IEA lectures on Environmental Economics
Lecture 1: The Cost of Climate Change

Adrien Bilal
Harvard University

Introduction

- The planet is warming and the climate is changing
- What does the economy react to climate change?
- Today: the **macroeconomics of climate change**
  - Why is the climate changing?
  - Framework to **trade off energy** and **climate damages**
    - Key concept: the **Social Cost of Carbon**
  - **Quantify** the Social Cost of Carbon

Cheap Energy Has Been Critical for Growth…

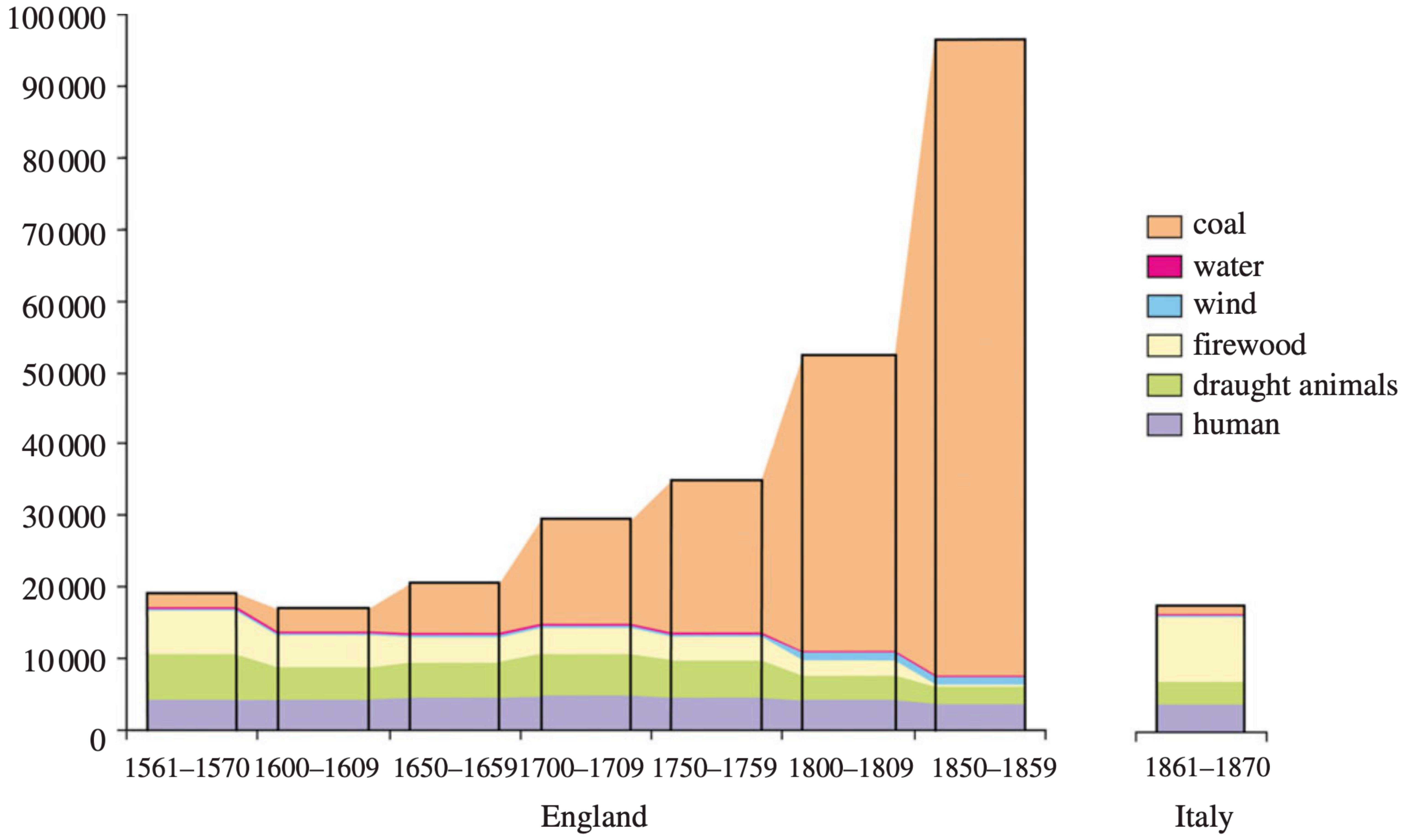
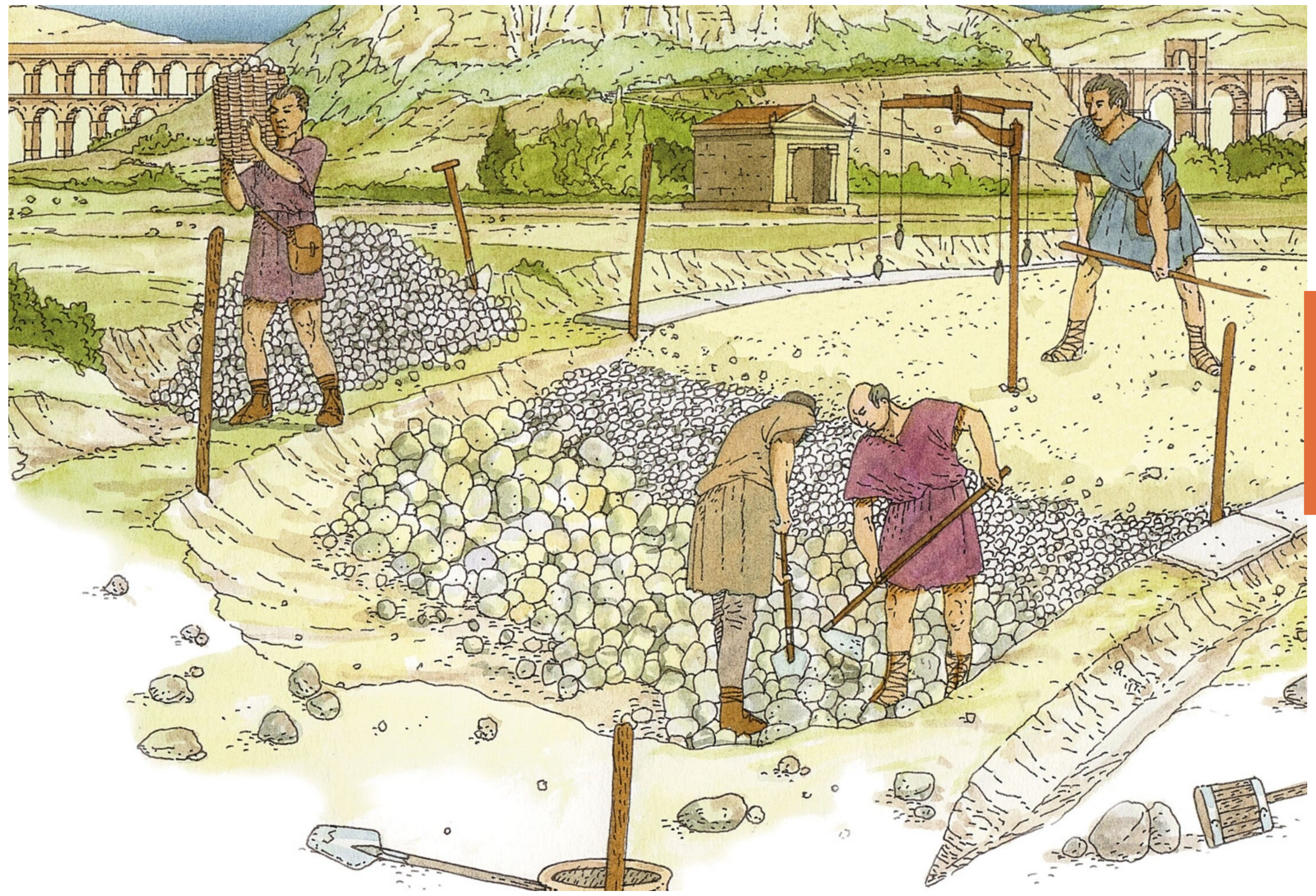


Figure 1. Annual energy consumption per head (megajoules) in England and Wales 1561–1570 to 1850–1859 and in Italy 1861–1870. Source: table 3 and [14, appendix 1, tables 2 and 3, pp. 96–101]. (Online version in colour.)

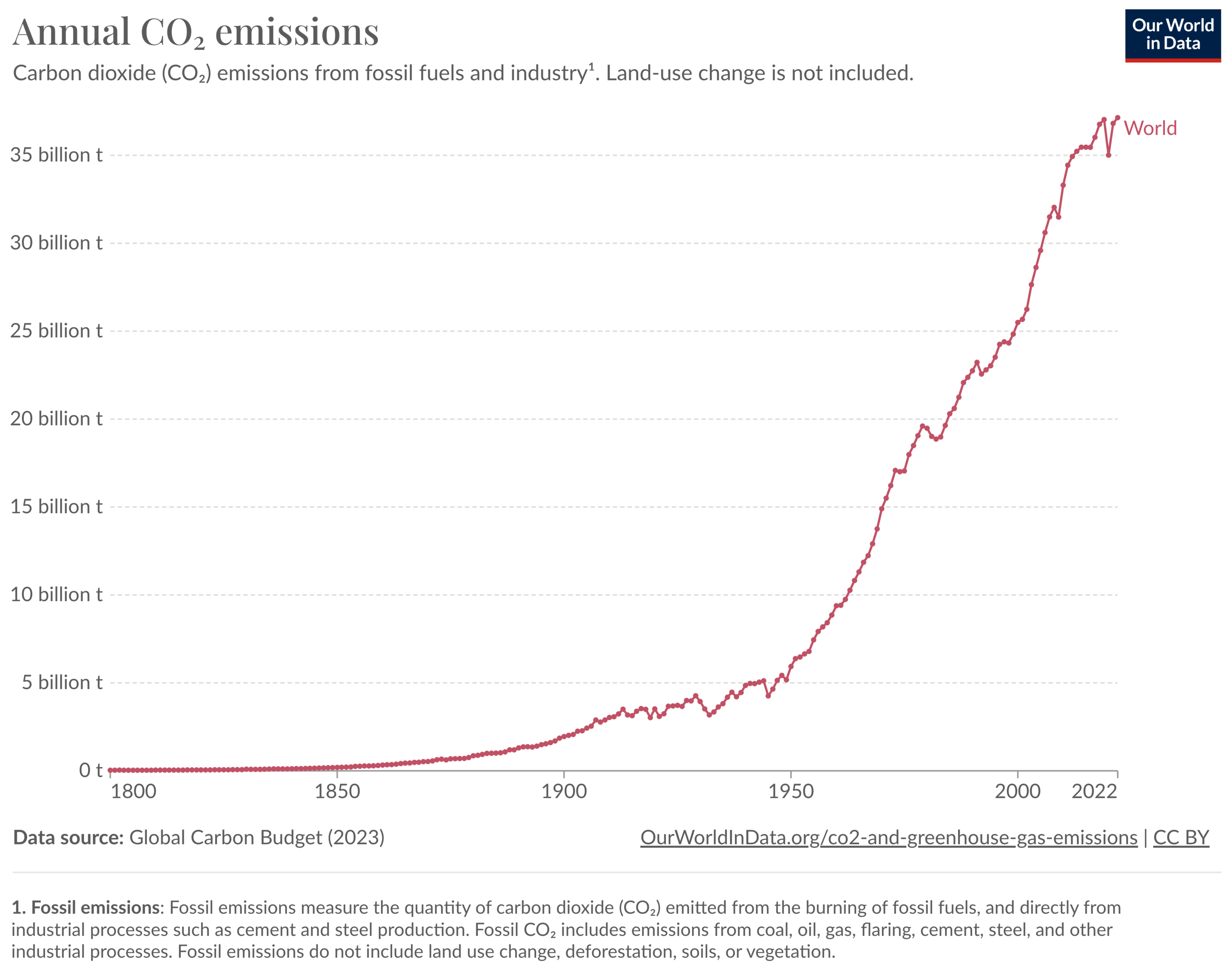
Source: Wrigley (2013)

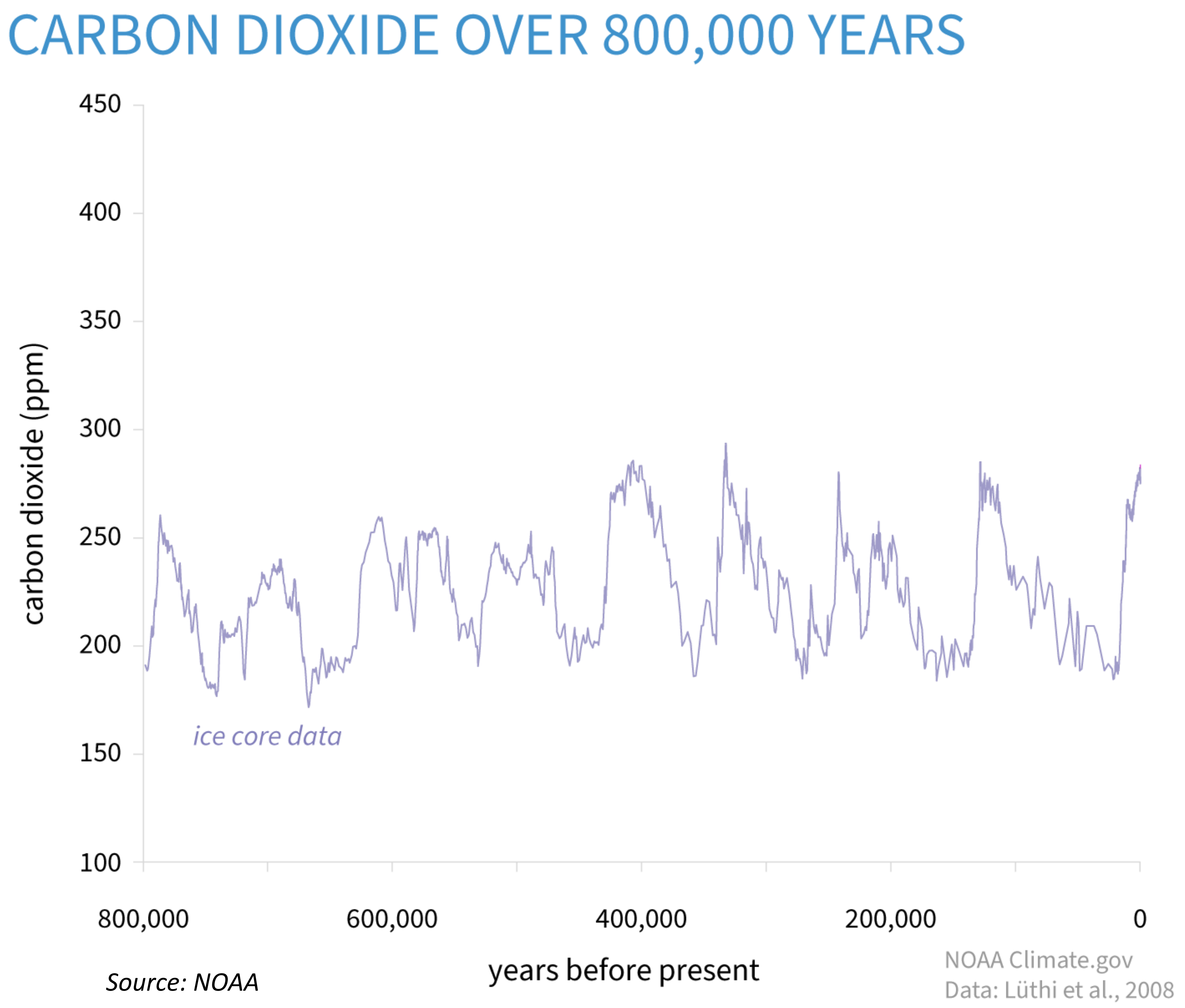
Cheap Energy Has Been Critical for Growth…

- Cheap coal was instrumental to jump-start the Industrial Revolution
  - Before that main source of energy was draught animals, human-power and firewood
- Since then **fossil fuels** have provided an **extremely cheap source of energy**
  - **Energy in 1 gallon of gas ($4) = Energy from 100 people working all day ($18,000)**
  - Construction, transportation, industry, heating, cooling



We have Burned Fossil Fuels For A While





Source: NOAA

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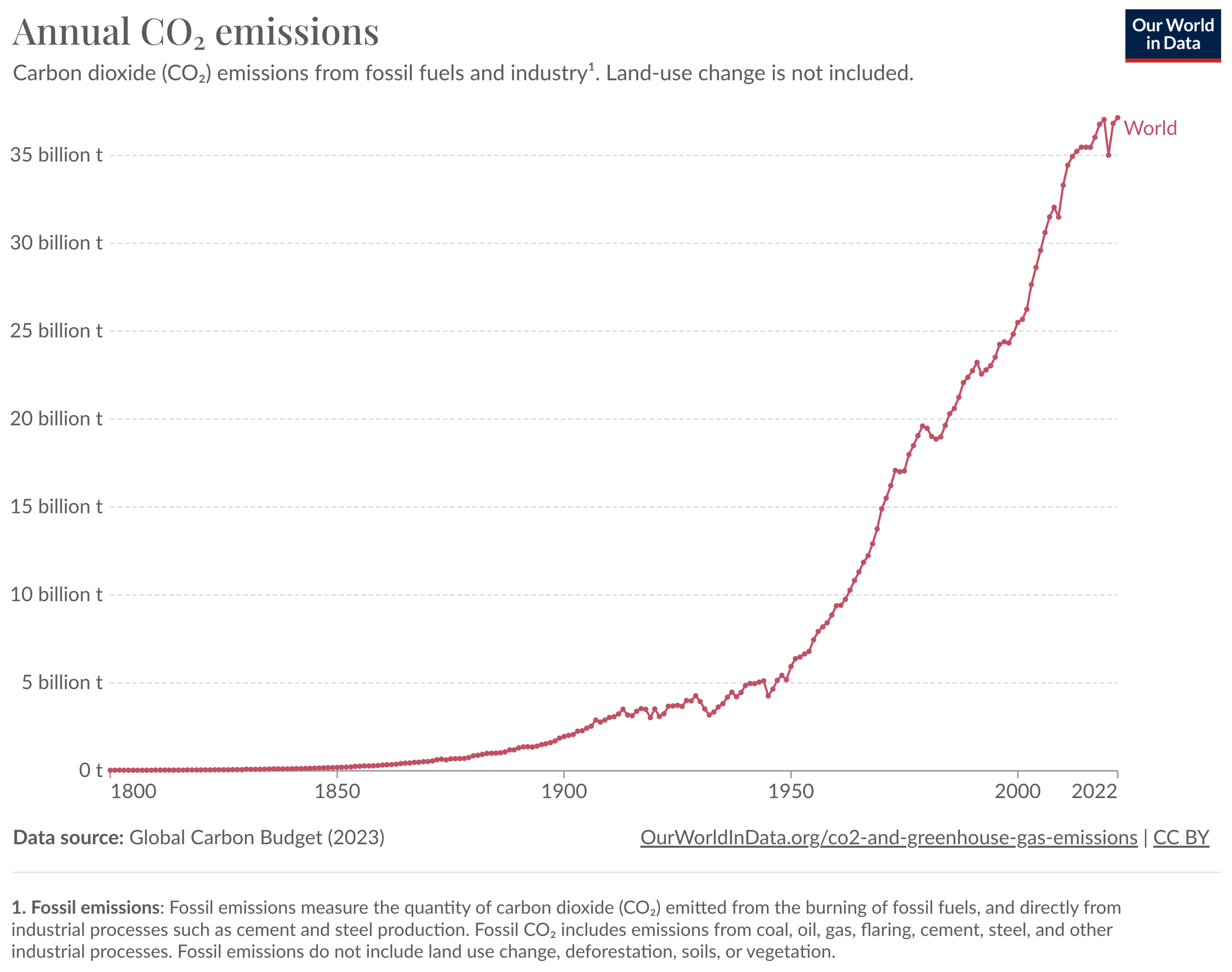
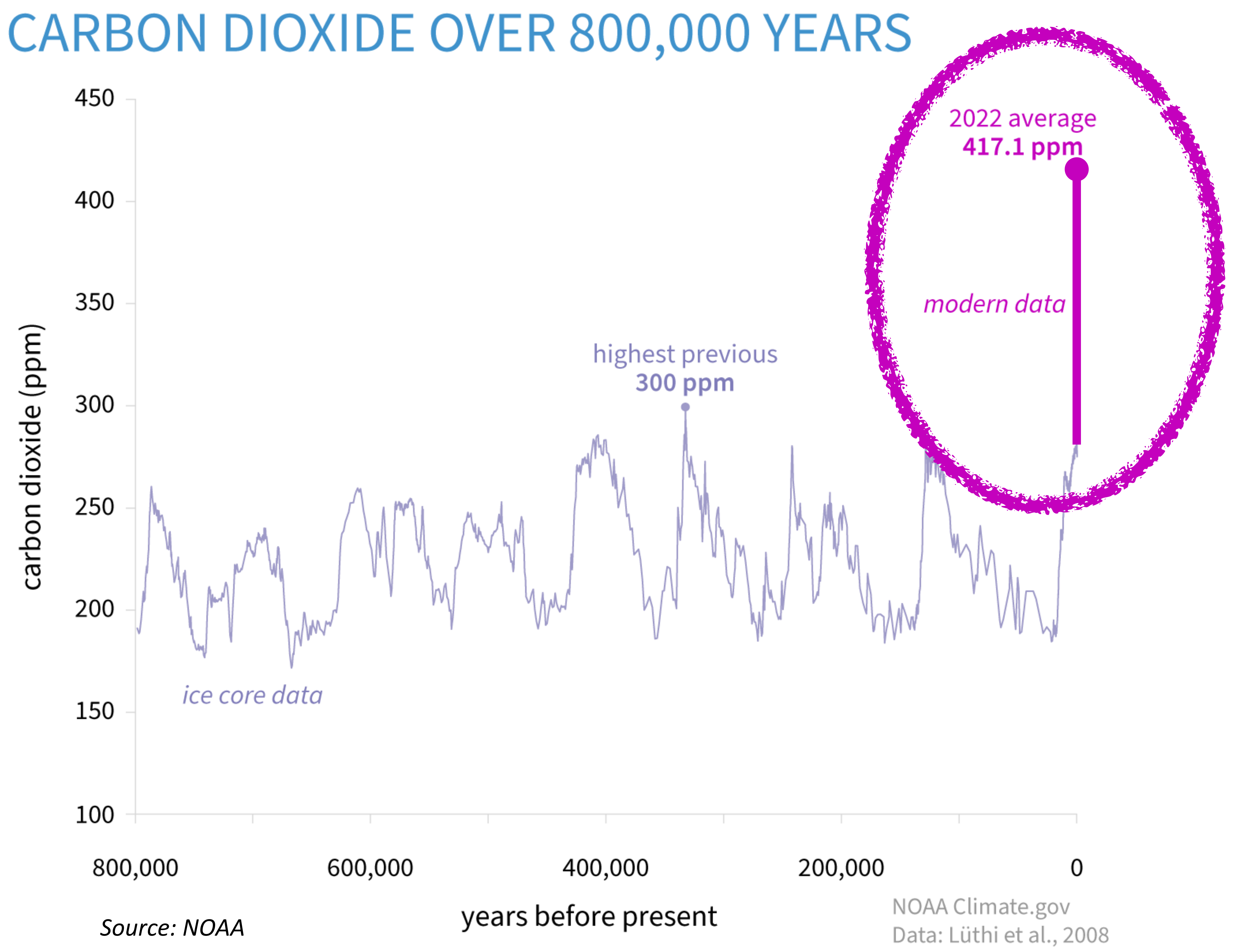


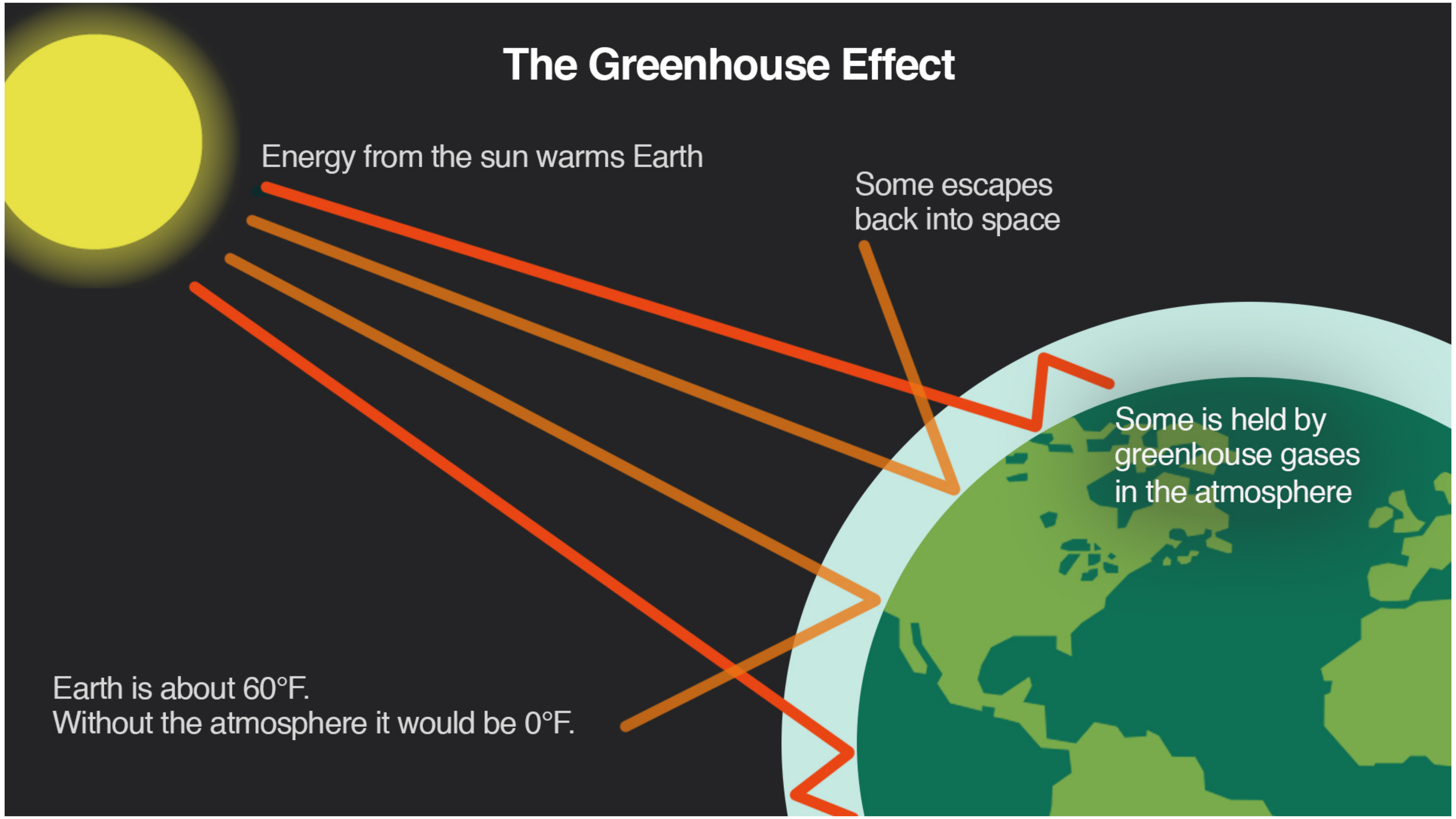
Carbon concentration +50% in last 200 years



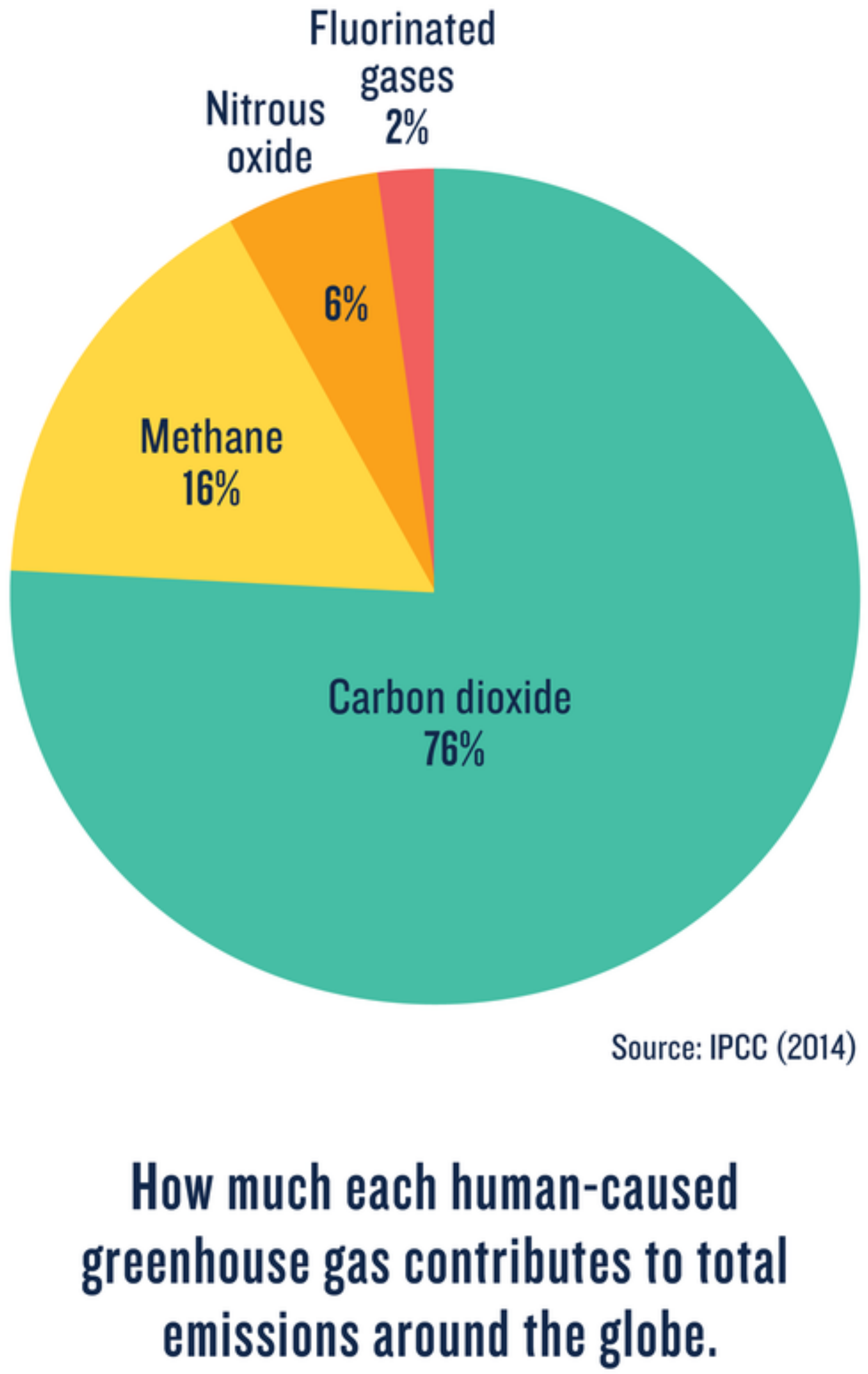
Source: NOAA

So What?

The Greenhouse Effect



Source: climate central

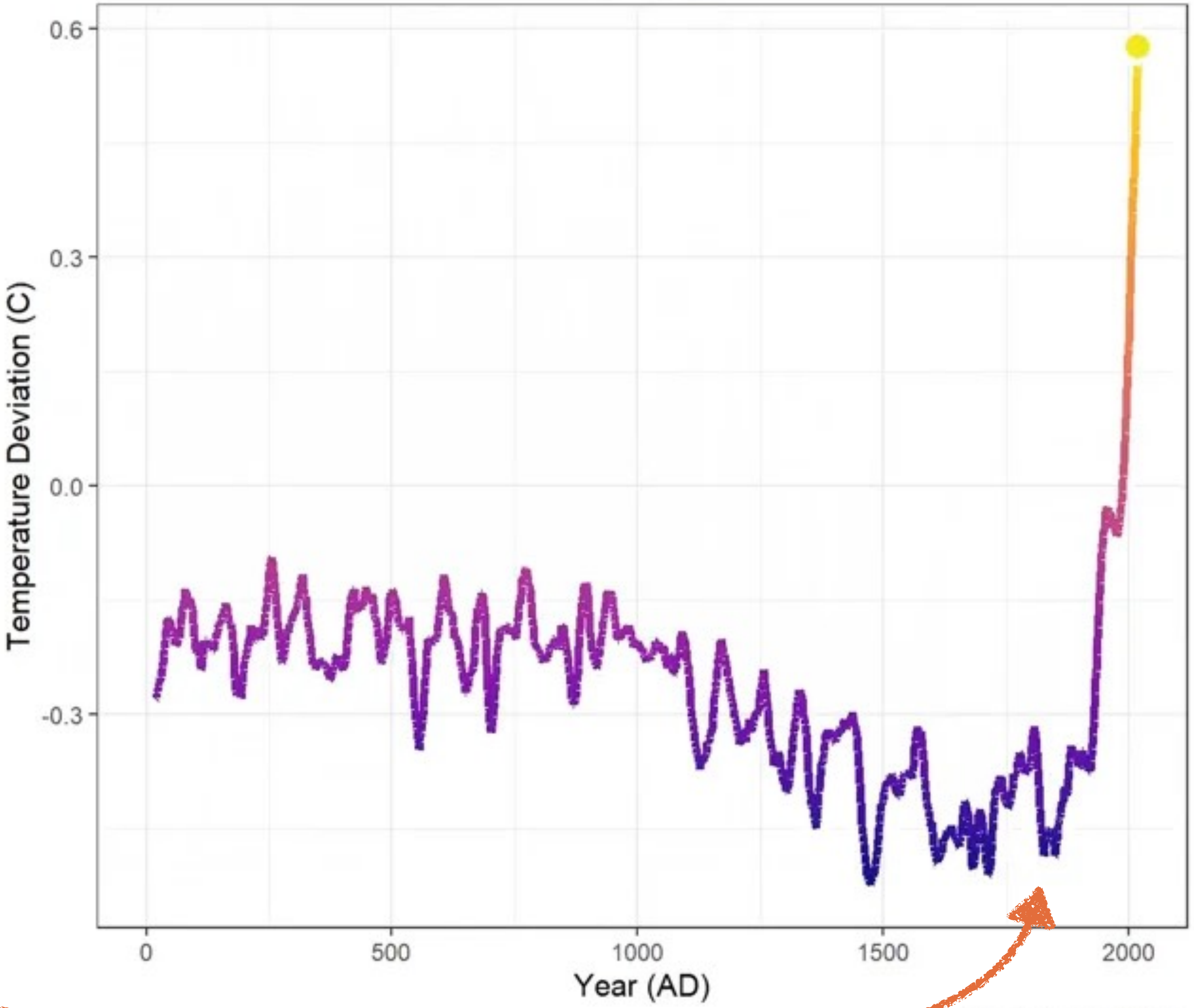


This is in mass, not warming potential
Methane responsible of 30% of warming!

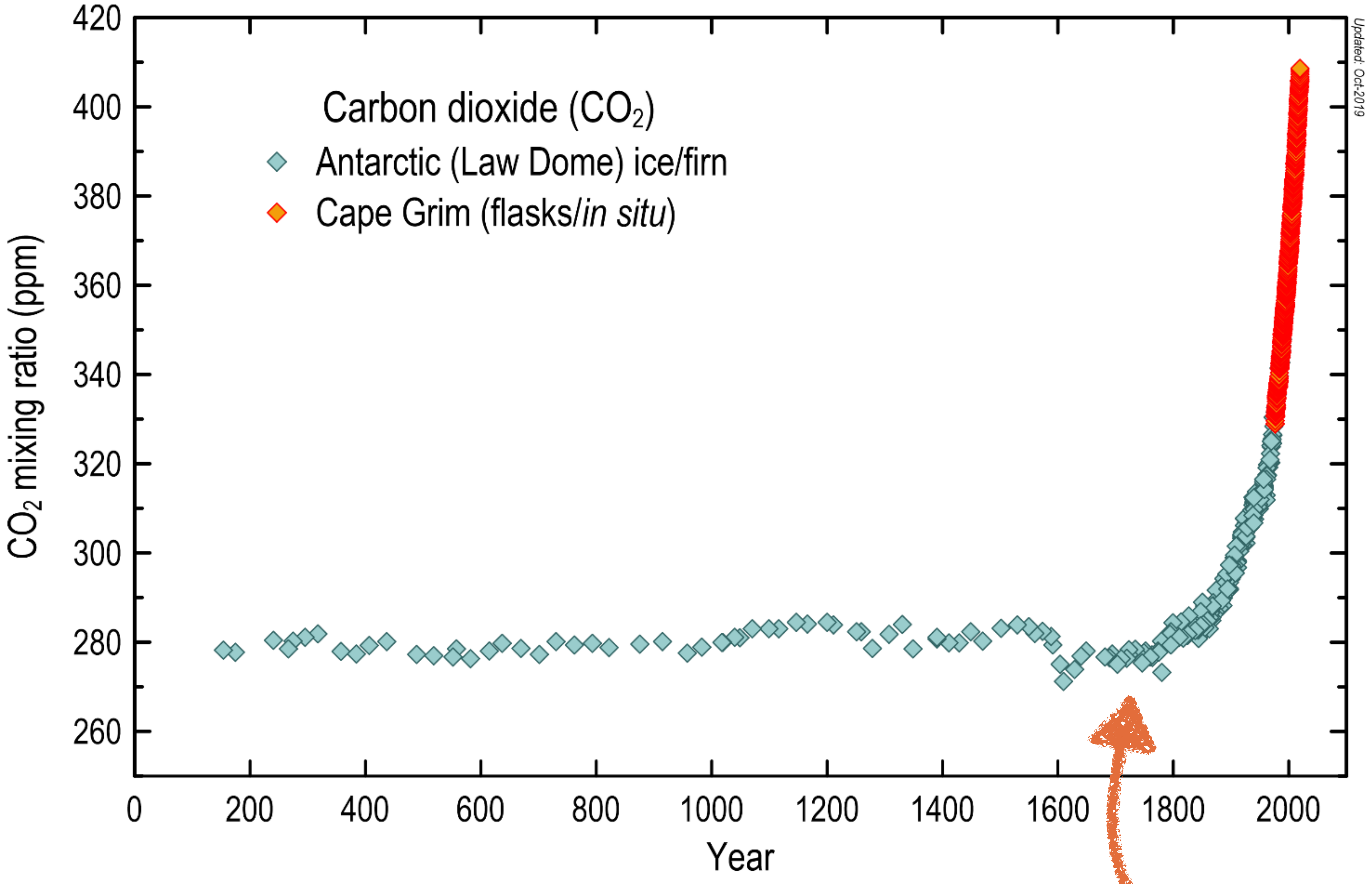
The Planet is Warming

+1°C (+1.8°F)

Global Mean Temperature

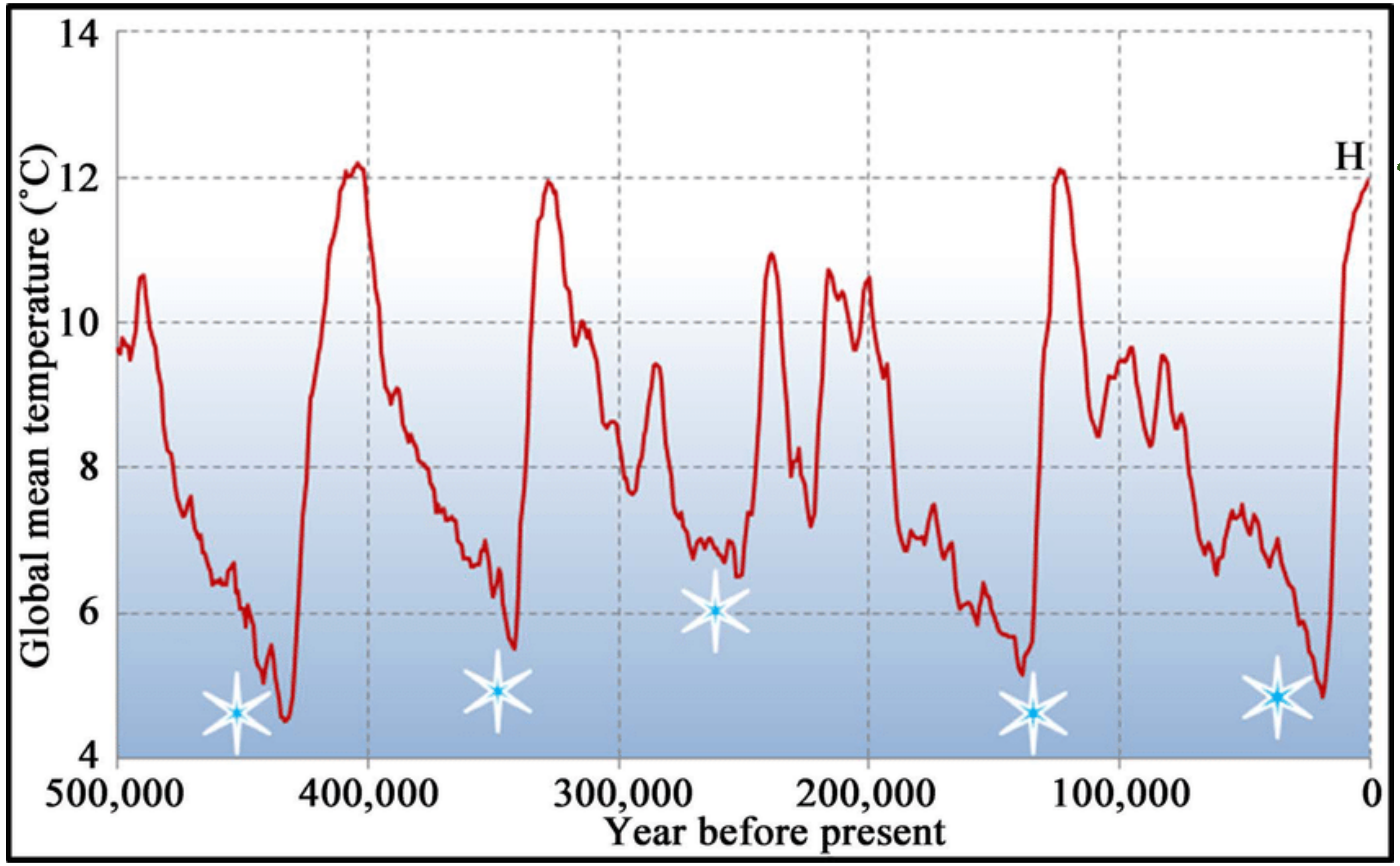


Atmospheric Carbon Dioxide



Industrial Revolution

Some History of Temperature



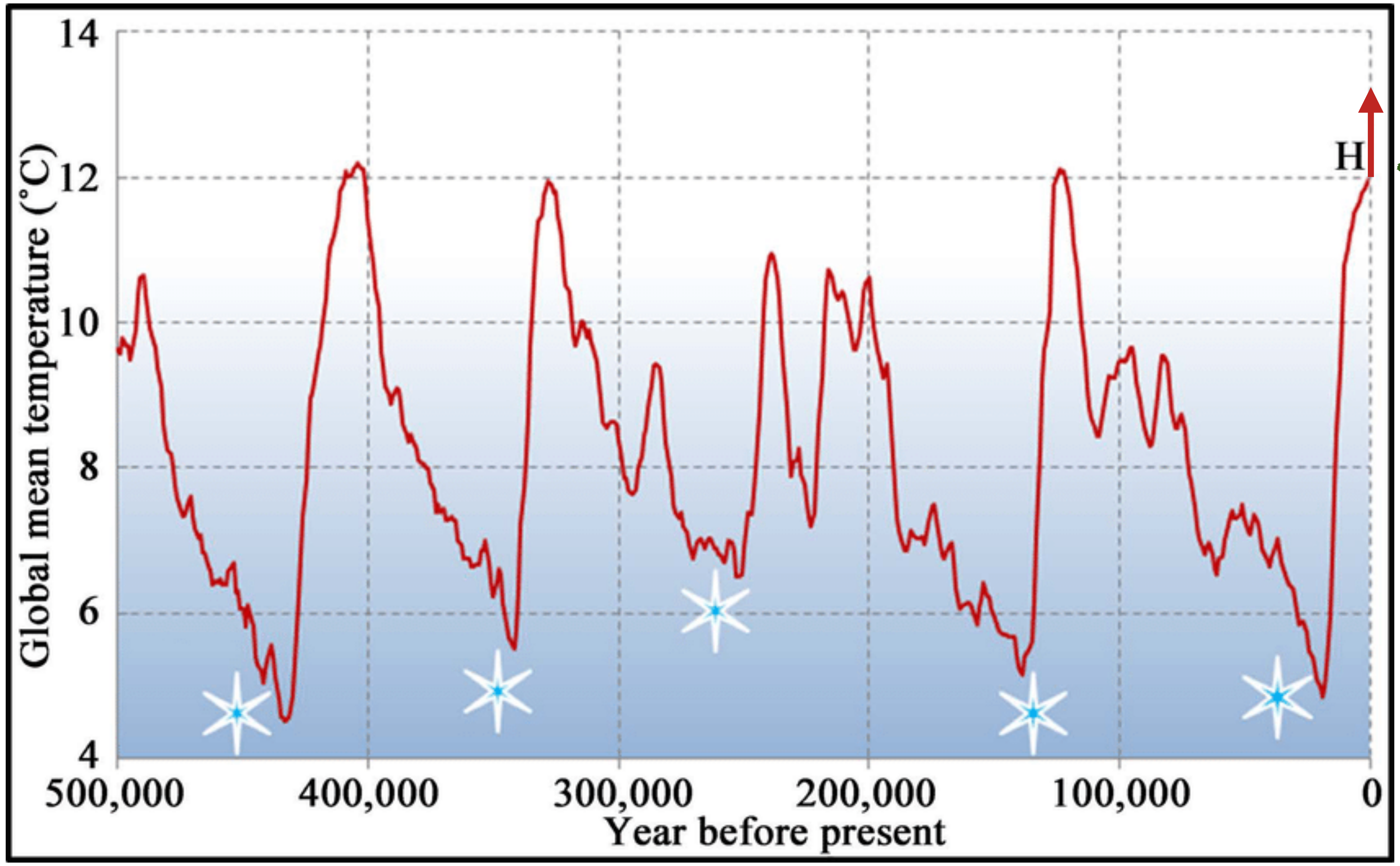
Source: Adamo et al. (2021)

We were here in 1800 Quite warm already by "recent" historical standards

Homo sapiens

Some History of Temperature

Warming happening faster than before
2024: +1°C

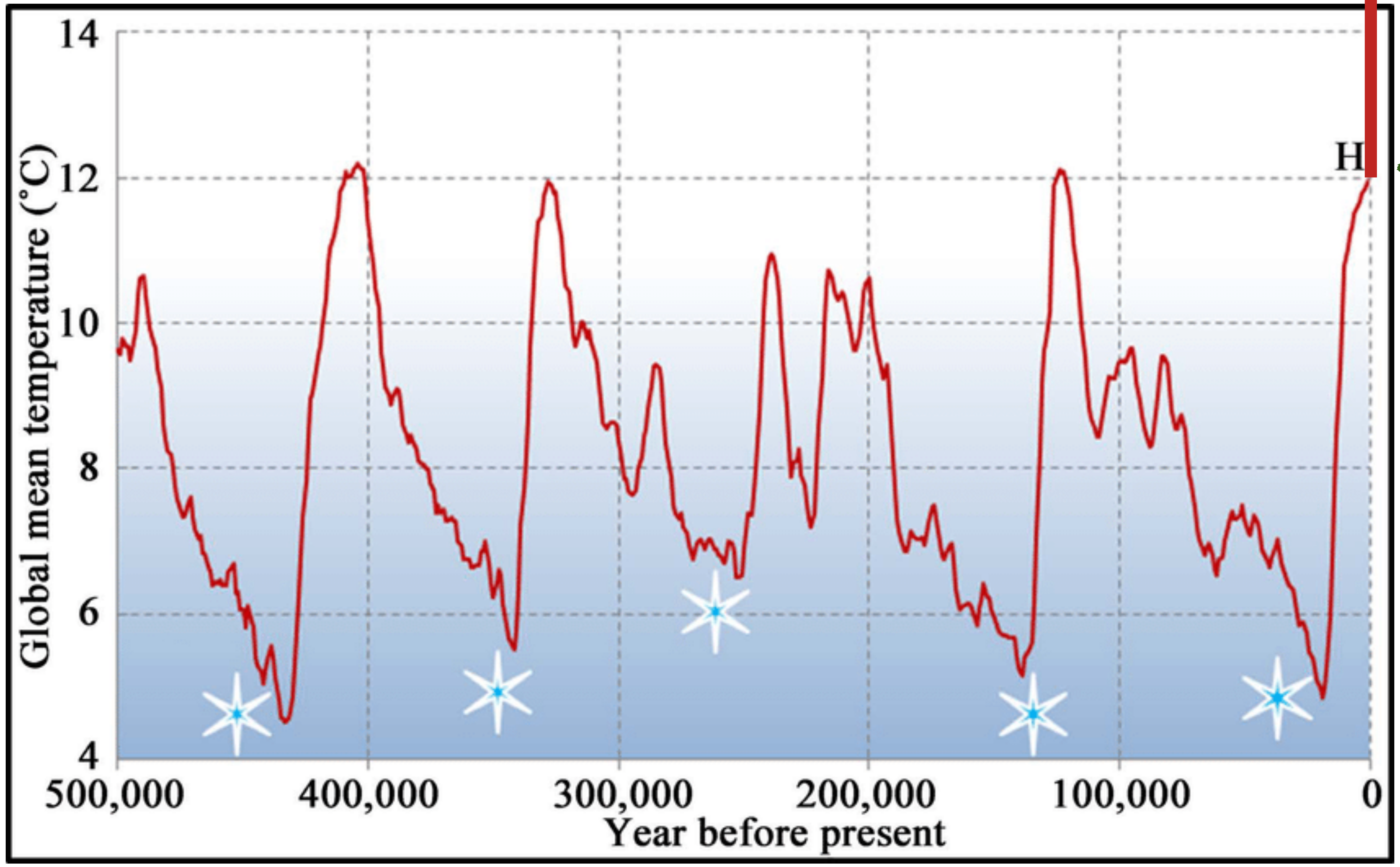


Source: Adamo et al. (2021)

We were here in 1800
Quite warm already by "recent" historical standards

Homo sapiens

Some History of Temperature



Source: Adamo et al. (2021)

Warming happening faster than before
2100: +4°C

We were here in 1800
Quite warm already by "recent" historical standards

Homo sapiens

What Do
Global Temperatures Do?

Global Temperatures Can Be Misleading

- Global mean temperature includes ocean surface temperature
  - Ocean warm much less (and more slowly) than land
- World is on track to warm by 3-4°C (7°F) by 2100
- For 4°C (7°F) of global warming, **land will warm by 8°C (14°F) on average**
  - Very different in different places
  - Regions closer to poles warm more than average, tropics less than average
  - US “only” **6°C (10°F) of warming**
- Average warming implies tough extremes, e.g. in Cambridge MA
  - Summer temperatures increase by **5°C (10°F)**
  - **1 month** with temperatures **above 35°C (95°F)**
  - **2 months** similar to **hottest/most humid days in parts of Louisiana today** (serious health risks)

Change in Extreme Heat Around the World

Increase in number of days above 95F/35C in a year by 2100 under RCP8.5. Source: Climate Impact Lab

Is Climate Change A Big Deal?

The Effects of Rising Temperatures

- Crop yields fall
- Overall labor productivity falls
- Mortality rises
- Sea level rises
- More hurricanes/more powerful
- Larger effects in lower-income countries
- Other effects of climate change?

OK but…

- Yes, climate change may be **damaging** to the economy (and beyond)
- We can **mitigate/reduce emissions** and **green energy:** David's lecture tomorrow
- We can **adapt**, e.g. by **trading with cooler places**: Joe's lecture on Thursday
- How to trade off **damages**, **mitigation and adaptation**?
    - Need to incorporate measures of the costs and benefits of all three
- **Next:** integrated framework to do just that
    - Due to Nordhaus (Nobel Prize 2018)
    - Today: will focus on **damages**

The Dynamic Integrated Climate Economy Model

Overview of DICE

- Block 1: **Neoclassical Growth Model** + energy use in production
  - Consumption and production generate carbon emissions
- Block 2: **Climate**
  - Carbon leads to changes in temperature
- Block 3: **Damage functions**
  - Temperature affects productivity (heat stress), capital depreciation (storms, floods)...

Block 1: Households

- Household earns wage w_t and accumulates a stock of savings a_t entering period t
- Household face **time-varying** interest rate r_t in period t
- Household then solves for optimal consumption path c_t :

$$\max_{c_0, c_1, \ldots} \; U(c_0) + \beta U(c_1) + \beta^2 U(c_2) + \ldots = \sum_{t=0}^{\infty} \beta^t U(c_t)$$

$$c_t + a_{t+1} = (1 + r_t)a_t + w_t \qquad t = 0,1,2,\ldots$$

Euler equation: How much to consume vs. save

$$U'(c_t) = \beta(1 + r_{t+1})U'(c_{t+1})$$

Block 1: Firms

- Representative firm that, **each period**:
  - Rents capital K_t from households at rate r_t and covers depreciation δ
  - Hires labor L_t the household at wage w_t
  - Uses energy E_t at exogenous price p (can microfound with constant extraction cost)
- Revenue production function $\tilde{Y} = \tilde{F}_t(K, L, E) = \gamma_0^{-\gamma_0}(1-\gamma_0)^{-(1-\gamma_0)} A_t^{1-\gamma_0} K^{\alpha_0} L^{\lambda_0} E^{\gamma_0}$

  normalization *damages* *CRS, Cobb-Douglas in K, L, E*
- Solve out for energy use given K, L and obtain **value added production function**
  - $Y = F_t(K, L) = \max_E \tilde{F}_t(K, L, E) - pE = p^{-\varepsilon} A_t K^{\alpha} L^{1-\alpha}$
  - With effective capital share $\alpha = \alpha_0/(\alpha_0 + \lambda_0)$ and $\varepsilon = \gamma_0/(1-\gamma_0)$

Block 1: Firms

- **Value added production function** $Y = F_t(K, L) = p^{-\varepsilon} A_t K^\alpha L^{1-\alpha}$
  - Now can use first-order optimality conditions

Capital expenditures

$$\max_{K_t, L_t} F(K_t, L_t) - \left(r_t + \delta\right) K_t - w_t L_t$$

Value added *wage payment*

Capital demand

$$(r_t + \delta)K_t = \alpha Y_t$$

Labor demand

$$w_t L_t = (1 - \alpha) Y_t$$

Energy demand (from revenue prod. func.)

$$pE_t = \varepsilon Y_t$$

Block 2: Climate

- Relate **temperature** to **energy** through the the **carbon stock** S and the **carbon cycle**

$$T_t - \overline{T} = \sigma \frac{S_t - \bar{S}}{\bar{S}}$$

σ is the climate sensitivity
Between 2.5 and 4

Temperature rises with the carbon stock

$$S_{t+1} - \bar{S} = (1 - \delta_S)(S_t - \bar{S}) + E_t$$

Accumulation equation
Just like for capital!

δ_S governs how long carbon stays in the atmosphere (ocean & biosphere absorption)
Typically 300-1000 years

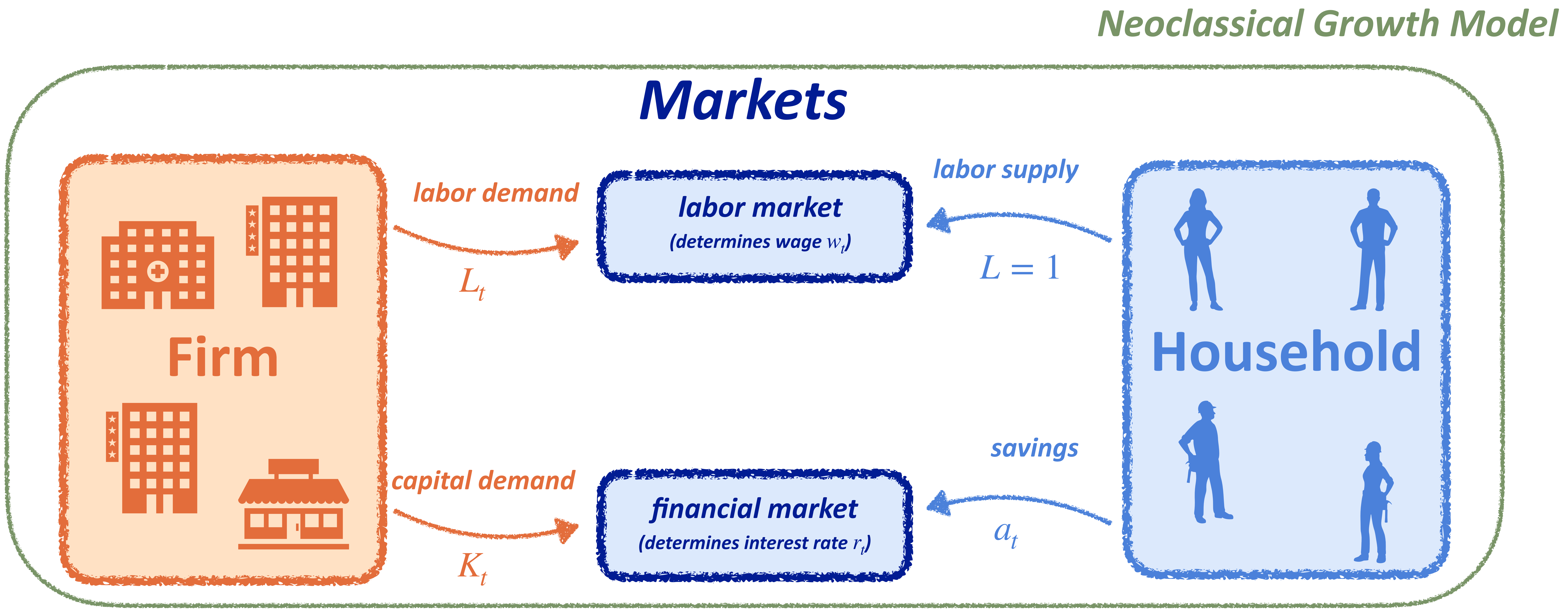
- Here, stylized carbon cycle model for simplicity
  - See Dietz et al. (2021) for a review and more realistic carbon cycles models

Block 3: Damage Functions

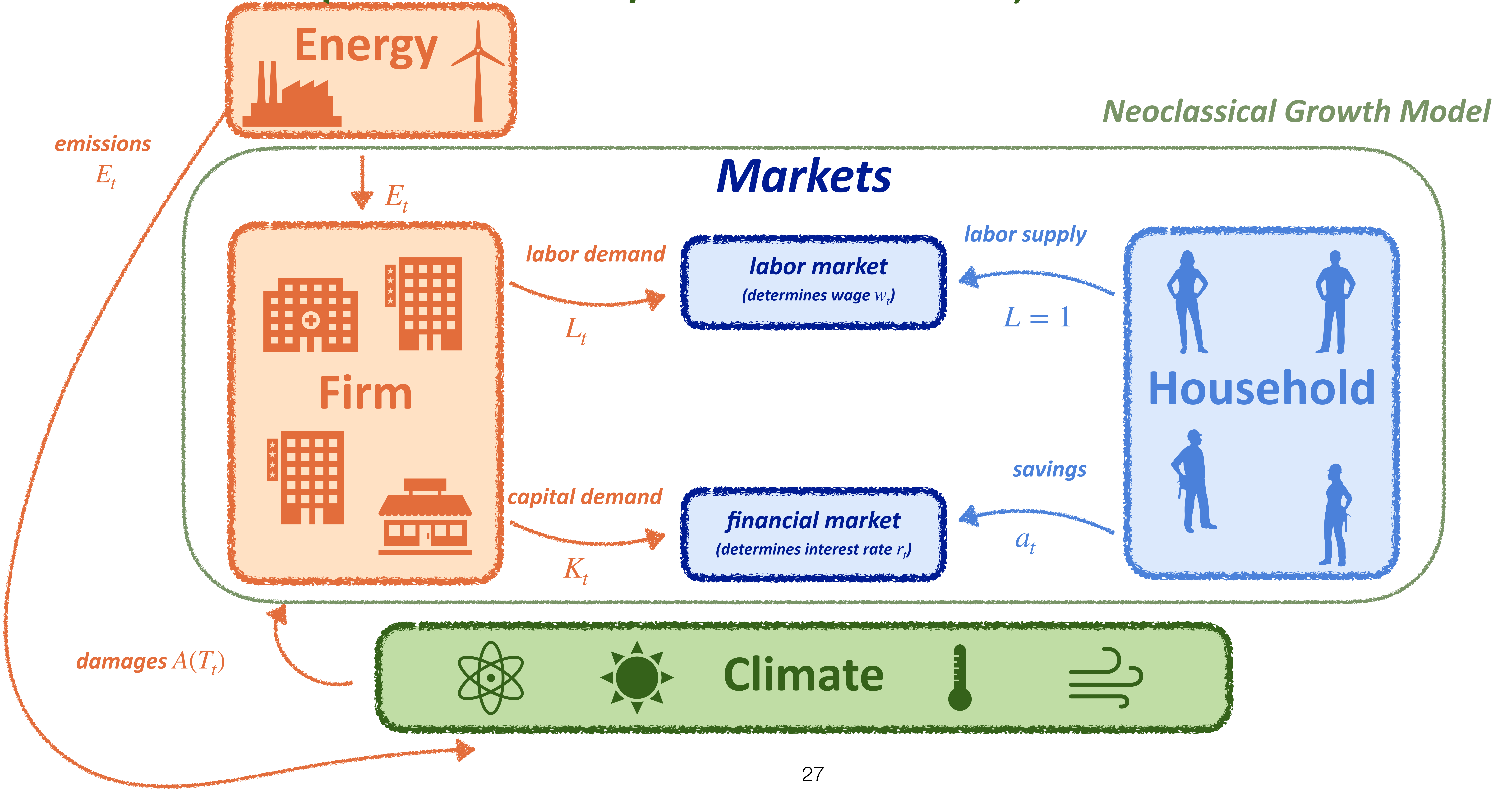
- Productivity depends on **temperature:** $A_t \equiv A(T_t) = \bar{A} \exp(-a \times (T_t - \bar{T}))$
- Reference temperature $\bar{T}$, e.g. pre-industrial level
- Productivity loss from deviating governed by a

Large? Small?

General Equilibrium b/w Household, Firm……………………



General Equilibrium b/w Household, Firm and Climate



The Social Cost of Carbon

- The **Social Cost of Carbon (SCC)** is
  - $ PDV of all present and future **consumption losses** caused by…
  - **Emitting one ton of carbon today**

$$SCC_0 = \frac{1}{u'(c_0)} \frac{d}{dS_0} \left(\sum_{t=0}^{+\infty} \beta^t u(c_t) \right) = \sum_{t=0}^{+\infty} \beta^t \frac{u'(c_t)}{u'(c_0)} \frac{dc_t}{dS_0}$$

- Depends on the whole climate system **and** the whole economy **over time**
  - See Golosov et al. (2014) for closed-form expression in special case
  - Local measure: $ losses from a **little bit more warming from a little more CO2**
- Alternatively can evaluate the % loss in permanent consumption from a warming scenario
  - Then directly specify a path $T_t - \overline{T}$ and abstract from carbon cycle block

Estimating the Cost of Climate Change

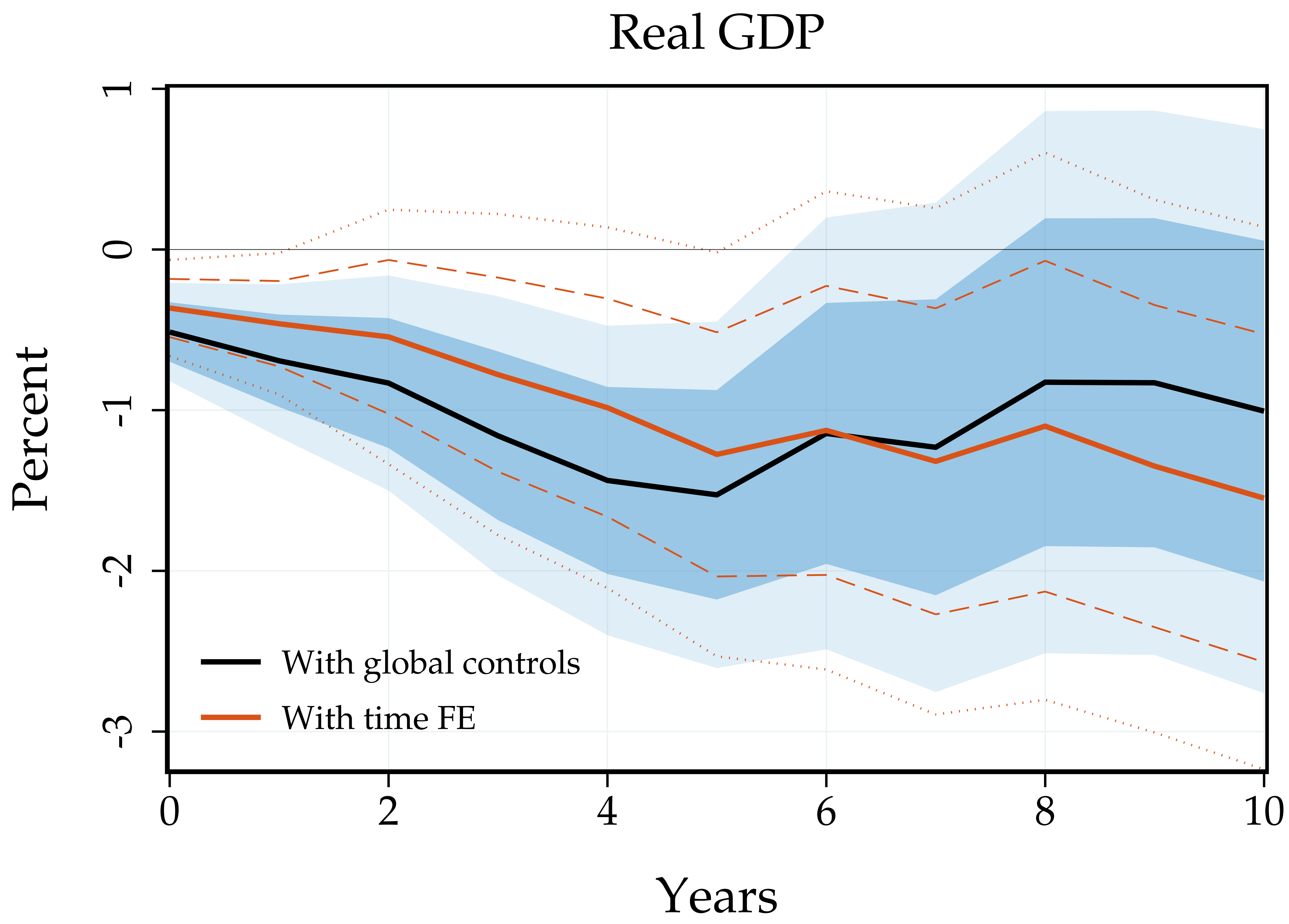
Estimating Climate Change Damages

- Goal is to estimate damage function, i.e. a
- Traditional panel literature relies on local/country-level temperature T_{it}

$$y_{i,t} - y_{i,t-1} = \gamma_i + \eta_t + \phi T_{i,t} + v_{it}$$

  - Estimate $a = \hat{\phi}$
  - Dell et al. (2012), Burke et al. (2015), Nath et al. (2023) use various refinements
- Can also trace out full dynamic impact rather than instantaneous impact

Local Temperature Implies Small Losses



Source: Bilal Känzig (2024)

- Find $a \approx 0.01$ per degree C
- 1% productivity loss per degree C
- Fairly small effects

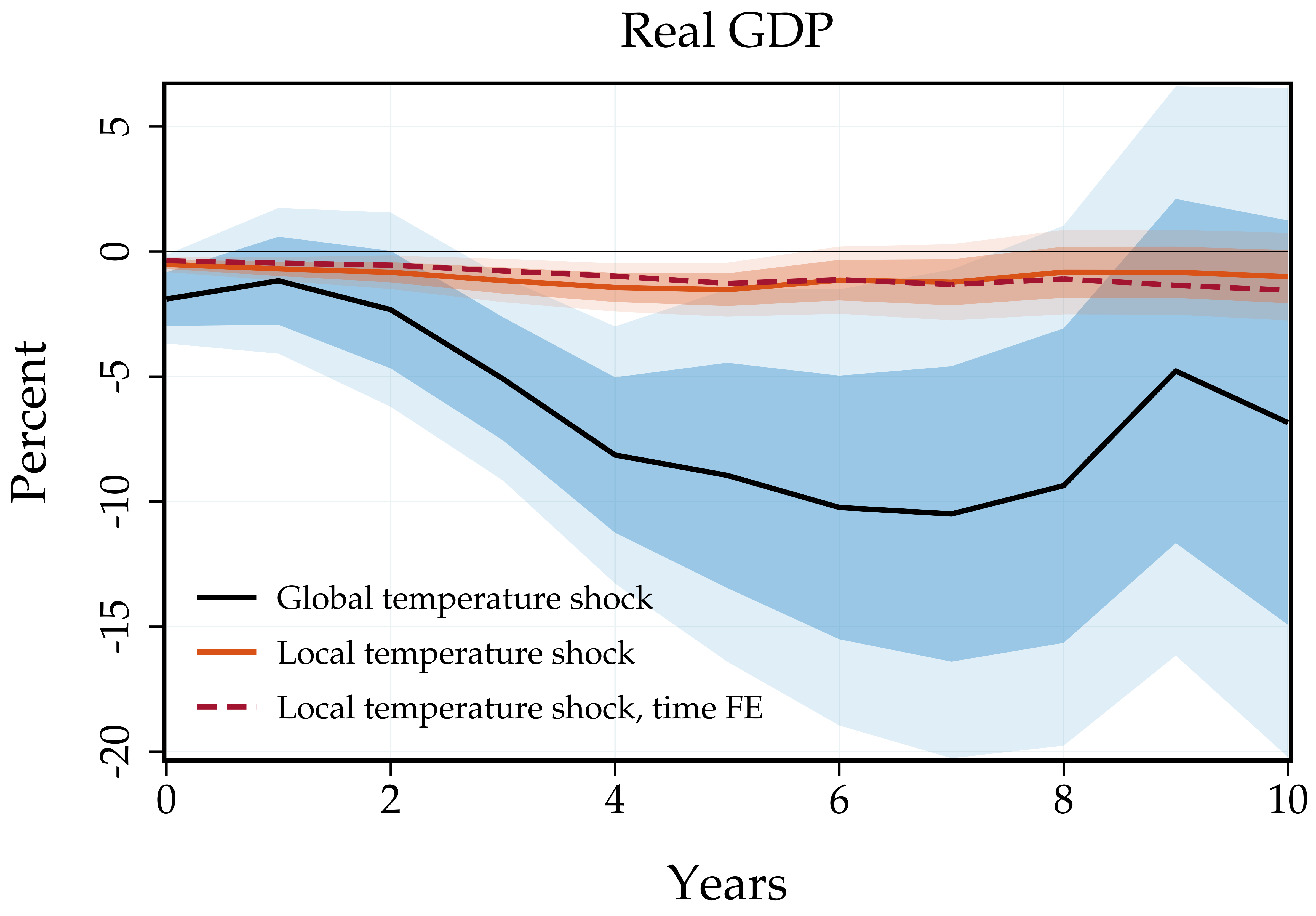
Global vs. Local Temperature

- Local temperature does not fully represent climate change
  - Excludes oceanic warming, storm formation, etc.
- Instead, Bilal Känzig (2024) use **global mean temperature** as the shock
  - Closer proxy of climate change

$$y_{i,t} - y_{i,t-1} = \gamma_i + \phi(T_t - \overline{T}) + \textbf{Controls}_t + \tilde{v}_{it}$$

  - Exclude the time fixed effect, can replace with global controls
  - Again trace out full response instead of instantaneous impact

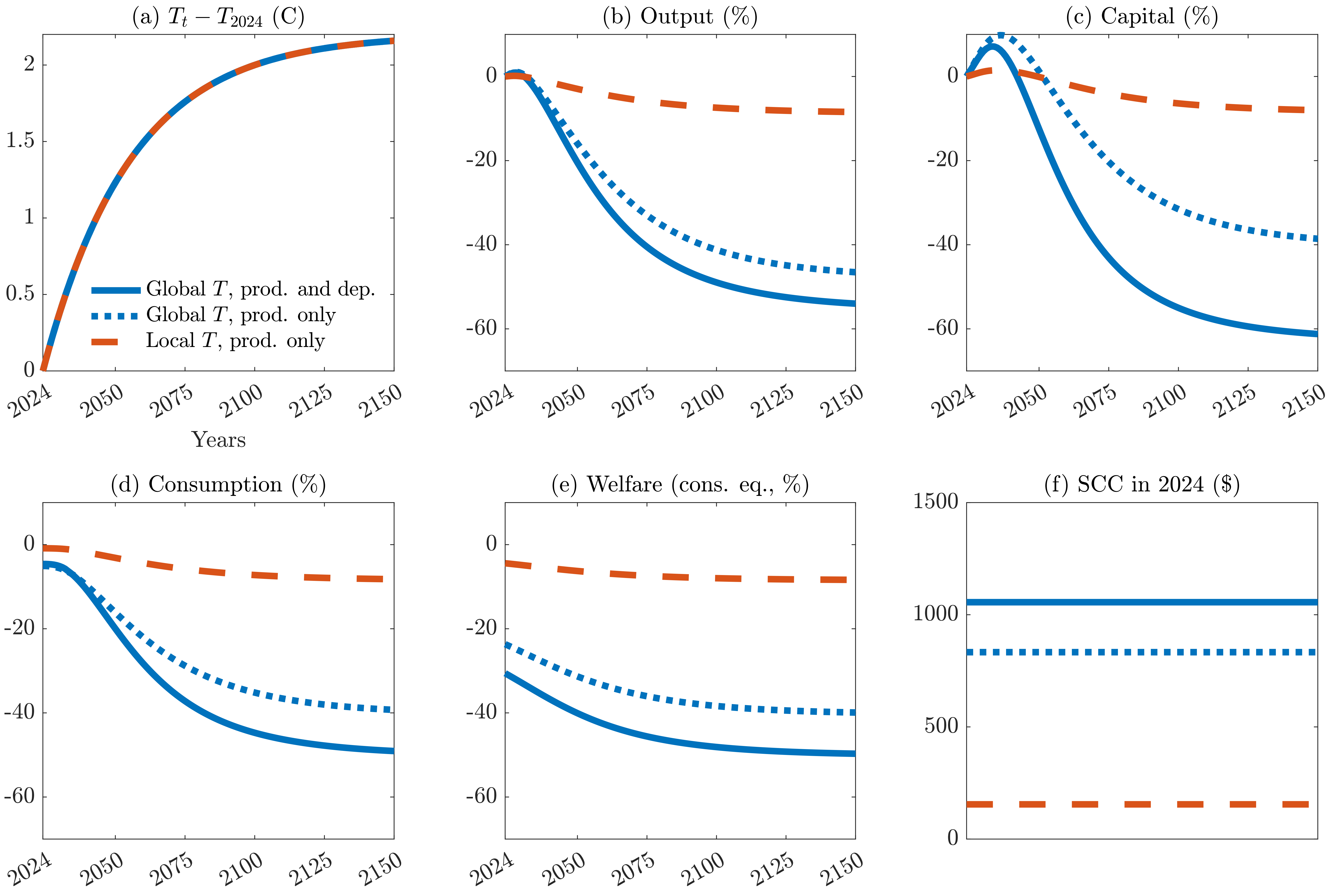
Global Temperature Implies Large Losses



Source: Bilal Känzig (2024)

- Find $a \approx 0.05$ per degree C
- 5% productivity loss per degree C
- **Five-six times larger effects!**
- Show because more extreme events
- Also important to account for persistence
  - Nath et al. (2023), Bilal Känzig (2024)

The SCC and Welfare in DICE



- SCC above $1,000/ton
- Welfare loss of 31%
- Output falls 50% by 2100

Source: Bilal Känzig (2024)

Conclusion

- Energy is critical for growth, but GHG emissions cause rising global temperatures
  - Causes economic losses
- Saw the workhorse climate-economy model: **DICE!**
  - NGM model with an energy and climate block
  - Defined the **Social Cost of Carbon**
- **Climate damages are large** when looking at global mean temperature
- **Next lectures**
  - How can we reduce emissions? David
  - How can we adapt to climate change through trade? Joe