Soylent Green (1973)

"Greenhouse effect…
everything is burning up"

Edward G. Robinson

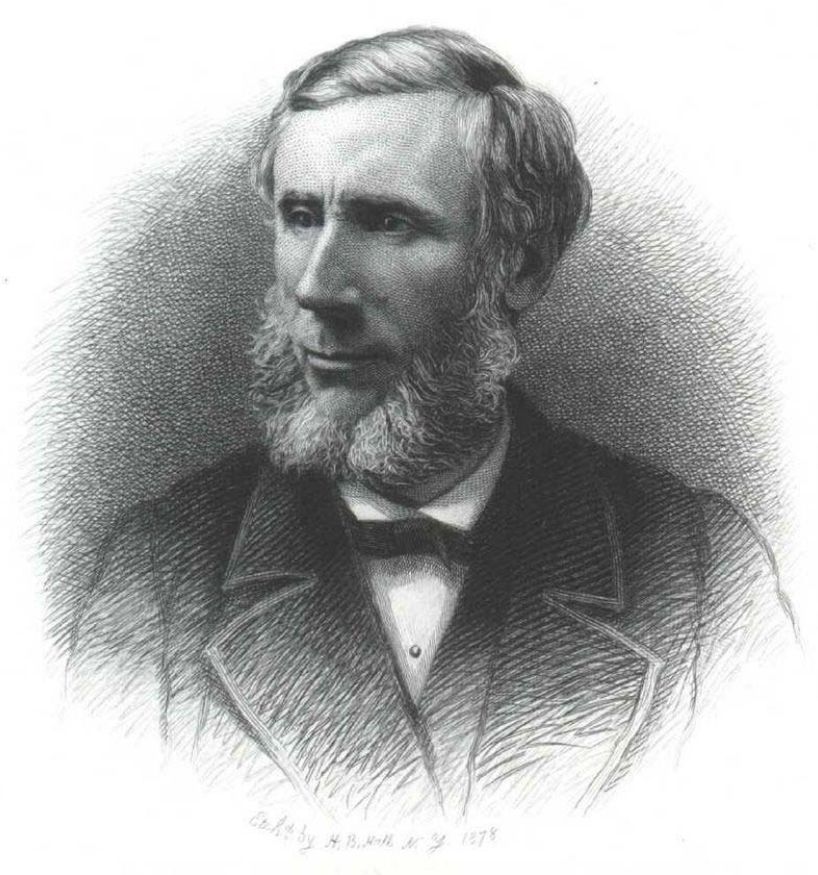
Charleston Heston

Brief history of global warming

1824 – French physicist Joseph Fourier discovered the *greenhouse effect* – atmosphere passes visible light and traps infrared

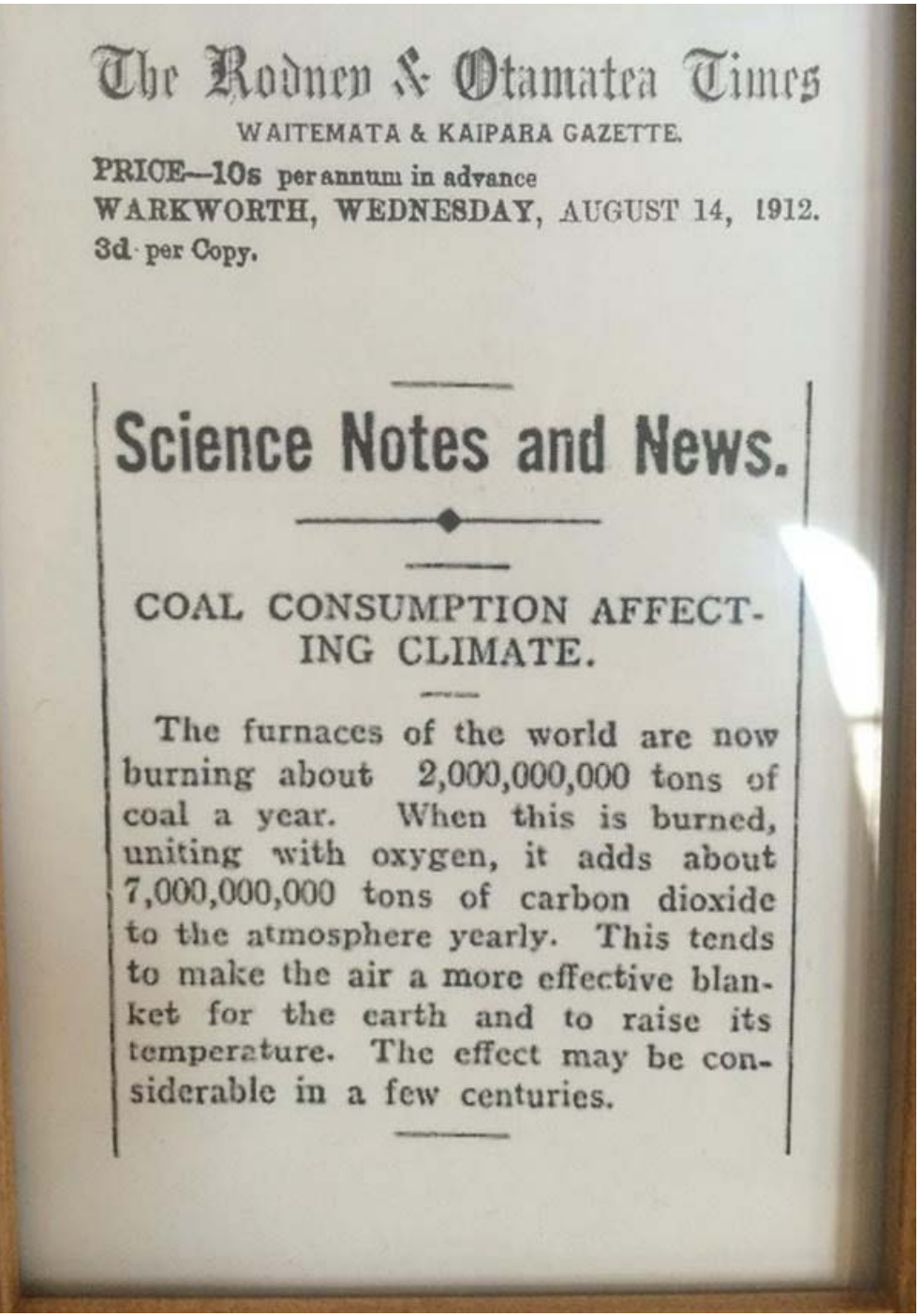
Brief history of global warming

1864 – British scientist John Tyndall measured infrared absorption of CH_4, CO_2 , and H_2O



Brief history of global warming

1896 – Swedish scientist Svante Arrhenius estimated that doubling atmospheric CO_2 will increase global T by 5 to 6°C



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.

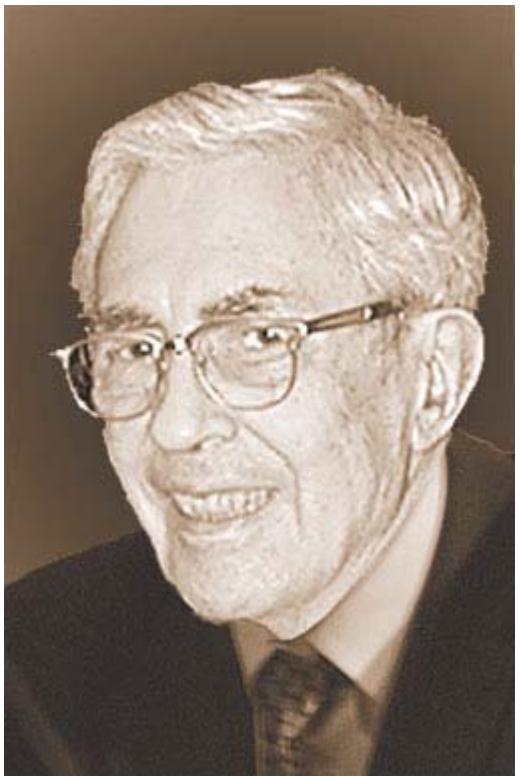
Brief history of globa warming

1912 –Article in New Zealand newsp

https://paperspast.natlib.govt.nz/newspapers/rodney-and-otamatea-times-waitemata-and-kaipara-gazette/

Brief history of global warming

1955 – Texas A&M physicist Gilbert Plass studied infra-red spectroscopy and determined impact of CO_2 and H_2O on climate

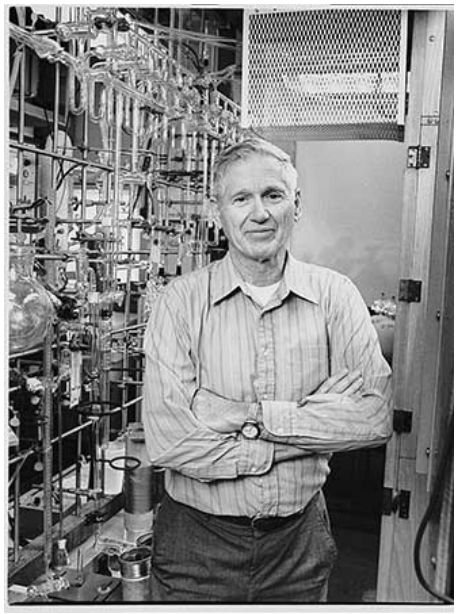


Conclusion:

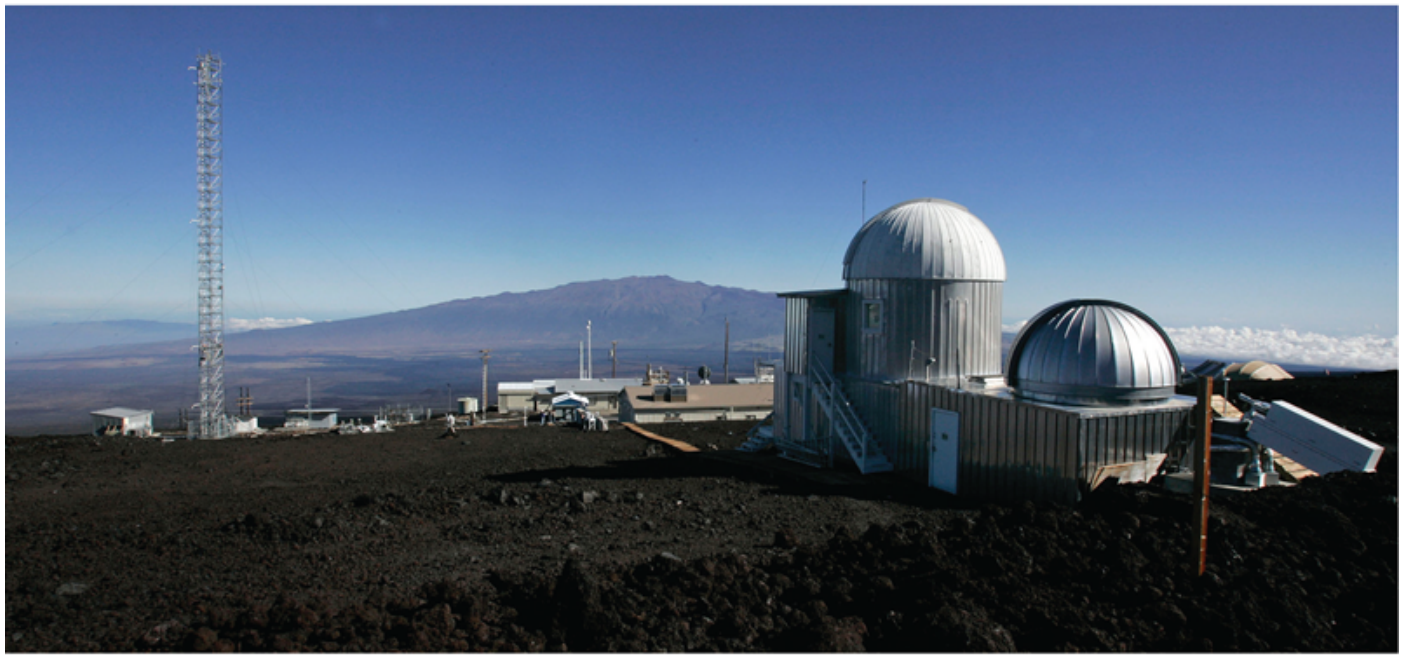
Doubling CO_2 conc. will increase global temperatures 3 to 4^oC

Brief history of global warming

1958 – Charles David Keeling begins measuring atmospheric CO_2 concentrations at Mauna Loa



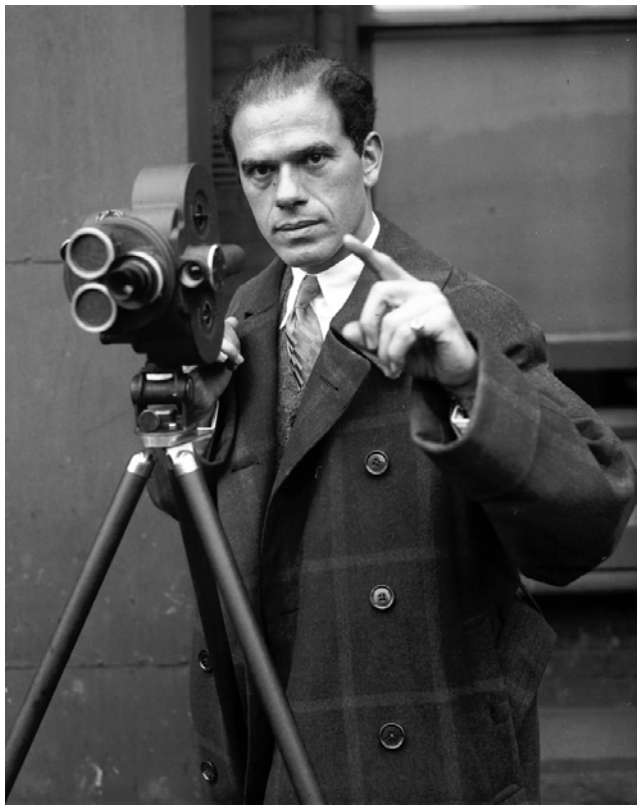
The Mauna Loa Observatory in Hawaii



Source: Chris Stewart/Associated Press

Brief history of global warming

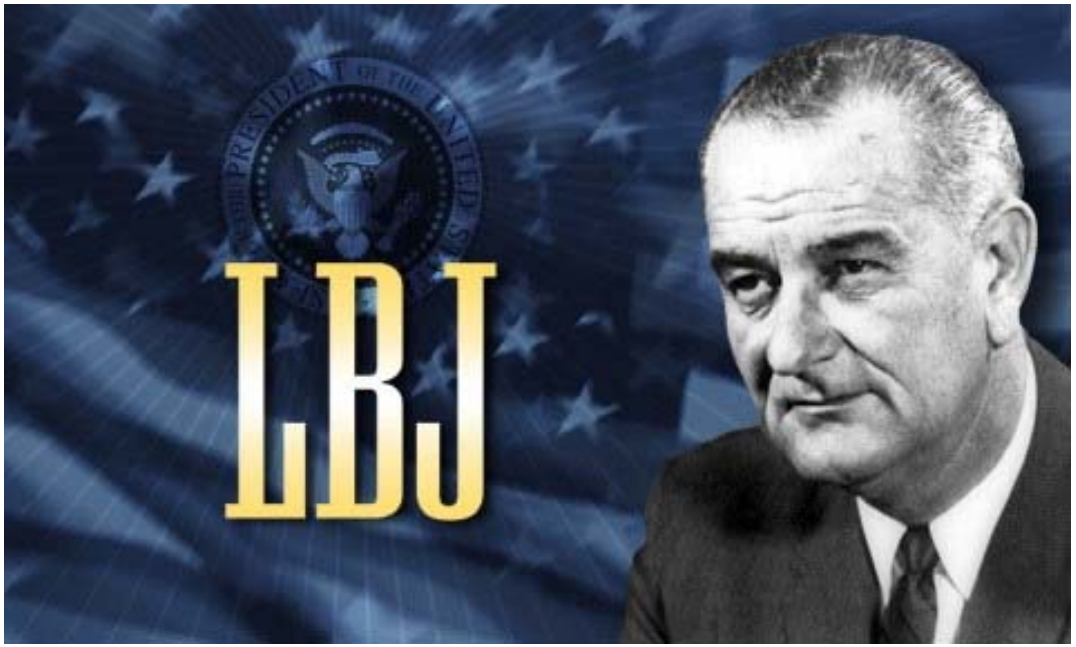
1958 – Hollywood's Frank Capra produces a film on global warming



Bell Telephone Science Hour

Brief history of global warming

1965 – US President's science advisory committee warns that greenhouse effect is a "real concern"



RESTORING THE QUALITY

OF

OUR ENVIRONMENT

Report of The
Environmental Pollution Panel
President's Science Advisory Committee

THE WHITE HOUSE

NOVEMBER 1965

Brief history of global warming

1988 – UN Intergovernmental Panel on Climate Change (IPCC) formed

IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

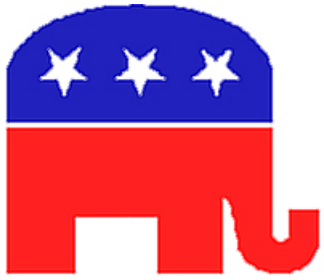
WMO UNEP

Brief history of global warming

2006 – Al Gore releases *An Inconvenient Truth*

Global warming

Politically Divided



Global warming

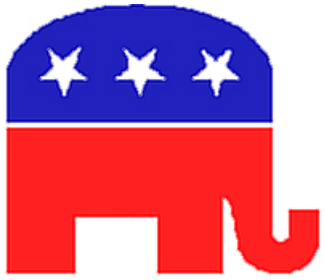
Democrat Position:

The sky is falling…we are all going to roast.

Global warming

Republican Position:

Weather and climate are inherently variable.

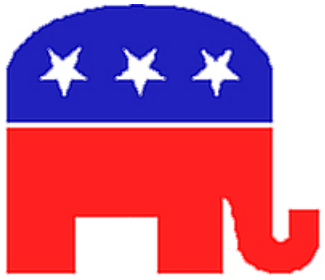


Global warming

Republican Position:

Weather and climate are inherently variable.

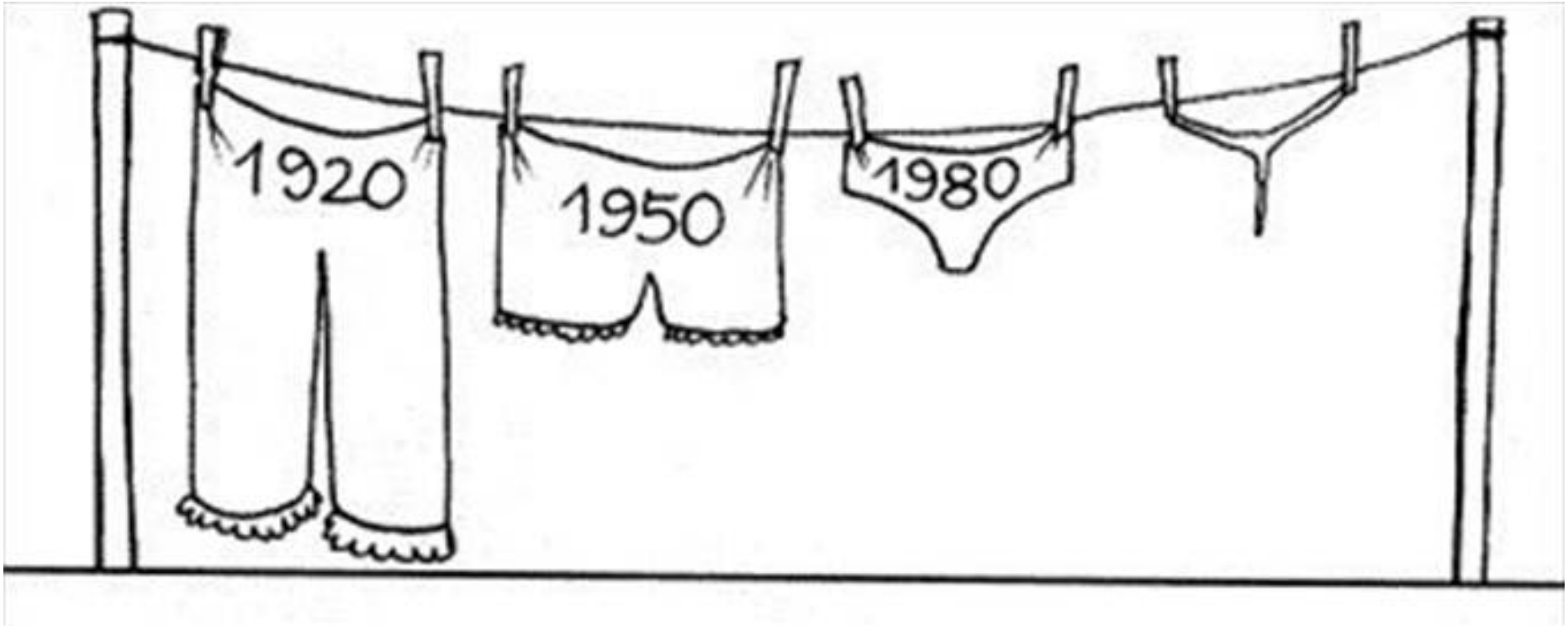
This fuss over global warming is just another Democrat plot to socialize the economy.



Global warming

Irrefutable Scientific Proof

Global warming



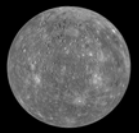
Global Warming: An Engineering Perspectiv

Mark Holtzapple
Department of Chemical Engineering
Texas A&M University
College Station, TX 77843

Quiz

Which planet is hotter?

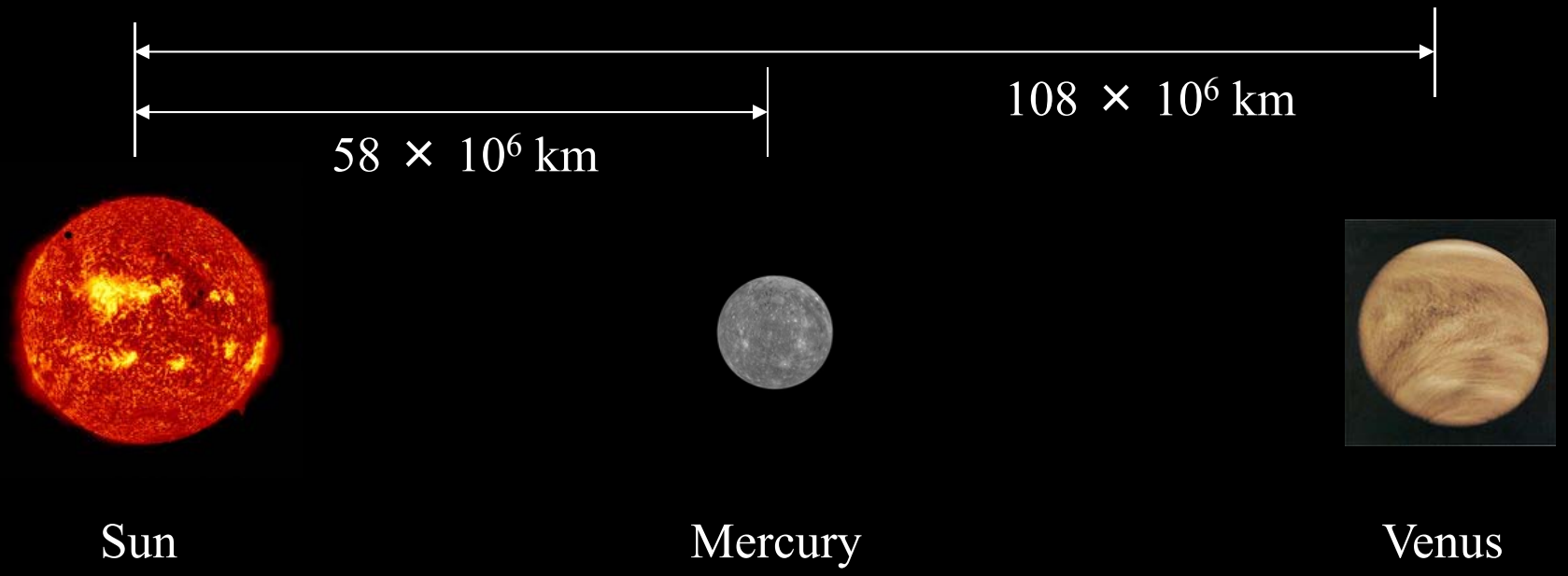
Sun



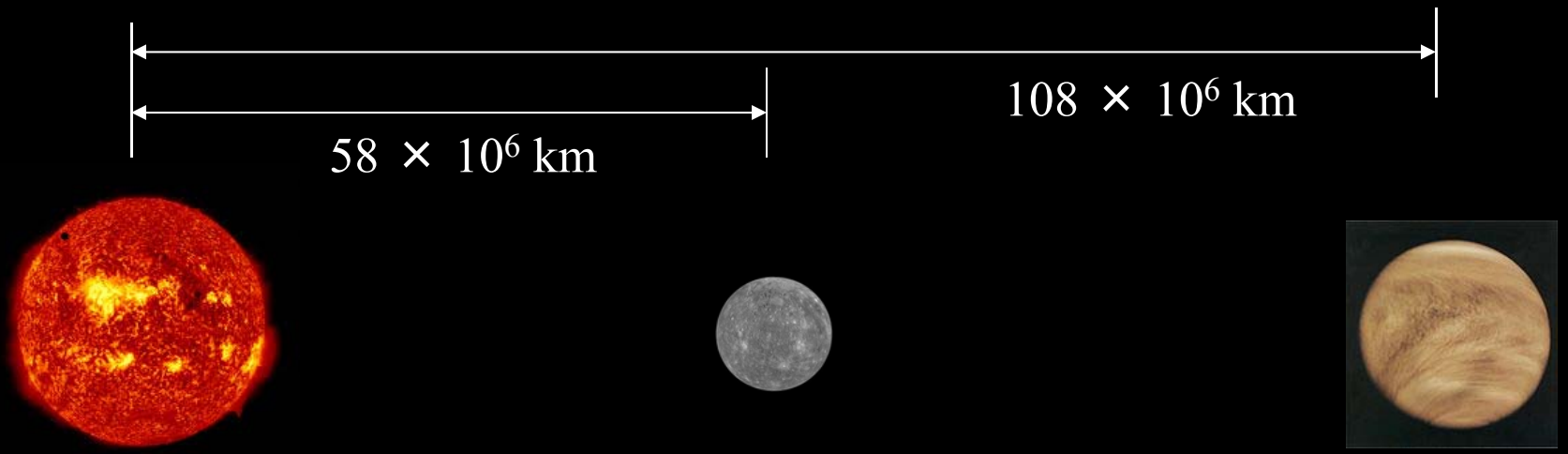
Mercury

Venus

Which planet is hotter?



Which planet is hotter?



Sun

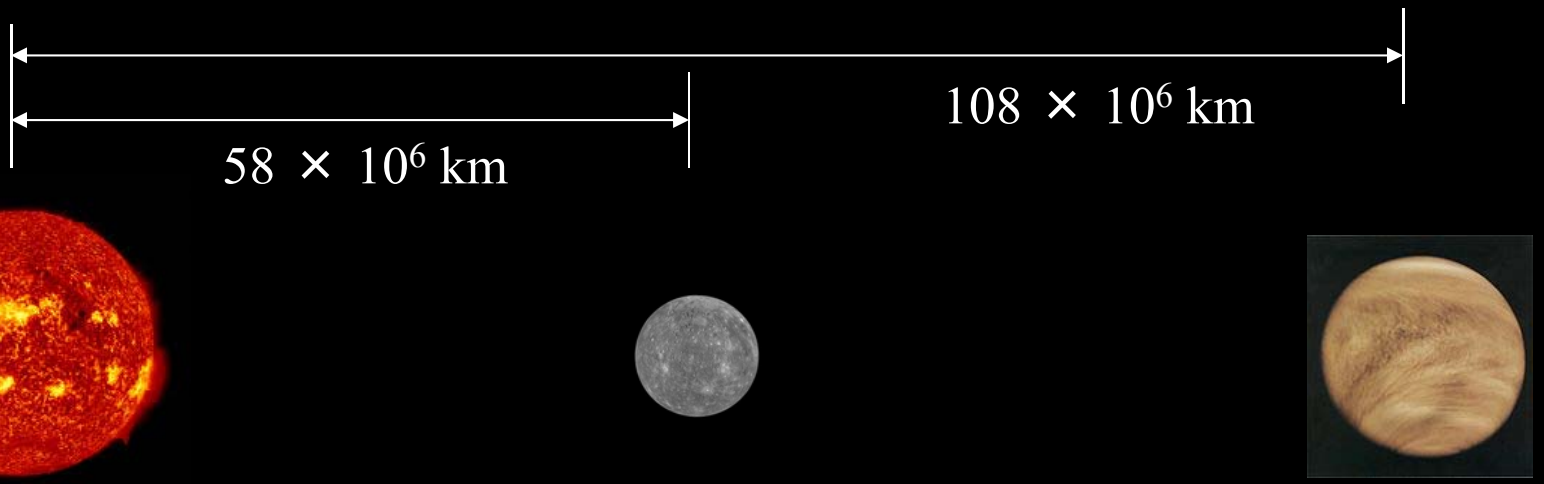
Mercury

T_{ave} = 167°C = 333°F

Venus

T_{ave} = 467°C = 873°F

Which planet is hotter?



Sun

Mercury

T_{ave} = 167°C = 333°F

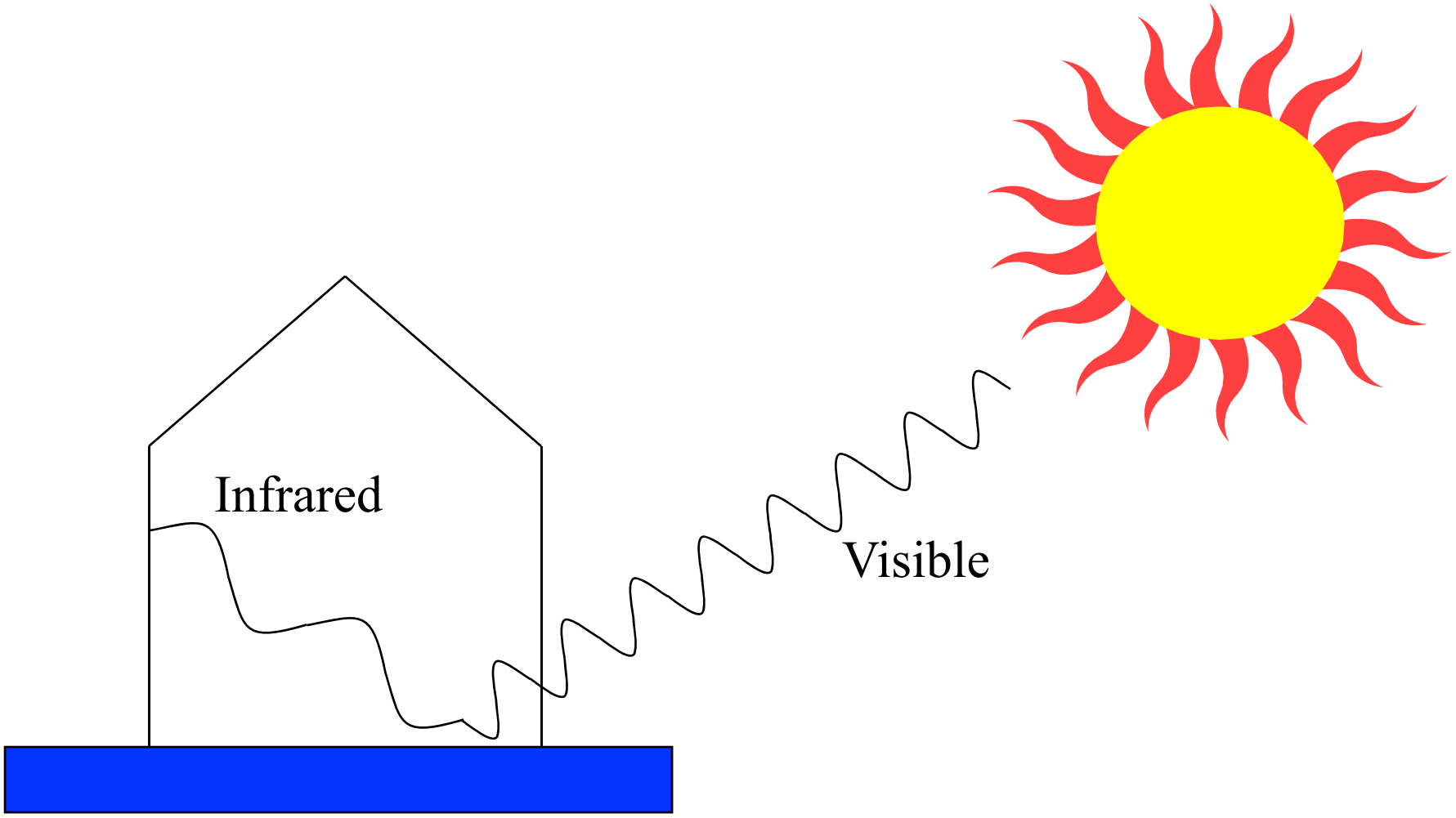
$P_{carbon\ dioxide}$ = 0 atm

Venus

T_{ave} = 467°C = 873°F

$P_{carbon\ dioxide}$ = 89 atm

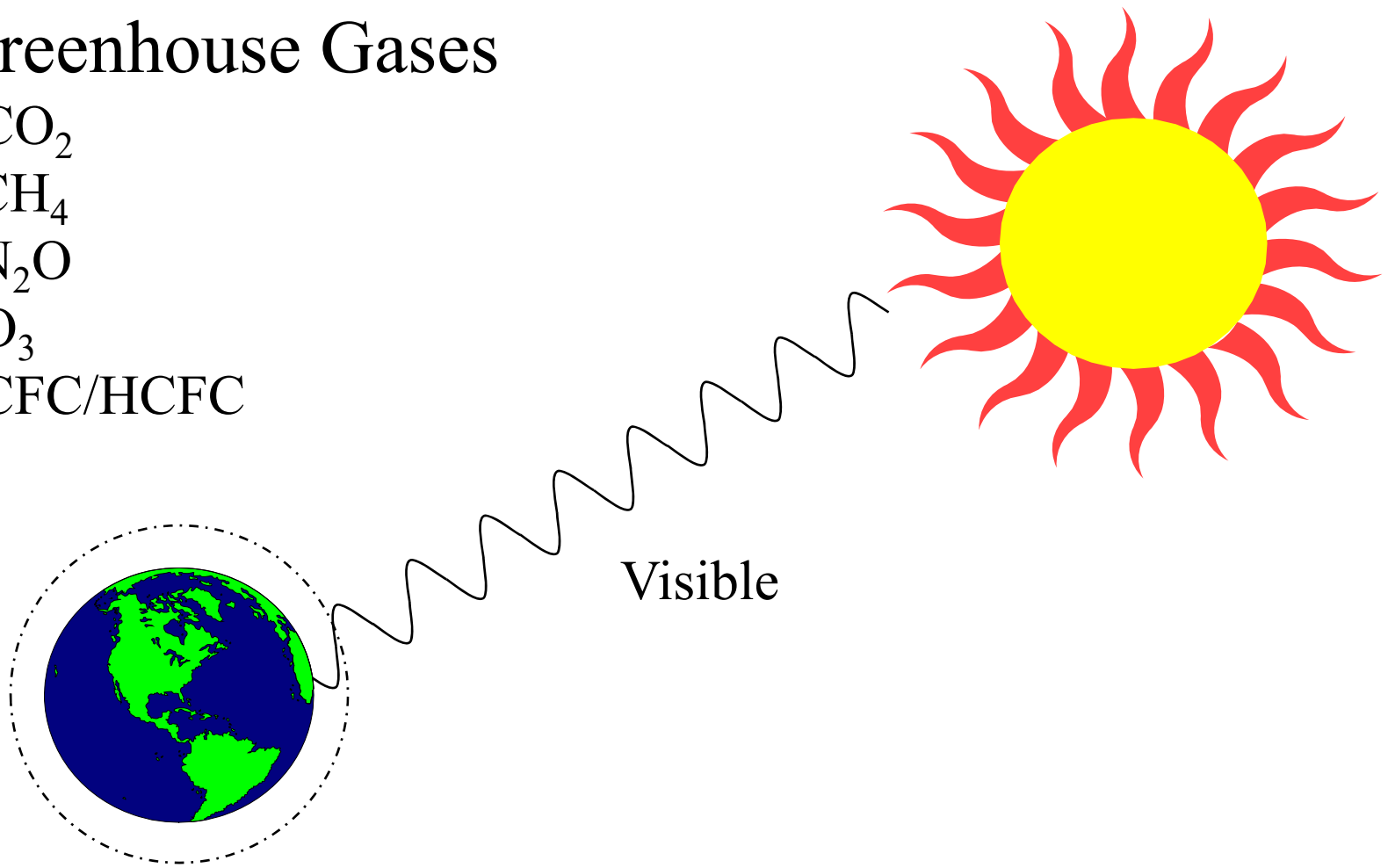
reenhouse Effect



nthropogenic Greenhouse Gases

Greenhouse Gases

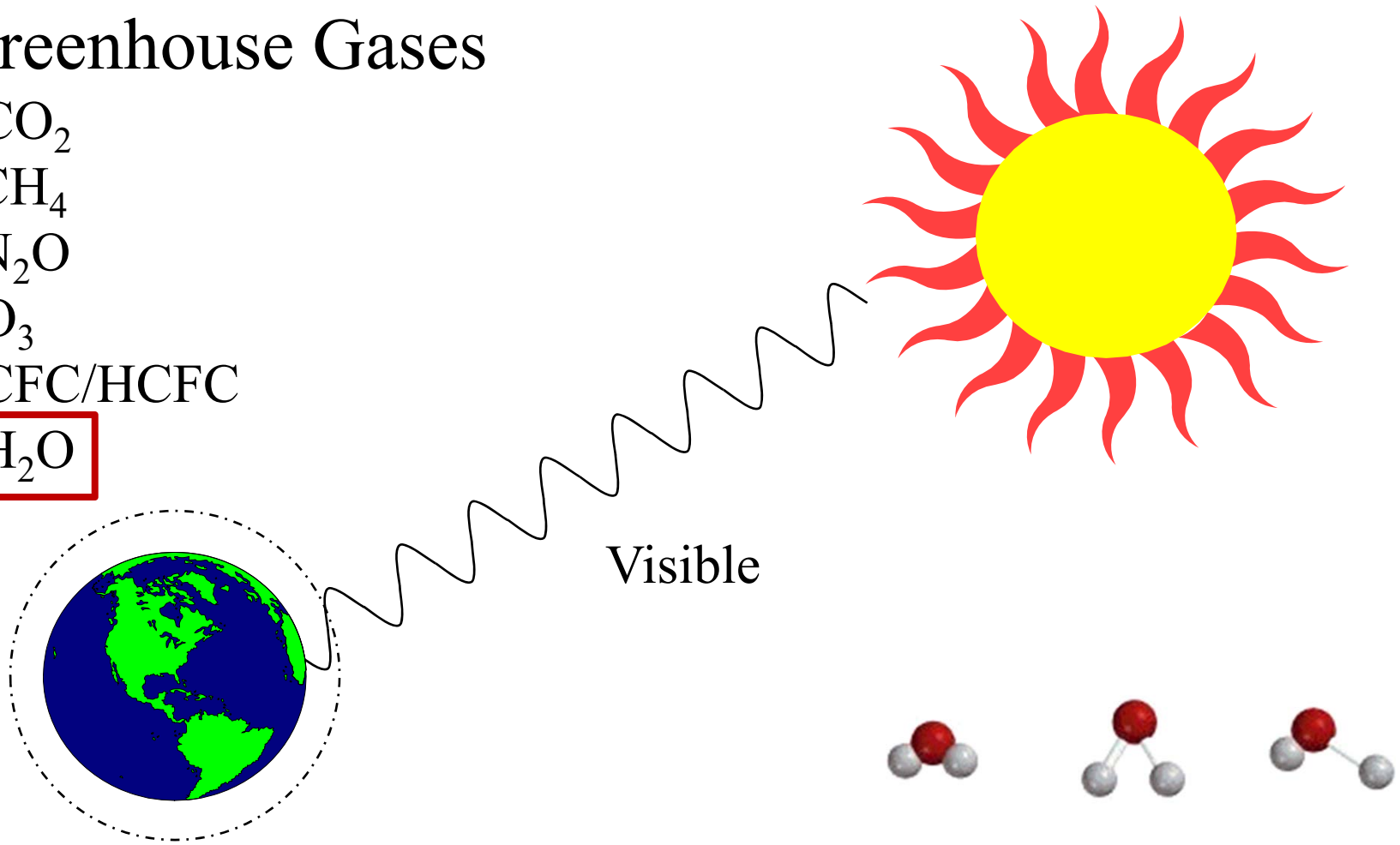
- CO_2
- CH_4
- N_2O
- O_3
- CFC/HCFC



Greenhouse Gases

Greenhouse Gases

- CO_2
- CH_4
- N_2O
- O_3
- CFC/HCFC
- H_2O



elative Contributions

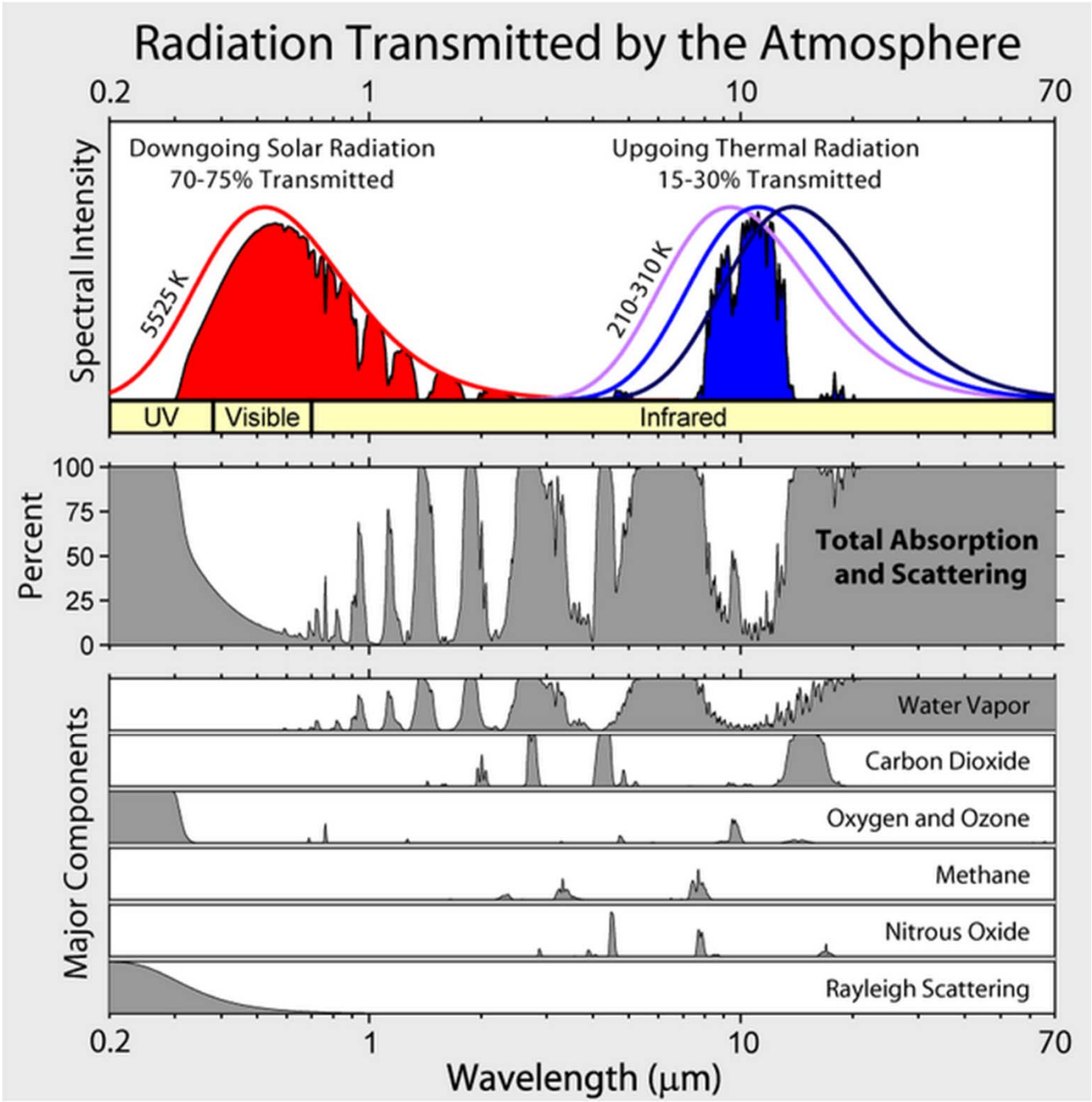
Gas	Formula	Contribution (%)
Water vapor	H_2O	36 – 72%
Carbon dioxide	CO_2	9 – 26%
Methane	CH_4	4 – 9%
Ozone	O_3	3 – 7%

http://en.wikipedia.org/wiki/Greenhouse_gas

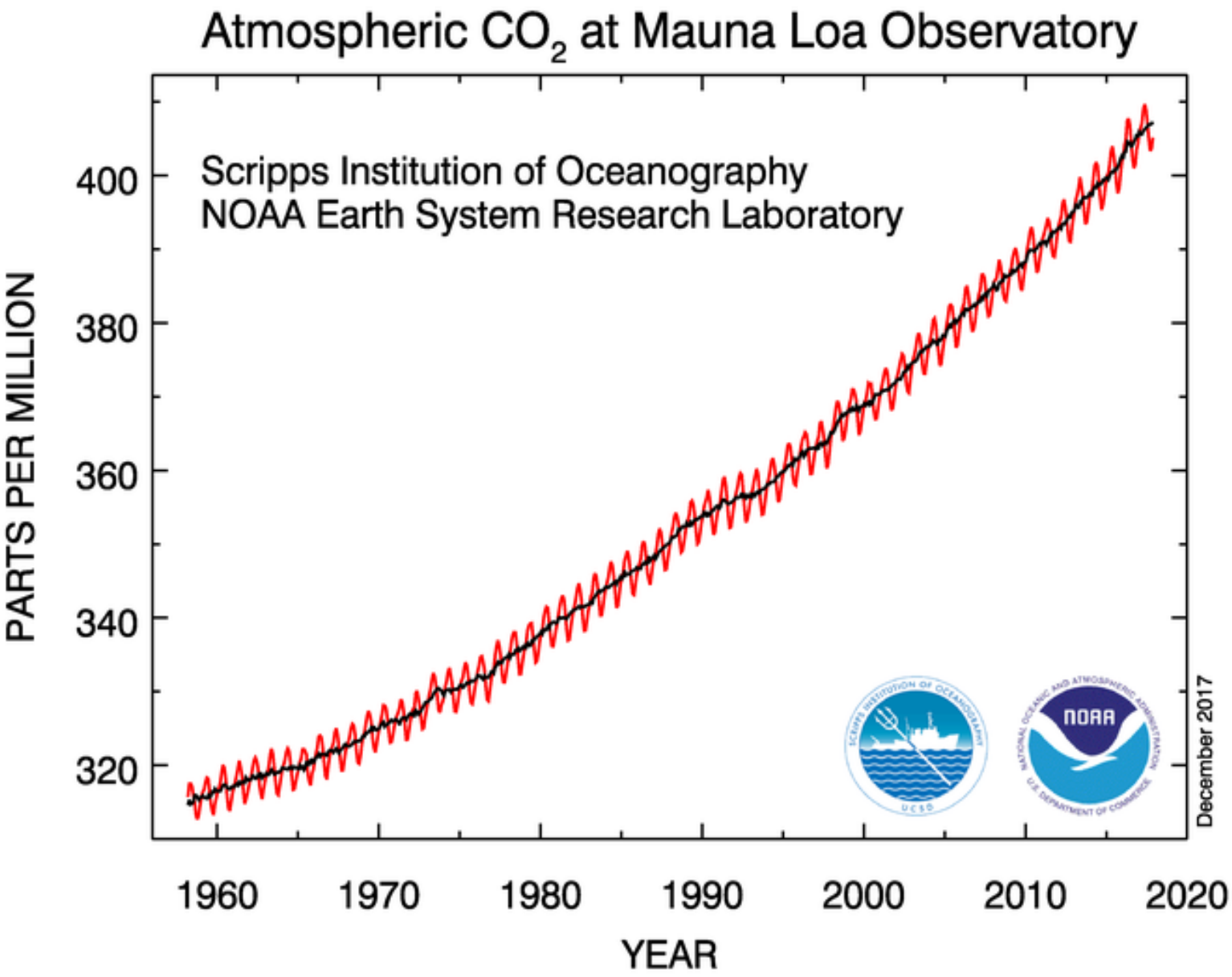
Slide 27

AD4 just a note: you don't have clouds on here. that probably explains the range for each contribution. you get the lower value if the scene is cloudy and the higher value if it's clear (but I'm just guessing). the numbers I remember are that water + clouds = 60%, CO2 = 25%, and other gases are the remainder.

Andrew Dessler, 5/22/2012



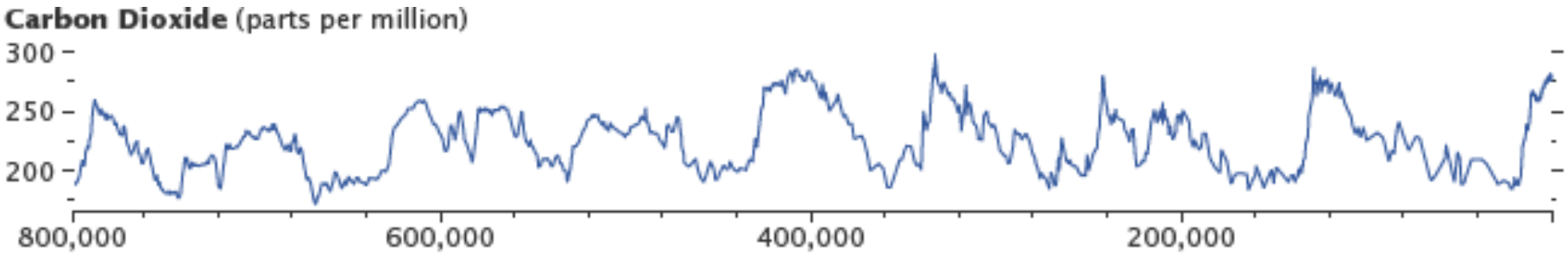
http://en.wikipedia.org/wiki/Greenhouse_gas



http://www.esrl.noaa.gov/gmd/ccgg/trends/full.html

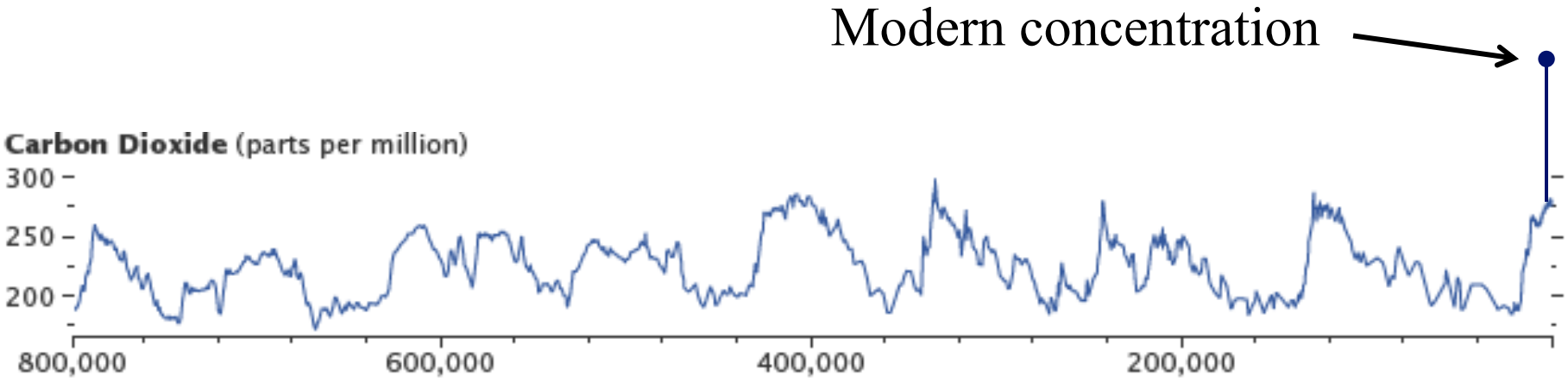
ce Cores

istorical CO_2 Concentration



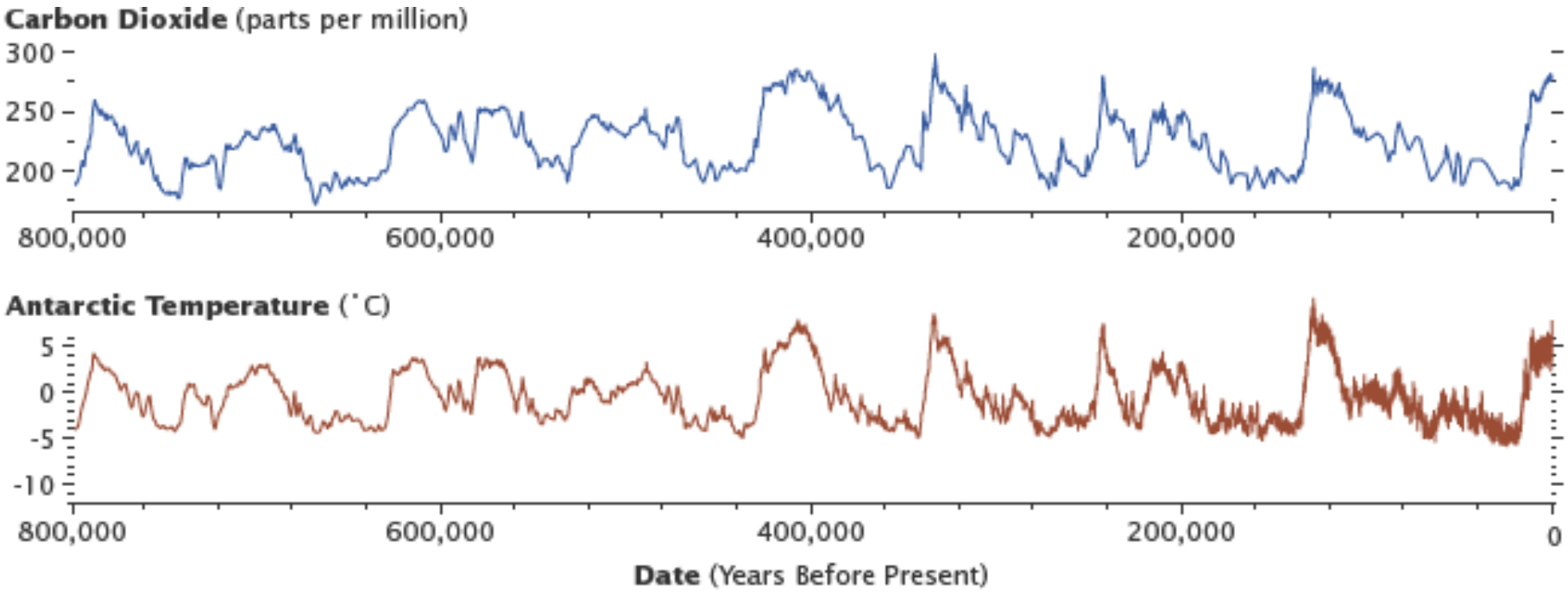
http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php

istorical CO_2 Concentration



http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php

ombined

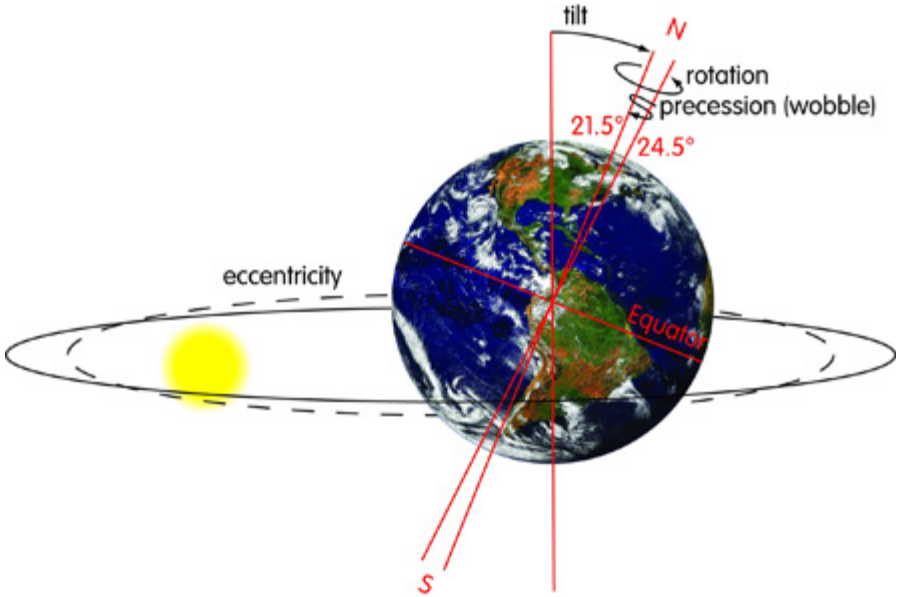


http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php

Correlation

Hypothesis	Independent	Dependent
1	Temp	CO_2
2	CO_2	Temp

istorical

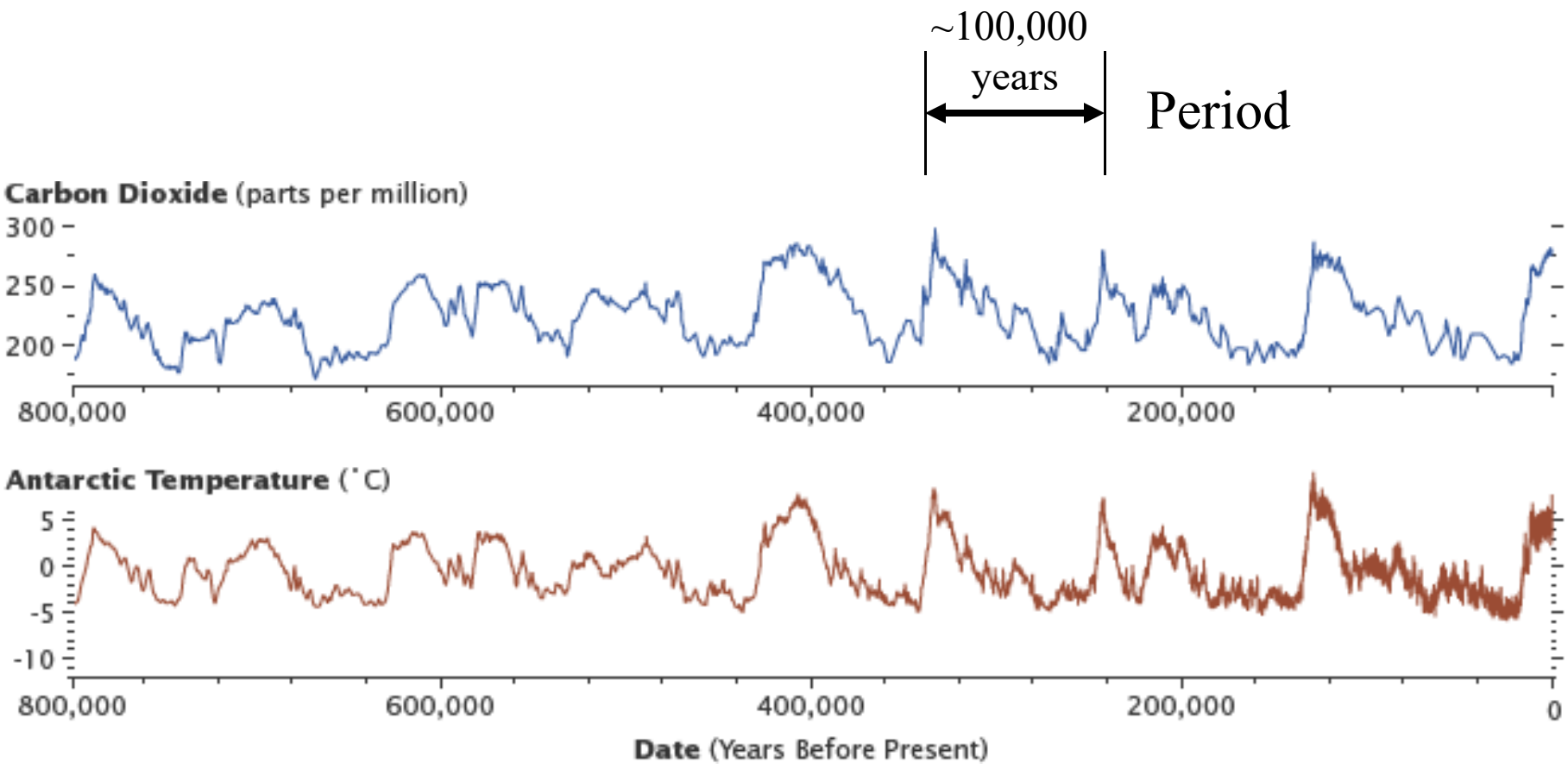


Periodic temperature changes are determined by

- ***Eccentricity*** – Changes in the shape of the ellipse (100,000 years).
- ***Obliquity*** – The tilt of the Earth toward the sun on its axis of rotation (40,000 years).
- ***Precession*** – The wobble of the Earth on its axis (26,000 years).

http://sparkcharts.sparknotes.com/gensci/geology_earthsci/section15.php

ombined



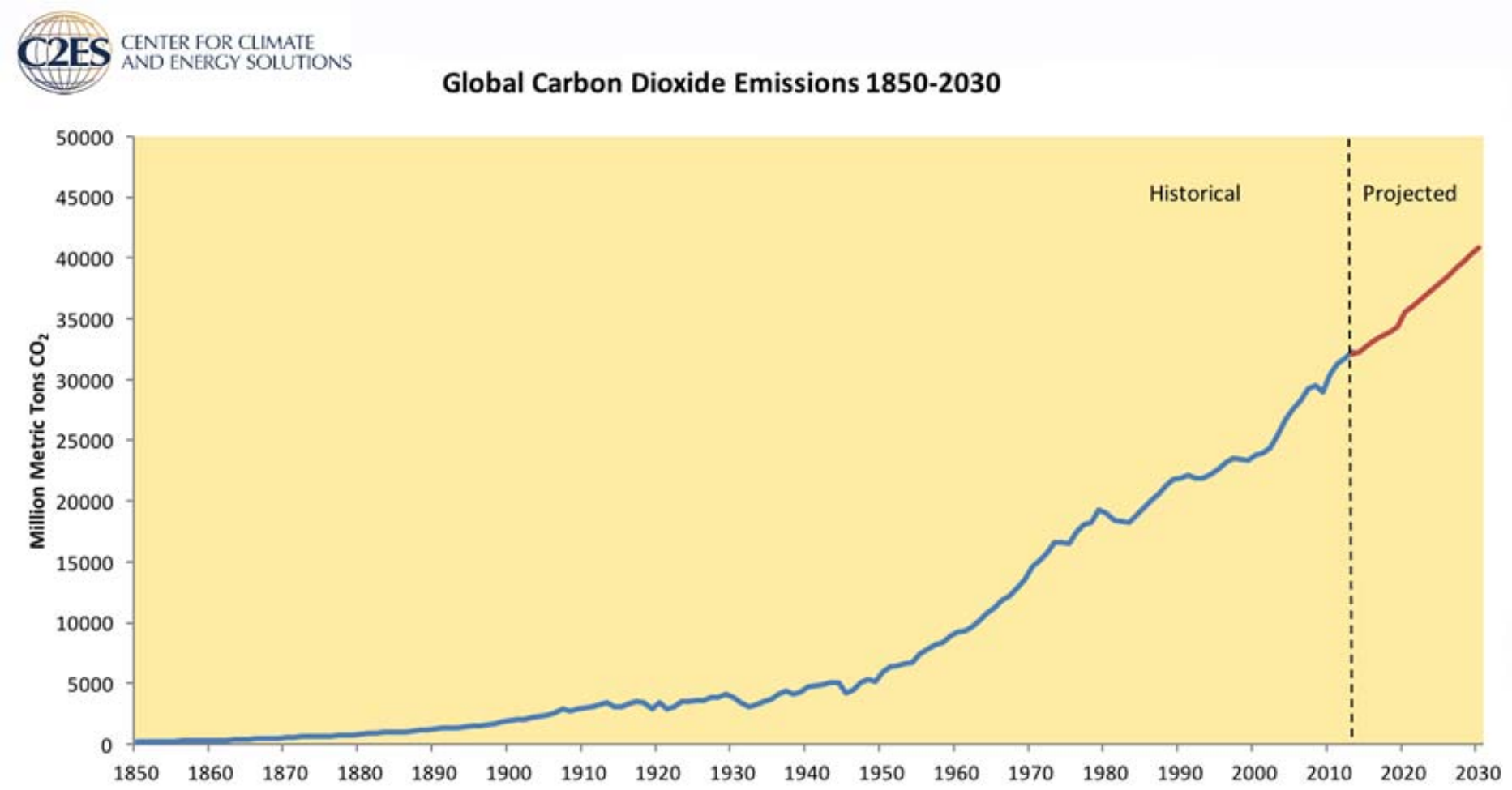
http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php

Correlation

	Hypothesis	Independent	Dependent
Historical	1	Temp	CO_2
	2	CO_2	Temp

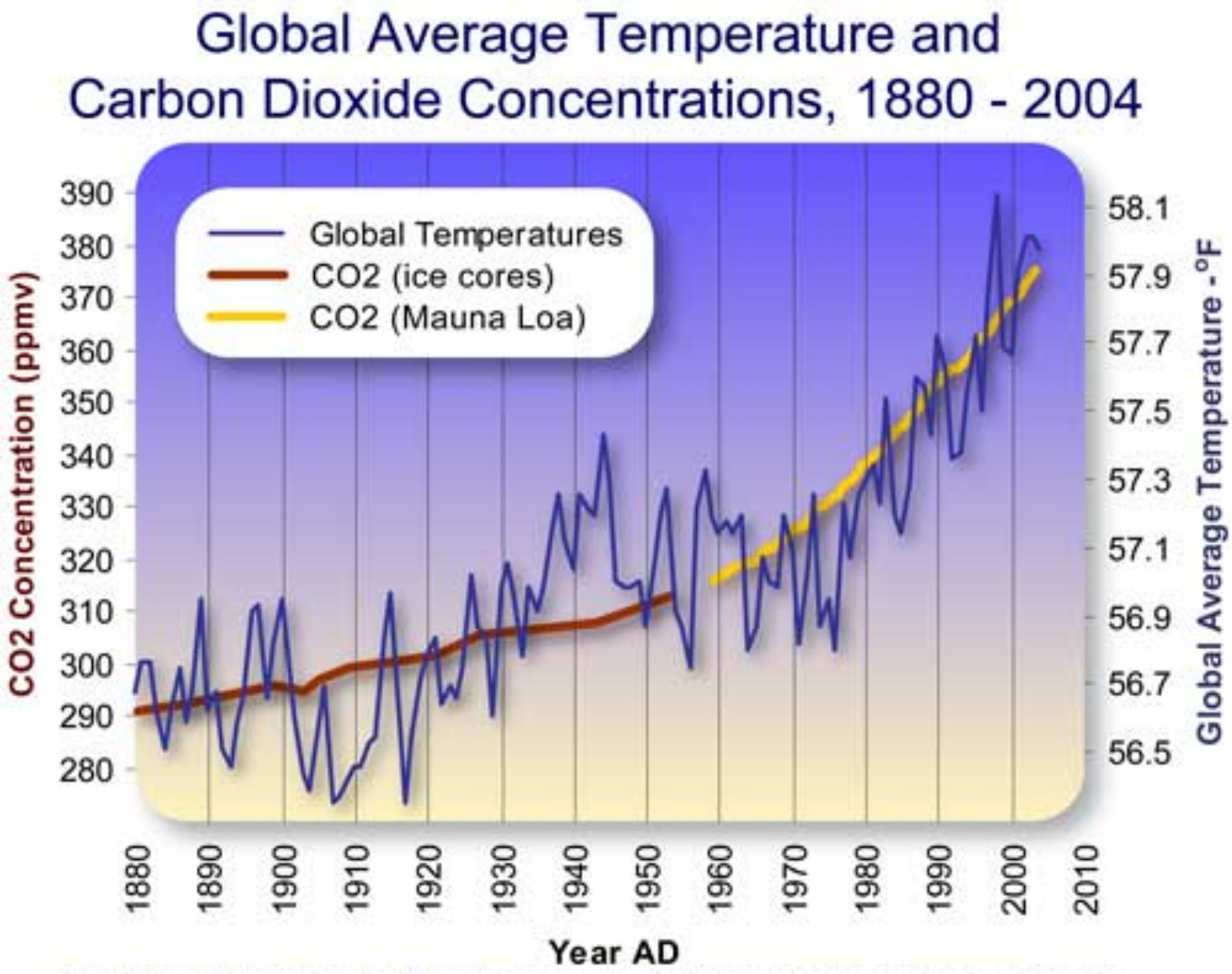
Experiment

What happens when we dump CO_2 into the atmosphere?



http://www.c2es.org/facts-figures/international-emissions/historical

Recent Correlation



Correlation

	Hypothesis	Independent	Dependent
	1	Temp	CO_2
Modern	2	CO_2	Temp

Correlation

	Hypothesis	Independent	Dependent
	1	Temp	CO_2
Modern	2	CO_2	Temp

This is the Greenhouse Effect

Question

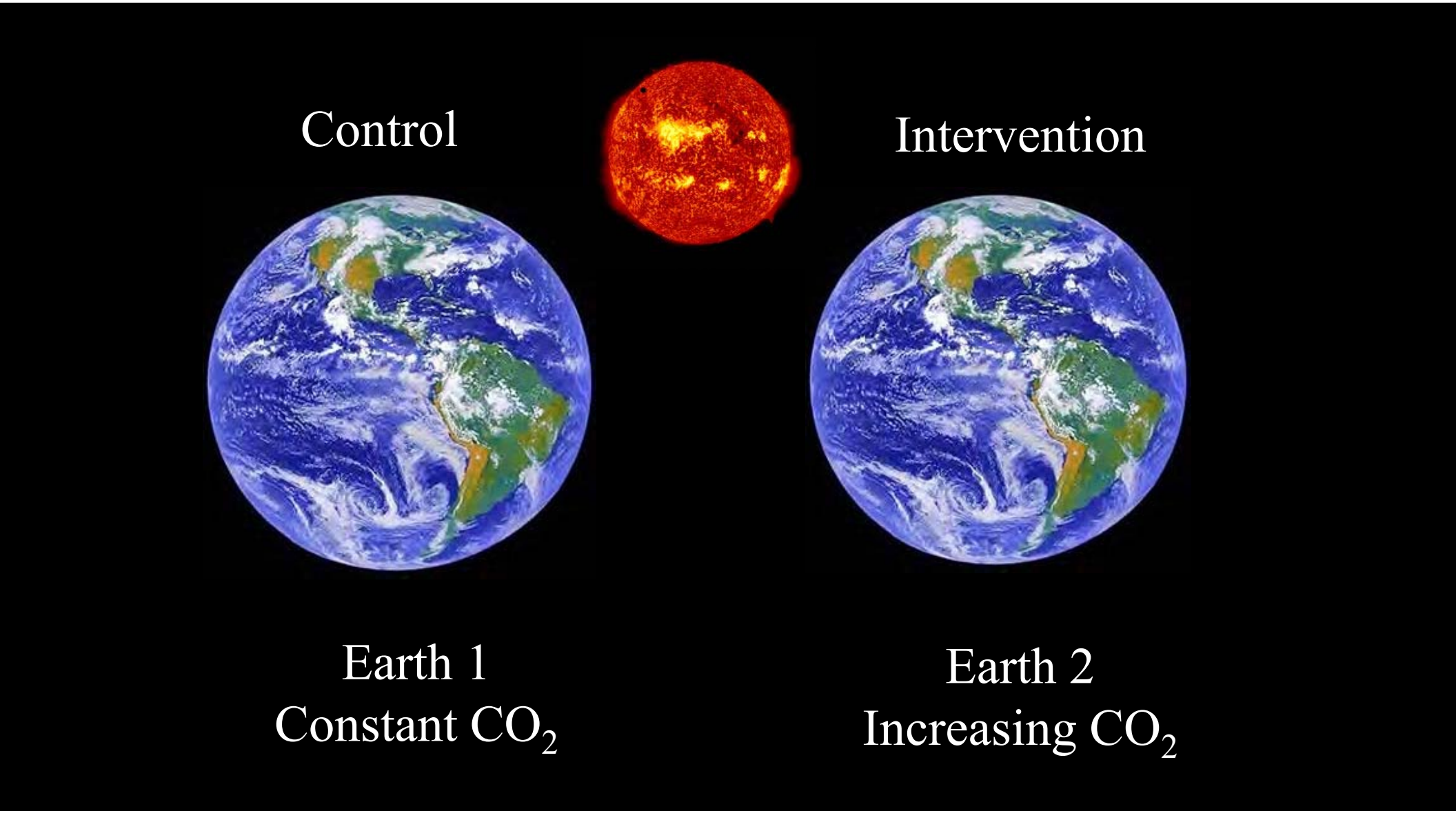
Classically, how does science learn truth?

Answer

Run a controlled experiment.

With fertilizer No fertilizer

ontrolled Experiment



uestion

We have only one planet...

How do we run the control?

Answer

Modeling

Do you trust models?

Do you trust models?

All models are wrong…

Do you trust models?

All models are wrong…

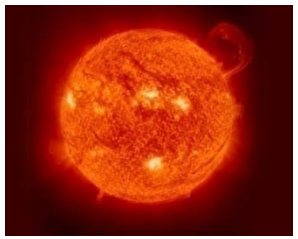
… but some are useful.

George Box – statistician

Simple physical models

No greenhouse gases

Energy out = Energy in



Albedo

107 W/m^2

342 W/m^2

Atmosphere

235 W/m^2

$F = \varepsilon\sigma T_1^4$

235 W/m^2

T_1

Ground

Black Body Radiation

Table 1. The summary of the former emissivity studies.

Emissivity	Study	Summary of the method
0.993	Buettner and Kern (1965)	not considering the skin layer
0.986	Saunders (1967b, 1968)	observation of the reflectance from the air plane
0.9875	Mikhaylov and Zolotarev (1970)	calculation from the optical constant
0.992 (11 μm)	Masuda *et al.* (1988)	calculation of the reflectance using the numerical model surface
0.972	Davies *et al.* (1971)	observation of sheltered watersurface from the sky

http://scienceofdoom.com/2010/12/27/emissivity-of-the-ocean/

$$F = \varepsilon\sigma T_1^4$$

F = Energy flux (W/m^2)

ε = Emissivity = ~1

σ = Stefan-Boltzmann constant = 5.67×10^{-8} W/(m^2 · K^4)

T = absolute temperature (K)

$$T_1 = \left(\frac{F}{\varepsilon\sigma}\right)^{1/4} = \left(\frac{235\,\frac{\mathrm{W}}{\mathrm{m}^2}}{(1)\left(5.67\times10^{-8}\ \mathrm{W/(m^2\cdot K^4)}\right)}\right)^{1/4} = 254\,\mathrm{K} = -19^{\circ}\mathrm{C}$$

$$-3.0^{\circ}\mathrm{F}$$

Black Body Radiation

$$F = \varepsilon\sigma T_1^4$$

Without greenhouse gases, Earth would be very cold!!

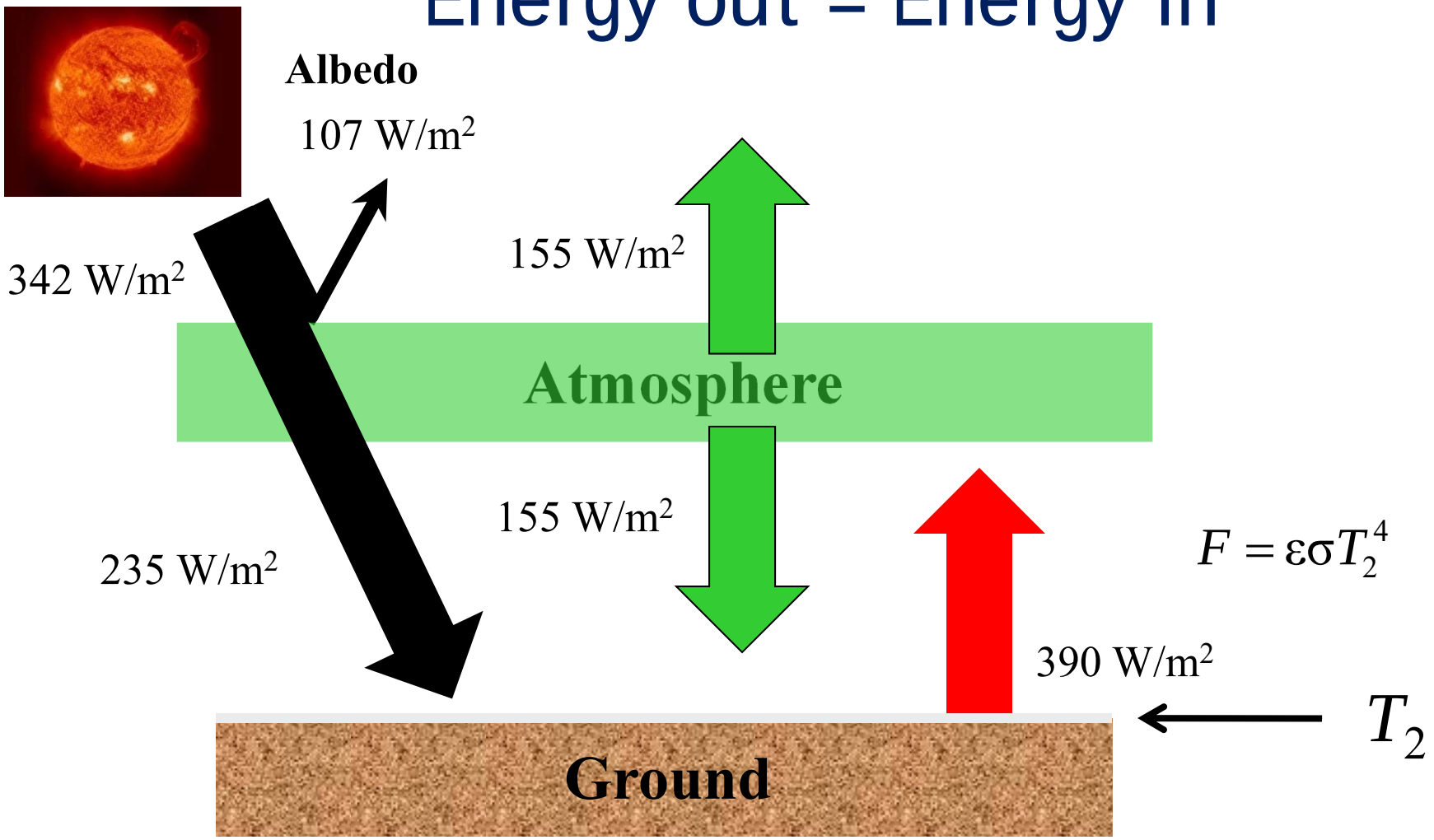
$$T_1 = \left(\frac{F}{\varepsilon\sigma}\right)^{1/4} = \left(\frac{235\,\frac{\mathrm{W}}{\mathrm{m}^2}}{(1)\left(5.67\times10^{-8}\ \mathrm{W/(m^2\cdot K^4)}\right)}\right)^{1/4} = 254\,\mathrm{K} = -19^{\circ}\mathrm{C}$$

$$-3.0^{\circ}\mathrm{F}$$

Simple physical models

With greenhouse gases

Energy out = Energy in



Black Body Radiation

$$F = \varepsilon \sigma T_2^4$$

F = Energy flux (W/m^2)

ε = Emissivity = ~1

σ = Stefan-Boltzmann constant = $5.67 \times 10^{-8}\ W/(m^2 \cdot K^4)$

T = absolute temperature (K)

$$T_2 = \left(\frac{F}{\varepsilon\sigma}\right)^{1/4} = \left(\frac{390\ \frac{W}{m^2}}{(1)\left(5.67\times10^{-8}\ W/(m^2\cdot K^4)\right)}\right)^{1/4} = 288\ K = 15^{o}C$$

$59^{o}F$

Black Body Radiation

$$F = \varepsilon\sigma T_2^4$$

This is the modern average temperature of the Earth

$$T_2 = \left(\frac{F}{\varepsilon\sigma}\right)^{1/4} = \left(\frac{390\,\frac{\mathrm{W}}{\mathrm{m}^2}}{(1)\left(5.67\times10^{-8}\ \mathrm{W/(m^2\cdot K^4)}\right)}\right)^{1/4} = 288\,\mathrm{K} = 15^{\circ}\mathrm{C}$$

$$59^{\circ}\mathrm{F}$$

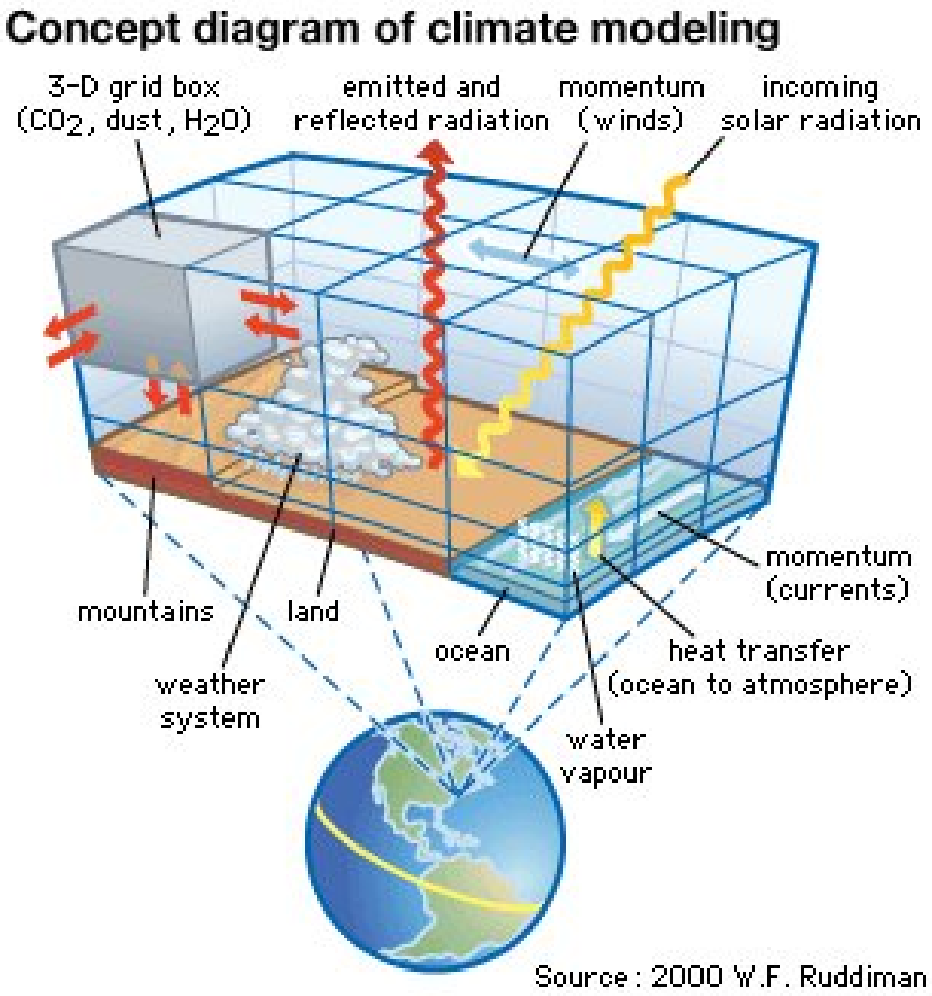
Global Climate Models (GCM)

First principles

- Conservation of energy
- Conservation of mass
- Conservation of momentum

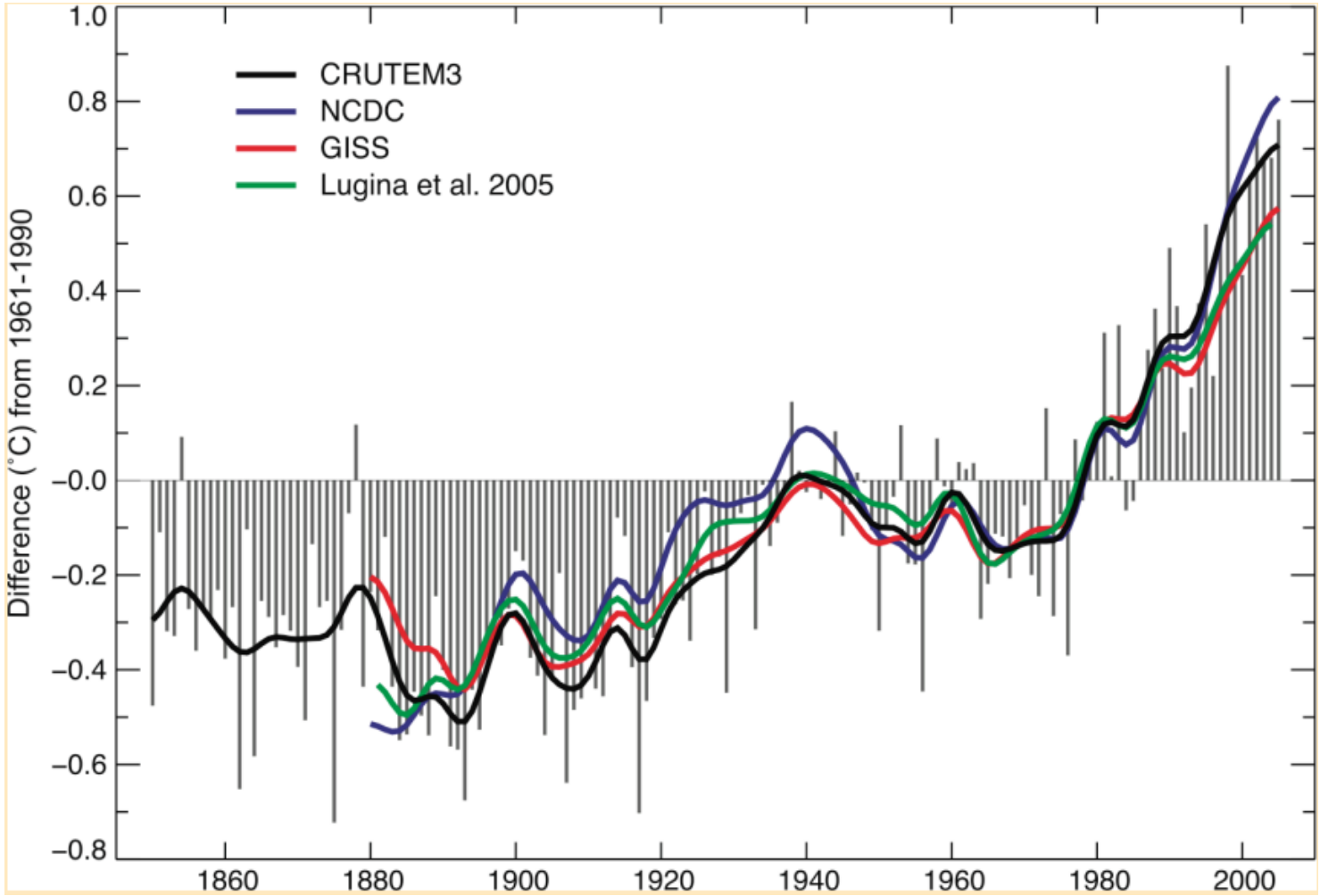
Measurements

- Thermal conductivity
- Density
- Viscosity
- Extinction coefficients
- etc.



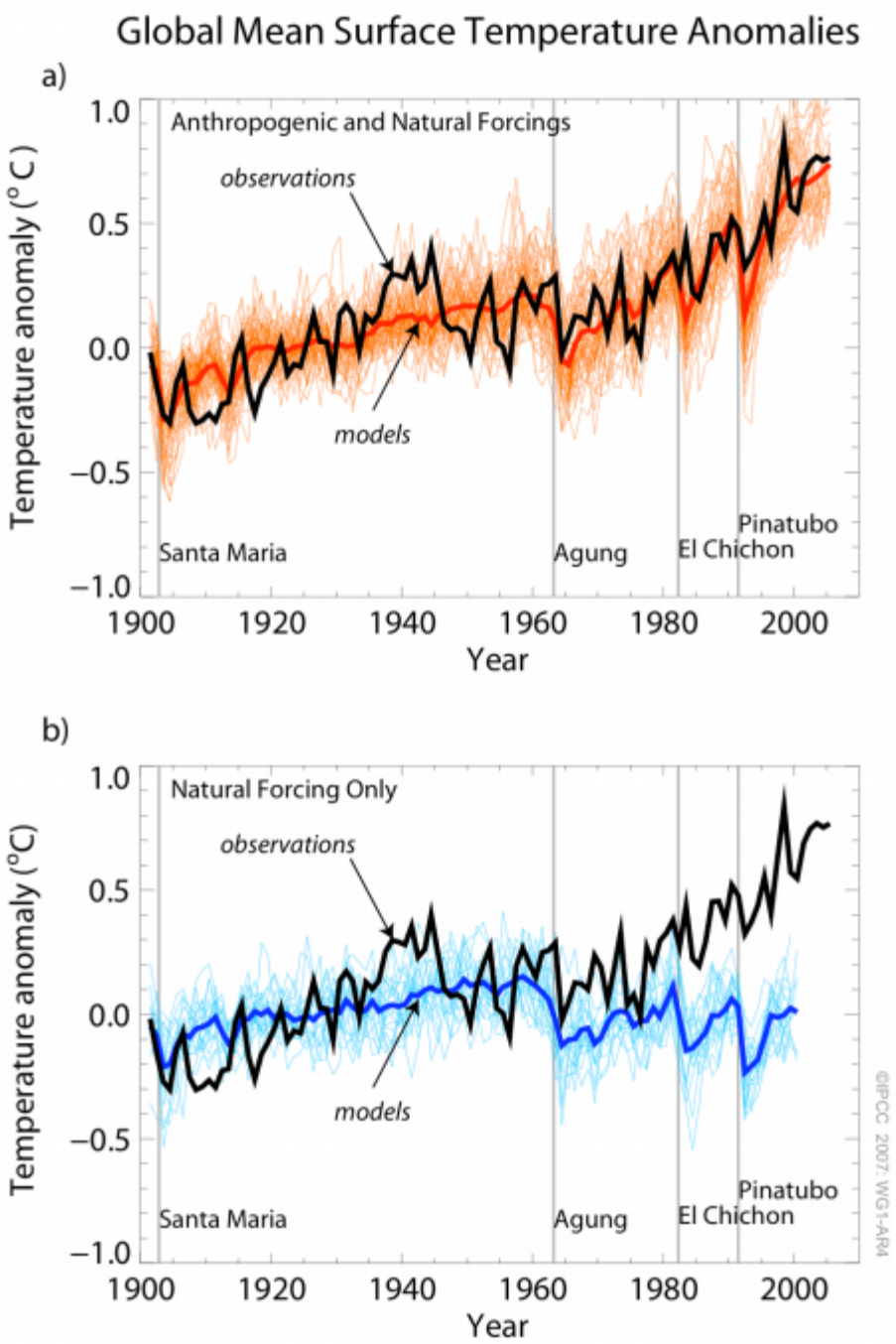
http://www.theresilientearth.com/?q=content/why-climate-modeling-not-climate-science

Model Predictions – Global Temperature Data



http://www.ucgis.org/summer2007/presentations/Wolter_Yellowstone_27jun07_PartA.pdf

THE
SMOKING
GUN

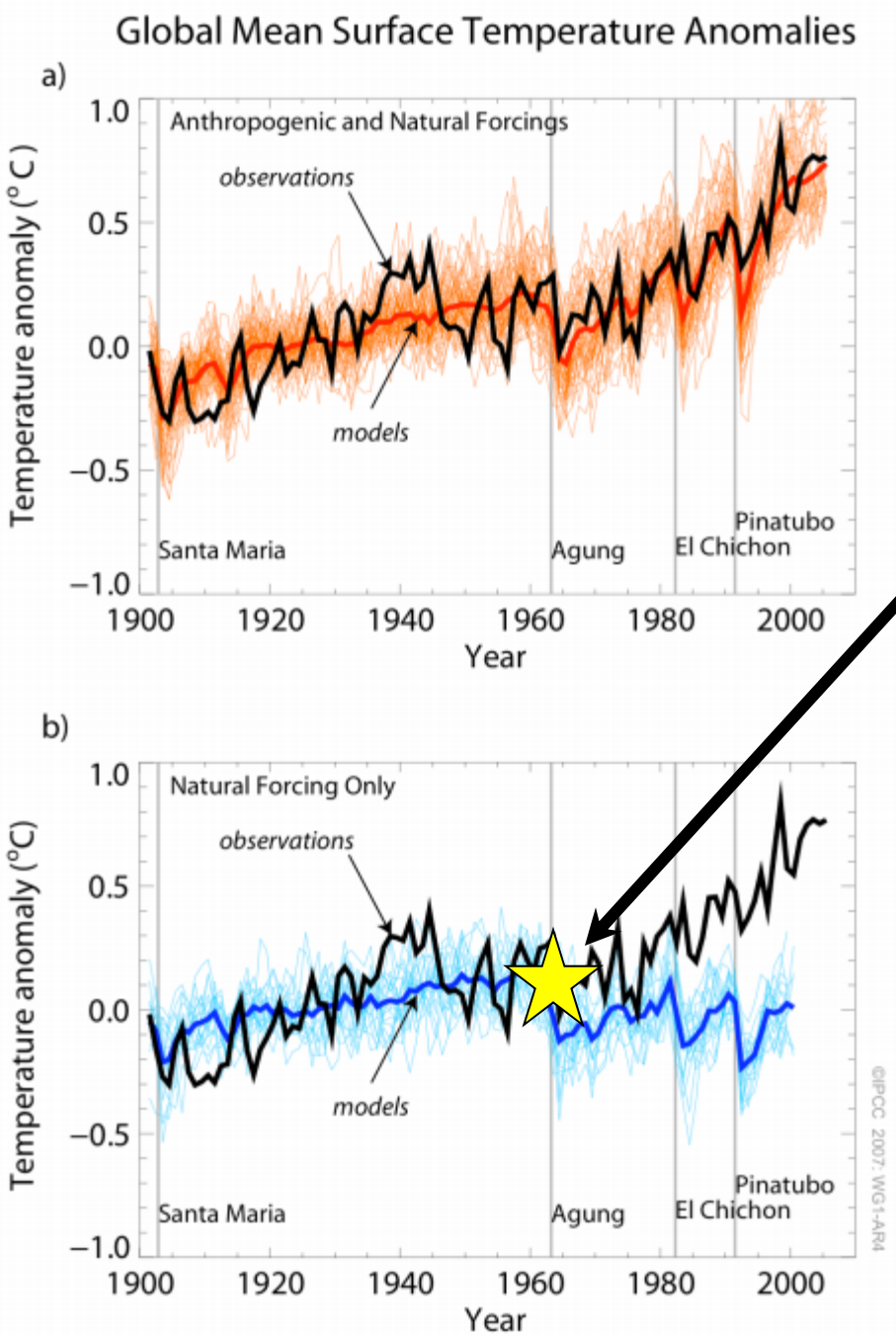


Forcings

Natural & Anthropogenic

Natural Only

http://www.ucgis.org/summer2007/presentations/Wolter_Yellowstone_27jun07_PartA.pdf



Forcings

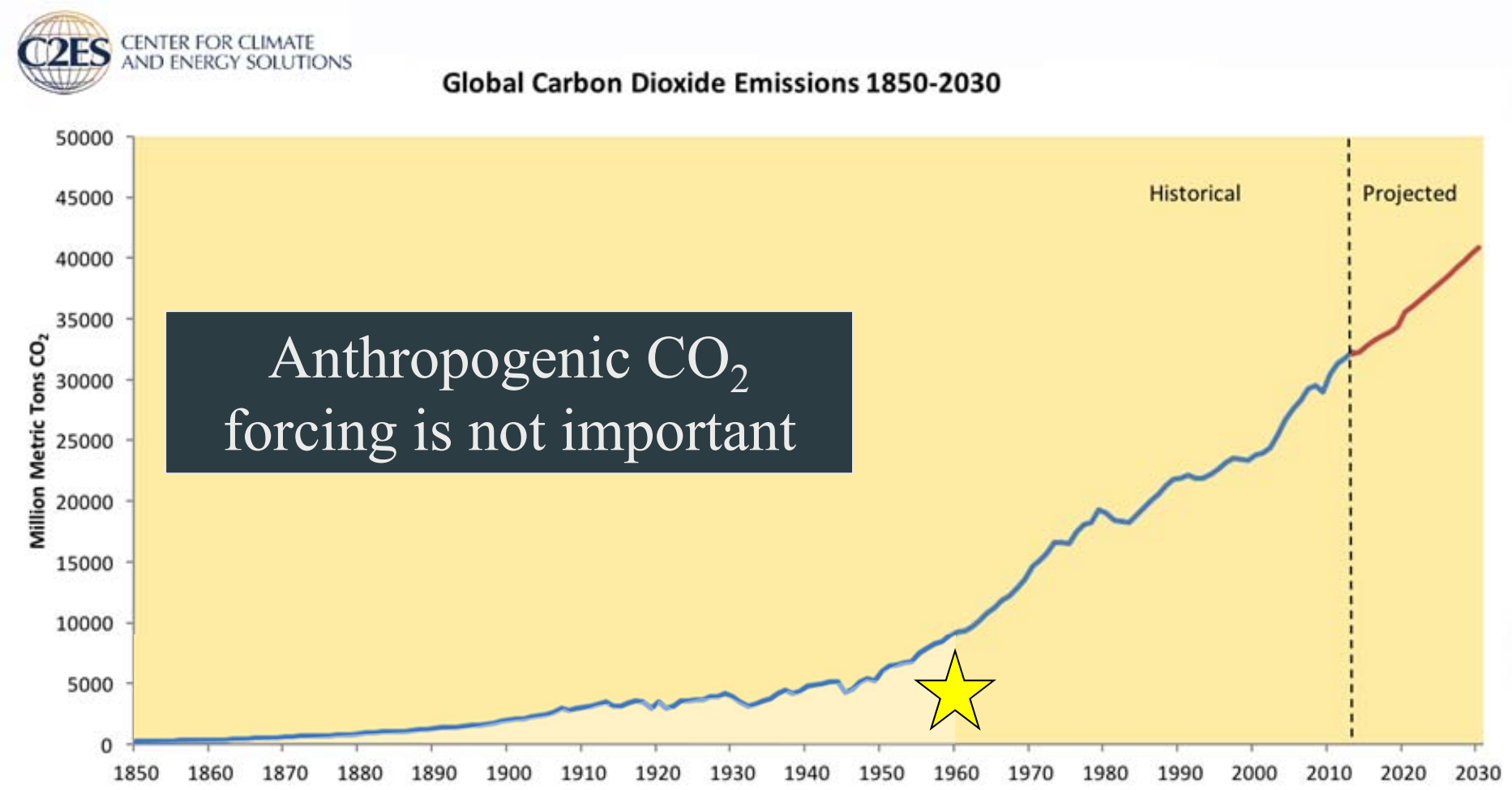
Natural & Anthropogenic

Anthropogenic CO_2 forcing becomes important

Natural Only

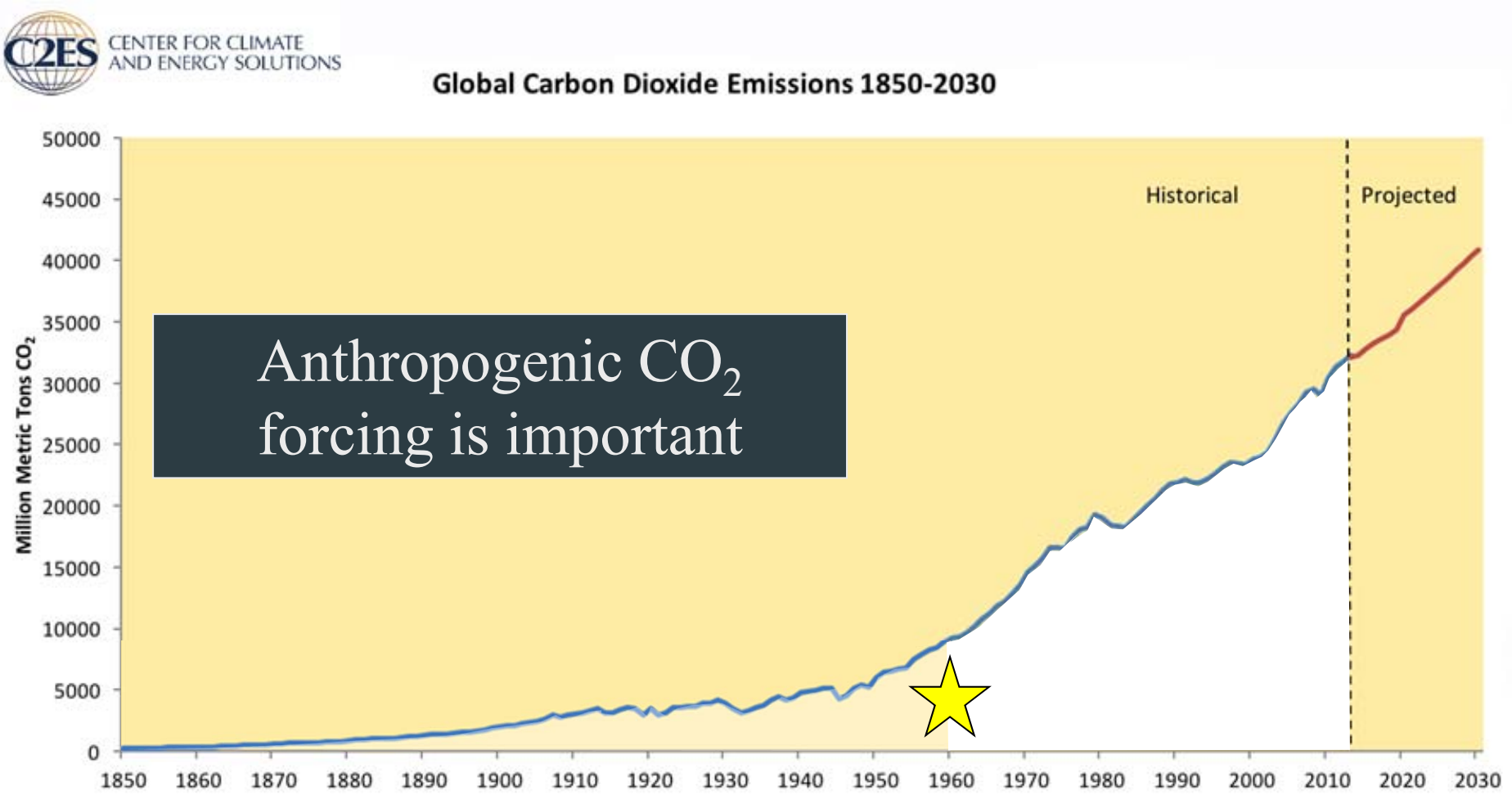
http://www.ucgis.org/summer2007/presentations/Wolter_Yellowstone_27jun07_PartA.pdf

Cumulative CO_2 prior to 1960



http://www.c2es.org/facts-figures/international-emissions/historical

umulative CO_2 after 1960



http://www.c2es.org/facts-figures/international-emissions/historical

lobal Warming Conclusion

The evidence that human activities are causing climate change is as certain as science gets in almost any area.

Bette Hileman
C&E News
October 20, 2003

ntergovernmental Panel on Climate hange (IPCC)

Probability than human activity is causing global warming

Year	Probability
2013	95%
2007	90%
2001	66%
1995	50%

http://knowledge.allianz.com/environment/climate_change/?2436/Science-issues-final-global-warning

ational academies that state human ctivities cause global warming

- Australia
- Belgium
- Brazil
- Canada
- Caribbean
- People's Republic of China
- France
- Germany
- India
- Indonesia
- Ireland
- Italy
- Malaysia
- New Zealand
- Sweden
- United Kingdom
- Japan
- Russia
- United States
- Mexico
- South Africa
- Network of African Science Academies
- Poland

http://en.wikipedia.org/wiki/Global_warming

rofessional societies that state human ctivities cause global warming

- American Astronomical Society
- American Chemical Society
- American Geophysical Union
- American Institute of Physics
- American Meteorological Society
- American Physical Society
- American Association for the Advancement of Science
- American Quaternary Association
- Australian Meteorological and Oceanographic Society
- Canadian Foundation for Climate and Atmospheric Sciences
- Canadian Meteorological and Oceanographic Society
- European Academy of Sciences and Arts
- European Geosciences Union
- European Science Foundation
- Geological Society of America
- Geological Society of Australia
- Geological Society of London-Stratigraphy Commission
- InterAcademy Council
- International Union of Geodesy and Geophysics
- International Union for Quaternary Research
- National Association of Geoscience Teachers
- National Research Council (US)
- Royal Meteorological Society
- World Meteorological Organization

http://en.wikipedia.org/wiki/Global_warming

Exxon's Position

Rising greenhouse gas emissions pose significant risks to society and ecosystems. **We focus on increasing energy efficiency in the short term; implementing current proven emission-reducing technologies in the near and medium term; and developing breakthrough, game-changing technologies for the long term.**

http://www.exxonmobil.com/Corporate/safety_climate.aspx

Shell's Position

For us the debate on climate change is over. **We are tackling the challenges of a new energy future. We continue to develop technologies to reduce CO_2 from our operations and to produce more efficient fuels and lubricants for customers. We are calling on governments to establish policies that will encourage a reduction in CO_2 emissions.**

http://www.shell.com/home/content/environment_society/environment/climate_change/

Oil giants ask for carb tax

Oil giants ask for carb tax

Total revenues = $1.4 trillion

Oil giants ask for carb tax

Figueres
etary of the UNFCCC
UN Campus
ationen1

His Excellency
Mr. Laurent Fabius
President of COP21
Ministry of Foreign Affairs
37, Quai d'Orsay
75007 Paris
France

Friday, May 29th 2015

a critical challenge for our world. As major companies from the oil & gas sector, we e importance of the climate challenge and the importance of energy to human life and knowledge that the current trend of greenhouse gas emissions is in excess of what the l Panel on Climate Change (IPCC) says is needed to limit the temperature rise to no ees above pre-industrial levels. The challenge is how to meet greater energy demand stand ready to play our part.

e already taking a number of actions to help limit emissions, such as growing the share oduction, making energy efficiency improvements in our operations and products, ble energy, investing in carbon capture and storage, and exploring new low-carbon business models. These actions are a key part of our mission to provide the greatest with access to sustainable and secure energy.

e, we need governments across the world to provide us with clear, stable, long-term, rameworks. This would reduce uncertainty and help stimulate investments in the right logies and the right resources at the right pace.

price on carbon should be a key element of these frameworks. If governments act to discourages high carbon options and encourages the most efficient ways of ns widely, including reduced demand for the most carbon intensive fossil fuels, fficiency, the use of natural gas in place of coal, increased investment in carbon age, renewable energy, smart buildings and grids, off-grid access to energy, cleaner bility business models and behaviors.

http://www.statoil.com/en/NewsAndMedia/News/2015/Downloads/Paying%20for%20Carbon%20letter.pdf

Oil giants ask for carb tax

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For us to do more, we need governments across the world to provide us with clear, stable, long-term ambitious policy frameworks.

http://www.statoil.com/en/NewsAndMedia/News/2015/Downloads/Paying%20for%20Carbon%20letter.pdf

Oil giants ask for carb tax

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http://www.statoil.com/en/NewsAndMedia/News/2015/Downloads/Paying%20for%20Carbon%20letter.pdf

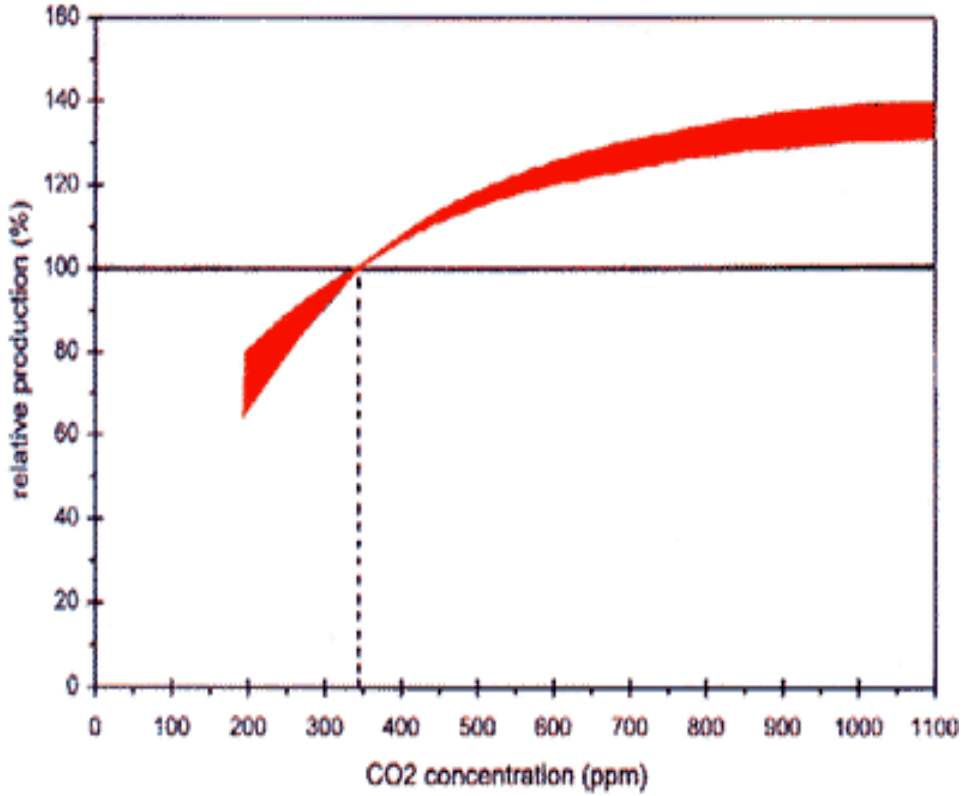
ositive Effects

ositive Effects

Canada

ositive Effects

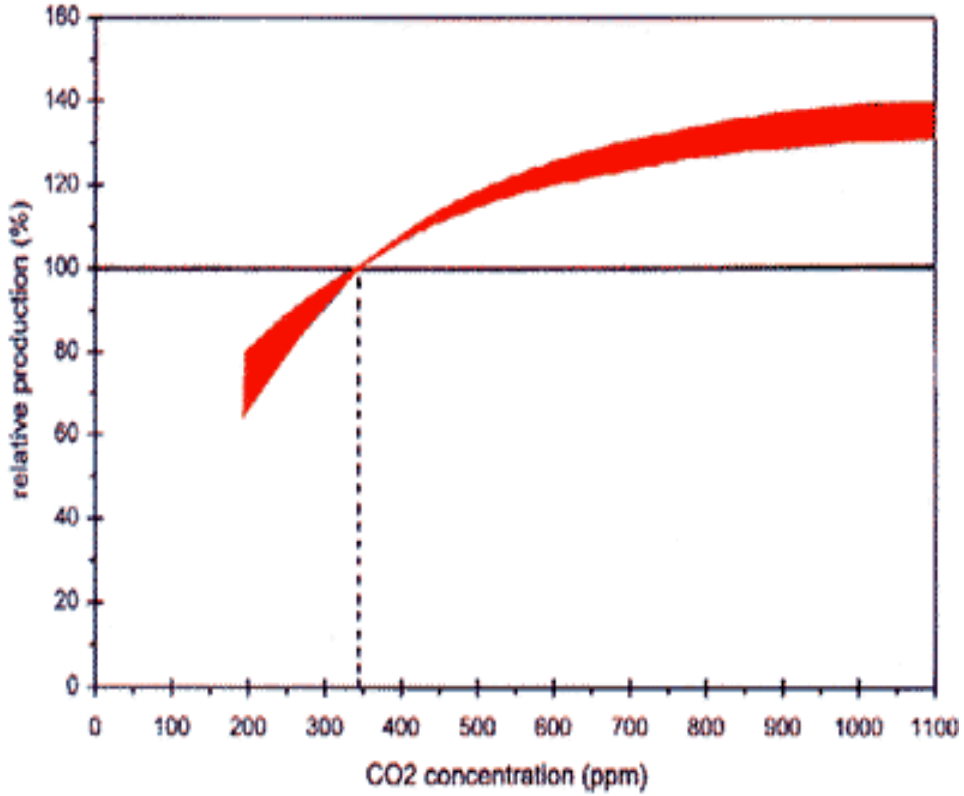
CO_2 Plant Fertilization



http://www.hortnet.co.nz/publications/science/n/neder/co2_nr4.htm#top

ositive Effects

CO_2 Plant Fertilization



http://www.hortnet.co.nz/publications/science/n/neder/co2_nr4.htm#top

egative Effects

Rapid extinctions

Warmer seas could render some turtle species entirely female.

egative Effects

Tropical diseases moving north

Mosquito-borne dengue fever is spreading to previously cold regions.

egative Effects

Grain Belt becomes Dust Belt

egative Effects

More insects

Locust

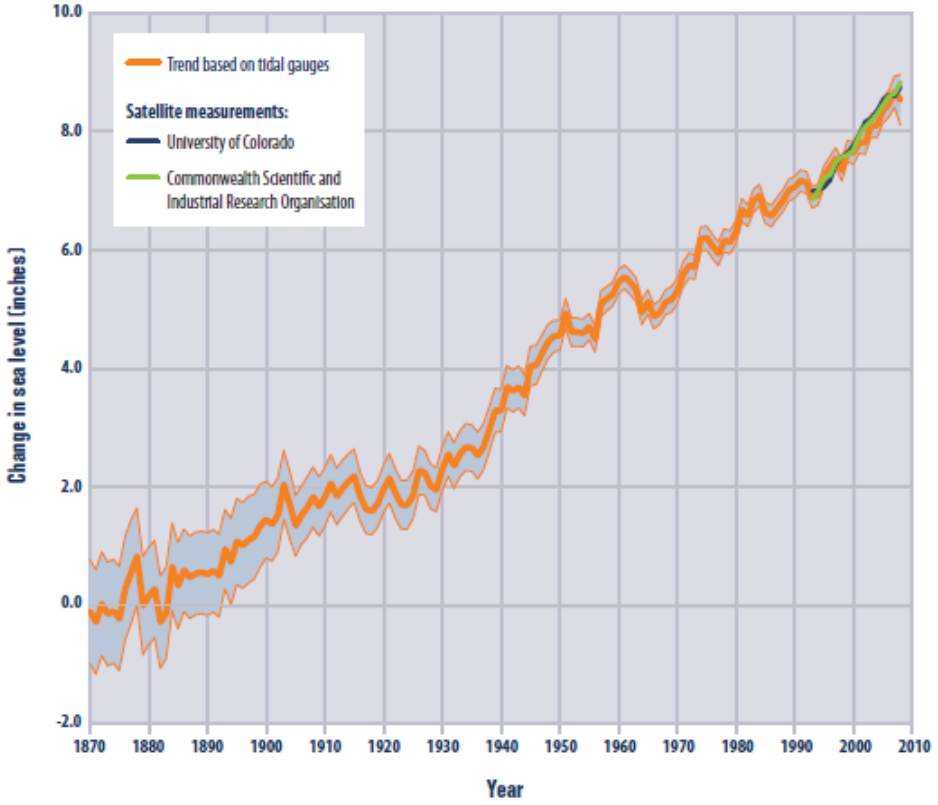
egative Effects

Rising ocean levels

Tuvalu Pacific coral atoll
4 meters maximum height
11,000 people

Figure 1. Trends in Global Average Absolute Sea Level, 1870–2008

This graph shows how the average absolute sea level of the world's oceans has changed since 1870, based on a combination of long-term tidal gauge measurements and recent satellite measurements. Absolute sea level does not account for changes in land elevation. The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.



http://epa.gov/climatechange/indicators/pdfs/CI-oceans.pdf

egative Effects

Rising ocean levels

Tuvalu Pacific coral atoll
4 meters maximum height
11,000 people

Figure 1. Trends in Global Average Absolute Sea Level, 1870–2008

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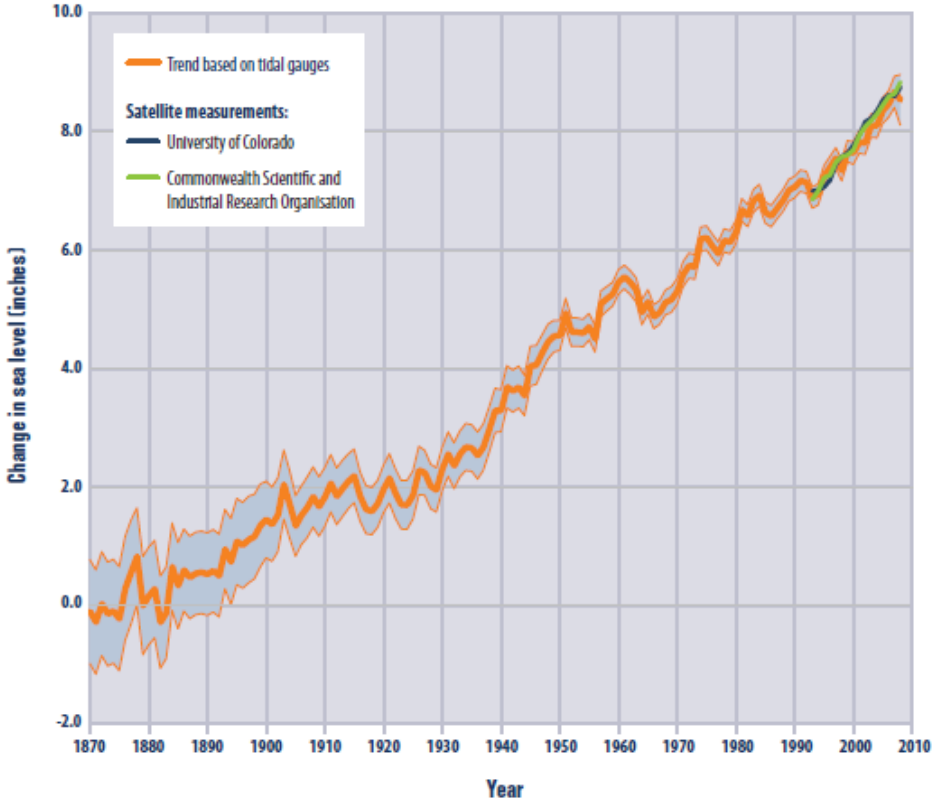
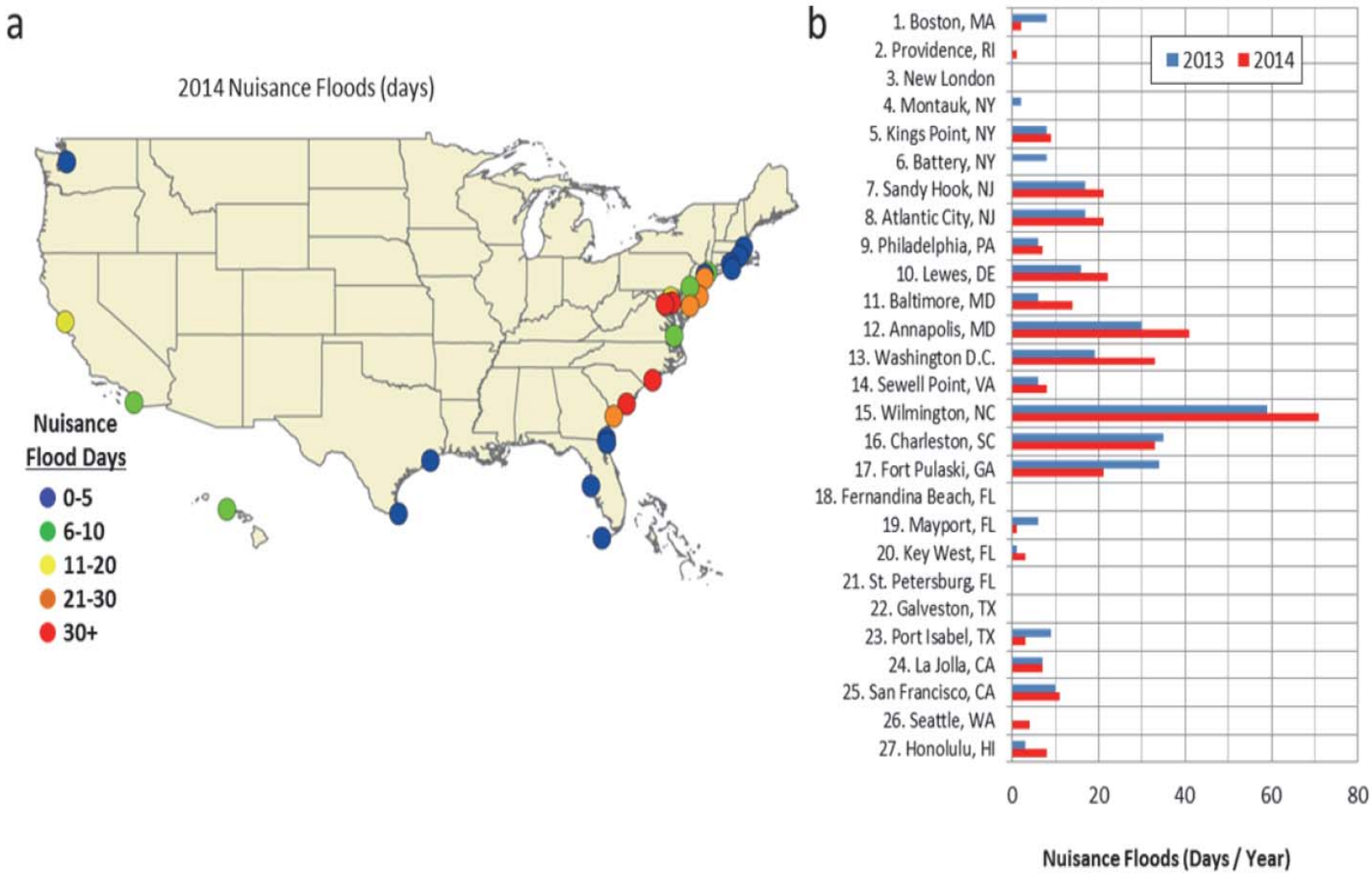


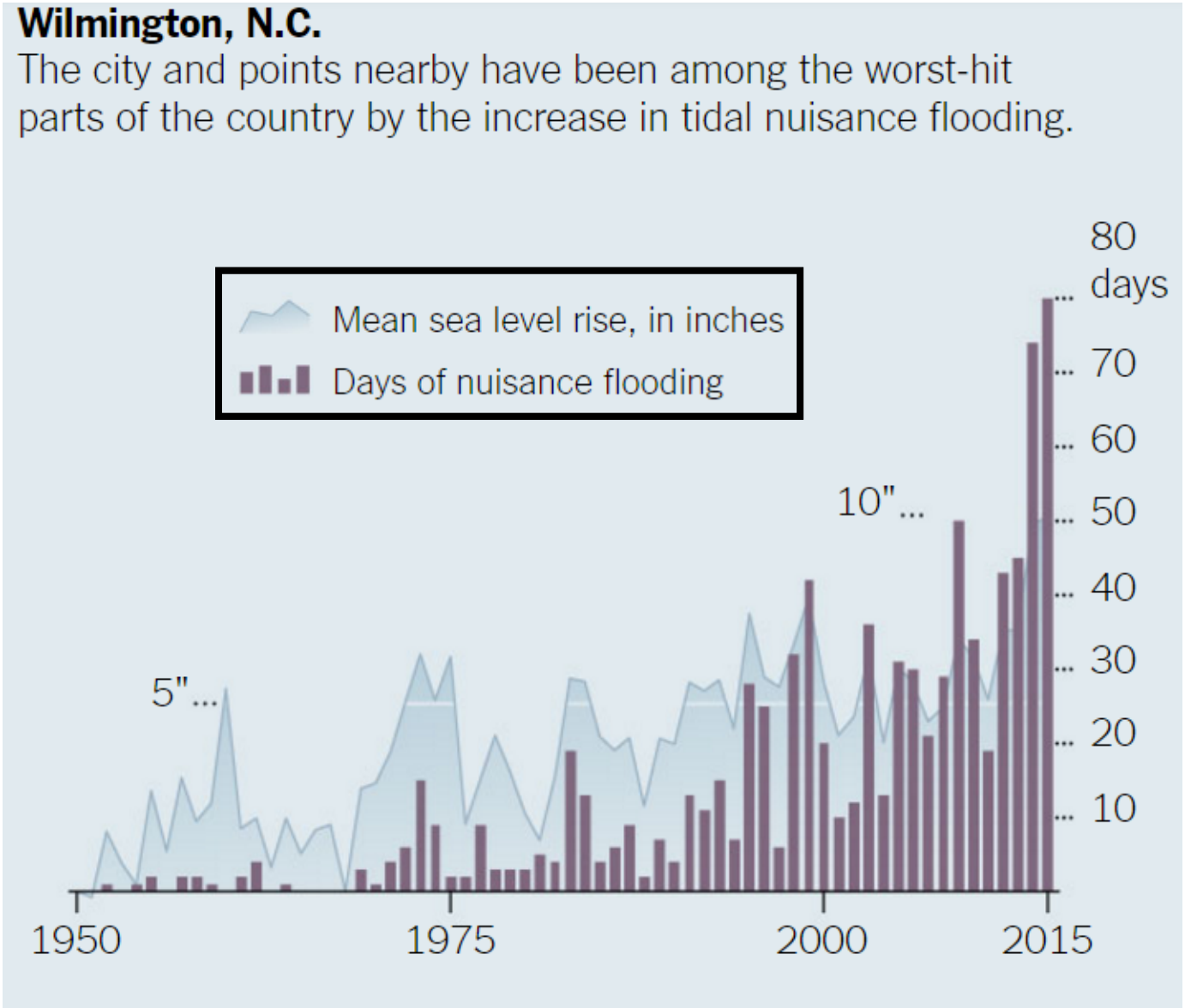
http://epa.gov/climatechange/indicators/pdfs/CI-oceans.pdf

uisance “Clear-sky” Flooding



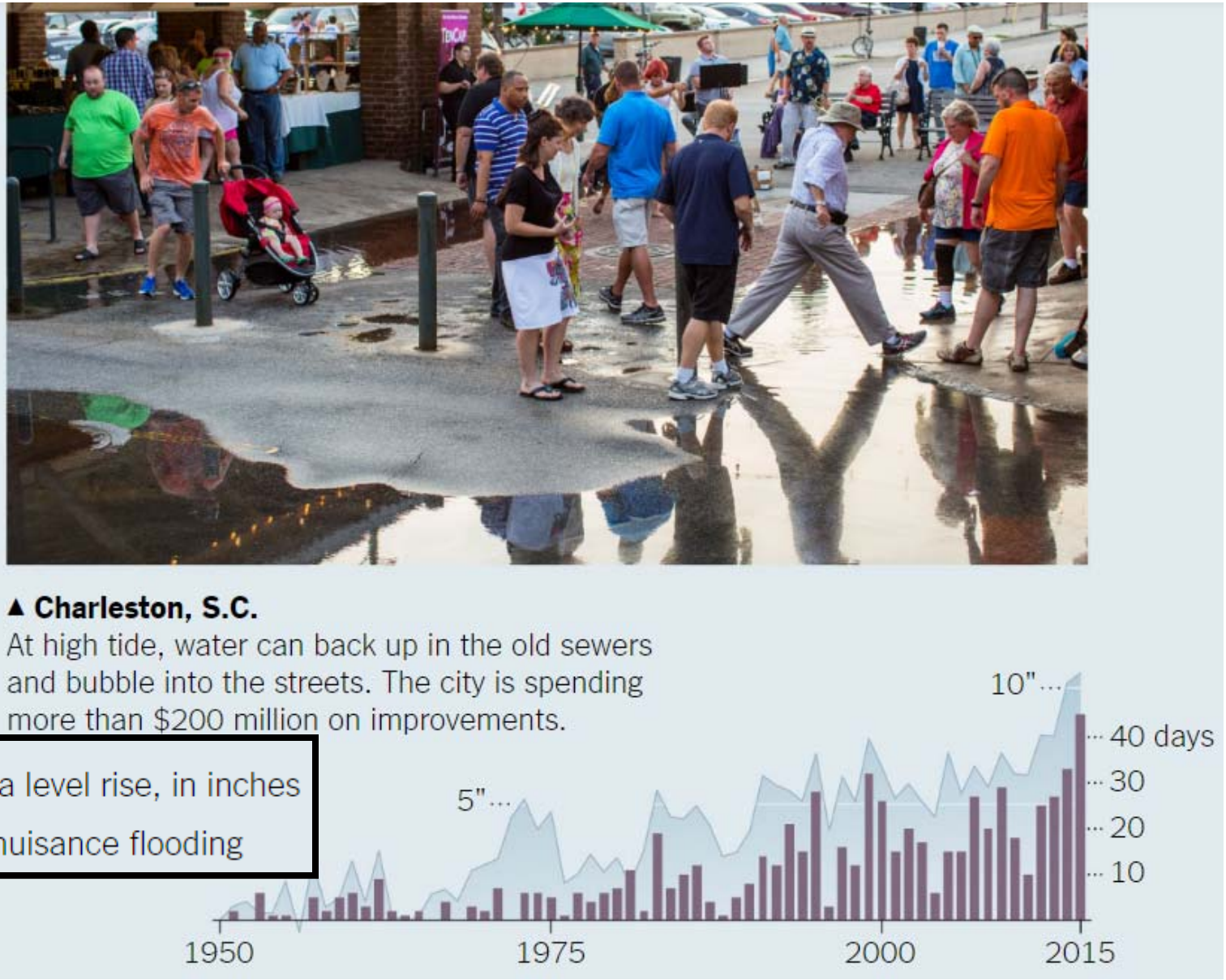
http://www.noaanews.noaa.gov/stories2015/2014%20State%20of%20Nuisance%20Tidal%20Flooding.pdf

ilmington, NC



http://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html

harleston, SC



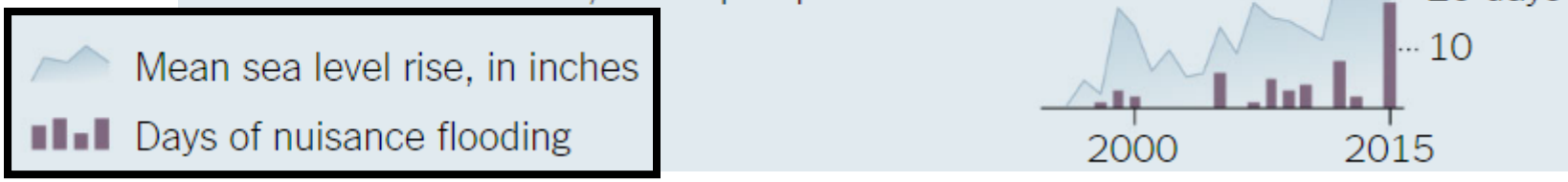
http://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html

ami, FL

"King Tide" – alignment of pull from moon and sun

Miami

Miami Beach plans to spend at least $400 million to raise streets, install pumps and



http://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html

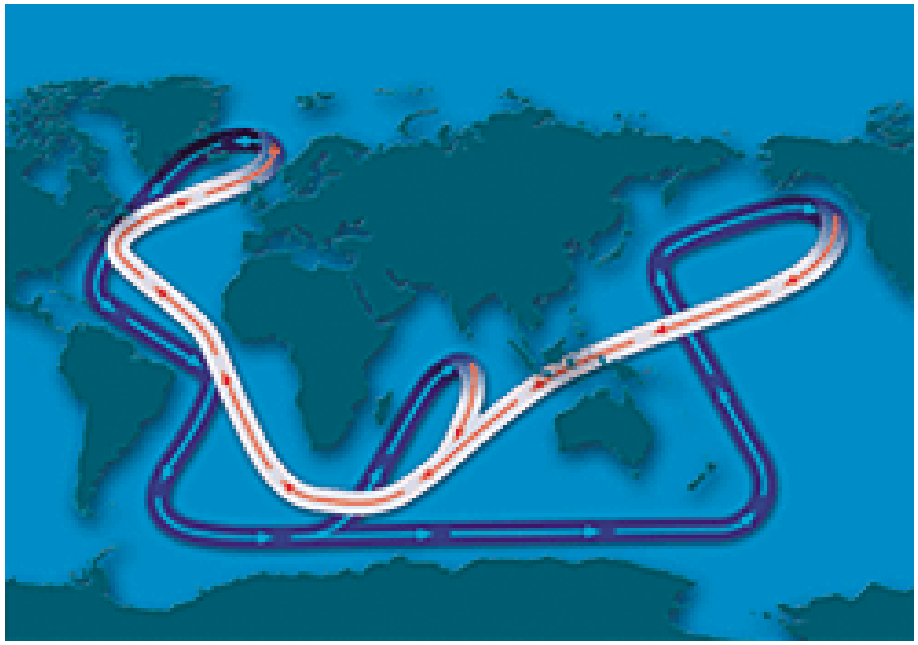
egative Effects

Increased heat-related deaths

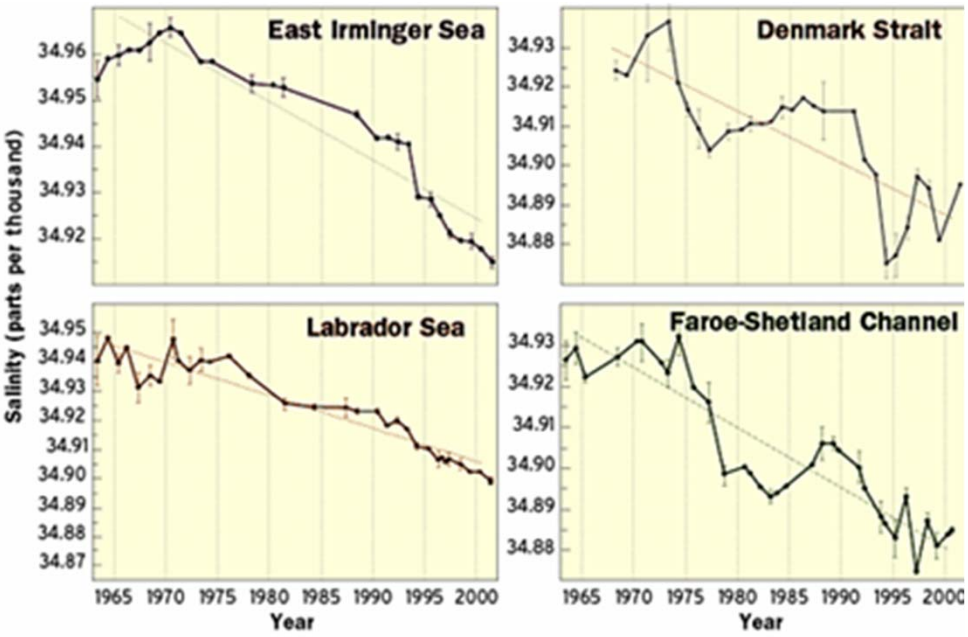
In Europe, an August 2003 heat wave caused ~70,000 deaths of mostly elderly.

egative Effects

Thermohaline circulation slows down → Europe cooler



Global Ocean Conveyor



Declining Ocean Salinity
(B. Dickson, et al., in *Nature*, April 2002)

egative Effects

Increased storms/floods/hurricanes

New Orleans French Quarter after Hurricane Katrina

egative Effects

Increased cyclone intensity

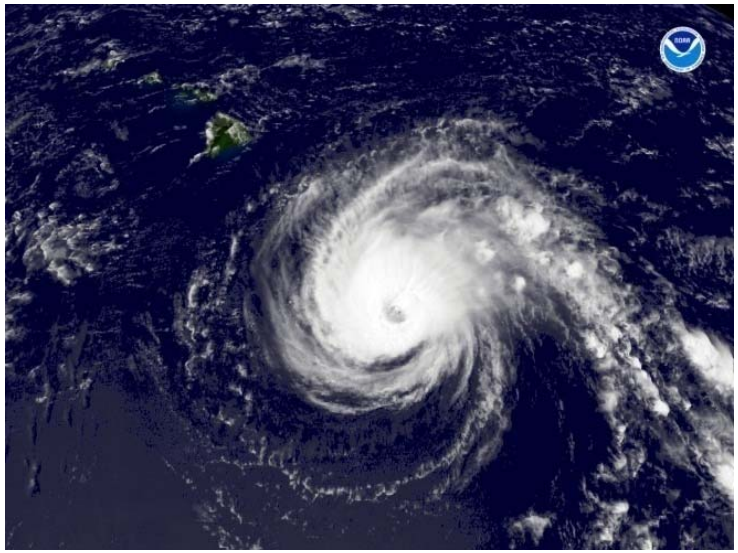
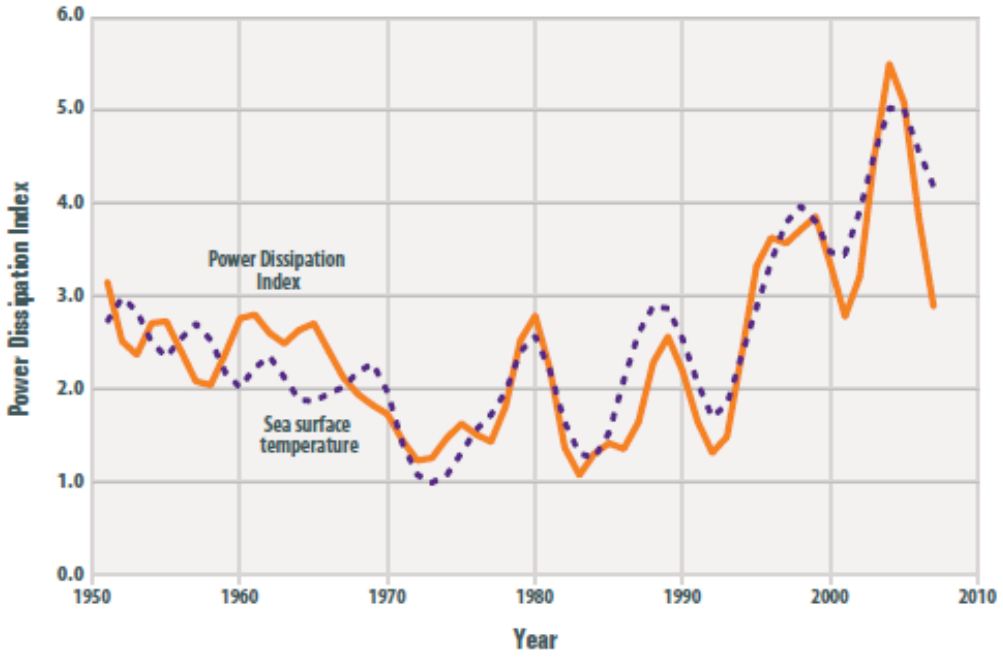


Figure 2. North Atlantic Cyclone Intensity According to the Power Dissipation Index, 1949–2009

This figure presents annual values of the Power Dissipation Index (PDI). North Atlantic sea surface temperature trends are provided for reference. Note that sea surface temperature uses different units, but the numbers have been adjusted here to show how the trends are similar. The lines have been smoothed using a five-year weighted average.

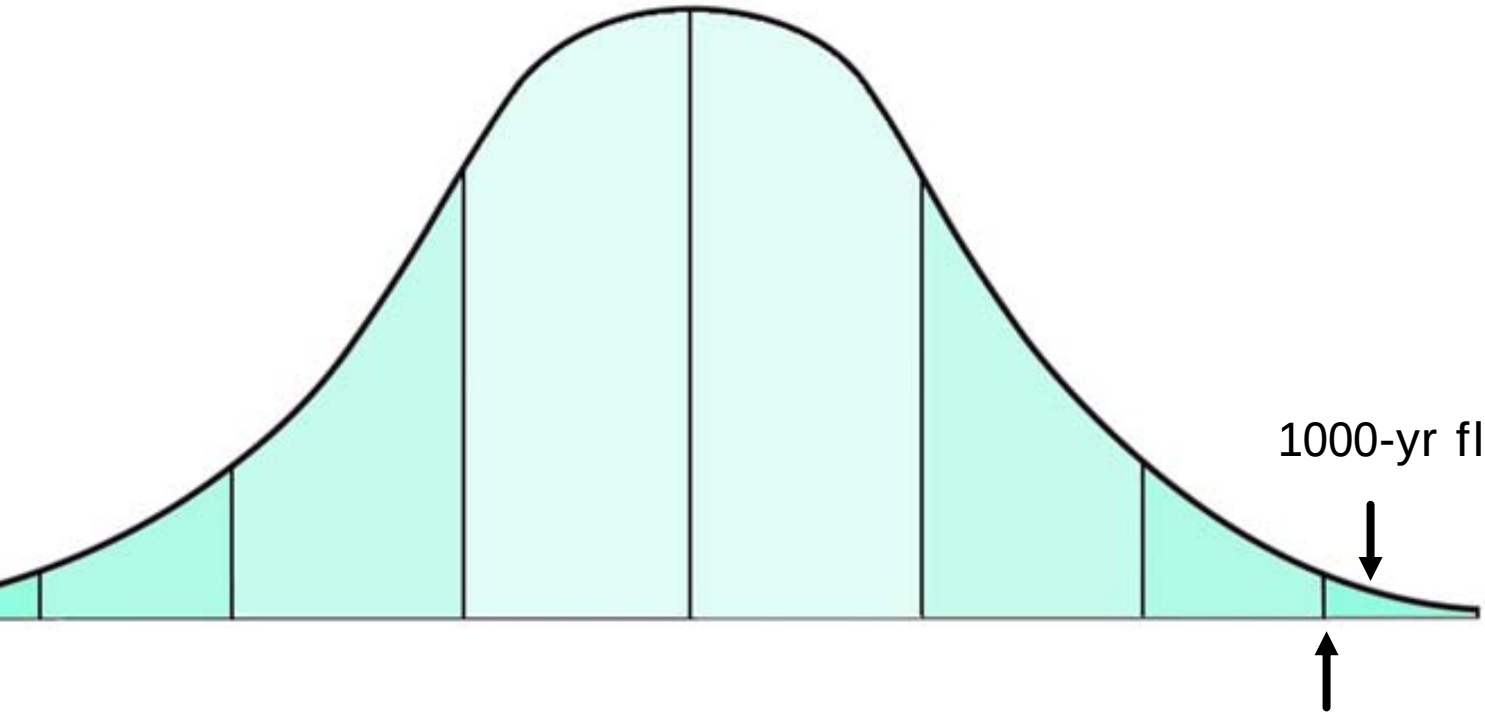


http://epa.gov/climatechange/indicators/pdfs/CI-weather-and-climate.pdf

Houston flooding events

Hurricane Harvey — 2017

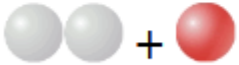
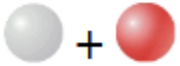
Houston flooding events



by random chance…

$$\text{Probability} = \underset{2015}{0.002} \times \underset{2016}{0.002} \times \underset{2017}{0.001} = 0.000000004 = \frac{1}{250{,}000{,}000}$$

Odds of winning POWERBALL

Match	Prize	Odds
	Grand Prize	1 in 292,201,338.00
	$1,000,000	1 in 11,688,053.52
	$50,000	1 in 913,129.18
	$100	1 in 36,525.17
	$100	1 in 14,494.11
	$7	1 in 579.76
	$7	1 in 701.33
	$4	1 in 91.98
	$4	1 in 38.32

by random chance...

$$\text{Probability} = 0.002 \times 0.002 \times 0.001 = 0.000000004 = \frac{1}{250{,}000{,}000}$$

egative Effects

Droughts and floods more common

egative Effects

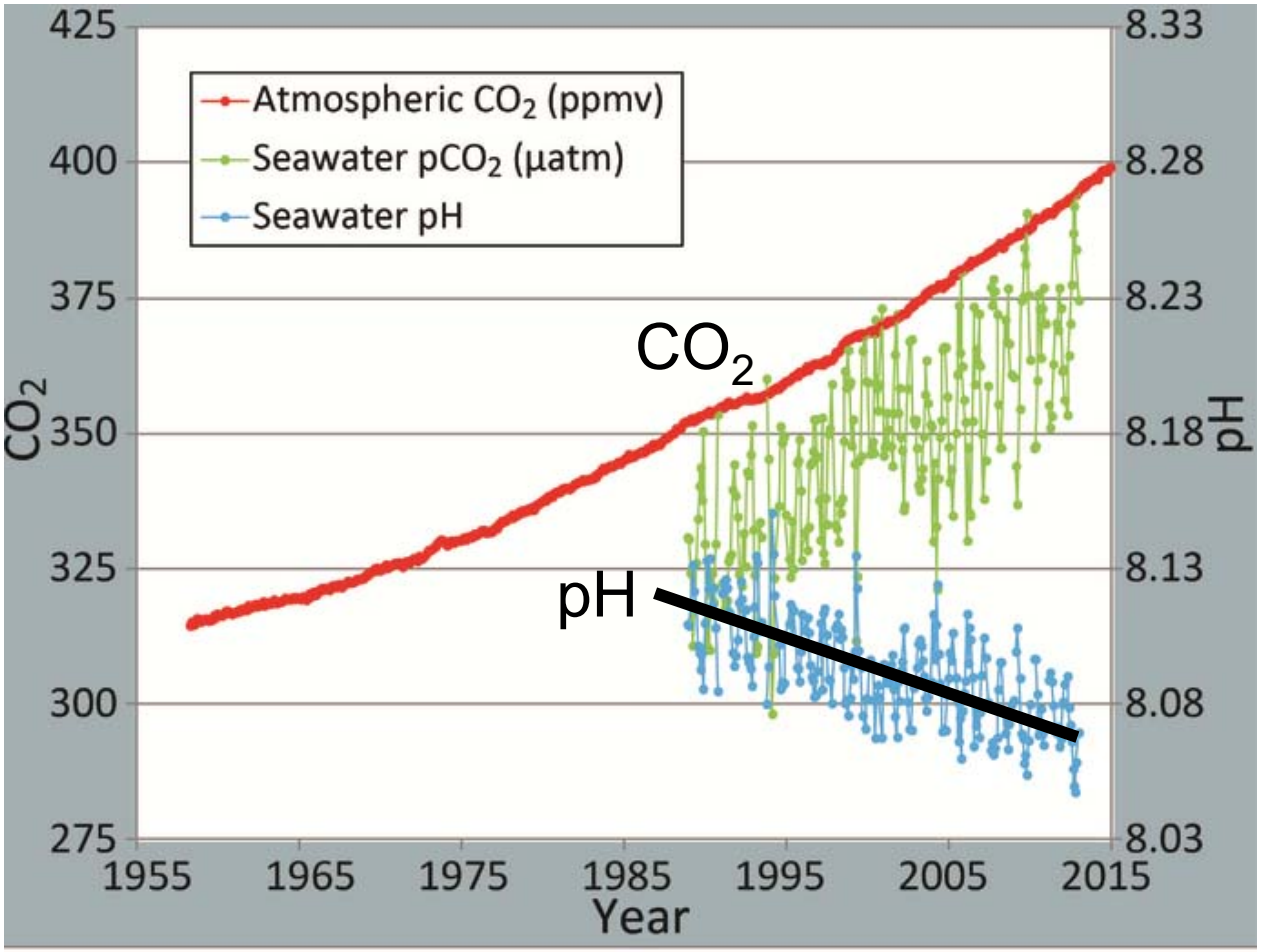
More forest fires caused by…

- Drought
- Heat
- Insects
- Dead trees increasing fuel load
- Earlier melting of snow pack

egative Effects

Ocean acidification

$CO_2 + H_2O \rightarrow H_2CO_3$ Carbonic acid



http://www.pmel.noaa.gov/co2/file/Hawaii+Carbon+Dioxide+Time-Series

egative Effects

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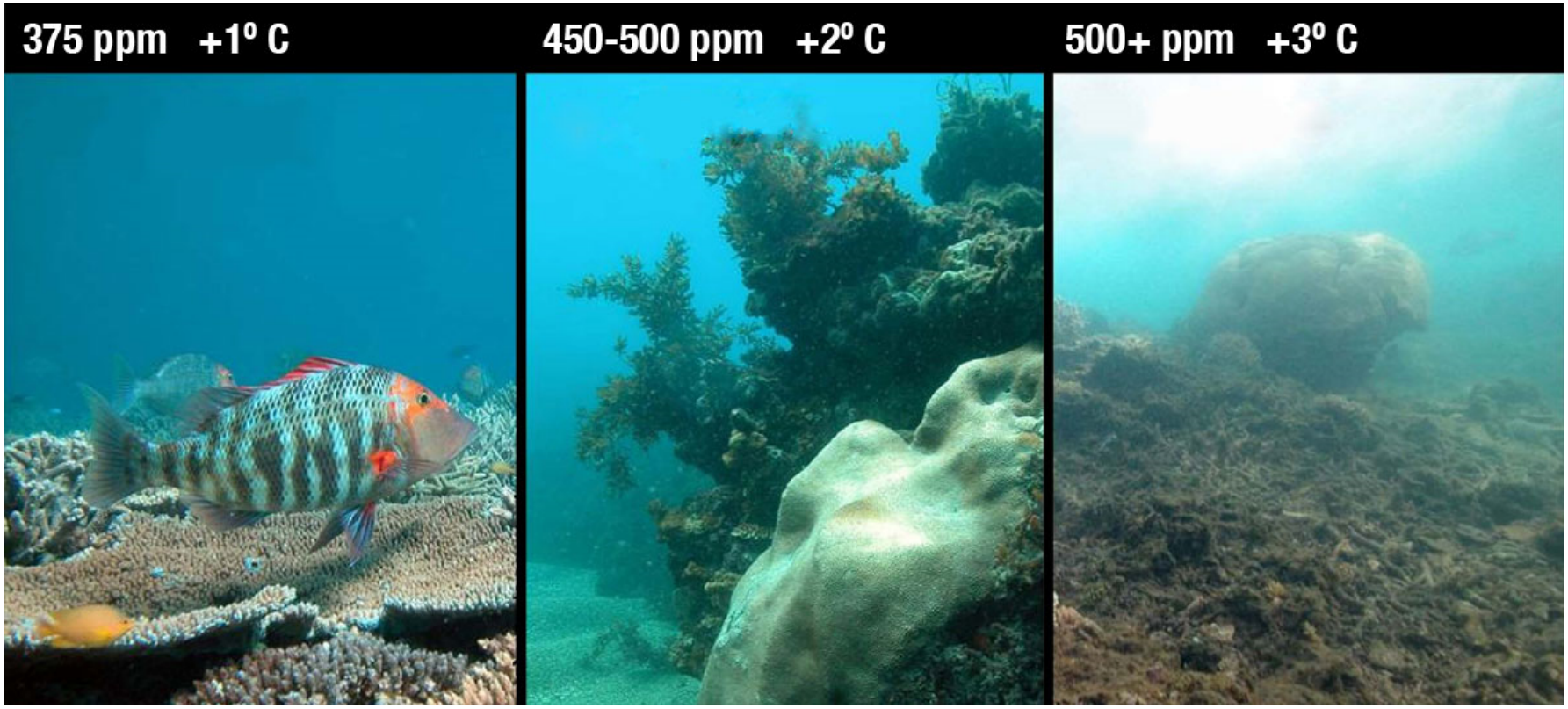
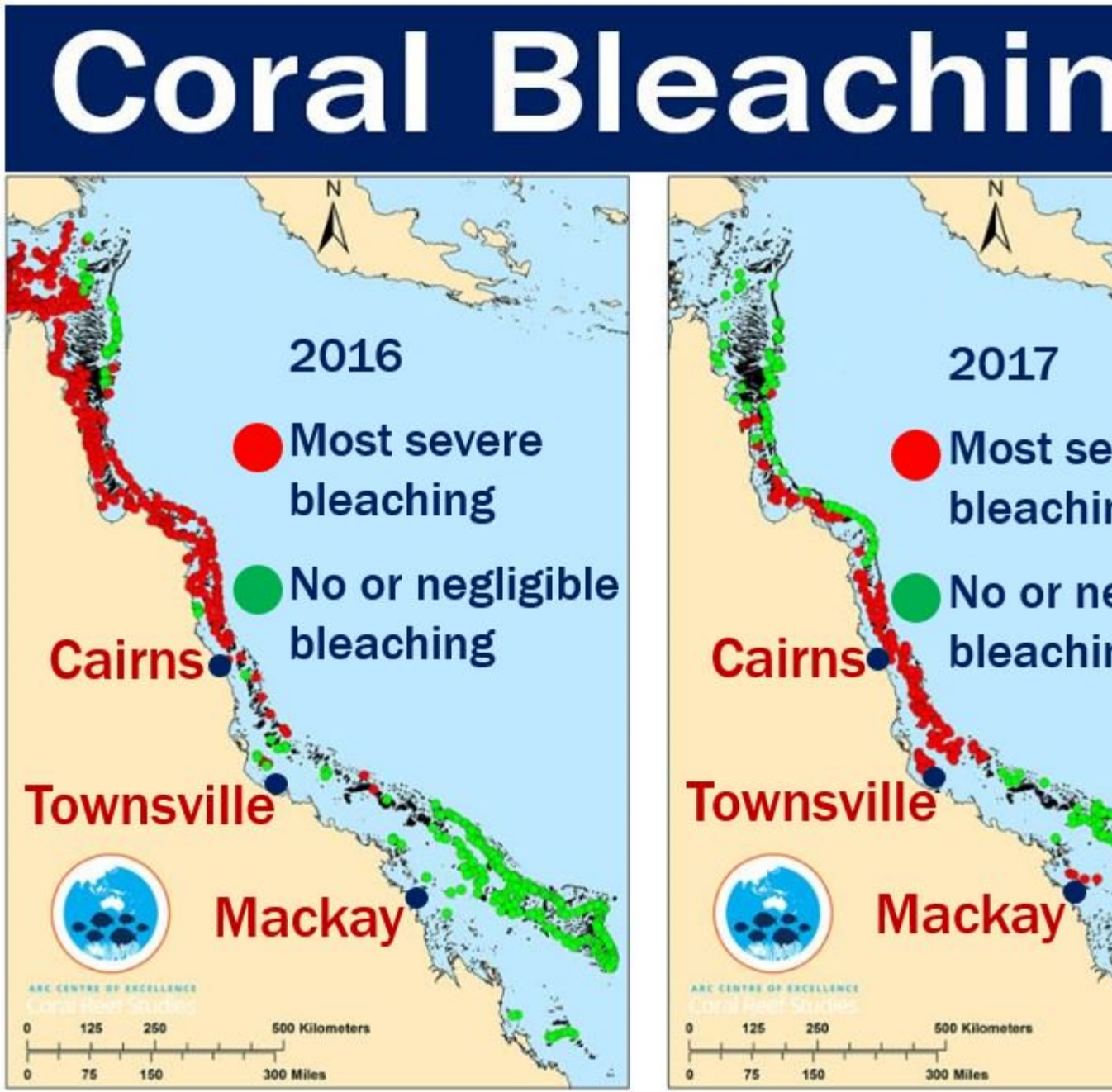


Coral Reef

http://www.amnh.org/learn/resources/climate/W3E3_2_full.jpg

egative Effects

at Barrier Reef
Australia



Coral Bleaching

https://www.facebook.com/Upworthy/videos/2044236332283881/

xacerbating Effects

Extended thaw in tundra

Alaskan ground frozen to 12-inch depth and covered by at least 6 inches of snow:

1970 = 200 days
2002 = 103 days

xacerbating Effects

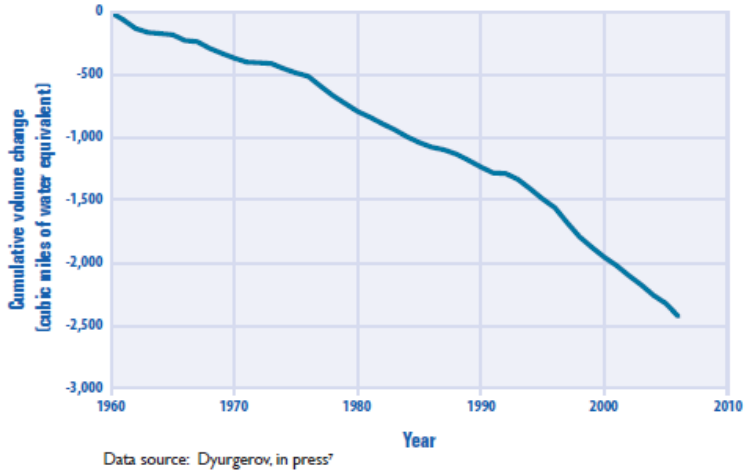
Photographs of Muir Glacier, Alaska, 1941 and 2004

Sources: Field, 1941;[3] Molnia, 2004[4]

Melting glaciers

Figure 1. Change in Volume of Glaciers Worldwide, 1960–2006

This figure shows the cumulative change in volume of glaciers worldwide beginning in 1960. Negative values in later years indicate a net loss of ice and snow compared with the base year of 1960. For consistency, measurements are in cubic miles of water equivalent, which means the total amount of ice or snow lost has been converted to the equivalent volume of liquid water.

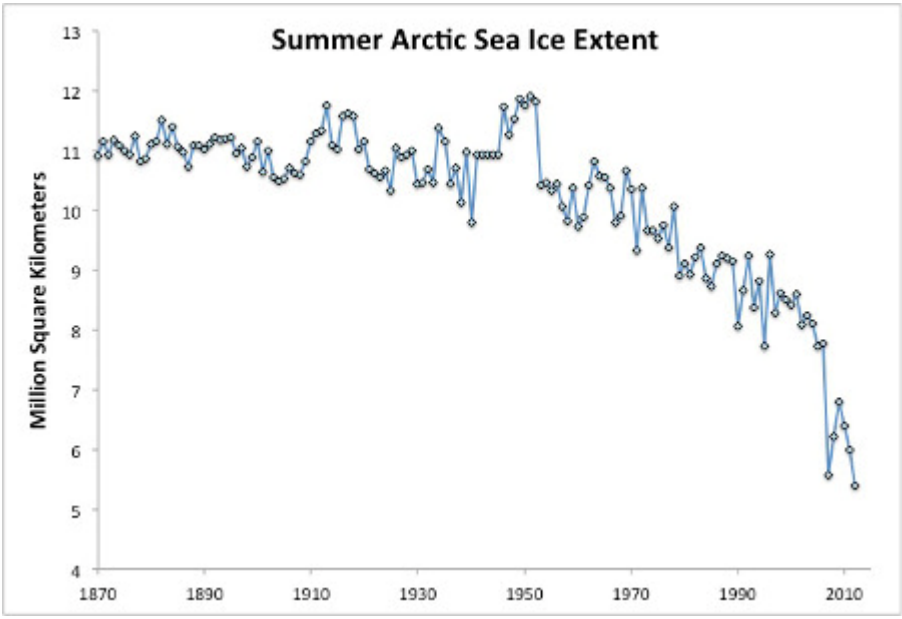


Data source: Dyurgerov, in press[7]

http://epa.gov/climatechange/indicators/pdfs/CI-snow-and-ice.pdf

xacerbating Effects

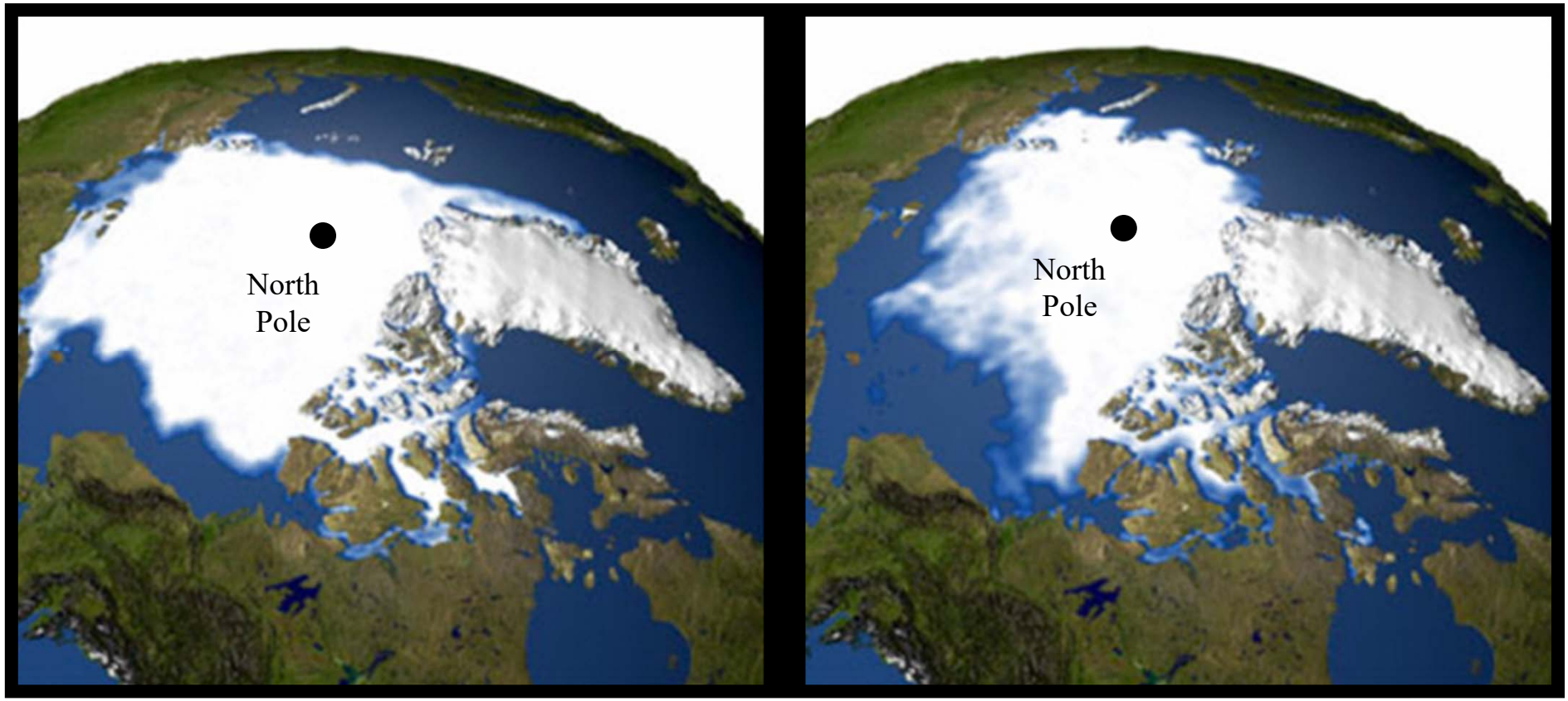
Less sea ice



http://www.guardian.co.uk/environment/climate-consensus-97-per-cent/2013/jul/23/climate-change-andrew-neil-bbc-errors-take2

xacerbating Effects

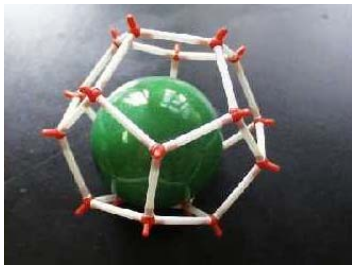
Polar ice caps melt

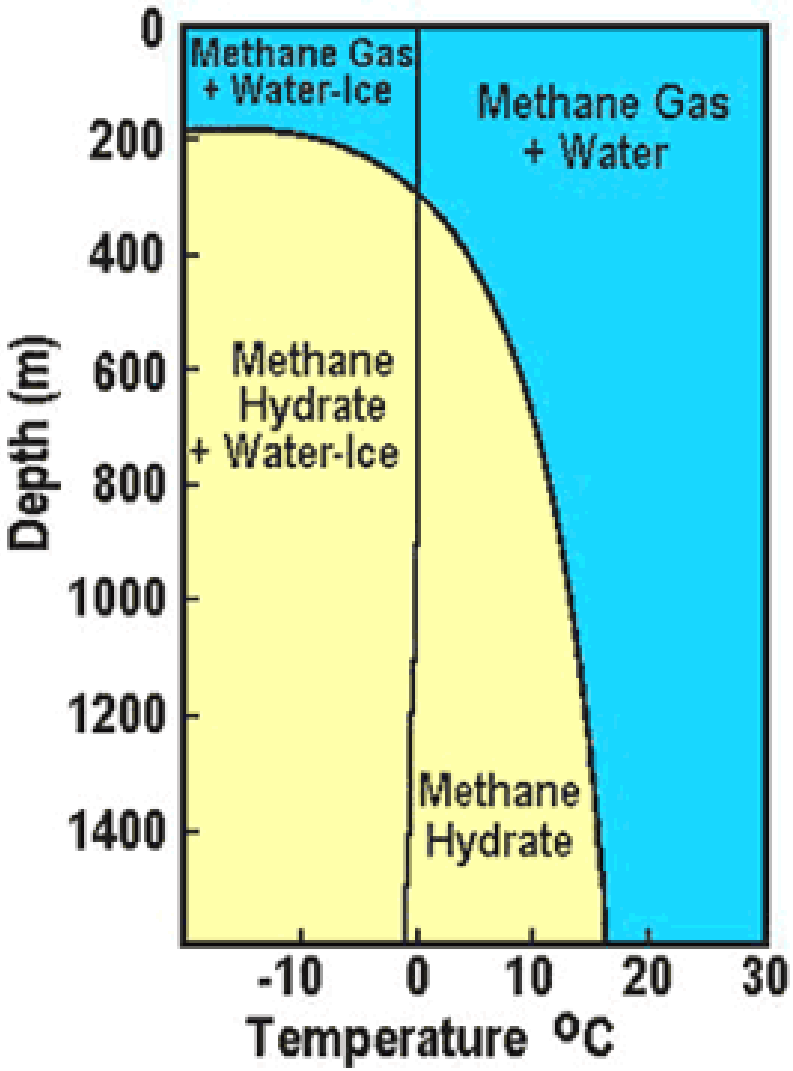


1979 2003

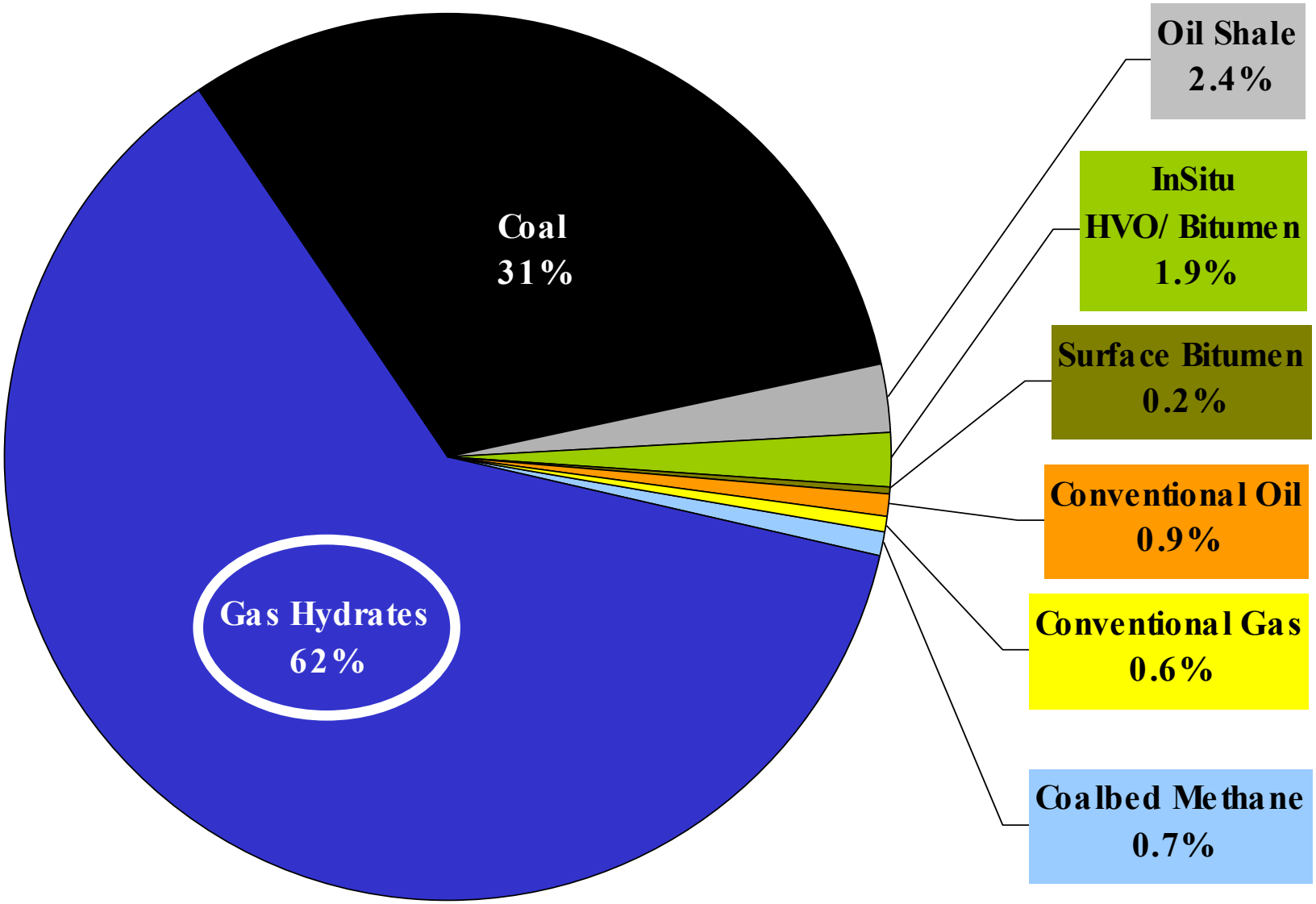
xacerbating Effects

Methane hydrates melt





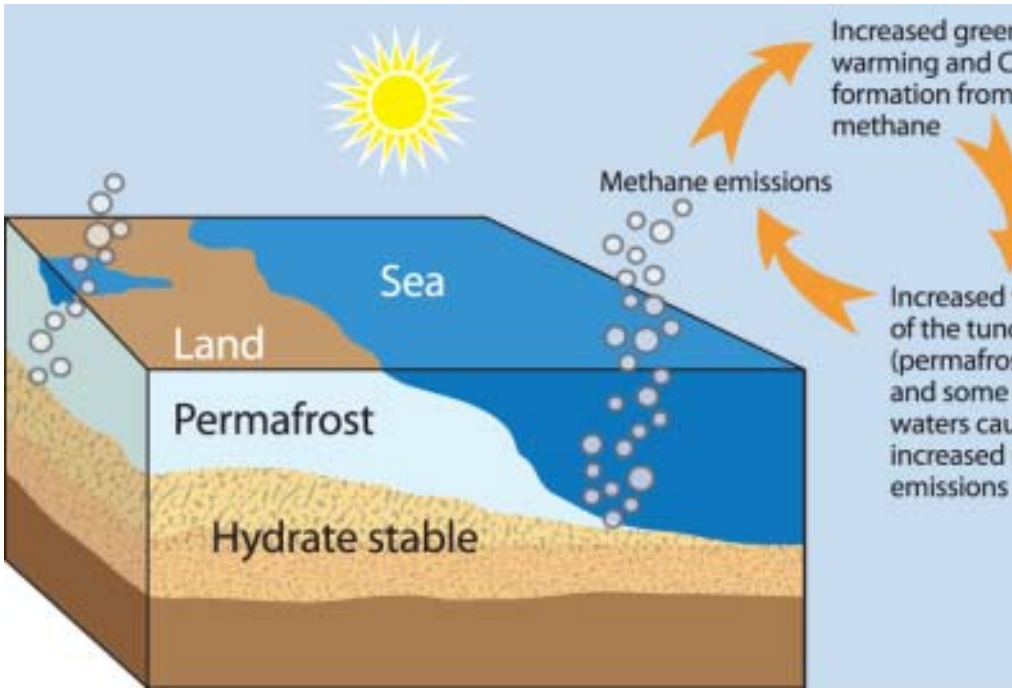
ossil Fuel Reserves



Source: Shell International Exploration and Production Company, personal communication

rctic Methane Release

Shallow methane hydrates



endent.co.uk/news/science/vast-methane-plumes-seen-in-arctic-ocean-as-sea-ice-retreats-

http://www.usgs.gov/blogs/features/usgs_science_pick/gas-hydrates-and-climate-warming/

r. James Hansen

1981–2013 Head NASA Goddard Institute for Space Studies

“Father of global warming”

Dr. James Hansen

http://robertscribbler.wordpress.com/2013/08/08/yedoma-region-of-russia-showing-significant-methane-pulse/

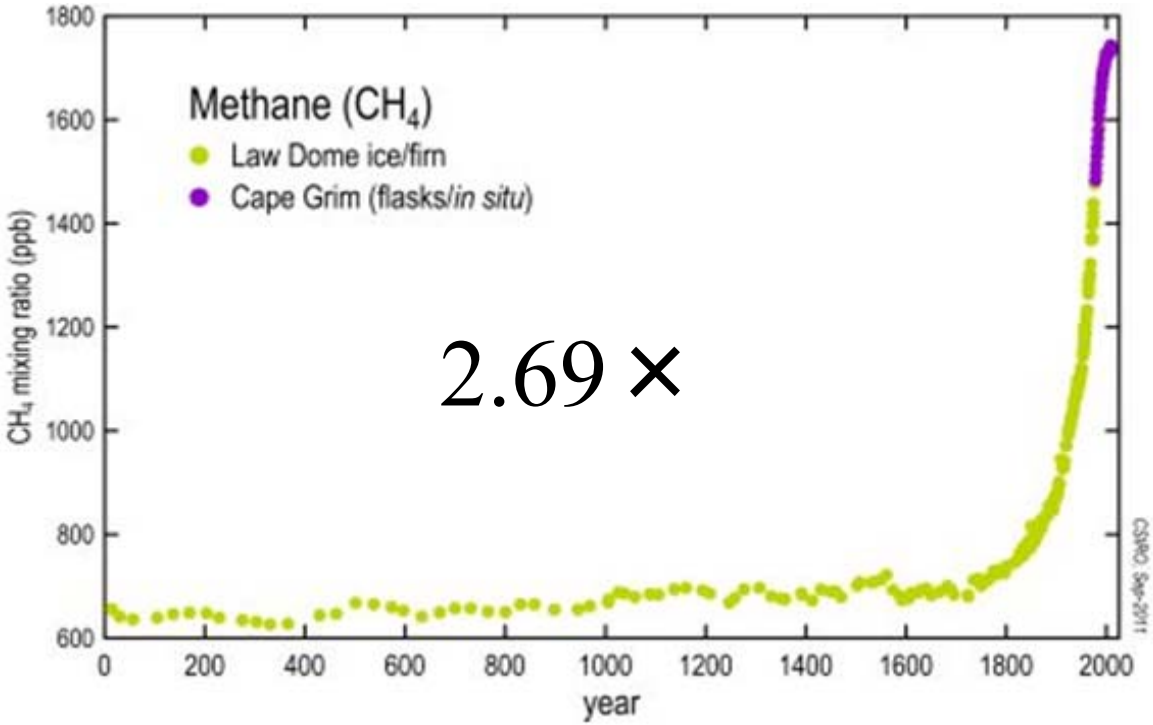
rctic Methane Release

https://www.youtube.com/watch?v=FM0hczFNDZI

rctic Methane Release

https://www.youtube.com/watch?v=LajZxIQmZzs
https://www.youtube.com/watch?v=pO_rXOEWnAA

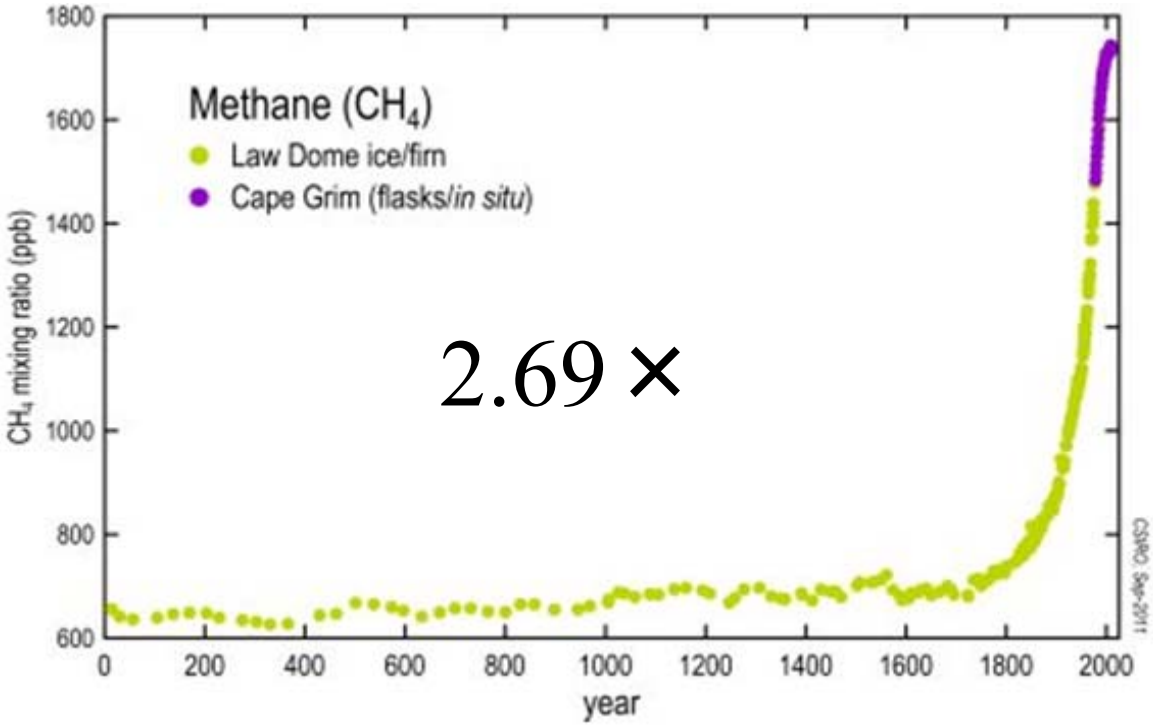
CH_4 Concentration



2.69 ×

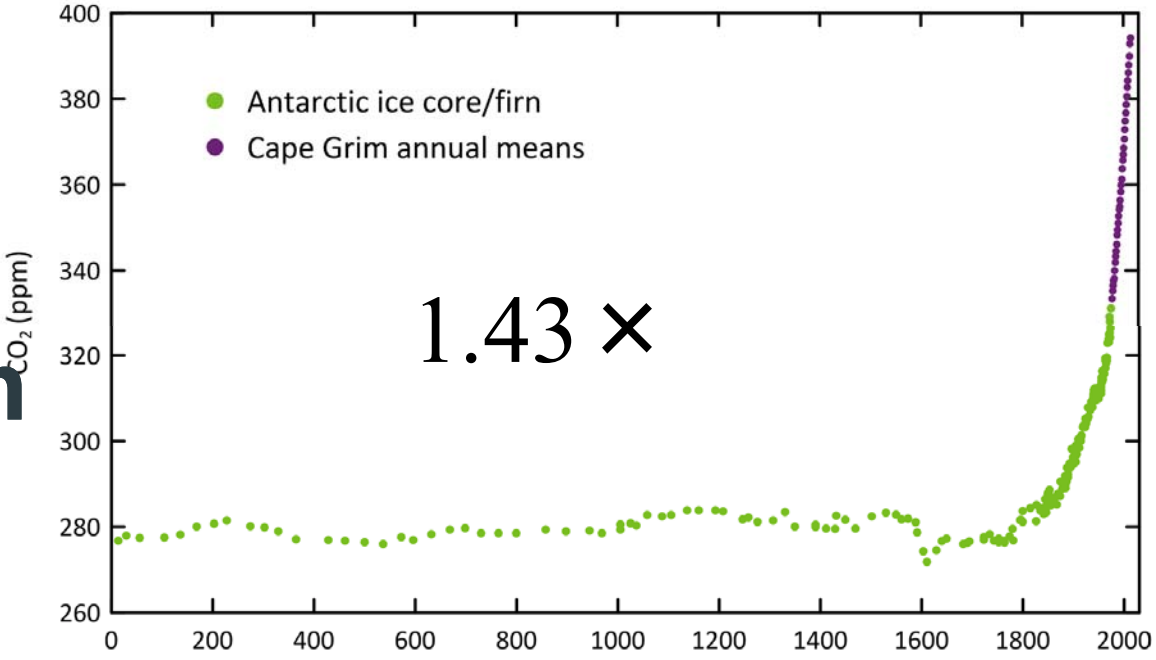
http://www.csiro.au/greenhouse-gases/

CH_4 Concentration



2.69 ×

CO_2 Concentration

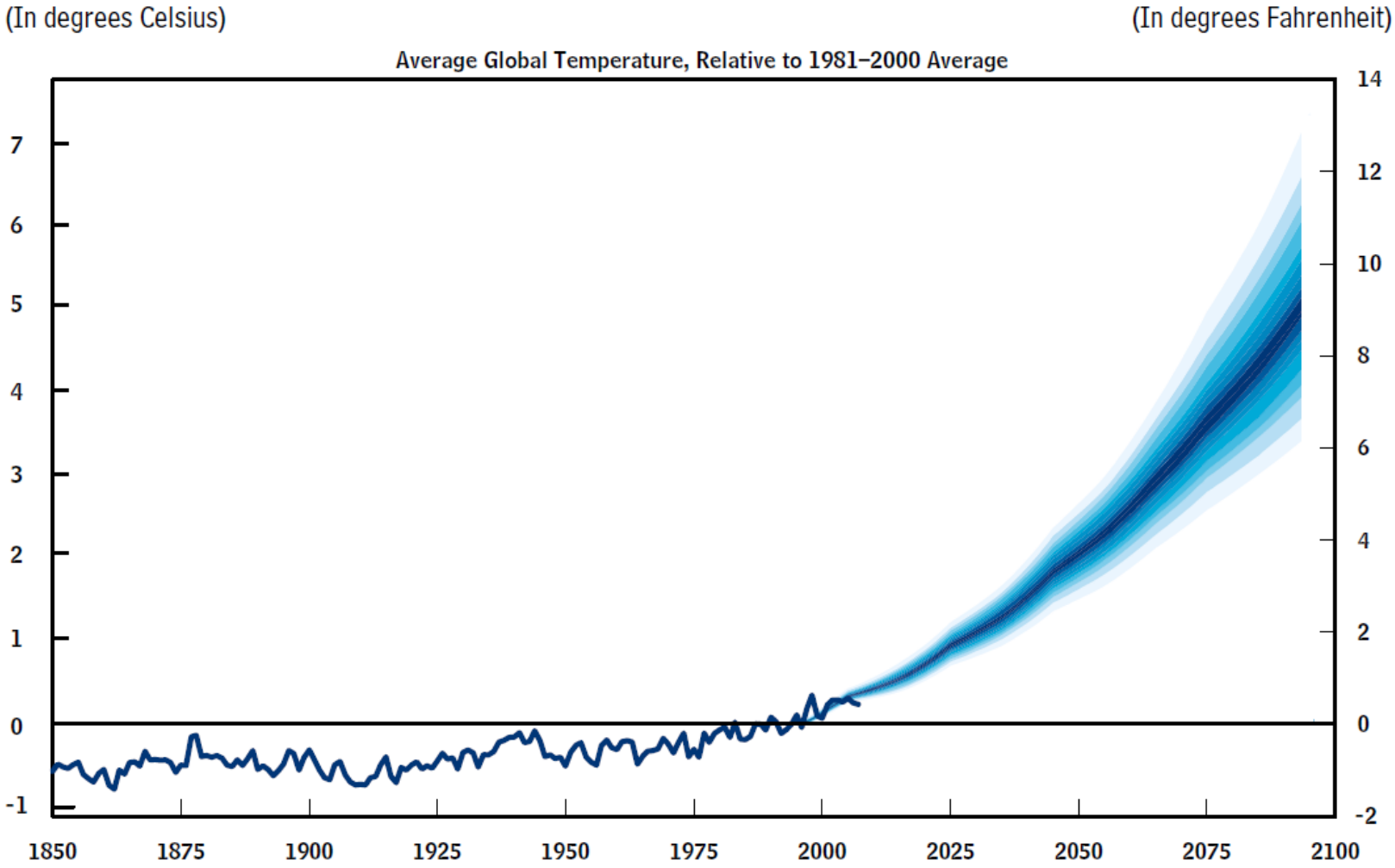


1.43 ×

http://www.csiro.au/greenhouse-gases/

Global warming projections

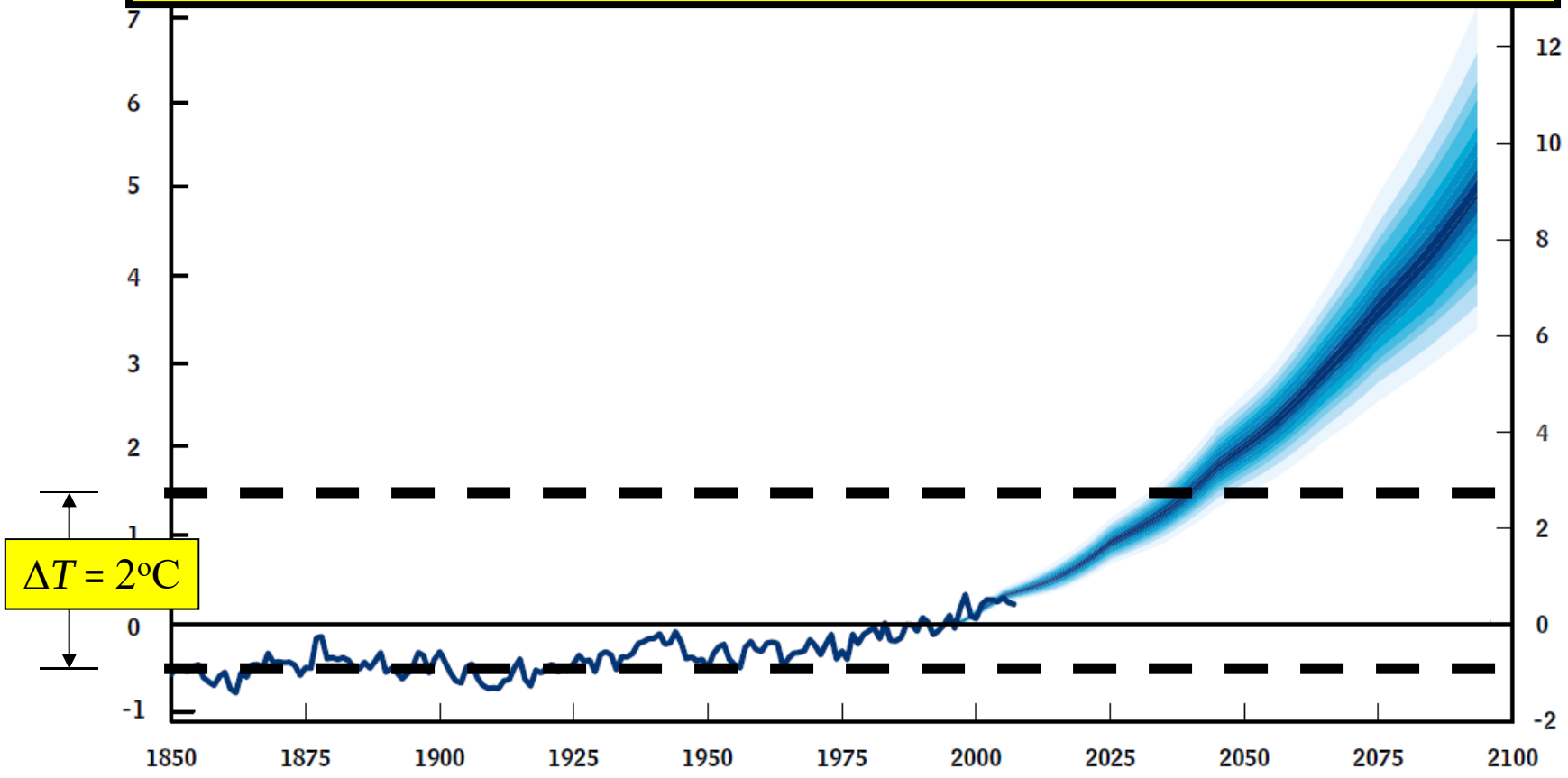
Projections of future global temperature increases provided to Congressional Budget Office by MIT



Global warming projections

…hold the increase in global average temperature below 2°C above preindustrial levels

United Nations Framework Convention on Climate Change(UNFCCC) (2011)



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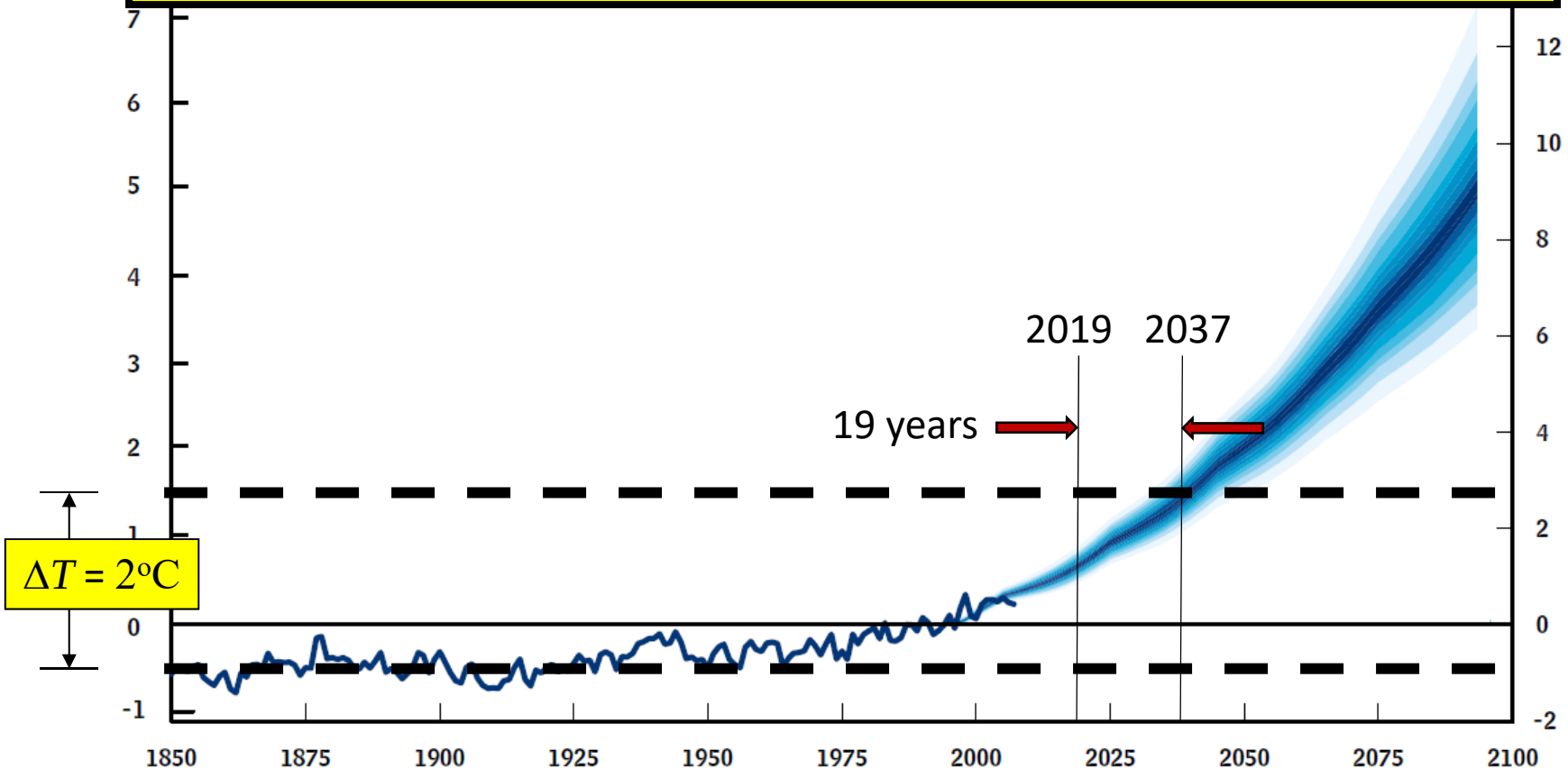
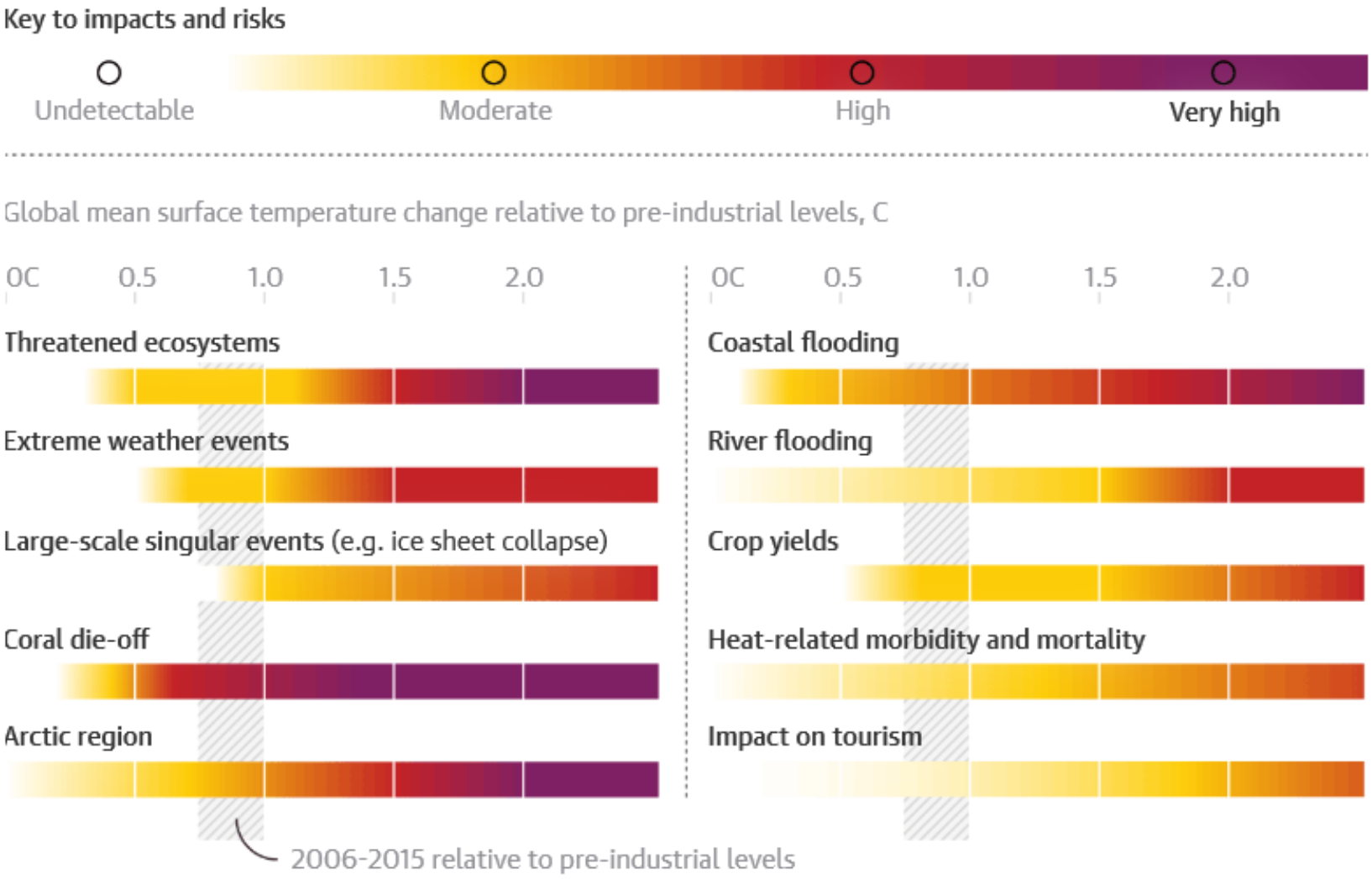
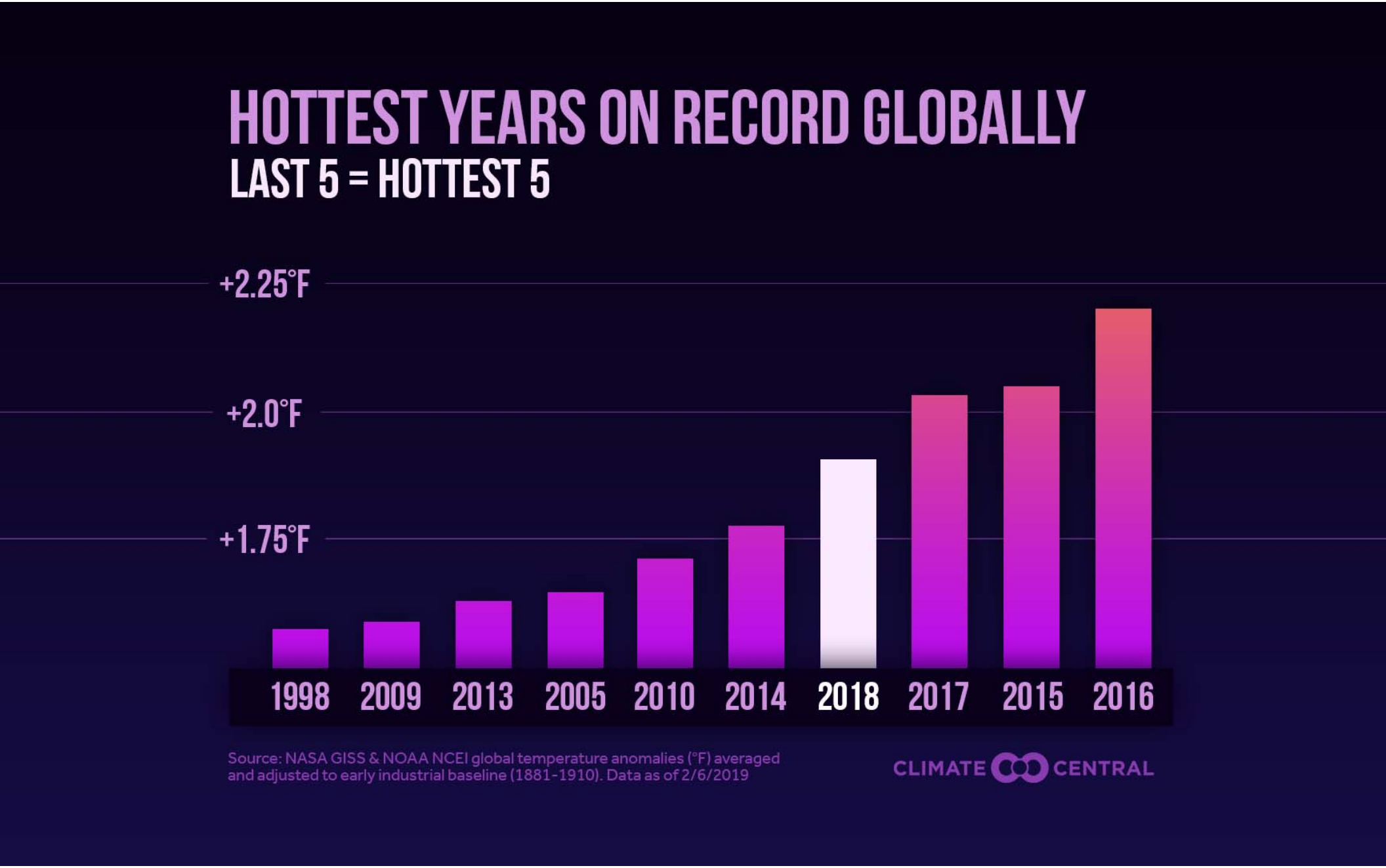


Rising temperatures, rising risks



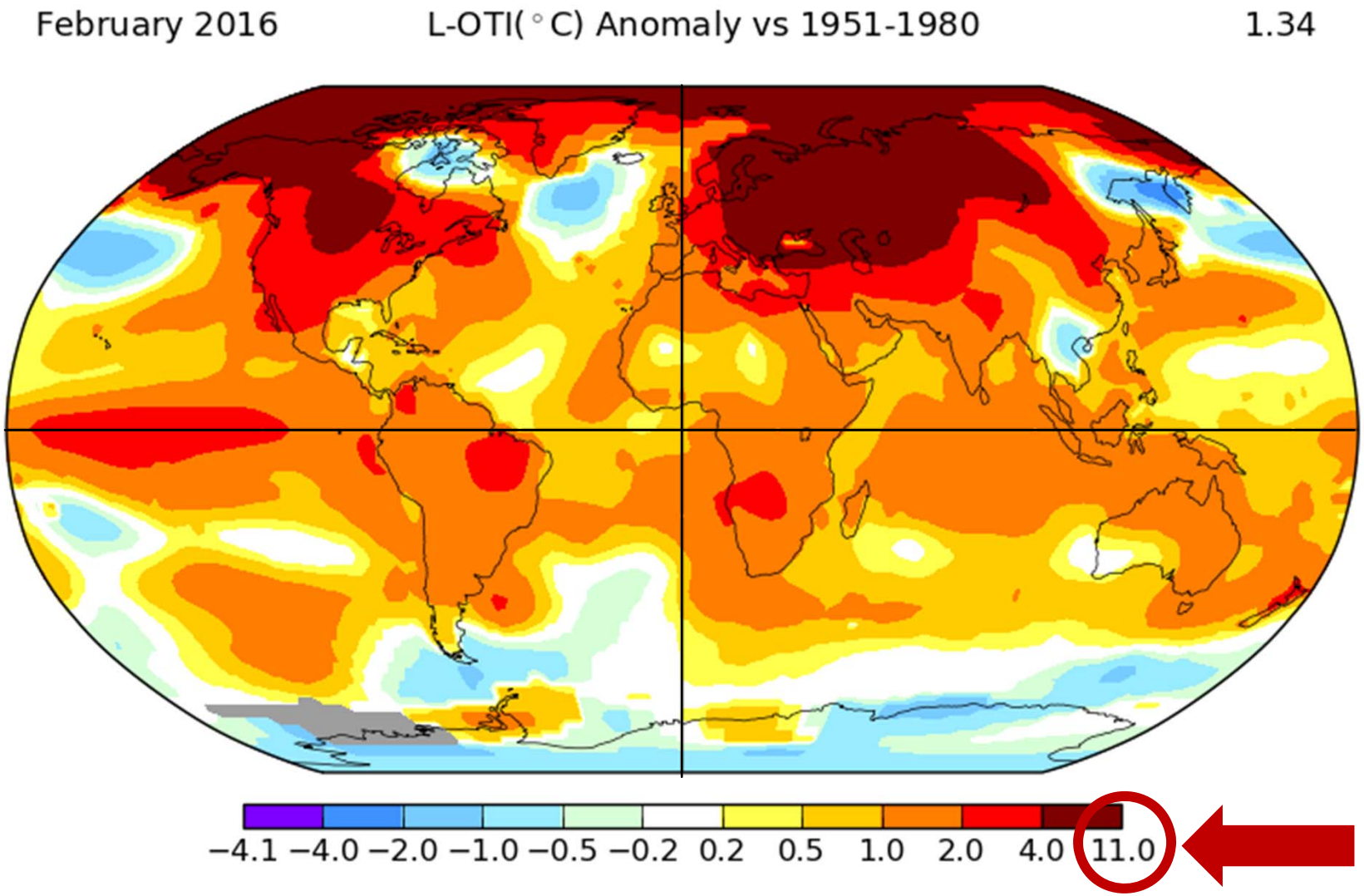
Guardian graphic. Source: IPCC Special Report on Global Warming of 1.5C

https://www.theguardian.com/environment/2018/oct/09/tipping-points-could-exacerbate-climate-crisis-scientists-fear



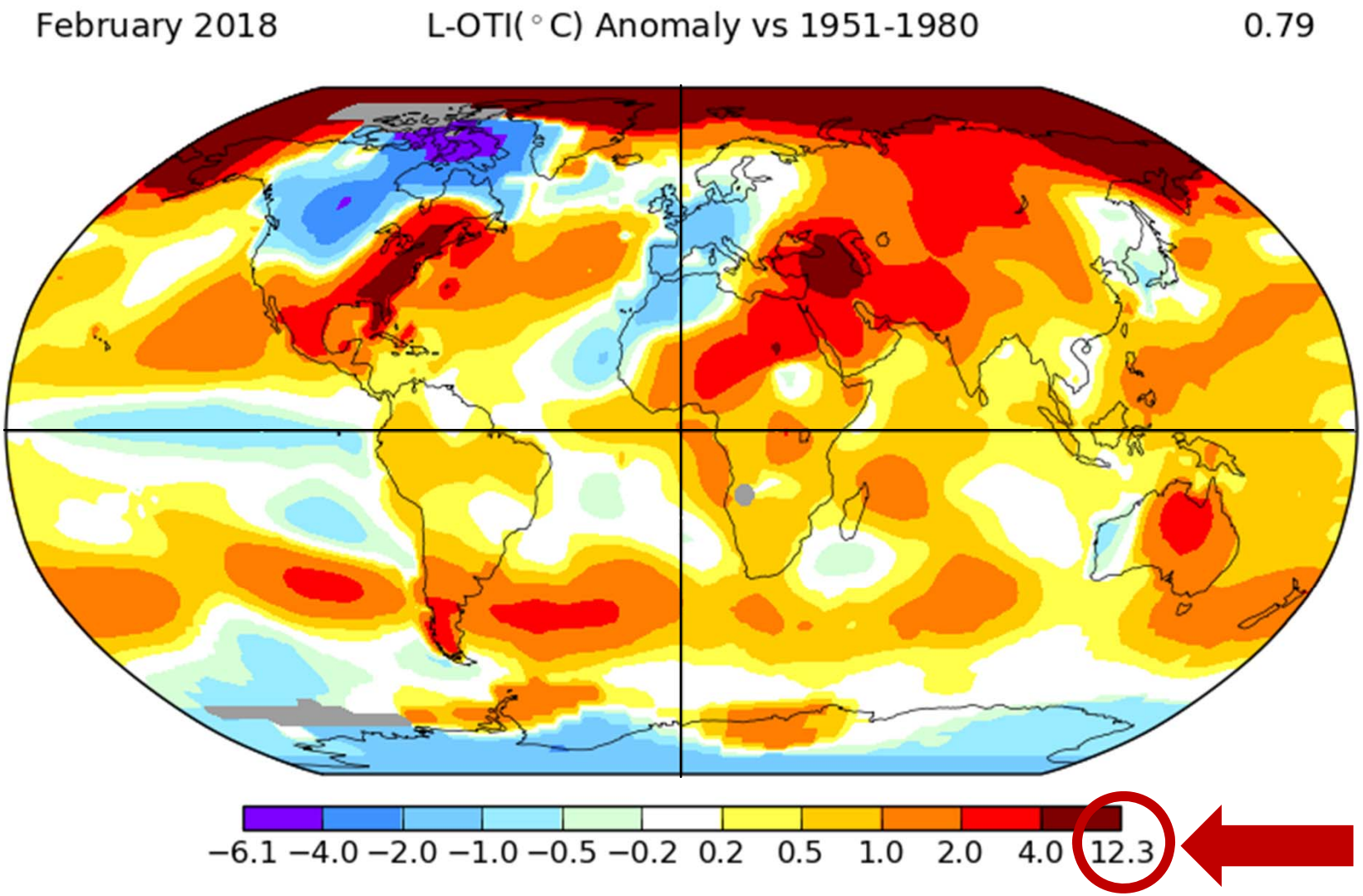
https://www.climatecentral.org/gallery/download/the-10-hottest-global-years-on-record

February 2016



https://data.giss.nasa.gov/gistemp/maps/

February 2018



https://data.giss.nasa.gov/gistemp/maps/

Record Heat Index

Bandar Mahshahr, Iran
30 July 2015
Temp = 109°F (43°C)
Relative humidity = 56%
Dew point = 90°F (32°C)
Wet-bulb = 94°F (34°C)
Heat index = 154°F (68°C)

Dhahran, Saudi Arabia
July 8, 2003
Temp = 108°F (42°C)
Relative humidity = 68%
Dew point = 95°F (35°C)
Wet bulb = 97°F (36°C)
Heat index = 178°F (81°C)

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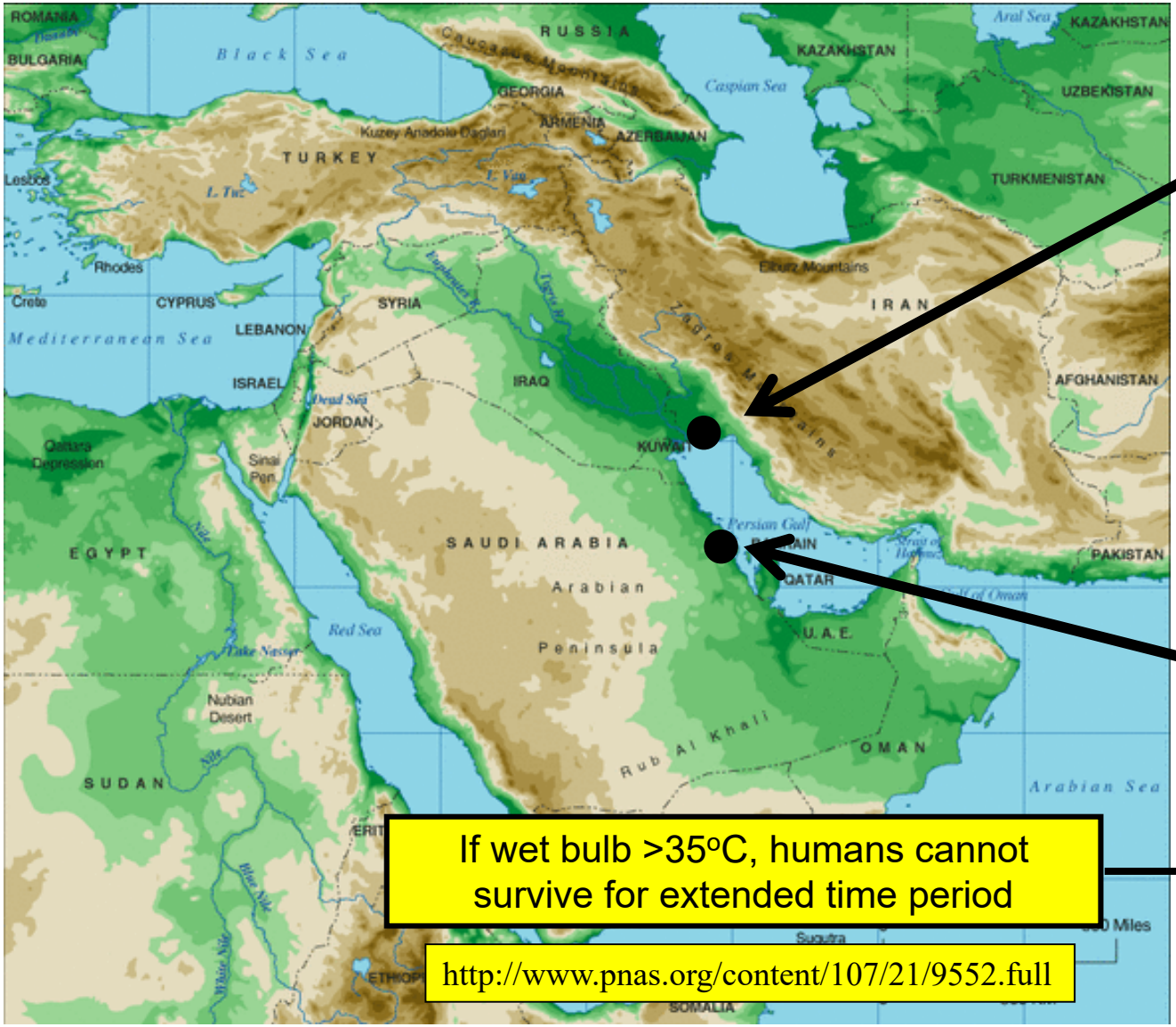

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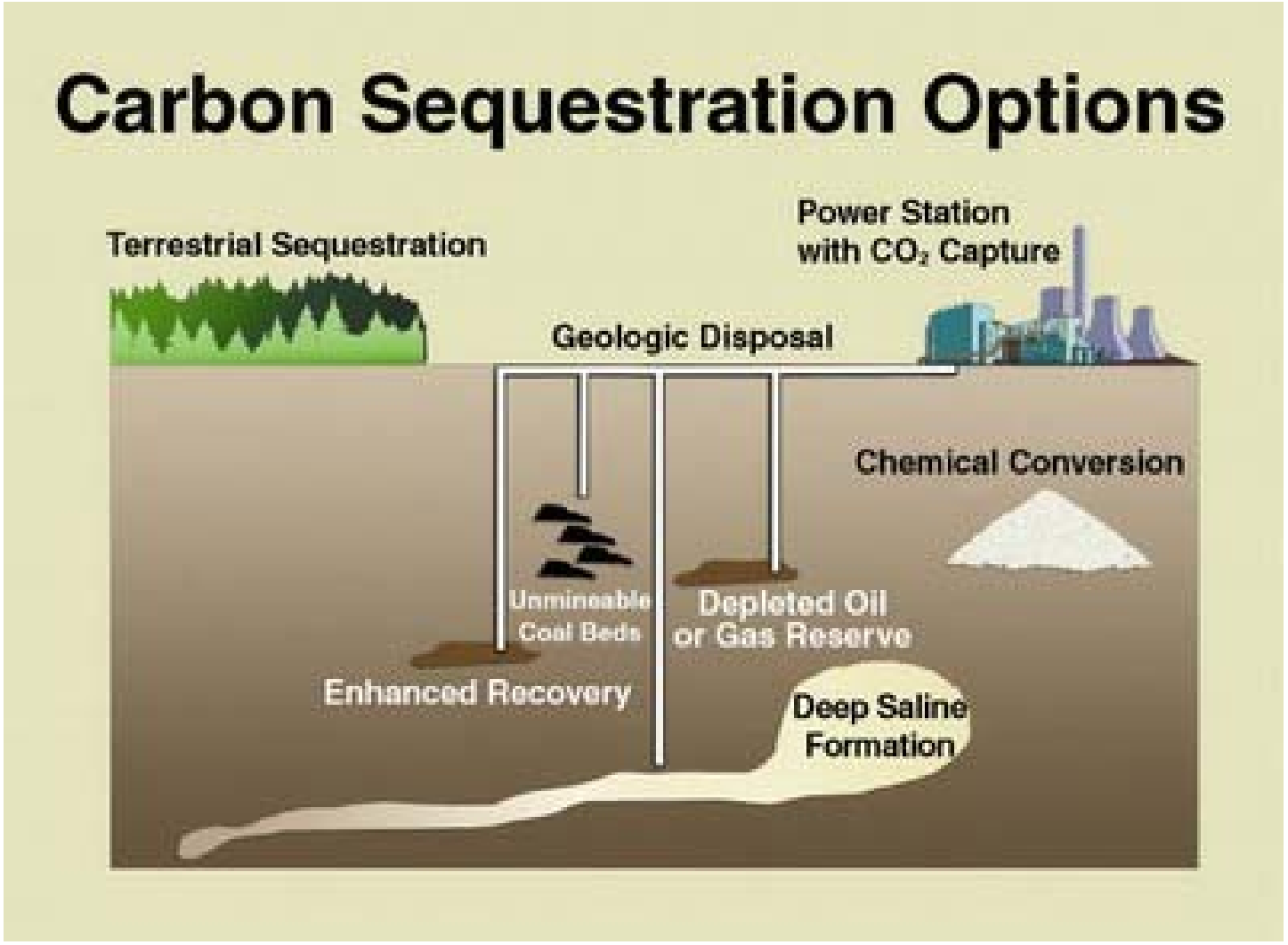
If wet bulb >35°C, humans cannot survive for extended time period

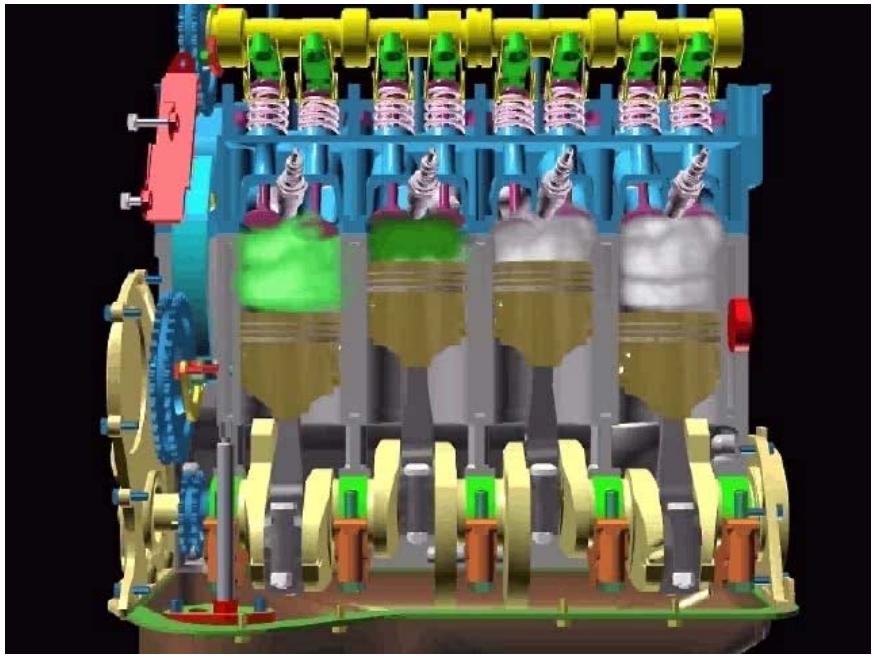
http://www.pnas.org/content/107/21/9552.full

Solutions

Carbon Capture and Sequestration (CCS)



Improve Efficiency

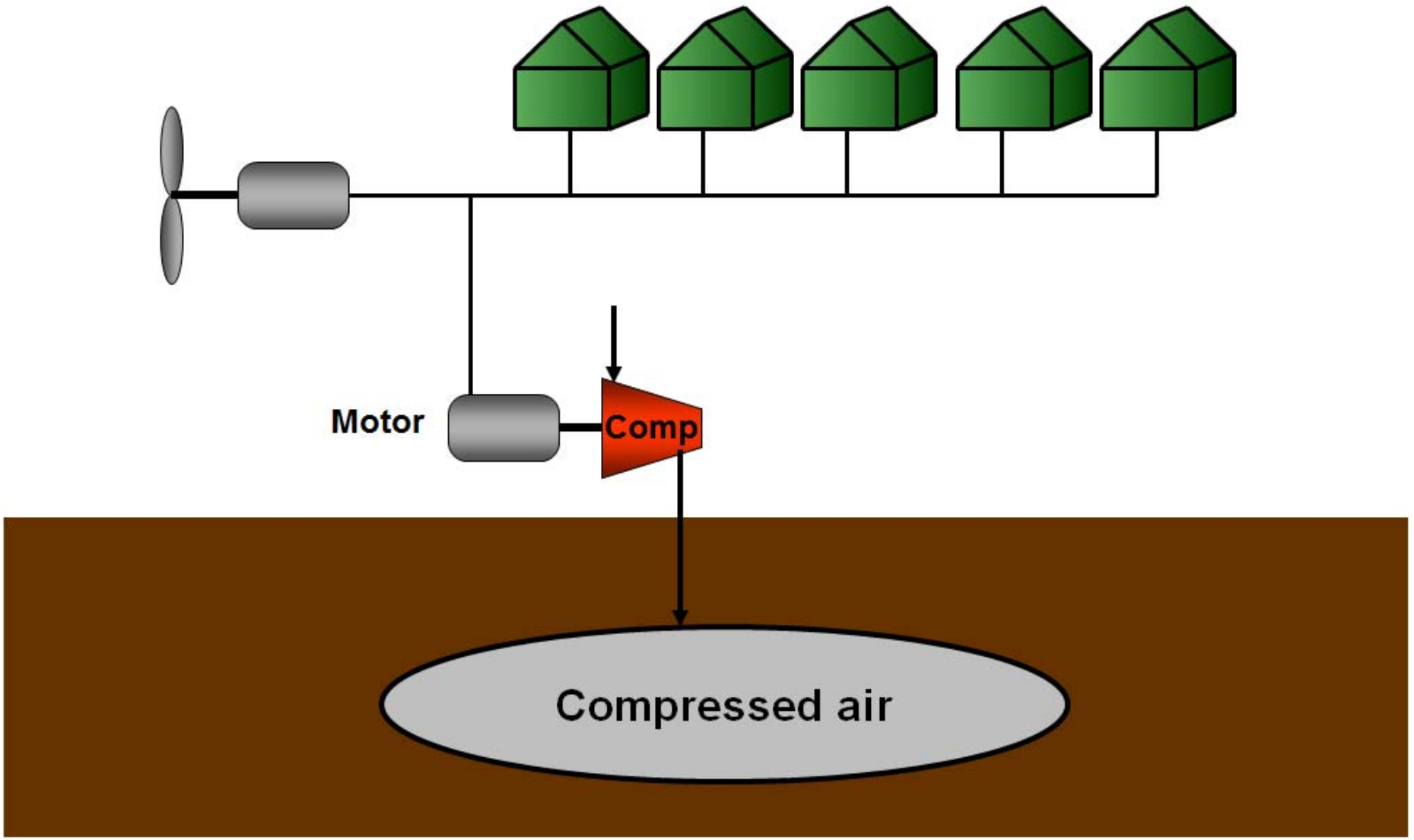
		Efficiency
Otto/Diesel Engine		20–40%
StarRotor Engine		50–75%

Nuclear Energy

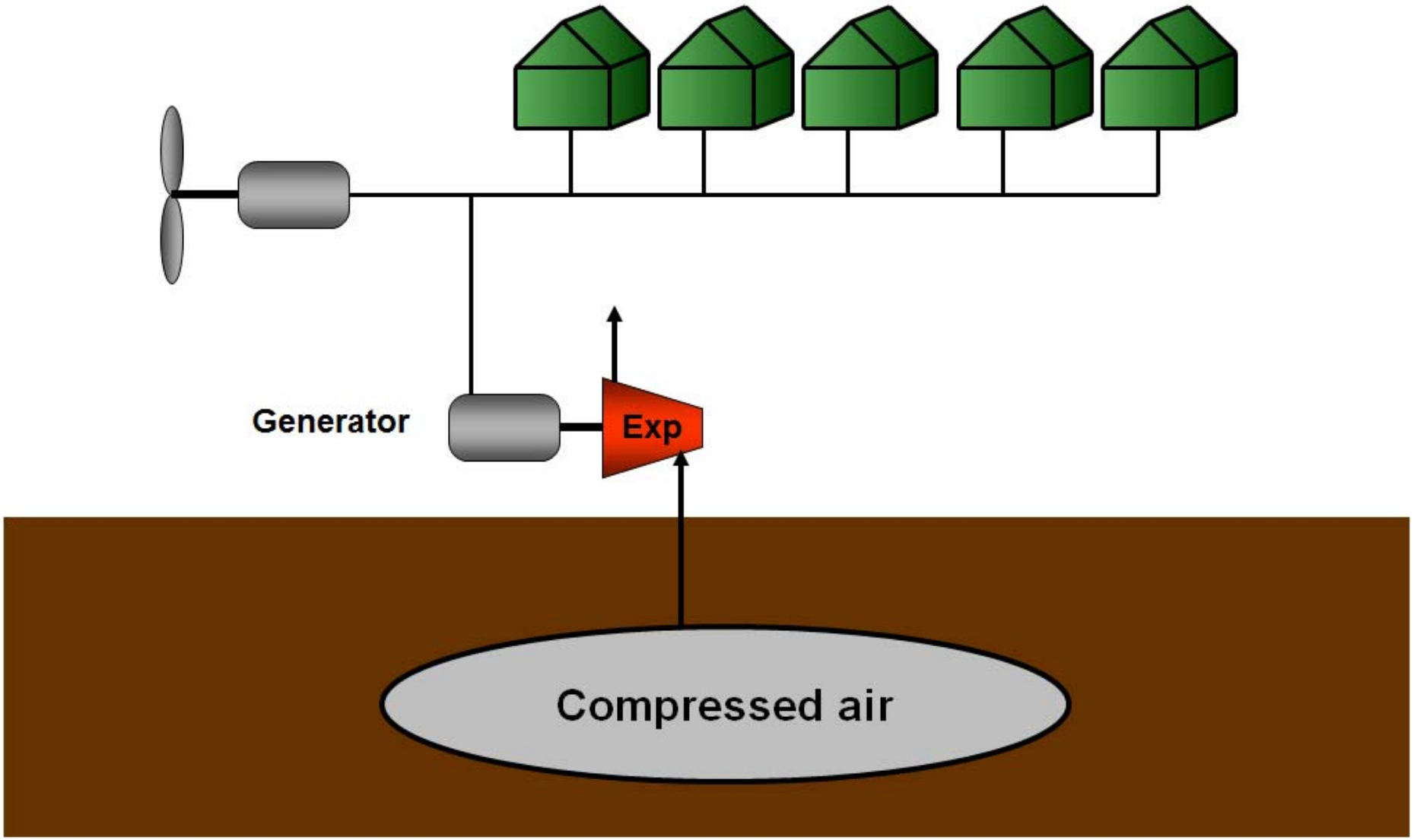
Solar Energy

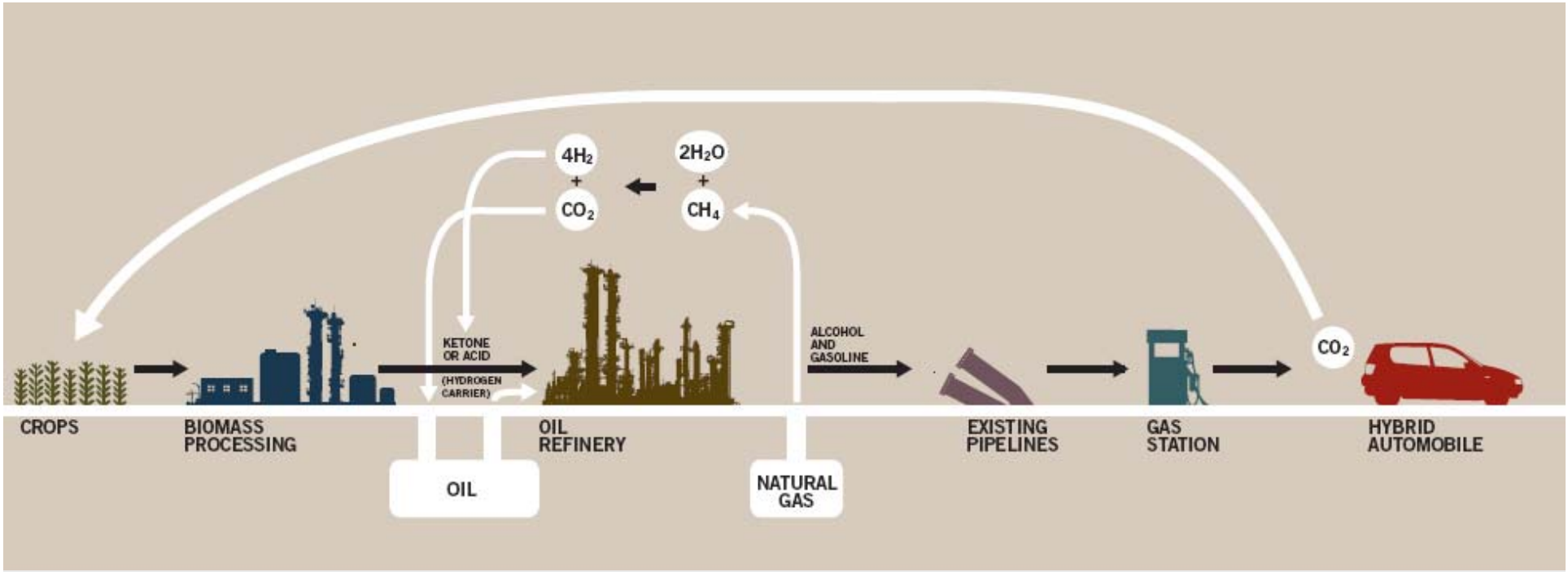
Wind Energy

Electricity Storage



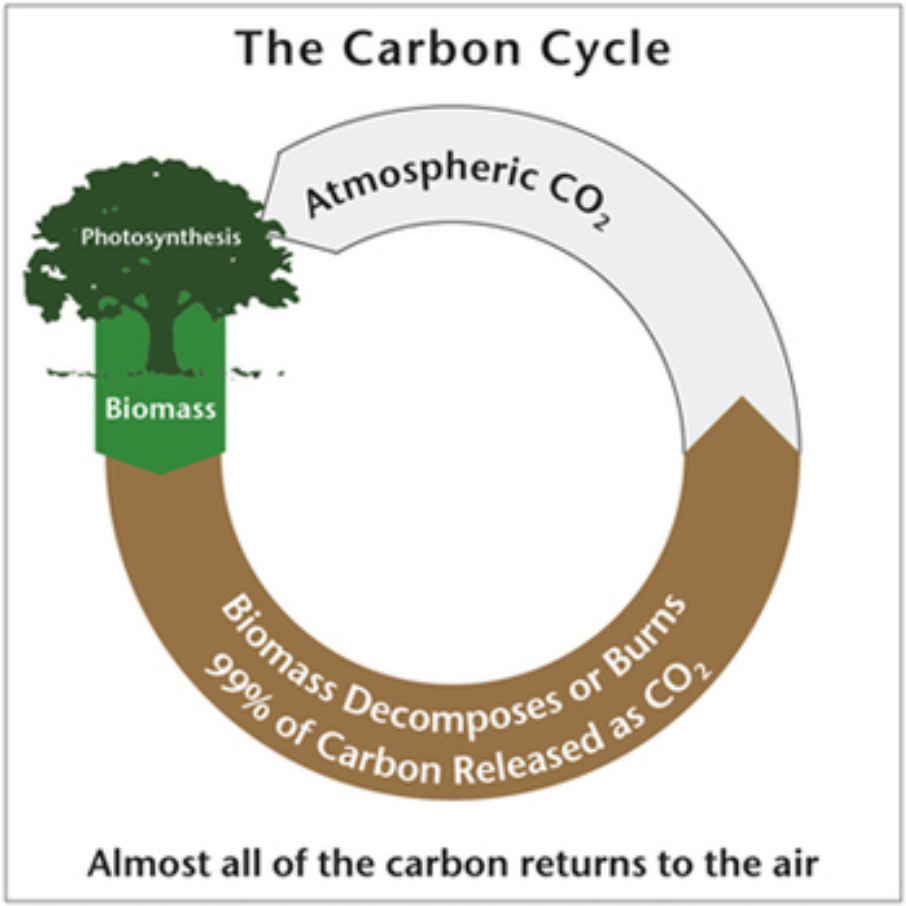
Electricity Storage

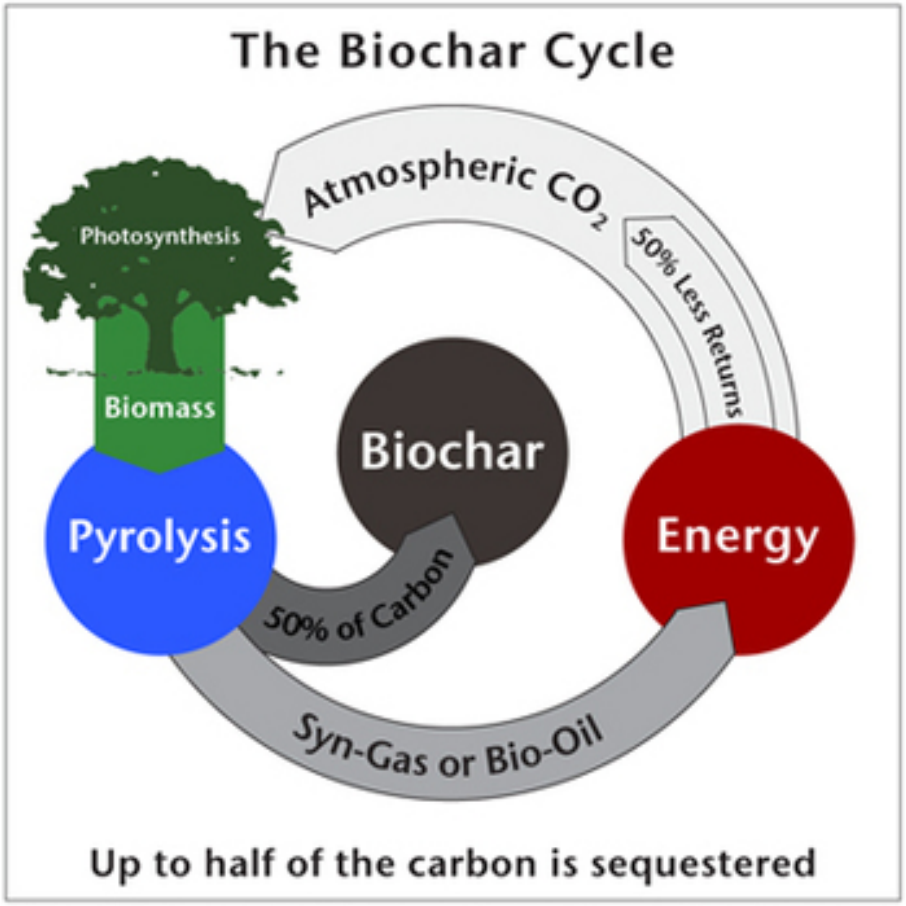
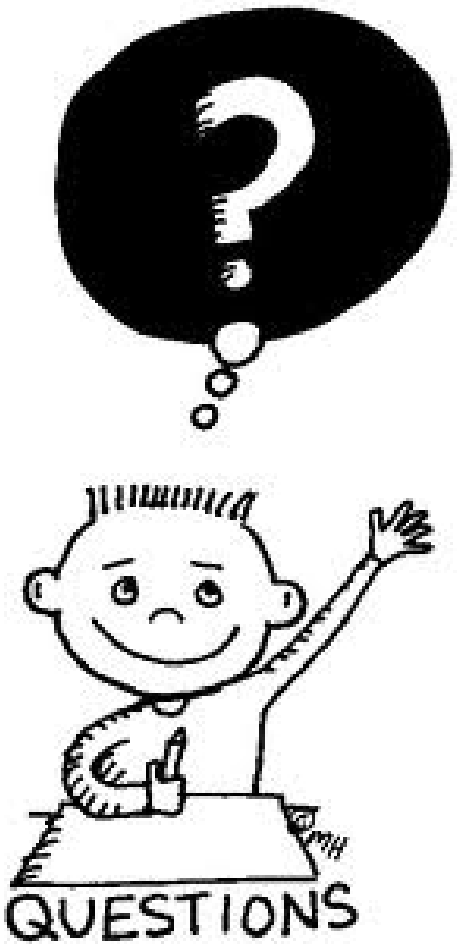



4H2
+
CO2
2H2O
+
CH4
KETONE
OR ACID
(HYDROGEN
CARRIER)
ALCOHOL
AND
GASOLINE
CO2
CROPS
BIOMASS
PROCESSING
OIL
REFINERY
EXISTING
PIPELINES
GAS
STATION
HYBRID
AUTOMOBILE
OIL
NATURAL
GAS

Biofuels

Biochar


The Carbon Cycle
Atmospheric CO_2
Photosynthesis
Biomass
Biomass Decomposes or Burns
99% of Carbon Released as CO_2
Almost all of the carbon returns to the air


The Biochar Cycle
Atmospheric CO_2
50% Less Returns
Photosynthesis
Biomass
Biochar
Pyrolysis
Energy
50% of Carbon
Syn-Gas or Bio-Oil
Up to half of the carbon is sequestered

Thank You!