

# **ENVIRONMENTAL SUSTAINABILITY, ECOSYSTEMS & CLIMATE CHANGE**

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To hold and sustain  
To maintain or endure

# What is **sustainability**?

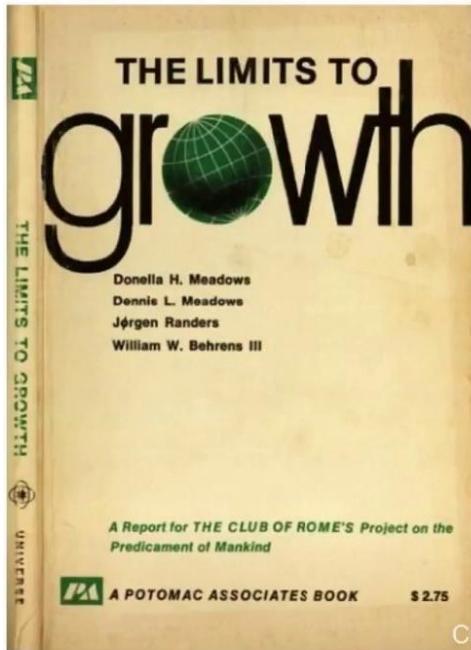
Can a civilization persist on its current path?

A photograph of a pond ecosystem. On the left, there are green aquatic plants growing in the water. The right side shows dark, rippling water with several small fish swimming. The overall scene is a close-up view of a natural water body.

# POND ECOSYSTEM

- └ Summer vs. Rainy season
- └ Can it be called unsustainable?

# Is it sustainable for civilization to continue, more or less on its current course?



We would run out of petroleum in 1992

**What all we need to consider?**

# SUSTAINABILITY THEMES

**WCED, 1987  
OUR COMMON FUTURE**

Population

Food Security

Species & Ecosystems

Energy

Industry

Urban Challenge

•

**NAS-BSD, 1999  
OUR COMMON JOURNEY**

Human Population

Agriculture

Living Resources

Energy

Industry

Cities

•

**KOFI ANNAN, 2002  
WSSD:AN ACHIEVABLE AGENDA**

Health

Agriculture

Biodiversity

Energy

•

•

Water

# Colony collapse disorder



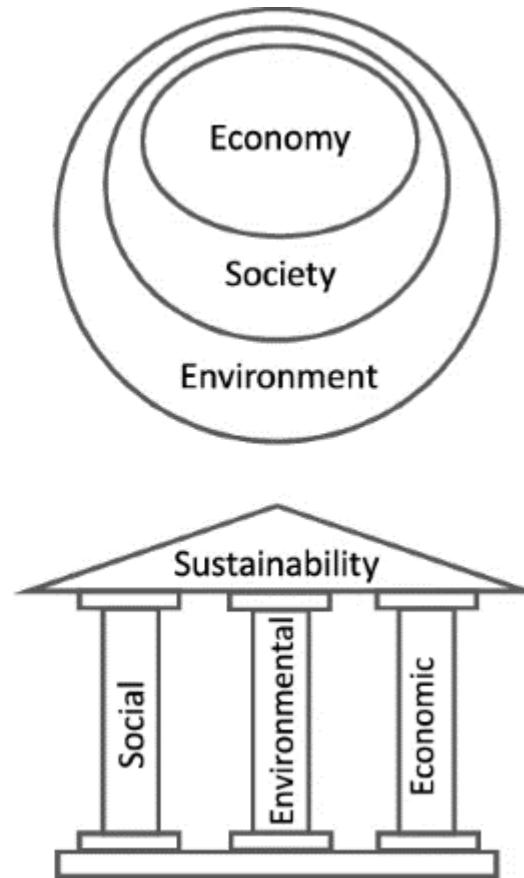
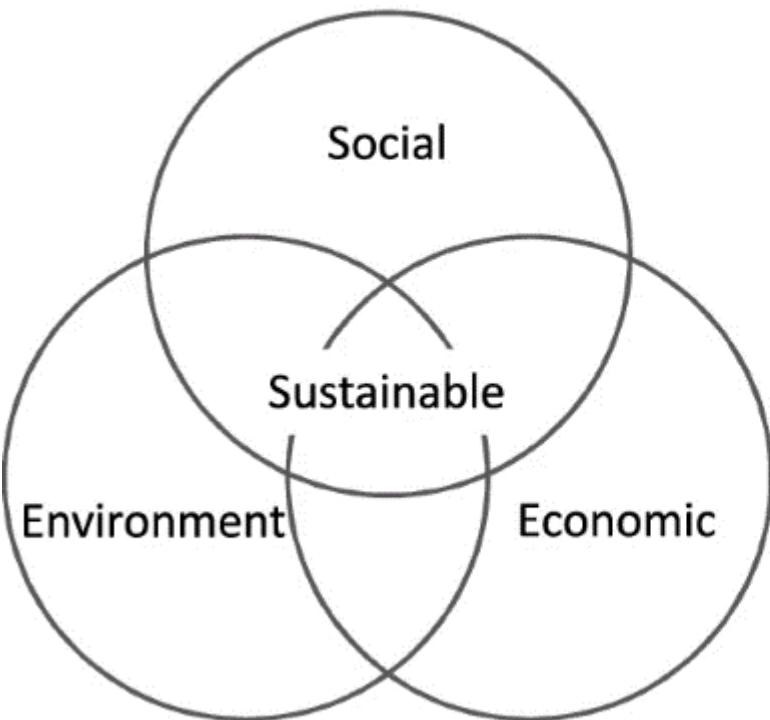
Decline in bee population from 2006 onwards

# What is Sustainability?

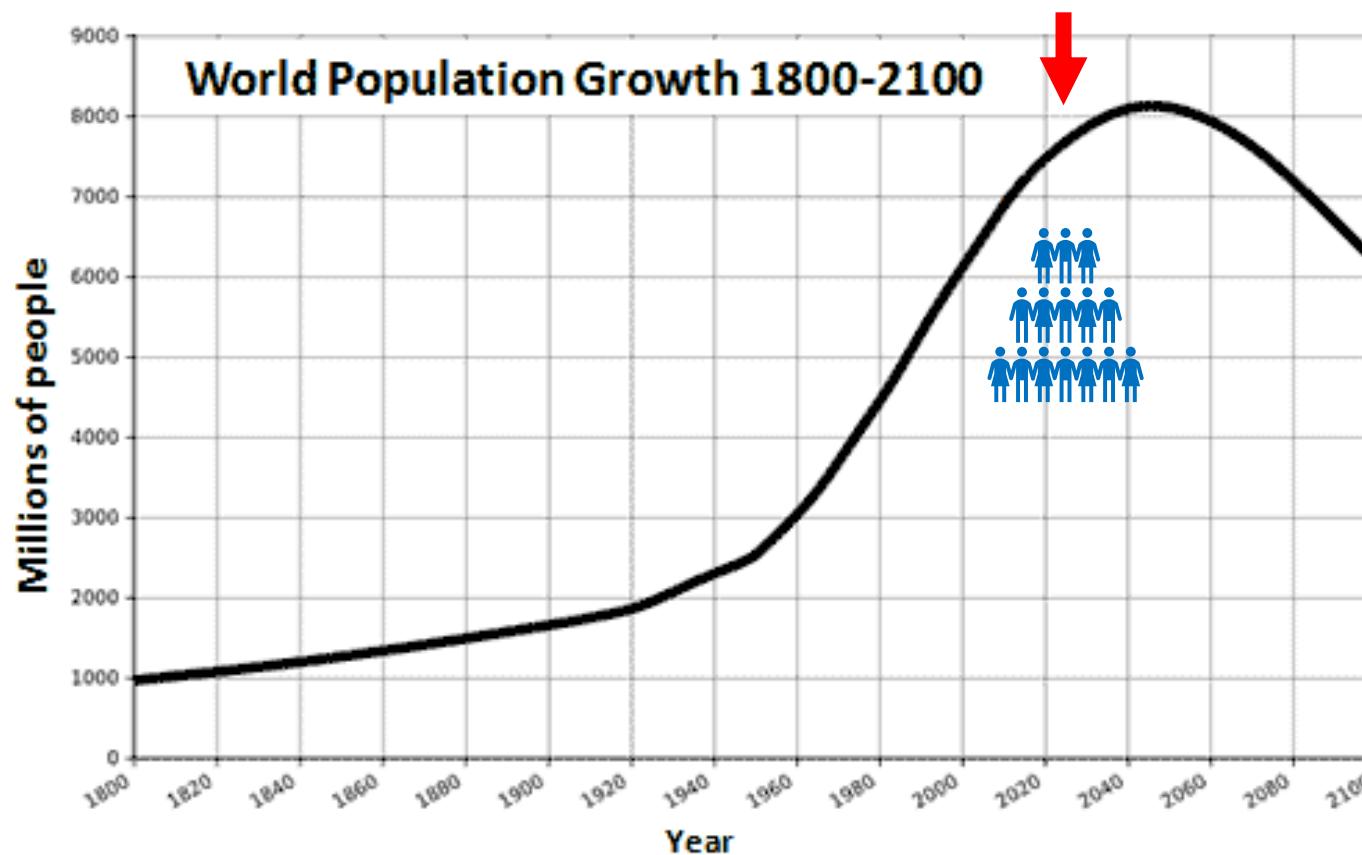
- In 1983 the United Nations General Assembly - Process of Preparation of the Environmental Perspective to the Year 2000 and Beyond.
- World Commission on Environment and Development (WCED)
- Our Common Future in 1987 – Brundtland report (Gro Harlem Brundtland)

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

# Three pillars of sustainability



# Sustainability and population growth



**Root cause of all our environmental issues is overpopulation**

**Paul Ehrlich and John Holdren in 1972**

$$I = P * A * T$$

Consumption  
Amount of resources needed, or wastes created (per unit of consumption)  
Impact

**I** = Impact

**P** = Population

**A** = Affluence

**T** = Technology

The most common way to express this underlying idea about population damaging the environment is the so-called IPAT equation.

# Sustainability impact equation

$$SI = P * C * \frac{I}{C}$$

SI = Sustainability impact

P = Population

C/P = Consumption per capita

I/C = Impact per consumption

Technology has an impact  
↳ Input  
↳ Output

What's wrong with this idea or formula?

Limitations

Independent

Not useful for the future

Not all the consumption is bad

# Growth curve

Relationship between sustainability and population

- ↳ Sustainable
- ↳ Unsustainable



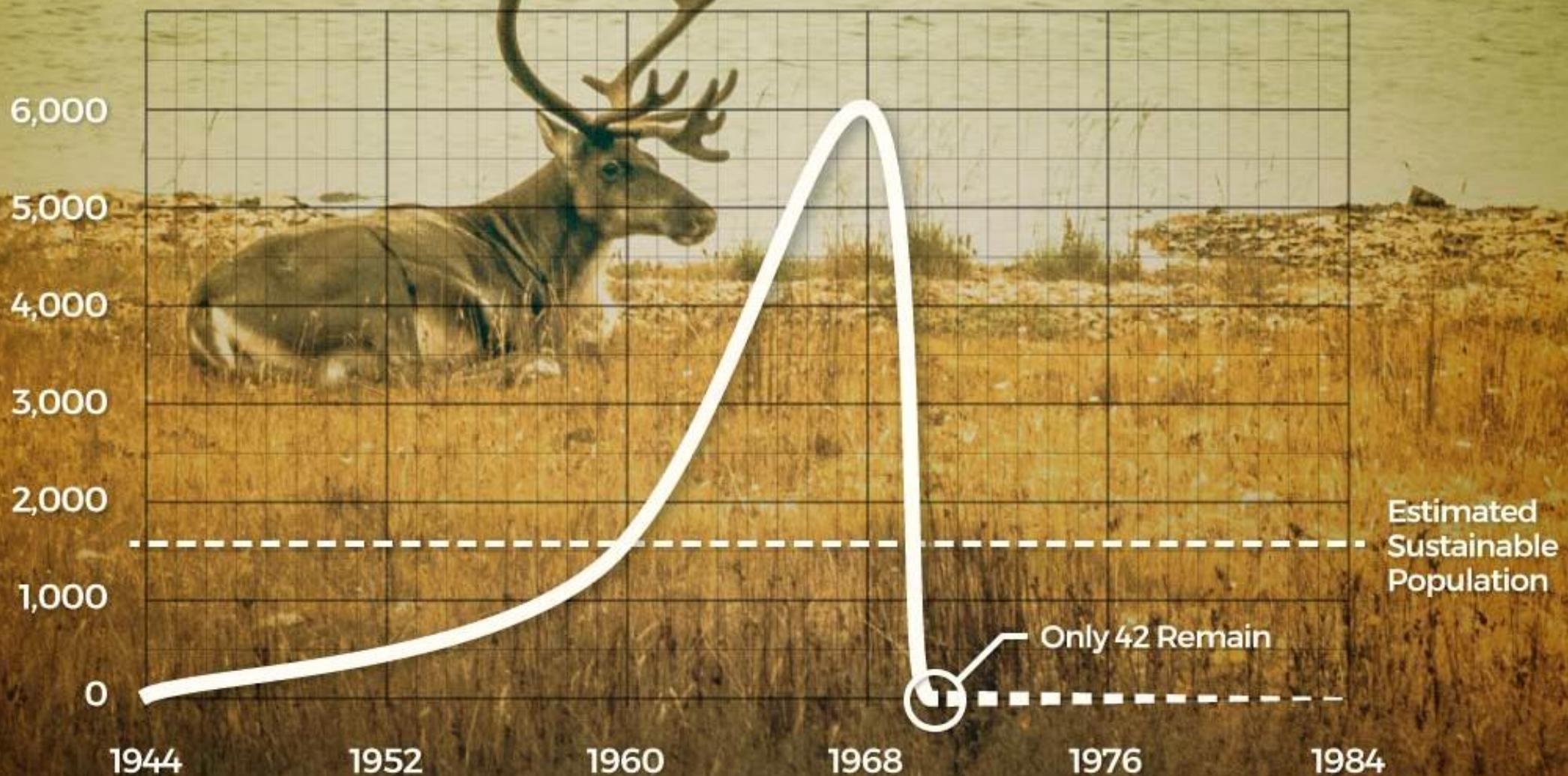
Resource vs. population

A **growth curve** is a visual depiction of the **growth** of a phenomenon, with the x-axis typically representing time and the y-axis **growth**.

Source: <https://www.investopedia.com/terms/g/growth-curve.asp>

# St. Mathew island





# ST. MATTHEW ISLAND

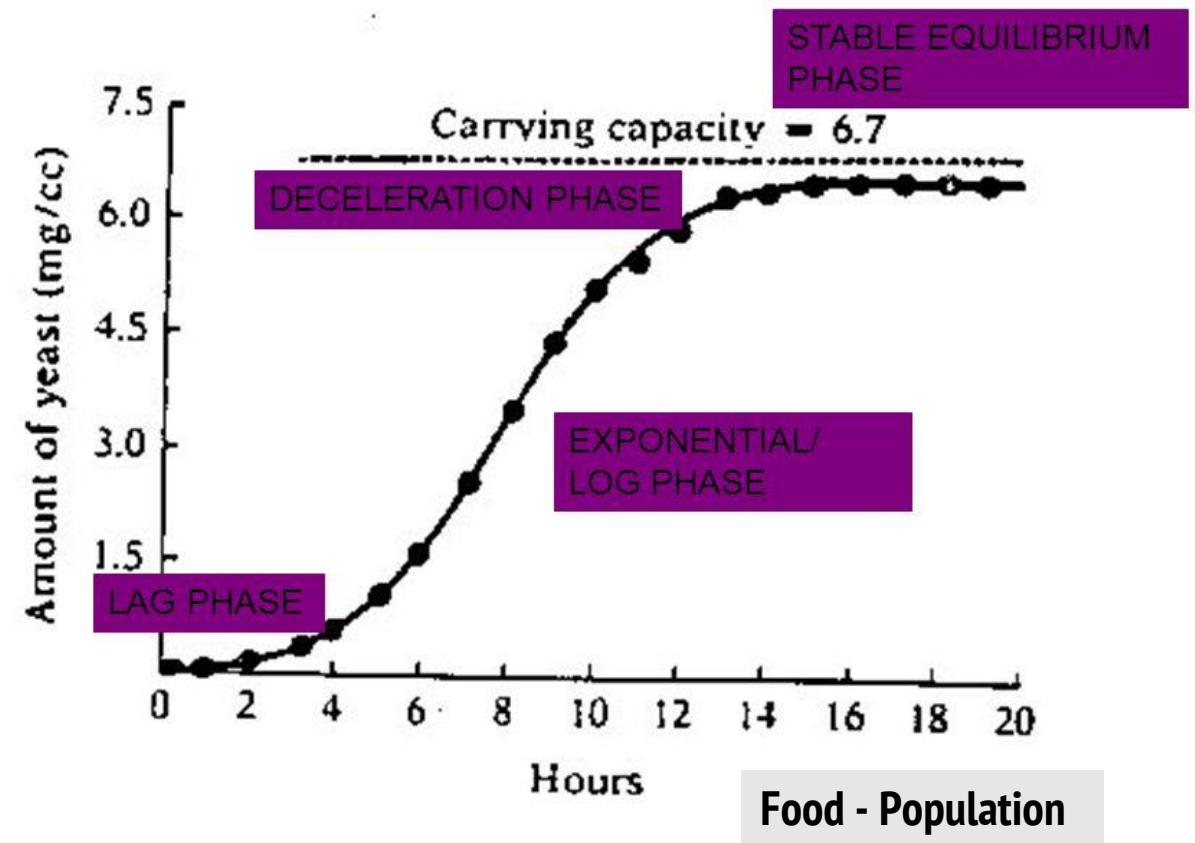
## REINDEER POPULATION

## Condition: Finite amount of food Will they grow exponentially?

Growth curve of a laboratory population of yeast cells.



Source: <https://www.pinterest.ca/mouellet2/petri-dishes-agar-plates/>



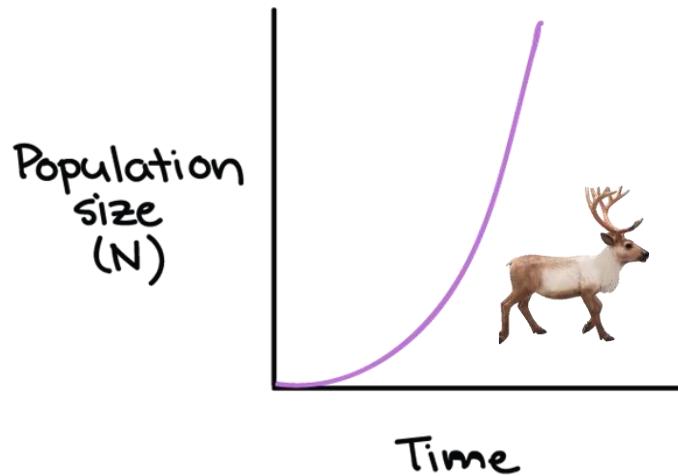
## Growth curves

Exponential growth

$$\frac{dN}{dt} = rN$$

Per capita growth rate ( $r$ ) doesn't change, even if pop. gets very large.

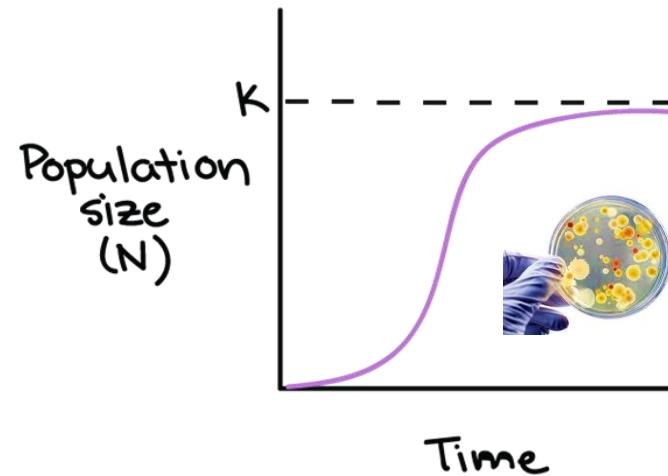
$$\frac{dN}{dt} = r_{\max} N$$



Logistic growth

Per capita growth rate ( $r$ ) gets smaller as pop. approaches its max. size.

$$\frac{dN}{dt} = r_{\max} \left( \frac{K-N}{K} \right) N$$

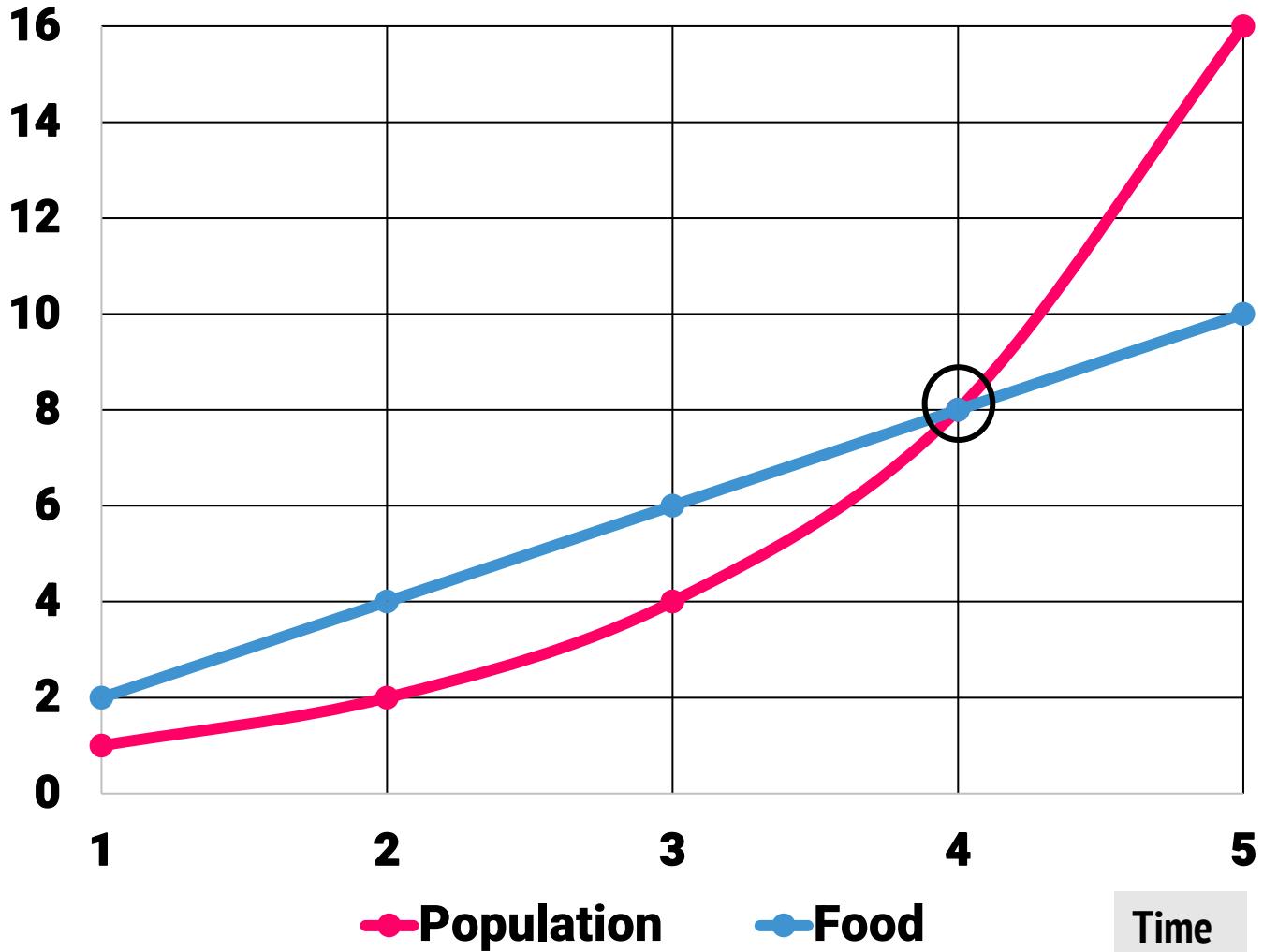


Population size, which represents the maximum population size that a particular environment can support, is called the **carrying capacity, or K**.

Source: <https://courses.lumenlearning.com/boundless-biology/chapter/environmental-limits-to-population-growth/>

# Malthusian theories

Amount



Exponential (population)

Time	1	2	3	4	5
Amount	1	2	4	8	16

Arithmetic (Food)

Time	1	2	3	4	5
Amount	2	4	6	8	10

Thomas Malthus

Point of crisis or Malthusian catastrophe

# Carrying capacity

Amount

16

14

12

10

8

6

4

2

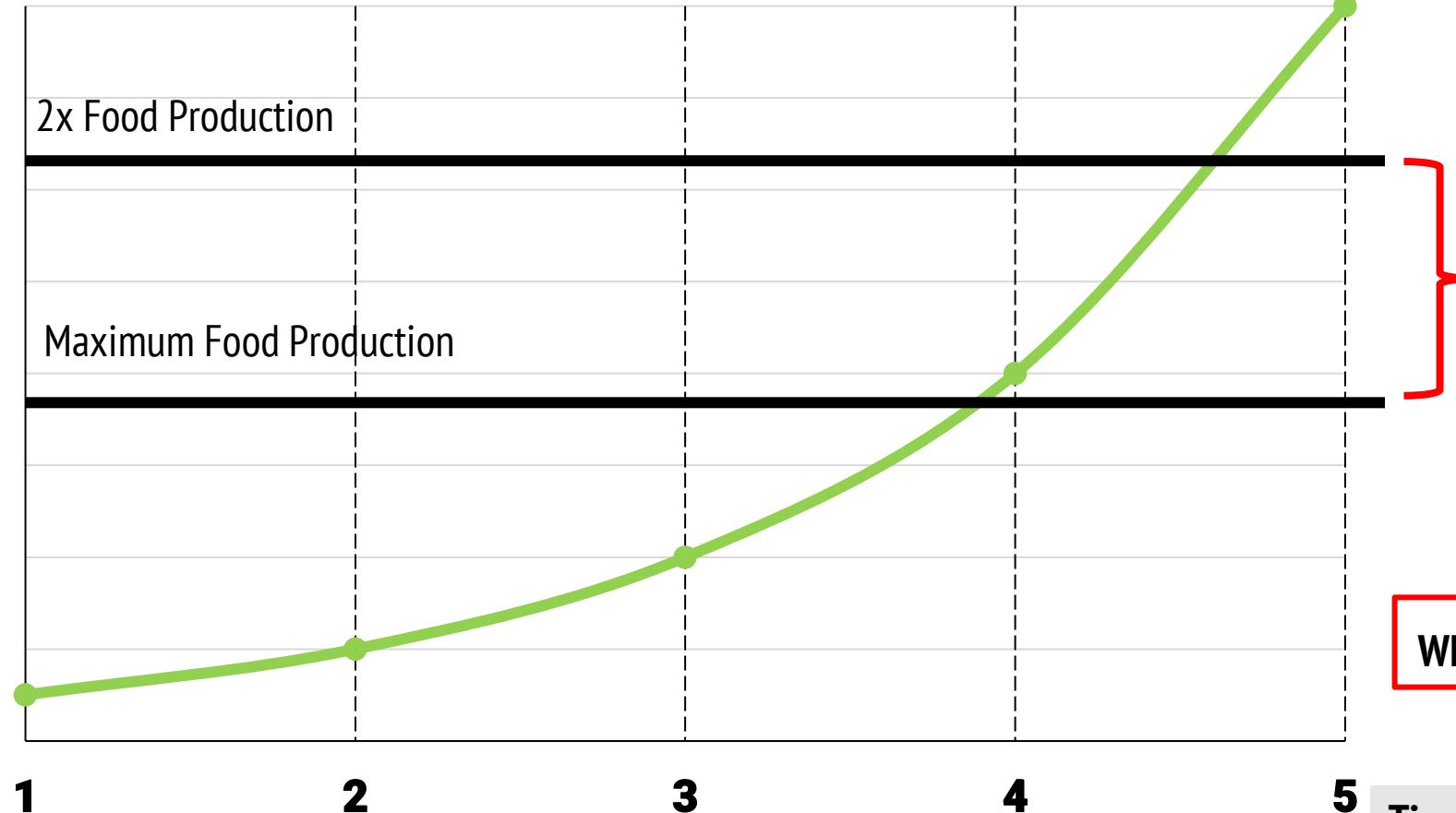
0

2x Food Production

Maximum Food Production

Population

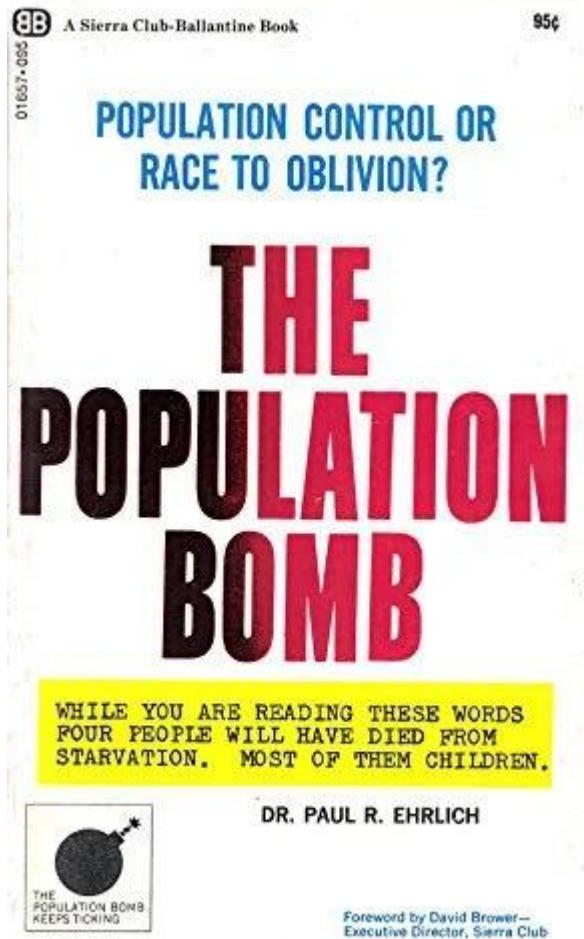
Time



Replace food with the  
following  
Energy  
Water  
Space

What will happen beyond the carrying capacity?

# Neo Malthusian prediction

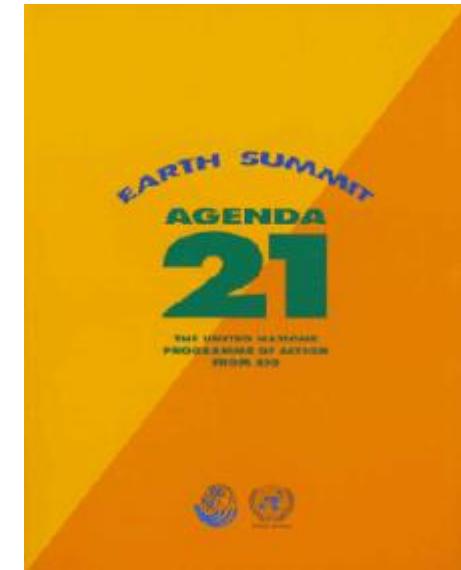


“The battle to feed all of humanity is over. In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate”

Example: 18<sup>th</sup> century Britain vs. now

## **Agenda 21, Rio Earth summit (1992)**

**Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being.**



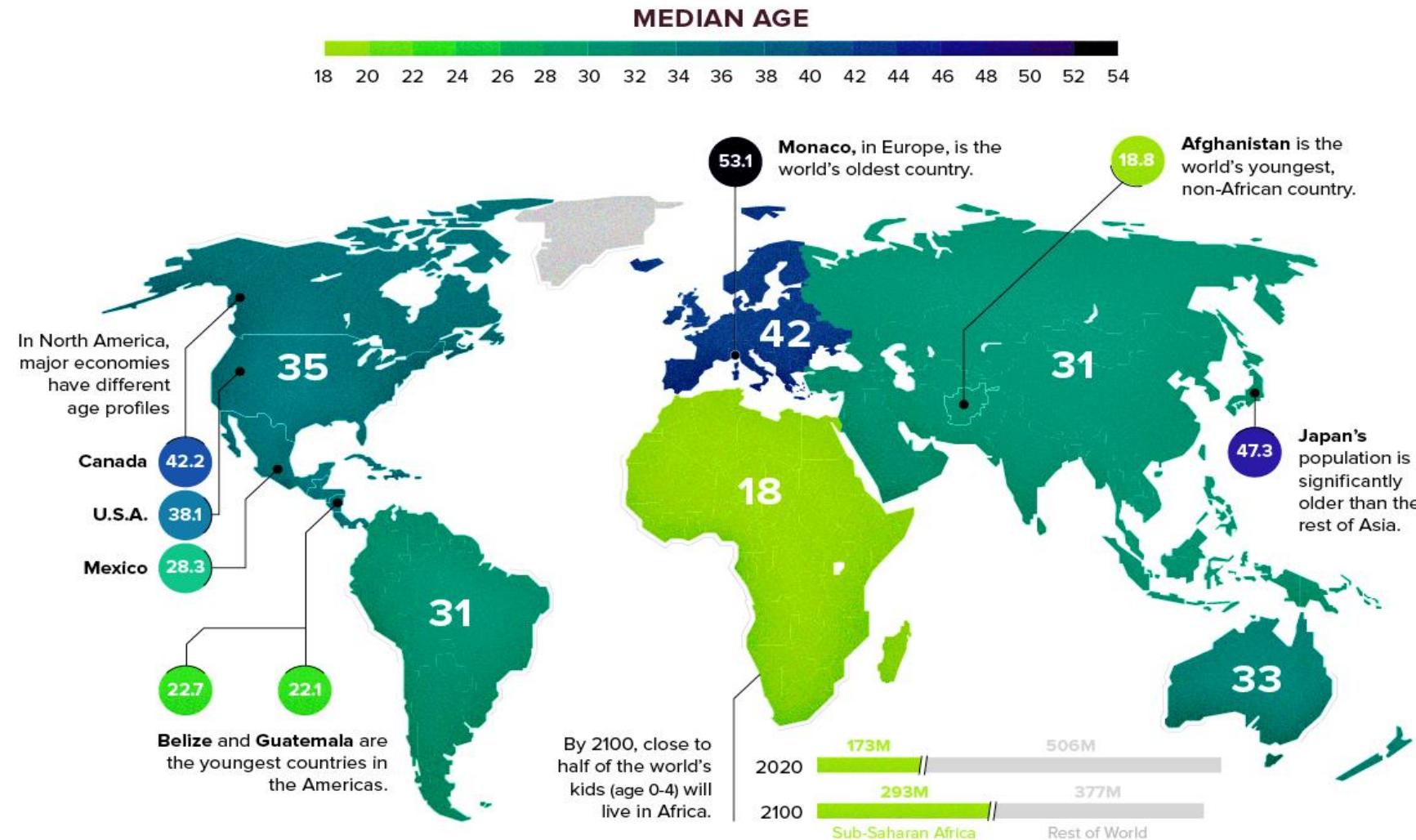
**Much of the sustainable worries are connected with**



**Population (past, present, future) & transitions**

# THE MEDIAN AGE OF CONTINENTS

Africa has the world's youngest population, with a median age in the teens



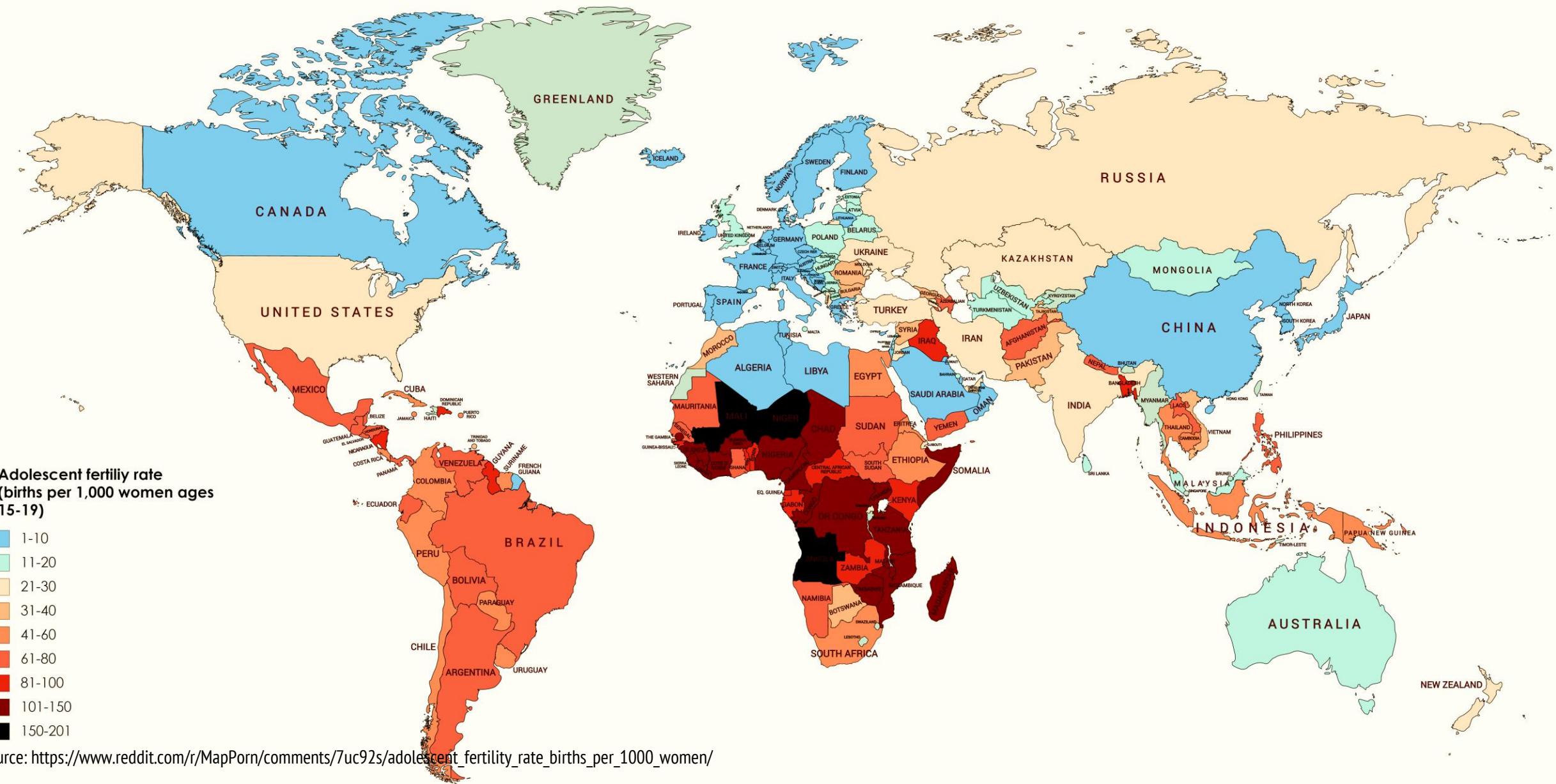
Current population

8 billion

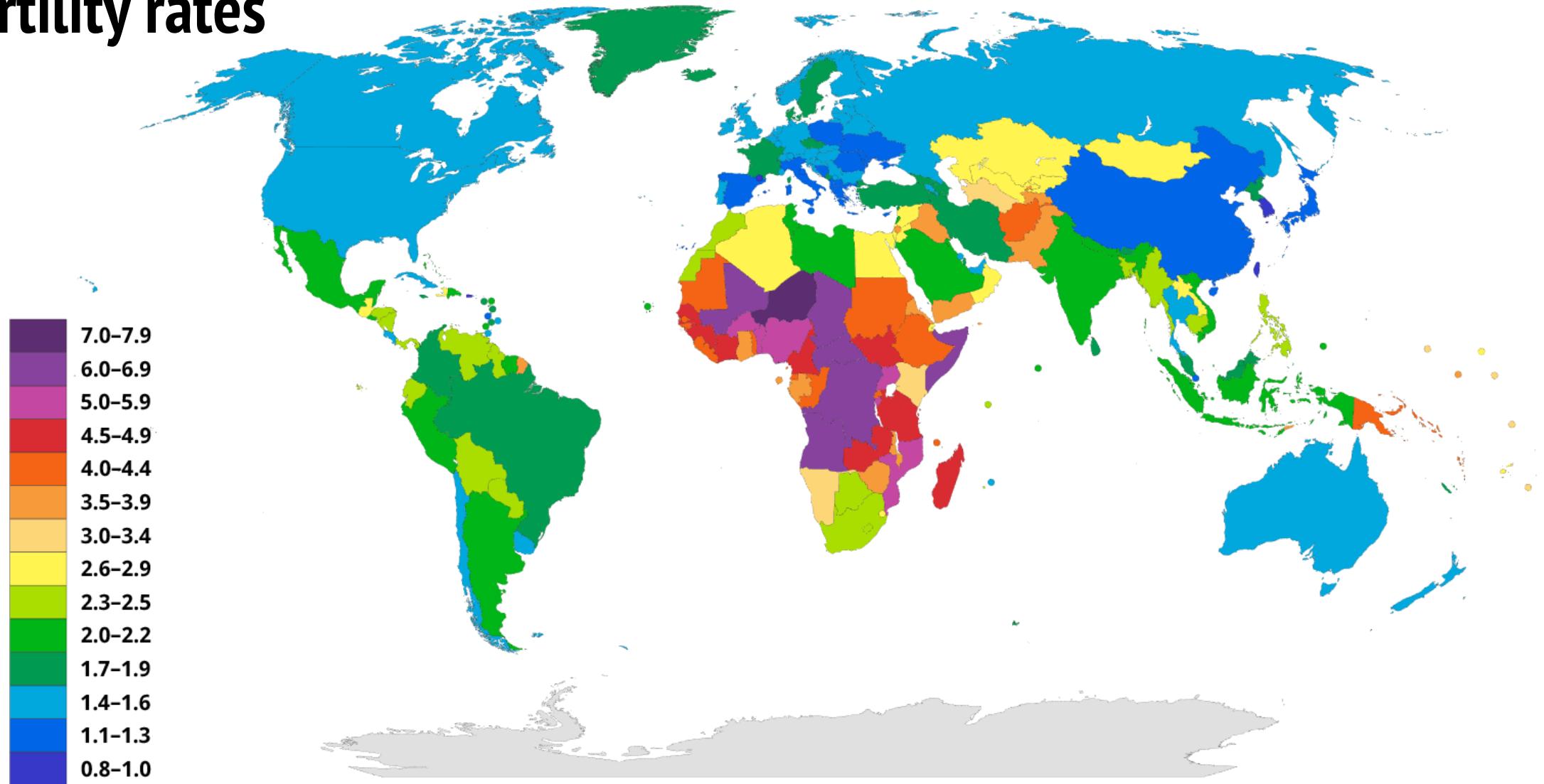
Median age is the age that divides a population into two numerically equally sized groups; that is, half the people are younger than this age and half are older.



# Fertility rates

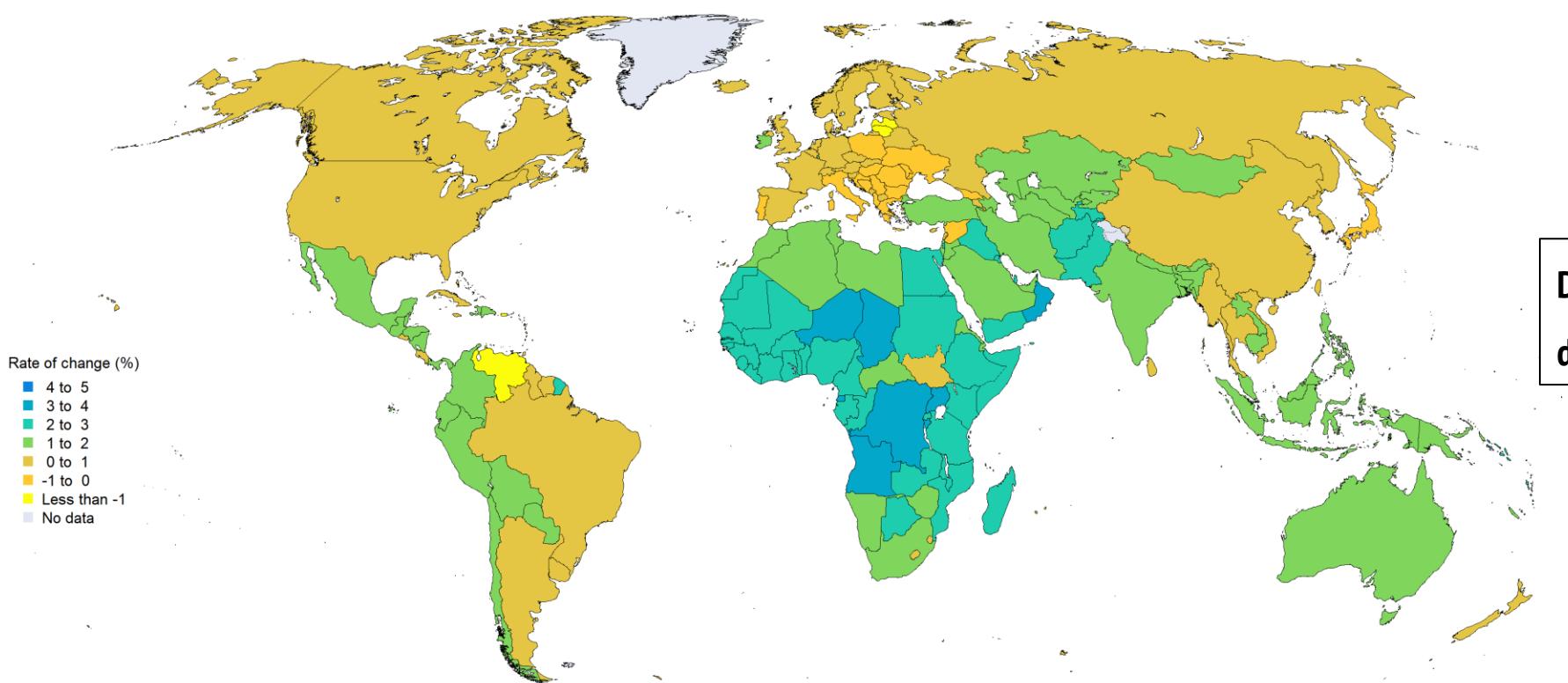


# Fertility rates



Population break even point – 2.1

Average annual rate of population change (%), 2015-2020



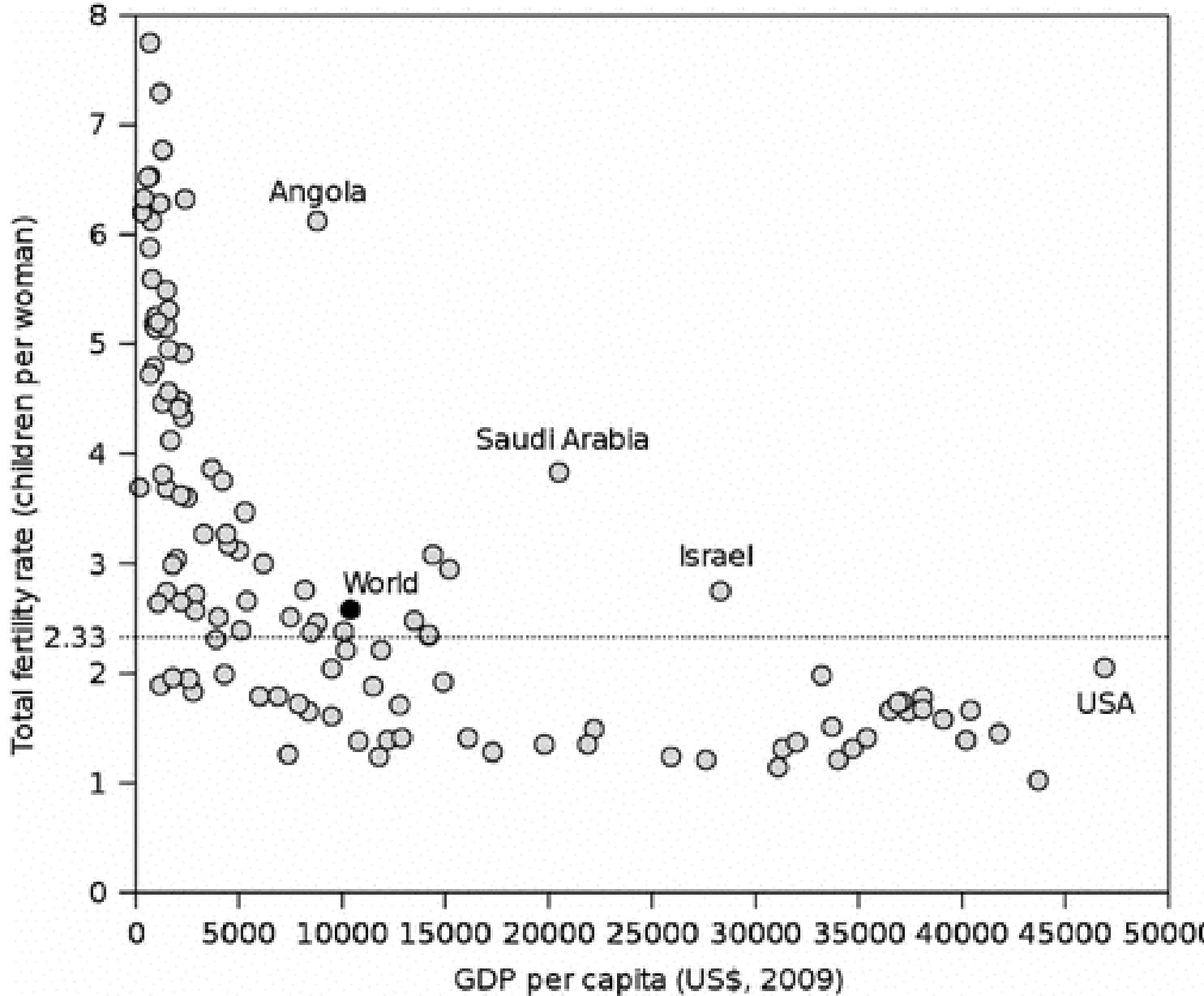
Different countries have different demographic transition

© 2019 United Nations, DESA, Population Division. Licensed under Creative Commons license CC BY 3.0 IGO.

Data source: United Nations, DESA, Population Division. *World Population Prospects 2019*. <http://population.un.org/wpp/>

The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

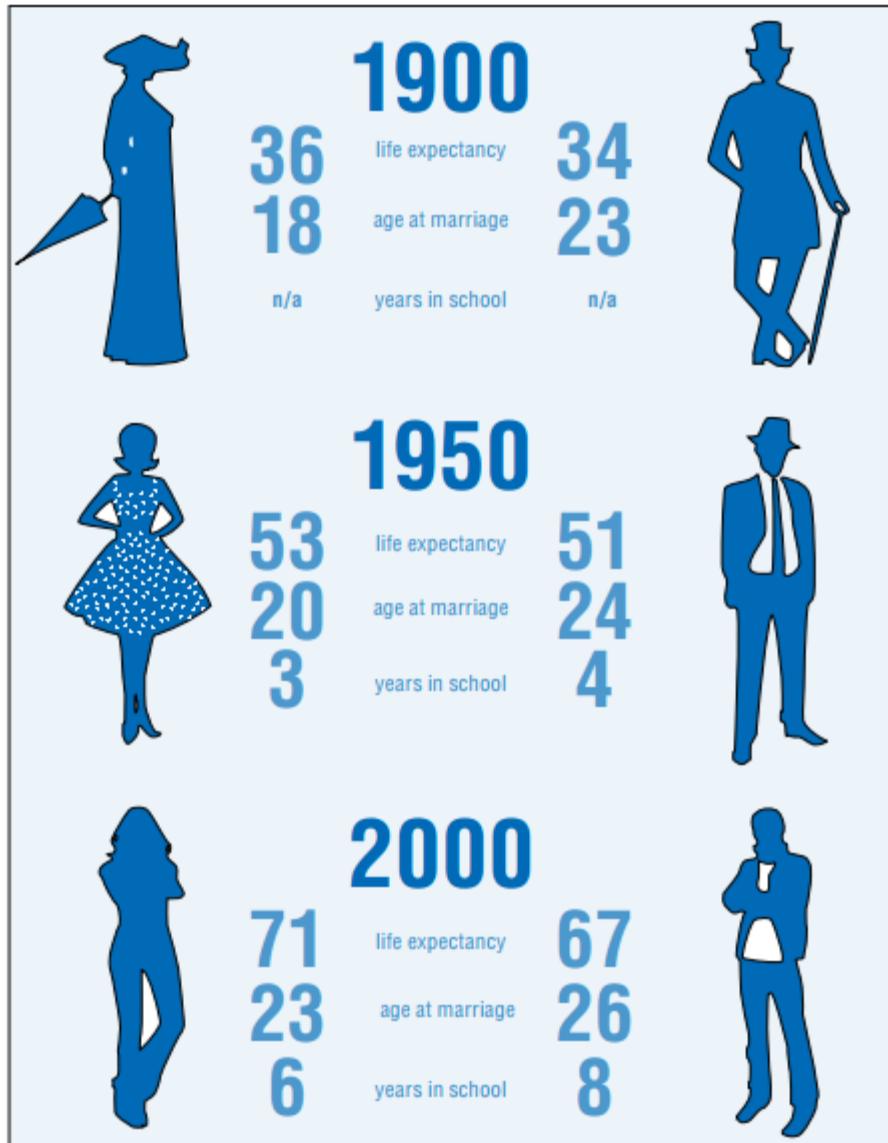
## World fertility rate



- Social construct
  - Cultural differences
  - Education of women
- Factors

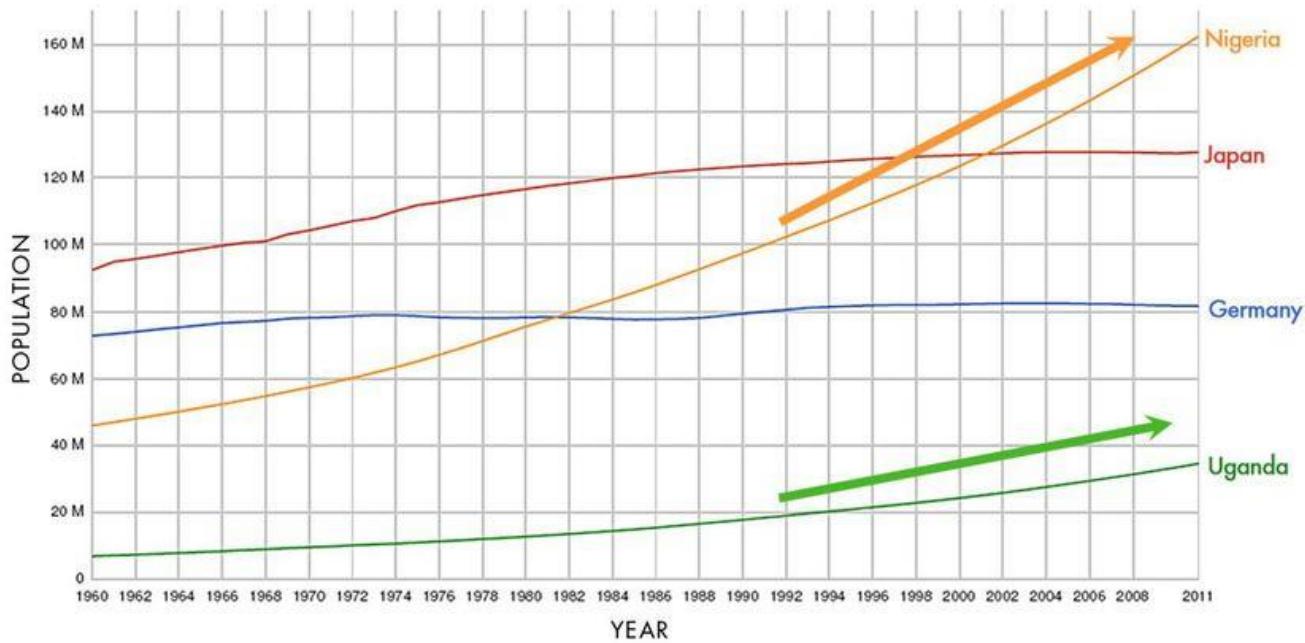
Figure 12.1. Average life expectancy at birth, marriage age and average years of education for women and men in the 20th century

Values in years



# Demographic transition

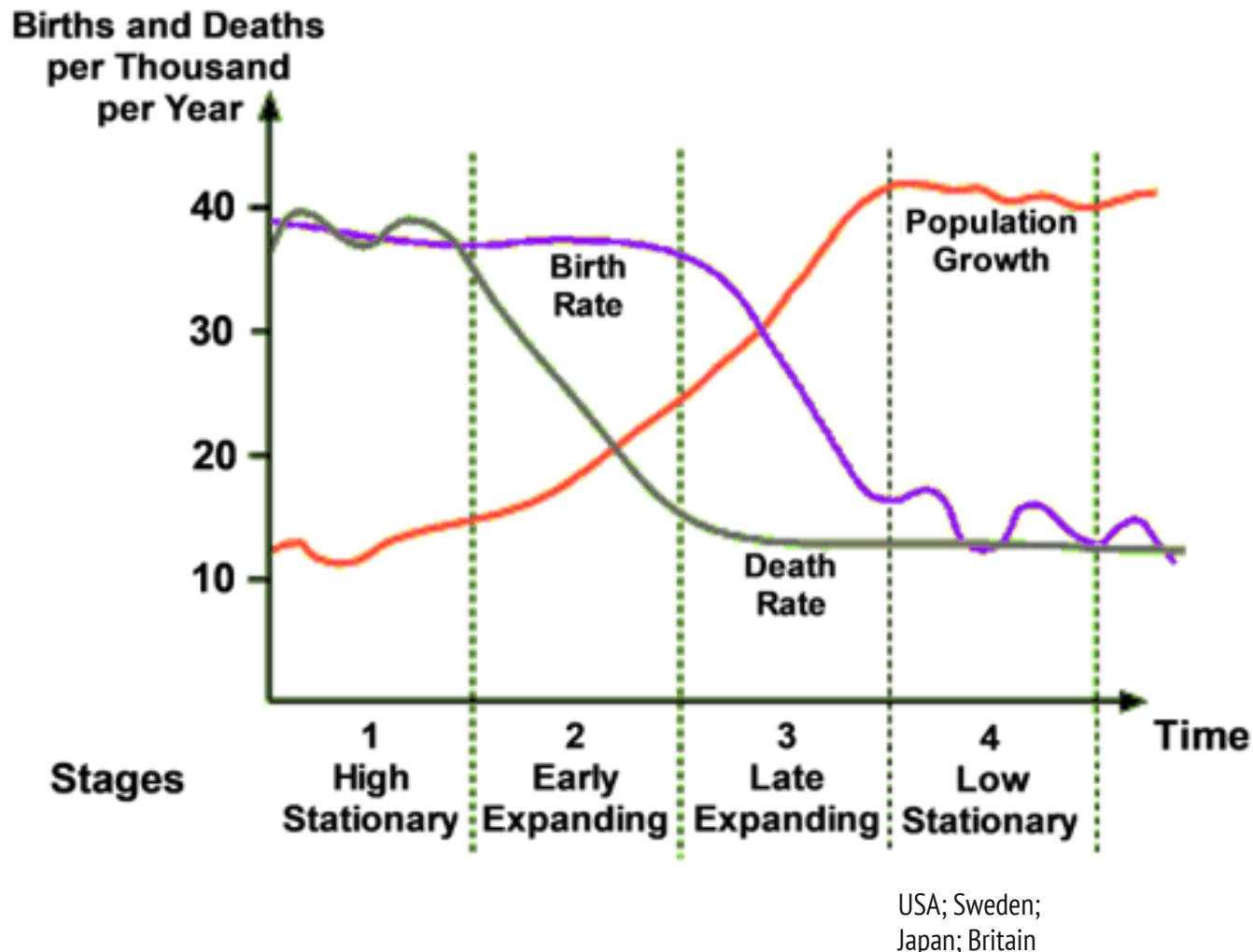
## DIFFERENT POPULATION PATTERNS



Note: For an assessment of data quality, see Table 12.2.

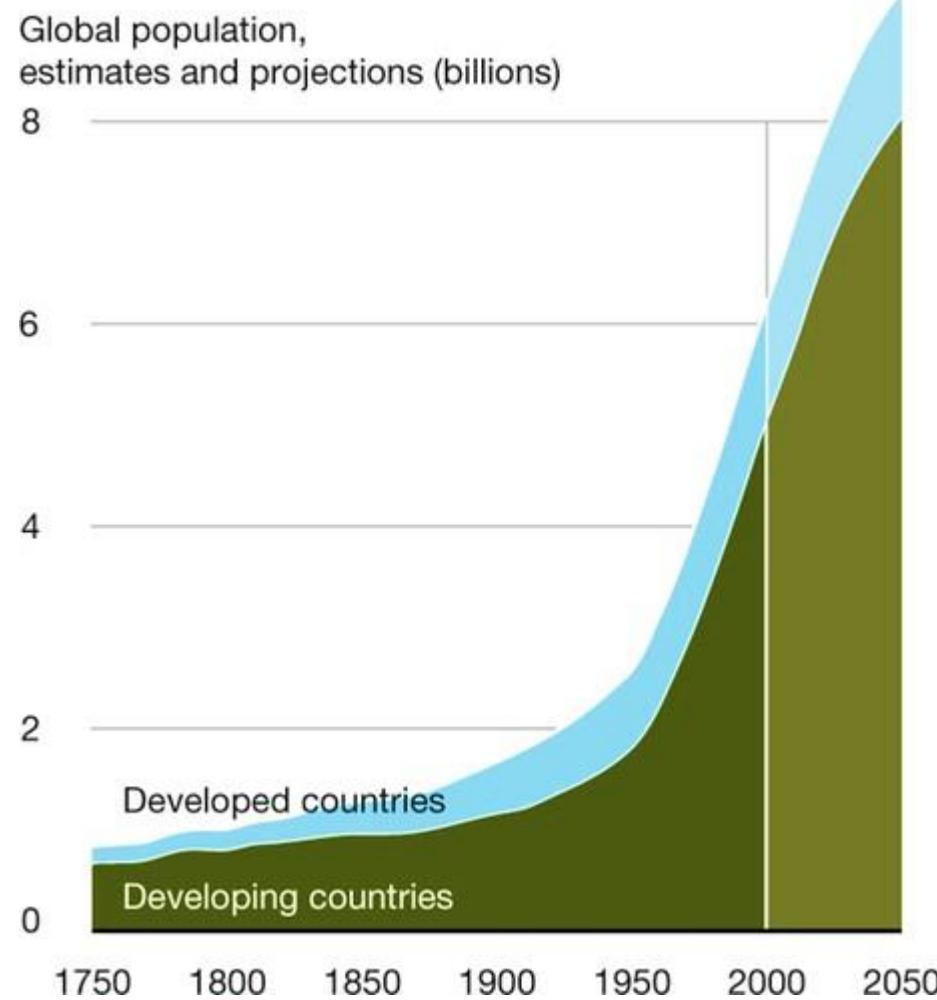
Source: Clio-Infra, [www.clio-infra.eu](http://www.clio-infra.eu).

## Demographic Transition Model



1. Birth Rate and Death rate are both high. Population growth is slow and fluctuating.
2. Birth Rate remains high. Death Rate is falling. Population begins to rise steadily.
3. Birth Rate starts to fall. Death Rate continues to fall. Population rising.
4. Birth Rate and Death Rate both low. Population steady.

<https://geographyfieldwork.com/DemographicTransition.htm>



## Future population

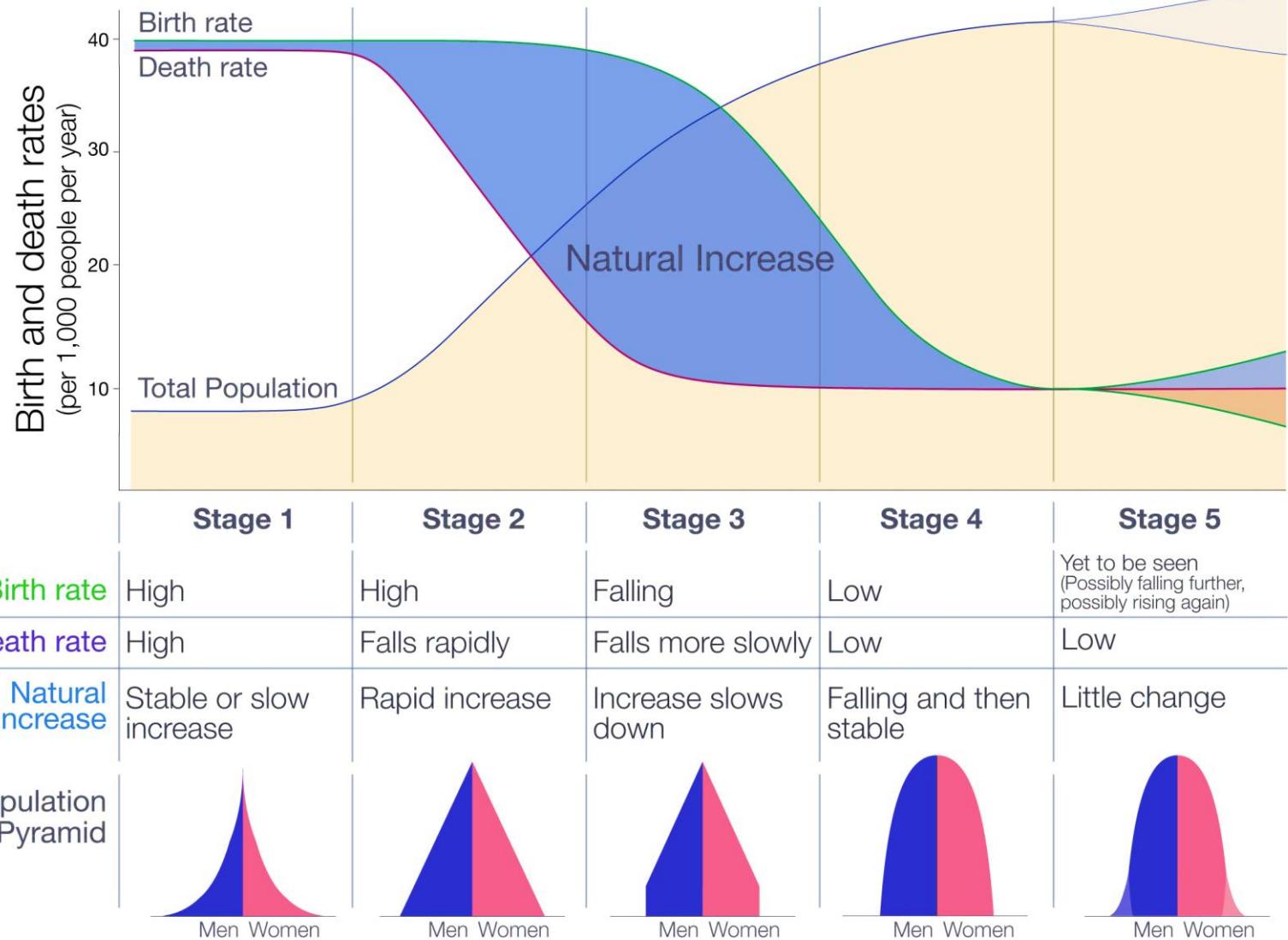
**Developed vs. developing countries**

- └ Does IPAT equation or Malthusian theory hold true here?
- └ USA vs. India

# The five stages of the demographic transition

The demographic transition is a model that describes why rapid population growth is a temporary phenomenon.

Our World  
in Data



This is a visualization from [OurWorldinData.org](https://ourworldindata.org/), where you find data and research on how the world is changing.

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## Population pyramid

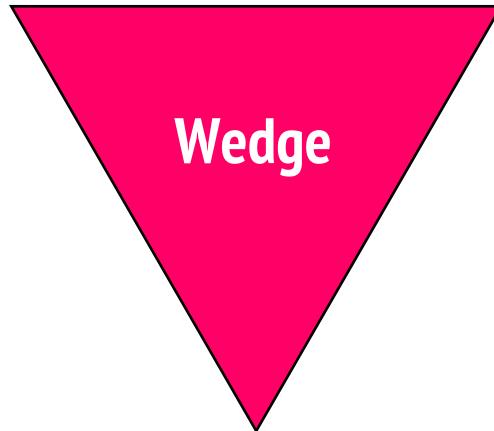
A population pyramid is a way to visualize two variables: age and sex. They are used by demographers, who study populations.

A population pyramid is a graph that shows the distribution of ages across a population divided down the center between male and female members of the population.

<https://education.nationalgeographic.org/resource/population-pyramid>

# Future population

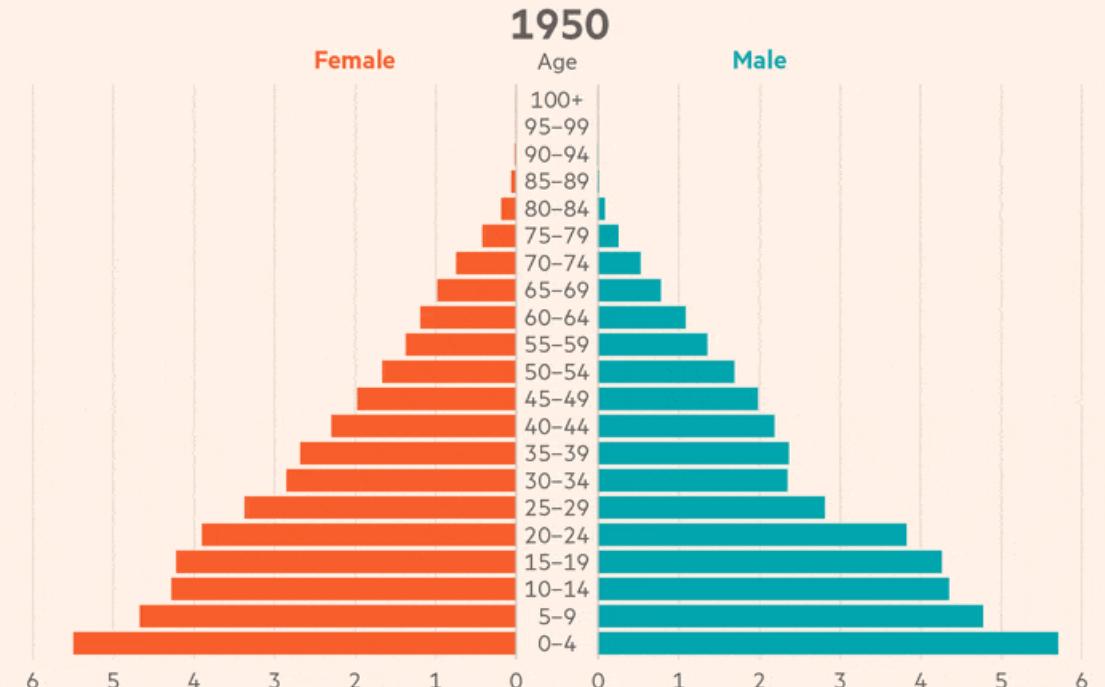
- Less births
- Less deaths



Japan

Japan's shrinking population

Population by age and sex (millions)



FT graphic: Chris Campbell Source: UN population estimates  
© FT

## **What happens when people decide to have only one child — or none**



**More retirees than working - age people**

Source: <https://timesofindia.indiatimes.com/india/what-happens-when-people-decide-to-have-only-one-child-or-less/articleshow/91851674.cms>



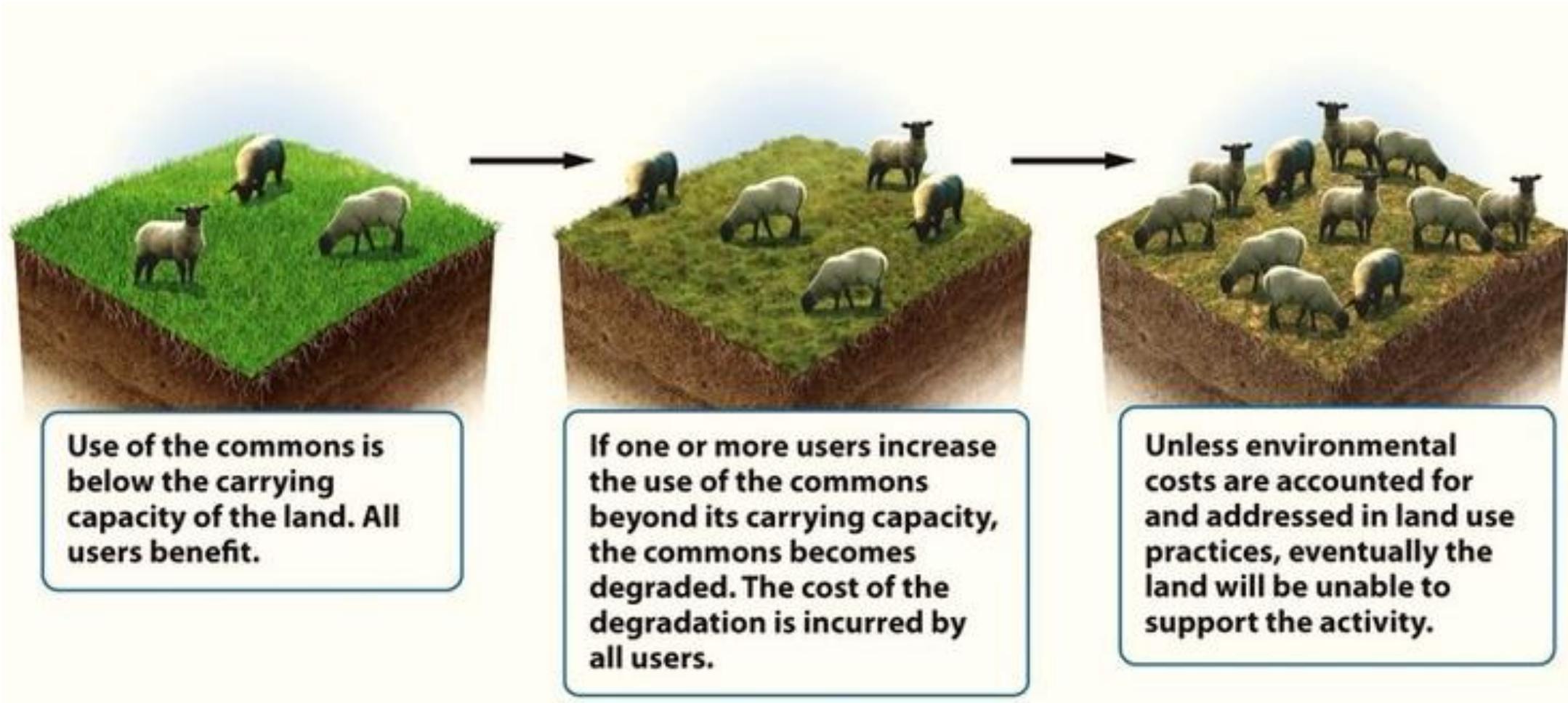
# Tragedy of the commons

**What is the “Tragedy of the Commons”?**

**Article:** published in 1968 by Garrett Hardin.

**Concept:** a shared resource in which any given user reaps the full benefit of his/her personal use, while the losses are distributed amongst all users.

**Recall carrying capacity - refers to the maximum number of individuals of a species that the environment can carry and sustain.**



Source: <https://sites.google.com/site/bloomsenvironmentalscience/environmental-science-homework/videonotestragedyofthecommons>

# What are Common?

↳ Atmosphere

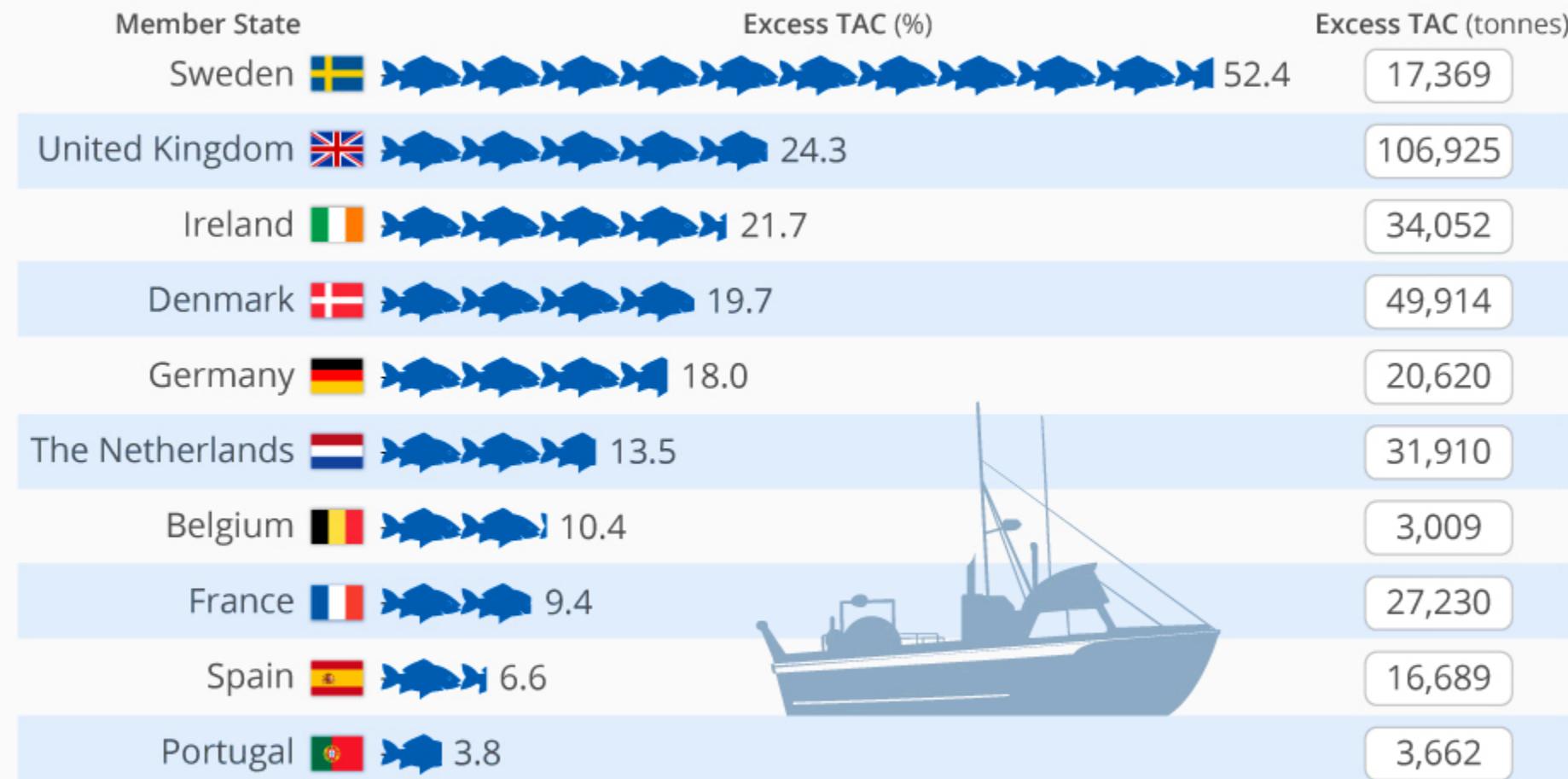
↳ Oceans

↳ Land

↳ Forests

## Atlantic Overfishing: Europe's Worst Offenders

Share of total allowable catch (TAC) in excess of scientific advice in the northeast Atlantic (2019)\*



\* Scientific bodies provide information on the state of fish stocks and recommended catch levels for sustainability.

Every year, fisheries ministers agree on a total allowable catch for commercial fish stocks.

Source: The Economics Foundation

# Air pollution rises in India a day after Diwali

Parts of India recorded dangerously high levels of air pollution on Friday, a day after the Diwali festival as people celebrated with late night fireworks despite a ban in multiple states. Concentration of fine particulate matter (PM2.5) in air rose to as high as 1,000 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) at some stations.

PM2.5 concentration across

309 monitoring stations

○ New Delhi ○ Other states

1000  $\mu\text{g}/\text{m}^3$  -

750 -

500 -

0 -

Average across  
stations

Friday night

Nov. 2

Nov. 3

Nov. 4

Nov. 5

Note: Data till Nov. 5, 8 AM local time

Source: India's Central Pollution Control Board

V. Kawoosa, 05/11/2021

REUTERS

Tragedy of common example  
from India

# Tragedy of commons – Solutions



- └ Government regulation
- └ Property rights

## Personal action

- „ It discriminates against people of good conscience and tends to eliminate them from the population.
- „ It won't work in the long run. Nature's revenge. People without conscience will outbreed the others, and population will increase again eventually.
- „ It is not psychologically healthy to force people to act against their own interests on the basis of conscience.

# Internal Governance

Swiss Alps - pastures



# External Governance

- „ Poor regulations
- „ Uncorrupted Government
- „ Local problems are easy to fix
- „ Transnational problems are difficult

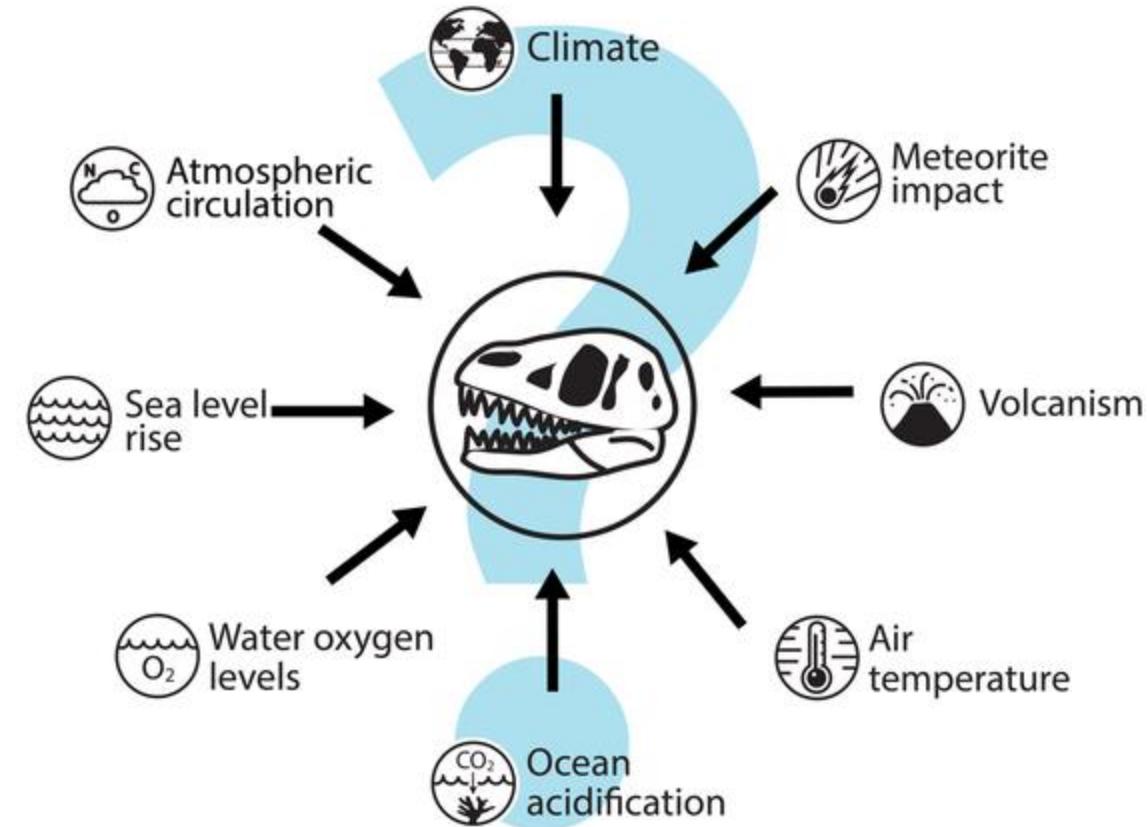
# Ecosystems and extinction

- Human based extinction (current)

- Natural extinction

- Five mass extinctions

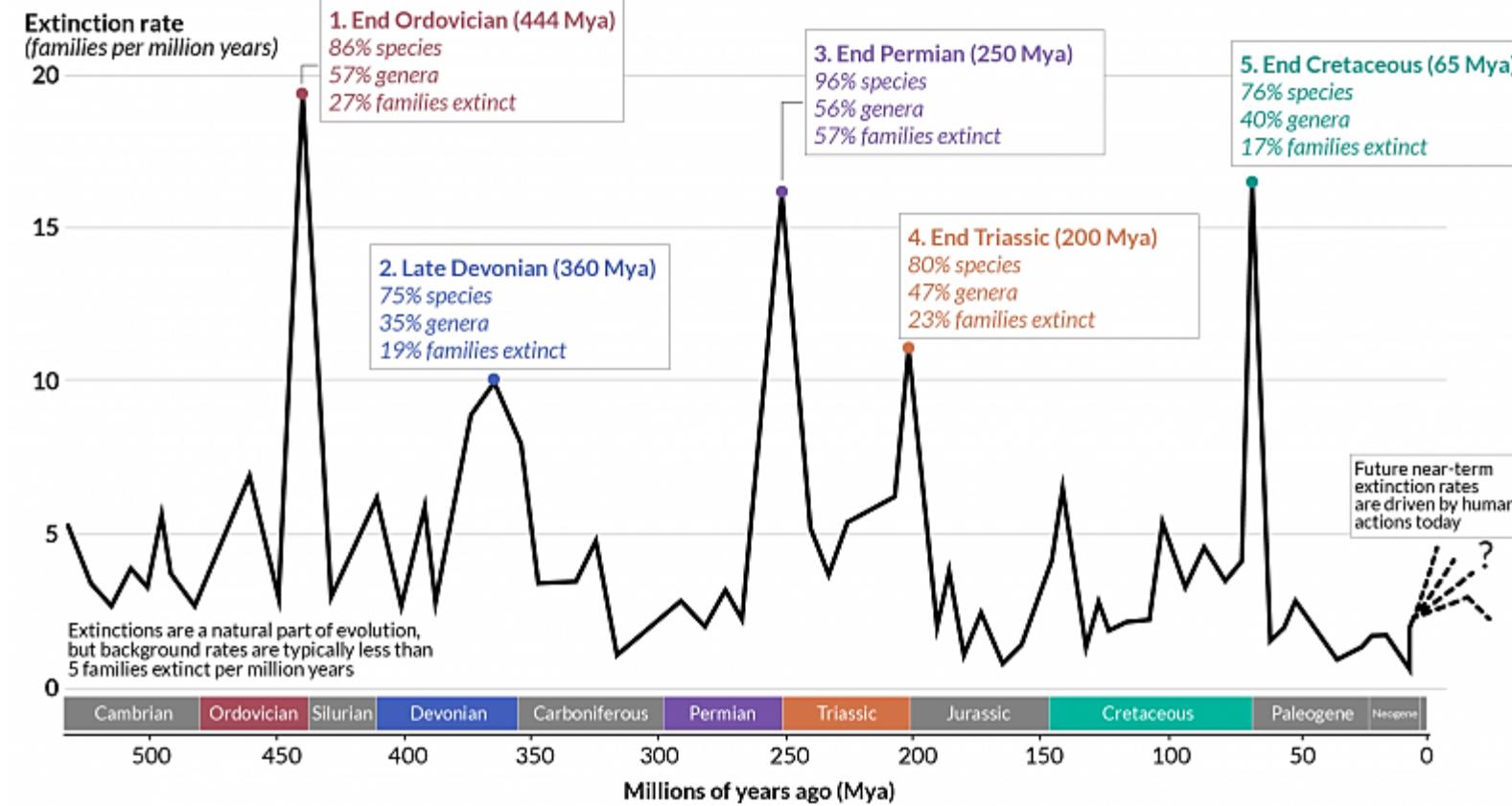
## What contributes to mass extinction?



# 'Big Five' Mass Extinctions in Earth's History

A mass extinction is defined by the loss of at least 75% of species within a short period of time (geologically, this is around 2 million years).

Our World  
in Data



Sources: Barnosky et al. (2011); Howard Hughes Medical Institute; McCallum (2015). Vertebrate biodiversity losses point to a sixth mass extinction.

OurWorldInData.org – Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the author Hannah Ritchie.

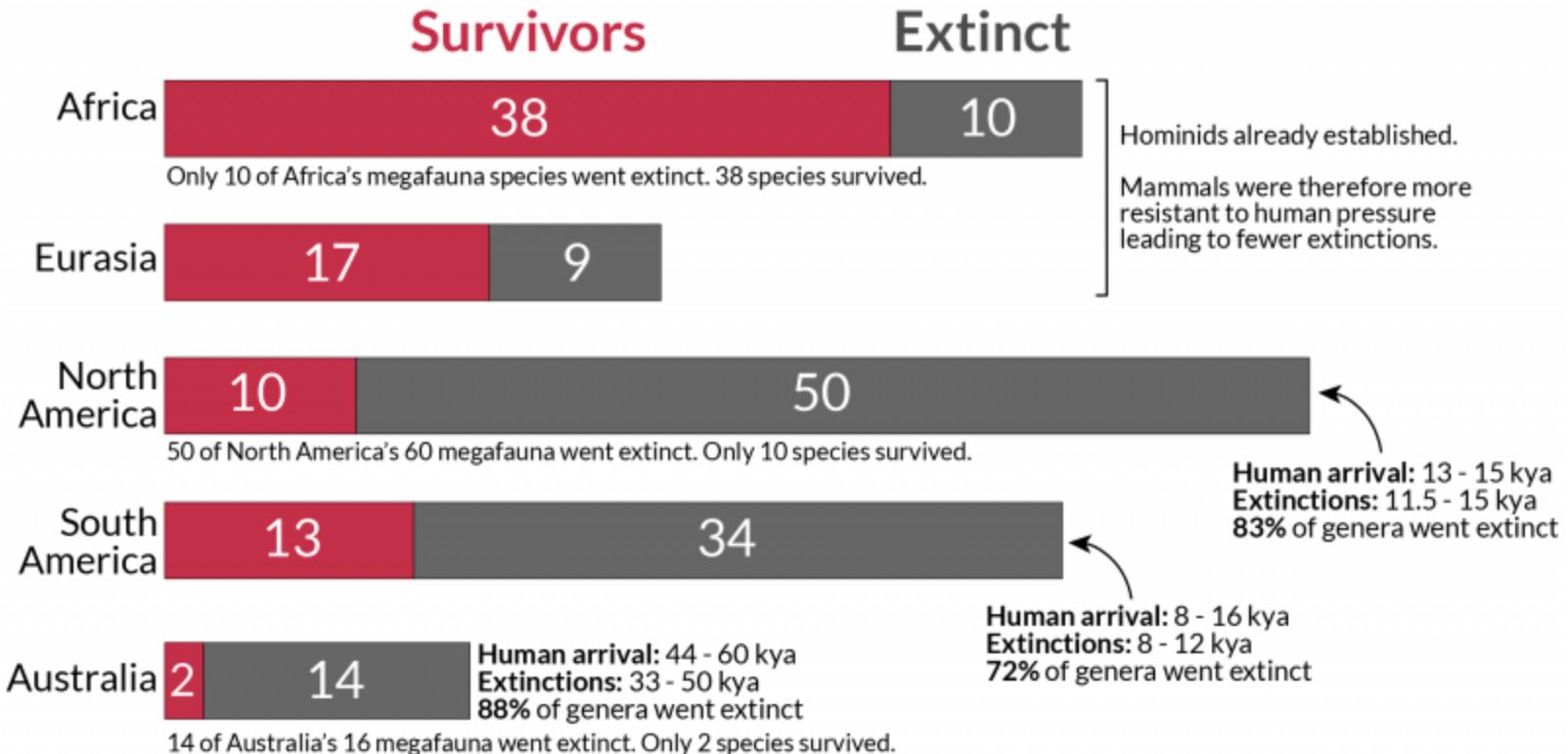
10% of species are lost every million years; 30% every 10 million years; and 65% every 100 million years

Magnitude is the percentage of species that are lost. Rate is how quickly this happens

In a mass extinction at least 75% of species go extinct within a relatively (by geological standard) short period of time. Typically less than two million years.

# Megafauna losses at the Quaternary Extinction

The Quaternary extinction event (52,000 years BC to 9,000 years BC) killed >178 species of the world's largest mammals. Humans were the primary driver of these extinctions.



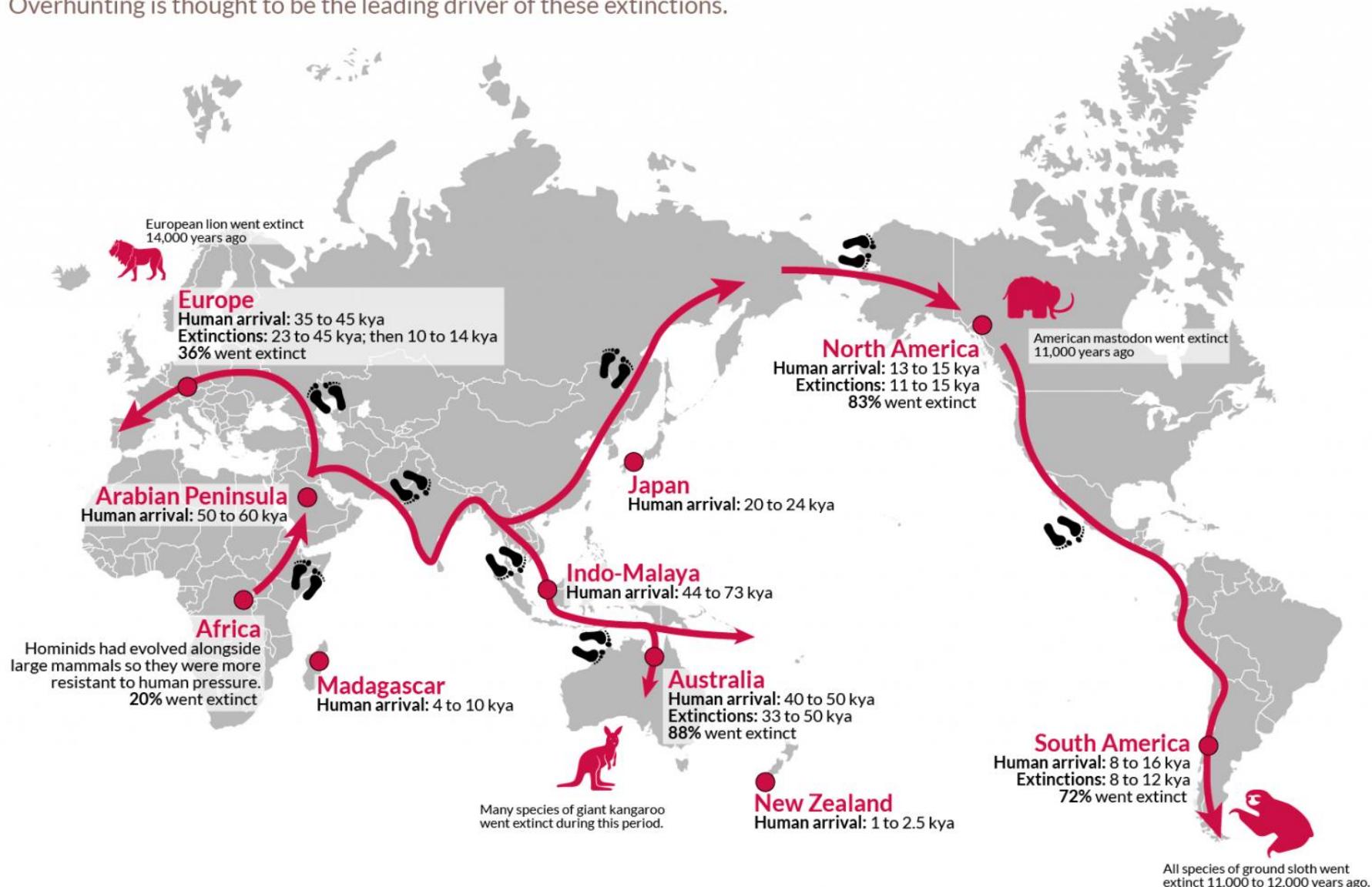
Data sources: Andermann et al. (2020). The past and future human impact on mammalian diversity. *Science*.

Barnkosky (2008). Megafauna biomass tradeoff as a driver of Quaternary and future extinctions. *PNAS*.

OurWorldinData.org – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the author Hannah Ritchie.

# Human migration and the extinction of large mammals

The Quaternary Megafauna extinction killed off more than 178 of the world's largest mammal species from 52,000 to 9,000 BC. These extinctions closely mapped human migrations across the world's continents. Overhunting is thought to be the leading driver of these extinctions.

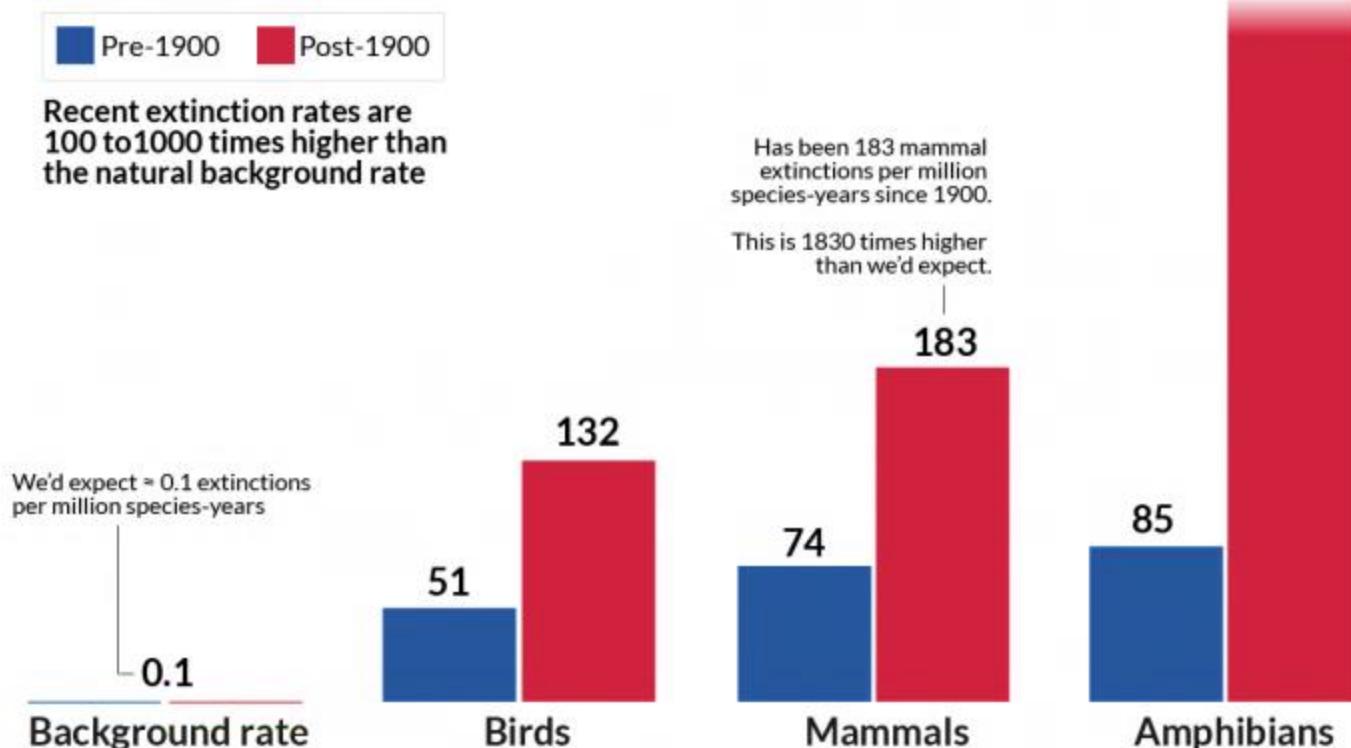


# Are species going extinct faster than we'd expect?

Species extinction rates are measured in extinctions per million species-years (E/MSY). If the E/MSY was equal to one, this would mean that if we had one million species, one species would go extinct every year; or if there was only one species it would go extinct in one million years.

Our World  
in Data

↑  
587



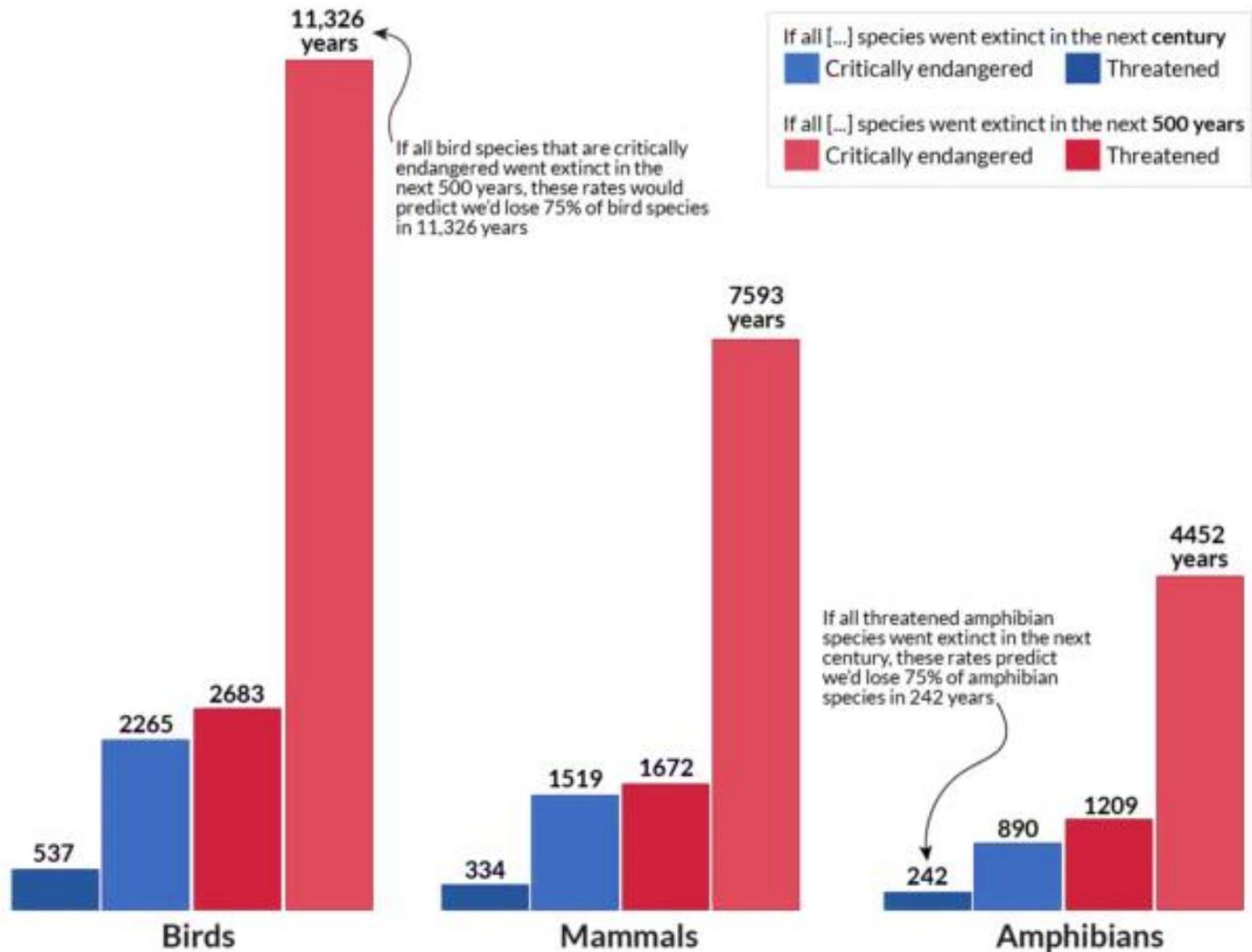
Note: Species defined as 'probably extinct' by the IUCN are included as species extinctions.

Data Source: Pimm et al. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science*.

[OurWorldInData.org](http://OurWorldInData.org) – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the author Hannah Ritchie.

# Are we heading for a sixth mass extinction?

How many years until we reach a sixth mass extinction?  
A mass extinction is defined by a 75% loss of species within a short period of time (less than two million years).  
Years until we reach this point is shown under a number of hypothetical future scenarios with varying extinction rates.



Data Source: Anthony Barnosky et al. (2011), Has the Earth's sixth mass extinction already arrived? *Nature*.  
[OurWorldInData.org](http://OurWorldInData.org) – Research and data to make progress against the world's largest problems.

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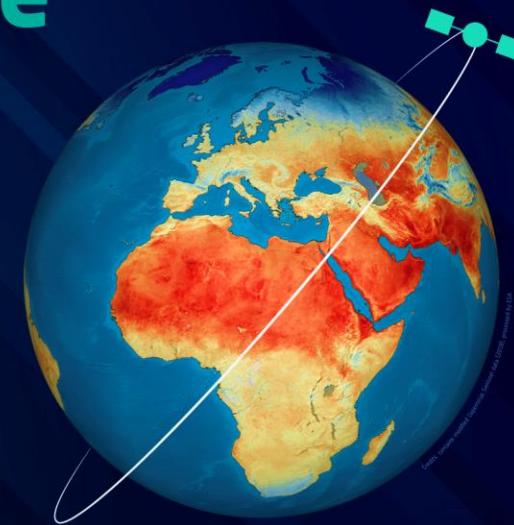
- 
- A wide-angle photograph of a forest at sunset or sunrise. The sky is filled with vibrant orange, yellow, and blue hues. In the foreground, dark silhouettes of various trees, including tall pines, are visible against the bright sky. The horizon shows distant hills or mountains under the colorful sky.
- „Can developments by human lead to extinction? Example: Deforestation
  - „Future climate change can significantly lead to extinctions

# Climate Change

- ↳ Weather vs. Climate
- ↳ Climate change in the past
- ↳ Modern climate change
- ↳ Climate change in the future
- ↳ Climate processes

# Weather versus Climate

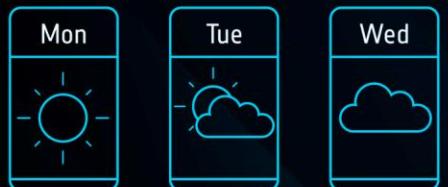
**The difference between weather and climate is a matter of time**



## Weather

refers to short-term changes in the atmosphere.

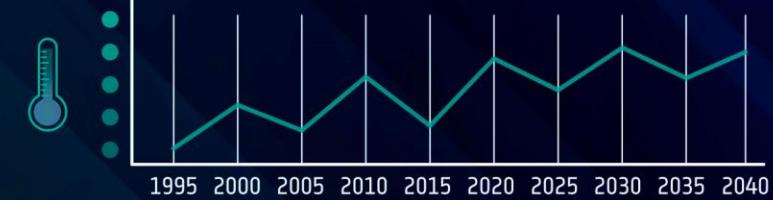
It can change minute-to-minute, hour-to-hour and day-to-day



Satellites measure several aspects of Earth's weather as well as provide essential data over decades to monitor how our climate is changing

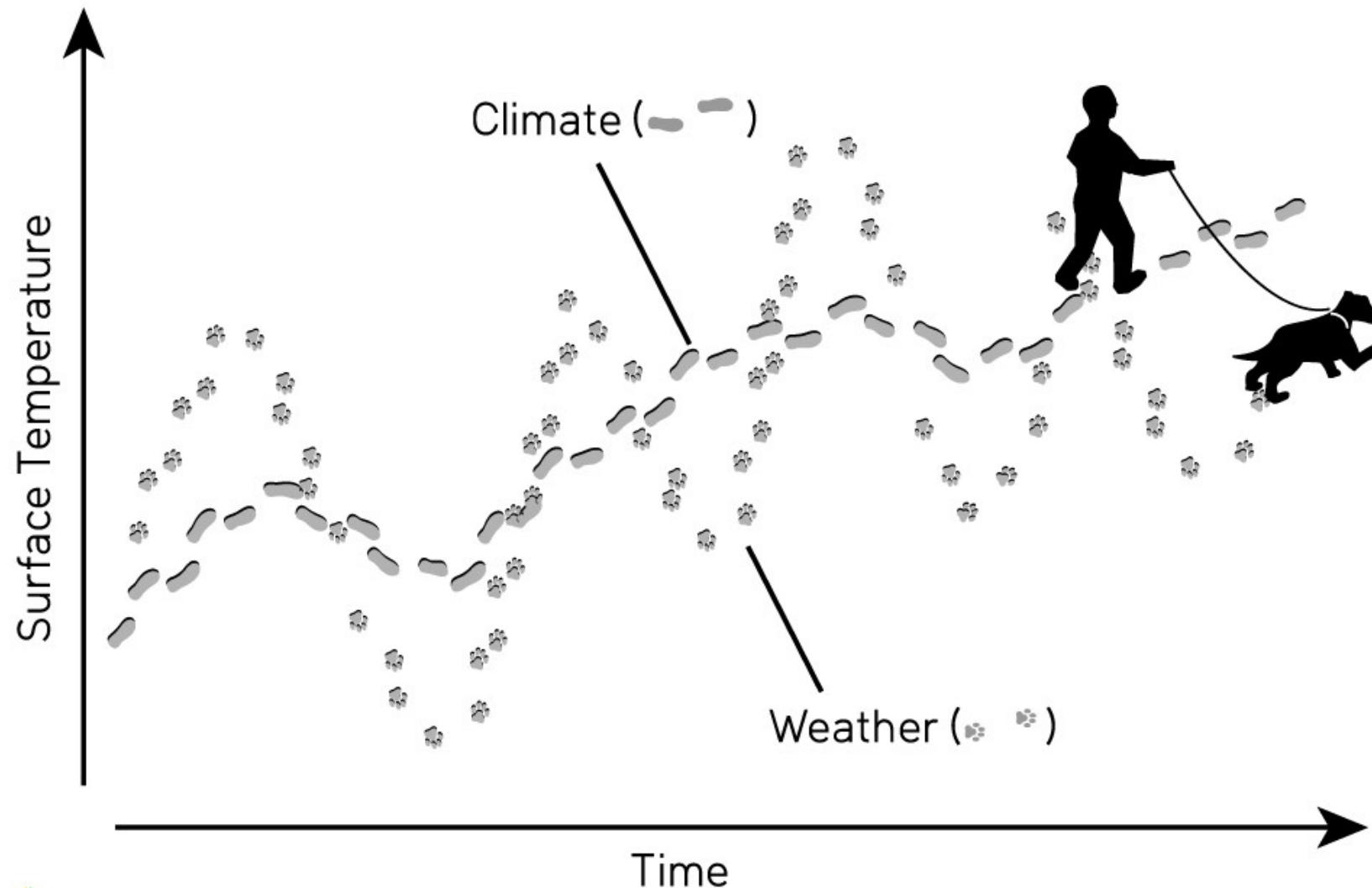
## Climate

describes the average weather conditions in a specific area over a long period of time – 30 years or more

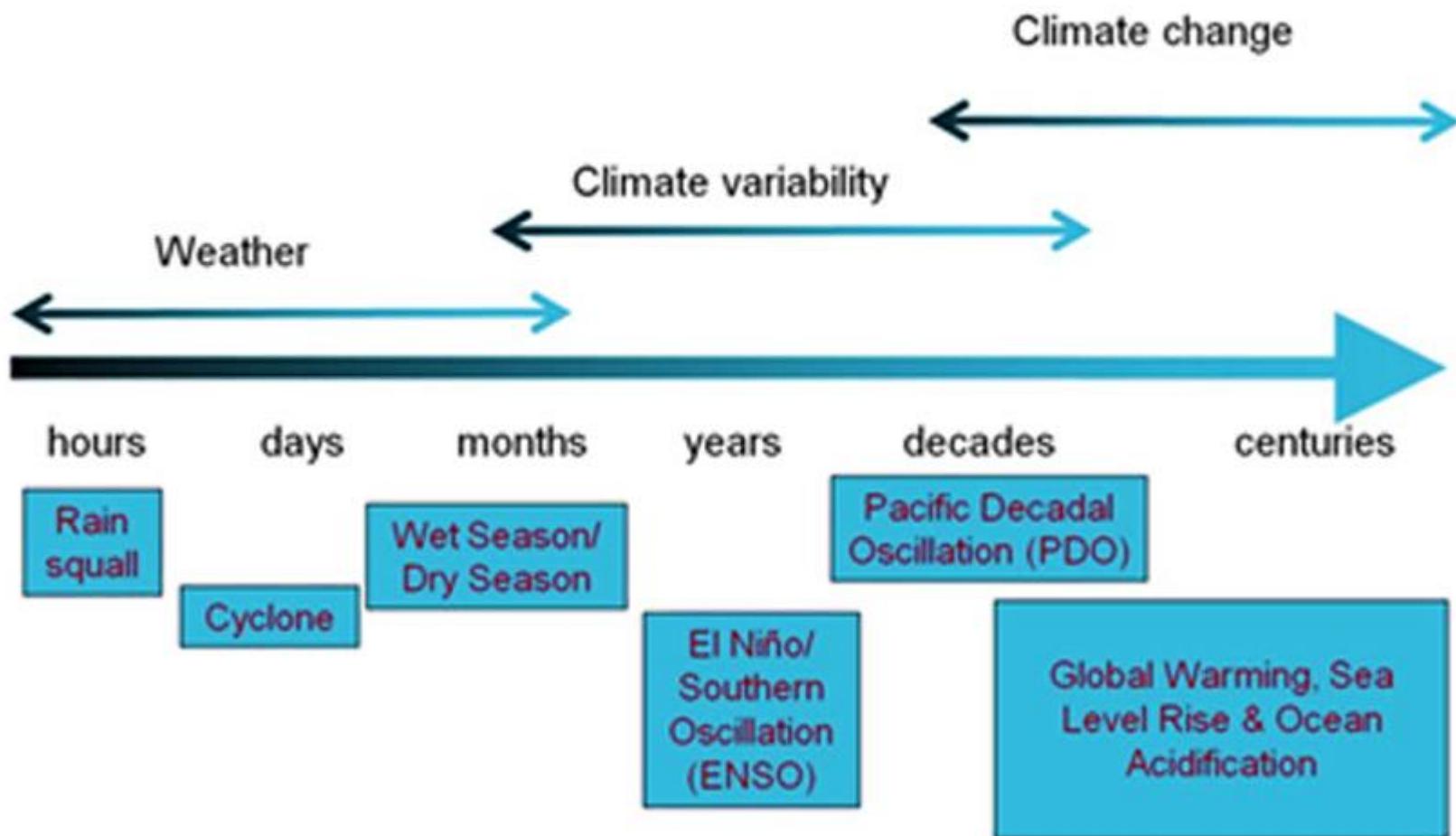


For more information, visit space for our climate:

## Example of weather and climate



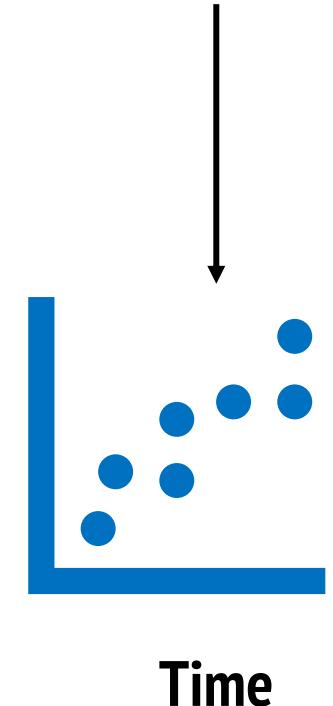
# Weather and climate scales



# Climate in the past

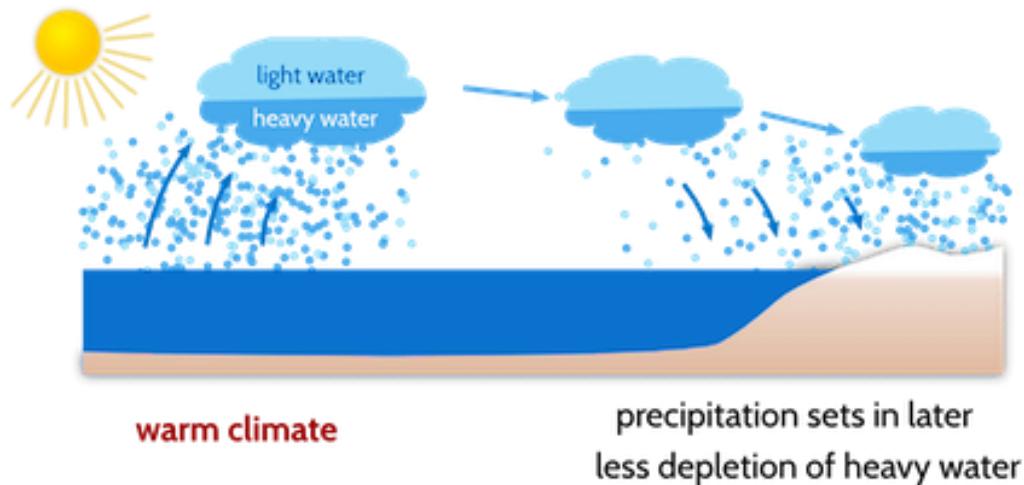
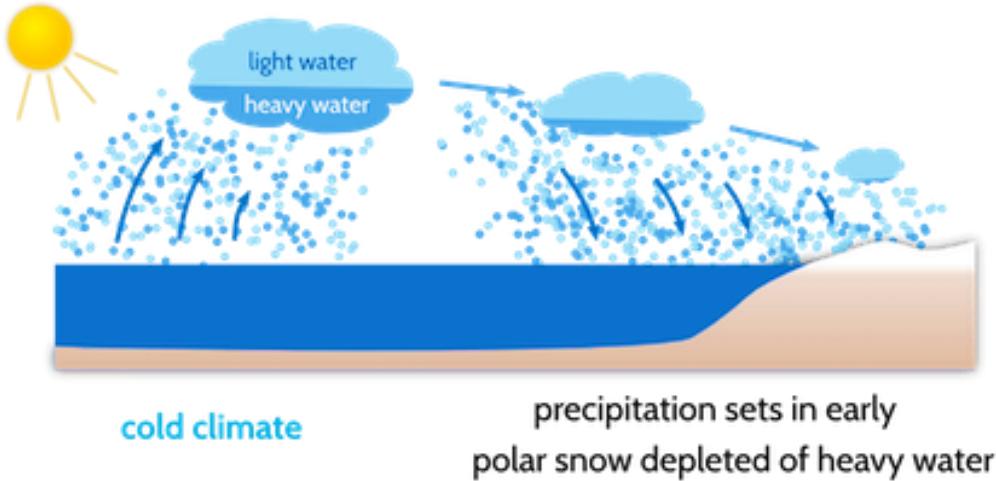


# Instrument and Proxy data

- ↳ Various instruments are used to measure the present day to day weather, example - temperature (thermometer), wind speed (cup anemometer) etc.
  - ↳ Long term climate data was accessed using **proxy**
    - ↳ Tree rings
    - ↳ Ice cores
    - ↳ Sediment cores
    - ↳ Coral reefs
    - ↳ Landscapes
- Natural processes**
- 

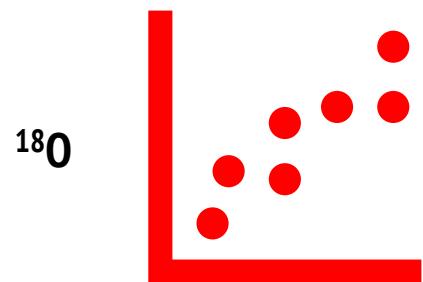
# Ice core data





Water isotope fractionation in the earth's atmosphere

- Light water**
- └ **Oxygen 16 ( $^{16}\text{O}$ ) – colder climate**
- └ **Oxygen 18 ( $^{18}\text{O}$ ) – warmer climate**
- heavy water**



Length of ice core



## Trapped air bubbles

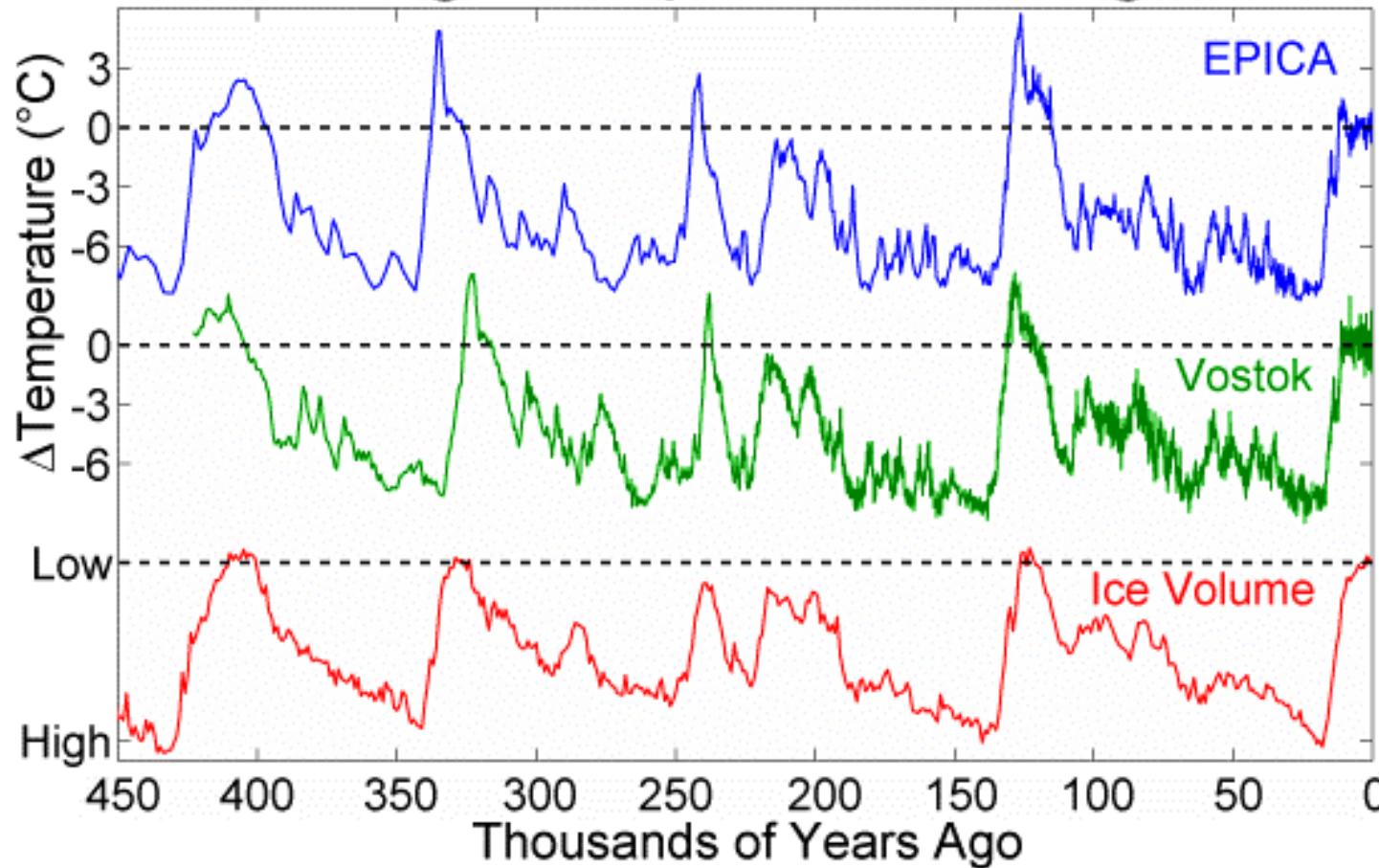
### in ice core

#### Composition of gases and aerosols

Particles settle down to dry or wet deposition (rain or snow)

Source: <https://www.chemedx.org/blog/ice-cores-stable-isotopes-climate-change-and-chemistry-part-2>

# Ice Age Temperature Changes



The European Project for Ice Coring in Antarctica (**EPICA**)

The Antarctic Vostok ice core

In the present there are more greenhouse gases (GHG) than in the past

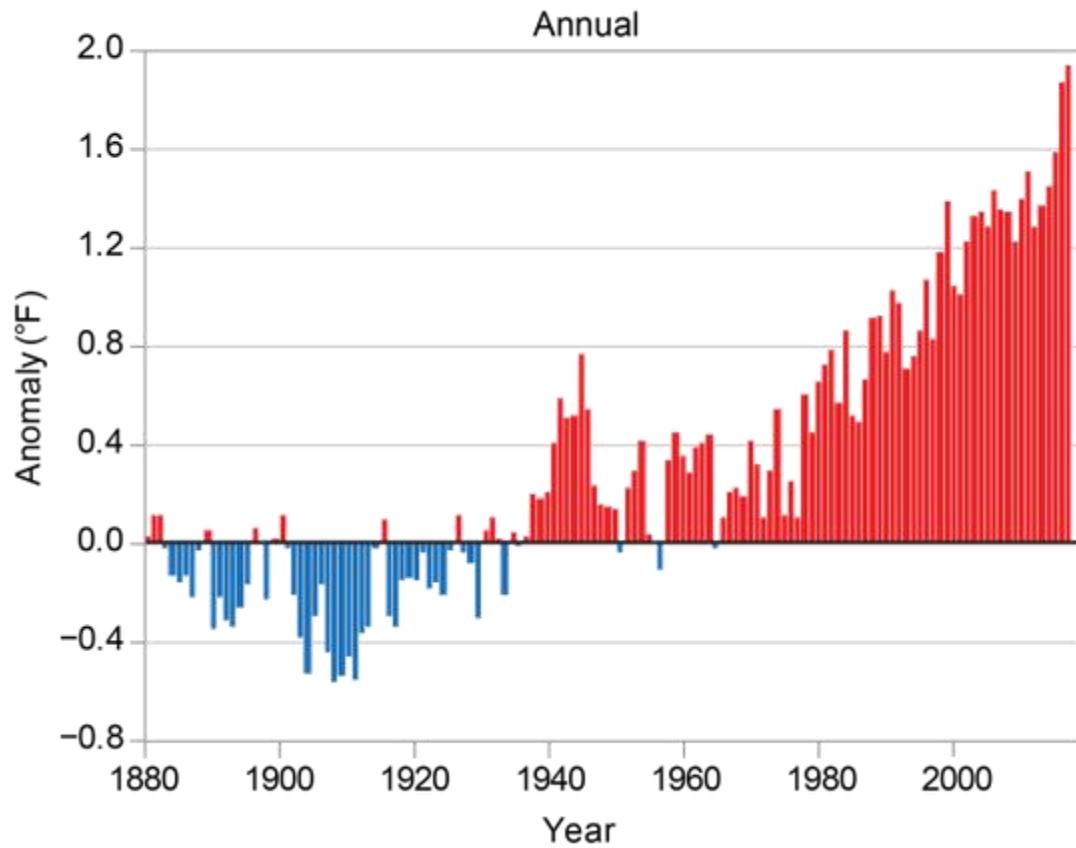
Do we see the change in temperature with the respect to increase in GHG?

# Take away points

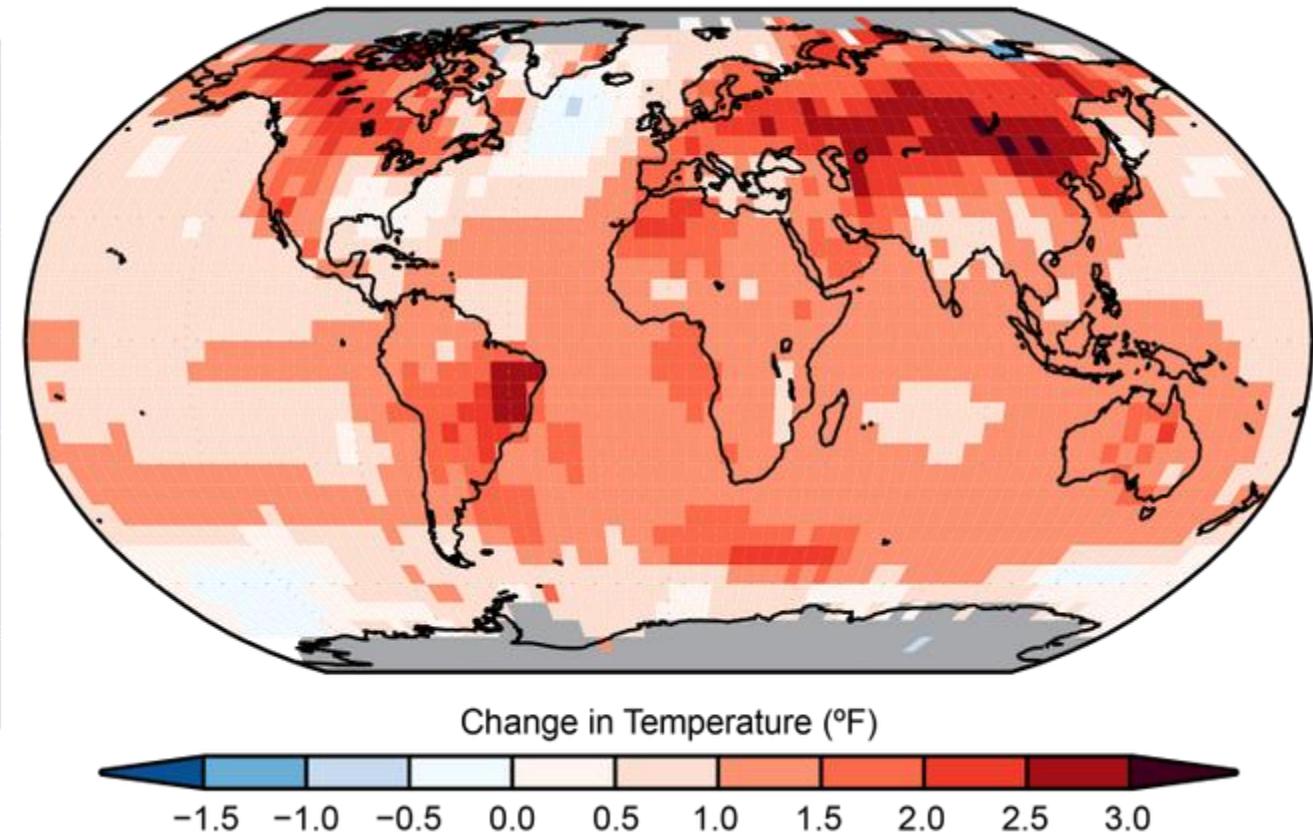
- └ Rate of change (  $\Delta T$  ) is much higher
- └ Correlation between **CO<sub>2</sub>** and **temperature** ?
- └ Climate is changing because of non-natural factors

# Modern climate change

## Global Land and Ocean Temperature Anomalies



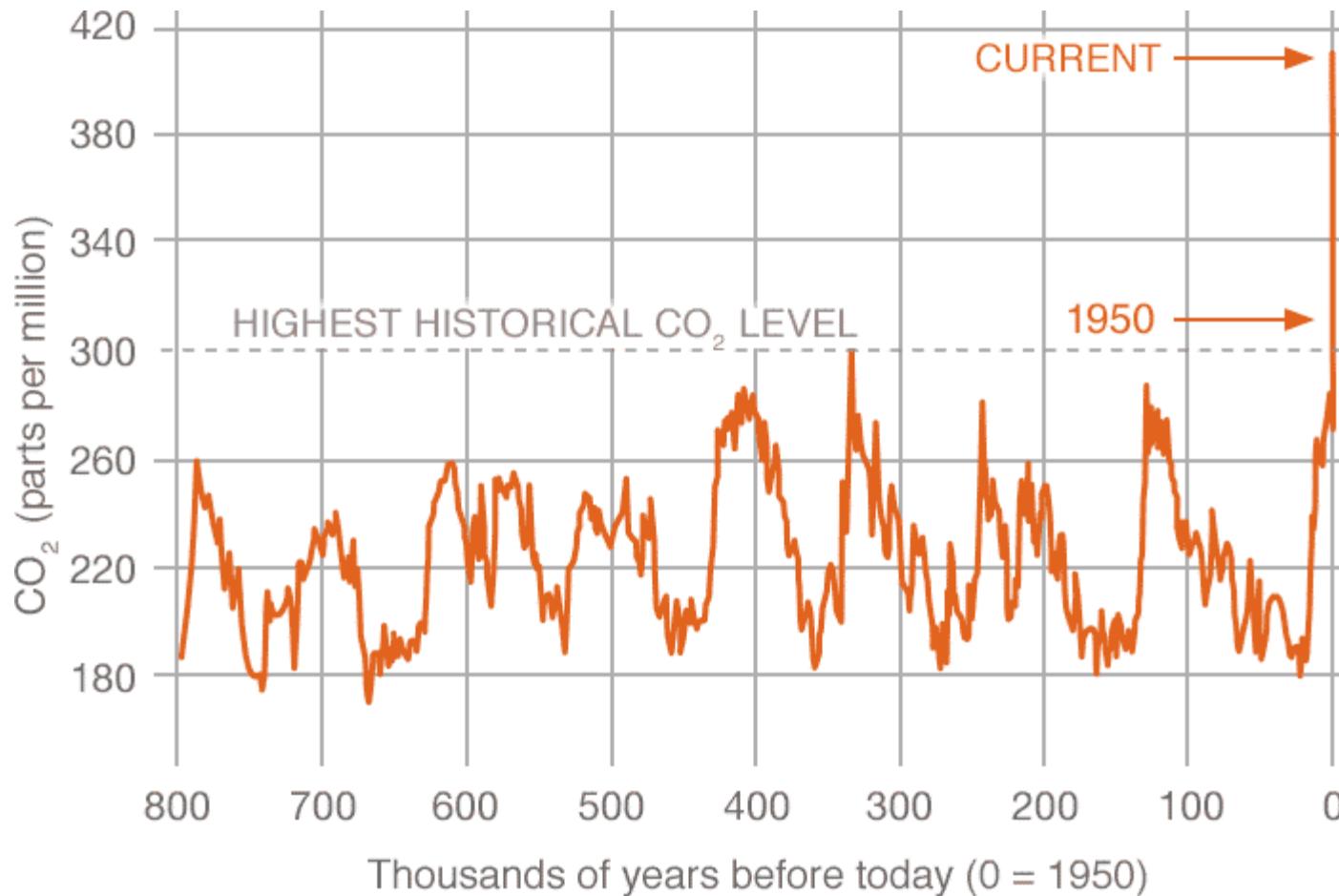
## Surface Temperature Change



(left) Global annual average temperature has increased by more than  $1.2^{\circ}\text{F}$  ( $0.7^{\circ}\text{C}$ ) for the period 1986–2016 relative to 1901–1960. Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average. (right) Surface temperature change (in  $^{\circ}\text{F}$ ) for the period 1986–2016 relative to 1901–1960. Gray indicates missing data.

A wide-angle photograph of an industrial complex, likely a refinery or chemical plant. Several tall, dark smokestacks rise from the structures, each billowing out a massive plume of smoke. The smoke is a mix of dark grey and bright orange-yellow, suggesting both unburned fuel and greenhouse gases like CO<sub>2</sub>. The background is a bright, overexposed sky, and the foreground shows a field of low-lying vegetation.

**Has CO<sub>2</sub> increased since industrial times?**



CO<sub>2</sub>

Increase in CO<sub>2</sub> – increase in greenhouse effect –  
increase in temperature

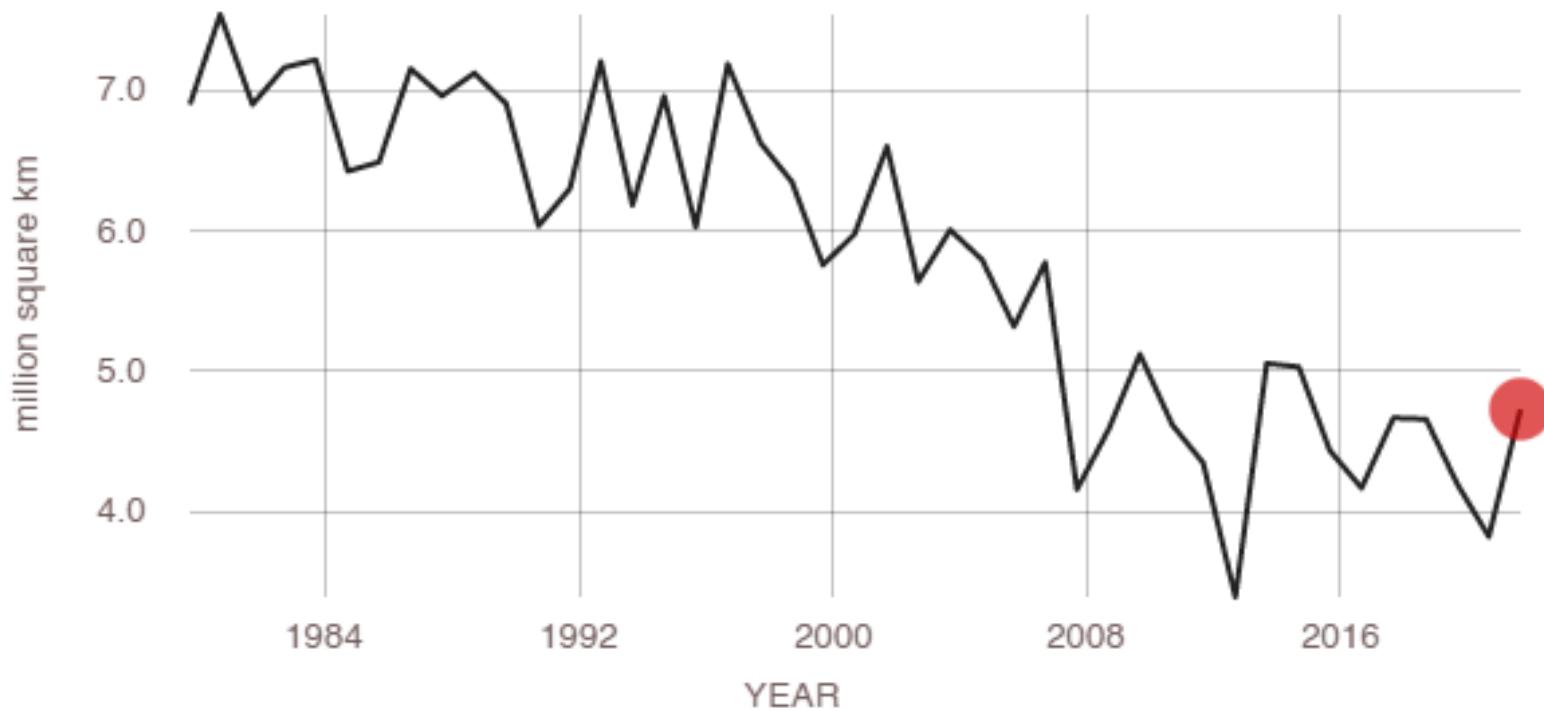
# Arctic sea ice extent

## ANNUAL SEPTEMBER MINIMUM EXTENT

Data source: Satellite observations. Credit: [NSIDC/NASA](#)

RATE OF CHANGE

↓ 13.0  
percent per decade



## SATELLITE DATA: 1993-PRESENT

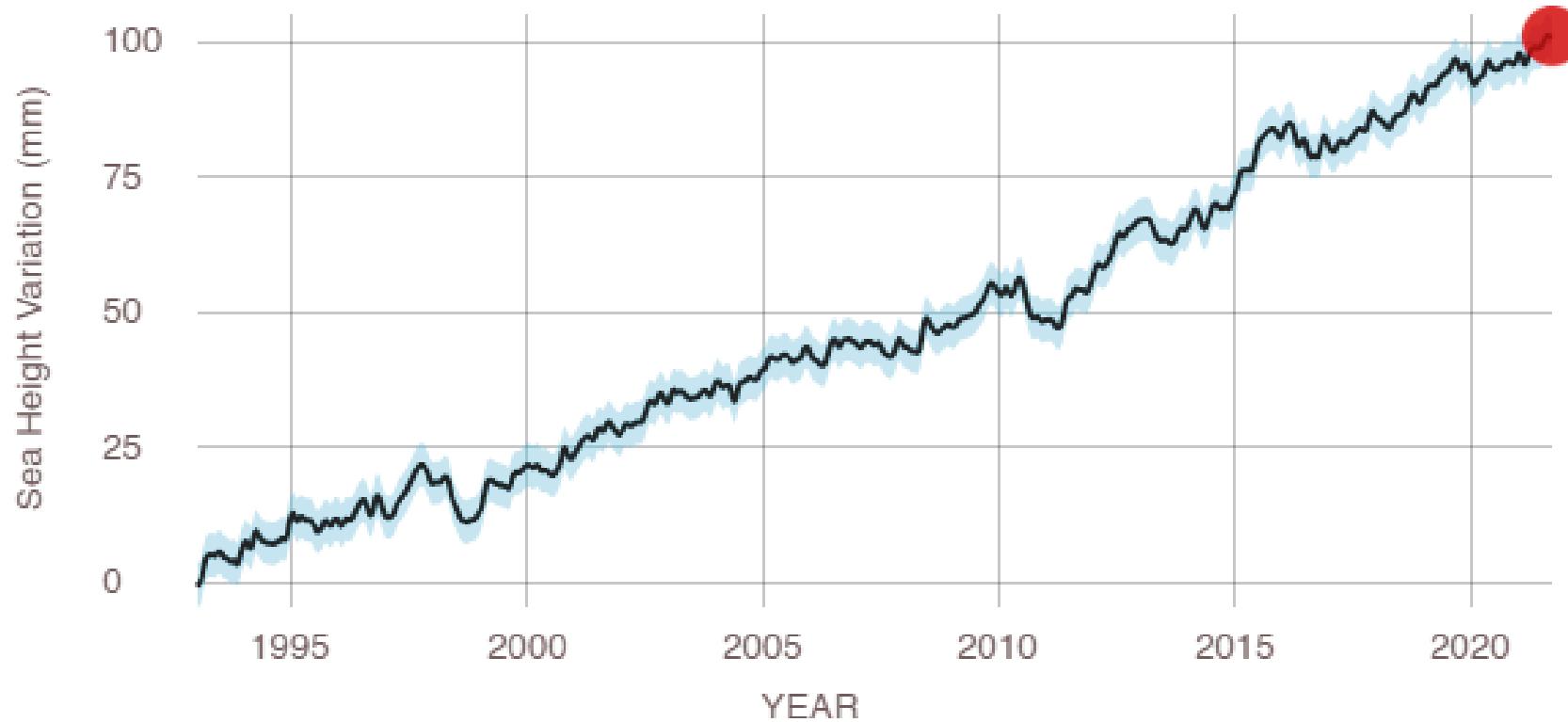
Data source: Satellite sea level observations.

Credit: NASA's Goddard Space Flight Center

### RATE OF CHANGE

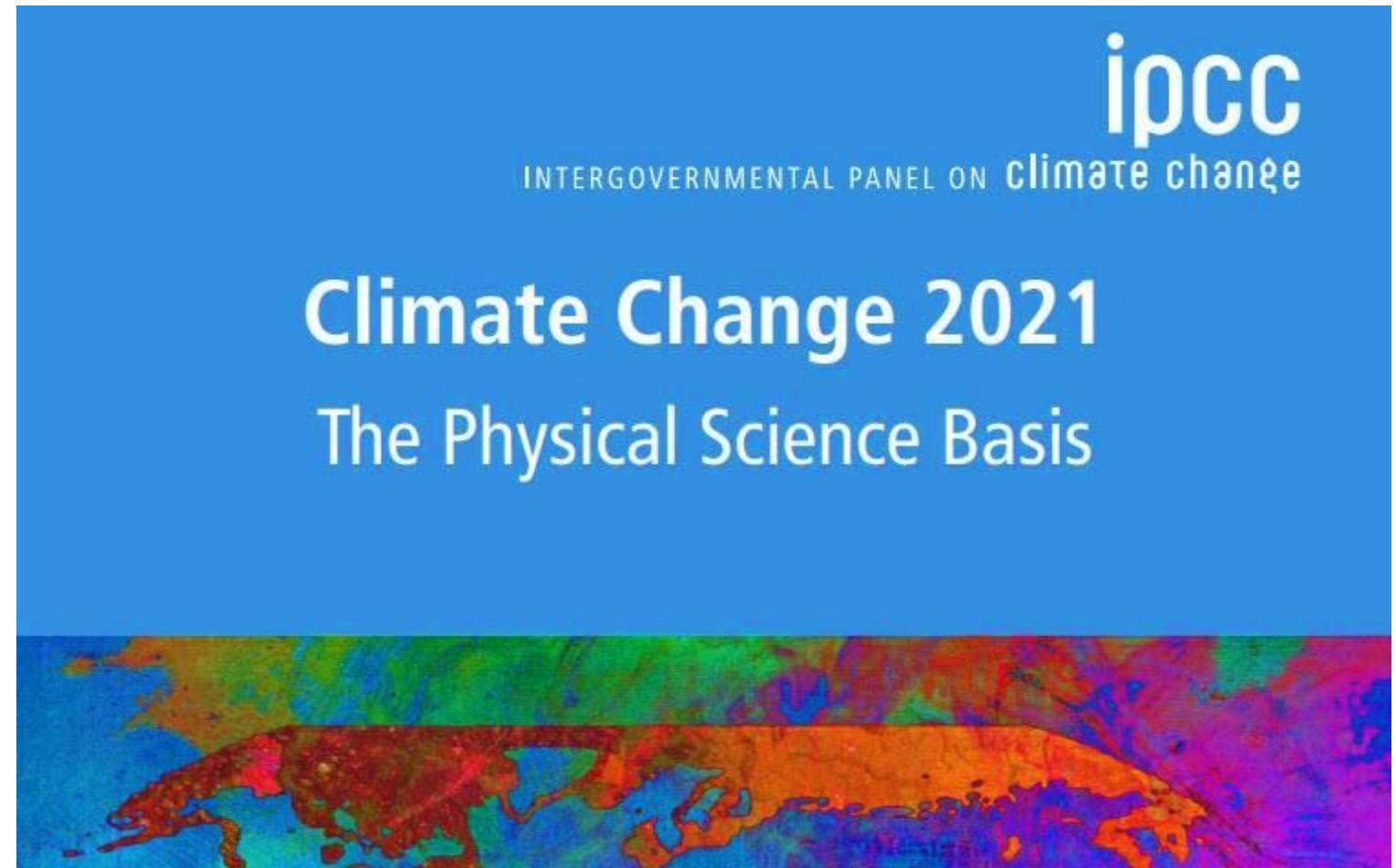
↑ 3.4

millimeters per year



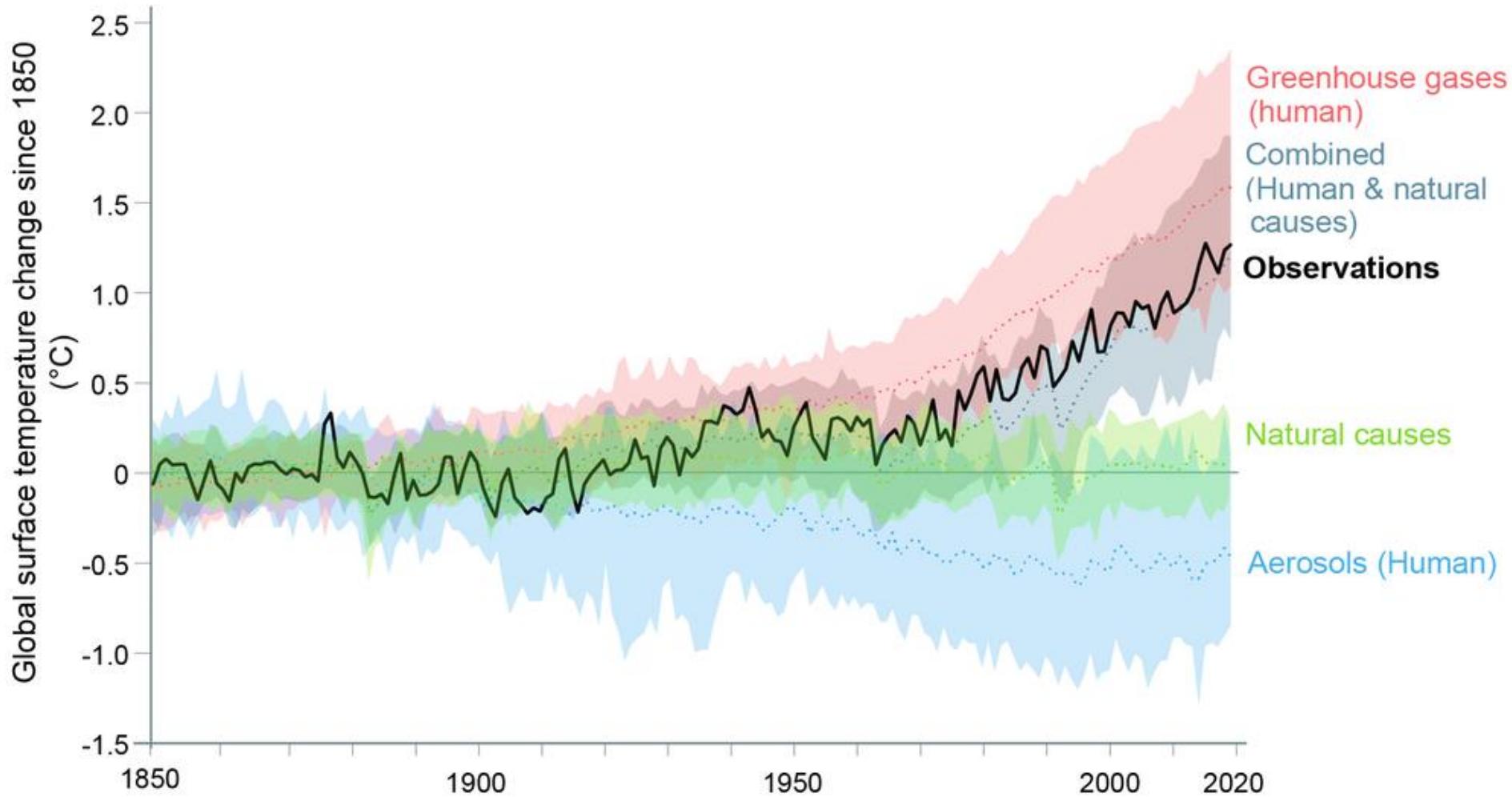
## Rise in sea level

# Future temperature projections

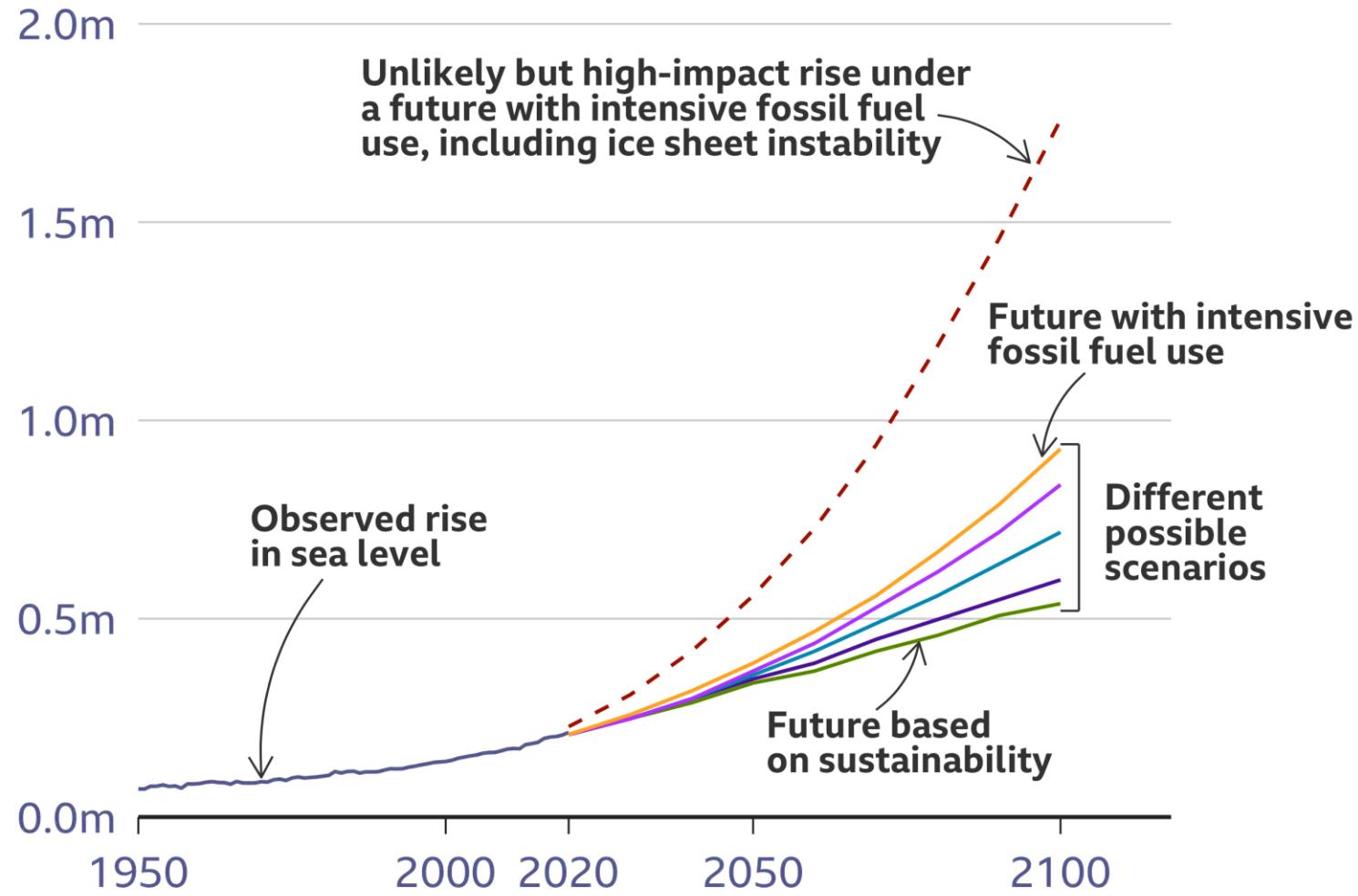


# Future temperature projections

How do we know humans are causing climate change?



## Average rise in sea level relative to 1900



Source: IPCC, 2021: Summary for Policymakers

BBC

# Climate change: IPCC report is 'code red for humanity'

- └ **Global surface temperature** was 1.09C higher in the decade between 2011-2020 than between 1850-1900.
- └ The past five years have been the hottest on record since 1850
- └ The recent rate of **sea level rise** has nearly tripled compared with 1901-1971
- └ Human influence is "very likely" (90%) the main driver of the global **retreat of glaciers** since the 1990s and the decrease in Arctic sea-ice
- └ It is "virtually certain" that **hot extremes** including heatwaves have become more frequent and more intense since the 1950s, while **cold events** have become less frequent and less severe

# Climate processes

Naturally-occurring climate processes are constantly occurring, most of which are driven by an influx of energy from the sun. The abundant supply of heat and light stimulate the Earth's atmosphere causing various climate processes to take place.

# Factors which determine a climate

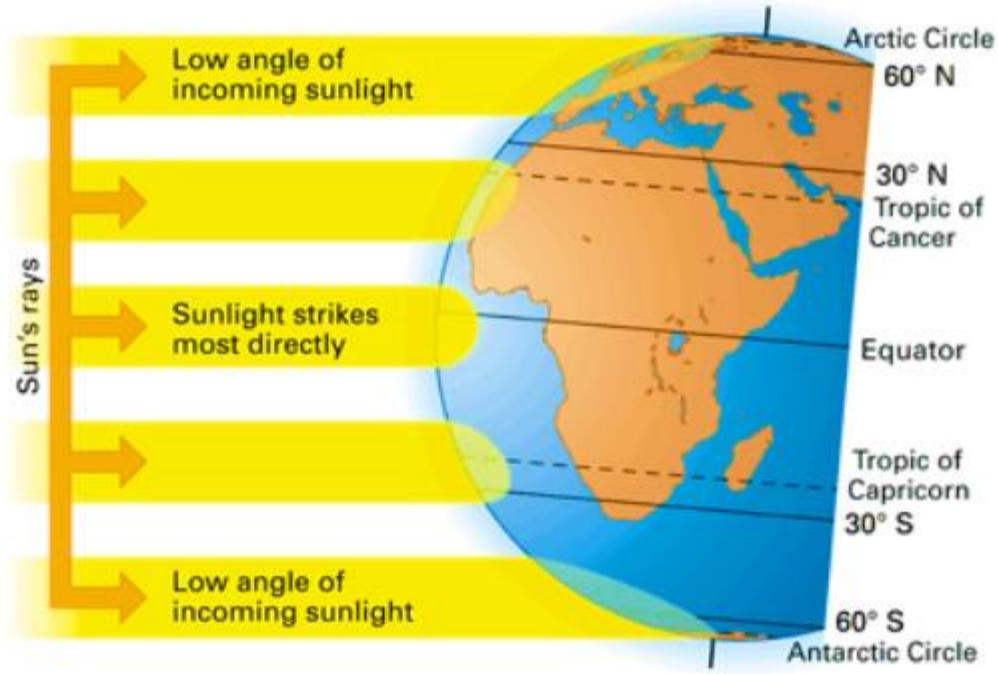
- └ Insolation
- └ Albedo
- └ Greenhouse gas effect



# **Insolation**

- It is the incident solar radiation onto some object.
- Specifically, it is a measure of the solar energy that is incident on a specified area over a set period of time.
- Generally, insolation is expressed two ways - One unit is kilowatt-hours per square meter ( $\text{kWh/m}^2$ ) per day and watts per square meter ( $\text{W/m}^2$ )

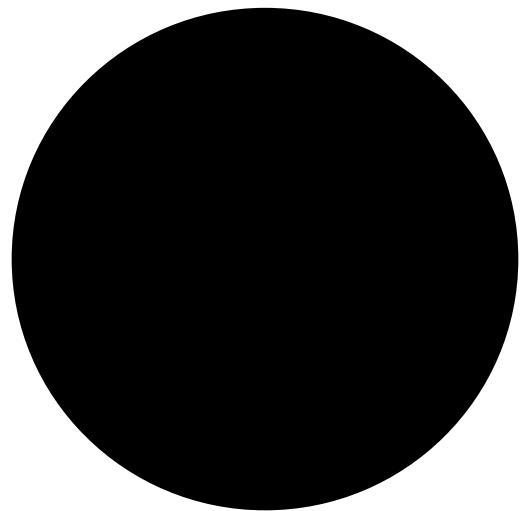
Different parts of the Earth receive different amounts of solar radiation. This is because the Sun's rays strike the Earth's surface most directly at the equator. As you move away from the equator, you will notice that different areas also receive different amounts of sunlight in different seasons.



**Difference in insolation also explains the seasons**

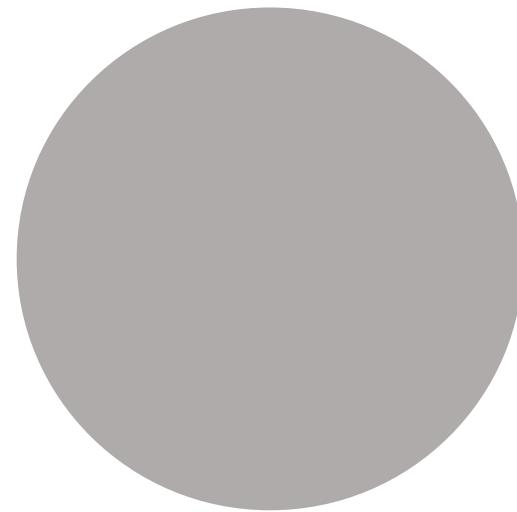
# Albedo

Albedo is a non-dimensional, unitless quantity that indicates how well a surface reflects solar energy.

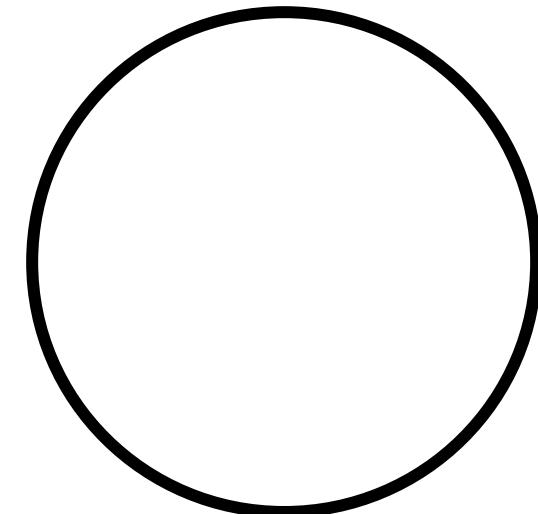


0

Perfect absorber



0.5



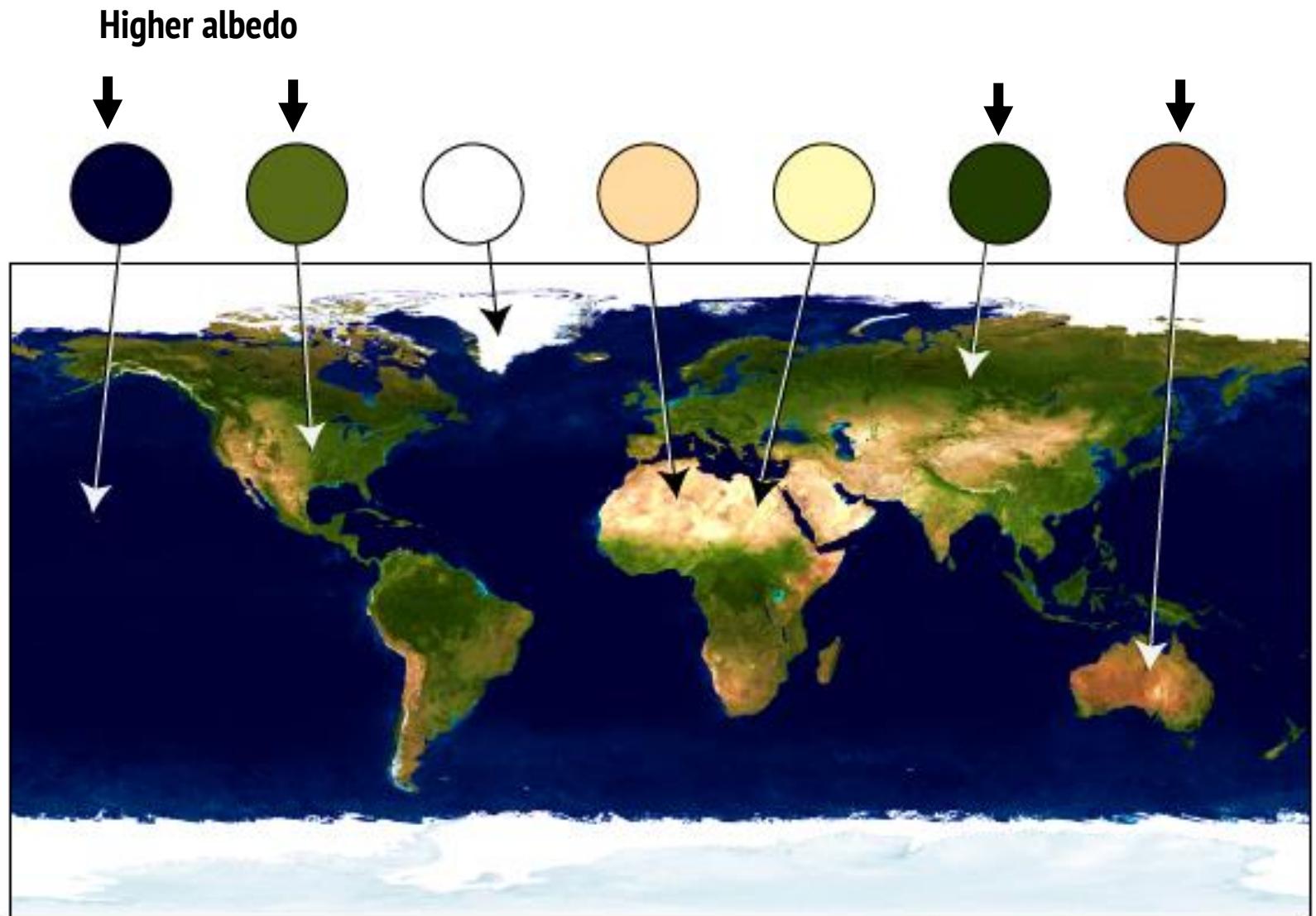
1

Perfect reflector

## Composite picture of Earth's albedo

Albedo - - close to 1 -- Earth's climate colder

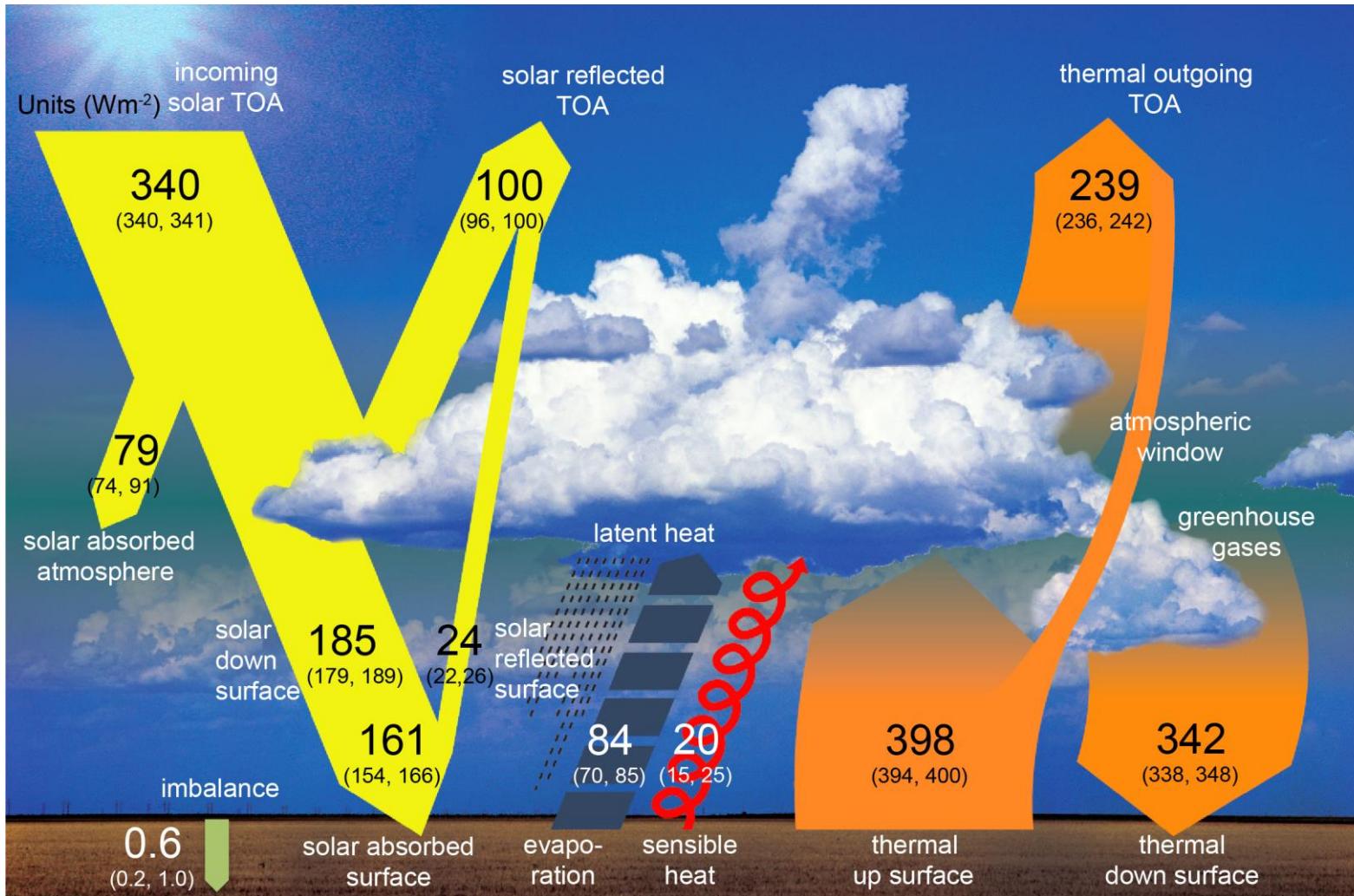
Albedo – close to 0-- Earth's climate warmer



Source: <https://scied.ucar.edu/learning-zone/how-climate-works/albedo-and-climate>

# Energy Balance

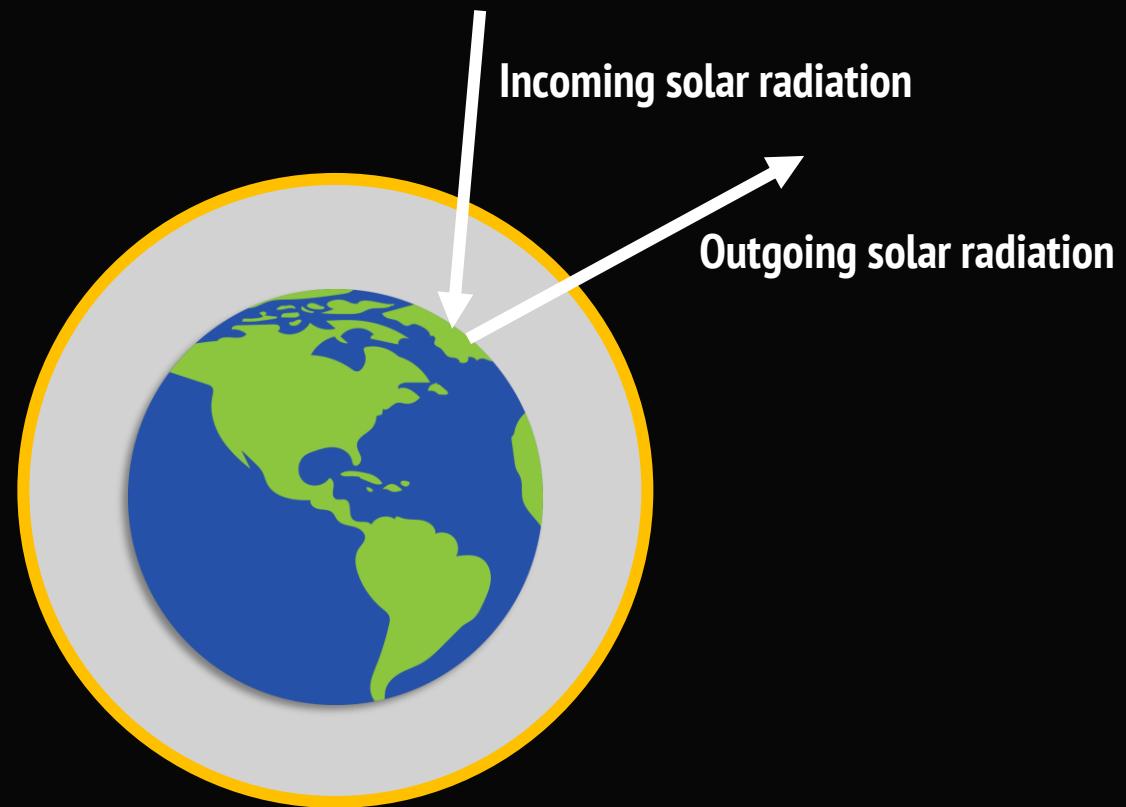
## Fundamental forces which control the climate – Energy balance



What temperature a planet will move to in equilibrium?

The imbalance between absorbed sunlight and outgoing thermal radiation determines whether the planet heats up or cools down.

# Greenhouse gases



**-18°C**

**no atmosphere**

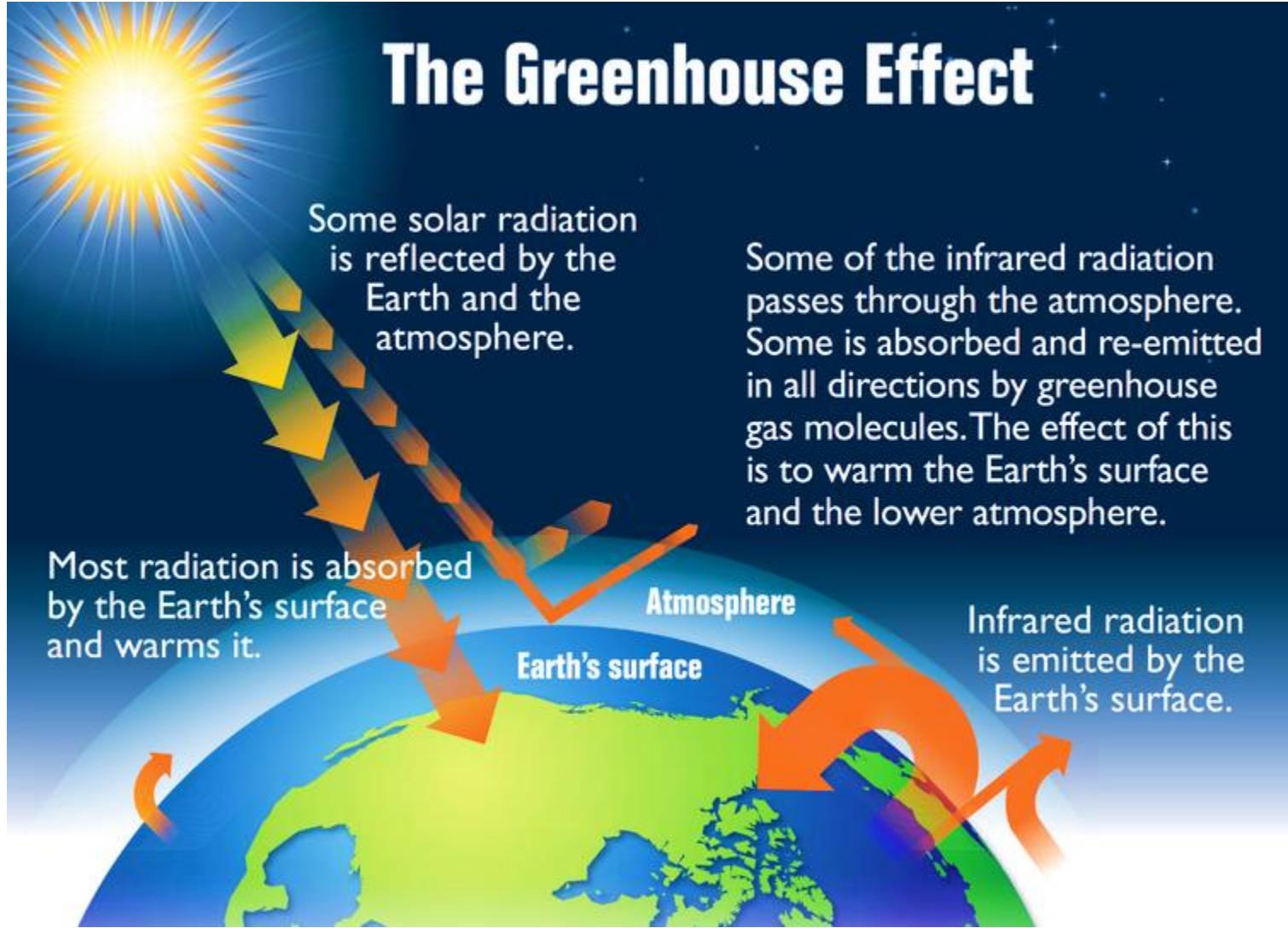
**15°C**

**atmosphere**

<https://www.pacificclimatefutures.net/en/help/climate-projections/understanding-climate-variability-and-change/>

**Earth's atmosphere trap the Sun's heat.**

# The Greenhouse Effect



# References

The images adopted in this lecture are from various sources of Google images.

**Give your biometric after I punch mine at  
10.40 a.m.**