Climate Change

An Imminent Risk

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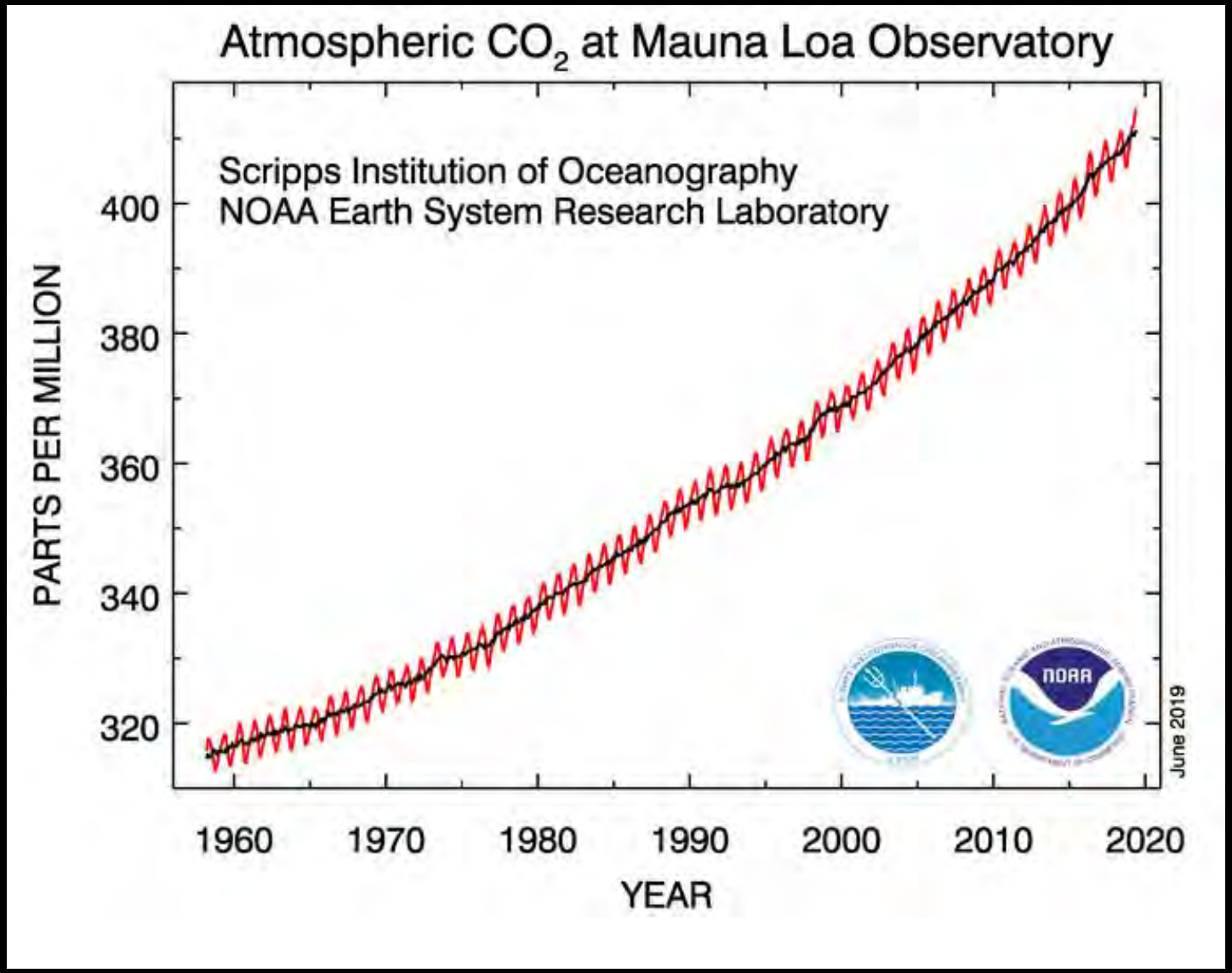
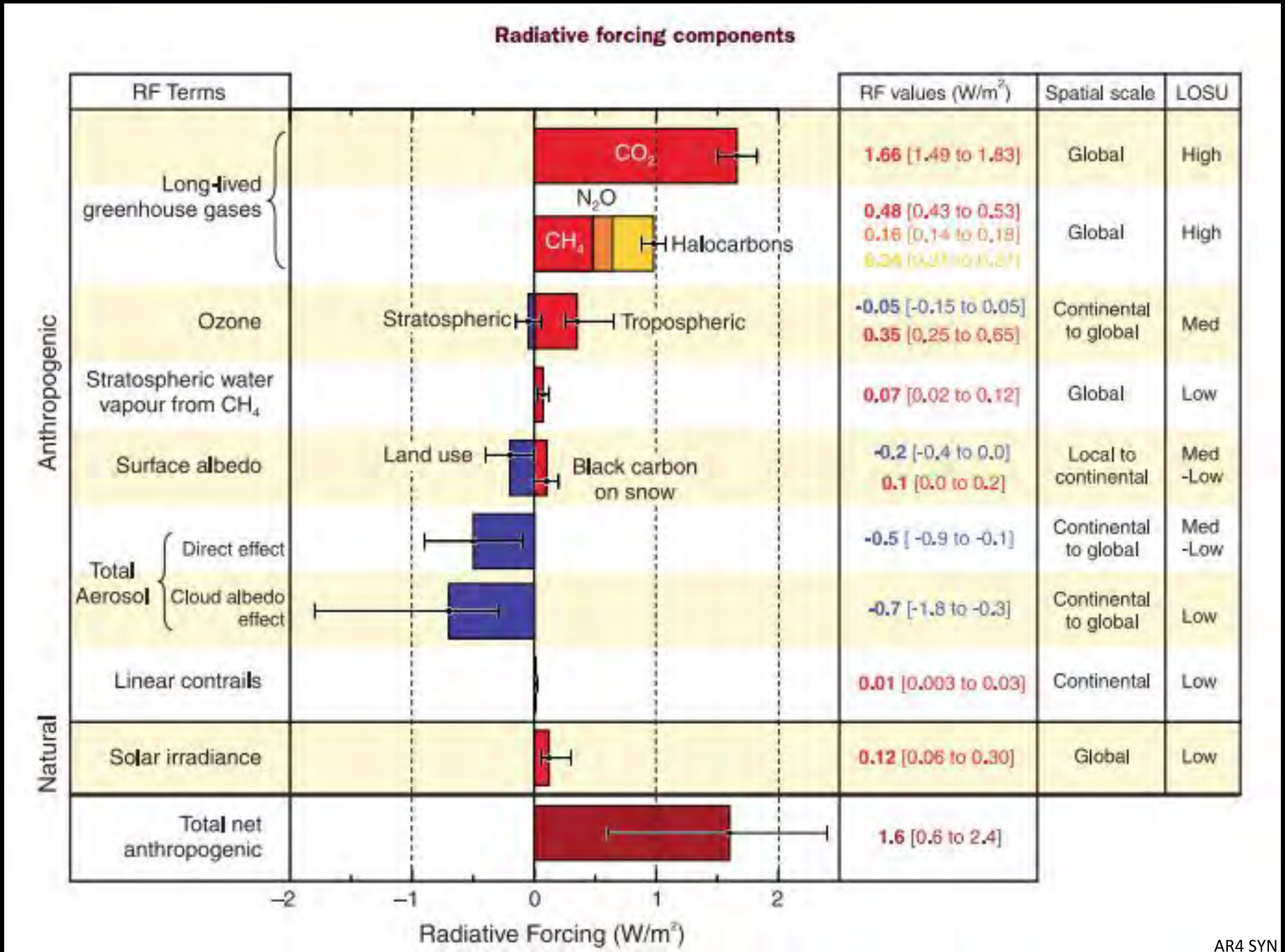
Four Topics

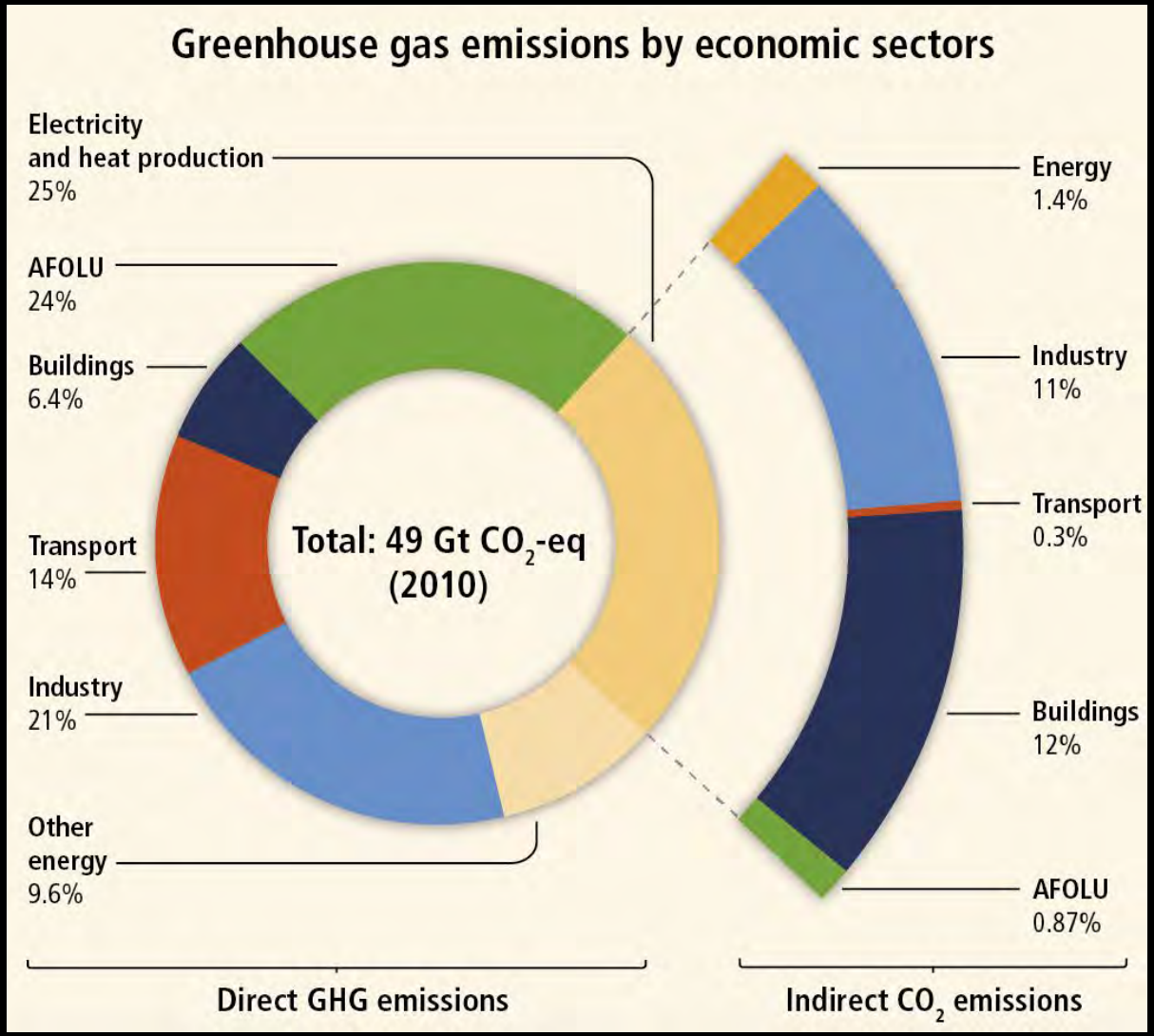
1 Basic Knowledge/Science
2 Climate Change All Around Us
3 Future Climates
4 Prognosis for Stabilizing Climate

1 Basic knowledge and the Science of Climate Change


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
YEAR
NOAA
June 2019


Radiative forcing components
RF Terms
RF values (W/m²)
Spatial scale
LOSU
Anthropogenic
Natural
Long-lived greenhouse gases
CO2
N2O
CH4
Halocarbons
1.66 [1.49 to 1.83]
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
Global
High
Ozone
Stratospheric
Tropospheric
-0.05 [-0.15 to 0.05]
0.35 [0.25 to 0.65]
Continental to global
Med
Stratospheric water vapour from CH4
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to continental
Med -Low
Total Aerosol
Direct effect
Cloud albedo effect
-0.5 [-0.9 to -0.1]
-0.7 [-1.8 to -0.3]
Continental to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Total net anthropogenic
1.6 [0.6 to 2.4]
–2
–1
0
1
2
Radiative Forcing (W/m²)

AR4 SYN


Greenhouse gas emissions by economic sectors
Electricity and heat production 25%
AFOLU 24%
Buildings 6.4%
Transport 14%
Industry 21%
Other energy 9.6%
Total: 49 Gt CO_2-eq (2010)
Energy 1.4%
Industry 11%
Transport 0.3%
Buildings 12%
AFOLU 0.87%
Direct GHG emissions
Indirect CO_2 emissions


The Largest Source of Global Warming Pollution Is the Burning of Fossil Fuels
Billion Metric Tons of Carbon
10
8
6
4
2
0
1850
1875
1900
1925
1950
1975
2000
2016
Data: U.S. Department of Energy/CDIAC

Temperature and CO_2 Concentration Increase in Lock Step

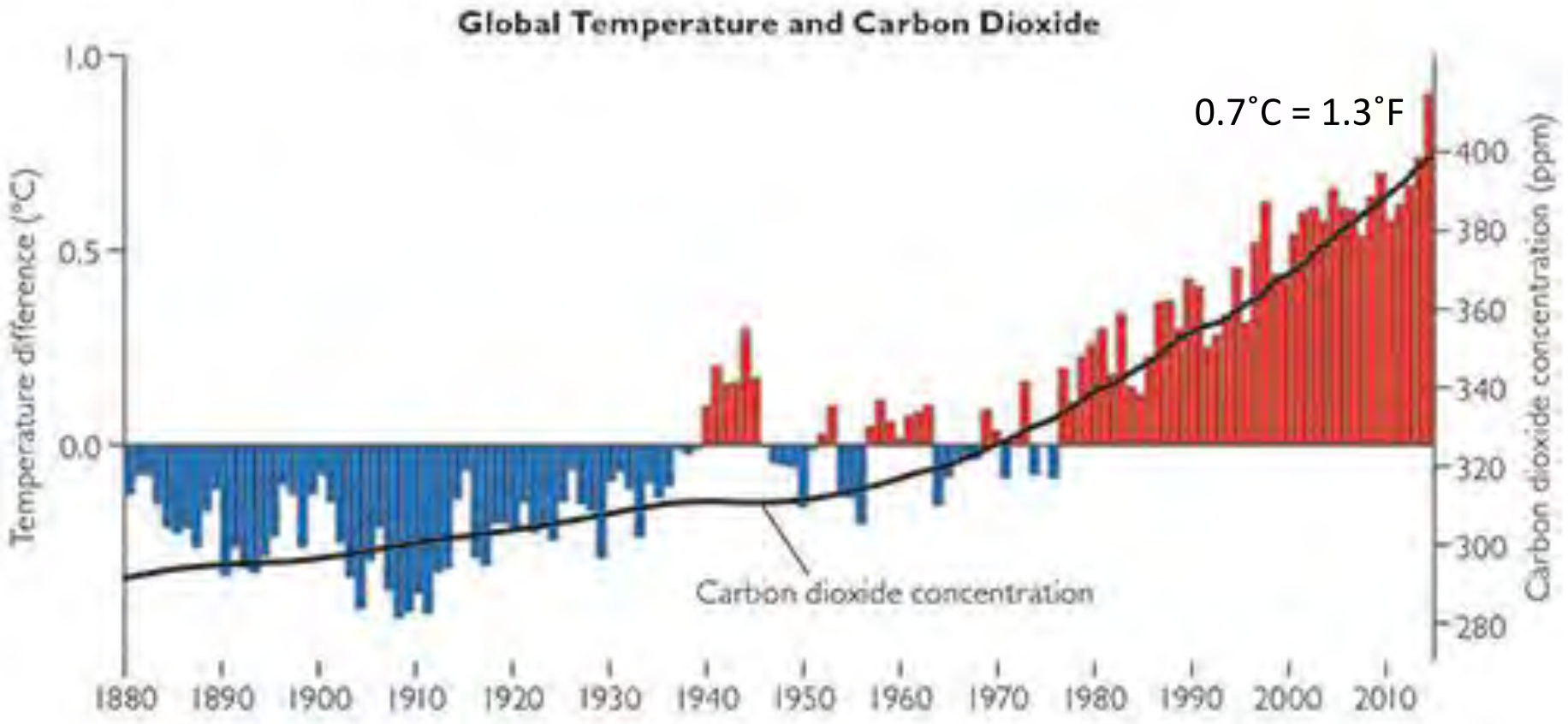
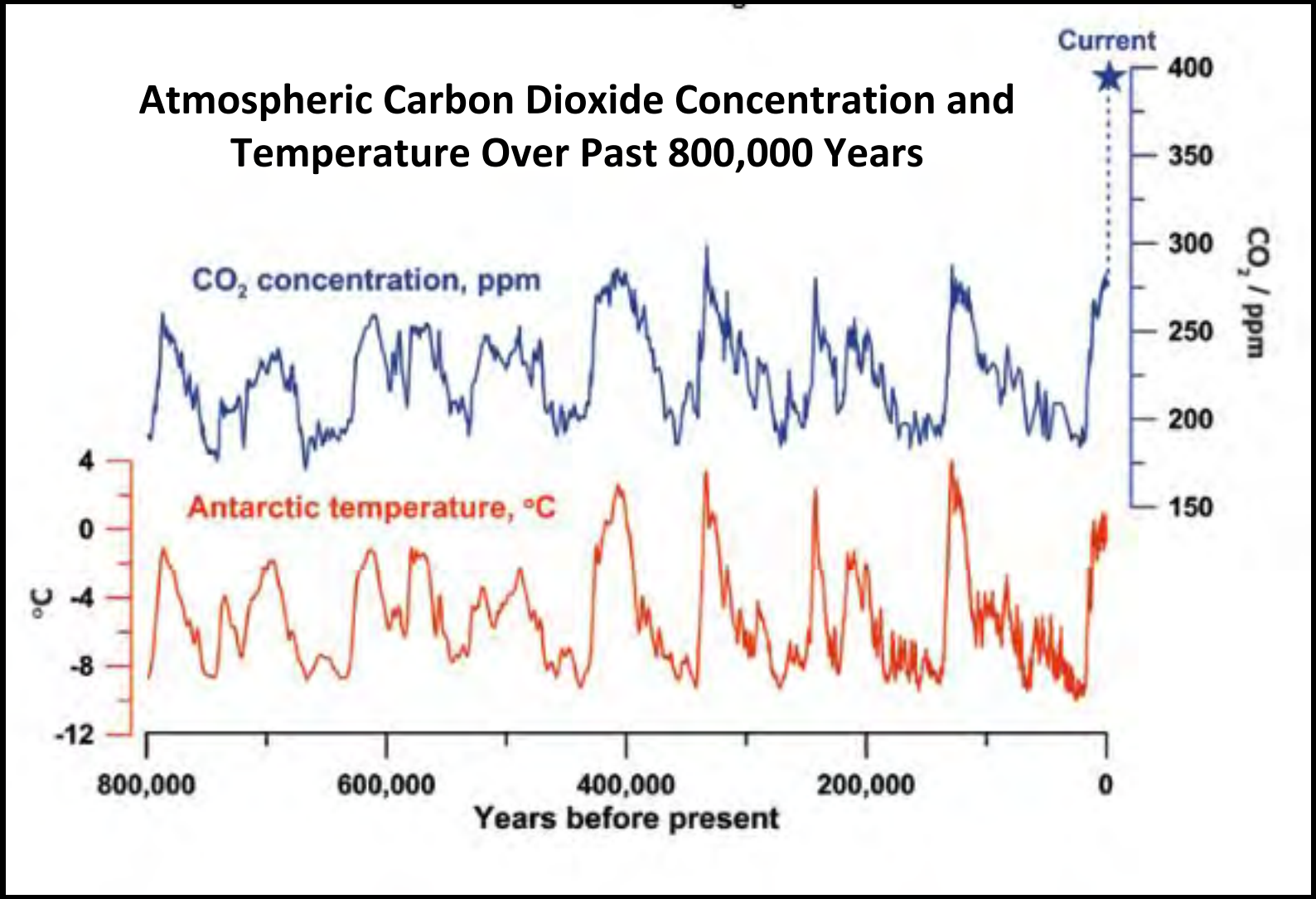
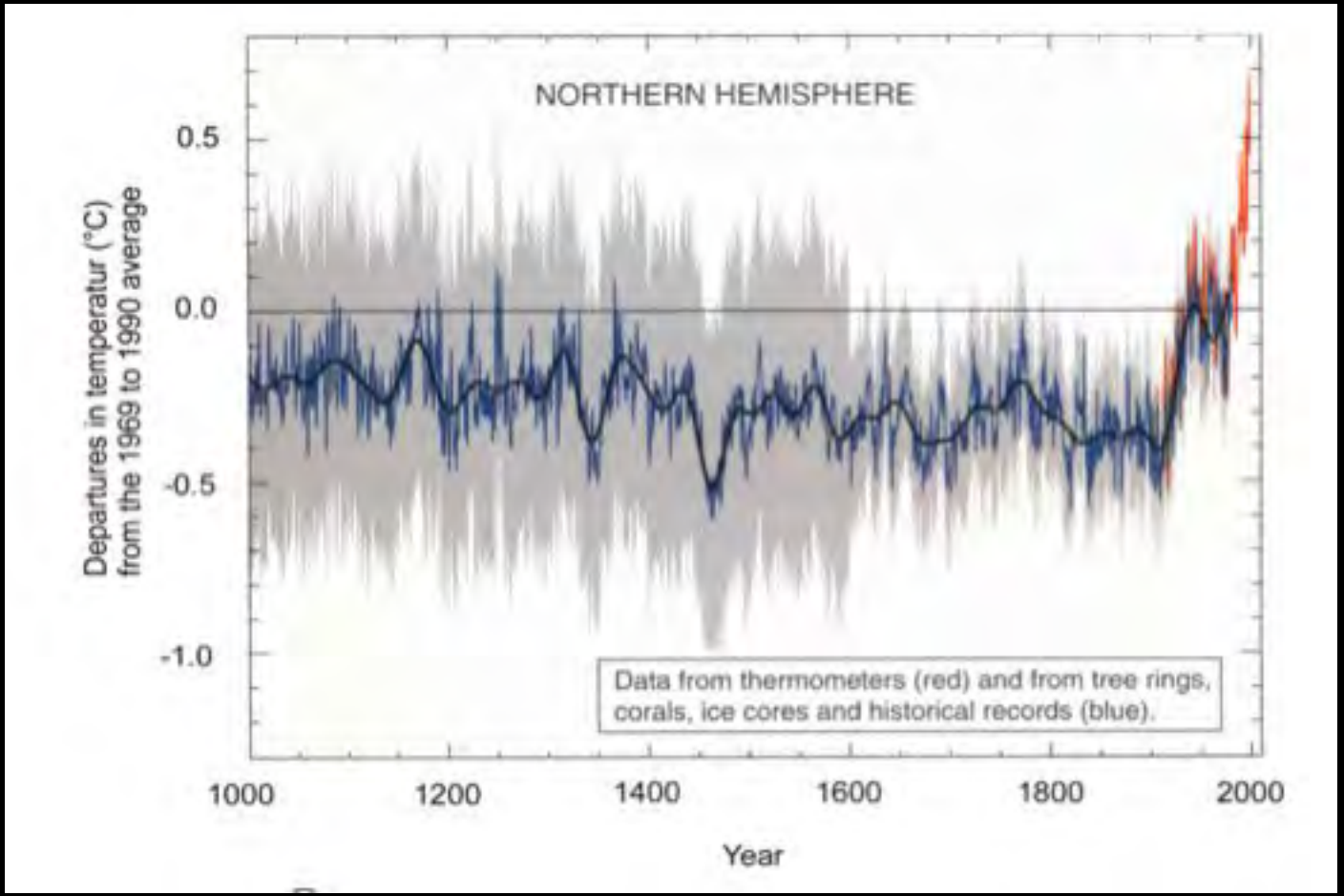


Figure 2.4 This graph repeats the temperature data from figure 2.1, with an overlay showing the carbon dioxide concentration (as an average for each year, so as to avoid seeing the seasonal wiggles shown in figure 1.8). The two are clearly moving in tandem for recent decades, lending support to the simplicity of our 1-2-3 logic for global warming.

Temperature and CO_2 Concentration Correlated over Past 800,000 Years!


Atmospheric Carbon Dioxide Concentration and Temperature Over Past 800,000 Years
Current
400
350
300
250
200
150
CO2 / ppm
CO2 concentration, ppm
4
0
-4
-8
-12
°C
Antarctic temperature, °C
800,000
600,000
400,000
200,000
0
Years before present

Highest temperature in Northern Hemisphere for the last 1000 Years

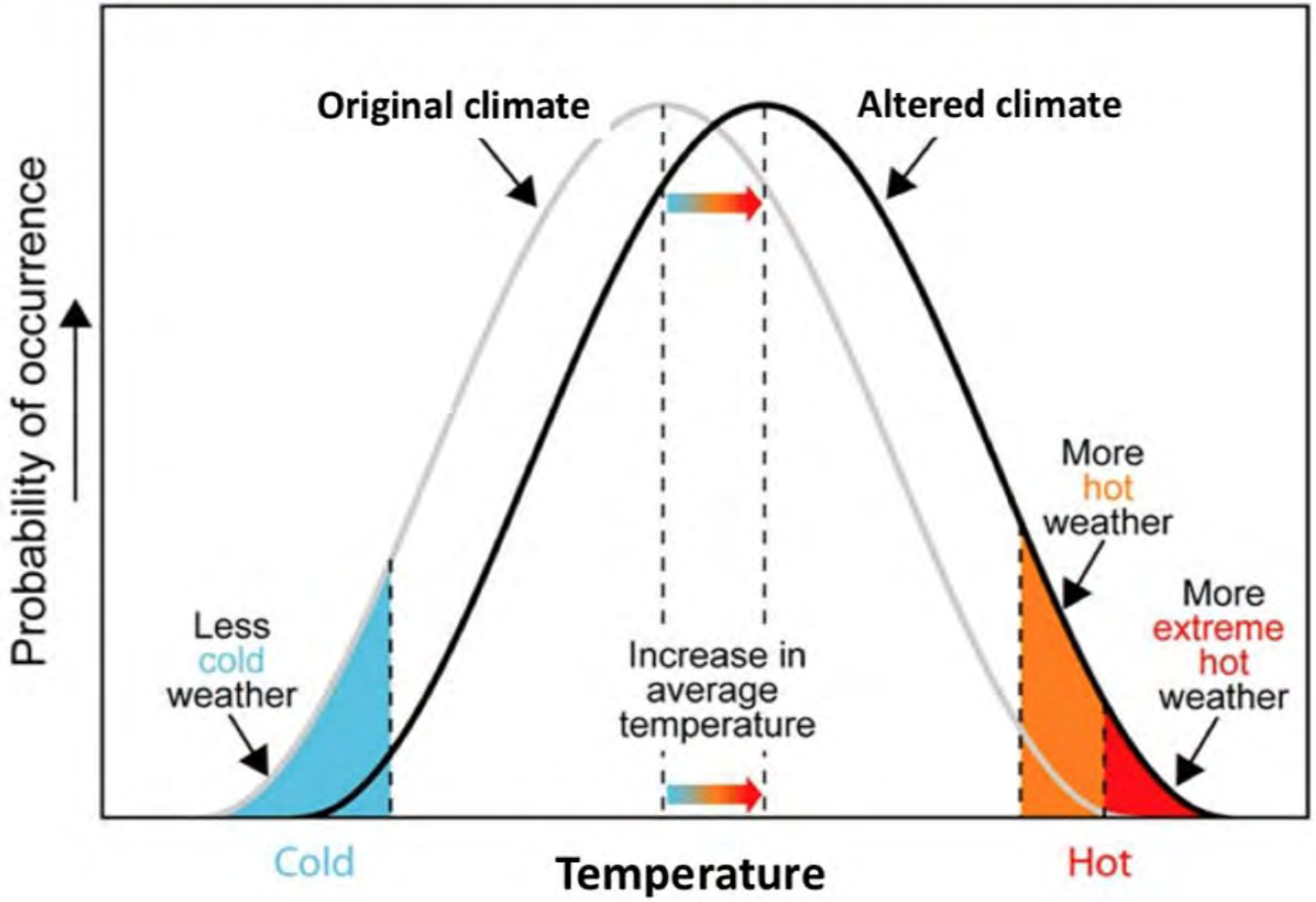

NORTHERN HEMISPHERE
Departures in temperatur (°C) from the 1969 to 1990 average
0.5
0.0
-0.5
-1.0
Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
1000
1200
1400
1600
1800
2000
Year

https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

2 Climate Change All Around Us

Why does ΔT of 1˚C matter so much?

When the average of any of these weather variables changes, the extremes change much more.



Record Temperatures
Around the World in 2017 and 2018

At least 117 locations around the world have set all-time heat records in 2018.

On July 6, 2018, the Los Angeles area broke its all-time heat record: 120° F in Chino.

Other L.A. locations that set all-time highs:

Burbank Airport	114° F	Van Nuys Airport	117° F
Santa Ana	114° F	Ramona	117° F
		Riverside	118° F


Bangkok, Thailand
April 27, 2016
On April 28, 2016, Thailand broke its all-time high temperature record at 112.4° F (44.6° C).
All-time national high temperature records were also broken in Cambodia and Laos.
© 2016 AP Photo/Mark Baker


Tokyo, Japan
July 14, 2018
125 people died and over
57,000 were taken to hospitals
during Japan's May-July heat waves.
© 2018 Kyodo via AP Images


Ouargla, Algeria
Ouargla, Algeria may have set
a new all-time heat record
for Africa: 124° F (51.1° C)
on July 5, 2018.
© 2010 Reuters/Louafi Larbi


Nawabshah reached
122.4° F (50.2° C)
on April 30, 2018,
a new world record
for the month.
Afghanistan
Iran
Pakistan
India
Nawabshah, Pakistan
Source: 2018 Landsat / Copernicus, Data SIO,
NOAA, U.S. Navy, NGA, GEBCO, Map data © Google

Kuwait City experienced
temperatures up to

124° F (51° C)

in July 2017.

In August, birds in the city died and
fell from the sky from heat exposure.


Baghdad, Iraq
July 28, 2017
On August 10, 2017 Baghdad reached 124° F (51° C). The government declared a mandatory holiday to prevent people from working in the heat.
© 2017 AP Photo/Hadi Mizban

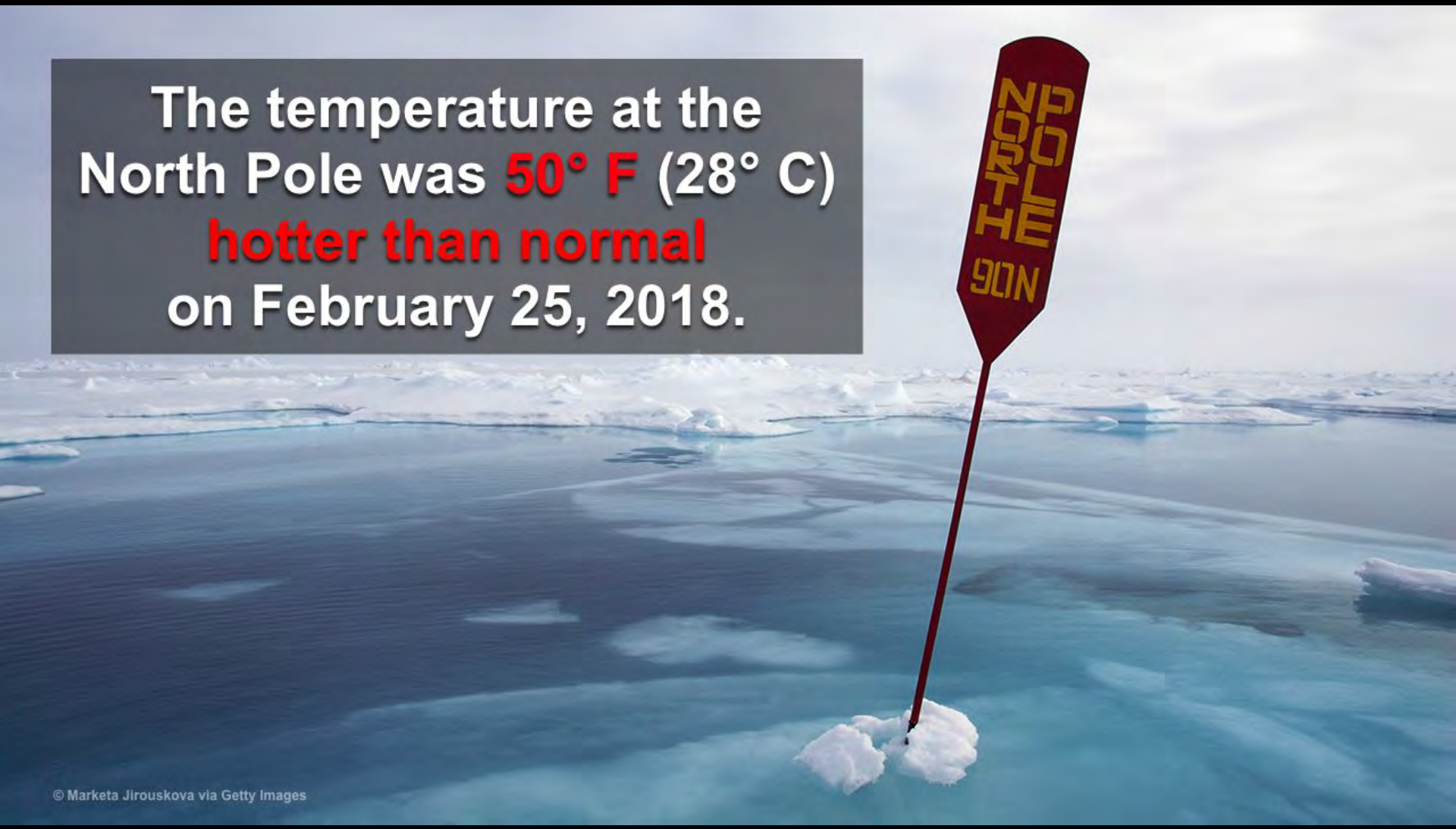

Mezairaa, United Arab Emirates
Mezairaa set the UAE's all-time record heat of 124.7° F (51.5° C) on June 16, 2017.
© Philip Lange via Shutterstock

On July 22nd, 2016
Basra, Iraq reached
129.0° F (53.9° C)

On July 21st, 2016
Mitribah, Kuwait
reached
129.2° F (54° C)

Source: WeatherUnderground


Quetta, Pakistan
June 2, 2017
The nearby town of Turbat, Pakistan set an all-time, country-wide record of 129.2° F (54° C) on May 28, 2017.
© 2017 Jamal Taraqai/EPA/Redux


The temperature at the North Pole was 50° F (28° C) hotter than normal on February 25, 2018.
NORTH POLE
90N
© Marketa Jirouskova via Getty Images

What we know: Ongoing impacts on people and ecosystems

Serious harm from climate change is here now

Around the world we're seeing, variously, increases in

- floods
- drought
- wildfires
- heat waves
- coral bleaching
- coastal erosion & inundation
- power of the strongest storms
- permafrost thawing & subsidence
- expanding impacts of pests & pathogens
- altered distribution/abundance of valued species

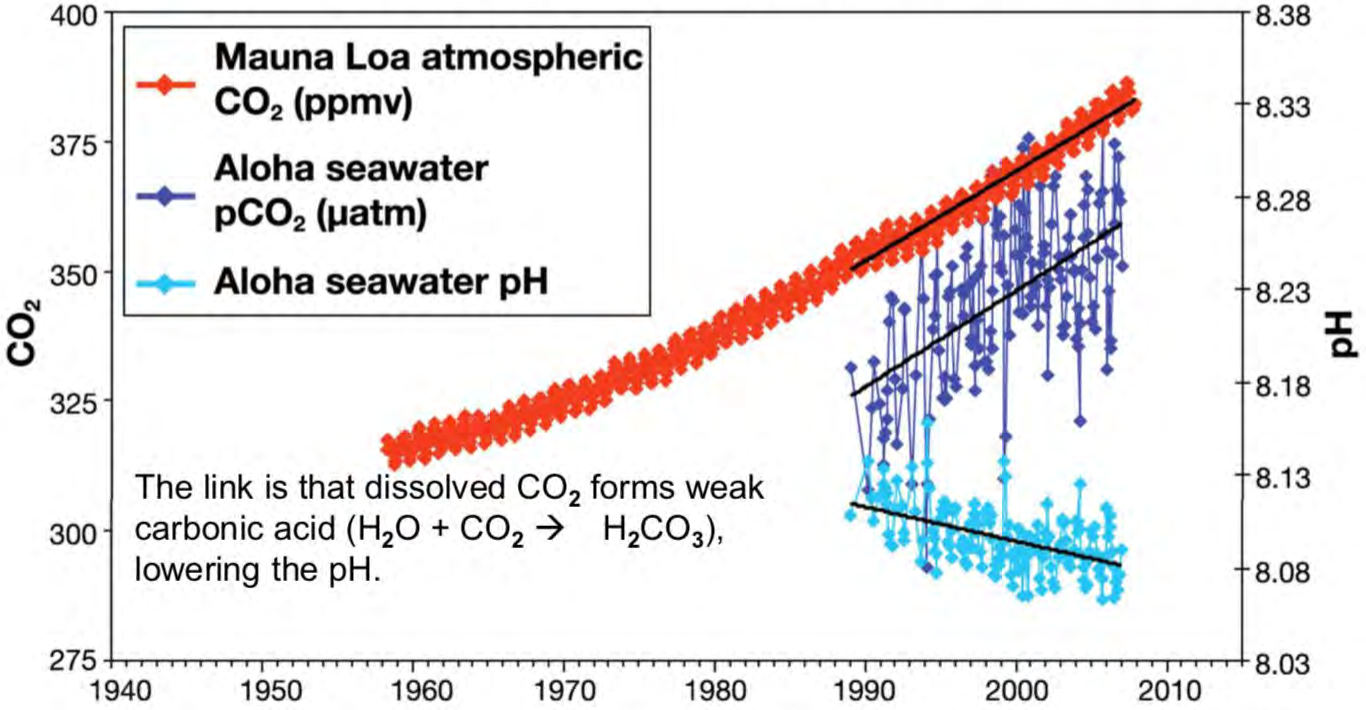
- loss of arctic ice
- sea level rising

All plausibly linked to climate change by theory, models, and observed "fingerprints", most worsening faster than projected.

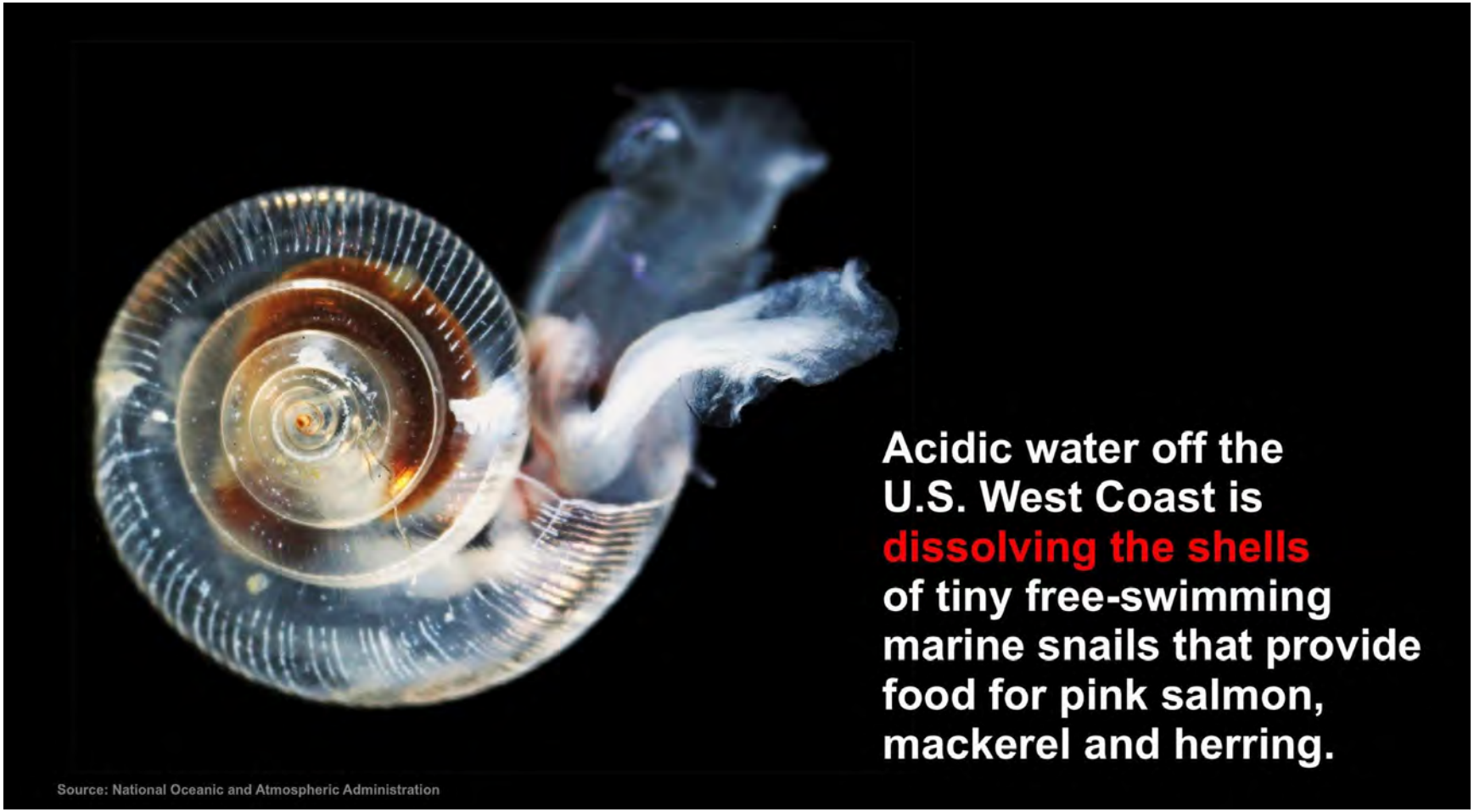
What we know: Ongoing impacts on people and ecosystems

Growing harm: Ocean acidification

About 1/3 of CO_2 added to atmosphere is quickly taken up by the surface layer of the oceans (roughly, the top 80 meters).

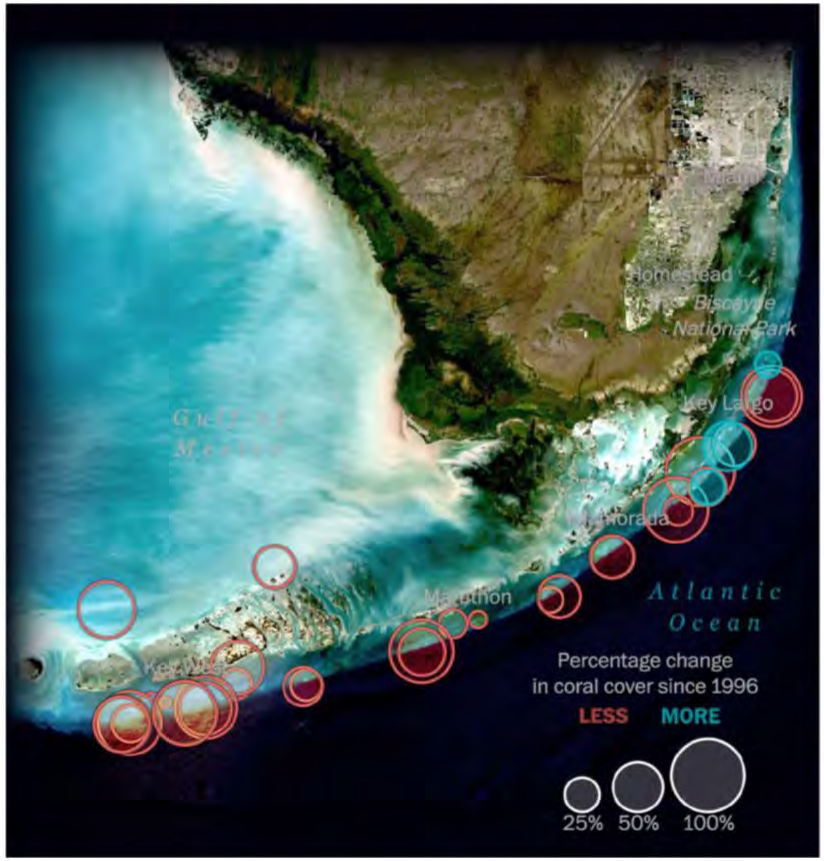


World Bank / Potsdam Institute Nov 2012


Acidic water off the
U.S. West Coast is
dissolving the shells
of tiny free-swimming
marine snails that provide
food for pink salmon,
mackerel and herring.
Source: National Oceanic and Atmospheric Administration

What we know: Ongoing impacts on people and ecosystems

Growing harm: Death of coral reefs in Florida Keys



Florida's coral reefs are being devastated by multiple stresses, of which warming water and acidification are the most important.

Less than 10% of the reef system is now covered by living coral. (Red circles show percentage declines since 1996.)

NASA Aqua satellite imagery. Washington Post, 26 June 2017


Sea turtle sex is determined by temperature.
At the northern edge of Australia's Great Barrier Reef, 99% of young green sea turtles are now female.
Source: World Wildlife Fund, 2015
Photo: ©2008 Brocken Inaglory/Wikicommons CC BY SA 3.0

What we know: The pace & character of change

Glaciers worldwide have been shrinking for decades

Muir Glacier, Alaska, 1941-2004

August 1941

August 2004

NSIDC/WDC for Glaciology, Boulder, compiler. 2002, updated 2006. *Online glacier photograph database.* Boulder, CO: National Snow and Ice Data Center.


The Arctic's oldest and thickest sea ice has never been observed breaking up.
It happened twice in 2018.
Photo © 2017 AP Photo/David Goldman
Canadian Arctic

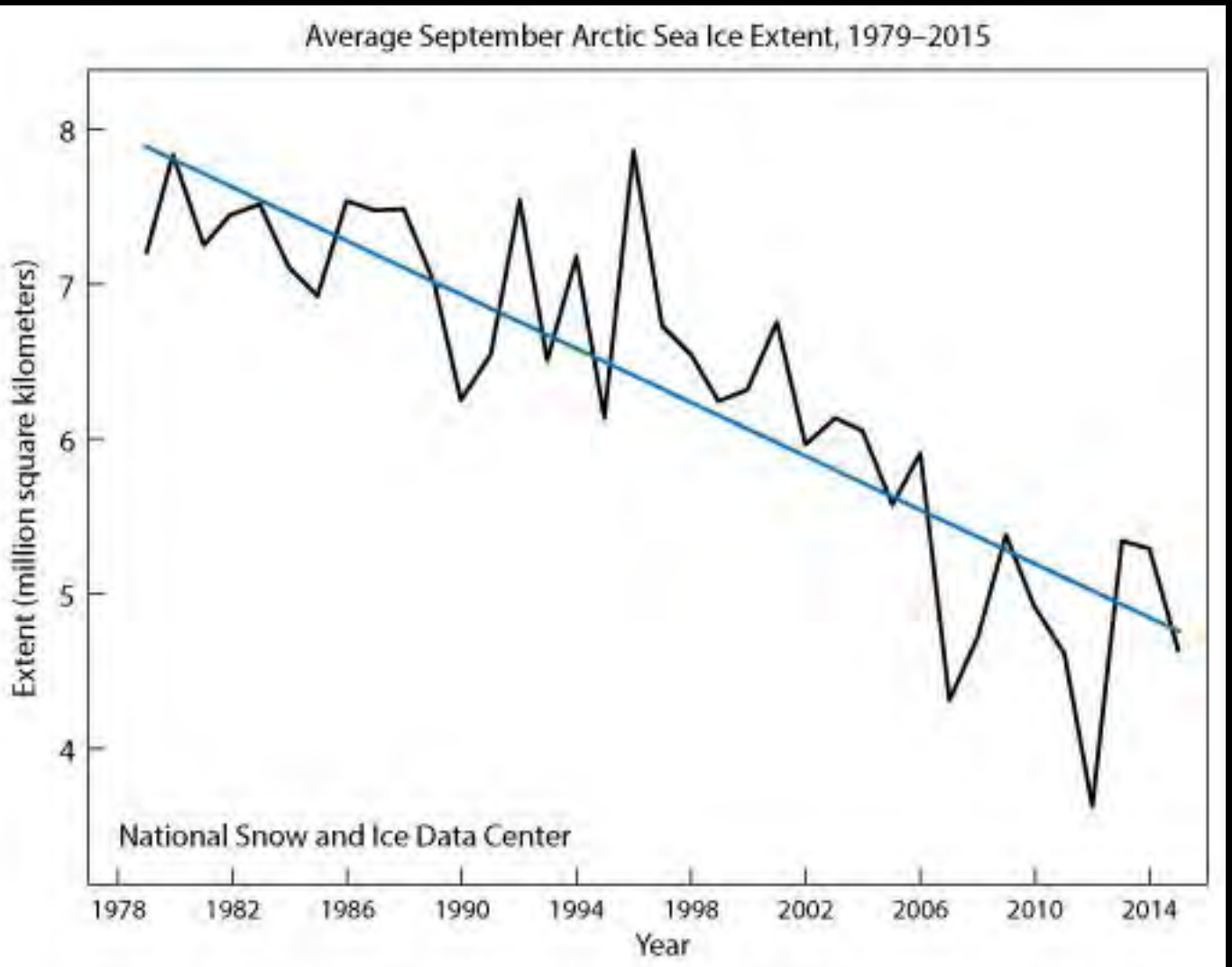
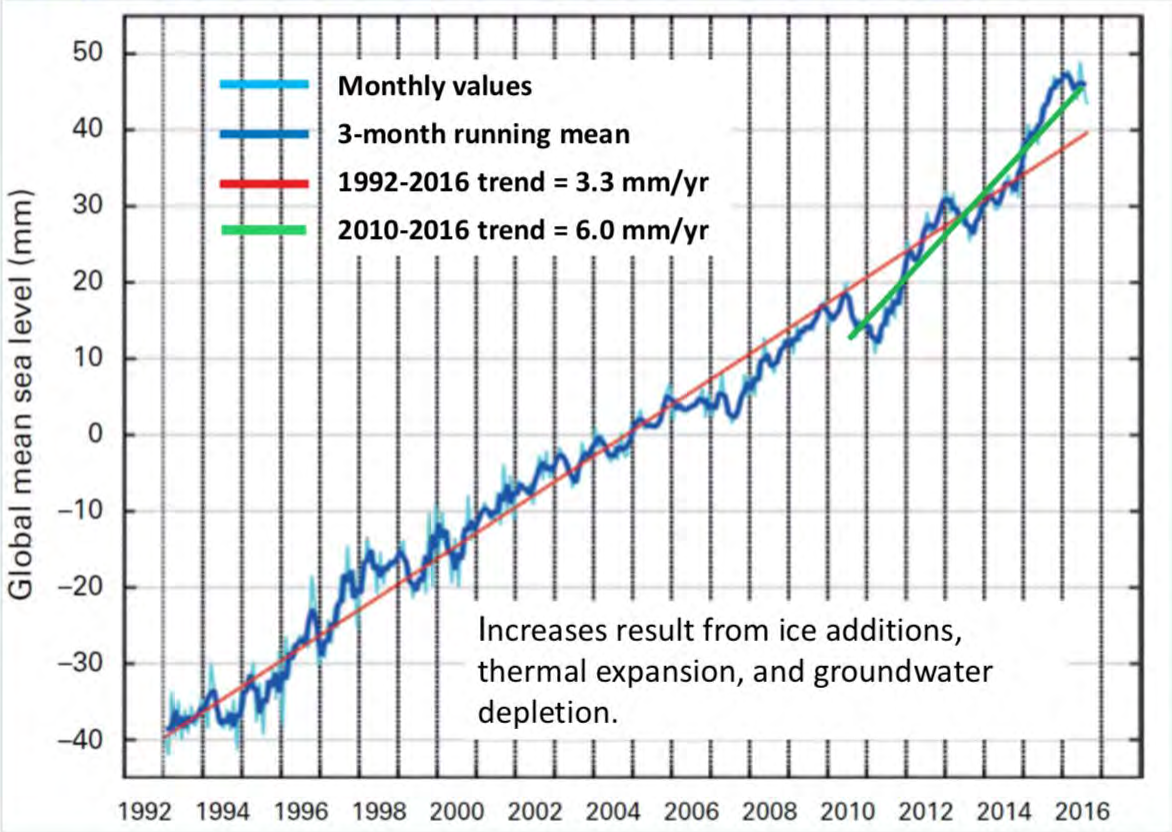


Figure 3.10 This graph shows the change in the total area of the Arctic covered by sea ice in September of each year (when the sea ice is near its minimum after summer melting) since satellite records have been available. The black curve shows the actual data, and the blue line is a "best fit" that shows the declining trend. The average rate of decline for the more than three-decade period has been more than 13% per decade, and the nine lowest September ice extents (over the satellite record) have all occurred in the last nine years through 2015. *Source: National Snow and Ice Data Center. (Latest monthly data available at nsidc.org/arcticseaicenews/)*

What We Know: The pace & character of change

The pace of sea-level rise is increasing



WMO 2017

What we know: Ongoing impacts on people and ecosystems

Downpours → Floods (continued)

"Hundred-year" floods now occur once a decade or more in many places.
Three "five-hundred-year" floods occurred in Houston in three years.

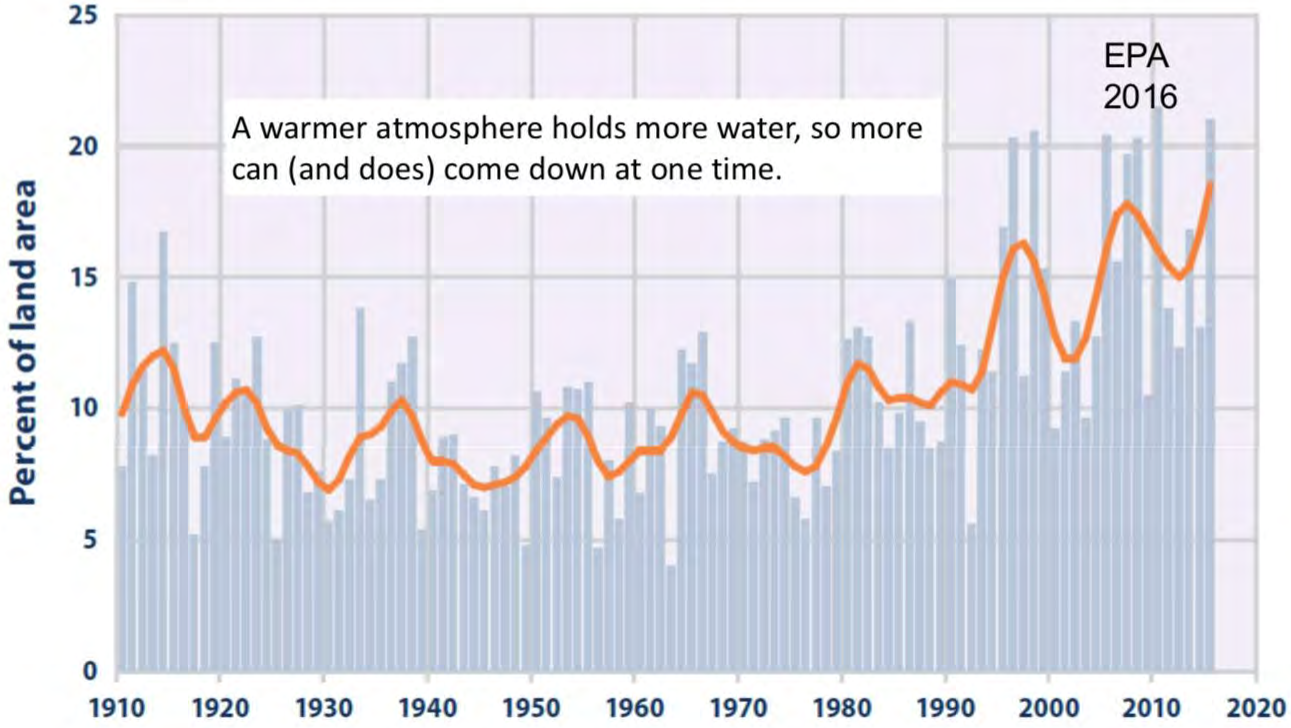
East Baton Rouge, LA, August 2016: Up to 20 inches of rain in 3 days

Hurricane Harvey brought >50 inches of rain over 5 days to parts of Texas in August 2017.

Rebutting the wafflers

Growing harm: Torrential downpours → floods

Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2015



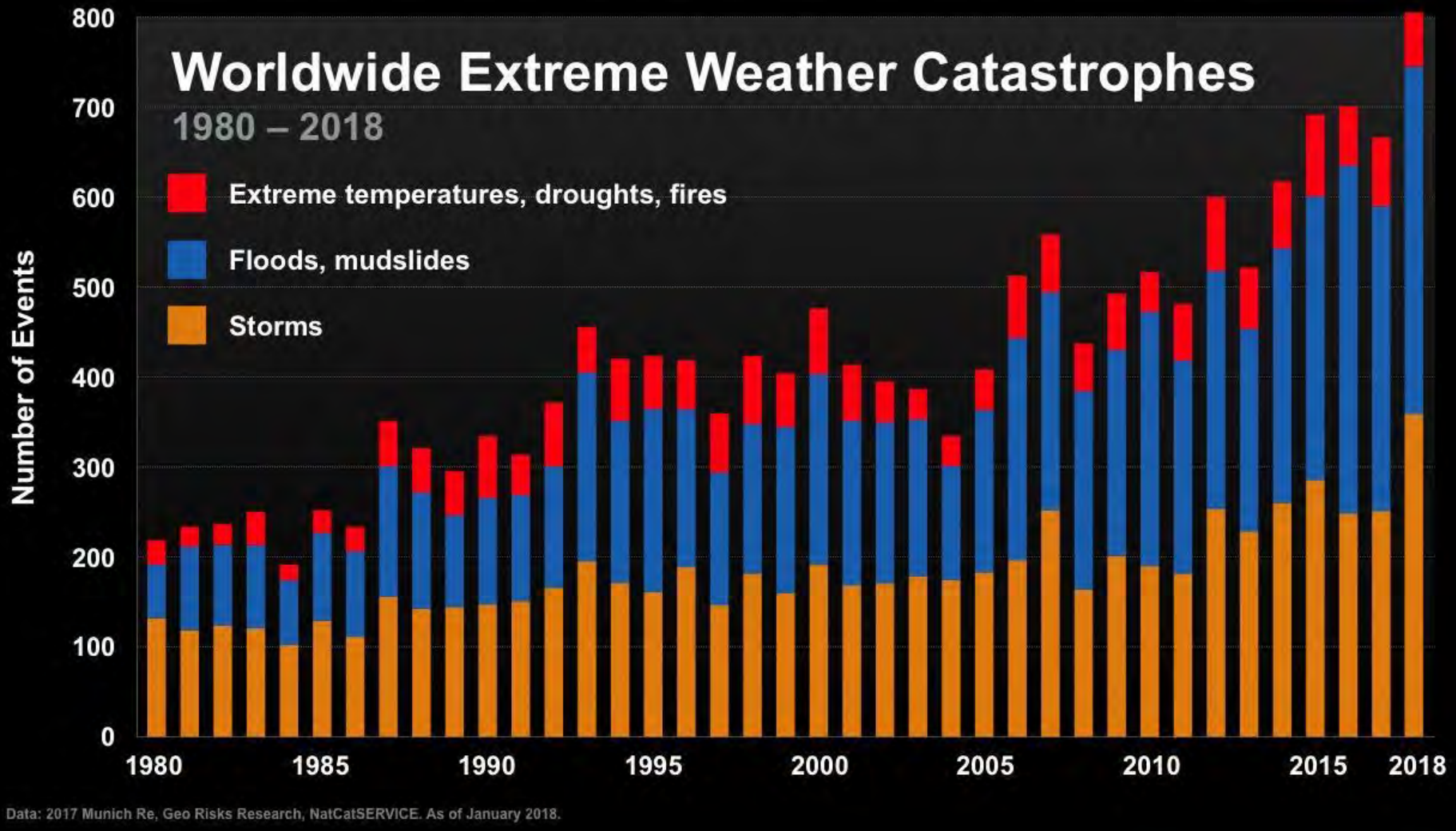
The 3 highest-volume U.S. rainfall events on record have happened in the last 3 years:

2017	Hurricane Harvey	Texas/Louisiana
2018	Hurricane Florence	North Carolina
2016	Spring Storm	Louisiana

Data: North Carolina Institute for Climate Studies

Globally, floods and
extreme rainfall events
now occur
four times more often
than in 1980.

Data: Munich Re via The Guardian



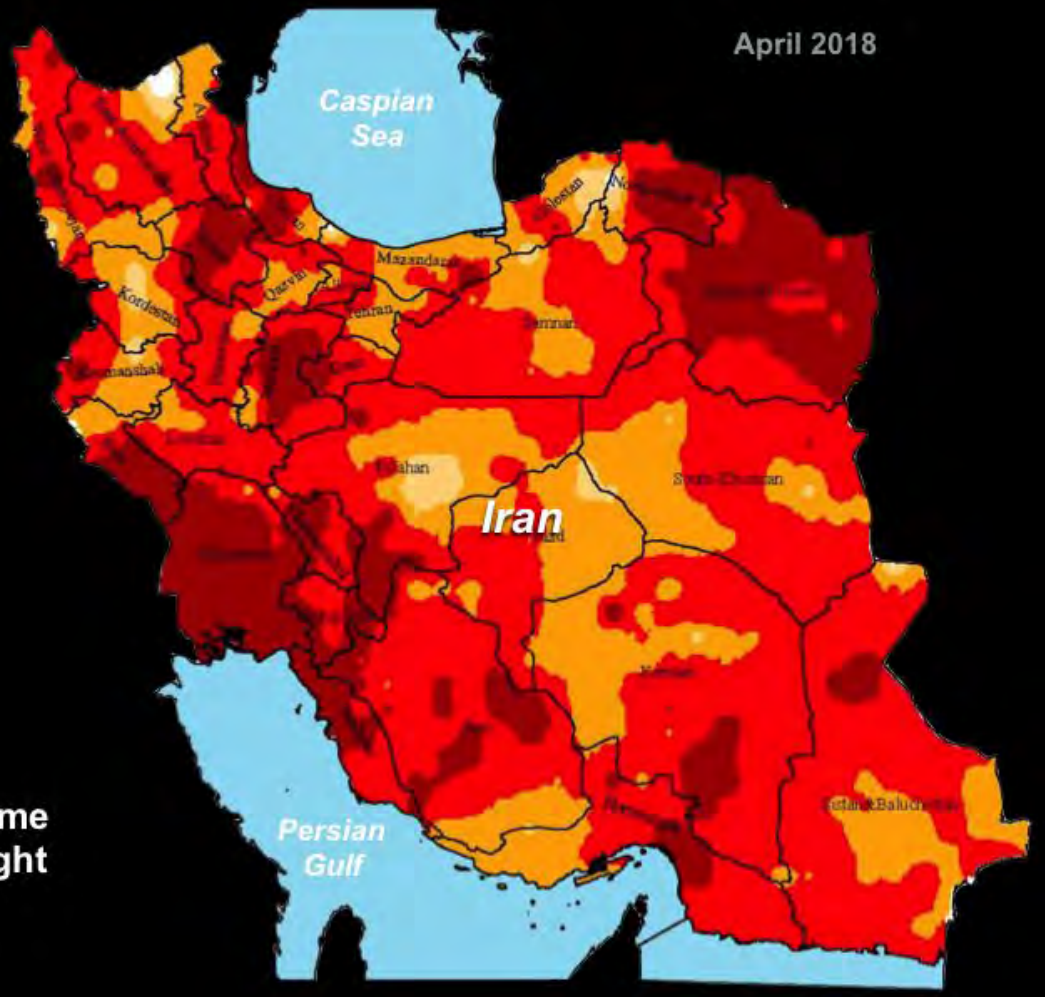
Data: 2017 Munich Re, Geo Risks Research, NatCatSERVICE. As of January 2018.


Nearly Dry Well, Gokwe, Zimbabwe
Southern Africa experienced one of its worst droughts in years.
© 2015 Reuters/Philimon Bulawayo


Harbin, China
June 1, 2018
© 2018 Tao Zhang/Getty Images


Chennai, India
May 17, 2017
Chennai's state of Tamil Nadu experienced it's worst drought in 140 years.
©2017 Arun Sankar/AFP/Getty Images

97% of Iran is experiencing a prolonged drought.

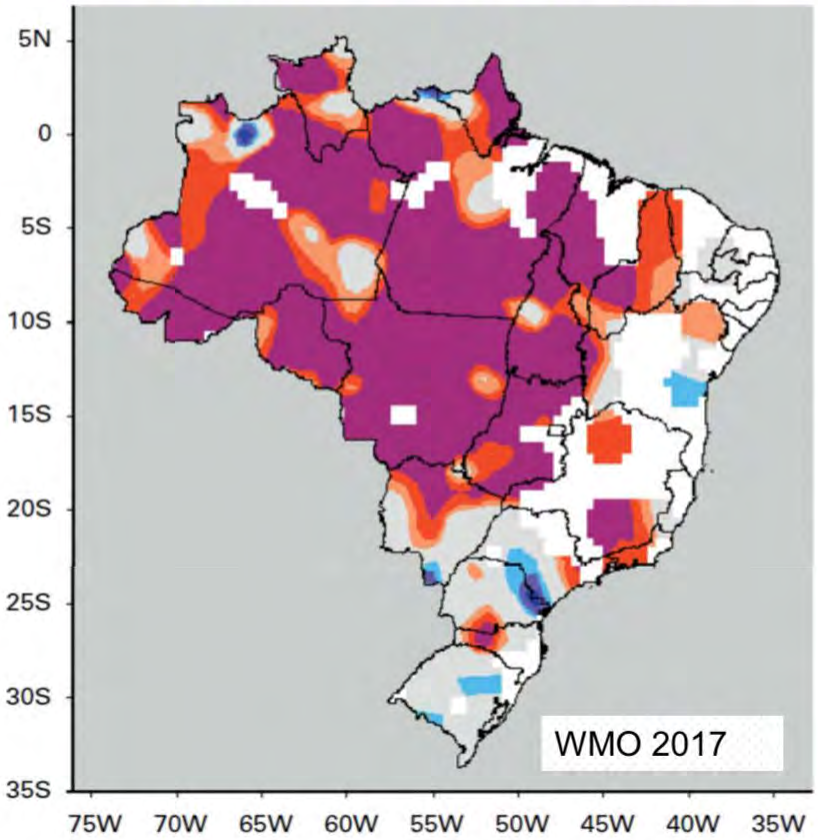


Source: I.R. of Iran Meteorological Organization

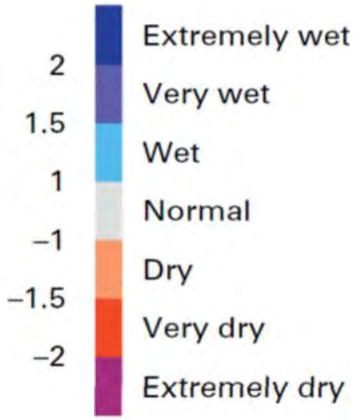

Po River, Linarolo, Italy
July 24, 2017
© 2017 AP Photo/Luca Bruno

What we know: Ongoing impacts on people and ecosystems

Growing harm: Drought in the Amazon



Precipitation index for Brazil, 1/15 – 12/16



The Woods Hole Research Center is a leader in work on drying & burning in the Amazon.

What we know: Ongoing harm

Wildfires (continued)

- The fire season in the USA is about 3 months longer than it was 40 years ago.
- The average fire is much bigger & hotter than before. Small wildfires burn at 1300-1400°F; big ones can burn at 2000°F or more, spreading faster, with far greater risks for firefighters.
- In Alaska, even the tundra has experienced wildfires in recent years.
- The smoke from today's big wildfires can carry health-harming fine particulates thousands of miles.

The total area burned in the western United States from 1984 to 2015 was nearly

TWICE

what it would have been without any human-caused warming.

Source: J.T. Abatzoglou and A.P. Williams, "Impact of anthropogenic climate change on wildfire across western US forests," *PNAS* vol. 113 no. 42, October 2016

The three most expensive wildfires in world history have happened in the last two years:

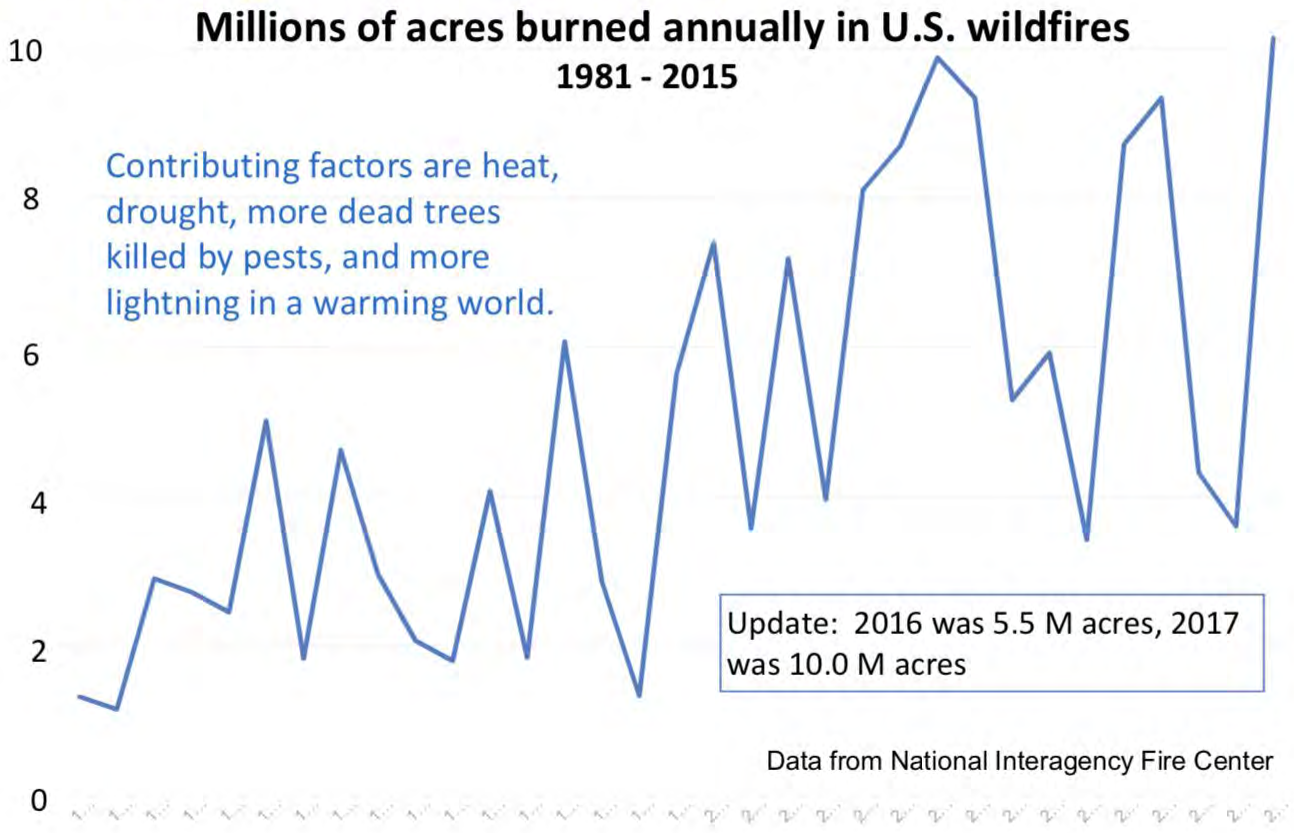
2018	Camp Fire	California
2017	Tubbs Fire	California
2018	Woolsey Fire	California

"Expensive" in terms of insured losses
Photo © 2018 AP Photo/Noah Berger
Data: Aon Benfield

Camp Fire Damage, Paradise, California

What we know: Ongoing impacts on people and ecosystems

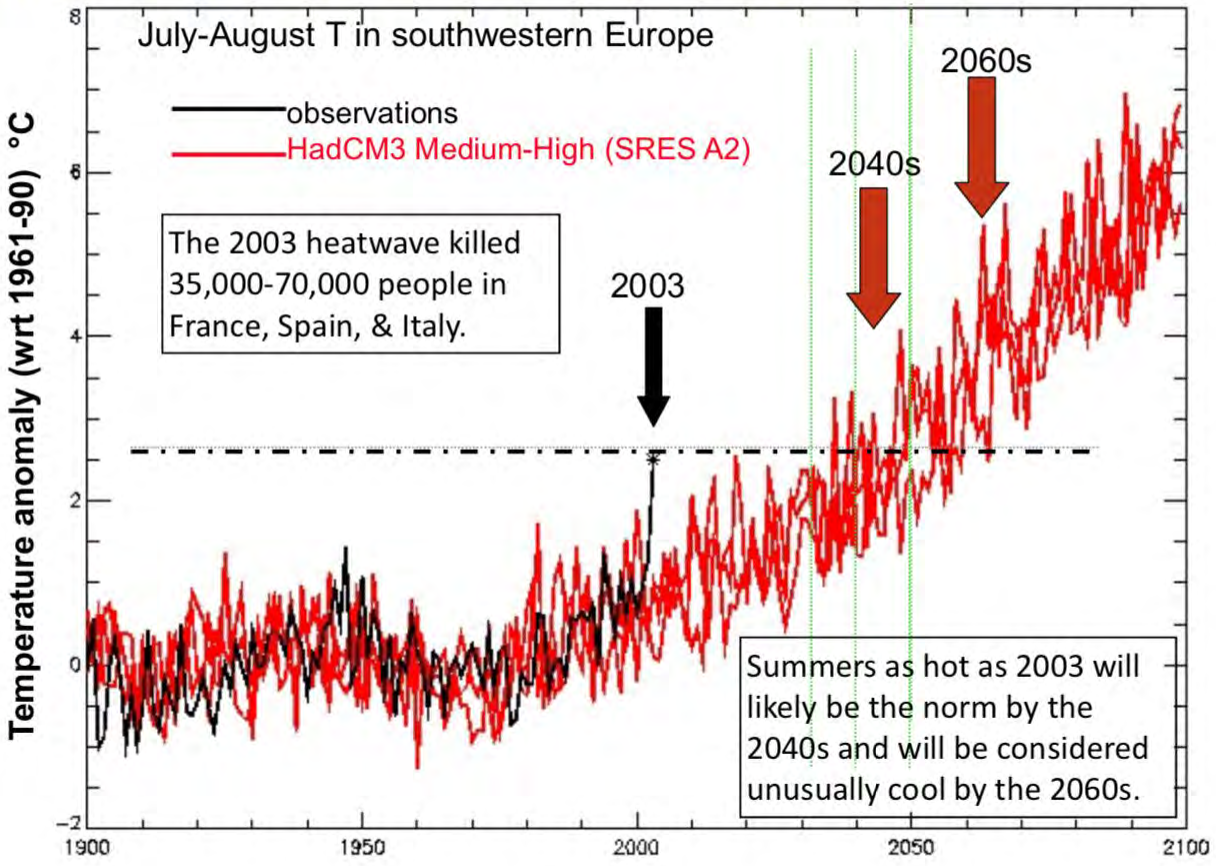
Growing harm: Wildfires



3 Future Climate

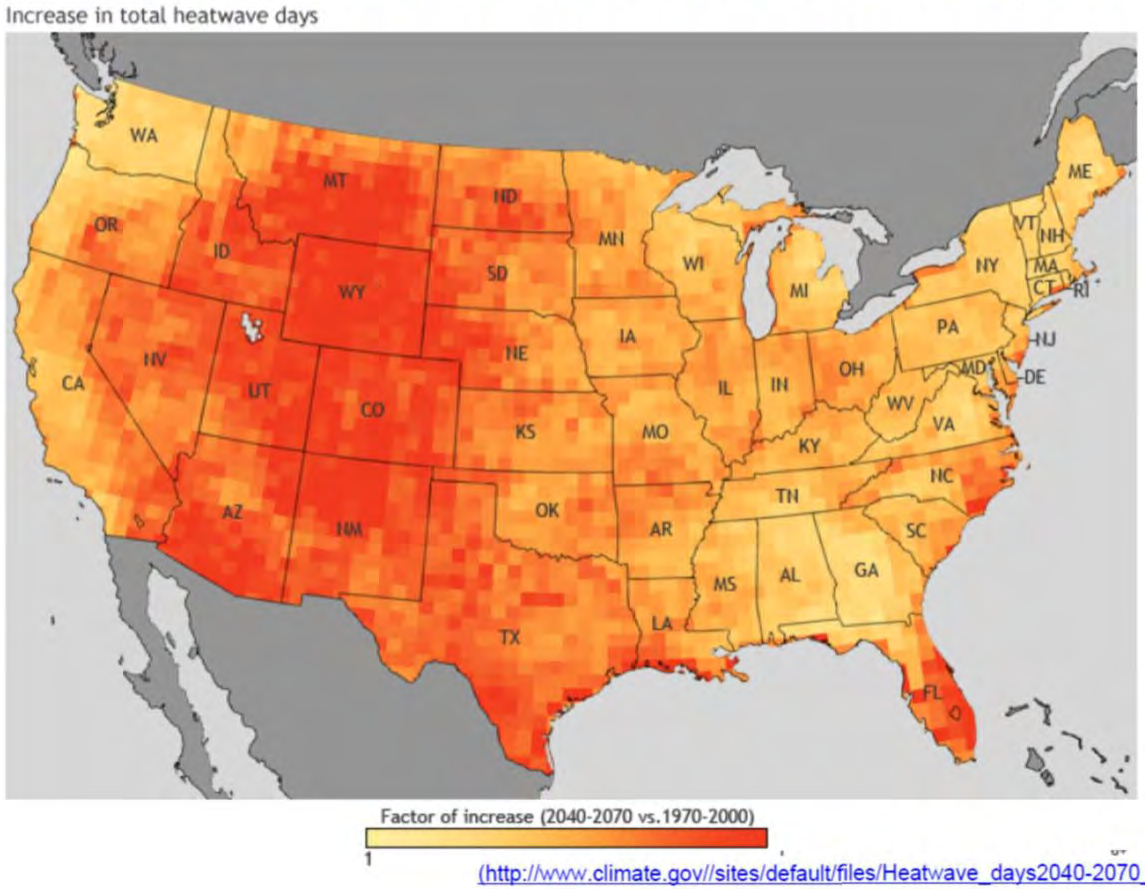
Scientific best estimates under specified future emissions

Under high emissions: SW Europe roasts



Scientific best estimates under specified future emissions

Under high emissions: much of USA roasts, too



(http://www.climate.gov//sites/default/files/Heatwave_days2040-2070_HR.jpg)

~2˚F

Projected Yield Declines For Each 1° C of Warming

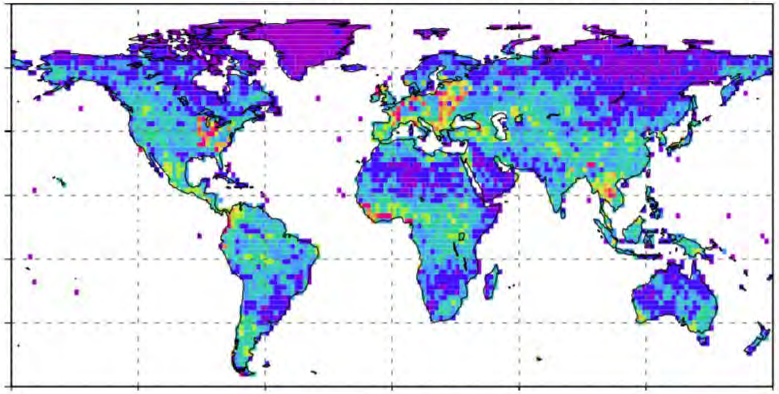
These four crops make up two thirds of human caloric intake.

Data: Chuang Zhao, et al., "Temperature increase reduces global yields of major crops in four independent estimates," *PNAS*, August 29, 2017.
Images: [Corn:] © EggHeadPhoto/Shutterstock; [Wheat:] © AlenKadr/Shutterstock; [Rice:] © ekotamak/Shutterstock; [Soy:] © Jiang HongYan/Shutterstock

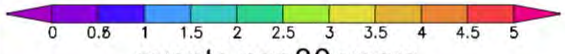
Scientific best estimates under specified future emissions

Under high emissions: Drought frequency soars

Frequency of 4-6 month duration droughts (events per 30 years)



Drought defined as soil moisture below historical 10th percentile value for that calendar month.

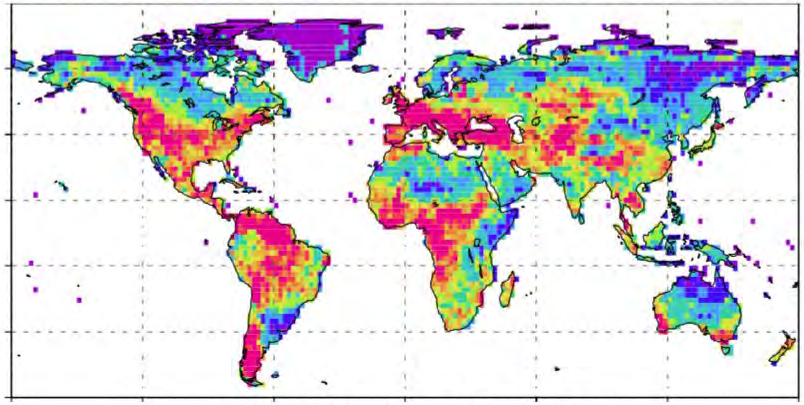


events per 30 years

the past 1961-1990

Results shown are the mean of 8 global climate models.

the future



2070-2099, IPCC A2 scenario

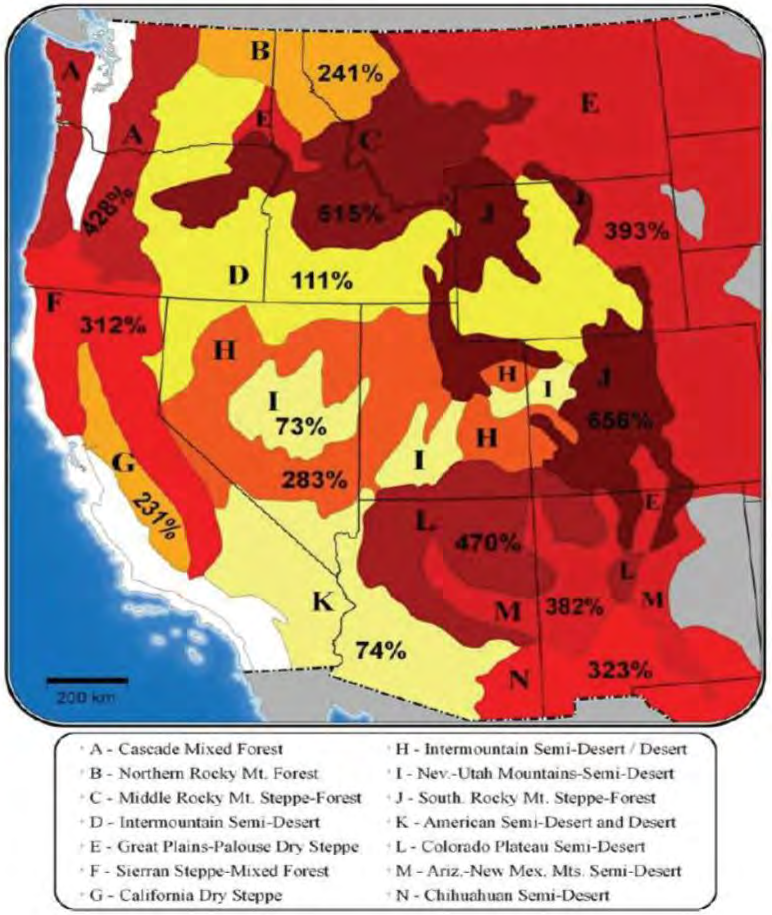
Source: Sheffield and Wood 2008 Climate Dynamics (2008) 31:79–105
DOI 10.1007/s00382-007-0340-z

Scientific best estimates under specified future emissions

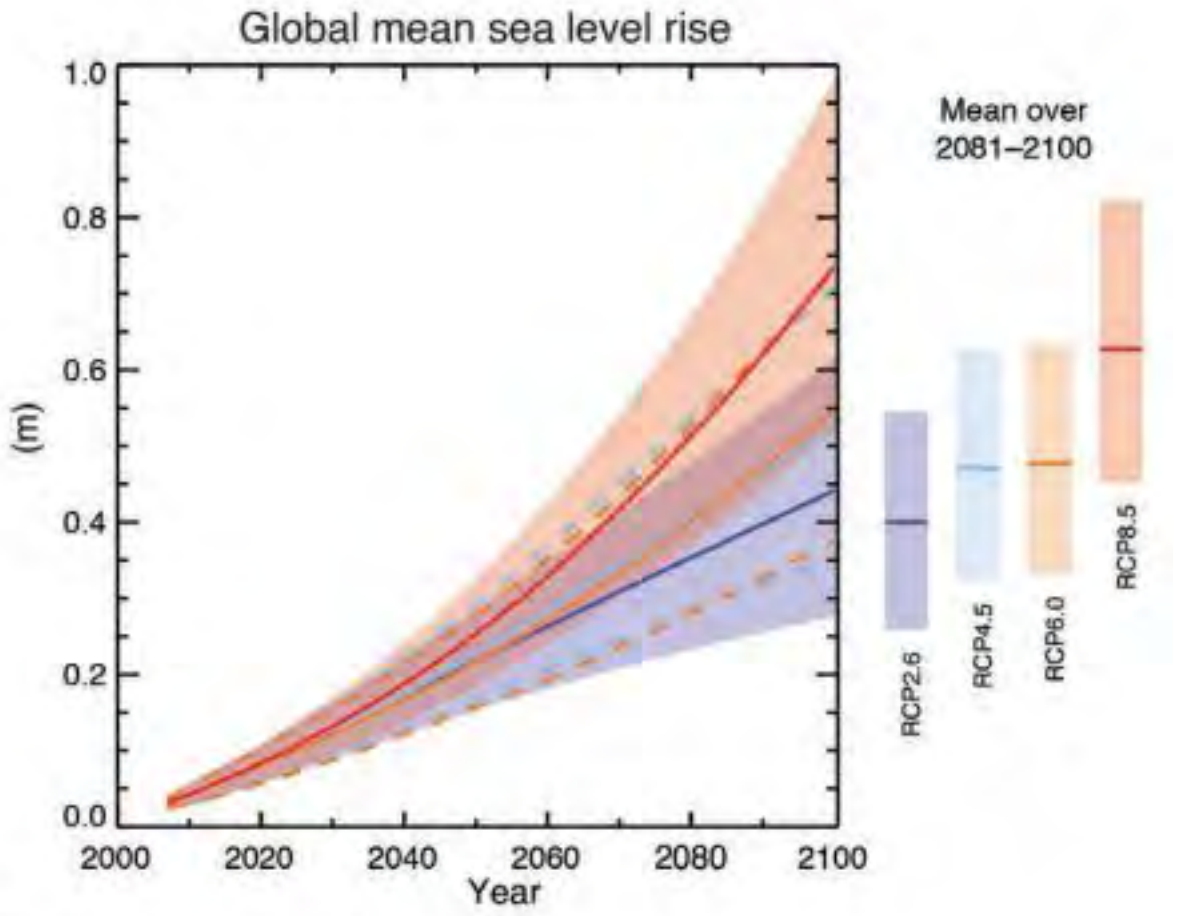
Even a 2°C increase (low emissions) portends a large worsening of wildfires

Percentages shown are increases in median annual area burned, referenced to 1950-2003 averages, for a 1°C rise in global average temperature.

National Academies, Stabilization Targets, 2010



IPCC conservative estimates of global mean sea level rise between 0.5 and 0.75 m in 2100



Source: AR5, IPCC 2013.

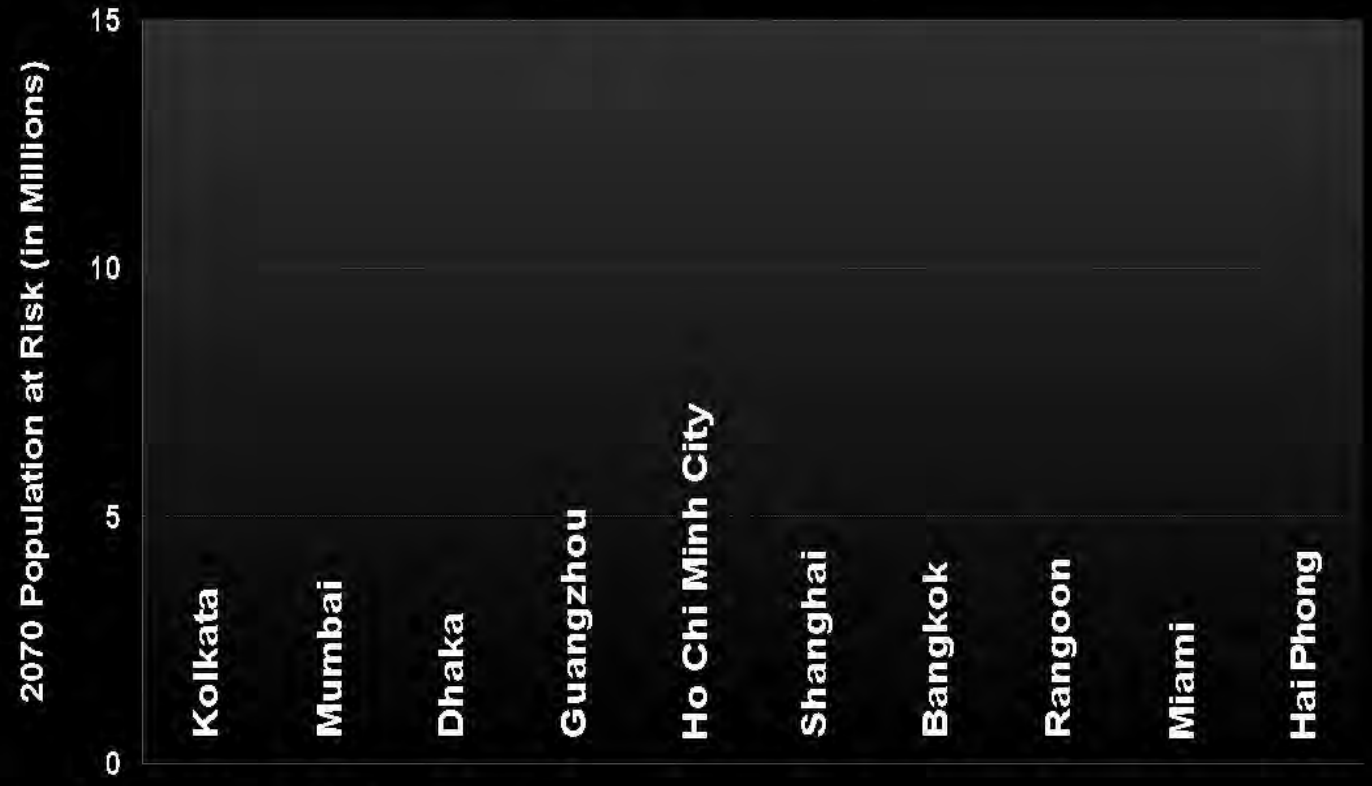
Worst Case of Sea Level Rise Now Thought to be Much Greater and Occur Sooner

Results of scientific studies in several labs

http://www.nytimes.com/2016/03/31/science/global-warming-antarctica-ice-sheet-sea-level-rise.html

Top 10 Cities at Risk from Sea Level Rise in 2070

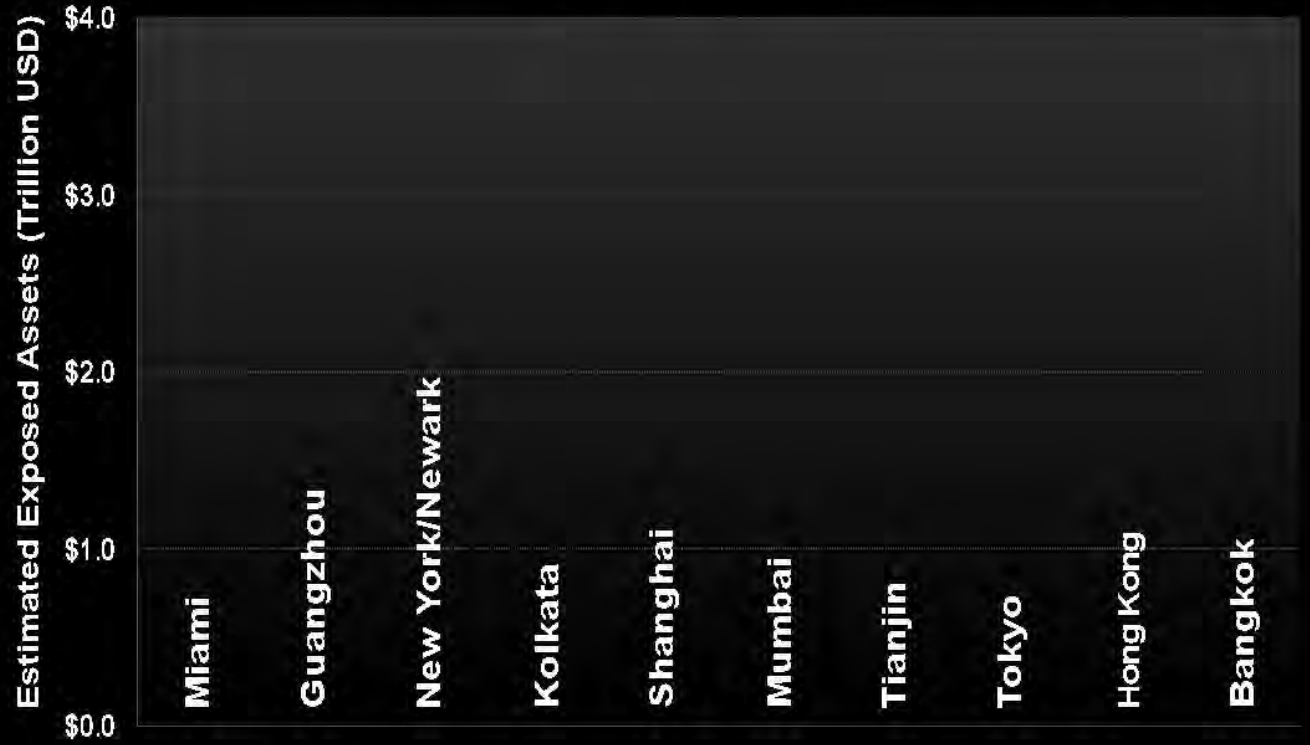
By Population at Risk



Data: Nichols, et al., OECD Environment Working Paper No. 1 (ENV/WKP(2007)1)

Top 10 Cities at Risk from Sea Level Rise in 2070

By Assets at Risk



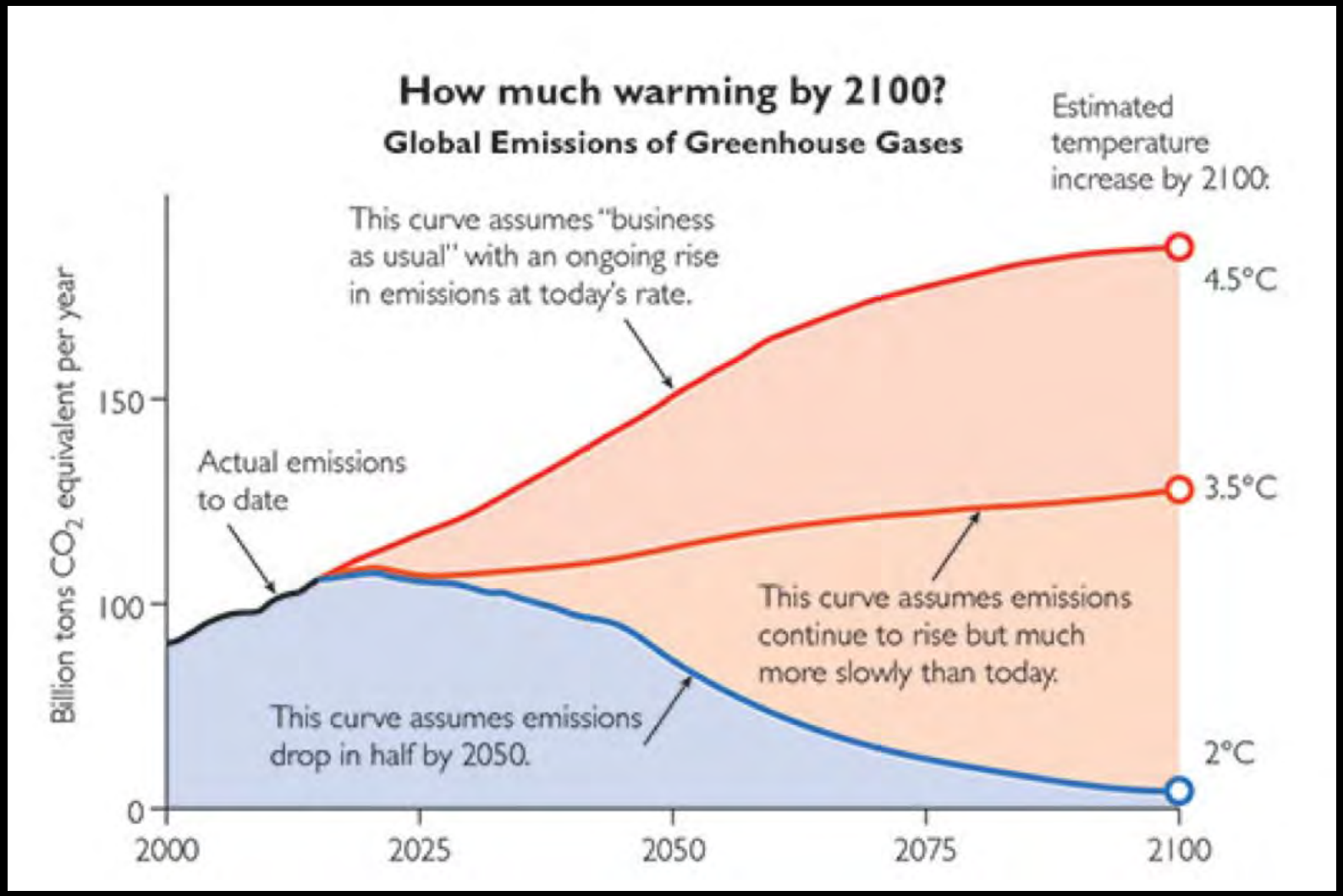
Data: Nichols, et al., OECD Environment Working Paper No. 1 (ENV/WKP(2007)1)

4 Prognosis for Climate Stabilization

Achieving stable temperatures

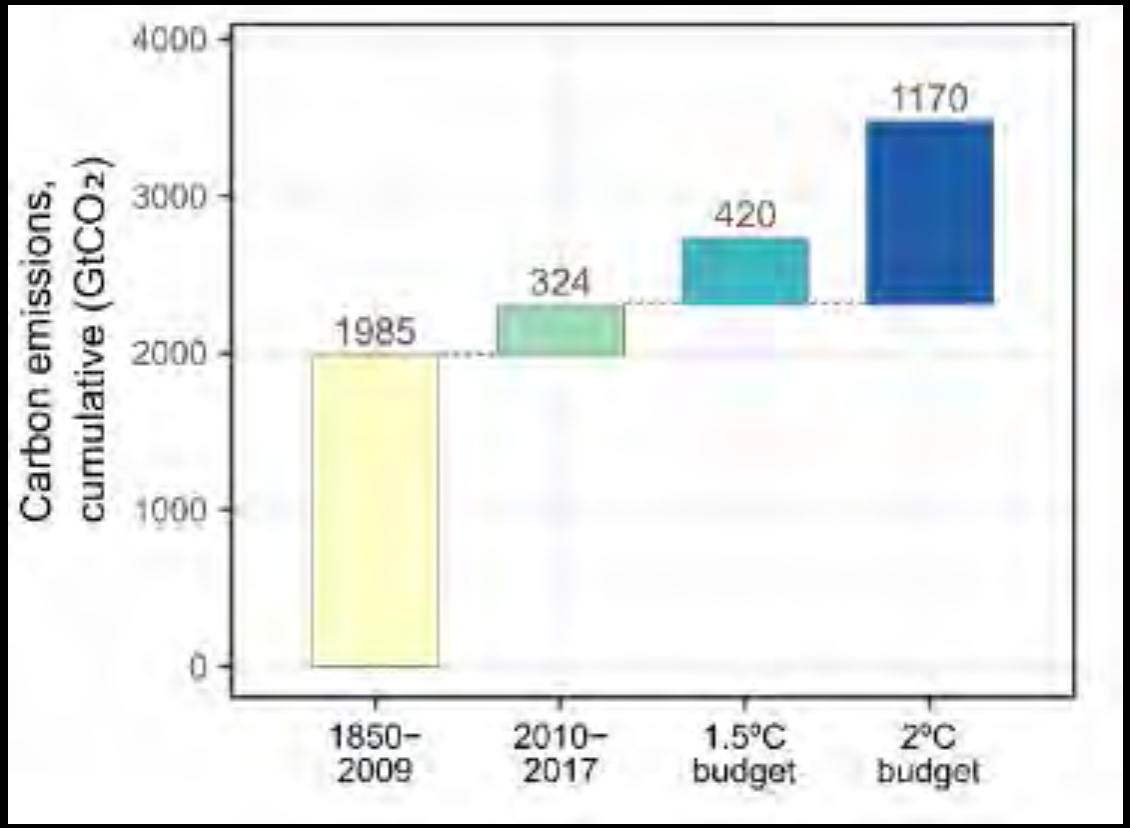
Intergovernmental Panel on Climate Change: "To stabilize global temperature at any given level, net carbon emissions would need to be reduced to zero."

Zero fossil fuel means retiring **all** fossil-based energy sources and associated technologies (at **a current value/cost of order of magnitude of tens of trillion dollars** of equipment and resources)


How much warming by 2100?
Global Emissions of Greenhouse Gases
Estimated temperature increase by 2100:
This curve assumes "business as usual" with an ongoing rise in emissions at today's rate.
4.5°C
Actual emissions to date
3.5°C
This curve assumes emissions continue to rise but much more slowly than today.
This curve assumes emissions drop in half by 2050.
2°C
Billion tons CO_2 equivalent per year
150
100
0
2000
2025
2050
2075
2100

2˚C Target

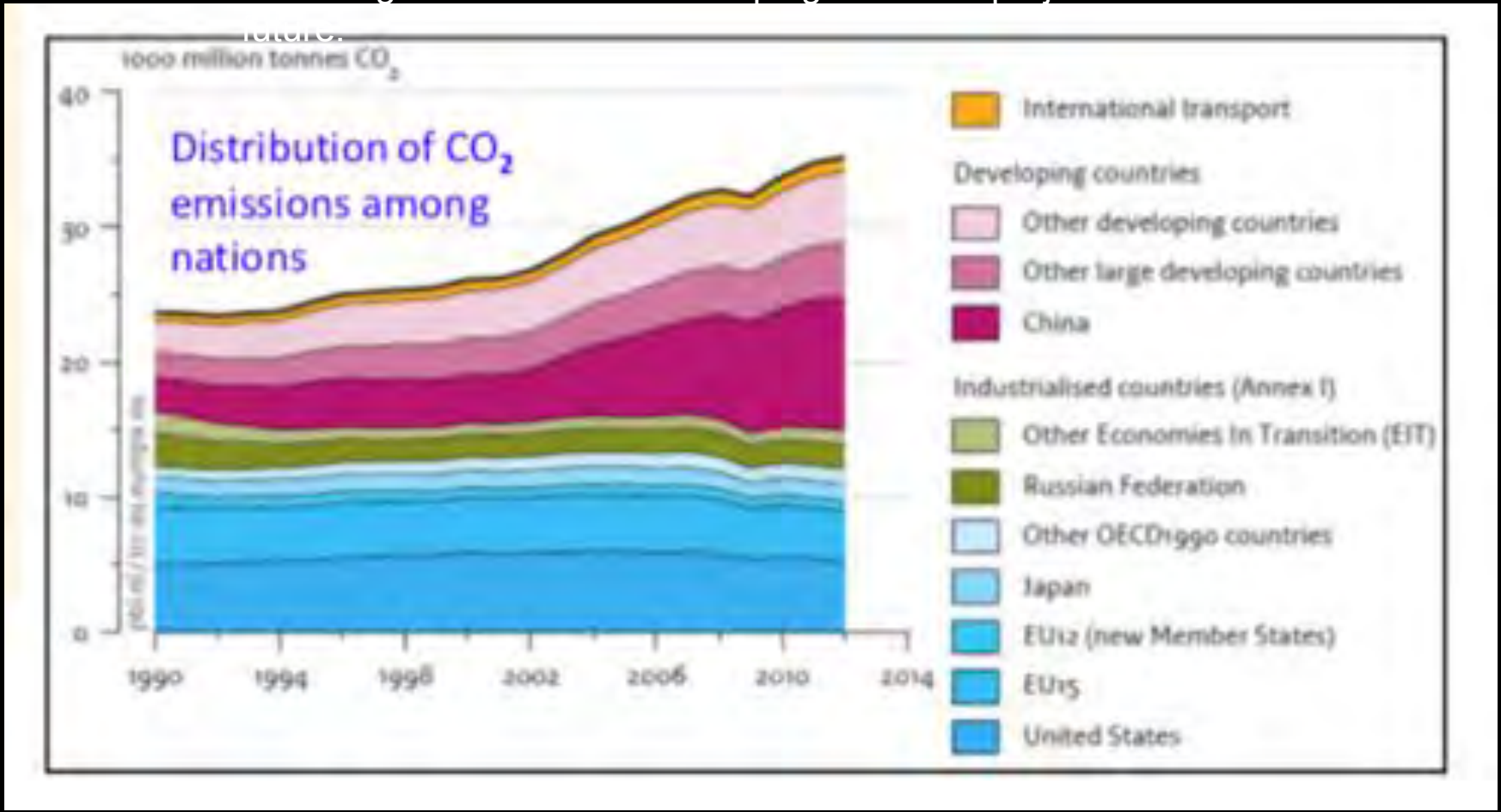
- Global target is <2˚C temperature increase from pre-industrial levels
- This is a very challenging goal



From AR6 WGIII ZOD

All increases in emissions from developing countries since 1990.

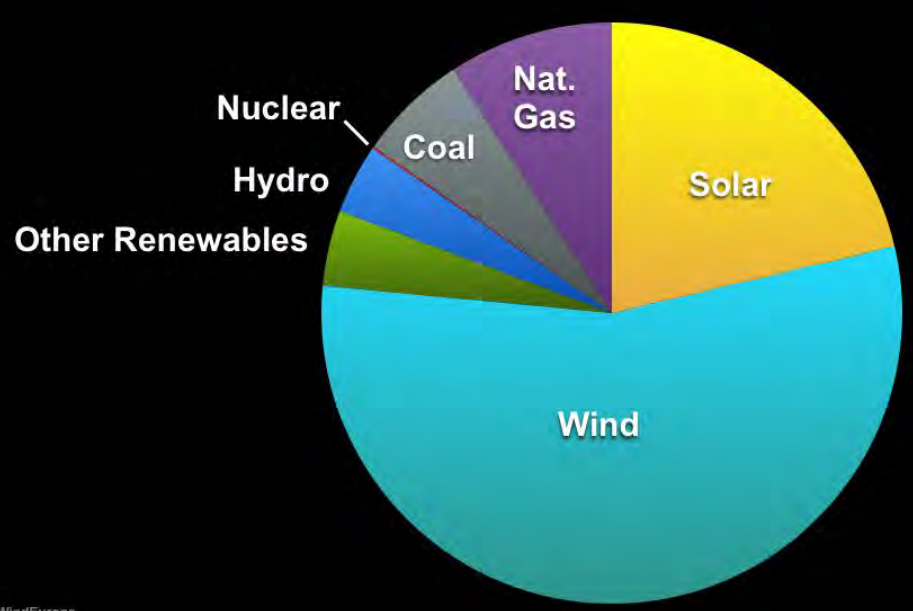
Even larger increases in developing countries projected into future.



Some Good News

There is some good news. Perhaps the most significant is the large increase of renewable electricity in new powerplant construction.

New Electricity Capacity in Europe, 2017

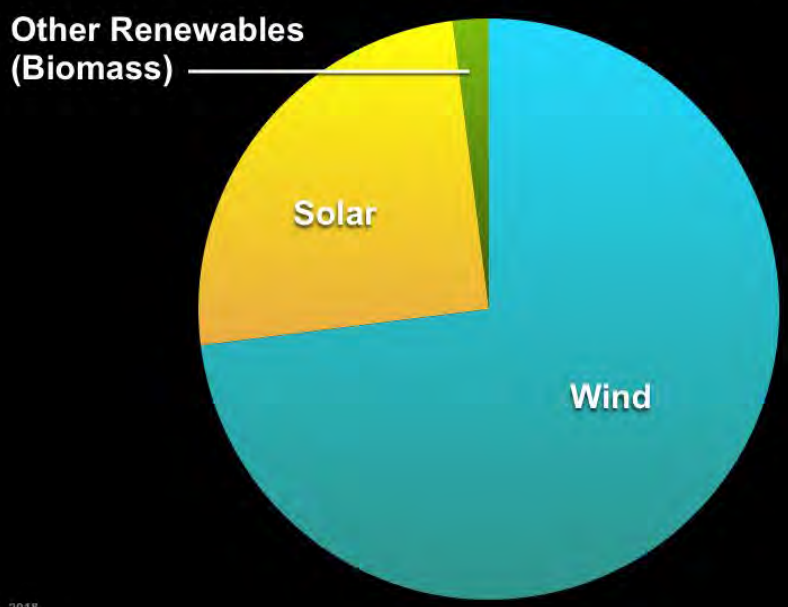


77% of new capacity was from solar and wind.

Data: WindEurope

New Electricity Capacity in Germany

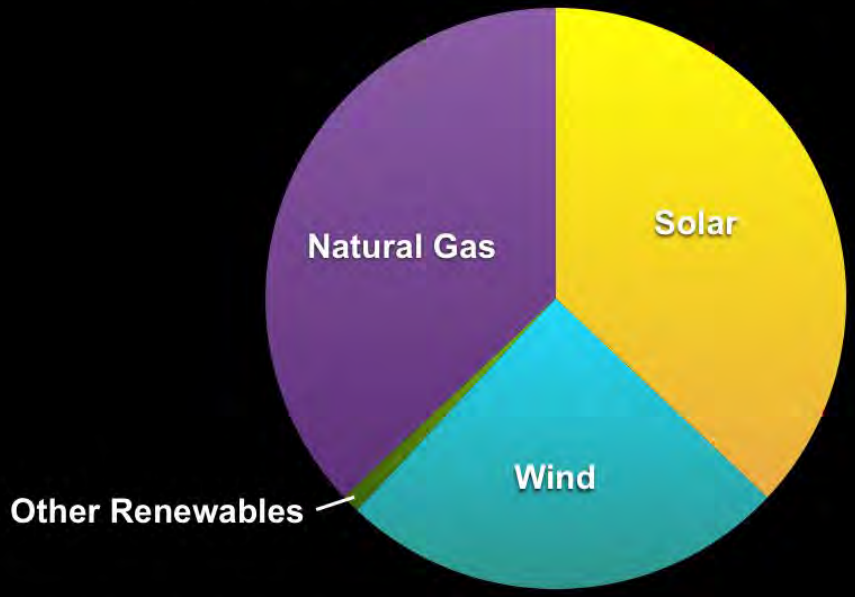
2017



100% of new electricity capacity came from renewables.

Data: Fraunhofer Institute, 2018

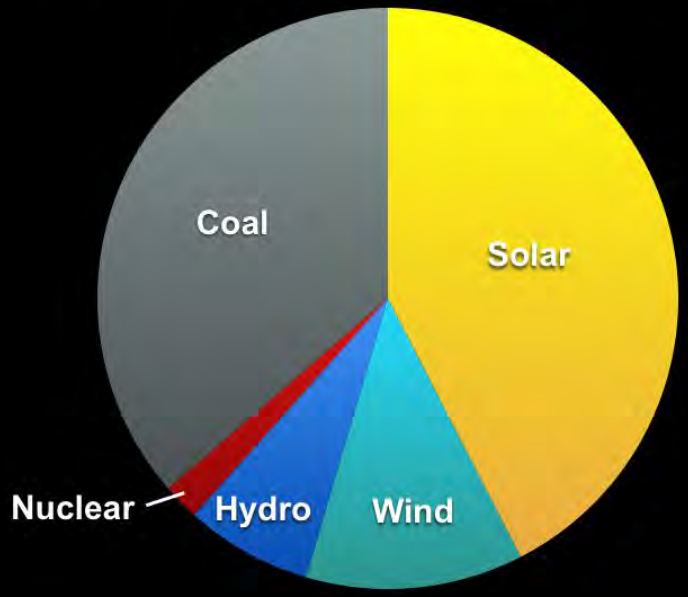
New Electricity Capacity in the U.S., 2017



62% of new capacity was from solar and wind.

Data: Bloomberg New Energy Finance/Business Council for Sustainable Energy (BCSE)

New Electricity Capacity in China, 2017

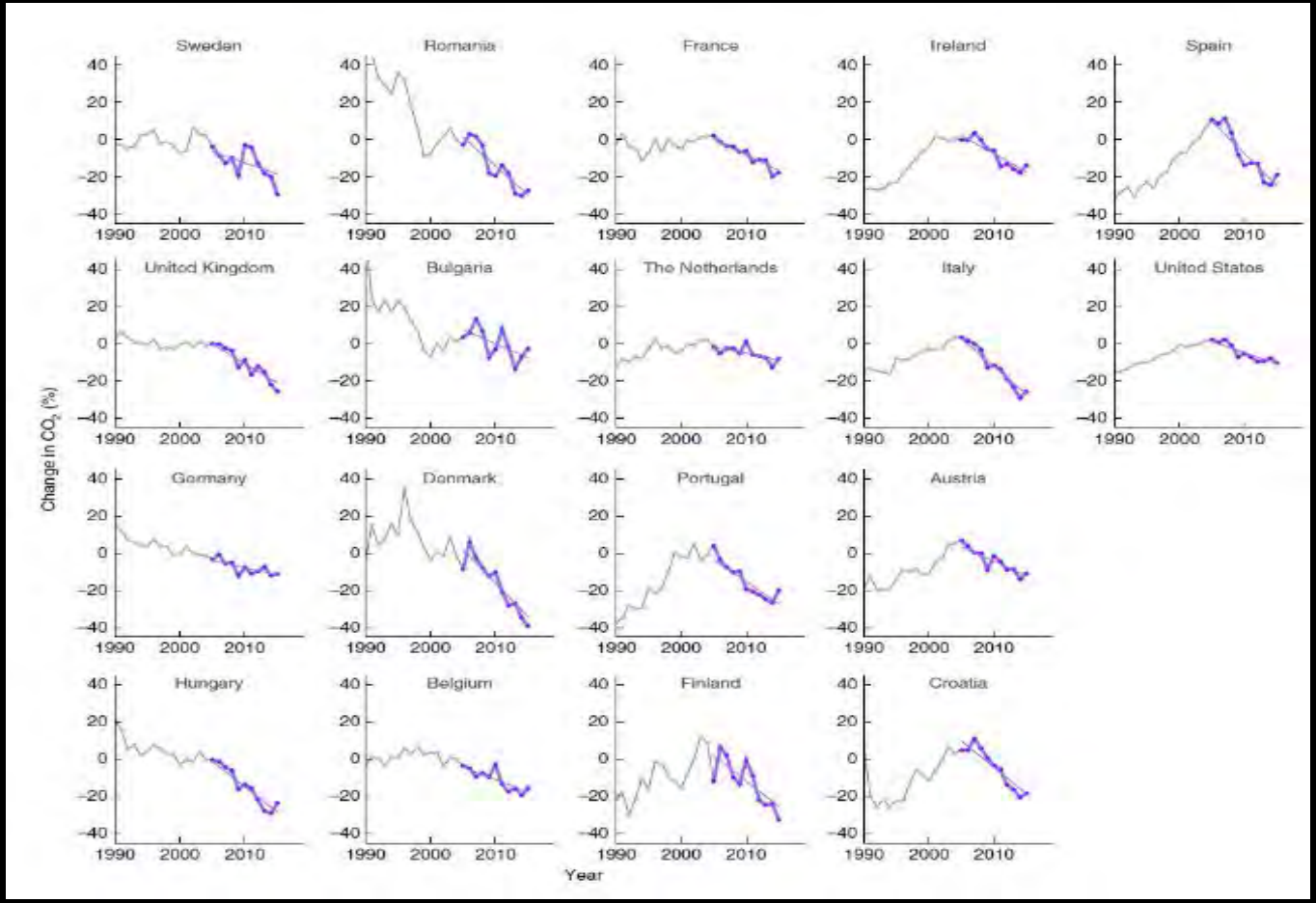


54% of new capacity was from solar and wind.

But ~30% from coal

Data: China Energy Portal

Other Good News



From AR6 WGIII ZOD

- Nonetheless, I am pessimistic that we can achieve a temperature increase of less than 2˚C by 2100; even 3˚C will be very difficult

  - Political and economic power of energy industry and high cost of stranded assets
  - Revolutionary change to achieve near zero emissions in developed world
  - Large number of developing countries without institutional and technical resources to achieve very low carbon future without significant aid from developed countries
  - Developed countries not prepared to provide resources to support developing countries.