

# Changes in the Earth System

November 5, 2019





RESEARCH REVIEW

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## Global Change Biology: A Primer

Rowan F. Sage

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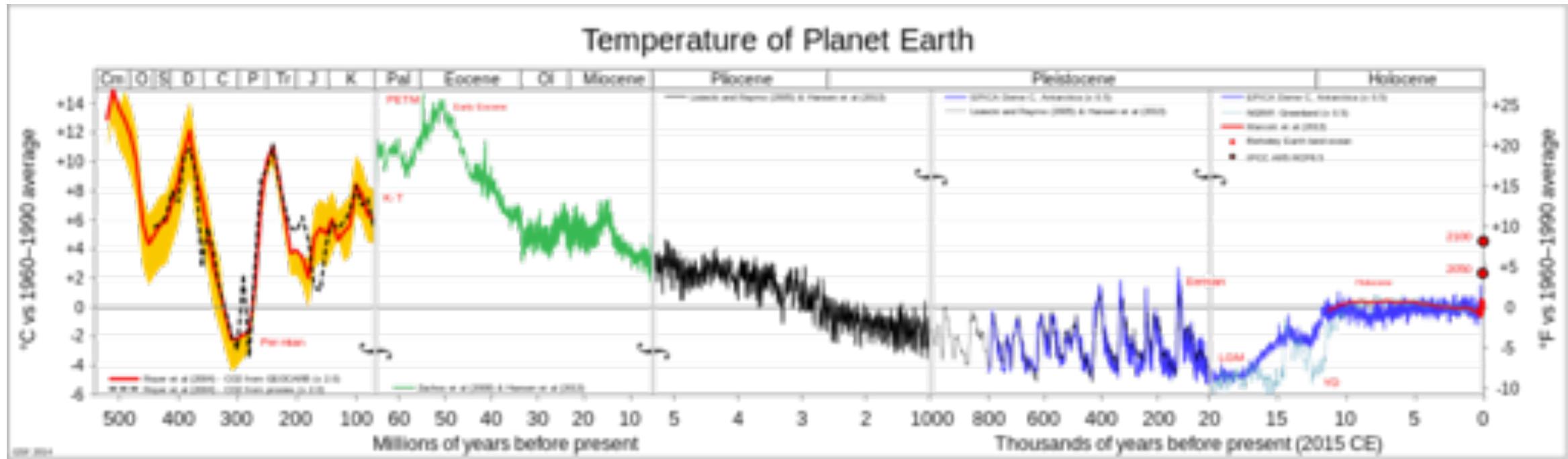


TOOLS



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# Have we entered a new epoch?



# The Case for the Anthropocene

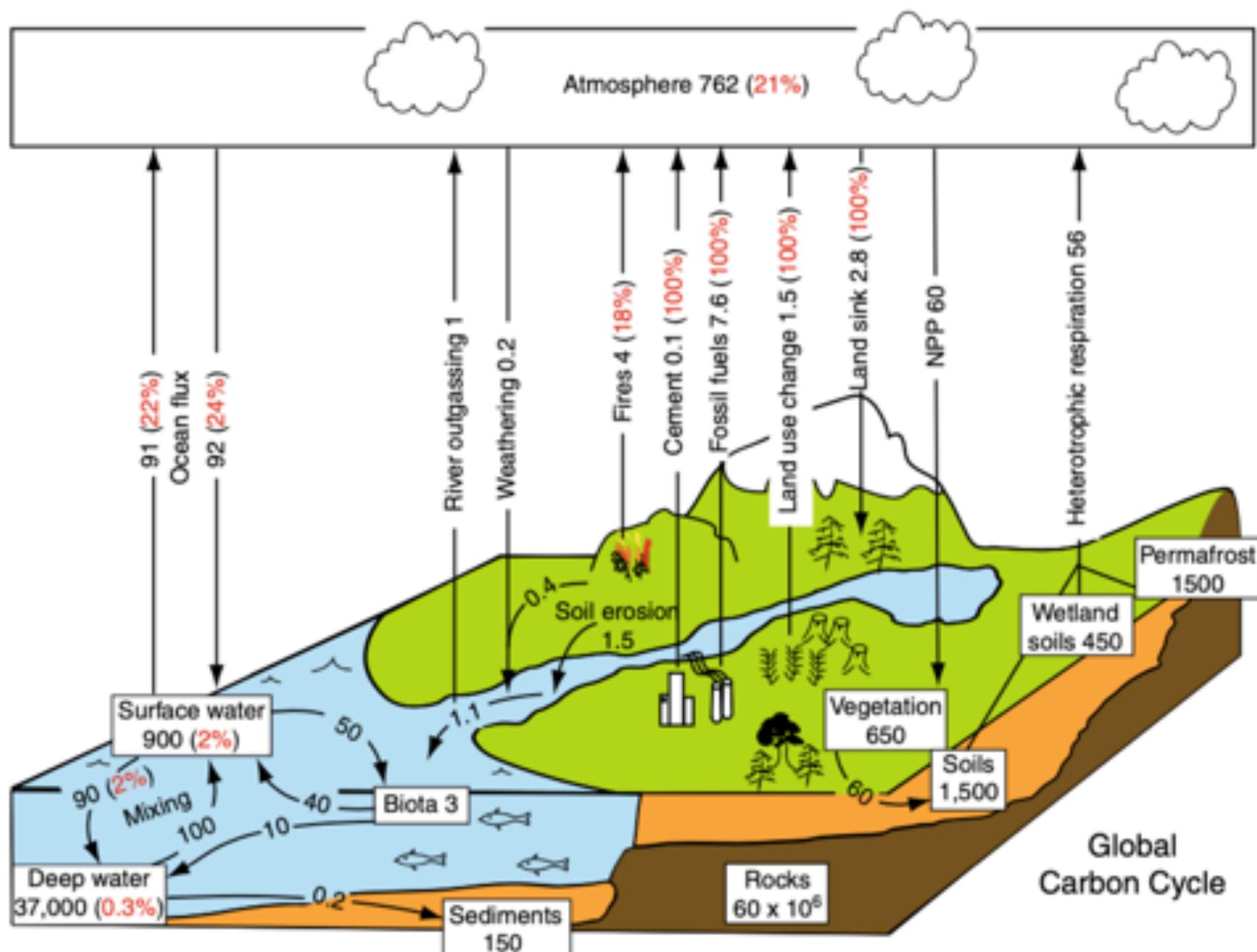
- Proposed new epoch that has resulted primarily from human changes to the planet's:
  - Elemental cycles
  - Climate
  - Biological diversity



# The Case for the Anthropocene

- Proposed new epoch that has resulted primarily from human changes to the planet's:
  - Elemental cycles
  - Climate
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# $\text{CO}_2$ is increasing in the atmosphere

Earth Syst. Sci. Data, 10, 2141–2194, 2018  
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## Global Carbon Budget 2018

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

Flux	Amount (Pg C/yr)
Fossil fuel burning	9.4
LULCC	1.5
Ocean uptake	2.4
Land uptake	3.2
Atmospheric growth	4.7
Uncertainty	0.5

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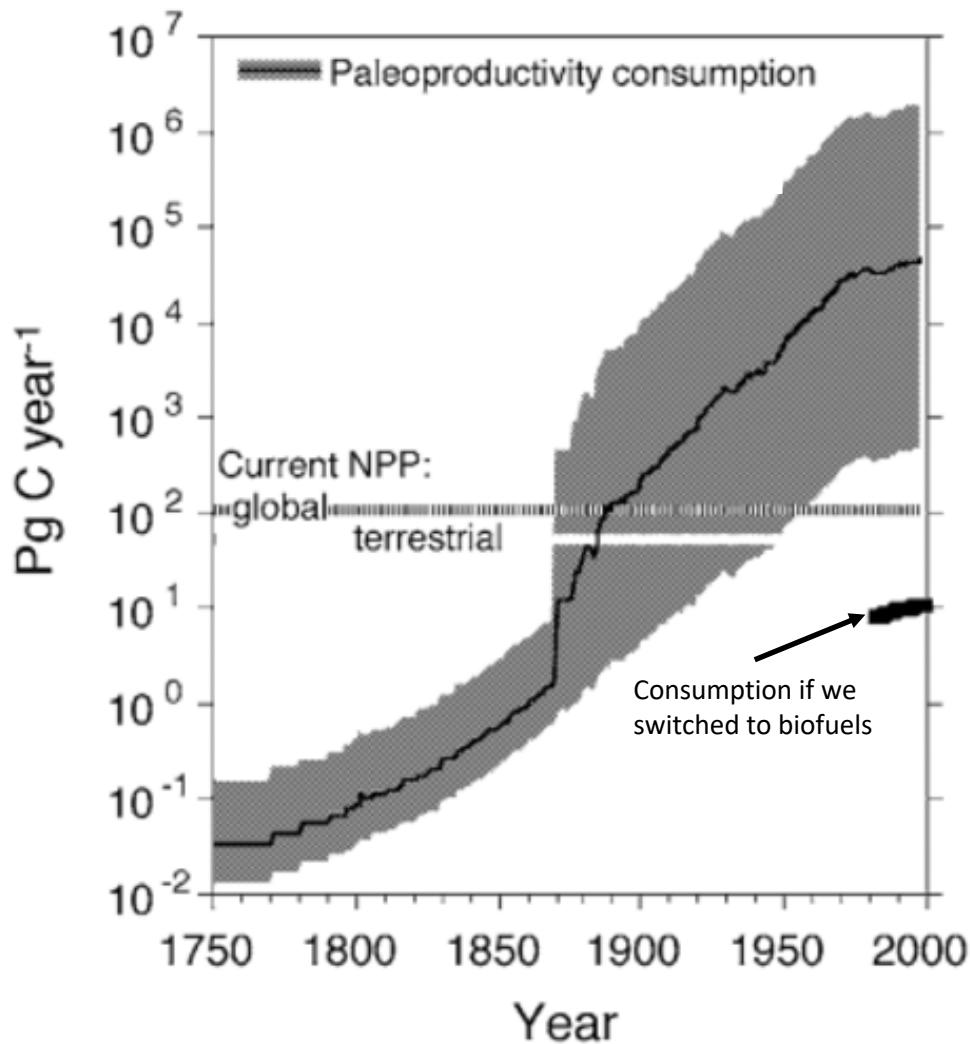
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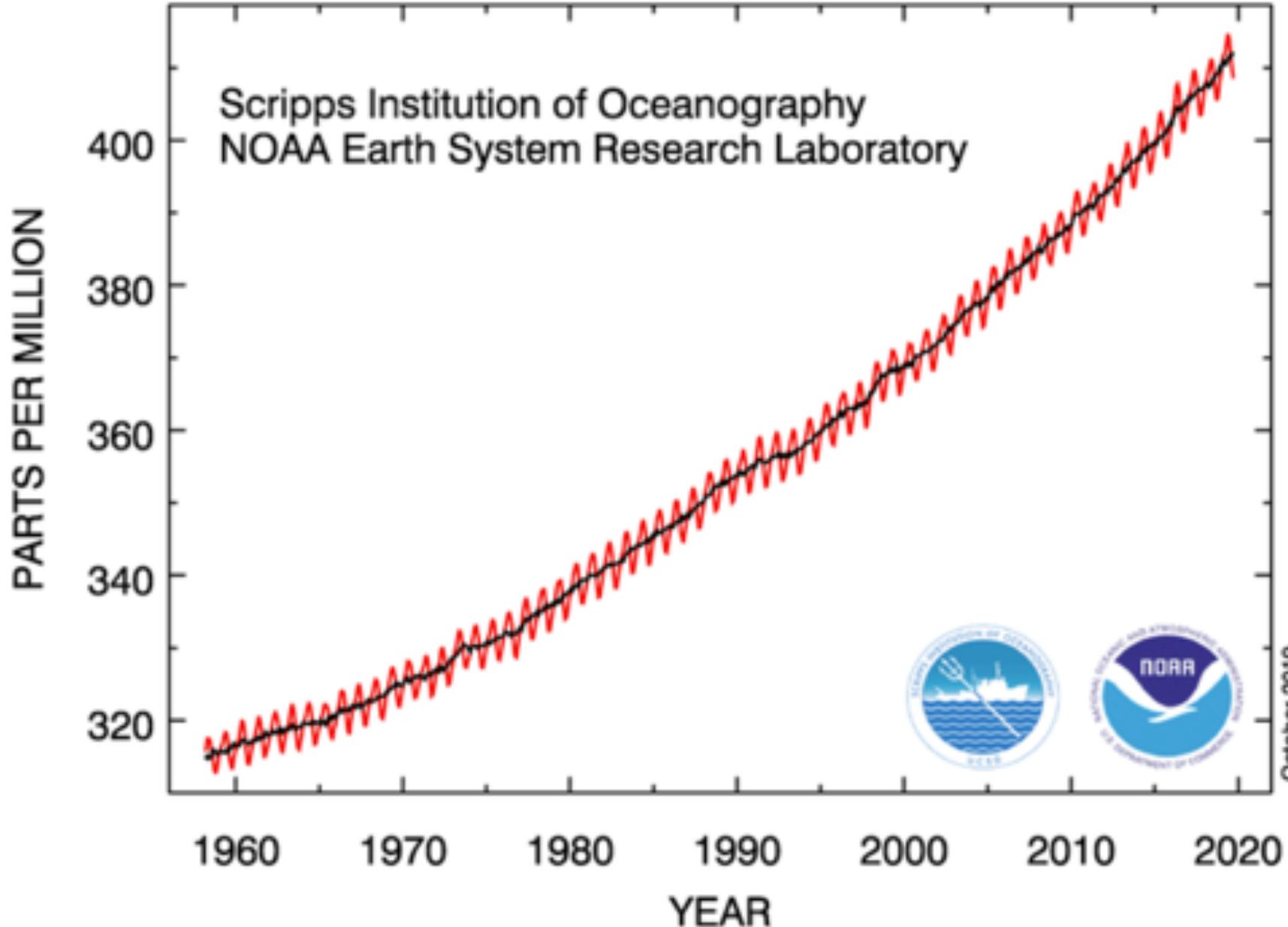
0.6 higher than book  
estimate (2007)



We are using more carbon than plants are putting back

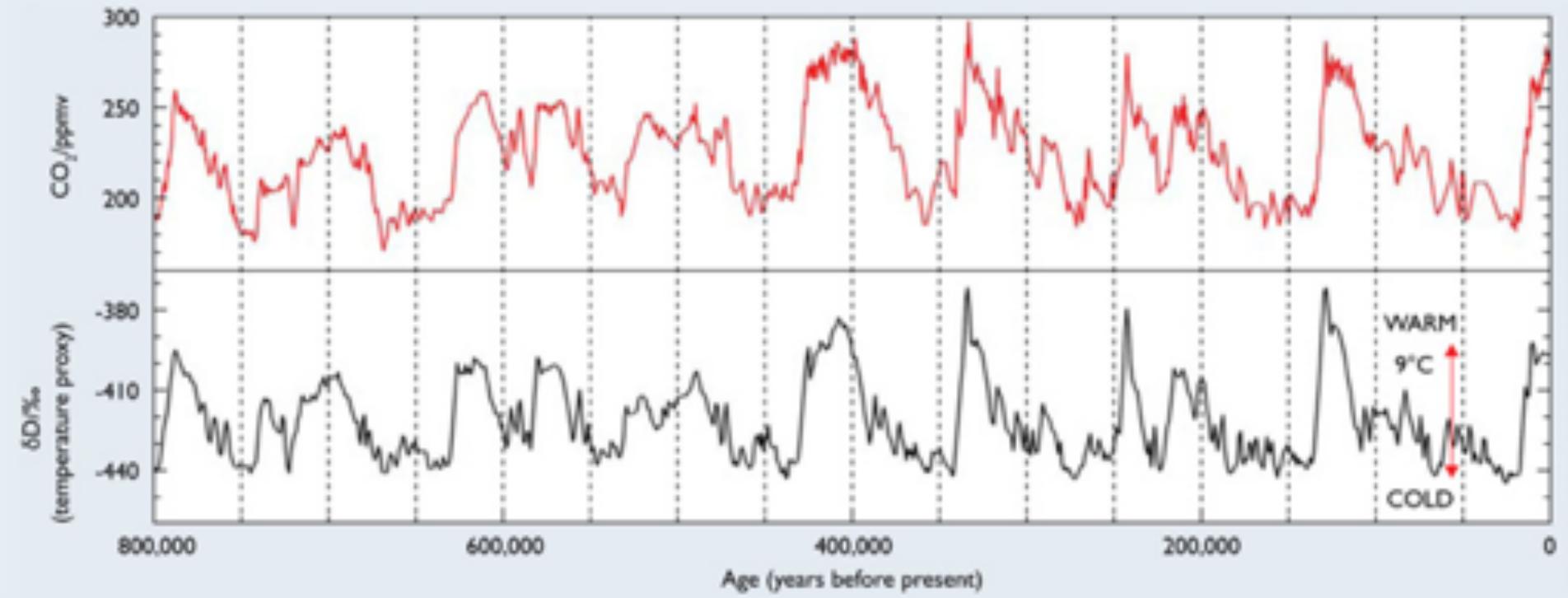
Dukes (2003) “Burning buried sunshine”

# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



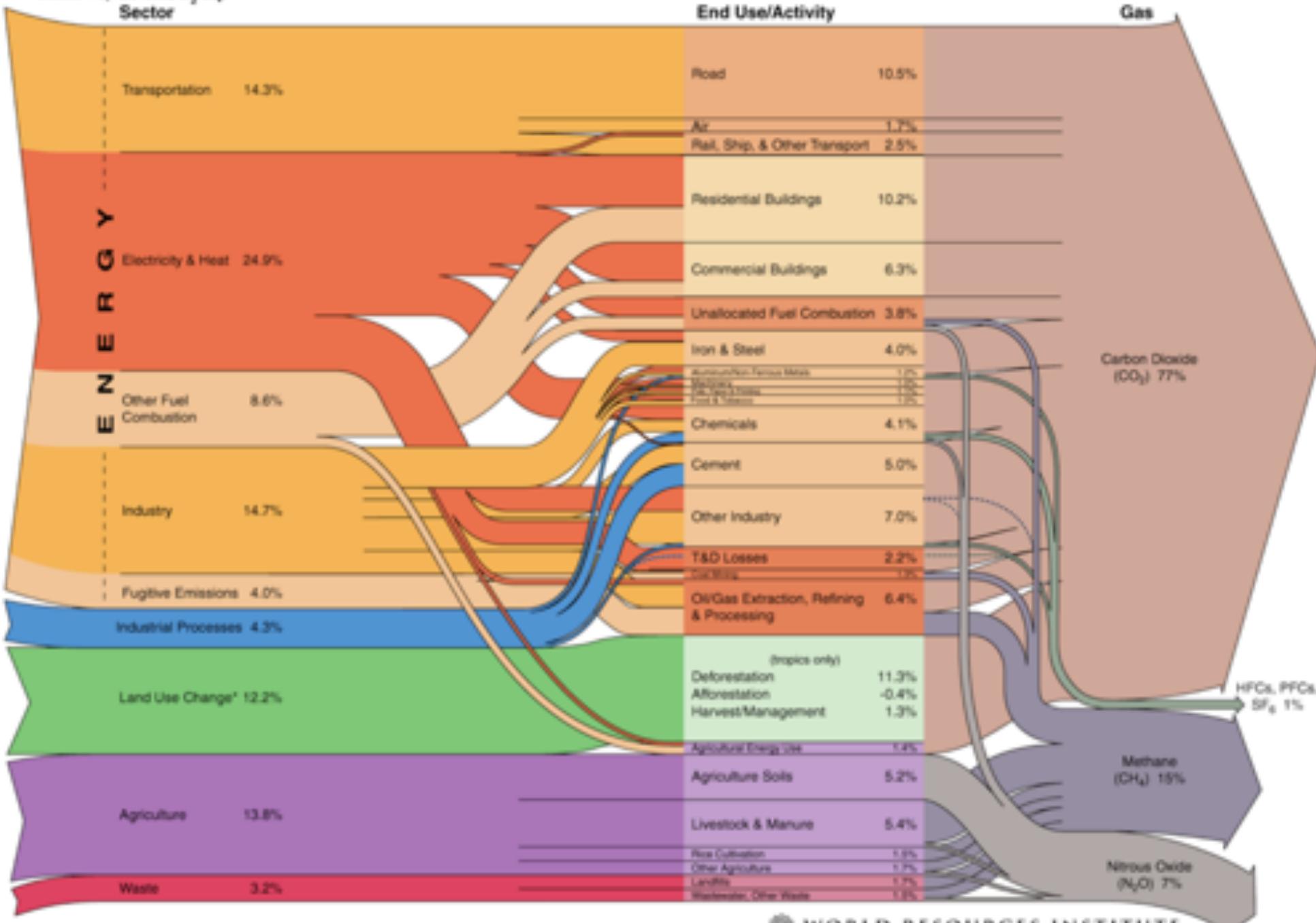
Going up 5  
ppm / year

Fig. 3: ice core data from the EPICA Dome C (Antarctica) ice core: deuterium ( $\delta D$ ) is a proxy for local temperature;  $CO_2$  from the ice core air<sup>(56)</sup>

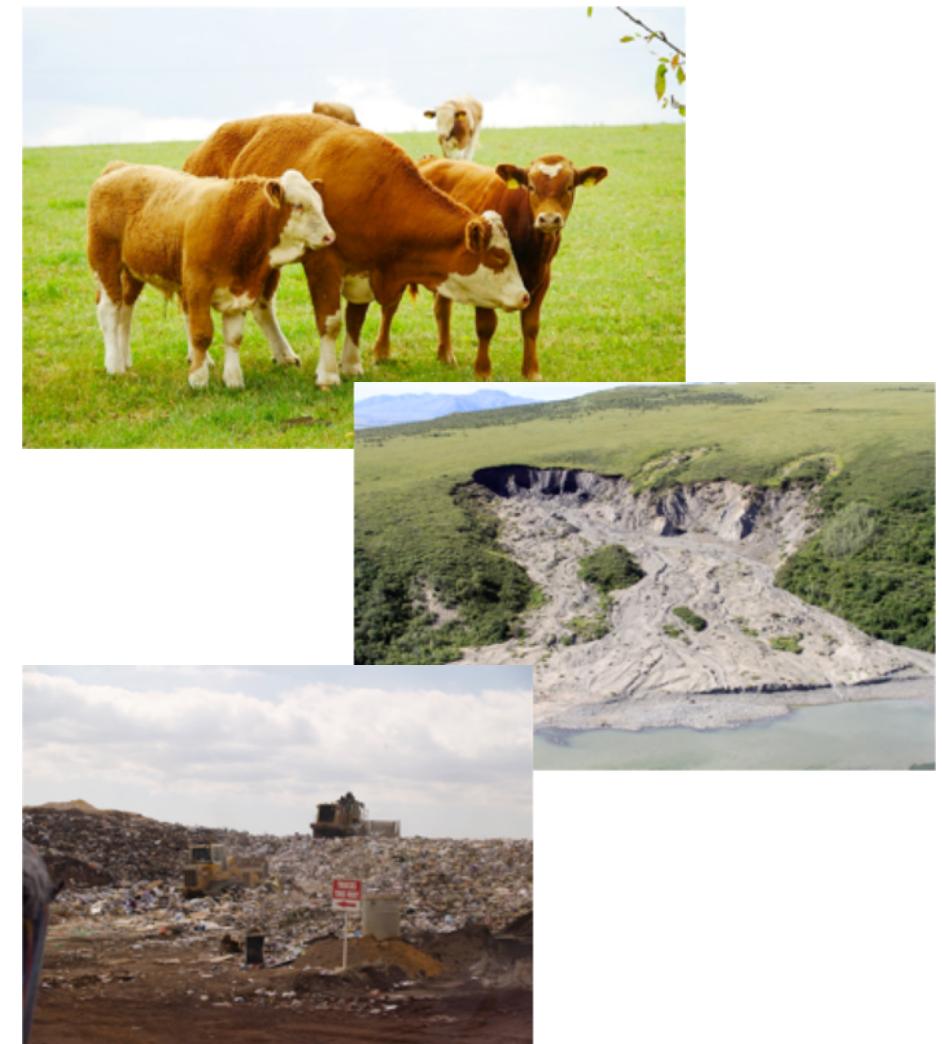
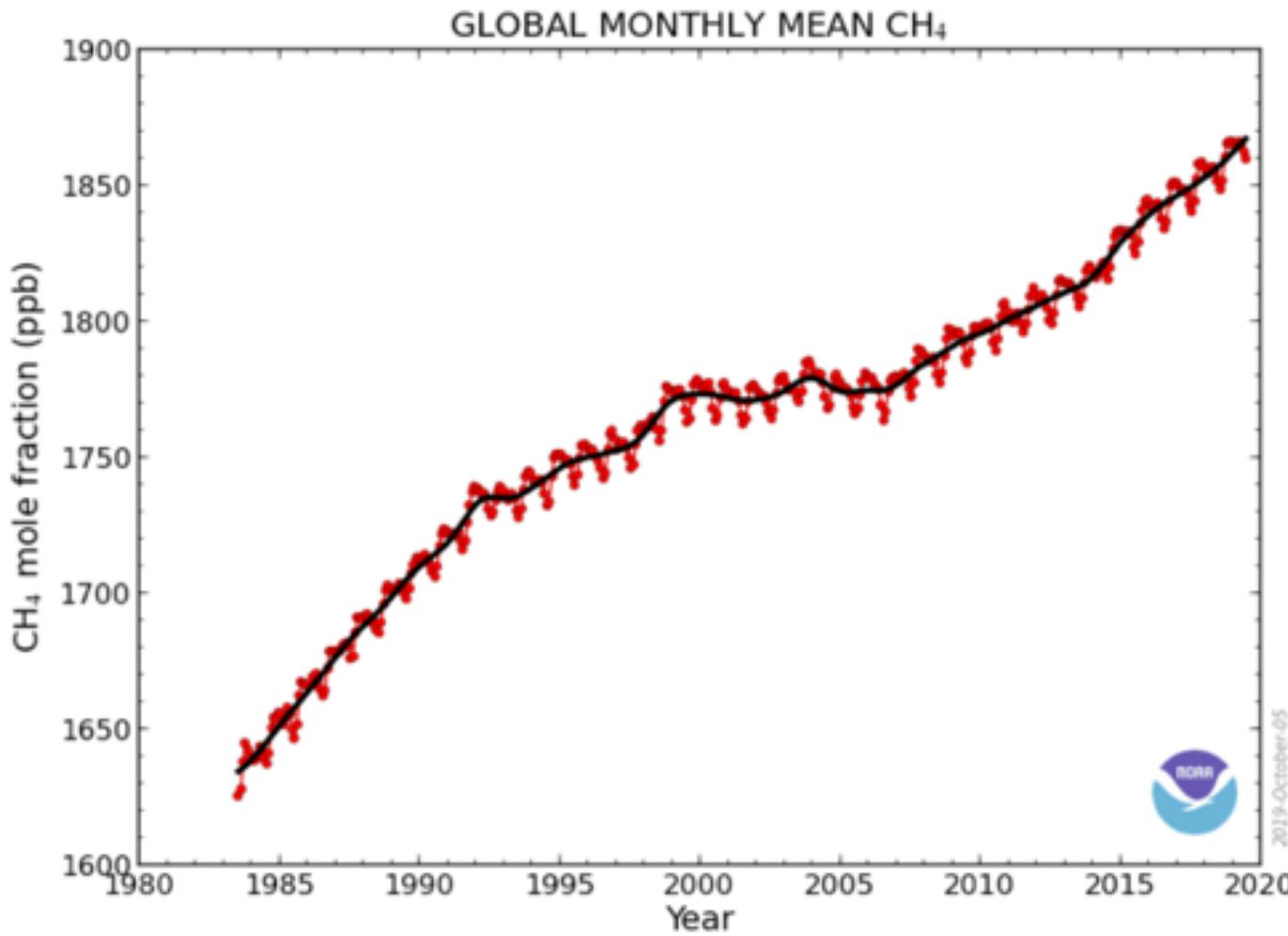


Historical rate of change: 0.002 ppm / year

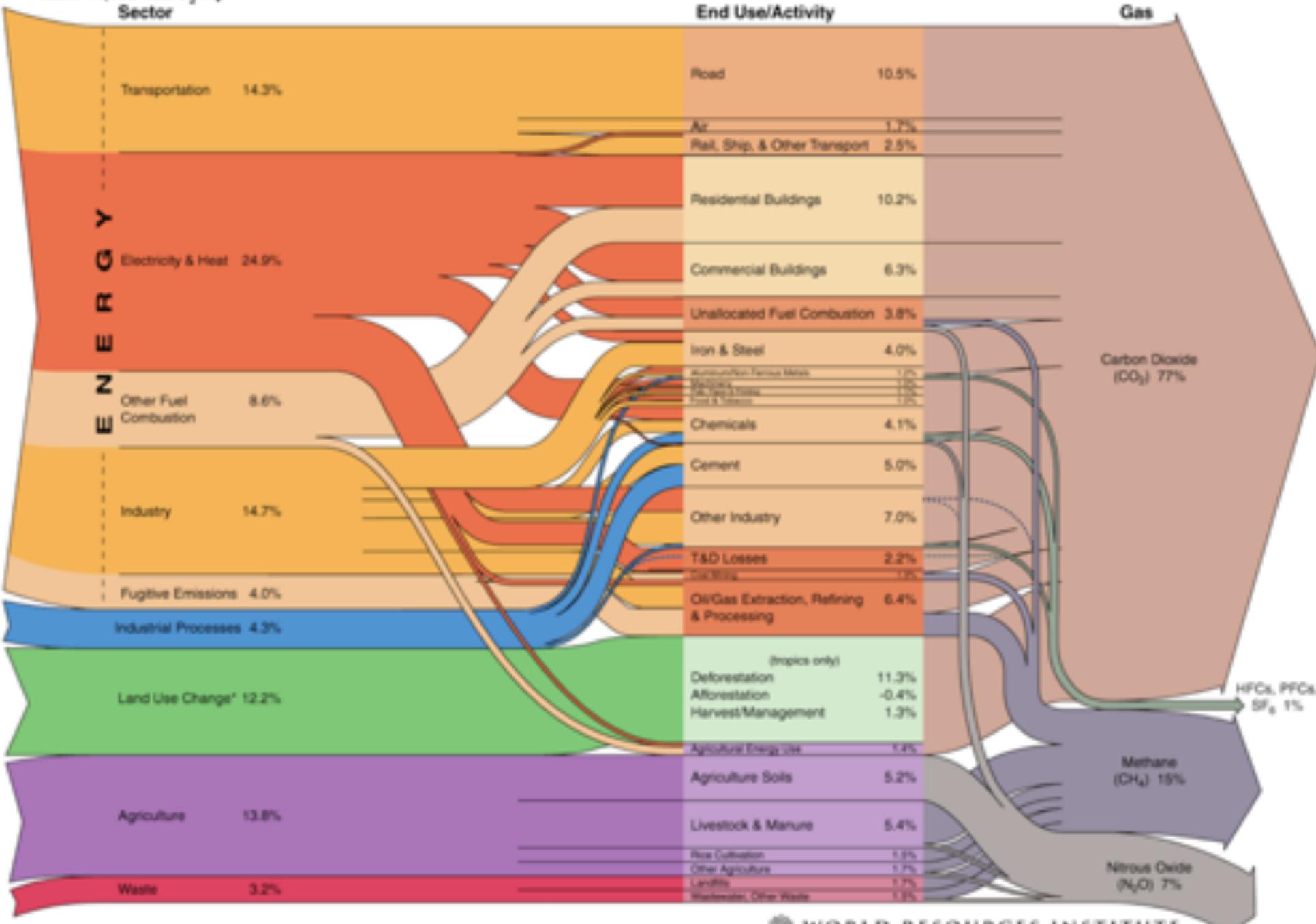
World Greenhouse Gas Emissions in 2005  
Total: 44,153 MtCO<sub>2</sub> eq.

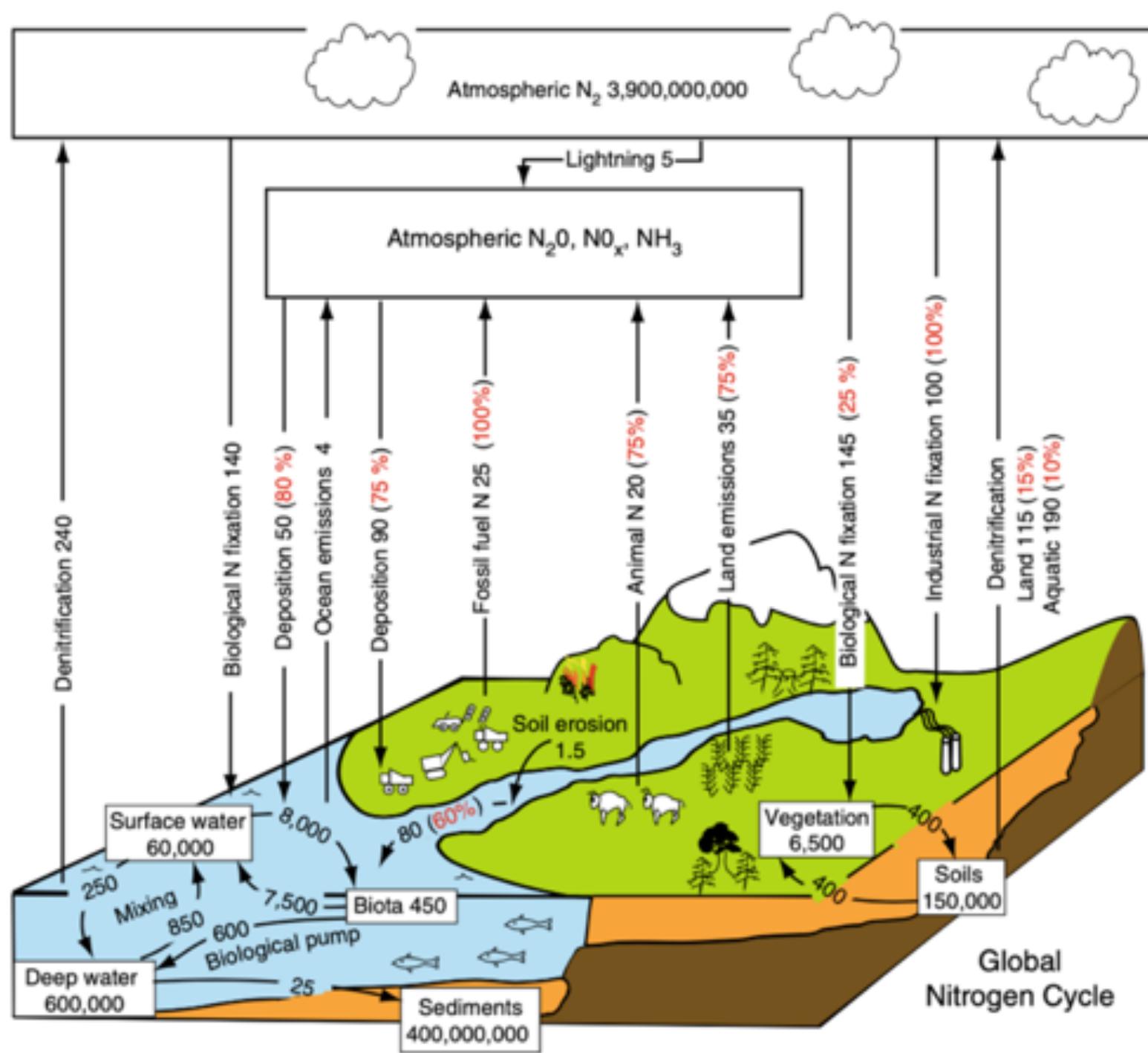


# Atmospheric methane (CH<sub>4</sub>) is also going up

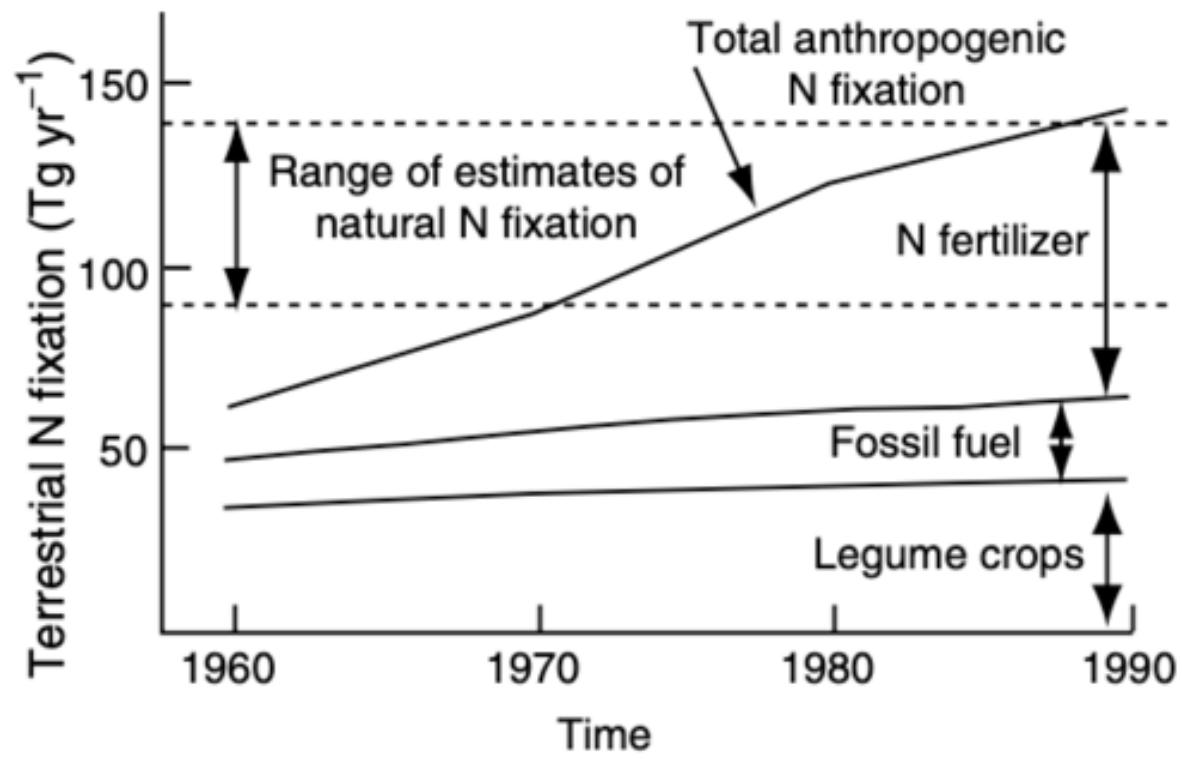


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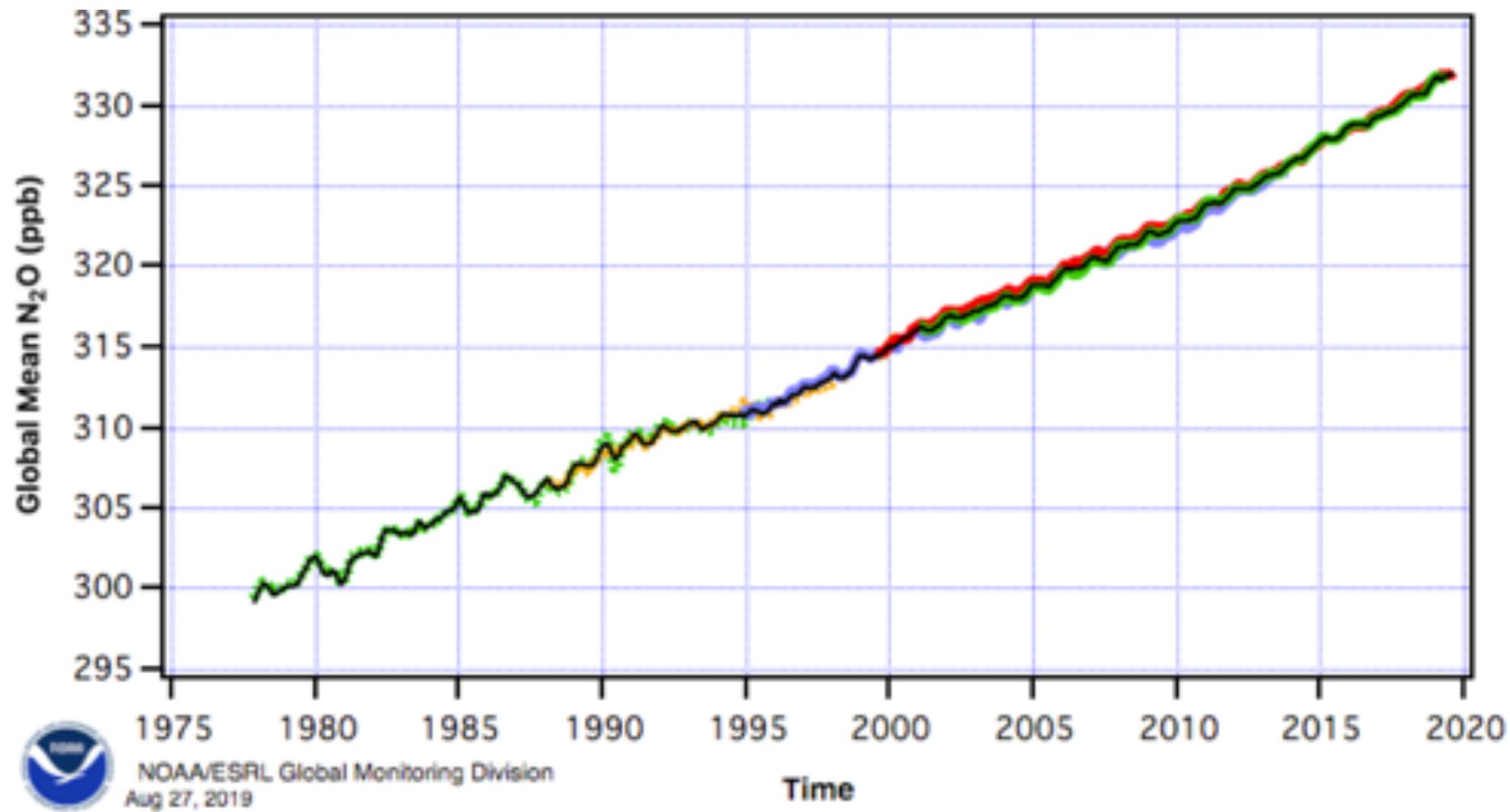




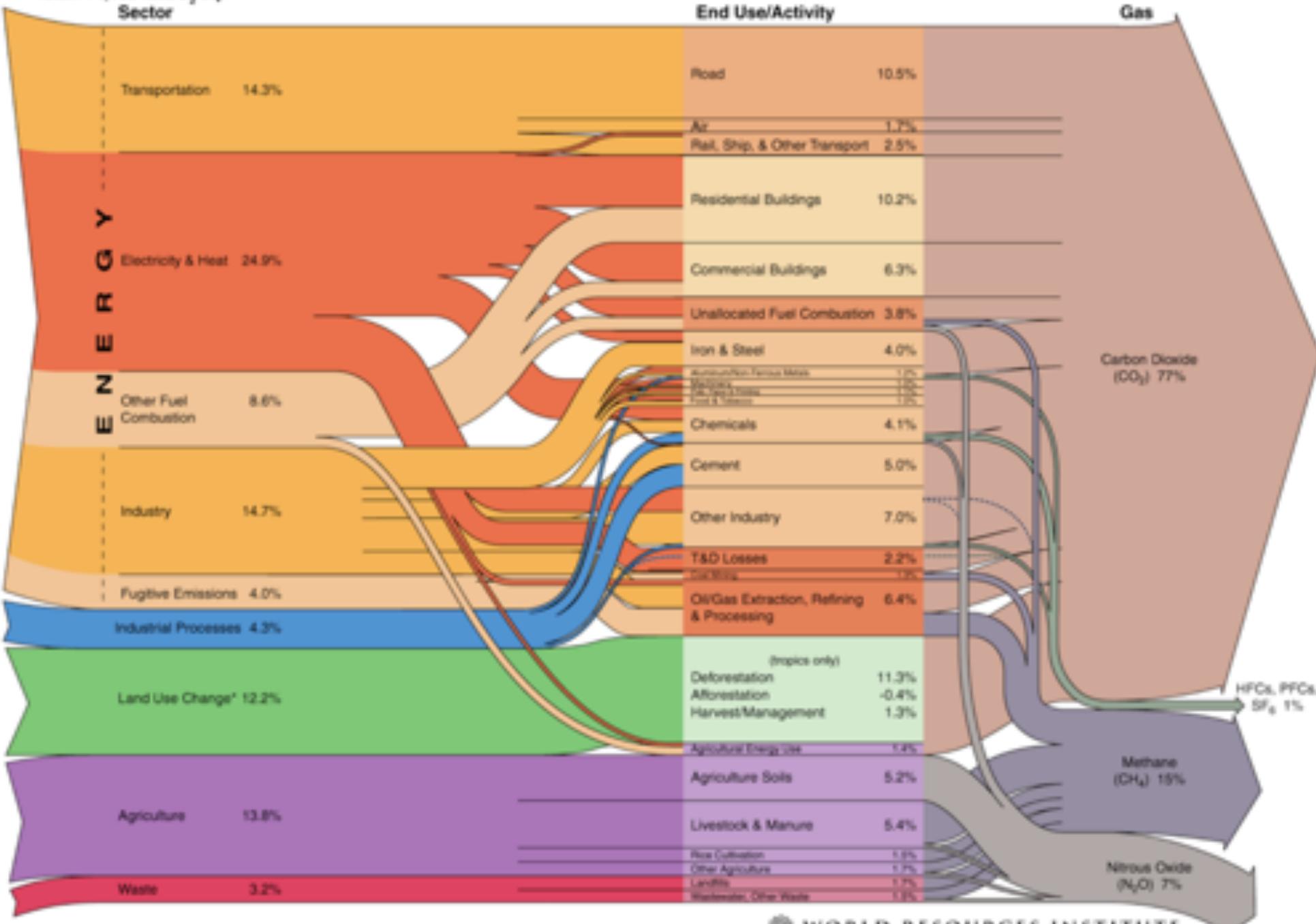
# We're pulling in a lot of atmospheric N...

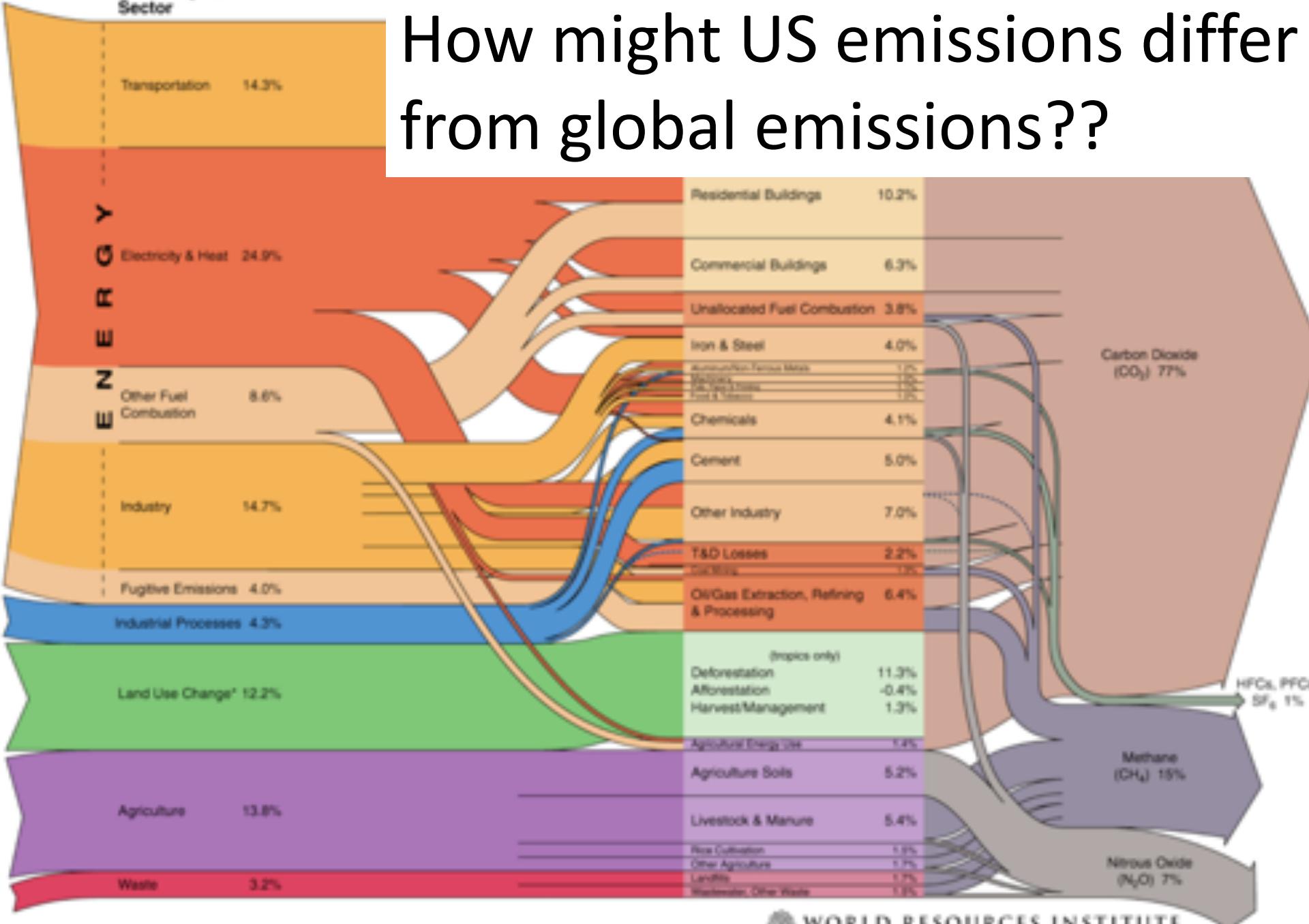


...while also pumping out a lot in new forms



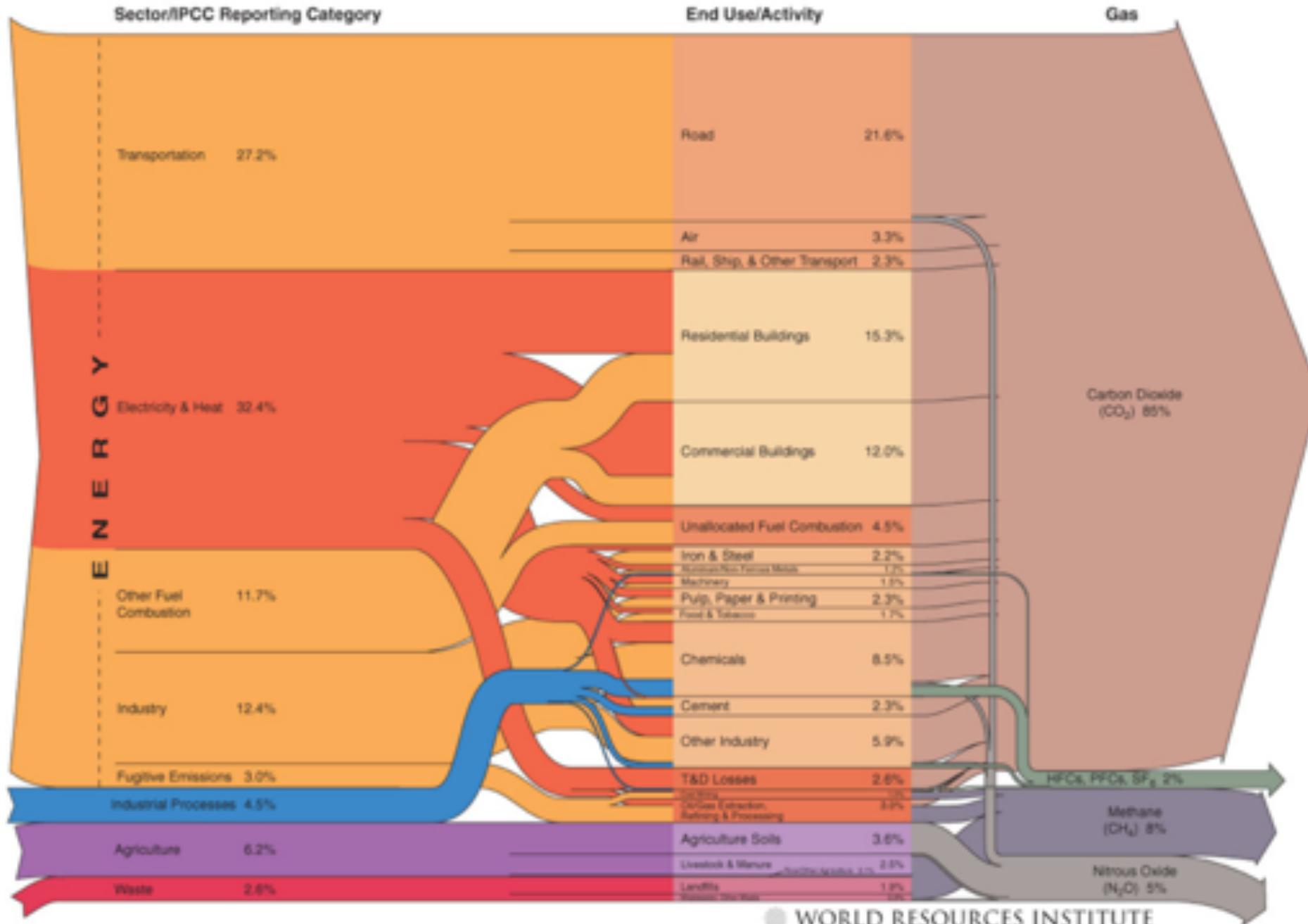
World Greenhouse Gas Emissions in 2005  
Total: 44,153 MtCO<sub>2</sub> eq.





# How might US emissions differ from global emissions??

# U.S. GHG Emissions Flow Chart



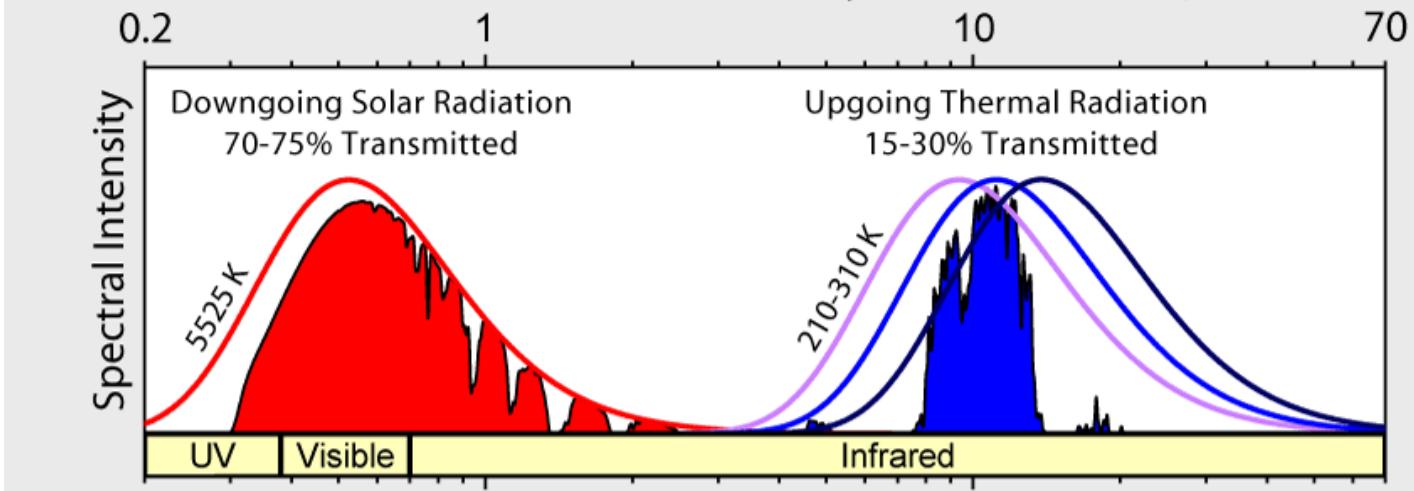
# The Case for the Anthropocene

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  - Elemental cycles
  - Climate
  - Biological diversity

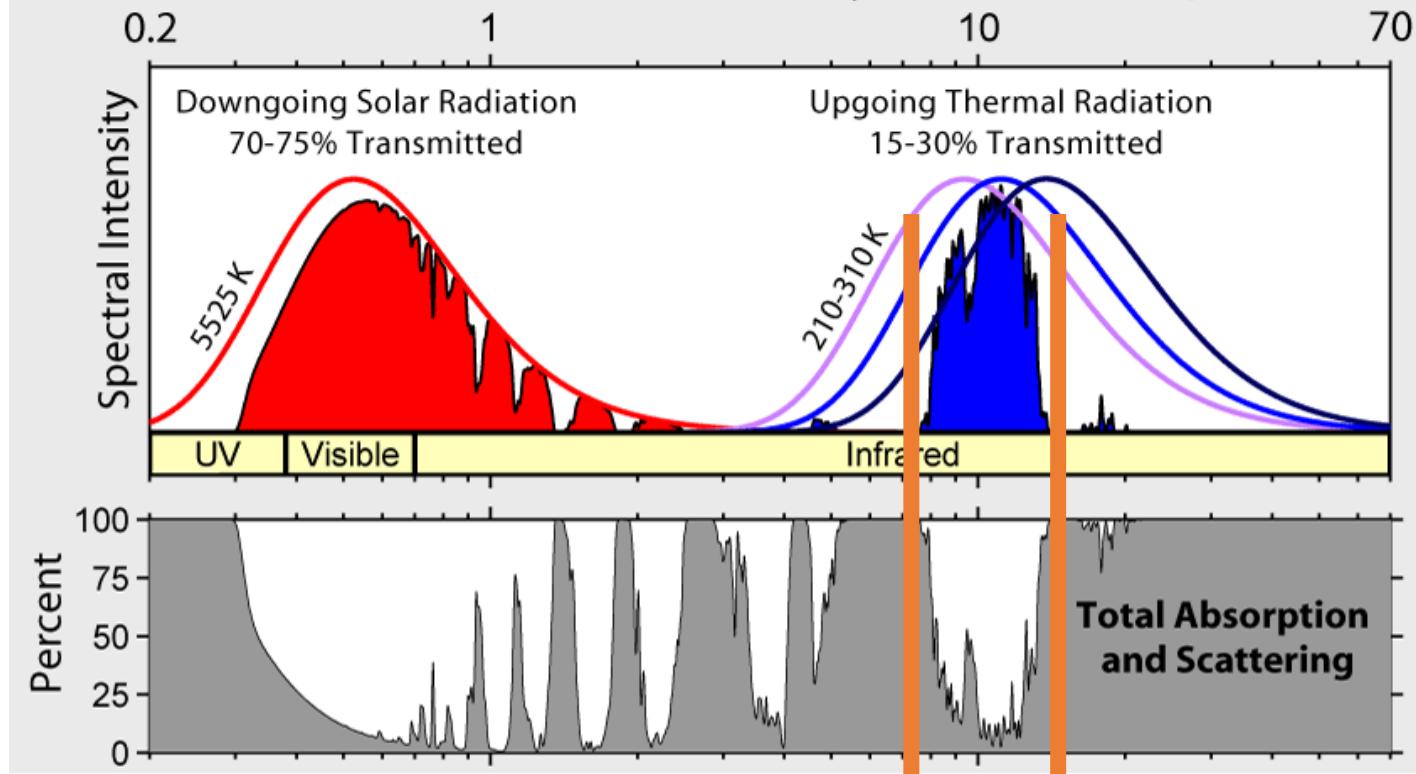


Climate change is the result of  
human changes to elemental  
cycles

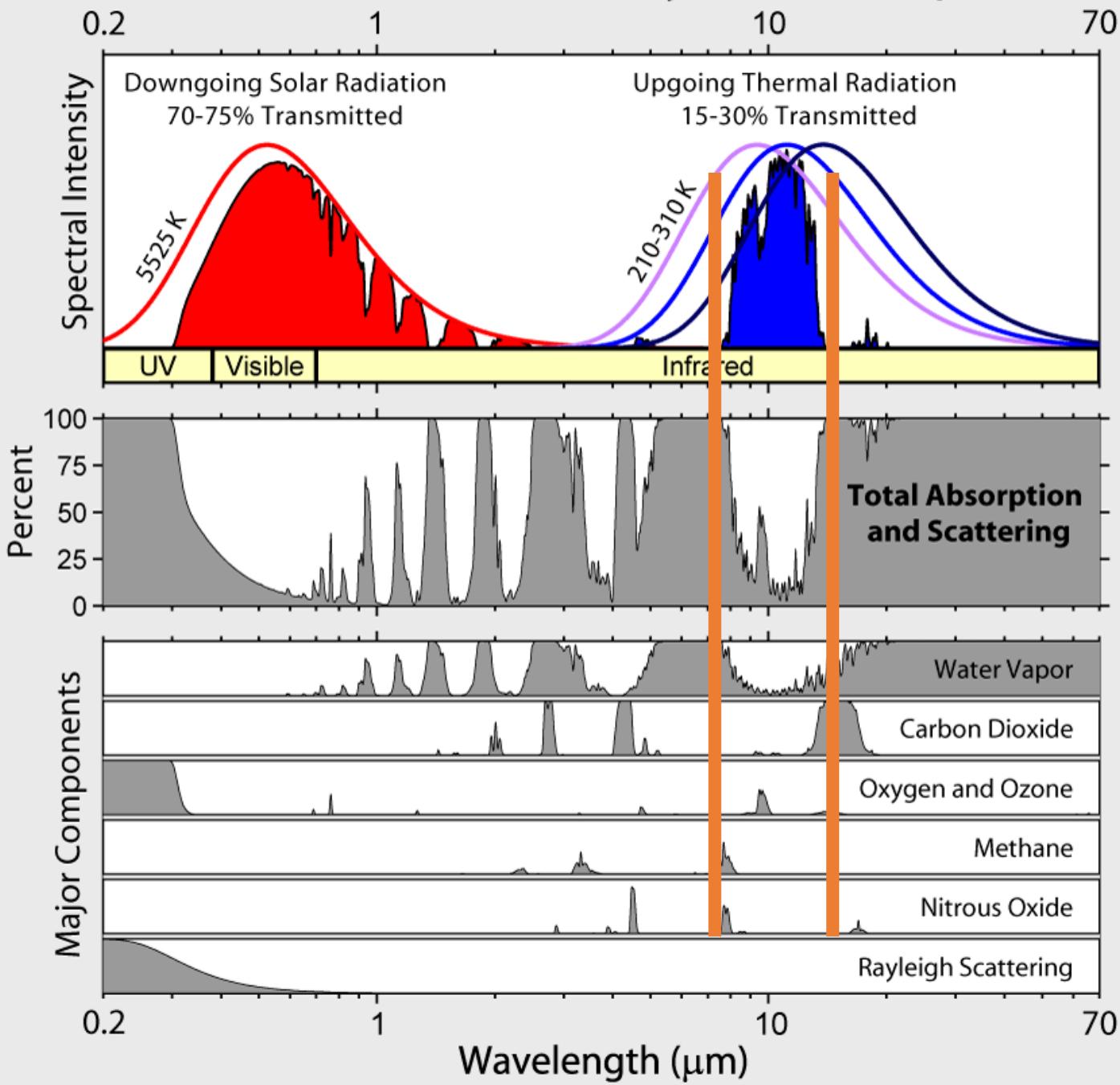
# Radiation Transmitted by the Atmosphere



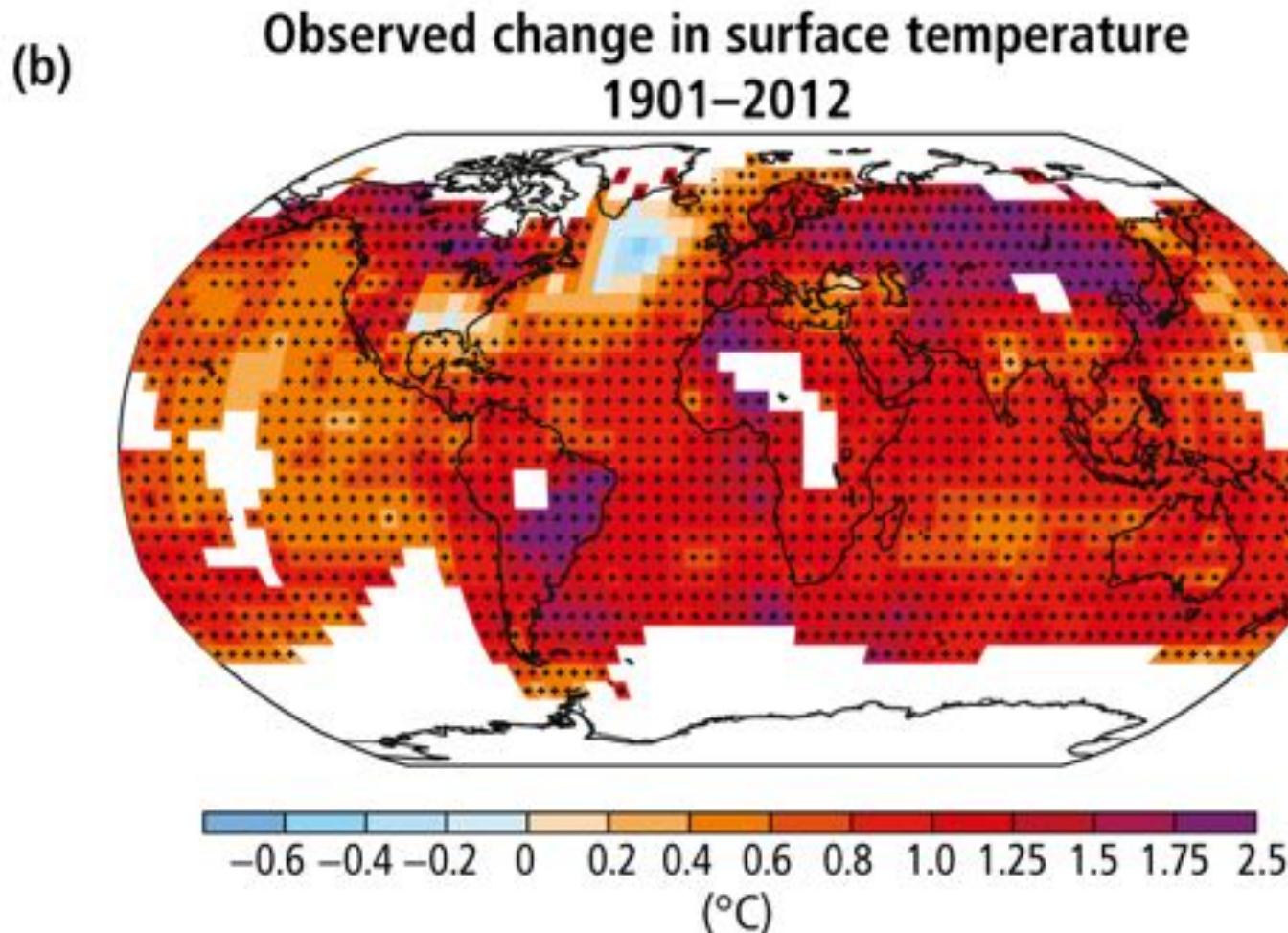
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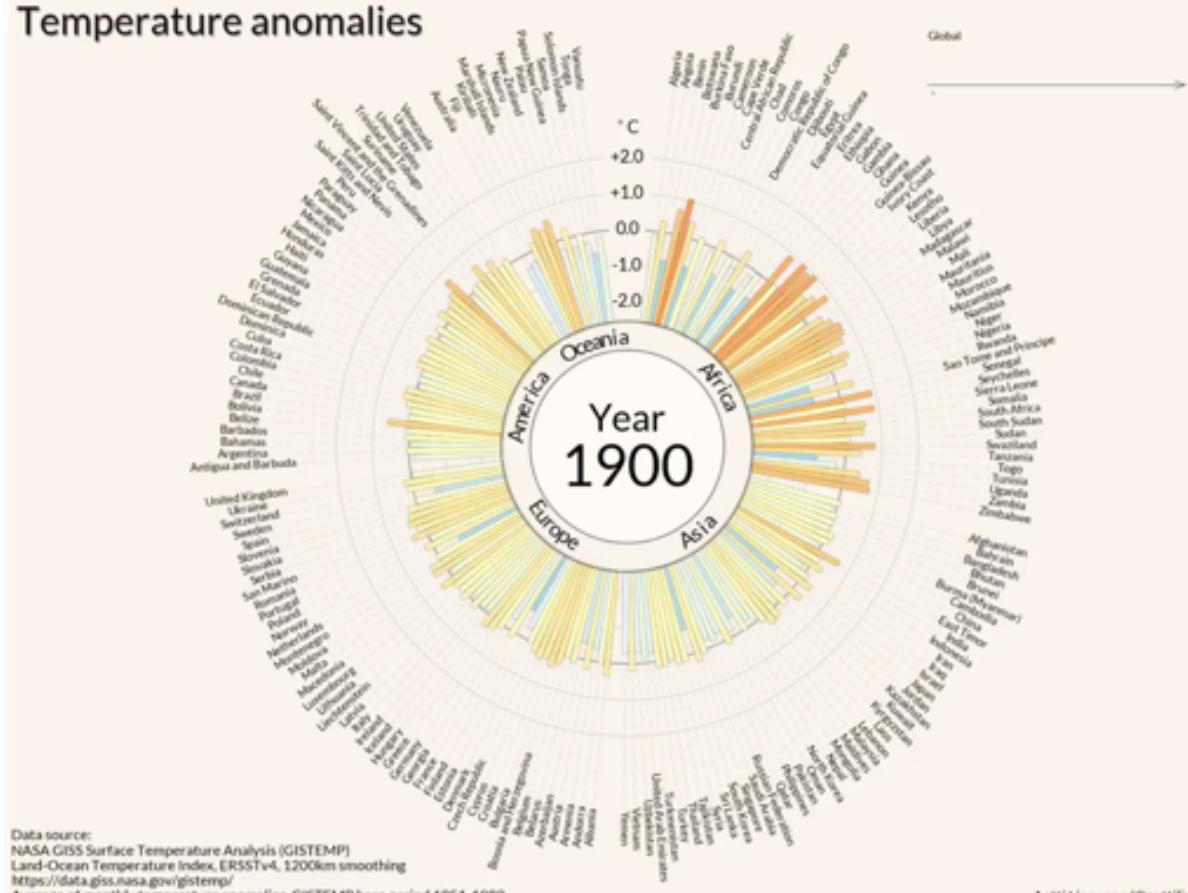


# The climate is warming

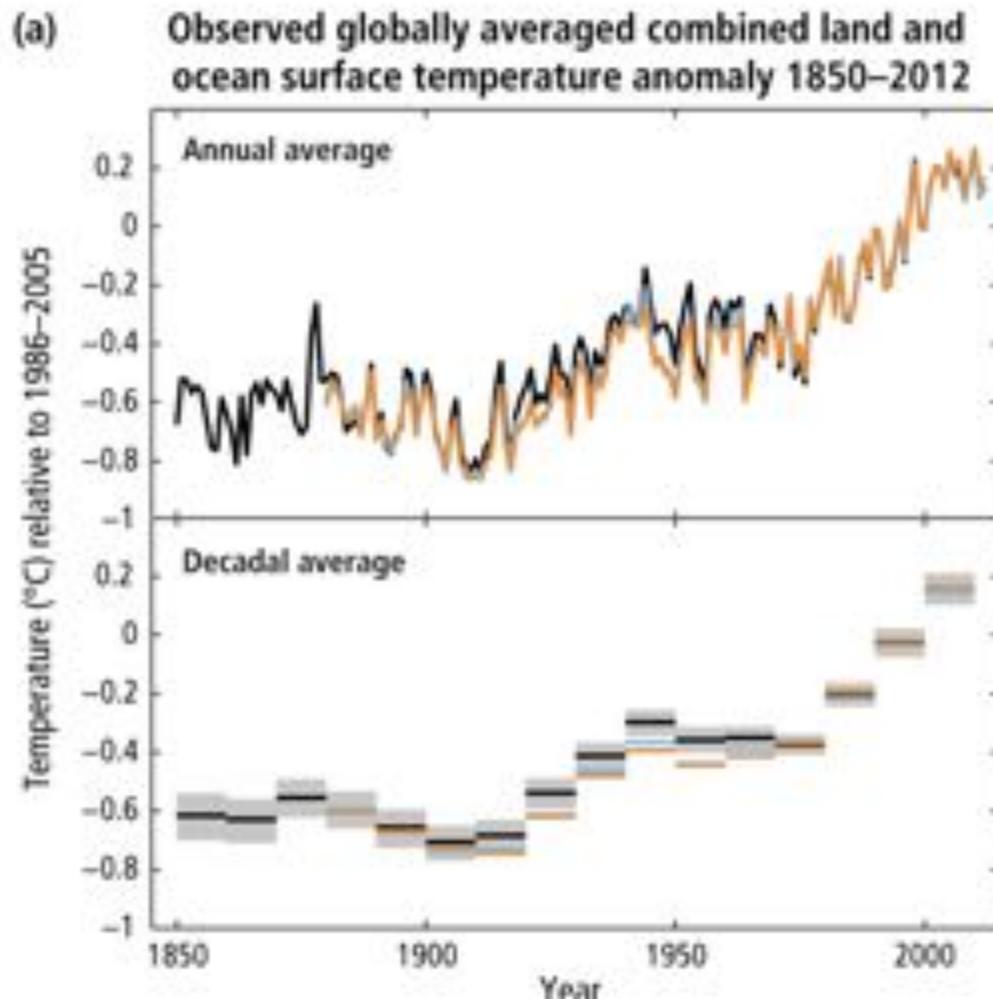


Poles and land  
are warming  
the fastest

## Temperature anomalies

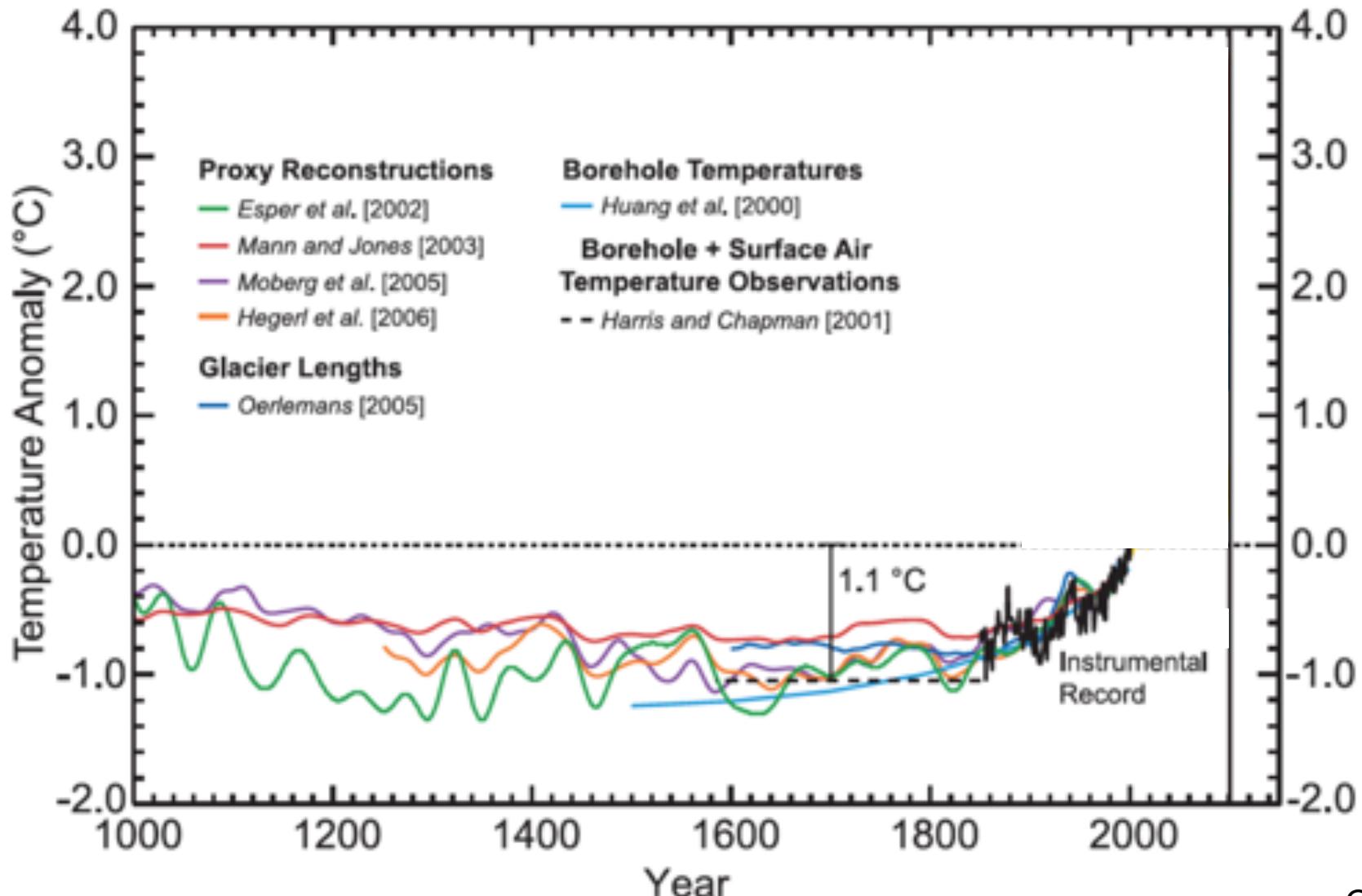


# It's warmer now than 150 years ago

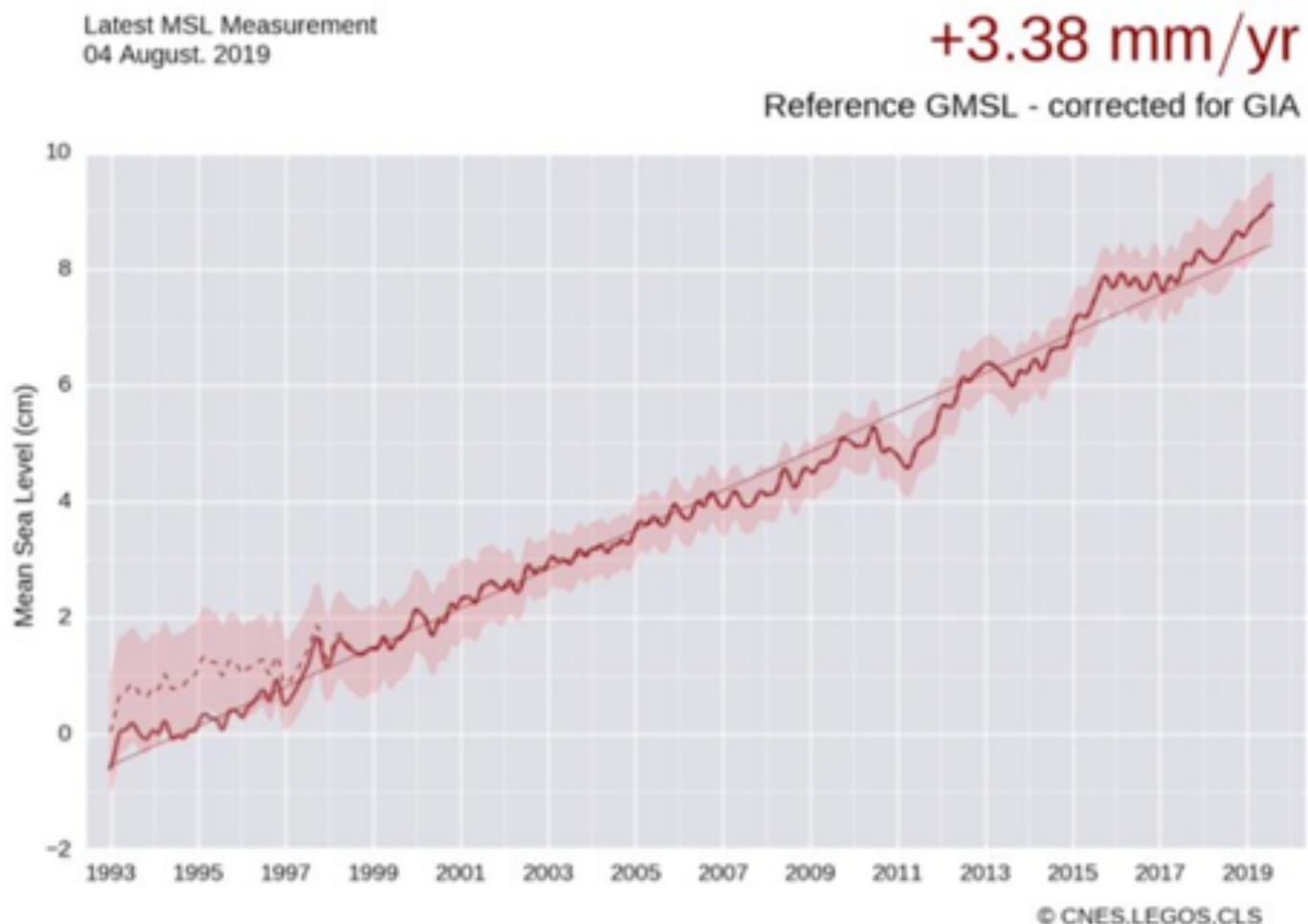


The global mean temperature has increased  $\sim 1.5^{\circ}\text{ F}$  ( $0.8^{\circ}\text{ C}$ ) over the past 150 years

# And warmest it's been in the past 1000 years

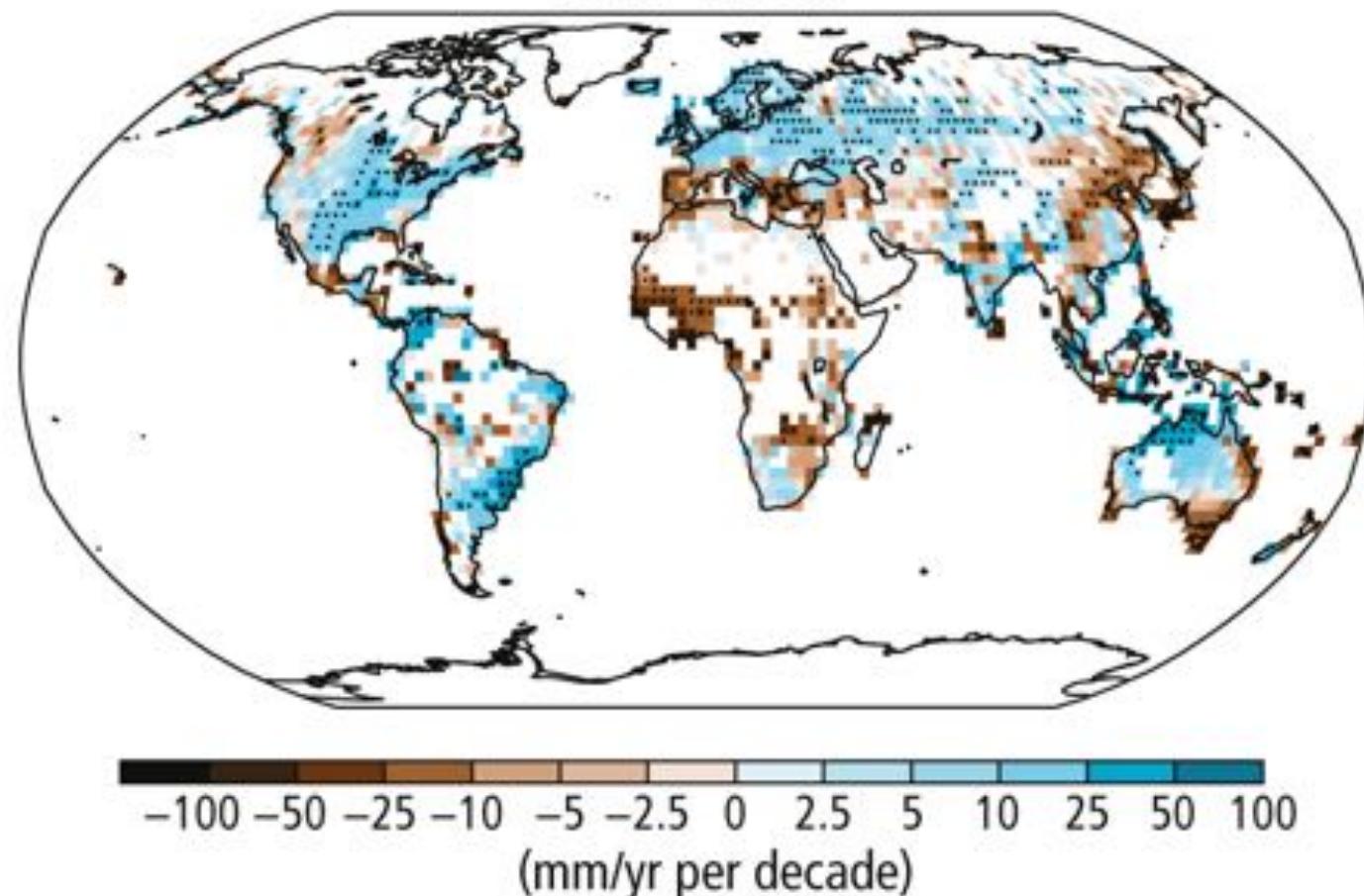


# Other evidence: sea levels are rising

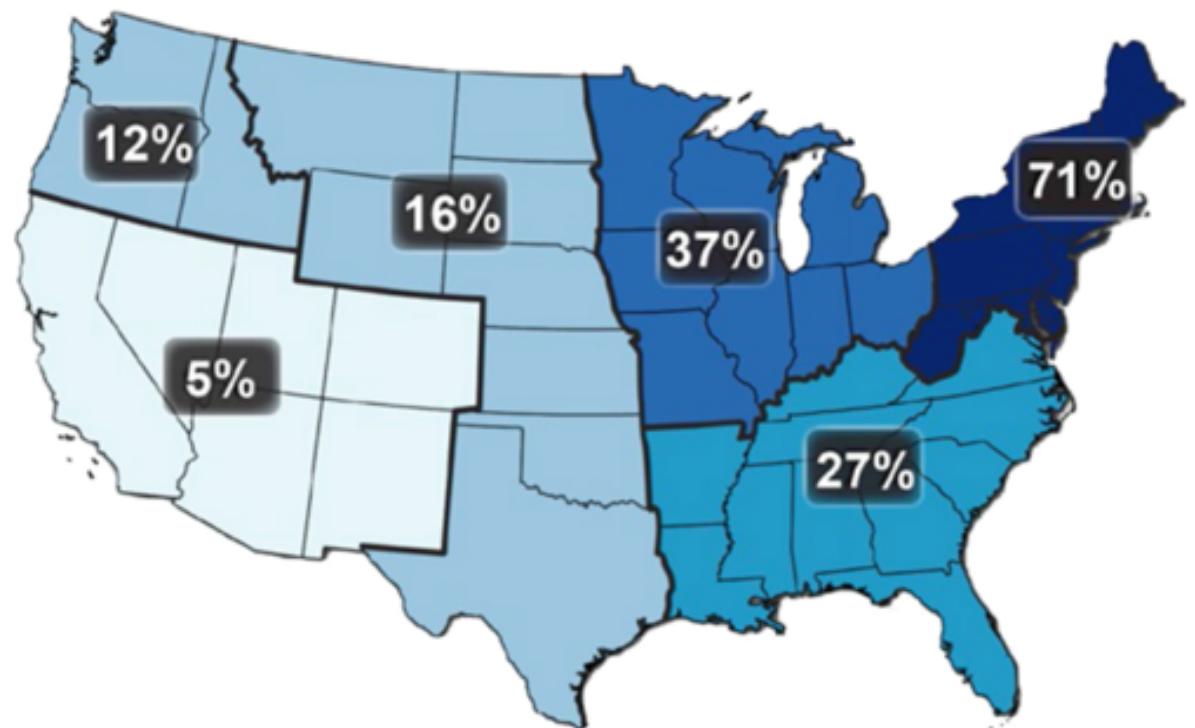
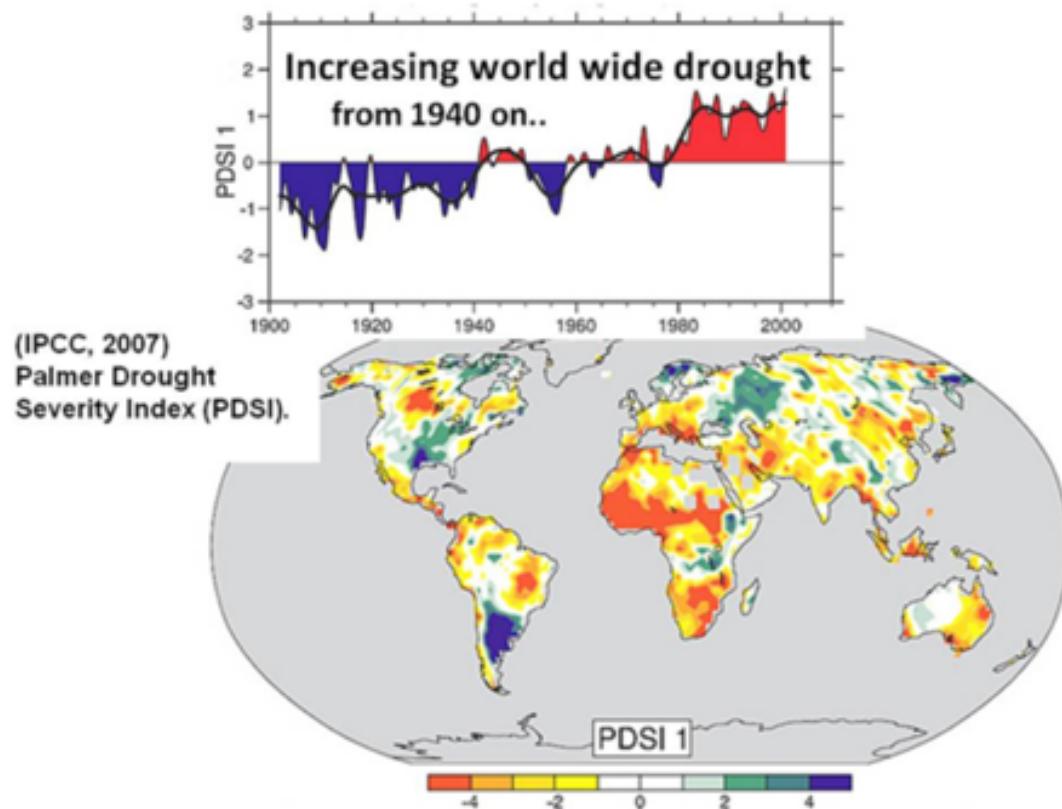


# Global total precipitation is also changing

(e) Observed change in annual precipitation over land  
1951–2010



# As is precipitation variability

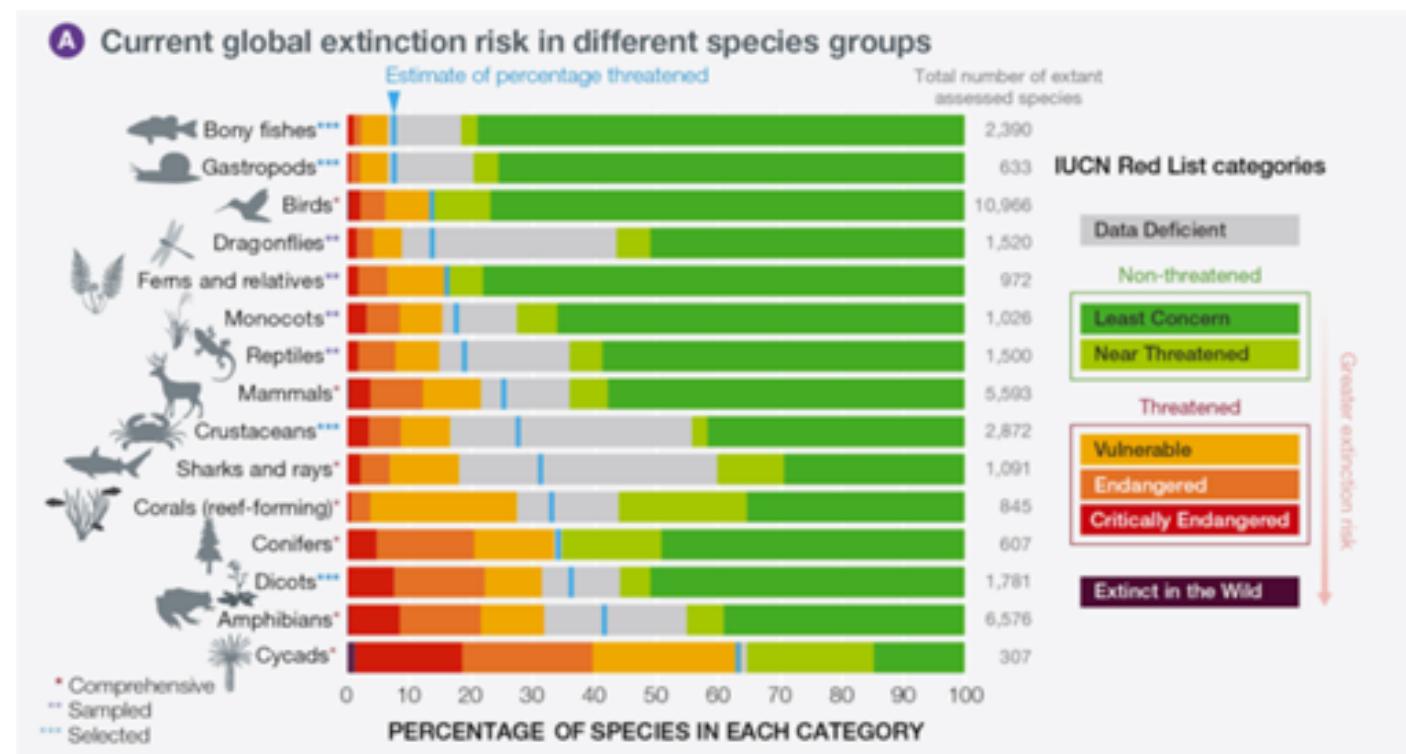


# The Case for the Anthropocene

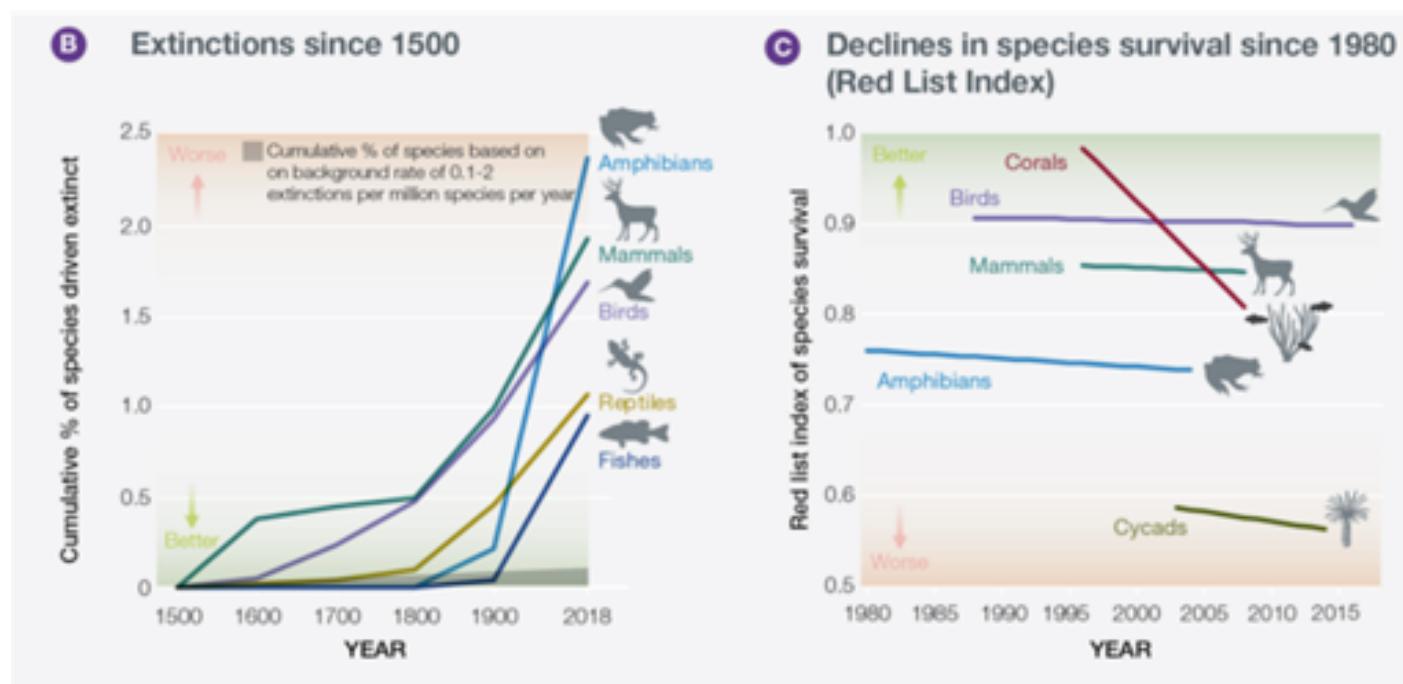
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# Humans are threatening species of all types



# And the threat is increasing



# Species loss results from habitat loss

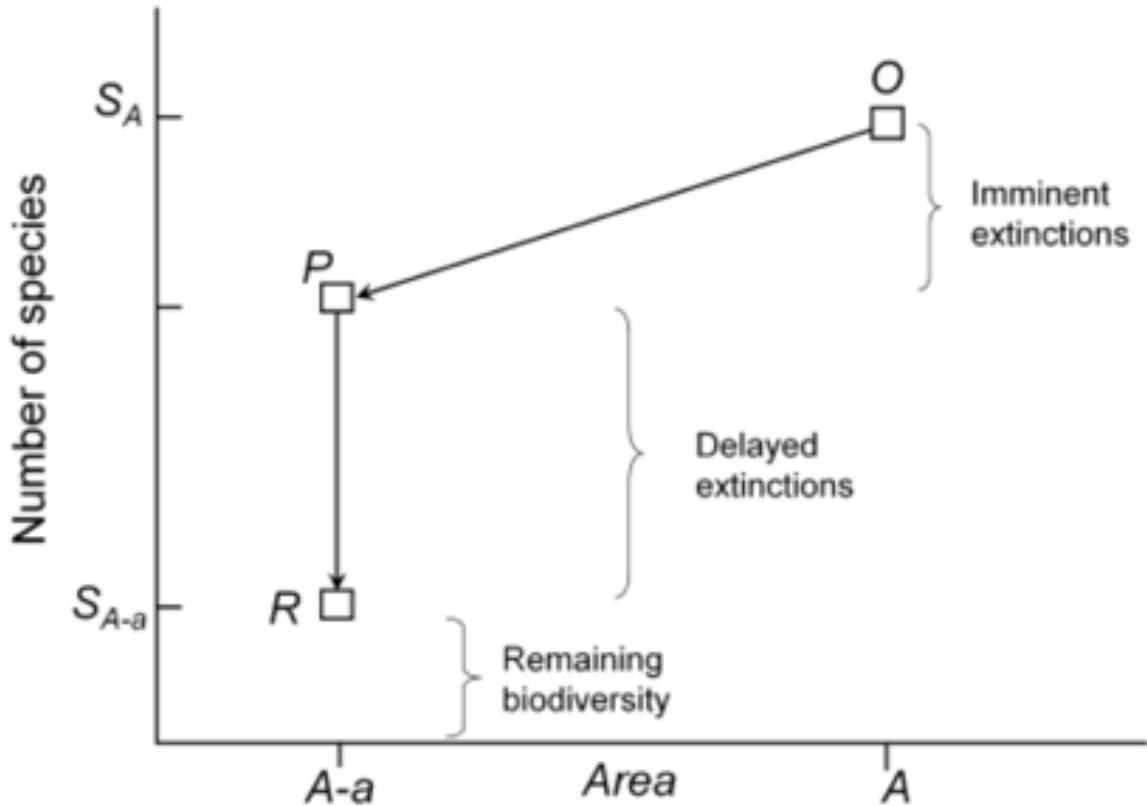
Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2014) 23, 113–123

RESEARCH  
PAPER



## Extinction debt and the species-area relationship: a neutral perspective

John M. Halley<sup>1\*</sup>, Vasiliki Sgardeli<sup>1</sup> and Kostas A. Triantis<sup>2,3,4</sup>



**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.

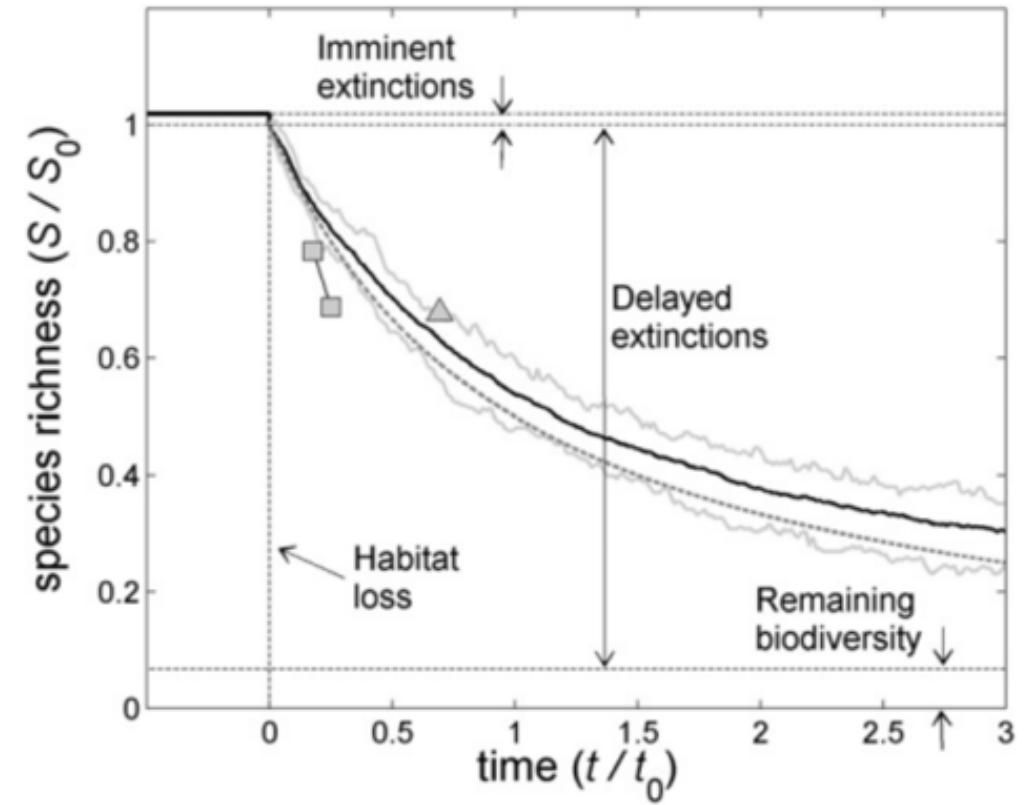
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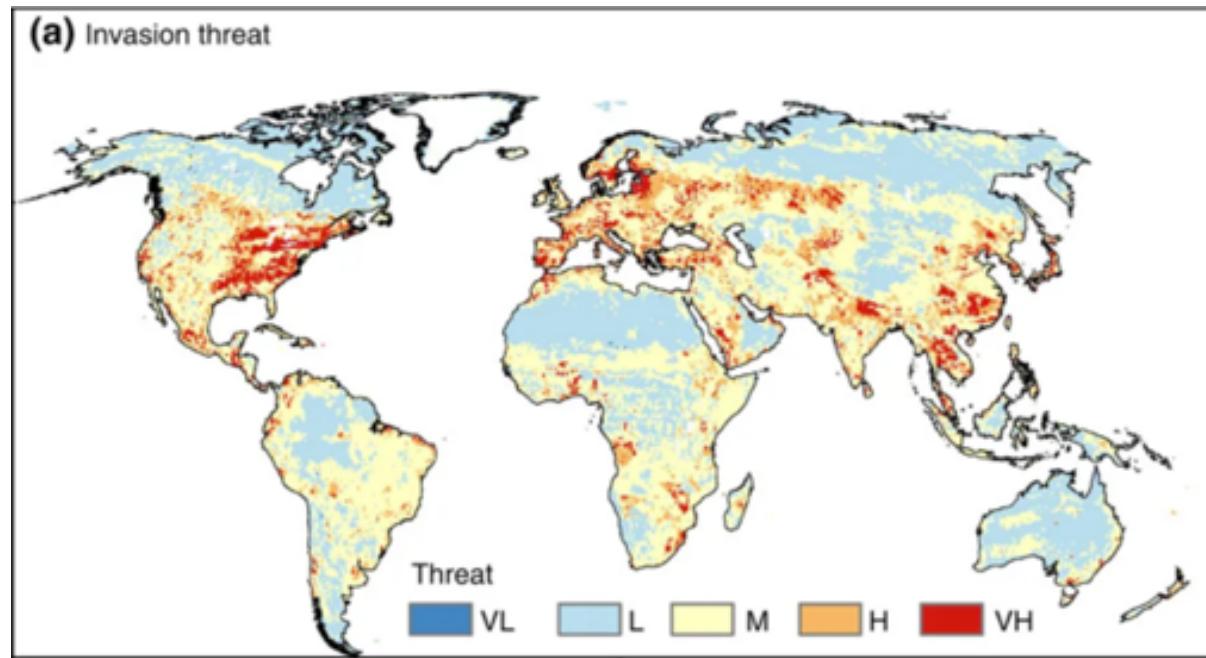
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# Invasive species are spreading...



# Invasives are a threat everywhere



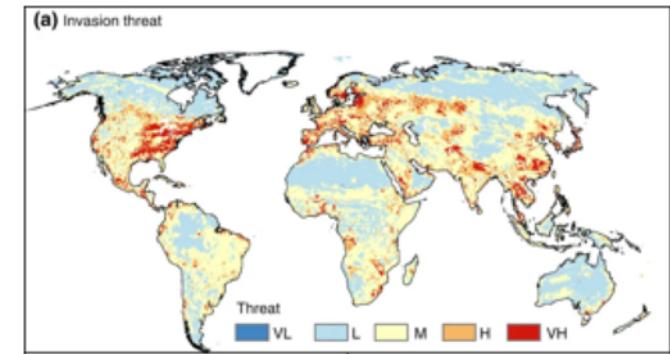
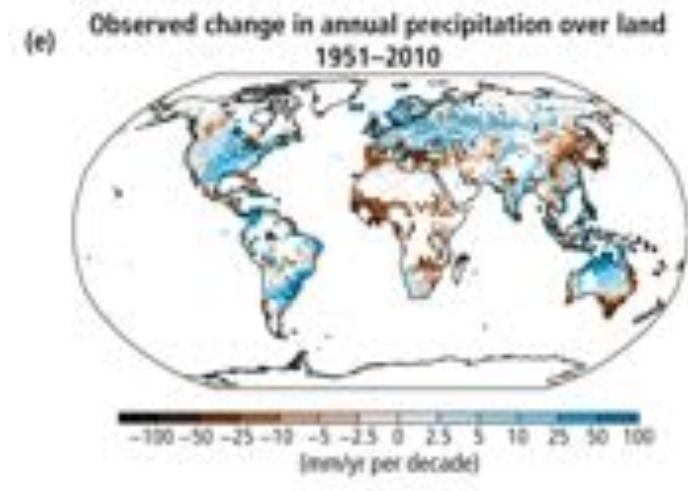
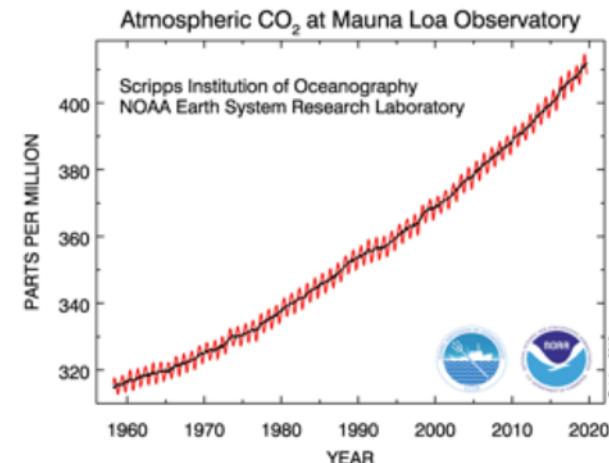
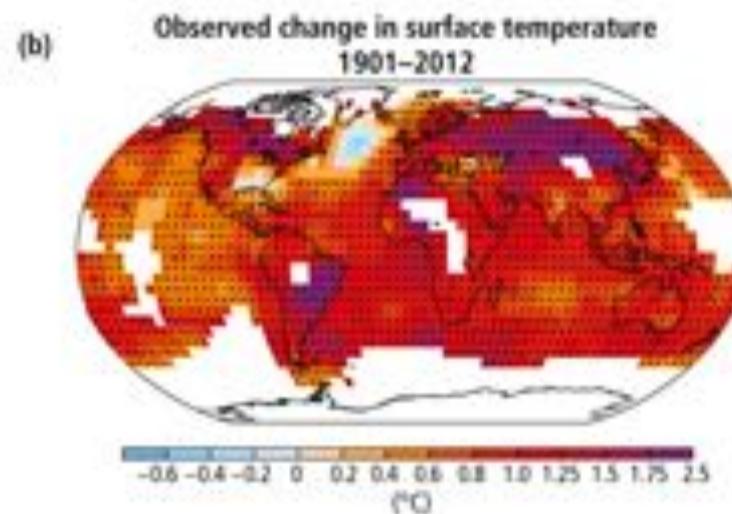
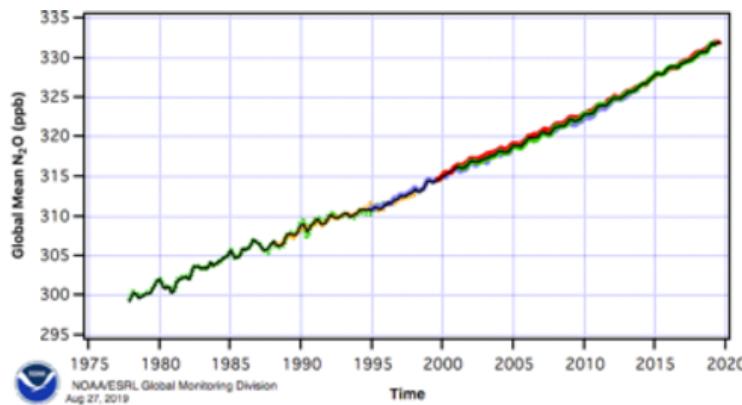
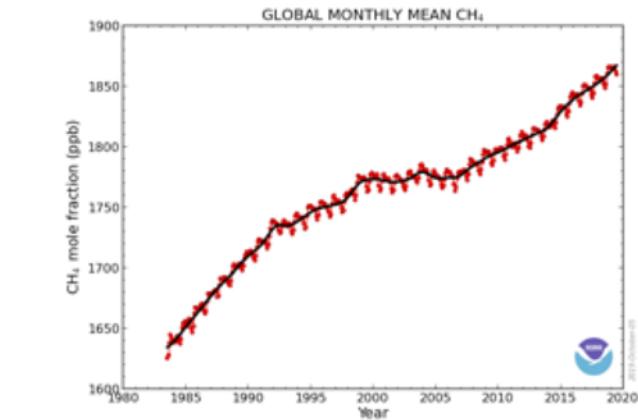
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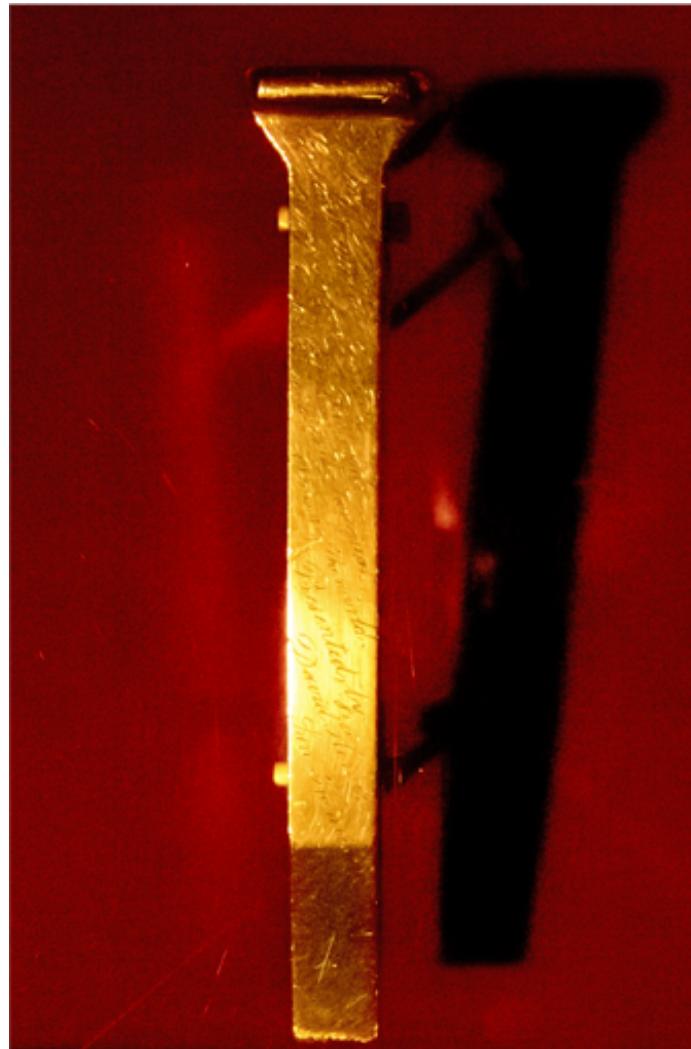


# The Case for the Anthropocene

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

