Effects of Climate Change

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2020
https://myelms.umd.edu/courses/1291919

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

1 October 2020

Announcements: Class

AOSC CHEM 433 & 633: 30 Sept Update <--- edit to Question 1 of Problem Set 2, take two

Ross Salawitch

All Sections

Sep 30 at 6:19pm

Hi Everyone,

Sorry for the confusion, which I will review at the start of class tomorrow.

I got confused about Q1 of P Set 2 and replied too quickly.

You still have until 3 Oct at 5 pm to complete the problem.

I think it is best if students can compute the mass of atmospheric **Carbon** in CO_2 as originally specified in part a); I have made some light edits to the original question to be clear we are after the amount of **Carbon** in the increasing atmospheric burden of CO_2, in units of Gt C.

For part b), after further thought, no change to the original instructions. The graph shows emissions of carbon in units of Gt C. You are asked to analyze this graph, in the same manner as in the original instructions, to arrive at the total cumulative emissions of **Carbon**, again in units of Gt C.

Sorry for my confusing prior message, which should be ignored.

Again, I'll discuss in class tomorrow and you'll have an extra day to complete.

Cheers,

Ross

Announcements: Class

Hi _____,

The formula is a complicated mess. You will get nearly the same value if you handle Mo and No as stated in the footnote, versus using pre-industrial values at all time for Mo and No, so either approach is fine. Please note that when evaluating the RF for CH4, Mo must be pre-industrial CH4 in all terms, and when evaluating RF for N2O, No must be pre-industrial N2O for all terms. The footnote introduces a nuance for which value of N2O to use for the No term of CH4, and which value of CH4 to use for the Mo term of N2O. Since you should get nearly the same answer either following the details of the footnote, or always using pre-industrial CH4 for Mo and pre-industrial N2O for No, either are acceptable.

Believe it or not, IPCC has gone back and forth over the years about which method is preferred.

Cheers,
Ross

> On 10/1/2020 12:19 PM,____ wrote:
>
> Hi Ross,
>
> I hope you are doing well. I have a question regarding the image below. The notes at the bottom of the equation states that N_0 and M_0 should refer to present day N20 and CH4. This goes against convention, especially because for CO2, C_0 represents the abundance at 1900 and C represents abundance at 2011. Am I misunderstanding the notes or is it actually meant that for N_0 and M_0 should be the abundance at 1900 and M and N are abundance at 2011?
>
> Best,
>
> _____

Table 8.SM.1 | Supplementary for Table 8.3: RF formulae for CO_2, CH_4 and N_2O.

Gas	RF (in W m^{-2})	Constant α
CO_2	$\Delta F = \alpha \ln(C/C_0)$	5.35
CH_4	$\Delta F = \alpha\left(\sqrt{M}-\sqrt{M_0}\right)-\left(f(M,N_0)-f(M_0,N_0)\right)$	0.036
N_2O	$\Delta F = \alpha\left(\sqrt{N}-\sqrt{N_0}\right)-\left(f(M_0,N)-f(M_0,N_0)\right)$	0.12

Notes:

$f(M, N) = 0.47 \ln[1+2.01\times10^{-5}(MN)^{0.75} + 5.31\times10^{-15} M (MN)^{1.52}]$

C is CO_2 in ppm.

M is CH_4 in ppb.

N is N_2O in ppb.

The subscript 0 denotes the unperturbed molar fraction for the species being evaluated. However, note that for the CH_4 forcing N_0 should refer to present-day N_2O, and for the N_2O forcing M_0 should refer to present-day CH_4.

Announcements: Class

No AT for Thursday, so that you can focus on the Problem Set. Also, the first exam which will be on-line, open book, open web, that I hope you will take on 8 Oct (you'll have 75 mins time to take either 7 Oct, 8 Oct, or 9 Oct) will cover material up to Lecture 8 (today's lecture). Next Tuesday's class will focus on the exam. However, please note that:

a) the exam will focus on a series of questions, about one per lecture, that you can only answer properly in the limited time IF you are already familiar with the contents of each lecture;

b) there will be no calculations on the exam so, in this sense, the exam will be qualitative rather than quantitative

c) if you have been doing all of the readings, answering the ATs based on a comprehensive understanding of the readings, and retaining knowledge from the readings and exams, as solidified by consistently high scores of the learning out come quizzes, then you'll be in great shape for the first exam. On the other hand, if you have been skimming the readings, doing the bare minimum to answer the ATs, and not completing the learning outcome quizzes, you will need to impart greater effort to prepare for the exam, in order to do well. The exam will open more than a week from this moment in time ... so there is still time to prepare.

I will not dwell on the exam this Thurs, but rather, will let this class announcement stand as my "word" about the exam, until the class review on Tues, 6 Oct. I will only answer this Thurs direct questions about anything written here that seems confusing or unclear, so that I have time to cover the effects of climate change material.

All the best,

Ross

Announcements: Outside of Class

1) Today, 1 Oct : AOSC Weekly Seminar (3:30 pm)

Dr. Erik van Sebille, Utrecht University

Chasing Water: How ocean currents transport plastic & plankton around the globe

The ocean is in constant motion, with water circulating within and flowing between basins. As the water moves around, it carries heat and nutrients, as well as planktonic organisms and plastic litter around the globe.

The most natural way to study the pathways of water and the connections between ocean basins is using particle trajectories. The trajectories can come from either computing of virtual floats in high-resolution ocean models.

In this seminar, I'll give an overview of some recent work with Lagrangian particles. I will introduce our new open-source oceanparcels.org framework. I will show applications to marine microbiology and ecology, palaeoclimatology and plastic pollution. Central to each of these studies is the question on how connected the different ocean basins are, and on what time scales water flows between the different regions of the ocean.

https://aosc.umd.edu/seminars/department-seminar

Email Joseph Knisely at jknisely@umd.edu for Zoom connection info

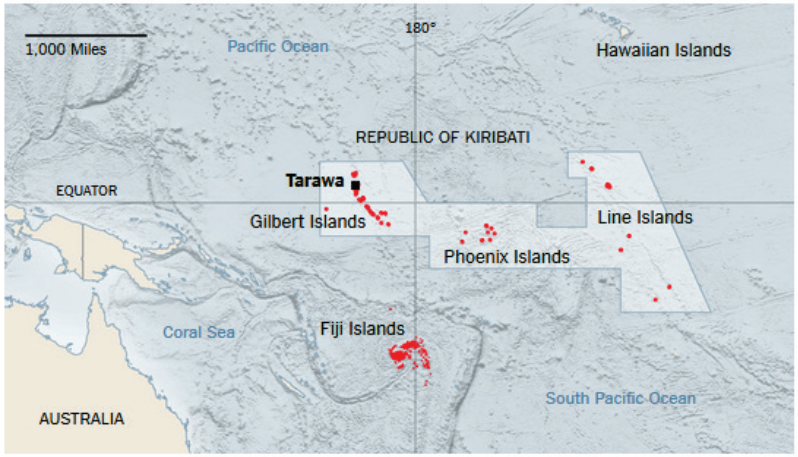
Kiribati

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

Jakarta

The Jakarta Post

NEWS > CITY

Jakarta braces for flooding as rainy season approaches, La Niña looms

Ivany Atina Arbi and Kharishar Kahfi
The Jakarta Post

Jakarta / Wed, September 30, 2020 / 05:21 pm

Two people ride bicycles through the rain on Jl. Merdeka Selatan in Central Jakarta on June 9. (Antara/Wahyu Putro)

Jakarta Governor Anies Baswedan has urged stakeholders to prepare for potentially hazardous flooding in the capital as the rainy season approaches. The season's dangers are compounded this year by La Niña, a periodic weather phenomenon that tends to cause extreme weather in the Indonesian archipelago.

"We need to be ready because we're facing not just the flooding but also the COVID-19 outbreak. This condition requires special care," the governor said during a ceremony to prepare for the rainy season in Jakarta on Wednesday morning.

He said disaster mitigation efforts should adhere to strict health protocols to prevent the spread of COVID-19 during evacuations.

"We need to set up more [flood shelter] tents to allow citizens to practice health protocols and physical distancing," Anies added.

La Niña is a meteorological phenomenon where surface water temperatures in the equatorial band of the Pacific Ocean become abnormally low. It is believed to occur every two to seven years and brings heavy rainfall to the Indonesian archipelago, which tends to trigger natural disasters such as floods and landslides.

https://www.thejakartapost.com/news/2020/09/30/jakarta-braces-for-flooding-as-rainy-season-approaches-la-nia-looms.html

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.

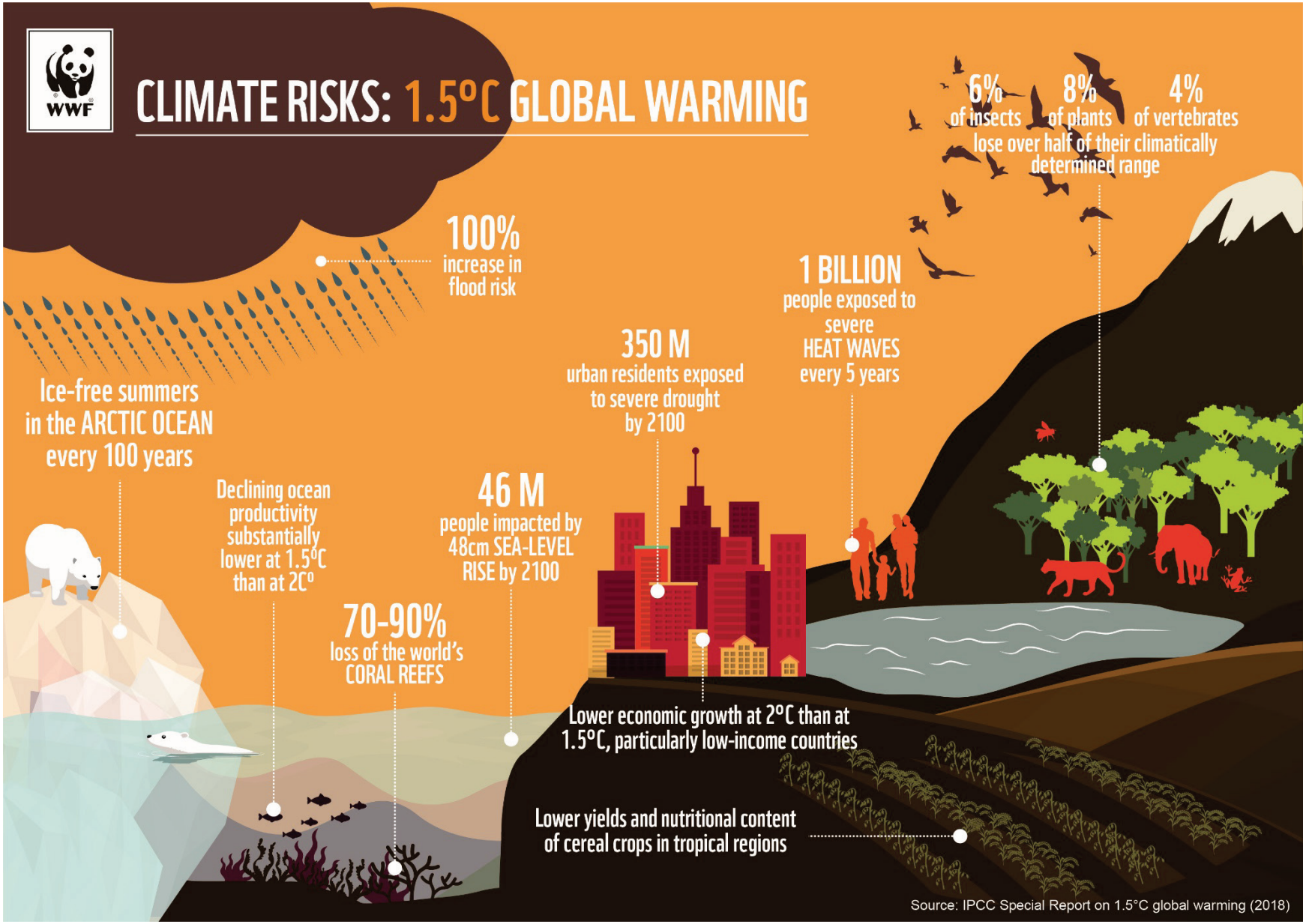
It's not clear exactly when this will happen, or where the new capital would be located. The idea has been out there for decades, though previous leaders have been unable to accomplish the ambitious plan.

"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.

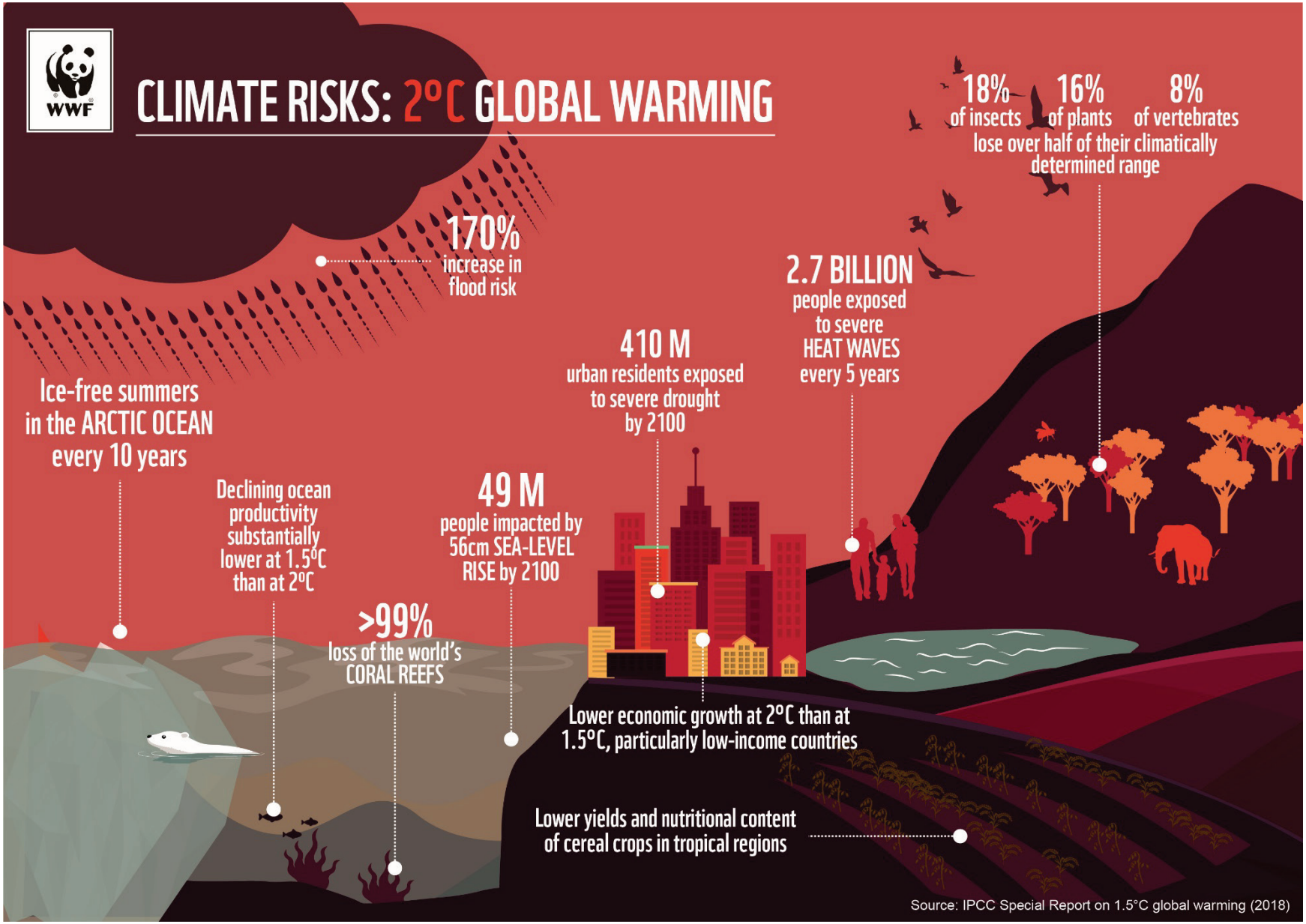
Jakarta faces massive challenges. As the BBC has reported, it's the fastest-sinking city in the world, with almost half of its area below sea level.

"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



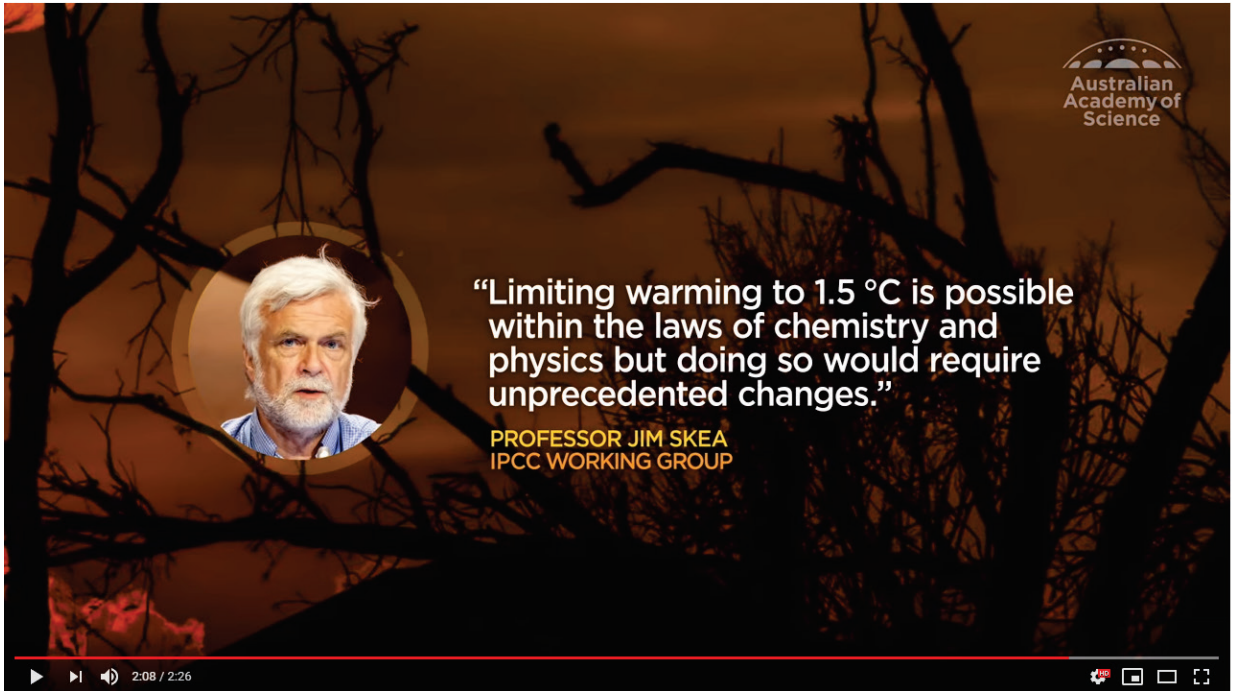
https://wwf.panda.org/our_work/climate_and_energy/cop24/



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

Possible Impacts of Climate Change

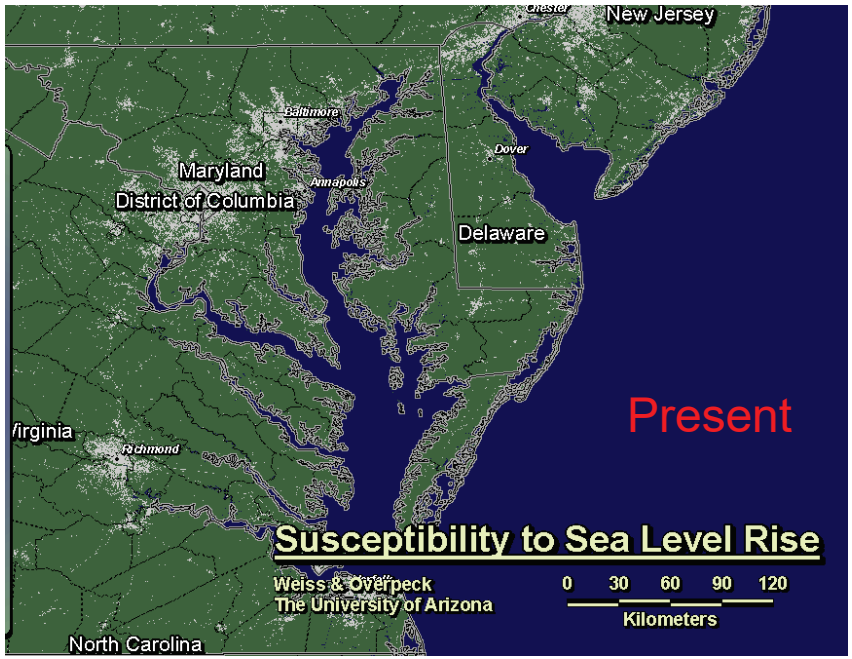
- **1°C (already committed to this)**
  - Loss of glacial waters in Africa & Asia, with regional declines in food production
  - Tropical islands such as Tuvalu, Kiribati, Marshall Islands, and Maldives severely threatened
- **2°C (Paris Climate Agreement Upper Limit)**
  - Polar bear habitat under severe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



Maryland:

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

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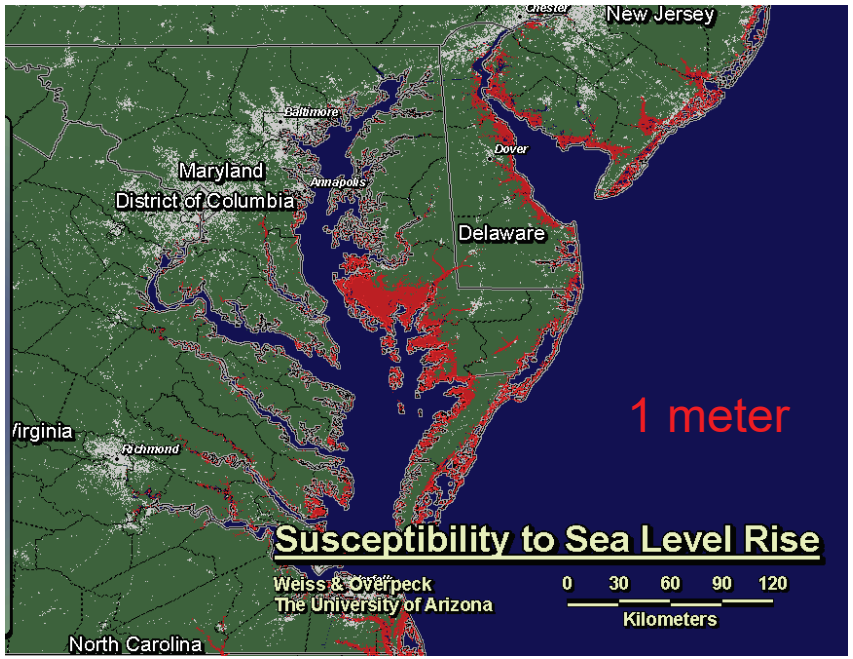

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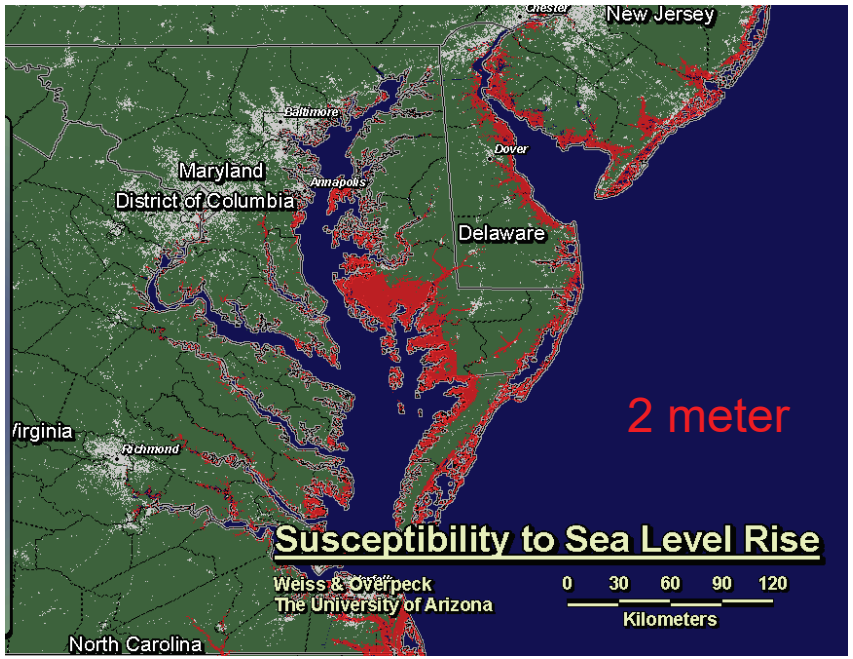

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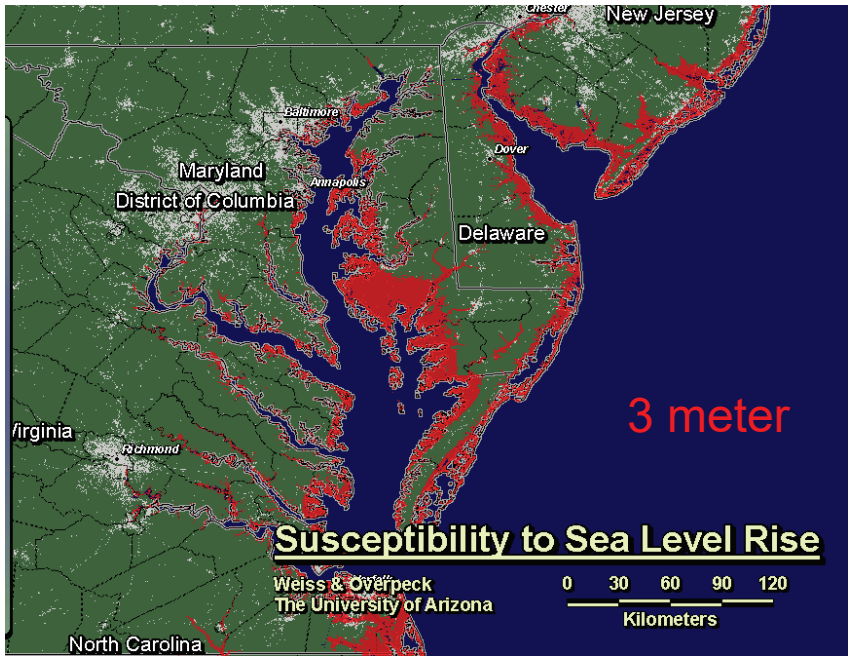

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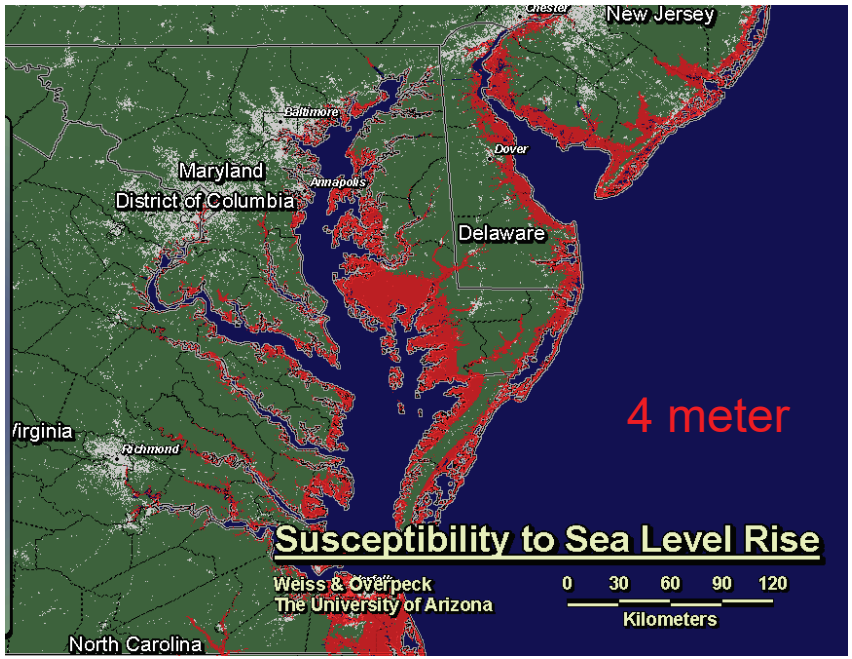

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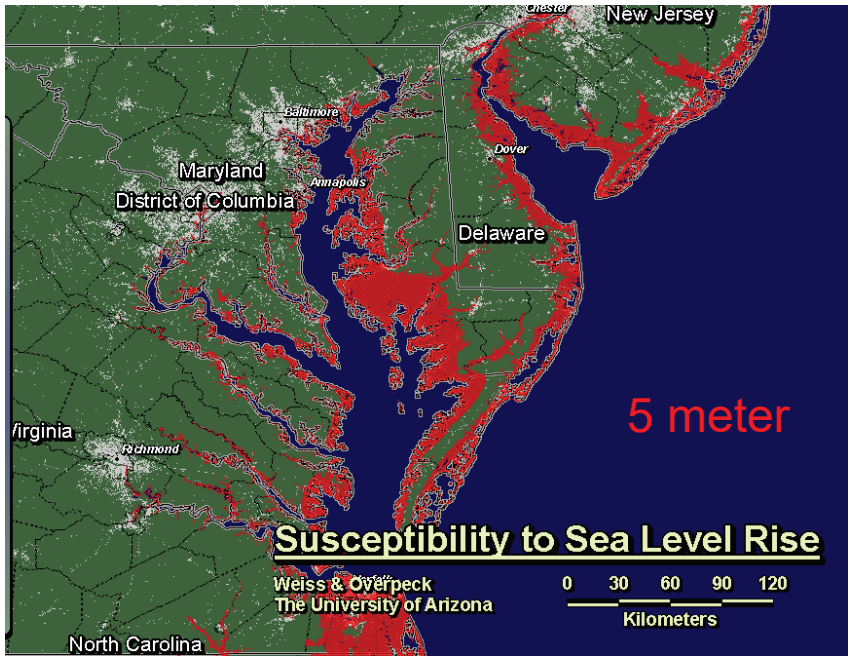

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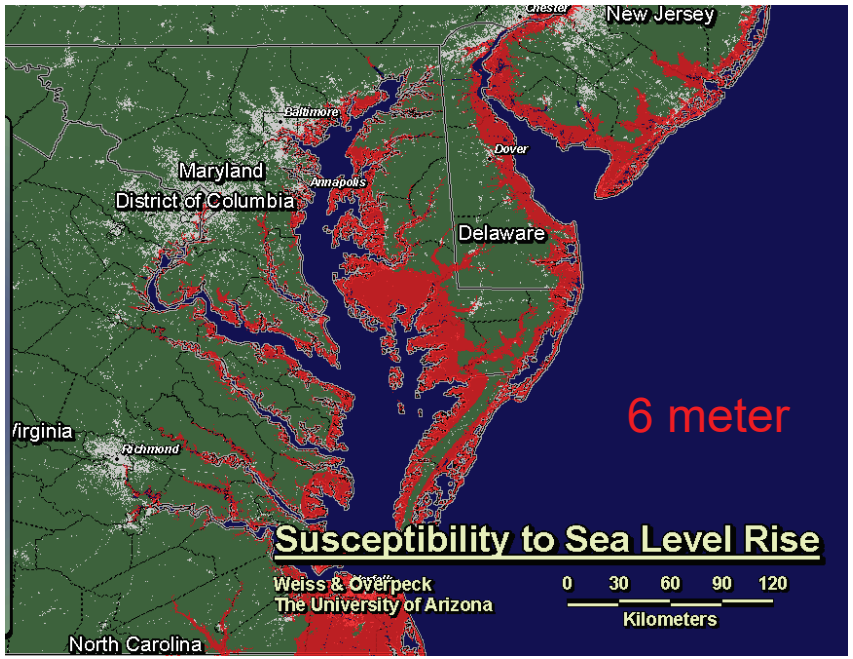

Maryland:

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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.

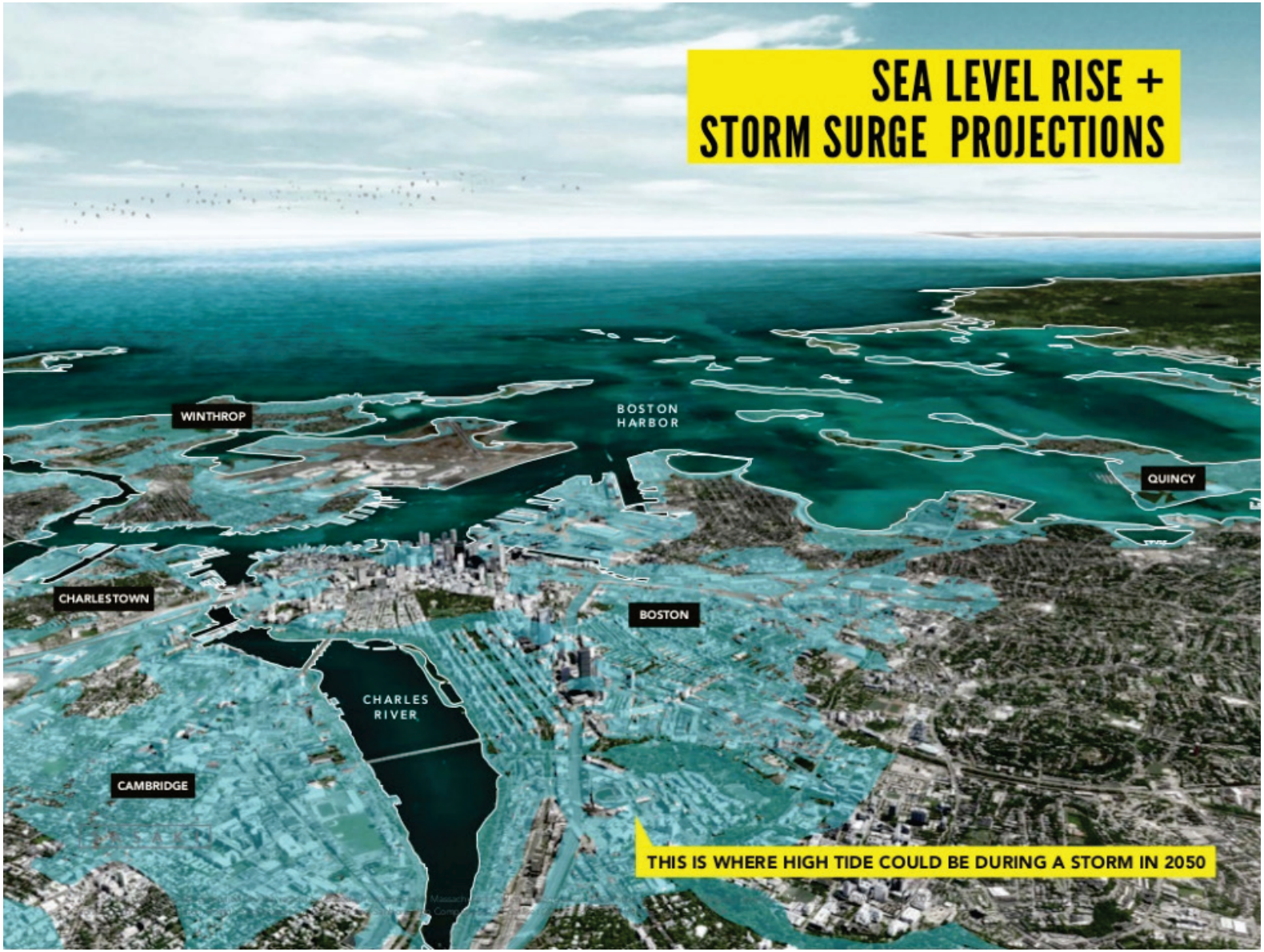
https://www.washingtonpost.com/national/health-science/vulnerable-maryland-weighs-threat-of-sea-level-rise/2013/07/21/37201d50-efe9-11e2-bed3-b9b6fe264871_story.html

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

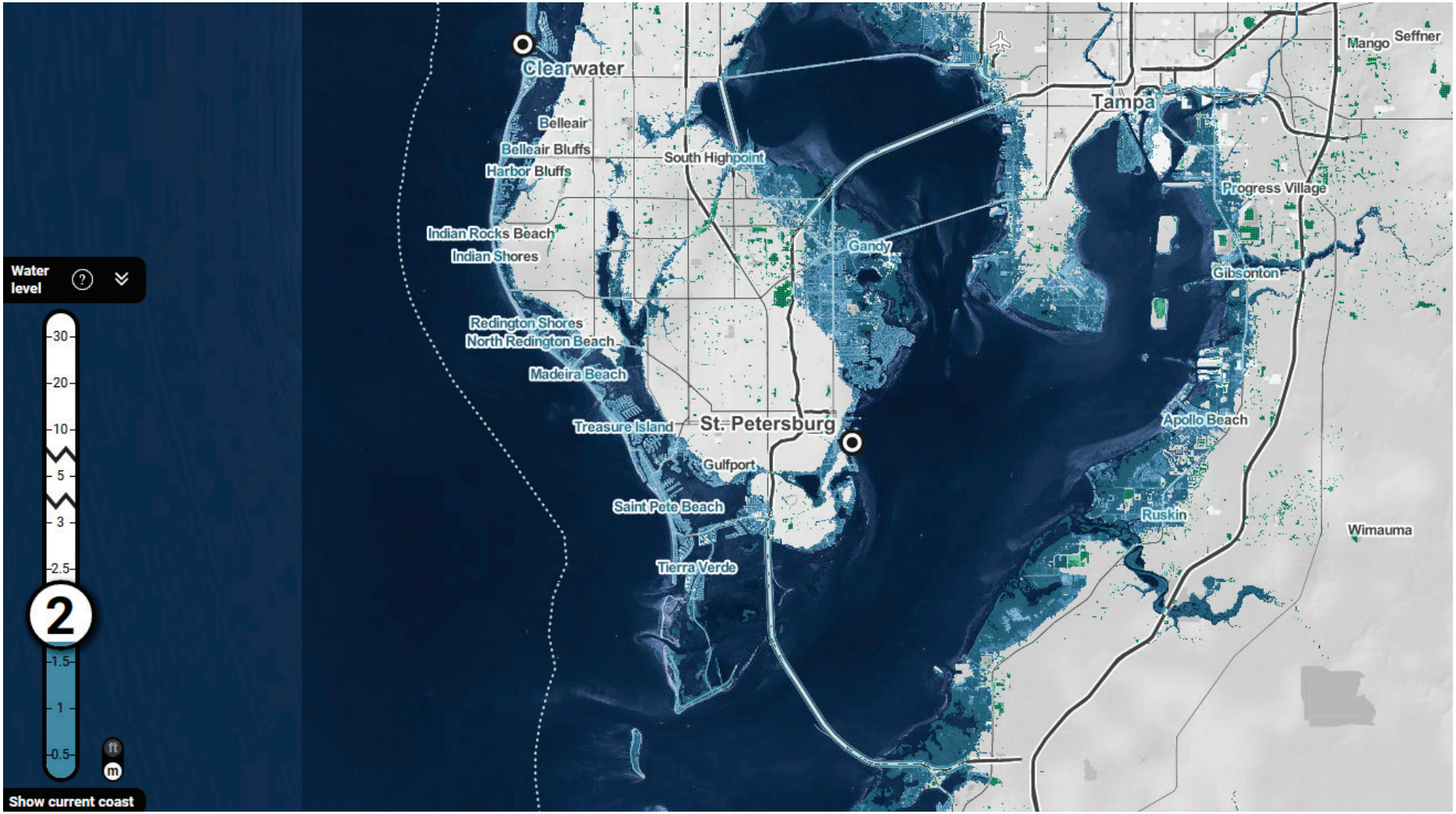
Toronto one of the top cities to feel climate change impacts by 2050: report

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

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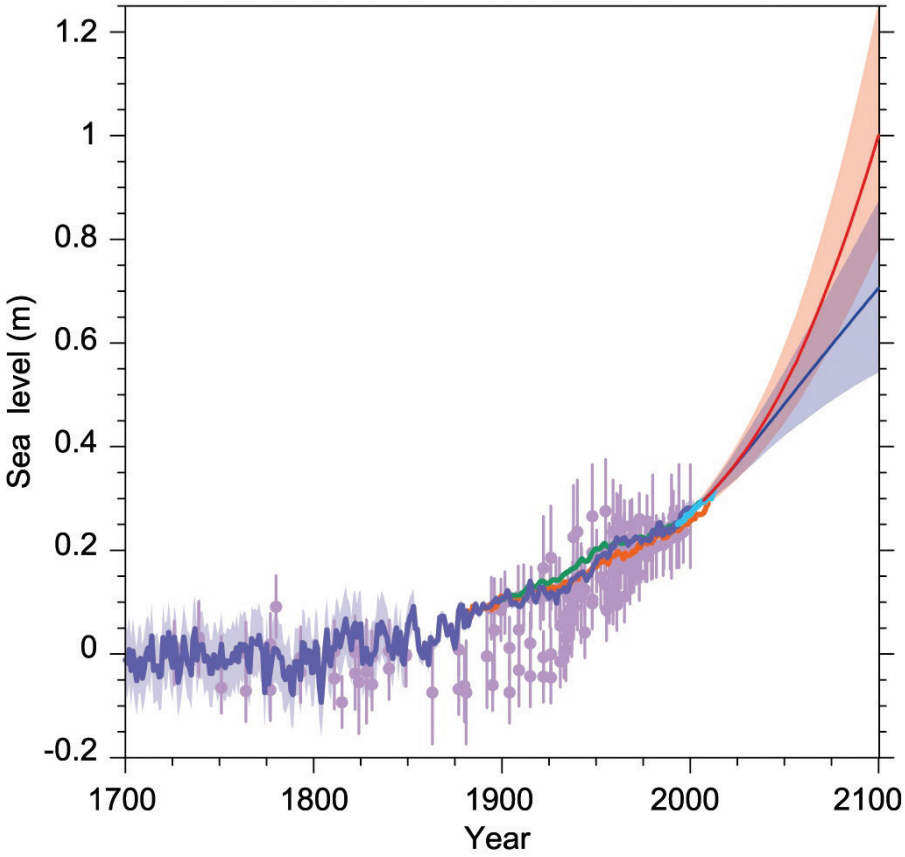

Compilation of paleo sea level data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and likely ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all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

IPCC (2013)

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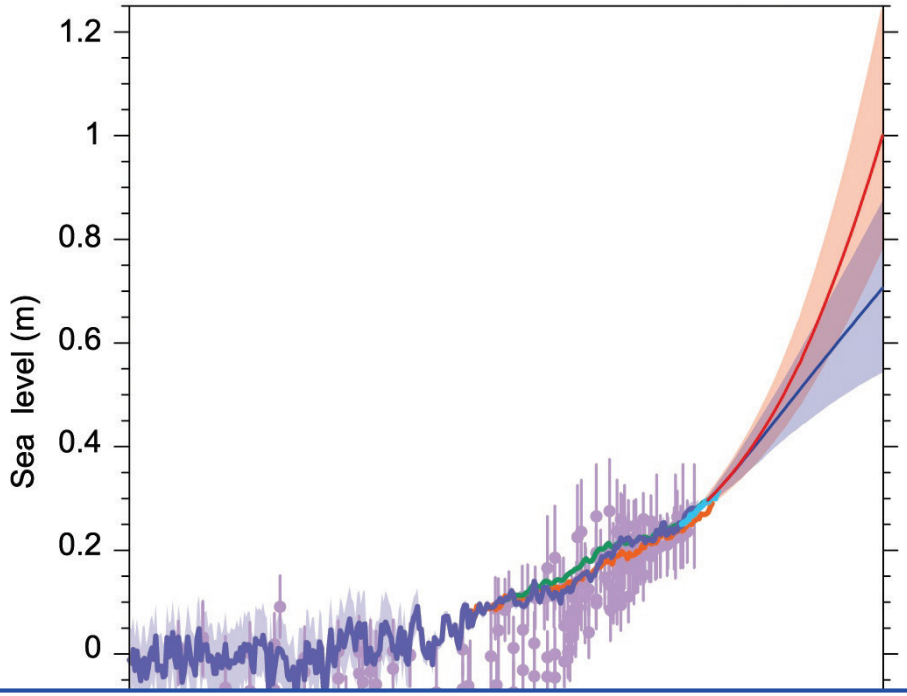

1 meter =

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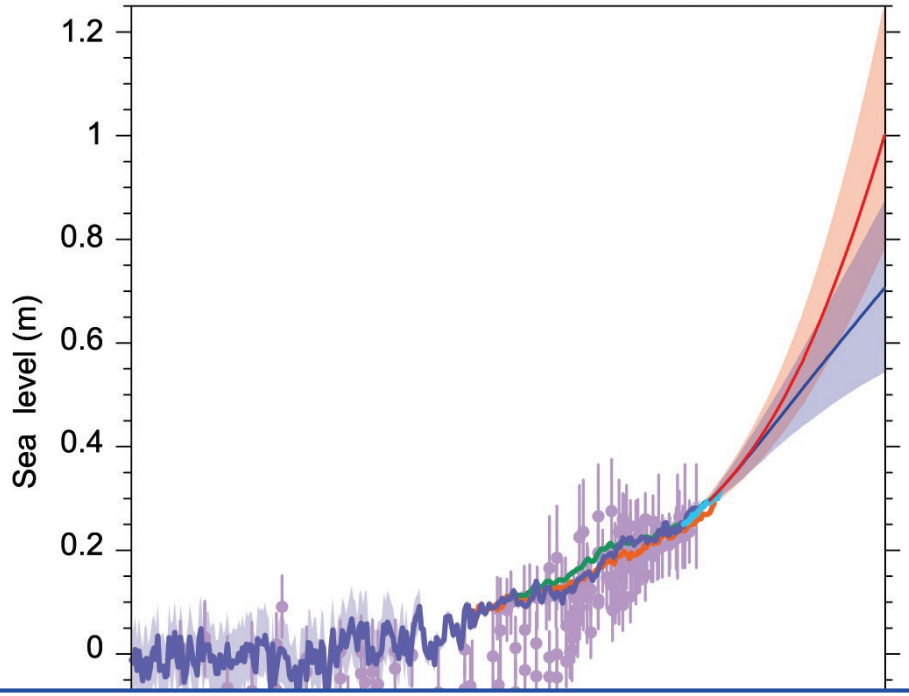

1 meter = 3.2 feet

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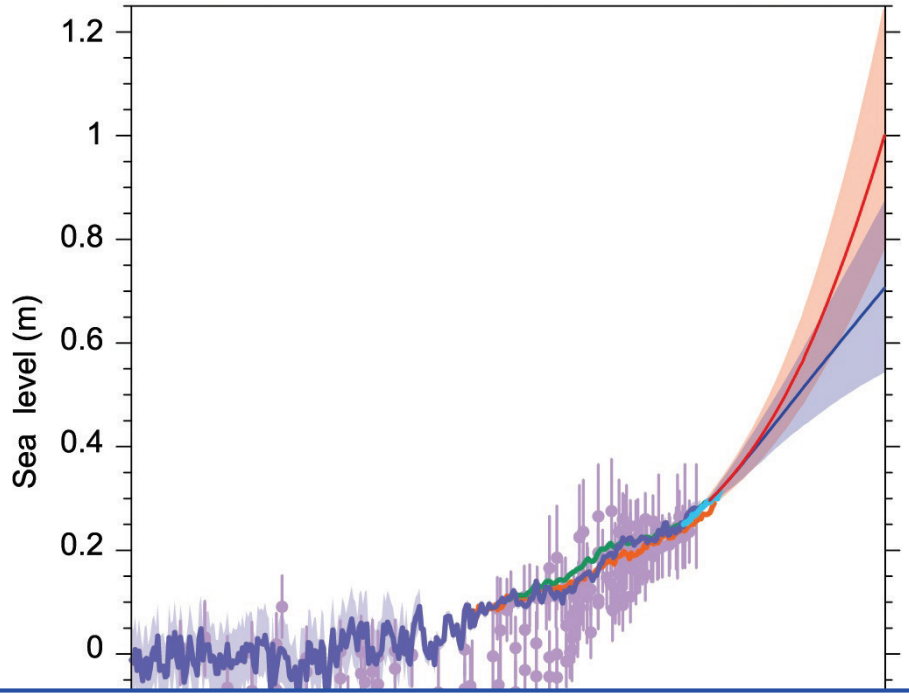

1 meter = 3.2 feet

If all of Greenland were to melt, SLR would be

Consequences of Climate Change

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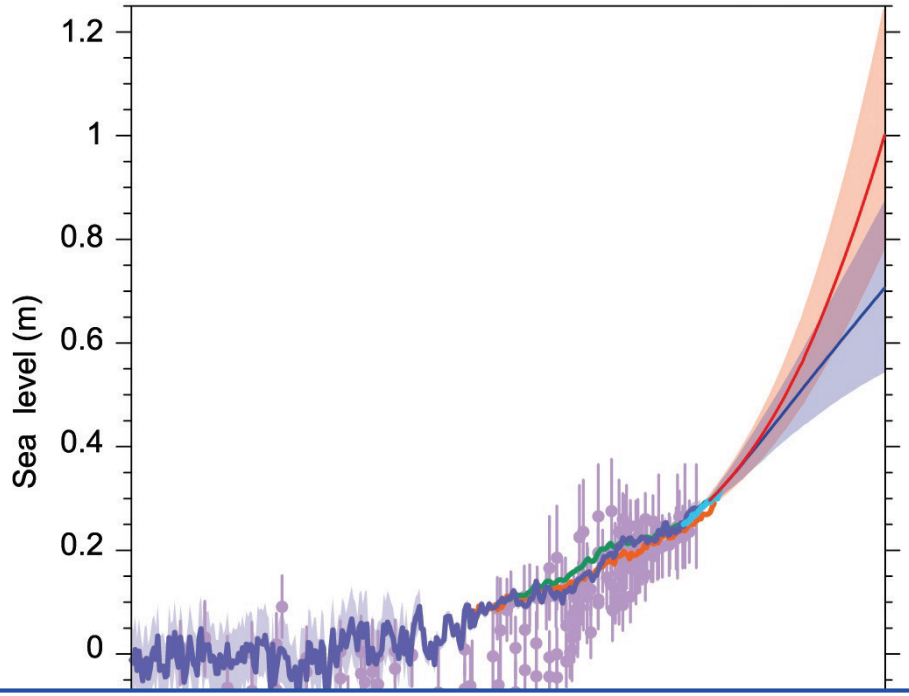

1 meter = 3.2 feet

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

Consequences of Climate Change

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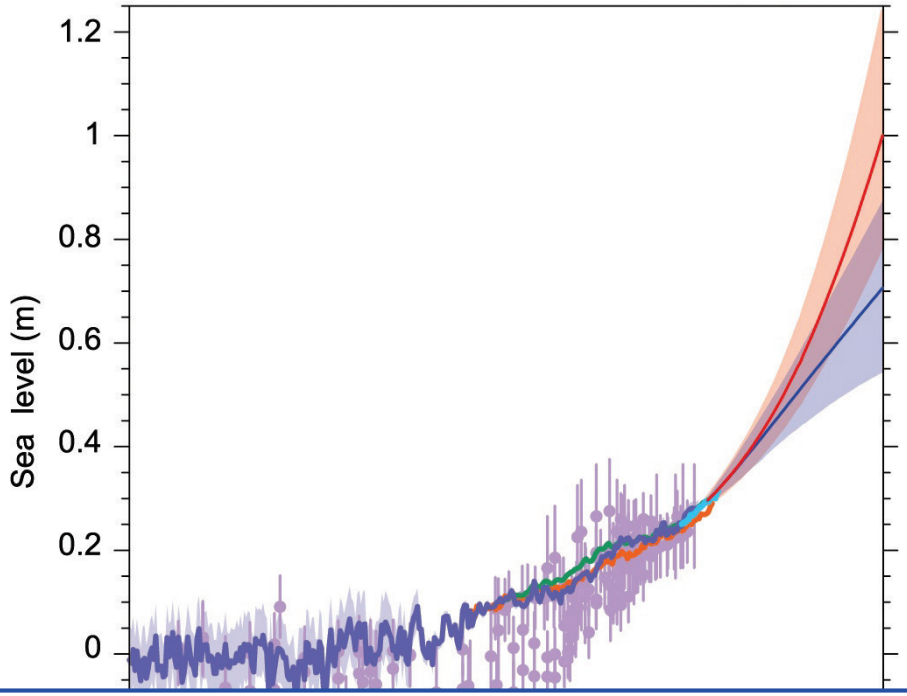

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If all of Greenland were to melt, SLR would be ~23 feet (7 meters)

If all of Antarctica were to melt, SLR would be

Consequences of Climate Change

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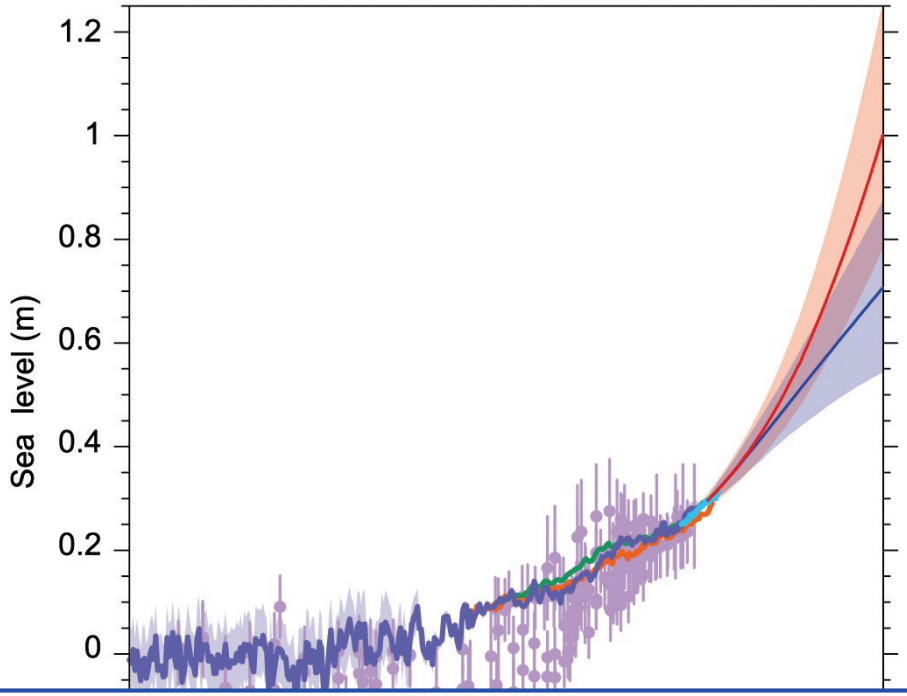


1 meter = 3.2 feet

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

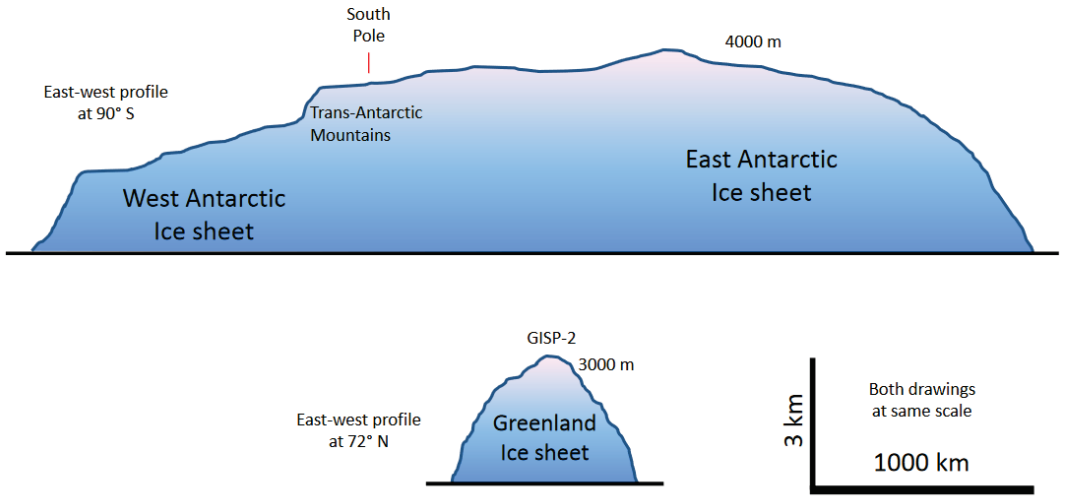
If all of Antarctica were to melt, SLR would be ~200 feet (60 meters)

Volume of Antarctic and **Greenland** Ice Sheets

Volume of Antarctic Ice Sheet ~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.

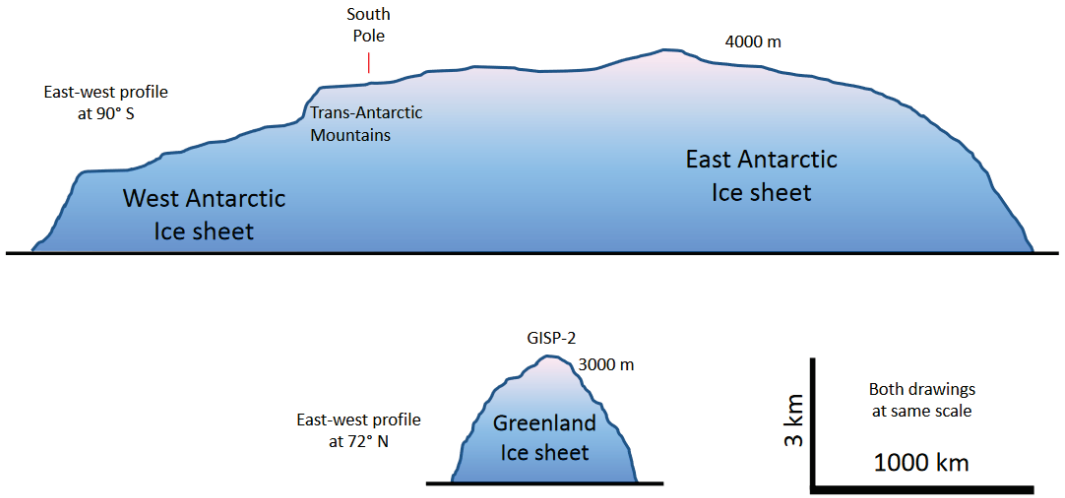
The complete collapse of Greenland would lead to sea-level rise of
2.85×10^6 km^3 / 357×10^6 km^2 = 8 meters according to these numbers.
Since more area would be covered by water following the collapse,
the actual rise in sea level is closer to 7 meters … or **23 feet**!

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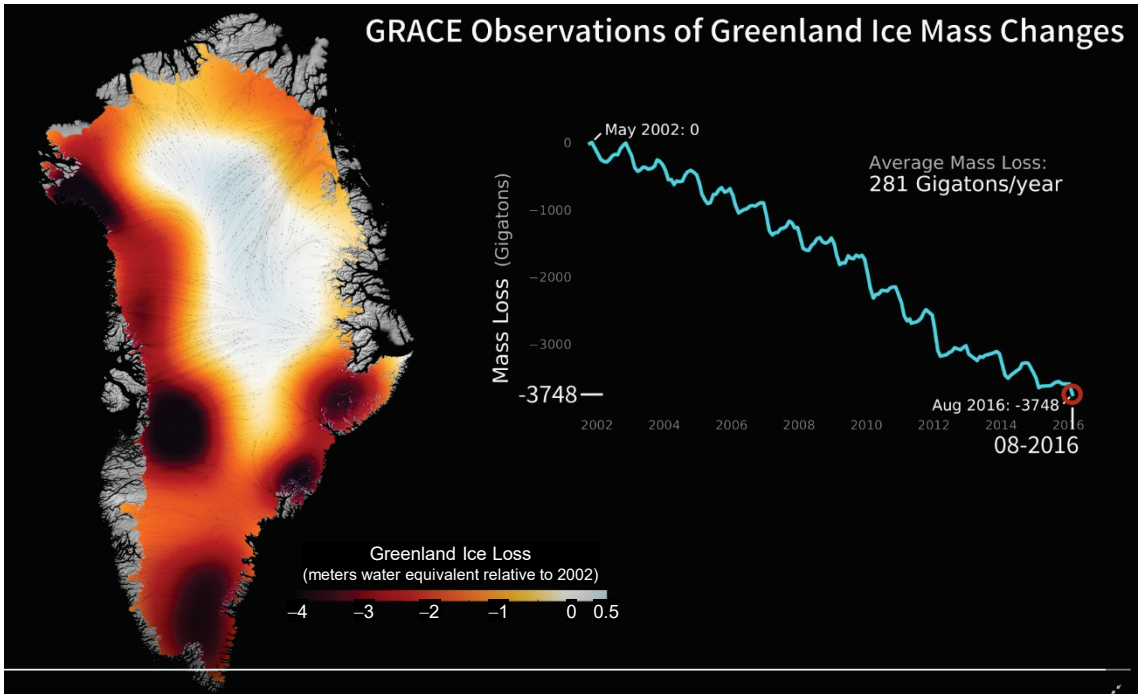
Radius of Earth = 6371 km; Surface area of Earth = 510 × 10^6 km^2
70% of earth, or 357 × 10^6 km^2 is covered by water.

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**!!!!!!!!

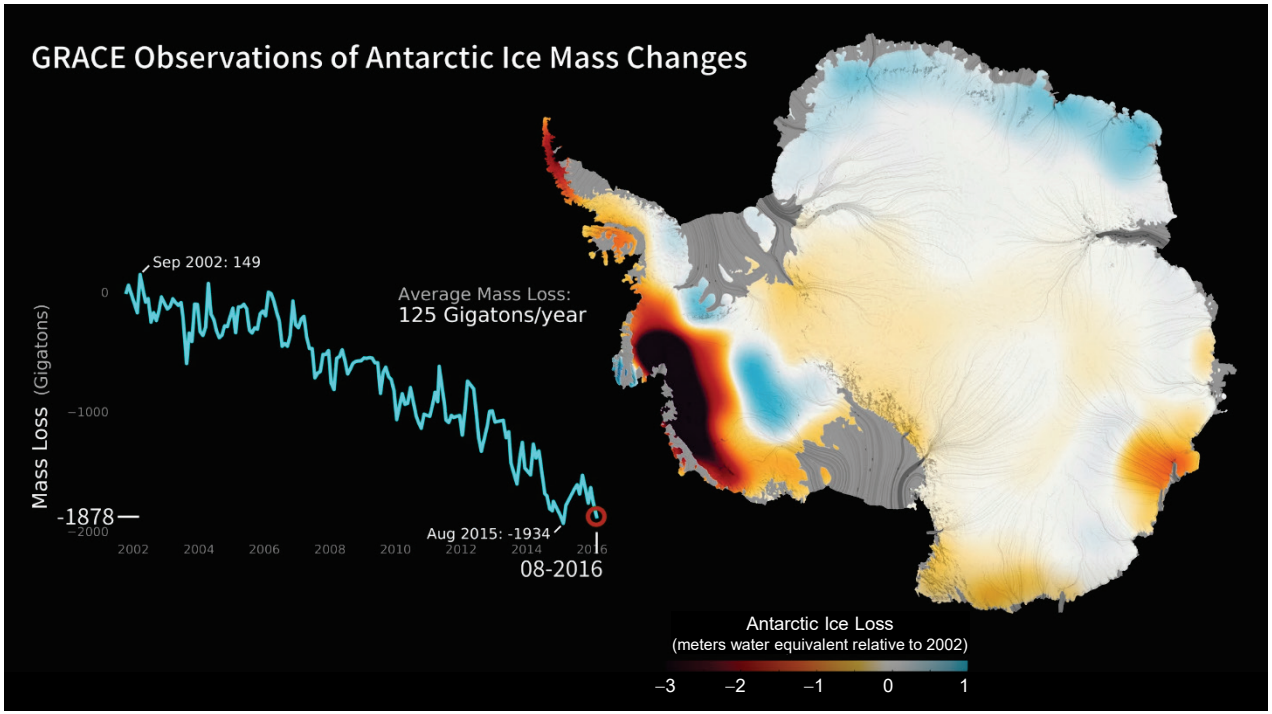
Greenland Ice Mass



Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~280 gigatons of ice per year from Greenland, causing global sea level to rise by a total of 0.4 inches between 2002 and 2016 (or 0.03 inches per year)

https://gracefo.jpl.nasa.gov/resources/33/greenland-ice-loss-2002-2016

Antarctica Ice Mass



Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~125 gigatons of ice per year from Antarctica, causing global sea level to rise by a total of 0.18 inches between 2002 and 2016 (or 0.014 inches per year)

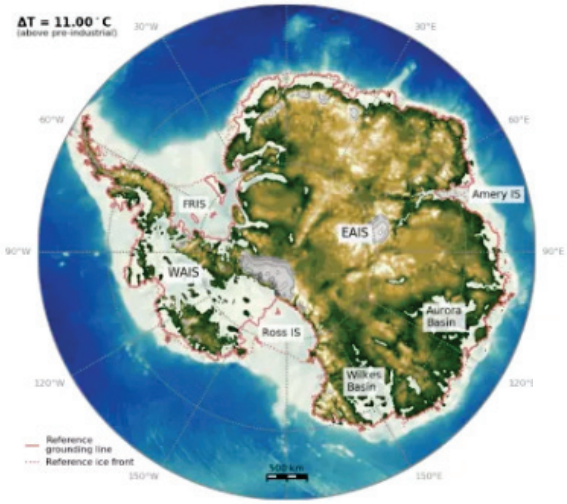
https://grace.jpl.nasa.gov/resources/31/antarctic-ice-loss-2002-2016

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 new study published Sep. 23 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

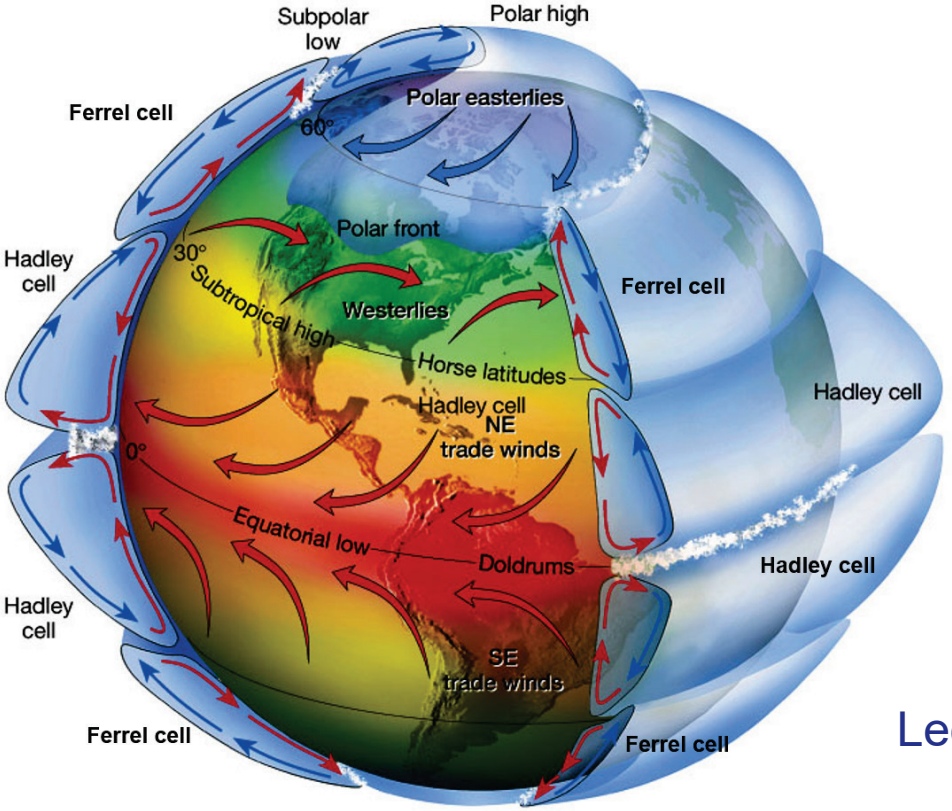
See also https://www.cnn.com/2020/09/30/weather/greenland-ice-sheet-melt-carbon-emissions-climate-change/index.html (yikes)

Consequences of Climate Change

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, and tropical diseases**

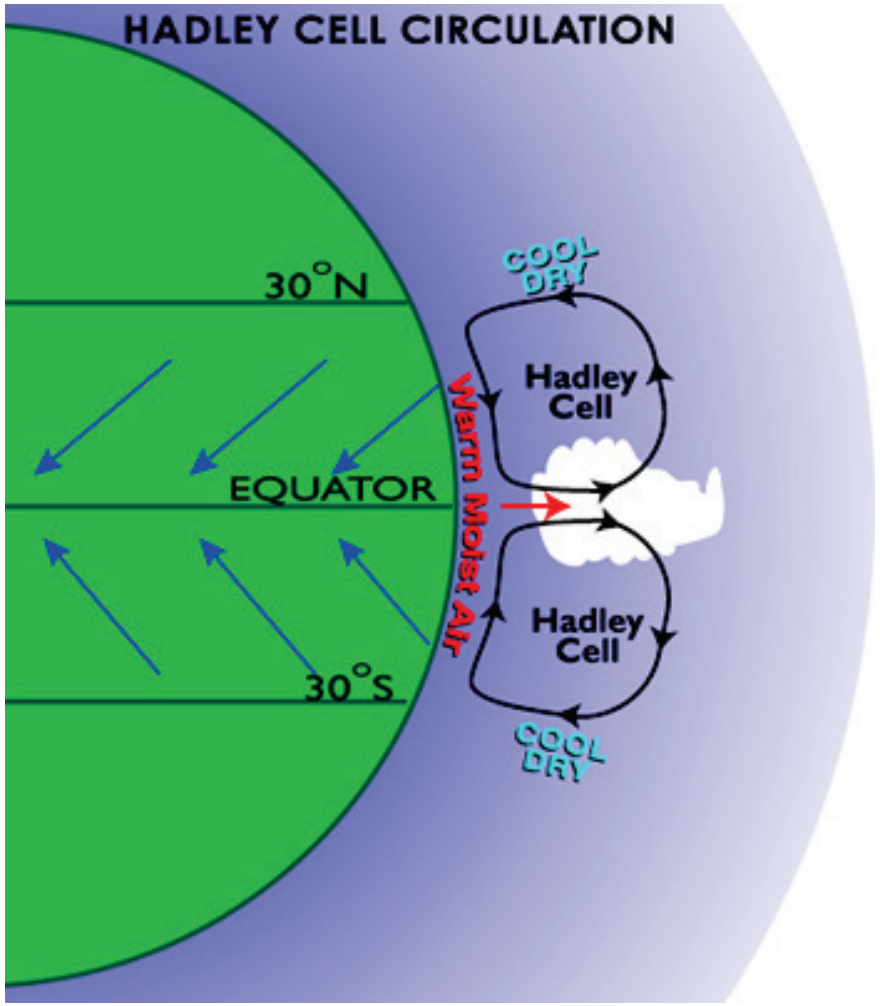
Ferrel Circulation (Modern View)



Lecture 3

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

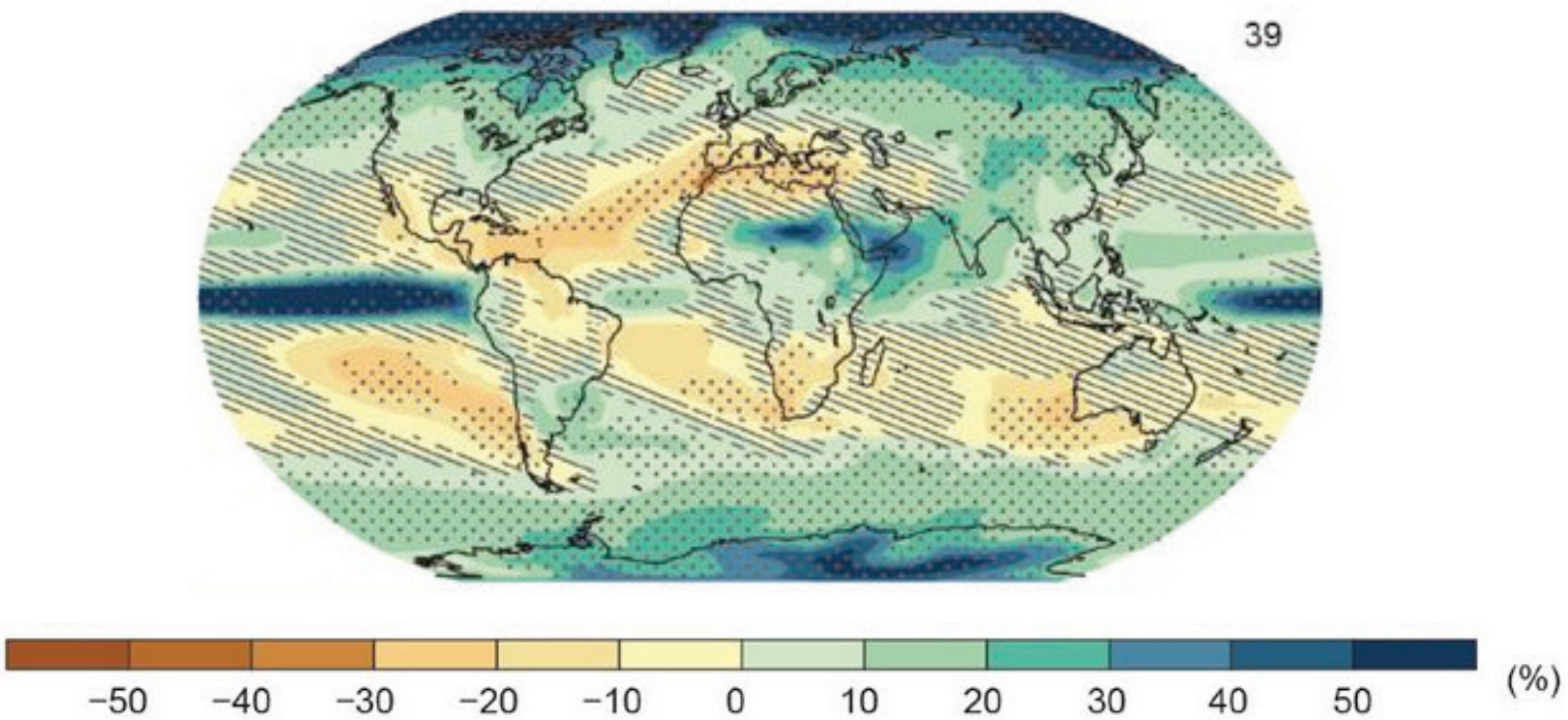
Connection to Climate Change
WWDD: Wet-gets-Wetter, Dry-gets-Drier (WWDD) paradigm



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

Climate Model Forecast of Precipitation Changes

Spatial Distribution of Precipitation Changes, 2081 −2100 relative to 1986−2005



Climate model projections, RCP 8.5 (aggressive growth of GHGs)

https://www.cnbc.com/2017/08/28/the-stunning-images-from-record-setting-flooding-in-houston-texas.html

IPCC 2013

Climate Model Forecast of Precipitation Changes

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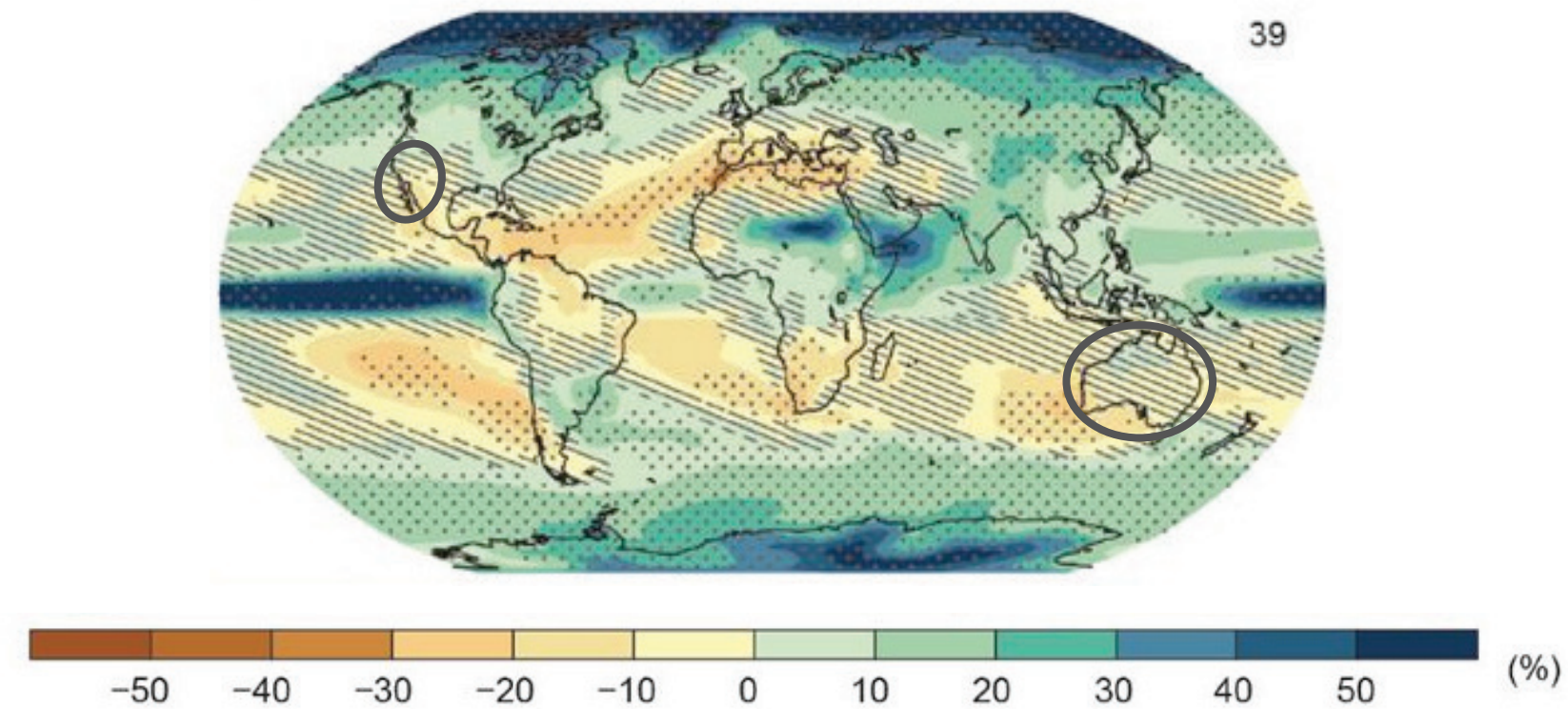


Climate model projections, RCP 8.5 (aggressive growth of GHGs)

https://www.cnbc.com/2017/08/28/the-stunning-images-from-record-setting-flooding-in-houston-texas.html

IPCC 2013

As CO_2 and other GHGs rise:

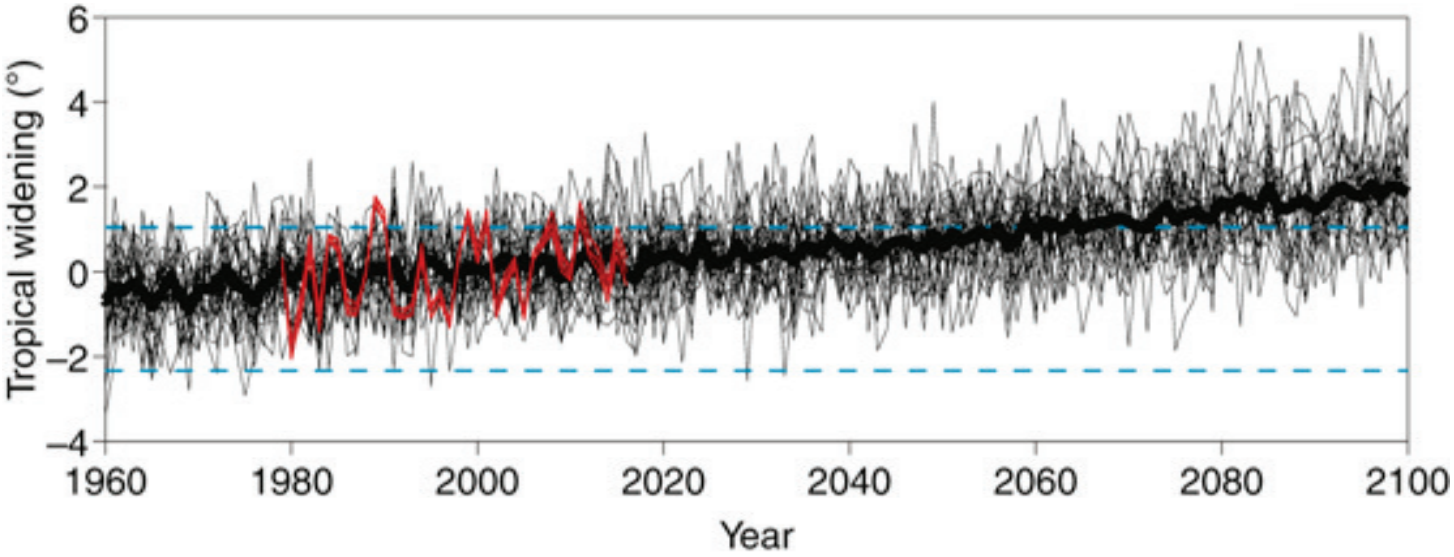
- Hadley Cell becomes more energetic
- WWDD: Wet gets wetter, dry gets drier
- Deserts expand poleward

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

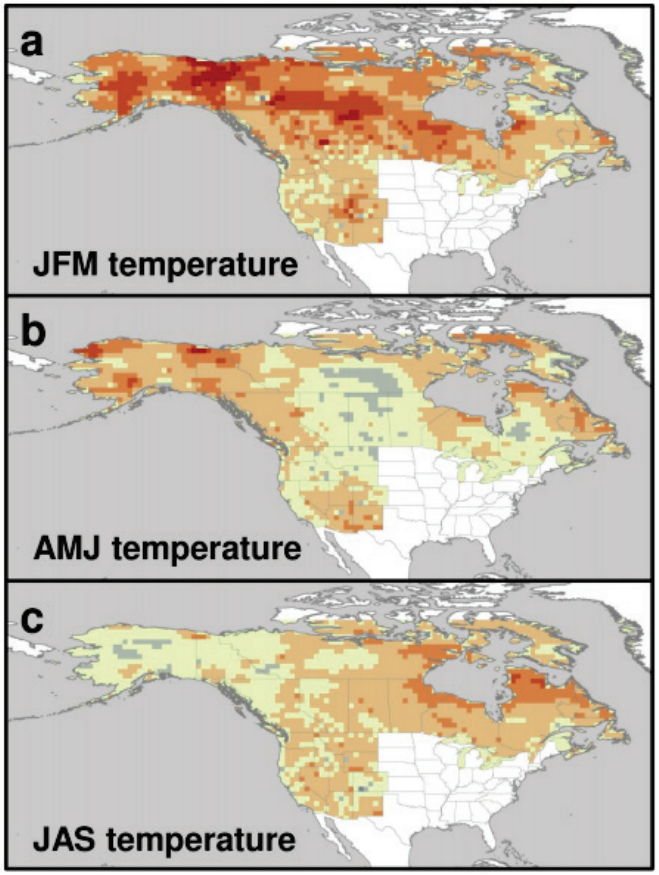
RESEARCH ARTICLE

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

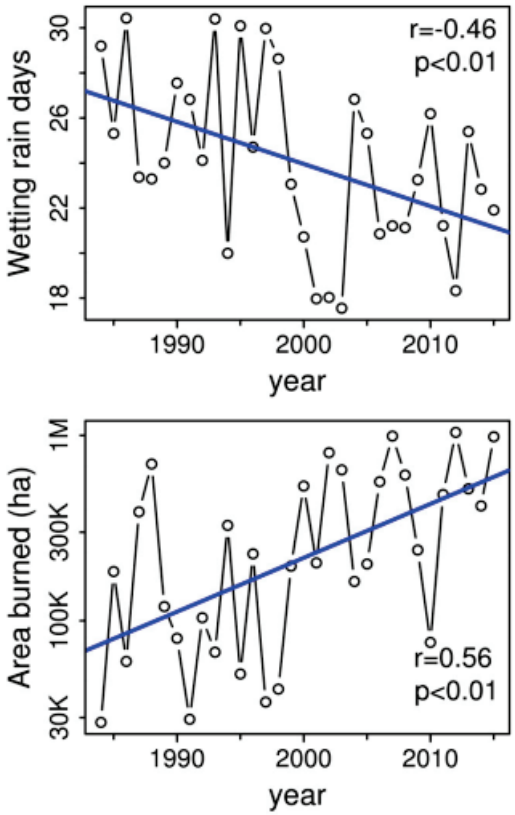
Recent papers linking fires to climate change

PNAS

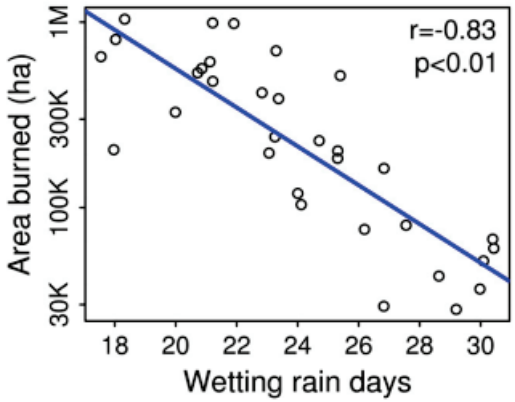
Decreasing fire season precipitation increased recent western US forest wildfire activity

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

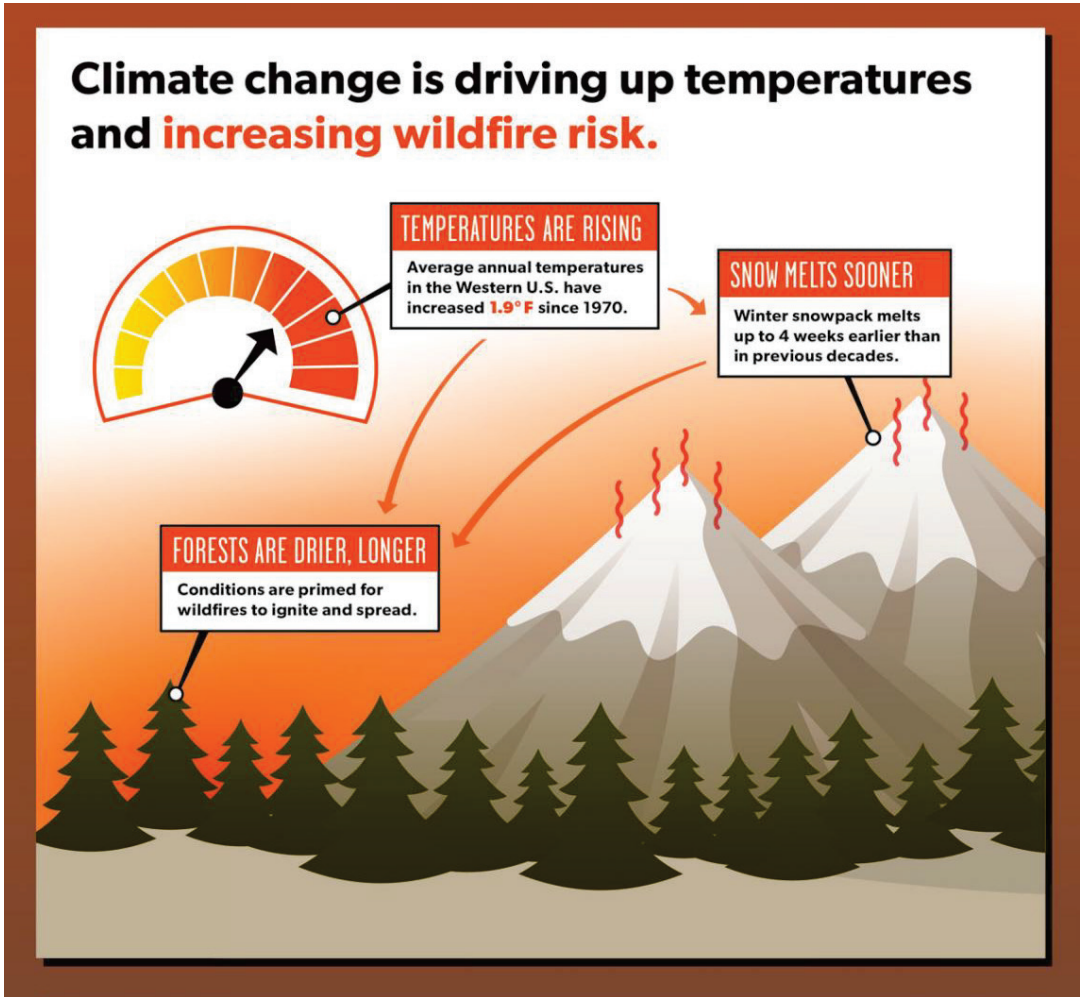


Linear trends in wetting rain days (left top), the logarithm of area burned (left bottom), and wetting rain days versus logarithm of area burned (right)



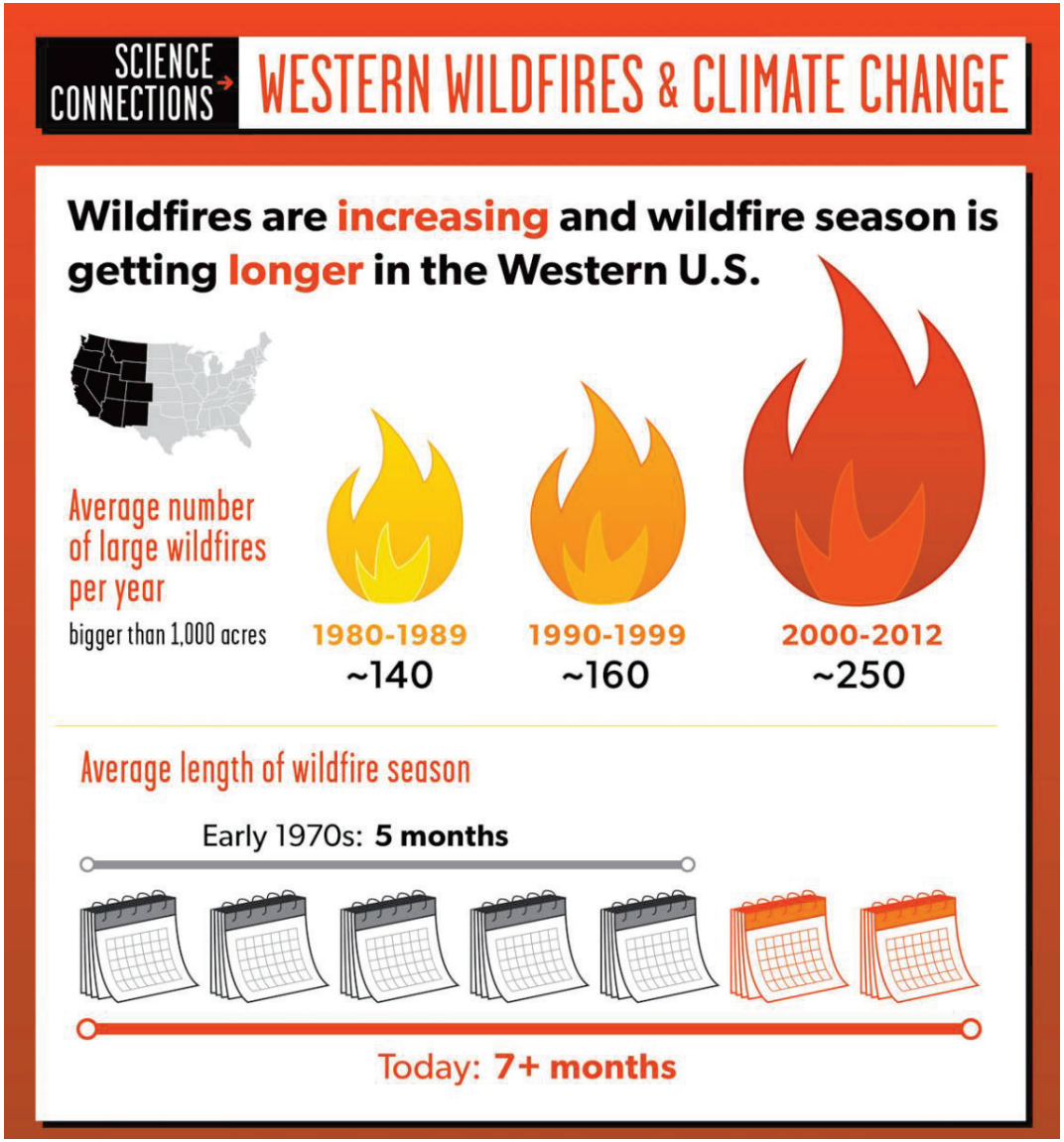
https://www.pnas.org/content/115/36/E8349

Forest Fires and Climate Change



https://www.ucsusa.org/global-warming/science-and-impacts/impacts/infographic-wildfires-climate-change.html

Forest Fires and Climate Change



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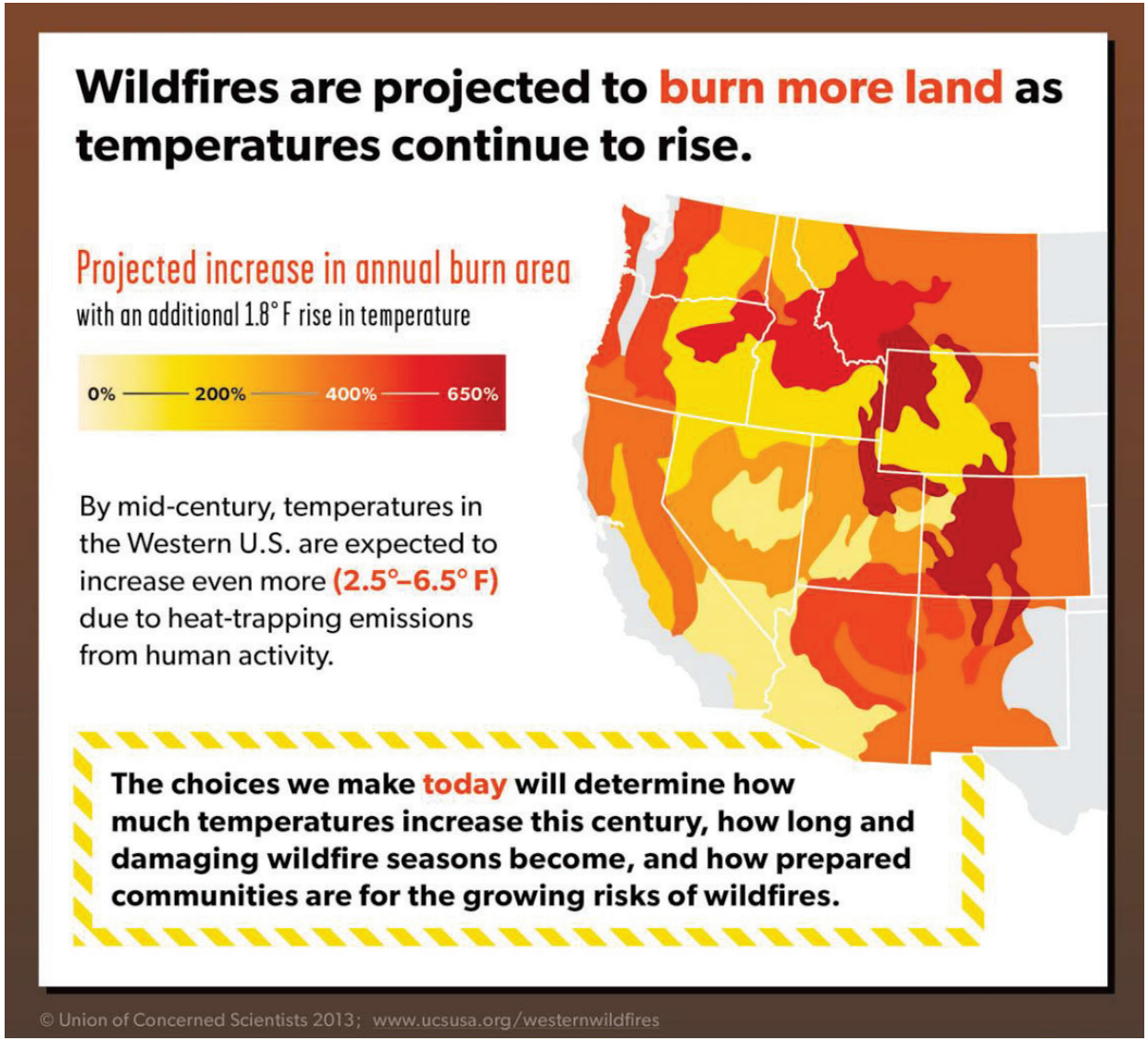
Forest Fires and Climate Change



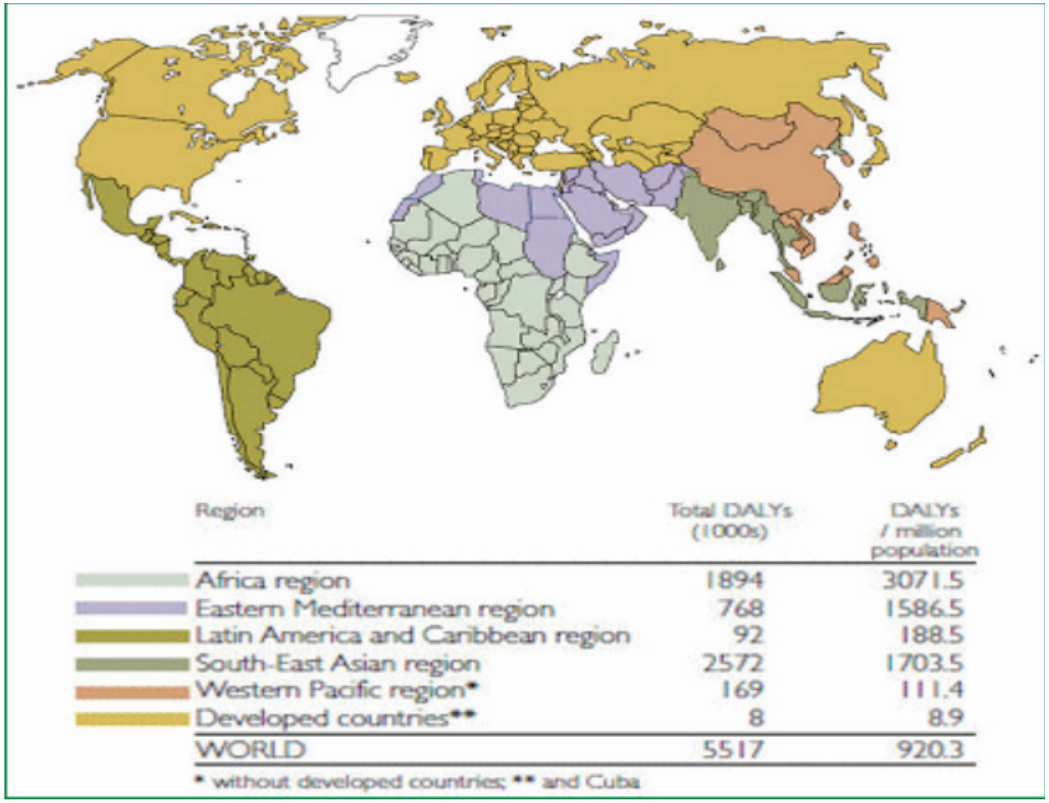
https://www.ucsusa.org/global-warming/science-and-impacts/impacts/infographic-wildfires-climate-change.html

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



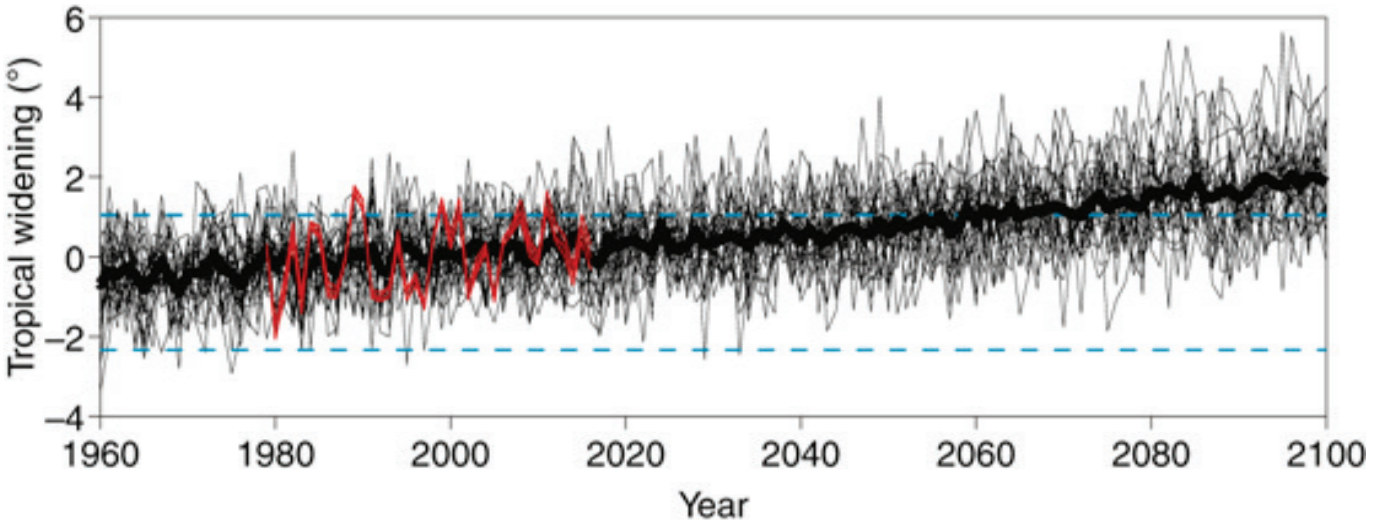
Region	Total DALYs (1000s)	DALYs / million population
Africa region	1894	3071.5
Eastern Mediterranean region	768	1586.5
Latin America and Caribbean region	92	188.5
South-East Asian region	2572	1703.5
Western Pacific region*	169	111.4
Developed countries**	8	8.9
WORLD	5517	920.3

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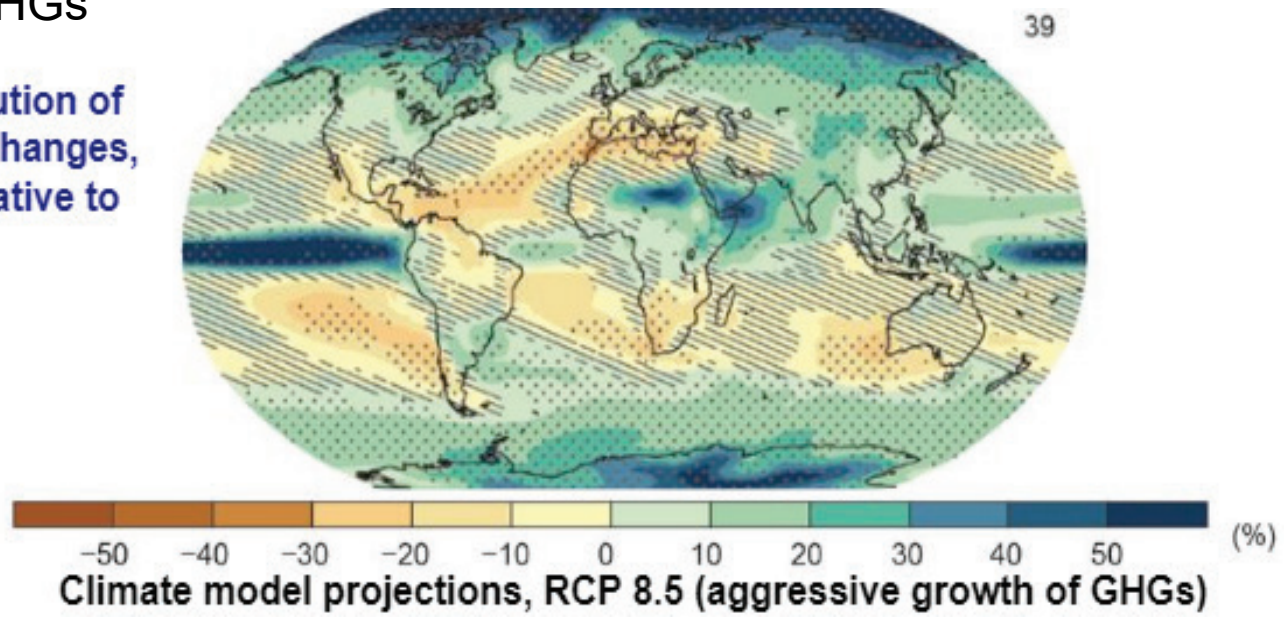
From Staten *et al*., *Nature Climate Change*, 2018. https://www.nature.com/articles/s41558-018-0246-2

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

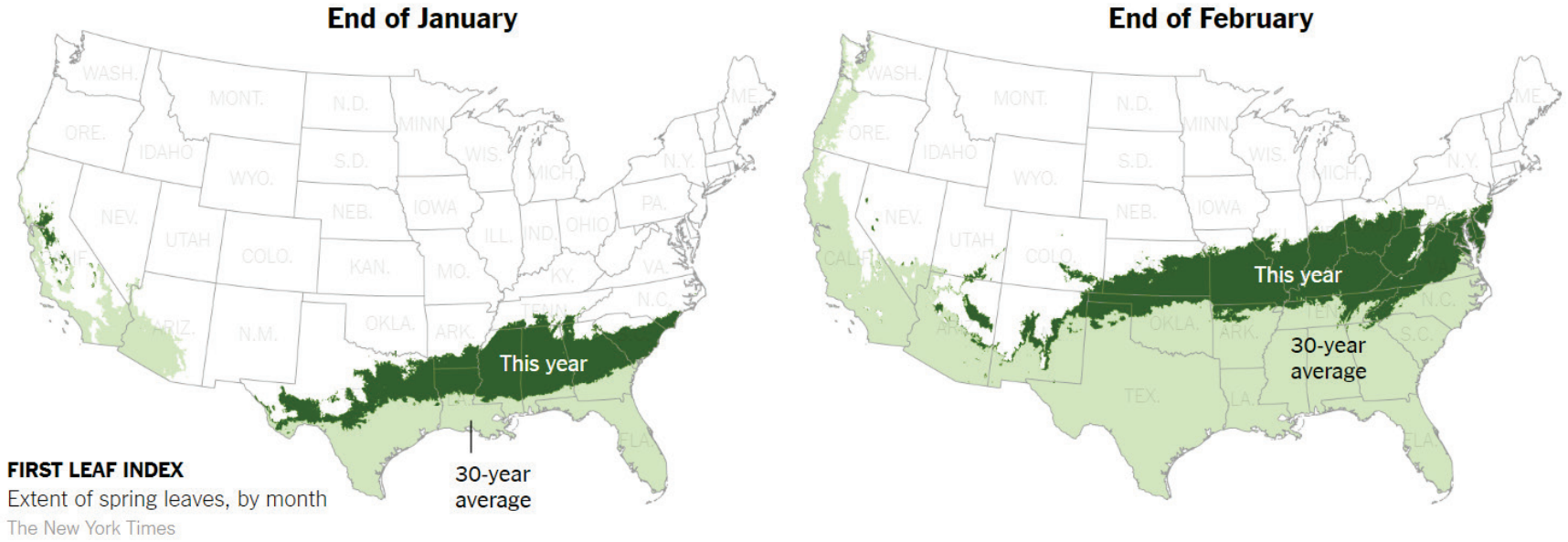
Figure: Projection of precipitation changes by 2100 with aggressive growth of GHGs

Spatial Distribution of Precipitation Changes, 2081 −2100 relative to 1986−2005
IPCC 2013



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

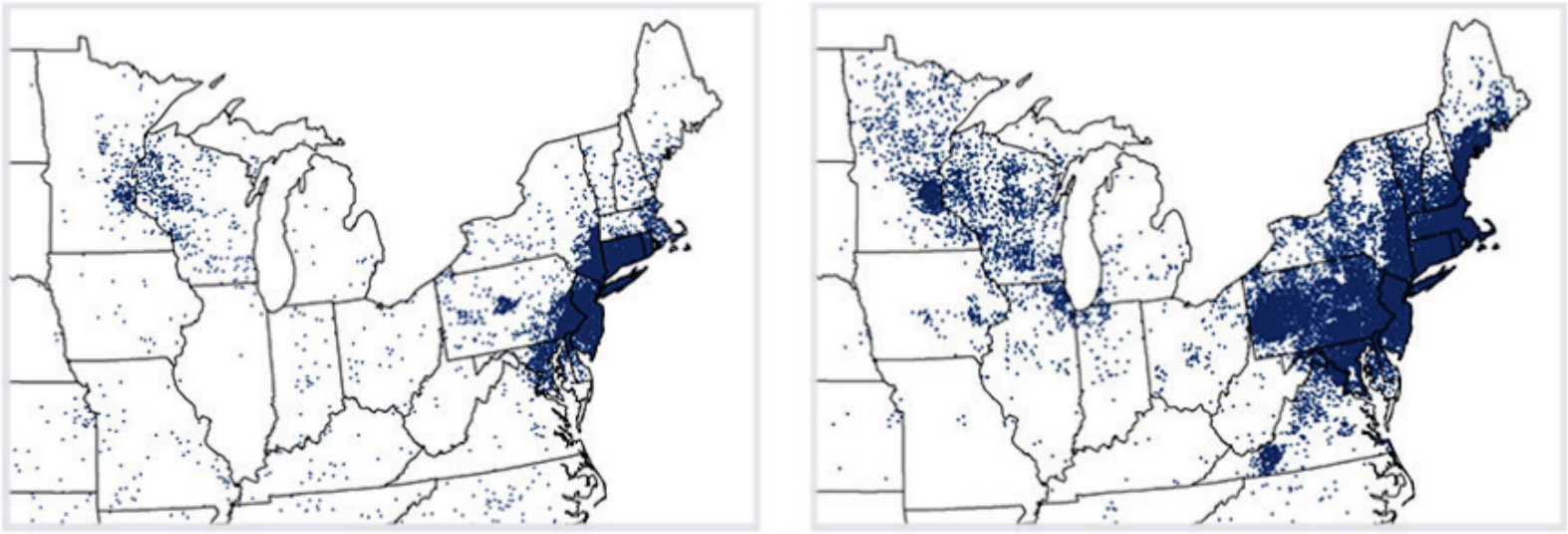


Regions in the US that experienced blooming by the end of Jan (left) and Feb (right) 2017

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

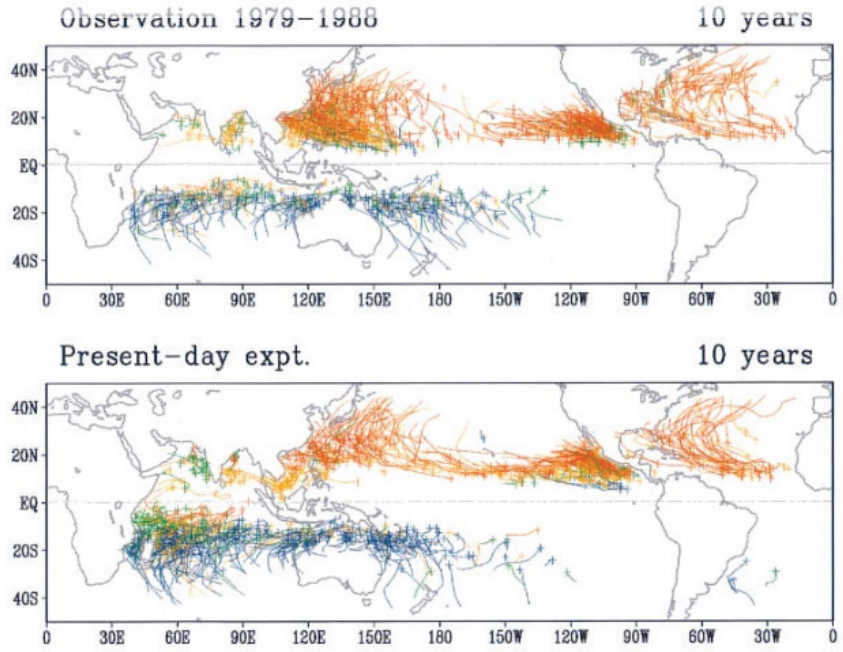
Distribution of reported cases of Lyme disease in 1996 and 2014. Each dot represents an individual case placed according to the patient's county of residence, which may be different than the county of exposure. Maps focus on the parts of the United States where Lyme disease is most common. (EPA)

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***



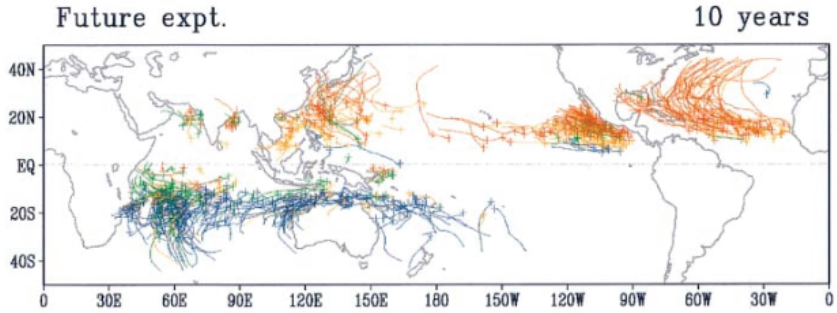


Fig. 2. Tropical cyclone tracks of the observational data (top), the present-day (middle), and the future climate experiments (bottom). The initial positions of tropical cyclones are marked with "plus" signs. The tracks detected at different seasons of each year is in different colors (blue for January,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

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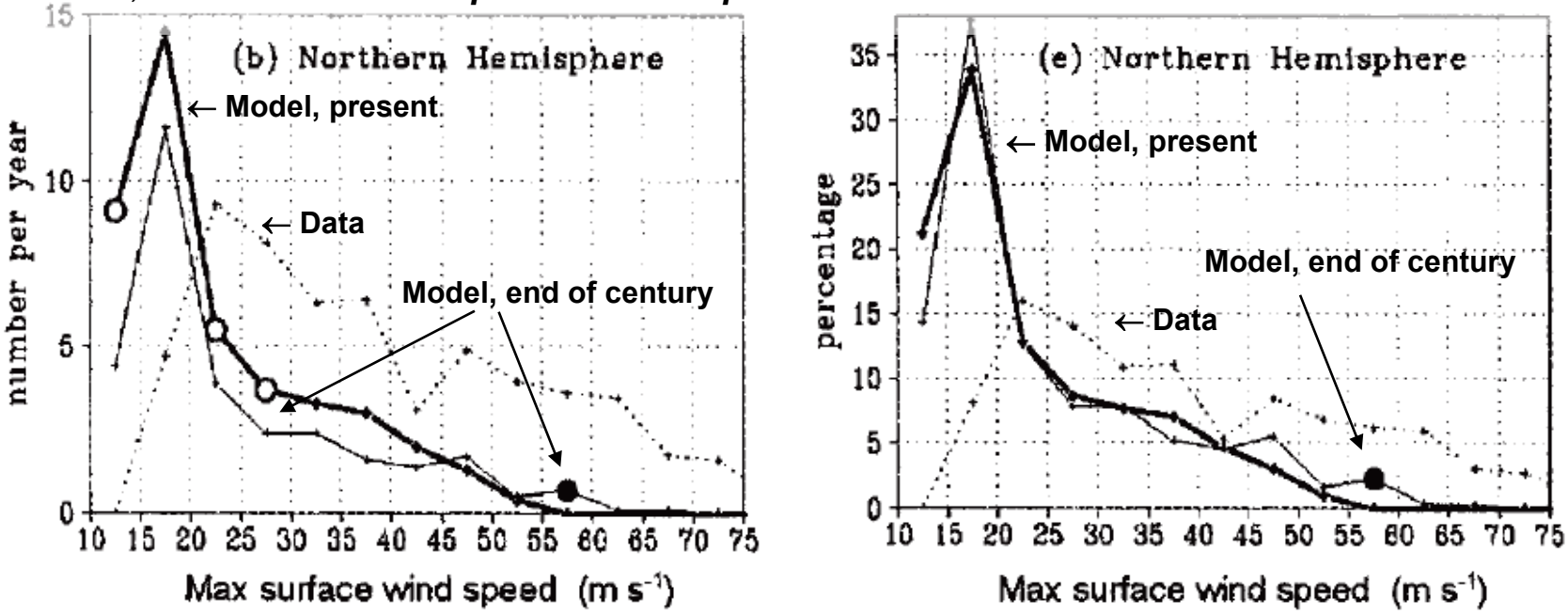

Oouchi *et al.*, *Journal Meteor. Soc. Japan*, 2006

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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… - Journal of the …, 2006 - jstage.jst.go.jp

Possible changes in the tropical cyclones in a future, greenhouse-warmed climate are investigated using a 20 km-mesh, high-resolution, global atmospheric model of MRI/JMA, with the analyses focused on the evaluation of the frequency and wind intensity. Two types …

☆ 99 Cited by 610 Related articles All 14 versions

Consequences of Climate Change

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

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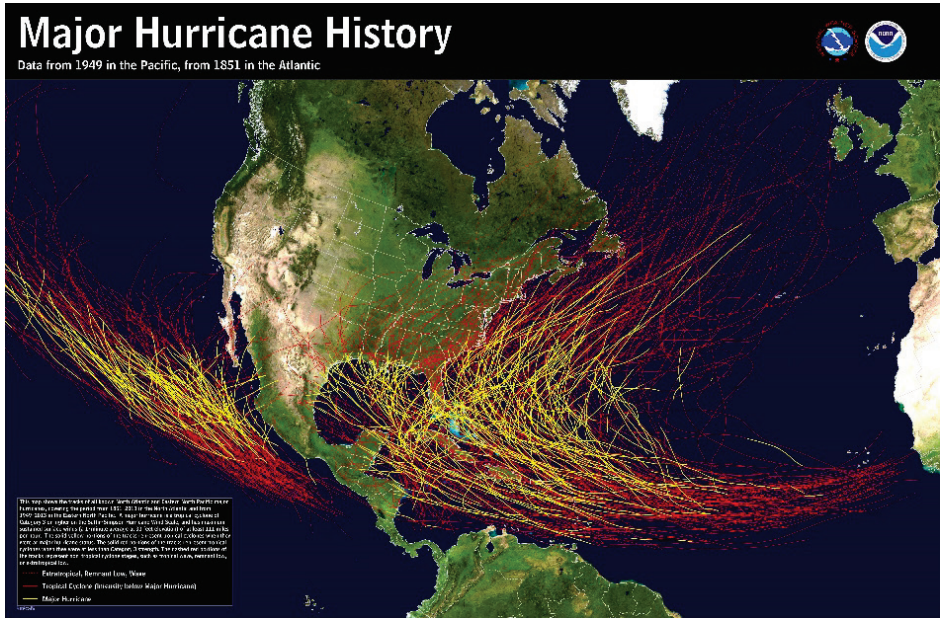
Confounding factor:



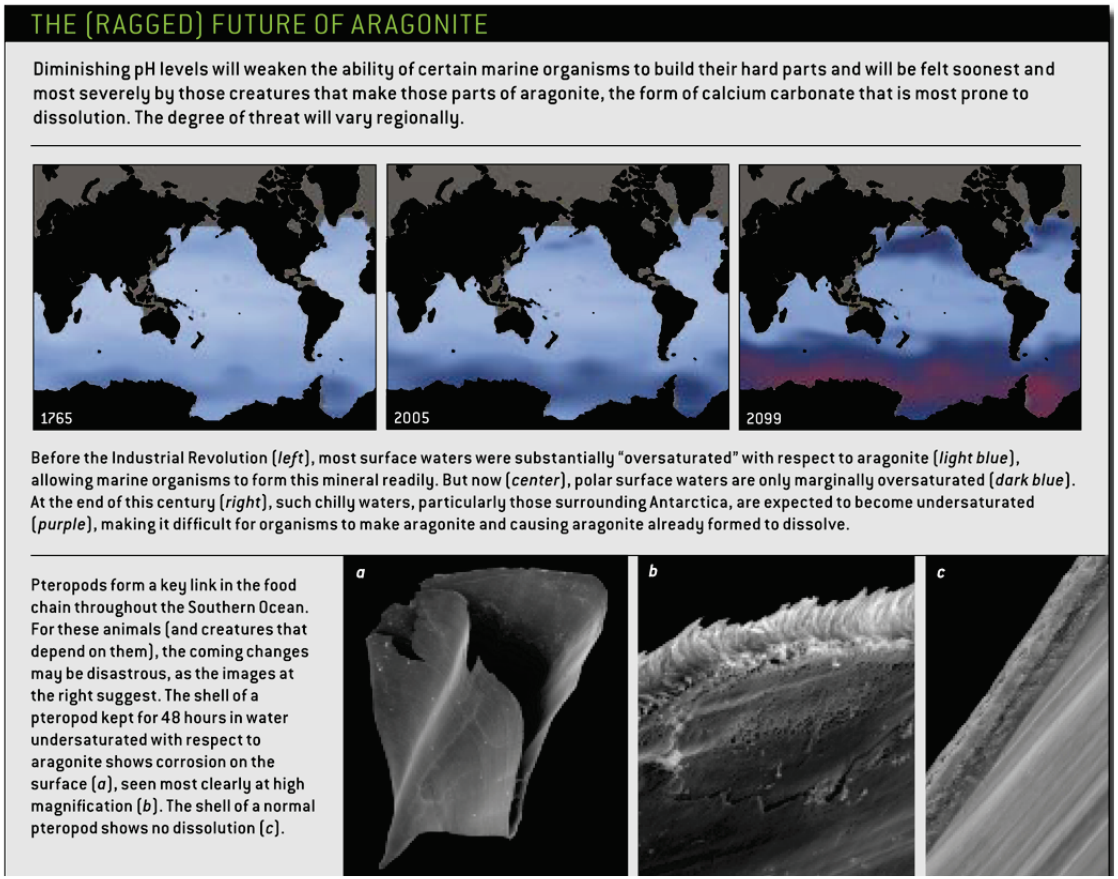
http://www.c2es.org/science-impacts/extreme-weather/hurricanes

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

Stratosphere Cools as the Troposphere Warms

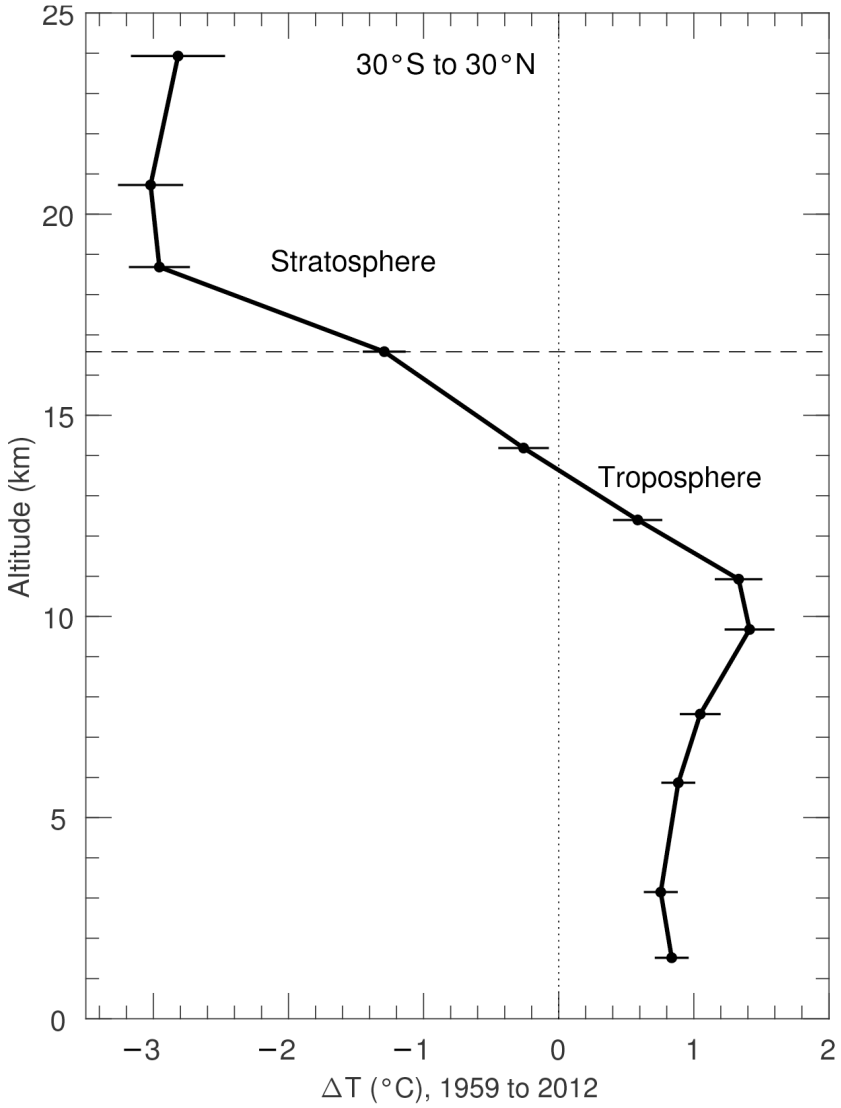
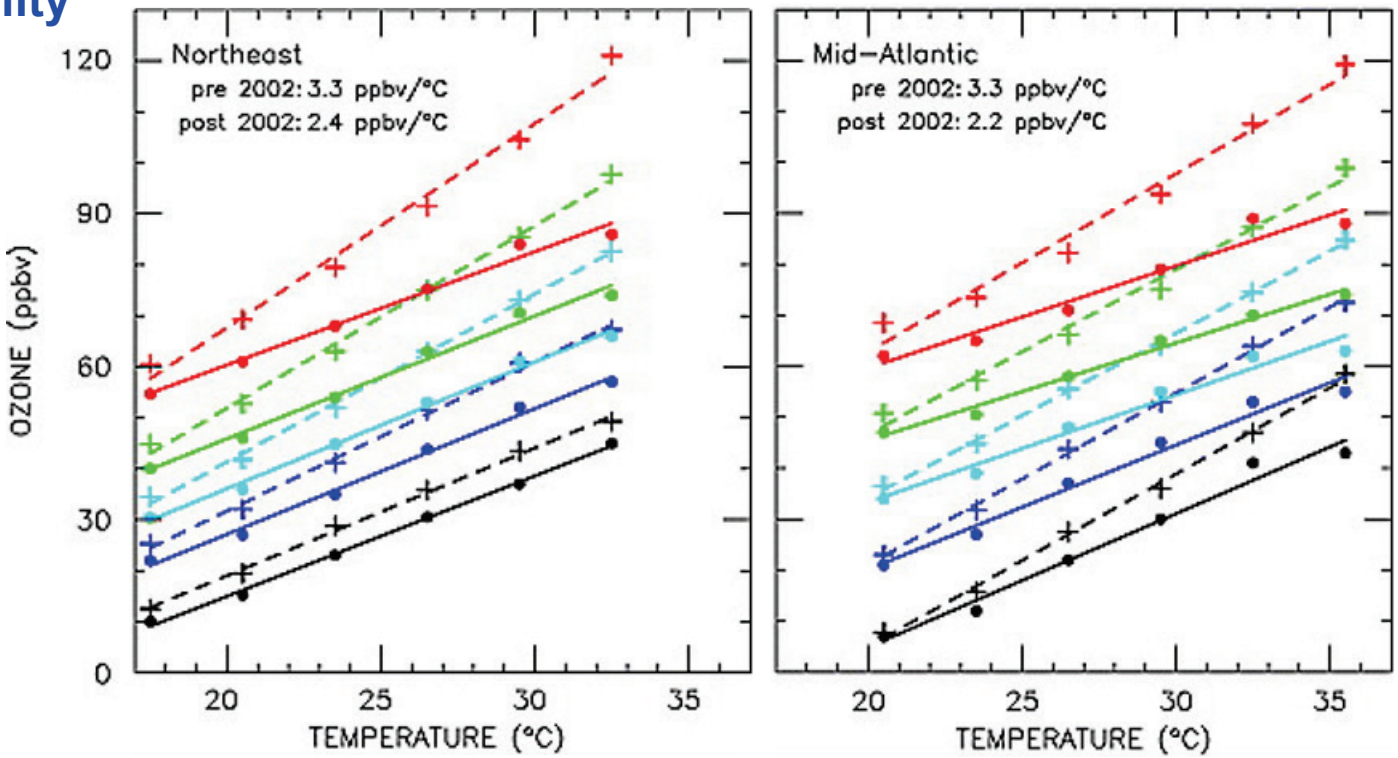


Fig. 1.5, Paris Beacon of Hope

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
Higher temperatures caused by increasing greenhouse gas concentrations are predicted to exacerbate photochemical smog if precursor emissions remain constant. We perform a statistical analysis of 21 years of ozone and temperature observations across the rural …
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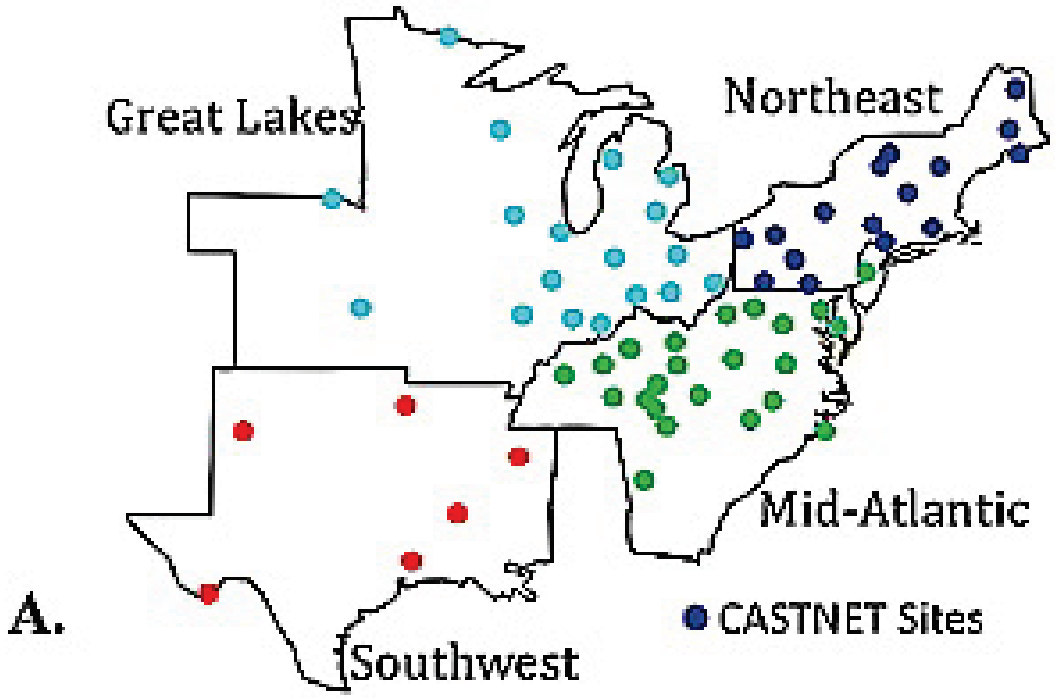
Consequences of Climate Change

6a. Air Quality



Grouping of States and CASTNET (circles with colors) representing chemically coherent receptor regions for ozone air pollution.

Clean Air Status and Trends Network (CASTNET), operated by the U.S. EPA since 1987 http://www.epa.gov/castnet

Observed relationships of **ozone air pollution** with temperature and emissions
BJ **Bloomer**, JW Stehr, CA Piety… - Geophysical …, 2009 - Wiley Online Library
Higher temperatures caused by increasing greenhouse gas concentrations are predicted to exacerbate photochemical smog if precursor emissions remain constant. We perform a statistical analysis of 21 years of ozone and temperature observations across the rural …
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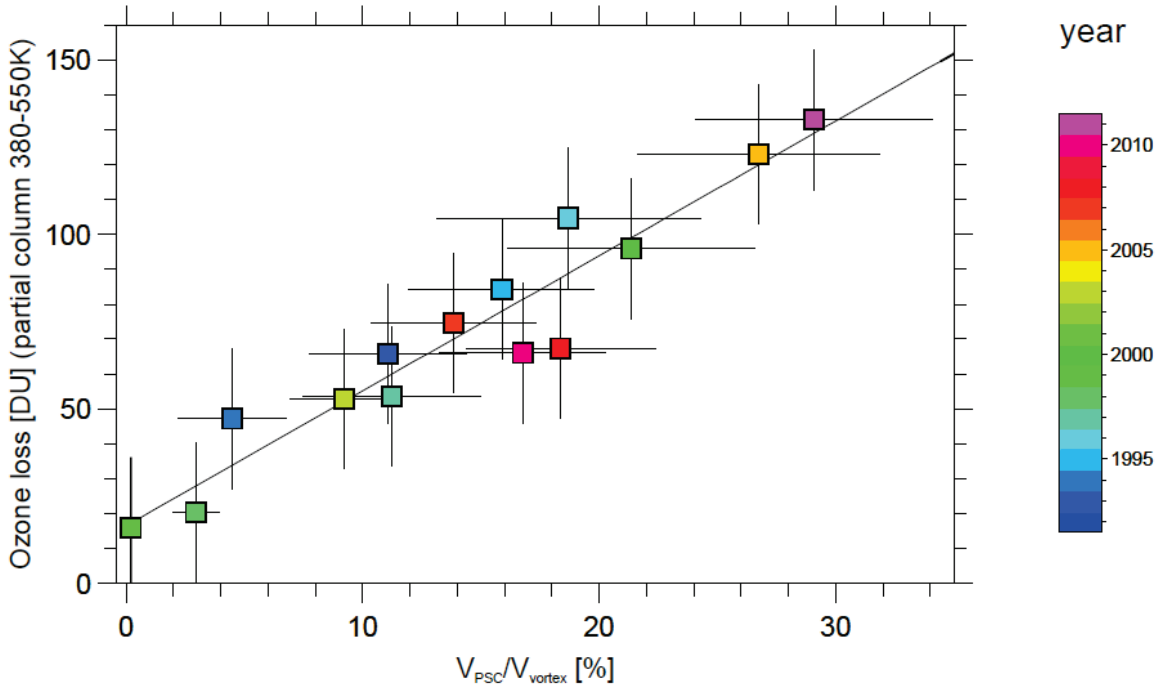
Consequences of Climate Change

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

We report the first empirical quantification of the relation between winter-spring loss of Arctic ozone and changes in stratospheric climate. Our observations show that~ 15 DU additional loss of column ozone can be expected per Kelvin cooling of the Arctic lower stratosphere, an …

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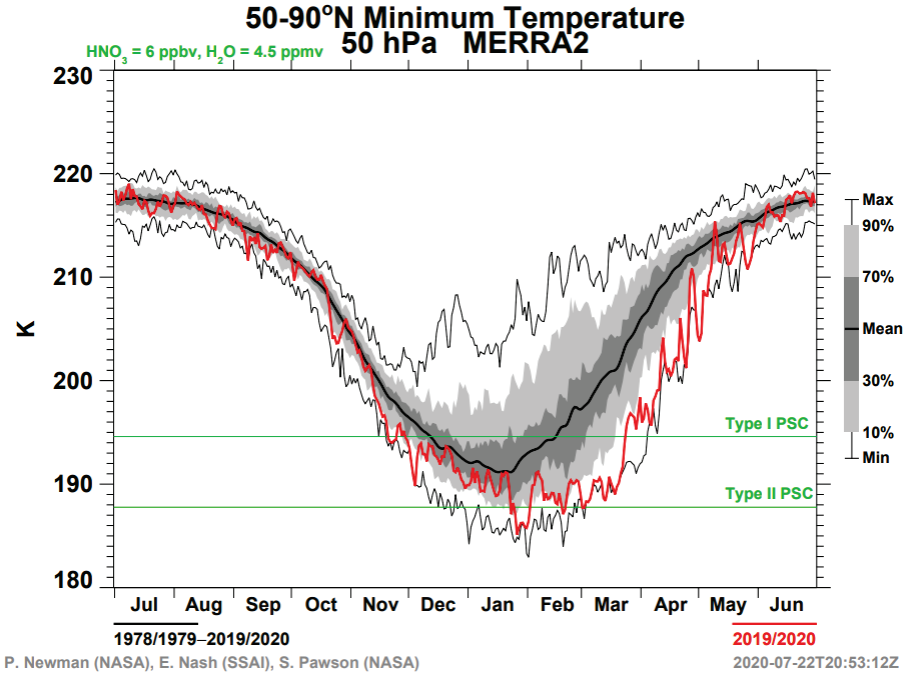
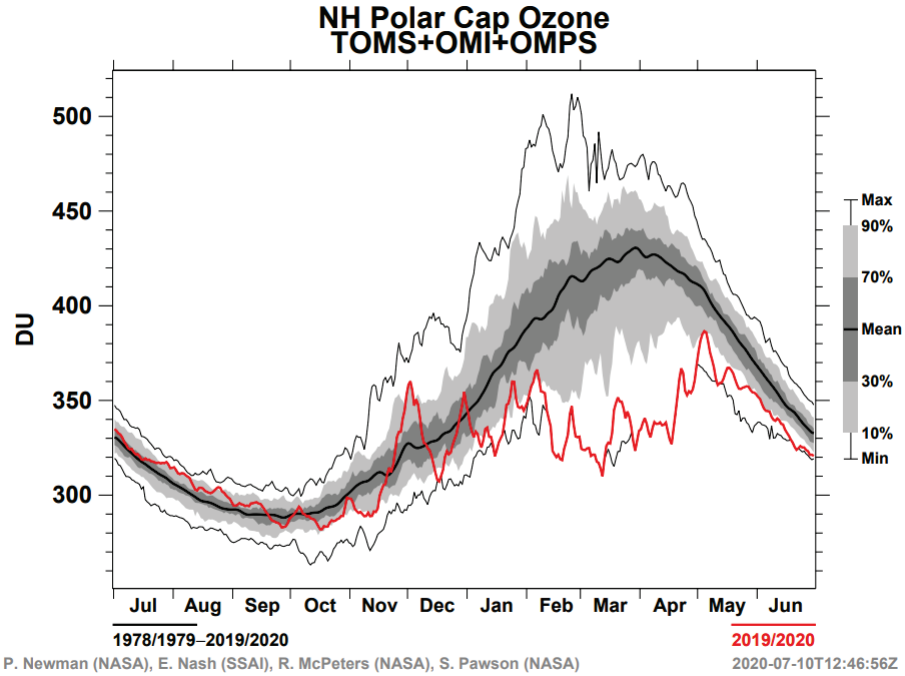
Consequences of Climate Change

6b. Stratospheric, Arctic Ozone Loss

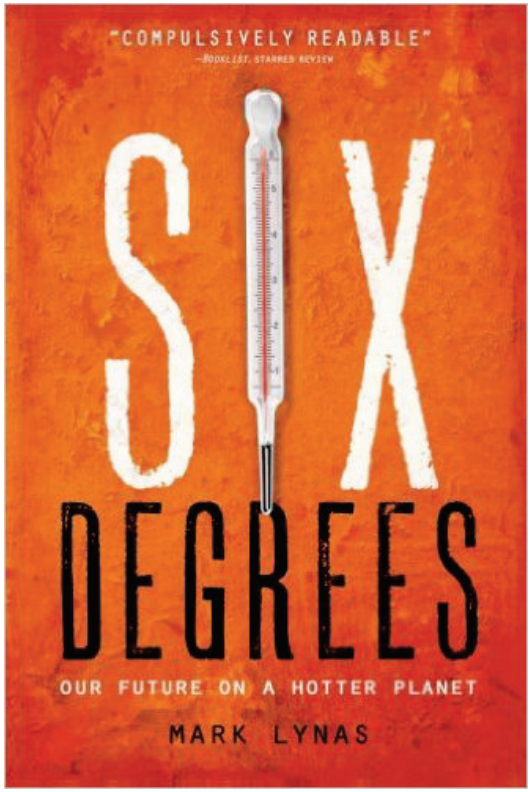




https://ozonewatch.gsfc.nasa.gov/meteorology/temp_2019_MERRA2_NH.html
https://ozonewatch.gsfc.nasa.gov/meteorology/NH.html

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