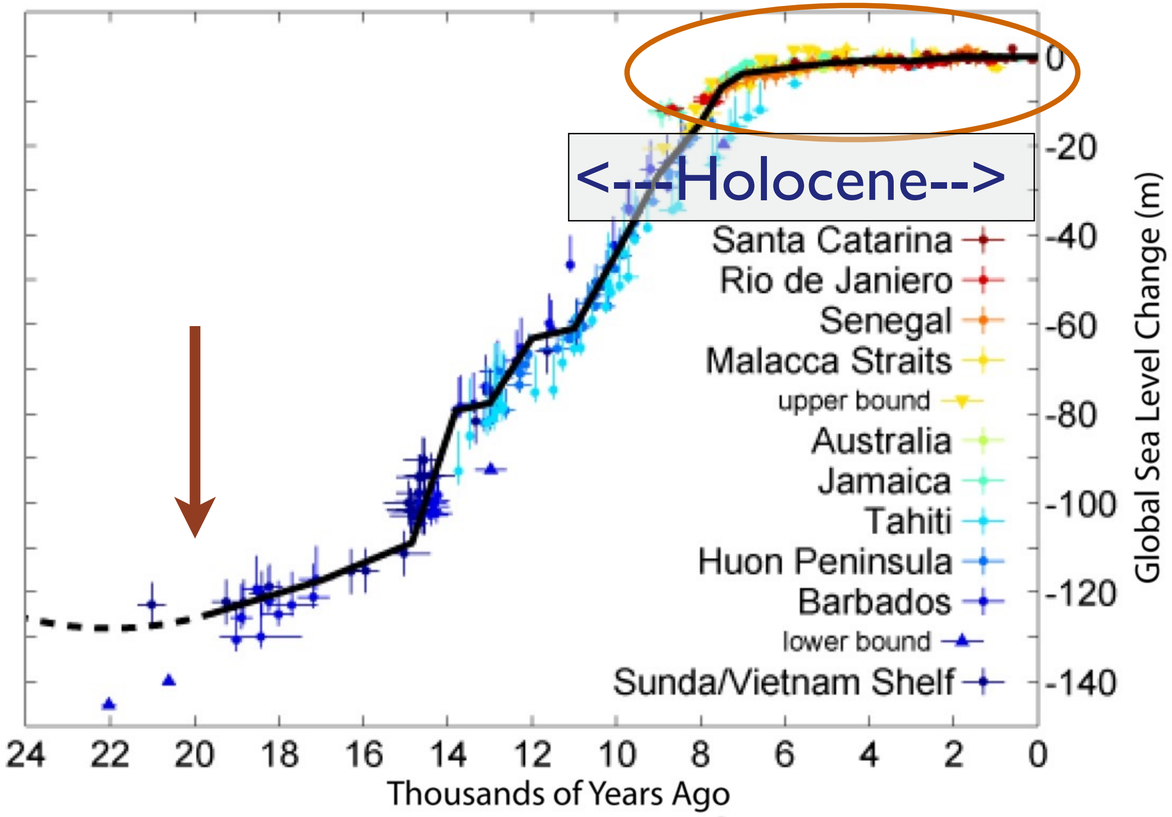

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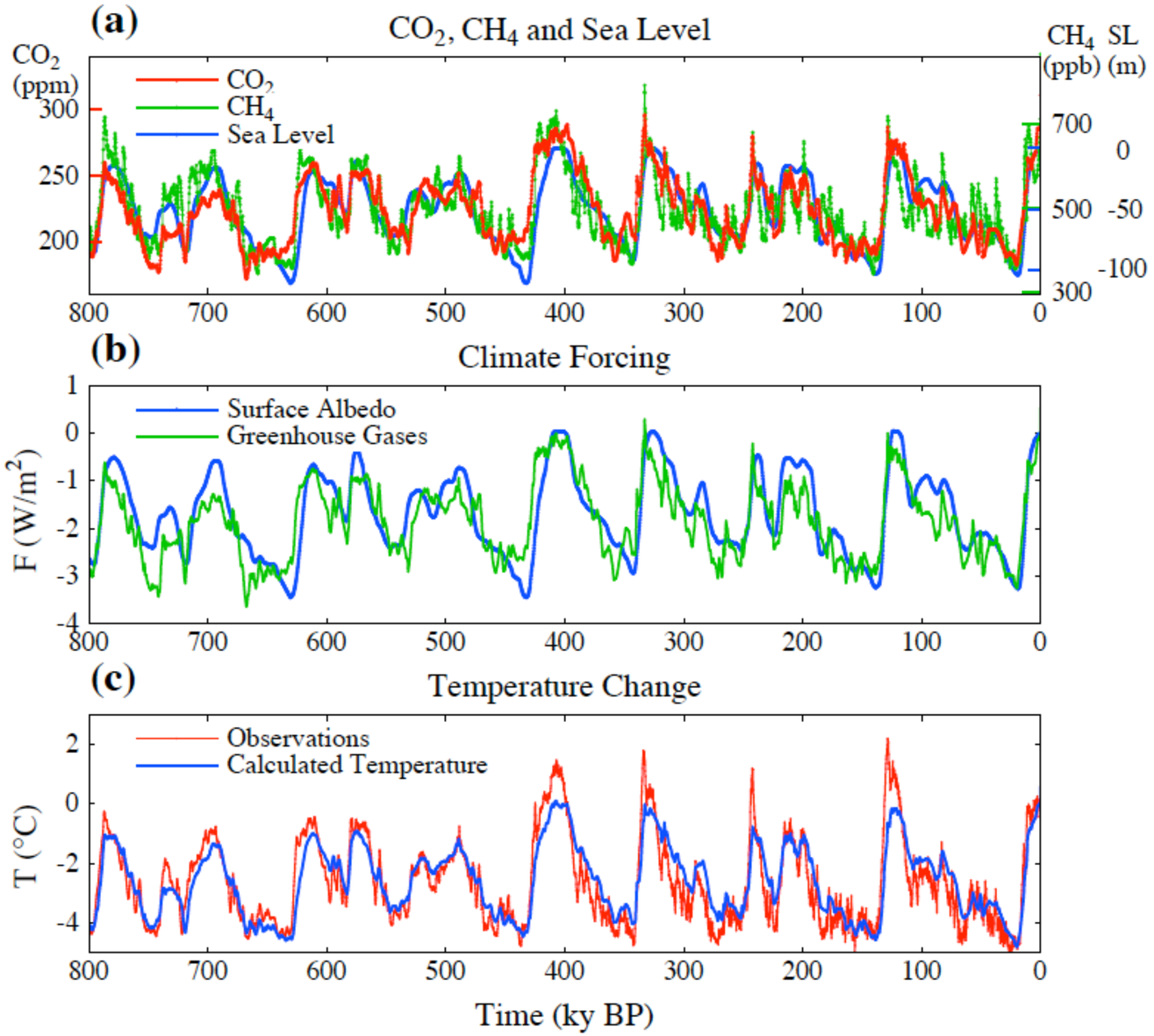

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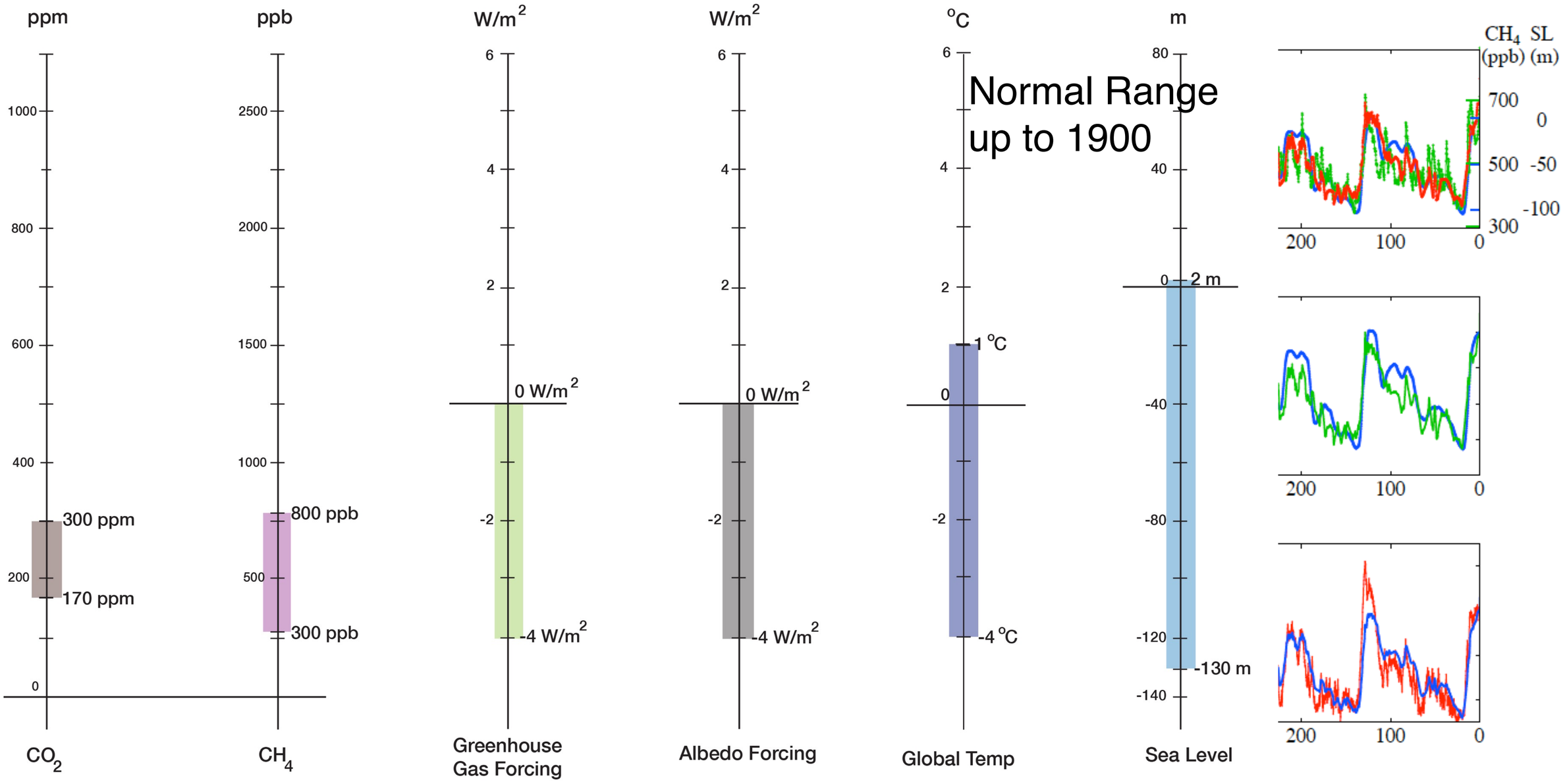

The Baseline: Past Climate Variability

Long-term (centuries to millennia) correlations:

- 130 ppm CO
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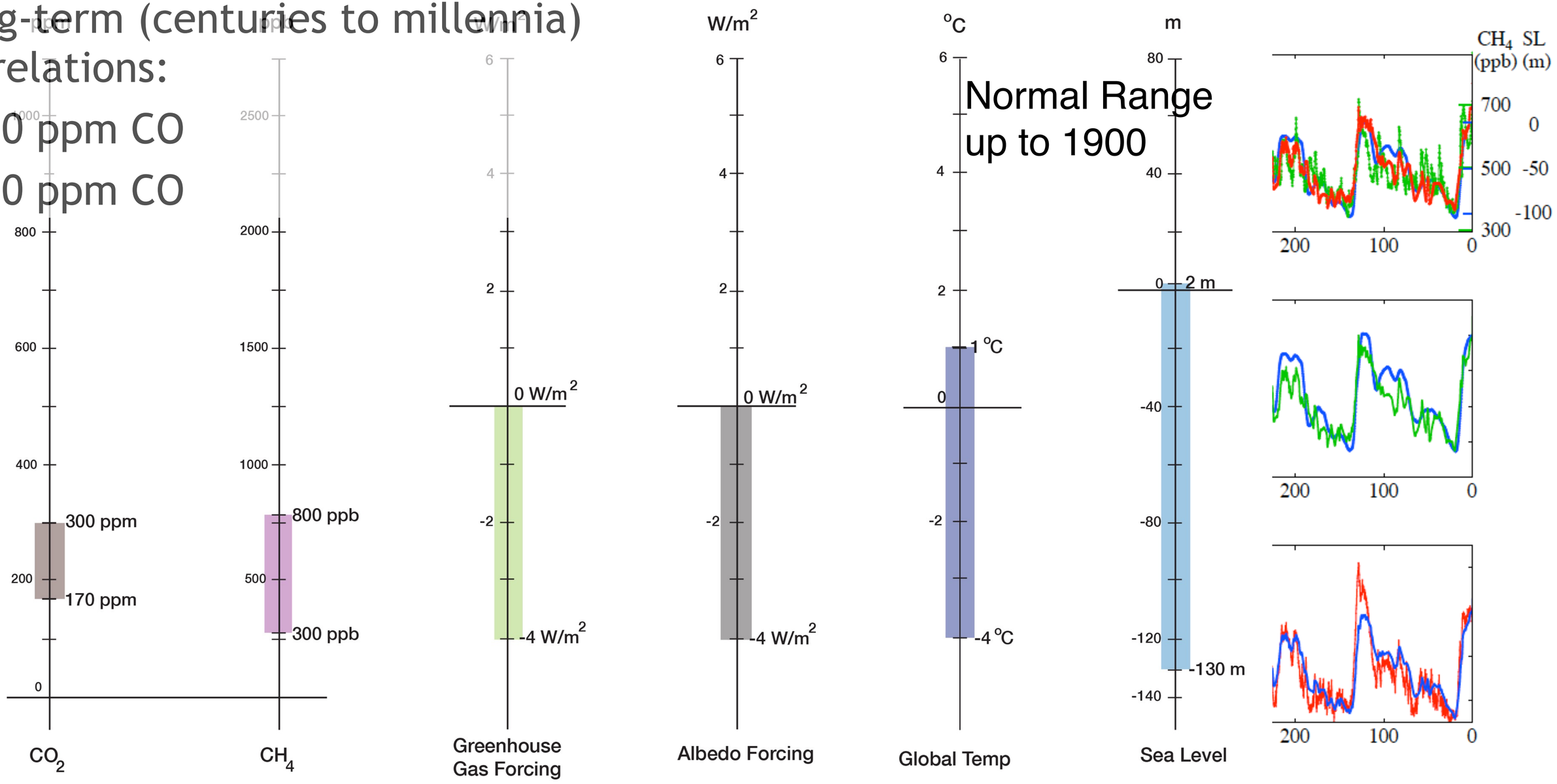

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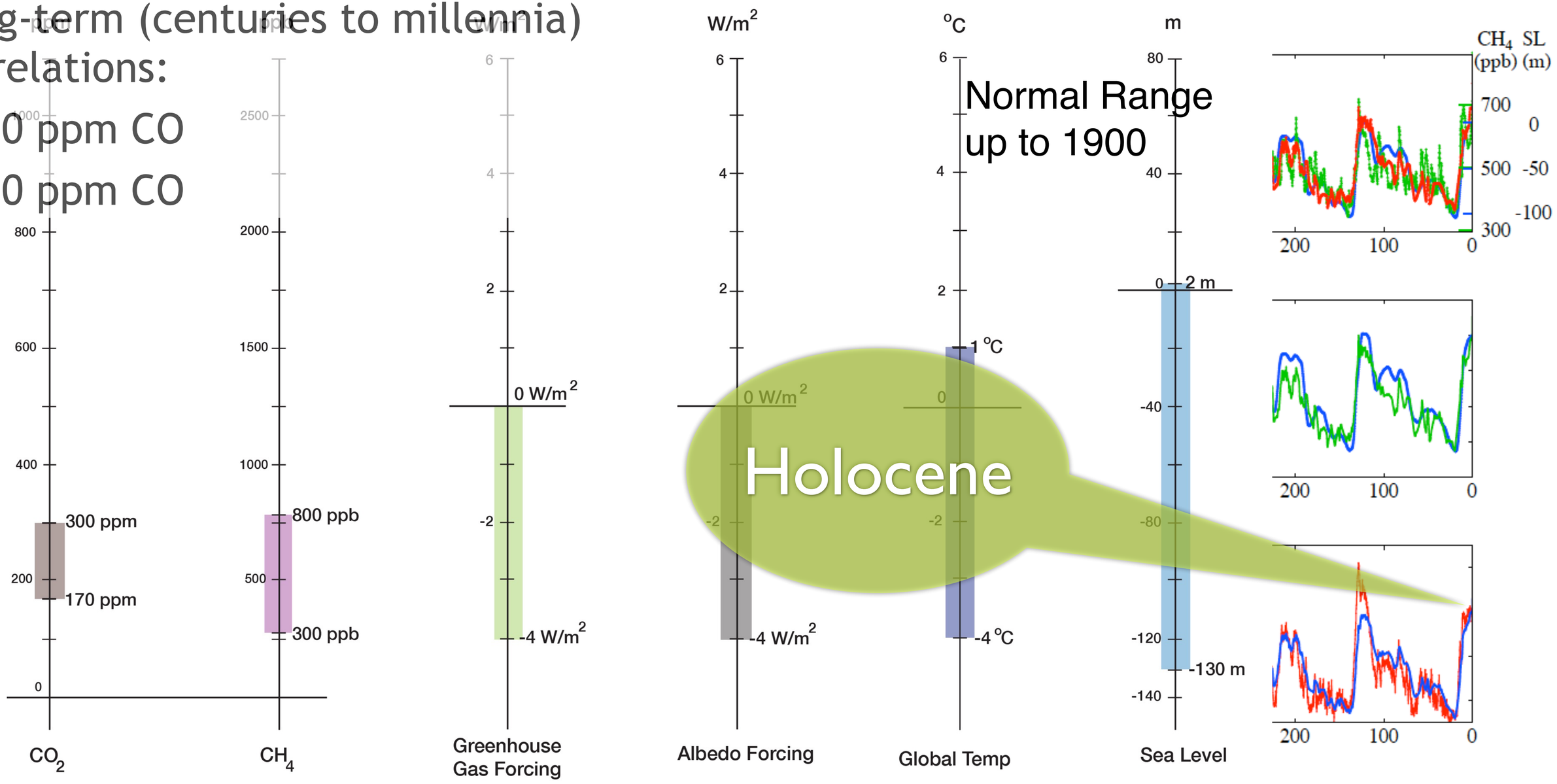

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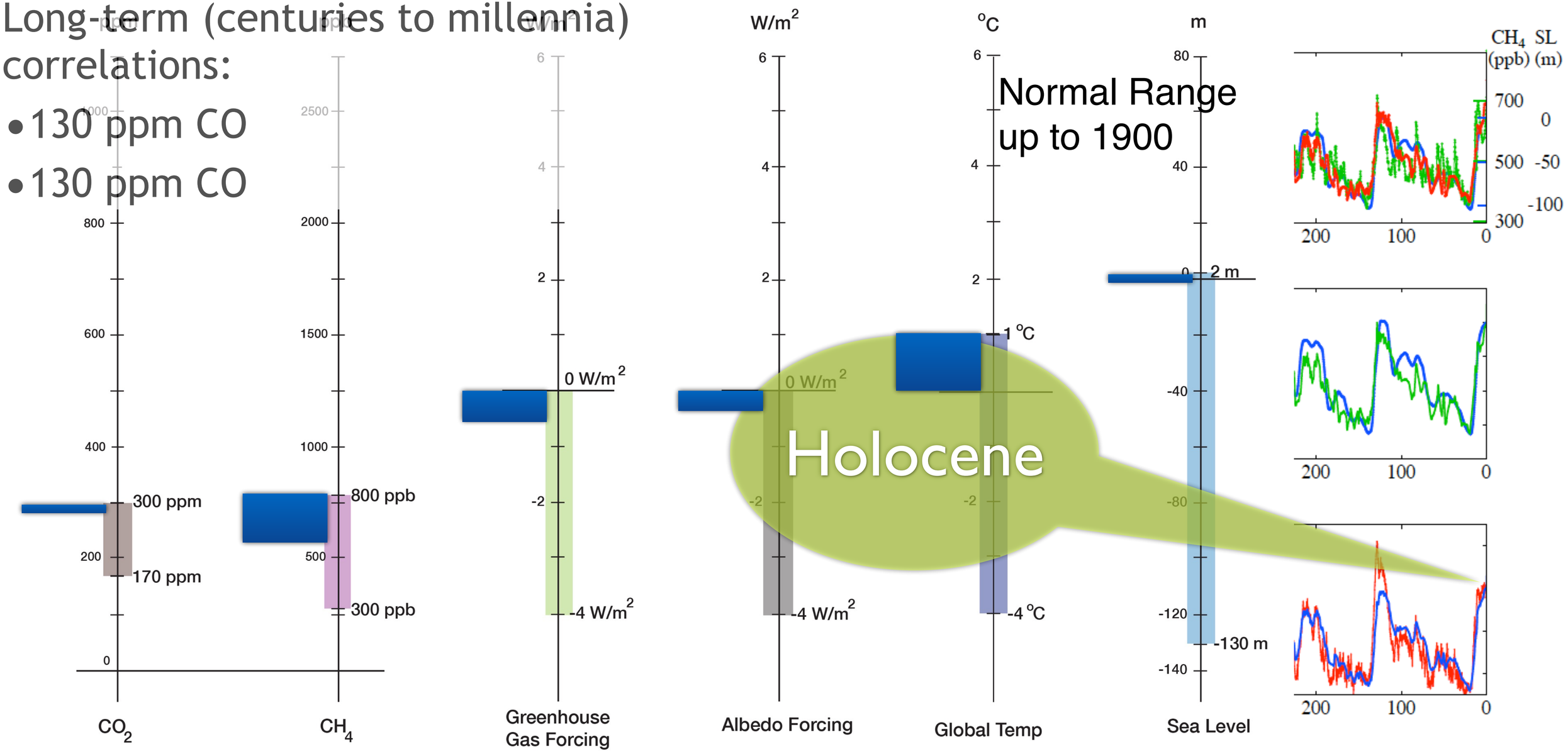

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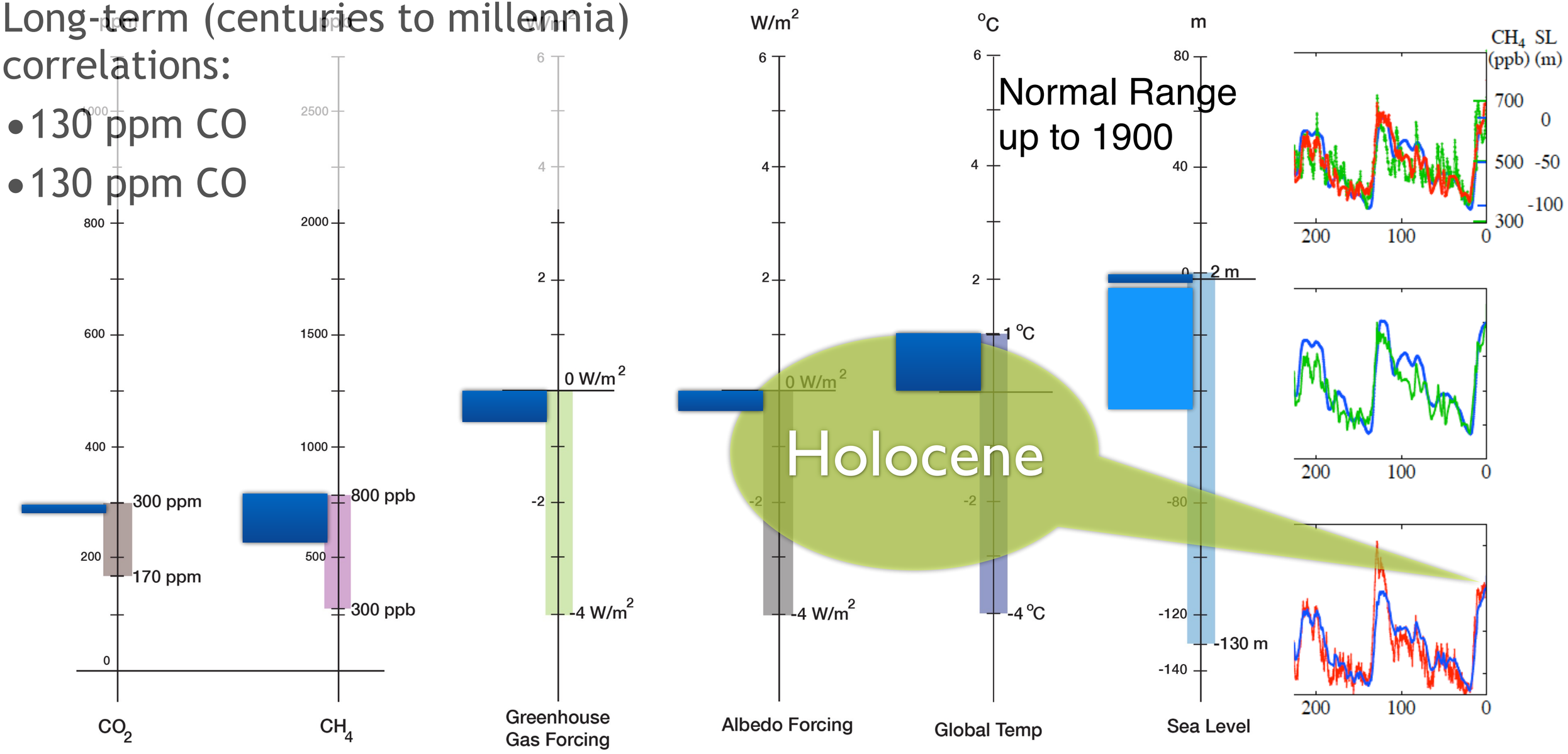

The Baseline: Past Climate Variability

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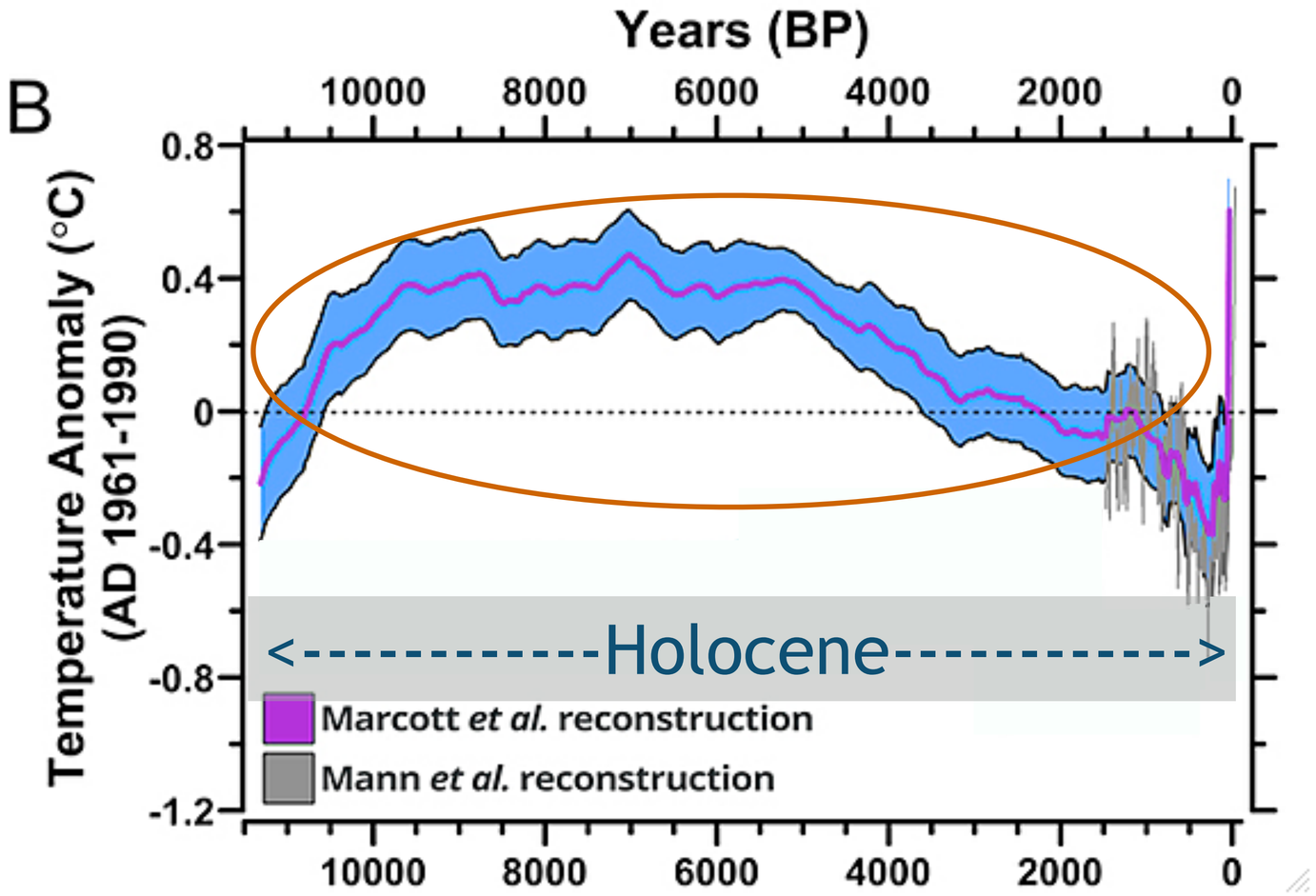
Global Temperature Changes



Marcott et al., 2013

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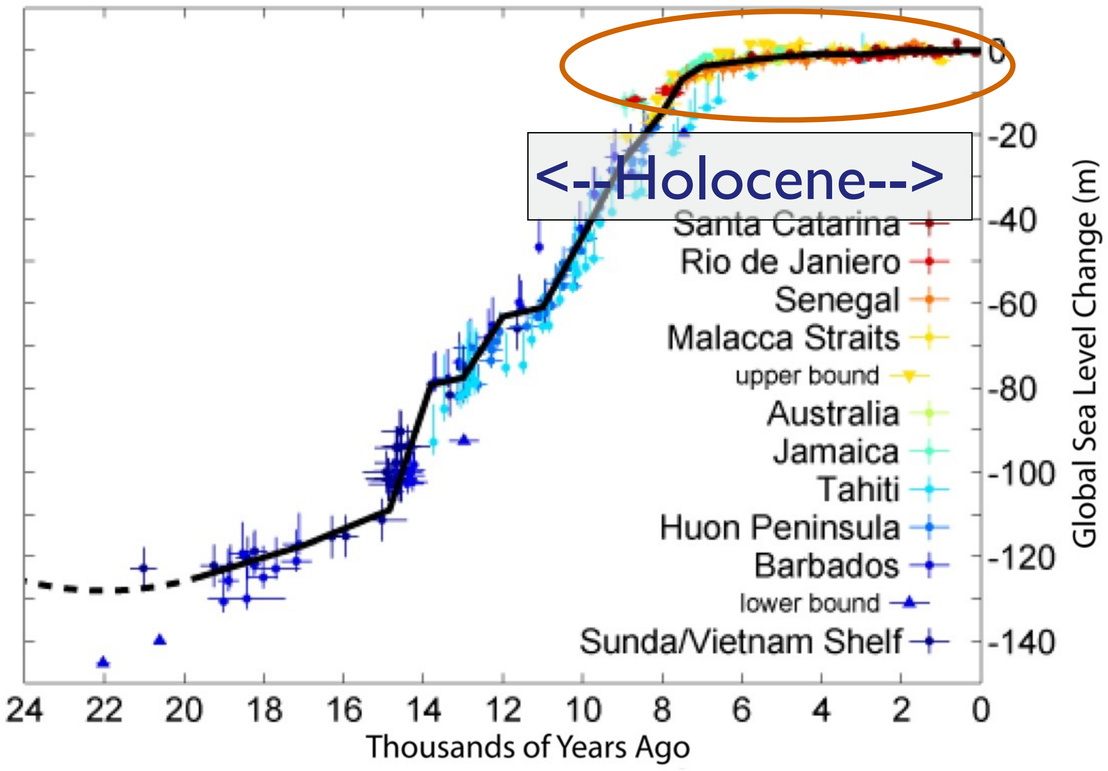

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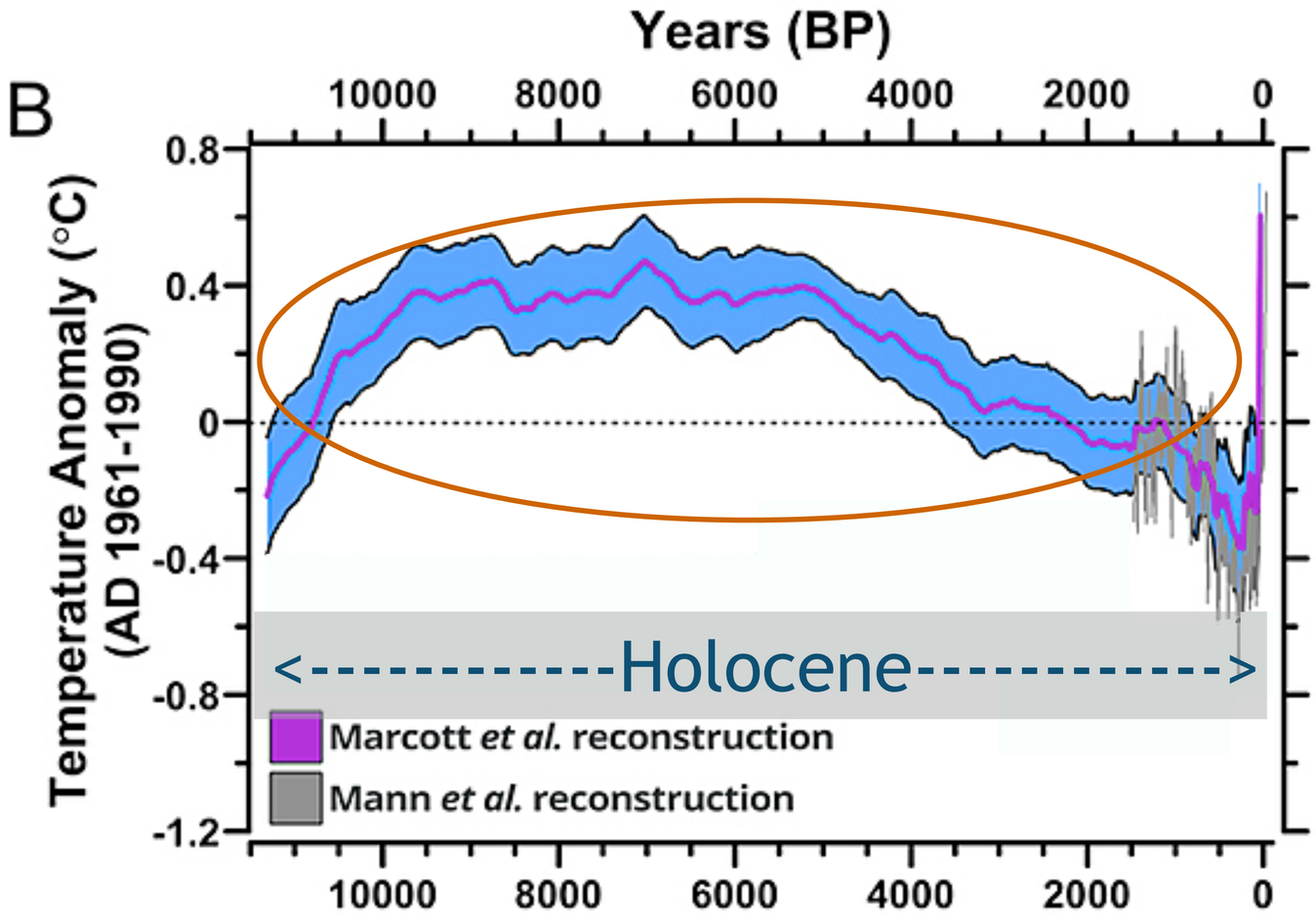

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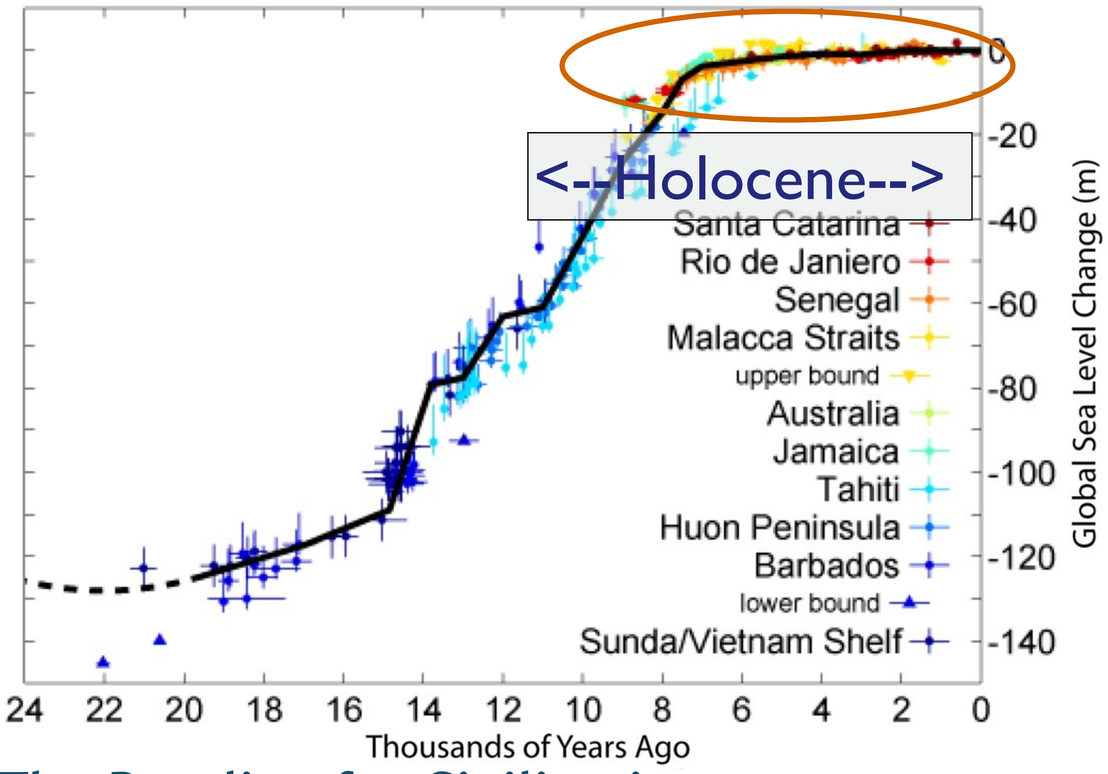
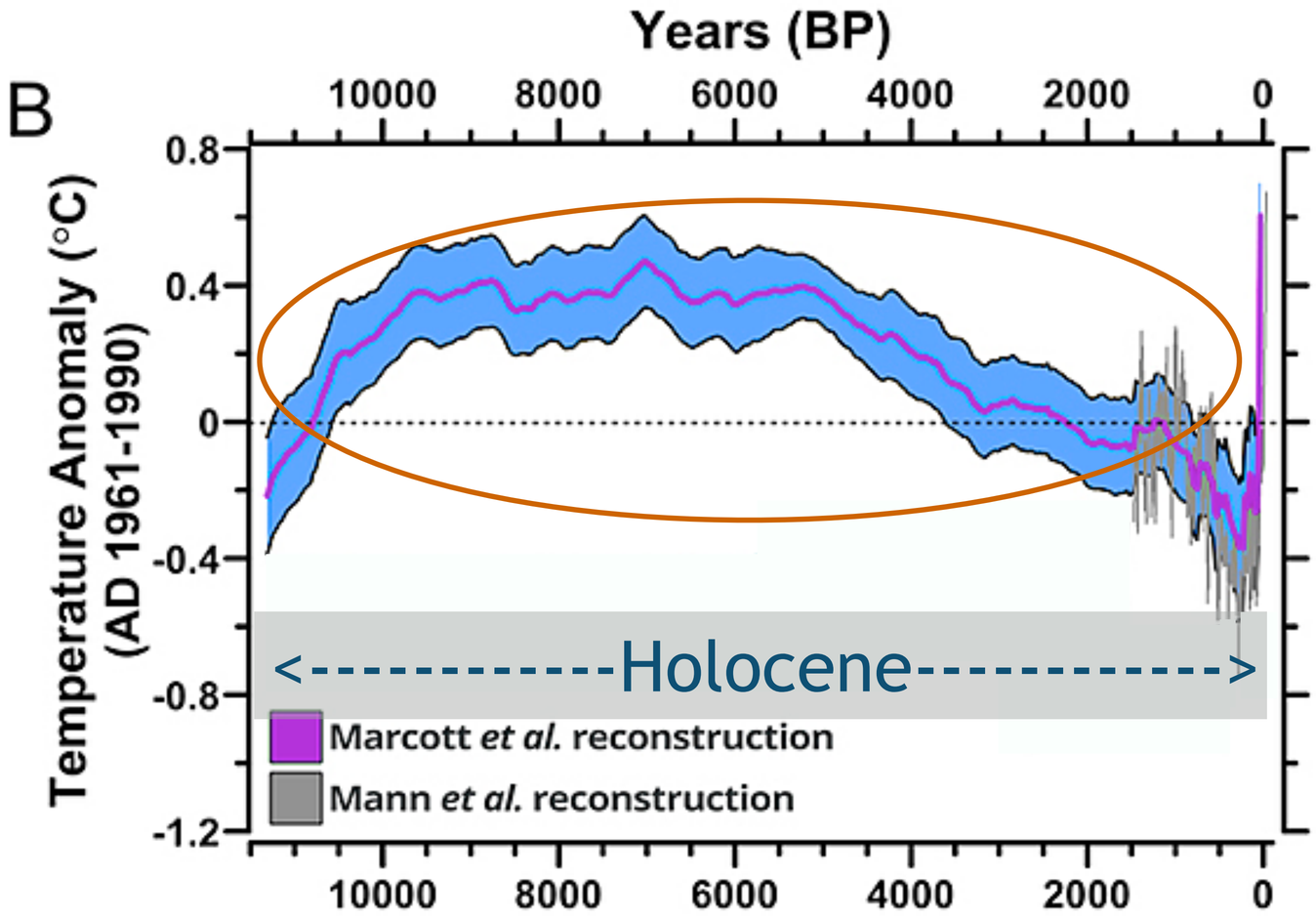


The Baseline for Civilization:
During the Holocene, climate, global temperature, and sea level were exceptionally stable; a perfect condition for the development of civilization.

The Baseline: Past Climate Variability

Global Temperature Changes



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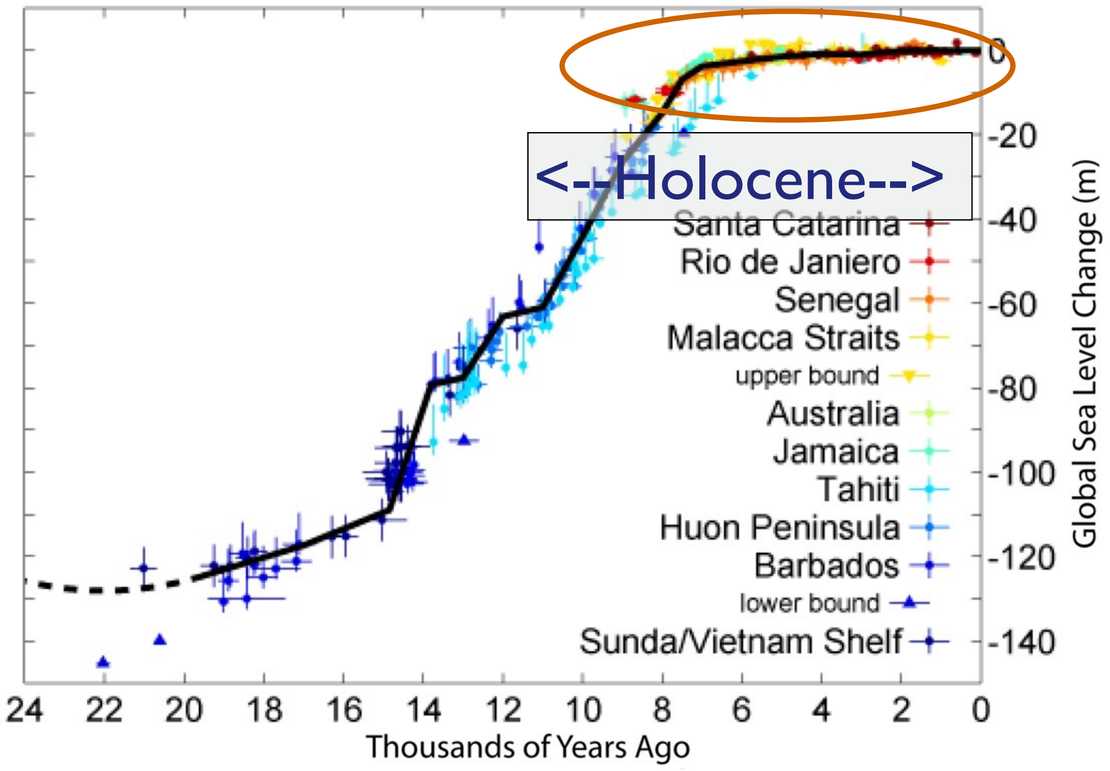
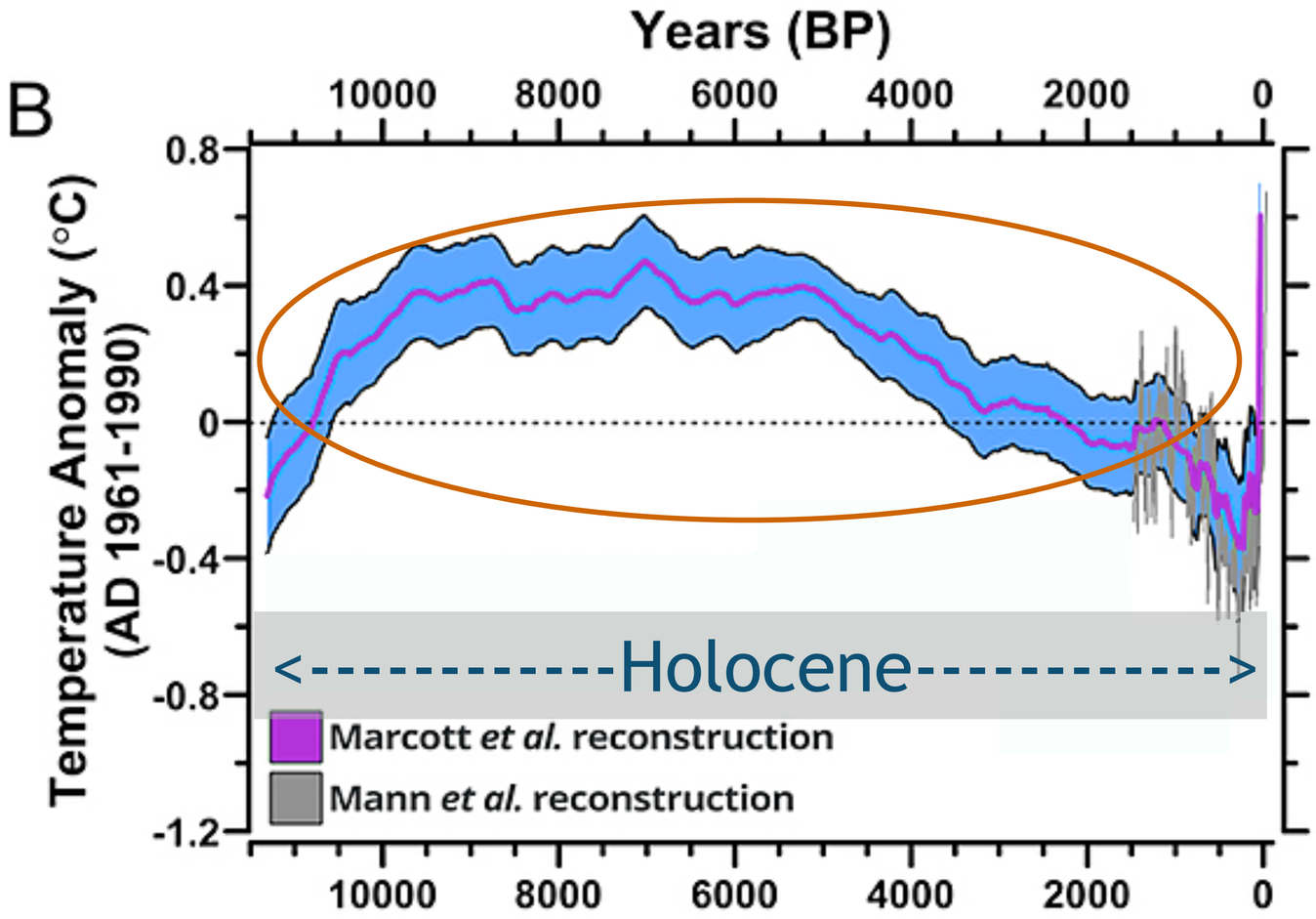


The Holocene was a "safe operating space for humanity"

The Baseline: Past Climate Variability

Global Temperature Changes



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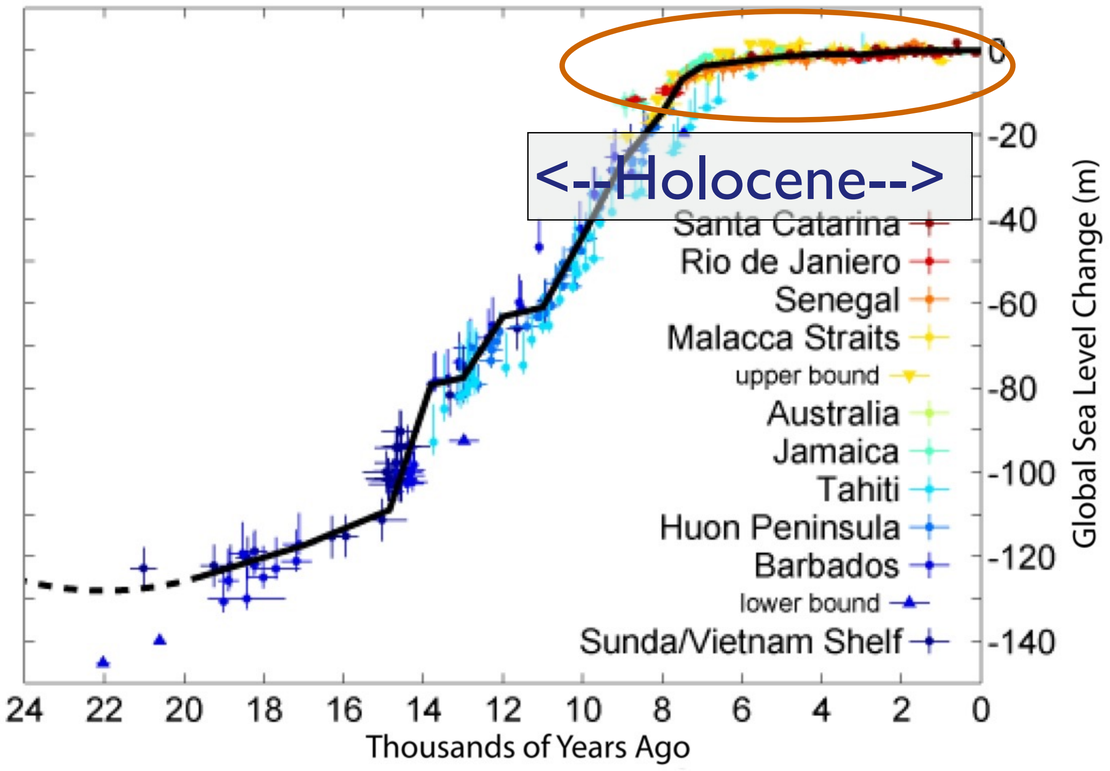

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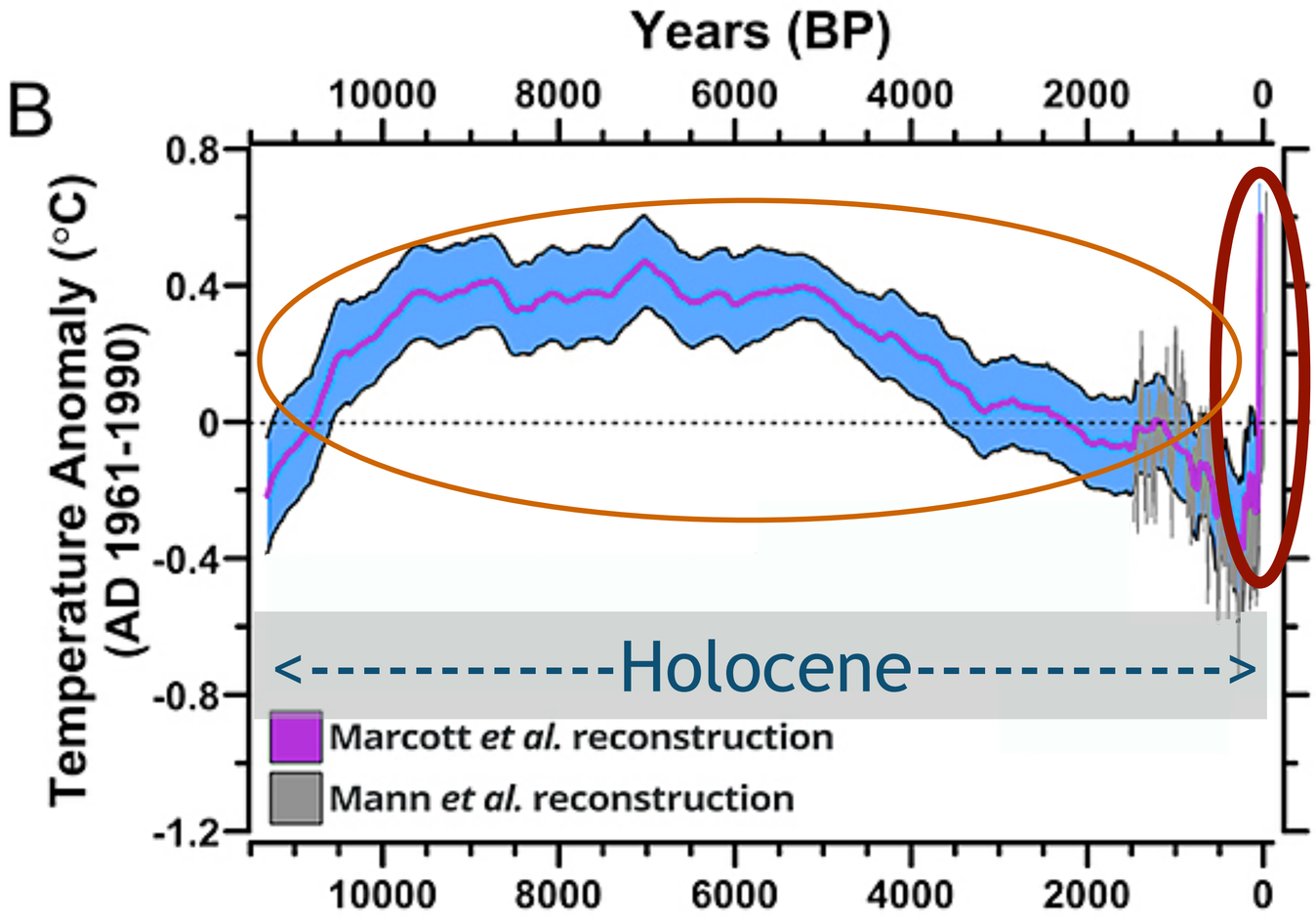

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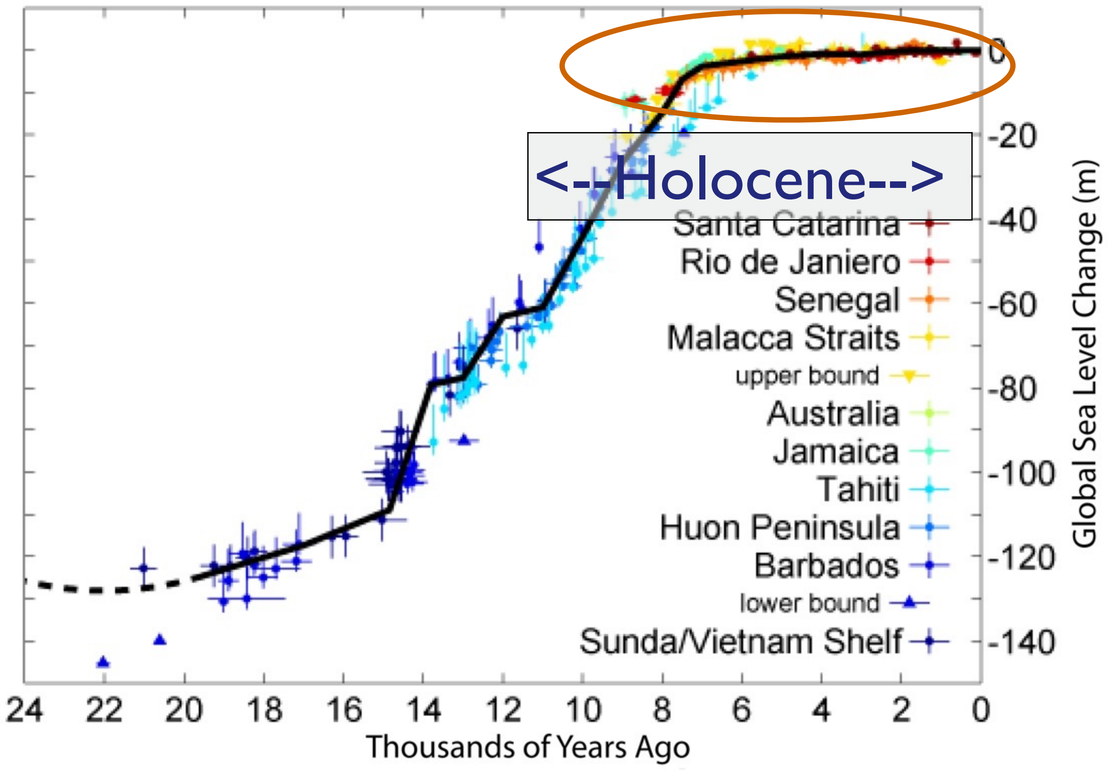

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Key Points

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The Syndrome: Recent Climate and Global Change

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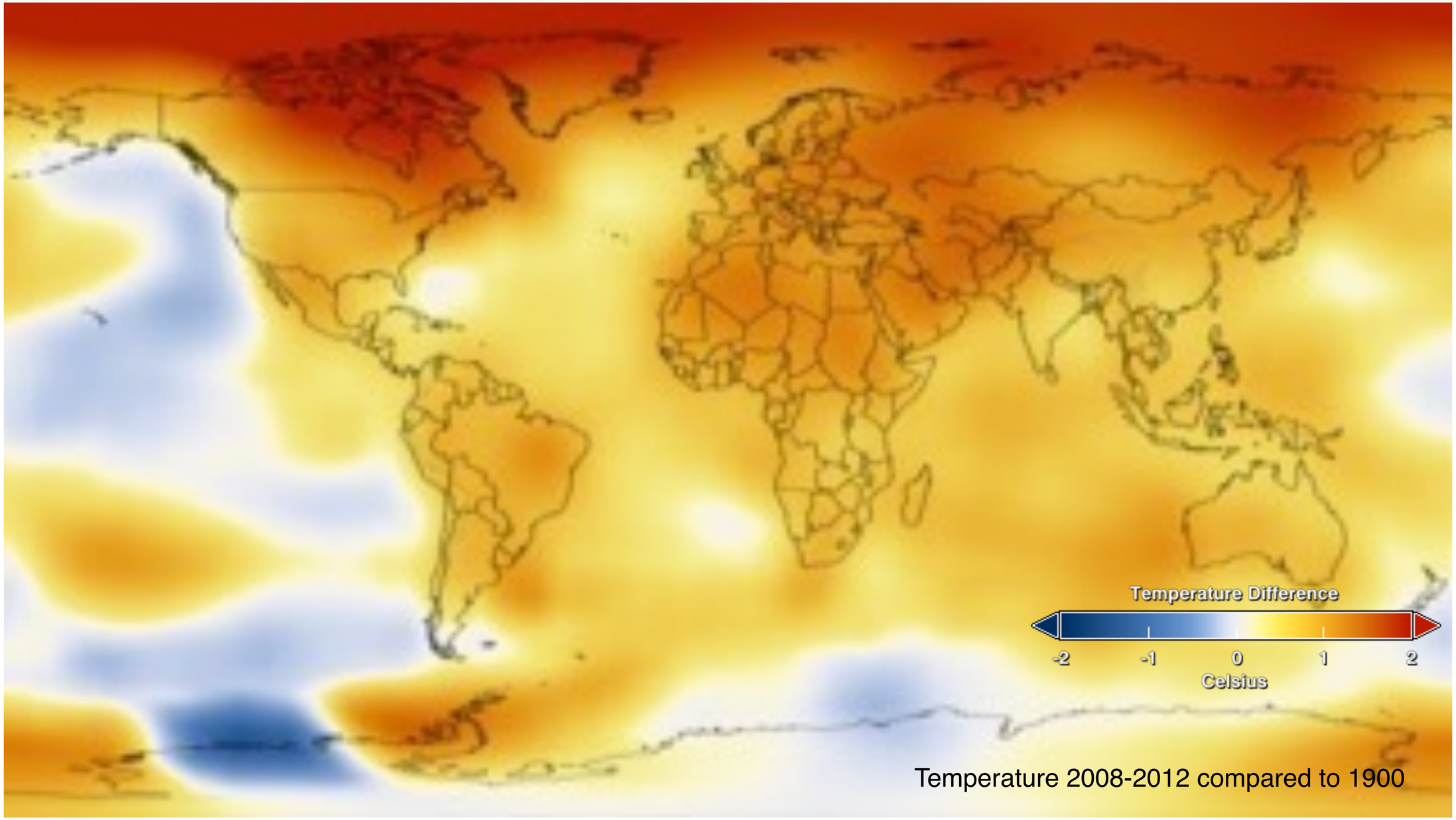

Temperature 2008-2012 compared to 1900

The Syndrome: Recent Climate and Global Change

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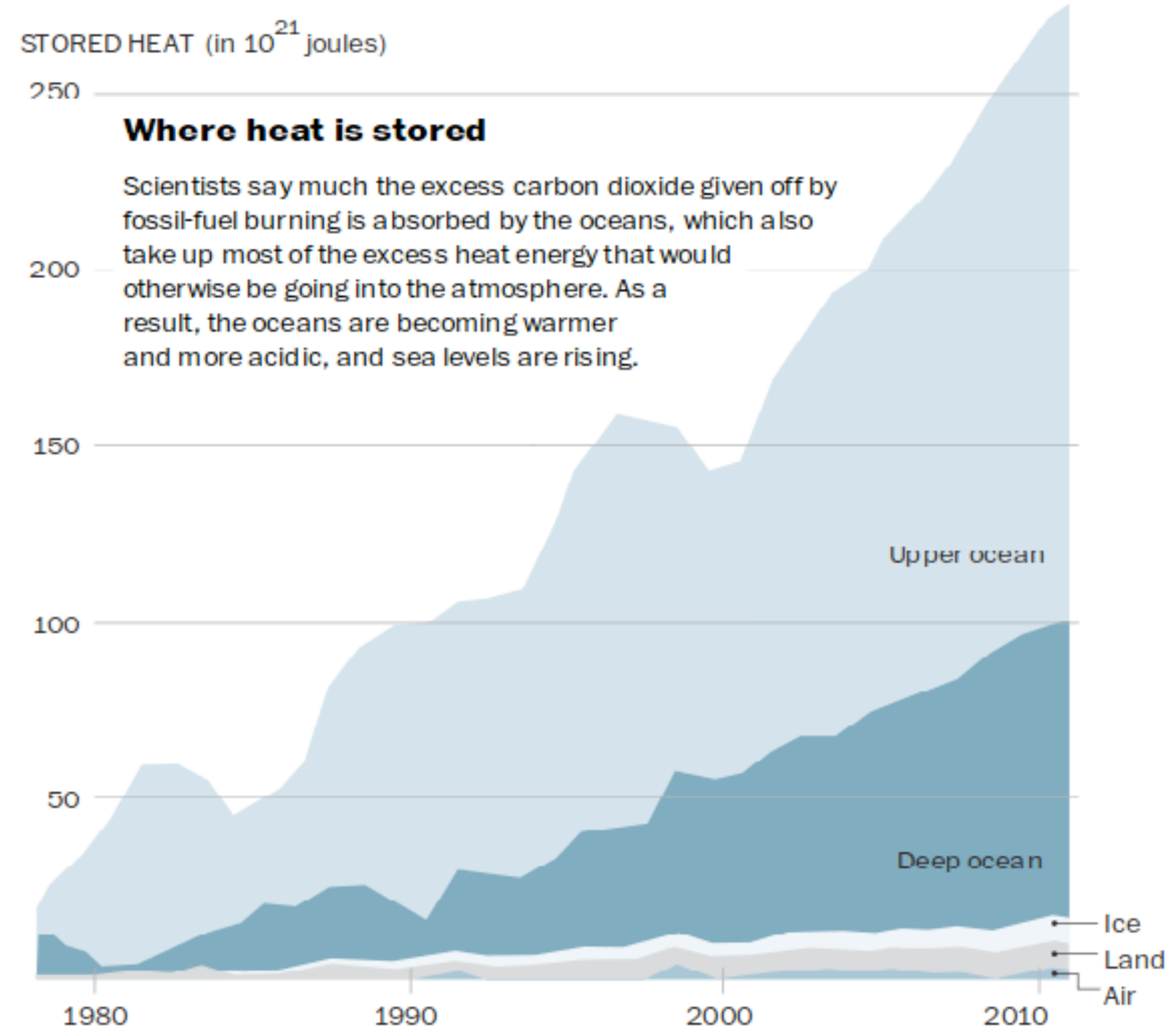
Heat storage:



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

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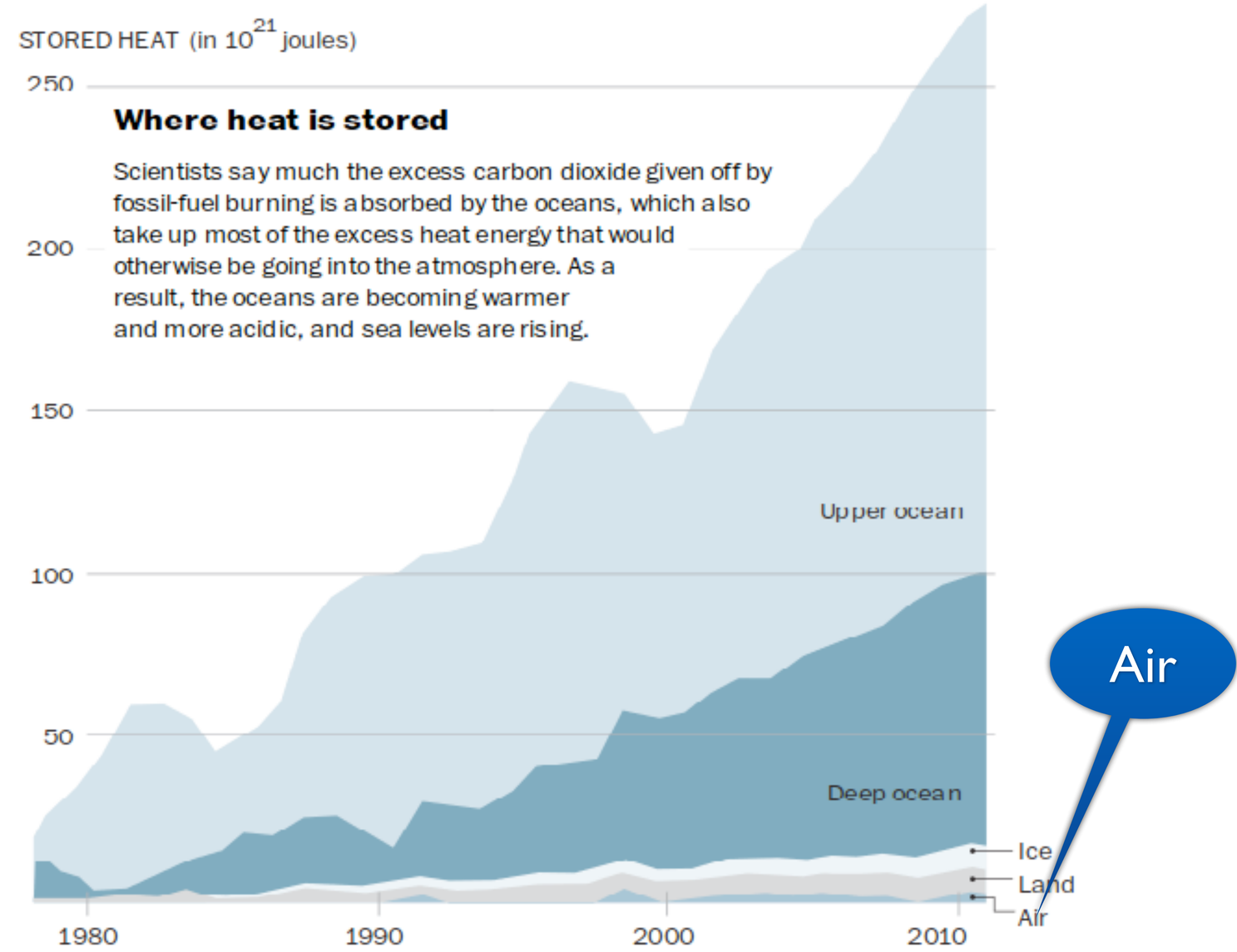

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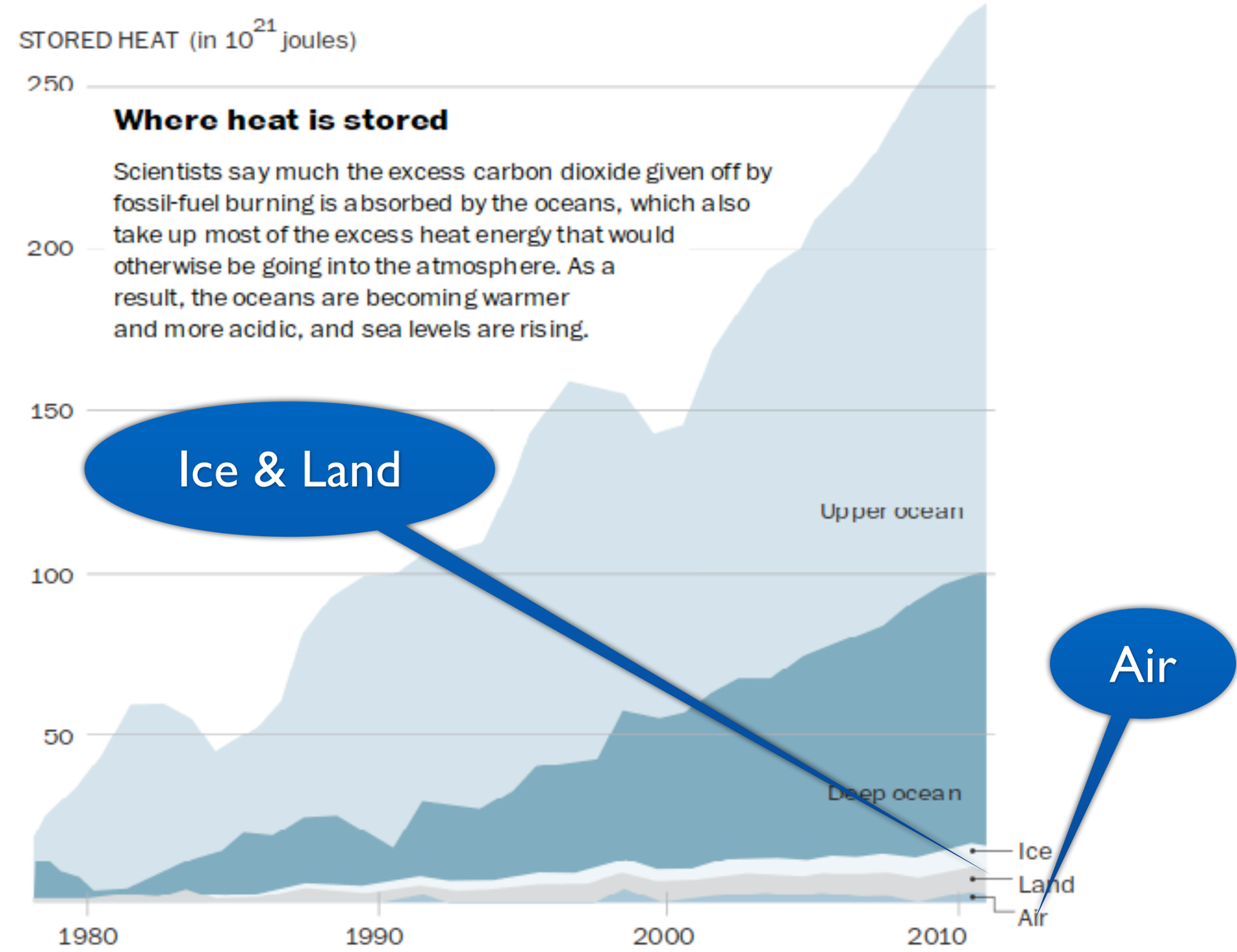

SOURCE: IPCC Fifth Assessment Synthesis Report. GRAPHIC: Patterson Clark - The Washington Post. Published Nov. 2, 2014.

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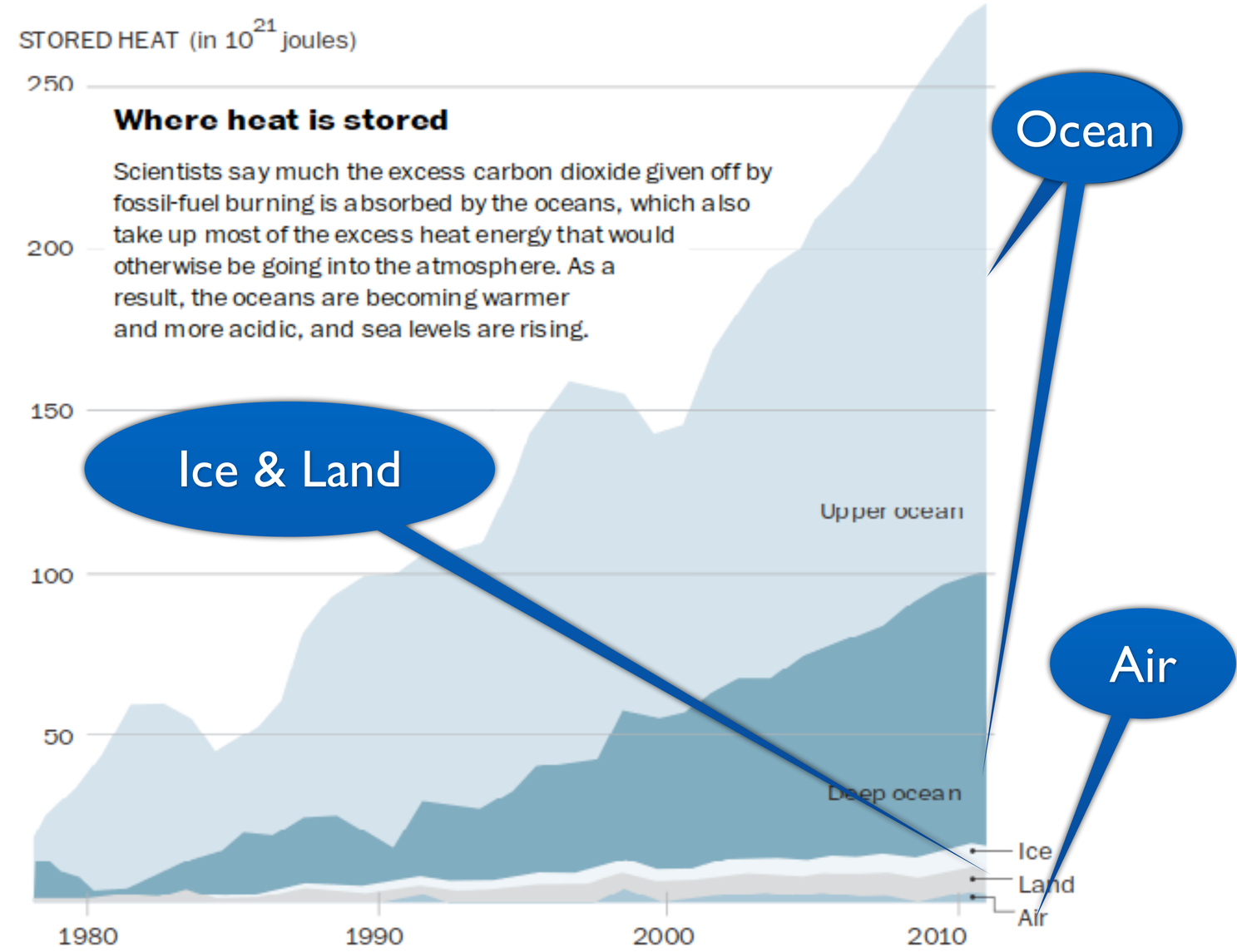

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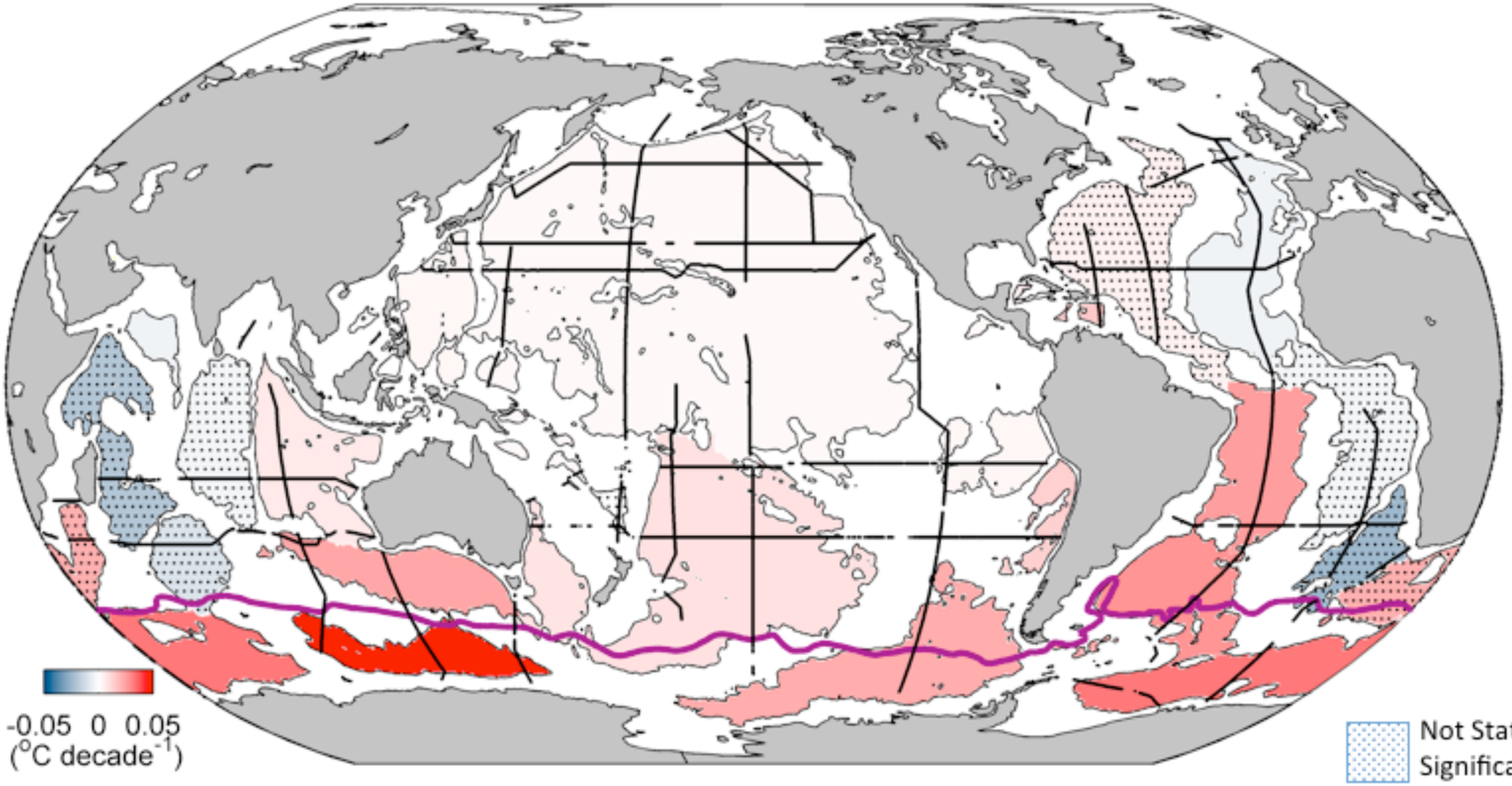

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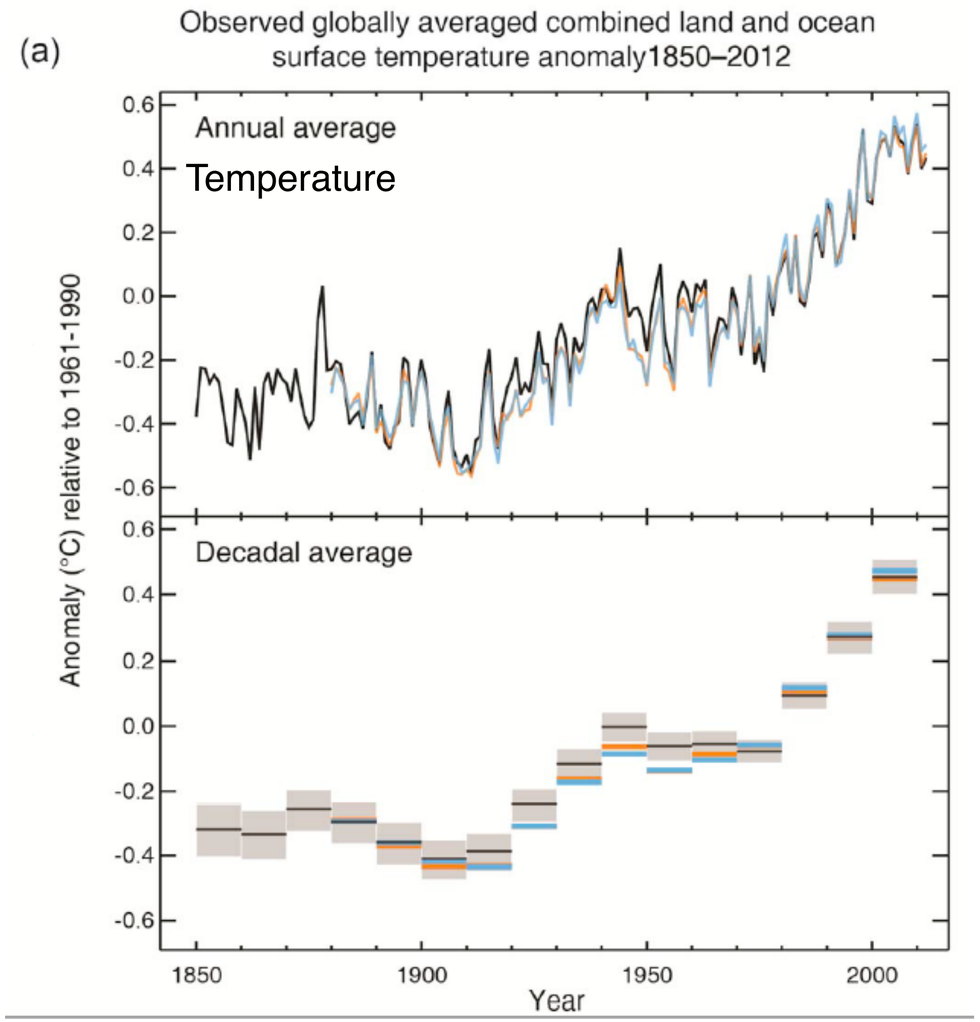

IPCC, 2013

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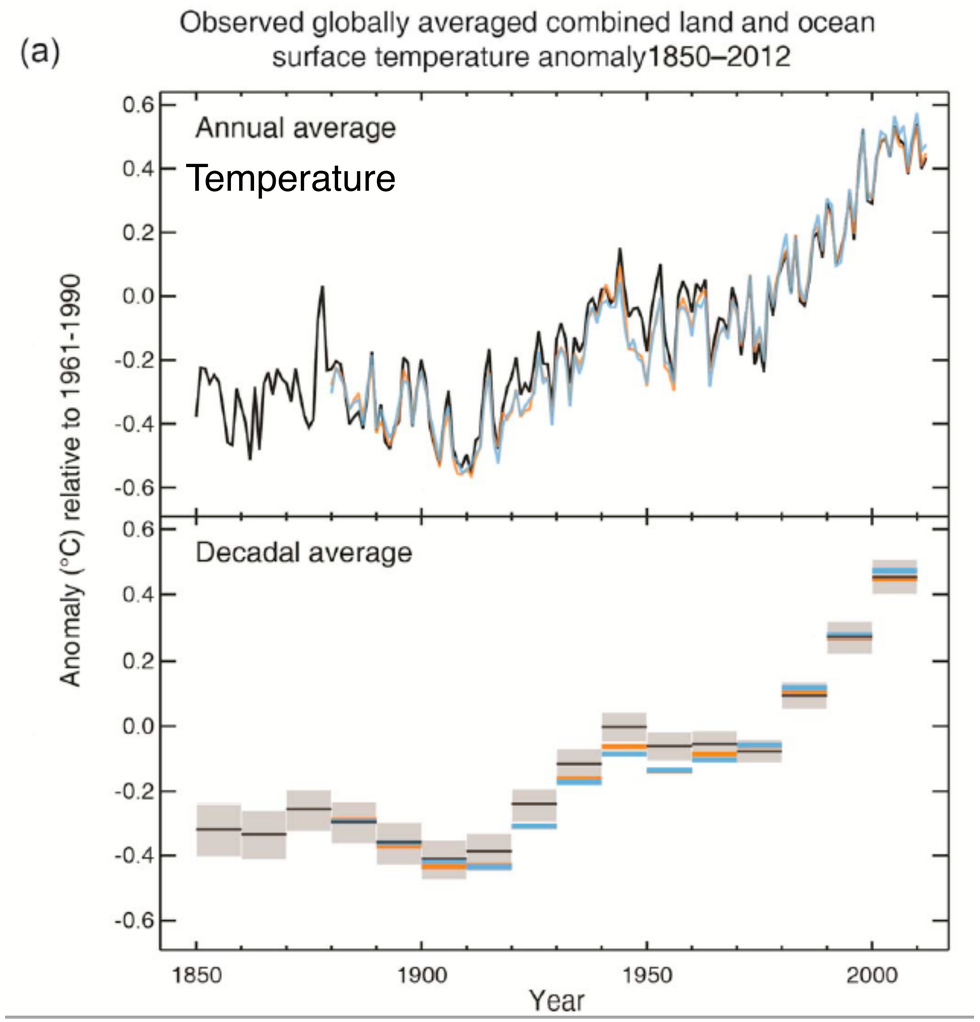

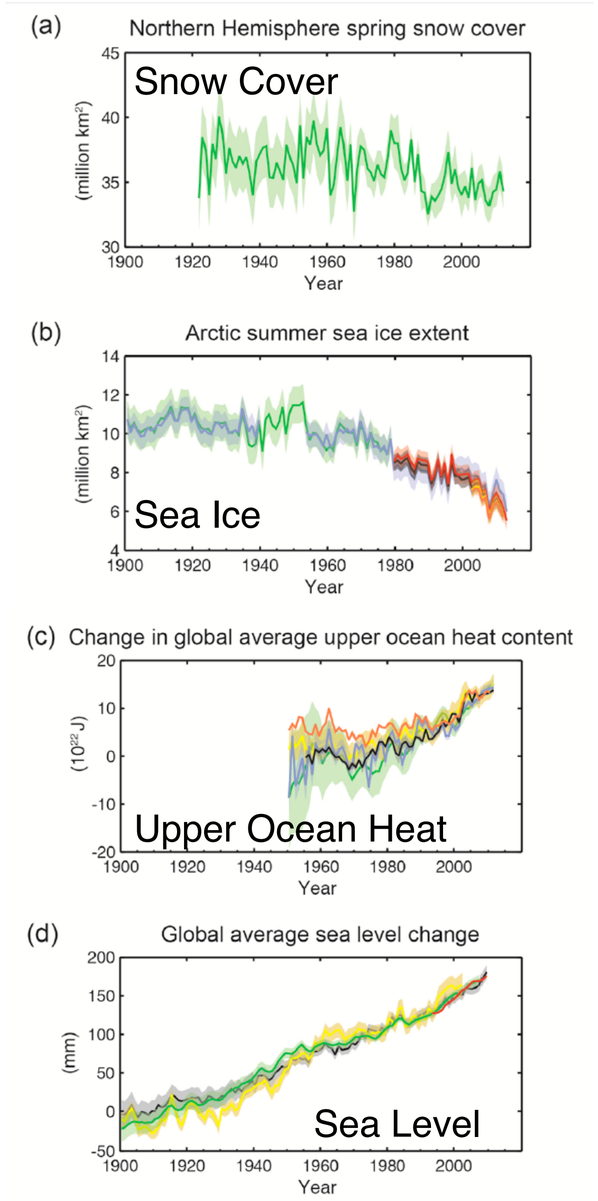

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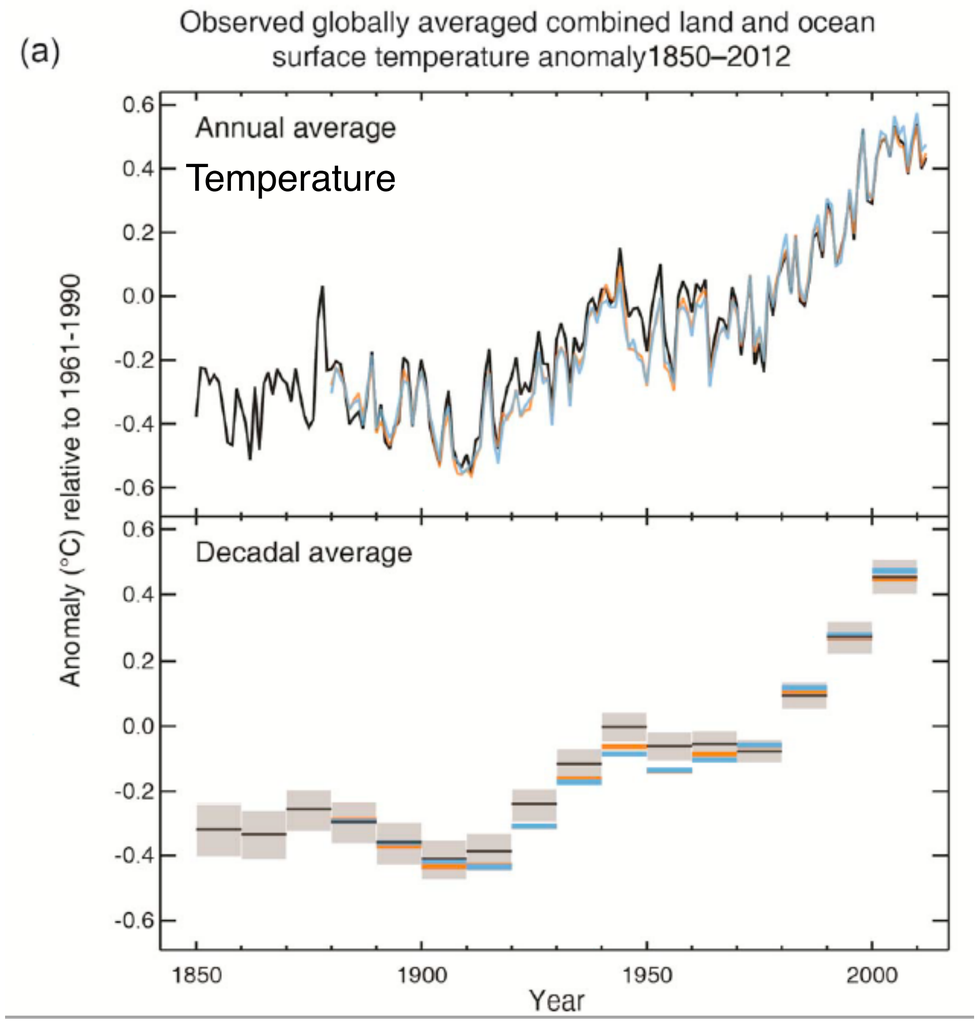

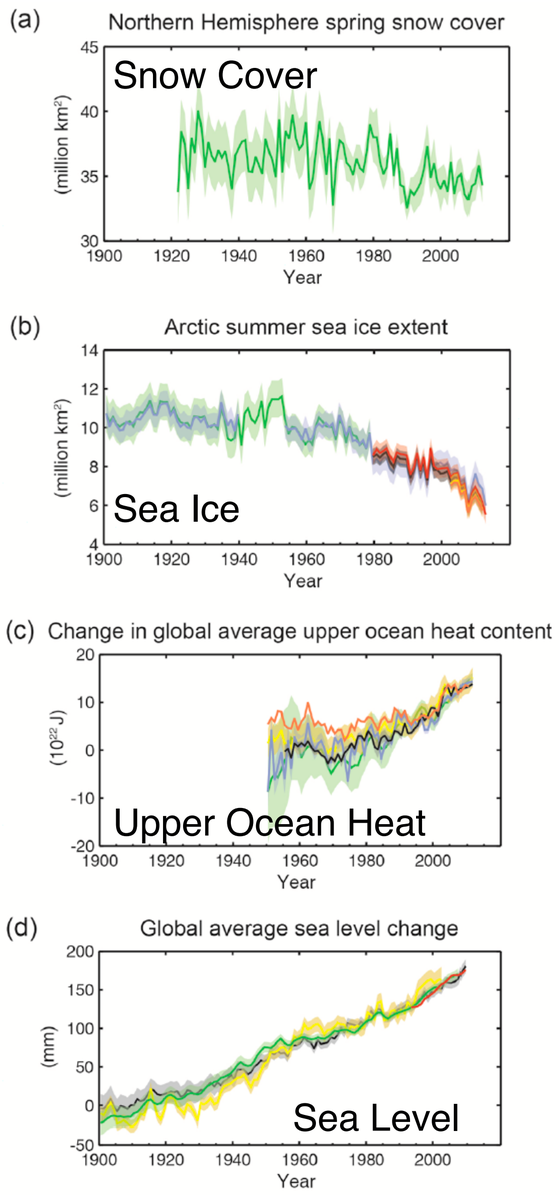

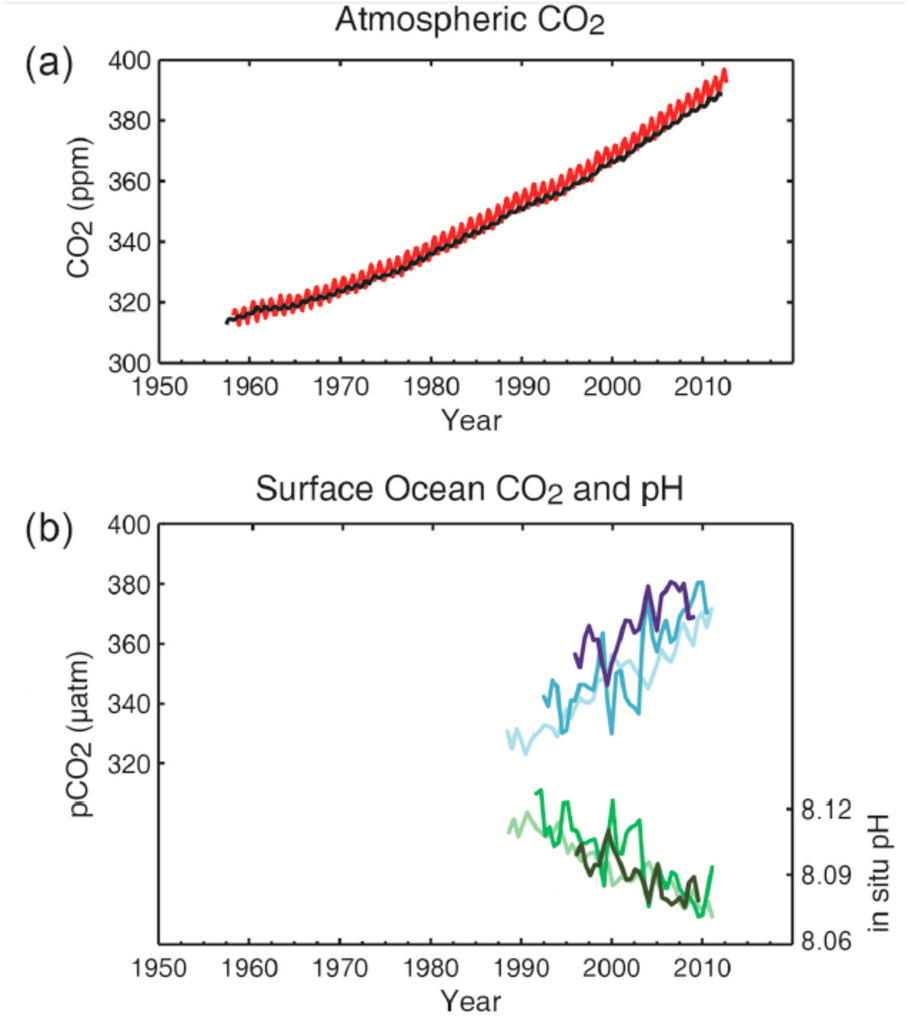

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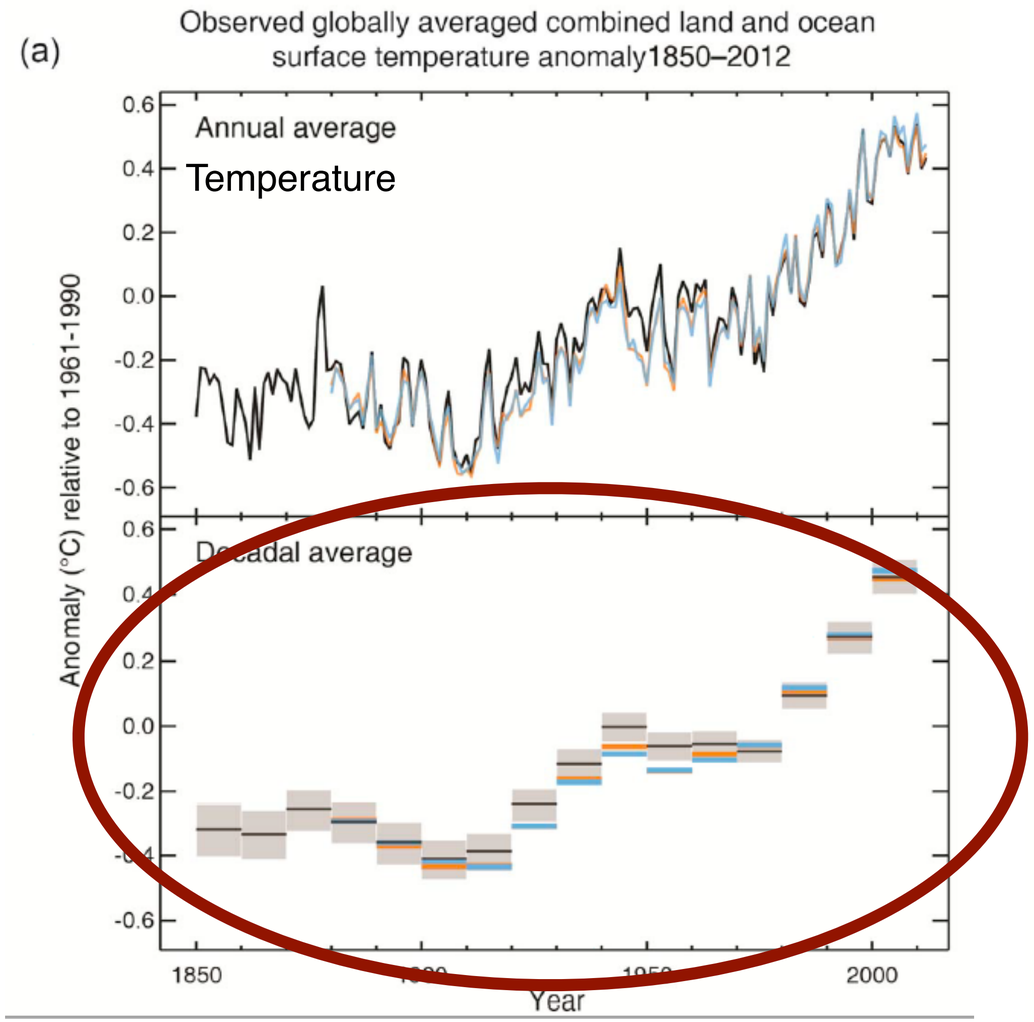

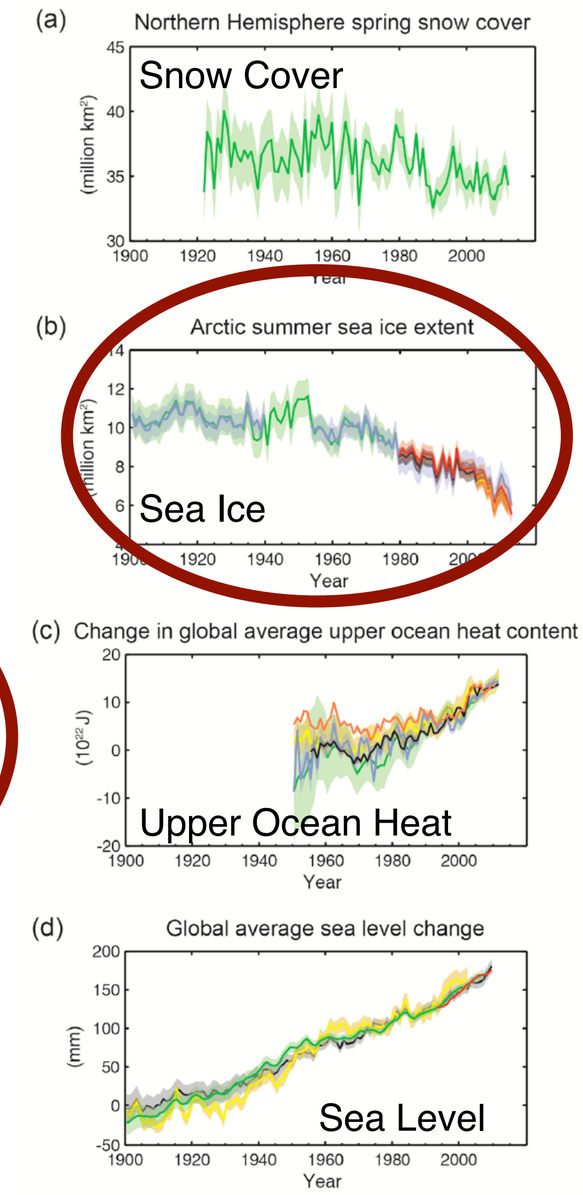

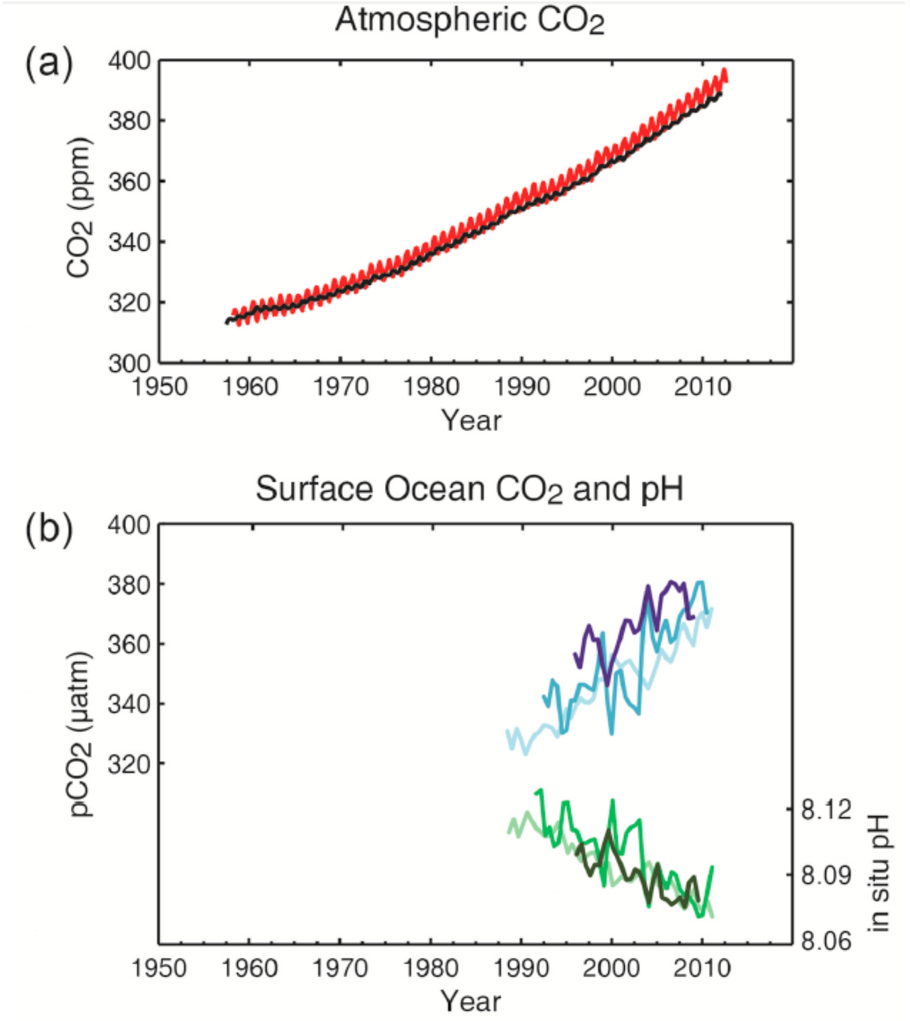

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Marcott et al., 2013

Kinnart et al., 2011

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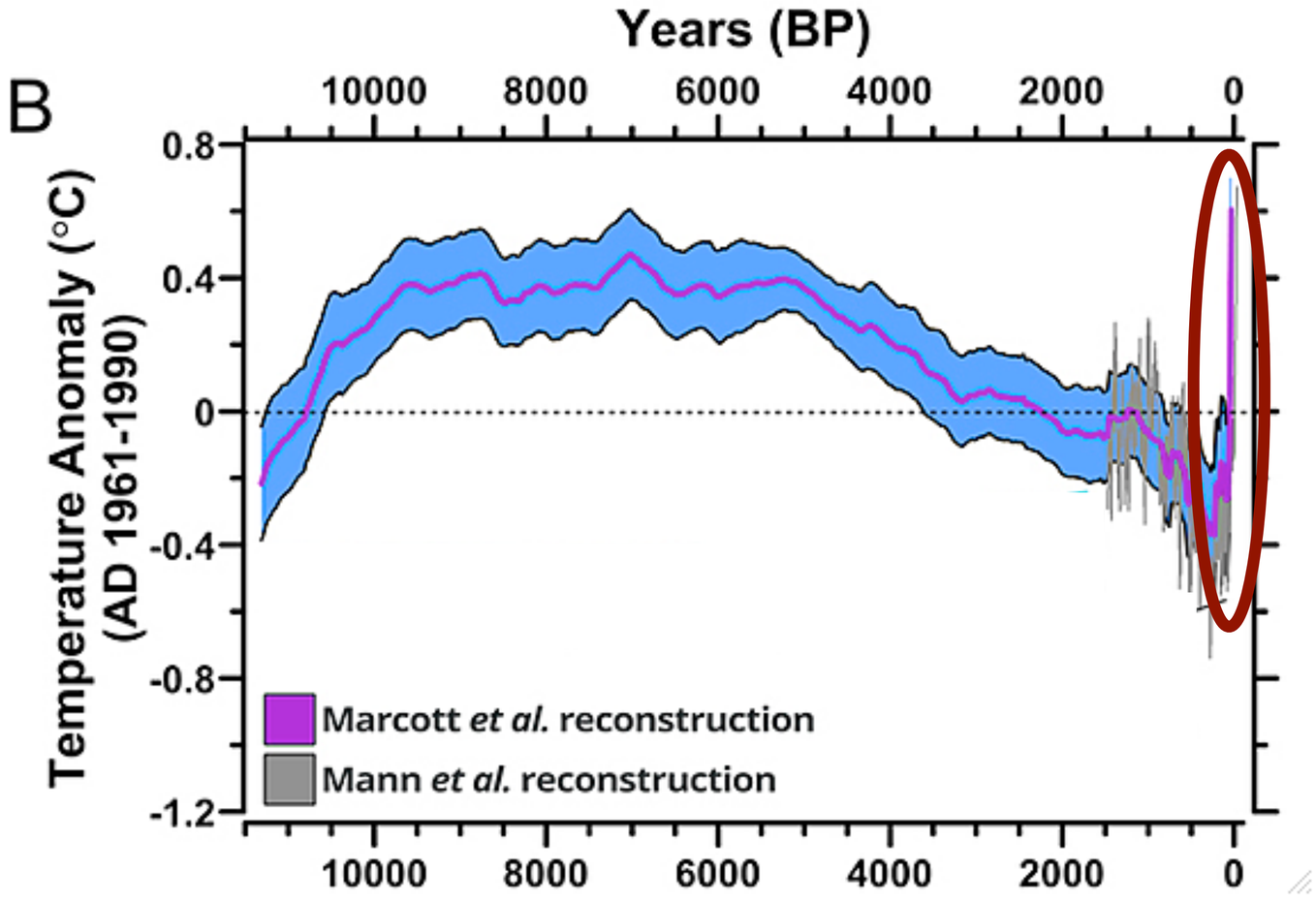

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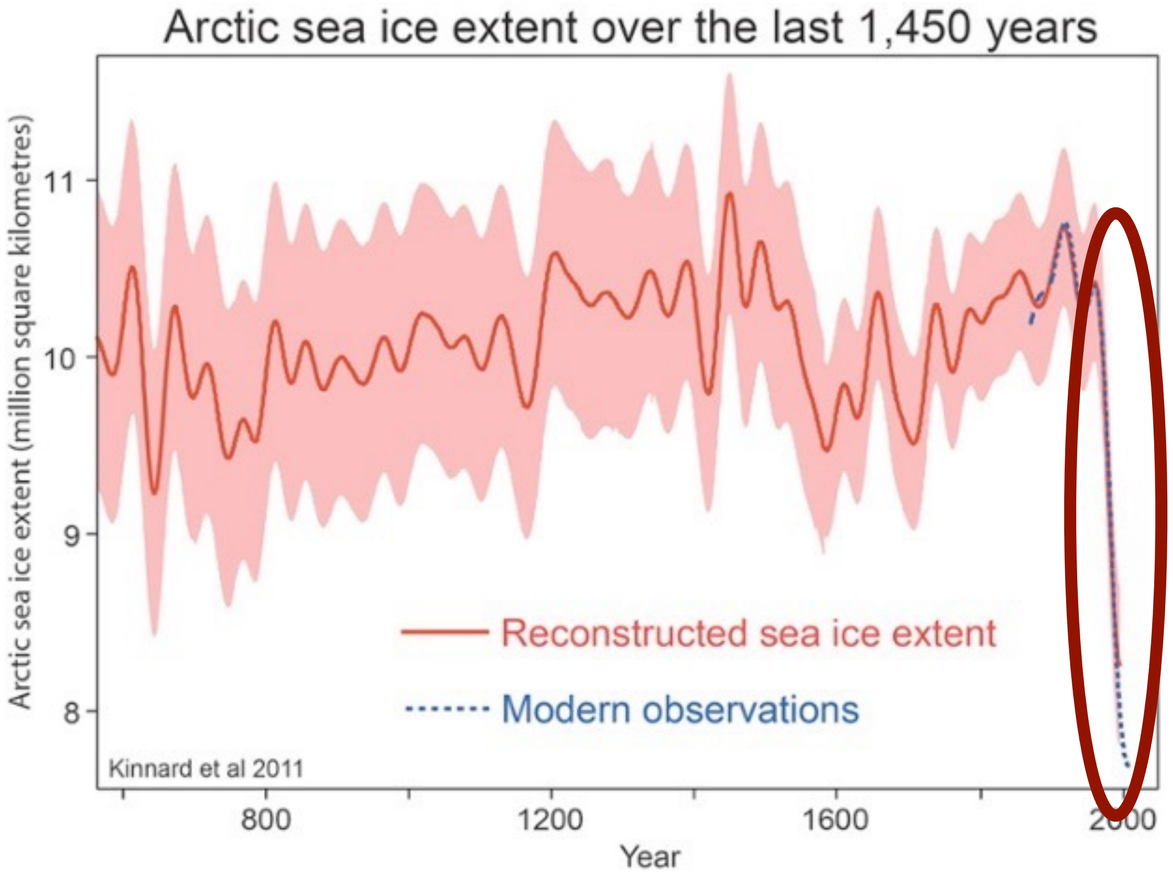

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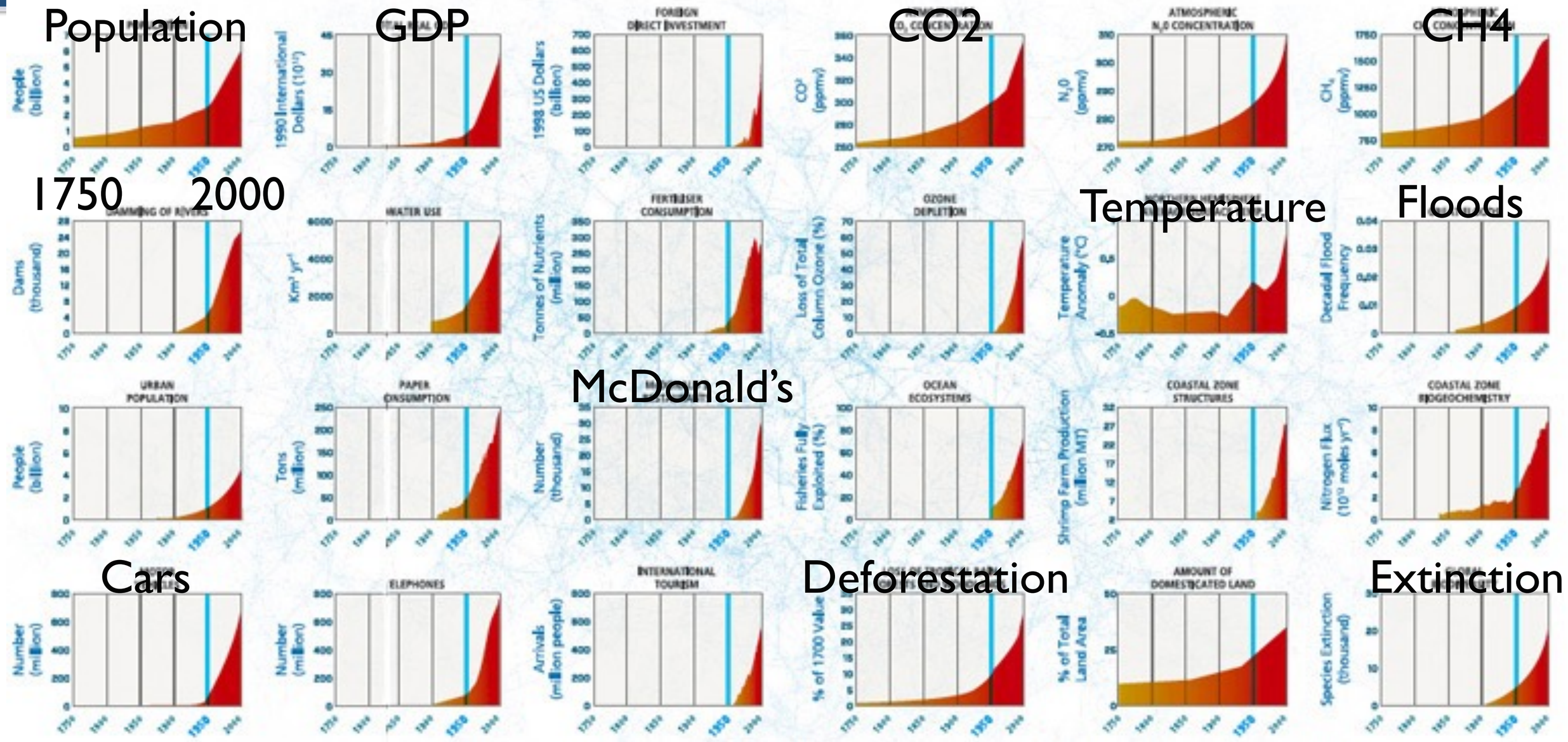

Figure 1. An enterprise to reckon with. Human nanipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP's Great Acceleration graphs show. Modified after Steffen W *et al.* (2004).

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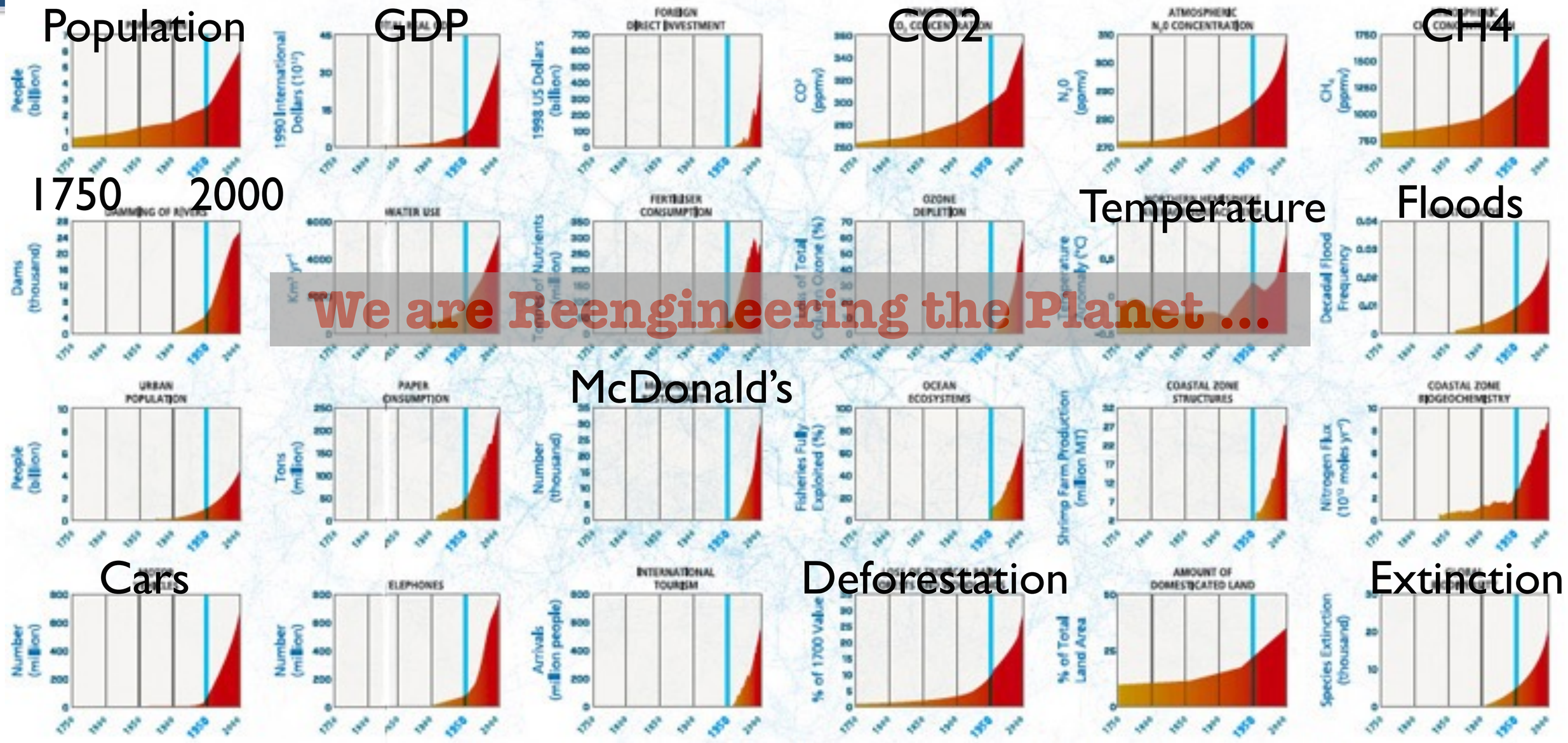

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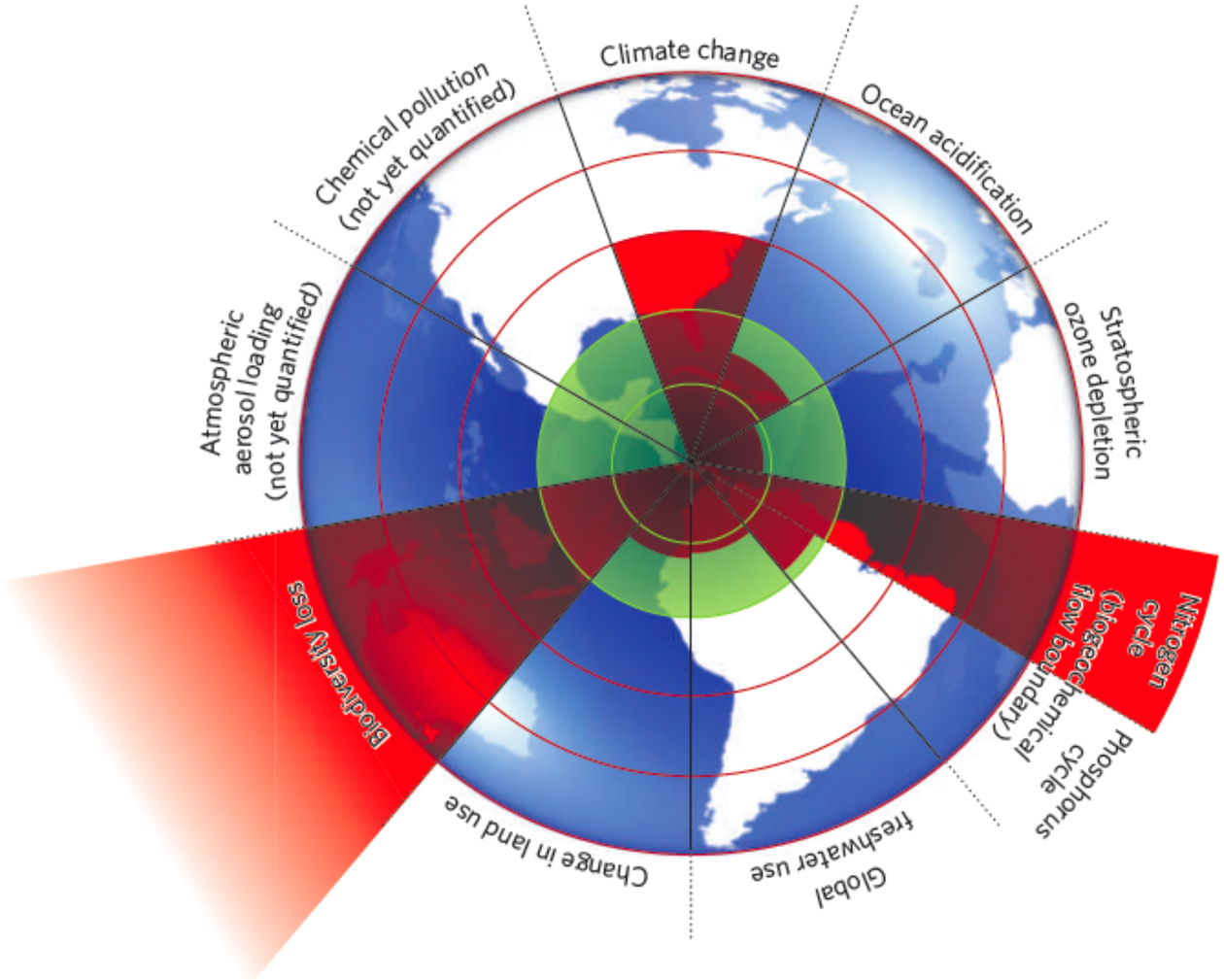

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

We are moving out of the Holocene and the "safe operating space for humanity" (Rockstroem et al., 2009):

Climate Change (***)

Ocean acidification (**)

Stratospheric ozone depletion (*)

Nitrogen (******) and Phosphorous cycles (**)

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Atmospheric aerosols (?)

Chemical pollution (?)

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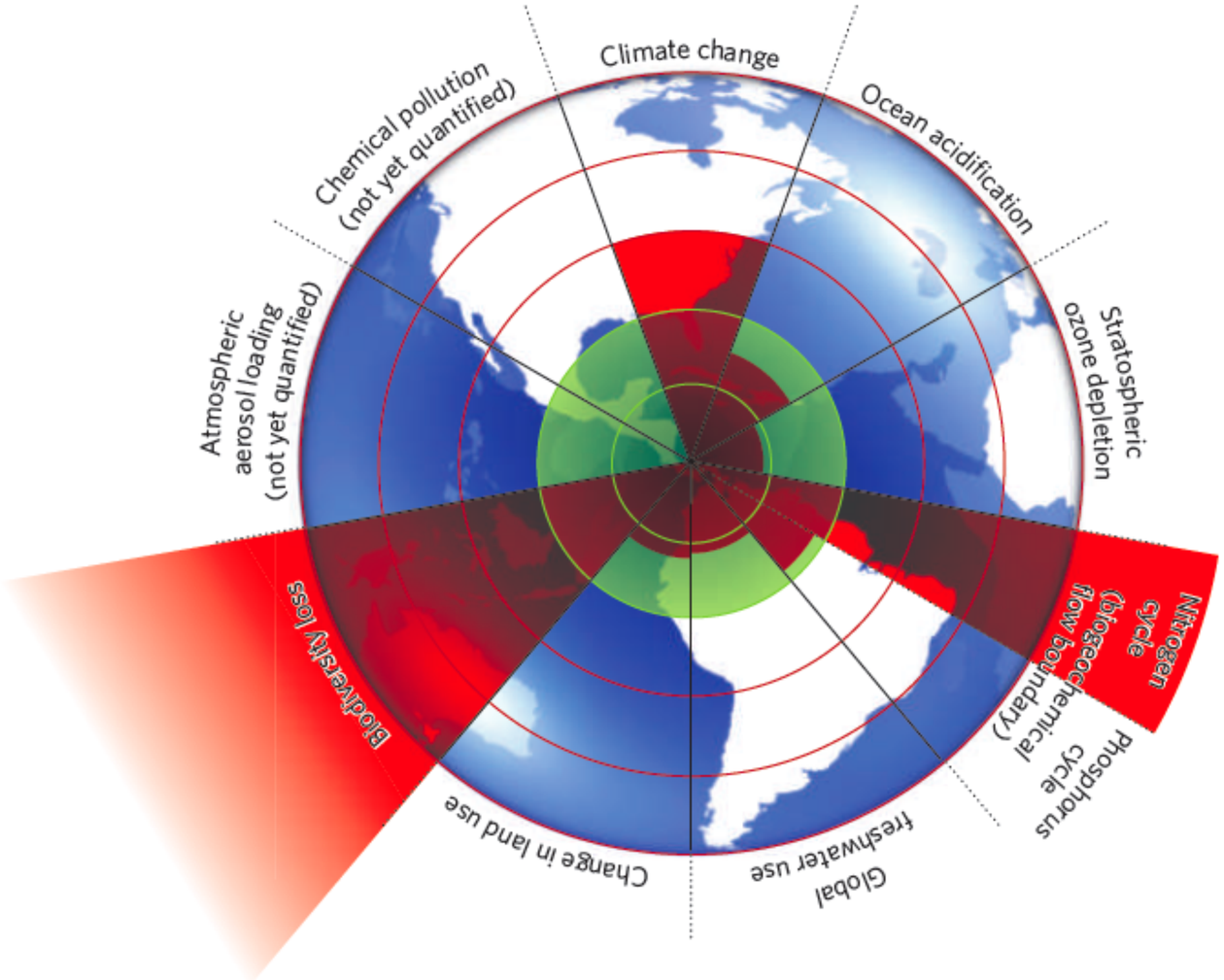

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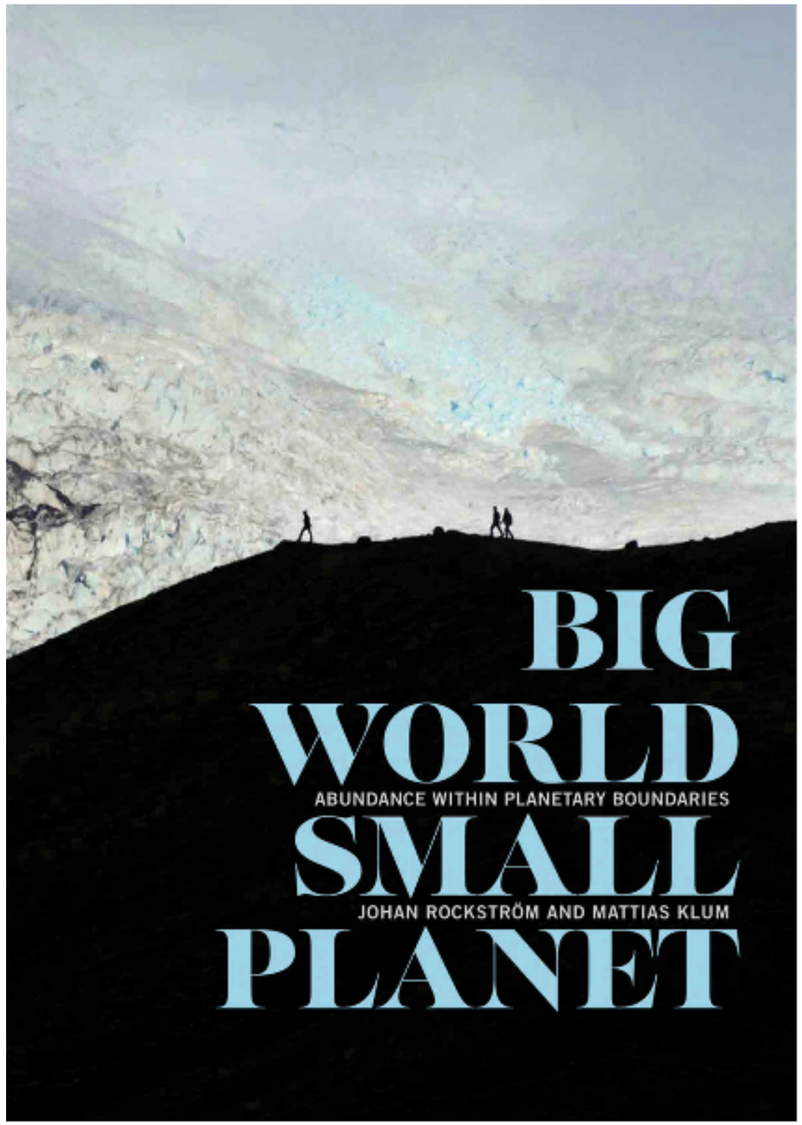

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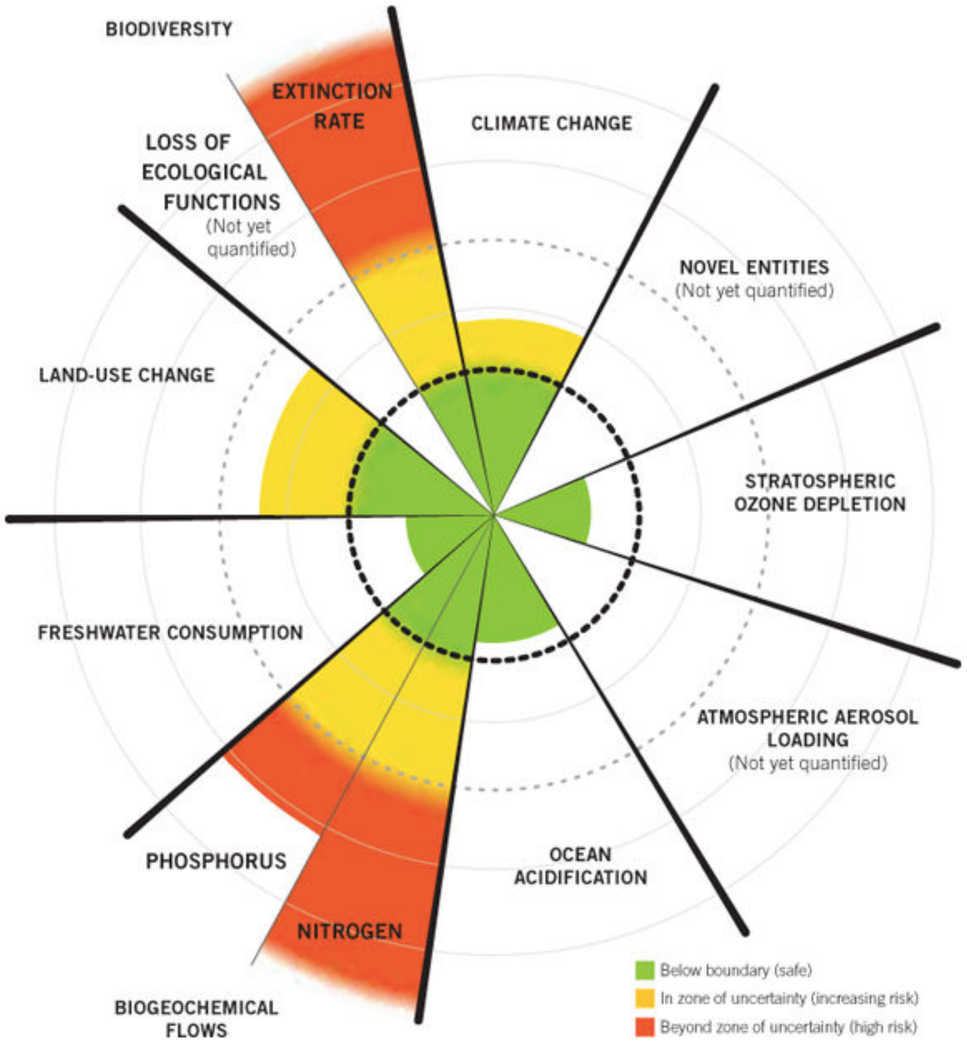

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Key Points

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The Diagnosis: Leaving the “Safe Operating Space”

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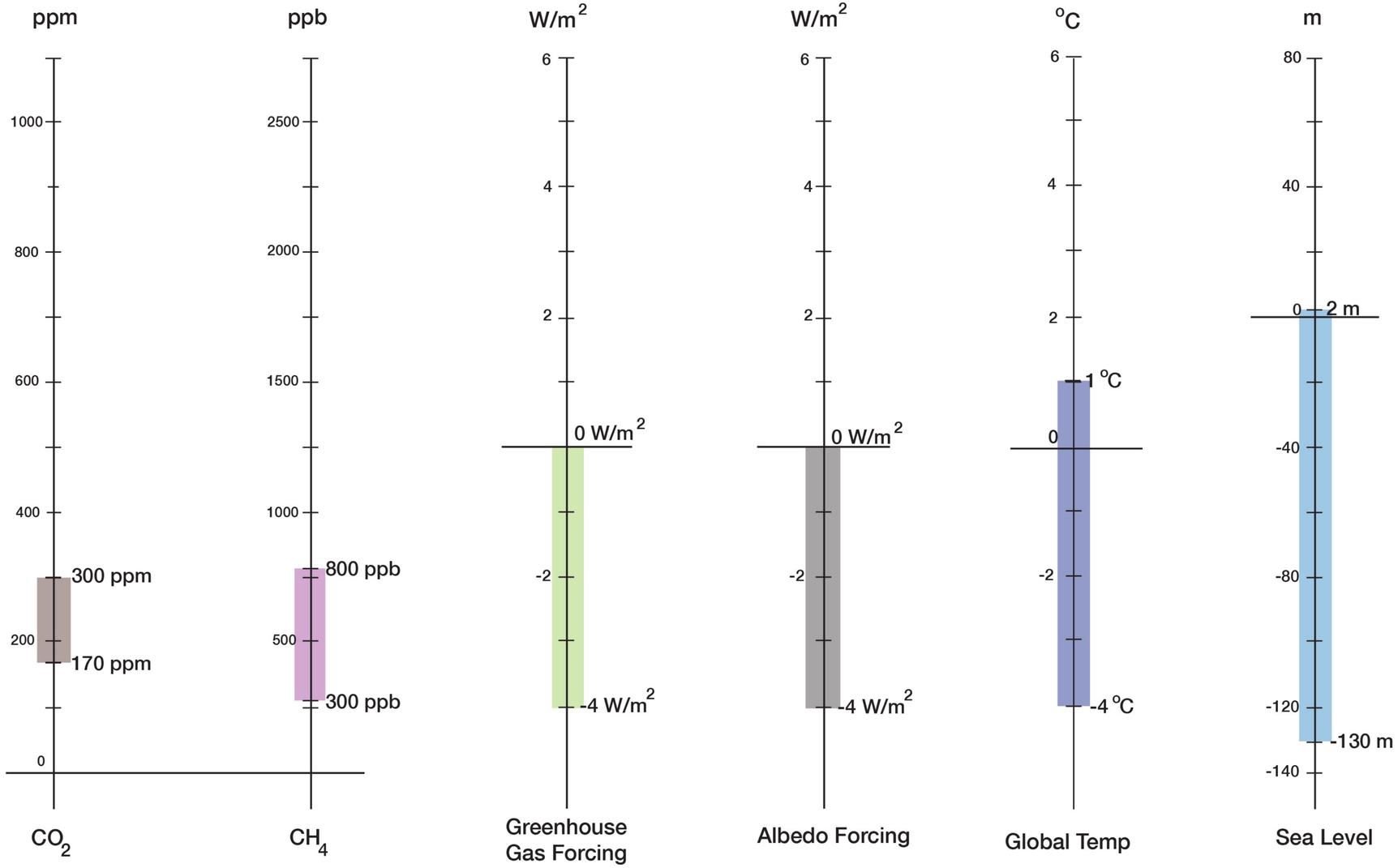
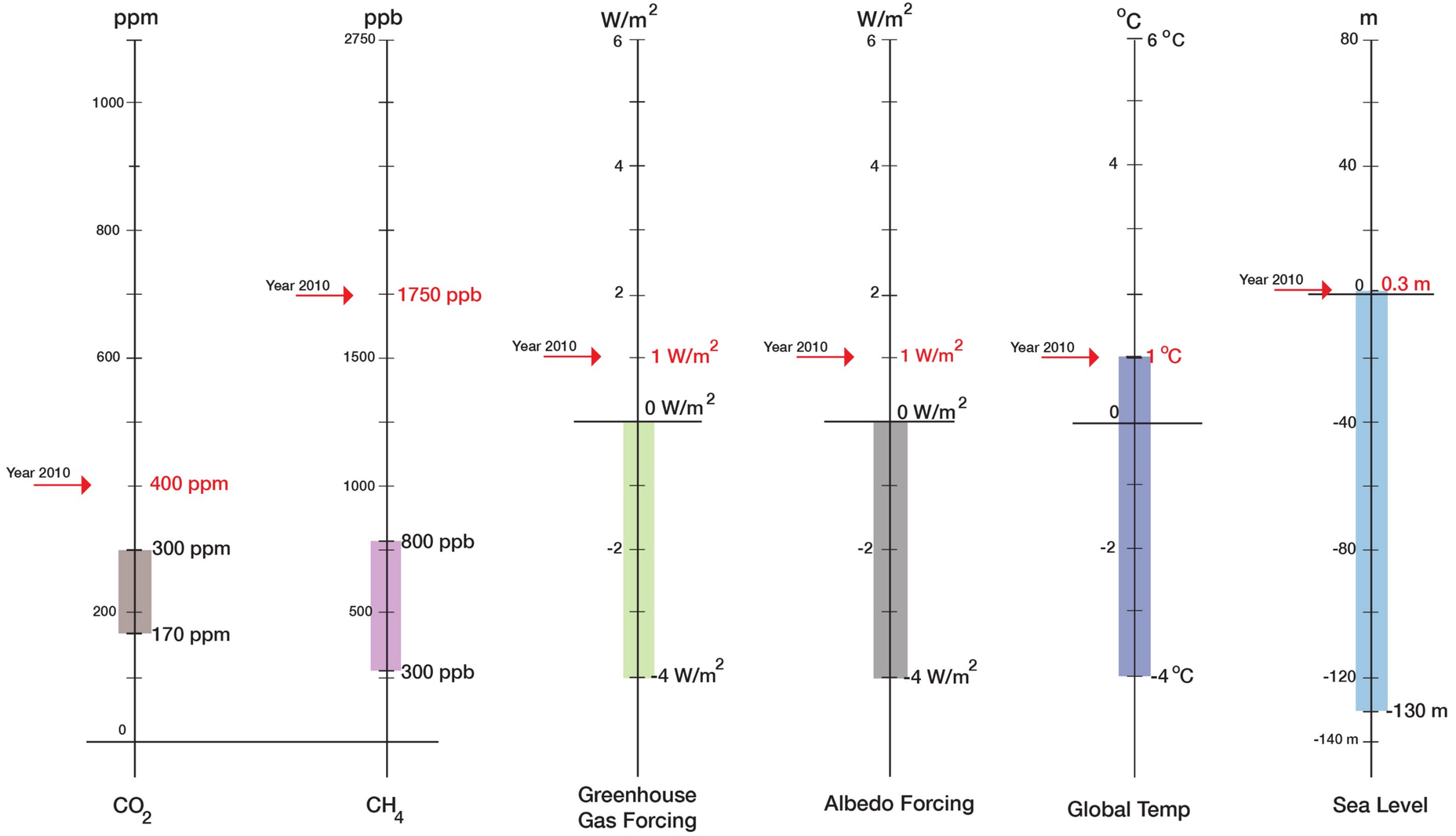


"Normal Range"
(800,000 years)

The Diagnosis: Leaving the "Safe Operating Space"

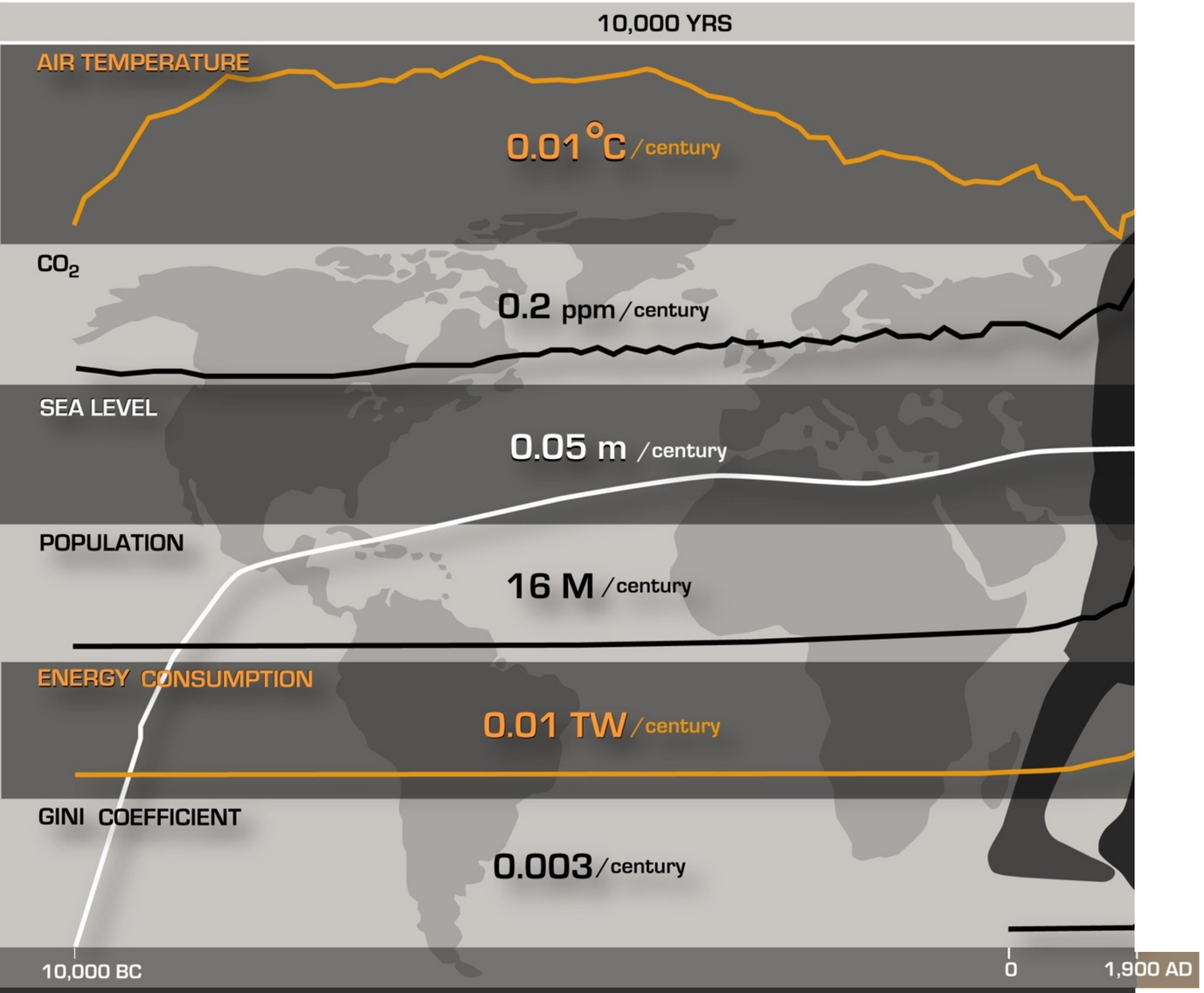


"Current State"

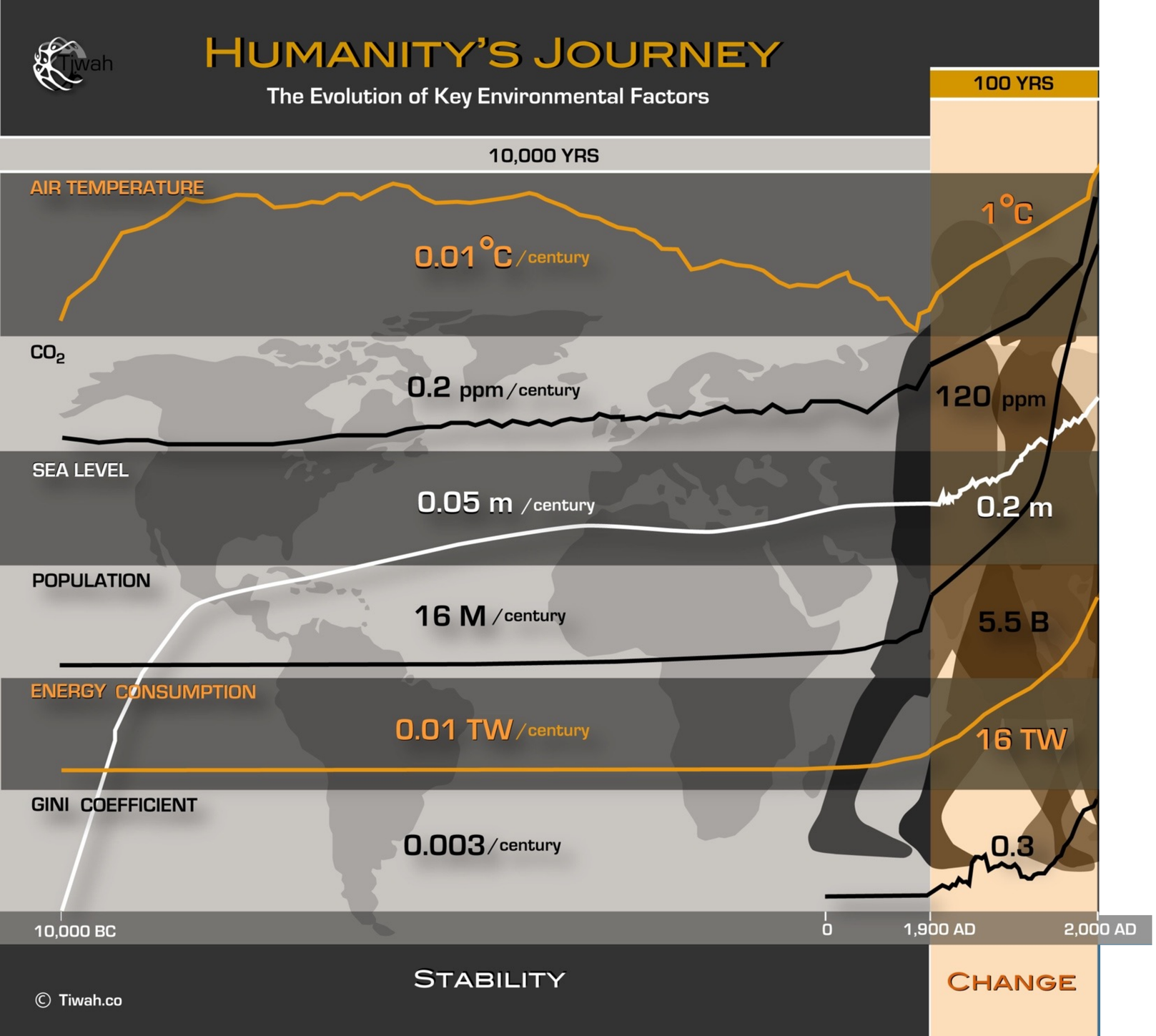
"Normal Range"
(800,000 years)

Humanity's Journey

The Evolution of Key Environmental Factors



Stability


Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
100 YRS
10,000 YRS
AIR TEMPERATURE
0.01 °C /century
1 °C
CO_2
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
0
1,900 AD
2,000 AD
STABILITY
CHANGE
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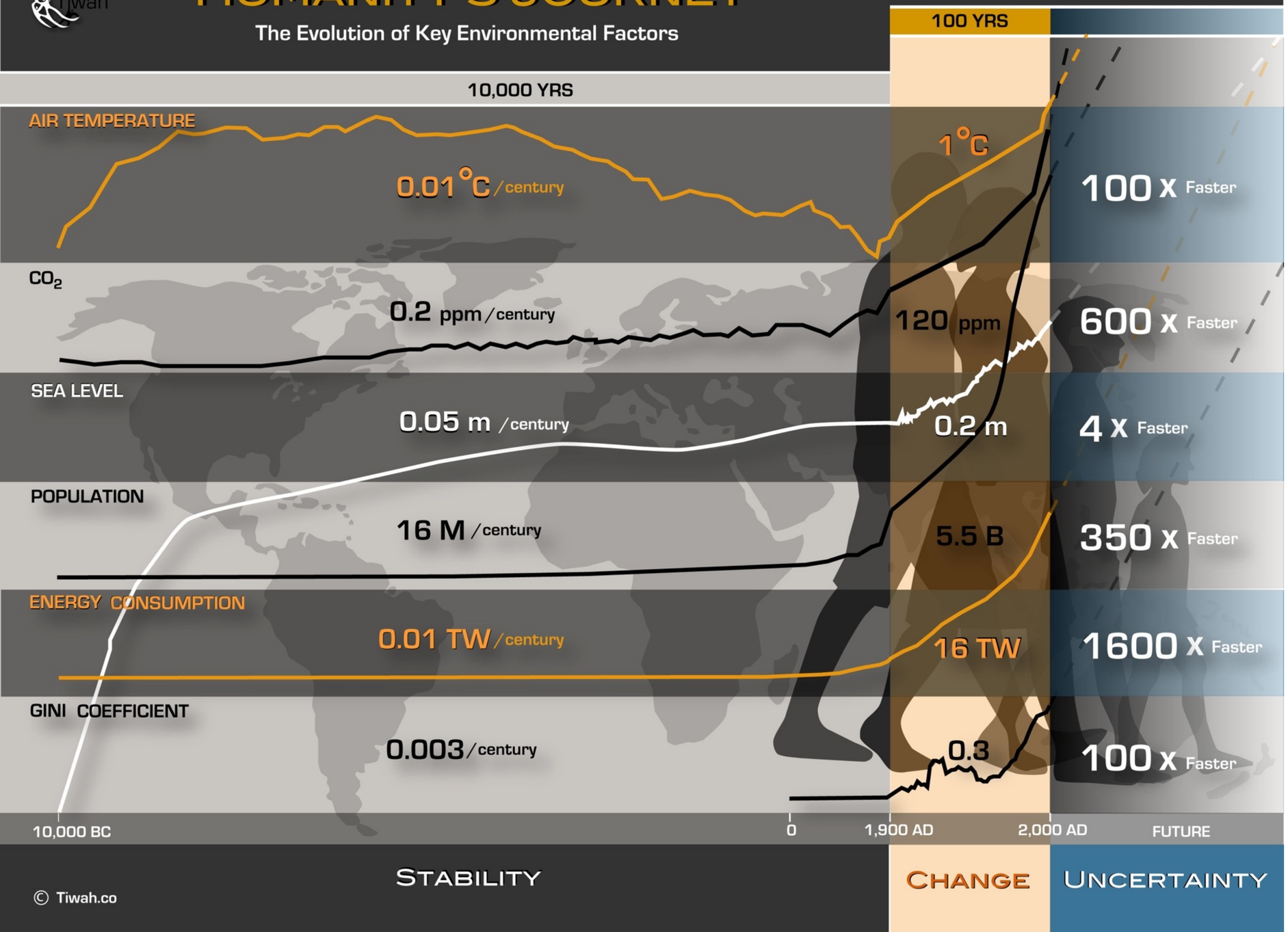
Humanity's Journey

The Evolution of Key Environmental Factors



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 — 0	1,900 AD — 2,000 AD	FUTURE
	STABILITY	CHANGE	UNCERTAINTY

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STABILITY — CHANGE — UNCERTAINTY

Holocene: Stability

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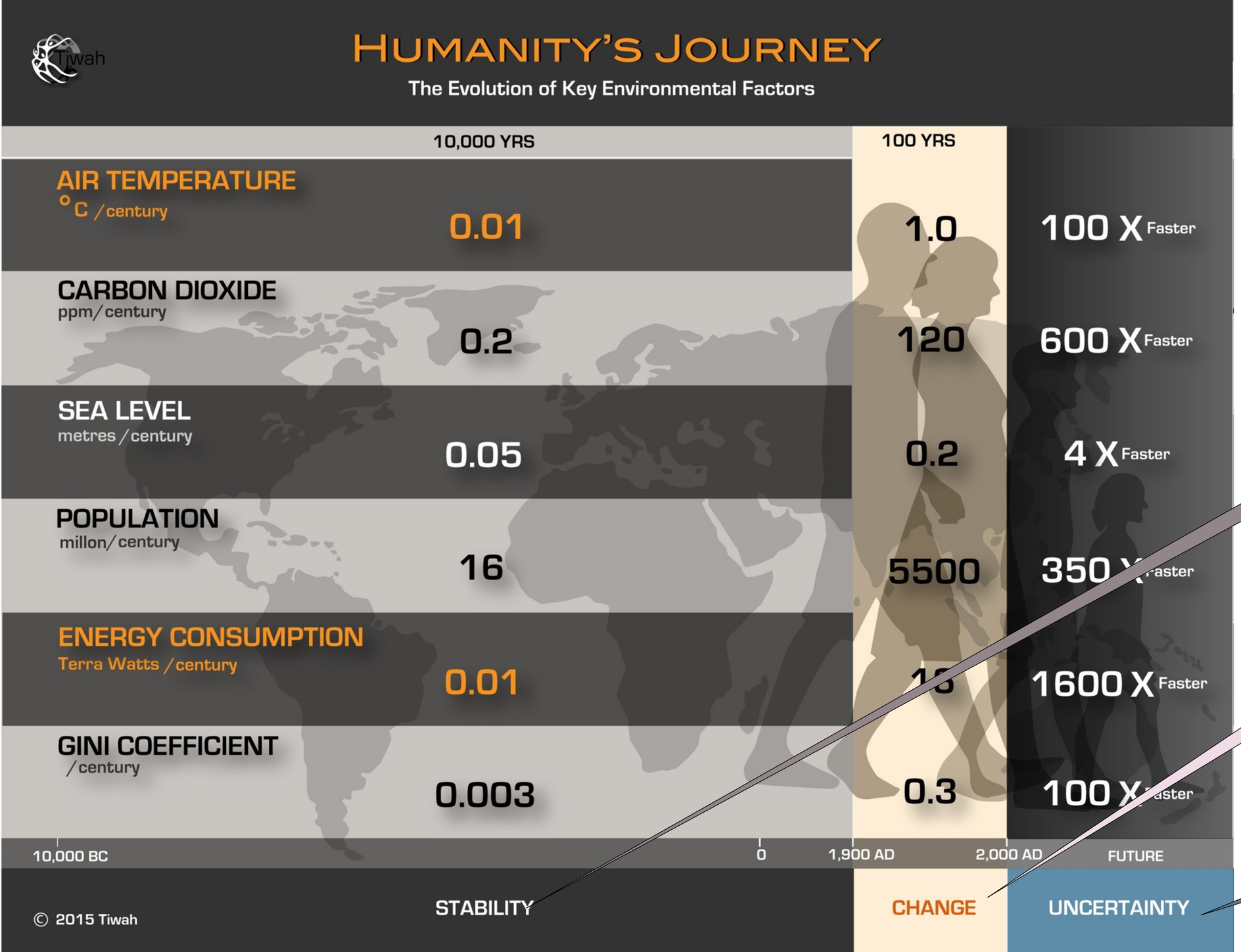
STABILITY — CHANGE — UNCERTAINTY

Holocene: Stability

20th and 21st Century: Change, imbalance



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The system is already now outside the “normal range” and in the dynamic transition to the Post-Holocene; we have increasing imbalances

The Prognosis: Anticipating Surprises

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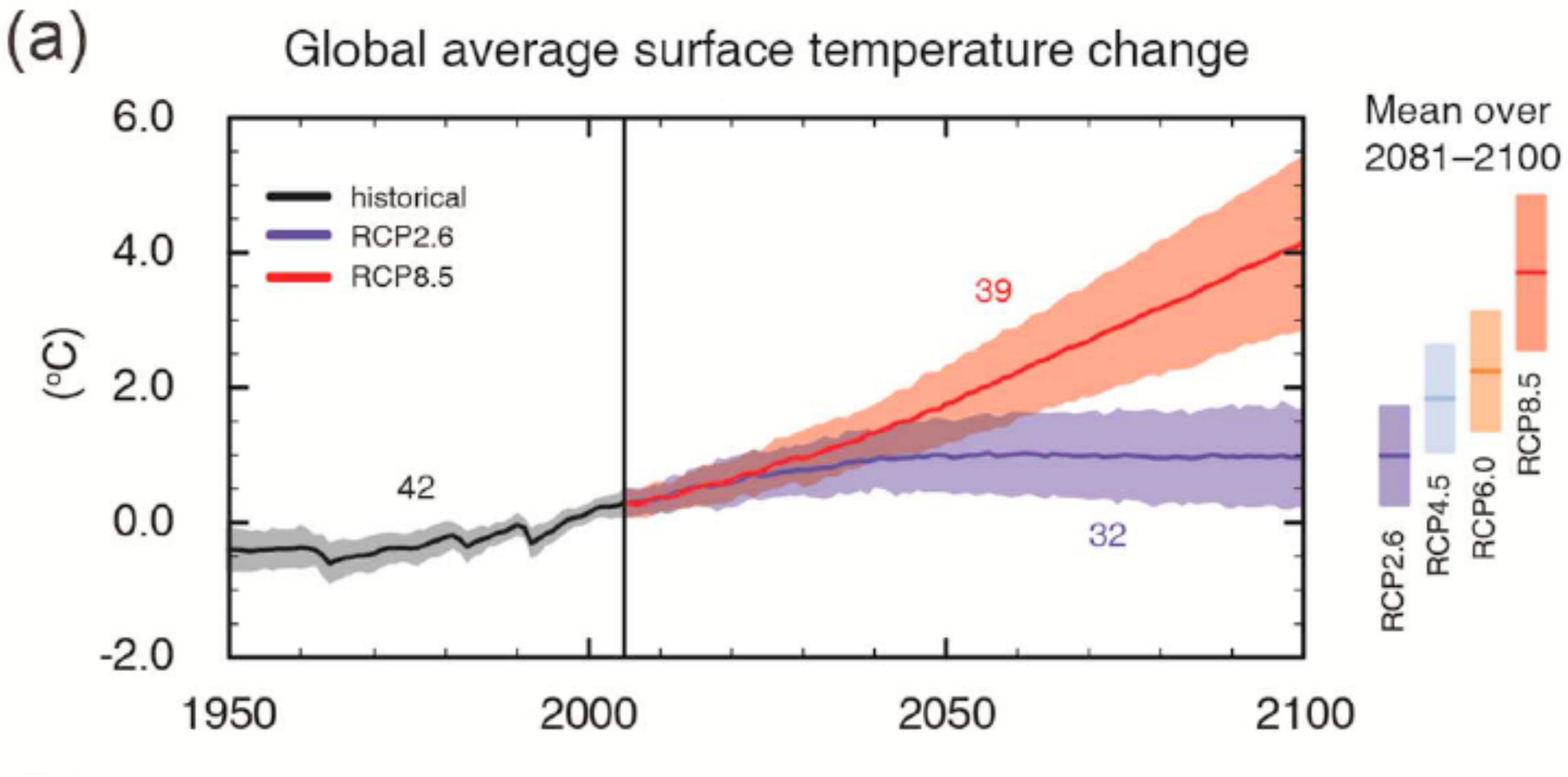

IPCC, 2013

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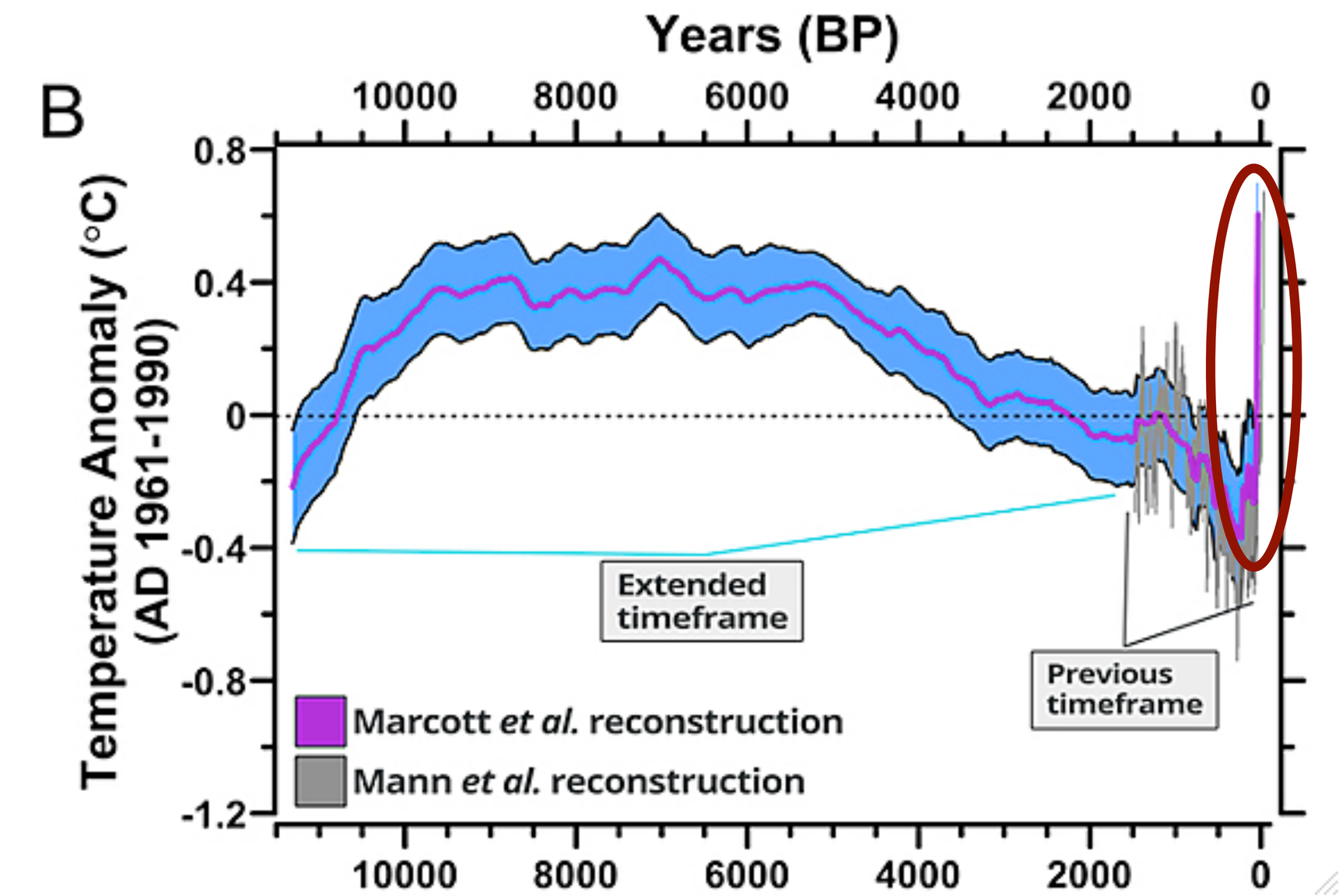


Marcott et al., 2013

The Prognosis: Anticipating Surprises

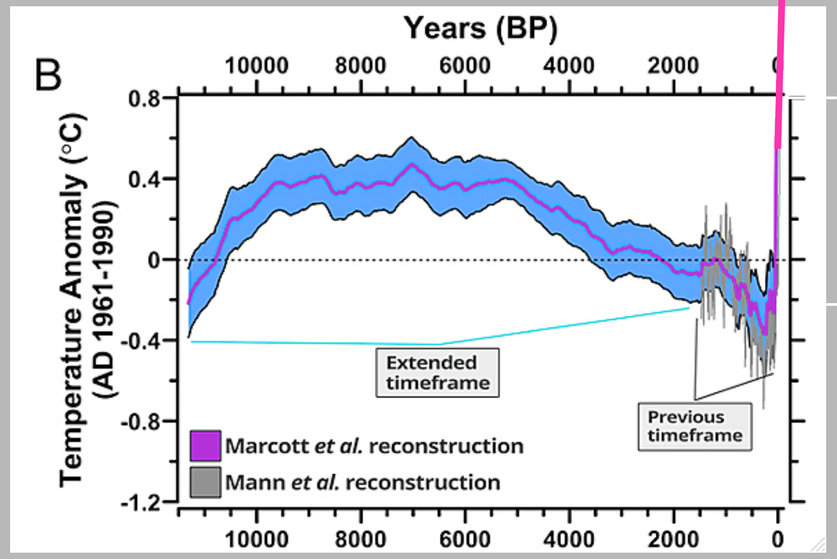
4

3

2

1°C

IPCC Assessment:
Very Likely by 2100



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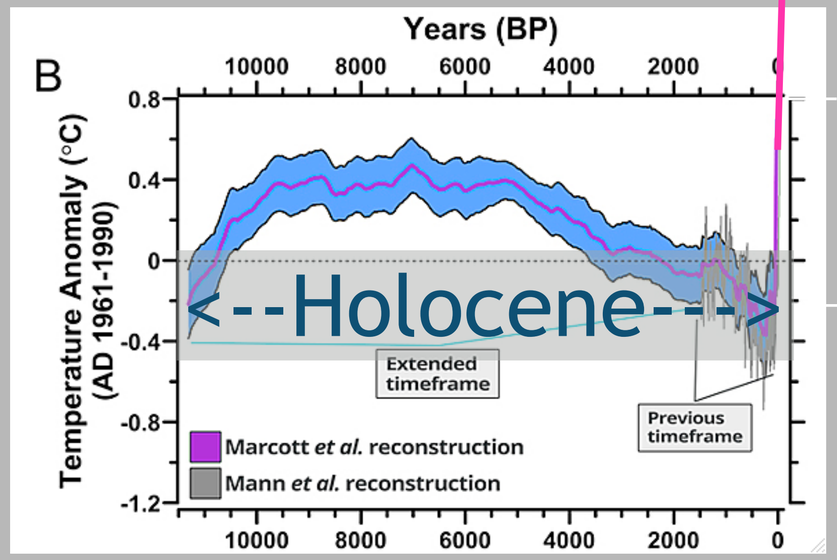

<--Post-Holocene

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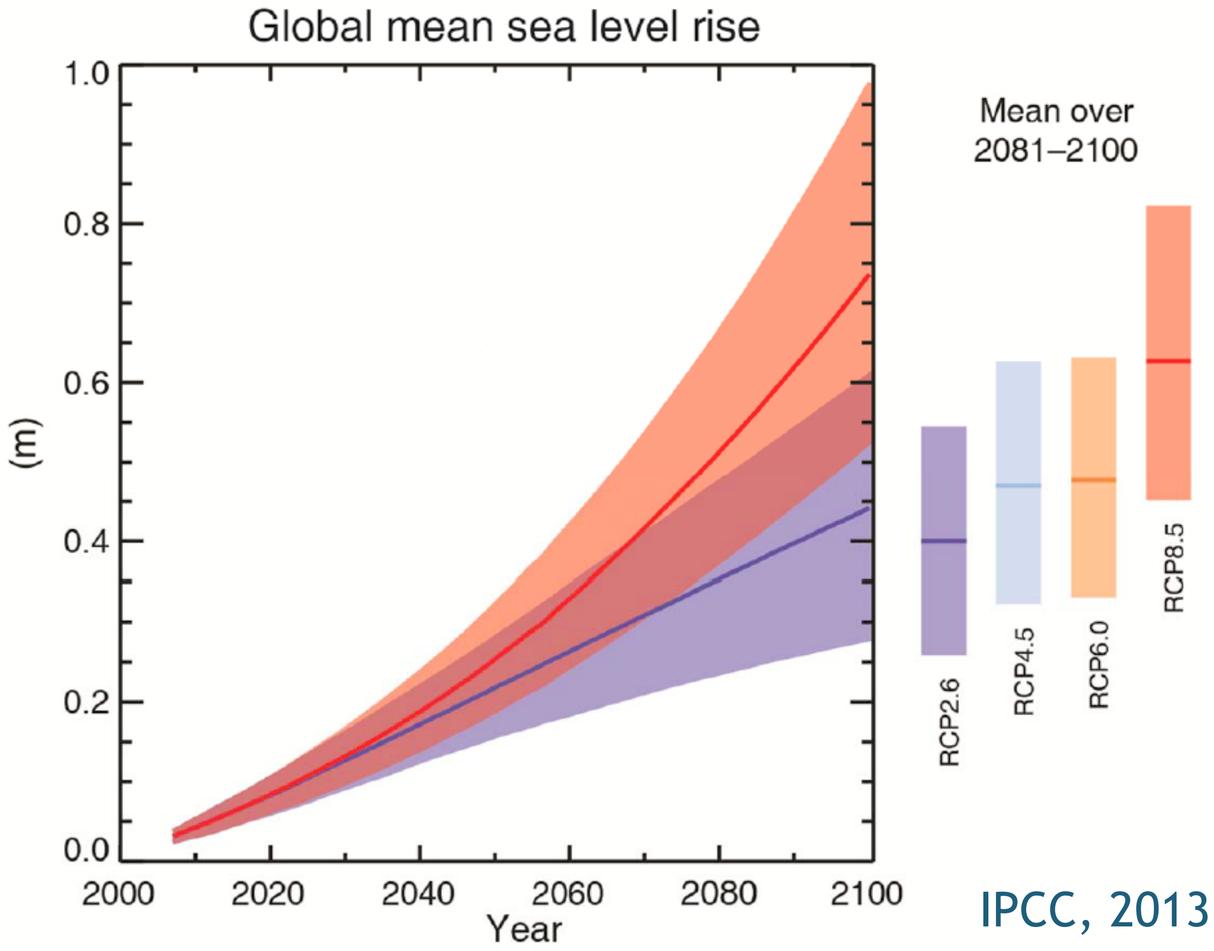

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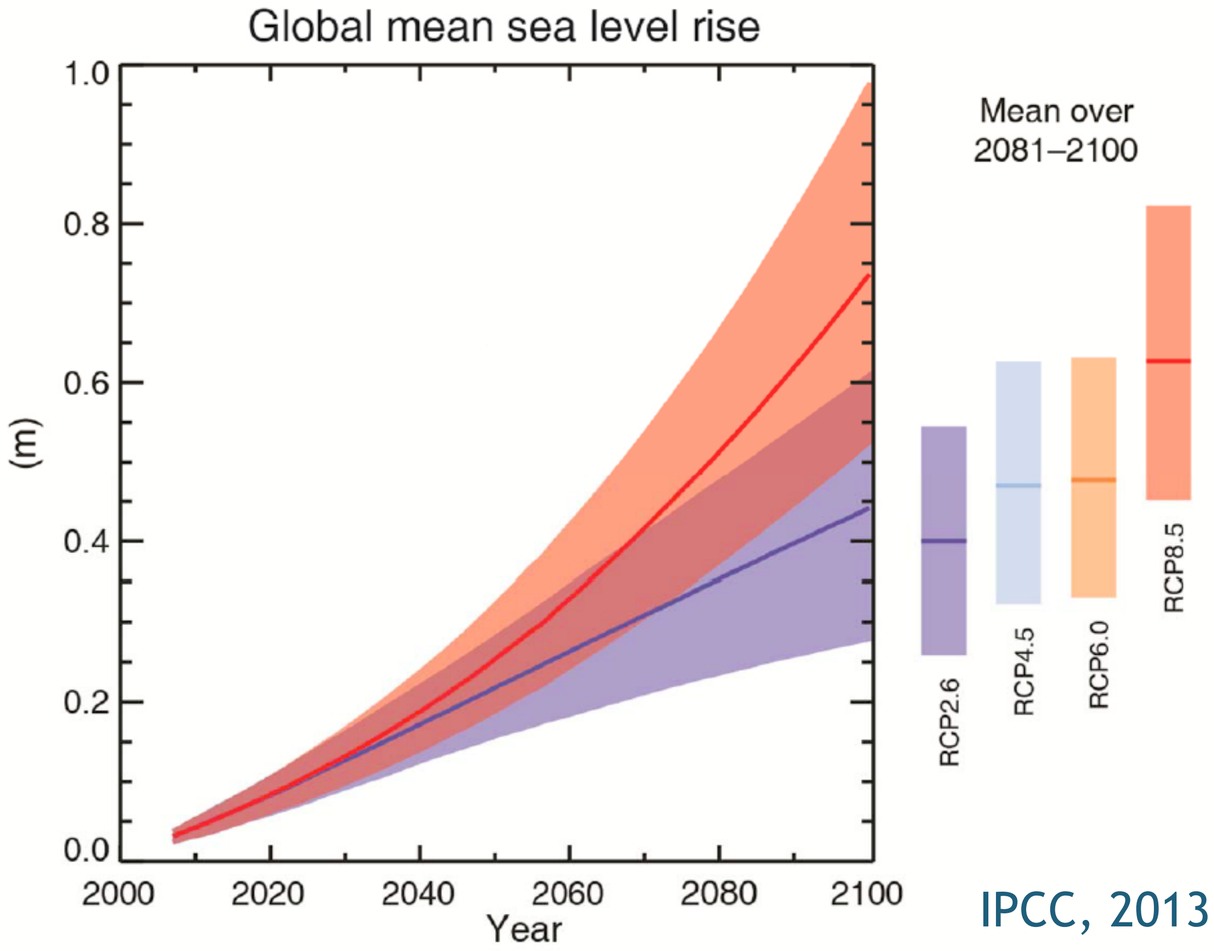

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Note: No accelerated contribution from Greenland and Antarctic ice sheets considered

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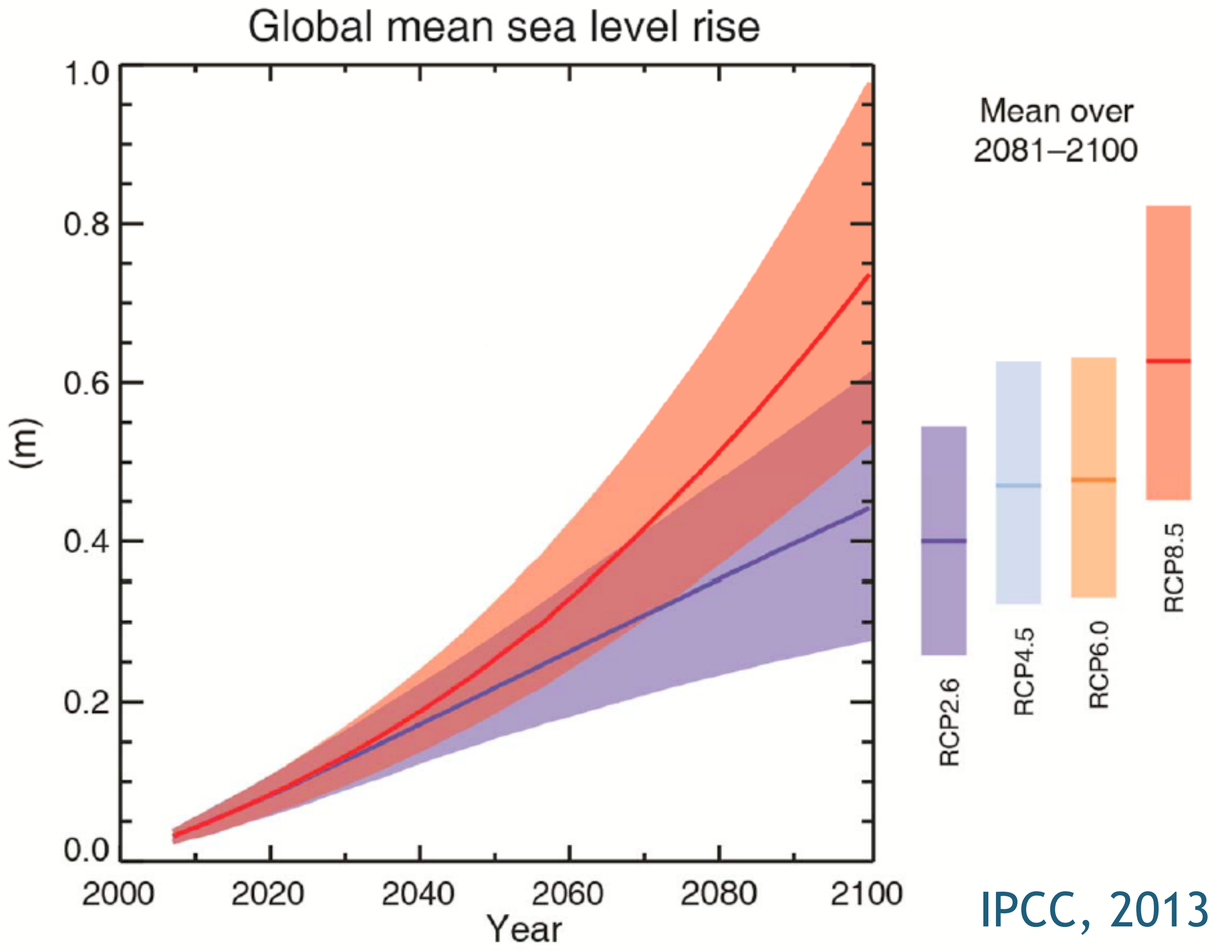

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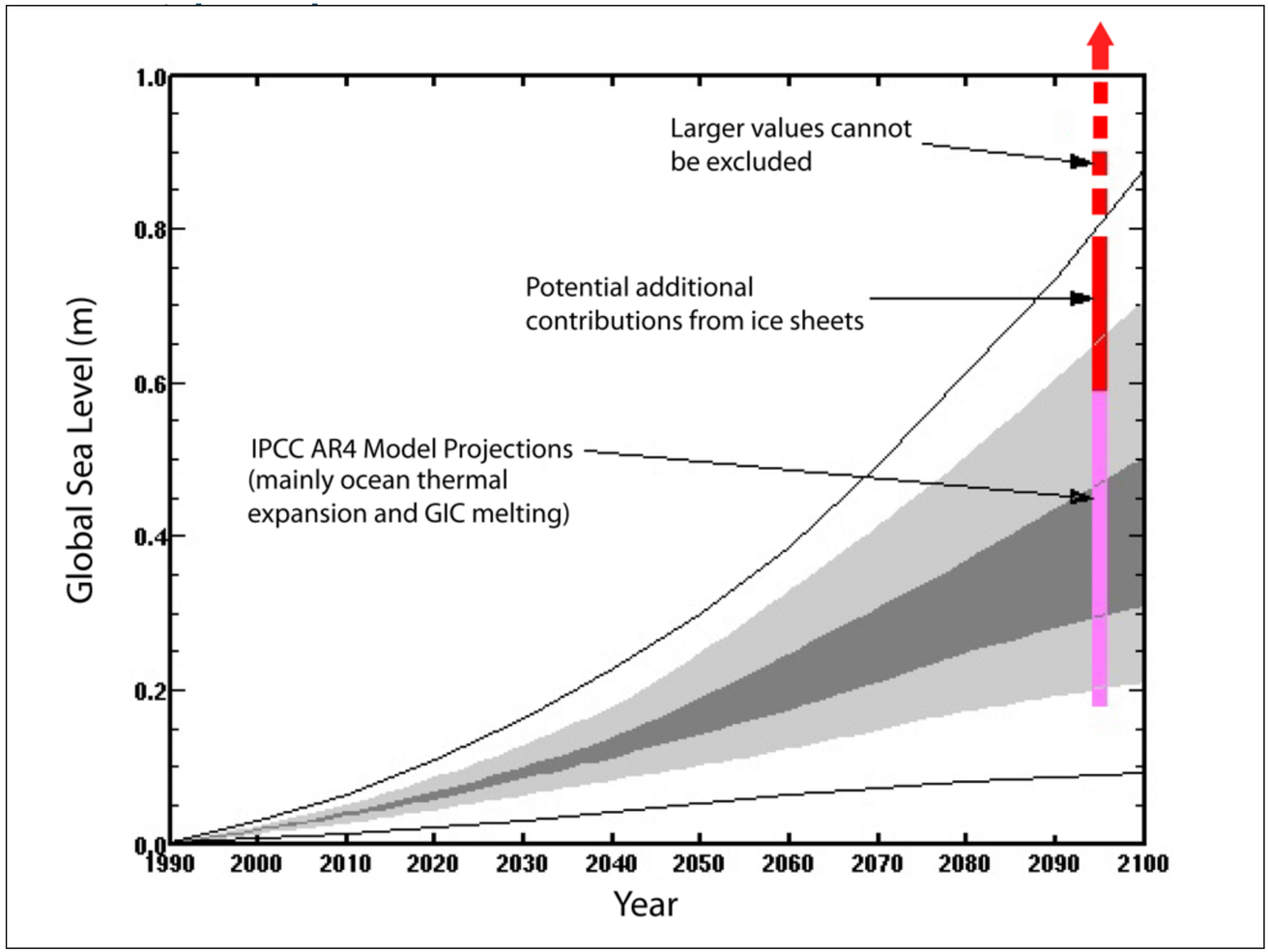

Modified from Church et al. (2010)

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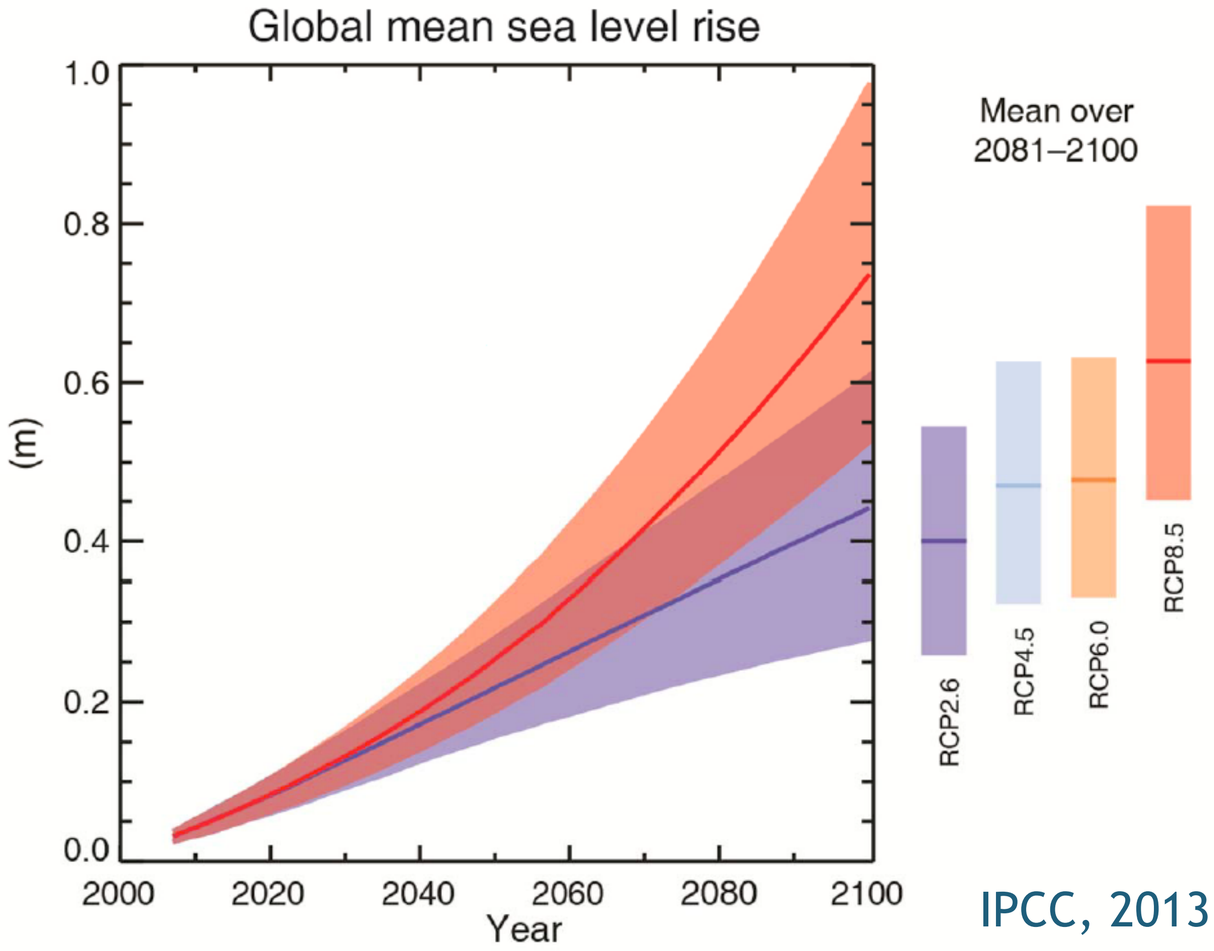

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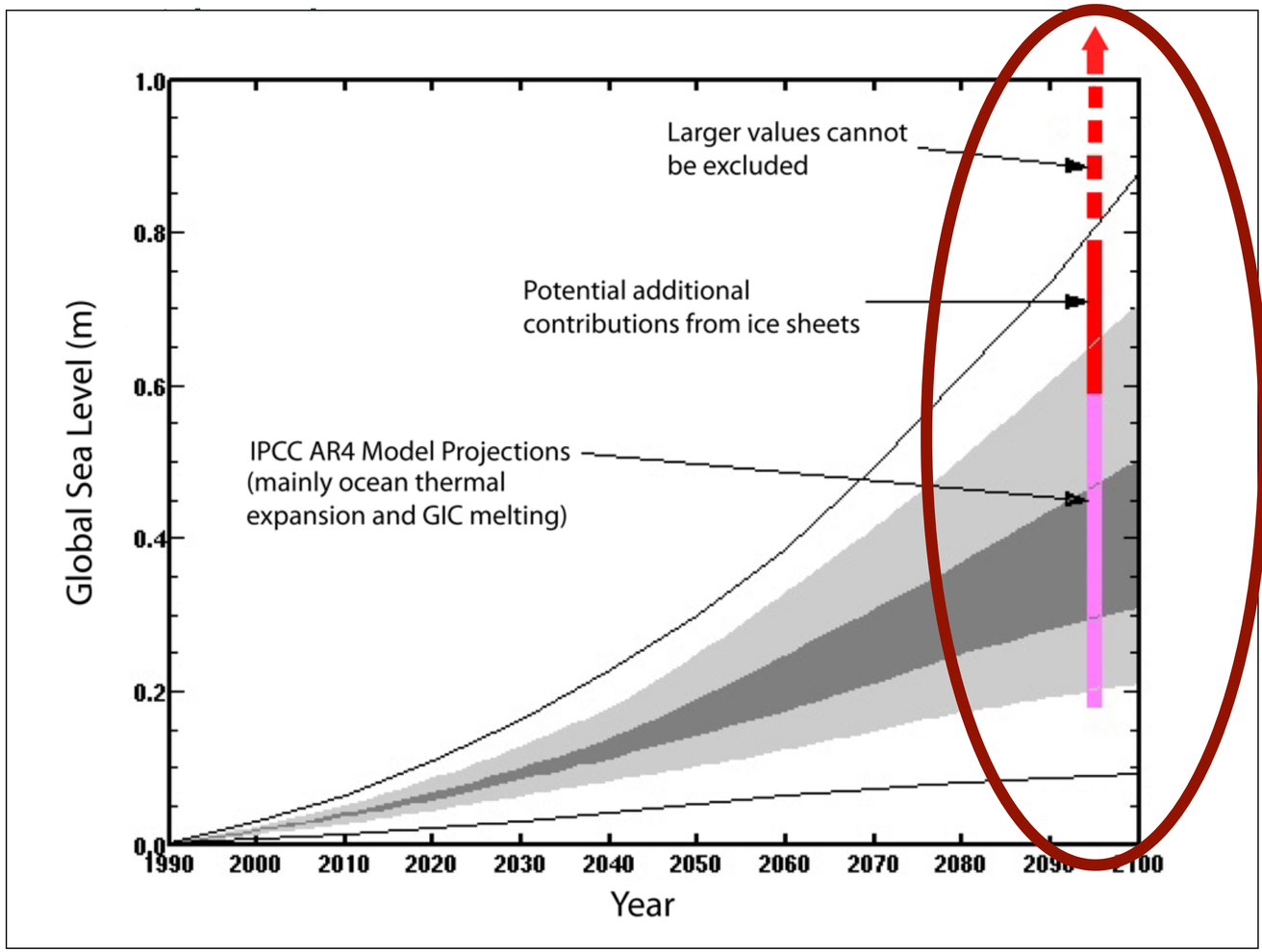

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Example: Greenland and Antarctic Ice Sheets

Accepted knowledge in 2000:

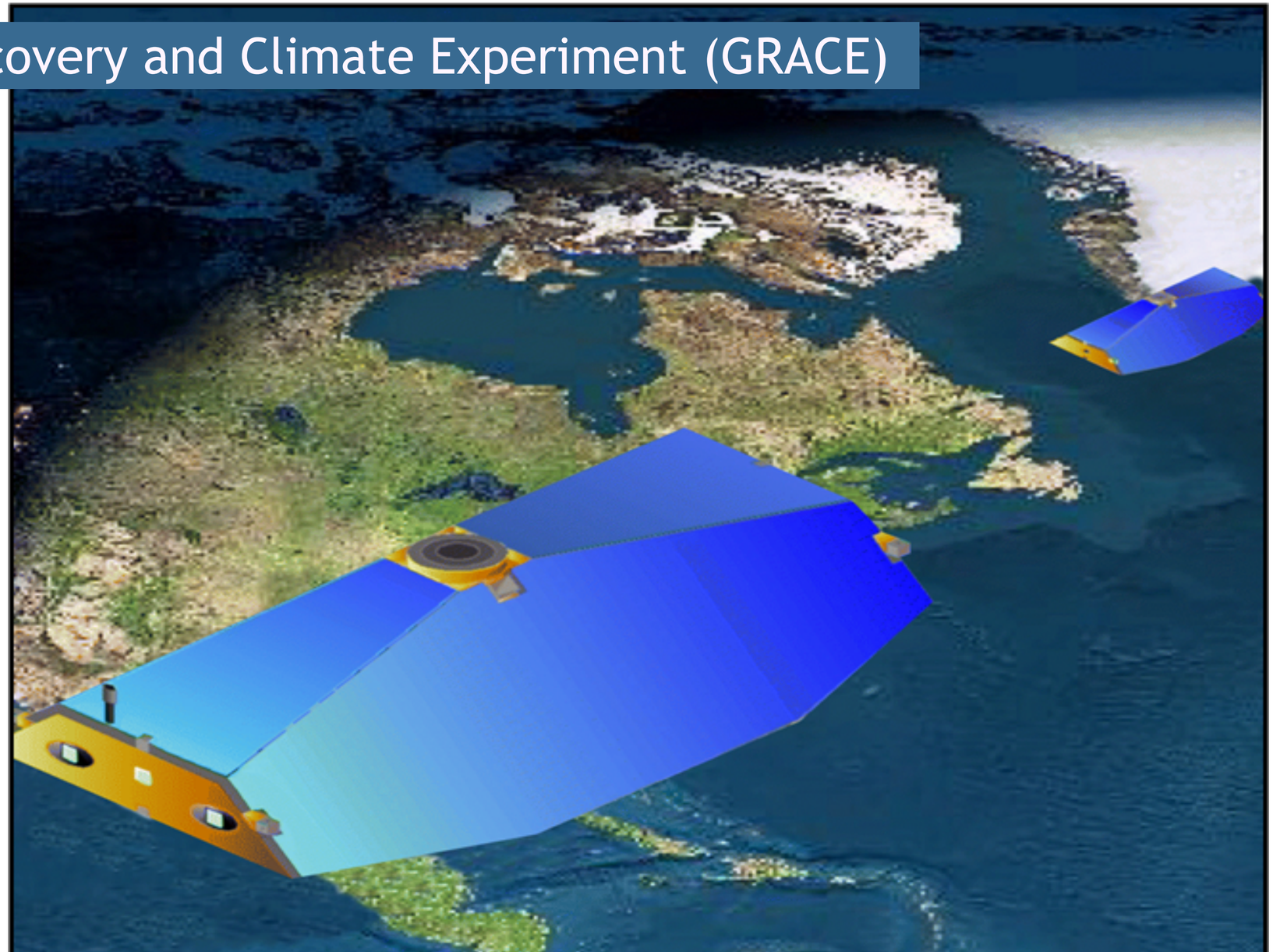
Greenland: no significant contribution to sea level rise

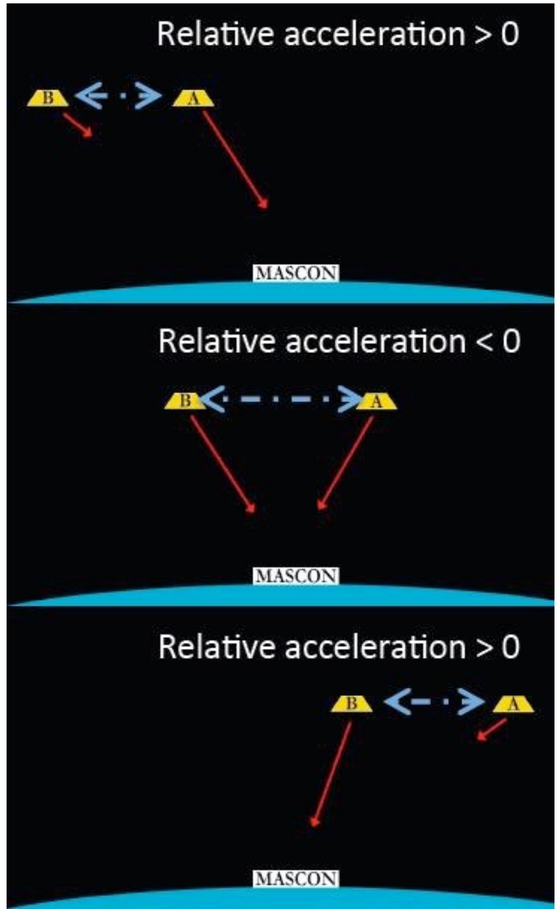
Antarctica: minor contribution

Main contribution: steric changes

The Prognosis: Anticipating Surprises

Gravity Recovery and Climate Experiment (GRACE)





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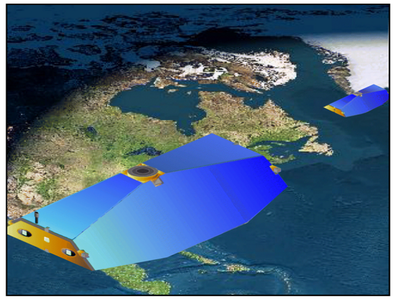
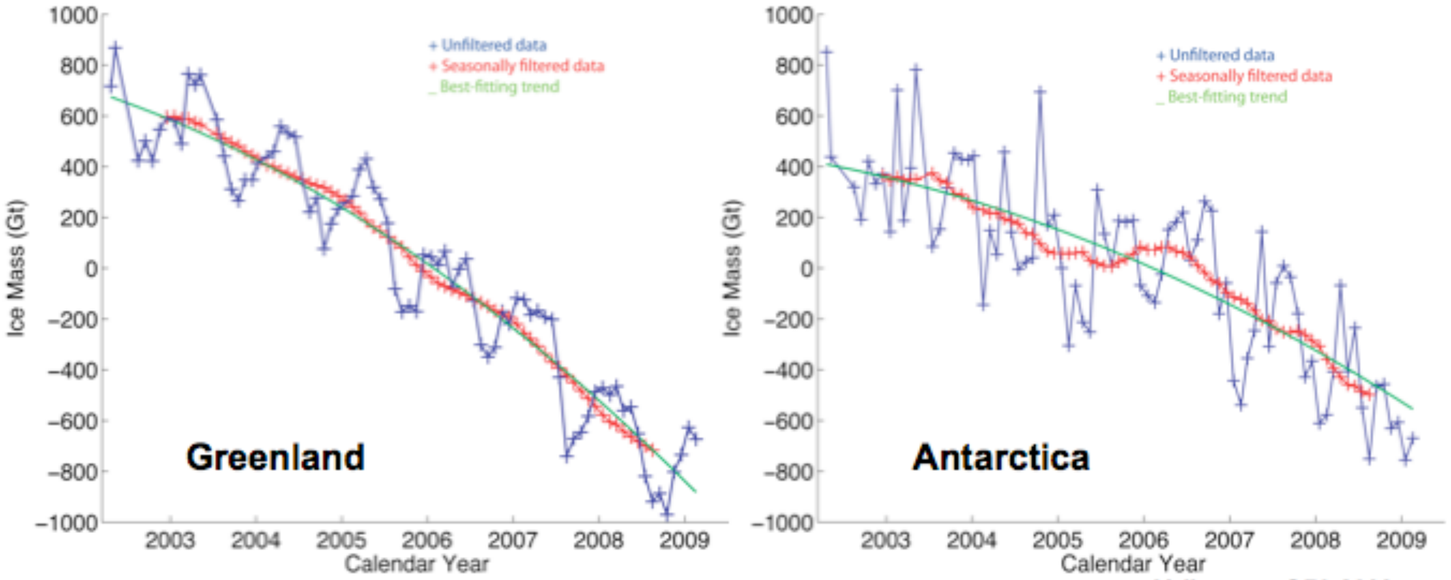


Greenland and Antarctica

During the period of April 2002 to February 2009 the mass loss of the polar ice sheets was not constant but increased with time, implying that the ice sheets' contribution to sea level rise was increasing.

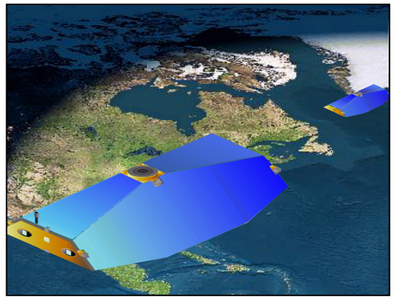
Greenland:
- mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- acceleration of -30 ± 11 Gt/yr^2 in 2002–2009.

Antarctica:
- mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009
- acceleration of -26 ± 14 Gt/yr^2 in 2002–2009.



Velicogna, *GRL*,2009

The Prognosis: Anticipating Surprises



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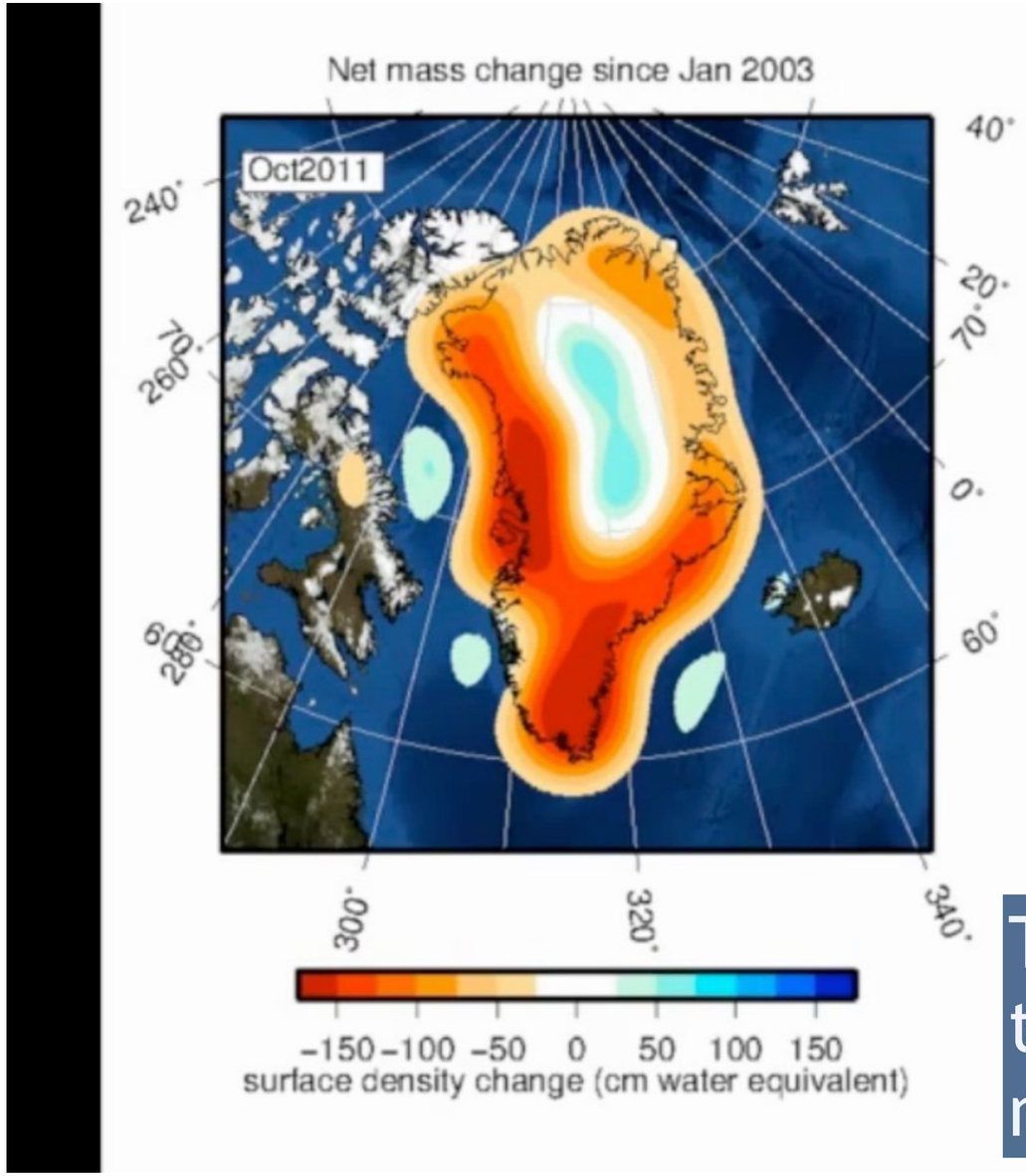

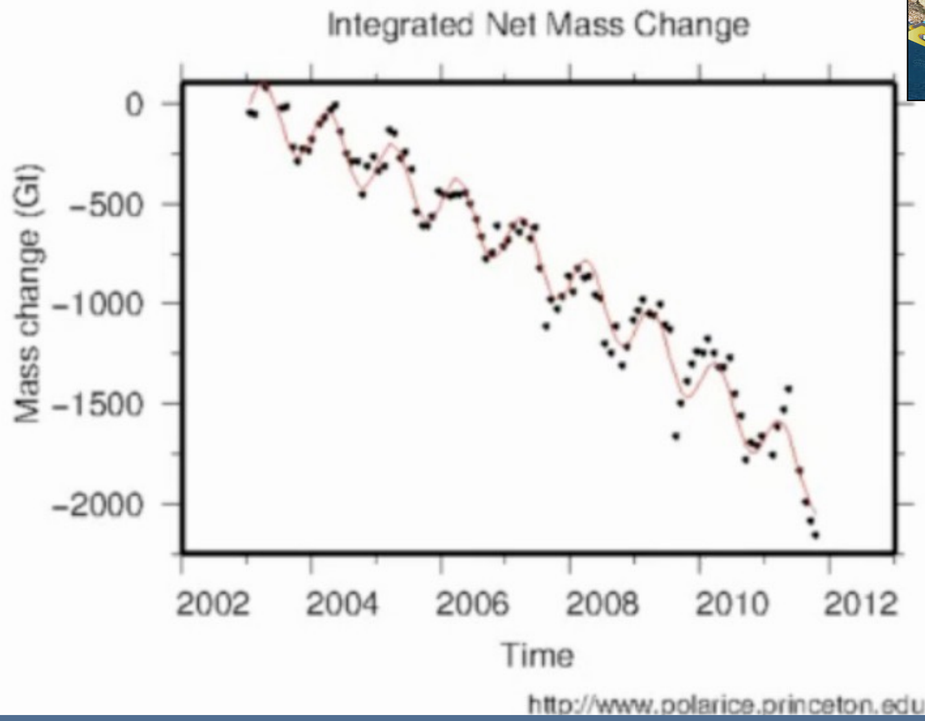

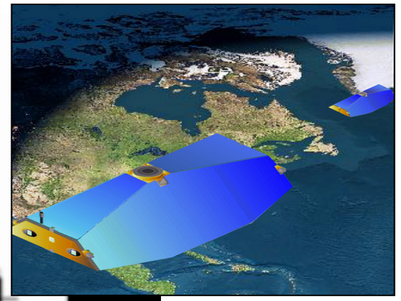

The last 12 years of observing the ice sheets have revealed many surprises ...

The Prognosis: Anticipating Surprises

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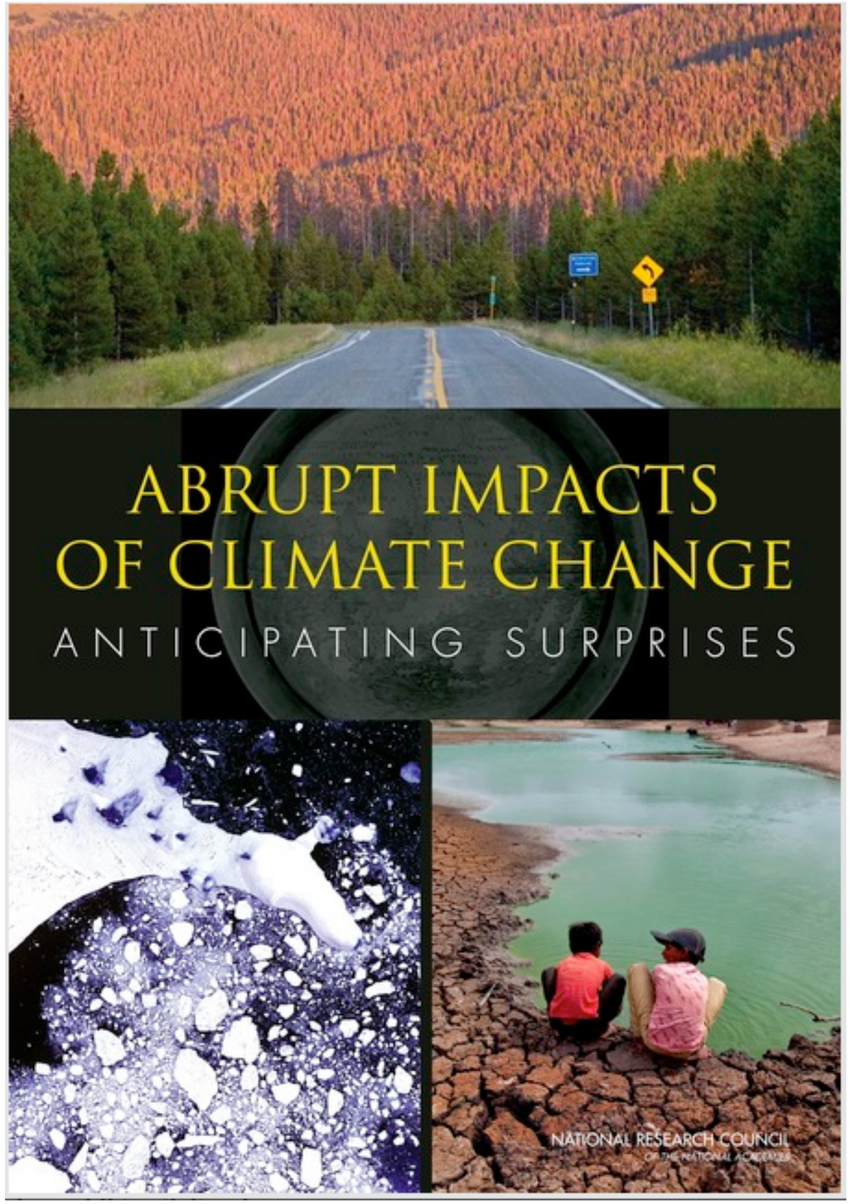

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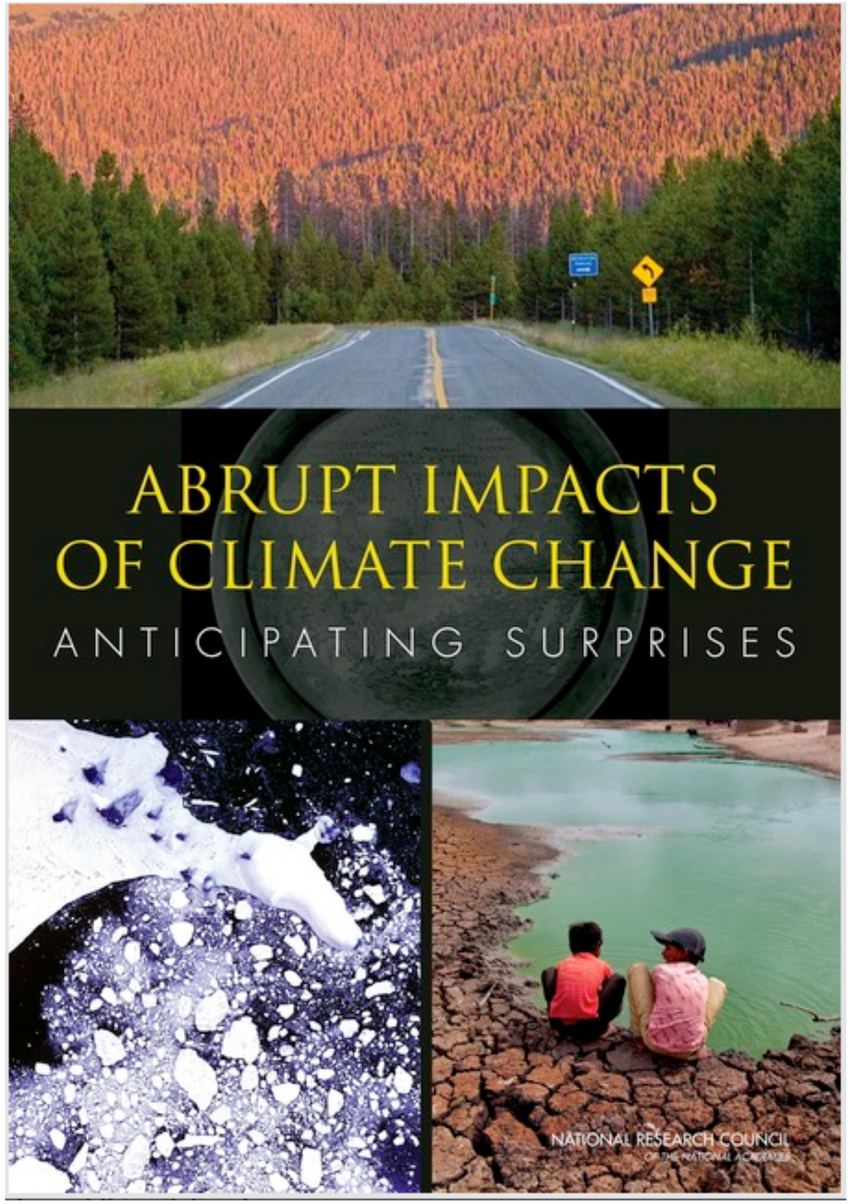

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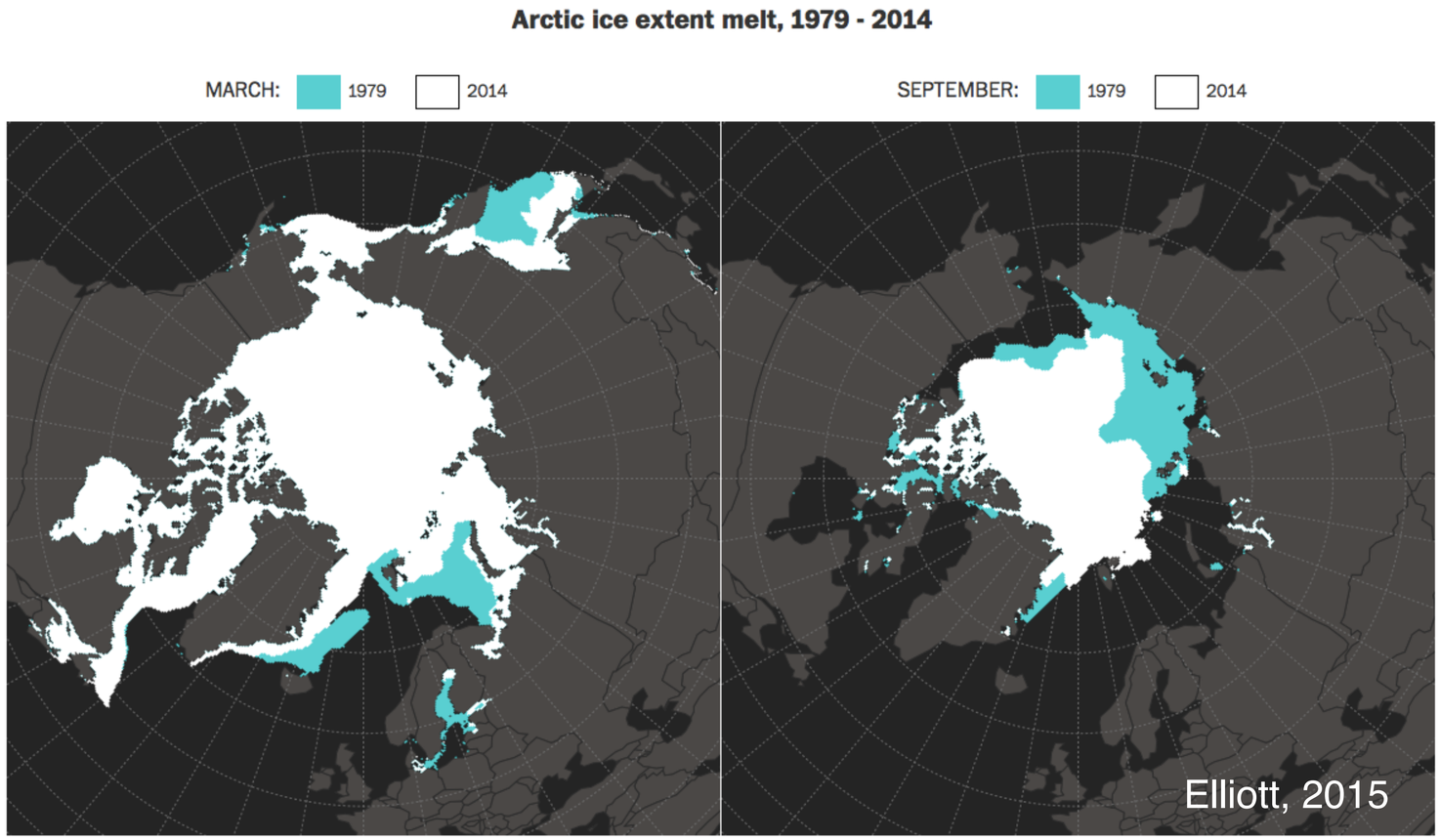

Elliott, 2015

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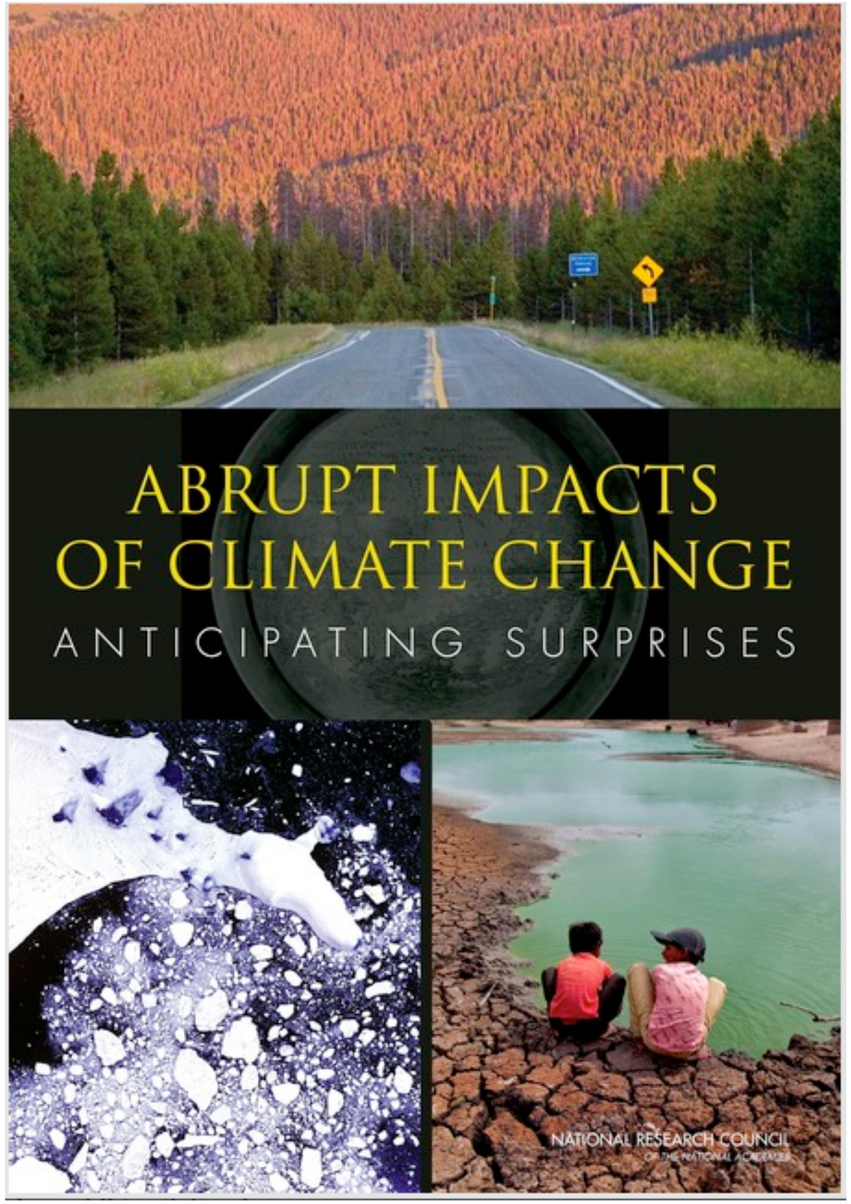

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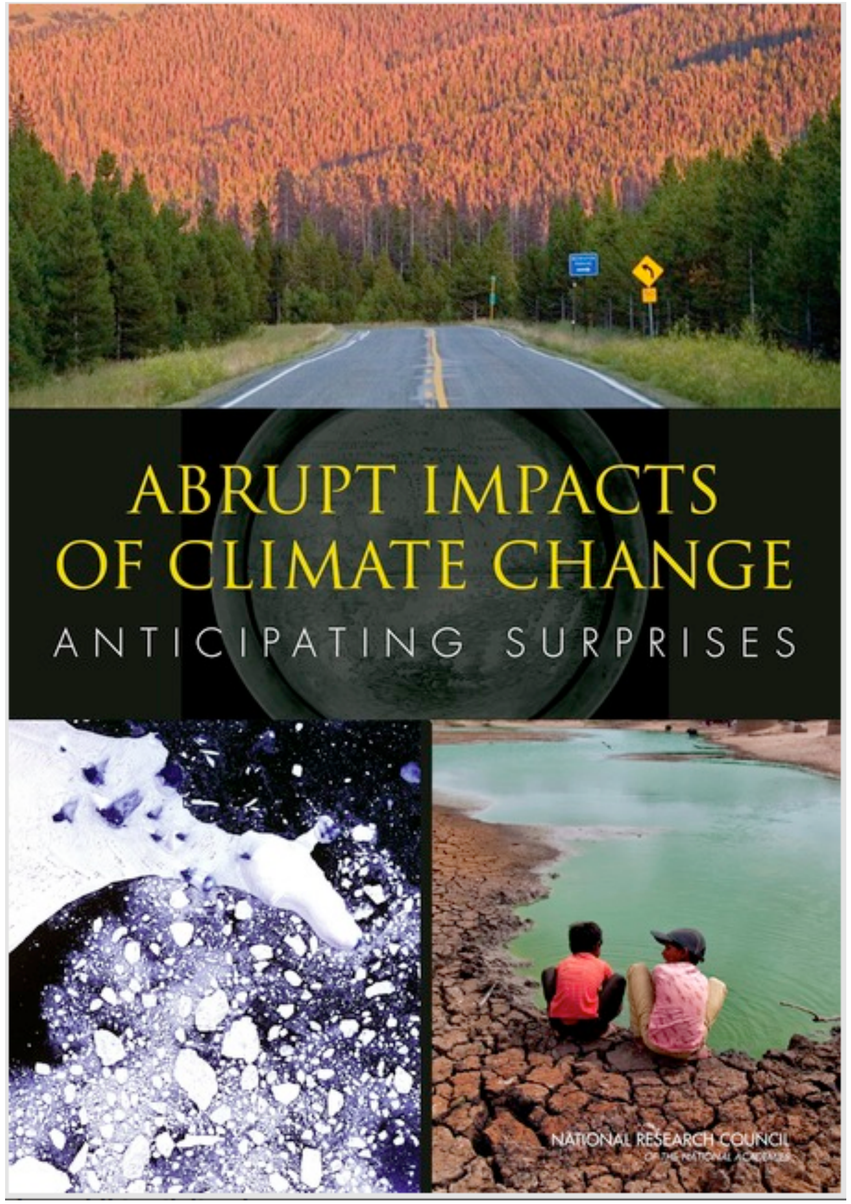

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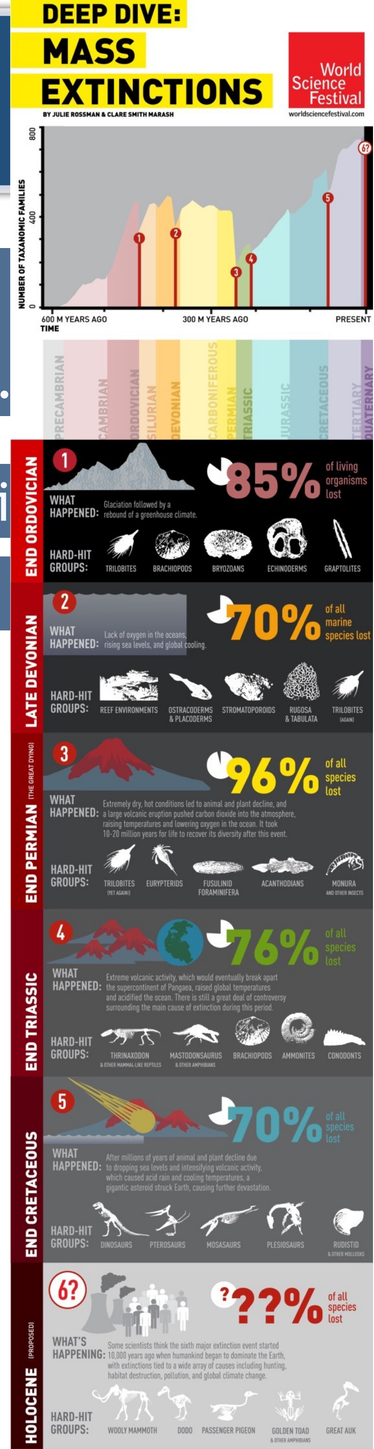

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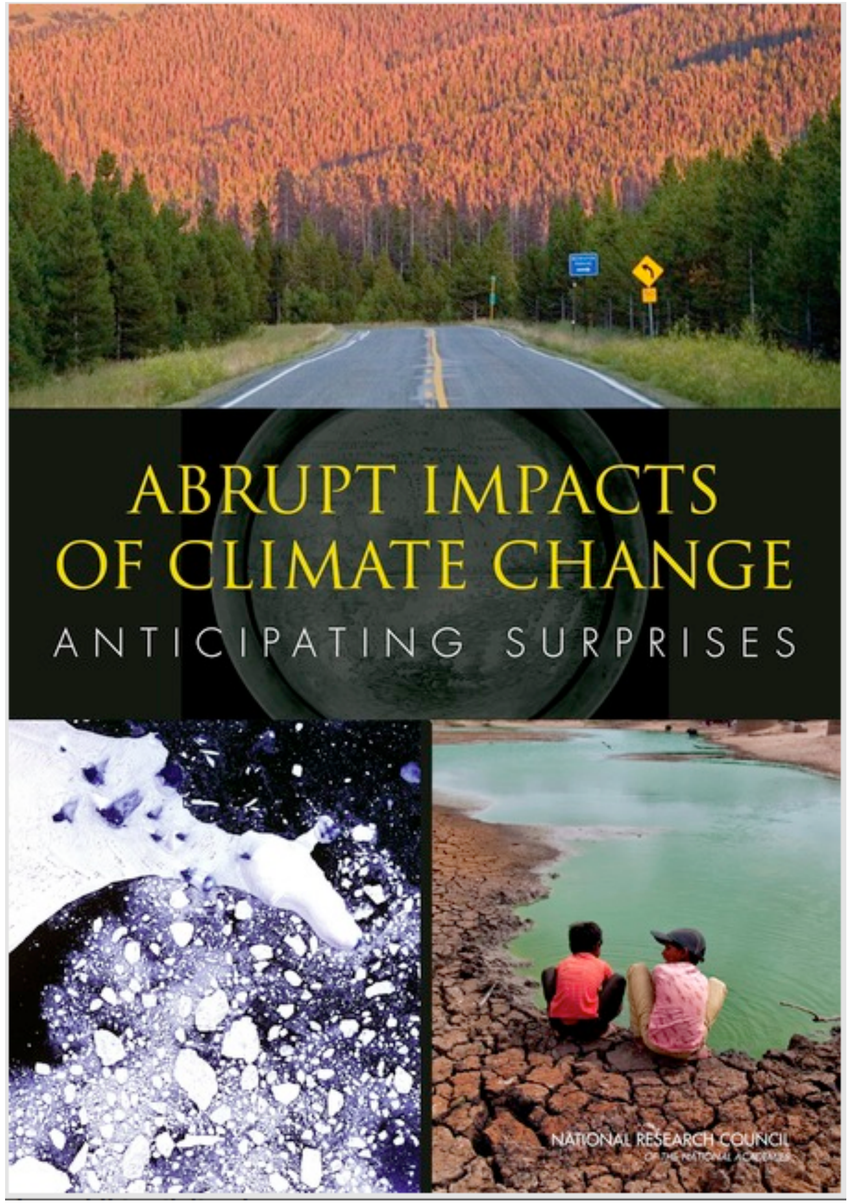

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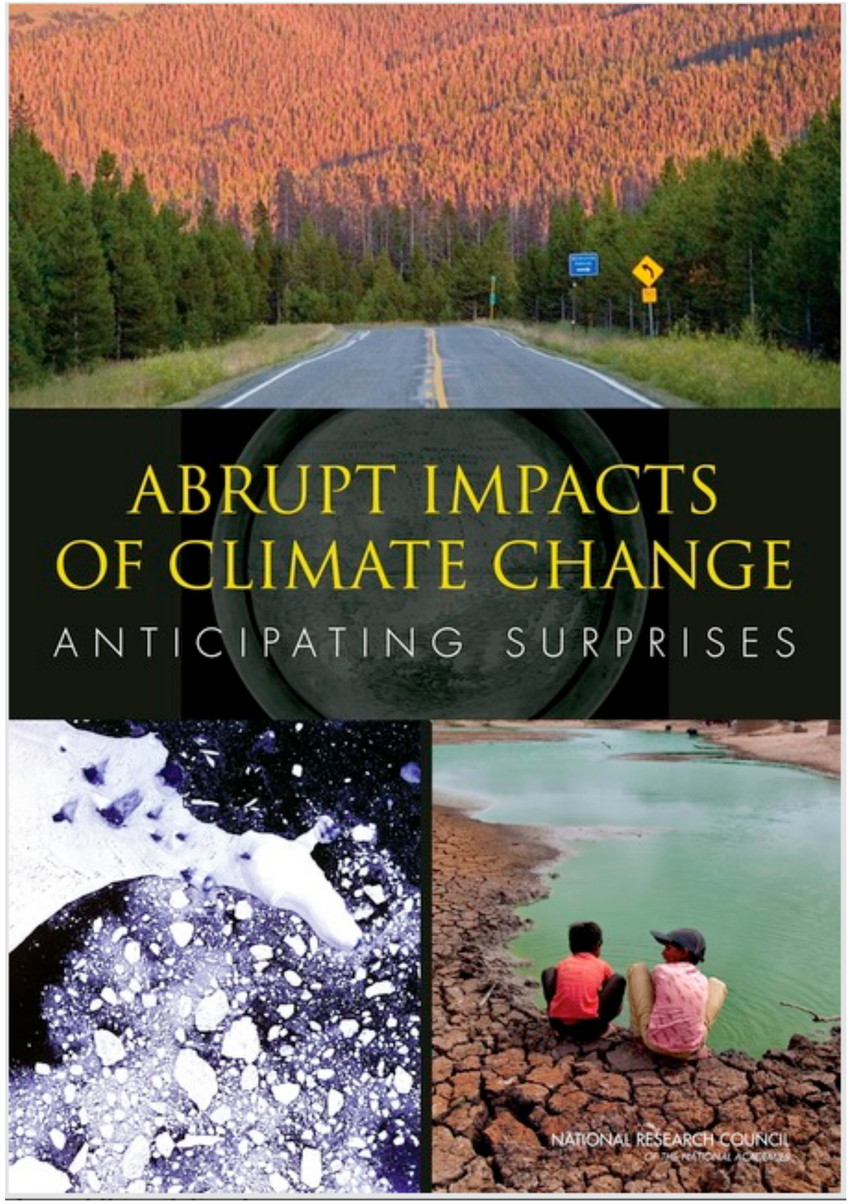

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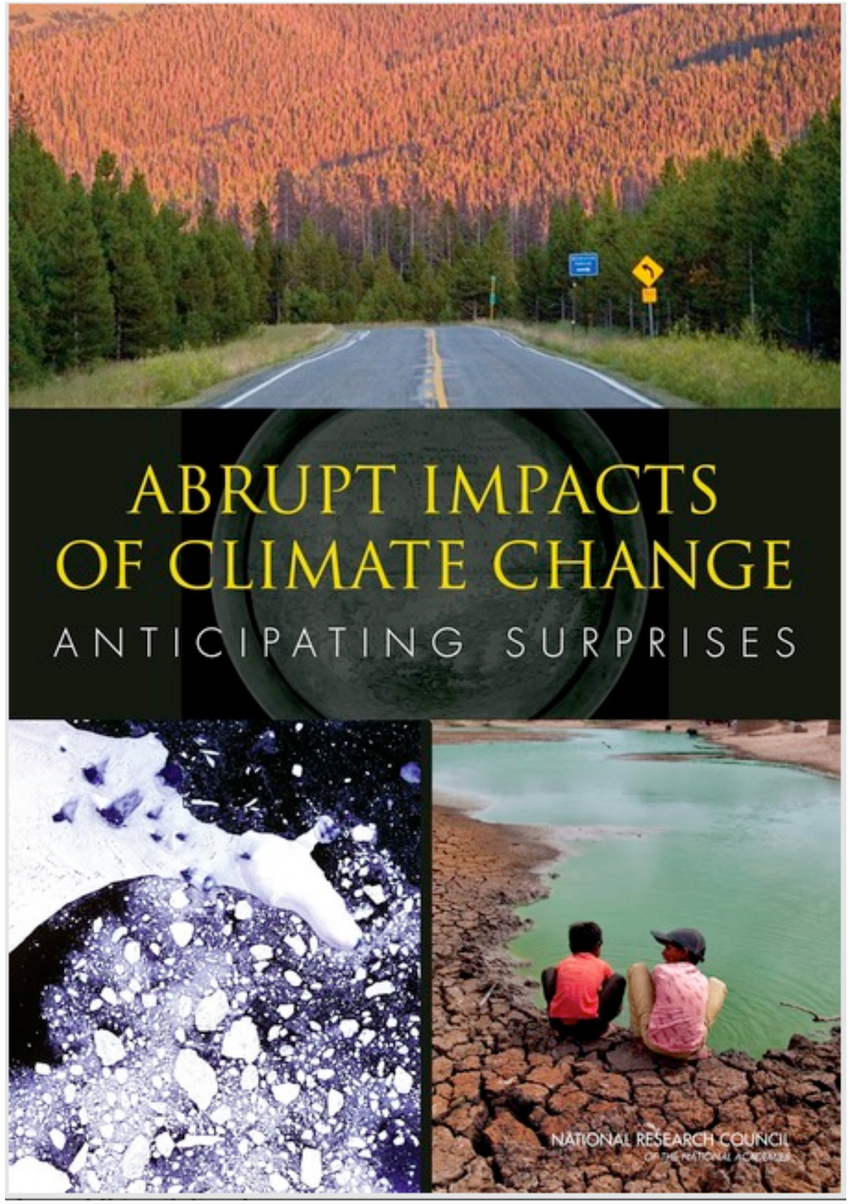

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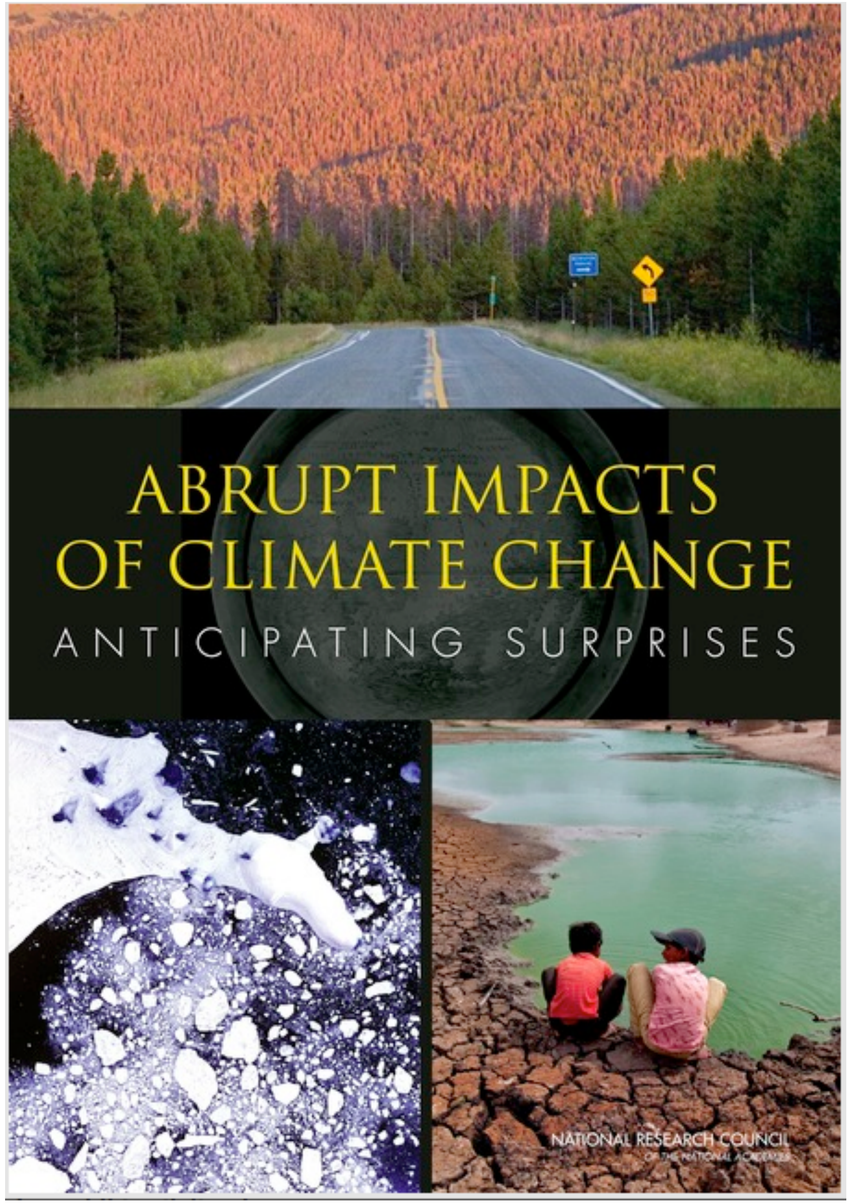

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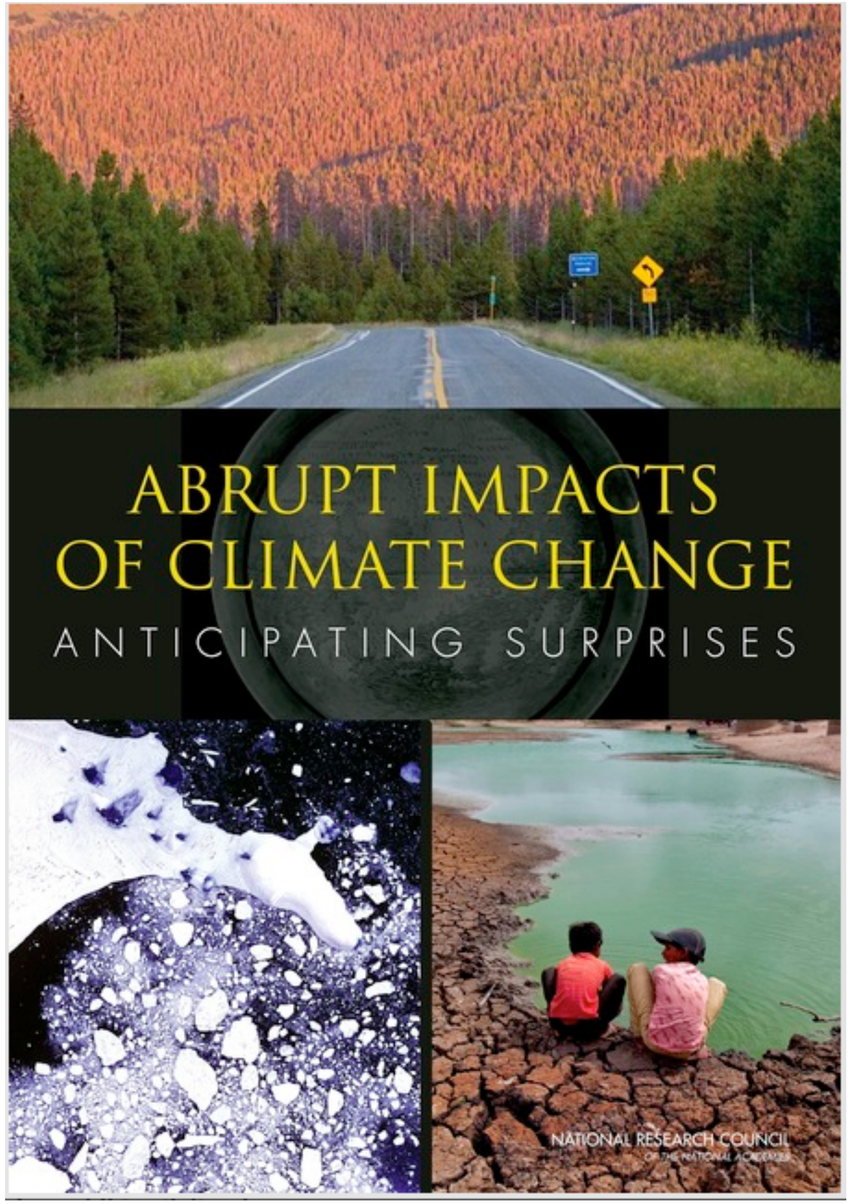

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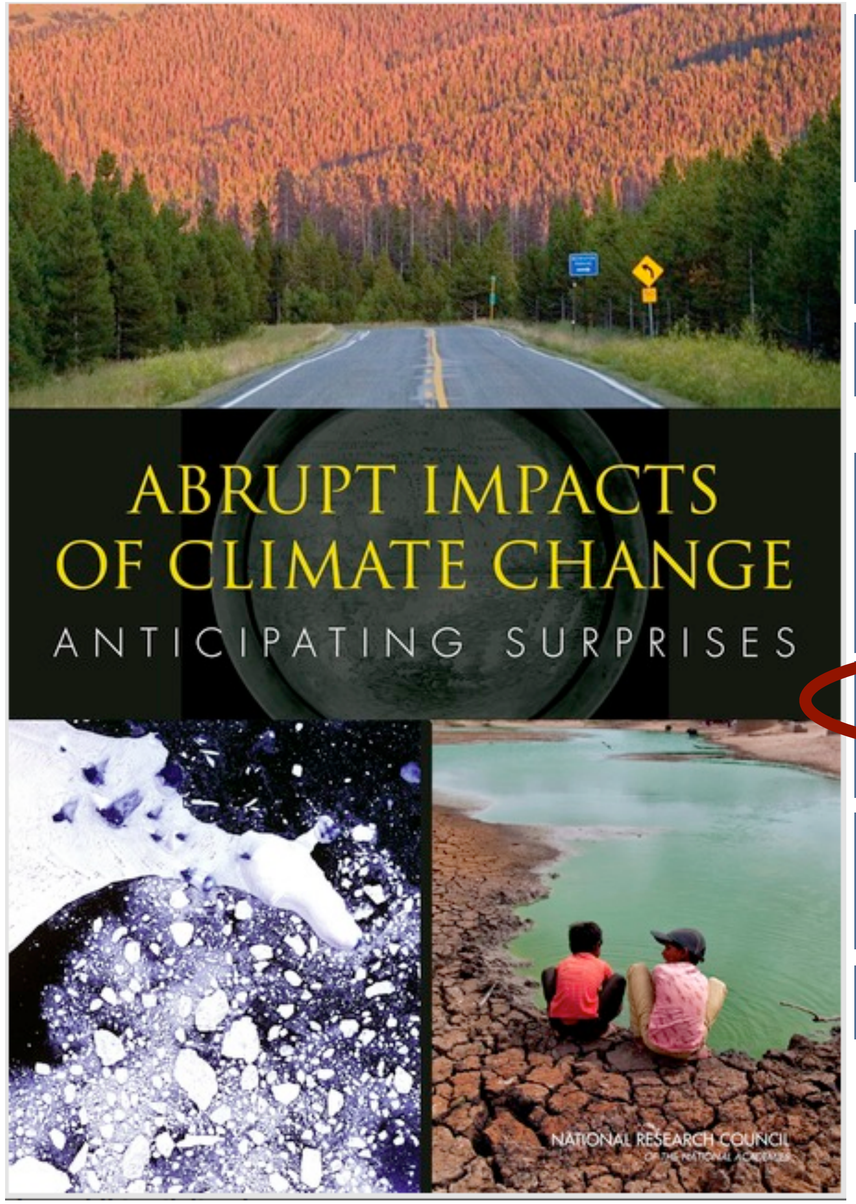

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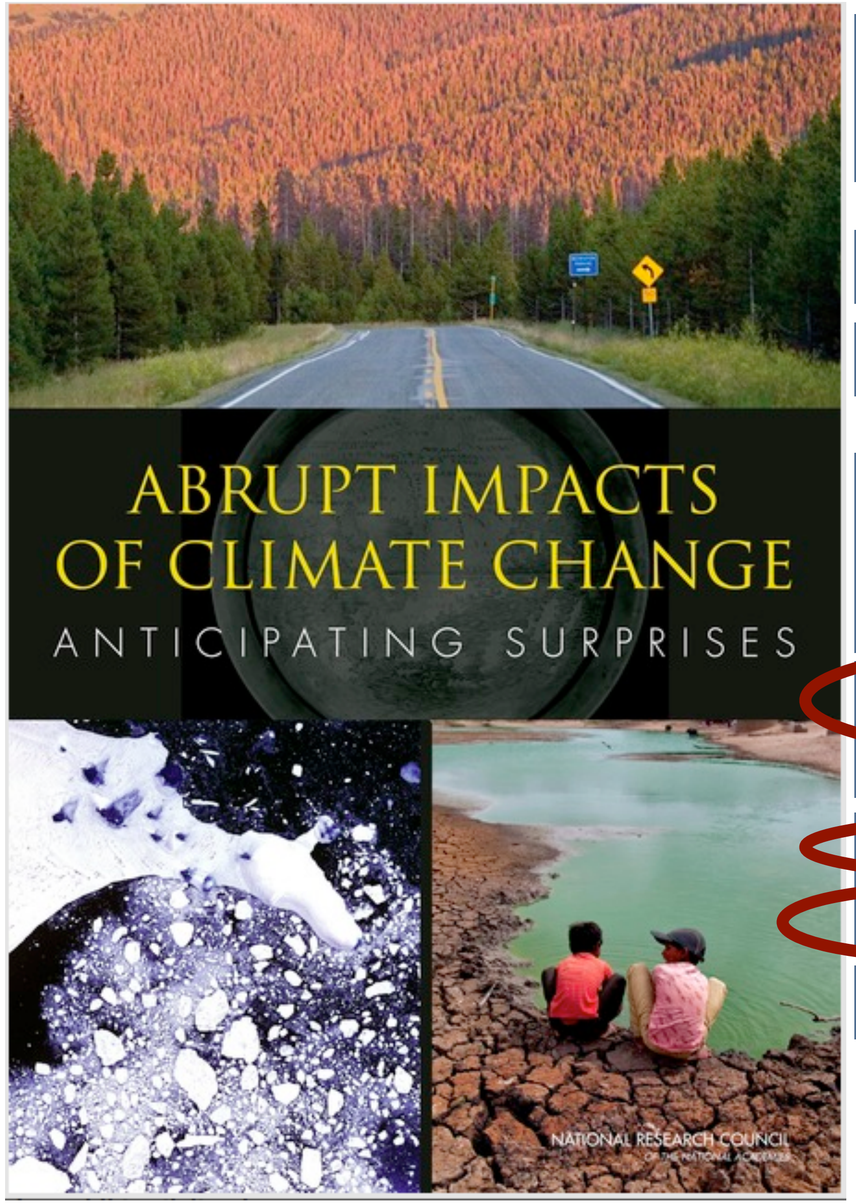

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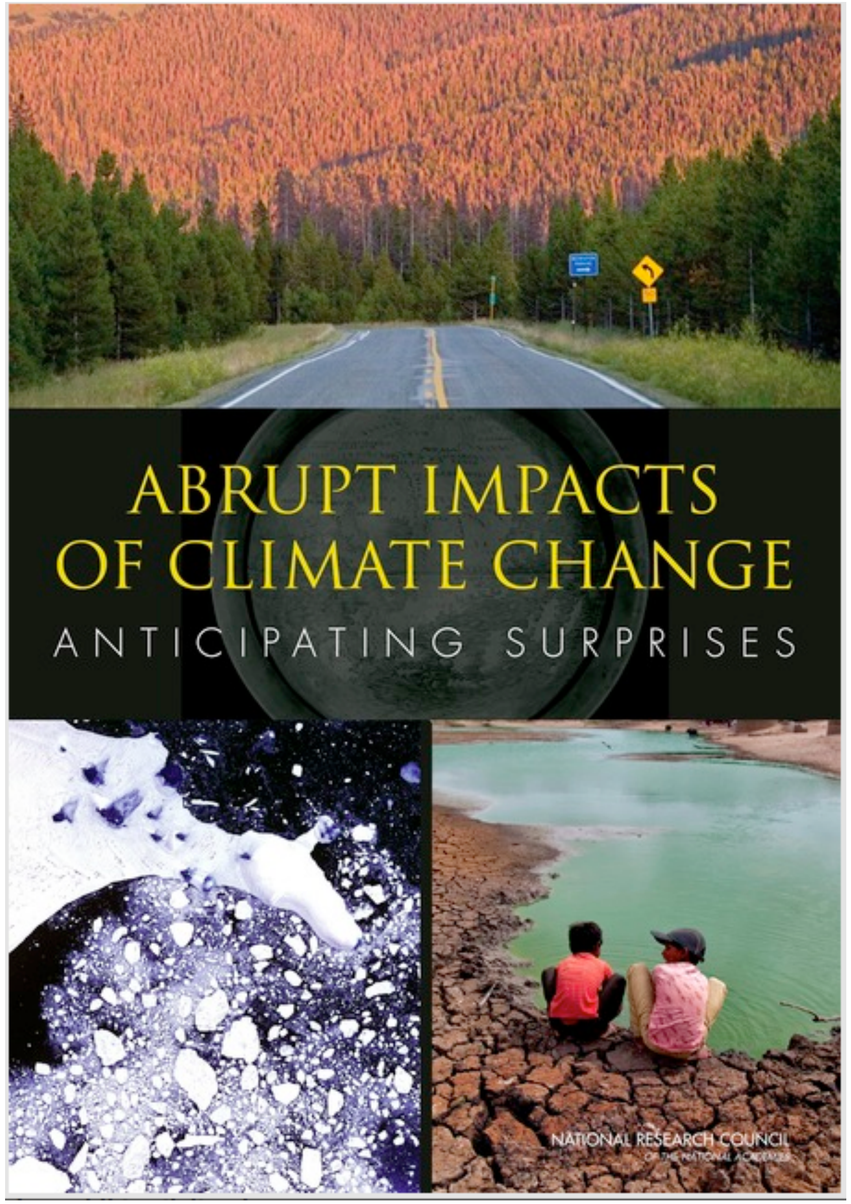

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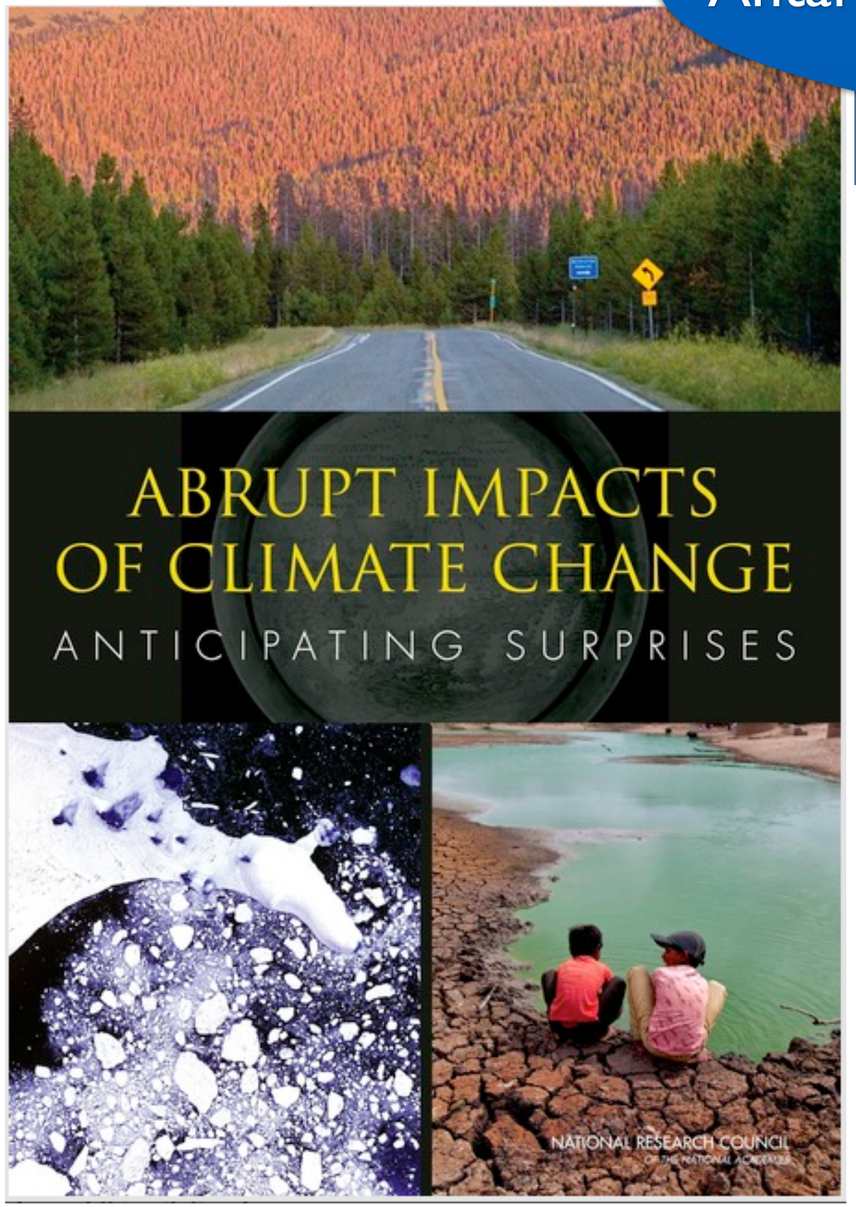

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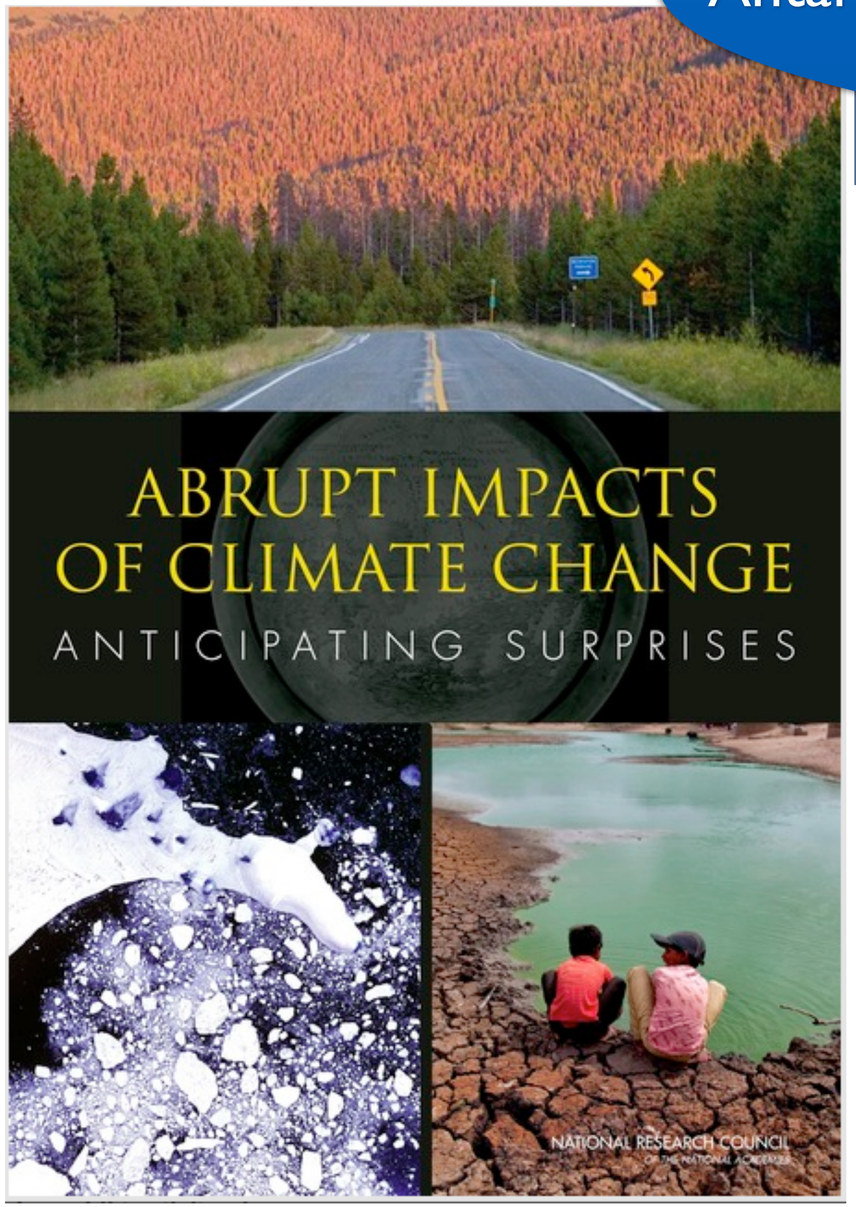

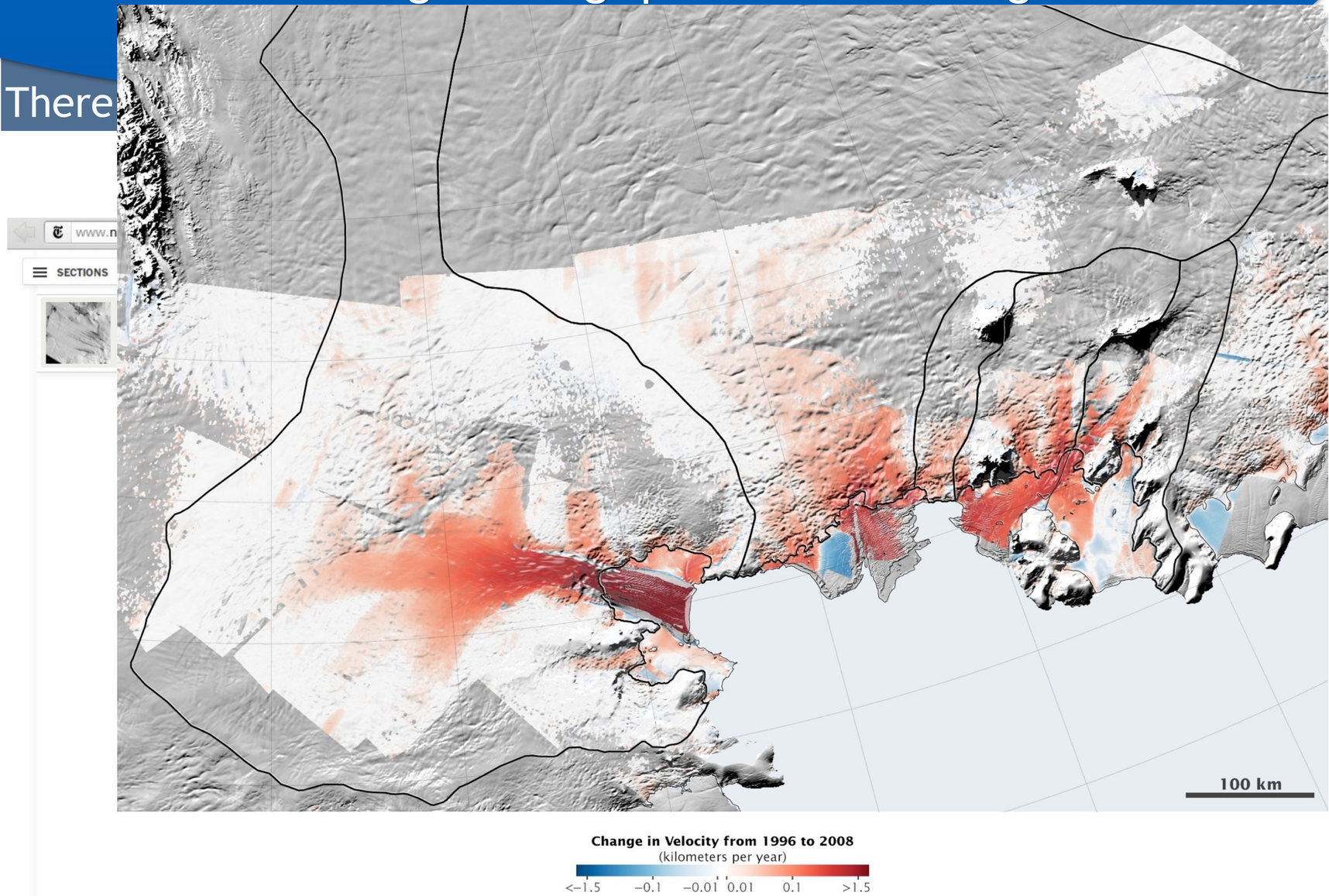

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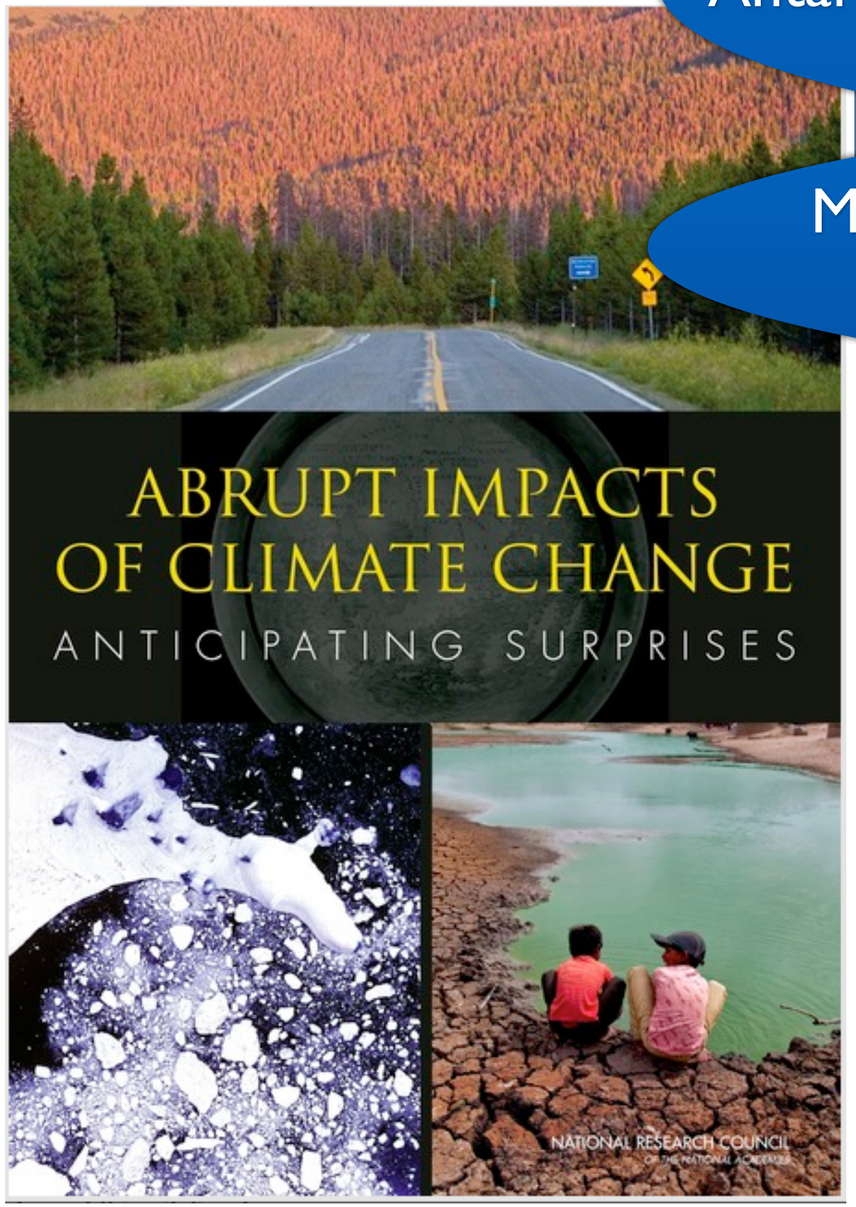

Greenland will be far greater contributor to sea rise than expected

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Greenland will be far greater ... to the ocean

Major UCI-NASA work reveals long, deep valleys connecting ice ... to the ocean

Irvine, Calif. – Greenland's icy reaches are far more vulnerable to warm ocean waters from climate change than had been thought, according to new research by UC Irvine and NASA glaciologists. The work, published today in *Nature Geoscience*, shows previously uncharted deep valleys stretching for dozens of miles under the Greenland Ice Sheet.

The bedrock canyons sit well below sea level, meaning that as subtropical Atlantic waters hit the fronts of hundreds of glaciers, those edges will erode much further than had been assumed and release far greater amounts of water.

Ice melt from the subcontinent has already accelerated as warmer marine currents have migrated north, but older models predicted that once higher ground was reached in a few years, the ocean-induced melting would halt. Greenland's frozen mass would stop shrinking, and its effect on higher sea waters would be curtailed.

"That turns out to be incorrect. The glaciers of Greenland are likely to retreat faster and farther inland than anticipated – and for much longer – according to this very different topography we've discovered beneath the ice," said lead author Mathieu Morlighem, a UCI associate project scientist. "This has major implications, because the glacier melt will contribute much more to rising seas around the globe."

To obtain the results, Morlighem developed a breakthrough method that for the first time offers a comprehensive view of Greenland's entire periphery. It's nearly impossible to accurately survey at ground level the subcontinent's rugged, rocky subsurface, which descends as much as 3 miles beneath the thick ice cap.

Since the 1970s, limited ice thickness data has been collected via radar pinging of the boundary between the ice and the bedrock. Along the coastline, though, rough surface ice and pockets of water cluttered the radar sounding, so large swaths of the bed remained invisible.

Measurements of Greenland's topography have tripled since 2009, thanks to NASA Operation IceBridge flights. But Morlighem quickly realized that while that data provided a fuller picture than had the earlier radar readings, there were still major gaps between the flight lines.

To reveal the full subterranean landscape, he designed a novel "mass conservation algorithm" that combined the previous ice thickness measurements with information on the velocity and direction of its movement and estimates of snowfall and surface melt.

The difference was spectacular. What appeared to be shallow glaciers at the very edges of Greenland are actually long, deep fingers stretching more than 100 kilometers (almost 65 miles) inland.

"We anticipate that these results will have a profound and transforming impact on computer models of ice sheet evolution in Greenland in a warming climate," the researchers conclude.

"Operation IceBridge vastly improved our knowledge of bed topography beneath the Greenland Ice Sheet," said co-author Eric Rignot of UC Irvine and NASA's Jet Propulsion Laboratory. "This new study takes a quantum leap at filling the remaining, critical data gaps on the map."

###

Other co-authors are Jeremie Mouginot of UC Irvine and Helene Seroussi and Eric Larour of JPL. Funding was provided by NASA.

The team also reported stark new findings last week on accelerated glacial melt in West Antarctica. Together, the papers "suggest that the globe's ice sheets will contribute far more to sea level rise than

Global warming caused by the human-driven release of greenhouse gases has helped to destabilize the ice sheet, though other factors may also be involved, the scientists said.

The rise of the sea is likely to continue to be relatively slow for the rest of the 21st century, the scientists added, but in the more distant future it may accelerate markedly, potentially throwing society into crisis.

The Prognosis: Anti

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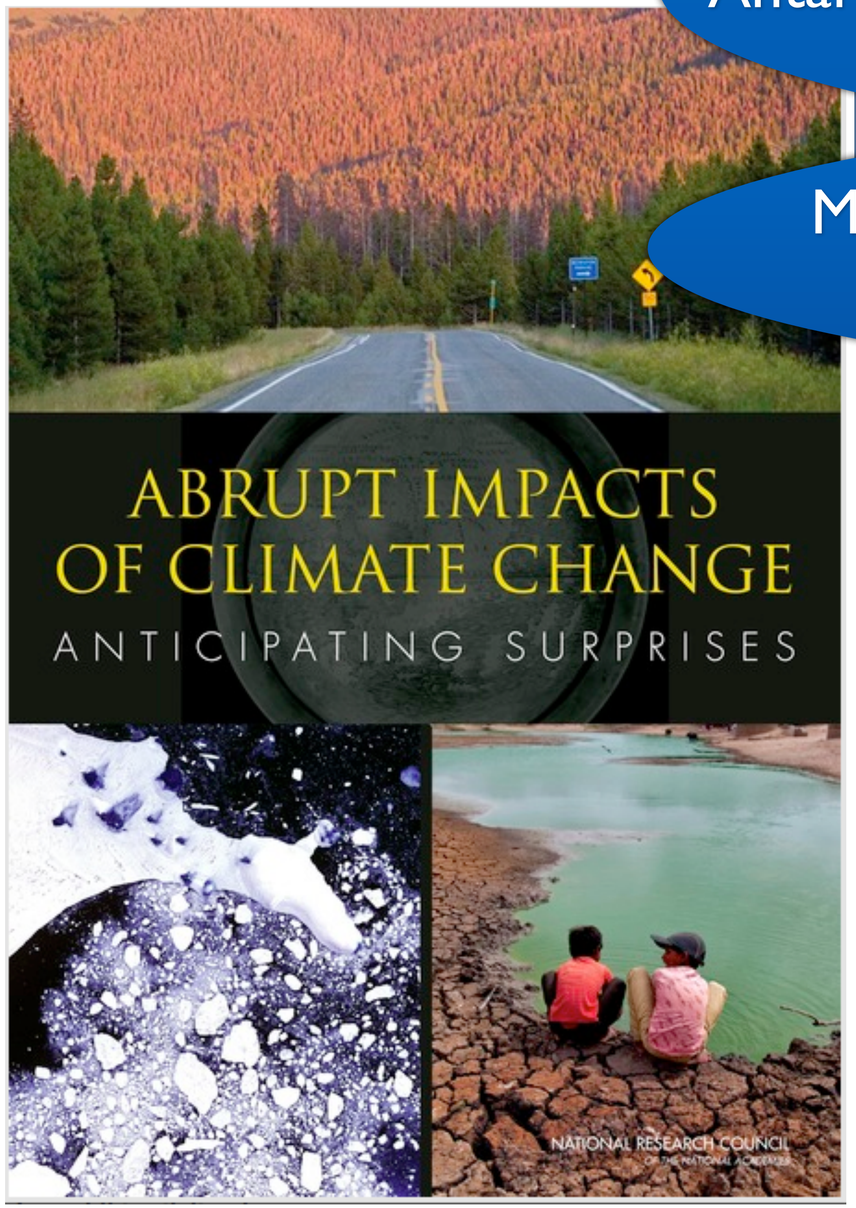

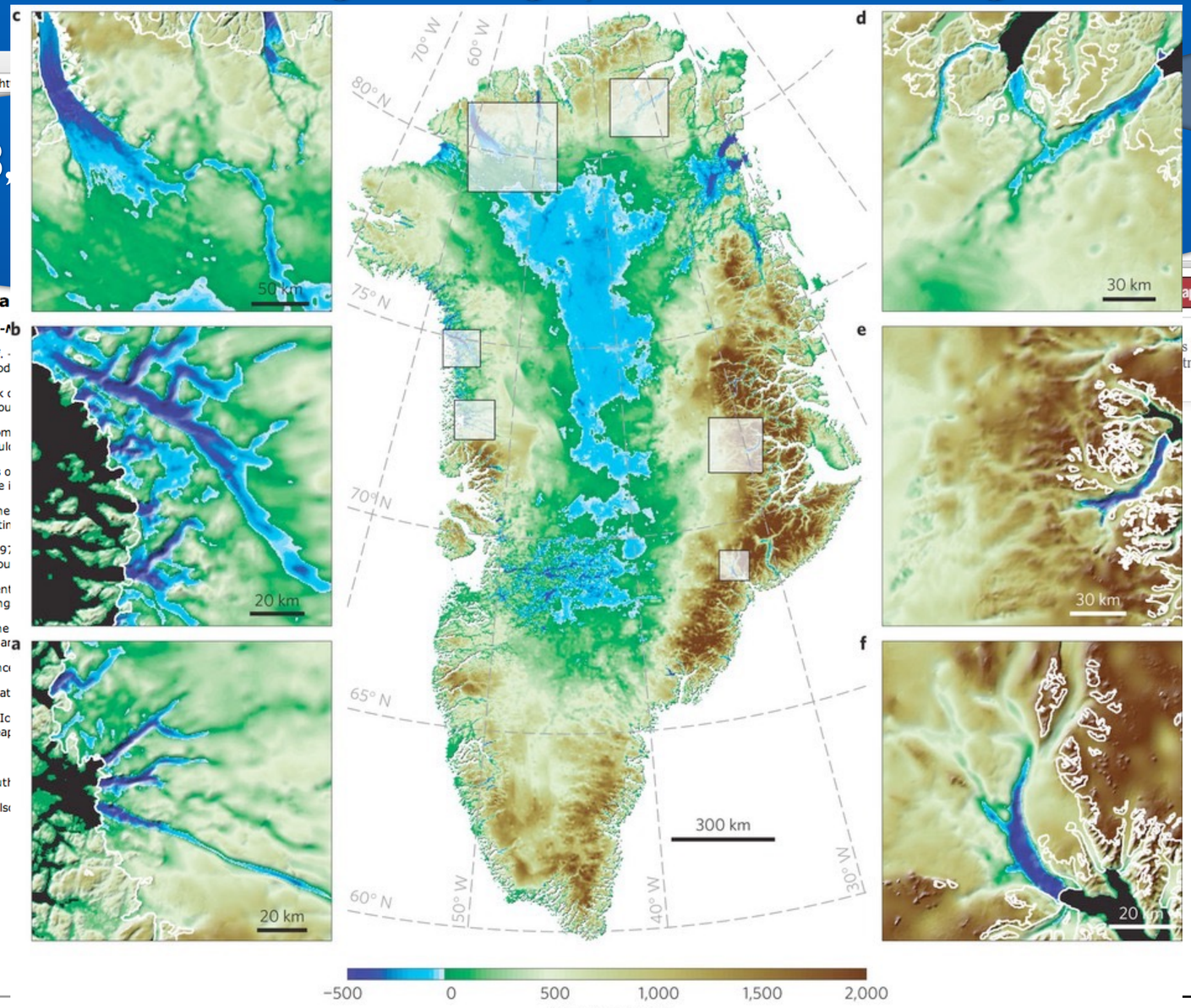

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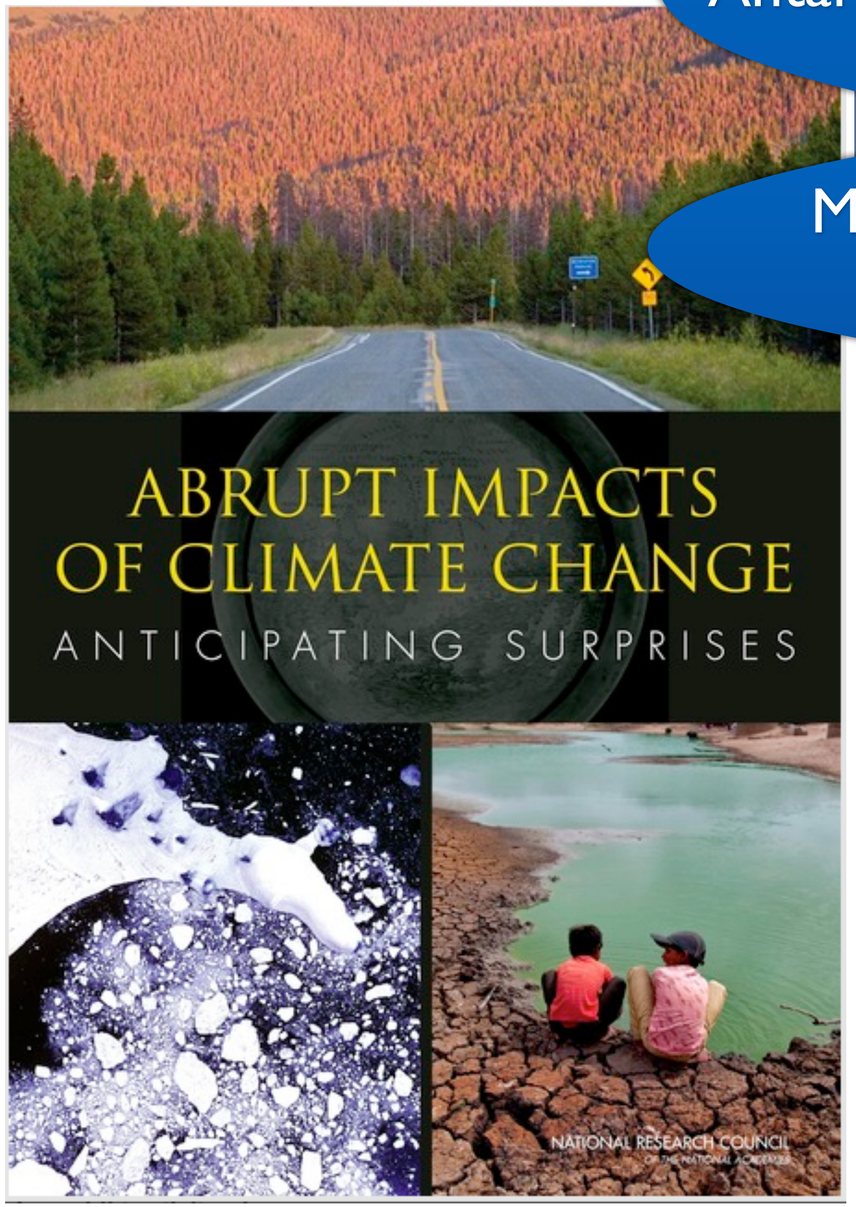

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New study finds Antarctic Ice Sheet unstable at end of last ice age

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Contact: Peter Clark
clarkp@geo.oregonstate.edu
541-740-5237
Oregon State University

New study finds Antarctic Ice Sheet unstable at end of last ice age

CORVALLIS, Ore. – A new study has found that the Antarctic Ice Sheet began melting about 5,000 years earlier than previously thought coming out of the last ice age – and that shrinkage of the vast ice sheet accelerated during eight distinct episodes

The international study, funded in part by the Na
part of the West Antarctic Ice Sheet h

Results of this latest study
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Periods of rapid increa
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The melting of the Antarctic Ice She

"Conventional thinking based on past research is that t process, and that its decline was slow and steady until it reached its present size," said

"The sediment record suggests a different pattern – one th ore episodic and suggests that parts of the ice sheet repeatedly became unstable during the last deglaciation," Weber added.

The research also provides the first solid evidence the Antarctic Ice Sheet contributed to what is known as meltwater pulse 1A, a period of very rapid sea level rise that began some 14,500 years ago, according to Peter Clark, an Oregon State University paleoclimatologist and co-author on the study.

The largest of the eight episodic pulses outlined in the new *Nature* study coincides with meltwater pulse 1A.

"During that time, the sea level on a global basis rose about 50 feet in just 350 years – or about 20 times faster than sea level rise over the last century," noted Clark, a professor in Oregon State's College of Earth, Ocean, and Atmospheric Sciences. "We don't yet know what triggered these eight episodes or pulses, but it appears that once the melting of the ice sheet began it was amplified by physical processes."

The researchers suspect that a feedback mechanism may have accelerated the melting, possibly by changing ocean circulation that brought warmer water to the Antarctic subsurface, according to co-author Axel Timmermann, a climate researcher at the University of Hawaii at Manoa.

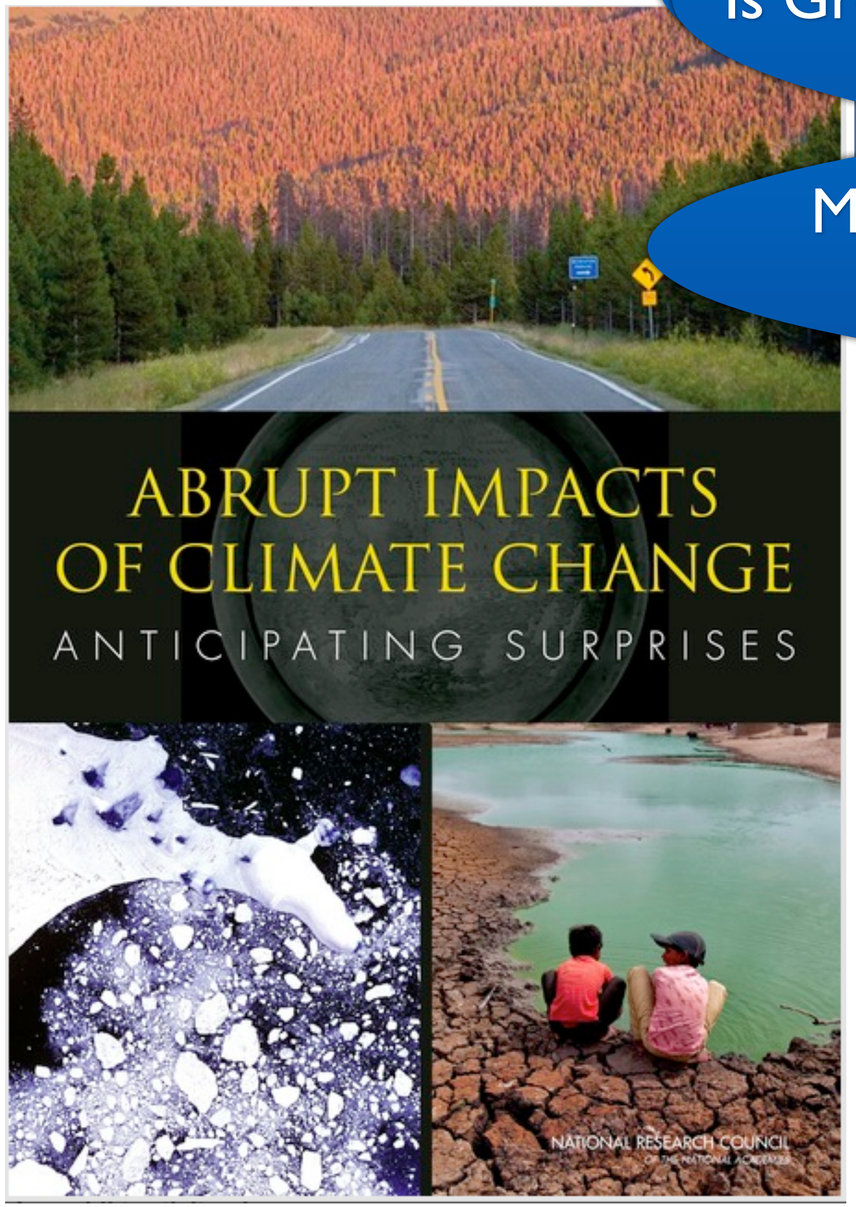
"This positive feedback is a perfect recipe for rapid sea level rise," Timmermann said.

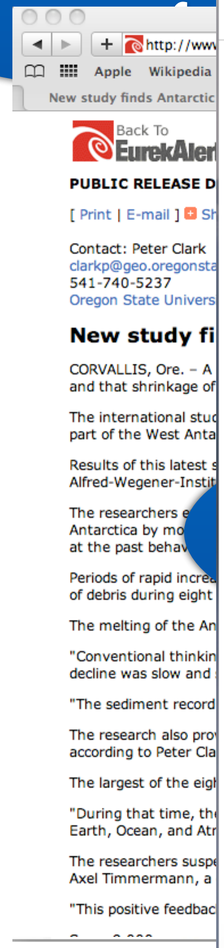
May 28, 2014: During that time, the sea level on a global basis rose about 50 feet in just 350 years

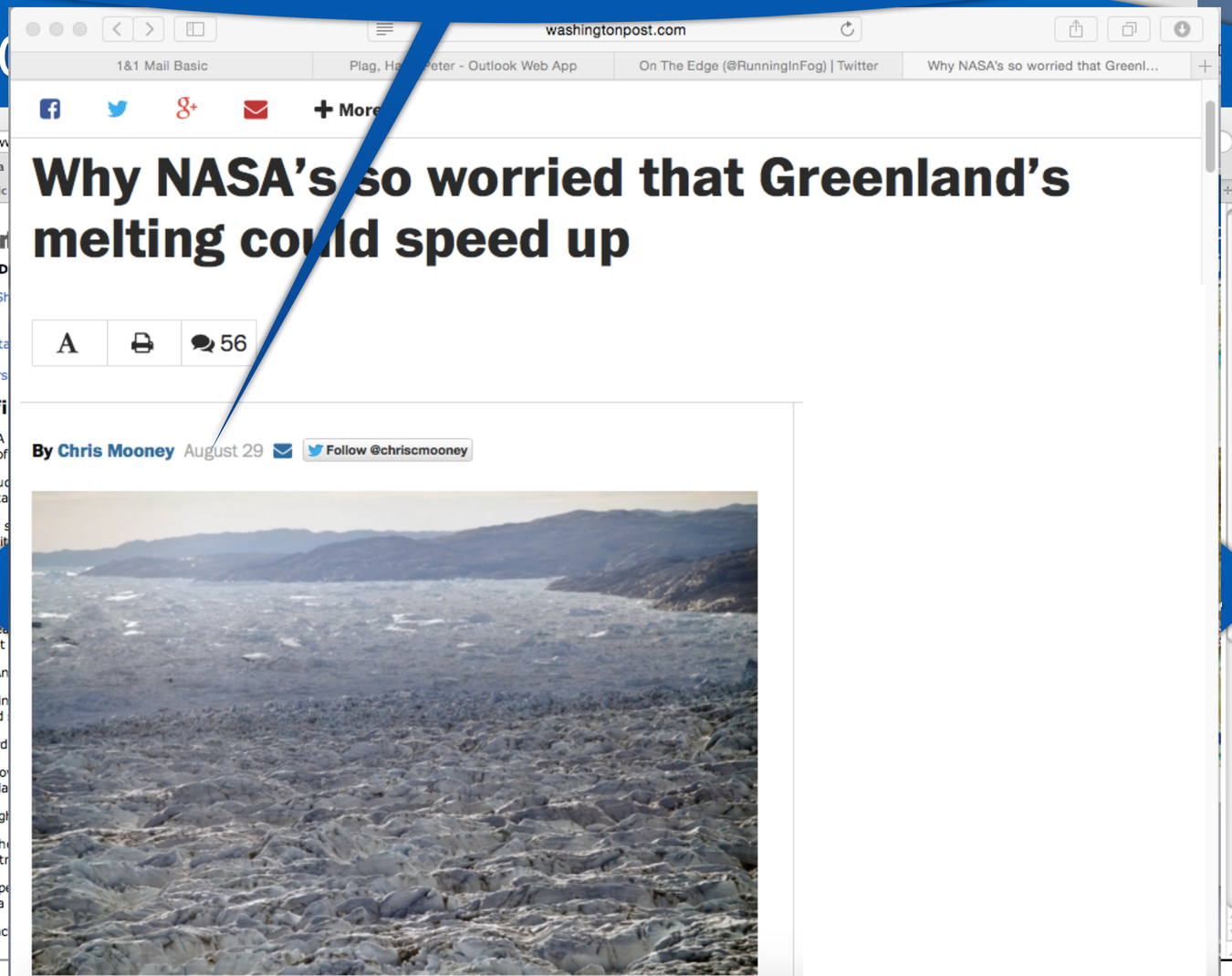
The Prognosis: Anti

August 29, 2015: "The critical question thus becomes: Is Greenland likely to lose even more ice than it's currently losing per year — and could Antarctica do the same?"

May 18, 20







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Antarctica: minor contribution
Main contribution: steric changes

Knowledge in 2015:
Greenland: is contributing, is accelerating, potentially a large contribution to sea level rise; increasing potential for a large contribution due to deep warm water around Greenland
Antarctica: West Antarctic ice sheet (WAIS) will contribute 4.5 m

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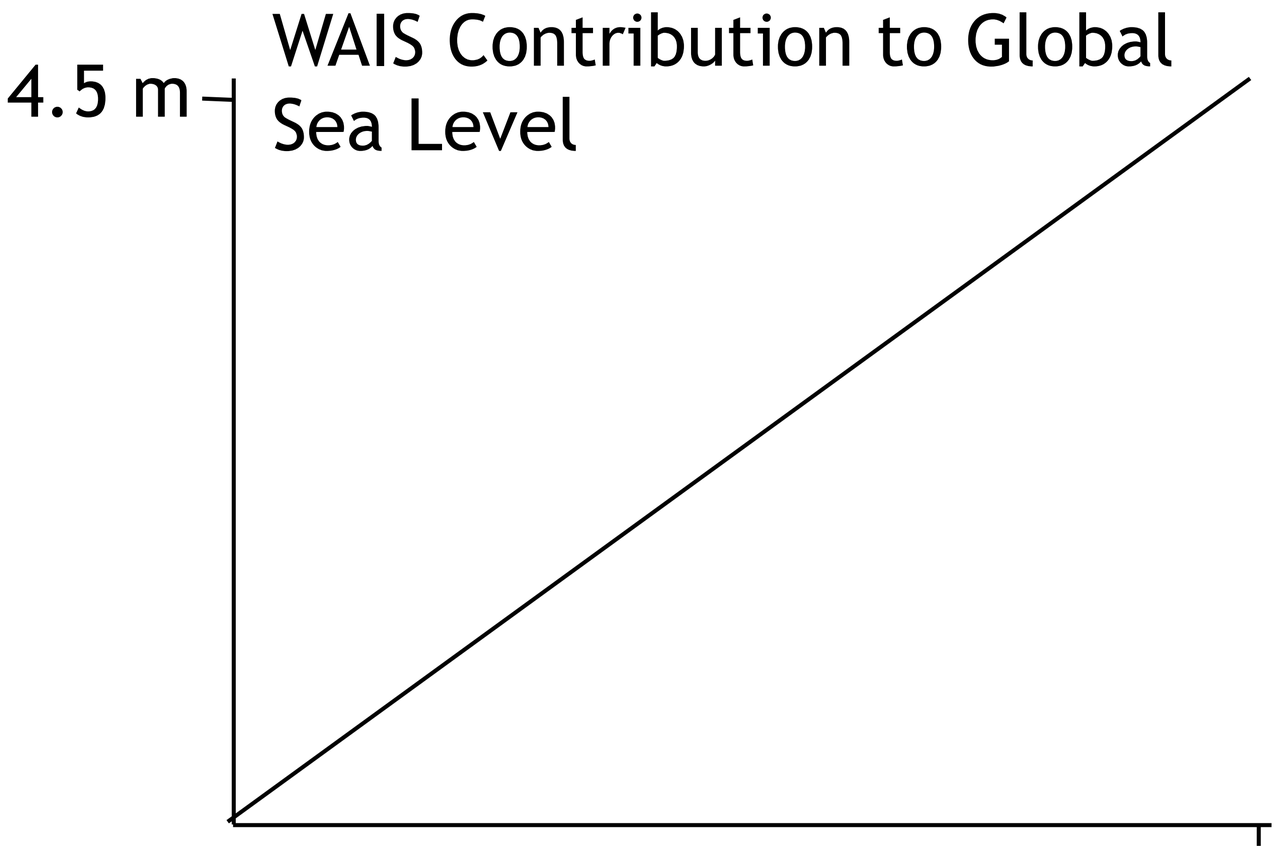

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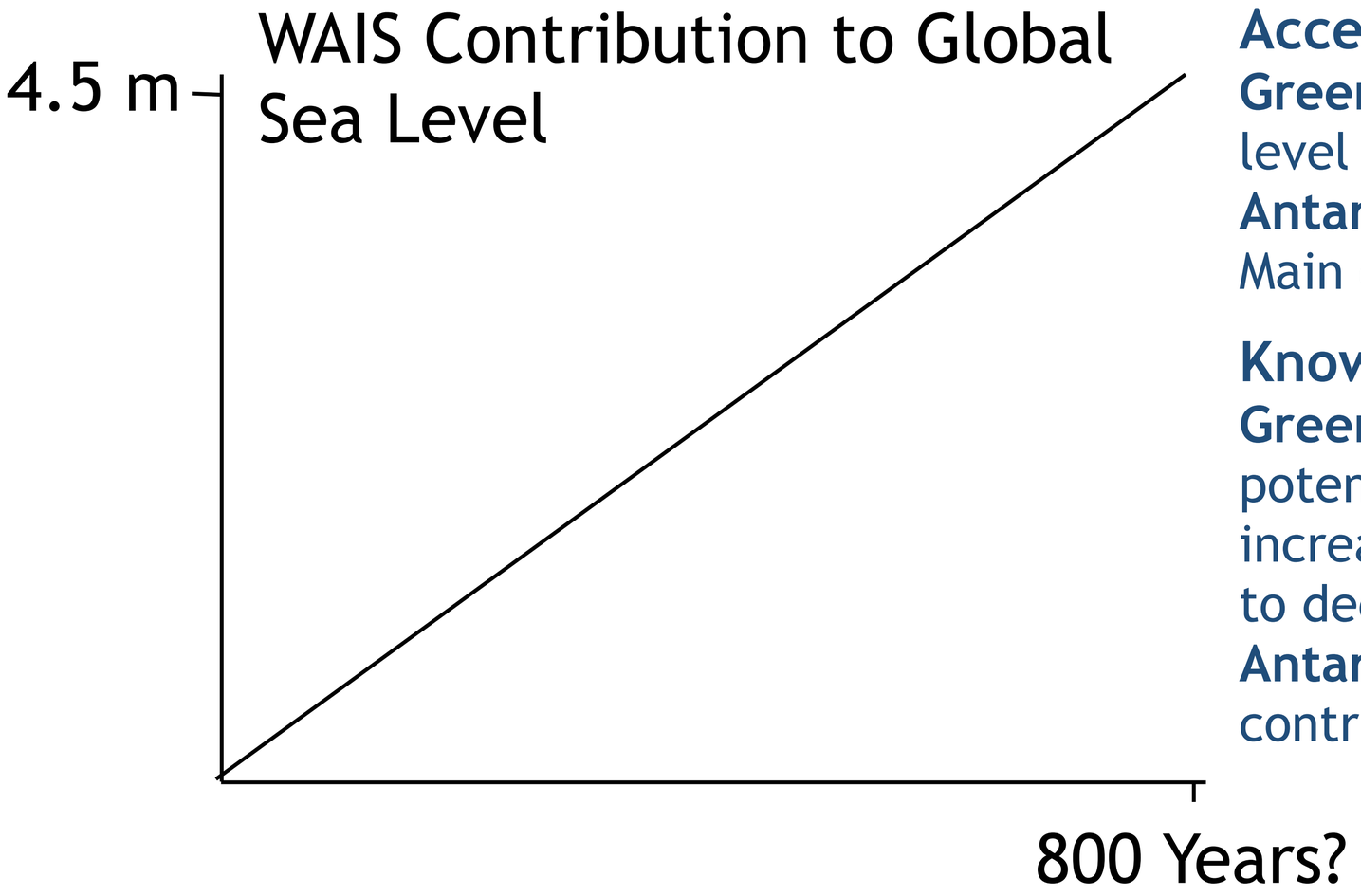

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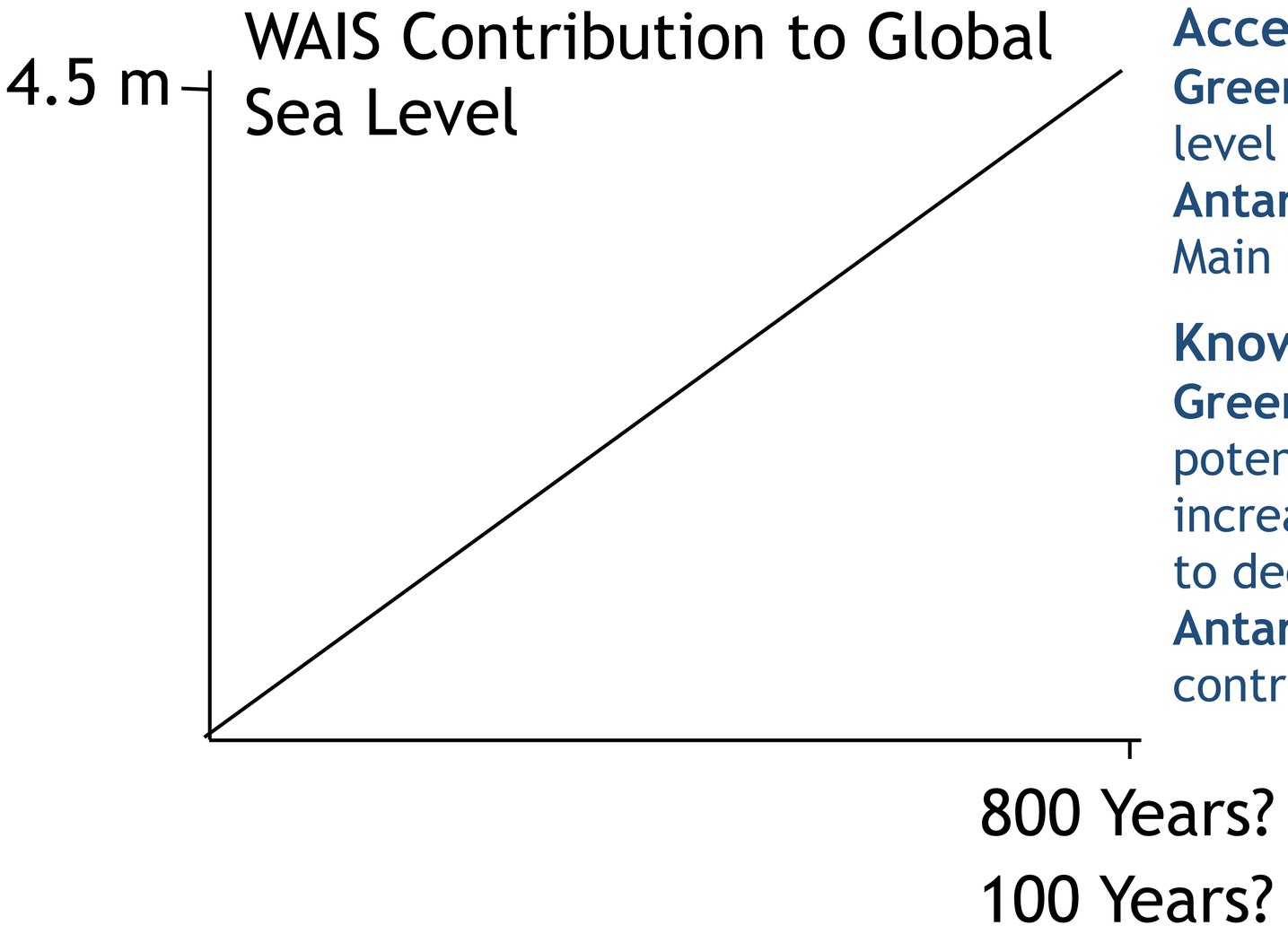

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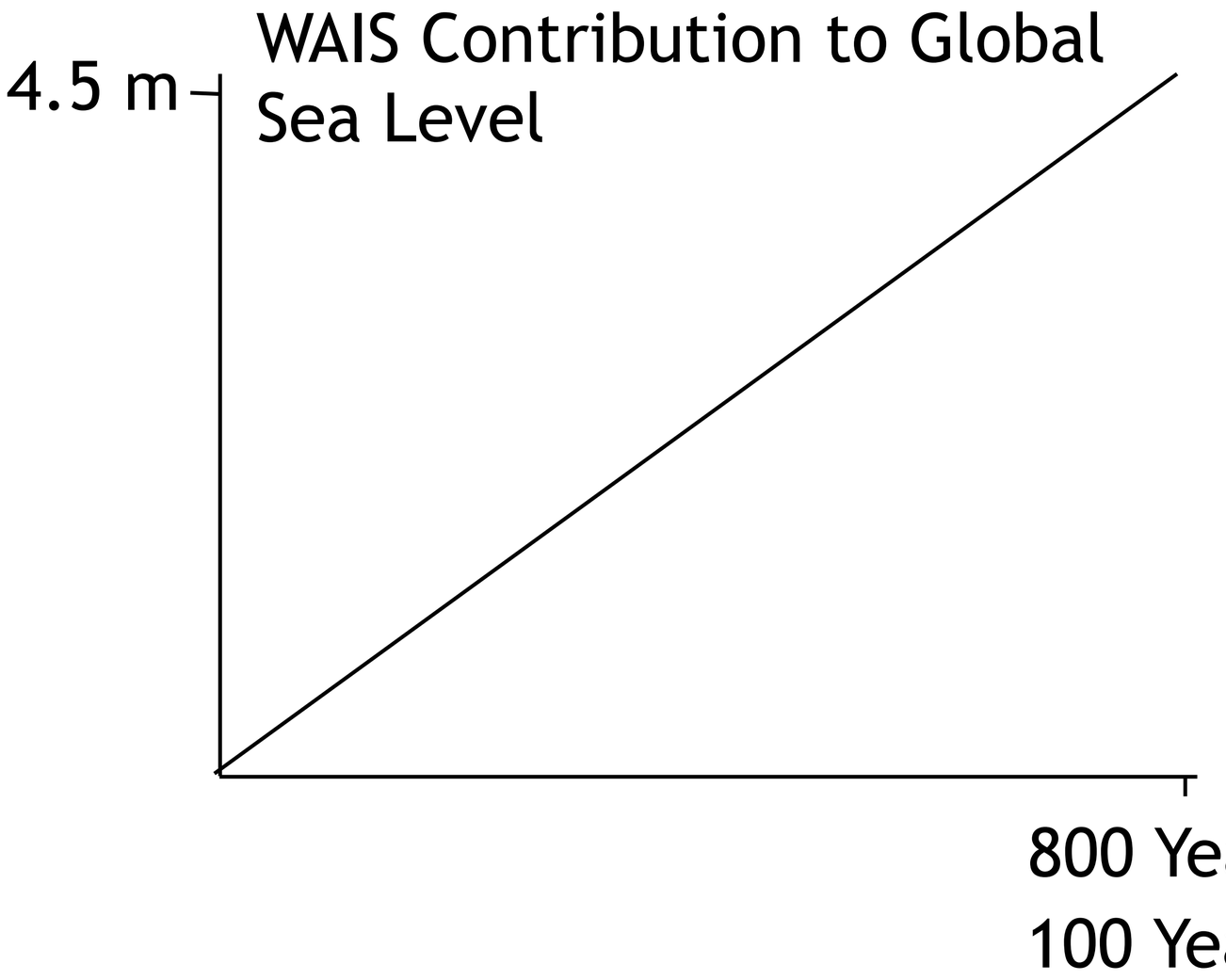

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How worried should we be?

The Prognosis: Anticipating Surprises

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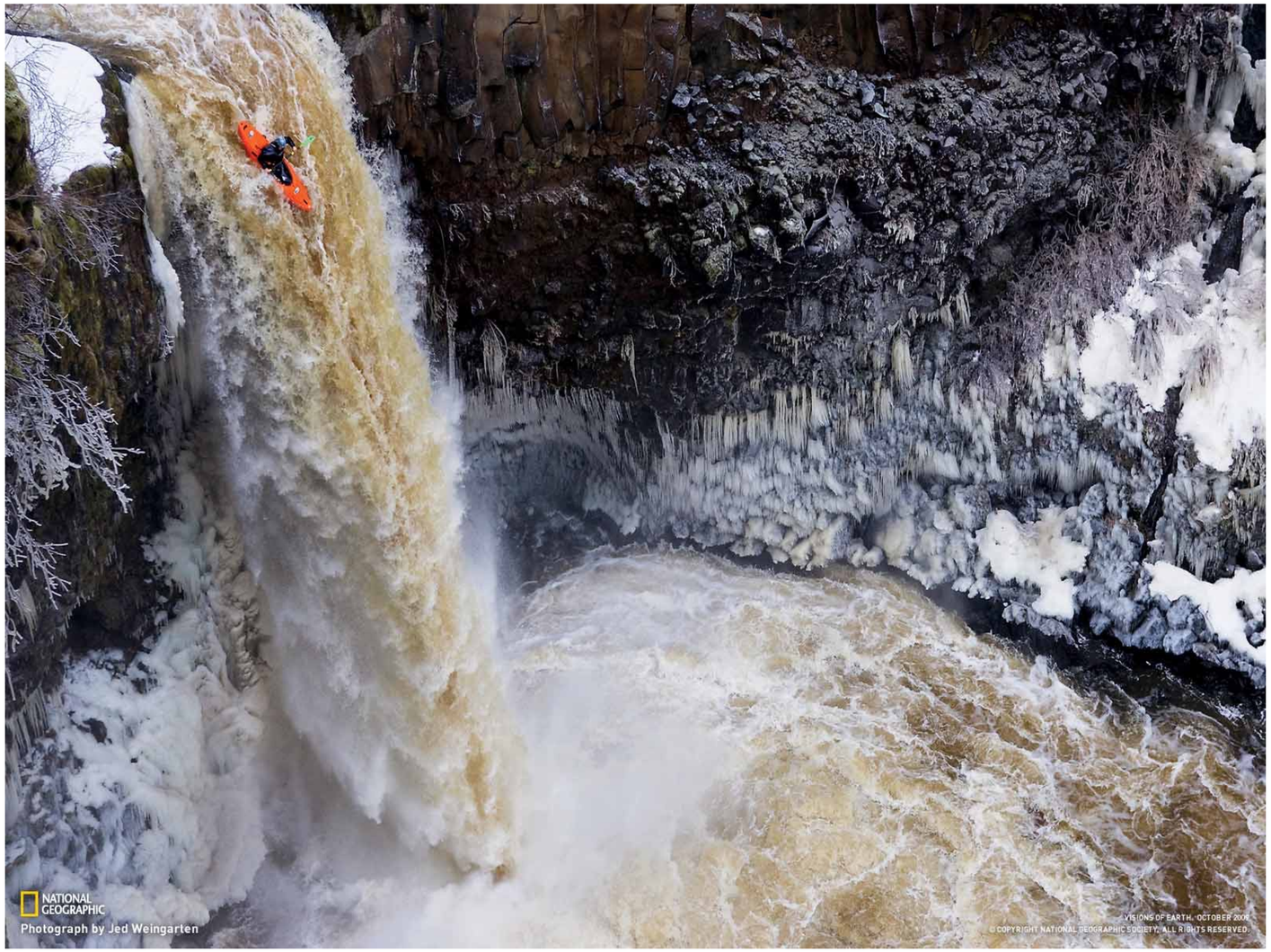
Understanding thresholds

The Prognosis: Anticipating Surprises

Understanding thresholds

The threshold is not where the boat goes over the edge, it is far up the river, when the people in the boat lose the option to get to the shore



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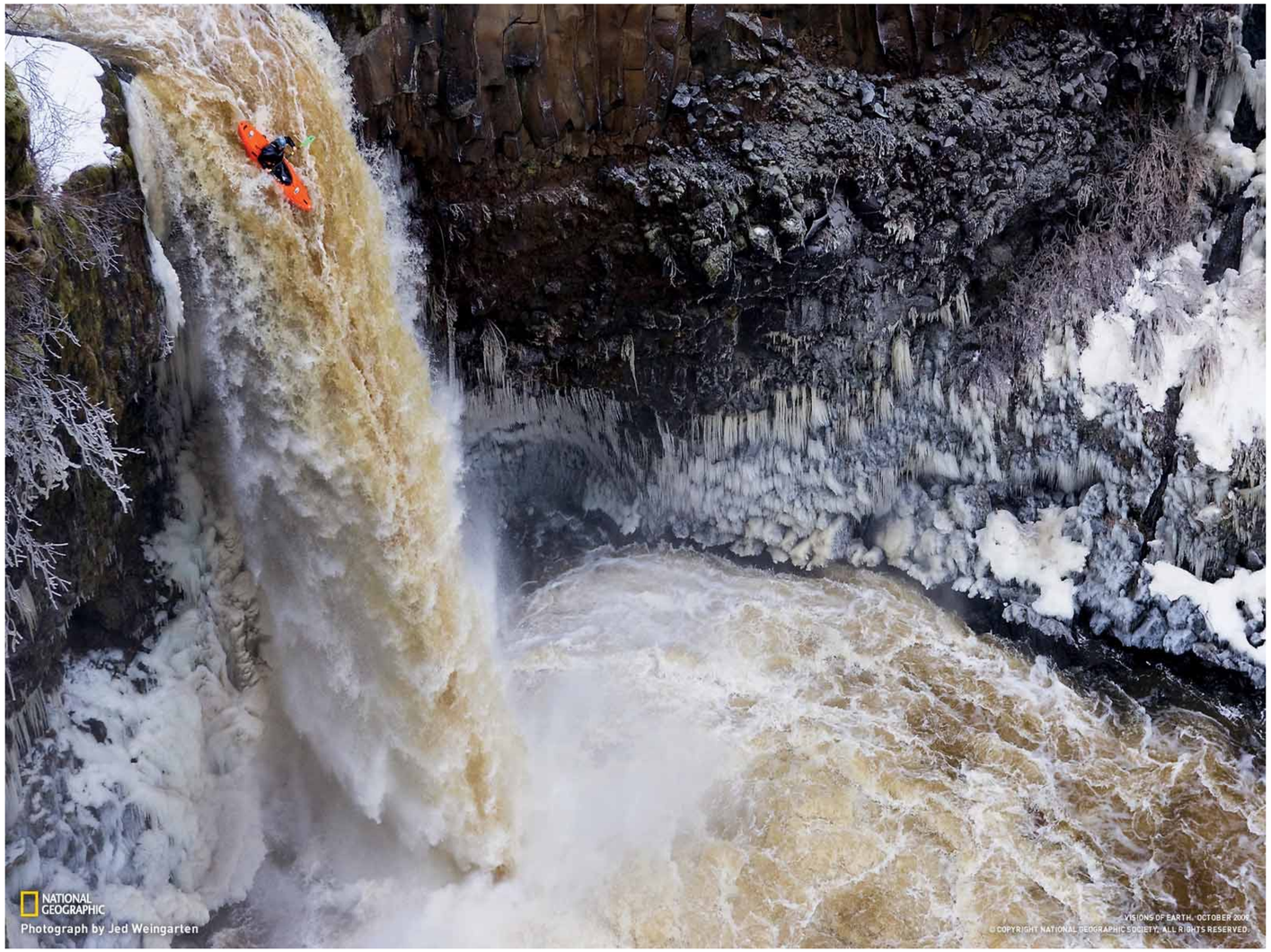
On a big, unknown river, don't go into the middle, stay close to the shore

Jim White



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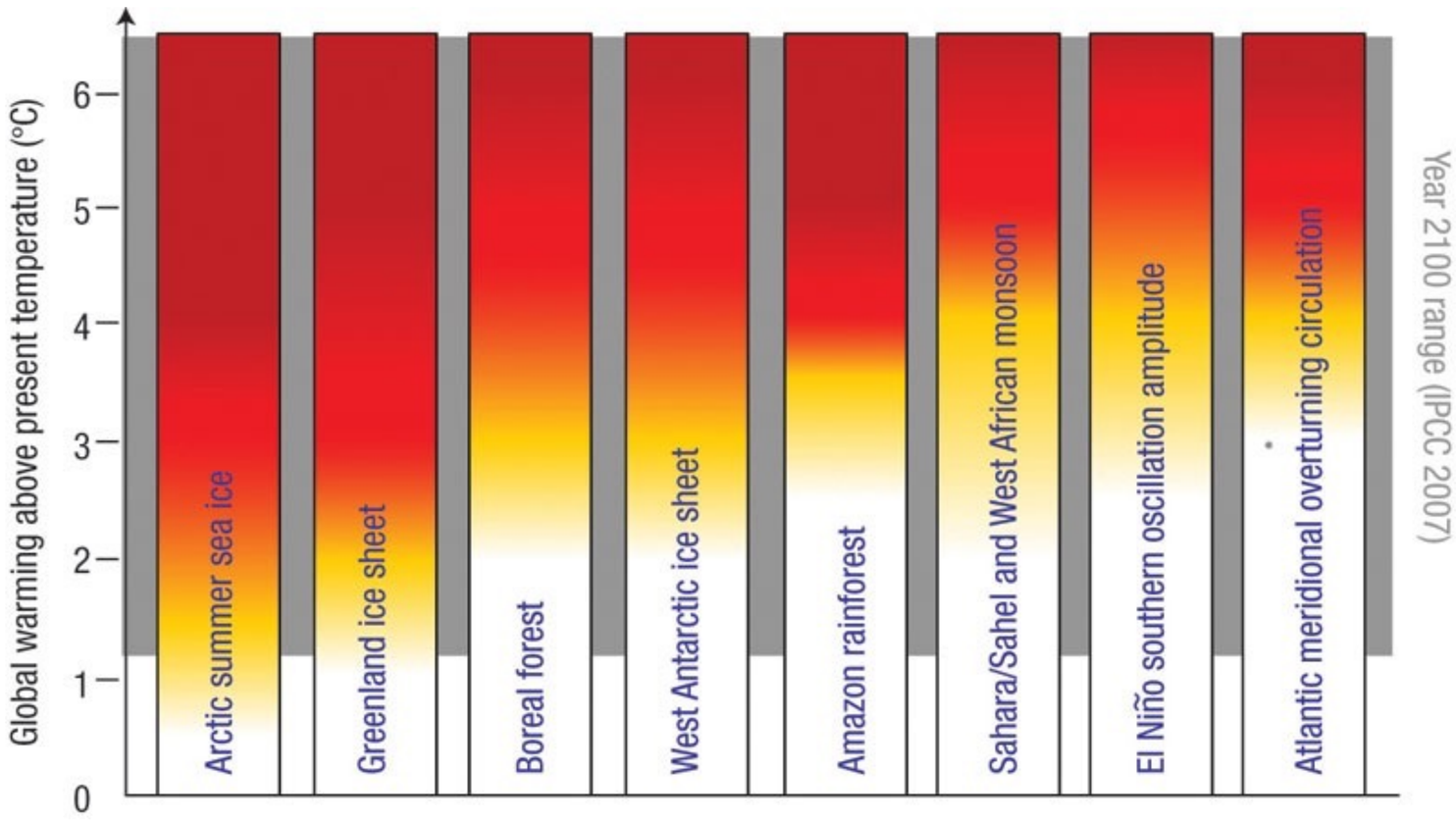
Many thresholds, including climate change related ones …



Lenton & Schellnhuber (2007) *Nature Reports Climate Change*

The Prognosis: Anticipating Surprises

Understanding thresholds

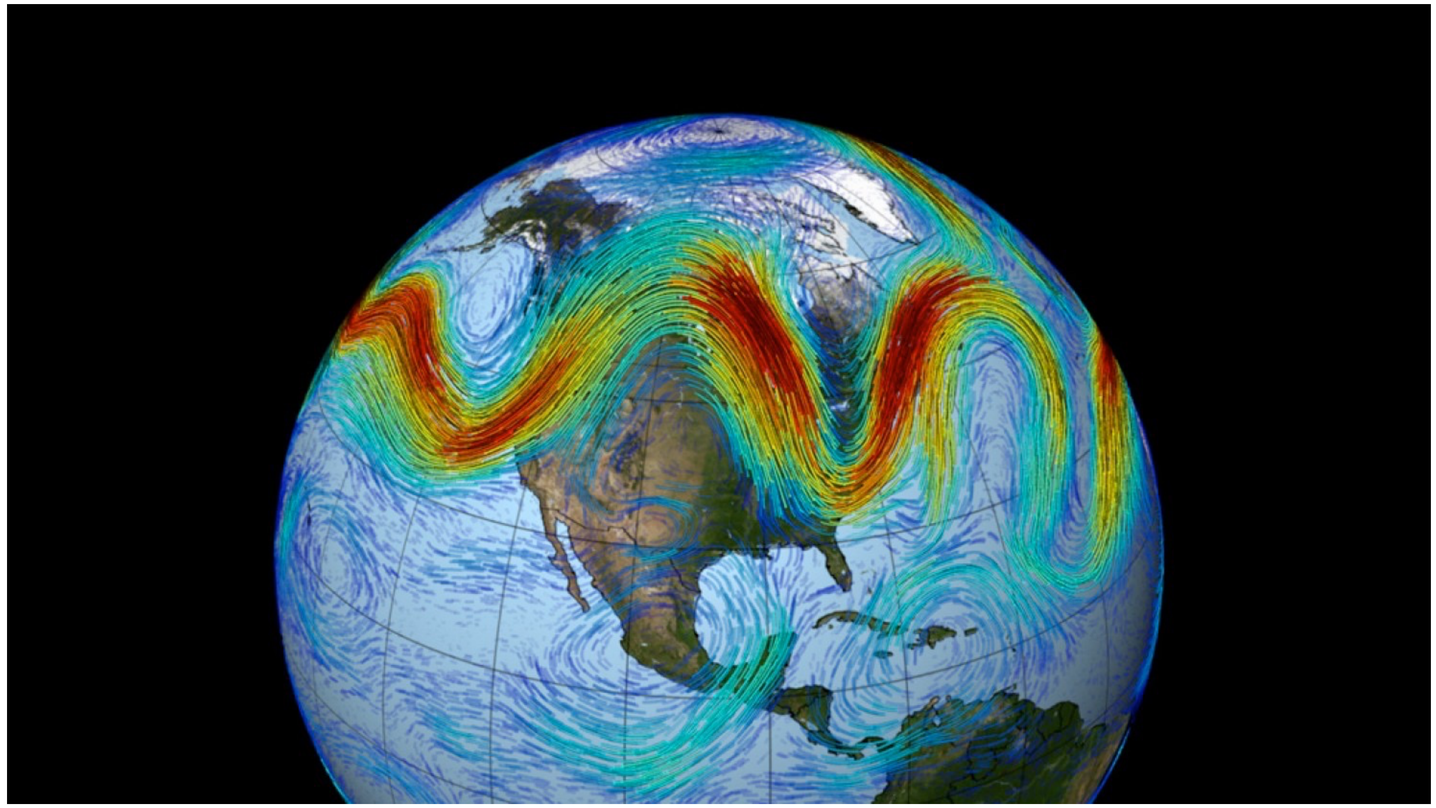
The threshold is not where the boat goes over the edge, it is far up the river, when the people in the boat lose the option to get to the shore

On a big, unknown river, don't go into the middle, stay close to the shore

Jim White

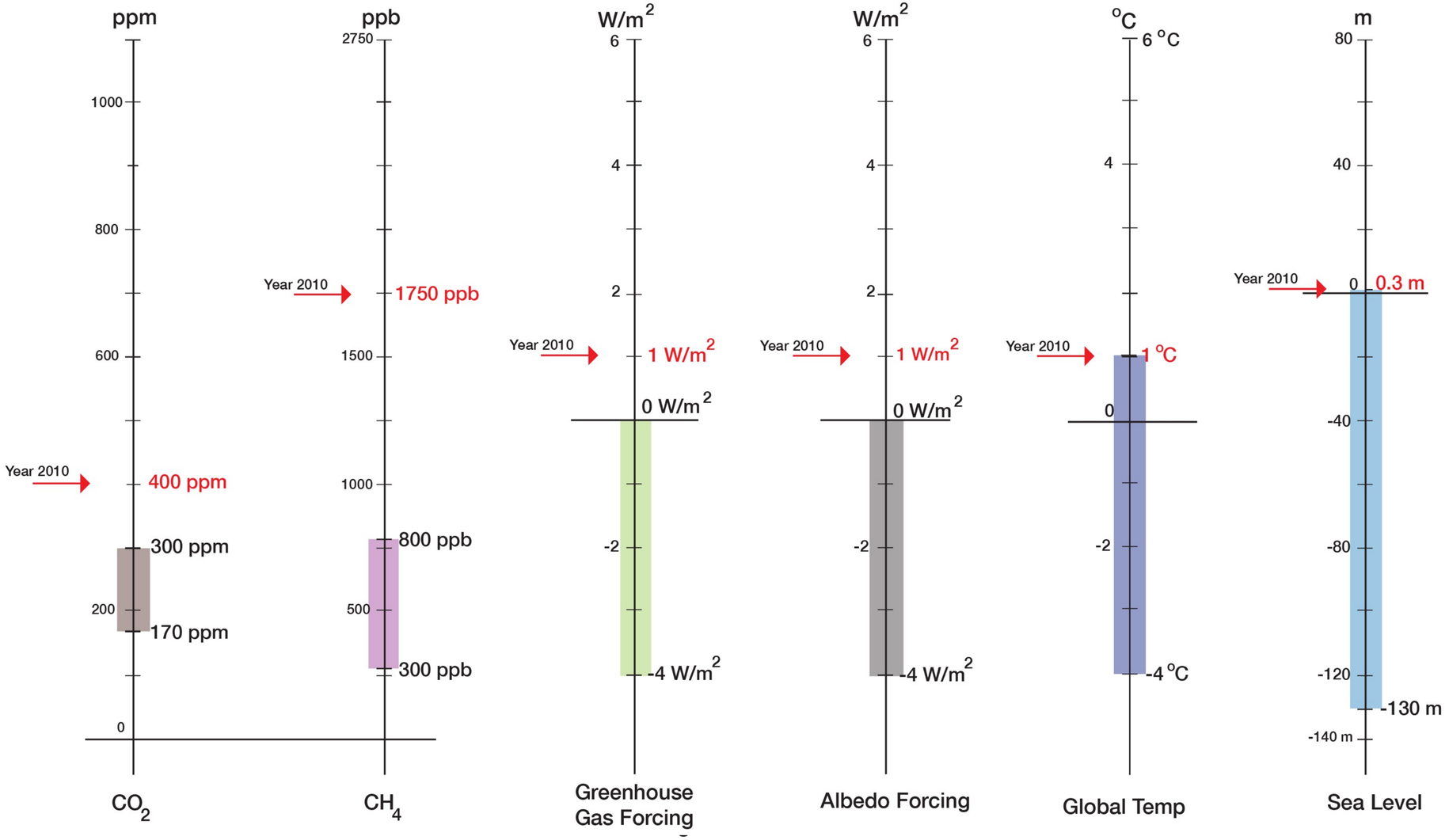
Many thresholds, including climate change related ones …

The warming of the Arctic could be a threshold we have crossed ...



Francis and Vavrus, 2015

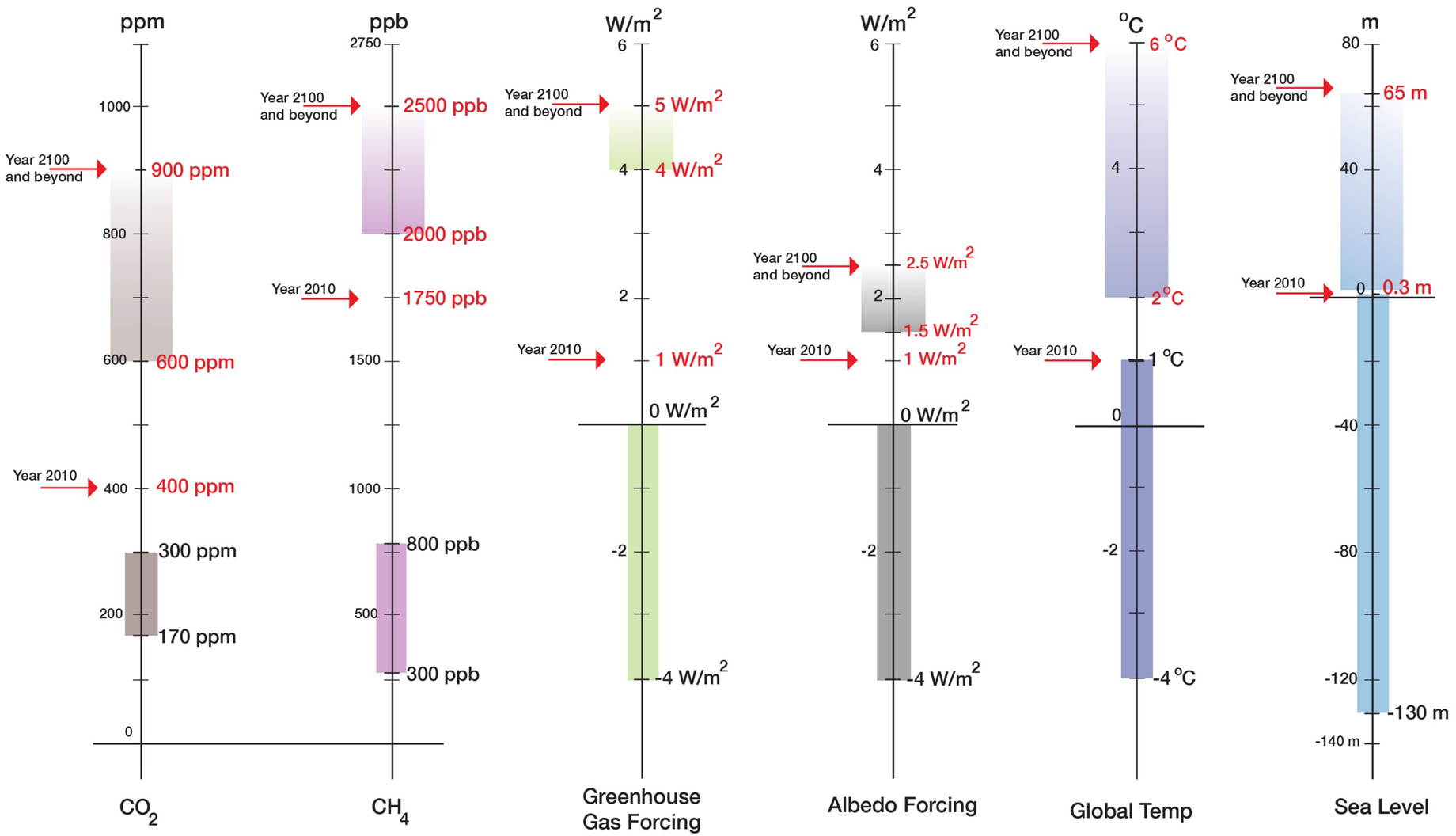
The Prognosis: Anticipating Surprises



"Current State"

"Normal Range"
(800,000 years)

The Prognosis: Anticipating Surprises



"Prognosis"

"Current State"

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(800,000 years)

The Prognosis: Anticipating Surprises

The Prognosis: Anticipating Surprises

Our Commitment: The "~400 ppm CO_2 World":

The Prognosis: Anticipating Surprises

Our Commitment: The "~400 ppm CO_2 World":

Example: Mid-Pliocene, 3.3 to 3.0 Million Years ago
Temperature: ~1 - 2 ^{o}C higher
Sea level:

- global average on the order of 10 m higher than today
- regionally 5 to 40 m higher;
- most likely, much stronger storms due to larger temperature difference between tropics and polar regions

The Prognosis: Anticipating Surprises

Hansen et al., 2015: "… Evidence … that 2°C global warming is highly dangerous."

Example: …
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Atmos. Chem. Phys. Discuss., 15, 20059-20179, 2015
www.atmos-chem-phys-discuss.net/15/20059/2015/
doi:10.5194/acpd-15-20059-2015

Research Article 23 Jul 2015

Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous

Review Status
This discussion paper is under review for the journal Atmospheric Chemistry and Physics (ACP).

J. Hansen[1], M. Sato[1], P. Hearty[2], R. Ruedy[3,4], M. Kelley[3,4], V. Masson-Delmotte[5], G. Russell[4], G. Tselioudis[4], J. Cao[6], E. Rignot[7,8], I. Velicogna[7,8], E. Kandiano[9], K. von Schuckmann[10], P. Kharecha[1,4], A. N. Legrande[4], M. Bauer[11], and K.-W. Lo[3,4]

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[9]GEOMAR, Helmholtz Centre for Ocean Research, Wischhofstrasse 1–3, Kiel 24148, Germany
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[11]Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY, 10027, USA

Received: 11 Jun 2015 – Accepted: 09 Jul 2015 – Published: 23 Jul 2015

Abstract. There is evidence of ice melt, sea level rise to +5–9 m, and extreme storms in the prior interglacial period that was less than 1 °C warmer than today. Human-made climate forcing is stronger and more rapid than paleo forcings, but much can be learned by combining insights from

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Key Points

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

During the last hundred years, we have introduced rapid and large changes

The system is already now outside the “normal range” and in the transition to the Post-Holocene

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The Therapy: “Lifestyle Changes”

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Decision Making Under Uncertainty (DMUU):

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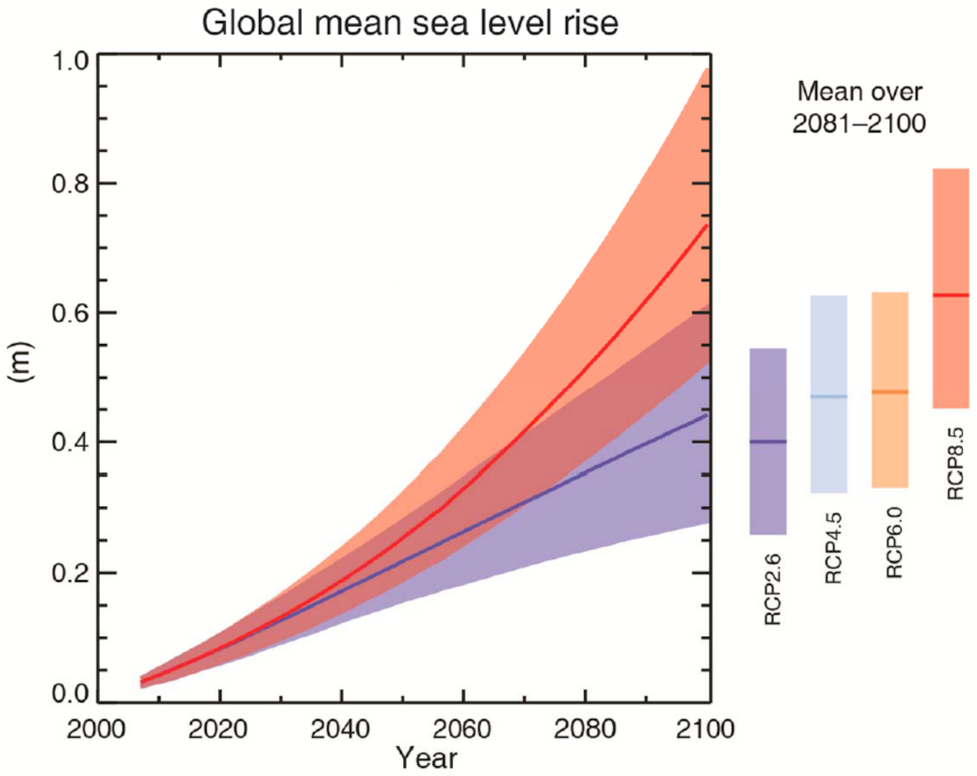

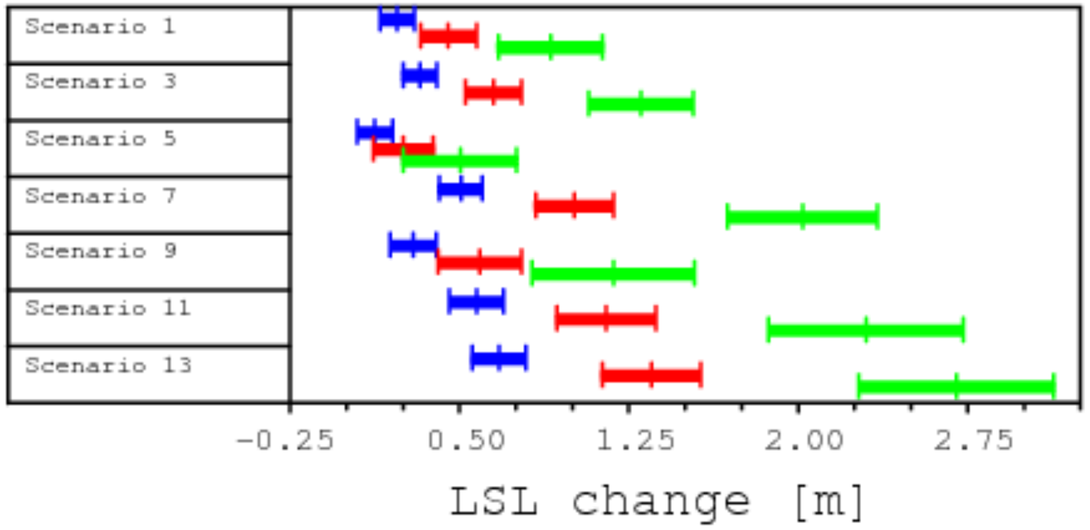

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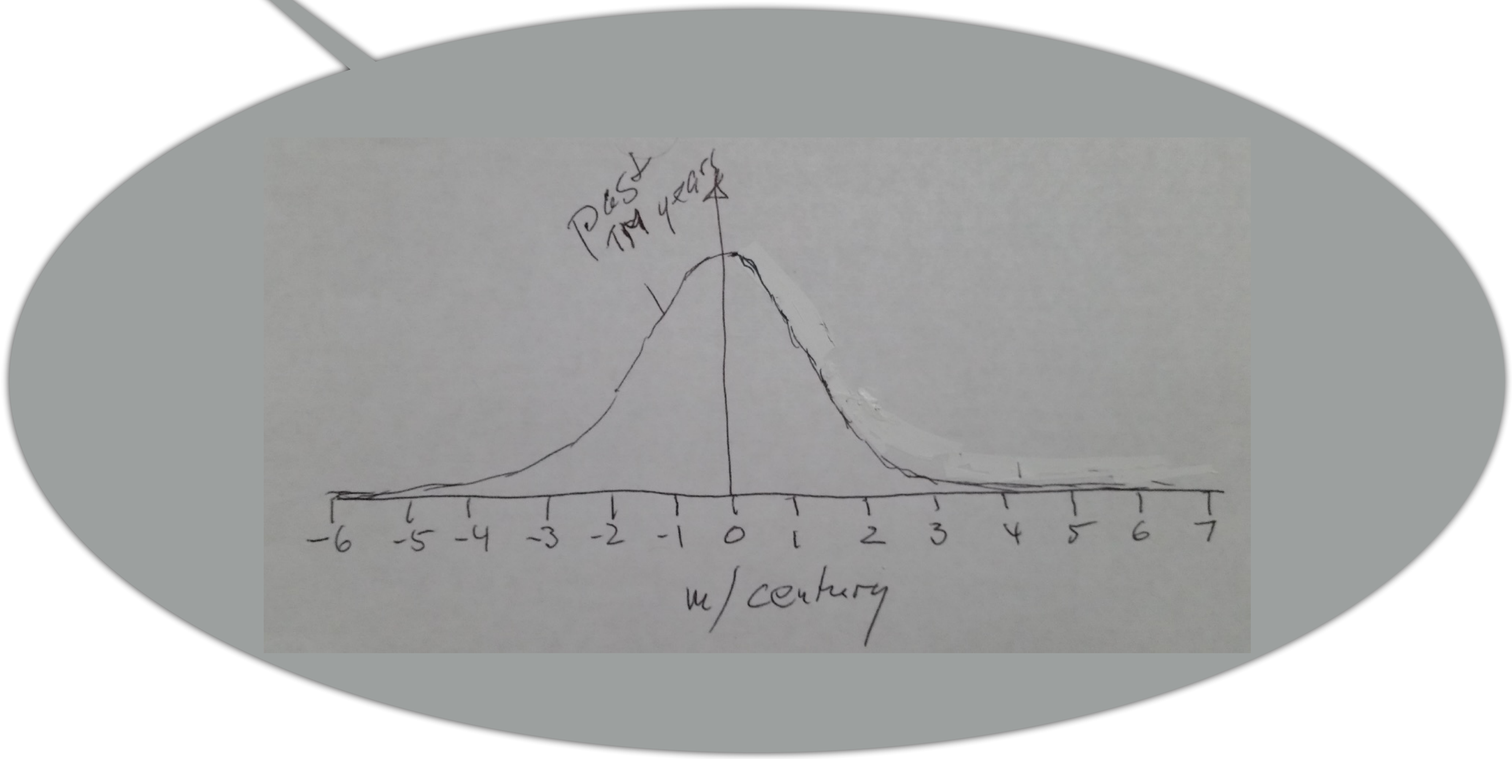

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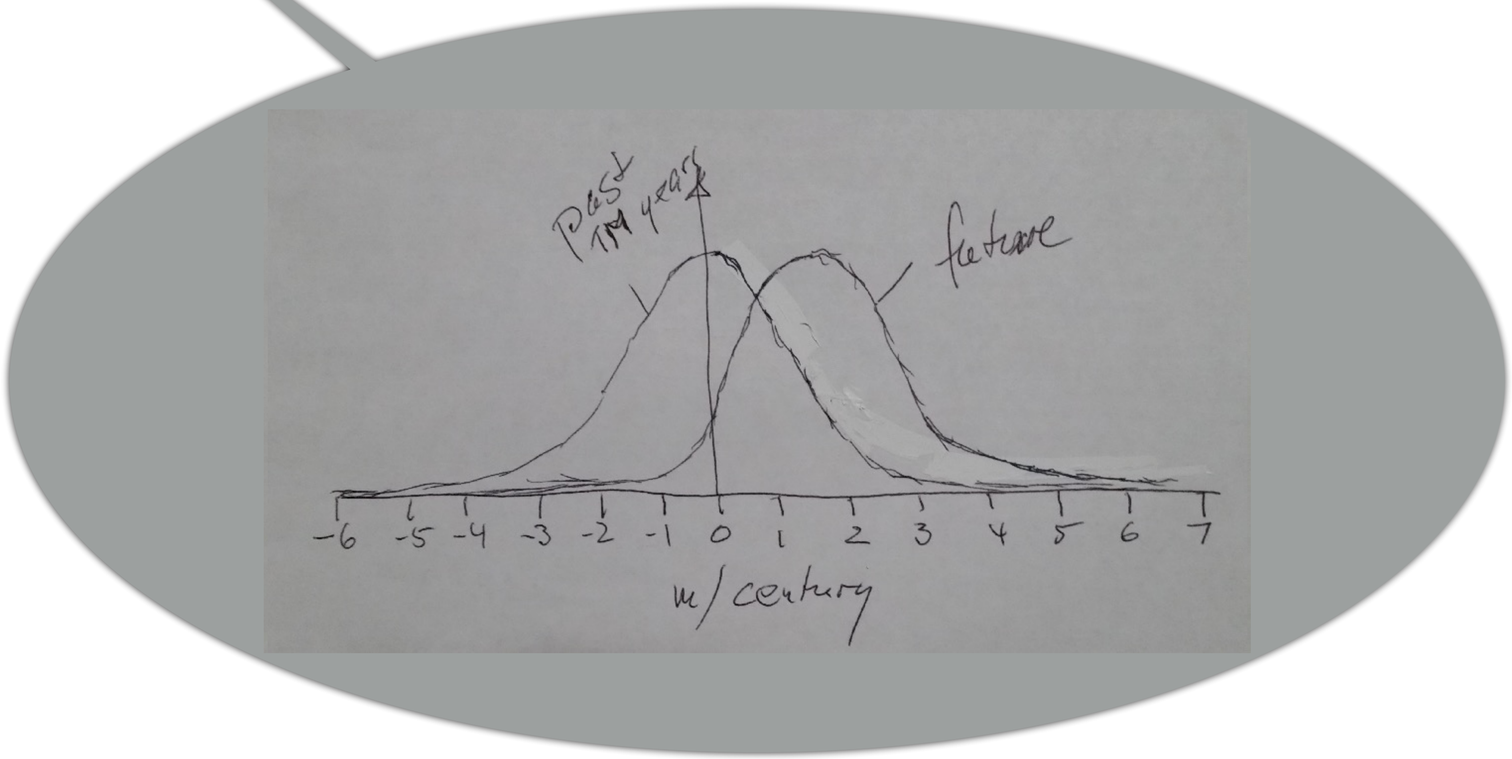

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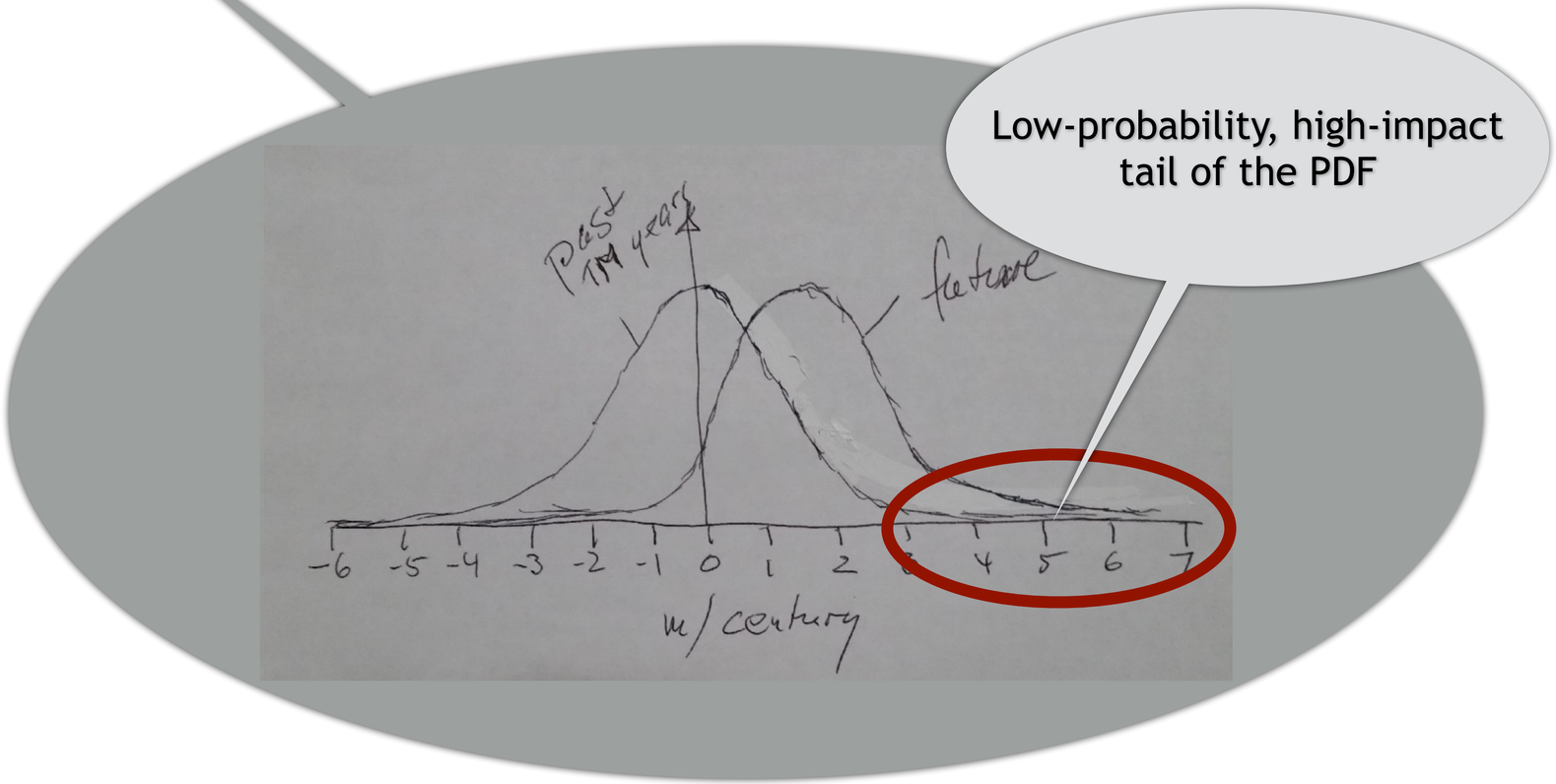

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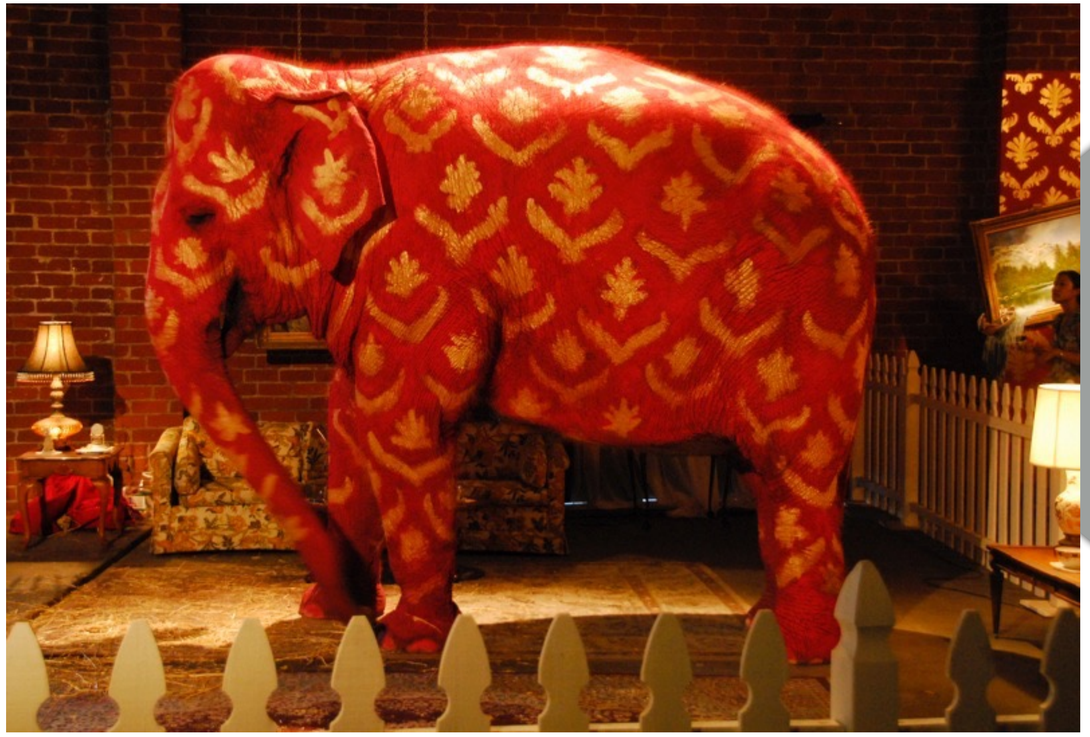

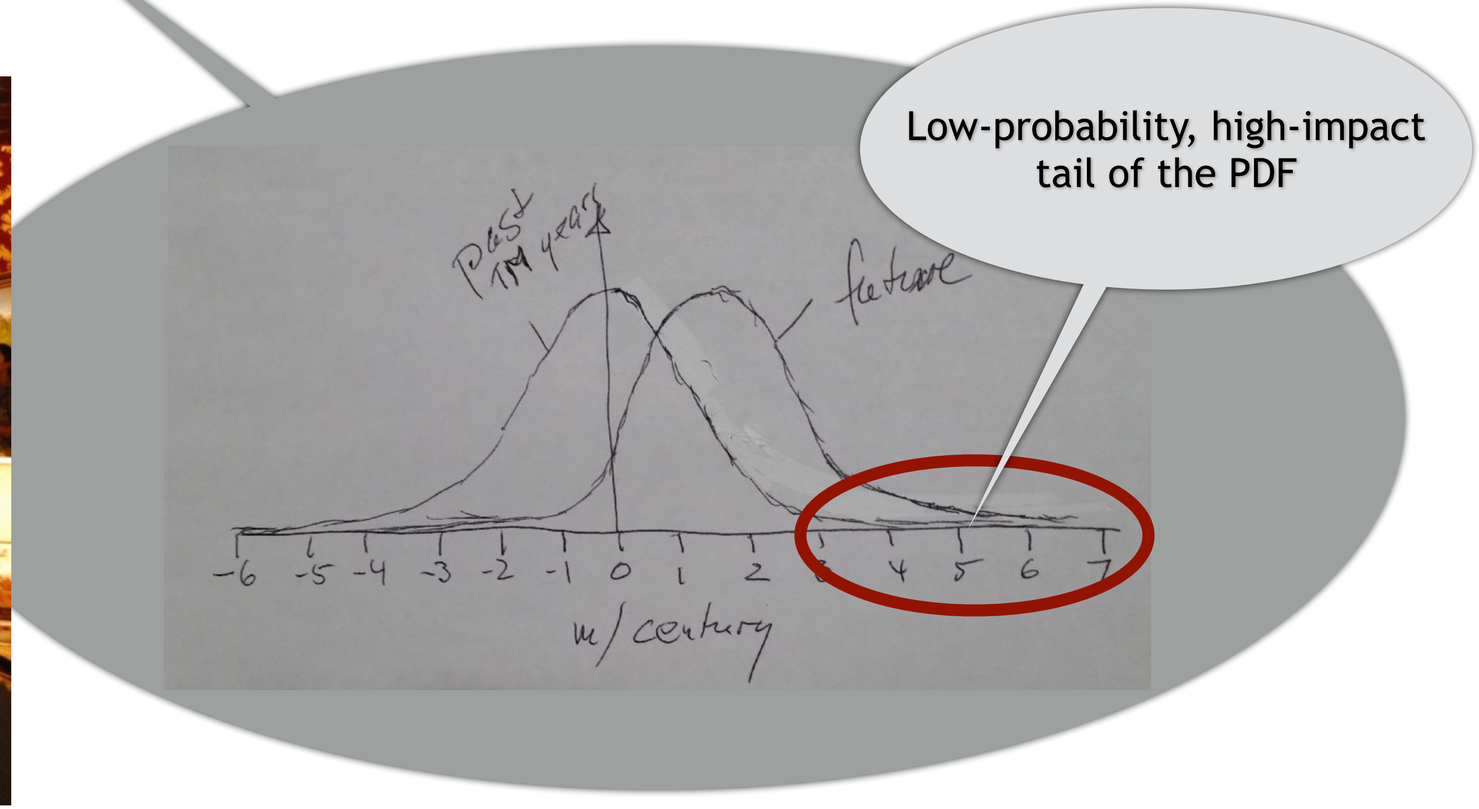

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How large is the risk associated with the part of the PDF not considered?
MOST LIKELY VERY LARGE, BUT WE DON’T HAVE A SOLID ASSESSMENT

How likely is it that LSL might by far outside the limited range considered?
WE CANNOT EXCLUDE THIS TO HAPPEN IN THE “Post-Holocene”

How likely would that turn into a low-probability, high-impact event?
MOST LIKELY, THIS WOULD BE A GLOBAL DISASTER

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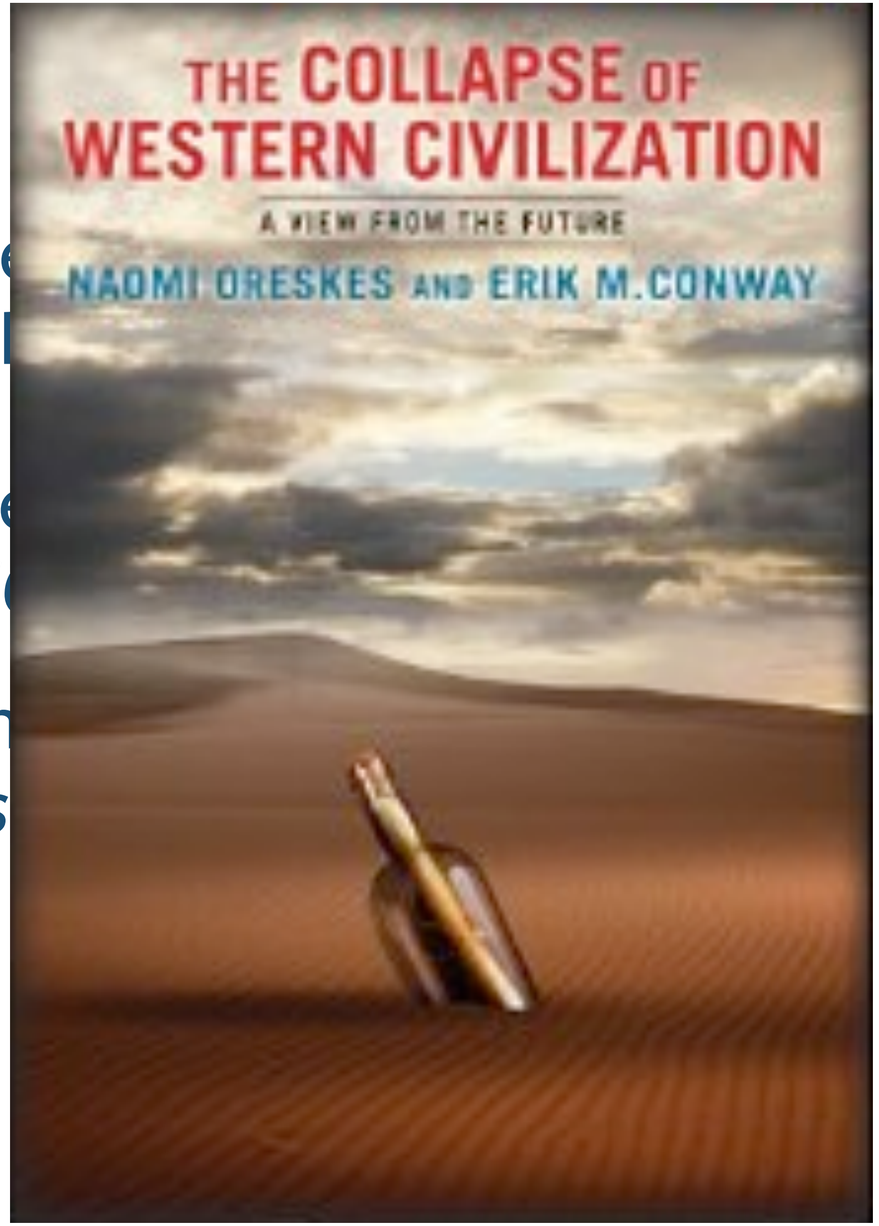

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Decision Making Under Foreseeability (DMUF): *Having Foresight*

The Therapy: “Lifestyle Changes”

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The Therapy: “Lifestyle Changes”

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Current paradigm (normalcy bias, based on 6,000 years):

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Necessary:

- develop concepts, governance, infrastructure, and built environment that allows us to benefit from working and living in the coastal zone under changing sea levels and moving coast lines.

The Therapy: “Lifestyle”Changes

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Biomes or ecosystems	Typical cost of restoration in USD (high scenario)	Estimated annual benefits from restoration (average scenario)	Net present value of benefit over 40 years (USD/ha)	Internal rate of return (%)	Benefit/ cost ratio
Coral reefs	542,500	129,200	1,166,000	7	2.8
Coastal ecosystems	232,700	73,900	935,400	11	4.4
Mangroves	2,880	4,290	86,900	40	26.4
Inland wetlands	33,000	14,200	171,300	12	5.4
Lakes and rivers	4,000	3,800	69,700	27	15.5
Tropical forests	3,450	7,000	148,700	50	37.3
Other forests	2,390	1,620	26,300	20	10.3
Woodland and shrubland	990	1,571	32,180	42	28.4
Grassland	260	1,010	22,600	79	75.1

Rockstrom and Klum, 2015

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Example of sea level rise:

- making room for the water
- a built environment for extreme floods (buildings and services)
- preparing the coastal zone for future inundation
- making room for ecosystem migration

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Living where it is safe, working where it is needed

Rockstrom and Klum, 2015

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Paradigm shifts may be required; for example: instead of “Sea level does not change very and changes in the coastal zone are gradual” assume “Sea level can change fast and coastal zones can migrate rapidly.”

The Therapy: “Lifestyle”Changes

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“Sustainable Development is a development that meets the needs of the presence while safeguarding Earth’s life support systems, on which the welfare of current and future generations depends.” (Griggs et al., 2013)

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Economy **against** humanity:
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“What is good for Earth’s life support system is good for humanity”

"No problem can be solved with the same consciousness that created it."

Albert Einstein

"It is difficult to get a man to understand something when his job depends on not understanding it"

Upton Sinclair