Effects of Climate Change

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/spr2022
https://myelms.umd.edu/courses/137772

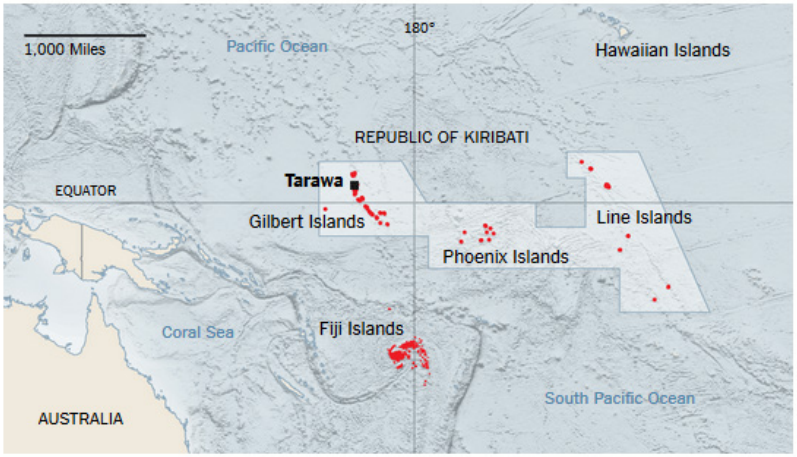
1. Rising sea-level threatens many populated coastal regions, including Maryland
2. Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions
3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, **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. Air Quality and Stratospheric Ozone Depletion

Lecture 9

24 February 2022

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

Jakarta

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.

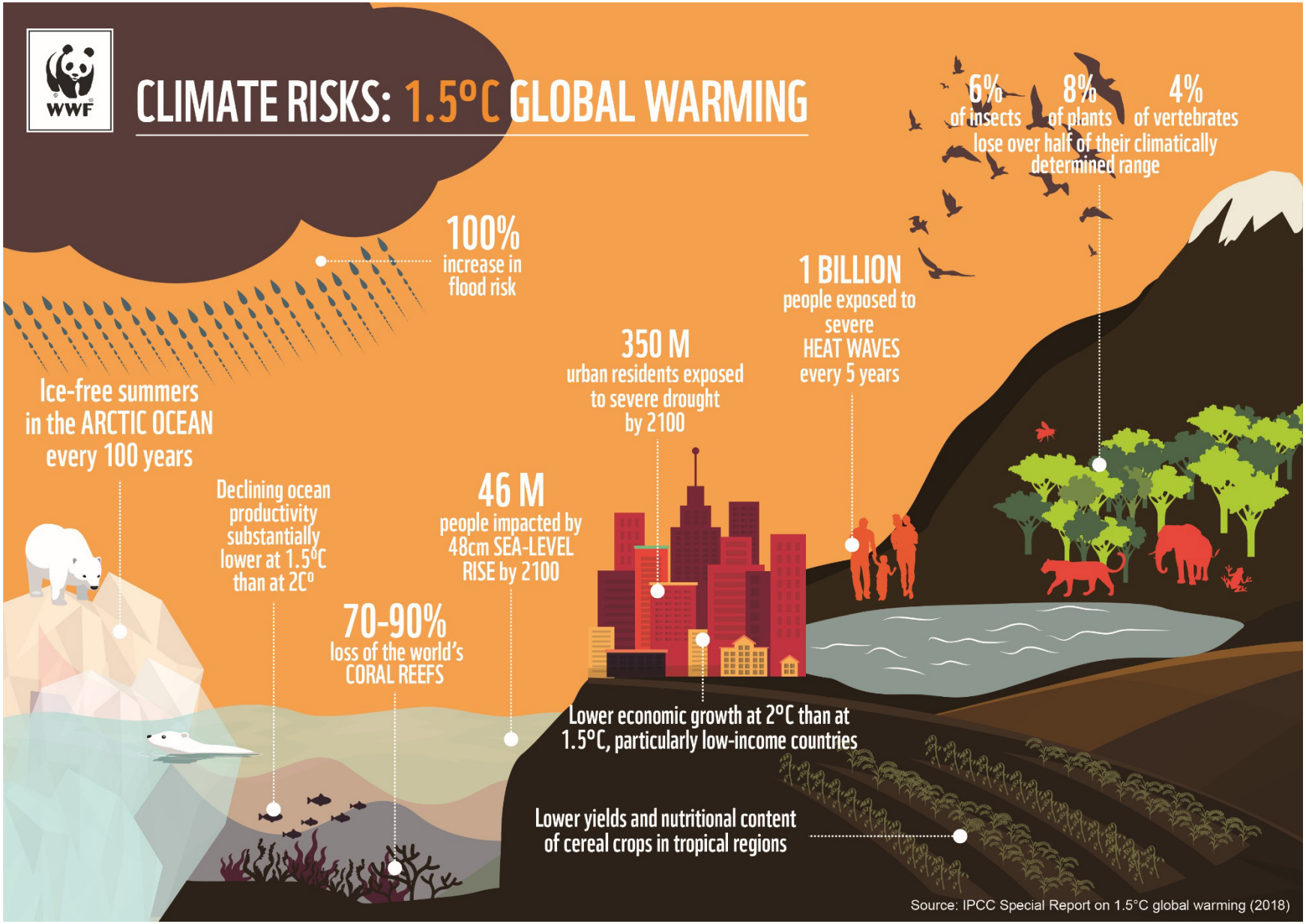
It's not clear exactly when this will happen, or where the new capital would be located. The idea has been out there for decades, though previous leaders have been unable to accomplish the ambitious plan.

"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.

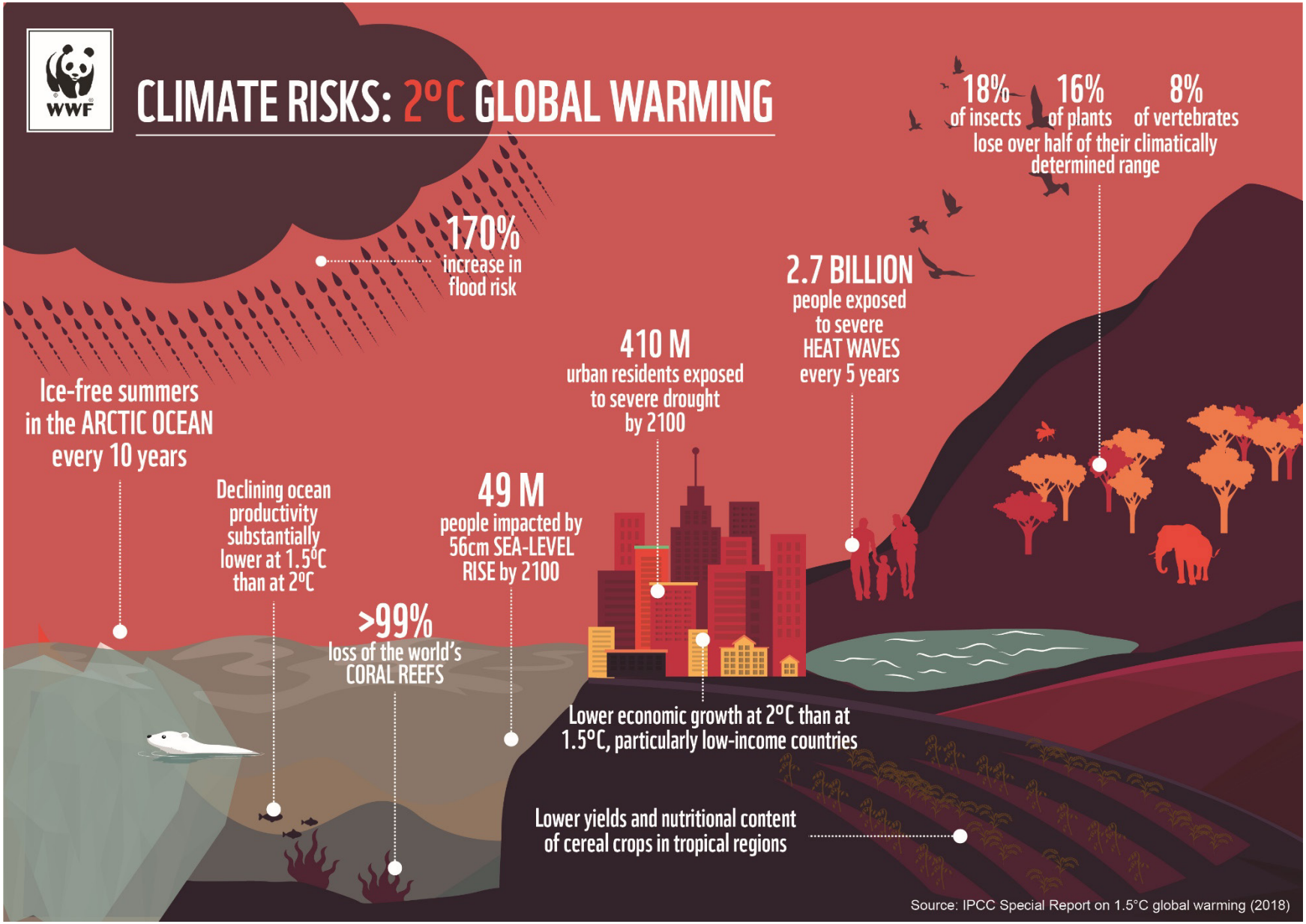
Jakarta faces massive challenges. As the BBC has reported, it's the fastest-sinking city in the world, with almost half of its area below sea level.

"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



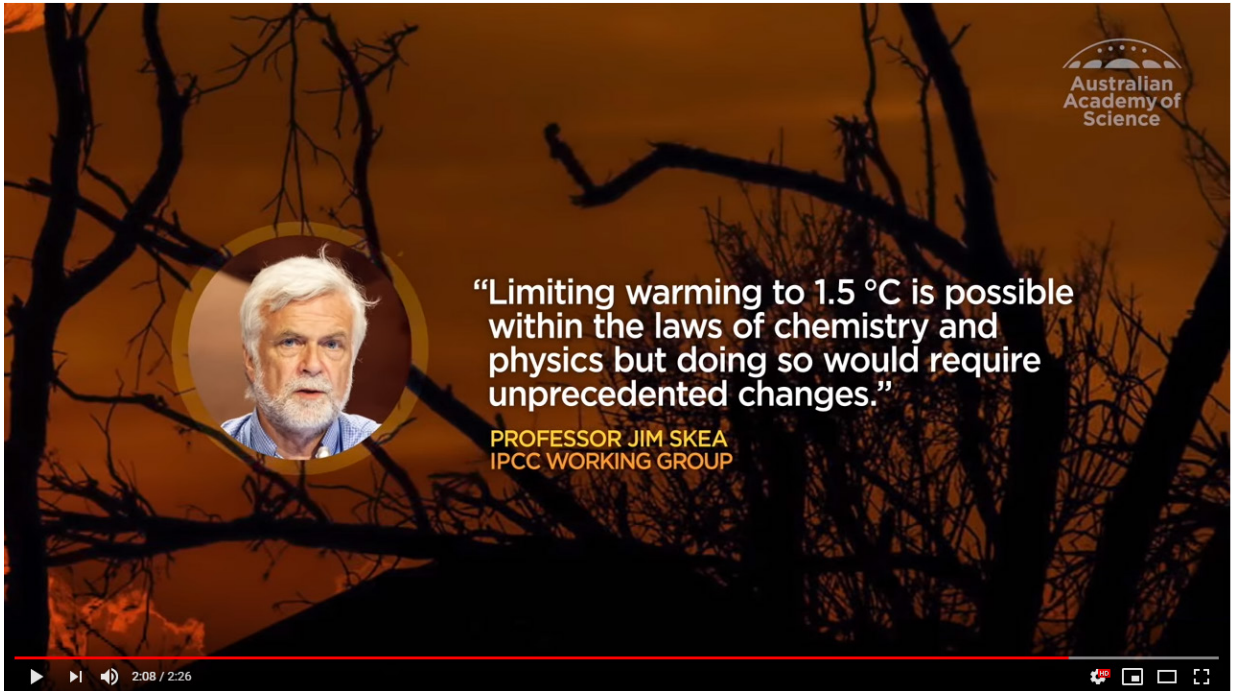
https://wwf.panda.org/our_work/climate_and_energy/cop24/



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

Possible Impacts of Climate Change

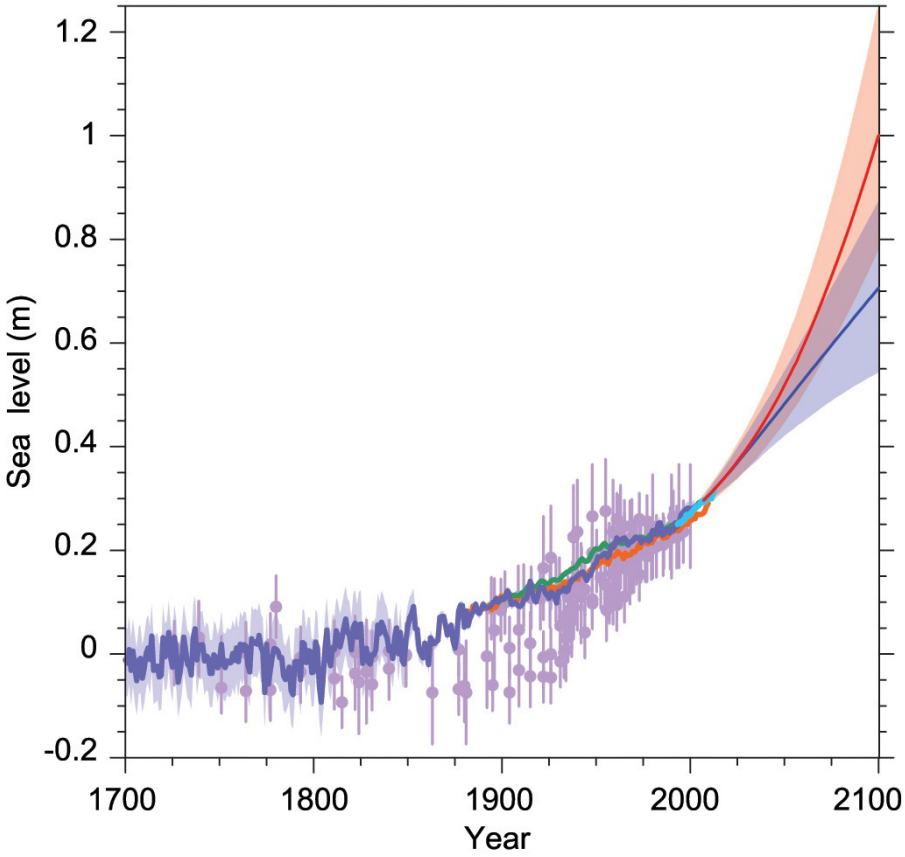
- **1°C (already committed to this)**
  - Loss of glacial waters in Africa & Asia, with regional declines in food production
  - Tropical islands such as Tuvalu, Kiribati, Marshall Islands, and Maldives severely threatened
- **2°C (Paris Climate Agreement Upper Limit)**
  - Polar bear habitat under severe 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



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.

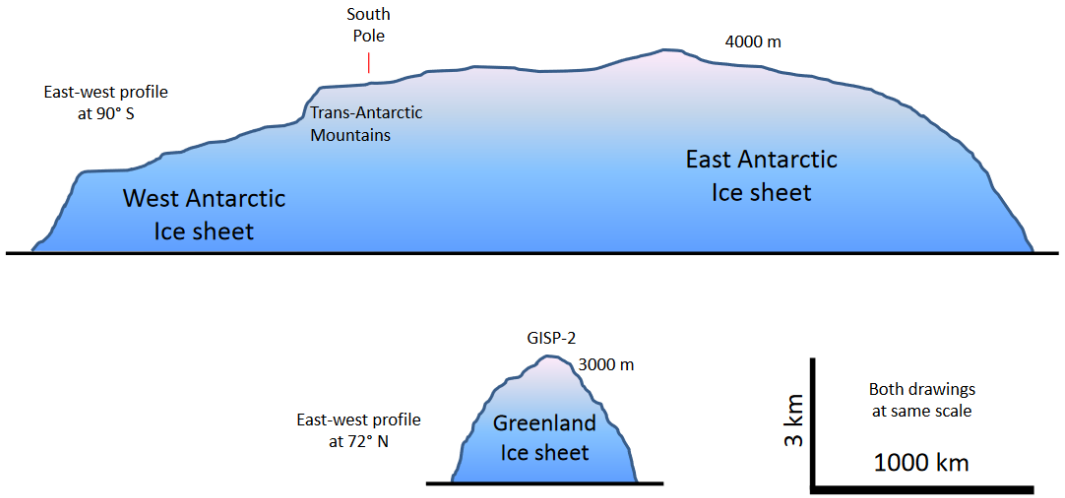
IPCC (2013)

Volume of Antarctic and **Greenland** Ice Sheets

Volume of Antarctic Ice Sheet ~26.5×10^6 km^3 and volume of cubic Greenland Ice Sheet **~2.85×10^6 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 = 510×10^6 km^2
70% of earth, or 357×10^6 km^2 is covered by water.

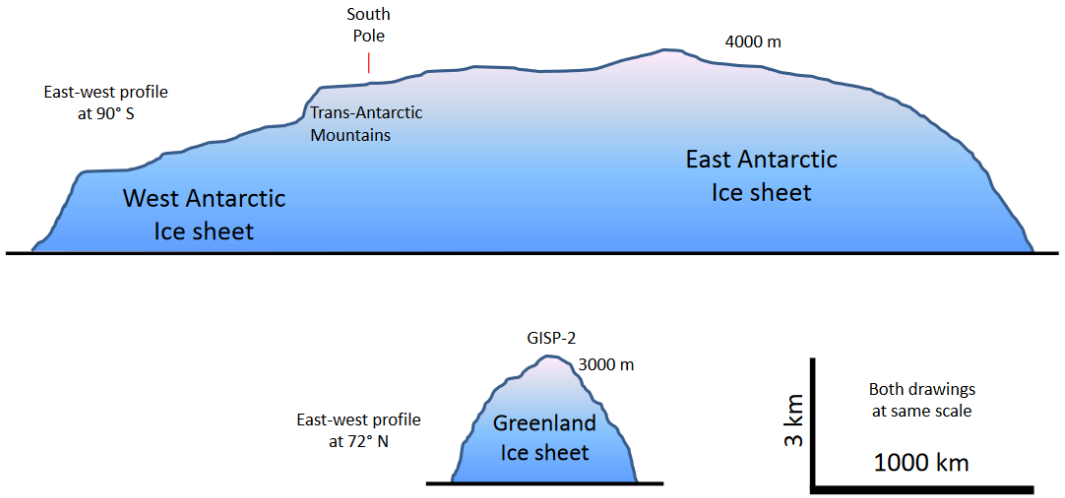
The complete collapse of Greenland would lead to sea-level rise of
2.85×10^6 km^3 / 357×10^6 km^2 = 8 meters according to these numbers.
Since more area would be covered by water following the collapse,
the actual rise in sea level is closer to 7 meters … or **23 feet**!

Volume of **Antarctic** and Greenland Ice Sheets

Volume of Antarctic Ice Sheet **~26.5 × 10⁶ km³** and volume of cubic Greenland Ice Sheet ~2.85 × 10^6 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



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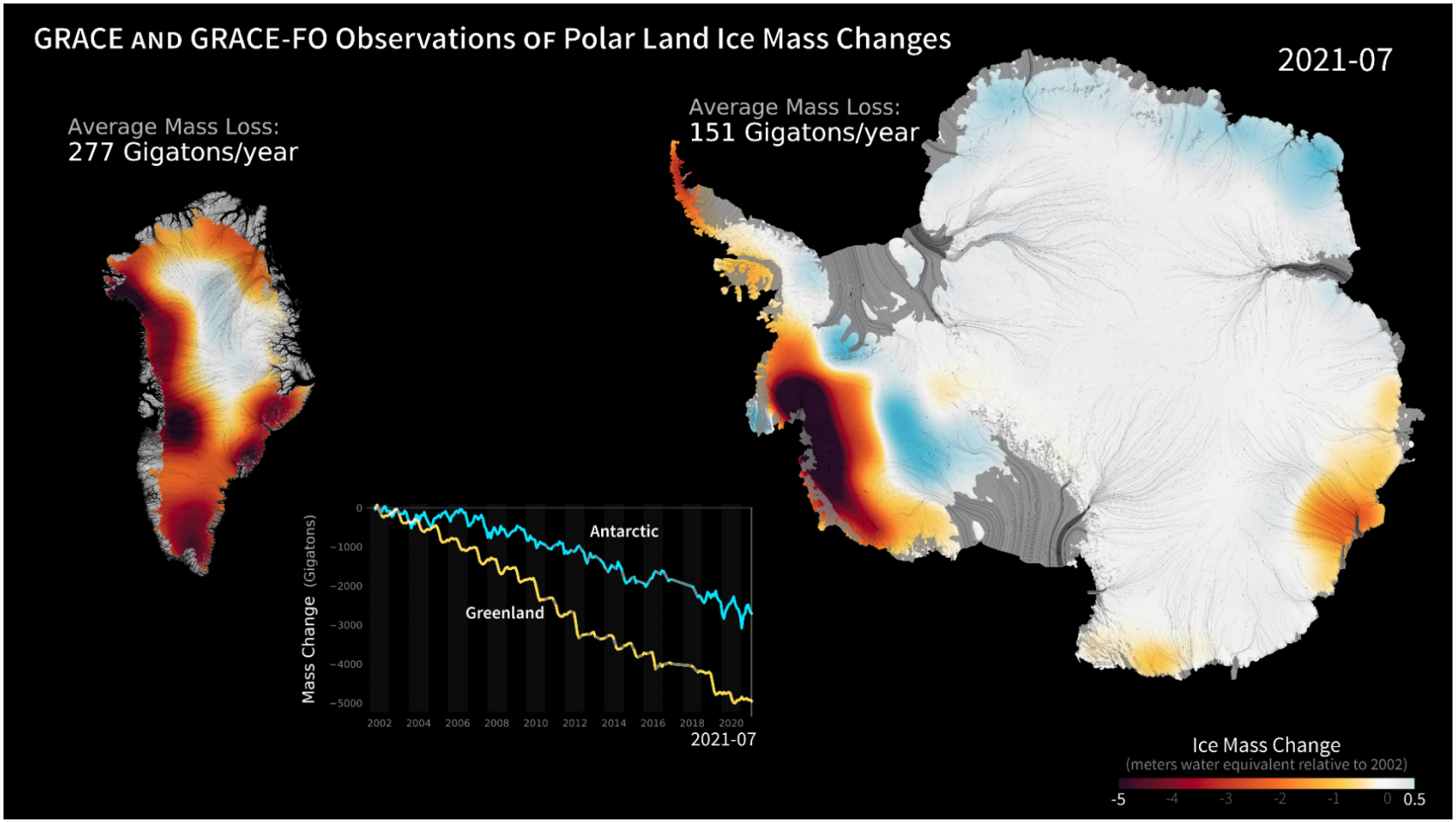
Radius of Earth = 6371 km; Surface area of Earth = 510 × 10^6 km^2
70% of earth, or 357 × 10^6 km^2 is covered by water.

The complete collapse of Antarctica would lead to sea-level rise of
26.5 × 10^6 km^3 / 357 × 10^6 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 and Antarctica Ice Mass



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

Antarctica News: February 2022

National

Soot is accelerating snow melt in popular parts of Antarctica, a study finds

By Rebecca Hersher
Published February 22, 2022 at 8:07 AM PST

▶ LISTEN • 2:40

Tourists visit the South Shetland Islands in Antarctica in 2019. A new study suggests that tourism and research activity in the most heavily trafficked part of the continent is leading to significantly more snow melt.

Soot pollution is accelerating climate-driven melting in Antarctica, a new study suggests, raising questions about how to protect the delicate continent from the increasing number of humans who want to visit.

Researchers estimate that soot, or black carbon, pollution in the most popular and accessible part of Antarctica is causing an extra inch of snowpack shrinkage every year.

The number of tourists visiting each year has ballooned from fewer than 10,000 in the early 1990s to nearly 75,000 people during the austral summer season that began in 2019, according to the International Association of Antarctica Tour Operators.

"It really makes us question, is our presence really needed?" says Alia Khan, a glaciologist at Western Washington University and one of the authors of the new study, which was published in the journal *Nature Communications*. "We have quite a large black carbon footprint in Antarctica, which is enhancing snow and ice melt."

https://www.kpbs.org/news/national/2022/02/22/soot-is-accelerating-snow-melt-in-popular-parts-of-antarctica-study-finds

As CO_2 and other GHGs rise:

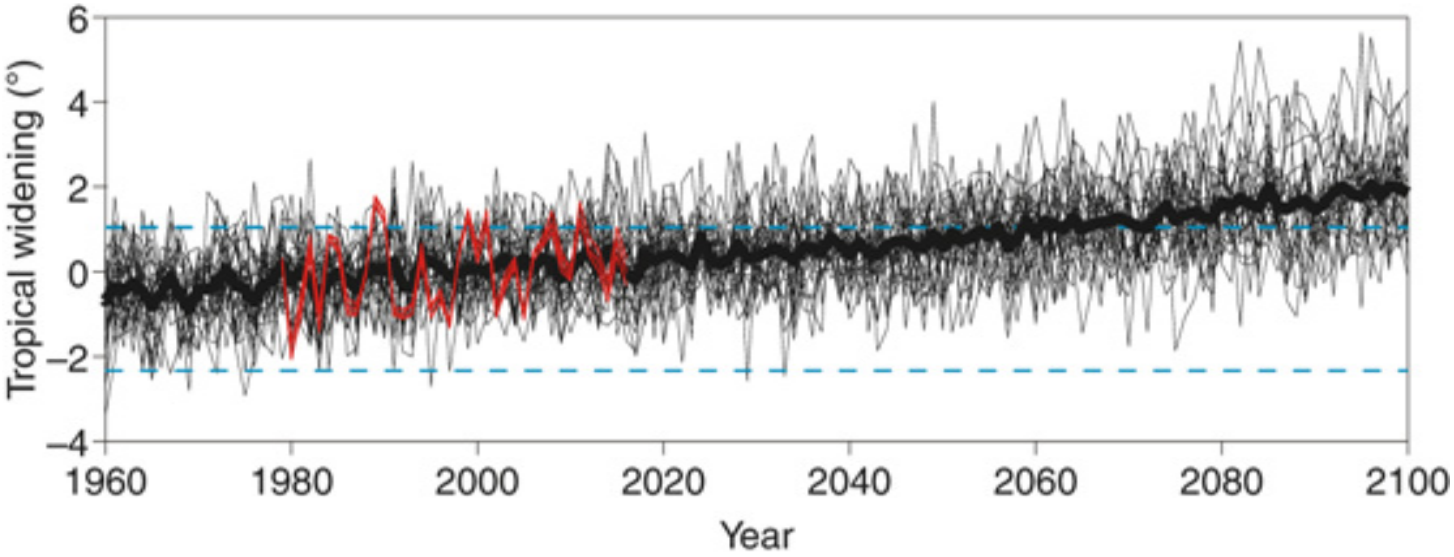
- Hadley Cell becomes more energetic
- WWDD: Wet gets wetter, dry gets drier
- Deserts expand poleward

REVIEW ARTICLE
https://doi.org/10.1038/s41558-018-0246-2
nature climate change

Re-examining tropical expansion

Paul W. Staten[1], Jian Lu[2*], Kevin M. Grise[3], Sean M. Davis[4,5] and Thomas Birner[6]

[1]Indiana University Bloomington, Bloomington, IN, USA. [2]Pacific Northwest National Laboratory, Richland, WA, USA. [3]University of Virginia, Charlottesville, VA, USA. [4]NOAA ESRL Chemical Sciences Division, Boulder, CO, USA. [5]Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder, Boulder, CO, USA. [6]Ludwig-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

Recent papers linking fires to climate change

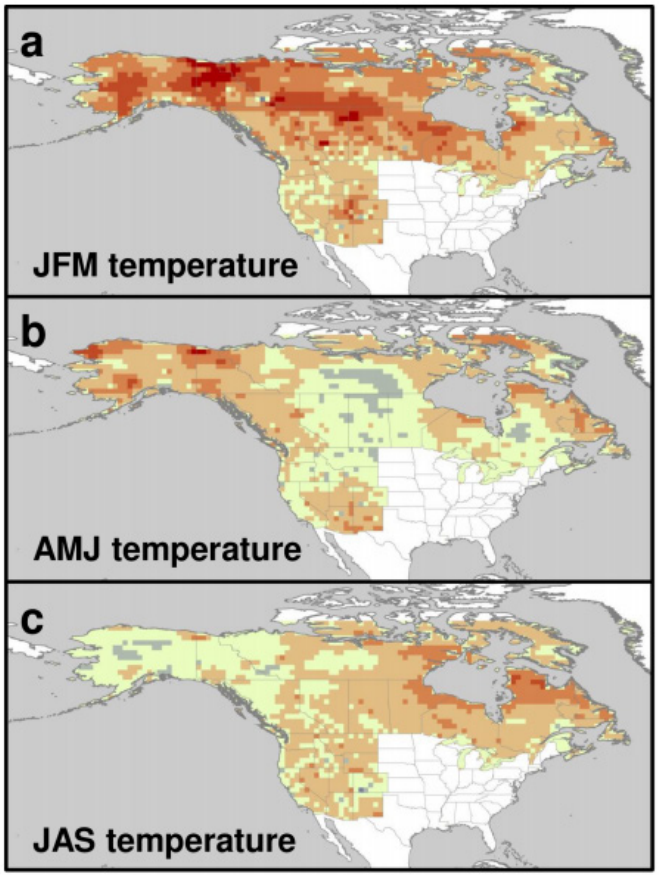
RESEARCH ARTICLE

Direct and indirect climate controls predict heterogeneous early-mid 21st century wildfire burned area across western and boreal North America

Thomas Kitzberger[1]*, Donald A. Falk[2,3], Anthony L. Westerling[4], Thomas W. Swetnam[2]

1 Laboratorio Ecotono, CONICET–INIBIOMA, Universidad Nacional del Comahue, Quintral, Bariloche, Argentina, **2** University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ, United States of America, **3** University of Arizona, School of Natural Resources and the Environment, Environment and Natural Resources Building, Tucson, AZ, United States of America, **4** Sierra Nevada Research Institute, University of California, Merced, California, United States of America

* kitzberger@comahue-conicet.gob.ar



Trends in temperature for:
(a) Winter (JFM)
(b) spring (AMJ)
(c) summer (JAS)
over the 1972–2006 time period

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0188486

Recent papers linking fires to climate change

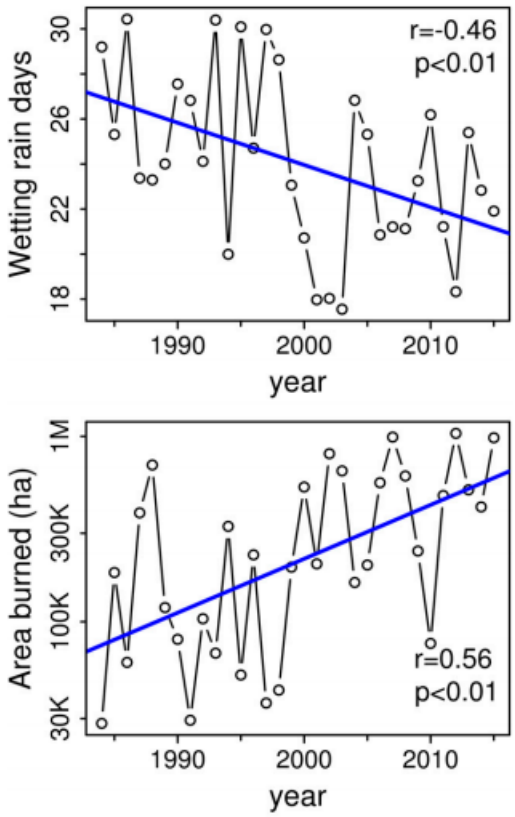
PNAS

Decreasing fire season precipitation increased recent western US forest wildfire activity

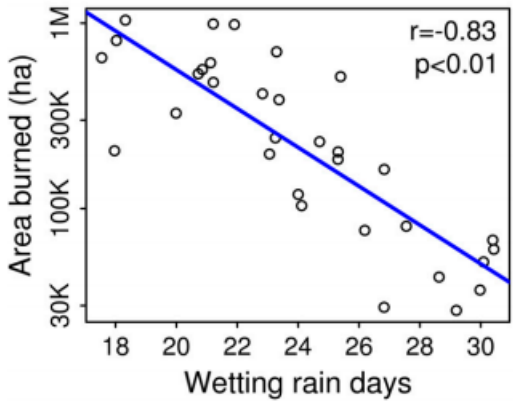
Zachary A. Holden[a,1], Alan Swanson[b], Charles H. Luce[c], W. Matt Jolly[d], Marco Maneta[e], Jared W. Oyler[f], Dyer A. Warren[b], Russell Parsons[d], and David Affleck[g]

[a]US Forest Service Region 1, Missoula, MT 59807; [b]School of Public and Community Health Sciences, University of Montana, Missoula, MT 59812; [c]US Forest Service Aquatic Science Laboratory, Rocky Mountain Research Station, Boise, ID 83702; [d]US Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT 59808; [e]Department of Geosciences, University of Montana, Missoula, MT 59812; [f]Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802; and [g]Department 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

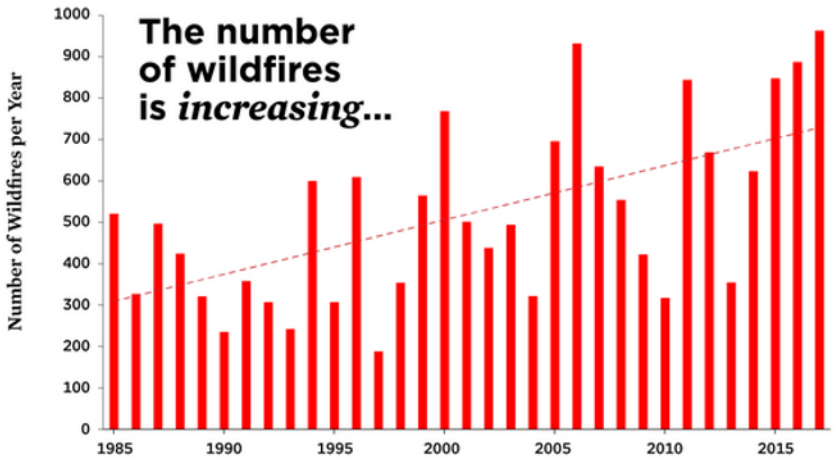


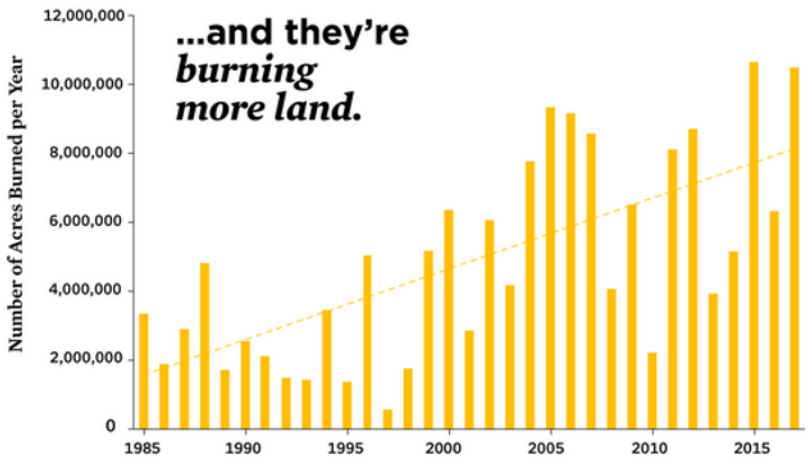
Linear trends in wetting rain days (left top), the logarithm of area burned (left bottom), and wetting rain days versus logarithm of area burned (right)



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

Forest Fires and Climate Change



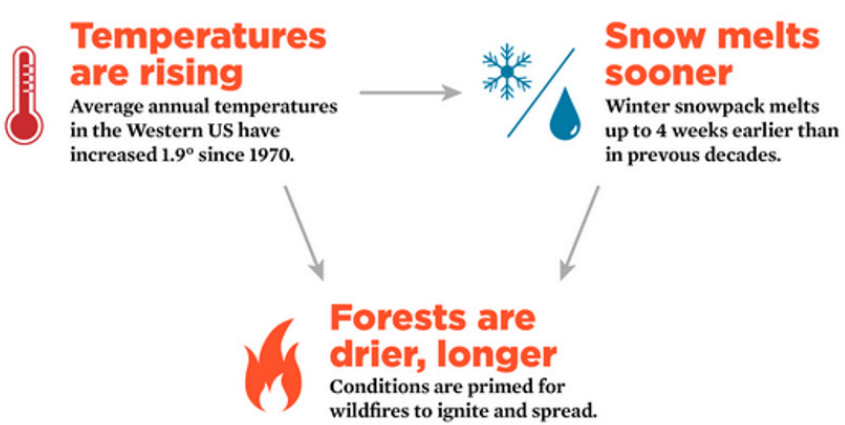


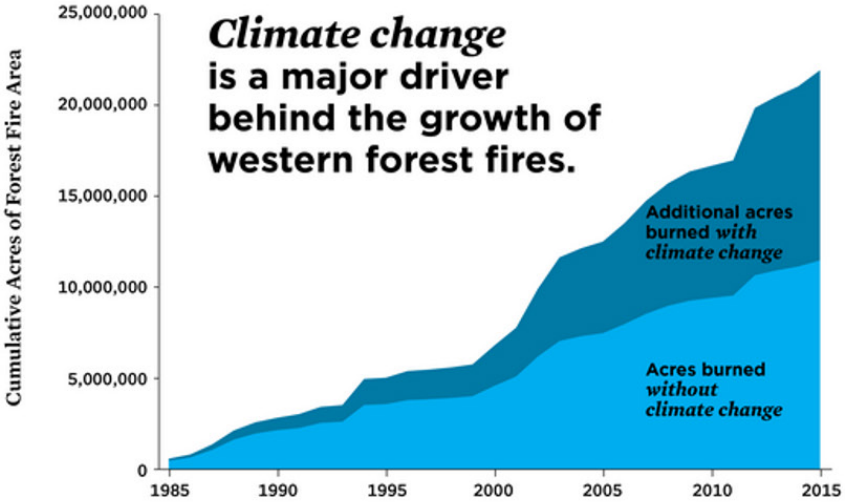
Data from the Monitoring Trends in Burn Severity program. MTBS only includes large fires in the United States (>500 acres for the eastern US, >1000 acres for the west). Prescribed fires removed.

Since 2015, the United States has experienced, on average, roughly 100 more large wildfires every year than the year before. This changes region by region, and year to year, but generally we're seeing more wildfires, more acres burned, and longer, more intense fire seasons.

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

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

Forest Fires and Climate Change

The New York Times

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

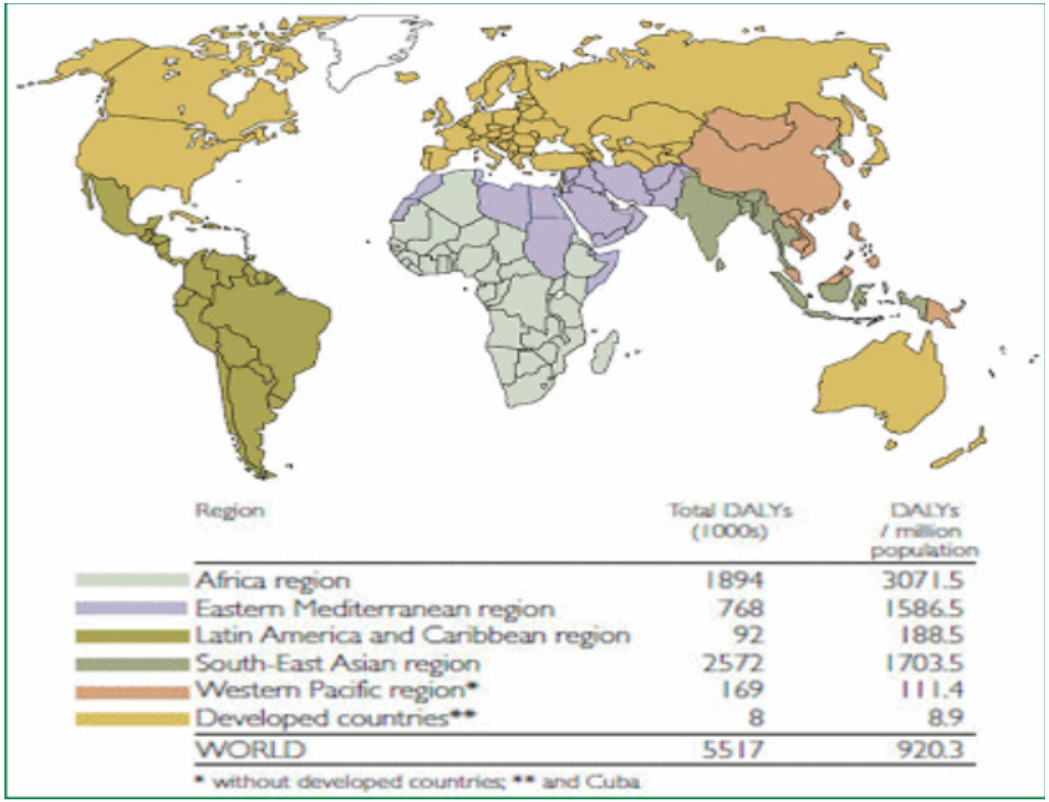
https://www.nytimes.com/2022/02/23/climate/climate-change-un-wildfire-report.html
https://www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires

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



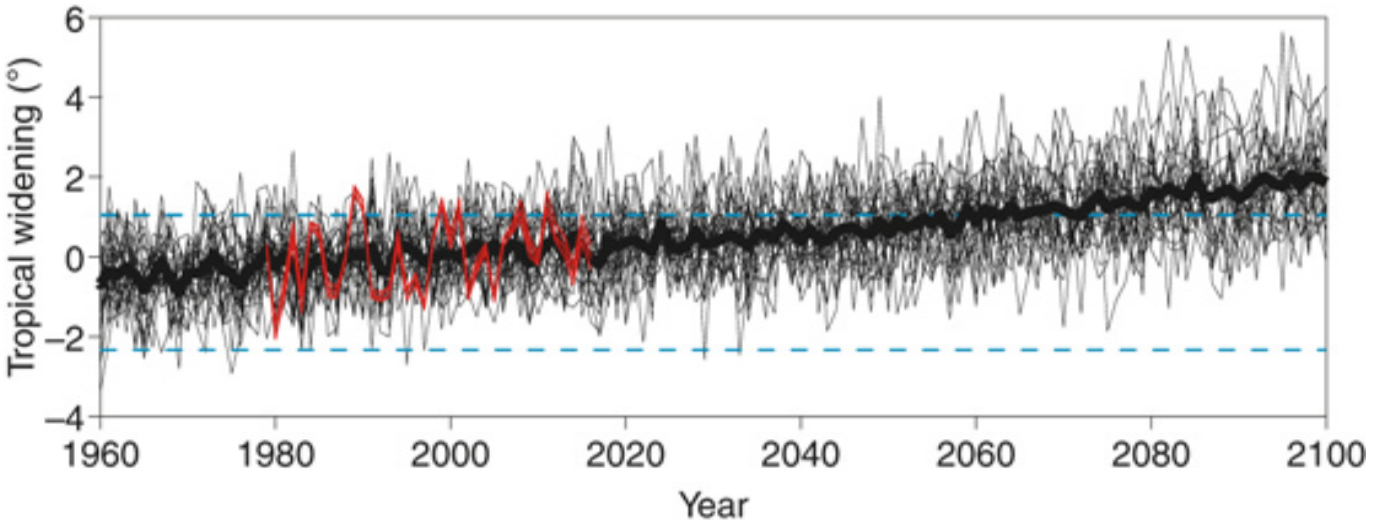
Region	Total DALYs (1000s)	DALYs / million population
Africa region	1894	3071.5
Eastern Mediterranean region	768	1586.5
Latin America and Caribbean region	92	188.5
South-East Asian region	2572	1703.5
Western Pacific region*	169	111.4
Developed countries**	8	8.9
WORLD	5517	920.3

* without developed countries; ** and Cuba

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



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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

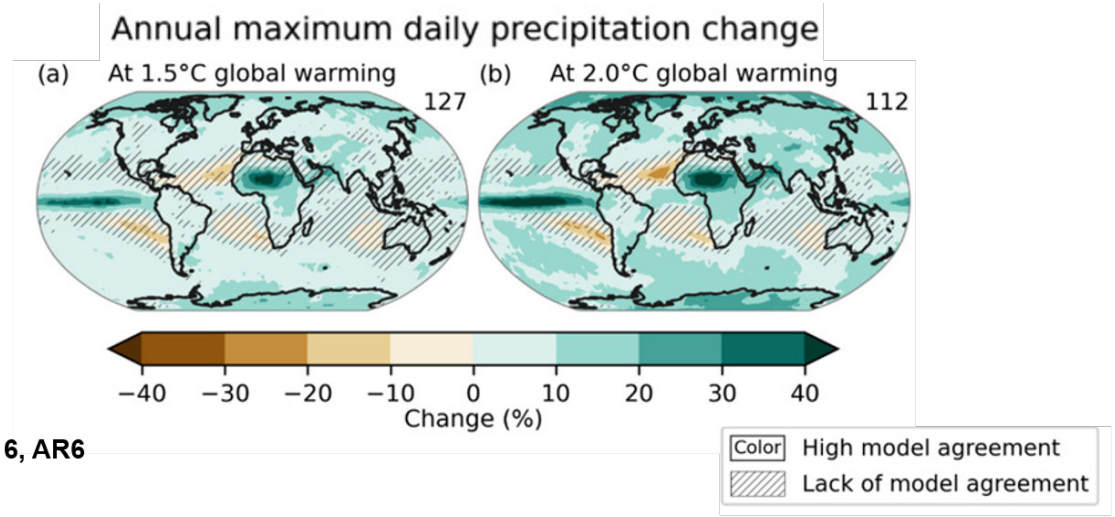


Fig 11-16, AR6

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

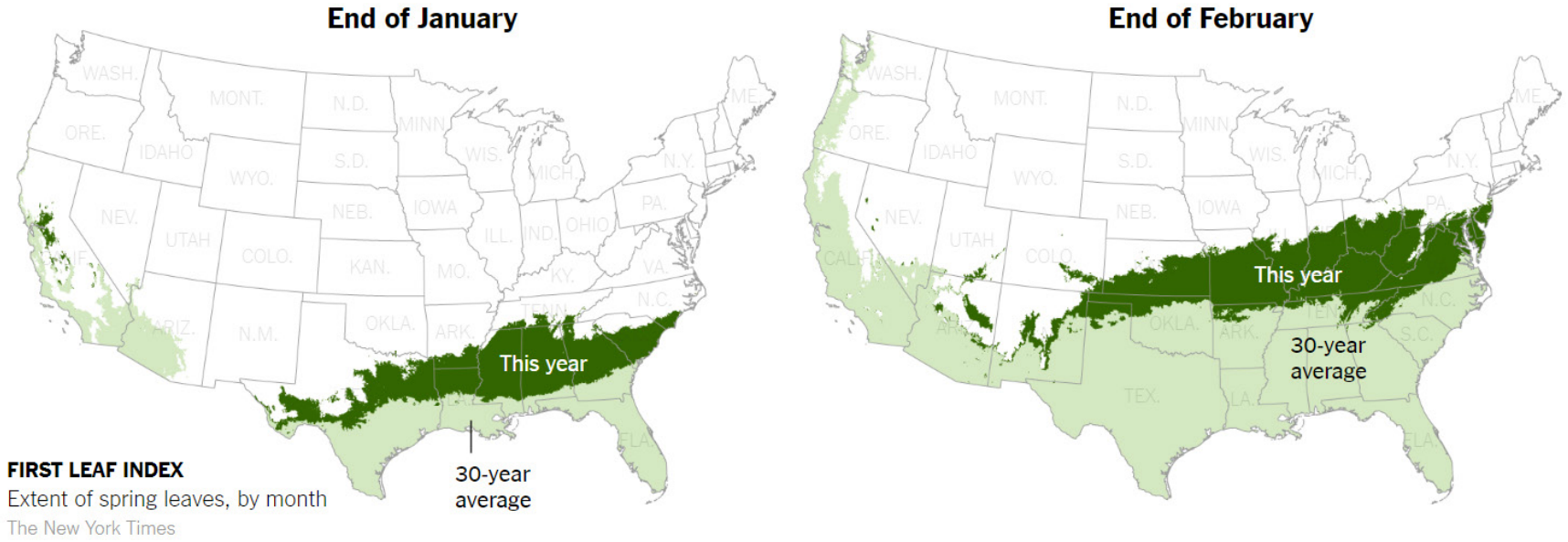
Results are based on simulations from the CMIP6 multi6 model ensemble under the SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. The numbers on the top right indicate the number of simulations included. Uncertainty is represented as follows: no overlay indicates regions with high model agreement, where ≥ 80% of models 9 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

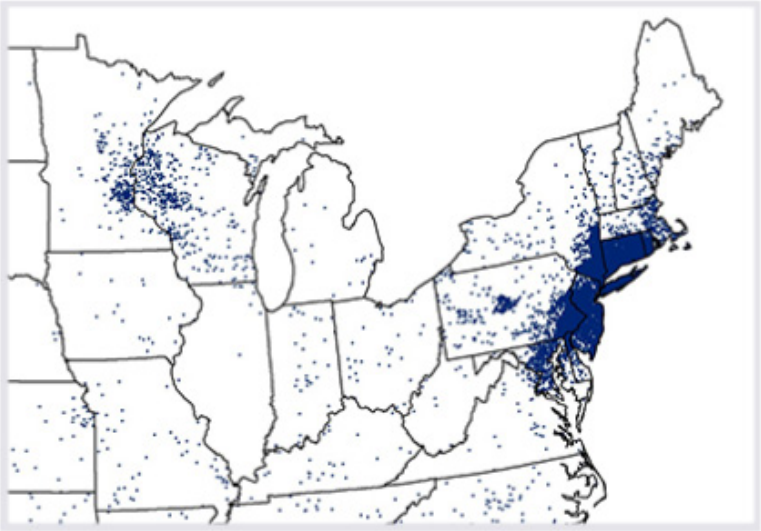


Regions in the US that experienced blooming by the end of Jan (left) and Feb (right) 2017

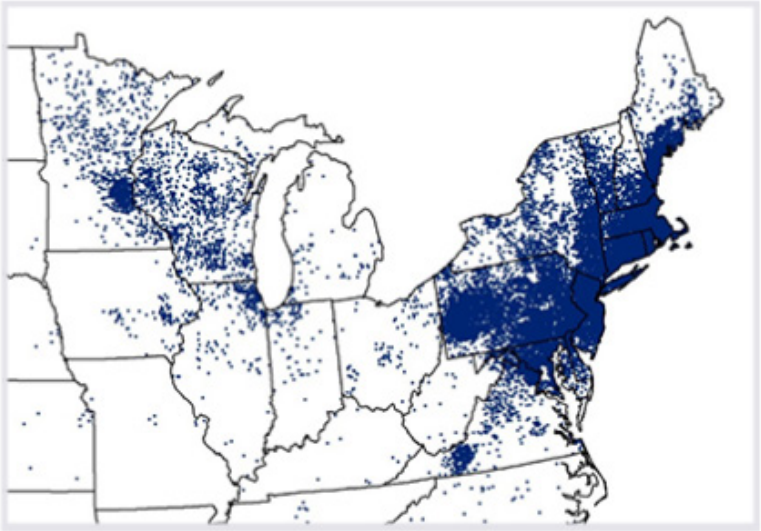
https://www.nytimes.com/interactive/2017/03/08/climate/early-spring.html

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

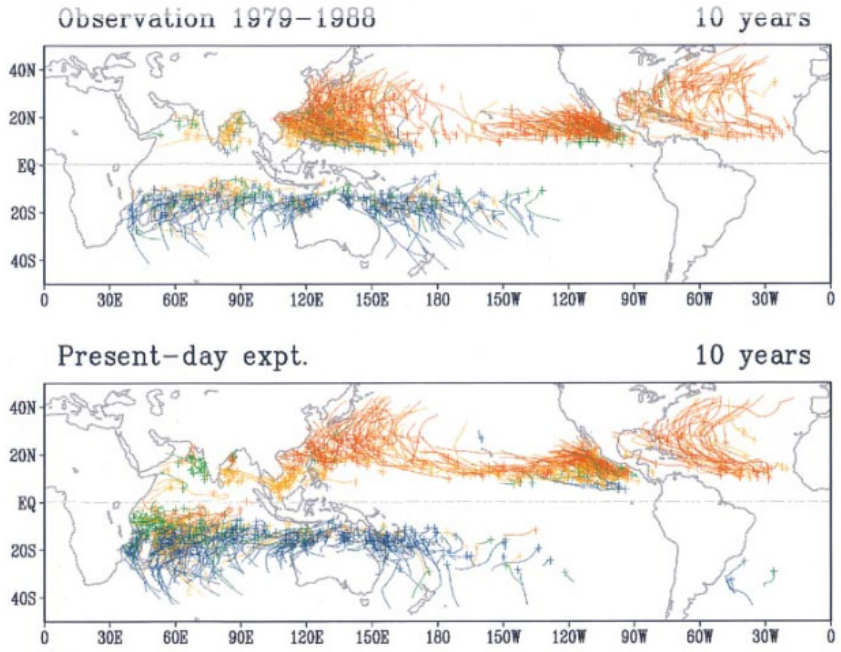
Distribution of reported cases of Lyme disease in 1996 and 2014. Each dot represents an individual case placed according to the patient's county of residence, which may be different than the county of exposure. Maps focus on the parts of the United States where Lyme disease is most common. (EPA)

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***



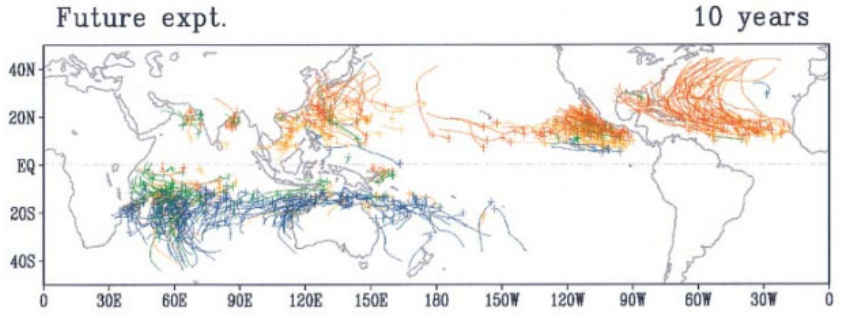


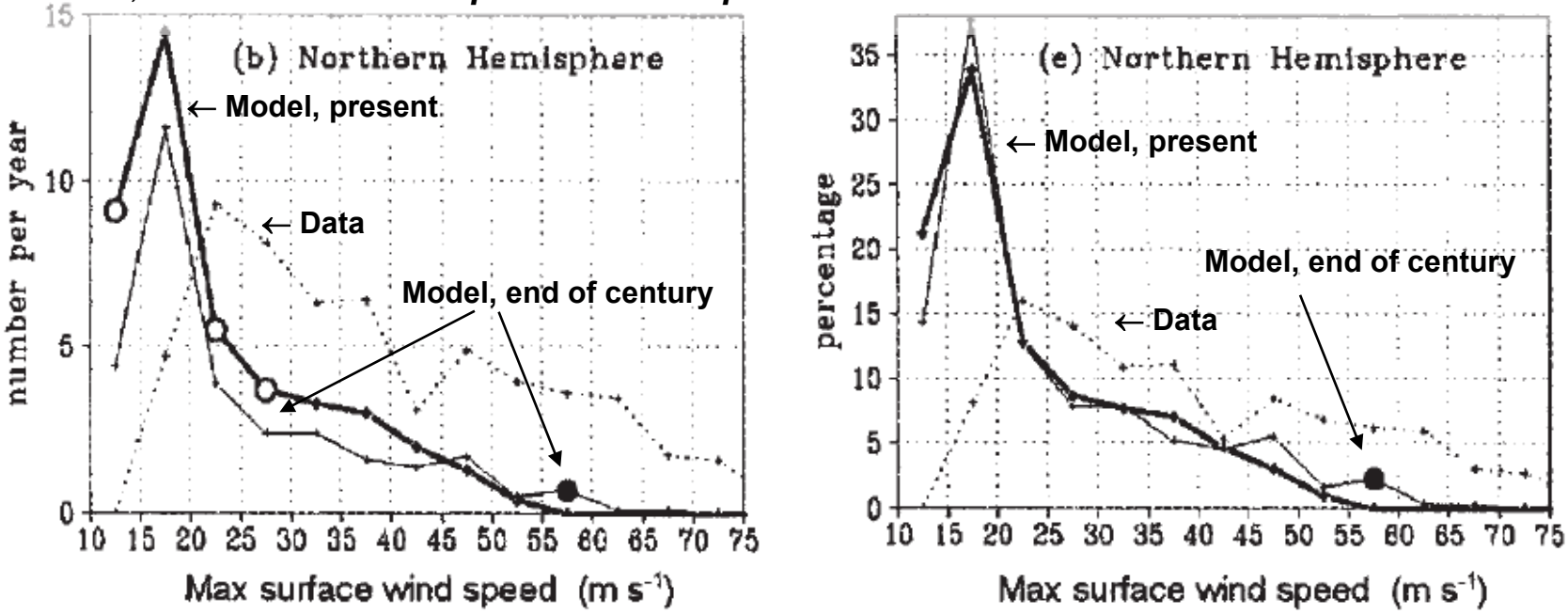
Fig. 2. Tropical cyclone tracks of the observational data (top), the present-day (middle), and the future climate experiments (bottom). The initial positions of tropical cyclones are marked with "plus" signs. The tracks detected at different seasons of each year is in different colors (blue for January, 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***



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

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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 ...

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Consequences of Climate Change

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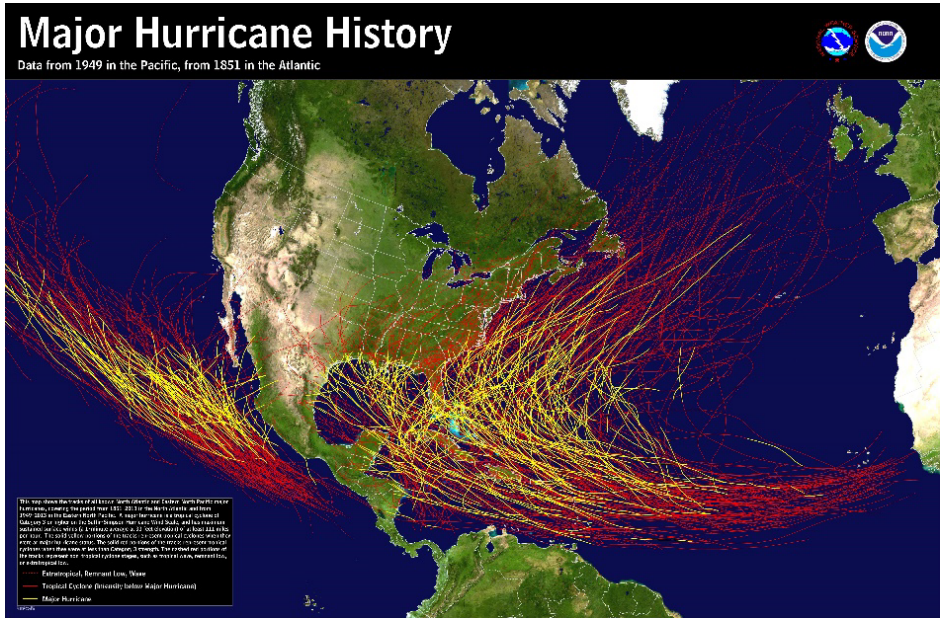
Confounding factor:



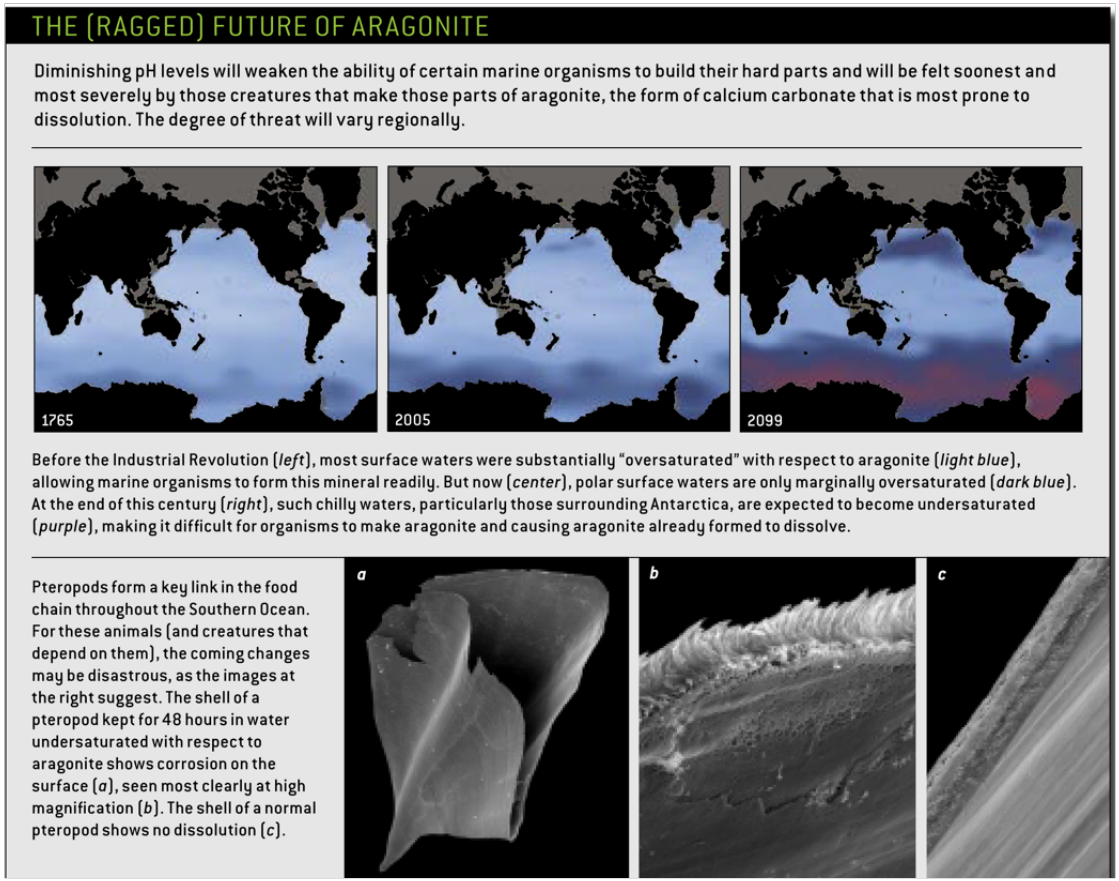
http://www.c2es.org/science-impacts/extreme-weather/hurricanes

Consequences of Climate Change

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

Future ocean uptake of atmospheric CO_2 will lead to ***ocean acidification***

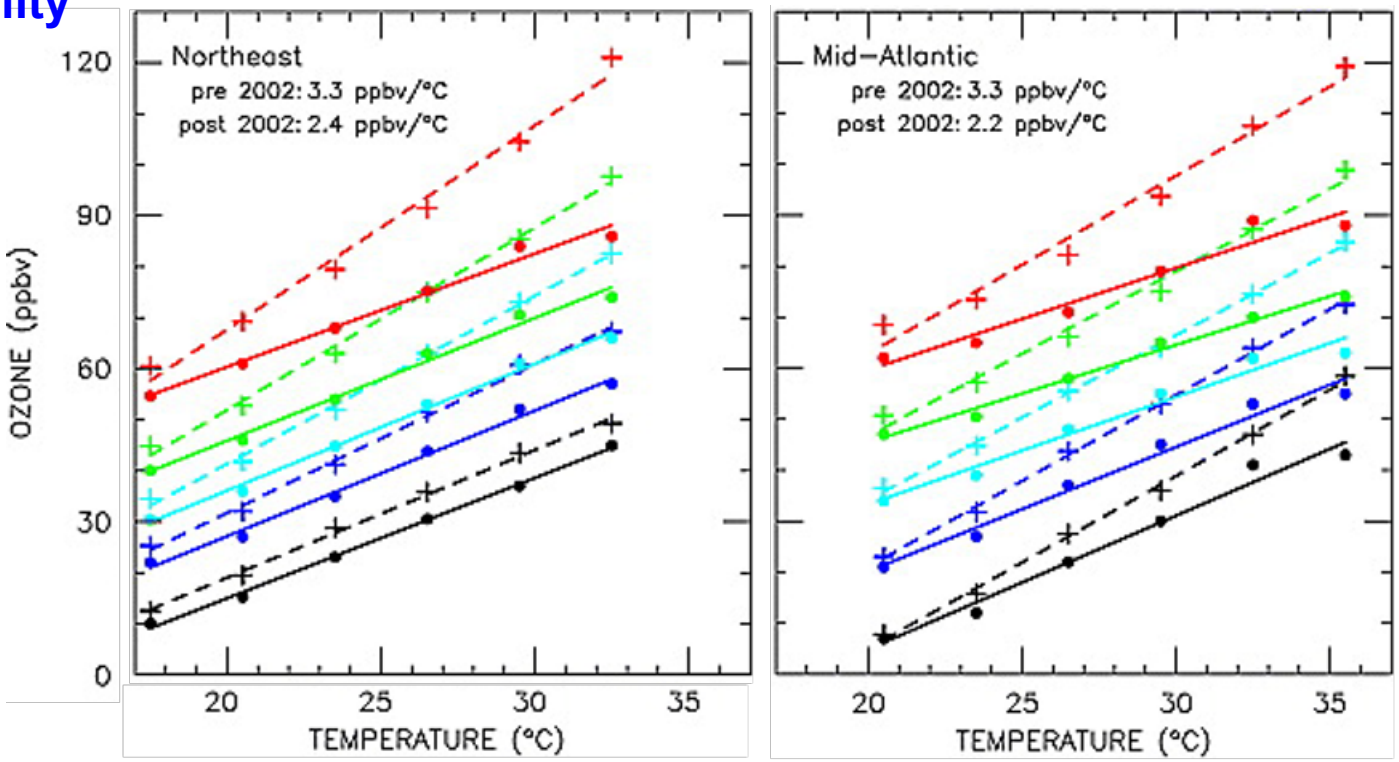
Bad news for ocean dwelling organisms that precipitate shells (basic materials)



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

Consequences of Climate Change

6a. Air Quality



Ozone (y-axs) vs. temperature (x-axis) for the 5th, 25th, 50th, 75th and 95th percentiles of the ozone distributions, in each temperature bin, before and after 2002. Dashed lines and + symbols are for a linear fit of ozone to the pre-2002 data; solid lines • symbols are for post-2002. Color and position correspond to percentile (on top in red are 95th, next pair down in green is 75th, light-blue is 50th, dark blue is 25th, and the bottom pair in black are the 5th percentile values). The slopes given on each panel indicate the **climate penalty factor**.

Observed relationships of ozone air pollution with temperature and emissions

BJ **Bloomer**, JW Stehr, CA Piety… - Geophysical …, 2009 - Wiley Online Library

… [17] We define the **climate penalty** factor as the slope of ozone versus temperature. This factor…

The **climate penalty** factor is remarkably similar across the Great Lakes, Northeast and Mid-…

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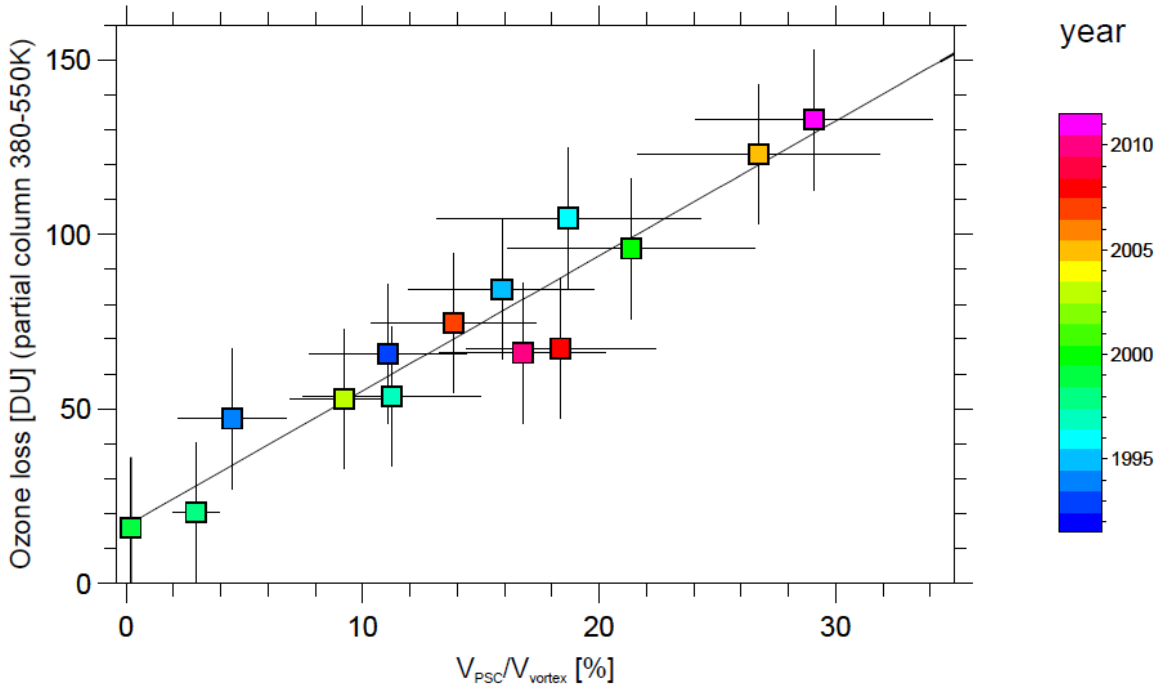
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009GL037308

Consequences of Climate Change

6b. Stratospheric, Arctic Ozone Loss



Relation of chemical loss of Arctic ozone (y-axis) and the volume of the NH vortex circulation cold enough to support the variation of polar stratospheric clouds (V_{PSC}) (x-axis). Updated from Rex et al. (2004). The surprisingly simple relationship between chemical loss of stratospheric ozone in the Arctic and the volume of air exposed to PSC temperature shows additional loss of 15 Dobson Units of ozone occurs per degree Kelvin cooling of the Arctic stratosphere.

Arctic ozone loss and climate change

M Rex, RJ Salawitch, P von der Gathen... - Geophysical ..., 2004 - Wiley Online Library

... **climate** conditions became significantly more favorable for large **Arctic ozone losses** over the

... Severe **Arctic ozone loss** during the past decade occurred as a result of the combined effect ...

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https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2003GL018844

Consequences of Climate Change

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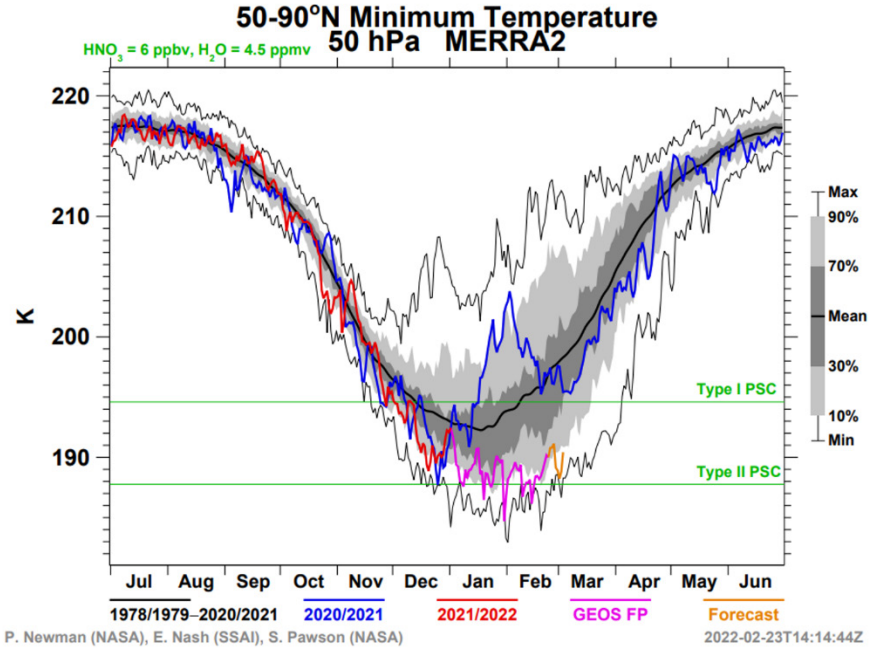
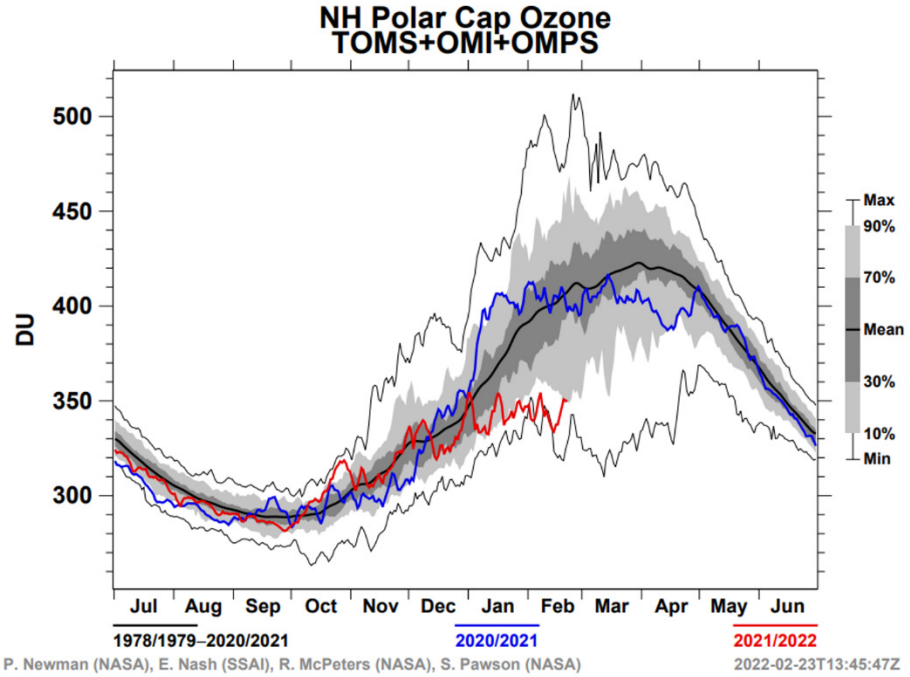
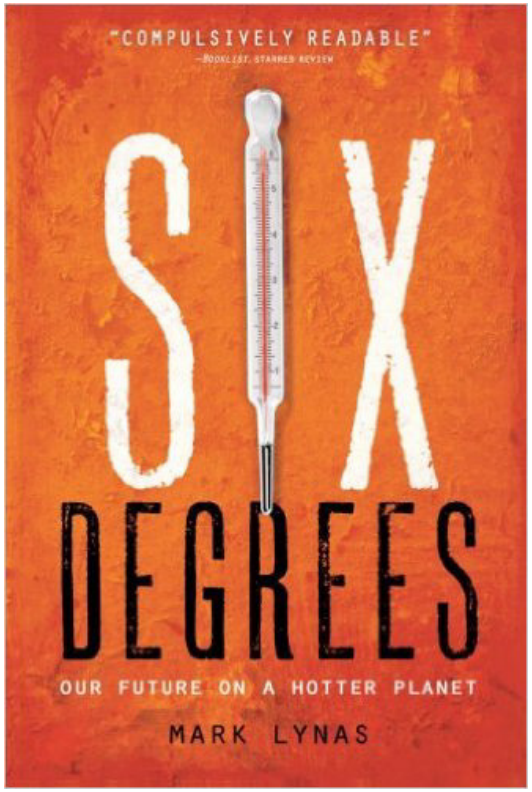




https://ozonewatch.gsfc.nasa.gov/meteorology/figures/merra2/temperature/tminn_50_2021_merra2.pdf
https://ozonewatch.gsfc.nasa.gov/meteorology/figures/ozone/to3capn_2021_toms+omi+omps.pdf

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% or 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