





Net Zero Emissions
Why and How

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Lecture 3

Two Issues from the State of the Union
Higher Climate Sensitivity?
Geoengineering: Solar Resource Management

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February 17, 2020

Lecture 3 Outline

- Weather-climate quiz
- Two issues from the State of the Union
- Energy independence
- Trillion trees
- Higher climate sensitivity?
- Geoengineering: solar resource management
- Summary

February 9, 2020
Fox News Flight Delay


LIVE
Washington Southwest 3121 11:35a B17 on time
Washington Southwest 3792 12:00p B26 on time
Baltimore / Washington Southwest 3566 12:50p B21 on time
Boston, MA Southwest 4801 10:55a B24 At 11:10a
Boston, MA Southwest 4443 1:05p B17 Cancelled
Burbank, CA Southwest 660 10:00a B7 At 10:10a
Cancun, MX Southwest 218 9:10a B17 Boarding
Cincinnati Southwest 3760 11:25a A19 Cancelled
Cleveland, OH Southwest 3692 10:55a B11 on time
Cleveland, OH Southwest 5867 1:05p A15 on time
Columbus, OH Southwest 1349 10:00a B2 Cancelled
Dallas / Love Field Southwest 6209 9:25a B9 Cancelled
Dallas / Love Field Southwest 3189 11:50a B5 on time
Denver, CO Southwest
Hartford / Springfiel
Houston Hobby
Kansas City, MO
Kansas City, MO
Las Vegas, NV
Las Vegas, NV
Las Vegas, NV
Little Rock, AR
Los Angeles, CA
Los Angeles, CA
Manistee, MI
Minneapolis / St
Minneapolis / St
Nashville, TN
New Orleans, L
MIDWAY AIRPORT
FOX 32
33° 9:02
CLIMATE CHANGE CAUSES DELAYS AT AIRPORTS
SOUTH SUBURBS 10AM 44° | 2PM 53° | 6PM 51°
TOYOTA
You can now wait to meet arriving passengers in the

Climate versus Weather Quiz

Climate Reality Project

How Much Do You Know About Weather and Climate?

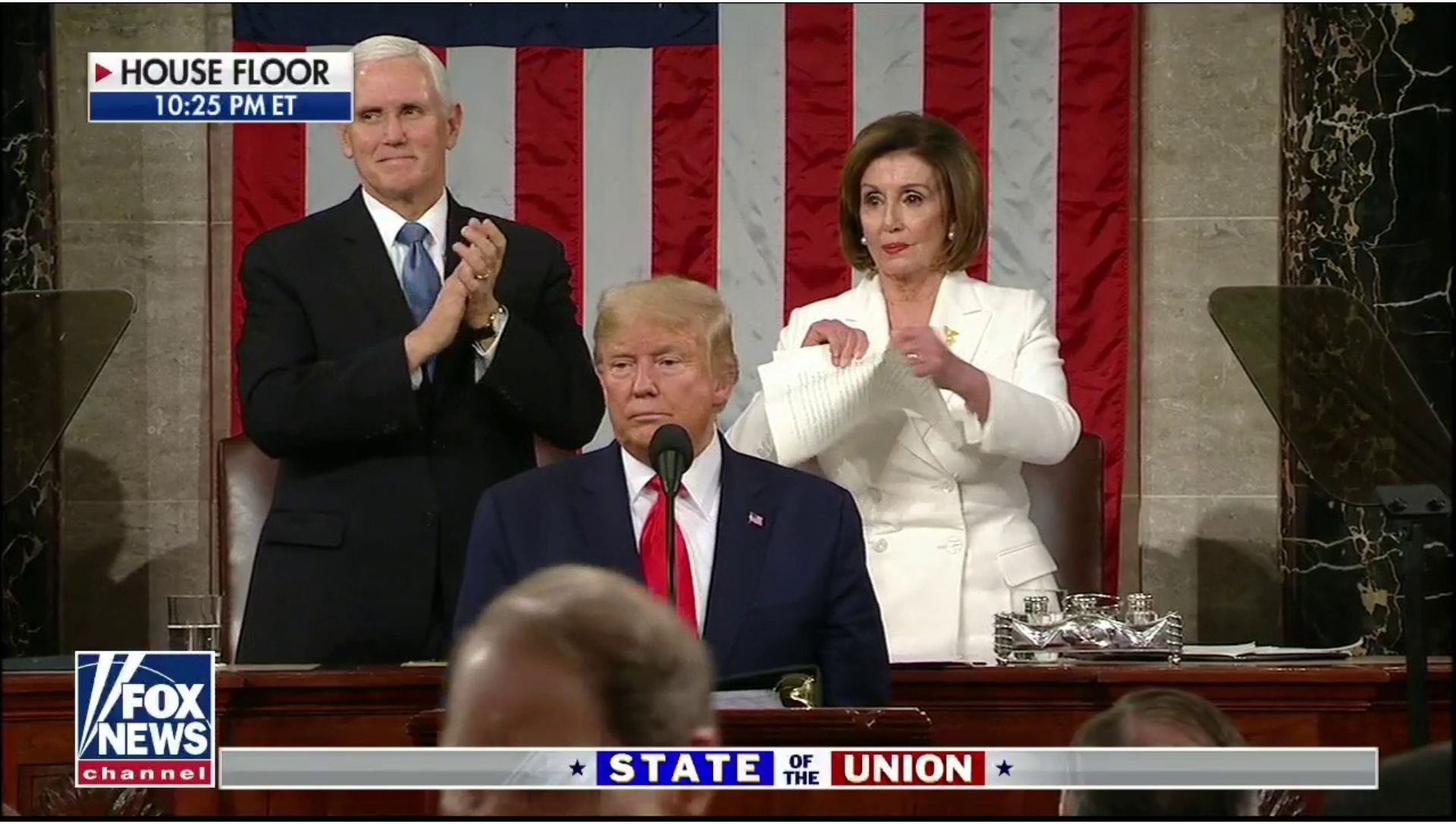
How much do you know about weather, climate, and how they're different? Put your knowledge to the test.

TAKE QUIZ

https://quiz.tryinteract.com/#/5e17706c7f7a370014f04384?method=iframe

State of the Union Address
February 4, 2020

State of the Union Address
February 4, 2020



State of the Union Address
February 4, 2020

“Thanks to our bold regulatory reduction campaign, the United States has become the No. 1 producer of oil and natural gas anywhere in the world, by far. (Applause.) With the tremendous progress we have made over the past three years, America is now energy independent, and energy jobs, like so many other elements of our country, are at a record high. (Applause.) We are doing numbers that no one would have thought possible just three years ago.”

State of the Union Address
February 4, 2020

“To protect the environment, days ago I announced that the United States will join the One Trillion Trees Initiative, an ambitious effort to bring together government and private sector to plant new trees in America and all around the world. (Applause.)”

U.S. Oil and Natural Gas Production

Ronald Reagan
1981-1989

George H. W. Bush
1989-1993

Bill Clinton
1993-2001

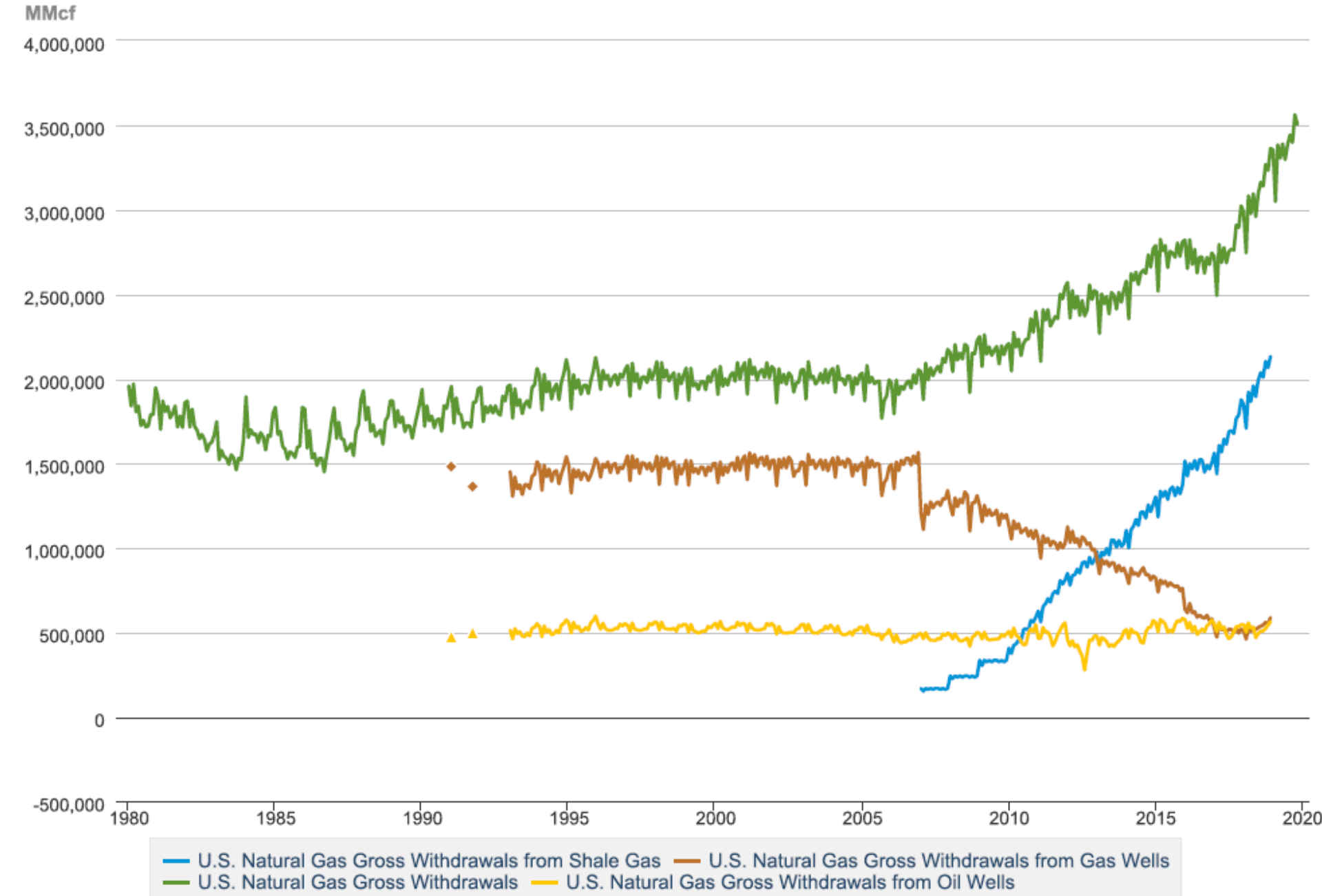
George W. Bush
2001-2009

Barack Obama
2009-2017

4,000,000
3,000,000
2,000,000
1,000,000
0
1980
1990
2000
2010
2020

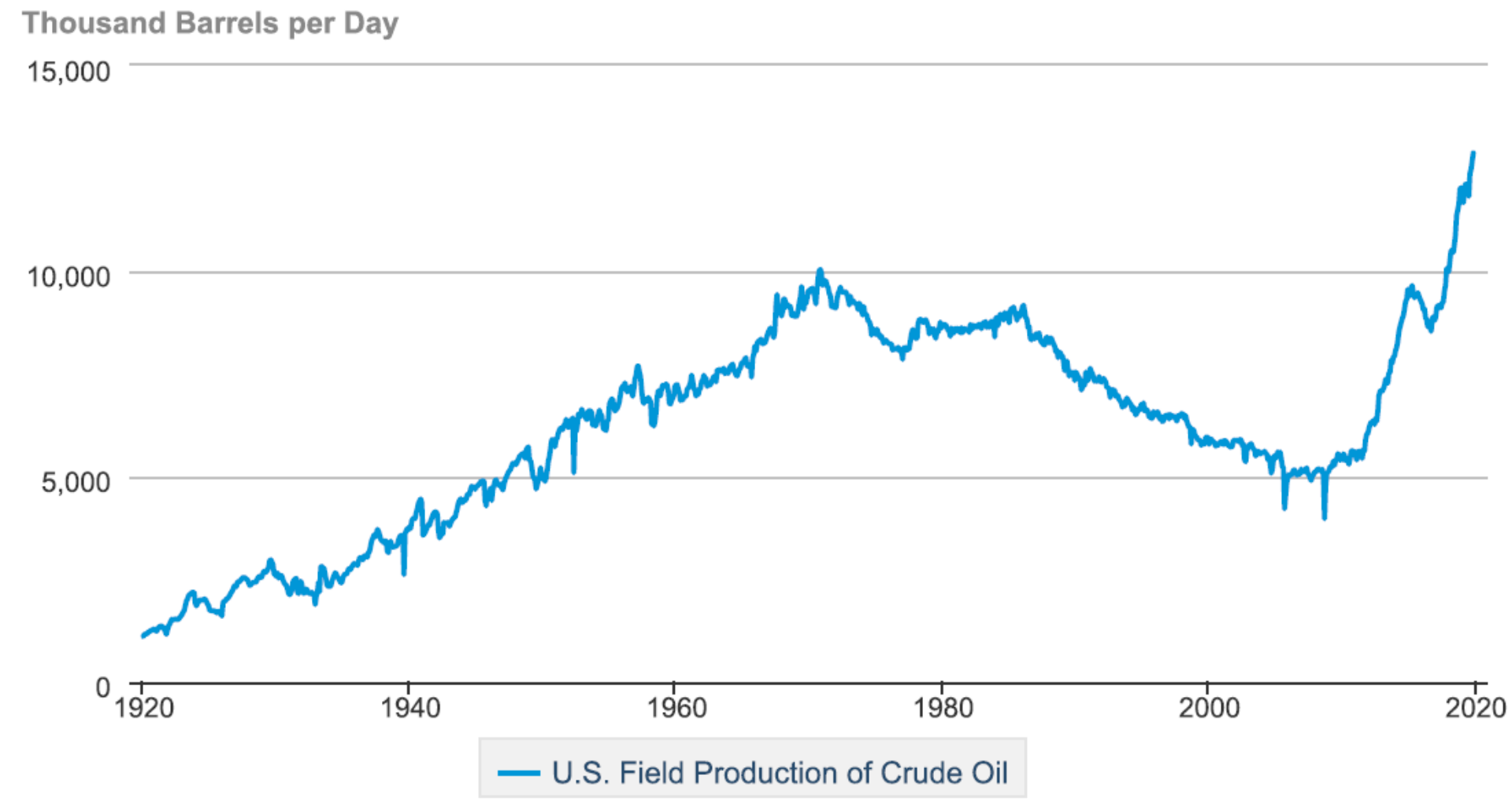
U.S. Natural Gas Gross Withdrawals

Natural Gas Gross Withdrawals and Production



Source: U.S. Energy Information Administration

U.S. Field Production of Crude Oil



Source: U.S. Energy Information Administration

U.S. Field Production of Crude Oil
Thousand Barrels per Day

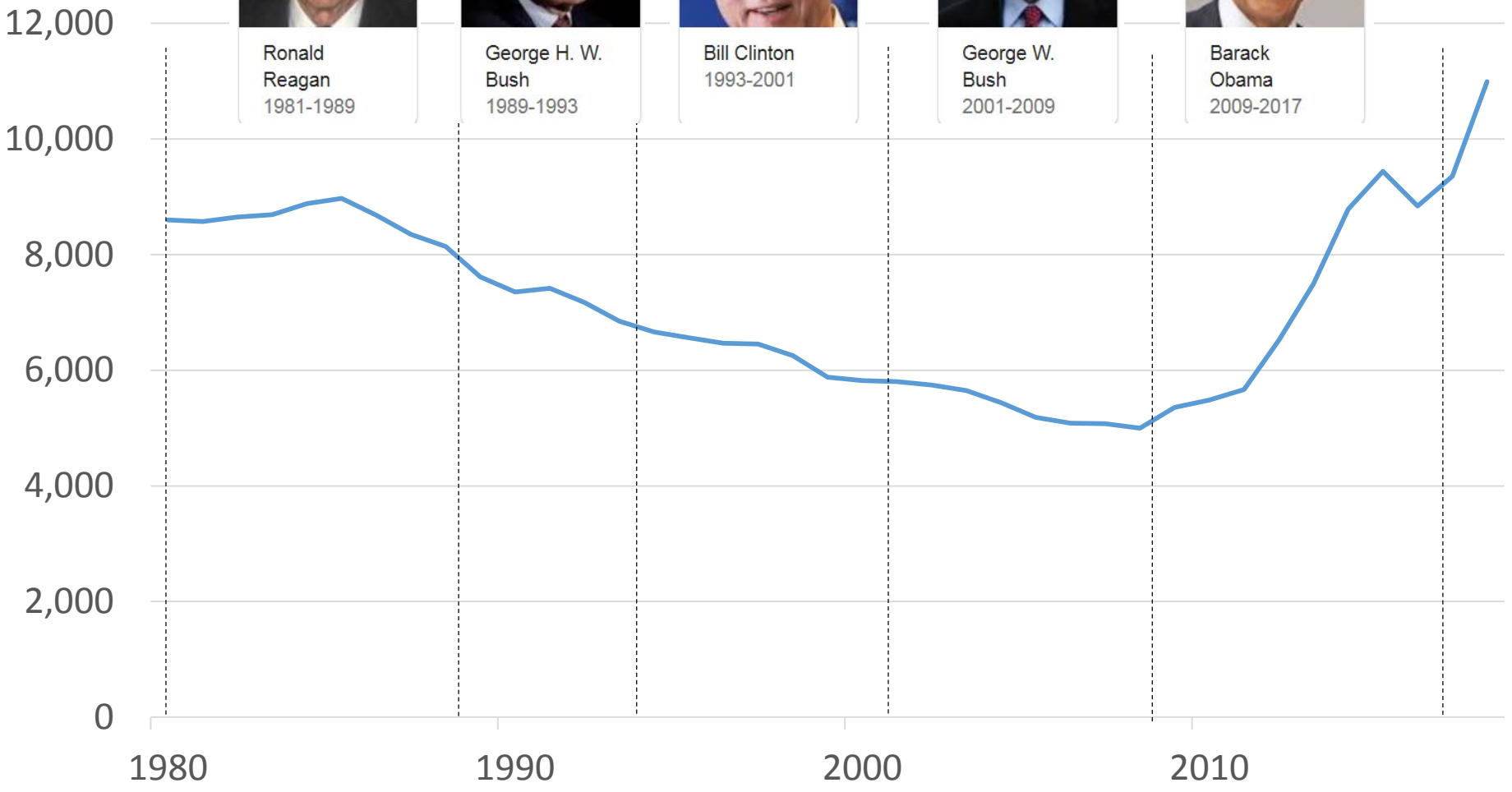
Ronald Reagan
1981-1989

George H. W. Bush
1989-1993

Bill Clinton
1993-2001

George W. Bush
2001-2009

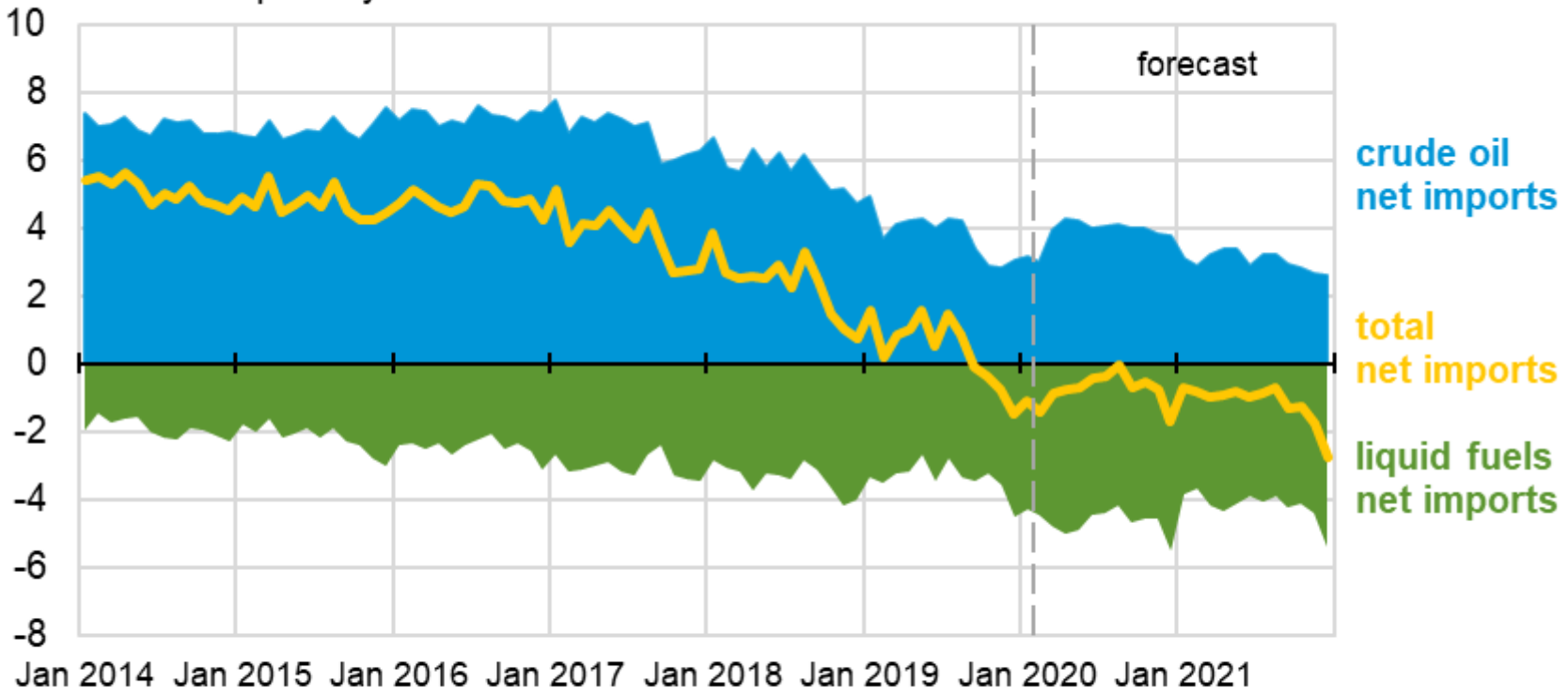
Barack Obama
2009-2017



Energy Independence

U.S. net imports of crude oil and liquid fuels

million barrels per day



Note: Liquids fuels include: gasoline, distillate fuels, hydrocarbon gas liquids, jet fuel, residual fuel oil, unfinished oils, other hydrocarbons/oxygenates, and other oils.

Source: Short-Term Energy Outlook, February 2020

eia

How U.S. Got Hooked on Foreign Oil

Sabin Center for Climate Change Law

Columbia Law School | Columbia University Earth Institute

The New York Times

December 21, 2019

95 Environmental Rules Being Rolled Back…

	58 ROLLBACKS COMPLETED	37 ROLLBACKS IN PROCESS	95 TOTAL ROLLBACKS
Air pollution and emissions	16	9	25
Drilling and extraction	10	9	19
Infrastructure and planning	11	1	12
Animals	7	3	10
Toxic substances and safety	5	3	8
Water pollution	4	6	10
Other	5	6	11

Completed Regulatory Changes Relevant to Oil and Gas Production

- Canceled a requirement for oil and gas companies to report methane emissions. Environmental Protection Agency.
- Revised and partially repealed an Obama-era rule limiting methane emissions on public land…
- Made significant cuts to the borders of two national monuments in Utah…
- Rescinded water pollution regulations for fracking on federal and Indian lands.
- Approved construction of the Dakota Access pipeline.
- Withdrew a requirement that Gulf oil rig owners prove they could cover the costs of removing rigs once they have stopped producing.
- Loosened offshore drilling safety regulations.
- Permitted the use of seismic air guns for gas and oil exploration in the Atlantic Ocean.

Forests
Trillion Trees Challenge

THE HILL

February 2, 2020

GOP bill will seek to commit US to planting 3.3 billion trees annually

The New York Times

February 12, 2020
How a Trillion Trees Triumphed Over Trump's Climate Denialism

Marc Benioff, chairman of Salesforce, at the World Economic Forum in Davos, Switzerland, where President Trump embraced his Trillion Trees climate initiative.

The New York Times

June 11, 2019

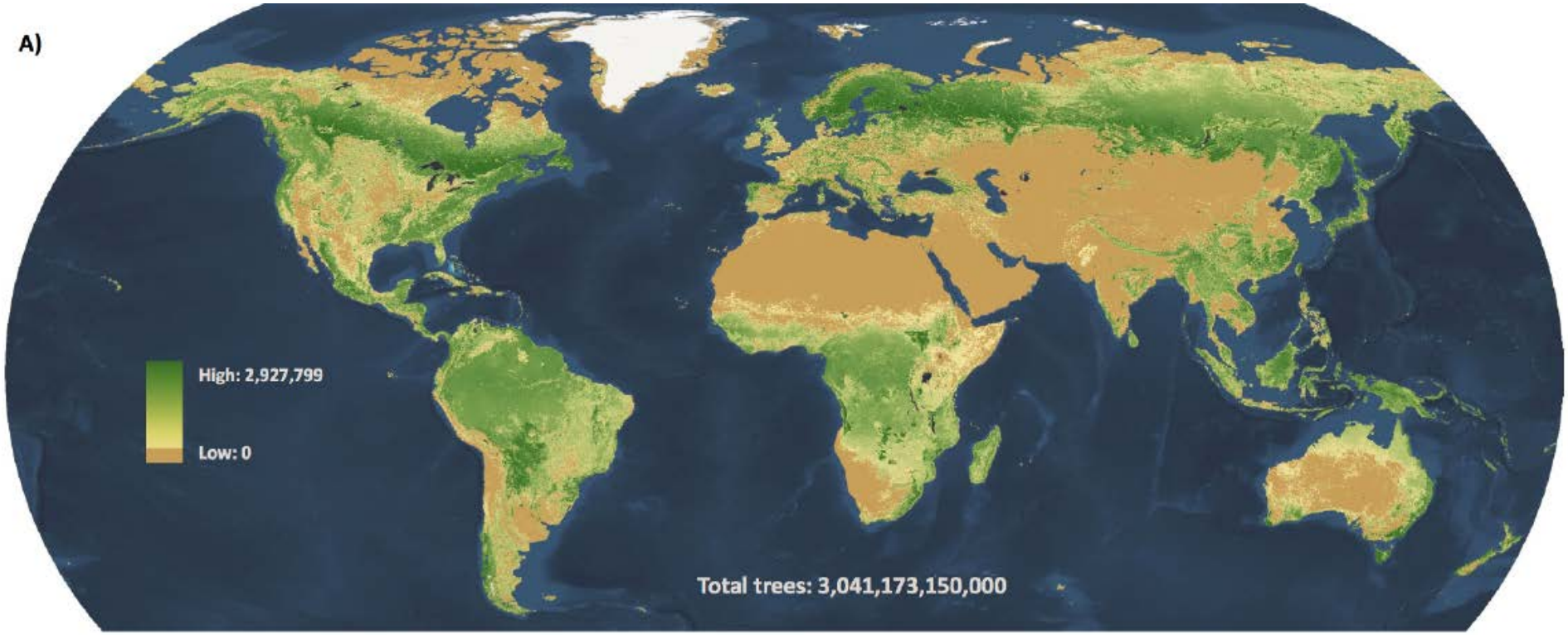
Oak Tree Given to Trump by French President Has Died

Ronald Reagan, September 1980

"Approximately 80 percent of our air pollution stems from hydro-carbons released by vegetation, so let's not go overboard in setting and enforcing tough emission standards from man-made sources."

“Trees cause more pollution than automobiles do.”

Mapping tree density at a global scale
M.W. Crowther et al.
Nature 525(2015)201



Global: 3.0 trillion; U.S. 0.23 trillion
Tropics and subtropics: 1.3 trillion; boreal: 0.74 trillion; temperate: 0.66 trillion
Annual harvest 15 billion.
Pre-agriculture estimate: 4.4 trillion

The New York Times

February 12, 2020

Planting trees Won't Save the World

Erle C. Ellis, Mark Maslin and Simon Lewis

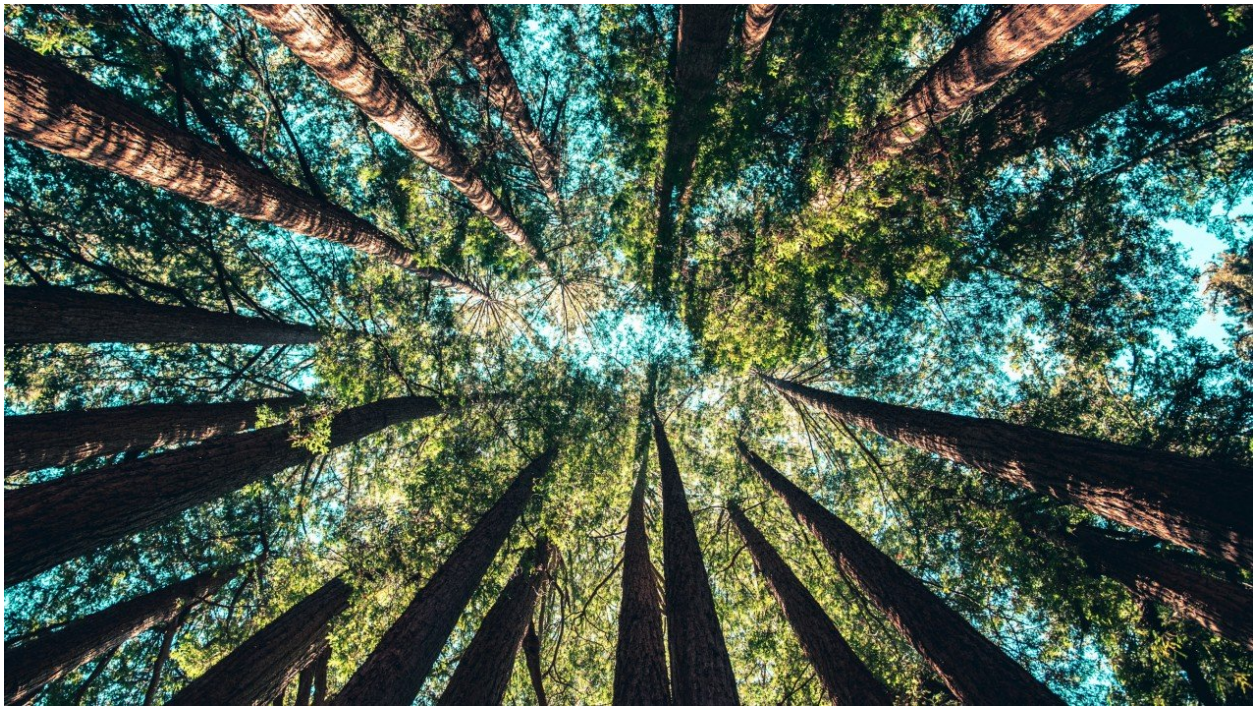
(The authors are scientists.)

"Planting trees, even as many as a trillion, will never absorb the enormous amounts of fossil carbon emitted from industrial societies."

James Temple

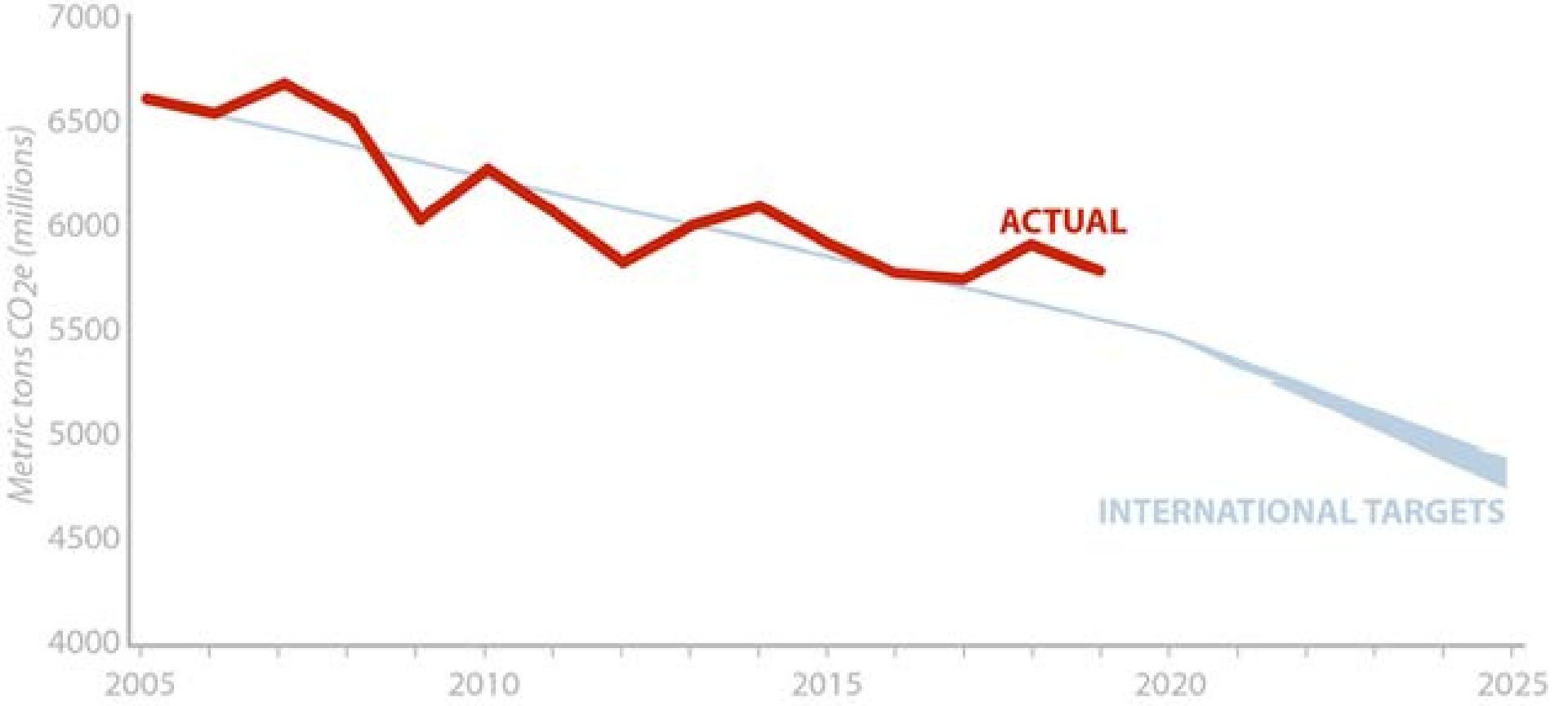
January 28, 2020

“A Trillion Trees” is a great idea—that could become a dangerous climate distraction. Reforestation is critical for lots of reasons, but it’s no substitute for cutting emissions



U.S. NET GREENHOUSE GAS EMISSIONS RELATIVE TO INTERNATIONAL COMMITMENTS

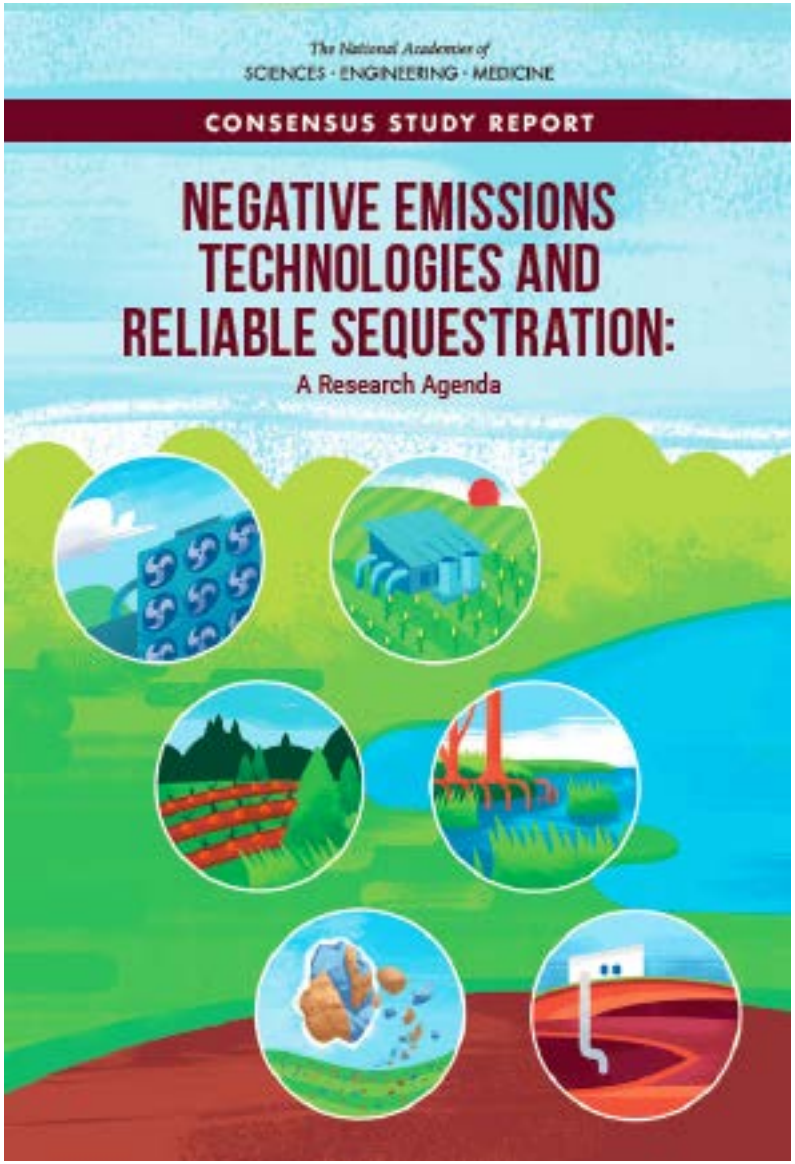
In millions of metric tons CO_2e, excludes international bunker fuel use, 2005-2019



SOURCE: Rhodium Climate Service

InsideClimate News

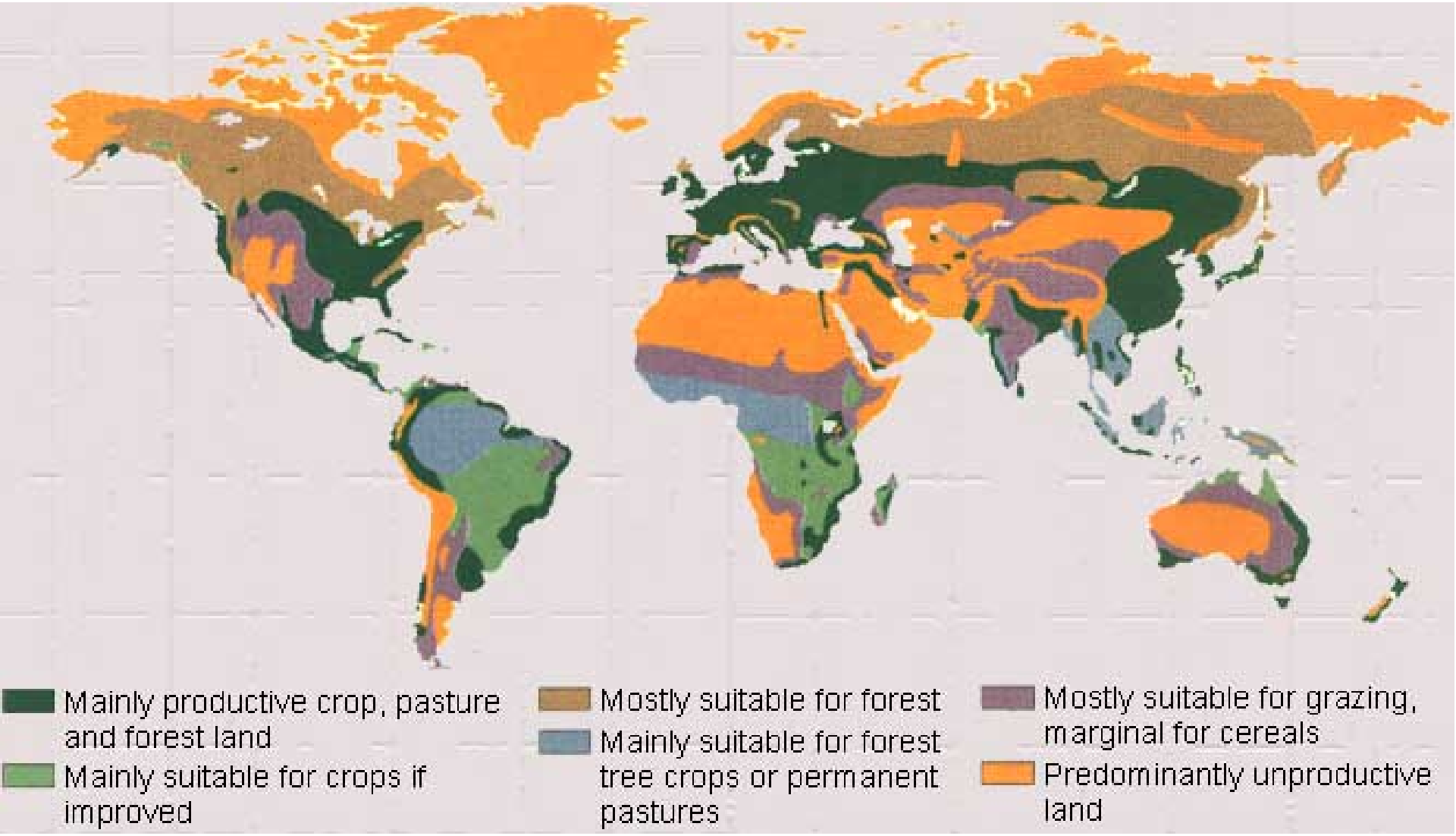
National Academy of Sciences, 2019



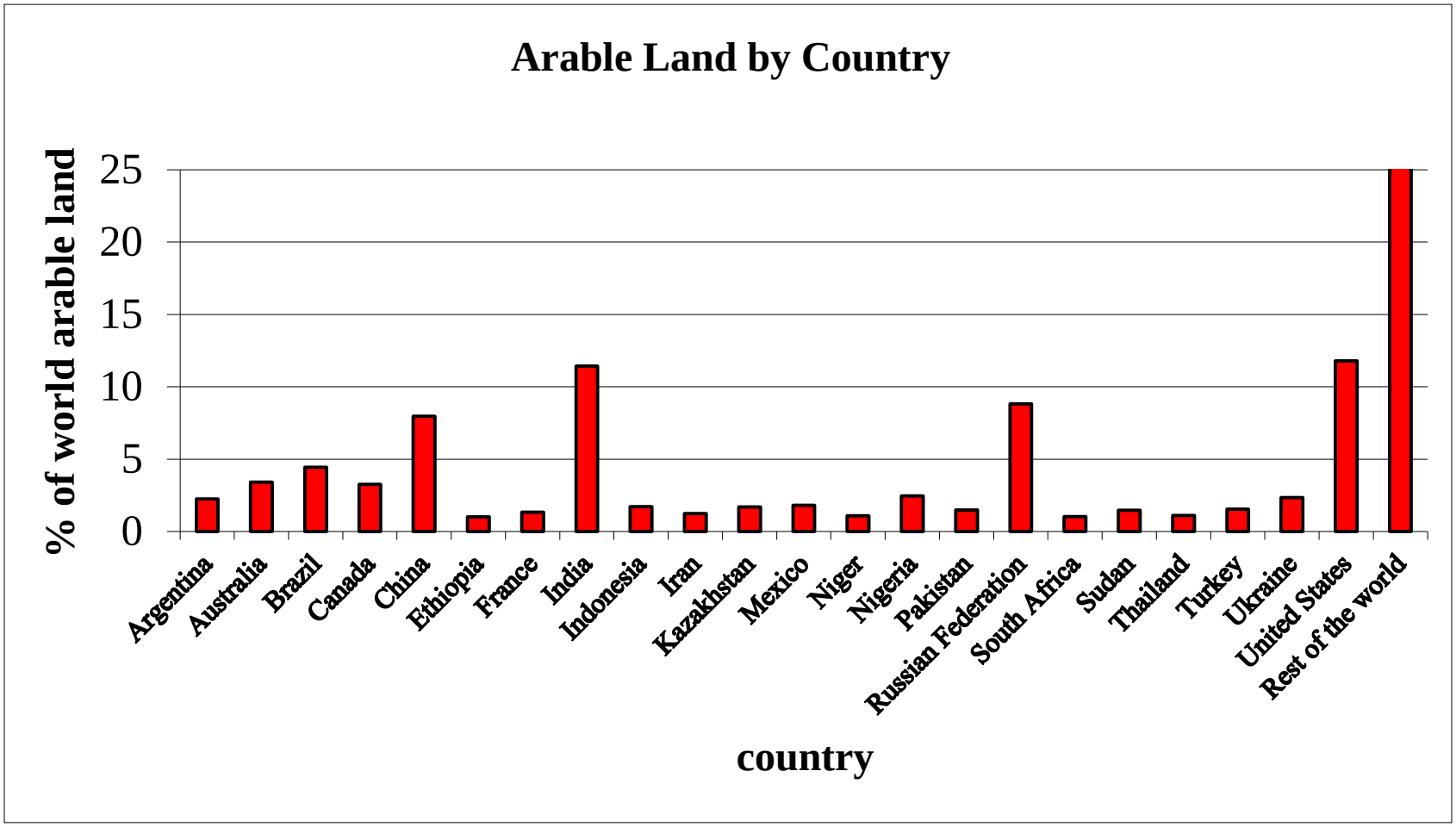
National Academy of Sciences, 2019

- Sequester 150 Mt CO_2 requires 9.9 million acres of new forest
  - Area as large as Maryland
  - Can never be harvested
  - In competition with farming, food production, logging, and other uses
  - Full growth in approximately 40 years
- U.S. emission 5.8 Gt CO_2 requires 370 million acres
  - Twice the area of Texas
- NAS estimates 250 Mt CO_2 “practically achievable”

Arable and Forest Land of the World

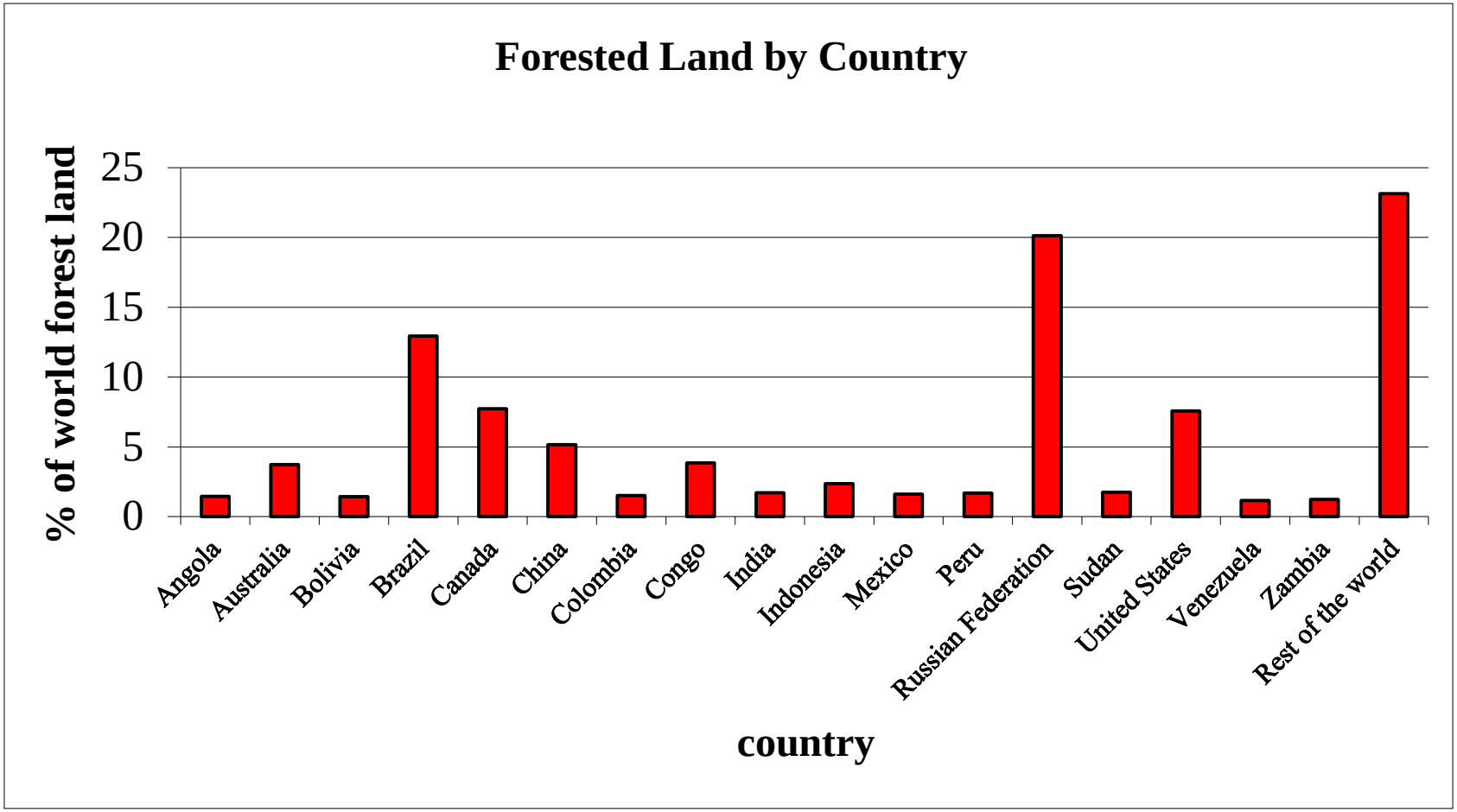


Arable Land by Country



from World Bank http://data.worldbank.org/

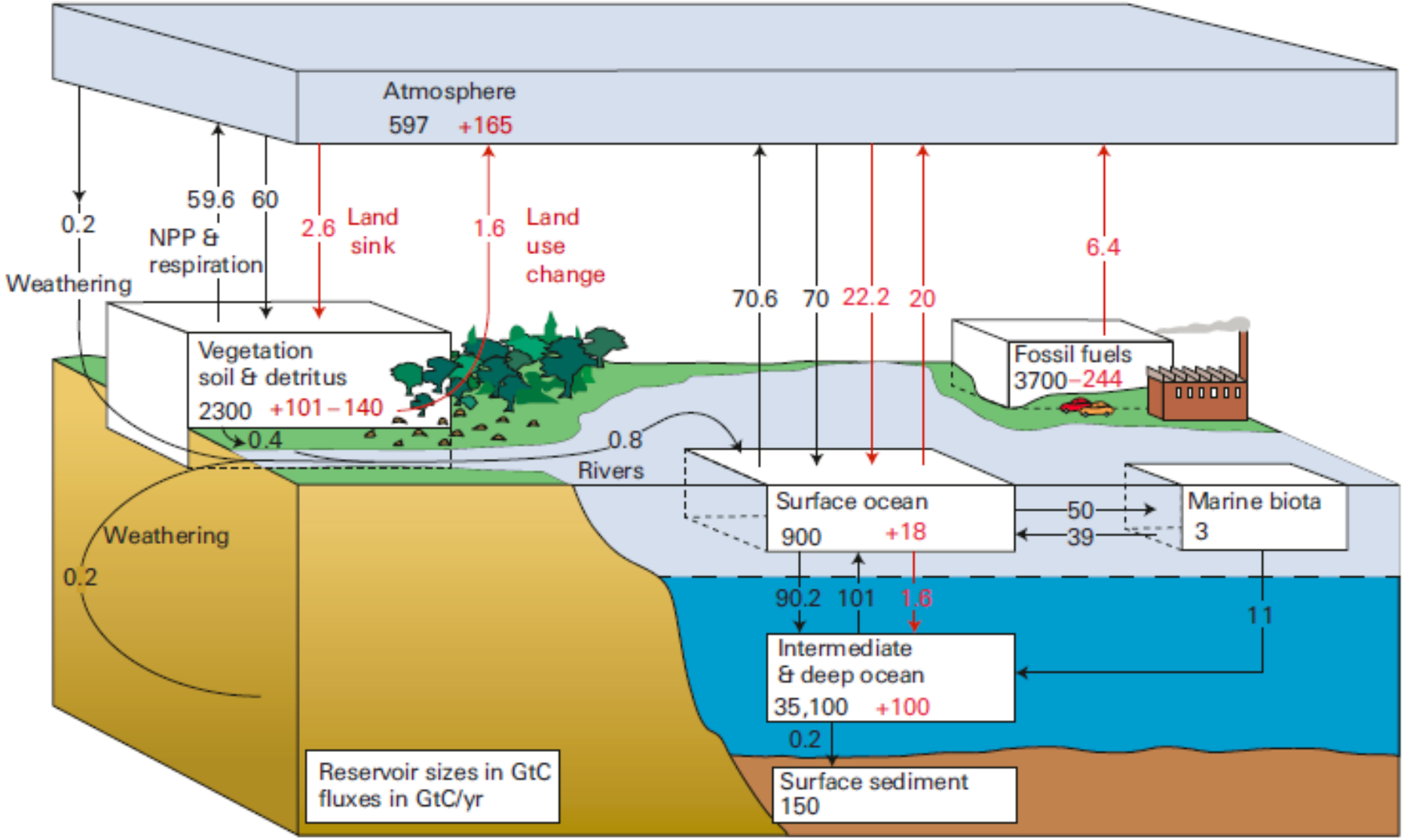
Forested Land by Country



from World Bank http://data.worldbank.org/

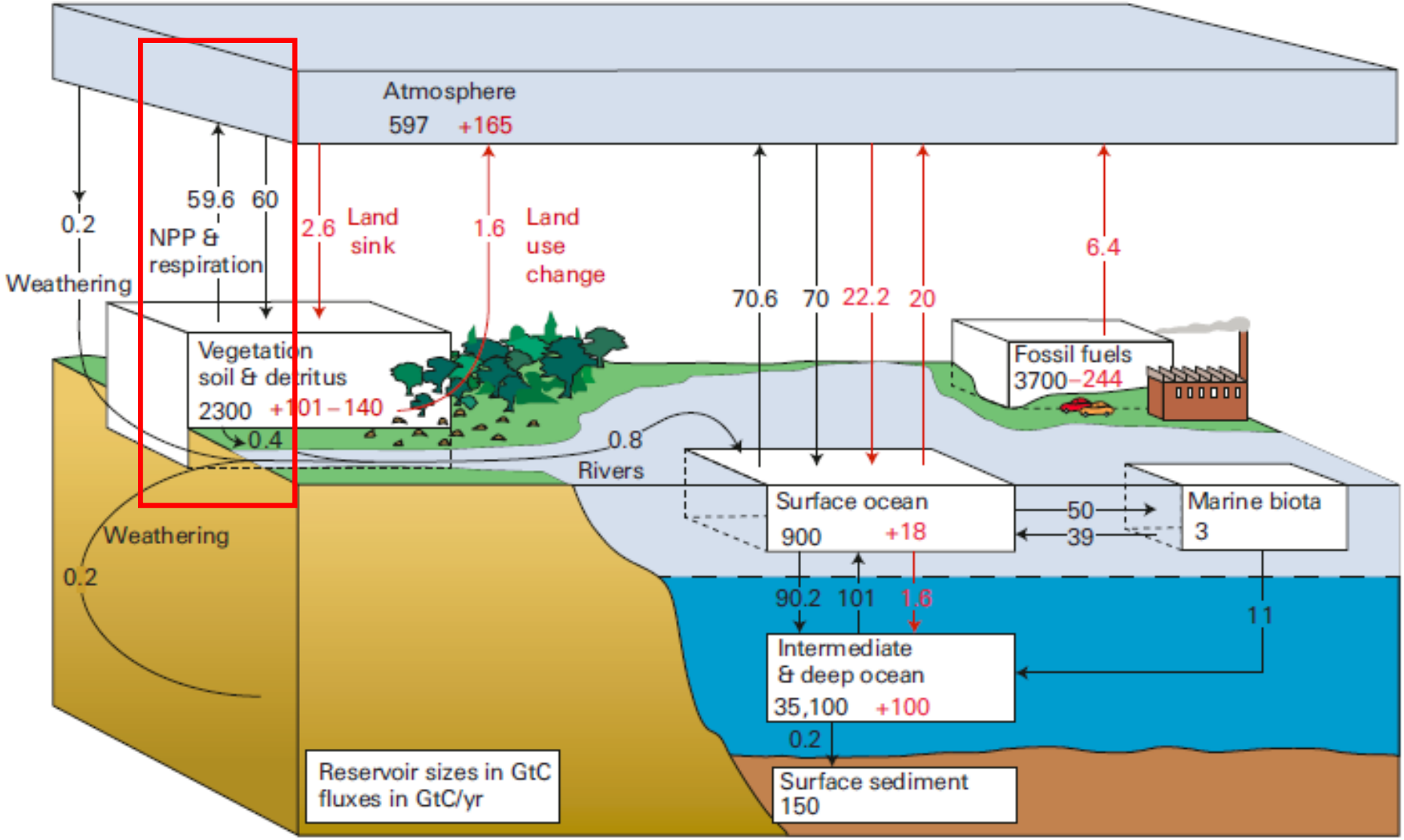
Carbon Cycle and Keeling Curve

Global Carbon Cycle



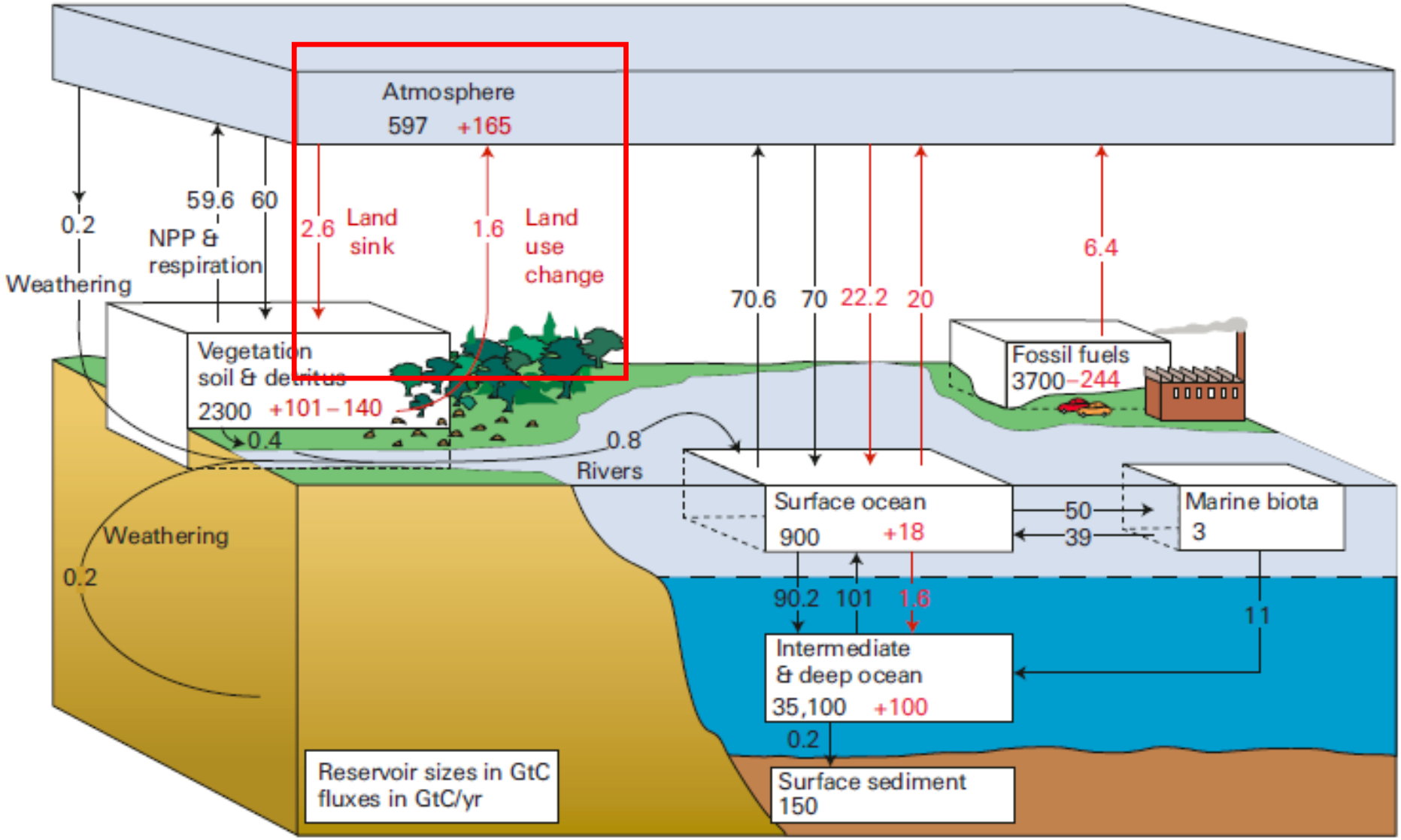
Black numbers pre-industrial steady state. Red numbers additions due to human activity.

Global Carbon Cycle Modification
Biomass Energy Carbon Capture Storage



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

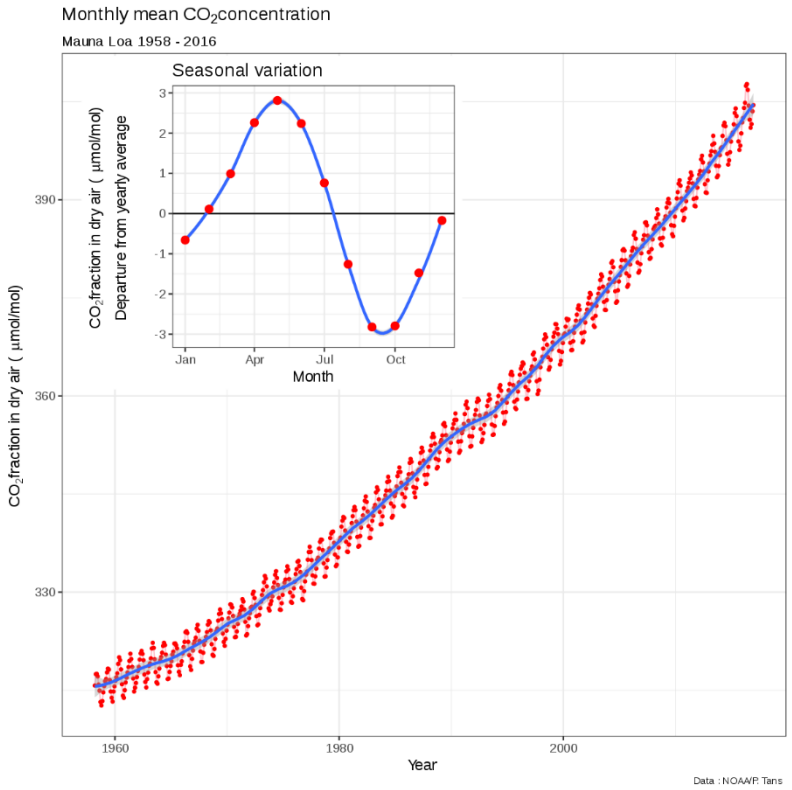
Global Carbon Cycle Modification
Afforestation/Reforestation

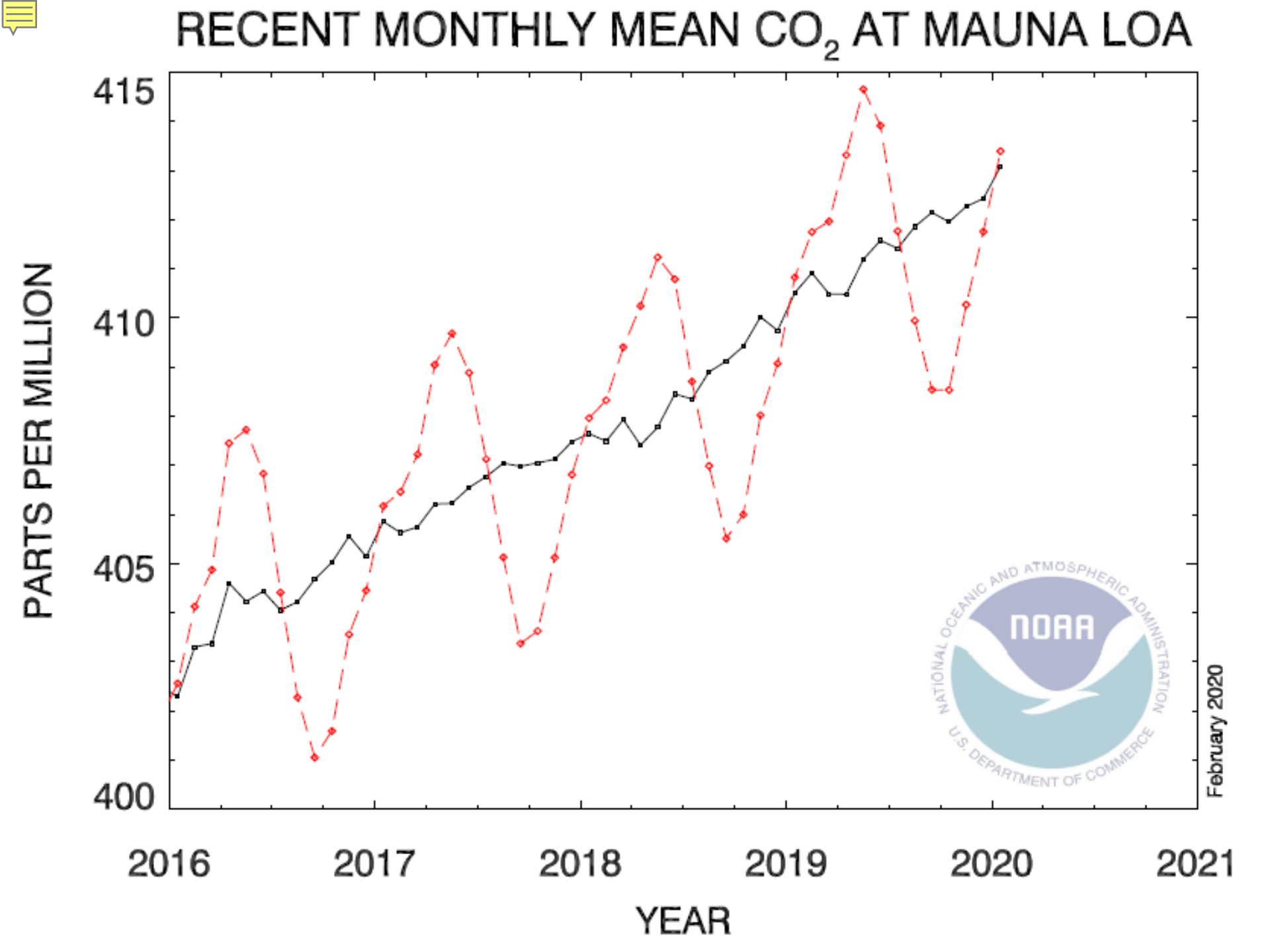


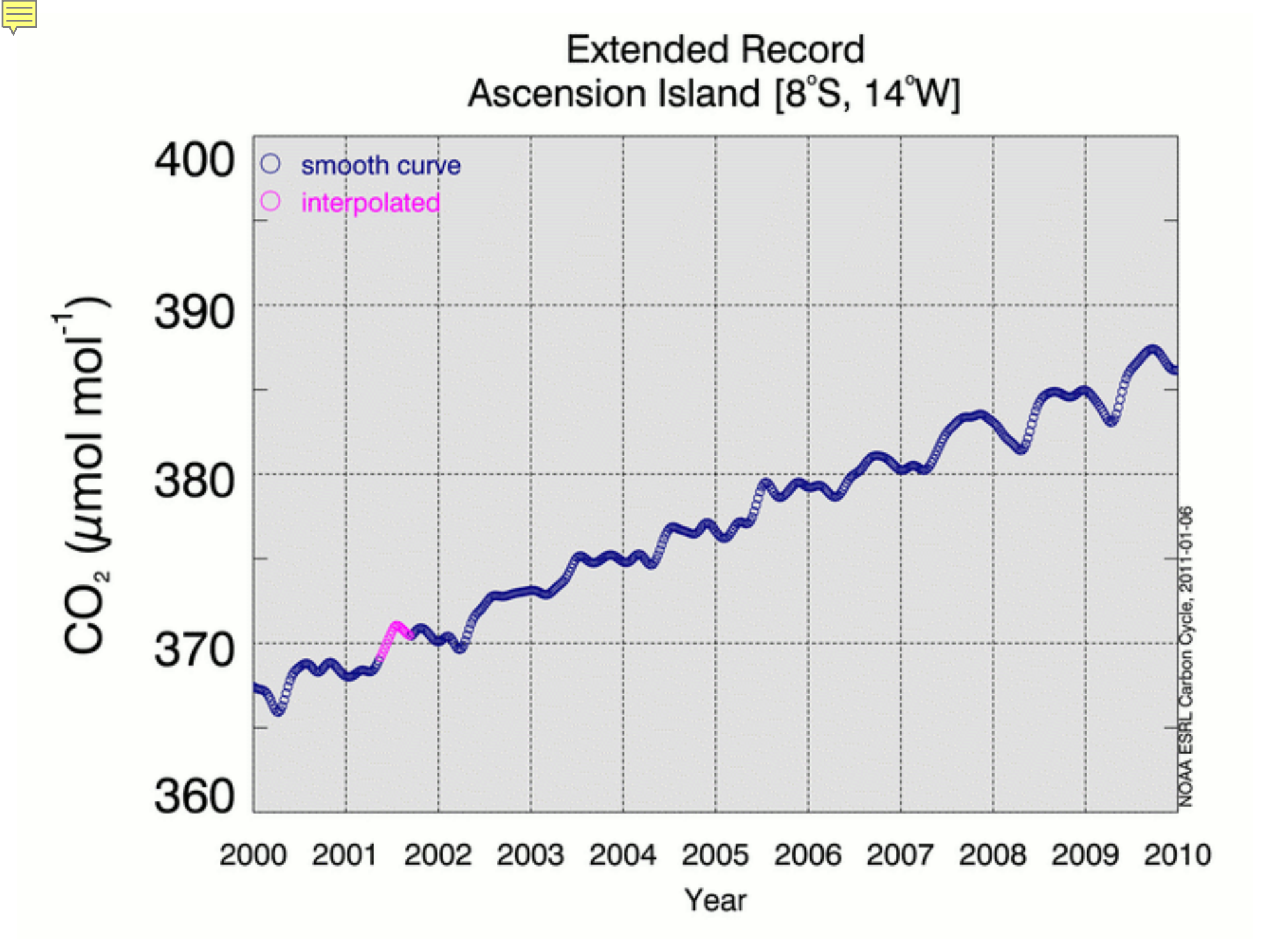
Black numbers pre-industrial steady state. Red numbers additions due to human activity.

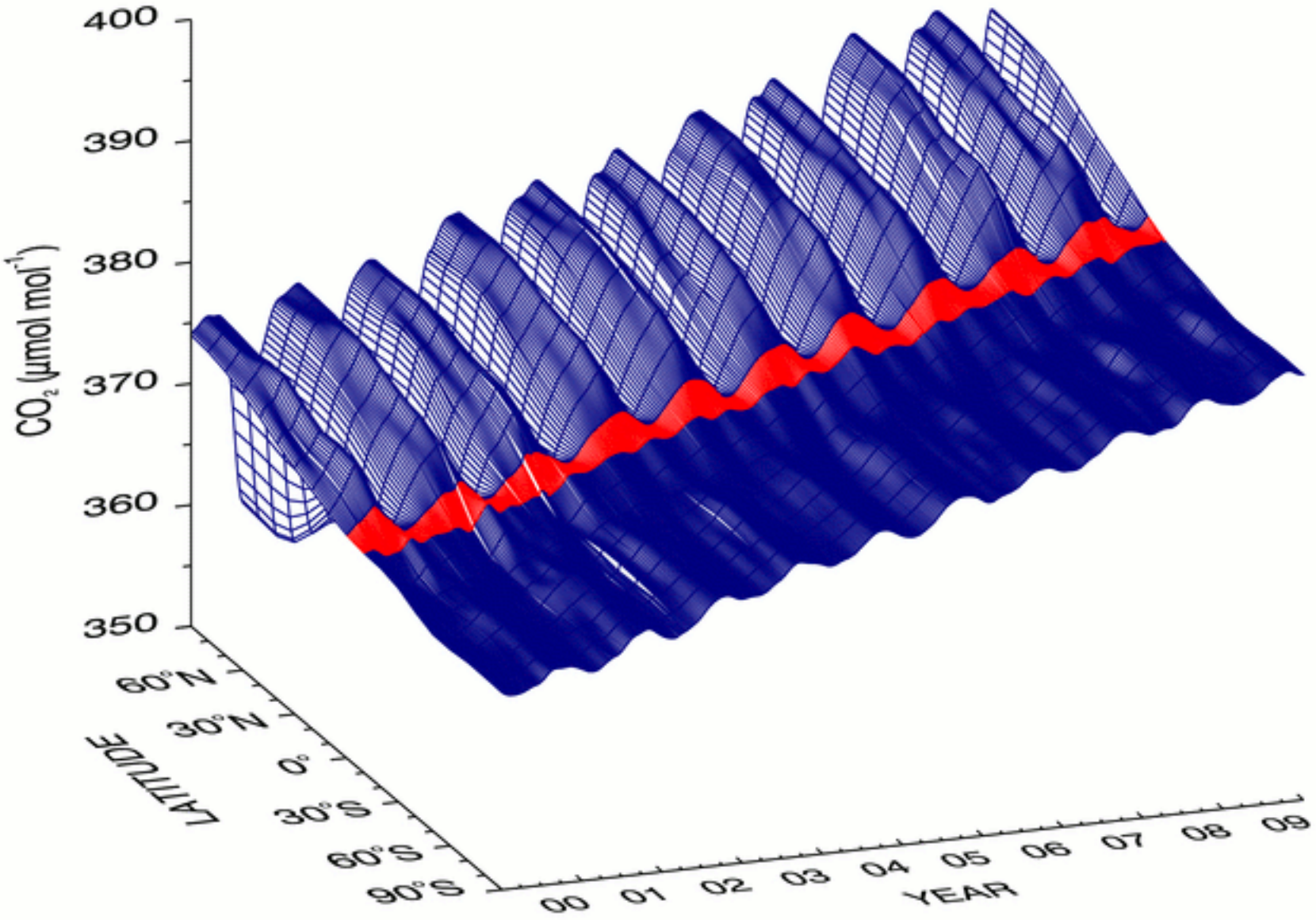
The annual variation shown in the insert is attributed to plant growth and decay.

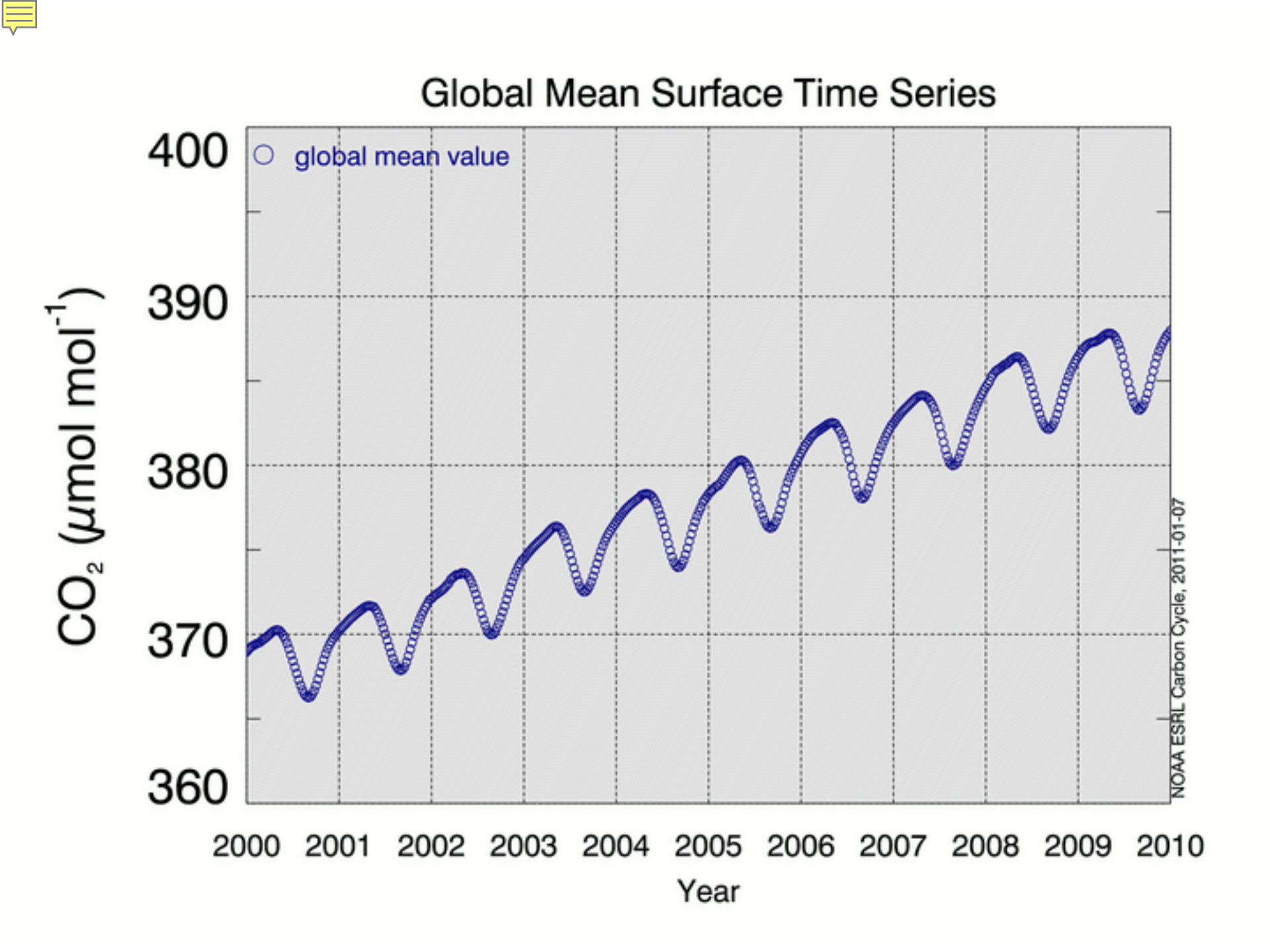
How many gigatonnes of CO_2 do plants absorb and release in one year?




RECENT MONTHLY MEAN CO_2 AT MAUNA LOA
PARTS PER MILLION
415
410
405
400
2016
2017
2018
2019
2020
2021
YEAR
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
February 2020

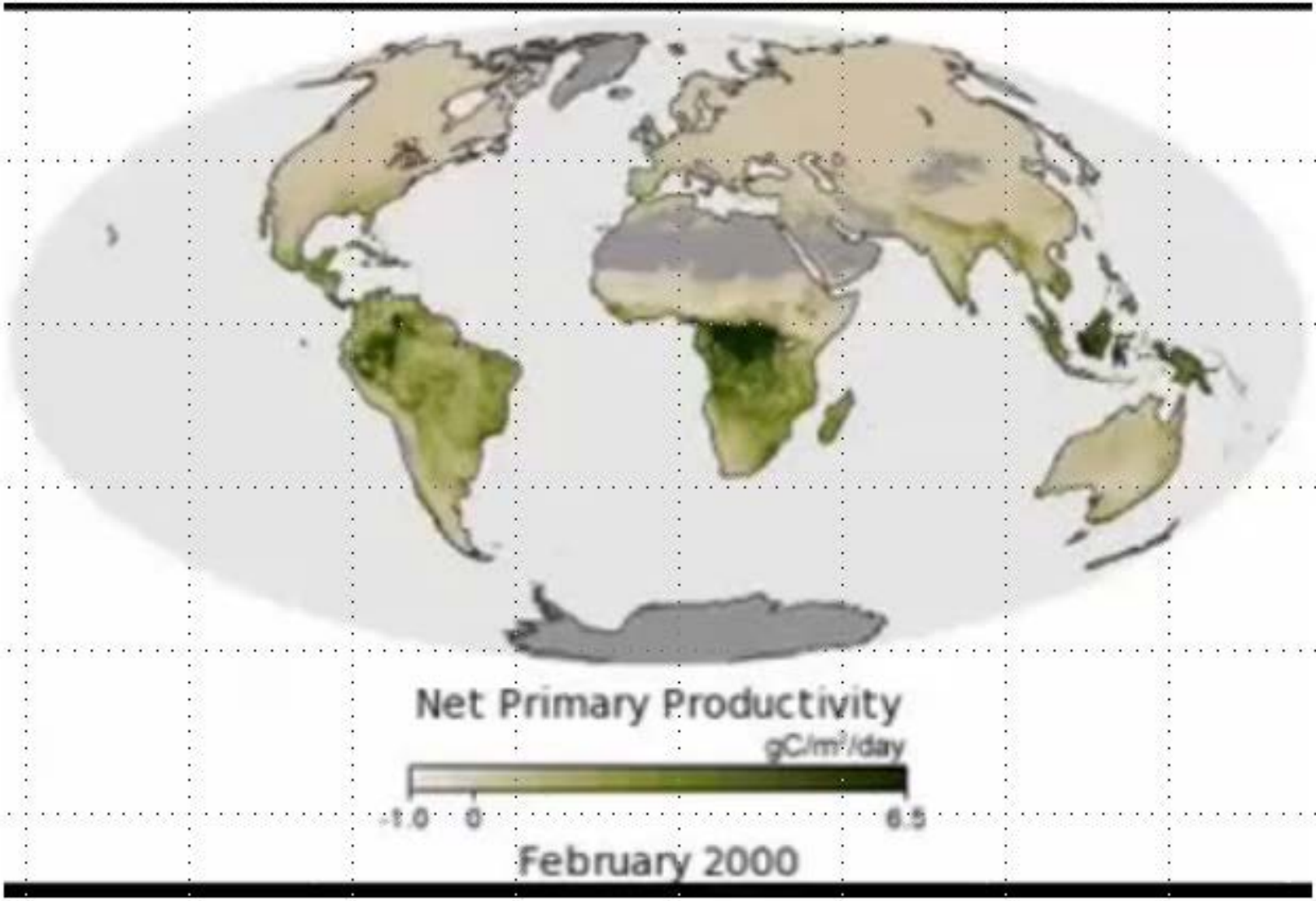

Extended Record
Ascension Island [8°S, 14°W]
smooth curve
interpolated
400
390
380
370
360
CO2 (μmol mol-1)
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year
NOAA ESRL Carbon Cycle, 2011-01-06


400
390
380
370
360
350
CO_2 (μmol mol^{-1})
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
00
01
02
03
04
05
06
07
08
09
YEAR


Global Mean Surface Time Series
global mean value
400
390
380
370
360
CO_2 (μmol mol^{-1})
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year
NOAA ESRL Carbon Cycle, 2011-01-07

How many gigatonnes of CO_2 do plants absorb and release in one year?

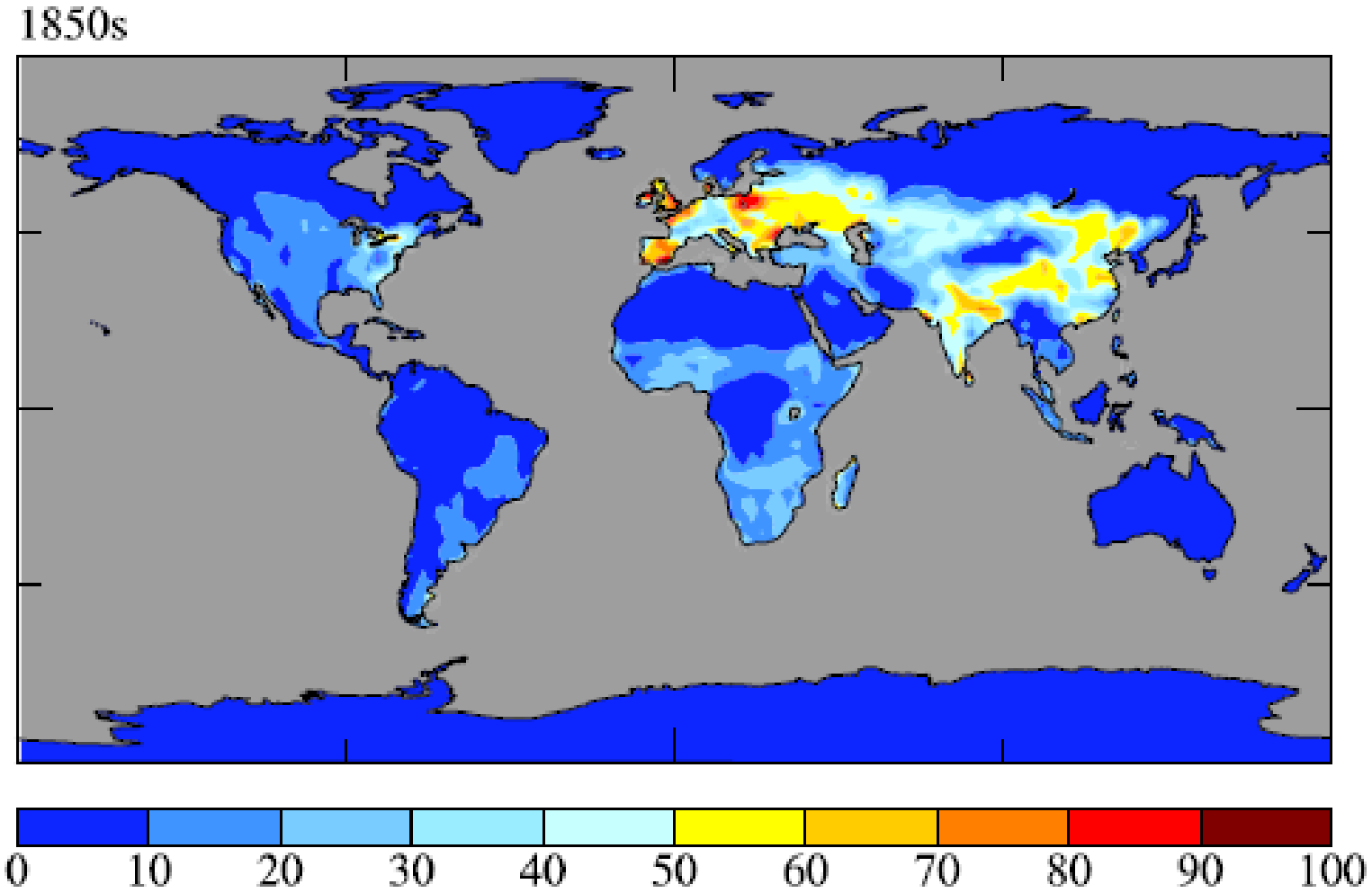
- Peak to peak variation in global average CO_2 concentration is approximately 4 ppm
- Currently CO_2 at about 400 ppm = 3,125 Gt CO_2
- 4 ppm then is 31.2 Gt CO_2
- Slope is approximately 2.3 ppm per year, but 25% of emissions are absorbed by the ocean, 28% by plants, and 46% stays in the atmosphere.


Net Primary Productivity
gC/m²/day
-1.0
0
6.5
February 2000

Land Use Change

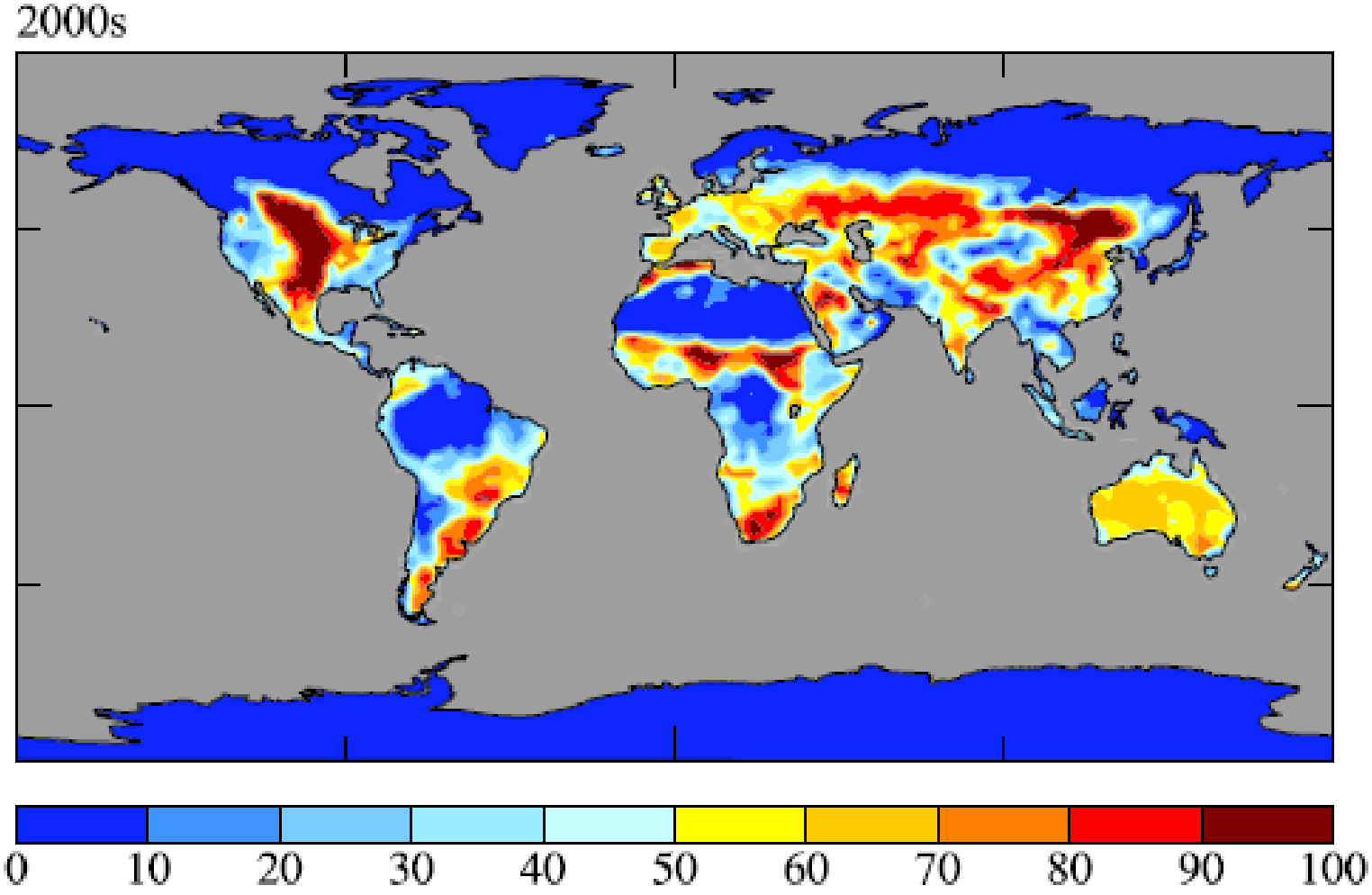
Land Cover Maps
and Land Cover Change Map

Land Cover 1850



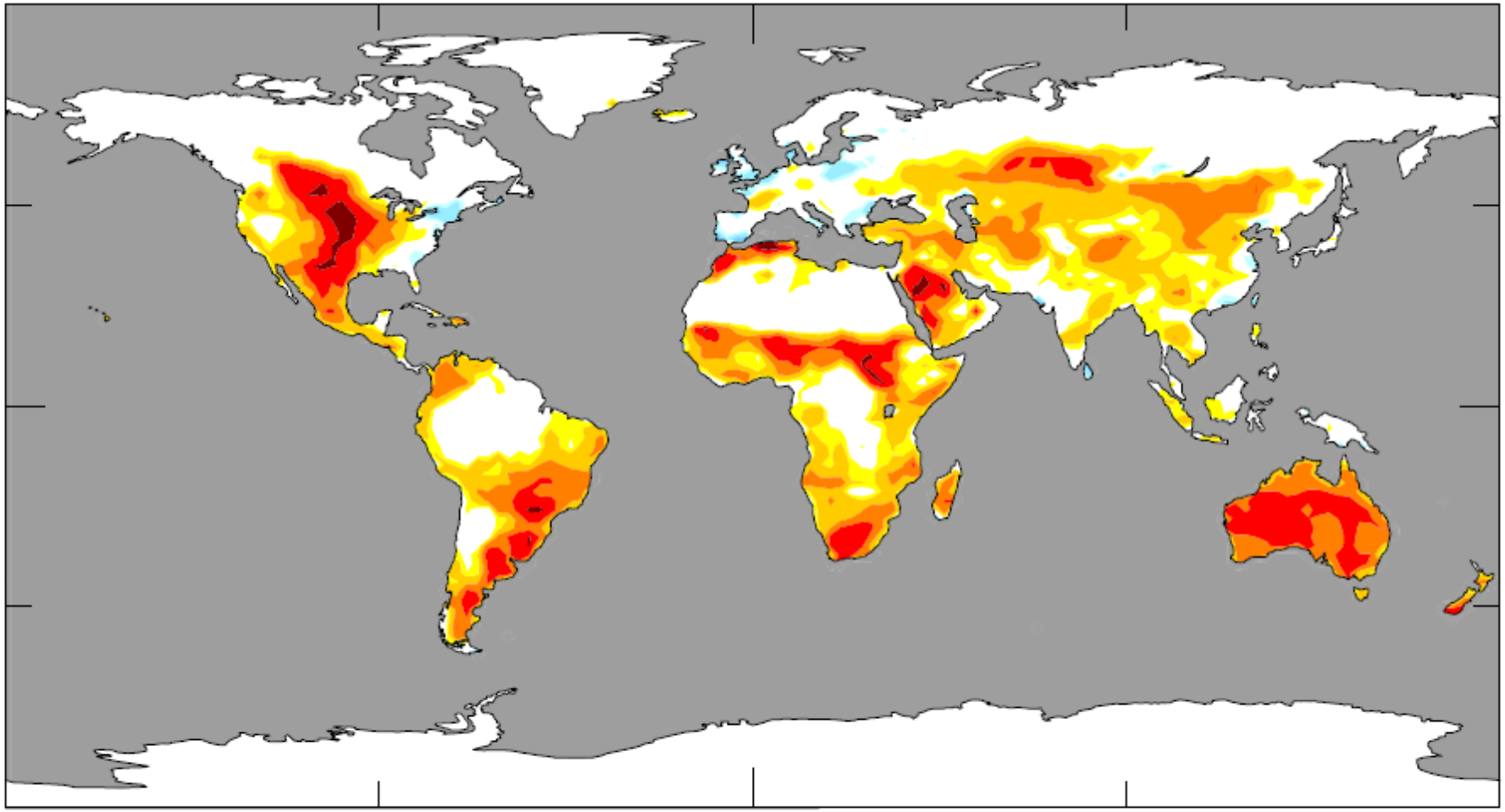
Fraction of vegetation that is cropland

Land Cover 2000



Fraction of vegetation that is cropland

Crop Cover Fraction Change (%) of Vegetated Land Area between 1850 and 2000

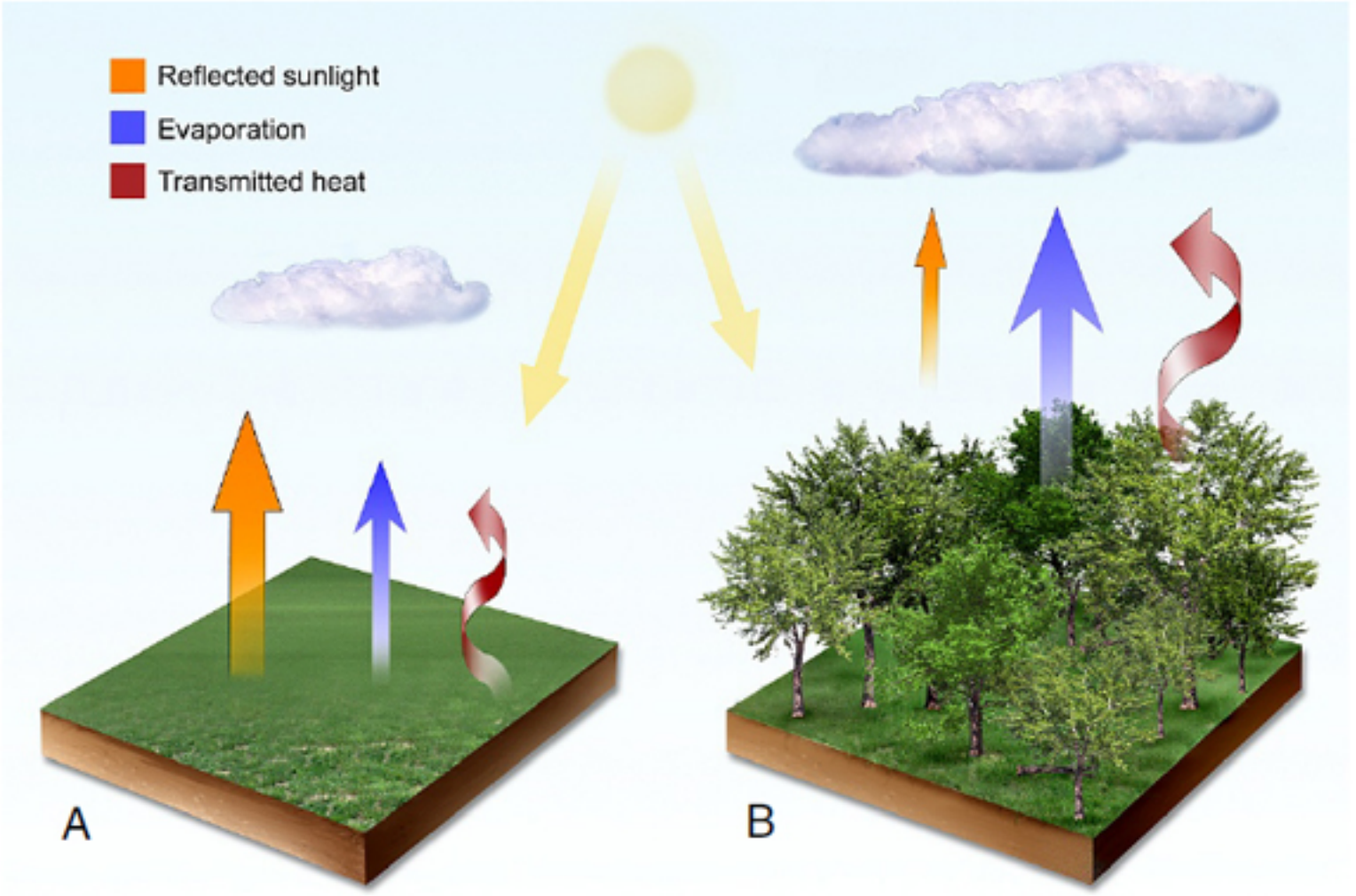


-100 -80 -60 -40 -20 -10 10 20 40 60 80 100

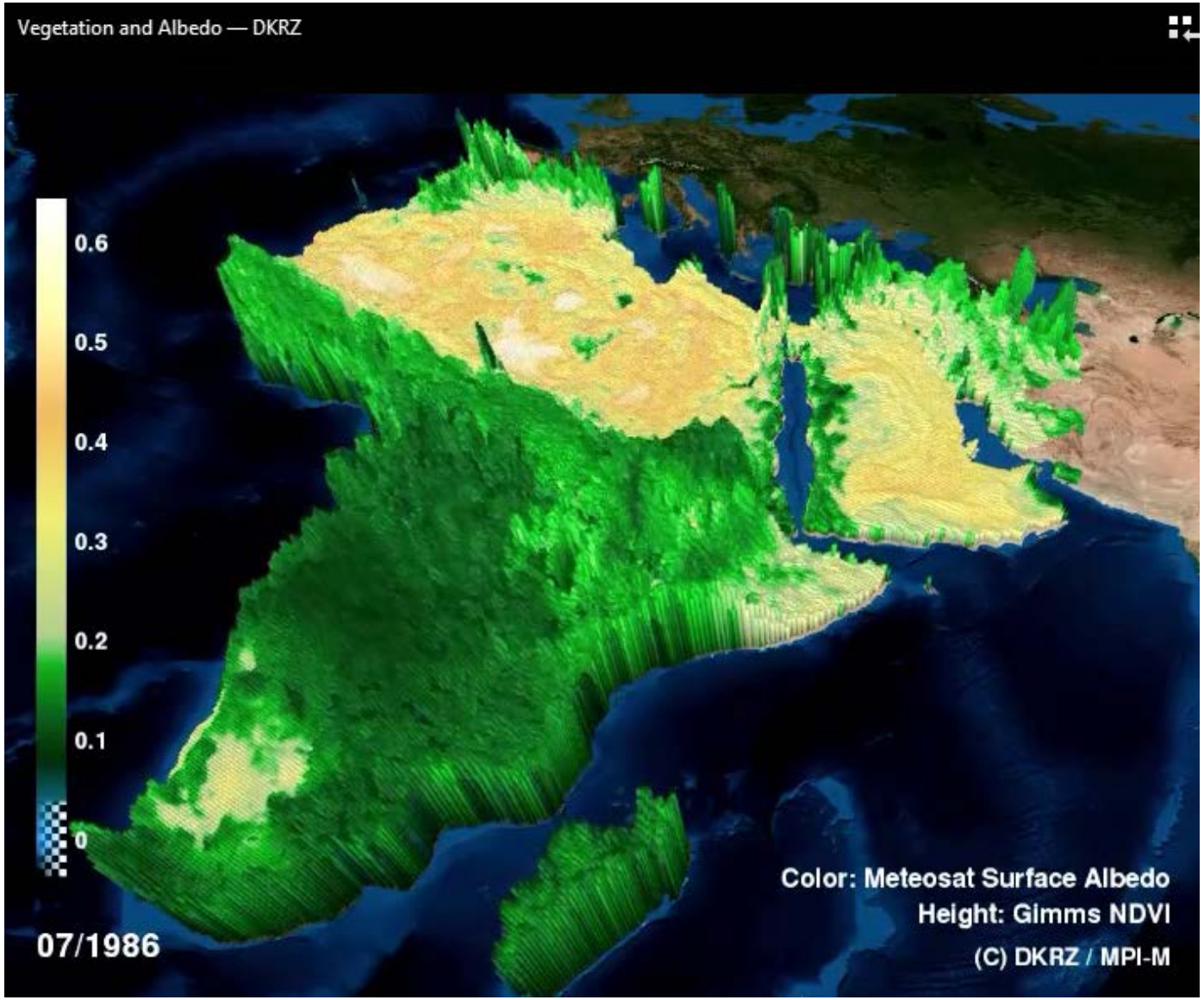
Radiative Forcing Due to Land Cover Change

- Albedo of forest is lower than cropland.
- Between 1850 and 2000 forest cover reduced, cropland increased, so albedo increased resulting in negative forcing (cooling).
- Forest sequesters more carbon than cropland.
- Between 1850 and 2000 forest cover reduced, cropland increased, so less carbon sequestered.
- Carbon goes into atmosphere, resulting in positive forcing (warming).

Land Use Change Energy Balance Effects

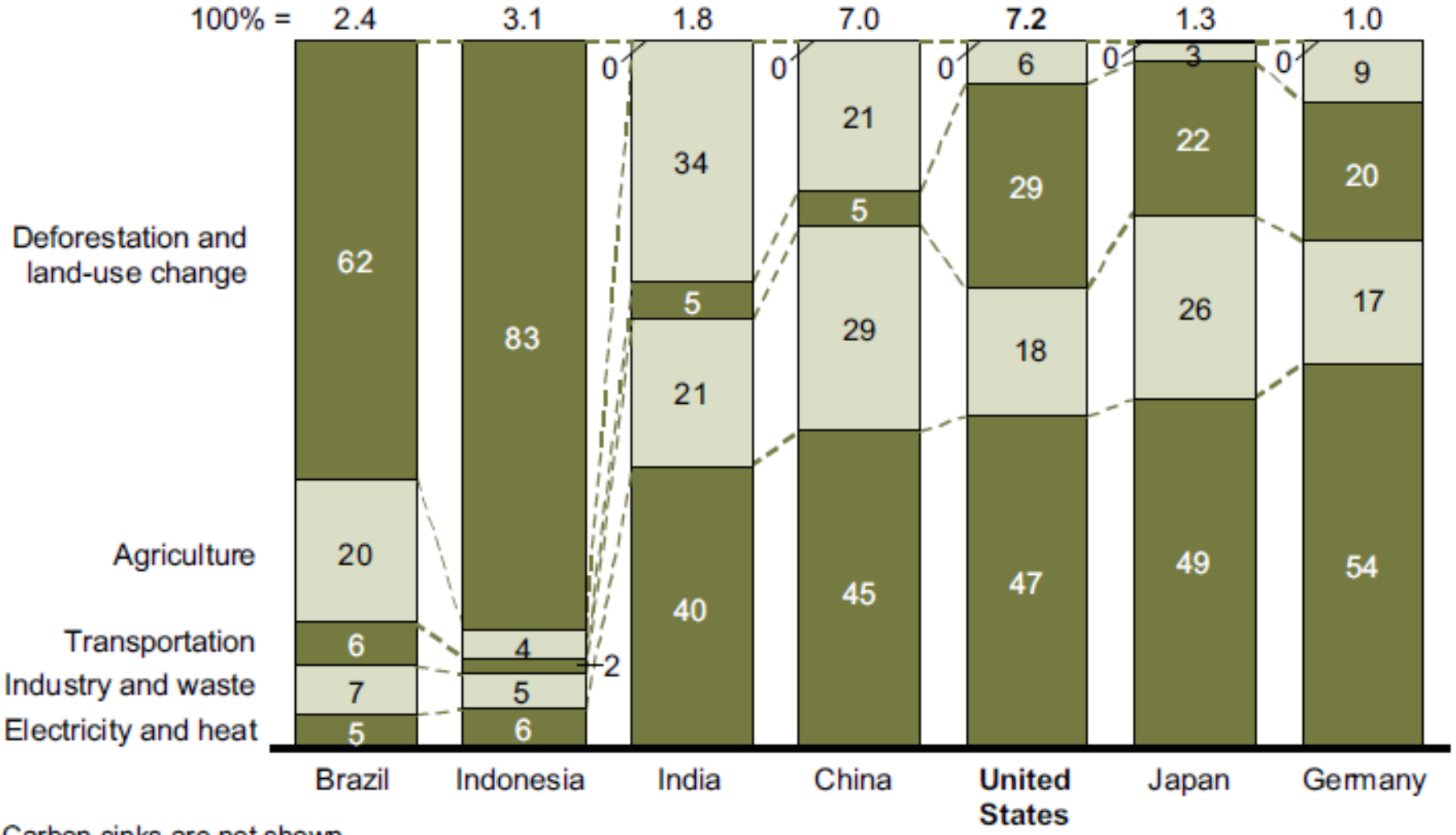


Vegetation and Albedo



Removal of CO_2 from Atmosphere
Afforestation and Reforestation

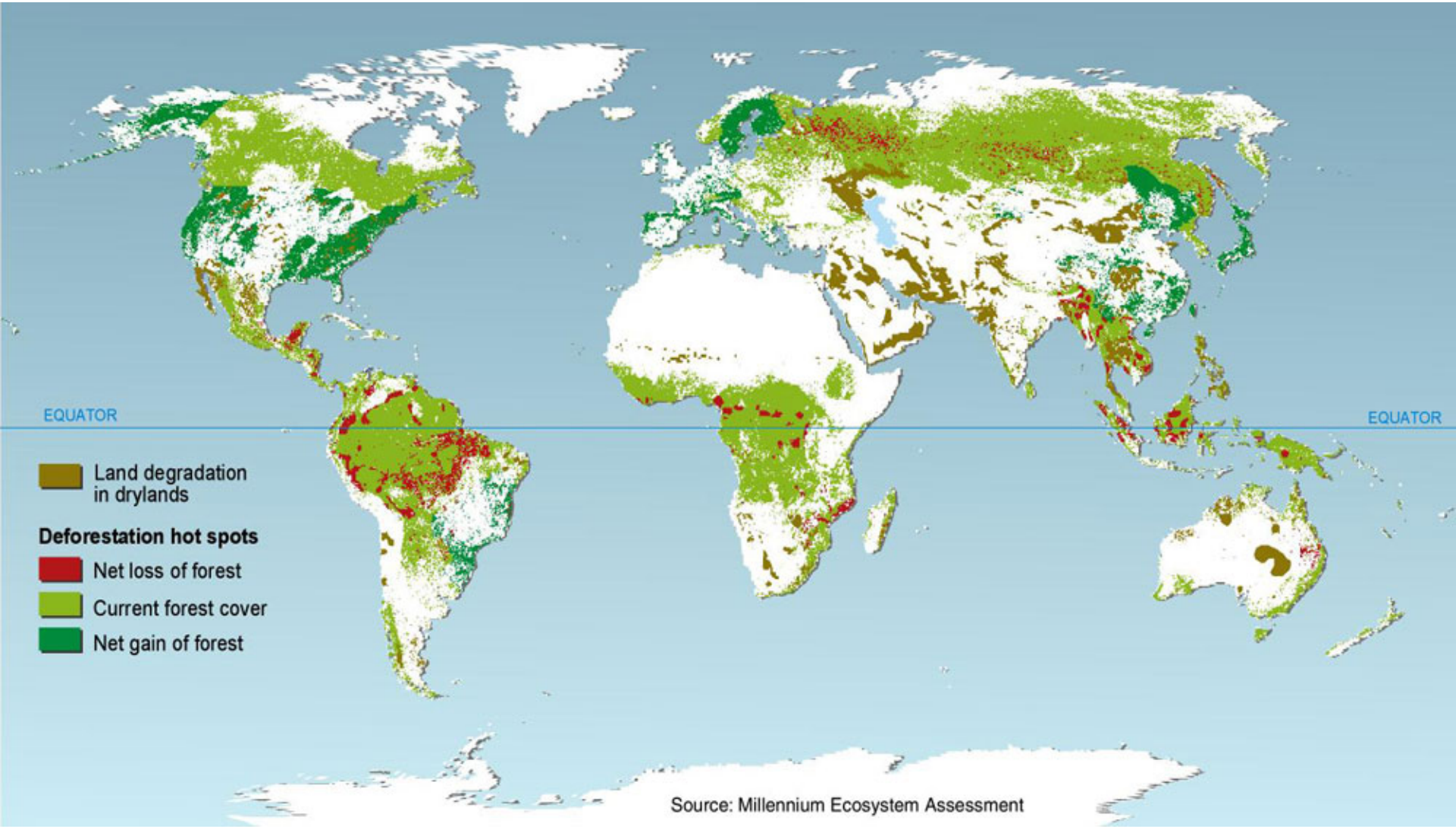
GHG Emissions Profiles for Selected Countries (2005)



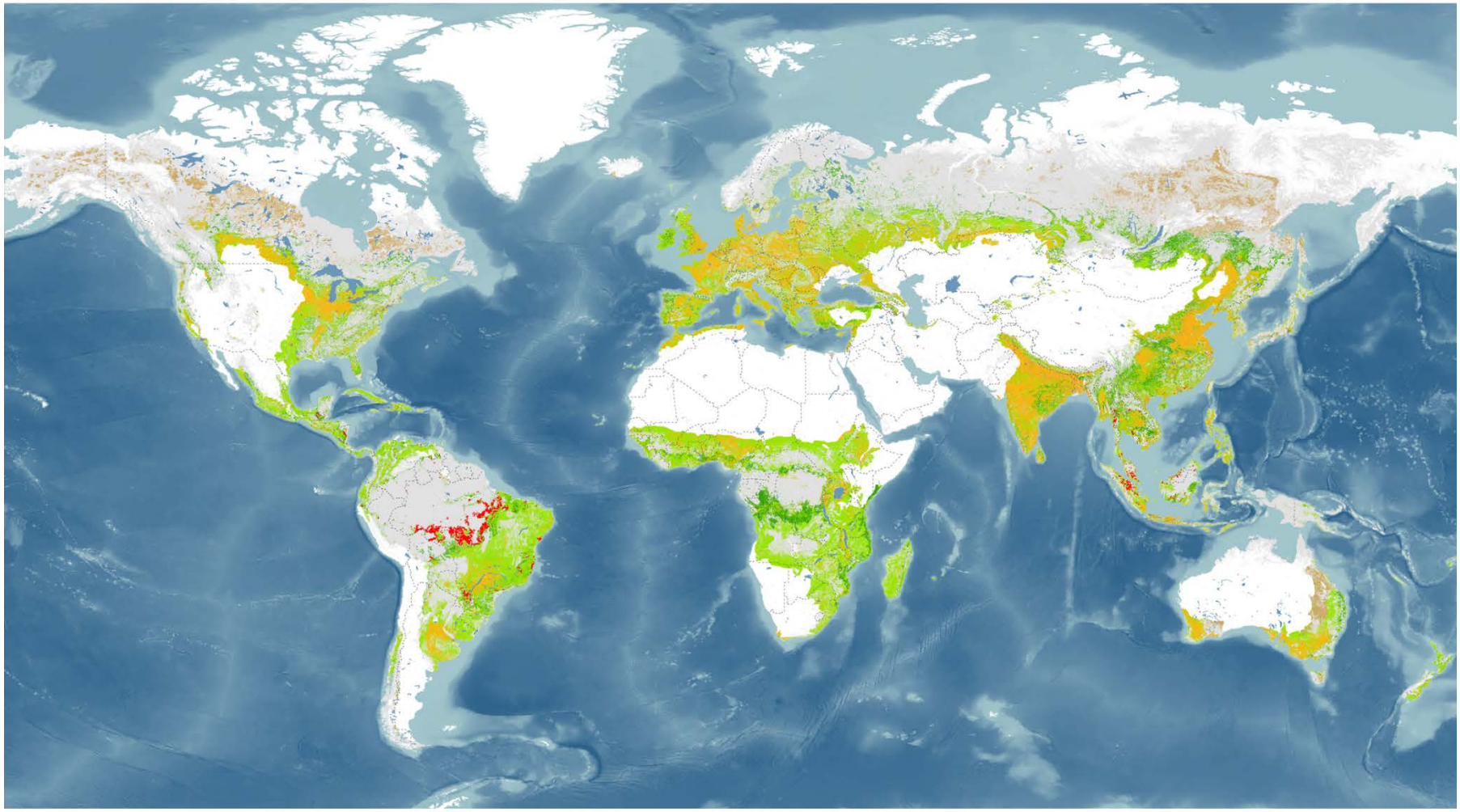
* Carbon sinks are not shown

Source: UNFCCC, WRI, IEA, EPA, McKinsey analysis

Global Deforestation Map (2012)



Reforestation Area Opportunities



The New York Times

When Being Green Raises the Heat

KEN CALDEIRA

January 16, 2007

It has been suggested that agreements to limit climate change should consider carbon stored in forests. If so, they would need to consider the direct climate effects of forests so as to avoid perverse incentives to plant warming forests in places like the United States, Canada, Europe and the former Soviet Union. However, tropical forests, which are generally found in developing countries, may be due a double climate credit — one for their carbon storage and another for their cooling clouds.

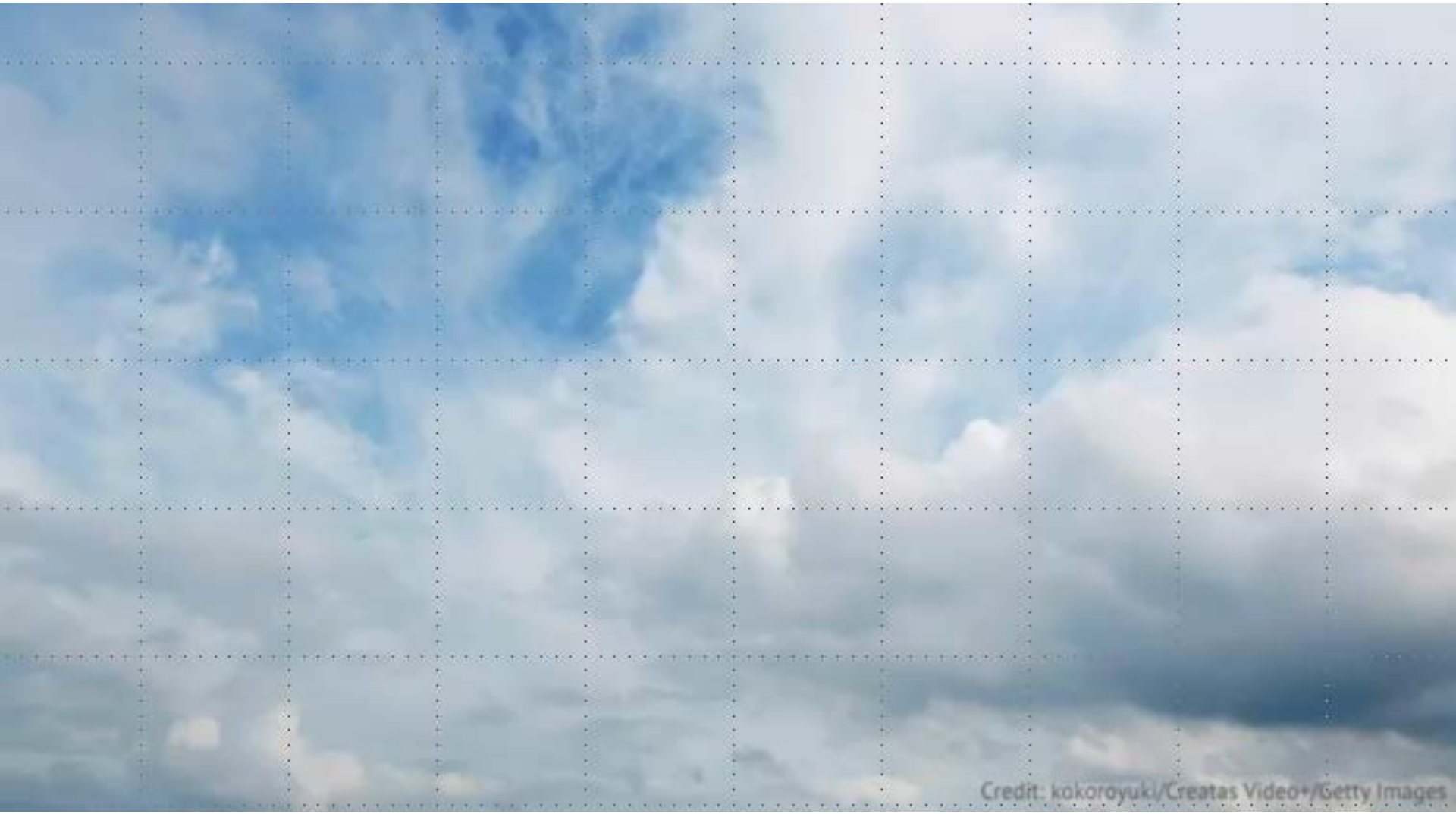
Potential Reforestation Carbon Storage

Scenario	Trees at 10 cm DBH	Area (hectares)	Carbon stocks
High: Maximise tree cover in all areas	589.2 billion	1.58 billion	65-91 Gt

- Current atmospheric carbon burden 762 GtC.
  - Reforestation can remove 8.5 – 11.9%.
- Current global forests 3.09 billion hectares.
  - Reforestation required in 51% of forested areas.
- Current trees at 10 cm DBH estimated at 3,040 billion.
  - Reforestation increases number of trees by 19.4%.
- Current carbon storage in trees 250 – 350 Gt.
  - Reforestation increases carbon storage in forests by 27 ± 7%.
- Reforestation accomplished in 50 to 100 years.

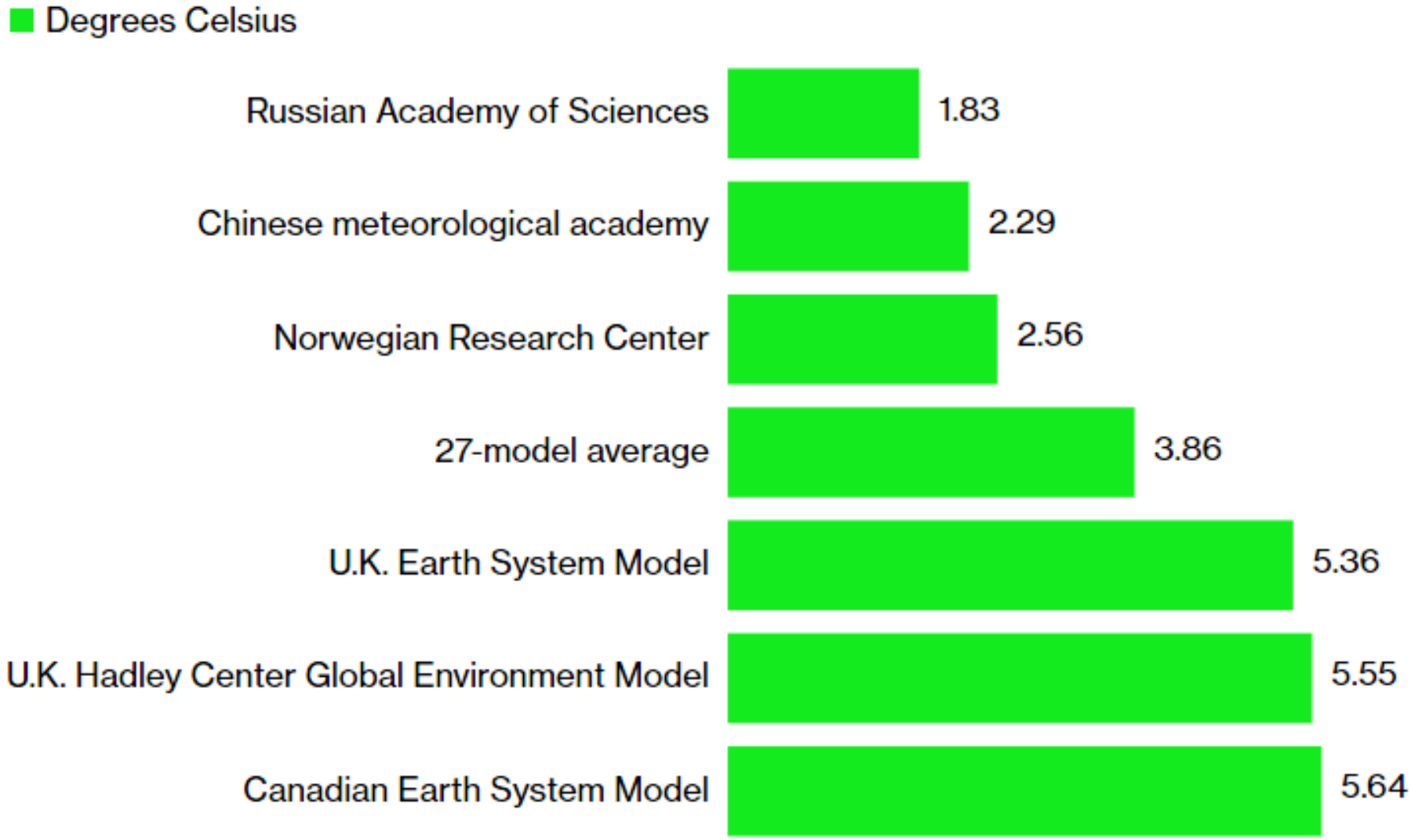
Climate Sensitivity

What is climate sensitivity?



February 3, 2020
Climate Models Are Running Red Hot…

Hot Climate Models



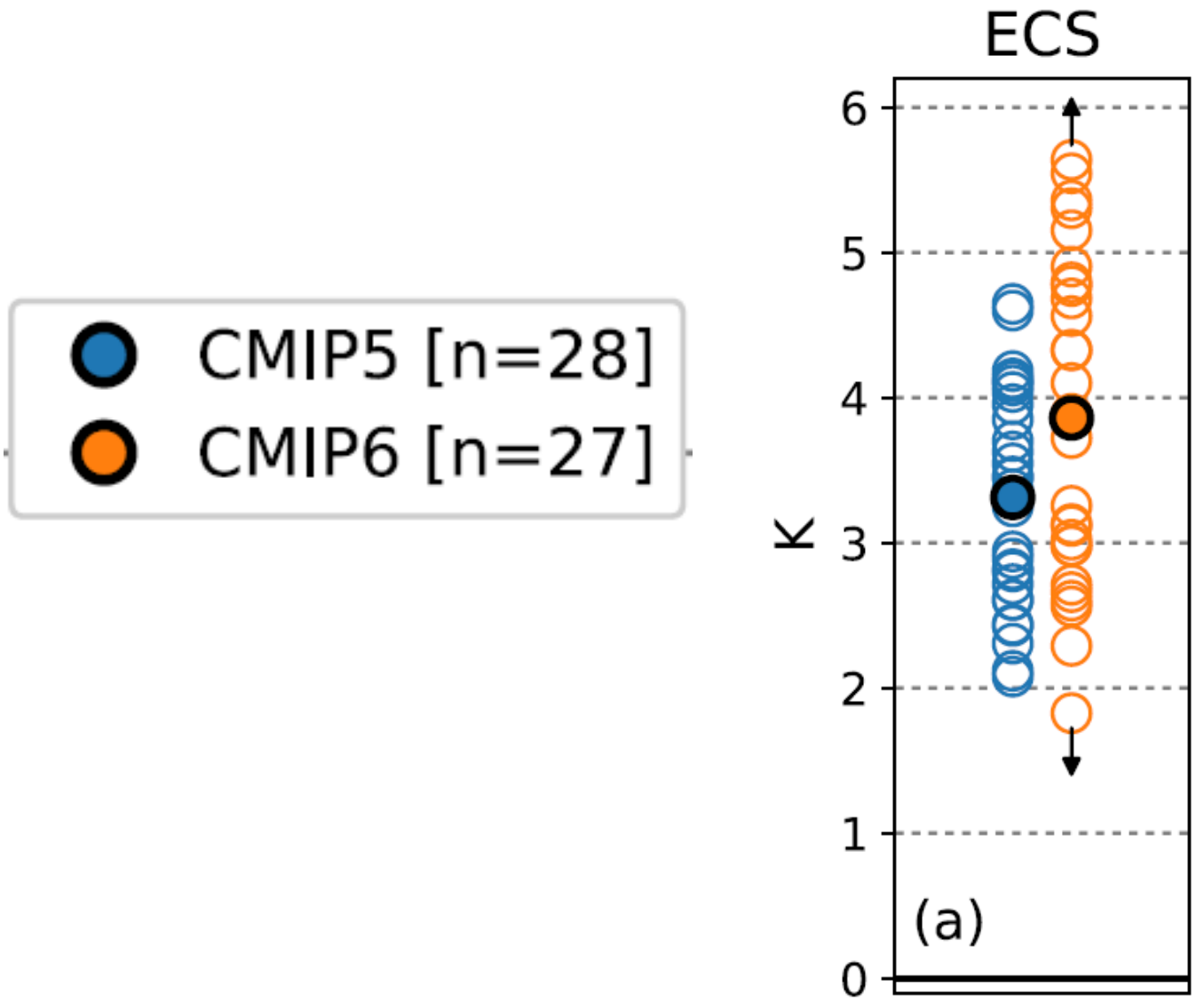
Mark D. Zelinka et al.
Geophysical Research Letters January, 2020

Causes of Higher Climate Sensitivity in CMIP6 Models

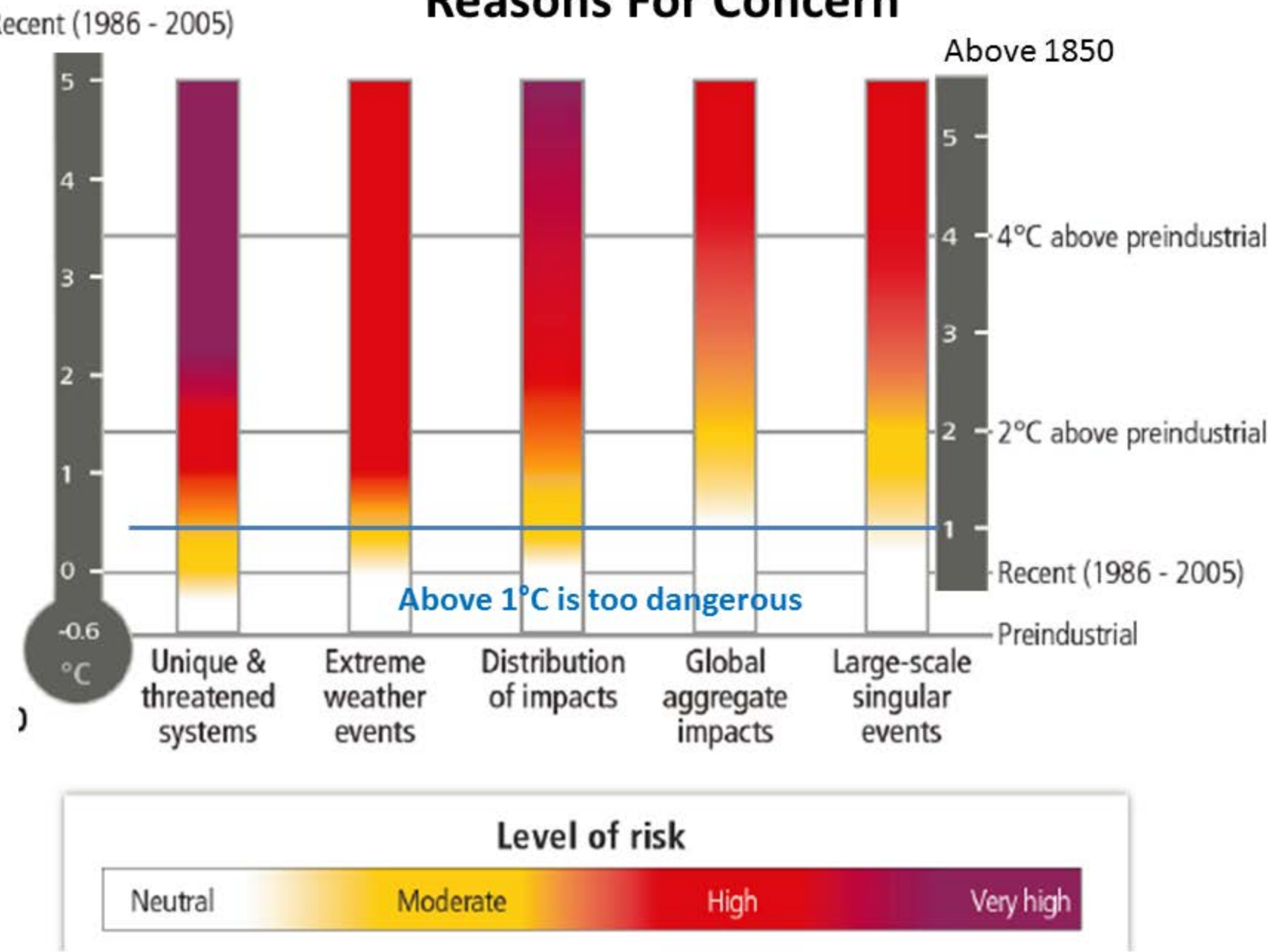
Plain Language Summary

The severity of climate change is closely related to how much the Earth warms in response to greenhouse gas increases. Here we find that the temperature response to… atmospheric carbon dioxide has increased substantially in the latest generation of global climate models. This is primarily because…[of] [d]ifferences in the physical representation of clouds...

Equilibrium Climate Sensitivity
CMIP5 versus CMIP6



Reasons For Concern



Box SPM 4

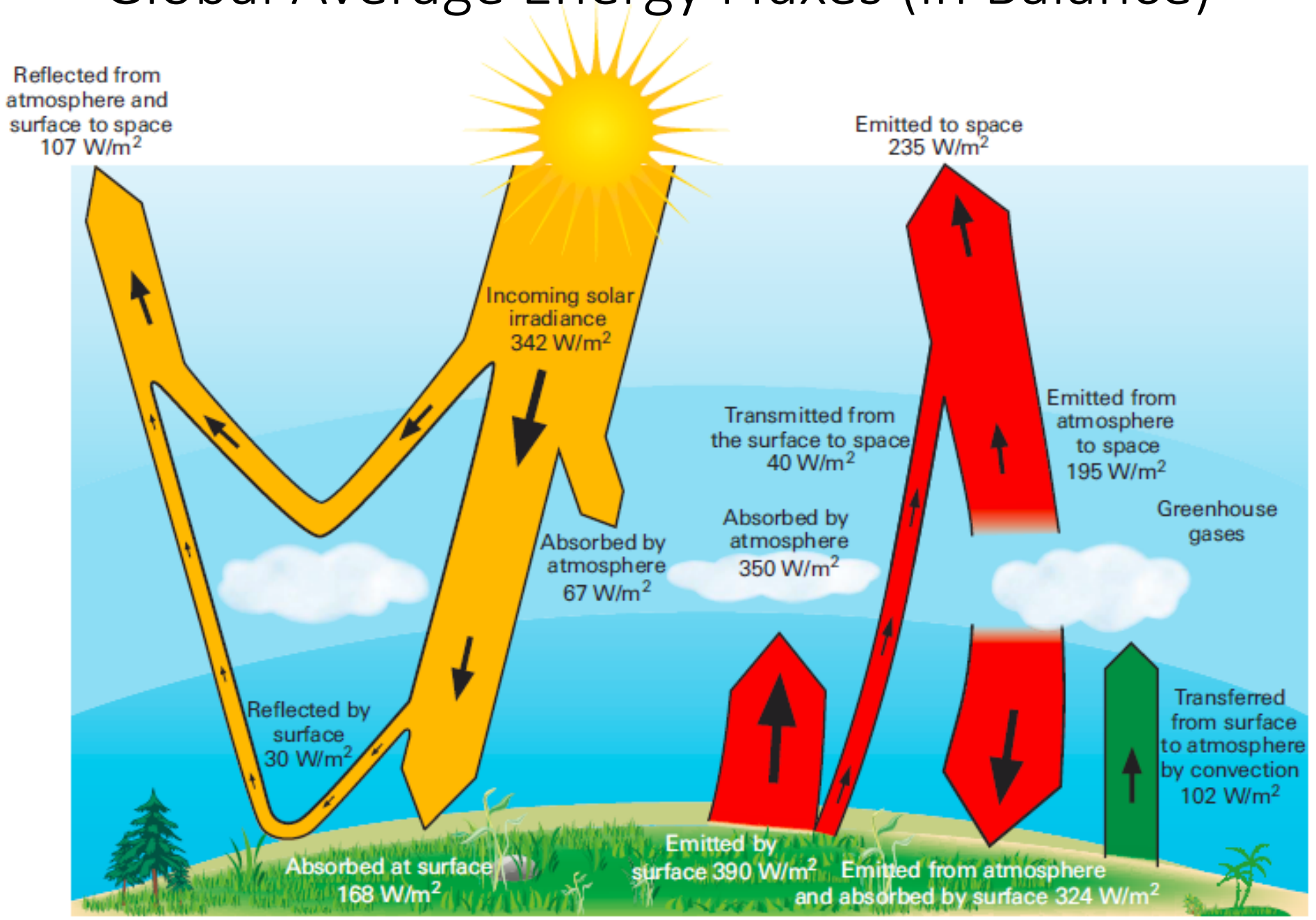
Geoengineering

Geoengineering Outline

- Climate science
- A New Tool to Address Climate Change
- Atmosphere
- SRM and CDR
- SRM examples: shields and marine cloud whitening
- Crutzen proposal aerosol injection
- Natural atmospheric aerosol injection: Mt. Pinatubo
- Artificial atmospheric aerosol injection
- Summary

Climate Science

Global Average Energy Fluxes (in Balance)



A New Tool

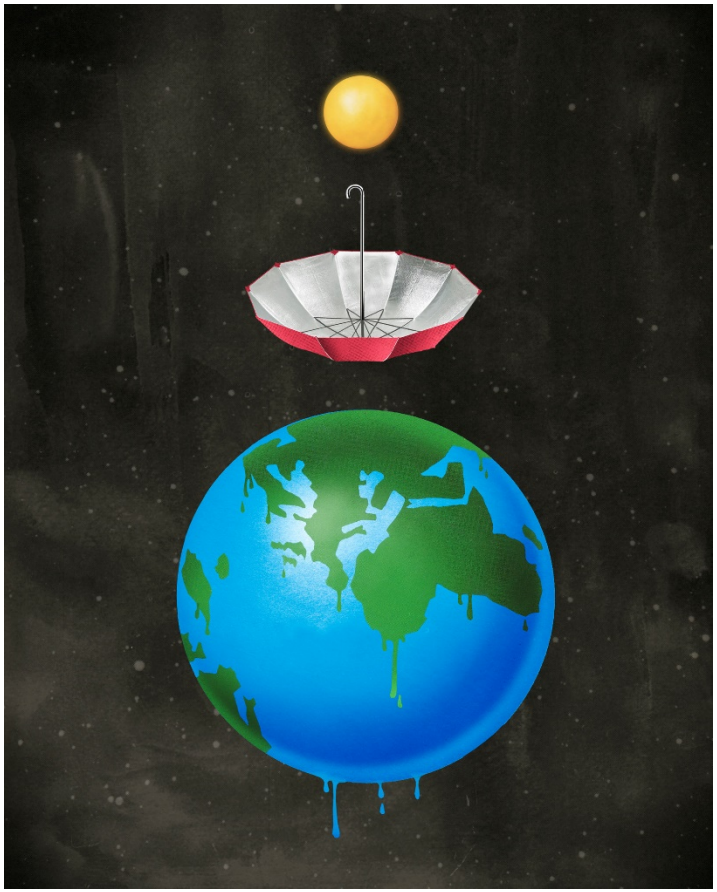
THE NEW YORKER

The Climate Fixers
Is there a technological solution to global warming?

by Michael Specter May 14, 2012

The New York Times

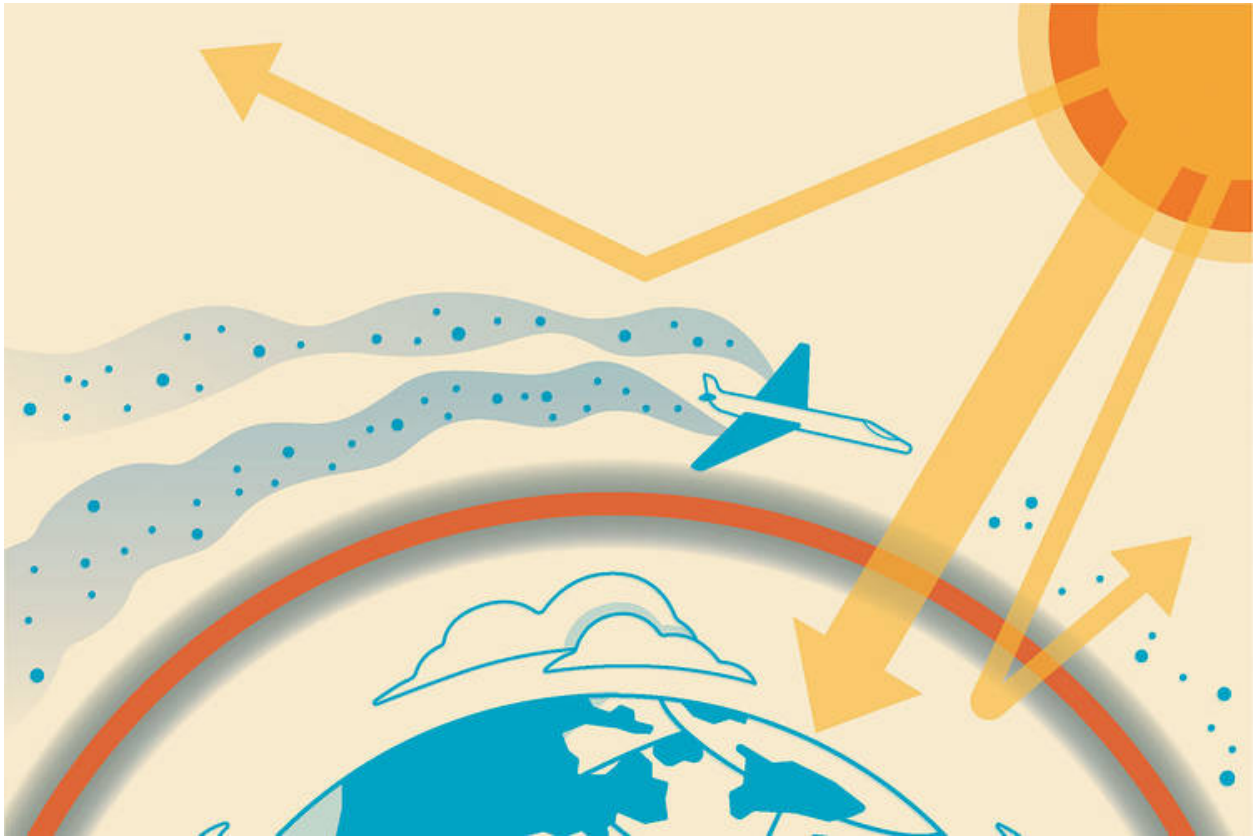
April 17, 2017
Is It O.K. to Tinker With the Environment to Fight Climate Change?



THE WALL STREET JOURNAL.

February 16, 2018

A Big-Sky Plan to Cool the Planet



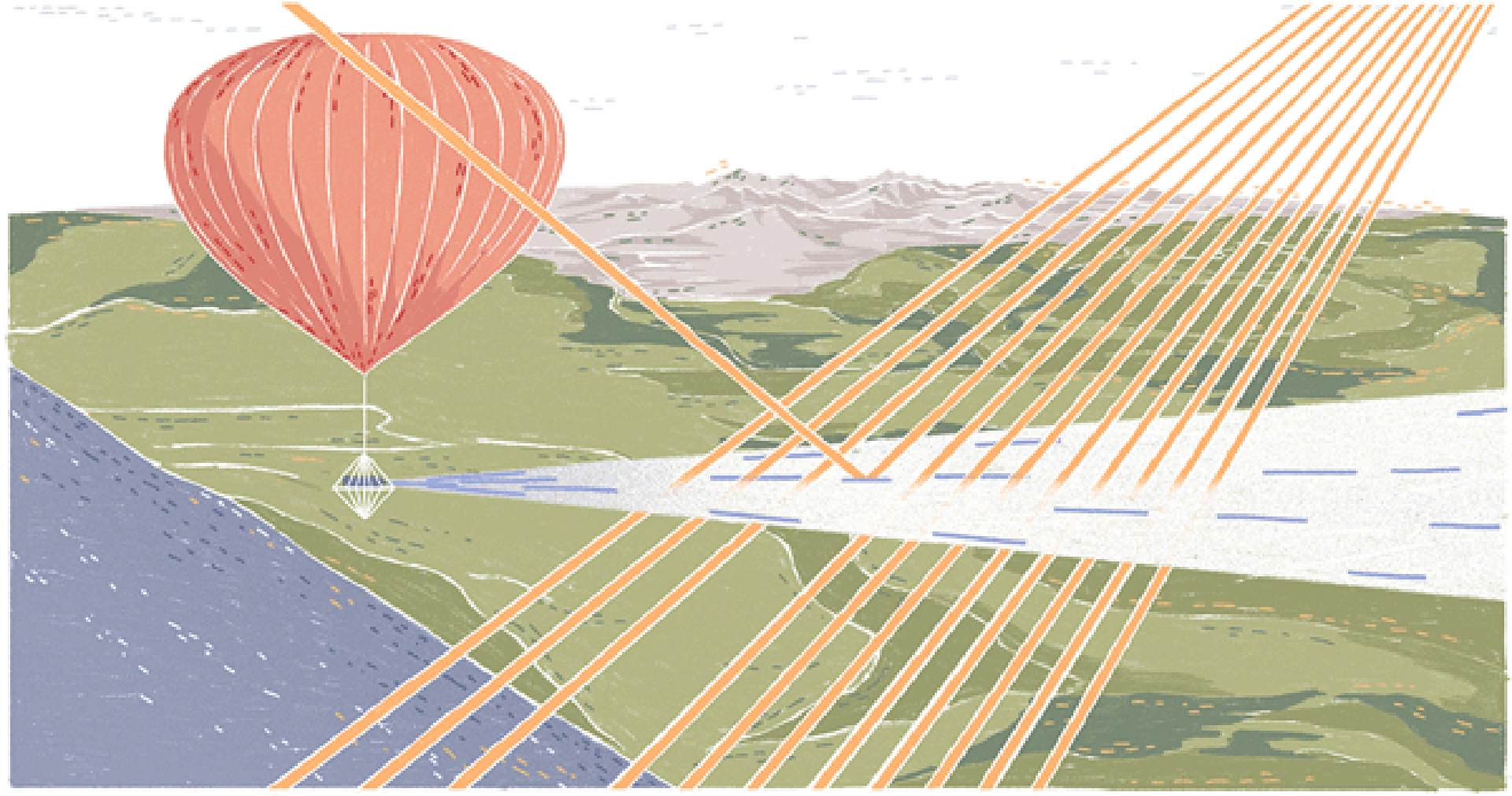
theguardian

November 22, 2018
Solar geoengineering could be ‘remarkably inexpensive’ – report

Putting sulfate particles into the stratosphere would mimic volcanic eruptions, which have reduced global temperatures in the past. Photograph: Alamy

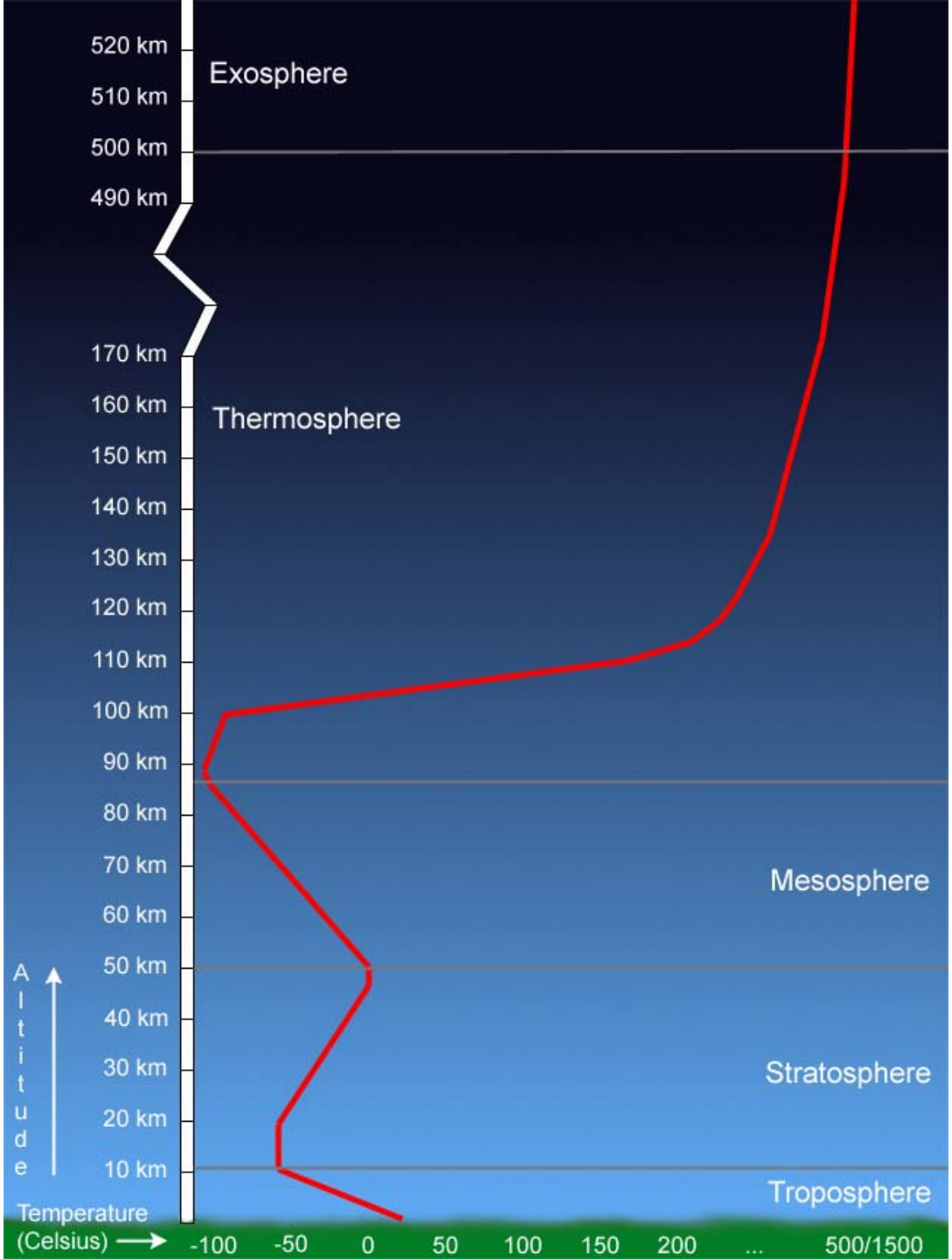
The New York Times

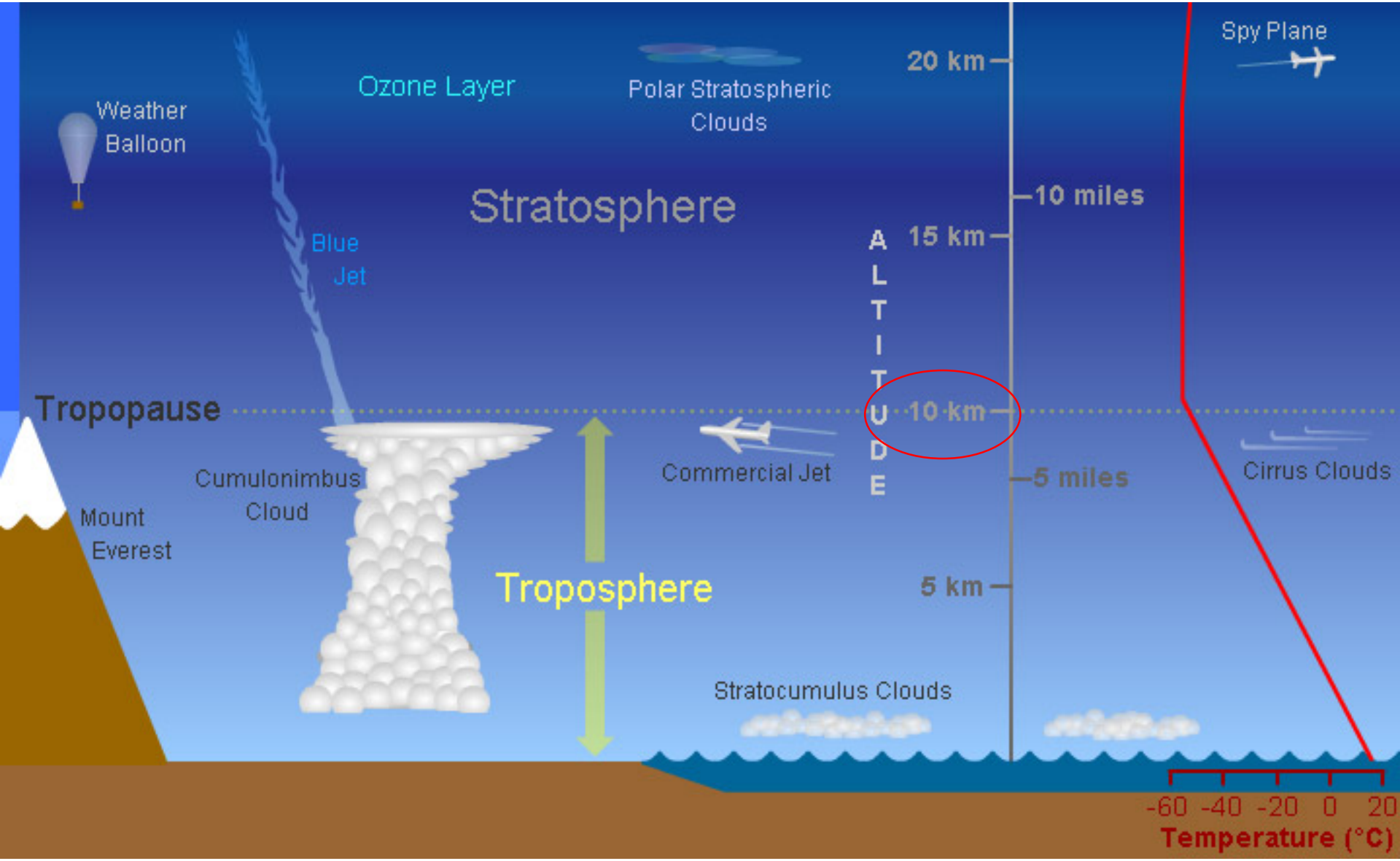
June 7, 2019
Maybe We're Not Doomed After All

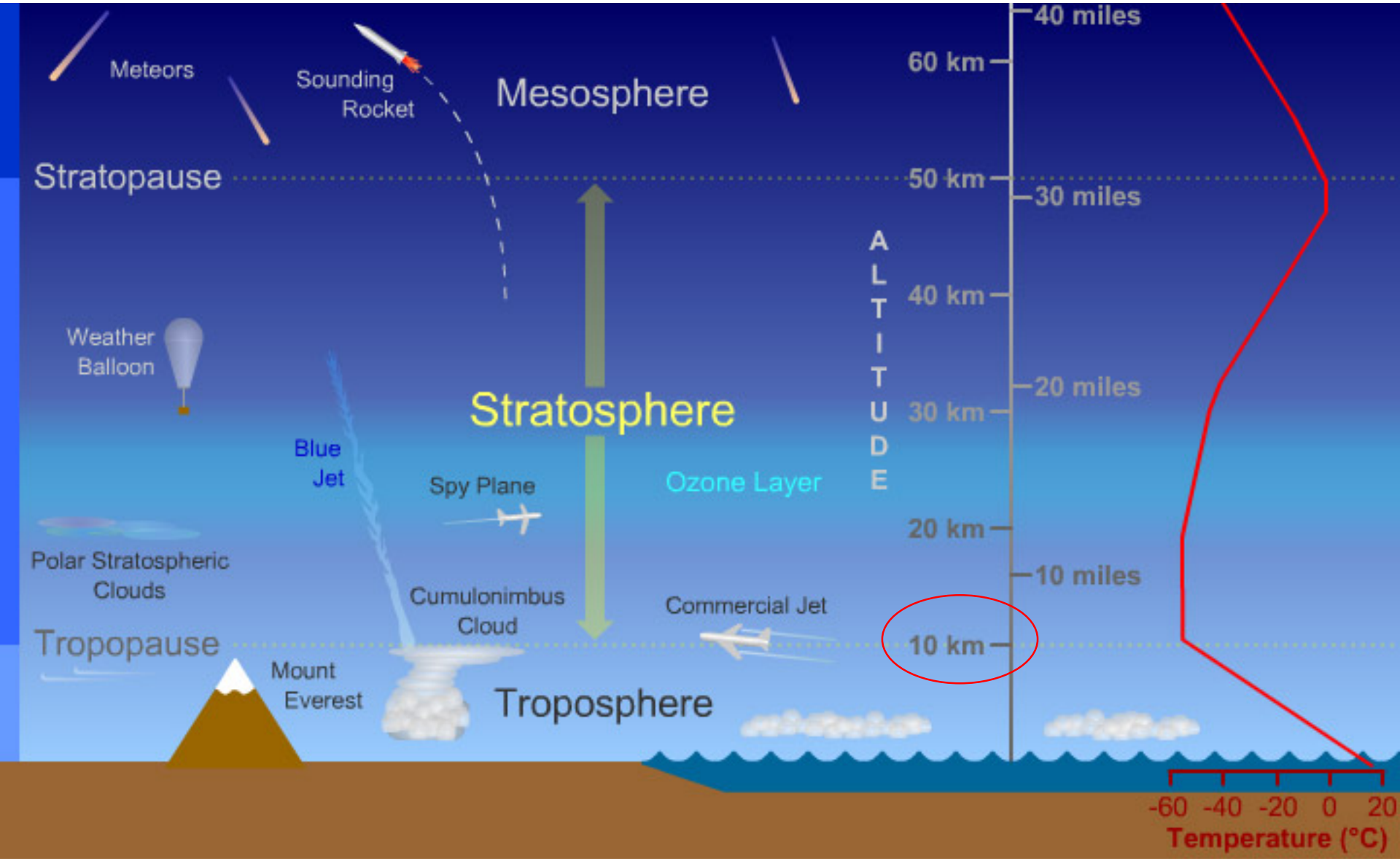


Harvard University
Center for the Environment

The Atmosphere


520 km
510 km
500 km
490 km
Exosphere
170 km
160 km
150 km
140 km
130 km
120 km
110 km
100 km
90 km
Thermosphere
80 km
70 km
60 km
50 km
40 km
30 km
20 km
10 km
Mesosphere
Stratosphere
Troposphere
Altitude
Temperature
(Celsius)
-100
-50
0
50
100
150
200
...
500/1500


Weather Balloon
Ozone Layer
Polar Stratospheric Clouds
Spy Plane
20 km
Stratosphere
10 miles
Blue Jet
15 km
ALTITUDE
Tropopause
10 km
Cumulonimbus Cloud
Commercial Jet
5 miles
Cirrus Clouds
Mount Everest
Troposphere
5 km
Stratocumulus Clouds
-60 -40 -20 0 20
Temperature (°C)


Meteors
Sounding Rocket
Mesosphere
Stratopause
Weather Balloon
Stratosphere
Blue Jet
Spy Plane
Ozone Layer
Polar Stratospheric Clouds
Cumulonimbus Cloud
Commercial Jet
Tropopause
Mount Everest
Troposphere
ALTITUDE
60 km
50 km
40 km
30 km
20 km
10 km
40 miles
30 miles
20 miles
10 miles
-60 -40 -20 0 20
Temperature (°C)

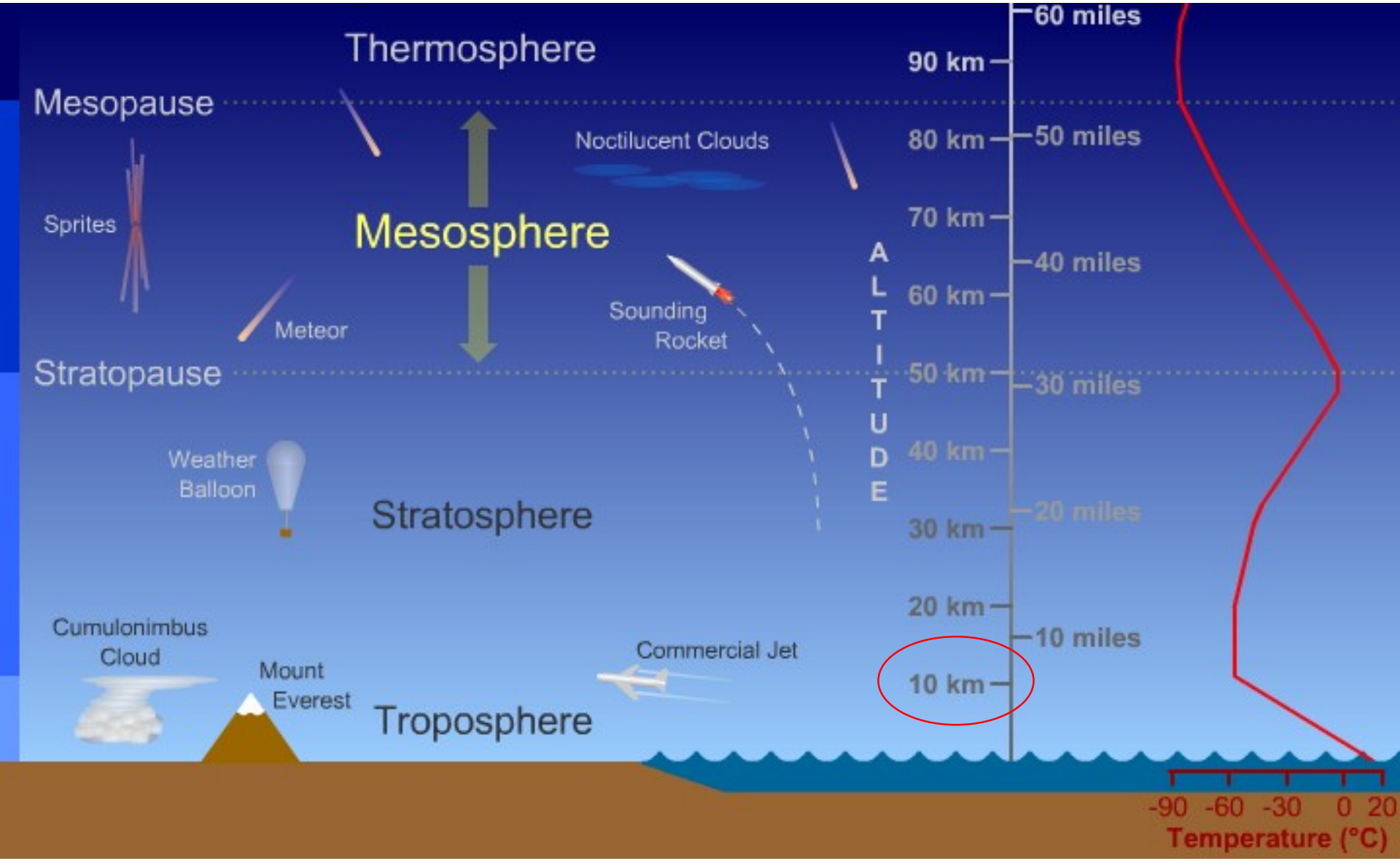
Troposphere, Stratosphere, Whatever

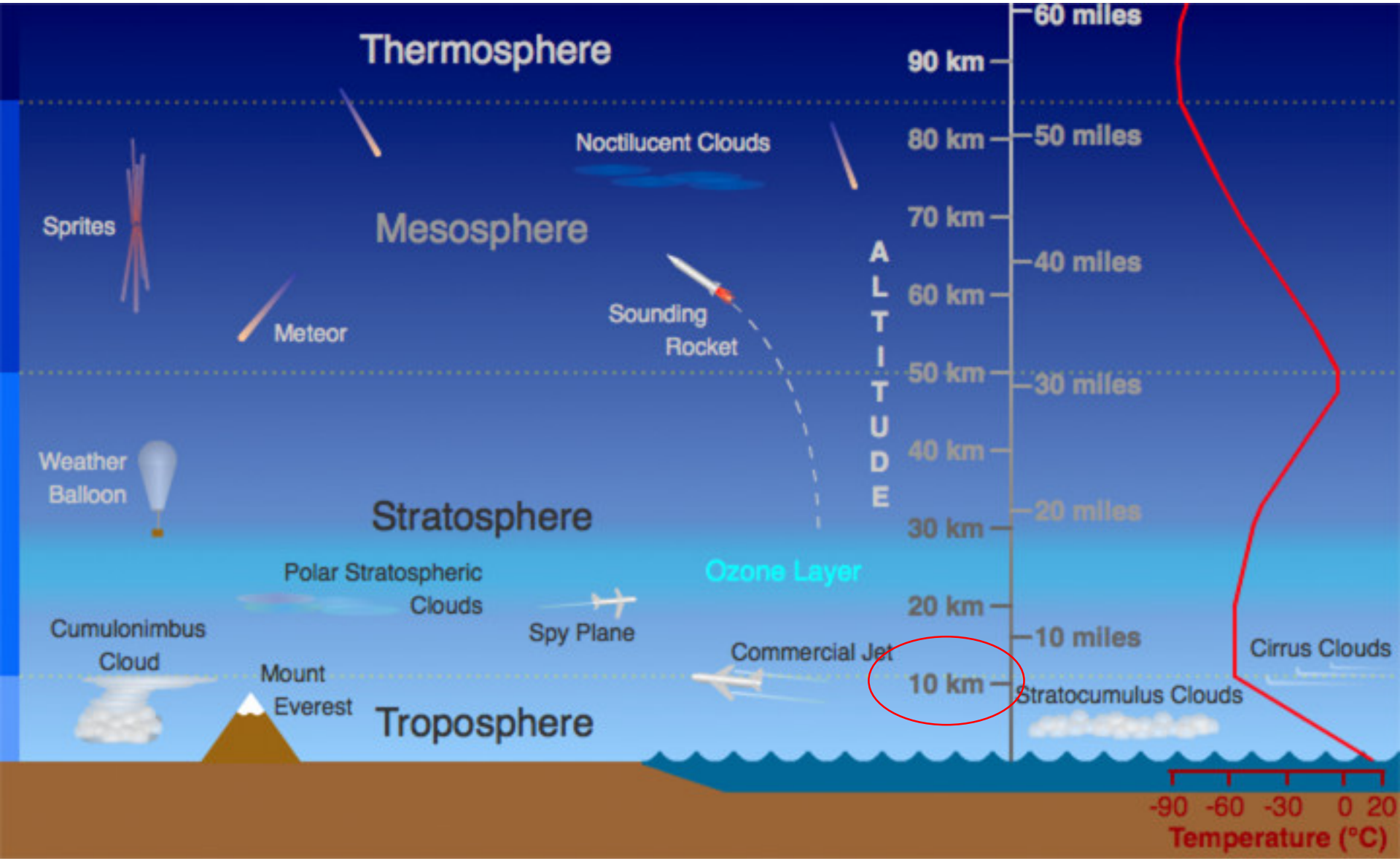
Justice Scalia: *But I always thought...the pollutant leaves the air and goes up into the stratosphere....*

Mr. Milkey: *Respectfully, Your Honor, it is not the stratosphere. It's the troposphere.*

Justice Scalia: *Troposphere, whatever. I told you before I'm not a scientist. That's why I don't want to have to deal with global warming, to tell you the truth.*

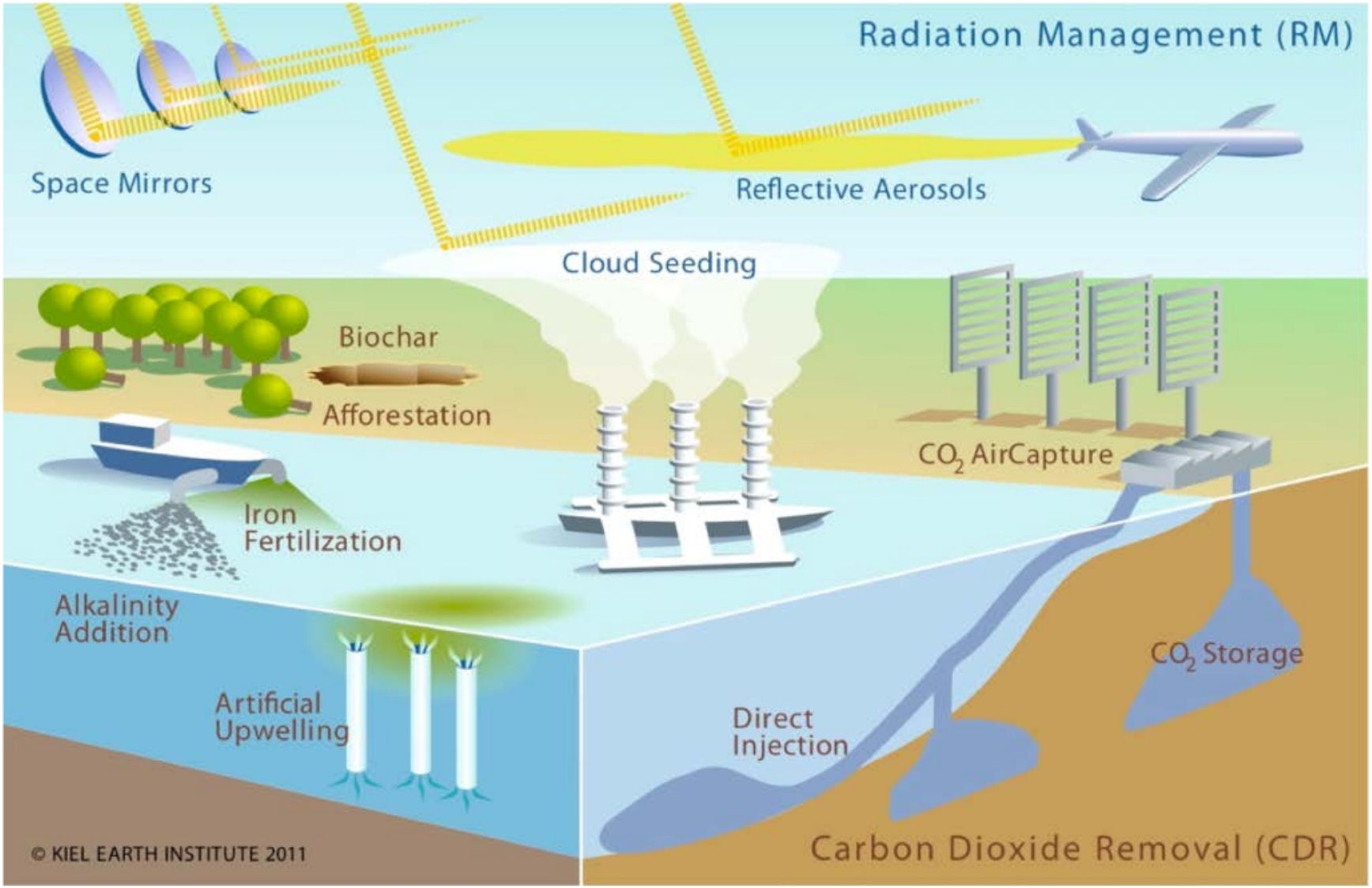
–Oral argument at the U.S. Supreme Court in *Massachusetts v. EPA* on Nov. 29, 2006


Thermosphere
Mesopause
Noctilucent Clouds
Sprites
Mesosphere
Meteor
Sounding Rocket
Stratopause
Weather Balloon
Stratosphere
Cumulonimbus Cloud
Mount Everest
Commercial Jet
Troposphere
ALTITUDE
90 km
80 km
70 km
60 km
50 km
40 km
30 km
20 km
10 km
60 miles
50 miles
40 miles
30 miles
20 miles
10 miles
-90 -60 -30 0 20
Temperature (°C)


Thermosphere
Noctilucent Clouds
Sprites
Mesosphere
Meteor
Sounding Rocket
Weather Balloon
Stratosphere
Polar Stratospheric Clouds
Ozone Layer
Spy Plane
Cumulonimbus Cloud
Mount Everest
Commercial Jet
Troposphere
Cirrus Clouds
Stratocumulus Clouds
ALTITUDE
90 km
80 km
70 km
60 km
50 km
40 km
30 km
20 km
10 km
60 miles
50 miles
40 miles
30 miles
20 miles
10 miles
-90 -60 -30 0 20
Temperature (°C)

CDR and SRM
Carbon Dioxide Removal and Solar Radiation Management

Solar Radiation Management and Carbon Dioxide Removal



CDR and SRM Strategies

Strategy	SRM ?	CDR ?
afforestation		✓
bioenergy with carbon capture and storage		✓
covering deserts or oceans with reflective material	✓	
crops with high reflectivity	✓	
deforestation avoidance		✓
direct capture of carbon dioxide from the atmosphere		✓
enhancing ocean cloud brightness	✓	
enhanced weathering		✓
injection of aerosols into the stratosphere	✓	
ocean fertilization		✓
soil improvement		✓
space based shields	✓	
white roofs on buildings	✓	

Positions on Geoengineering

- In favor of research
  - American Geophysical Union
  - Environmental Defense Fund
  - National Academy of Sciences
  - Natural Resources Defense Council
  - Union of Concerned Scientists
  - World Wildlife Fund
- Opposed to research
  - Action Group on Erosion, Technology and Concentration
  - Friends of the Earth
  - Greenpeace International

ILLINOIS
College of Engineering

Department of Civil and Environmental Engineering
Open Rank Faculty Positions
College of Engineering
University of Illinois at Urbana-Champaign

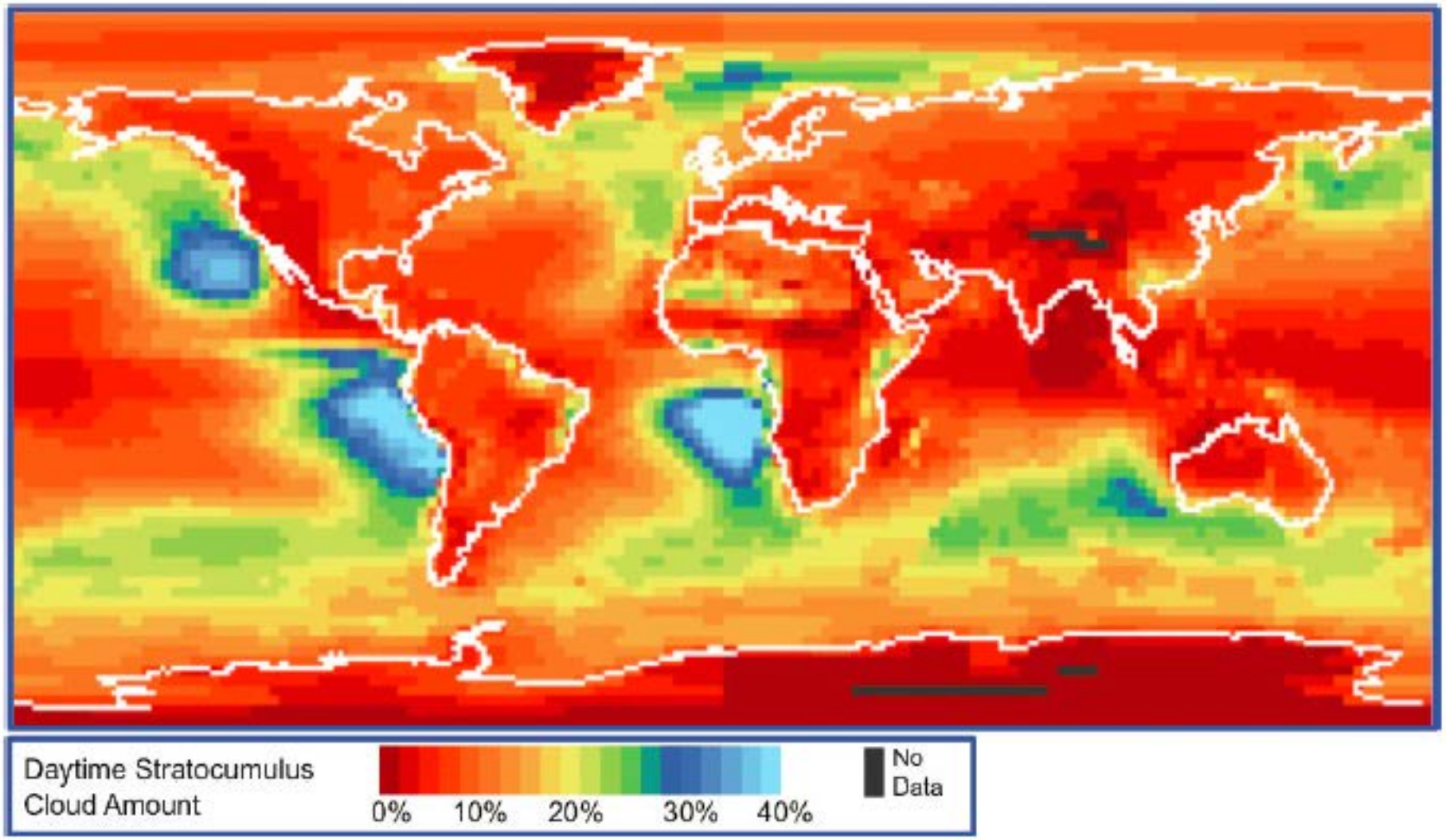
Description: Geoengineering to Address Climate Change Risks to the Built and Natural Environment and Geoengineering for Urban and Offshore Development Sustainability

SRM Examples:
Shields and Mirrors

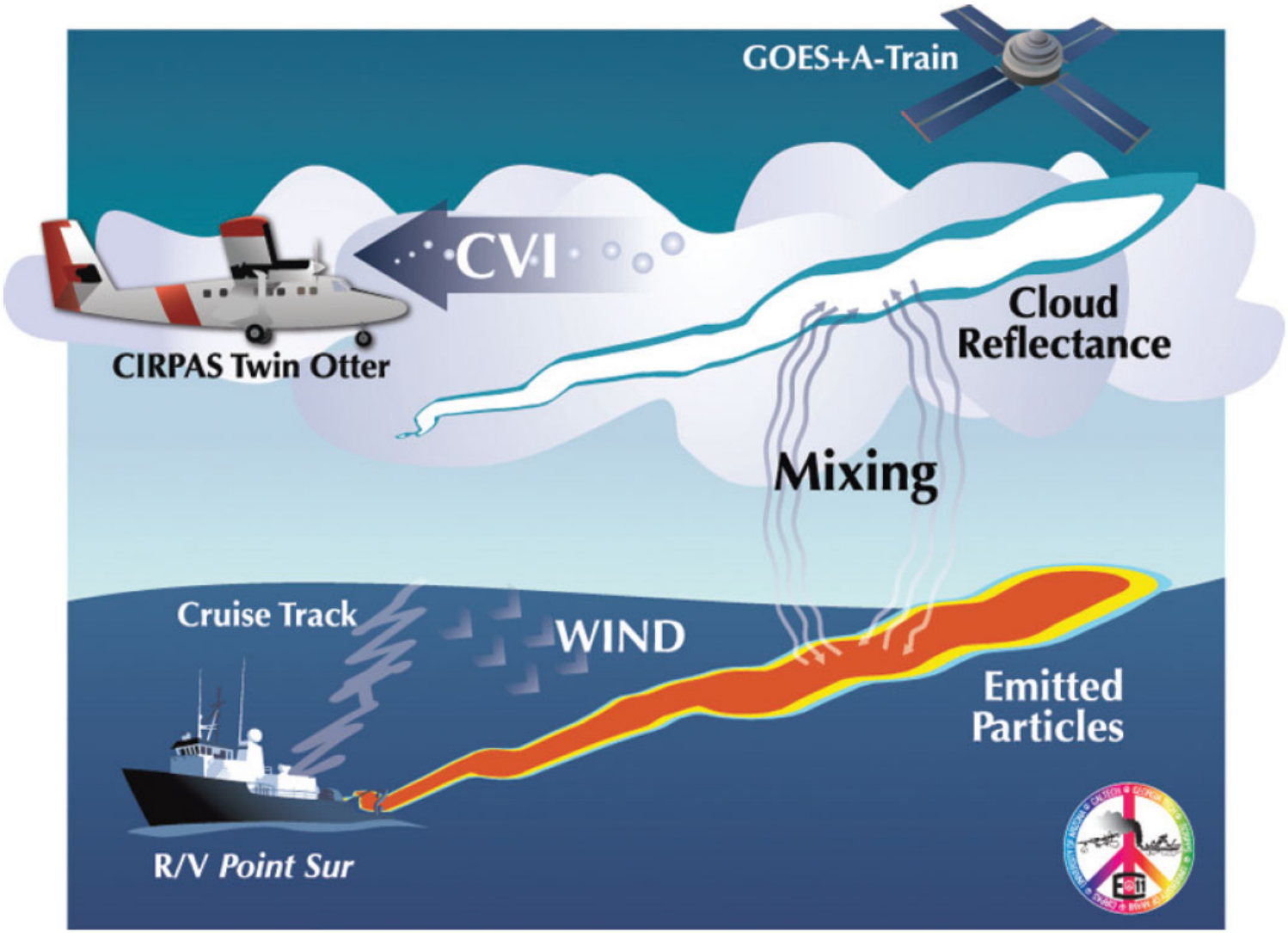
Futurama “Crimes of the Hot”

SRM Example:
Marine Cloud Whitening

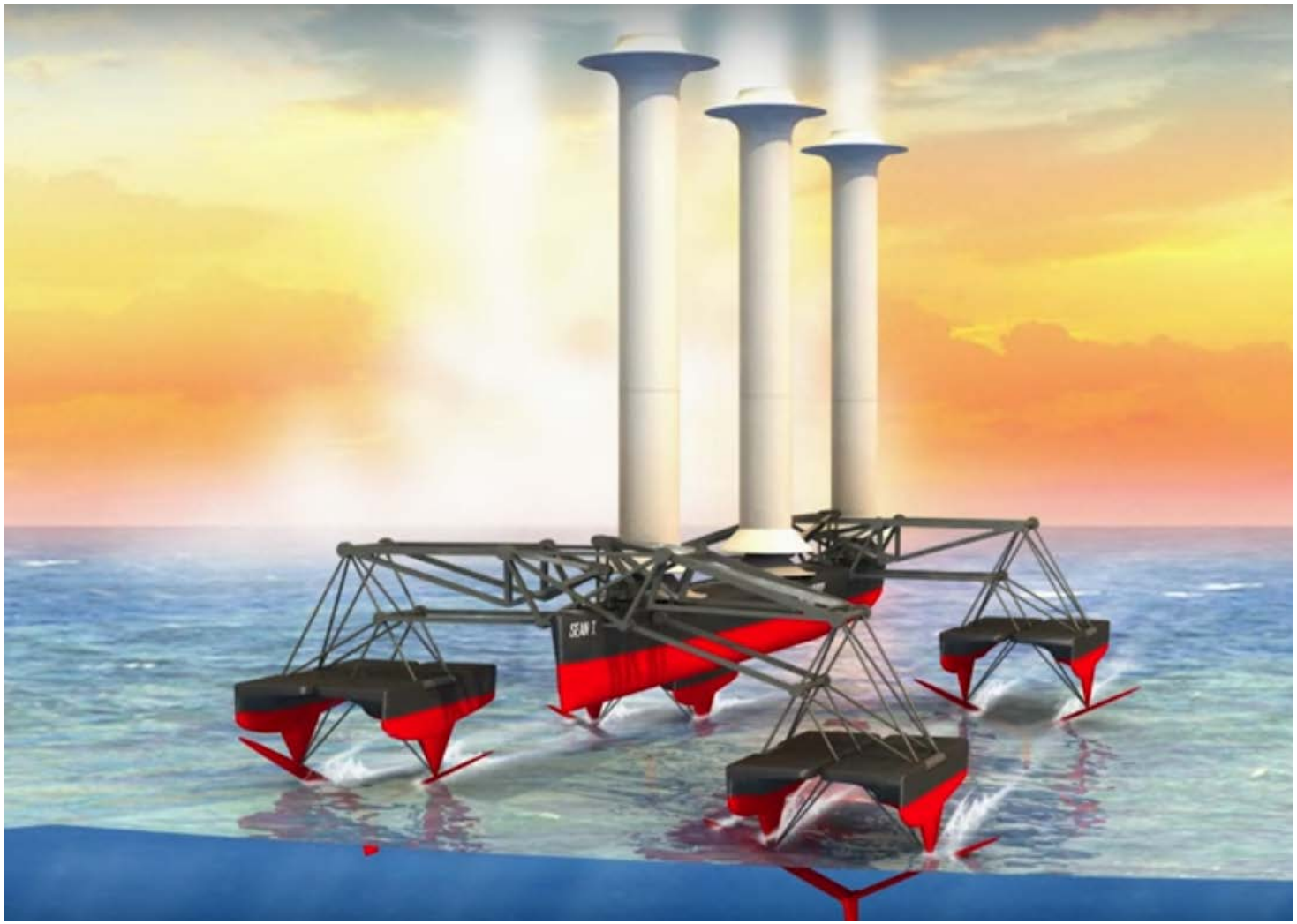
Daytime Stratocumulus Cloud Amount 1983 - 2009



Eastern Pacific Emitted Aerosol Cloud Experiment (E-PEACE) July-August 2011

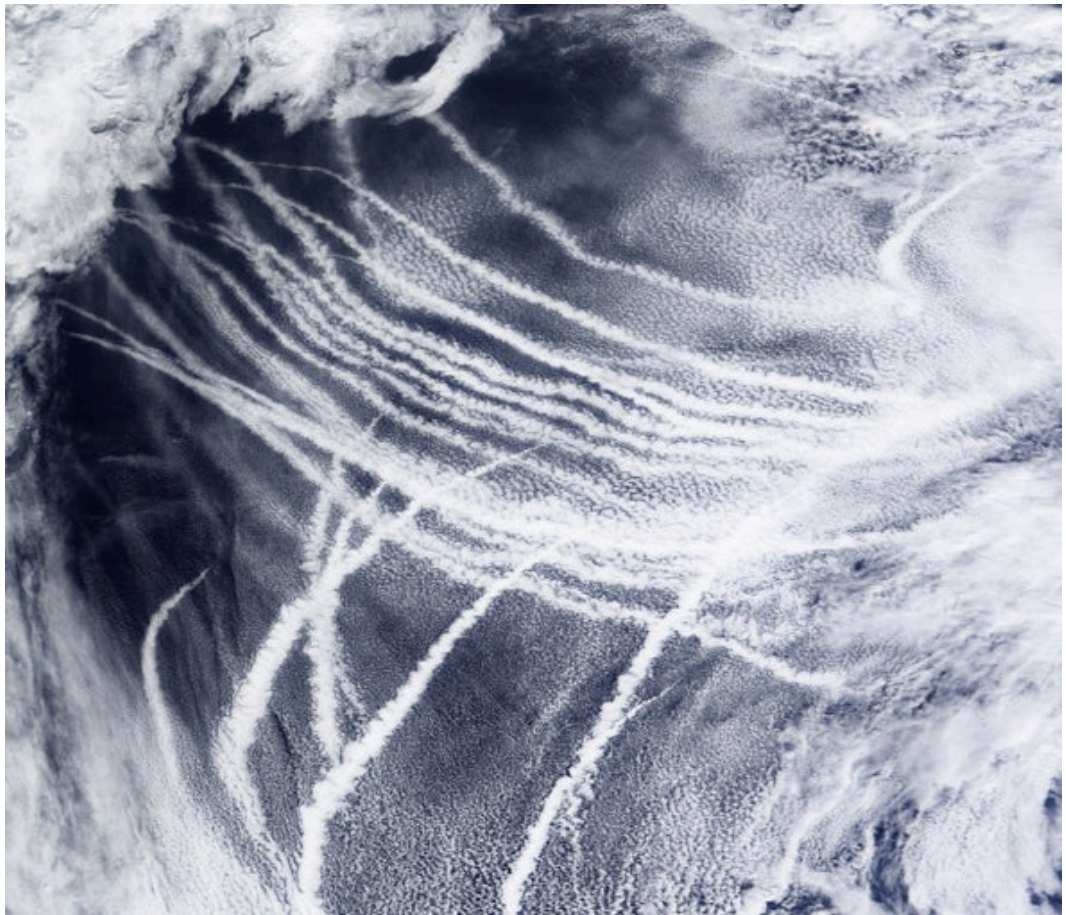


Marine Cloud Brightening
Stephen Salter, TEDx, October, 2016



SCIENTIFIC AMERICAN™

January 23, 2020
NOAA Gets Go-Ahead to Study Controversial Climate Plan B



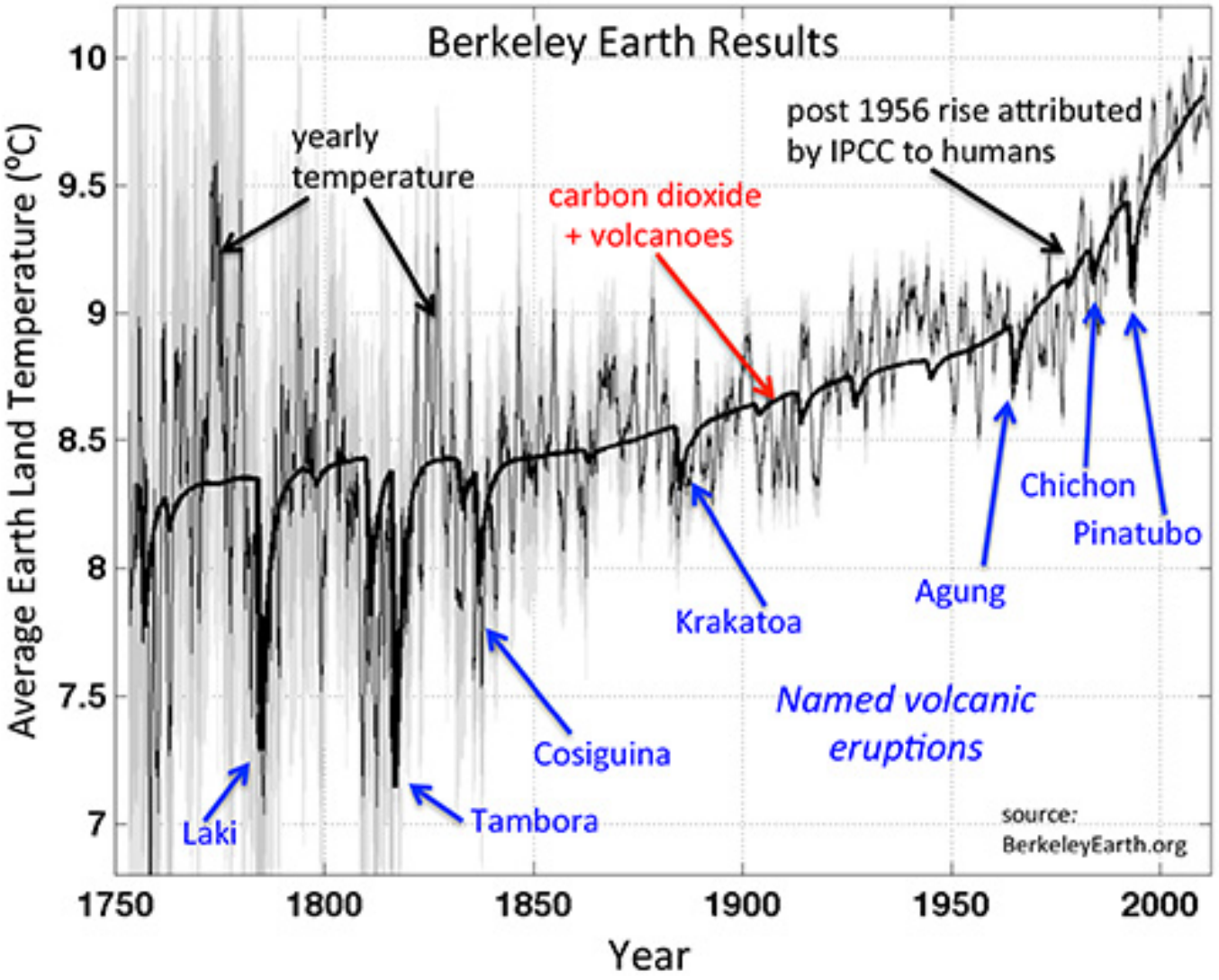
Paul J. Crutzen
Climatic Change 77(2006)211

Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?

Aerosol Injection Requirement

- Climate effect from Mt. Pinatubo eruption in June, 1991 analyzed by Hansen et al. in 1992
- 6 Mt of sulfur in atmosphere after 6 months resulted in radiative forcing of 4.5 W/m^2
- GHG emissions result in radiative forcing of 1.4 W/m^2
- Residence time of sulfur in stratosphere 1 to 2 years
- 1 or 2 Mt. Pinatubo sulfur injected per year balances GHG
- National Academy of Sciences 1992 cost estimate $25-$50 billion

Global Land Surface Temperature

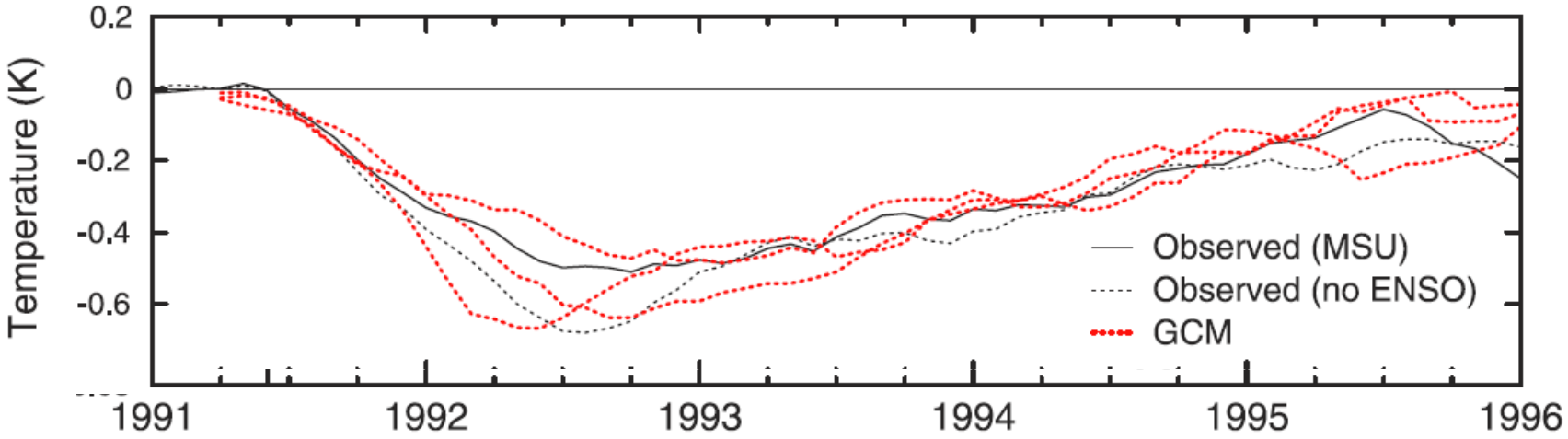


Mt. Pinatubo Eruption June 12, 1991

Mt. Pinatubo in Philippines

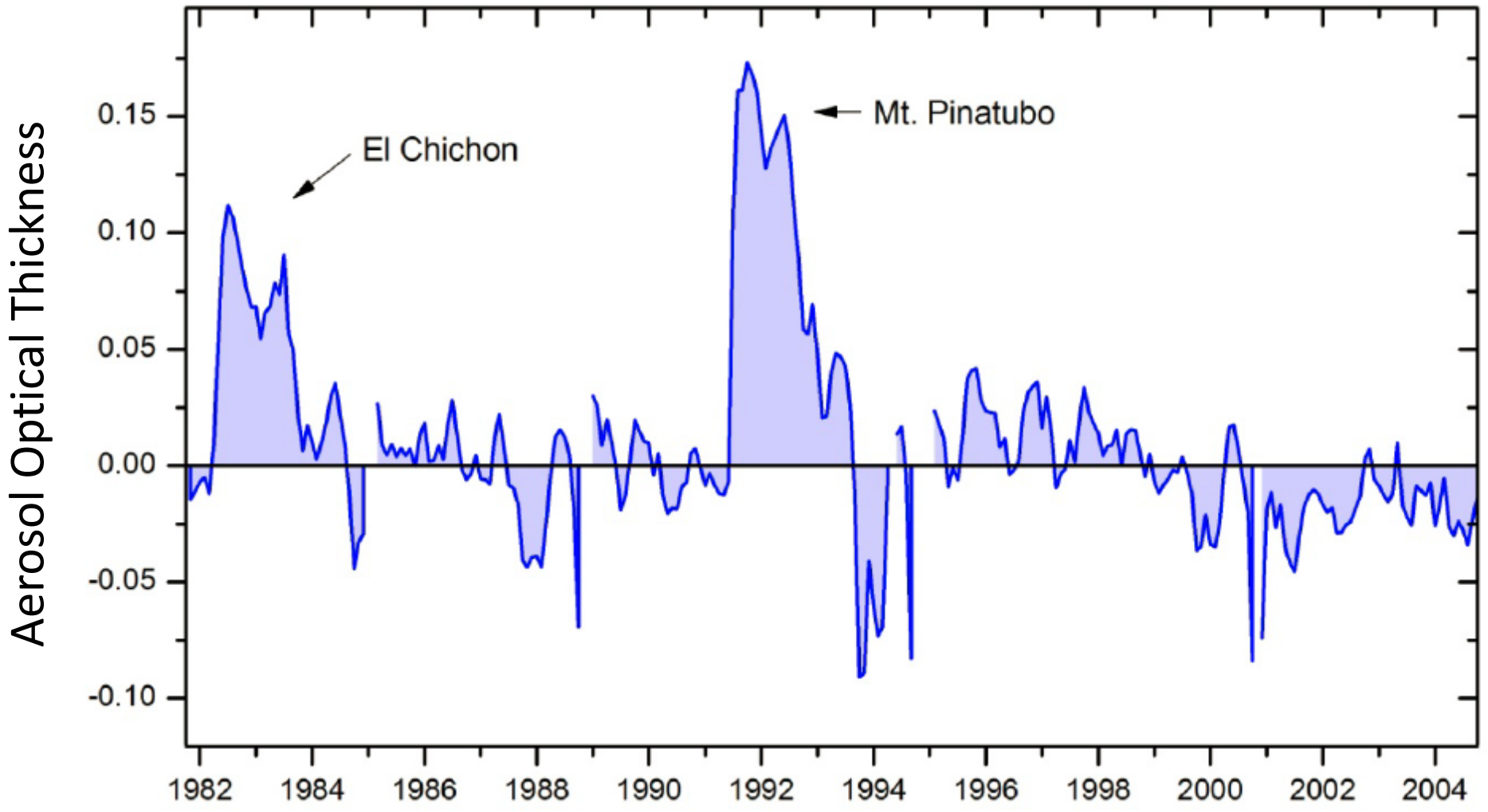
June 12, 1991 Mt. Pinatubo Eruption

Global Cooling After the Eruption of Mt. Pinatubo



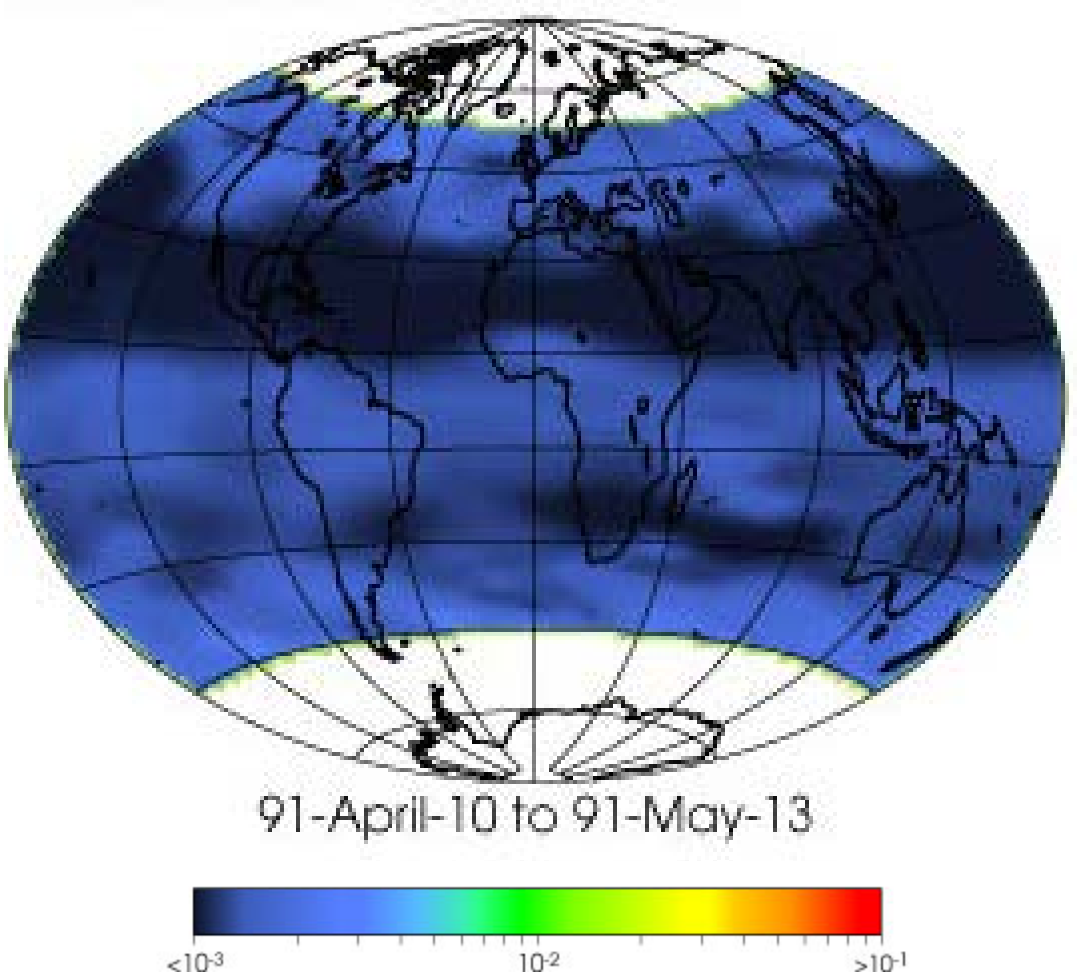
MSU: lower tropospheric temperature from NASA microwave sounding unit
ENSO: El Niño–Southern Oscillation
GCM: atmospheric general circulation model

Aerosol Optical Thickness 1982-2005

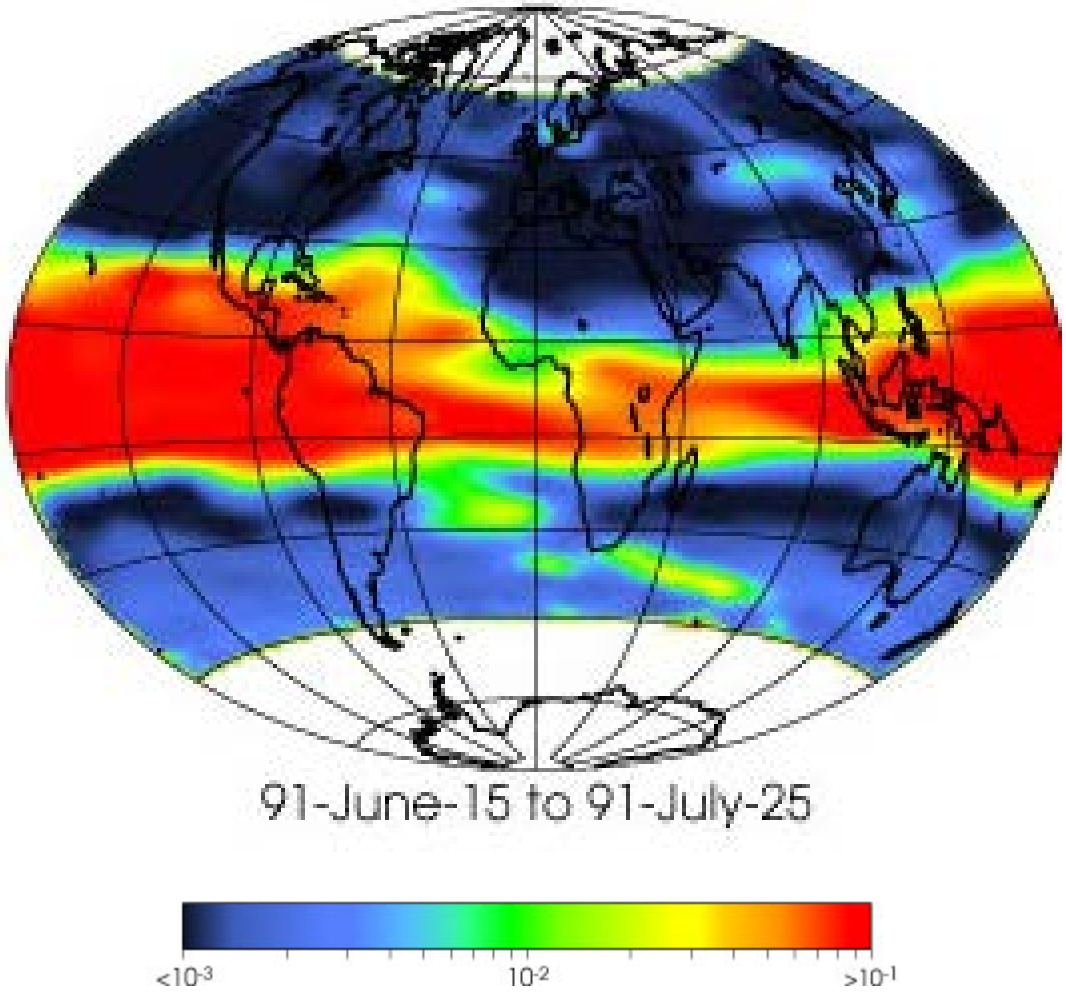


AOT = 0.1 approximately 10% attenuation

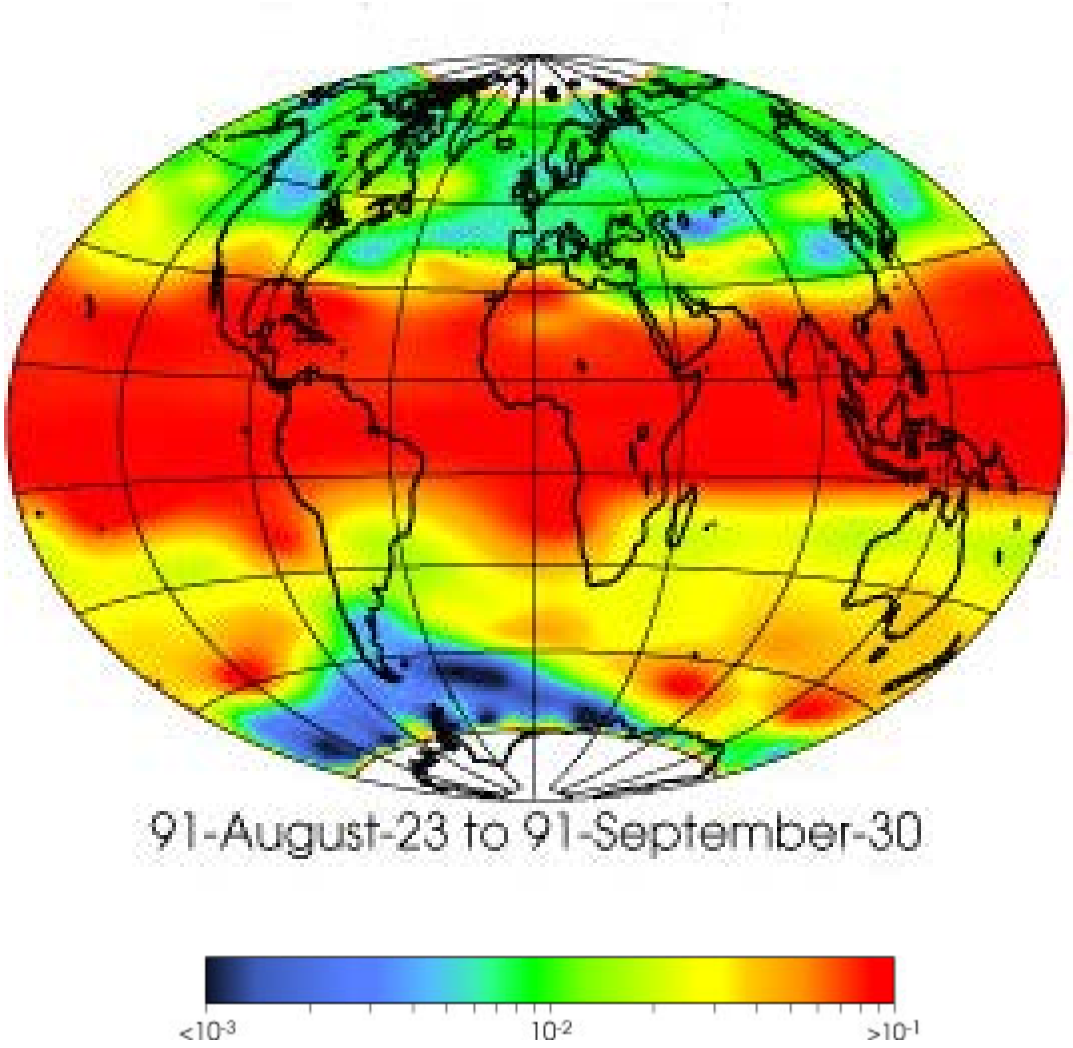
Atmosphere Optical Depth
April 10, 1991 – May 13, 1991
eruption minus one month



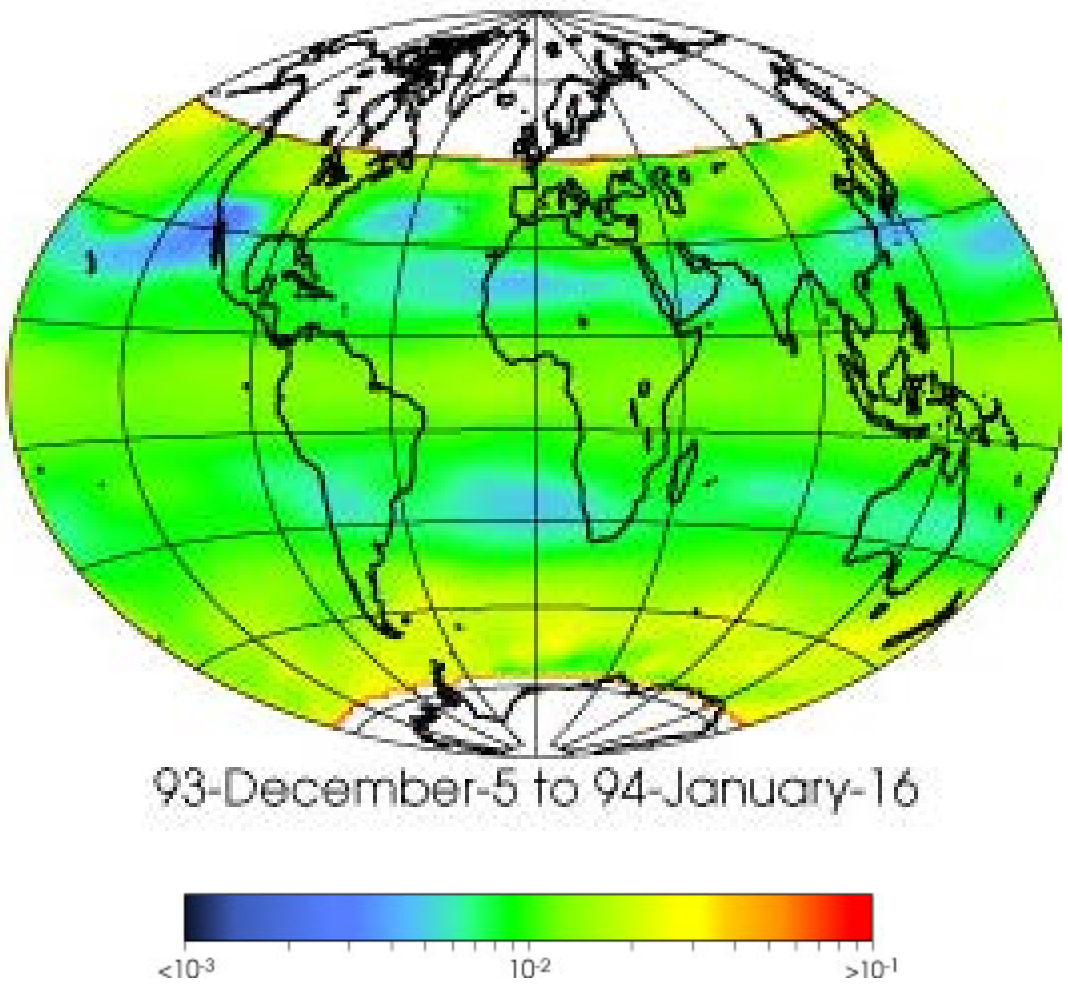
Atmosphere Optical Depth
June 15, 1991 – July 25, 1991
eruption plus one month

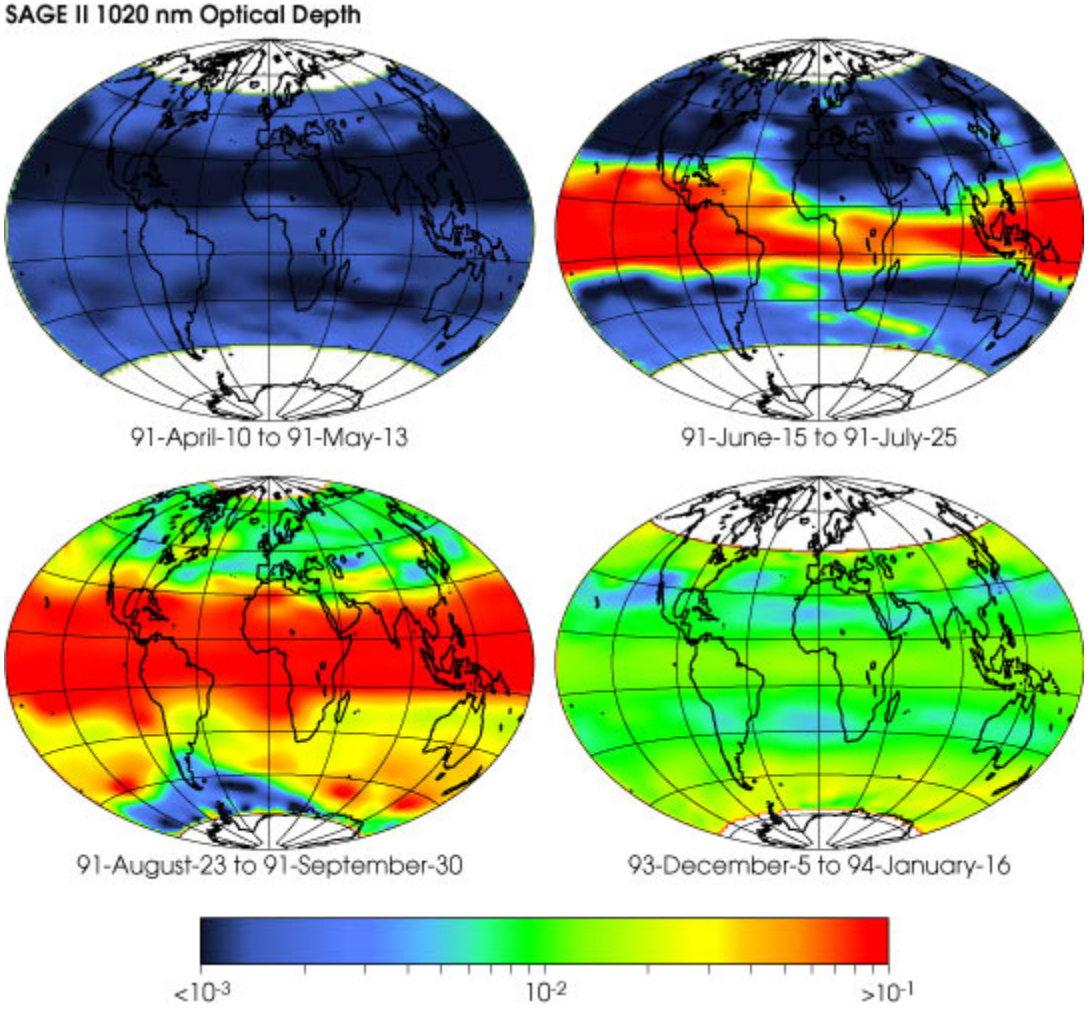


Atmosphere Optical Depth
August 23, 1991 – September 30, 1991
eruption plus two months

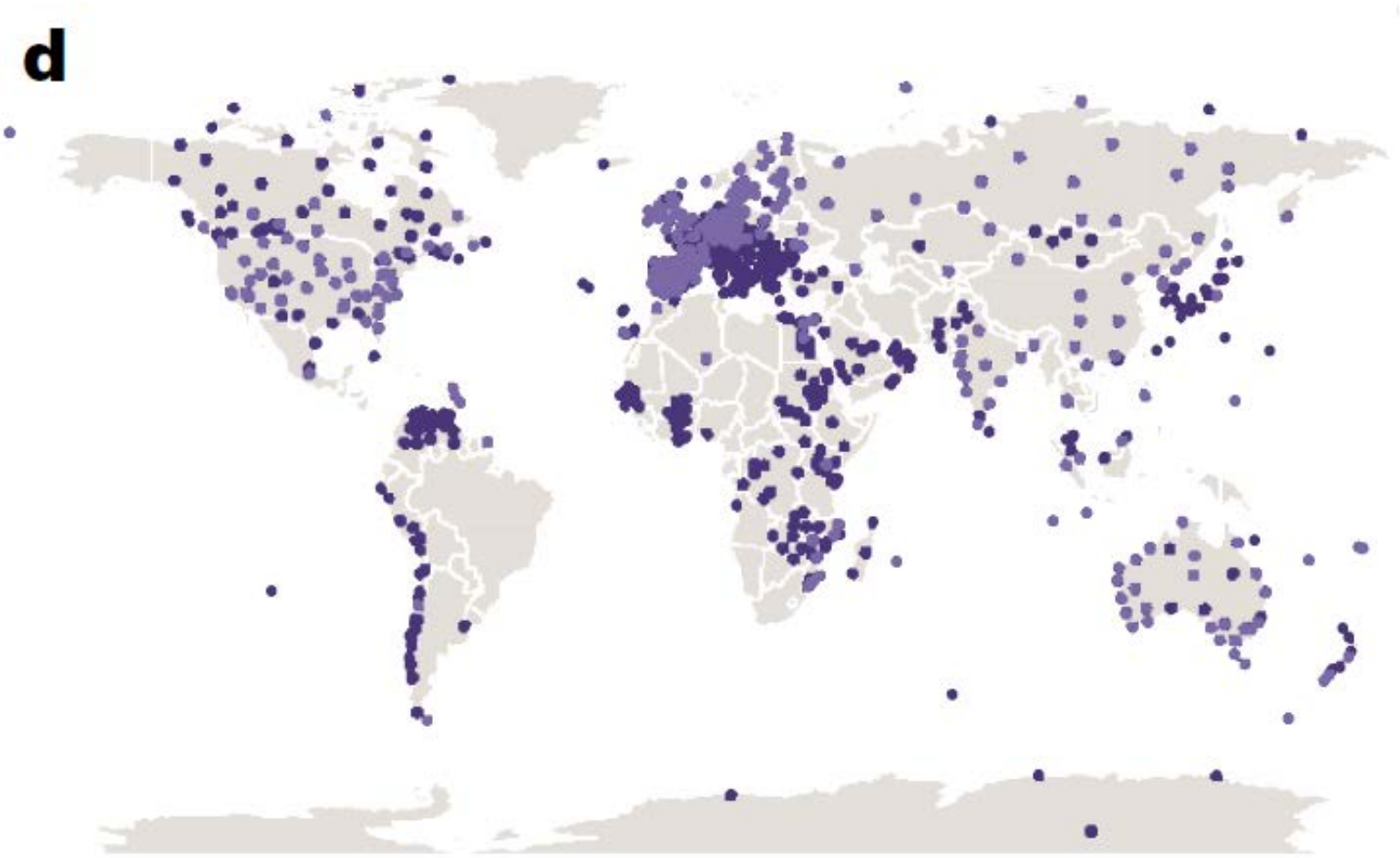


Atmosphere Optical Depth
December 5, 1993 – January 16, 1994
eruption plus thirty months

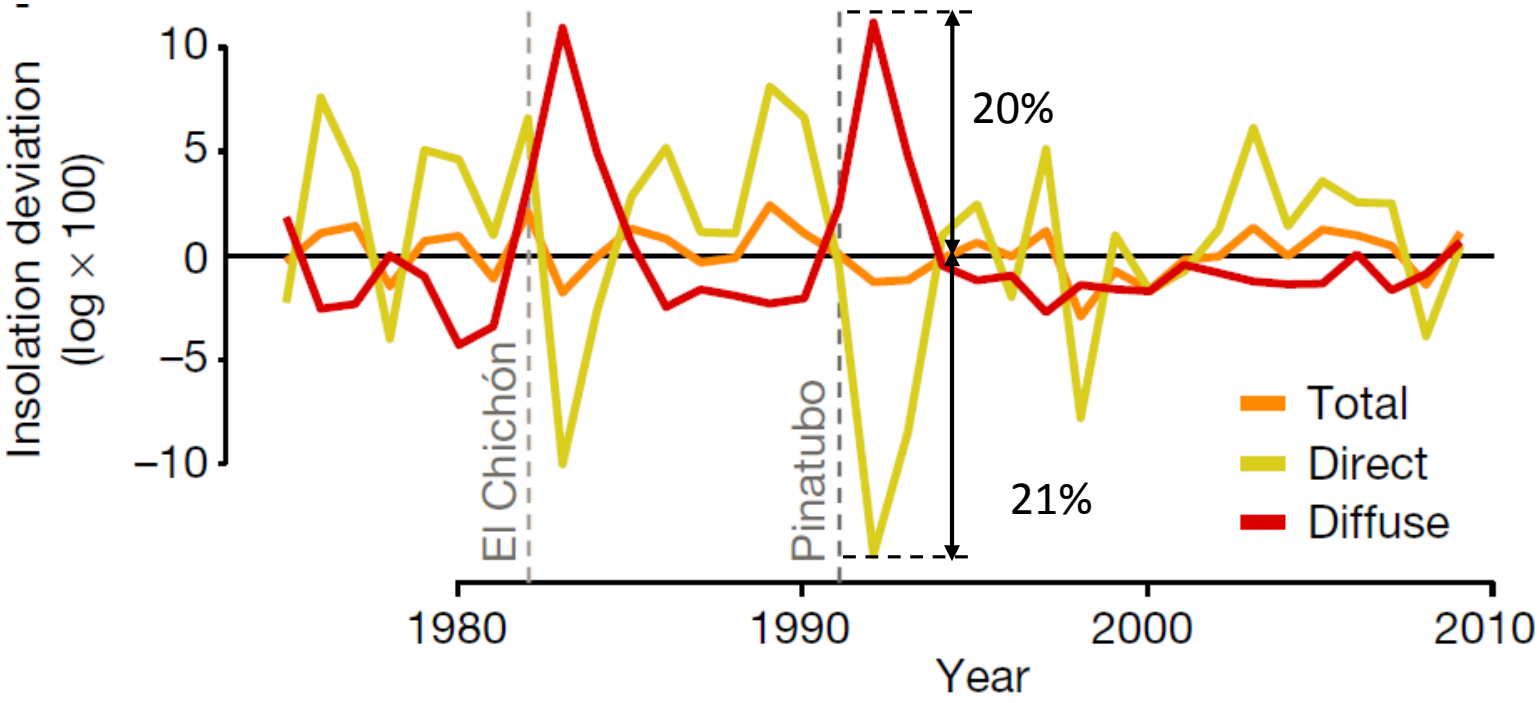



SAGE II 1020 nm Optical Depth
91-April-10 to 91-May-13
91-June-15 to 91-July-25
91-August-23 to 91-September-30
93-December-5 to 94-January-16
<10-3
10-2
>10-1

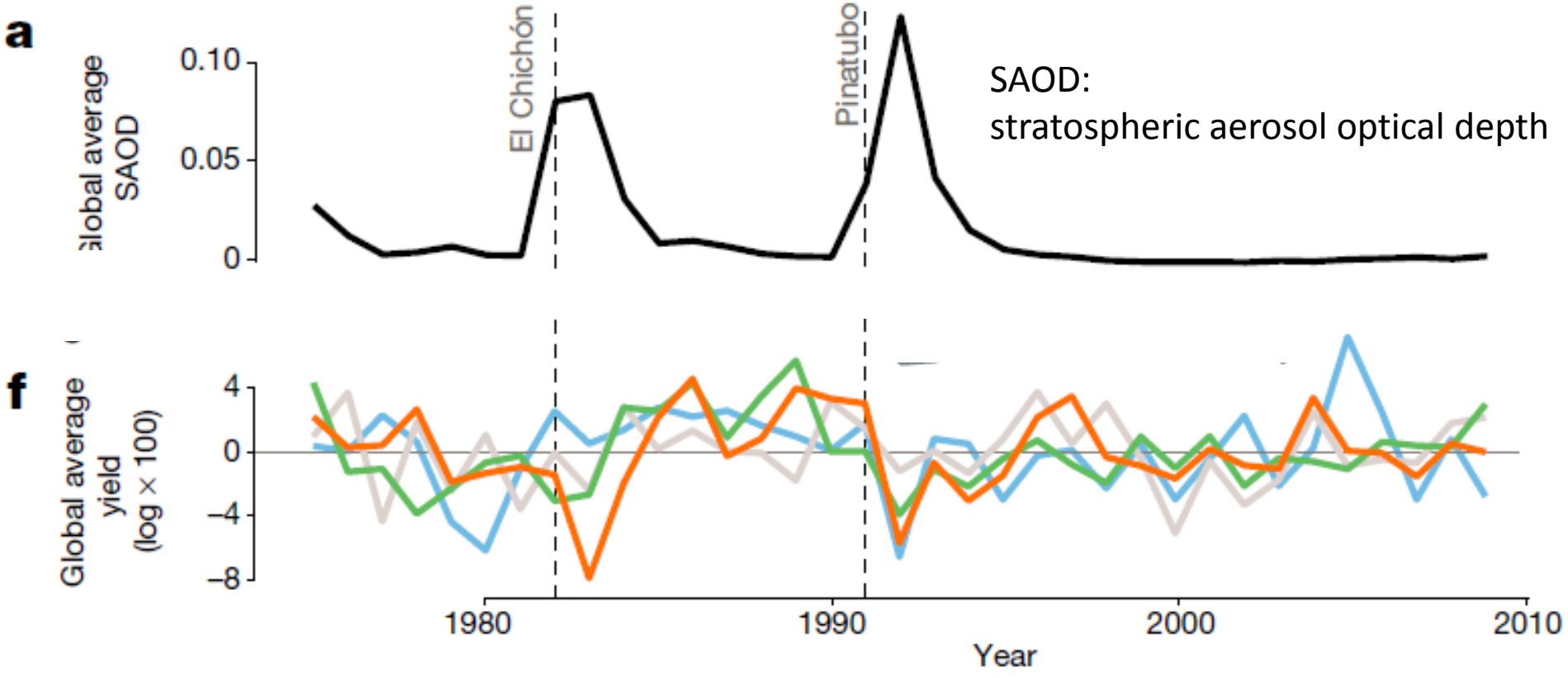
Estimating global agricultural effects of geoengineering using volcanic eruptions
J. Proctor et al., Nature 560(2018)480
Observation Stations



J. Proctor et al., Nature 560(2018)480 Direct and Diffuse Insolation Change



J. Proctor et al., Nature 560(2018)480
Change in SAOD and Change in Crop Yields



corn wheat soy rice

Large Scale Artificial Atmospheric Aerosol Injection

Alan Robock
APS Physics of Sustainable Energy III, March, 2014

To inject 1 Mt of S as H_2S into the lower stratosphere per year

Method	Maximum Payload	Ceiling (km)	# of Units	Price per unit (2007 dollars)	Total Purchase Price (2008 dollars)	Annual Operation Costs
F-15C Eagle	8 tons	20	167 planes 3 flights/day	$38,100,000	**$6,362,700,000** but there are already 522	**$4,175,000,000***
KC-135 Strato-tanker	91 tons	15	15 planes 3 flights/day	$50,292,000	**$755,000,000** but there are already more than 481, and they will become surplus	**$375,000,000**
KC-10 Extender	160 tons	13	9 planes 3 flights/day	$112,000,000	**$1,000,000,000** but there are already 59	**$225,000,000***
~~Balloons~~	4 tons	30	37,000 per day	$1,711		~~$30,000,000,000~~
~~Naval~~ Rifles	500 kg	20	8,000 shots per day			~~$30,000,000,000~~

KC-10 Extender

Ceiling: 12.73 km

Payload: 160 tons gas

Cost: $88,400,000
(1998 dollars)

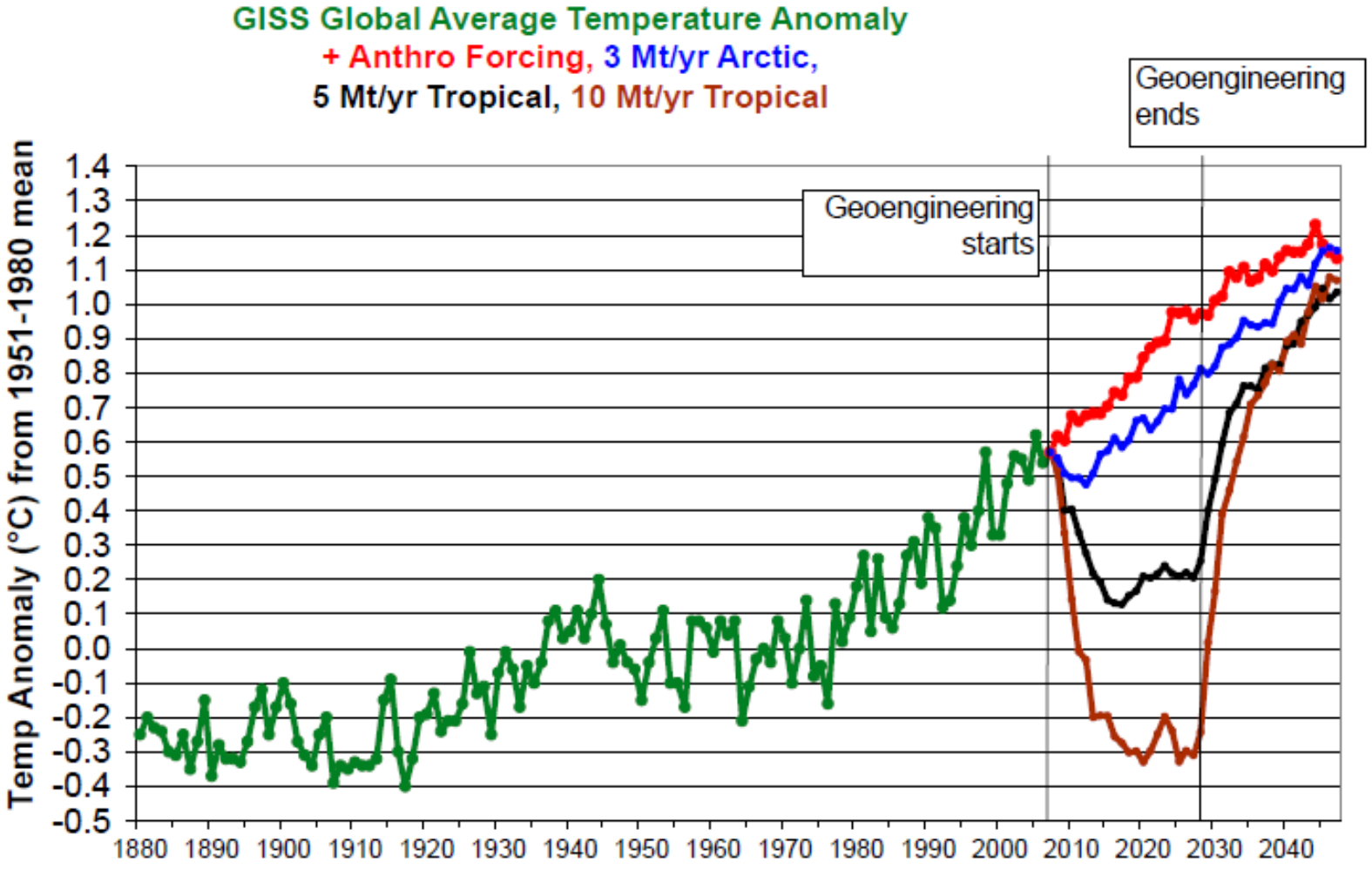
http://www.af.mil/shared/media/factsheet/kc_10.jpg

http://www.af.mil/shared/media/photodb/photos/030317-F-7203T-013.jpg

With 3 flights/day,
operating 250 days/year

would need 9 planes
to deliver 1 Tg gas per year
to Arctic stratosphere.

KC-10 Extender


GISS Global Average Temperature Anomaly
+ Anthro Forcing, 3 Mt/yr Arctic,
5 Mt/yr Tropical, 10 Mt/yr Tropical
Geoengineering ends
Geoengineering starts
Temp Anomaly (°C) from 1951-1980 mean
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
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 2030 2040

Alan Robock

Albedo enhancement by stratospheric sulfur injections: More research needed Earth's Future_4(2016)644

Risks or Concerns and Benefits of Stratospheric Geoengineering

Benefits

1. Reduce surface air temperatures, which could reduce or reverse negative impacts of global warming, including floods, droughts, stronger storms, sea ice melting, and sea level rise
2. Increase plant productivity
3. Increase terrestrial CO_2 sink
4. Beautiful red and yellow sunsets
5. Unexpected benefits
6. Prospect of implementation could increase drive for mitigation

Risks or Concerns and Benefits of Stratospheric Geoengineering
Risks or Concerns

Physical and biological climate system

1. Drought in Africa and Asia
2. Perturb ecology with more diffuse radiation
3. Ozone depletion
4. Continued ocean acidification
5. May not stop ice sheets from melting
6. Impacts on tropospheric chemistry
7. Rapid warming if stopped

Risks or Concerns and Benefits of Stratospheric Geoengineering

Risks or Concerns

Human impacts

8. Less solar electricity generation
9. Degrade passive solar heating
10. Effects on airplanes flying in stratosphere
11. Effects on electrical properties of atmosphere
12. Affect satellite remote sensing
13. Degrade terrestrial optical astronomy
14. More sunburn
15. Environmental impact of implementation

Risks or Concerns and Benefits of Stratospheric Geoengineering
Risks or Concerns

Esthetics

16. Whiter skies

17. Affect stargazing

Unknowns

18. Human error during implementation

19. Unexpected consequences

Risks or Concerns and Benefits of Stratospheric Geoengineering

Risks or Concerns

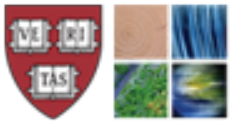
Governance

20. Cannot stop effects quickly
21. Commercial control
22. Whose hand on the thermostat?
23. Societal disruption, conflict between countries
24. Conflicts with current treaties
25. Moral hazard—the prospect of it working could reduce drive for mitigation

Ethics

26. Military use of technology
27. Moral authority—do we have the right to do this?

SRM Research

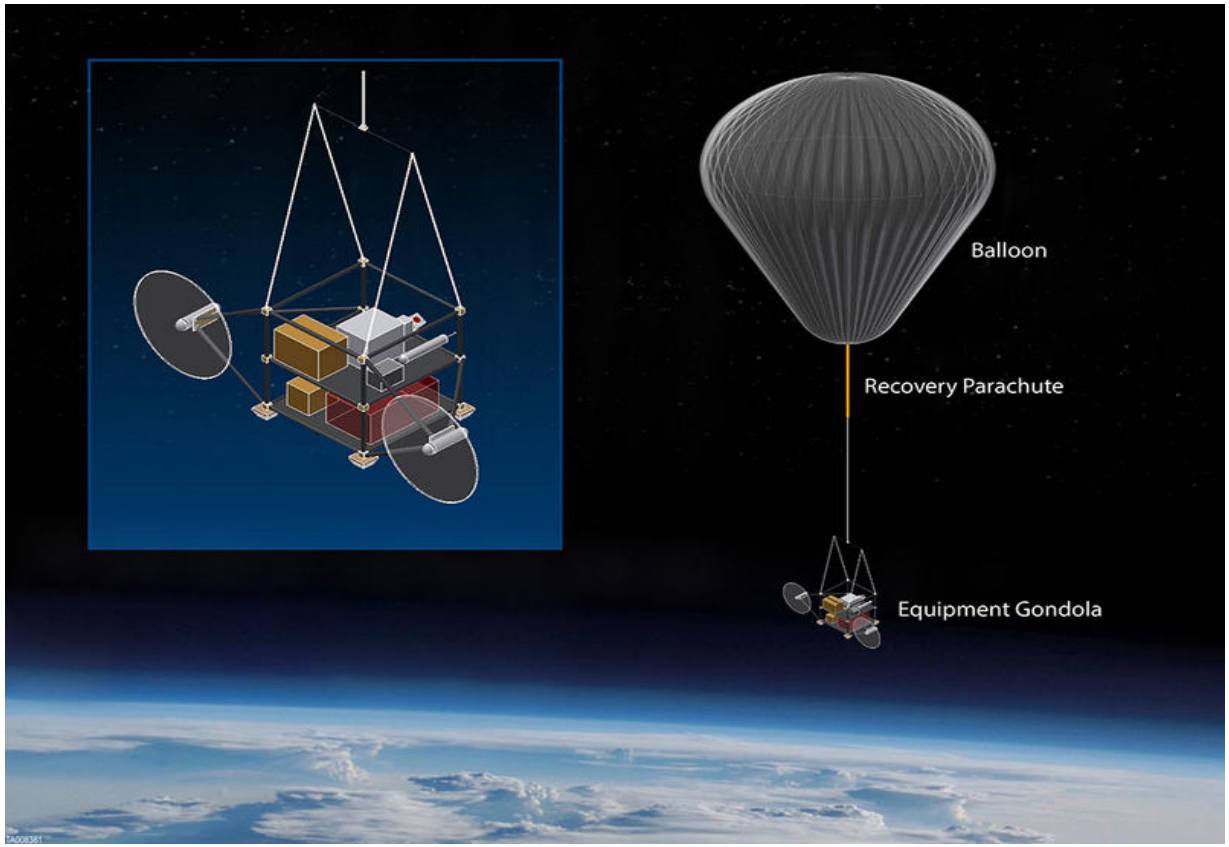


HARVARD'S SOLAR GEOENGINEERING RESEARCH PROGRAM

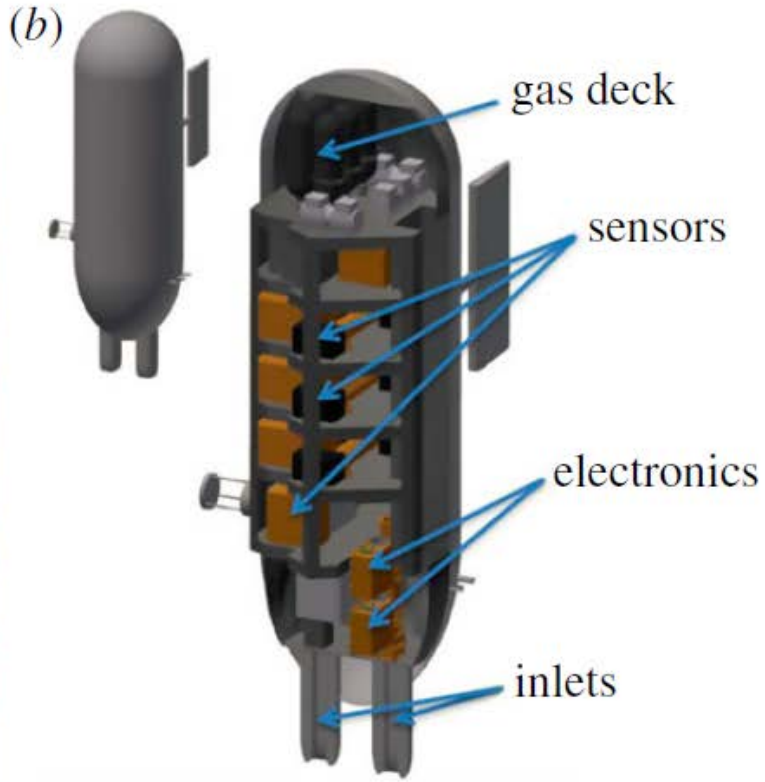
Stratospheric Controlled Perturbation Experiment SCoPEx

Harvard's Solar Geoengineering Research Program is funded by the following foundations and individuals. All donations are philanthropic gifts.

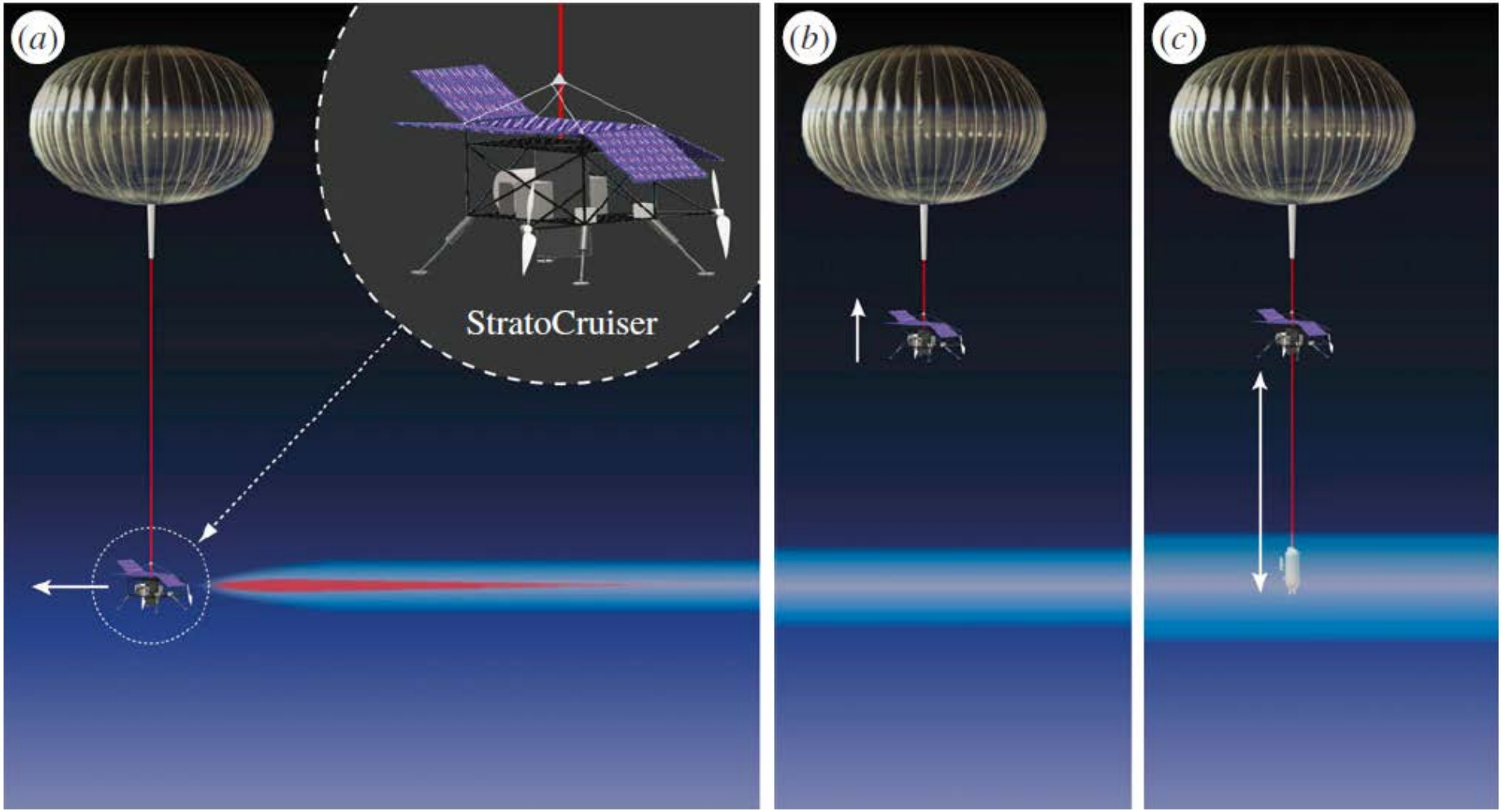
Stratospheric Controlled Perturbation Experiment SCoPEx



Stratospheric Controlled Perturbation Experiment SCoPEx



Stratospheric Controlled Perturbation Experiment SCoPEx



Convention on Biological Diversity

Climate-related Geoengineering and Biodiversity

"…no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies…"

nature International weekly journal of science

March 7, 2019
Geoengineering debate shifts to United Nations Environment Assembly (UNEA)

theguardian

March 18, 2019

US and Saudi Arabia blocking regulation of geoengineering

nature International weekly journal of science

July 30, 2019

Harvard creates advisory panel to oversee solar geoengineering project

nature climate change

LETTERS

https://doi.org/10.1038/s41558-019-0398-8

Nature Climate Change 9(2019)295

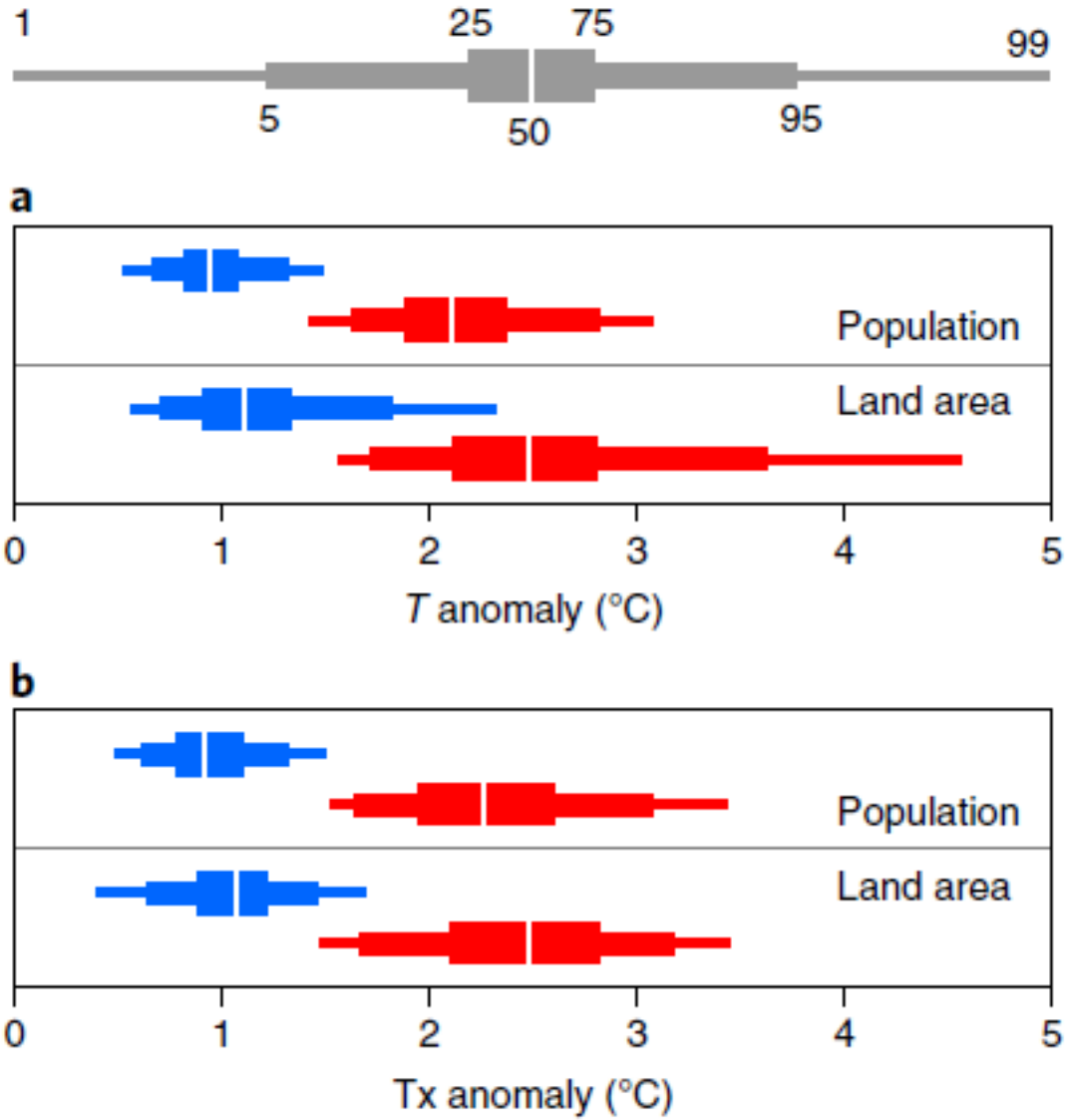
Halving warming with idealized solar geoengineering moderates key climate hazards

Peter Irvine, Kerry Emanuel, Jie He, Larry W. Horowitz, Gabriel Vecchi and David Keith

Distribution of 2×CO_2 and half-SG temperature anomalies weighted by land area and population

580 ppm CO2 concentration

1% decrease solar insolation



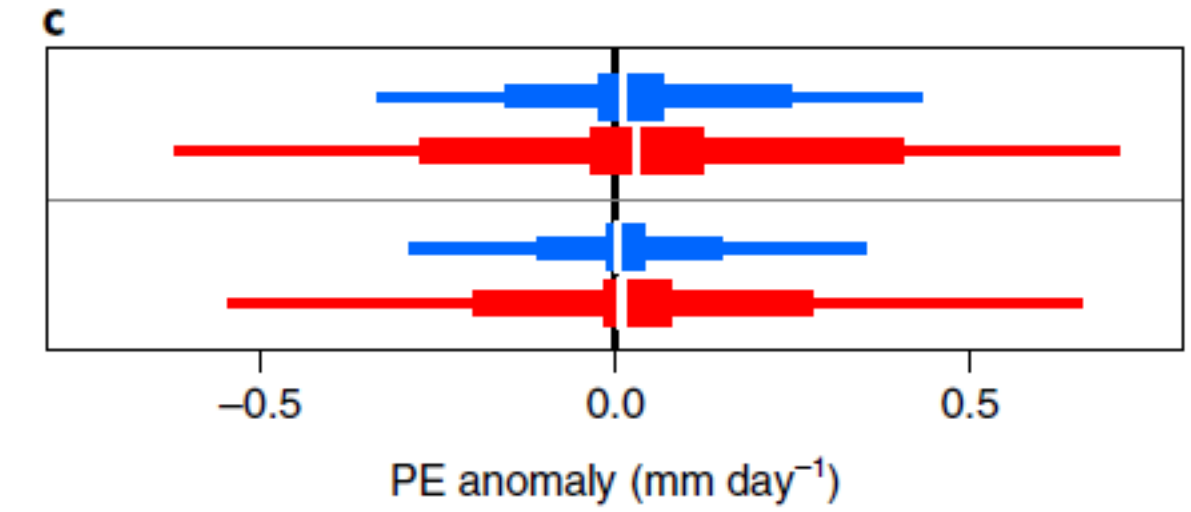
2×CO_2

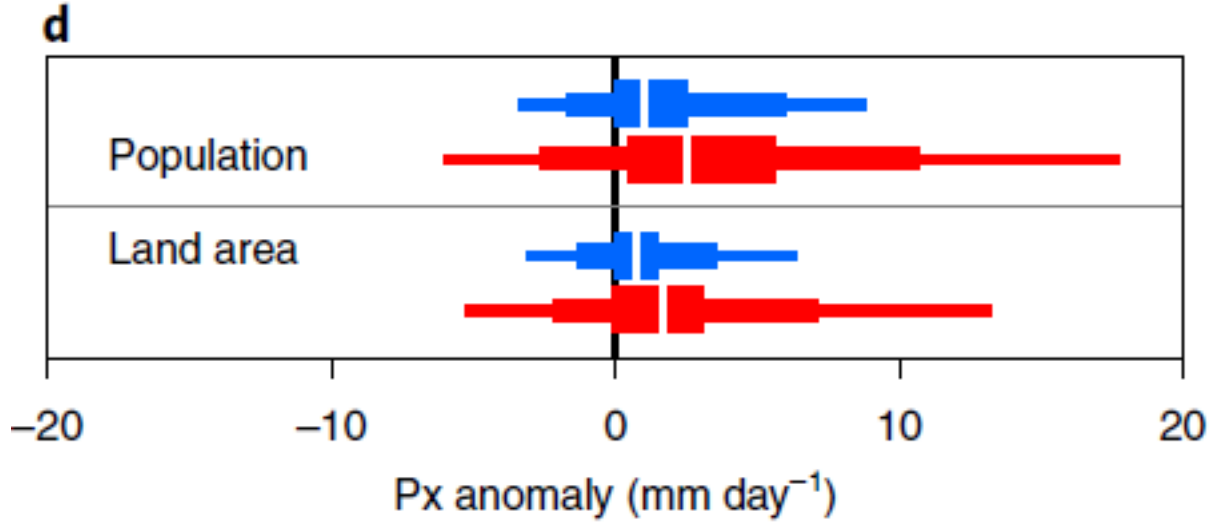
half-SG

Distribution of 2×CO_2 and half-SG precipitation anomalies weighted by land area and population

580 ppm CO2 concentration

1% decrease solar insolation

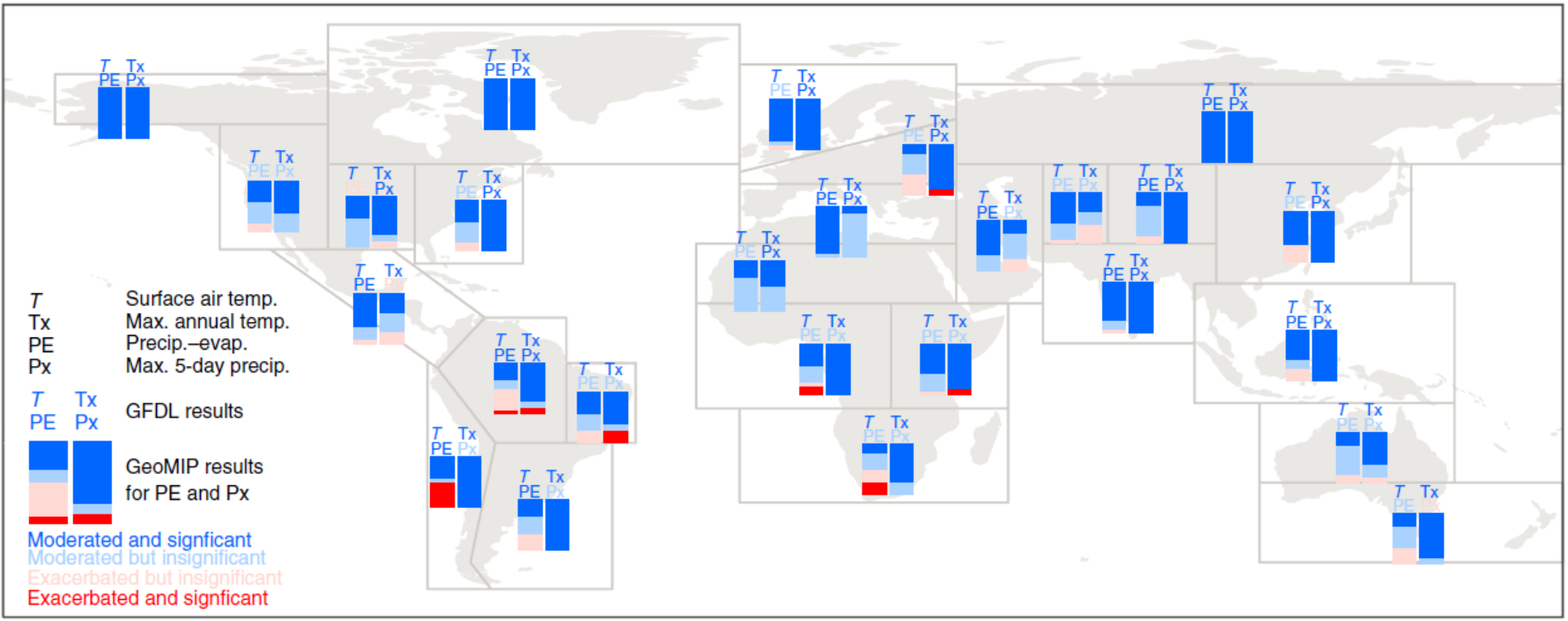




2×CO_2

half-SG

Regional distribution of half-SG moderation or exacerbation



Moderated and signficant
Moderated but insignificant
Exacerbated but insignificant
Exacerbated and signficant

Gordon Research Conferences

frontiers of science

Physical Processes and Societal Impacts of Radiation Management Approaches to Climate Change

Dates
June 27 – 28, 2020

Organizers
Chairs: Katherine Dagon an Daniele Visioni

Location
Newry, ME

Apply Now

Geoengineering Summary

- GHG emissions reduction proceeding slowly
- Atmospheric GHG burden increasing
- Global average temperature peak uncertain in both magnitude and time
- CDR and SRM can in principle reduce global temperature
- Some SRM strategies could be effective, feasible, rapid, and affordable
- Research in SRM controversial, some recommend and some oppose