

Effects of Climate Change

AOSC 680

Ross Salawitch

Class Web Sites:

<http://www2.atmos.umd.edu/~rjs/class/fall2023>

<https://umd.instructure.com/courses/1347818>

1. Rising sea-level threatens many populated coastal regions, including Maryland
2. Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions
3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, **fire risk** and **tropical diseases**
4. Hurricane intensity is increasing, affecting populations that reside in coastal regions
5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem
6. Climate Change, Wildfires, Air Quality, and the Ozone Layer

Lecture 9

28 September 2023

Gap Filling #1

The notion of photons emitted by a GHG in the upper trop or lower strat having a strong likelihood of reaching outer space without being re-absorbed is applicable for a “clear sky” (no clouds) atmosphere in which only GHGs absorb, because such absorption is wavelength specific

- Key concepts: 1) Clouds absorb and re-emit over broad spectral regions in the thermal IR, in contrast to the energy specific absorption & remission by GHGs
- 2) Interaction of clouds w/ radiative field in thermal IR depends on particle size, concentration concentration, whether particles are solid or liquid, if solid particle shape [Wang et al., 2020](#)
- 3) Realistic computation of interaction of clouds with thermal IR requires spatial scales (tiny) & temporal scales (brief) not amenable to global climate models. Also, phase of cloud particle existence can be highly non-LTE. As such, cloud resolving models are used to generate parameterizations used in climate models [Zhou et al., 2014](#) [Ceppi et al., 2017](#) [Jin et al., 2019](#)

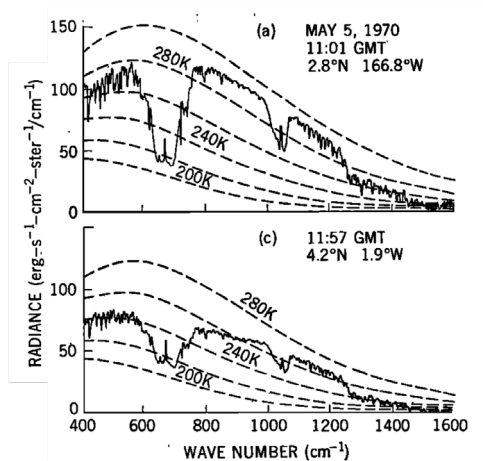


Fig. 13. Sample spectra illustrating effects of clouds in the window region of 800 to 1000 cm^{-1} . In this spectral region, a pronounced departure from a blackbody curve is noted in b and c in contrast to the spectra shown in Figure 14, for example.

The spectra in Figure 13 have been chosen to demonstrate the effect of partial cloudiness. All three spectra were recorded over tropical areas; Figure 13a was recorded over Micronesia, when the field of view was cloud free but there was possibly some haze present, and Figures 13b and 13c were recorded over the Ivory Coast when there were increasing amounts of cold and possibly thin clouds within the field of view of the instrument. In the nearly clear case (Figure 13a), the radiance of the atmospheric window follows a blackbody brightness of approximately 295°K, except for the 800 cm^{-1}

range where a slight drop in the temperature may be noted. When a substantial part of the field-of-view is covered by cold clouds, a lower brightness temperature than the actual surface temperature, as well as a deviation from a blackbody function, is expected. The effect is apparent in Figure 13b and even more so in Figure 13c. The transmission characteristics of cirrus clouds also contribute to the effect [*Yamamoto et al., 1970*].

Hanel *et al.*, JGR, 1972: <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JC077i015p02629>

See also: <https://earthobservatory.nasa.gov/features/Clouds>

<http://hogback.atmos.colostate.edu/cmmmap/learn/clouds/climate1.html>

Gap Filling #2

- 1) Stratosphere Cools as the Troposphere Warms
- 2) Upper Troposphere from about 8 to 10 km warms faster than the Surface

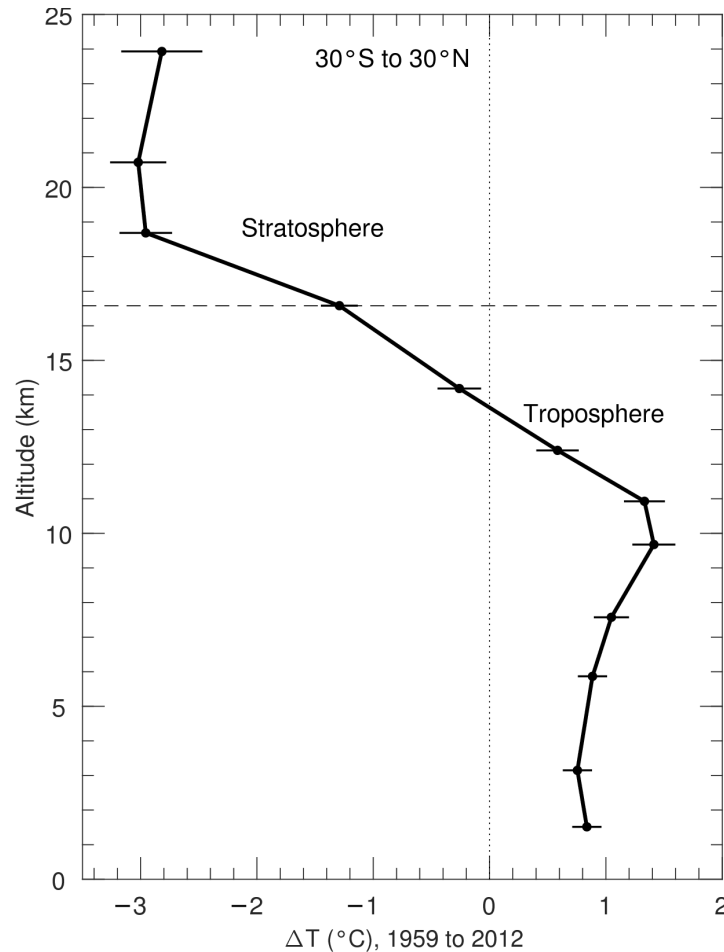


Fig. 1.5, Paris Beacon of Hope

Kiribati

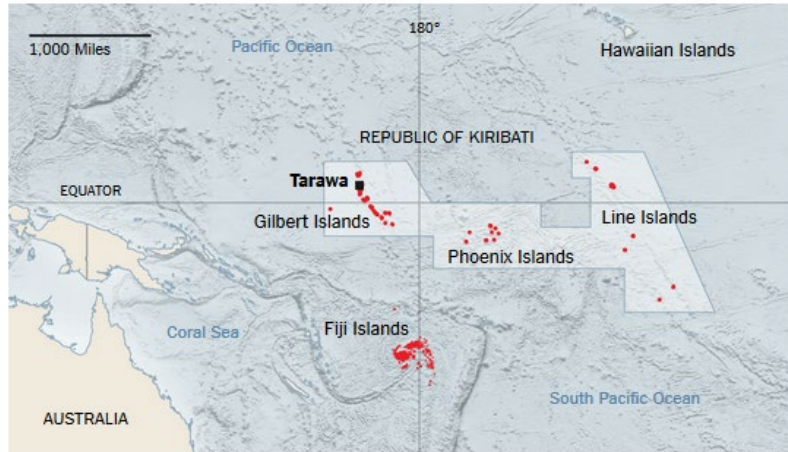


Kianteata Bwaurerei, 70, has decided not to replant his crops in Abiang after they were inundated. Josh Haner/The New York Times

<https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html>

Kiribati

- Population 122,000 as of 2019
- Undergoing intrusion of salt water into freshwater supplies
- Some farmers unable to grow food because of saltwater intrusion



High tide keeps rising on the islands of the Republic of Kiribati – 33 coral atolls in the Pacific Ocean that rest only a few feet above sea level. In Kiribati culture, Nareau the Creator scattered stones to the north and south to create this mosaic of coral and rock. But, today, the effects of climate change are closing in and there's no higher land to move to. Even as the atolls shrink, Kiribati's population grows. The country is experiencing ***baki-aba***: ***"land hunger"***. ***In 2014, Kiribati president, Anote Tong purchased 20 square km on Vanua Levu, a Fiji island making this the first international land purchase intended for climate refugees.***

For Kiribati, adapting to climate change might mean relocating entirely.

Pacific islanders' identities are very much tied to their ancestral land, the physical islands on which they live. Migration may mean a national and cultural loss, especially when most traditions are preserved orally.

<https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html>

<https://thewire.in/culture/kiribati-migration-climate-change>

<https://www.dw.com/en/fiji-sees-threat-of-coming-climate-exodus/a-41247402>

ASIA

Indonesia Plans To Move Its Capital Out Of Jakarta, A City That's Sinking



MERRIT KENNEDY



April 29, 2019 - 3:15 PM ET

The central business district skyline is seen at dusk on Monday in Jakarta, Indonesia.

Indonesia has announced plans to build a new capital city as its current capital, Jakarta, struggles with pollution, traffic gridlock — and the fact that the city is sinking.

After a Cabinet meeting on Monday, planning minister Bambang Brodjonegoro said President Joko Widodo has decided to move the capital out of Indonesia's main island, Java.

It's not clear exactly when this will happen, or where the new capital would be located. The idea has been out there for decades, though previous leaders have been unable to accomplish the ambitious plan.

"The idea to move the capital city appeared long ago. ... But it has never been decided or discussed in a planned and mature manner," Widodo said before the meeting, according to The Associated Press.

Jakarta faces massive challenges. As the BBC has reported, it's the fastest-sinking city in the world, with almost half of its area below sea level.

"If we look at our models, by 2050 about 95% of North Jakarta will be submerged," Heri Andreas, an expert in Jakarta's land subsidence at the Bandung Institute of Technology, told the broadcaster.

<https://www.npr.org/2019/04/29/718234878/indonesia-plans-to-move-its-capital-out-of-jakarta-a-city-thats-sinking>

See also <https://www.bbc.com/news/world-asia-60037163>

Nusantara

"archipelago" in Javanese



ESCAP
Economic and Social Commission
for Asia and the Pacific



**DECADE
OF
ACTION**

ABOUT

COMMISSION

2030 AGENDA

OUR WORK

KNOWLEDGE PRODUCTS

MORE



More Expert Opinions and Stories Blogs

Navigating the Challenges of New City Development for Nusantara, Indonesia's Future Capital

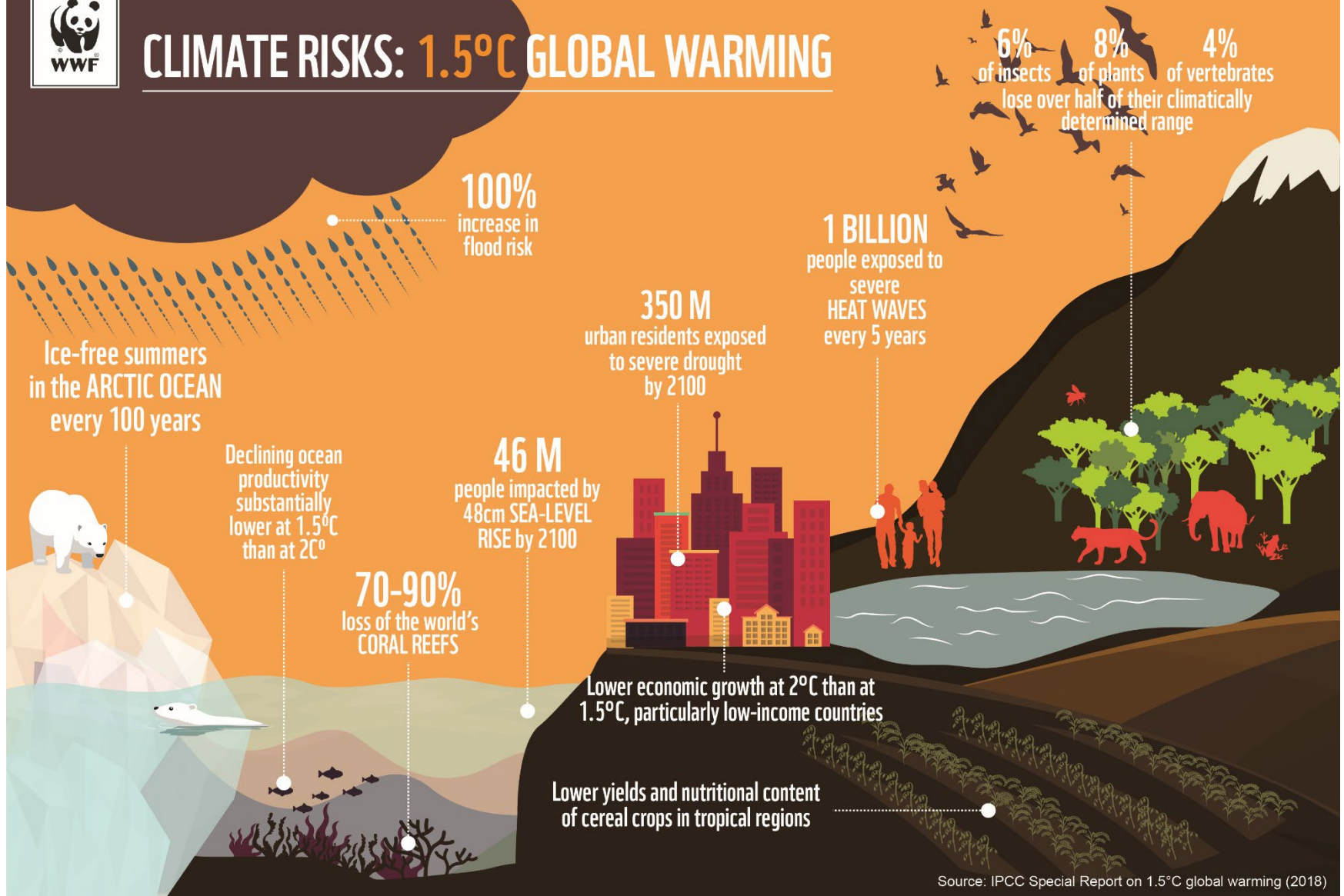
18 September 2023



<https://www.unescap.org/blog/navigating-challenges-new-city-development-nusantara-indonesias-future-capital>



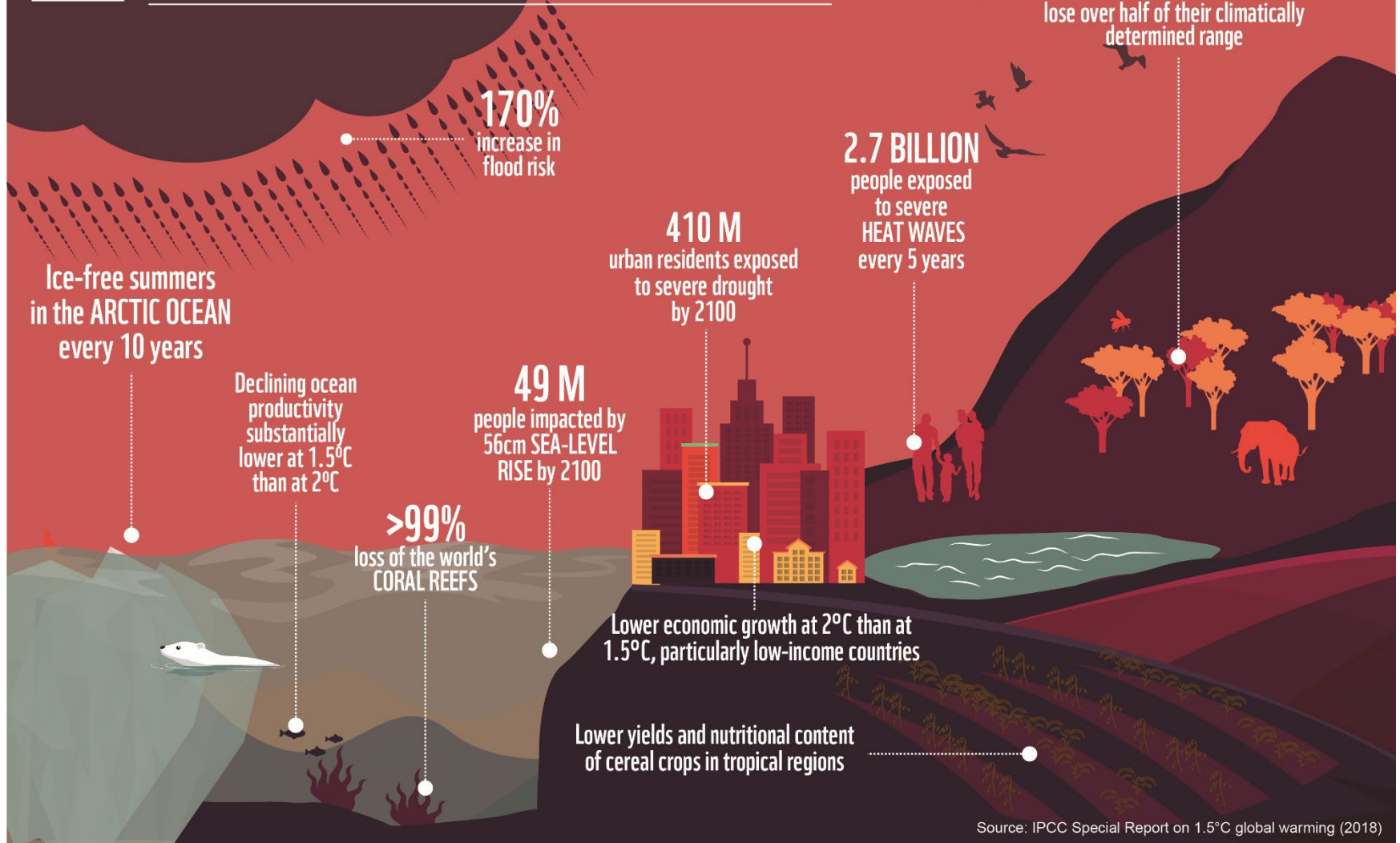
CLIMATE RISKS: 1.5°C GLOBAL WARMING



https://wwf.panda.org/our_work/climate_and_energy/cop24/



CLIMATE RISKS: 2°C GLOBAL WARMING



https://wwf.panda.org/our_work/climate_and_energy/cop24/

CLIMATE RISKS: 1.5°C vs 2°C GLOBAL WARMING

Based on the IPCC Special Report on Global Warming of 1.5°C and Special Report on Oceans and Cryosphere in a Changing Climate.

EXTREME WEATHER

1.5°C
100% increase in flood risk
2°C
170% increase in flood risk

PEOPLE

1.5°C
9% of the world's population (700 million people) will be exposed to extreme heat waves at least once every 20 years
2°C
28% of the world's population (2 billion people) will be exposed to extreme heat waves at least once every 20 years



SPECIES

1.5°C
6% of insects, 8% of plants and 4% of vertebrates will be affected
2°C
18% of insects, 16% of plants and 8% of vertebrates will be affected

SEA-LEVEL RISE

1.5°C
10cm higher at 2°C than at 1.5°C in 2100.
This difference would expose up to 10 million more people to risks.

ARCTIC SEA ICE

1.5°C
Ice free summers in the Arctic at least once every 100 years
2°C
Ice free summers in the Arctic at least once every 10 years

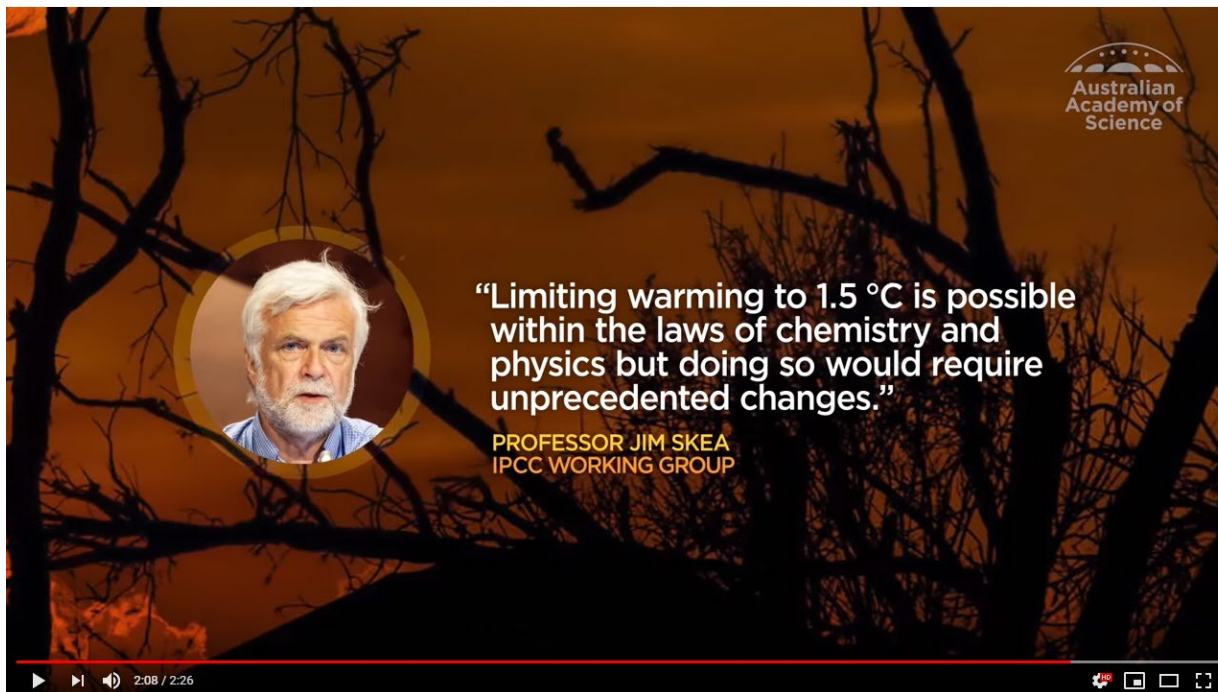
CORAL BLEACHING

1.5°C
70% of world's coral reefs are lost by 2050
2°C
Virtually all coral reefs are lost by 2050

<https://twitter.com/climateWWF/status/1420396141921935362>

Possible Impacts of Climate Change

- **1°C (already committed to this)**
 - Loss of glacial waters in Africa & Asia, with regional declines in food production
 - Tropical islands such as Tuvalu, Kiribati, Marshall Islands, and Maldives severely threatened
- **2°C (Paris Climate Agreement Upper Limit)**
 - Polar bear habitat under severe threat
 - Glacial melt rate doubles; disappearance of glaciers will create water shortages in places such as India, Peru, Ecuador, and Bolivia
 - Stability of Greenland ice sheet threatened



https://www.youtube.com/watch?time_continue=19&v=Yvkm9t7xRF4

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

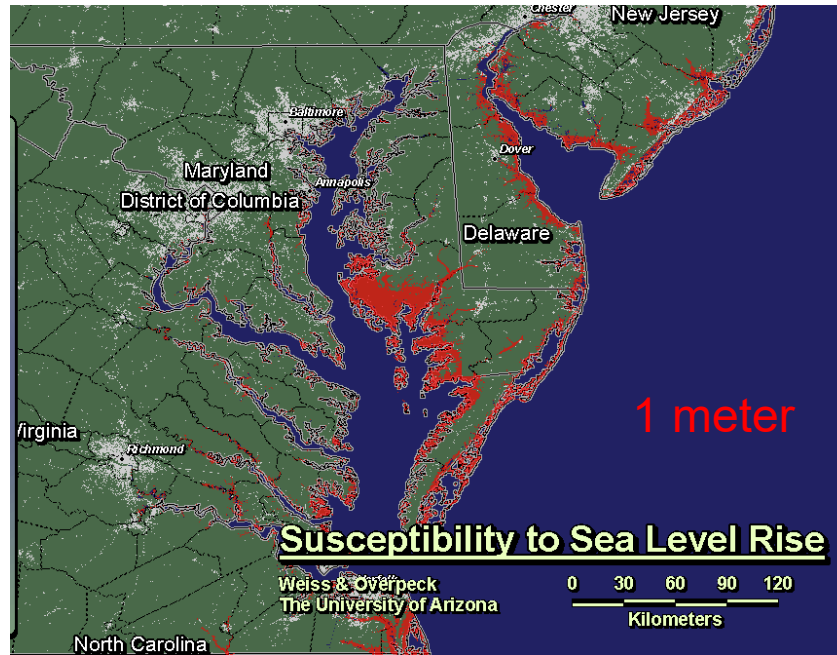


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

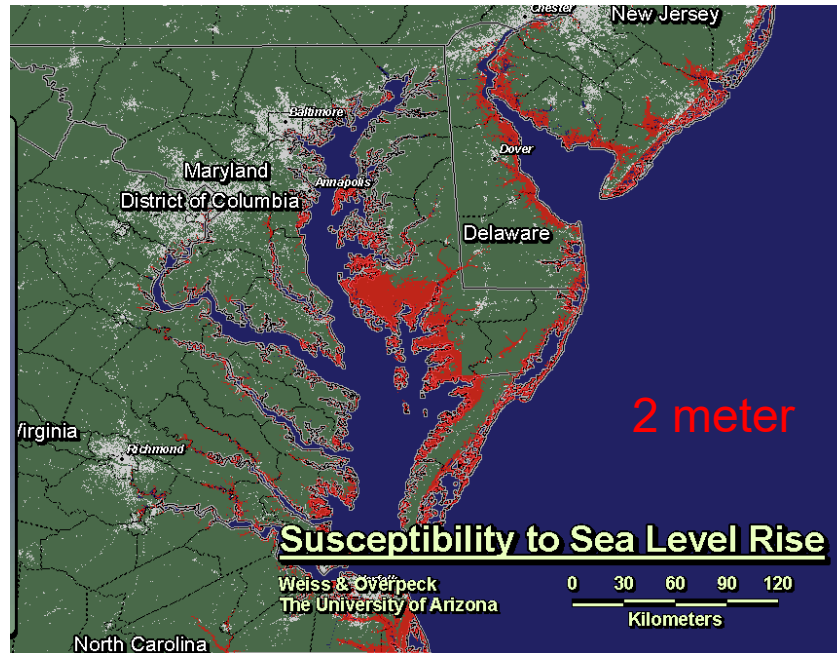


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

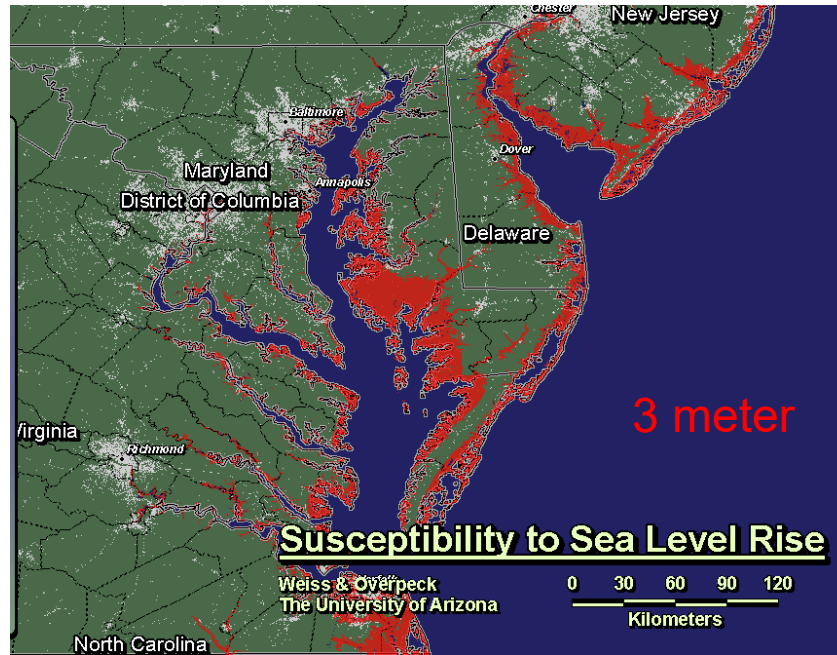


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

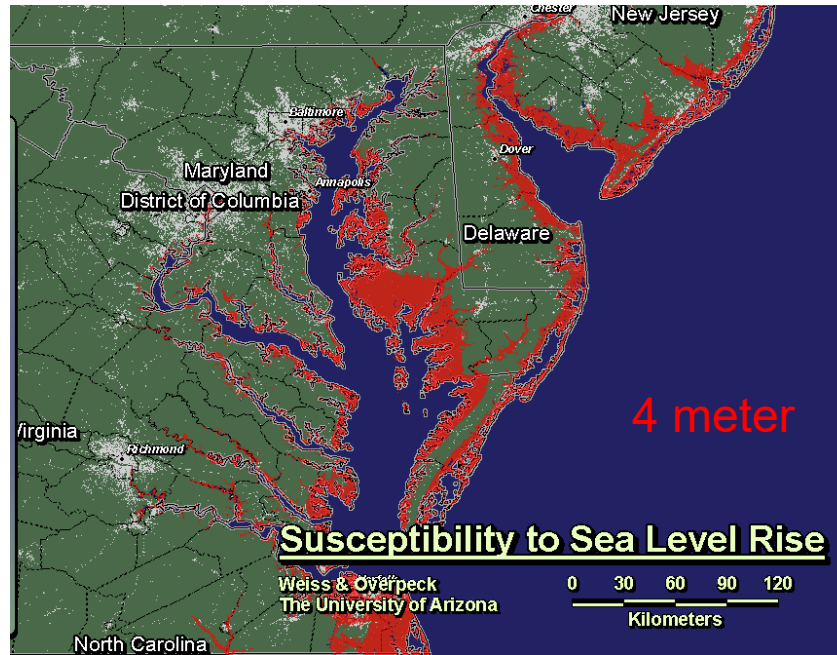


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

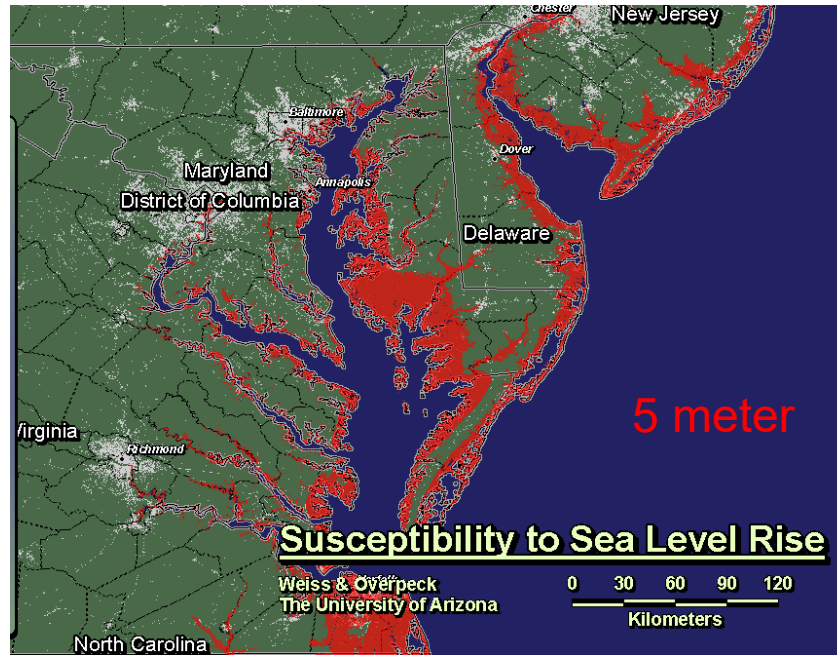


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

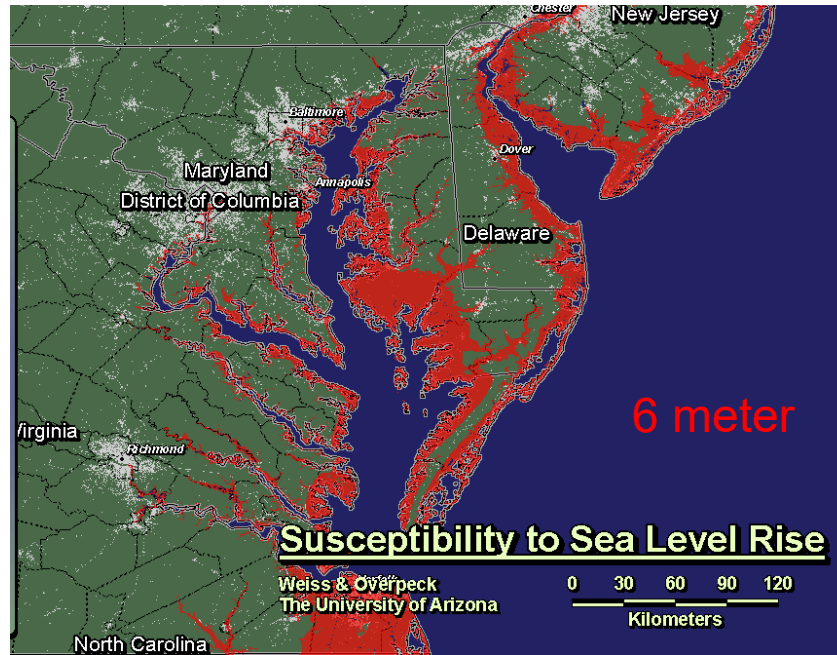


Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland



Maryland:

- more coastline than California !
- more susceptible to sea level rise than all but 2 other states

Consequences of Climate Change

- 1. Rising sea-level threatens many populated coastal regions, as well of course Washington, D.C.**



Nickolay Lamm from self-storage search engine StorageFront.com created this visualization of the Jefferson Memorial under 0, 5 feet (1.5 meters), 12 feet (3.6 metes), and 25 feet (7.6 meters) of water.

https://www.washingtonpost.com/national/health-science/vulnerable-maryland-weighs-threat-of-sea-level-rise/2013/07/21/37201d50-e9e9-11e2-bed3-b9b6fe264871_story.html

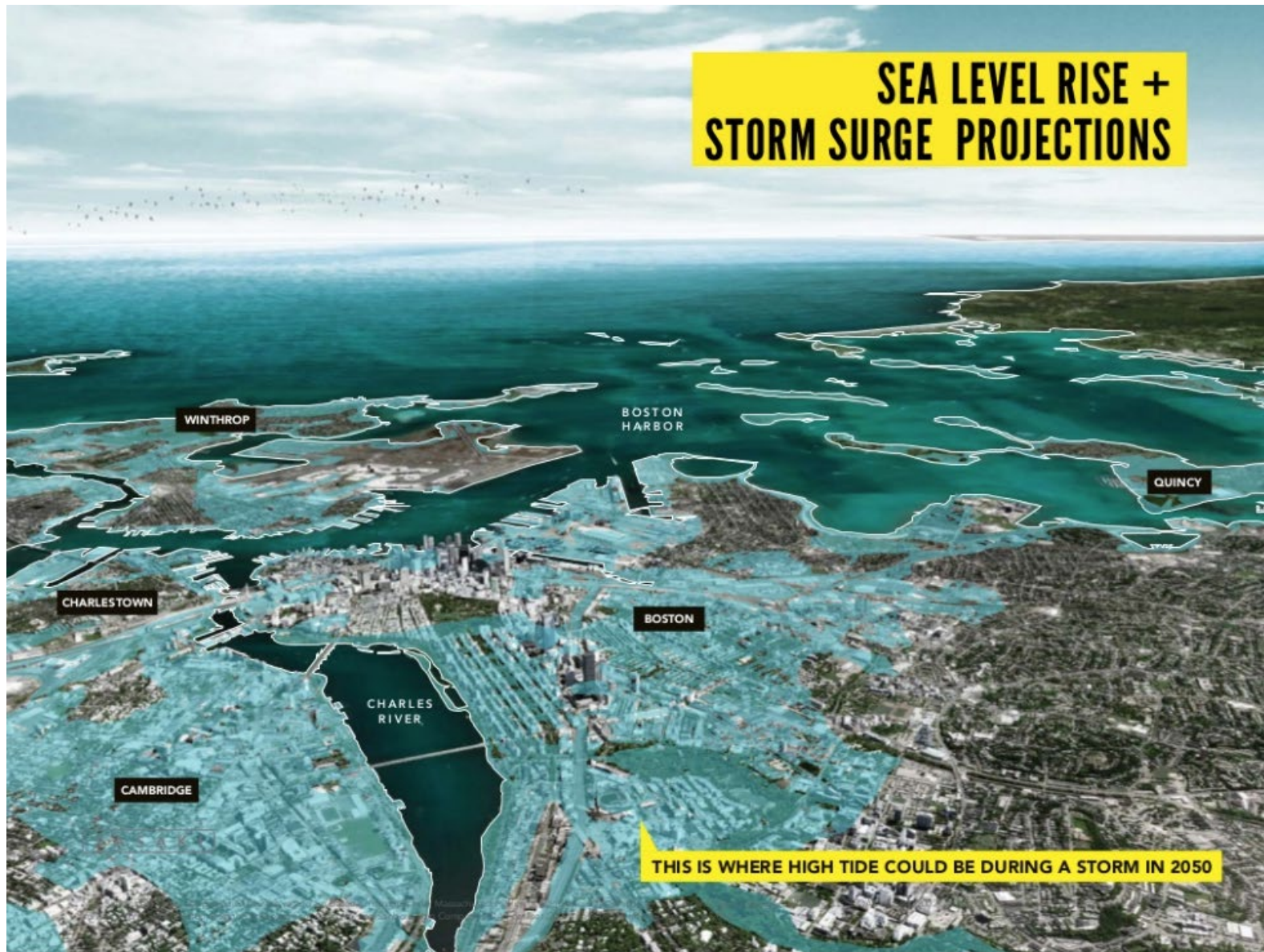
New York



New York City was worried about sea level rise when it issued new recommendations this year that future buildings and other structures that are expected to last through the end of the century be raised 3 feet above current requirements. Credit: FEMA National Flood Hazard Layer

<https://insideclimatenews.org/news/23102017/nyc-sea-level-storm-surge-climate-change-building-codes-sandy>

Boston



<https://www.slideshare.net/SasakiAssociates/sea-change-boston-detailed-overview>

Toronto



NEWS

WEATHER



Toronto one of the top cities to feel climate change impacts by 2050: report



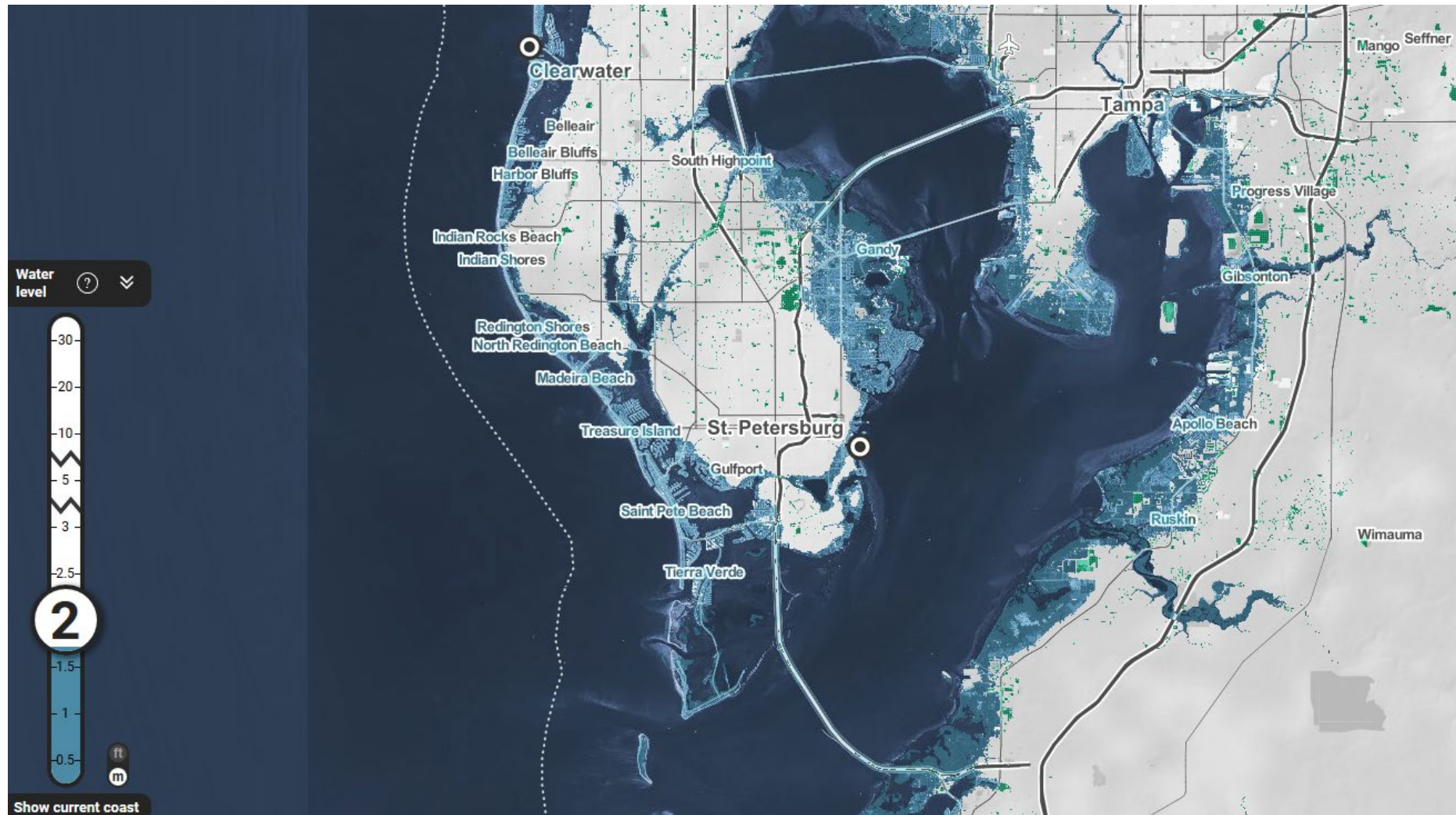
Kayla Gladysz | Jan 30 2020, 12:45 pm



shutterstock

<https://dailyhive.com/toronto/toronto-climate-change-impacts-report>

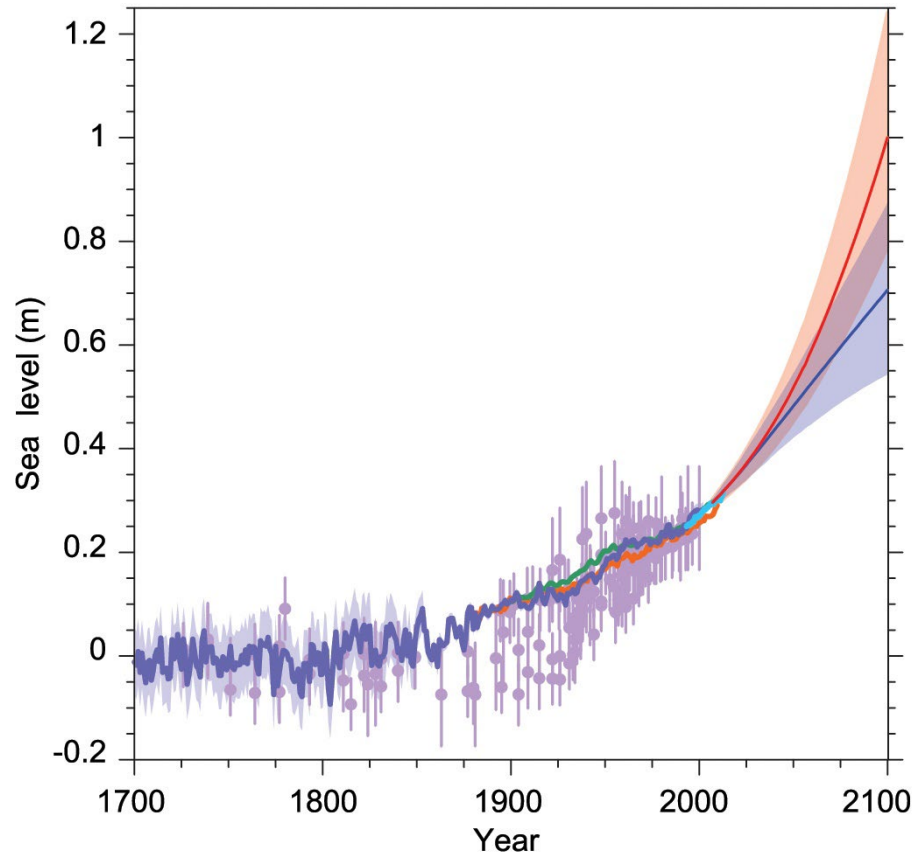
Tampa Bay / St. Petersburg



https://ss2.climatecentral.org/#11/27.7789/-82.4991?show=satellite&projections=0-DP16_RCP85-SLR&level=2&unit=meters&pois=hide

Consequences of Climate Change

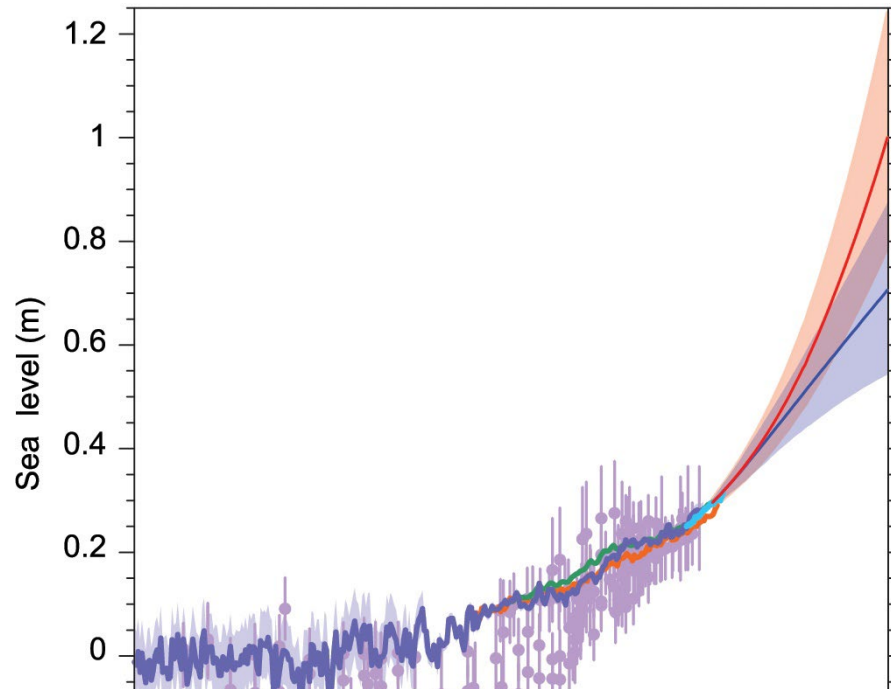
1. Rising sea-level threatens many populated coastal regions, including Maryland



Compilation of paleo sea level data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and likely ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values.

Consequences of Climate Change

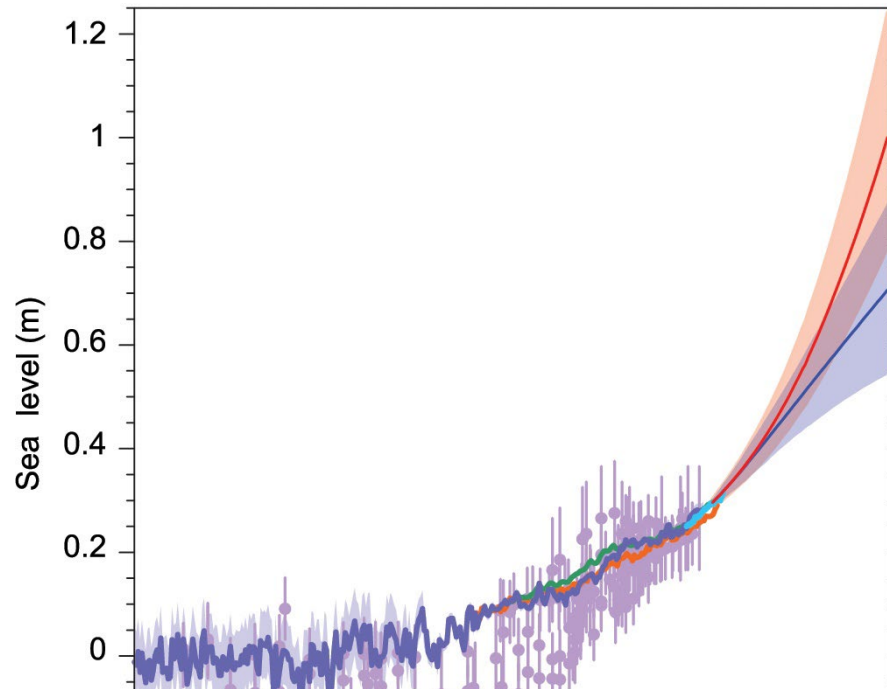
1. Rising sea-level threatens many populated coastal regions, including Maryland



1 meter =

Consequences of Climate Change

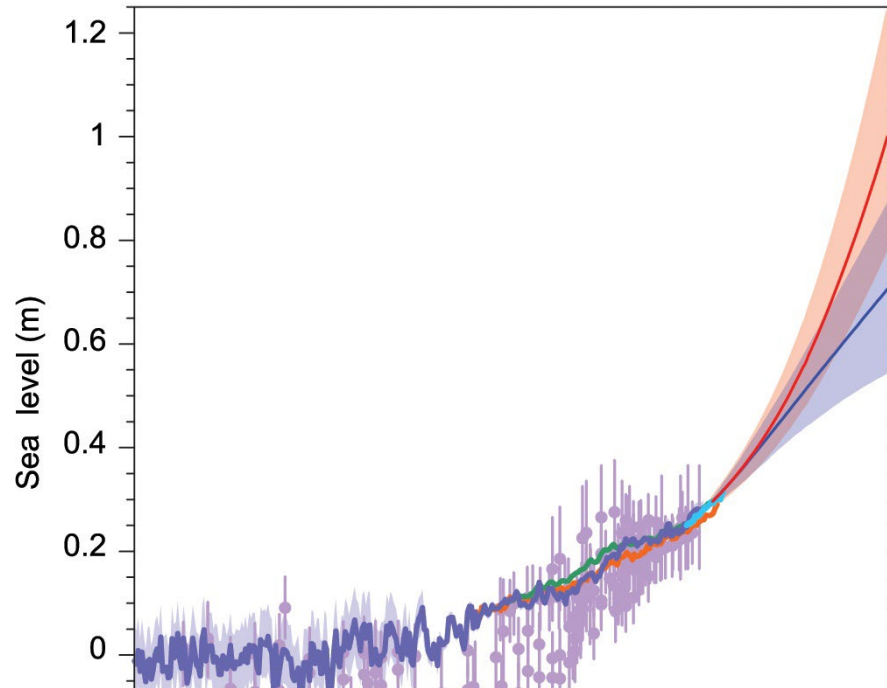
1. Rising sea-level threatens many populated coastal regions, including Maryland



1 meter = 3.2 feet

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

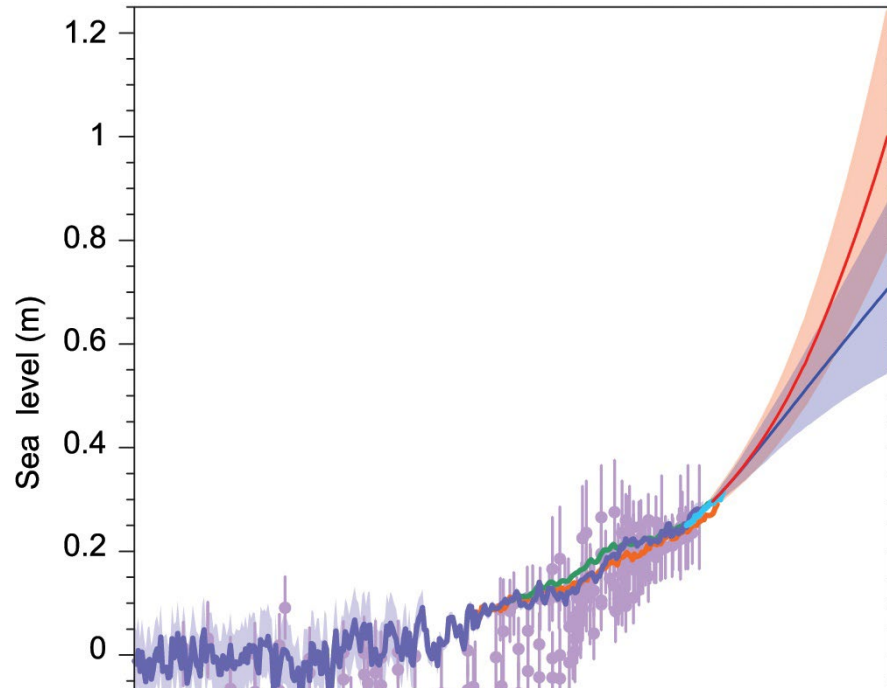


1 meter = 3.2 feet

If all of Greenland were to melt, SLR would be

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

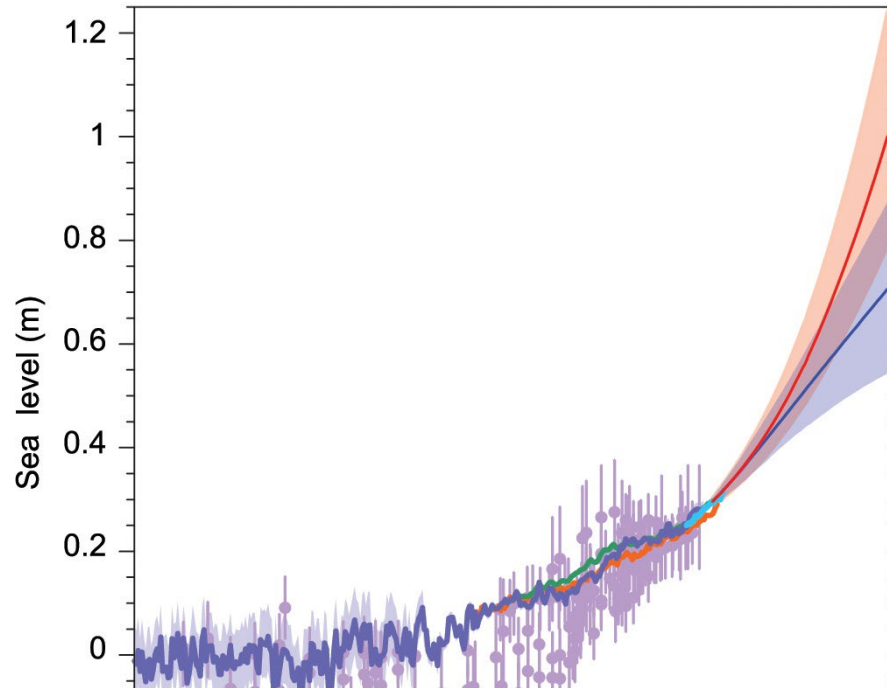


1 meter = 3.2 feet

If all of Greenland were to melt, SLR would be ~23 feet (7 meters)

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland



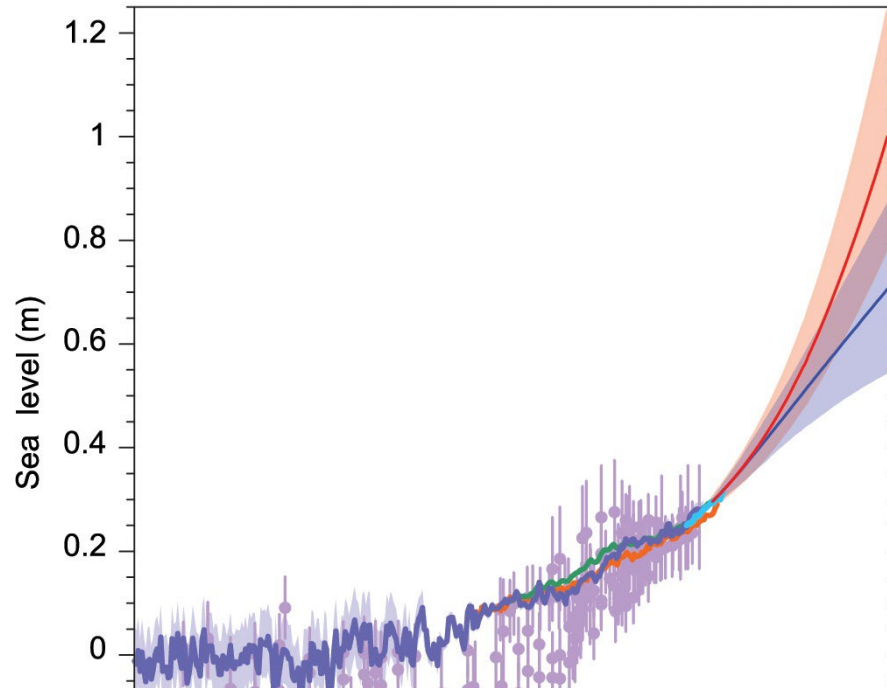
1 meter = 3.2 feet

If all of Greenland were to melt, SLR would be ~23 feet (7 meters)

If all of Antarctica were to melt, SLR would be

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland



1 meter = 3.2 feet

If all of Greenland were to melt, SLR would be ~23 feet (7 meters)

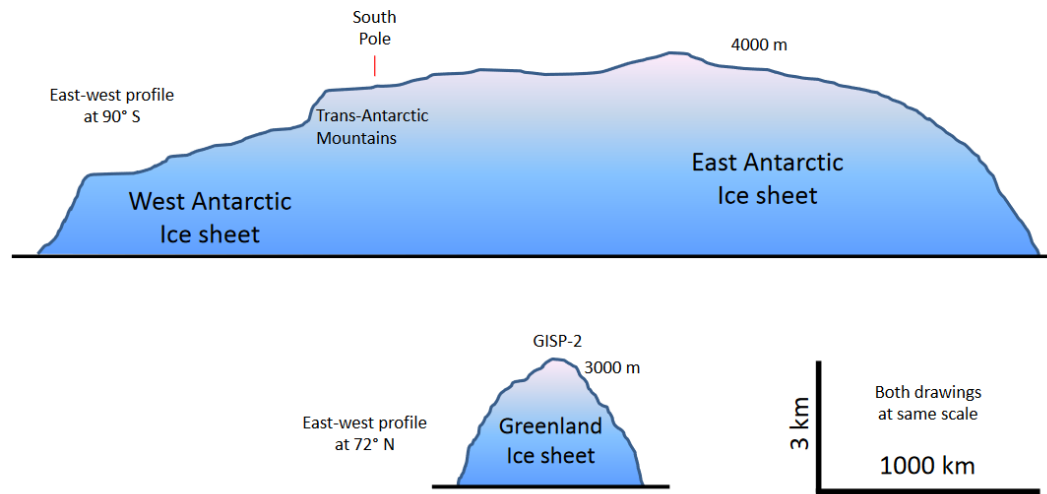
If all of Antarctica were to melt, SLR would be ~200 feet (60 meters)

Volume of Antarctic and **Greenland** Ice Sheets

Volume of Antarctic Ice Sheet $\sim 26.5 \times 10^6 \text{ km}^3$ and volume of cubic Greenland Ice Sheet $\sim \mathbf{2.85 \times 10^6 \text{ km}^3}$

https://en.wikipedia.org/wiki/Antarctic_ice_sheet & https://en.wikipedia.org/wiki/Greenland_ice_sheet

Profiles of the Antarctic and Greenland Ice Sheets



<https://web.viu.ca/earle/geol305/The%20Greenland%20Ice%20Sheet.pdf>

Radius of Earth = 6371 km; Surface area of Earth = $510 \times 10^6 \text{ km}^2$
70% of earth, or $357 \times 10^6 \text{ km}^2$ is covered by water.

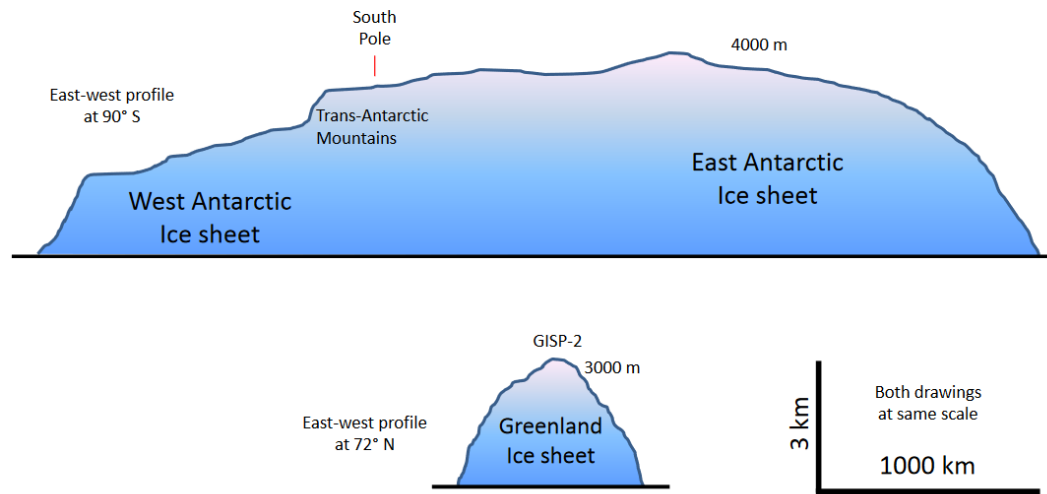
The complete collapse of Greenland would lead to sea-level rise of
 $\mathbf{2.85 \times 10^6 \text{ km}^3} / 357 \times 10^6 \text{ km}^2 = 8 \text{ meters}$ according to these numbers.
Since more area would be covered by water following the collapse,
the actual rise in sea level is closer to 7 meters ... or **23 feet!**

Volume of **Antarctic** and Greenland Ice Sheets

Volume of Antarctic Ice Sheet $\sim 26.5 \times 10^6 \text{ km}^3$ and volume of cubic Greenland Ice Sheet $\sim 2.85 \times 10^6 \text{ km}^3$

https://en.wikipedia.org/wiki/Antarctic_ice_sheet & https://en.wikipedia.org/wiki/Greenland_ice_sheet

Profiles of the Antarctic and Greenland Ice Sheets

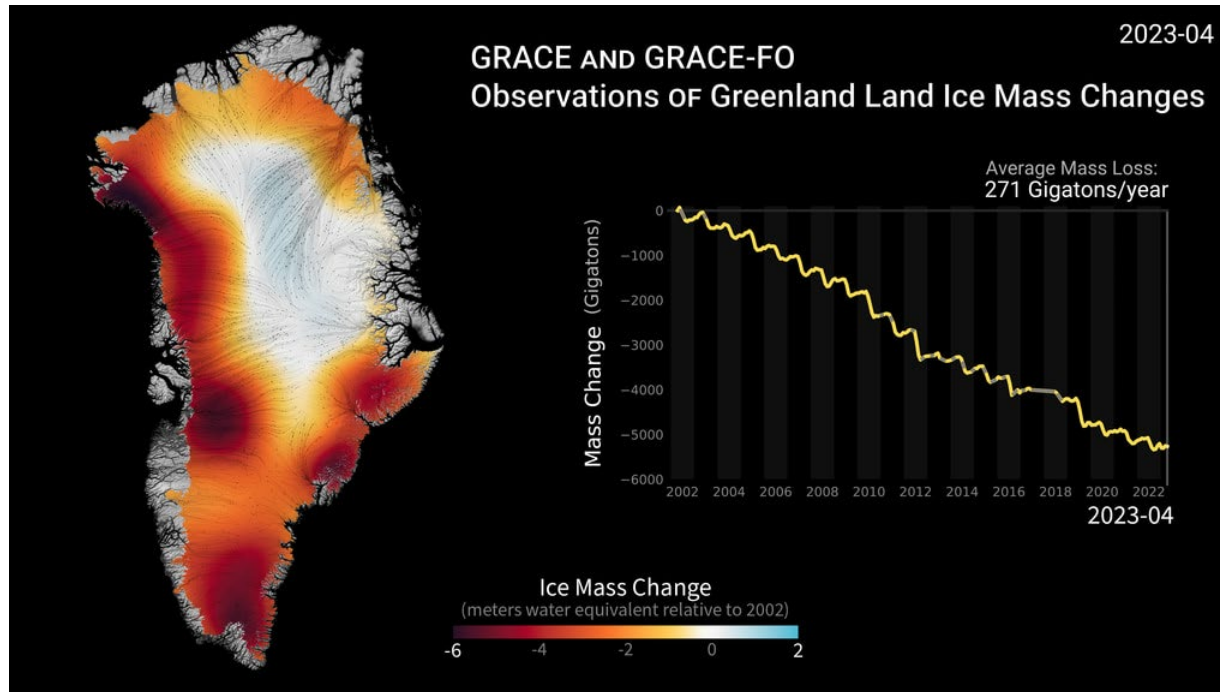


<https://web.viu.ca/earle/geol305/The%20Greenland%20Ice%20Sheet.pdf>

Radius of Earth = 6371 km; Surface area of Earth = $510 \times 10^6 \text{ km}^2$
70% of earth, or $357 \times 10^6 \text{ km}^2$ is covered by water.

The complete collapse of Antarctica would lead to sea-level rise of $26.5 \times 10^6 \text{ km}^3 / 357 \times 10^6 \text{ km}^2 = 74$ meters according to these numbers.
Since more area would be covered by water following the collapse, the actual rise in sea level is closer to 60 meters ... or **200 feet!!!!!!!!!!**

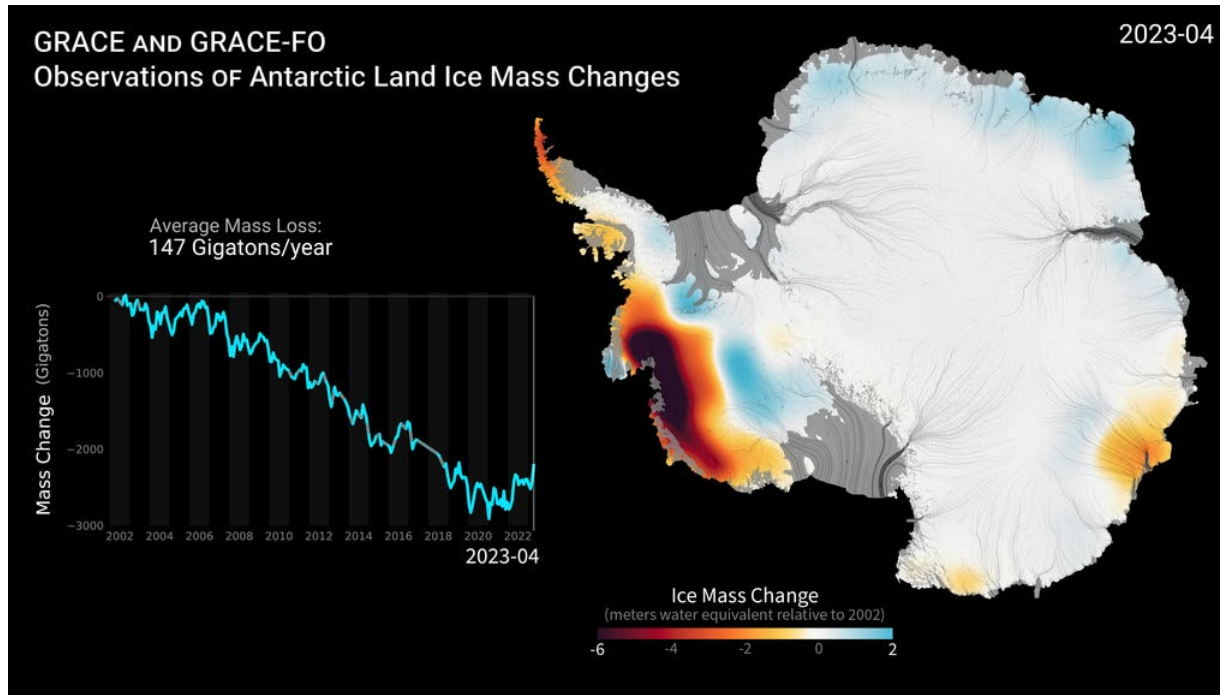
Greenland Ice Mass



Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~277 gigatons of ice per year from Greenland, causing global sea level to rise by a total of 0.63 inches between 2002 and 2023 (or 0.03 inches per year)

<https://svs.gsfc.nasa.gov/31156>

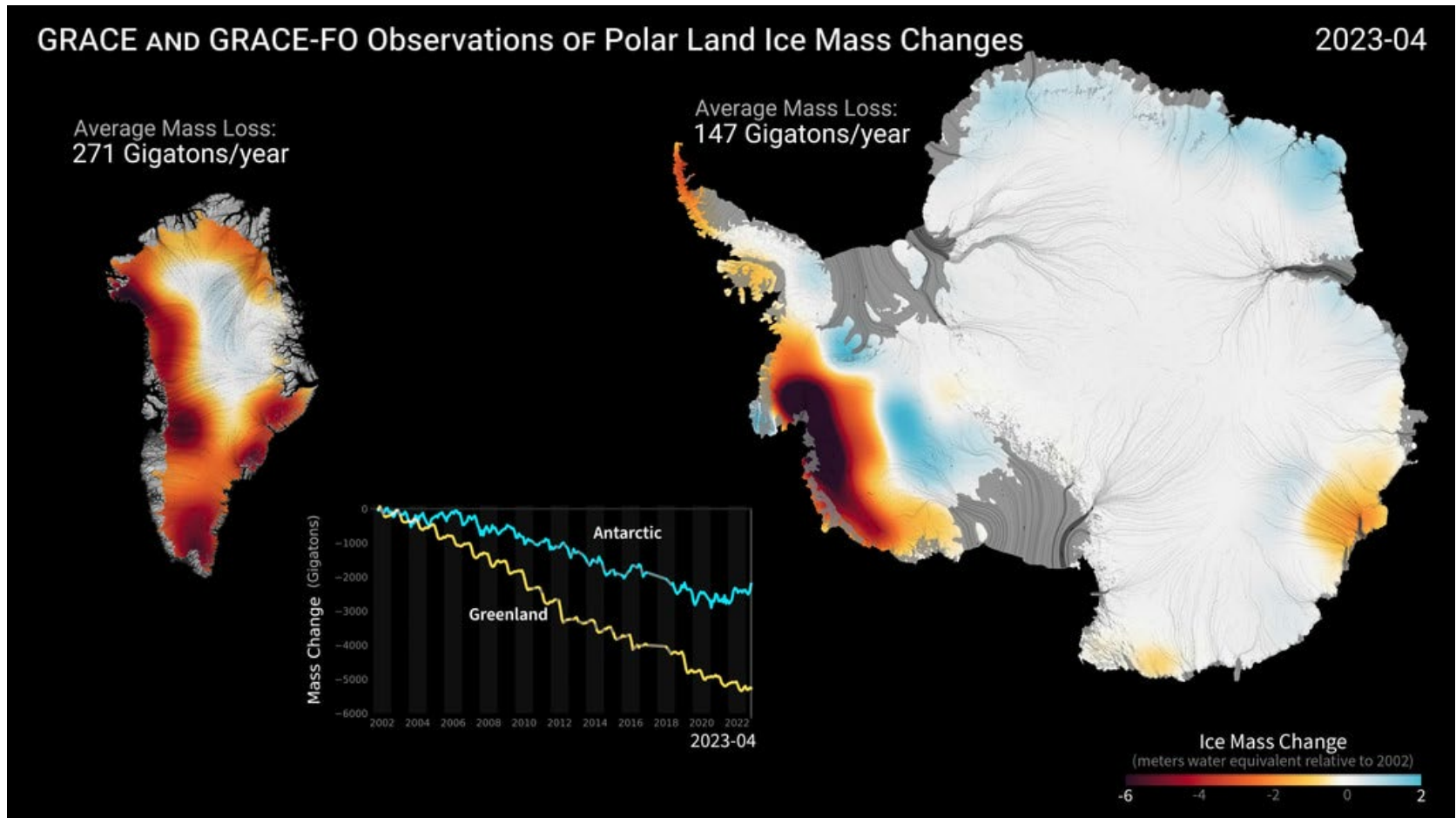
Antarctica Ice Mass



Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~150 gigatons of ice per year from Antarctica, causing global sea level to rise by about 0.34 inches between 2002 and 2023 (0.016 inches per year)

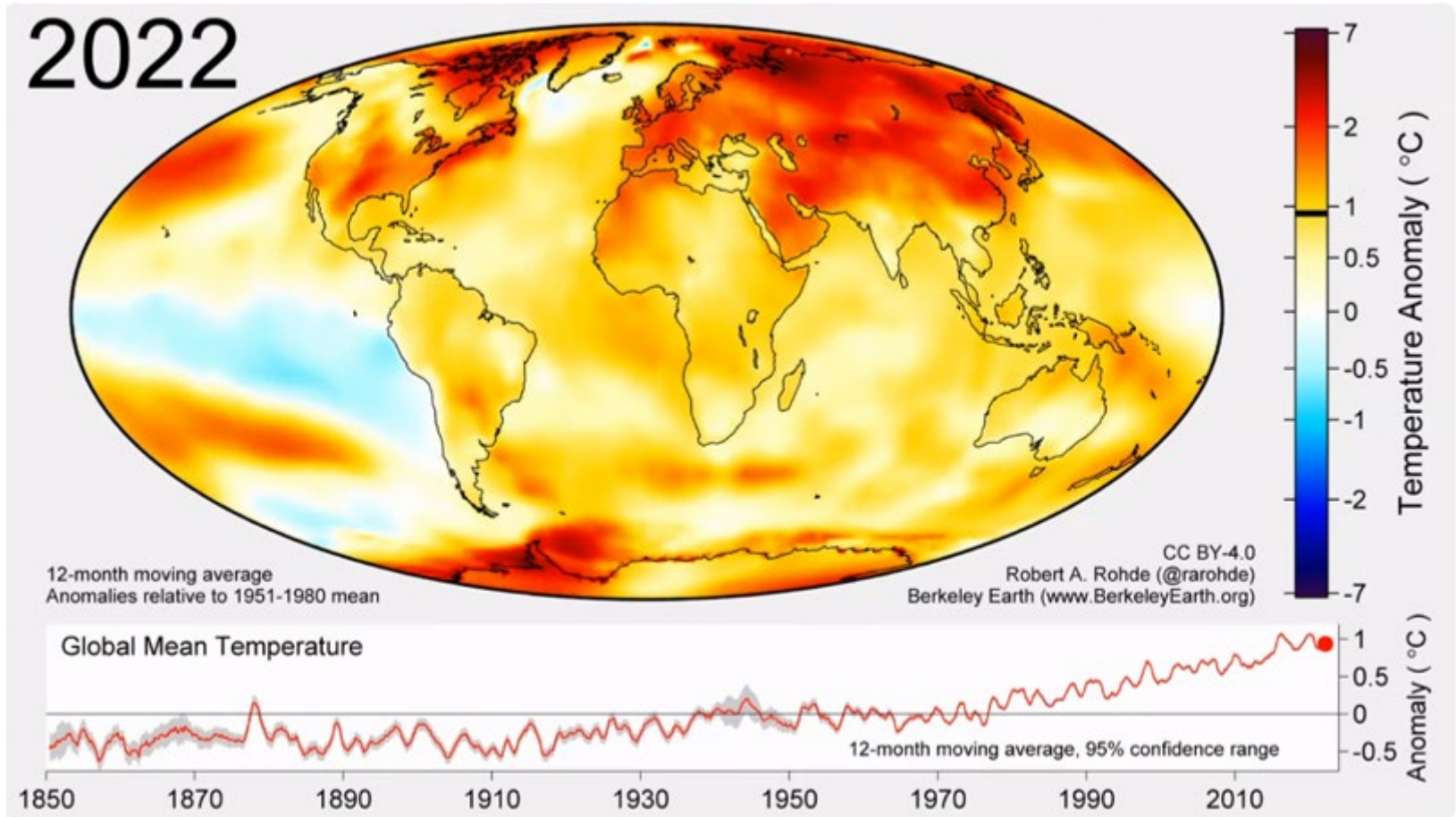
<https://svs.gsfc.nasa.gov/31158>

Greenland and Antarctica Ice Mass



<https://svs.gsfc.nasa.gov/31166>

Berkeley Earth Animation of Global Warming



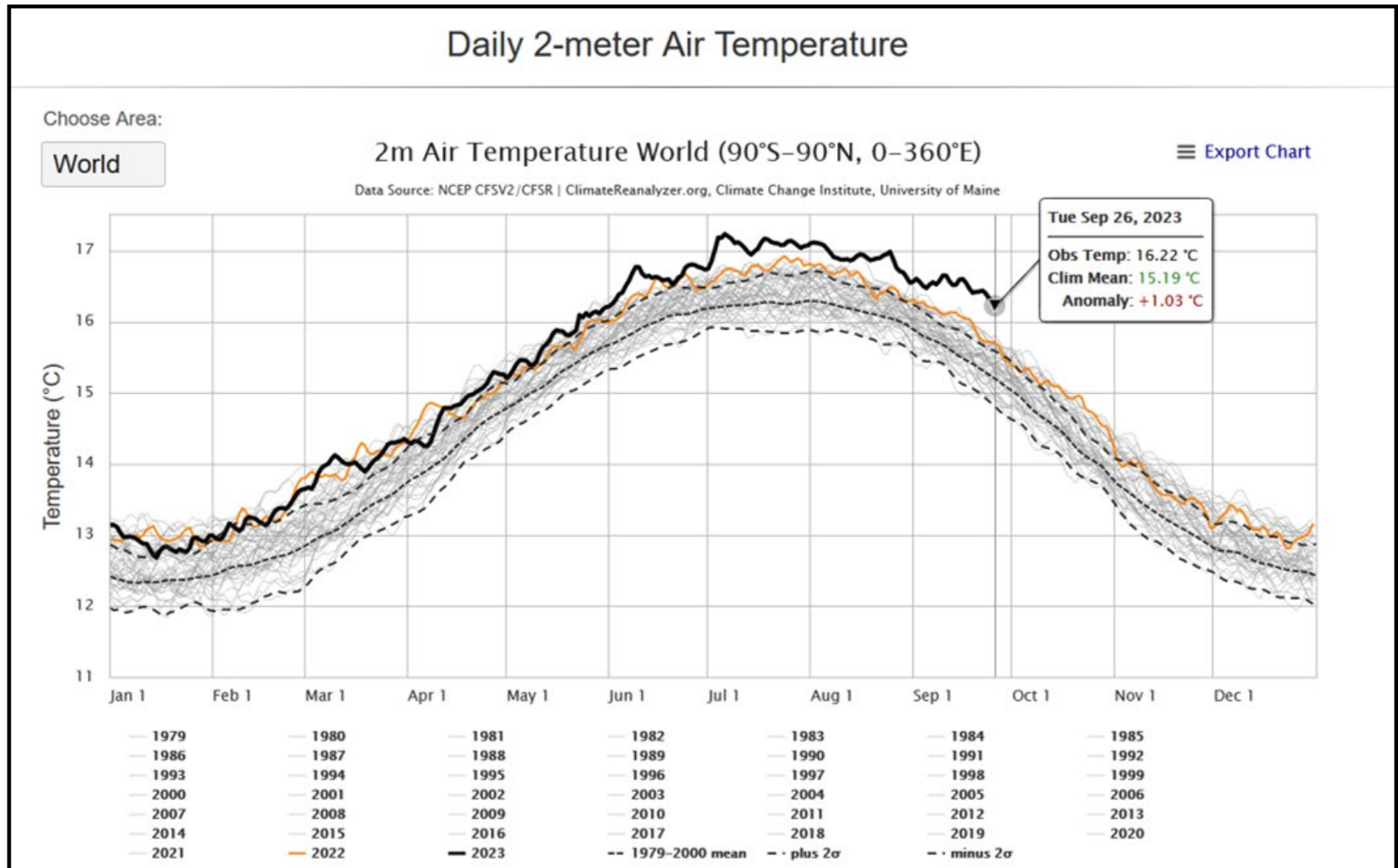
2022 was nominally the 5th warmest year of the modern instrument record

Work of Robert Rohde and the Berkeley Earth Team

<http://berkeleyearth.org>

Animation at <https://youtu.be/XdKQZnhwcTs?si=HTFplyMEMbf67tPw&t=45>

2023 Will Almost Certainly Replace 2006 As The Warmest Year On Record



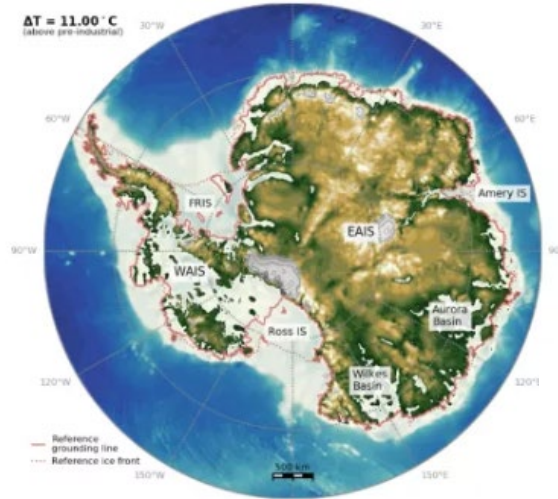
https://climatereanalyzer.org/clim/t2_daily

Antarctica News: September 2020

Antarctica could melt 'irreversibly' due to climate change, study warns

By Brandon Specktor - Senior Writer 29 Sept 2020

The change will take thousands of years, but we only have a century to stop it.



A simulation shows Antarctica, totally stripped of ice.
(Image: © Garbe et al.)

Antarctica contains more than half of the world's freshwater in its sprawling, frozen ice sheet, but humanity's decisions over the next century could send that water irreversibly into the sea.

If global warming is allowed to continue unchecked, Antarctica will soon pass a "point of no return" that could reduce the continent to a barren, ice-free mass for the first time in more than 30 million years, according to a study published in the journal *Nature*.

They found that, if average temperatures rise 7.2 degrees Fahrenheit (4 degrees Celsius) above pre-industrial levels for any sustained period of time, much of the ice in West Antarctica will crumble, resulting in 21 feet (6.5 meters) of global sea-level rise; that amount of rise would devastate coastal cities like New York, Tokyo and London. This scenario could be a reality within decades; a global average temperature rise of 9 F (5 C) is currently considered the "worst-case" warming scenario if current greenhouse gas emission levels are allowed to continue through the year 2100, according to the UN's Intergovernmental Panel on Climate Change (IPCC).

<https://www.livescience.com/antarctica-ice-free-climate-change.html>

<https://www.nature.com/articles/s41586-020-2727-5>

See also <https://www.cnn.com/2020/09/30/weather/greenland-ice-sheet-melt-carbon-emissions-climate-change/index.html> (yikes)

Antarctica News: September 2023

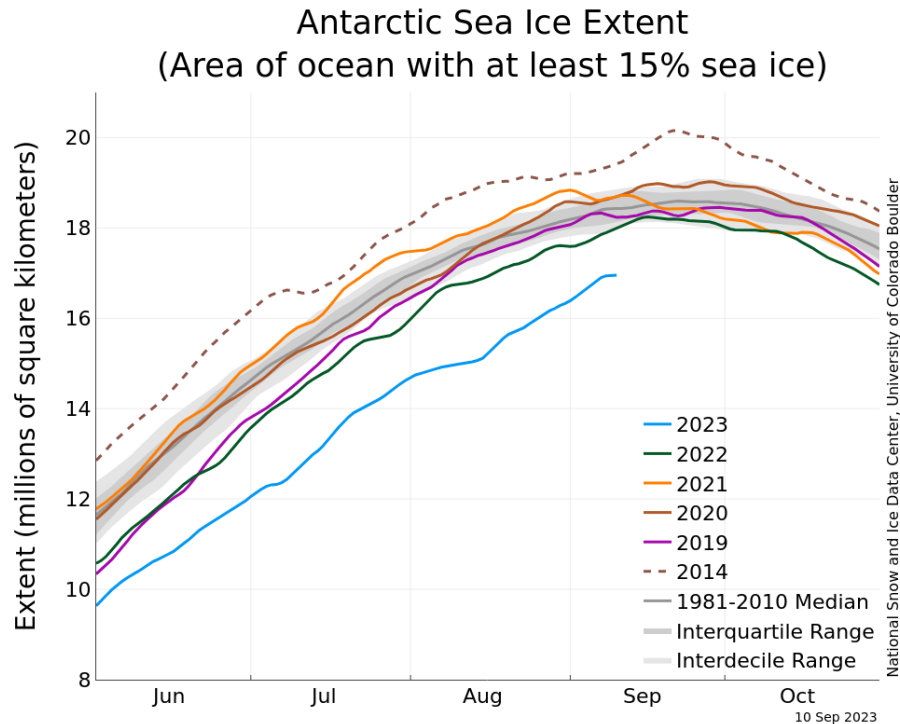


Figure 2. The graph above shows Antarctic sea ice extent as of September 10, 2023, along with daily ice extent data for four previous years and the record maximum year. 2023 is shown in blue, 2022 in green, 2021 in orange, 2020 in brown, 2019 in magenta, and 2014 in dashed brown. The 1981 to 2010 median is in dark gray. The gray areas around the median line show the interquartile and interdecile ranges of the data. [Sea Ice Index](#) data.

This year marks a significant record low maximum in Antarctic sea ice extent (Figure 2). Since early April 2023, sea ice maintained record low ice growth. From early to mid-August, growth slowed considerably, maintaining a difference of nearly 1.5 million square kilometers (579,000 square miles) between 2023 and 1986, the second lowest year on satellite record. After that period, ice growth quickened and narrowed the gap to about 1 million square kilometers (386,000 square miles). This is the first time that sea ice extent has not surpassed 17 million square kilometers (6.56 million square miles), falling more than one million square kilometers below the previous record low maximum extent set in 1986.

<https://www.livescience.com/antarctica-ice-free-climate-change.html>

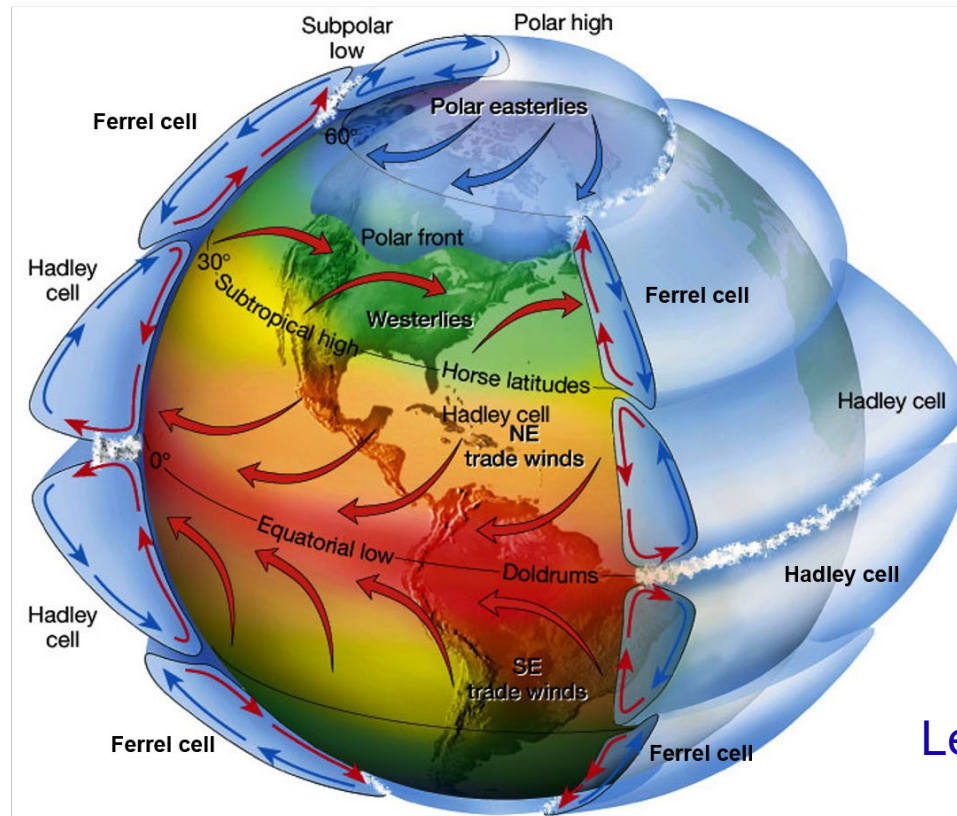
<https://www.nature.com/articles/s41586-020-2727-5>

See also <https://twitter.com/RARohde/status/1706998806582034566>

Consequences of Climate Change

2. Deserts are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions
3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases

Ferrel Circulation (Modern View)

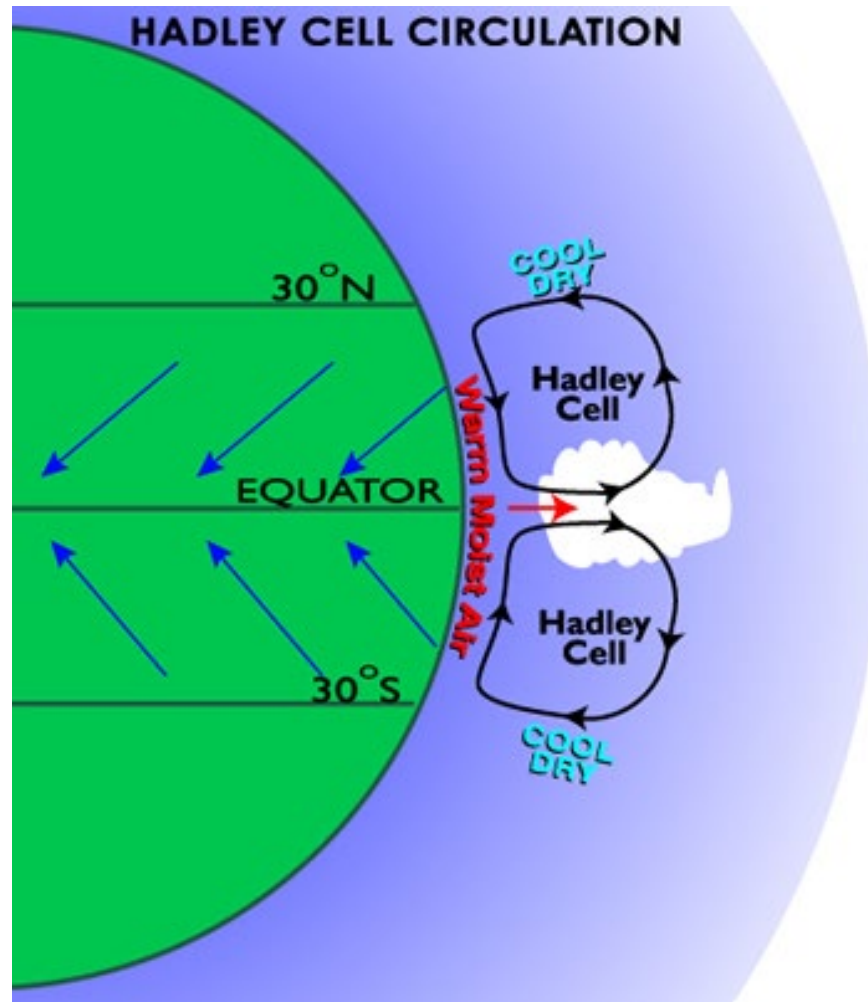


Lecture 3

<http://www.ux1.eiu.edu/~cfjps/1400/circulation.html>

Connection to Climate Change

WWDD: Wet-gets-Wetter, Dry-gets-Drier (WWDD) paradigm



http://www.windows2universe.org/vocals/images/HadleyCell_small.jpg

As CO₂ and other GHGs rise:
Hadley Cell becomes more energetic
WWDD: Wet gets wetter, dry gets drier
Deserts expand poleward

REVIEW ARTICLE

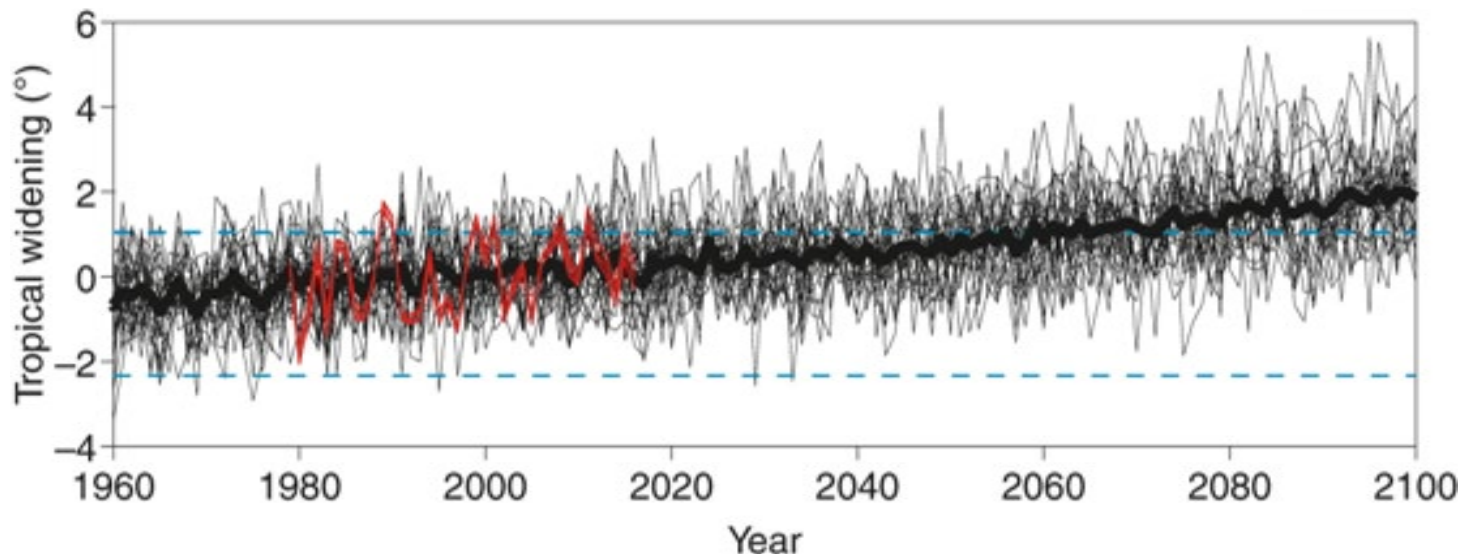
<https://doi.org/10.1038/s41558-018-0246-2>

nature
climate change

Re-examining tropical expansion

Paul W. Staten¹, Jian Lu^{2*}, Kevin M. Grise³, Sean M. Davis^{4,5} and Thomas Birner⁶

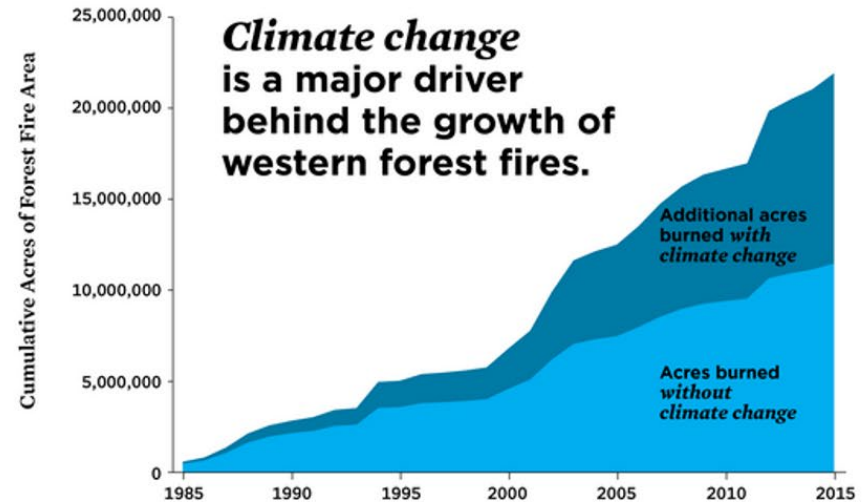
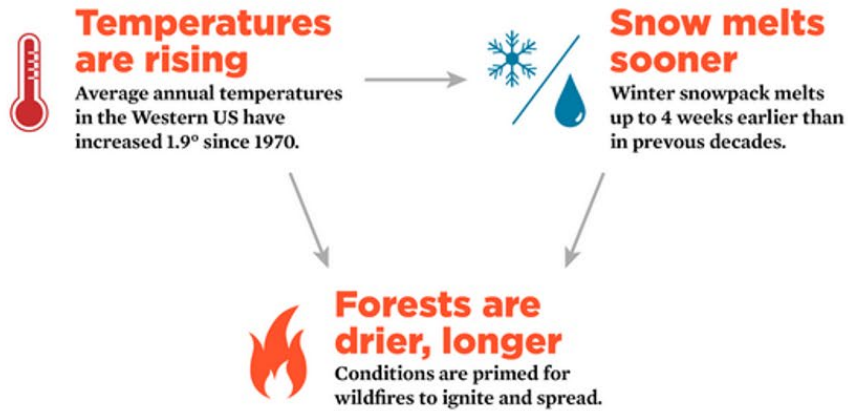
¹Indiana University Bloomington, Bloomington, IN, USA. ²Pacific Northwest National Laboratory, Richland, WA, USA. ³University of Virginia, Charlottesville, VA, USA. ⁴NOAA ESRL Chemical Sciences Division, Boulder, CO, USA. ⁵Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder, Boulder, CO, USA. ⁶Ludwig-Maximilians-University Munich, Munich, Germany. *e-mail: jian.lu@pnnl.gov



Change in the latitudinal width of the tropics relative to 1981–2010 mean from satellite observations (red) and climate models (thin black lines), along with the multi-model mean (thick black). The blue dashed lines show the 2σ range of the width of the tropics due to natural variability for pre-industrial levels of GHGs.

From Staten *et al.*, *Nature Climate Change*, 2018. <https://www.nature.com/articles/s41558-018-0246-2>

Forest Fires and Climate Change



Data shown are from John T. Abatzoglou and A. Park Williams, [Impact of anthropogenic climate change on wildfire across western US forests](#), which models forest fire area as a function of fuel dryness both with and without climate change.

<https://www.ucsusa.org/resources/infographic-wildfires-and-climate-change>

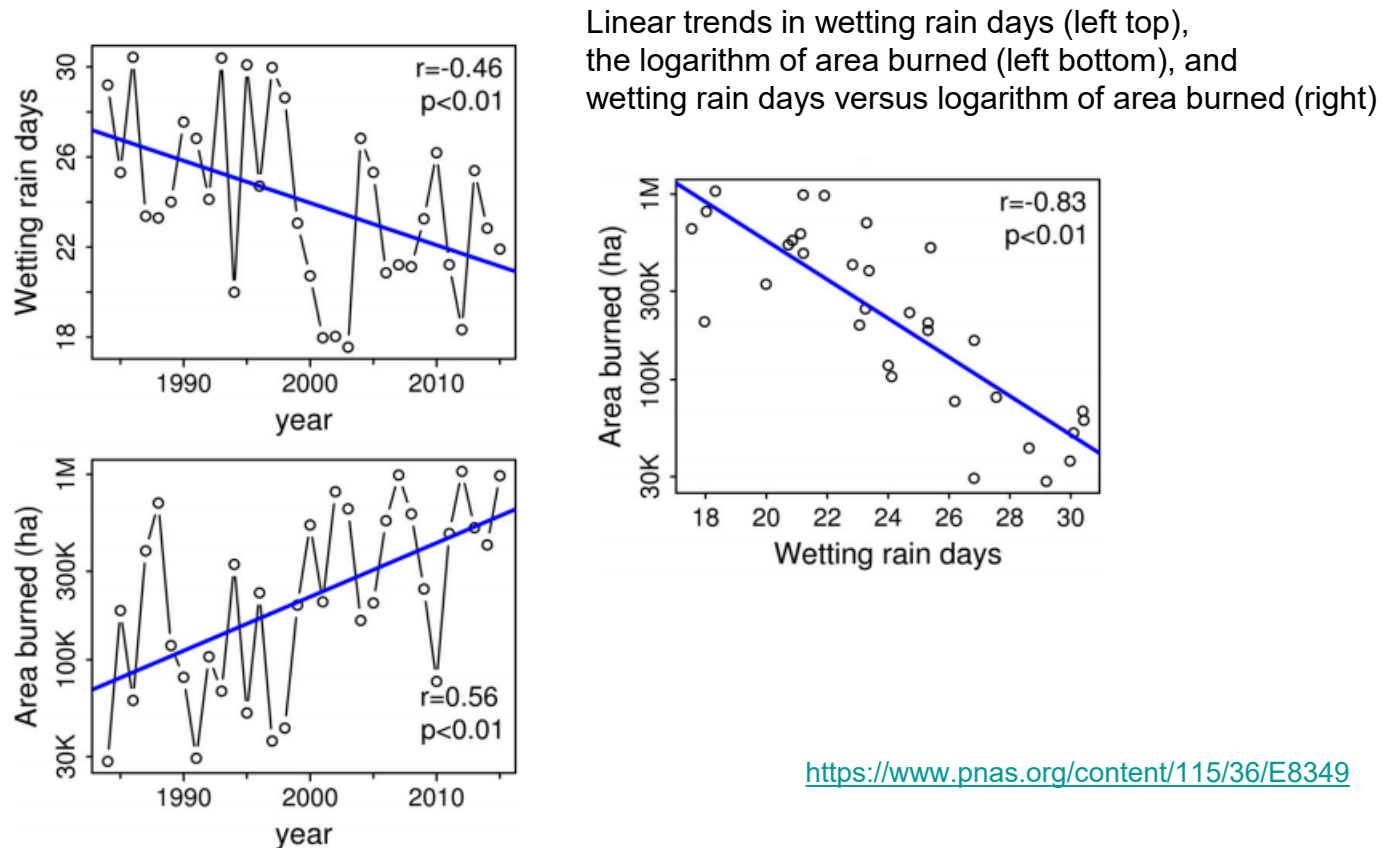
Recent papers linking fires to climate change

Decreasing fire season precipitation increased recent western US forest wildfire activity

Zachary A. Holden^{a,1}, Alan Swanson^b, Charles H. Luce^c, W. Matt Jolly^d, Marco Maneta^e, Jared W. Oyster^f, Dyer A. Warren^b, Russell Parsons^d, and David Affleck^g

^aUS Forest Service Region 1, Missoula, MT 59807; ^bSchool of Public and Community Health Sciences, University of Montana, Missoula, MT 59812; ^cUS Forest Service Aquatic Science Laboratory, Rocky Mountain Research Station, Boise, ID 83702; ^dUS Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT 59808; ^eDepartment of Geosciences, University of Montana, Missoula, MT 59812; ^fEarth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802; and ^gDepartment of Forestry and Conservation, University of Montana, Missoula, MT 59812

PNAS September 4, 2018 115 (36) E8349–E8357; first published August 20, 2018; <https://doi.org/10.1073/pnas.1802316115>



<https://www.pnas.org/content/115/36/E8349>

Climate Scientists Warn of a 'Global Wildfire Crisis'

Worsening heat and dryness could lead to a 50 percent rise in off-the-charts fires, according to a United Nations report.



By Raymond Zhong

Feb. 23, 2022

A landmark [United Nations report](#) has concluded that the risk of devastating wildfires around the world will surge in coming decades as climate change further intensifies what the report described as a “global wildfire crisis.”

The scientific assessment is the first by the organization’s environmental authority to evaluate wildfire risks worldwide. It was inspired by a string of deadly blazes around the globe in recent years, burning the American West, vast stretches of [Australia](#) and even [the Arctic](#).

The images from those fires — cities glowing under [orange skies](#), smoke billowing around [tourist havens](#) and heritage sites, woodland animals badly injured and killed — have become grim icons of this era of unsettled relations between humankind and nature.

“The heating of the planet is turning landscapes into tinderboxes,” said the report, which was published on Wednesday by the United Nations Environment Program.



A wildfire near Hillville, New South Wales, Australia, in 2019.

Matthew Abbott for The New York Times

<https://www.nytimes.com/2022/02/23/climate/climate-change-un-wildfire-report.html>
<https://www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires>

Australian wildfires depleted the ozone layer

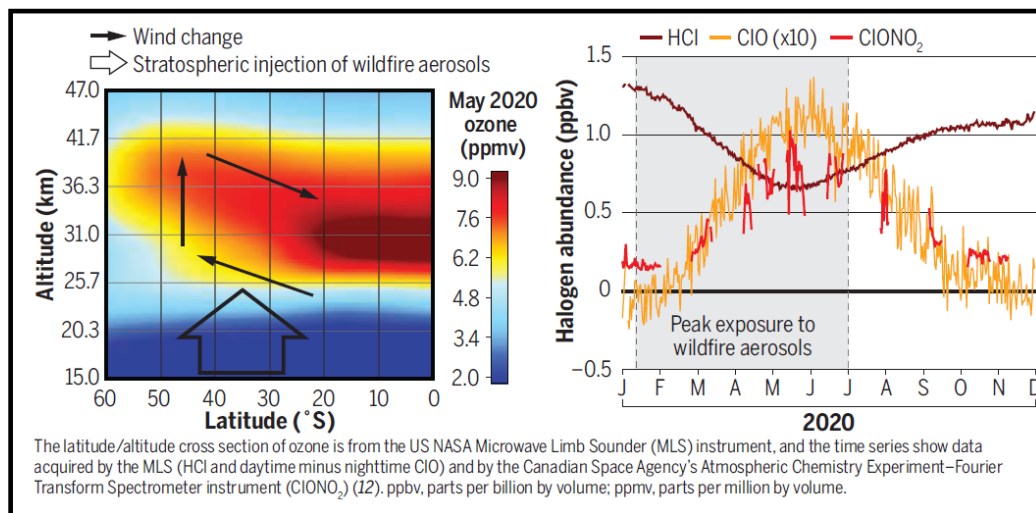
Various mechanisms initiated by wildfires thinned the stratospheric ozone layer

By Ross J. Salawitch^{1,2,3} and Laura A. McBride^{1,2,4}

25 NOVEMBER 2022 • VOL 378 ISSUE 6622

Abstract

The Australian wildfires of late 2019 and early 2020 claimed the lives of 33 people and more than 1 billion animals (1). The fires blanketed southeastern Australia with thick smoke that may have caused the loss of an additional 417 people from hospitalizations associated with elevated levels of fine particulate matter in the air (2). The smoke layer led to a series of atmospheric phenomena that reduced the thickness of Earth's protective ozone layer in the stratosphere, which lies between ~15- and 50-km altitude above the surface. The reduction of total column ozone (TCO), a measure of ozone layer thickness, was particularly strong at mid-latitudes of the Southern Hemisphere during late 2020. Various explanations linking smoke from these wildfires to this observed decline in TCO have been proposed. This debate highlights the shortcomings in our understanding of how wildfires, which are increasingly common because of climate change, affect stratospheric chemistry and Earth's protective ozone layer.



<https://www.science.org/doi/abs/10.1126/science.add2056>

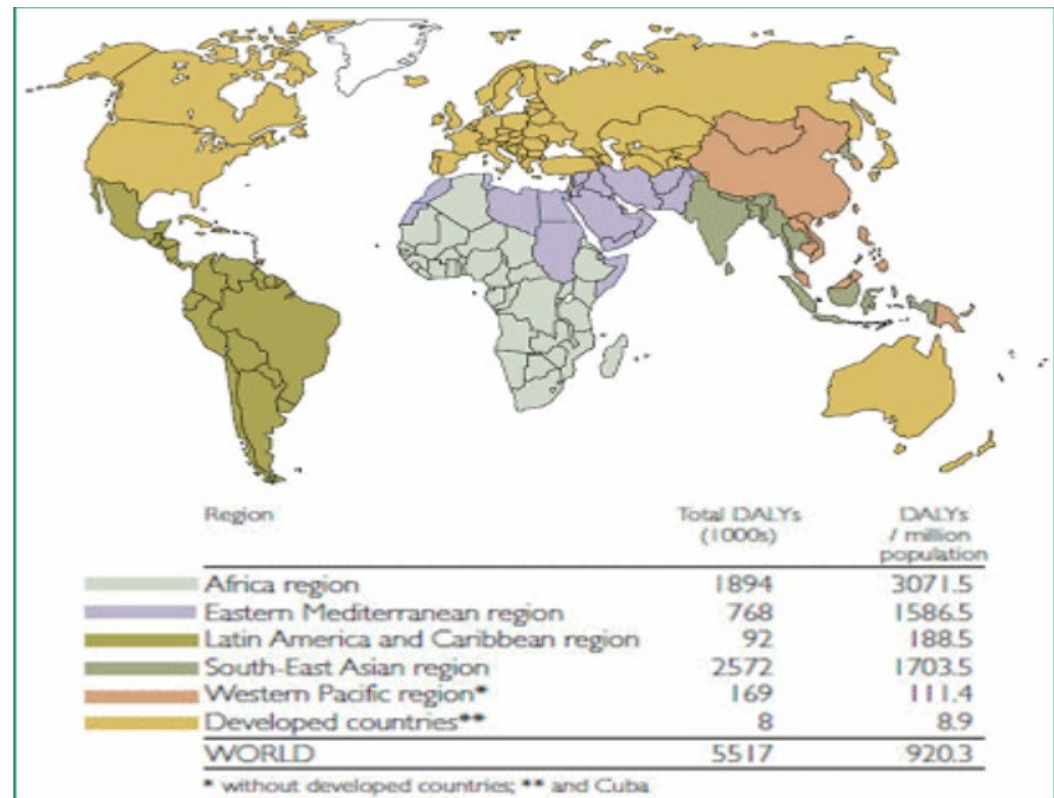
Infectious Disease

How does climate change impact public health?

- Creates more favorable conditions for some disease-carrying insects, like mosquitoes
- Increases flooding, which leads to standing water and the contamination of water sources
- Destroys habitats of animals, bringing them into contact with humans more frequently

Figure: Estimated effects of climate change on health through number of Disability Adjusted Life Years (DALYs) -- the sum of years of potential life lost due to premature death, and the years of productive life lost due to disability, associated with climate change.

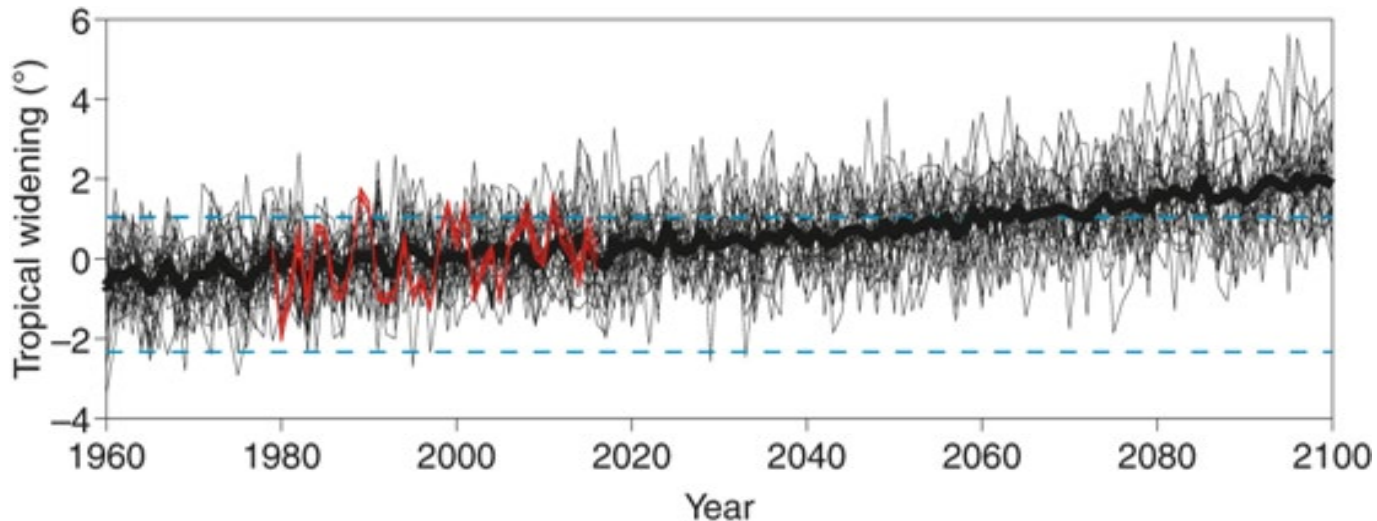
Credit: WHO



<https://www.who.int/globalchange/summary/en/index6.html>

Insect Vectors: Dengue Fever

- Transmitted by *Aedes* mosquitoes
 - Typically inhabits tropical and subtropical regions
- As of 2017, the CDC reports finding conditions favorable to the survival and reproduction of *Aedes aegypti* as far north as Pennsylvania
 - Result of the expanding tropics phenomenon
- Increasing temperatures, rainfall, and humidity will increase mosquito survival worldwide, exacerbating the spread of many of the diseases they carry



Change in the latitudinal width of the tropics relative to 1981-2010 mean from satellite observations (red) and climate models (thin black lines), along with the multi-model mean (thick black). The blue dashed lines show the 2σ range of the width of the tropics due to natural variability for pre-industrial levels of GHGs.

From Staten *et al.*, *Nature Climate Change*, 2018. <https://www.nature.com/articles/s41558-018-0246-2>

Insect Vectors: Malaria

- Impacts on insect host similar to Dengue
- In warmer temperatures, mosquitoes take blood meals more frequently
- Warmer temperatures cause the *plasmodium* parasite to digest blood and reproduce more quickly
- Higher rainfall and humidity levels may allow for incidences of malaria in areas where the parasite previously could not survive

Projection of precipitation changes by 2100 with aggressive growth of GHGs

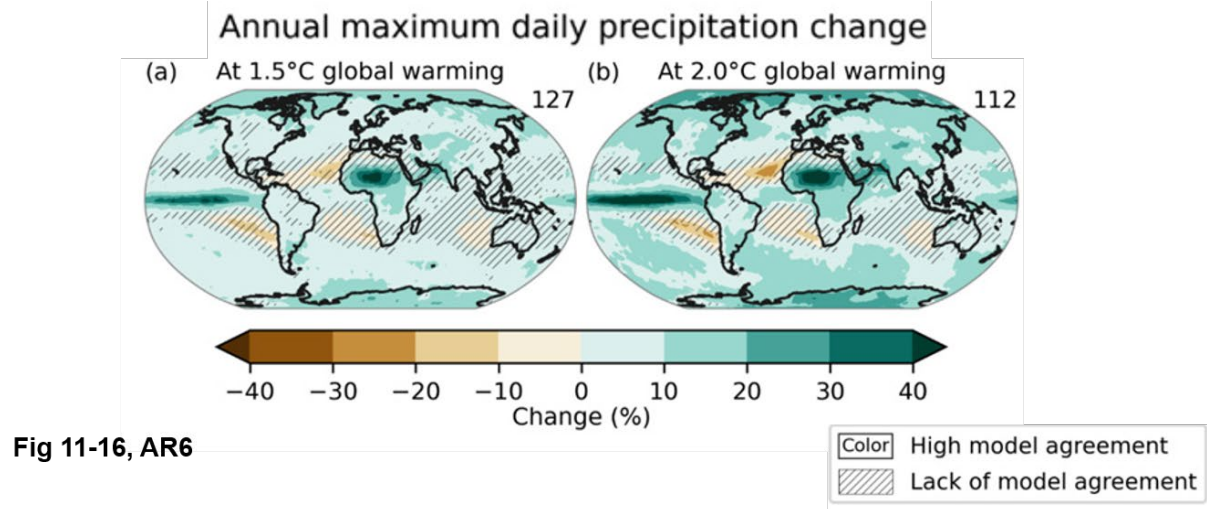


Fig 11-16, AR6

Projected changes in annual maximum daily precipitation at (a) 1.5°C, (b) 2°C warming compared to the 1851-1900 baseline.

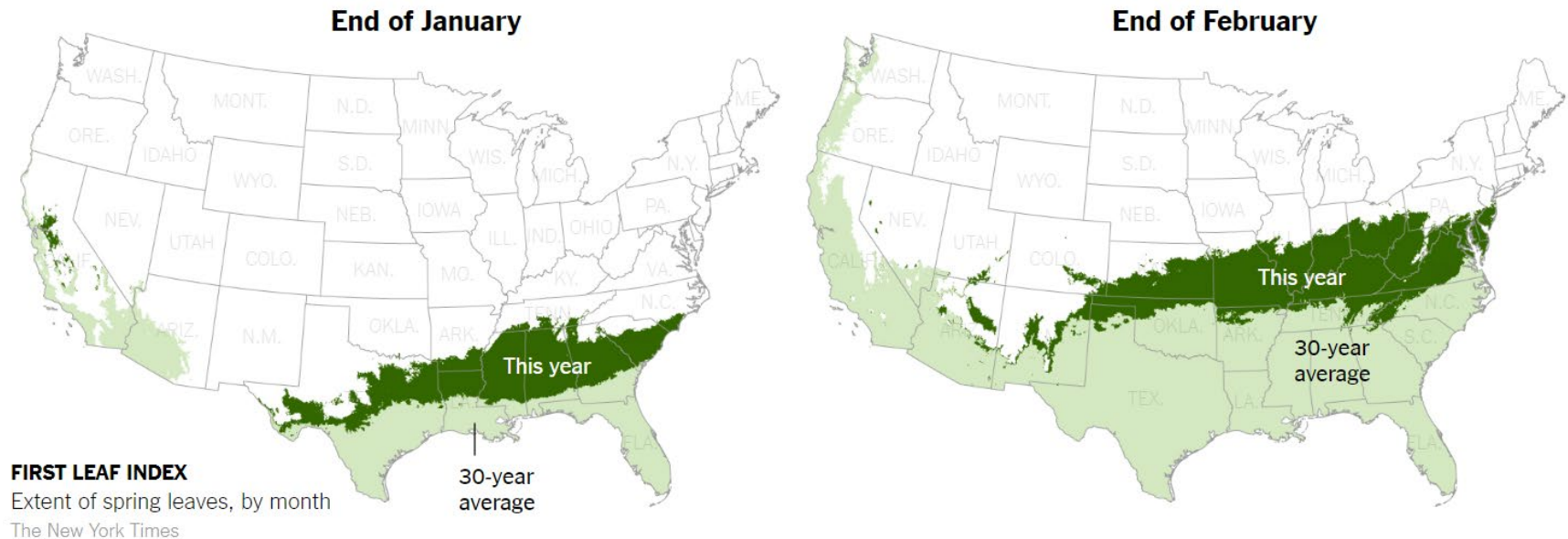
Results are based on simulations from the CMIP6 multi6 model ensemble under the SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. The numbers on the top right indicate the number of simulations included. Uncertainty is represented as follows: no overlay indicates regions with high model agreement, where $\geq 80\%$ of models agree on sign of change; diagonal lines indicate regions with low model agreement, where $< 80\%$ of models agree on sign of change

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_11.pdf

See also <https://www.preventionweb.net/news/explainer-what-new-ipcc-report-says-about-extreme-weather-and-climate-change>

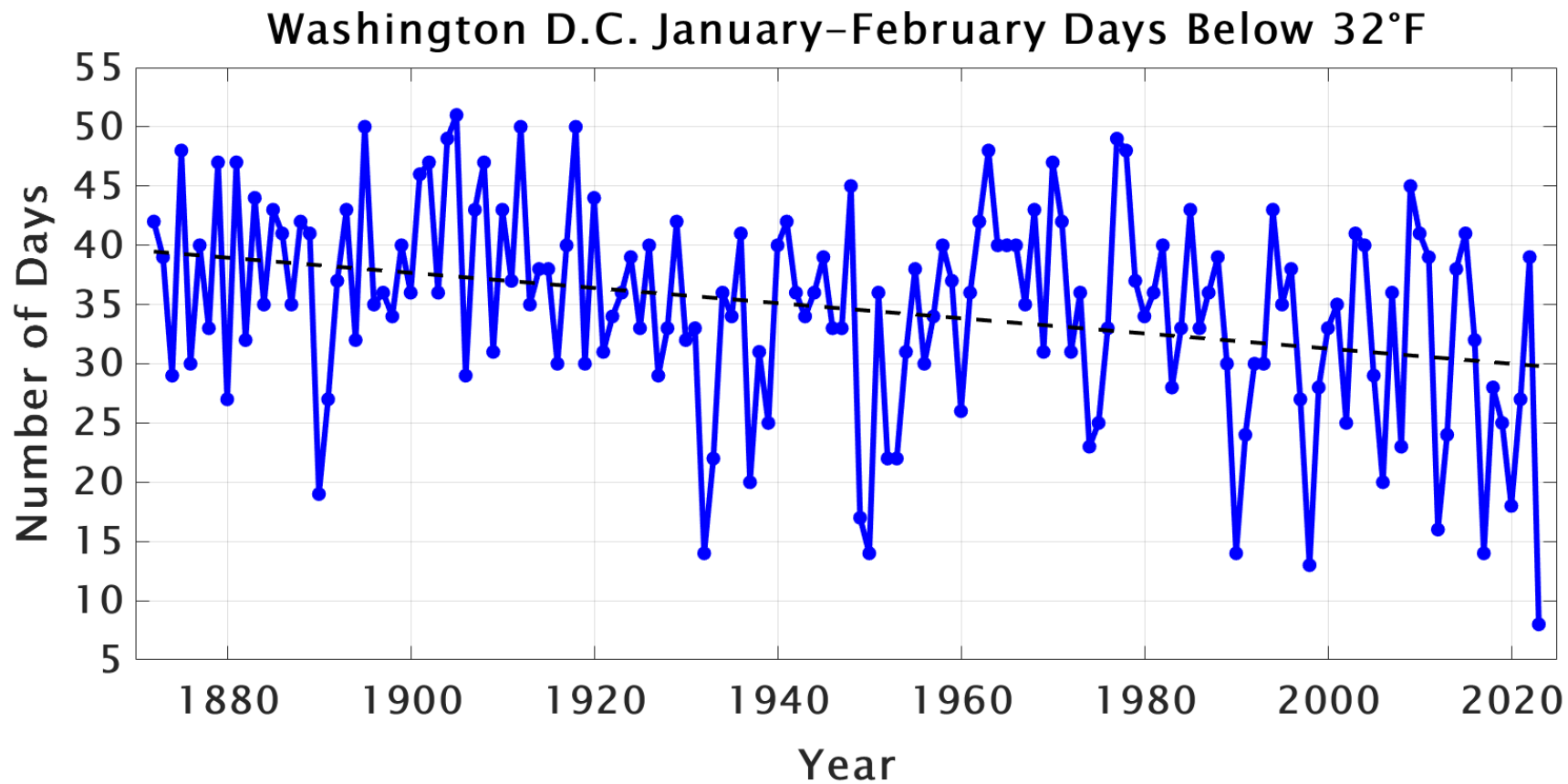
Insect Vectors in North America

- Freezes in the winter usually cause massive decreases in insect populations
- The average freeze season in the United States was a month shorter in 2016 than in 1916 (Weather.com)
- Higher external temperatures cause insects to have higher metabolic rates
- These two factors mean that with rising global temperature, more insects will survive the winter and reproduce- with a need to take more meals



Regions in the US that experienced blooming by the end of Jan (left) and Feb (right) 2017

<https://www.nytimes.com/interactive/2017/03/08/climate/early-spring.html>



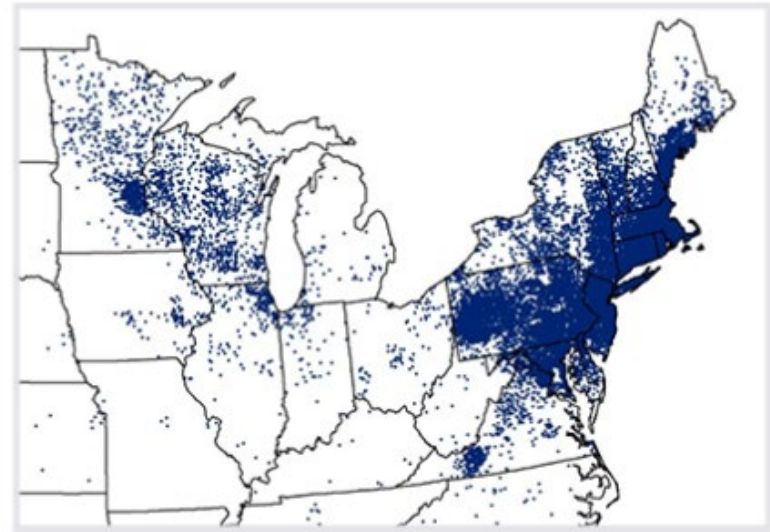
https://twitter.com/ryans_wx/status/1629863144502747139

Insect Vectors: Lyme Disease

- Infects over 20,000 people annually in the US
- Transmitted by deer ticks
 - Active in temperatures above 45 degrees F
 - Thrive in 85% humidity or greater (EPA)
- Ticks are not being killed off as significantly due to shorter/milder winters
- Earlier arrival of spring extends their active period; warmer temperatures cause ticks to feed on humans and deer more frequently
- Conditions favorable to deer ticks are becoming more frequent/widespread in the US



1996



2014

Distribution of reported cases of Lyme disease in 1996 and 2014. Each dot represents an individual case placed according to the patient's county of residence, which may be different than the county of exposure. Maps focus on the parts of the United States where Lyme disease is most common. (EPA)

<https://www.epa.gov/climate-indicators/climate-change-indicators-lyme-disease>

Consequences of Climate Change

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid (“serious supercomputer”)
- Some simulations project that at end of century, rising GHGs will lead to:
 - a) ~ 30% decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere, as well as a reduction in the mid-latitude to tropical temperature gradient
 - b) increase in maximum surface winds of the tropical cyclones that do occur:
i.e., ***hurricanes less frequent but more powerful***

Tropical cyclone climatology in a global-warming climate as simulated in a 20 km-mesh global atmospheric model: Frequency and wind intensity analyses

[K Oouchi](#), J Yoshimura, H Yoshimura... - ... **Society of Japan**. Ser ..., 2006 - jstage.jst.go.jp

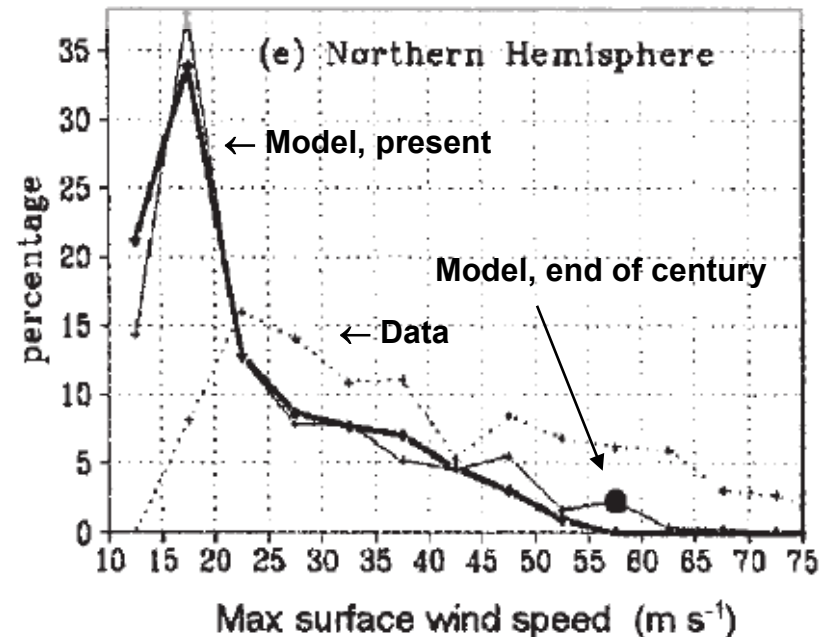
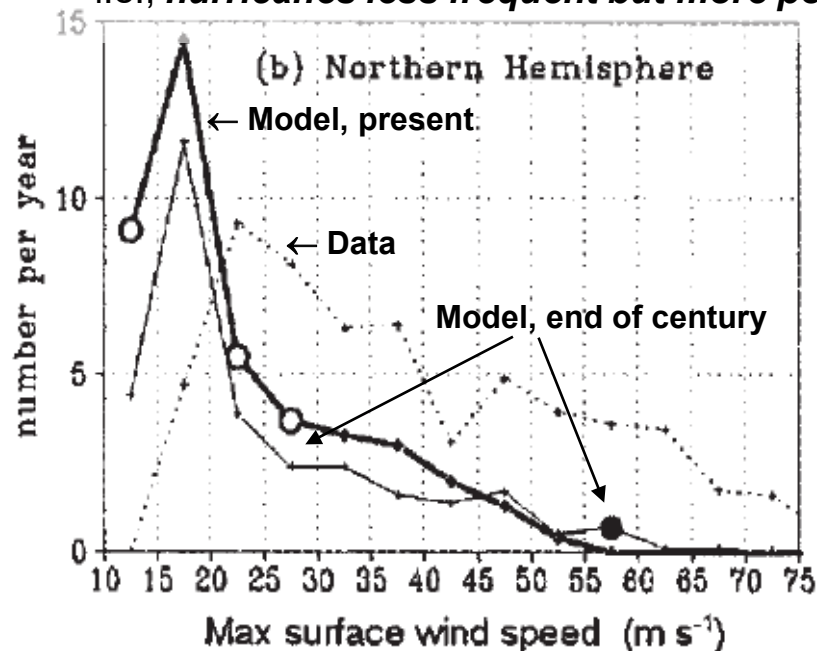
... In addition, considering also the versatile aims of the current numerical experiments (Mizuta et al. 2006; Kusunoki et al. 2005), only a limited number of output variables, but minimizing ...

☆ Save  Cite Cited by 707 Related articles All 16 versions Web of Science: 411 

Consequences of Climate Change

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~ 20 -km grid (“serious supercomputer”)
- Some simulations project that at end of century, rising GHGs will lead to:
 - a) $\sim 30\%$ decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere, as well as a reduction in the mid-latitude to tropical temperature gradient
 - b) increase in maximum surface winds of the tropical cyclones that do occur:
i.e., **hurricanes less frequent but more powerful**



Oouchi *et al.*, *Journal Meteor. Soc. Japan*, 2006

Consequences of Climate Change

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid (“serious supercomputer”)
- Some simulations project that at end of century, rising GHGs will lead to:
 - a) ~ 30% decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere, as well as a reduction in the mid-latitude to tropical temperature gradient
 - b) increase in maximum surface winds of the tropical cyclones that do occur:
i.e., **hurricanes less frequent but more powerful**

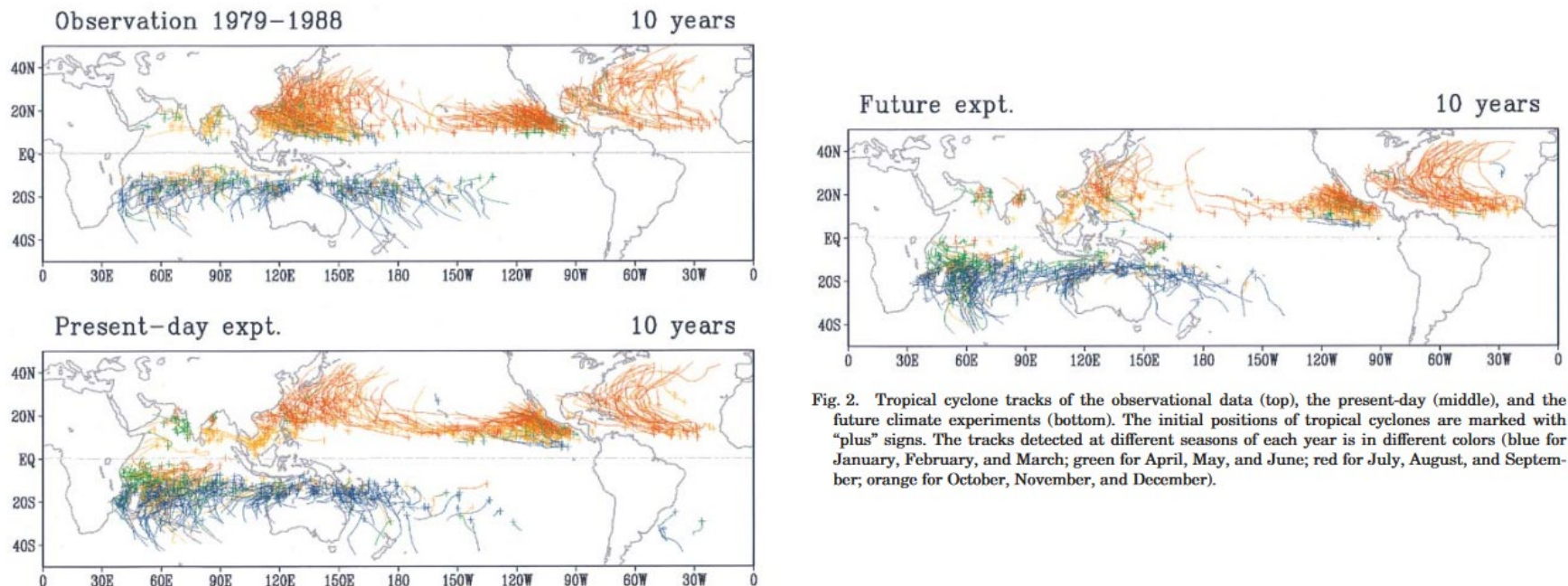


Fig. 2. Tropical cyclone tracks of the observational data (top), the present-day (middle), and the future climate experiments (bottom). The initial positions of tropical cyclones are marked with “plus” signs. The tracks detected at different seasons of each year is in different colors (blue for January, February, and March; green for April, May, and June; red for July, August, and September; orange for October, November, and December).

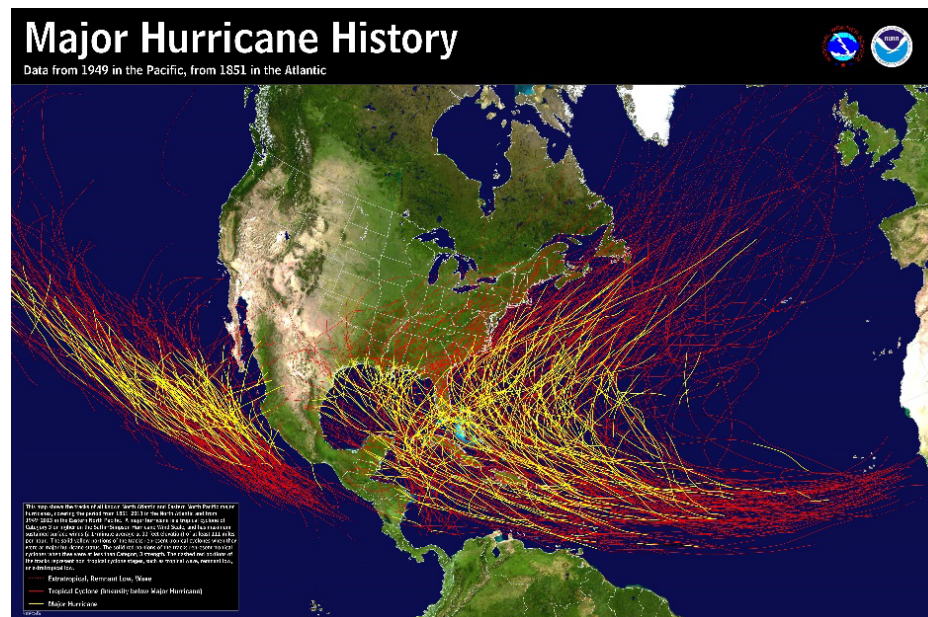
Oouchi *et al.*, *Journal Meteor. Soc. Japan*, 2006

Consequences of Climate Change

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid (“serious supercomputer”)
- Some simulations project that at end of century, rising GHGs will lead to:
 - a) ~ 30% decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere, as well as a reduction in the mid-latitude to tropical temperature gradient
 - b) increase in maximum surface winds of the tropical cyclones that do occur:
i.e., ***hurricanes less frequent but more powerful***

Confounding factor:



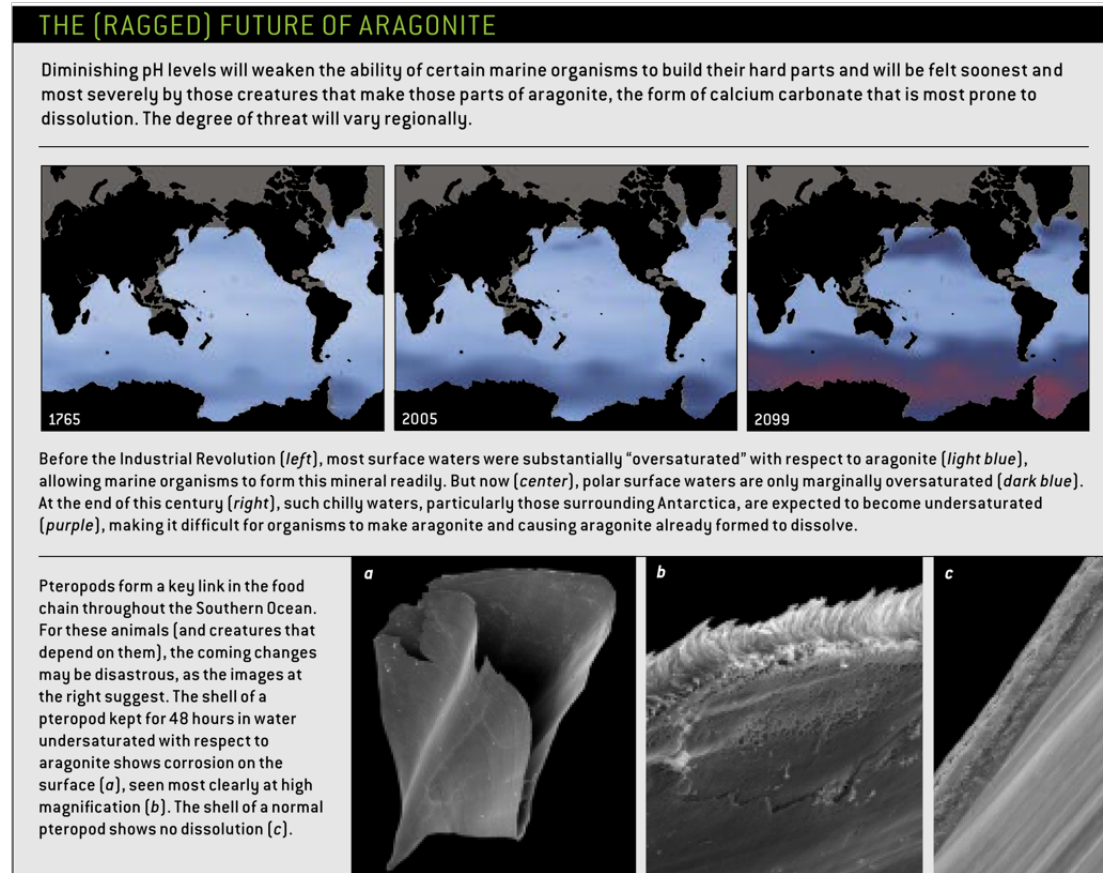
<http://www.c2es.org/science-impacts/extreme-weather/hurricanes>

Consequences of Climate Change

5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem

Future ocean uptake of atmospheric CO₂ will lead to **ocean acidification**

Bad news for ocean dwelling organisms that precipitate shells (basic materials)



Doney, The Dangers of Ocean Acidification, *Scientific American*, March, 2006



Consequences of Climate Change

6a. Air Quality

ENVIRONMENTAL RESEARCH
LETTERS

Climate change penalty and benefit on surface ozone: a global perspective based on CMIP6 earth system models

PUBLISHED
28 January 2022

Prodromos Zanis^{1,*}, Dimitris Akritidis¹, Steven Turnock^{2,3}, Vaishali Naik⁴, Sophie Szopa⁵, Aristeidis K Georgoulas¹, Susanne E Bauer⁶, Makoto Deushi⁷ , Larry W Horowitz⁴, James Keeble^{8,9}, Philippe Le Sager¹⁰, Fiona M O'Connor², Naga Oshima⁷ , Konstantinos Tsigaridis^{6,11} and Twan van Noije¹⁰

¹ Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract

This work presents an analysis of the effect of climate change on surface ozone discussing the related penalties and benefits around the globe from the global modelling perspective based on simulations with five CMIP6 (Coupled Model Intercomparison Project Phase 6) Earth System Models. As part of AerChemMIP (Aerosol Chemistry Model Intercomparison Project) all models conducted simulation experiments considering future climate (ssp370SST) and present-day climate (ssp370pdSST) under the same future emissions trajectory (SSP3-7.0). A multi-model global average climate change benefit on surface ozone of -0.96 ± 0.07 ppbv $^{\circ}\text{C}^{-1}$ is calculated which is mainly linked to the dominating role of enhanced ozone destruction with higher water vapour abundances under a warmer climate. Over regions remote from pollution sources, there is a robust decline in mean surface ozone concentration on an annual basis as well as for boreal winter and summer varying spatially from -0.2 to -2 ppbv $^{\circ}\text{C}^{-1}$, with strongest decline over tropical oceanic regions. The implication is that over regions remote from pollution sources (except over the Arctic) there is a consistent climate change benefit for baseline ozone due to global warming. However, ozone increases over regions close to anthropogenic pollution sources or close to enhanced natural biogenic volatile organic compounds emission sources with a rate ranging regionally from 0.2 to 2 ppbv $^{\circ}\text{C}^{-1}$, implying a regional surface ozone penalty due to global warming.

<https://iopscience.iop.org/article/10.1088/1748-9326/ac4a34>

Consequences of Climate Change

6a. Air Quality

The Washington Post
Democracy Dies in Darkness

Wildfire smoke is eroding decades of air quality improvements, study finds

The onslaught of wildfire smoke amid a warming climate has rolled back years of air quality gains in the U.S.



By Joshua Partlow

Updated September 20, 2023 at 11:32 a.m. EDT | Published September 20, 2023 at 11:00 a.m. EDT

Data from air quality sensors around the country had been showing steady improvement since 2000 in most states. But around 2016 — and earlier in some Western states — the trend broke. Since then, air quality progress has significantly slowed in 30 states. In 11 others, it began to reverse.

The statistical analysis by Burke and his colleagues through 2022 found that wildfire smoke significantly influenced air quality trends in 35 of the contiguous states. States that are still improving would have done so faster without smoke, they found. In some Western states, air quality that otherwise would have kept improving is now getting worse because of that smoke.

Many studies have documented how smoky days can send patients into emergency rooms in greater numbers with respiratory, cardiovascular and other problems. Burke, Childs and other researchers published a second study this week in Proceedings of the National Academy of Sciences that found that visits to California emergency rooms between 2006 and 2017 for asthma, chronic obstructive pulmonary disease (COPD) and other respiratory symptoms rose more than 30 percent in the week after an extreme smoke day, relative to a day without smoke.



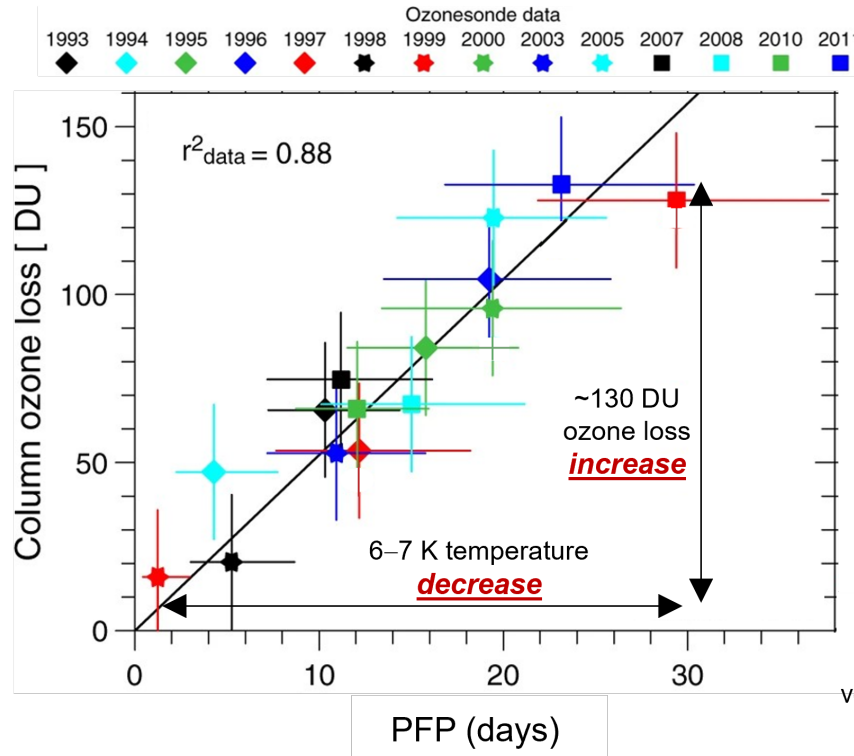
A hazy view of D.C. on June 8. (Eric Lee for The Washington Post)

<https://www.nature.com/articles/s41586-023-06522-6>
<https://www.nature.com/articles/d41586-023-02794-0>
<https://wapo.st/45c97SF>

Consequences of Climate Change

6b. Stratospheric, Arctic Ozone Loss

Data:



von der Gathen, *Nature Communications*, 2021

- Surprisingly simple relationship between chemical loss of column ozone and volume of air exposed to Polar Stratospheric Clouds over winter, where

$$\text{PFP} = \int_{1 \text{ Nov}}^{30 \text{ Apr}} \frac{V_{\text{PSC}}(t)}{V_{\text{VORTEX}}(t)} dt ; \text{ PFP stands for PSC Formation Potential}$$

and V_{PSC} is volume of the stratospheric polar vortex where T is cold enough to allow for formation of PSCs
 V_{VORTEX} is the volume of the Arctic stratospheric polar vortex

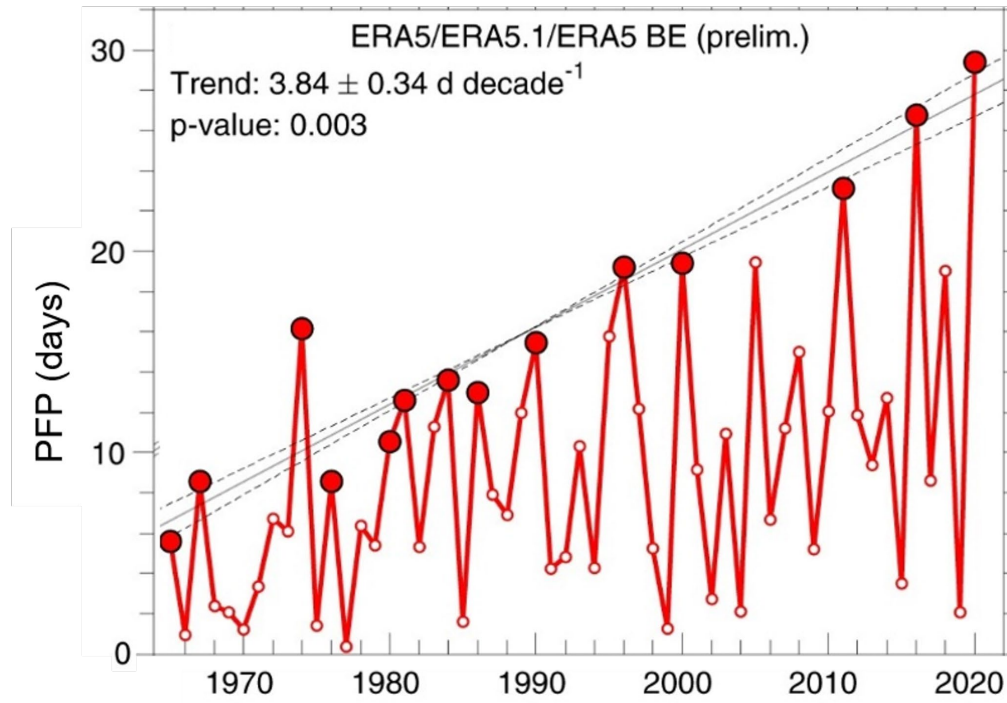
- Relation leads to estimate of ~20 DU additional loss of ozone per degree Kelvin cooling of **Arctic** stratosphere

Consequences of Climate Change

6b. Stratospheric, Arctic Ozone Loss

Cold Arctic Winters Tend to Exhibit Larger PFP as a Function of Time

More Data: PFP is PSC Formation Potential



von der Gathen, *Nature Communications*, 2021

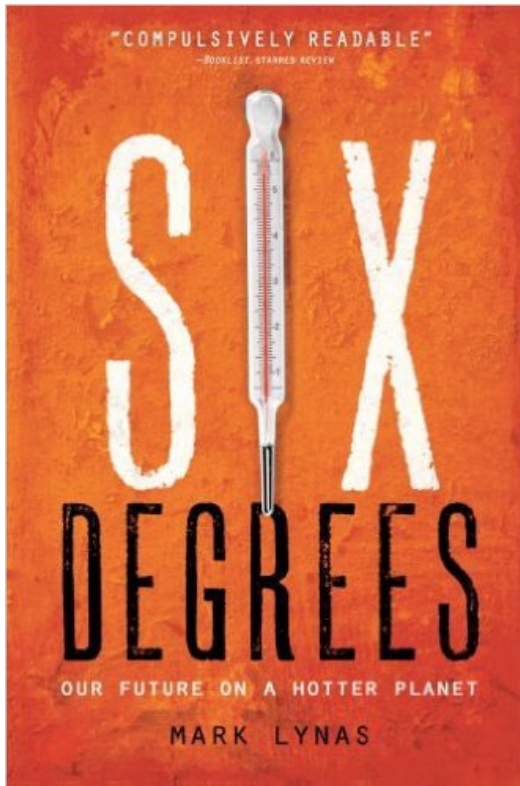
PSC Formation Potential in Arctic Vortex

based on 55 years of data from the European Centre for Medium-Range Weather Forecasts (ECMWF)

SOLID CIRCLES denote local maxima in PFP relative to a trend line

Possible Impacts of Climate Change

- **1°C (already committed to this)**
 - Loss of glacial waters in Africa & Asia, with regional declines in food production
 - Tropical islands such as Tuvalu, Kiribati, Marshall Islands, and Maldives severely threatened
- **2°C (Paris Climate Agreement Upper Limit)**
 - Polar bear habitat under severe threat
 - Glacial melt rate doubles; disappearance of glaciers will create water shortages in places such as India, Peru, Ecuador, and Bolivia
 - Stability of Greenland ice sheet threatened



Book: <https://www.amazon.com/Six-Degrees-Future-Hotter-Planet>

Summary: <http://www.sustainablewoodstock.co.uk/onetwo%20degrees%20summary.pdf>

Possible Impacts of Climate Change

- **3°C (occurs in ~2050 according to IPCC climate models using RCP 8.5)**
 - 80% of Arctic sea ice melted
 - Loss of Himalayan glaciers threaten water supply of Pakistan & China's hydro-electric industry
 - Indian monsoon, essential to 60% of world's population, more variable and possibly fails on a persistent basis
 - Many plant species become extinct if they can not adapt, an ecological catastrophe but also another source of atmospheric carbon
- **4°C (occurs in ~2080 according to IPCC climate models using RCP 8.5)**
 - Mass displacement of populations from places such as Bangladesh, Egypt, etc
 - Major flooding in Mumbai, Shanghai, Boston, New York, London, etc
 - Australia supports little to no agriculture
 - Stability of Antarctic ice sheet threatened
- **5°C (possibly end of this century)**
 - Stability of all of world's ice sheets threatened, leading to drastic change in coast line geography
 - Risk of methane release from hydrates, a strong positive feedback that is considered one of several tipping points
 - Possible massive decline in supportable, global population
- **6°C (next century)**
 - Sea level rise could be 20 meters (65 feet!)
 - **Dystopian world**

[Six Degrees: Our Future on a Hotter Planet](#) by Mark Lynas