





Net Zero Emissions
Why and How

Paul Debevec (debevec@uiuc.edu)
Osher Lifelong Learning Institute at
University of Illinois
January 27, 2020

Net Zero Emissions: Course Description

The effects of global warming are evident. Already a 1° C global average temperature rise from pre-industrial times, the world is on a trajectory to exceed a global average temperature beyond that experienced in all human history. Greenhouse gas emissions from the burning of fossil fuels are the major cause of this temperature rise. But fossil fuels are still at the center of modern life, and their replacement is going slowly. A world without fossil fuels is both possible and necessary, but not without commitments from individuals, communities, and nations. Much of the technology exists, but little of the political will.

Net Zero Emissions

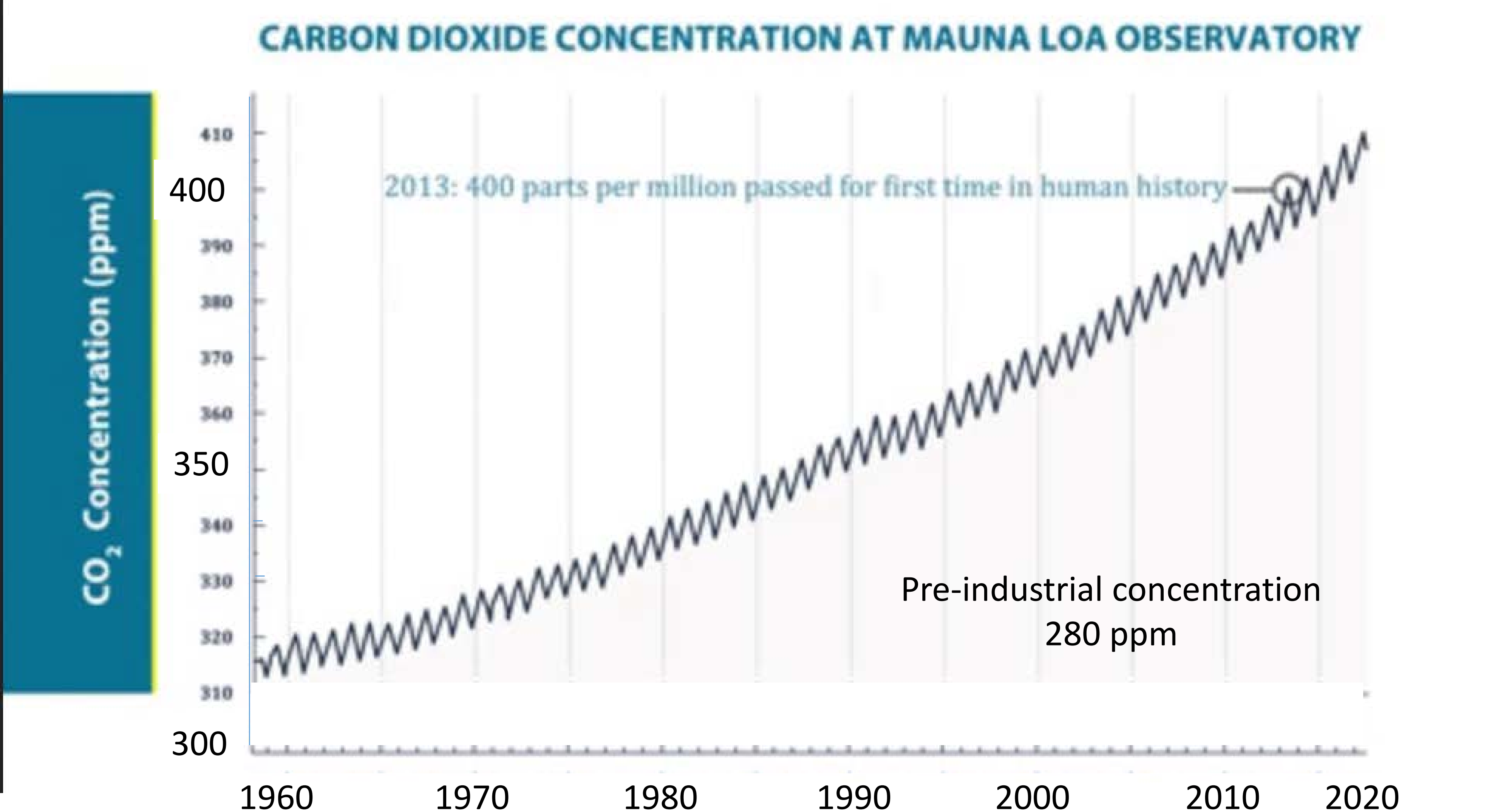
- Why? Climate change.
- How? Stop burning fossil fuels.

Week 1
Global Warming and Global Emissions

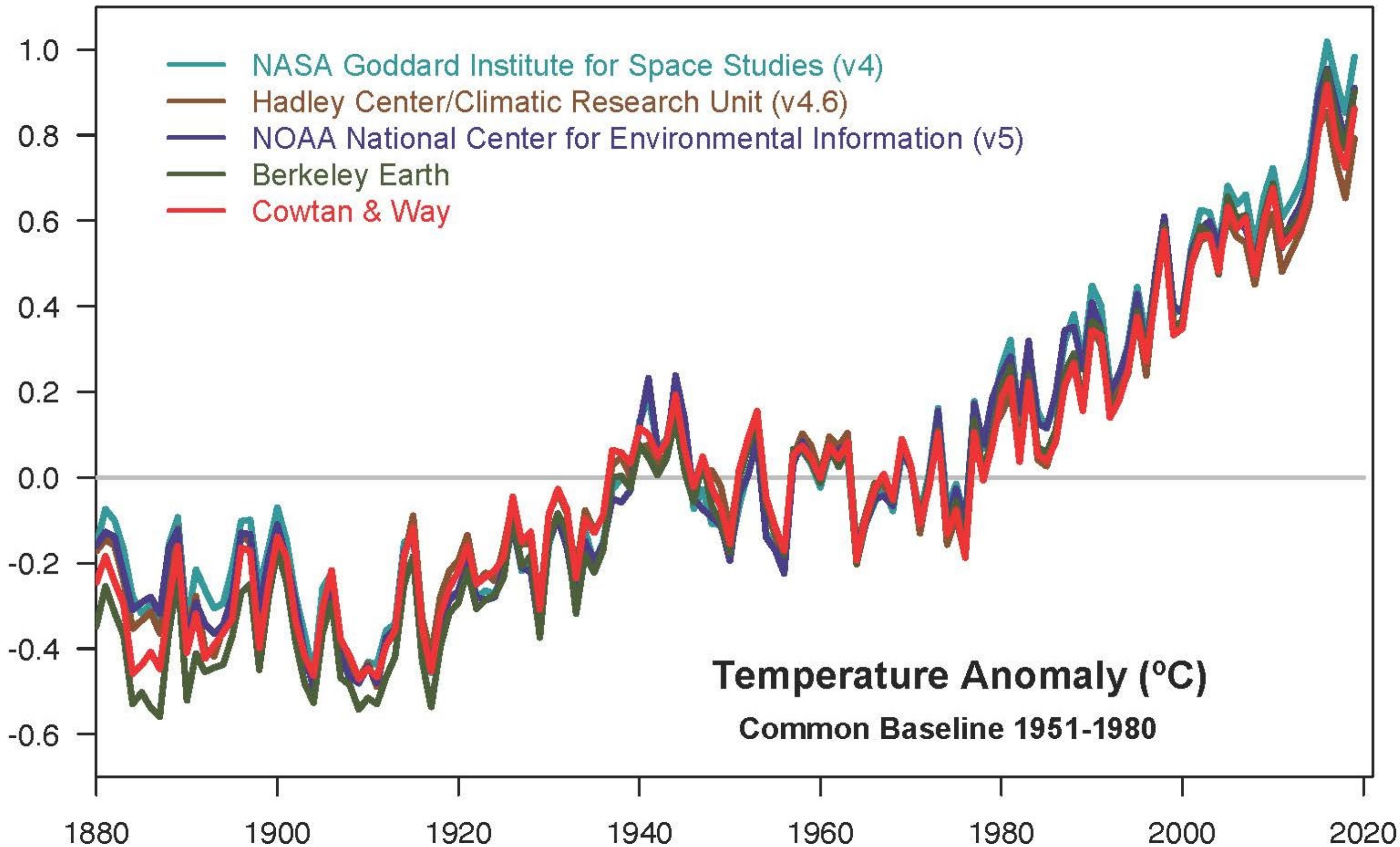
The IPCC October, 2018 Special Report on Global Warming of 1.5 ºC provides the basis for the understanding of why the world must come to net zero emissions by 2050. It authoritatively describes the impact of global warming even at this level of temperature rise to all aspects of the environment and human society. The IPCC has been criticized by some as being alarmist and by others by being conservative in its projections. Which evaluation is more justified?

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

Keeling Curve: Atmospheric CO_2 Concentration

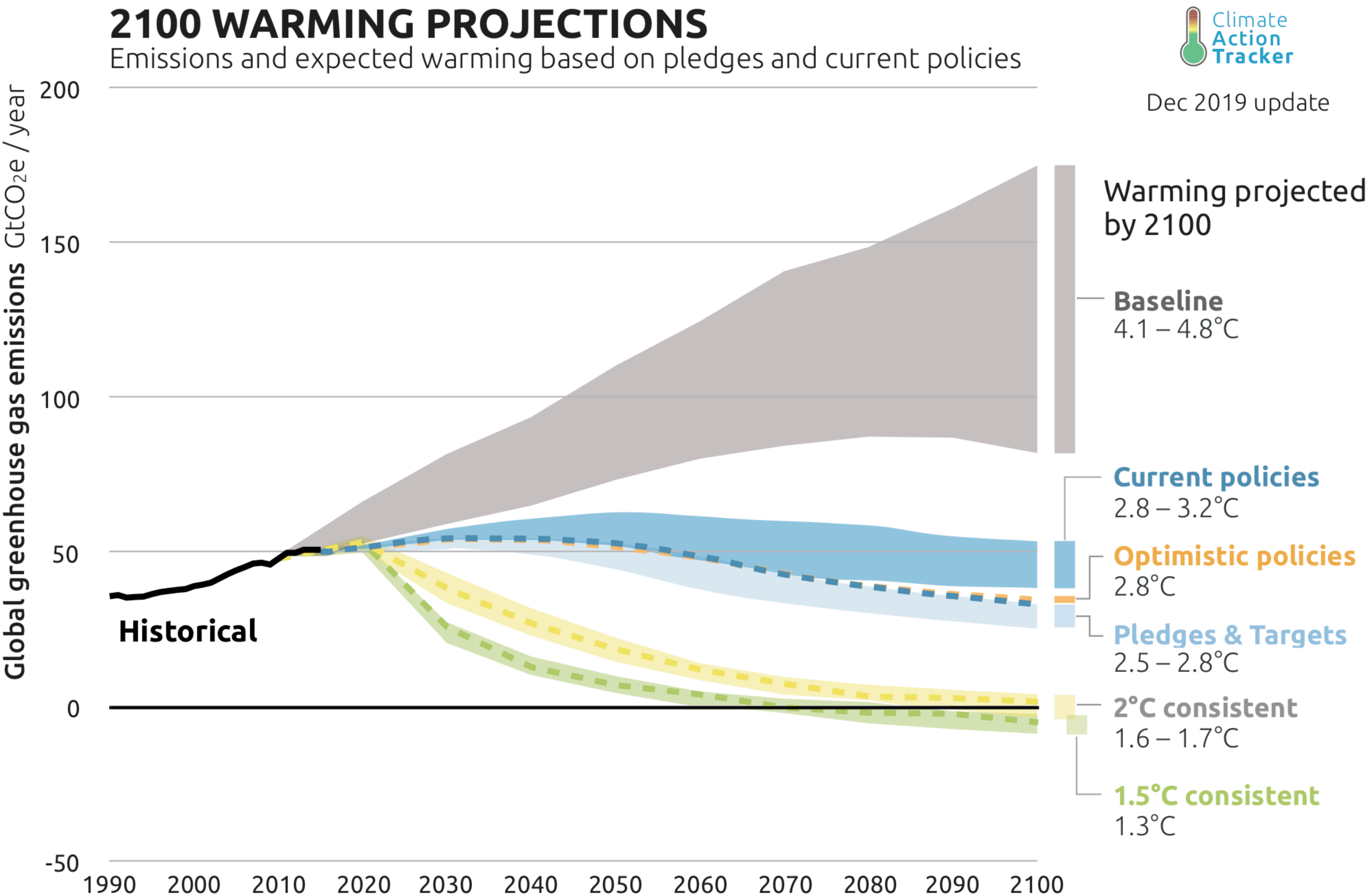


National Aeronautics and Space Administration
Goddard Institute for Space Studies



Week 2
Paris Agreement and NDCs

The Paris Agreement of December, 2015 is the international framework by which governments declare their goals and policies toward climate change through nationally determined contributions (NDCs). The Agreement provided for continued negotiations through annual conferences of the Conference of the Parties, since Paris in Marrakesh, in Bonn, in Katowice, and most recently in Madrid. Has the international community made progress in efforts to address climate change?

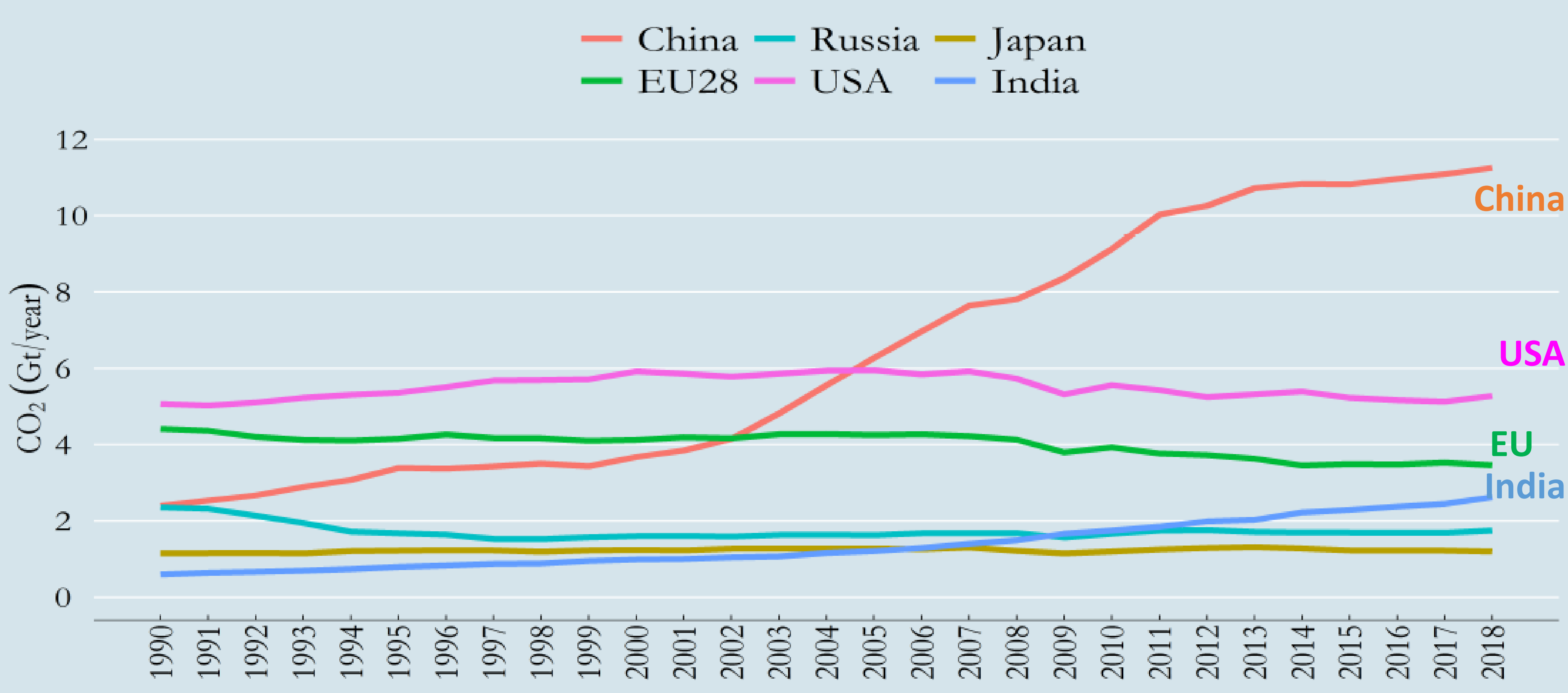


2100 WARMING PROJECTIONS
Emissions and expected warming based on pledges and current policies
Climate Action Tracker
Dec 2019 update
Global greenhouse gas emissions GtCO2e / year
200
150
100
50
0
-50
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Historical
Warming projected by 2100
Baseline
4.1 – 4.8°C
Current policies
2.8 – 3.2°C
Optimistic policies
2.8°C
Pledges & Targets
2.5 – 2.8°C
2°C consistent
1.6 – 1.7°C
1.5°C consistent
1.3°C

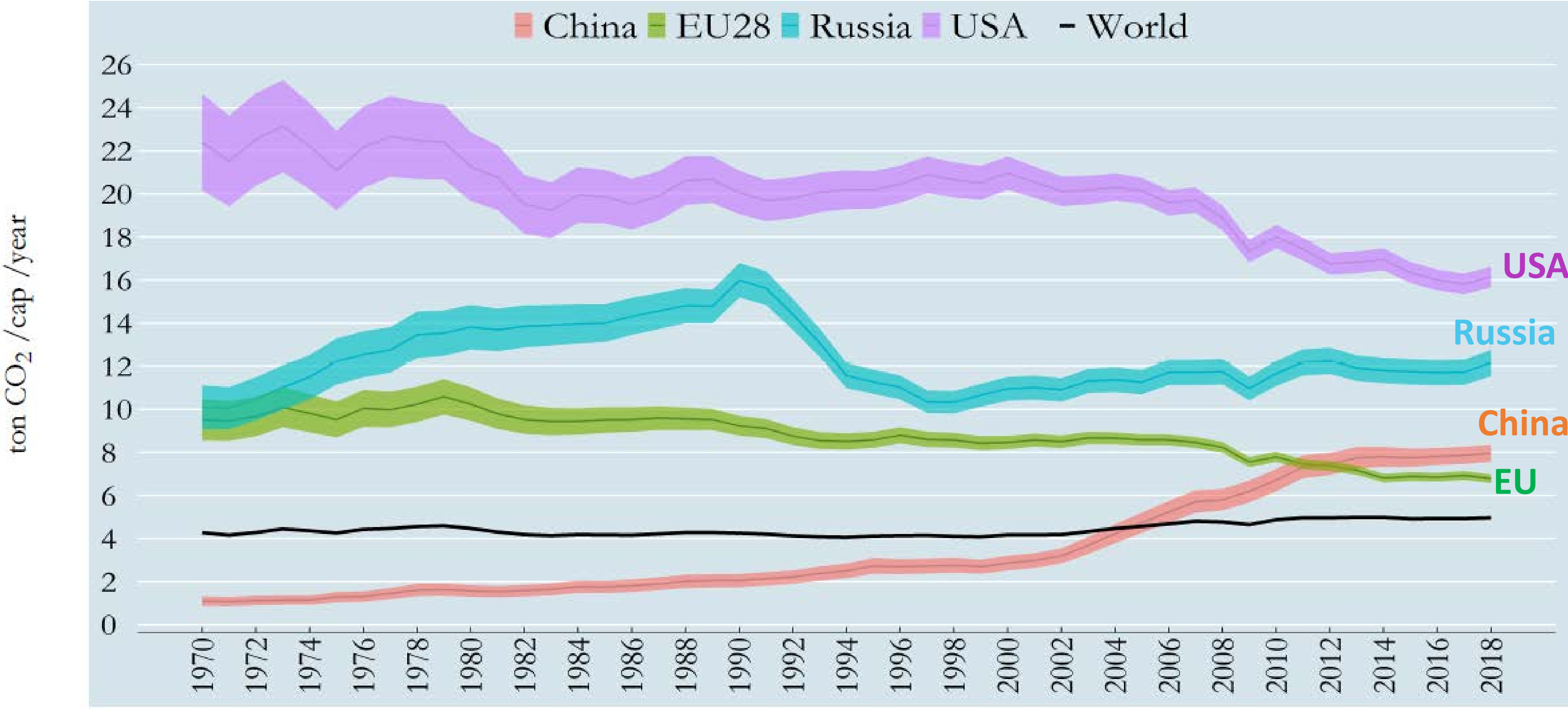
Week 3
China and the United States

China with 27% of global GHG emissions and the United States with 15% account for 42% of global GHG emissions. But GDP per capita in China is only 15% of that in the United States. The actions of both countries will have a major impact on global emissions reduction. This issue will be an important component in our upcoming national elections. The Green New Deal and Democratic candidates Climate Change Plans are worthy of discussion. Would they be sufficient?

Fossil CO_2 Emissions of Selected Economies



Annual Per capita CO_2 Emissions



$$\text{rate of possible change} = \frac{\text{institutional efforts}}{\text{infrastructure inertia}}$$

John R. Holdren
Memorandum to the President
November, 2000
The Energy-Climate Challenge

"Today's fossil-fuel-dominated world energy system (worth some $10 trillion at replacement cost and characterized by equipment-turnover times of 20 to 50 years) could not be rapidly replaced with non-CO2-emitting alternatives even if these were no more expensive than conventional fossil-fuel technologies have been (and today, the non-CO2 options are considerably more expensive.)"

World Bank data: 2000 World GDP 33.3 trillion in 2000 US$

Try to Fathom Some Big Numbers

1 trillion dollars

With one trillion dollars, Apple could buy everyone in San Francisco an apartment.

Total student debt in the U.S. is 1.5 trillion dollars.

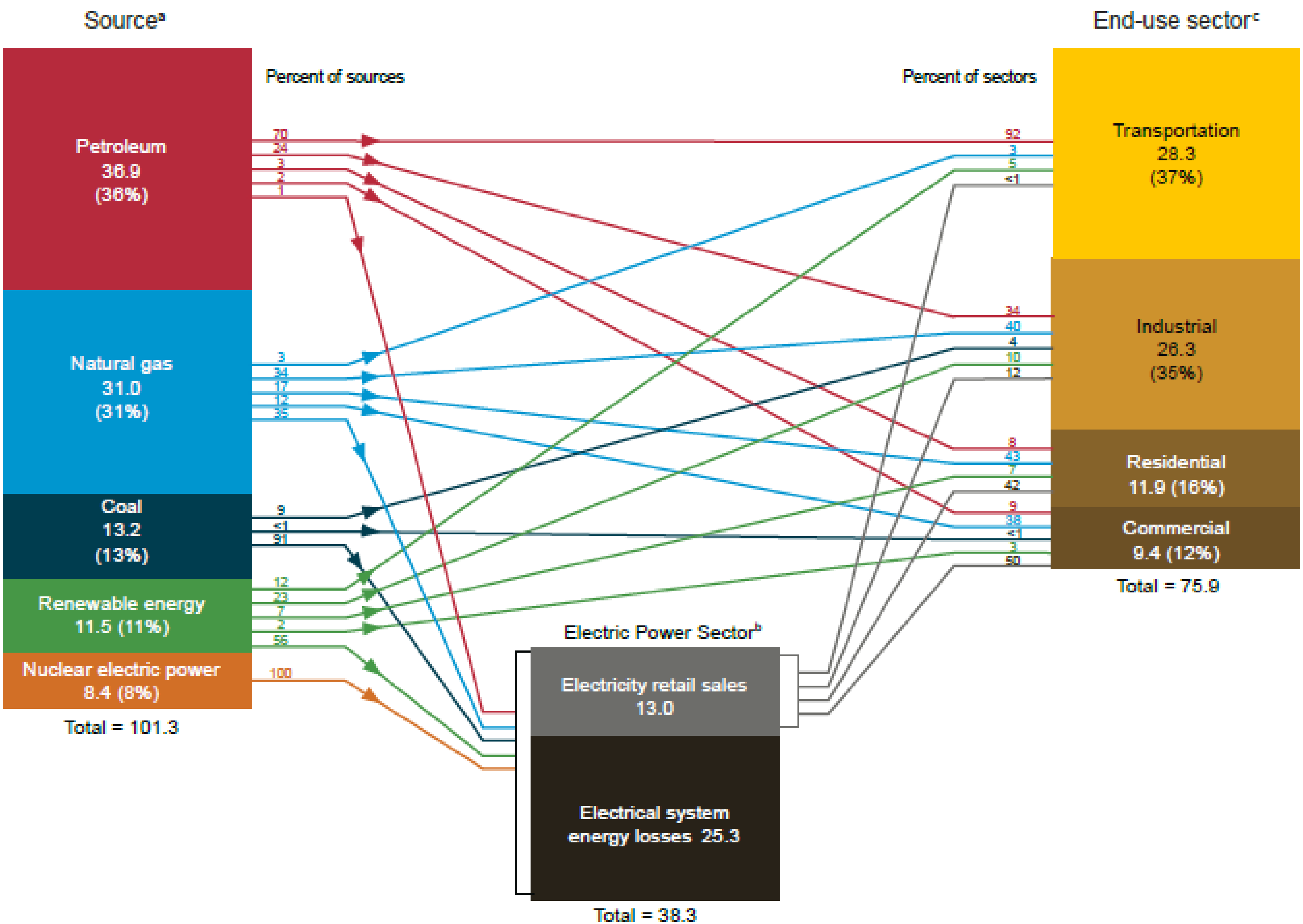
The American Society of Civil Engineers reports that 4.5 trillion dollars is need to repair American's roads, bridges, dams, airports, and schools.

Week 4
Zero Carbon Options

In the United States the three fossil fuels, coal, oil, and natural gas, provide for 60% of our electrical generation, 92% of our transportation, 88% of our industry, 58% of residential and 48% of commercial energy use. Obviously, net zero emissions by 2050 will require the dramatic disruption of the fossil fuel industry. Can this transformation be made without devastating economic dislocation?

U.S. energy consumption by source and sector, 2018

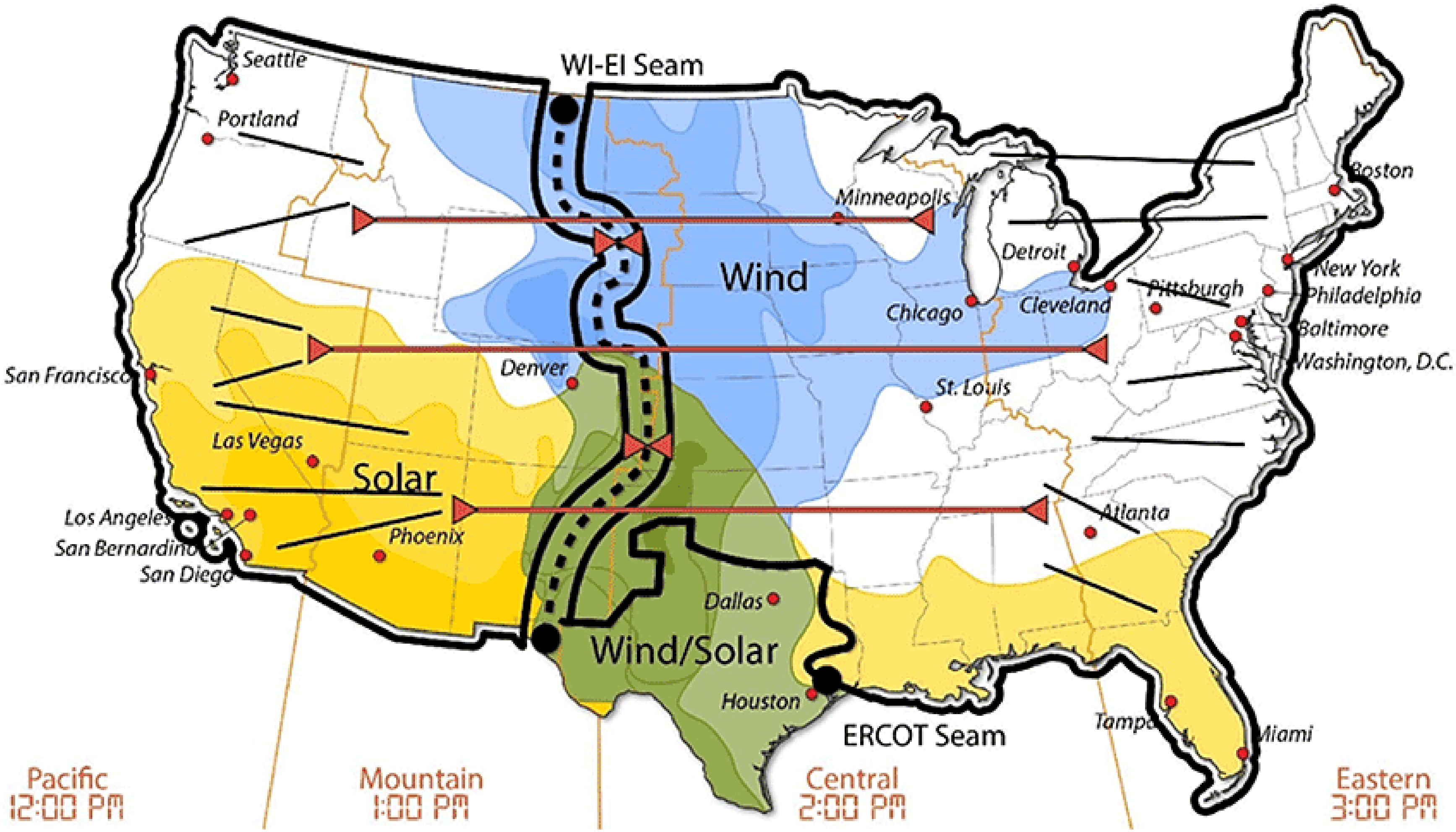
(Quadrillion Btu)



Week 5

Two plentiful sources of renewable energy, wind and solar, have experienced near exponential growth in the past decades and now provide in the United States 3% of total primary energy (8% of electricity generation). Intermittency and variability of these resources require either a dispatchable resource or energy storage. What is a possible mix of wind, solar, storage, and dispatchable resources, given technological and economic considerations?

U.S. Wind, Solar, and Transmission



Week 6

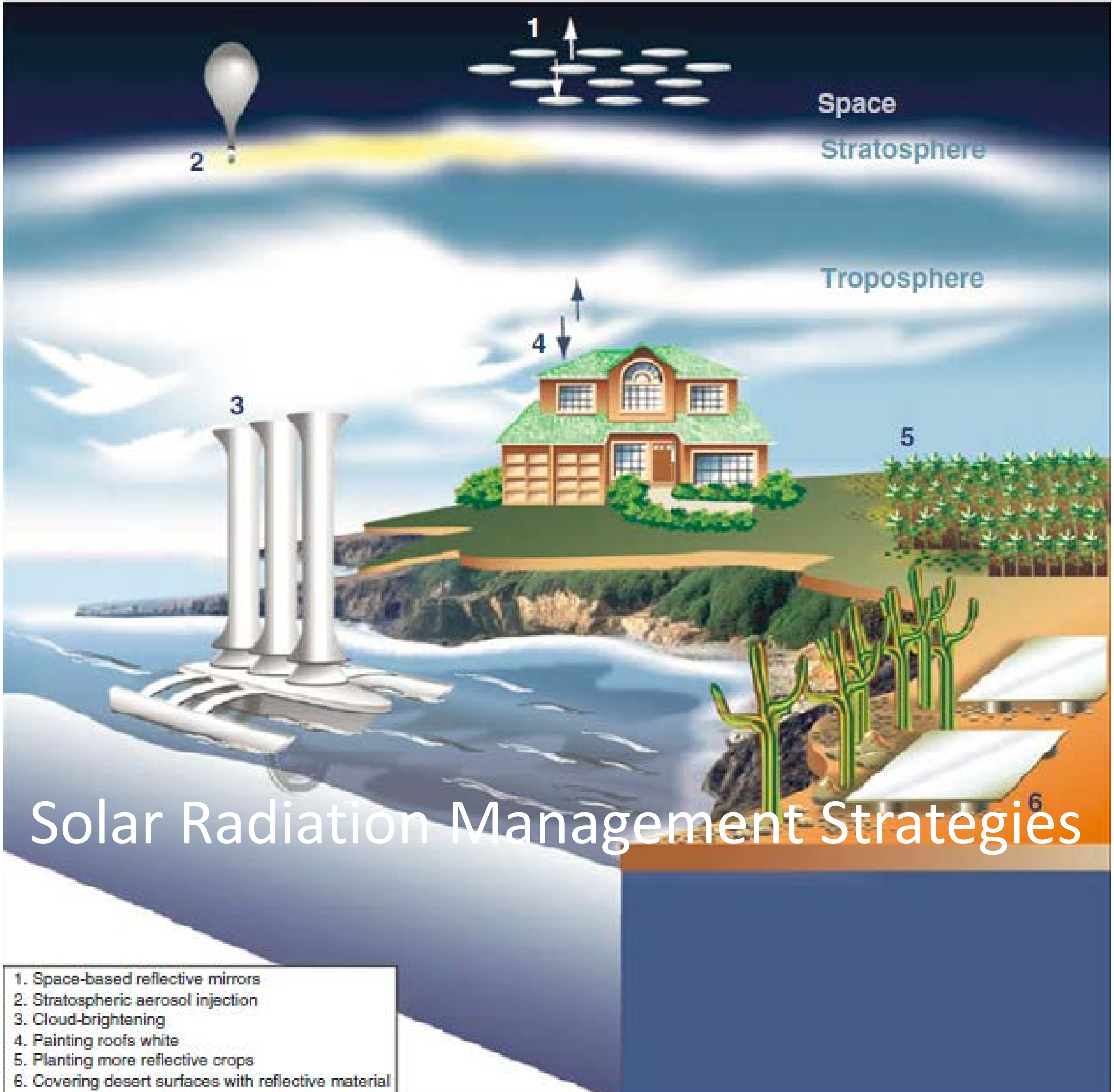
The transition to net zero emissions may be too slow to limit global warming to an acceptable level. Warming would subside if greenhouse gases could be removed from the atmosphere. A handful of technologies have been identified, all of which require implementation on a massive scale. Do negative emissions have a role in producing net zero emissions?

Carbon Dioxide Removal Strategies

Week 7

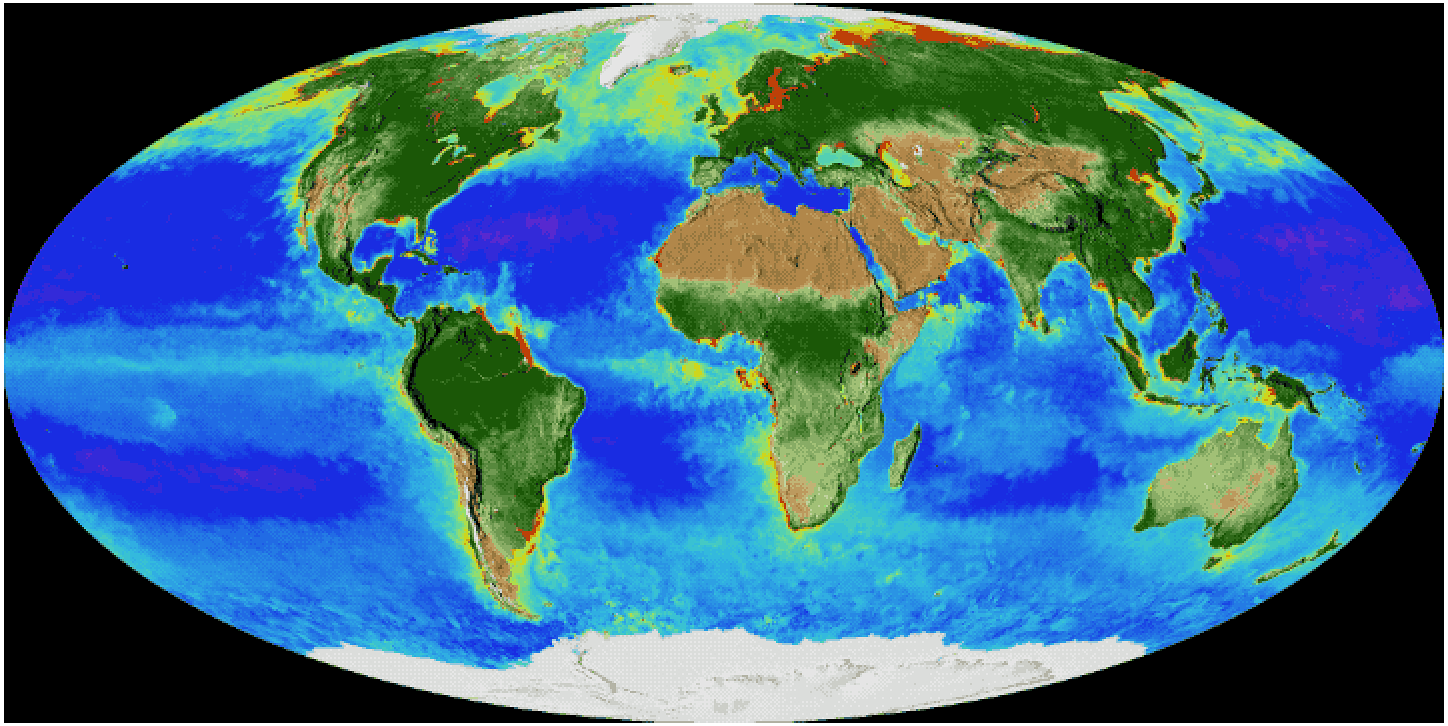
Suppose neither emissions reduction nor negative emissions are implemented effectively and in a timely fashion. Should management of solar radiation or other geoengineering technologies be considered? Should research and pilot projects be pursued in the near term?

Solar Radiation Management Strategies



Week 8

Fossil fuel resources are not renewable, and their use will eventually end. In human history there have been other energy transitions, but none with this urgency. Along with energy there must be a transition for water resources and food production. What will be “The Future That We Will Not See?”



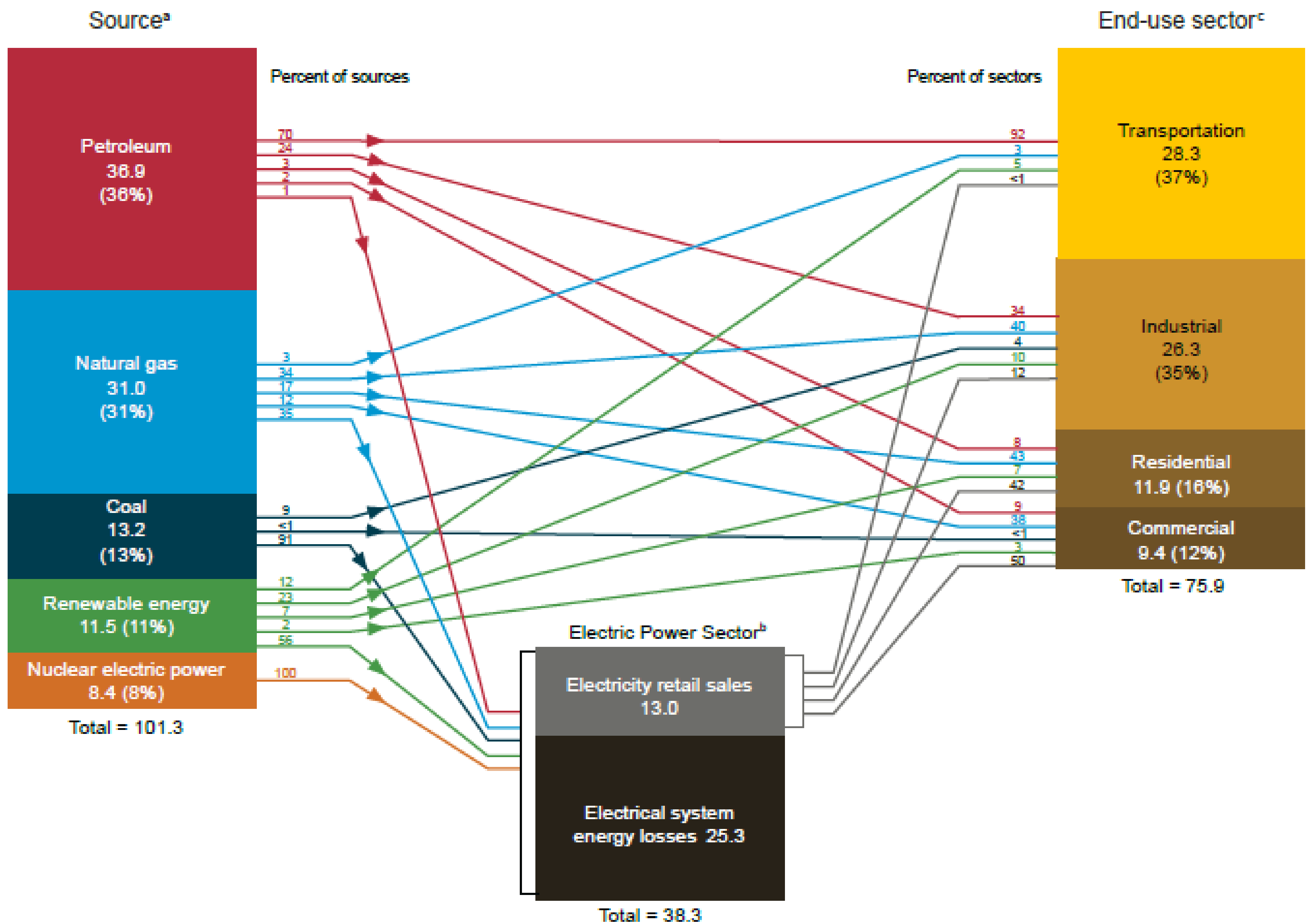
Energy, Climate, and Emissions

- U.S. and Global Energy Sources and Use
  - Energy flow
- Climate science
  - Temperature analysis
  - Weather 2050
- Climate change and GHG emissions
  - Stripes
  - Billion dollar weather events
- Climate models
  - Climate model accuracy
- Sea level rise
- Review

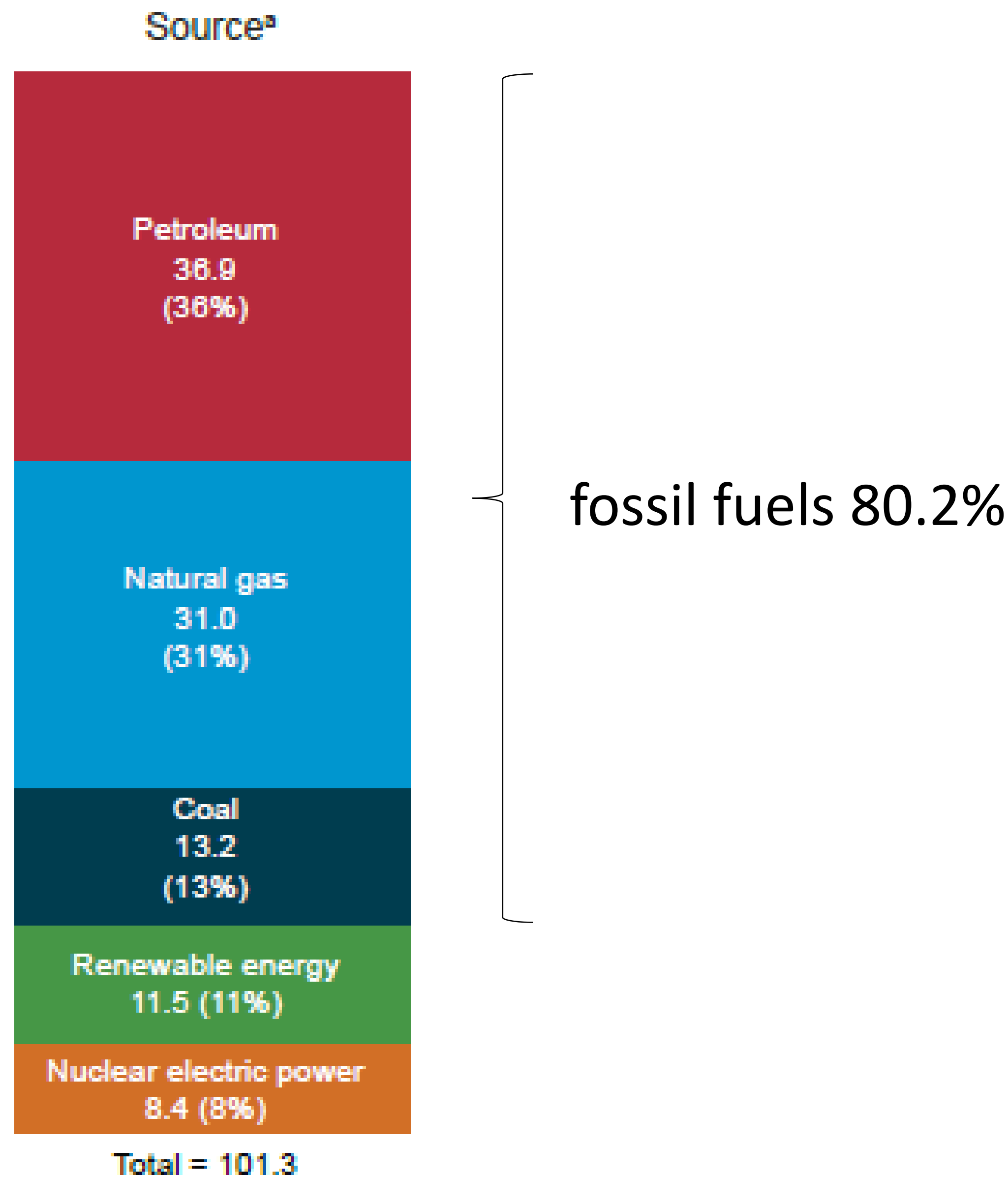
U.S. and Global Energy Sources and Use

U.S. energy consumption by source and sector, 2018

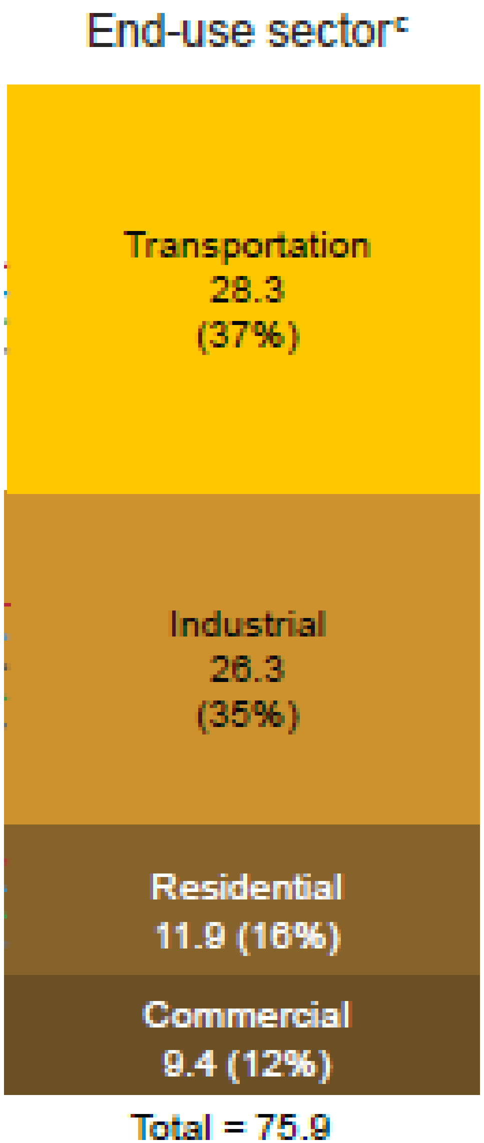
(Quadrillion Btu)



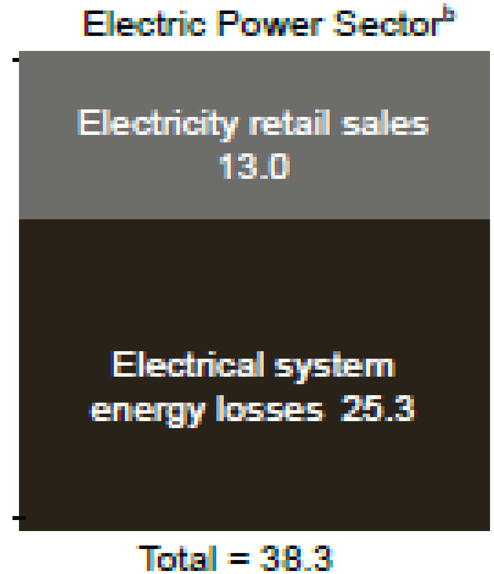
U.S. Primary Energy Sources, 2018



U.S. Energy Use Sectors, 2018



biofuels
electricity
hydrogen



hydroelectric power
photovoltaic
wind
biomass
geothermal

substitutes for space and water heating, lighting

Try to Fathom Some Big Numbers

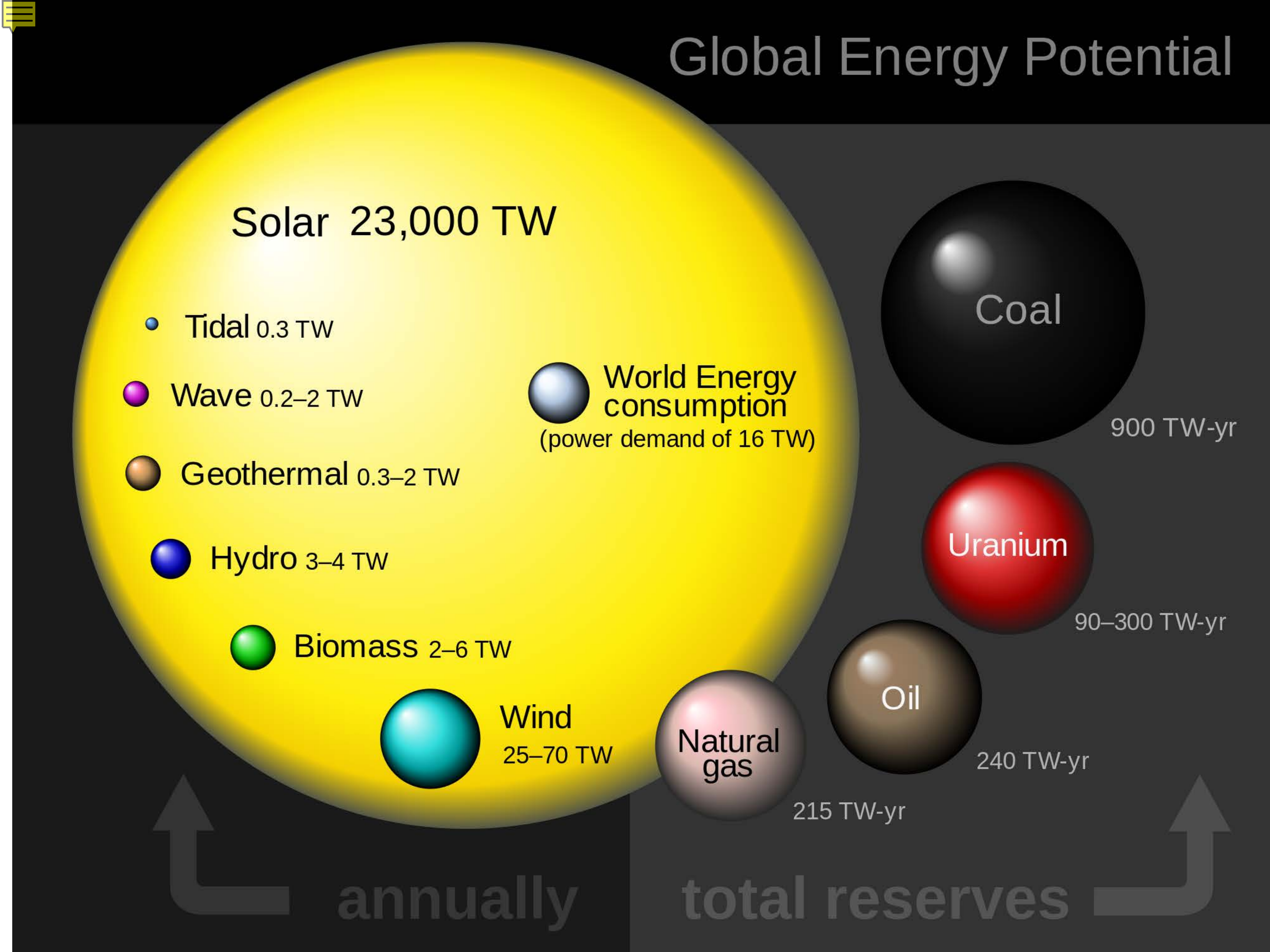
1 quad = 10^{15} BTU = 293 TWh

In the U.S. 235 million passenger cars and light-duty trucks consume 16.6 quads of energy.

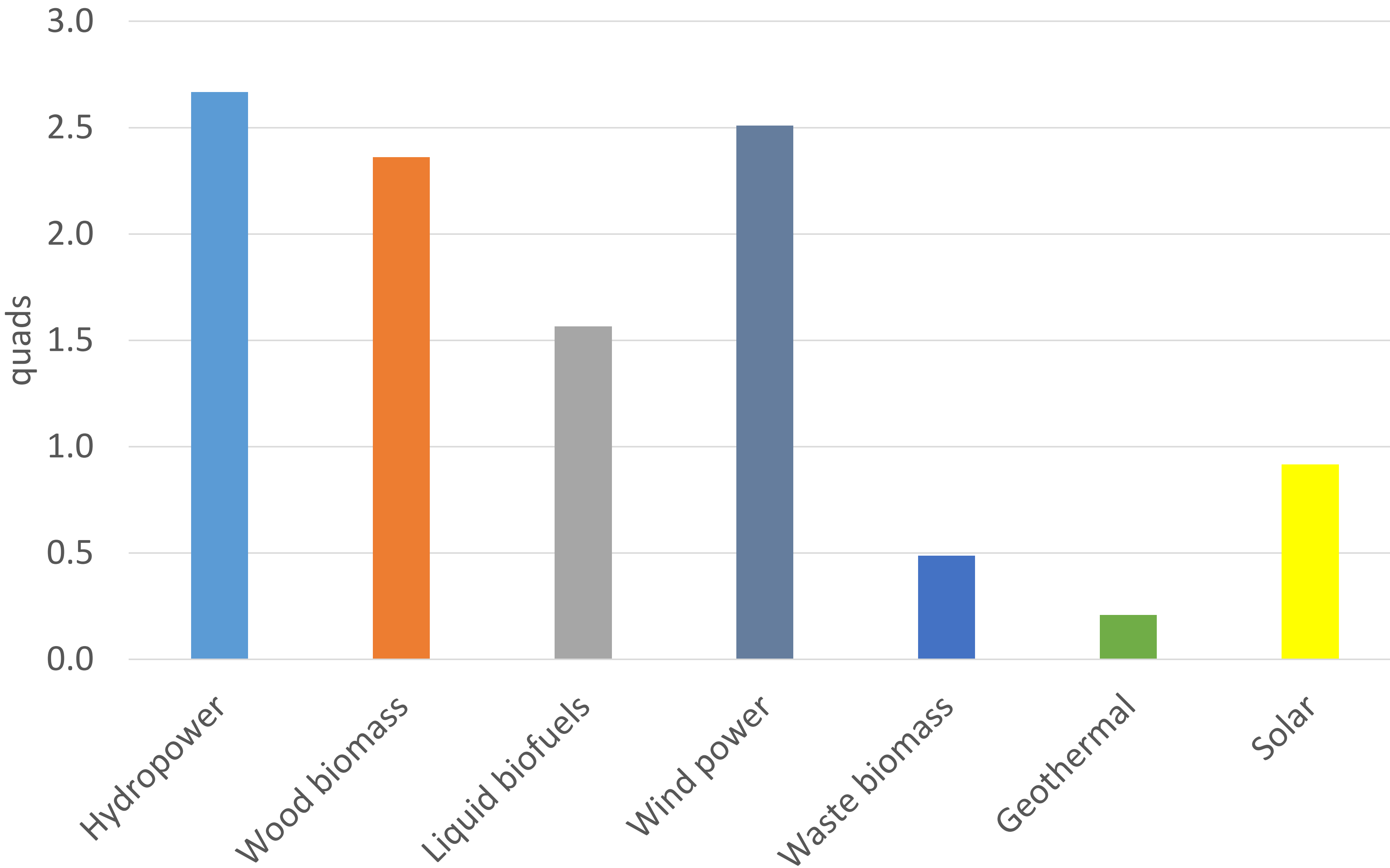
14 million light-duty vehicles consume about one quad.

In the U.S. 98 nuclear reactors consume 8.4. quads of energy.

12 reactors consume about one quad.

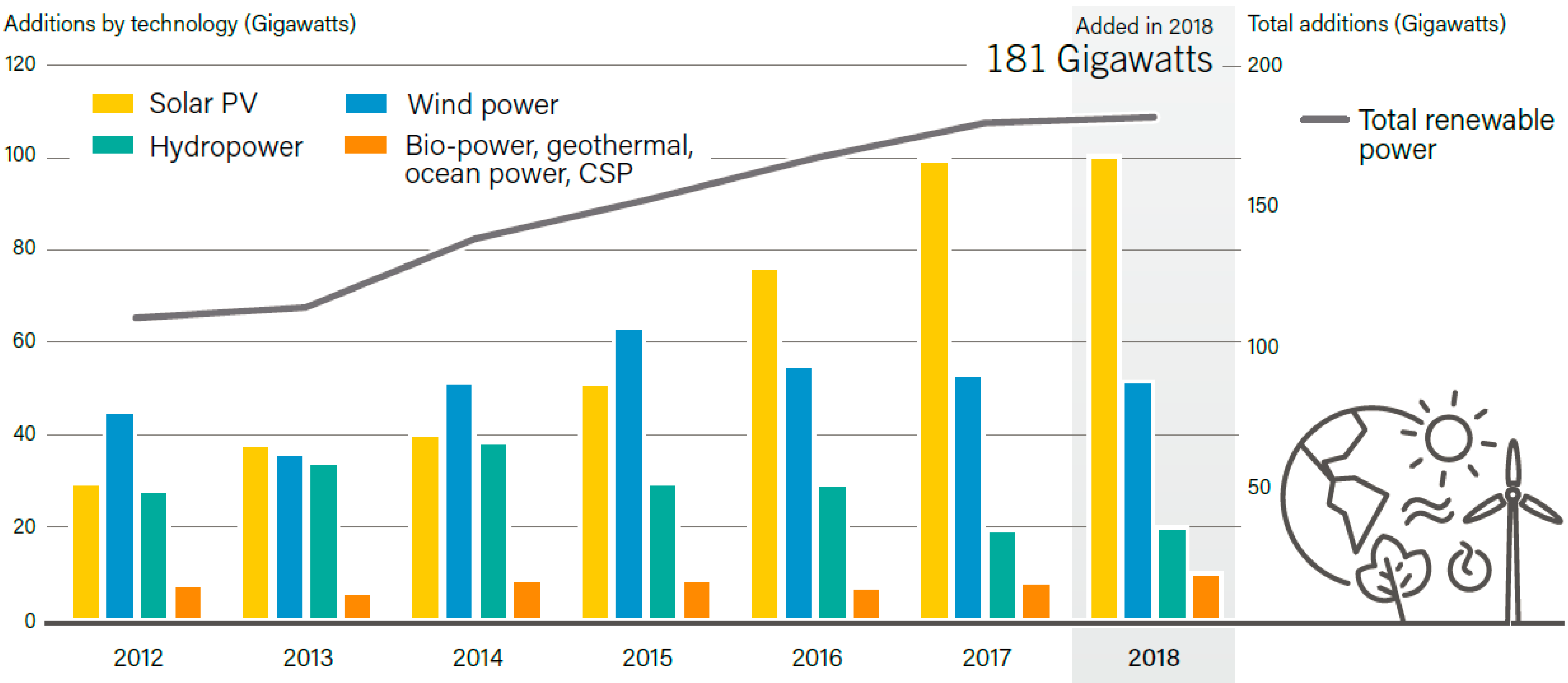

Global Energy Potential
Solar 23,000 TW
Tidal 0.3 TW
Wave 0.2–2 TW
Geothermal 0.3–2 TW
Hydro 3–4 TW
Biomass 2–6 TW
Wind 25–70 TW
World Energy consumption
(power demand of 16 TW)
Coal
900 TW-yr
Uranium
90–300 TW-yr
Oil
240 TW-yr
Natural gas
215 TW-yr
annually
total reserves

U.S. Renewable Energy Sources, 2018



Total renewable fraction of primary energy is 11%

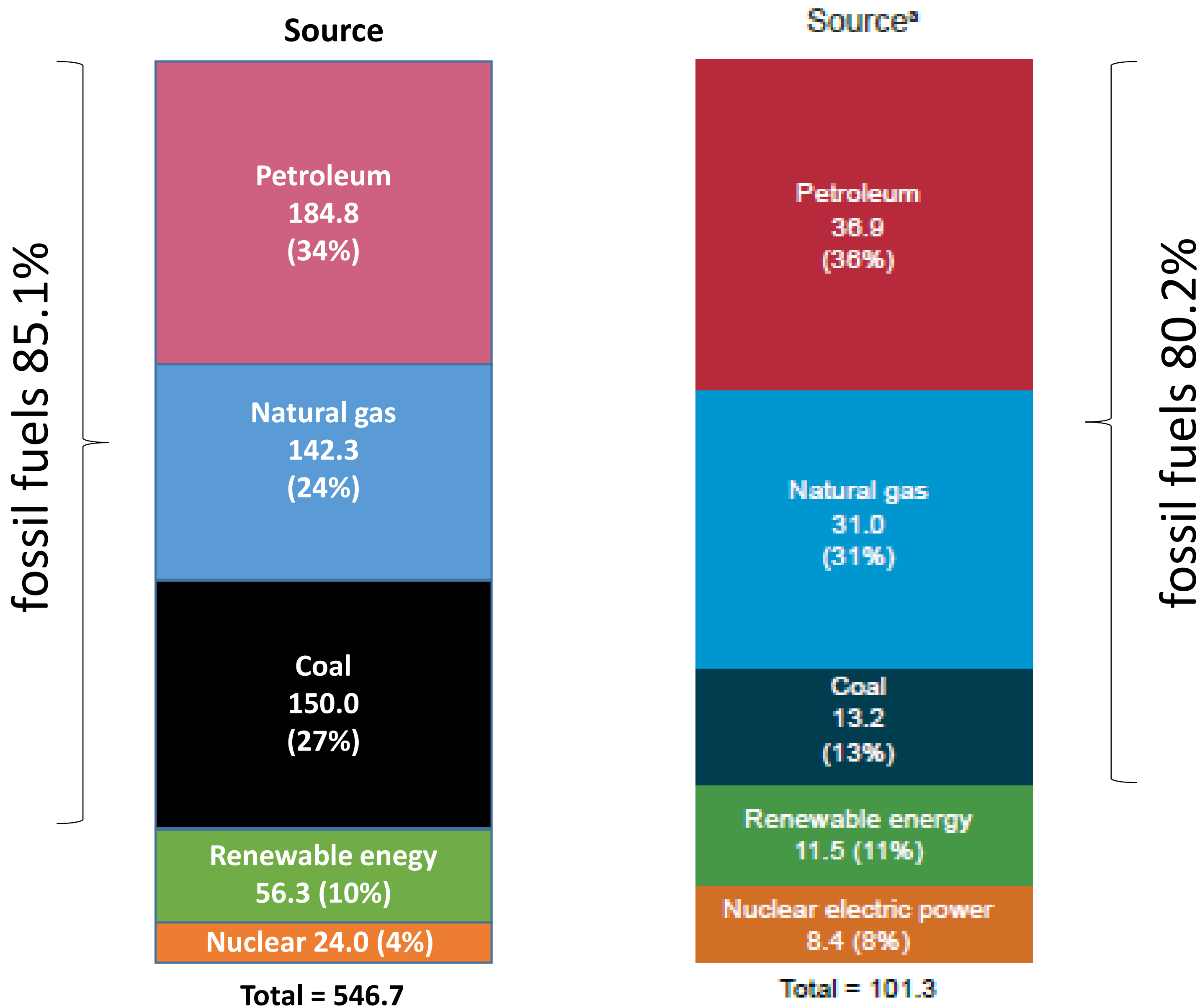
Annual Additions of Global Renewable Power Capacity, by Technology and Total, 2012-2018



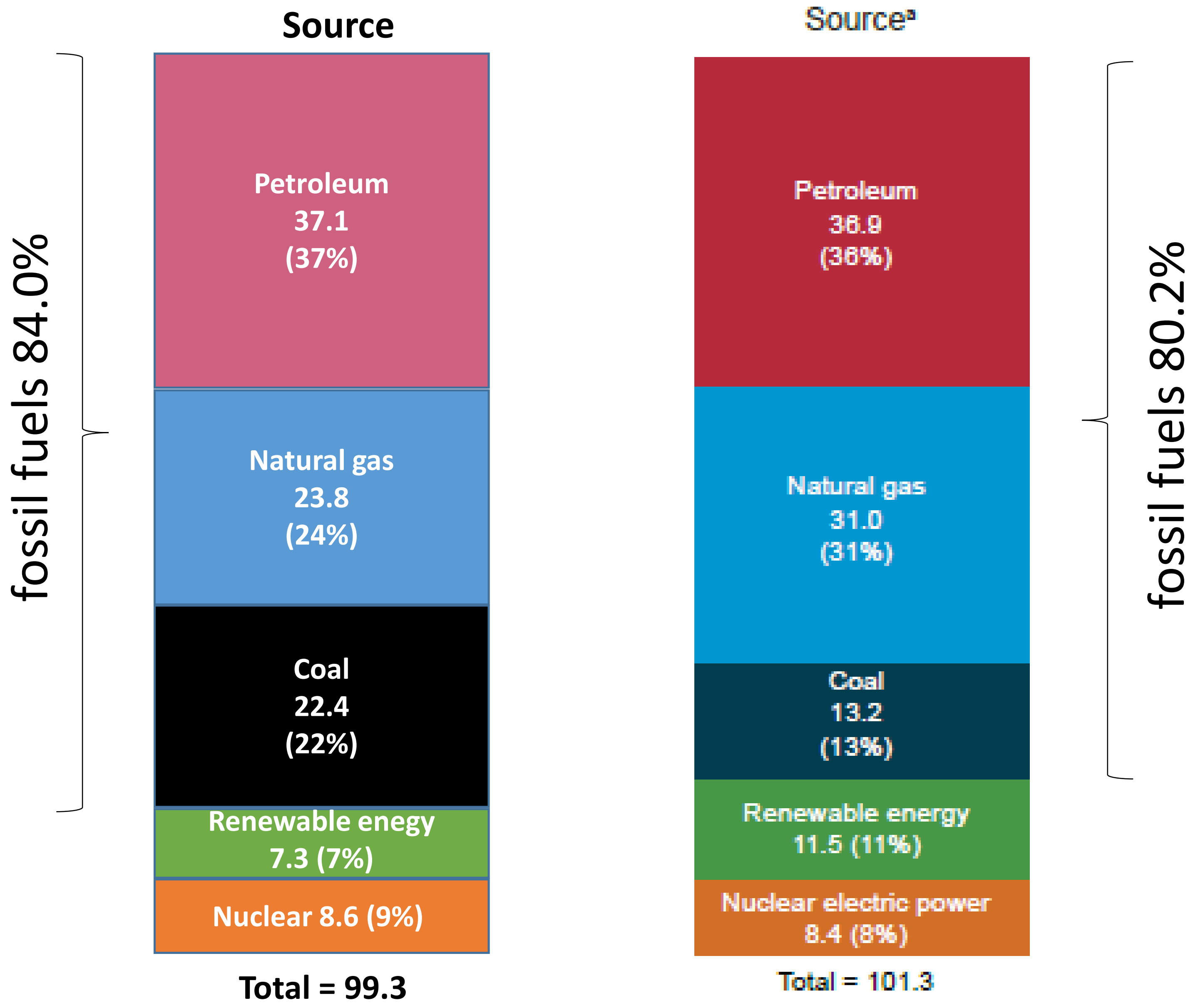
Note: Solar PV capacity data are provided in direct current (DC).

Source: See endnote 183 for this chapter.

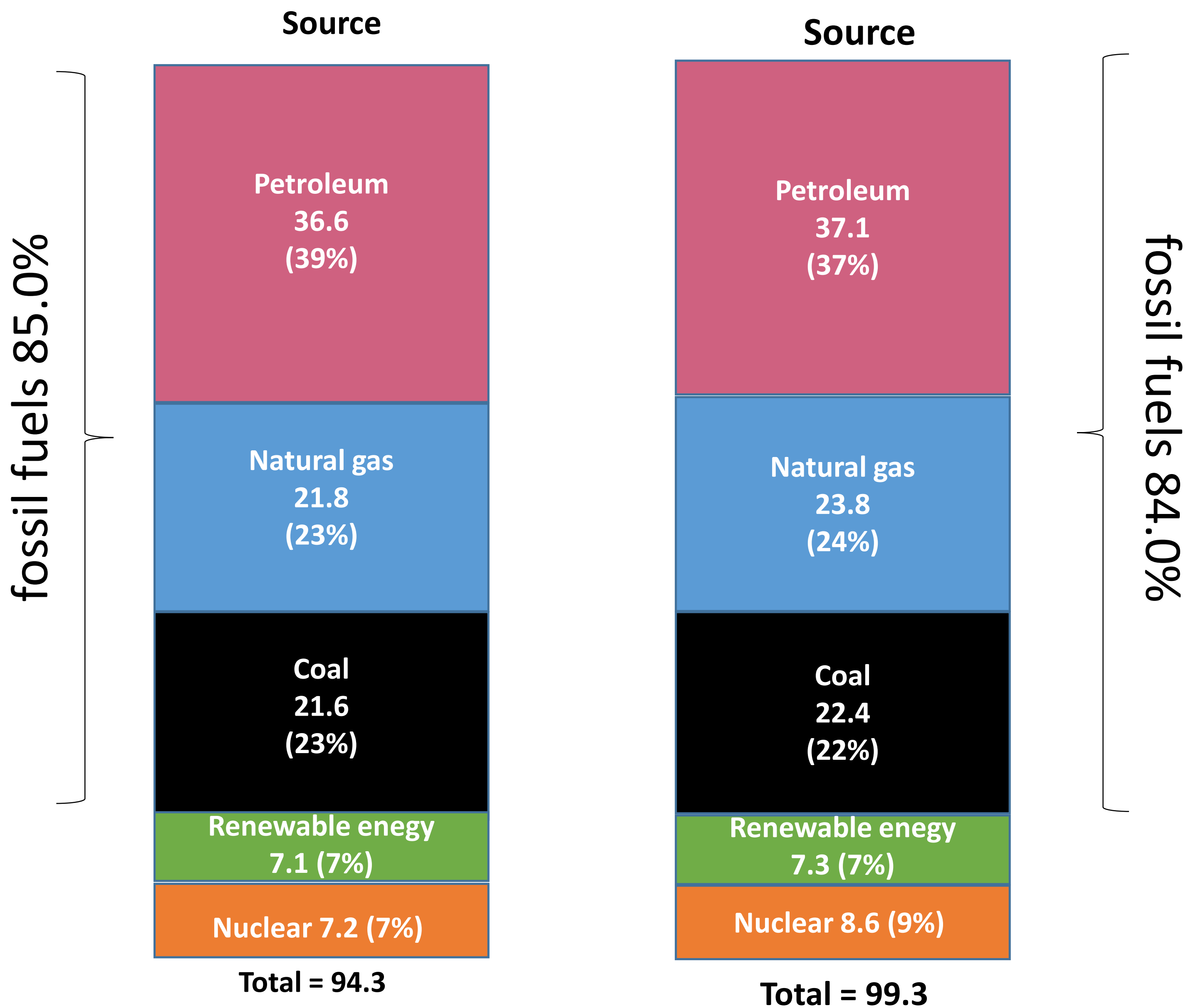
Global and U.S. Primary Energy Sources, 2018



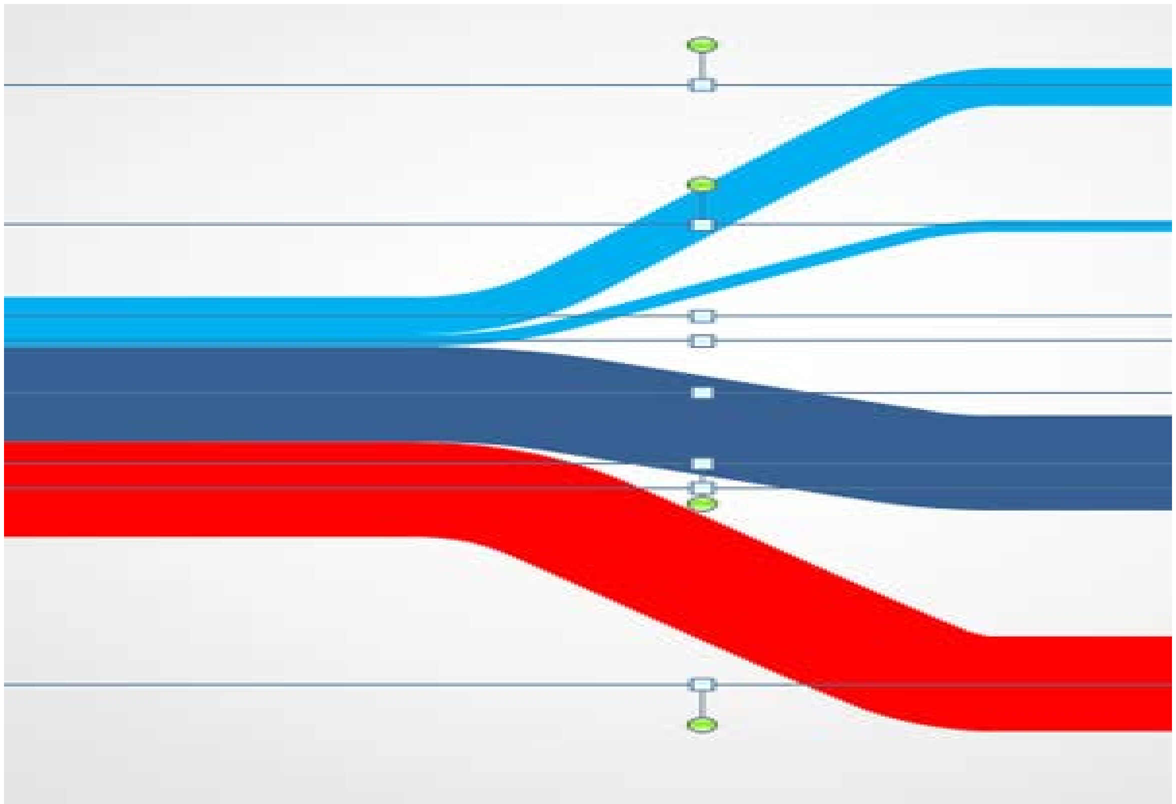
U.S. Primary Energy Sources, 2008 and 2018



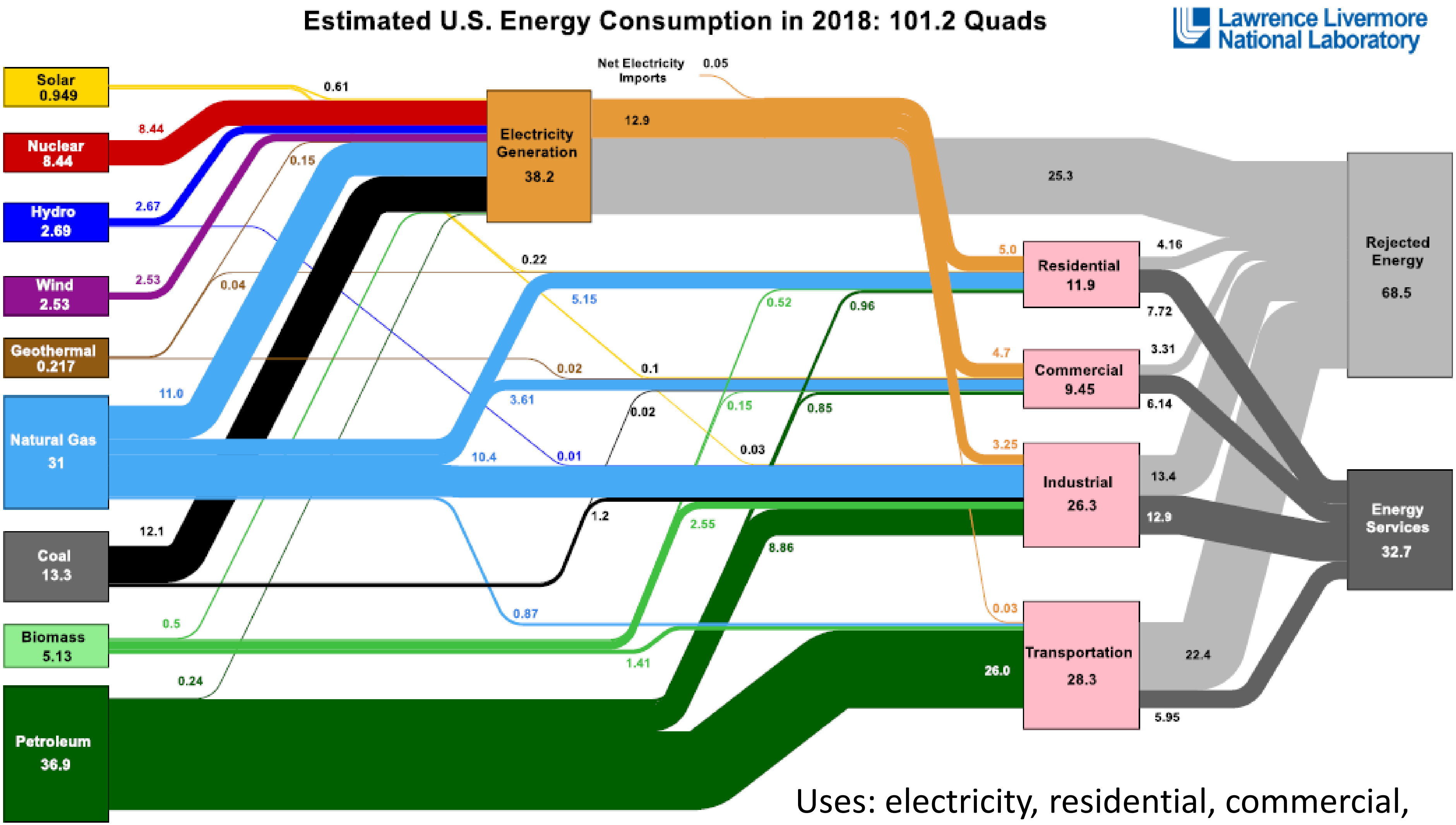
U.S. Primary Energy Sources, 1980 and 2008



Flow Concept Sankey Diagram



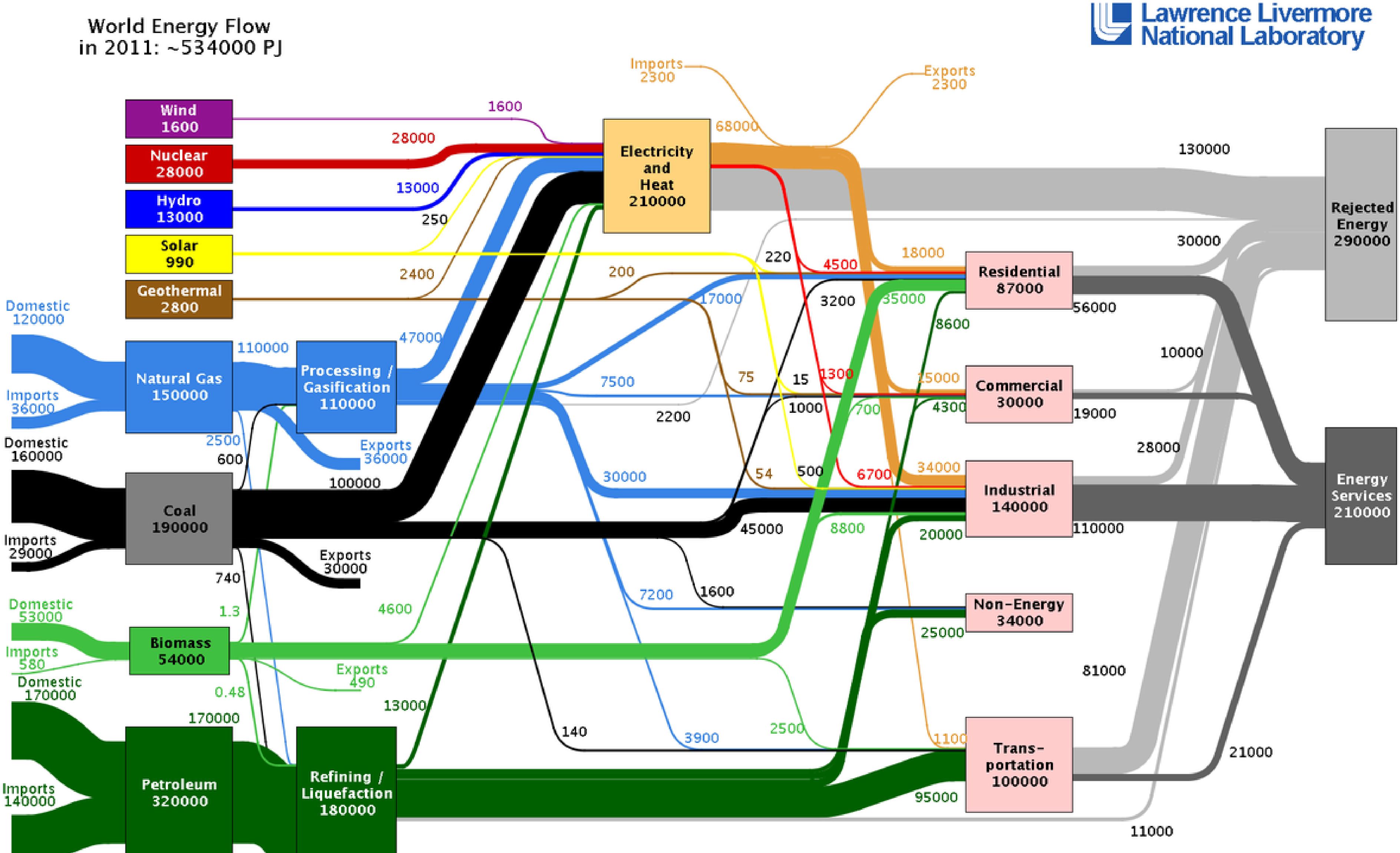
U.S. Energy Flow 2018



Uses: electricity, residential, commercial, Industrial, transportation.

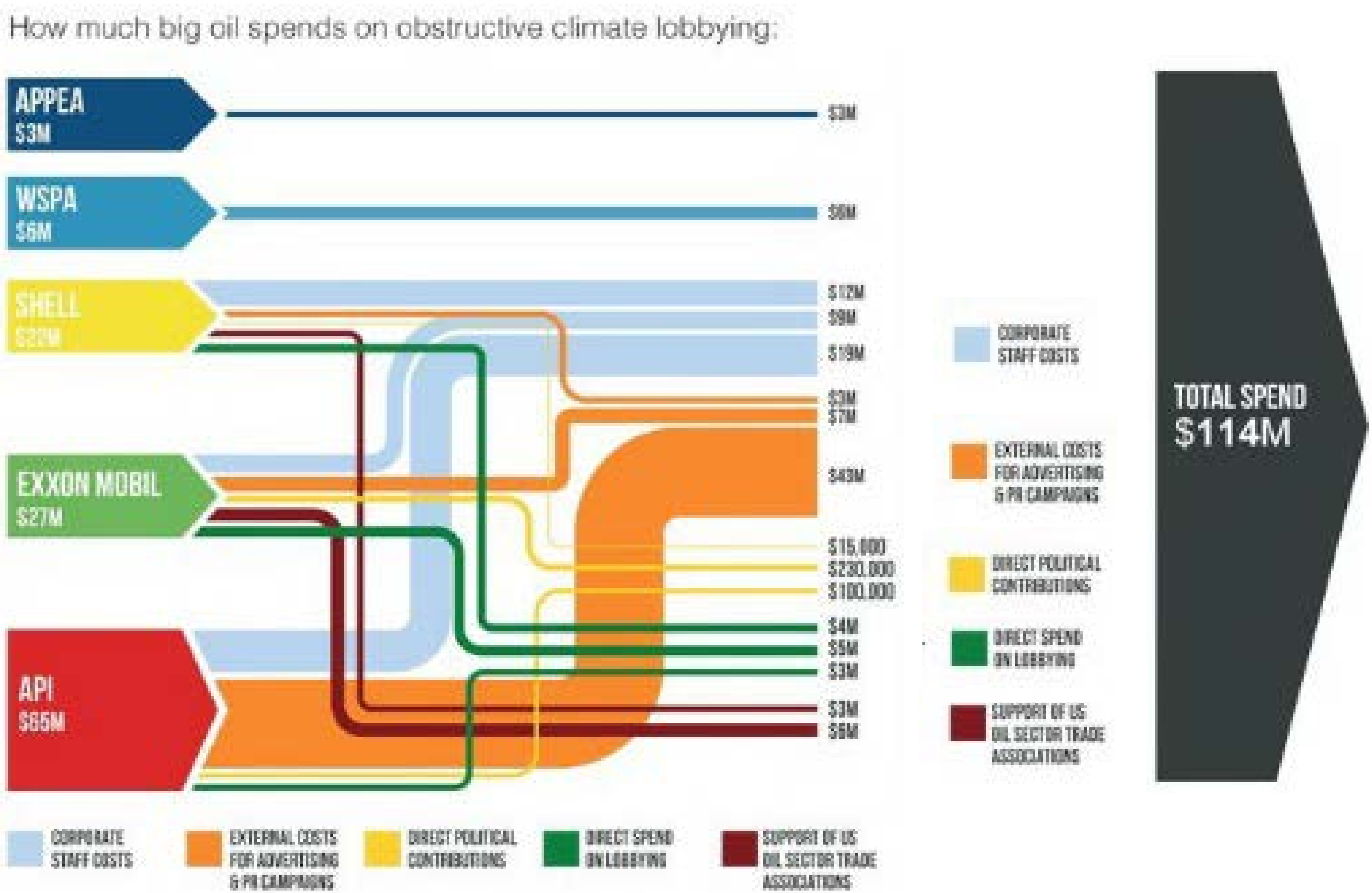
Sources: fossil fuels, nuclear, renewables

Global Energy Flow, 2011



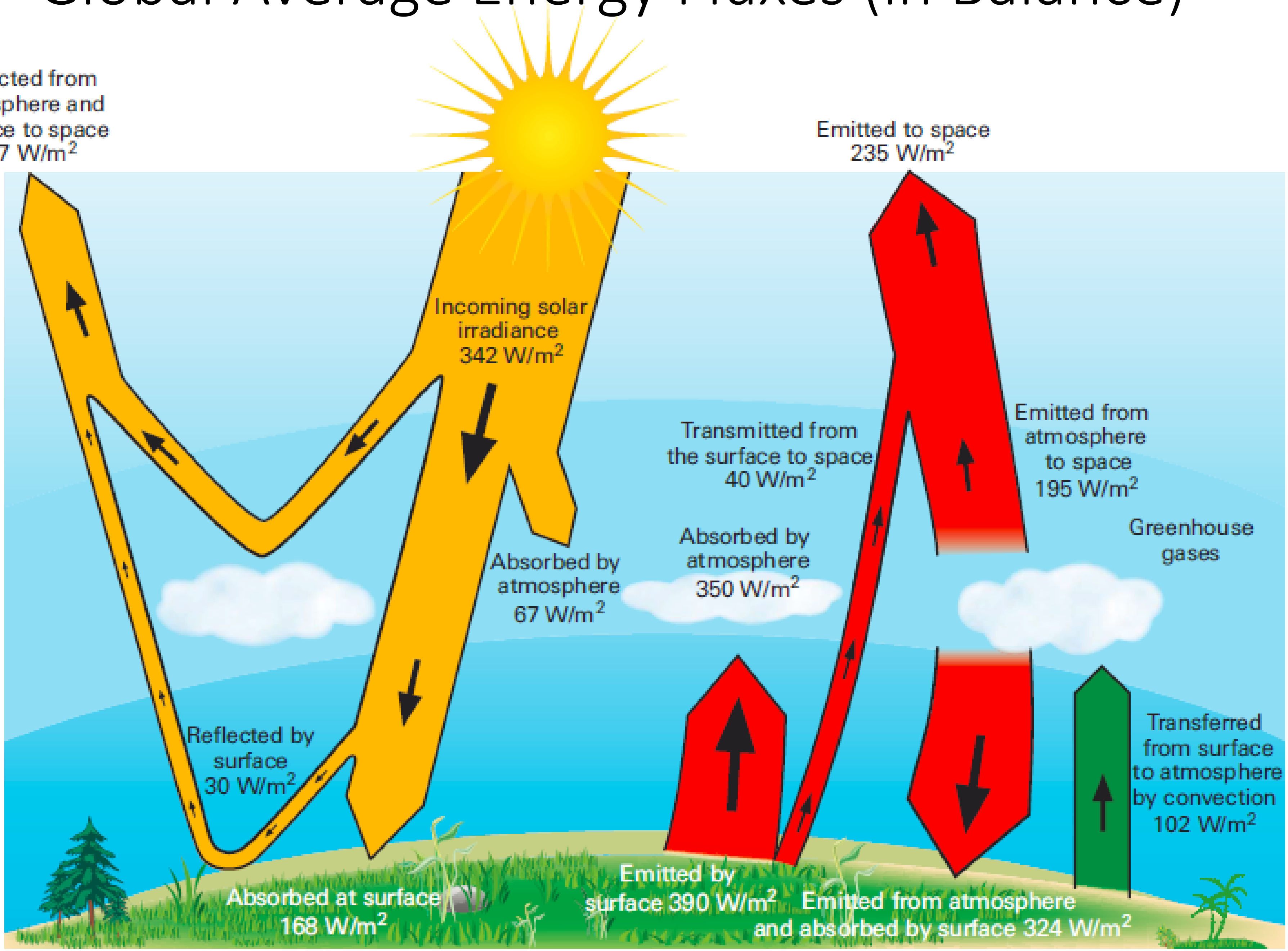
Source: LLNL 2014. Data is based on IEA's Extended World Energy Balances (2013 Edition). If this information or a reproduction of it is used, credit must be given to the Laurence Livermore National Laboratory and the U.S. Department of Energy, under whose auspices the work was performed. All quantities are rounded to 2 significant digits and annual flows of less than 0.05 PJ are not included. Totals may not equal sum of flows due to statistical differences. Imports and Exports represent gross global trade. Further detail on how all flows are calculated can be found at http://flowcharts.llnl.gov. LLNL-MI-410527.

Oil Company Climate Lobbying 2015

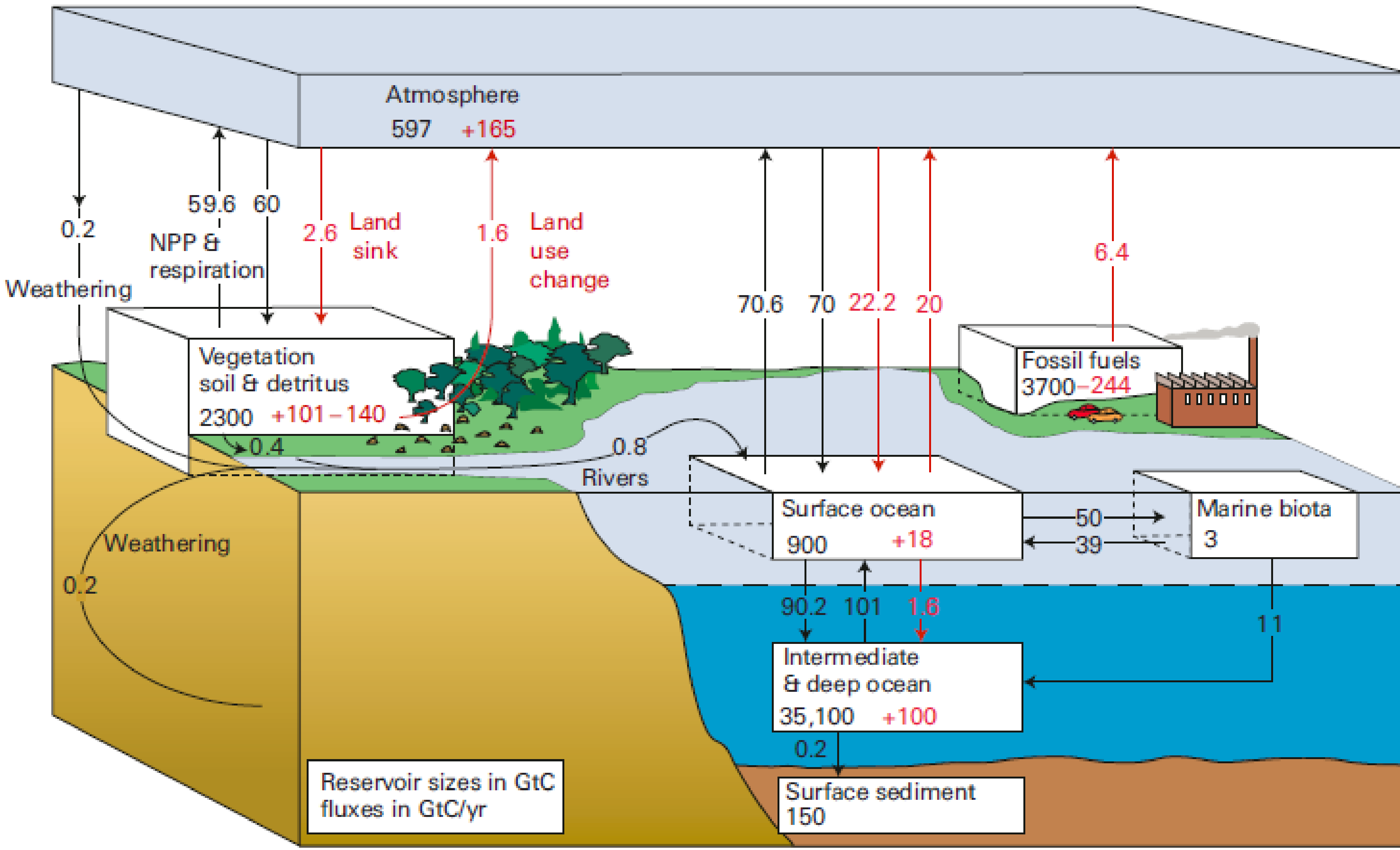


Climate Science

Global Average Energy Fluxes (in Balance)



Global Carbon Cycle



Black numbers pre-industrial steady state. Red numbers additions due to human activity.

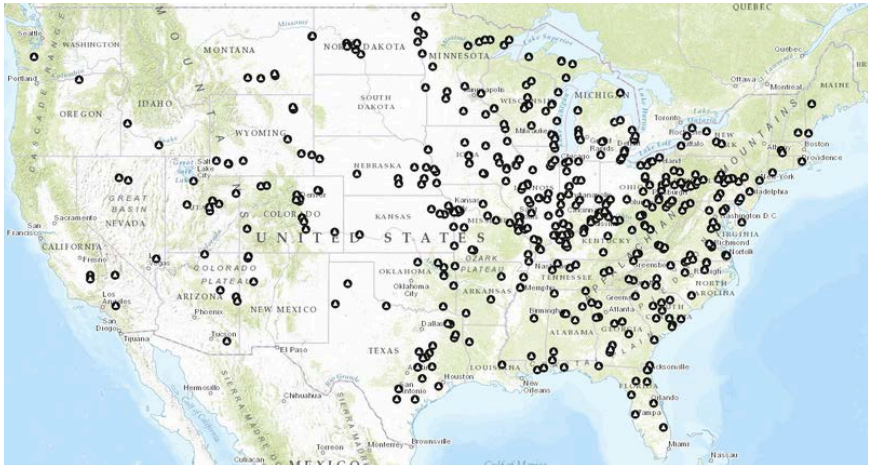
How Much CO_2 in the Atmosphere?

- Atmospheric pressure P = 101 kPa
- Mass of atmosphere $M = P\times(4\pi R^2)/g$
  - $101\ \text{kPa} \times (4\pi(6.4 \times 10^6\ \text{m}^{\,2})^2)/(9.8\ \text{N} / \text{kg}) = 5.3 \times 10^6\ \text{Gt}$
- GMW of atmosphere 78% O_2, 21% N_2, 1% Ar → 29 g per mole
- Atmosphere contains 1.83×10^{20} moles
- Currently CO_2 at 411 ppm = 7.52×10^{16} moles = 3,300 $GtCO_2$
- Pre-industrial CO_2 at 280 ppm 2,250 $GtCO_2$
- 1,050 $GtCO_2$ emitted in atmosphere since industrialization

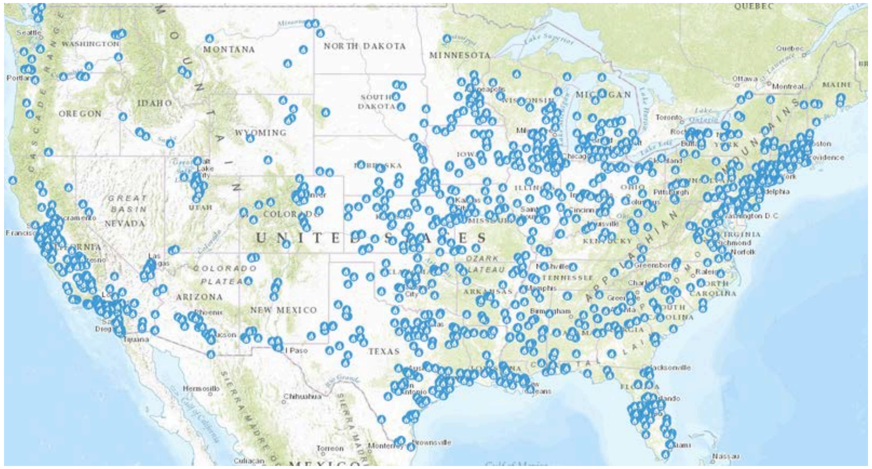
Try to Fathom Some Big Numbers

1 Gt CO_2

In the U.S. in 2018 9,719 power plants emitted 1.763 GT CO_2

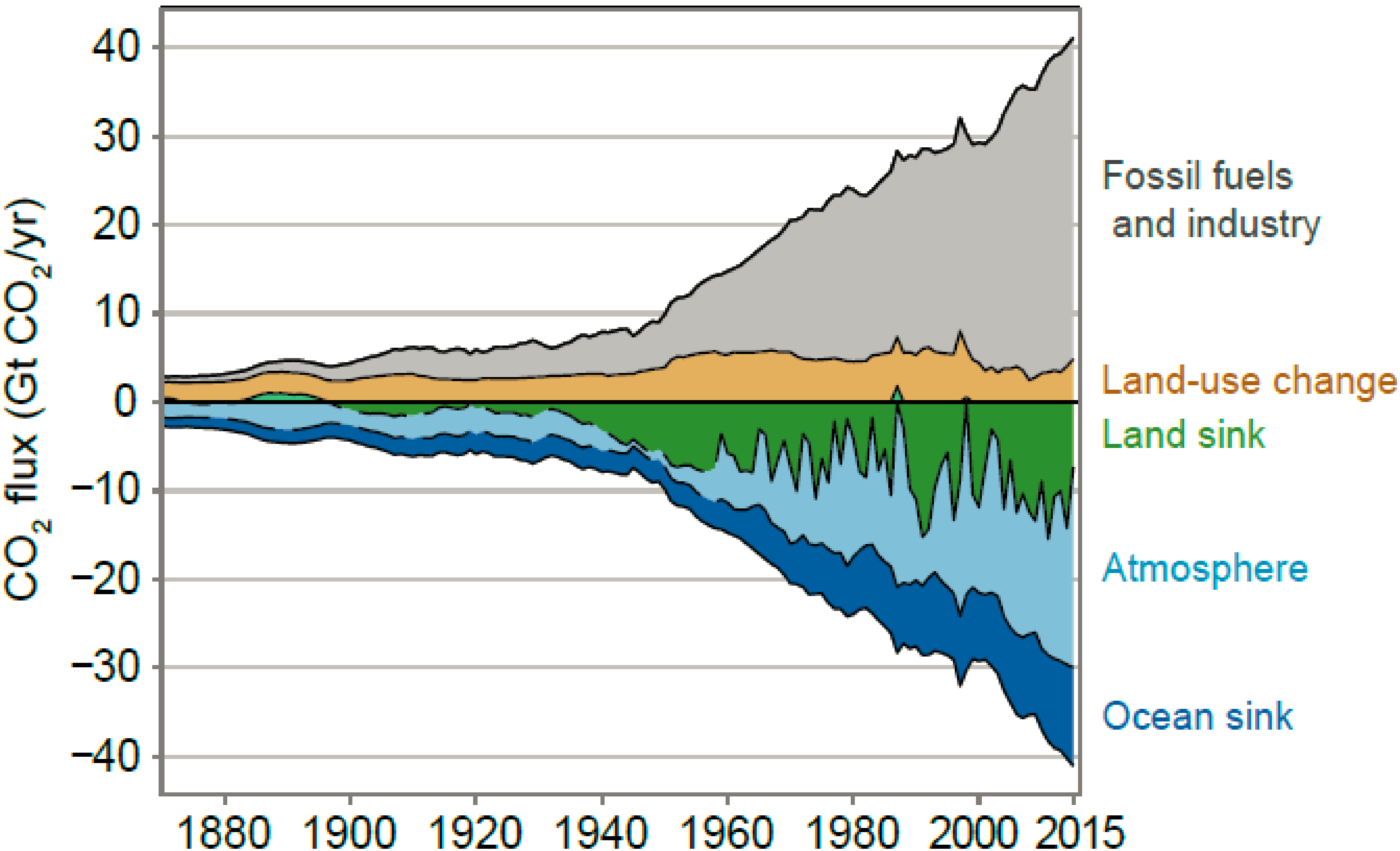


Coalfired plants

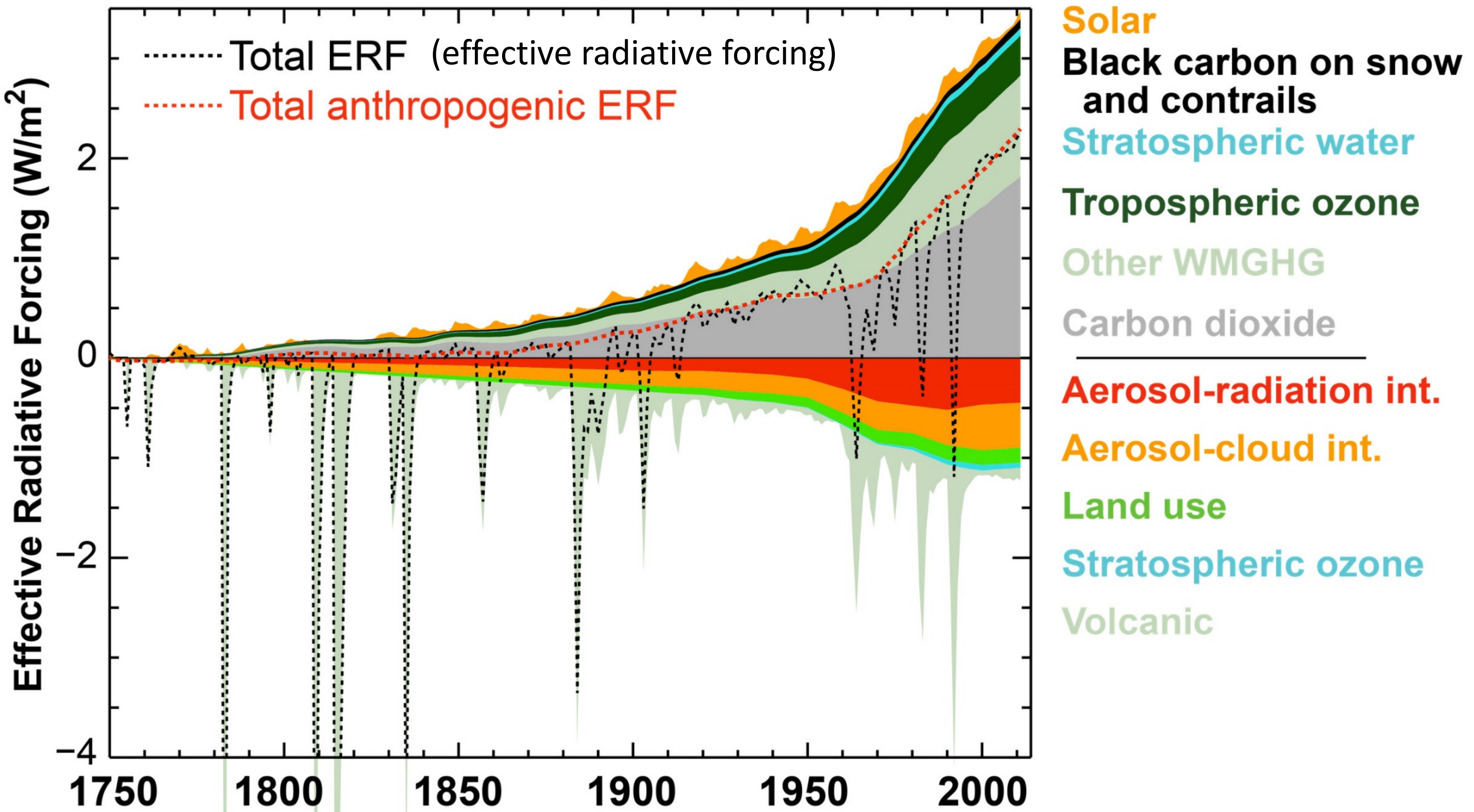


Natural gas fired plants

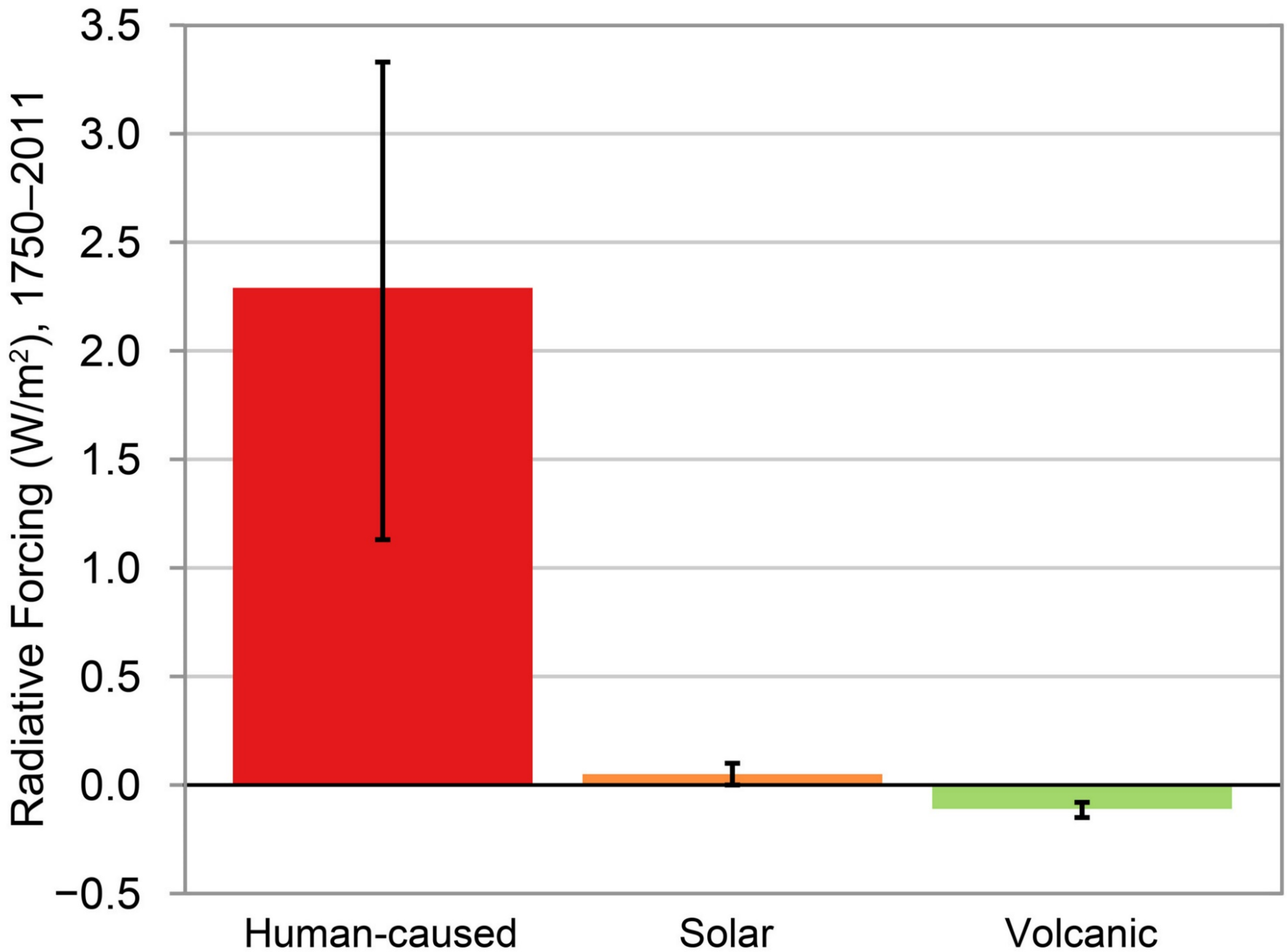
CO_2 Sources and Sinks 1870–2015



Time Evolution of Forcings

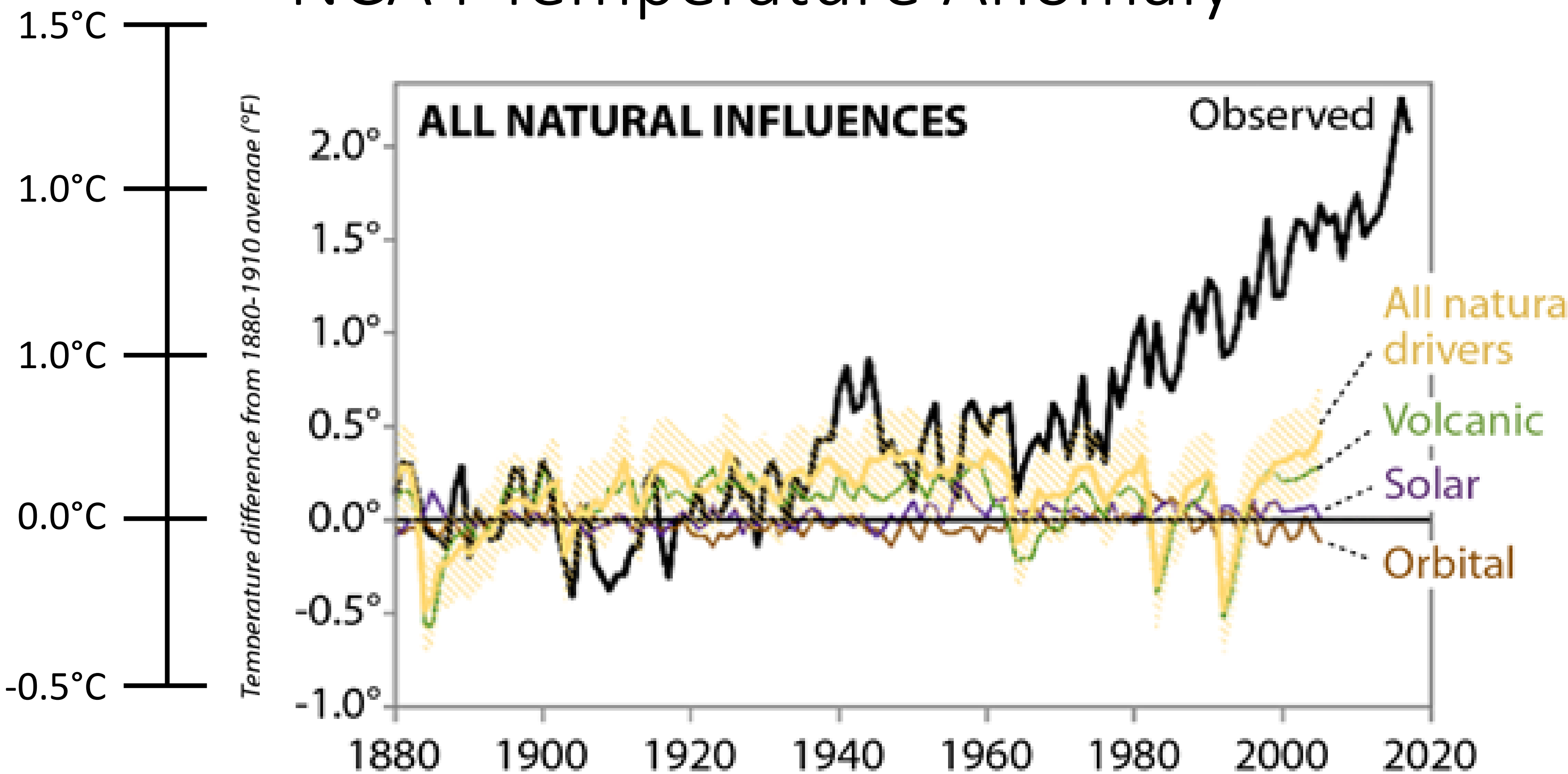


Causes of Radiative Forcing

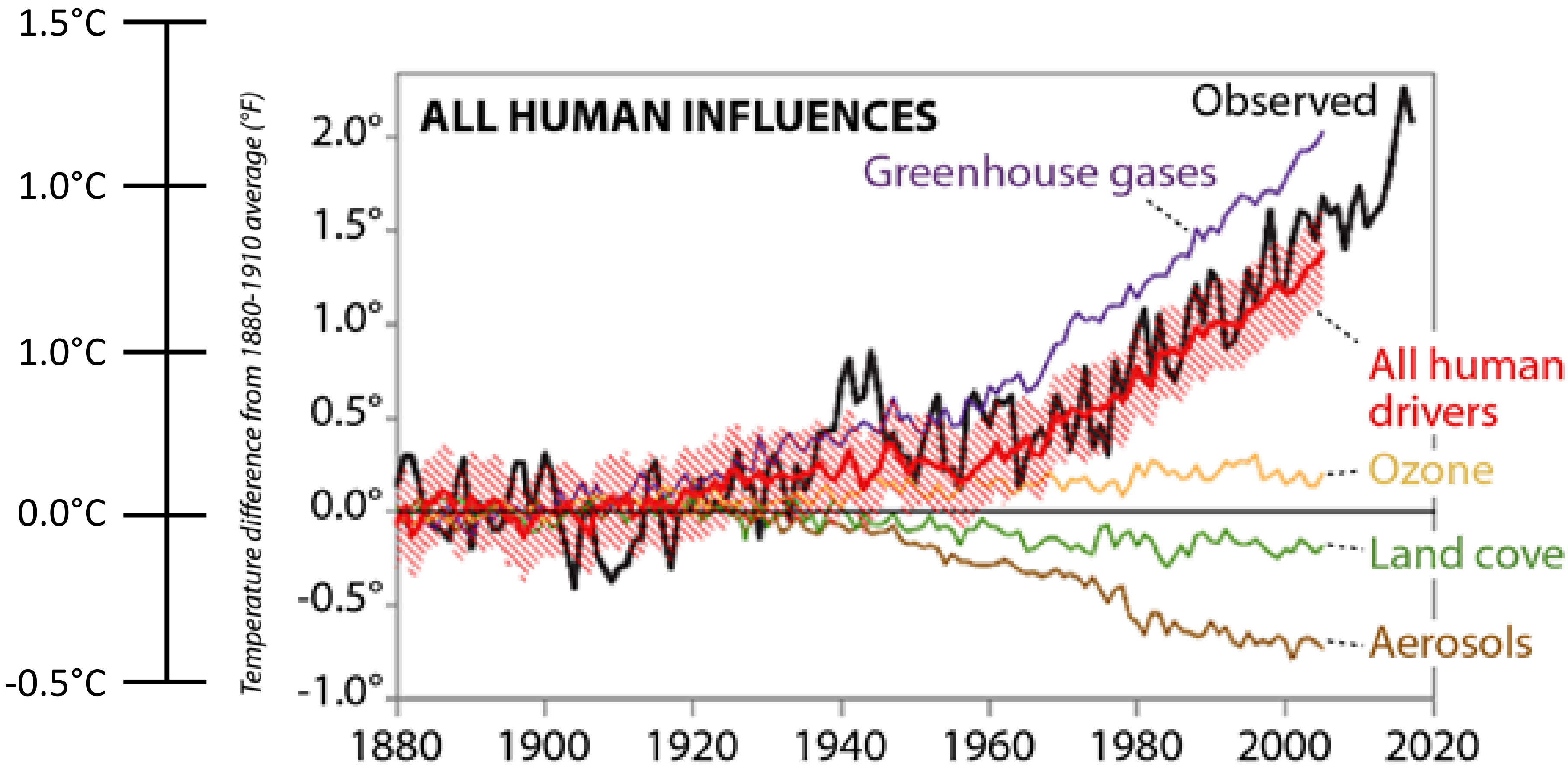


Temperature Analysis

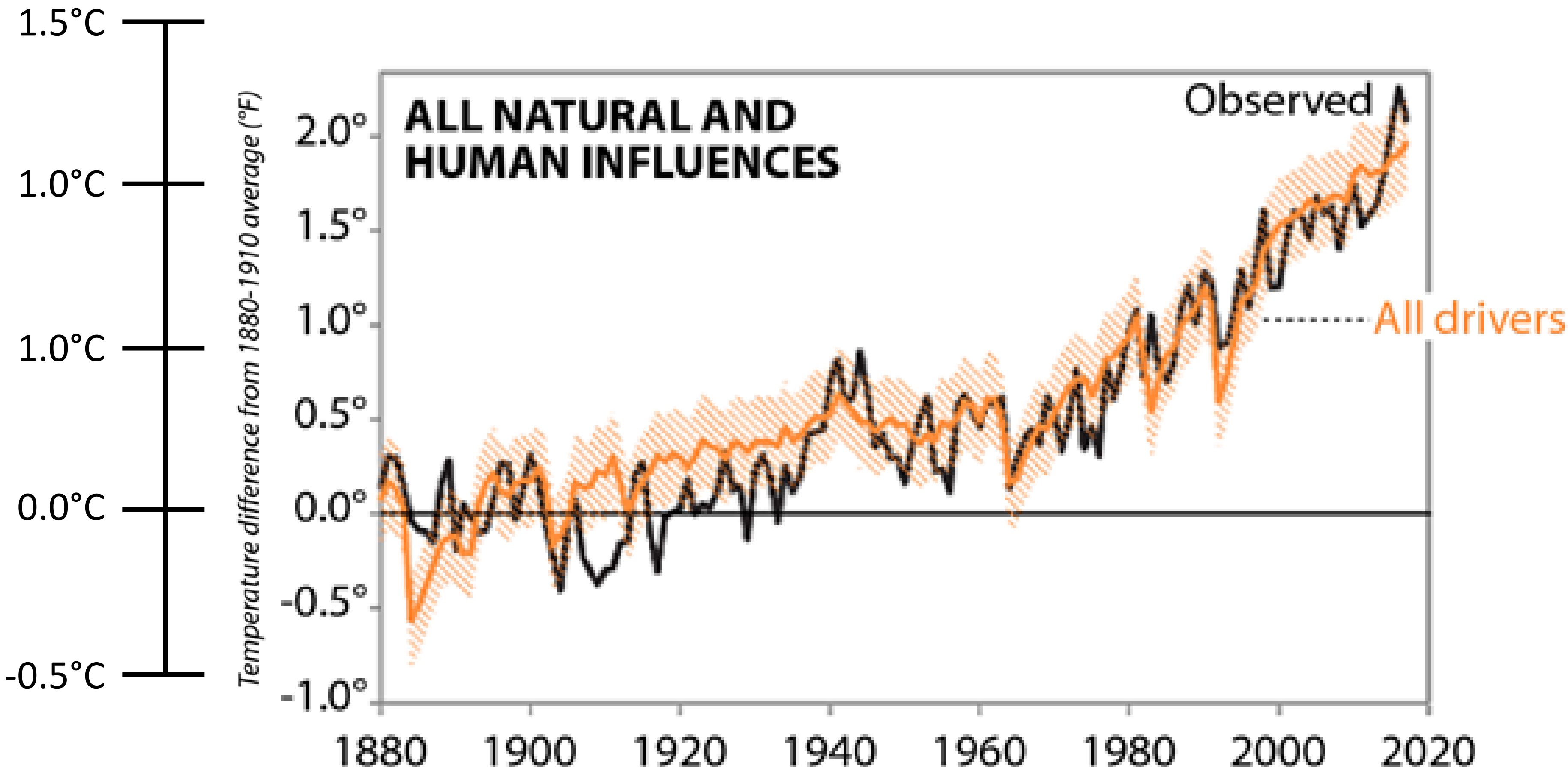
NCA4 Temperature Anomaly



NCA4 Temperature Anomaly



NCA4 Temperature Anomaly



Weather 2050

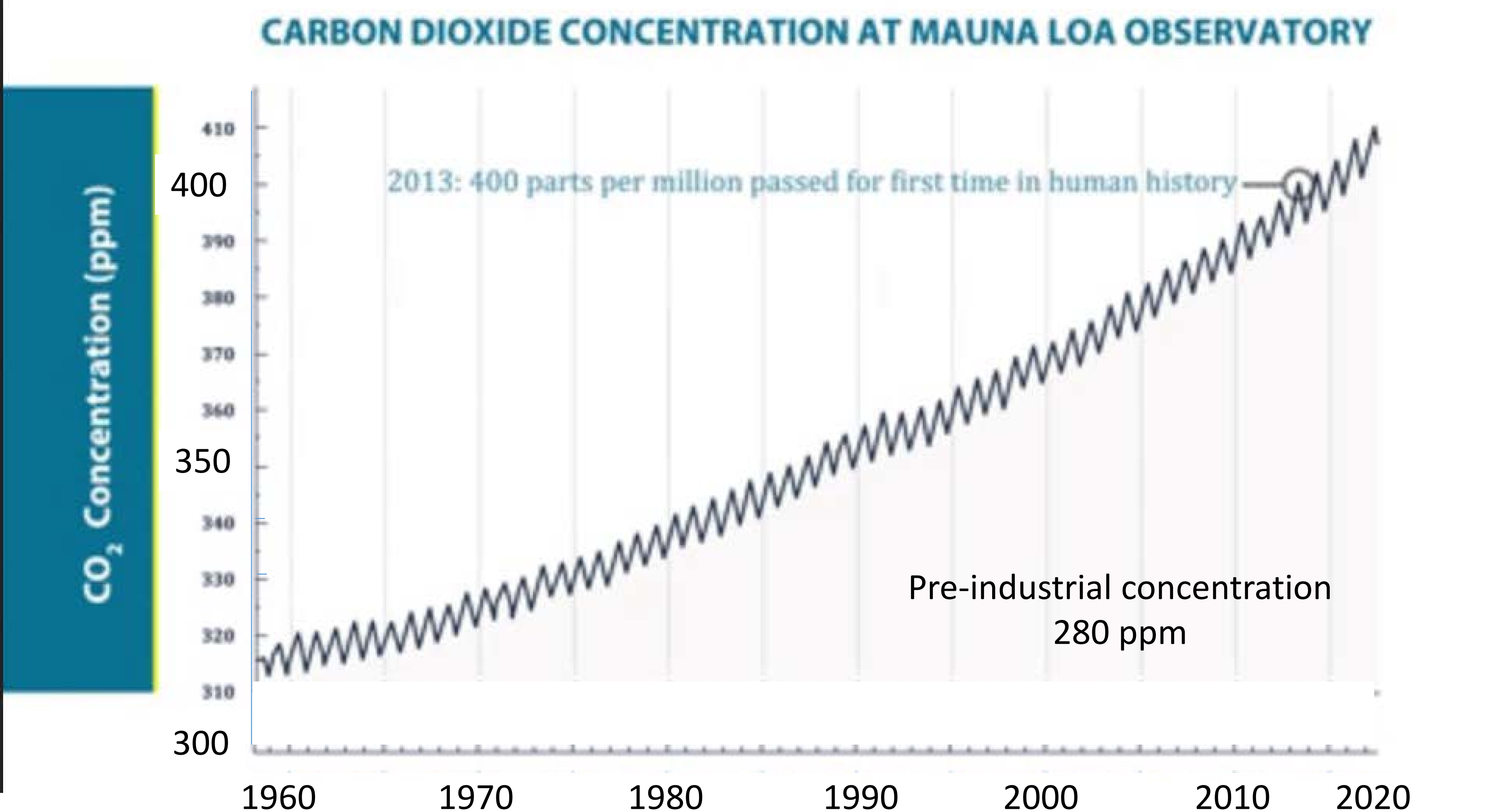

WMO Weather Report 2050 - USA Weather Channel 720
Weather Report
23 September 2050
The Weather Channel, USA
00:06


Weather Report
23 September 2050
NHK, Japan
00:06

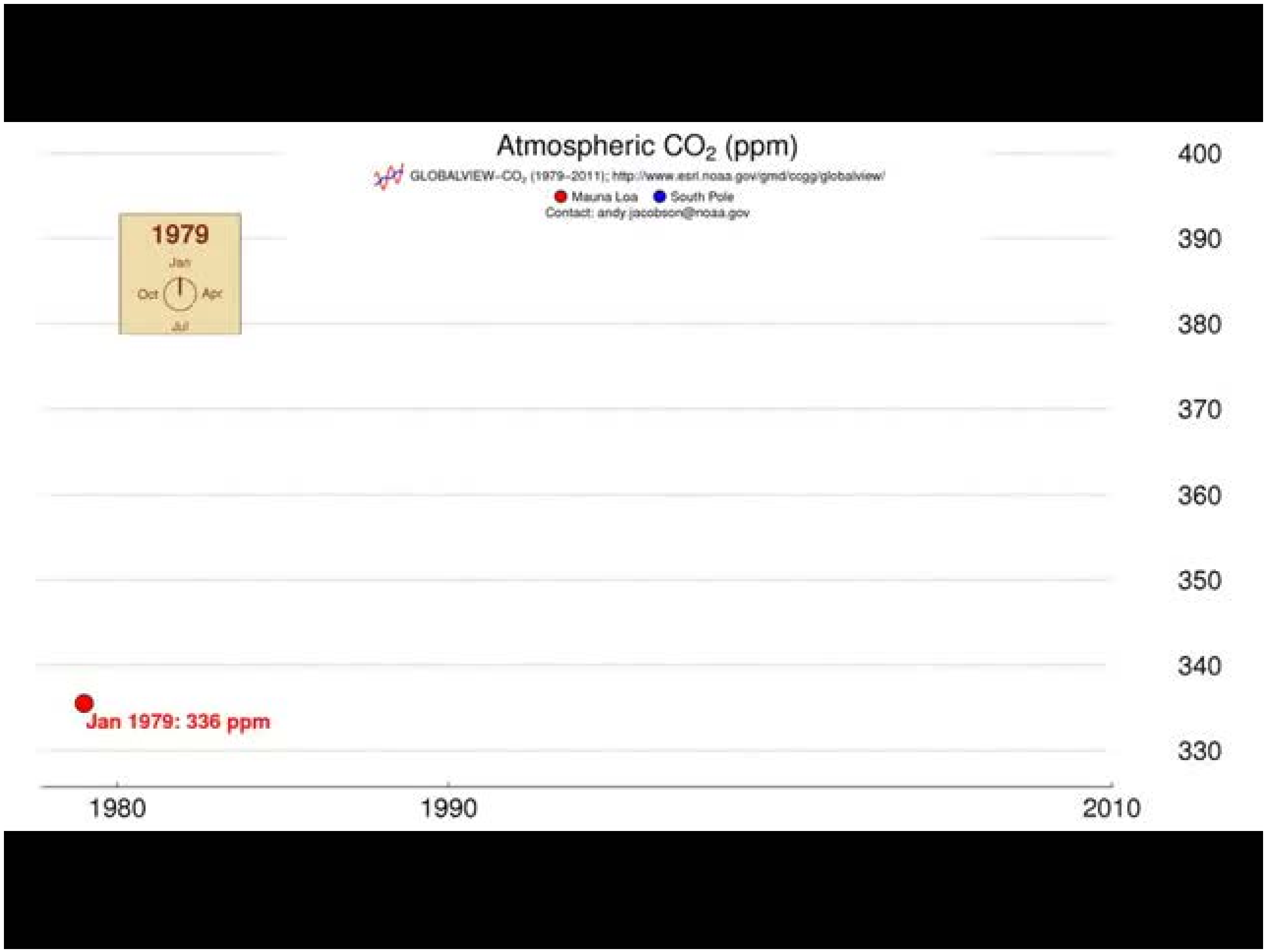
Climate Change and GHG Emissions

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

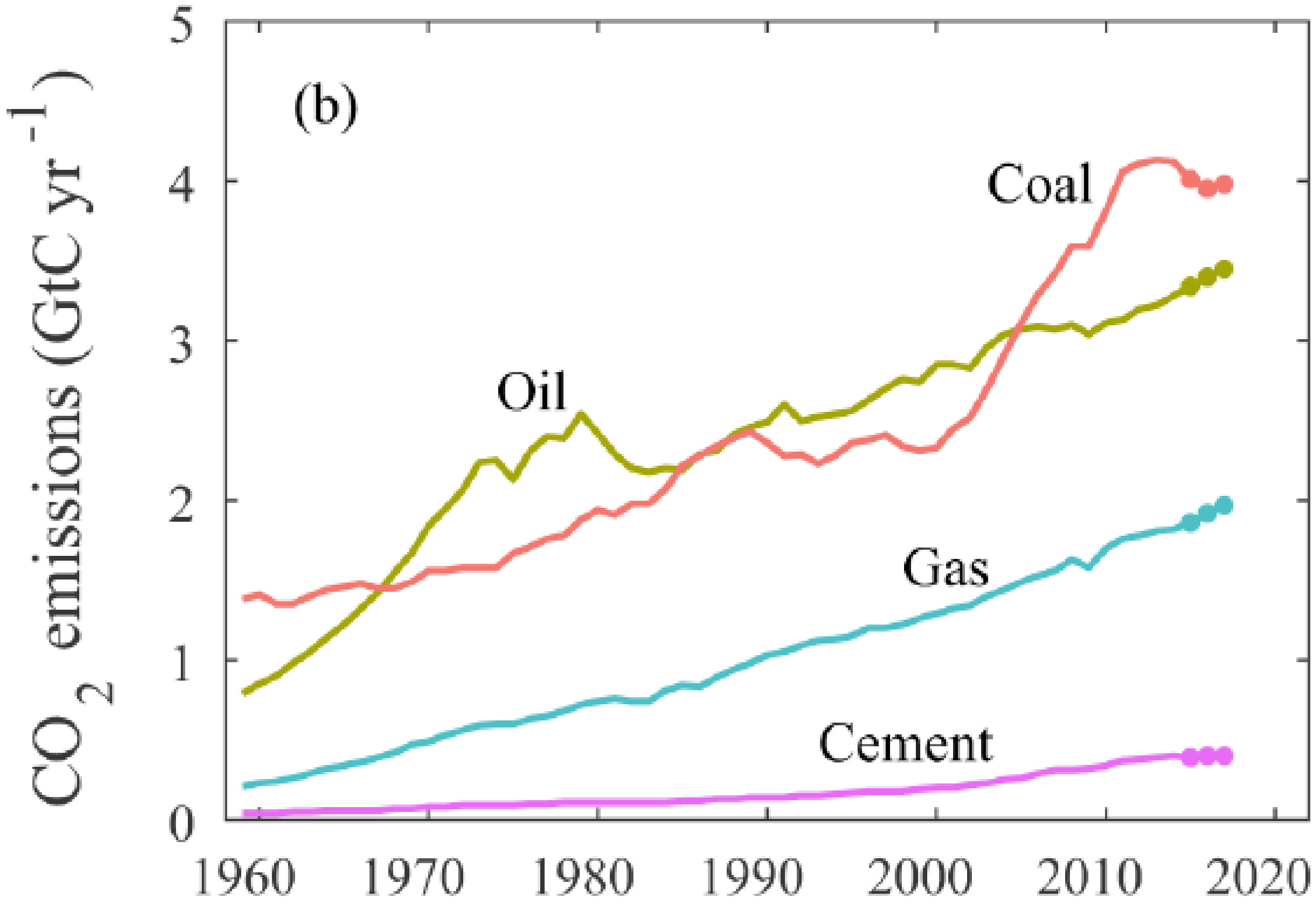
Keeling Curve: Atmospheric CO_2 Concentration



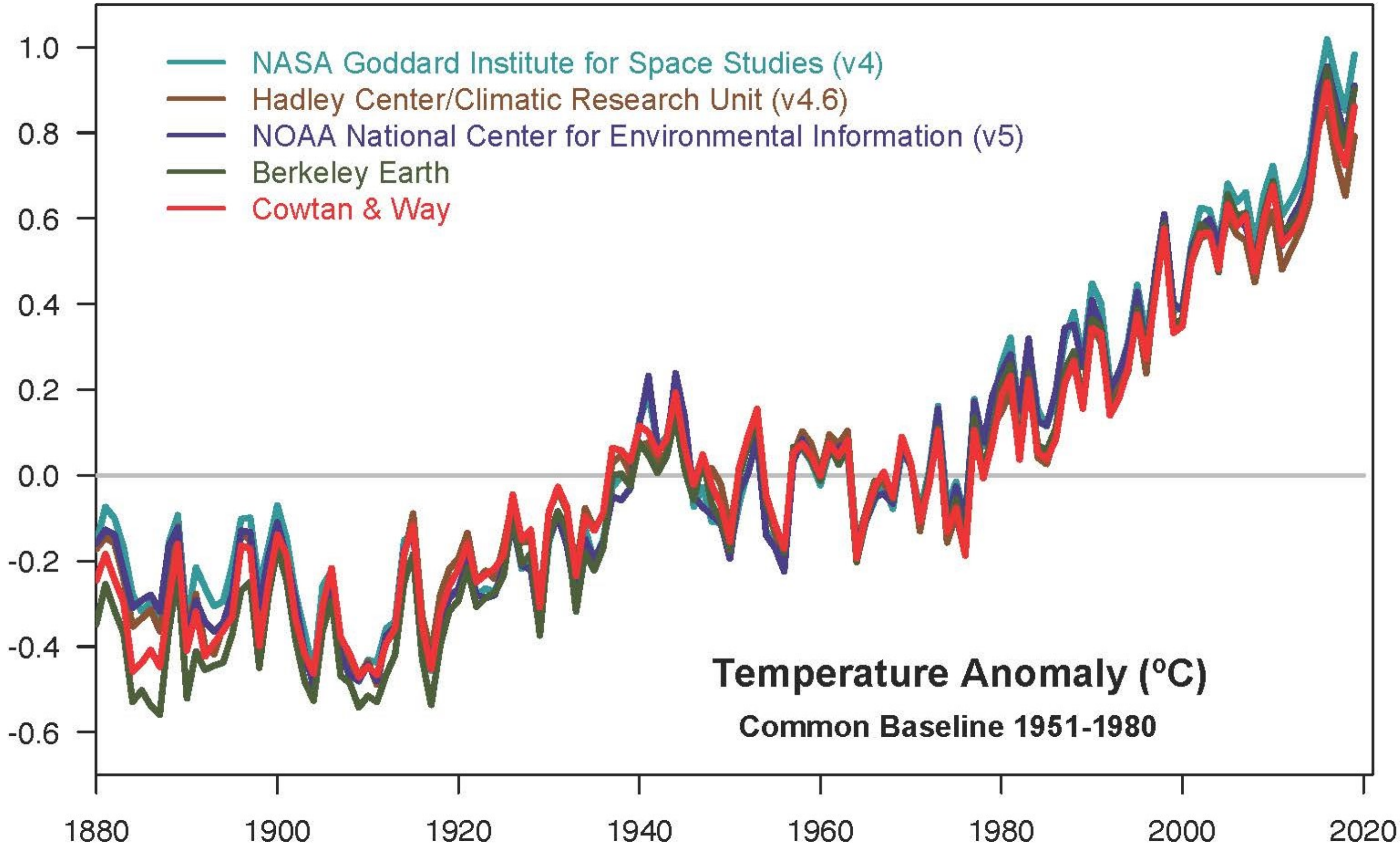
NOAA 800,000 Years of CO_2 Emissions

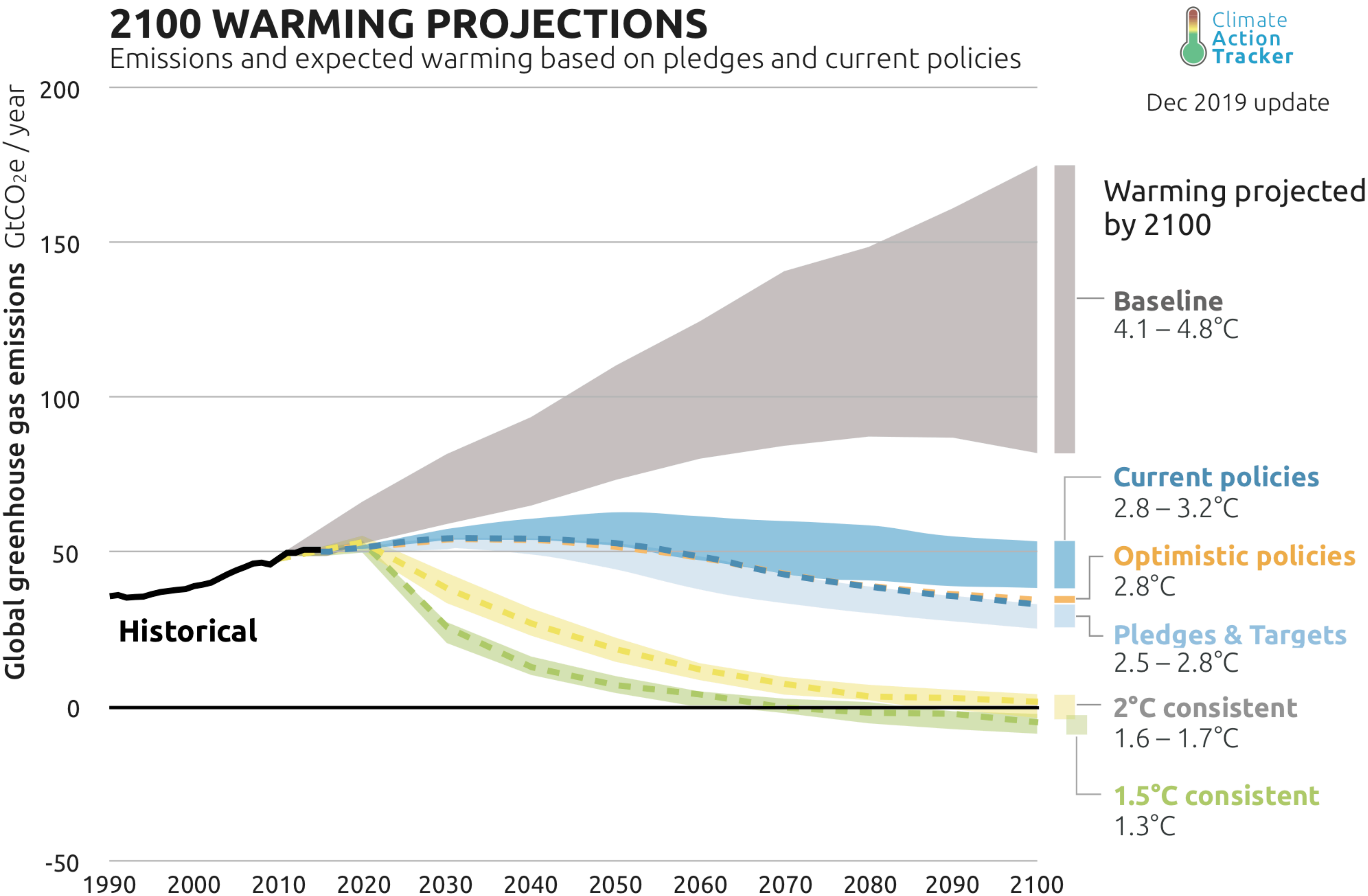


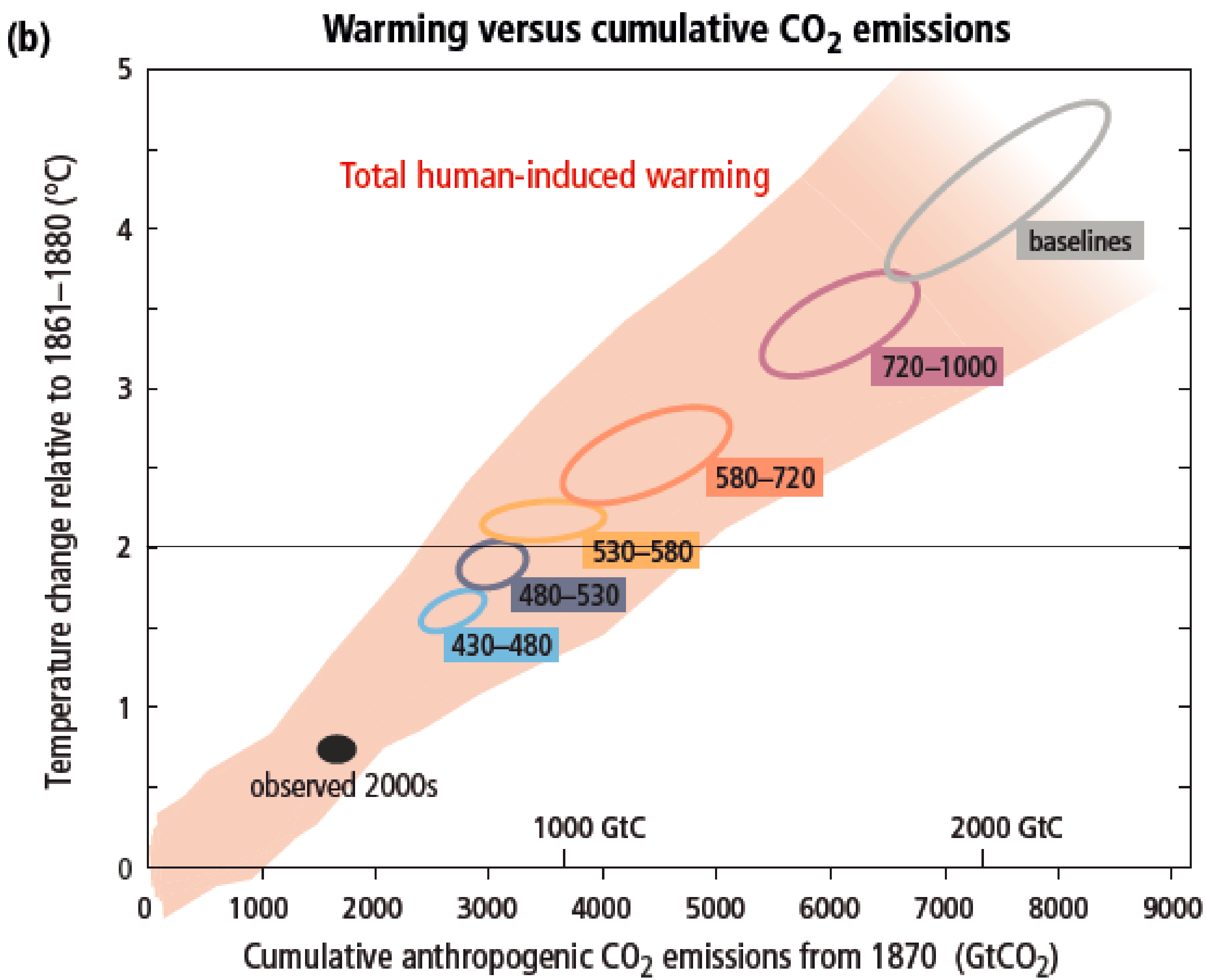
Global Emission by Fuel Type



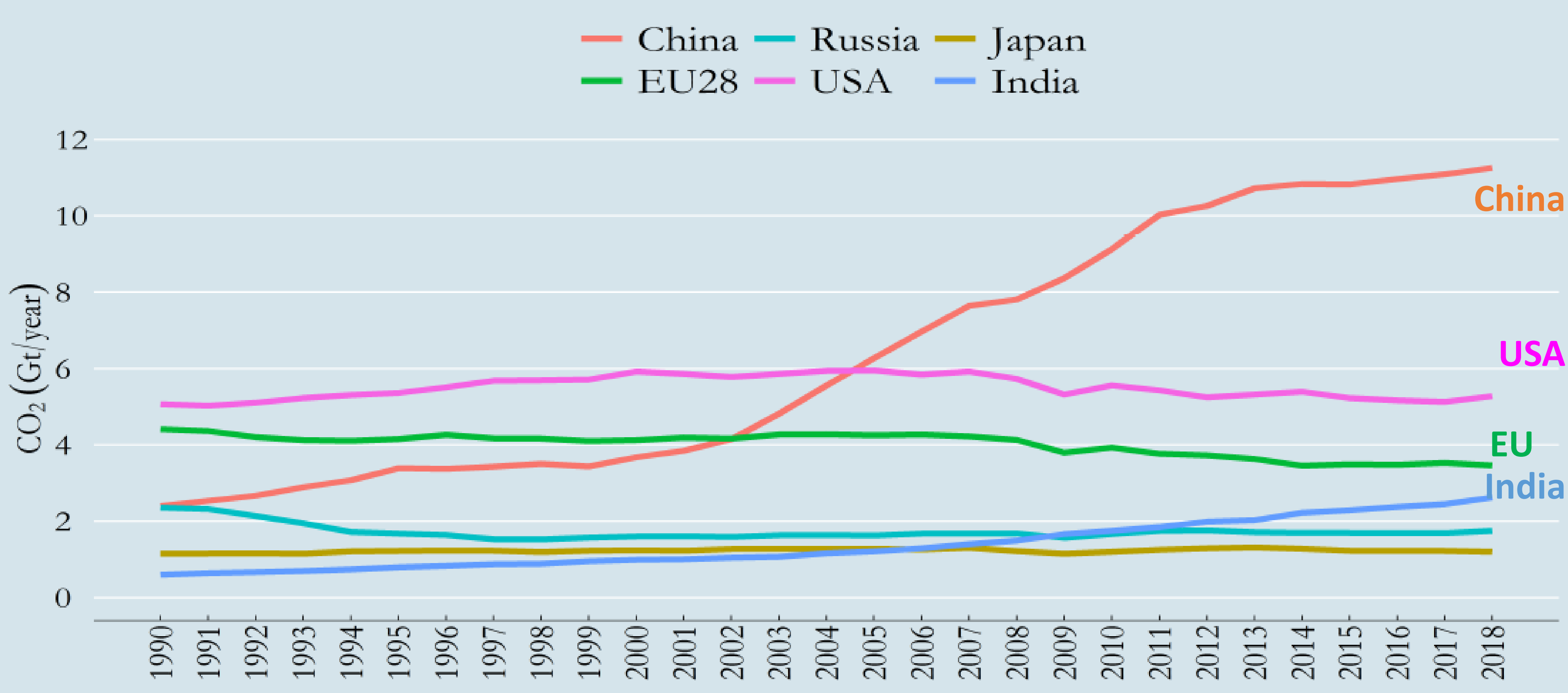
National Aeronautics and Space Administration
Goddard Institute for Space Studies



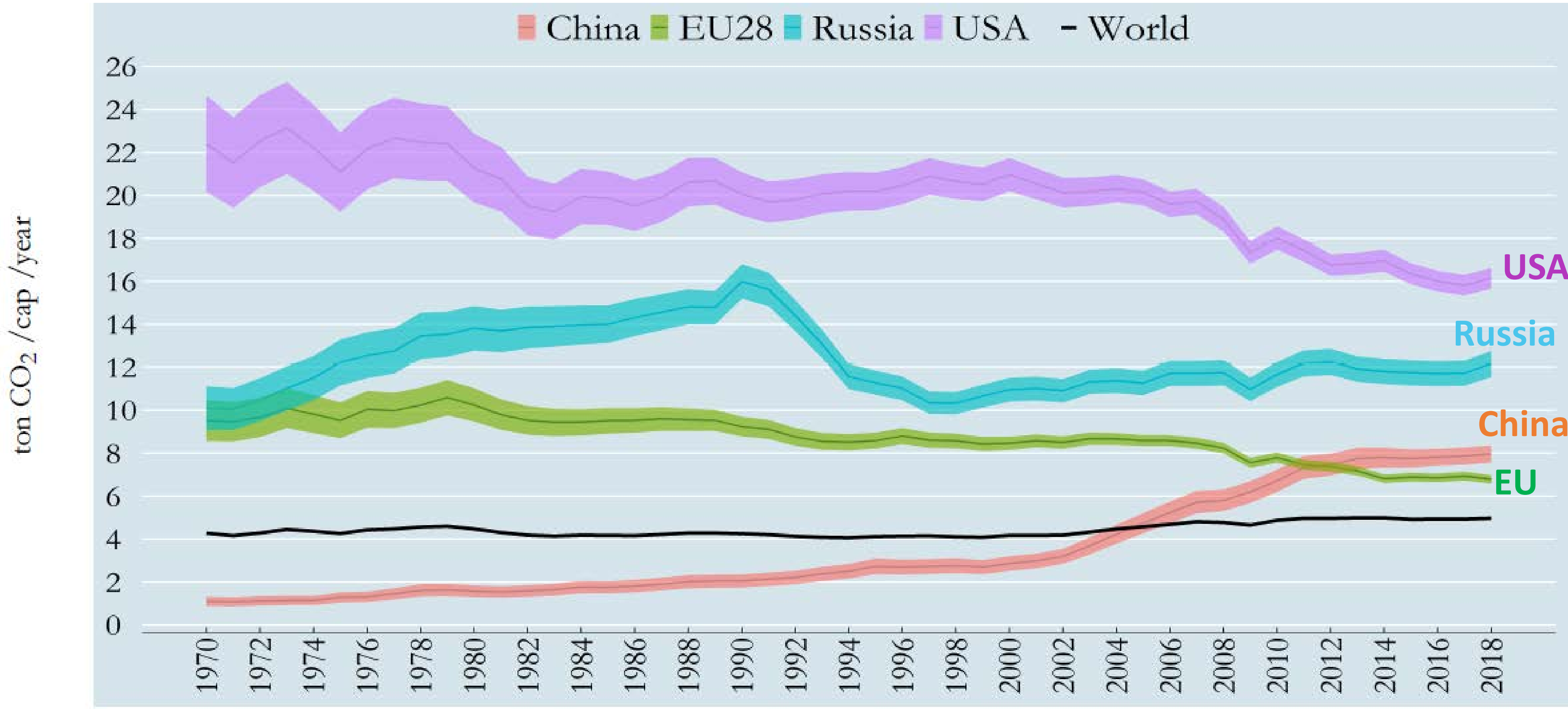

2100 WARMING PROJECTIONS
Emissions and expected warming based on pledges and current policies
Climate Action Tracker
Dec 2019 update
Global greenhouse gas emissions GtCO2e / year
200
150
100
50
0
-50
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Historical
Warming projected by 2100
Baseline
4.1 – 4.8°C
Current policies
2.8 – 3.2°C
Optimistic policies
2.8°C
Pledges & Targets
2.5 – 2.8°C
2°C consistent
1.6 – 1.7°C
1.5°C consistent
1.3°C


(b)
Warming versus cumulative CO2 emissions
Total human-induced warming
baselines
720–1000
580–720
530–580
480–530
430–480
observed 2000s
1000 GtC
2000 GtC
Temperature change relative to 1861–1880 (°C)
0
1
2
3
4
5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Cumulative anthropogenic CO2 emissions from 1870 (GtCO2)

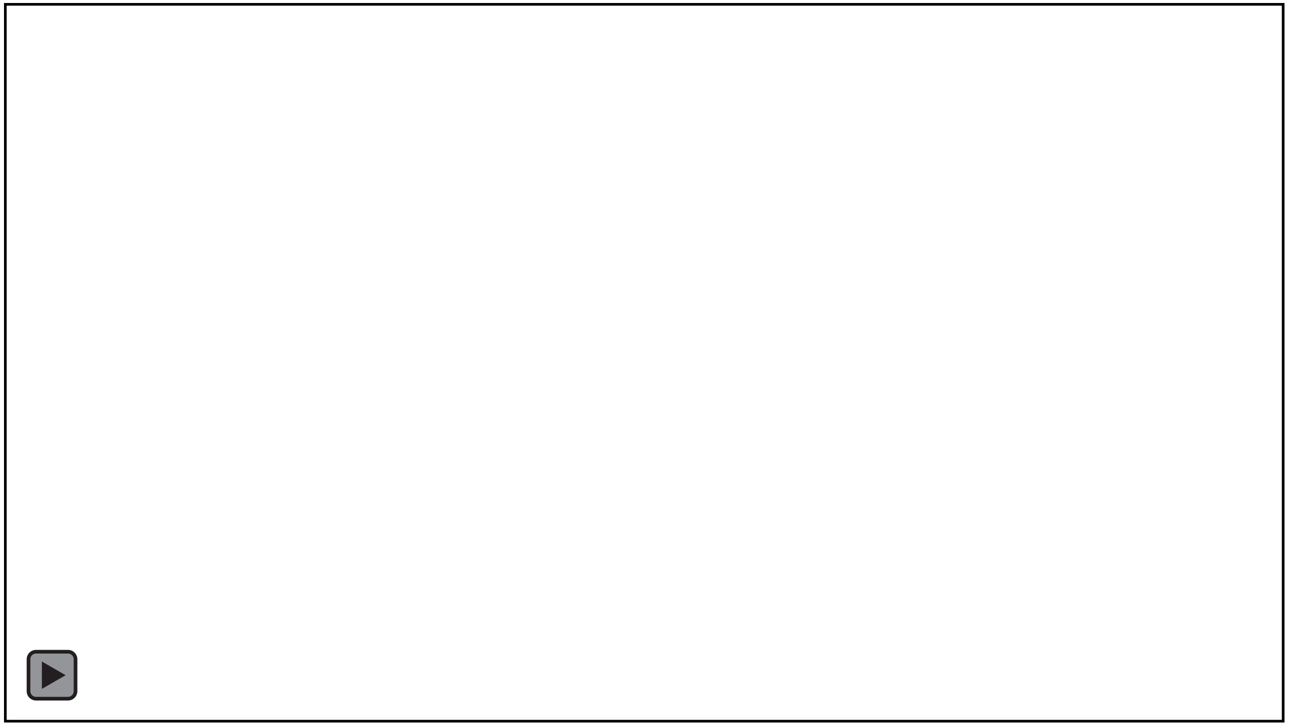
Fossil CO_2 Emissions of Selected Economies



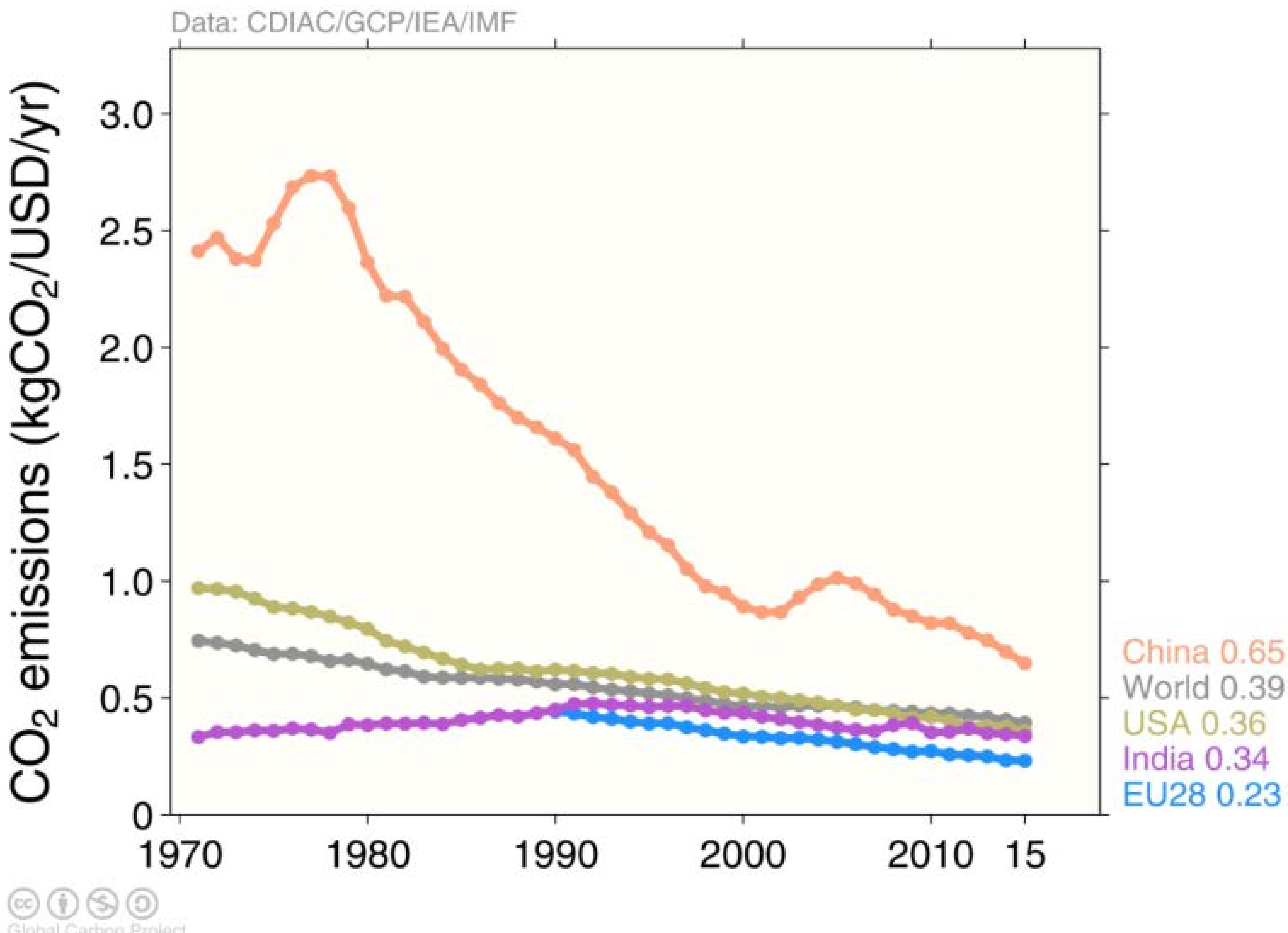
Annual Per Capita CO_2 Emissions



CO_2 Emission Timeline Selected Countries



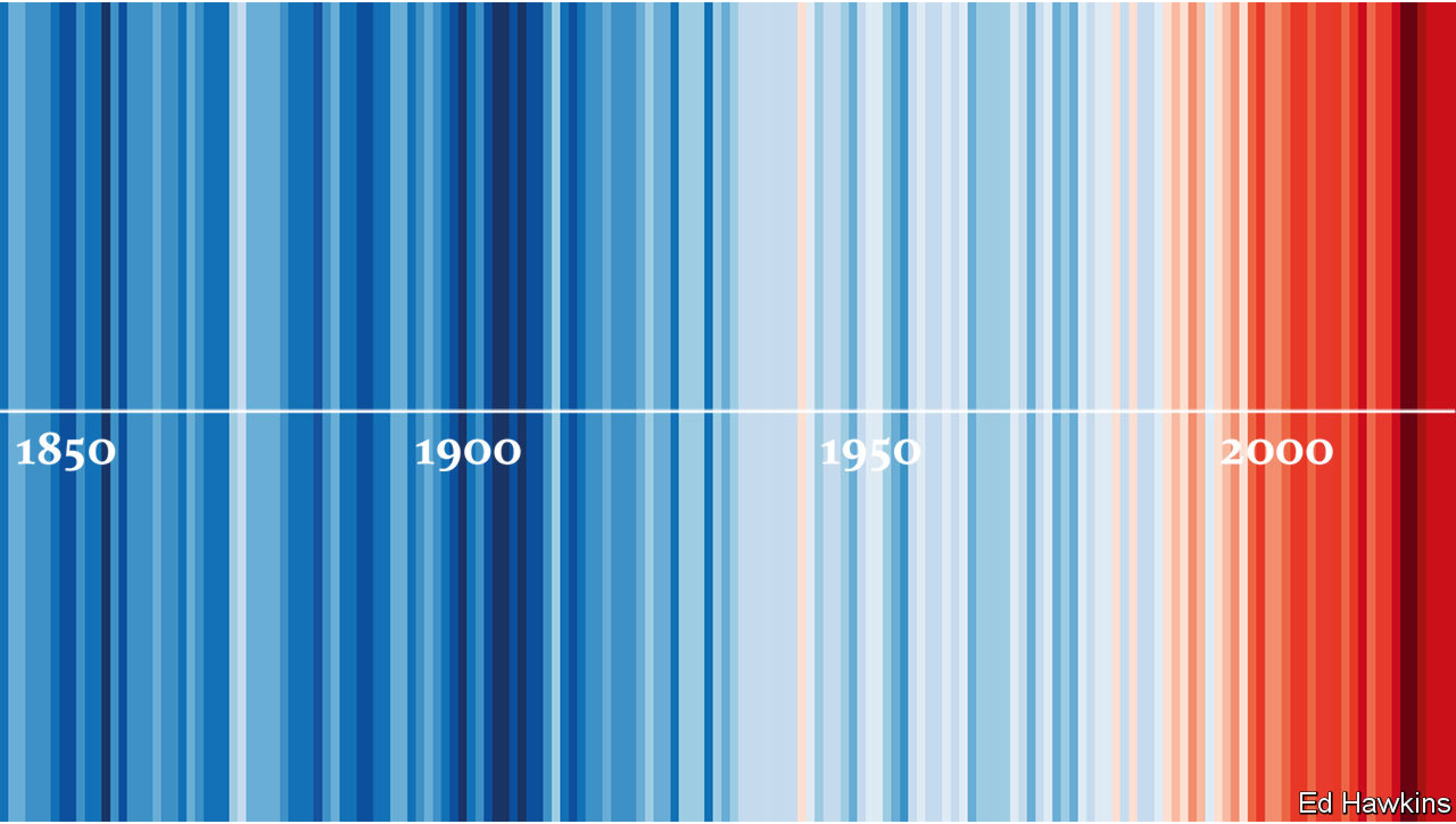
Emission Intensity 1970 - 2015



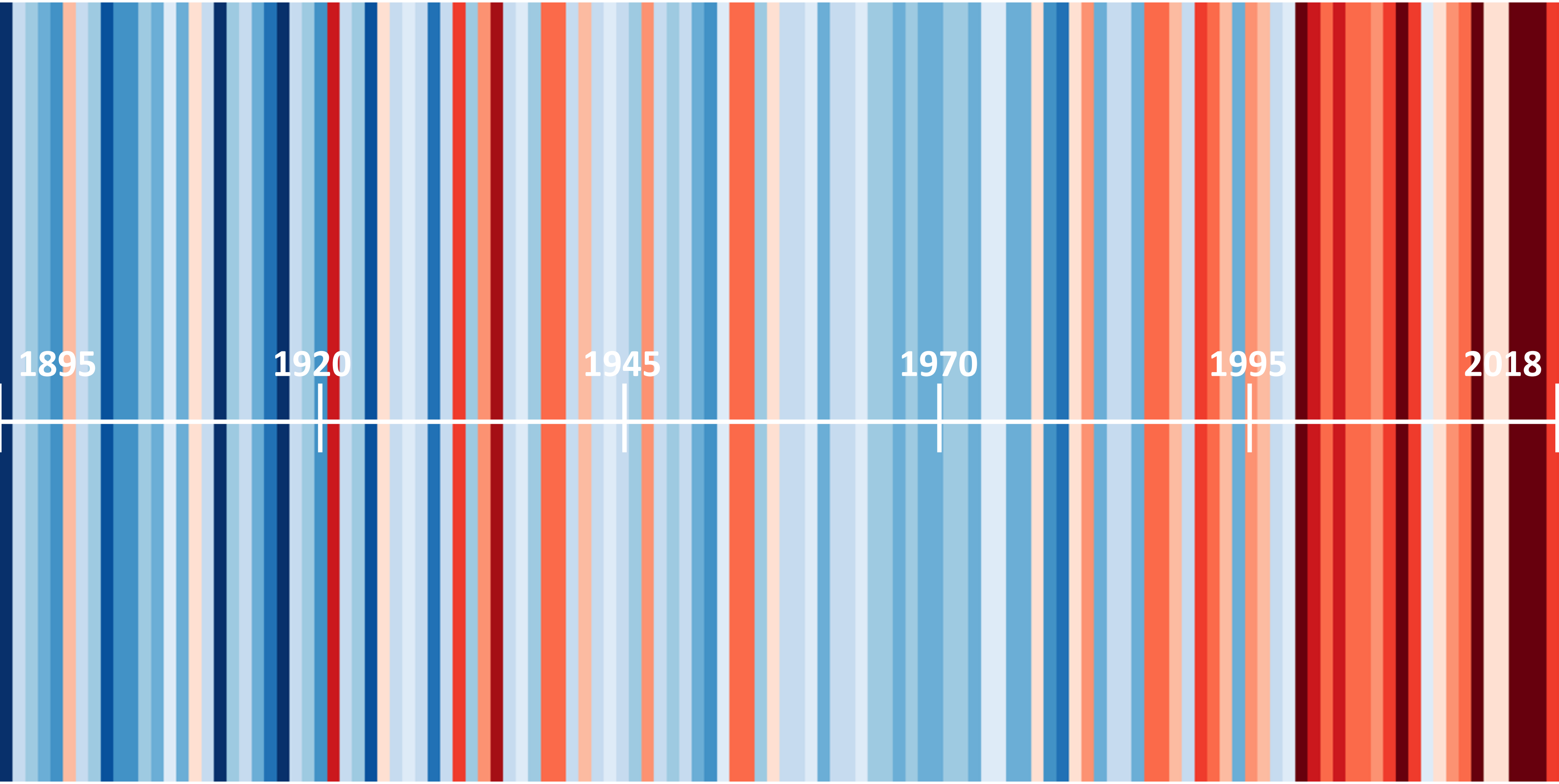
Stripes


The Economist
Iran's dangerous game
Lessons from a Wall Street titan
Why rent controls are wrong-headed
Goddess of the Taiwan Strait
The climate issue
1850
1900
1950
2000

Warming Stripes for GLOBE from 1850-2018



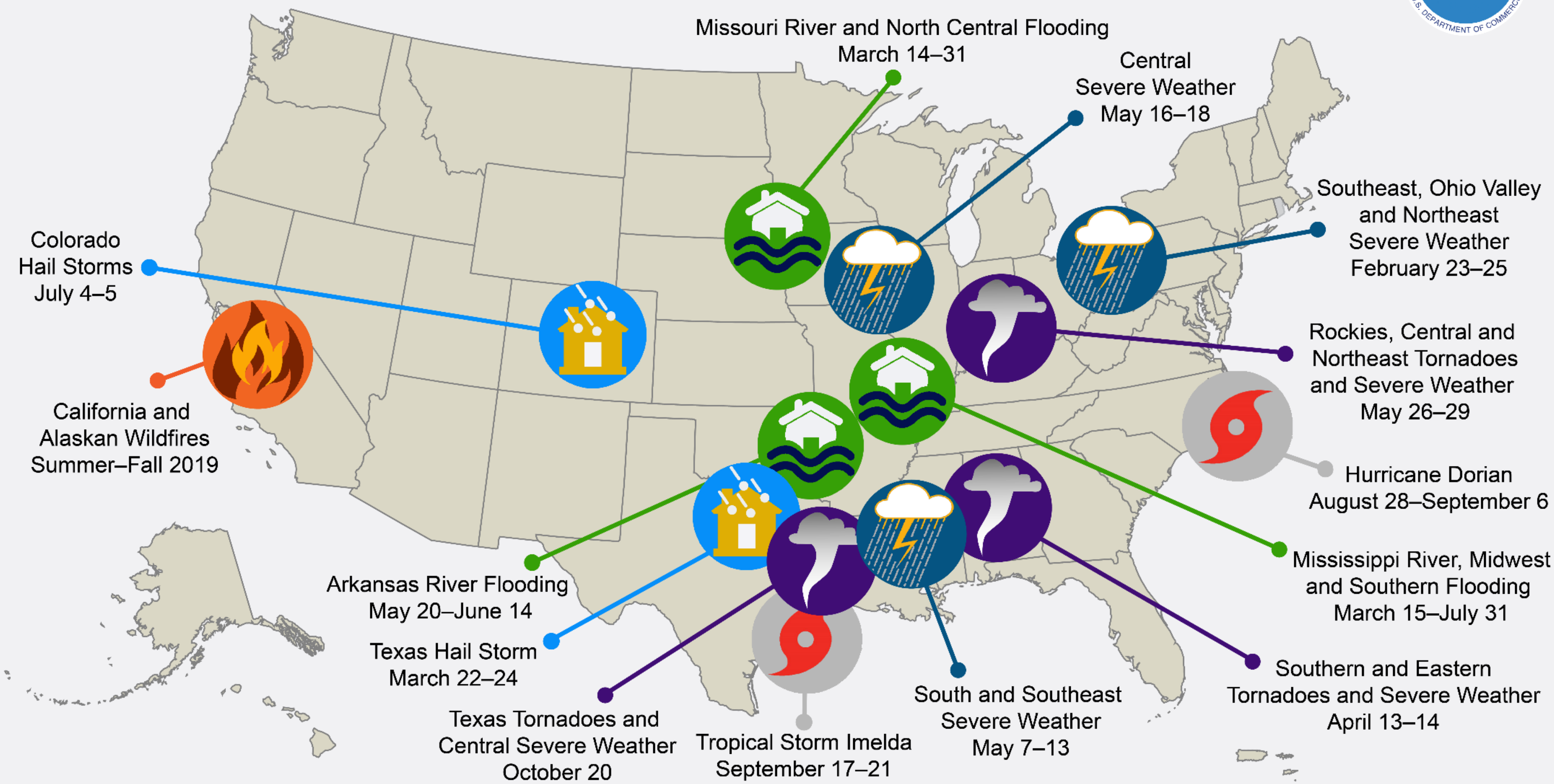
Warming Stripes for All of USA from 1895-2018



Billion Dollar Weather Events

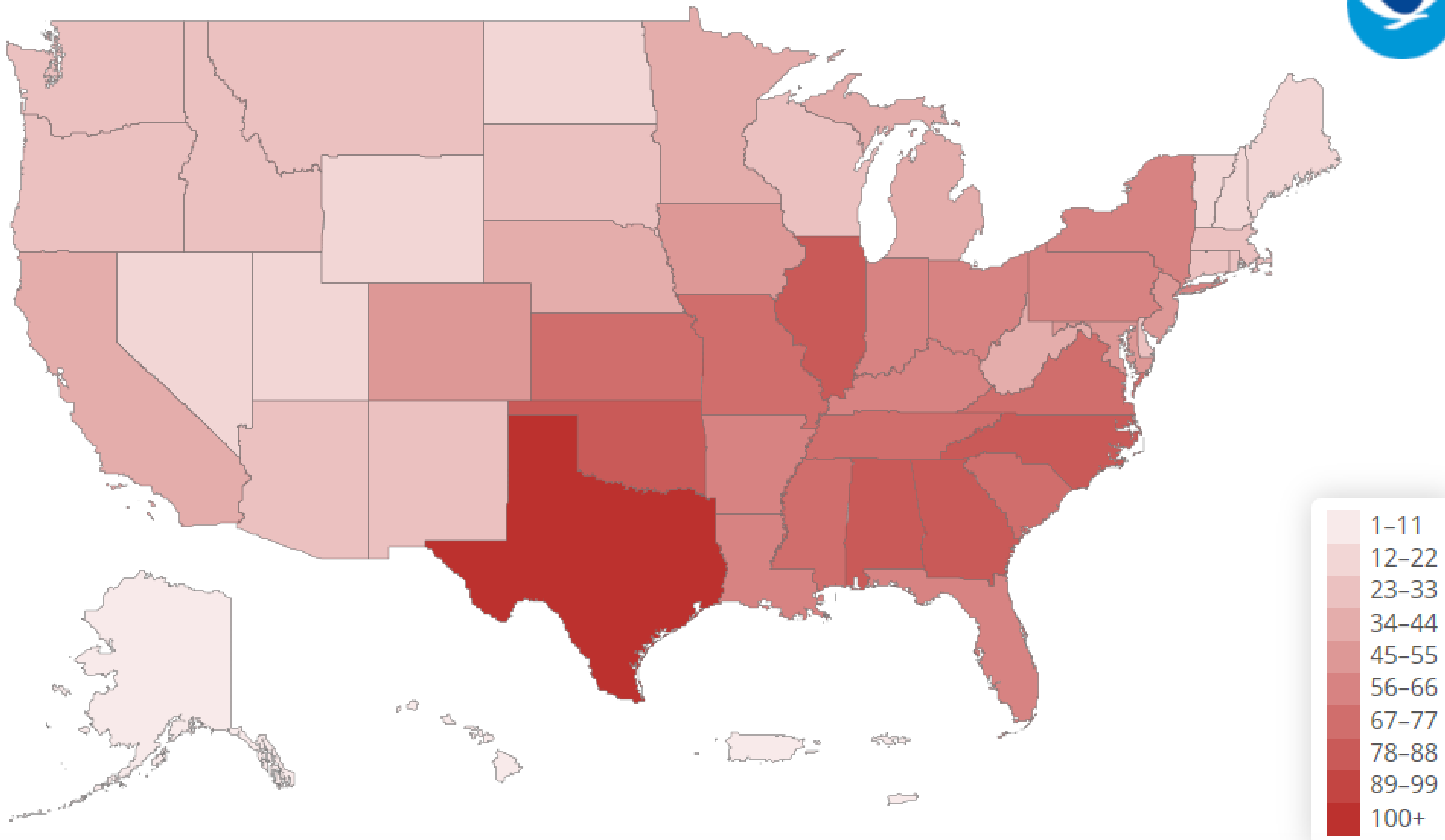
NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. 2019 Billion-Dollar Weather and Climate Disasters



This map denotes the approximate location for each of the ***14 separate billion-dollar weather and climate disasters*** *that impacted the United States* ***during 2019****.*

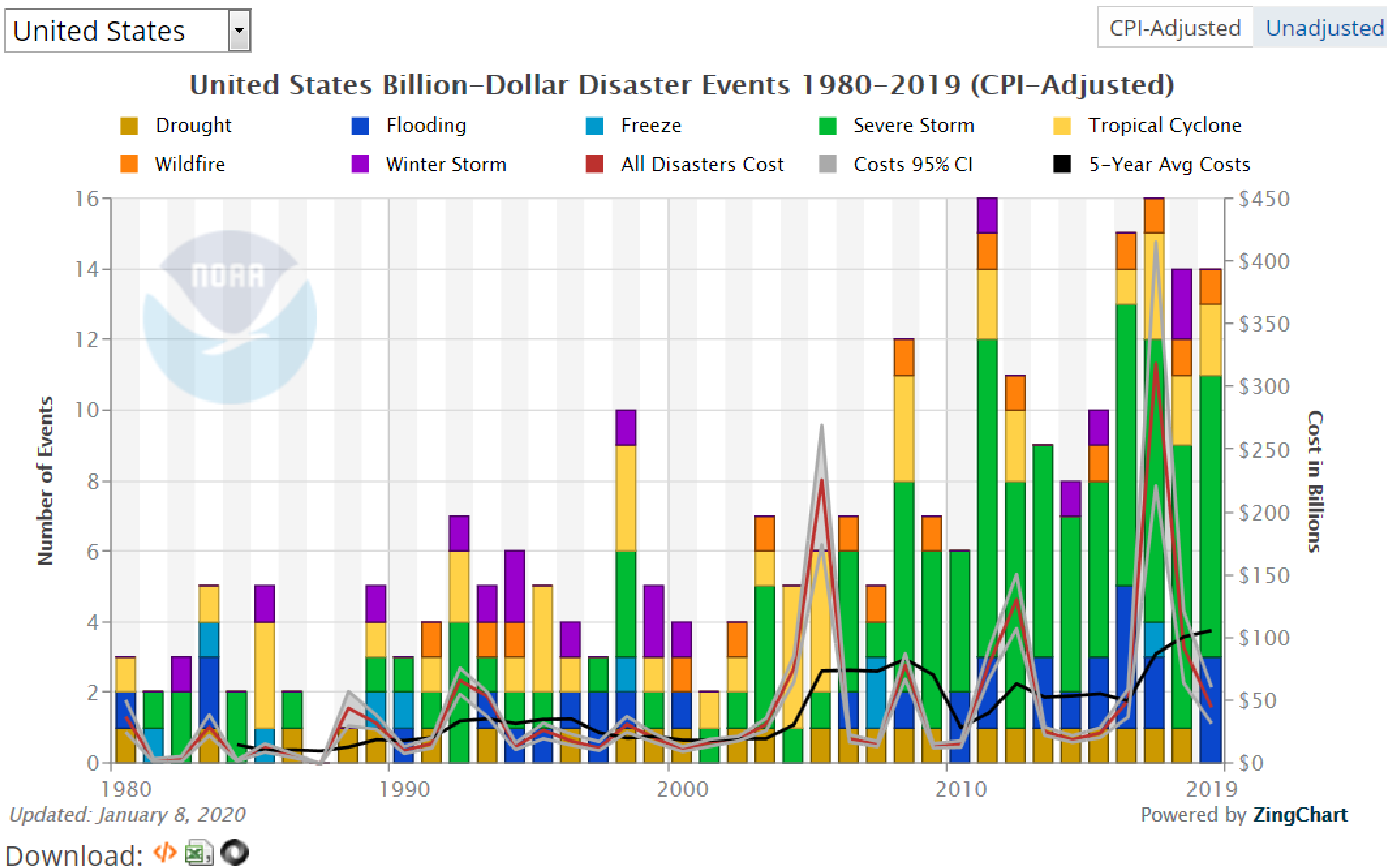
1980-2019 Billion-Dollar Weather and Climate Disasters (CPI-Adjusted)



United States

Drought:	26	Flooding:	32	Freeze:	9	Severe Storm:	113
Tropical Cyclone:	44	Wildfire:	17	Winter Storm:	17	All Disasters:	258

Billion Dollar Disaster Events



Billion Dollar Disaster Events

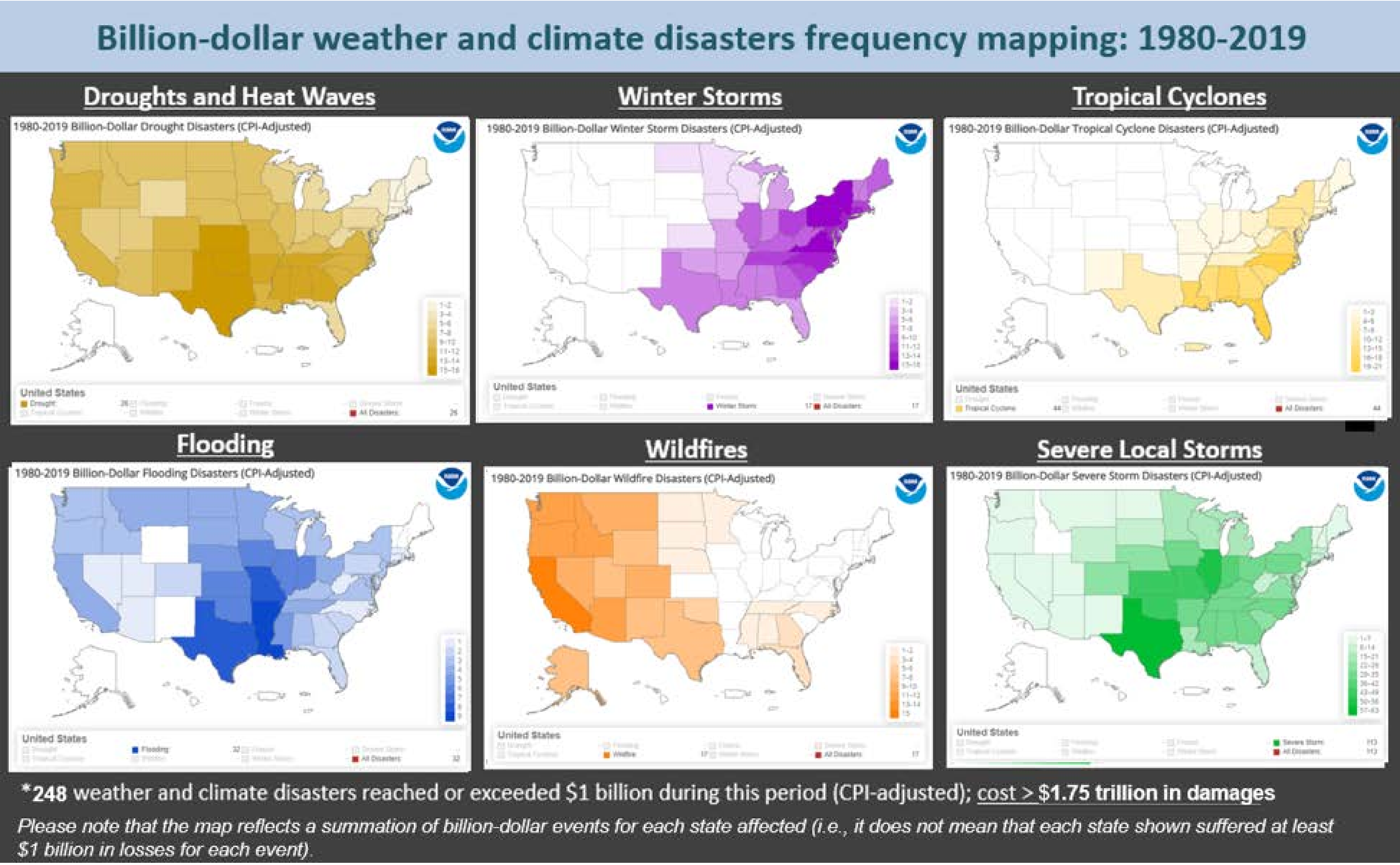
CPI-Adjusted | Unadjusted

Begin Year: 1980 End Year: 2019 Update « 2019 1980 »

Billion-dollar events to affect the U.S. from 1980 to 2019 (CPI-Adjusted)

DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	CPI-ADJUSTED LOSSES *(BILLIONS OF DOLLARS)*	PERCENT OF TOTAL LOSSES	AVERAGE EVENT COST *(BILLIONS OF DOLLARS)*	DEATHS
Drought	26	10.1%	$249.7 CI	14.2%	$9.6	2,993[†]
Flooding	32	12.4%	$146.5[§] CI	8.3%[§]	$4.6[§]	555
Freeze	9	3.5%	$30.5 CI	1.7%	$3.4	162
Severe Storm	113	43.8%	$247.8 CI	14.1%	$2.2	1,642
Tropical Cyclone	44	17.1%	$945.9 CI	53.9%	$21.5	6,502
Wildfire	17	6.6%	$84.9 CI	4.8%	$5.0	347
Winter Storm	17	6.6%	$49.3 CI	2.8%	$2.9	1,048
All Disasters	**258**	**100.0%**	**$1,754.6** CI	**100.0%**	**$6.8**	**13,249**

Billion Dollar Disaster Events



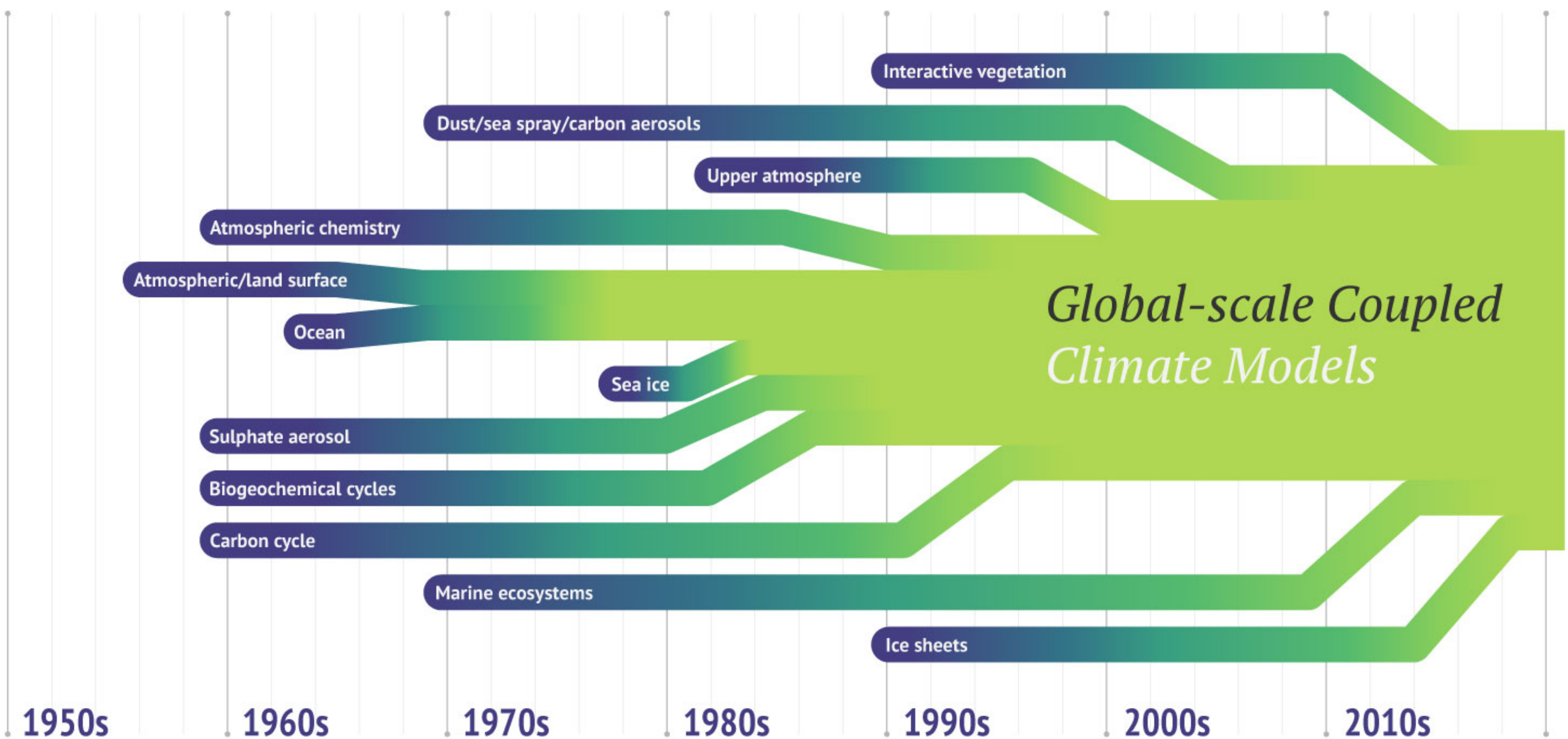
Climate Models

Climate Change and Models from "Fair and Unbiased" to "Most Watched, Most Trusted"

Fox News Compilation

Climate models

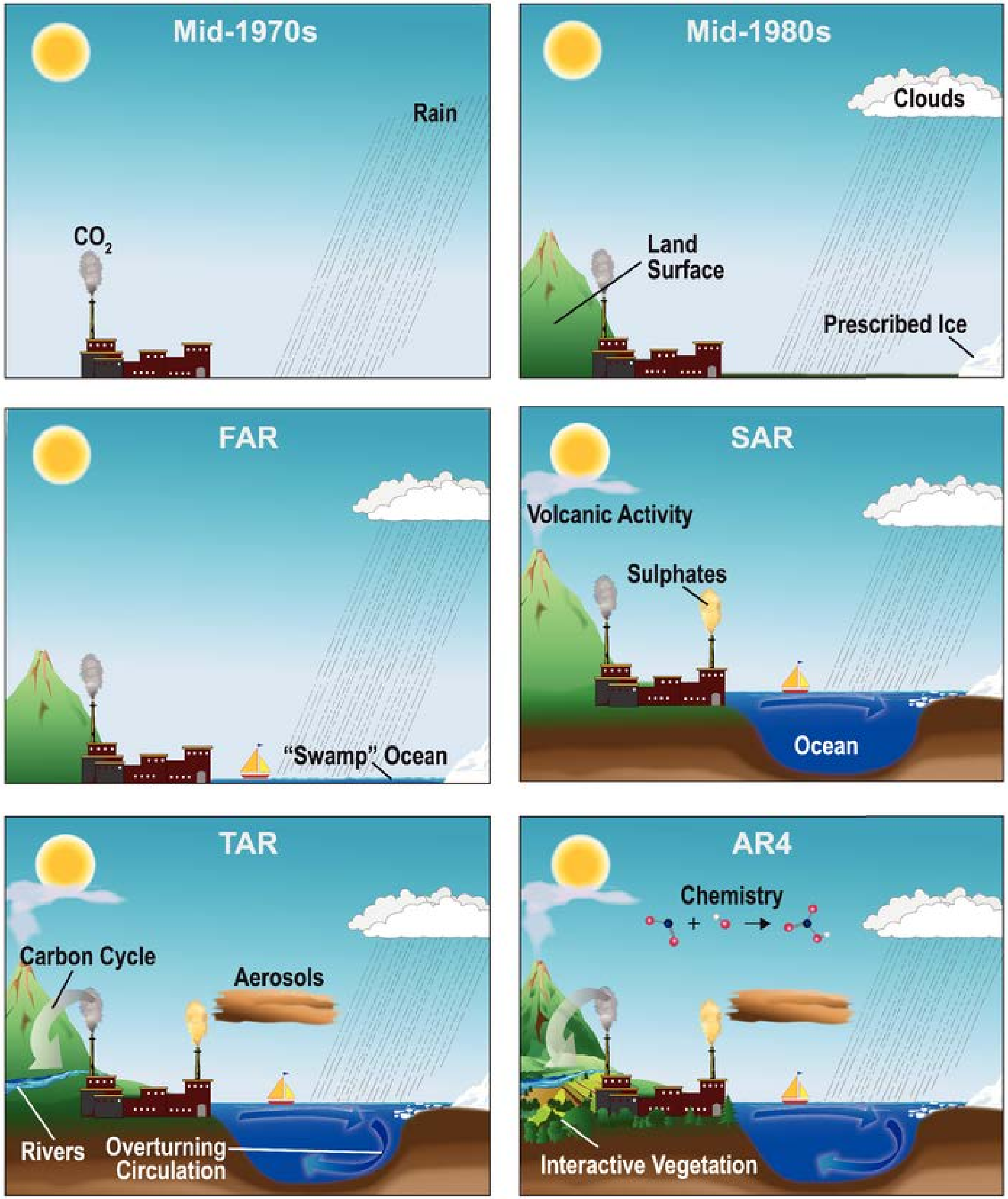
For decades scientists have been using mathematical models to help us learn more about the Earth's climate. Known as climate models, they are driven by the fundamental physics of the atmosphere and oceans, and the cycling of chemicals between living things and their environment. Over time they have increased in complexity, as separate components have merged to form coupled systems.



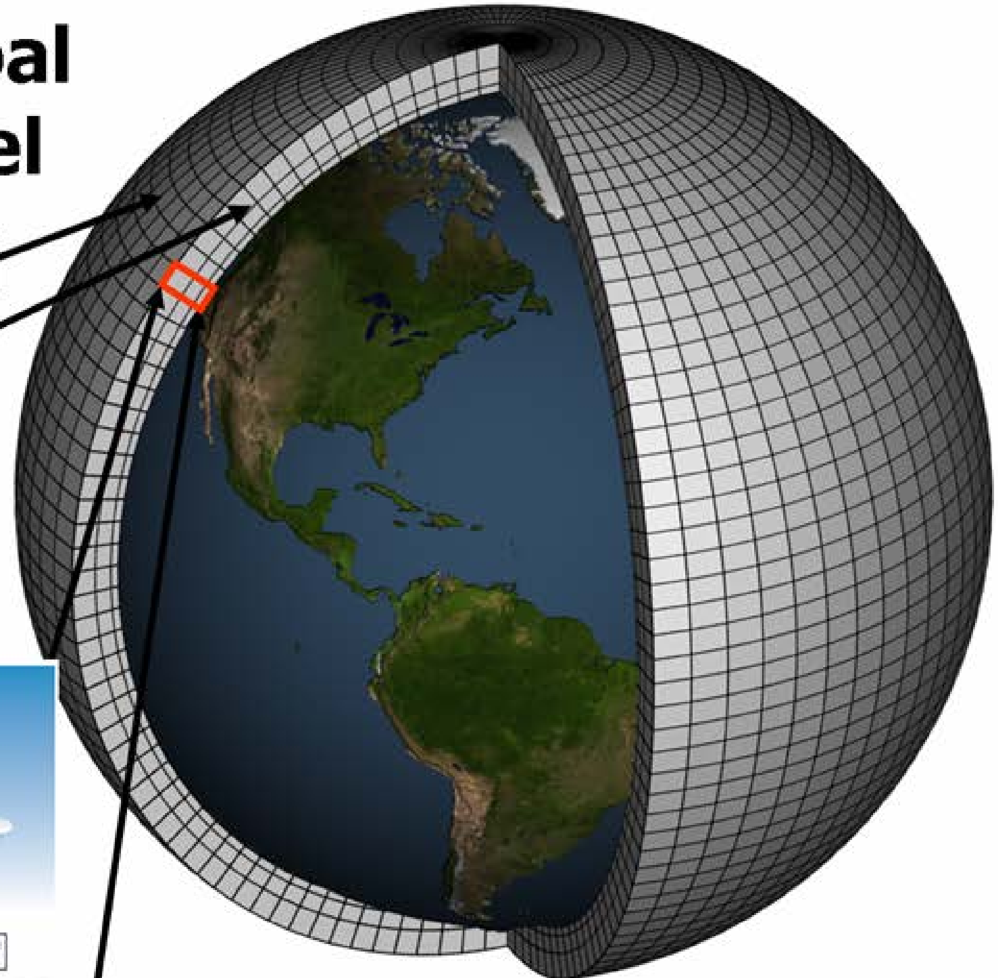
Note: There were some very simplified models before the dates mentioned.

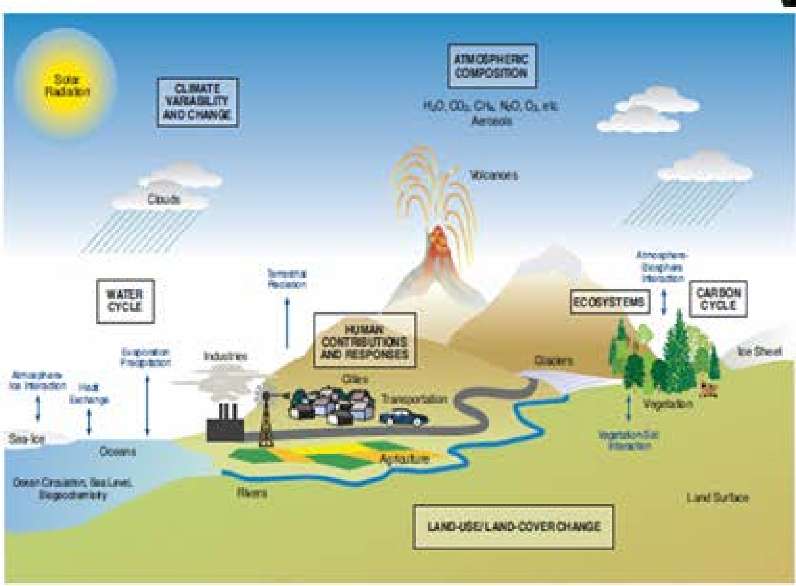
CarbonBrief CLEAR ON CLIMATE

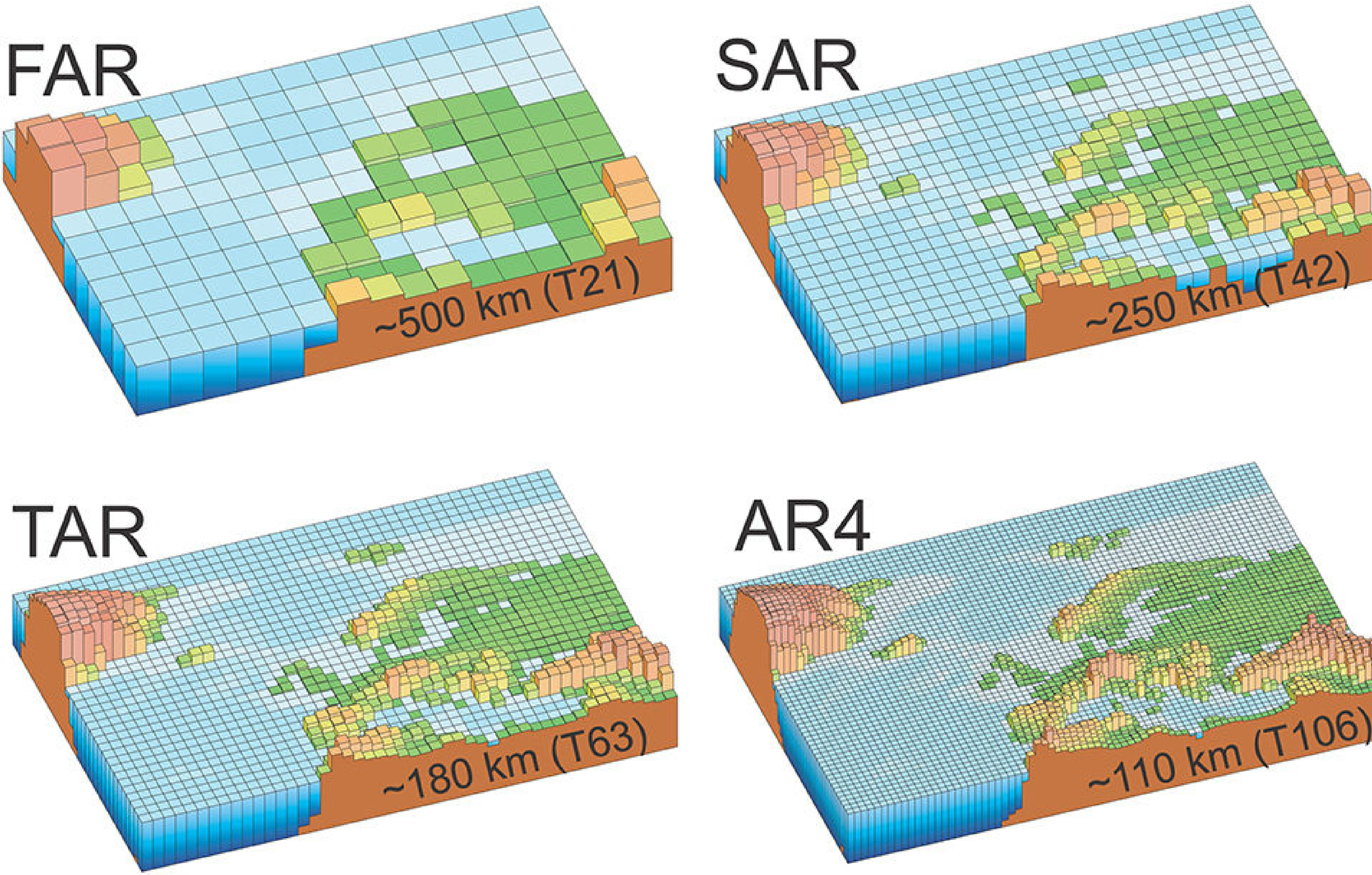
The World in Global Climate Models

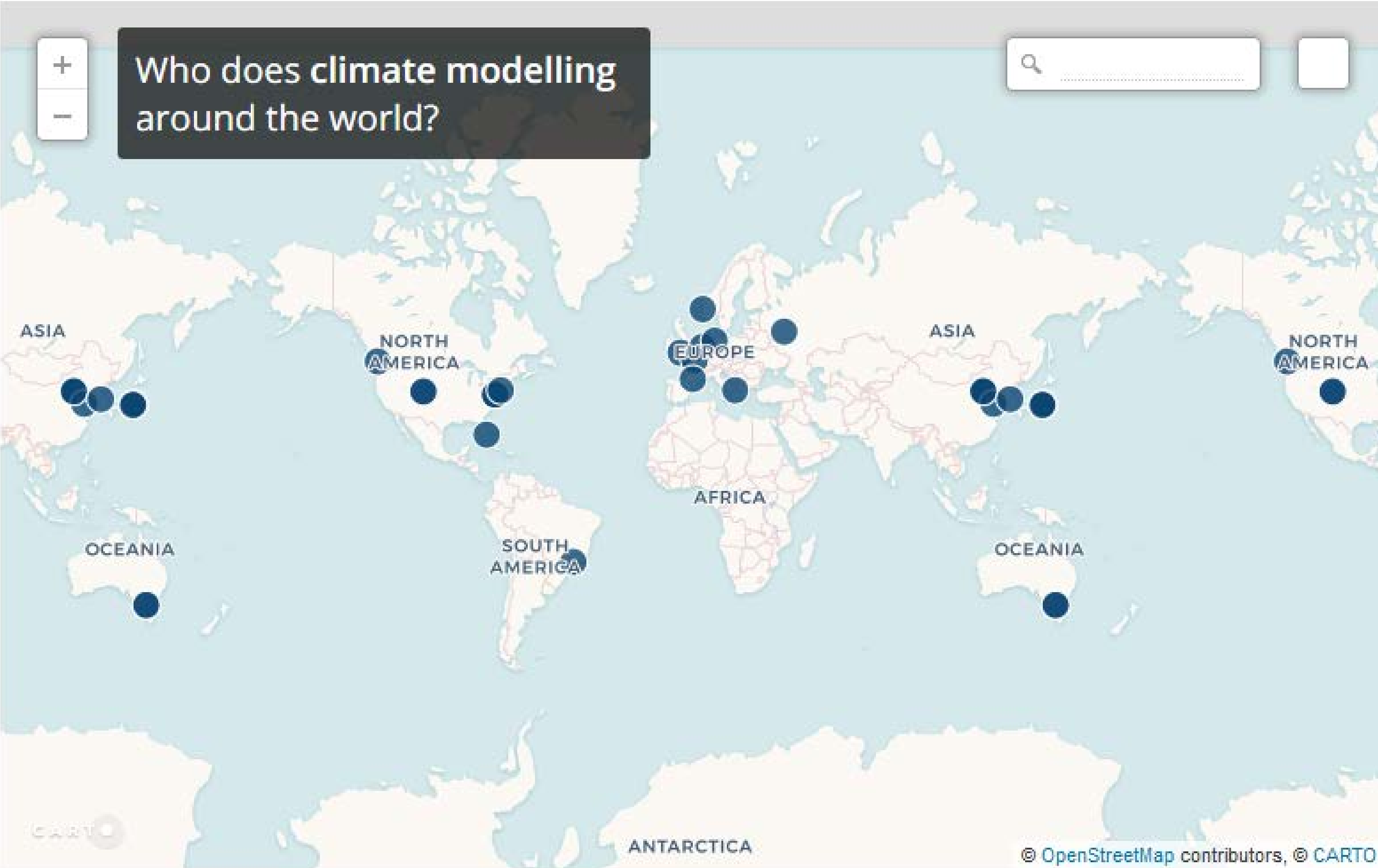


Schematic for Global Atmospheric Model

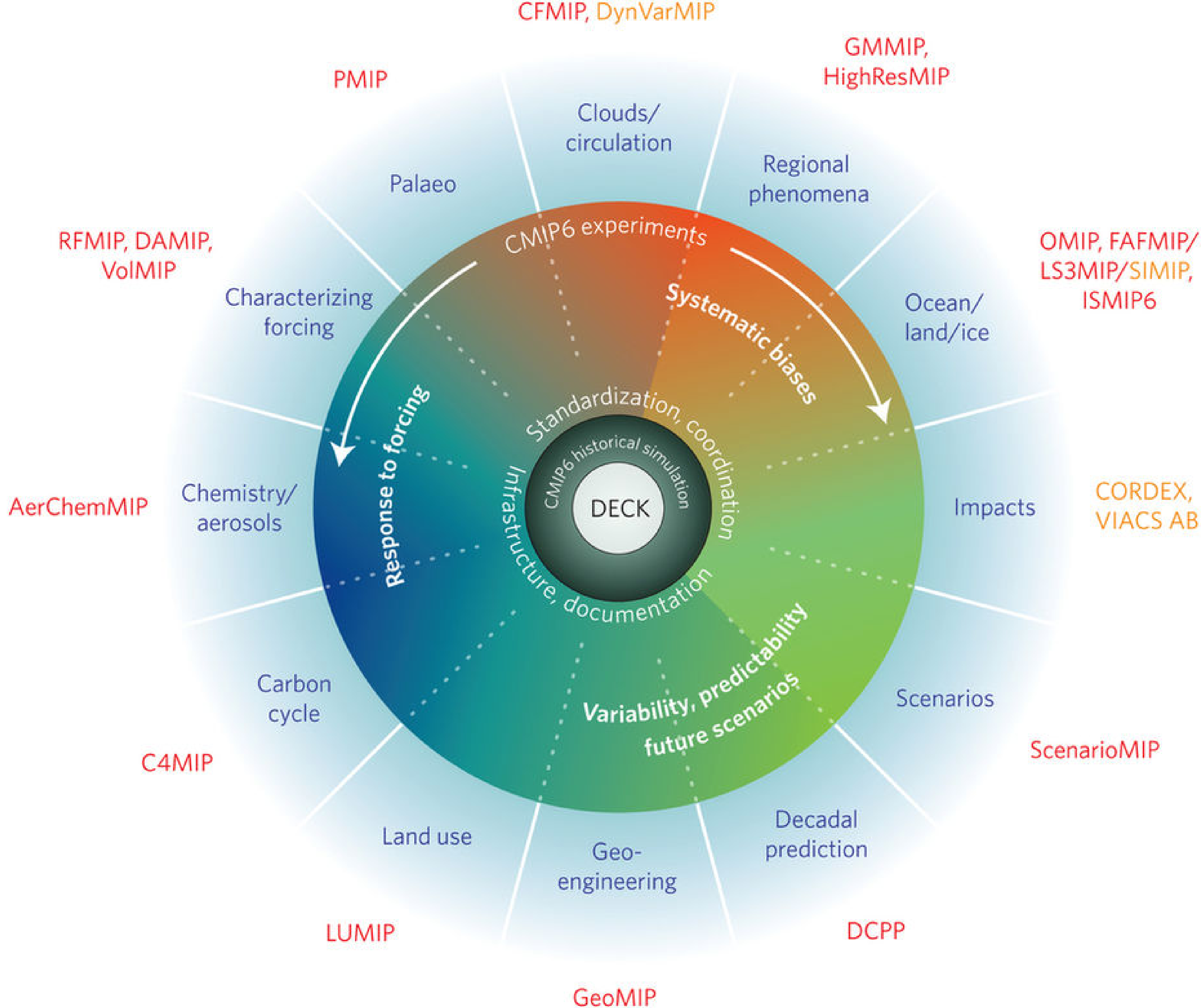





FAR
~500 km (T21)
SAR
~250 km (T42)
TAR
~180 km (T63)
AR4
~110 km (T106)



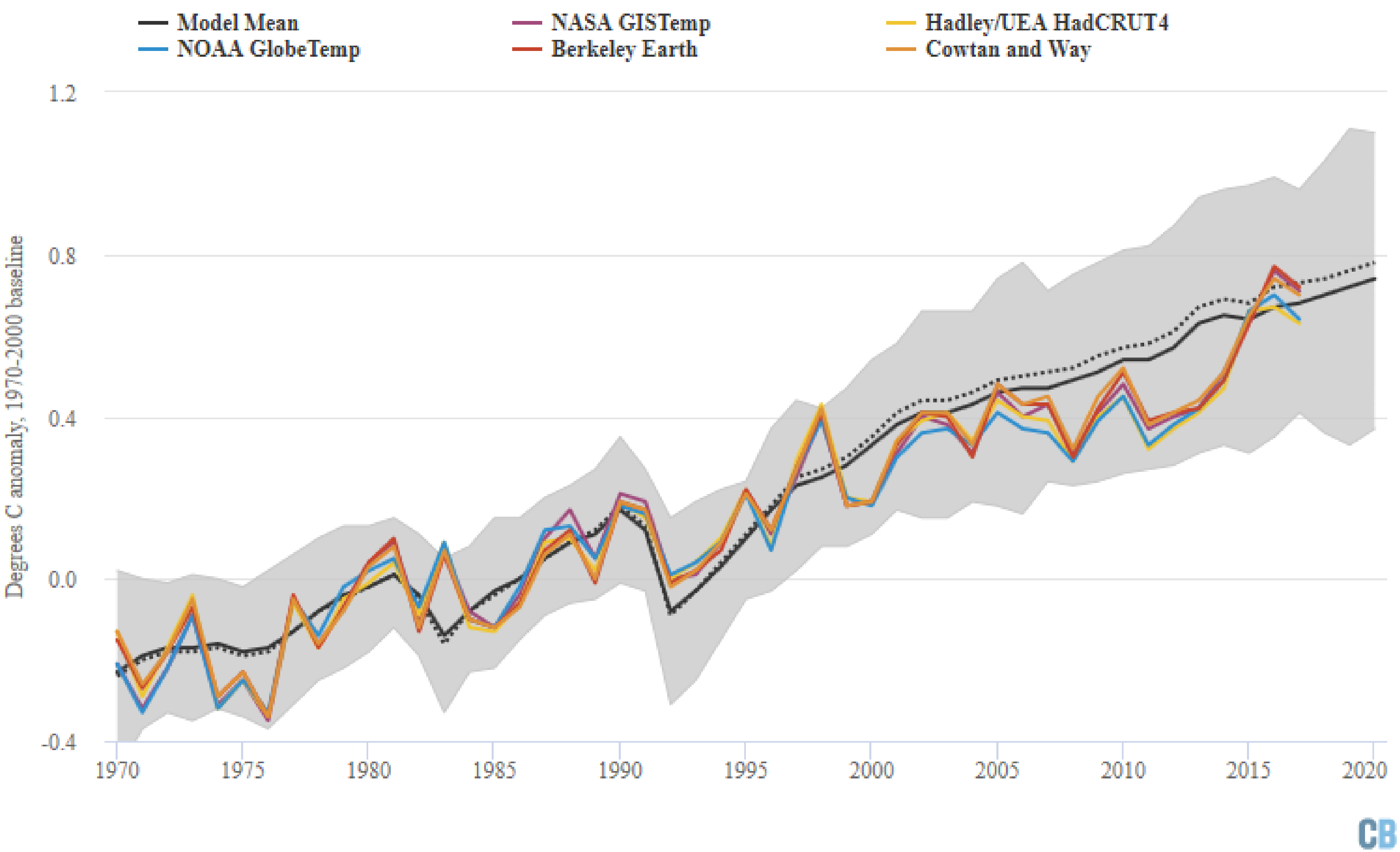
Map created by Carbon Brief



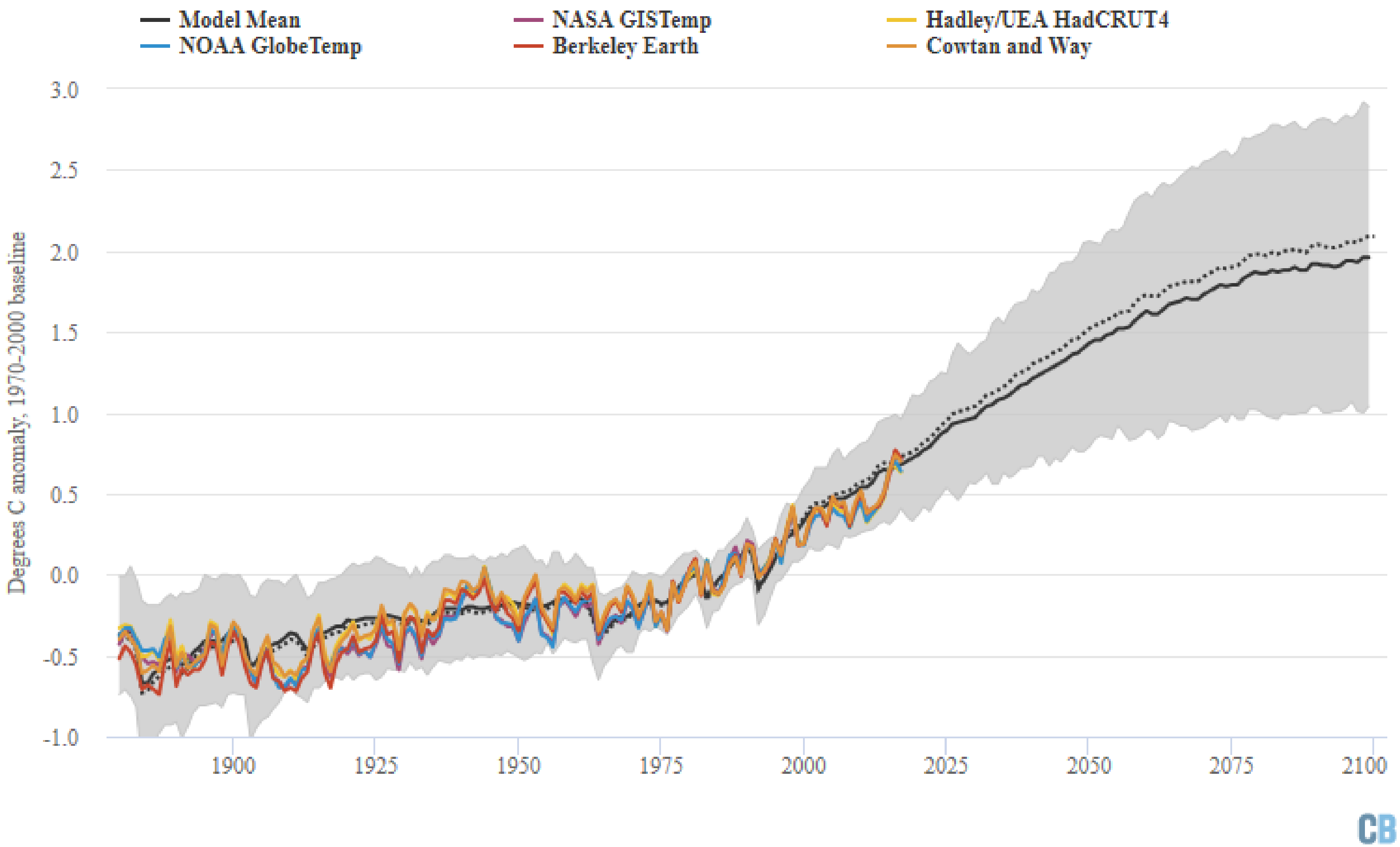
CFMIP, DynVarMIP
GMMIP, HighResMIP
PMIP
Clouds/ circulation
Regional phenomena
Palaeo
RFMIP, DAMIP, VolMIP
OMIP, FAFMIP/ LS3MIP/SIMIP, ISMIP6
CMIP6 experiments
Characterizing forcing
Systematic biases
Ocean/ land/ice
Response to forcing
Standardization, coordination
CMIP6 historical simulation
DECK
Infrastructure, documentation
AerChemMIP
Chemistry/ aerosols
Impacts
CORDEX, VIACS AB
Variability, predictability
future scenarios
Carbon cycle
Scenarios
ScenarioMIP
C4MIP
Land use
Geo- engineering
Decadal prediction
LUMIP
DCPP
GeoMIP

Parametrized Systems in Climate Models

Climate models and observations, 1970-2017



Climate models and observations, 1880-2100



The Software Architecture of Global Climate Models

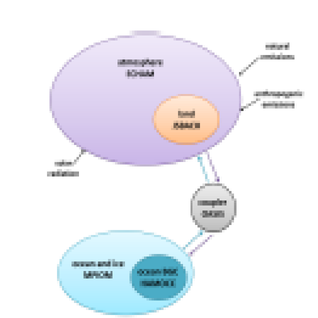
Kaitlin Alexander[1,2], Steve Easterbrook[2]

umalexak@cc.umanitoba.ca sme@cs.toronto.edu

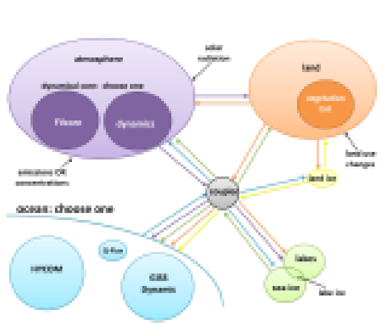
[1]Department of Mathematics, University of Manitoba

[2]Software Engineering Lab, Department of Computer Science, University of Toronto

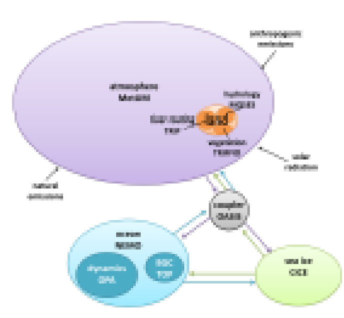
COSMOS 1.2.1
Max-Planck-Institut für Meteorologie, Germany



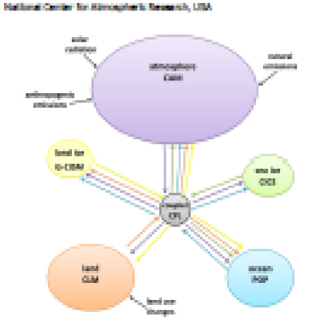
Model E October 11, 2011 revision
NASA Goddard Institute for Space Studies, USA



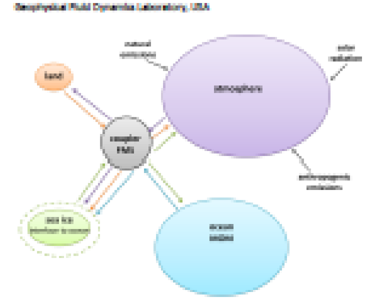
HadGEM3
Met Office, UK



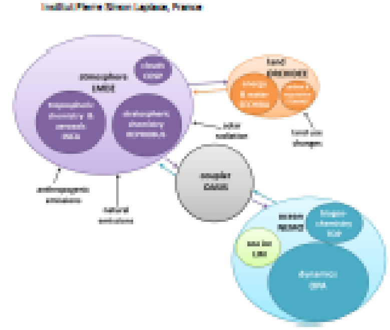
CESM 1.0.3
National Center for Atmospheric Research, USA



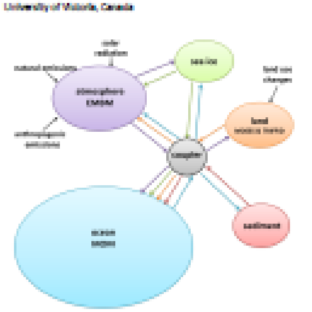
GFDL Climate Model 2.1 (coupled to MOM 4.1)
Geophysical Fluid Dynamics Laboratory, USA



IPSL Climate Model 5A
Institut Pierre Simon Laplace, France



UVic Earth System Climate Model 2.9
University of Victoria, Canada



Key to Diagrams

Each component of the climate system has been assigned a colour:
atmosphere ocean land sea ice land ice sediment

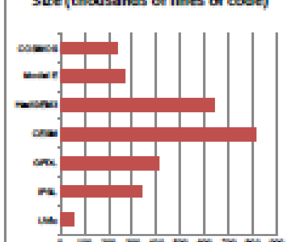
Model code for a component is represented with a bubble. Fluxes are represented with arrows, in a colour showing where they originated.

Couplers are grey. Components can pass fluxes either directly to each other or through the coupler.

The area of a bubble represents the size of its code base, relative to other components in the same model.

A smaller bubble within a larger one represents a small, highly encapsulated model of a system (eg clouds) that is used by the component.

Radiative forcings are passed to components with plain arrows.



Generated using David A. Wheeler's "SLOCCount".

Introduction

It has become common to compare and contrast the output of multiple global climate models (GCMs), such as in the Climate Model Intercomparison Project Phase 5 (CMIP5). However, intercomparisons of the software architecture of GCMs are almost nonexistent. In this qualitative study of seven GCMs from Canada, the United States and Europe, we attempted to fill this gap in research. By examining the model source code, reading documentation, and interviewing developers, we created diagrams of software structure and compared metrics such as encapsulation, coupler design, and complexity.

Component-Based Software Engineering

A global climate model is really a collection of models (components), each representing a major realm of the climate system, such as the atmosphere or the land surface. They are highly encapsulated, for stand-alone use as well as a mix-and-match approach that facilitates code sharing between institutions.

This strategy, known as component-based software engineering (CBSE), pools resources to create high-quality components that are used by many GCMs. For example,

- **UVic** uses a modified version of GFDL's ocean model, MOM.
- **HadGEM3** and **CESM** both use CICE, a sea ice model developed a third institution (Los Alamos).

Contrary to CBSE goals, there is no universal interface for climate models, so components need to be modified when they are passed between institutions. Furthermore, the right to edit the master copy of a component's source code is generally restricted to the development team at the hosting institution. As a result, many different branches of the software develop.

A drawback to CBSE is the fact that, in the real world, components of the climate system are not encapsulated. For example, how does one represent the relationship between sea ice and the ocean? Many different strategies exist:

- **CESM:** sea ice and ocean are completely separate components.
- **IPSL:** sea ice is a sub-component of the ocean.
- **GFDL:** sea ice is an interface to the ocean. All fluxes to and from the ocean must pass through the sea ice region, even if no ice is actually present.

Acknowledgements

Gavin Schmidt (NASA GISS); Tim Johns (Met Office); Gary Strand (NCAR); Arnaud Caubel, Marie-Alice Foujols, and Anne Cozic (IPSL); Reinhard Budich (MPI); and Michael Eby (University of Victoria) answered questions about their work developing GCMs and helped to verify our observations. Additionally, Michael Eby from the University of Victoria was instrumental in improving the diagram design.

This project was funded by NSERC and the Centre for Global Change Science at the University of Toronto.

The Coupling Process

Since the climate system is highly interconnected, a CBSE approach requires code to tie the components together - interpolating fluxes between grids and controlling interactions between components. These tasks are performed by the coupler. While all GCMs contain some form of coupler, the extent to which it is used varies widely:

- **CESM:** Every interaction is managed by the coupler.
- **IPSL:** Only the atmosphere and the ocean are connected to the coupler. The land component is directly called by the atmosphere.
- **HadGEM3:** all components are connected to the coupler, but ocean-ice fluxes are passed directly, since NEMO and CICE have similar grids.

A CBSE approach has even affected coupling. OASIS, a coupler used by many models (including COSMOS, HadGEM3, and IPSL) is built to handle any number and any type of components, as well as the flux fields within.

Complexity and Focus

A simple line count of GCM source code serves as a reasonable proxy for relative complexity. A model that represents many processes will generally have a larger code base than one that represents only a few. Between models, complexity varies widely. Within models, the bulk of a GCM's complexity is often concentrated in a single component, due to the origin of the model and the institution's goals:

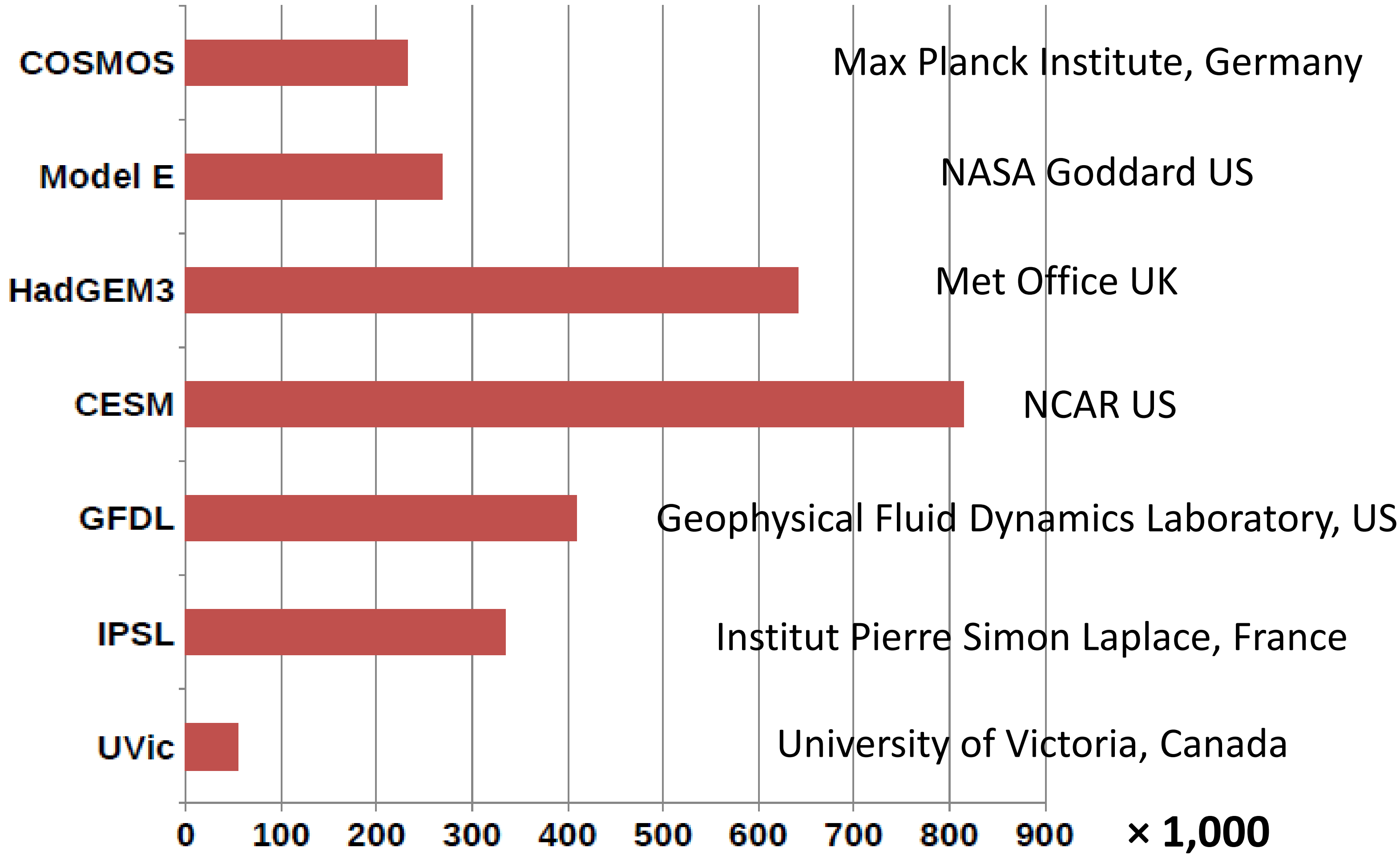
- **HadGEM3:** atmosphere-centric. It grew out of the atmospheric model MetUM, which is also used for weather forecasting, requiring high atmospheric complexity.
- **UVic:** ocean-centric. It began as a branch of MOM, and kept the combination of a complex ocean and a simple atmosphere due to its speed and suitability to very long simulations.
- **CESM:** atmosphere-centric, but land is catching up, having even surpassed the ocean. It is embracing the "Earth System Model" frontier of terrestrial complexity, particularly feedbacks in the carbon cycle.

Conclusions

While every GCM we studied shares a common basic design, a wide range of structural diversity exists in areas such as coupler structure, relative complexity between components, and levels of component encapsulation. This diversity can complicate model development, particularly when components are passed between institutions. However, the range of design choices is arguably beneficial for model output, as it inadvertently produces the software engineering equivalent of perturbed physics (although not in a systematic manner).

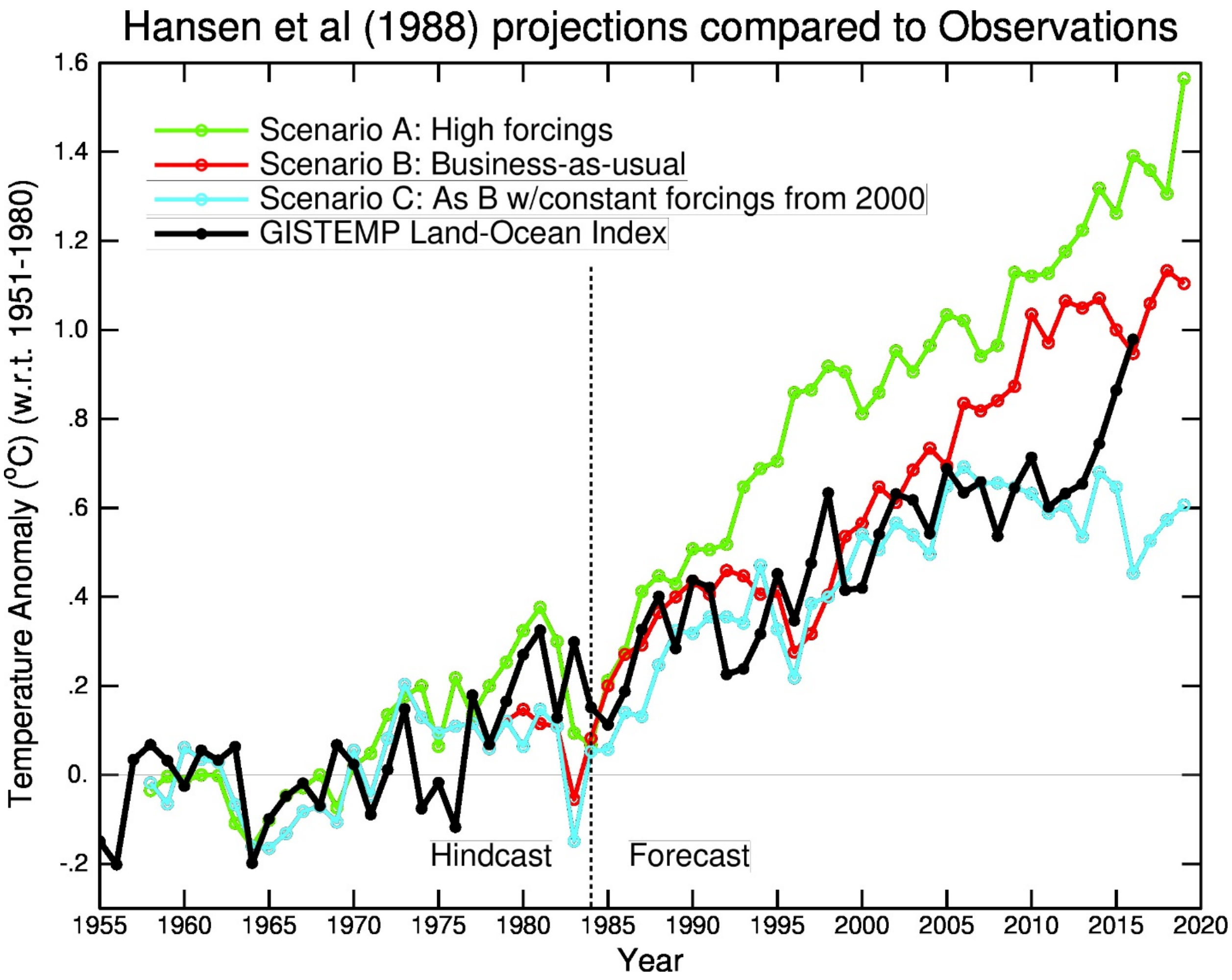
Additionally, architectural differences may provide new insights into variability and spread between model results. By examining software variations, as well as scientific variations, we can better understand discrepancies in GCM output.

Climate Model Lines of Code



Climate Model Accuracy

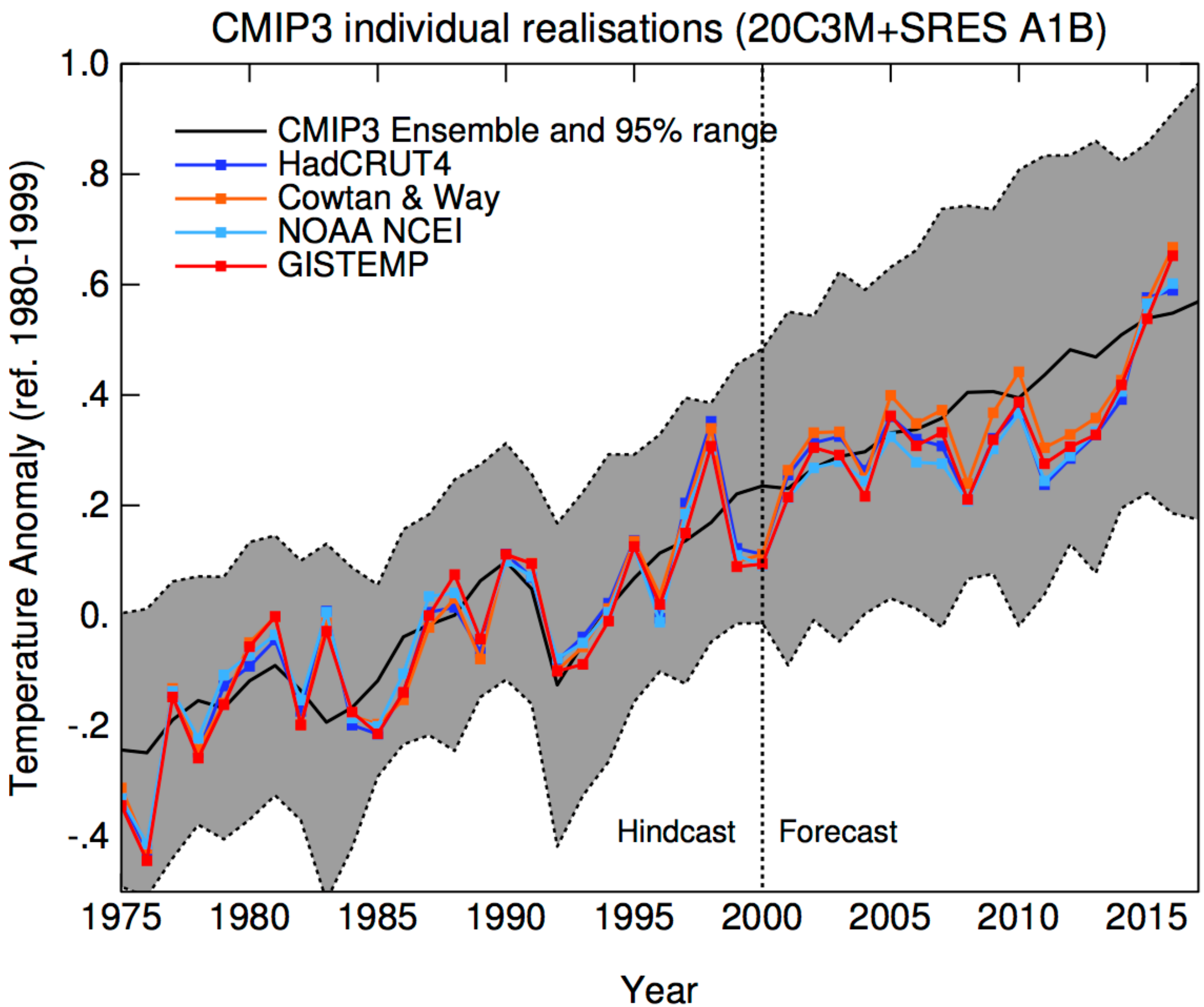
April 11, 2017



RealClimate

Climate science from climate scientists

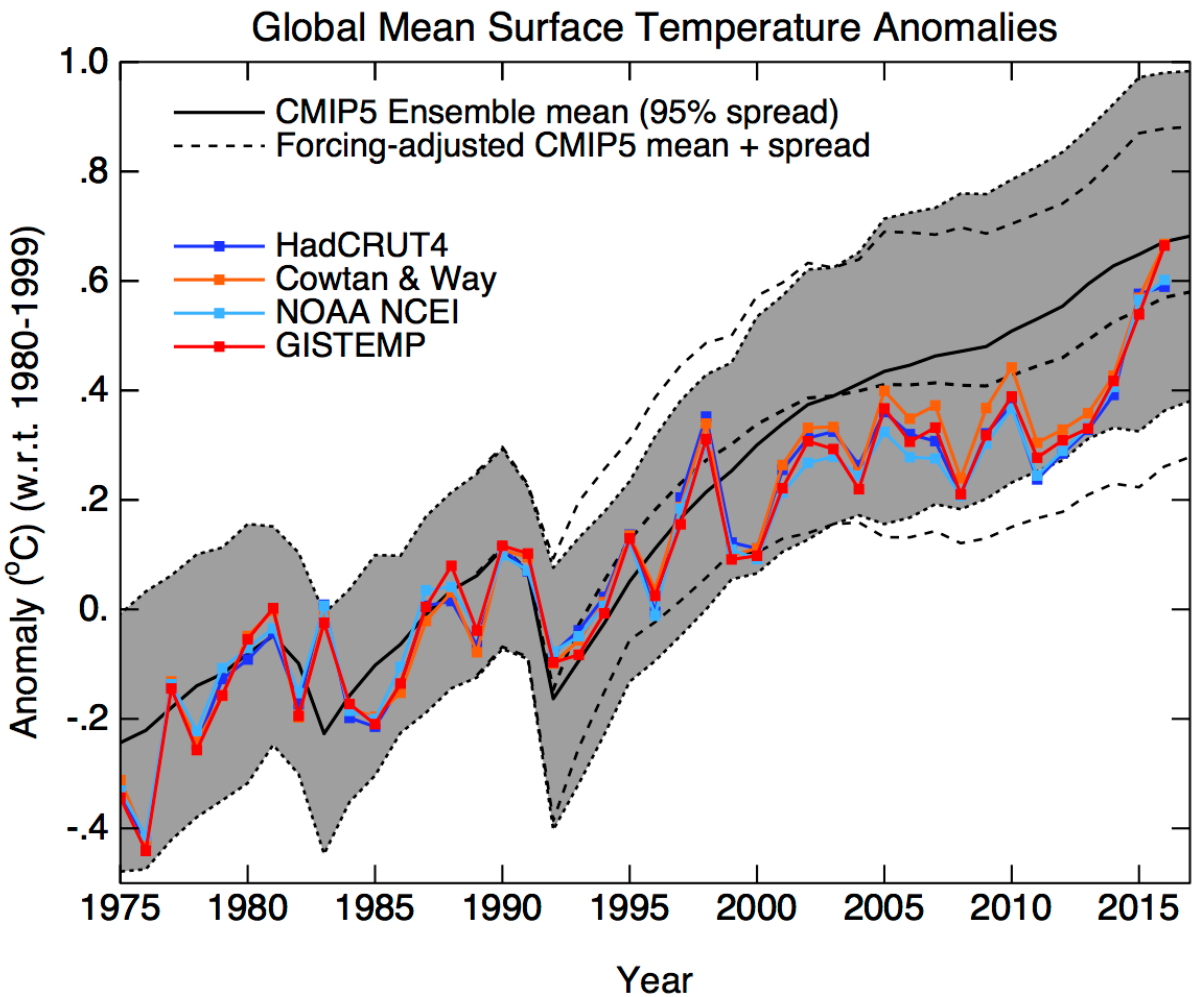
April 11, 2017



RealClimate

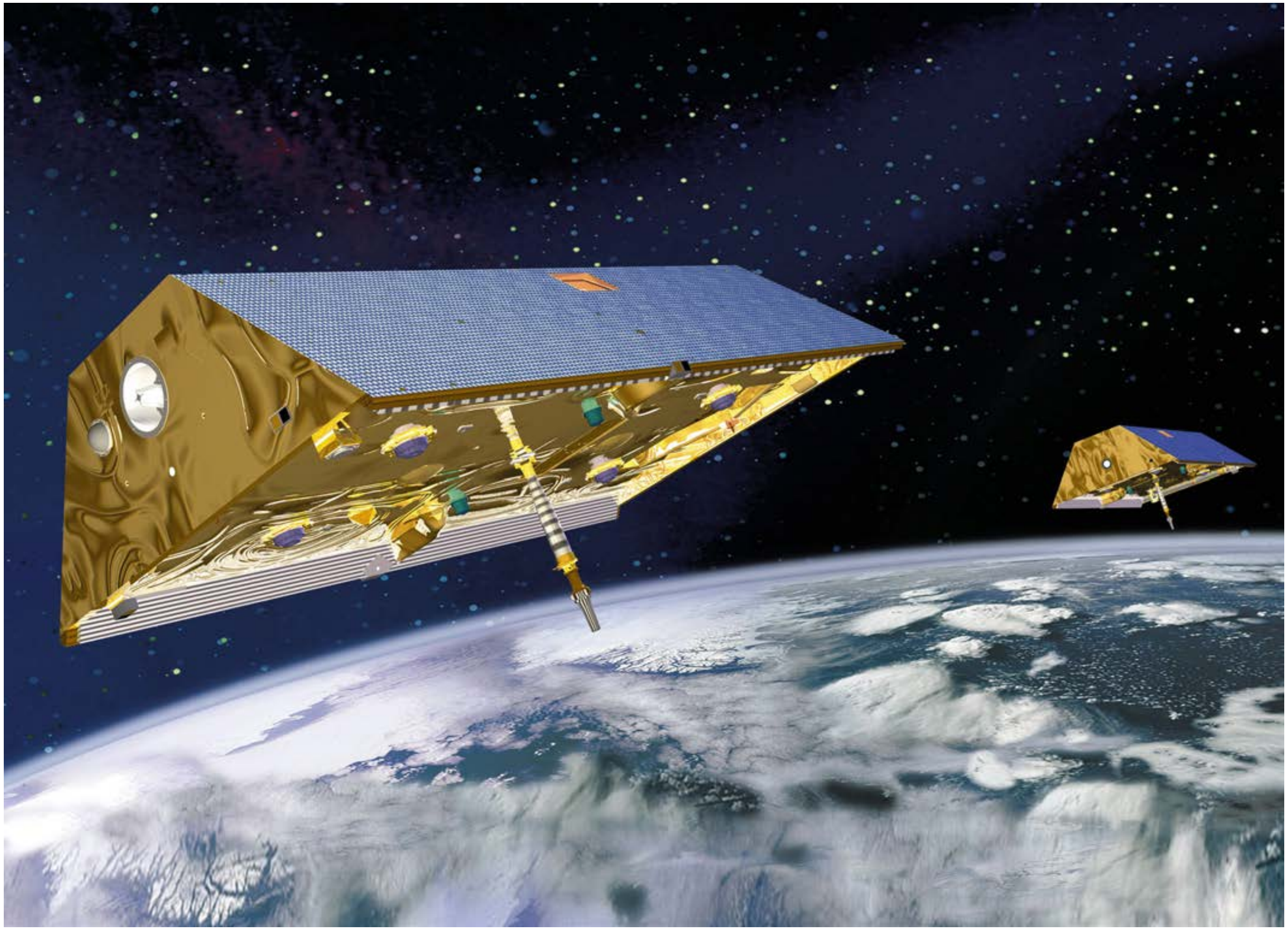
Climate science from climate scientists

April 11, 2017

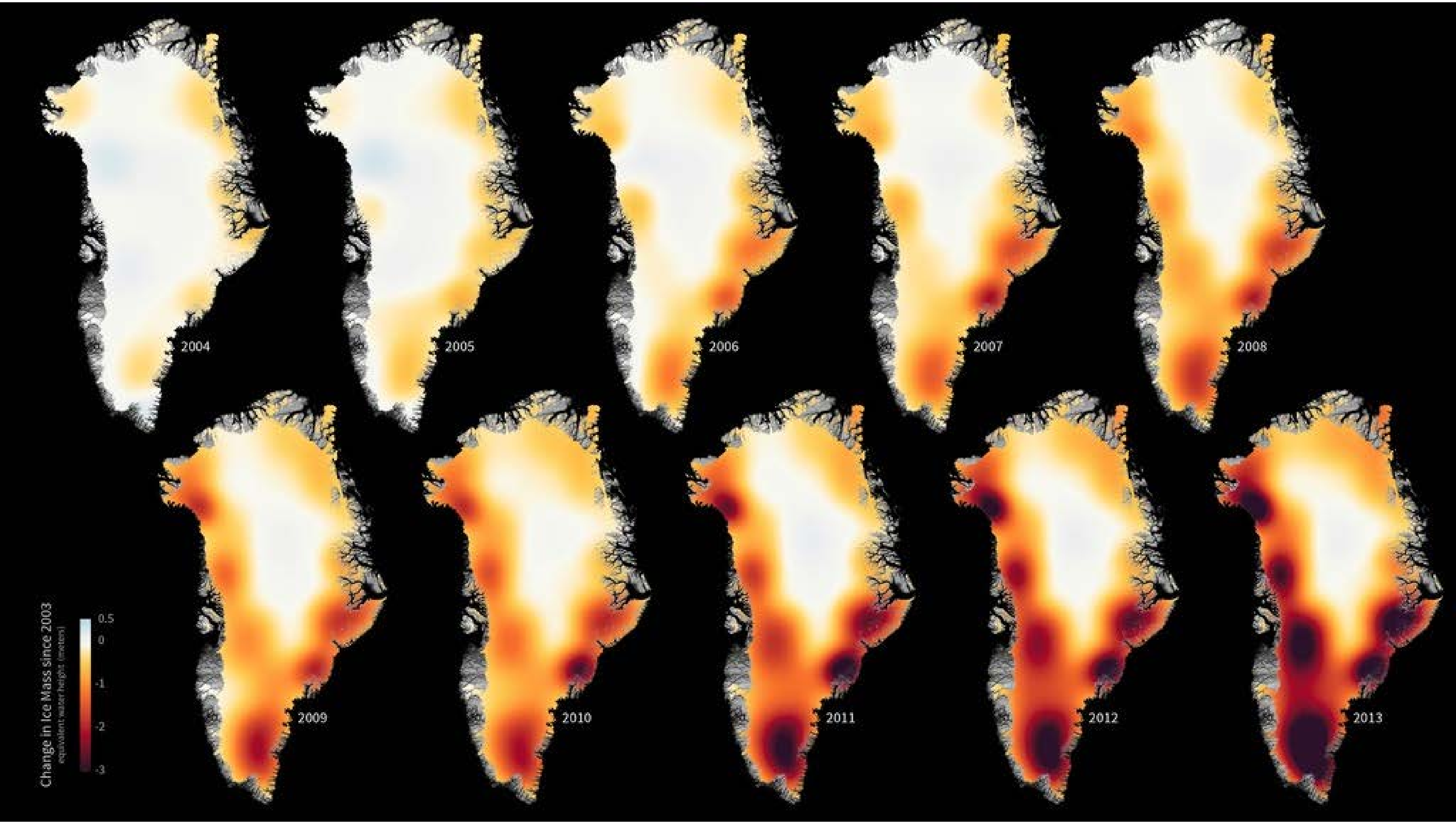


Sea Level Rise

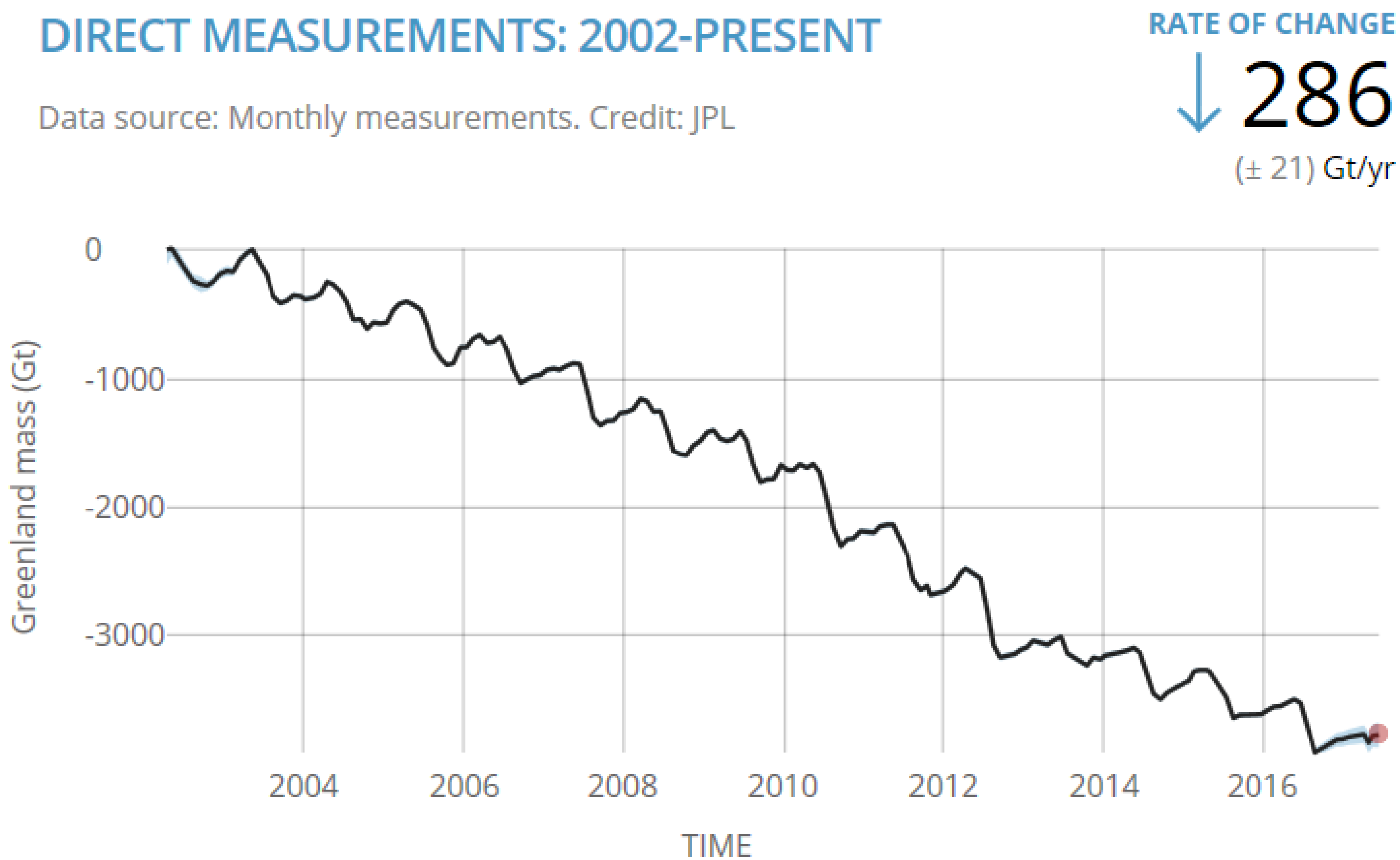
GRACE Satellites



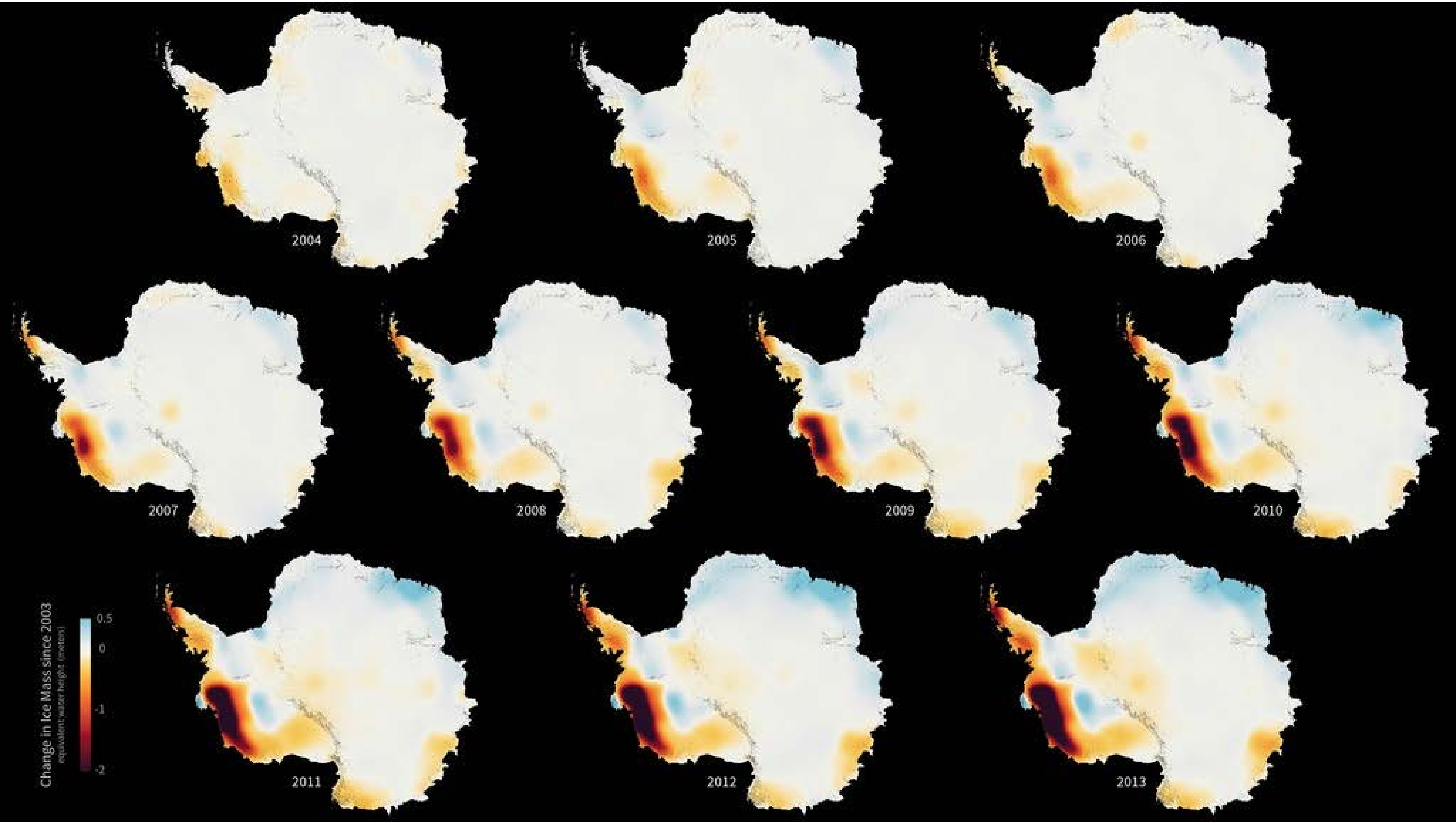
GRACE Greenland Ice Mass Loss



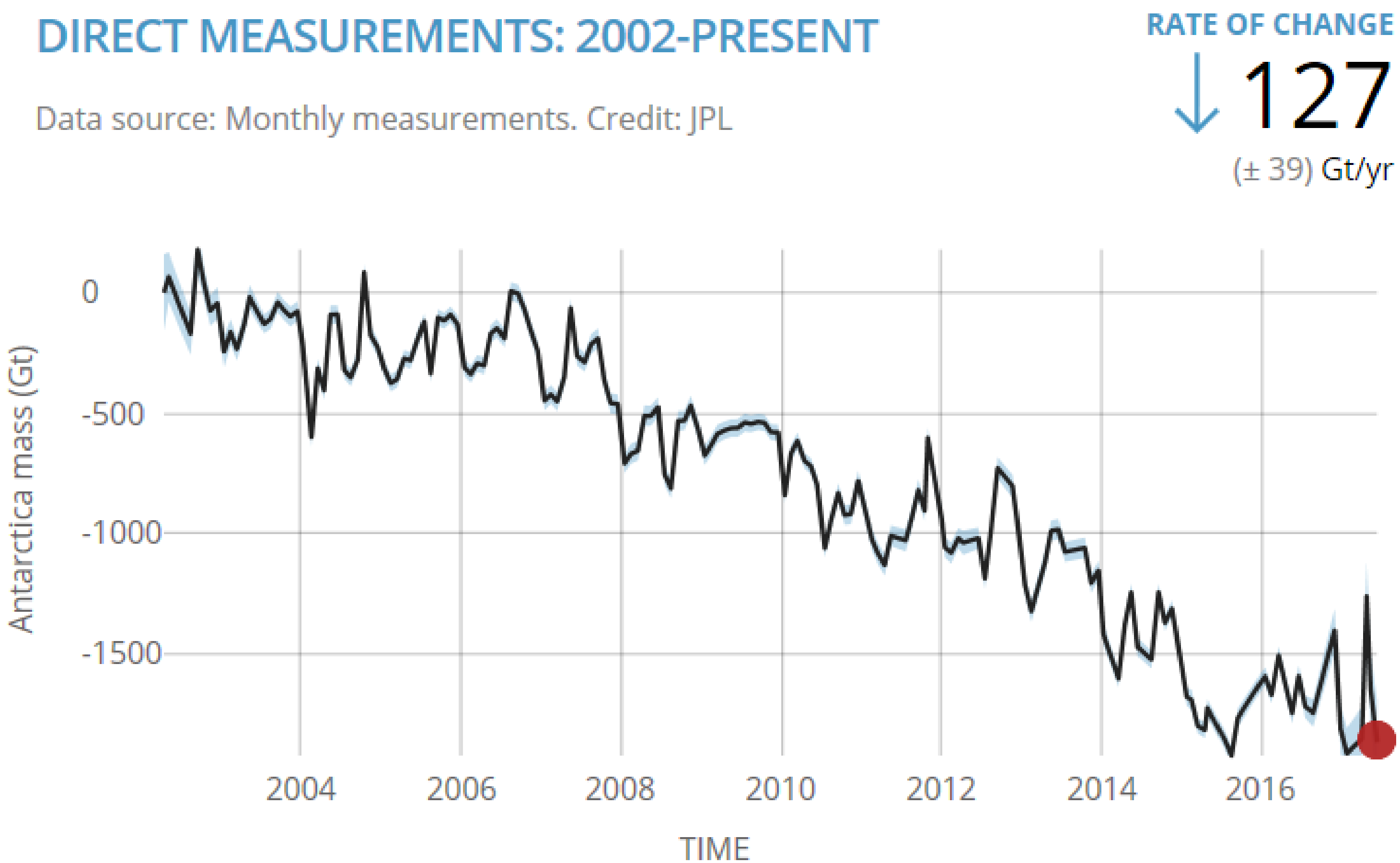
GRACE Greenland Ice Mass Loss



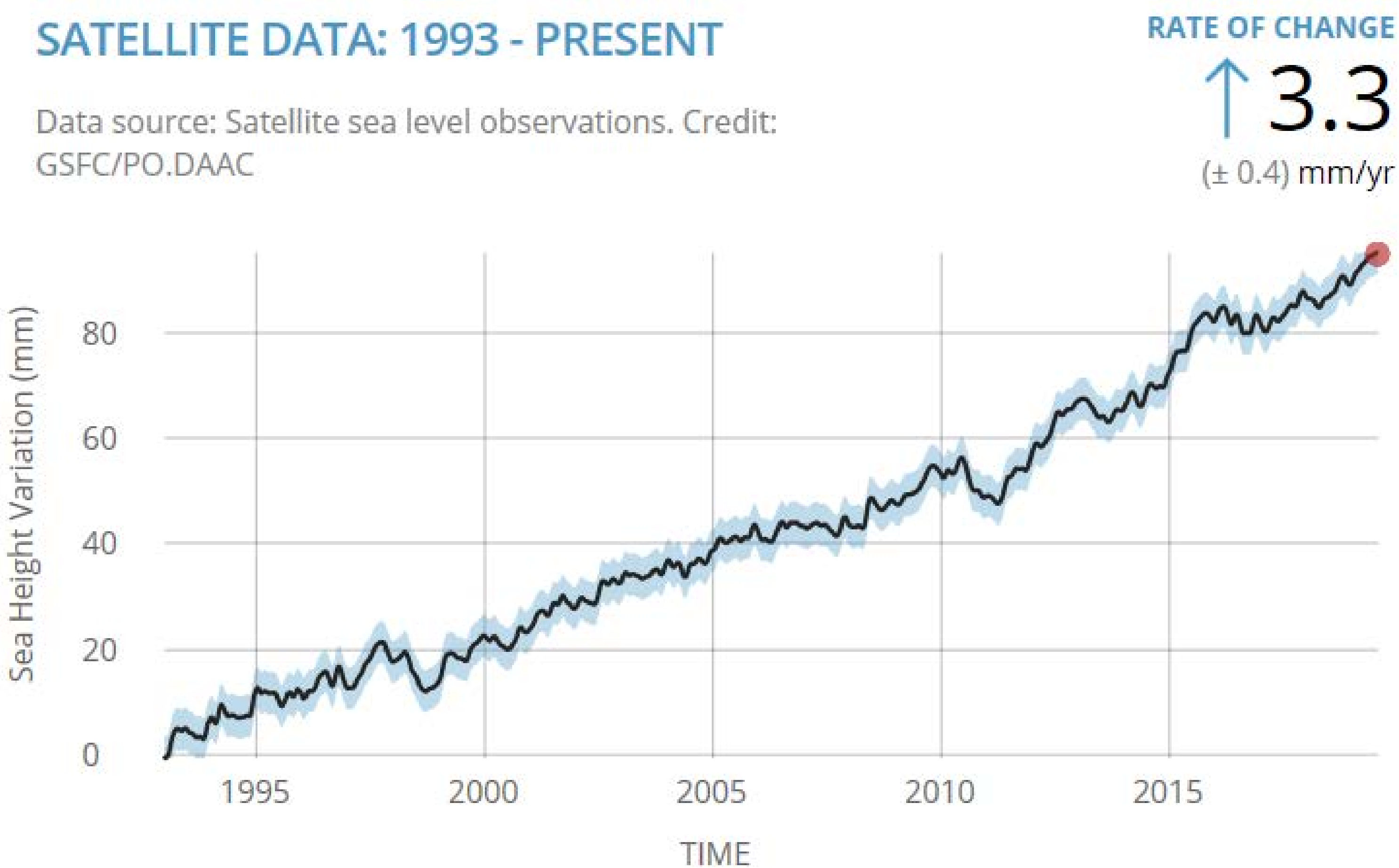
GRACE Antarctic Ice Mass Loss



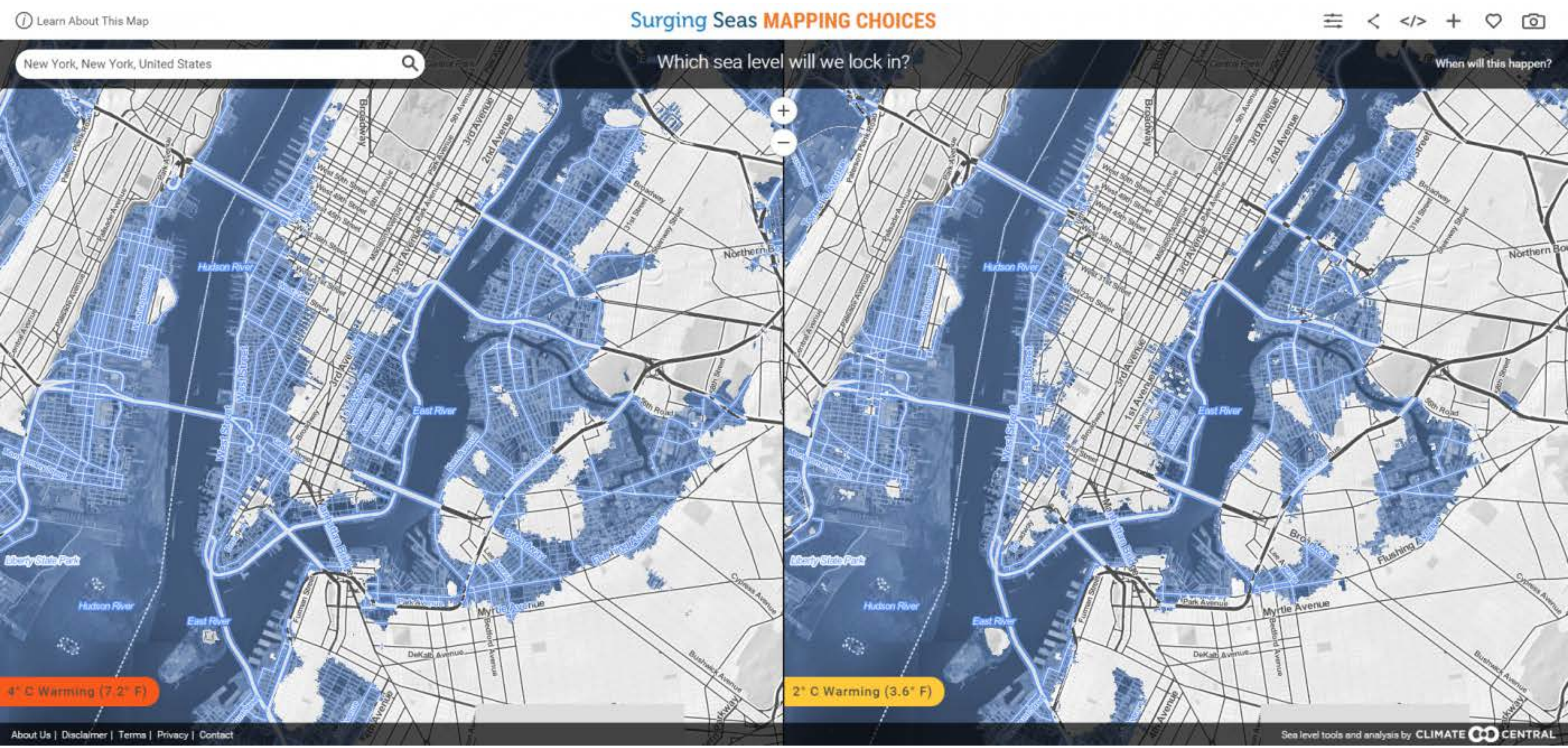
GRACE Antarctic Ice Mass Loss



Satellite Sea Level Rise Measurement



Sea Level Rise Affect on Manhattan



4 °C temperature rise

2 °C temperature rise

The New York Times

October 29, 2019

Rising Seas Will Erase More Cities by 2050

nature COMMUNICATIONS

ARTICLE

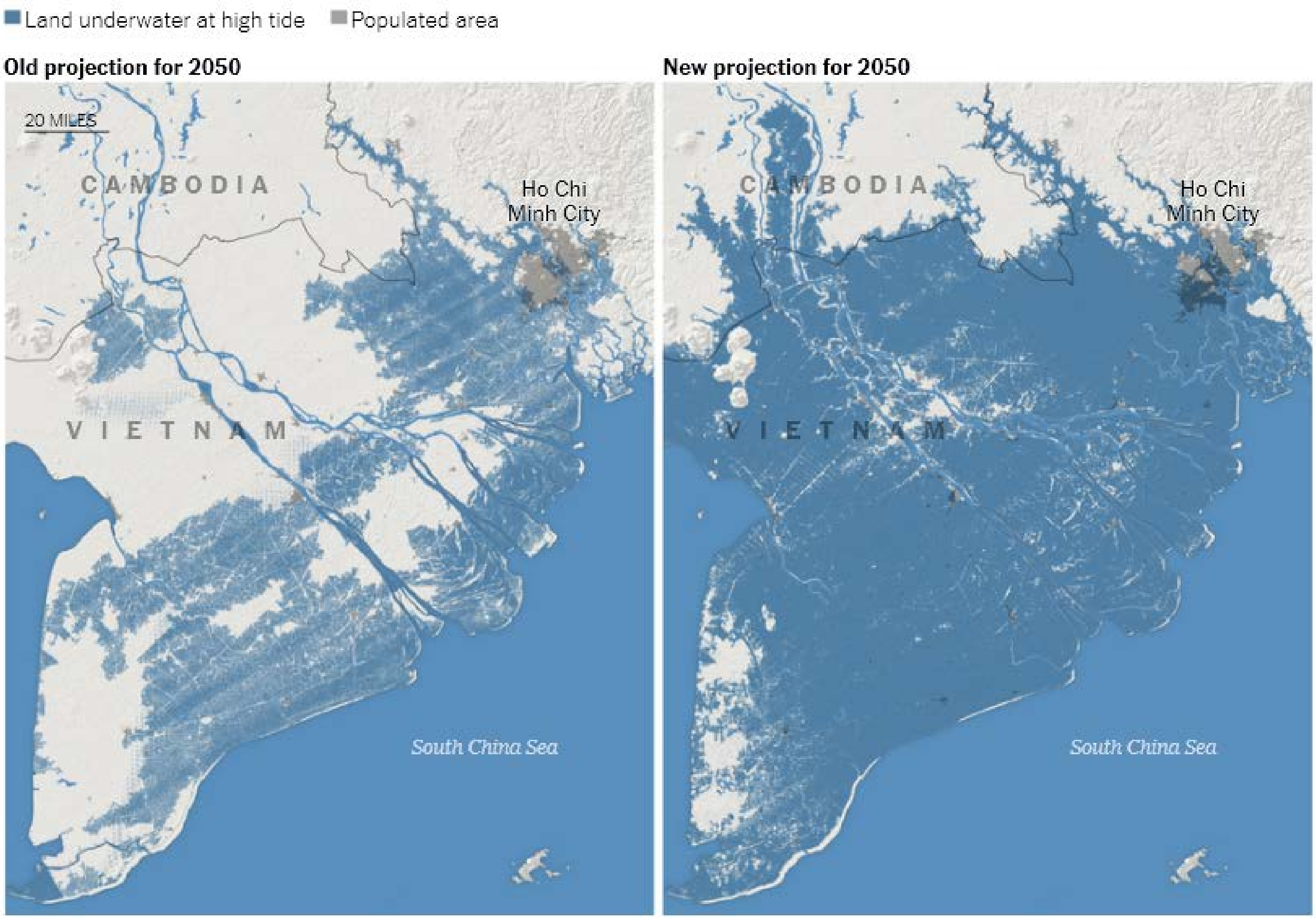
Corrected: Author correction

https://doi.org/10.1038/s41467-019-12808-z OPEN

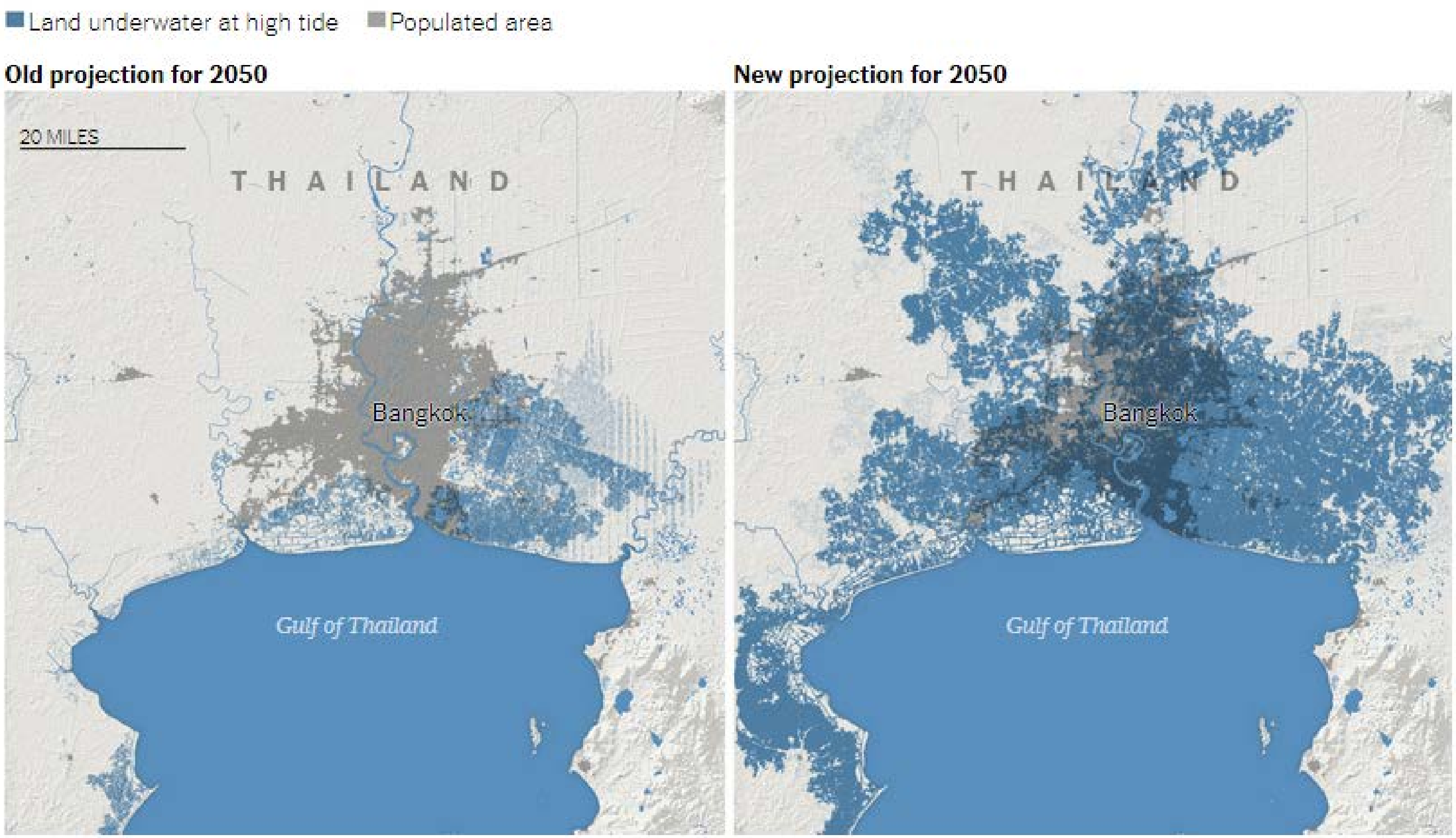
New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding

Scott A. Kulp[1]* & Benjamin H. Strauss[1]

Ho Chi Min City

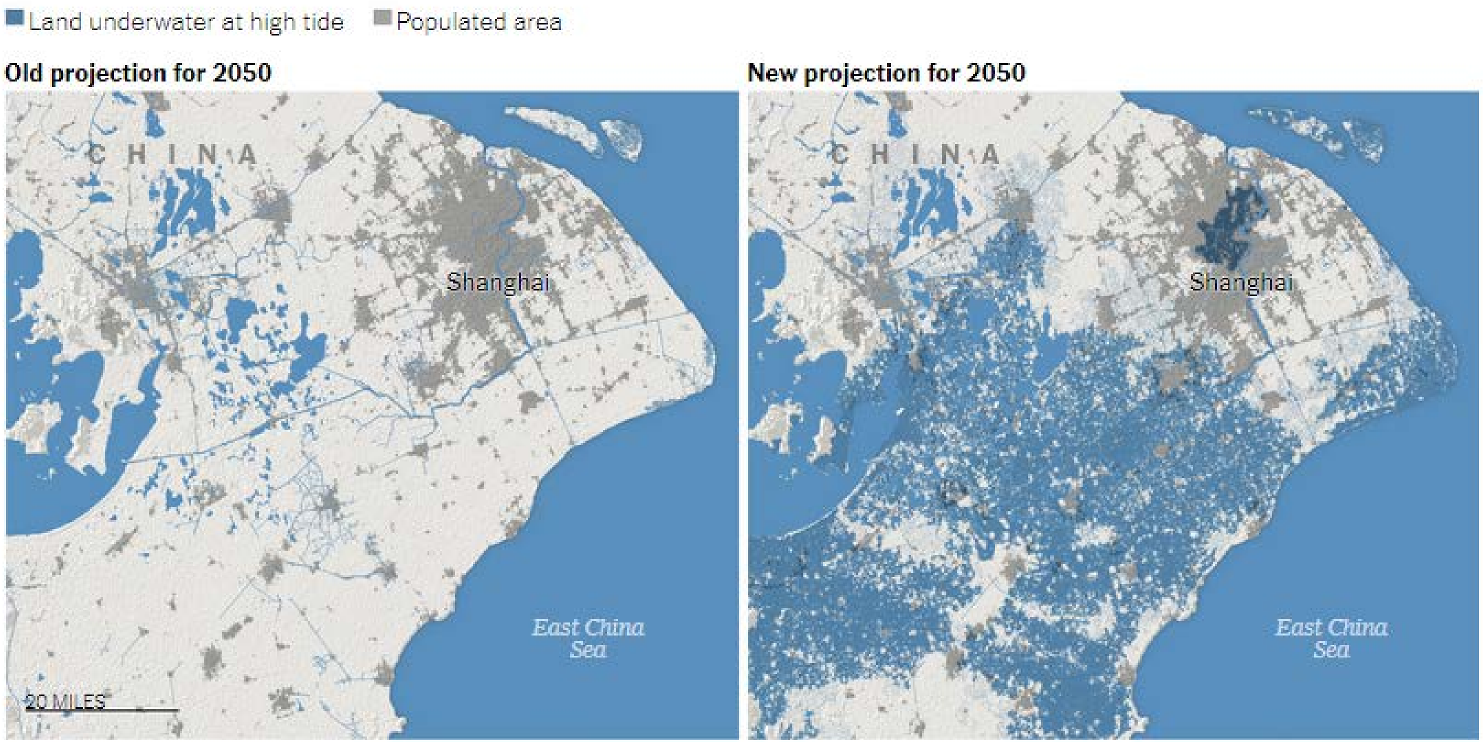


Bangkok



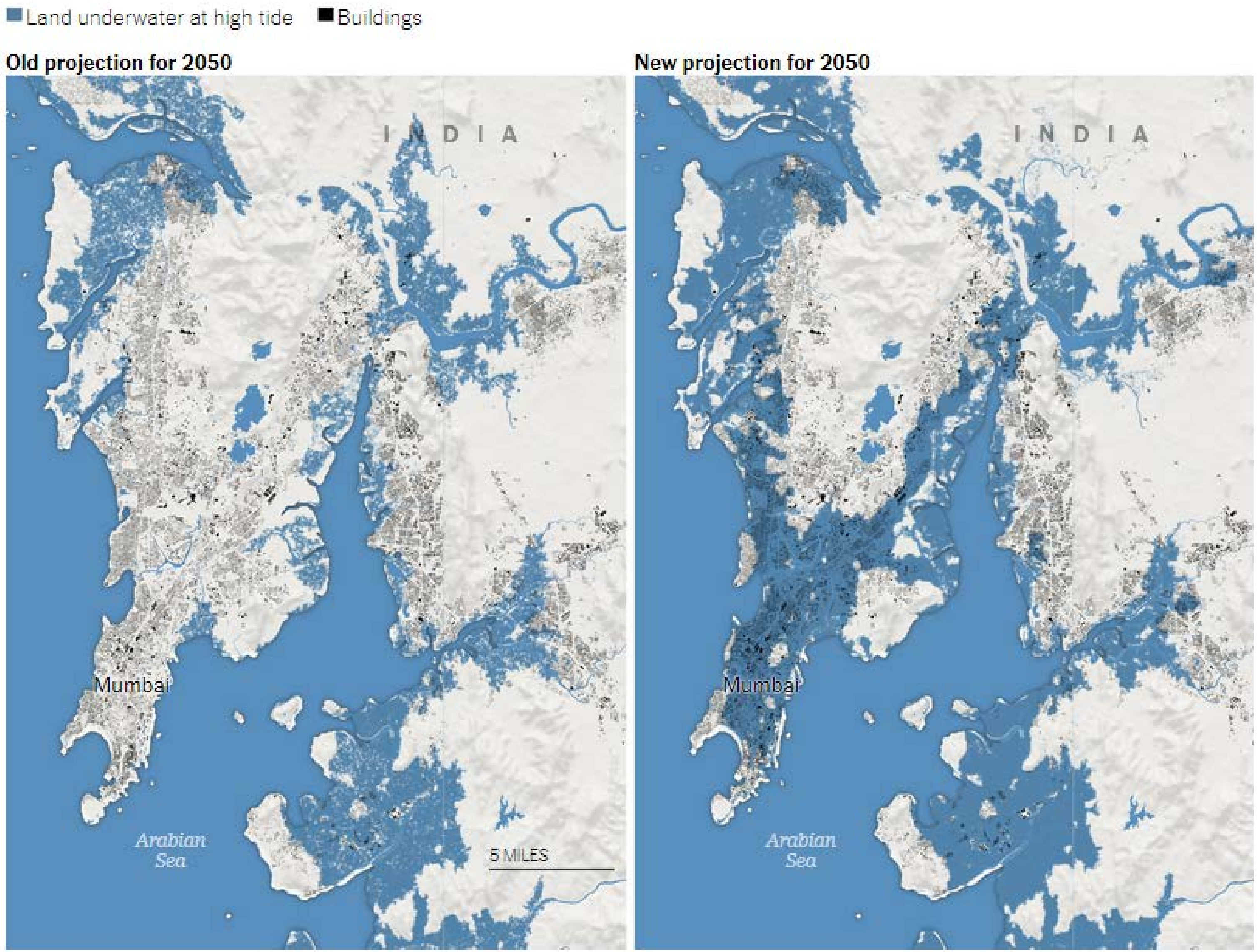
Land underwater at high tide
Populated area
Old projection for 2050
New projection for 2050
20 MILES
THAILAND
Bangkok
Gulf of Thailand
THAILAND
Bangkok
Gulf of Thailand

Shanghai

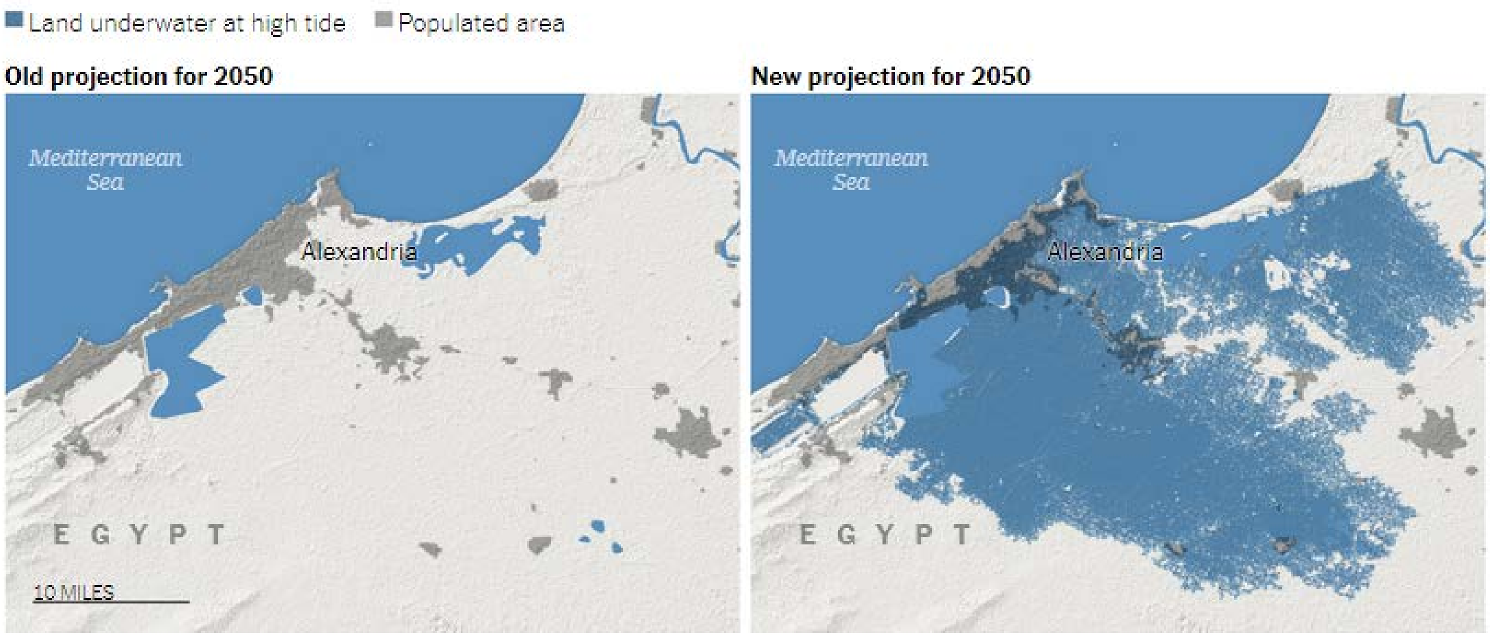


Land underwater at high tide
Populated area
Old projection for 2050
New projection for 2050
C H I N A
Shanghai
East China Sea
20 MILES

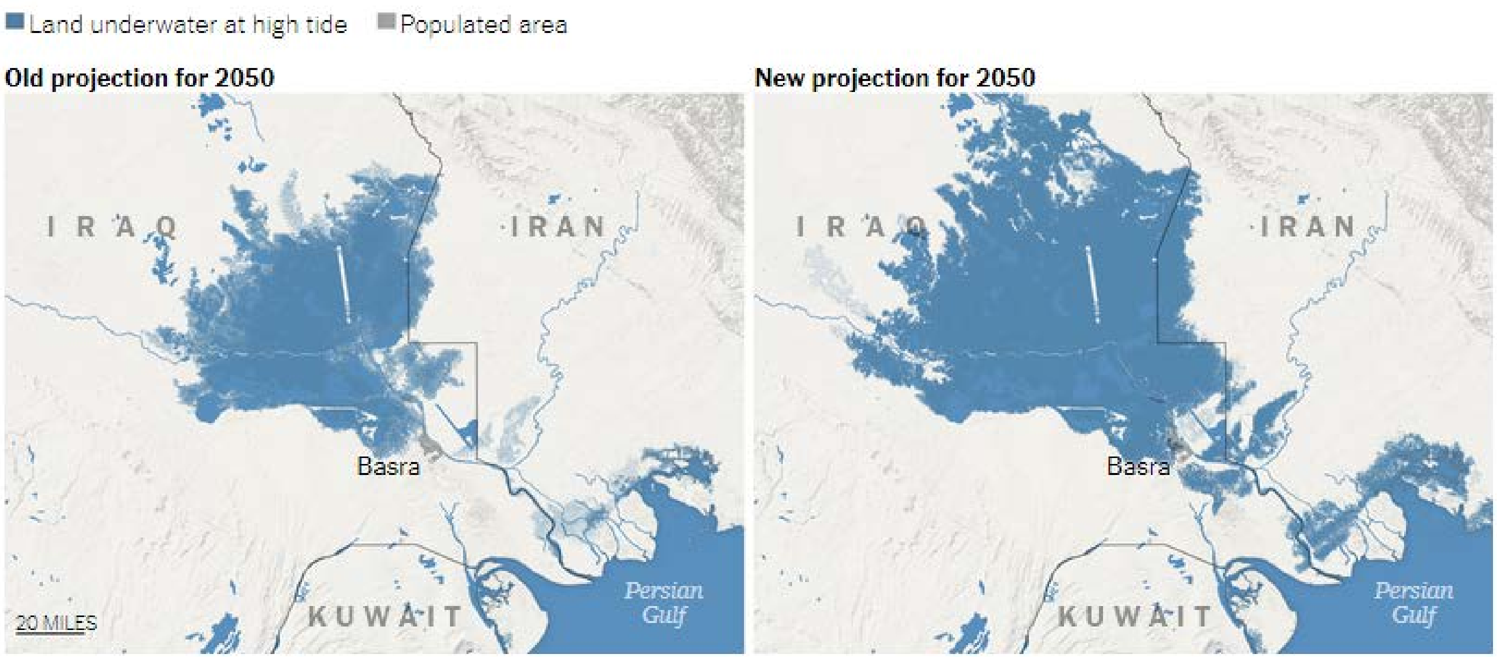
Mumbai


Land underwater at high tide
Buildings
Old projection for 2050
New projection for 2050
INDIA
Mumbai
Arabian Sea
5 MILES
INDIA
Mumbai
Arabian Sea

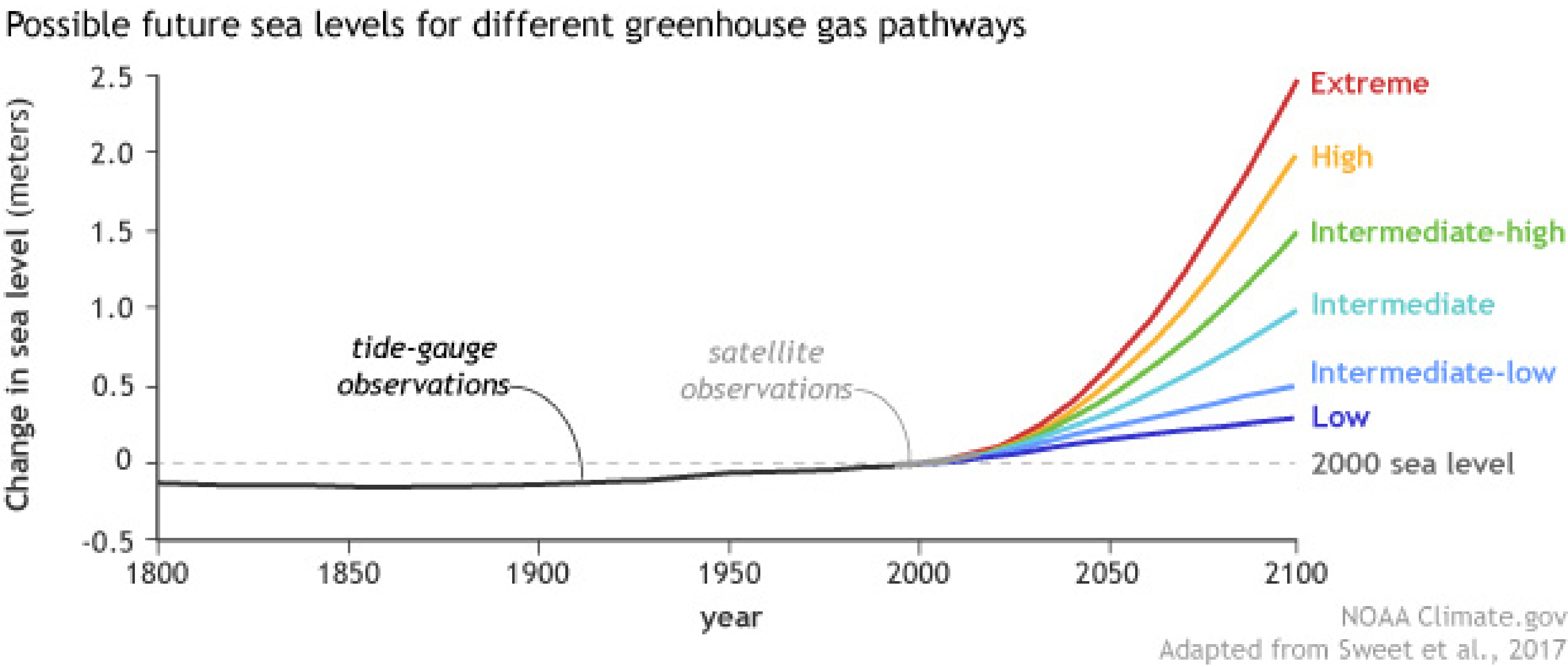
Alexandria


Land underwater at high tide
Populated area
Old projection for 2050
Mediterranean Sea
Alexandria
EGYPT
10 MILES
New projection for 2050
Mediterranean Sea
Alexandria
EGYPT

Basra


Land underwater at high tide
Populated area
Old projection for 2050
New projection for 2050
IRAQ
IRAN
Basra
KUWAIT
Persian Gulf
20 MILES
IRAQ
IRAN
Basra
KUWAIT
Persian Gulf

NOAA Sea Level Rise Projections



Energy, Climate, and Emissions Review

- U.S. and Global Energy Sources and Use
  - Energy flow
- Climate science
  - Temperature analysis
  - Weather 2050
- Climate change and GHG emissions
  - Stripes
  - Billion dollar weather events
- Climate models
  - Climate model accuracy
- Sea level rise

Weather Channel 2100