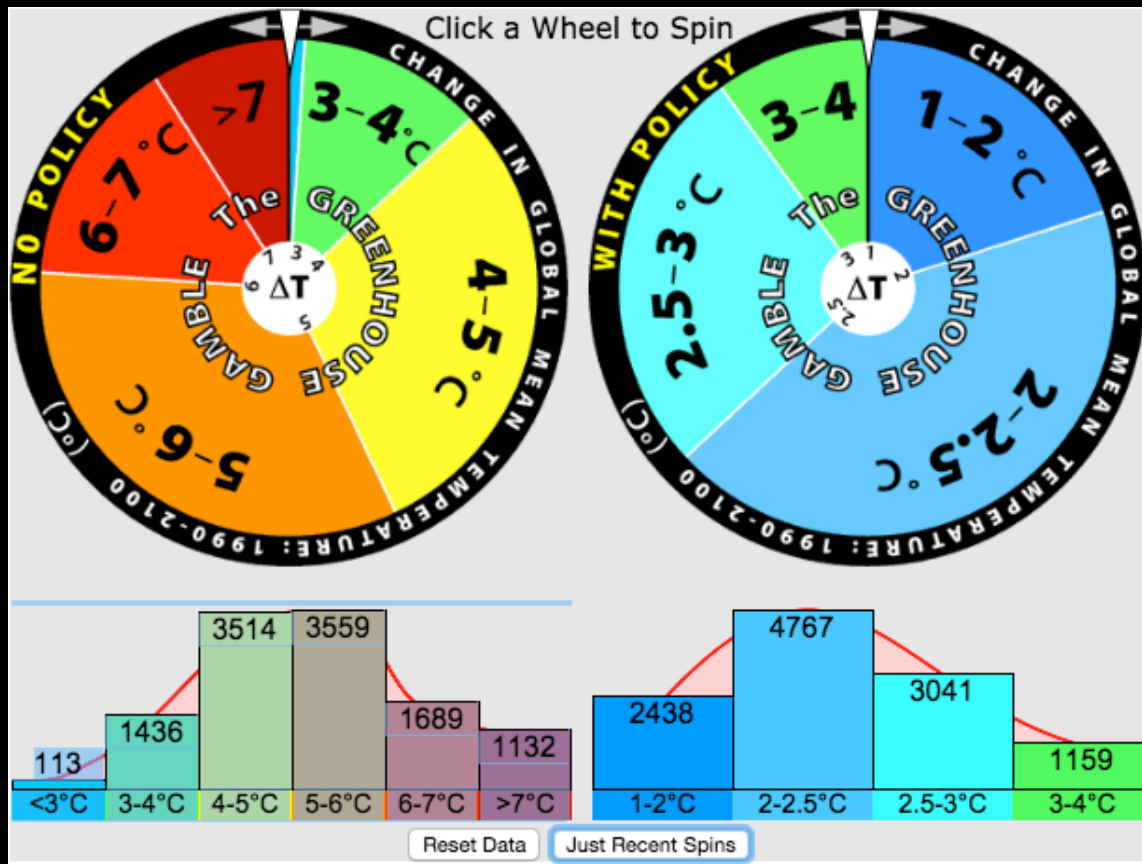
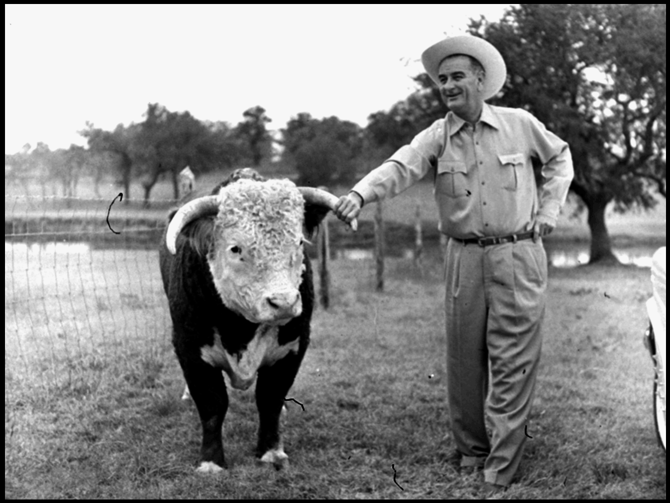
Climate Changes. Do Policies?



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

Nov 2017. Public Affairs 850

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?

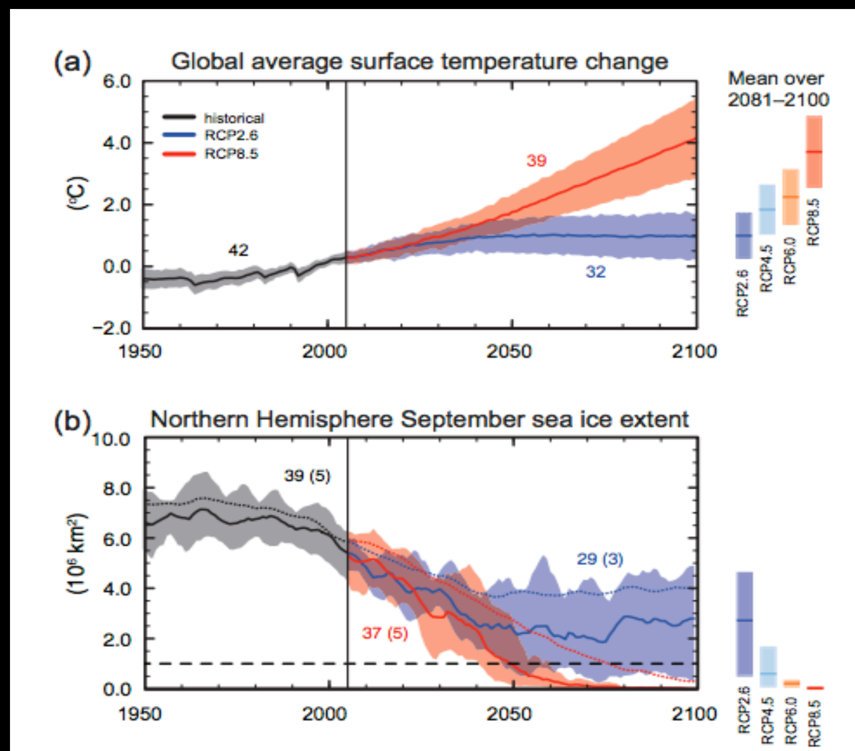
It was supposed to be a quiet year.

The IPCC *et al*

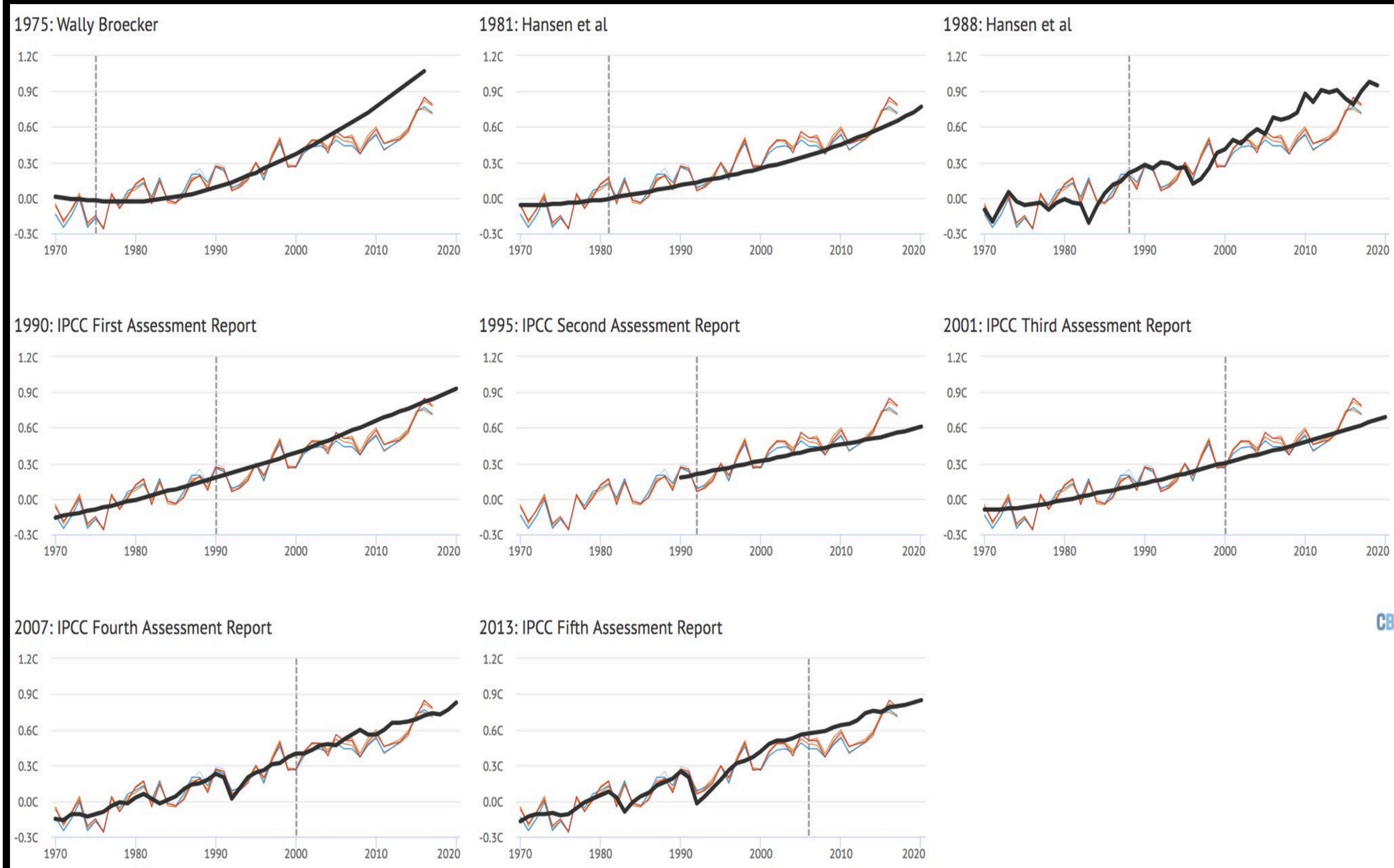
- Intergovernmental Panel on Climate Change (http://www.ipcc.ch/)
  - Established 1985 by UNEP and WMO
  - Provides review of science on causes of climate change (WG1), impacts of climate change (WG2), options of adaptation and mitigation (WG3)
  - Entirely volunteer run, with nomination process, support 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 annually 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)

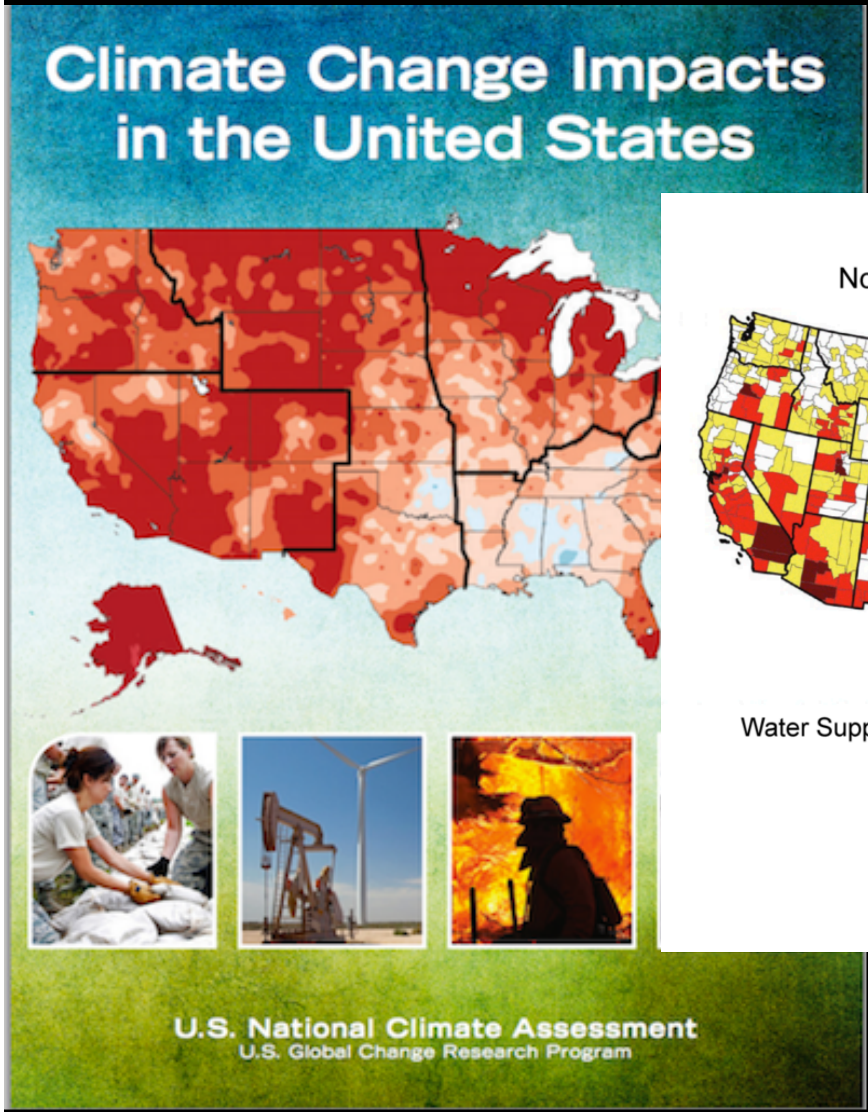
IPCC @IPCC_CH · 2m

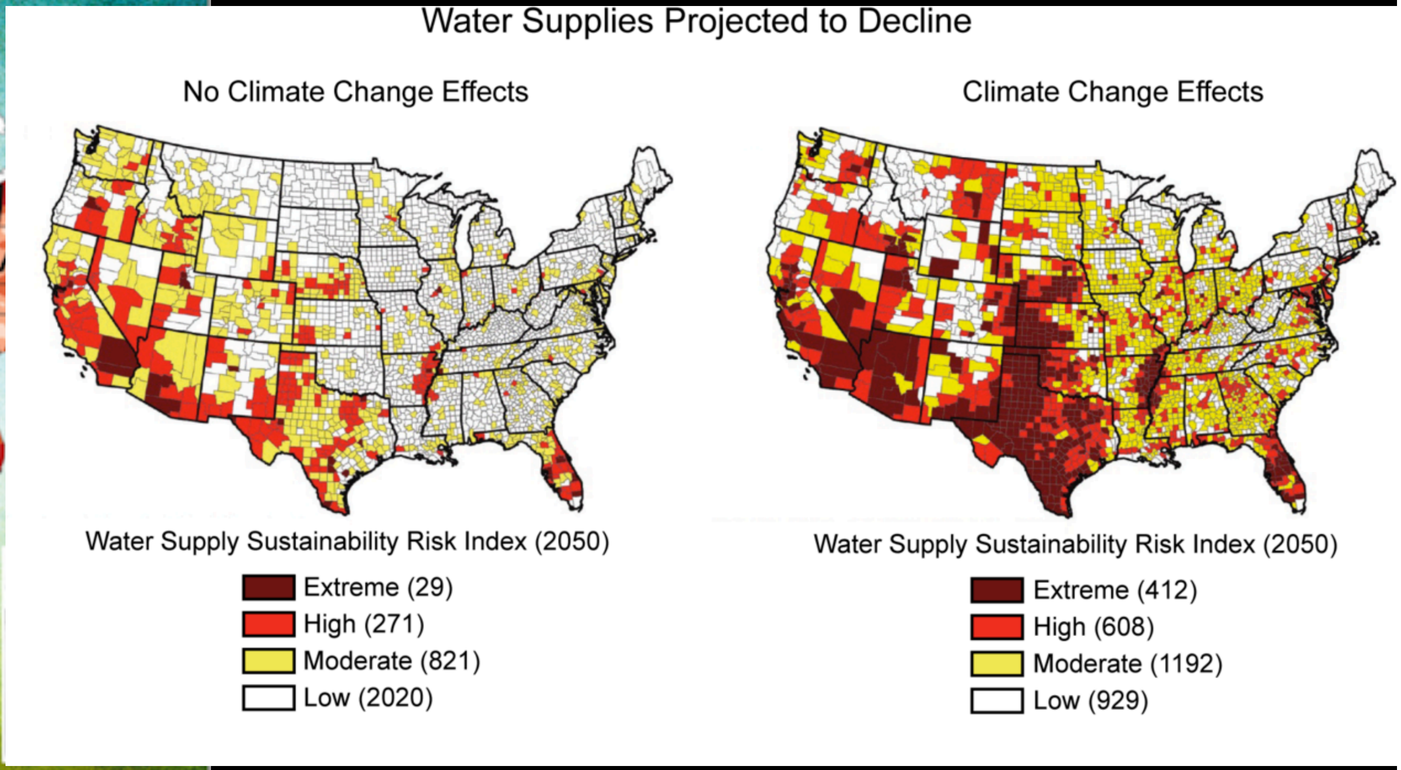
Call for nominations of authors for the #AR6 is open till 27 October! Full WGI outline here: bit.ly/2fyx9B2 #IPCC #climatechange



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


1975: Wally Broecker
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
1981: Hansen et al
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
1988: Hansen et al
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
1990: IPCC First Assessment Report
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
1995: IPCC Second Assessment Report
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
2001: IPCC Third Assessment Report
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
2007: IPCC Fourth Assessment Report
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
2013: IPCC Fifth Assessment Report
1.2C 0.9C 0.6C 0.3C 0.0C -0.3C
1970 1980 1990 2000 2010 2020
CB



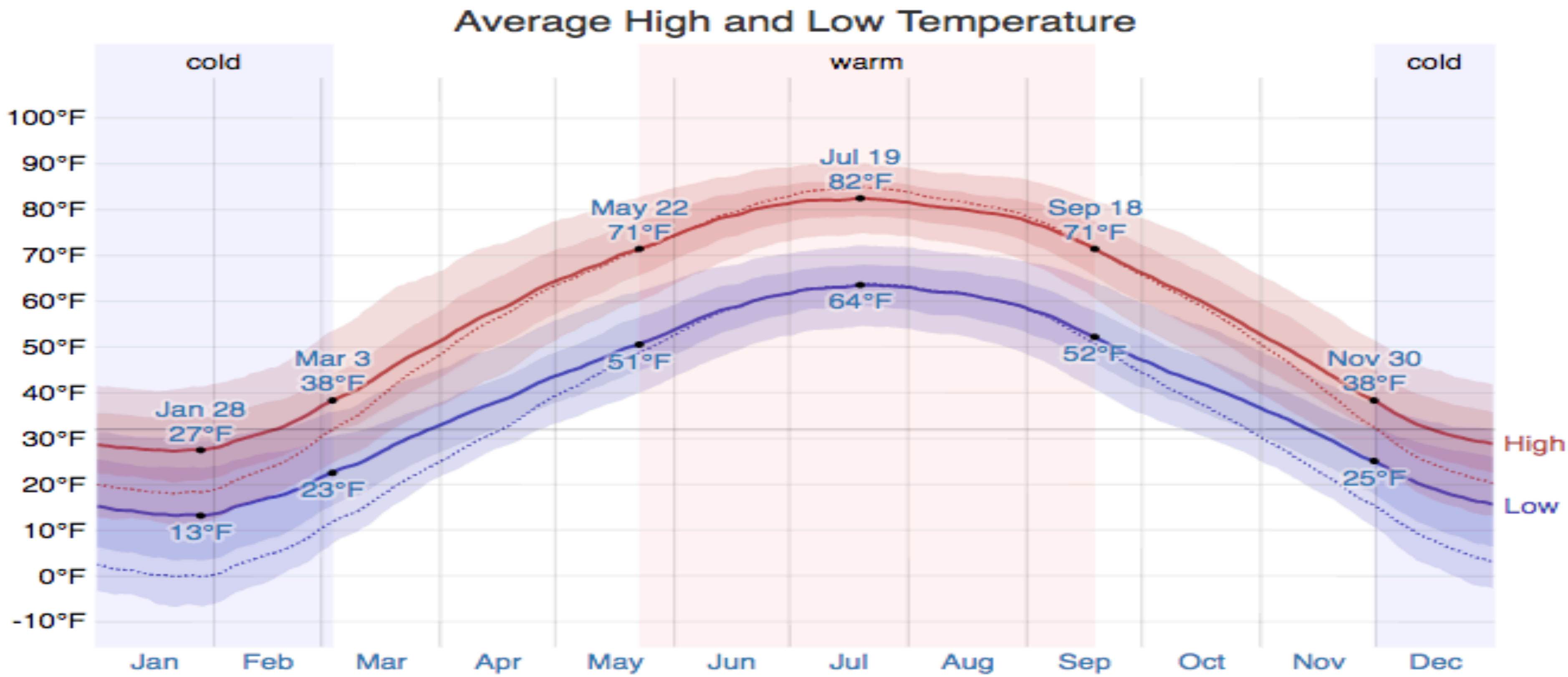


http://nca2014.globalchange.gov/

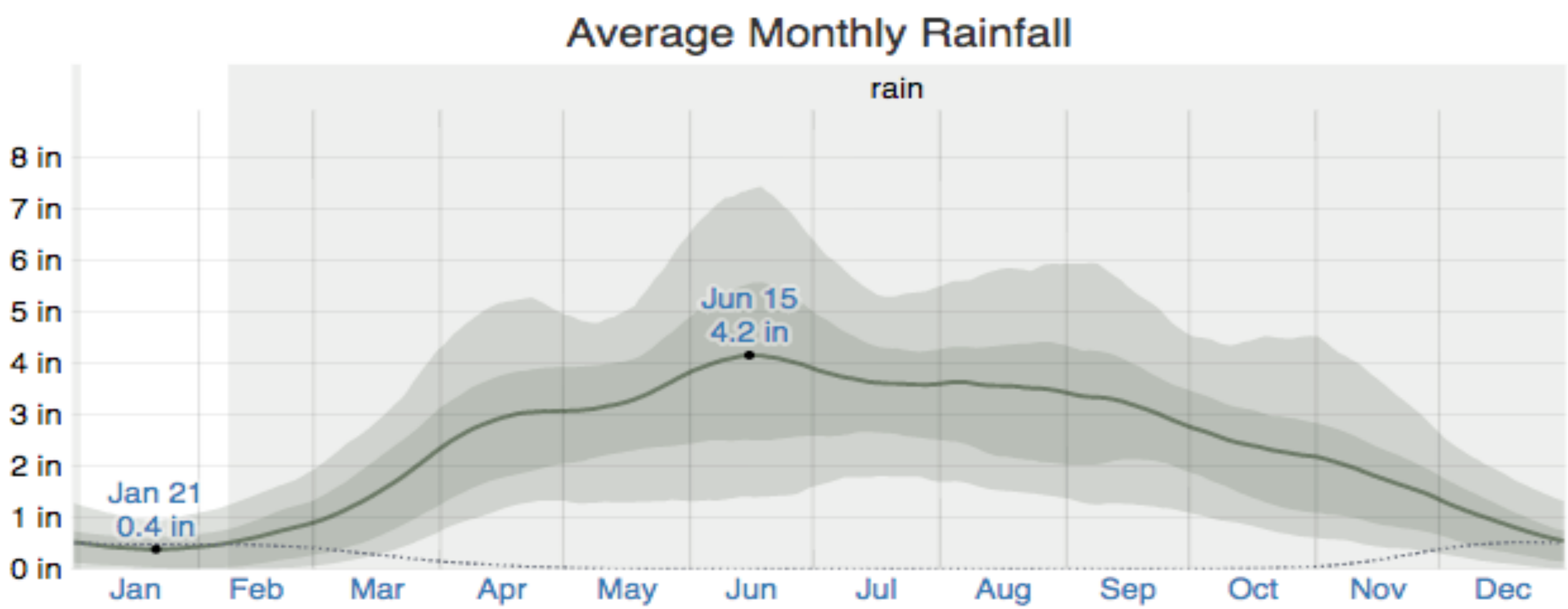
Three things about climate

Three things about climate

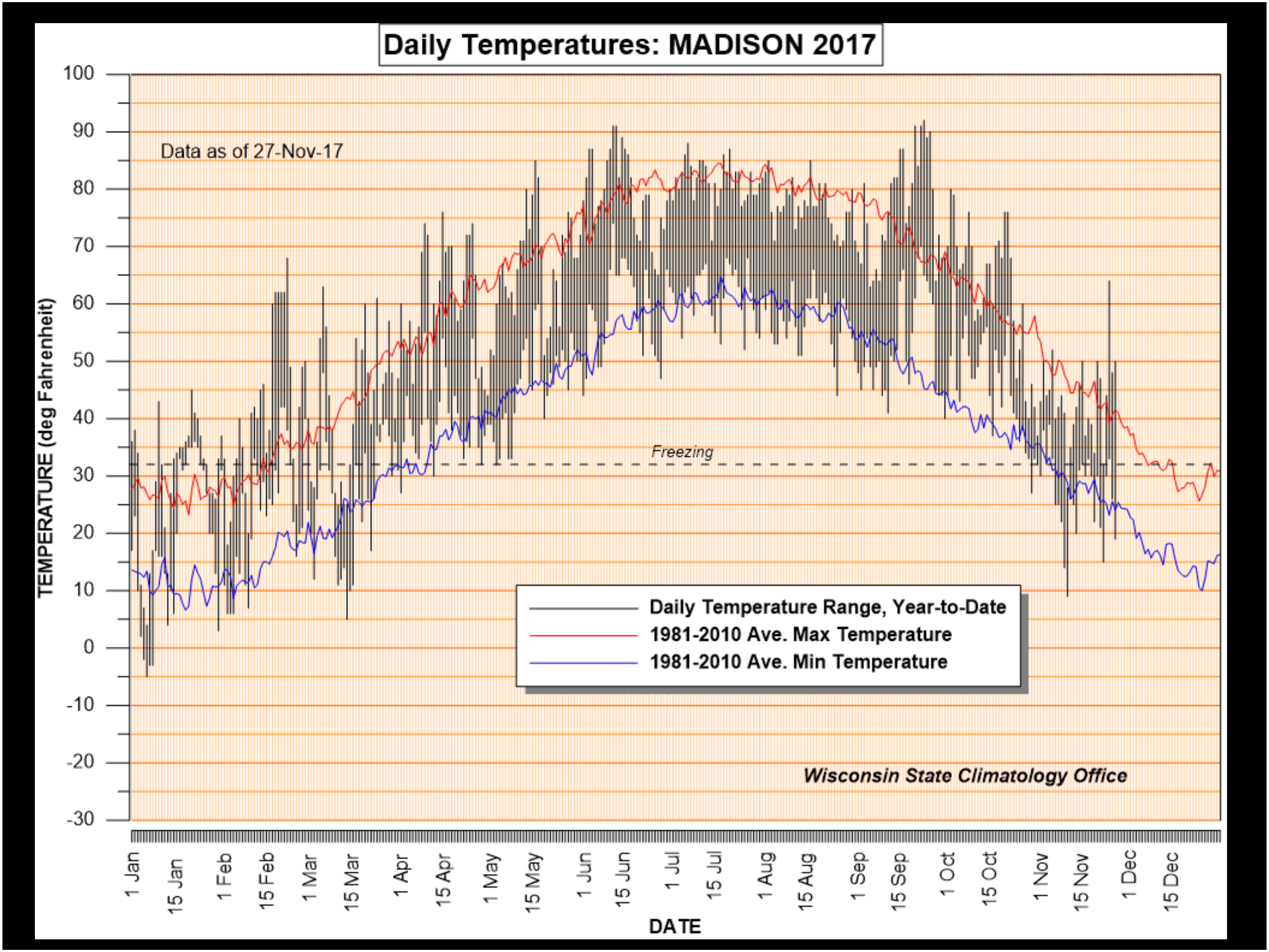
- Climate is the average of weather



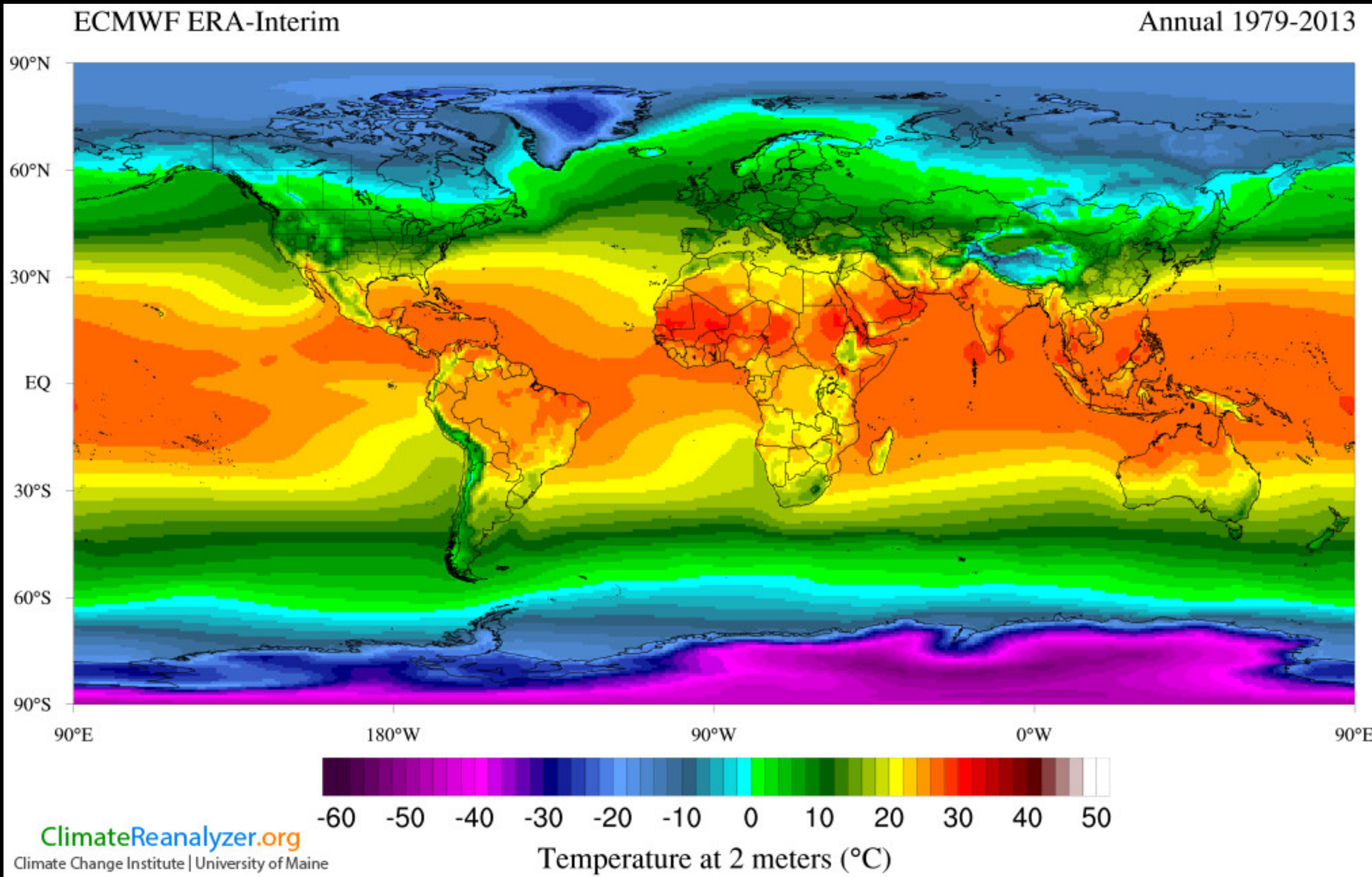
Average High and Low Temperature
cold
warm
cold
100°F
90°F
80°F
70°F
60°F
50°F
40°F
30°F
20°F
10°F
0°F
-10°F
Jul 19
82°F
May 22
71°F
Sep 18
71°F
64°F
Mar 3
38°F
51°F
52°F
Nov 30
38°F
Jan 28
27°F
23°F
25°F
13°F
High
Low
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



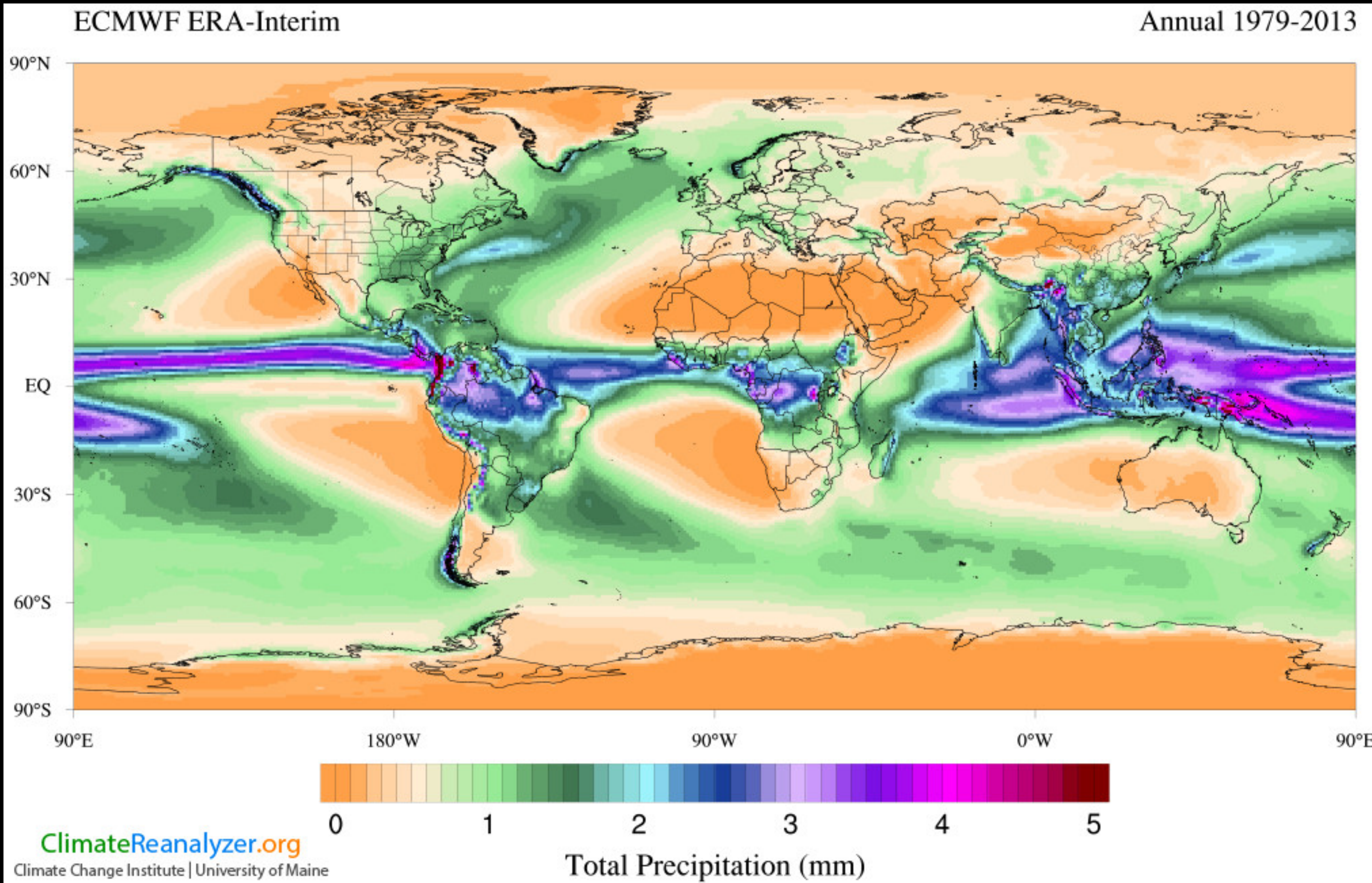
Average Monthly Rainfall
rain
8 in
7 in
6 in
5 in
4 in
3 in
2 in
1 in
0 in
Jun 15
4.2 in
Jan 21
0.4 in
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



Daily Temperatures: MADISON 2017
Data as of 27-Nov-17
TEMPERATURE (deg Fahrenheit)
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
Freezing
Daily Temperature Range, Year-to-Date
1981-2010 Ave. Max Temperature
1981-2010 Ave. Min Temperature
Wisconsin State Climatology Office
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



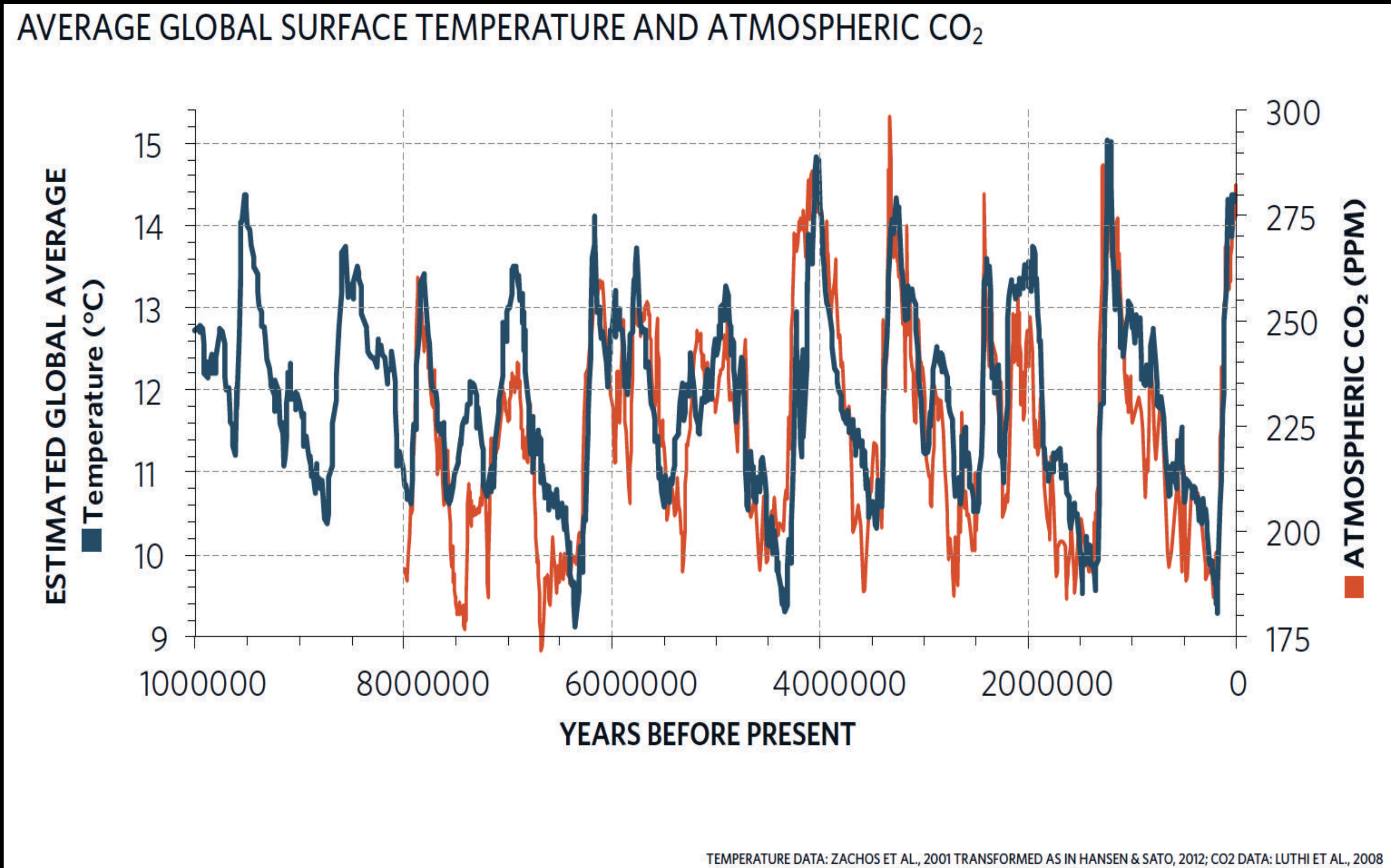
http://cci-reanalyzer.org/



http://cci-reanalyzer.org/

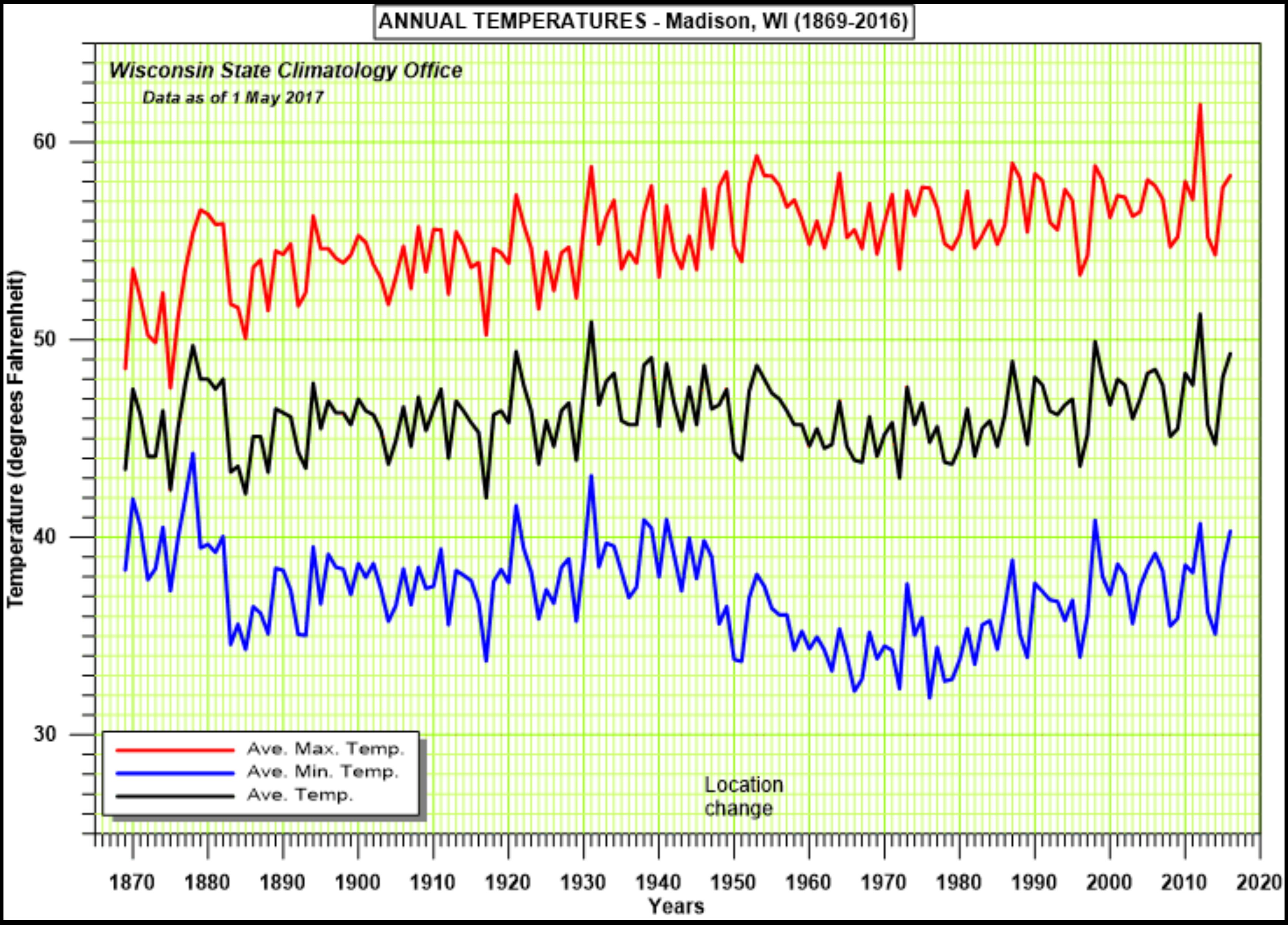
Three things about climate

- Climate is the average of weather
- Climate changes naturally



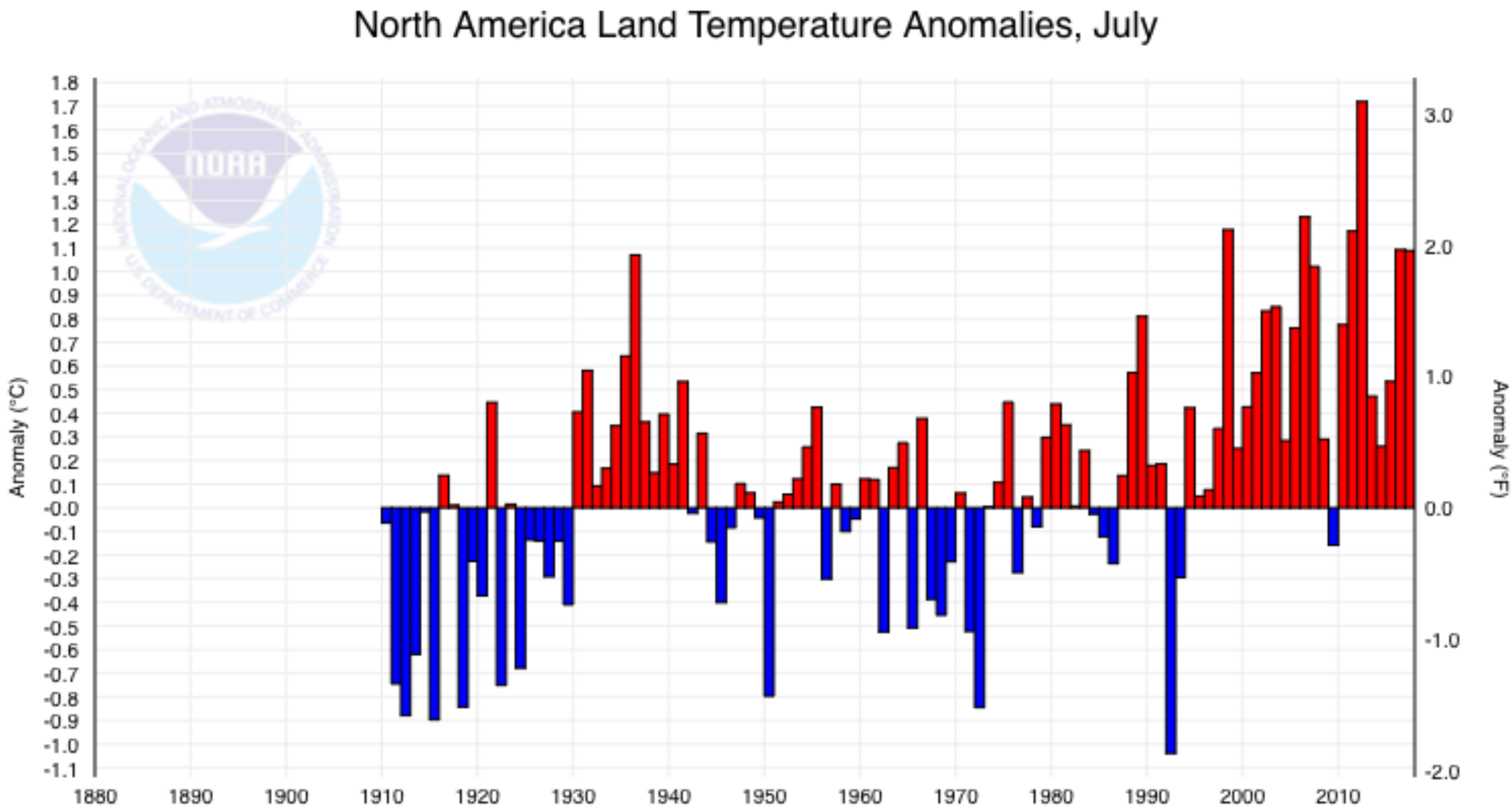
Mann et al., 2003, EOS

Madison



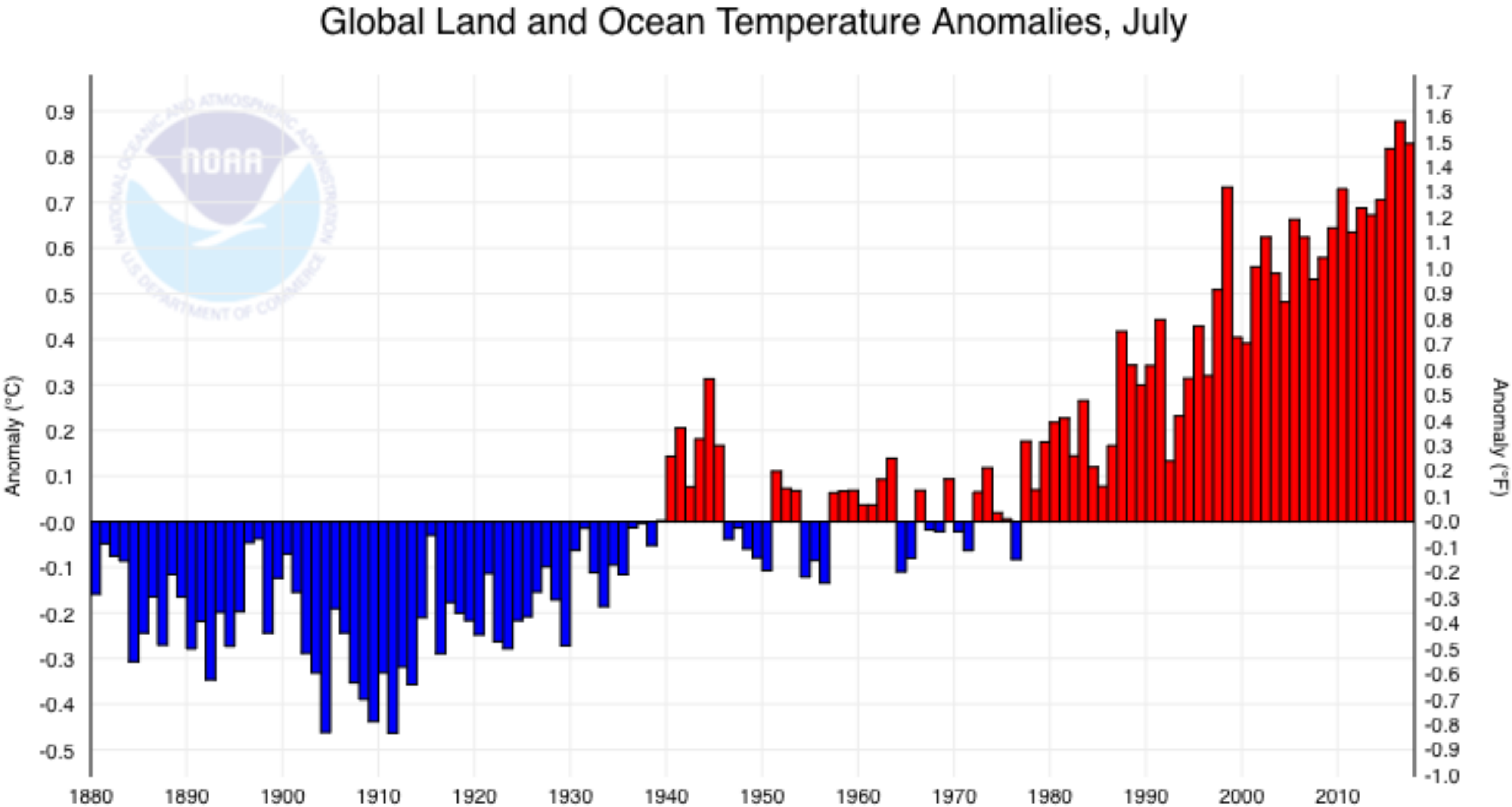
ANNUAL TEMPERATURES - Madison, WI (1869-2016)
Wisconsin State Climatology Office
Data as of 1 May 2017
Temperature (degrees Fahrenheit)
60
50
40
30
Ave. Max. Temp.
Ave. Min. Temp.
Ave. Temp.
Location change
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Years

N America

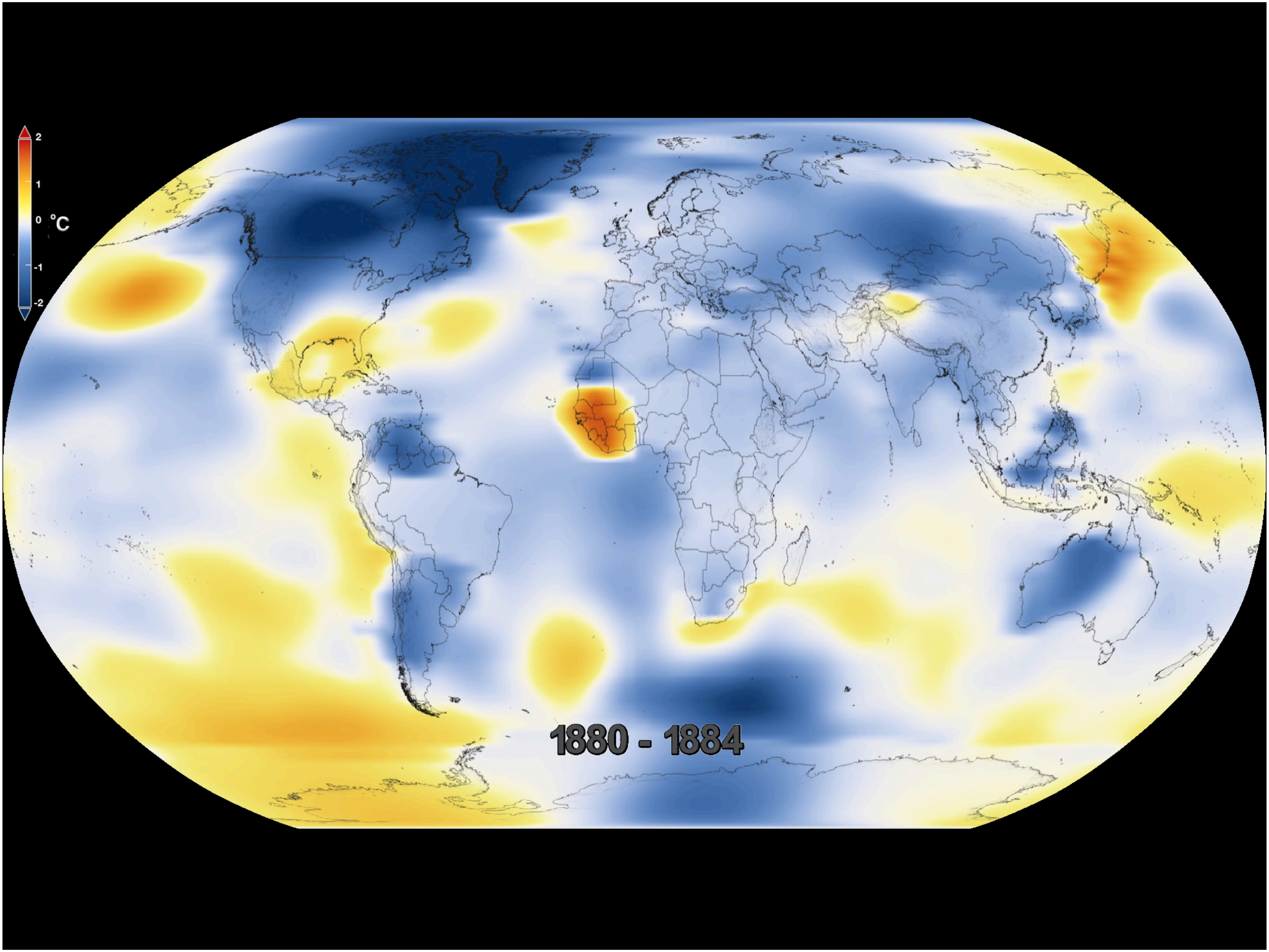


North America Land Temperature Anomalies, July
Anomaly (°C)
Anomaly (°F)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
3.0
2.0
1.0
0.0
-1.0
-2.0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

WORLD



Global Land and Ocean Temperature Anomalies, July
Anomaly (°C)
Anomaly (°F)
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
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

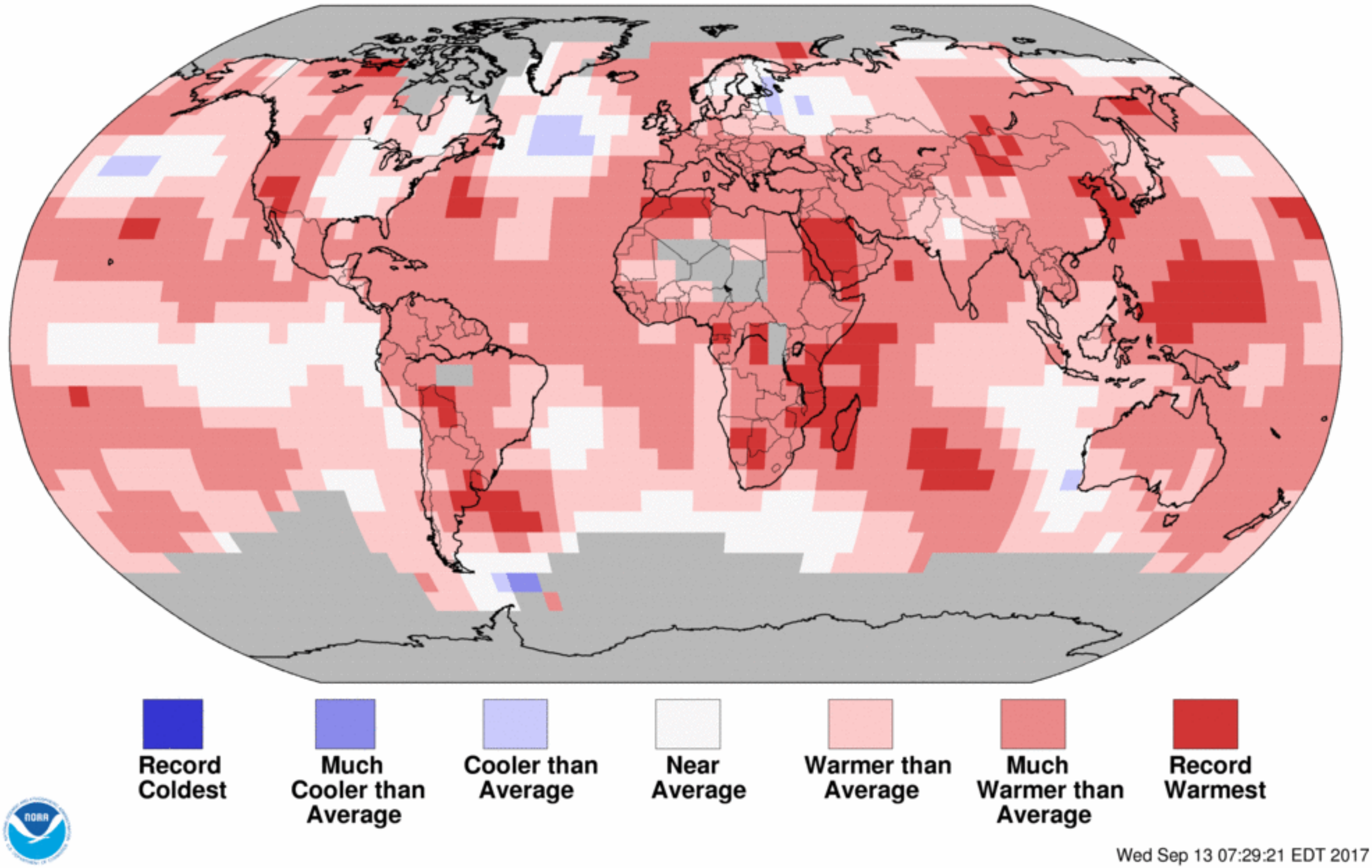


2
1
0
°C
-1
-2
1880 - 1884

Land & Ocean Temperature Percentiles Jun 2017–Aug 2017

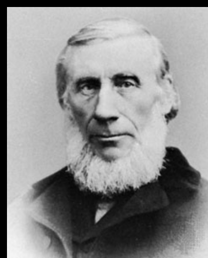
NOAA's National Centers for Environmental Information

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



Three things about climate

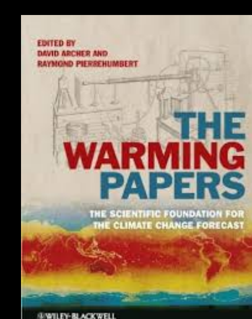
- Climate is the average of weather
- Climate changes naturally
- The study of climate change is well-established. We know how climate changes and what is mostly causing current change

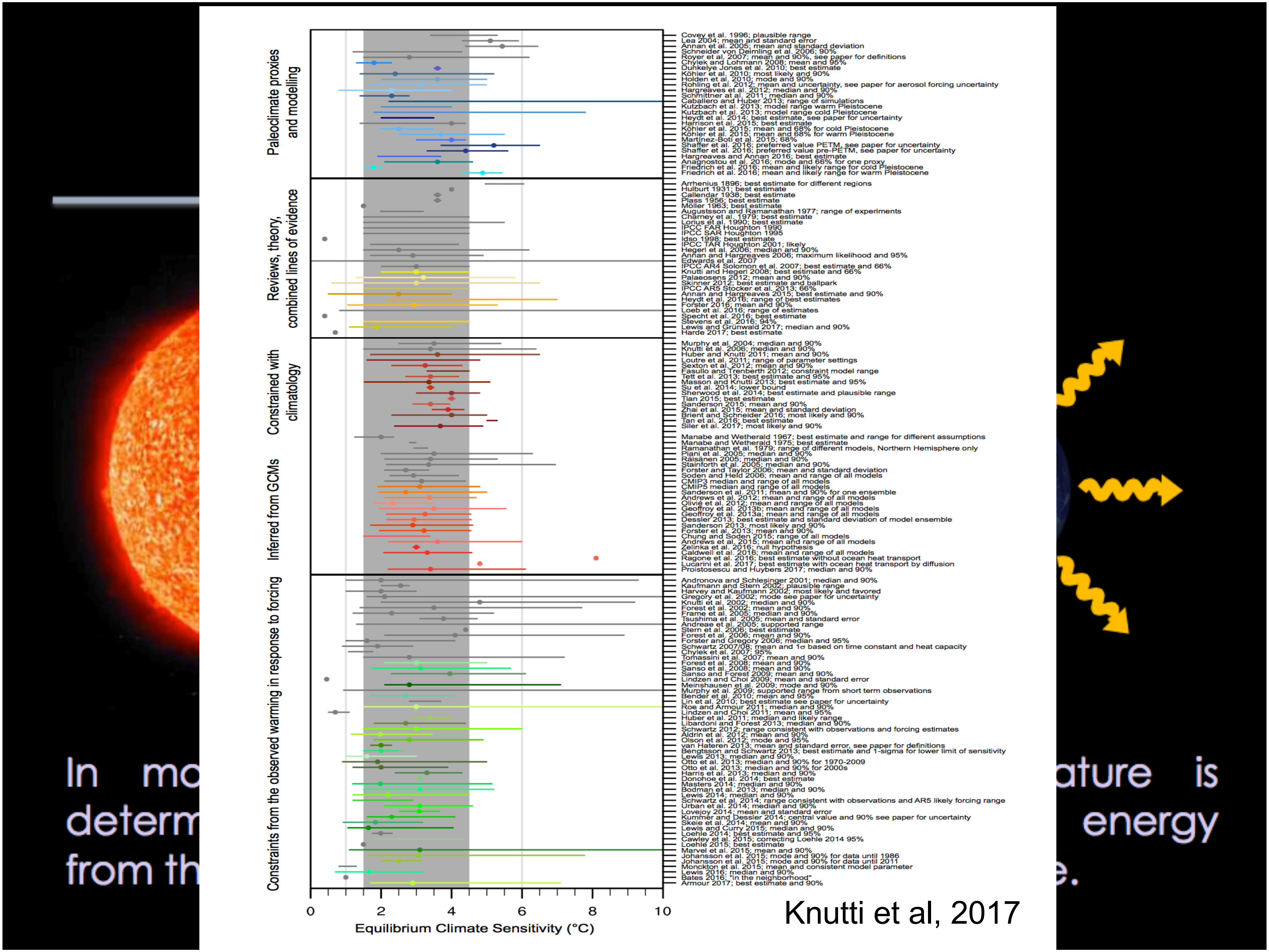



- Planetary (inc. Earth) temperature is determined by interaction of sunlight warming Earth's surface, and "greenhouse" gases that absorb infrared radiation (Fourier 1824, Tyndall 1861)

- 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)

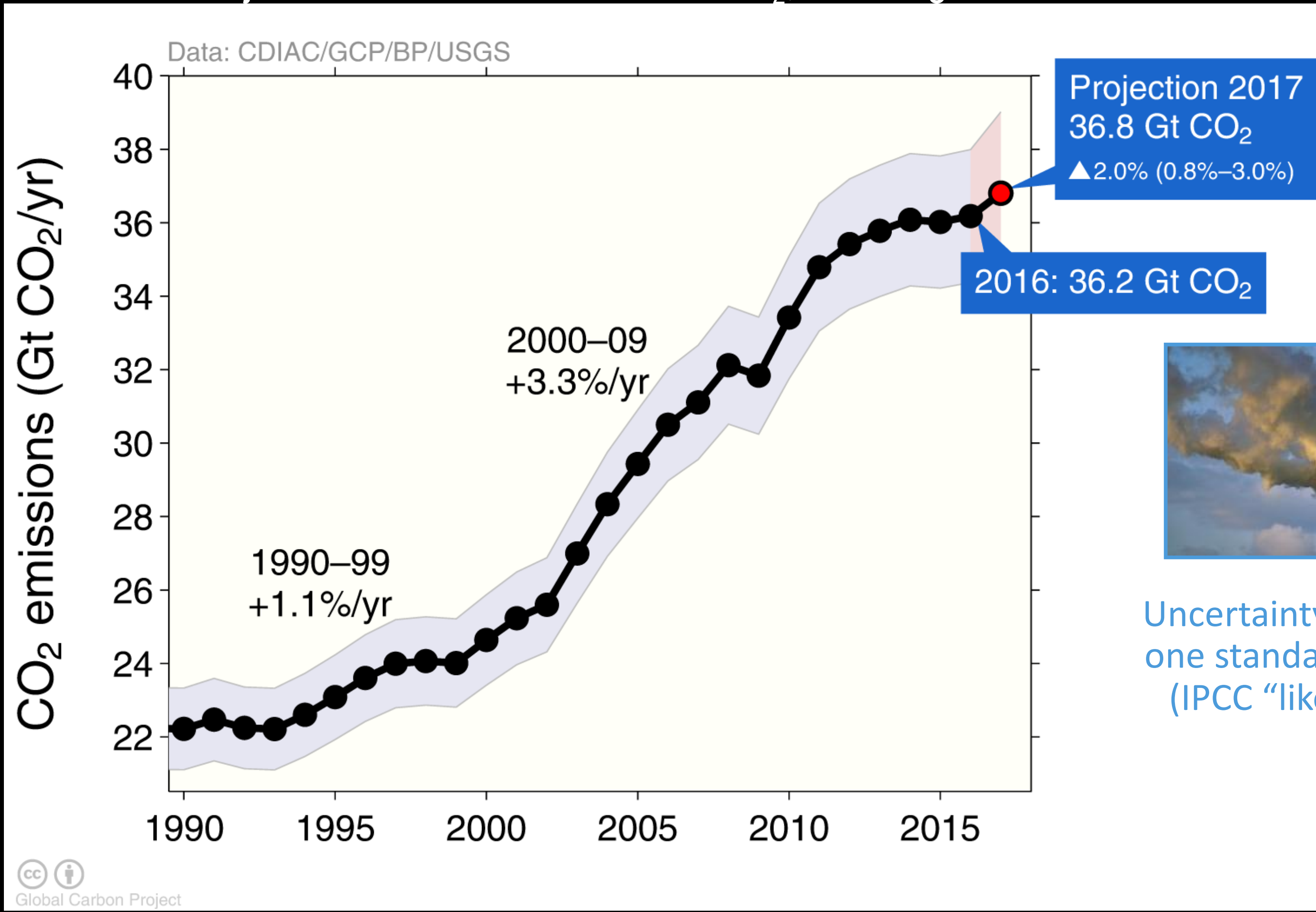



Paleoclimate proxies and modelling
Reviews, theory, combined lines of evidence
Constrained with climatology
Inferred from GCMs
Constraints from the observed warming in response to forcing
Covey et al. 1996; plausible range
Lea 2004; mean and standard error
Annan et al. 2005; mean and standard deviation
Schneider von Deimling et al. 2006; 90%
Royer et al. 2007; mean and 90%, see paper for definitions
Chylek and Lohmann 2008; mean and 95%
Dunkelye Jones et al. 2010; best estimate
Köhler et al. 2010; most likely and 90%
Holden et al. 2010; mode and 90%
Rohling et al. 2012; mean and uncertainty, see paper for aerosol forcing uncertainty
Hargreaves et al. 2012; median and 90%
Schmittner at al. 2011; median and 90%
Caballero and Huber 2013; range of simulations
Kutzbach et al. 2013; model range warm Pleistocene
Kutzbach et al. 2013; model range cold Pleistocene
Heydt et al. 2014; best estimate, see paper for uncertainty
Harrison et al. 2015; best estimate
Köhler et al. 2015; mean and 68% for cold Pleistocene
Köhler et al. 2015; mean and 68% for warm Pleistocene
Martínez-Botí et al. 2015; 68%
Shaffer et al. 2016; preferred value PETM, see paper for uncertainty
Shaffer et al. 2016; preferred value pre-PETM, see paper for uncertainty
Hargreaves and Annan 2016; best estimate
Anagnostou et al. 2016; mode and 66% for one proxy
Friedrich et al. 2016; mean and likely range for cold Pleistocene
Friedrich et al. 2016; mean and likely range for warm Pleistocene
Arrhenius 1896; best estimate for different regions
Hulburt 1931; best estimate
Callendar 1938; best estimate
Plass 1956; best estimate
Möller 1963; best estimate
Augustsson and Ramanathan 1977; range of experiments
Charney et al. 1979; best estimate
Lorius et al. 1990; best estimate
IPCC FAR Houghton 1990
IPCC SAR Houghton 1995
Idso 1998; best estimate
IPCC TAR Houghton 2001; likely
Hegerl et al. 2006; median and 90%
Annan and Hargreaves 2006; maximum likelihood and 95%
Edwards et al. 2007
IPCC AR4 Solomon et al. 2007; best estimate and 66%
Knutti and Hegerl 2008; best estimate and 66%
Palaeosens 2012; mean and 90%
Skinner 2012; best estimate and ballpark
IPCC AR5 Stocker et al. 2013; 66%
Annan and Hargreaves 2015; best estimate and 90%
Heydt et al. 2016; range of best estimates
Forster 2016; mean and 90%
Loeb et al. 2016; range of estimates
Specht et al. 2016; best estimate
Stevens et al. 2016; 94%
Lewis and Grünwald 2017; median and 90%
Harde 2017; best estimate
Murphy et al. 2004; median and 90%
Knutti et al. 2006; median and 90%
Huber and Knutti 2011; mean and 90%
Loutre et al. 2011; range of parameter settings
Sexton et al. 2012; mean and 90%
Fasullo and Trenberth 2012; constraint model range
Tett et al. 2013; best estimate and 95%
Masson and Knutti 2013; best estimate and 95%
Su et al. 2014; lower bound
Sherwood et al. 2014; best estimate and plausible range
Tian 2015; best estimate
Sanderson 2015; mean and 90%
Zhai et al. 2015; mean and standard deviation
Brient and Schneider 2016; most likely and 90%
Tan et al. 2016; best estimate
Siler et al. 2017; most likely and 90%
Manabe and Wetherald 1967; best estimate and range for different assumptions
Manabe and Wetherald 1975; best estimate
Ramanathan et al. 1979; range of different models, Northern Hemisphere only
Piani et al. 2005; median and 90%
Räisänen 2005; median and 90%
Stainforth et al. 2005; median and 90%
Forster and Taylor 2006; mean and standard deviation
Soden and Held 2006; mean and range of all models
CMIP3 median and range of all models
CMIP5 median and range of all models
Sanderson et al. 2011; mean and 90% for one ensemble
Andrews et al. 2012; mean and range of all models
Olivié et al. 2012; mean and range of all models
Geoffroy et al. 2013b; mean and range of all models
Geoffroy et al. 2013a; mean and range of all models
Dessler 2013; best estimate and standard deviation of model ensemble
Sanderson 2013; most likely and 90%
Forster et al. 2013; mean and 90%
Chung and Soden 2015; range of all models
Andrews et al. 2015; mean and range of all models
Zelinka et al. 2016; null hypothesis
Caldwell et al. 2016; mean and range of all models
Ragone et al. 2016; best estimate without ocean heat transport
Lucarini et al. 2017; best estimate with ocean heat transport by diffusion
Proistosescu and Huybers 2017; median and 90%
Andronova and Schlesinger 2001; median and 90%
Kaufmann and Stern 2002; plausible range
Harvey and Kaufmann 2002; most likely and favored
Gregory et al. 2002; mode see paper for uncertainty
Knutti et al. 2002; median and 90%
Forest et al. 2002; mean and 90%
Frame et al. 2005; median and 90%
Tsushima et al. 2005; mean and standard error
Andreae et al. 2005; supported range
Stern et al. 2006; best estimate
Forest et al. 2006; mean and 90%
Forster and Gregory 2006; median and 95%
Schwartz 2007/08; mean and 1σ based on time constant and heat capacity
Chylek et al. 2007; 95%
Tomassini et al. 2007; mean and 90%
Forest et al. 2008; mean and 90%
Sanso et al. 2008; mean and 90%
Sanso and Forest 2009; mean and 90%
Lindzen and Choi 2009; mean and standard error
Meinshausen et al. 2009; mode and 90%
Murphy et al. 2009; supported range from short term observations
Bender et al. 2010; mean and 95%
Lin et al. 2010; best estimate see paper for uncertainty
Roe and Armour 2011; median and 90%
Lindzen and Choi 2011; mean and 95%
Huber et al. 2011; median and likely range
Libardoni and Forest 2013; median and 90%
Schwartz 2012; range consistent with observations and forcing estimates
Aldrin et al. 2012; mean and 90%
Olson et al. 2012; mode and 95%
van Hateren 2013; mean and standard error, see paper for definitions
Bengtsson and Schwartz 2013; best estimate and 1-sigma for lower limit of sensitivity
Lewis 2013; median and 90%
Otto et al. 2013; median and 90% for 1970-2009
Otto et al. 2013; median and 90% for 2000s
Harris et al. 2013; median and 90%
Donohoe et al. 2014; best estimate
Masters 2014; median and 90%
Bodman et al. 2013; median and 90%
Lewis 2014; median and 90%
Schwartz et al. 2014; range consistent with observations and AR5 likely forcing range
Urban et al. 2014; median and 90%
Lovejoy 2014; mean and standard error
Kummer and Dessler 2014; central value and 90% see paper for uncertainty
Skeie et al. 2014; mean and 90%
Lewis and Curry 2015; median and 90%
Loehle 2014; best estimate and 95%
Cawley et al. 2015; correcting Loehle 2014 95%
Loehle 2015; best estimate
Marvel et al. 2015; mean and 90%
Johansson et al. 2015; mode and 90% for data until 1986
Johansson et al. 2015; mode and 90% for data until 2011
Monckton et al. 2015; mean and consistent model parameter
Lewis 2016; median and 90%
Bates 2016; "in the neighborhood"
Armour 2017; best estimate and 90%
0
2
4
6
8
10
Equilibrium Climate Sensitivity (°C)
Knutti et al, 2017
In mo
determ
from th
ature is
energy
e.

Emissions from fossil fuel use and industry

Global emissions from fossil fuel and industry: 36.2 ± 2 $GtCO_2$ in 2016, 62% over 1990

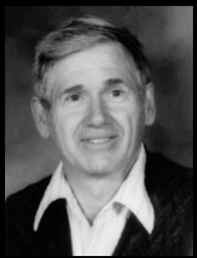
- Projection for 2017: 36.8 ± 2 $GtCO_2$, 2.0% higher than 2016



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

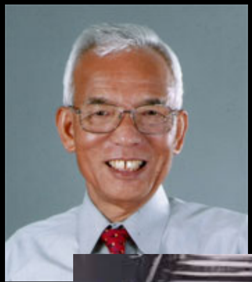
Estimates for 2015 and 2016 are preliminary. Growth rate is adjusted for the leap year in 2016.

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017

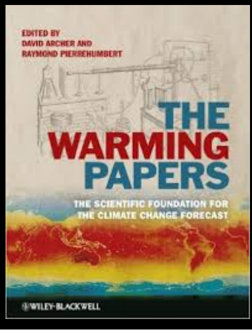


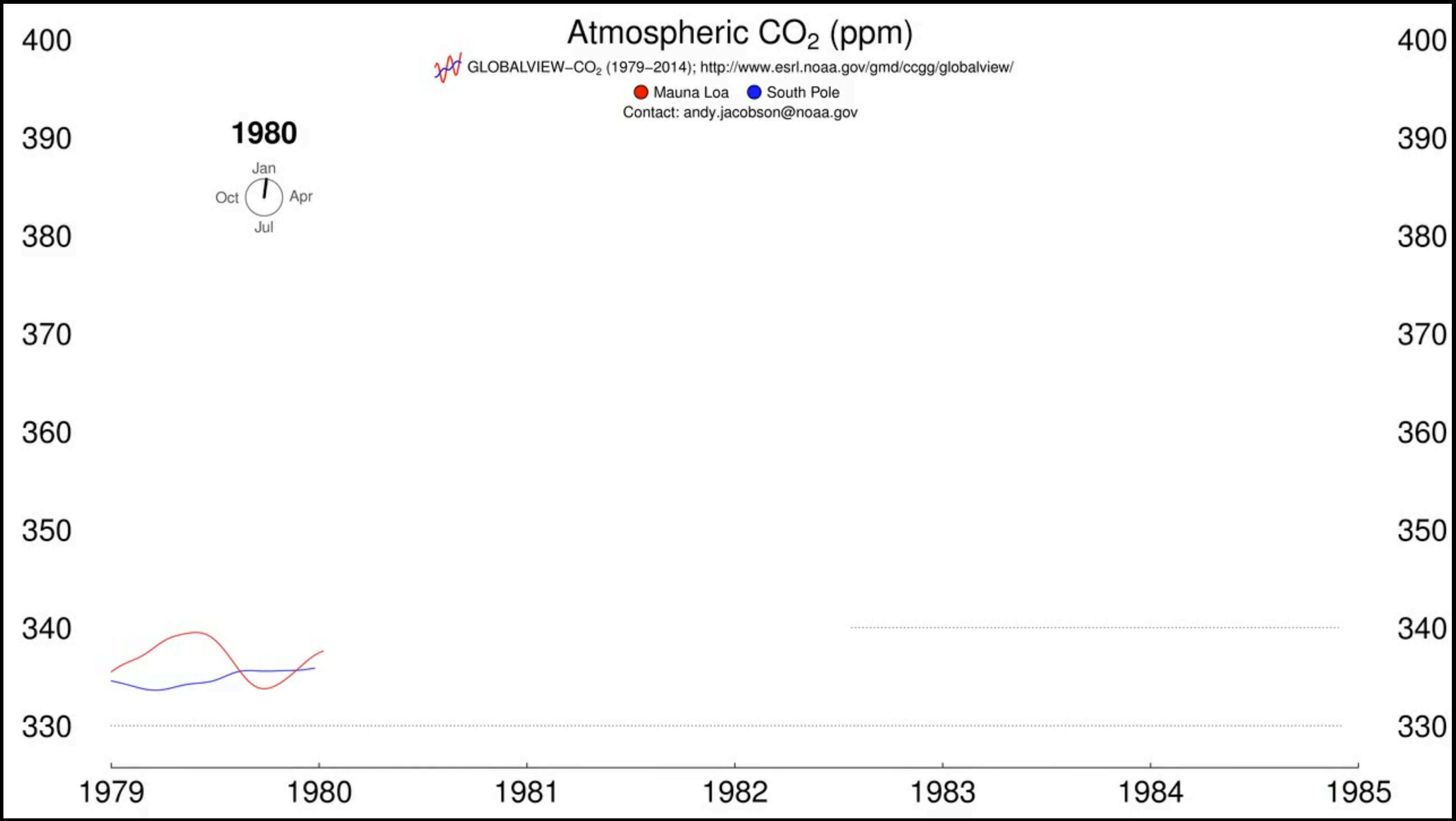
- Atmospheric CO_2 increasing ~ 2 ppm/yr from fossil fuel combustion, with 50% going into land and ocean sinks (Keeling 1960, Tans 1990)

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



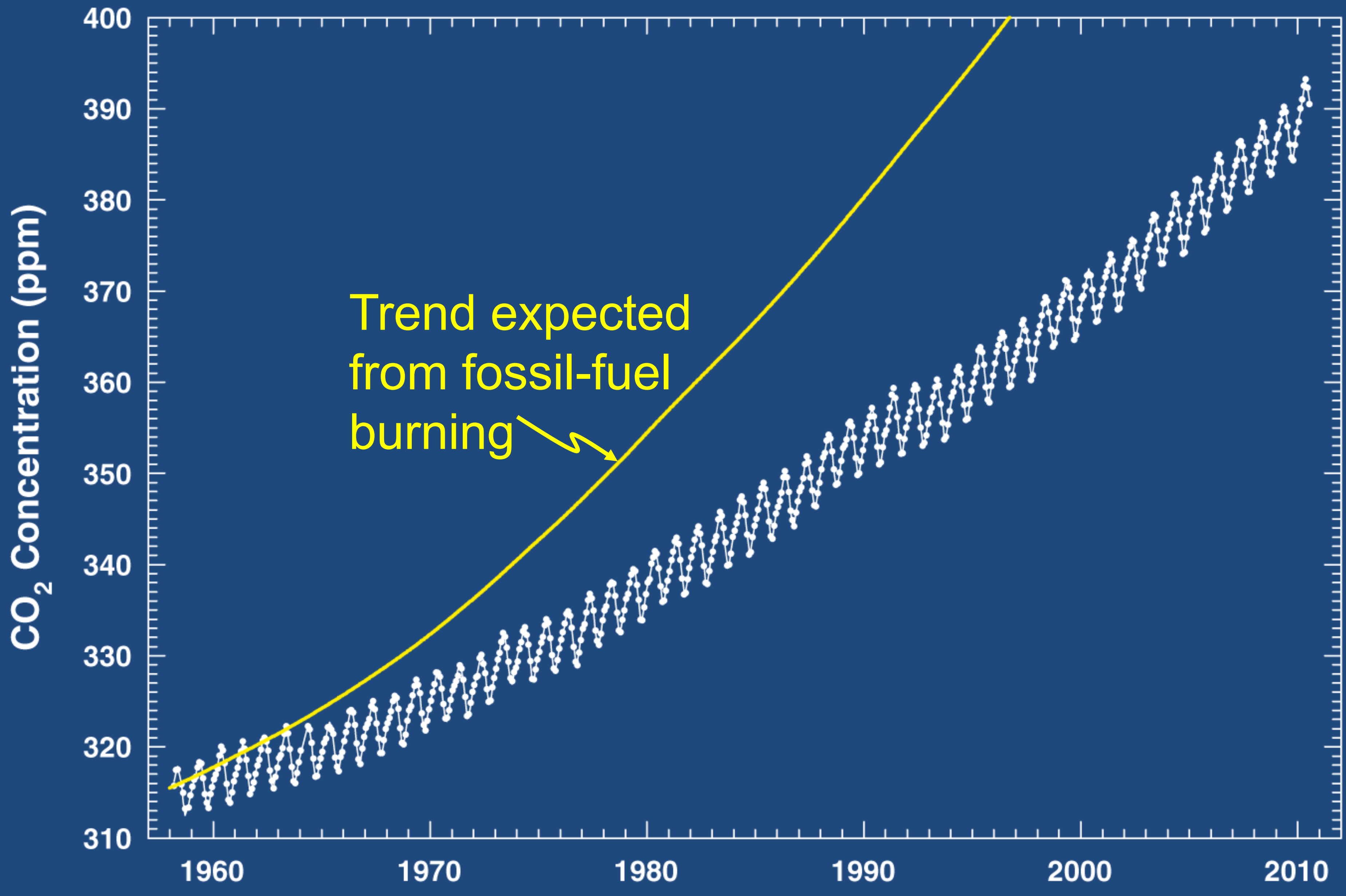
- Significant warming in the 20th century is mostly explained by atmospheric CO_2 (Manabe 1967, Hansen 1984)





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

Atmospheric CO_2 records



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

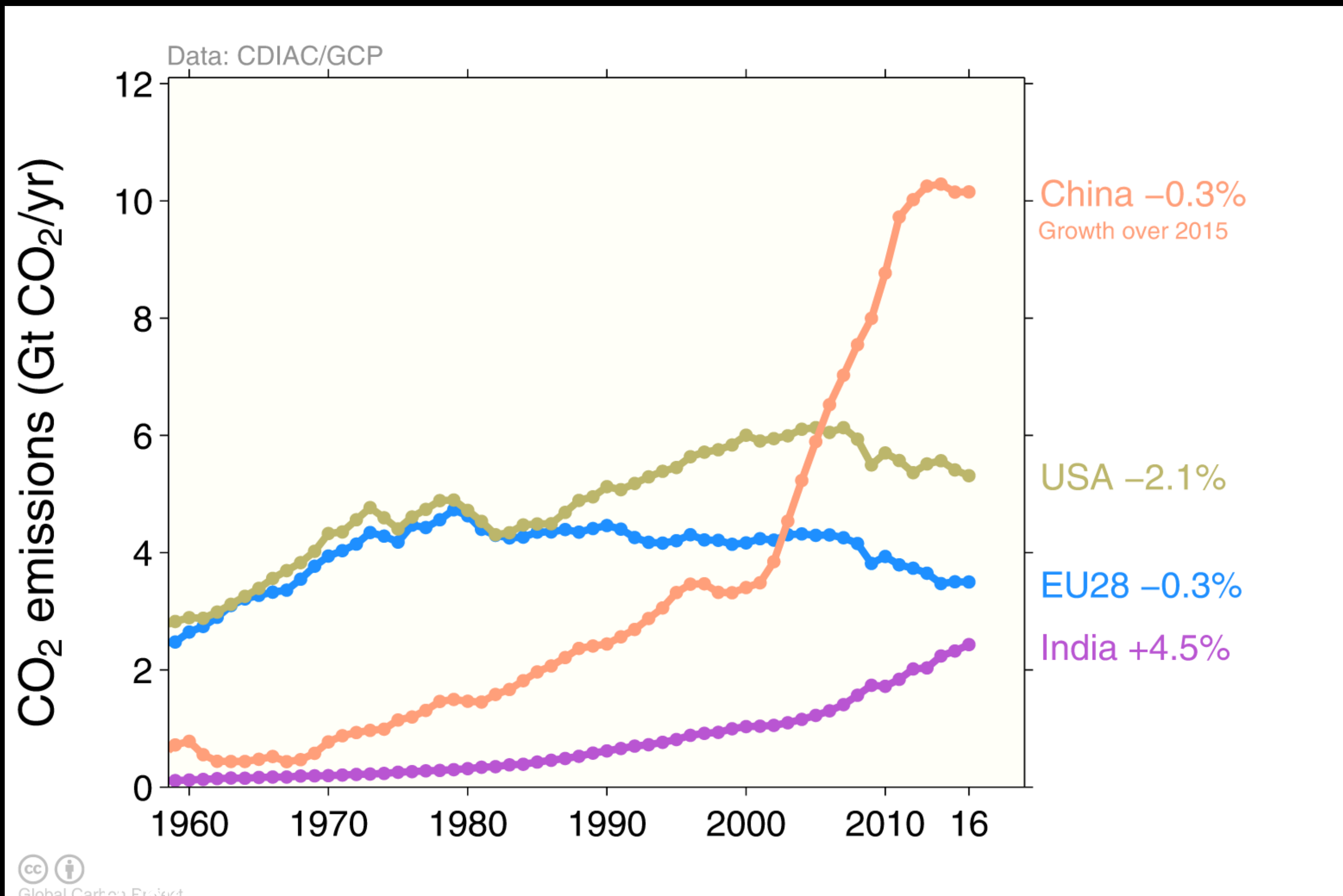
- US per capita fossil fuel emissions exceed most of the world (DOE, GCP). China total emissions now exceeds the US (IEA).

- 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 emitters: fossil fuels and industry (absolute)

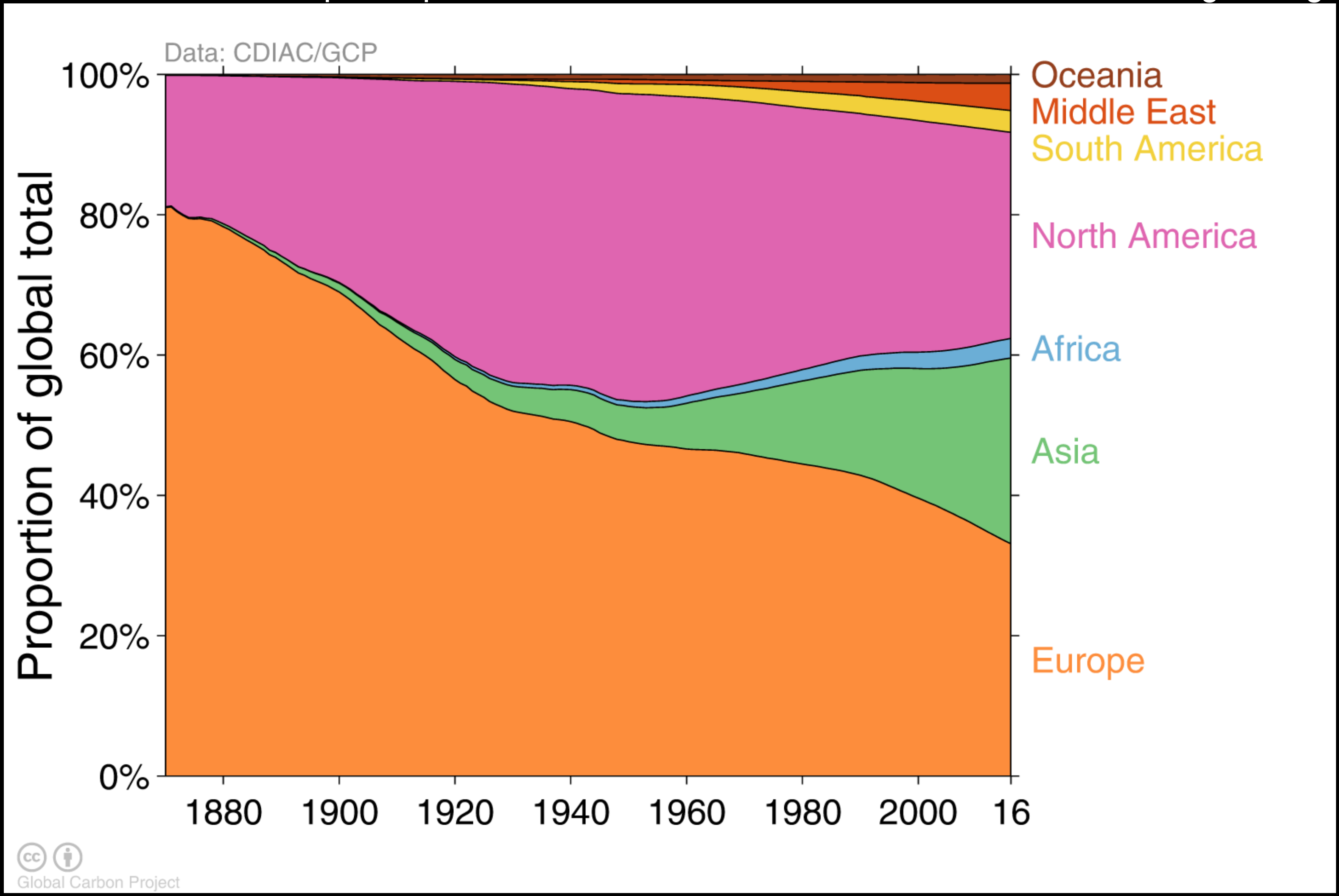
The top four emitters in 2016 covered 59% of global emissions
China (28%), United States (15%), EU28 (10%), India (7%)



Bunker fuels are used for international transport is [illegible]% of global emissions.
Statistical differences between the global estimates and sum of national totals are 0.6% of global emissions.
Source: [CDIAC]; [Le Quéré et al 2017]; [Global Carbon Budget 2017]

Historical cumulative emissions by continent

Cumulative emissions from fossil-fuel and industry (1870–2016)
North America and Europe responsible for most cumulative emissions, but Asia growing fast

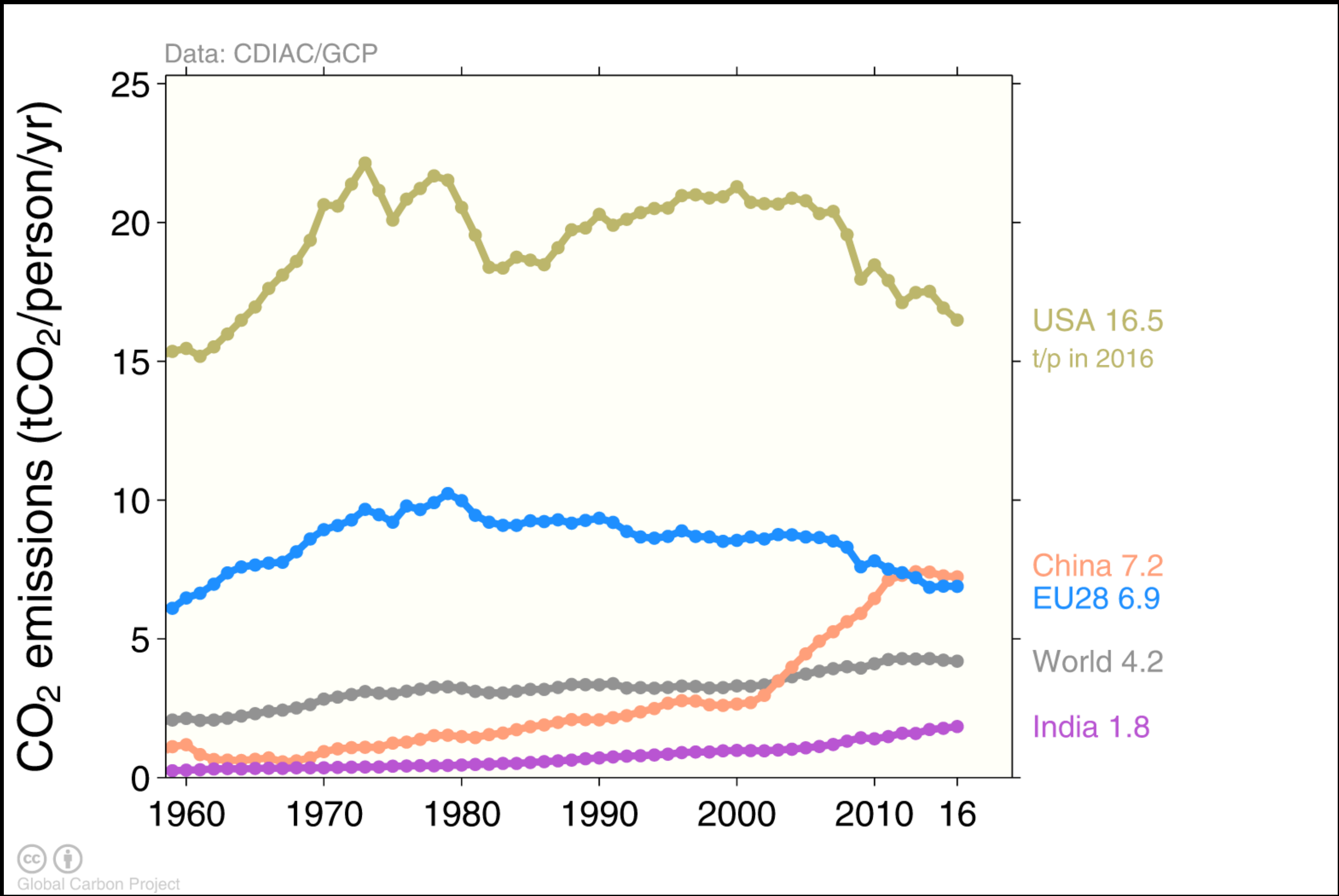


The figure excludes bunker fuels and statistical differences

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017

Top emitters: fossil fuels and industry (per capita)

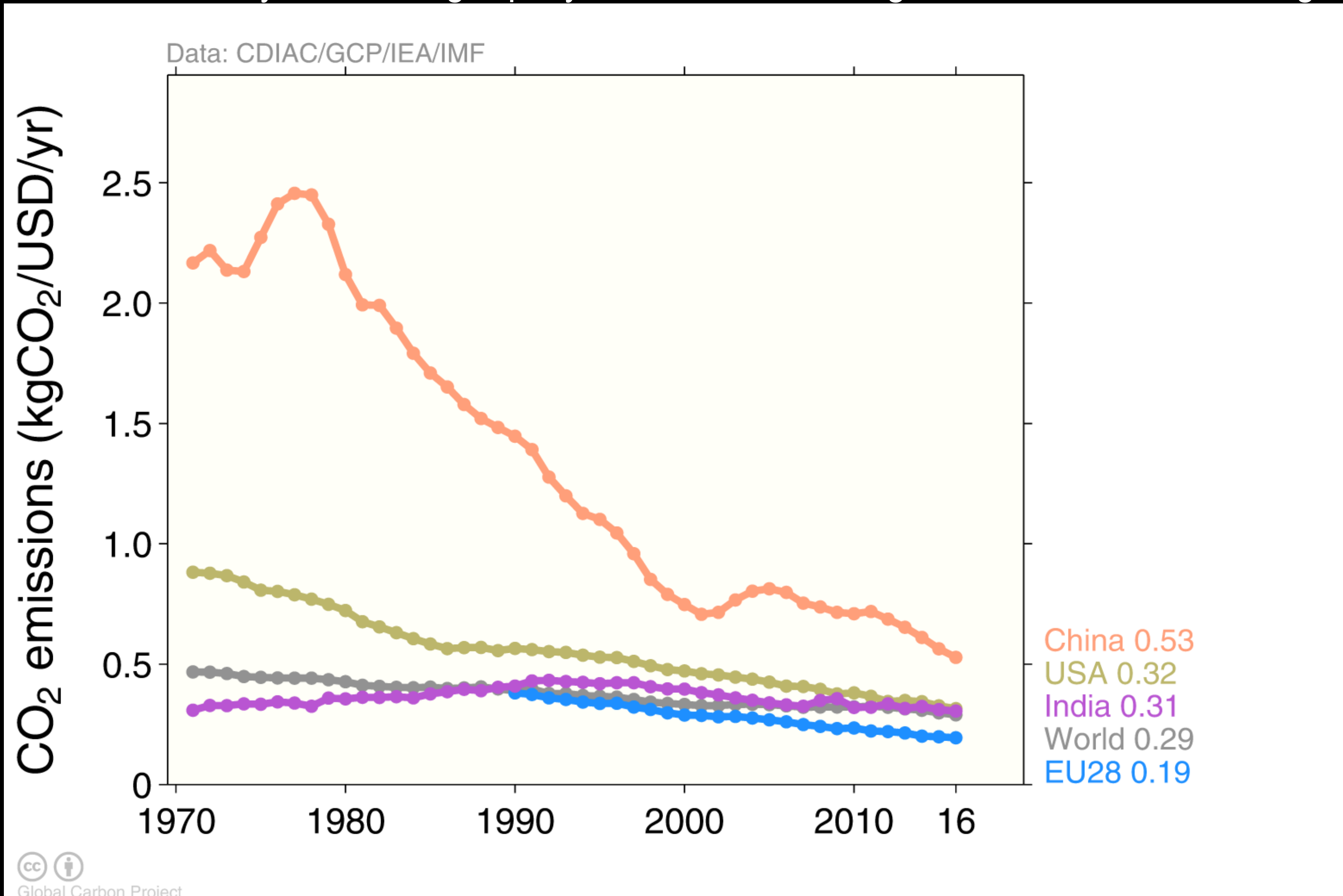
Countries have a broad range of per capita emissions reflecting their national circumstances



Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017

Top emitters: fossil fuels and industry (per dollar)

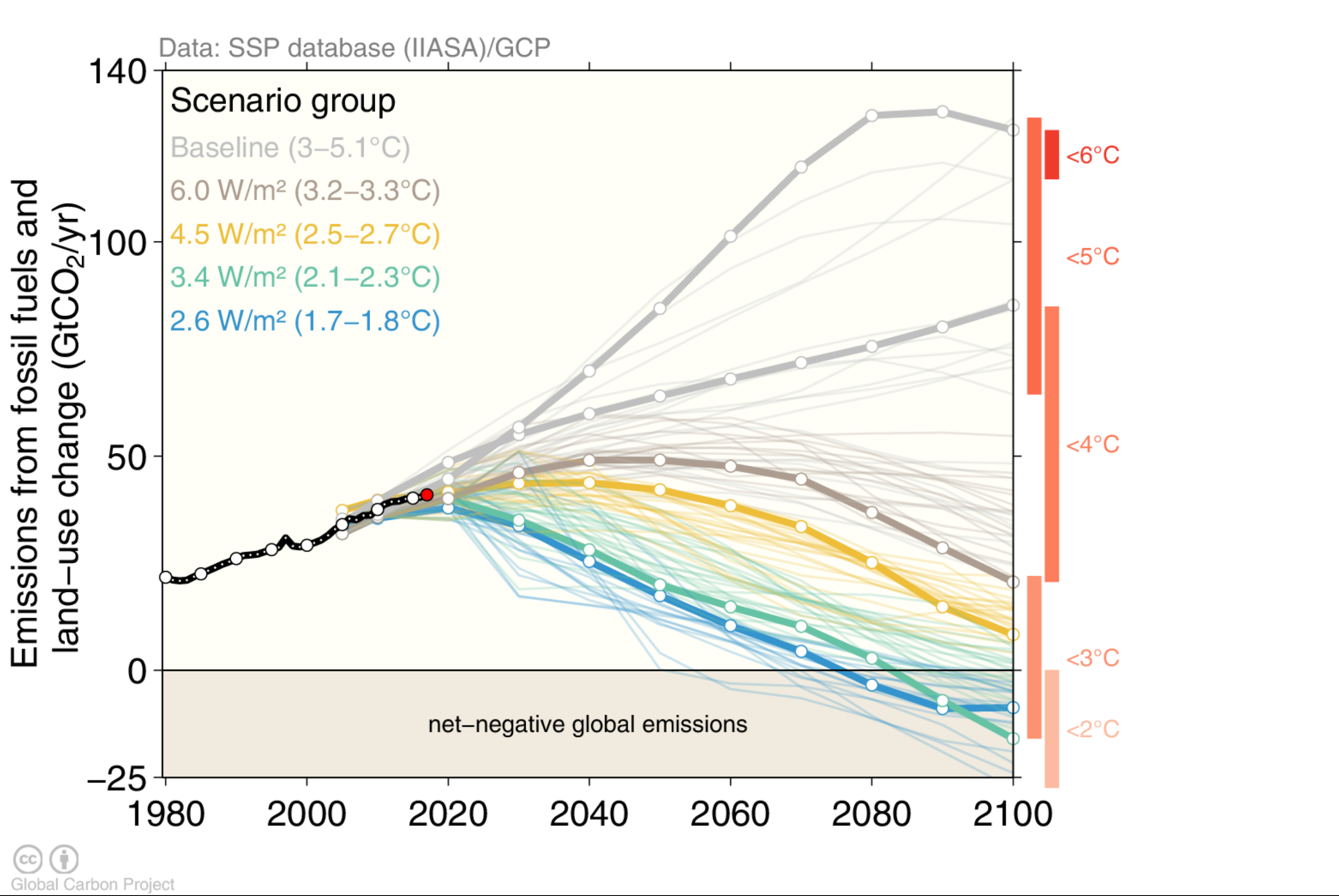
Emissions per unit economic output (emissions intensities) generally decline over time
China's intensity is declining rapidly, but is still much higher than the world average



Source: CDIAC; IEA 2016 GDP to 2014, IMF 2017 growth rates to 2016; Le Quéré et al 2017; Global Carbon Budget 2017

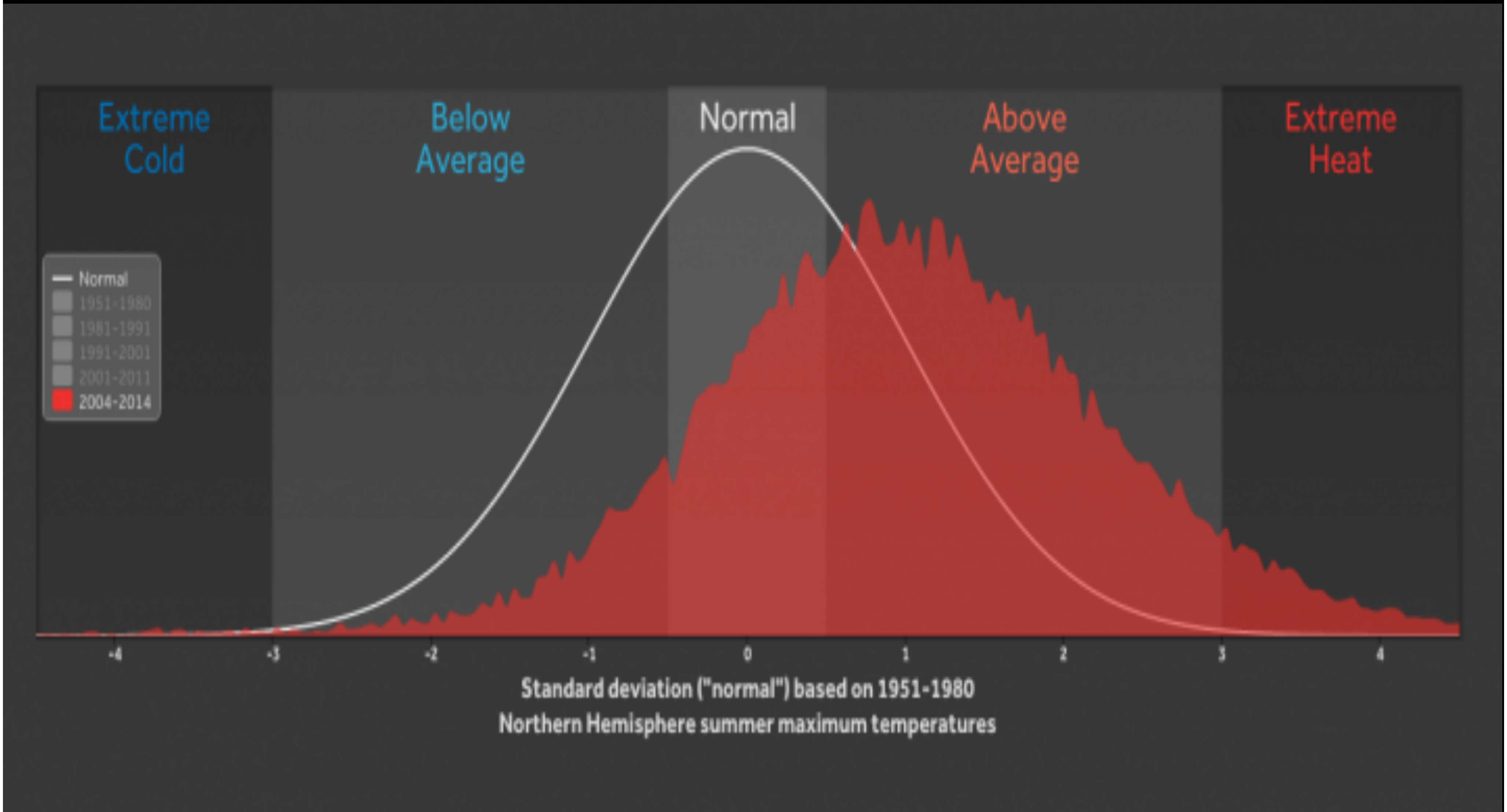
New generation of emissions scenarios

In the lead up to the IPCC's Sixth Assessment Report new scenarios have been developed to more systematically explore key uncertainties in future socioeconomic developments



Five Shared Socioeconomic Pathways (SSPs) have been developed to explore challenges to adaptation and mitigation. Shared Policy Assumptions (SPAs) are used to achieve target forcing levels (W/m^2). Marker Scenarios are indicated.

Source: Riahi et al. 2016; IIASA SSP Database; Global Carbon Budget 2017

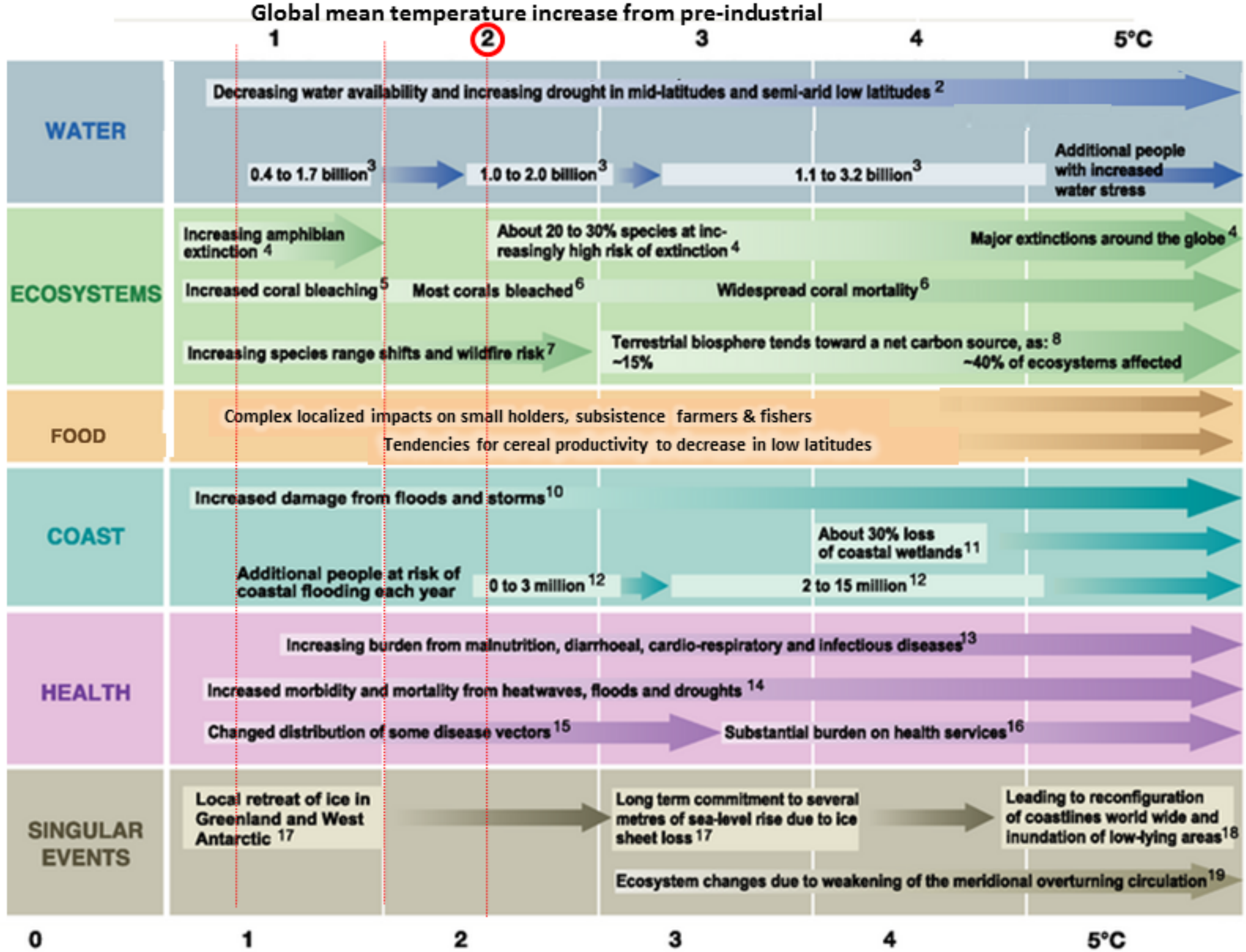

Extreme Cold
Below Average
Normal
Above Average
Extreme Heat
Normal
1951-1980
1981-1991
1991-2001
2001-2011
2004-2014
-4
-3
-2
-1
0
1
2
3
4
Standard deviation ("normal") based on 1951-1980
Northern Hemisphere summer maximum temperatures

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.



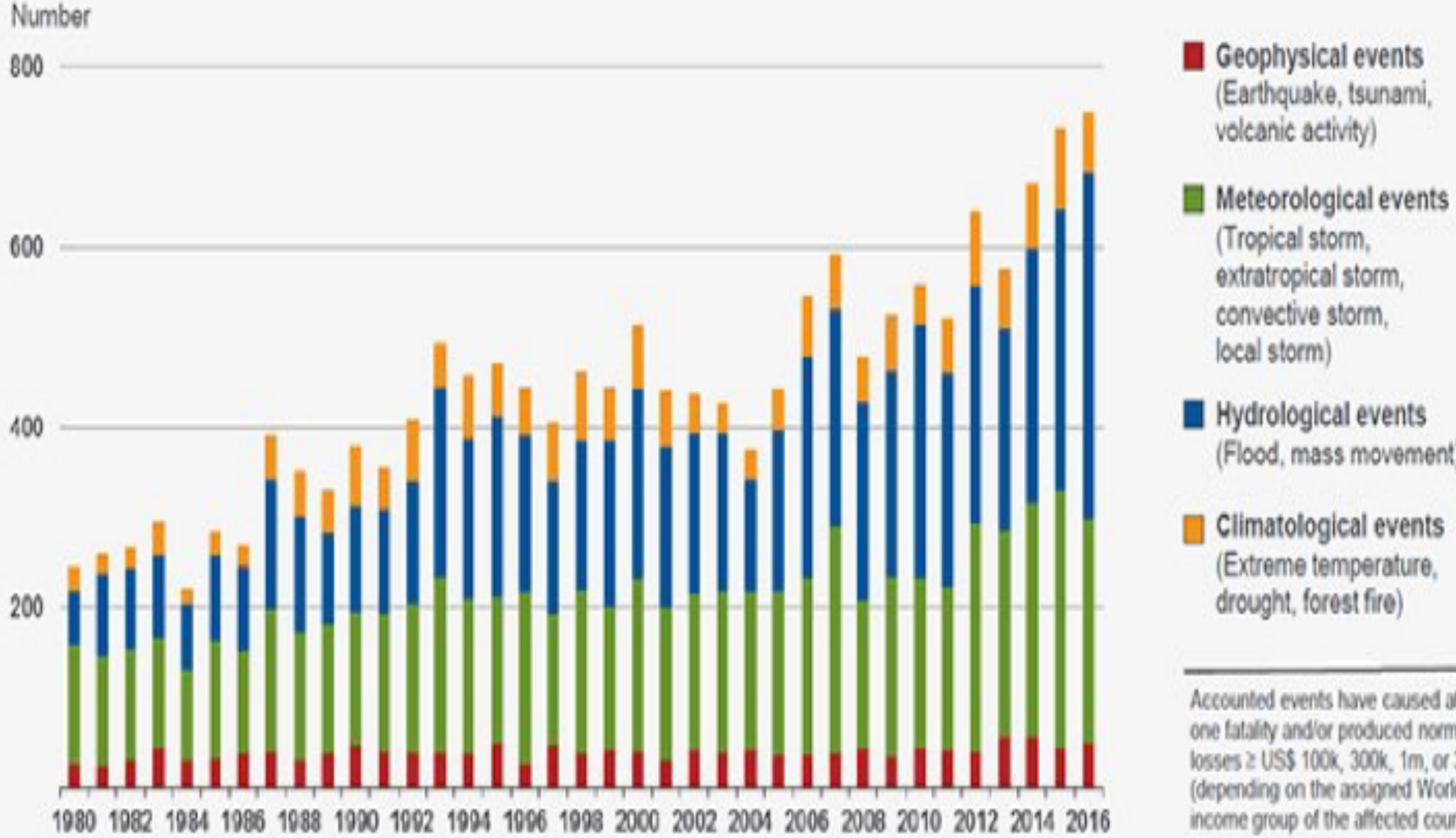
Peter Carter

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'

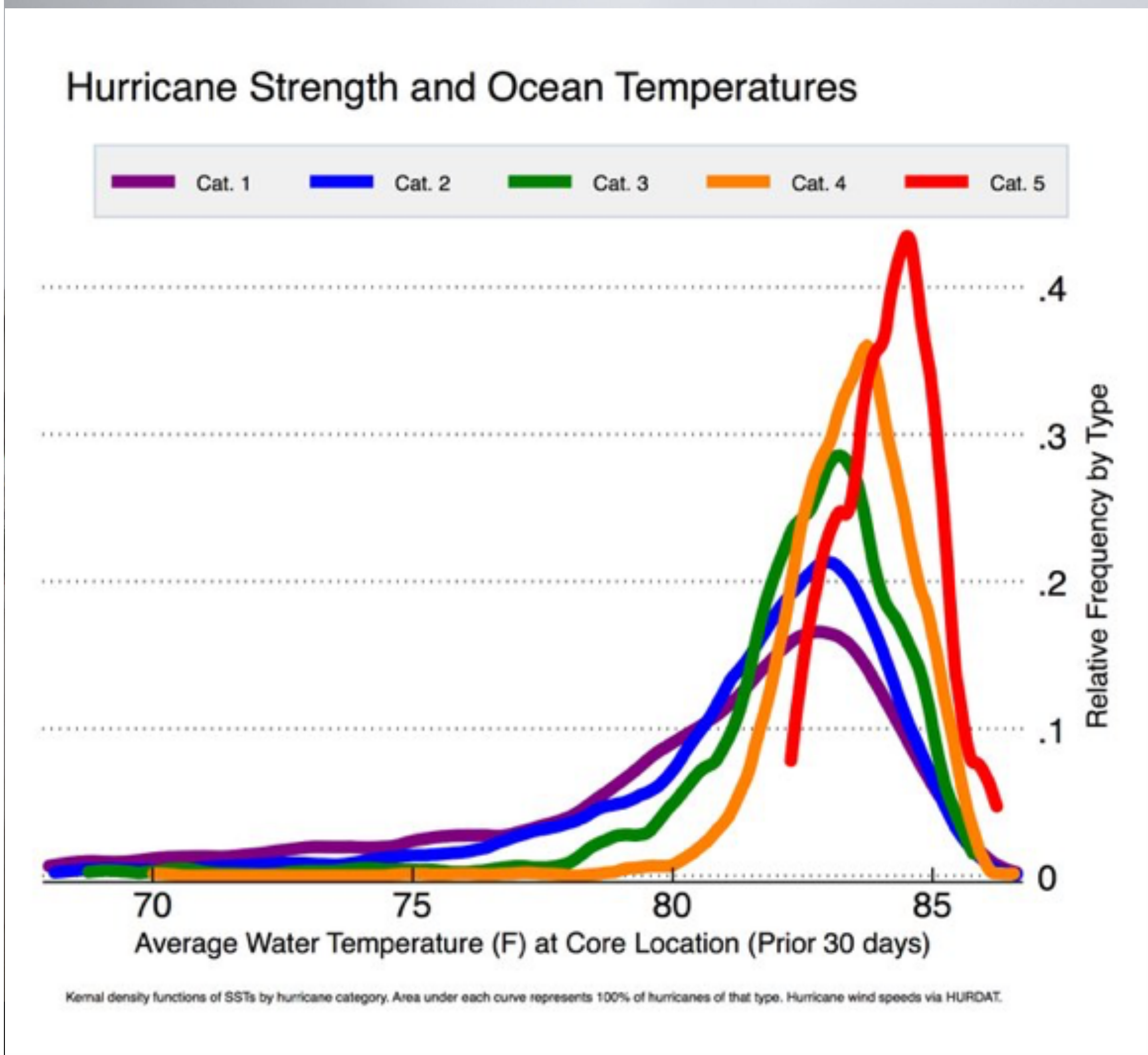
Number Of Natural Catastrophes

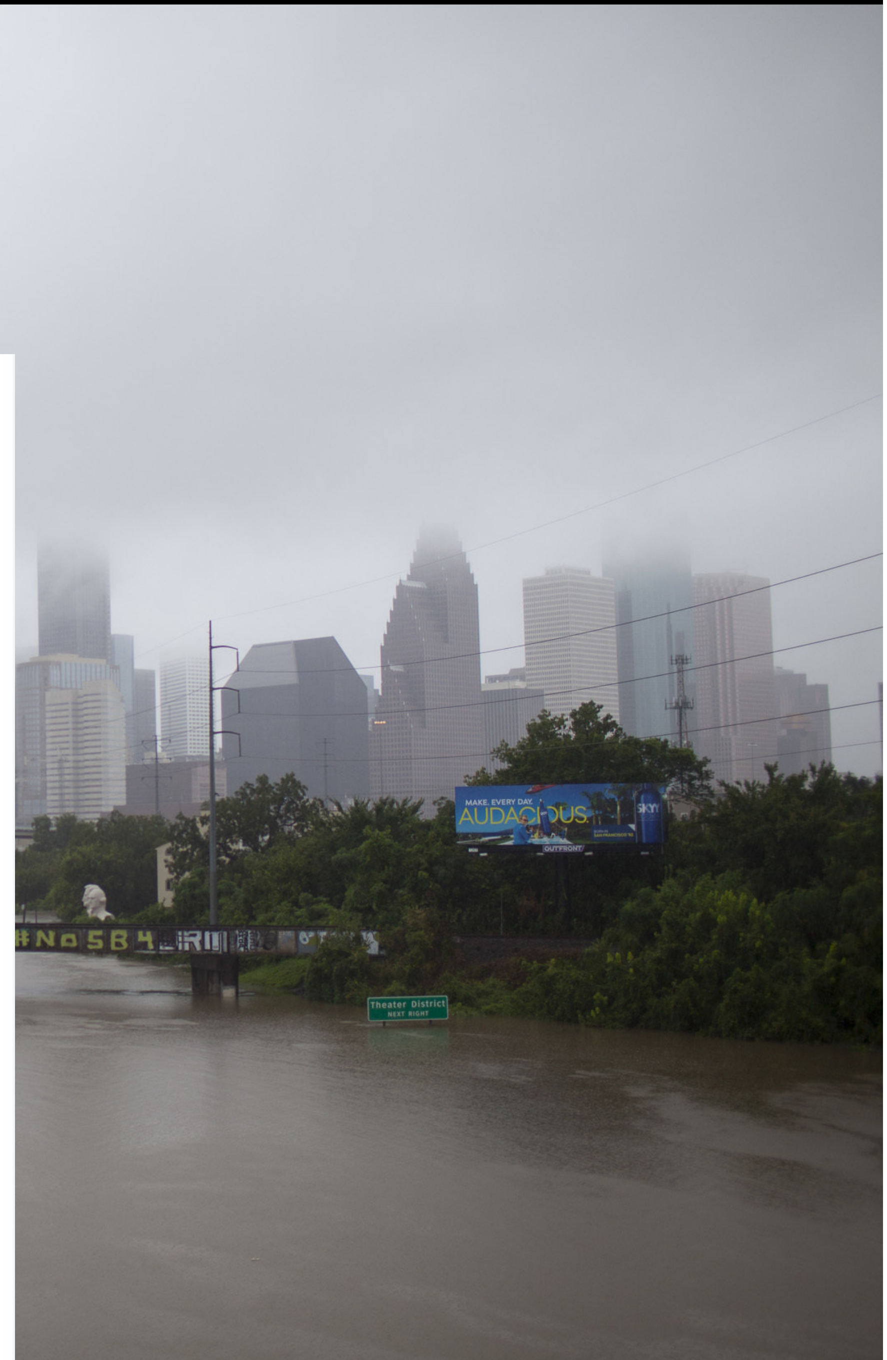
Global - 1980-2016

Source: Munich Re, Geo Risks Research

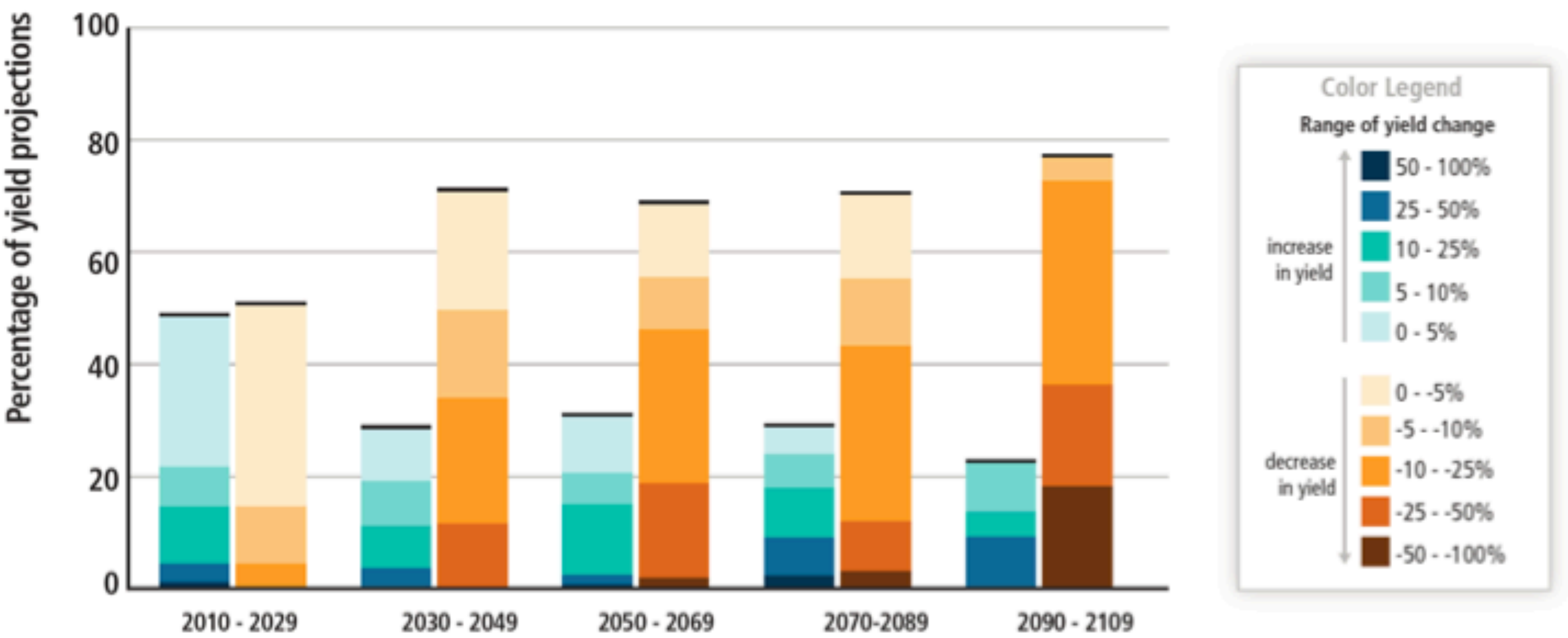


Accounted events have caused at least one fatality and/or produced normalized losses ≥ US$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country).


Hurricane Strength and Ocean Temperatures
Cat. 1
Cat. 2
Cat. 3
Cat. 4
Cat. 5
.4
.3
.2
.1
0
Relative Frequency by Type
70
75
80
85
Average Water Temperature (F) at Core Location (Prior 30 days)
Kernal density functions of SSTs by hurricane category. Area under each curve represents 100% of hurricanes of that type. Hurricane wind speeds via HURDAT.


MAKE. EVERY DAY.
Theater District

Crop Yields Decline under Higher Temperatures

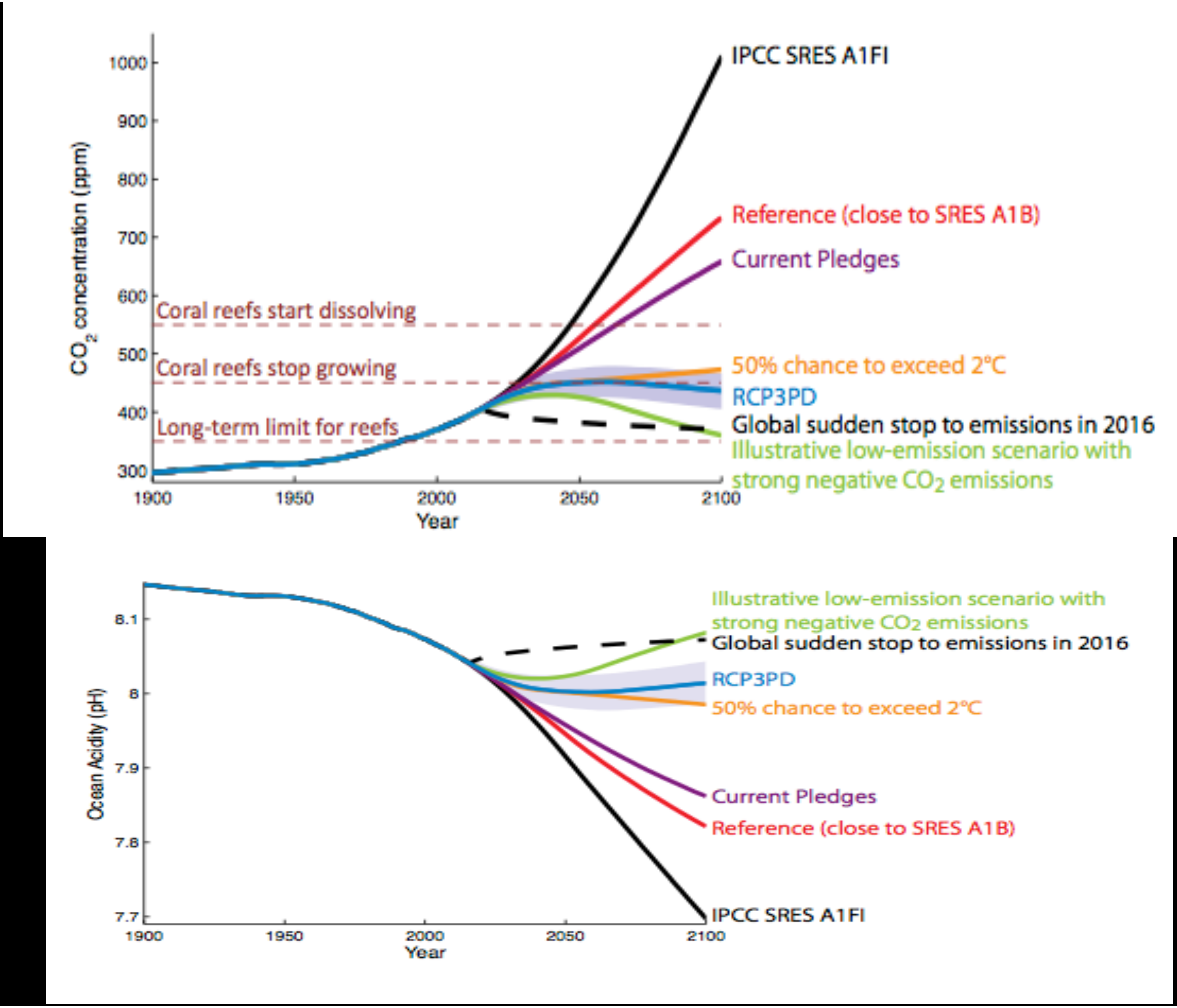


What Are The Options?

- 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

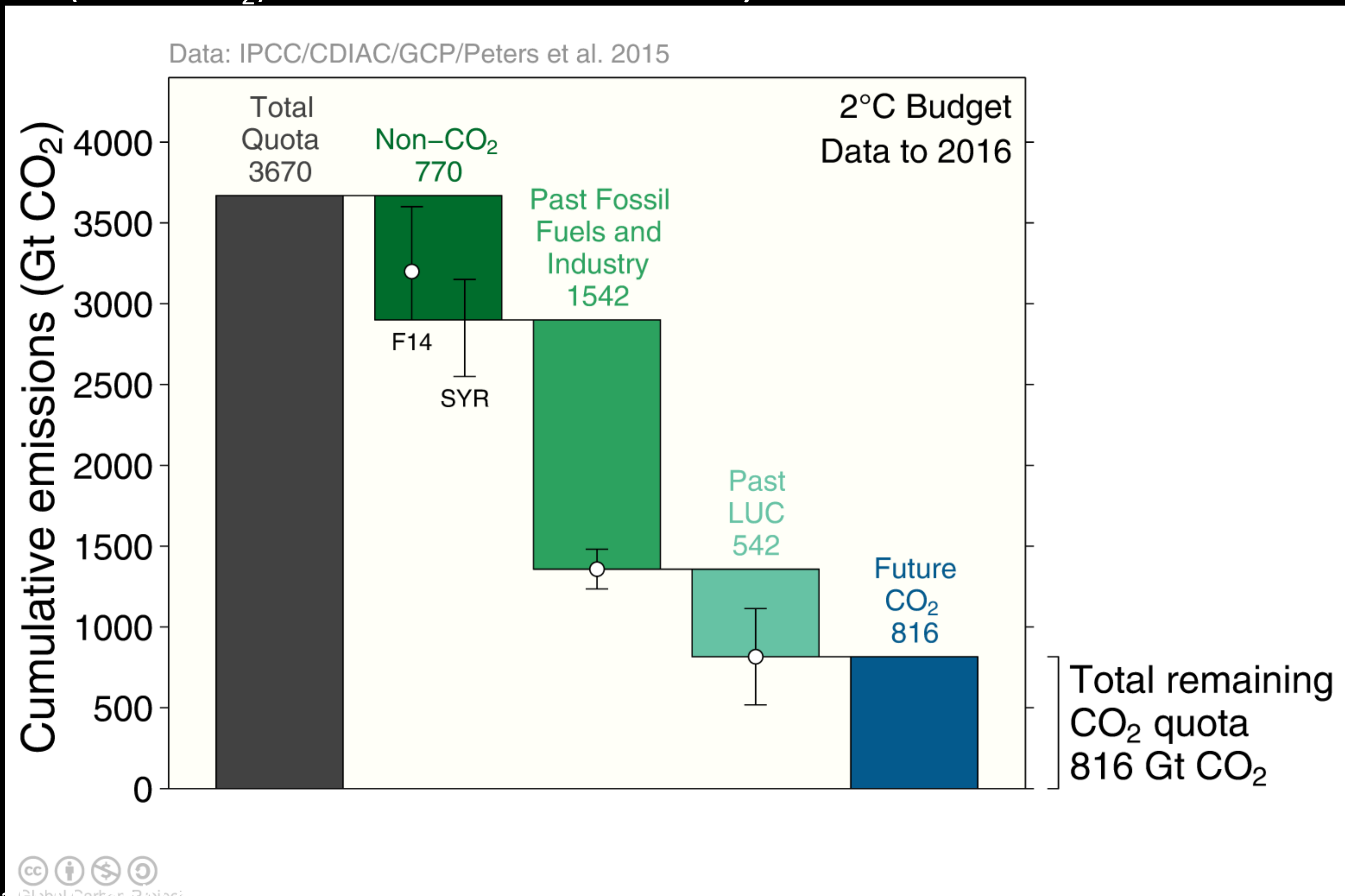

IPCC SRES A1FI
Reference (close to SRES A1B)
Current Pledges
Coral reefs start dissolving
Coral reefs stop growing
Long-term limit for reefs
50% chance to exceed 2°C
RCP3PD
Global sudden stop to emissions in 2016
Illustrative low-emission scenario with strong negative CO_2 emissions
CO_2 concentration (ppm)
Year
Ocean Acidity (pH)
Year

What Are The Options?

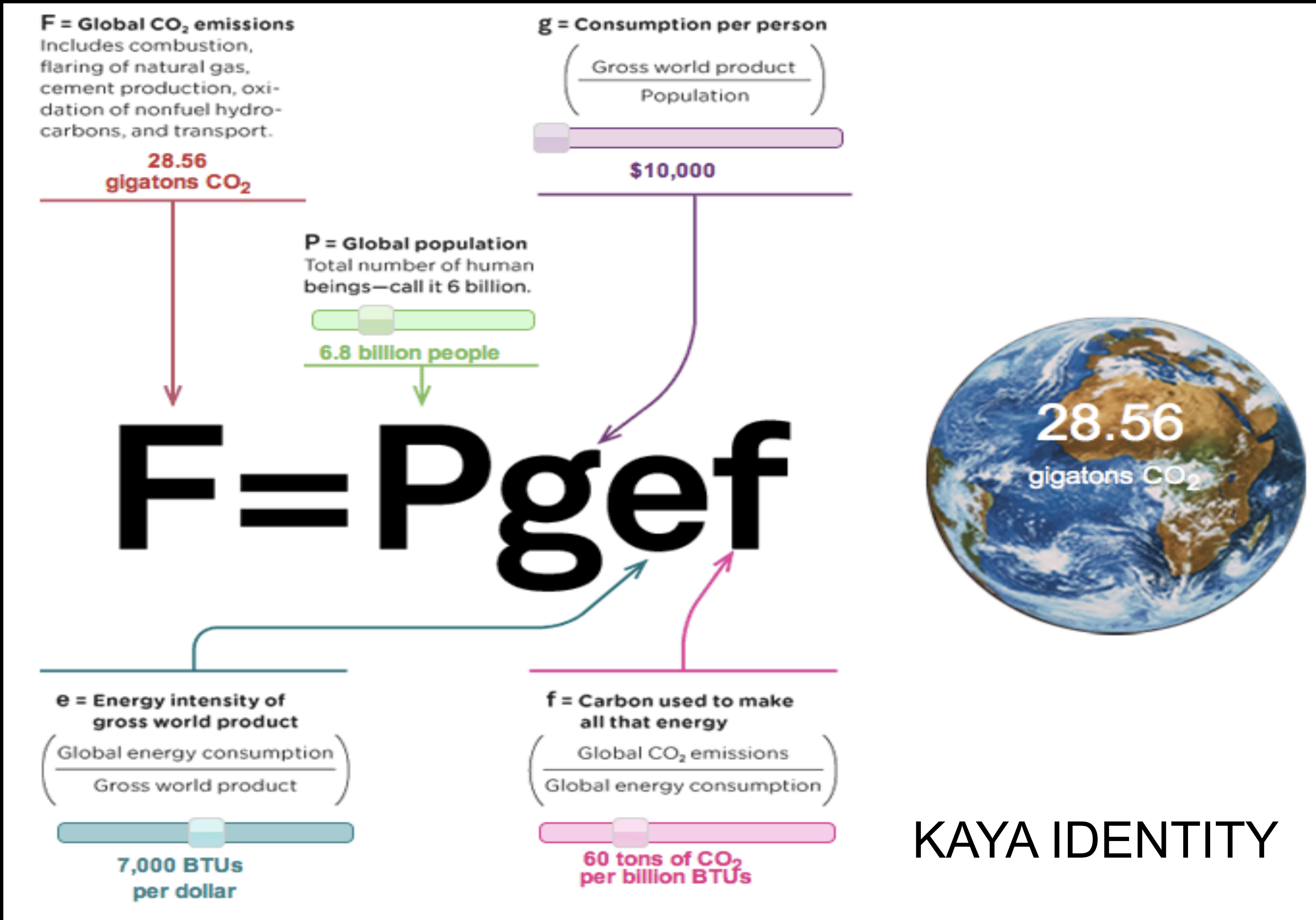
- Adaptation
  - Economic/political (relocation, tech transfer, payments for damages, reduce poverty, educate)
  - Technological (resilient tech, seawalls, genetic hybrids, cure malaria, colonize new planet)
- Mitigation
  - Economic (taxes, cap and trade, R&D)
  - Regulatory (treaties, bans, compacts, 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

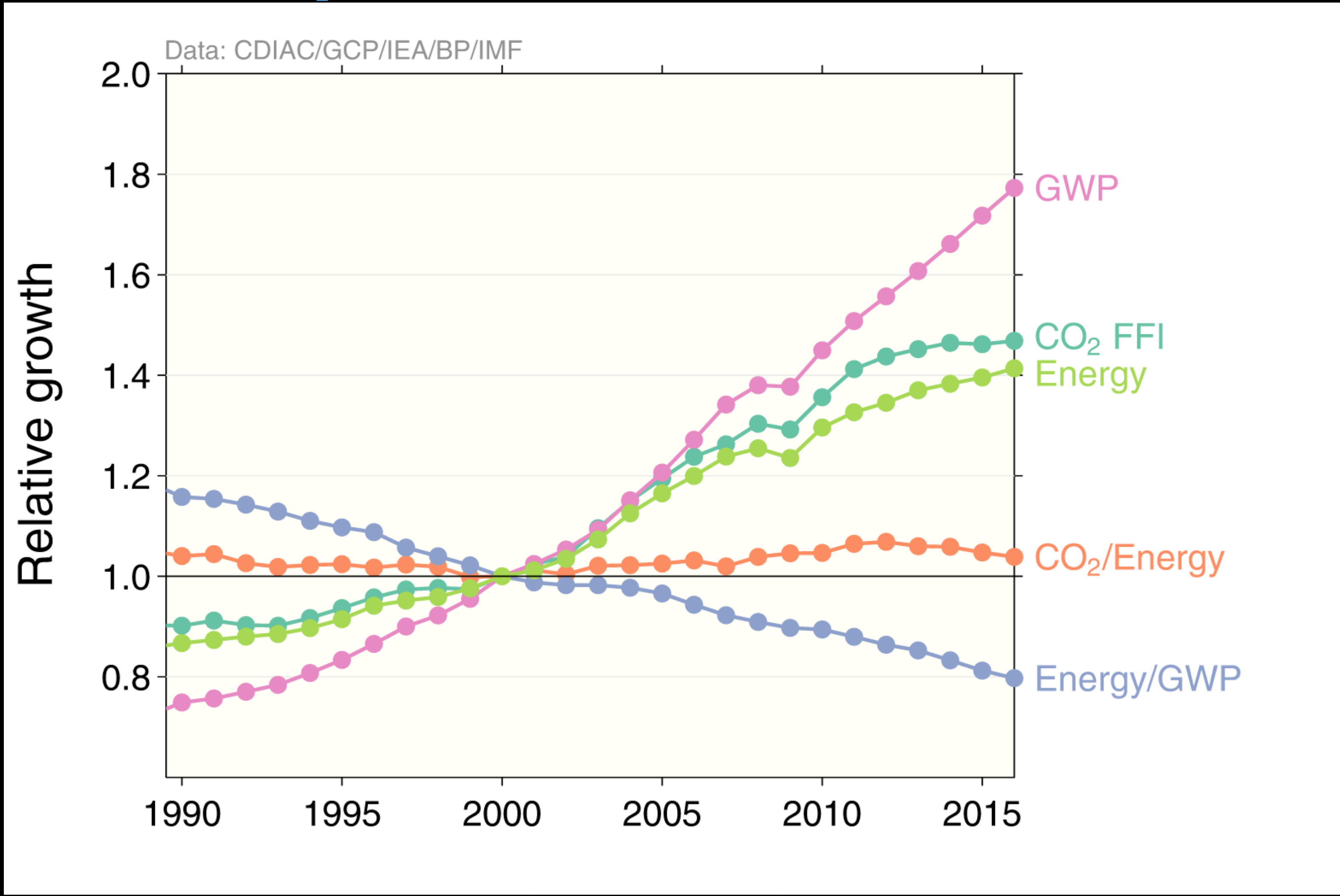


KAYA IDENTITY

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

Kaya decomposition

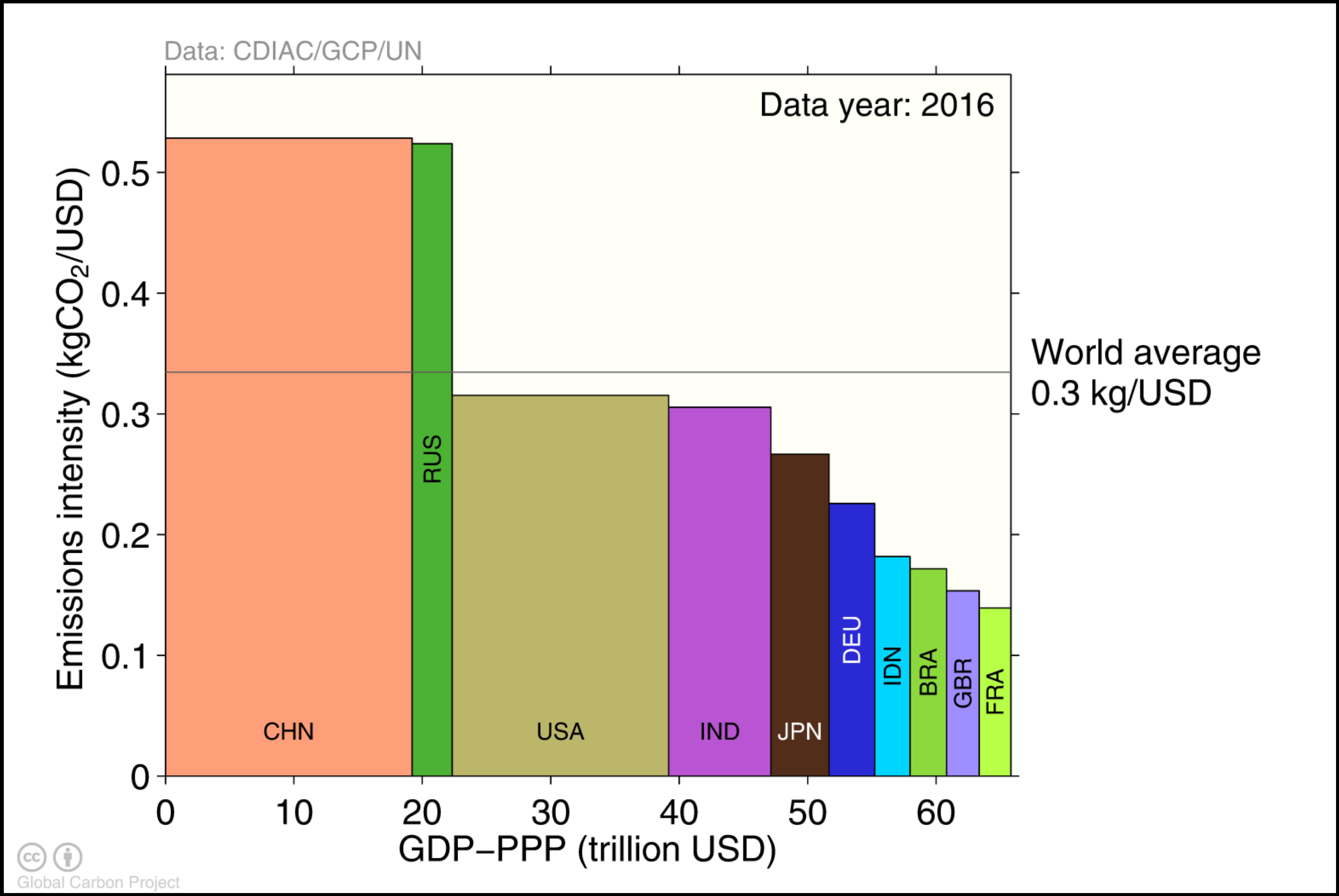
The Kaya decomposition demonstrates the recent relative decoupling of economic growth from CO_2 emissions, driven by improved energy intensity



GWP: Gross World Product (economic activity), FFI: Fossil Fuel and Industry,
Energy is Primary Energy from BP statistics using the substitution accounting method
Source: Jackson et al 2017; Global Carbon Budget 2017

Emissions intensity per unit economic activity

The 10 largest economies have a wide range of emissions intensity of economic production

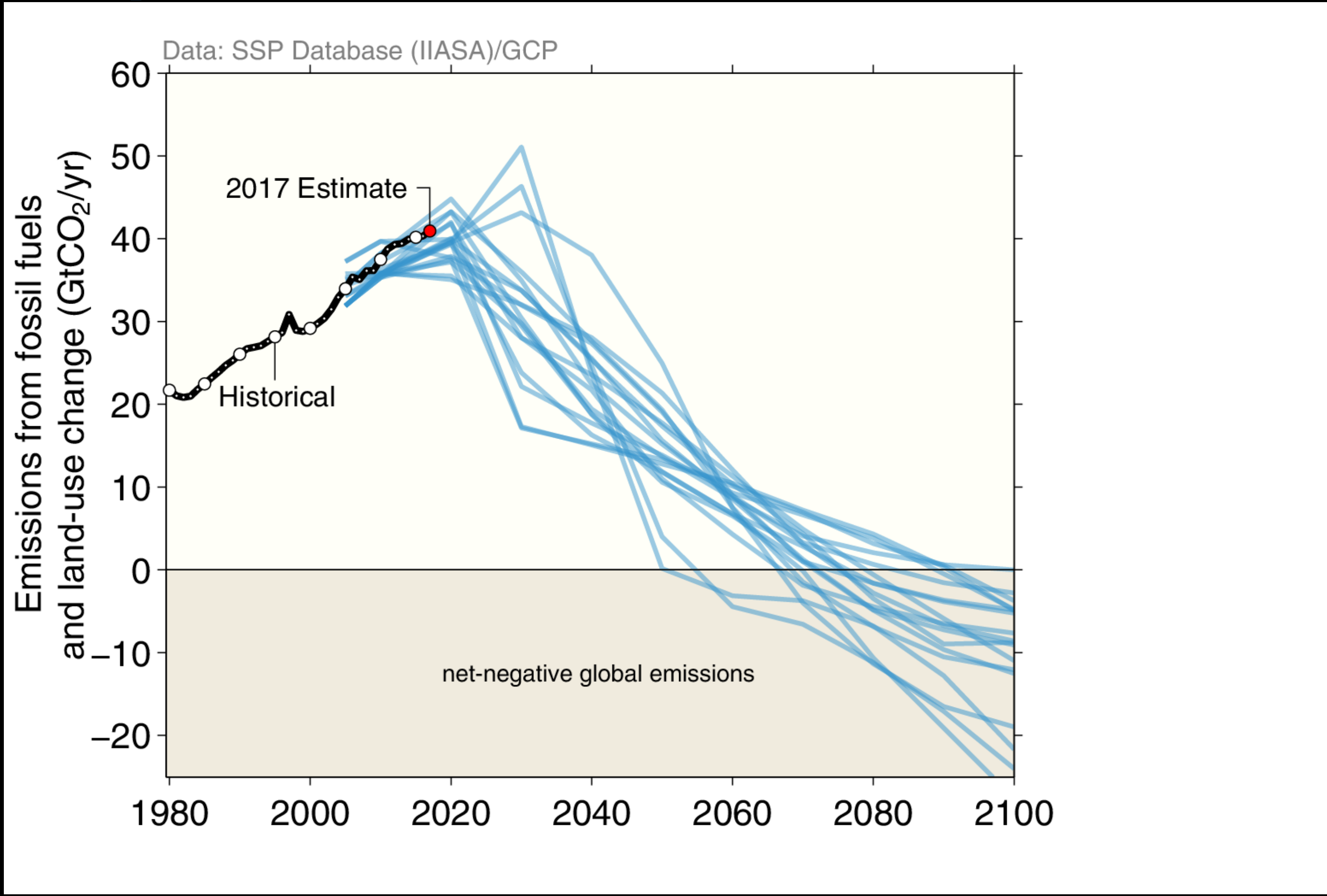


Emission intensity: CO_2 emissions from fossil fuel and industry divided by Gross Domestic Product

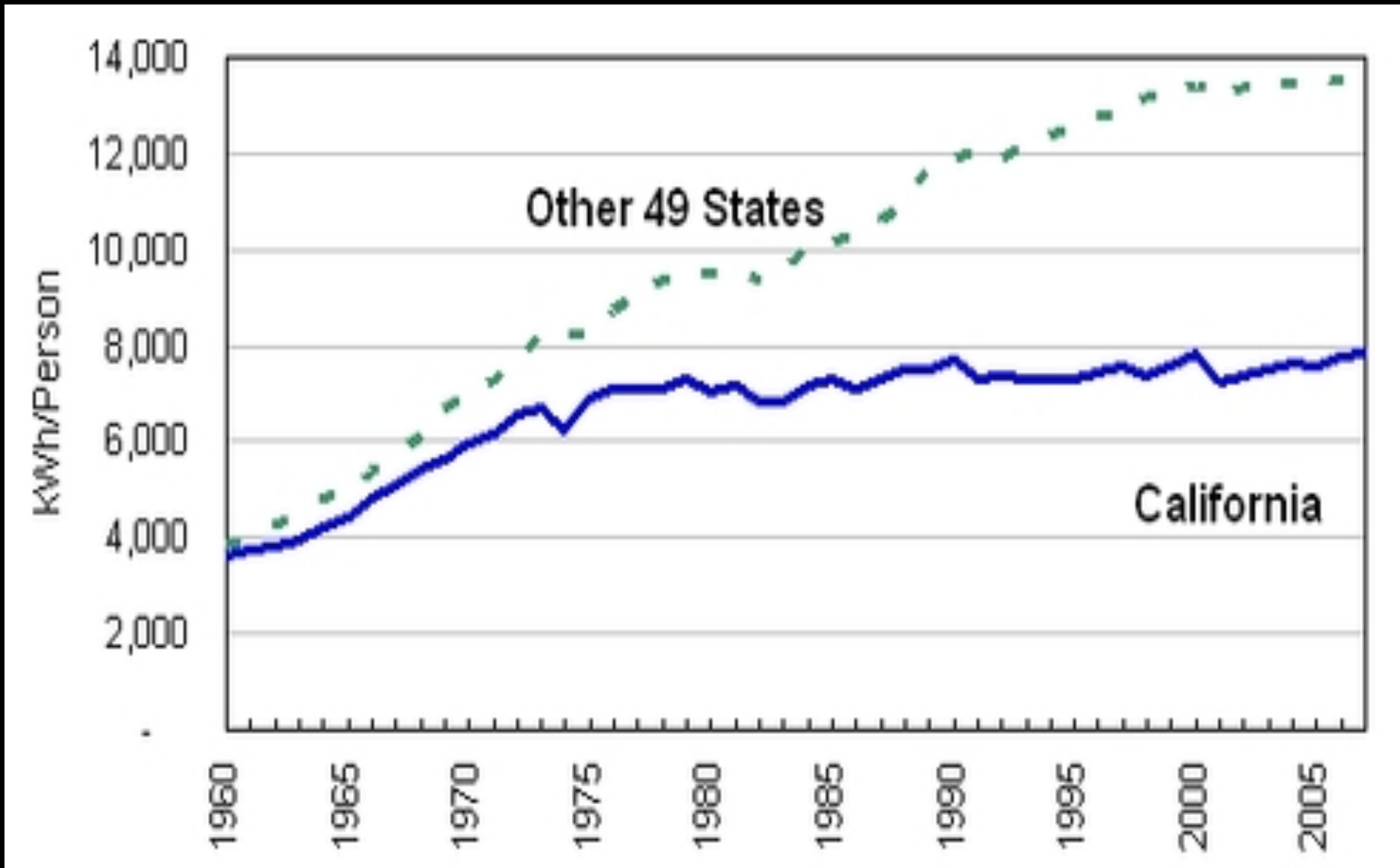
Source: Global Carbon Budget 2017

Pathways that avoid 2° C of warming

According to the Shared Socioeconomic Pathways (SSP) that avoid 2° C of warming, global CO_2 emissions need to decline rapidly and cross zero emissions after 2050



Source: Riahi et al. 2016; IIASA SSP Database; Global Carbon Budget 2017

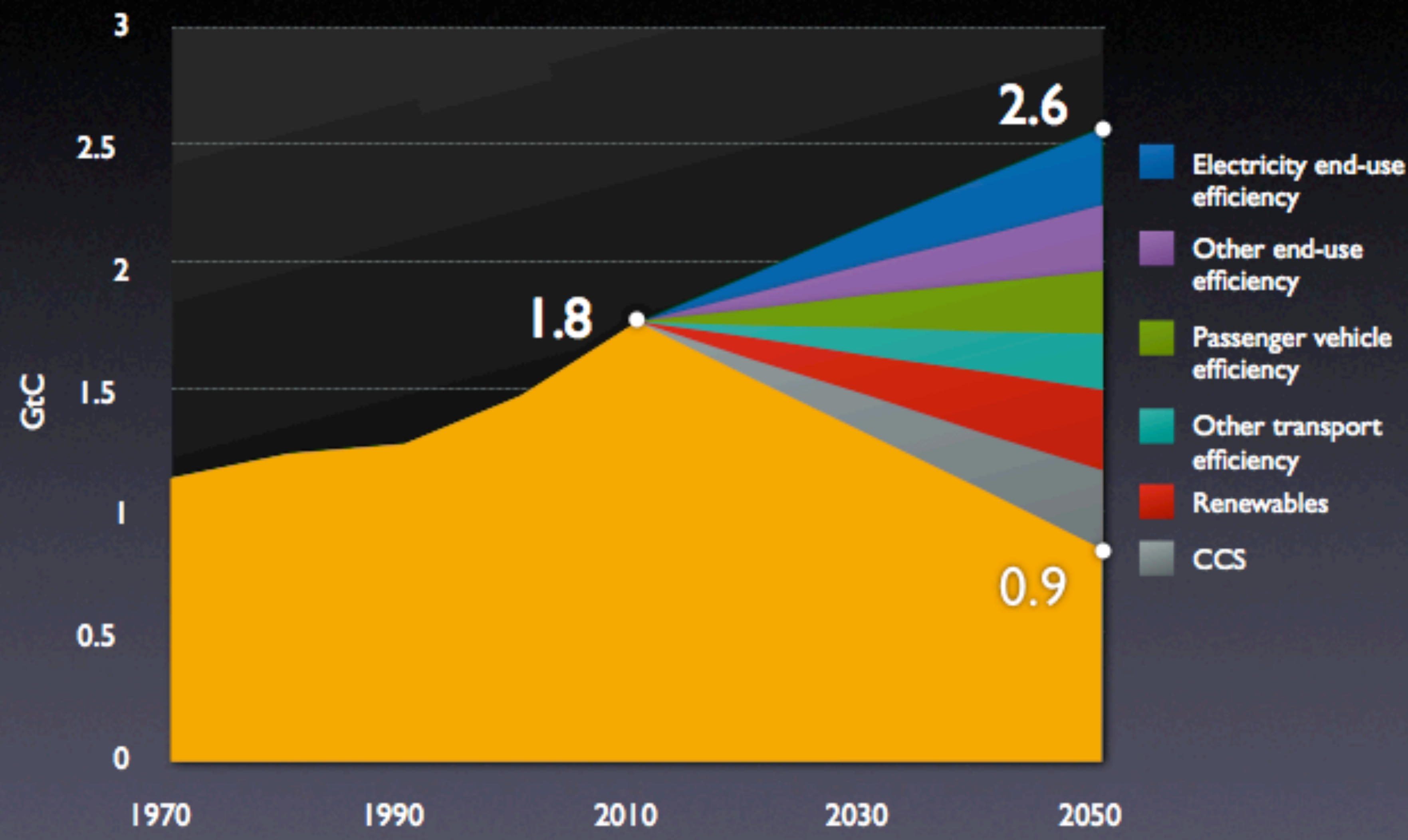


14,000
12,000
10,000
8,000
6,000
4,000
2,000
KWh/Person
Other 49 States
California
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

U.S. Emissions

After Pacala and Socolow, 2004;
ARI CarBen3 Spreadsheet

- Carbon Capture & Storage



CLEAN FOSSIL POWER

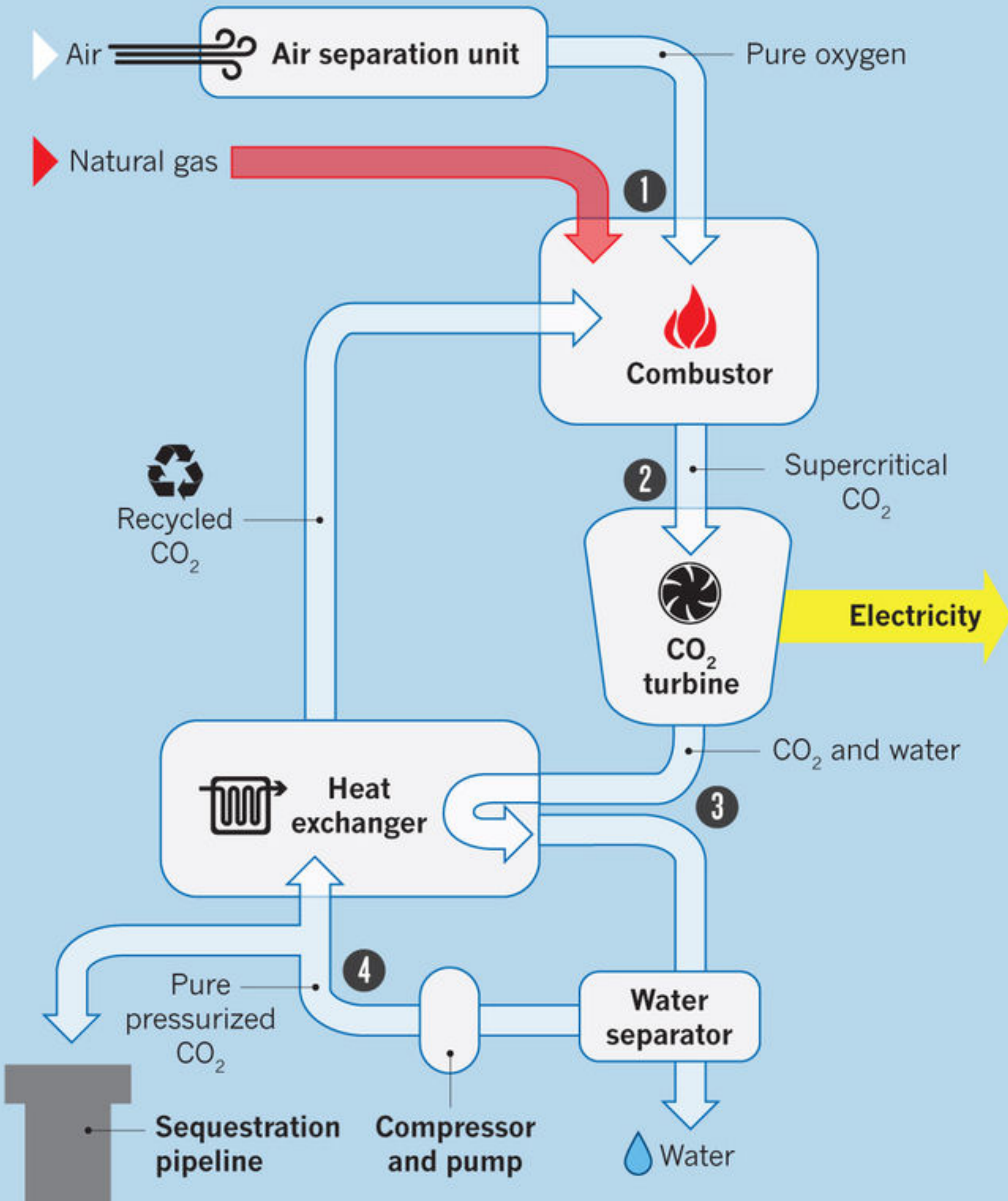
Electricity can be generated from fossil fuels without producing any atmospheric emissions.

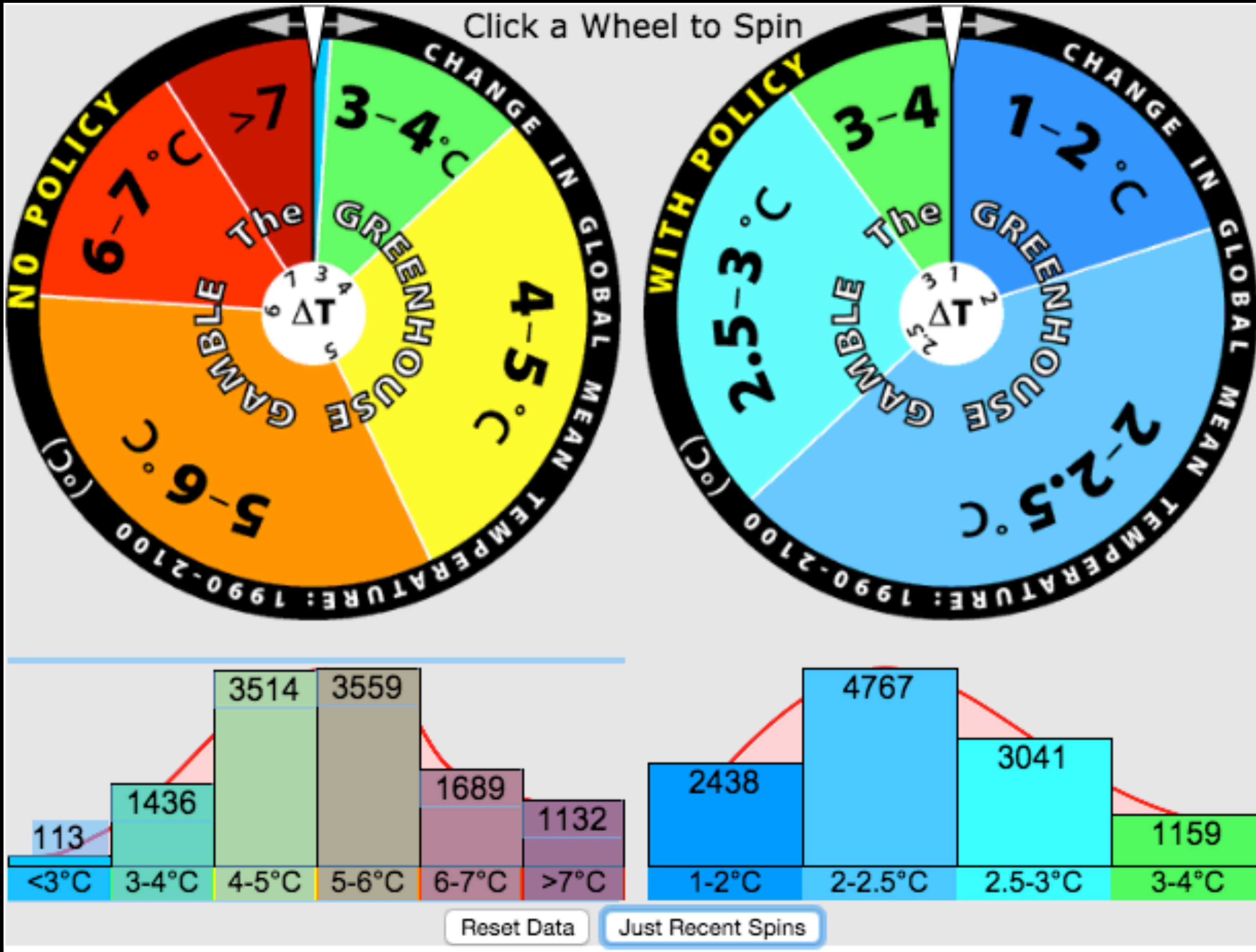
❶ NetPower's system burns natural gas in pure oxygen in the presence of carbon dioxide. The CO_2, which is 95% of the gas mix, is heated and pressurized to a supercritical state.

❷ In this state it can drive a fluid turbine to generate electricity.

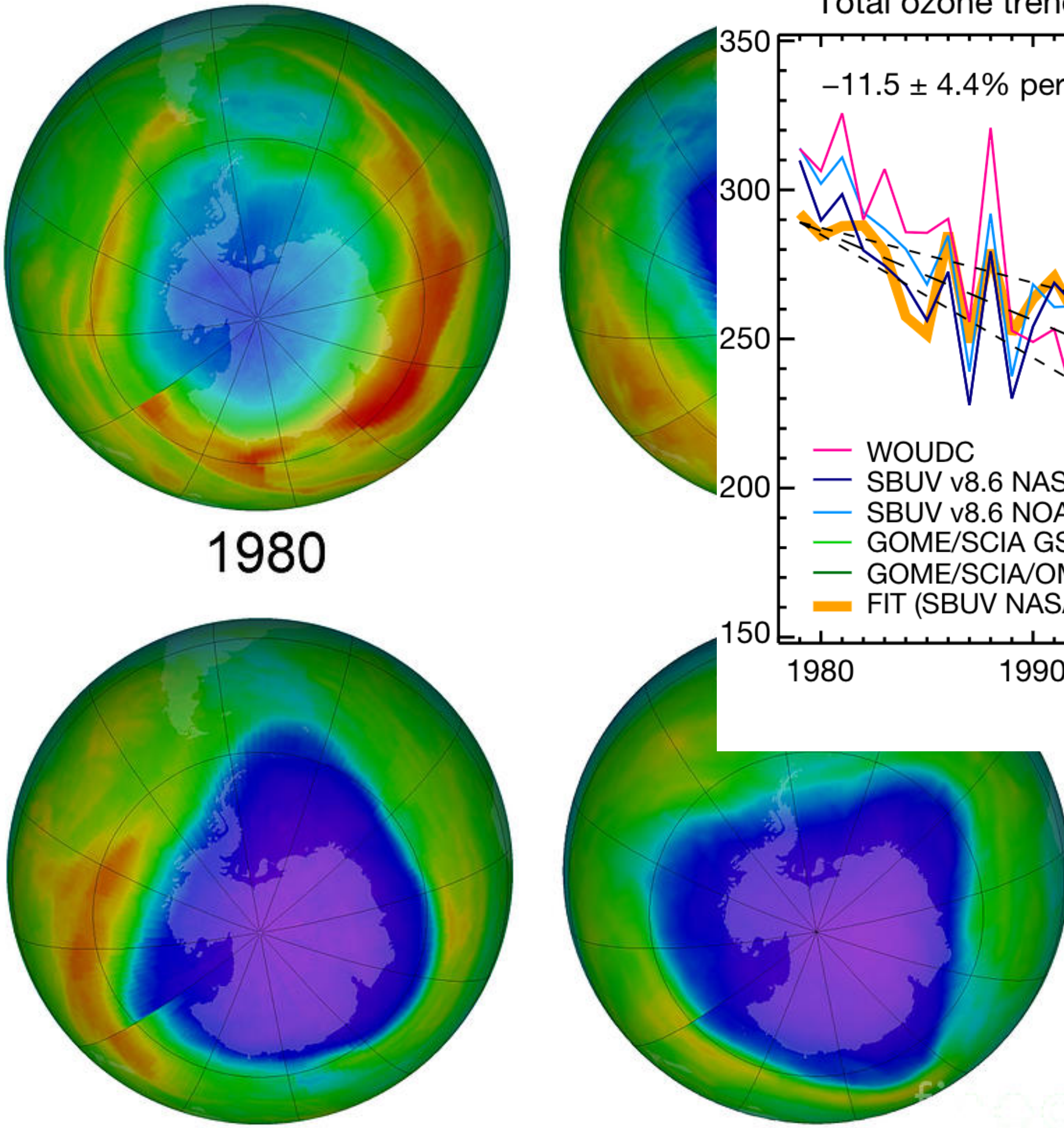
❸ Water present in the turbine's exhaust begins to condense in a heat exchanger before being fully separated out and removed from the system.

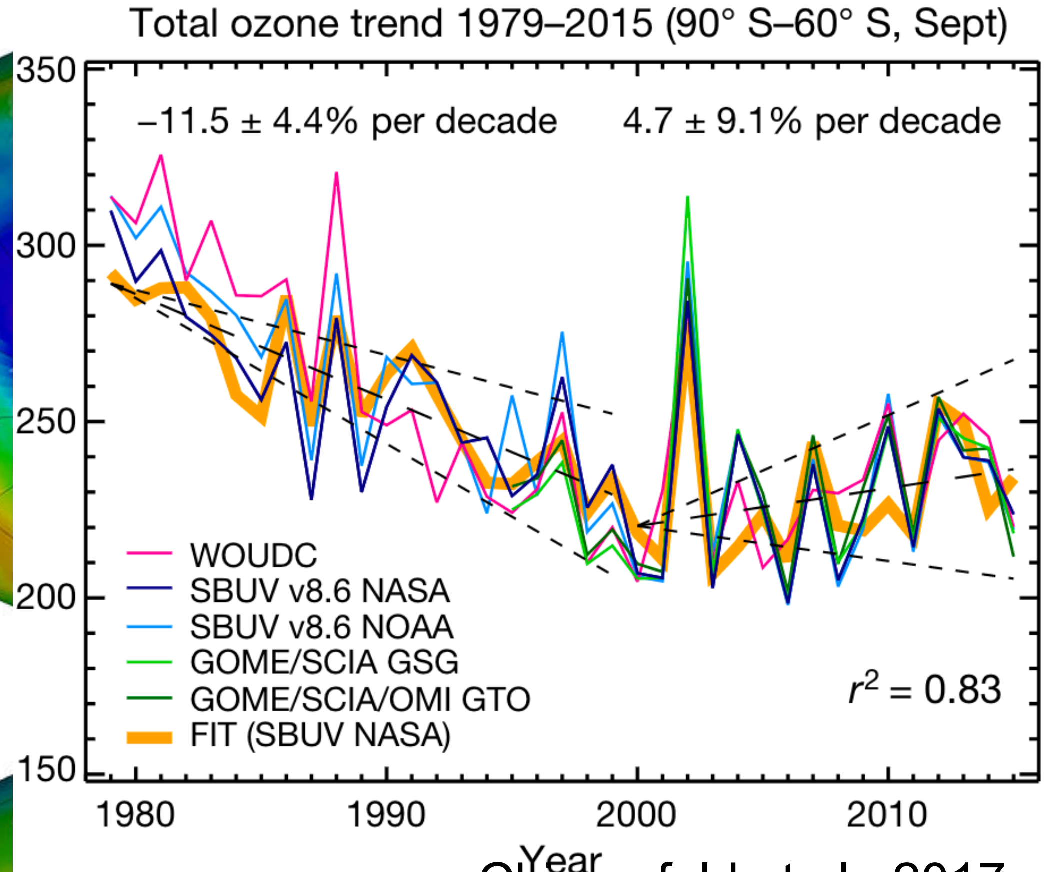
❹ The remaining stream of more than 90% CO_2 is repressurized, reheated via the heat exchanger and returned to the combustor. Excess CO_2 generated by the system is directed to a pipeline after repressurization, ready for sequestration.





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





Chipperfeld et al., 2017

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

CLIMATE

Syria Joins Paris Climate Accord, Leaving Only U.S. Opposed

By LISA FRIEDMAN NOV. 7, 2017

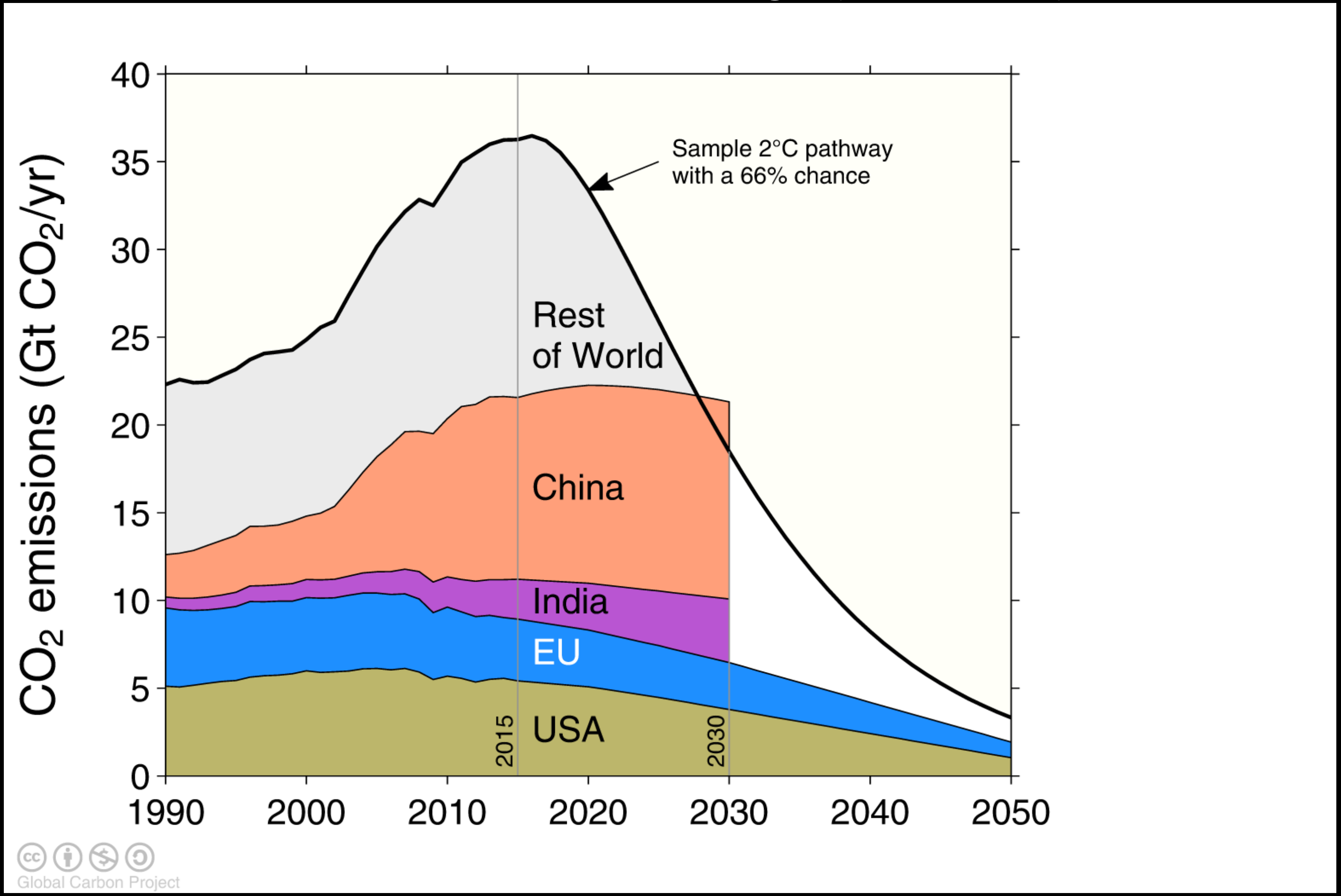
- $100 billion fund for developing countries
- Is set to be in force, now that > 55% of emissions included in ratified countries*
- Compliance and monitoring will be a key challenge

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

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

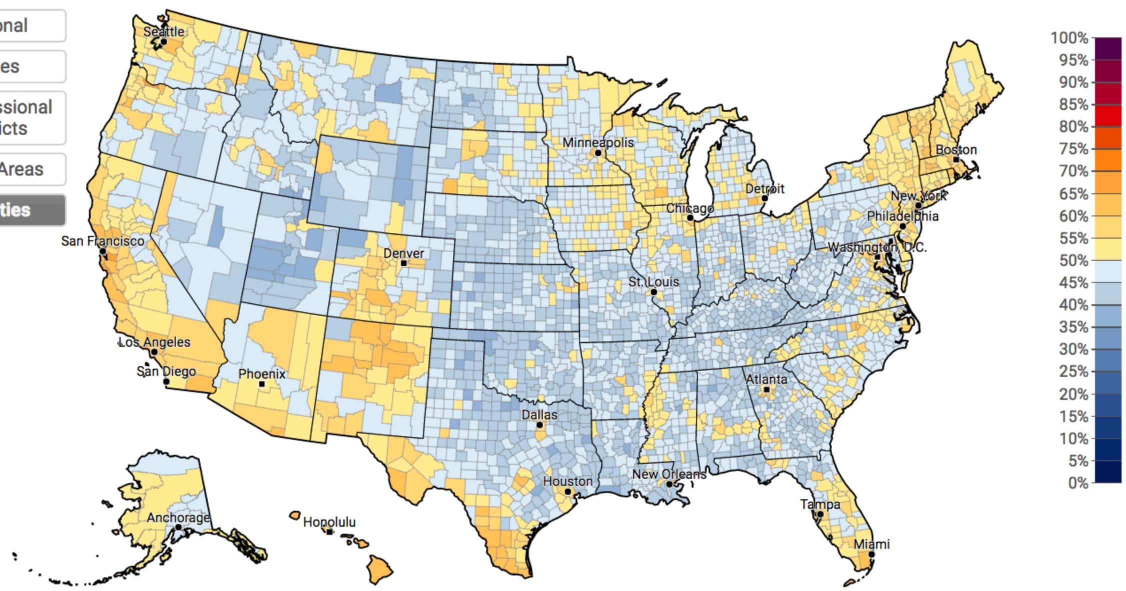
National

States

Congressional Districts

Metro Areas

Counties



Tweet

14 Like

United States

50%

Human activities 53% | 32% Natural changes

Public Opinion Estimates, United States, 2016

BELIEFS

Global warming is happening

50%

Yes 70% | 12% No

Global warming is caused mostly by human activities

Human activities 53% | 32% Natural changes

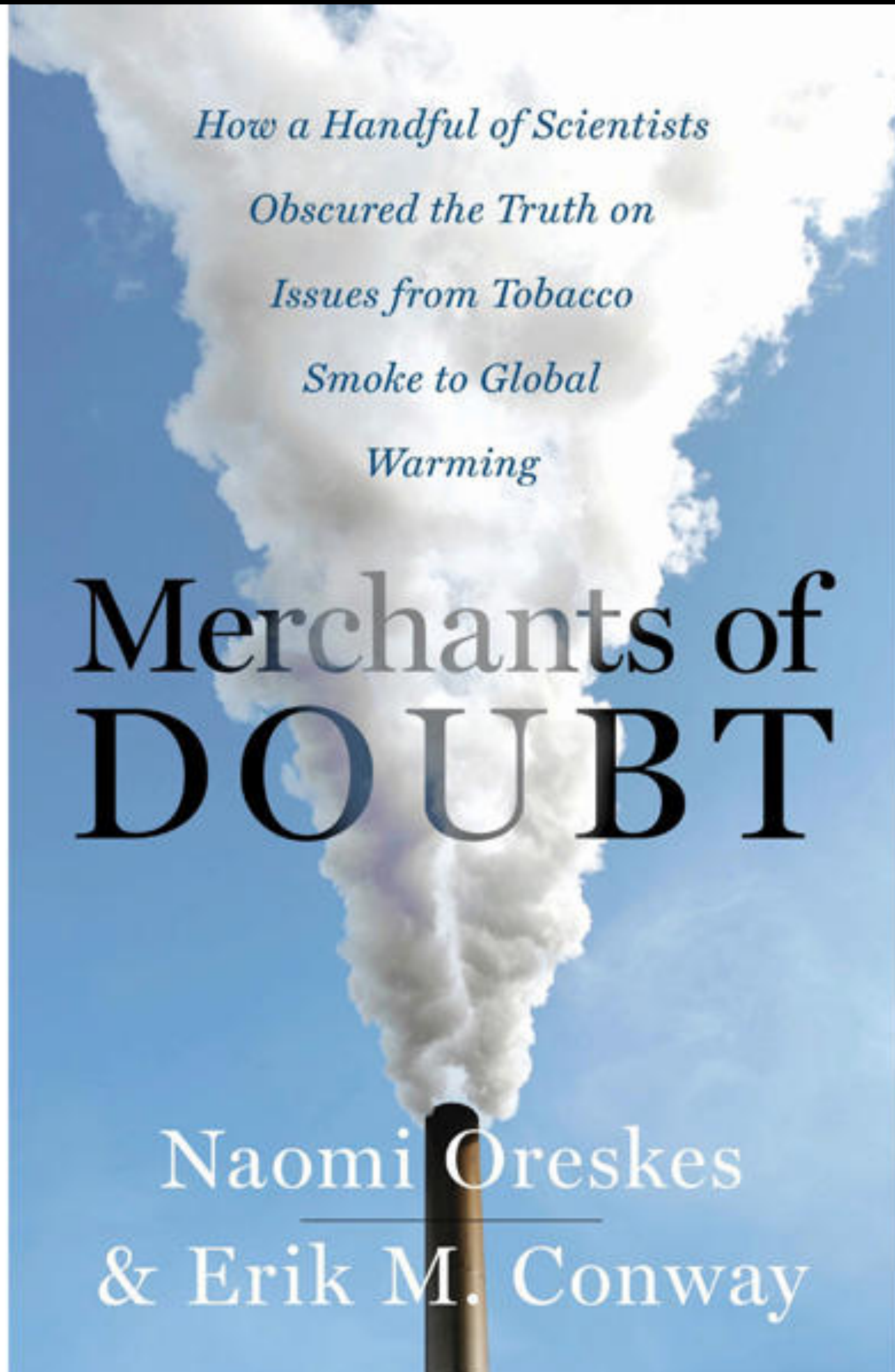
Most scientists think global warming is happening

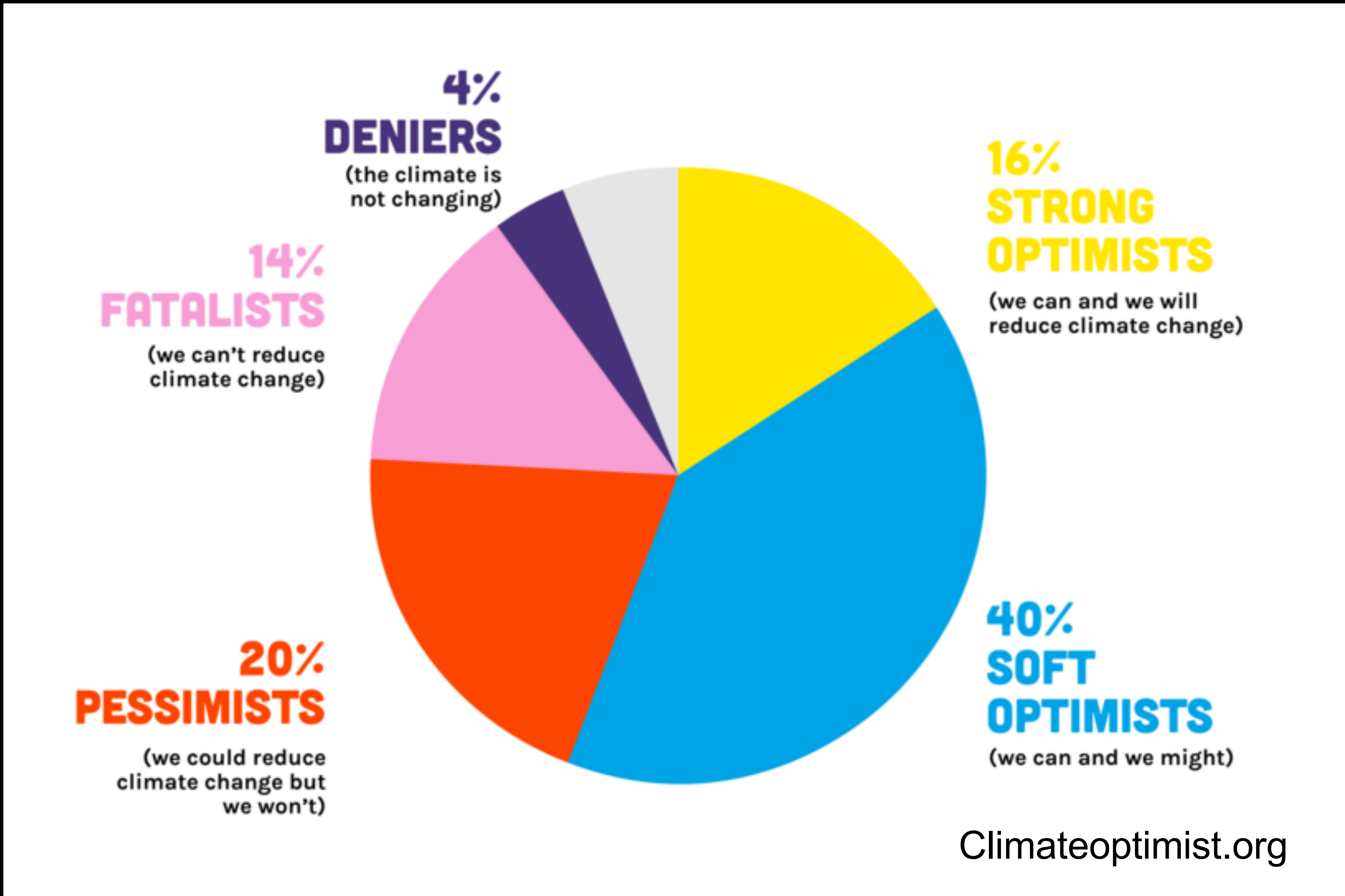
Yes 49% | 28% There is a lot of disagreement

Trust climate scientists about global warming

Somewhat/Strongly trust 71% | 26% Somewhat/Strongly distrust

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


4%
DENIERS
(the climate is not changing)
16%
STRONG OPTIMISTS
(we can and we will reduce climate change)
14%
FATALISTS
(we can't reduce climate change)
20%
PESSIMISTS
(we could reduce climate change but we won't)
40%
SOFT OPTIMISTS
(we can and we might)
Climateoptimist.org

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.

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