Oluwakemi Izomo

Preparing for a Journey Into the Unknown: The Transition to the Post-Holocene

Hans-Peter Plag
May 16, 2015

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The Baseline: Past Climate Variability

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The Prognosis: Anticipating Surprises

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Preparing for a Journey Into the Unknown: The Transition to the Post-Holocene

ODU IDEA FUSION

MITIGATION & ADAPTATION RESEARCH INSTITUTE MARI OLD DOMINION UNIVERSITY

The Baseline: Past Climate Variability

The Syndrome: Recent Climate and Global Changes

The Diagnosis: Leaving the “safe operating space”

The Prognosis: Anticipating Surprises

The Therapy: “Lifestyle” changes

Hans-Peter Plag

May 16, 2015

The Baseline: Past Climate Variability

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Climate Change is a long-term shift in the statistics of weather - averages, frequency and magnitude of extremes.

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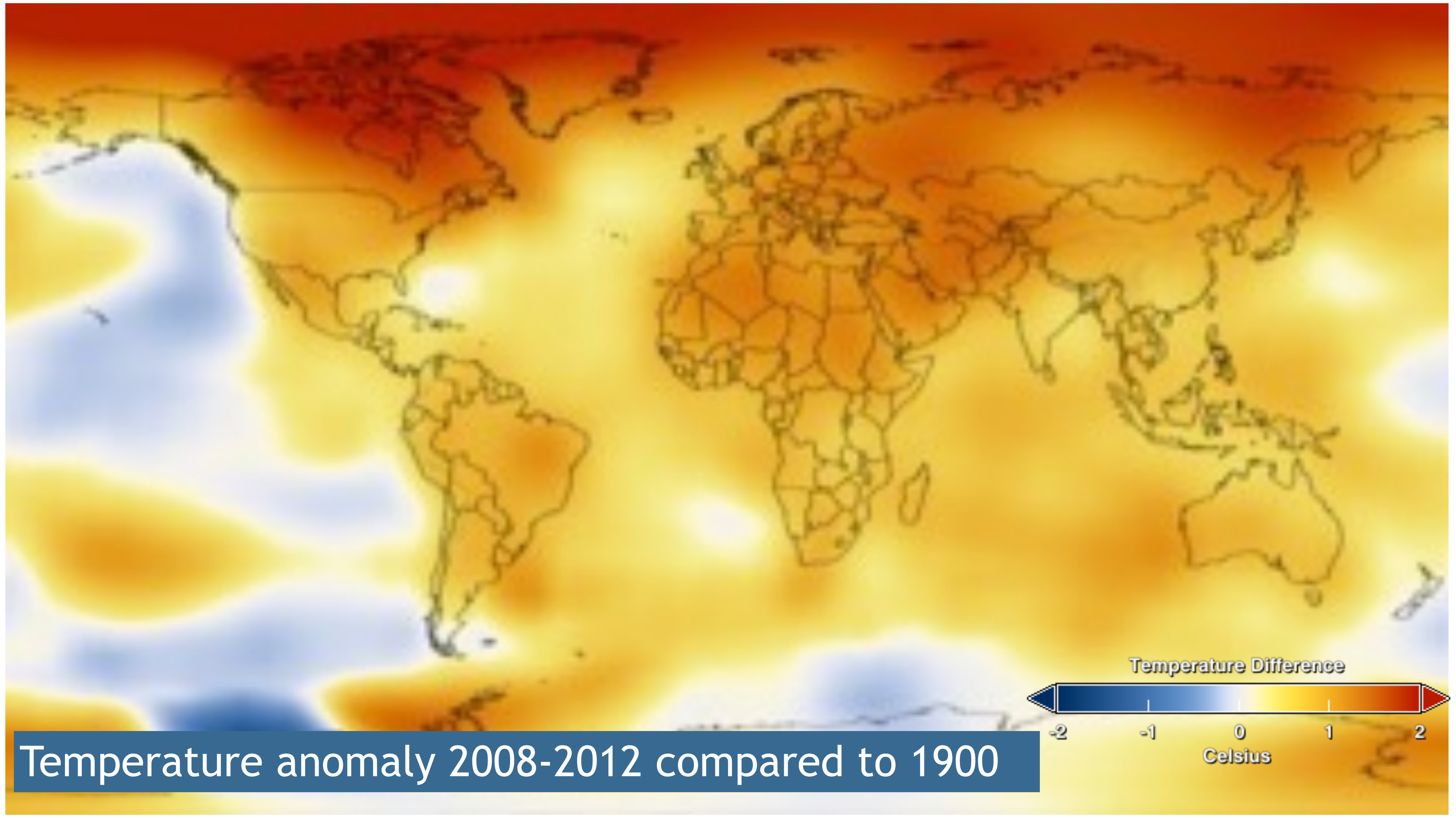

Temperature anomaly 2008-2012 compared to 1900

Climate can change from local to global scales.

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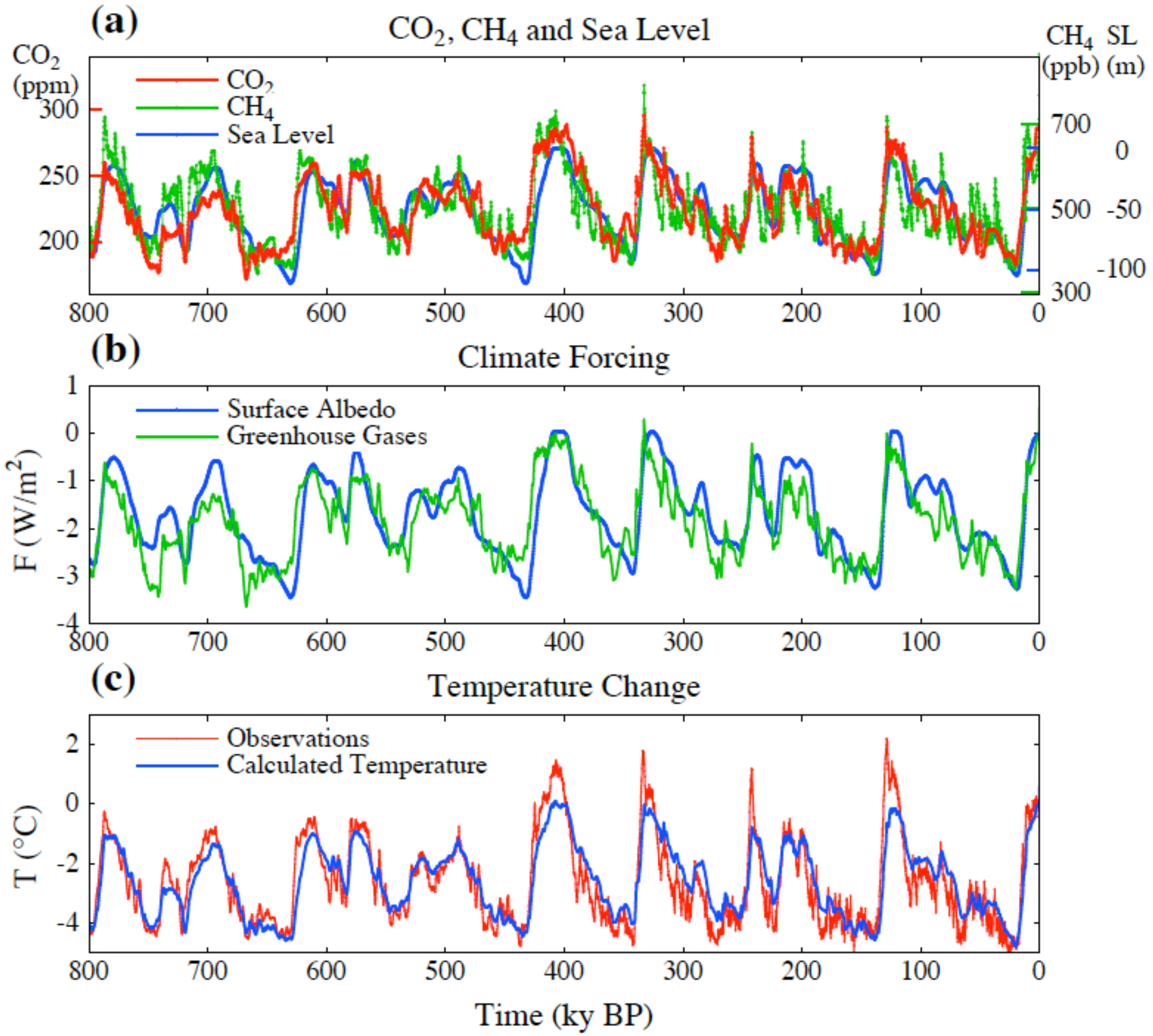
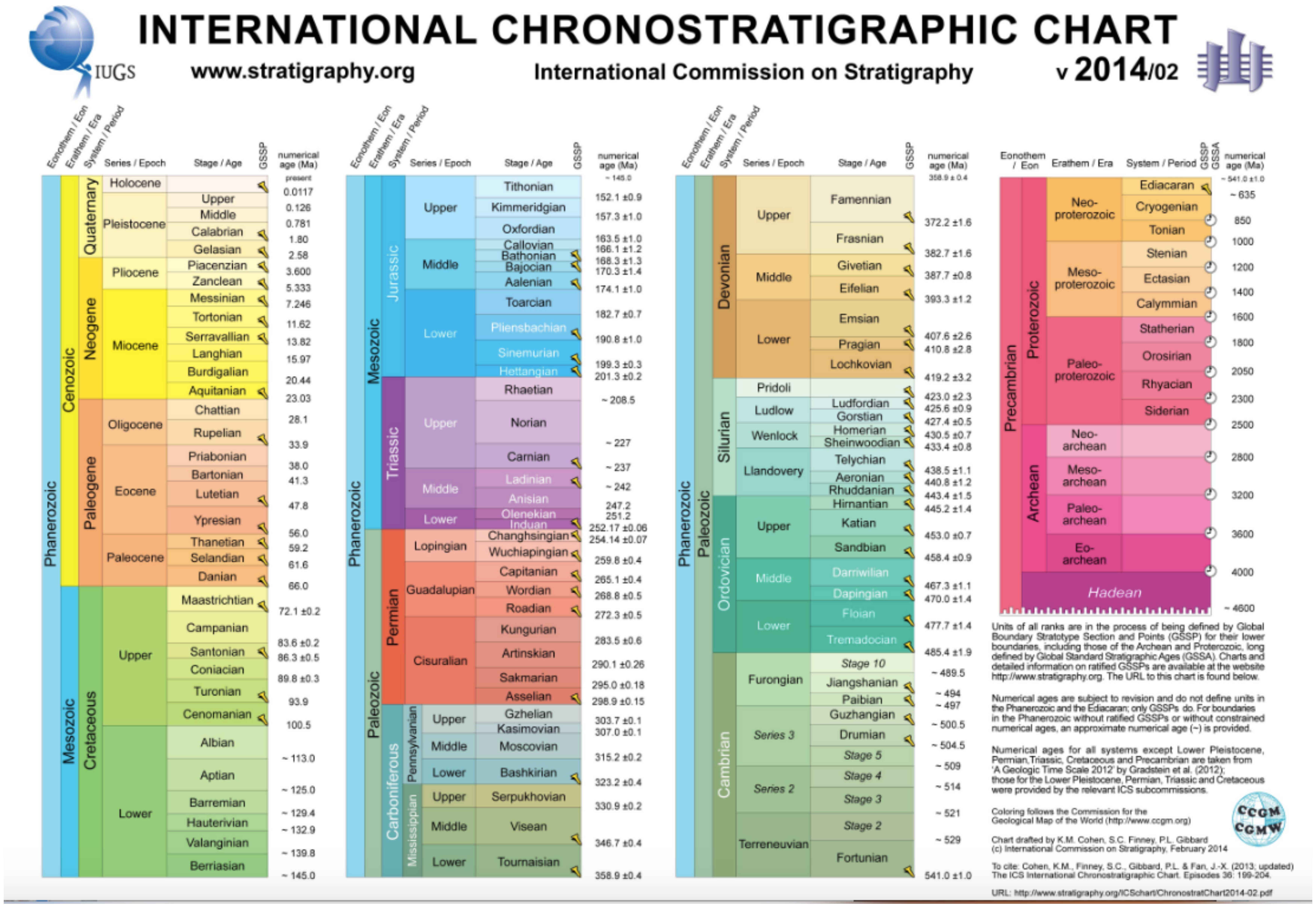
Climate can change a lot over time.

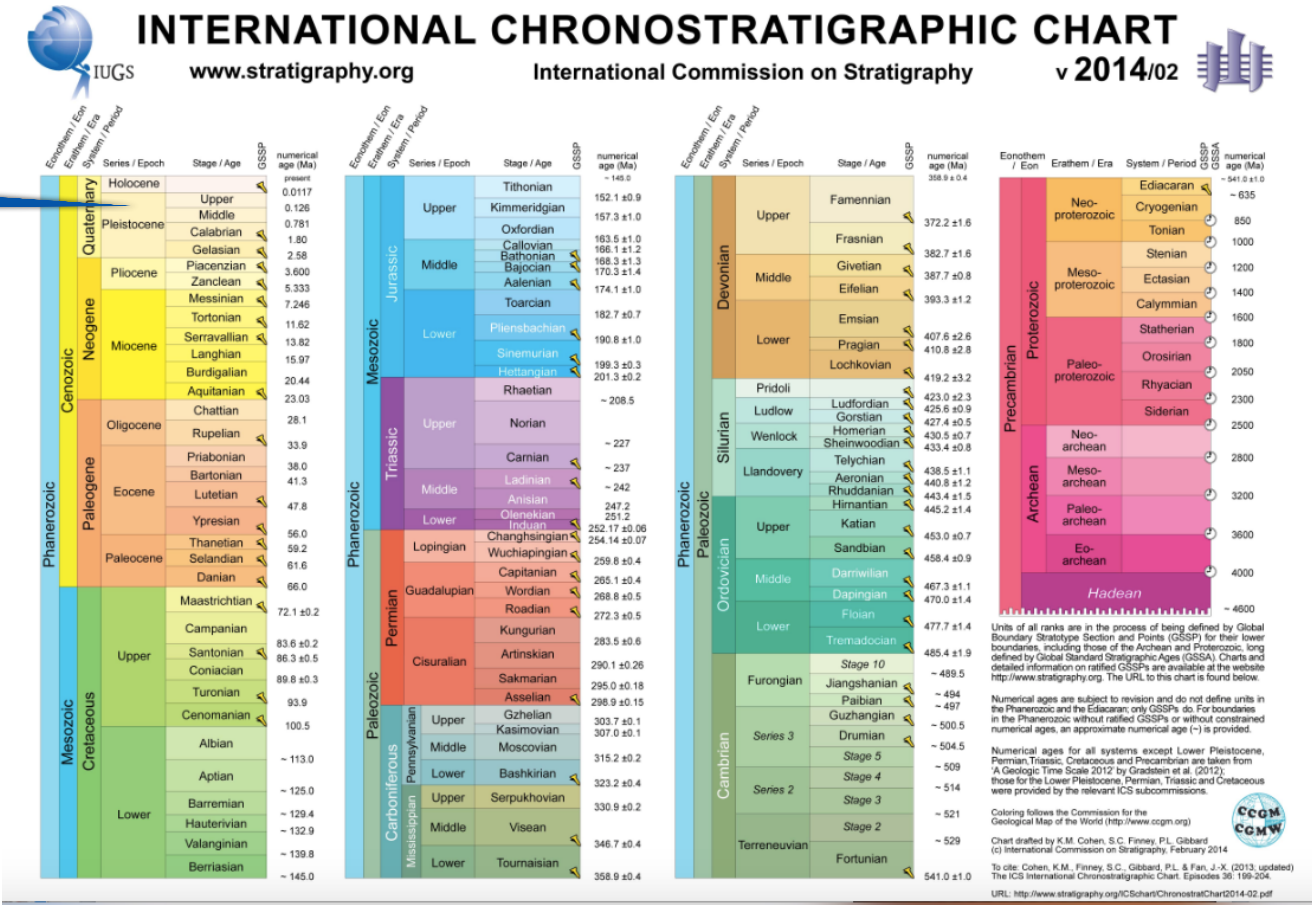


The Baseline: Past Climate Variability



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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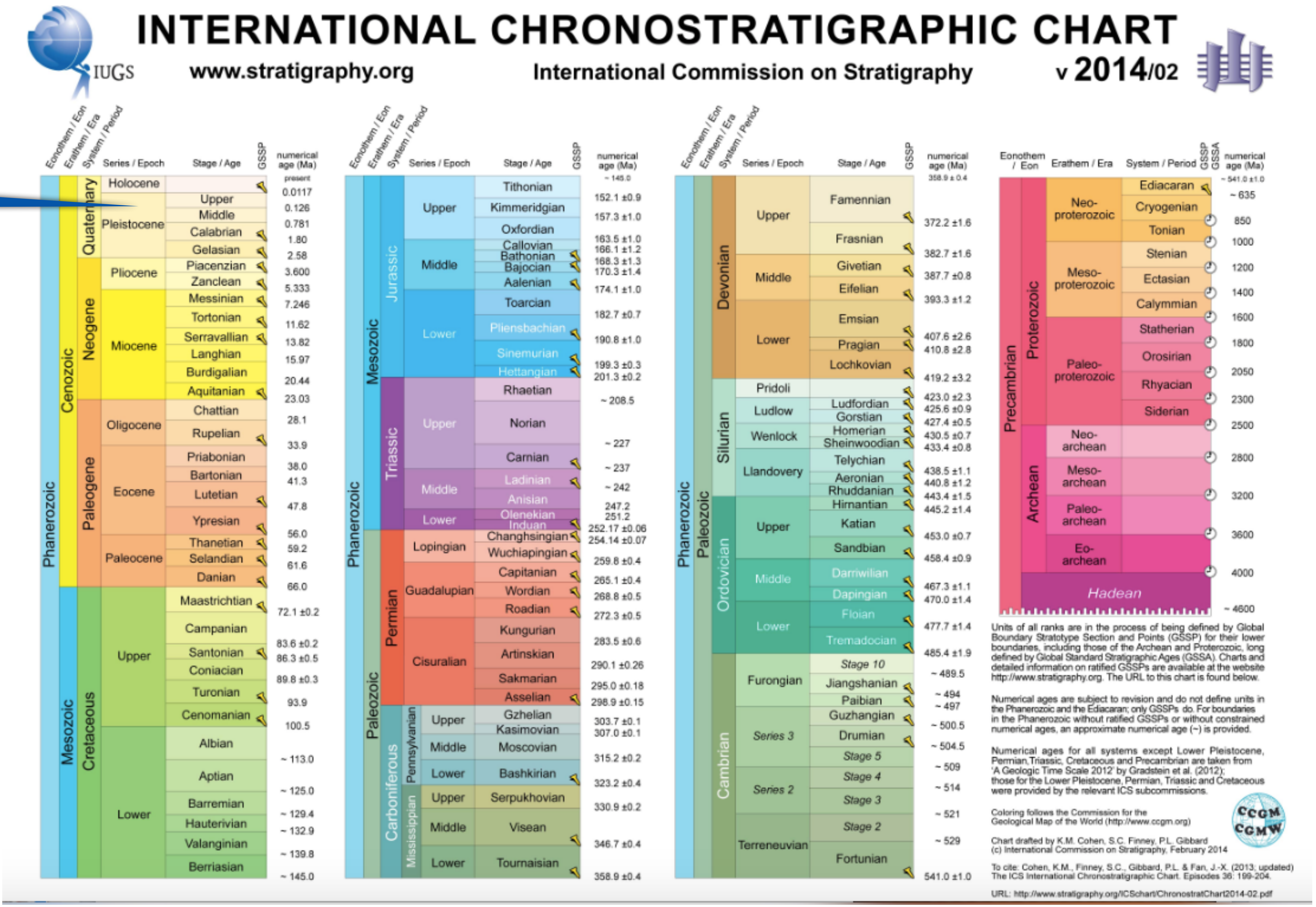

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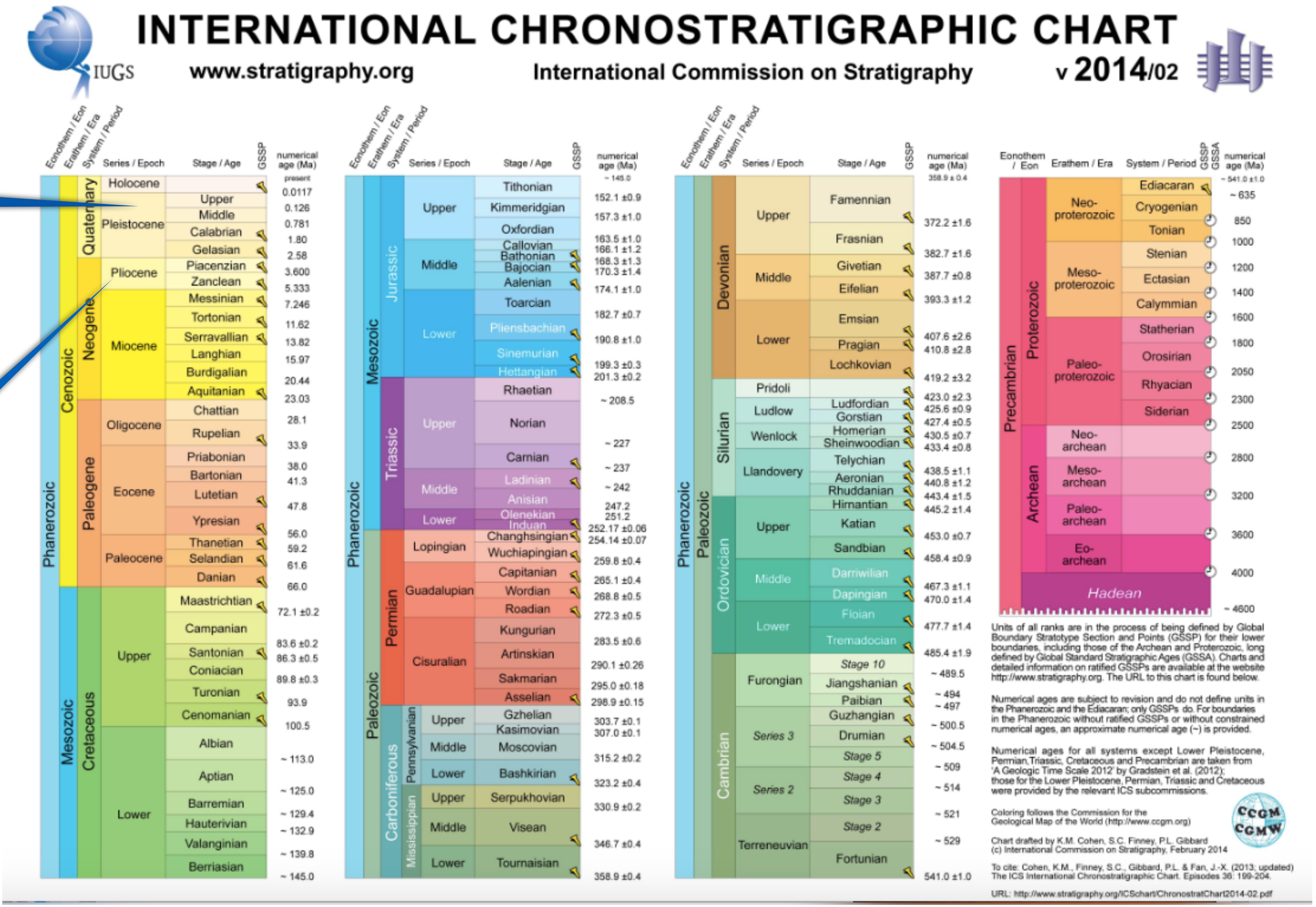
Neogene	Pliocene	Piacenzian	3.600–2.58
		Zanclean	5.333–3.600
	Miocene	Messinian	7.246–5.333
		Tortonian	11.62–7.246
		Serravallian	13.82–11.62
		Langhian	15.97–13.82
		Burdigalian	20.44–15.97
		Aquitanian	23.03–20.44
Paleogene	Oligocene	Chattian	older



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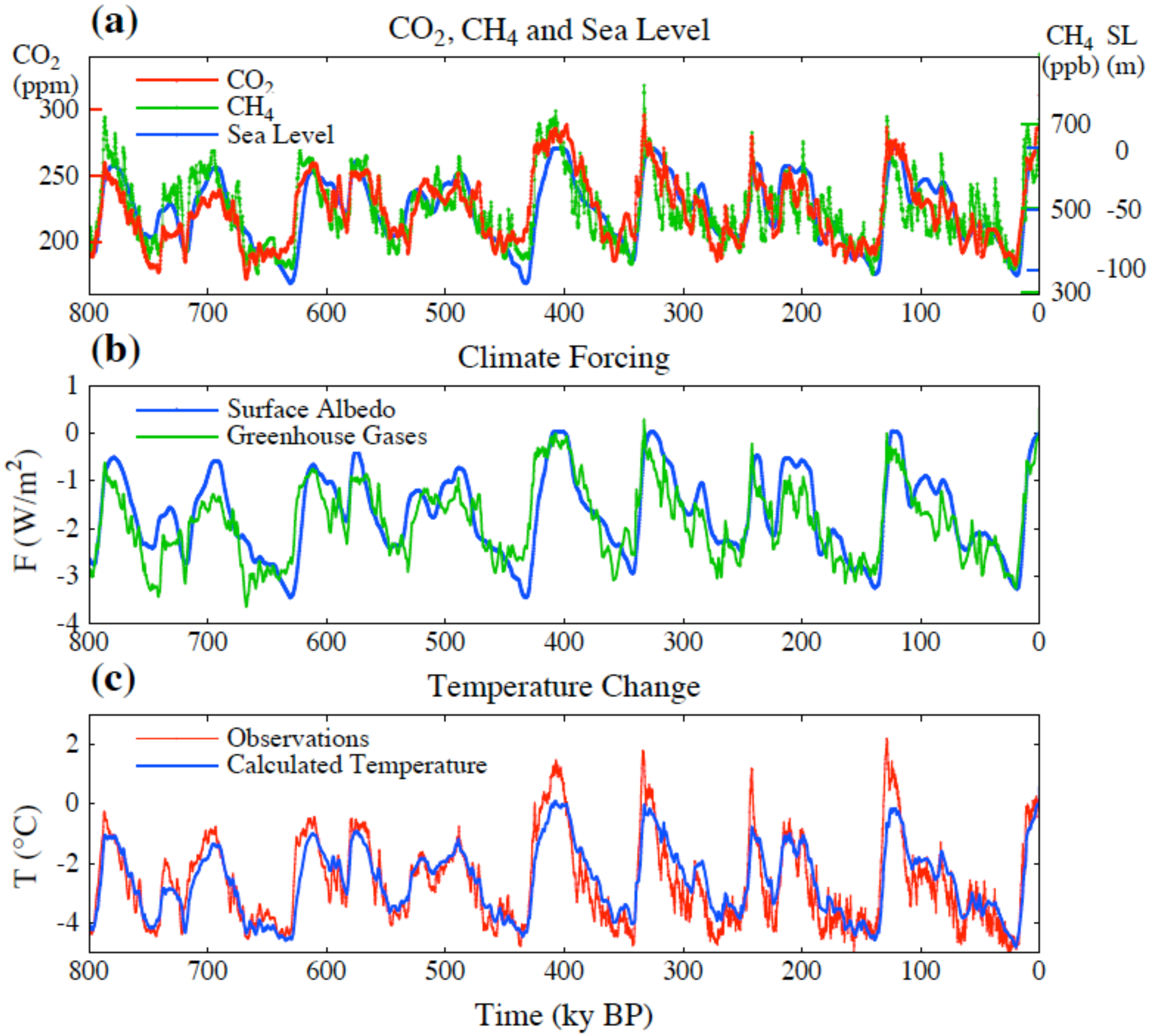

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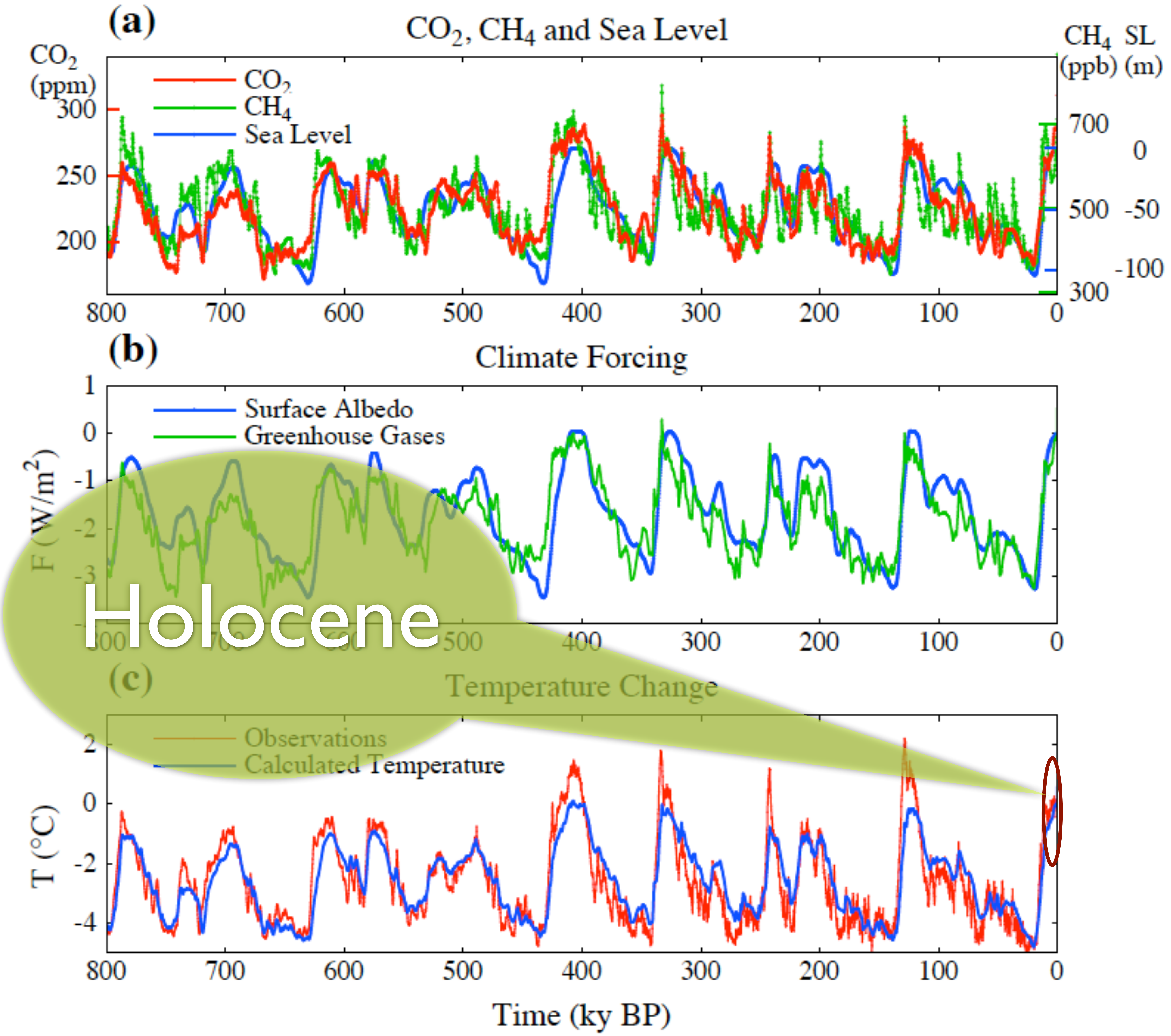

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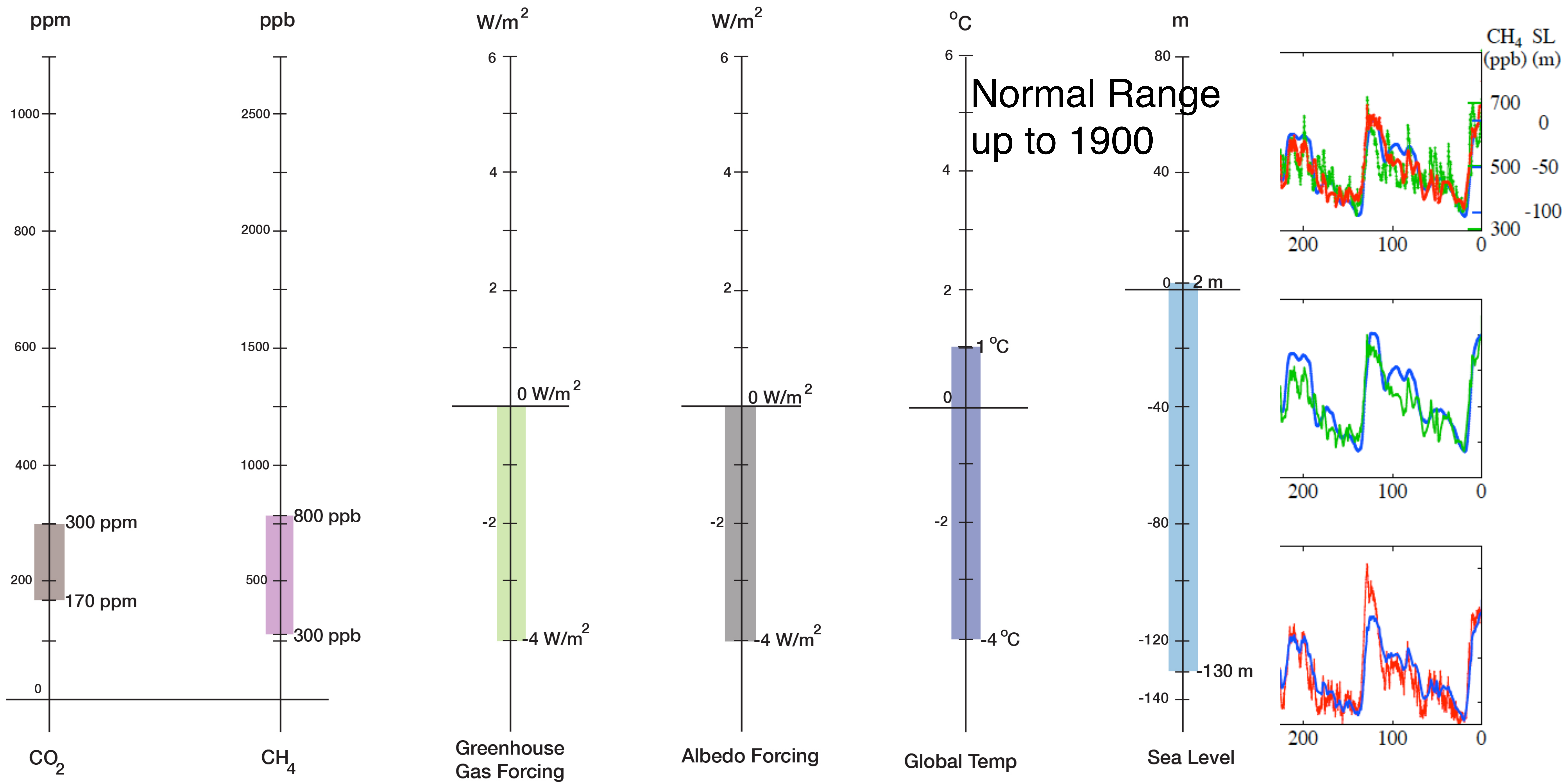
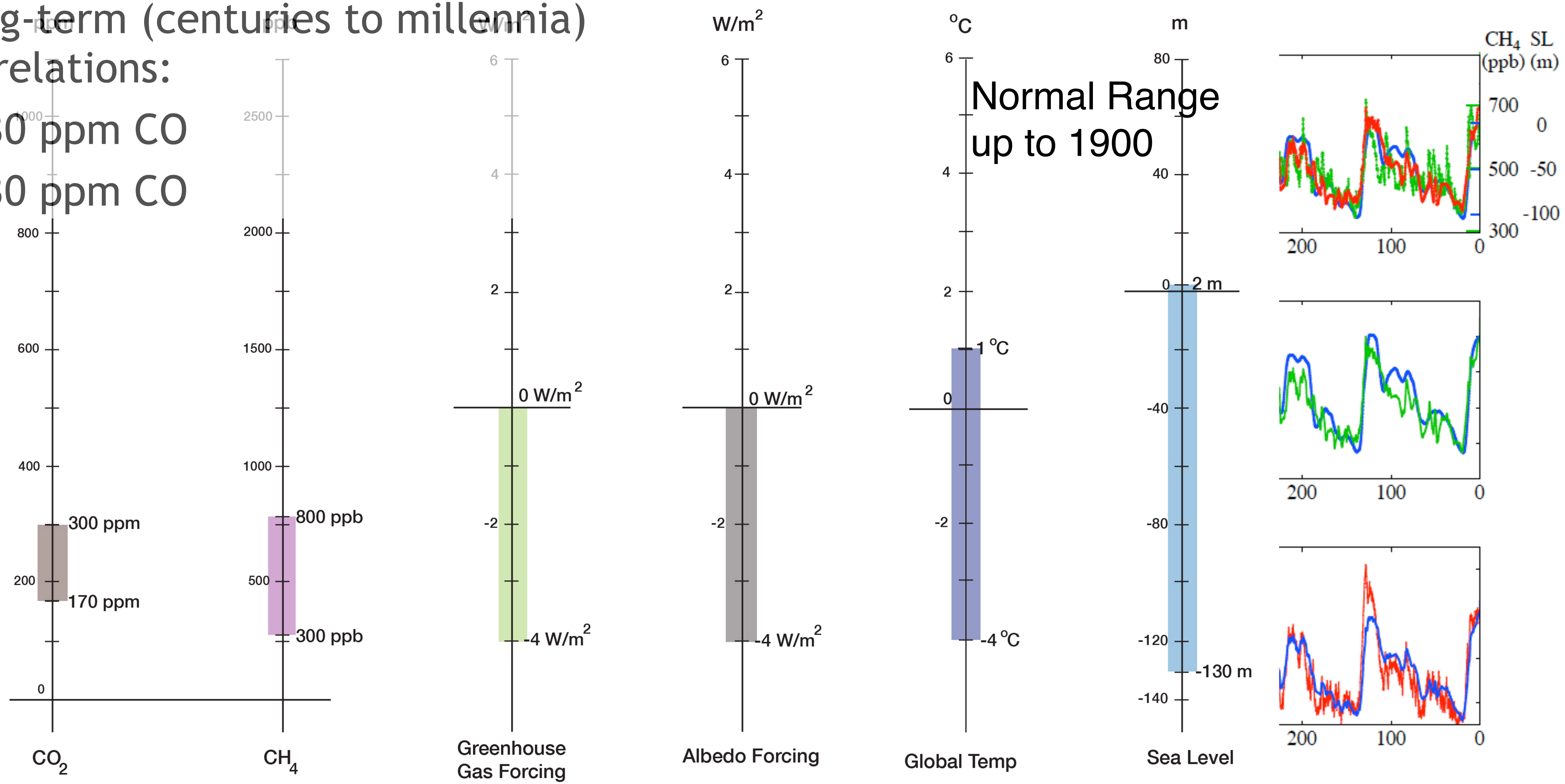


The Baseline: Past Climate Variability

Long-term (centuries to millennia) correlations:

- 130 ppm CO
- 130 ppm CO



The Baseline: Past Climate Variability

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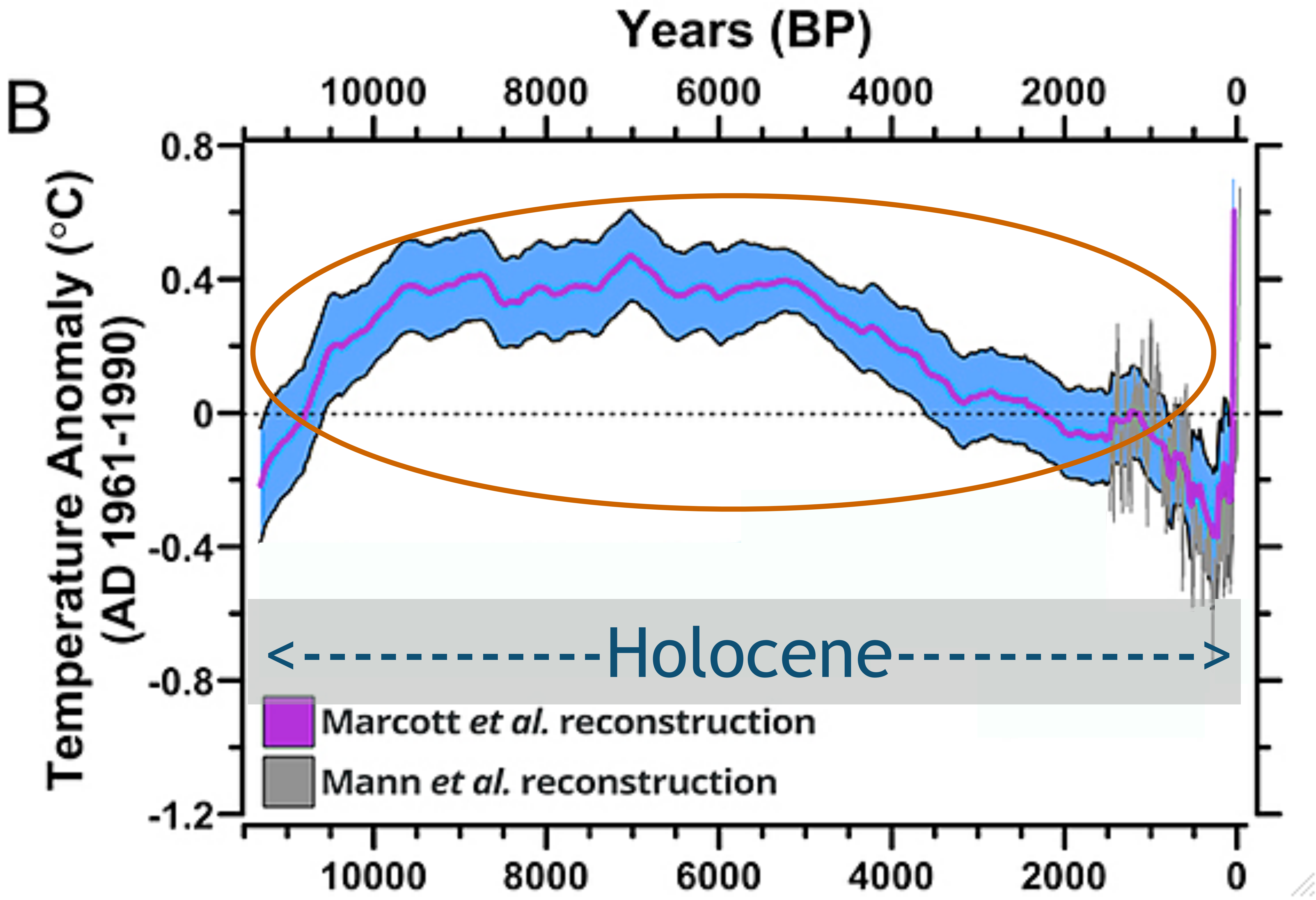
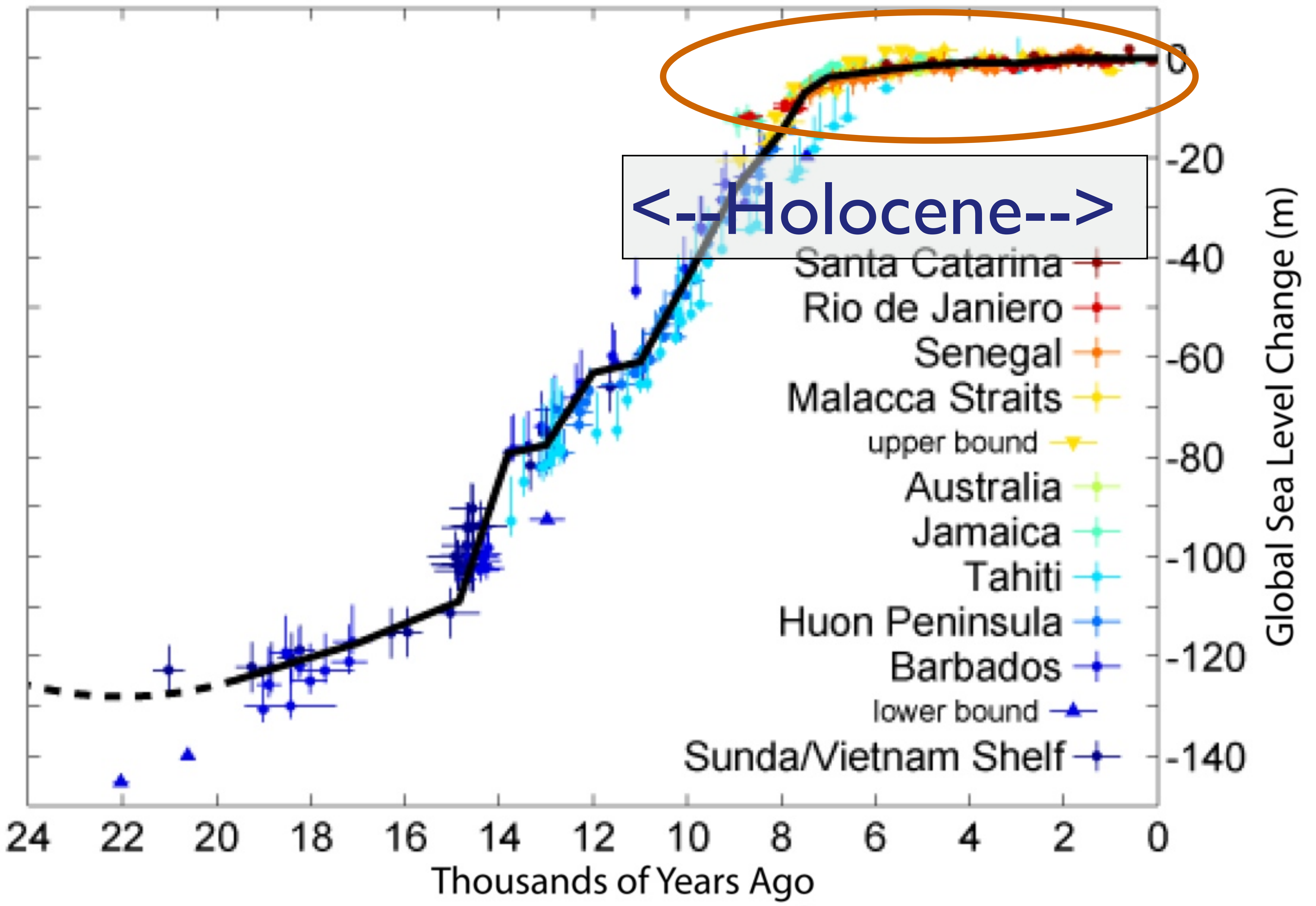
Global Temperature Changes



Marcott et al., 2013

Global Sea Level Changes



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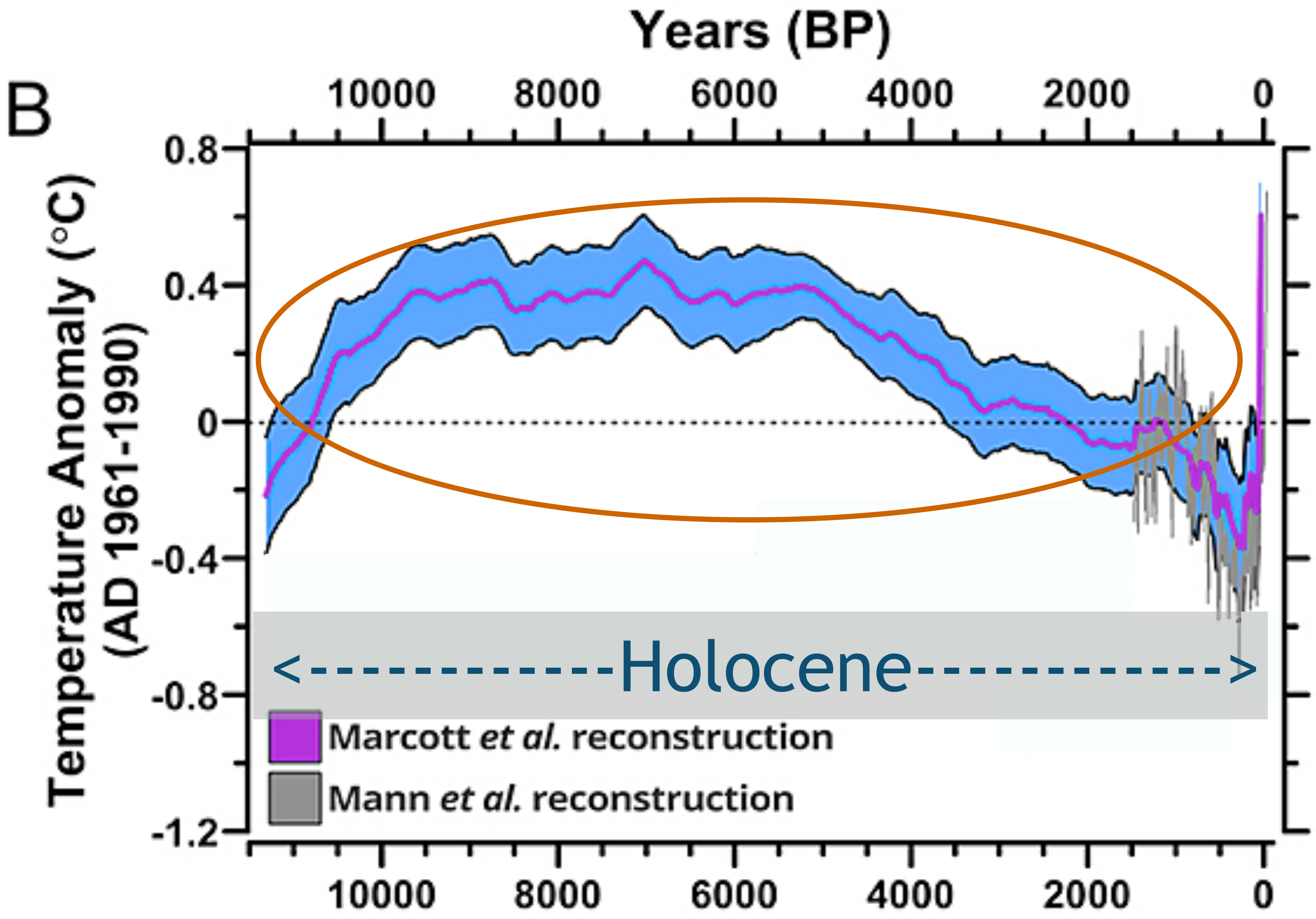

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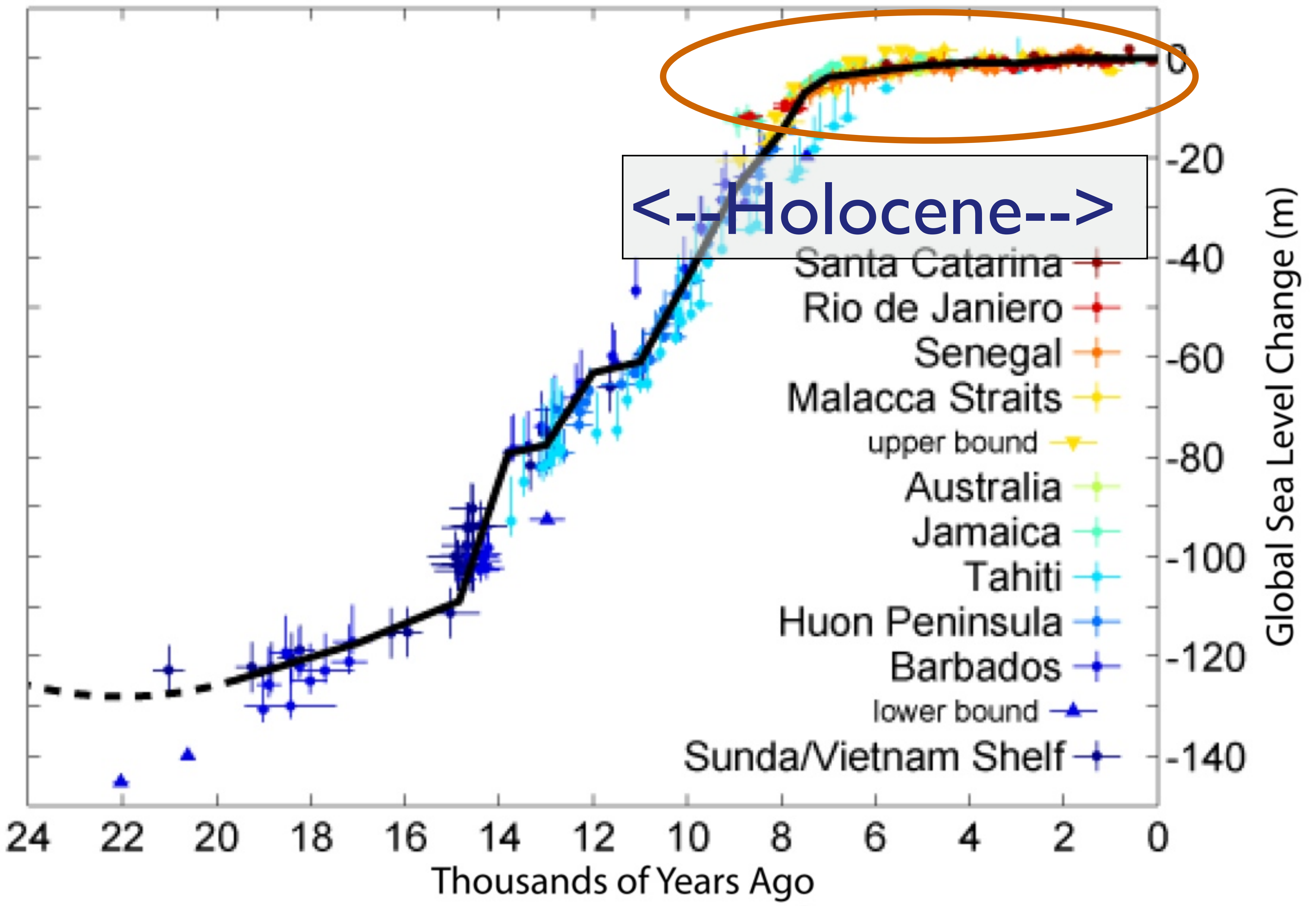
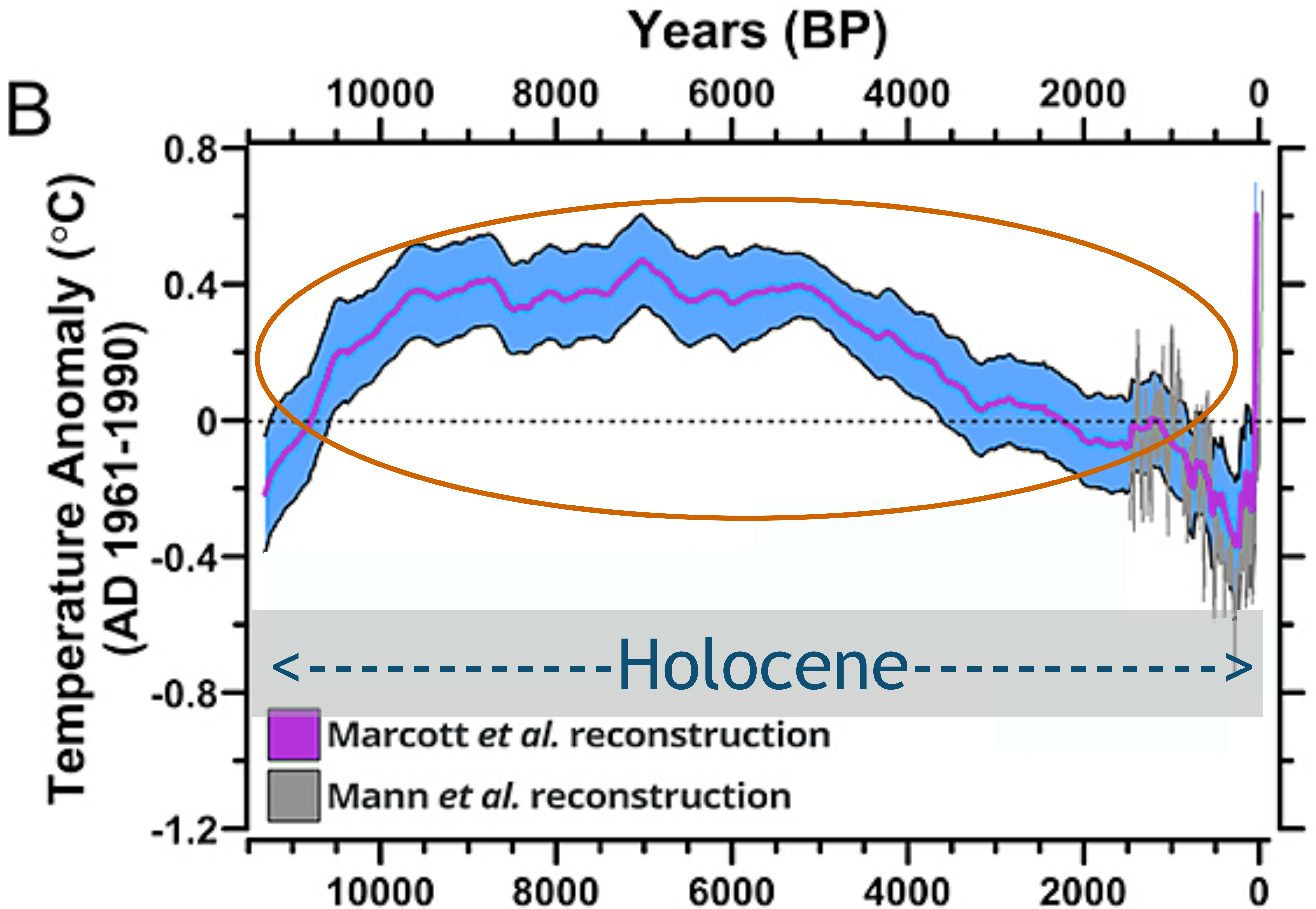


The Baseline for Civilization:
During the Holocene, climate, global temperature, and sea level were exceptionally stable; a perfect condition for the development of civilization.

The Baseline: Past Climate Variability

Global Temperature Changes



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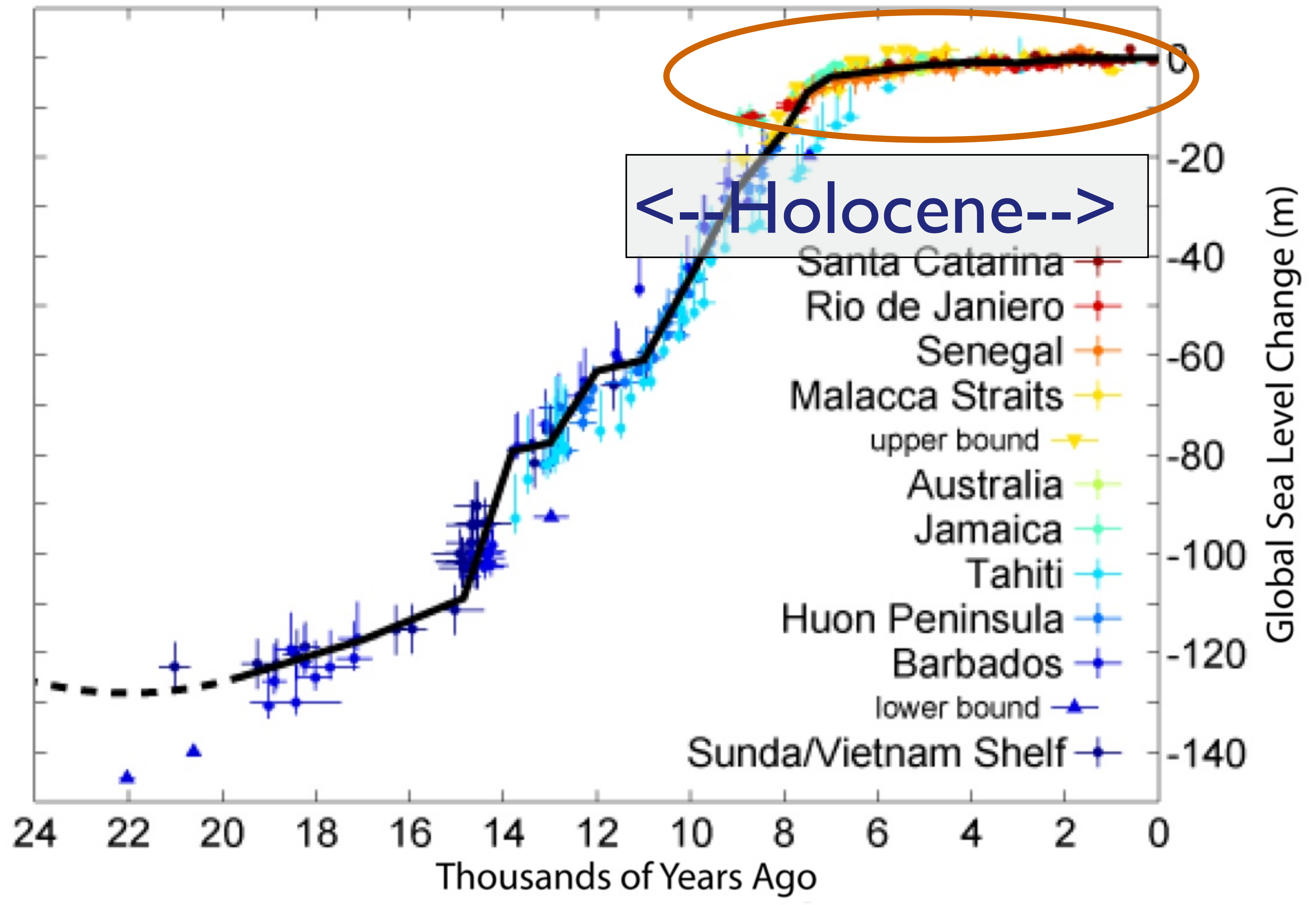
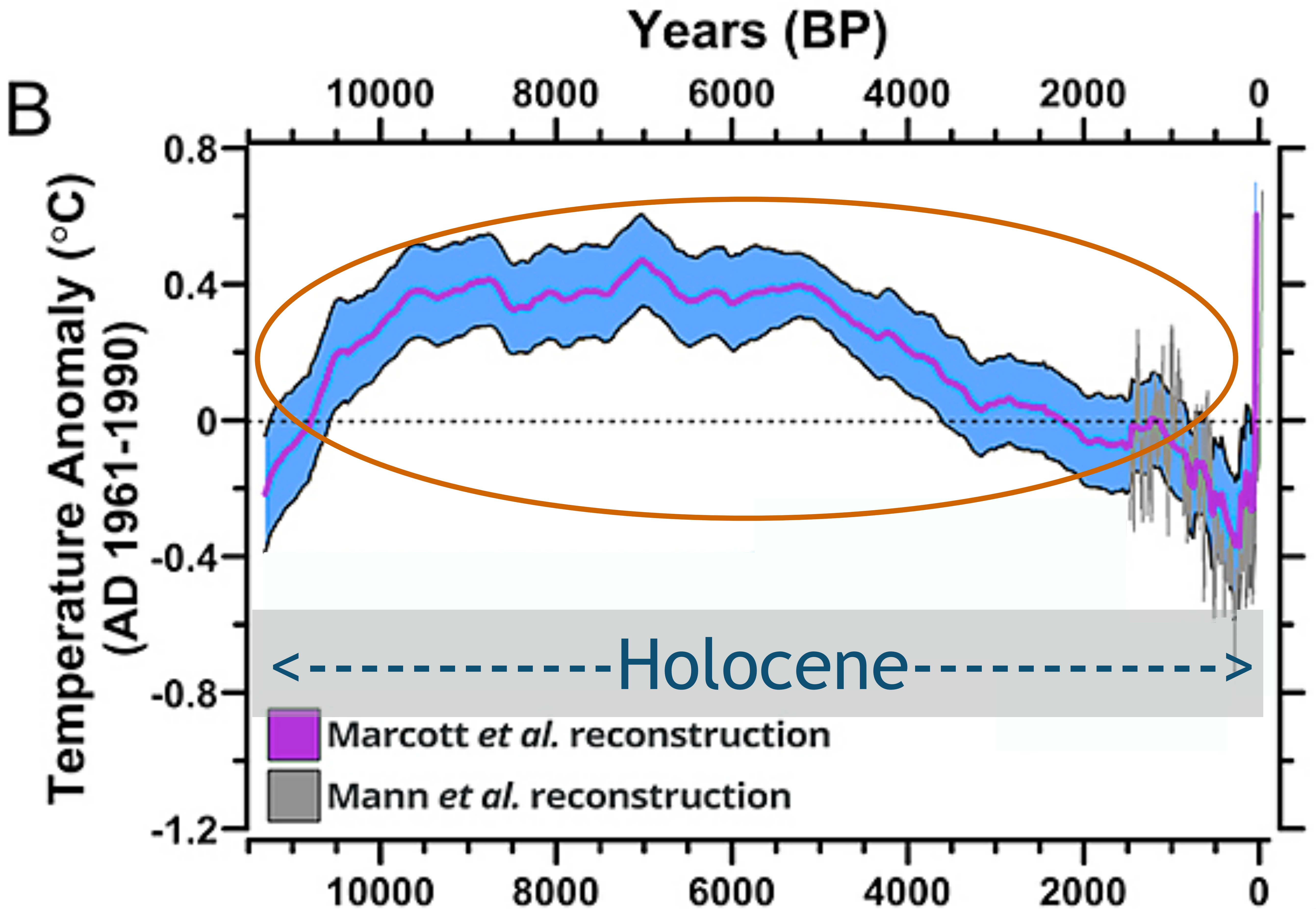


The Holocene was a “safe operating space for humanity”

The Baseline: Past Climate Variability

Global Temperature Changes



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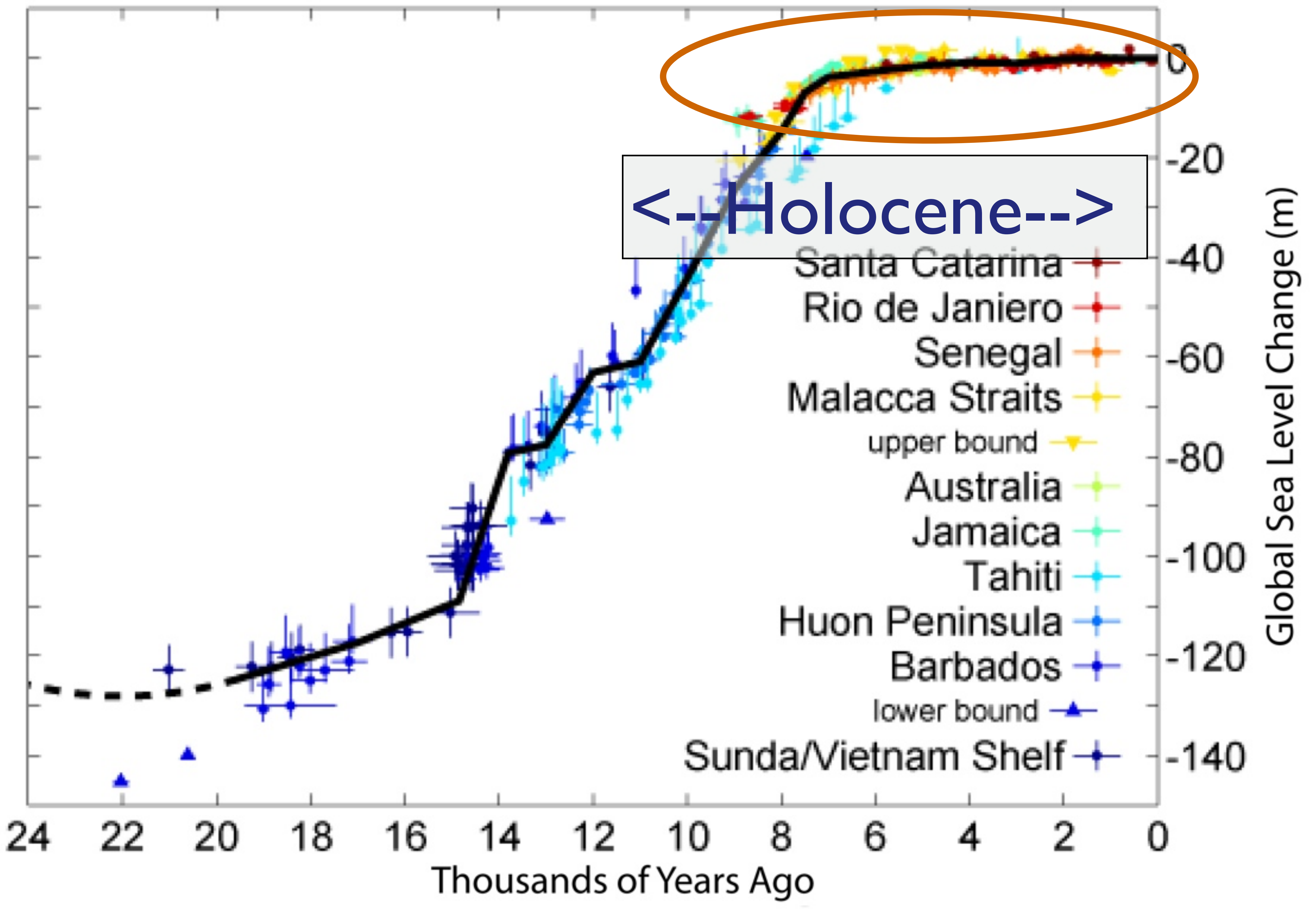

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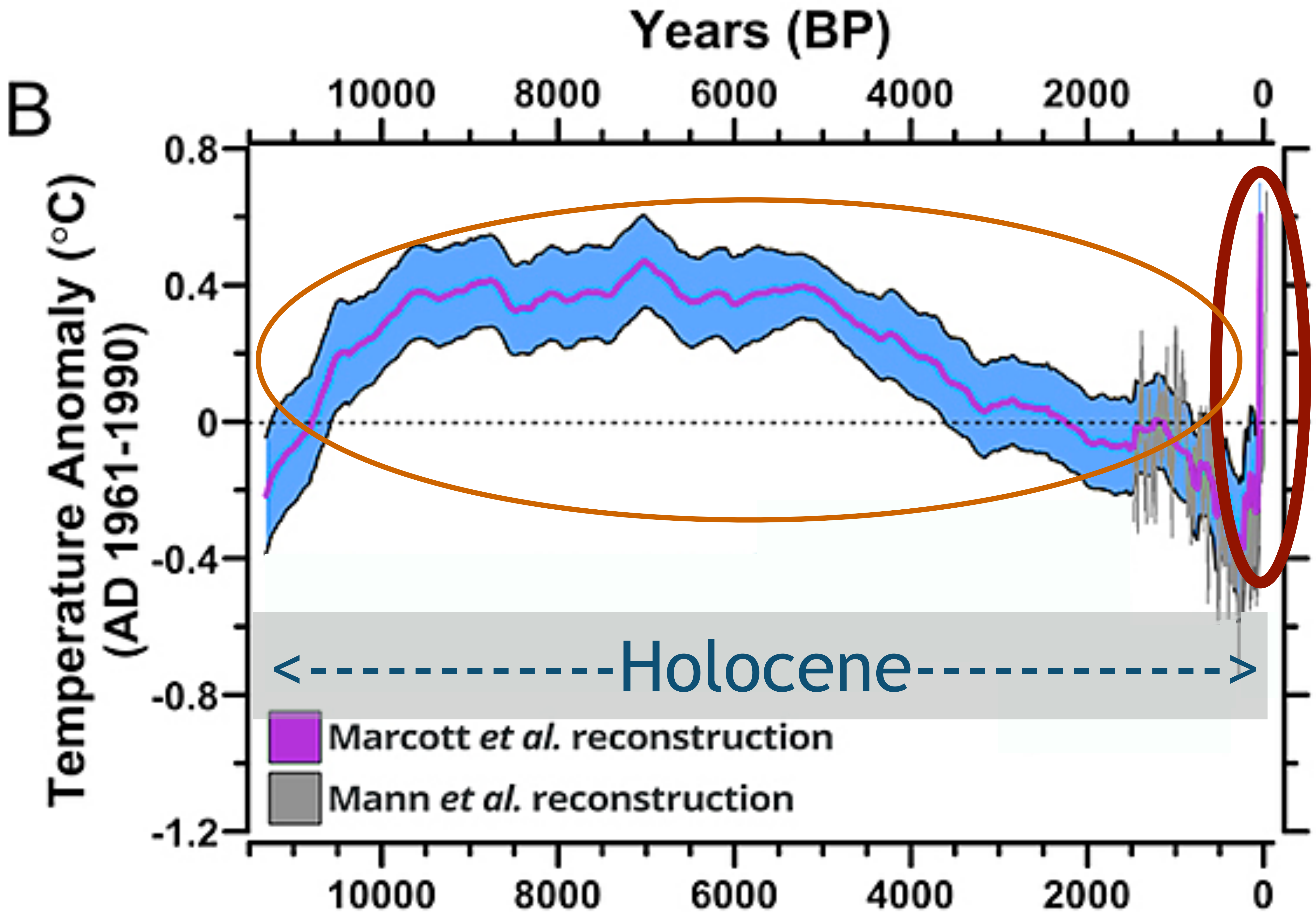

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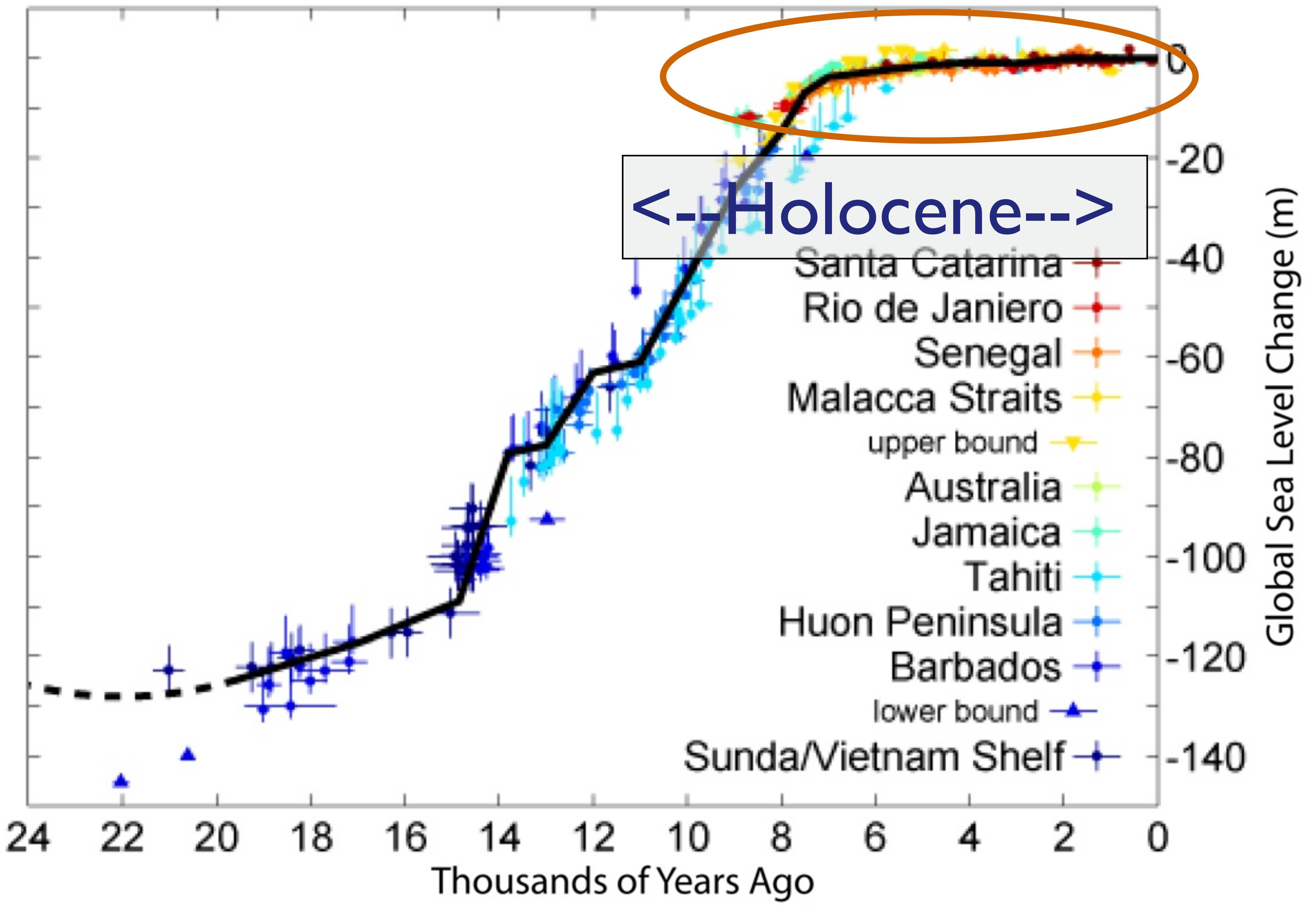

The Holocene was a "safe operating space for humanity"

Key Points

Key Points

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

The Syndrome: Recent Climate and Global Change

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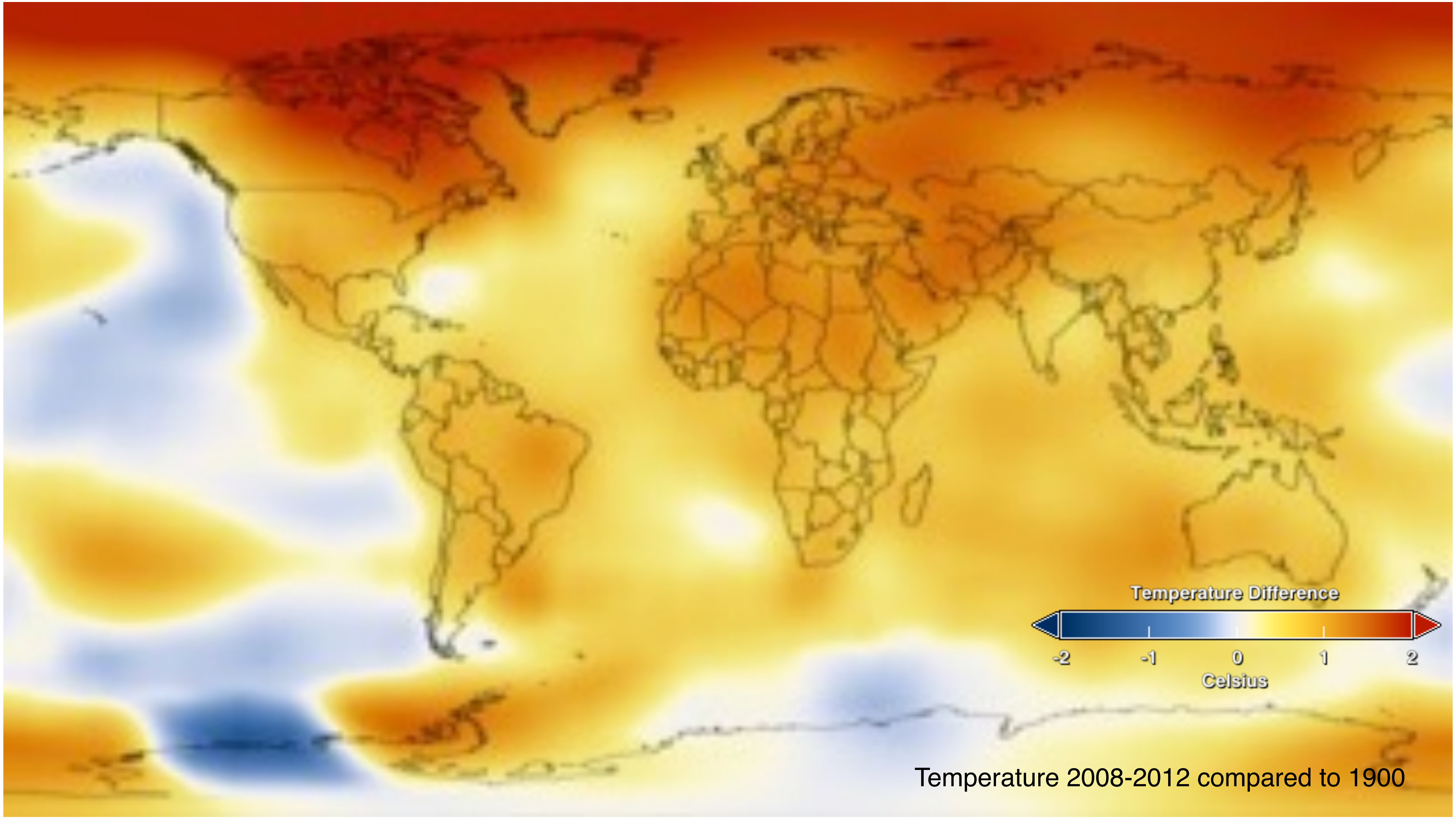

The Syndrome: Recent Climate and Global Change

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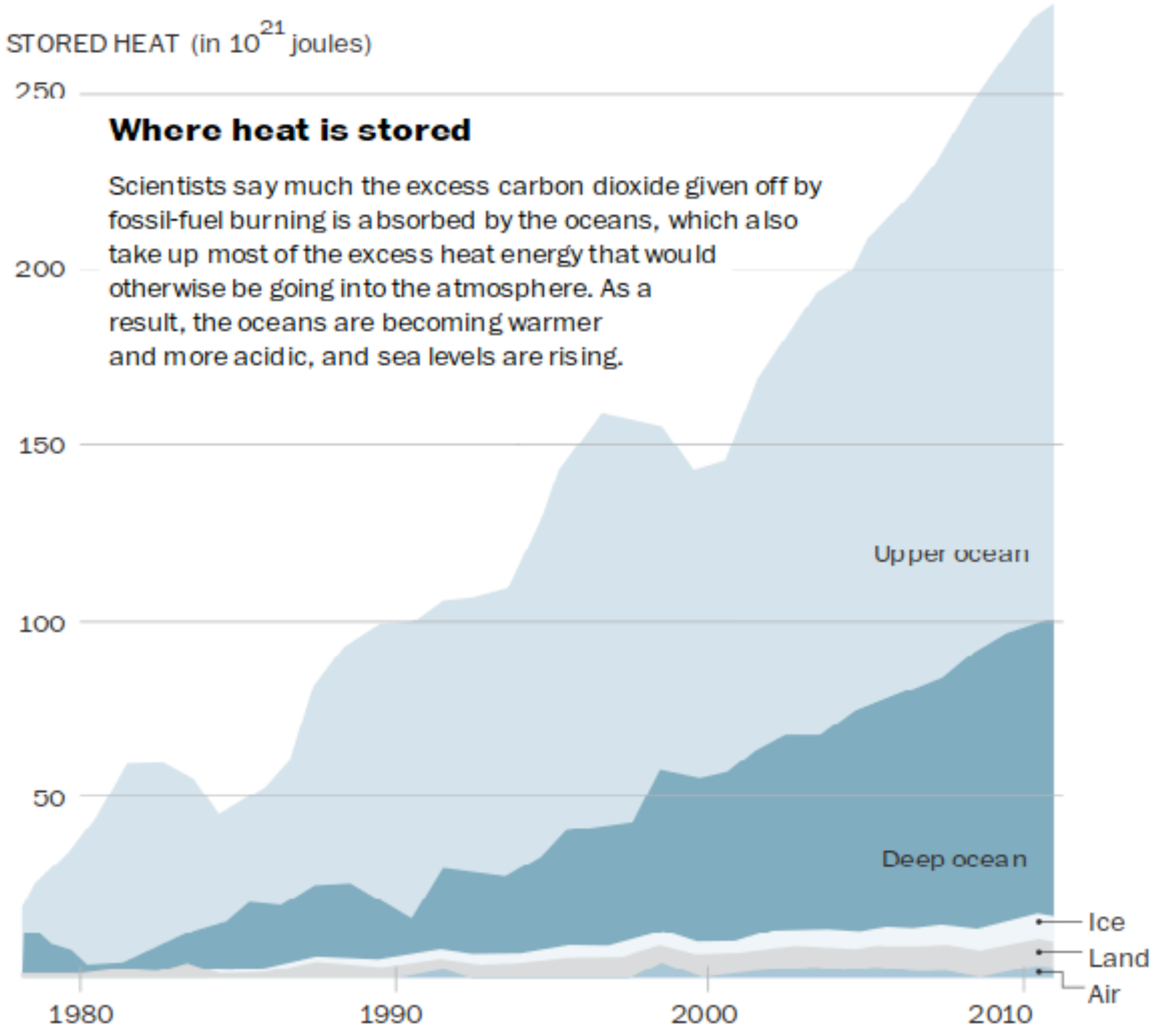
Heat storage:



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

The Syndrome: Recent Climate and Global Change

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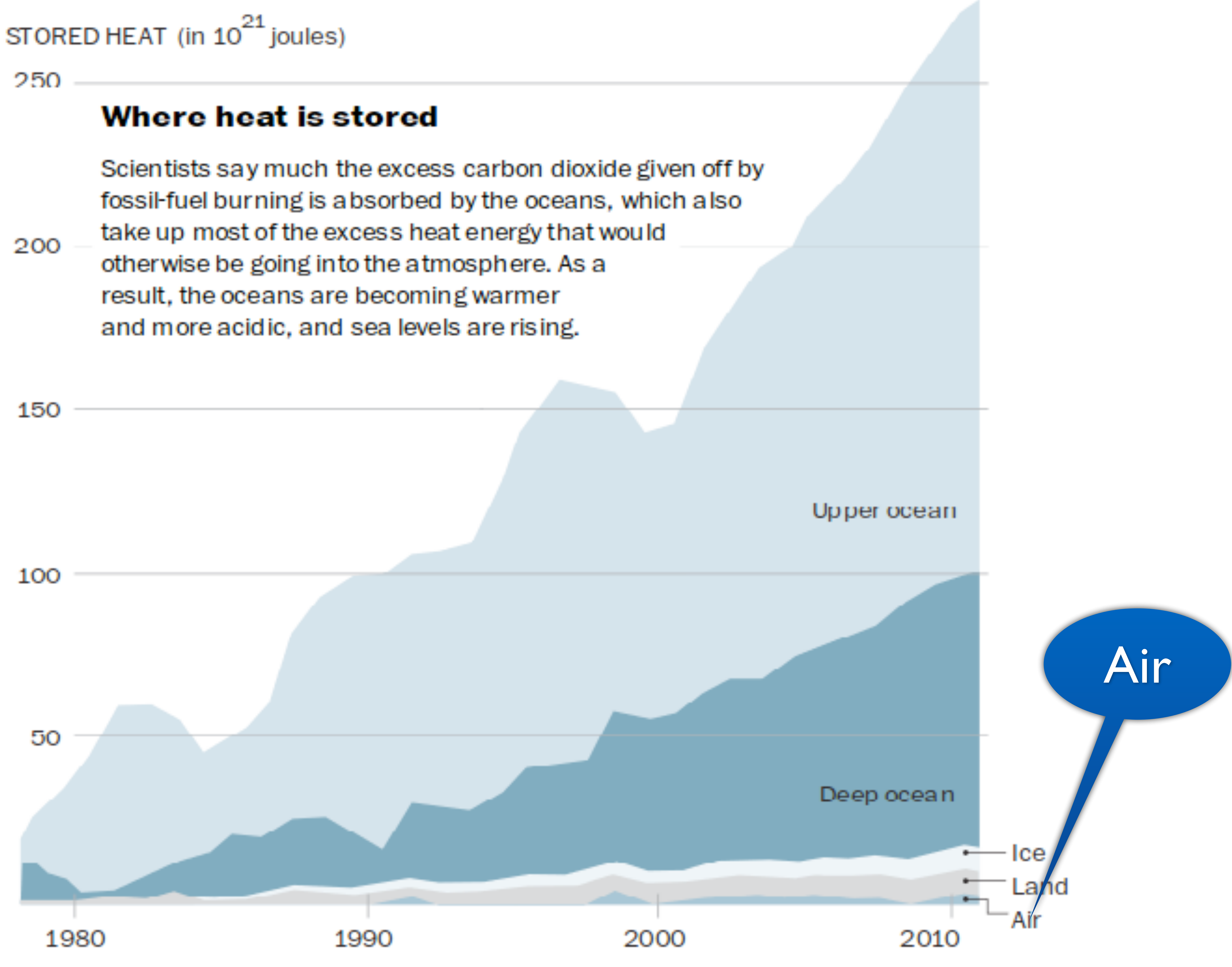

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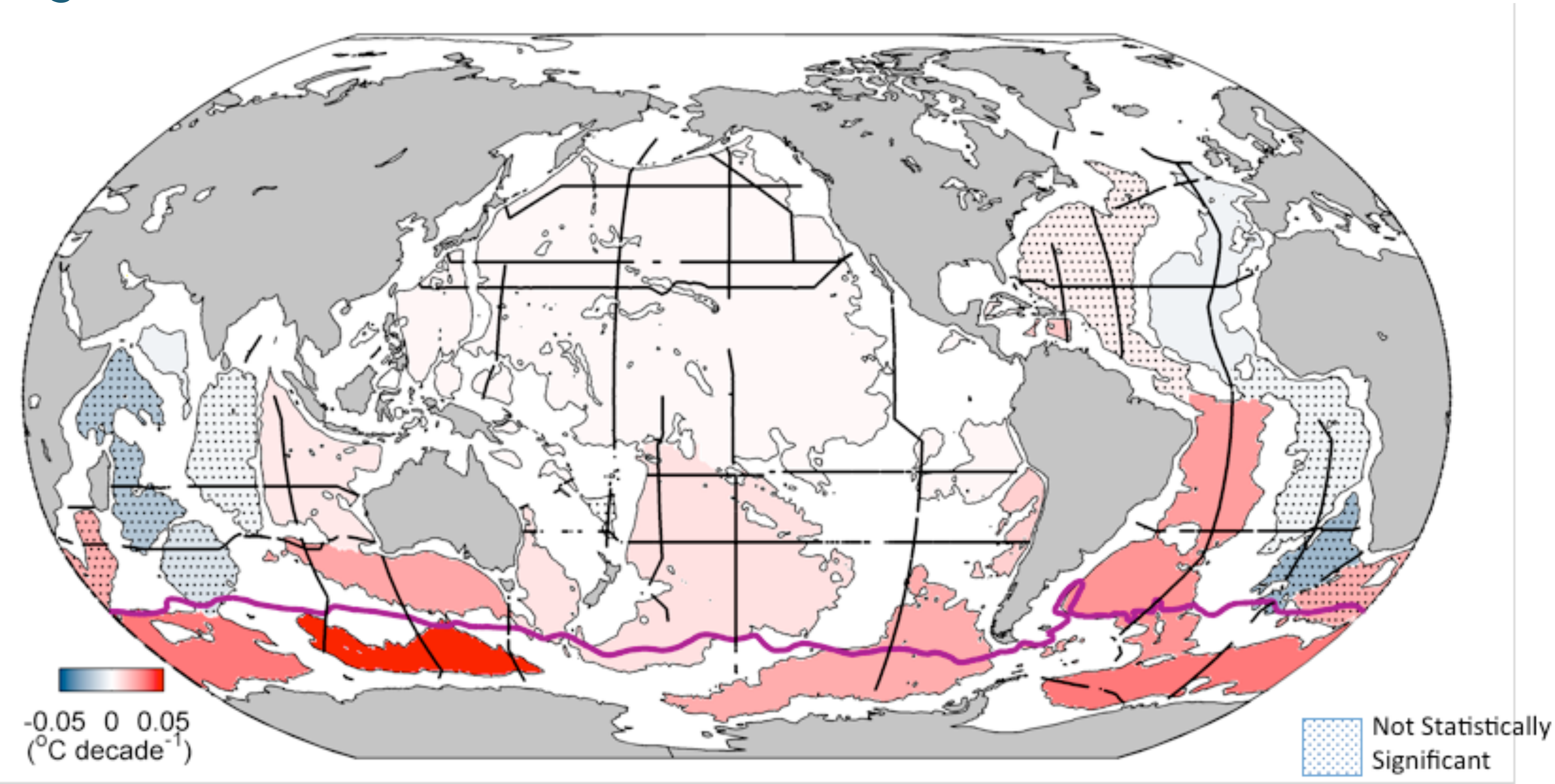

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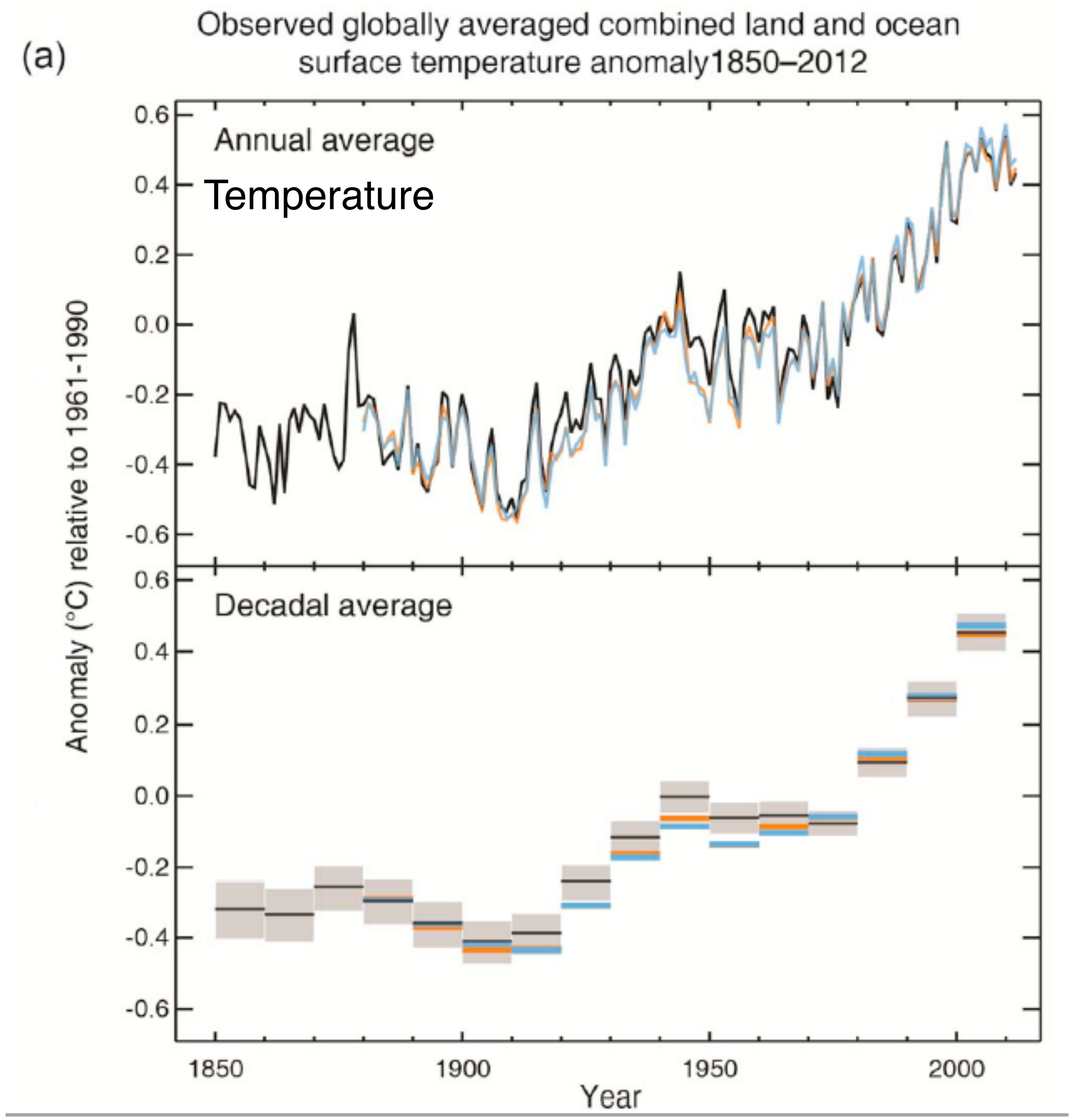

IPCC, 2013

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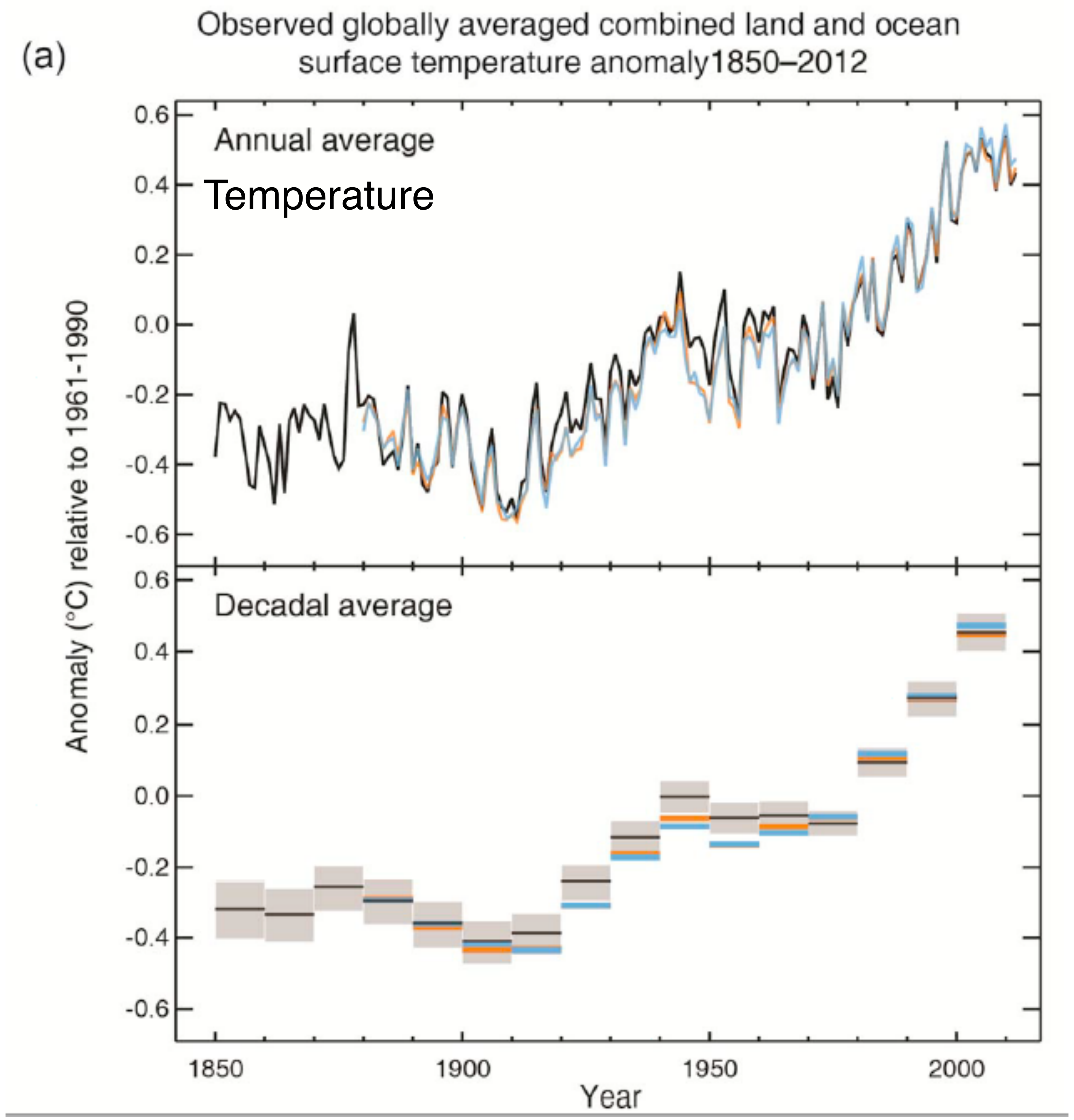

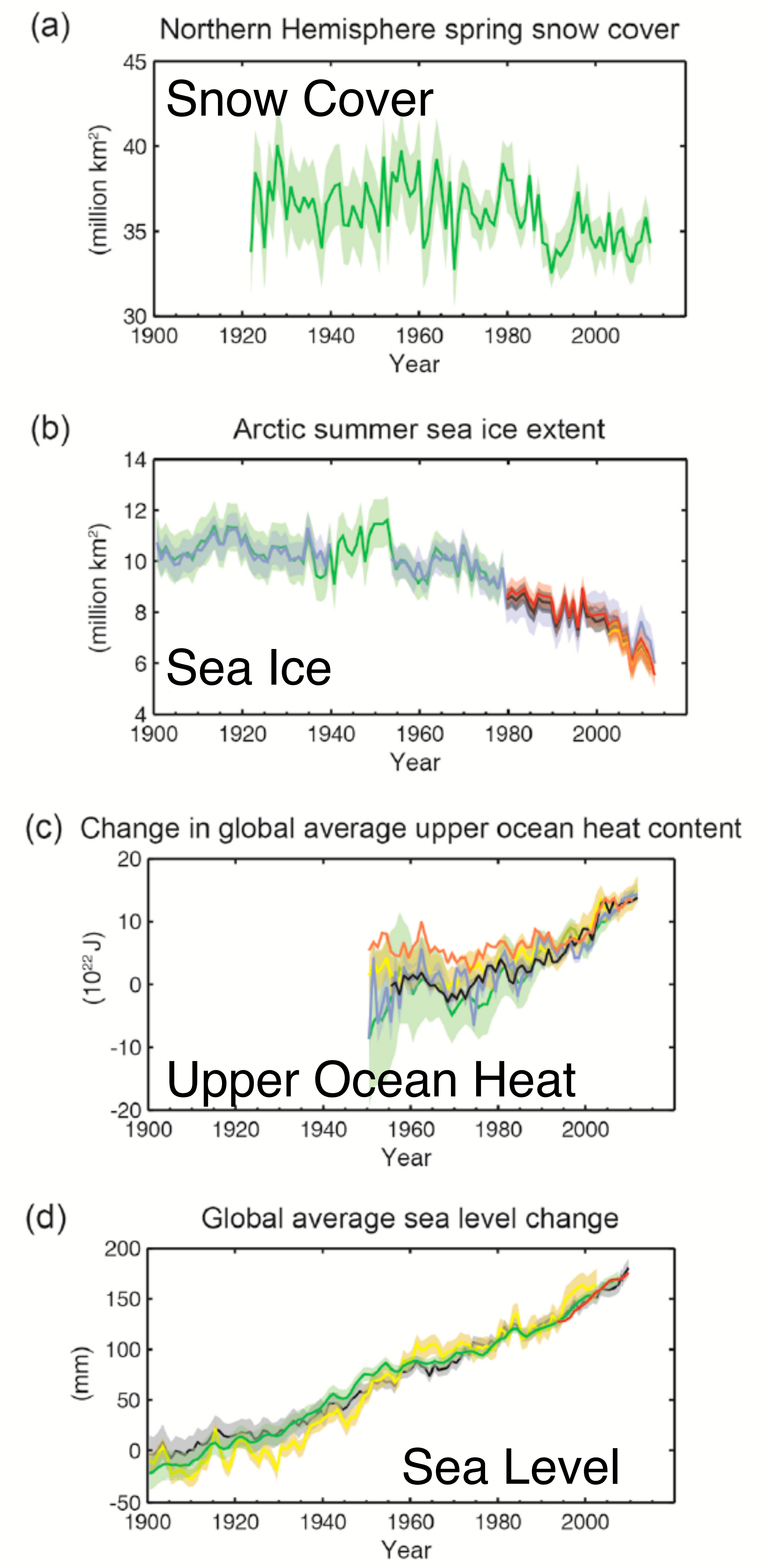

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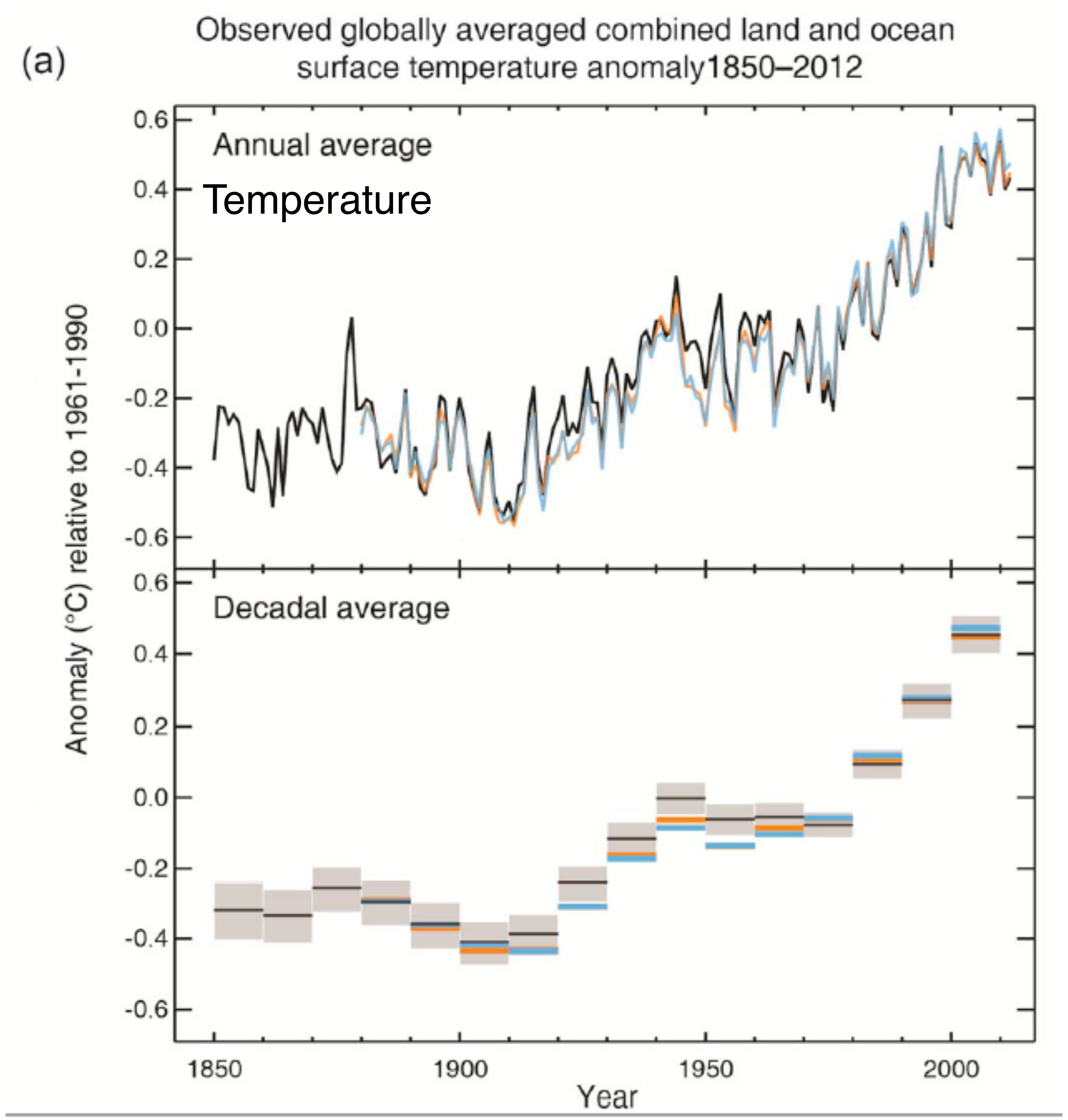

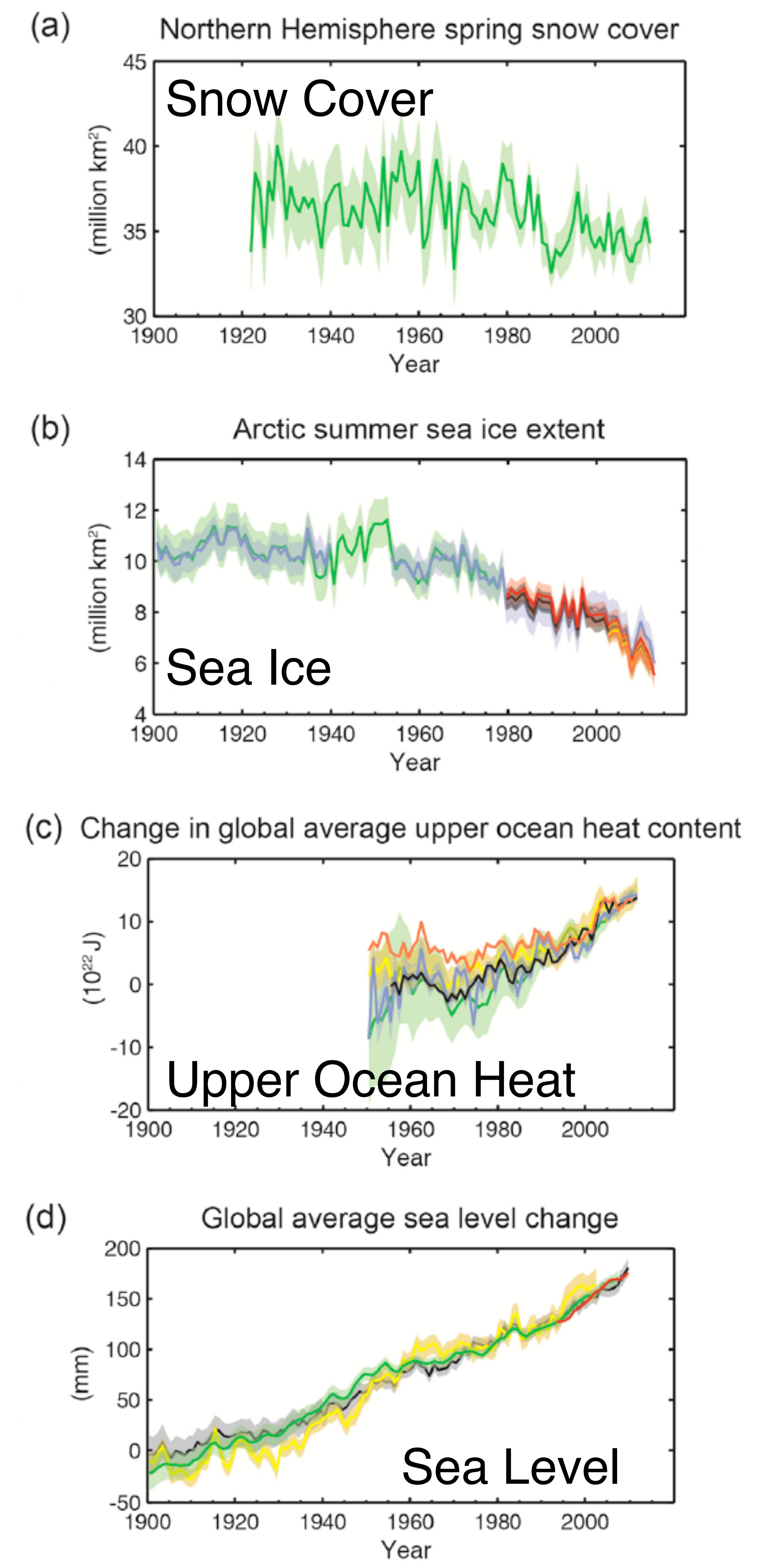

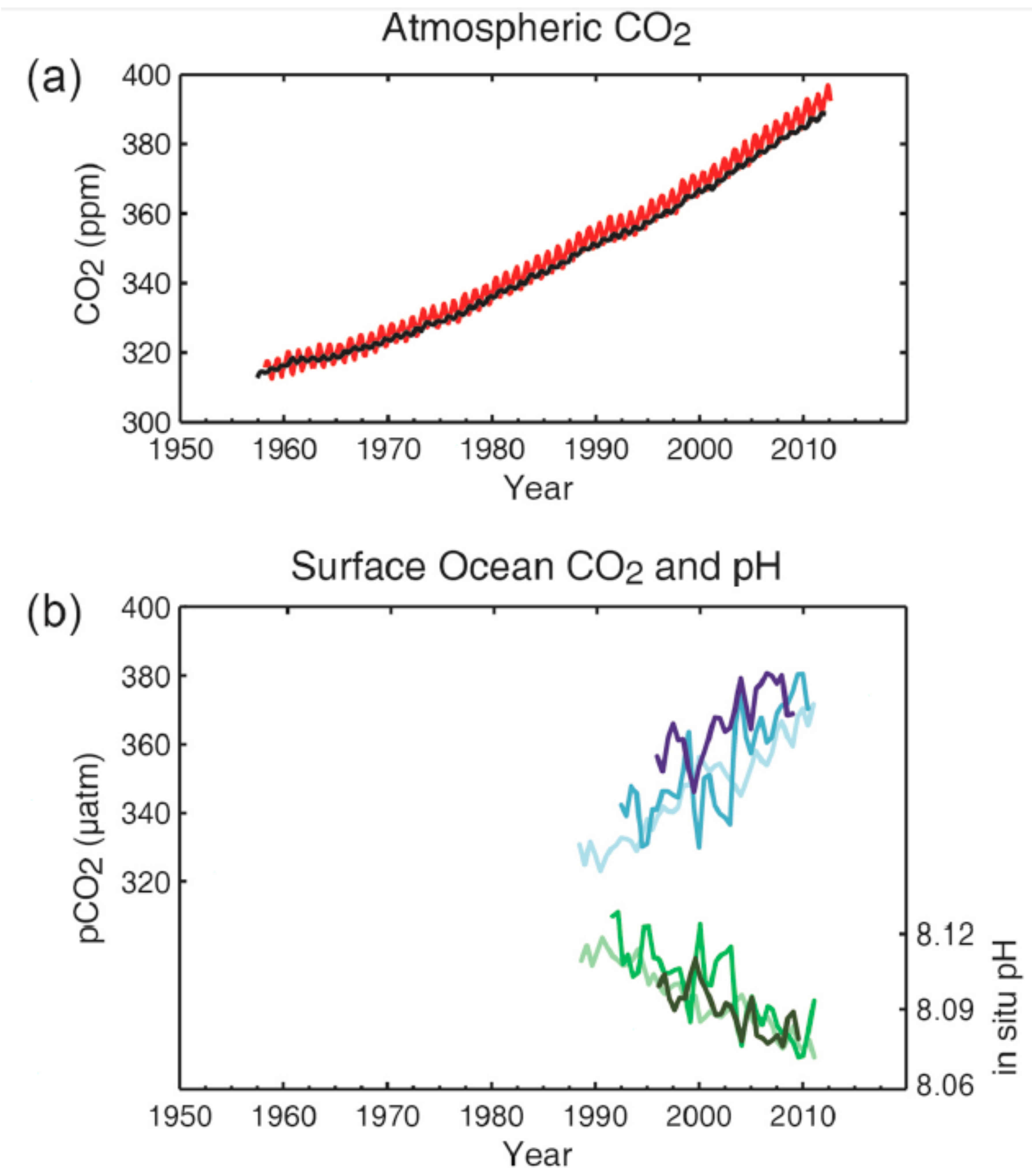

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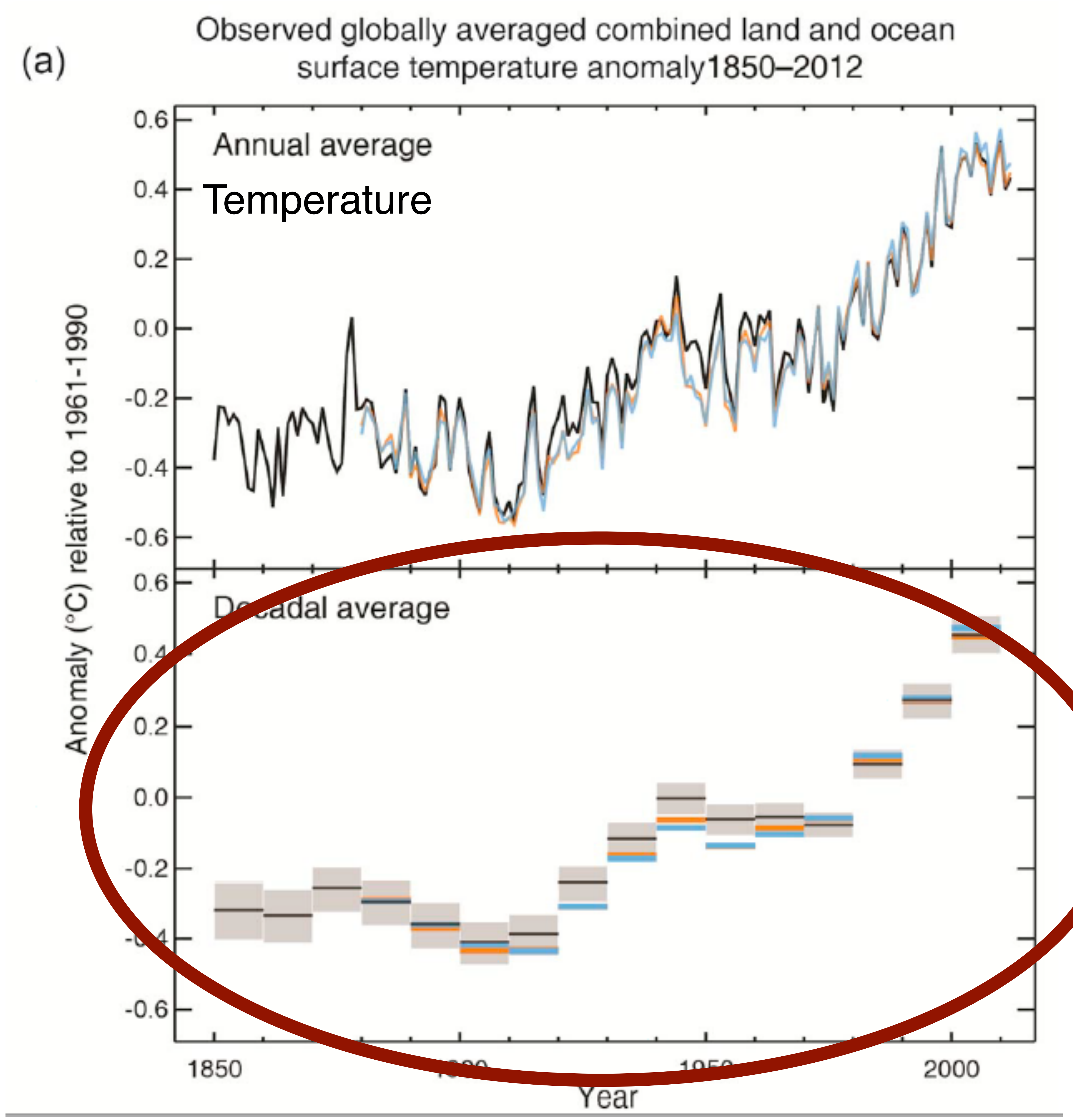

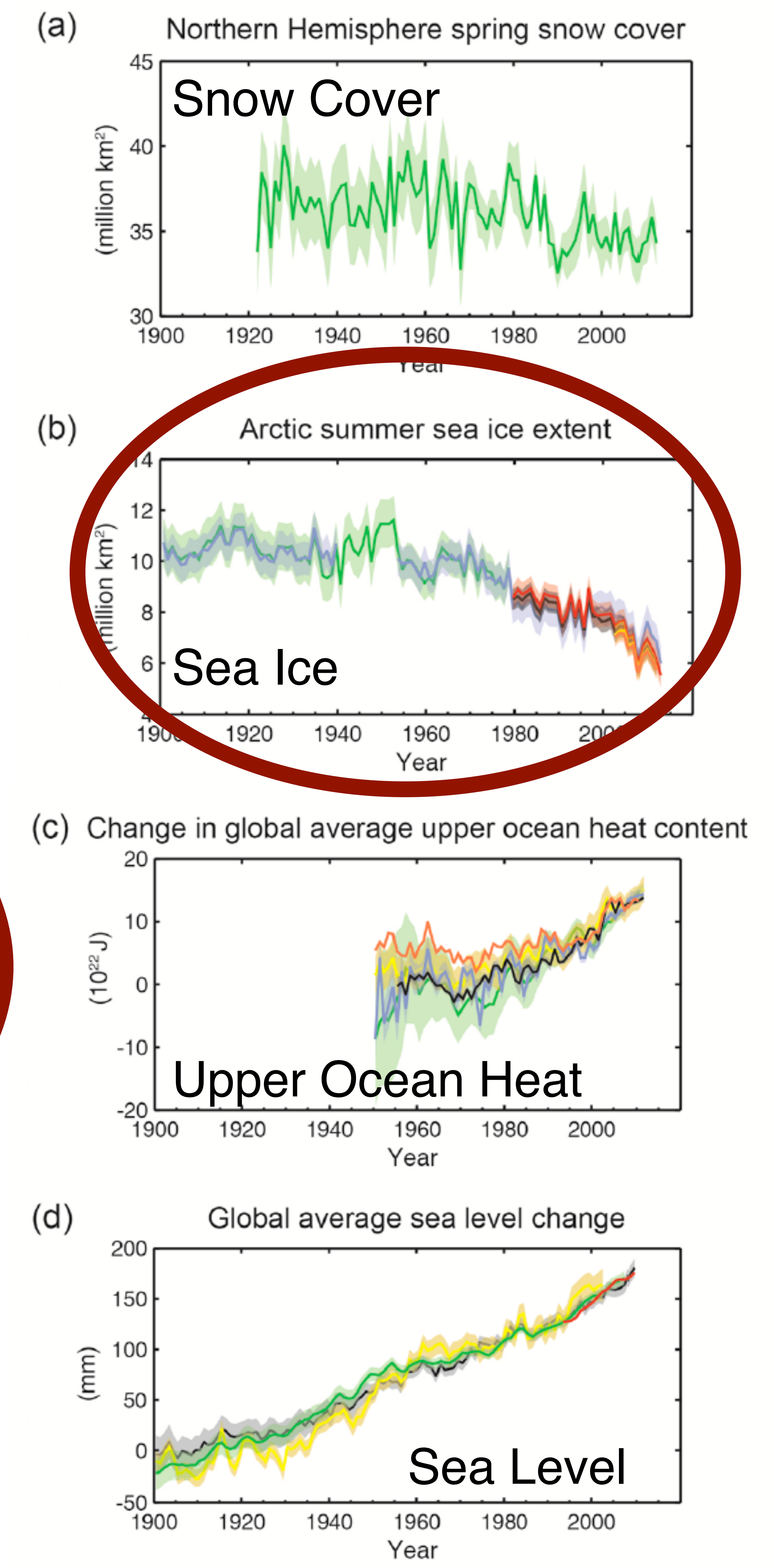

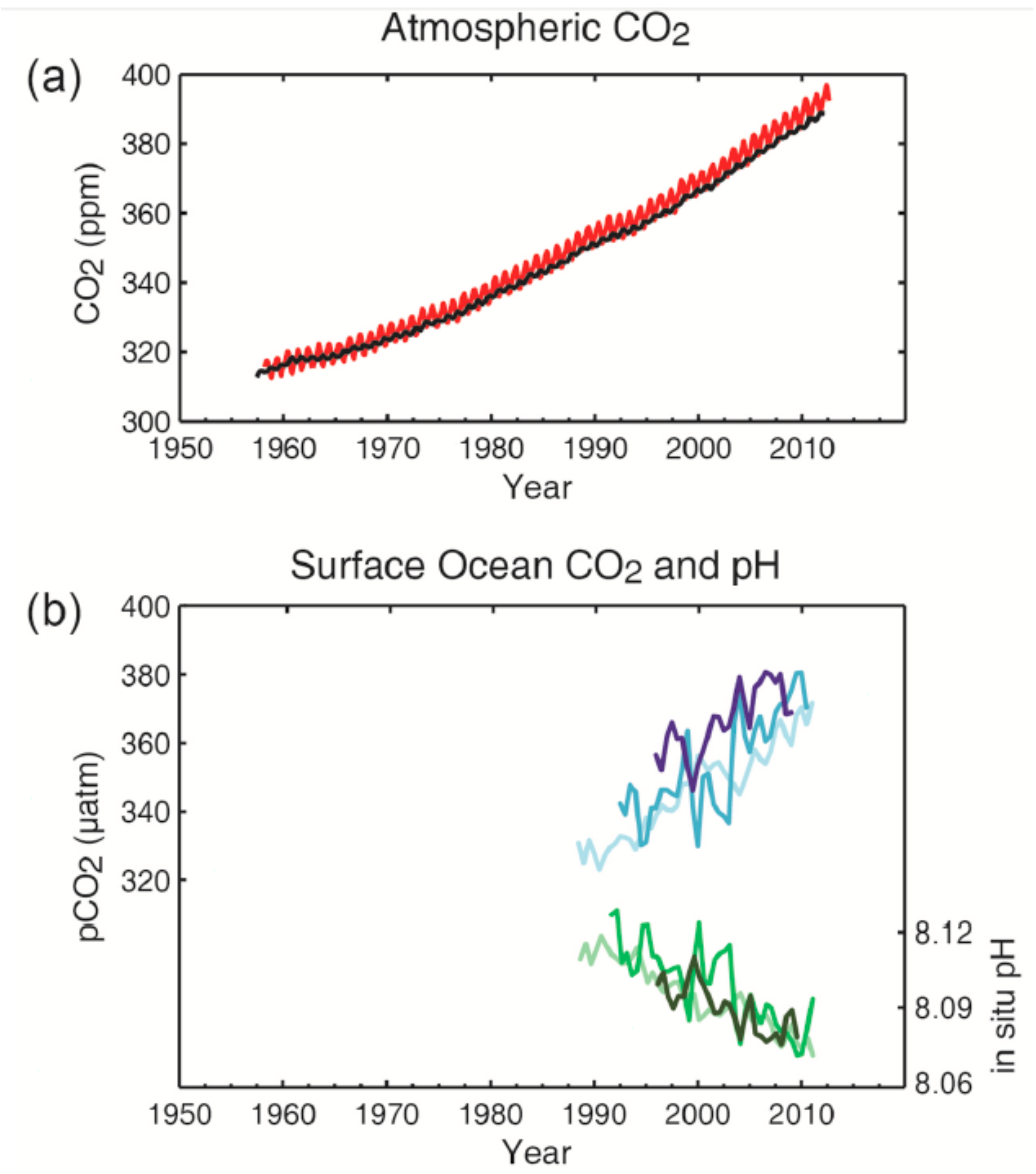

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The Syndrome: Recent Climate and Global Change

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Kinnart et al., 2011

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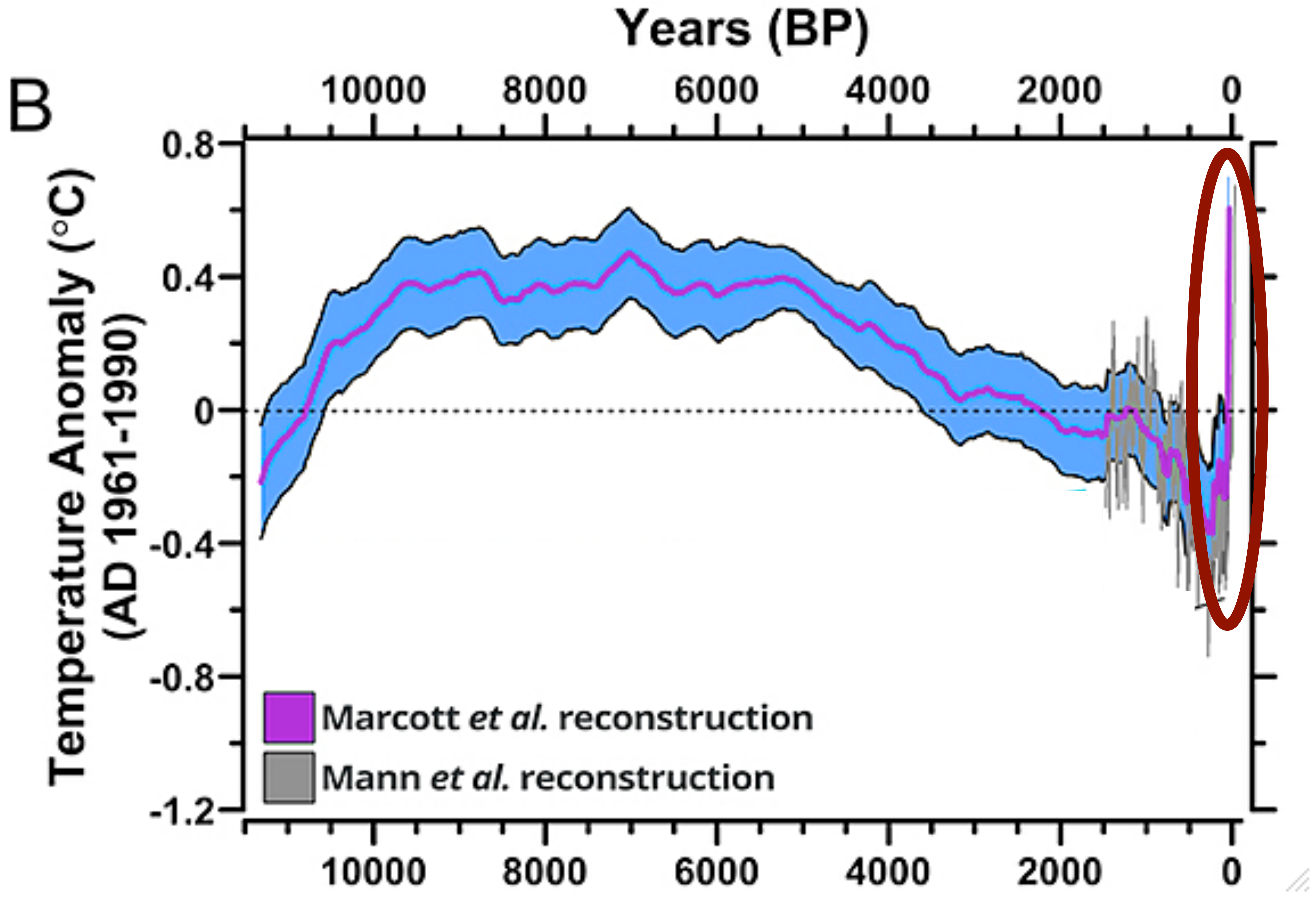

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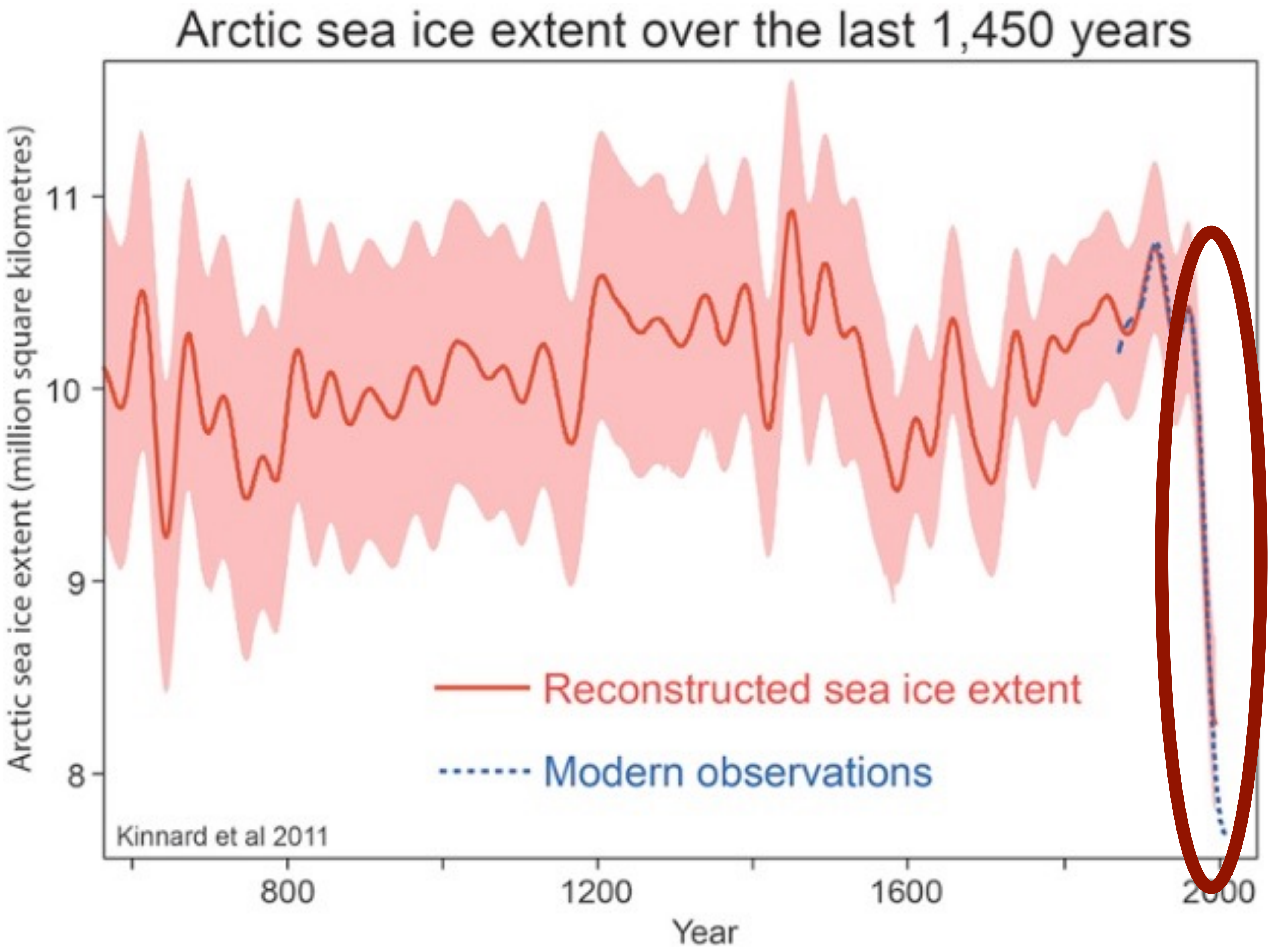

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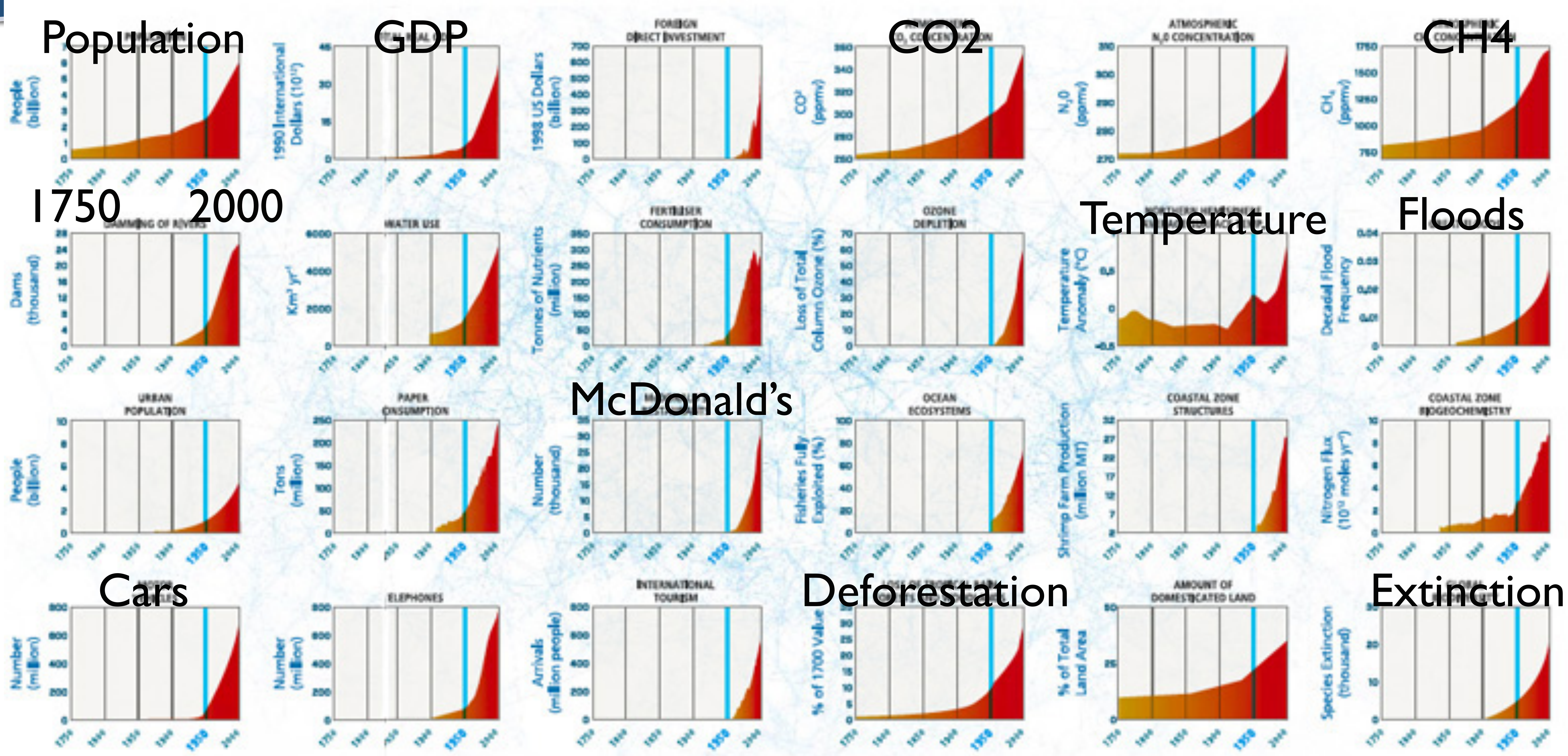
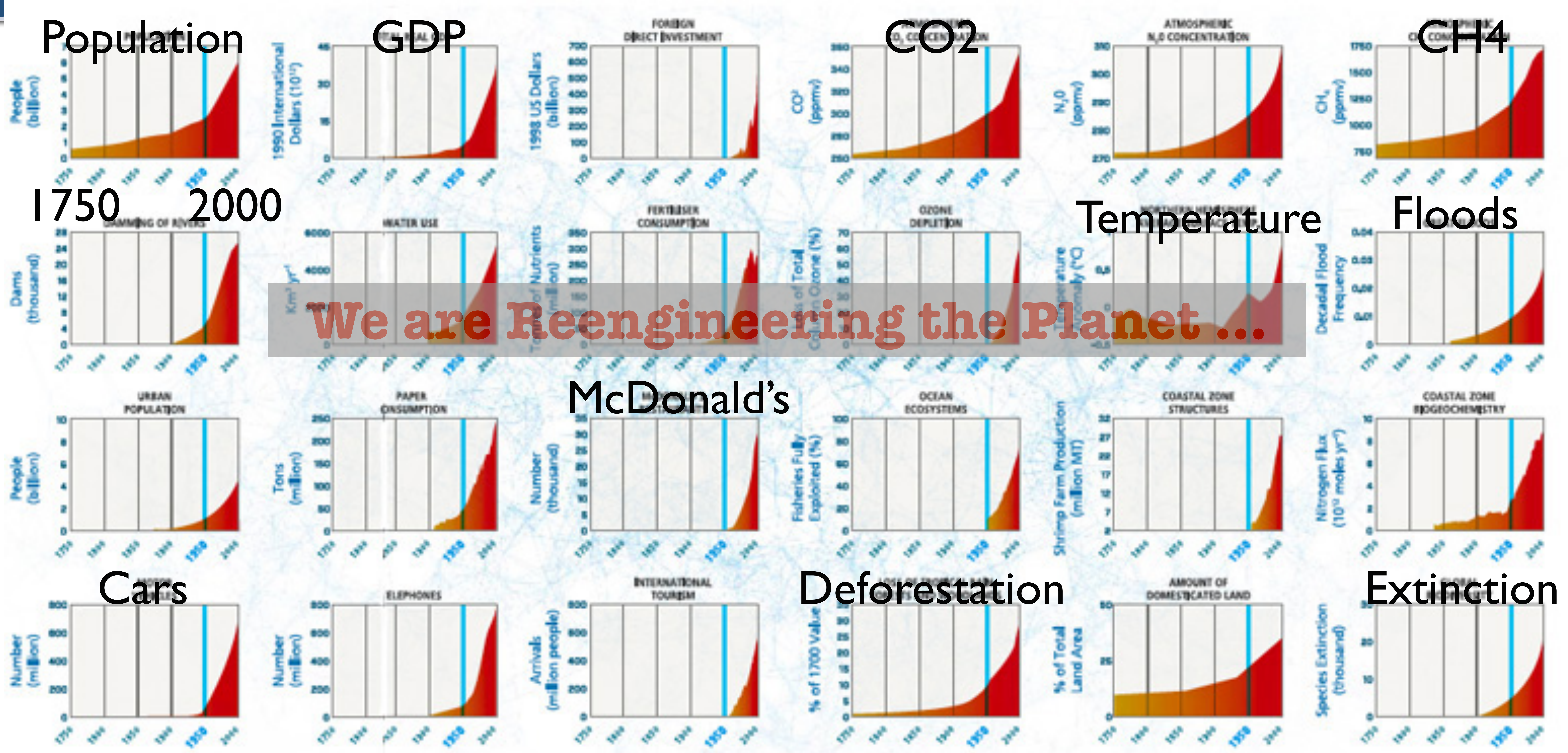


Figure 1. An enterprise to reckon with. Human nanipulation of their environment began in earnest during the Industrial Revolution and accelerated markedly after the 1950s, as IGBP's Great Acceleration graphs show. Modified after Steffen W et al. (2004).

The Syndrome: Recent Climate and Global Change



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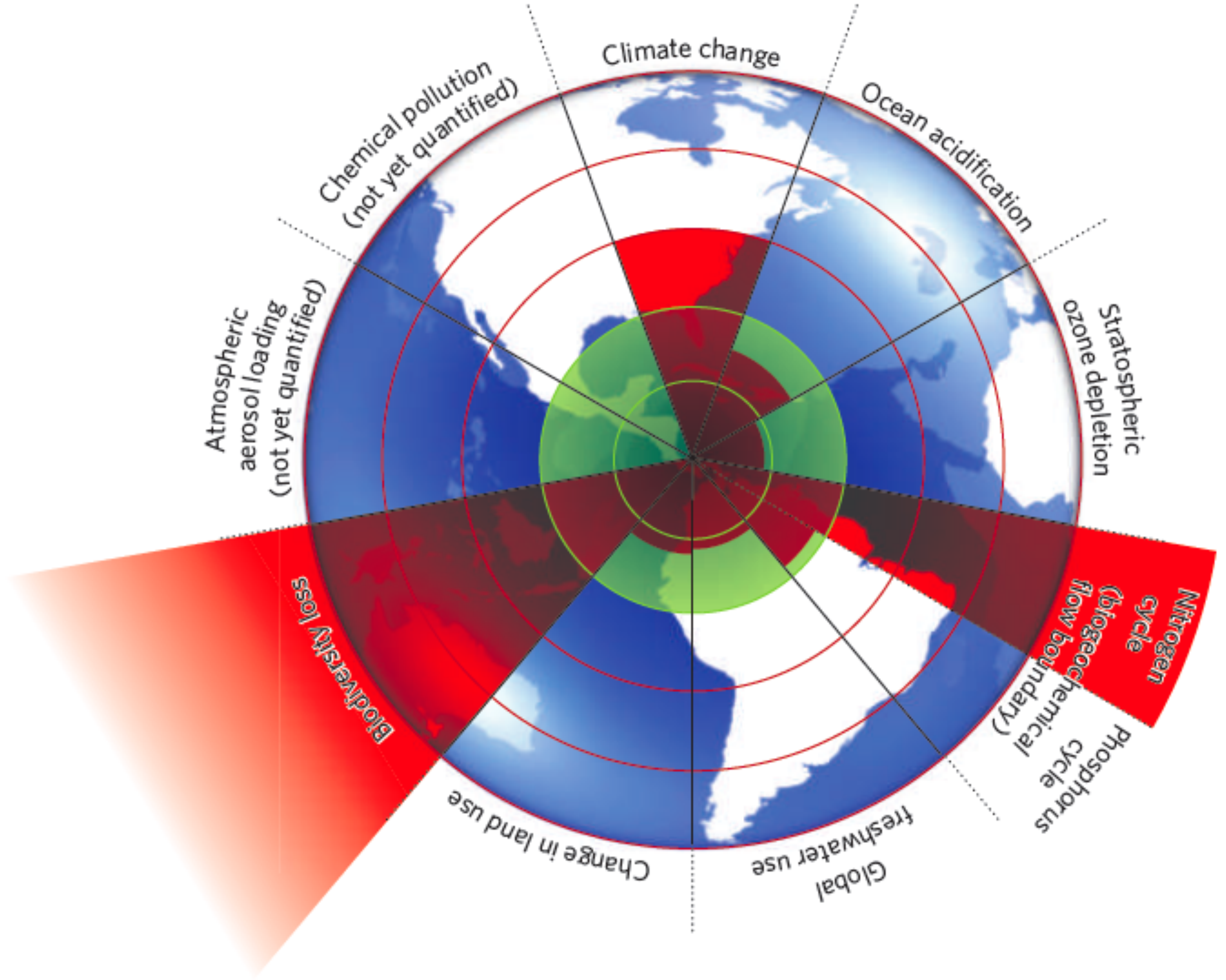

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference 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 (**)
- Global freshwater (*)
- Change in land use (*)
- Biodiversity loss (*******)
- Atmospheric aerosols (?)
- Chemical pollution (?)

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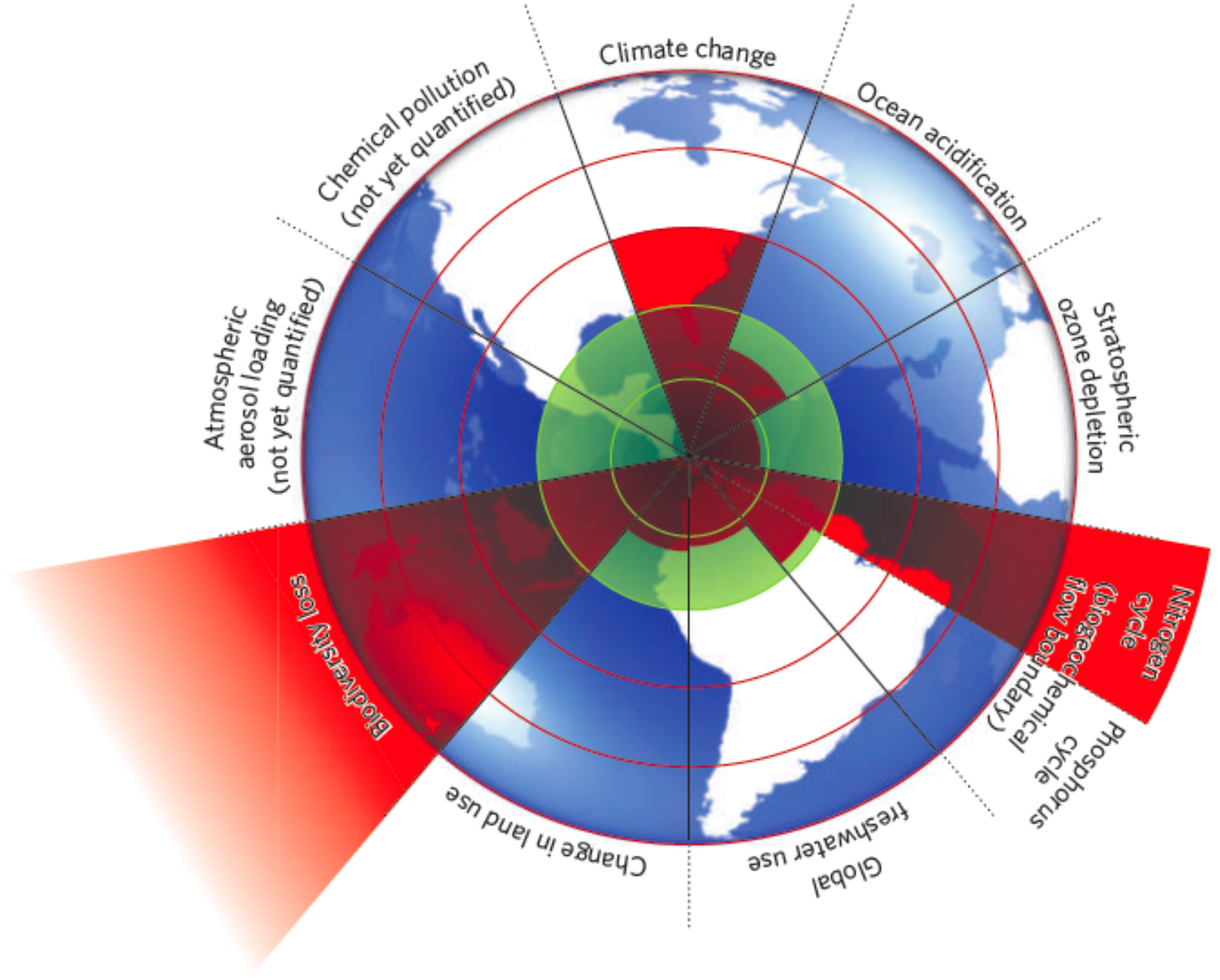

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- Atmospheric aerosols (?)
- Chemical pollution (?)

Climate change and sea level rise are symptoms, not the cause, the "sickness."

Key Points

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The Holocene was a “safe operating space for humanity”

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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 Diagnosis: Leaving the “Safe Operating Space”

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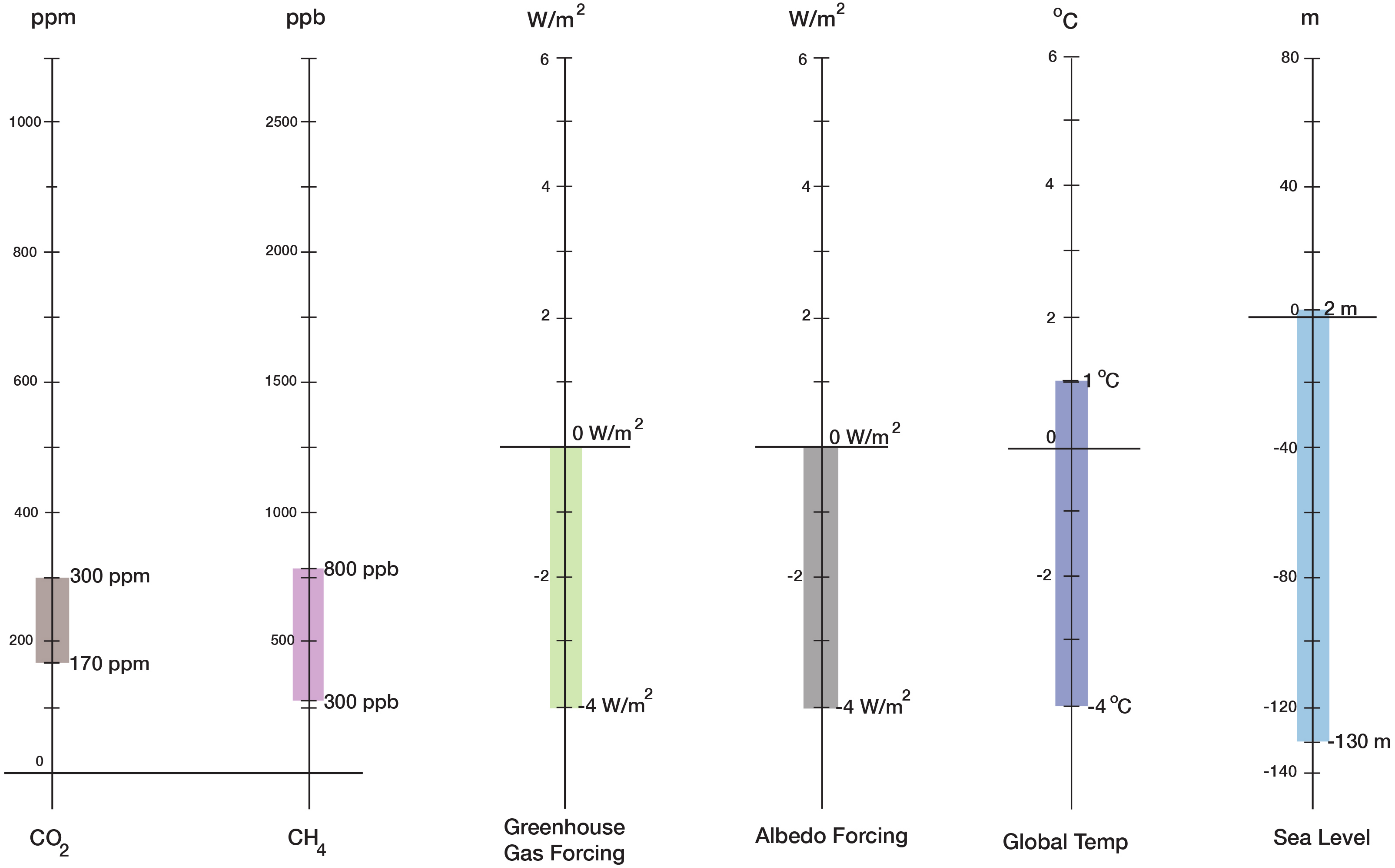
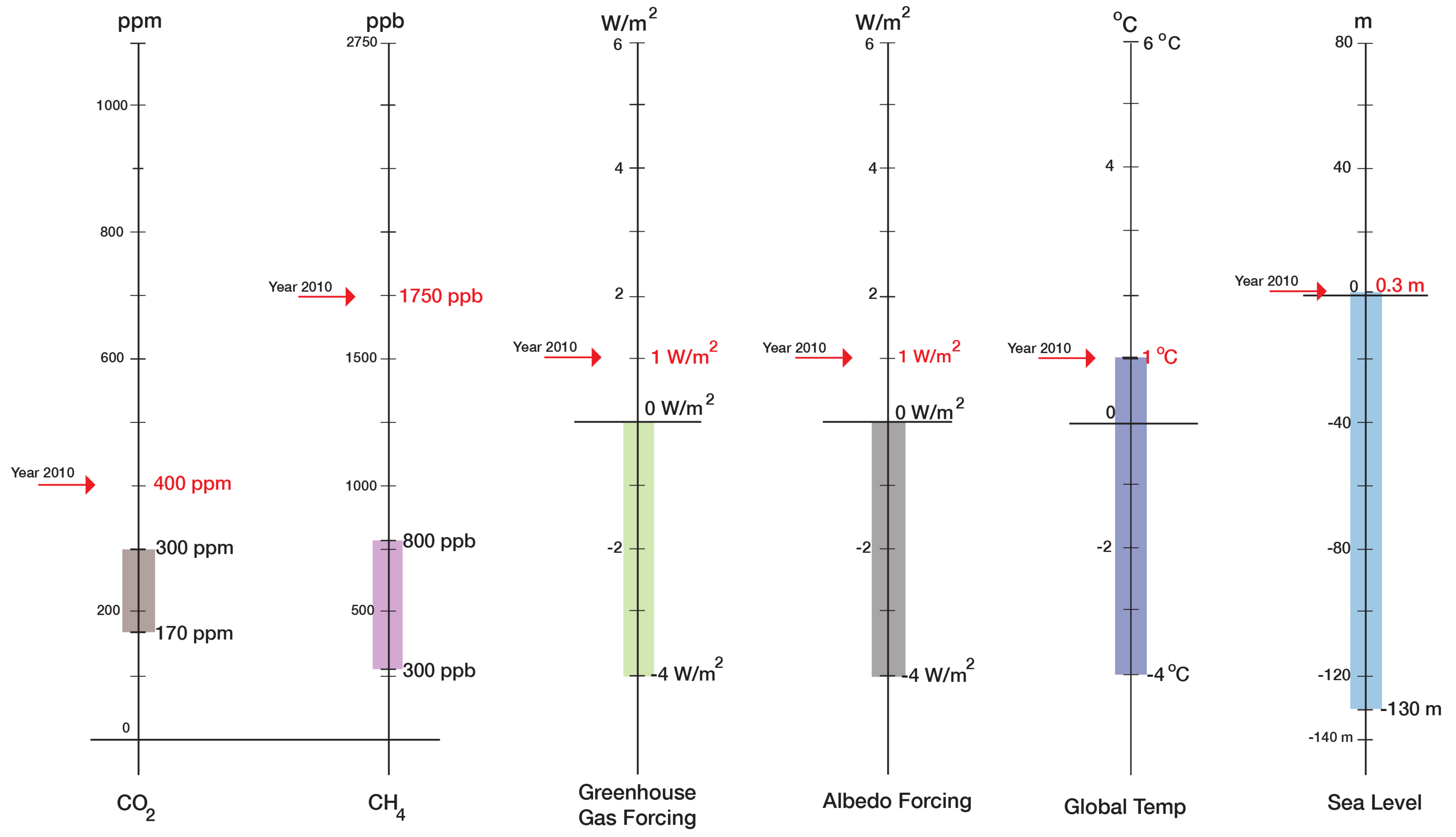


"Normal Range"
(800,000 years)

The Diagnosis: Leaving the "Safe Operating Space"



"Current State"

"Normal Range" (800,000 years)

The Diagnosis: Leaving the "Safe Operating Space"

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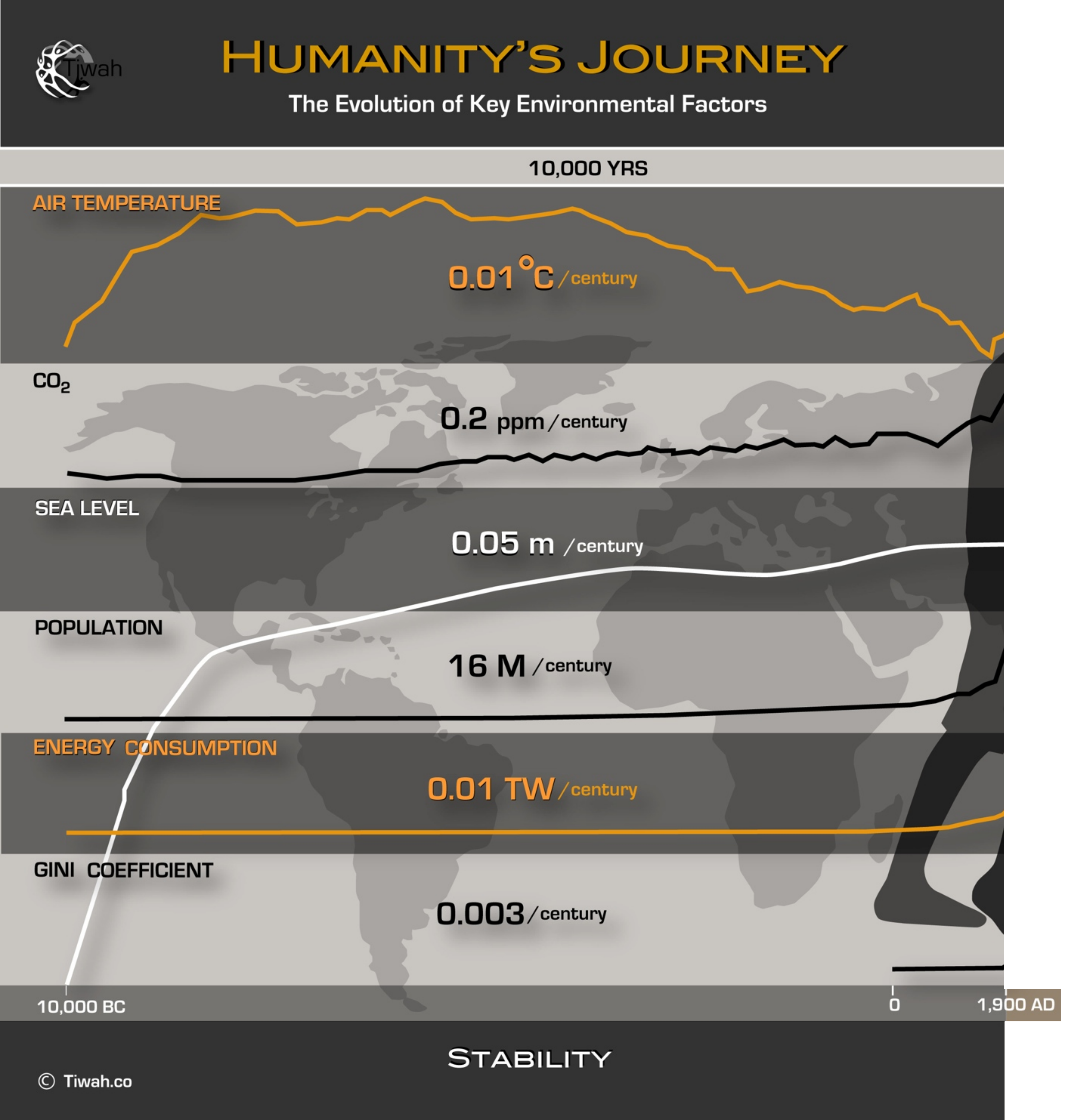
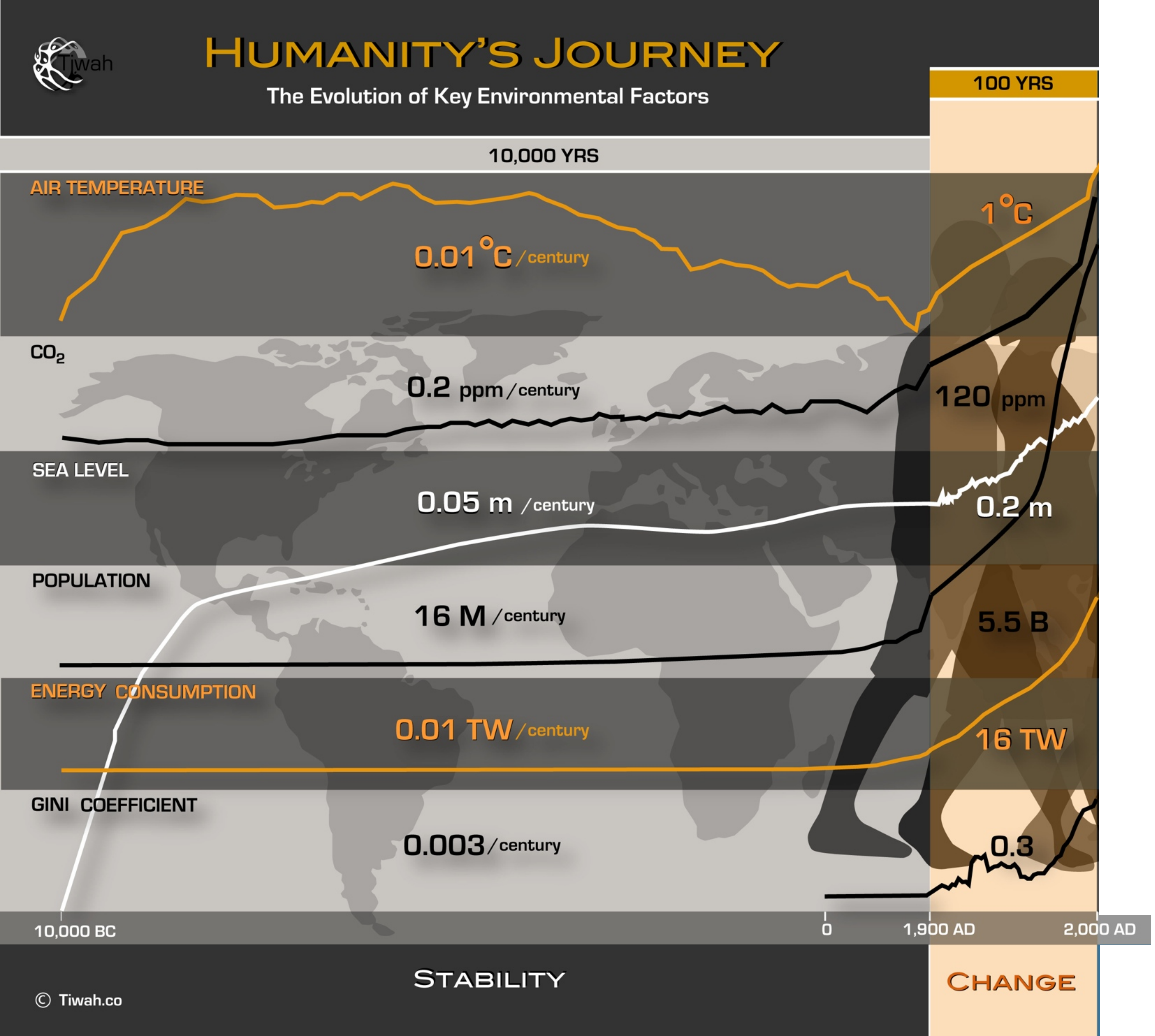
"What would you like to tell your 20 year old self?"

Eva Wilkerson, 2013



Tiwah
HUMANITY'S JOURNEY
The Evolution of Key Environmental Factors
10,000 YRS
AIR TEMPERATURE
0.01 °C / century
CO_2
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
0
1,900 AD
STABILITY
© Tiwah.co



Tiwah
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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
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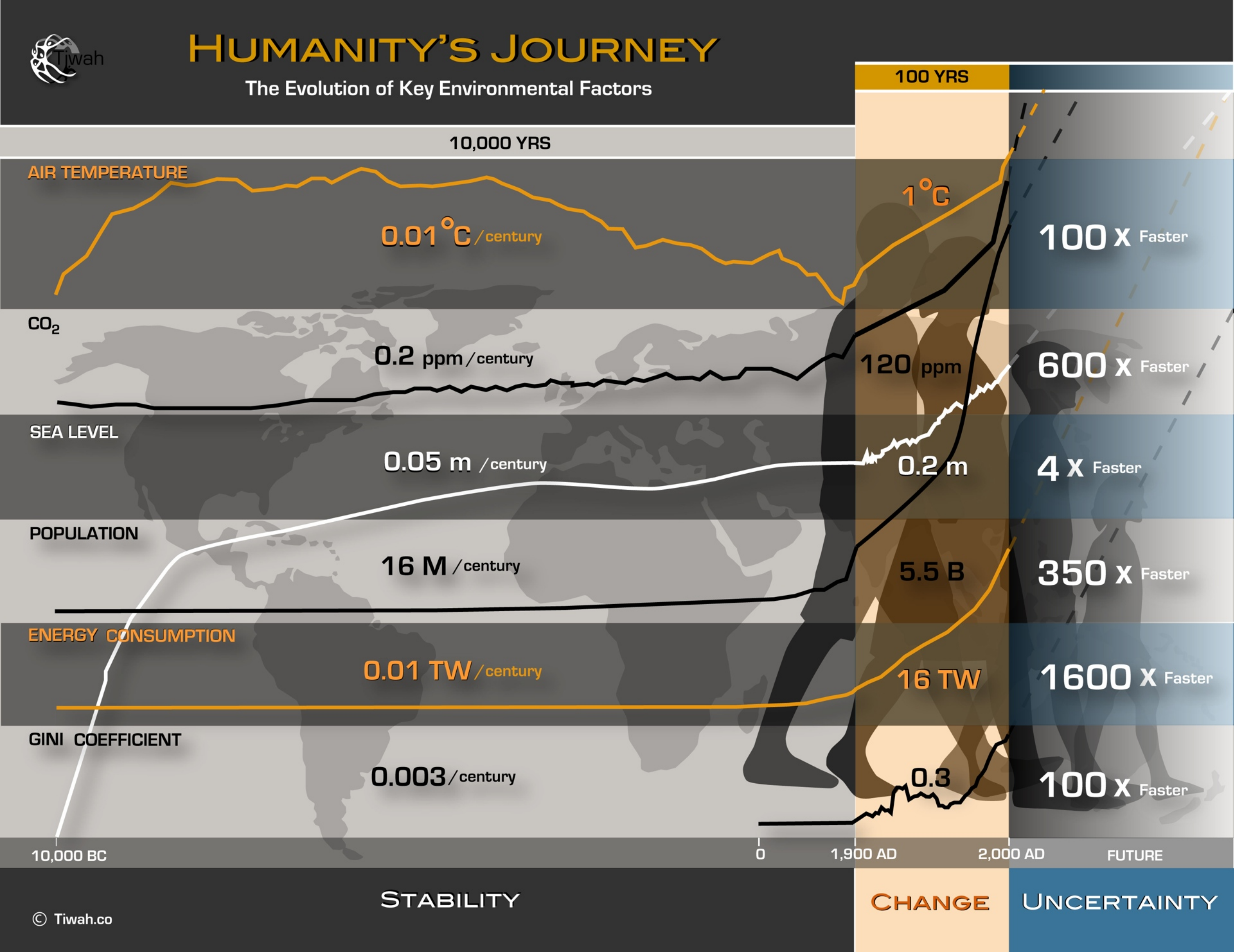
2,000 AD
STABILITY
CHANGE
© Tiwah.co



Tiwah
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10,000 YRS
100 YRS
AIR TEMPERATURE
0.01 °C / century
1 °C
100 x Faster
CO_2
0.2 ppm / century
120 ppm
600 x Faster
SEA LEVEL
0.05 m / century
0.2 m
4 x Faster
POPULATION
16 M / century
5.5 B
350 x Faster
ENERGY CONSUMPTION
0.01 TW / century
16 TW
1600 x Faster
GINI COEFFICIENT
0.003 / century
0.3
100 x Faster
10,000 BC
0
1,900 AD
2,000 AD
FUTURE
STABILITY
CHANGE
UNCERTAINTY
© Tiwah.co

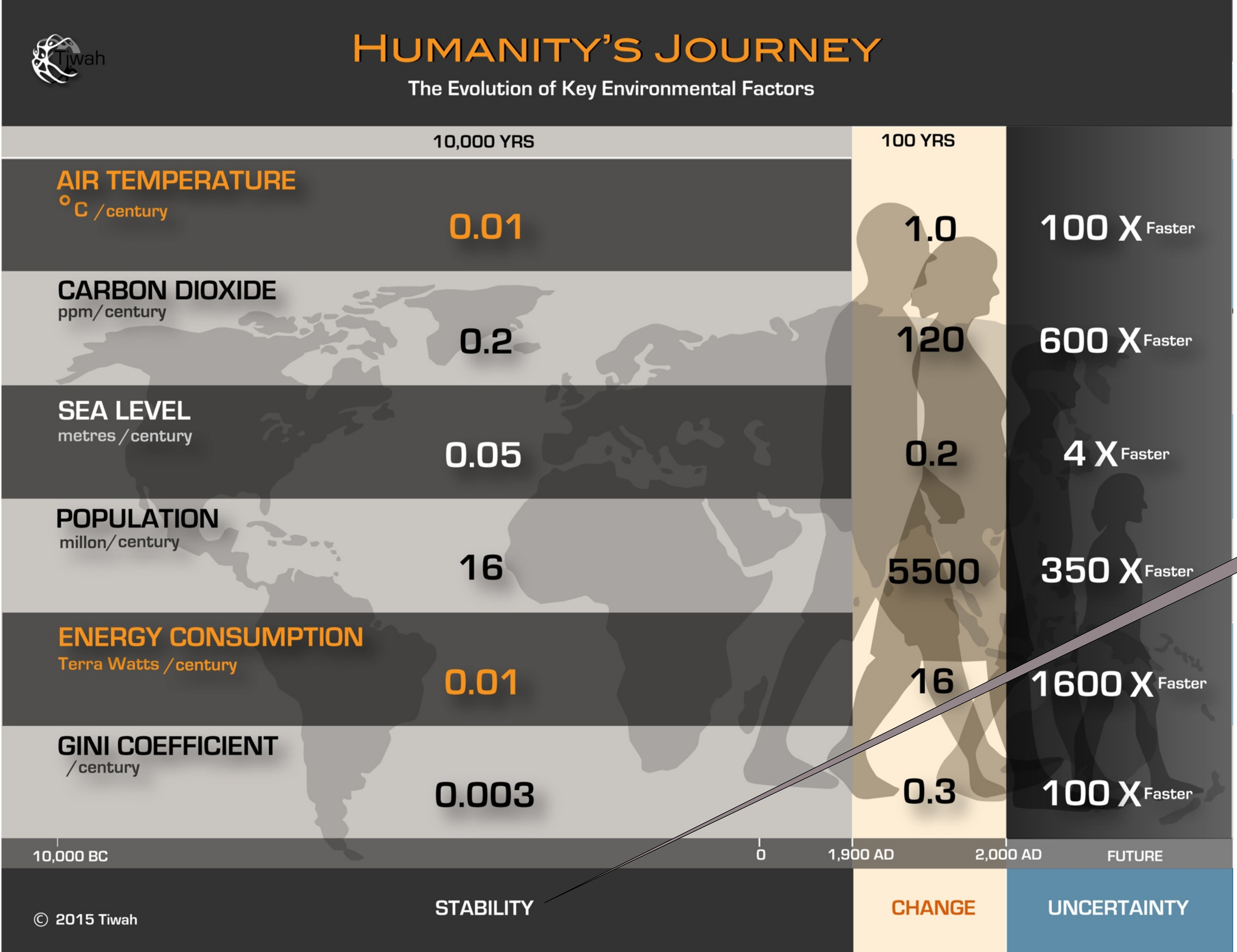
Humanity's Journey

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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10,000 YRS
100 YRS
AIR TEMPERATURE
°C / century
0.01
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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
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1600 X Faster
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/ century
0.003
0.3
100 X Faster
10,000 BC
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1,900 AD
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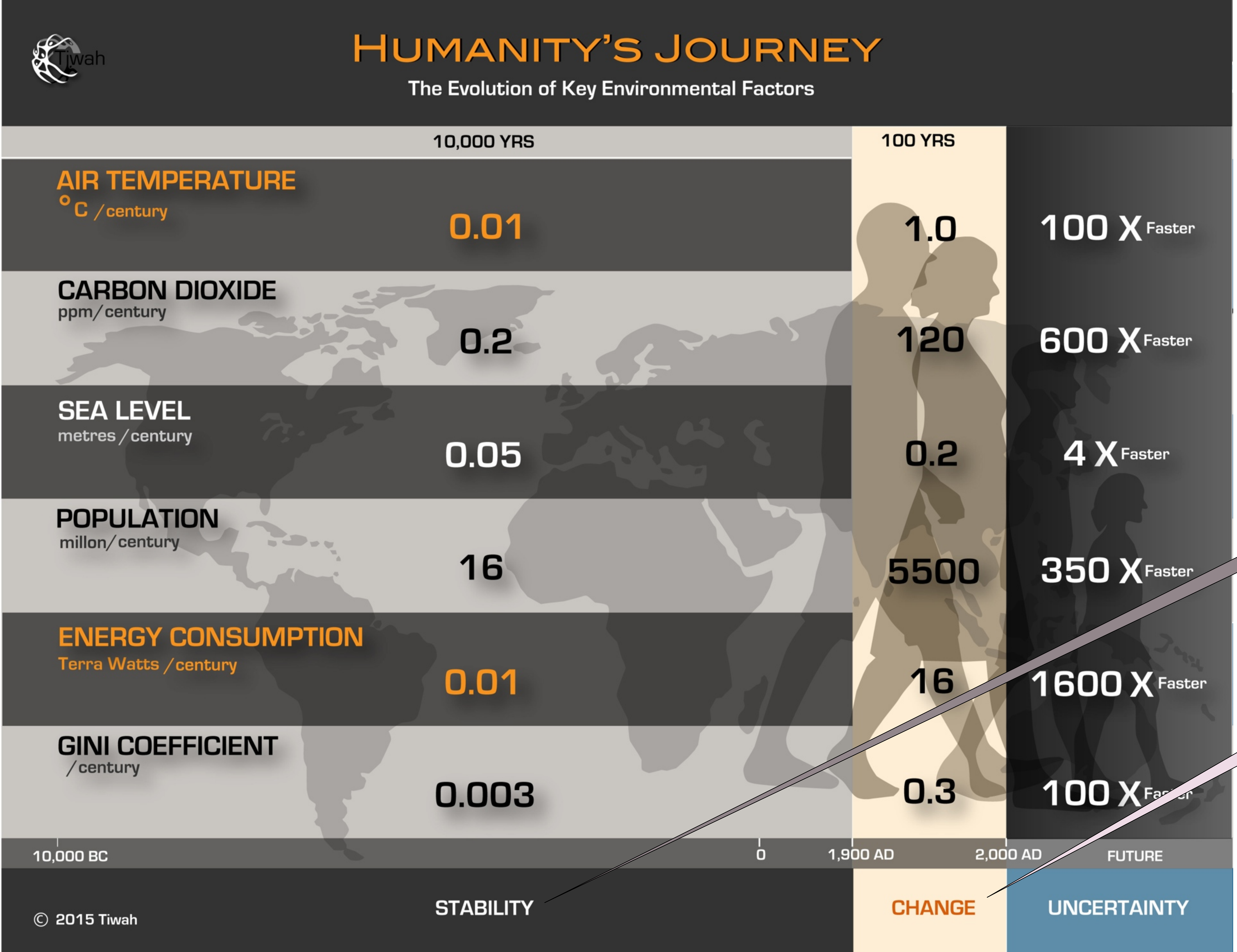
FUTURE
© 2015 Tiwah
STABILITY
CHANGE
UNCERTAINTY

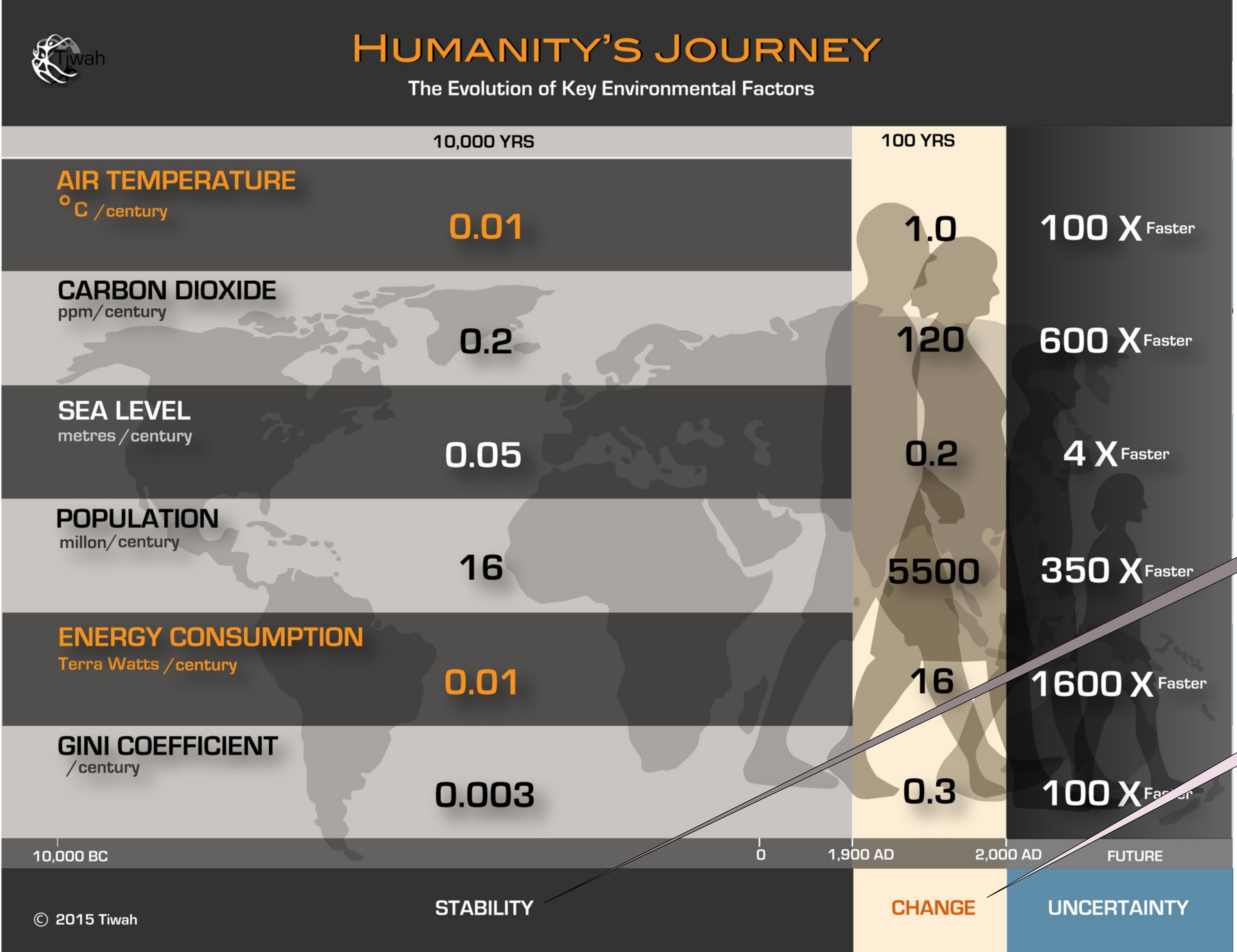
Holocene



Holocene

20th and 21st Century

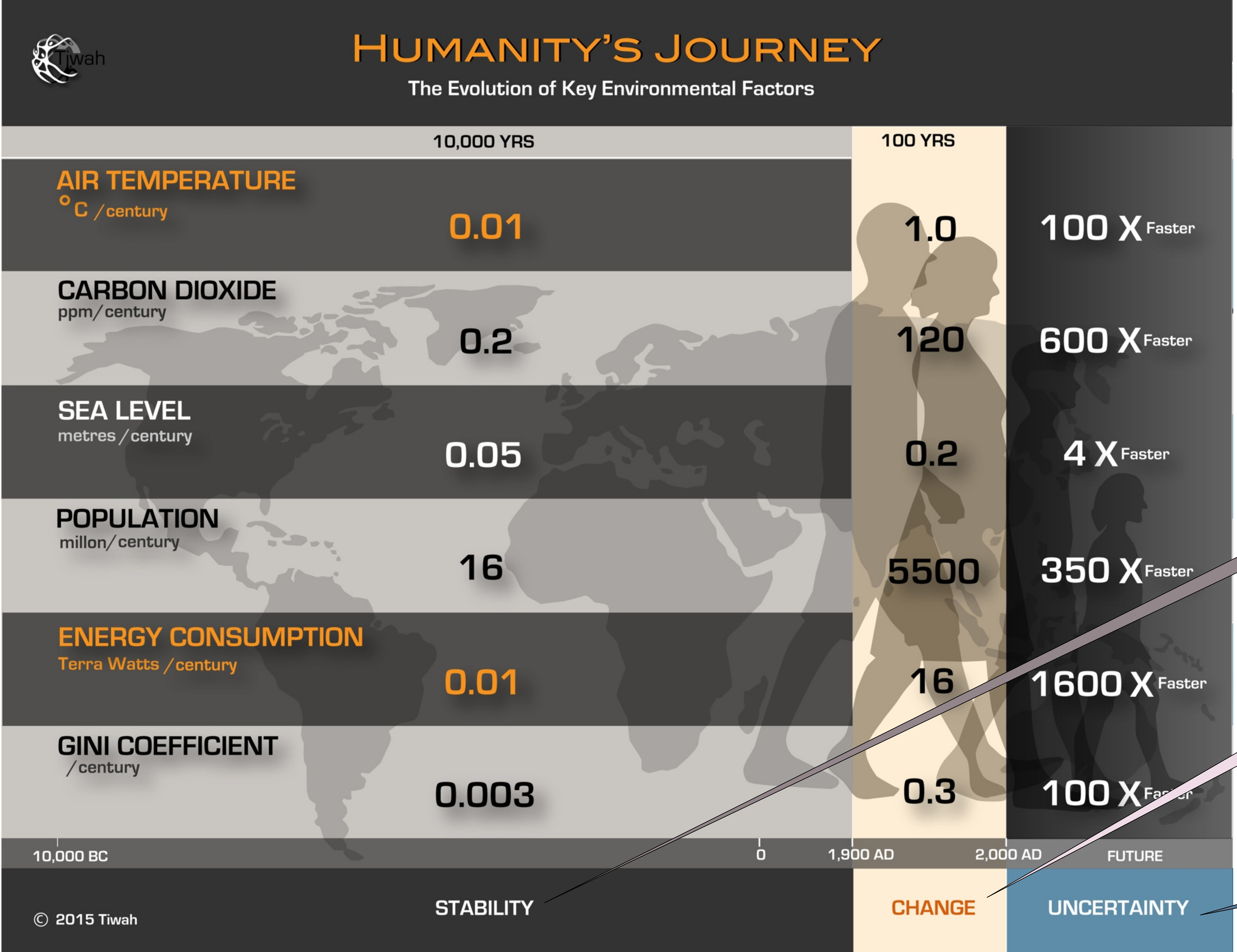
Humanity is in the “Emergency Room”



Holocene

20th and 21st Century

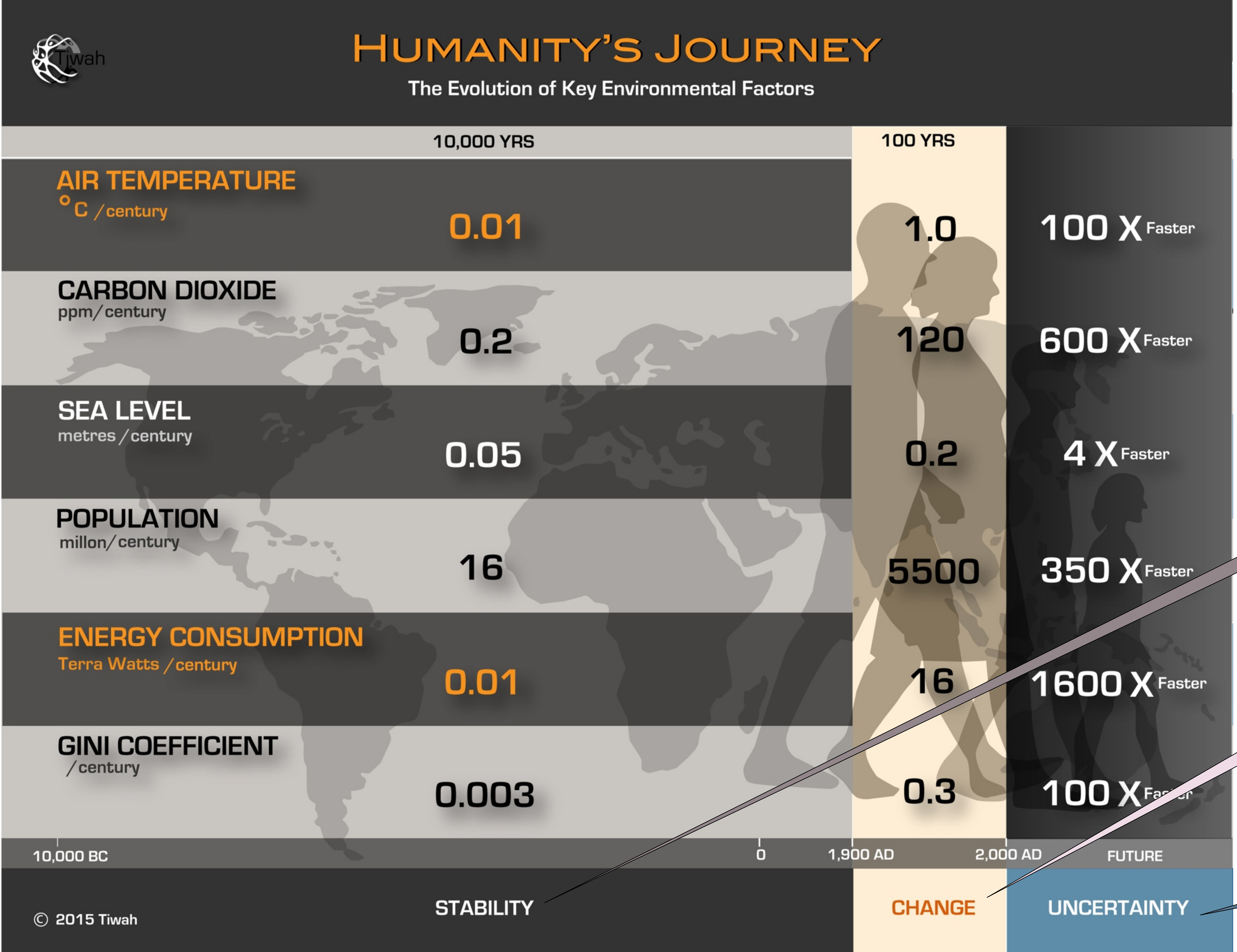
Best news from the Emergency Room?



Holocene

20th and 21st Century

Future



Best news from the Emergency Room?

"The patient is stable"

Holocene

20th and 21st Century

Future

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

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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

The Prognosis: Anticipating Surprises

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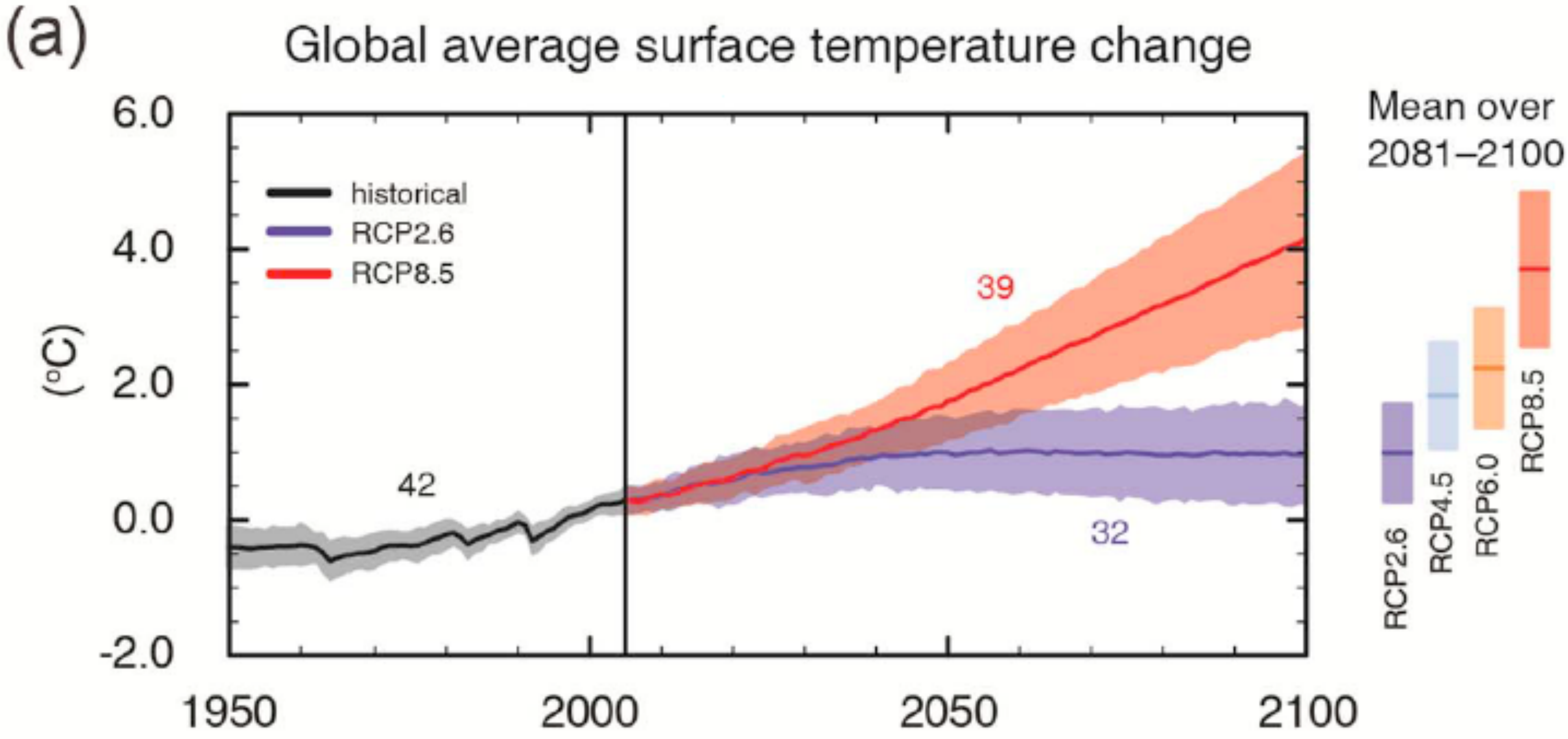
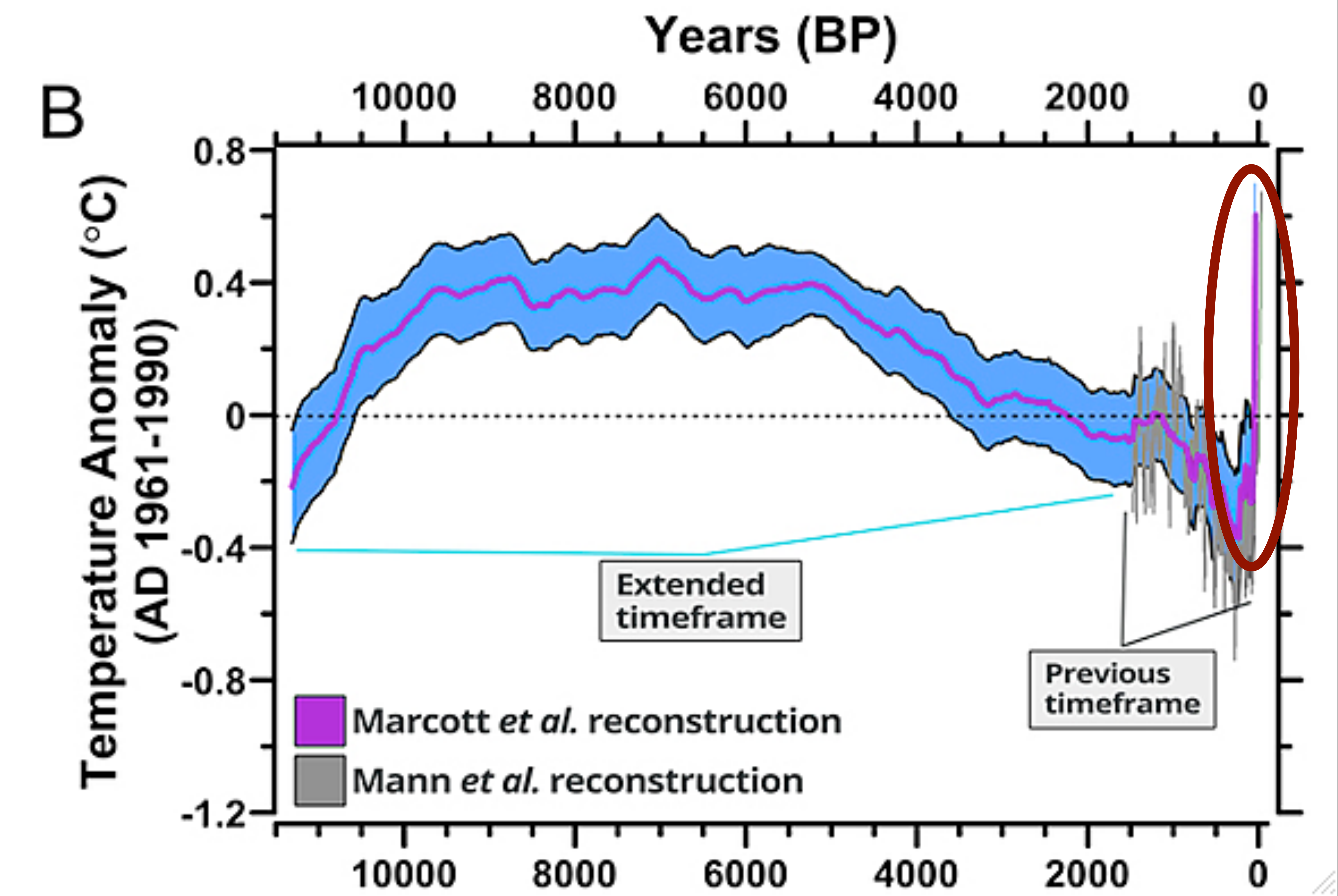


IPCC, 2013

The Prognosis: Anticipating Surprises



Marcott et al., 2013

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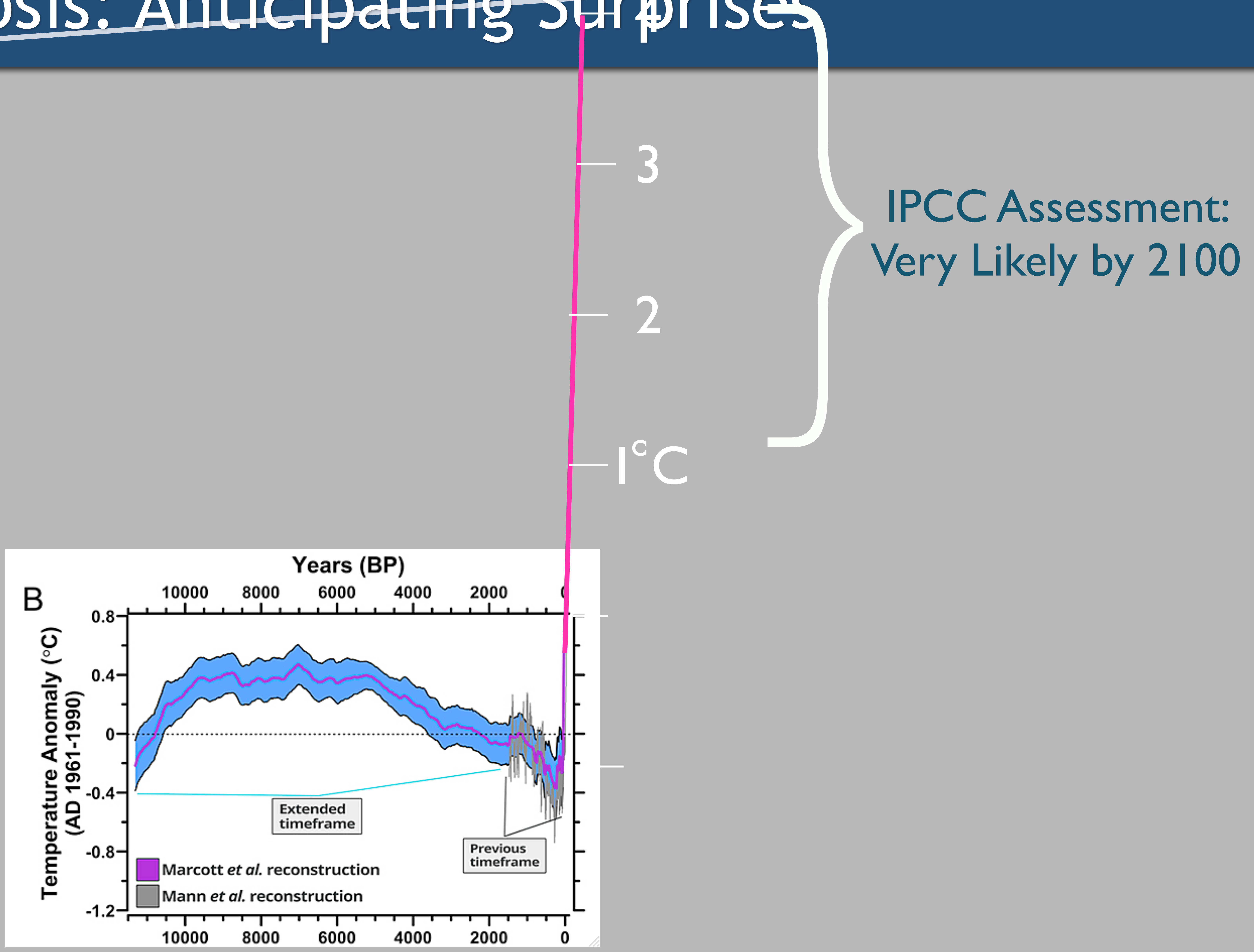

Marcott et al., 2013

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4

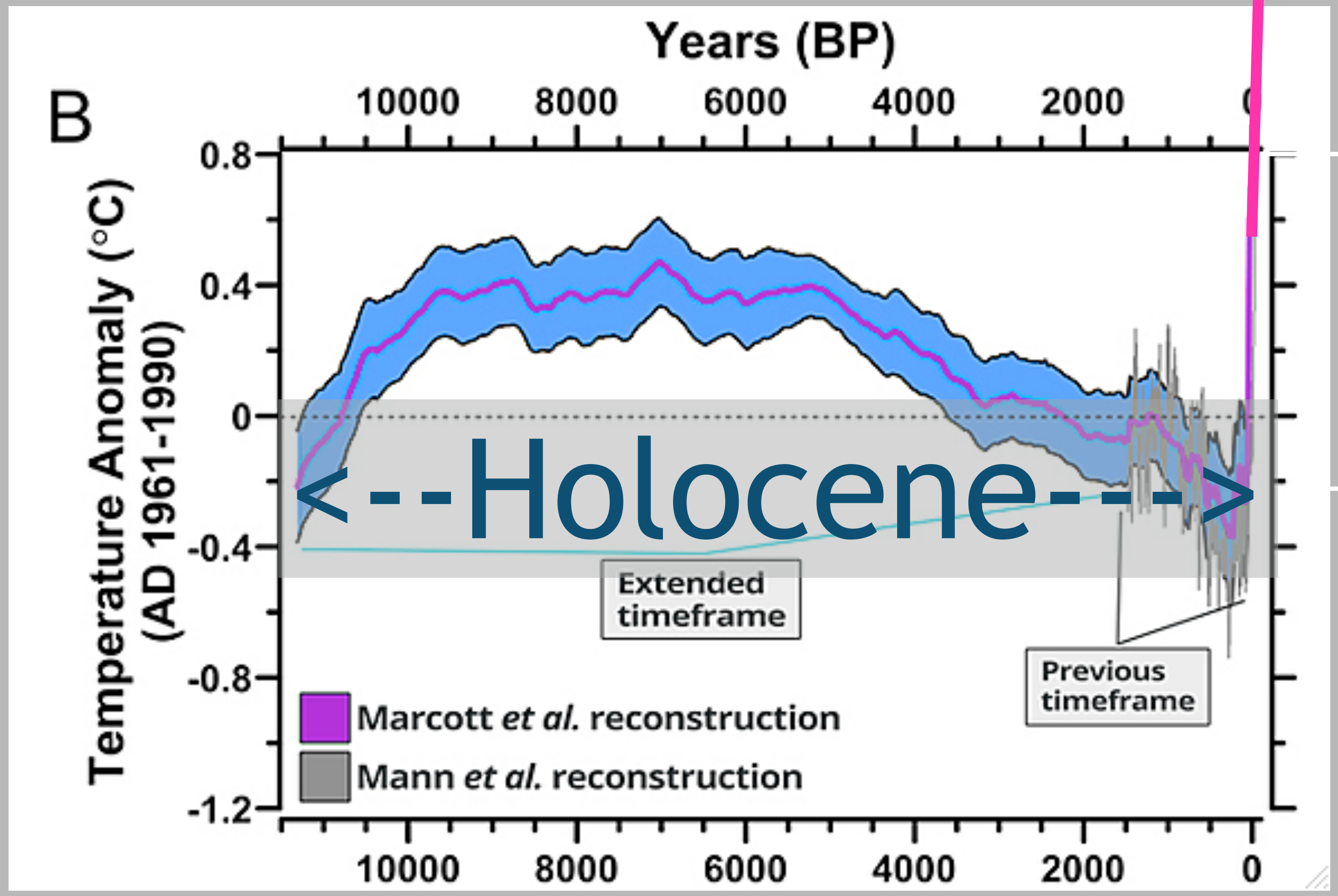
<--Post-Holocene

3

IPCC Assessment:
Very Likely by 2100

2

1°C



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Marcott et al., 2013

The Prognosis: Anticipating Surprises

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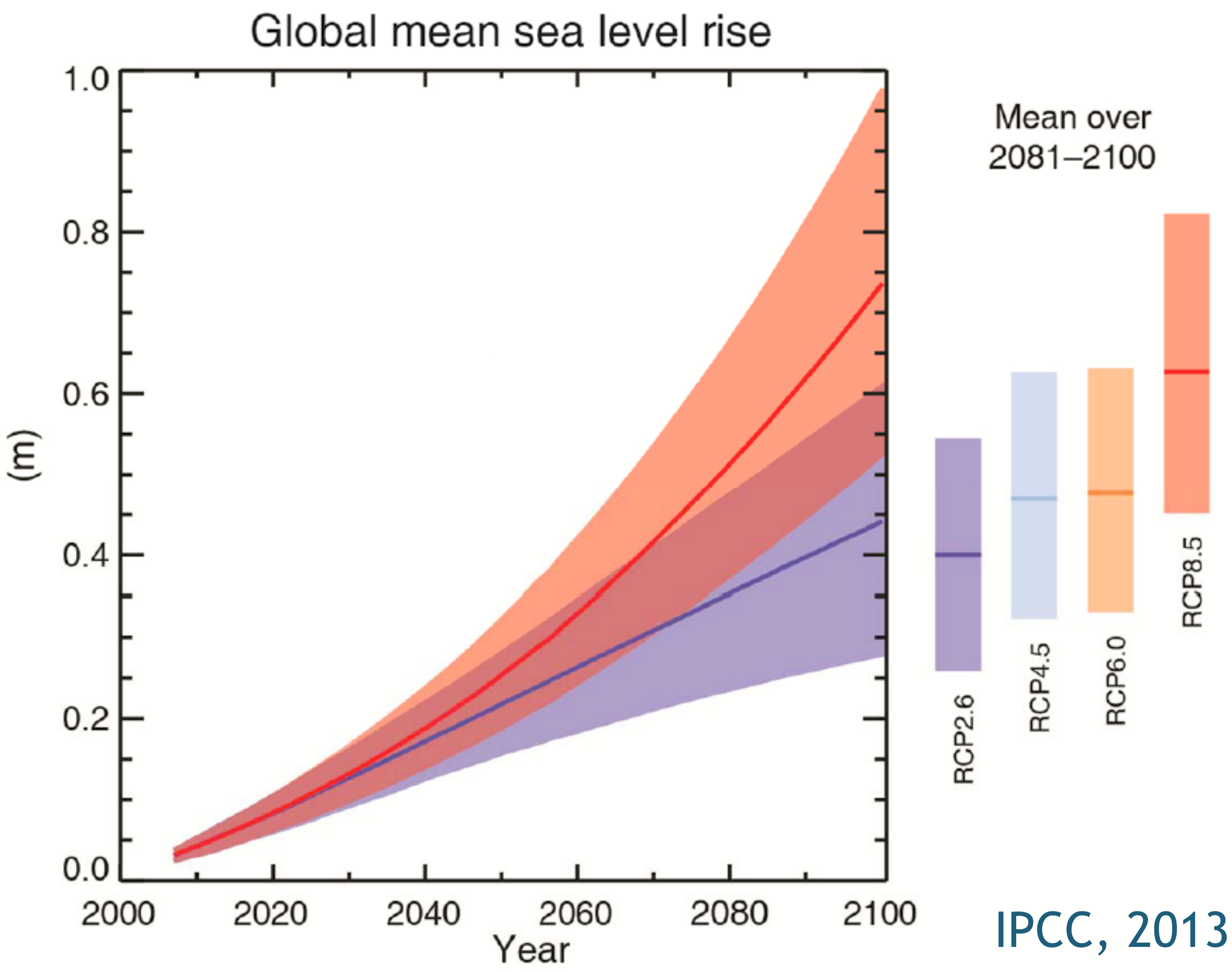

IPCC, 2013

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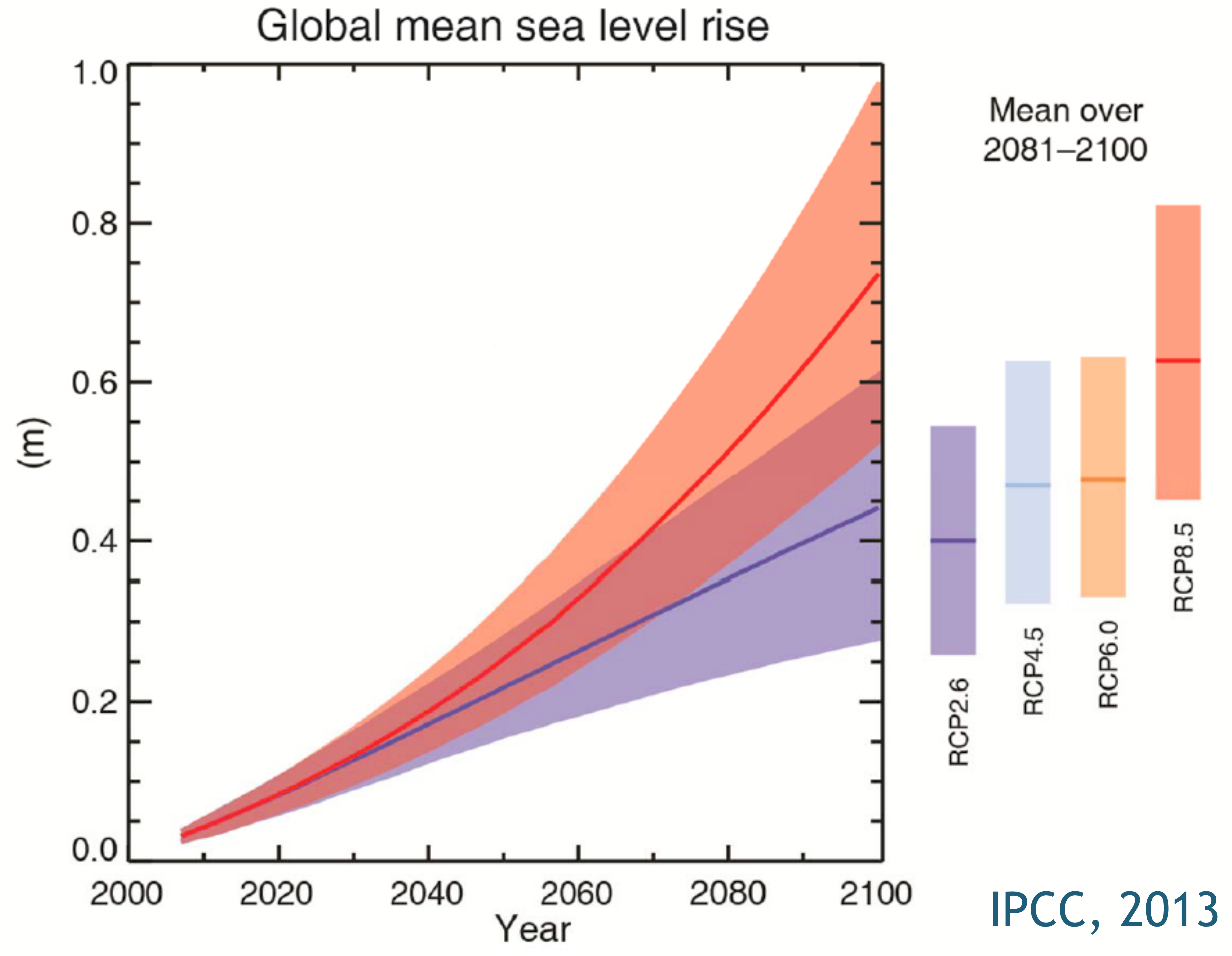
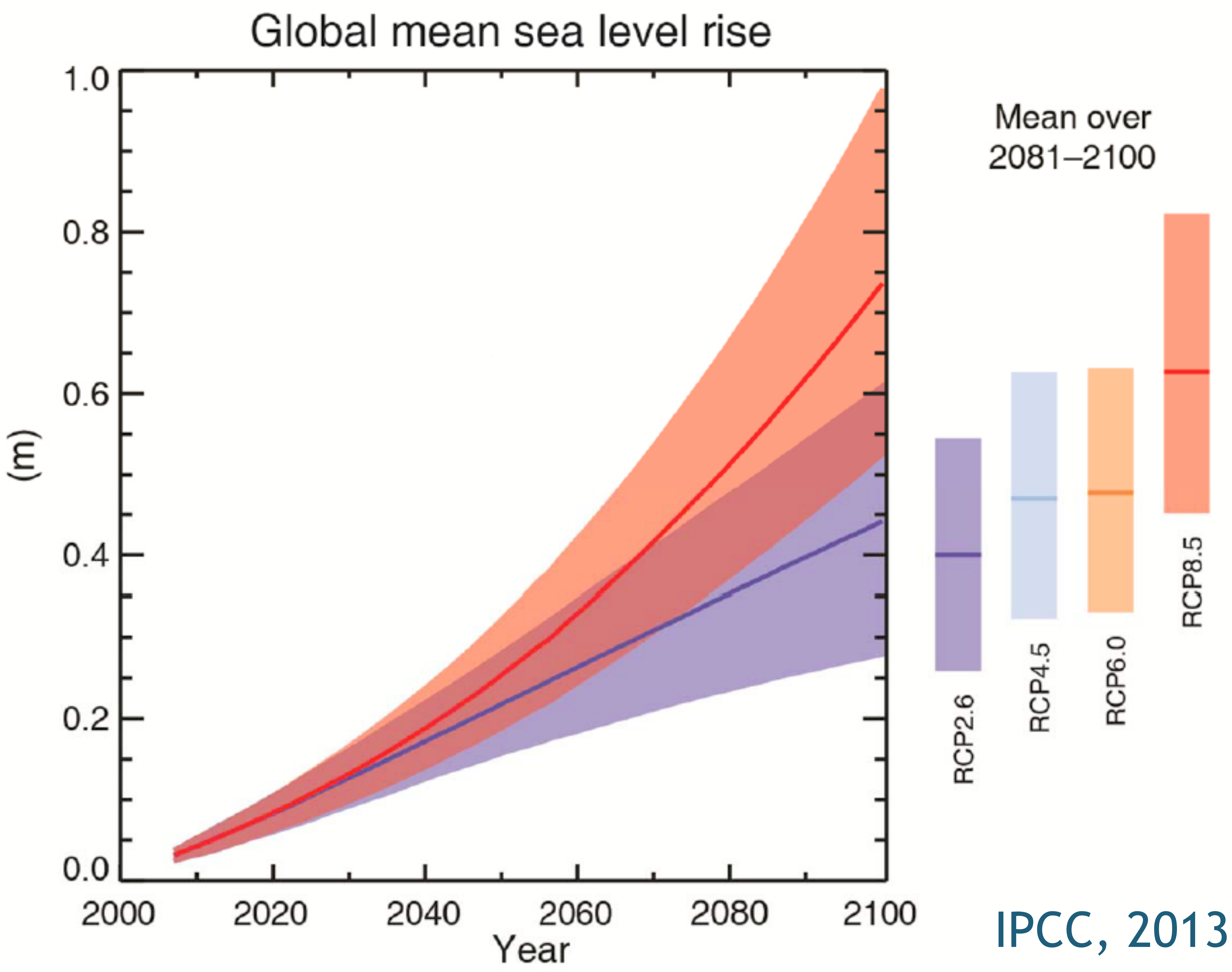


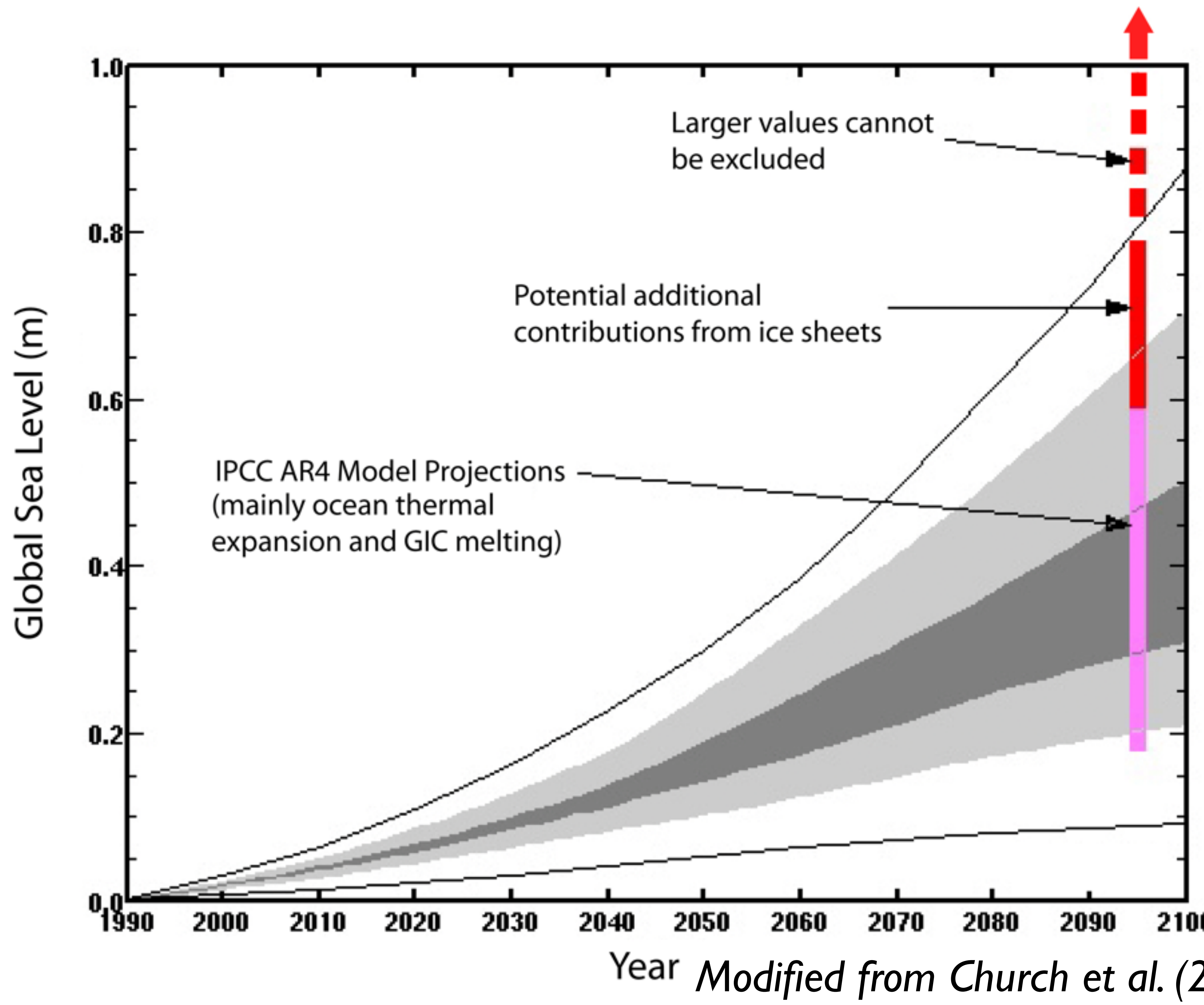
IPCC, 2013

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

The Prognosis: Anticipating Surprises

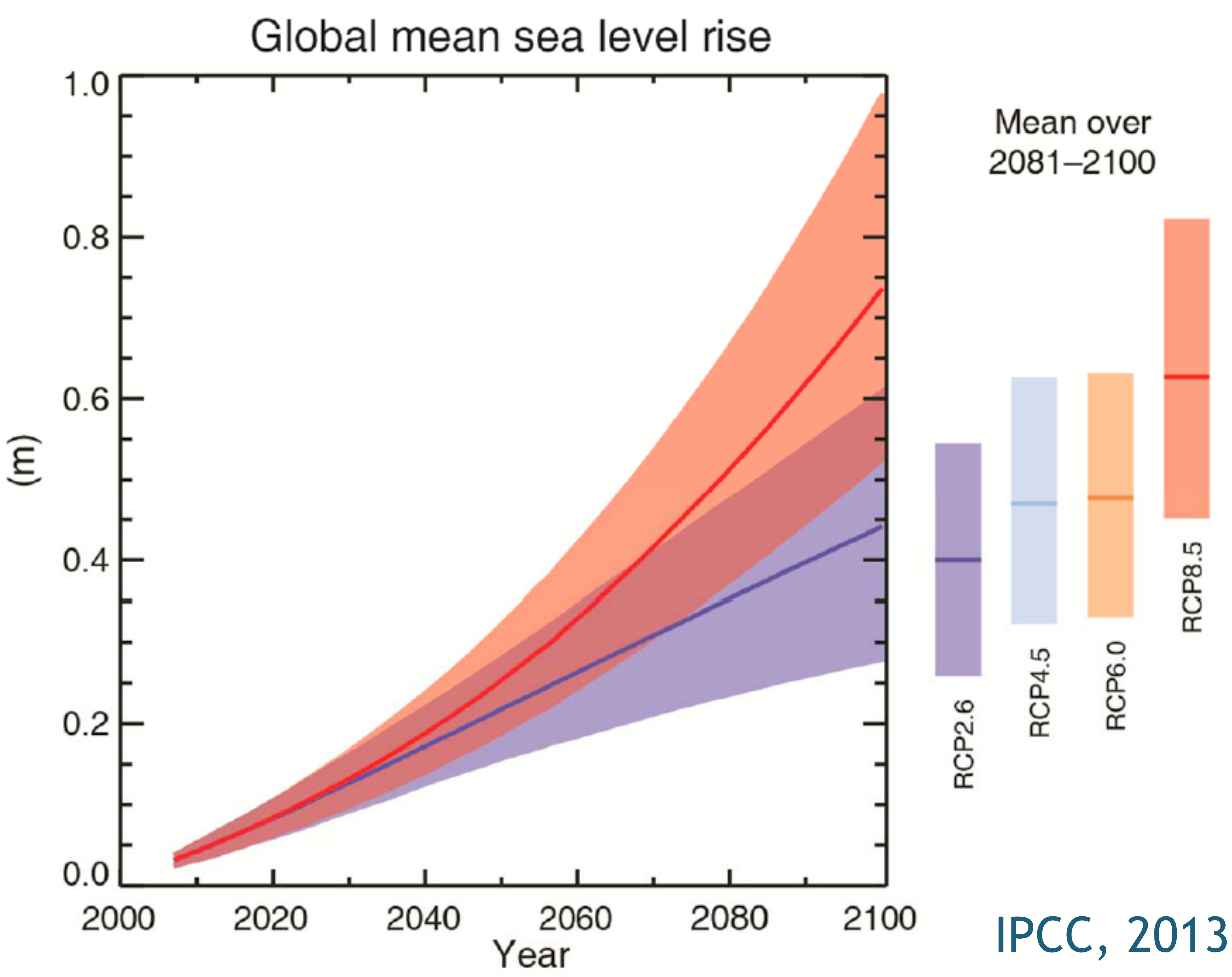


IPCC, 2013

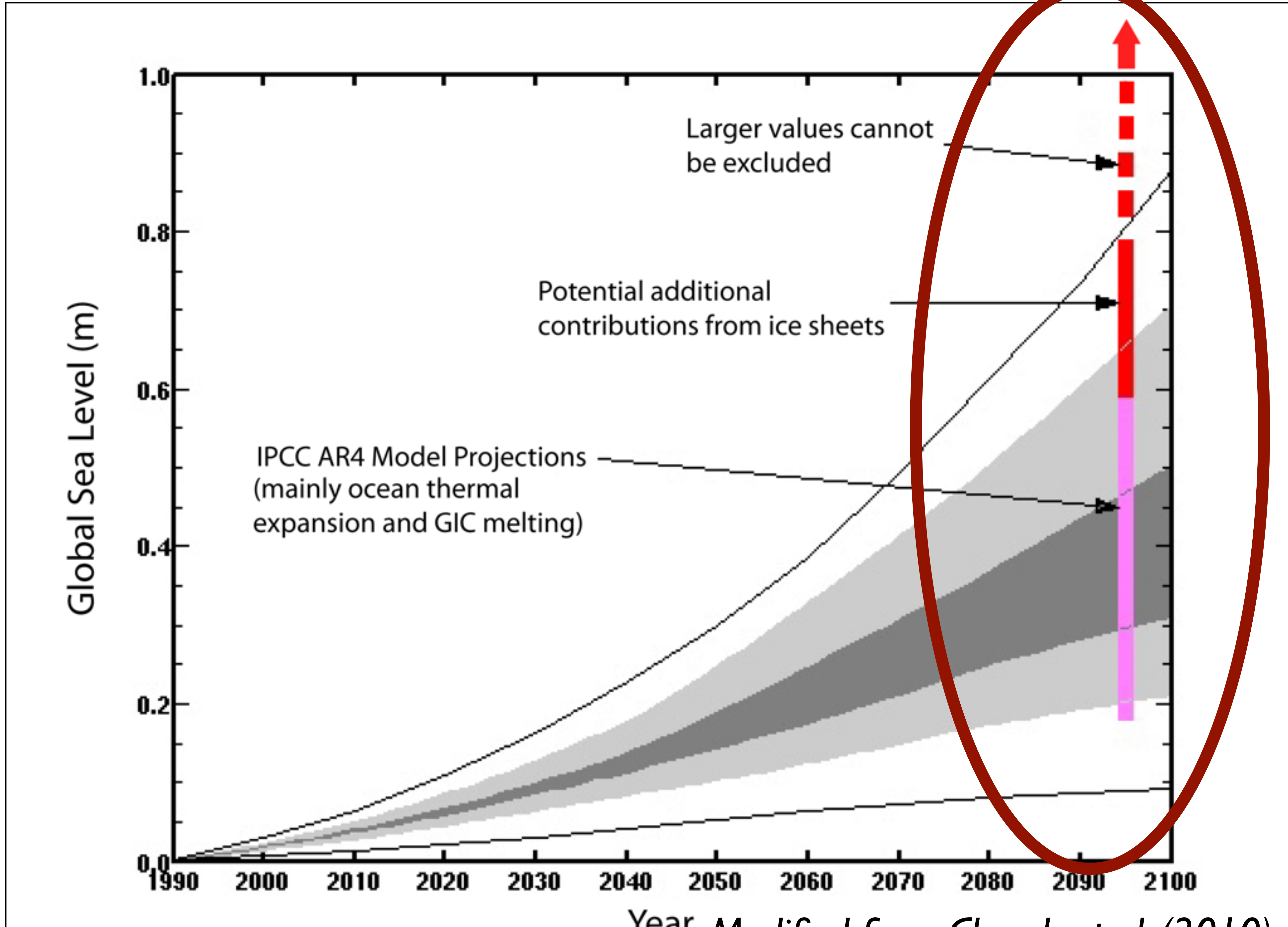


Modified from Church et al. (2010)

The Prognosis: Anticipating Surprises



IPCC, 2013



Modified from Church et al. (2010)

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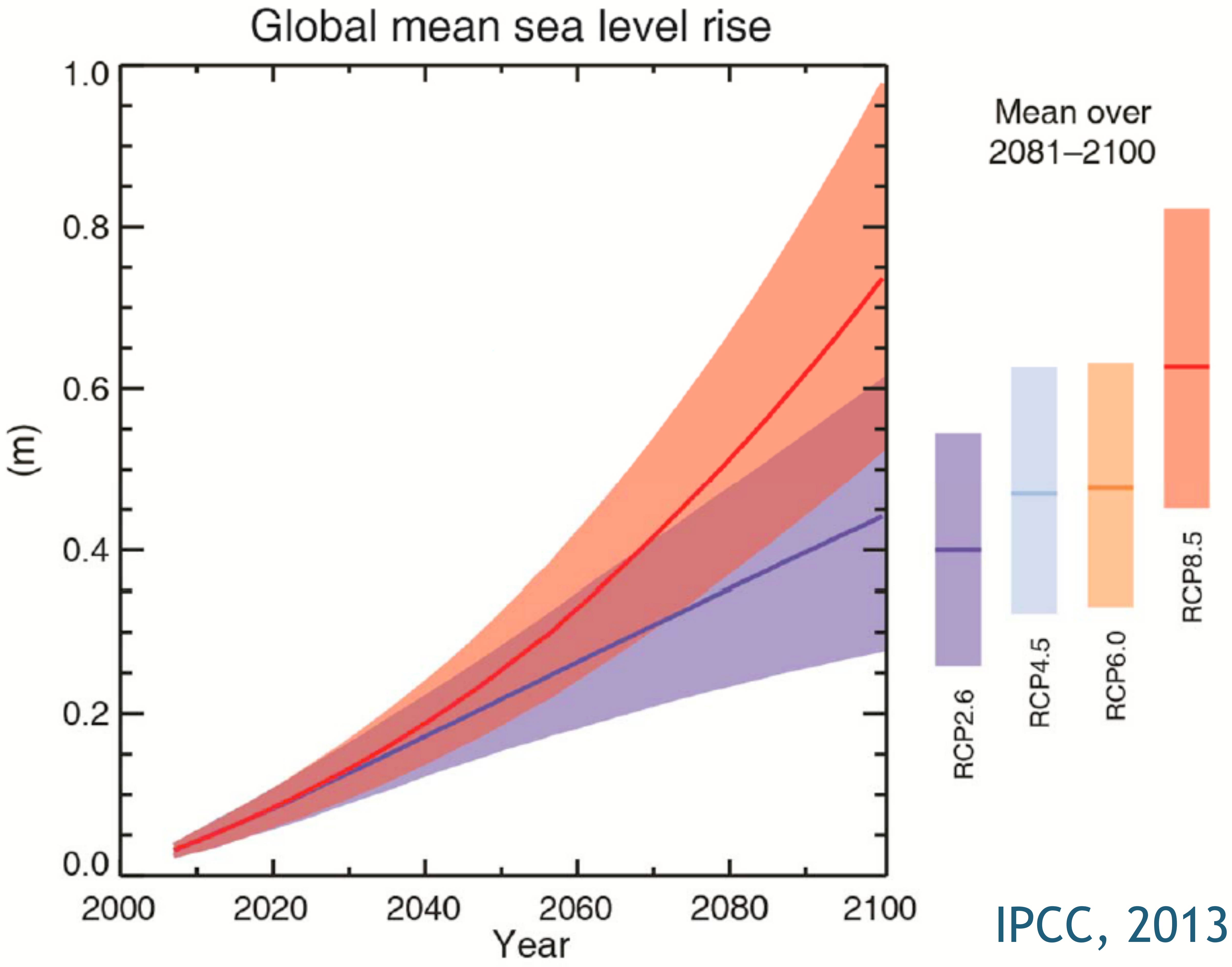
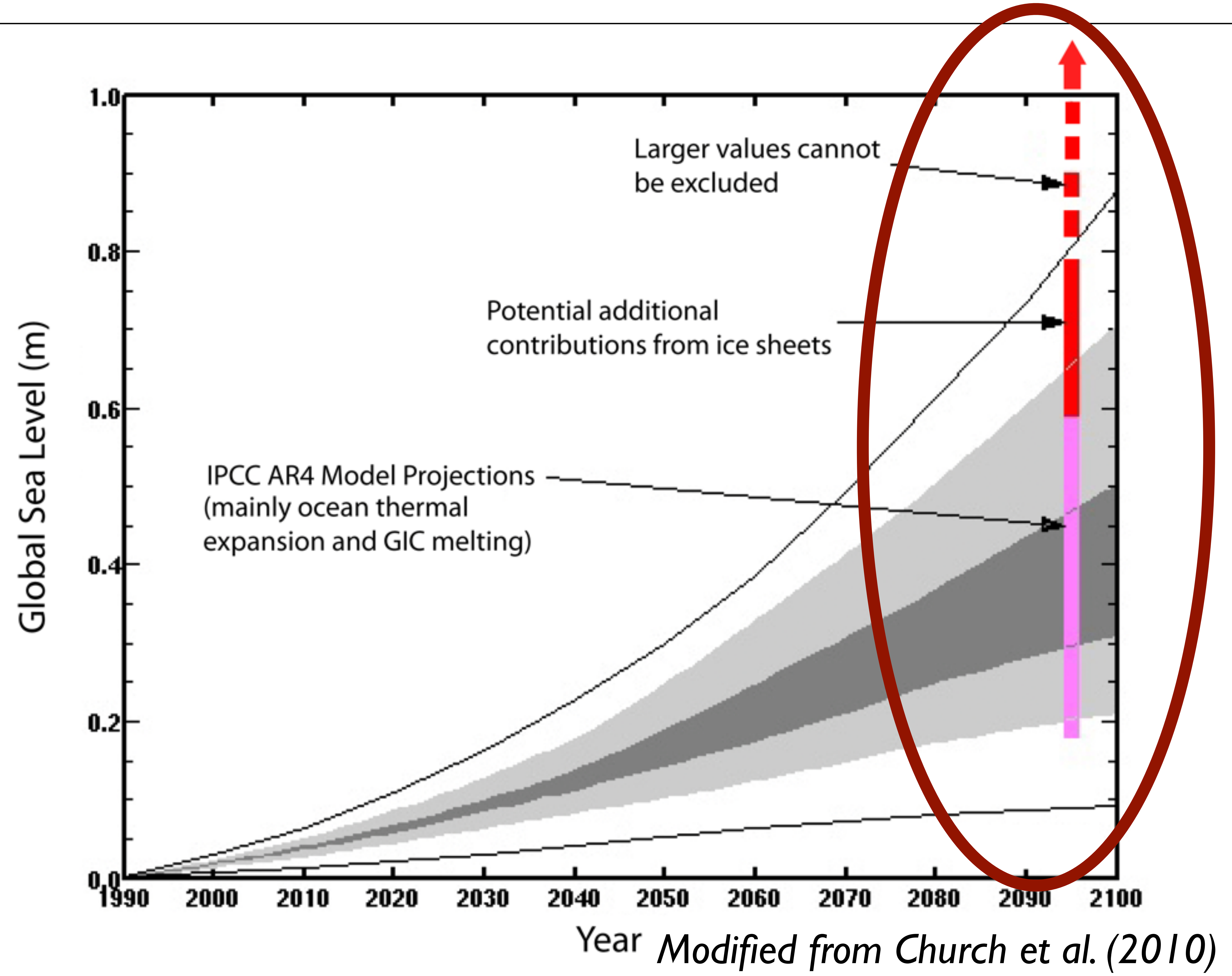


IPCC, 2013



Modified from Church et al. (2010)

Decision making under uncertainties (DMUU)

Decision making under foreseeability (DMUF)

The Prognosis: Anticipating Surprises

The Prognosis: Anticipating Surprises

Example: Greenland and Antarctic Ice Sheets

Accepted knowledge in 2000:

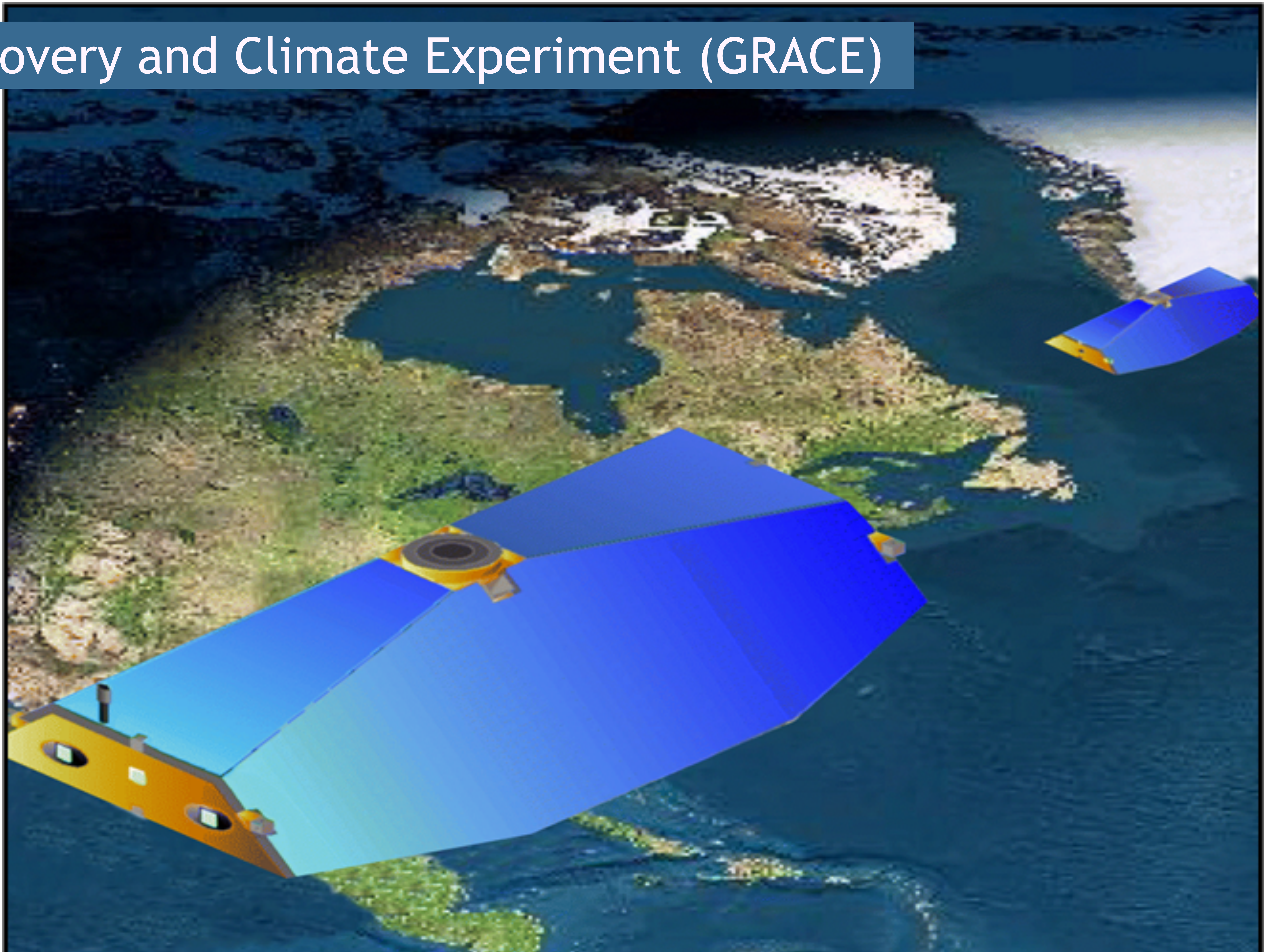
Greenland: no significant contribution to sea level rise

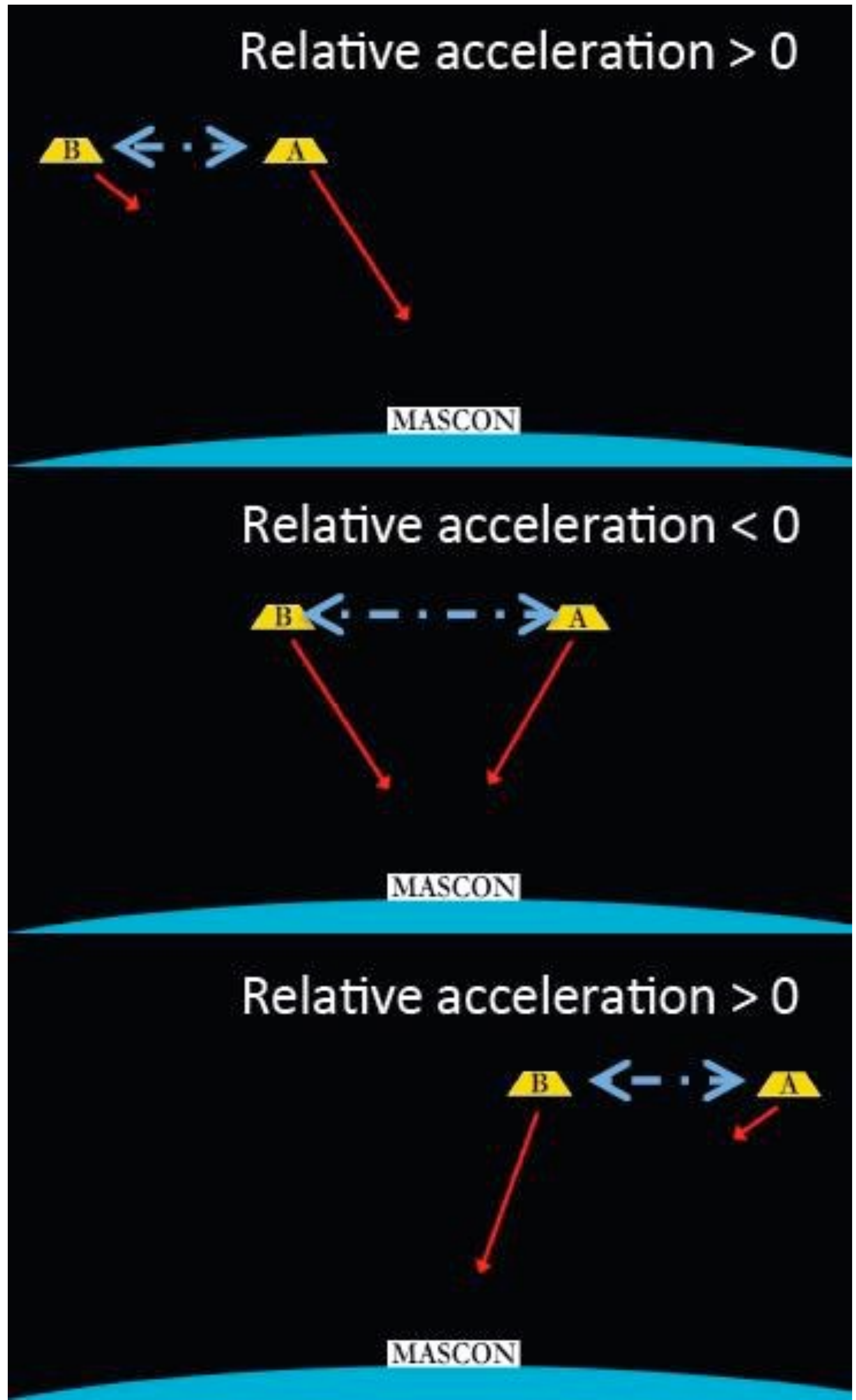
Antarctica: minor contribution

Main contribution: steric changes

The Prognosis: Anticipating Surprises

Gravity Recovery and Climate Experiment (GRACE)





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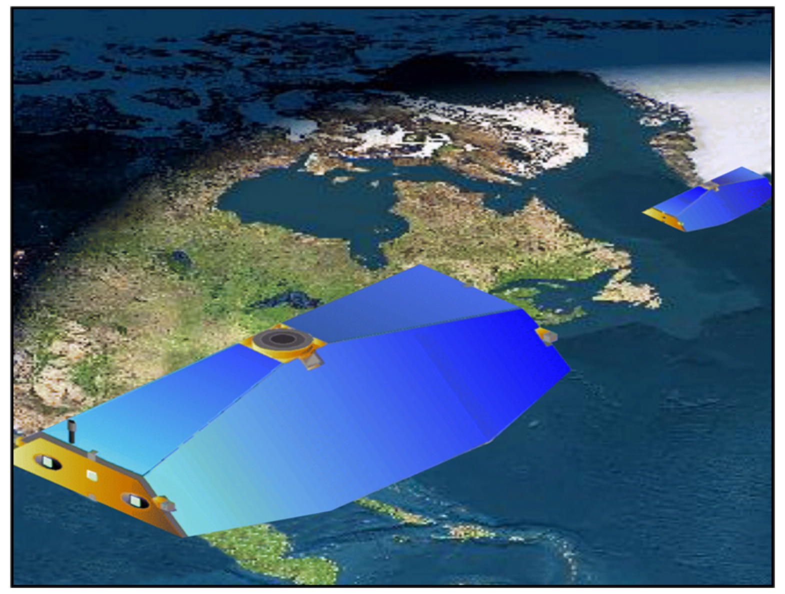
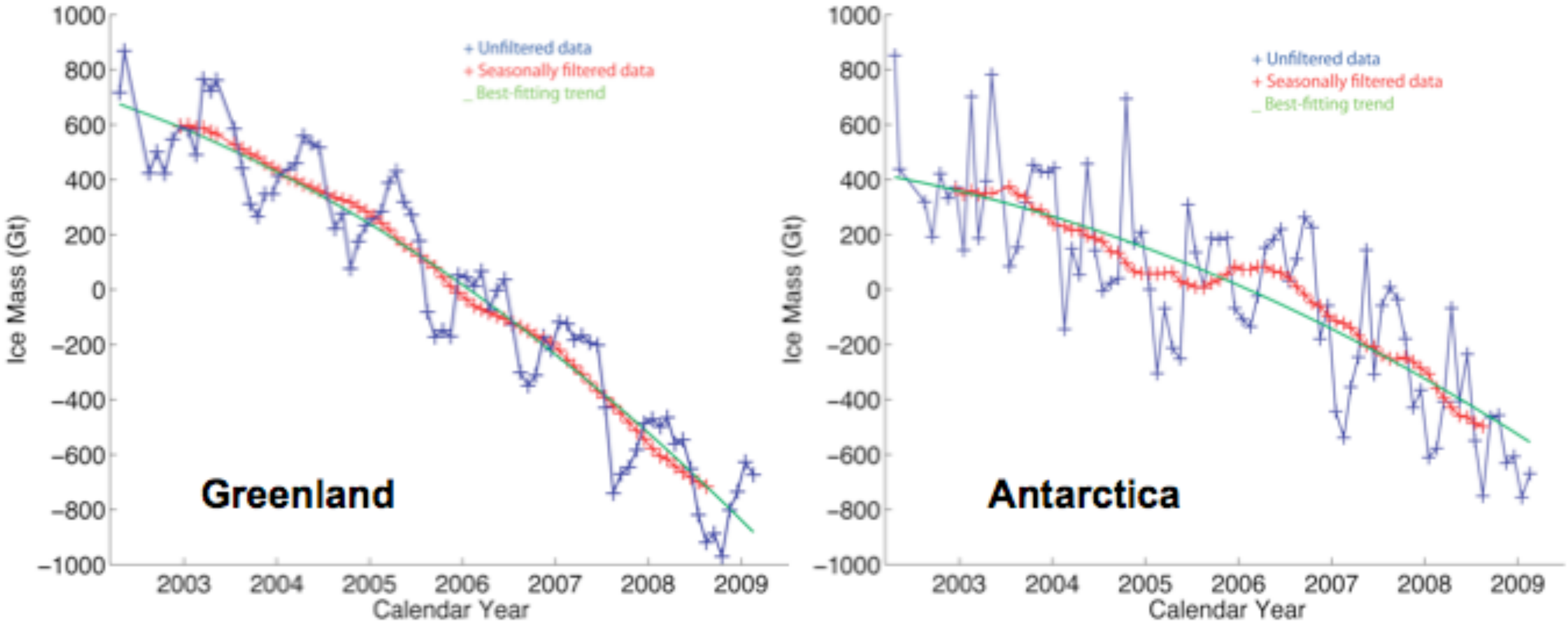


Greenland and Antarctica

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

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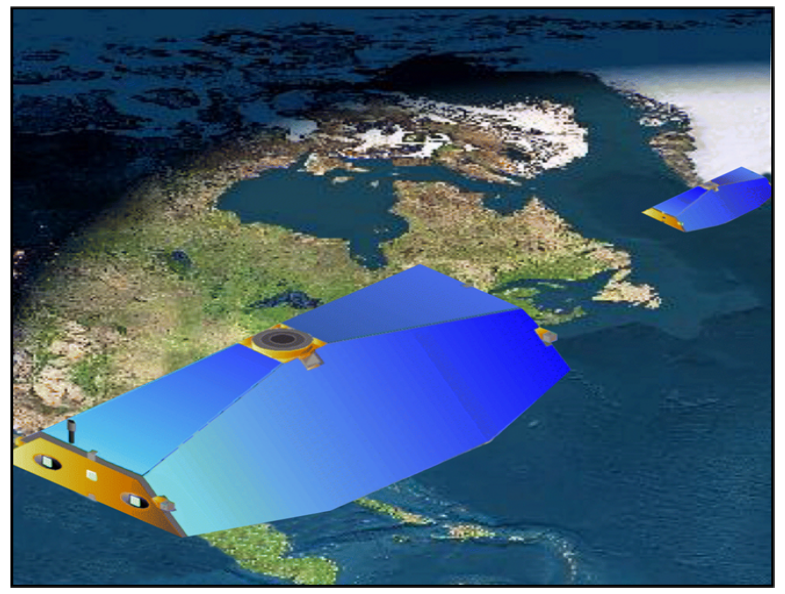

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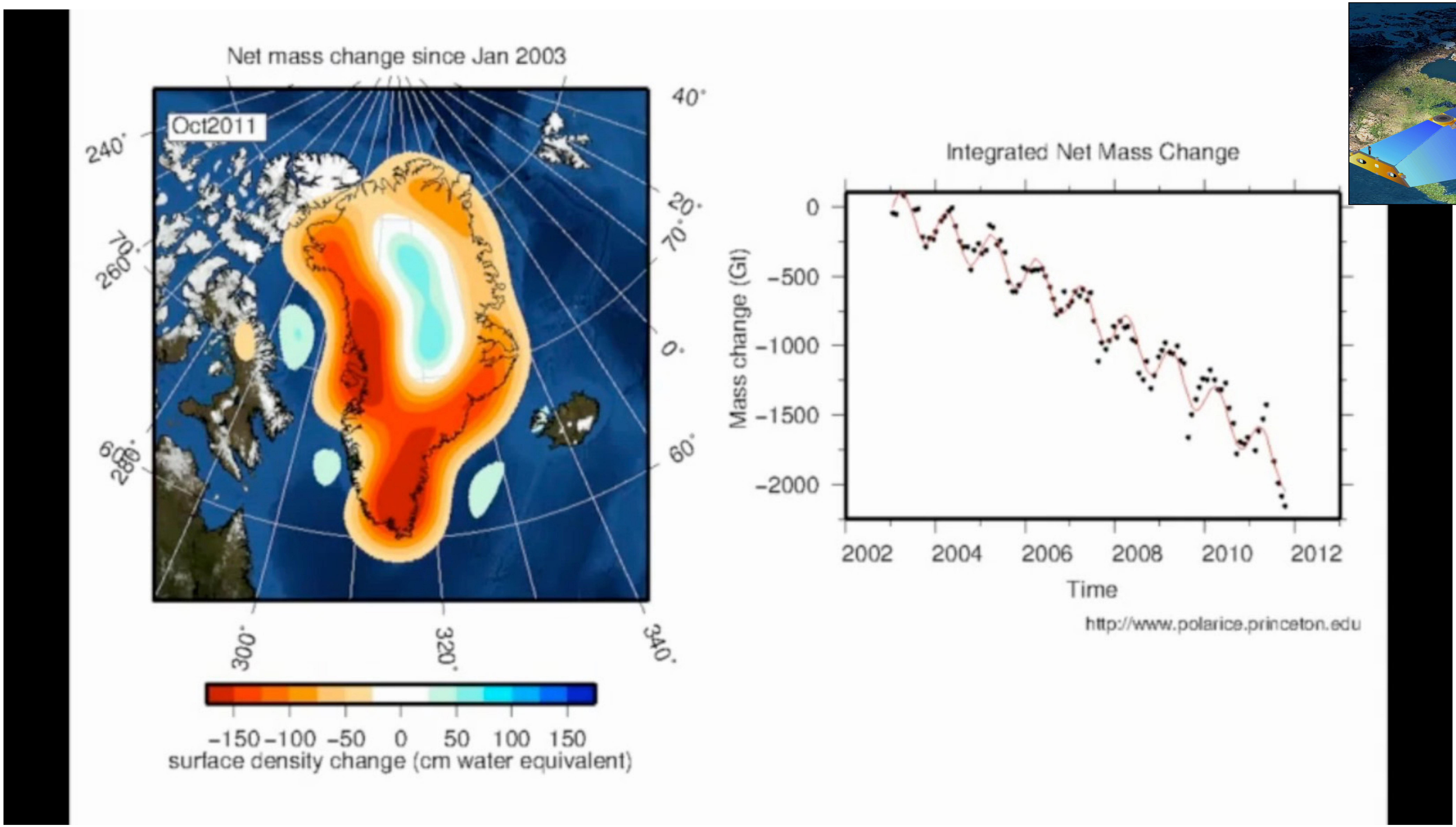

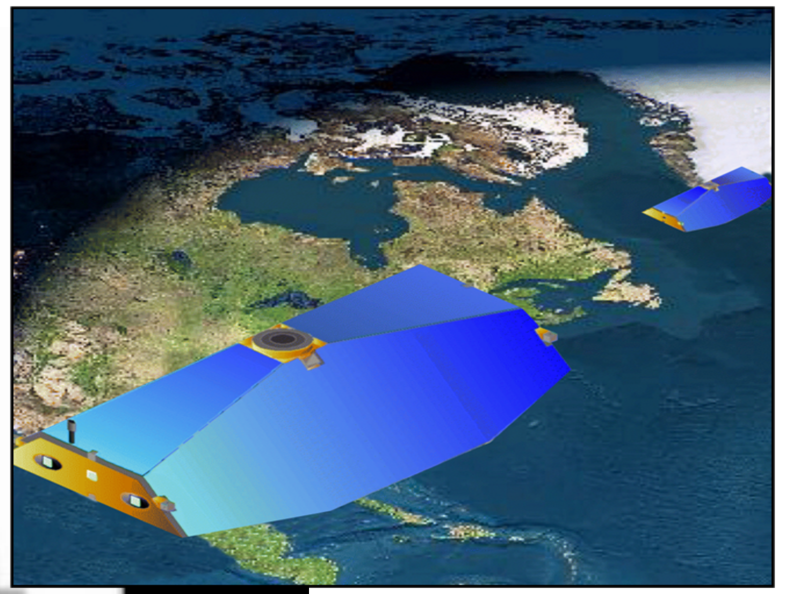

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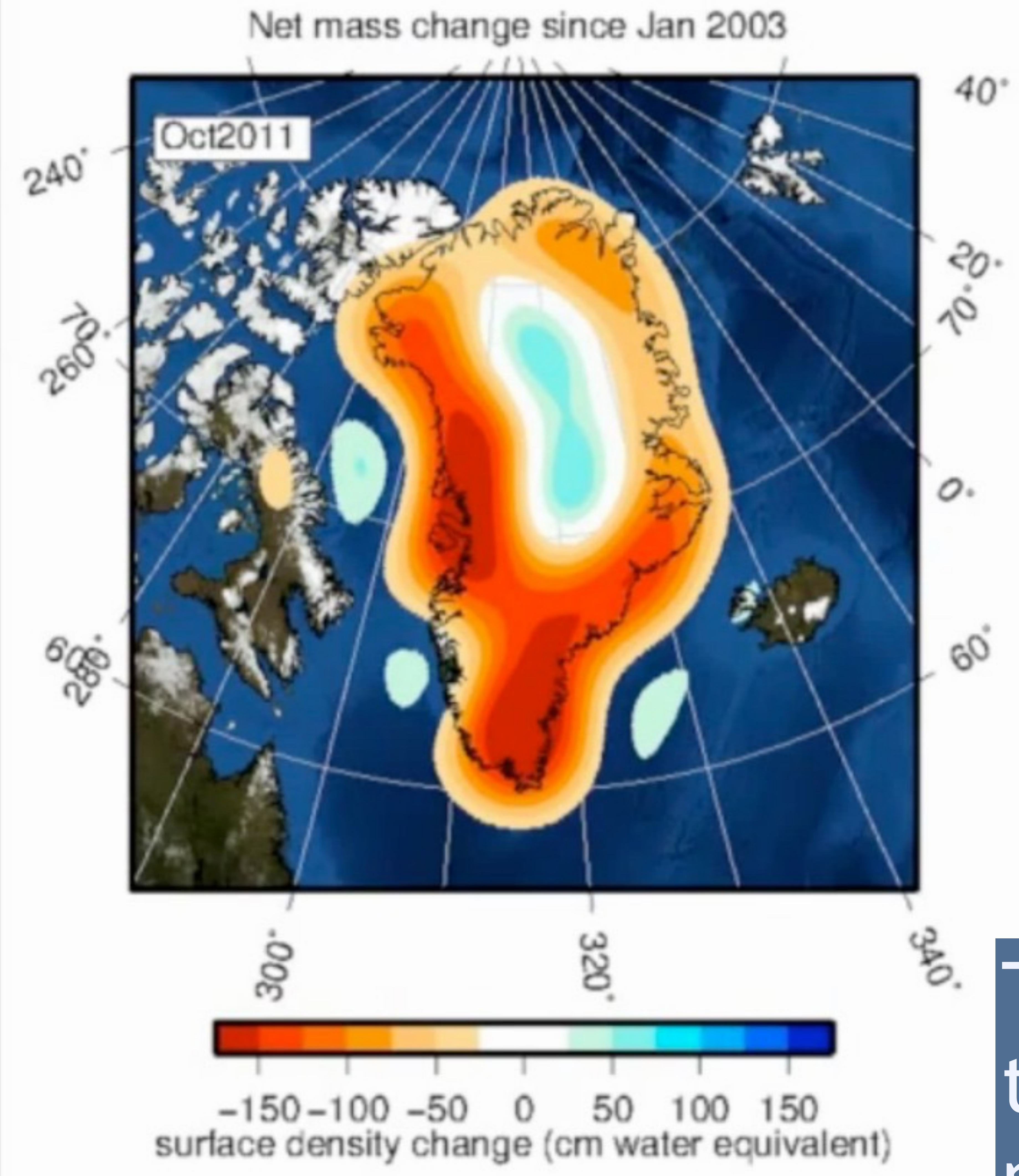
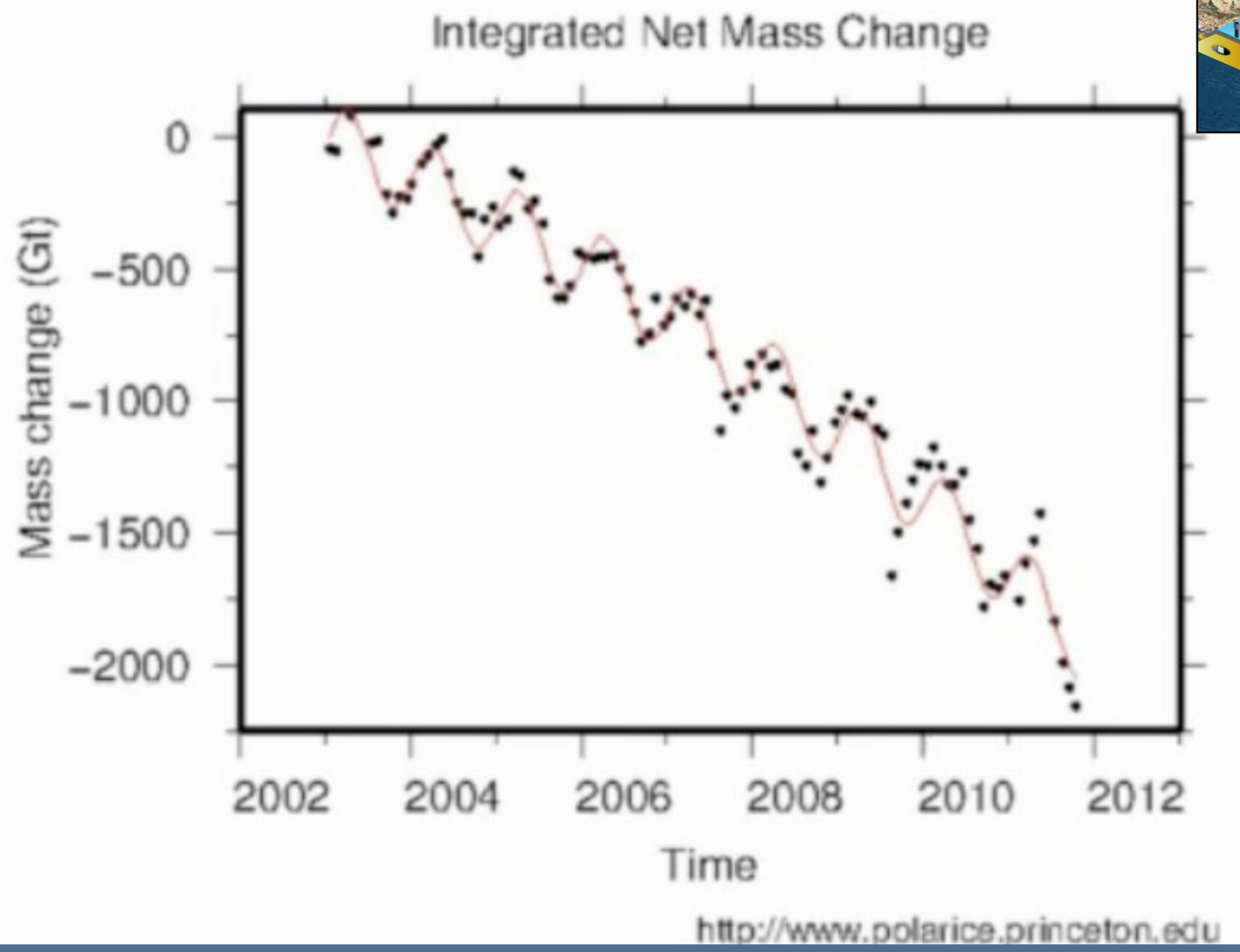
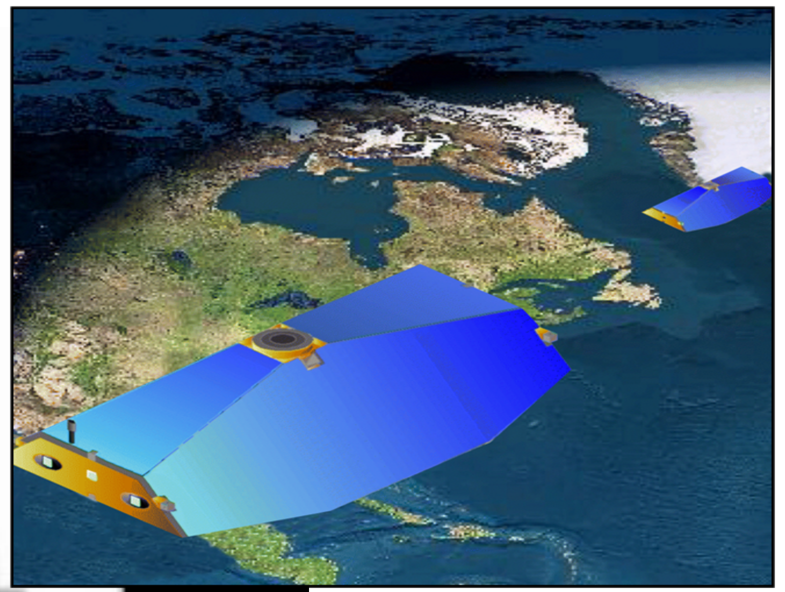


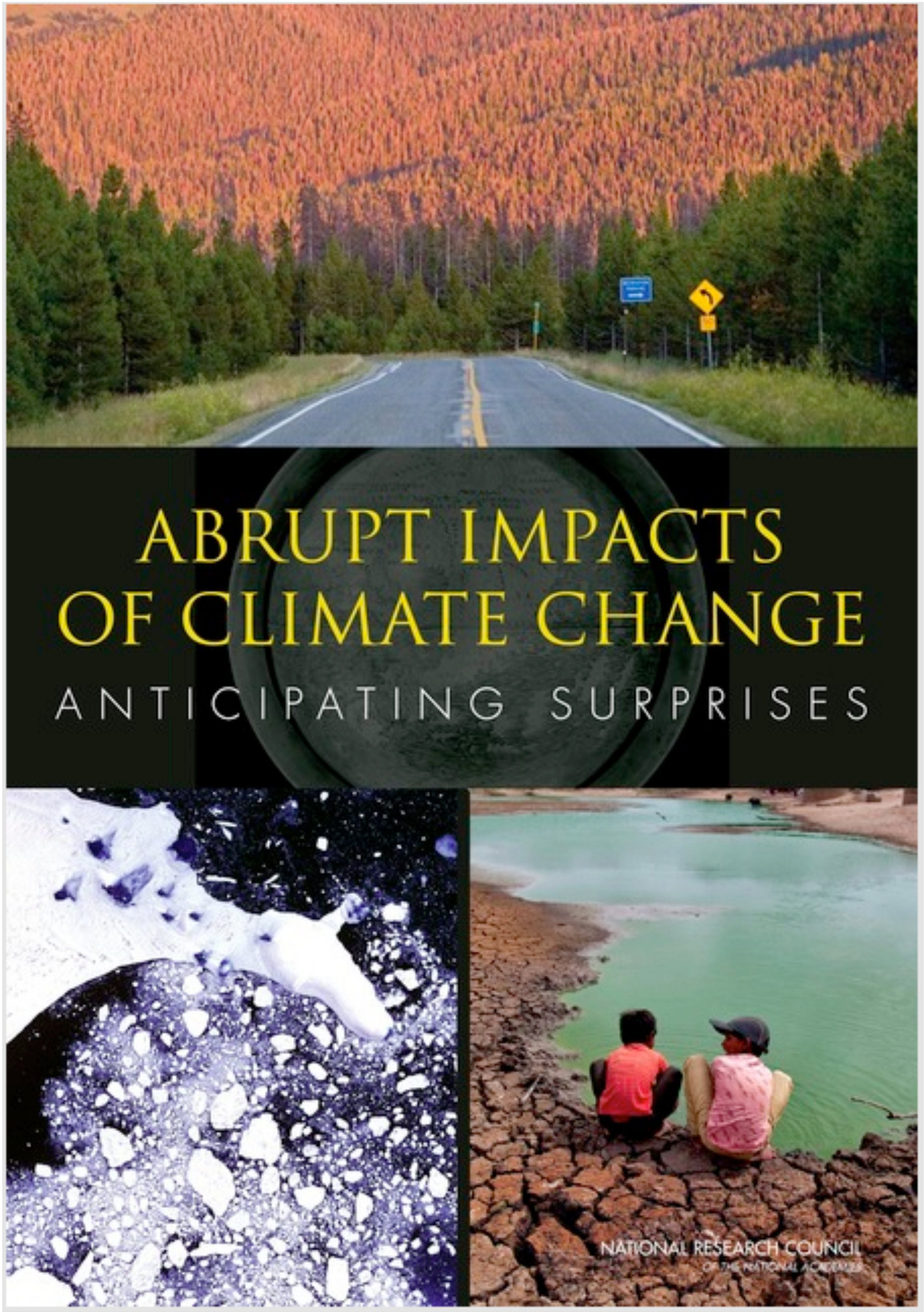




The last 12 years of observing the ice sheets have revealed many surprises …

The Prognosis: Anticipating Surprises

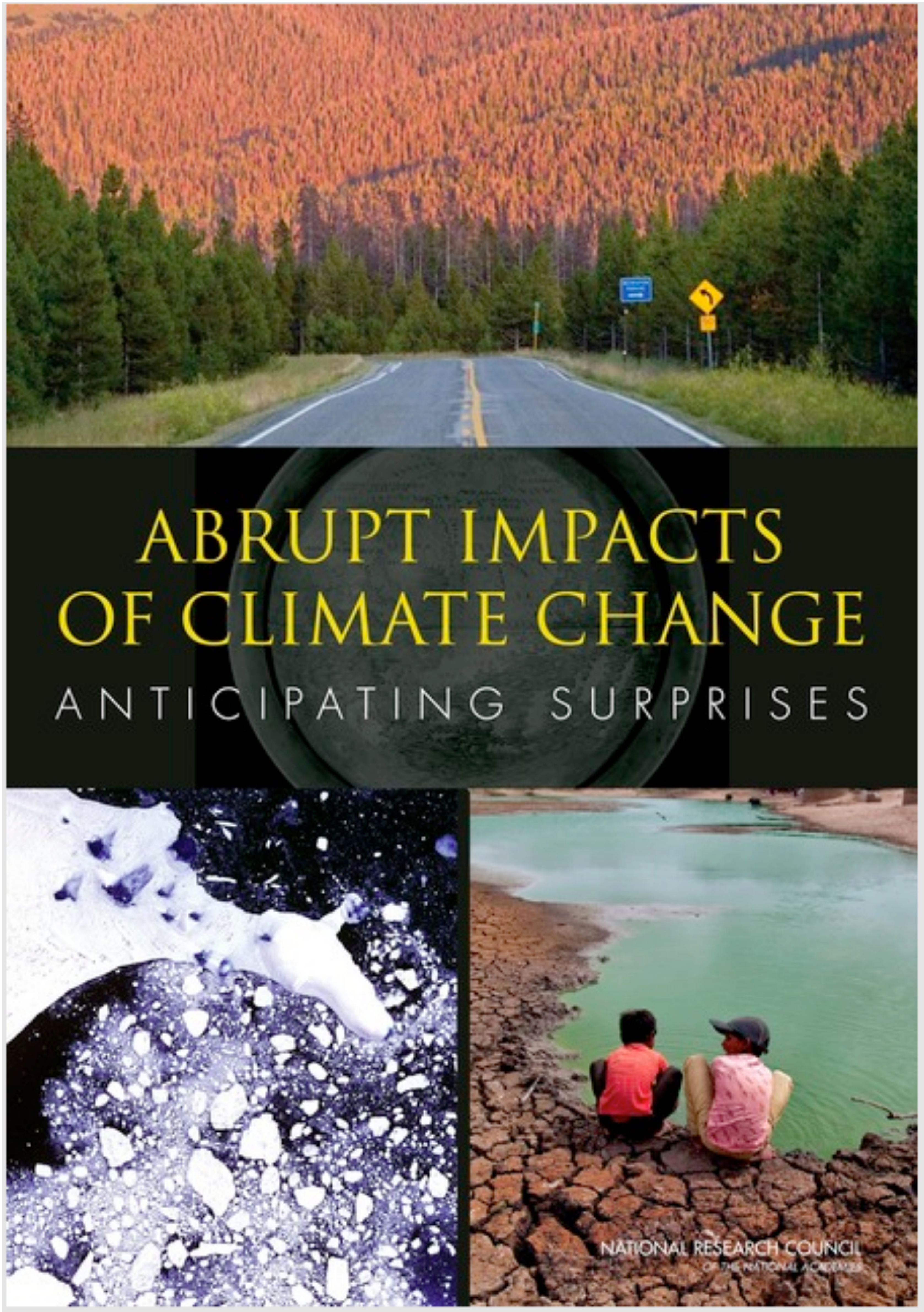
The Prognosis: Anticipating Surprises



National Research Council in 2013:

There is the potential for surprises and new extremes ...

The Prognosis: Anticipating Surprises



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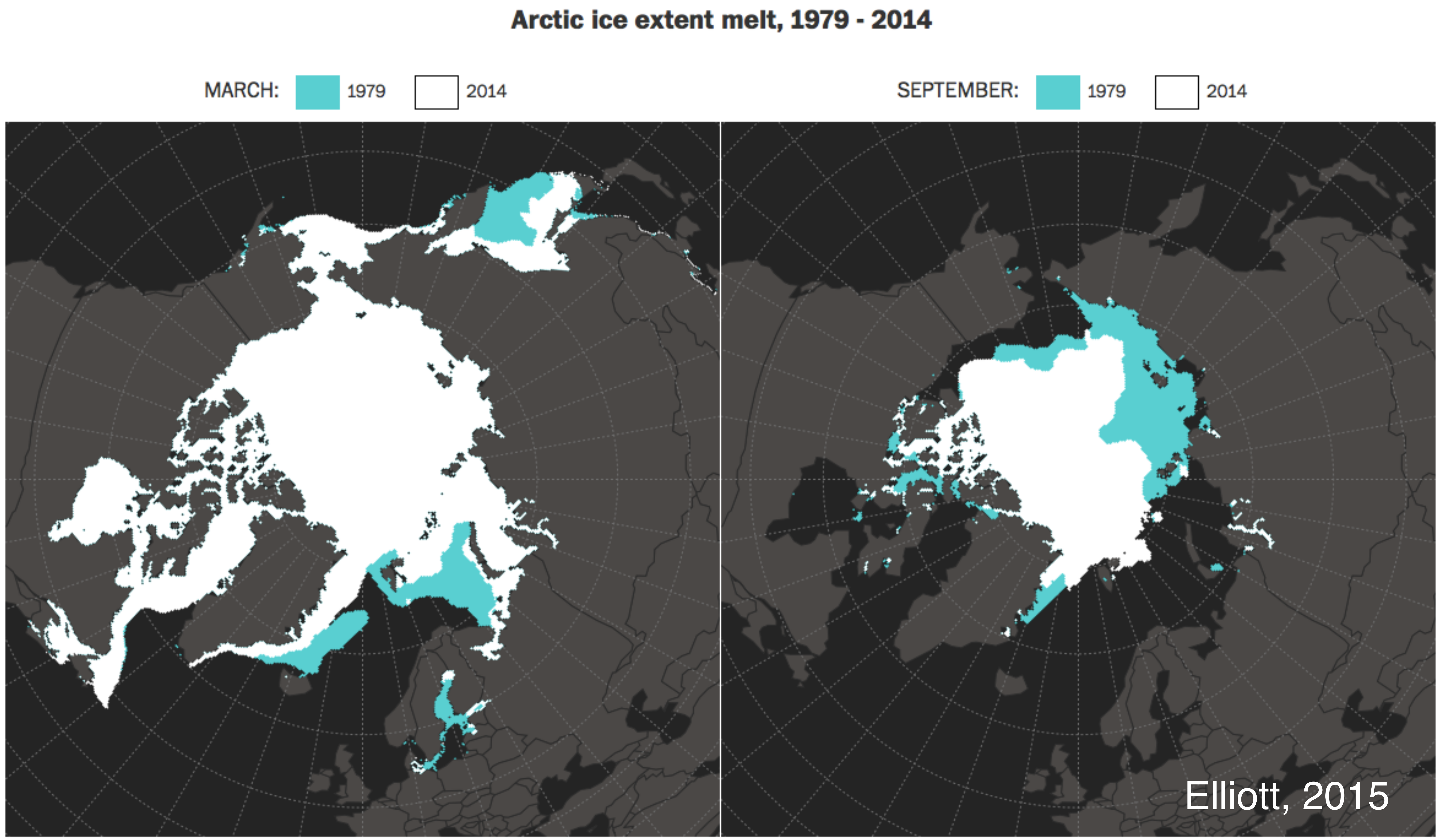
Already happening: Disappearance of late-summer Arctic sea ice



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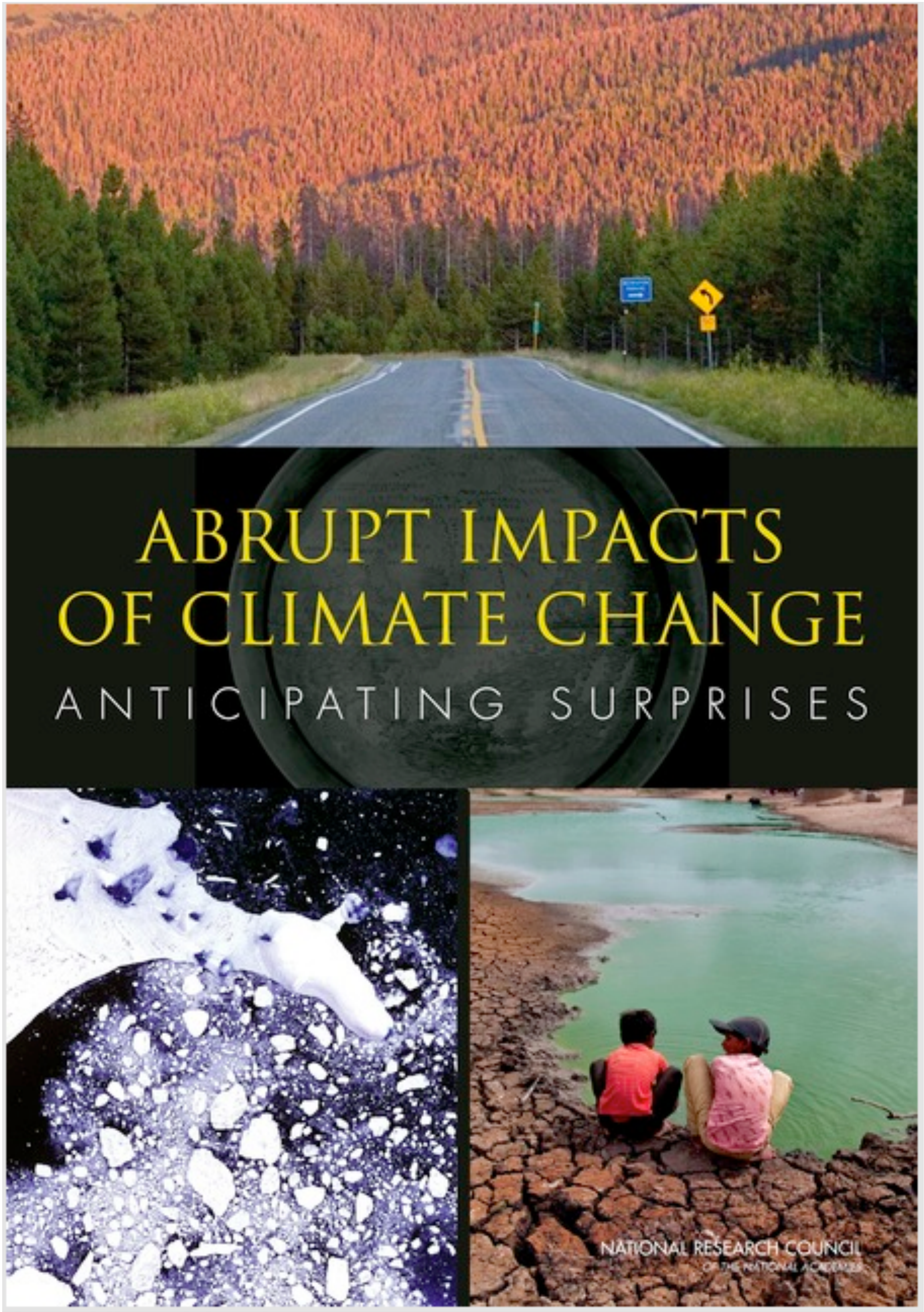

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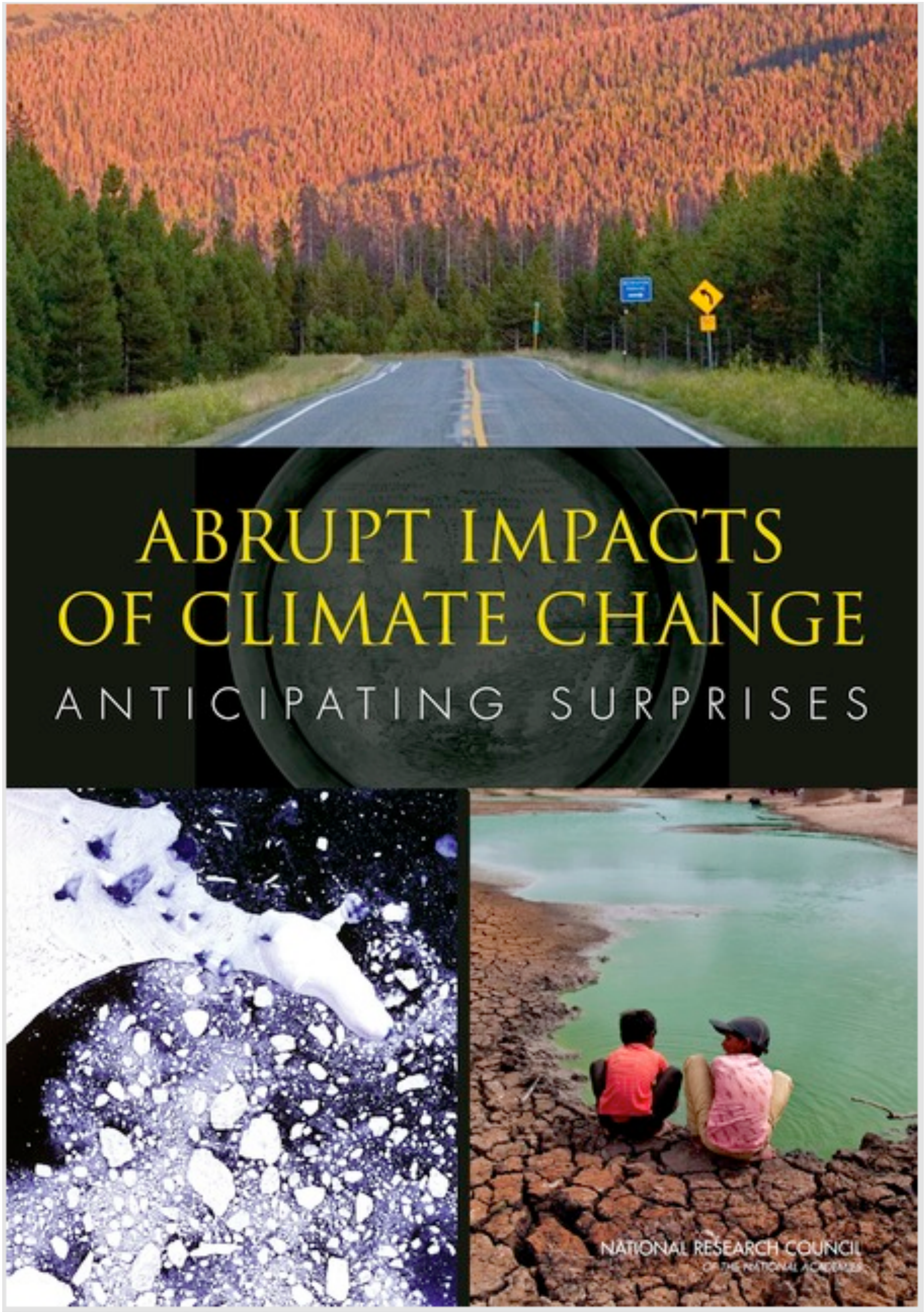

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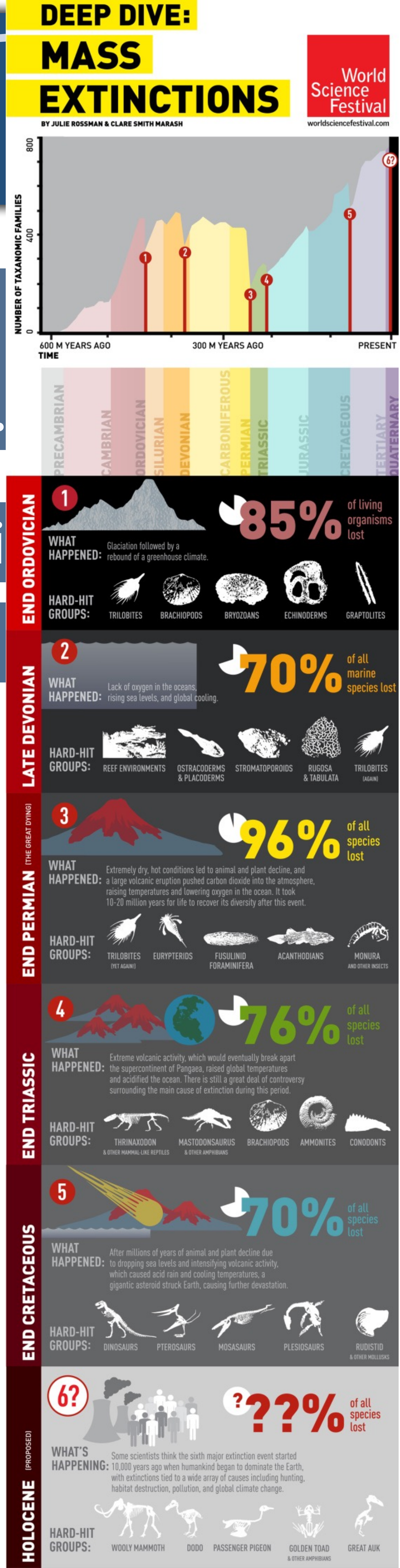
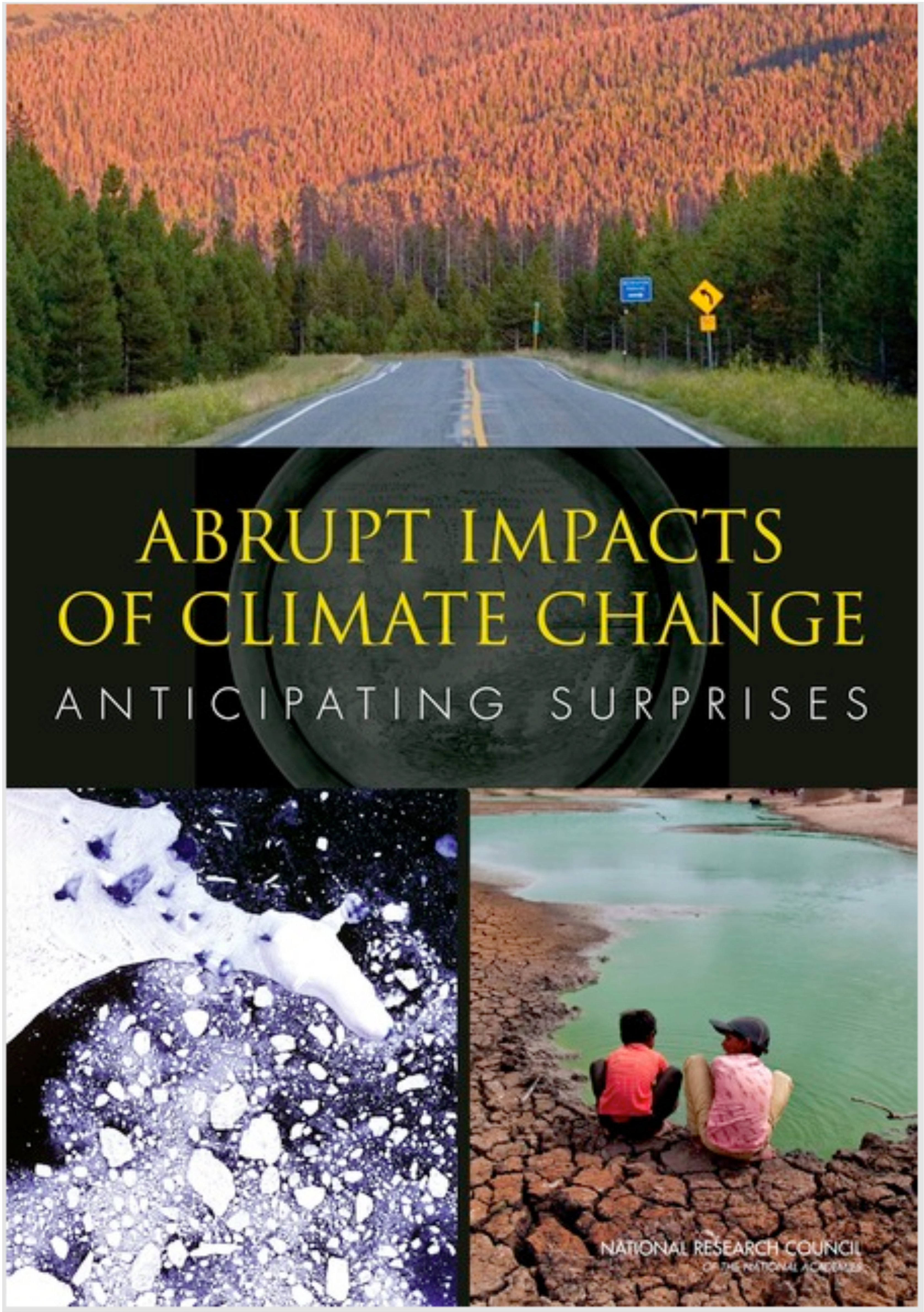


Rossman&Marash (2014)

The Prognosis: Anticipating Surprises



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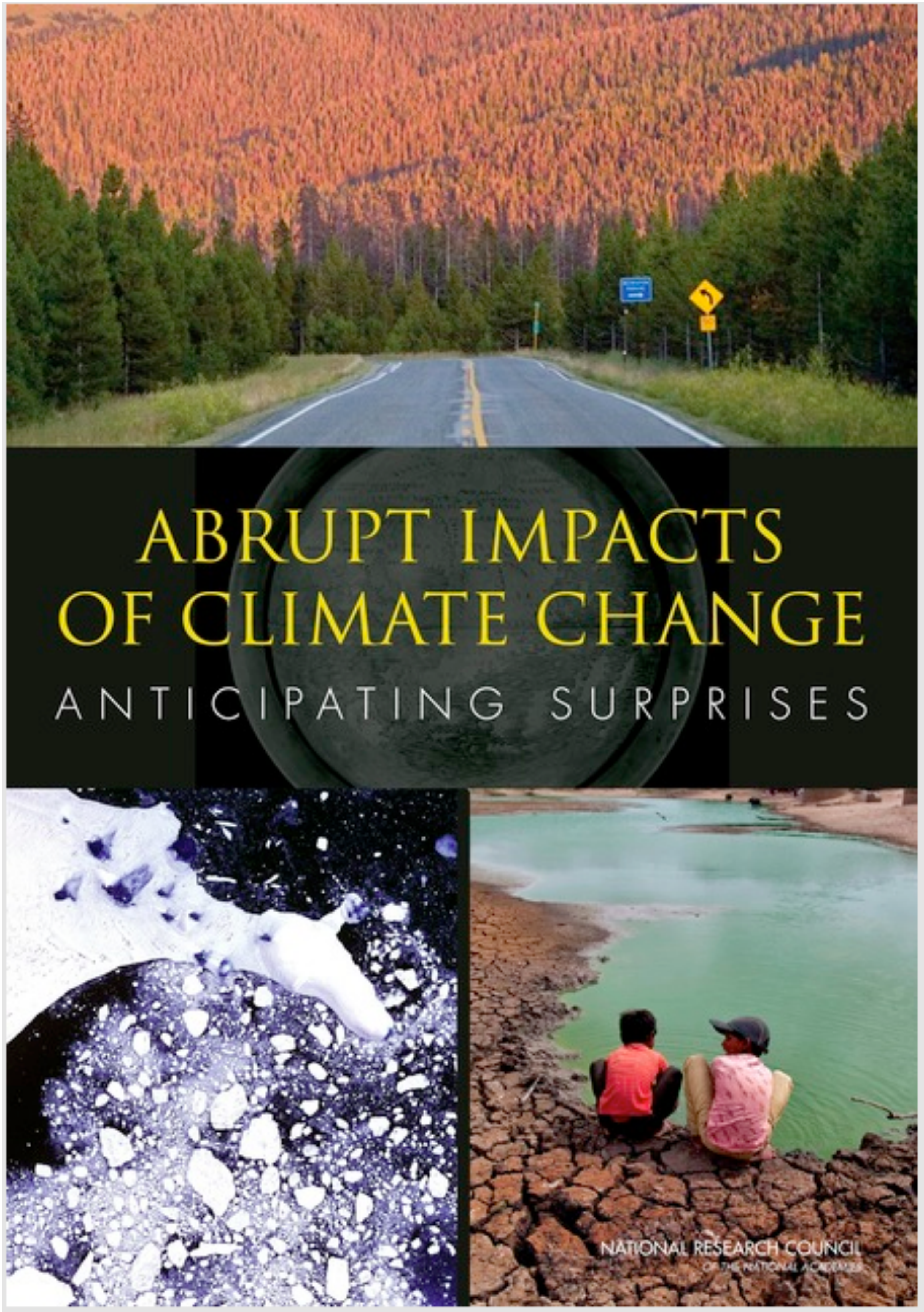

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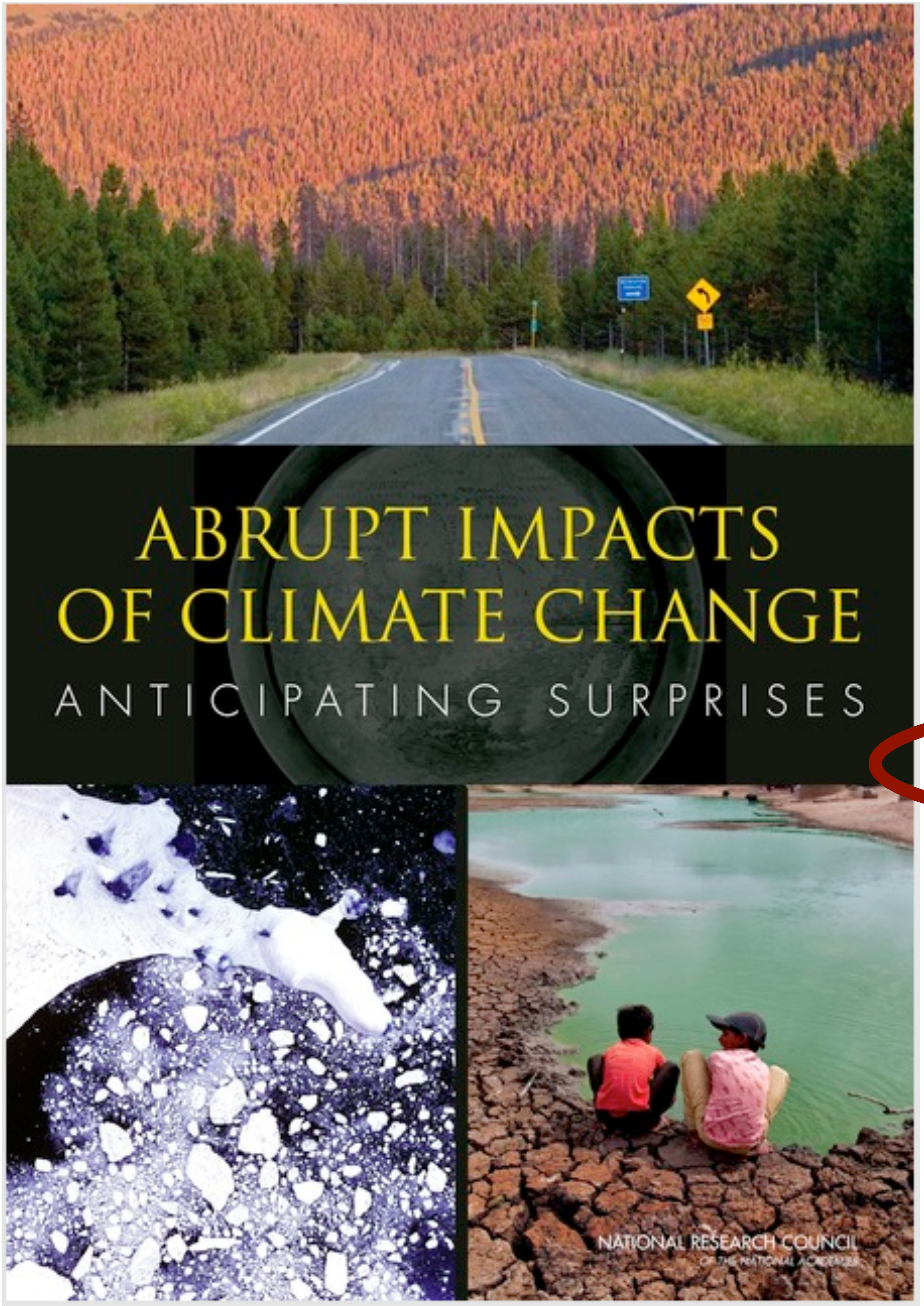
Greenland ice sheet: abrupt changes very unlikely in the 21st century

West Antarctic Ice Sheet: up to 4.8 m sea level rise; abrupt changes unlikely in the 21st century

Most likely (low-probability) rapid impact: ocean acidification

The Prognosis: Anticipating Surprises



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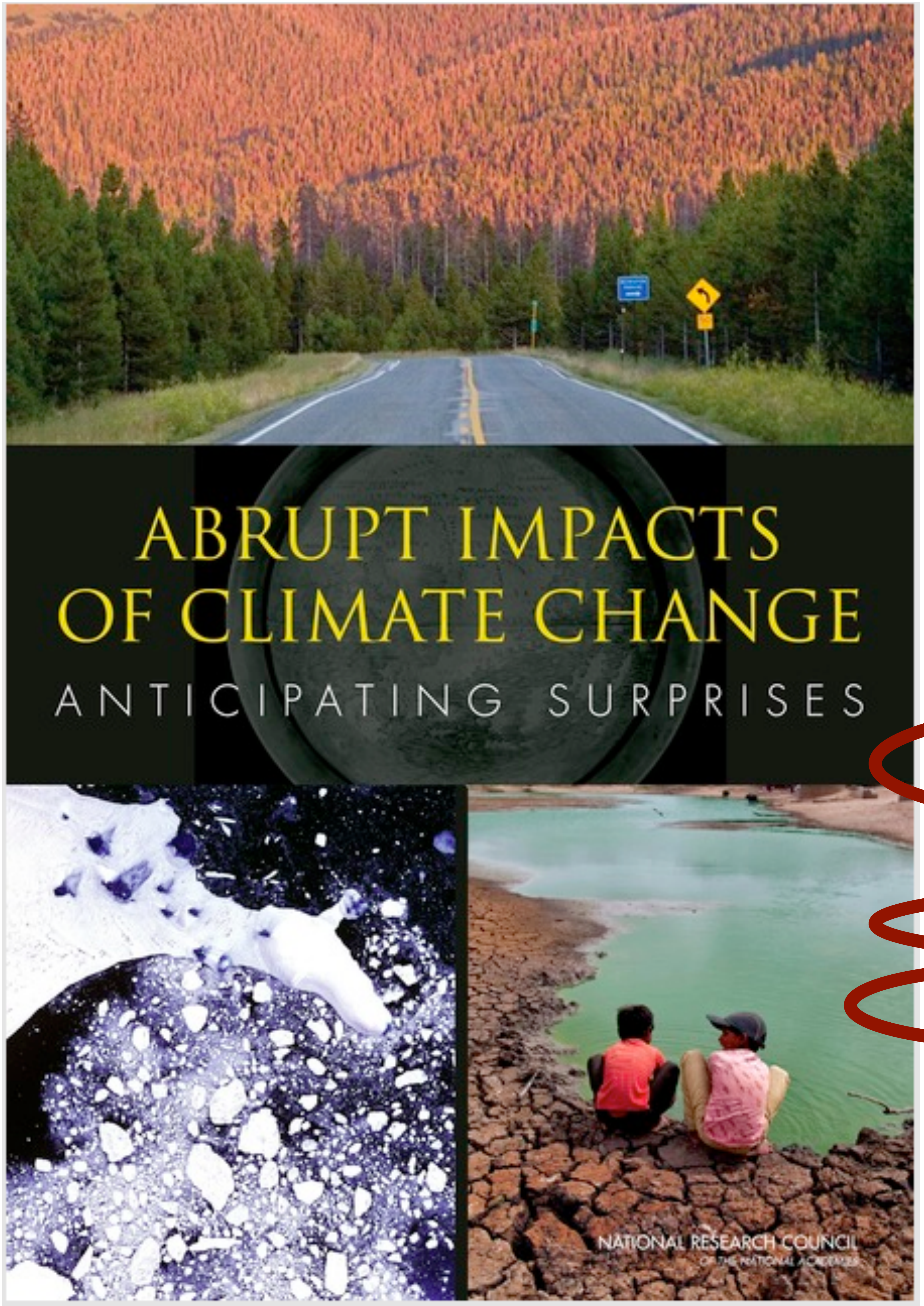

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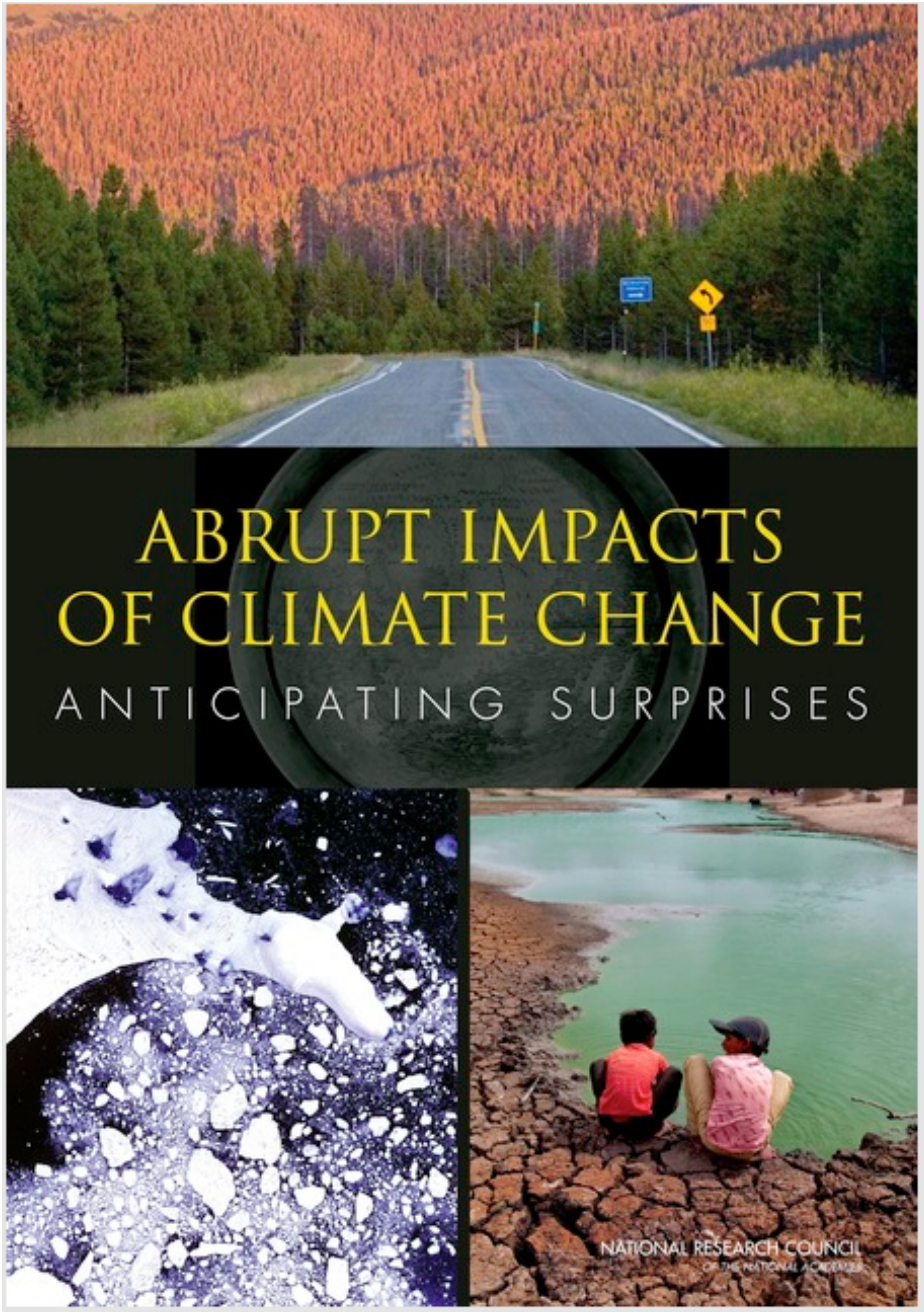

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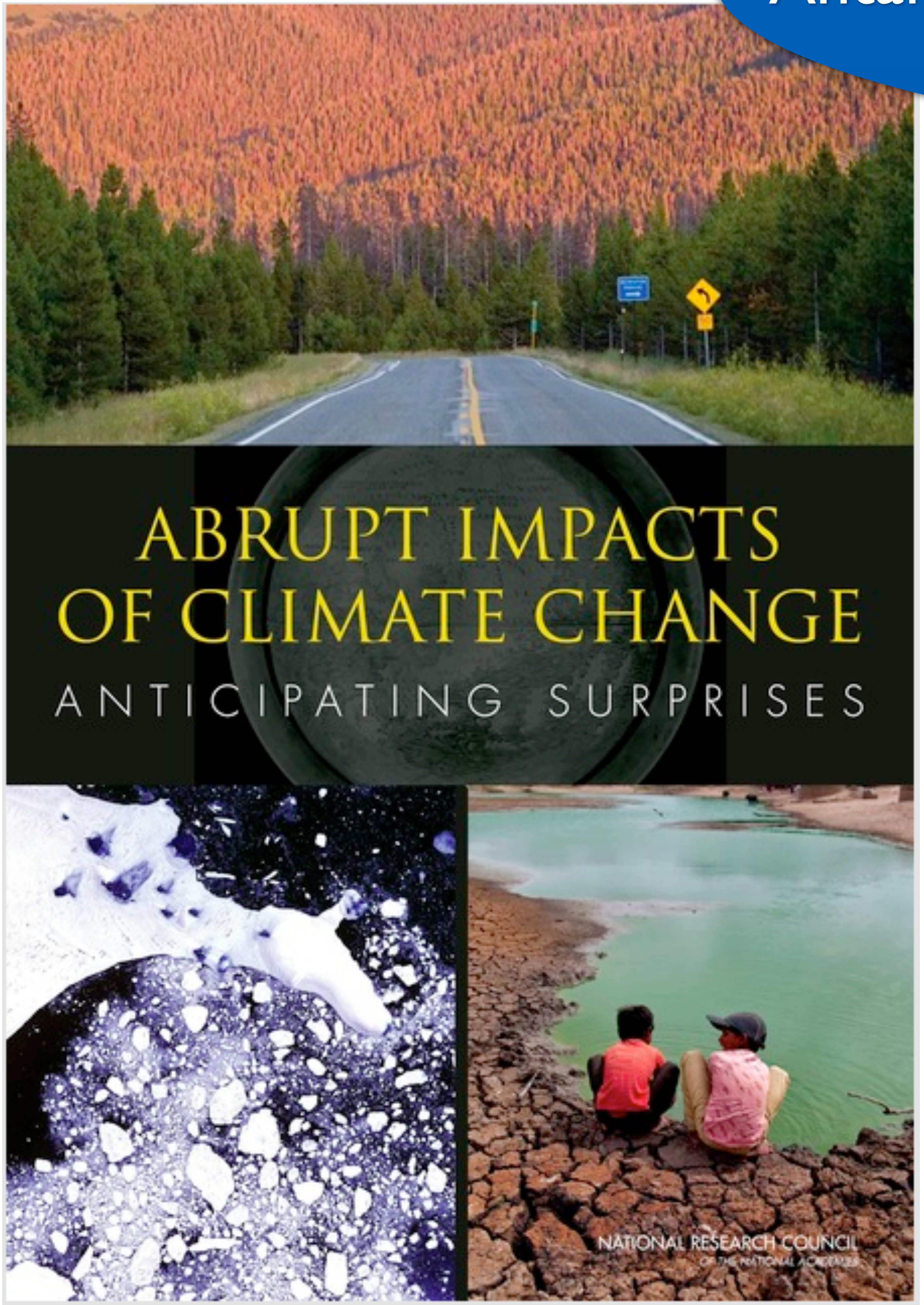

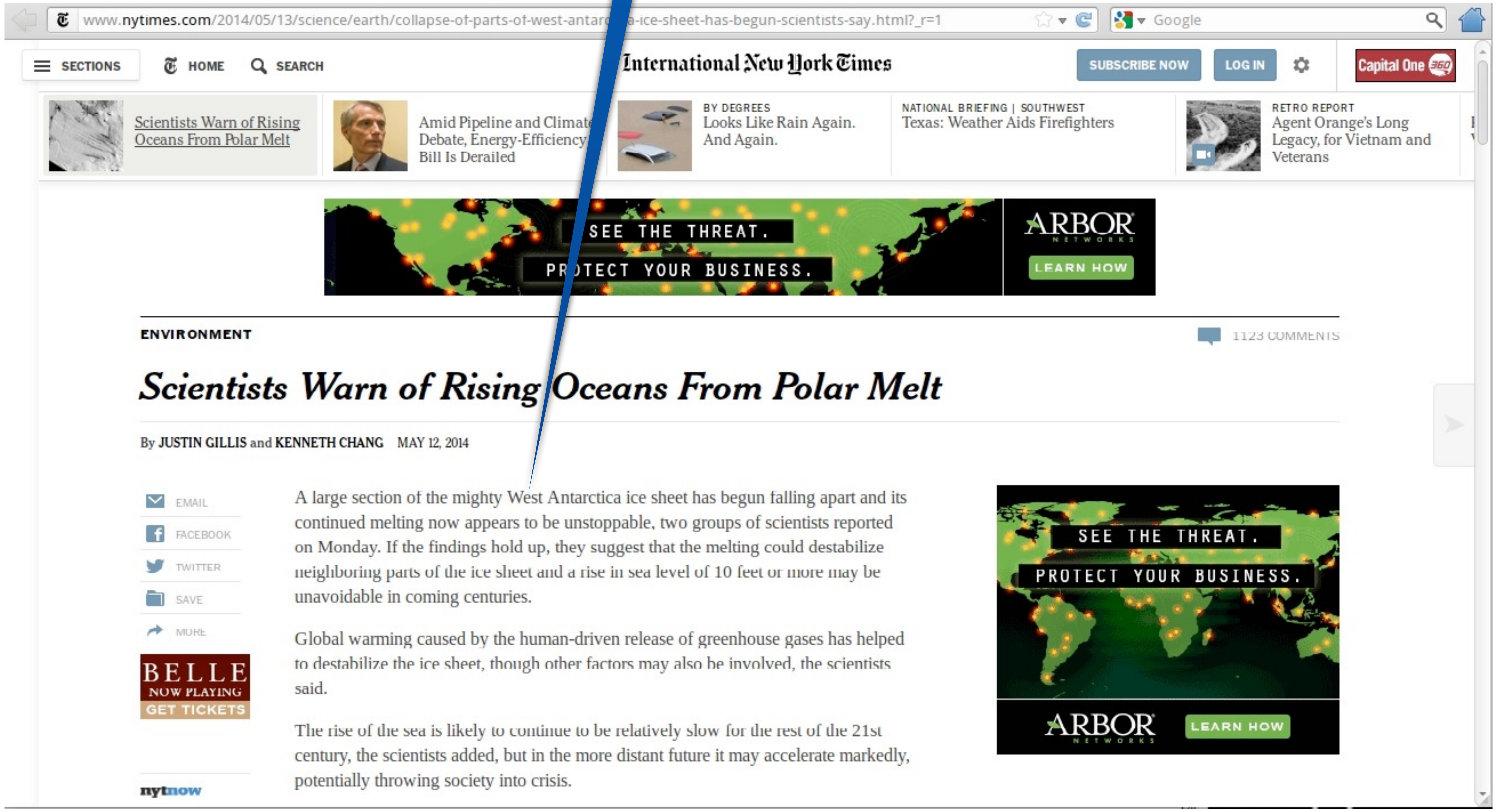

www.nytimes.com/2014/05/13/science/earth/collapse-of-parts-of-west-antarctica-ice-sheet-has-begun-scientists-say.html?_r=1

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ENVIRONMENT

1123 COMMENTS

Scientists Warn of Rising Oceans From Polar Melt

By JUSTIN GILLIS and KENNETH CHANG MAY 12, 2014

EMAIL FACEBOOK TWITTER SAVE MORE

A large section of the mighty West Antarctica ice sheet has begun falling apart and its continued melting now appears to be unstoppable, two groups of scientists reported on Monday. If the findings hold up, they suggest that the melting could destabilize neighboring parts of the ice sheet and a rise in sea level of 10 feet or more may be unavoidable in coming centuries.

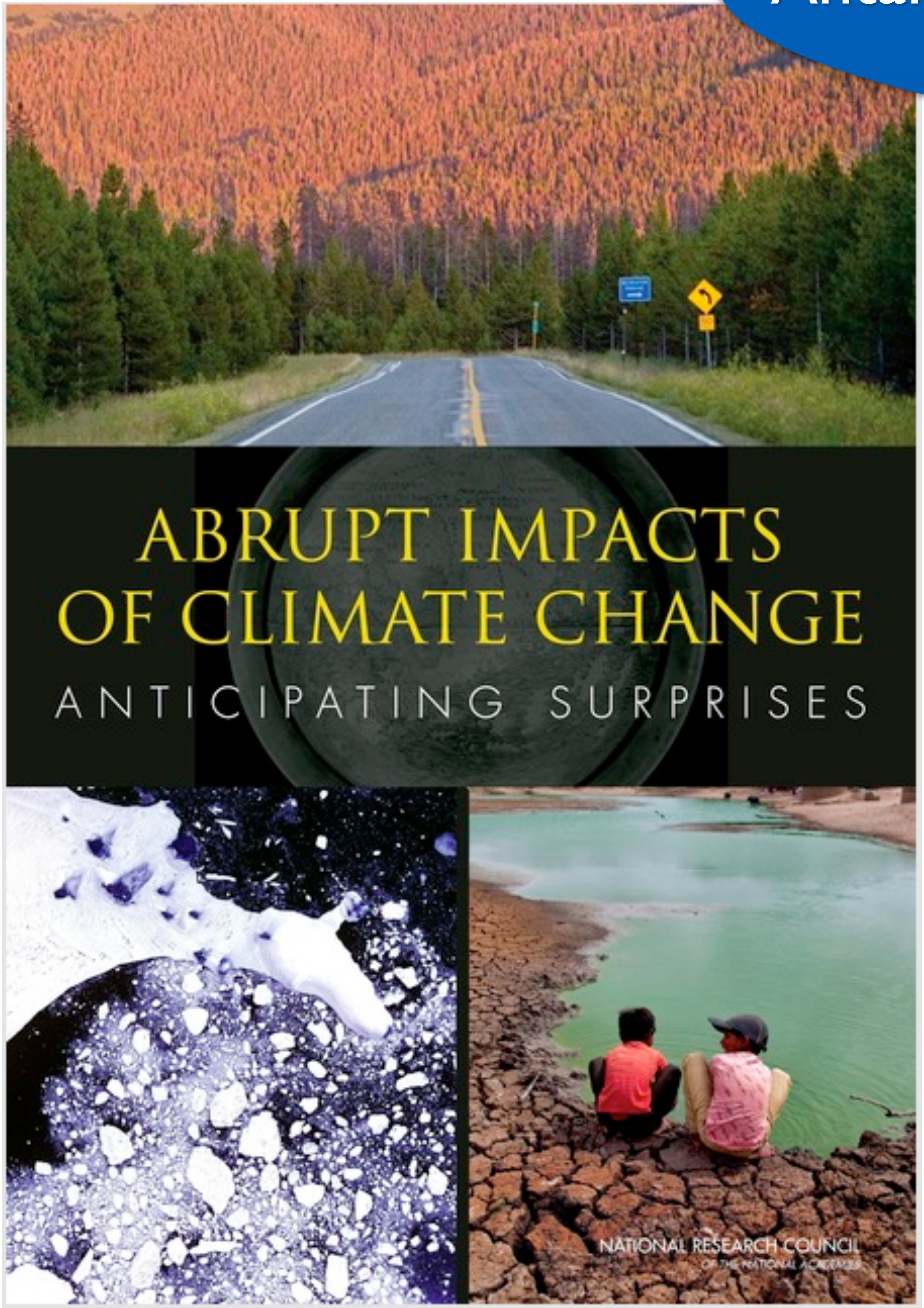
Global warming caused by the human-driven release of greenhouse gases has helped to destabilize the ice sheet, though other factors may also be involved, the scientists said.

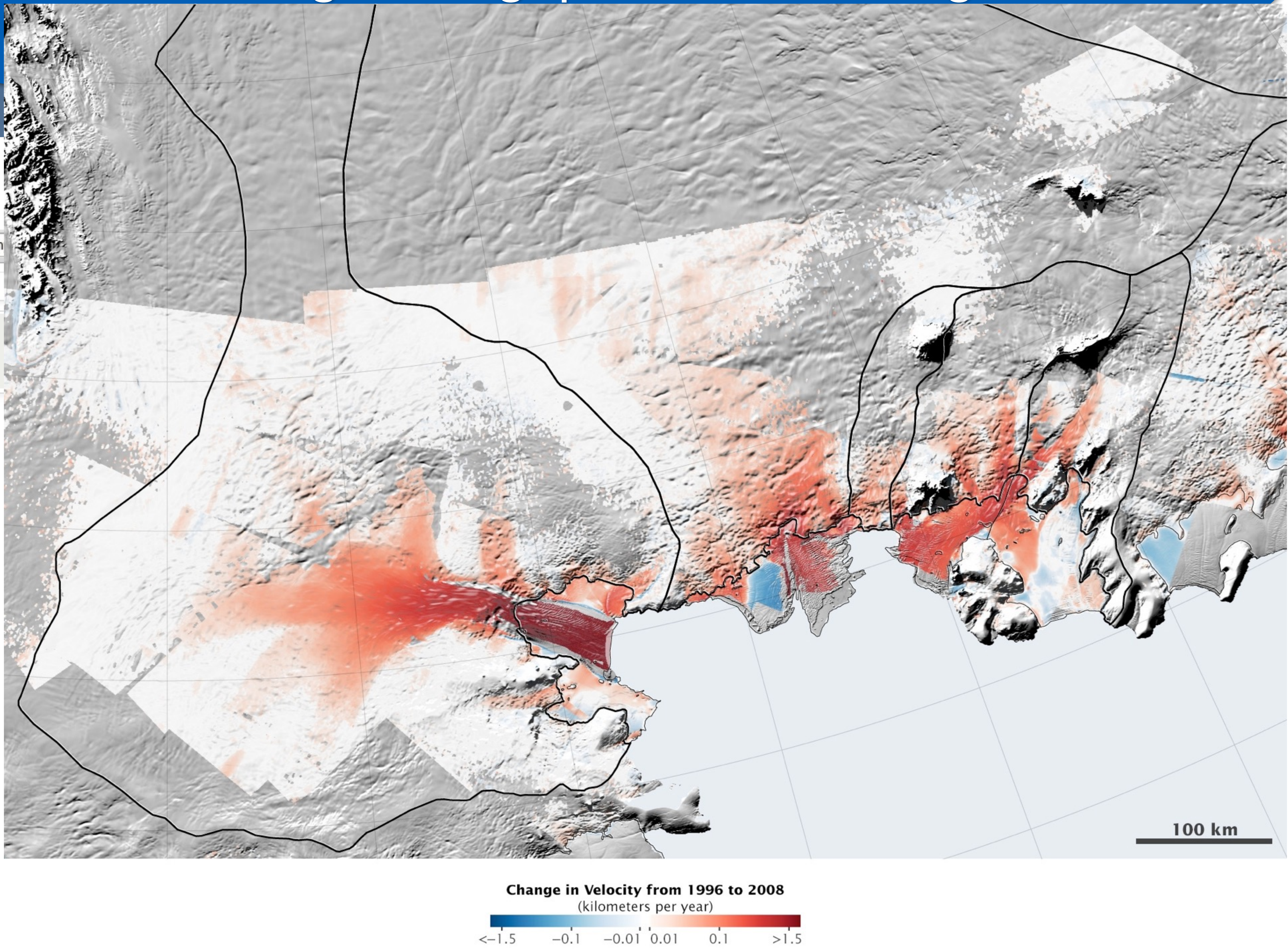
The rise of the sea is likely to continue to be relatively slow for the rest of the 21st century, the scientists added, but in the more distant future it may accelerate markedly, potentially throwing society into crisis.

nytnow

The Prognosis: Anti...

May 12, 2014: A large section of the mighty West Antarctic ice sheet has begun falling apart ... That's enough ice to raise





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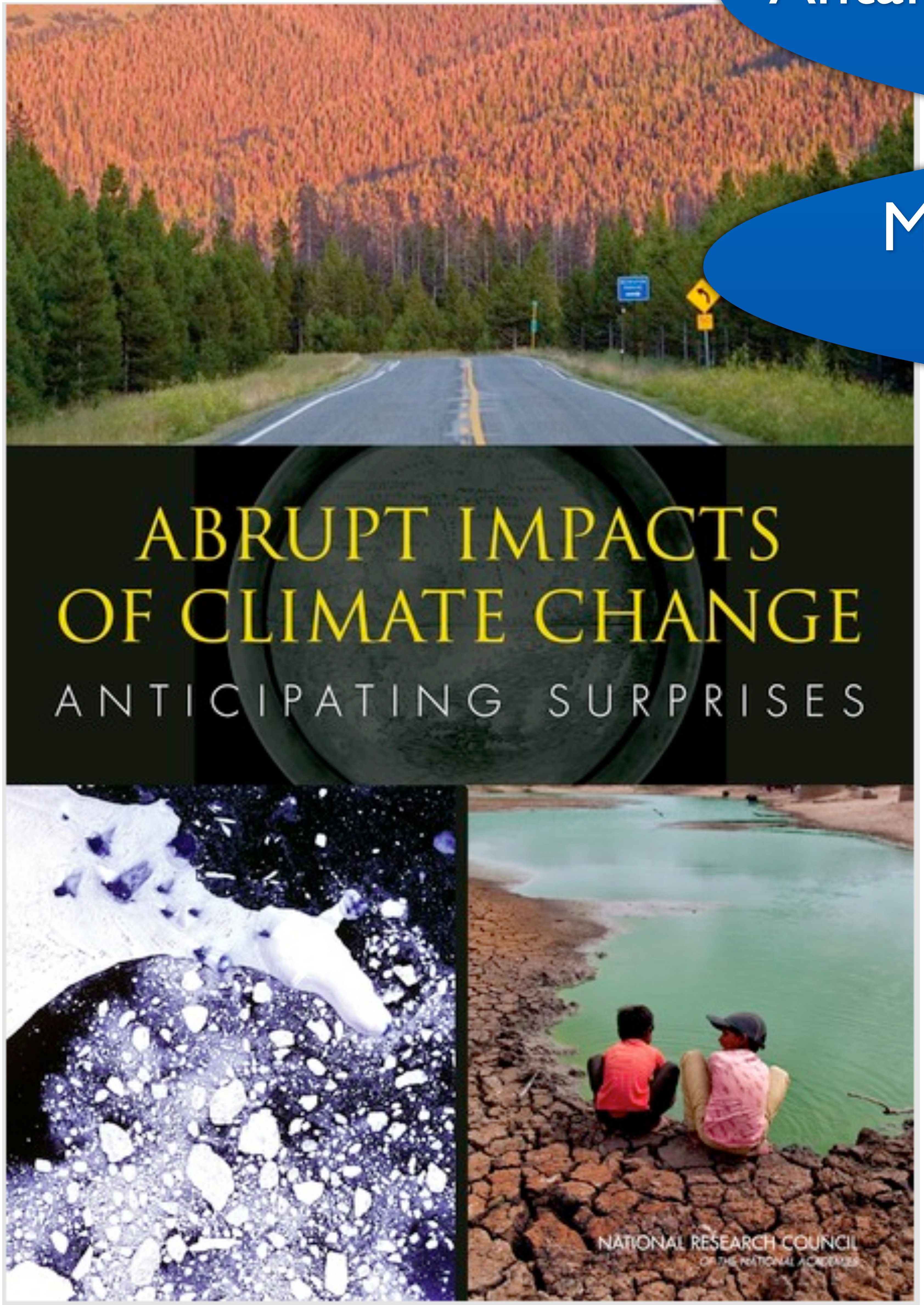
May 18, 2014: The glaciers of Greenland are likely to retreat faster and further inland than anticipated ....



Greenland will be far greate

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

Irvine, Calif. – Greenland's icy reaches are far more vulnerable to w 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 unchart eep valleys stretching for dozens of miles under the Greenland Ice Sheet.

The bedrock canyons sit well below sea level, meaning that a ubtropical 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 accelerat 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 top 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.

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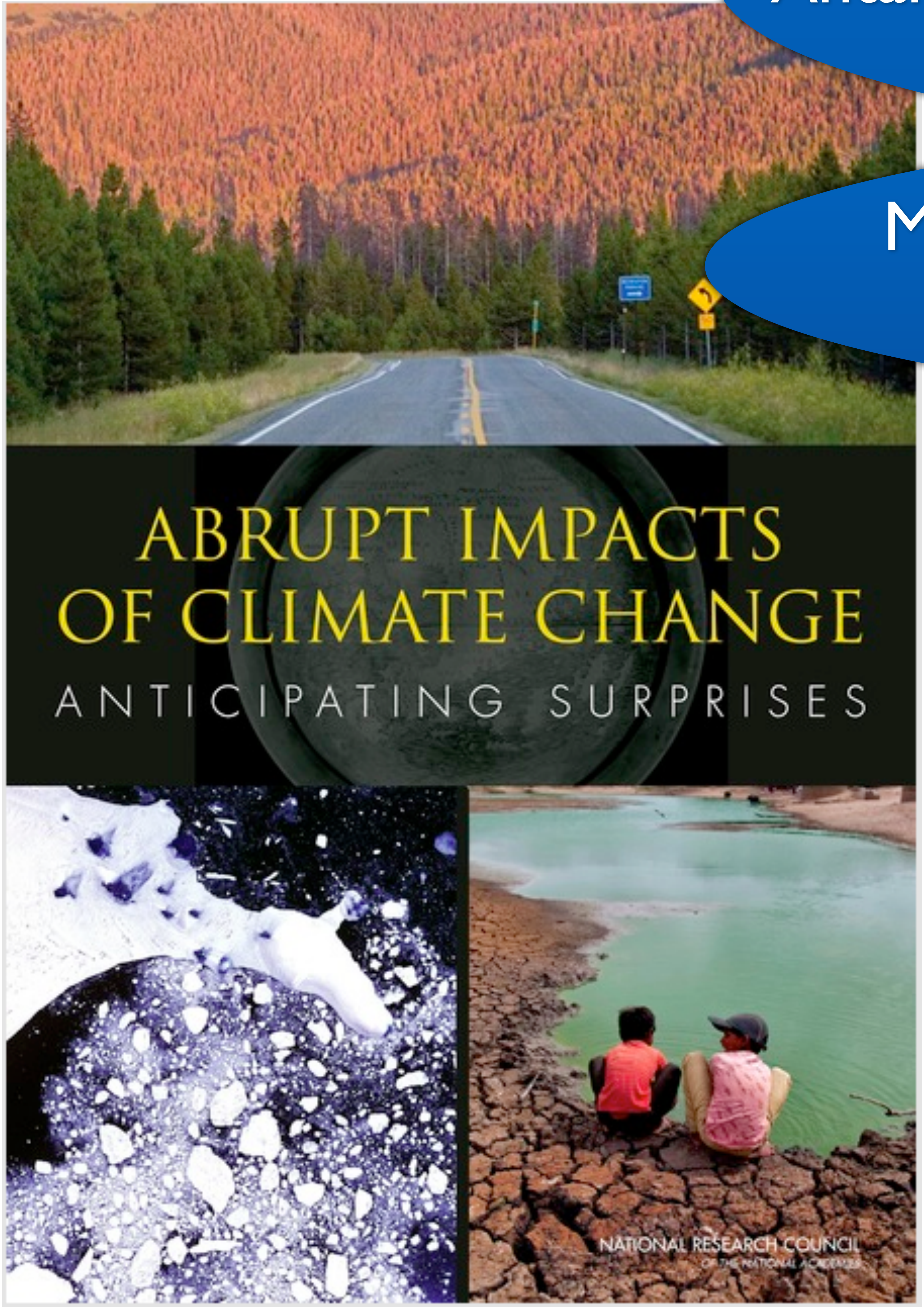

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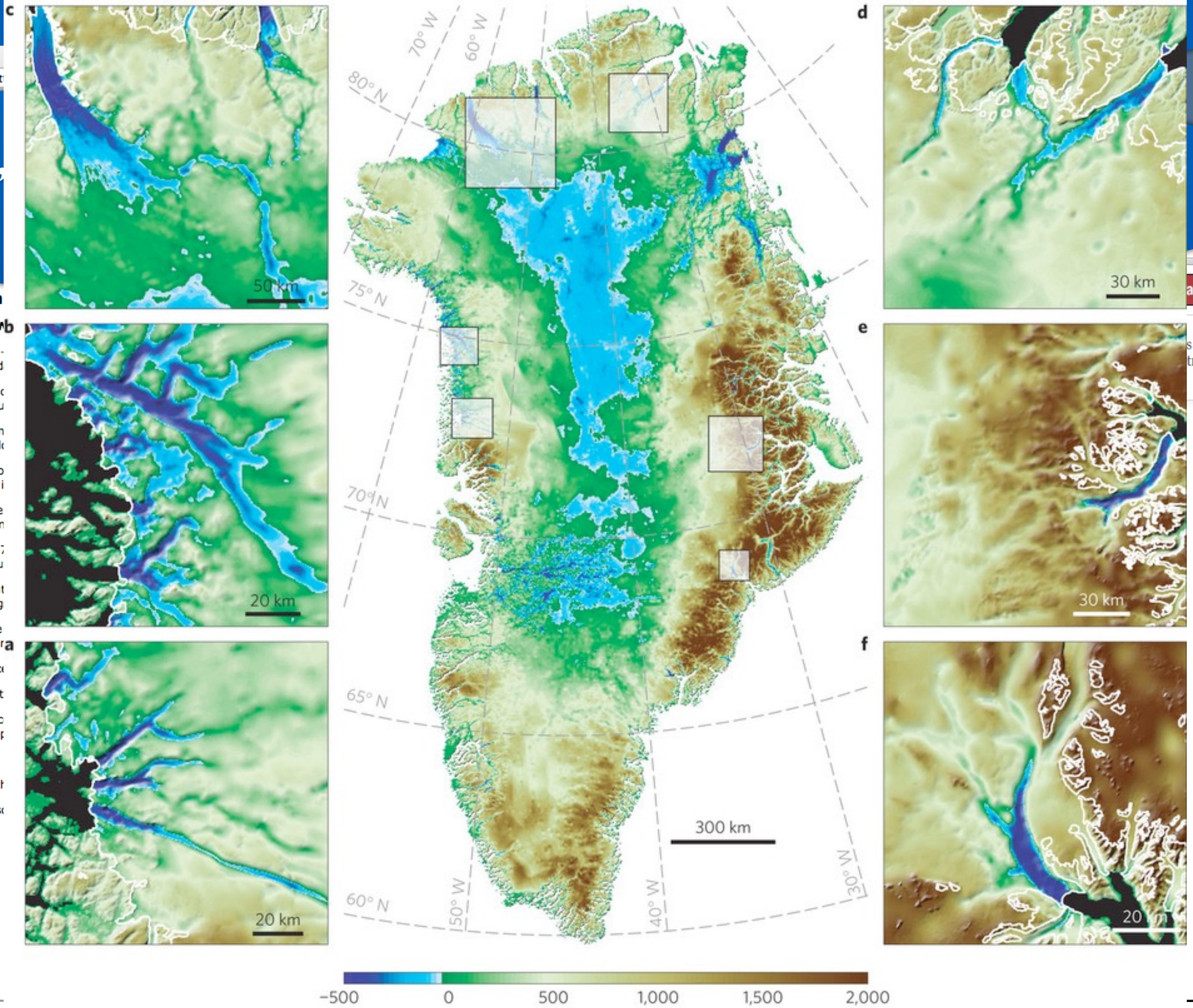

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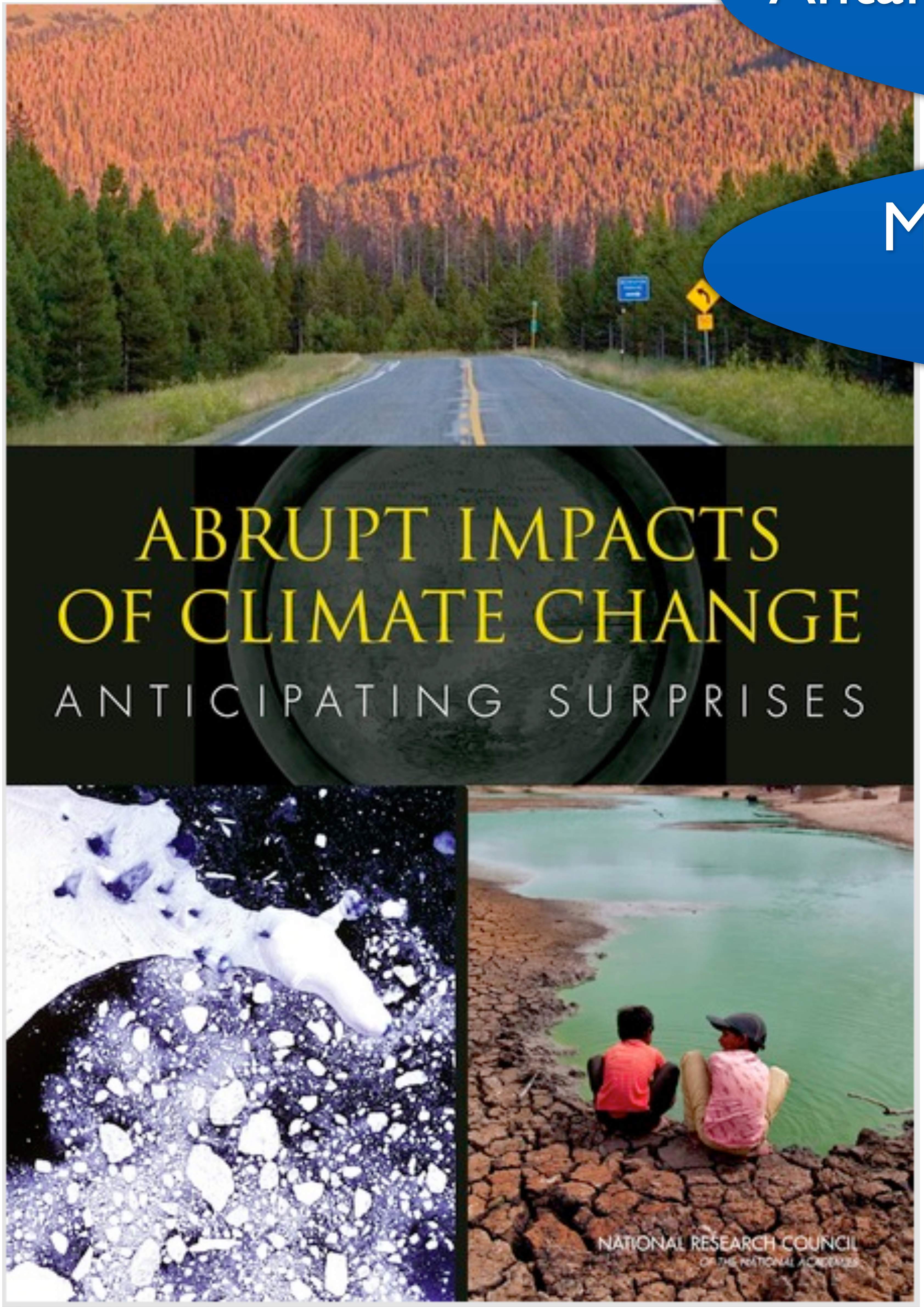
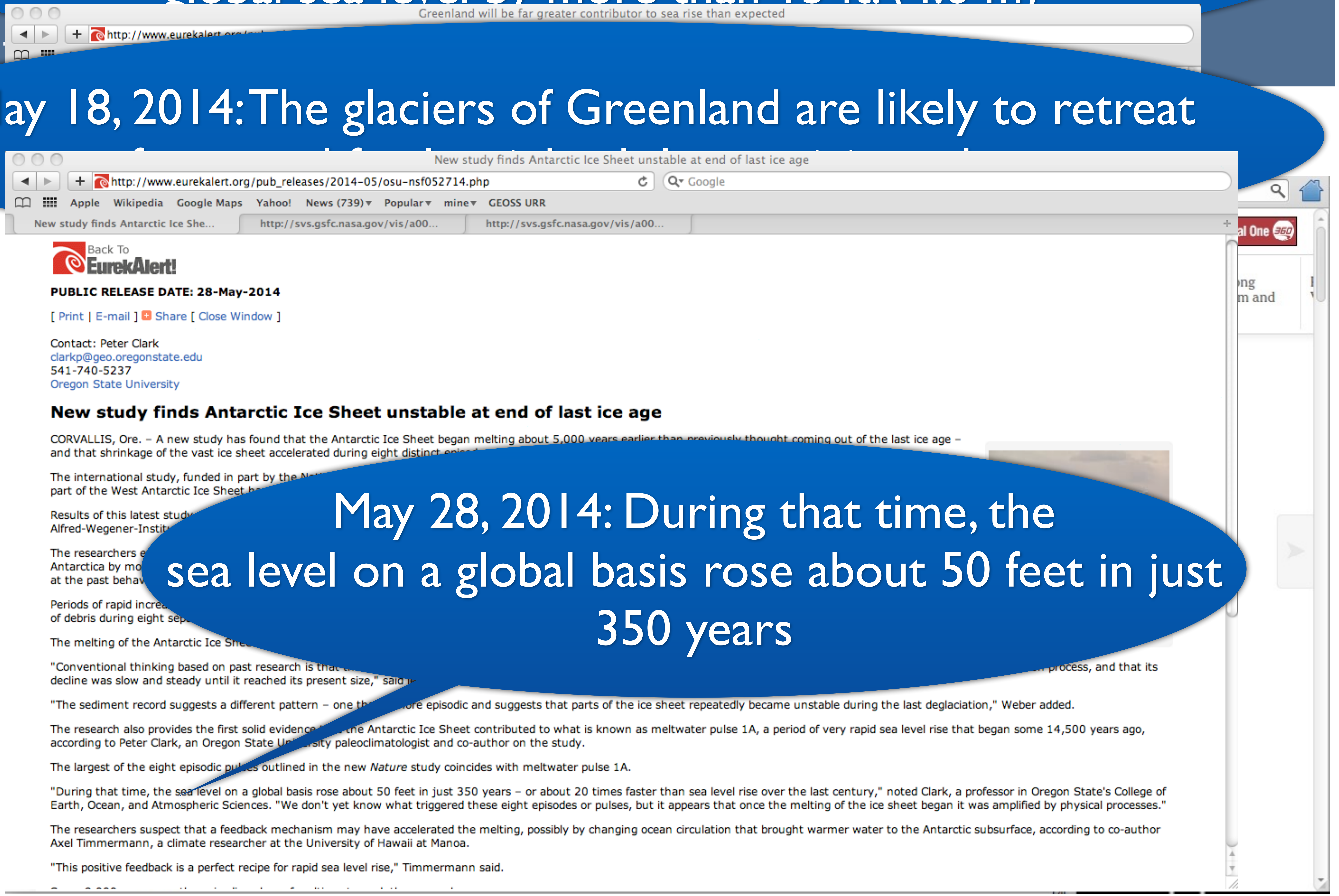
May 28, 2014: During that time, the sea level on a global basis rose about 50 feet in just 350 years





Greenland will be far greater contributor to sea rise than expected

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

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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

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

Results of this latest study
Alfred-Wegener-Instit

The researchers
Antarctica by mo
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Periods of rapid incre
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The melting of the Antarctic Ice She

"Conventional thinking based on past research is that ... 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.

The Prognosis: Anticipating Surprises

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Accepted knowledge in 2000:
Greenland: no significant contribution to sea level rise
Antarctica: minor contribution
Main contribution: steric changes

Knowledge in 2014:
Greenland: is contributing, is accelerating, potentially a large contribution to sea level rise
Antarctica: West Antarctic ice sheet (WAIS) will contribute 4.5 m

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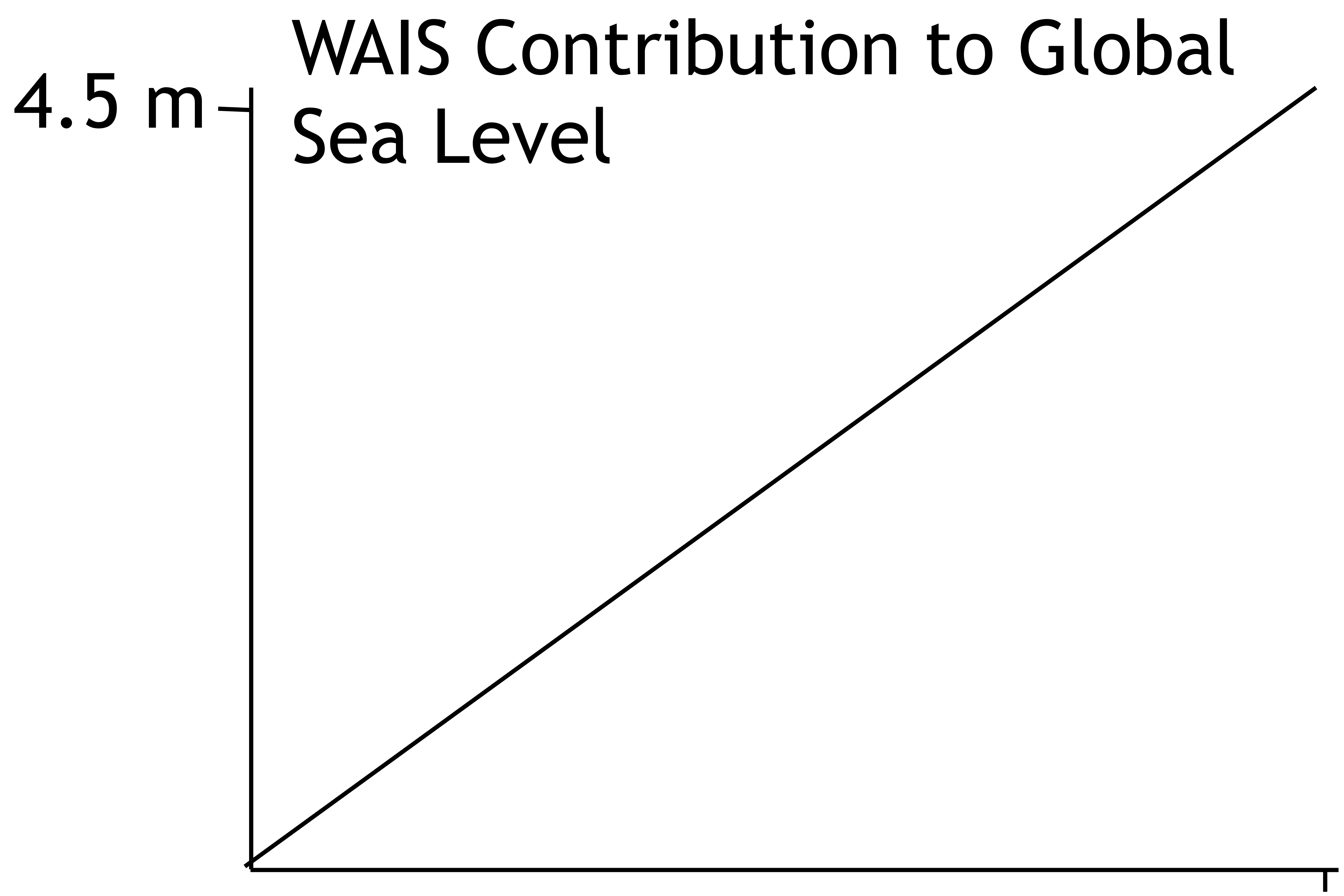

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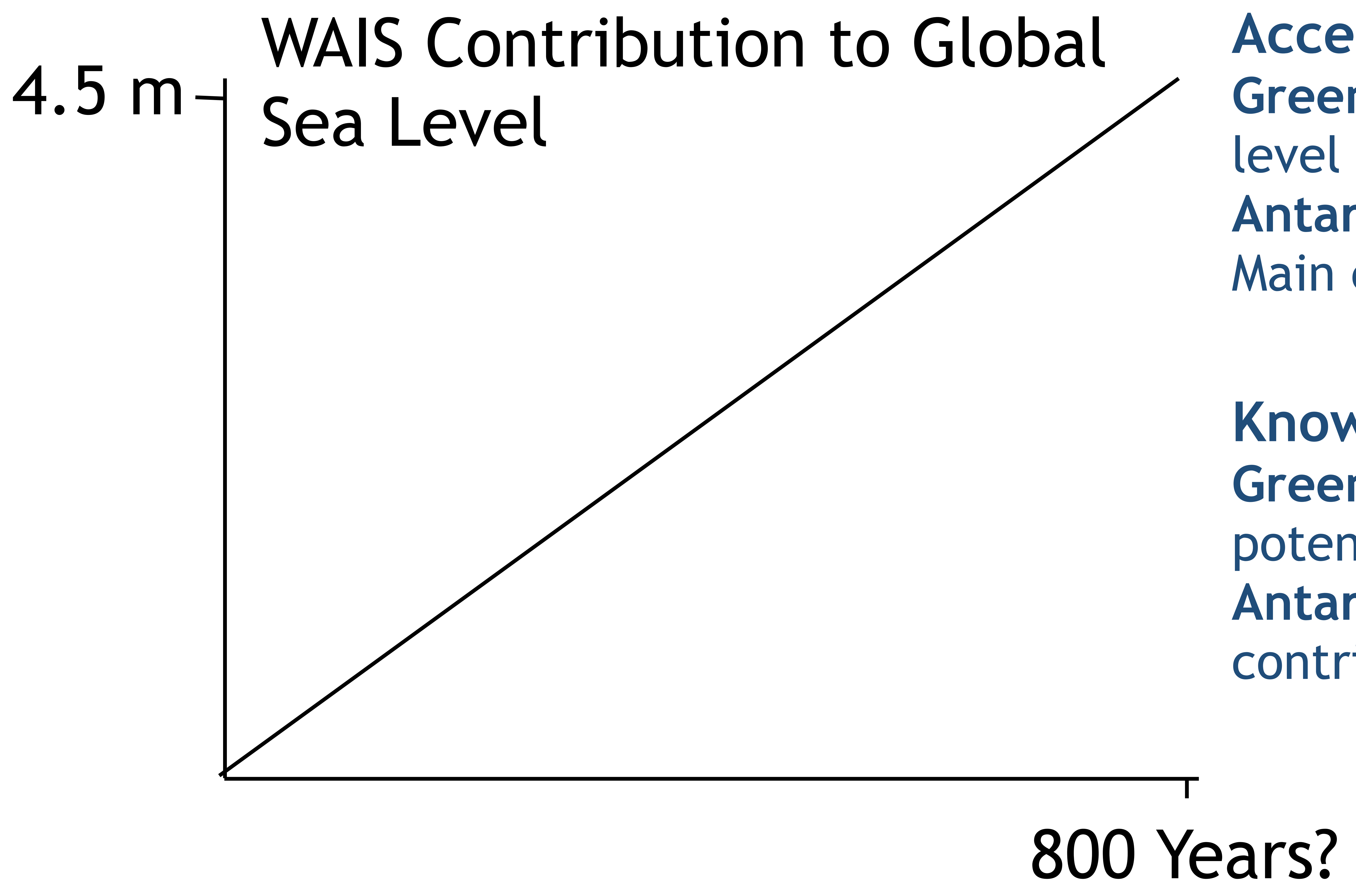

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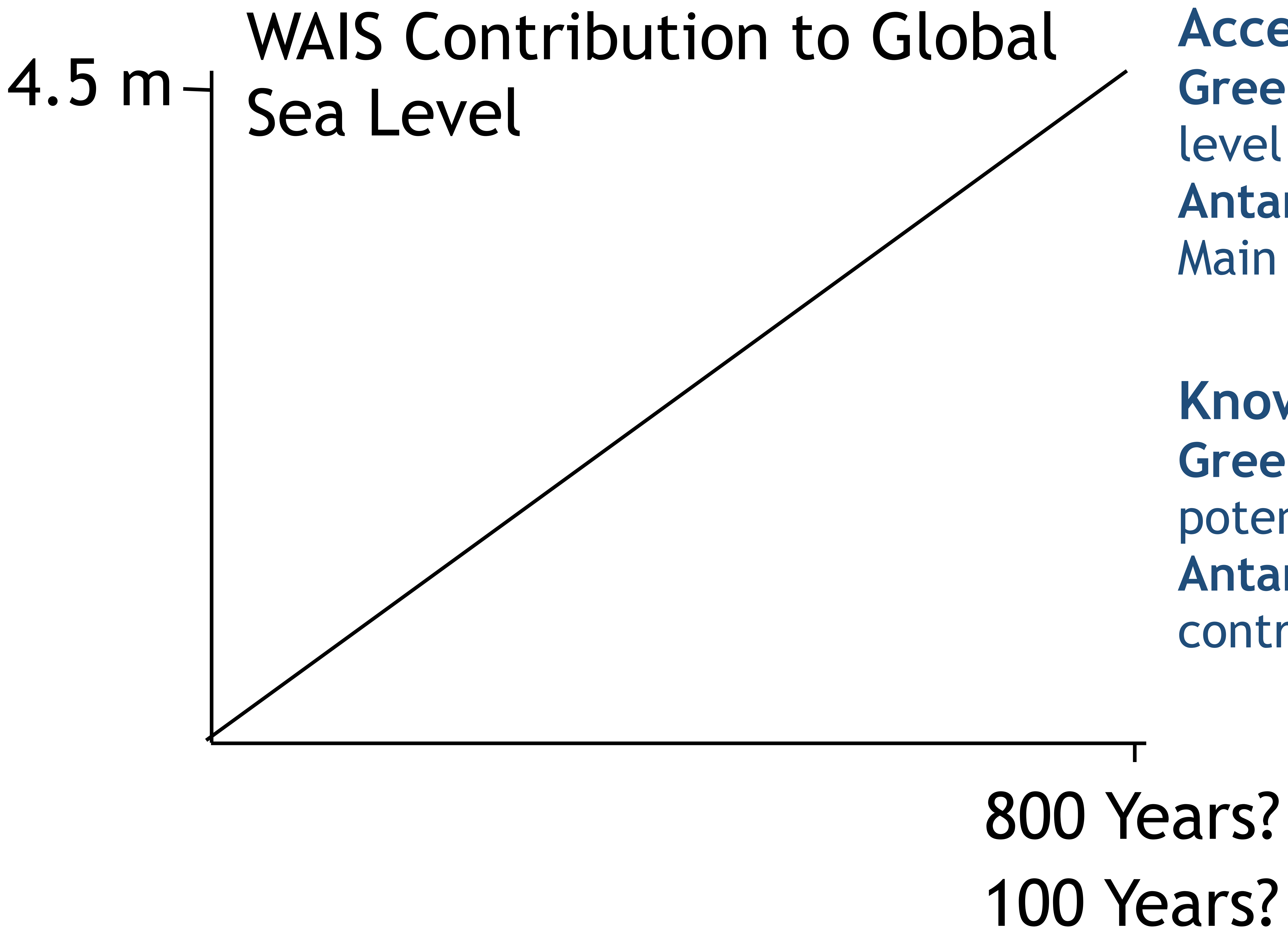

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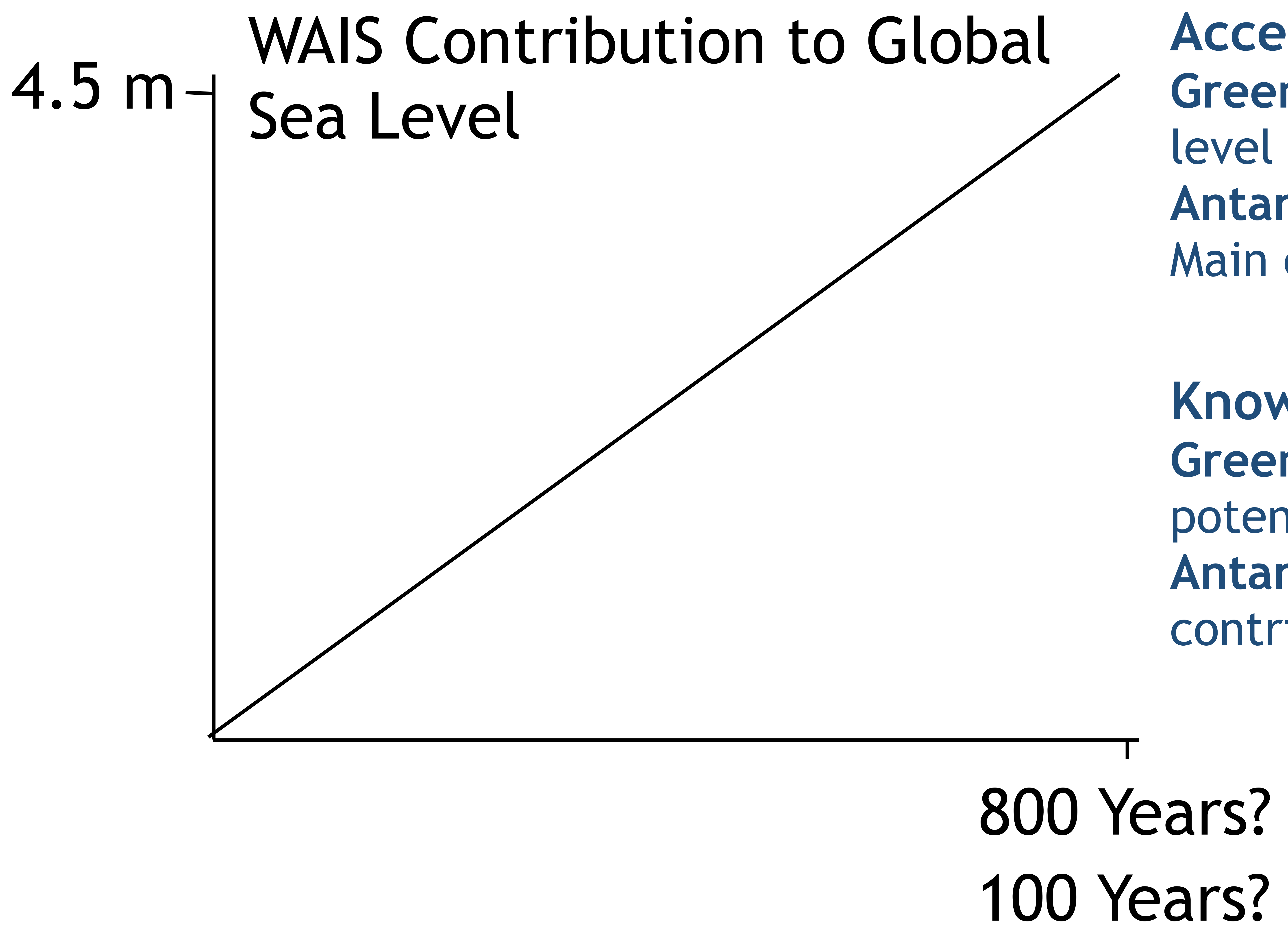

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How worried should we be?

The Prognosis: Anticipating Surprises

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Understanding thresholds

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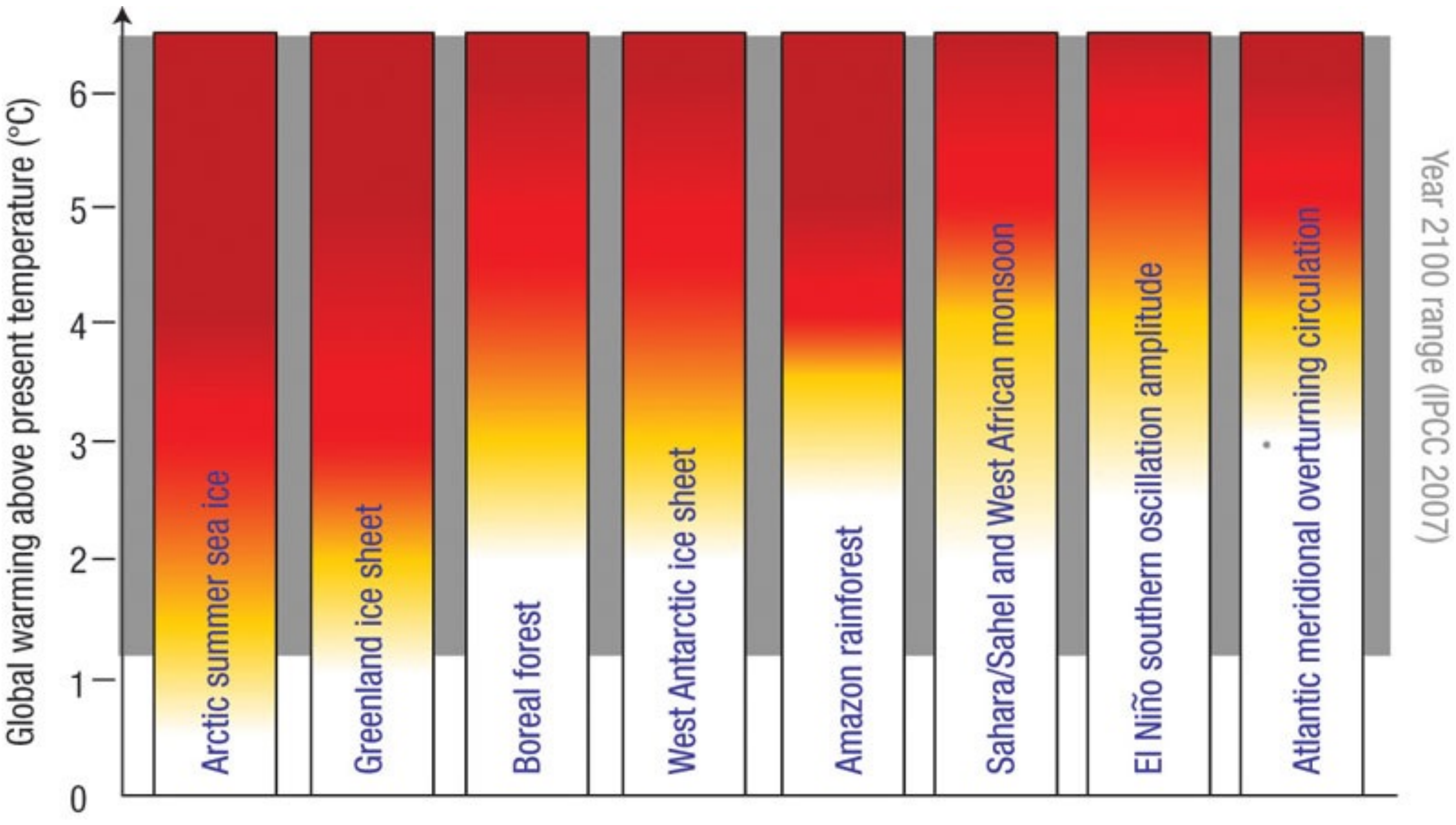

Lenton & Schellnhuber (2007) *Nature Reports Climate Change*

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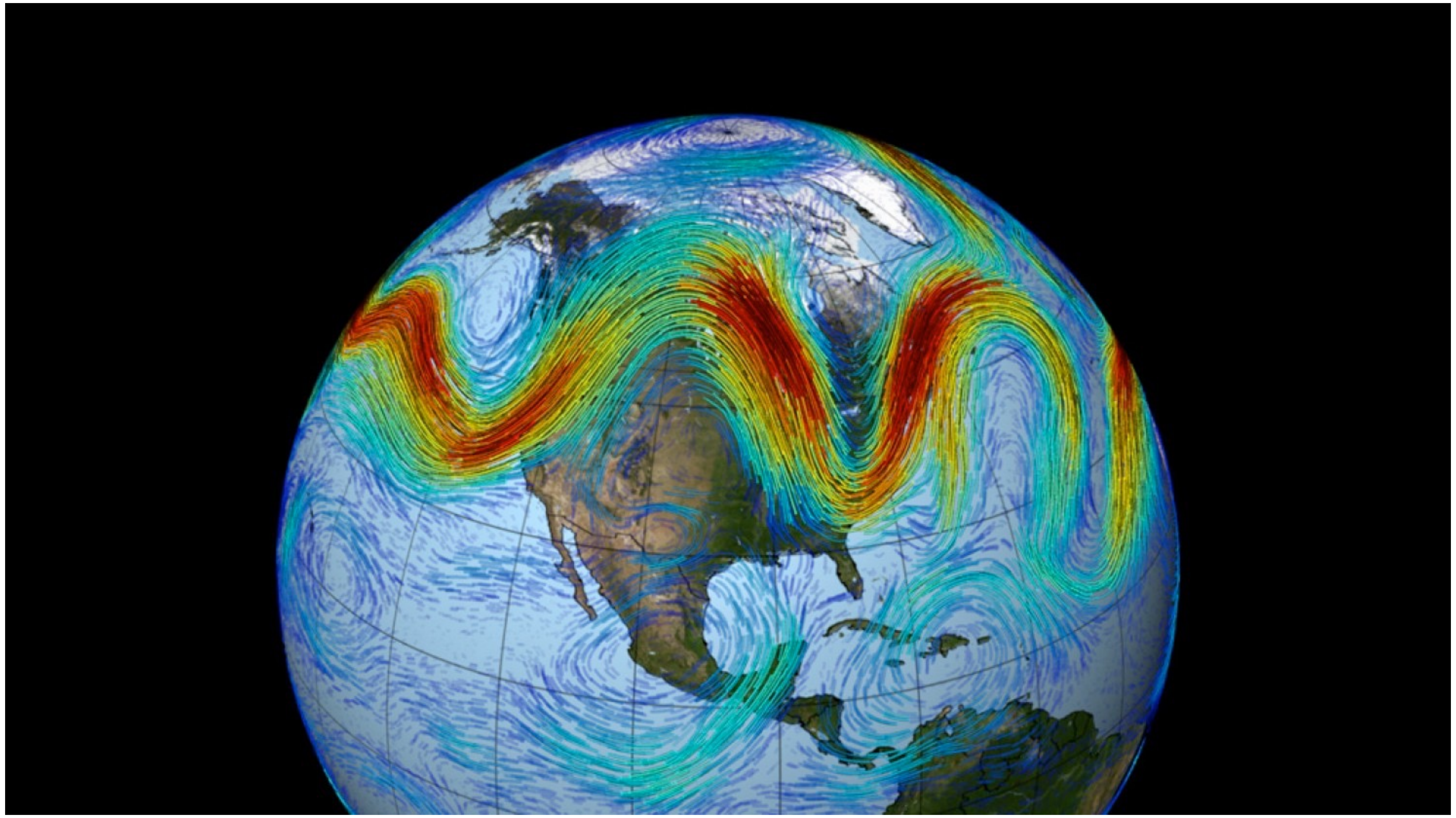
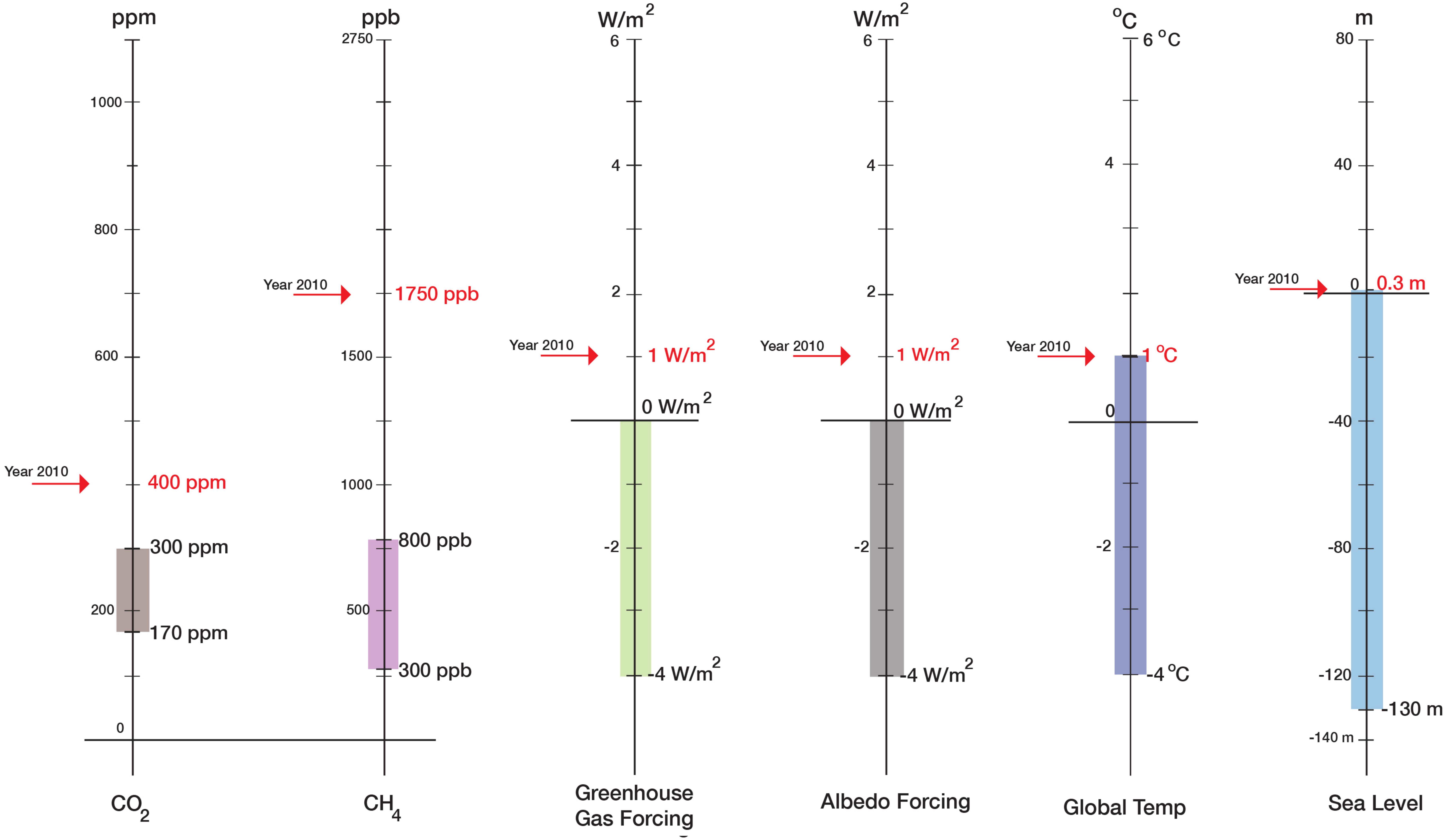


Francis and Vavrus, 2015

The Prognosis: Anticipating Surprises



"Current State"

"Normal Range" (800,000 years)

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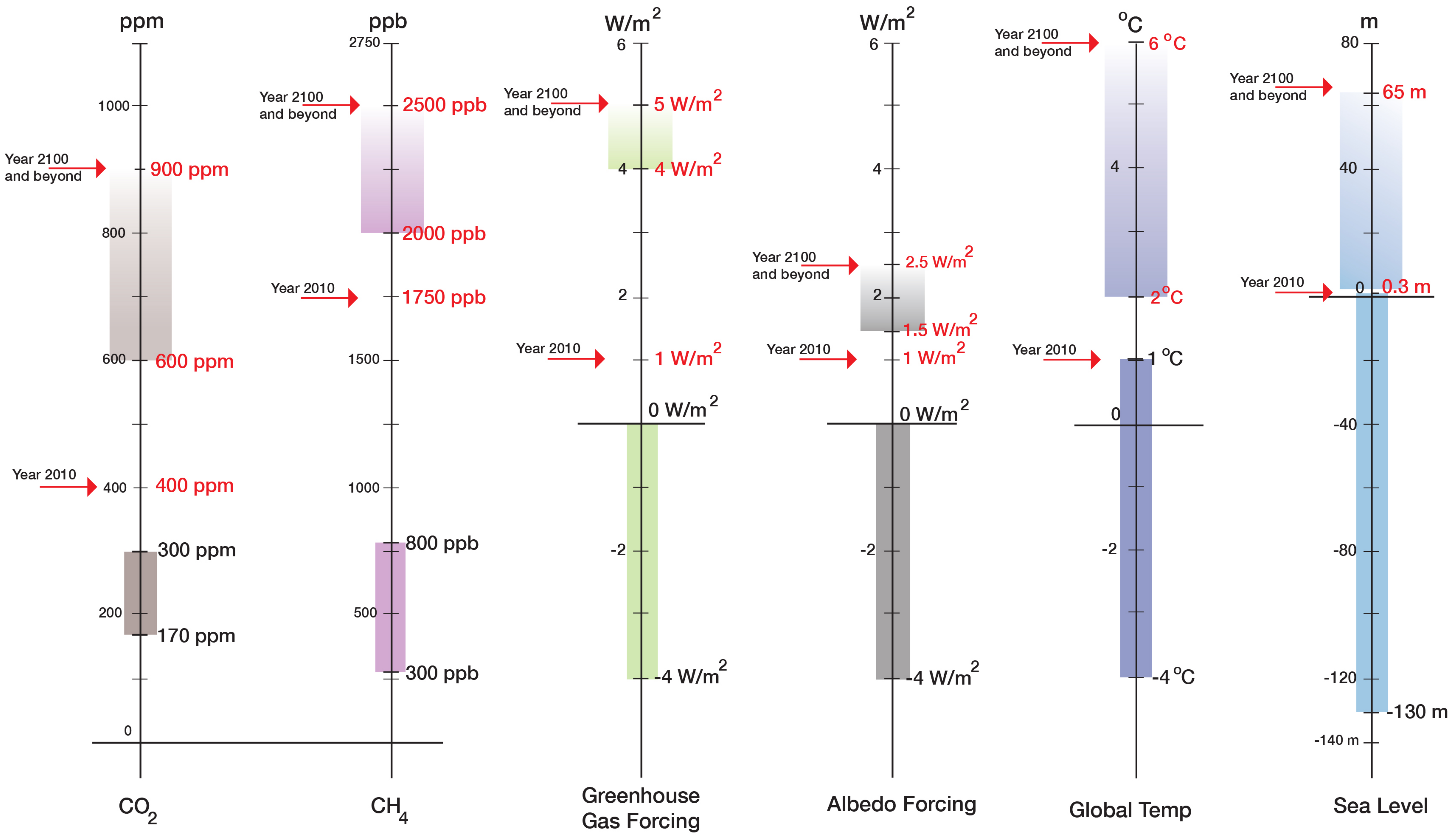

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Temperature: 2 to 3°C higher
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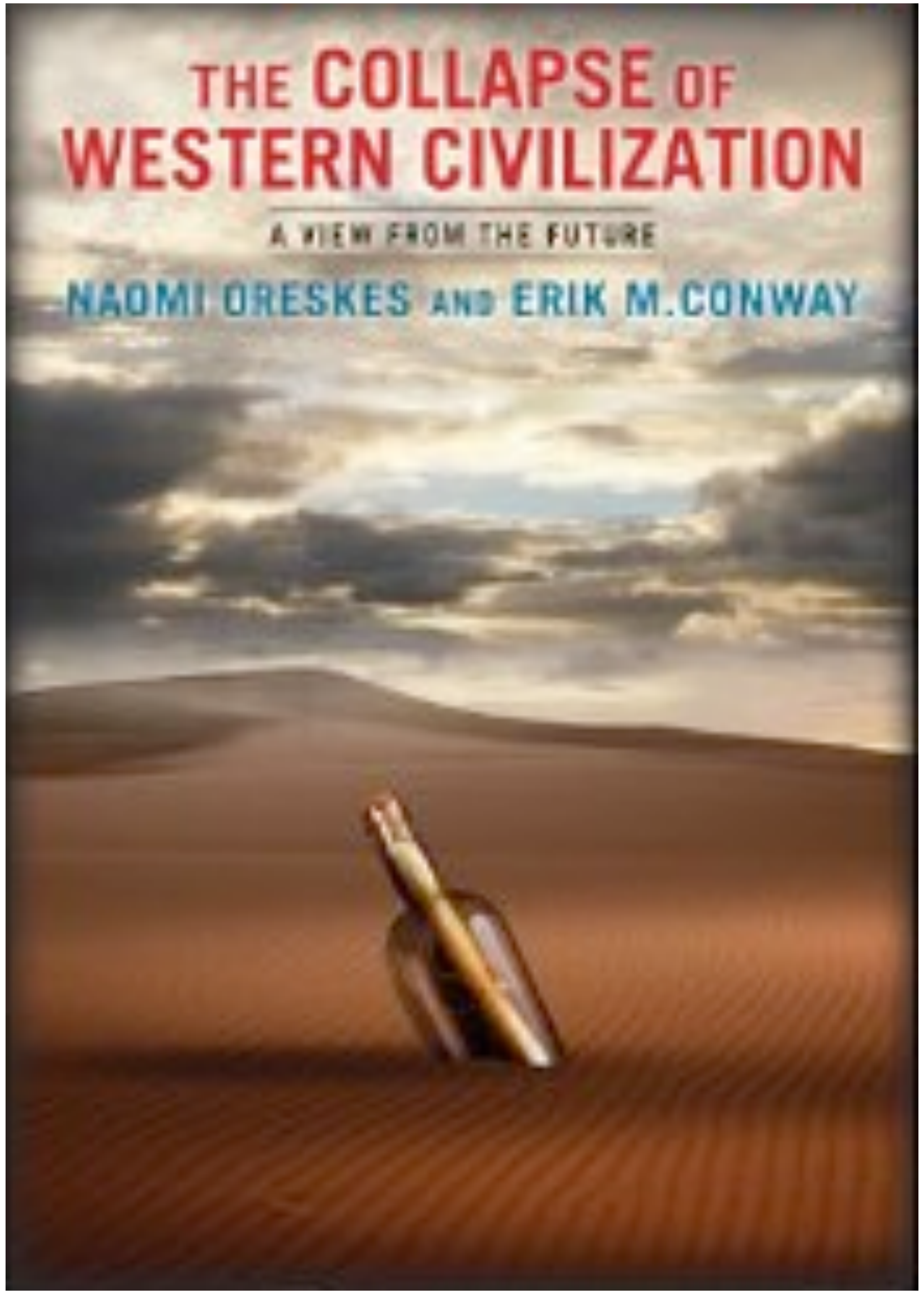

Key Points

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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- Determine the range of risks to be reduced based on these trajectories and vulnerabilities
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Knowing the paradigms our decision making is based on …

The Therapy: “Lifestyle”Changes

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The Therapy: “Lifestyle”Changes

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Example: sea level rise

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“Sea level does not change very much, coastal zones change slowly, and the potential for surprises is low.”

New paradigm:

“Sea level may change rapidly and coastal zones can migrate fast.”

Consequence:

- be prepared to move with the coastal zone
- keep the coastal zone clean and prepared for inundation
- have early warning systems in place

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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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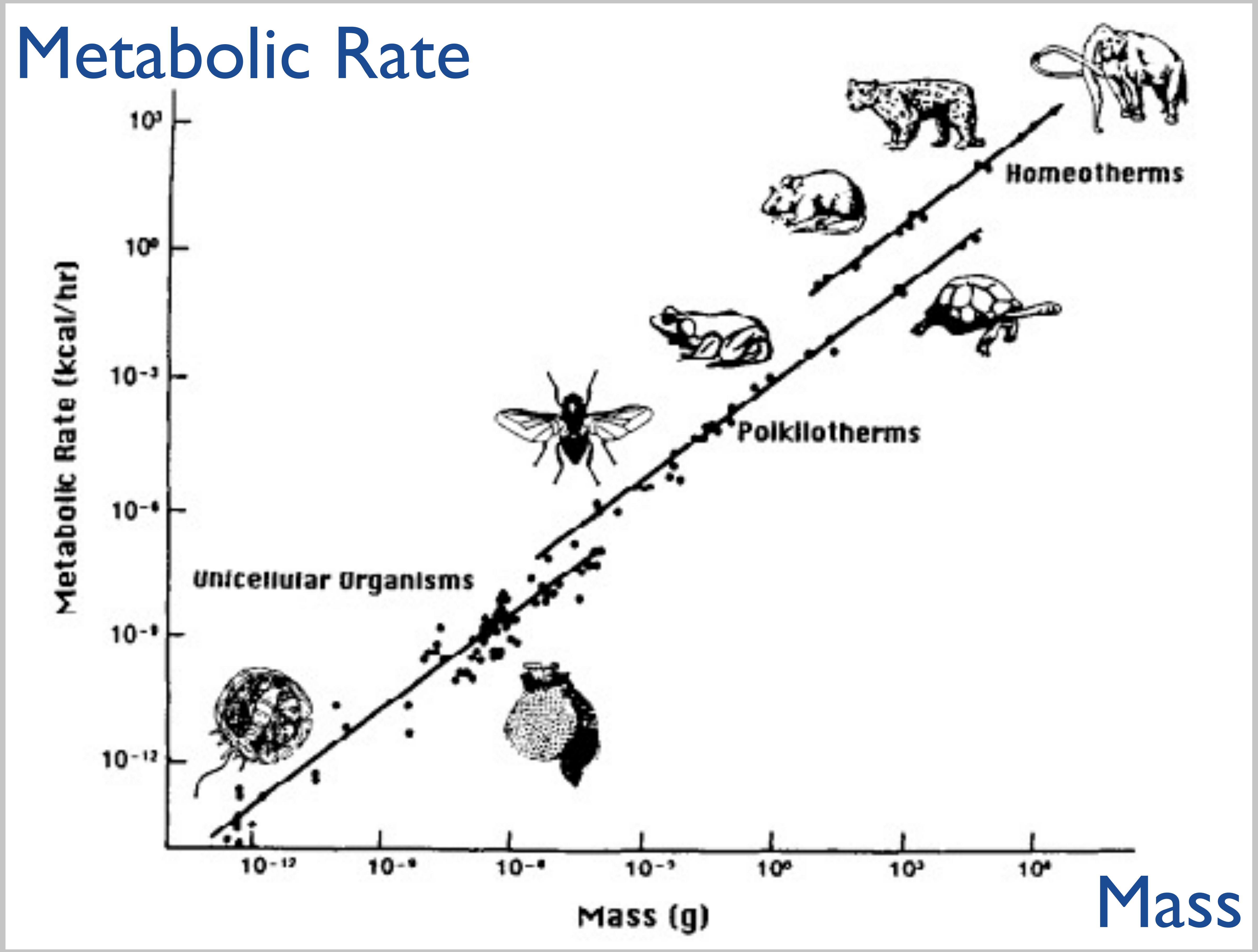
Being out of scale



The Therapy: "Lifestyle" Changes

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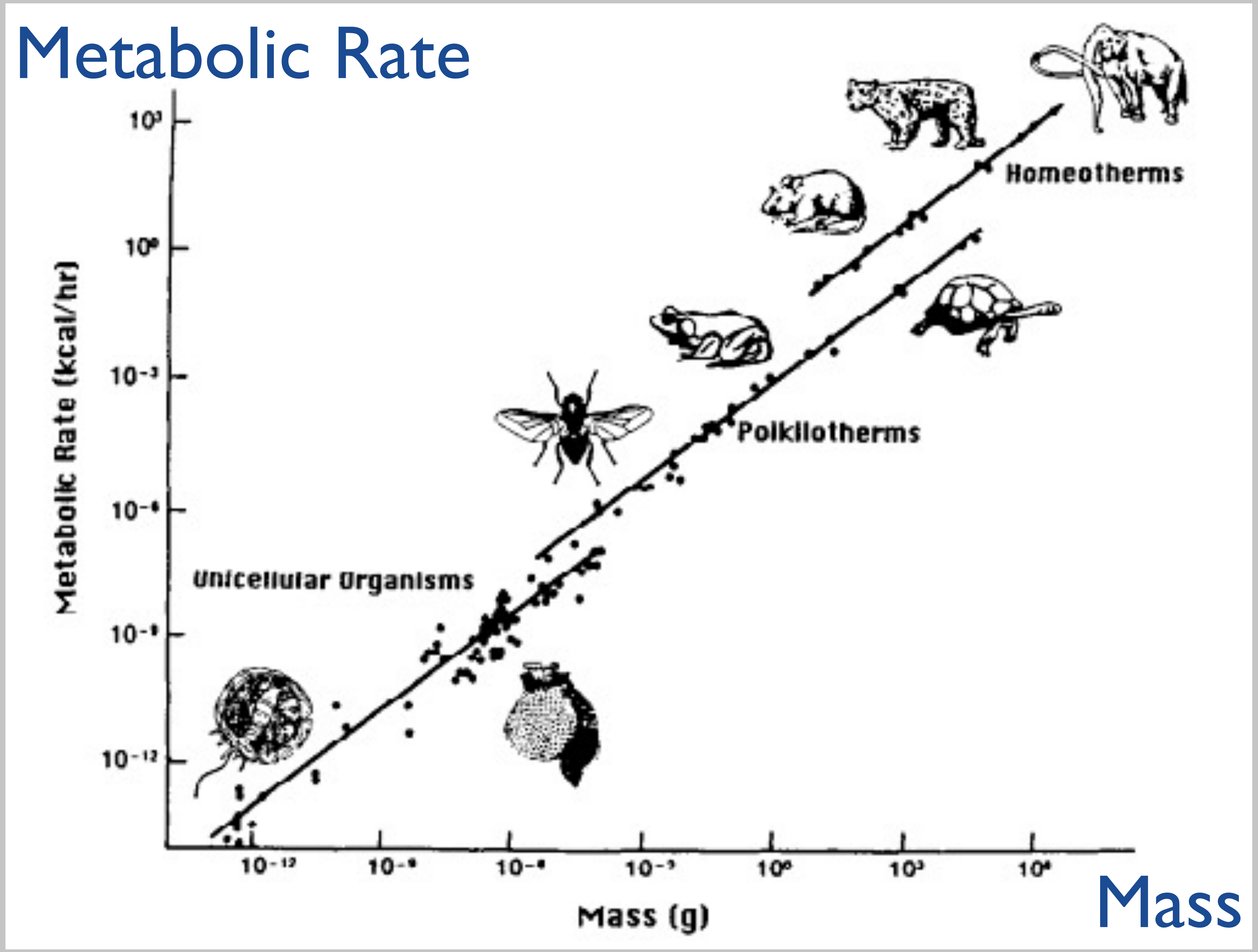
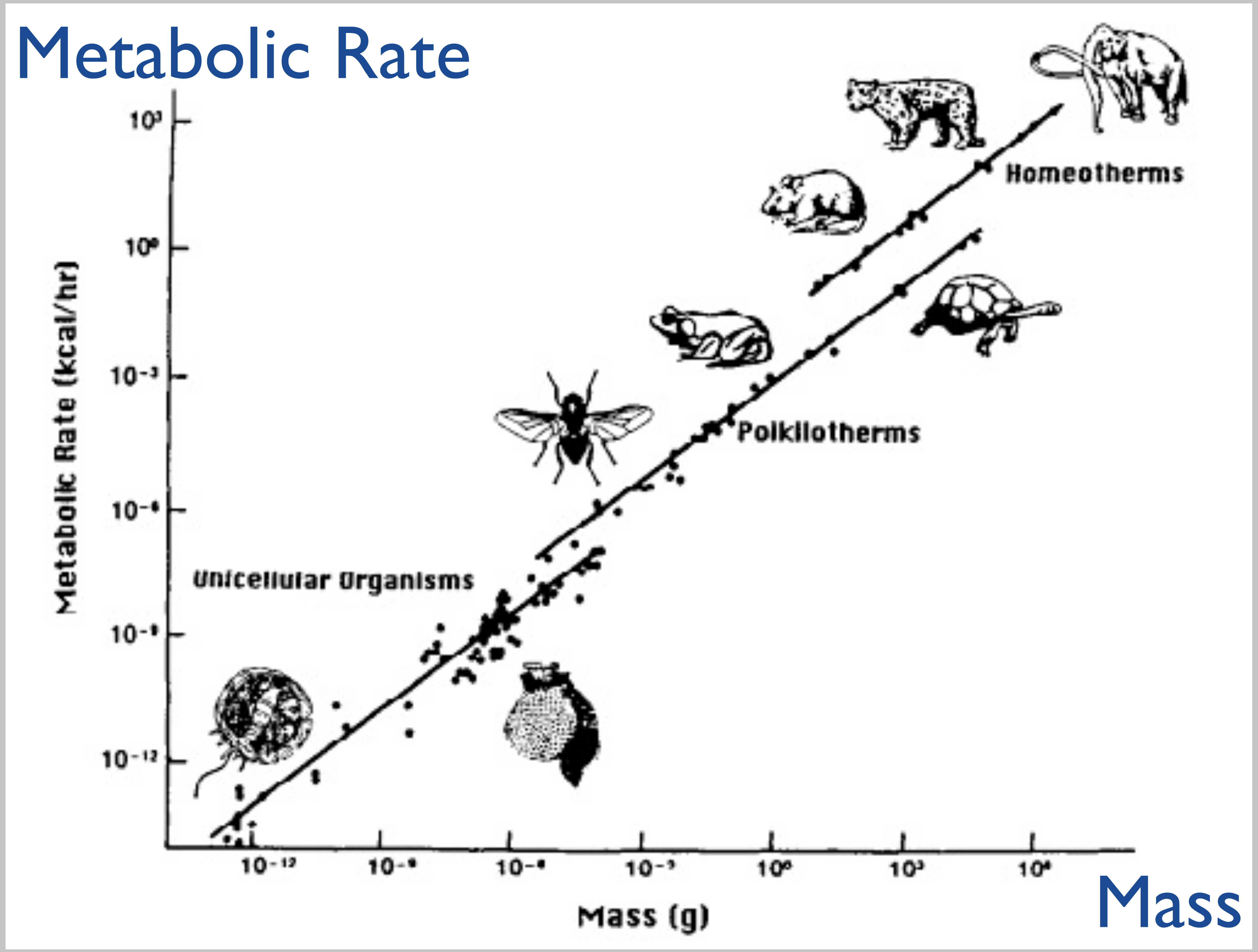


Scaling law for metabolic rate:

$Y = Y_0 * M^{(3/4)}$

The Therapy: “Lifestyle”Changes

Being out of scale



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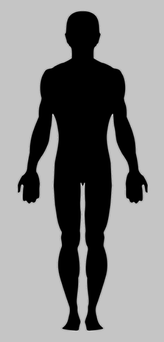

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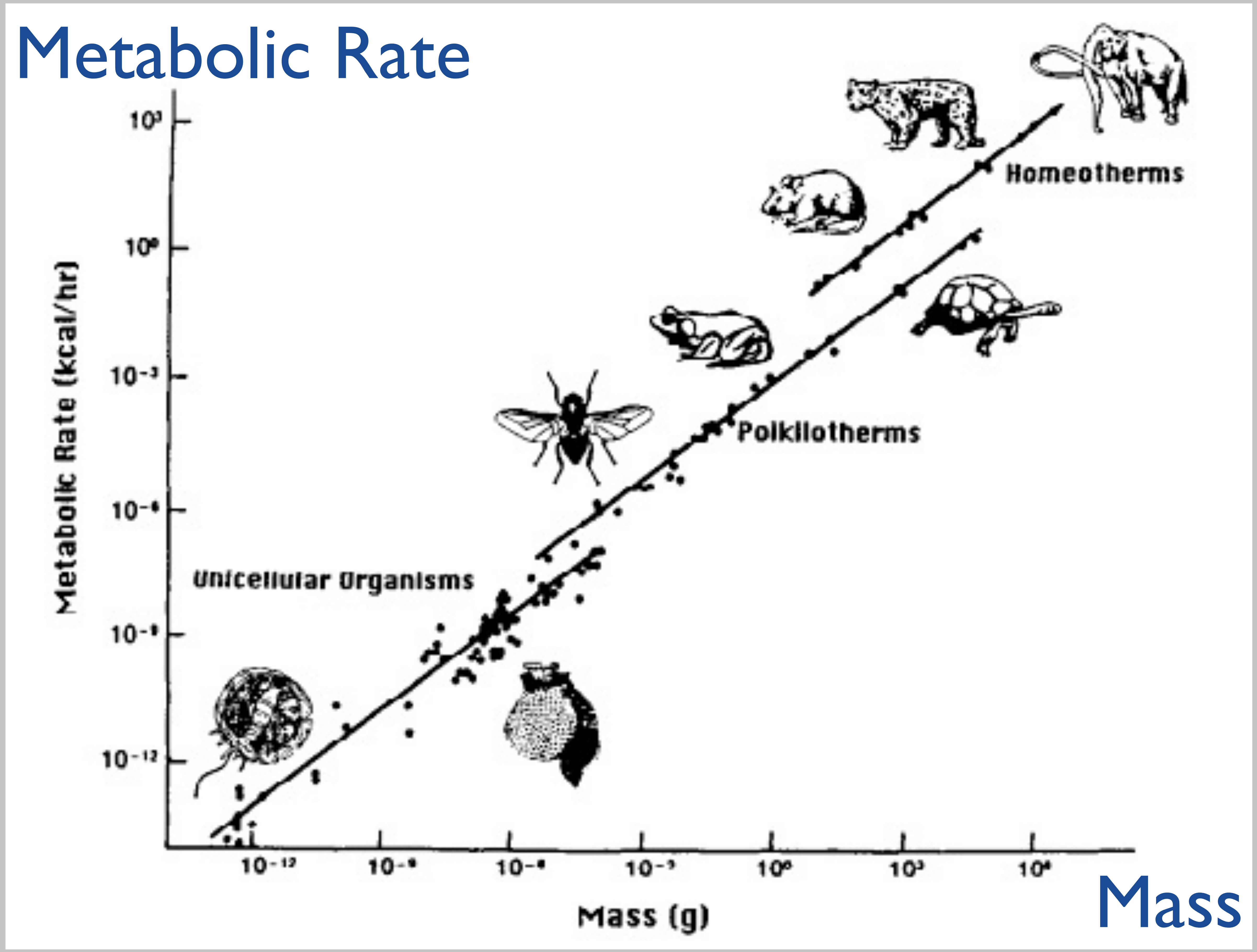

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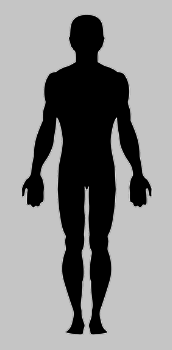

Extended metabolic rate:

$Y_E = Y + C_E$

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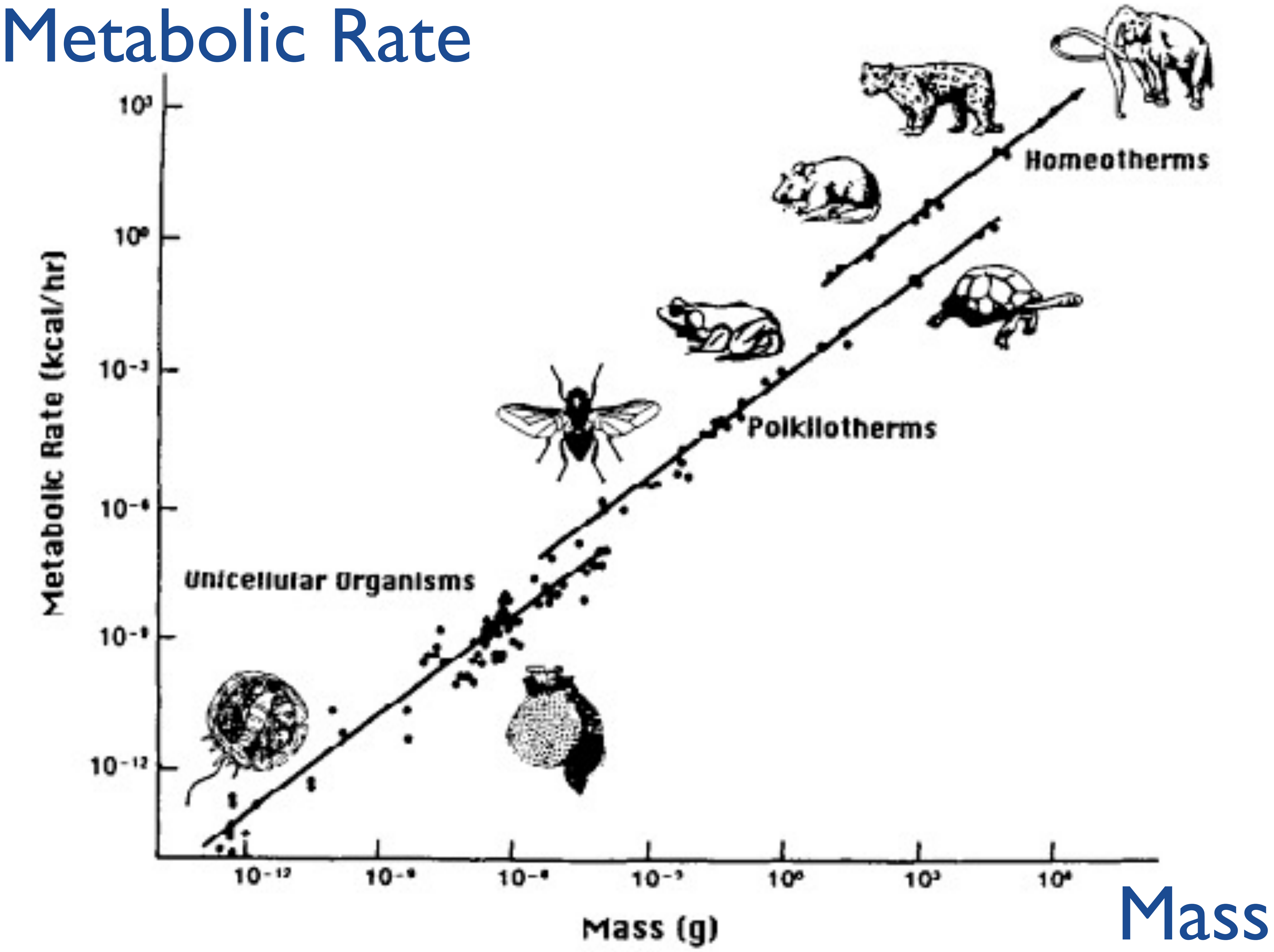
The Therapy: "Lifestyle" Changes

Being out of scale

Metabolic Rate



Mass

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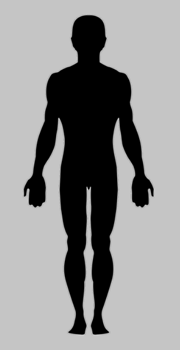

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Global Average: Y_E = 2,735 Watt
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The Therapy: "Lifestyle" Changes

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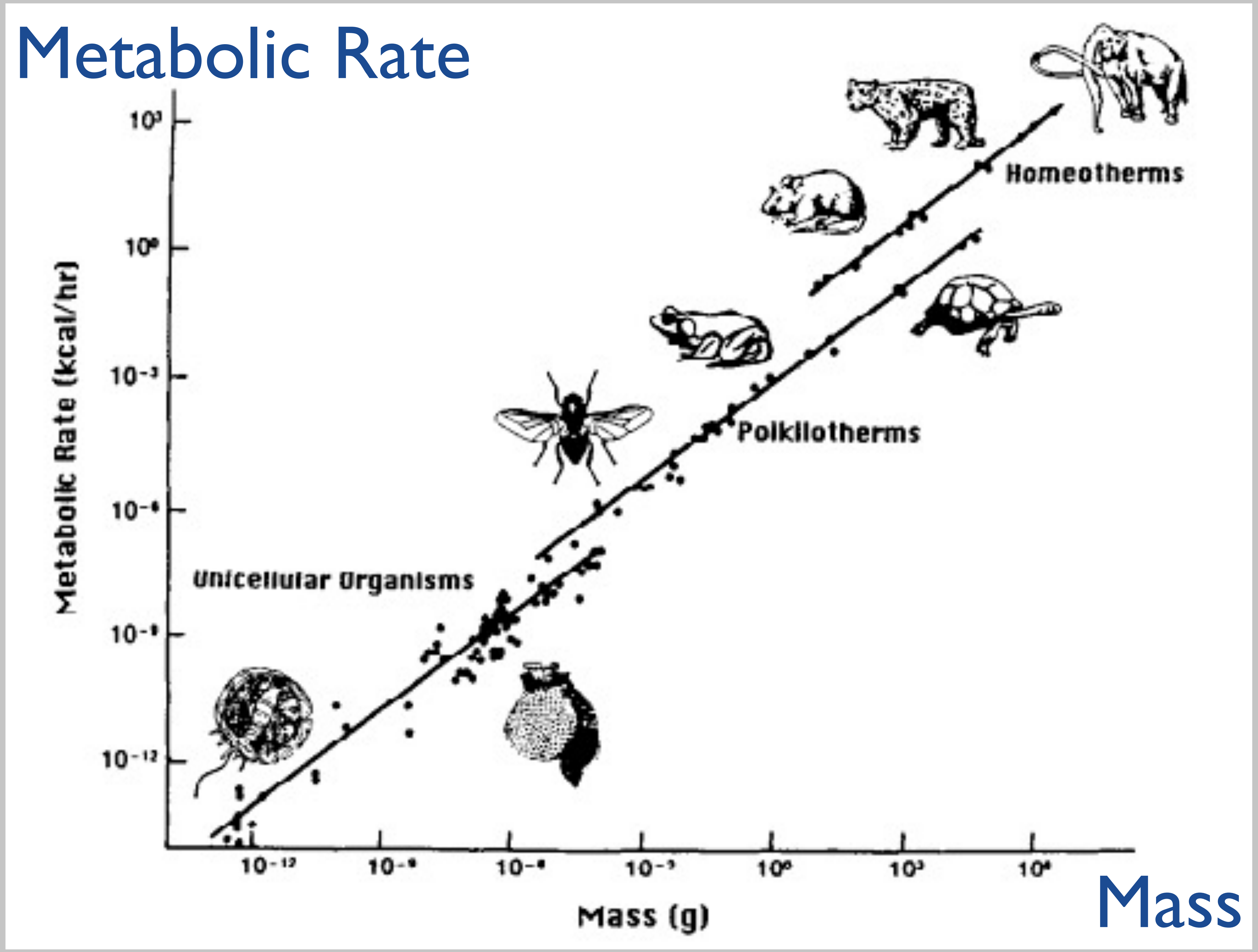

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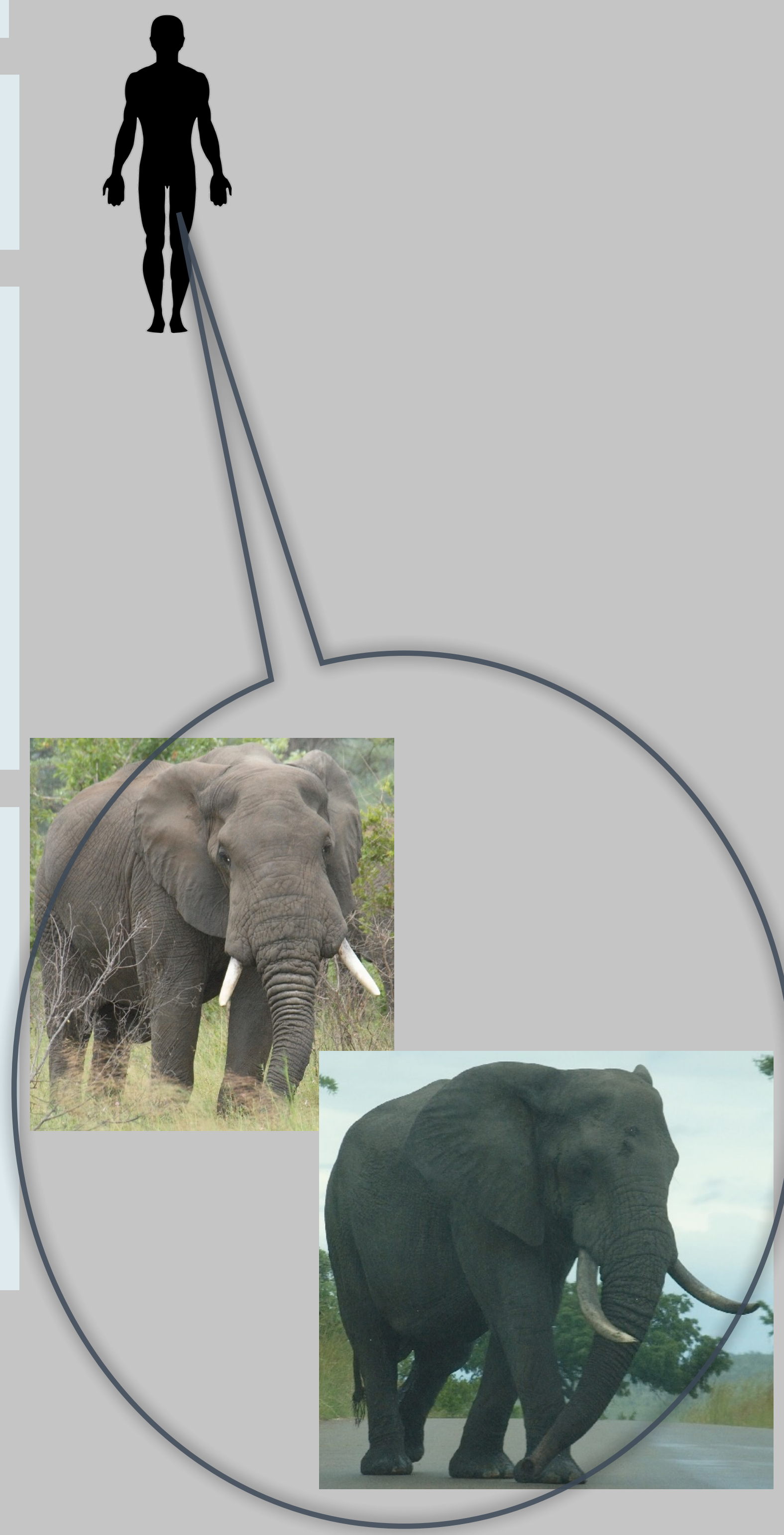

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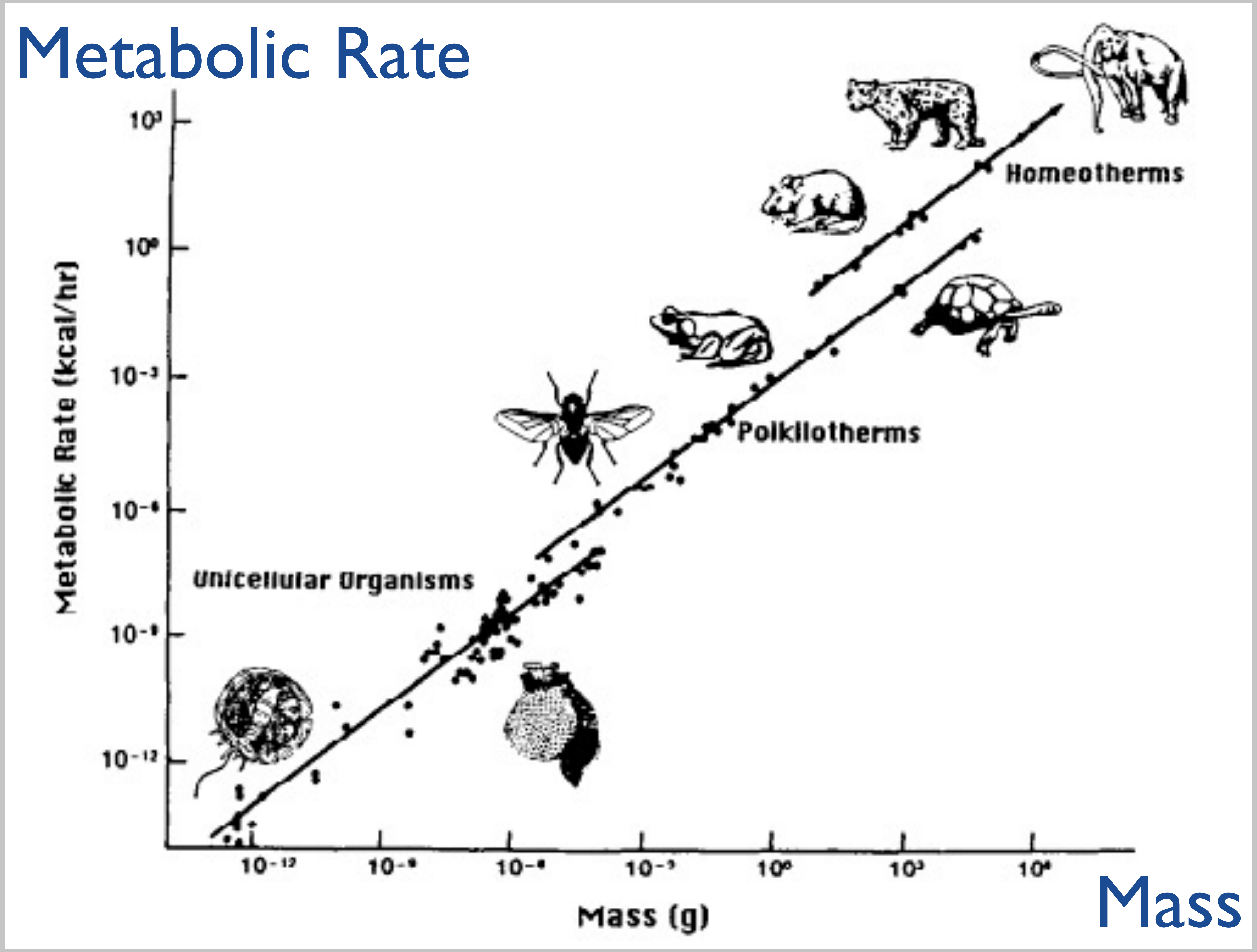

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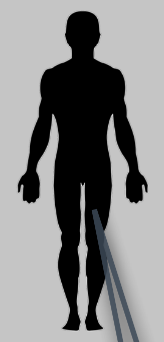

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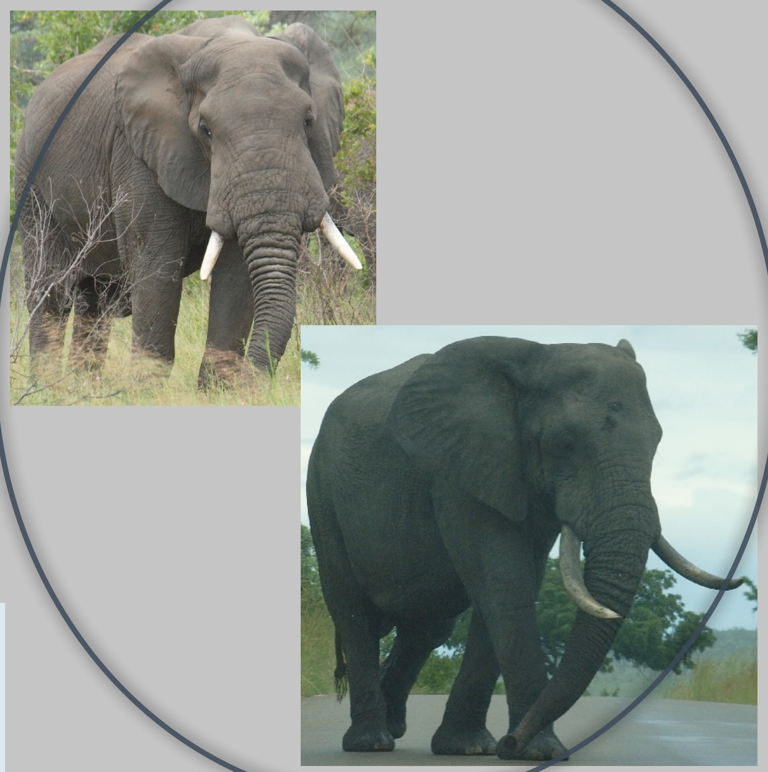

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The Therapy: "Lifestyle" Changes

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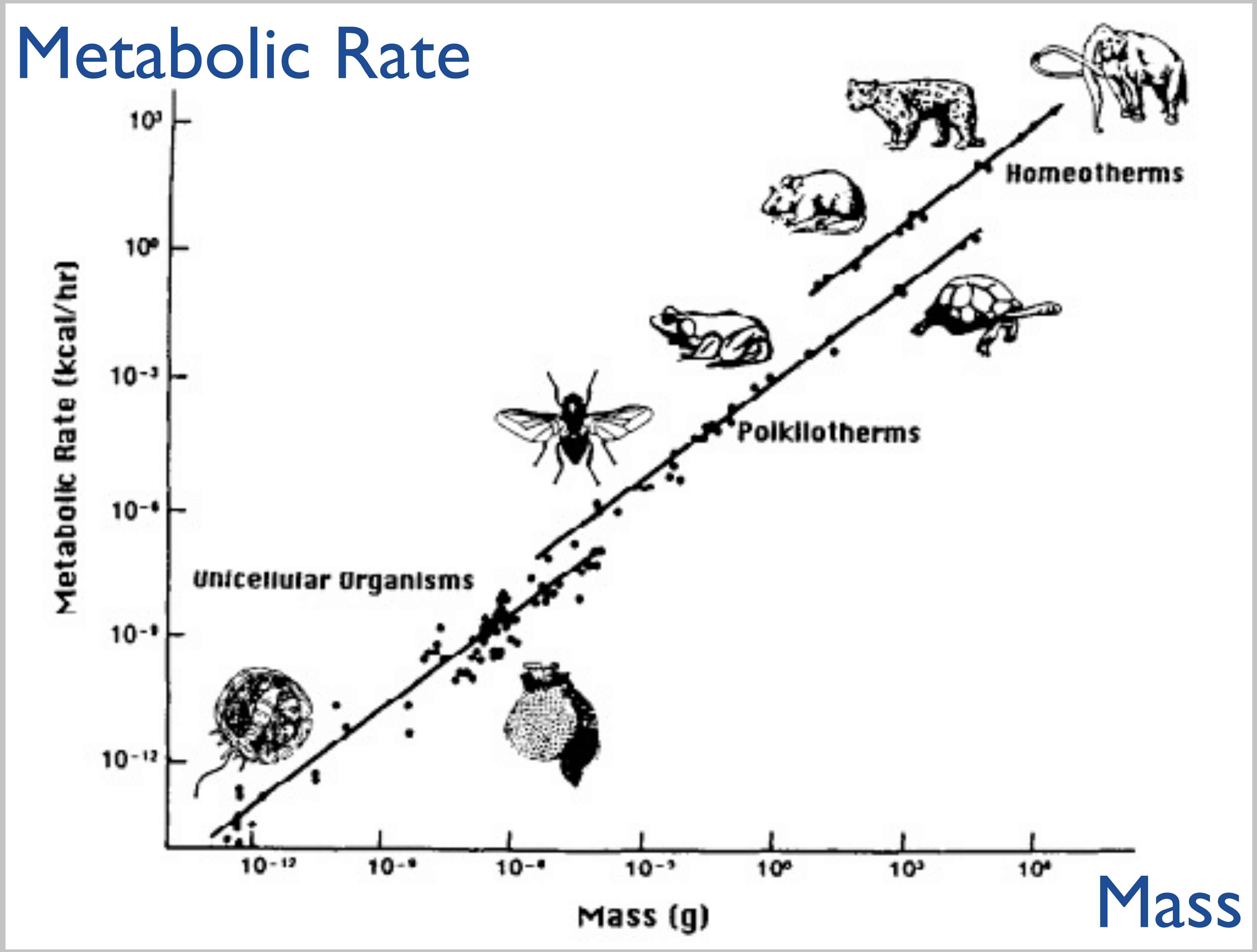

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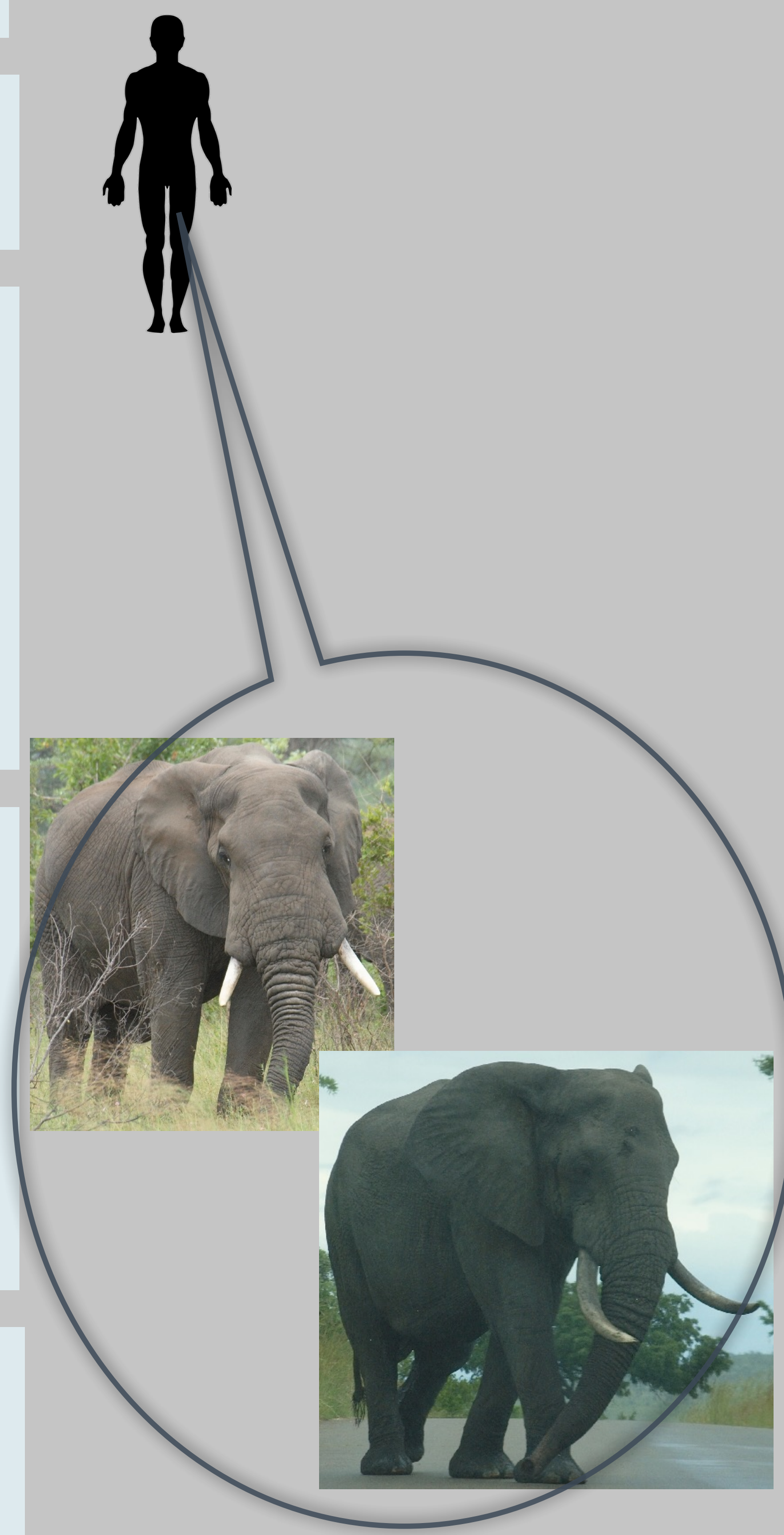

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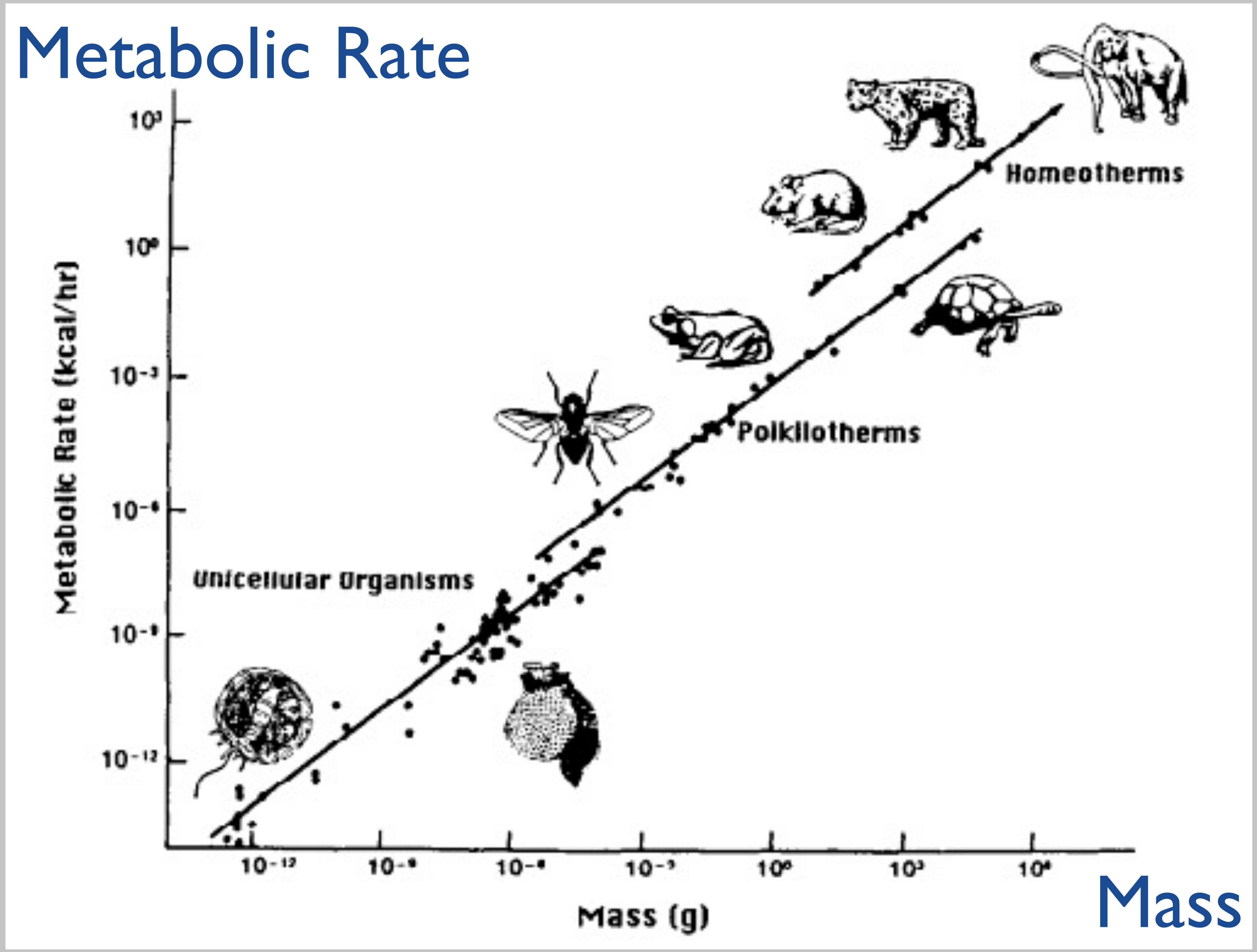

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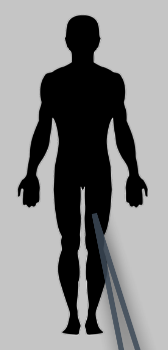

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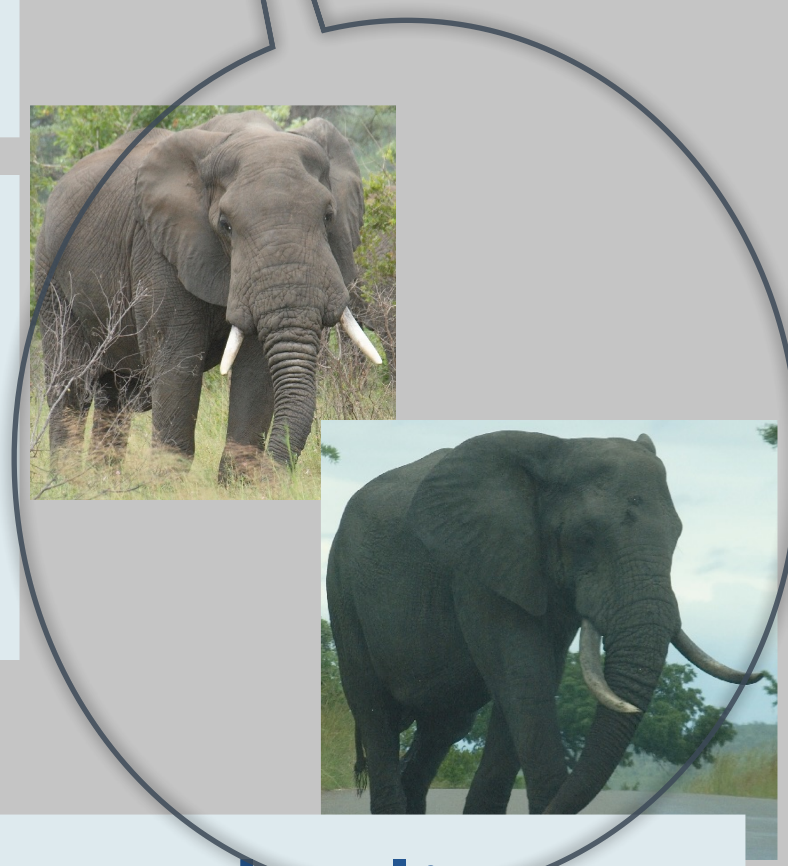

Humanity has an extended metabolic rate equivalent to 14 Billion elephants (2.7 Billion for the U.S. alone)

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Being out of scale

14 Billion elephants: a heavy “load’ for Earth

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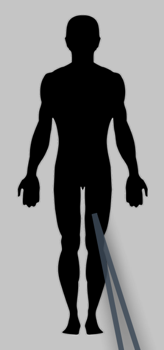

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“Sustainable Development is a development that meets the needs of the presence while safeguarding Earth’s life support systems, on which the welfare of current and future generations depends.” (Griggs et al., 2013)

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Economy is the link between humanity and Earth's life-support system

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Economy **against** humanity:
An economy that meets our needs by burning fossil fuels and destroying Earth's life-support system is like a doctor who practices medicine by killing the patients.

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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