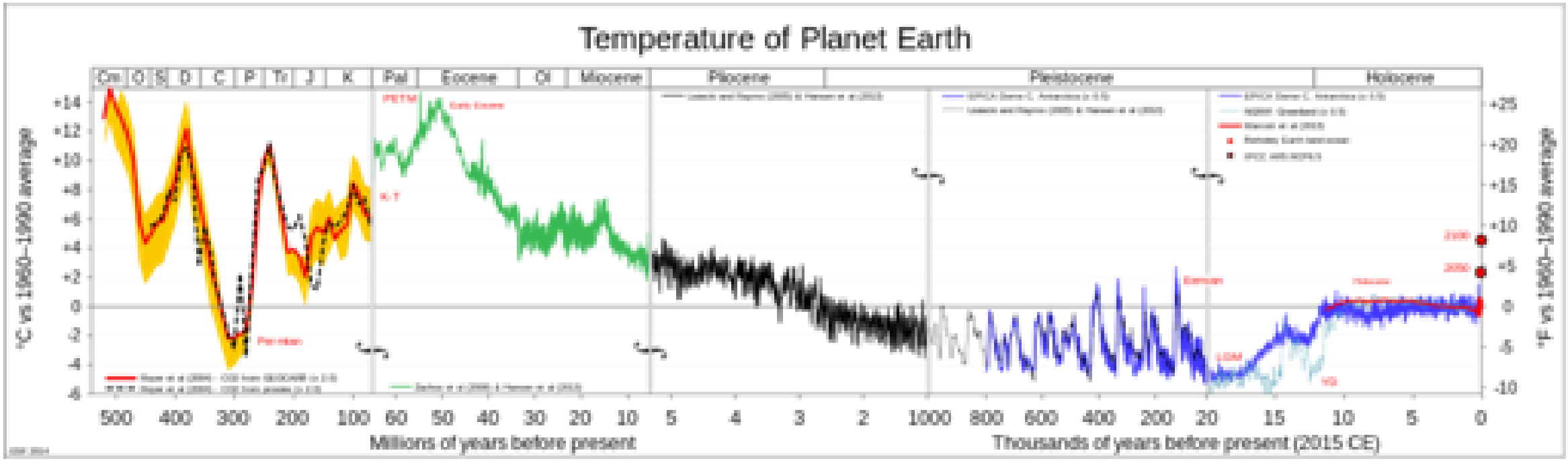
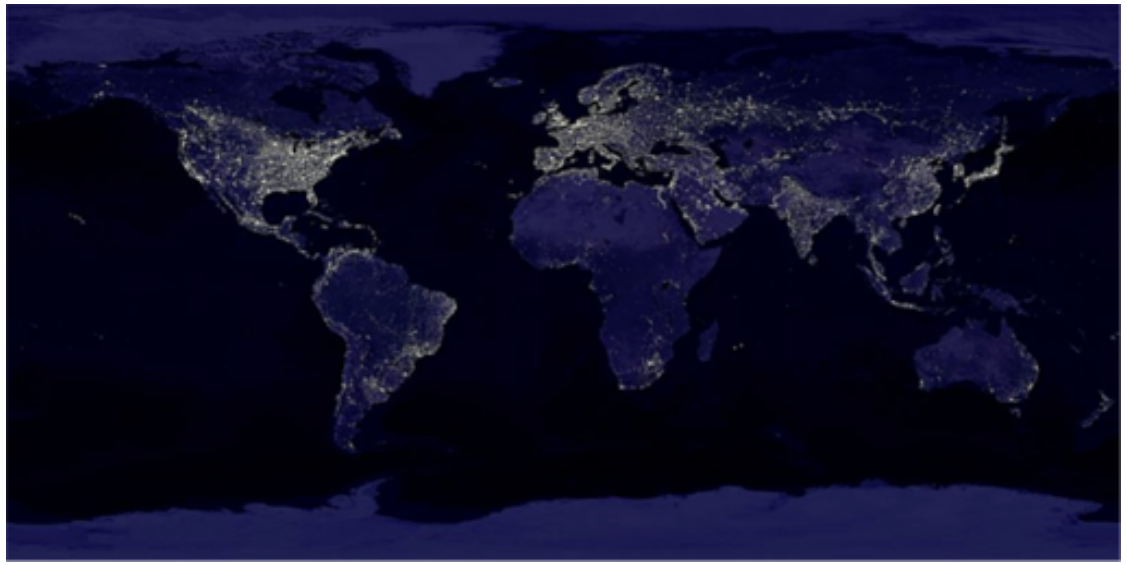
Changes in the Earth System

Have we entered a new epoch?



The Case for the Anthropocene

- Proposed new epoch that has resulted primarily from human changes to the planet's:
  - Elemental cycles
  - Climate
  - Biological diversity



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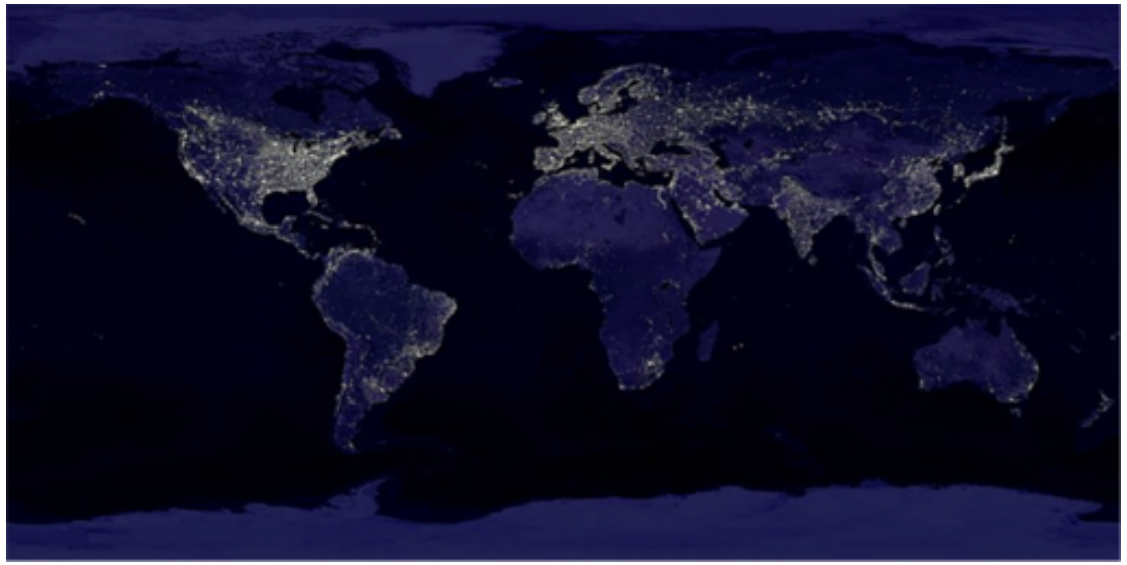

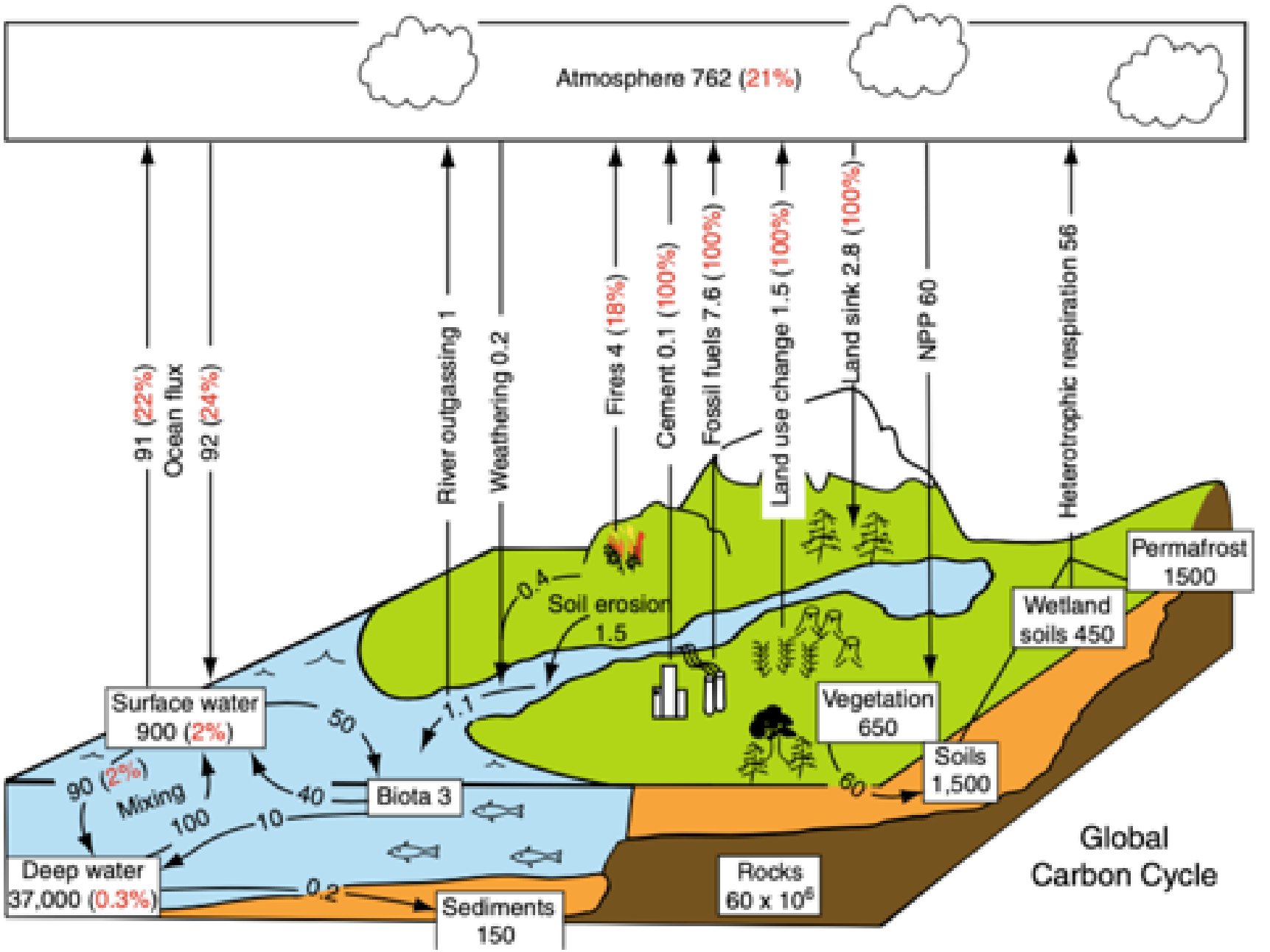

Units: 10^{15} g/yr

Chapin et al. (2011)

CO_2 is increasing in the atmosphere

Earth System Science Data

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Data description paper | 11 Nov 2022

Global Carbon Budget 2022

Pierre Friedlingstein, Michael O'Sullivan, Matthew W. Jones, Robbie M. Andrew, Luke Gregor, Judith Hauck, Corinne Le Quéré, Ingrid T. Luijkx, Are Olsen, Glen P. Peters, Wouter Peters, Julia Pongratz, Clemens Schwingshackl, Stephen Sitch, Josep G. Canadell, Philippe Ciais, Robert B. Jackson, Simone R. Alin, Ramdane Alkama, Almut Arneth, Vivek K. Arora, Nicholas R. Bates, Meike Becker, Nicolas Bellouin, Henry C. Bittig, Laurent Bopp, Frédéric Chevallier, Louise P. Chini, Margot Cronin, Wiley Evans, Stefanie Falk, Richard A. Feely, Thomas Gasser, Marion Gehlen, Thanos Gkritzalis, Lucas Gloege, Giacomo Grassi, Nicolas Gruber, Özgür Gürses, Ian Harris, Matthew Hefner, Richard A. Houghton, George C. Hurtt, Yosuke Iida, Tatiana Ilyina, Atul K. Jain, Annika Jersild, Koji Kadono, Etsushi Kato, Daniel Kennedy, Kees Klein Goldewijk, Jürgen Knauer, Jan Ivar Korsbakken, Peter Landschützer, Nathalie Lefèvre, Keith Lindsay, Junjie Liu, Zhu Liu, Gregg Marland, Nicolas Mayot, Matthew J. McGrath, Nicolas Metzl, Natalie M. Monacci, David R. Munro, Shin-Ichiro Nakaoka, Yosuke Niwa, Kevin O'Brien, Tsuneo Ono, Paul I. Palmer, Naiqing Pan, Denis Pierrot, Katie Pocock, Benjamin Poulter, Laure Resplandy, Eddy Robertson, Christian Rödenbeck, Carmen Rodriguez, Thais M. Rosan, Jörg Schwinger, Roland Séférian, Jamie D. Shutler, Ingunn Skjelvan, Tobias Steinhoff, Qing Sun, Adrienne J. Sutton, Colm Sweeney, Shintaro Takao, Toste Tanhua, Pieter P. Tans, Xiangjun Tian, Hanqin Tian, Bronte Tilbrook, Hiroyuki Tsujino, Francesco Tubiello, Guido R. van der Werf, Anthony P. Walker, Rik Wanninkhof, Chris Whitehead, Anna Willstrand Wranne, Rebecca Wright, Wenping Yuan, Chao Yue, Xu Yue, Sönke Zaehle, Jiye Zeng, and Bo Zheng

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Flux	Amount (GtC/yr)
Fossil fuel burning	10.1
LULCC	1.1
Ocean uptake	2.9
Land uptake	3.5
Atmospheric growth	5.2
Uncertainty	1

CO_2 is increasing in the atmosphere

Earth Syst. Sci. Data, 10, 2141–2194, 2018
https://doi.org/10.5194/essd-10-2141-2018

Open Access Earth System Science Data

Global Carbon Budget 2018

Corinne Le Quéré[1], Robbie M. Andrew[2], Pierre Friedlingstein[3], Stephen Sitch[4], Judith Hauck[5], Julia Pongratz[6,7], Penelope A. Pickers[8], Jan Ivar Korsbakken[2], Glen P. Peters[2], Josep G. Canadell[9], Almut Arneth[10], Vivek K. Arora[11], Leticia Barbero[12,13], Ana Bastos[6], Laurent Bopp[14], Frédéric Chevallier[15], Louise P. Chini[16], Philippe Ciais[15], Scott C. Doney[17], Thanos Gkritzalis[18], Daniel S. Goll[15], Ian Harris[19], Vanessa Haverd[20], Forrest M. Hoffman[21], Mario Hoppema[5], Richard A. Houghton[22], George Hurtt[16], Tatiana Ilyina[7], Atul K. Jain[23], Truls Johannessen[24], Chris D. Jones[25], Etsushi Kato[26], Ralph F. Keeling[27], Kees Klein Goldewijk[28,29], Peter Landschützer[7], Nathalie Lefèvre[30], Sebastian Lienert[31], Zhu Liu[1,54], Danica Lombardozzi[32], Nicolas Metzl[30], David R. Munro[33], Julia E. M. S. Nabel[7], Shin-ichiro Nakaoka[34], Craig Neill[35,36], Are Olsen[24], Tsueno Ono[38], Prabir Patra[39], Anna Peregon[15], Wouter Peters[40,41], Philippe Peylin[15], Benjamin Pfeil[24,37], Denis Pierrot[12,13], Benjamin Poulter[42], Gregor Rehder[43], Laure Resplandy[44], Eddy Robertson[25], Matthias Rocher[45], Christian Rödenbeck[46], Ute Schuster[4], Jörg Schwinger[37], Roland Séférian[45], Ingunn Skjelvan[37], Tobias Steinhoff[47], Adrienne Sutton[48], Pieter P. Tans[49], Hanqin Tian[50], Bronte Tilbrook[35,36], Francesco N. Tubiello[51], Ingrid T. van der Laan-Luijkx[40], Guido R. van der Werf[52], Nicolas Viovy[15], Anthony P. Walker[53], Andrew J. Wiltshire[25], Rebecca Wright[1,8], Sönke Zaehle[46], and Bo Zheng[15]

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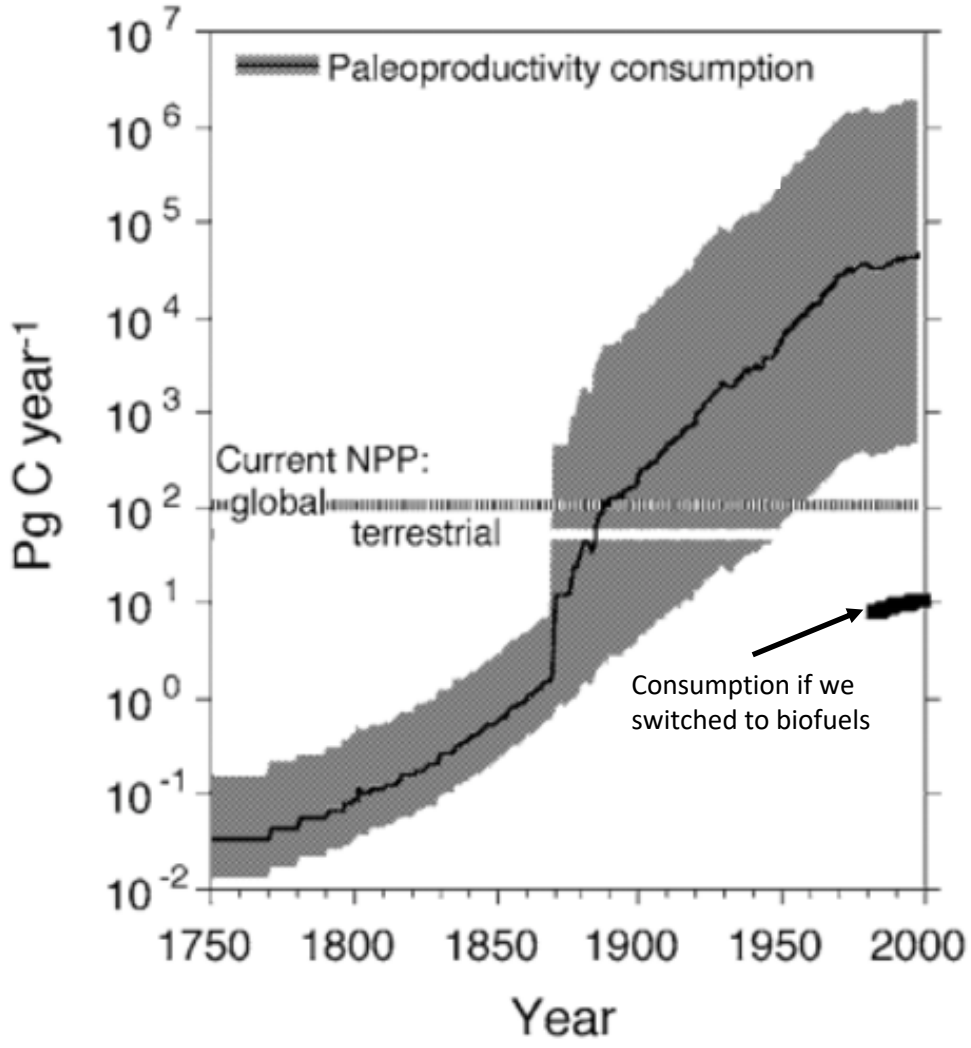
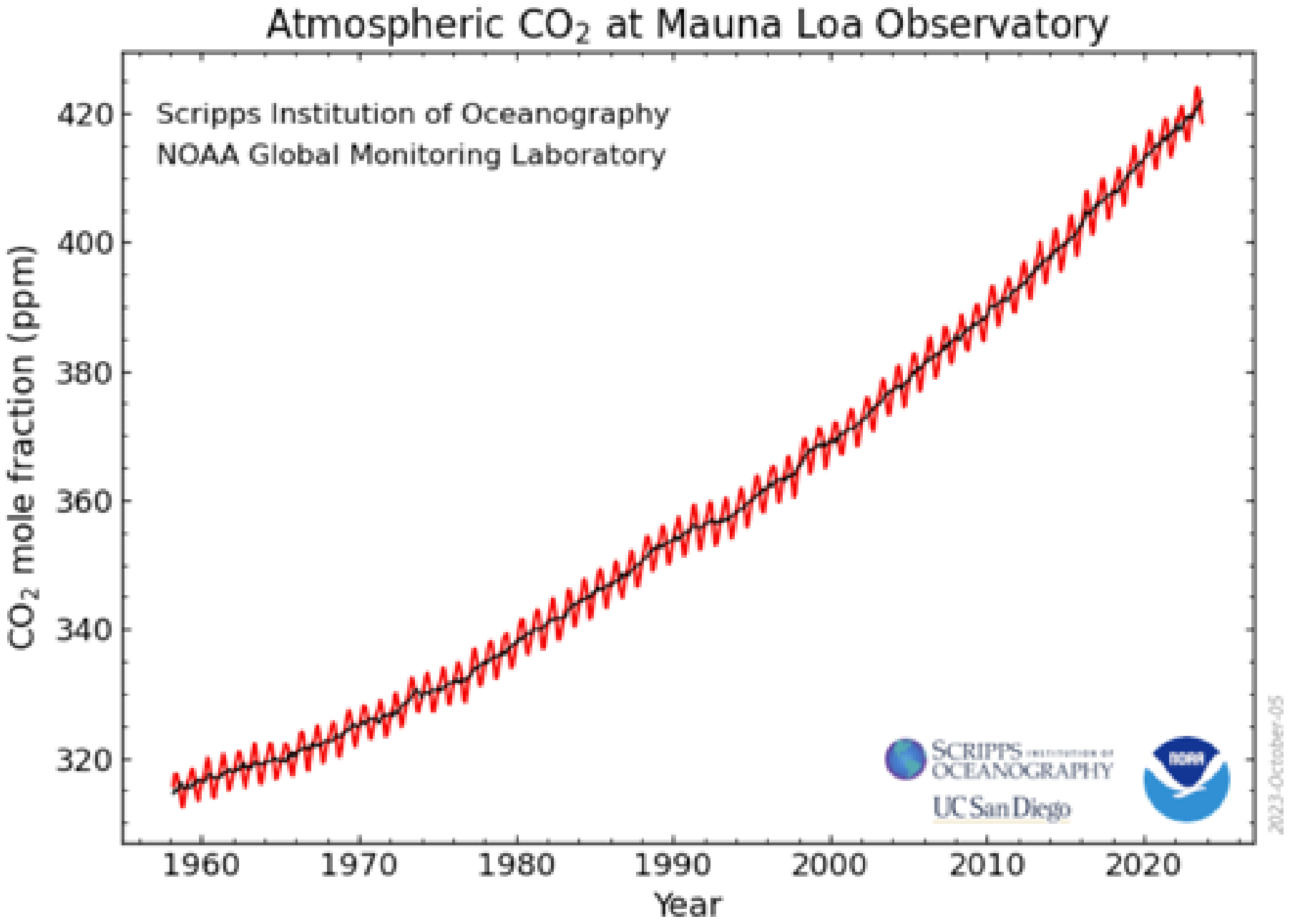
Uncertainty	1

1.1 higher than book estimate (2007)

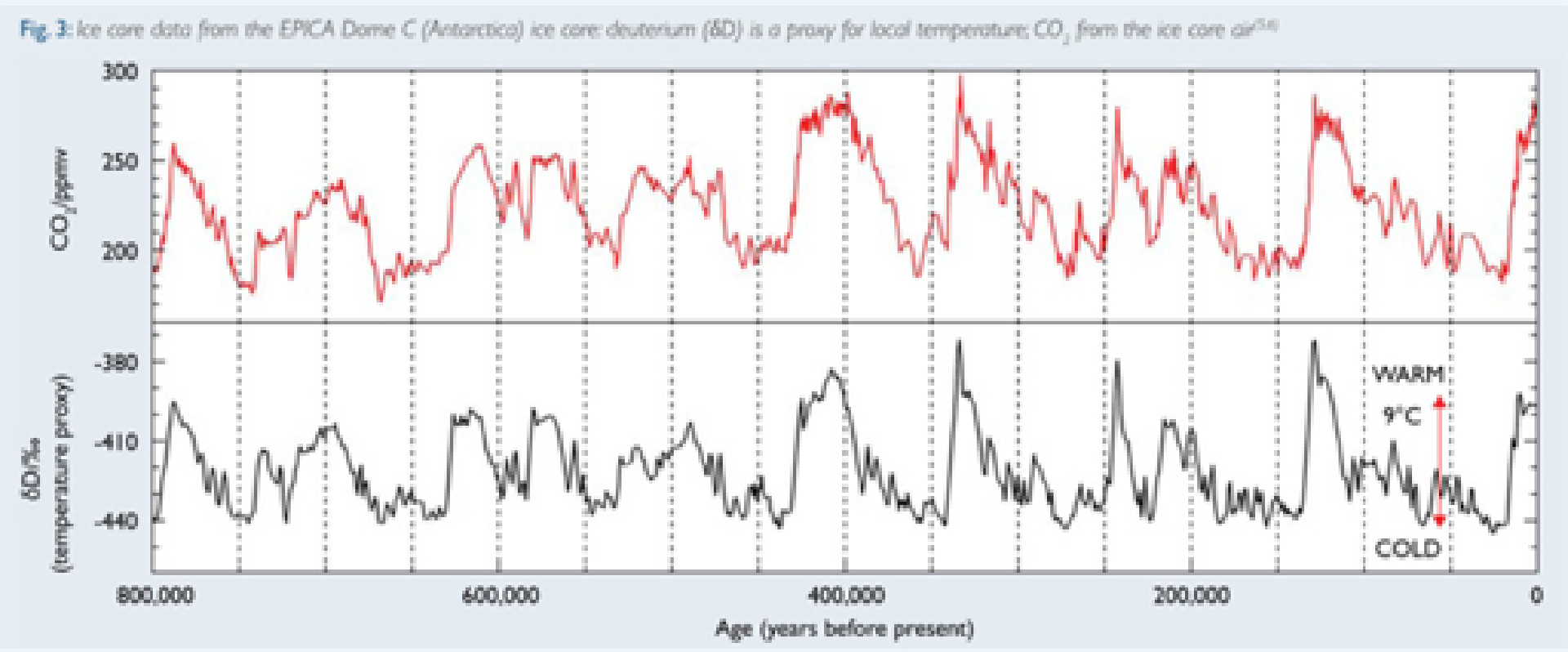


We are using more carbon than plants are putting back

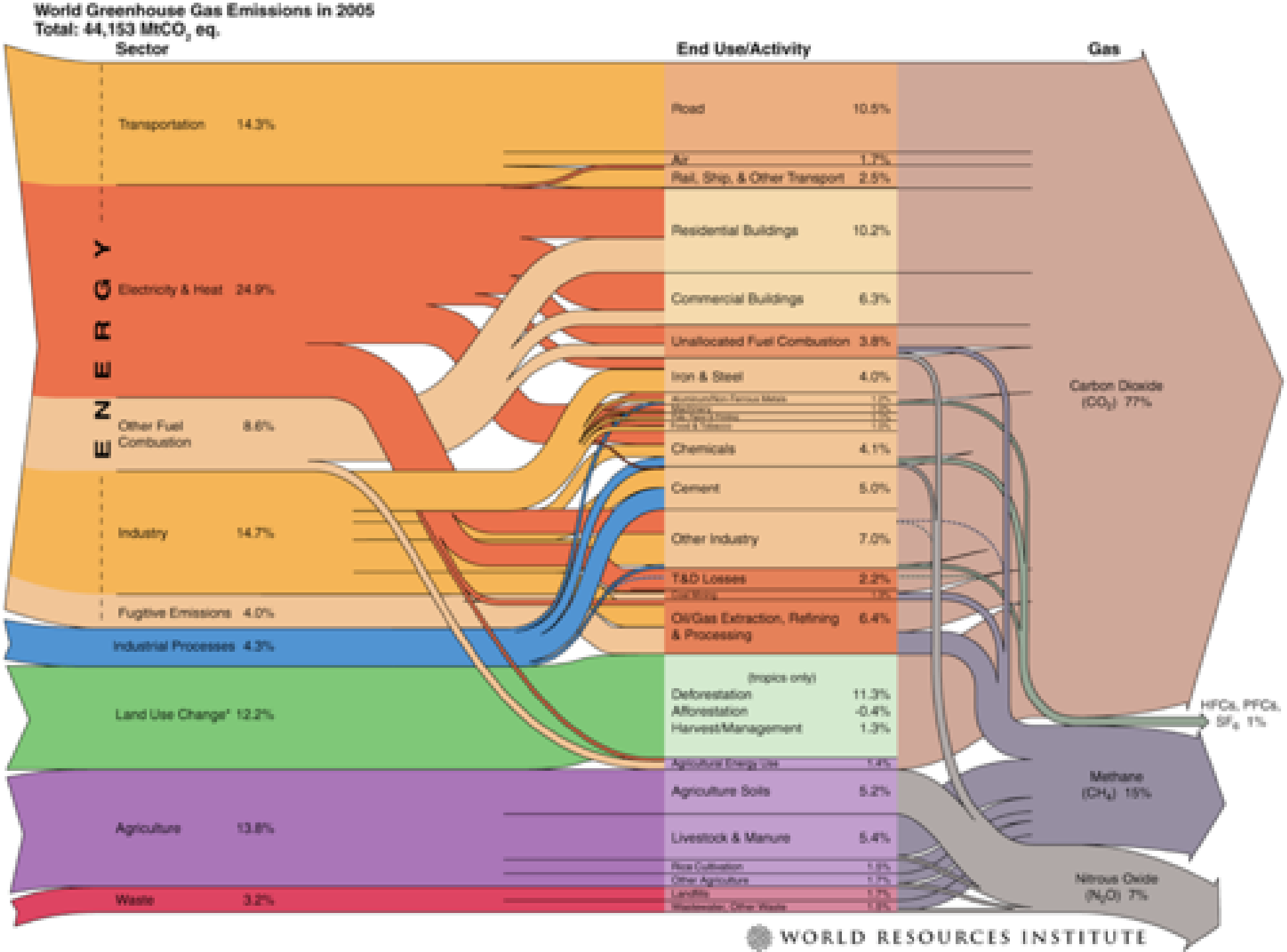
Dukes (2003) “Burning buried sunshine”



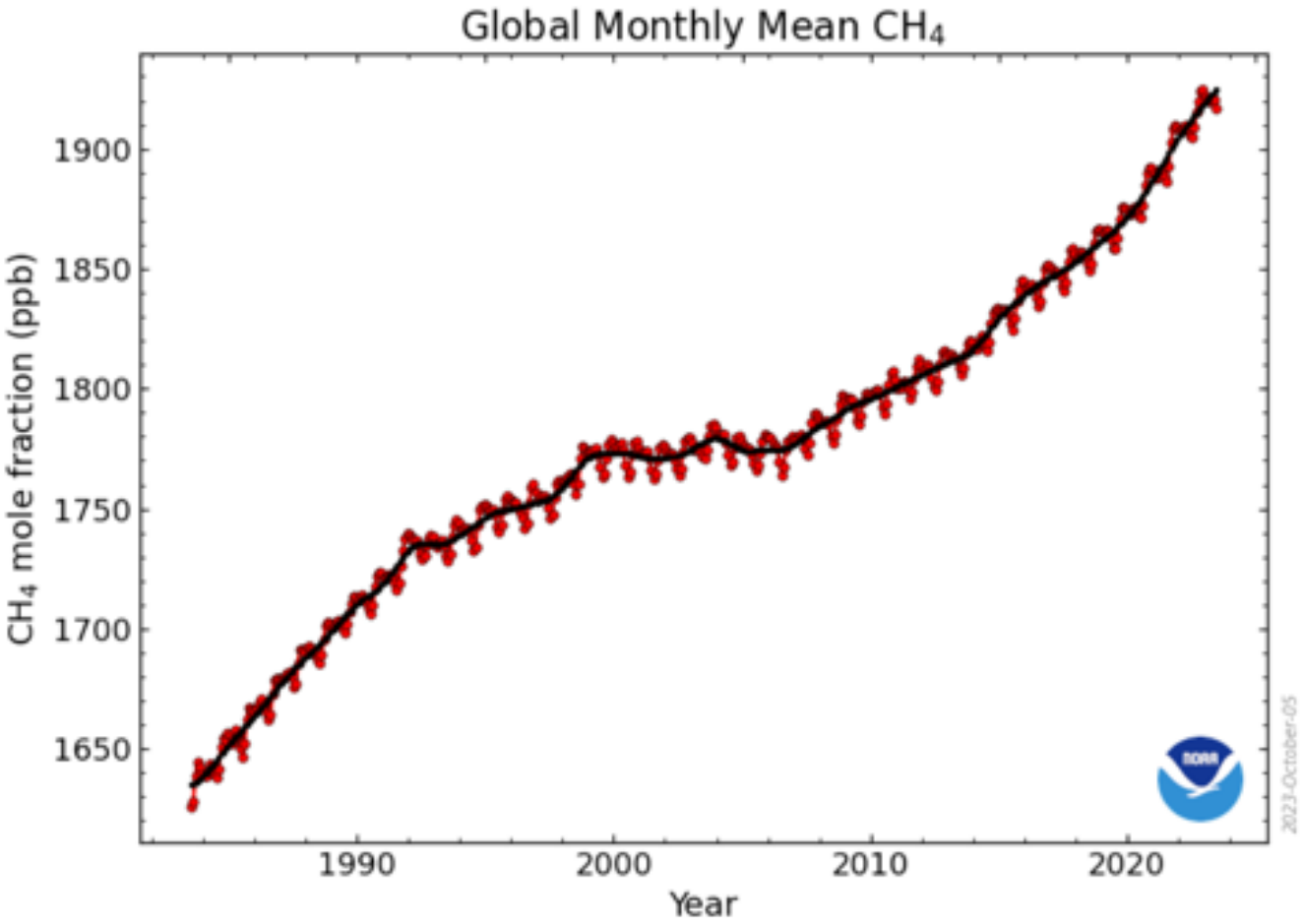
Going up ~1.5 ppm / year over the record, but 2.6 ppm over last 12 months

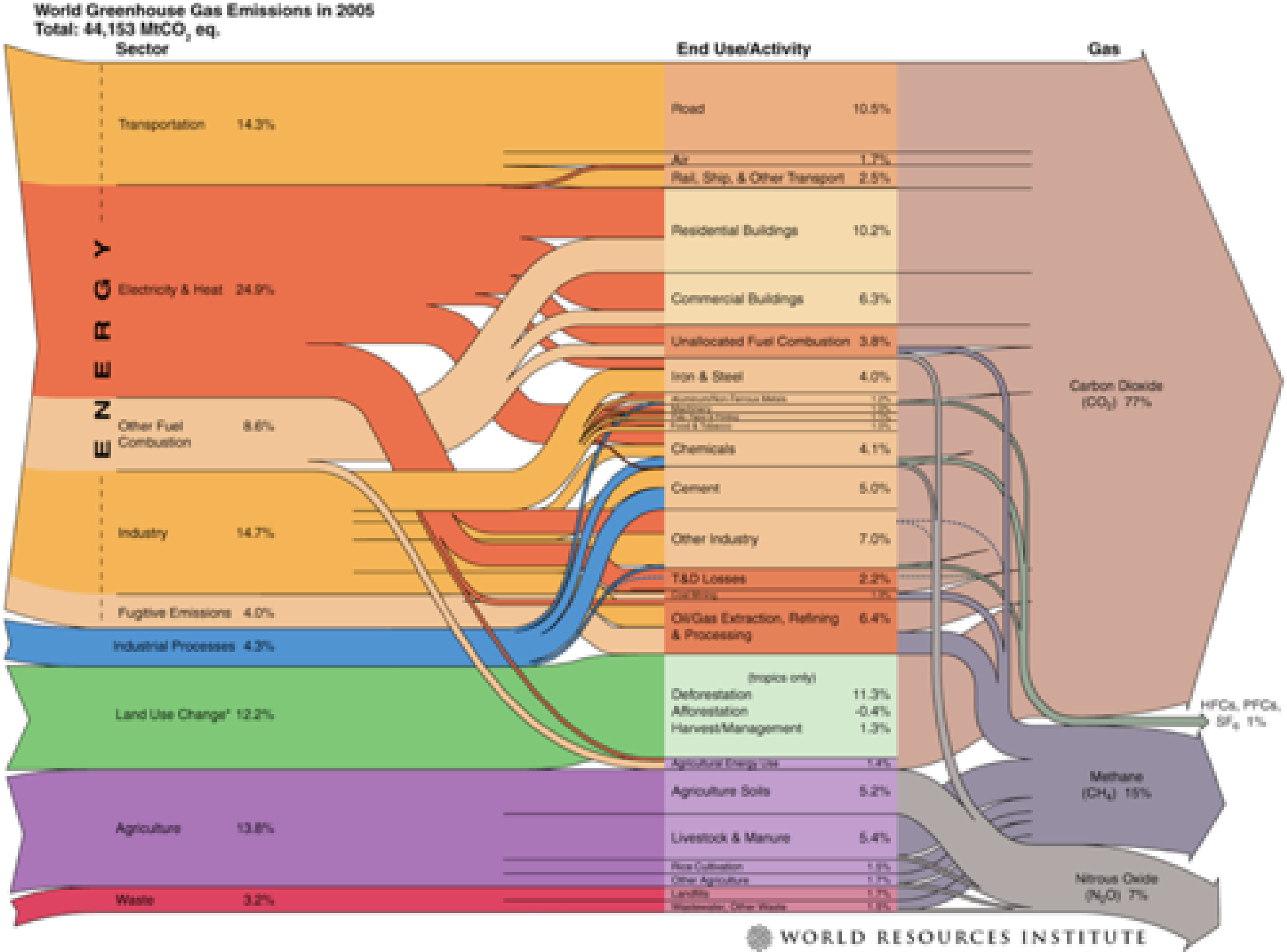


Historical rate of change: ~0.002 ppm / year


World Greenhouse Gas Emissions in 2005
Total: 44,153 MtCO2 eq.
Sector
End Use/Activity
Gas
ENERGY
Transportation 14.3%
Electricity & Heat 24.9%
Other Fuel Combustion 8.6%
Industry 14.7%
Fugitive Emissions 4.0%
Industrial Processes 4.3%
Land Use Change* 12.2%
Agriculture 13.8%
Waste 3.2%
Road 10.5%
Air 1.7%
Rail, Ship, & Other Transport 2.5%
Residential Buildings 10.2%
Commercial Buildings 6.3%
Unallocated Fuel Combustion 3.8%
Iron & Steel 4.0%
Chemicals 4.1%
Cement 5.0%
Other Industry 7.0%
T&D Losses 2.2%
Oil/Gas Extraction, Refining & Processing 6.4%
(tropics only)
Deforestation 11.3%
Afforestation -0.4%
Harvest/Management 1.3%
Agriculture Soils 5.2%
Livestock & Manure 5.4%
Carbon Dioxide (CO2) 77%
HFCs, PFCs, SF6 1%
Methane (CH4) 15%
Nitrous Oxide (N2O) 7%
WORLD RESOURCES INSTITUTE

Atmospheric methane (CH4) is also going up

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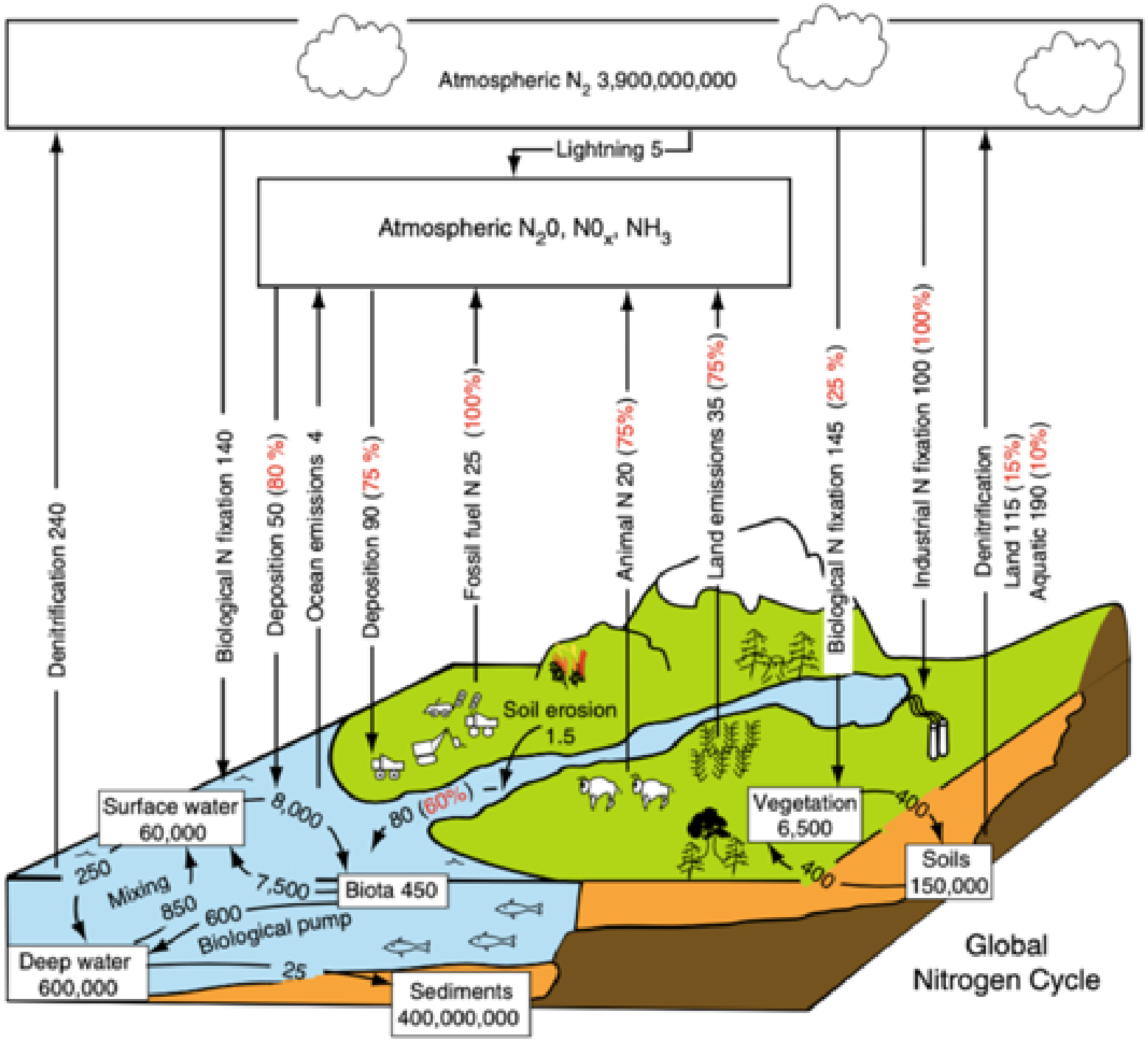
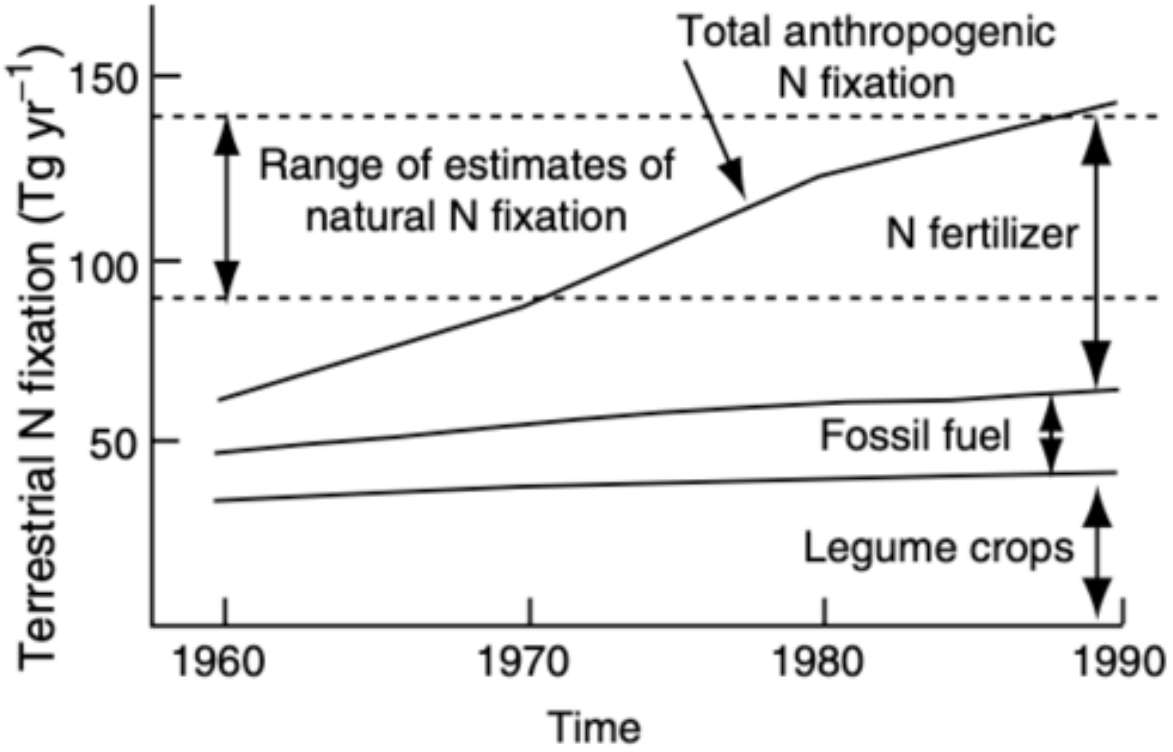


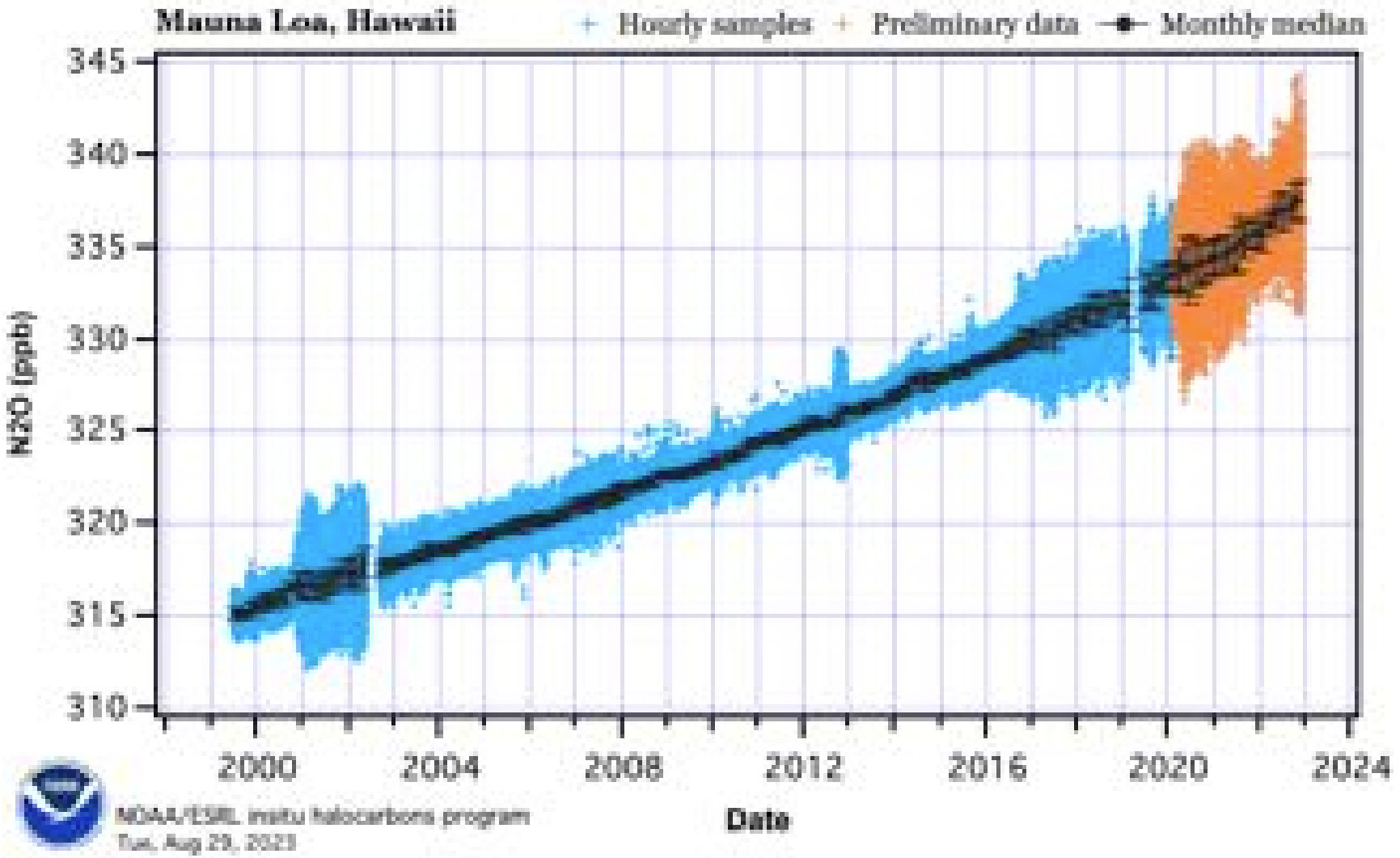
Units: 10^{12} g/yr

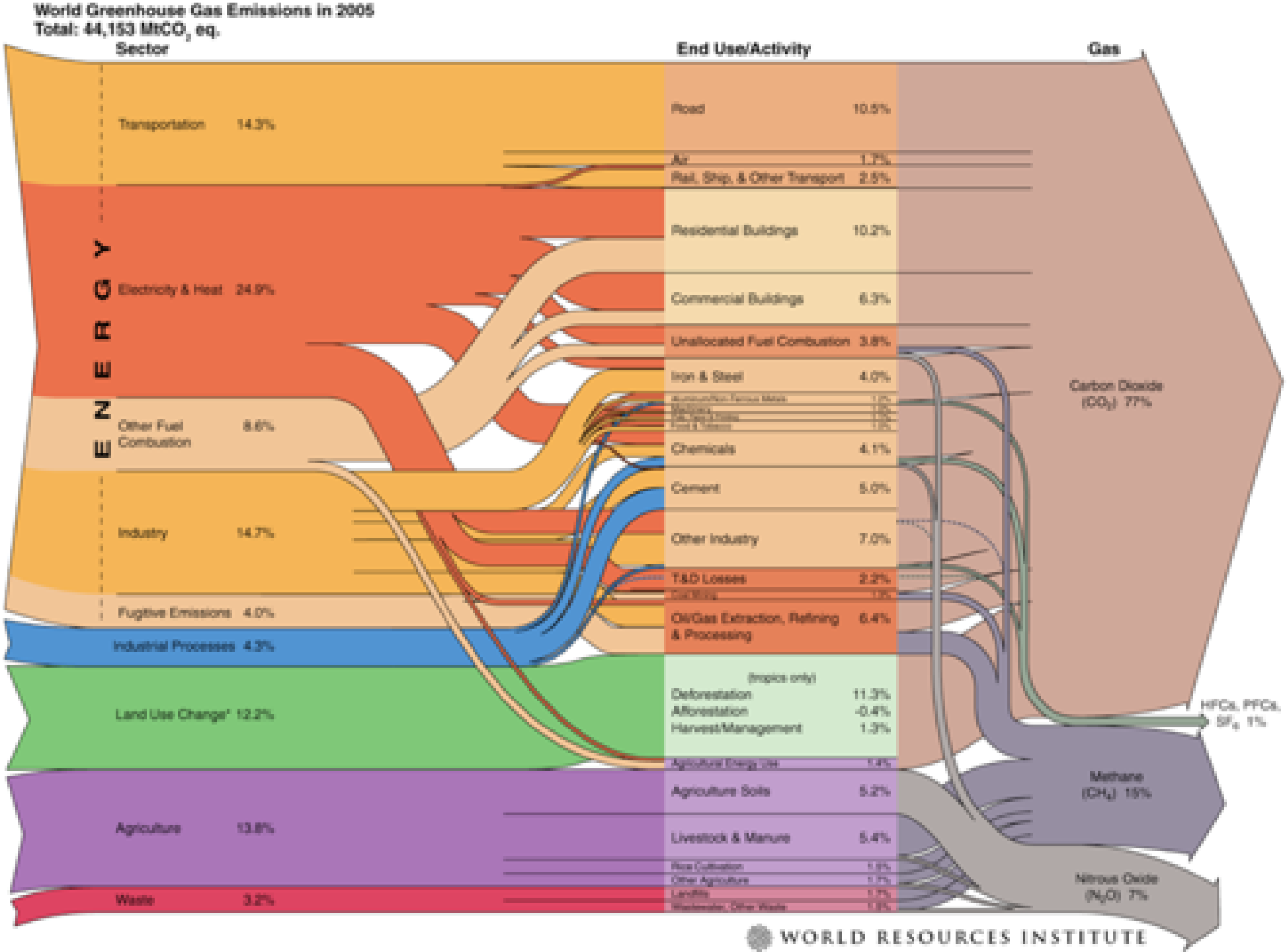
Chapin et al. (2011)

We’re pulling in a lot of atmospheric N…



…while also pumping out a lot in new forms

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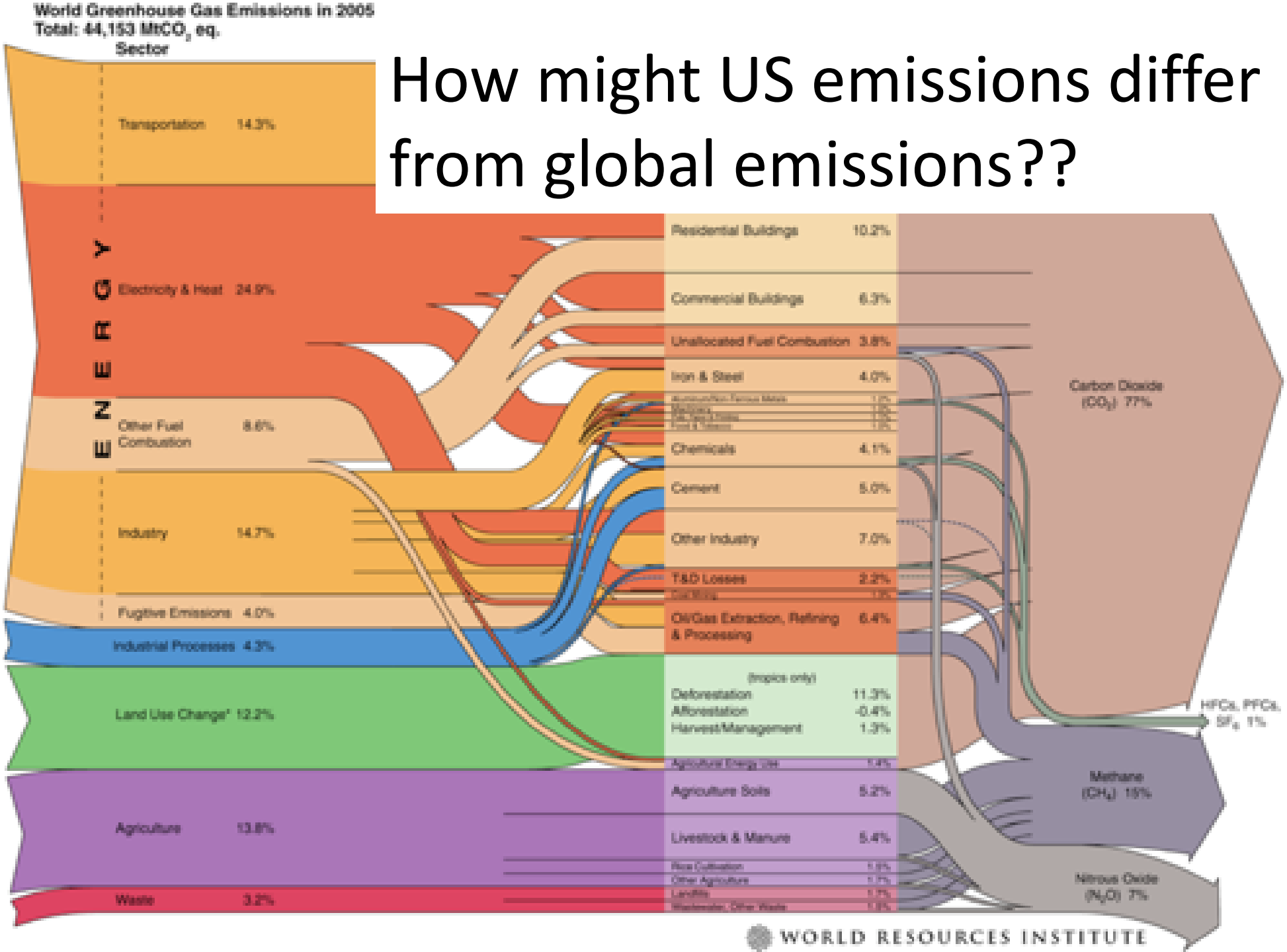
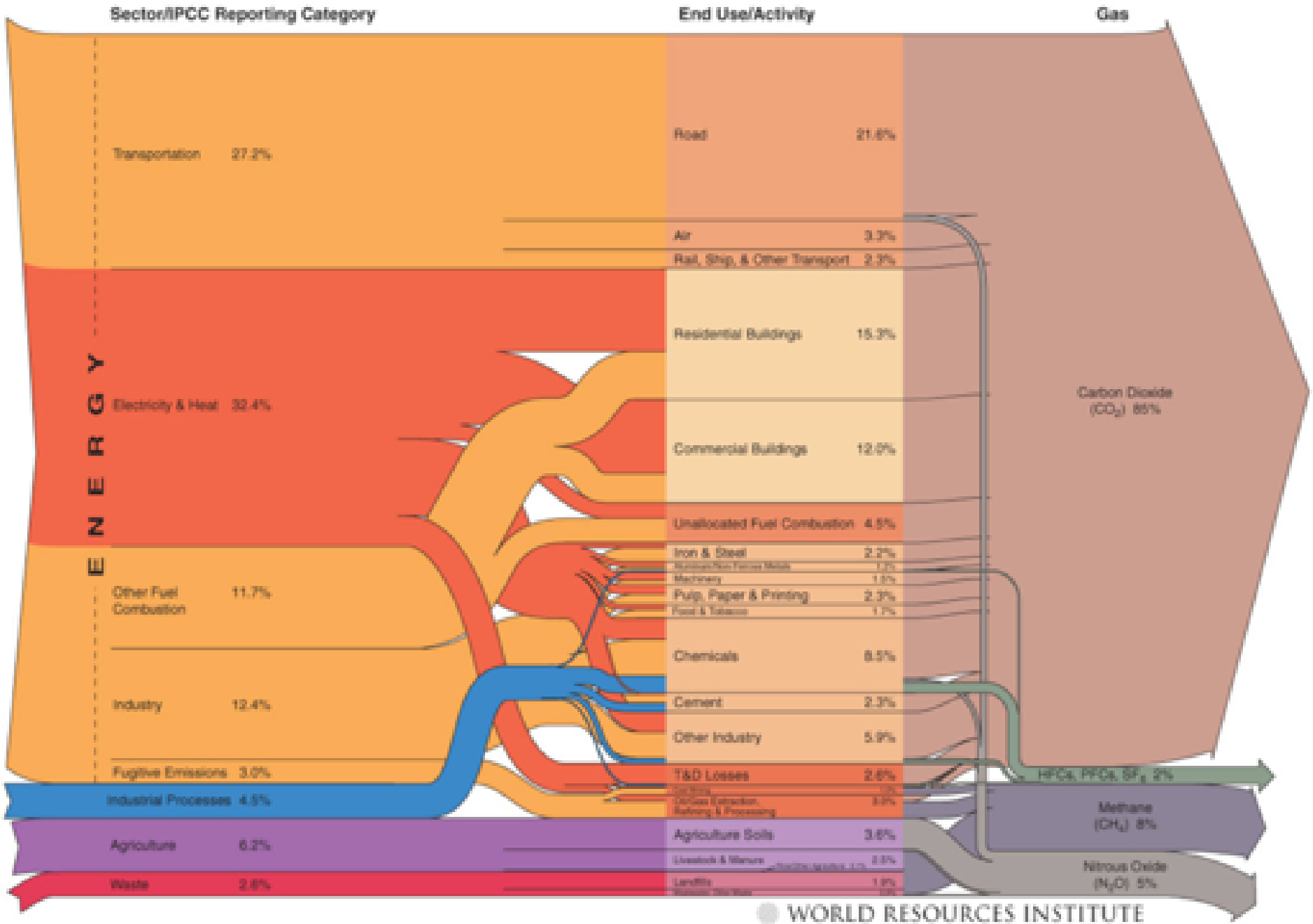
How might US emissions differ from global emissions??



U.S. GHG Emissions Flow Chart



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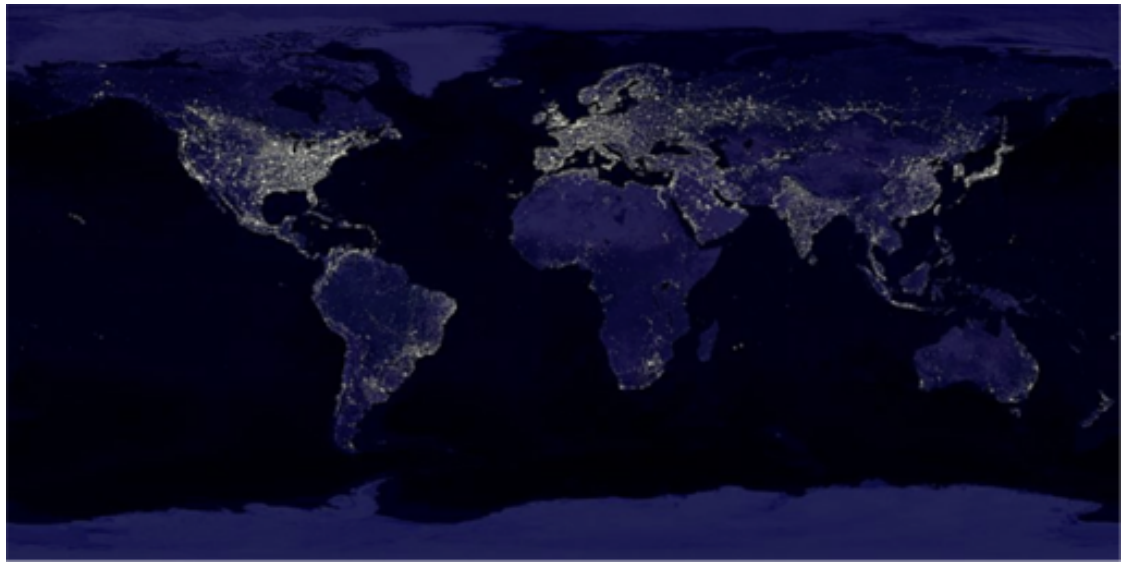
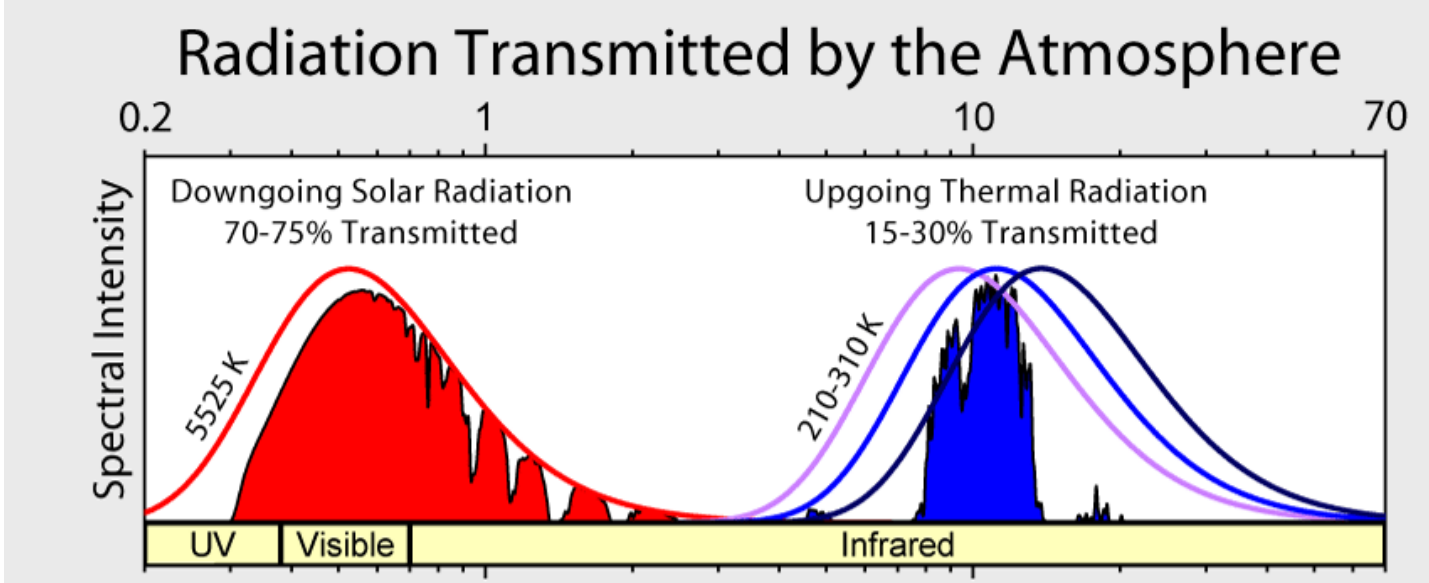
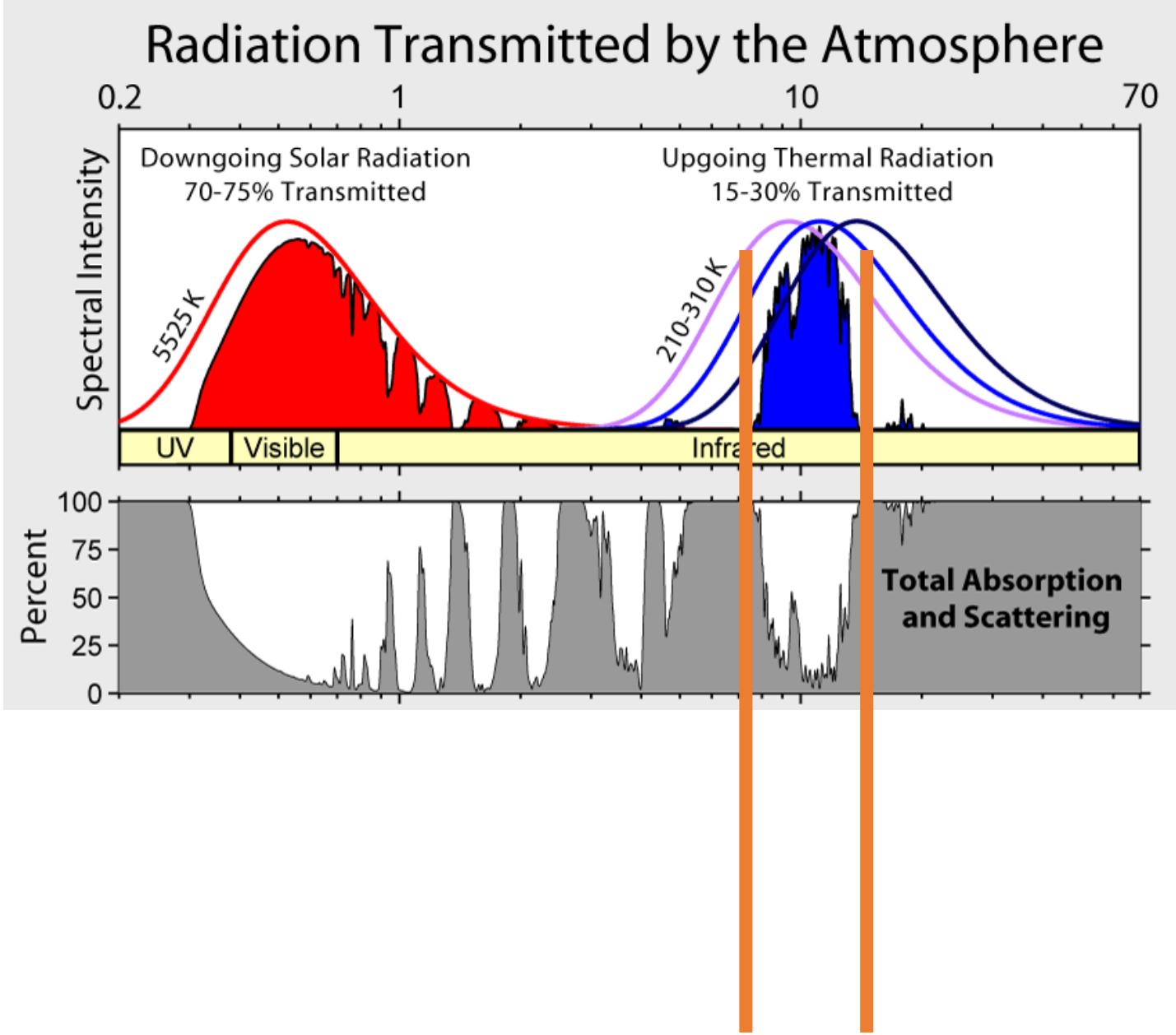


Climate change is the result of human changes to elemental cycles


Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared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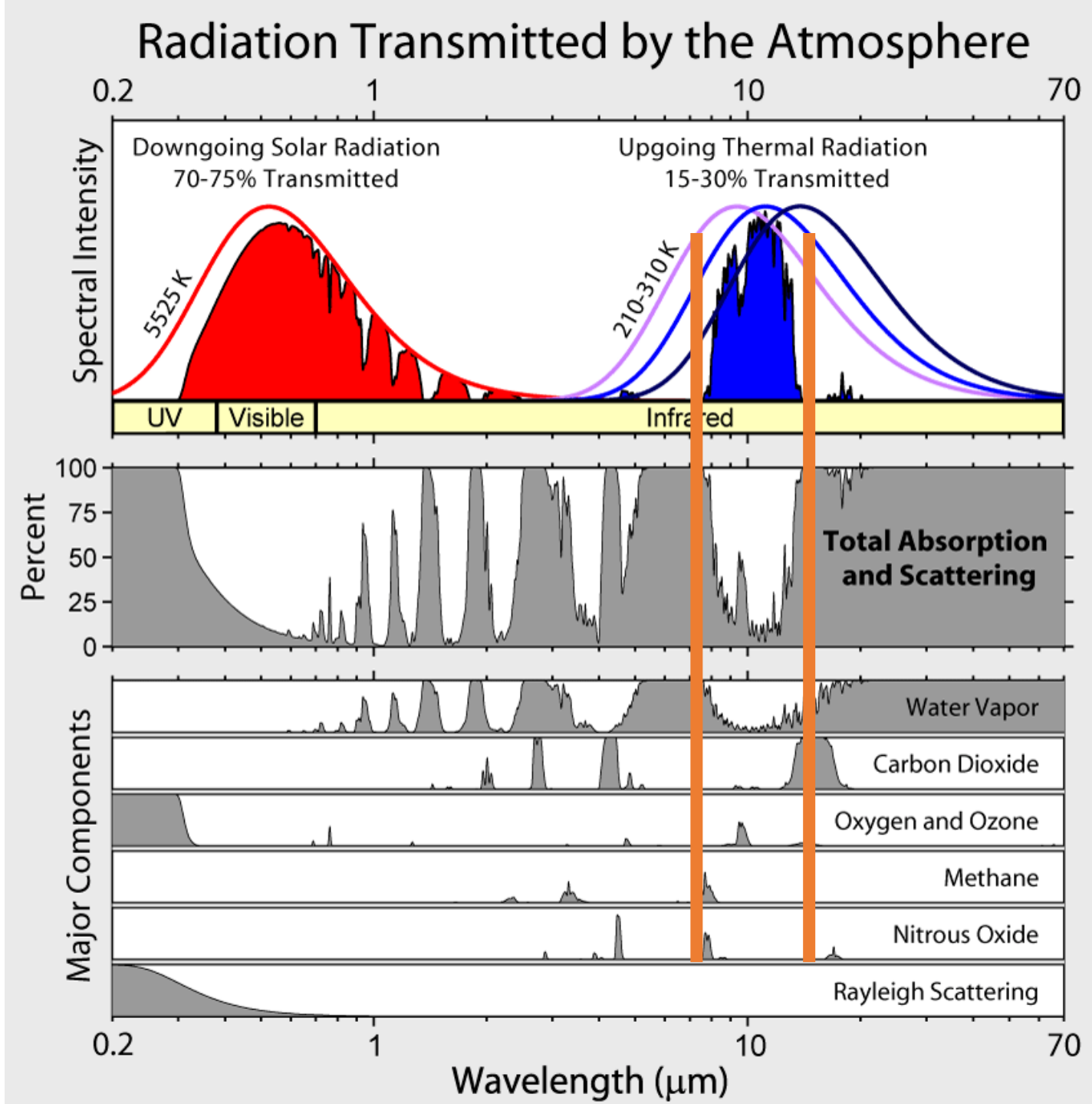
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption
and Scattering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Infrared
Percent
100
75
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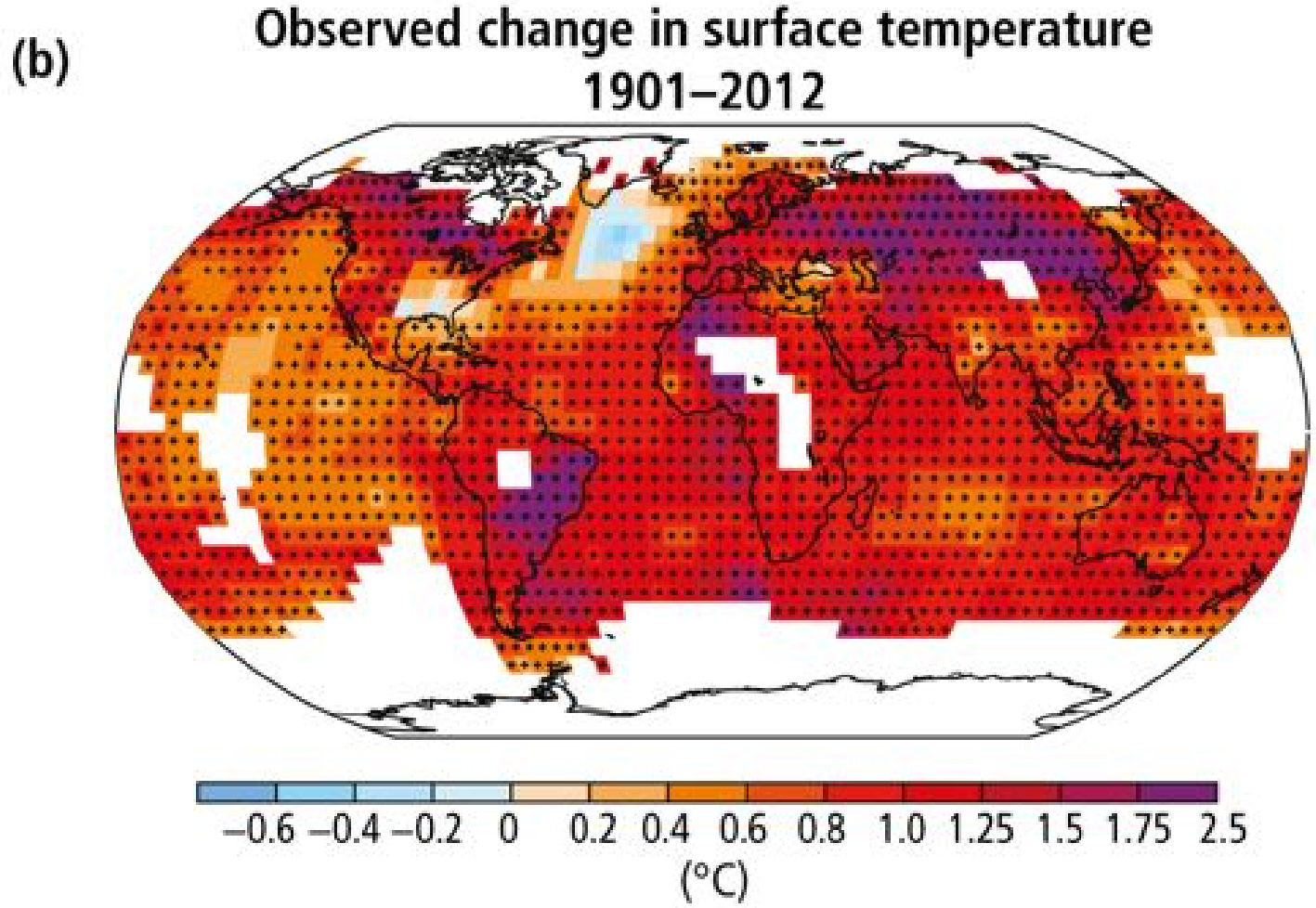
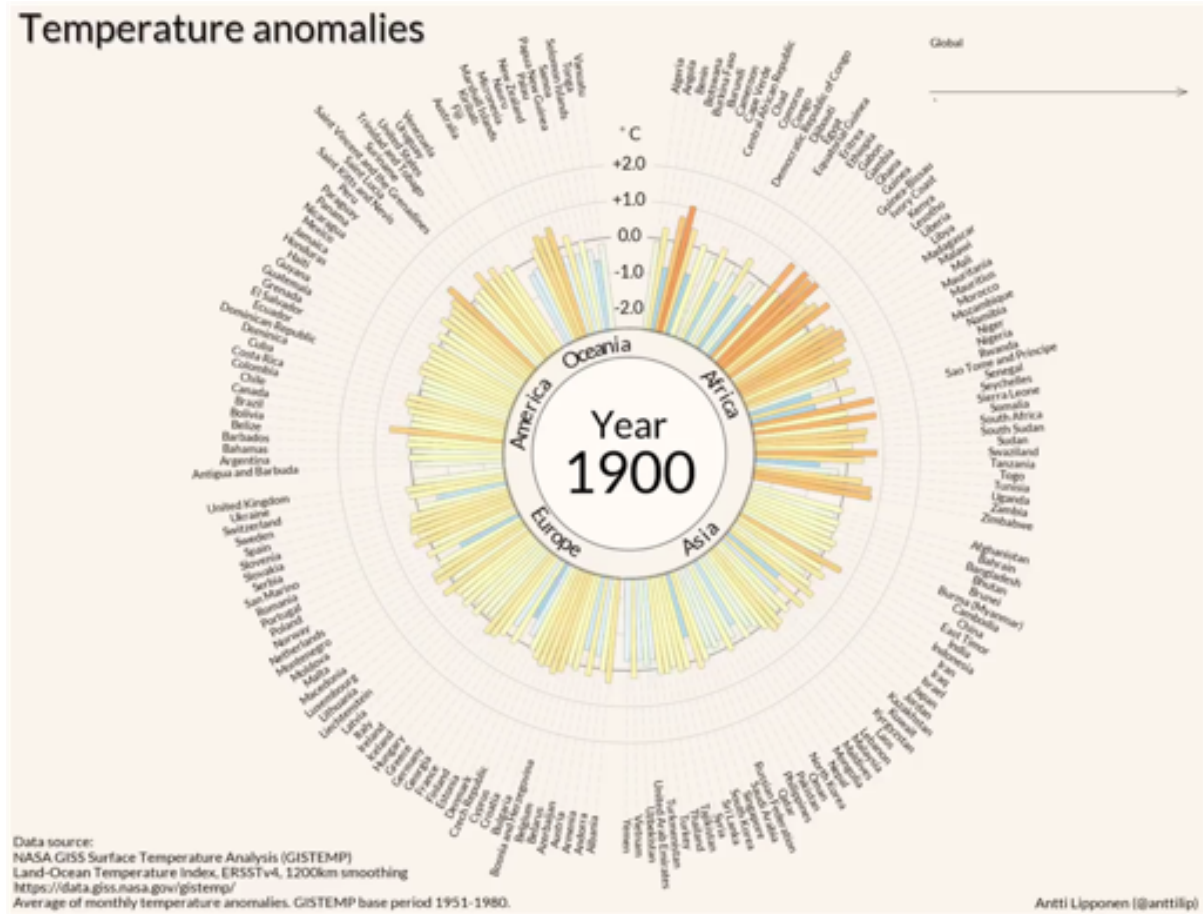
25
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

The climate is warming

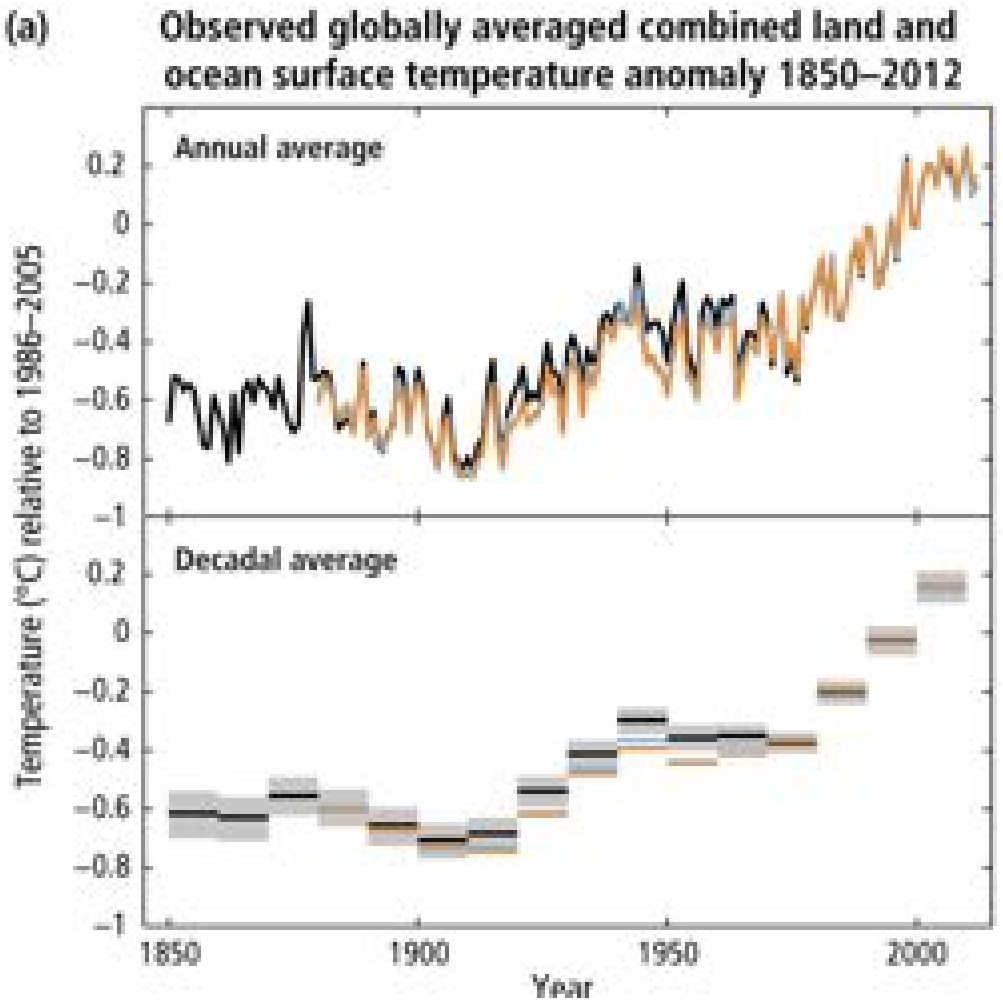


Poles and land are warming the fastest

IPCC (2013)


Temperature anomalies
Global
°C
+2.0
+1.0
0.0
-1.0
-2.0
Oceania
Africa
America
Asia
Europe
Year
1900
Data source:
NASA GISS Surface Temperature Analysis (GISTEMP)
Land-Ocean Temperature Index, ERSSTv4, 1200km smoothing
https://data.giss.nasa.gov/gistemp/
Average of monthly temperature anomalies. GISTEMP base period 1951-1980.
Antti Lipponen (@anttilip)

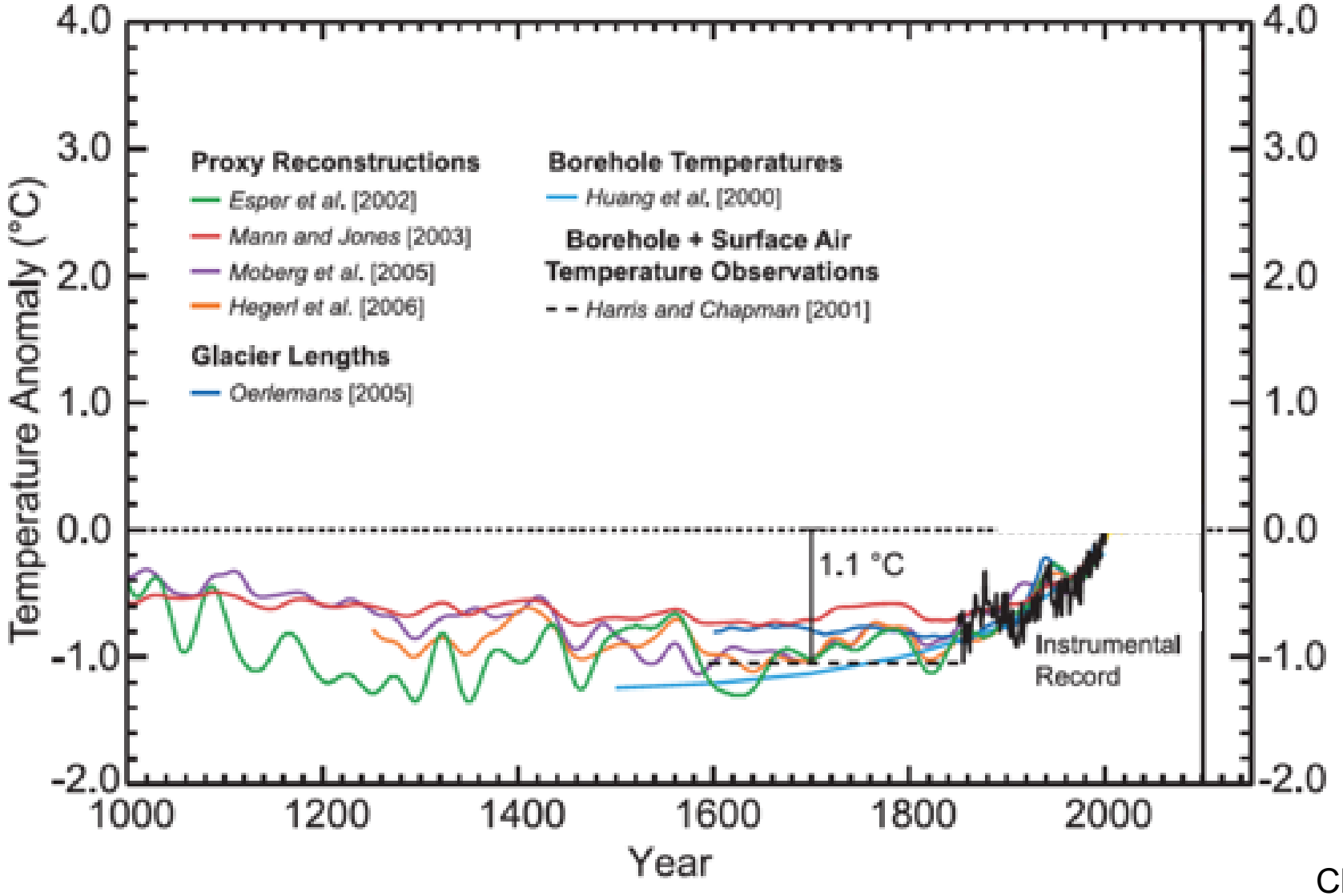
It’s warmer now than 150 years ago



The global mean temperature has increased ~1.5° F (0.8° C) over the past 150 years

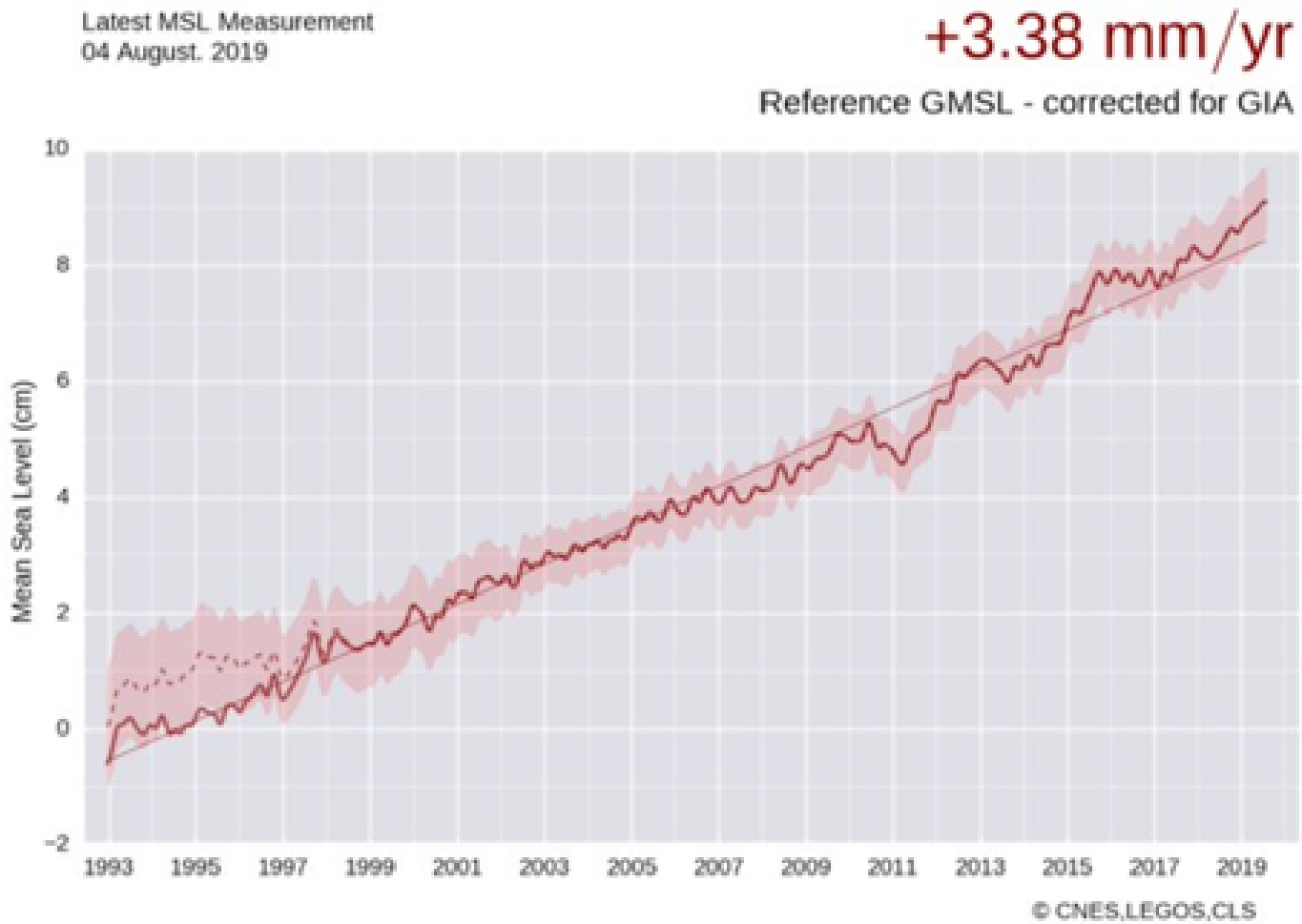
IPCC (2013)

And warmest it's been in the past 1000 years

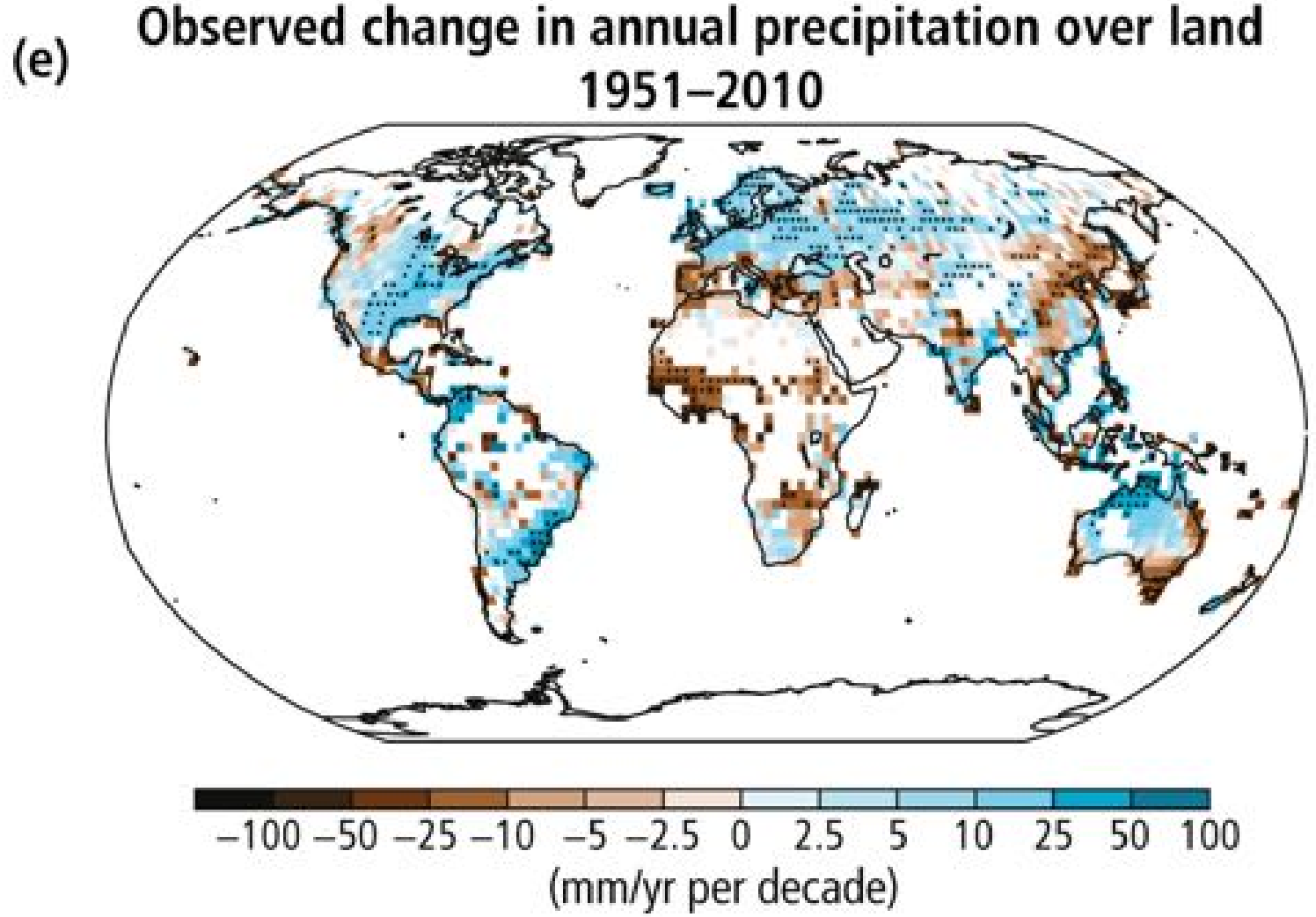


Chapman & Davis (2010)

Other evidence: sea levels are rising

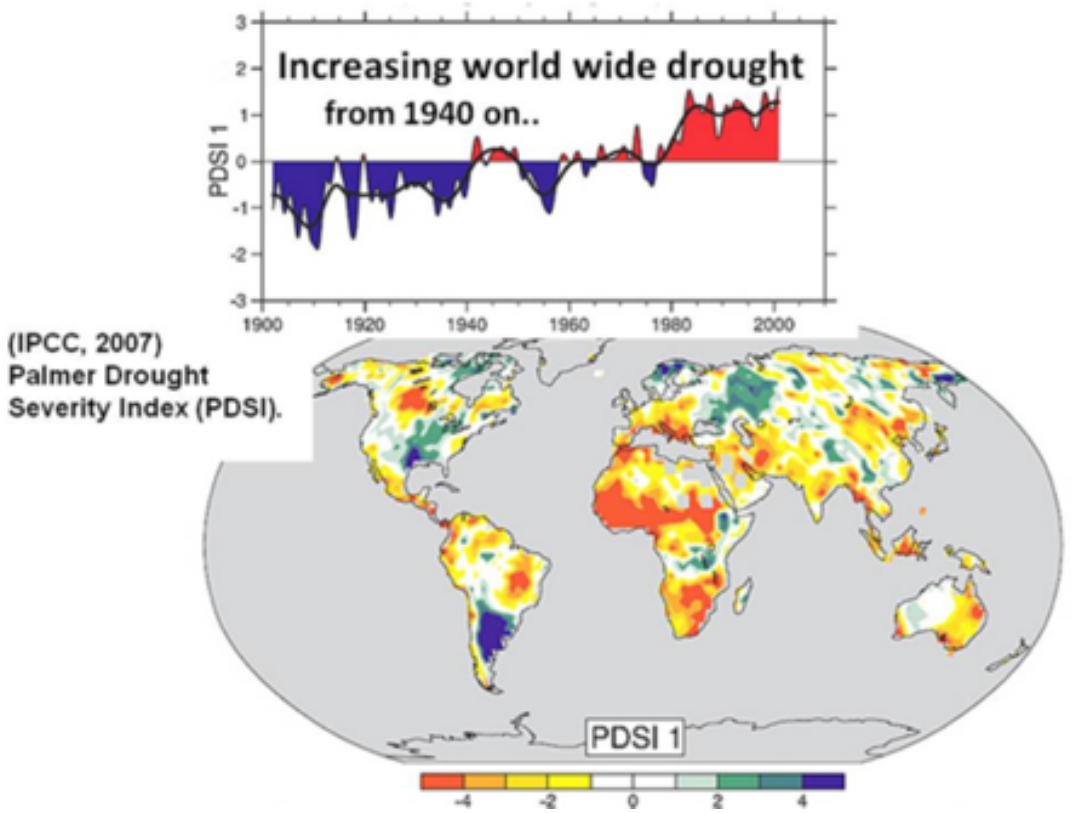


Global total precipitation is also changing

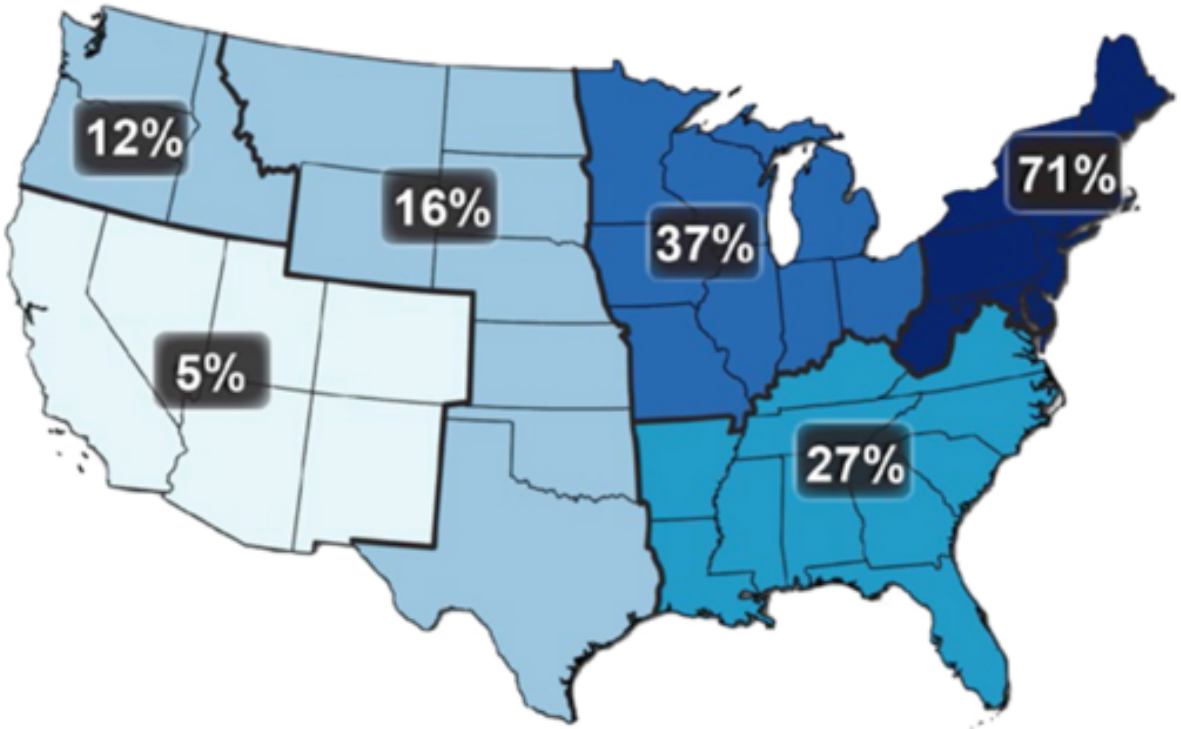


IPCC (2013)

As is precipitation variability



(IPCC, 2007)
Palmer Drought
Severity Index (PDSI).



Increase in heaviest 1% precipitation (U. Michigan)

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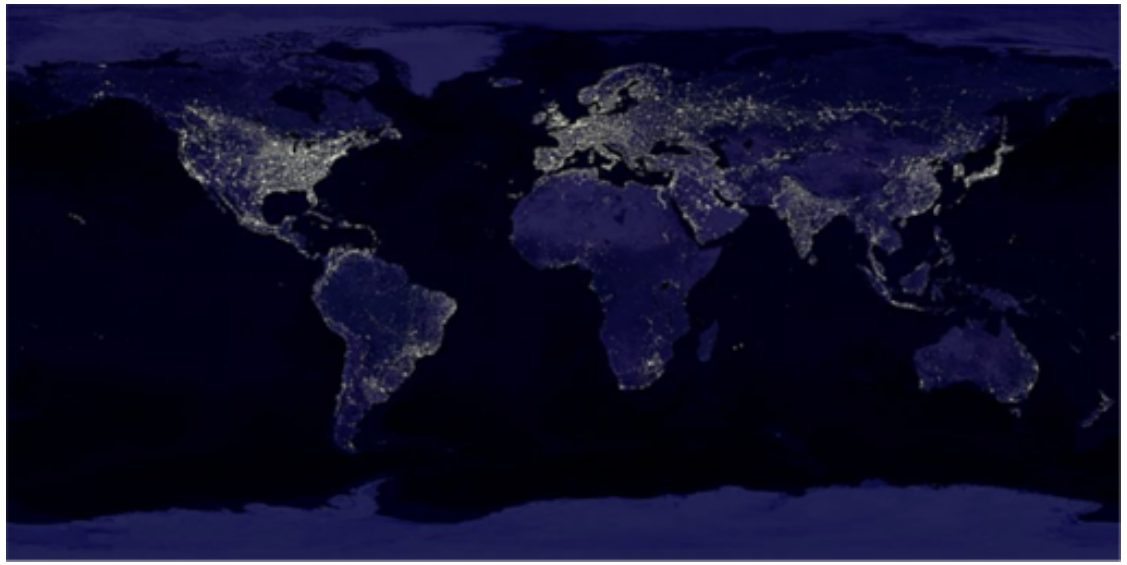
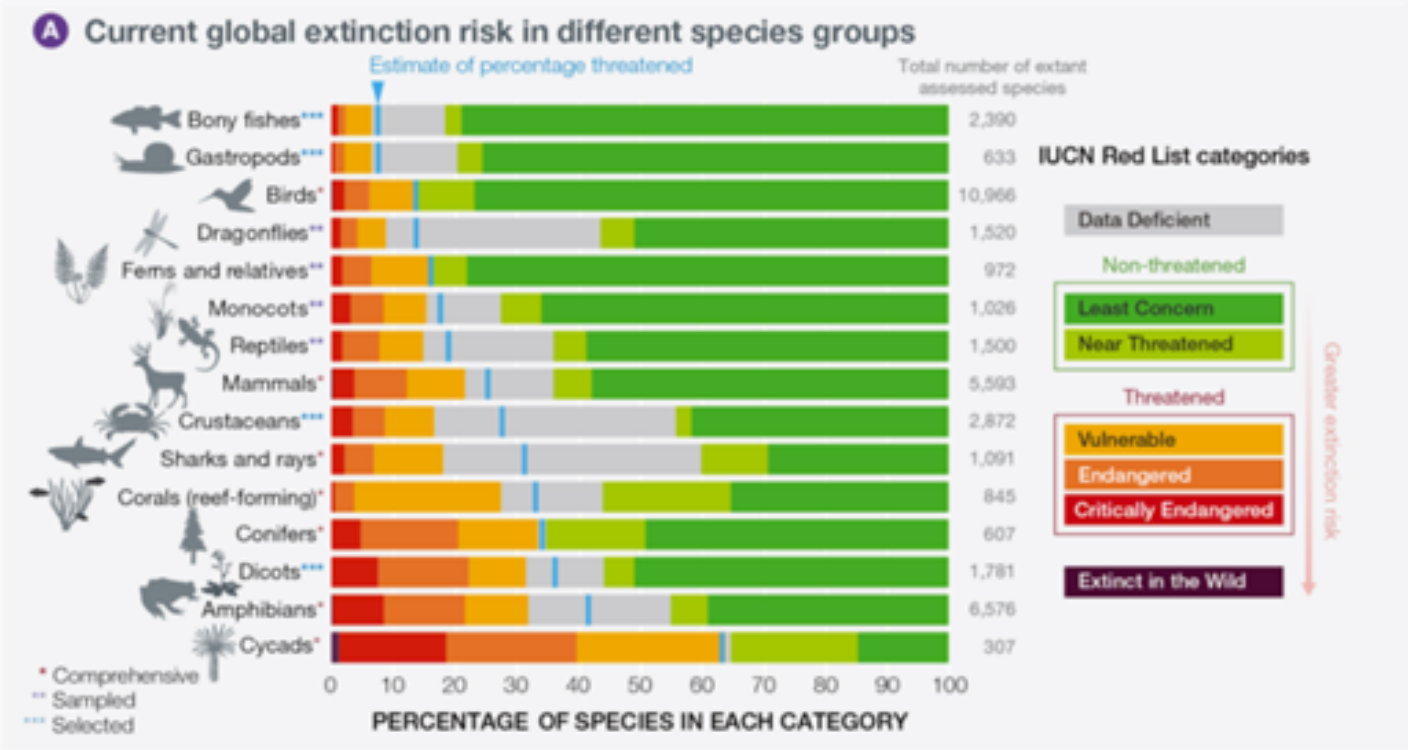
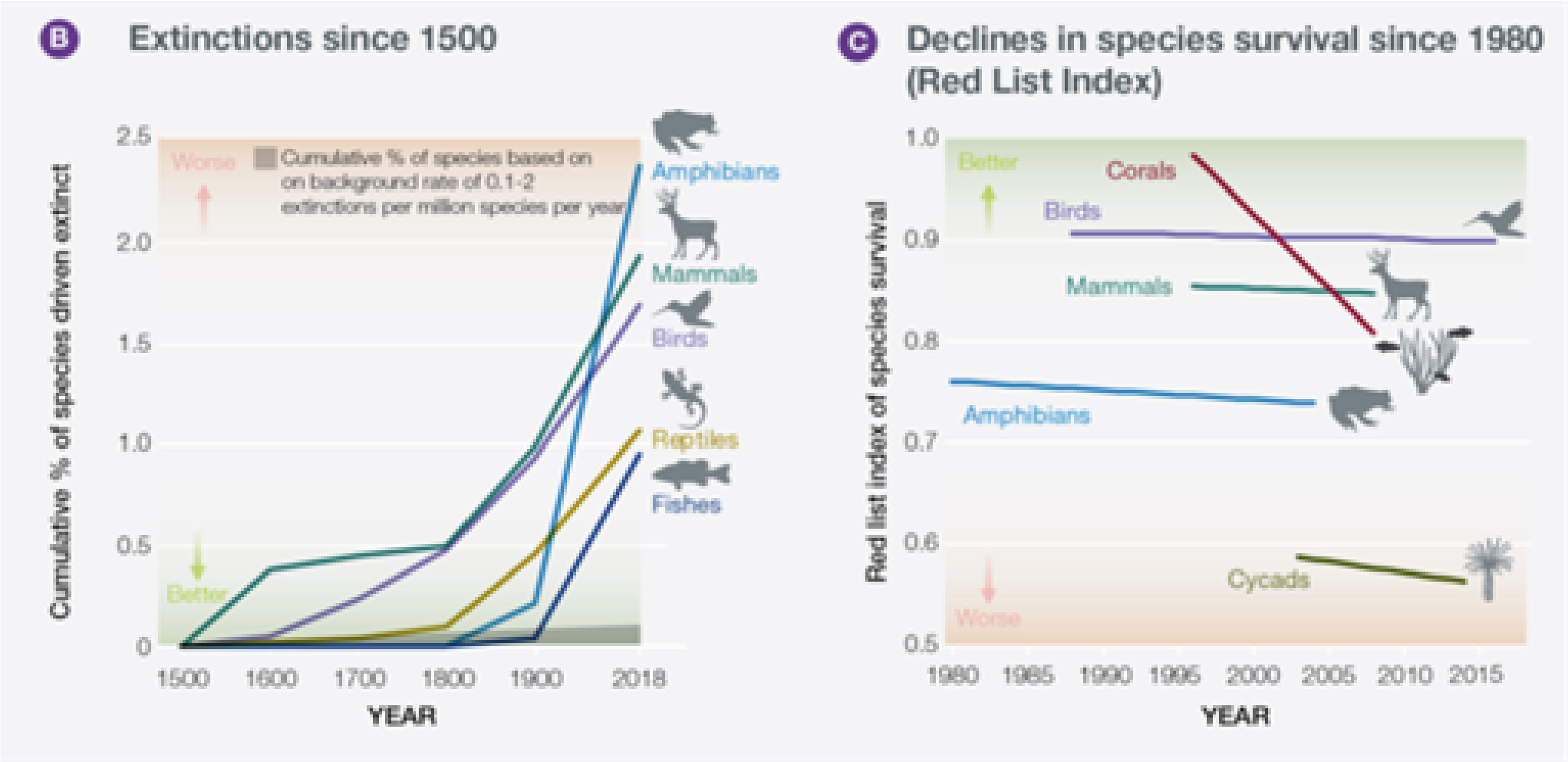


Humans are threatening species of all types



IPBES

And the threat is increasing



IPBES

Species loss results from habitat loss

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2014) **23**, 113–123

RESEARCH PAPER

Extinction debt and the species–area relationship: a neutral perspective

John M. Halley[1]*, Vasiliki Sgardeli[1] and Kostas A. Triantis[2,3,4]

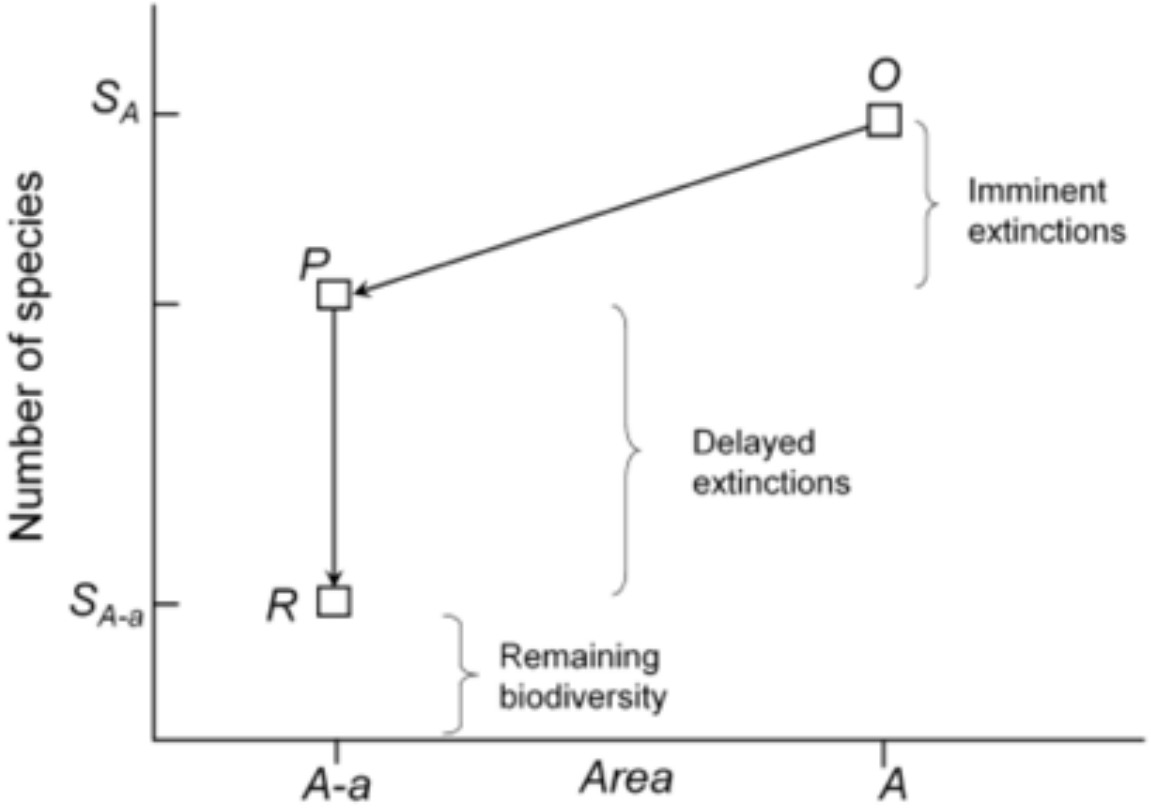


Figure 1 The phases of extinction following habitat loss. Initially the community of S_A species is in equilibrium (point O) in a habitat of area A. When habitat is lost, some extinctions happen immediately because there are species found only in the lost area (OP). More extinctions follow later due to increased isolation and smaller populations in the remaining area $A - a$. Eventually the community arrives at the new equilibrium (R) where local extinction and colonization are in balance (c.f. Rosenzweig, 2001). In this paper, although the path PR spans anything from a few years to millennia, we assume OP always to be rapid.

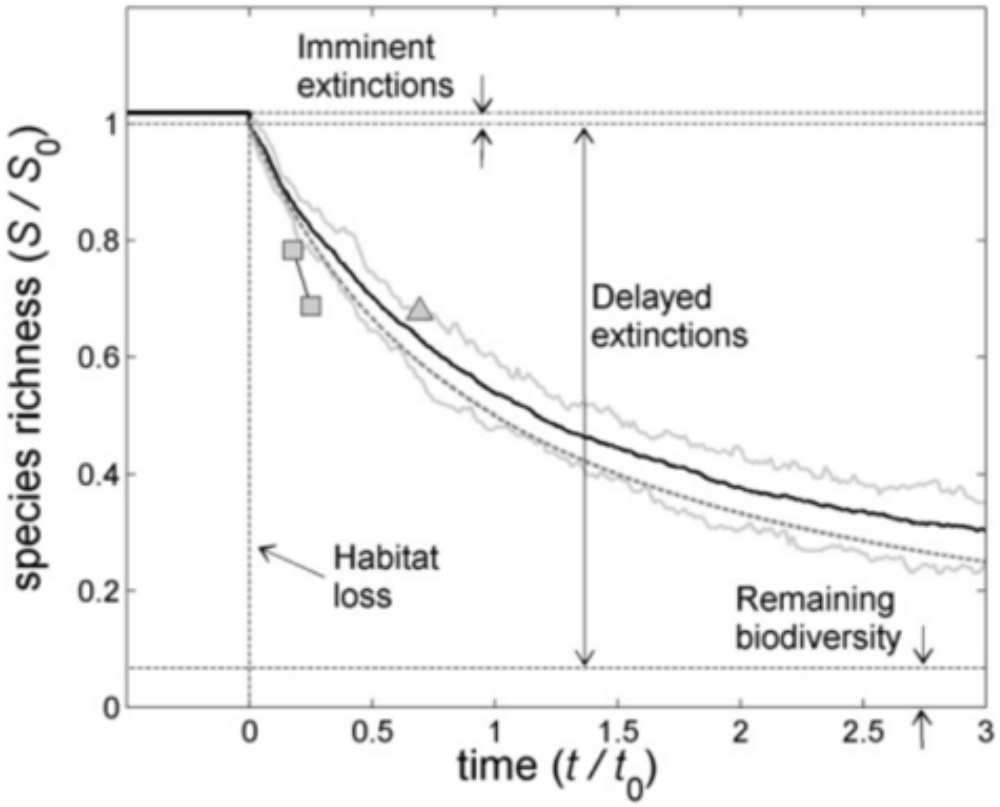
Species loss results from habitat loss

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2014) **23**, 113–123

RESEARCH PAPER

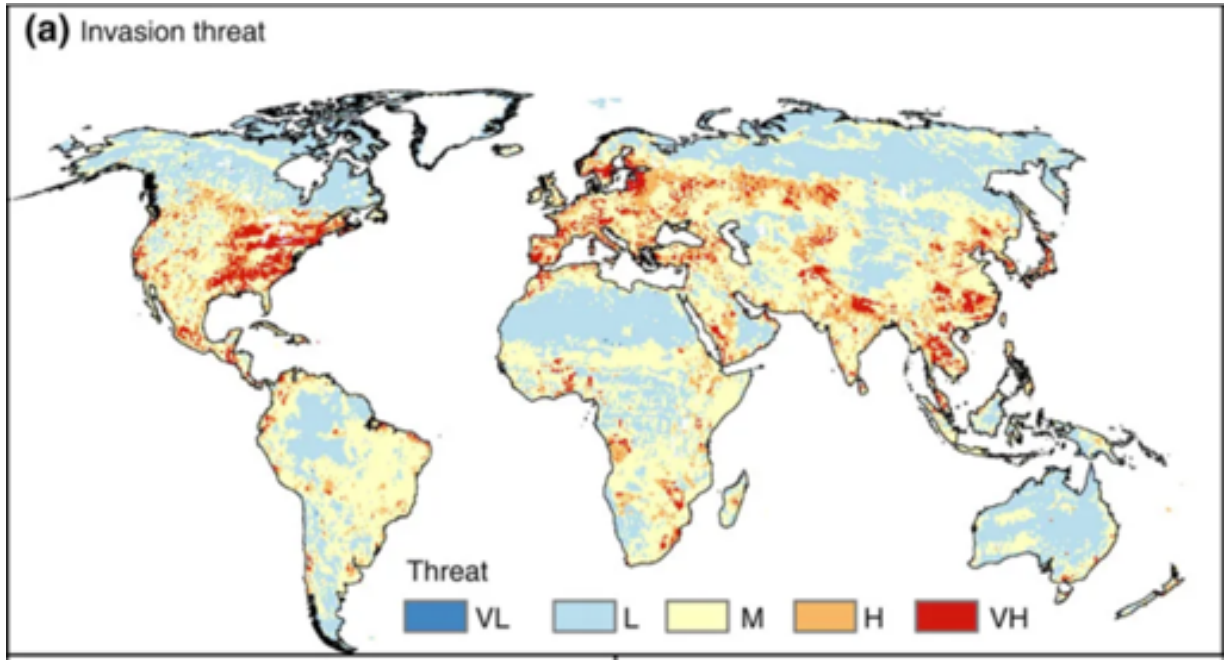
Extinction debt and the species–area relationship: a neutral perspective

John M. Halley[1]*, Vasiliki Sgardeli[1] and Kostas A. Triantis[2,3,4]



Invasive species are spreading…

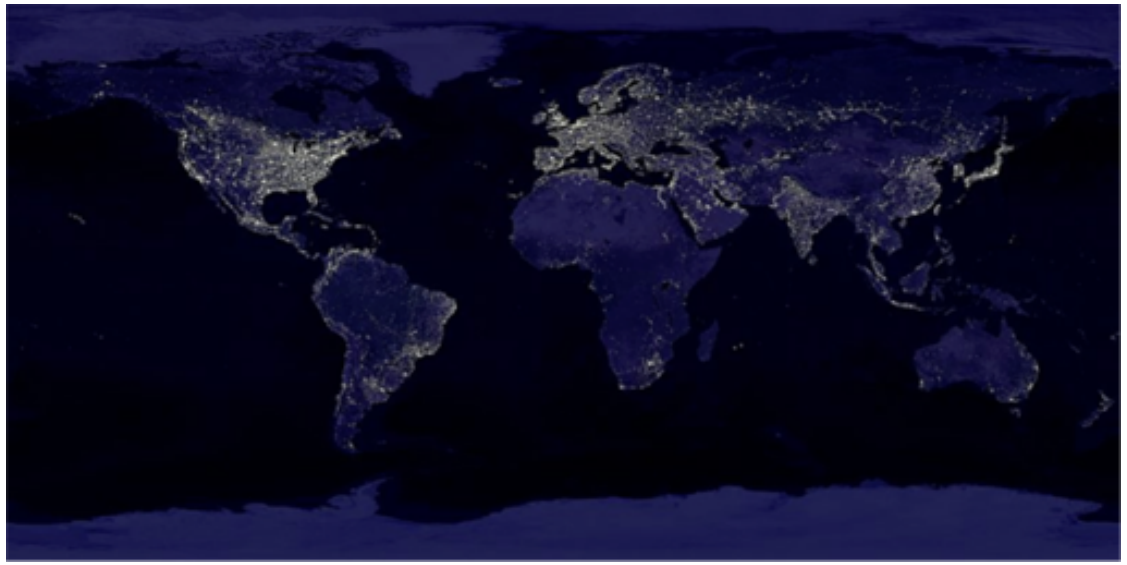
Invasives are a threat everywhere



Early et al. (2016)

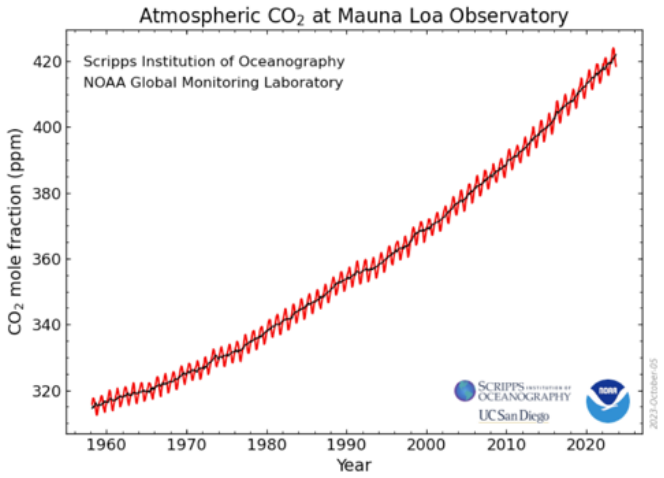
The Case for the Anthropocene

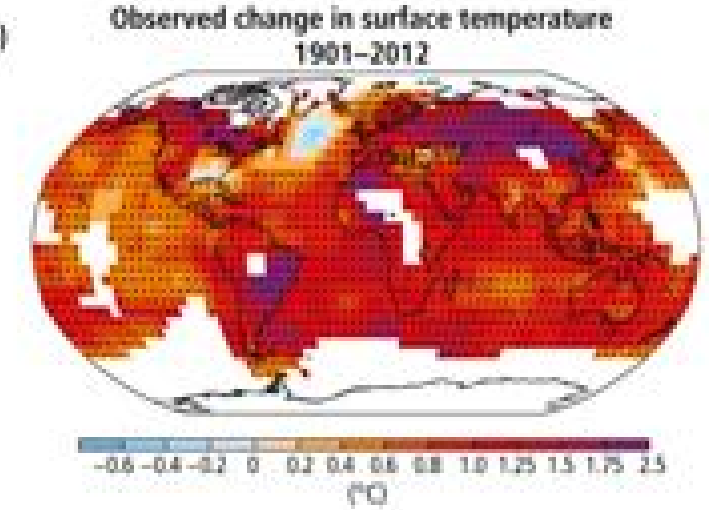
- Proposed new epoch that has resulted primarily from human changes to the planet's:
  - Elemental cycles
  - Climate
  - Biological diversity

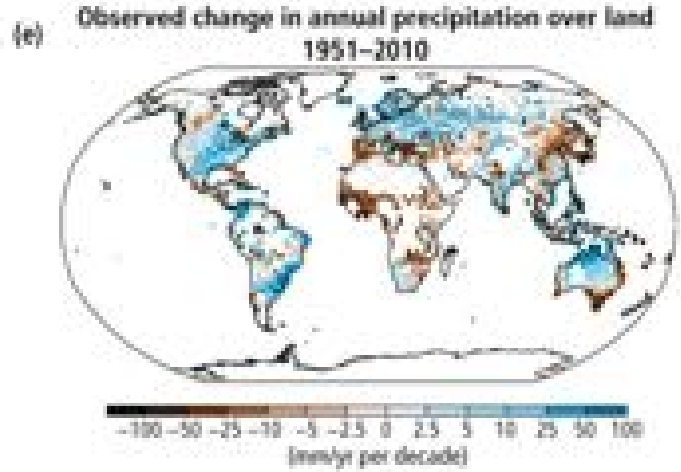


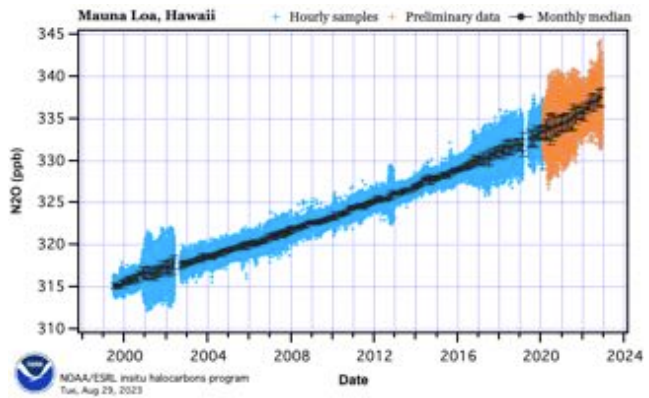
The Case for the Anthropocene

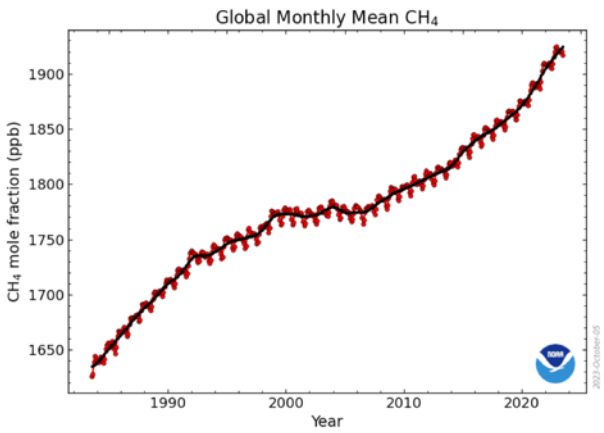
Do you buy it?

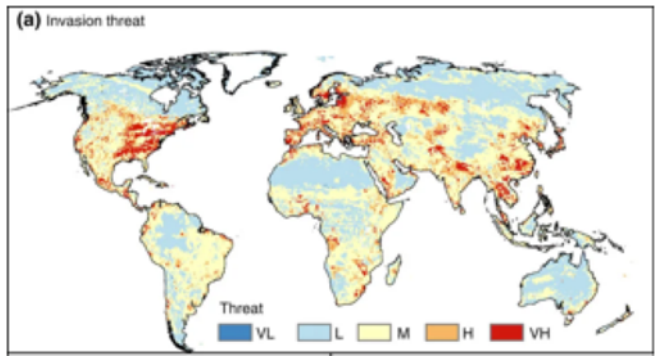












What would be the “golden spike”?

Class activity (in groups of four)

1. Pick an ecosystem service provided by West Texas ecosystems

1. Food
2. Fiber
3. Pollination
4. Water purity
5. Air purity
6. Energy
7. Climate regulation
8. Pest & disease control
9. Culture
10. History
11. Spiritual services
12. Recreation
13. Science Education
14. Therapy

2. Use a systems diagram to indicate how it will be impacted by global change