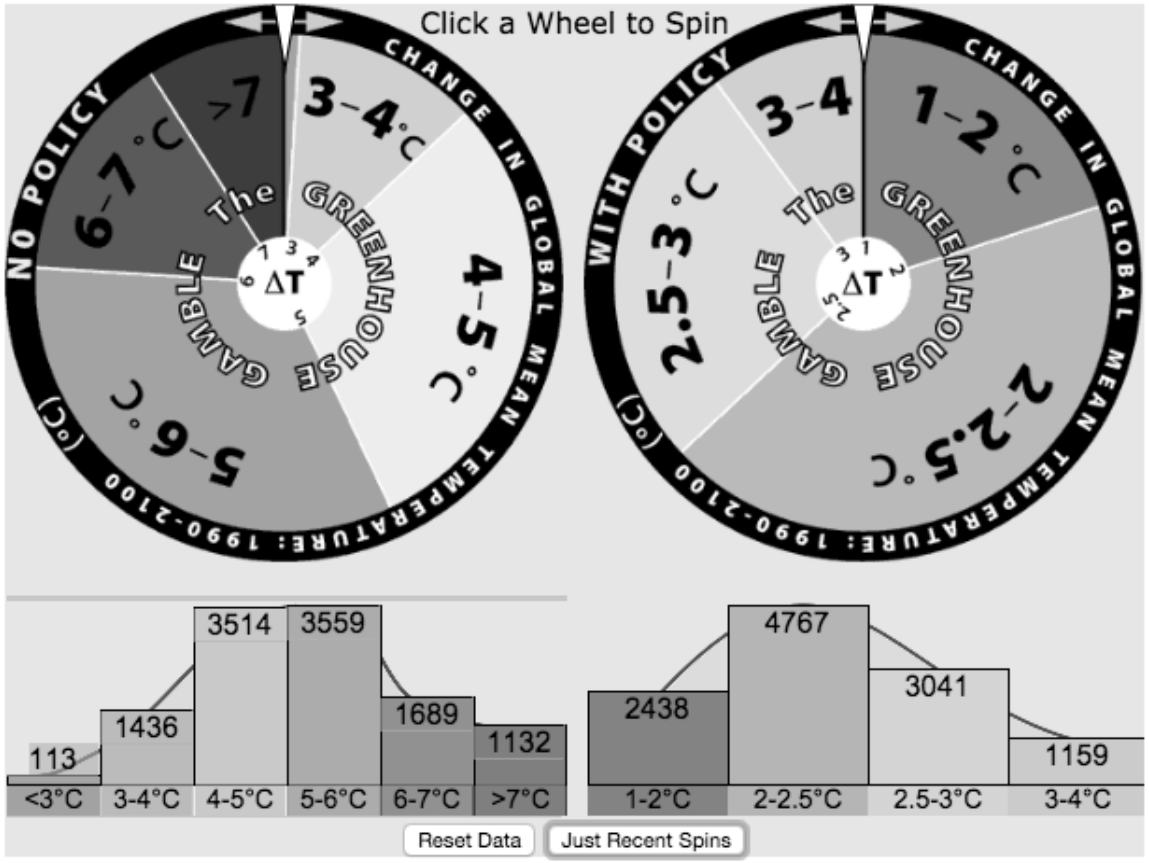
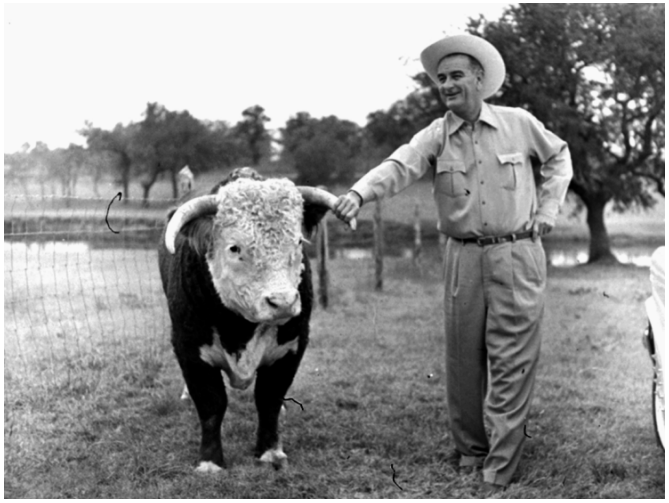
Risky business and the management of climate change



Ankur Desai
Dept of Atmospheric & Oceanic Sciences
University of Wisconsin-Madison

Oct 16, 2017 RMI 650

The continued release of CO_2 to the atmosphere from burning fossil fuels would "almost certainly cause significant changes" and "could be deleterious from the point of view of human beings […] and marked changes in climate, not controllable through local or even national efforts.



U.S. President's Science Advisory to President Lyndon B. Johnson 1966

The Rodney & Otamatea Times
WAITEMATA & KAIPARA GAZETTE.
PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

LA Times

Fires, droughts and hurricanes: What's the link between climate change and natural disasters?

NY Times

Hurricane Irma Linked to Climate Change? For Some, a Very 'Insensitive' Question.

The Atlantic

Has Climate Change Intensified 2017's Western Wildfires?

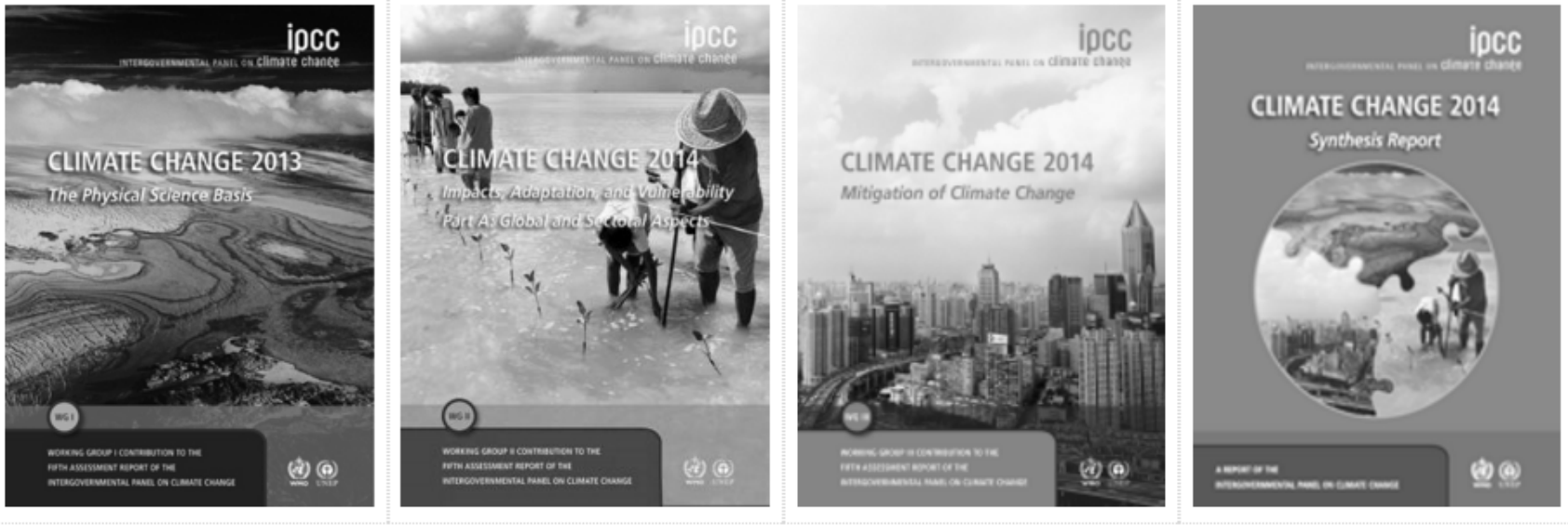
It was supposed to be a quiet year.

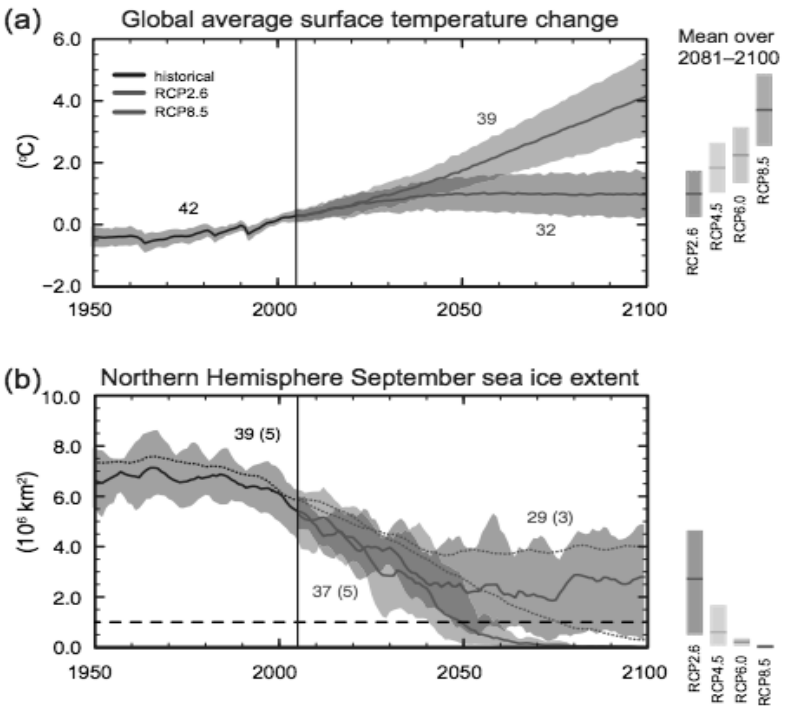
The IPCC *et al*

- Intergovernmental Panel on Climate Change (http://www.ipcc.ch/)
  - Established 1985 by UNEP and WMO
  - Provides review of science on causes of climate change (WG1), impacts of climate change (WG2), options of adaptation and mitigation (WG3)
  - Entirely volunteer run, with nomination process, support from UN trust fund
  - Assessment report ever ~4 yrs since 1990, a conservative estimate of state of science, in details and summary for policymakers
- Supports efforts of global climate change harm reduction under U.N. Framework Convention on Climate Change (UNFCCC), adopted 1992
  - Conference of Parties (165 signatories, 197 ratifiers) meets annual to update plans and form protocols for emissions reduction: Kyoto Protocol (1997, effective 2008-2012/2013-2020) and Paris Agreement (2015, effective 2016-)
- Has spurred many national and regional efforts on climate change assessment (National Academies, DOD, World Bank, WICCI), regulations (Clean Power Plan, Regional Greenhouse Gas Initiative, state level energy mandates), and industries (Tesla, BP carbon capture)

IPCC @IPCC_CH · 2m

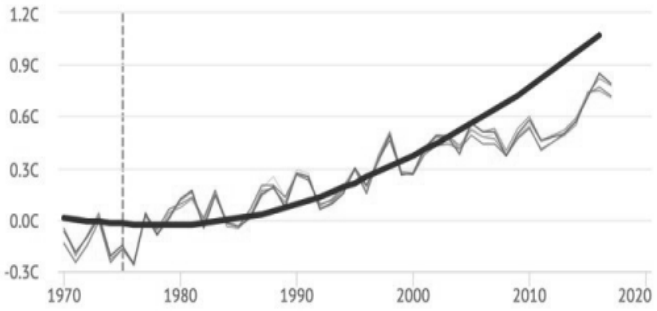
Call for nominations of authors for the #AR6 is open till 27 October! Full WGI outline here: bit.ly/2fyx9B2 #IPCC #climatechange



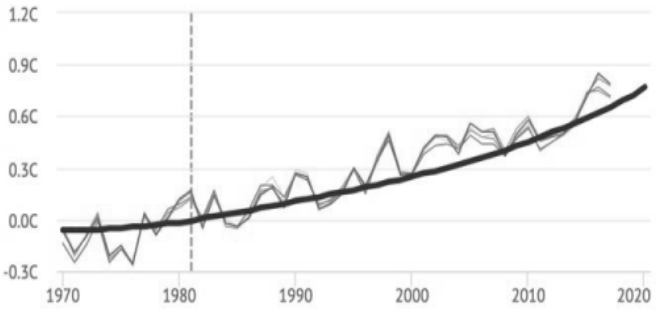


https://www.ipcc.ch/report/ar5/

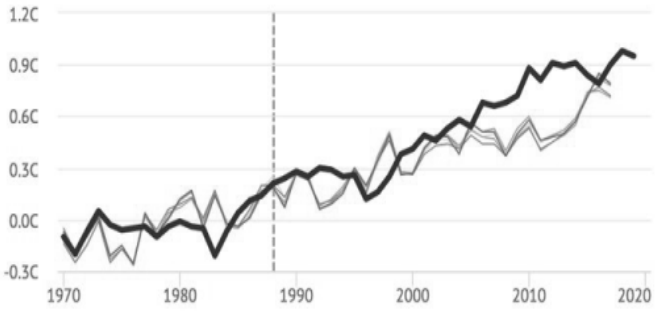
1975: Wally Broecker



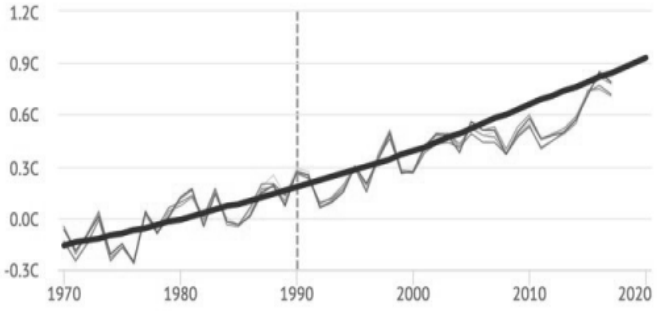
1981: Hansen et al



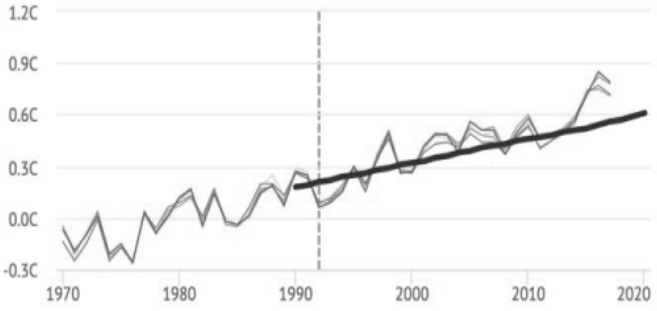
1988: Hansen et al



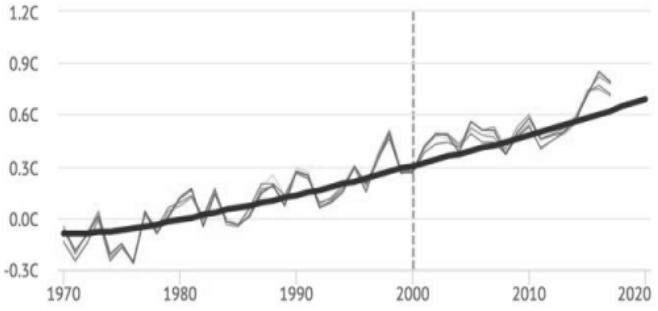
1990: IPCC First Assessment Report



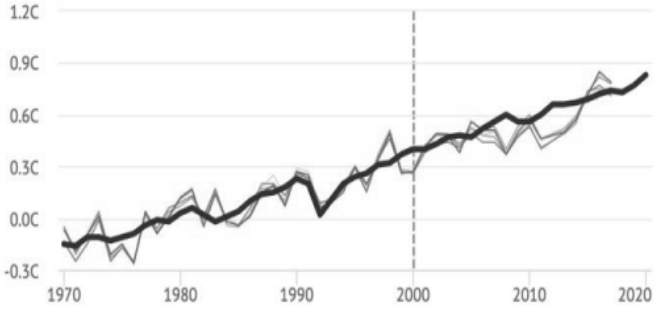
1995: IPCC Second Assessment Report



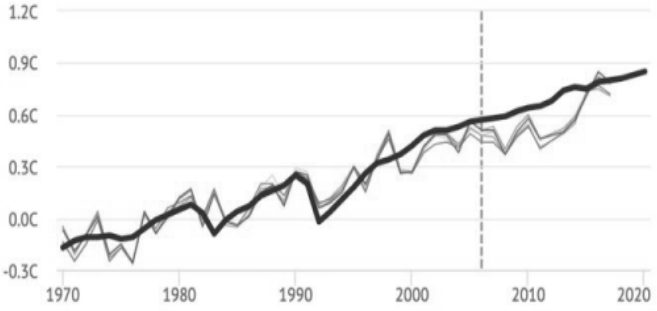
2001: IPCC Third Assessment Report



2007: IPCC Fourth Assessment Report



2013: IPCC Fifth Assessment Report



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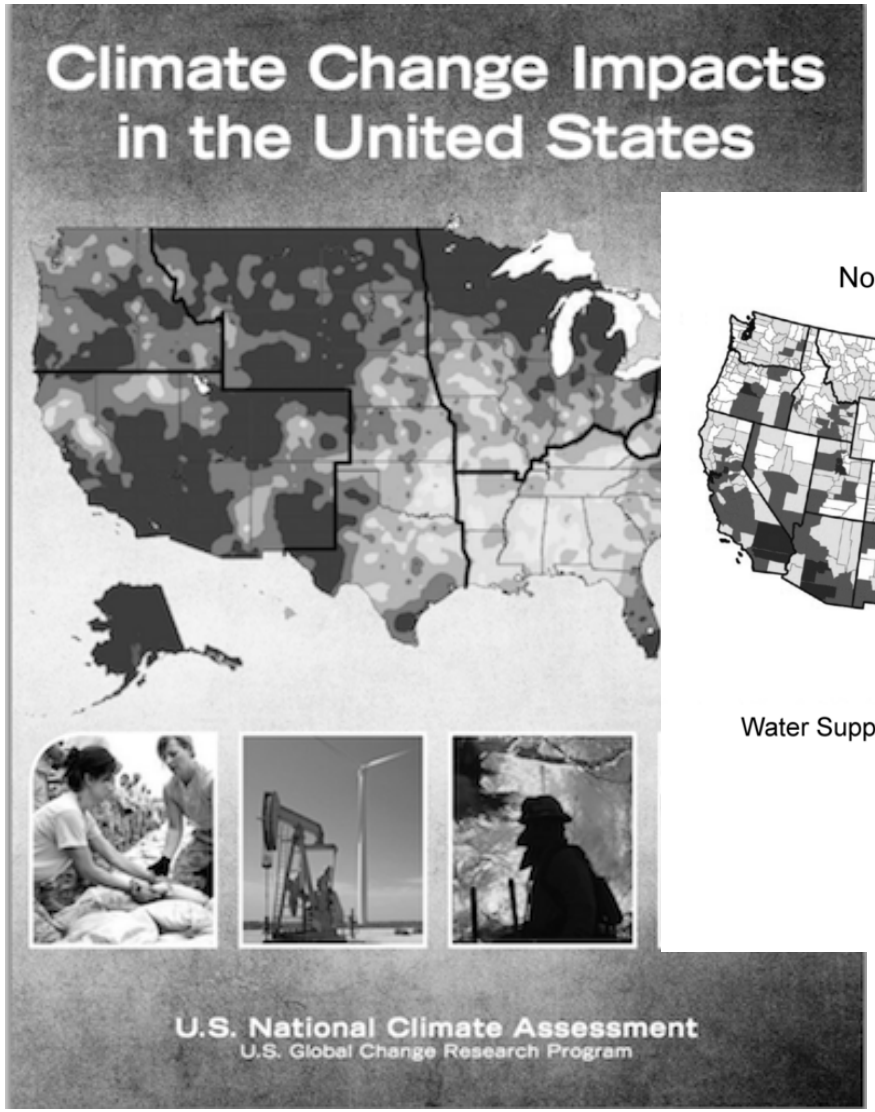
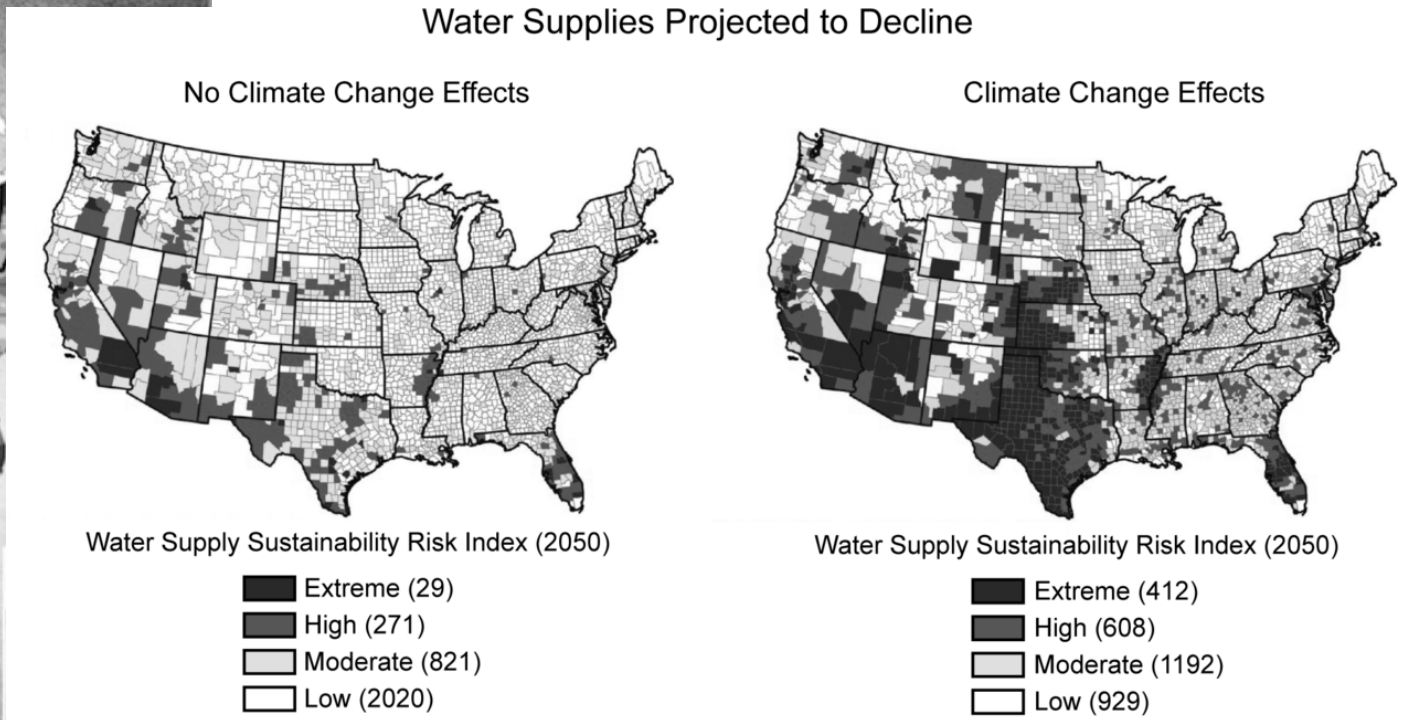




http://nca2014.globalchange.gov/

Innovations

Death of gas and diesel begins as GM announces plans for 'all-electric future'

By Peter Holley October 2 at 2:53 PM

Wash Post

After nearly a century of building vehicles powered by fossil fuels, General Motors — one of the world's largest automakers — announced Monday that the end of GM producing internal combustion engines is fast approaching.

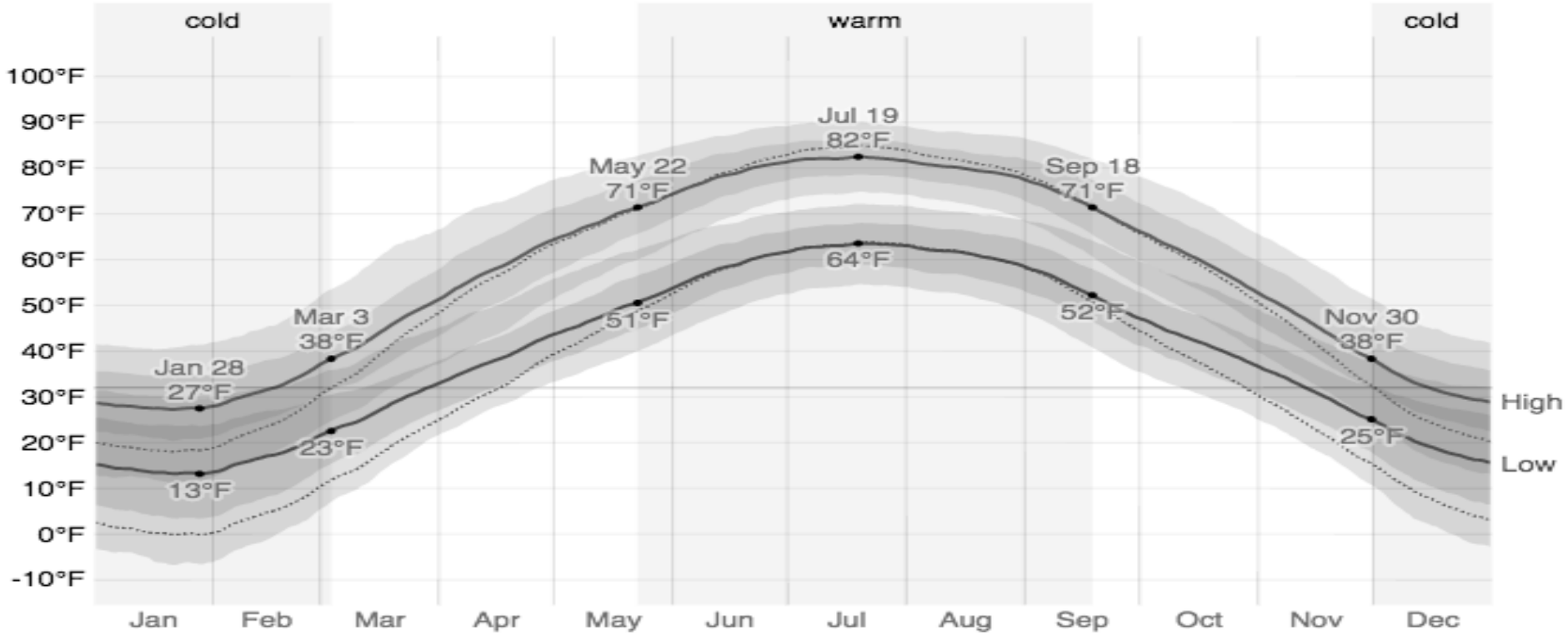
The acceleration to an all-electric future will begin almost immediately, with GM releasing two new electric models next year and an additional 18 by 2023.

Three things about climate

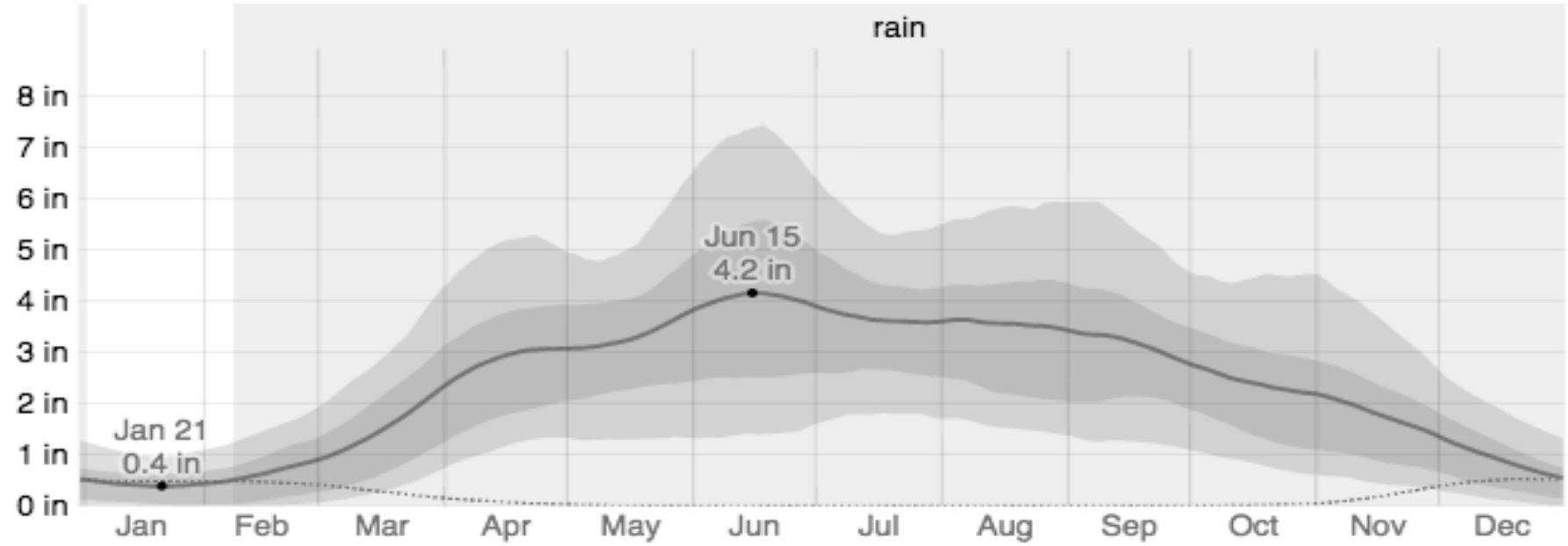
Three things about climate

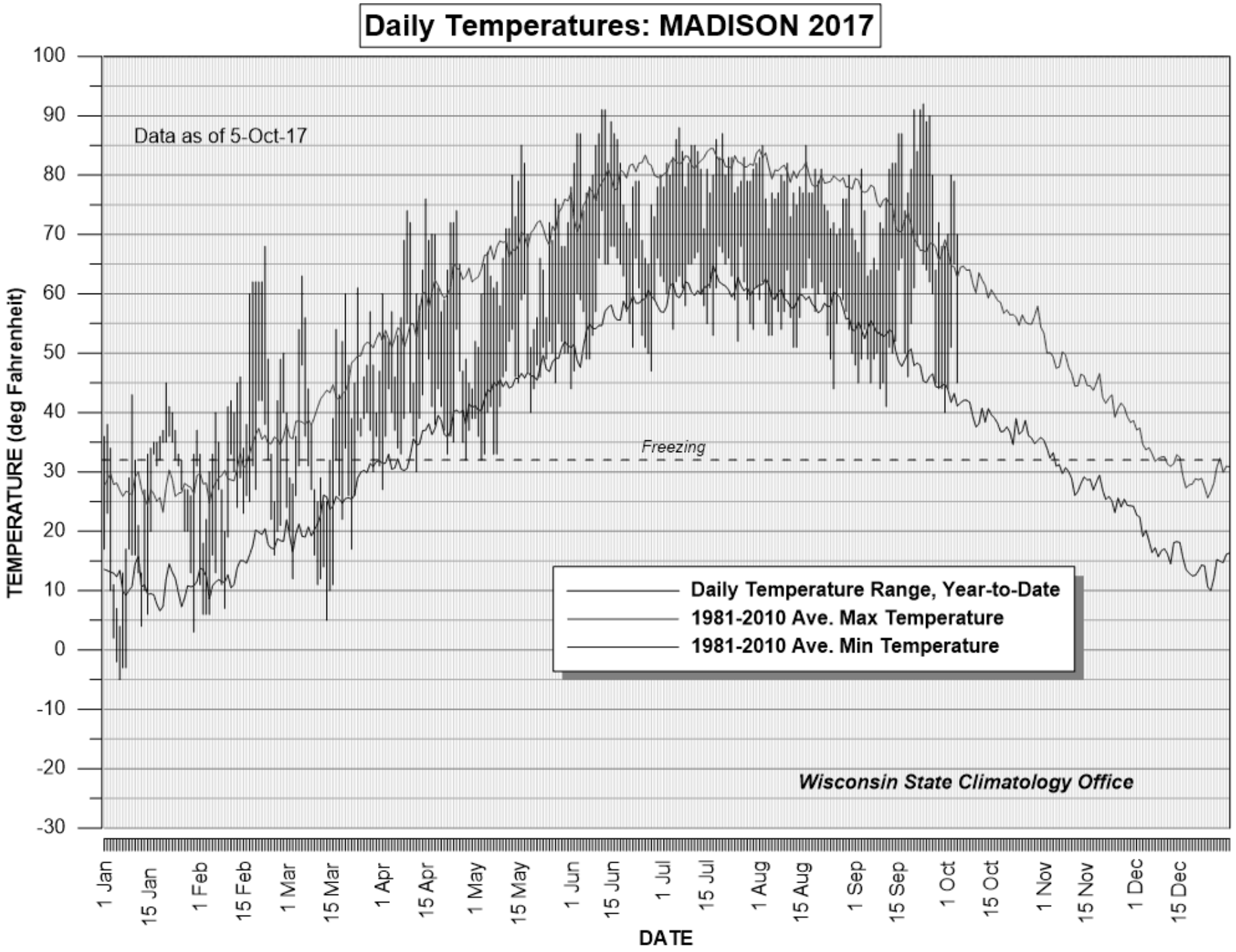
- Climate is the average of weather

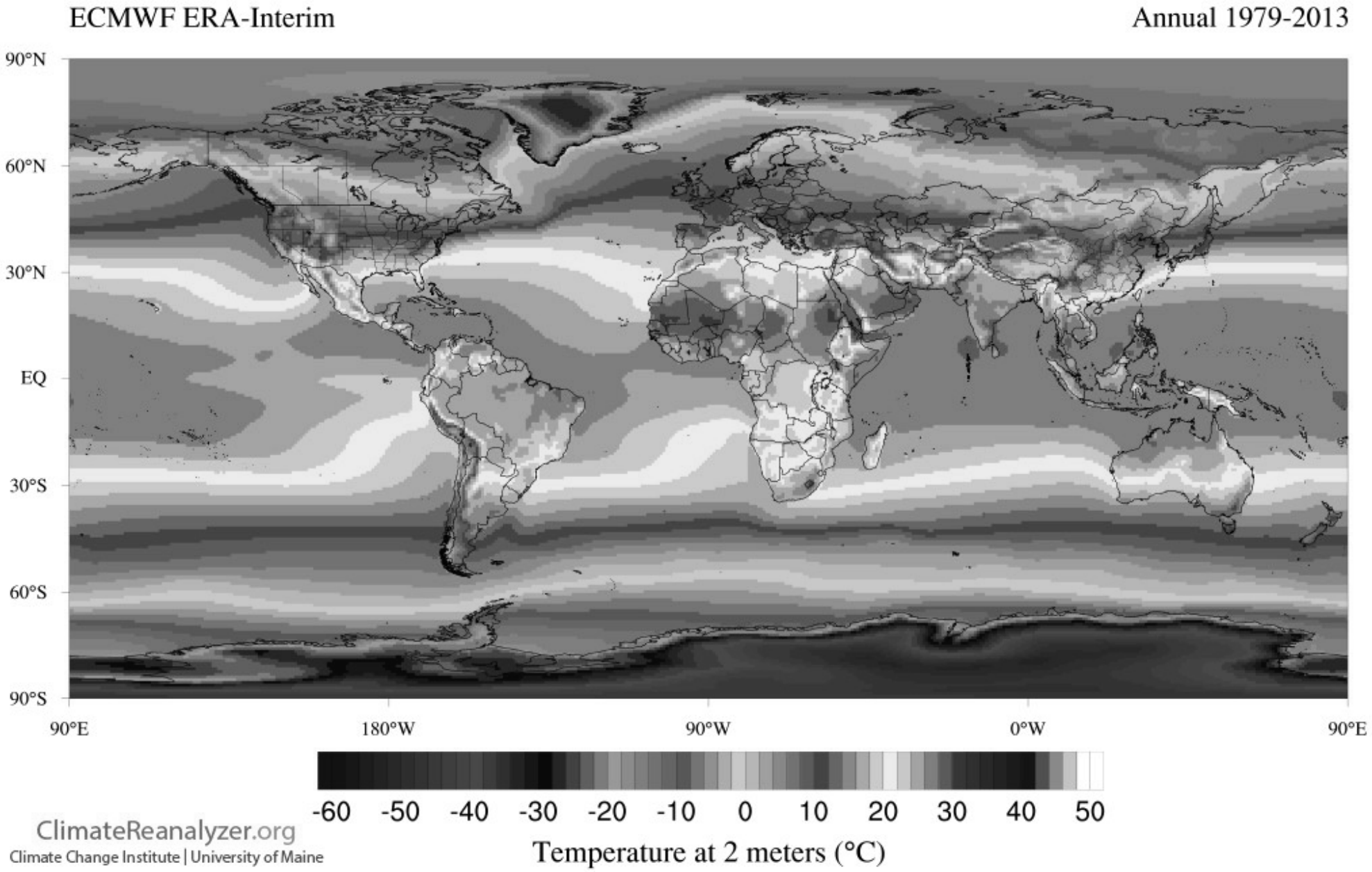
Average High and Low Temperature



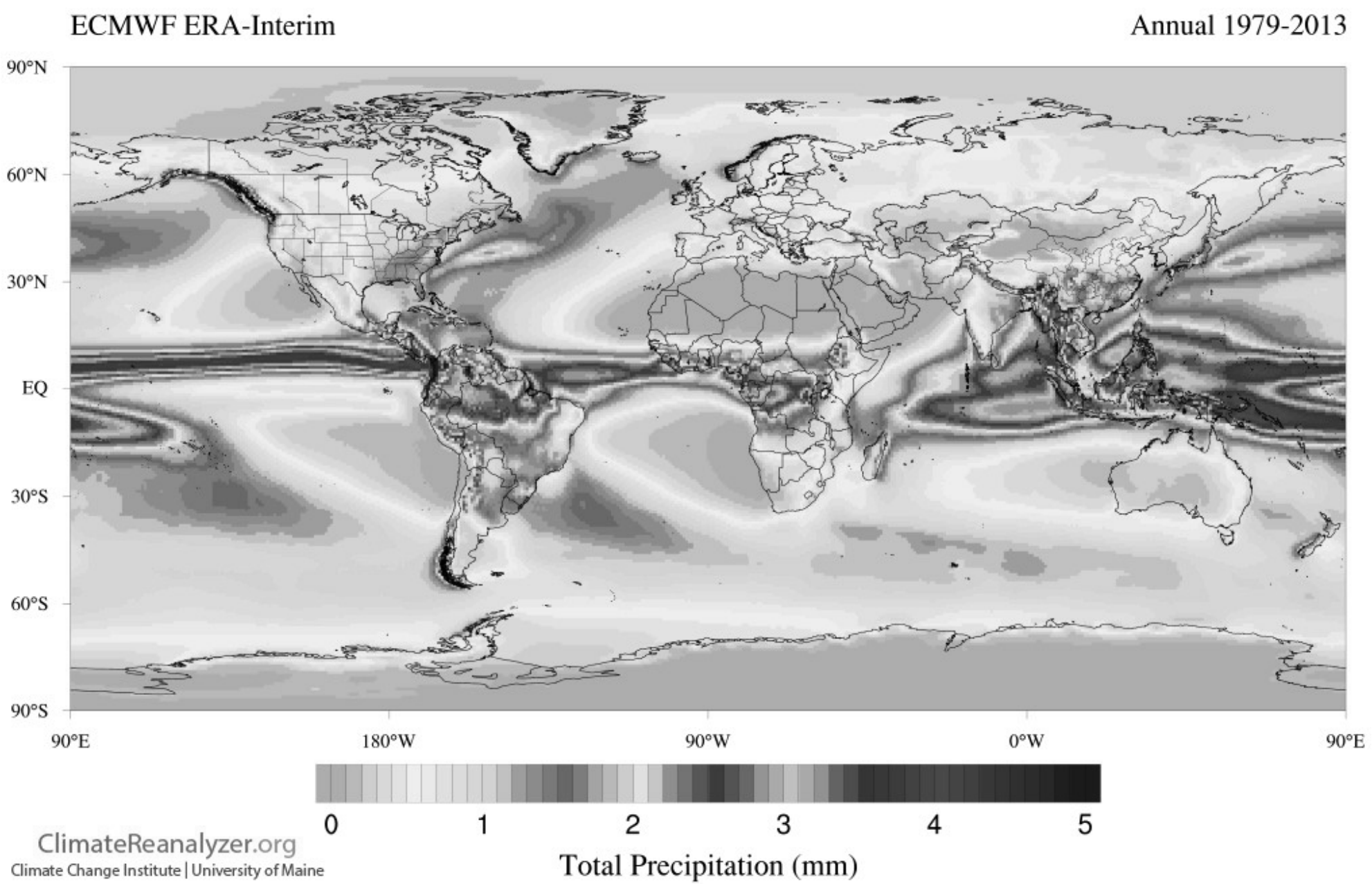
Average Monthly Rainfall




Daily Temperatures: MADISON 2017
Data as of 5-Oct-17
Freezing
Daily Temperature Range, Year-to-Date
1981-2010 Ave. Max Temperature
1981-2010 Ave. Min Temperature
Wisconsin State Climatology Office
TEMPERATURE (deg Fahrenheit)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
1 Jan
15 Jan
1 Feb
15 Feb
1 Mar
15 Mar
1 Apr
15 Apr
1 May
15 May
1 Jun
15 Jun
1 Jul
15 Jul
1 Aug
15 Aug
1 Sep
15 Sep
1 Oct
15 Oct
1 Nov
15 Nov
1 Dec
15 Dec
DATE



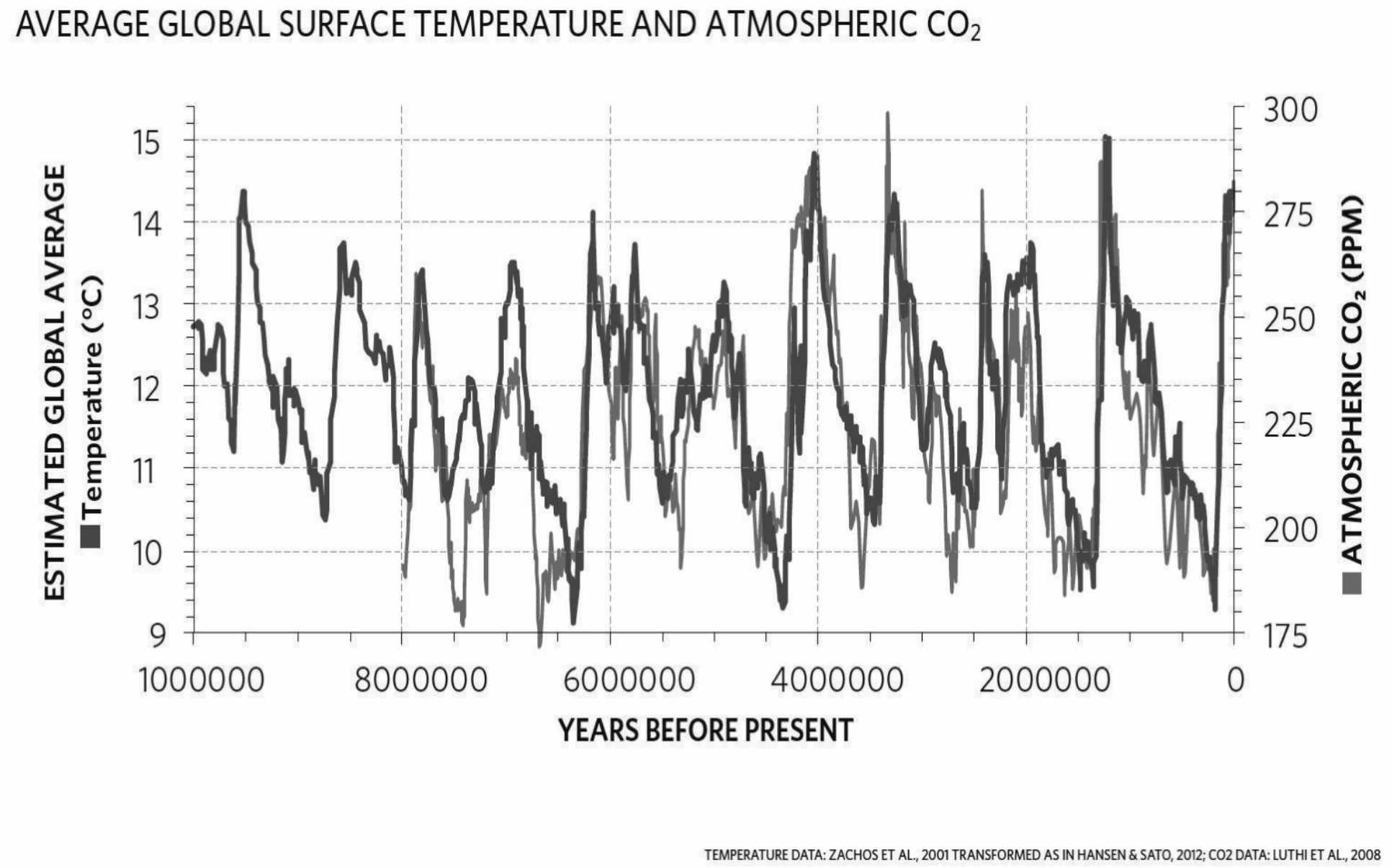
http://cci-reanalyzer.org/



http://cci-reanalyzer.org/

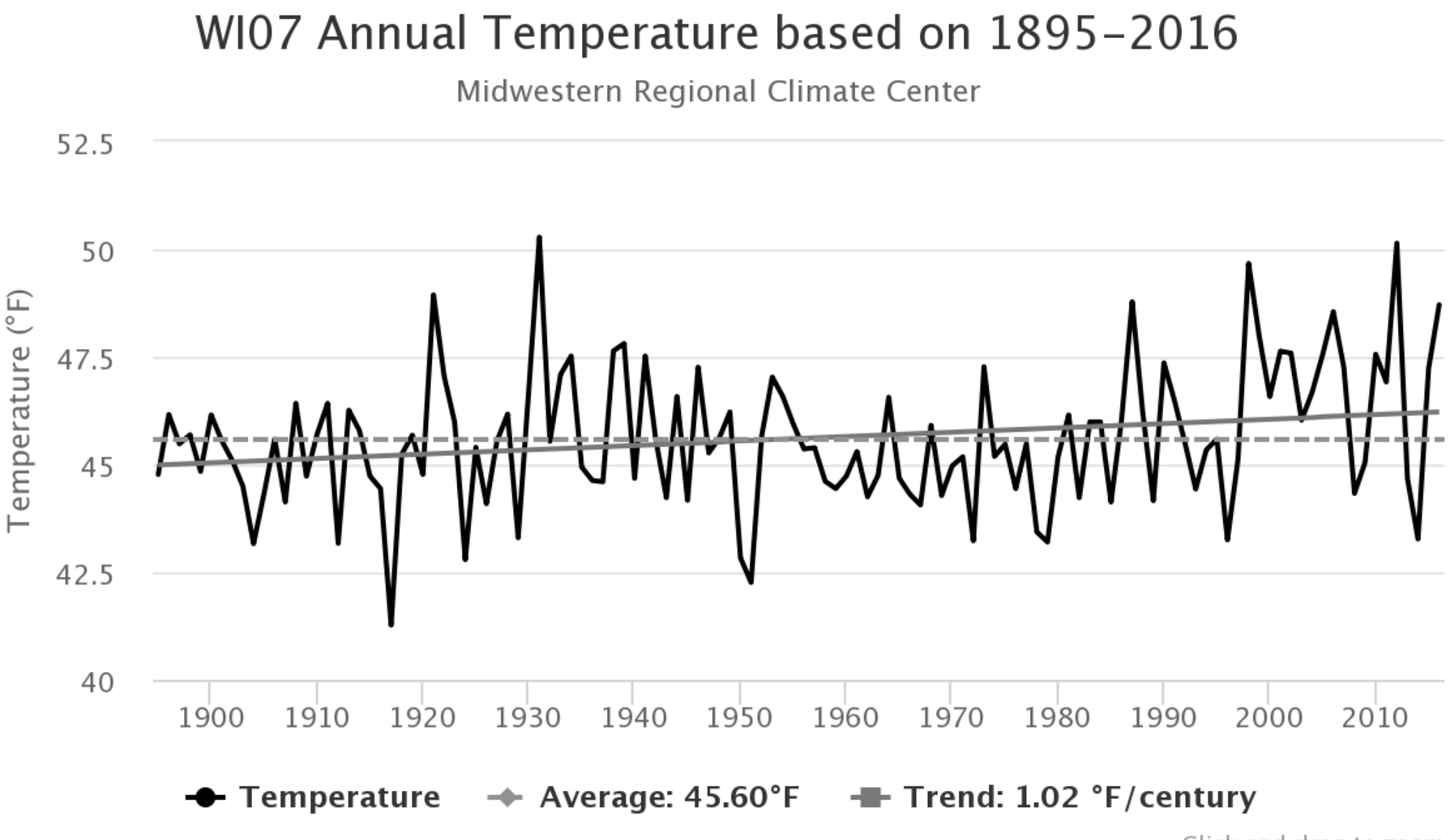
Three things about climate

- Climate is the average of weather
- Climate changes naturally

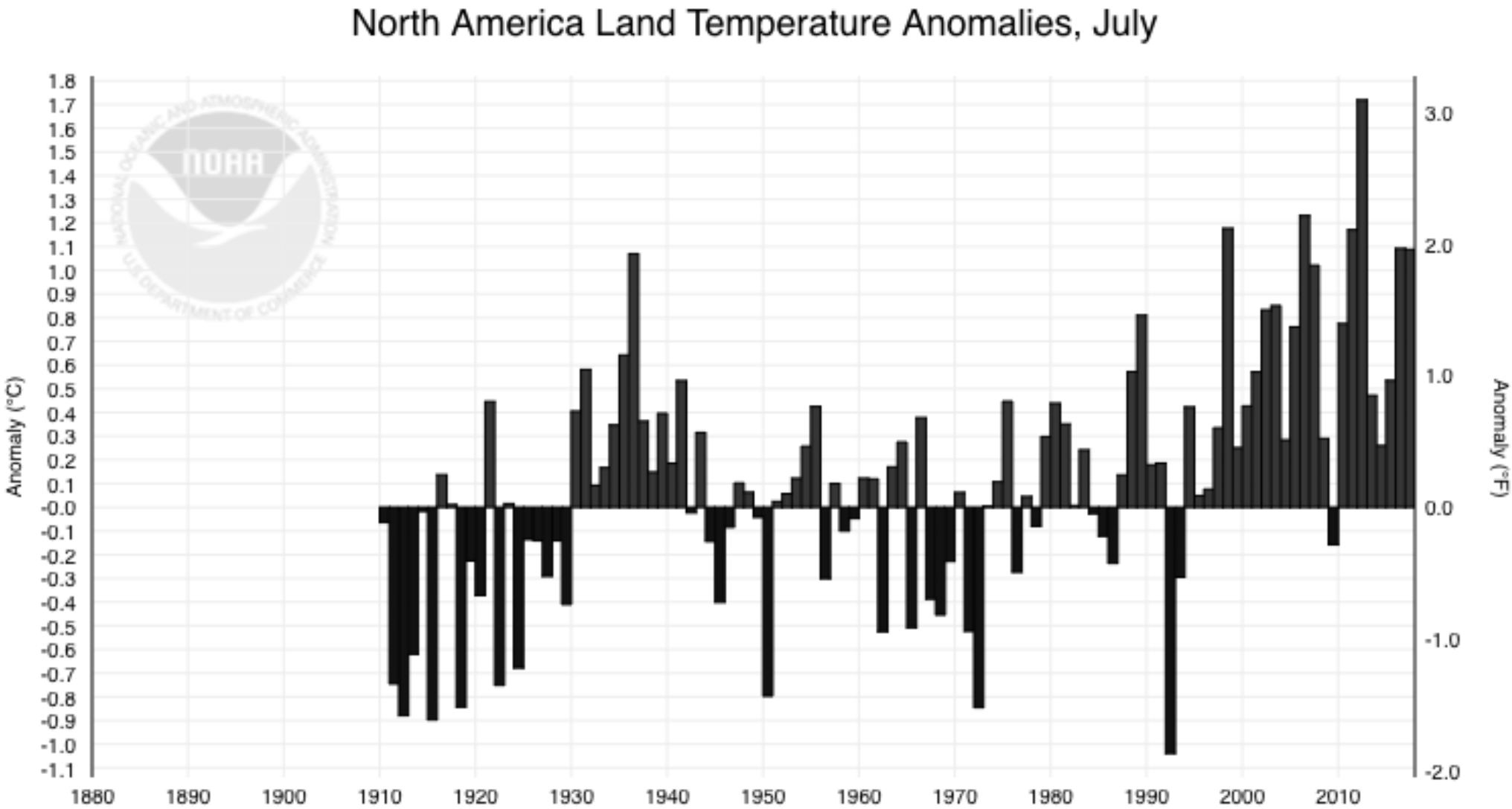


Mann et al., 2003, EOS

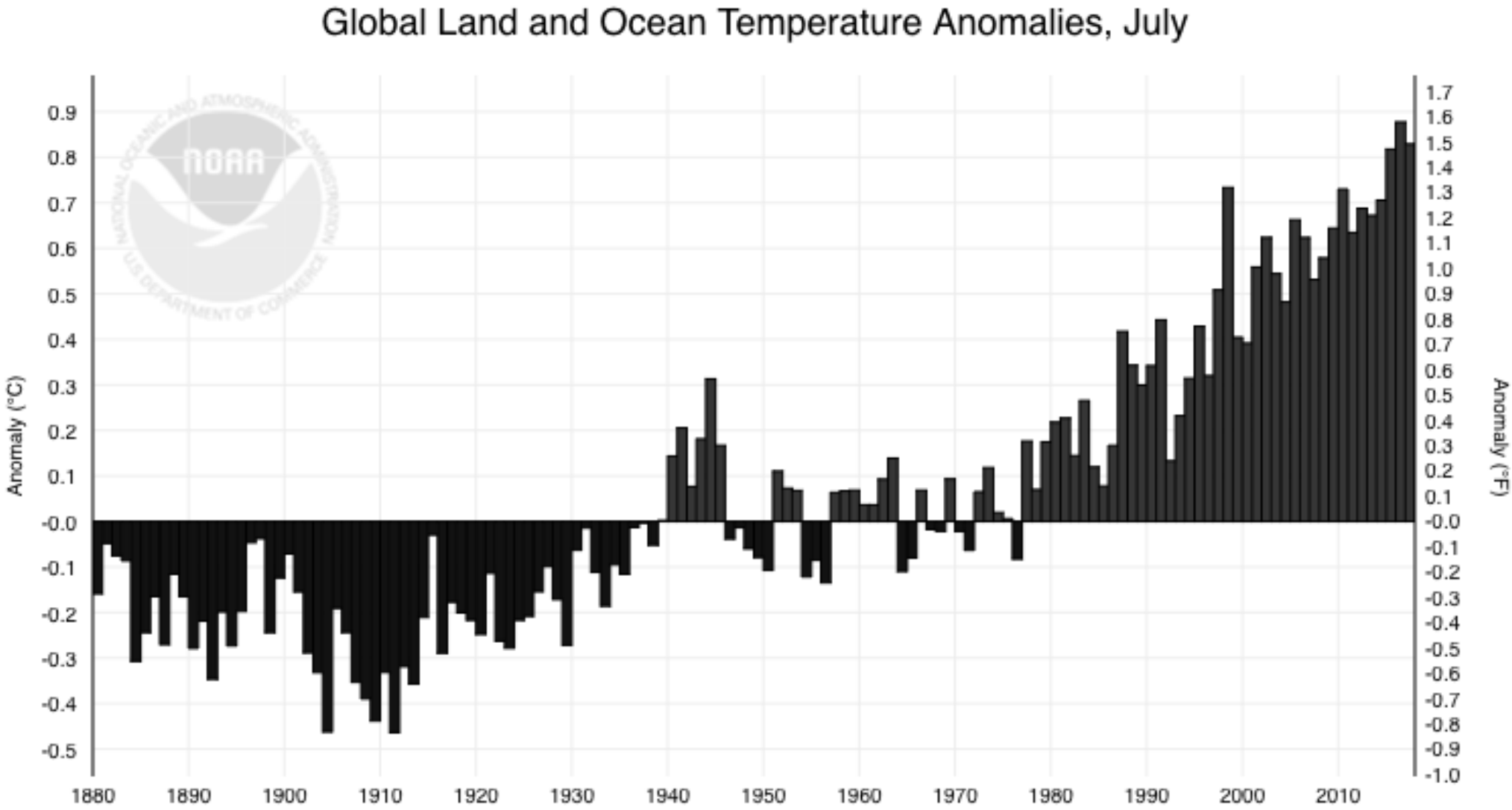
Southern Wisconsin

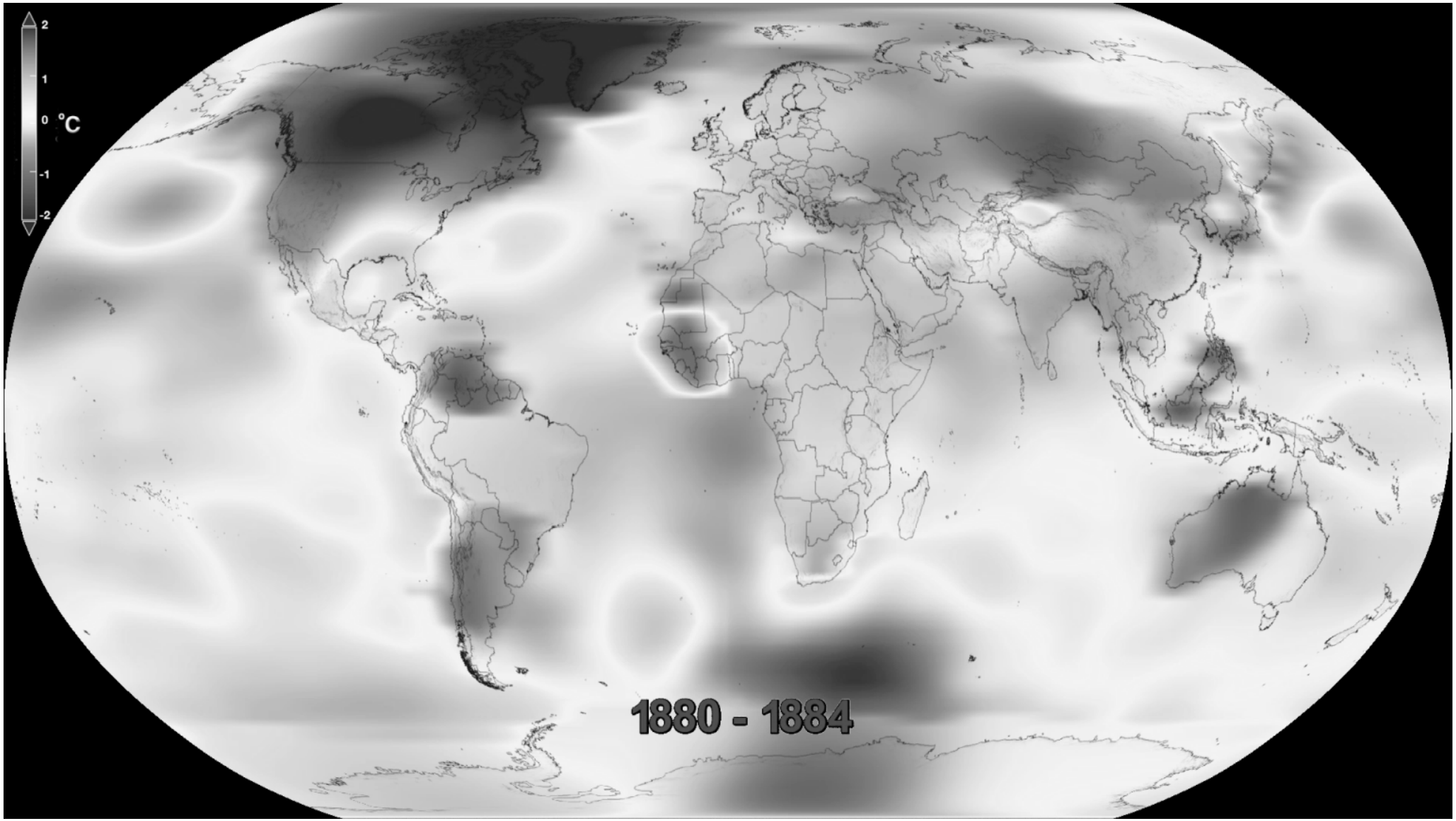


N America


North America Land Temperature Anomalies, July
Anomaly (°C)
Anomaly (°F)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
3.0
2.0
1.0
0.0
-1.0
-2.0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

WORLD

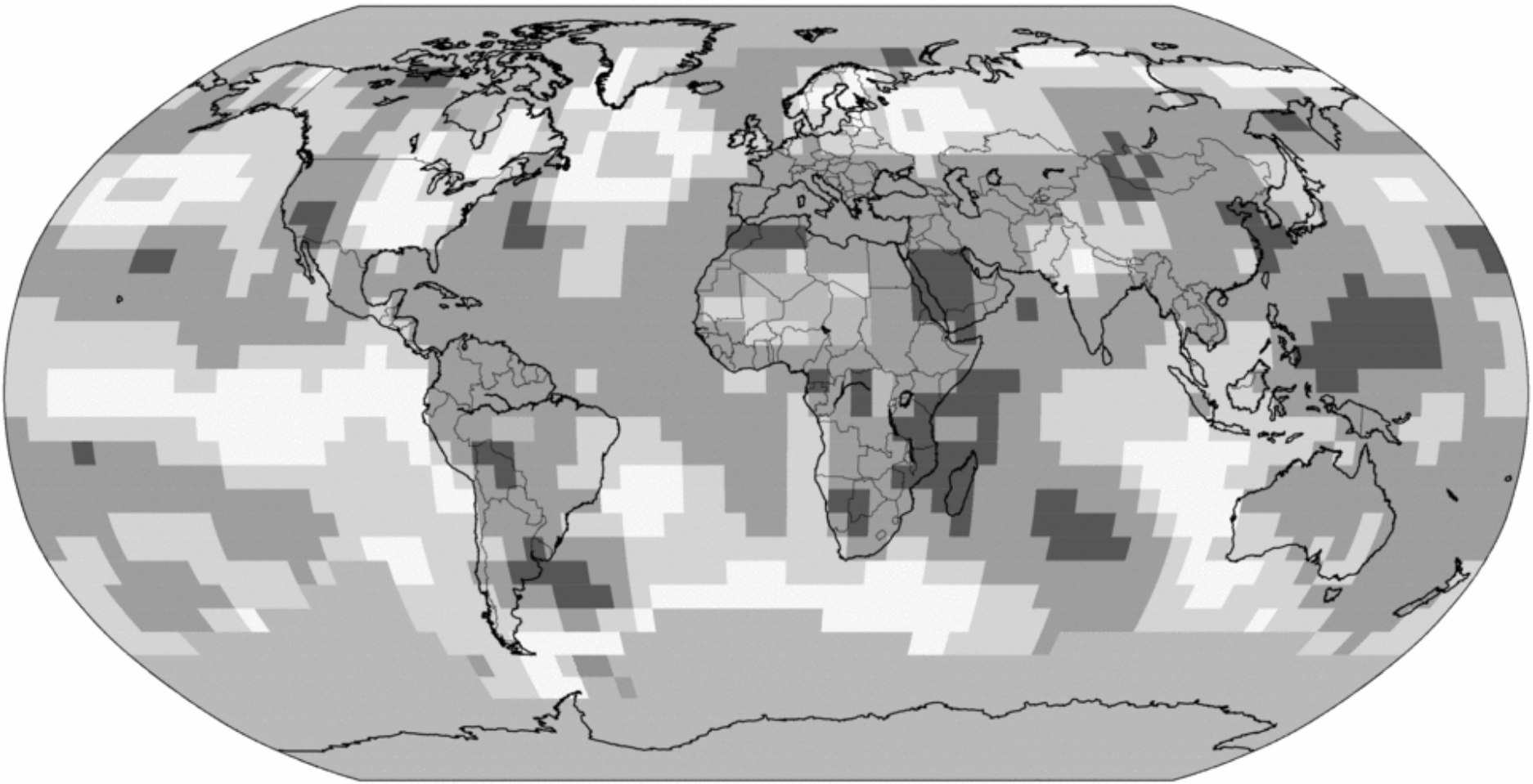

Global Land and Ocean Temperature Anomalies, July
Anomaly (°C)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
-0.4
-0.5
Anomaly (°F)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010


2
1
0
°C
-1
-2
1880 - 1884

Land & Ocean Temperature Percentiles Jun 2017–Aug 2017

NOAA's National Centers for Environmental Information

Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0

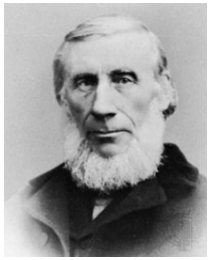


Record Coldest | Much Cooler than Average | Cooler than Average | Near Average | Warmer than Average | Much Warmer than Average | Record Warmest

Wed Sep 13 07:29:21 EDT 2017

Three things about climate

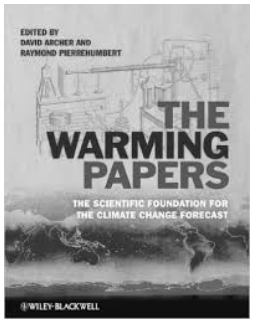
- Climate is the average of weather
- Climate changes naturally
- The study of climate change is well-established. We know how climate changes and what's is mostly causing current change

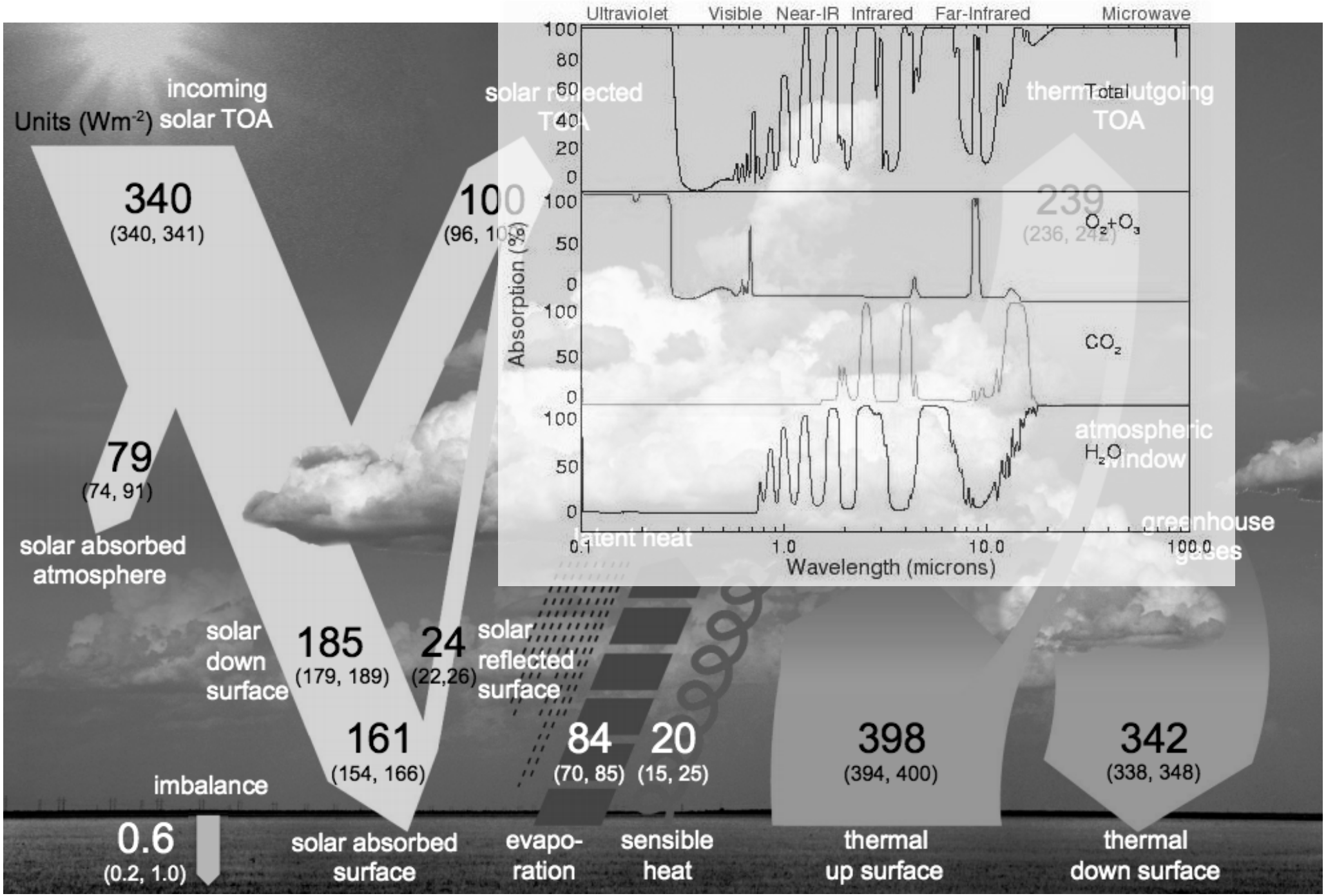


- Planetary (inc. Earth) temperature is determined by interaction of sunlight warming Earth's surface, and "greenhouse" gases that absorb infrared radiation (Fourier 1824, Tyndall 1861)

- CO_2 is a greenhouse warming gas and emitted from coal, oil, gas (Arrhenius 1896)

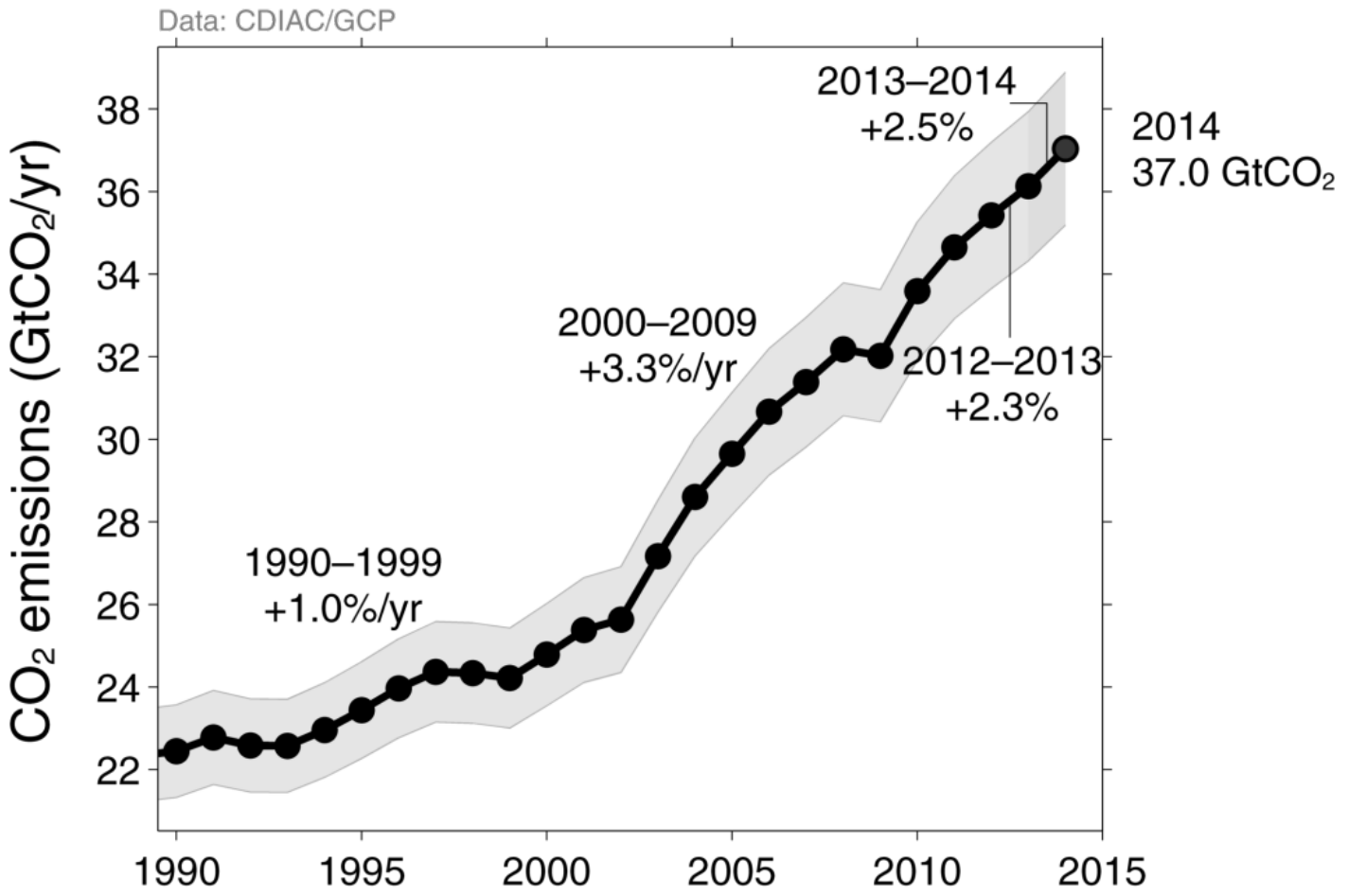
- Oceans can only take up a fraction of CO_2 produced by combustion (Revelle 1957)



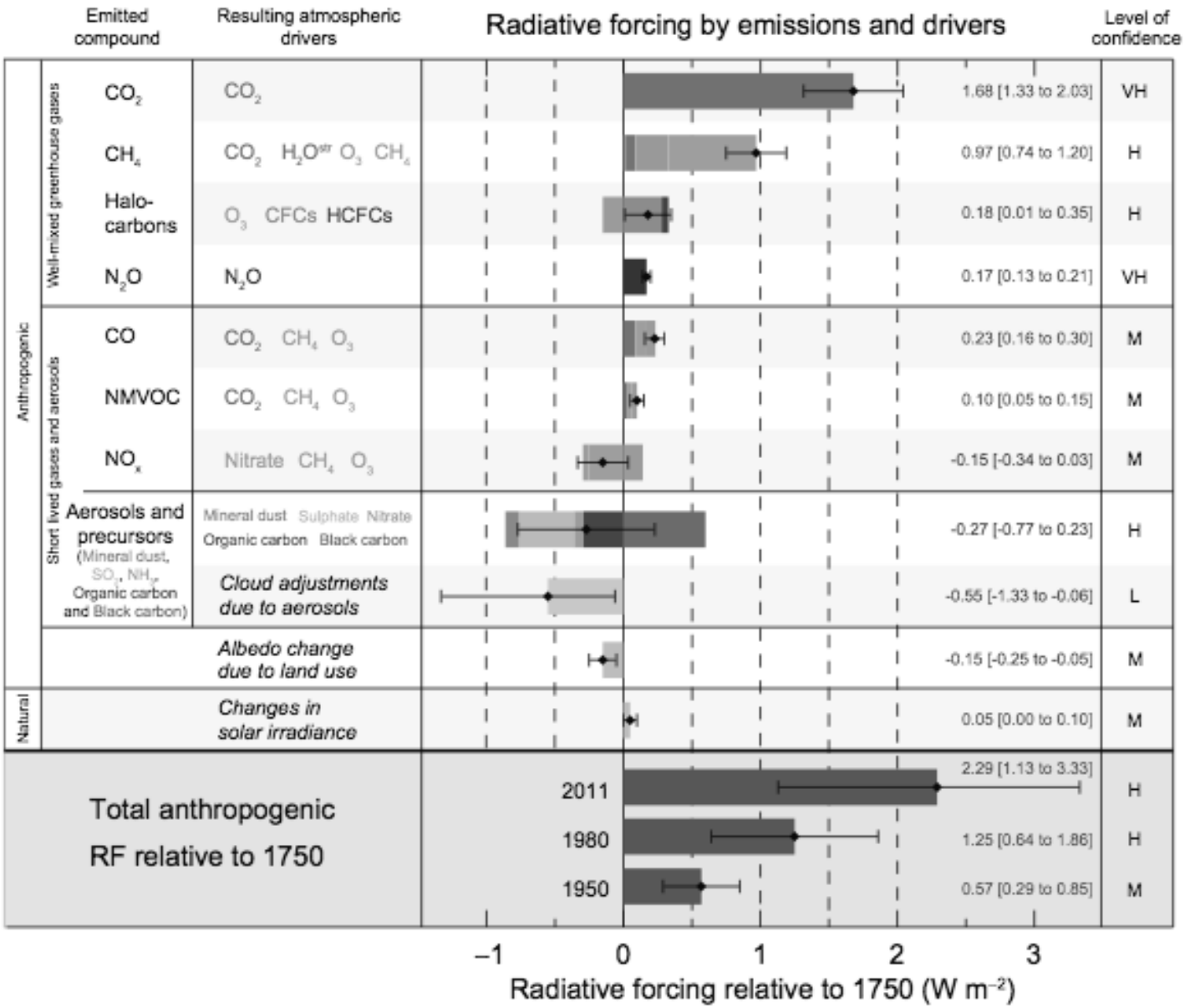


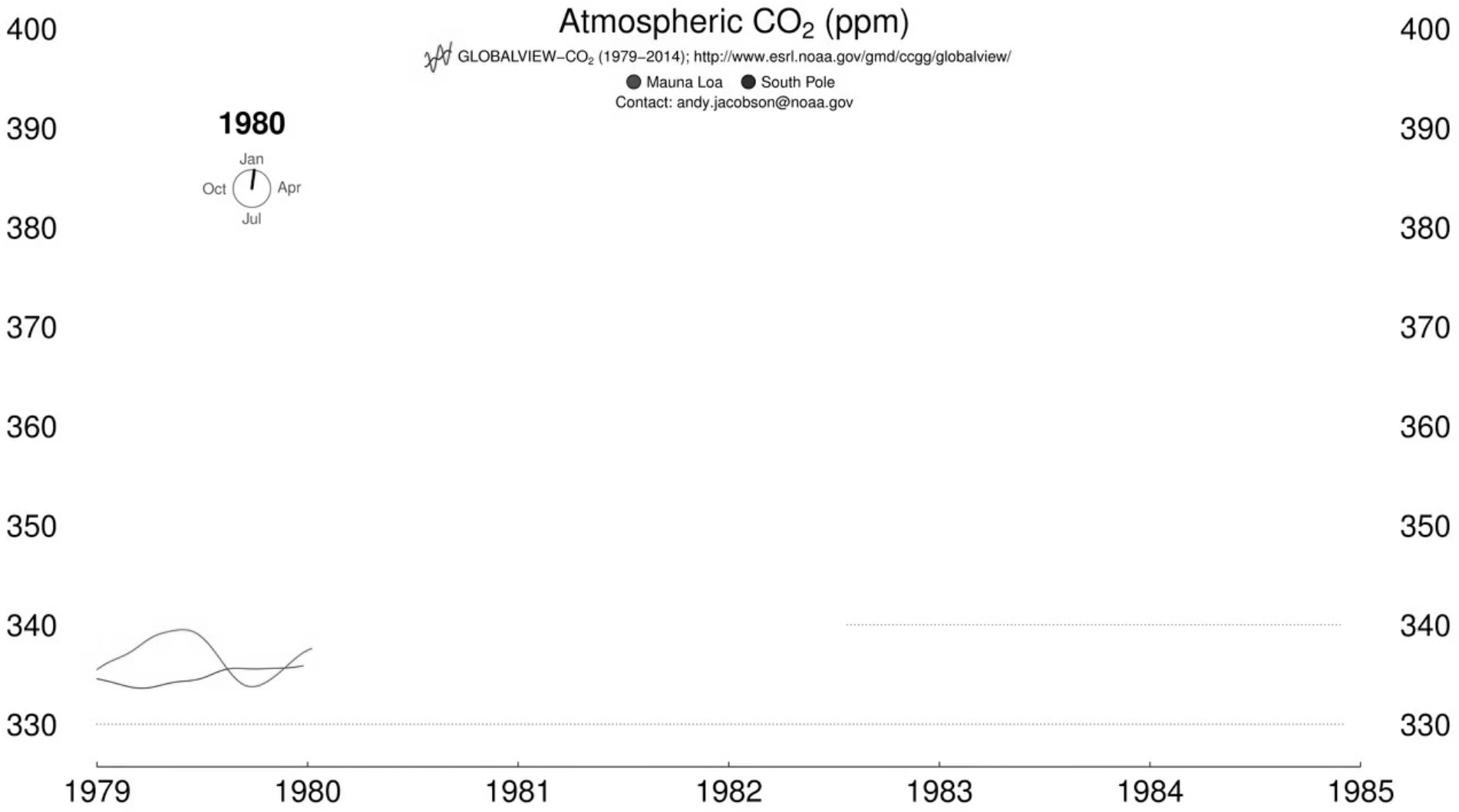
Trenberth et al., 2009

World Energy Consumption

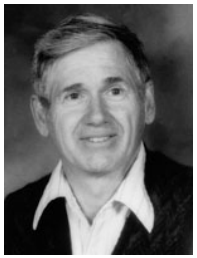


Forcings


Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
Short lived gases and aerosols
Natural
CO2
CO2
1.68 [1.33 to 2.03]
VH
CH4
CO2 H2Ostr O3 CH4
0.97 [0.74 to 1.20]
H
Halo-carbons
O3 CFCs HCFCs
0.18 [0.01 to 0.35]
H
N2O
N2O
0.17 [0.13 to 0.21]
VH
CO
CO2 CH4 O3
0.23 [0.16 to 0.30]
M
NMVOC
CO2 CH4 O3
0.10 [0.05 to 0.15]
M
NOx
Nitrate CH4 O3
-0.15 [-0.34 to 0.03]
M
Aerosols and precursors (Mineral dust, SOx, NHy, Organic carbon and Black carbon)
Mineral dust Sulphate Nitrate Organic carbon Black carbon
-0.27 [-0.77 to 0.23]
H
Cloud adjustments due to aerosols
-0.55 [-1.33 to -0.06]
L
Albedo change due to land use
-0.15 [-0.25 to -0.05]
M
Changes in solar irradiance
0.05 [0.00 to 0.10]
M
Total anthropogenic RF relative to 1750
2011
2.29 [1.13 to 3.33]
H
1980
1.25 [0.64 to 1.86]
H
1950
0.57 [0.29 to 0.85]
M
−1
0
1
2
3
Radiative forcing relative to 1750 (W m−2)



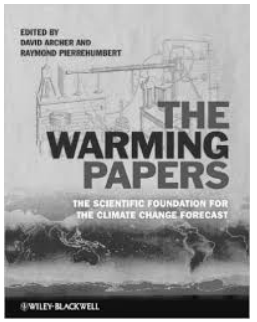
Other evidence: decreasing radiocarbon content of atmosphere, acidification of ocean, increased water use efficiency of plants, concentrations tracks emissions



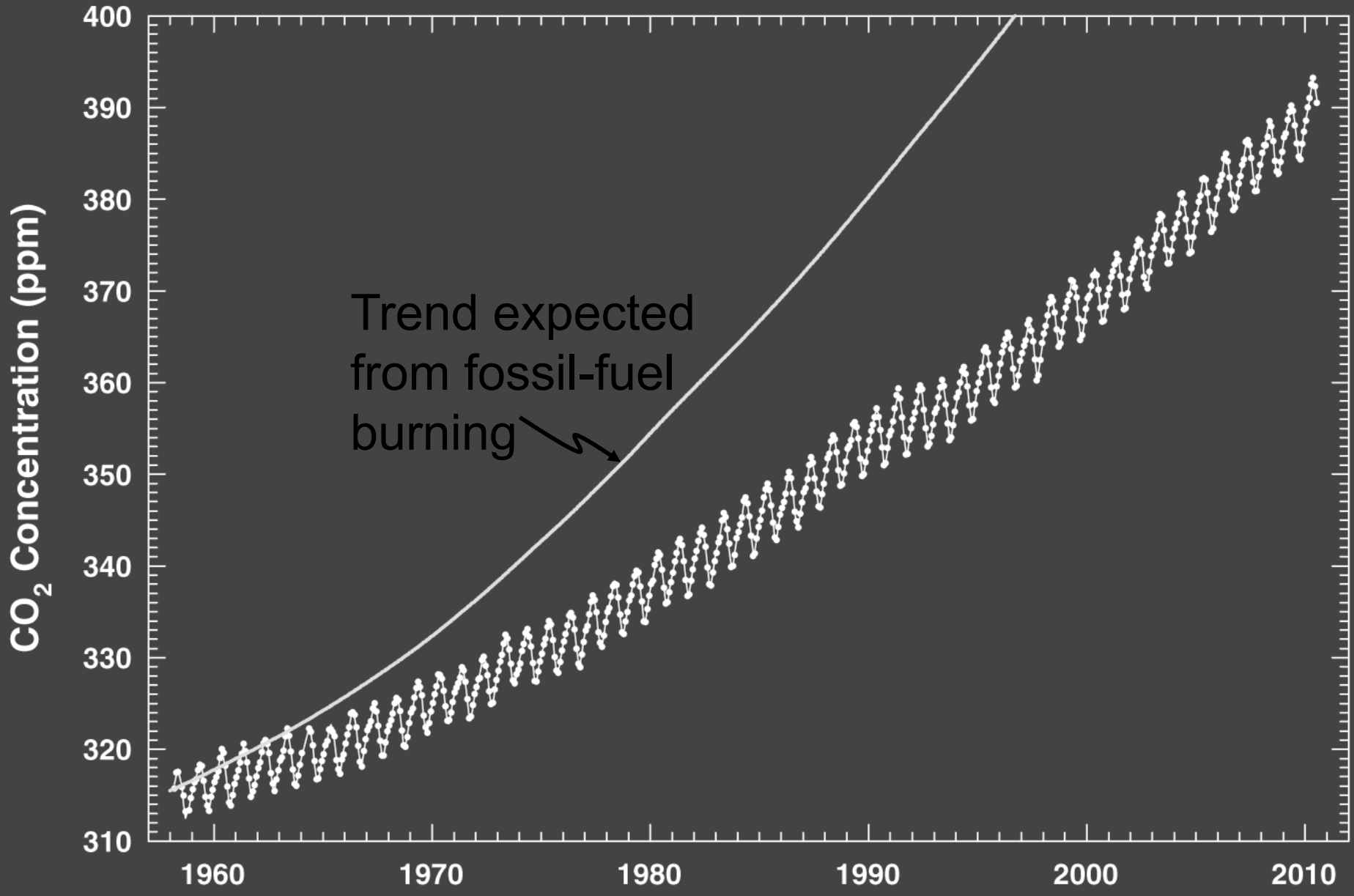
- Atmospheric CO_2 increasing ~ 2 ppm/yr from fossil fuel combustion, with 50% going into land and ocean sinks (Keeling 1960, Tans 1990)

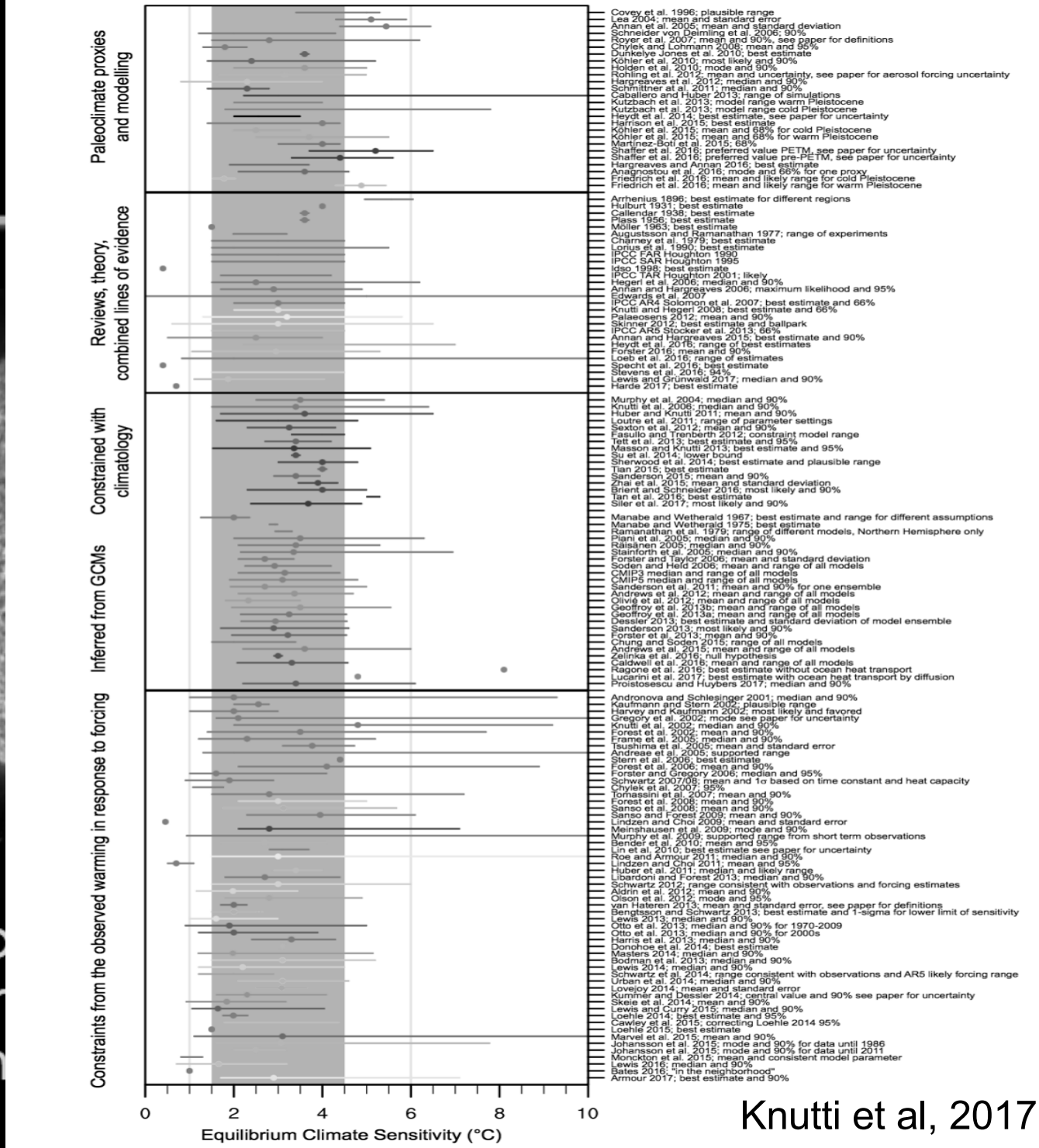
- Short and long term observed warming patterns are linked to greenhouse gases (Callendar 1938, Mann 1999)

- Significant warming in the 20th century is mostly explained by atmospheric CO_2 (Manabe 1967, Hansen 1984)



Atmospheric CO_2 records





Knutti et al, 2017

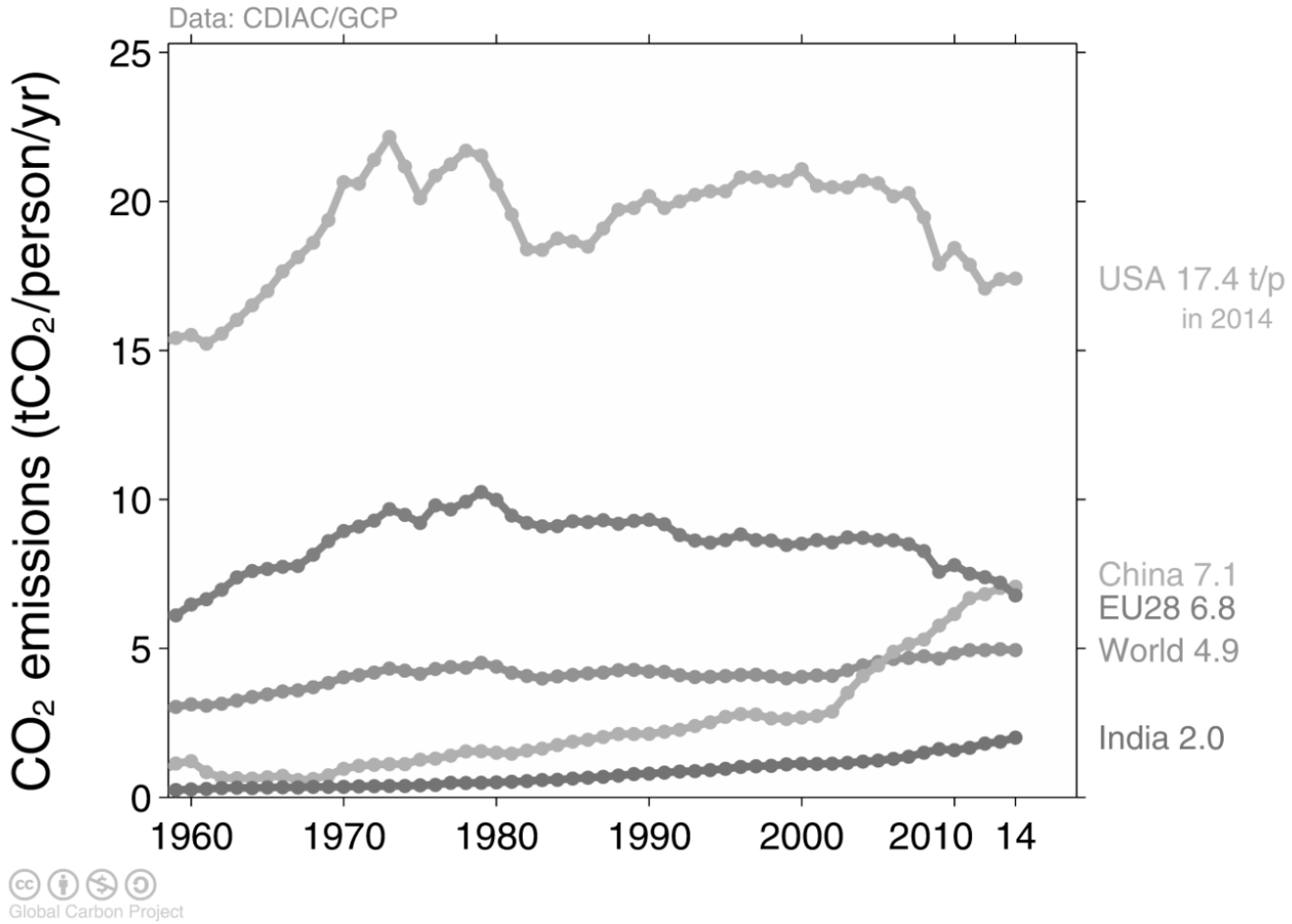

Hotter
What's Really Warming the World?
Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet's rising temperature? Watch to see how much different factors, both natural and industrial, contribute to global warming, based on findings from NASA's Goddard Institute for Space Studies.
1880
Colder
1880
2014
Based on an interactive by Bloomberg

Bloomberg

- US per capita fossil fuel emissions exceed most of the world (DOE, GCP). China total emissions now exceeds the US (IEA).
- Climate projections show a 3 C +/- 1.5 C response to doubling of CO_2 by 2100 with the primary uncertainty in range of emissions (IPCC 1990, 1995, 2001, 2007, 2013)
- Modest warming (0-2 C) creates both winners and losers; warming above 2C or 550 ppm, losers > winners; warming above 4C, mostly losers (WMO, ExxonMobil, Stern Review, World Bank, NCA, WICCI, DOD 1979-present)

Top fossil fuel emitters (per capita)

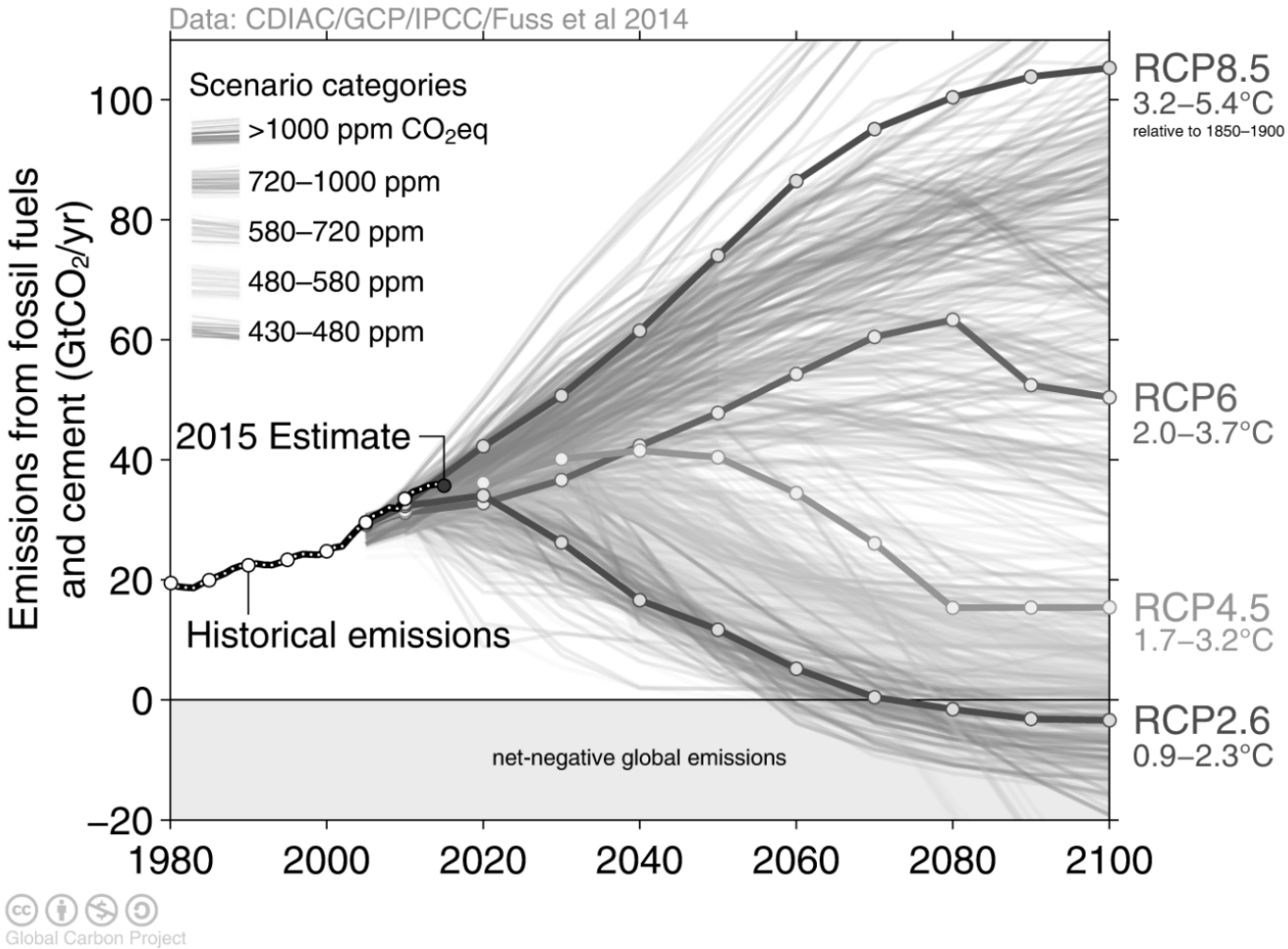
Countries have a broad range of per capita emissions reflecting their national circumstances China's per capita emissions have passed the EU28 and are 43% above the global average



Source: CDIAC; Le Quéré et al 2015; Global Carbon Budget 2015

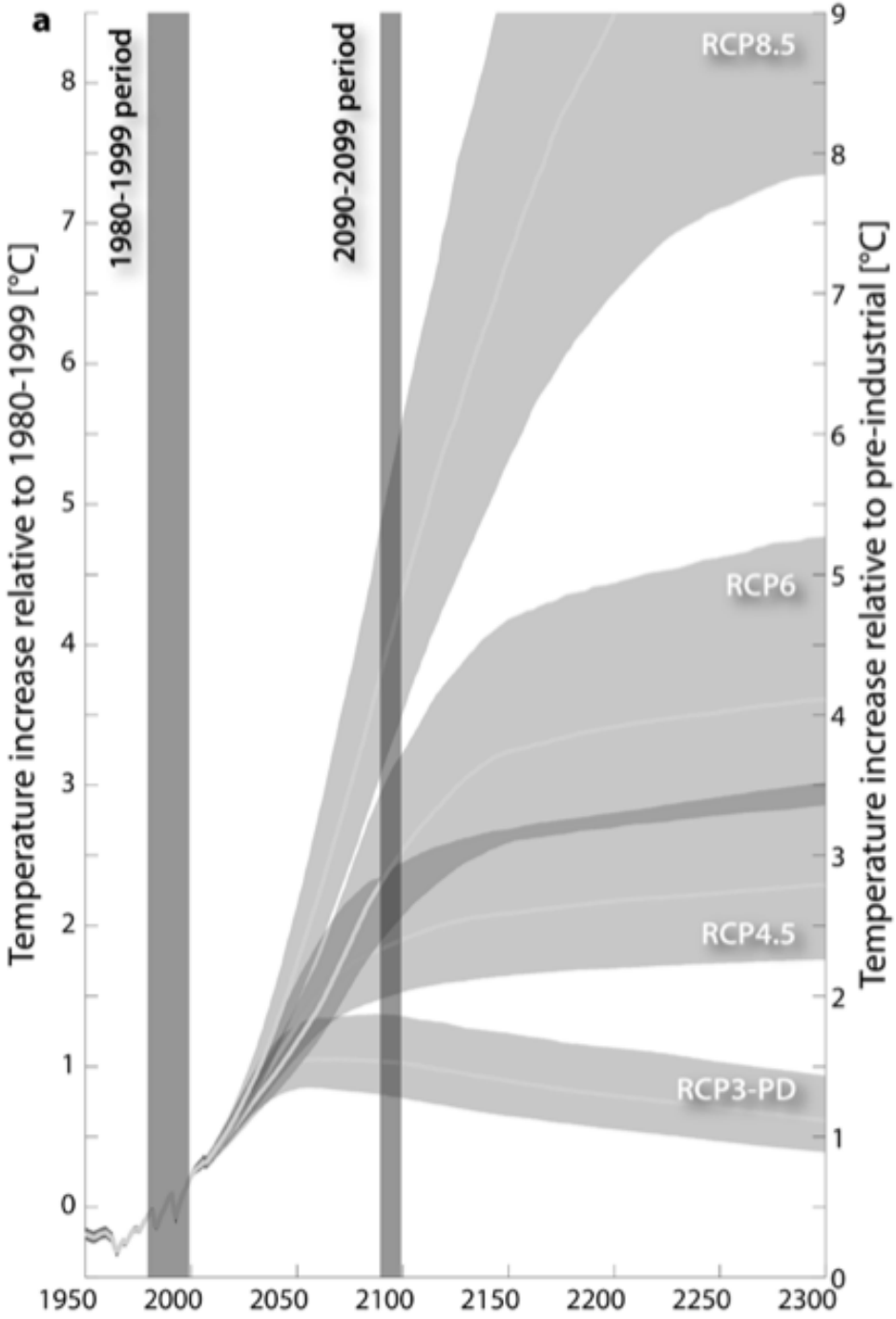
Observed emissions and emissions scenarios

The emission pledges submitted to the Paris climate summit avoid the worst effects of climate change (red), most studies suggest a likely temperature increase of about 3° C (brown)

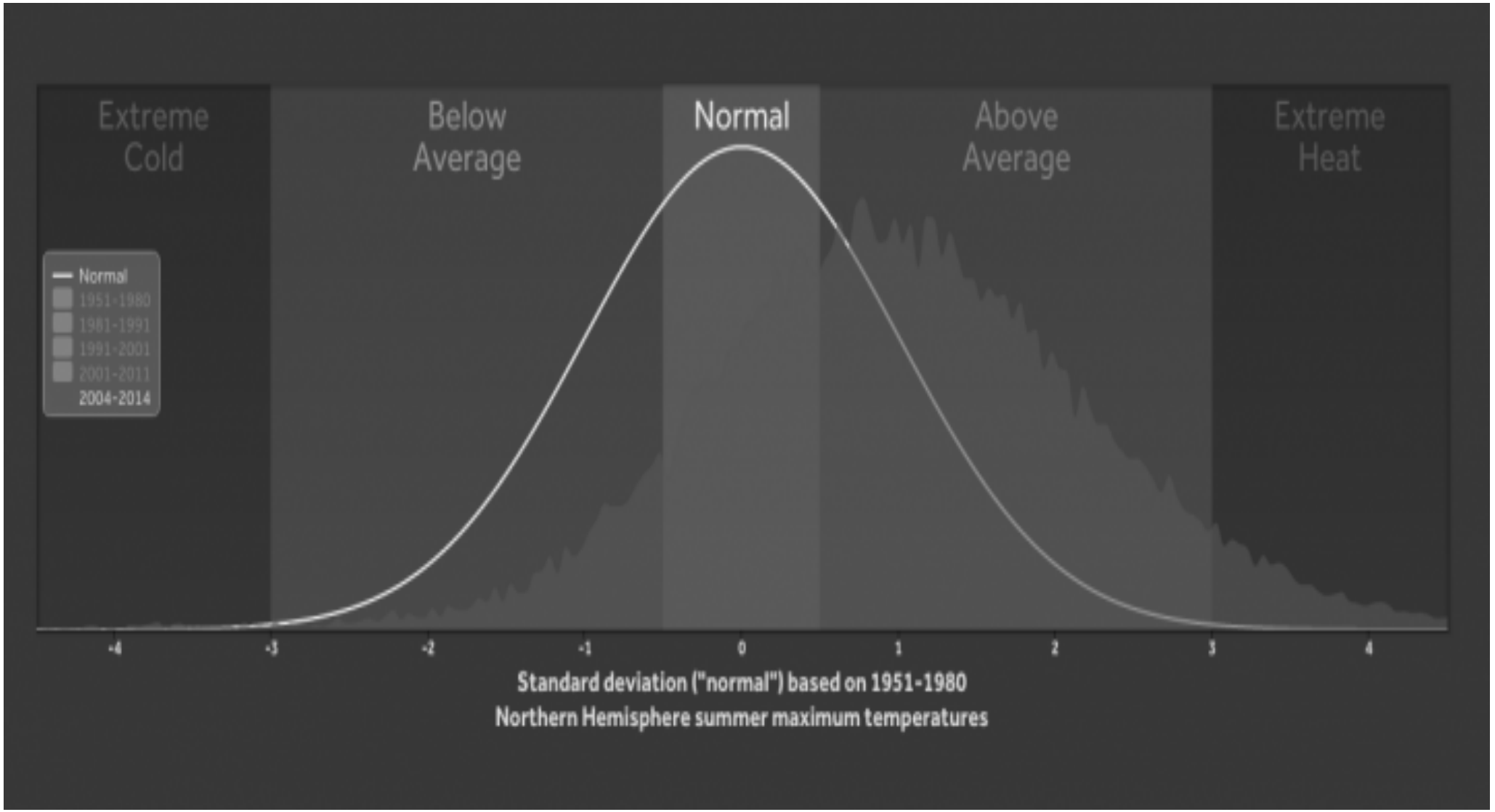


Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2015



Source: Rogelj, Meinshausen et al. 2012

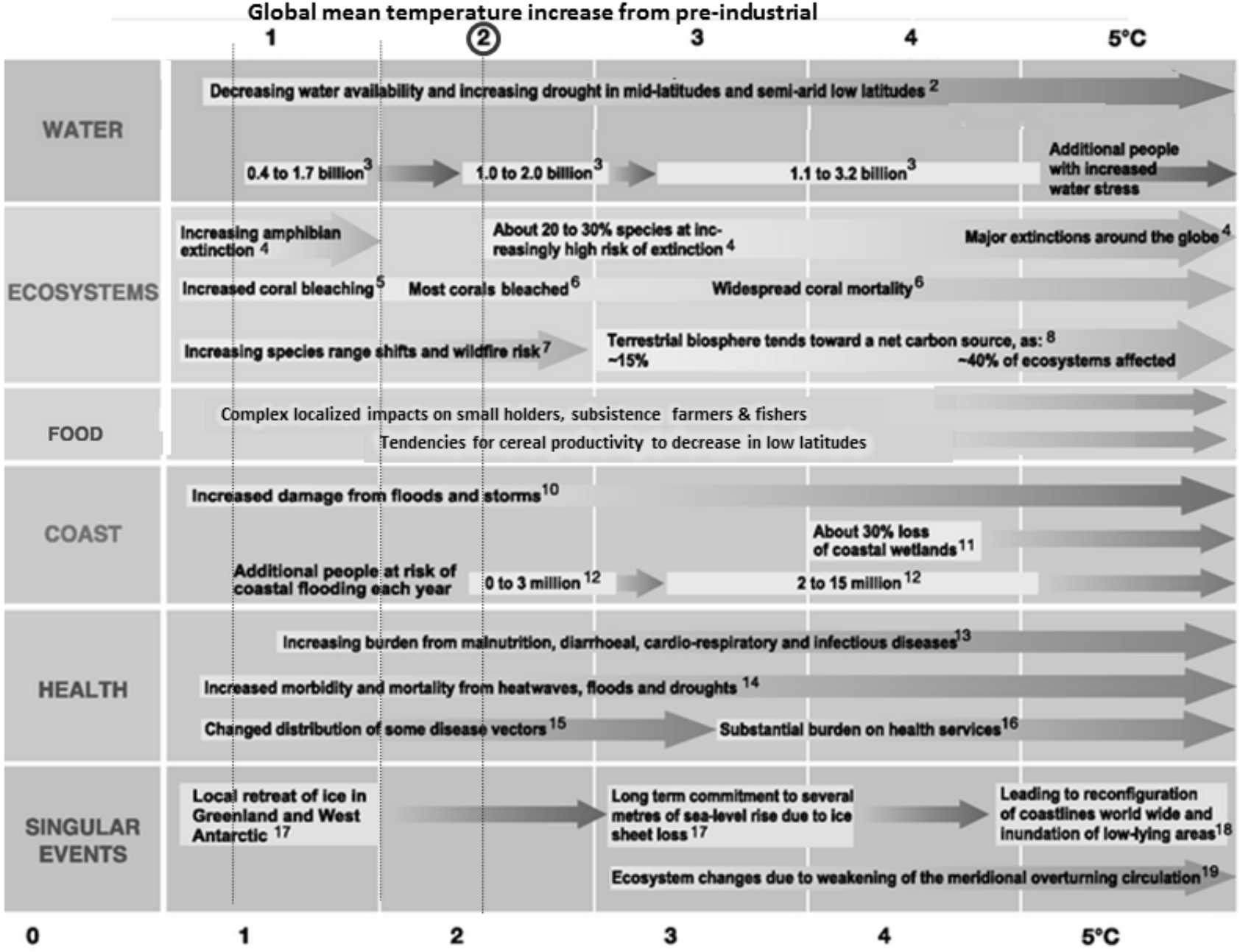

Extreme Cold
Below Average
Normal
Above Average
Extreme Heat
Normal
1951-1980
1981-1991
1991-2001
2001-2011
2004-2014
-4
-3
-2
-1
0
1
2
3
4
Standard deviation ("normal") based on 1951-1980
Northern Hemisphere summer maximum temperatures

IPCC 2007 AR4 TS.4.3 Magnitudes of ADVERSE impacts for varying amounts of climate change

IPCC quotes in blue. Impacts start where text box begins. Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate.

The impact chart omitted extreme weather events, that increase most impacts The SPM impact chart was identical except it omitted the singular events

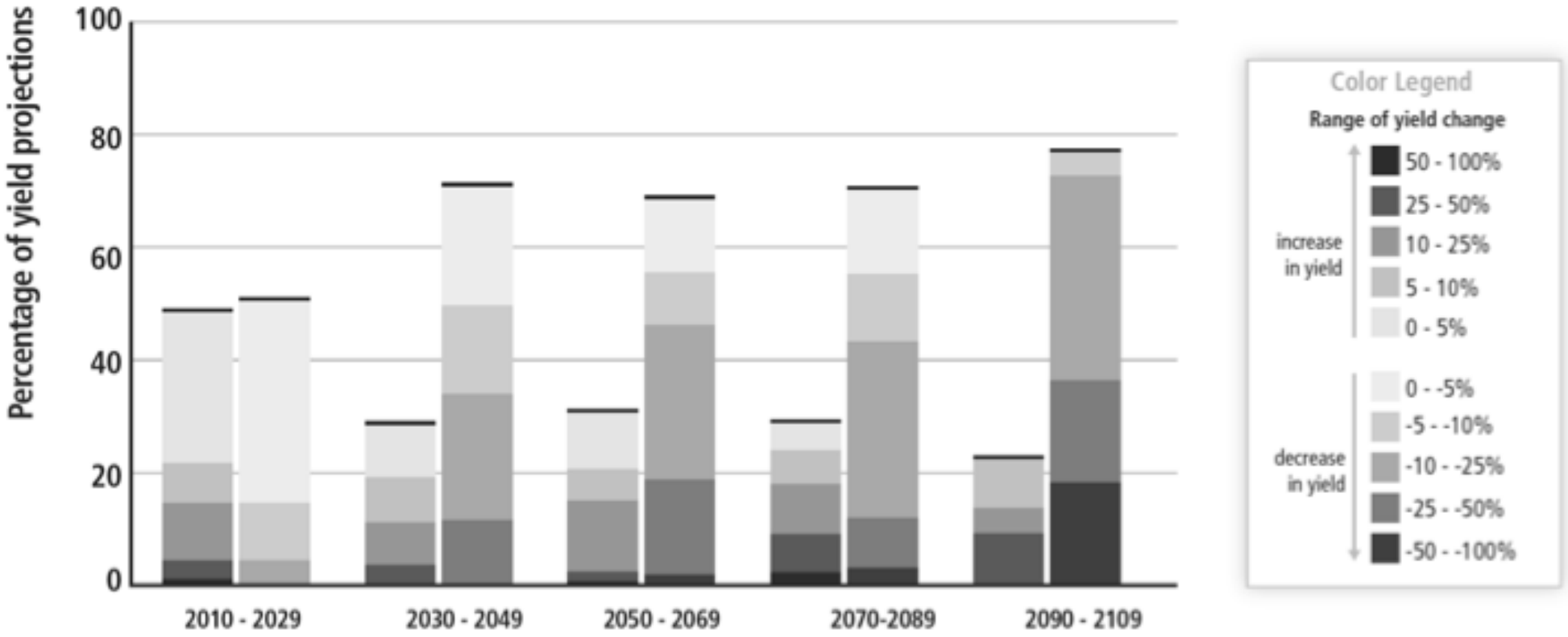
Estimates are for the 2020s, 2050s and 2080s, (used by he IPCC Data Distribution Centre) and for the 2090s.
Note that equilibrium temperatures would not be reached until decades or centuries after greenhouse gas stabilisation.

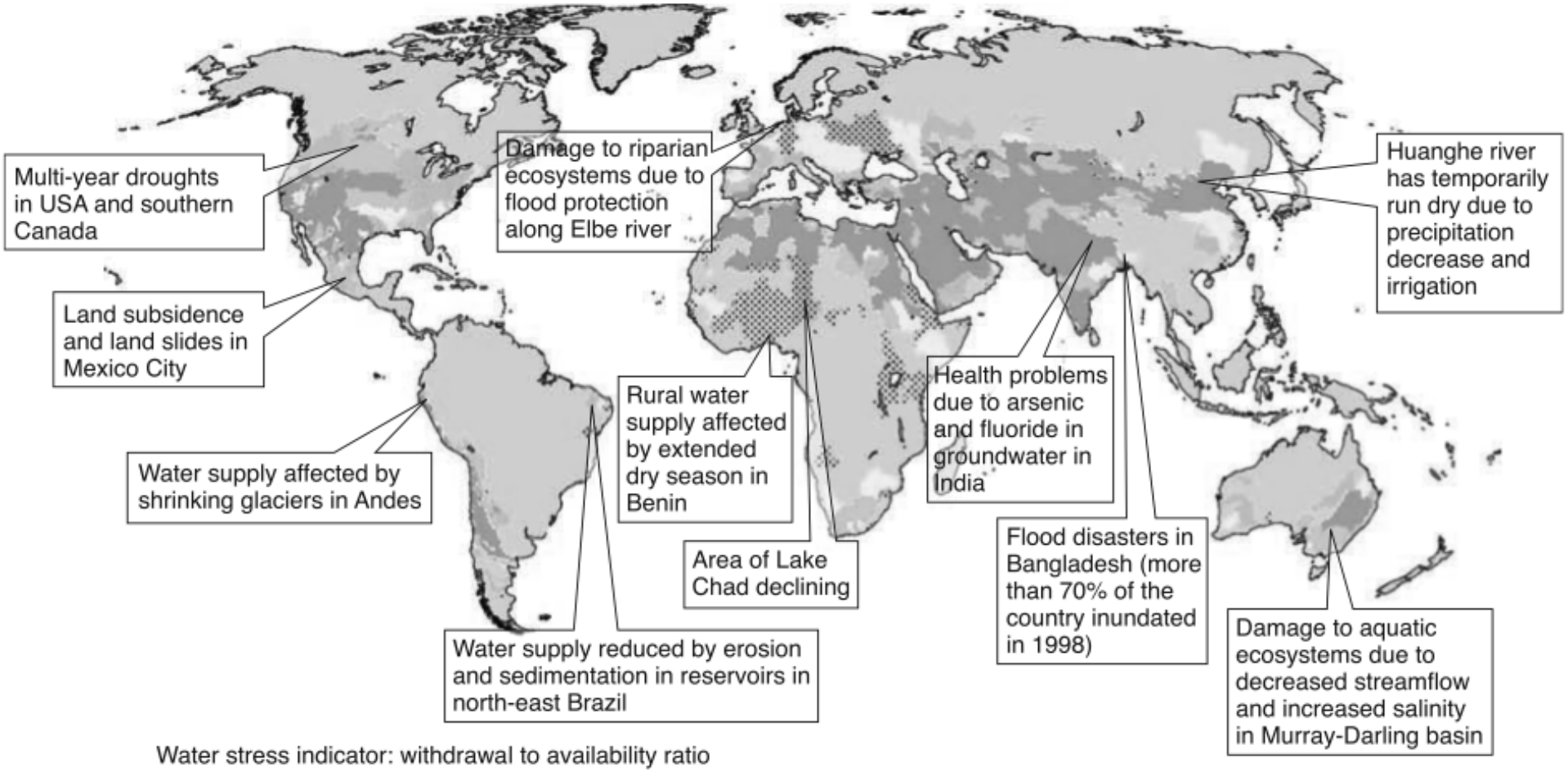


UNFCCC objective quoted in AR4 …'prevent dangerous …interference with the climate system….within a time frame sufficient to allow ecosystems to adapt naturally to climate change, and to ensure that food production is not threatened'

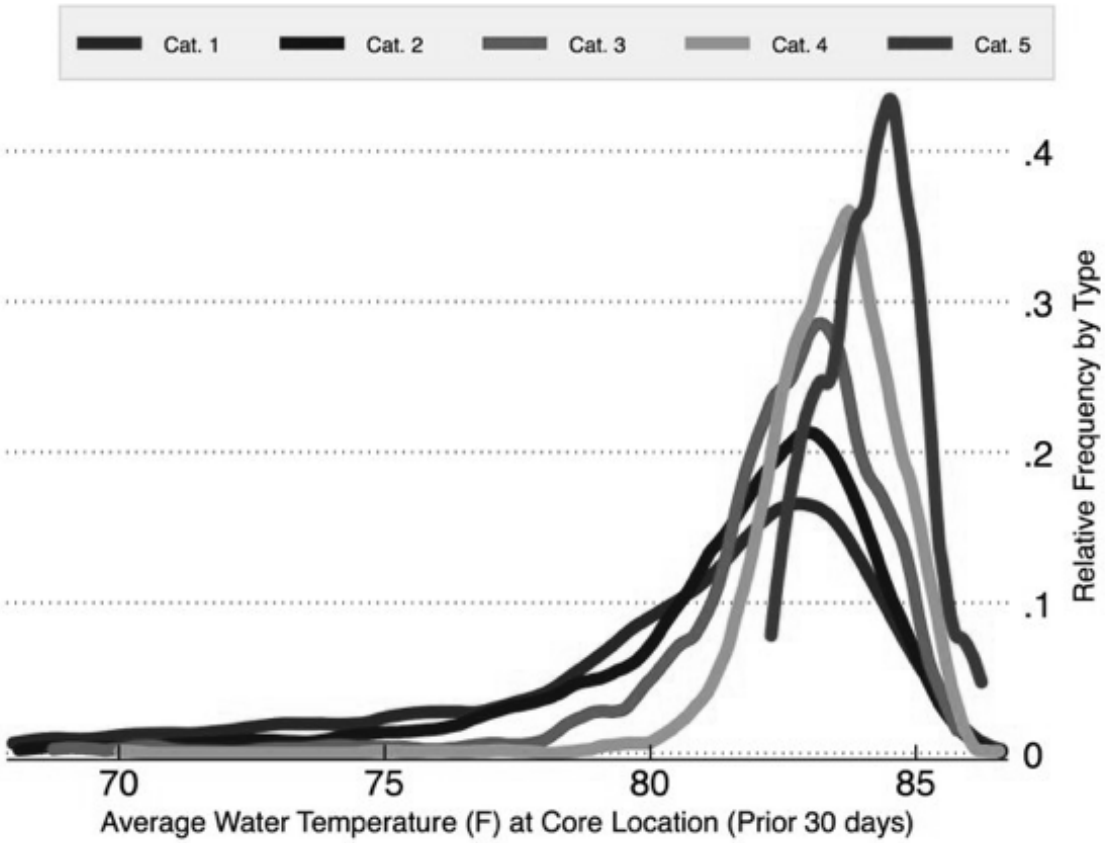
Peter Carter

Crop Yields Decline under Higher Temperatures




Multi-year droughts in USA and southern Canada
Land subsidence and land slides in Mexico City
Water supply affected by shrinking glaciers in Andes
Damage to riparian ecosystems due to flood protection along Elbe river
Rural water supply affected by extended dry season in Benin
Area of Lake Chad declining
Water supply reduced by erosion and sedimentation in reservoirs in north-east Brazil
Health problems due to arsenic and fluoride in groundwater in India
Flood disasters in Bangladesh (more than 70% of the country inundated in 1998)
Huanghe river has temporarily run dry due to precipitation decrease and irrigation
Damage to aquatic ecosystems due to decreased streamflow and increased salinity in Murray-Darling basin
Water stress indicator: withdrawal to availability ratio
no stress
low stress
mid stress
high stress
very high stress
0
0.1
0.2
0.4
0.8
No/low stress and per capita water availability <1,700m3/yr
Water withdrawal: water used for irrigation, livestock, domestic and industrial purposes (2000)
Water availability: average annual water availability based on the 30-year period 1961-90

Hurricane Strength and Ocean Temperatures

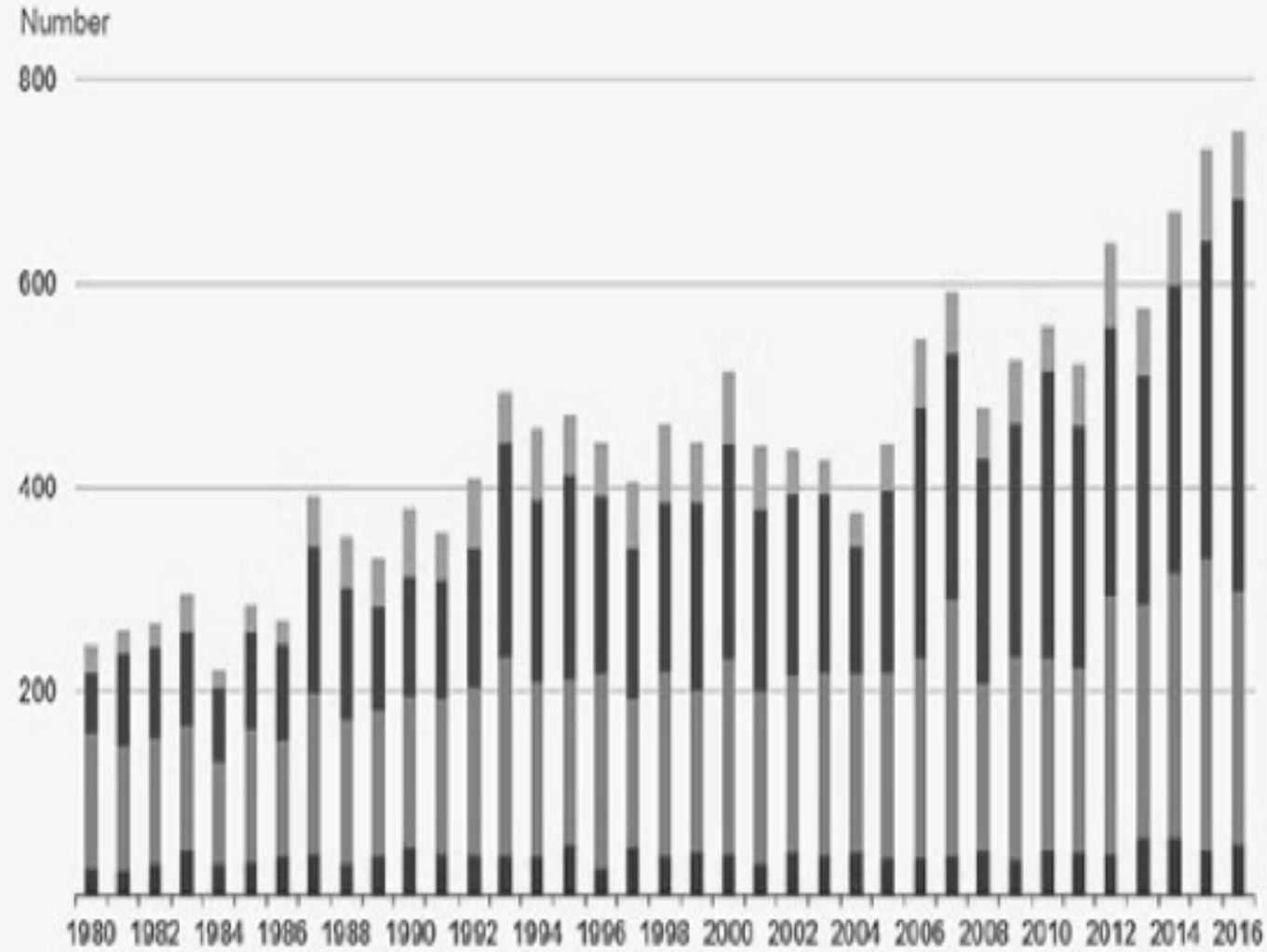


Kernal density functions of SSTs by hurricane category. Area under each curve represents 100% of hurricanes of that type. Hurricane wind speeds via HURDAT.

Number Of Natural Catastrophes

Global - 1980-2016

Source: Munich Re, Geo Risks Research



Geophysical events
(Earthquake, tsunami, volcanic activity)

Meteorological events
(Tropical storm, extratropical storm, convective storm, local storm)

Hydrological events
(Flood, mass movement)

Climatological events
(Extreme temperature, drought, forest fire)

Accounted events have caused at least one fatality and/or produced normalized losses ≥ US$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country).

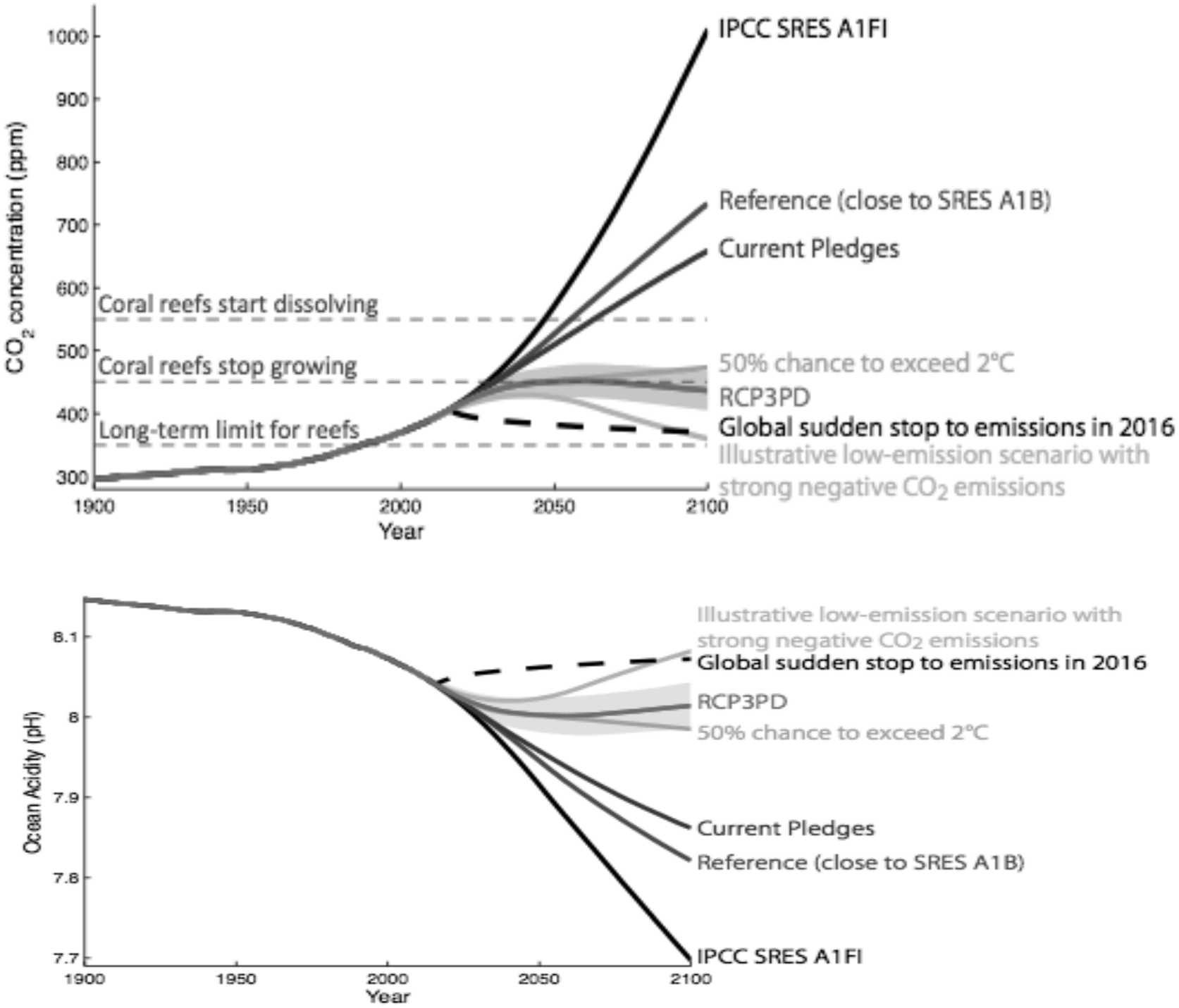
What Are The Options?

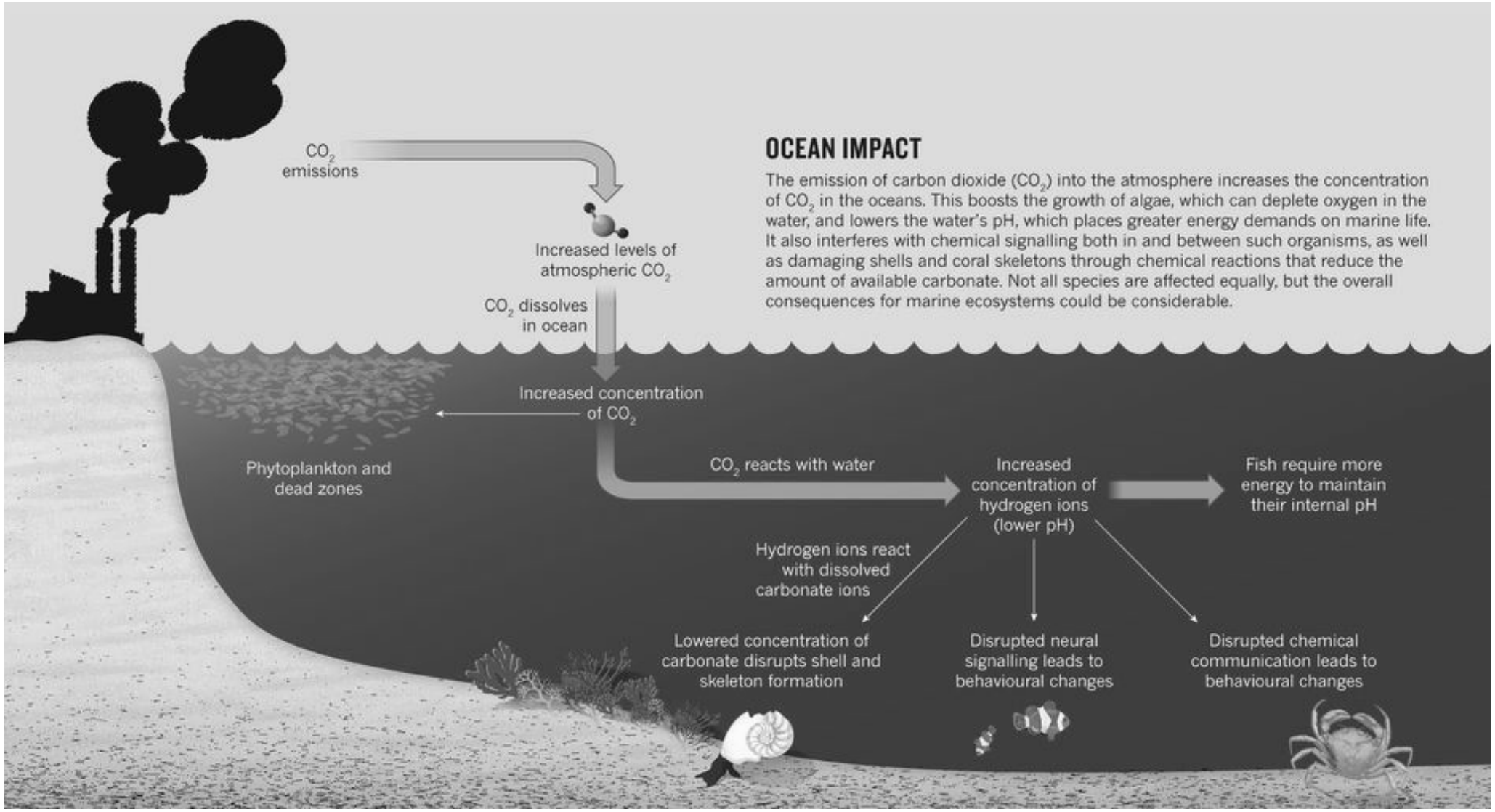
- Adaptation

- Mitigation

What Are The Options?

- Adaptation
  - Economic/political (relocation, tech transfer, payments for damages, reduce poverty, educate)
  - Technological (resilient tech, seawalls, genetic hybrids, cure malaria, colonize new planet)
- Mitigation


IPCC SRES A1FI
Reference (close to SRES A1B)
Current Pledges
Coral reefs start dissolving
Coral reefs stop growing
50% chance to exceed 2°C
RCP3PD
Long-term limit for reefs
Global sudden stop to emissions in 2016
Illustrative low-emission scenario with strong negative CO_2 emissions
CO_2 concentration (ppm)
1000
900
800
700
600
500
400
300
1900
1950
2000
2050
2100
Year
Illustrative low-emission scenario with strong negative CO_2 emissions
Global sudden stop to emissions in 2016
RCP3PD
50% chance to exceed 2°C
Current Pledges
Reference (close to SRES A1B)
IPCC SRES A1FI
Ocean Acidity (pH)
8.1
8
7.9
7.8
7.7
1900
1950
2000
2050
2100
Year



OCEAN IMPACT

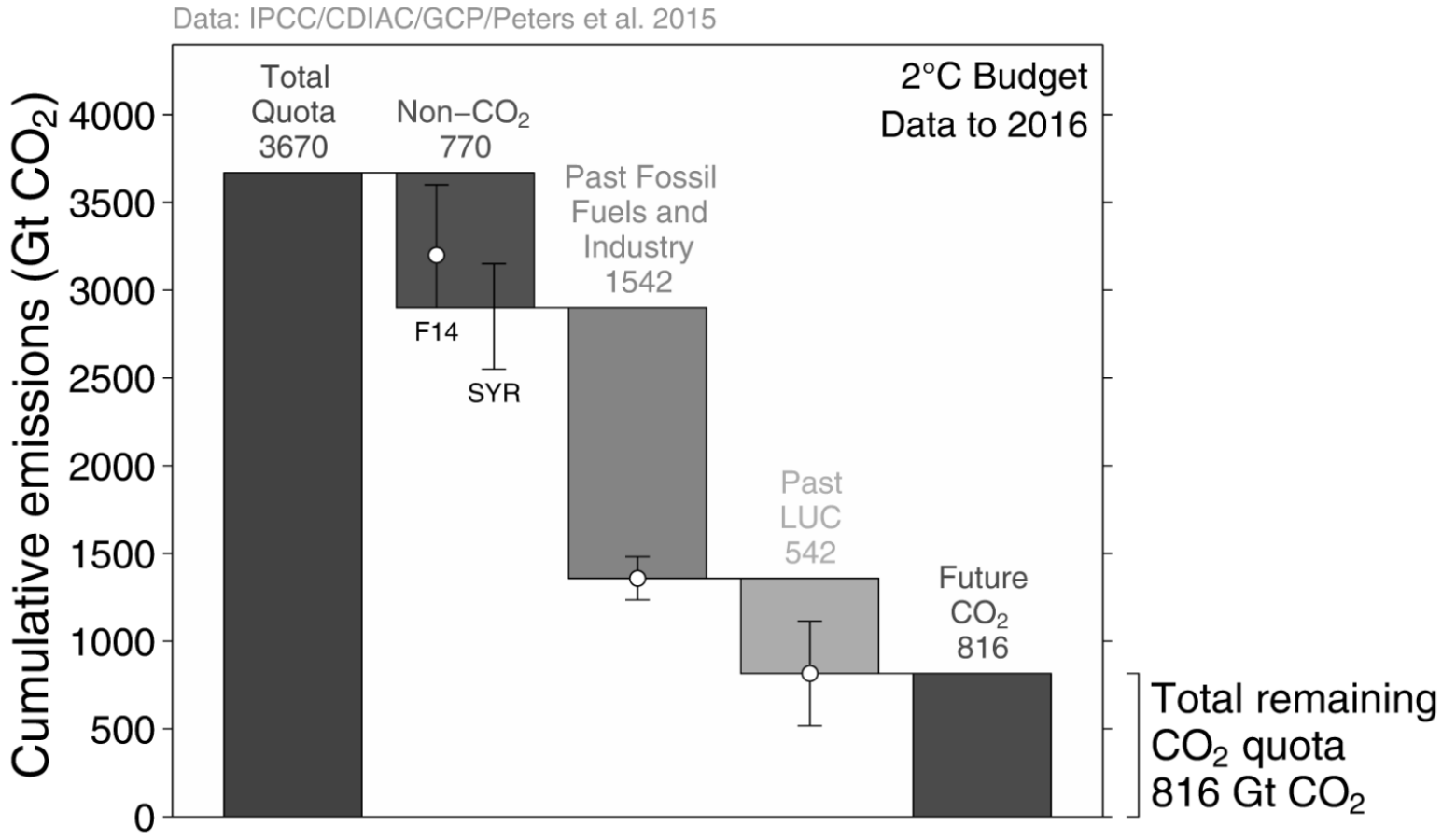
The emission of carbon dioxide (CO_2) into the atmosphere increases the concentration of CO_2 in the oceans. This boosts the growth of algae, which can deplete oxygen in the water, and lowers the water's pH, which places greater energy demands on marine life. It also interferes with chemical signalling both in and between such organisms, as well as damaging shells and coral skeletons through chemical reactions that reduce the amount of available carbonate. Not all species are affected equally, but the overall consequences for marine ecosystems could be considerable.

What Are The Options?

- Adaptation
  - Economic/political (relocation, tech transfer, payments for damages, reduce poverty, educate)
  - Technological (resilient tech, seawalls, genetic hybrids, cure malaria, colonize new planet)
- Mitigation
  - Economic (taxes, cap and trade, R&D)
  - Regulatory (treaties, bans, compacts, fuel/energy standards, public transit, voluntary agreements)
  - Societal (sustainable development, education)
  - Technological (CO_2 capture, geoengineering, green tech, alternative energy, energy efficiency)

Carbon quota for a 66% chance to keep below 2° C

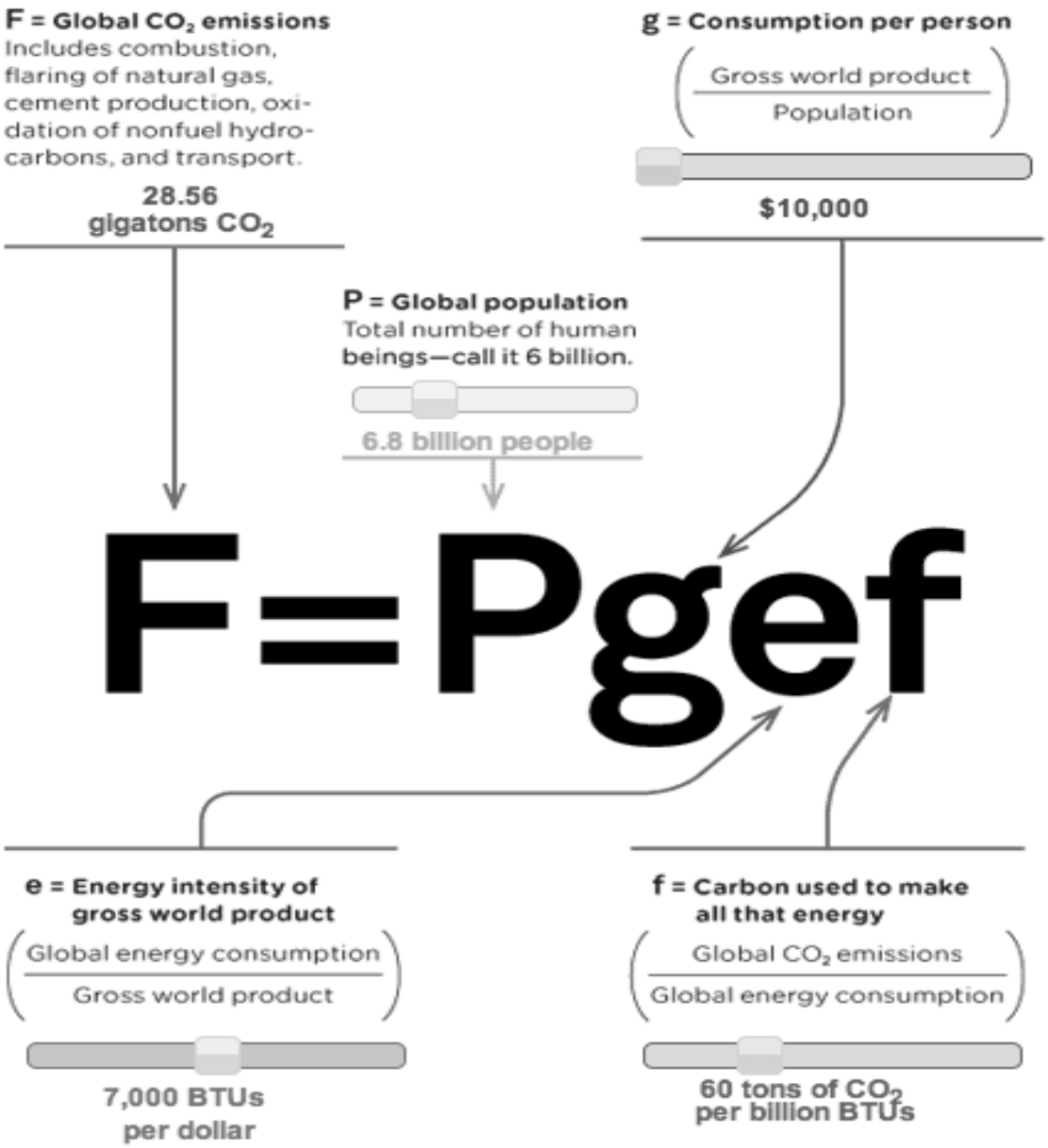
The total remaining emissions from 2017 to keep global average temperature below 2° C ($800GtCO_2$) will be used in around 20 years at current emission rates



Grey: Total CO_2-only quota for 2° C with 66% chance. Green: Removed from CO_2 only quota. Blue: Remaining CO_2 quota.

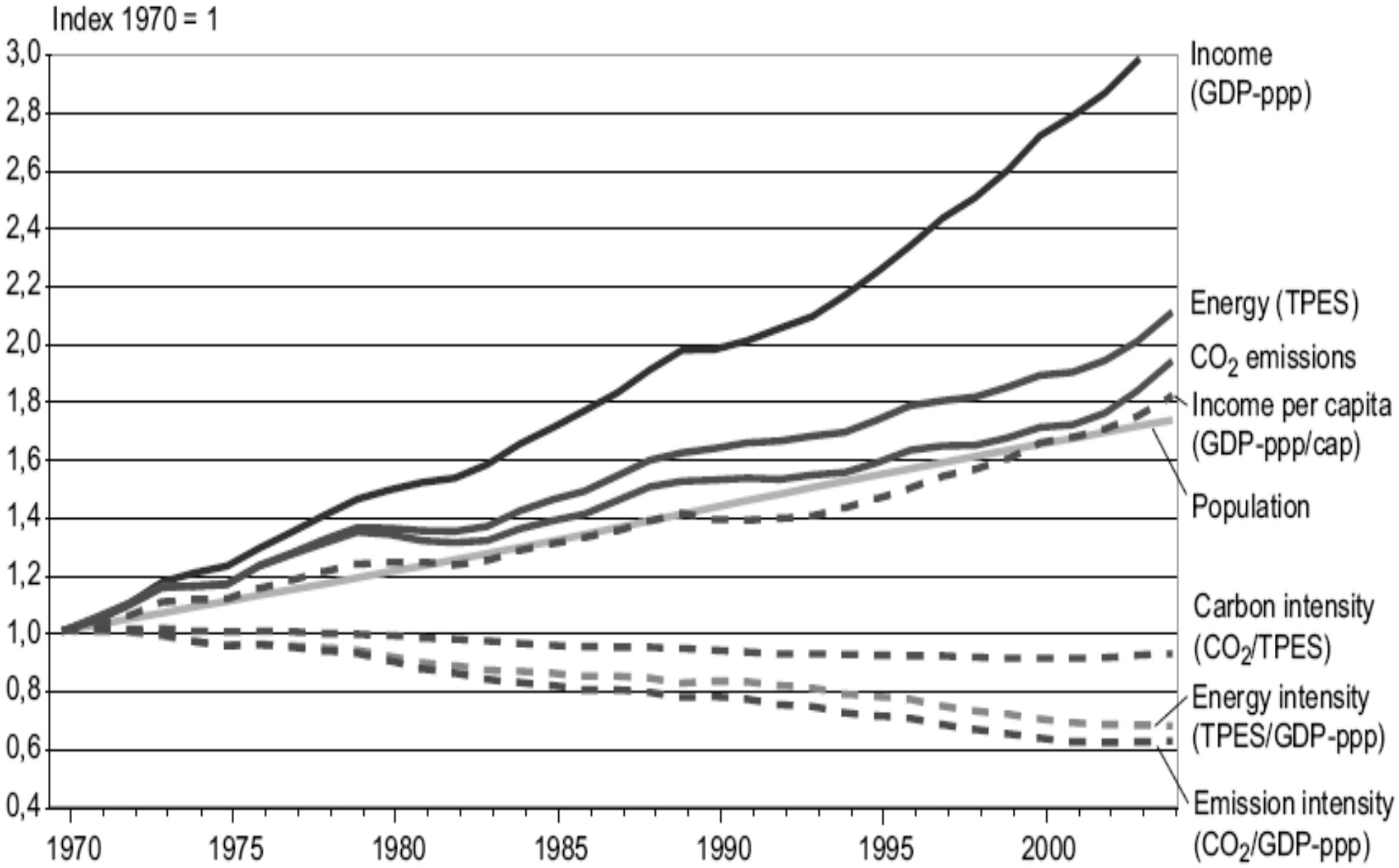
The remaining quotas are indicative and vary depending on definition and methodology

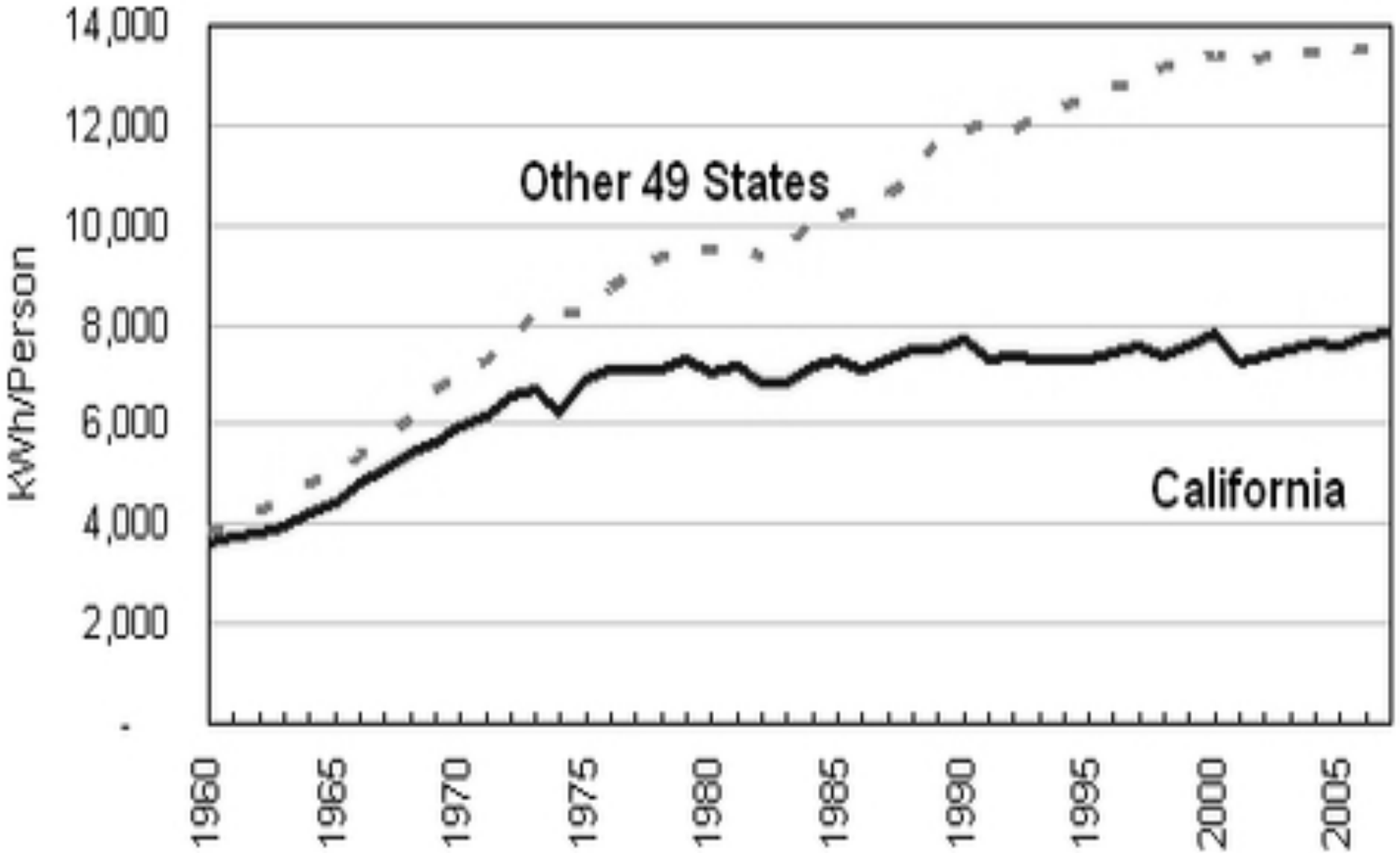
Source: Peters et al 2015; Global Carbon Budget 2016



KAYA IDENTITY

http://climatemodels.uchicago.edu/kaya/

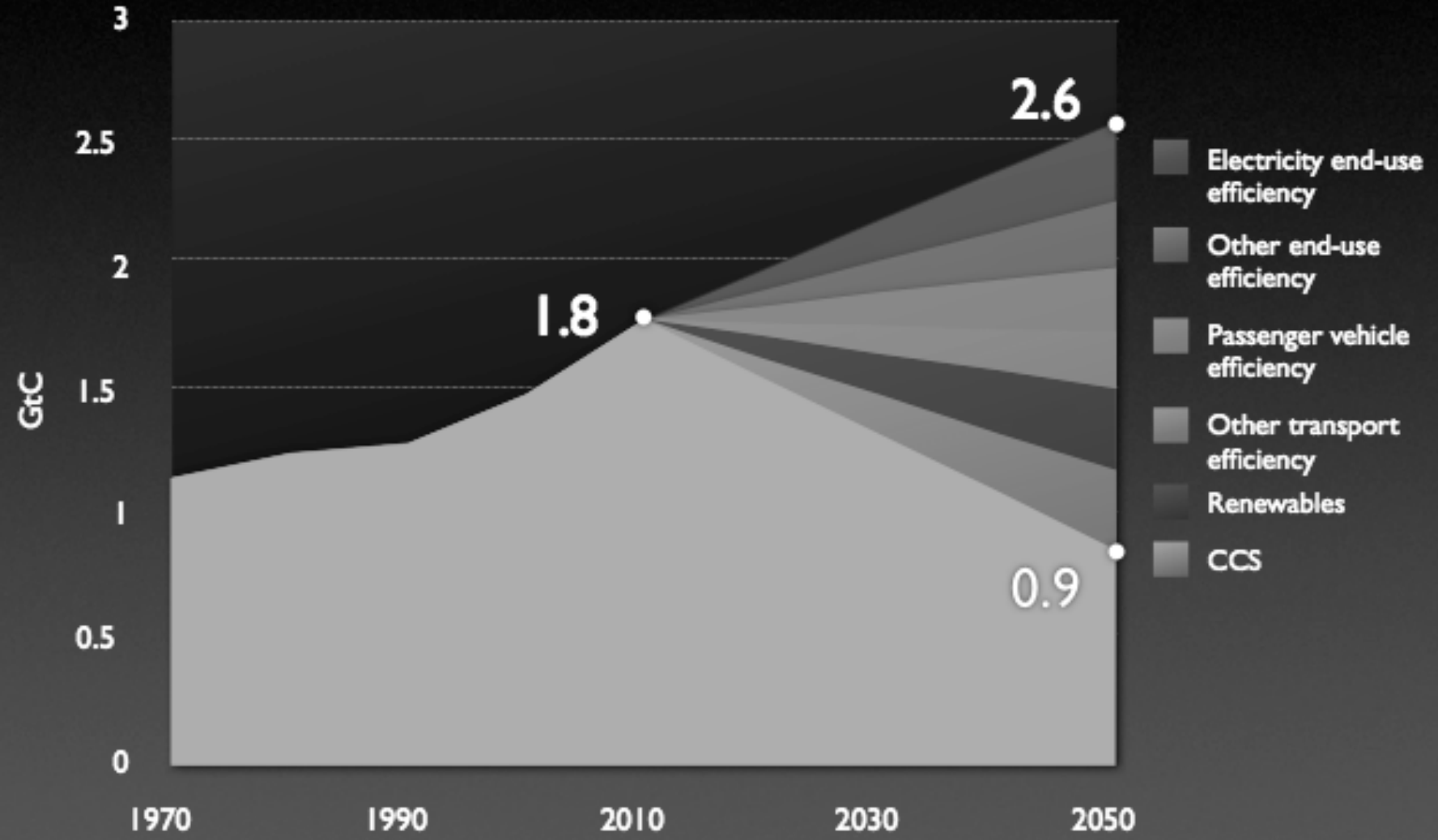

Index 1970 = 1
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
1970
1975
1980
1985
1990
1995
2000
Income (GDP-ppp)
Energy (TPES)
CO2 emissions
Income per capita (GDP-ppp/cap)
Population
Carbon intensity (CO2/TPES)
Energy intensity (TPES/GDP-ppp)
Emission intensity (CO2/GDP-ppp)


14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
KWh/Person
Other 49 States
California
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

U.S. Emissions

After Pacala and Socolow, 2004;
ARI CarBen3 Spreadsheet

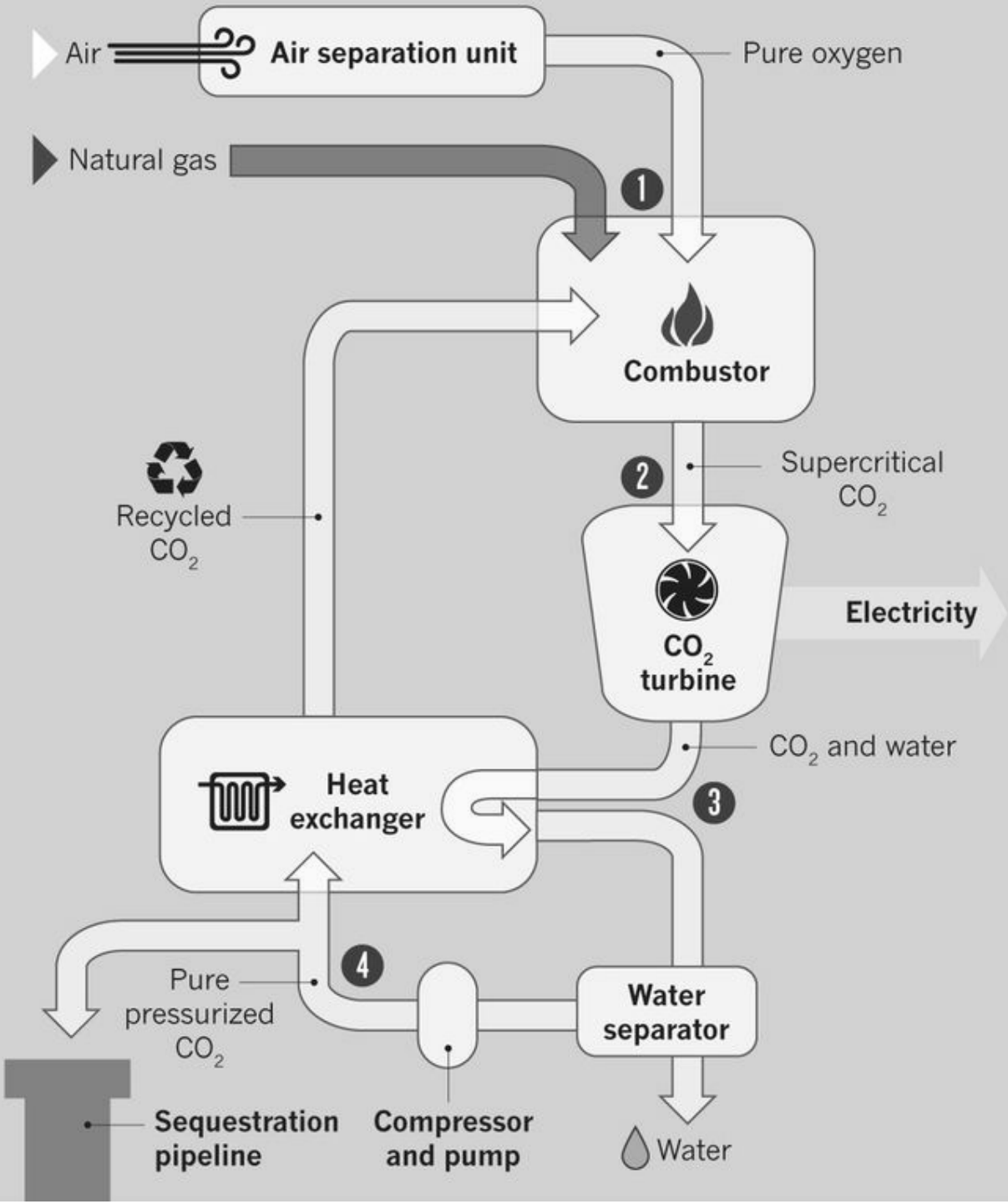
- Carbon Capture & Storage

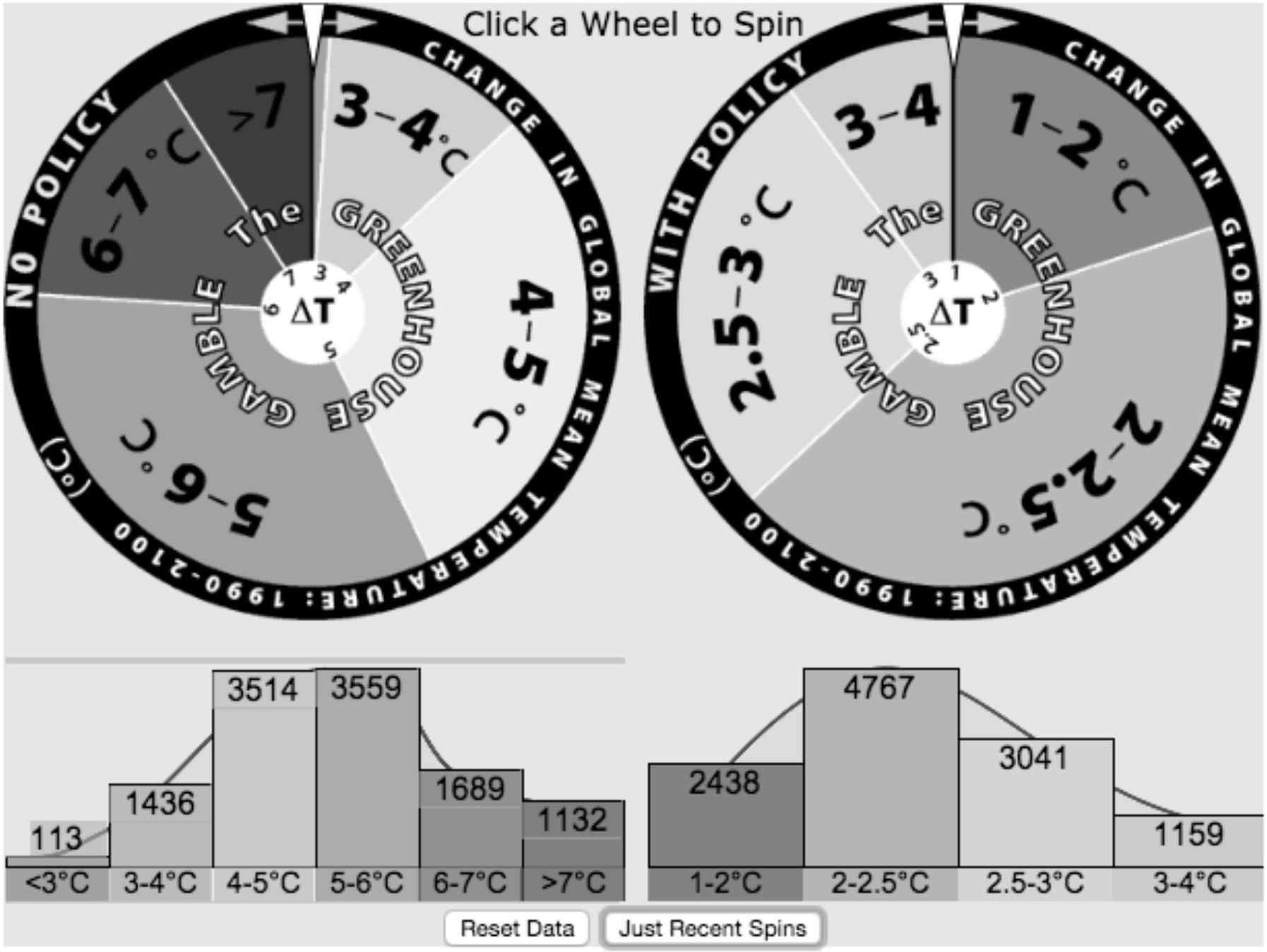


CLEAN FOSSIL POWER

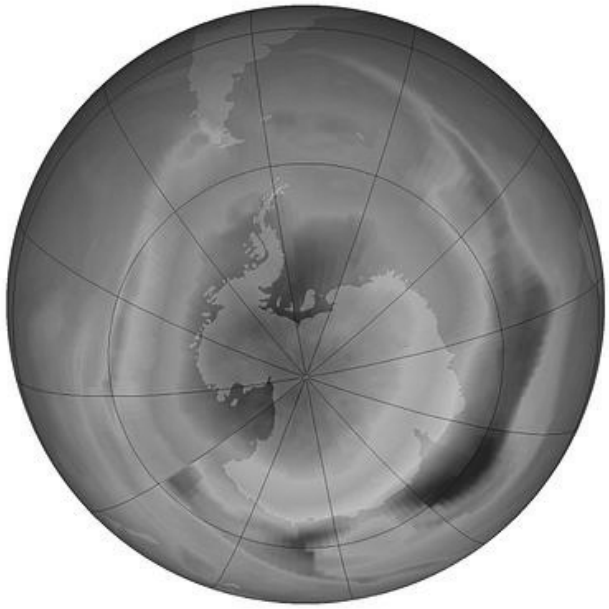
Electricity can be generated from fossil fuels without producing any atmospheric emissions.

❶ NetPower's system burns natural gas in pure oxygen in the presence of carbon dioxide. The CO_2, which is 95% of the gas mix, is heated and pressurized to a supercritical state.
❷ In this state it can drive a fluid turbine to generate electricity.
❸ Water present in the turbine's exhaust begins to condense in a heat exchanger before being fully separated out and removed from the system.
❹ The remaining stream of more than 90% CO_2 is repressurized, reheated via the heat exchanger and returned to the combustor. Excess CO_2 generated by the system is directed to a pipeline after repressurization, ready for sequestration.

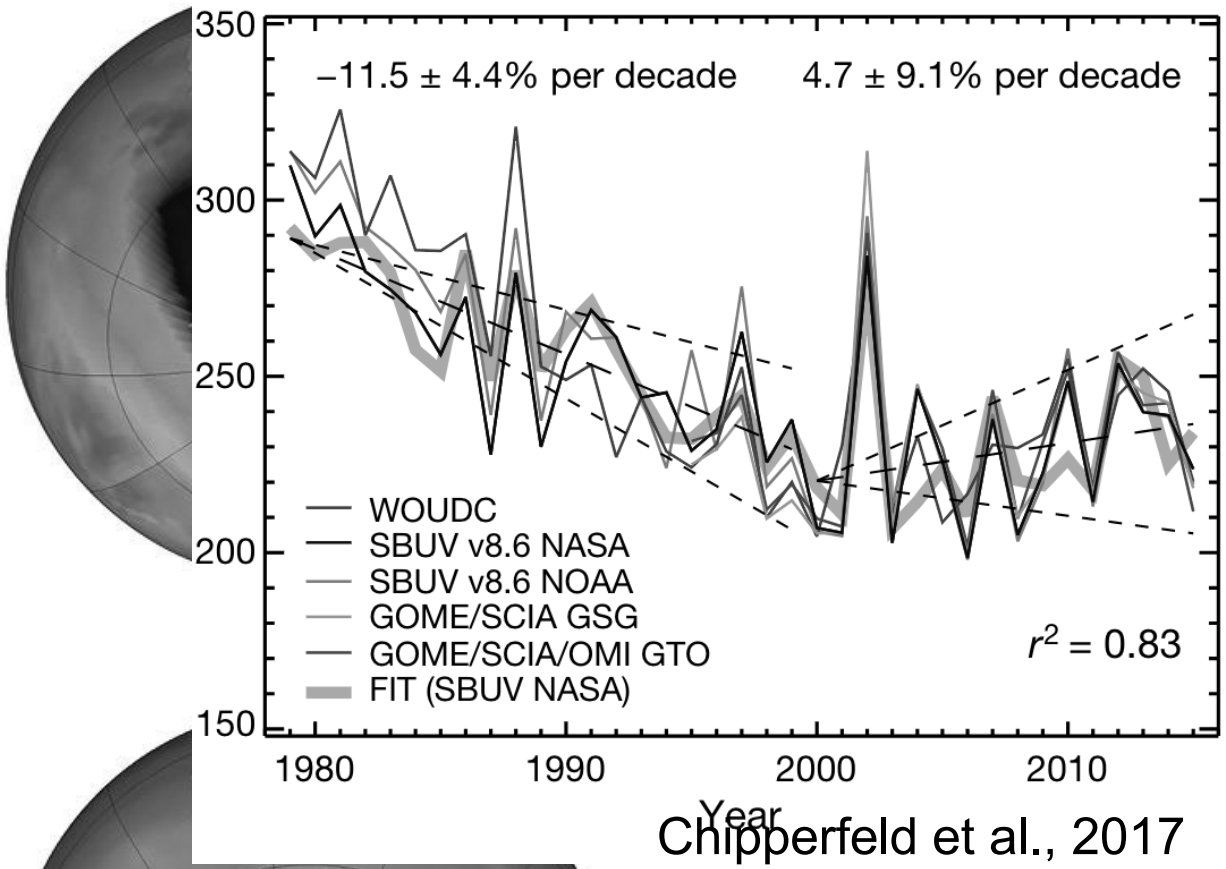




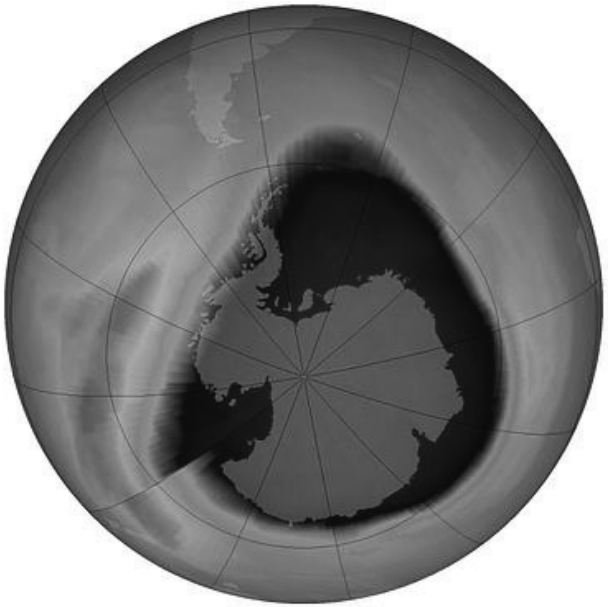
http://globalchange.mit.edu/focus-areas/uncertainty/gamble



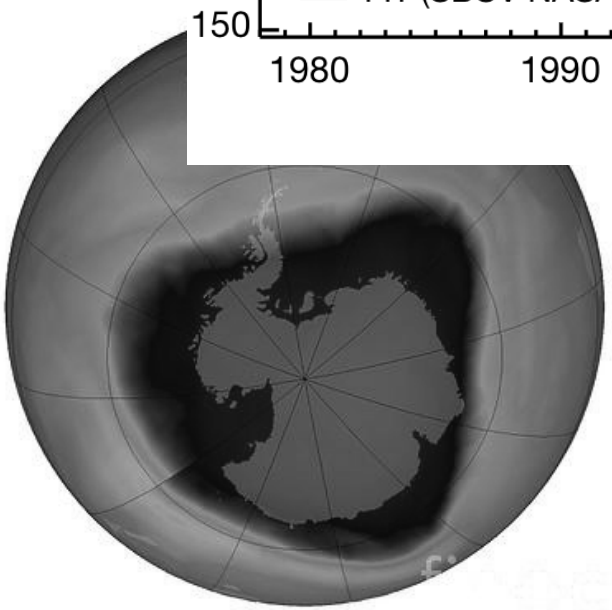
1980



Chipperfeld et al., 2017



2000



2015

Global Treaties

- There is no international rules making body!
- Treaties are a game of incentives and disincentives to sign and to comply
- Individual countries weigh costs and benefits
- Compliance and monitoring are contentious issues

Global Environmental Policy

- 1963, 67, 70, 77 U.S. Clean Air Act
- 1972 UNEP formed
- 1979 WMO conference
- 1979 UNCLRTAP
- 1985 Vienna Convention for O3
- 1987 Montreal protocol for O3 signed
- 1989 Montreal in force
- 1990 IPCC First Assessment Report (FAR)
- 1990 US Clean Air Act revision - Cap and Trade
- 1992 Rio Earth Summit - UNFCCC
- 1995 IPCC 2nd report
- 1997 Kyoto signed, ratified in 2004
- 2001 IPCC 3rd report
- 2005 Kyoto in force
- 2007 IPCC 4th report
- Dec 2007 – Bali
- 2008-2012 First commitment period for Kyoto
- 2013 IPCC 5th report
- Dec 2009-2015 (COP 15-21) – Copenhagen, Cancun, Durban, **Doha**, Warsaw, Lima, **Paris**
- 2012-2020 Second period for Kyoto
- Summer 2016 Paris in force
- Dec 2016 – Marrakech
- 2020 – Paris in force

Kyoto Protocol

- Signed 1997 in Kyoto,Japan, into force in Feb 2005, first commitment, 2008-2012, amended in Doha to go to 2020
- Targets for developed countries (Annex B) for emissions below a “baseline” (1990)
- Market mechanisms:
  - Emissions trading
  - Clean Development Mechanism
  - Joint Implementation
- Also: compliance, monitoring, adaptation fund, registry/reporting requirements

Paris

- Refocuses goal on temperature below 2 C limit (global emissions will need to peak in <20 years, sources must balance sinks by 2050)
- Lets countries determines their contribution
- $100 billion fund for developing countries
- Is set to be in force, now that > 55% of emissions included in ratified countries*
- Compliance and monitoring will be a key challenge

UNFCCC and Kyoto Protocol and the Paris Agreement

Signed and Ratified

Signed with intent to Ratify

Signed with no intent to Ratify

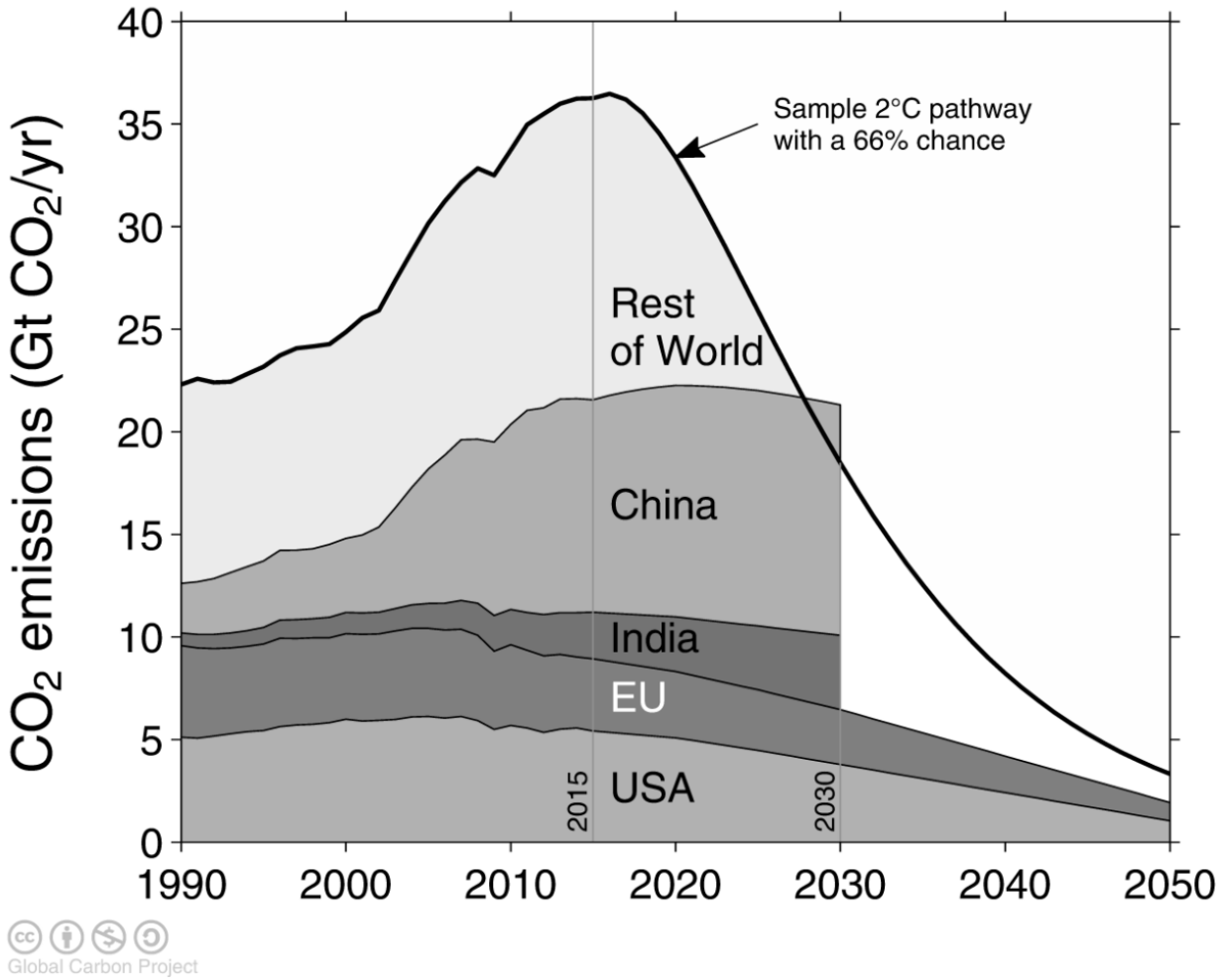
Non-Signatory

Commitments

- China: carbon intensity in 2020 40% below 2005 (emissions still rise), peak carbon emissions 2030
- U.S.: 2025 26-28% emissions below 2005 (double earlier pace), 2050 83% below
- South Korea: 30% below business as usual by 2020 (emissions doubled 1990-2005)
- Russia: 25%
- Brazil: 38-42% below 2020 projection, half by deforestation reduction (REDD)
- Australia: 5-20% below 2000 by 2020
- India: carbon intensity 20% lower by 2020

The emission pledges (INDCs) of the top-4 emitters

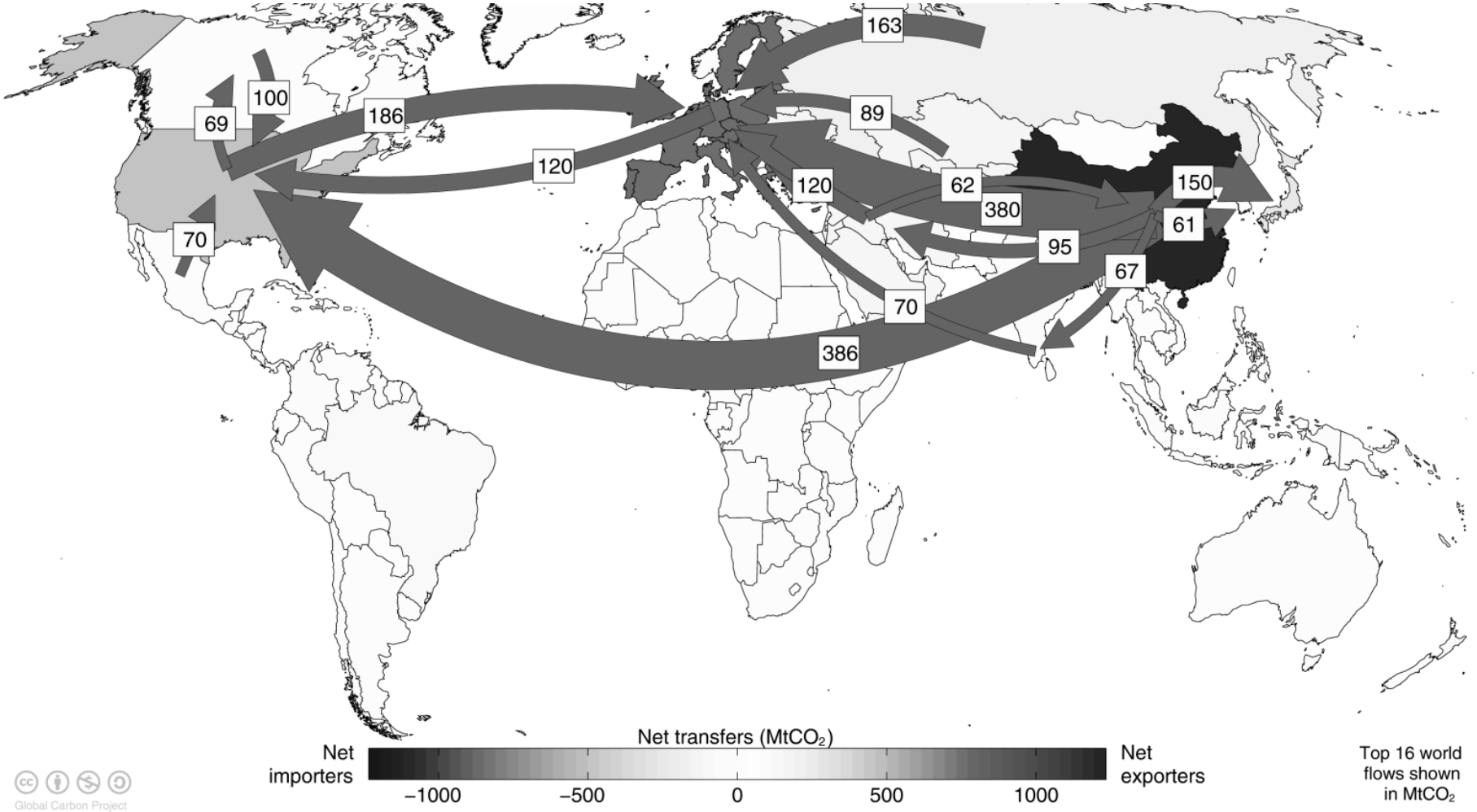
The emission pledges from the US, EU, China, and India leave no room for other countries to emit in a 2˚ C emission budget (66% chance)



Source: Peters et al 2015; Global Carbon Budget 2016

Major flows from production to consumption

Flows from location of generation of emissions to location of consumption of goods and services

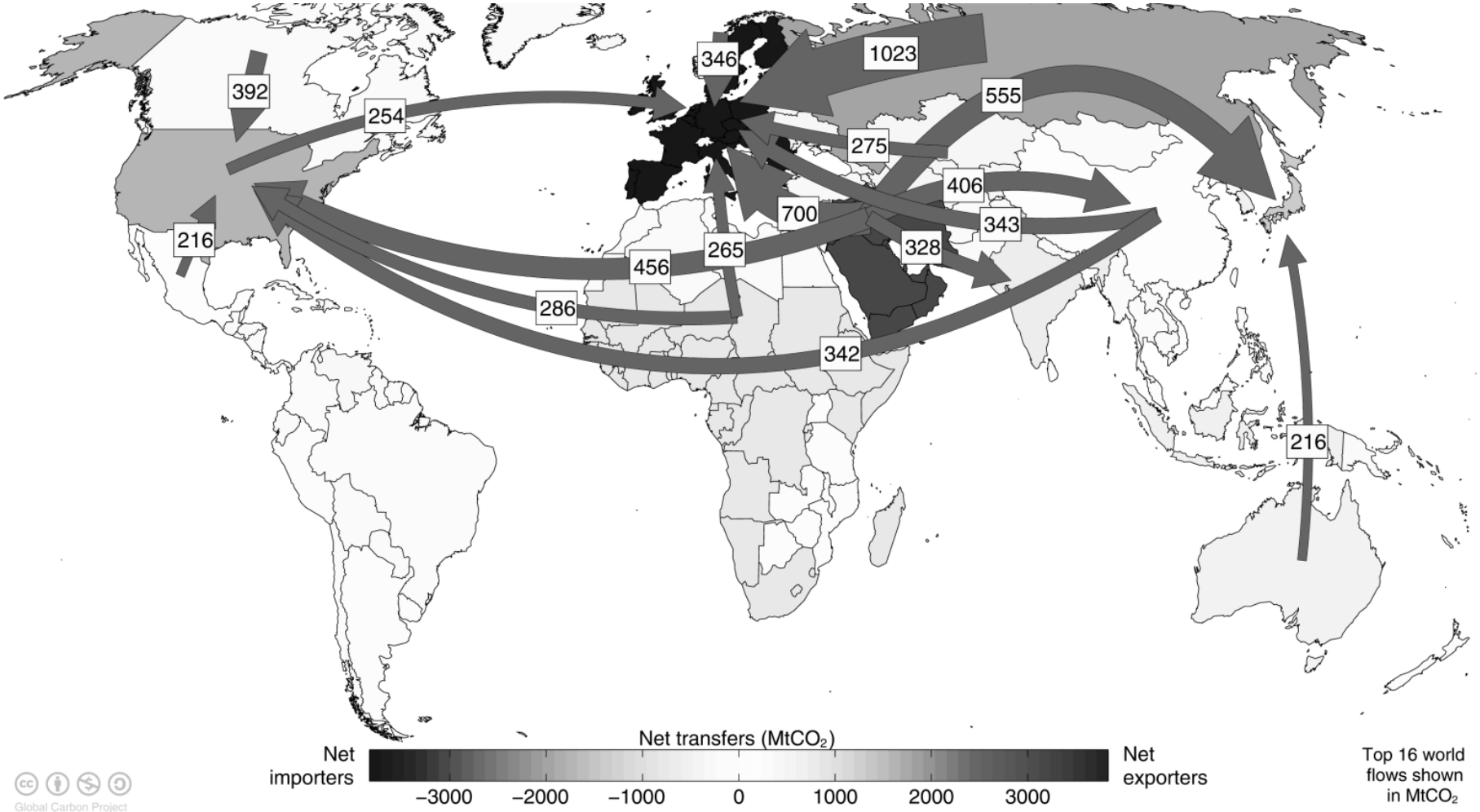


Values for 2011. EU is treated as one region. Units: $MtCO_2$

Source: Peters et al 2012

Major flows from extraction to consumption

Flows from location of fossil fuel extraction to location of consumption of goods and services



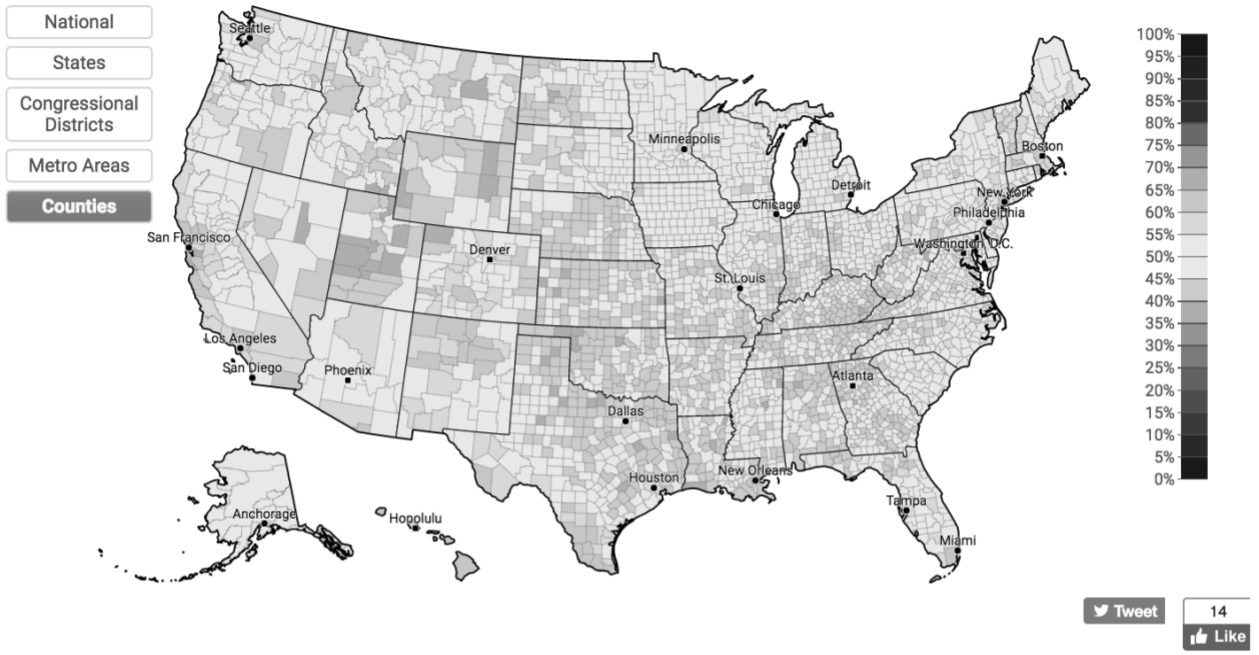
Values for 2011. EU is treated as one region. Units: $MtCO_2$

Source: Andrew et al 2013

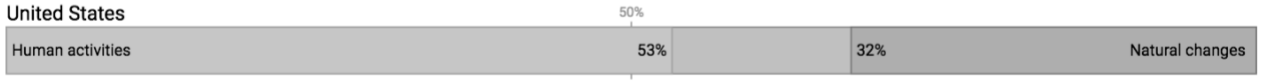
Estimated % of adults who think global warming is mostly caused by human activities, 2016

Display model output: Global warming is caused mostly by human activities | Absolute Value | Permalink

Click on map to select geography, or: Wisconsin | Select a County

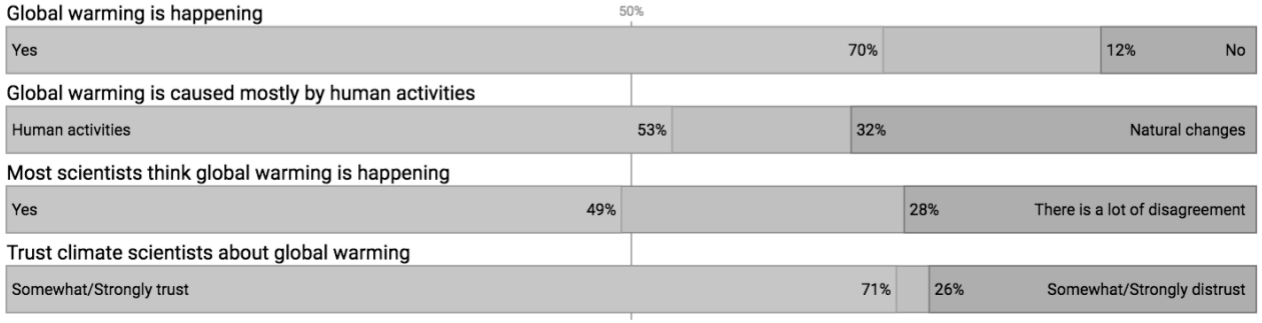


Tweet 14 Like

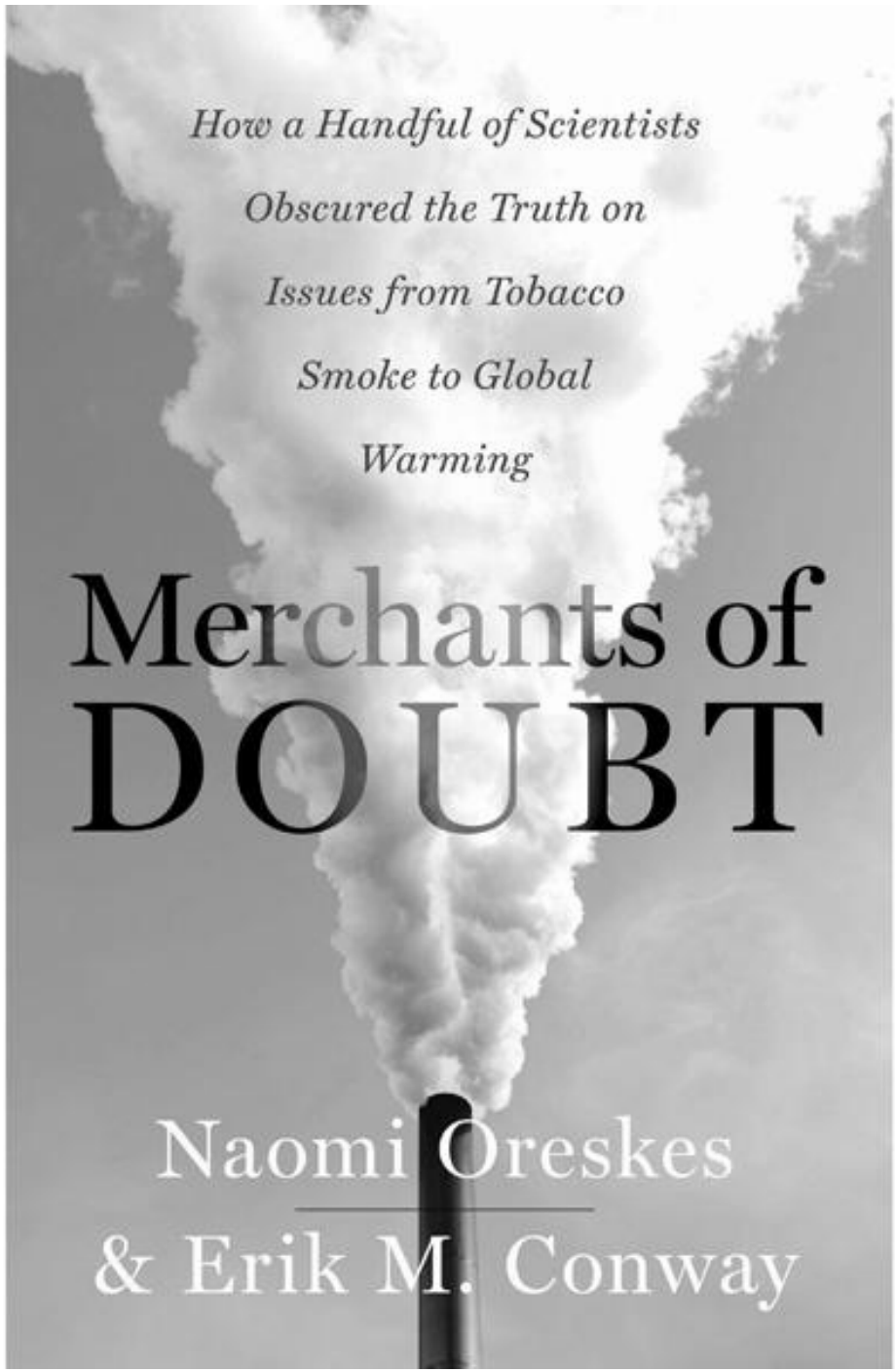


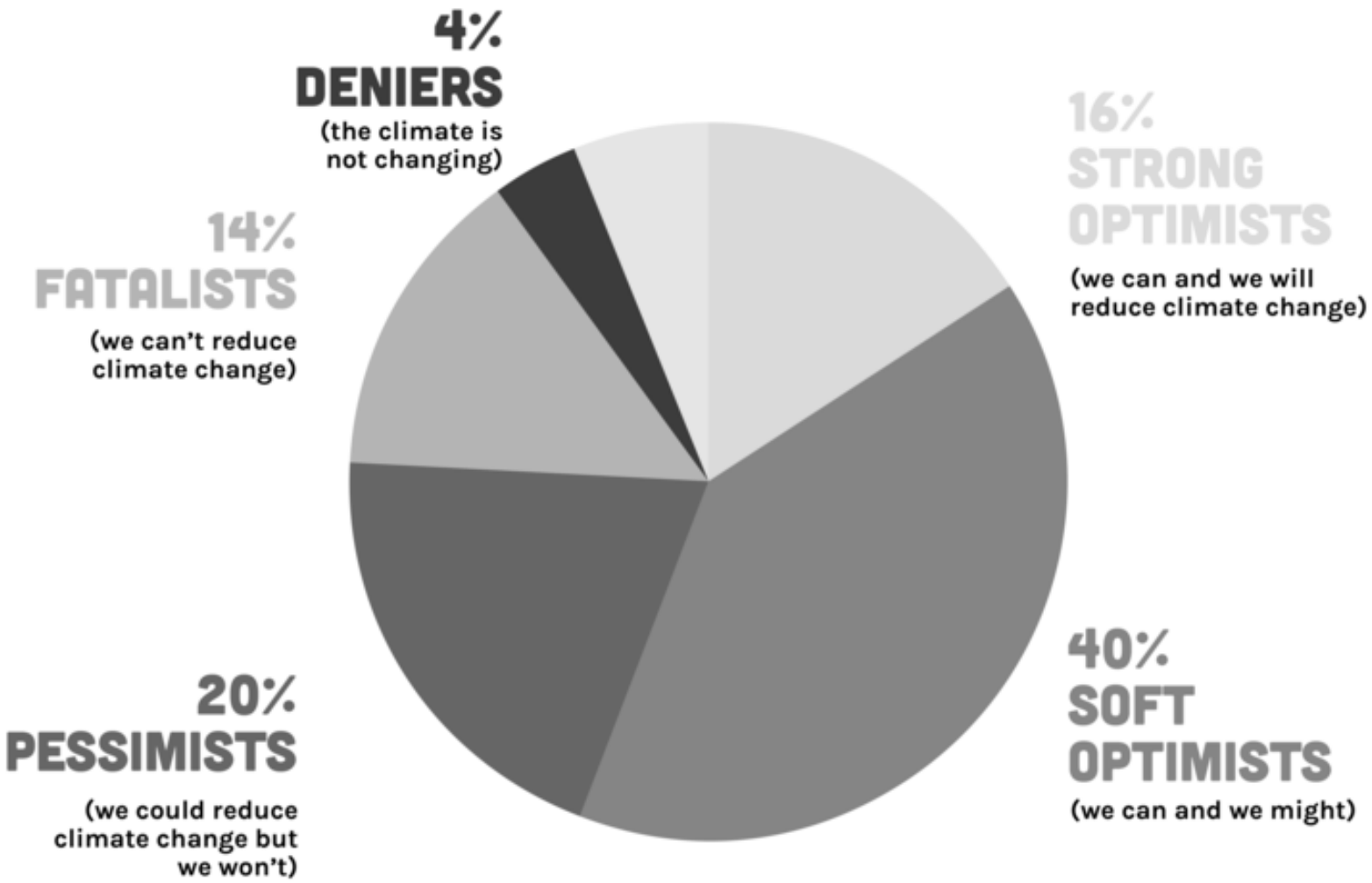
Public Opinion Estimates, United States, 2016

BELIEFS



RISK PERCEPTIONS


How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming
Merchants of DOUBT
Naomi Oreskes
& Erik M. Conway



Climateoptimist.org

The future?

- Climate scientists will continue to refine projections of future change and impacts in response to emissions and/or policy
- Global treaty progress will likely be slow, but there are successes in deforestation reduction, developing country support, and renewal energy infrastructure
- Bi- or Multi- lateral agreements (e.g., US-China) and within country “energy arms race” may end up having the biggest bang for buck
- Fossil fuel reserves are getting scarcer, but not running out anytime soon. Given lags in climate response, some level of adaptation is inevitable
- The current US federal administration just threw a really big monkey-wrench into the whole thing