HONR 229L: Climate Change: Science, Economics, and Governance

Discussion #11: Impacts of Climate Change

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Class Web Site: http://www.atmos.umd.edu/~rjs/class/honr229L

ELMS Page: https://myelms.umd.edu/courses/1269254

Kianteata Bwaurerei, 70, has decided not to replant his crops after they were inundated.
https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html

8 October 2019

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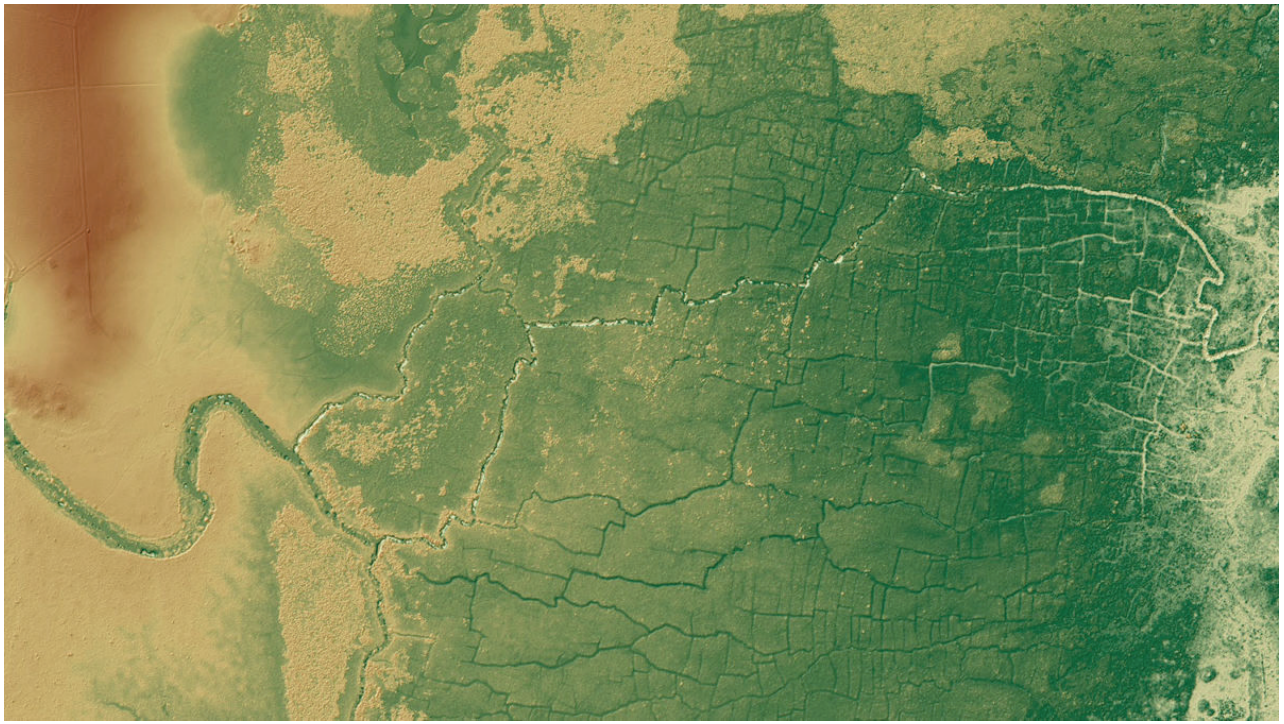
In the news:



- First study to combine airborne lidar imagery with excavation and dating for Maya
- Wetland field complex to be five times larger than previously thought
- Researchers hypothesized that from about 2000 to 1000 years ago:
  - expanding wetland complexes added atmospheric CO_2 through burning events
  - expanding wetland complexes added atmospheric CH_4 through creation of wetland farming

https://news.utexas.edu/2019/10/07/ancient-maya-canals-and-fields-show-early-and-extensive-impacts-on-tropical-forests/

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AT 10, Q1

Briefly and in your own words, what are the two findings from the 1990 IPCC report that Nate Silver describes as being absolutely certain?

The 1990 IPCC report concluded with absolute certainty that

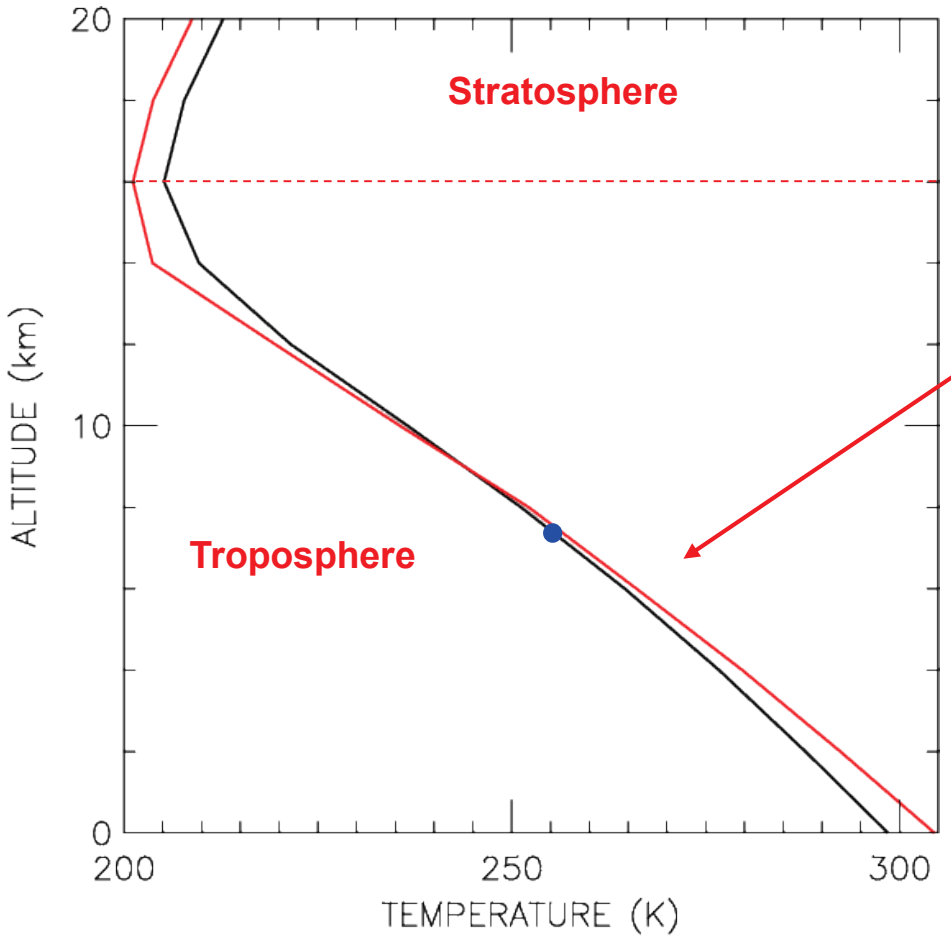
1) there exists a natural greenhouse effect on Earth that helps it retain more heat than it otherwise would.

2) The report also concluded with certainty that:

- **a) human activities are adding greenhouse gasses into the atmosphere**
- **b) which, on average, will warm the planet**
- **c) This atmospheric warming will increase the water vapor content in the atmosphere which, since water vapor is a greenhouse gas, will cause further warming.**

Please note this was all confidently known in 1990 !

Lapse Rate Feedback

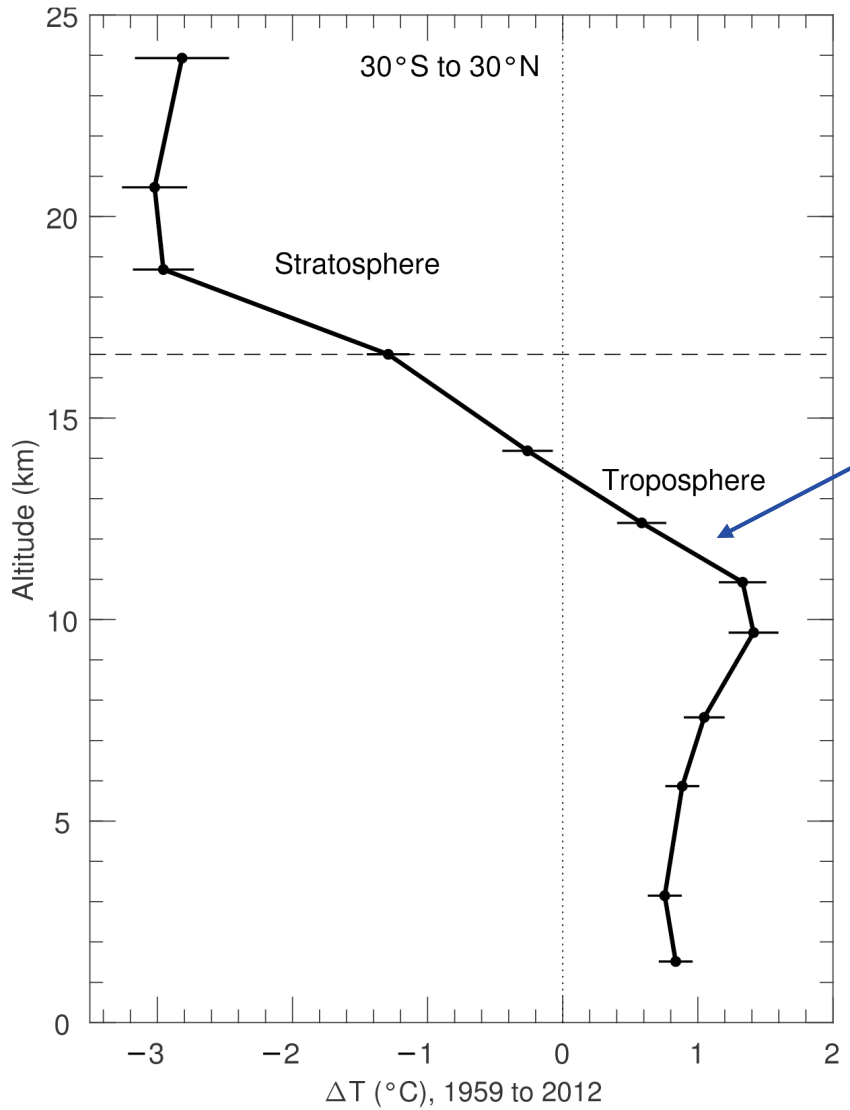


RED: Perturbed temperature profile

Earth's characteristic "black body" temperature is ~255 K (–18 °C or –0.67 °F).

If altitude above 255 K warms then energy will radiate to space more effectively than in unperturbed state: *negative feedback*

Lapse Rate Feedback



This figure shows warming at 10 km is larger than warming at the surface supporting notion that the *lapse rate feedback is negative*

Fig. 1.5, Paris Beacon of Hope

Best Current Understanding

$$\Delta T = \lambda_{BB} \, (1 + f_{H2O+LapseRate} + f_{Clouds,\ Ice,\ Land\ Cover}) \, (\Delta F_{CO2} + \Delta F_{CH4+N2O+O3+CFCs} + \Delta F_{AEROSOLS})$$

where

$$\lambda_{BB} = 0.3 \text{ K} \ / \ \text{W m}^{-2}$$

Climate models that considering water vapor & lapse rate feedback find:

$$f_{H2O+LapseRate} = 0.45$$

Therefore, doubling of CO2 with only the water & lapse rate feedback operating will lead to a warming of:

$$\Delta T = 0.3 \text{ K} \ / \ \text{W m}^{-2} \ (1 + 0.45) \, (5.35 \ln 2 \text{ W m}^{-2})$$

$$= (1.45) \times (1.1 \text{ K}) = 1.6 \text{ K}$$

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AT 10, Q2

What are the "three prongs" of the critique of IPCC forecasts in the Armstrong and Green paper?

Armstrong and Green the IPCC forecasts on the grounds that:

1) Forecasters do not agree, which is more related to bias than accuracy

2) Complex models are not better than simpler versions

3) Forecasters may be overconfident is their model

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AT 10, Q3

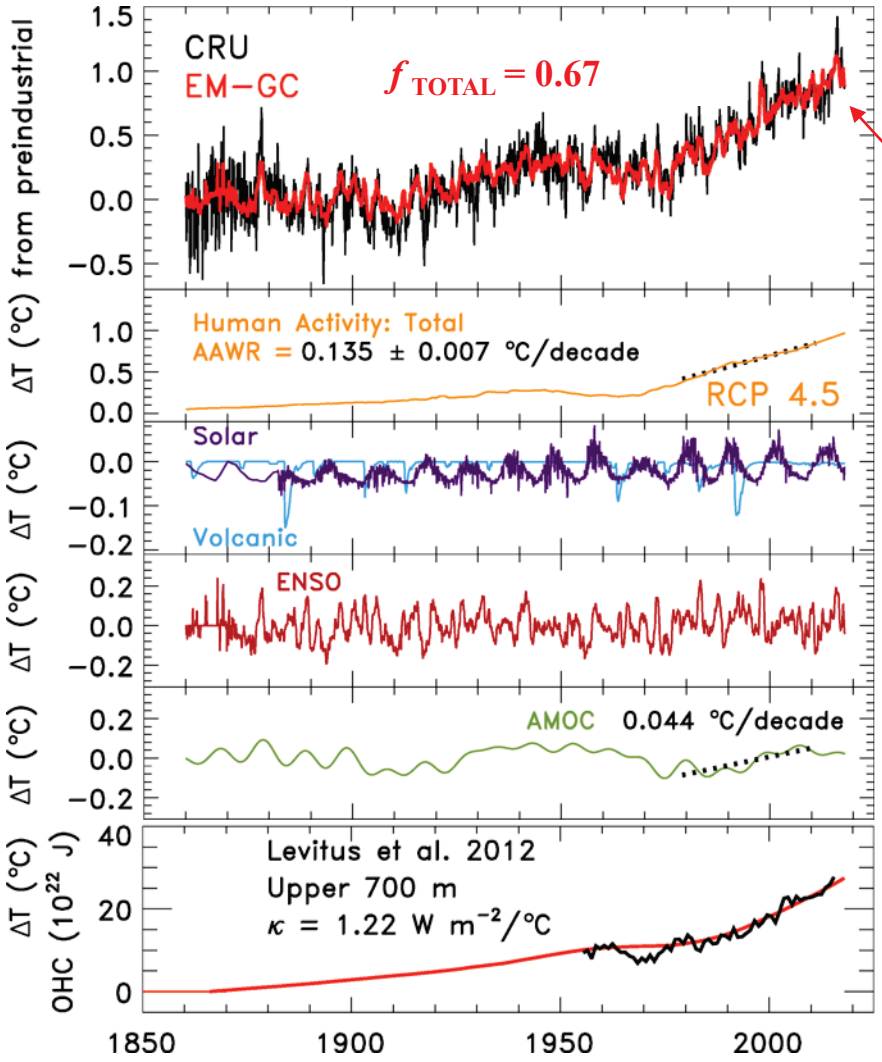
Explain, in a short essay of 5 to 8 sentences one of these three prongs. Try to use a strong topic sentence.

Prong 1:

The first critique of IPCC Forecasts by Armstrong and Green is that *agreement among forecasters is not related to accuracy*. By this critique, Armstrong and Green are saying *that just because a group of people agree on a forecast does not necessarily mean that the forecast is accurate*. As Armstrong is quoted as saying, "voting...that's not the way that science progresses". Furthermore, the reading hints that consensus may be a sign of bias more than anything, but this an especially true point that is worth mentioning. If a group of forecasters get together and have to agree on a single forecast, some people will be afraid to speak up if they have an idea different than the group's idea, even if it may actually be correct. Thus, the group's forecast will likely ultimately be representative of the thoughts of the majority, but that does mean that this forecast will be accurate and may be missing key aspects that a minority of forecasters were afraid to or unwilling to bring up. (i.e. groupthink) Thus, Armstrong and Green accurately state that agreement among forecasters is not necessarily related to accuracy.

Please note a key factor that has likely taken place in the real world of climate modeling is that groups thought they knew the "right answer" (i.e, how much the surface had warmed) for part of the recent past. Models were tuned to match these data. When it became apparent some of this change was due to natural variability of ocean circulation, rather than climate feedback, it was too late to revise the models. So many groups proceeded with climate models that warm too fast.!

Empirical Model of Global Climate (EM-GC)



$$\Delta T_{MDL\,i} = (1 + f_{TOTAL})\lambda_{BB}(GHG\ RF_i + LUC\ RF_i + Aerosol\ RF_i) + C_0 + C_1 \times SOD_{i-6} + C_2 \times TSI_{i-1} + C_3 \times ENSO_{i-2} + C_4 \times AMOC_i - \lambda_{BB}\, Q_{OCEAN_i}$$

where:

i = month

$\lambda_{BB} = 0.3\ °C / W\ m^{-2}$

$$1 + f_{TOTAL} = \frac{1}{1 - FB_{\Sigma}\,\lambda_{BB}}$$

FB_{Σ} = Sum of All Feedbacks, i.e.,

$FB_{\Sigma} = FB_{WV} + FB_{LR} + FB_{SURFACE\ ALBEDO} + FB_{CLOUDS}$

in units of $W\ m^{-2}\ °C^{-1}$

Aerosol RF = total RF due to Tropospheric Aerosols

LUC RF = RF due to Land Use Change

SOD = Stratospheric Optical Depth

TSI = Total Solar Irradiance

ENSO = El Niño Southern Oscillation

AMOC = Atlantic Meridional Overturning Circ.

Q_{OCEAN} = Ocean heat export =

$$\kappa(1 + f_{TOTAL})\{\Delta T_{MDL\,i} - \Delta T_{OCEAN\ SURFACE\ i}\}$$

Canty *et al.*, *ACP*, 2013 https://www.atmos-chem-phys.net/13/3997/2013/acp-13-3997-2013.html
updated by Austin Hope & Laura McBride

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AT 10, Q3

Explain, in a short essay of 5 to 8 sentences one of these three prongs. Try to use a strong topic sentence.

Prong 2:

The global warming problem is *complex to predict*, but that *does not mean that prediction is impossible*. Many wonder how can we predict the climate system decades from now if the weatherman can be wrong about the weather tomorrow.

The further out in time one goes, the more likely one will need complex models that can factor in issues such as future drought, changes in the distribution of ecosystems brought about by climate change, or feedbacks that take a long time to manifest (i.e., the *ice sheets do not melt instantly*).

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AT 10, Q3

Explain, in a short essay of 5 to 8 sentences one of these three prongs. Try to use a strong topic sentence.

Prong 3:

Underestimating uncertainty related to global warming can produce overconfident forecasts. **Climate scientists meticulously account for uncertainties in their models, yet there is still an uncertainty about the degree of uncertainty. There is initial condition uncertainty, in which short-term factors can cause temperature fluctuations that make it harder to interpret warming caused by the greenhouse effect. There is also scenario uncertainty, which increases over time and is associated with the level of greenhouse gases in the atmosphere. However, the hardest uncertainty to quantify is structural uncertainty in climate models. This relates to our understanding of the climate system and how successful we can translate these processes into model equations.**

My research group has harped on the inability of the climate modeling world to come to grips with the structural uncertainties of their models, which should rise over time much more so than shown in Fig 12-3.

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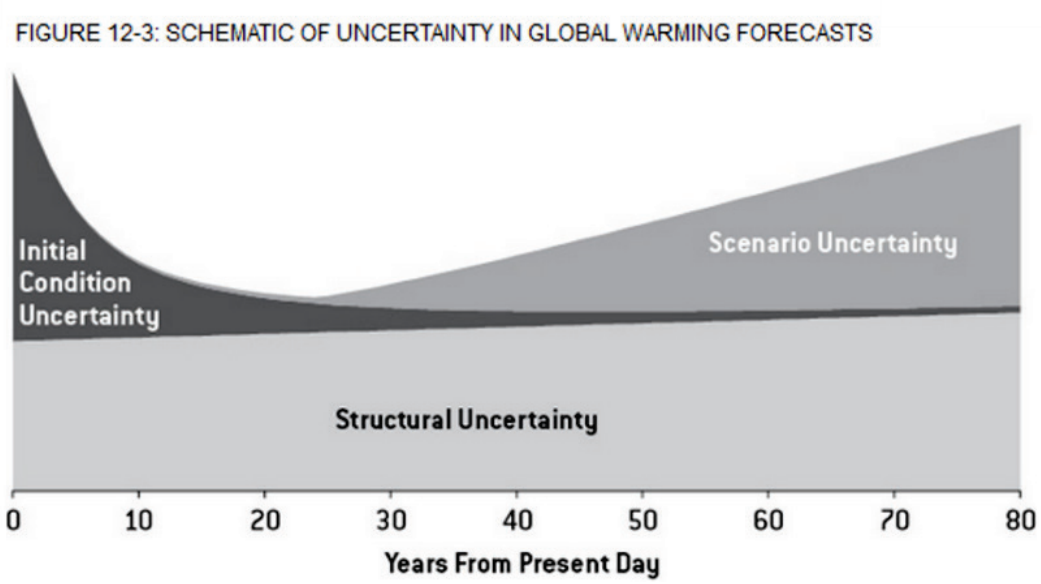
AT 10, Q4. In a sentence or two, state what Fig 12-3 shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

Figure 12-3 depicts the random factors that are inherent in global warming forecasts, through the three different types of uncertainty. The uncertainties are *initial condition uncertainty*, of *short term natural weather influxes*, structural uncertainty, of consistently difficult calculations, and scenario uncertainty, of long term atmospheric composition. This figure helps explain much of the skepticism revolving around climate change, as well as how some climate models can seem like a drastic over or underestimation. In class, we discussed the structural uncertainty of climate change predictions, noting that because of the unknown effect of aerosols in the atmosphere, the [future] increase in global temperature is currently [difficult to accurately forecast]. Should the aerosols be playing a significant role in limiting the effect of greenhouse gases already in the atmosphere, when the aerosols disperse the climate will be much warmer than anticipated and vice versa.



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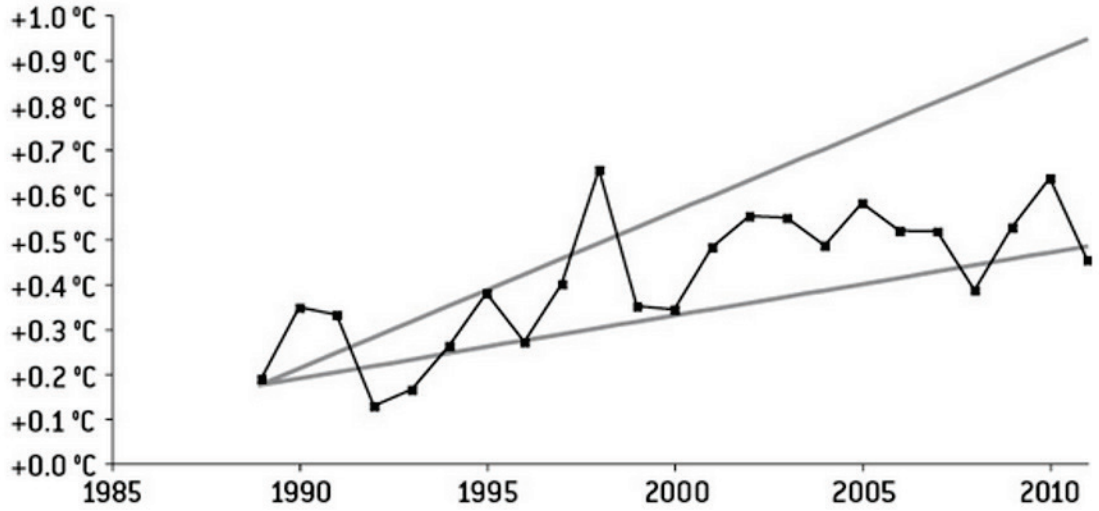
AT 10, Q4. In a sentence or two, state what Fig 12-7 shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

Figure 12.7 shows global temperatures from 1990 to 2011, relative to a baseline of temperatures from 1951 to 1980. It also shows the IPCC's temperature forecasts from 1990, in the form of two lines showing the low end and high end of the forecast. Since the statistical uncertainty of climate models levels off after about 20 years, and 2011 is 21 years after 1990, it was a good time to evaluate the IPCC's earliest forecast - and there was still a lot of year-to-year fluctuation, the average global temperature tended to tilt towards the lower line, suggesting that the IPCC's predictions were a bit high - though *Silver does mention that the IPCC's 1990 forecast was based on a "business as usual" trajectory.*

FIGURE 12-7: ACTUAL GLOBAL TEMPERATURES, 1990–2011 VS. 1990 IPCC FORECAST RANGE
Anomaly vs. 1951–1980 Baseline



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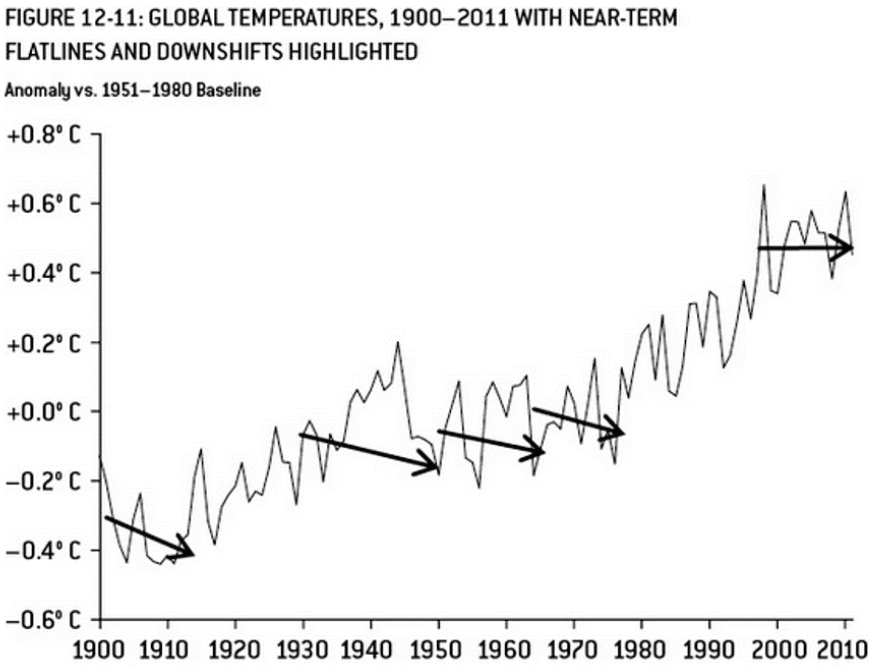
AT 10, Q4. In a sentence or two, state what Fig 12-11 shows, and then state how the chosen figure relates to the debate about climate change. Feel free to draw upon the book, other material, or your own intuition.

Figure 12-11 shows the global temperatures between 1900 and 2011 with near-term *flat-lines* and *downward shifts* highlighted. The figure mainly illustrates that global warming is not constantly increasing in a linear line. Instead, there are periods where temperatures flat-line or even decrease, but over time, global temperatures are still generally rising. This relates to the debate about climate change as *some argue that global temperatures are not rising and point to the periods of time when temperatures flat-line or decline*. However, the issue of global temperature rise should not be looked at under a lens, but instead viewed as the bigger picture. Even though temperatures might fluctuate, *overall they follow an upward trend*, which means that global temperature rise is a long term problem that needs to be solved.



Impacts of Climate Change

Luke Lu

8 October 2019

Impacts of Climate Change

Impacts of Climate Change

- Increased wildfires

Impacts of Climate Change

- Increased wildfires
- Sea level rise

Impacts of Climate Change

- Increased wildfires
- Sea level rise
- Ocean acidification

Impacts of Climate Change

- Increased wildfires
- Sea level rise
- Ocean acidification
- Spread of disease

Impacts of Climate Change

- Increased wildfires
- Sea level rise
- Ocean acidification
- Spread of diseases

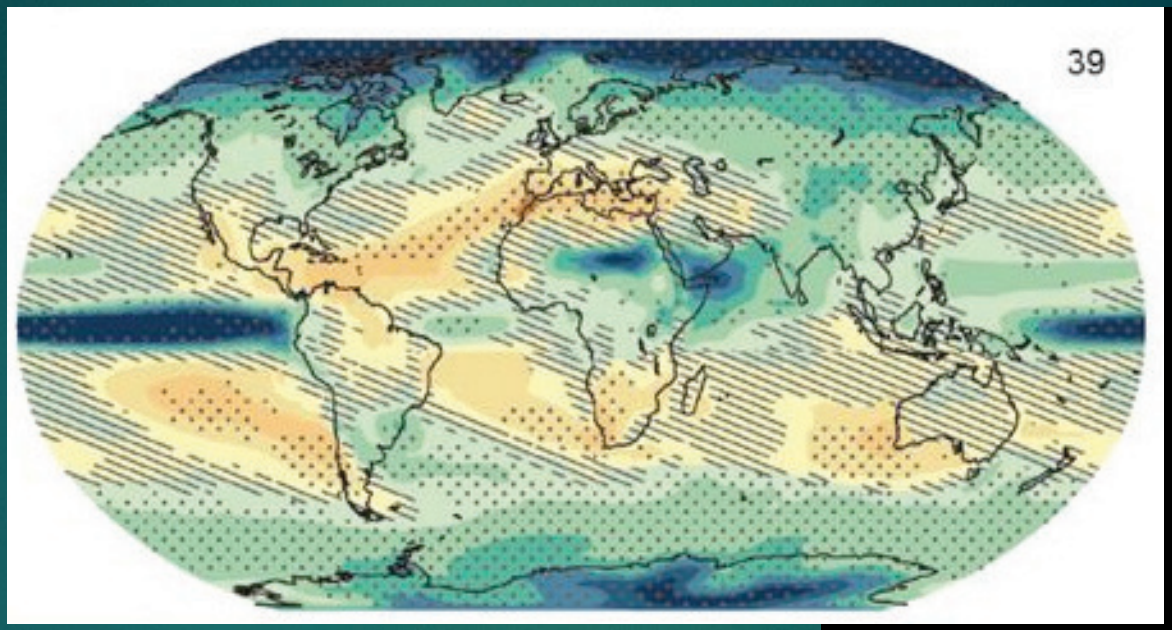
Also:

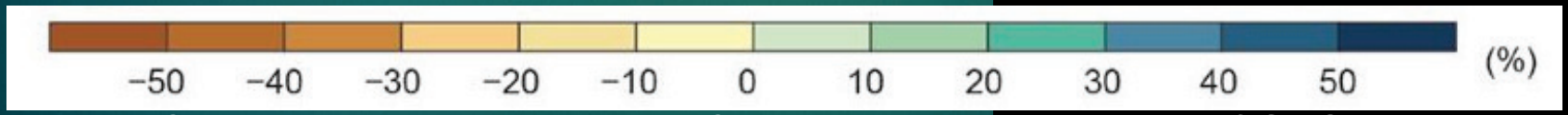
- Increased droughts and flooding
- Melting icecaps and glaciers
- Destruction of marine ecosystems
- Increased extreme weather
- Agricultural disruption
- Water supply disruption
- Environmental migration

https://www.ucsusa.org/our-work/global-warming/science-and-impacts/global-warming-impacts#.W4CXQ8PPyUk

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

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



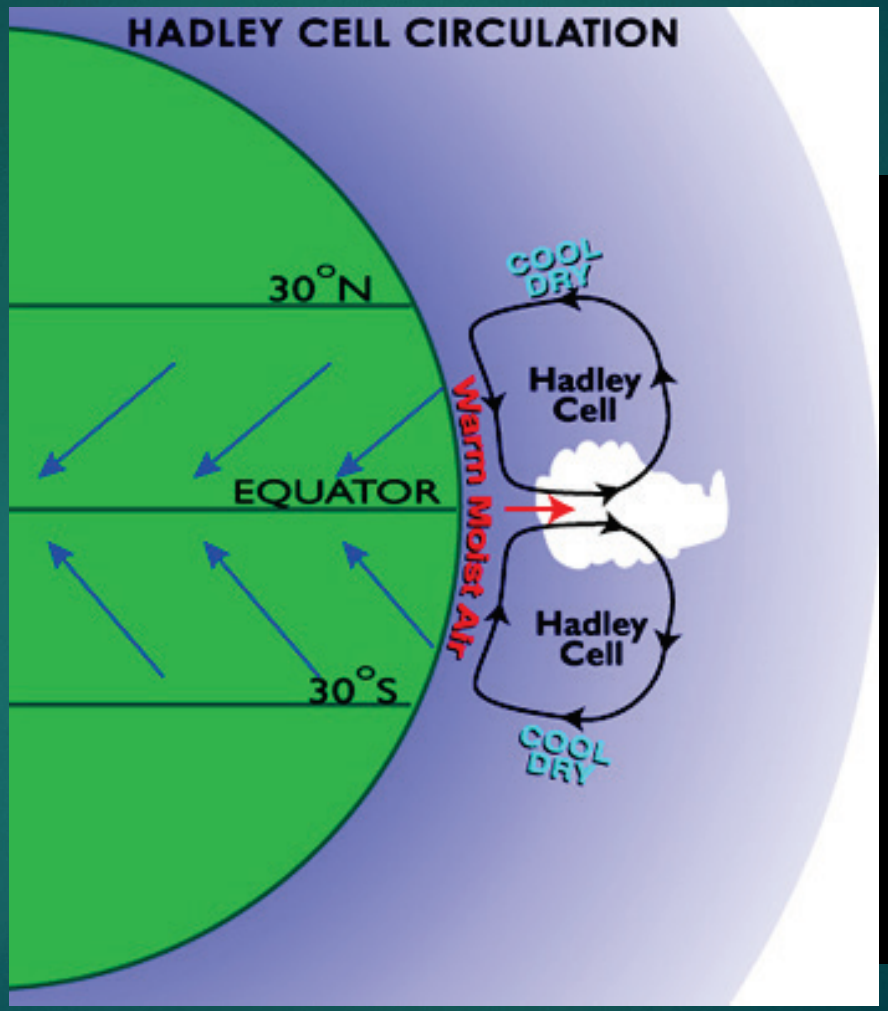


Climate model projections, RCP 8.5 (aggressive growth of GHGs)

IPCC 2013

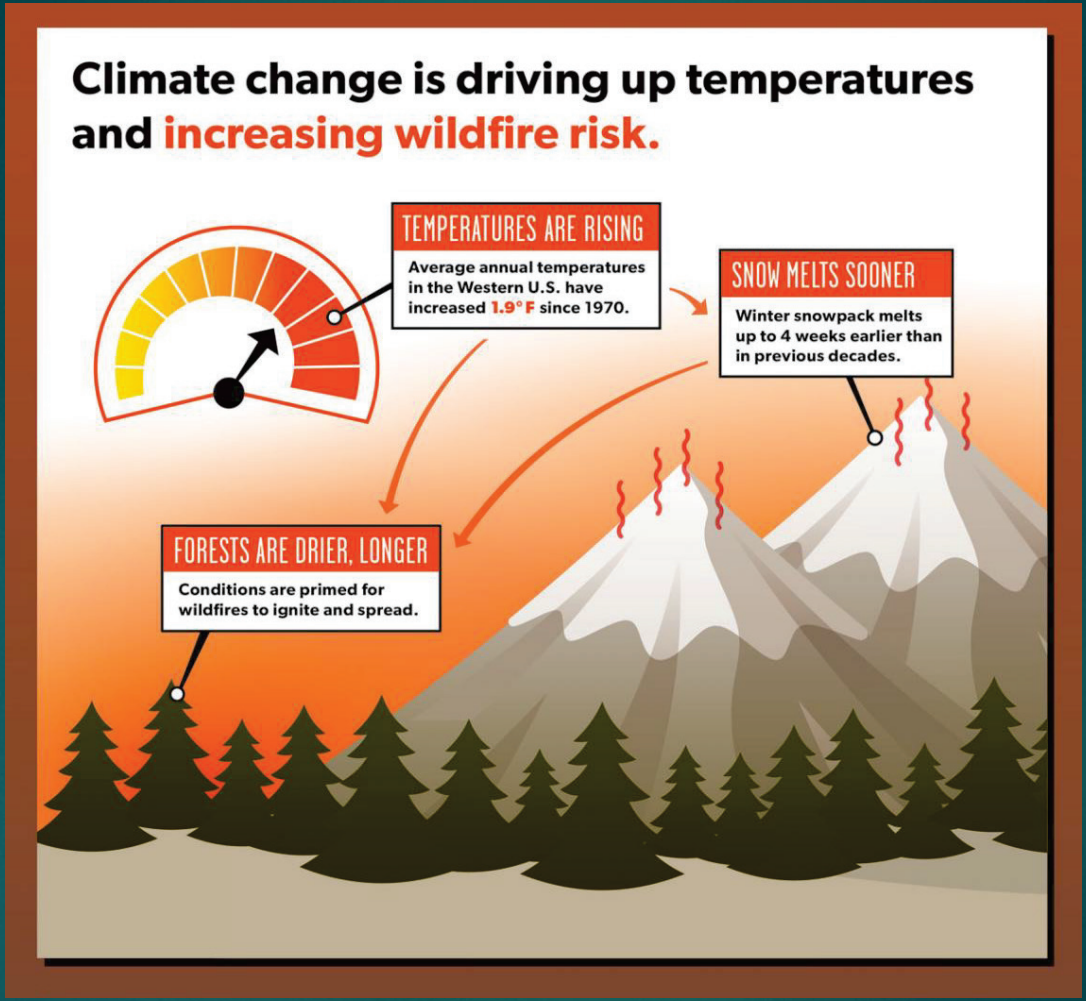
https://www.cnbc.com/2017/08/28/the-stunning-images-from-record-setting-flooding-in-houston-texas.html

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

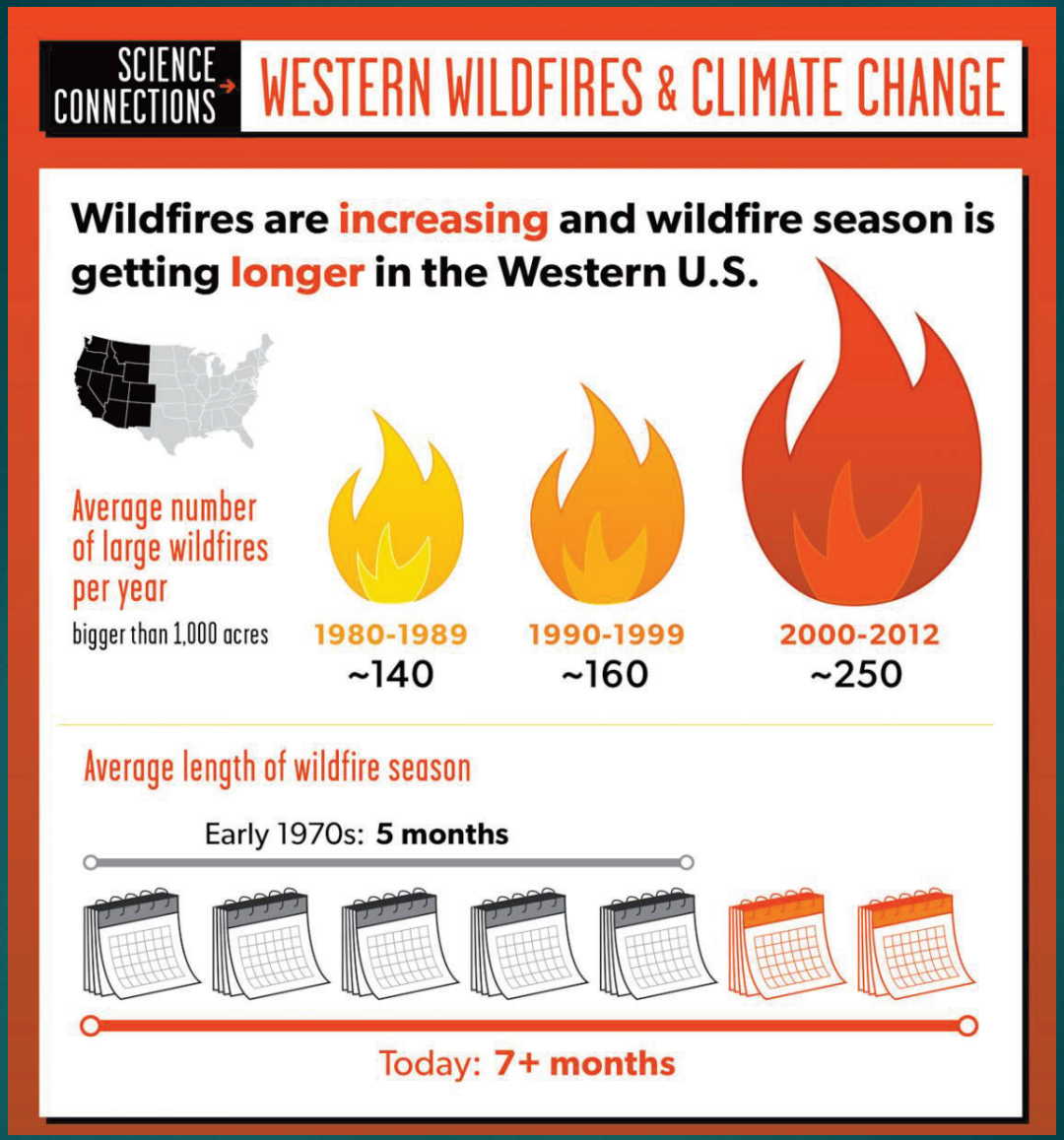


http://www.windows2universe.org/vocals/images/HadleyCell_small.jpg

Wildfires



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



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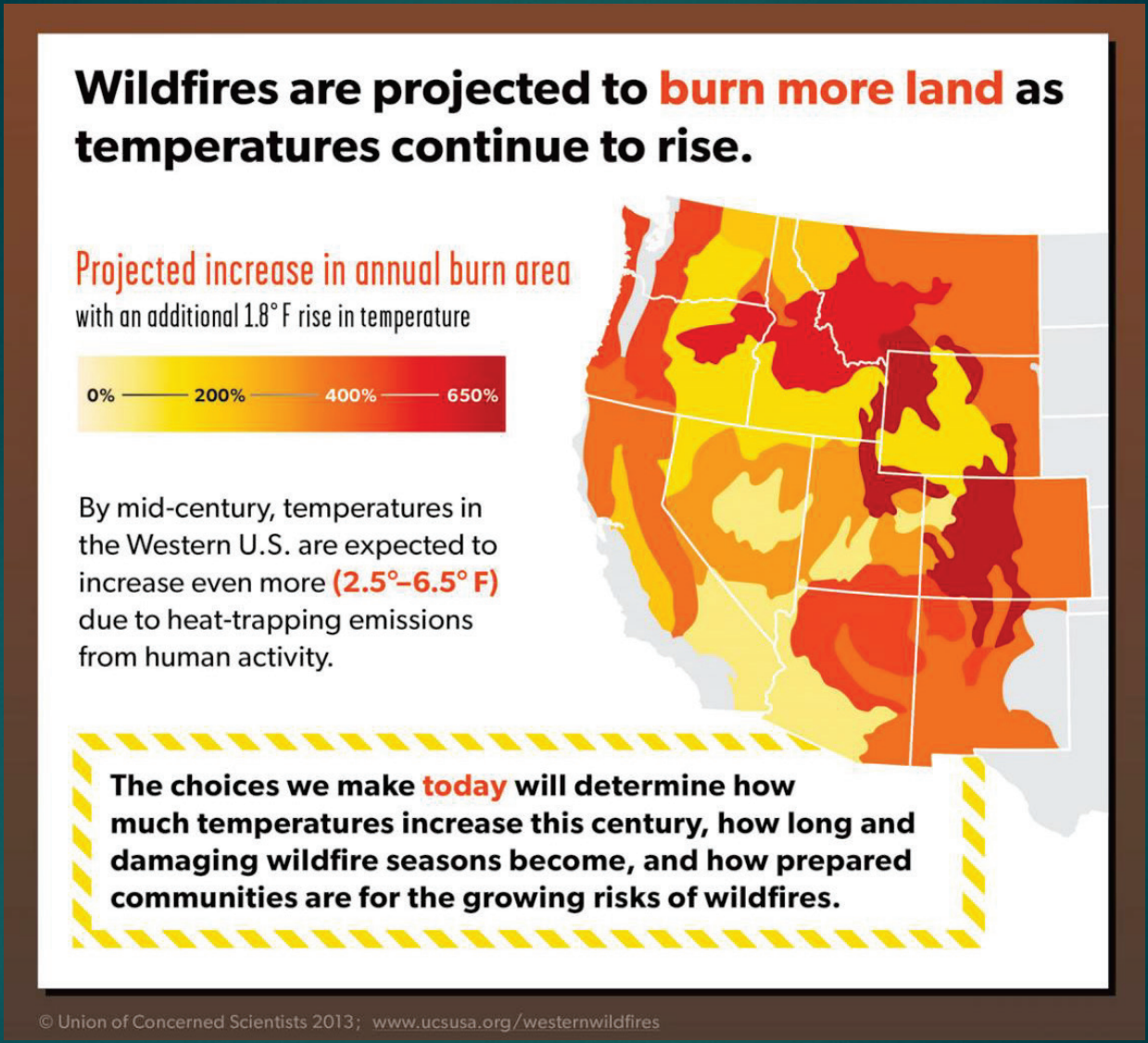
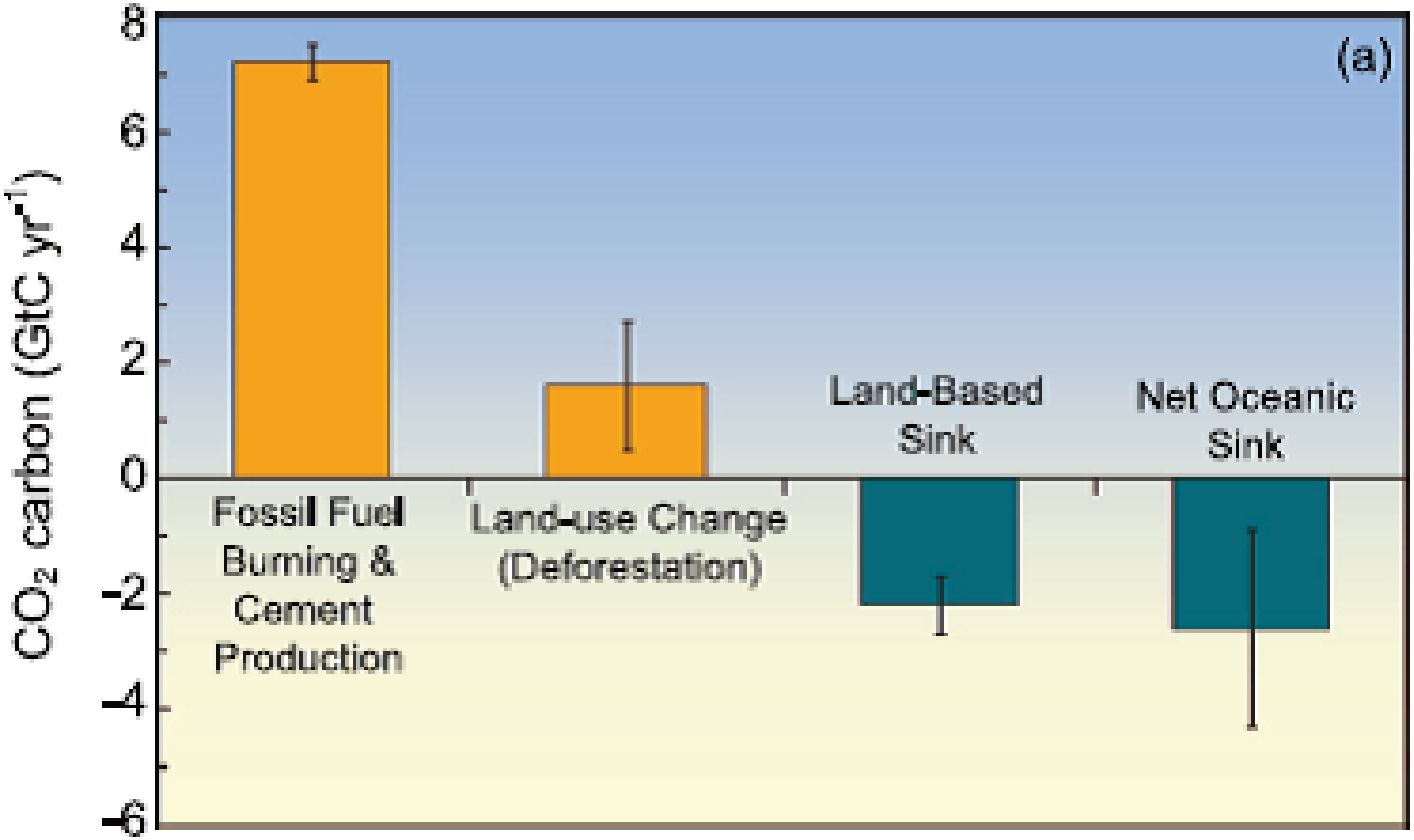
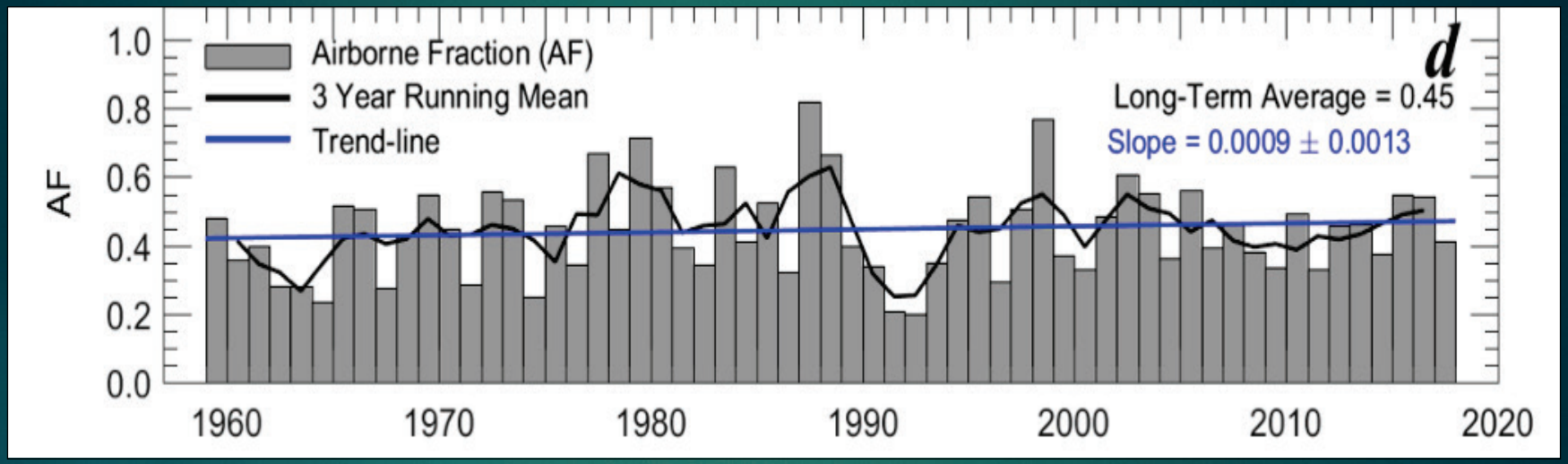


https://www.ucsusa.org/global-warming/science-and-impacts/impacts/infographic-wildfires-climate-change.html

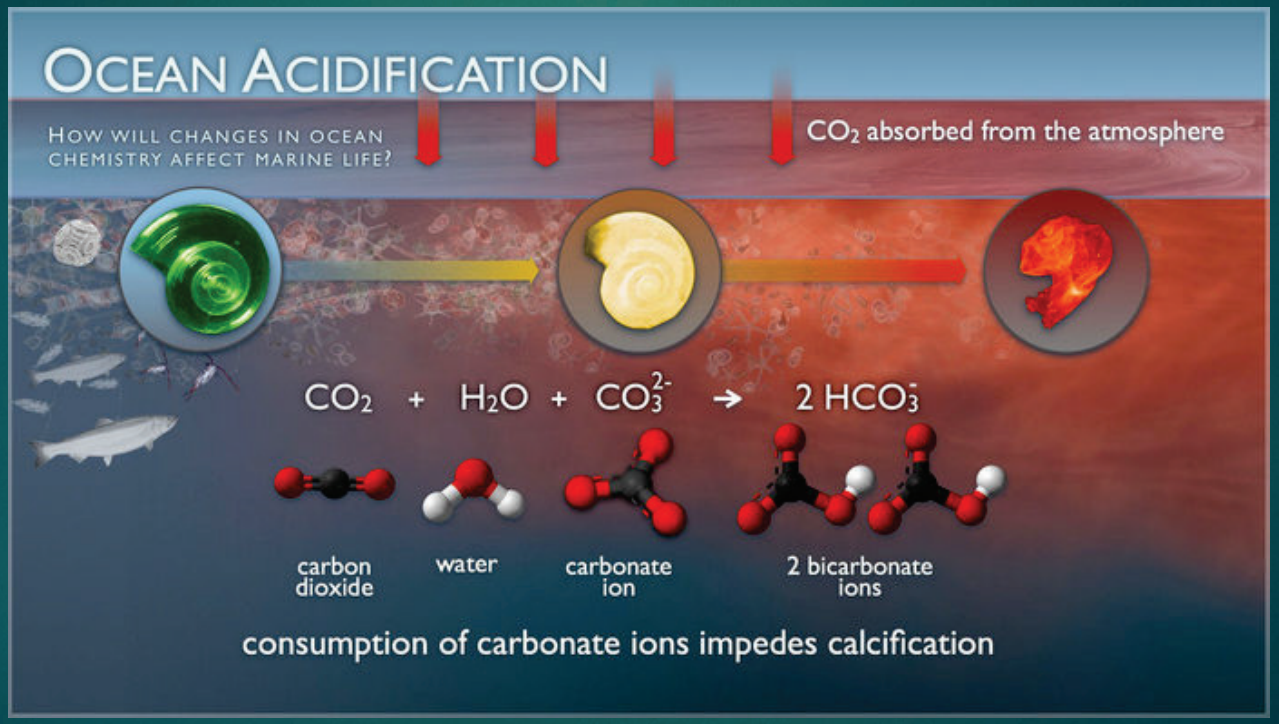
Ocean Acidification





Caption: (***a***) Time series of CO_2 (global mean as well as amount measured at Mauna Loa Observatory; (***b***) total anthropogenic emissions of CO_2 from fossil fuel & land use change (green bars) atmospheric growth (blue bars) and major volcanic eruptions (red triangle, for Mt Agung, El Chichón, Fuego, and Mt Pinatubo); (***c***) tropical Pacific ENSO 3.4 index (red denotes El Niño events; blue denotes strong La Niña conditions); and (d) Airborne Fraction of CO_2 (i.e., amount that remains in the atmosphere each year), three 3 yr running mean of AF (black), and trend-line of a least squares fit to the 3 yr running mean (blue).

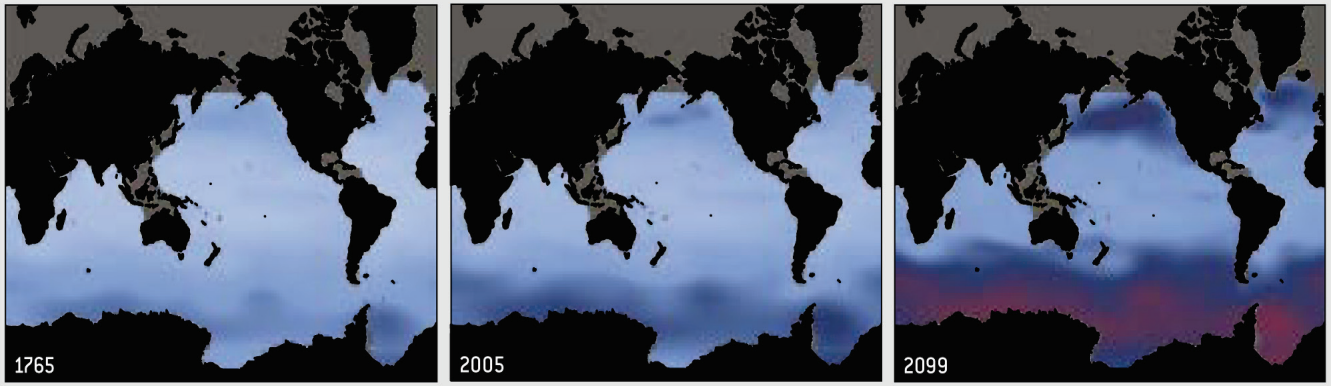
Atmospheric CO_2	280 ppm Pre-Industrial	400 ppm Present Day	560 ppm 2 × Pre-Indus.
pH	8.32	8.19	8.06



https://www.pmel.noaa.gov/co2/story/Ocean%2BAcidification

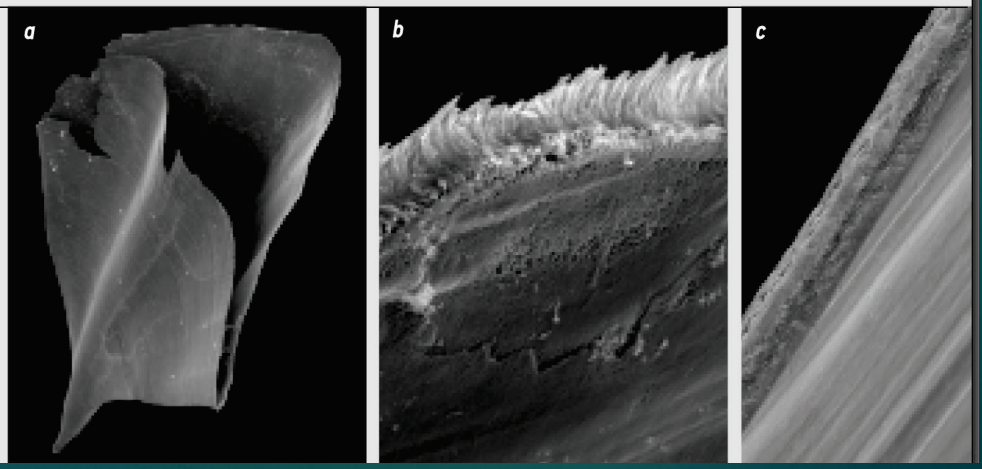
THE (RAGGED) FUTURE OF ARAGONITE

Diminishing pH levels will weaken the ability of certain marine organisms to build their hard parts and will be felt soonest and most severely by those creatures that make those parts of aragonite, the form of calcium carbonate that is most prone to dissolution. The degree of threat will vary regionally.



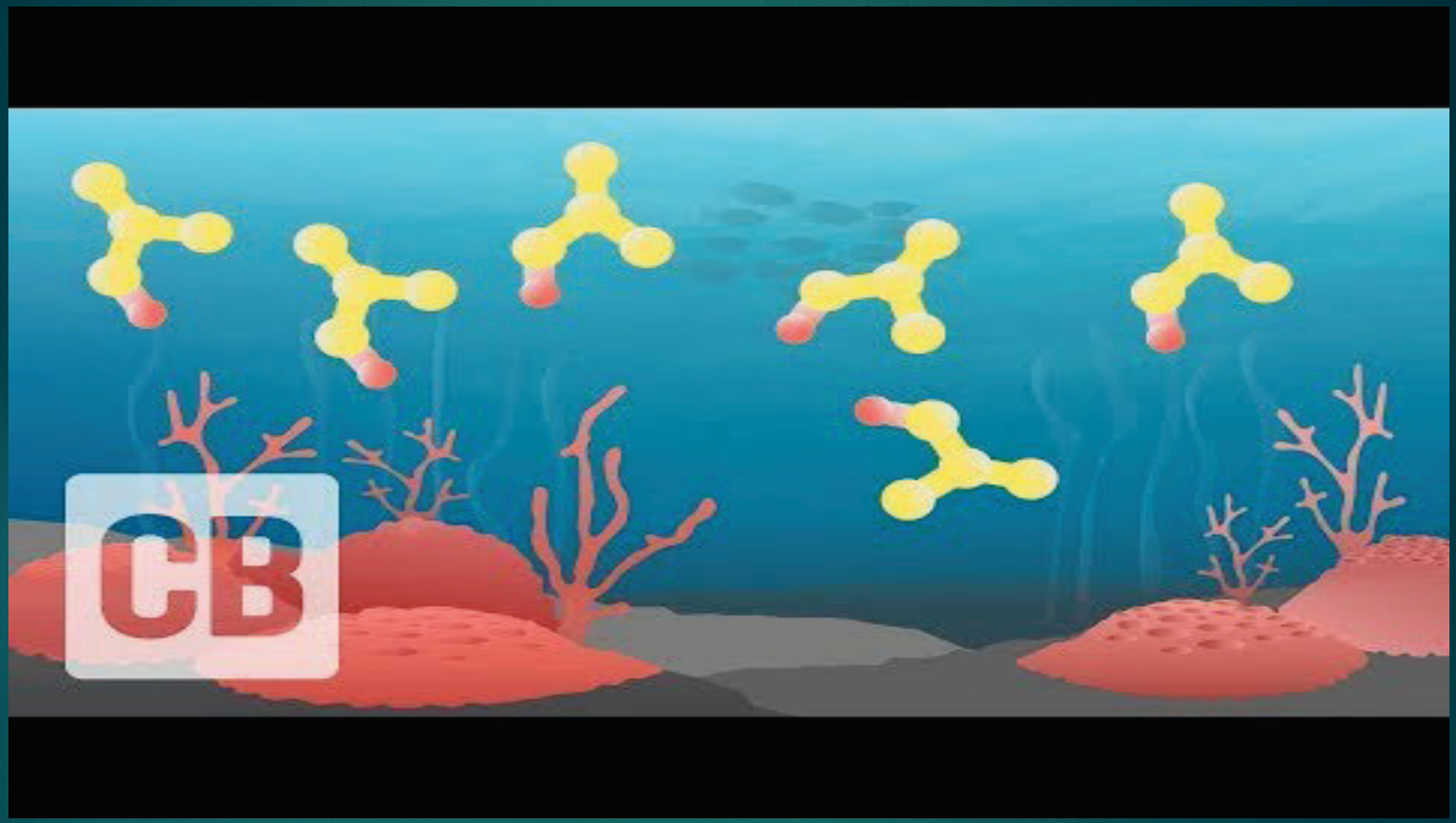
Before the Industrial Revolution (*left*), most surface waters were substantially "oversaturated" with respect to aragonite (*light blue*), allowing marine organisms to form this mineral readily. But now (*center*), polar surface waters are only marginally oversaturated (*dark blue*). At the end of this century (*right*), such chilly waters, particularly those surrounding Antarctica, are expected to become undersaturated (*purple*), making it difficult for organisms to make aragonite and causing aragonite already formed to dissolve.

Pteropods form a key link in the food chain throughout the Southern Ocean. For these animals (and creatures that depend on them), the coming changes may be disastrous, as the images at the right suggest. The shell of a pteropod kept for 48 hours in water undersaturated with respect to aragonite shows corrosion on the surface (*a*), seen most clearly at high magnification (*b*). The shell of a normal pteropod shows no dissolution (*c*).



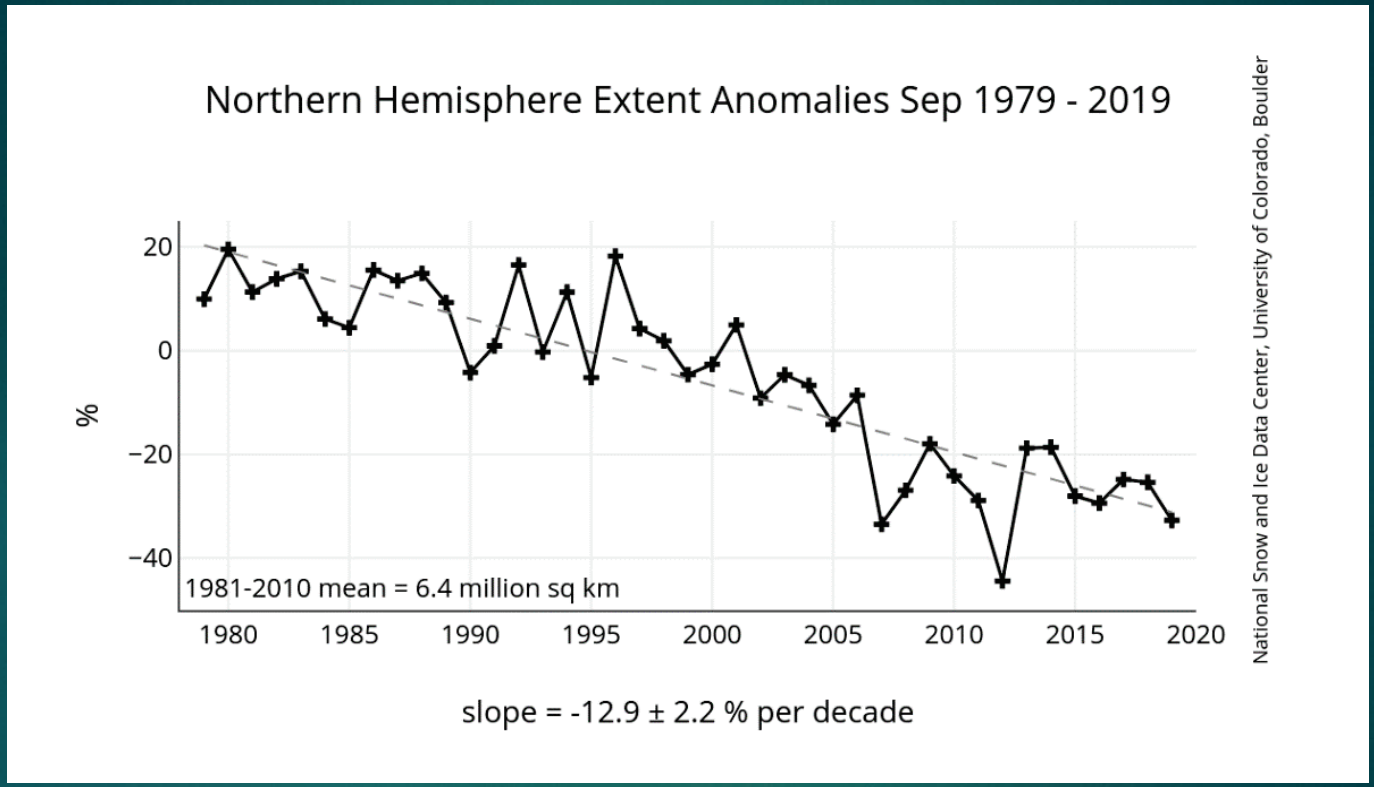
Doney, The Dangers of Ocean Acidification, *Scientific American*, March, 2006

Also, coral:



https://www.youtube.com/watch?v=ccYvlbcBITY

Sea Level Rise



https://nsidc.org/data/seaice_index

What effect do you think floating ice has on sea level?

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- Brine rejection – salt doesn't freeze into ice crystals
- Salt water is denser than fresh water
- Ice is fresh
- Ice melts -> water becomes less salty -> water becomes less dense -> water rises

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How much of sea level rise does melting sea ice contribute?

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How much of sea level rise does melting sea ice contribute?

- About 1.6%

https://skepticalscience.com/Sea-level-rise-due-to-floating-ice.html

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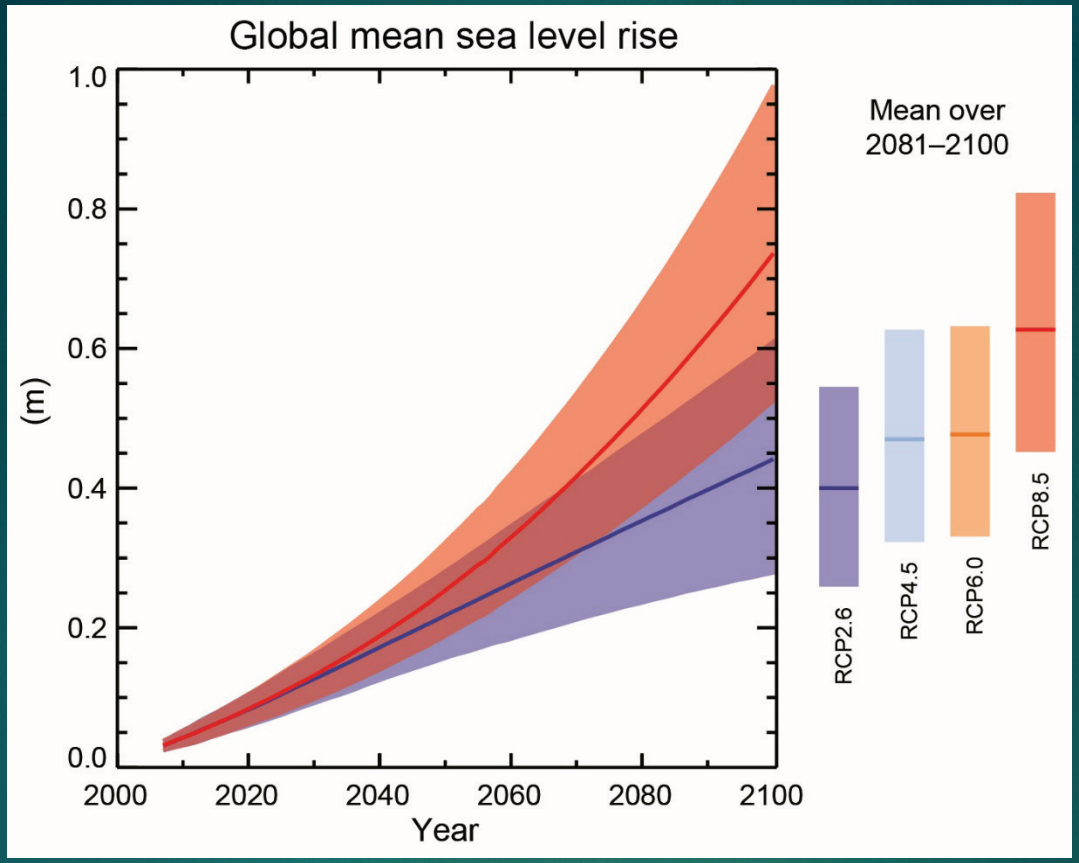
How much of sea level rise does melting sea ice contribute?

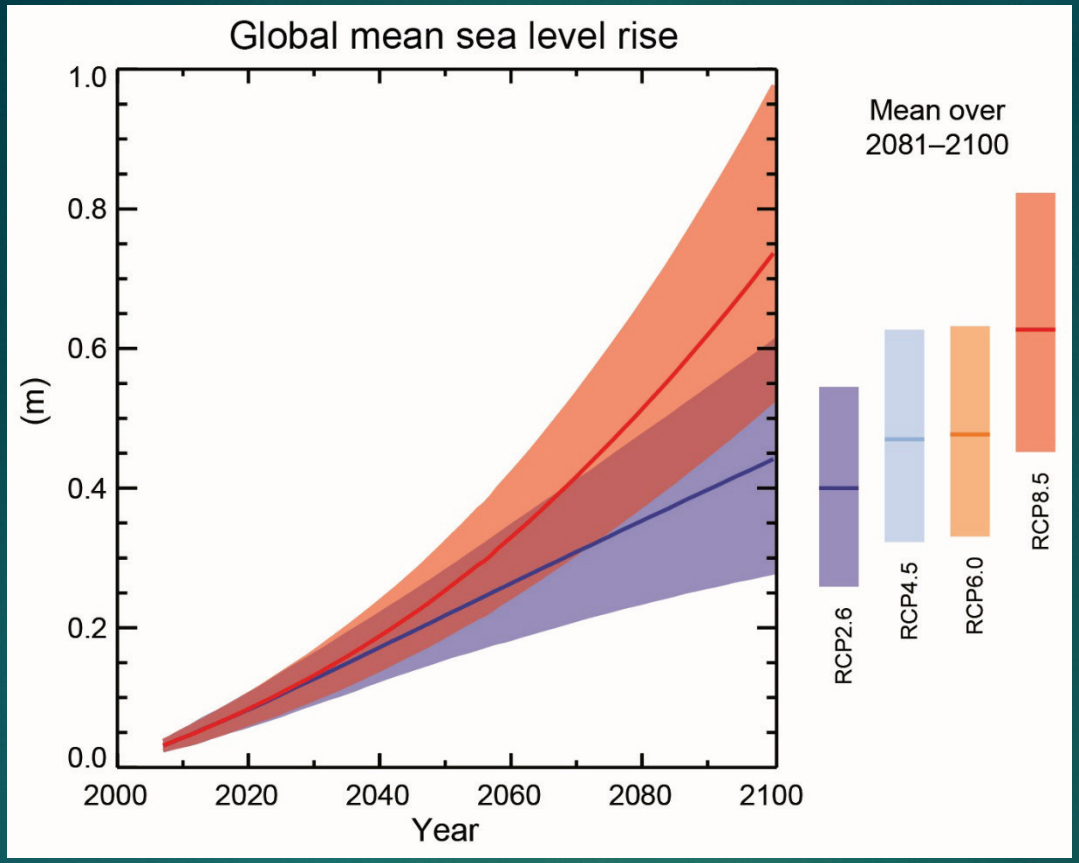
- About 1.6%
- Most sea level rise comes from melting land ice and thermal expansion

https://skepticalscience.com/Sea-level-rise-due-to-floating-ice.html



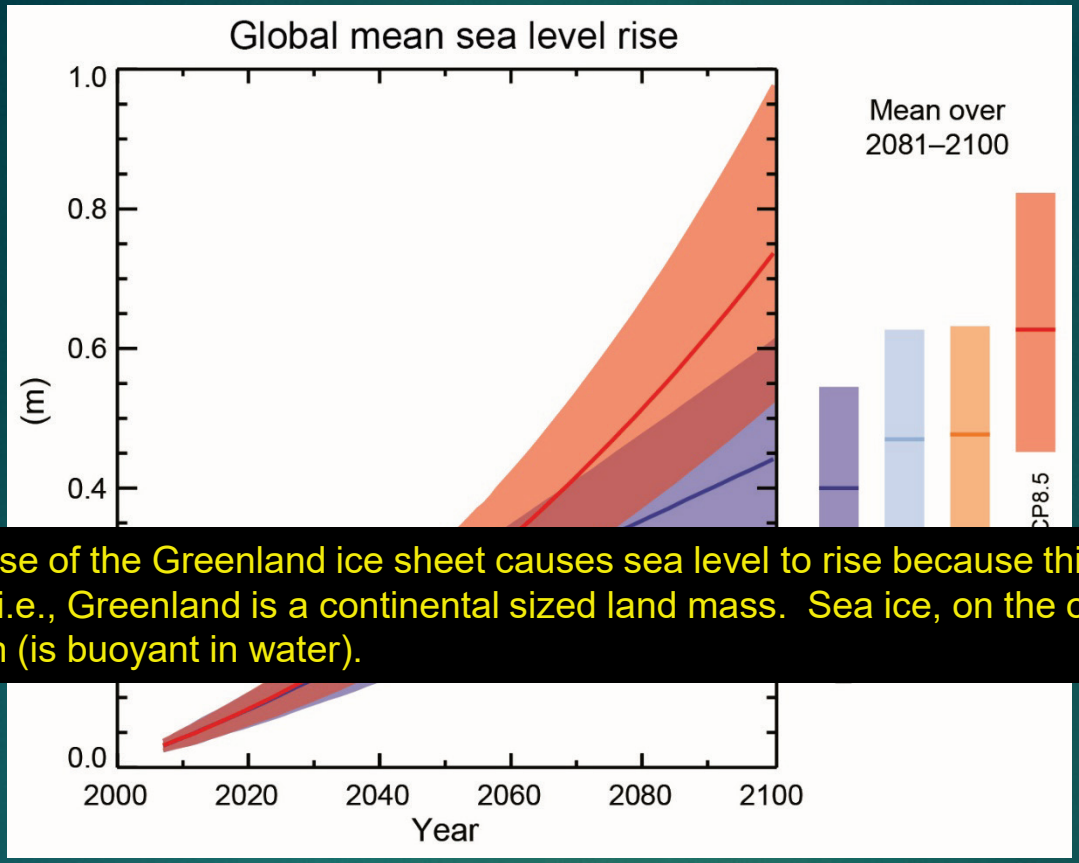
By the way, how much would sea level rise if the entire Greenland ice sheet melted?

http://www.atmos.umd.edu/~rjs/class/honr229L/readings/WG1AR5_SPM_FINAL_carbon.pdf



By the way, how much would sea level rise if the entire Greenland ice sheet melted?
Answer: 7 meters

http://www.atmos.umd.edu/~rjs/class/honr229L/readings/WG1AR5_SPM_FINAL_carbon.pdf



Note: collapse of the Greenland ice sheet causes sea level to rise because this ice sheet lies on top of land: i.e., Greenland is a continental sized land mass. Sea ice, on the other hand, lies on top of the ocean (is buoyant in water).

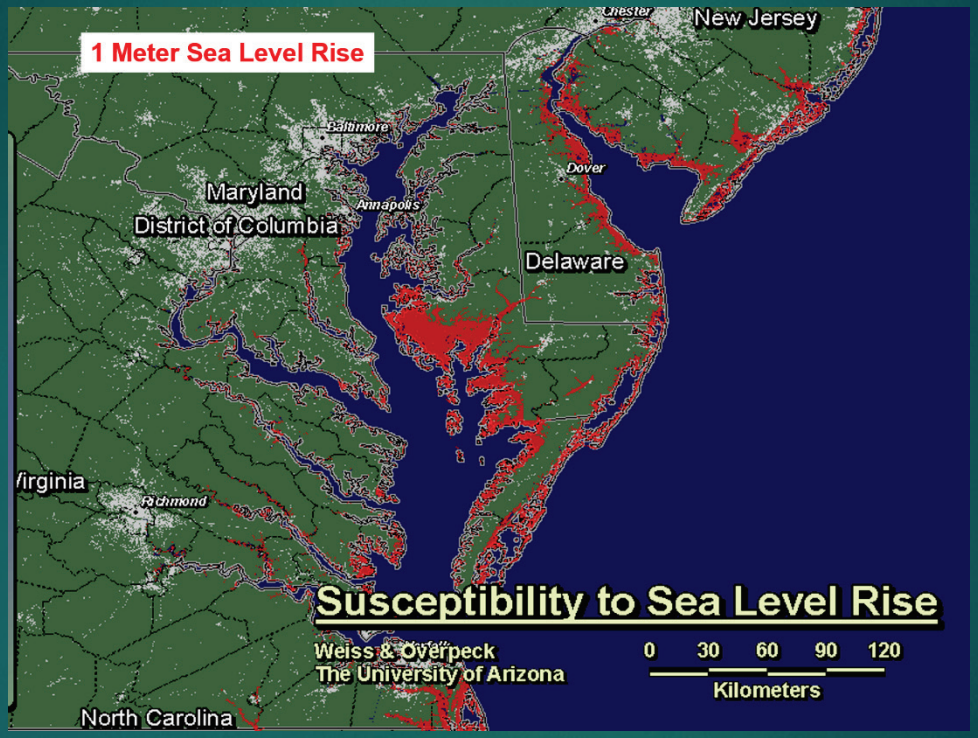
By the way, how much would sea level rise if the entire Greenland ice sheet melted?
Answer: 7 meters

http://www.atmos.umd.edu/~rjs/class/honr229L/readings/WG1AR5_SPM_FINAL_carbon.pdf

Sea level today:

Source: Jeremy Weiss and Jonathan Overpeck, University of Arizona

Sea level by 2100 (RCP 8.5 scenario)



Source: Jeremy Weiss and Jonathan Overpeck, University of Arizona

Sea level if most of Greenland's ice sheet melts:

Source: Jeremy Weiss and Jonathan Overpeck, University of Arizona

Water levels today, 5 feet higher than today, 12 feet, and 25 feet higher

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

Infectious Disease

How does global warming increase the spread of disease?

How does global warming increase the spread of disease?

- Increased rainfall creates more potential breeding grounds for mosquitoes
- Increased temperature extends transmission season for certain diseases
- Increased droughts cause malnutrition
- Increased droughts and flooding affect clean water supply (cholera)
- Habitat destruction brings animals closer to humans

Cholera

- Caused by bacteria *Vibrio cholerae*
- Thrives in aquatic environments
- Can cause vomiting, fever and (extreme) diarrhea
- Mainly affects regions with poor water sanitation and crowded living conditions

Cholera

- Caused by bacteria *Vibrio cholerae*
- Thrives in aquatic environments
- Can cause vomiting, fever and (extreme) diarrhea
- Mainly affects regions with poor water sanitation and crowded living conditions
- High temperatures and rainfall create good conditions for bacterial growth
- Rising seas contaminate clean water
- Droughts concentrate the bacteria
- Floods bring bacteria to new places

Ebola

- Caused by ebolaviruses
- Symptoms start about 2-3 weeks after infection, with fever, headache, vomiting, and diarrhea
- Leads to internal and external bleeding
- Virus lives in apes and bats

Ebola

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- Symptoms start about 2-3 weeks after infection, with fever, headache, vomiting, and diarrhea
- Leads to internal and external bleeding
- Virus lives in apes and bats
- Deforestation causes more animals to come in contact with humans
  - Habitat destruction causes animals to relocate closer to humans
- Global warming may be expanding bat ranges
- Agricultural disruption drives increased bushmeat consumption

Other diseases affected by climate change

- Malaria
- Dengue fever
- Schistosomiasis
- Hantavirus
- Lyme disease
- West Nile virus
- Chikungunya
- Yellow fever
- Rift Valley fever

Impacts of Climate Change: The Last Word

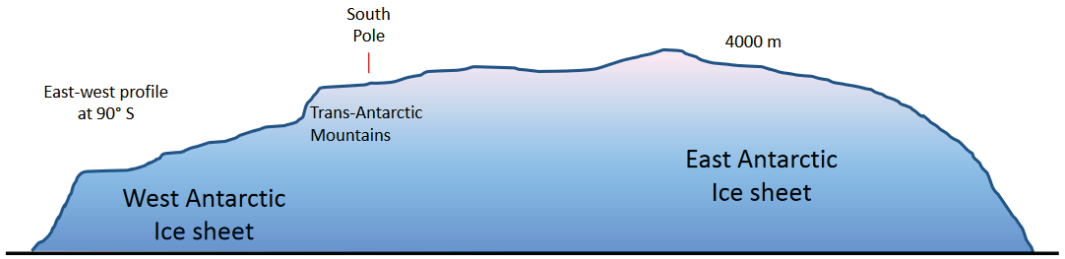
Ross Salawitch

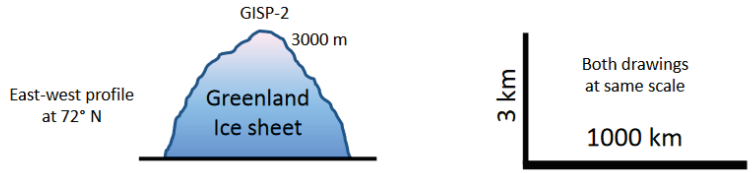
9 October 2018

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!

Wed, Oct 10, 2018

Newsweek

SIGN IN SUBSCRIBE >

TECH & SCIENCE

SEA LEVEL RISE COULD REACH 50 FEET BY 2300, DEVASTATING COASTAL CITIES GLOBALLY

BY ARISTOS GEORGIOU ON 10/9/18 AT 12:31 PM

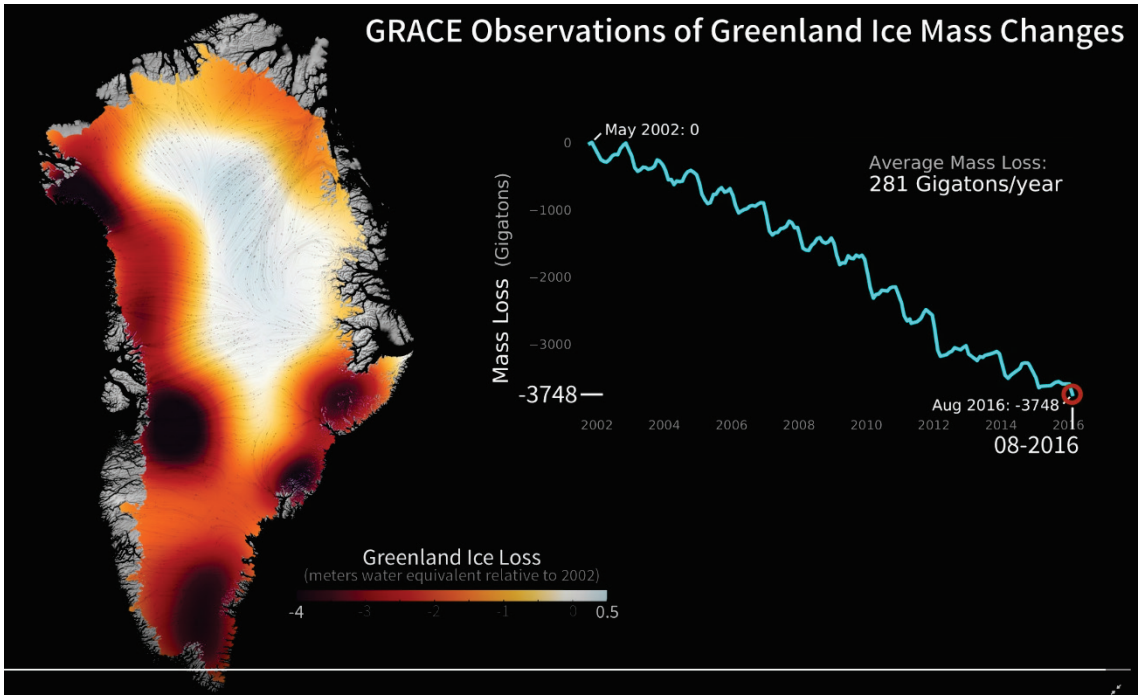
The global average sea level could rise nearly 50 feet by 2300 if greenhouse gas emissions remain high, according to a study published in the journal *Annual Review of Environment and Resources*.

An international team of scientists reviewed research on sea-level change in order to synthesize our current understanding of the topic and help make better projections for the future. In the paper, they summarize this understanding over the near, medium and long terms.

Sea level rise varies over location and time, and researchers have developed a range of methods to reconstruct past changes and project future ones. But despite the different approaches, the evidence from the reviewed studies reveals clear trends, although the uncertainty of future projections increases over time.

"Our review of the literature shows that central estimates of future sea level range from 0.2 to 0.3 meters [0.7-1 feet] by 2050; 0.4 to 1.5 meters by 2100; 0.6 to 4.1 meters by 2150; and 1.0 to 11.7 meters by 2300, with projections for high emissions scenarios reaching as high as 2.4 meters in 2100 and 15.5 meters in 2300," Robert Kopp, a professor in the department of Earth and planetary sciences at Rutgers University and an author of the study, told *Newsweek*.

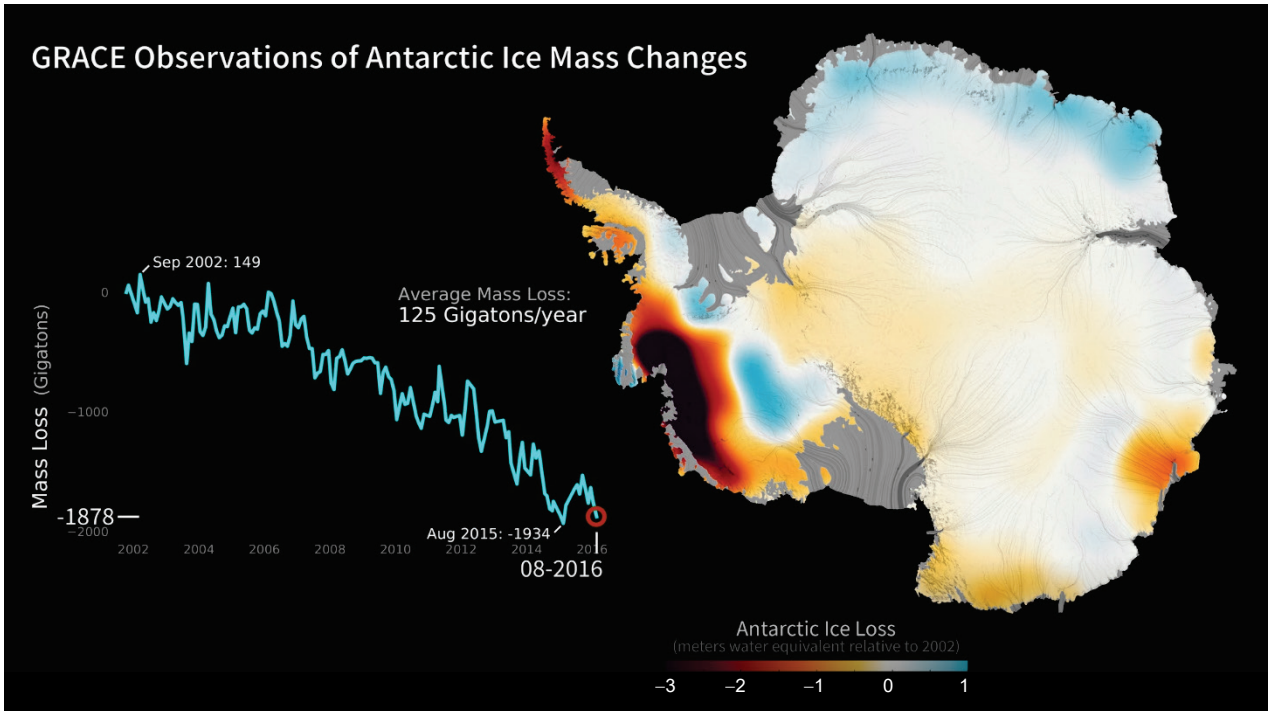
https://www.newsweek.com/sea-level-rise-could-reach-50-feet-2300-devastating-coastal-cities-globally-1160279



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

HONR 229L: Climate Change: Science, Economics, and Governance



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

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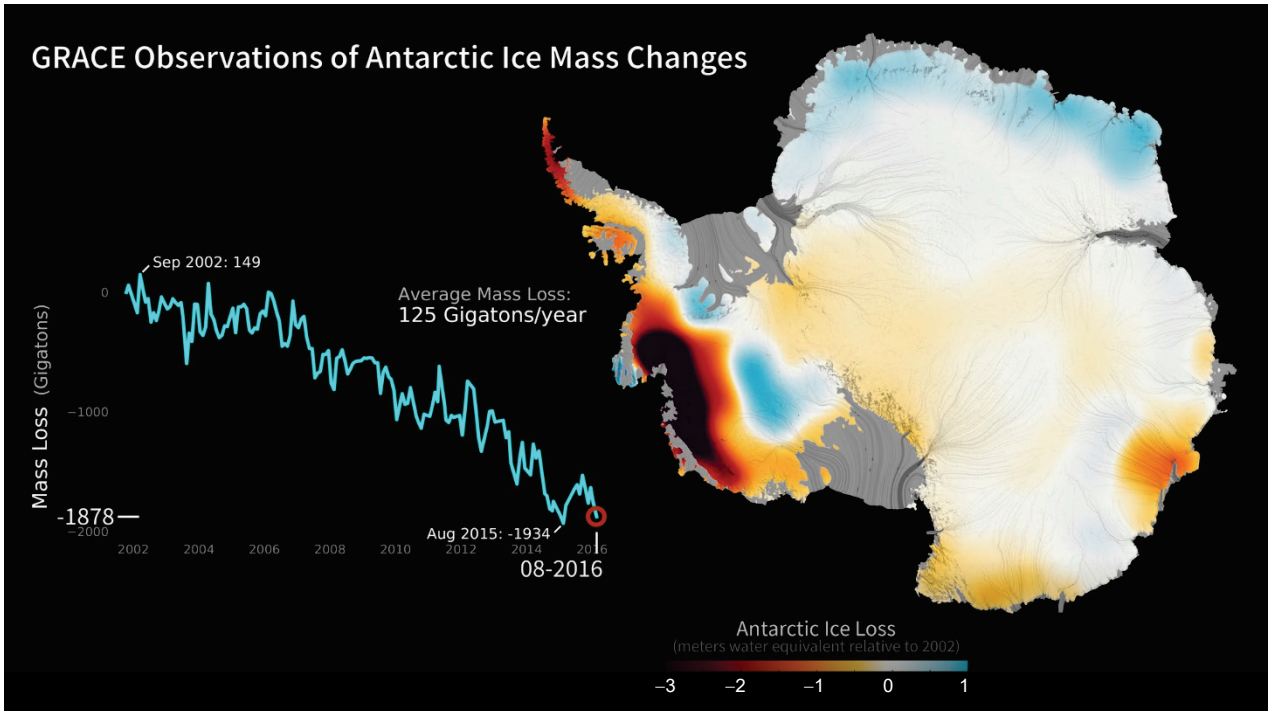

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Steve Case

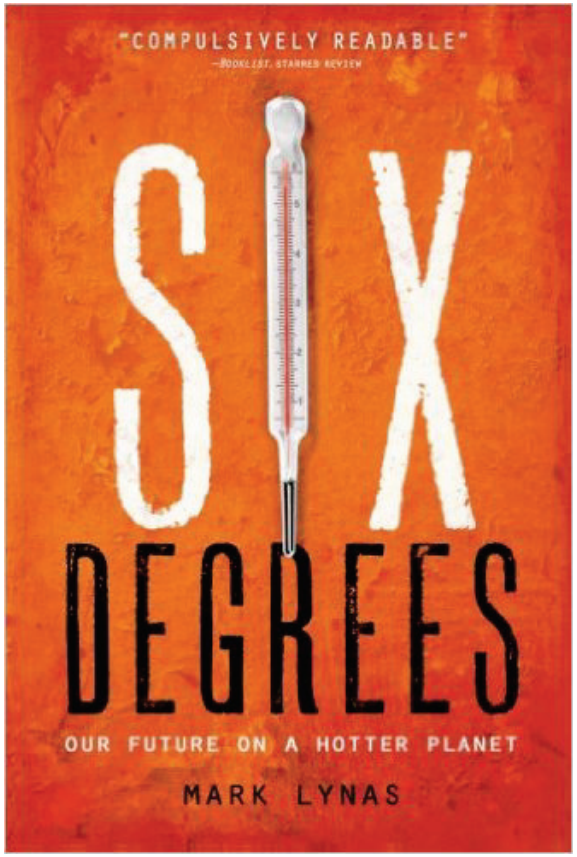
50 feet by 2300 comes to 54 mm/yr every year for the next 282 years starting right now. The current rate of sea level rise is around 3 mm/yr. Why anyone takes claims like this seriously is a mystery.

Steve Case - Milwaukee, WI

Current rate of sea level rise from satellite altimetry 3.0 ± 0.4 millimetres (0.118 ± 0.016 in) per year, for 1993–2017.
1.18 inch per decade or ~foot per century
https://en.wikipedia.org/wiki/Sea_level_rise

Possible Impacts of Climate Change

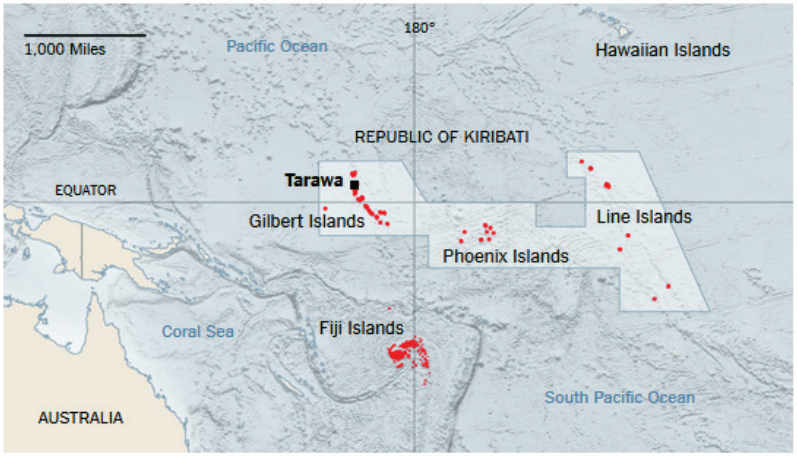
- **1°C (already committed to this)**
  - Loss of glacial waters in Africa & Asia, with regional declines in food production
  - Tropical islands such as Tuvalu, ***Kiribati***, Marshall Islands, and Maldives severely threatened



Book: https://www.amazon.com/Six-Degrees-Future-Hotter-Planet
Summary: http://www.sustainablewoodstock.co.uk/onetwo%20degrees%20summary.pdf

Kiribati: Population 118,000 as of 2018

- Undergoing intrusion of salt water into freshwater supplies
- Some farmers unable to grow food because of saltwater intrusion



High tide keeps getting higher 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.

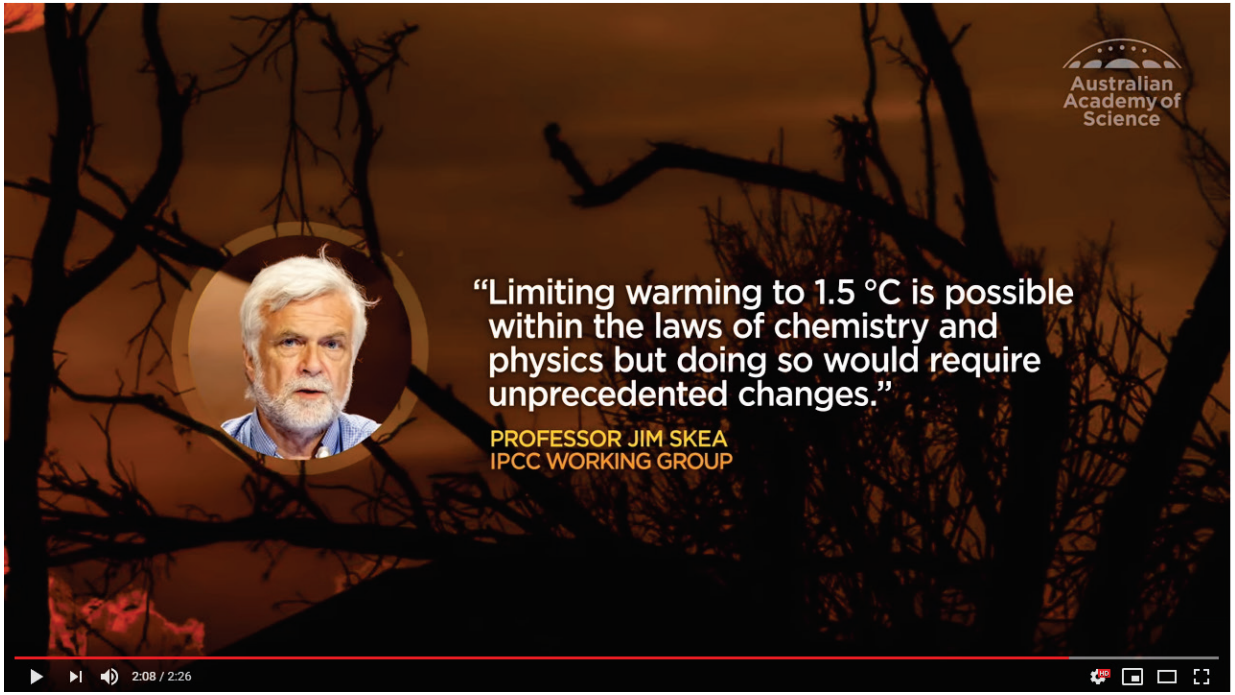
Pacific islanders' identities are very much tied to their ancestral land, the physical islands on which they live. Migration may mean a national and cultural loss, especially when most traditions are preserved orally.

https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html
https://thewire.in/culture/kiribati-migration-climate-change

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

Six Degrees: Our Future on a Hotter Planet by Mark Lynas



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

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

HONR 229L: Climate Change: Science, Economics, and Governance

Reading for Thurs:

Please read either

a) Chapter 2 (30 pages; solar PV)

OR

b) Chapter 3 (29 pages; concentrated solar)

but everyone please *read from the words "THESE PHOTOVOLTAIC INVENTORS" on pg 40 to the end of Chapter 2 (middle page 44), because this section on feed-in tariff, carbon tax, and cap-and-trade are vitally important for the rest of the semester.*

Abhay will have to read both. This material is a breeze to read.

Have posted an AT for both chapters; please complete only one.

How many students need a copy of the reading from us?

Energy and Power

Simple equation connects energy and power:

Energy = Power $\times$ Time

Size of a **power** plant is commonly measured in units of power:

kW (kilo: 10^3 Watts): Home solar

MW (mega: 10^6 Watts) Industrial

GW (giga: 10^9 Watts): Massive Hydroelectric

TW (terra: 10^{12} Watts): Large Nation and/or Global

(Footnote, pg 18, Krupp & Horn)

Output of a **power** plant in units of energy:

kWh (kilo: 10^3 W hour)

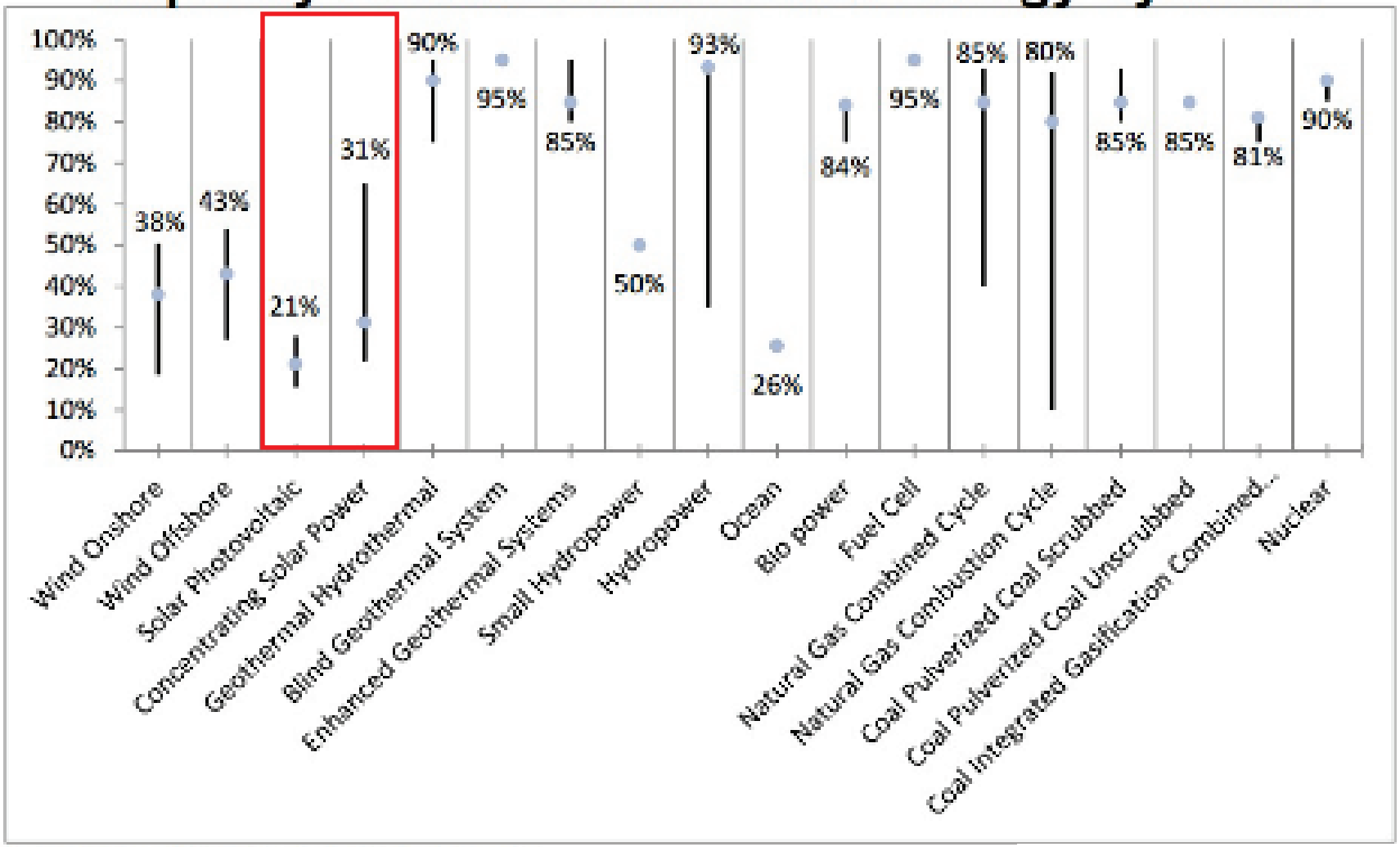
MWh (mega: 10^6 W hour)

GWh (gig: 10^9 W hour)

Capacity Factor: actual output of a power plant (energy) divided by maximum output if plant could run 24/7/365 at full capacity

(Footnote, pg 47, Krupp & Horn)

Capacity Factors for Assorted Energy Systems



Source: DOE and NREL "Transparent Costs Database"
Note: Blue dots represent estimate for the average capacity factor of each technology.

http://www.lightevolution.co.uk/blog/geothermal-visual-capacity-factors-for-assorted-energy-systems/