Key Points

Baseline

During the Holocene, climate and sea level were exceptionally stable

The Holocene was a “safe operating space for humanity”

Syndrome

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

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

Diagnosis

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

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

Prognosis

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

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

Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

Plan for the rest of class:

- Hazards (*Extinction, Ecosystem Services*, Climate and Coastal, Public Health and Food-Water-Energy Nexus)
- Vulnerabilities (Environment, Built Environment, Economy, Inequality, Injustice)
- Foresight (understanding uncertainty, Decision blocks)
- Decision making (human nature, facing threats)
- Developing options (avoiding adaptation, changing paradigms, mitigating degradation; economy and governance)

Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

Class 15: Knowing the Hazards: Climate Hazards, Public Health, Food-Water-Energy Nexus

Contents:

- Some Definitions
- Climate Change and Sea Level Hazards
  - Observing the Planet
  - Detecting Changes
  - Assessing Knowledge
  - Understanding the Processes and Causes
  - Predicting Future Changes
  - Having Foresight
- Public Health
- Food-Water-Energy Nexus

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Hazardous event

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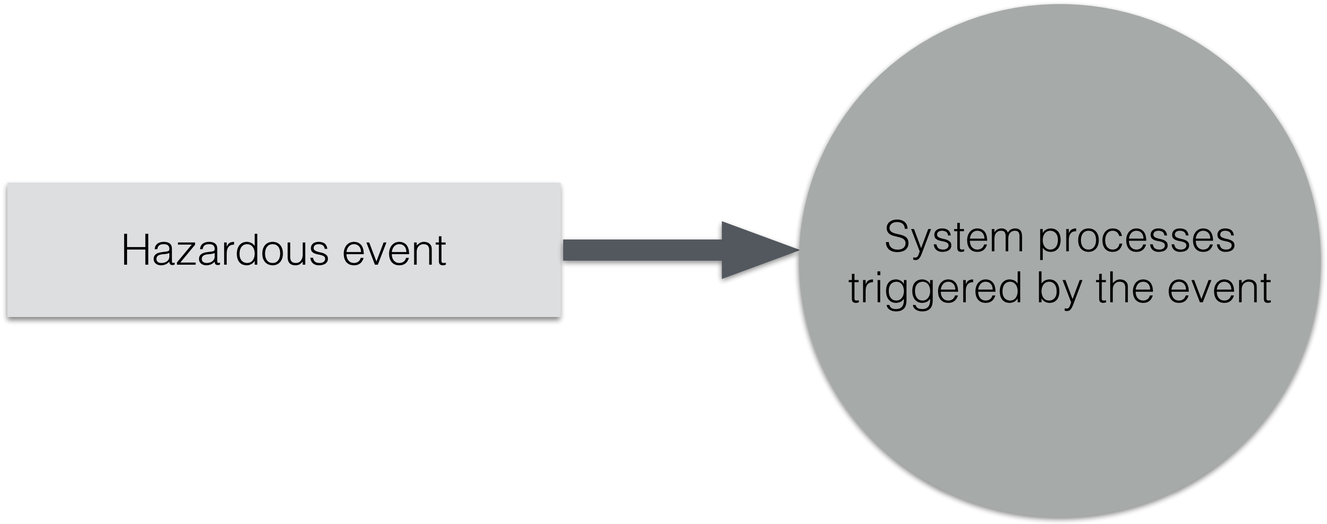

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Important: Risk Concept

Risk

Disasters, Hazards, Vulnerability, Risks

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Insurance: Risk (in $) = Hazard Probability * Vulnerability * Exposed Assets

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Inability of a system to withstand the effects of a hostile environment.

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Here we take a risk-based approach that is commonly used for natural hazards and particularly geohazards. For a given hazard h, a given recurrence time interval T, and for a prescribed intensity I, the associated risk $r(I)$ expressed in currency is given by

$$r_h^T(I,x,t) = p_h^T(I,t) \cdot V_h^{a(x,t)}(I,t) \cdot a(x,t) \qquad [1]$$

where x is the location, t time, p the hazard giving the probability that the hazard with intensity I will occur in the considered recurrence interval, V the vulnerability of an asset a for hazard h at intensity I, and a being the asset exposed at location x. To assess the total risk R associated with a hazard, we can use

$$R_h^T(x,t) = \int_0^{I_{\max}} r_h^T(I,x,t)\mathrm{d}i. \qquad [2]$$

Plag and Jules-Plag, 2013

Disasters, Hazards, Vulnerability, Risks

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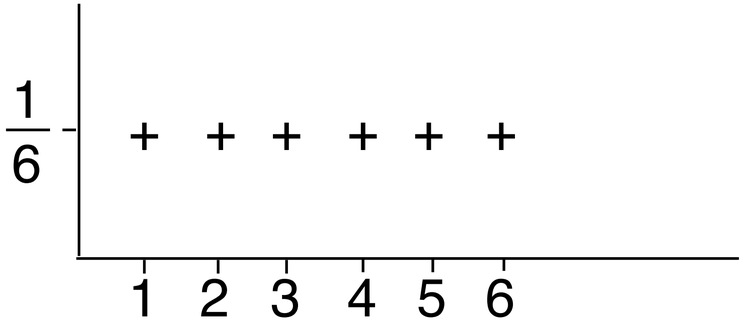
Knowing the probability density function of a hazard

Probability Density Function
Dice



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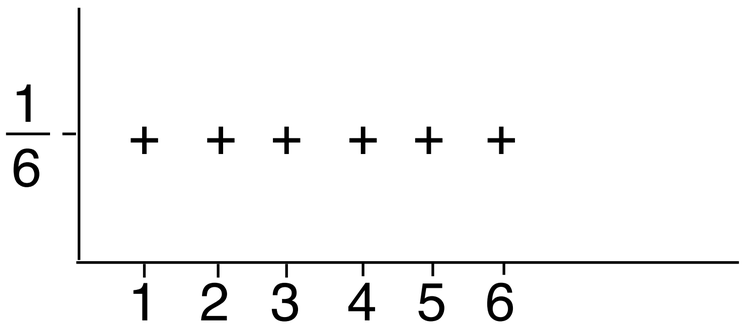
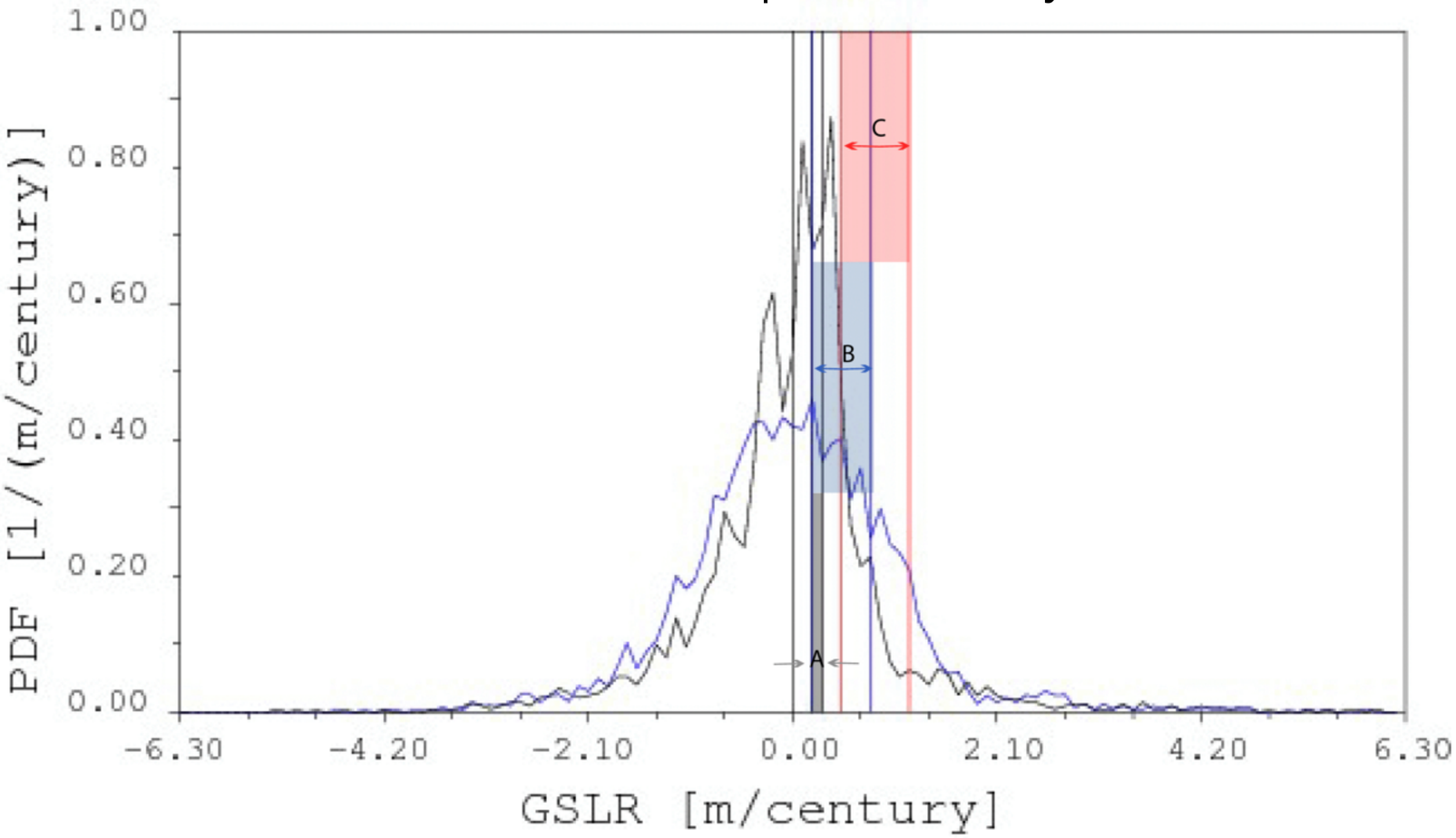


Probability Density Function
Global sea-level rise per century



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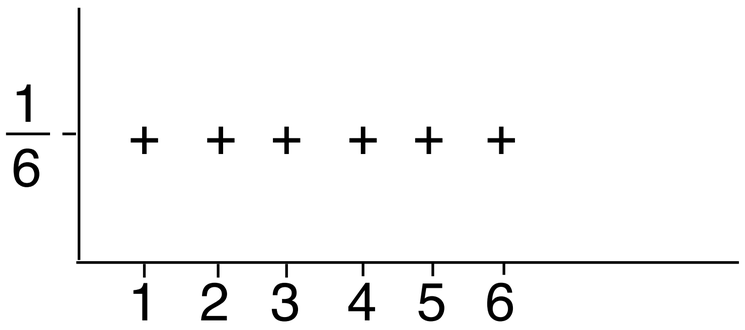

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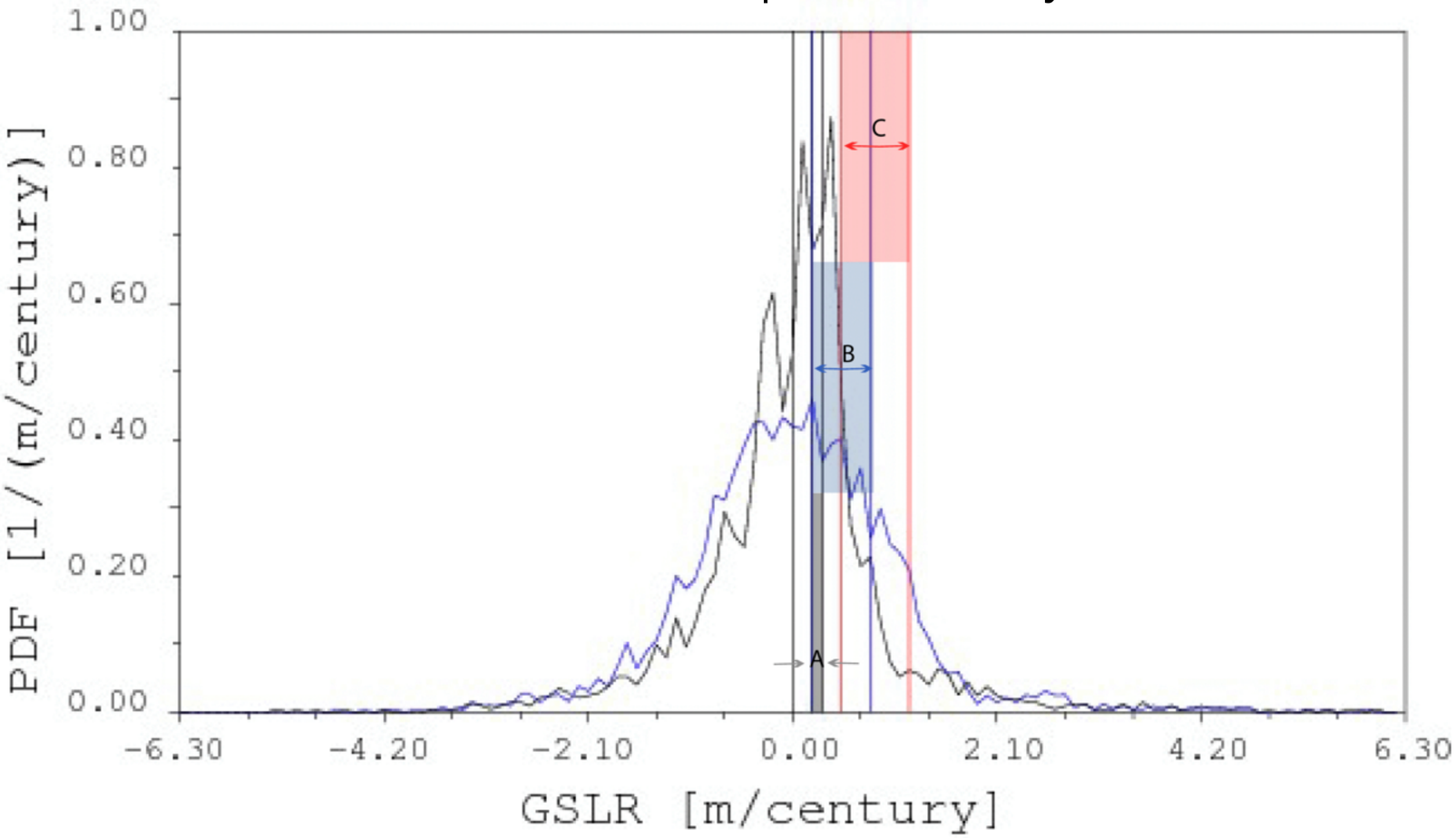

Knowing the probability density function of a hazard

Knowing the Hazards

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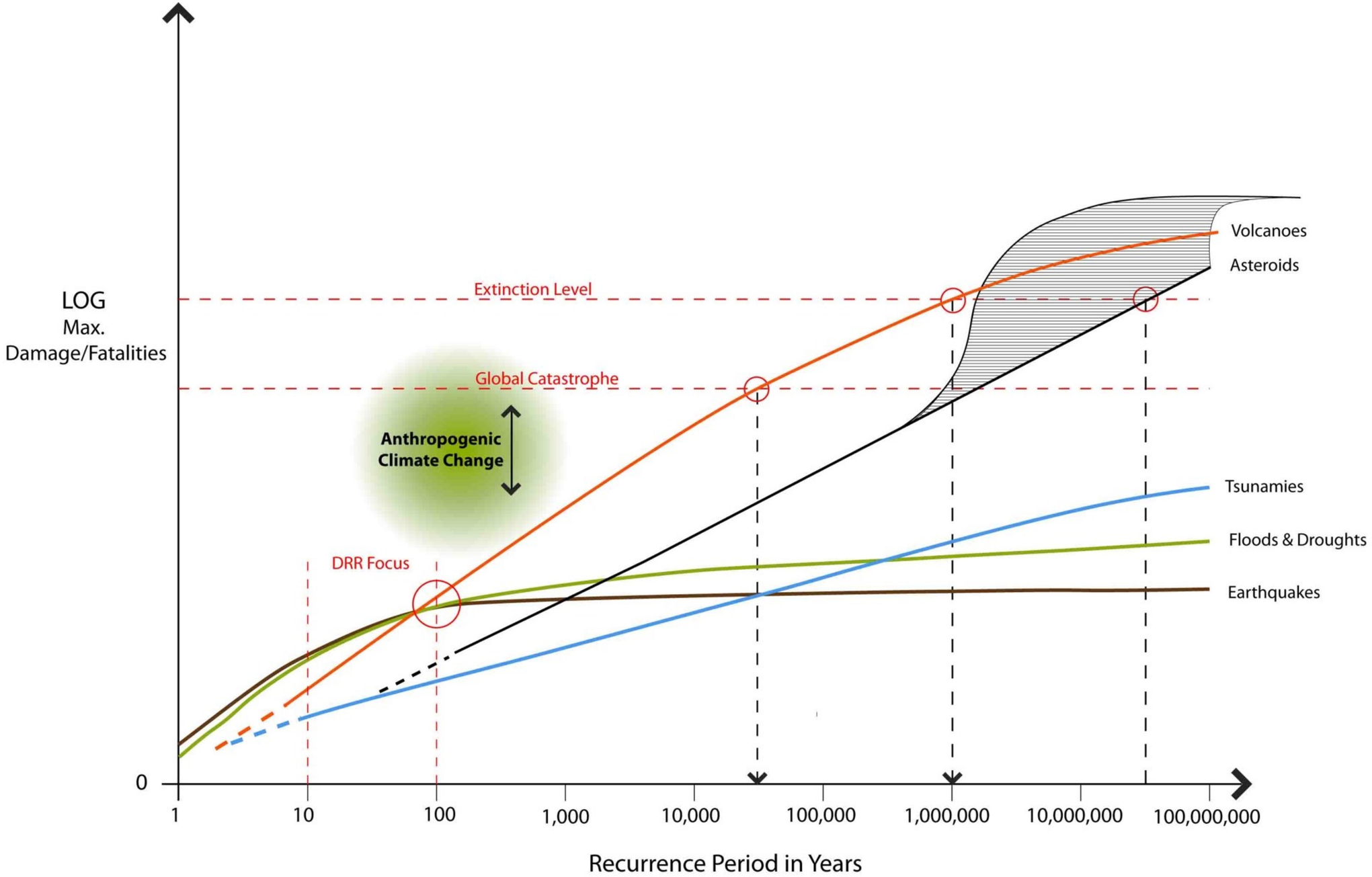

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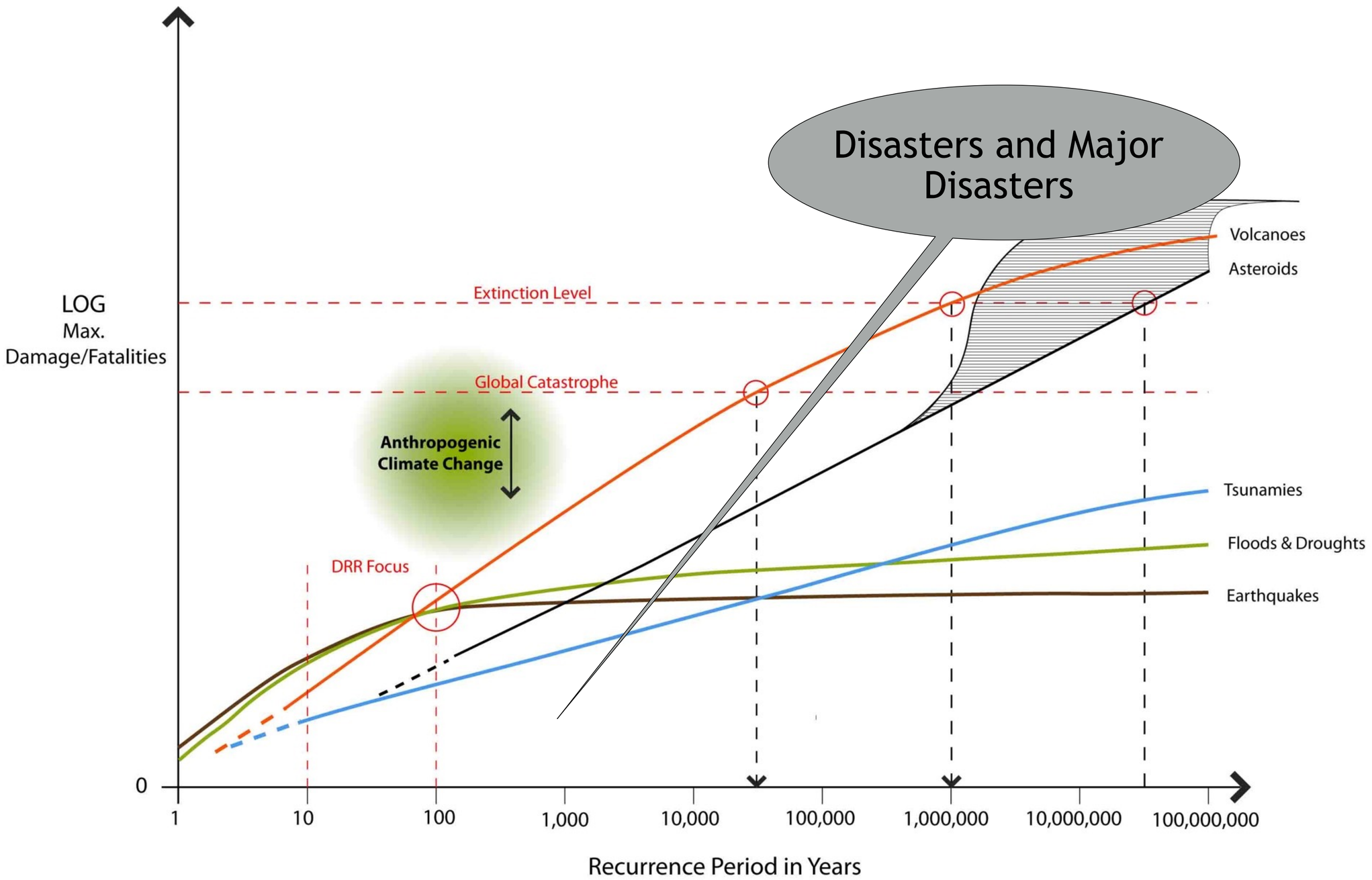

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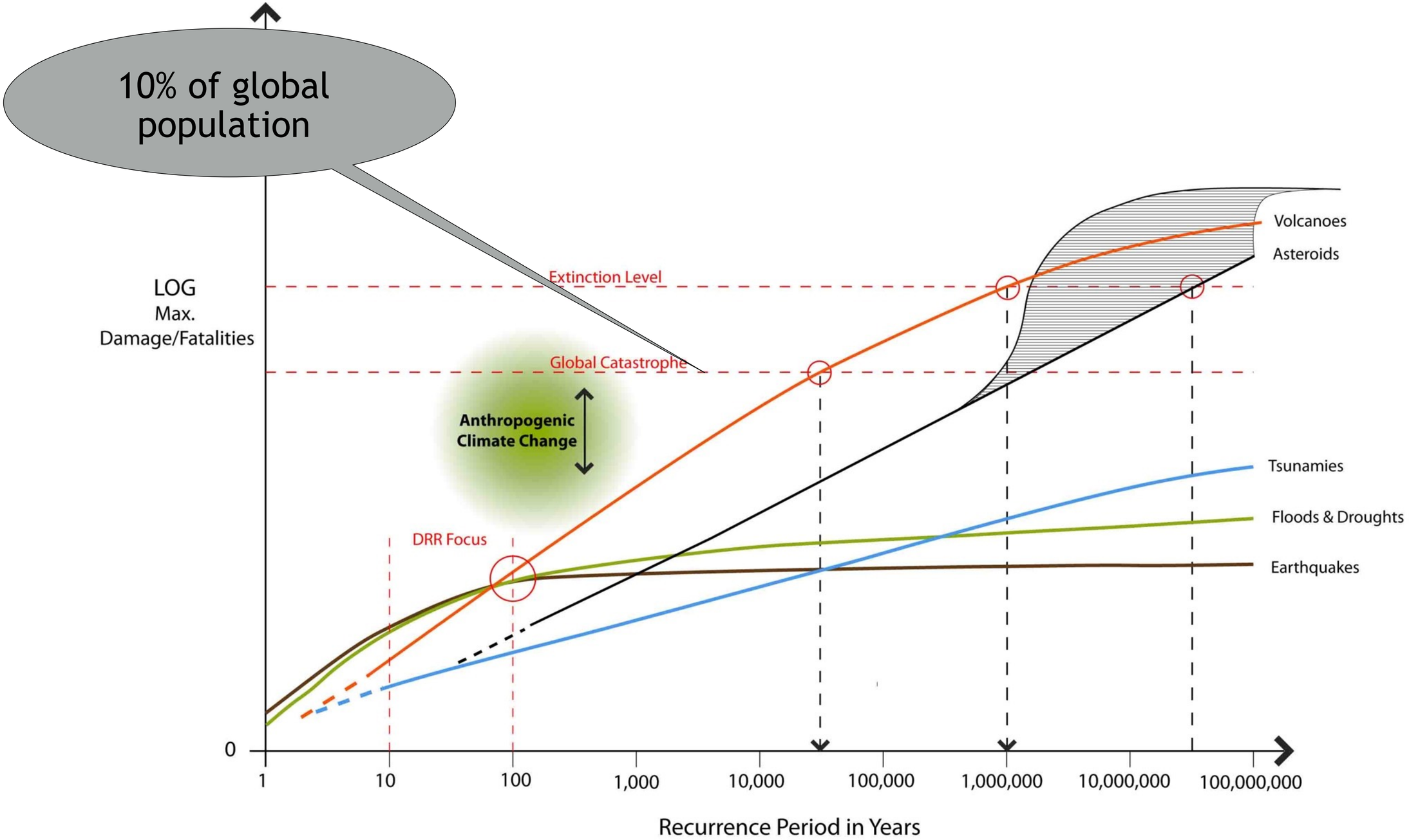

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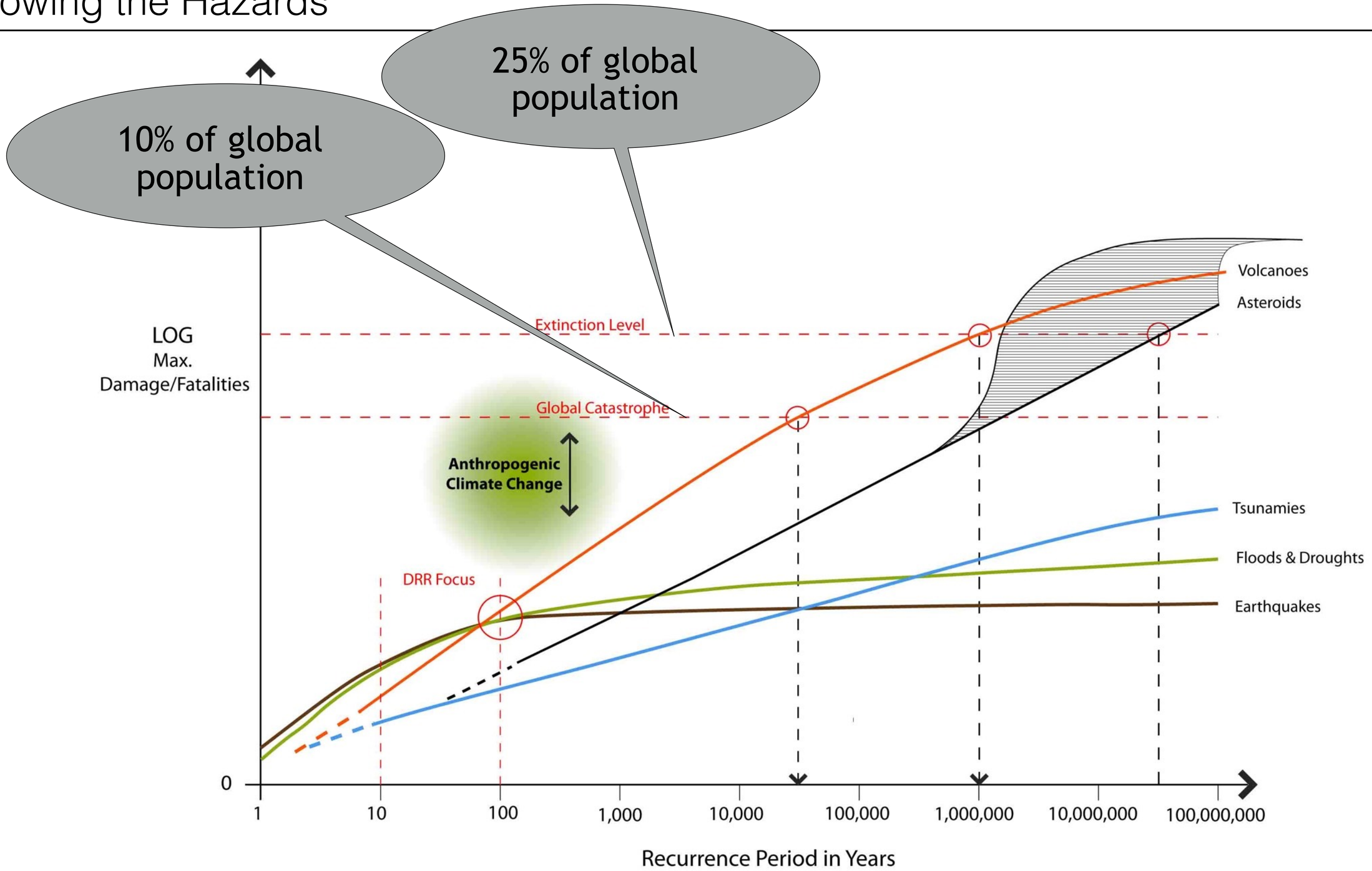

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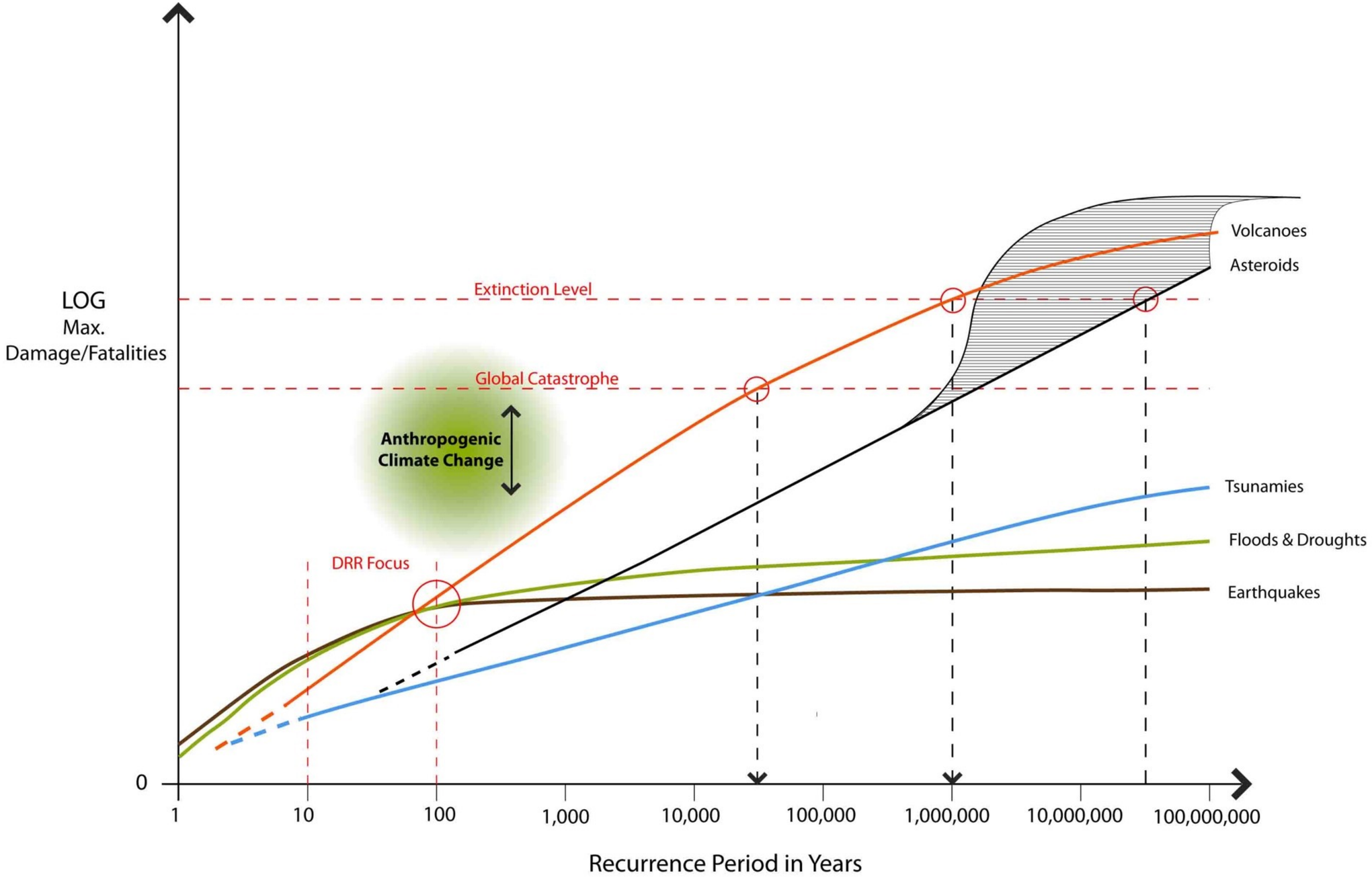
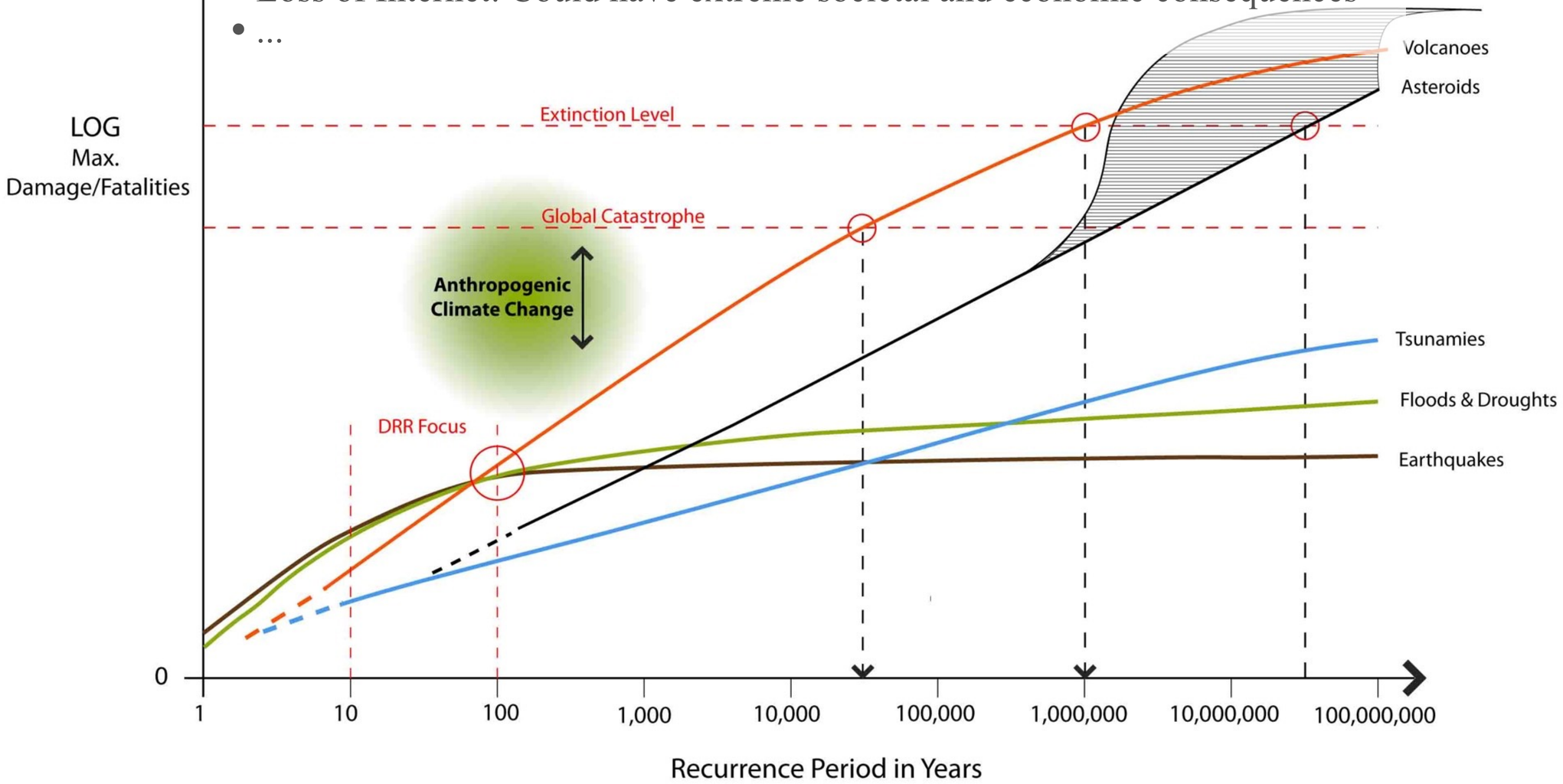


Knowing the Hazards

Other potential X-Events (see, e.g., John Casti, 2012)**:**

- Solar Storms: could take out major parts of the power grids
- Pandemics: Black Death killed 30-60% of the population in impacted areas
- Despots: Genghis Khan eliminated 11.1% of global population
- Loss of Internet: Could have extreme societal and economic consequences
- ...



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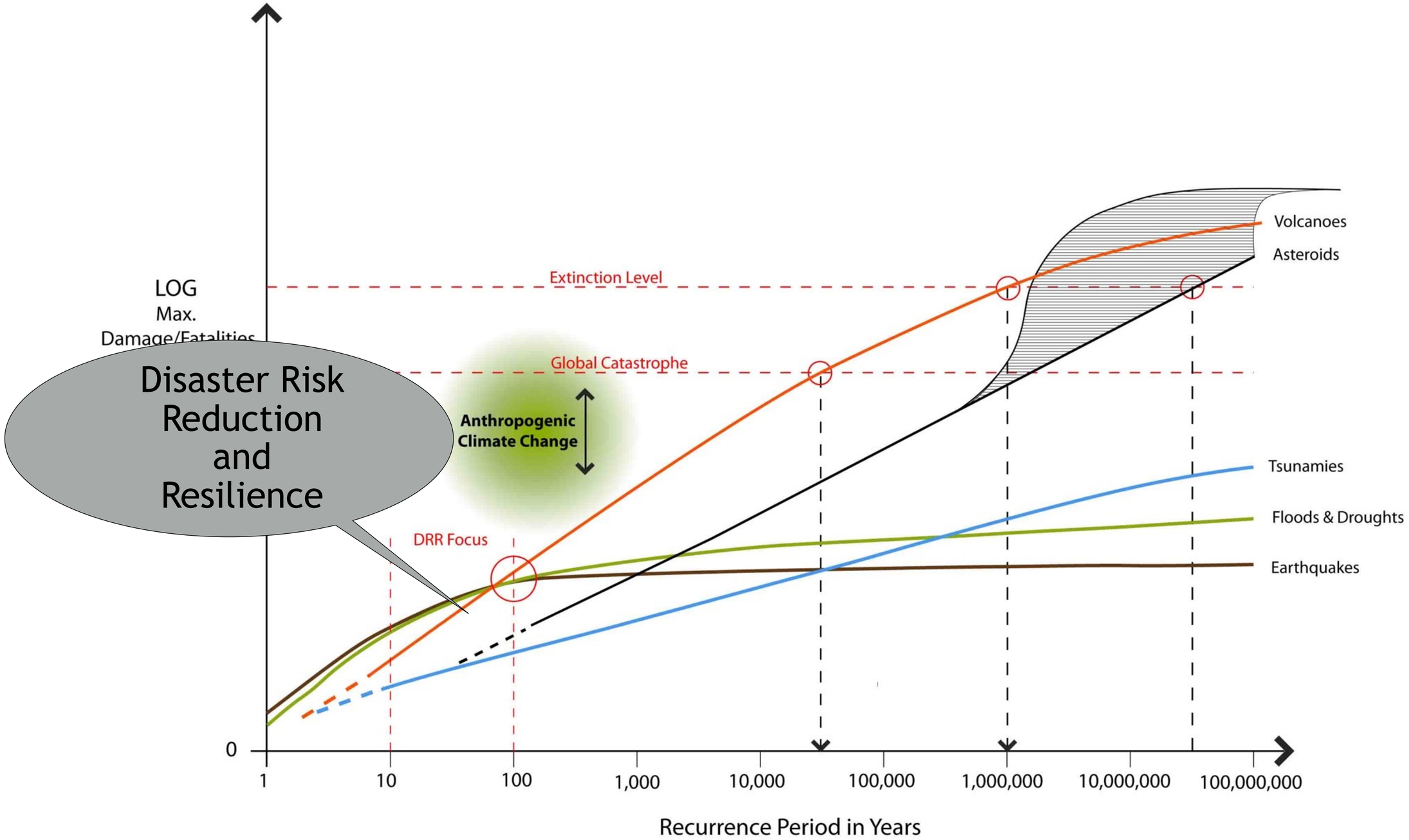

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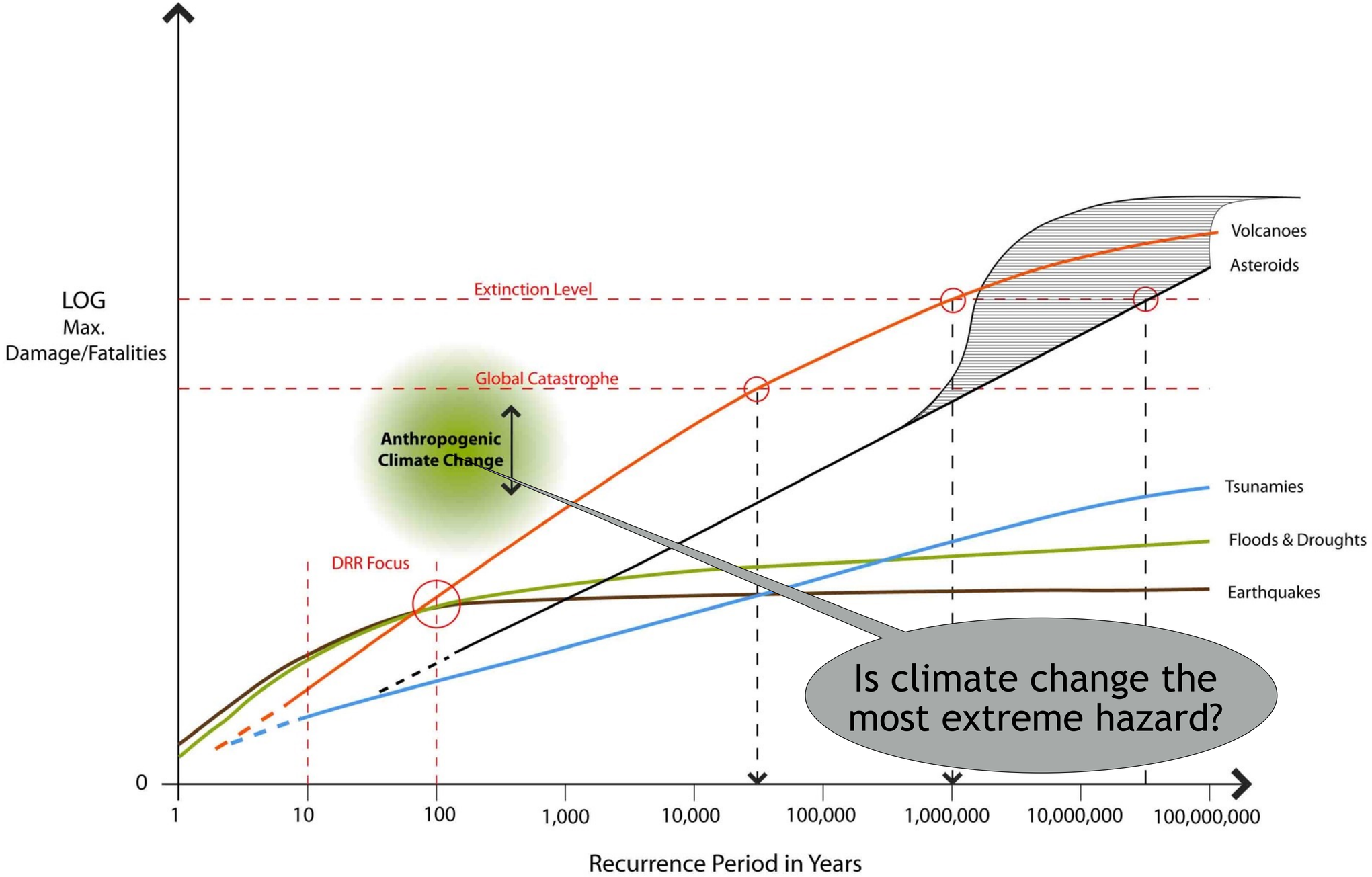

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Data base
Detecting Change
Assessing Knowledge

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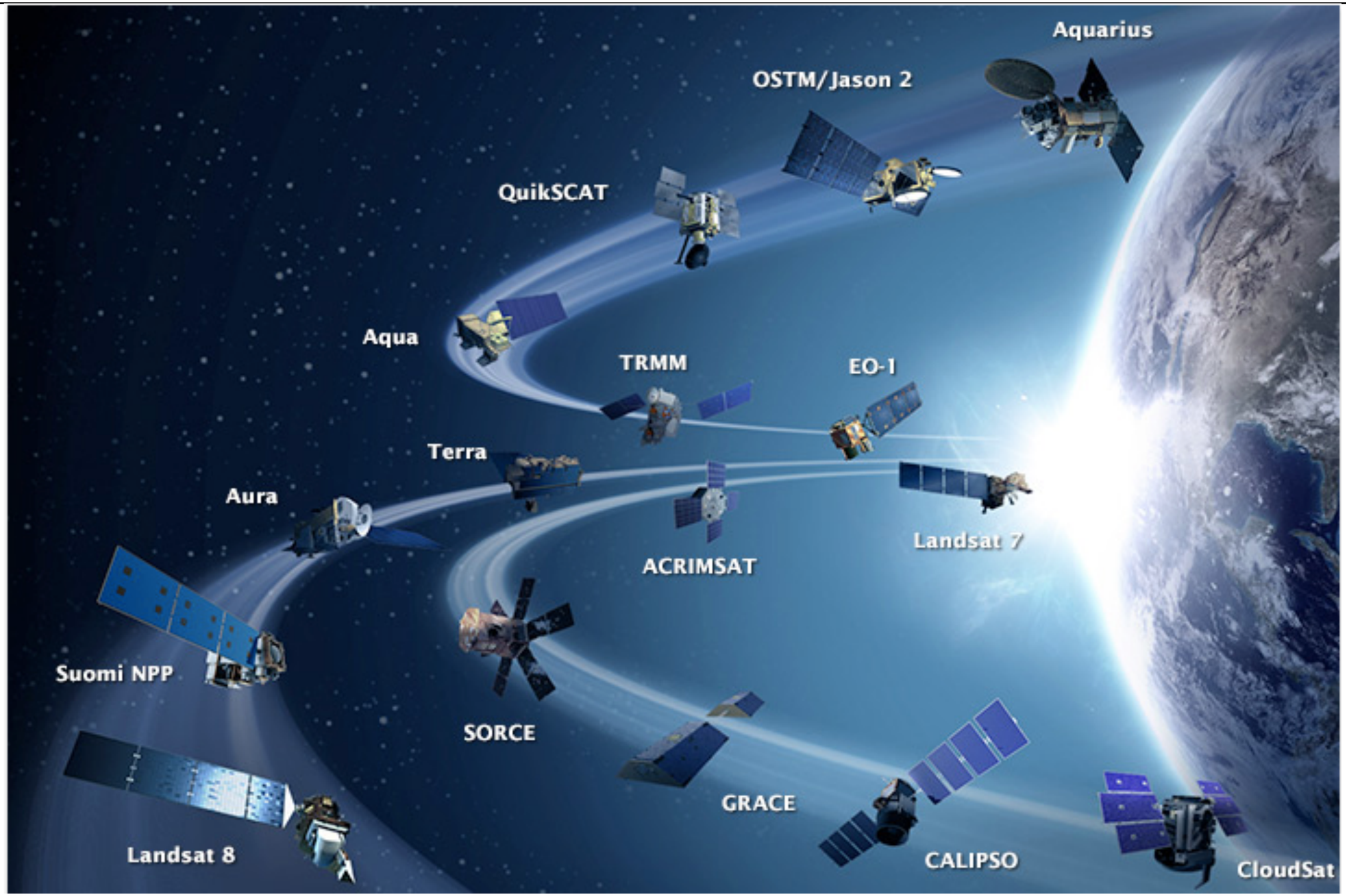

2013

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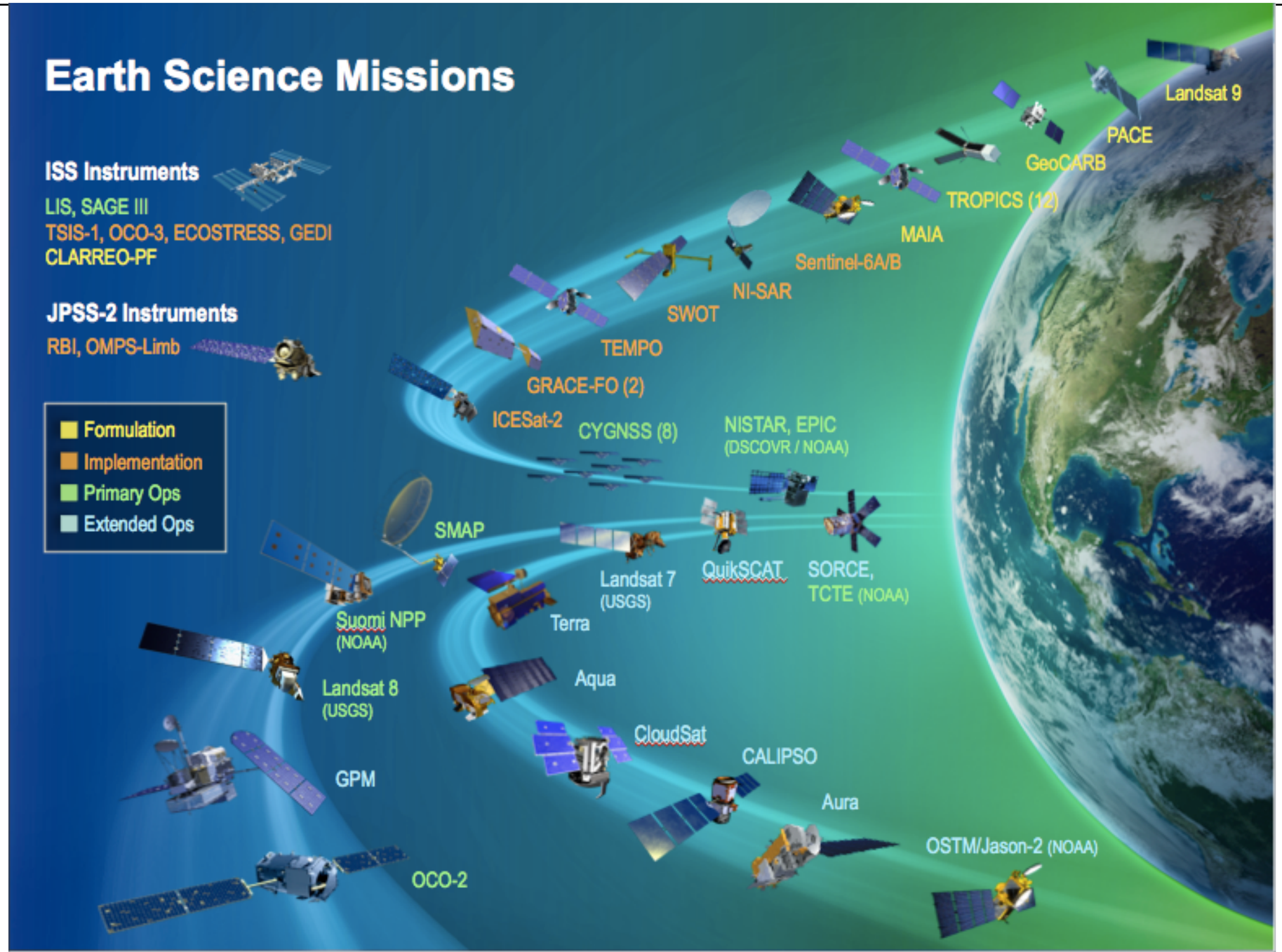
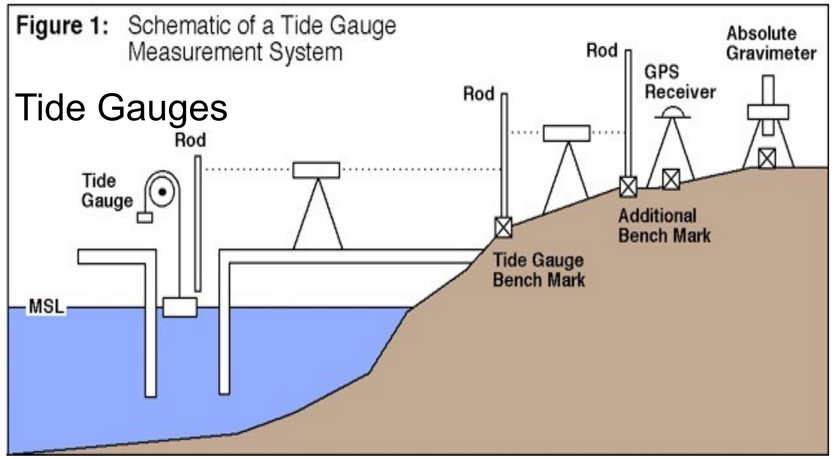


2018

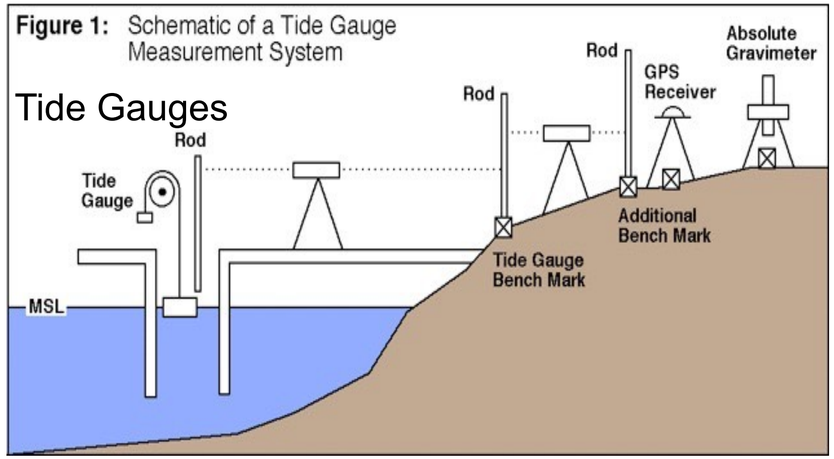
Geodetic Monitoring of Sea Level



http://sealevel.colorado.edu/tidegauges.html

The Data: Example Sea Level Changes

Geodetic Monitoring of Sea Level



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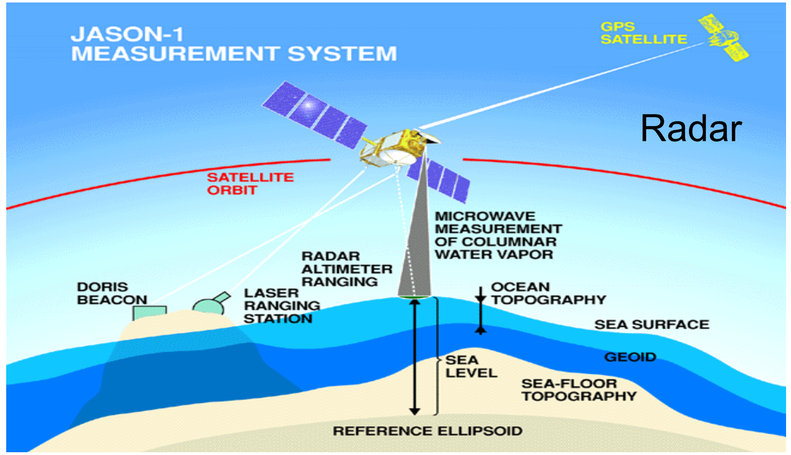
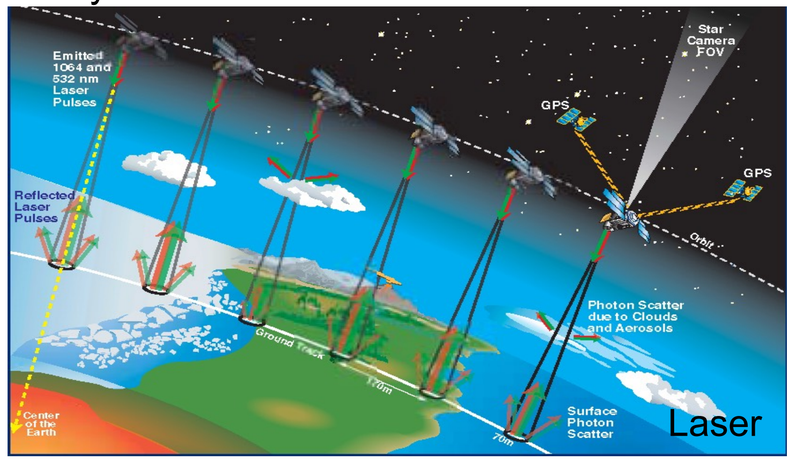
Satellite Altimetry





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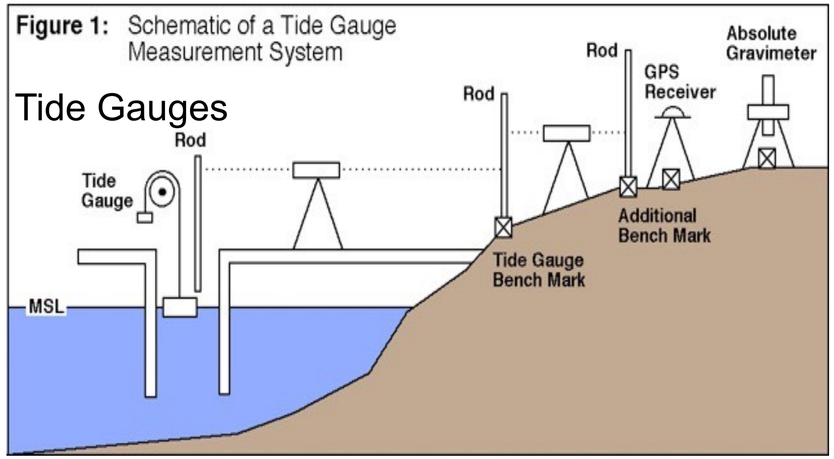

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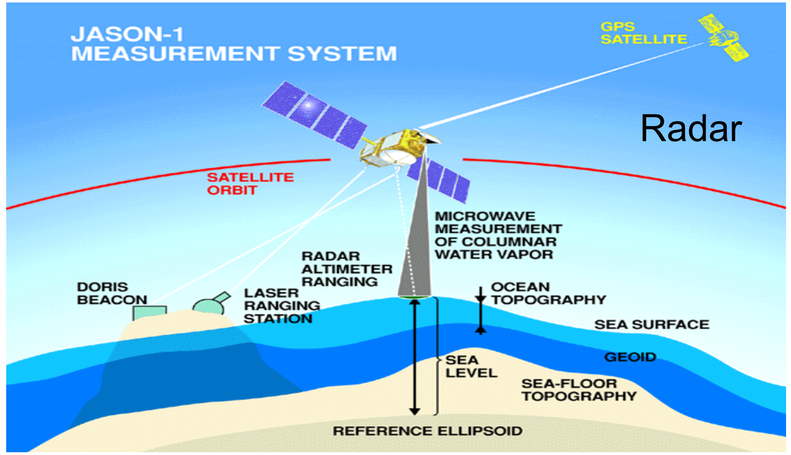

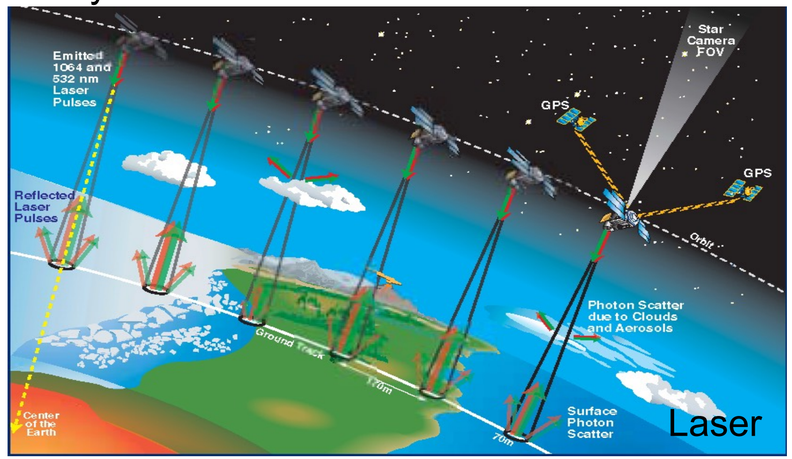

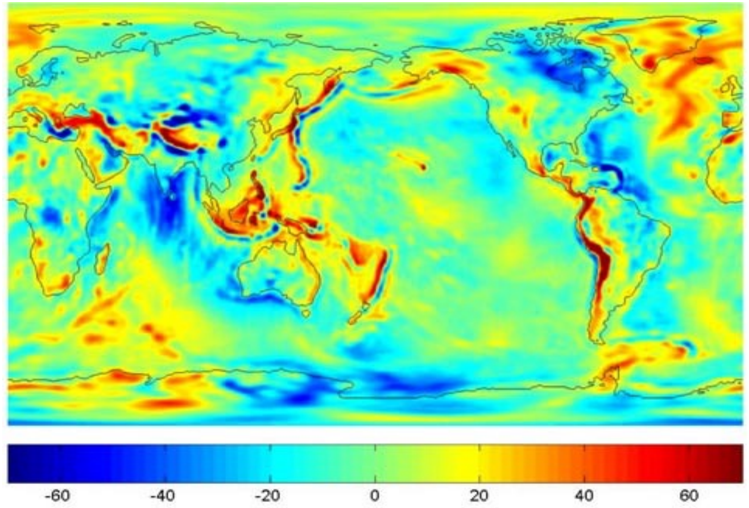

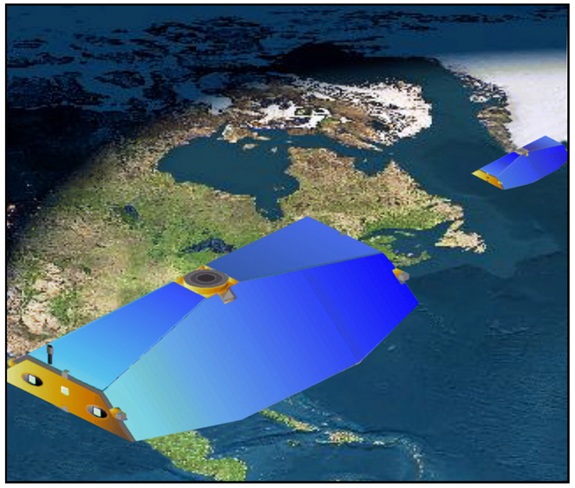

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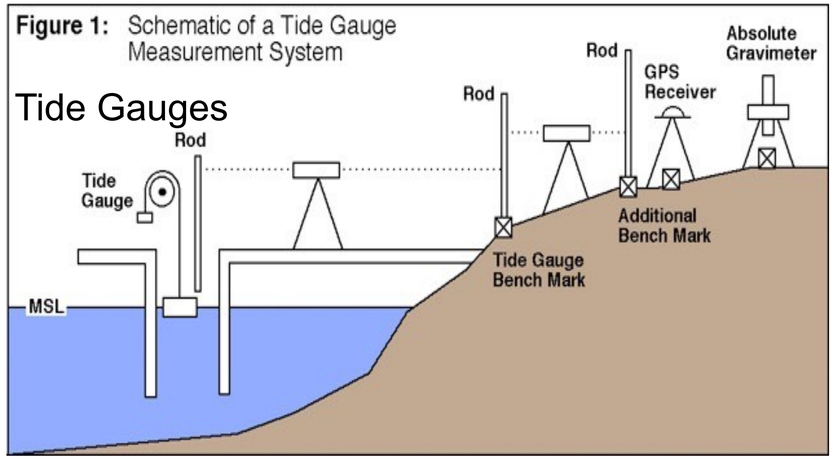

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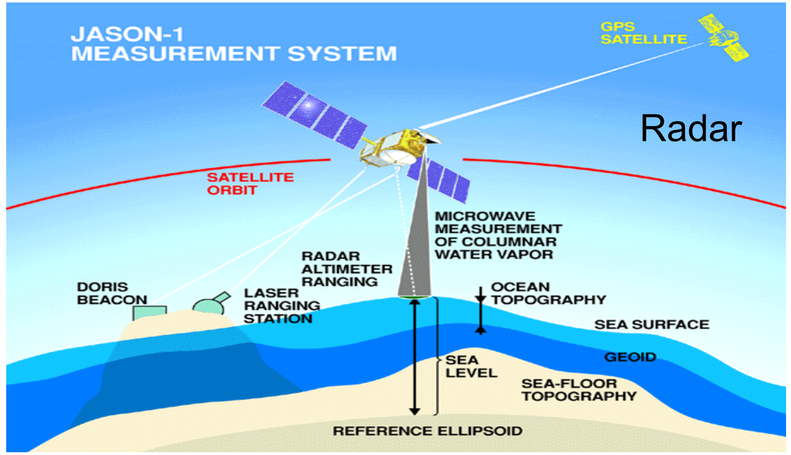
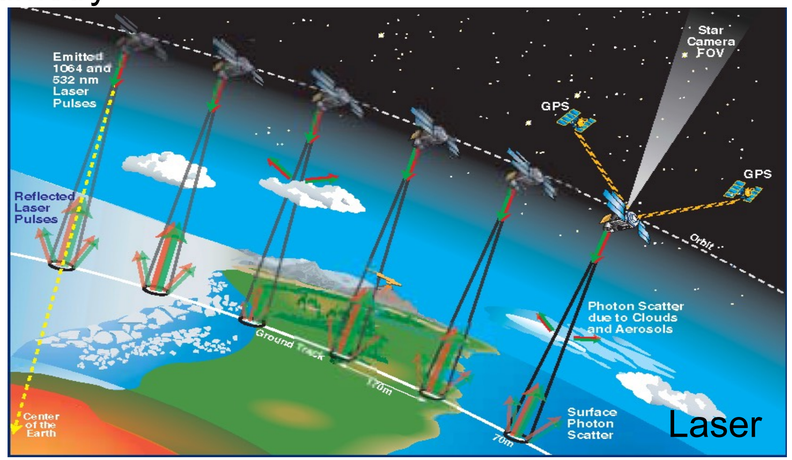
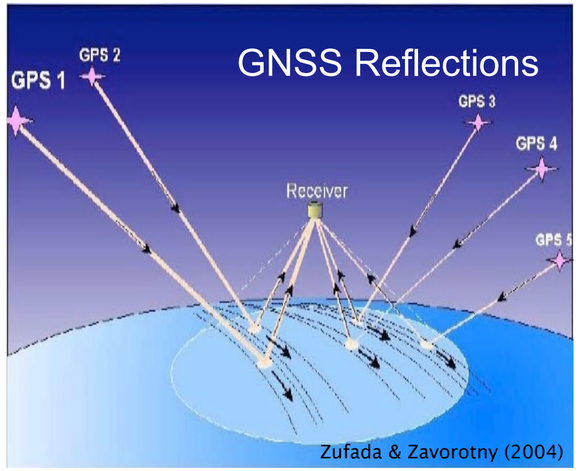
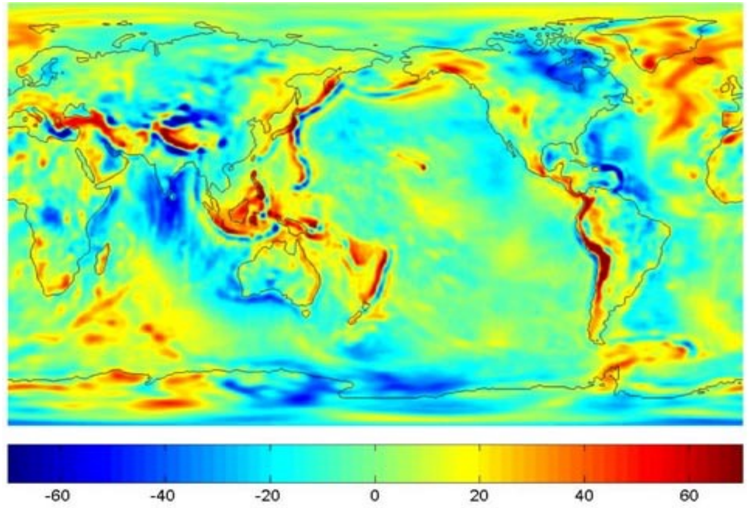


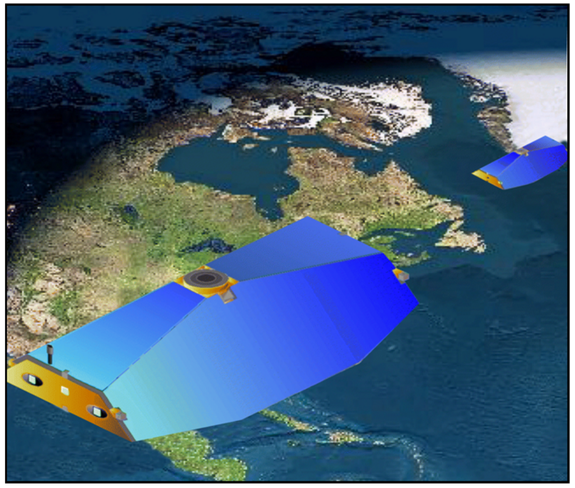


Larson eta l. (2014)

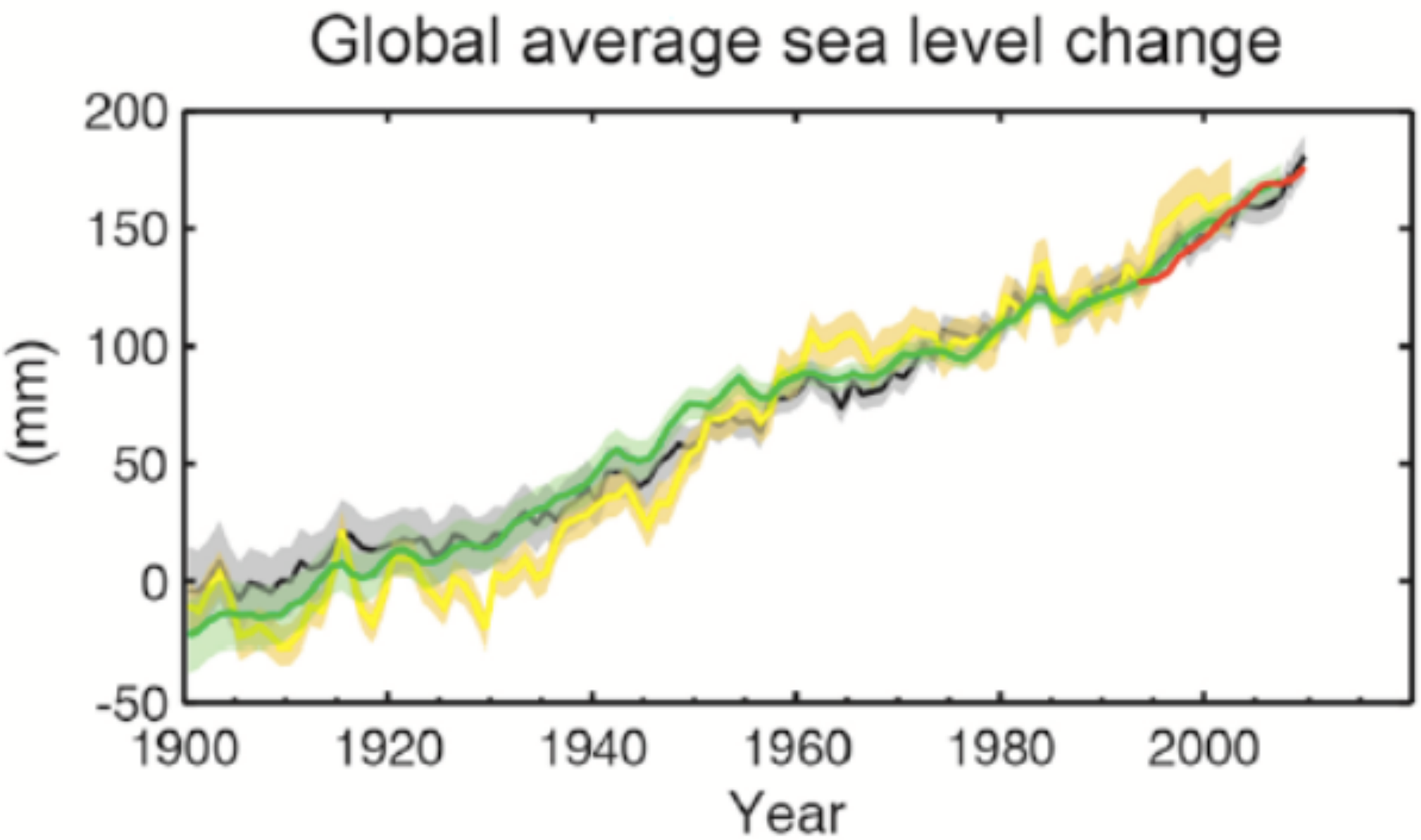


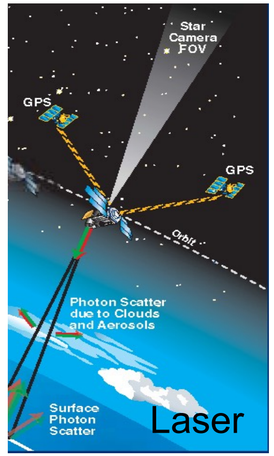
Zufada & Zavorotny (2004)

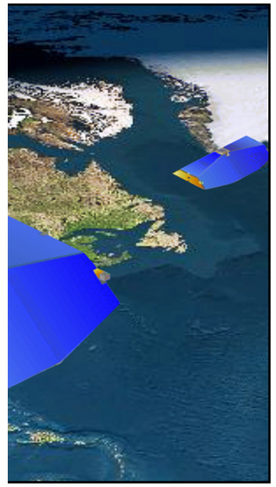




The Data: Example Sea Level Changes

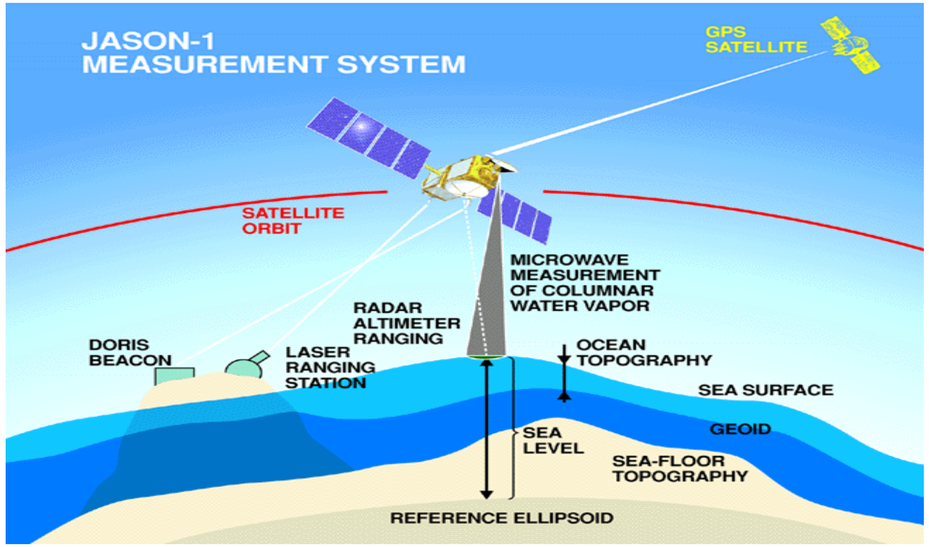






Observing the Planet

Sea surface height (not sea level):



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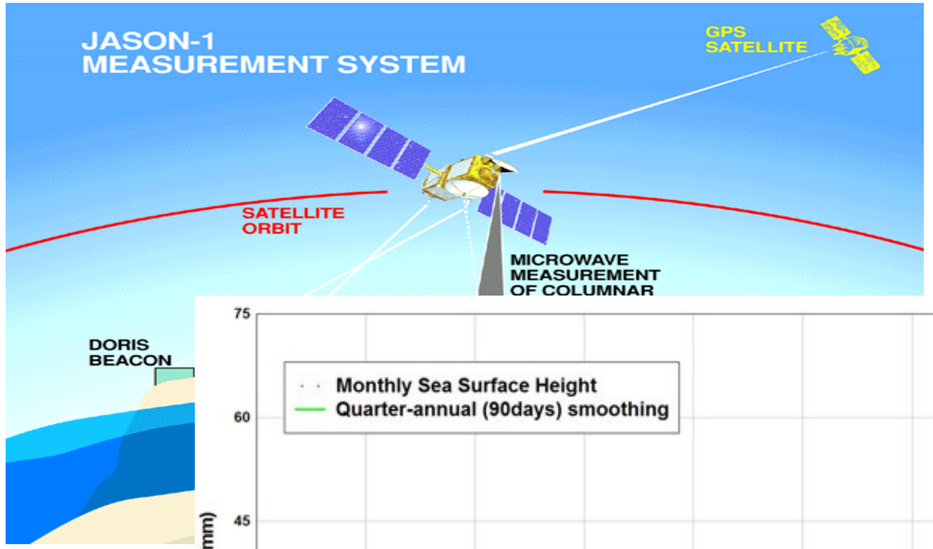

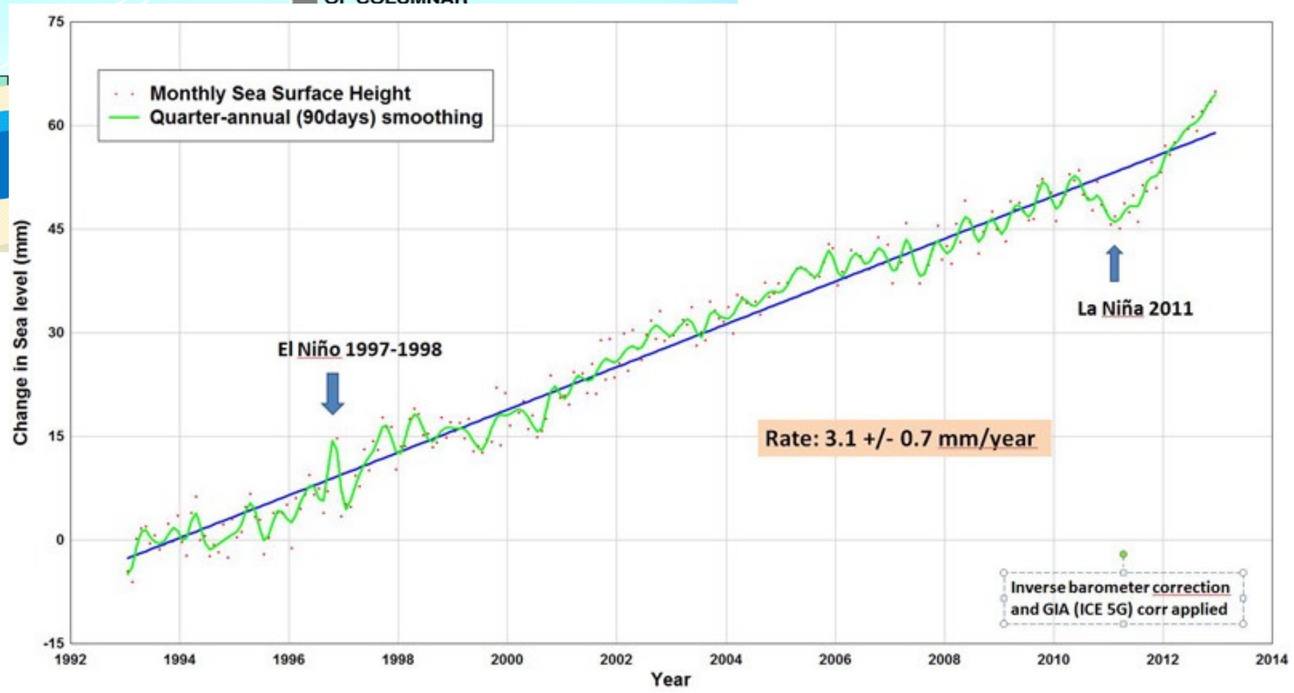

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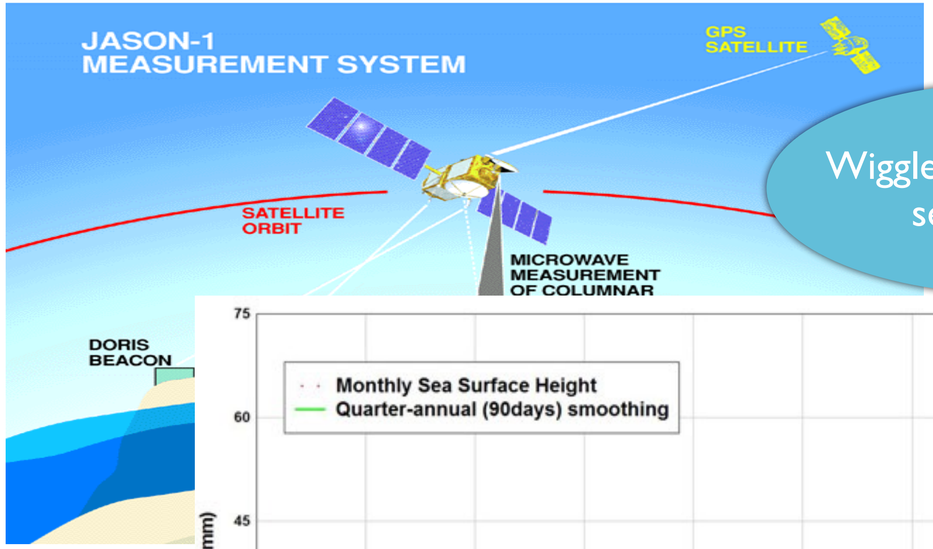
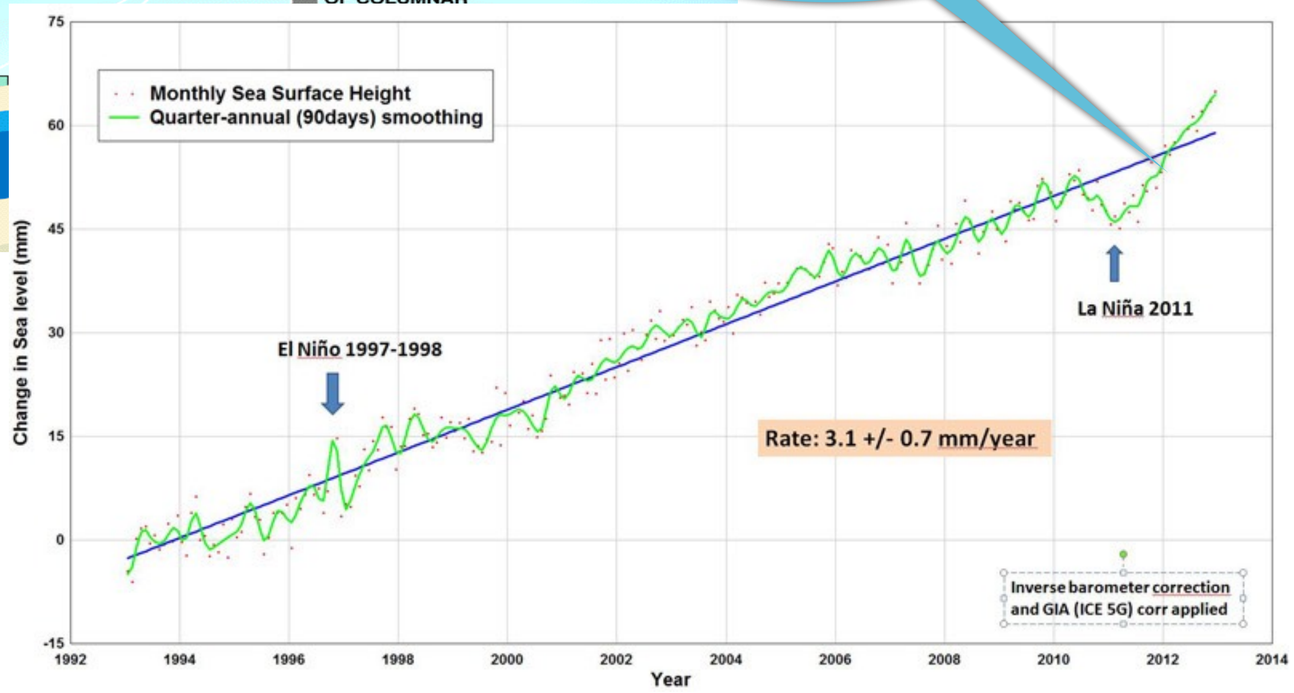


Wiggles of 1-2 cm over several years



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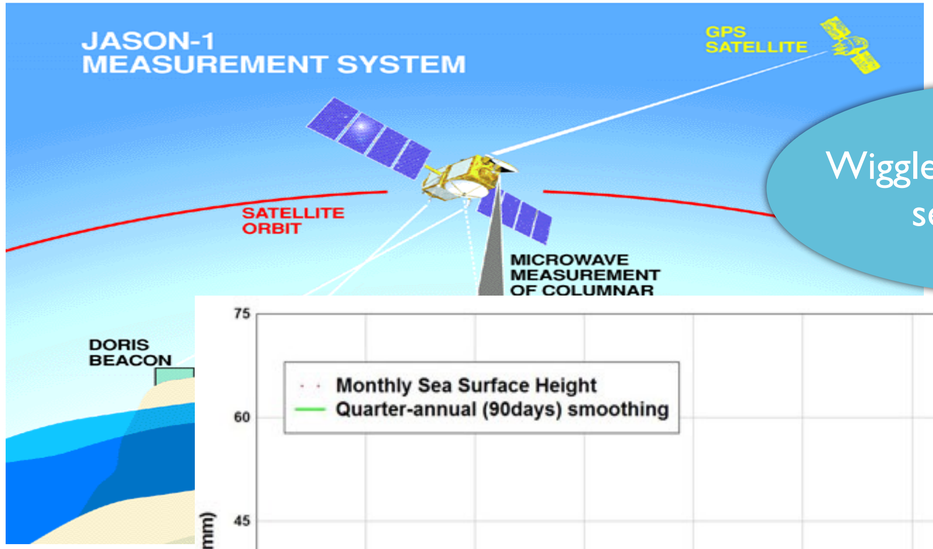

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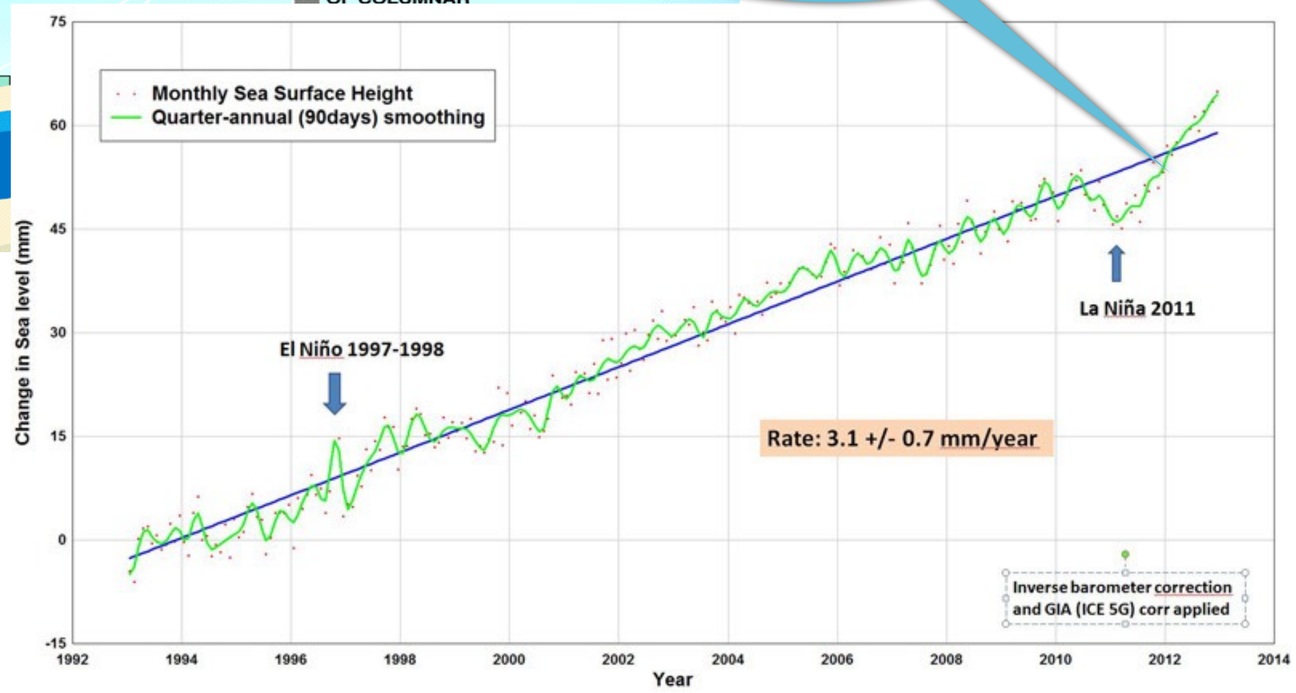
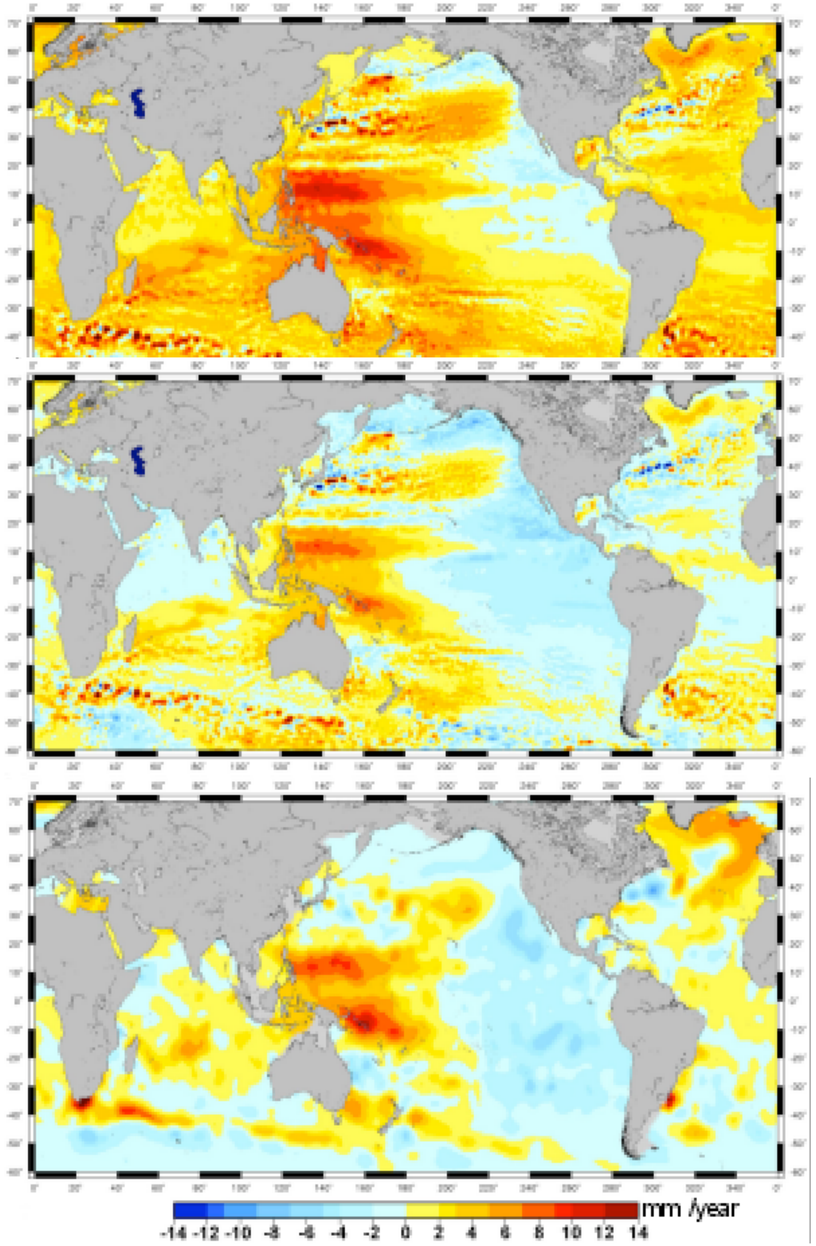


Sea surface height

1993-2010

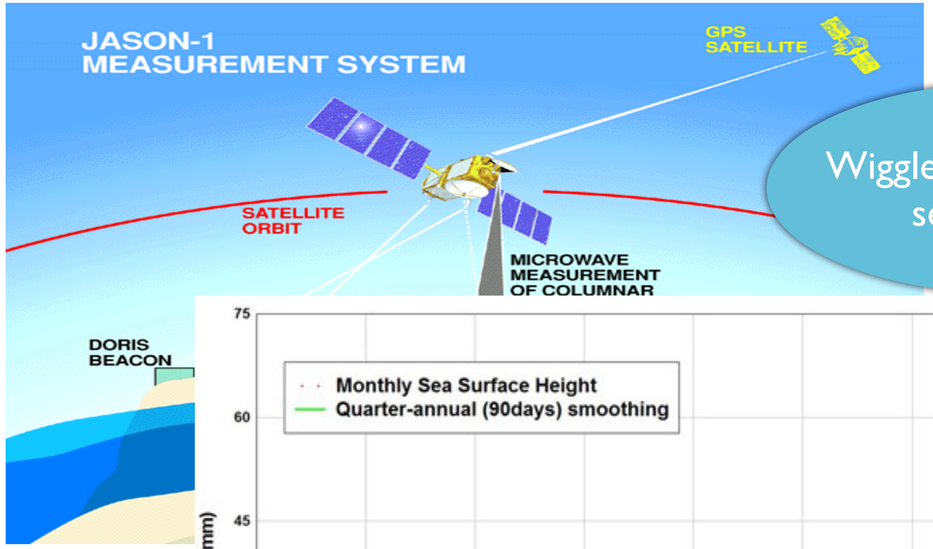


minus
3.2 mm/yr

steric height

Meyssignac and Cazenave, 2012

Sea surface height (not sea level):



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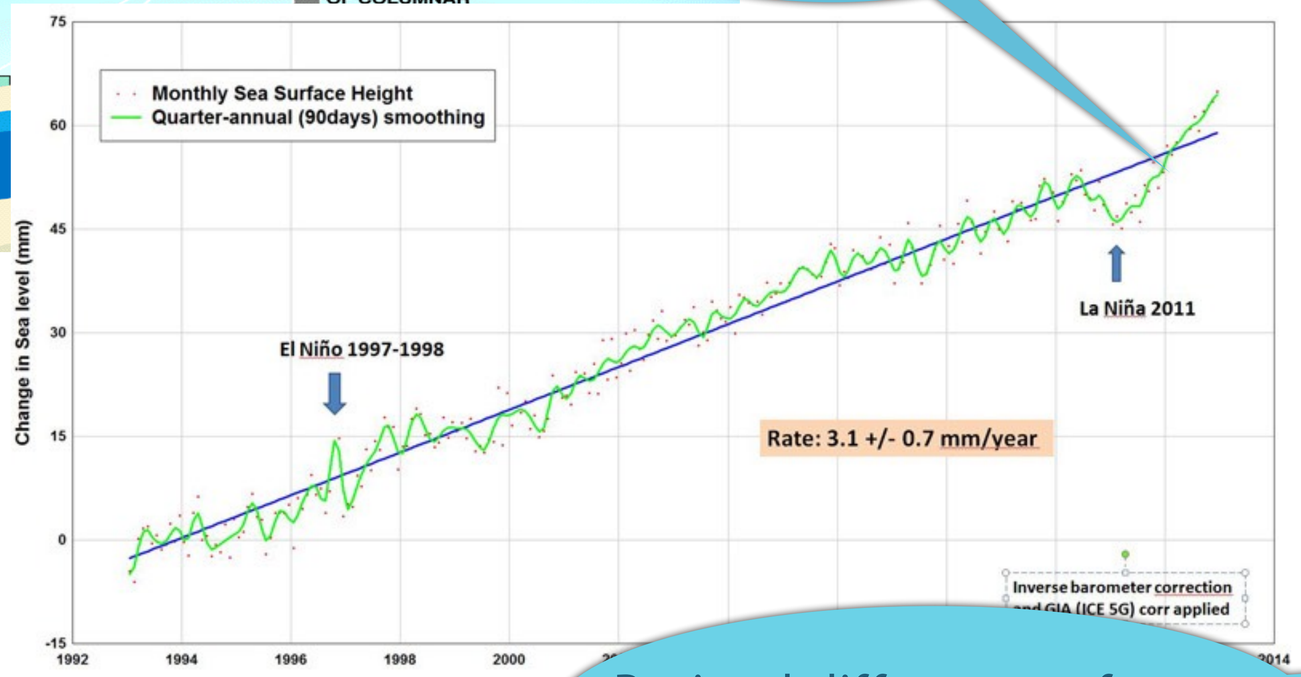


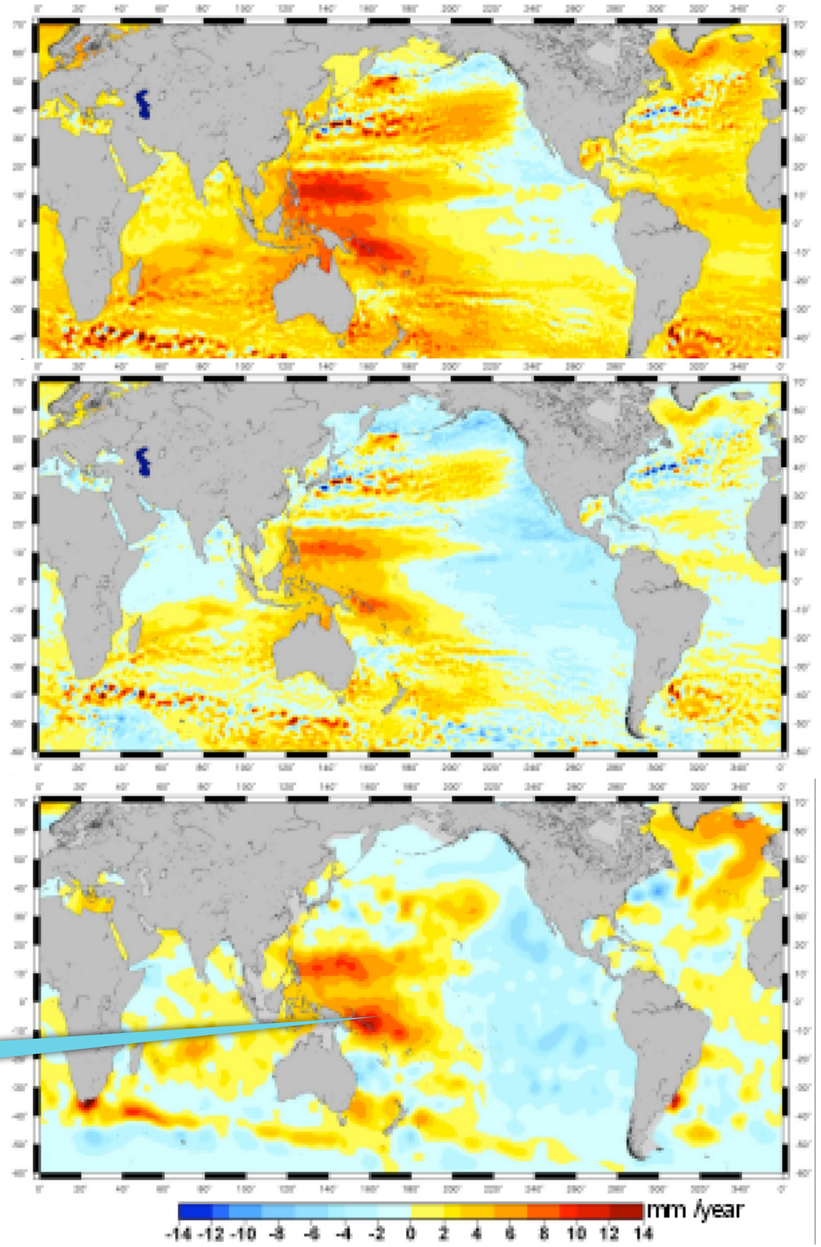
Regional differences of more than 30 cm over 20 years

Sea surface height

1993-2010

minus 3.2 mm/yr

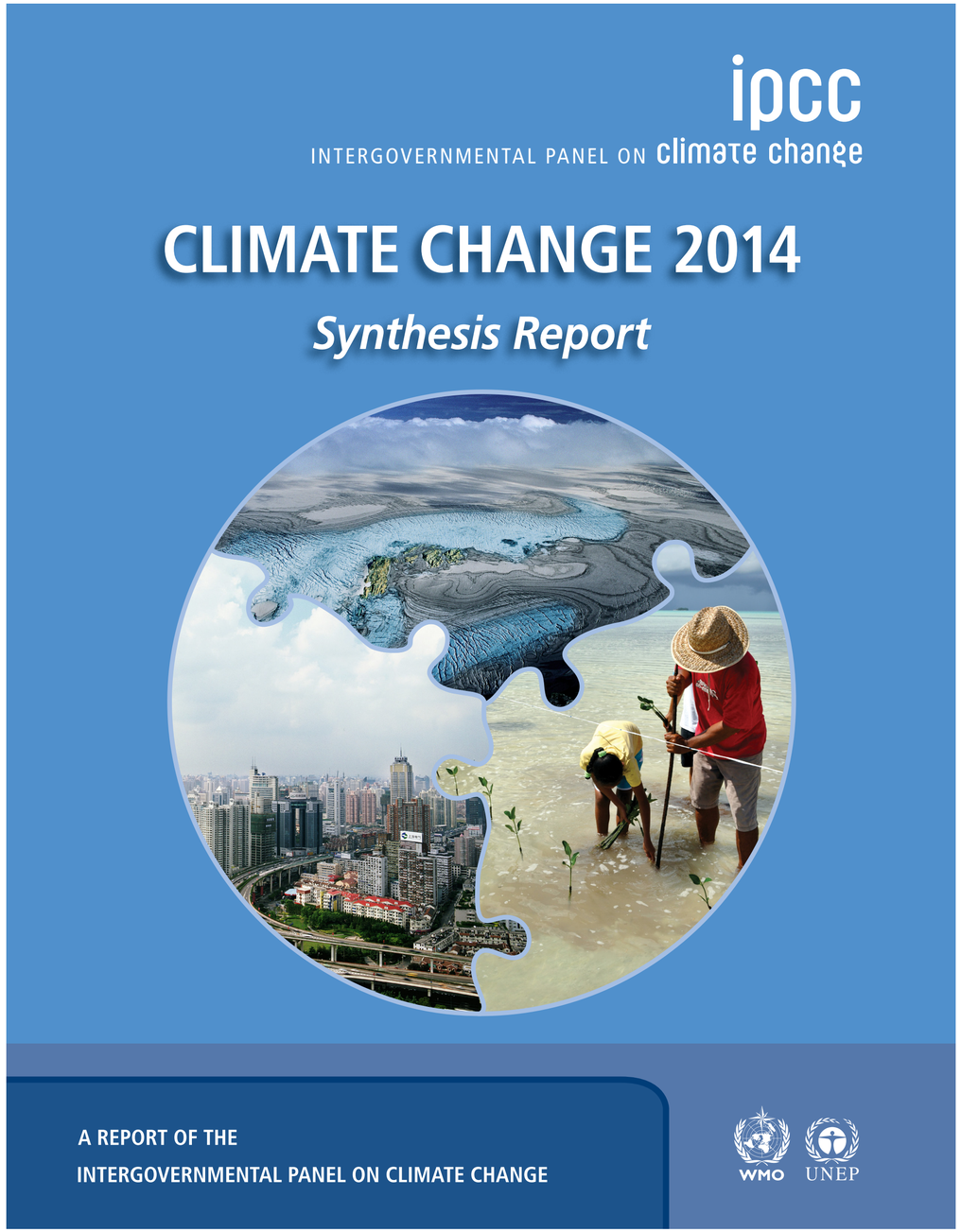
steric height



Meyssignac and Cazenave, 2012

Observing the Planet

Observing the Planet



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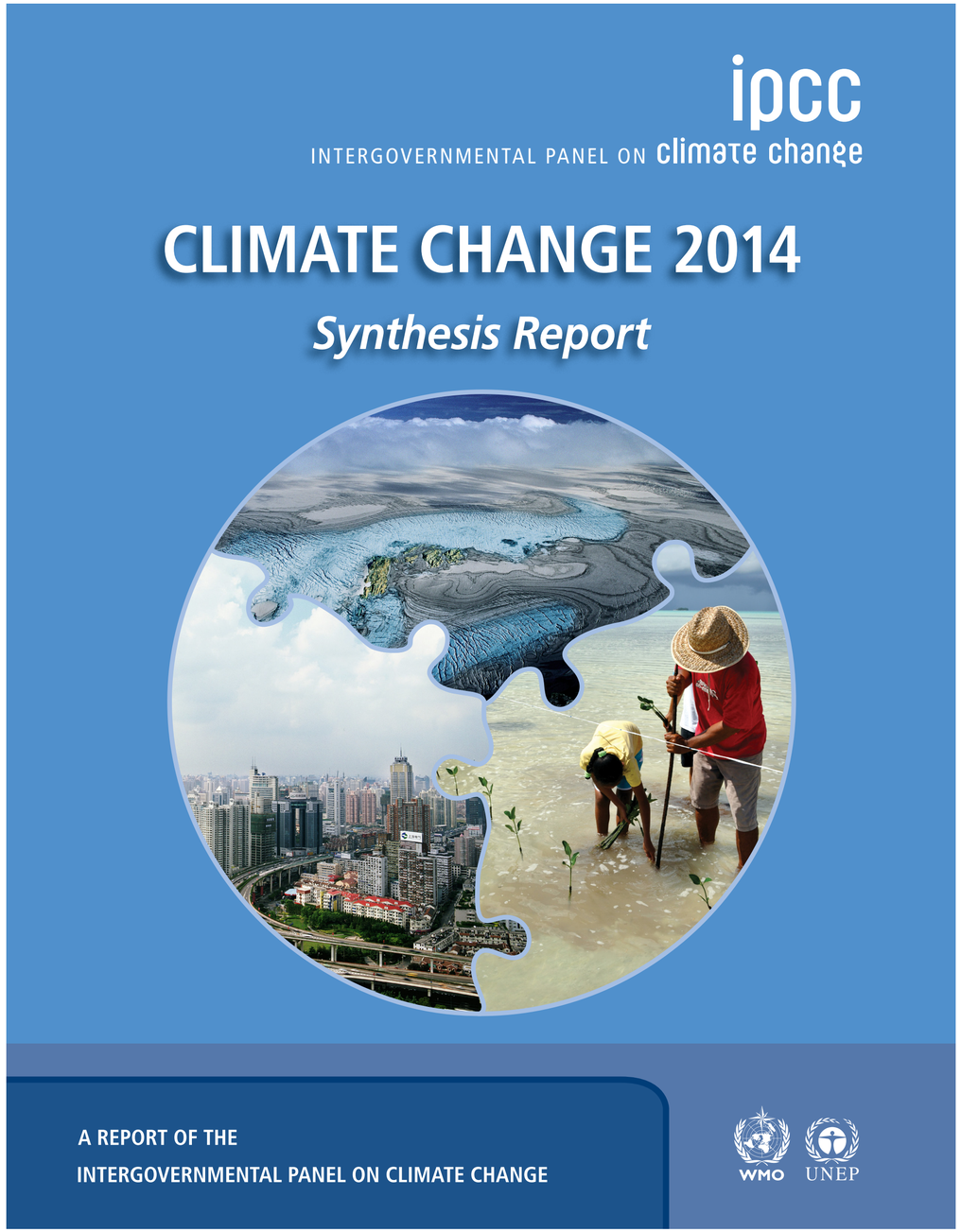
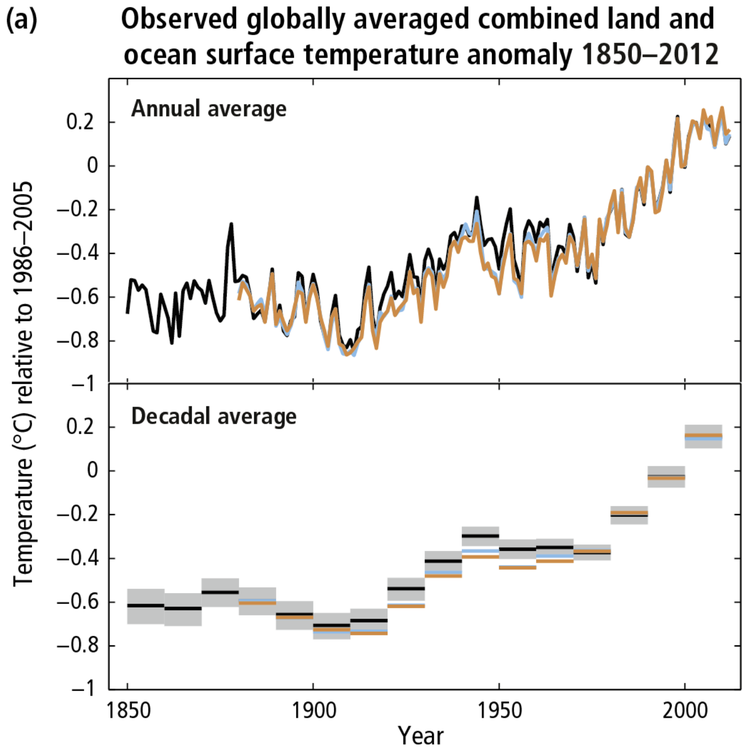
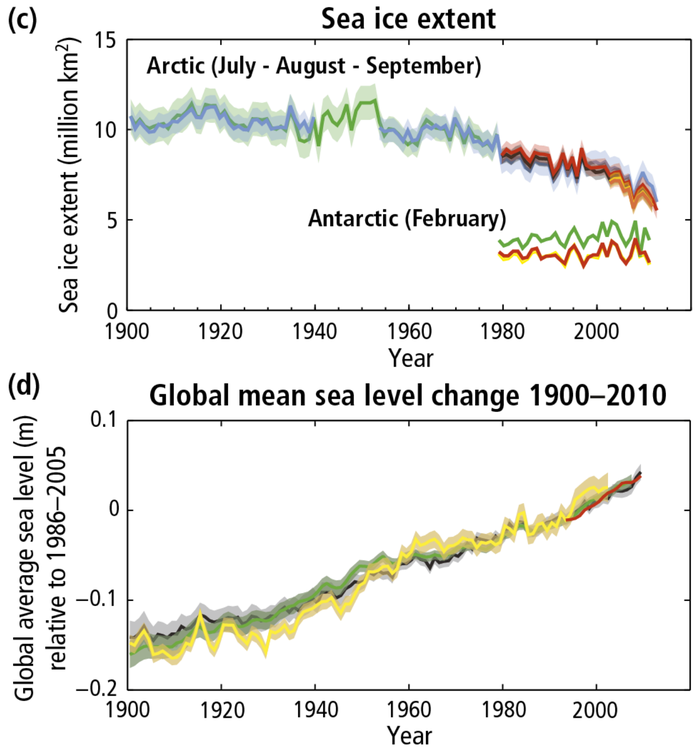
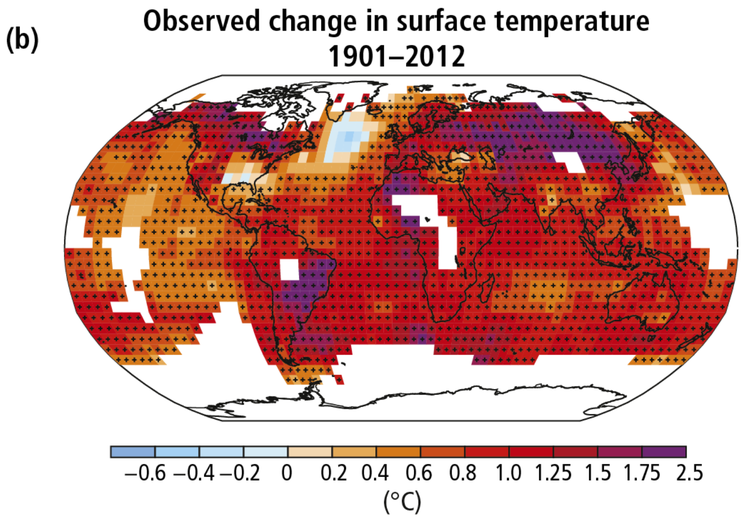
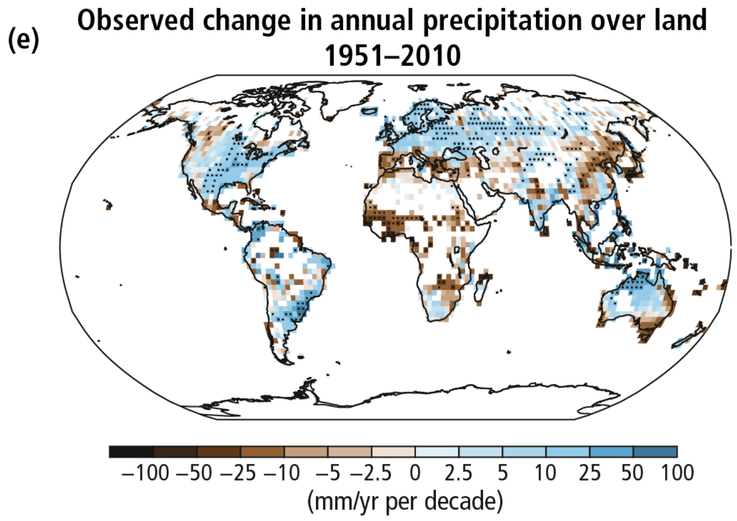
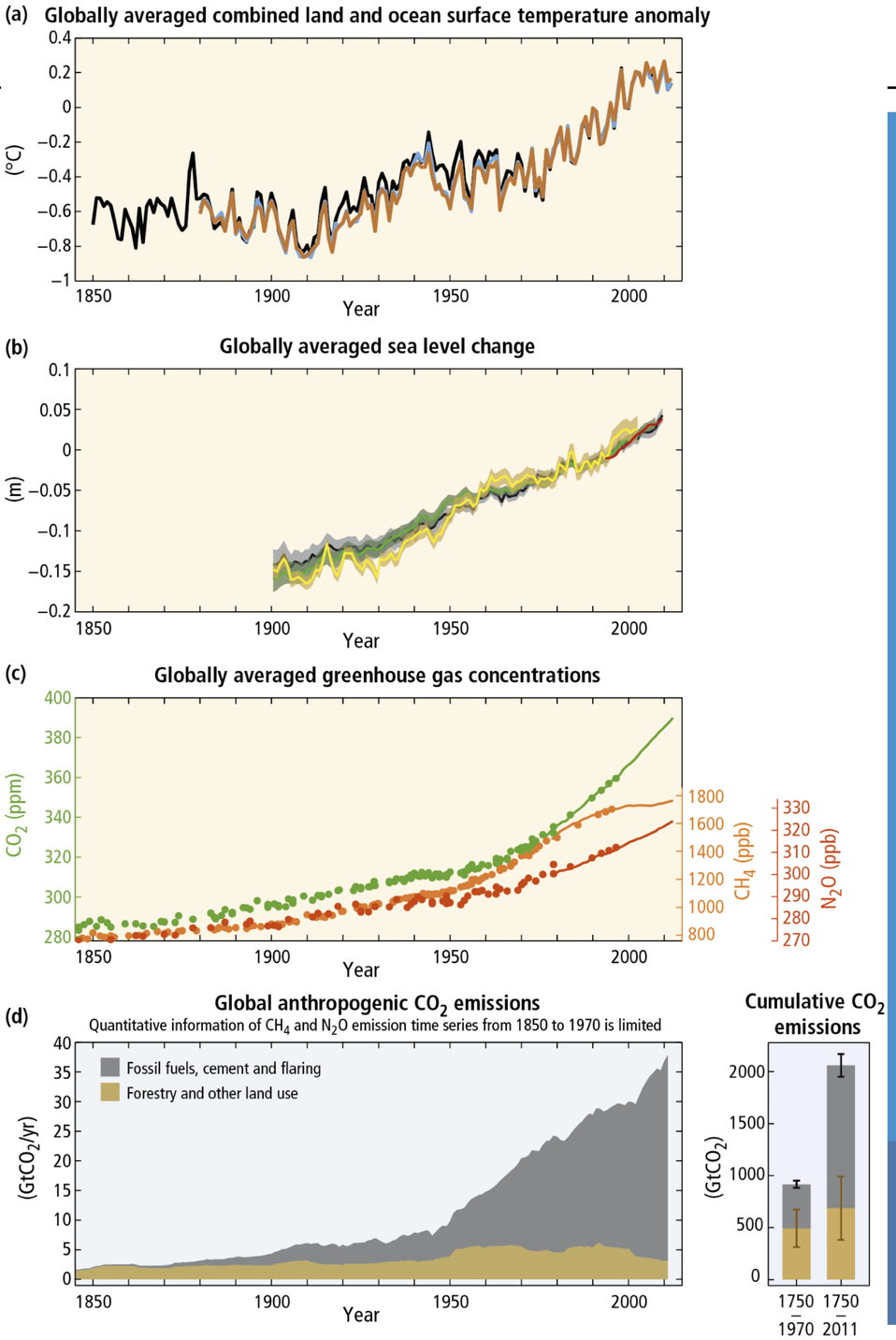


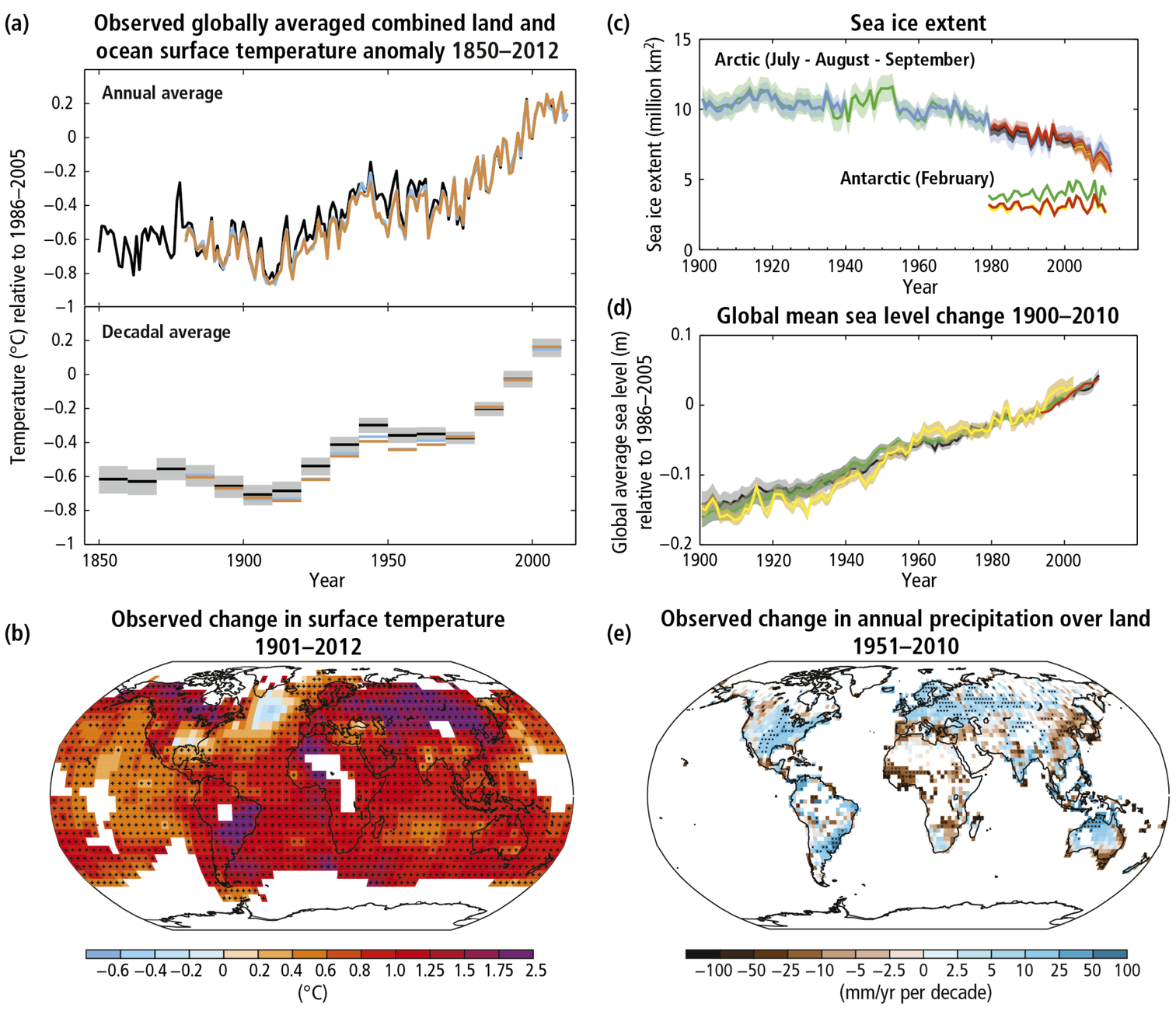






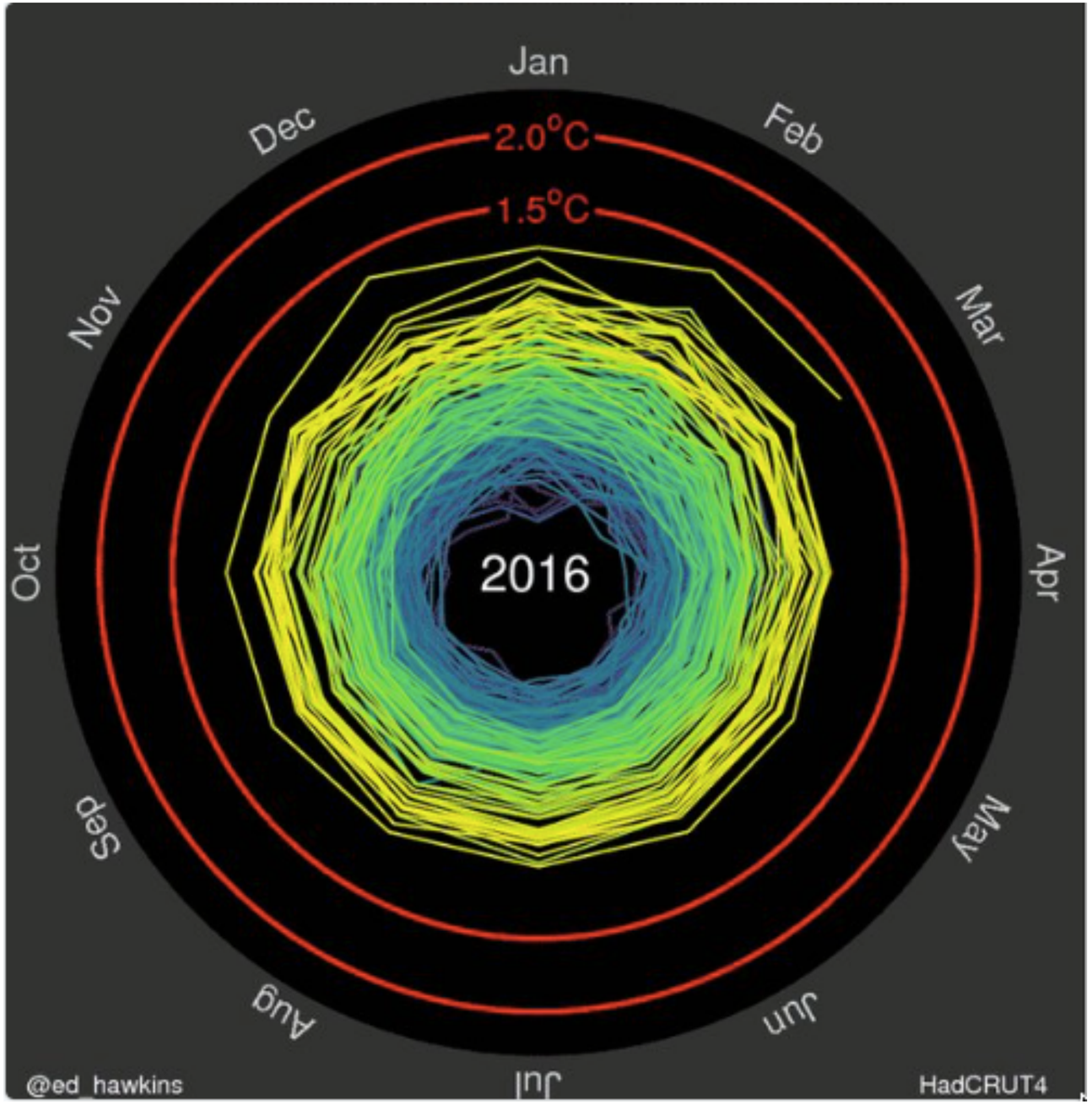



(a) Globally averaged combined land and ocean surface temperature anomaly
(°C)
Year
(b) Globally averaged sea level change
(m)
Year
(c) Globally averaged greenhouse gas concentrations
CO_2 (ppm)
CH_4 (ppb)
N_2O (ppb)
Year
(d) Global anthropogenic CO_2 emissions
Quantitative information of CH_4 and N_2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
($GtCO_2$/yr)
Year
Cumulative CO_2 emissions
($GtCO_2$)
1750–1970
1750–2011


(a) Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012
Annual average
Decadal average
Temperature (°C) relative to 1986–2005
Year
(b) Observed change in surface temperature 1901–2012
(°C)
(c) Sea ice extent
Arctic (July - August - September)
Antarctic (February)
Sea ice extent (million km²)
Year
(d) Global mean sea level change 1900–2010
Global average sea level (m) relative to 1986–2005
Year
(e) Observed change in annual precipitation over land 1951–2010
(mm/yr per decade)

Detecting Changes

Detecting Changes



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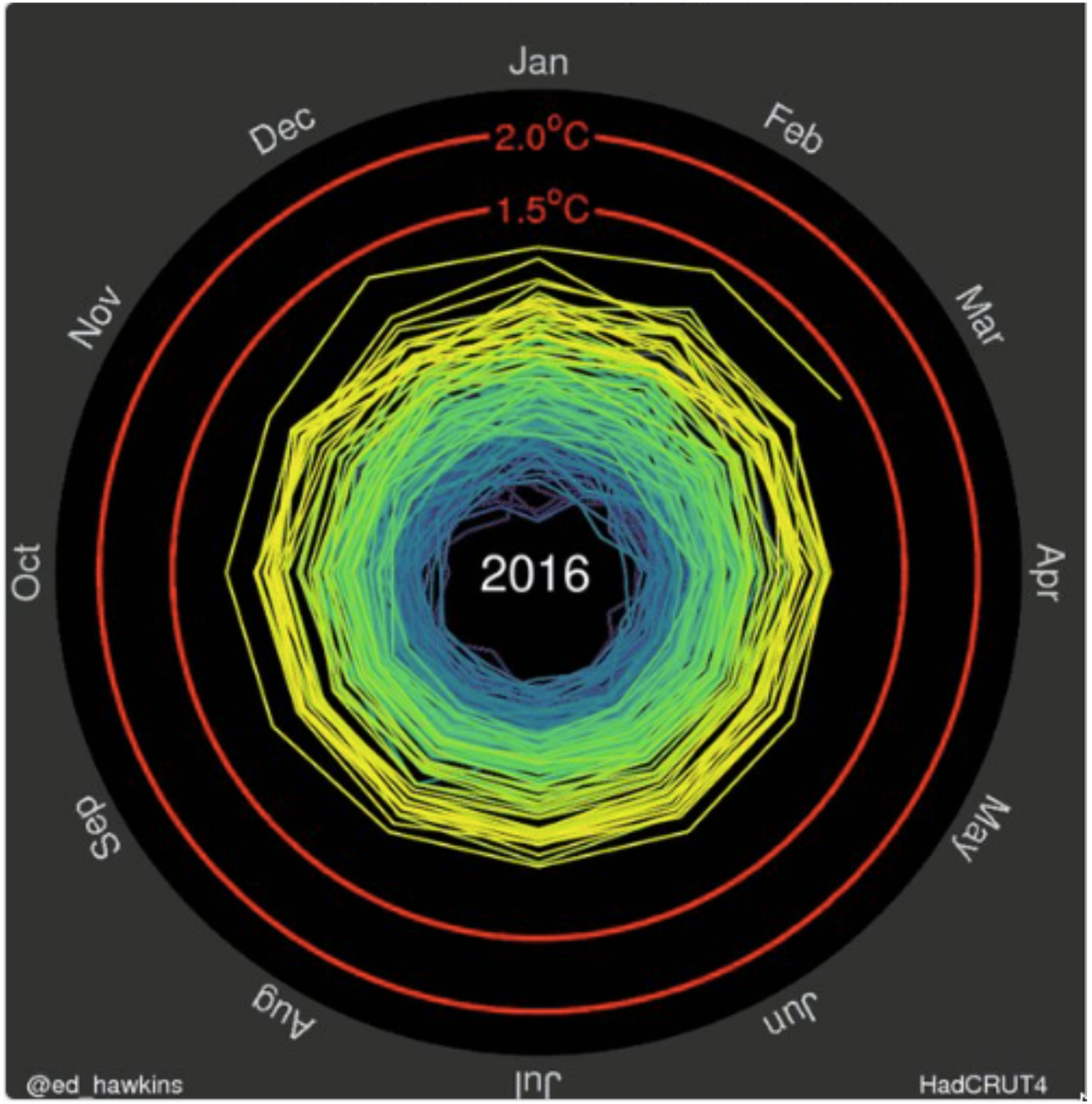

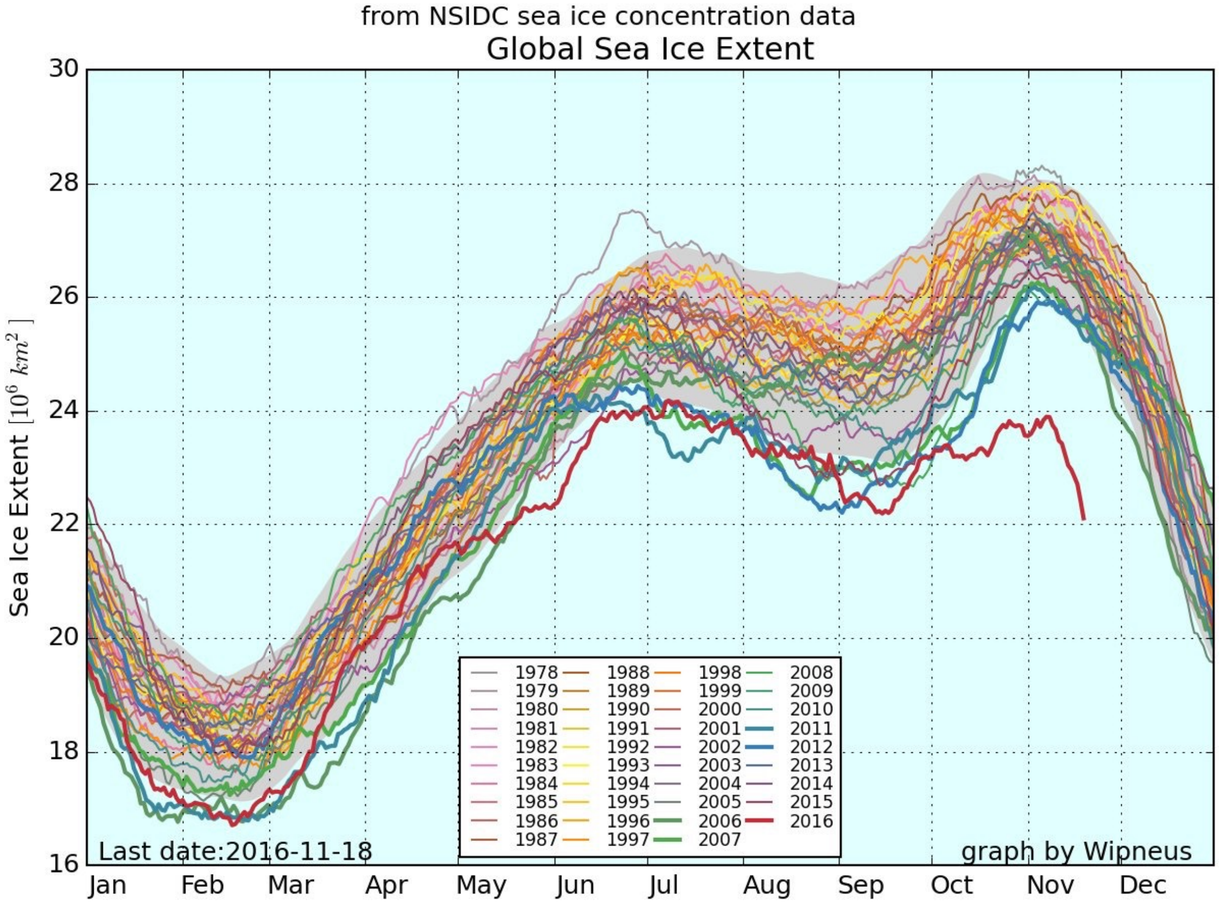

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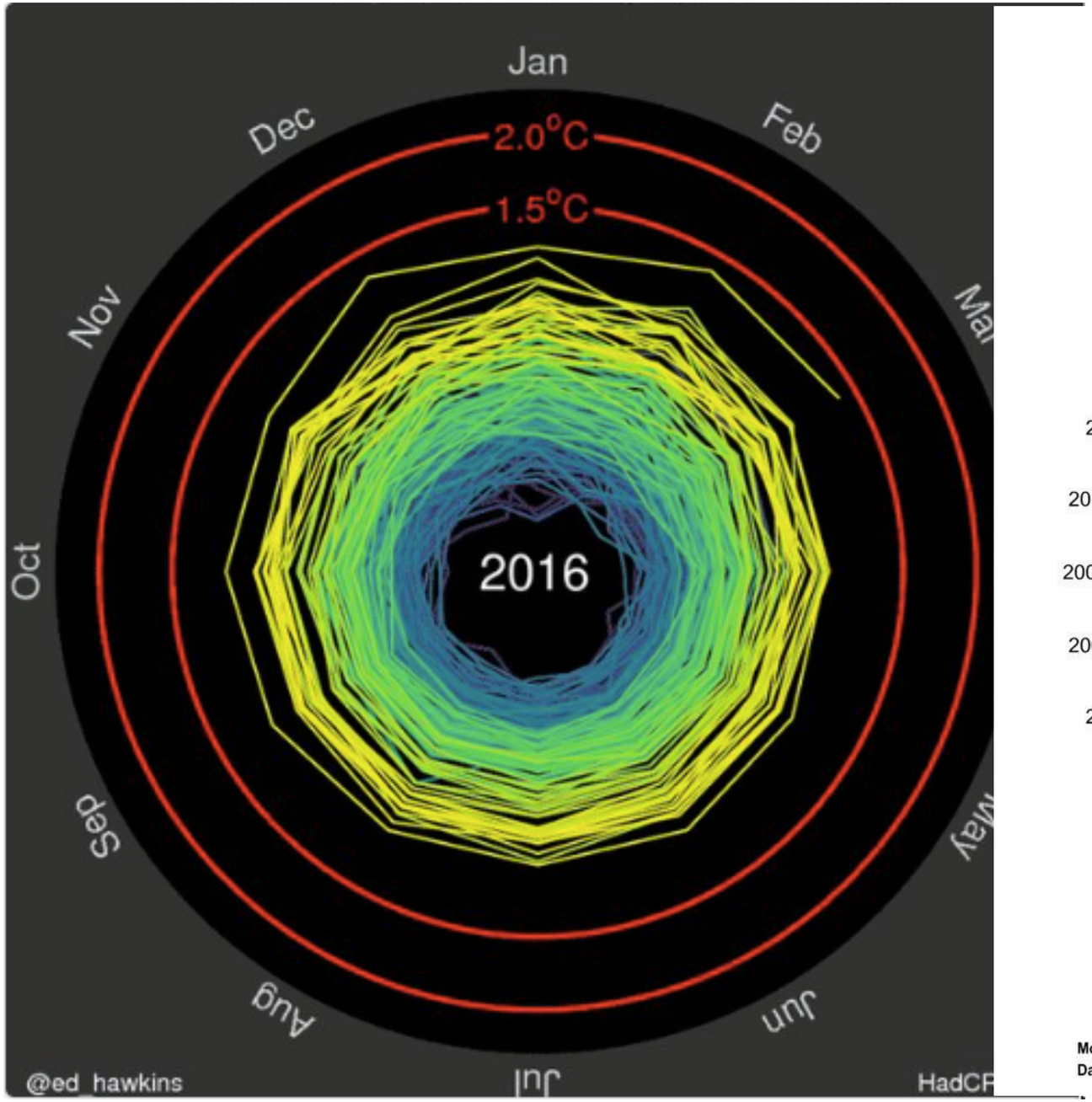

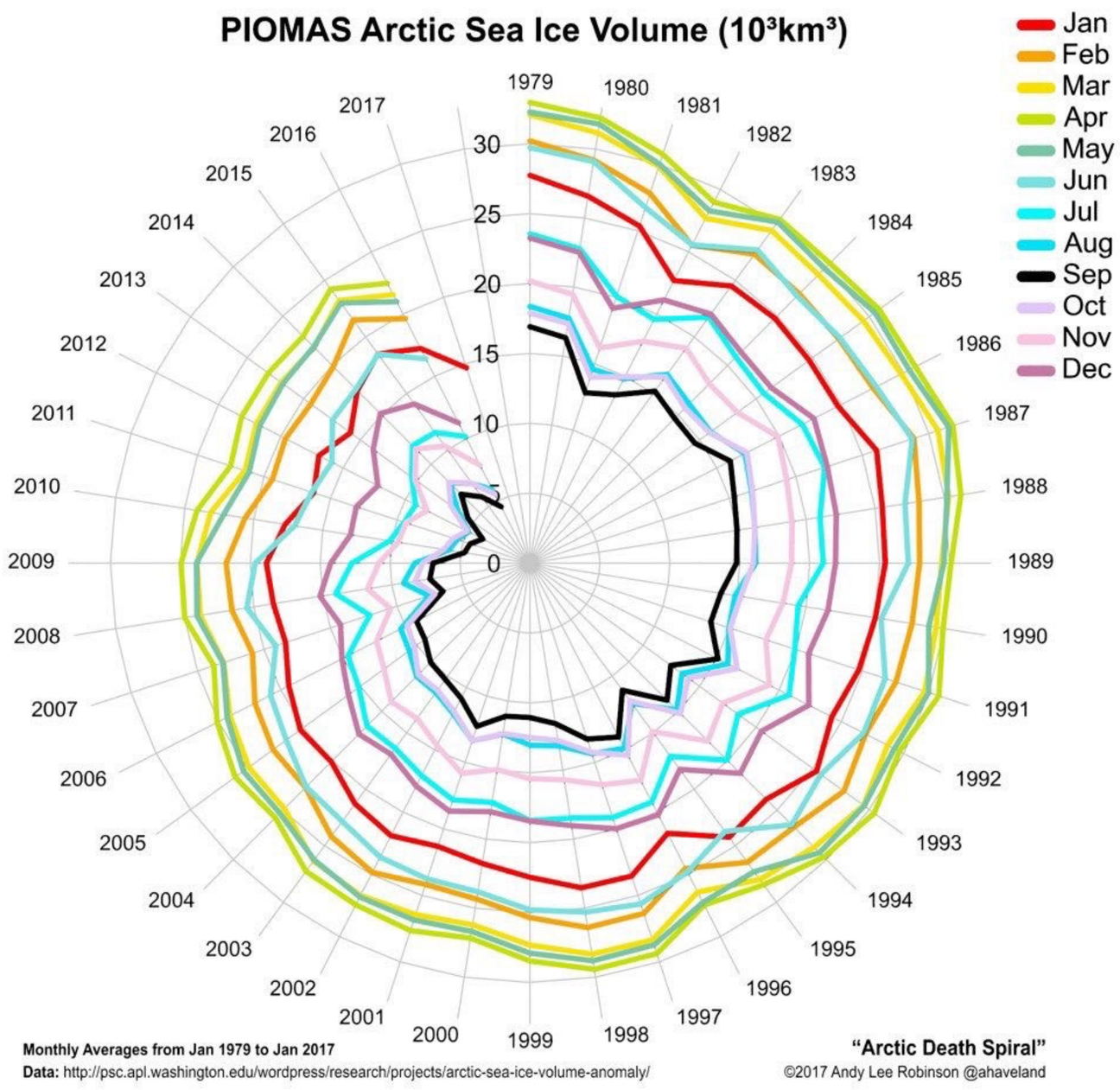

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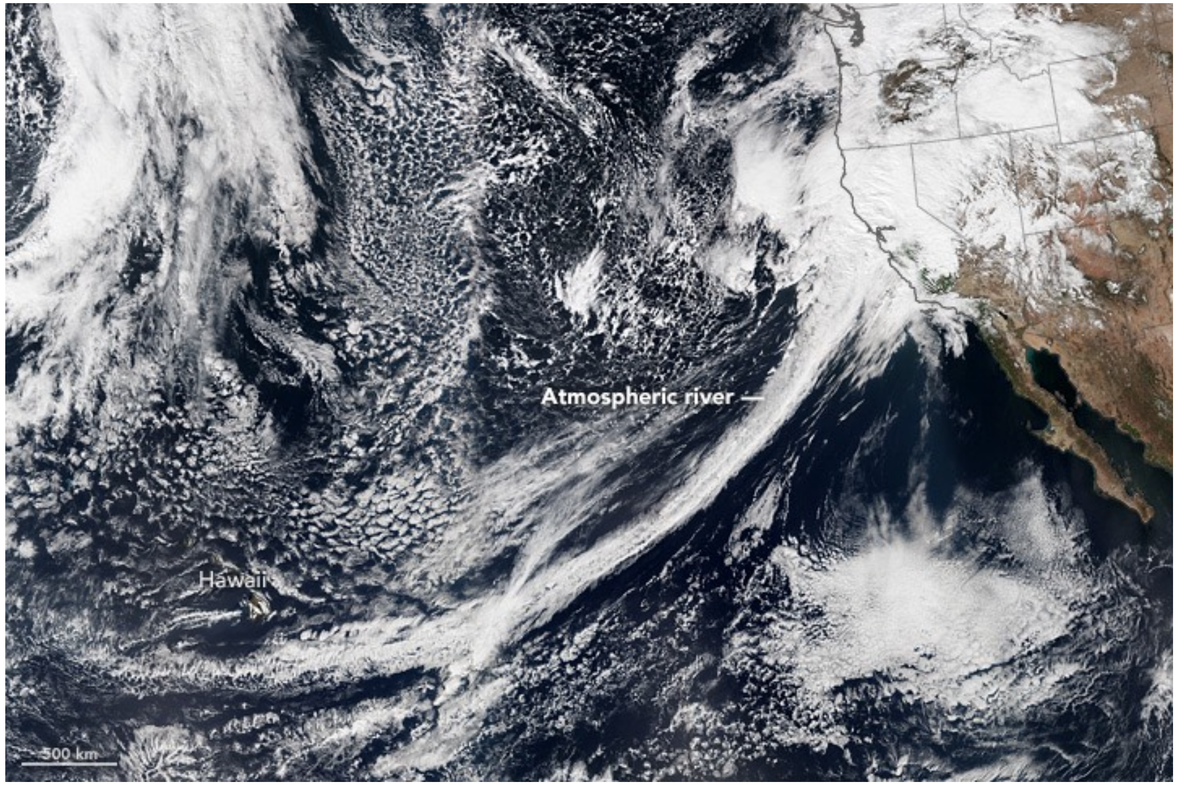

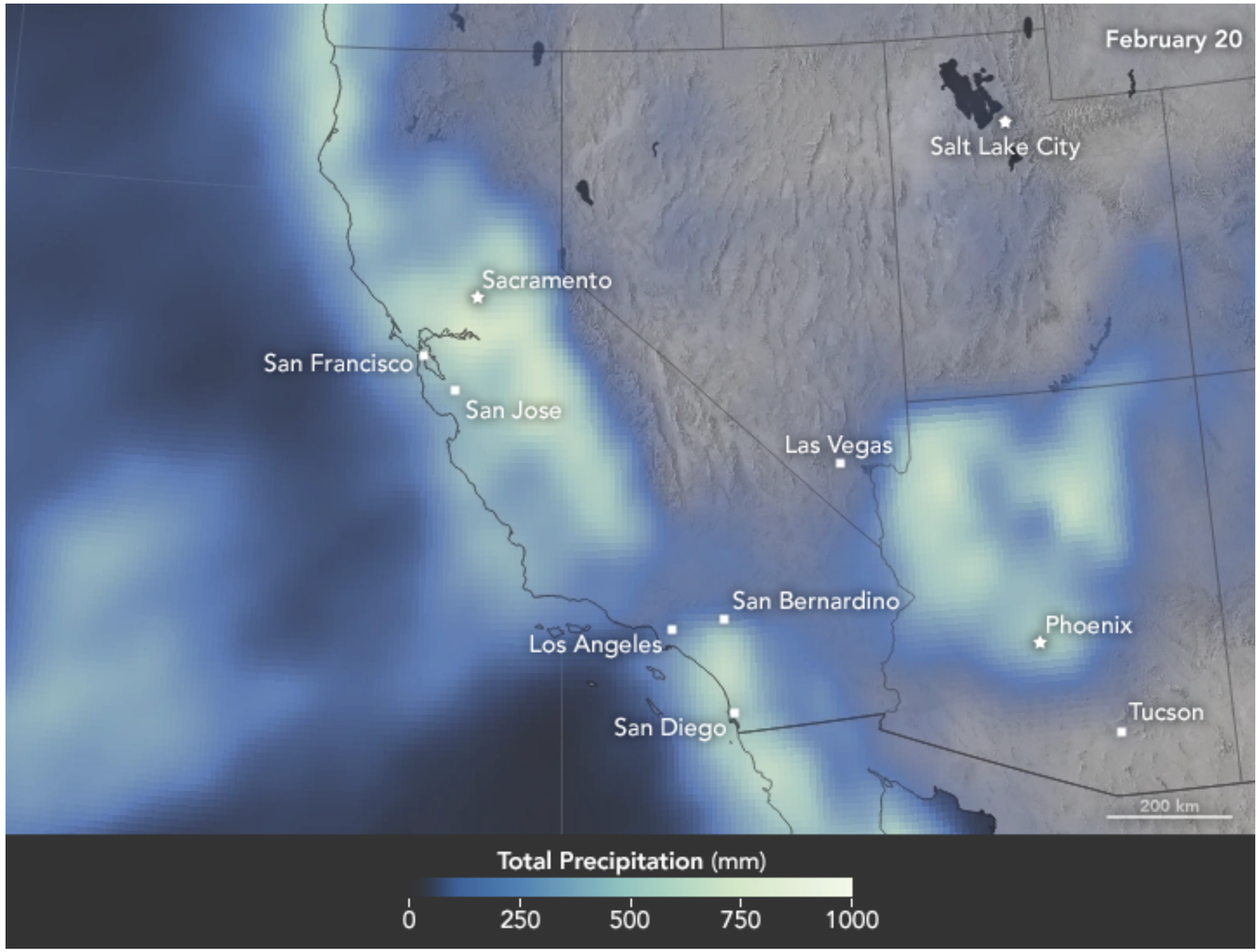

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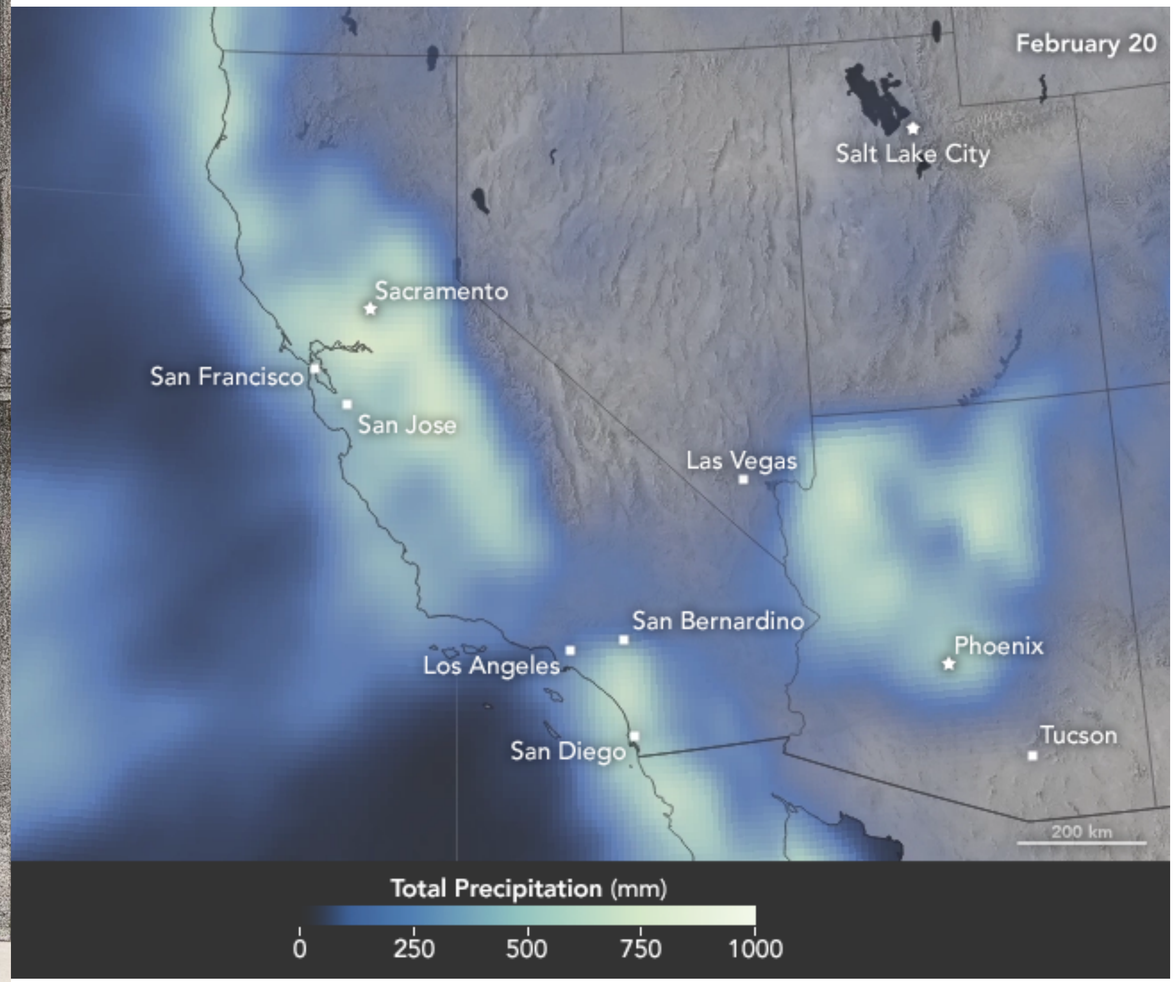

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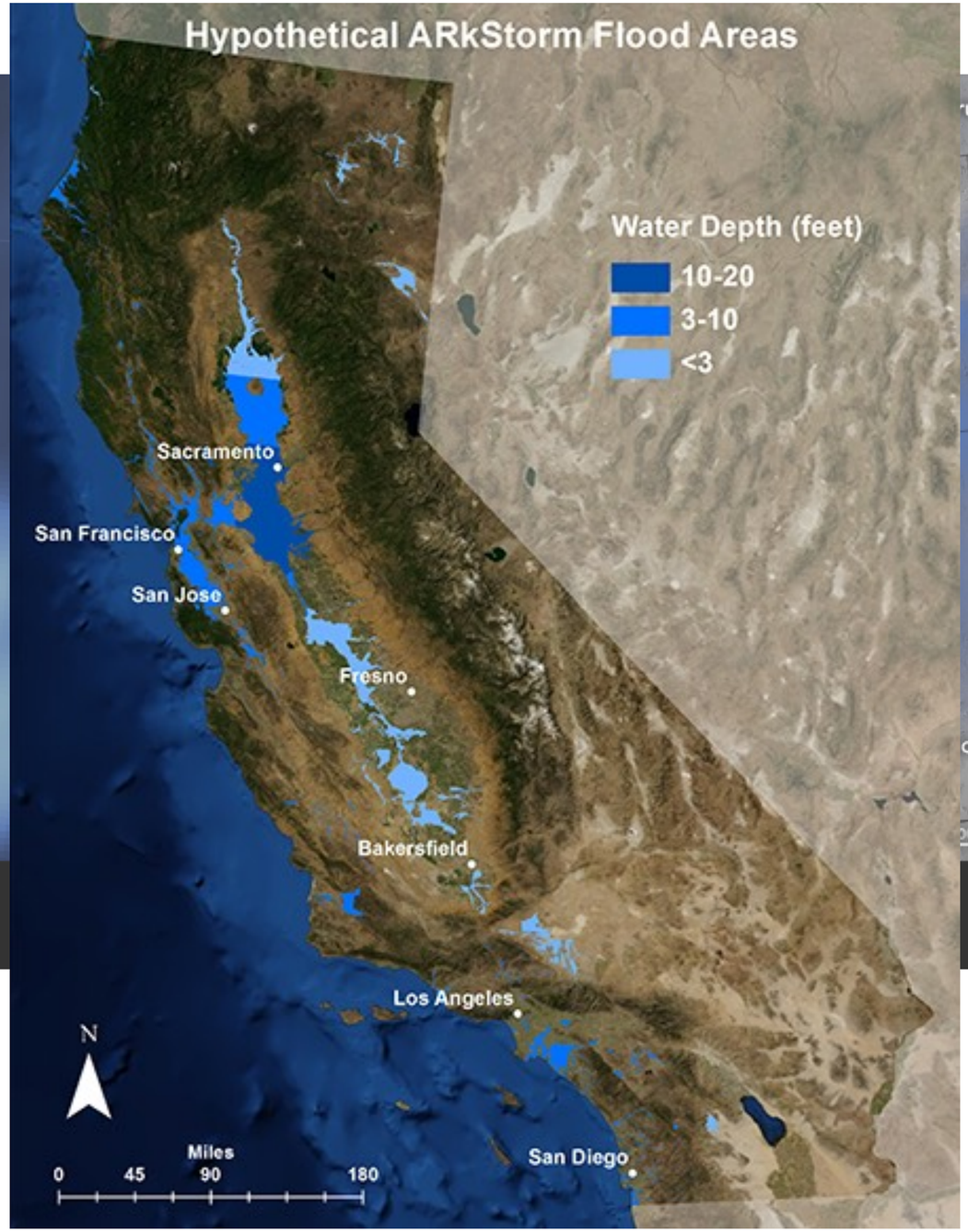
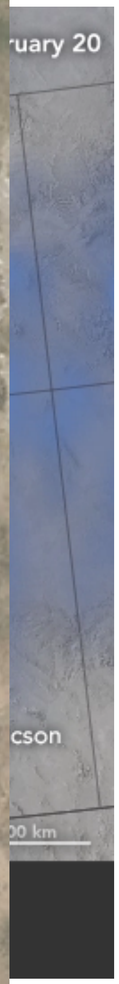


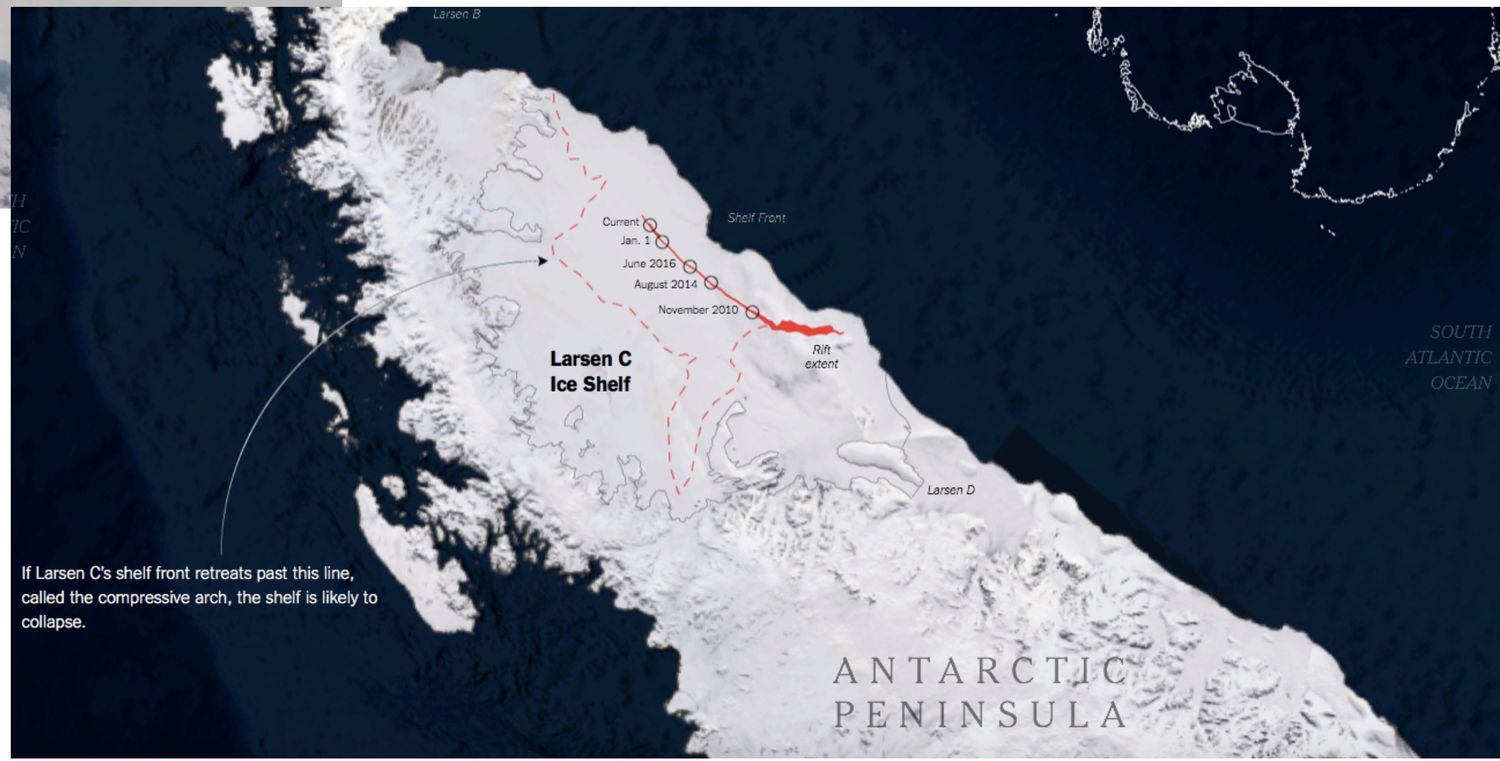


Detecting Changes

A Crack in an Antarctic Ice Shelf Grew 17 Miles in the Last Two Months

By JUGAL K. PATEL FEB. 7, 2017

A rapidly advancing crack in Antarctica's fourth-largest ice shelf has scientists concerned that it is getting close to a full break. The rift has accelerated this year in an area already vulnerable to warming temperatures. Since December, the crack has grown by the length of about five football fields each day.



Detecting Changes

Detecting Changes

Is climate change intensifying typhoons in Asia?

In the past four decades, the frequency of category 4 and 5 typhoons increased four-fold from a once-a-year occurrence to four times a year.

By Seth Borenstein, Associated Press | SEPTEMBER 5, 2016

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Bullit Marquez/AP | View Caption

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REPORT

An unexpected disruption of the atmospheric quasi-biennial oscillation

Scott M. Osprey[1,*], Neal Butchart[2], Jeff R. Knight[2], Adam A. Scaife[2,3], Kevin Hamilton[4], James A. Anstey[5], Verena Schenzinger[1], Chunxi Zhang[4]

+ Author Affiliations

*Corresponding author. Email: scott.osprey@physics.ox.ac.uk

Science 08 Sep 2016:

DOI: 10.1126/science.aah4156

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Terrifying Tornado Clusters on the Rise

By Becky Oskin, Senior Writer | October 16, 2014 02:00pm ET

57

28

1

4

57

MORE

Credit: NOAA

Tornadoes are touching down in clusters more often than 50 years ago, a new study reports. On some days, more than 30 twisters strike the United States.

Even as storms spawn more tornadoes, there are fewer days on which tornadoes occur, according to the study, published today (Oct. 15) in the journal Science. Since the 1970s, the number of days with at least one EF-1 tornado has dropped from a mean (or average) of 150 to 100.

"When people ask, 'Are we getting more tornadoes, are we getting fewer tornadoes, are they later, are they earlier?' — the answer to everything is yes," said lead study author Harold Brooks, senior scientist at the National Oceanic and Atmospheric Administration's Severe Storms Laboratory in Norman, Oklahoma.

http://www.livescience.com/48316-tornados-cluster-more-often.html

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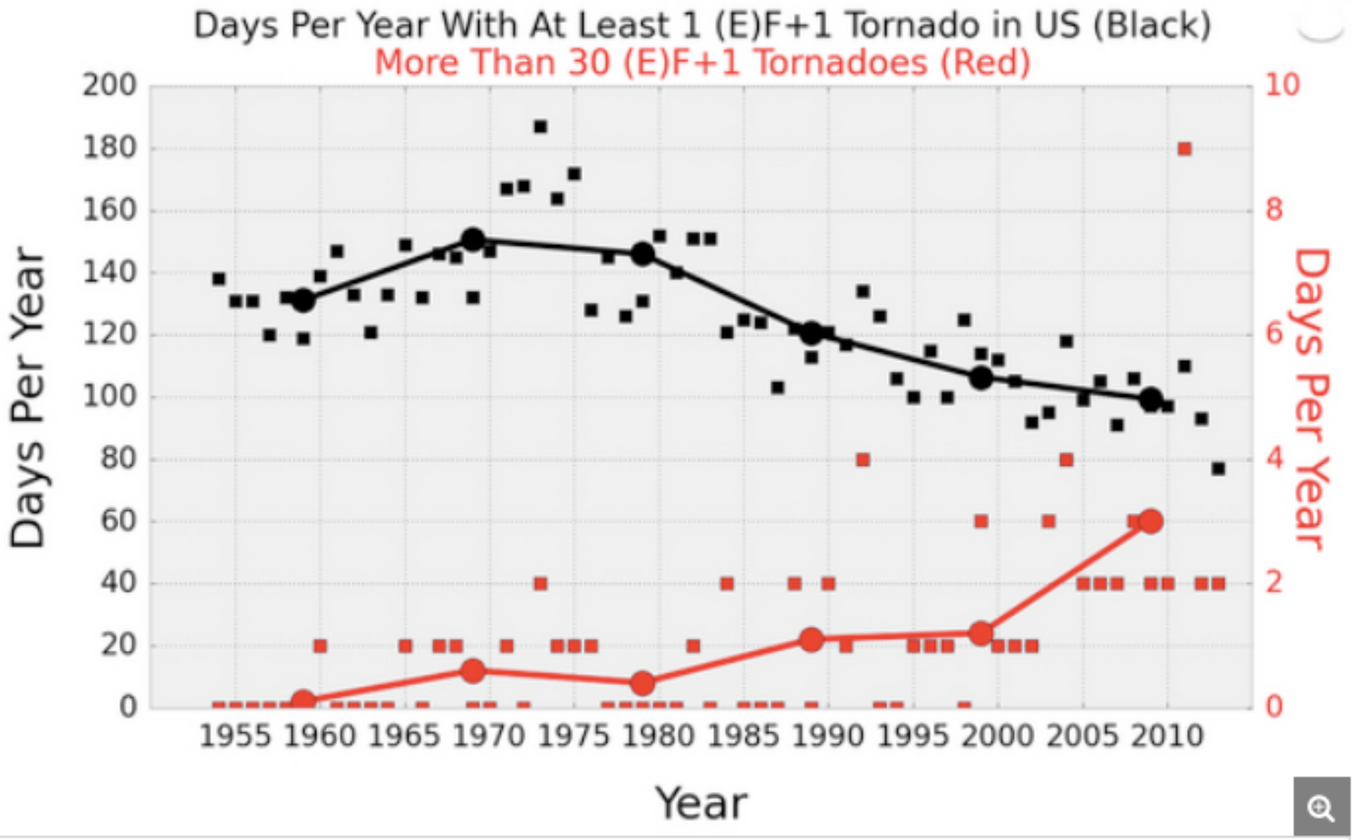

Black squares show one tornado that is rated EF-1 or greater on the Enhanced Fujita Scale, and red squares show there were more than 30 tornadoes rated EF-1 or higher.

Credit: NOAA

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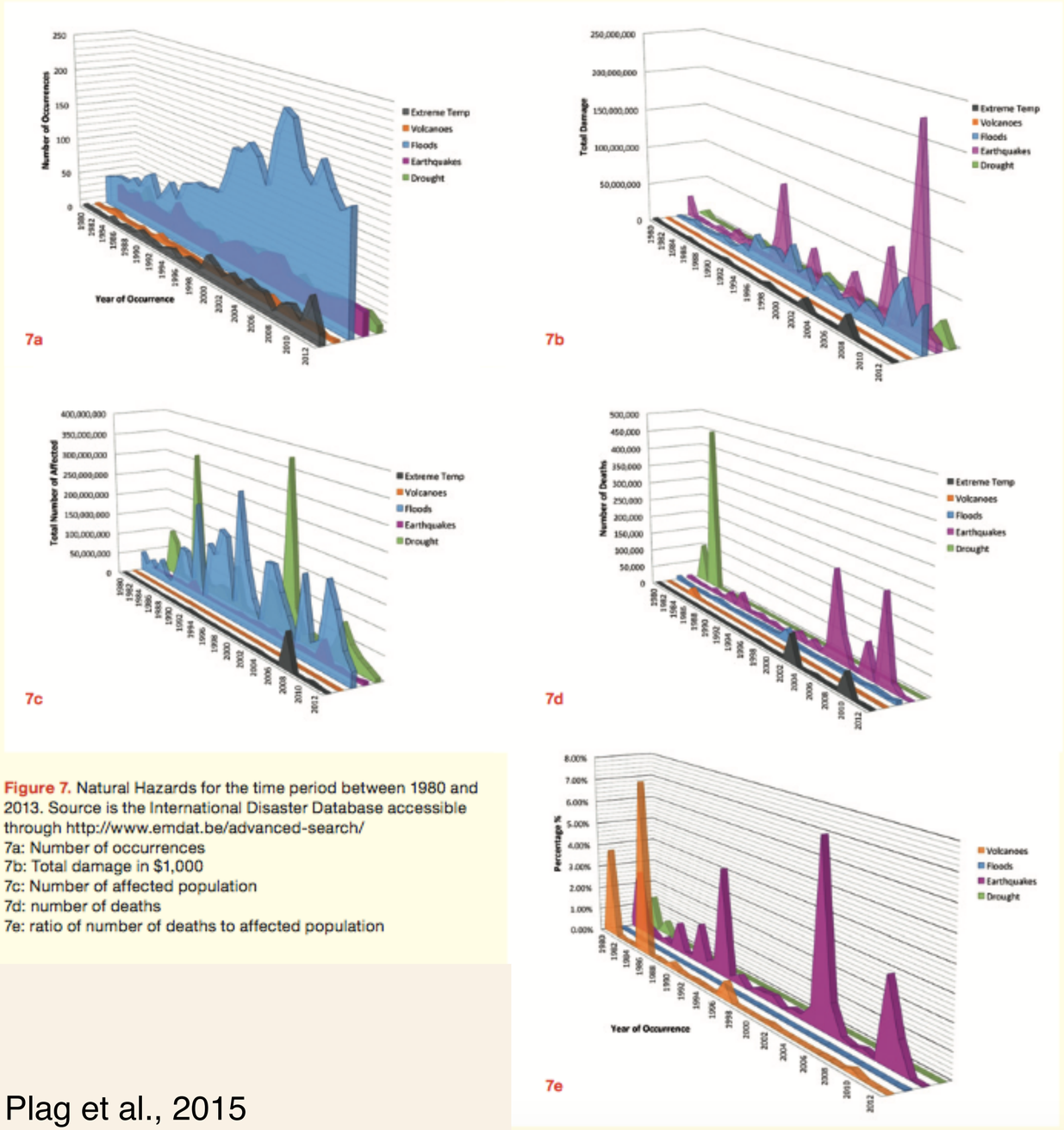

Figure 7. Natural Hazards for the time period between 1980 and 2013. Source is the International Disaster Database accessible through http://www.emdat.be/advanced-search/
7a: Number of occurrences
7b: Total damage in $1,000
7c: Number of affected population
7d: number of deaths
7e: ratio of number of deaths to affected population

Plag et al., 2015

Detecting Changes

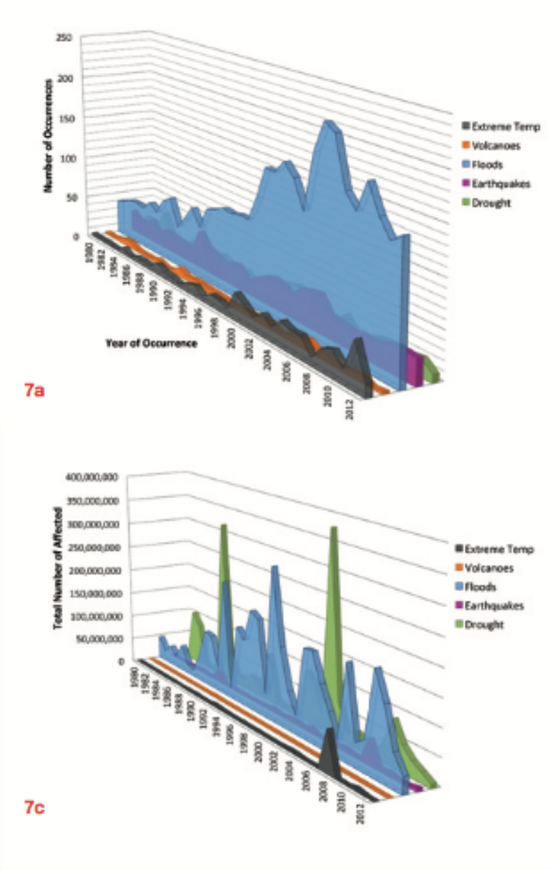

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Table 4. Detailed disaster statistics for the period 1980 to 2008. Data from http://www.preventionweb.net/english/professional/statistics/. The database is the OFDA/CRED International Disaster Database, maintained by University Catholique de Louvain, Brussels, Belgium. Data version: v11.08. Damage is in million US $. Hazards are ordered according to fatalities. *R* is the ratio of fatalities to the affected population in percent. See Table 3 for a caveat on the accuracy of the numbers.

Hazard	Events	Fatalities	Per year	Affected	Per year	Damage	Per year	*R*
Drought	410	558,565	19,261	1,551,455,122	53,498,452	76,949	2,653	0.036
Cyclone	1,211	402,911	13,893	496,560,639	17,122,781	533,371	18,392	0.081
Earthquake	706	385,630	13,298	136,333,515	4,701,156	351,079	12,106	0.283
Tsunami	18	229,551	7,916	2,481,879	85,582	10,046	0.346	9.249
Flood	2,887	195,843	6,753	2,809,481,489	96,878,672	397,334	13,701	0.007
Heatwave	126	89,889	3,100	4,614,411	159,118	21,990	758	1.948
Volcano	140	25,197	869	4,080,791	140,717	2,871	99	0.617
Landslide	366	20,008	690	7,031,523	242,466	6,060	209	0.285
Cold wave	156	11,595	400	6,875,103	237,073	5,902	204	0.169
Tornado	182	4,780	165	12,710,204	438,283	31,511	1,087	0.038
Avalanche	73	3,532	122	69,637	2,401	807	28	5.072
Wild fire	294	1,666	57	5,766,092	198,831	42,807	1,476	0.029

Plag et al., 2015

Assessing Knowledge

Assessing Knowledge

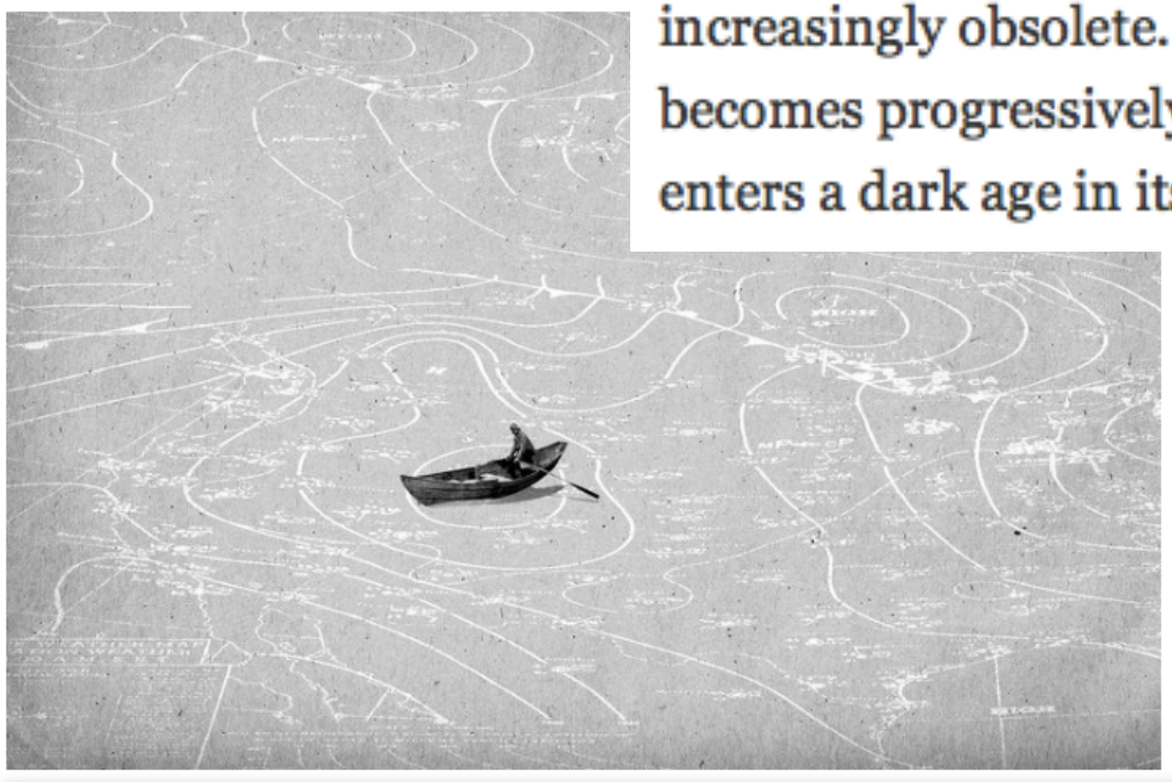
HOME SEARCH

The New York Times

The Opinion Pages | OP-ED CONTRIBUTOR

A New Dark Age Looms

By WILLIAM B. GAIL APRIL 19, 2016



Boulder, Colo. — IMAGINE a future in which humanity's accumulated wisdom about Earth — our vast experience with weather trends, fish spawning and migration patterns, plant pollination and much more — turns increasingly obsolete. As each decade passes, knowledge of Earth's past becomes progressively less effective as a guide to the future. Civilization enters a dark age in its practical understanding of our planet.

Assessing Knowledge

How solid is our knowledge?

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Example sea level rise

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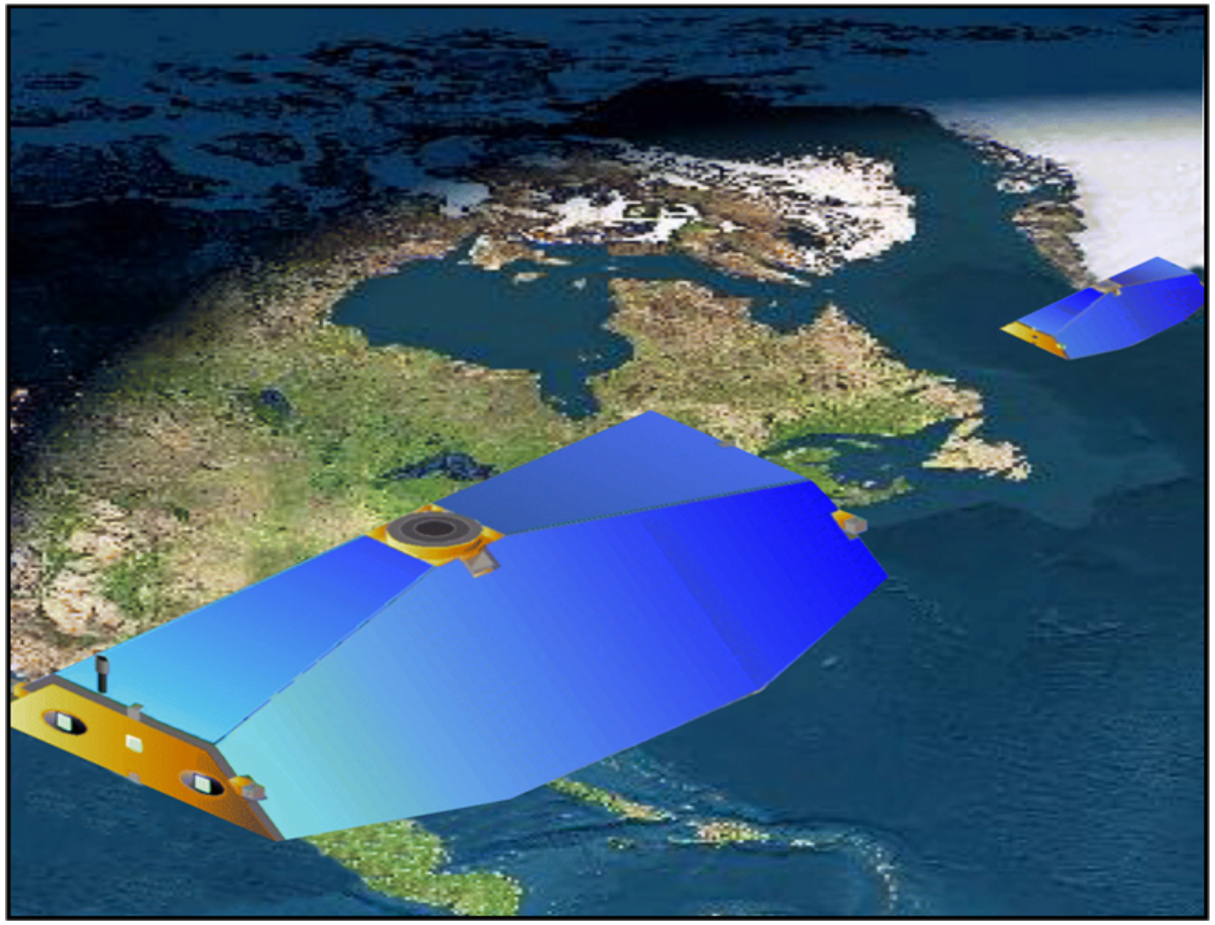
Accepted knowledge in 2000:

Greenland: no significant contribution to sea level rise

Antarctica: minor contribution

Main contribution: steric changes

How solid is our knowledge?



Gravity Recovery and Climate Experiment (GRACE)

Example sea level rise

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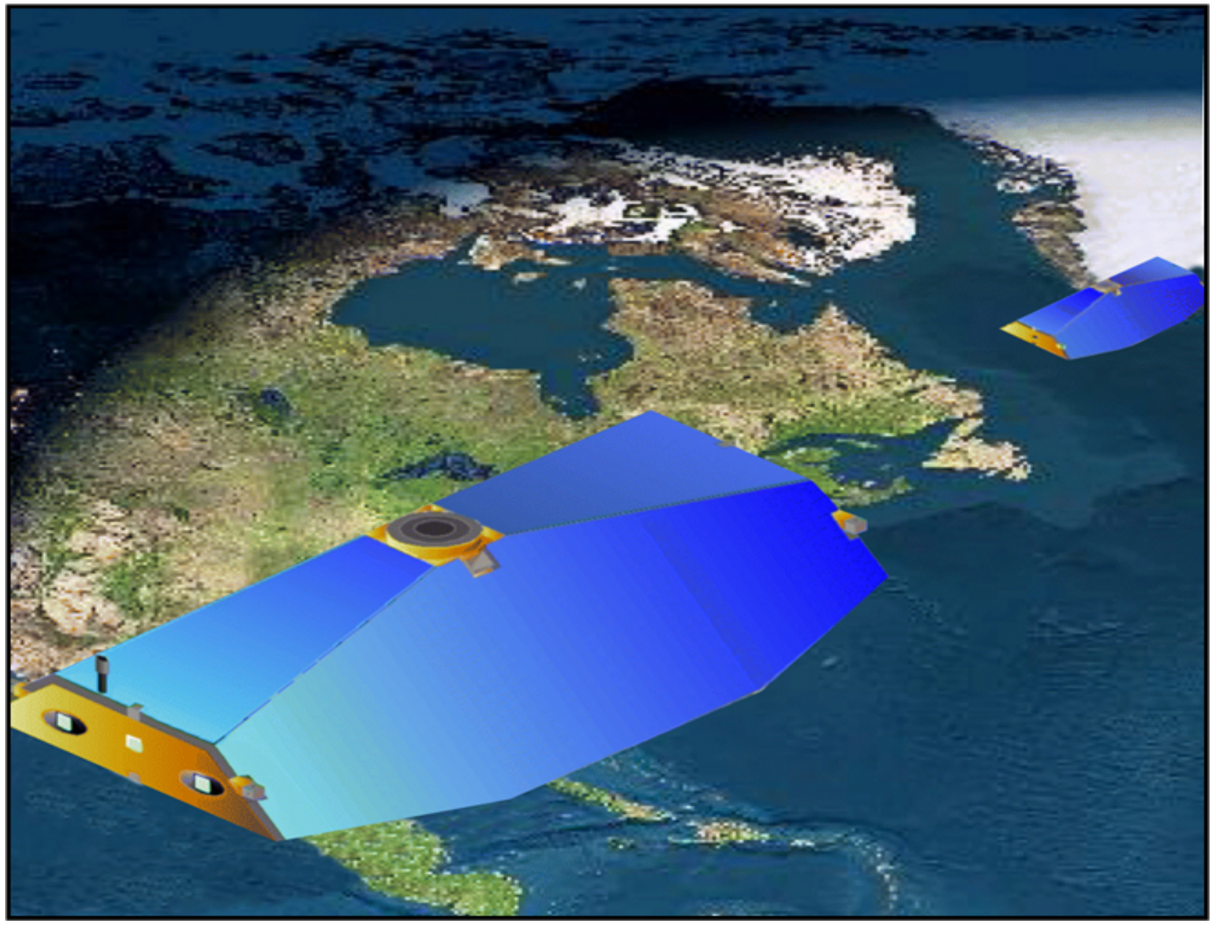
How solid is our knowledge?



Gravity Recovery and Climate Experiment (GRACE)

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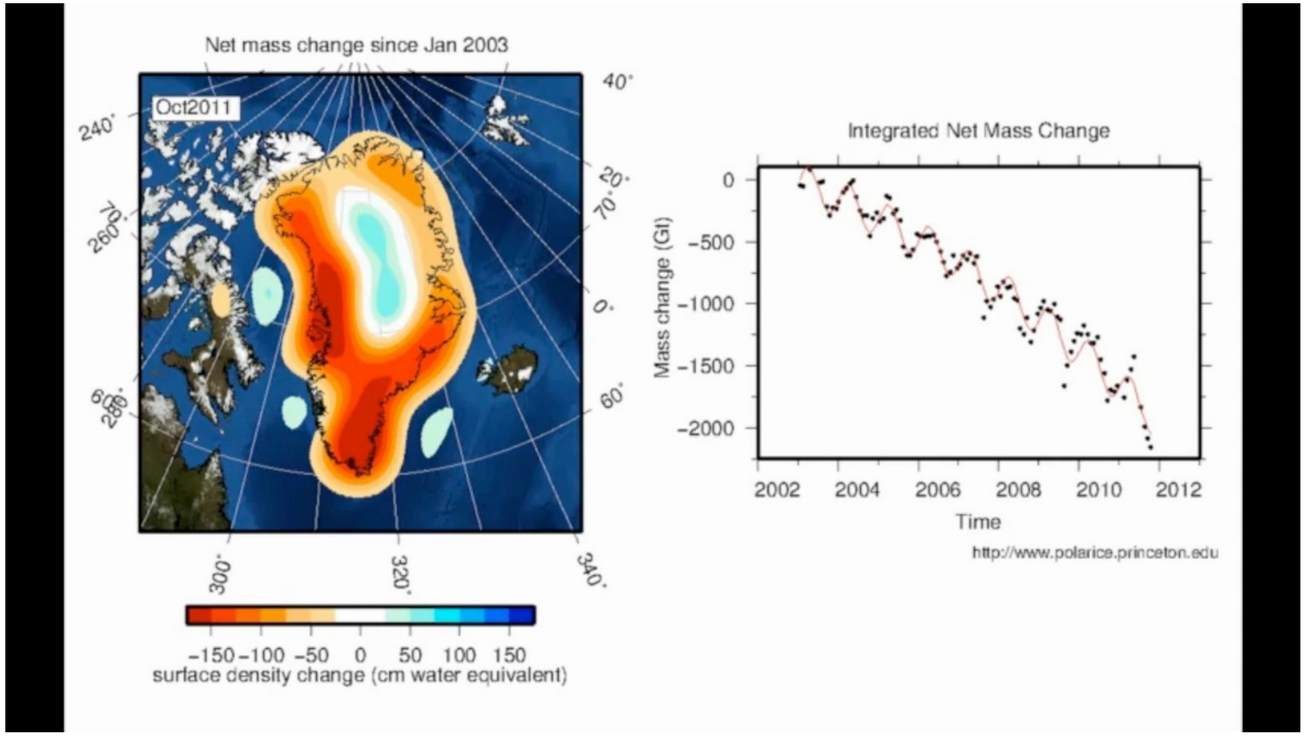

Assessing Knowledge

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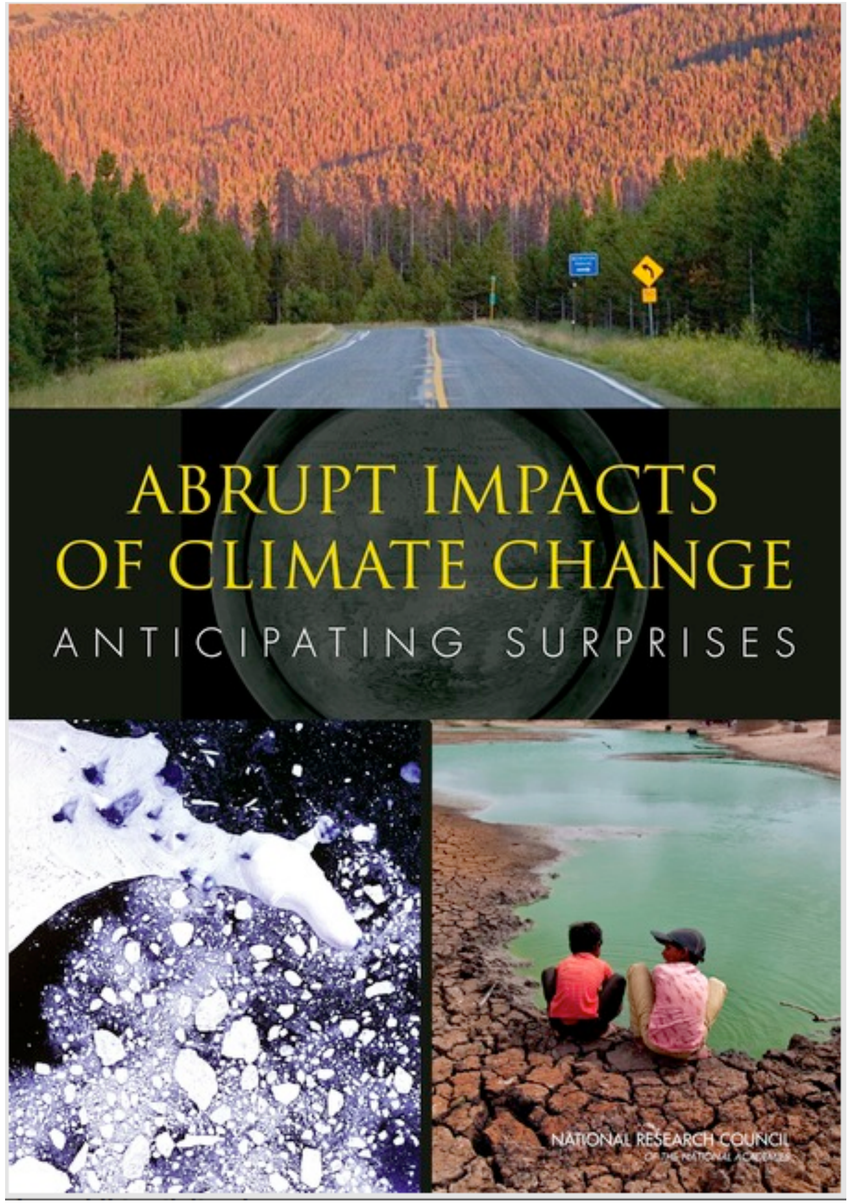
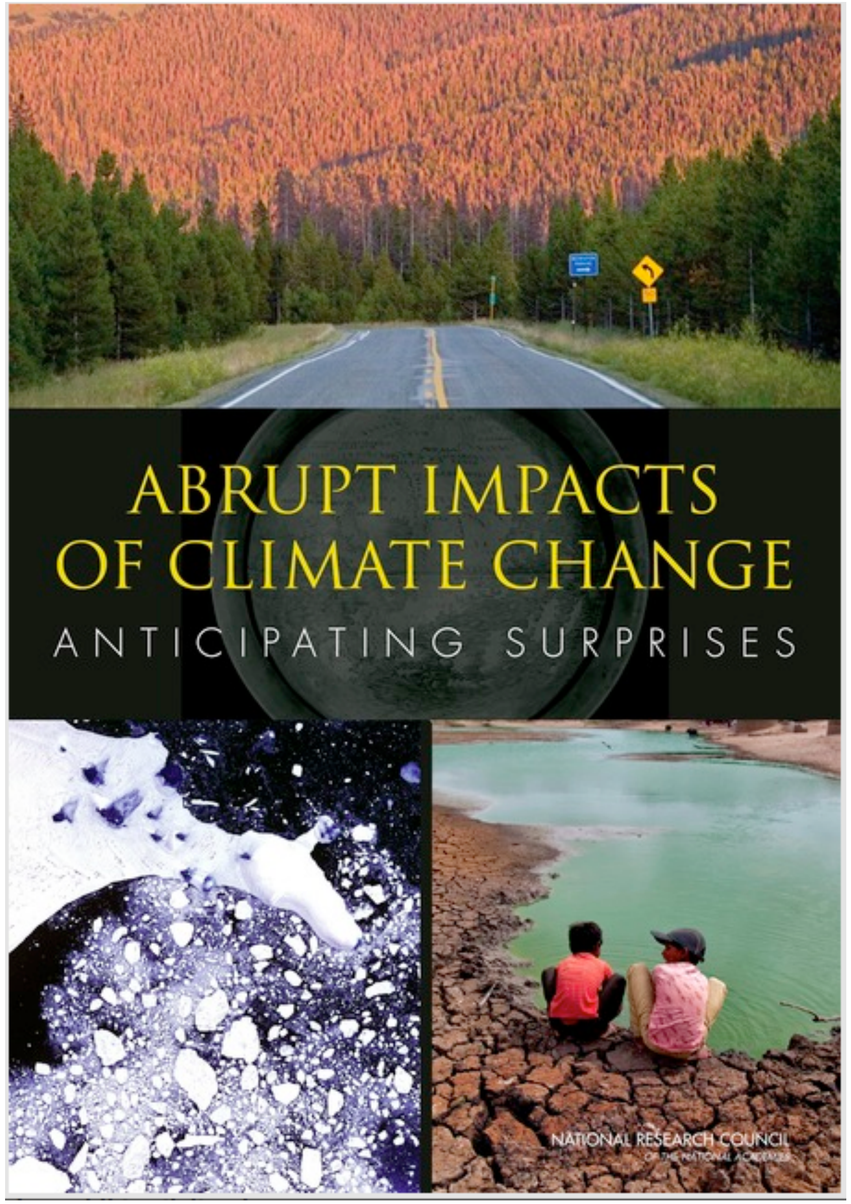


National Research Council in 2013:

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

Assessing Knowledge



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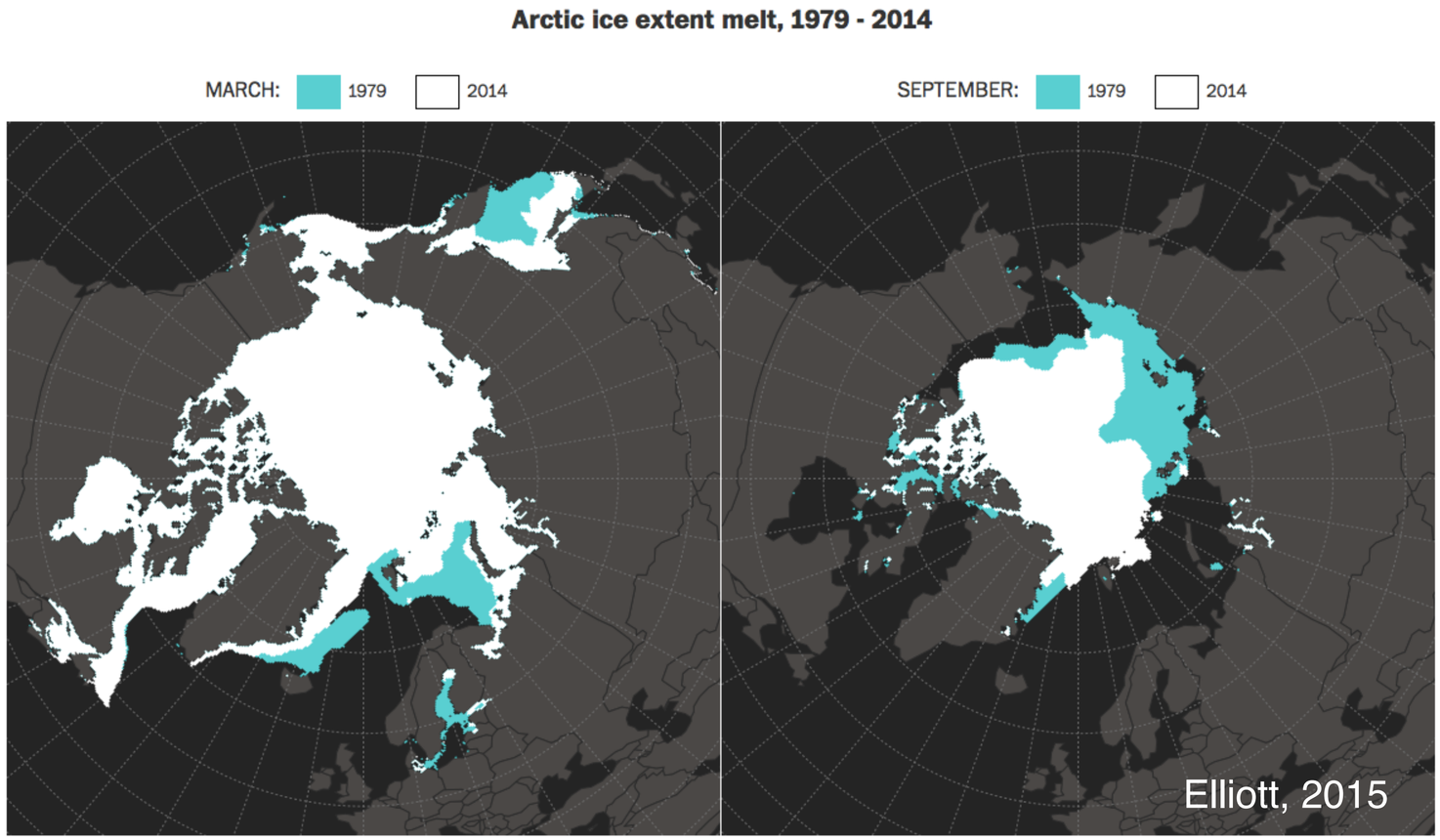
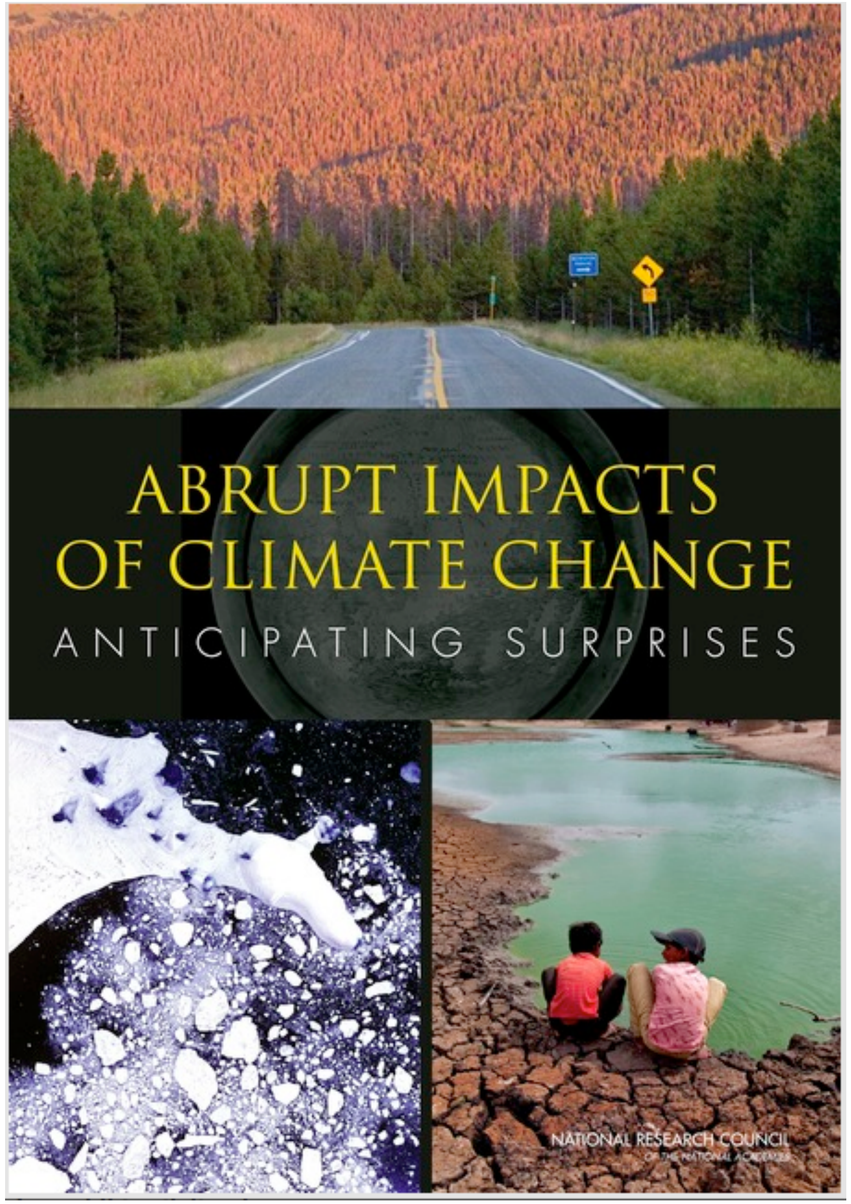


Elliott, 2015

Assessing Knowledge



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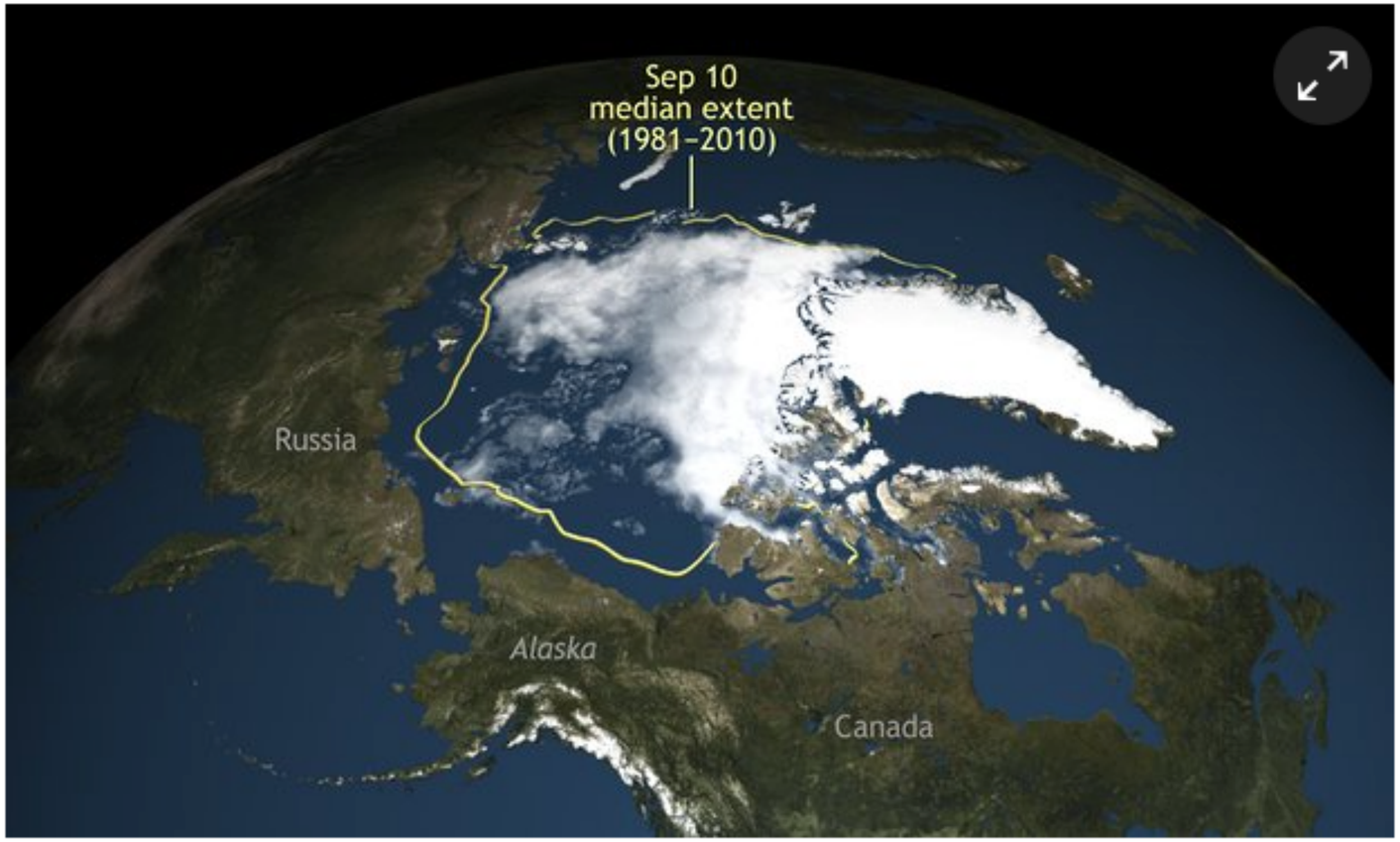
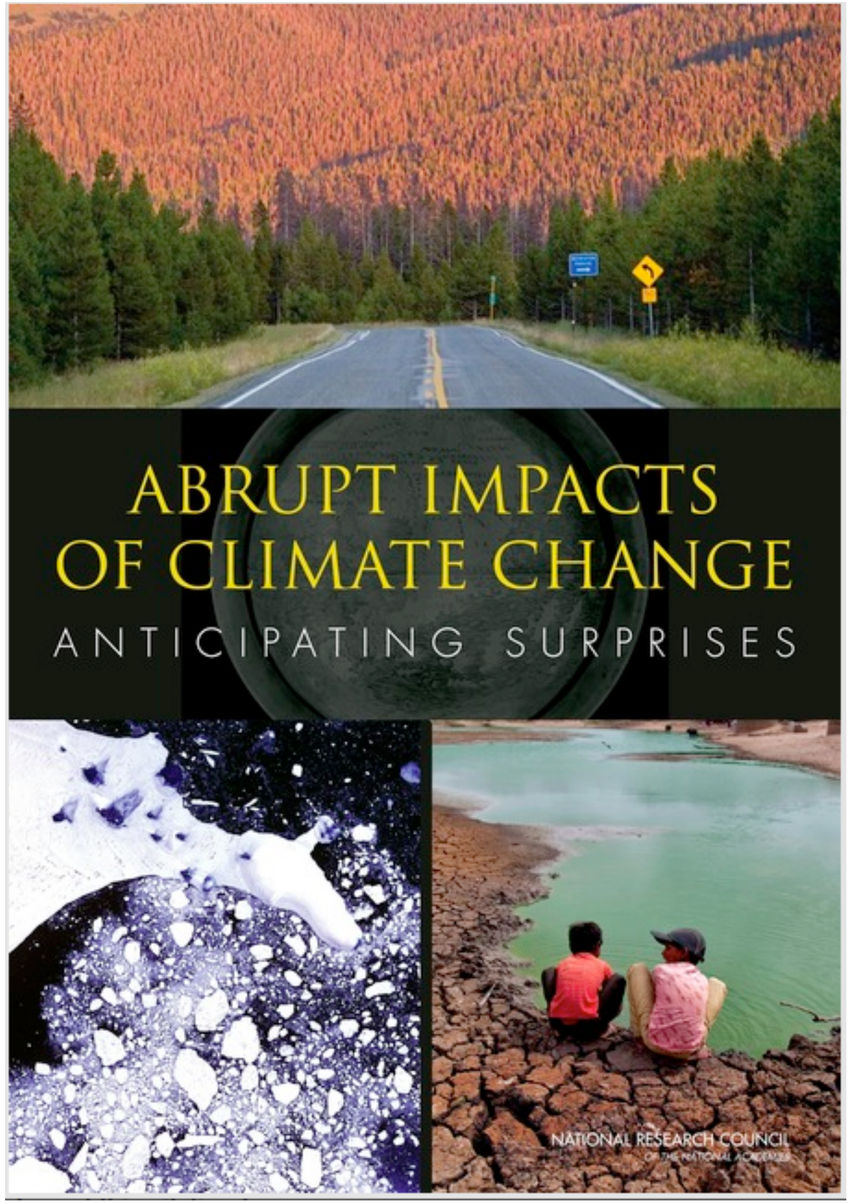
Arctic sea ice shrinks to second lowest level ever recorded

'Tremendous loss' of ice reinforces clear downward trend towards ice-free summers due to effects of climate change



Arctic sea ice this summer shrank to its second lowest level since scientists started to monitor it by satellite. Photograph: AP

Assessing Knowledge



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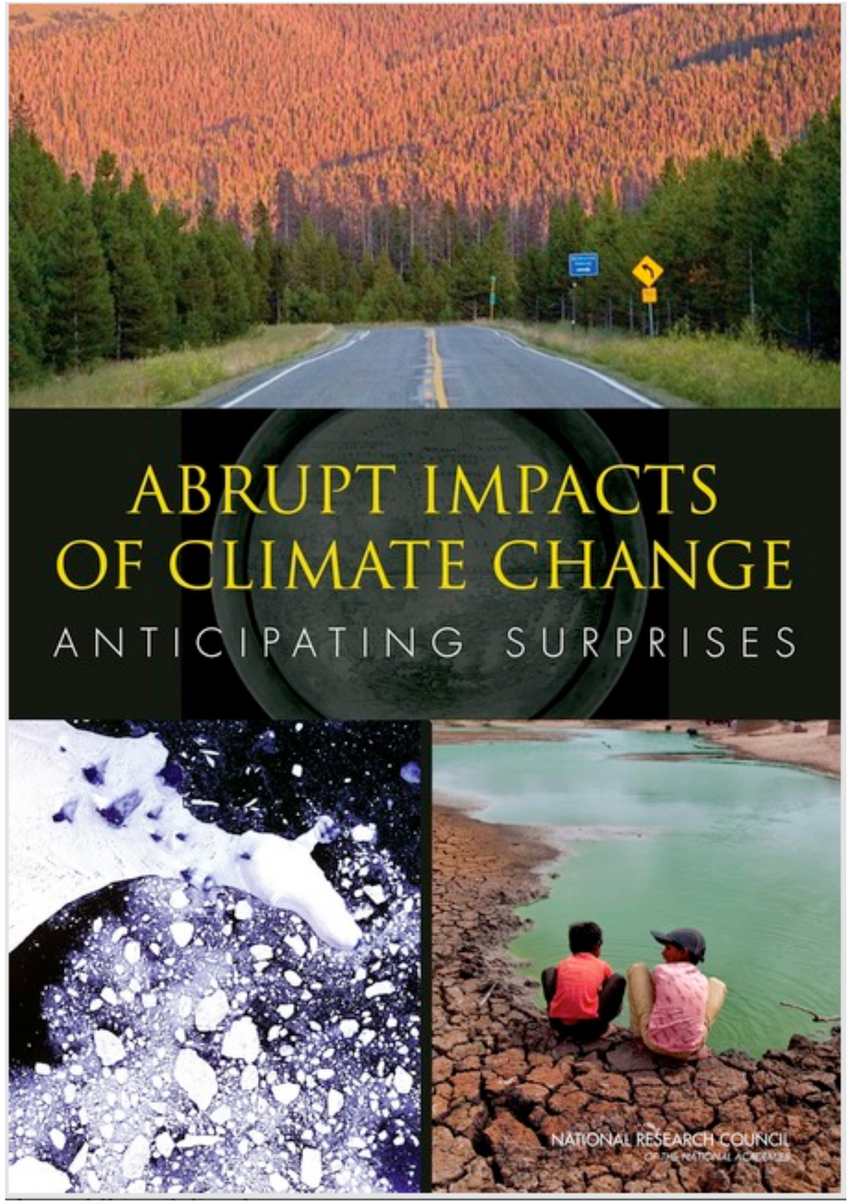

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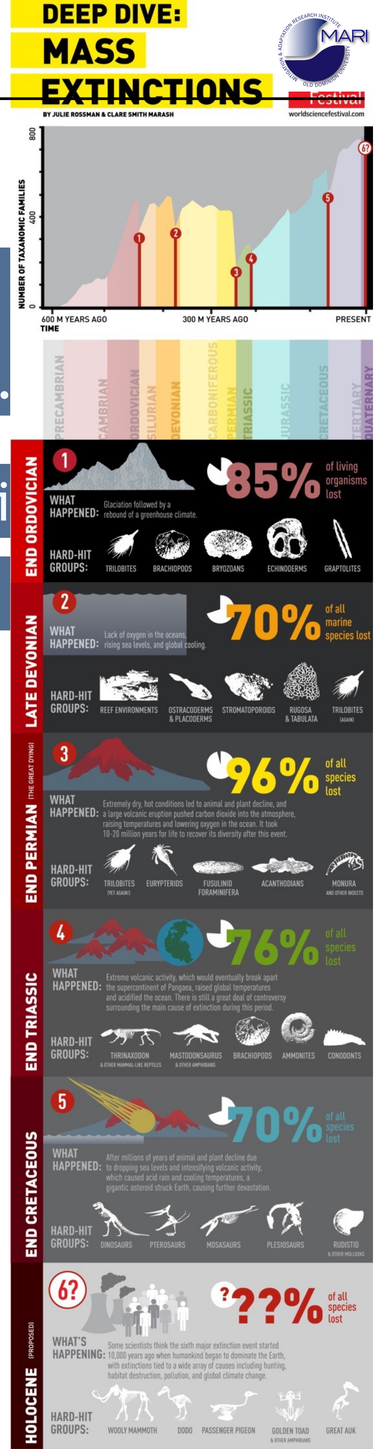

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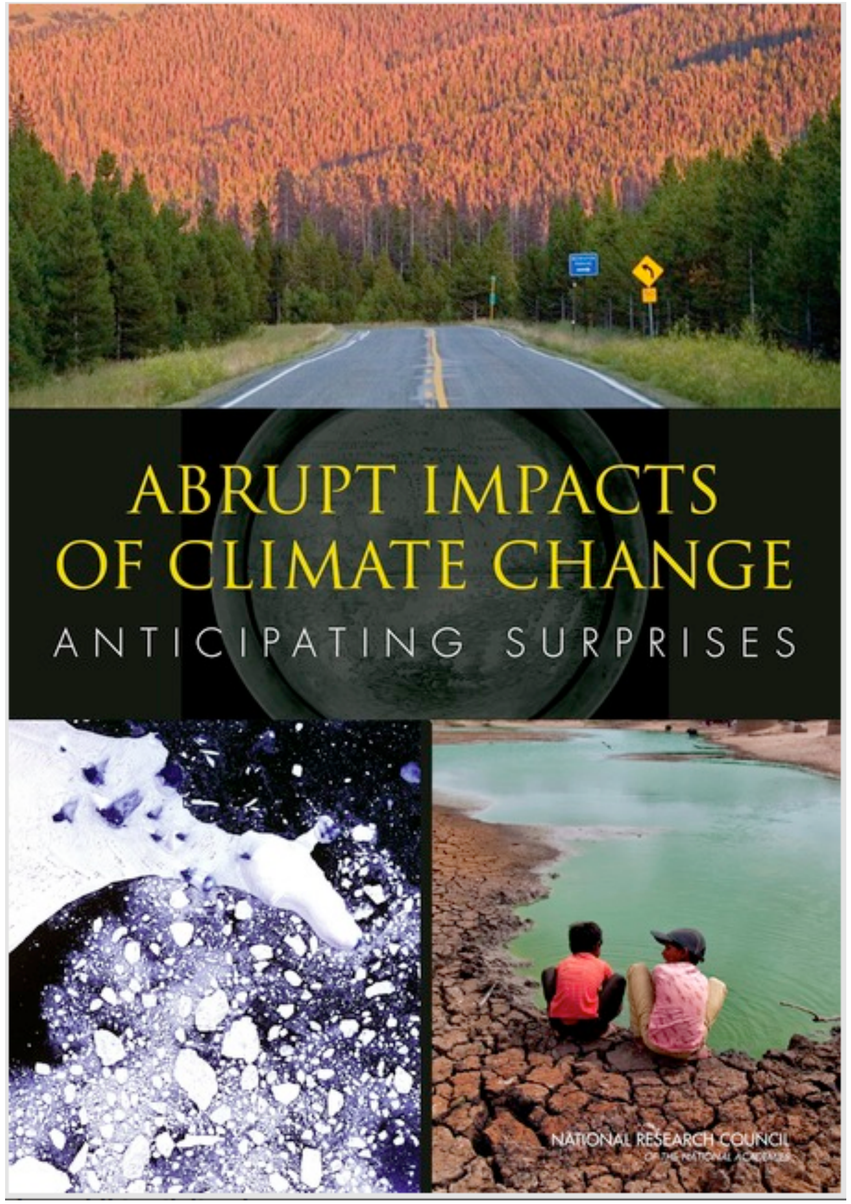

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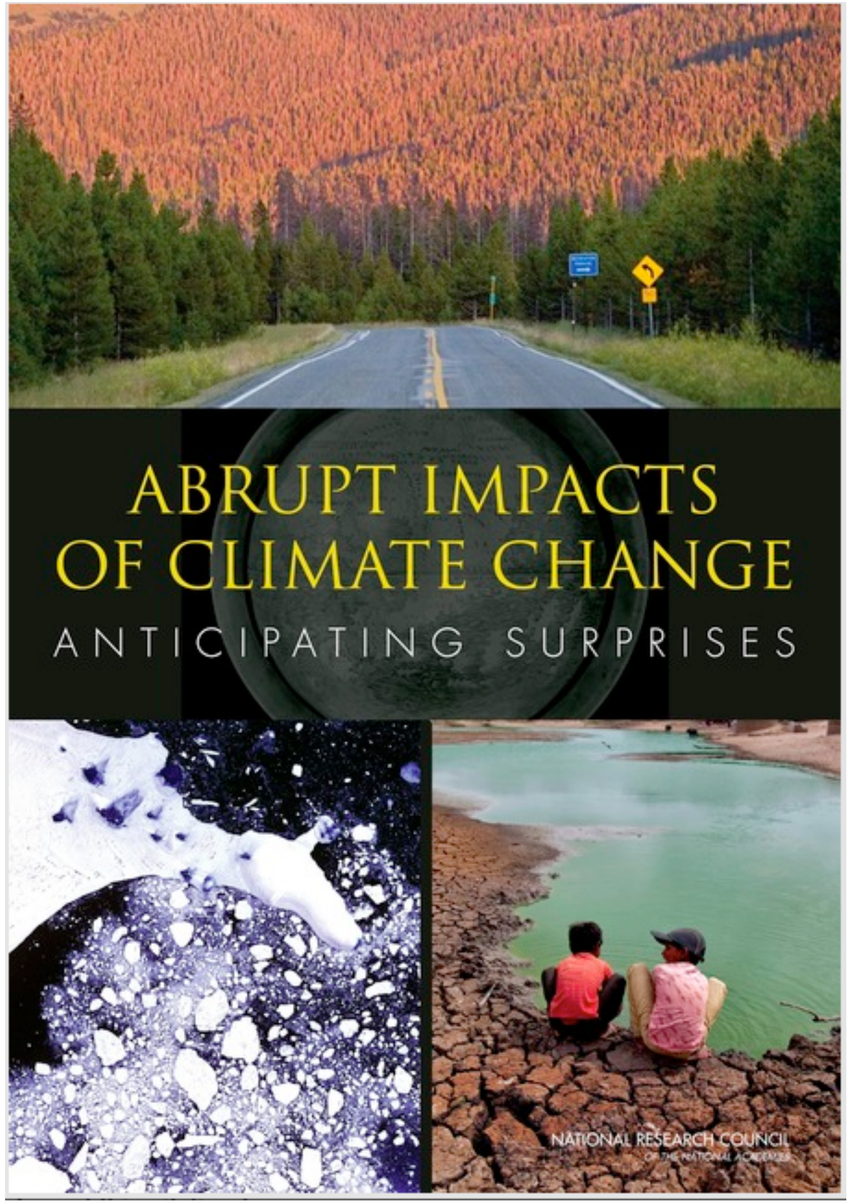

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Most likely (low-probability) rapid impact: ocean acidification

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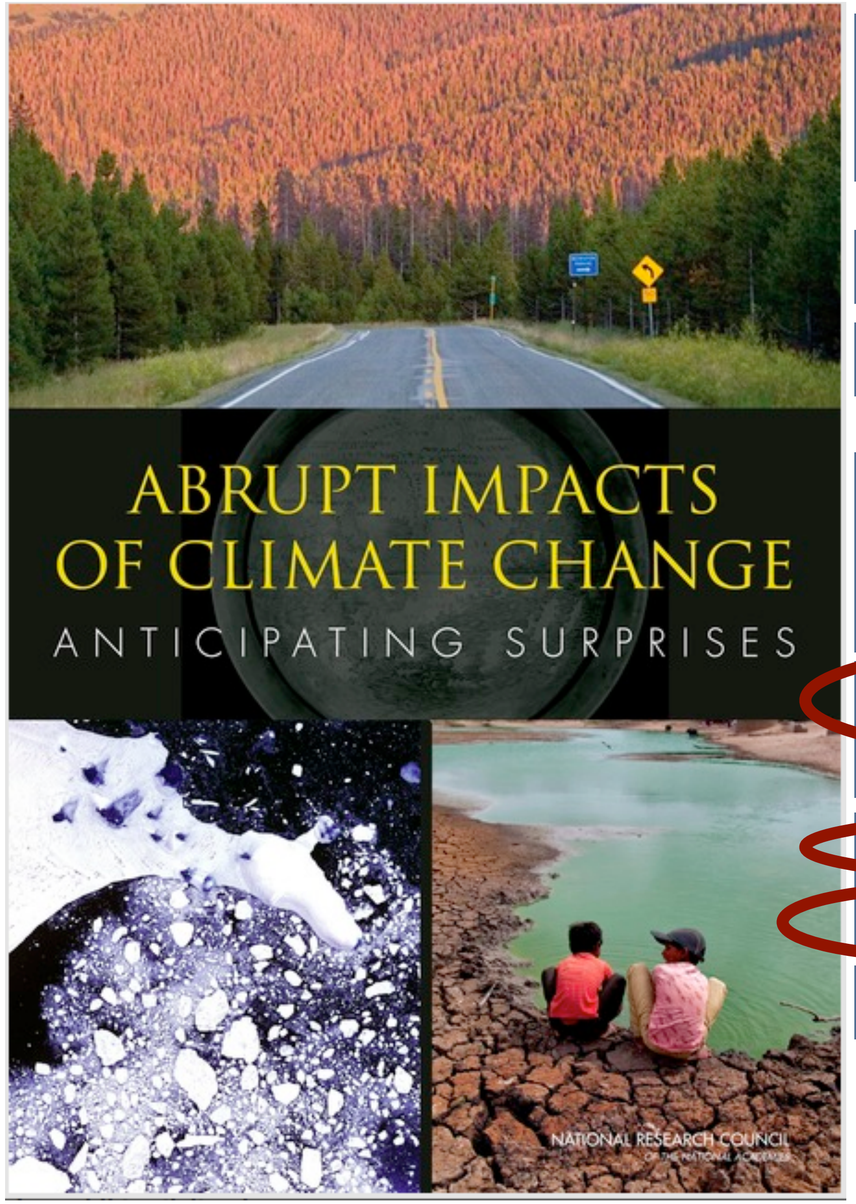

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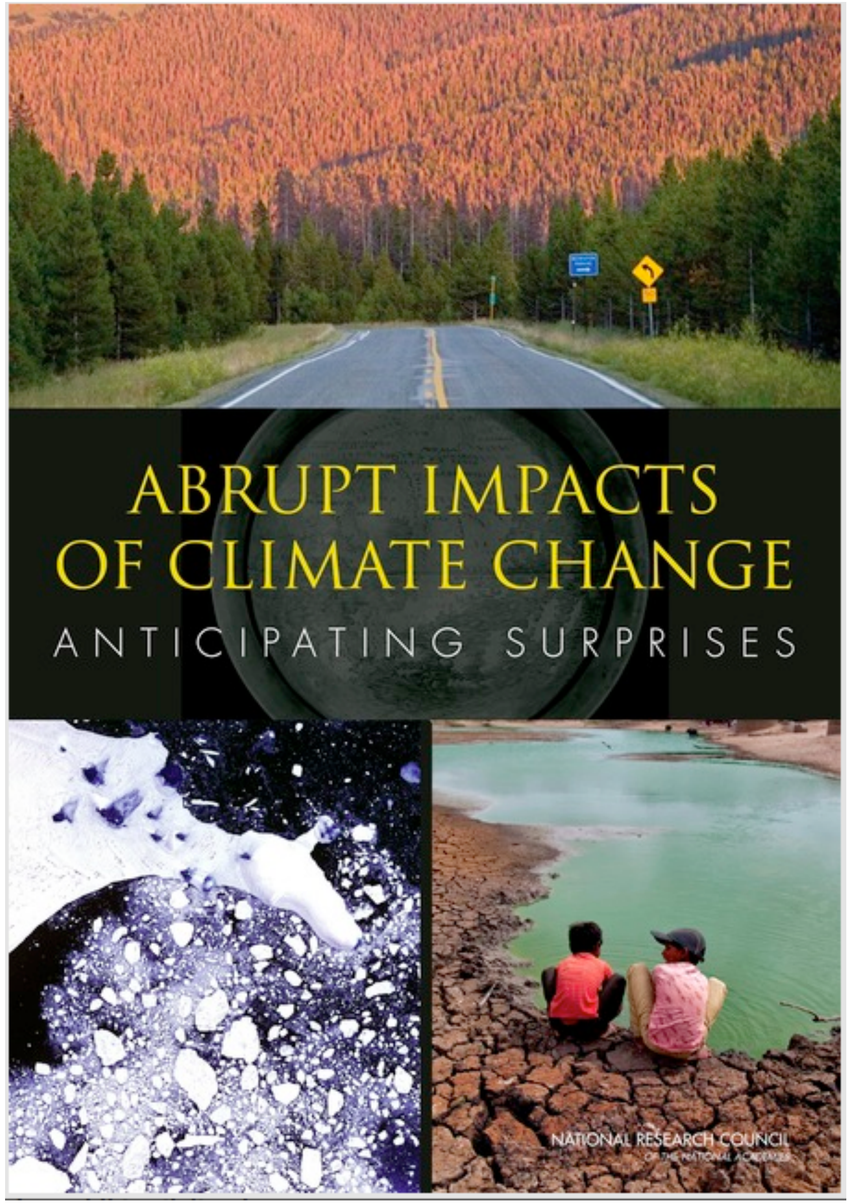

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Assessing Knowledge

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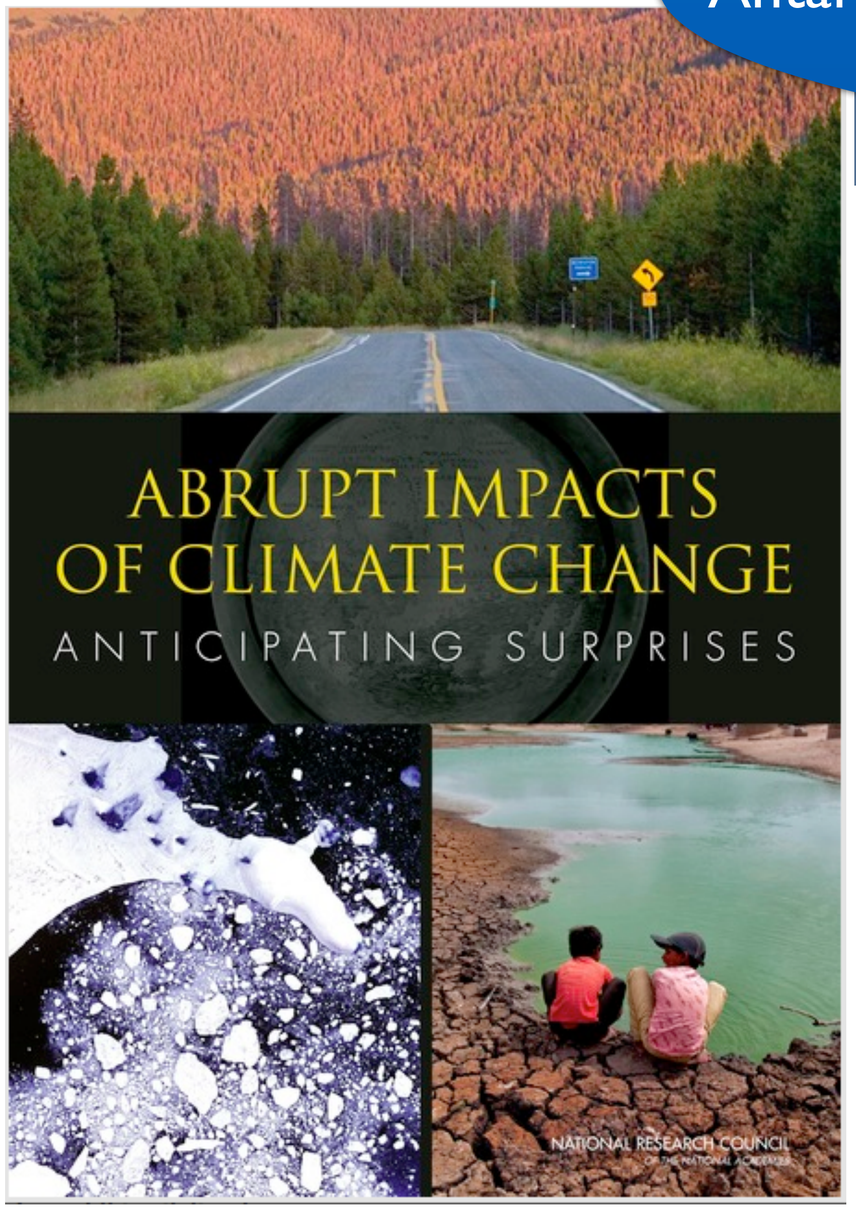

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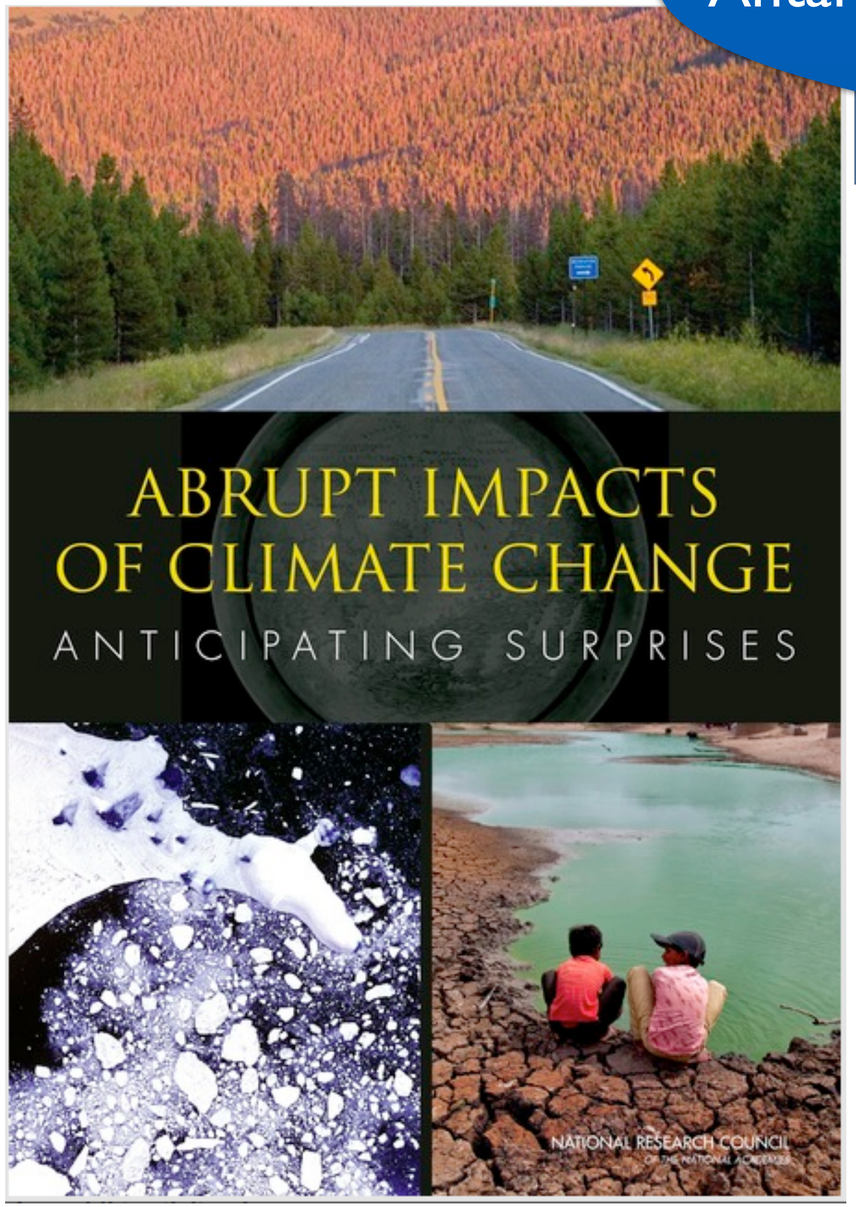

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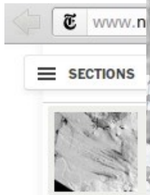

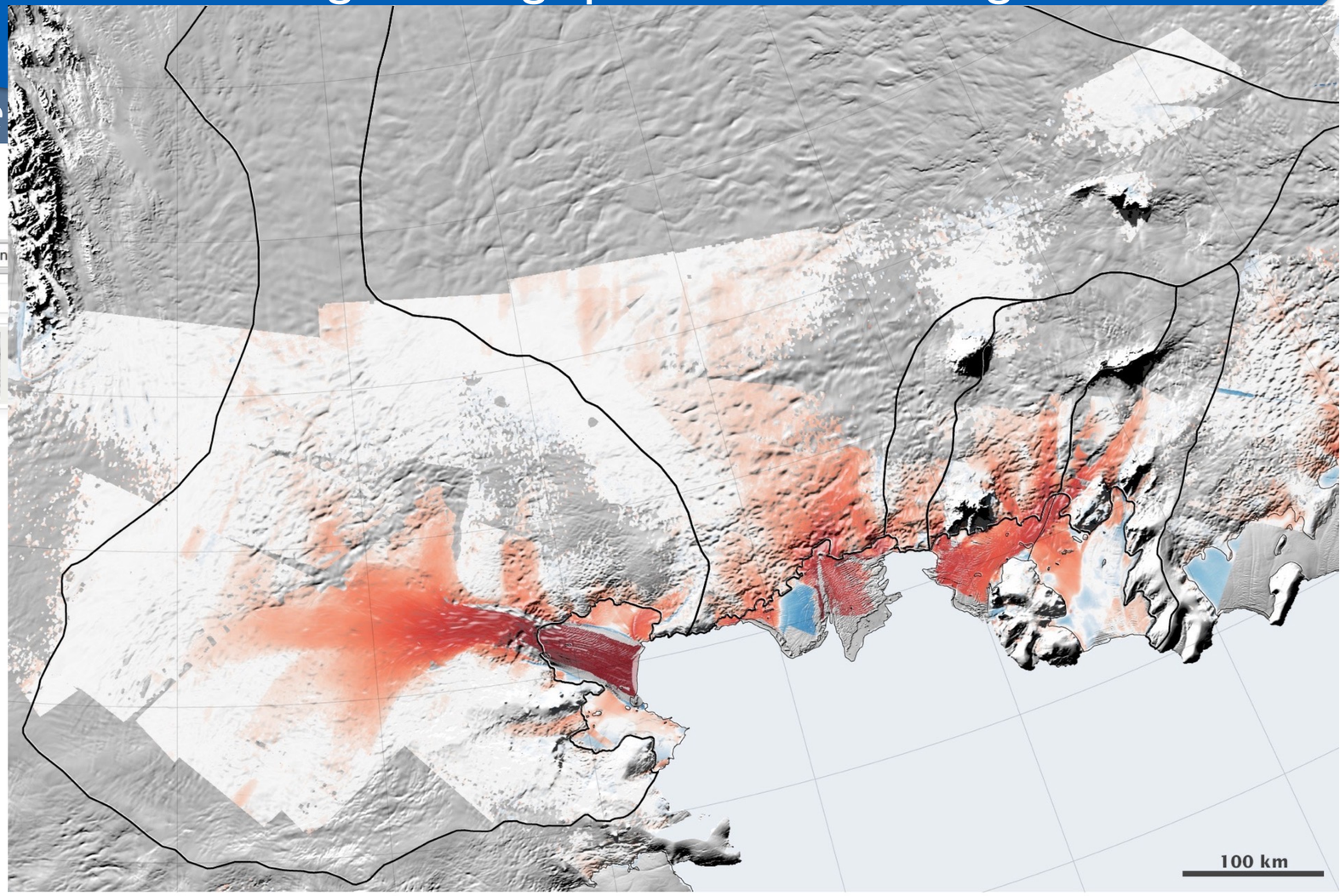

Change in Velocity from 1996 to 2008
(kilometers per year)

<−1.5 −0.1 −0.01 0.01 0.1 >1.5

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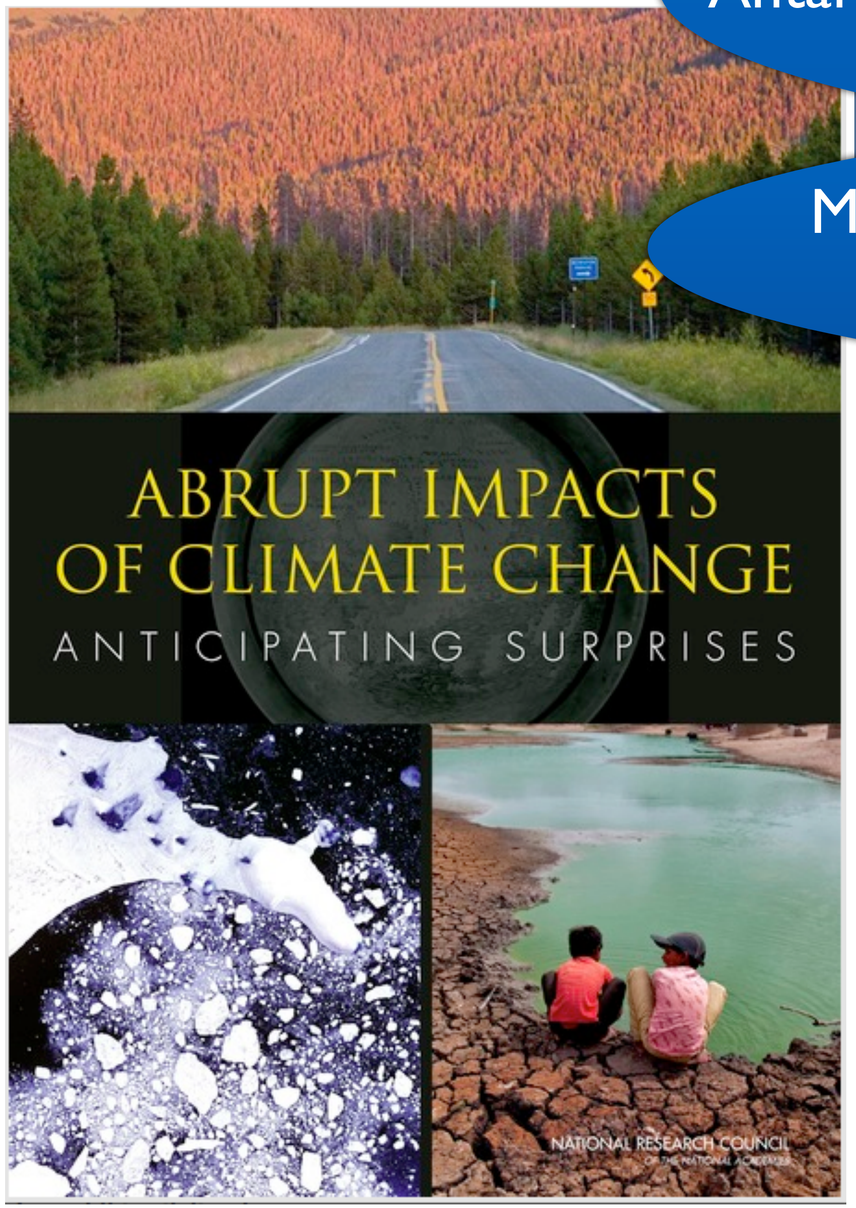
May 18, 2014: The glaciers of Greenland are likely to retreat faster and further inland than anticipated ....



Greenland will be far greater contributor to sea rise than expected

http://www.eurekalert.org/

Greenland will be far greater ...

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

MORE

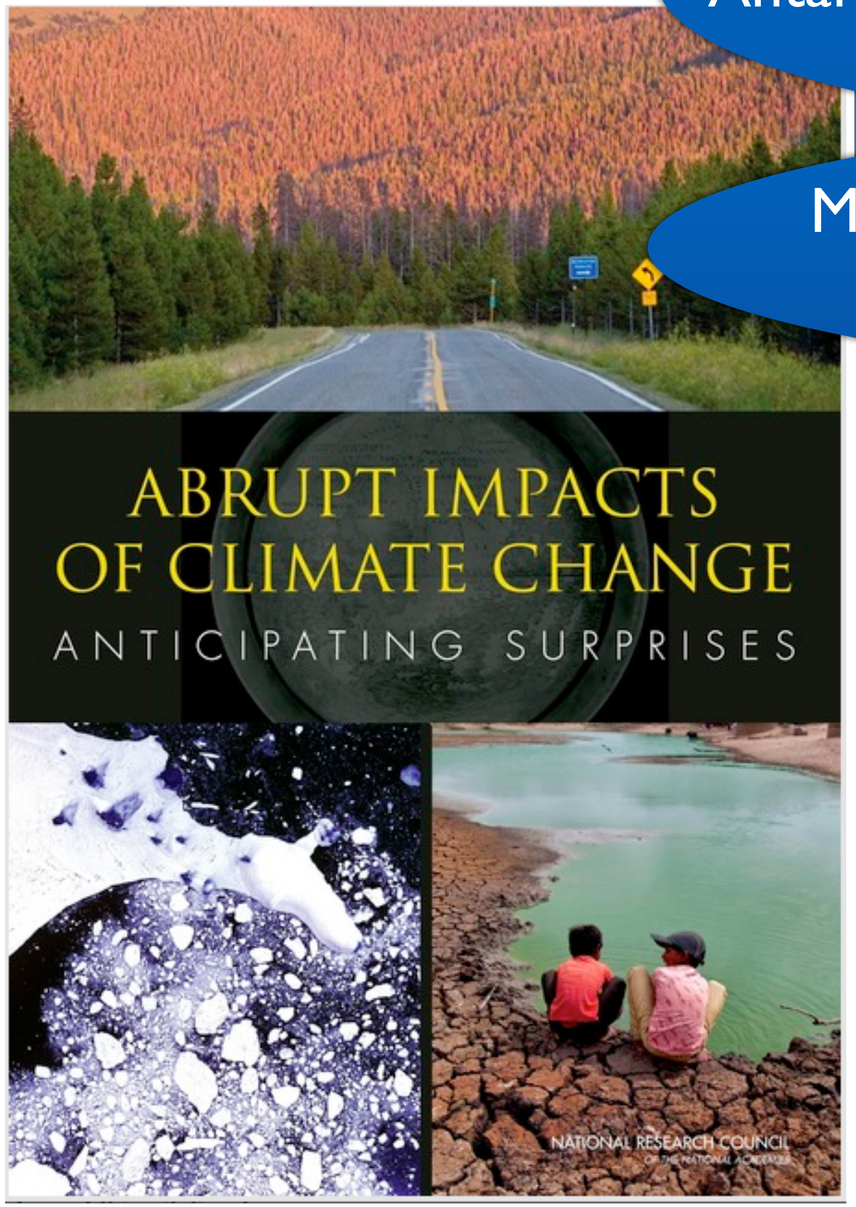
Global warming caused by the human-driven release of greenhouse gases has helped to destabilize the ice sheet, though other factors may also be involved, the scientists said.

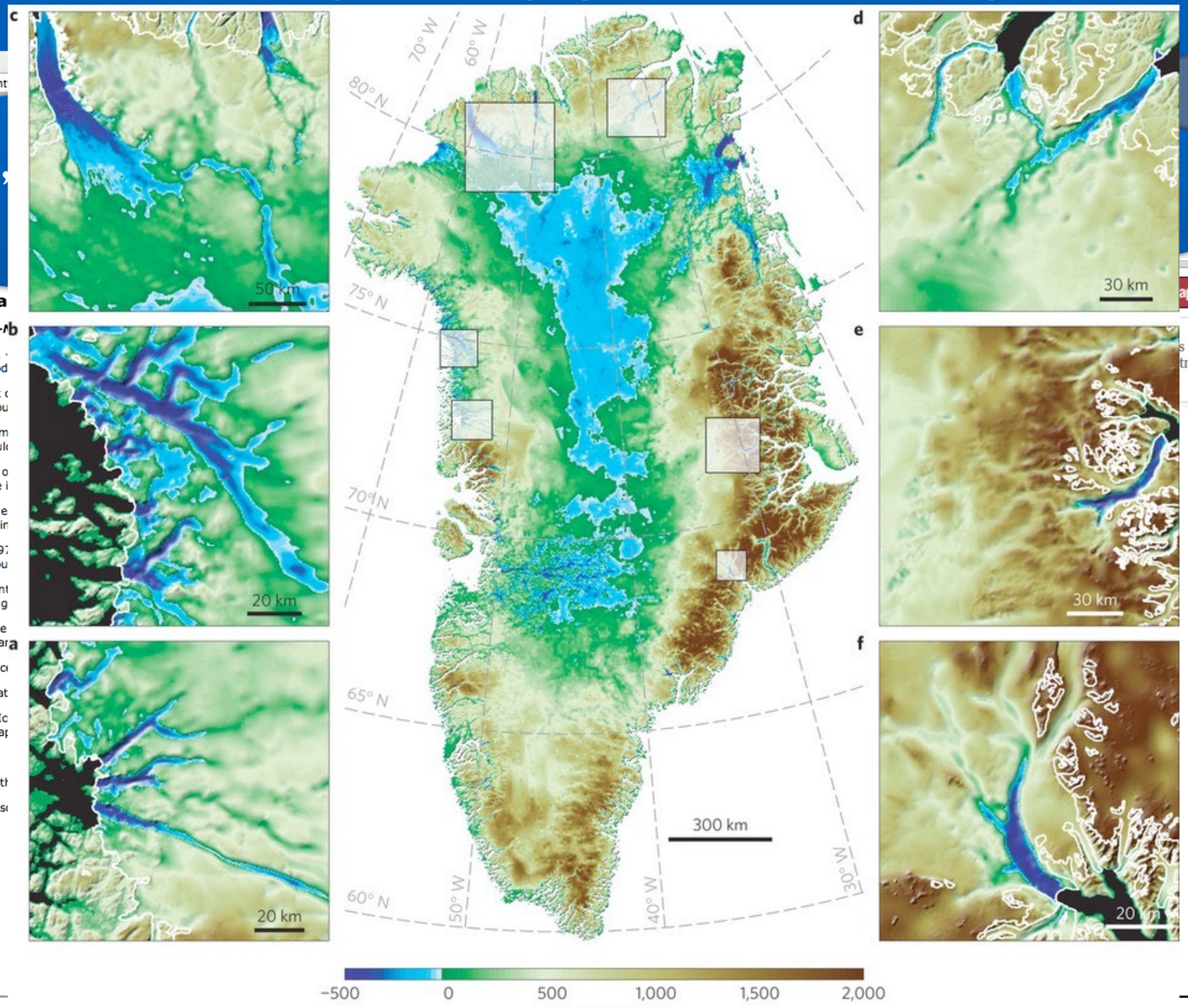
The rise of the sea is likely to continue to be relatively slow for the rest of the 21st century, the scientists added, but in the more distant future it may accelerate markedly, potentially throwing society into crisis.

Assessing Knowledge

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

May 18,





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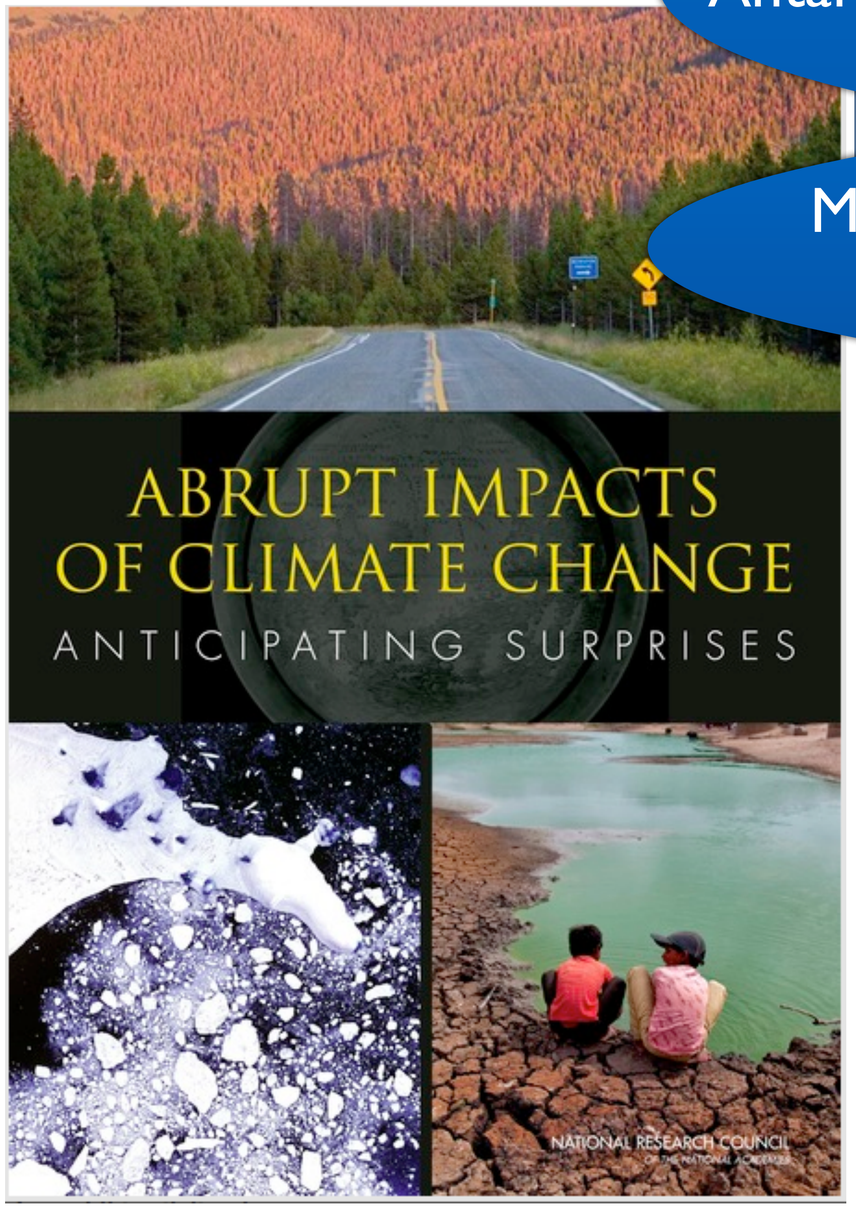
May 28, 2014: During that time, the sea level on a global basis rose about 50 feet in just 350 years



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

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PUBLIC RELEASE DATE: 28-May-2014

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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 ... Alfred-Wegener-Institut...

The researchers e... Antarctica by mo... at the past behav...

Periods of rapid increa... of debris during eight sep...

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 Un...sity 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."

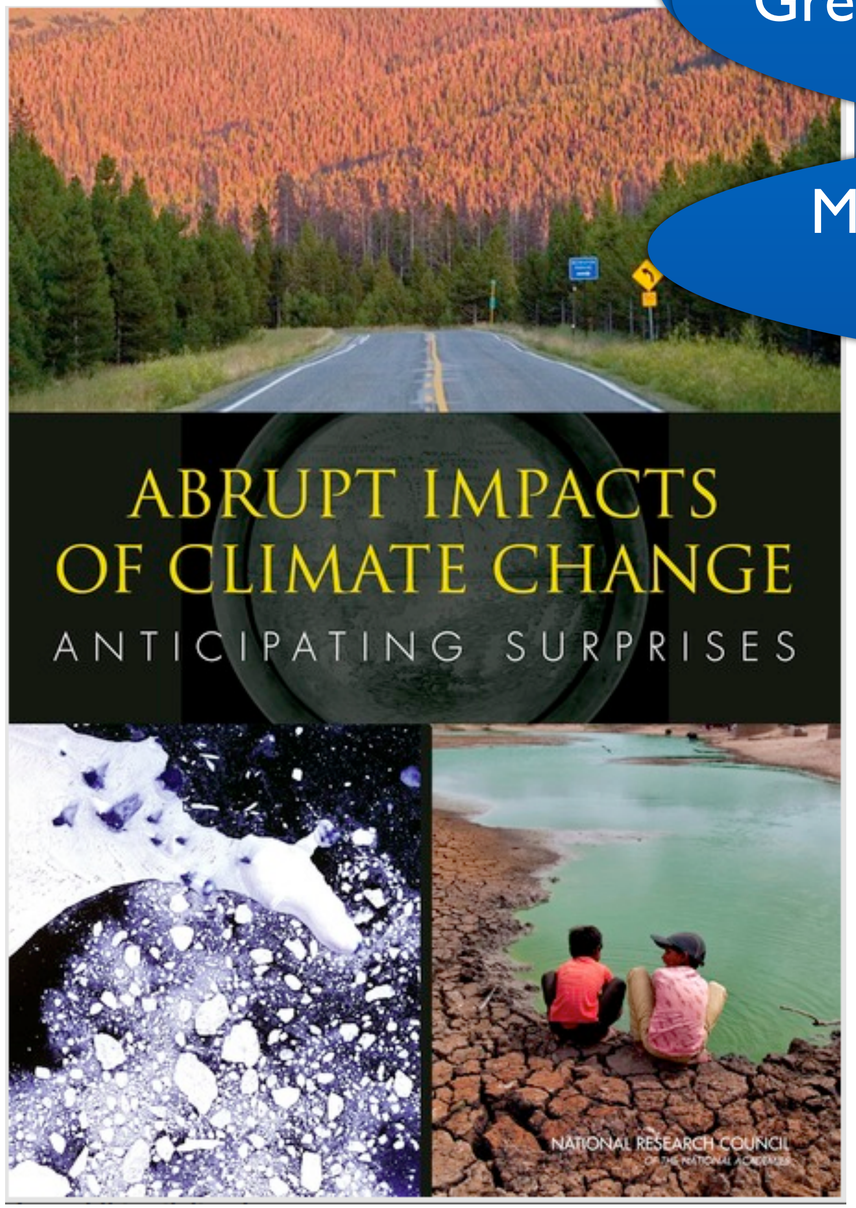
The researchers suspect that a feedback mechanism may have accelerated the melting, possibly by changing ocean circulation that brought warmer water to the Antarctic subsurface, according to co-author Axel Timmermann, a climate researcher at the University of Hawaii at Manoa.

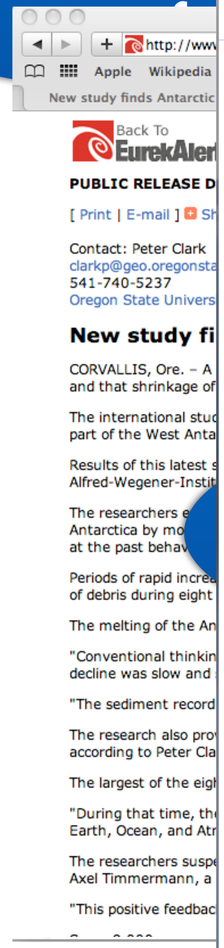
"This positive feedback is a perfect recipe for rapid sea level rise," Timmermann said.

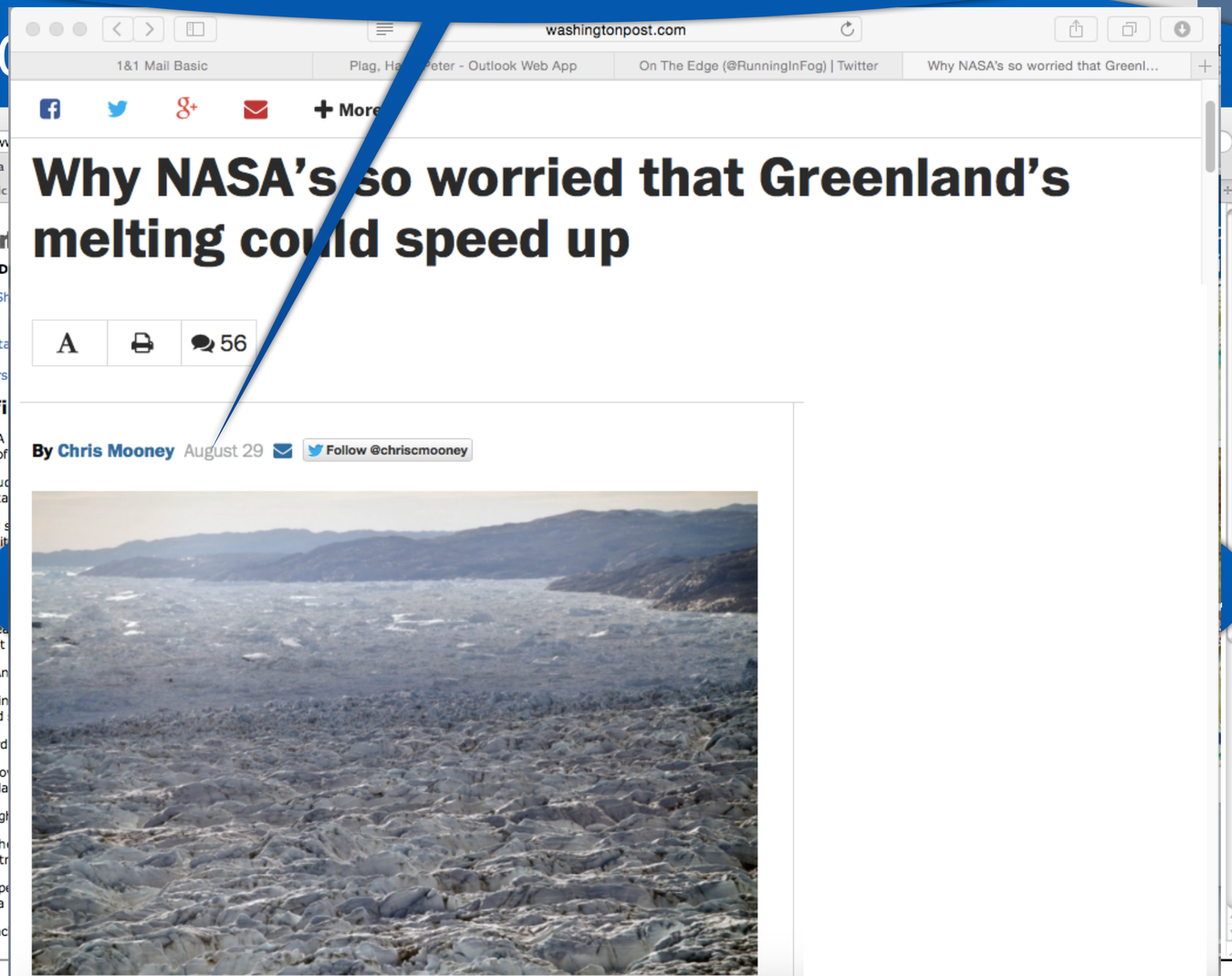
Assessing Knowledge

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







Assessing Knowledge

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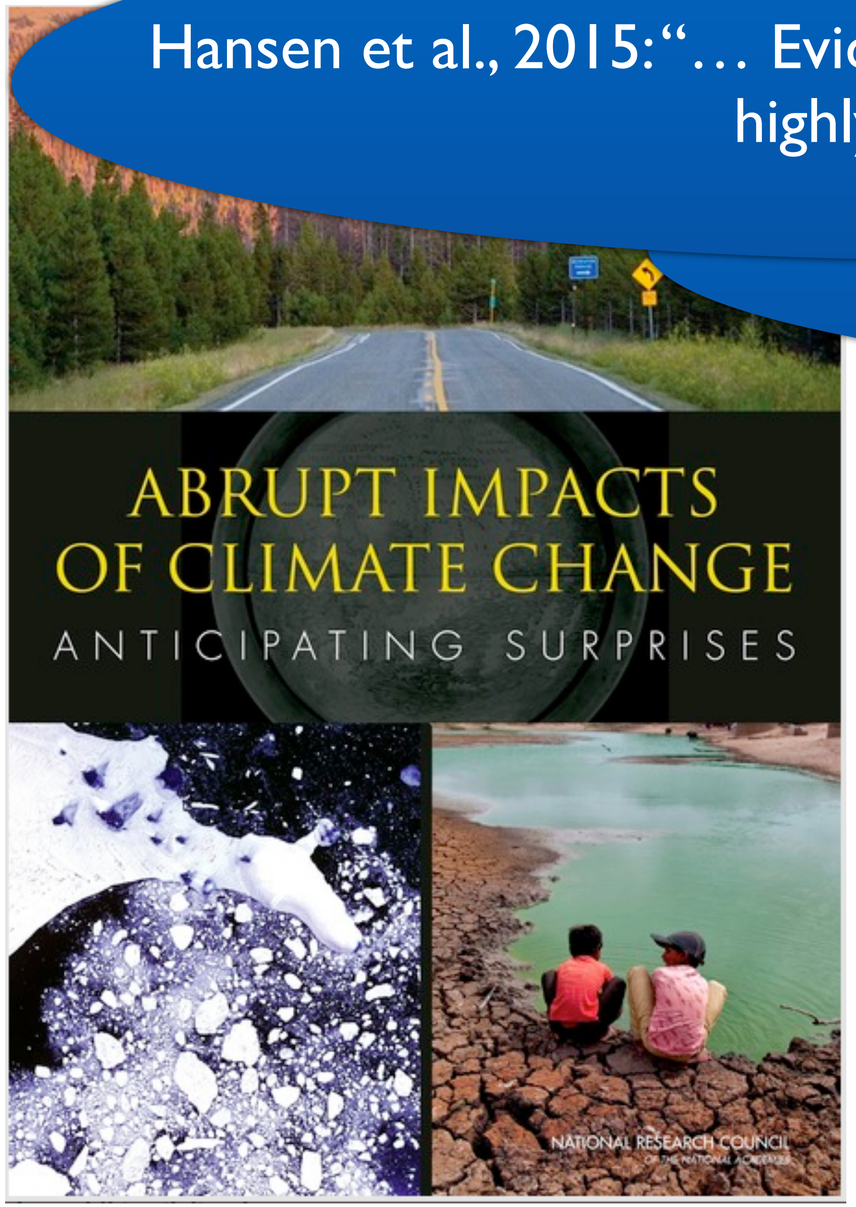
Hansen et al., 2015: "… Evidence … that 2°C global warming is highly dangerous."



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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]
[1]Climate Science, Awareness and Solutions, Columbia University Earth Institute, New York, NY 10115, USA
[2]Department of Environmental Studies, University of North Carolina at Wilmington, North Carolina 28403, USA
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[6]Key Lab of Aerosol Chemistry & Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China
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[8]Department of Earth System Science, University of California, Irvine, California, 92697, USA
[9]GEOMAR, Helmholtz Centre for Ocean Research, Wischhofstrasse 1–3, Kiel 24148, Germany
[10]Mediterranean Institute of Oceanography, University of Toulon, La Garde, France
[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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The Washington Post

Energy and Environment

Scientists find more reasons that Greenland will melt faster

By Chris Mooney April 30

Photograph of Torsukatat Avannarleq, a tidewater glacier in West Greenland, with 2 visible sediment plumes at its terminus. These plumes are made up of

The Washington Post

Energy and Environment

Dominoes fall: Vanishing Arctic ice shifts jet stream, which melts Greenland glaciers

By Chelsea Harvey May 2

Iceberg, with Mount Dundas in the background, Qaasuitsup, west Greenland, Denmark. (Photo by DeAgostini/Getty Images)

Assessing Knowledge

attribution: NASA Goddard

Cracks in the Greenland Ice Sheet let one of its aquifers drain to the ocean, new NASA research finds. The aquifers, discovered only recently, are unusual in that they trap large amounts of liquid water within the ice sheet. Until now, scientists did not know what happened to the water stored away in this reservoir -- the discovery will help fine tune computer models of Greenland's contribution to sea level rise.

http://www.dailykos.com/story/2017/2/20/1635162/-NASA-defies-Trump-s-doubts-on-climate-science-Identifies-new-path-for-Greenland-meltwater-to-Ocean

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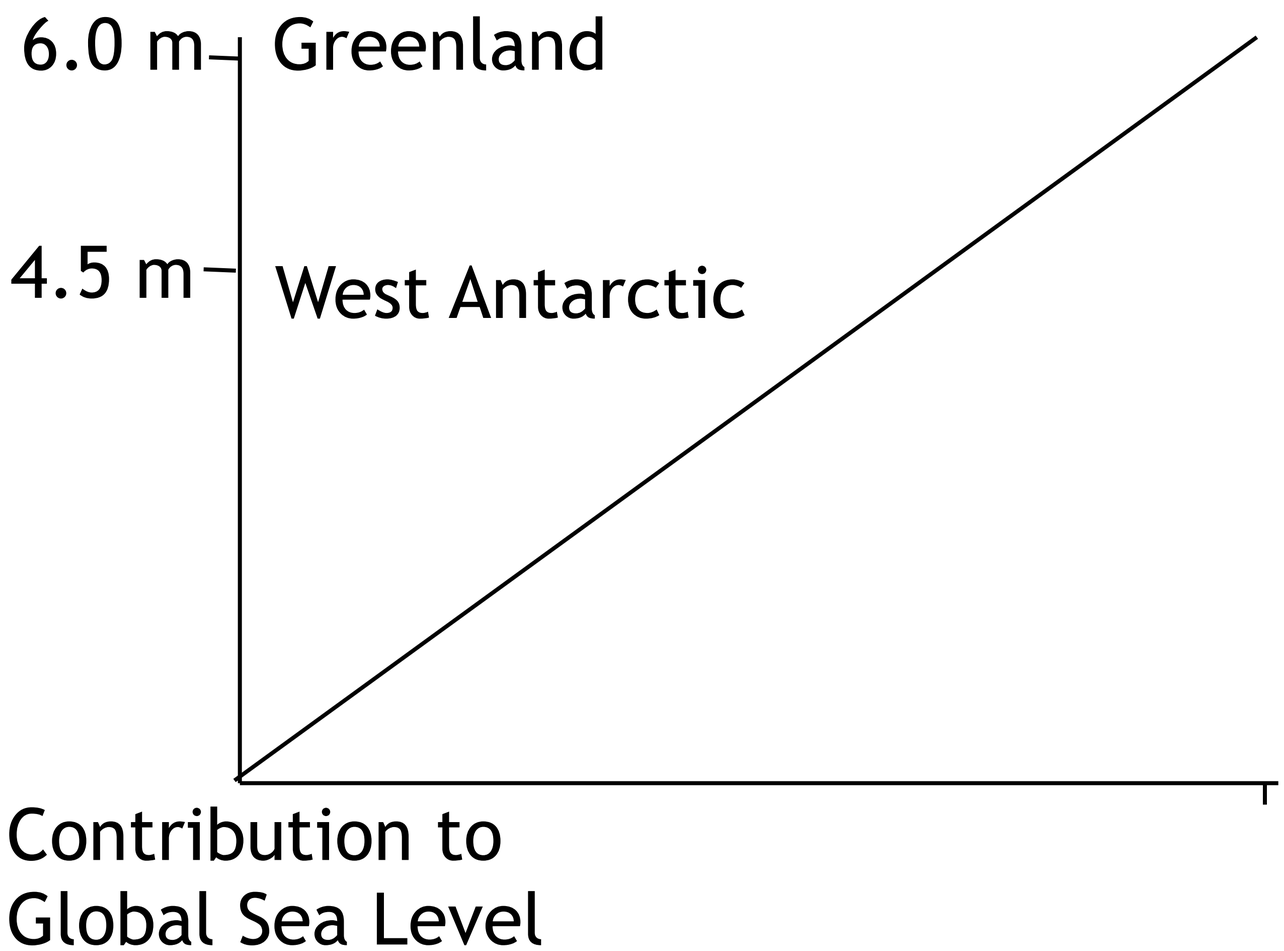

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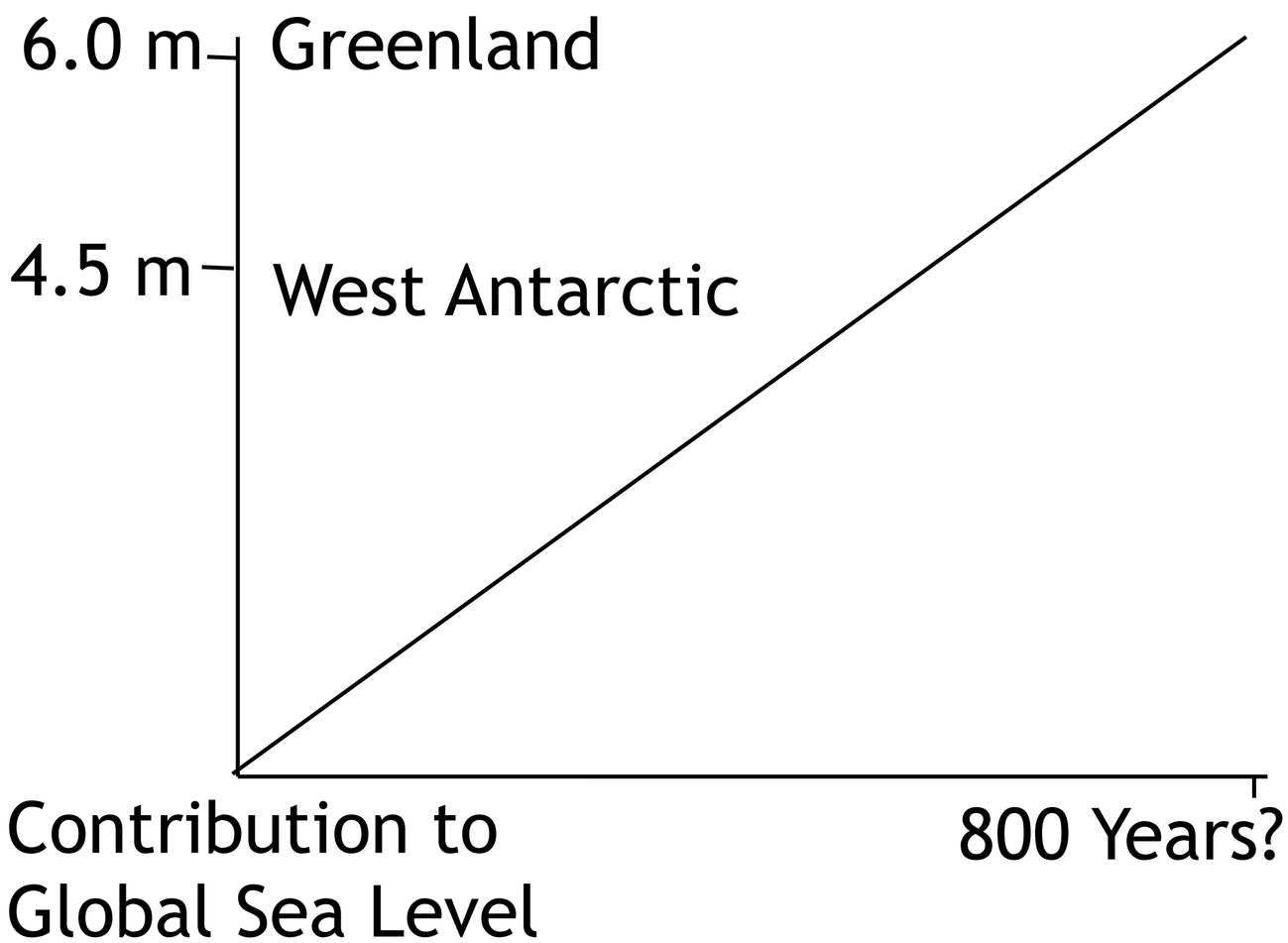

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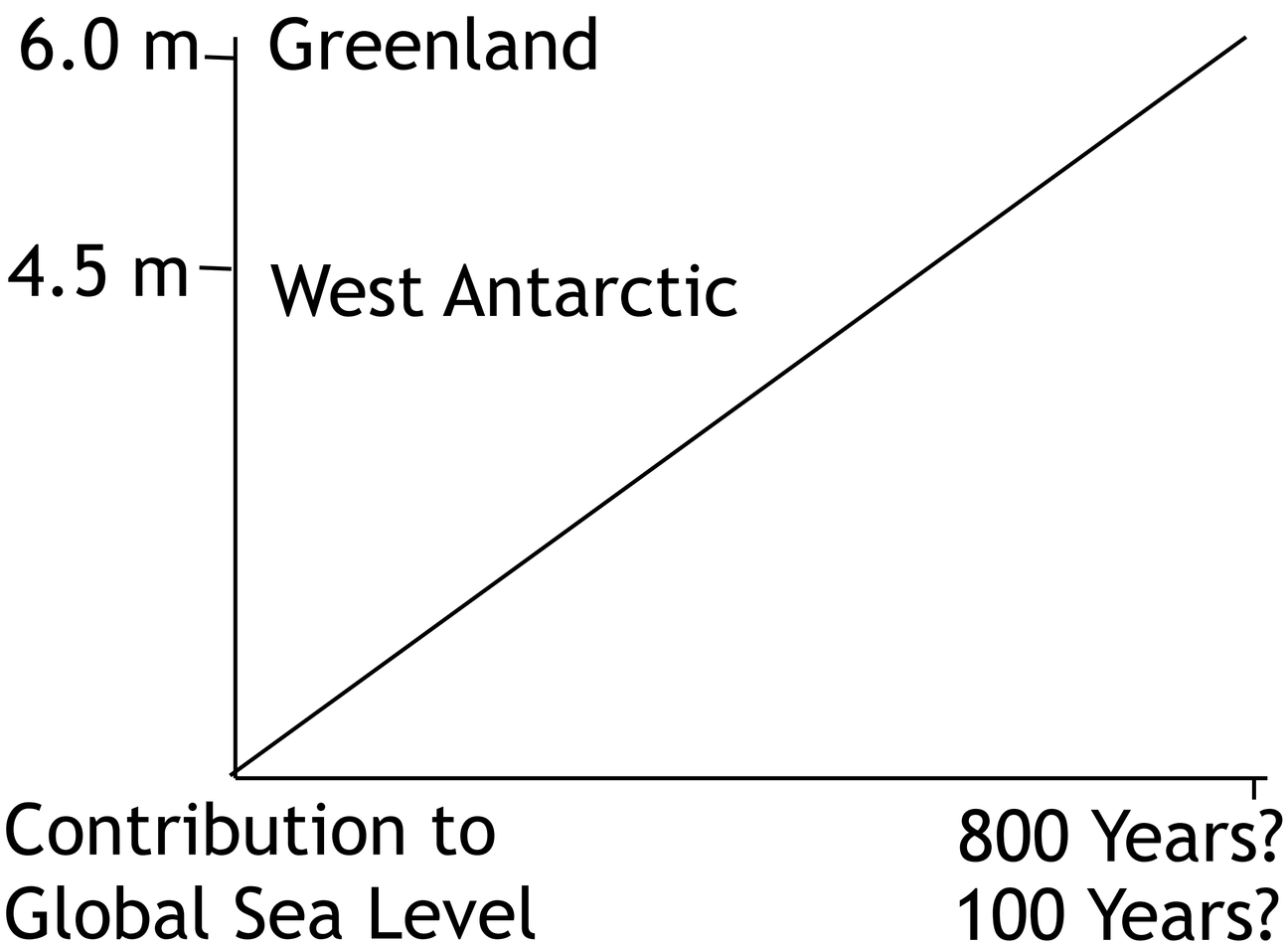

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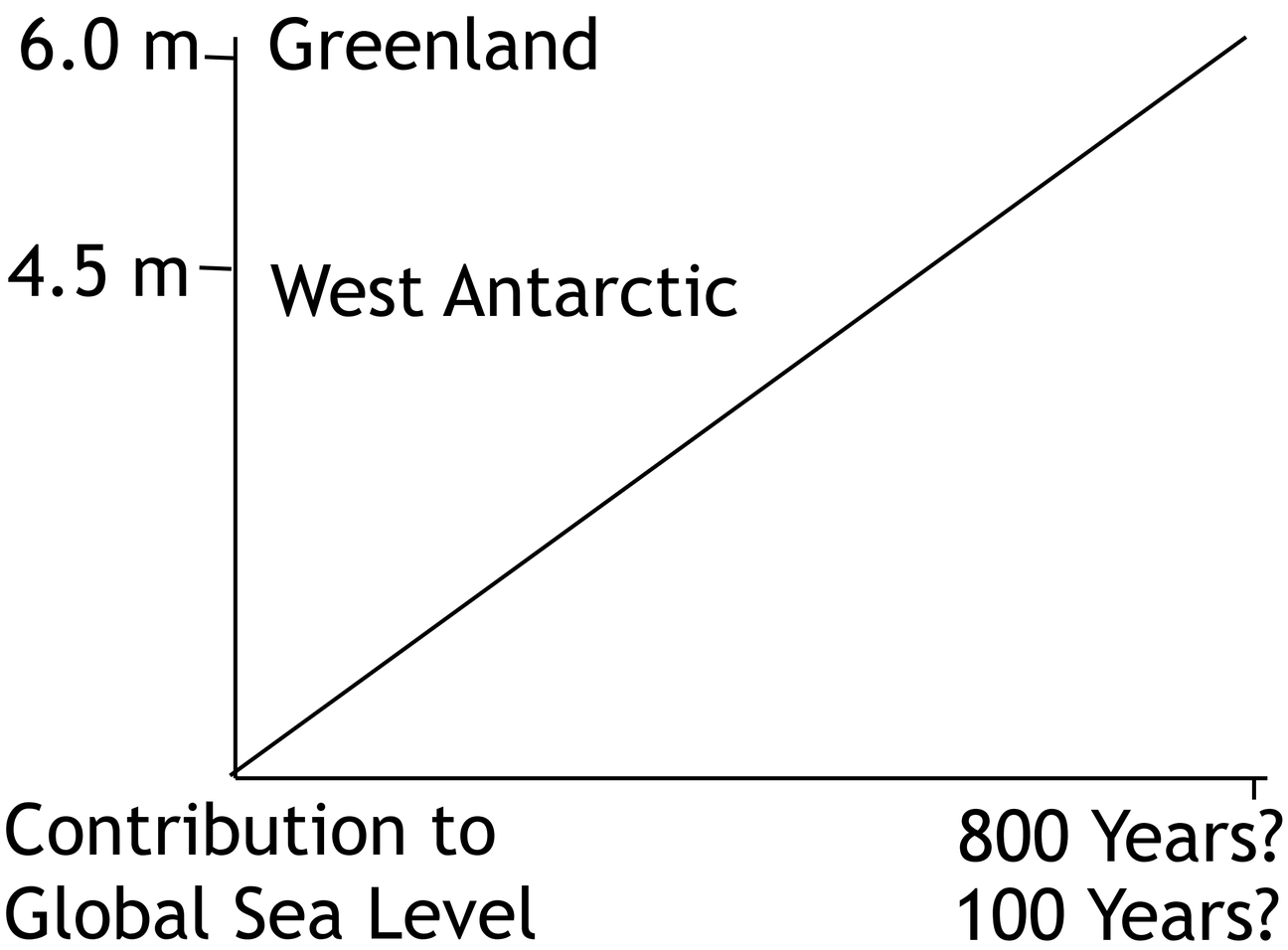

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Main contribution: steric changes

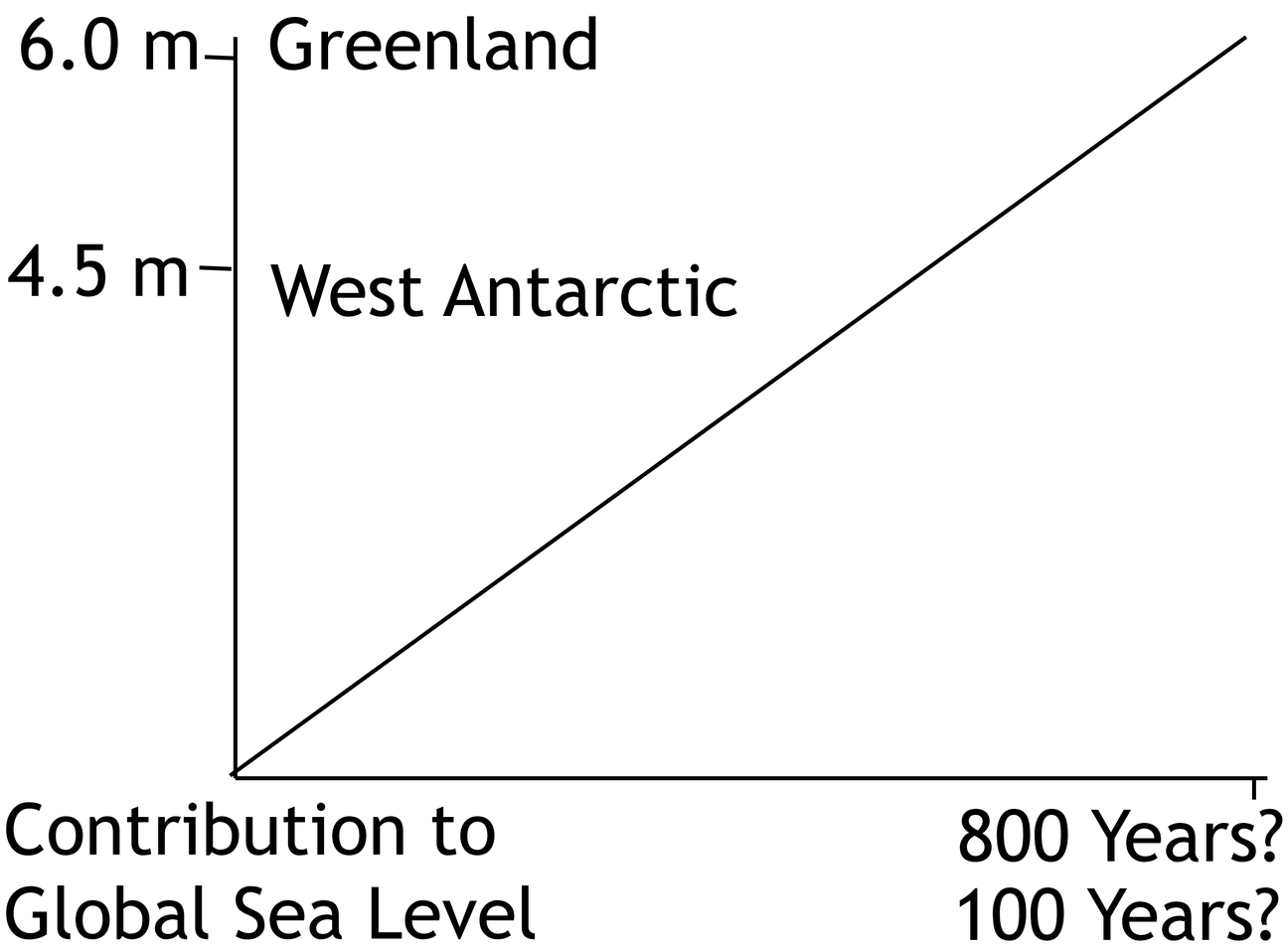
Knowledge in 2016:

Greenland: is contributing, is accelerating; increasing potential for a large contribution to sea level rise due to deep warm water around Greenland and impact of changes in atmospheric circulation.

Antarctica: West Antarctic ice sheet (WAIS) will contribute 4.5 m

How worried should we be?

How solid is our knowledge?



Example sea level rise

Accepted knowledge in 2000:

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Antarctica: minor contribution

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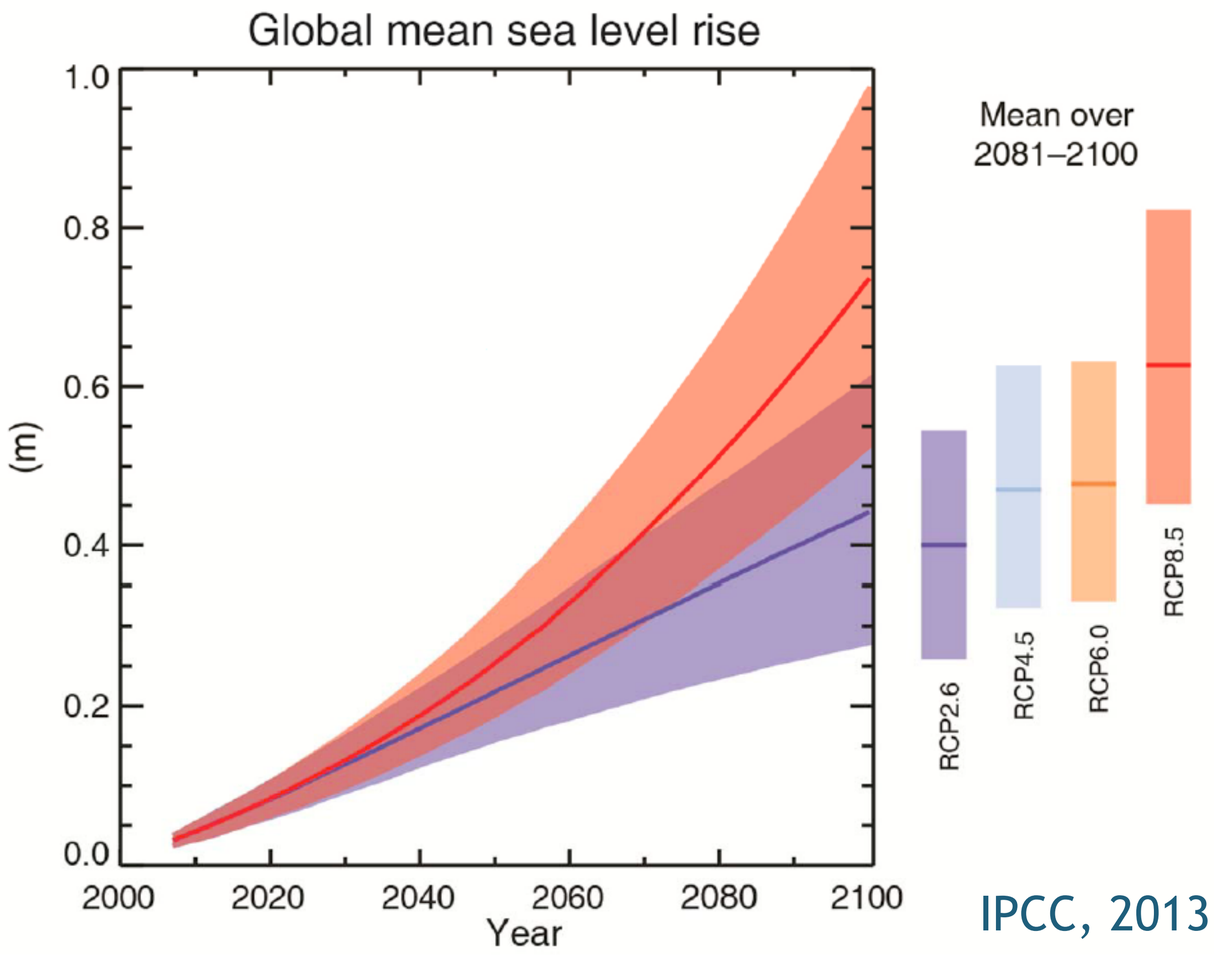
How worried should we be?

What should we be worried about?

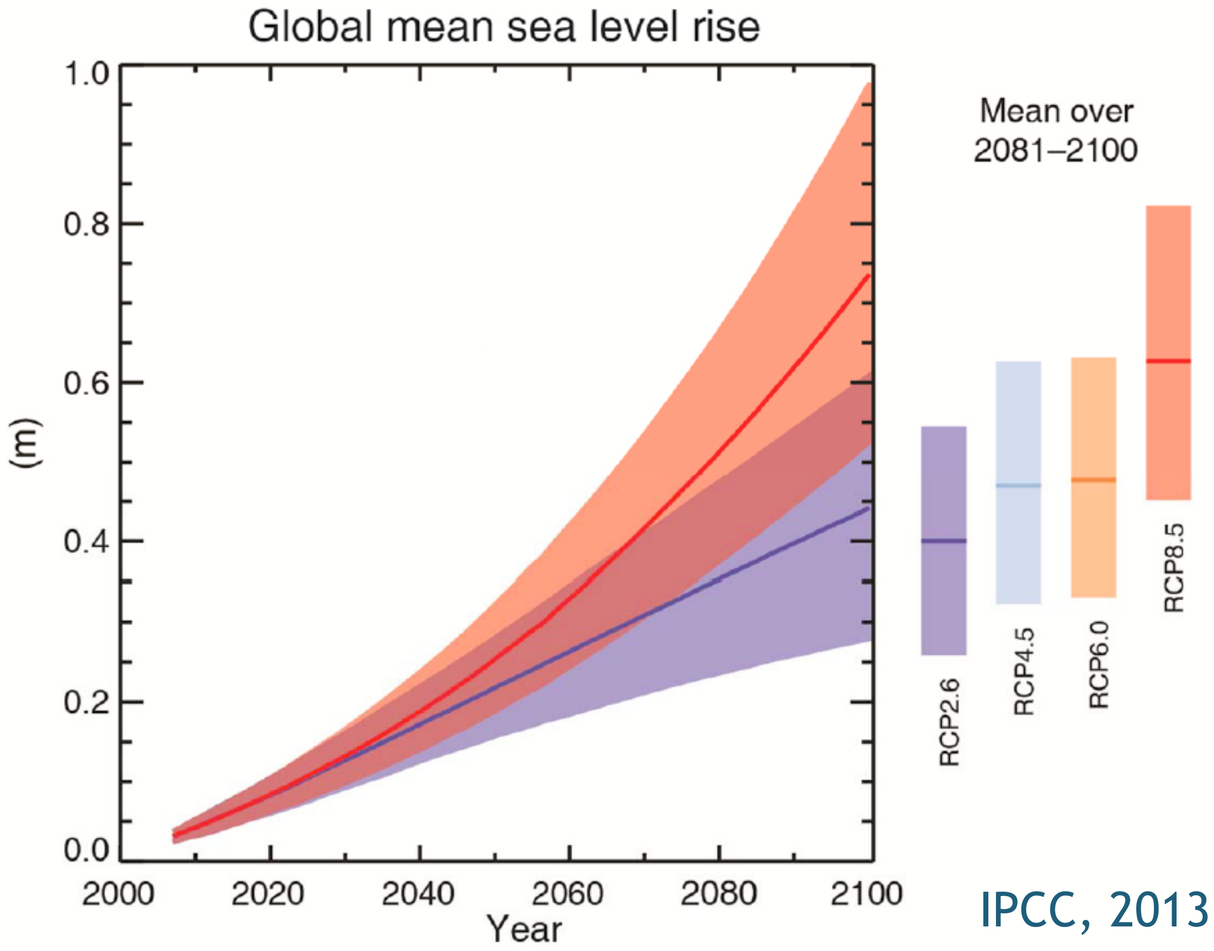
Sea Level Change

Sea Level Change



IPCC, 2013

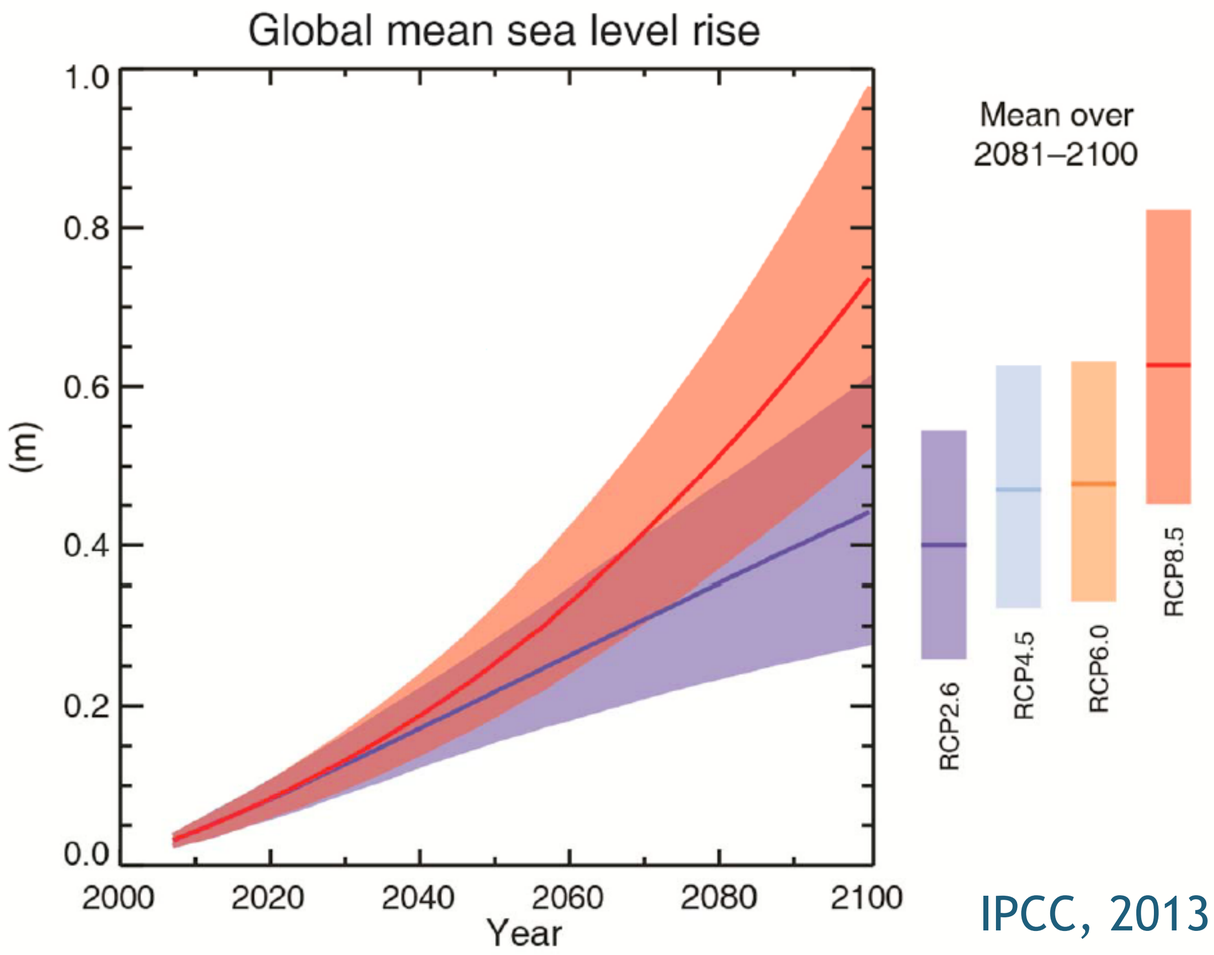
Sea Level Change



IPCC, 2013

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

Sea Level Change



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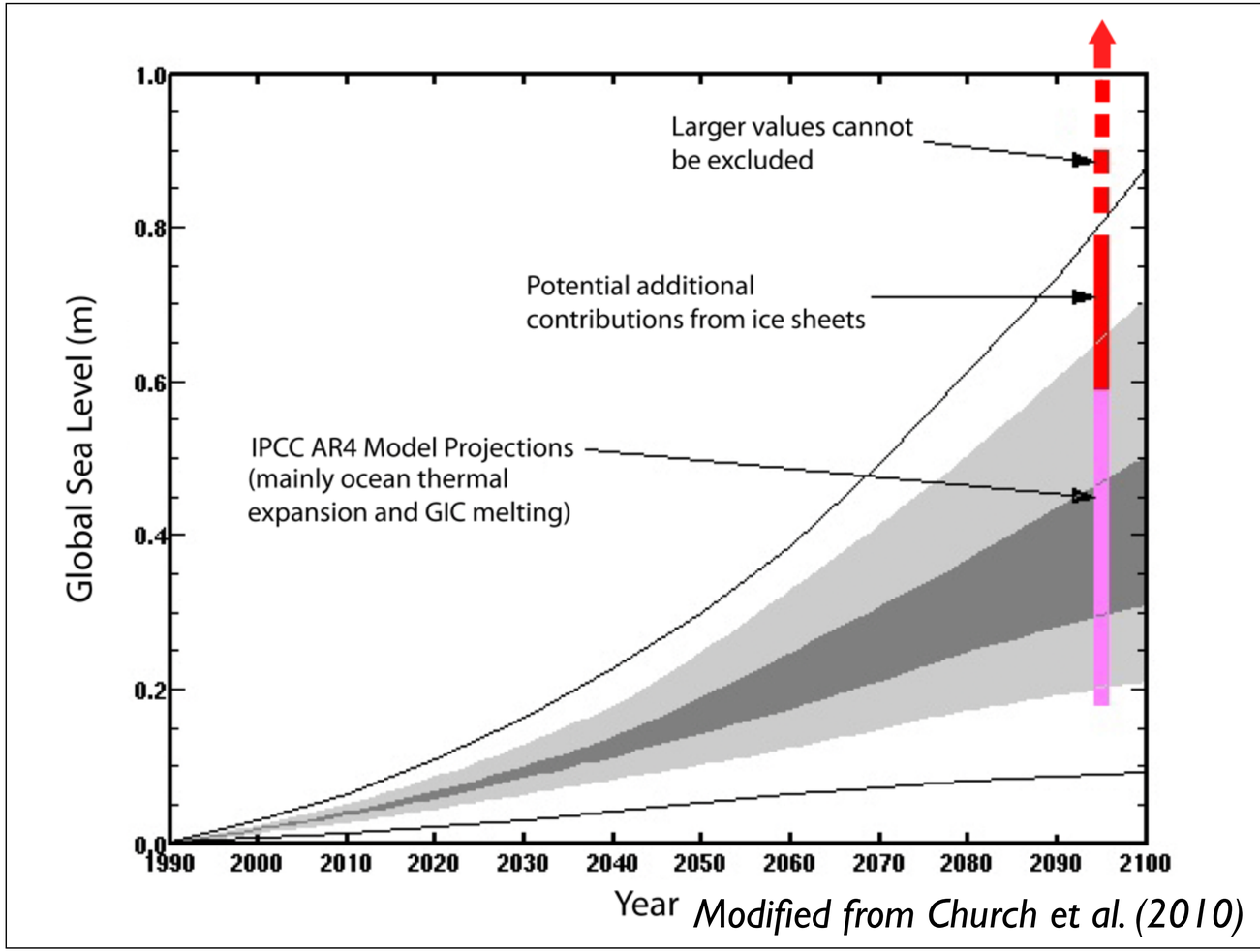
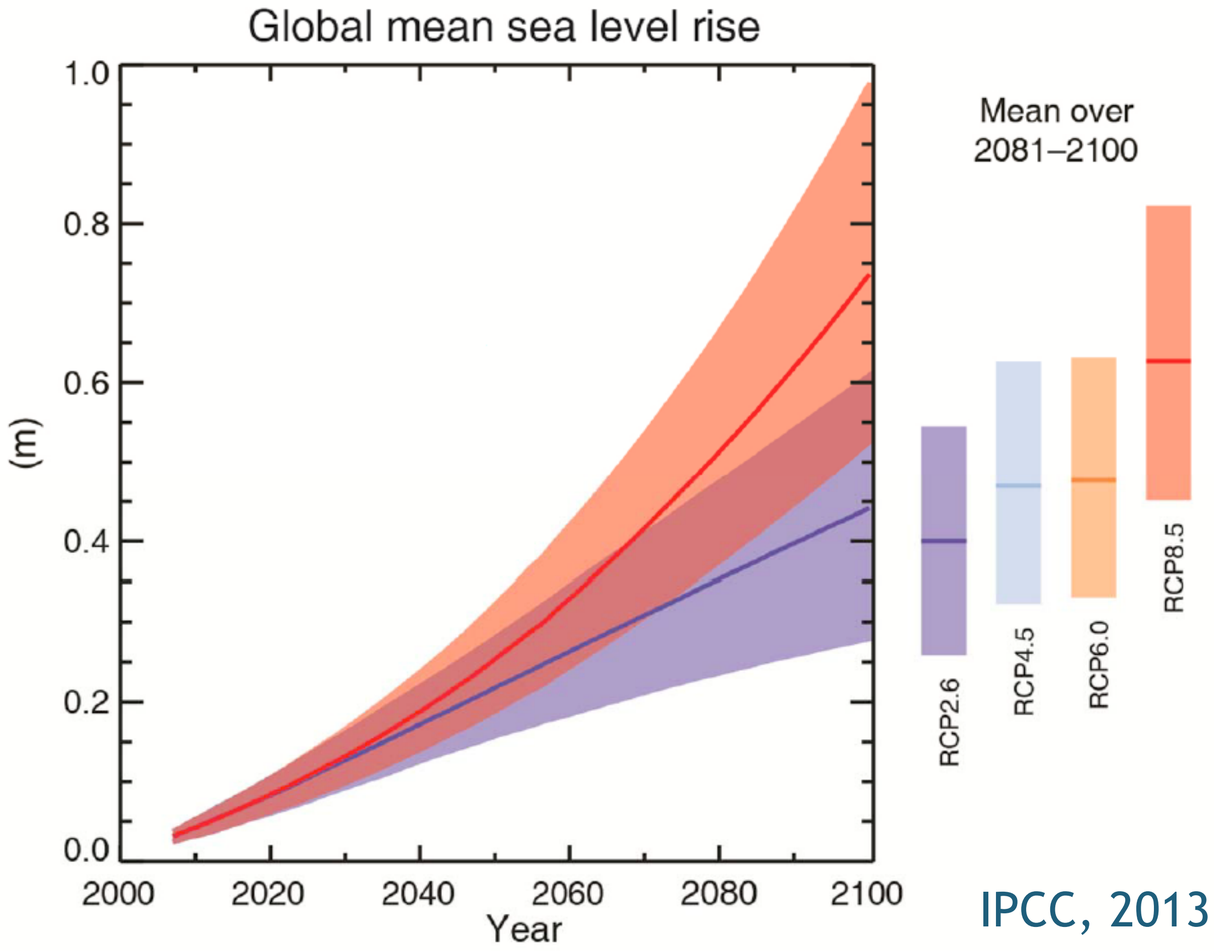


Modified from Church et al. (2010)

Sea Level Change



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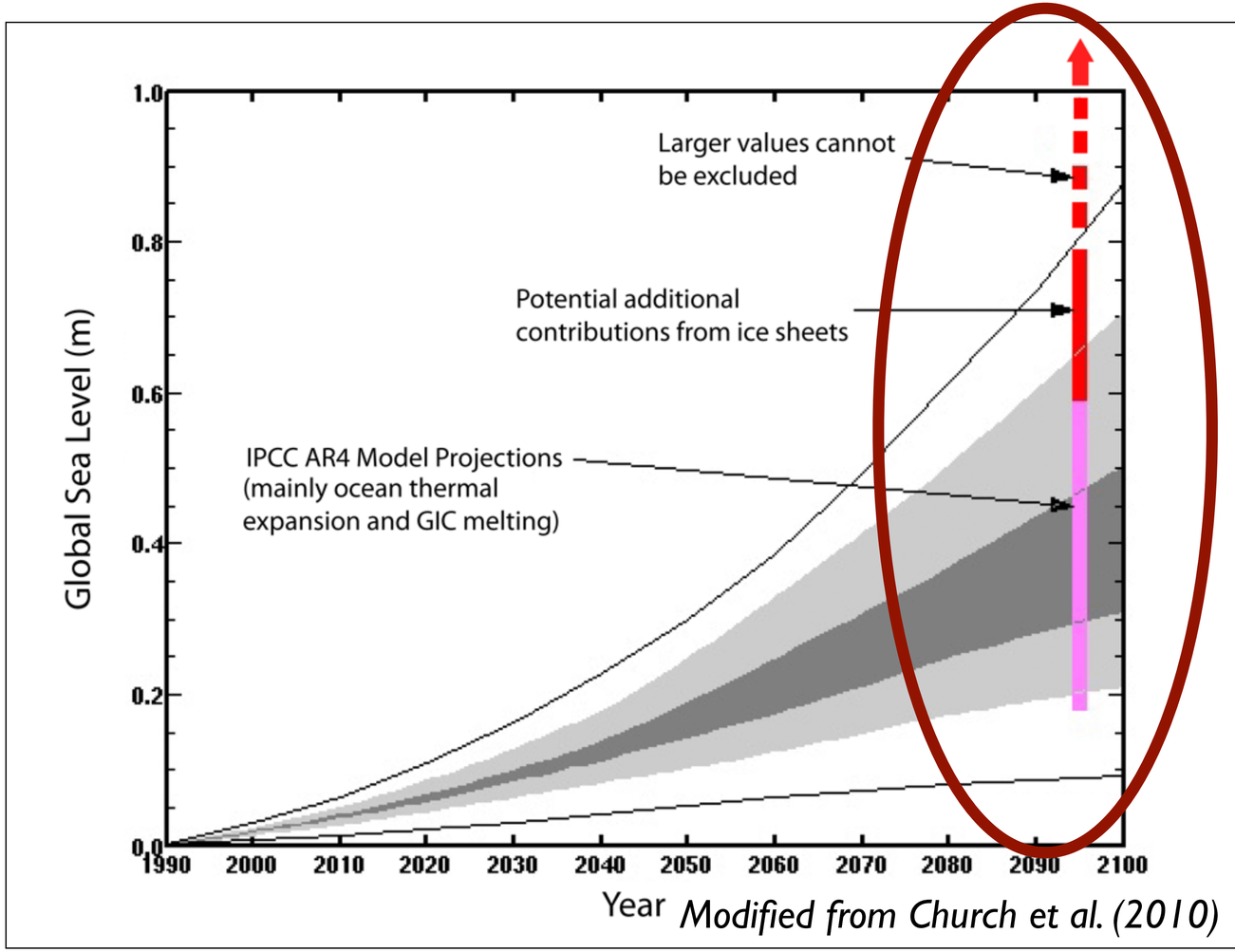

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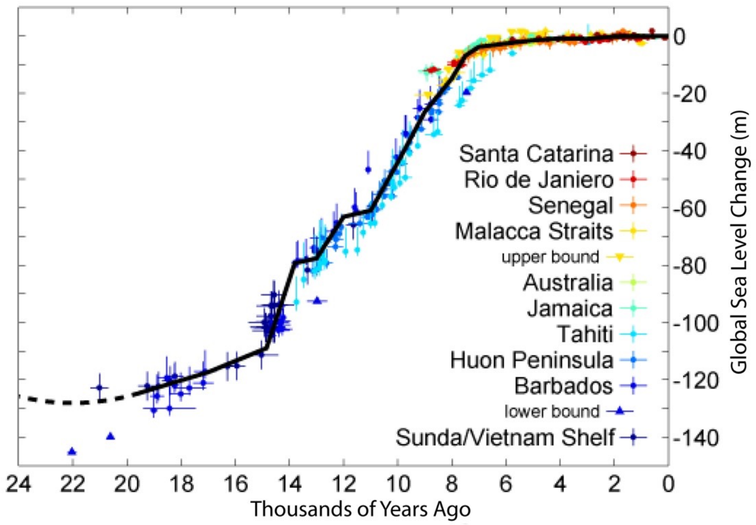
Sea Level Change

Sea Level Change

Question: What is the probability density function for sea level change per century?

Sea Level Change



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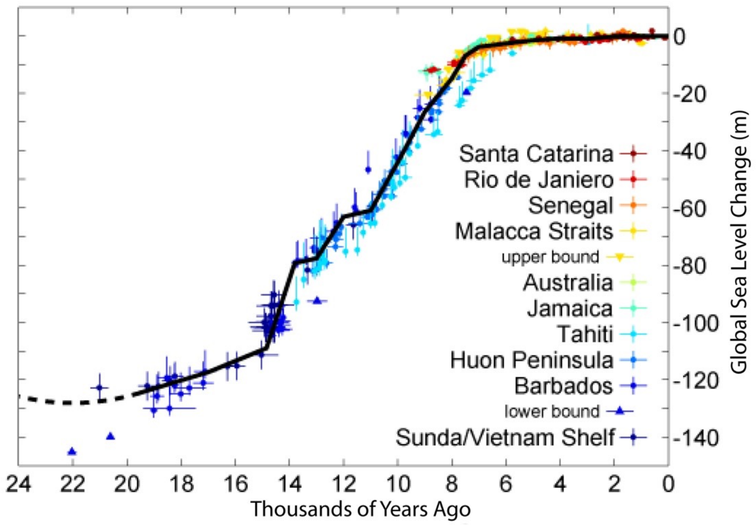
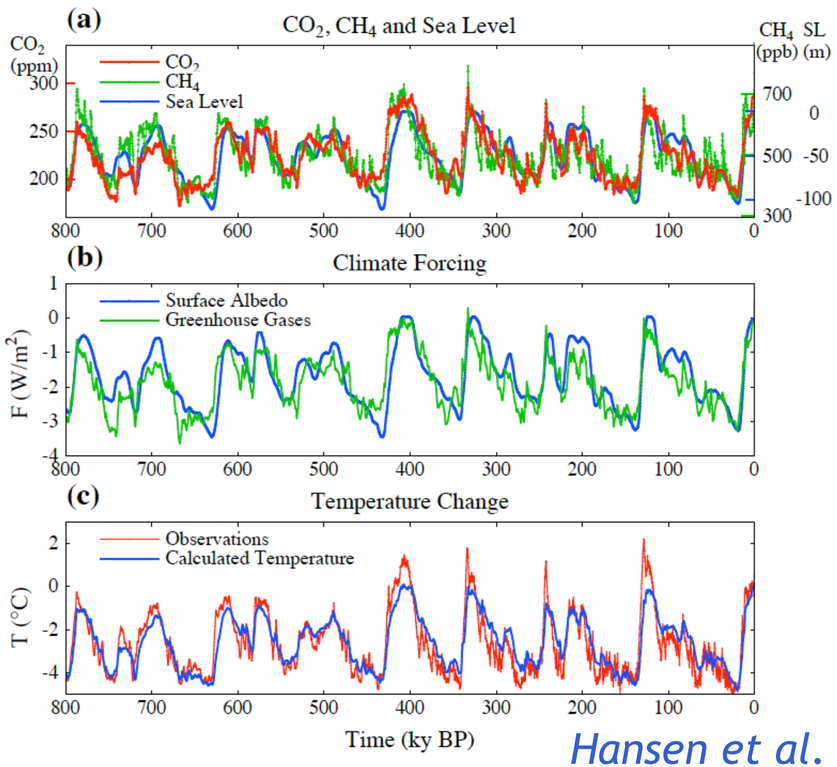
Look at paleo-data …

Sea Level Change





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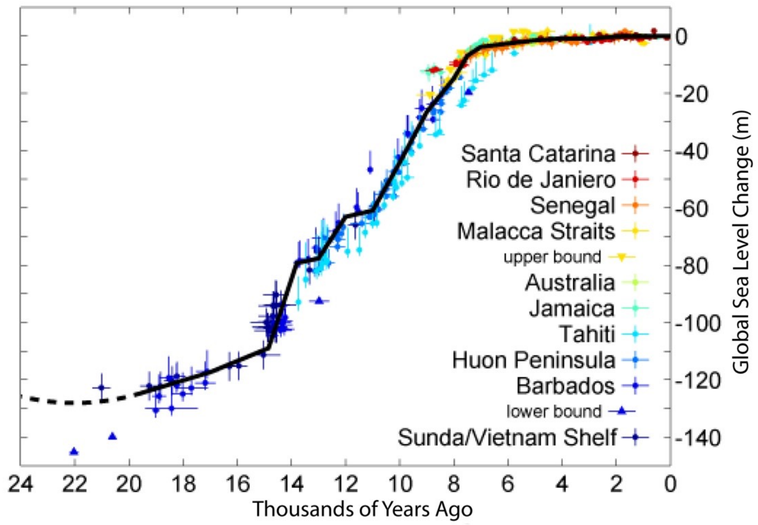

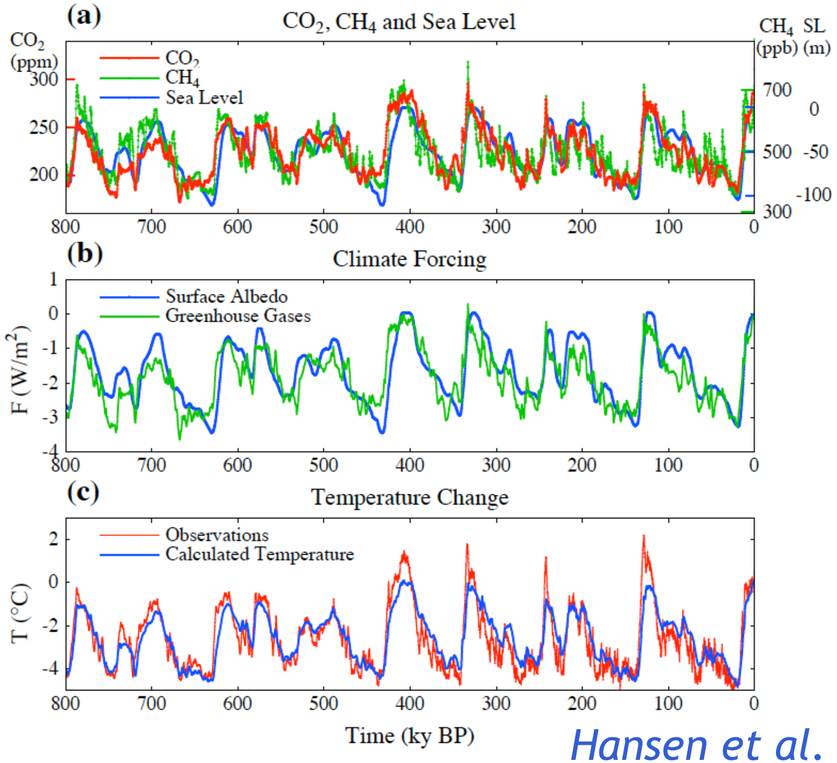

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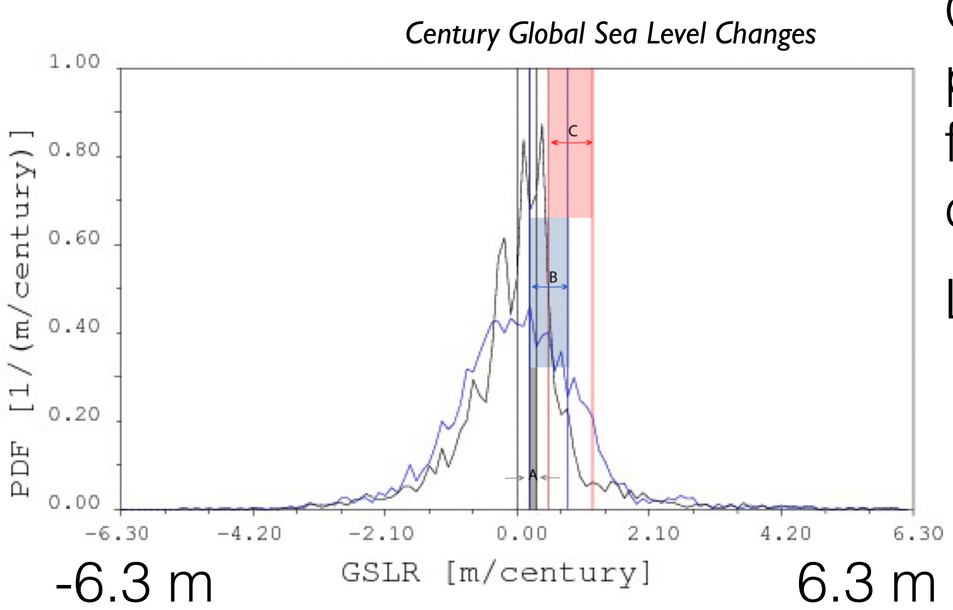

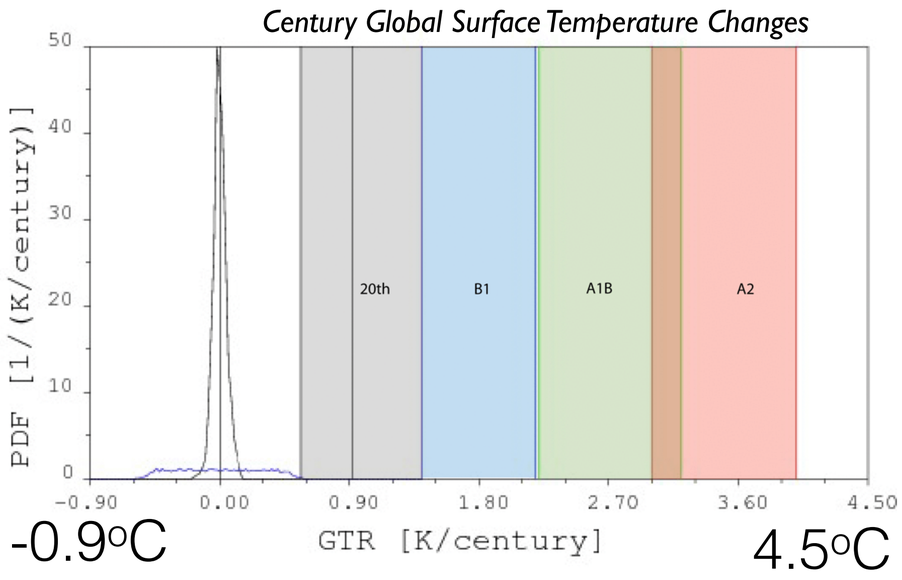

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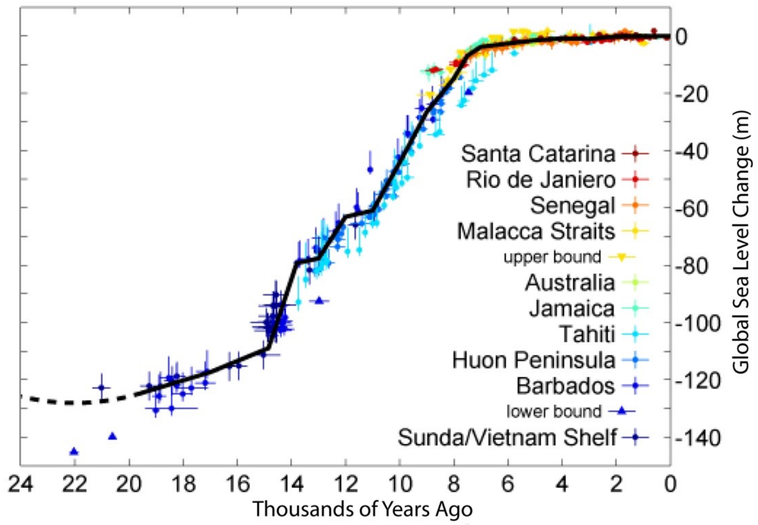

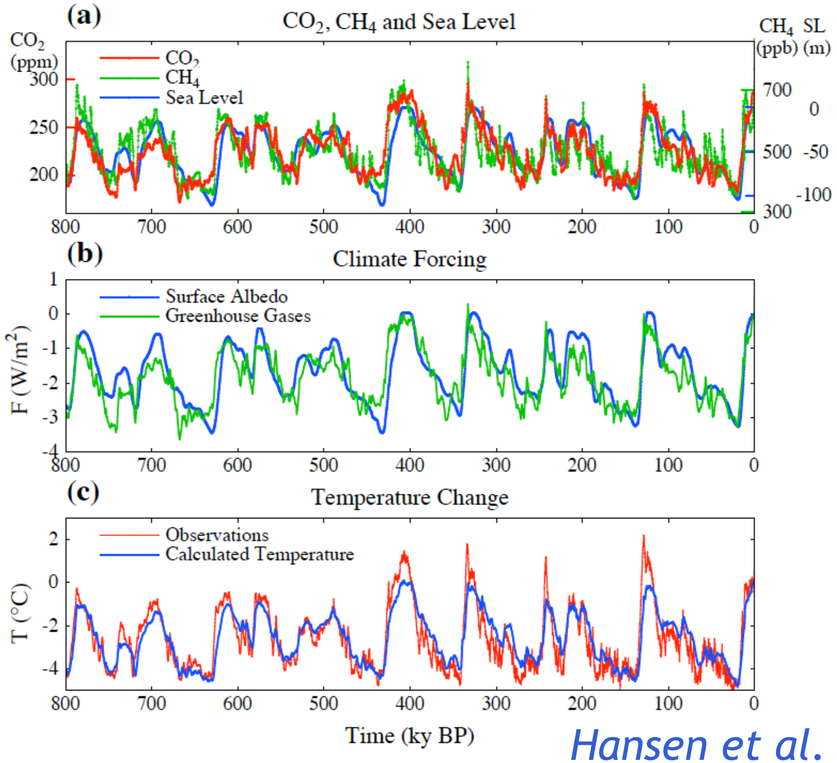

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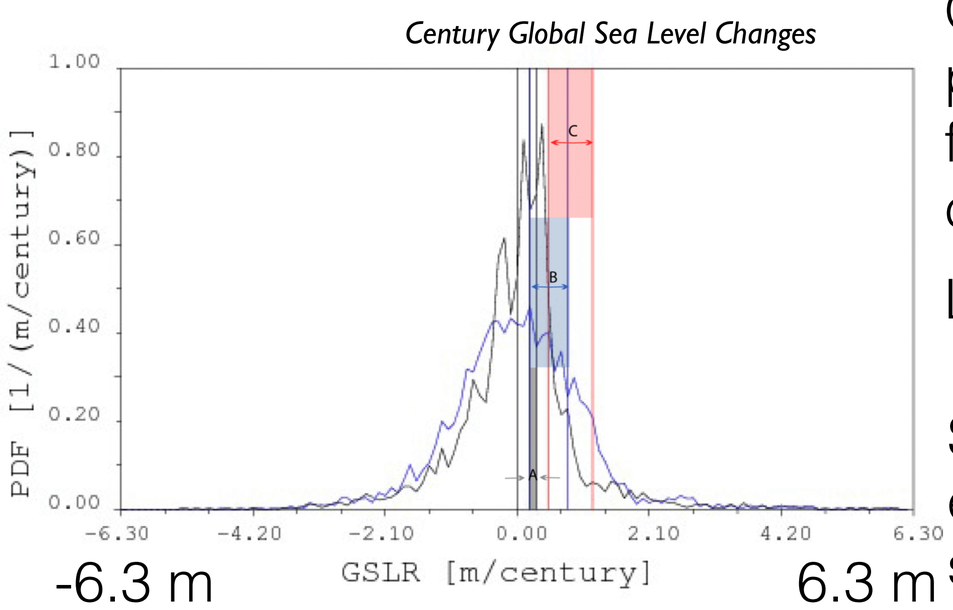

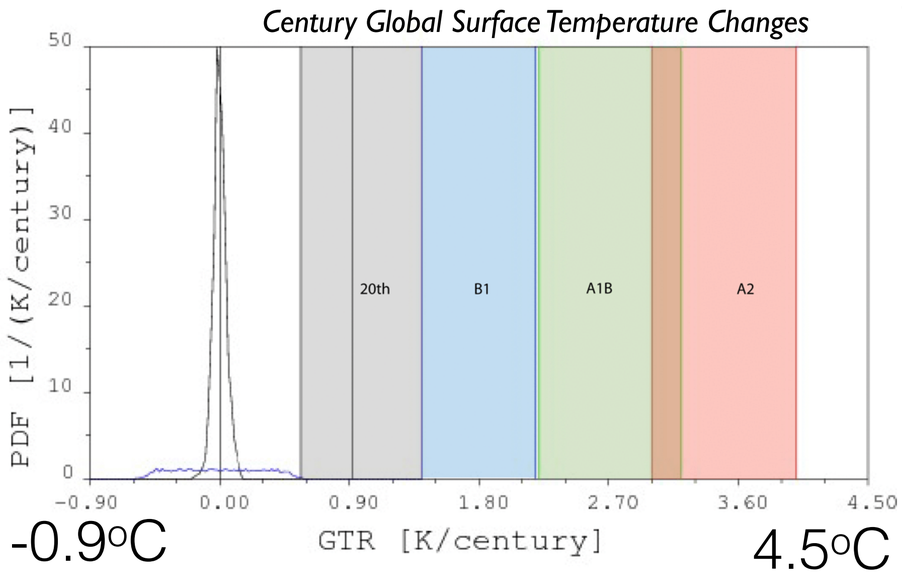

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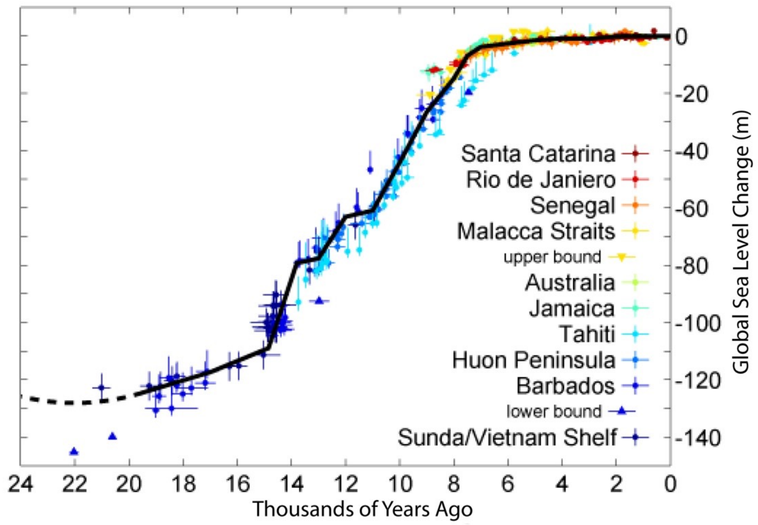
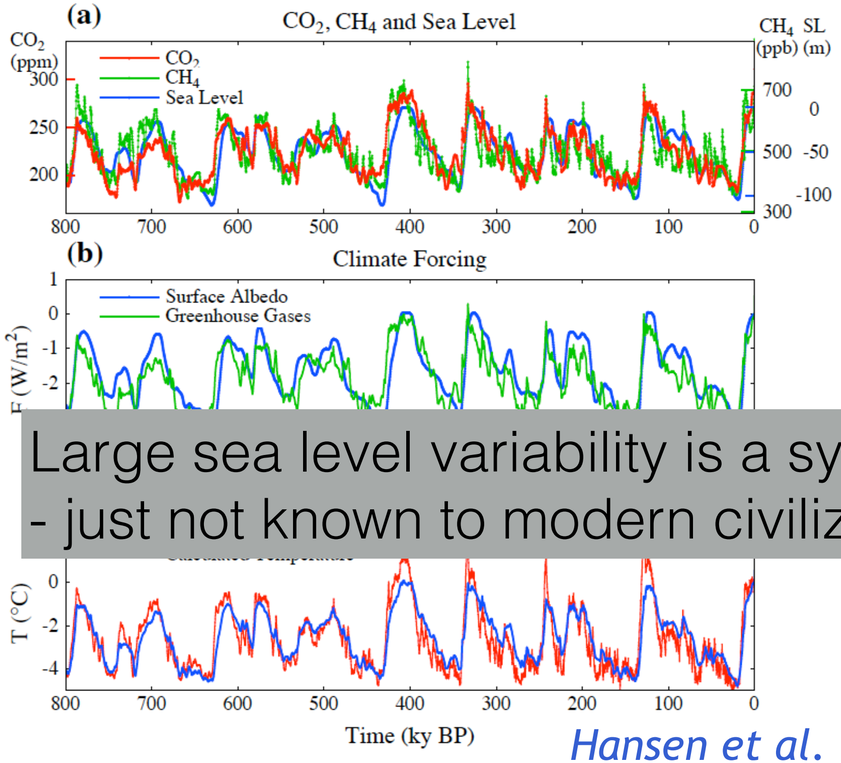
Look at paleo-data …

Scientifically, we cannot exclude a large, rapid global sea level rise with large spatial variability in local sea level rise.

Sea Level Change





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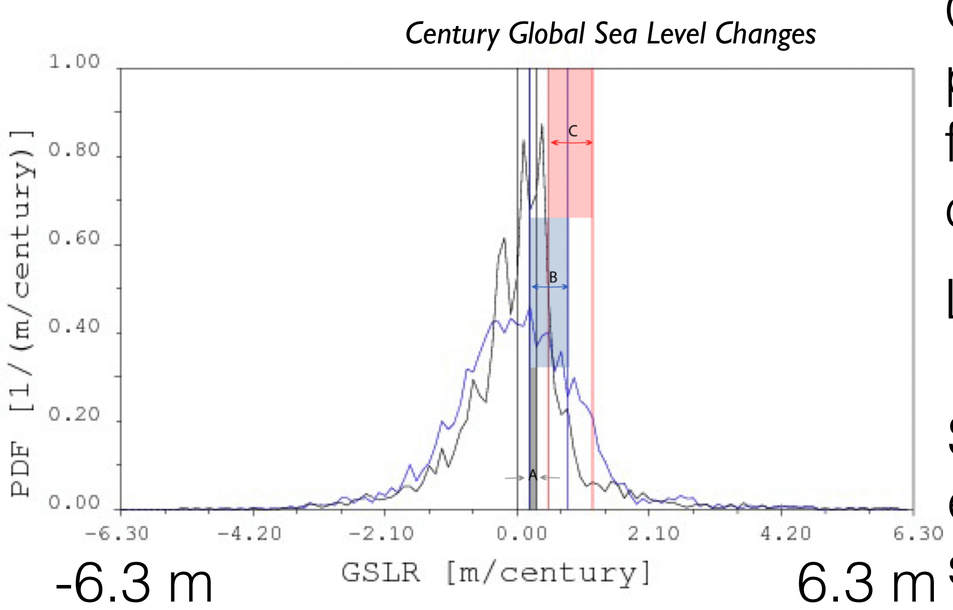

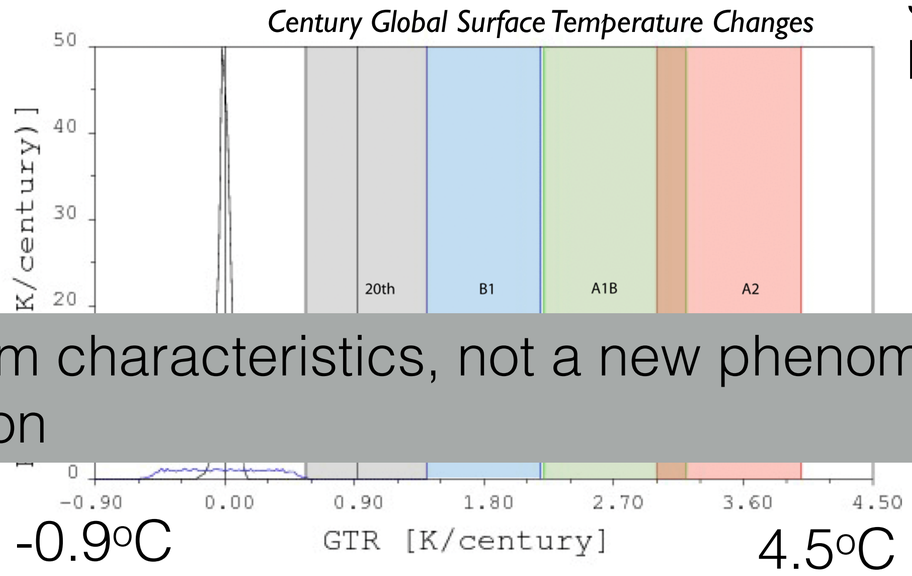

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Question: What is the probability density function for sea level change per century?

Look at paleo-data …

Scientifically, we cannot exclude a large, rapid global sea level rise with large spatial variability in local sea level rise.

Large sea level variability is a system characteristics, not a new phenomenon, not a problem - just not known to modern civilization

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The Anthropocene equation

Owen Gaffney, Will Steffen

First Published February 10, 2017 | research-article

Abstract

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

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Humans causing climate to change 170 times faster than natural forces

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

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

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

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