

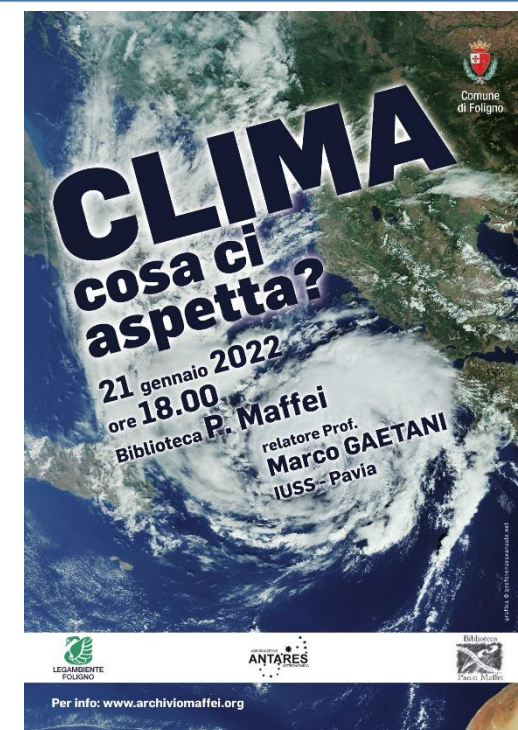


IUSS

Scuola Universitaria Superiore Pavia

CLIMA: Cosa ci aspetta?

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CARISMA Centre



Per info: www.archiviomaffei.org

Cos'è il clima? Quale relazione con il meteo?



World Meteorological Organization

@WMO

Words cannot describe this historic event, says

@ECCCWeatherBC

British Columbia set more than 40 all-time records

🌡️ Lytton broke #Canada's temperature record for the THIRD straight day on 29 June with 49.5°C.

HIGHER than Las Vegas all-time record high of 47.2°C.

#Climatechange

Canada Lytton: Heatwave record village overwhelmingly burned in wildfire

3 days ago



[\[https://www.bbc.com/news/world-us-canada-57678054\]](https://www.bbc.com/news/world-us-canada-57678054)

Record heatwave may have killed 500 people in western Canada

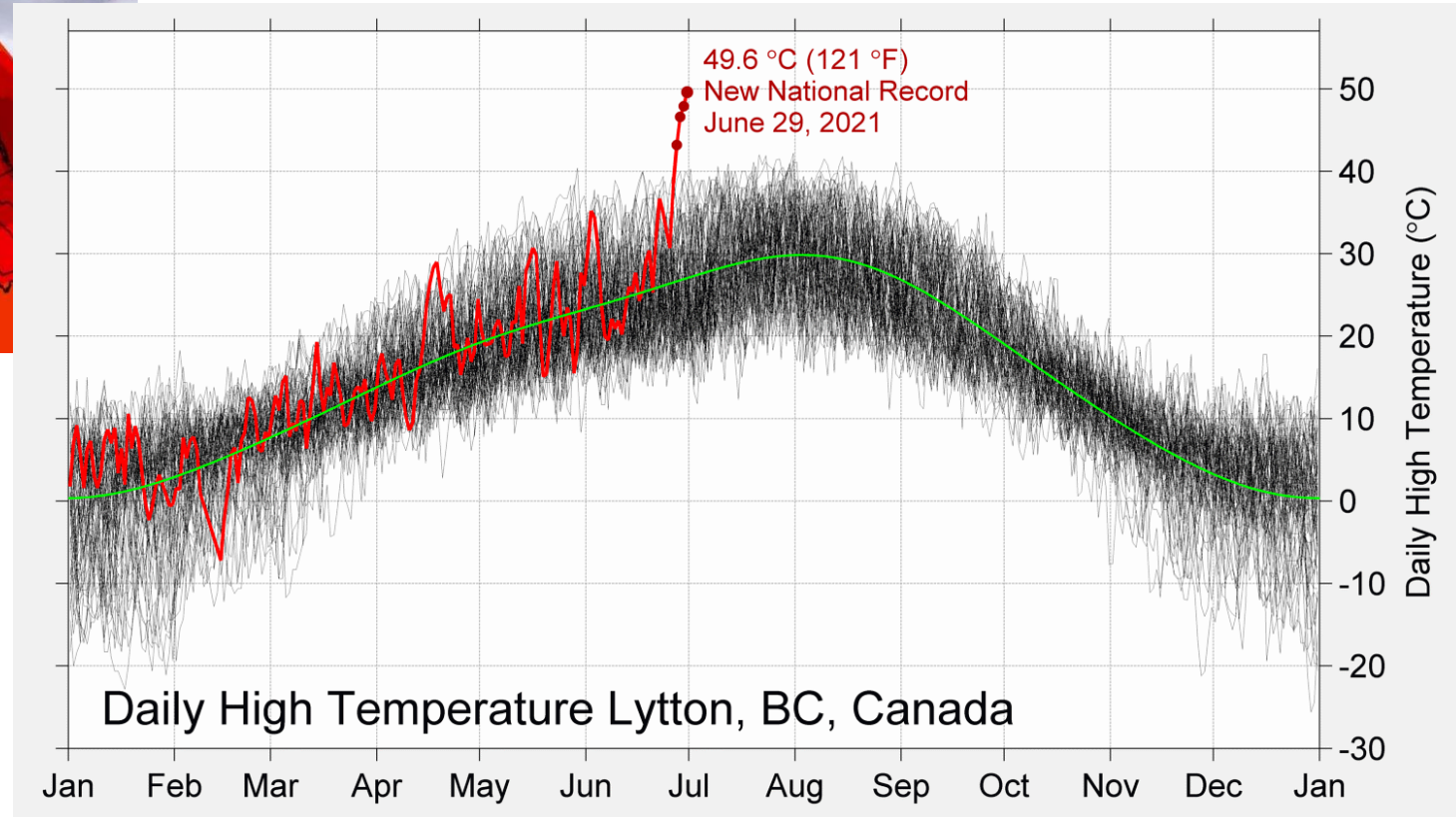
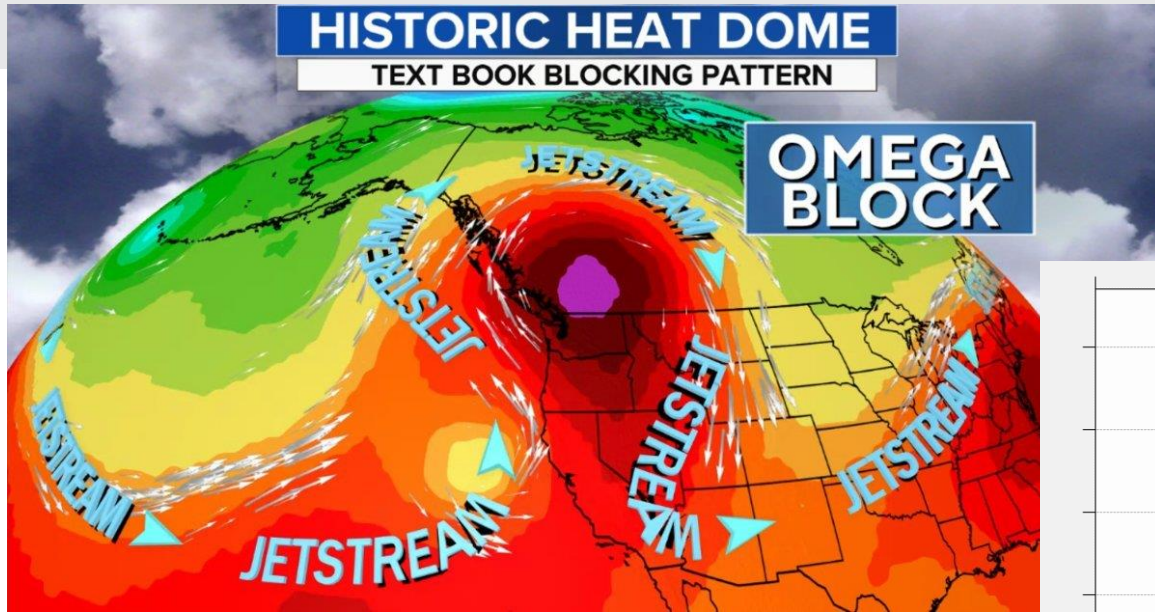
British Columbia reports jump in number of 'sudden and unexpected deaths' and links them to extreme weather



[\[https://www.theguardian.com/world/2021/jul/02/canada-heatwave-500-deaths\]](https://www.theguardian.com/world/2021/jul/02/canada-heatwave-500-deaths)



Cos'è il clima? Quale relazione con il meteo?



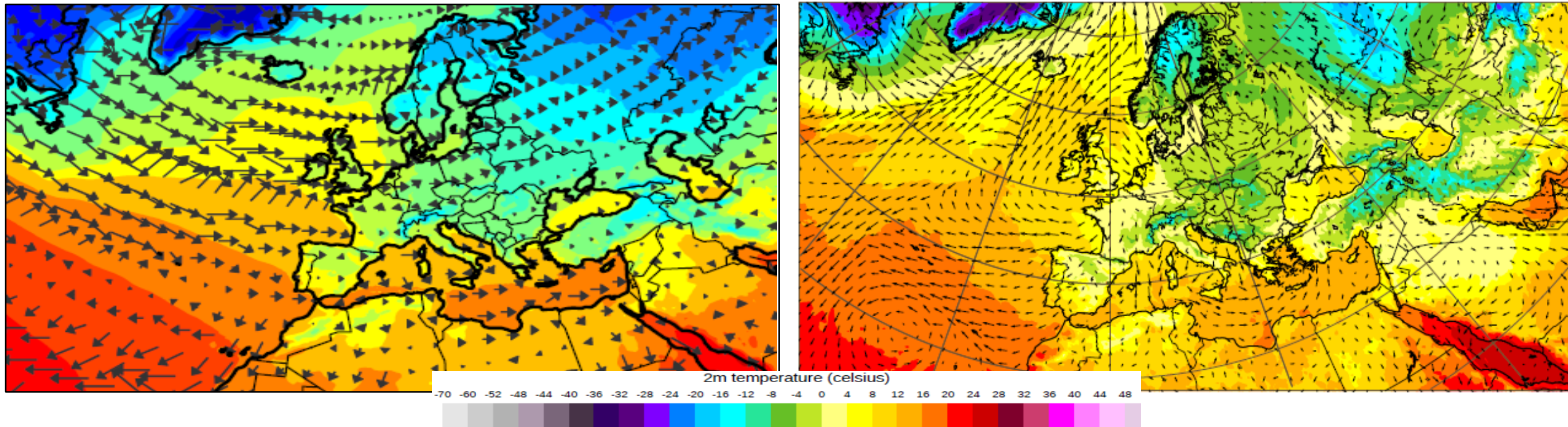
Cos'è il clima? Quale relazione con il meteo?

Meteo: stato dell'atmosfera in questo momento.

Clima: stato medio dell'atmosfera su lunghi periodi (30 anni).

[dati ERA5] climatologia di gennaio

[previsioni ECMWF] 21 gennaio 2022



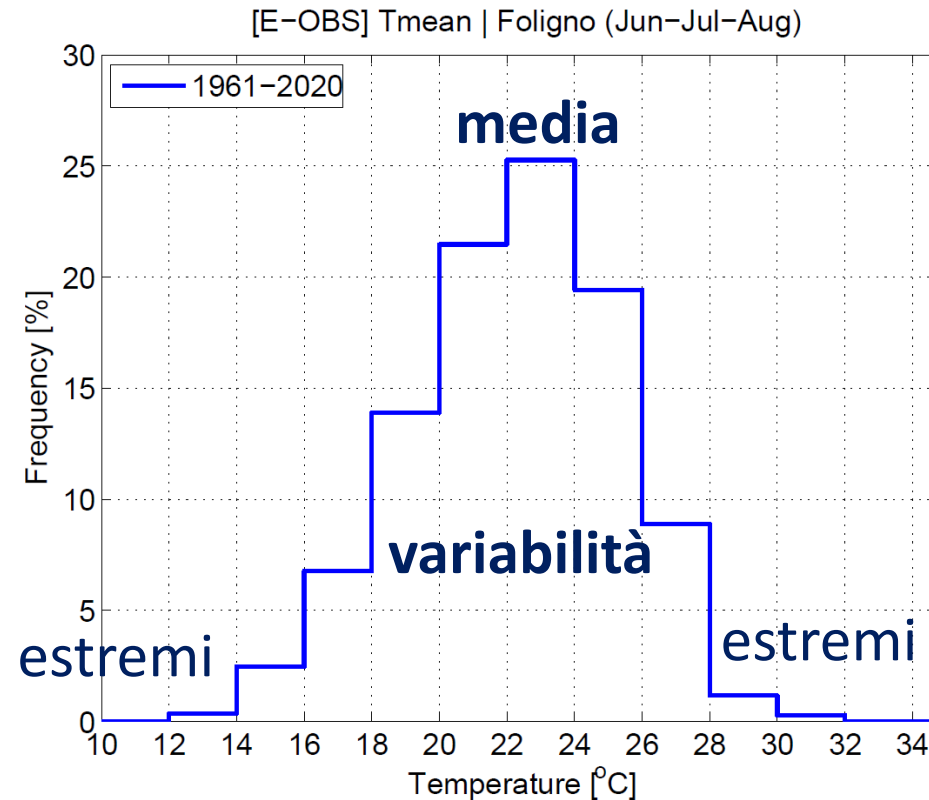
[<https://cds.climate.copernicus.eu/cdsapp#!/home>]

[<https://apps.ecmwf.int/webapps/opencharts/>]



Cos'è il clima? Quale relazione con il meteo?

Definizione statistica: il clima è definito dalle caratteristiche (es. media, variabilità) della distribuzione di probabilità delle variabili climatiche (es. temperatura, precipitazione) → il clima è la probabilità di osservare il meteo.

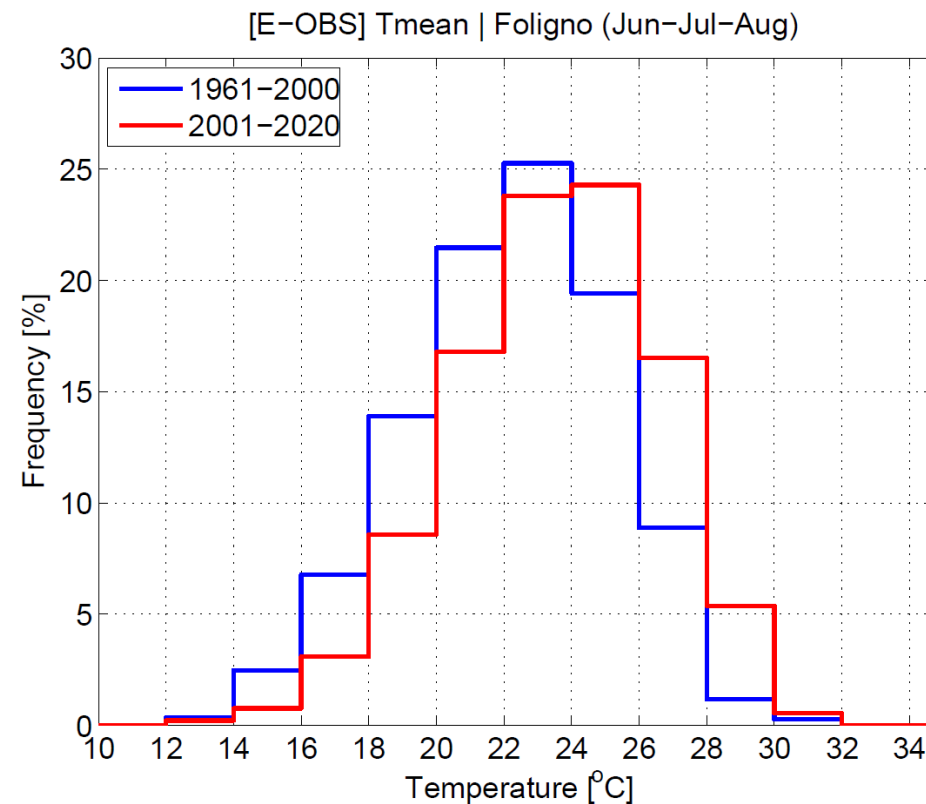


[<https://www.ecad.eu/download/ensembles/download.php>]



Cos'è il clima? Quale relazione con il meteo?

Cambiamento climatico: cambiamento statisticamente significativo nella distribuzione di probabilità delle variabili climatiche.

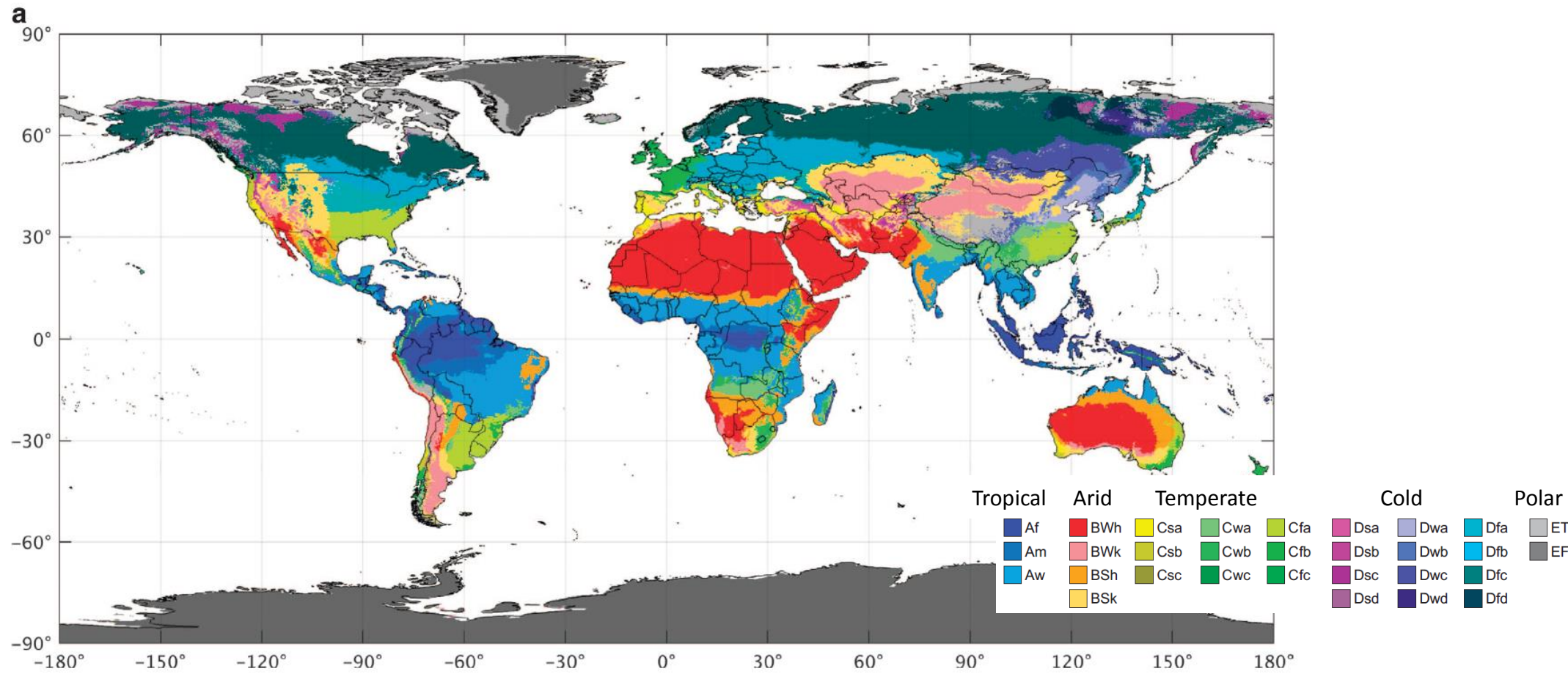


[<https://www.ecad.eu/download/ensembles/download.php>]



Cos'è il clima? Quale relazione con il meteo?

Classificazione di Köppen-Geiger (1936)



[Beck et al. 2018: <https://www.nature.com/articles/sdata2018214.pdf>]

Clima Mediterraneo

Table 1. Description of Köppen climate symbols and defining criteria.

1st	2nd	3rd	Description	Criteria*
A	f m w		Tropical	$T_{cold} \geq 18$
			- Rainforest	$P_{dry} \geq 60$
			- Monsoon	Not (Af) & $P_{dry} \geq 100 - MAP/25$
			- Savannah	Not (Af) & $P_{dry} < 100 - MAP/25$
B	W S		Arid	$MAP < 10 \times P_{threshold}$
			- Desert	$MAP < 5 \times P_{threshold}$
			- Steppe	$MAP \geq 5 \times P_{threshold}$
		h k	- Hot - Cold	$MAT \geq 18$ $MAT < 18$
C	s w f		Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
			- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
			- Dry Winter	$P_{wdry} < P_{swet}/10$
			- Without dry season	Not (Cs) or (Cw)
		a b	- Hot Summer - Warm Summer	$T_{hot} \geq 22$ Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D	s w f		Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
			- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
			- Dry Winter	$P_{wdry} < P_{swet}/10$
			- Without dry season	Not (Ds) or (Dw)
		a b c d	- Hot Summer - Warm Summer - Cold Summer - Very Cold Winter	$T_{hot} \geq 22$ Not (a) & $T_{mon10} \geq 4$ Not (a, b or d) Not (a or b) & $T_{cold} < -38$
E	T F		Polar	$T_{hot} < 10$
			- Tundra	$T_{hot} > 0$
			- Frost	$T_{hot} \leq 0$

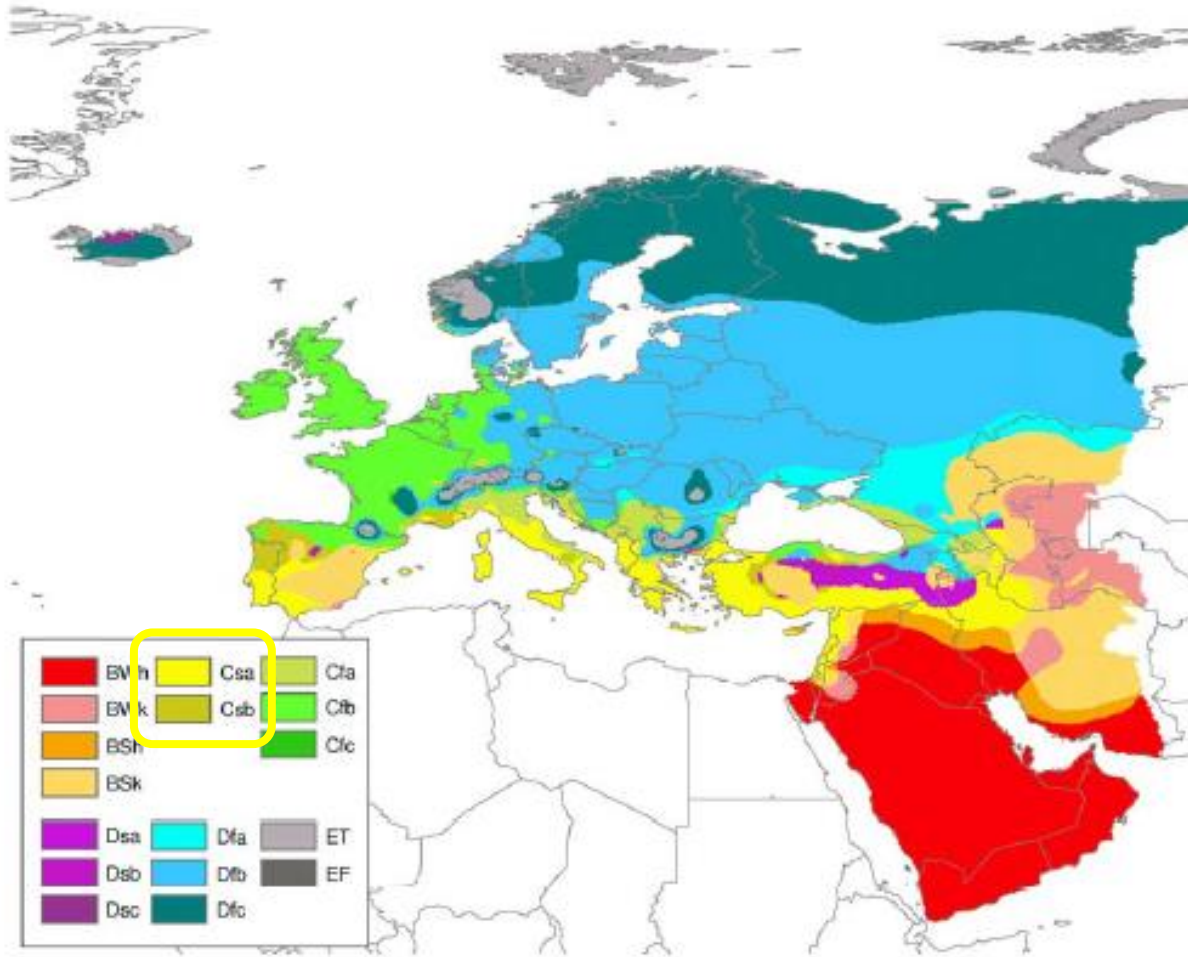
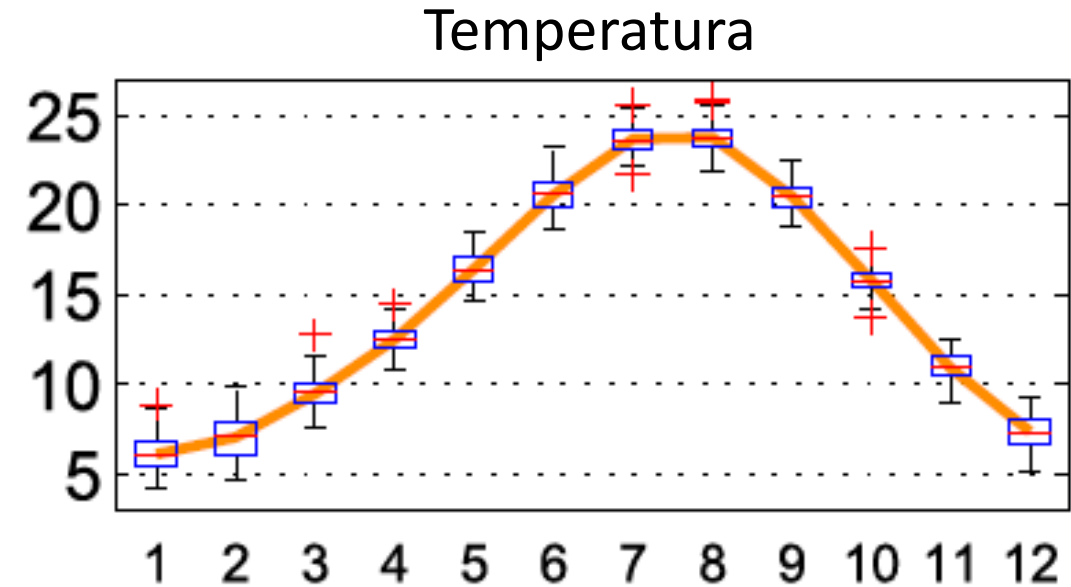
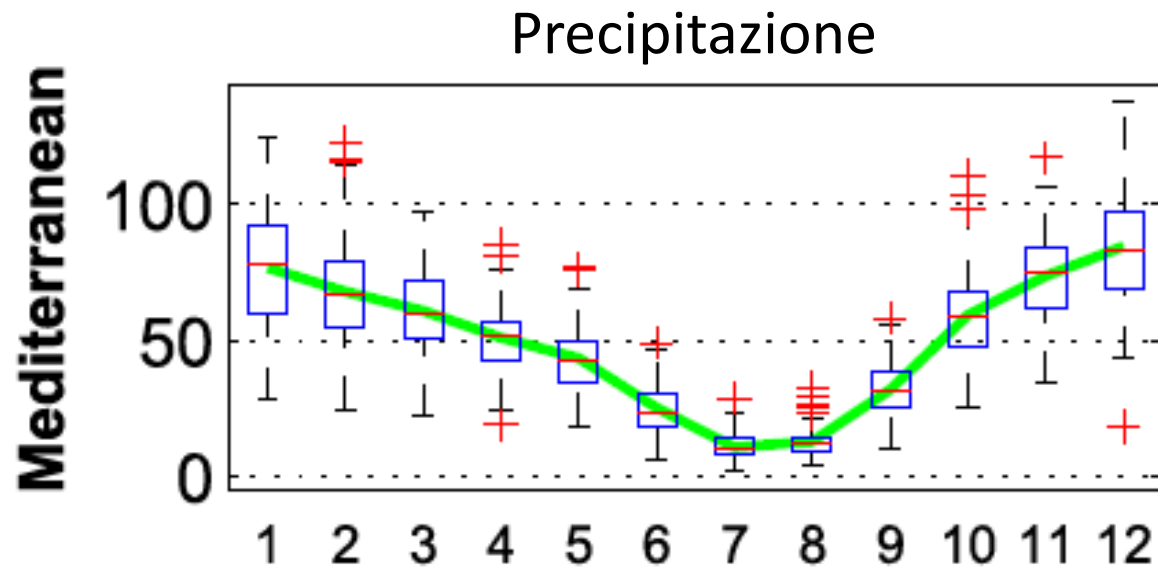


Fig. 8. Köppen-Geiger climate type map of Europe.

[Peel et al. 2007, www.hydrol-earth-syst-sci.net/11/1633/2007/]



Clima Mediterraneo

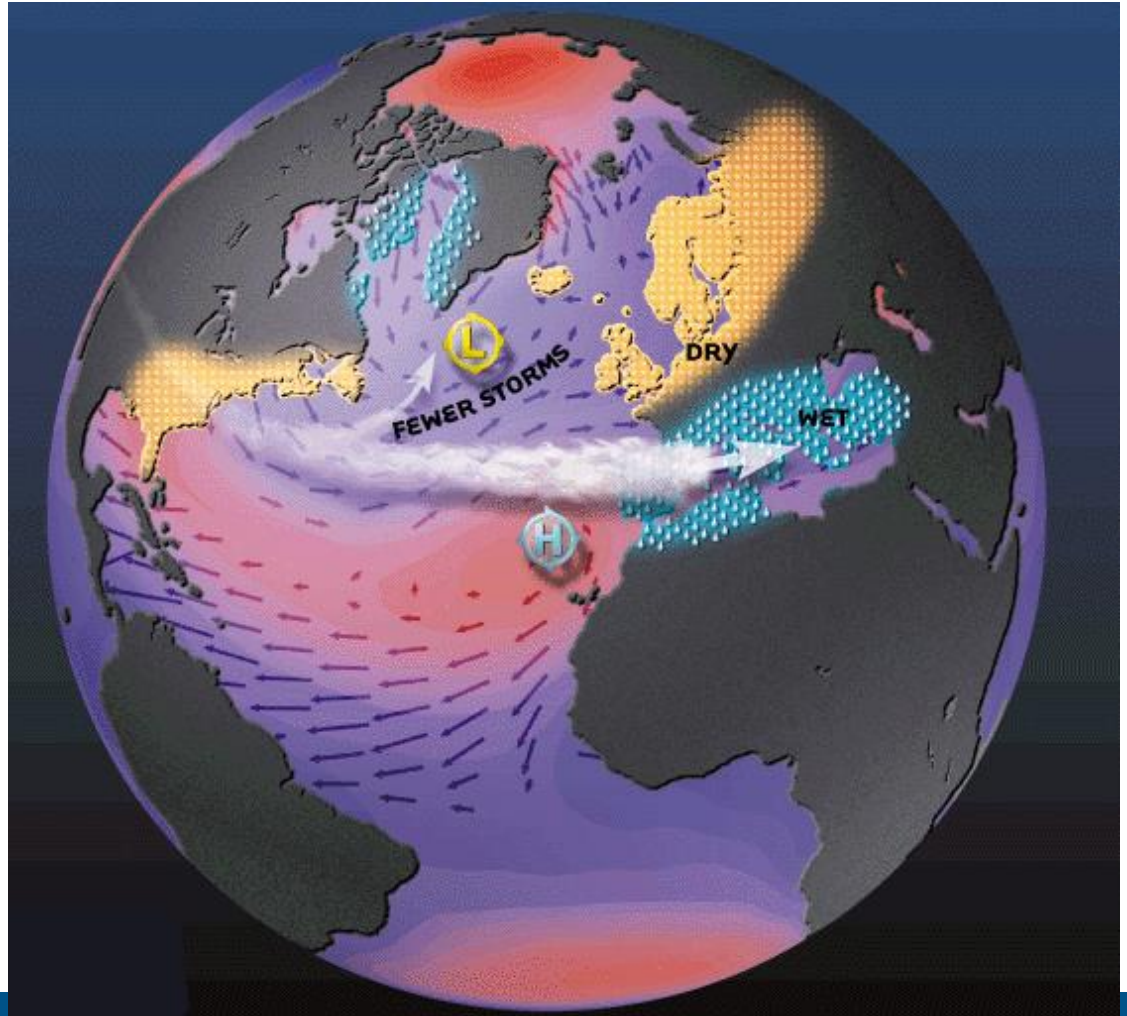
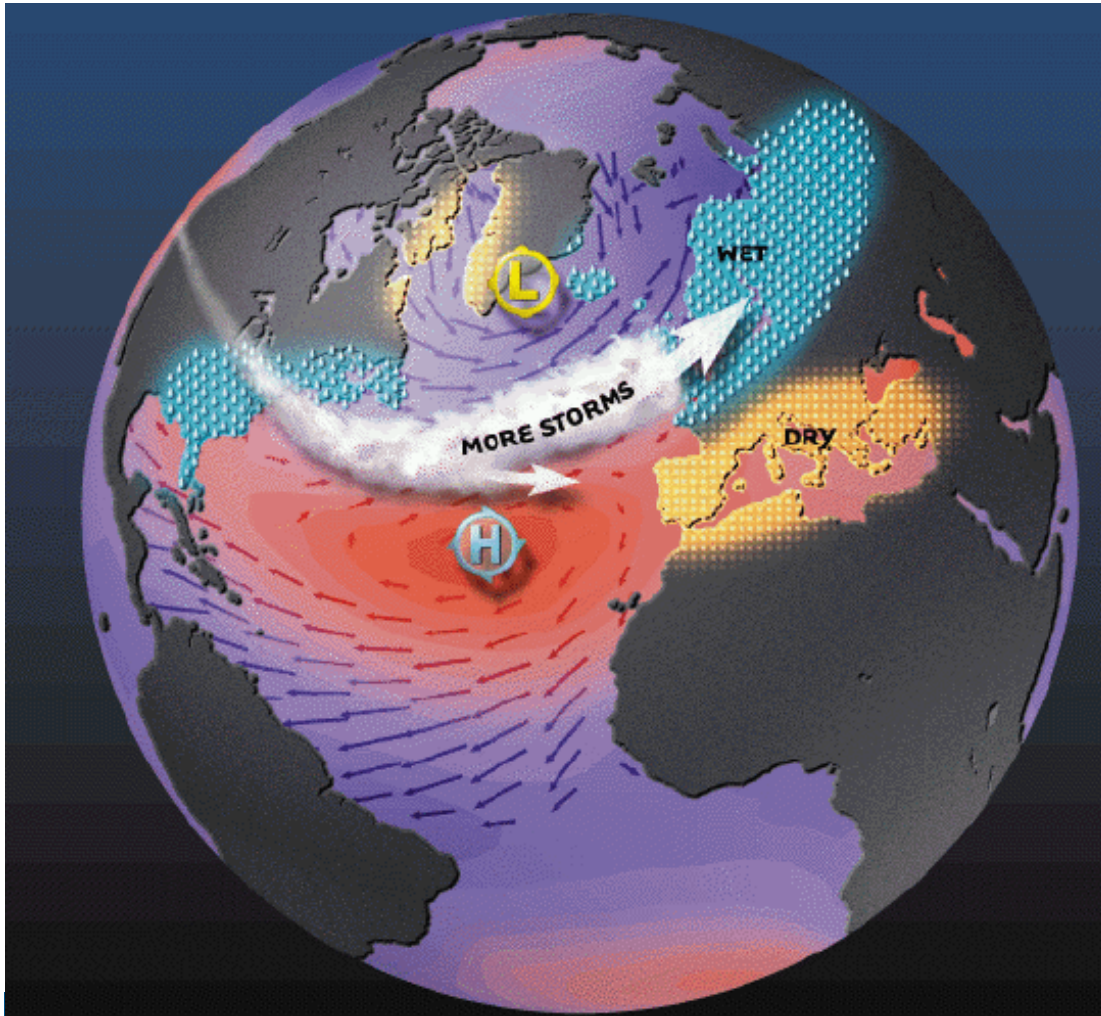


[Seager et al. (2019) <https://journals.ametsoc.org/view/journals/clim/32/10/jcli-d-18-0472.1.xml>]



Clima Mediterraneo

North Atlantic Oscillation



Clima Mediterraneo

Indian Monsoon

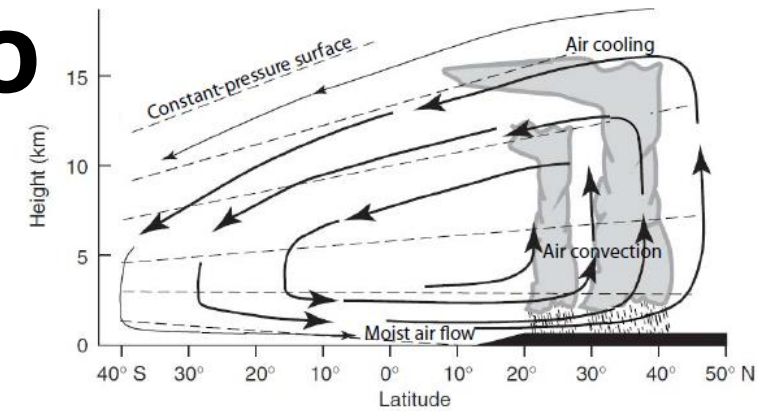
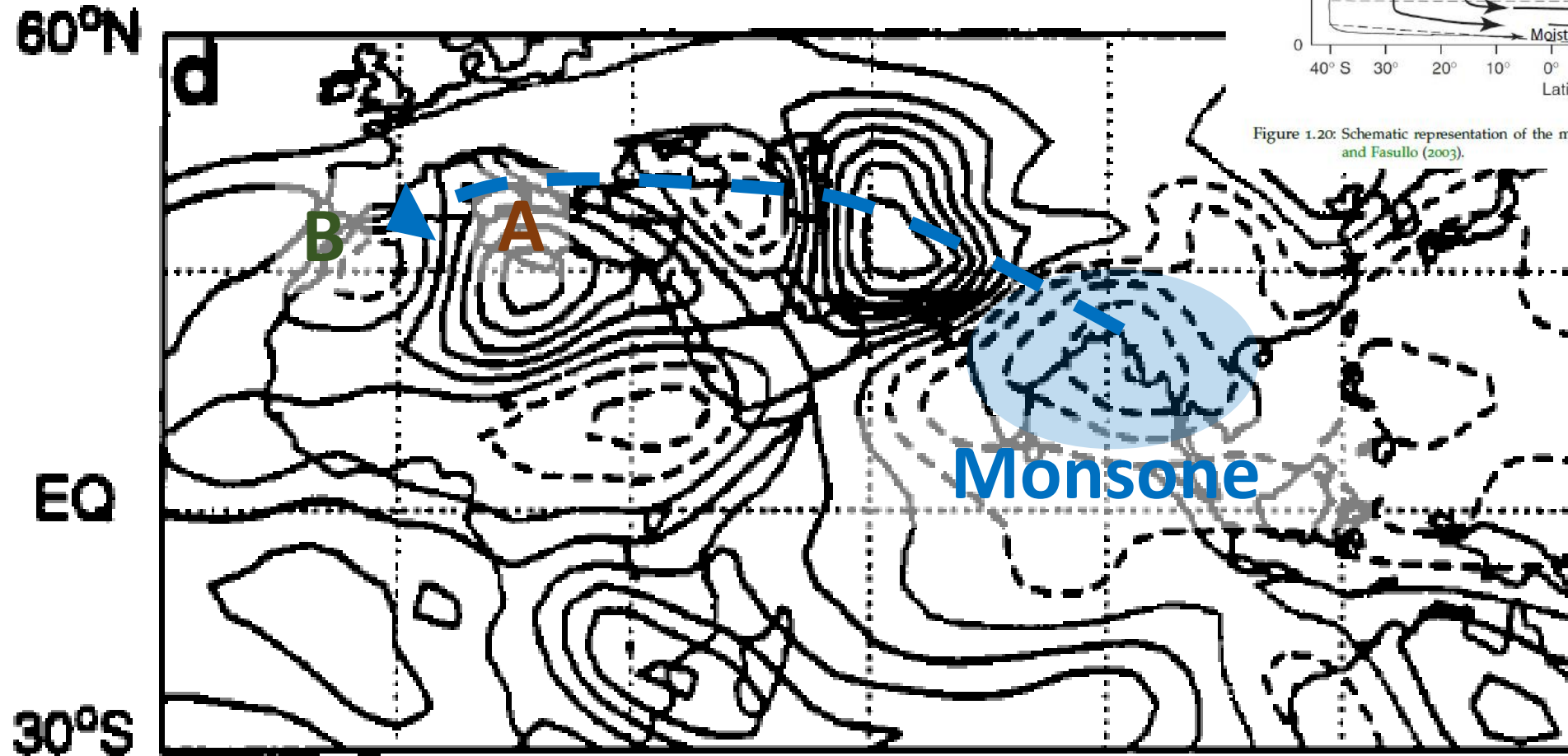
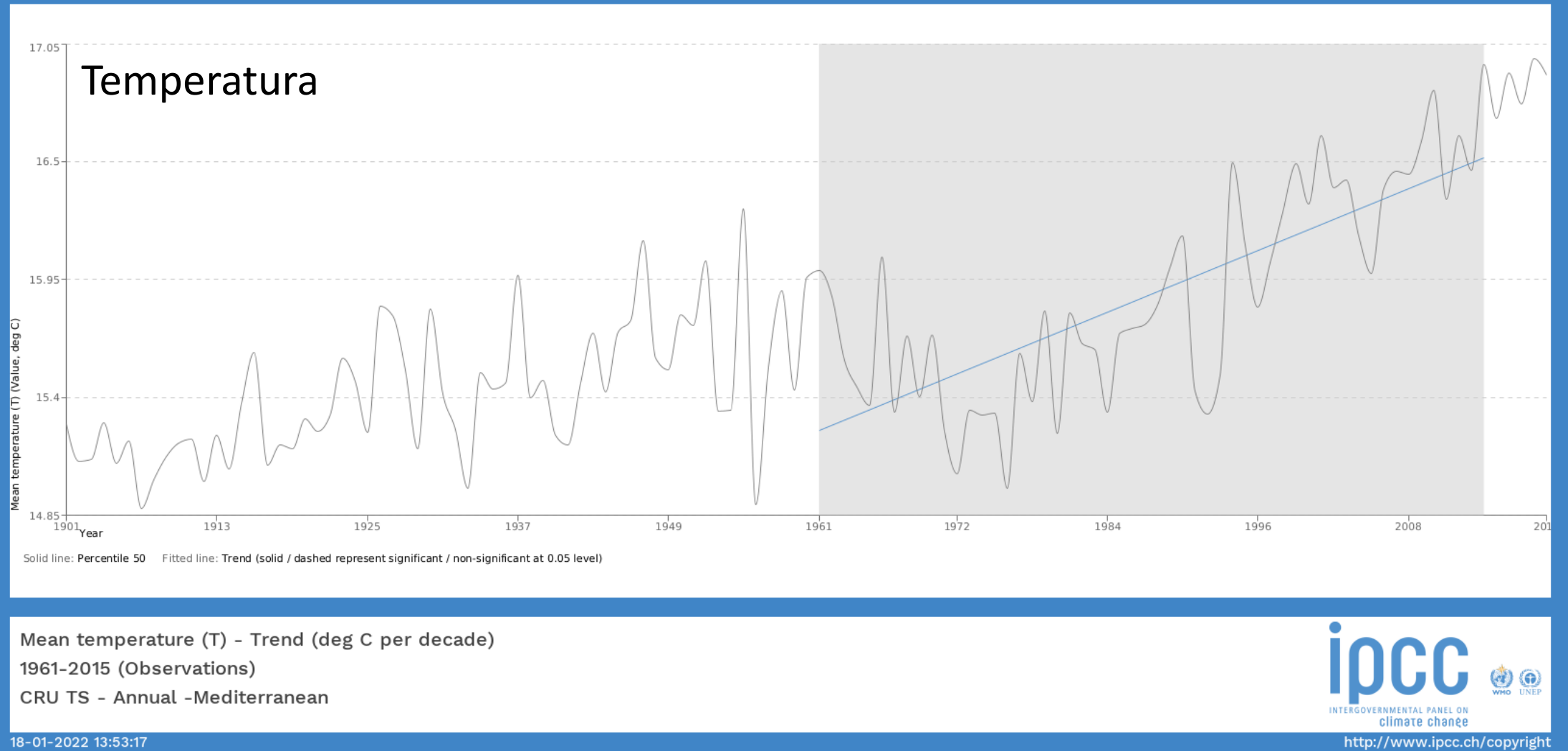


Figure 1.20: Schematic representation of the monsoon circulation. Adapted from Webster and Fasullo (2003).

Rodwell & Hoskins 1996 [<https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.49712253408>]

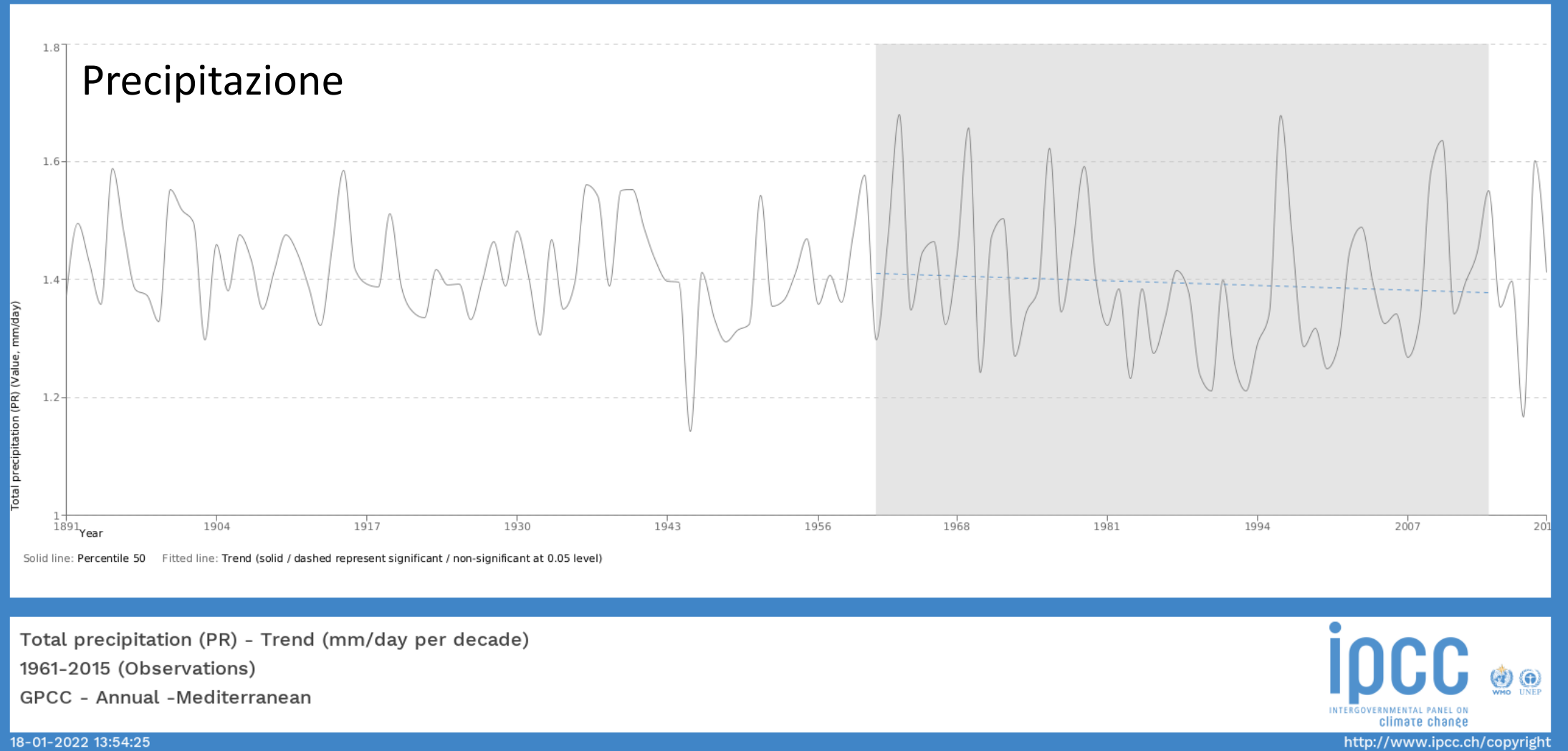


Clima Mediterraneo, in evoluzione



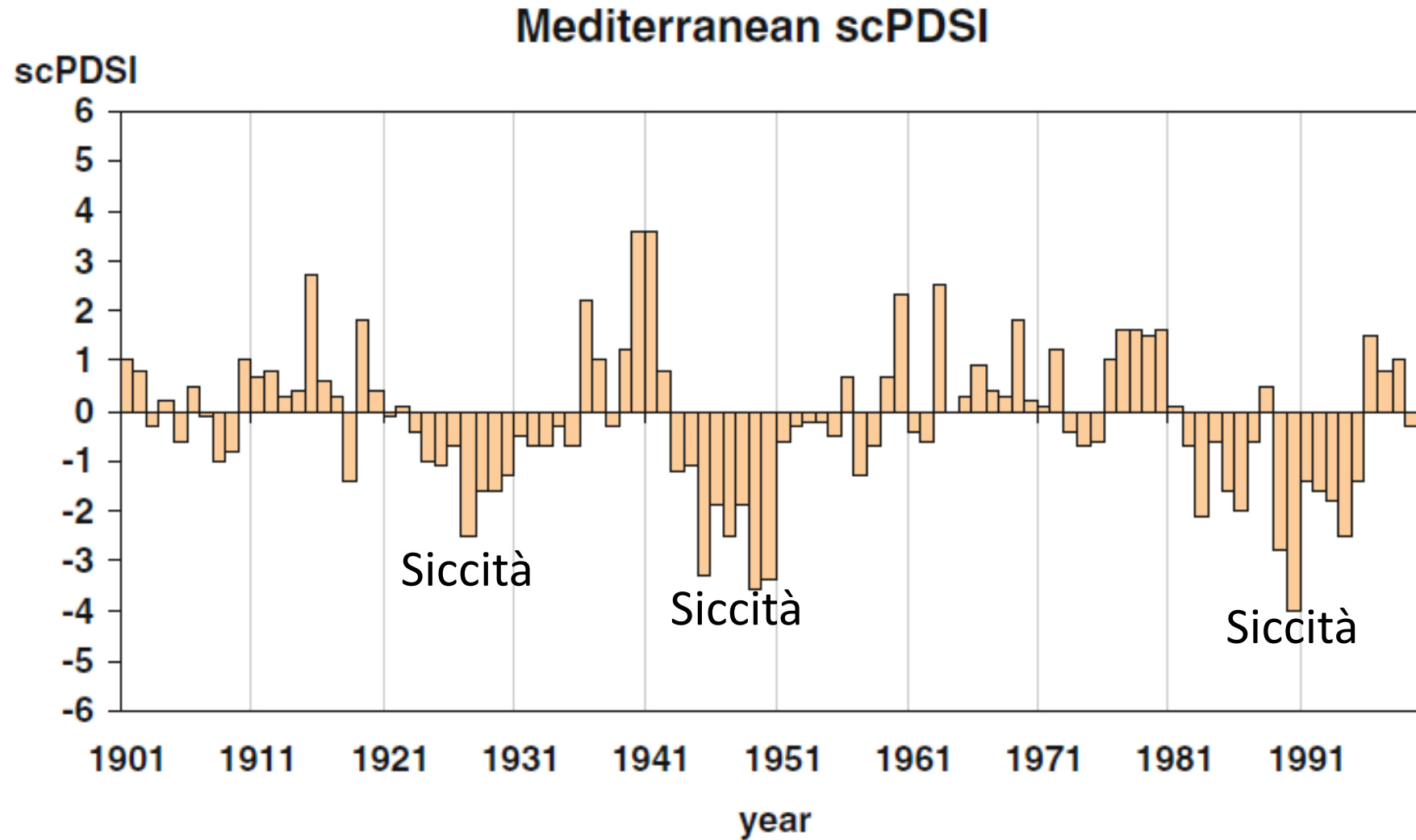
[<https://interactive-atlas.ipcc.ch/>]

Clima Mediterraneo, in evoluzione



[<https://interactive-atlas.ipcc.ch/>]

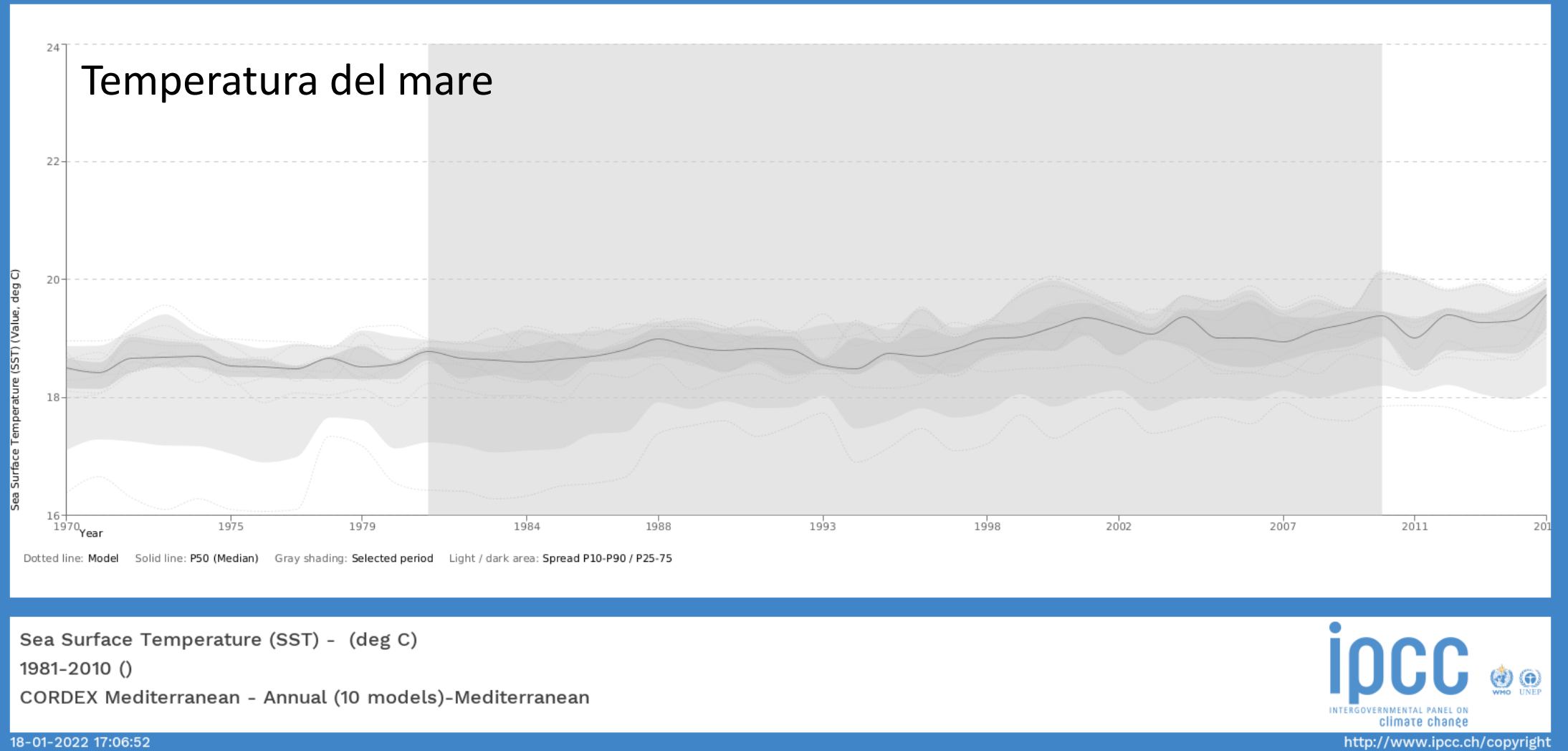
Clima Mediterraneo, in evoluzione



[Ulbrich U. et al. (2013) https://doi.org/10.1007/978-94-007-5781-3_2]



Clima Mediterraneo, in evoluzione



[<https://interactive-atlas.ipcc.ch/>]

Clima Mediterraneo, in evoluzione

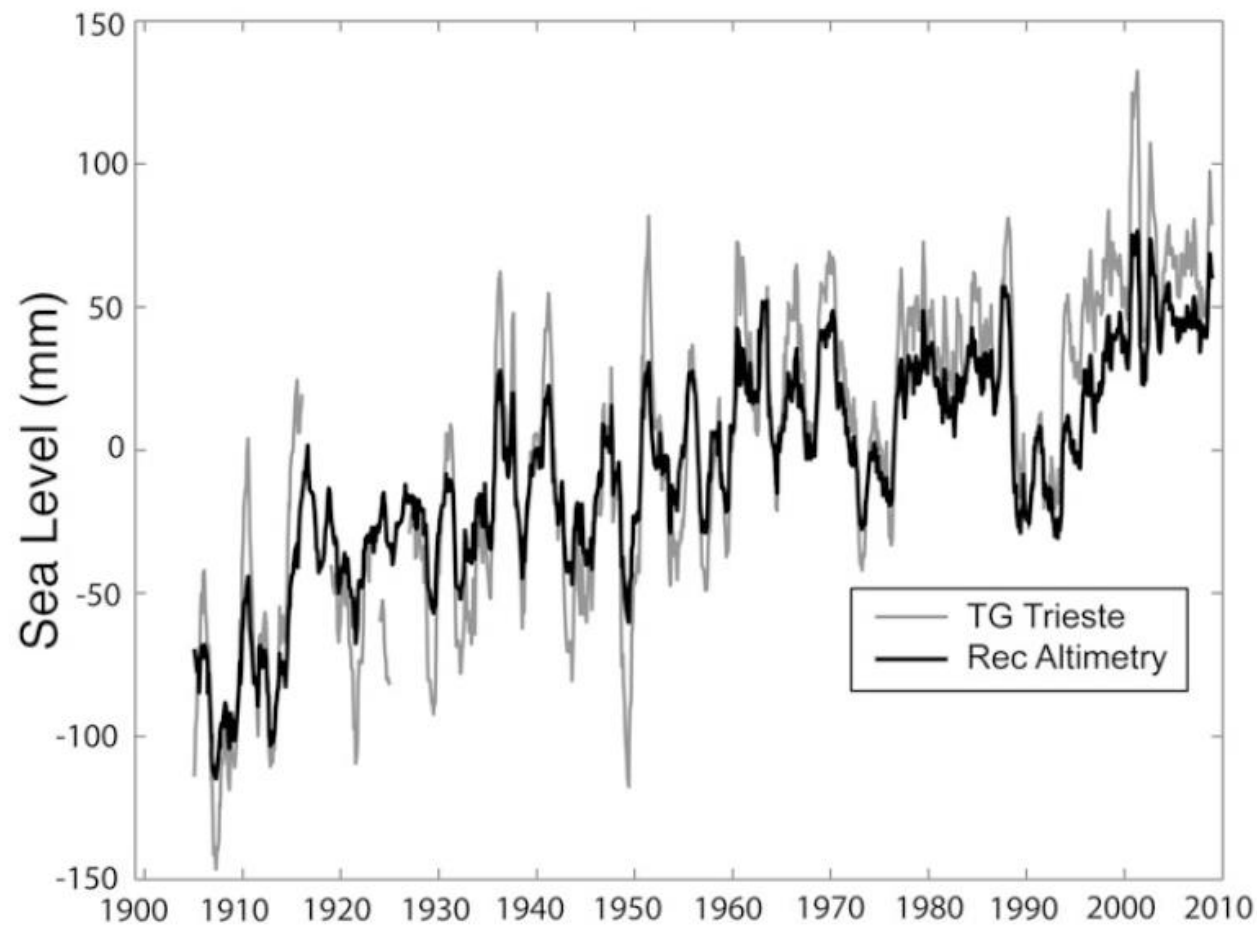


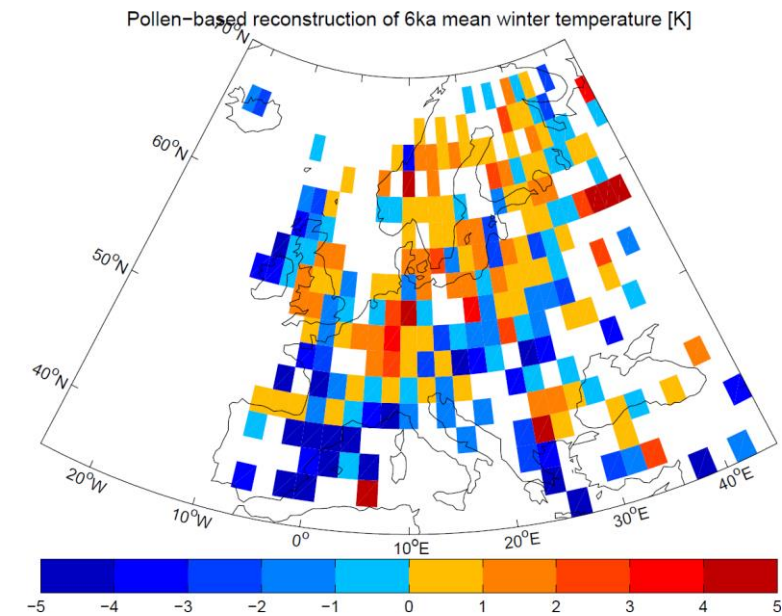
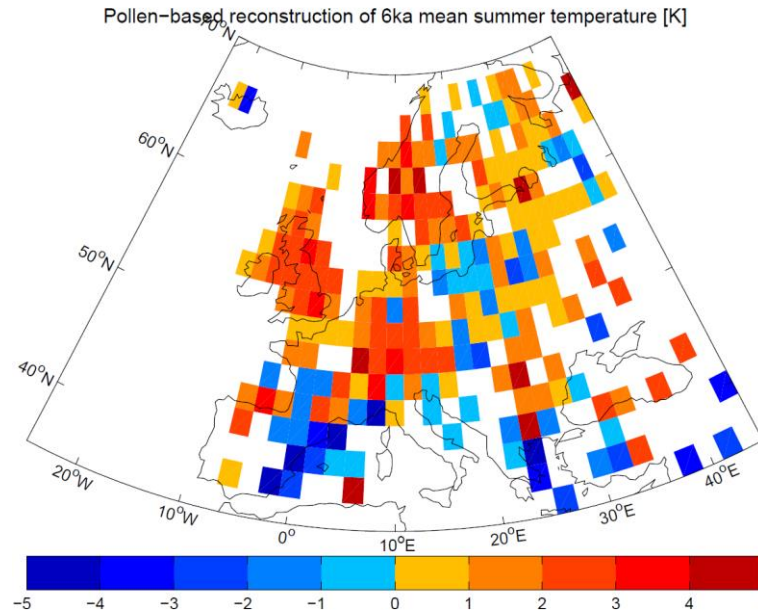
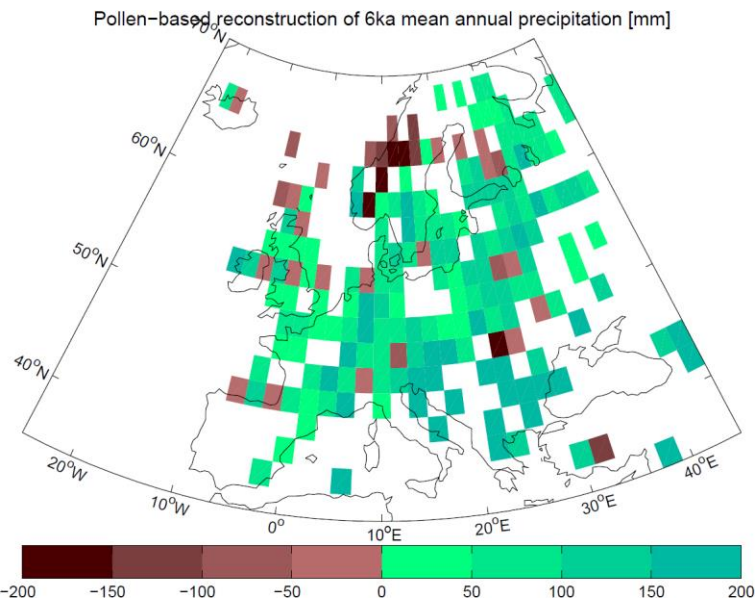
Fig. 2.7 Sea level rise in the Mediterranean from the tide-gauge in Trieste (corrected for atmospheric pressure and glacio-isostatic rebound) (*gray line*); and reconstruction of basin wide sea level from altimetry and tide gauges (*black*)

[Ulbrich U. et al. (2013) https://doi.org/10.1007/978-94-007-5781-3_2]



Cambiamenti climatici

Medio Olocene (10-5 mila anni fa)



Cambiamenti climatici



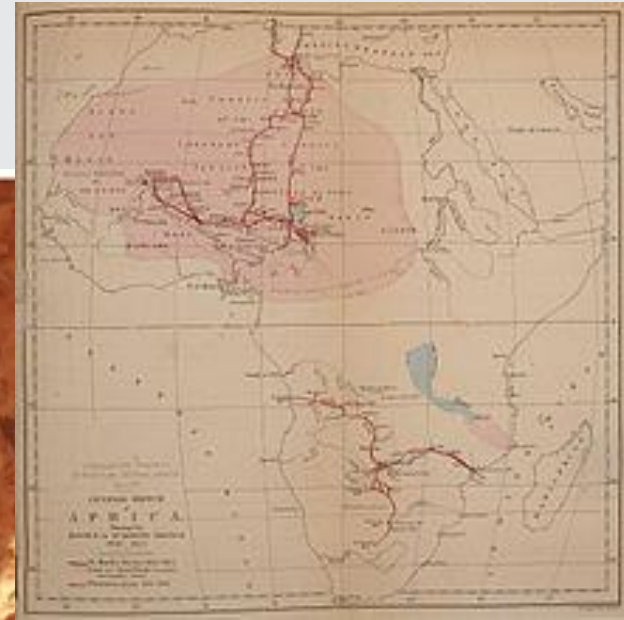
**Heinrich Barth
(1821-1865)**



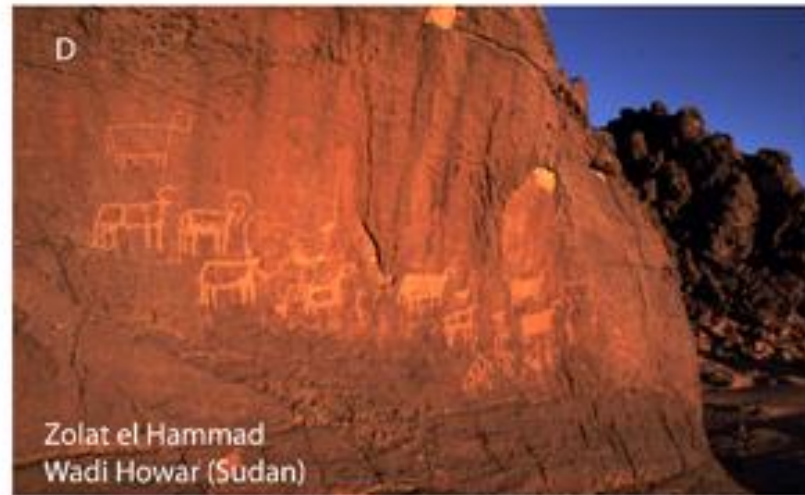
Swimmers' Cave
Wadi Sura (Egypt)



Swimmers' Cave
Wadi Sura (Egypt)



Ennedi (Chad)

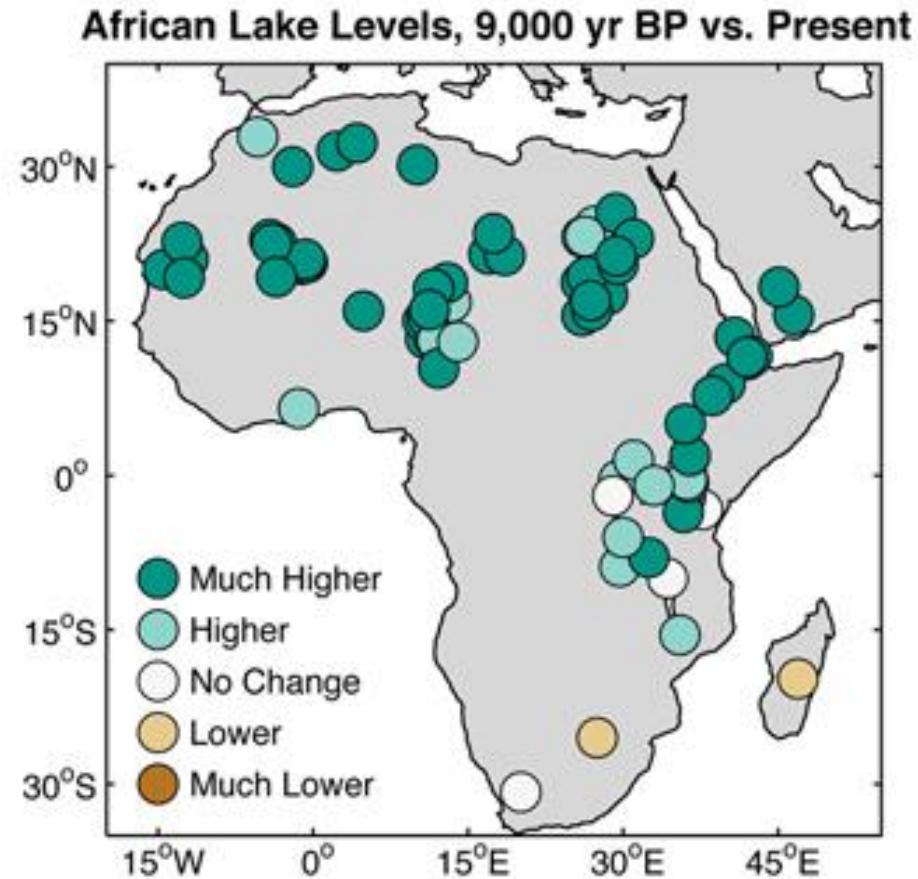


Zolat el Hammad
Wadi Howar (Sudan)



Cambiamenti climatici

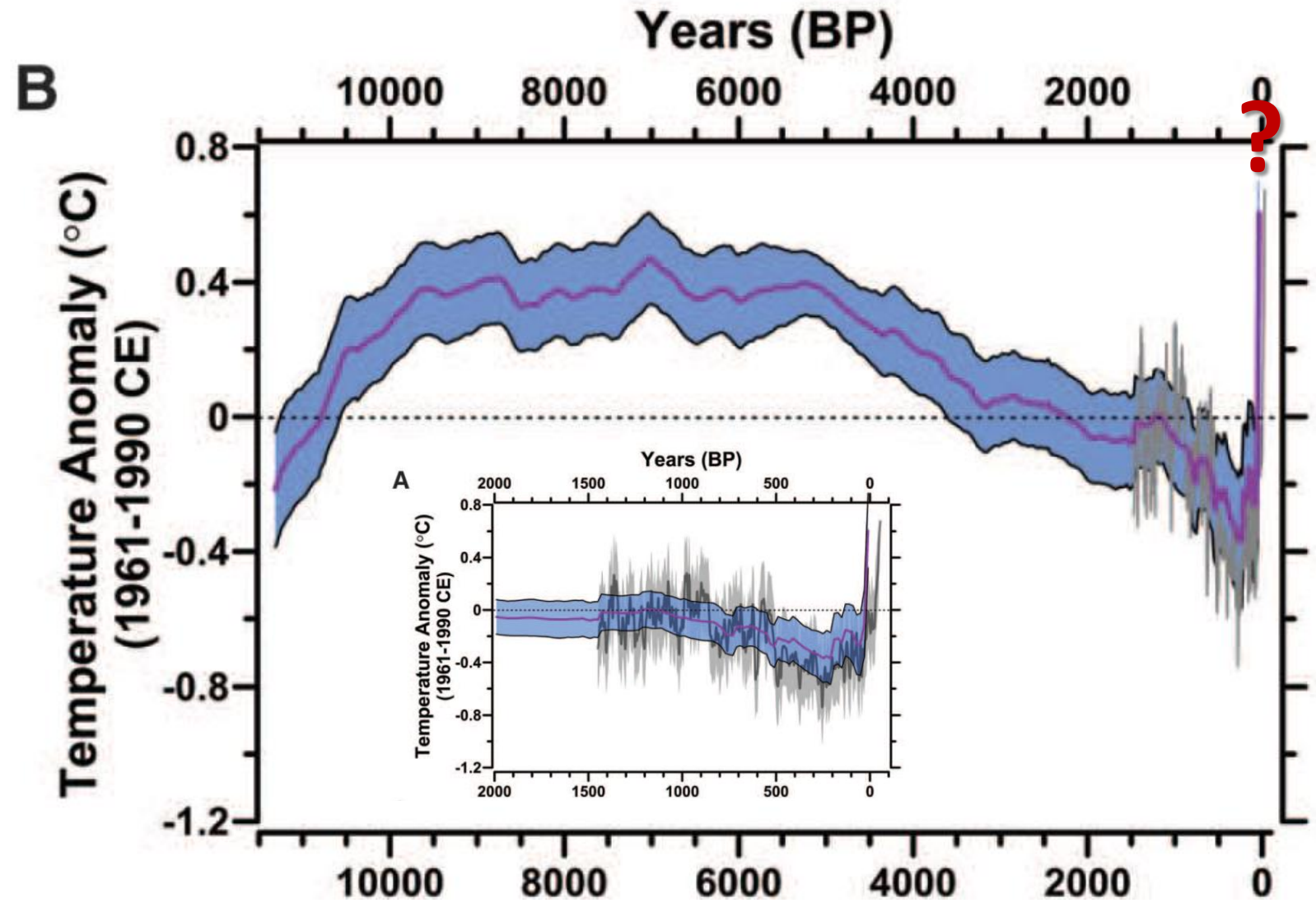
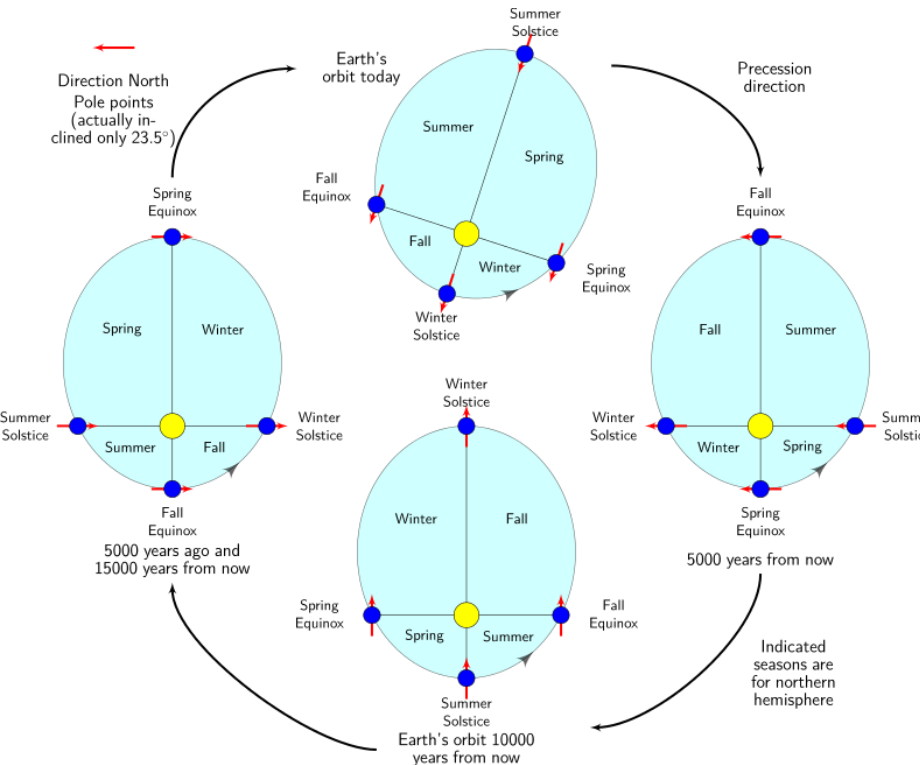
Medio Olocene (10-5 mila anni fa)



[<https://www.nature.com/scitable/knowledge/library/green-sahara-african-humid-periods-paced-by-82884405>]



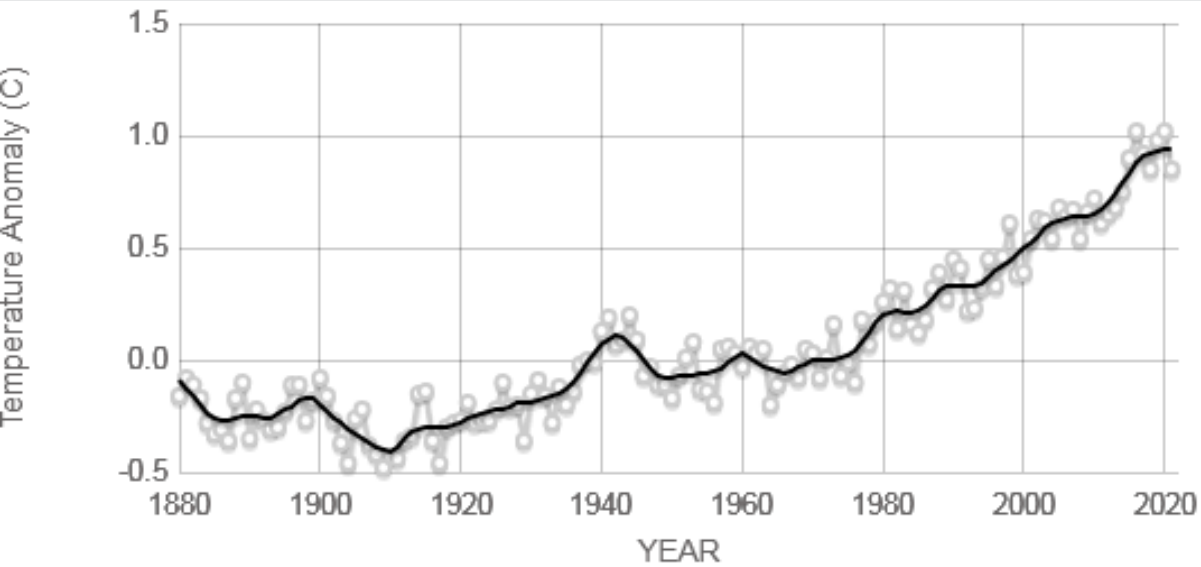
Cambiamenti climatici, cause (natural?)



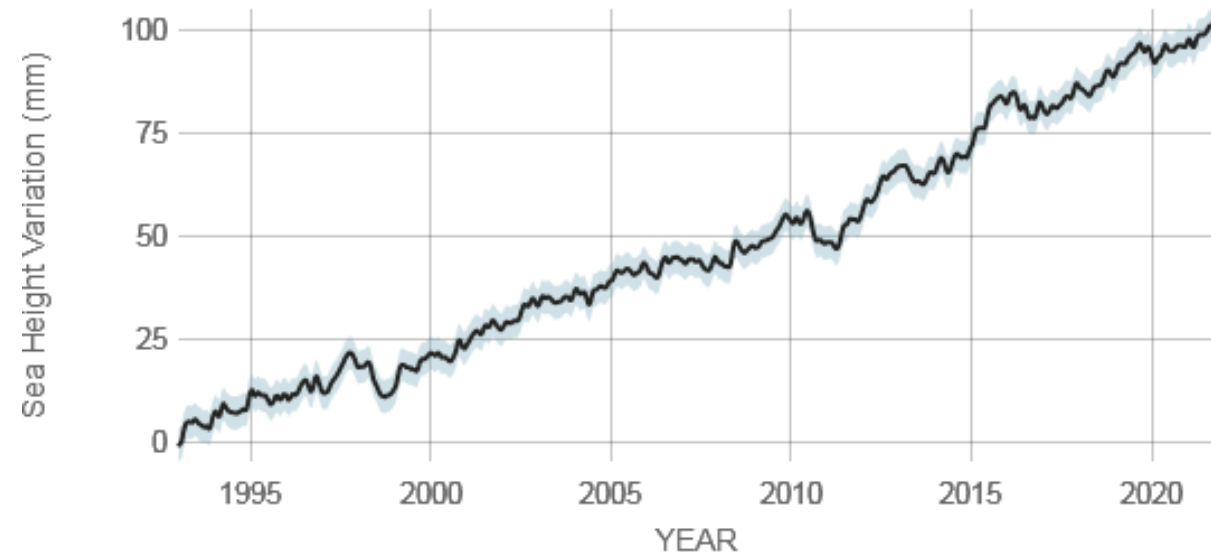
[Marcott et al. 2013, <https://www.science.org/doi/10.1126/science.1228026>]



Cambiamenti climatici, cause (naturali?)



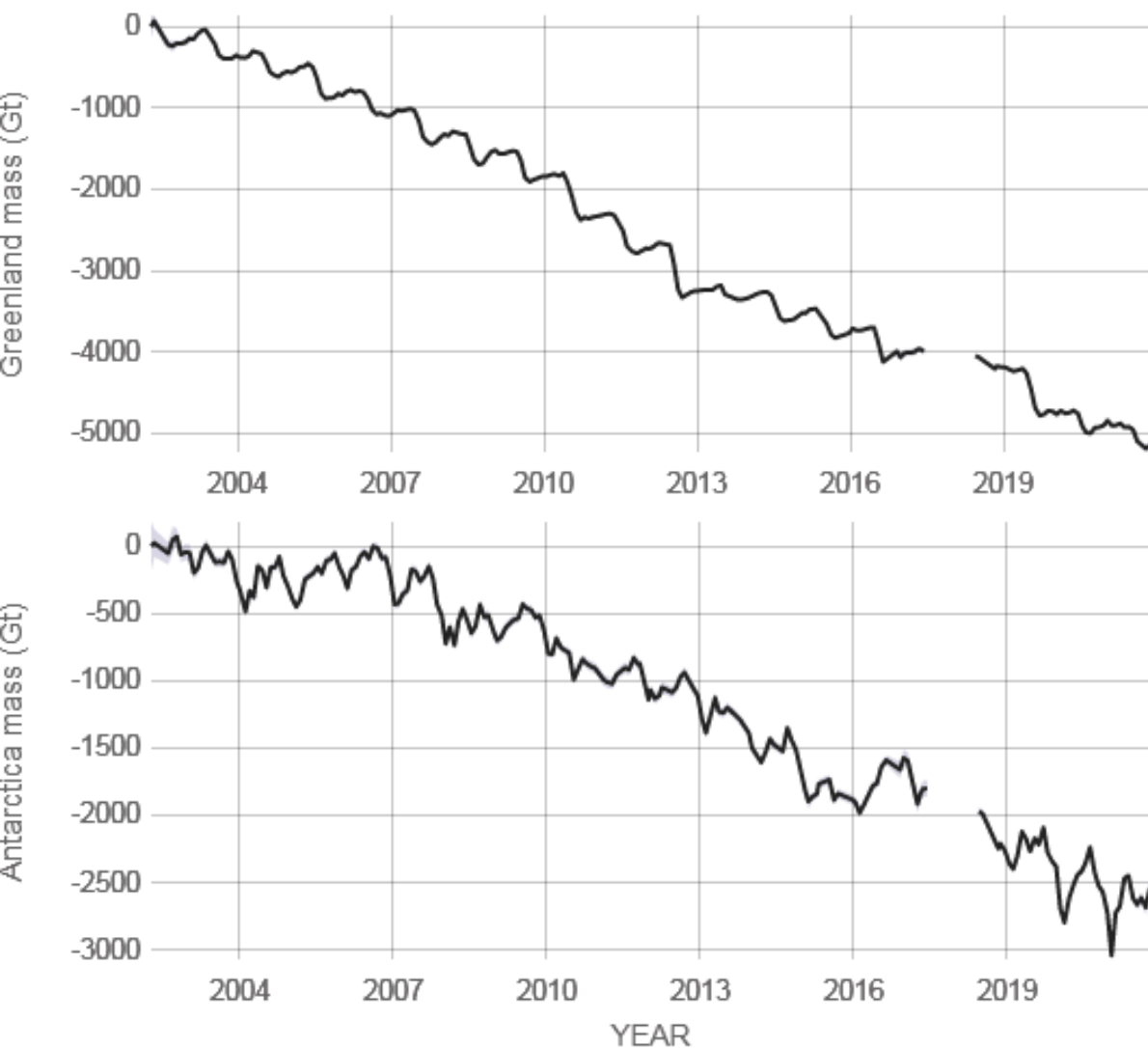
Source: climate.nasa.gov



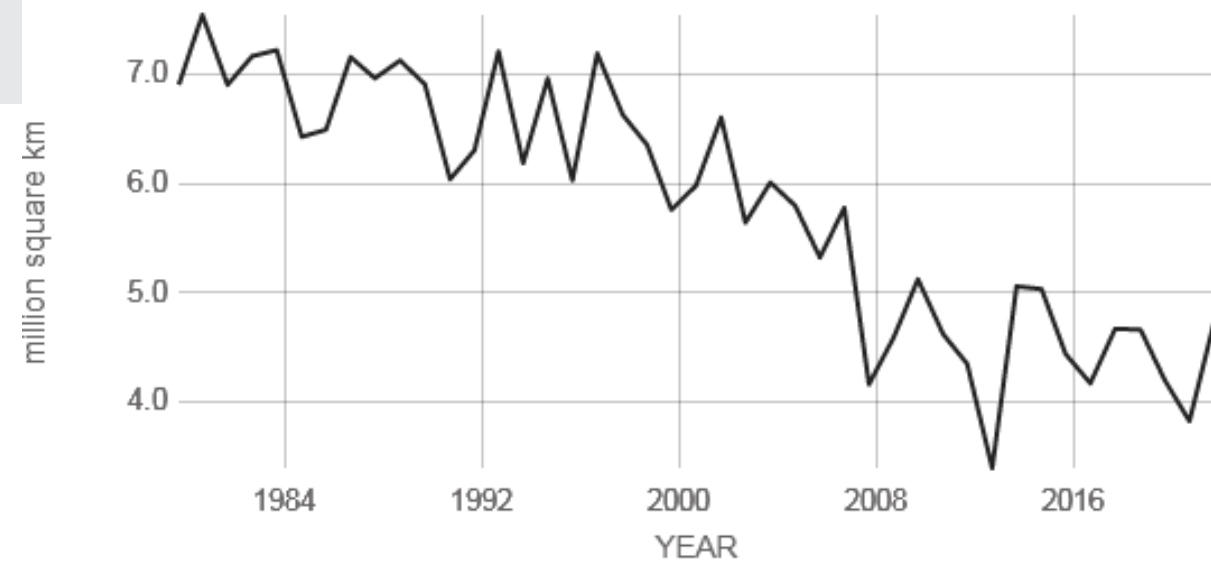
Source: climate.nasa.gov



Cambiamenti climatici, cause (naturali?)



Source: climate.nasa.gov



Source: climate.nasa.gov

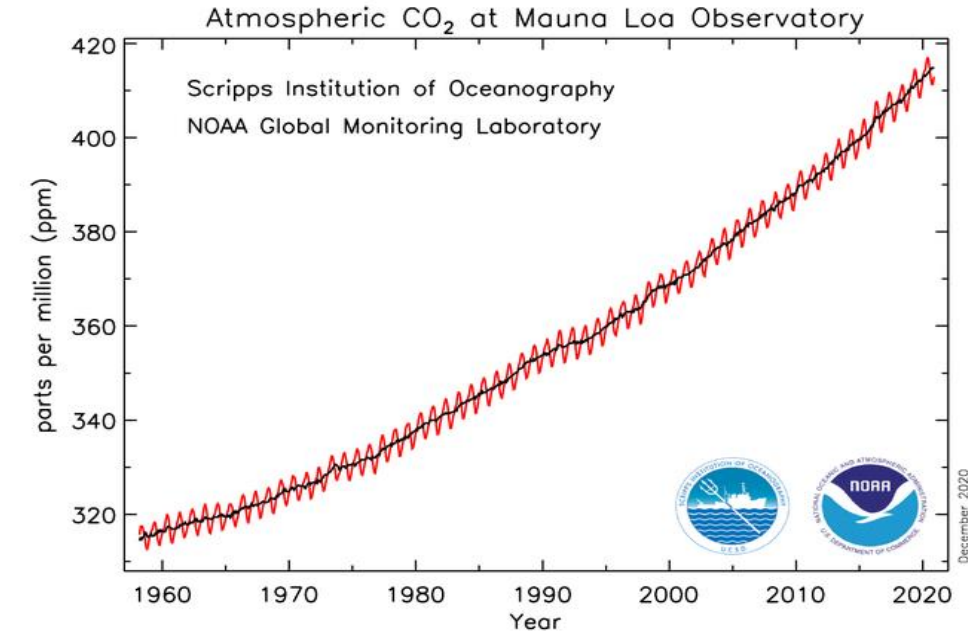
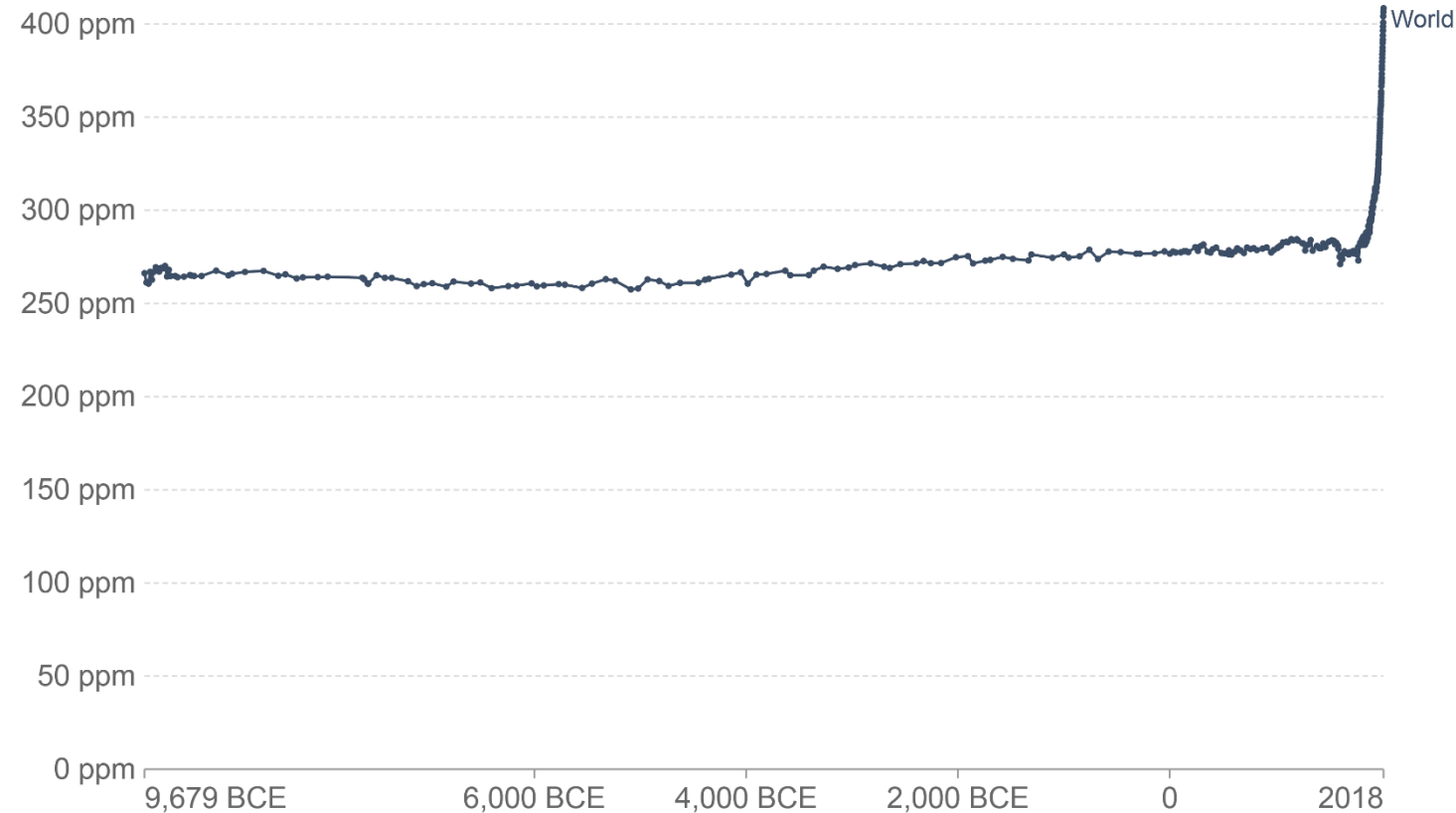


Cambiamenti climatici, cause (naturali?)

Atmospheric CO₂ concentration

Global average long-term atmospheric concentration of carbon dioxide (CO₂), measured in parts per million (ppm). Long-term trends in CO₂ concentrations can be measured at high-resolution using preserved air samples from ice cores.

Our World
in Data



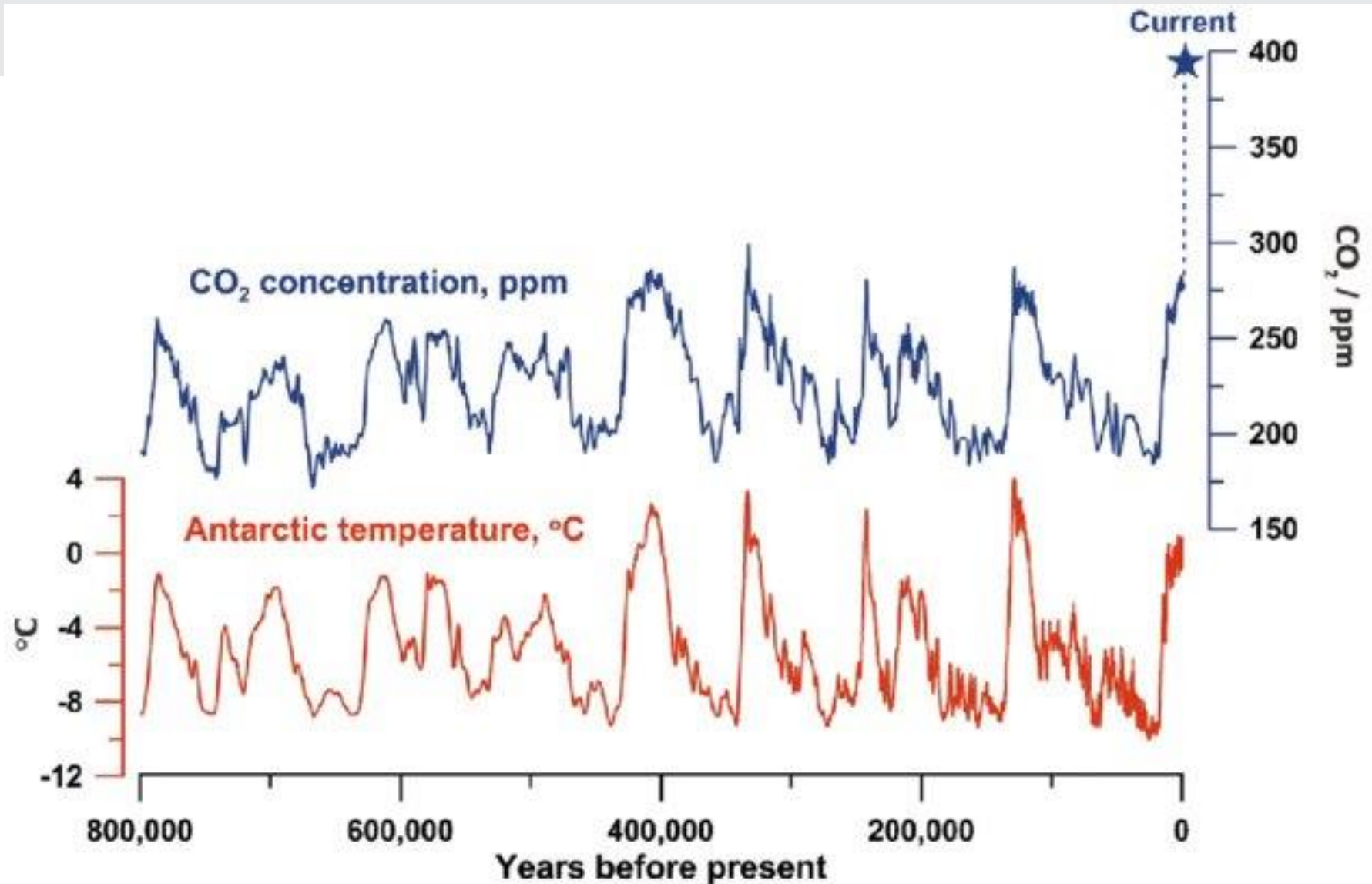
Source: EPICA Dome C CO₂ record (2015) & NOAA (2018)

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

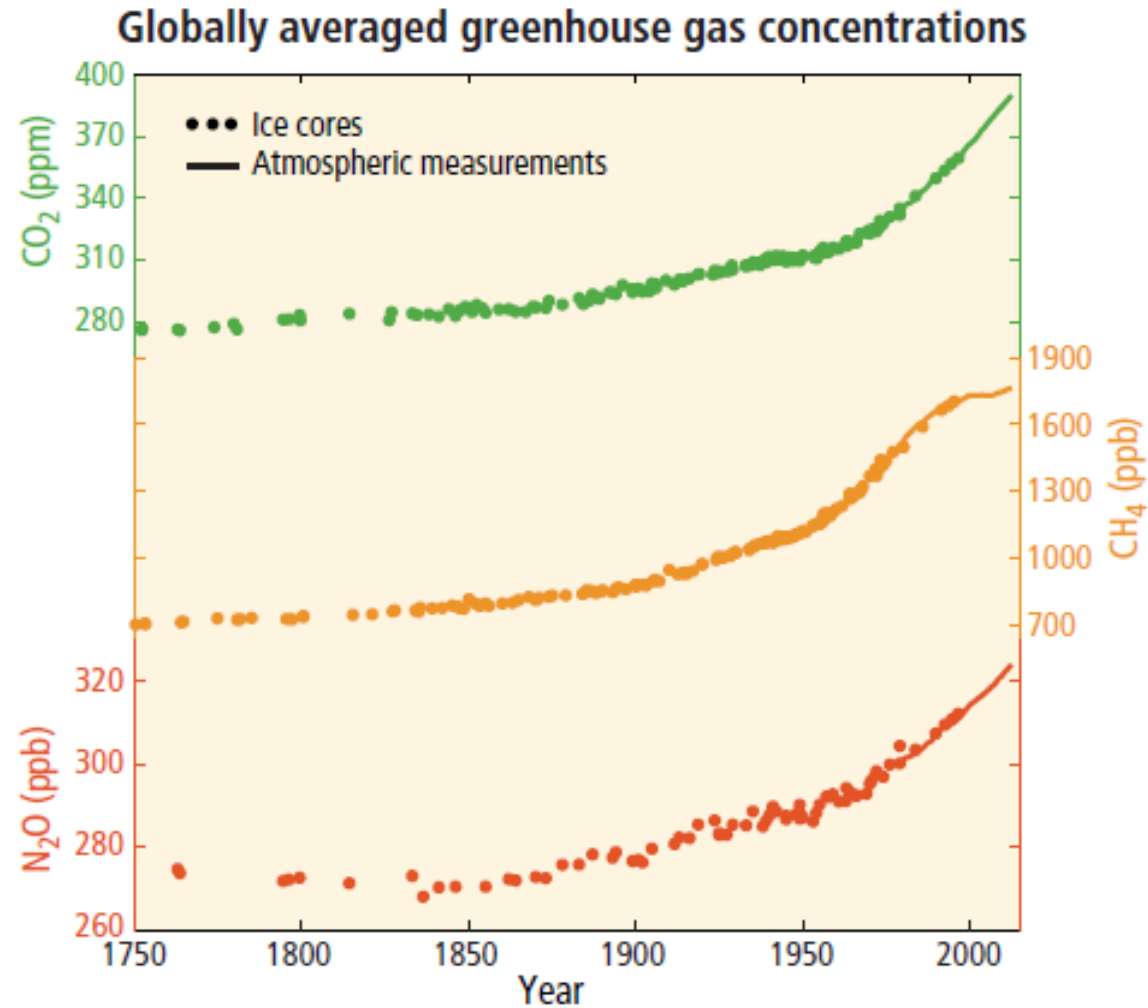
<https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>



Cambiamenti climatici, cause (naturali?)



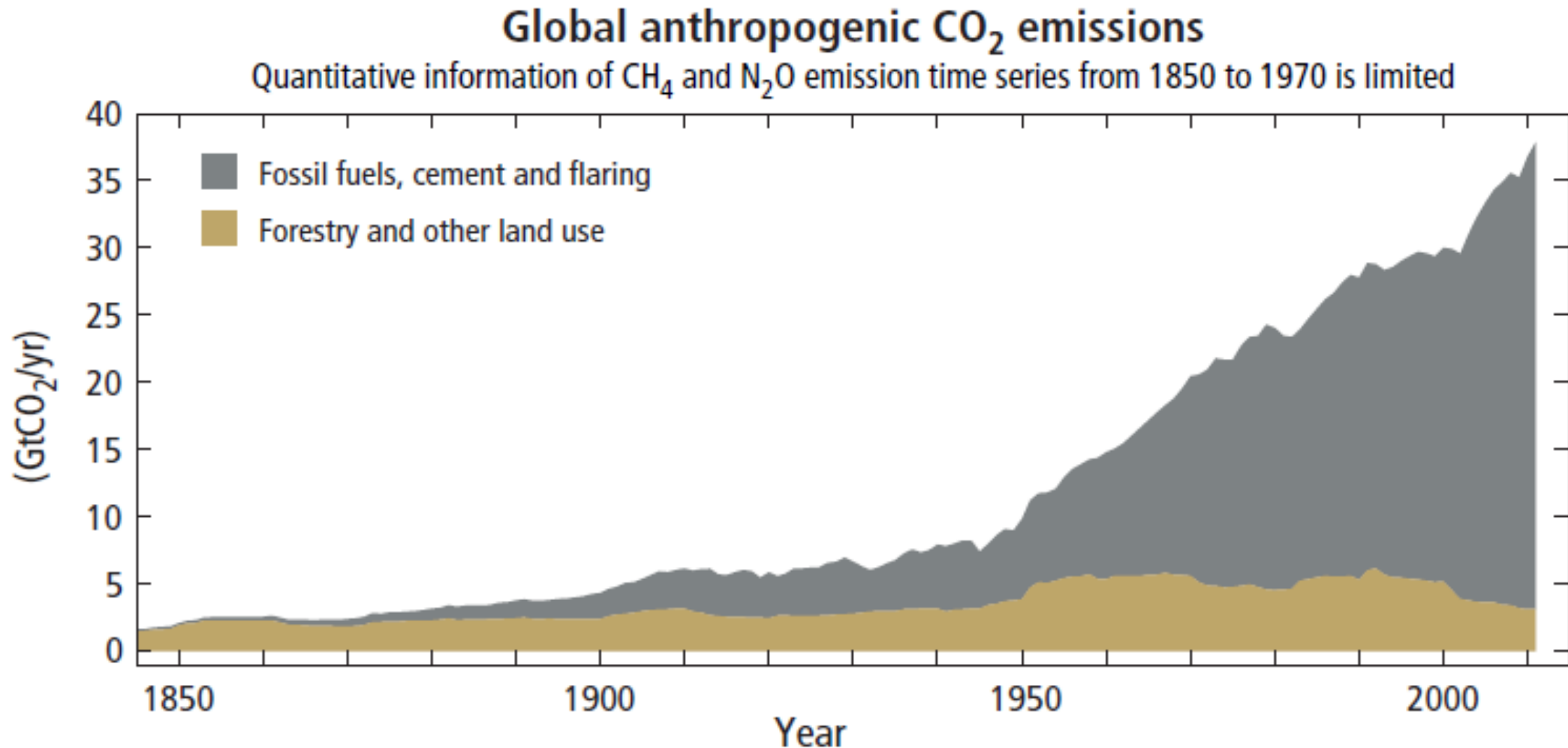
Cambiamenti climatici e attività umane



[<https://www.ipcc.ch/report/ar5/syr/>]



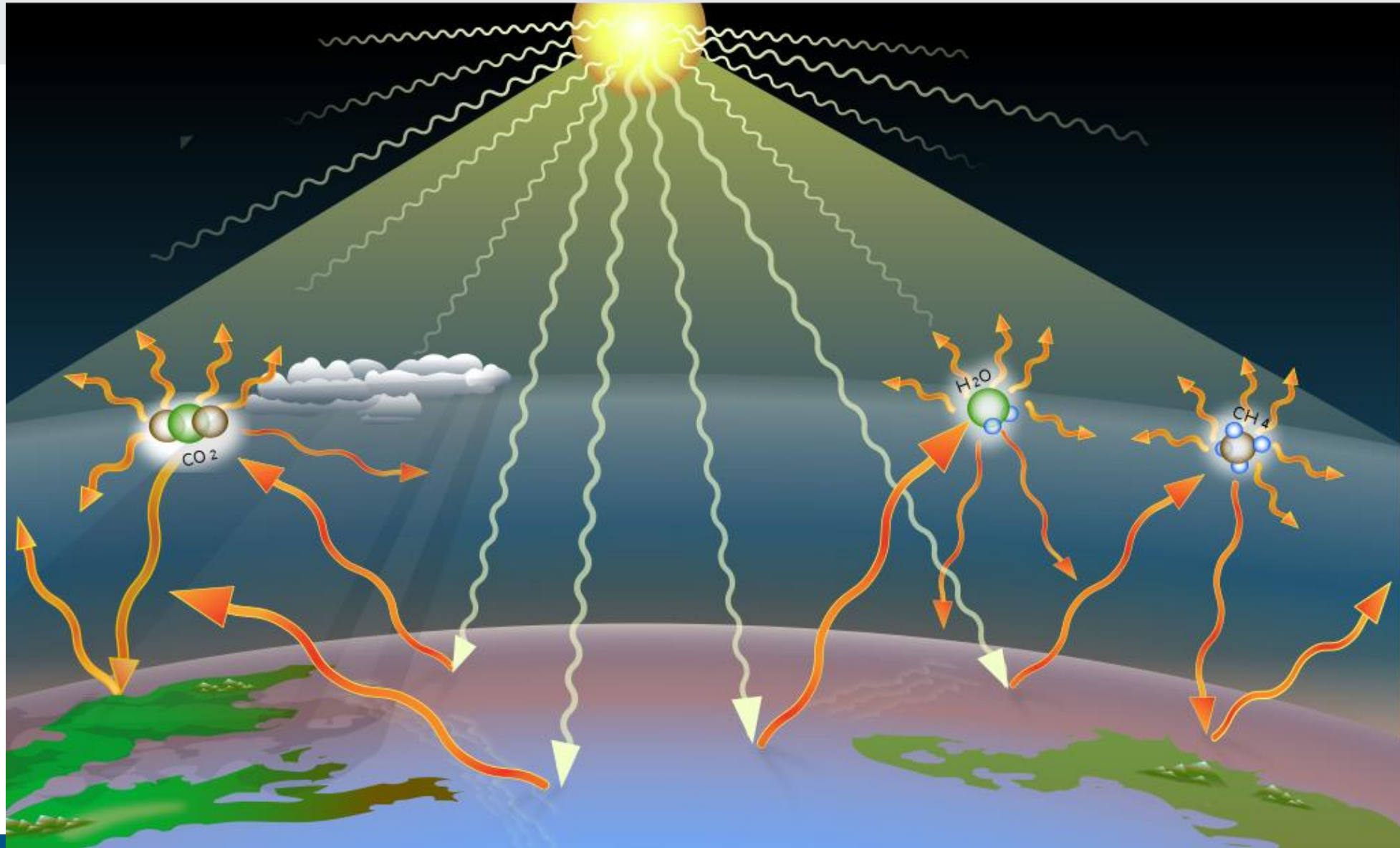
Cambiamenti climatici e attività umane



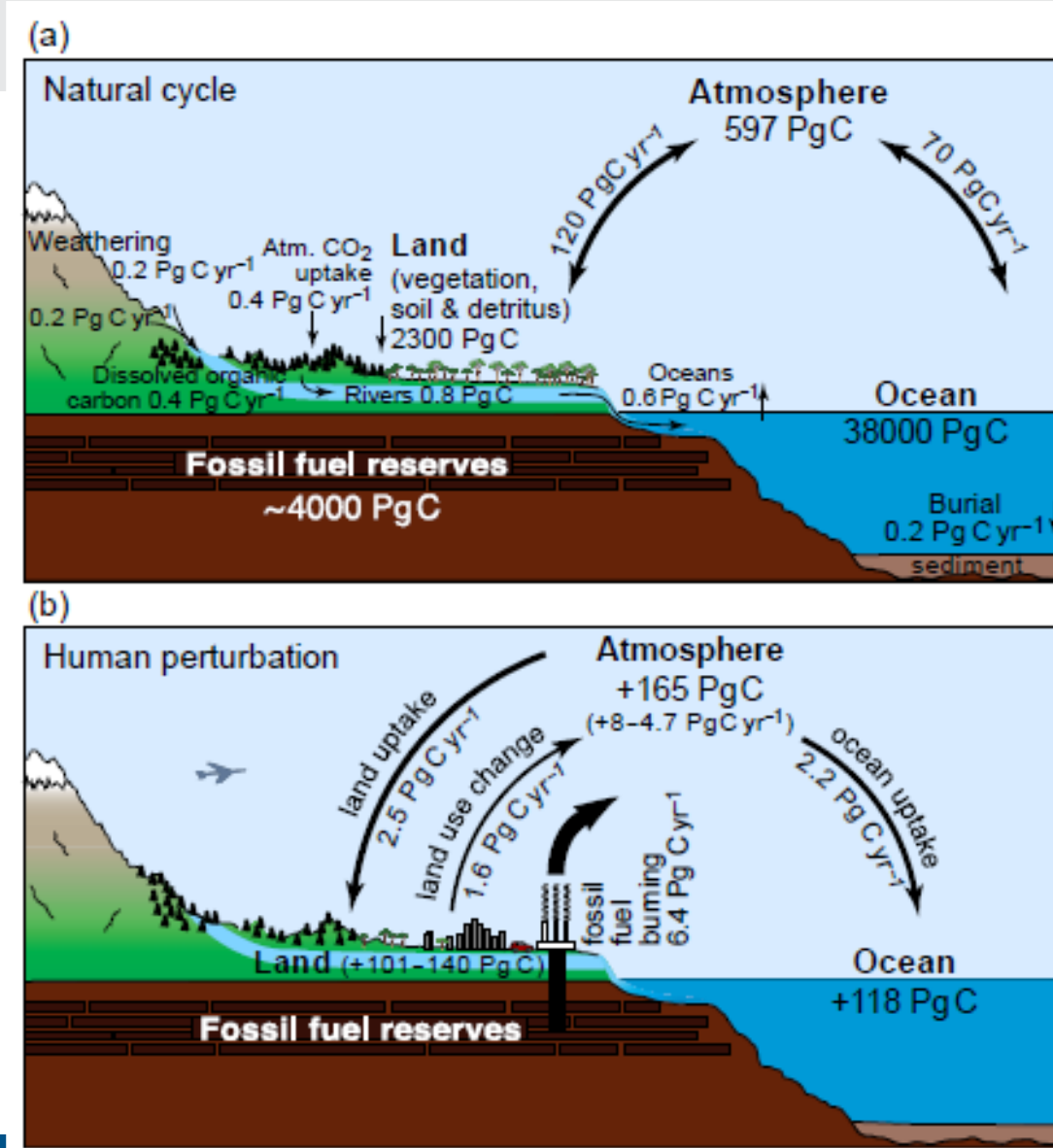
[<https://www.ipcc.ch/report/ar5/syr/>]



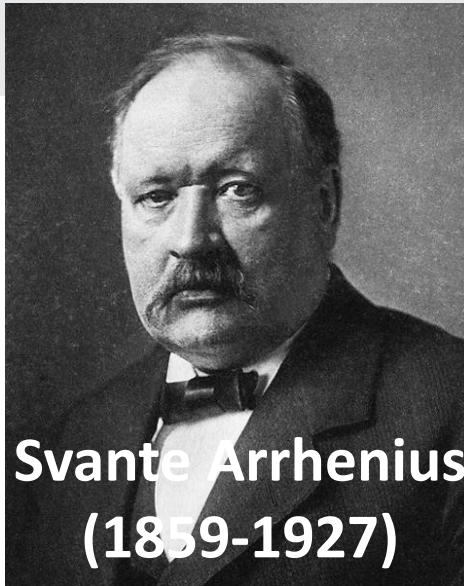
Effetto Serra



Ciclo del carbonio ed effetto serra

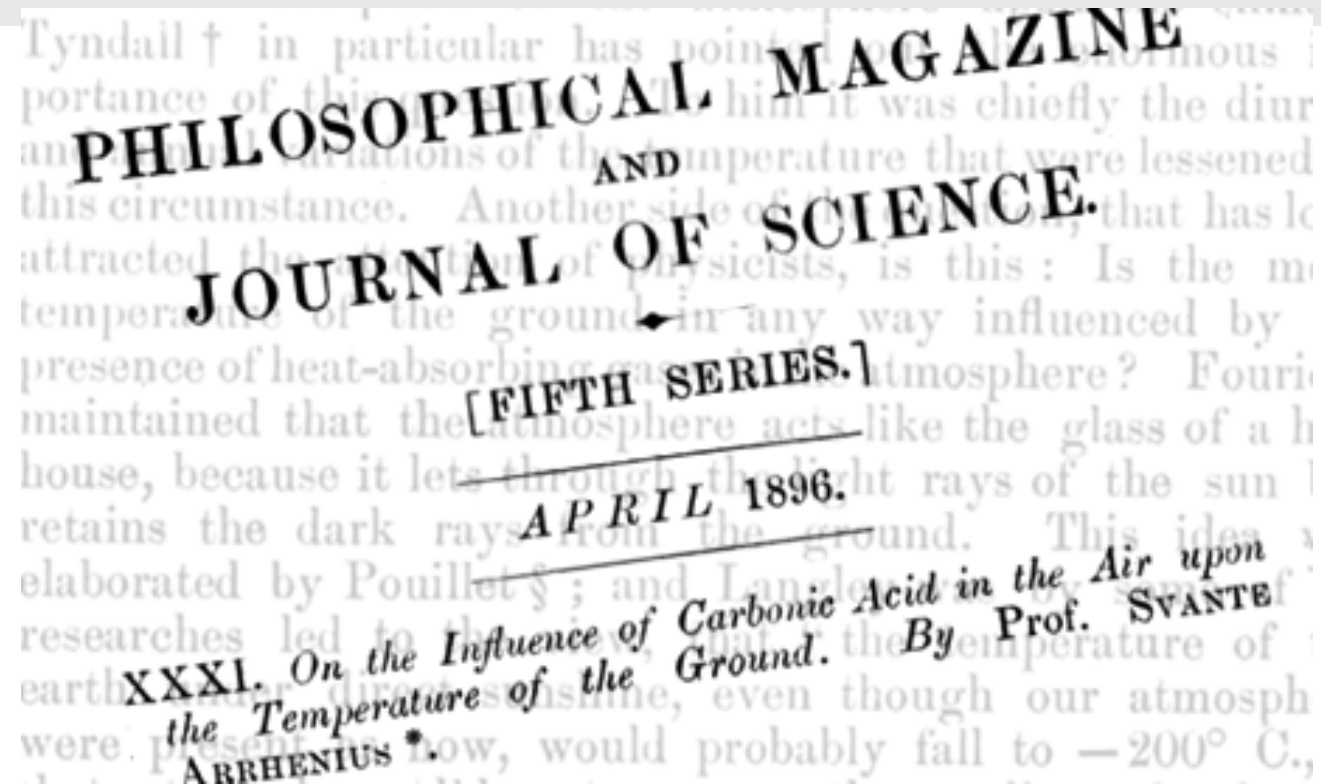


Effetto serra, una vecchia storia



Svante Arrhenius
(1859-1927)

Relative CO ₂	Relative Temperature (°C)
.67	-3.19
1.5	+3.42
2.0	+5.49
2.5	+7.16
3.0	+8.40



Legge di Stefan-Boltzmann

$$(1 - a) S \pi r^2 = 4 \pi r^2 \epsilon \sigma T^4$$

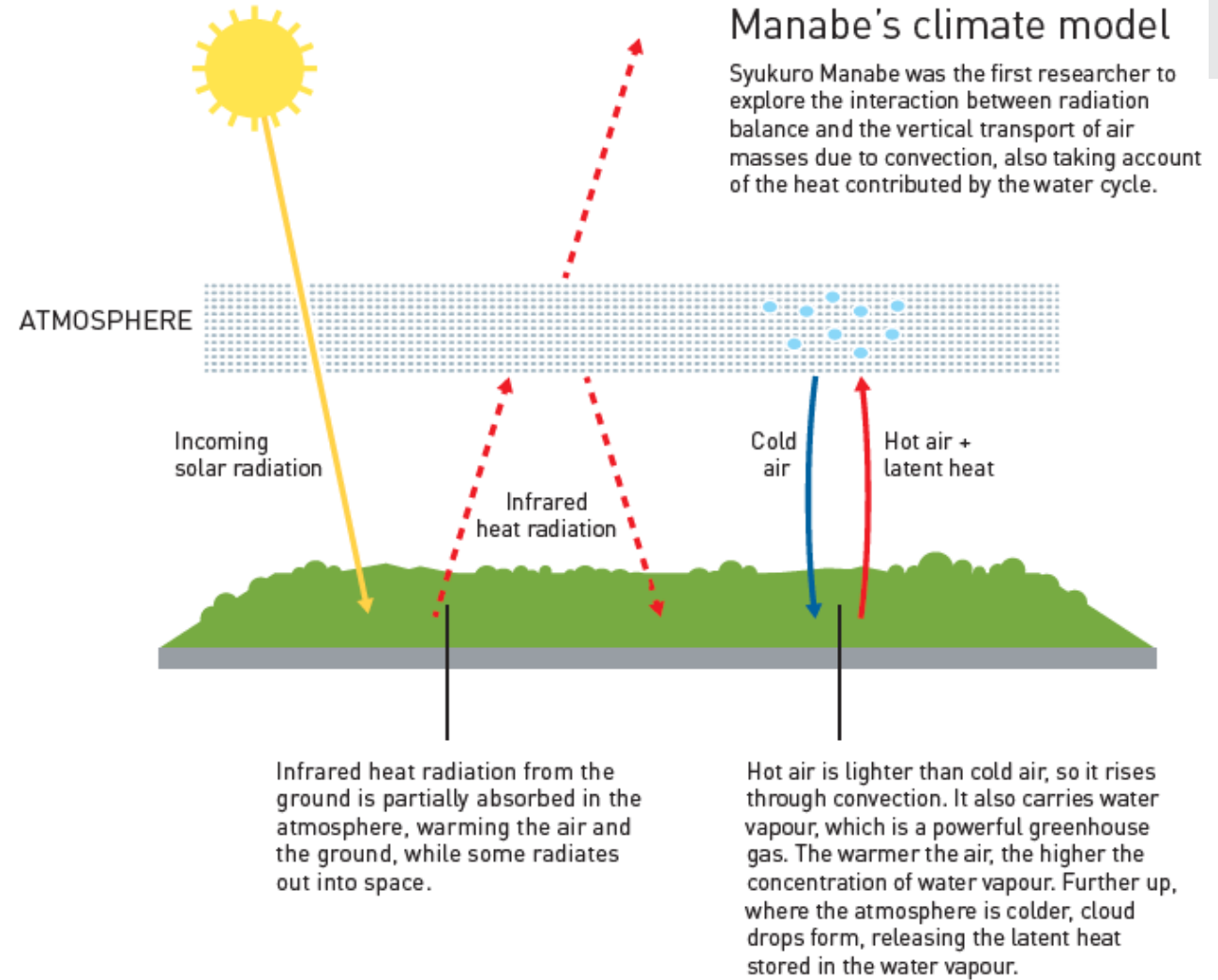
[<https://earthobservatory.nasa.gov/features/ModelingIntro>]



Effetto serra, una vecchia storia



Syukuro Manabe
[Nobel per la Fisica 2021]



[\[https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf\]](https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf)



Effetto serra, una vecchia storia

1982

PROPRIETARY INFORMATION
FOR AUTHORIZED COMPANY USE ONLY

CO₂ GREENHOUSE EFFECT
A TECHNICAL REVIEW

PREPARED BY THE
COORDINATION AND PLANNING DIVISION
EXXON RESEARCH AND ENGINEERING COMPANY

APRIL 1, 1982

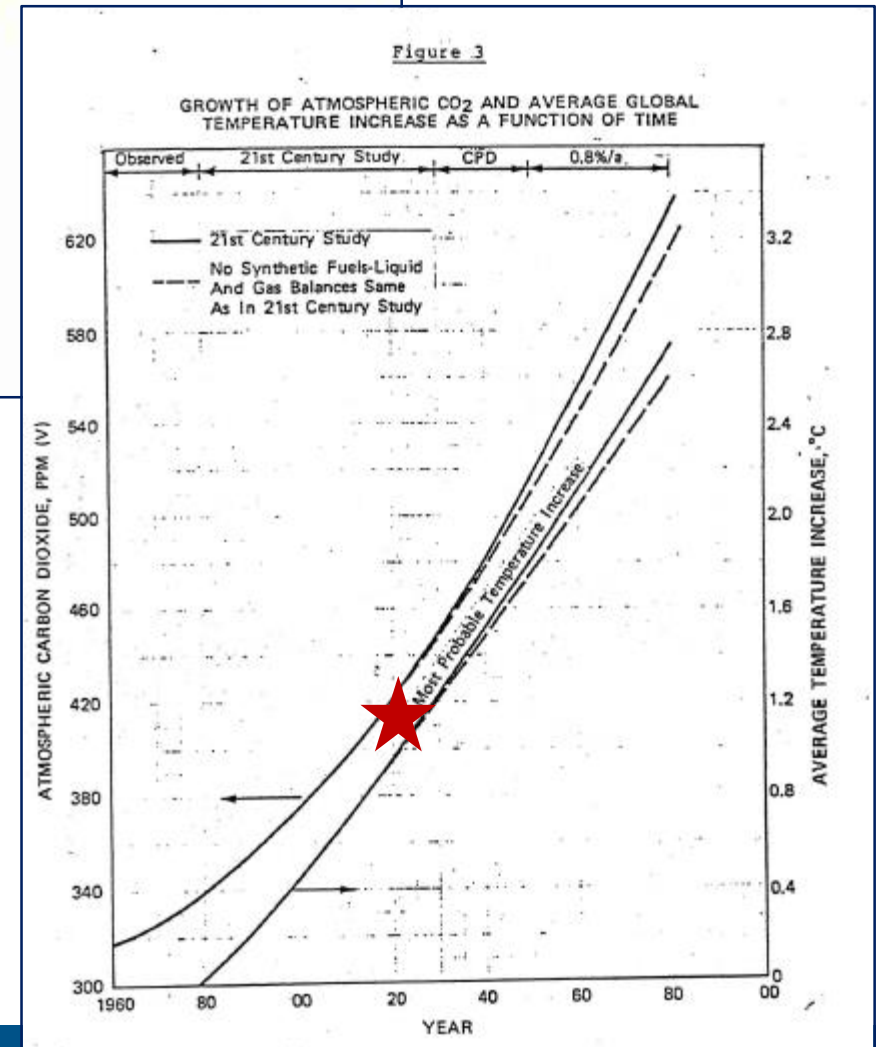
1988



Report Series HSE 88-001

CONFIDENTIAL

THE GREENHOUSE EFFECT



→ <https://www.climatefiles.com/exxonmobil/1982-memo-to-exxon-management-about-co2-greenhouse-effect/>

→ <https://www.climatefiles.com/shell/1988-shell-report-greenhouse/>

Modelli climatici

$$\begin{cases} \frac{d}{dt}u = fv - \frac{1}{\rho} \frac{\partial p}{\partial x} + a_{Dx} \\ \frac{d}{dt}v = -fu - \frac{1}{\rho} \frac{\partial p}{\partial y} + a_{Dy} \end{cases}$$

Momento

$$\rho = \frac{p}{RT}$$

Stato

$$\frac{\partial \rho}{\partial t} + \vec{v} \cdot \nabla \rho + \rho \nabla \cdot \vec{v} = 0$$

Continuità

$$c_p \frac{dT}{dt} - \frac{1}{\rho} \frac{dp}{dt} = Q$$

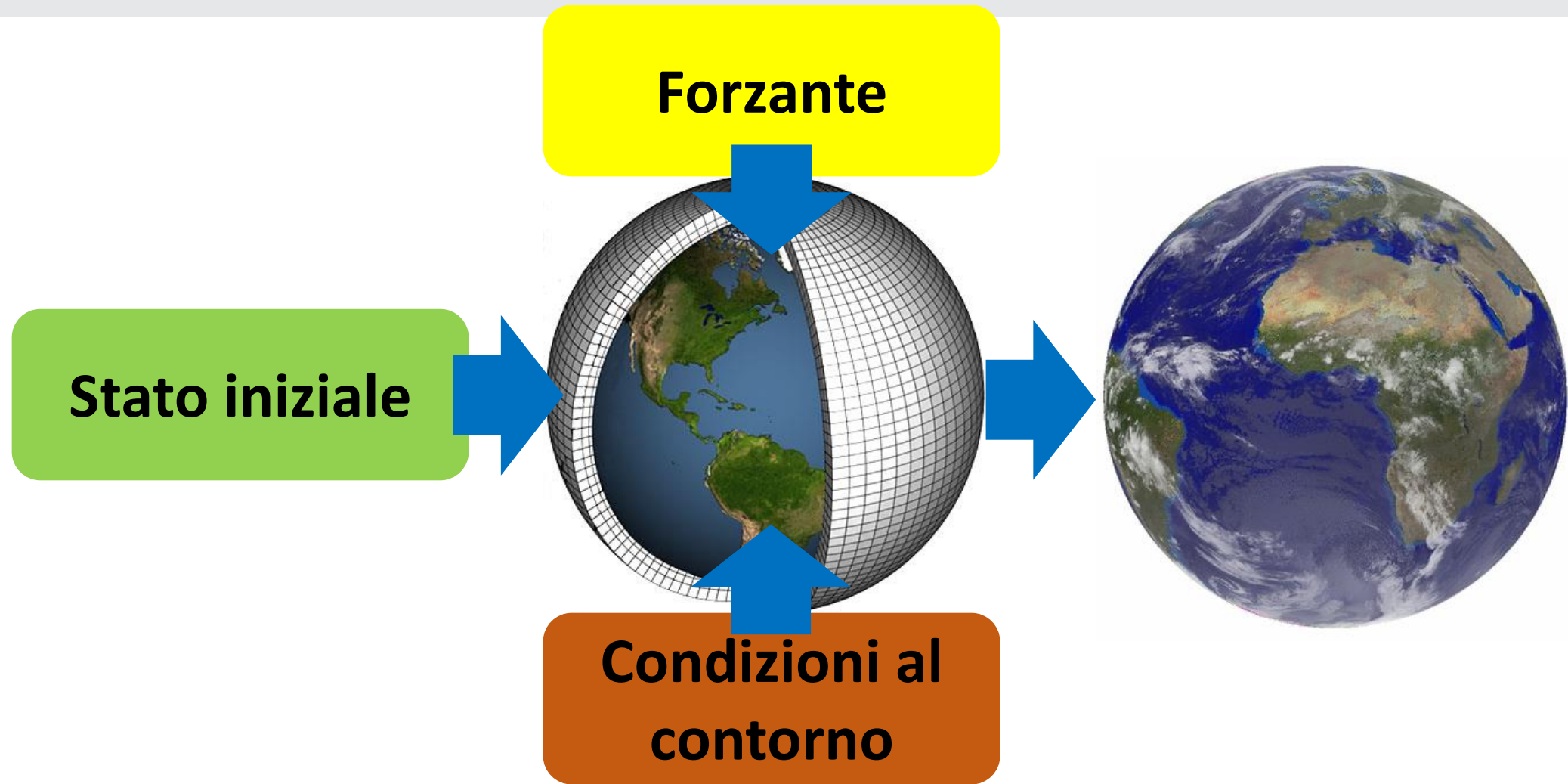
Temperatura

$$\frac{dm}{dt} = S$$

Umidità/Salinità

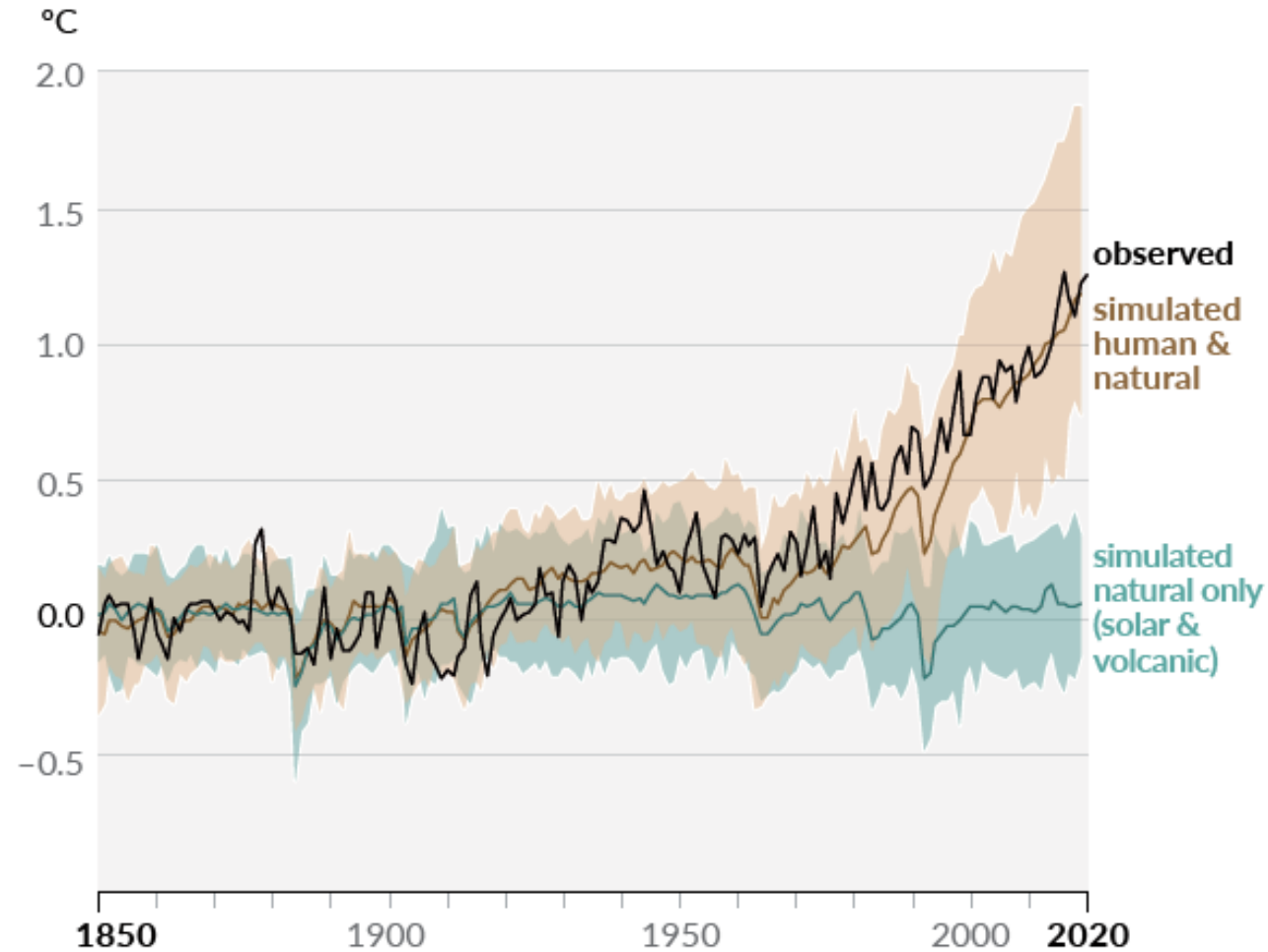


Modelli climatici



Attribuzione del cambiamento climatico

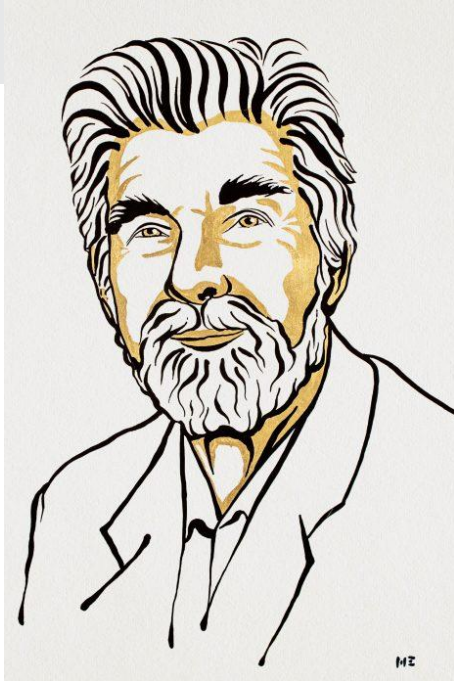
(b) Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)



[<https://www.ipcc.ch/assessment-report/ar6/>]



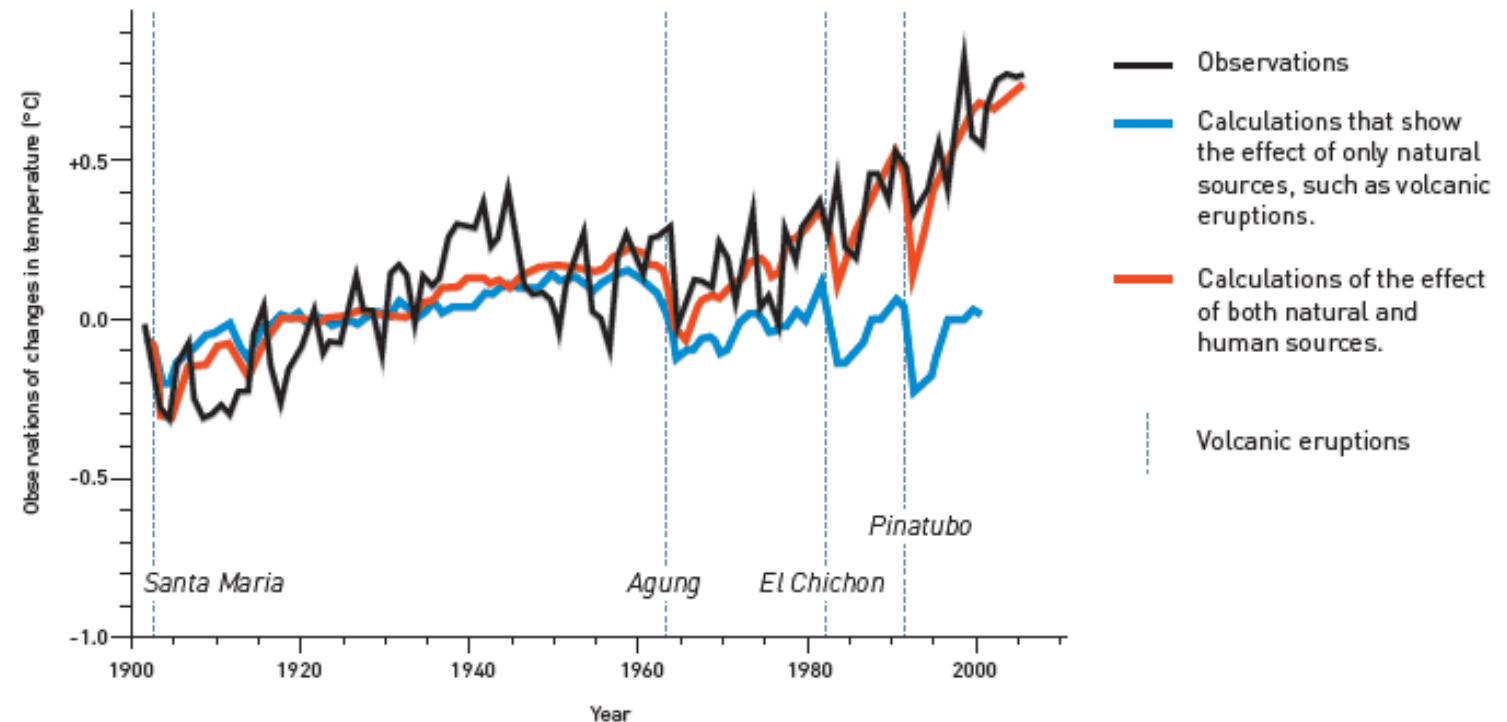
Attribuzione del cambiamento climatico



Klaus Hasselmann
[Nobel per la Fisica 2021]

Identifying fingerprints in the climate

Klaus Hasselmann developed methods for distinguishing between natural and human causes (fingerprints) of atmospheric heating. Comparison between changes in the mean temperature in relation to the average for 1901–1950 (°C).



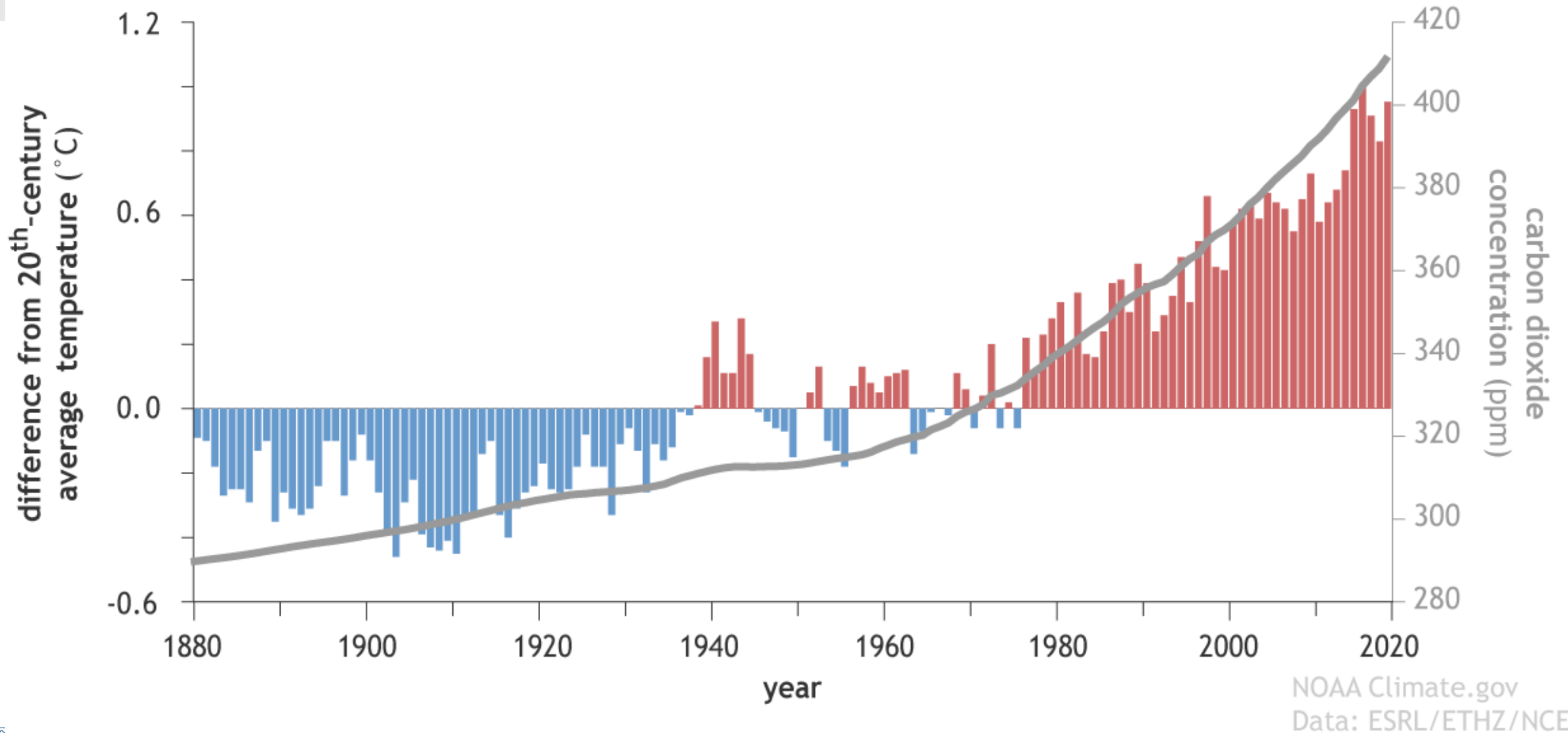
Source: Hegerl and Zweirs (2011) Use of models in detection & attribution of climate change, *WIREs Climate Change*.

[\[https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf\]](https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf)



Attribuzione del cambiamento climatico

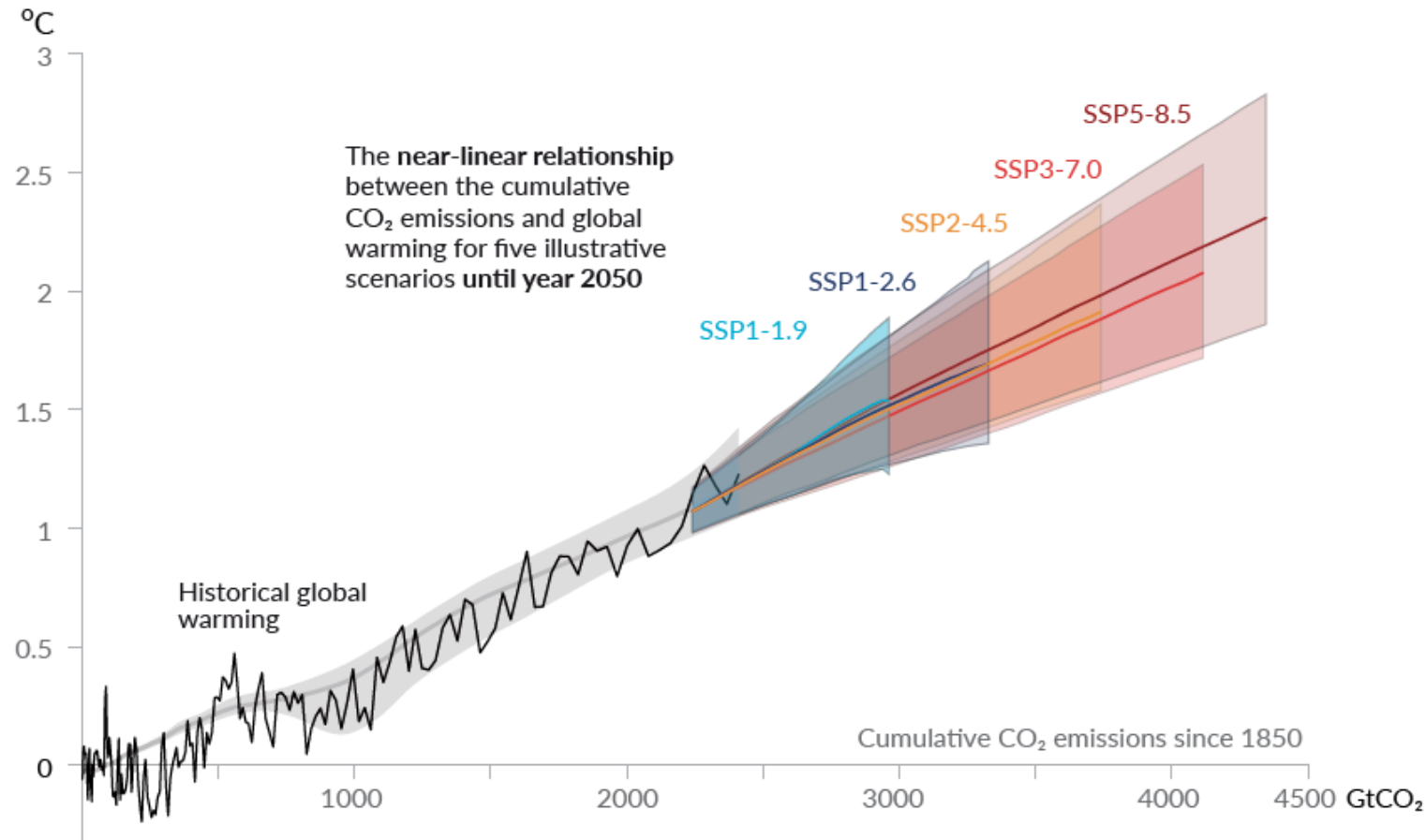
Atmospheric carbon dioxide and Earth's surface temperature (1880-2019)



Sensibilità climatica

Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



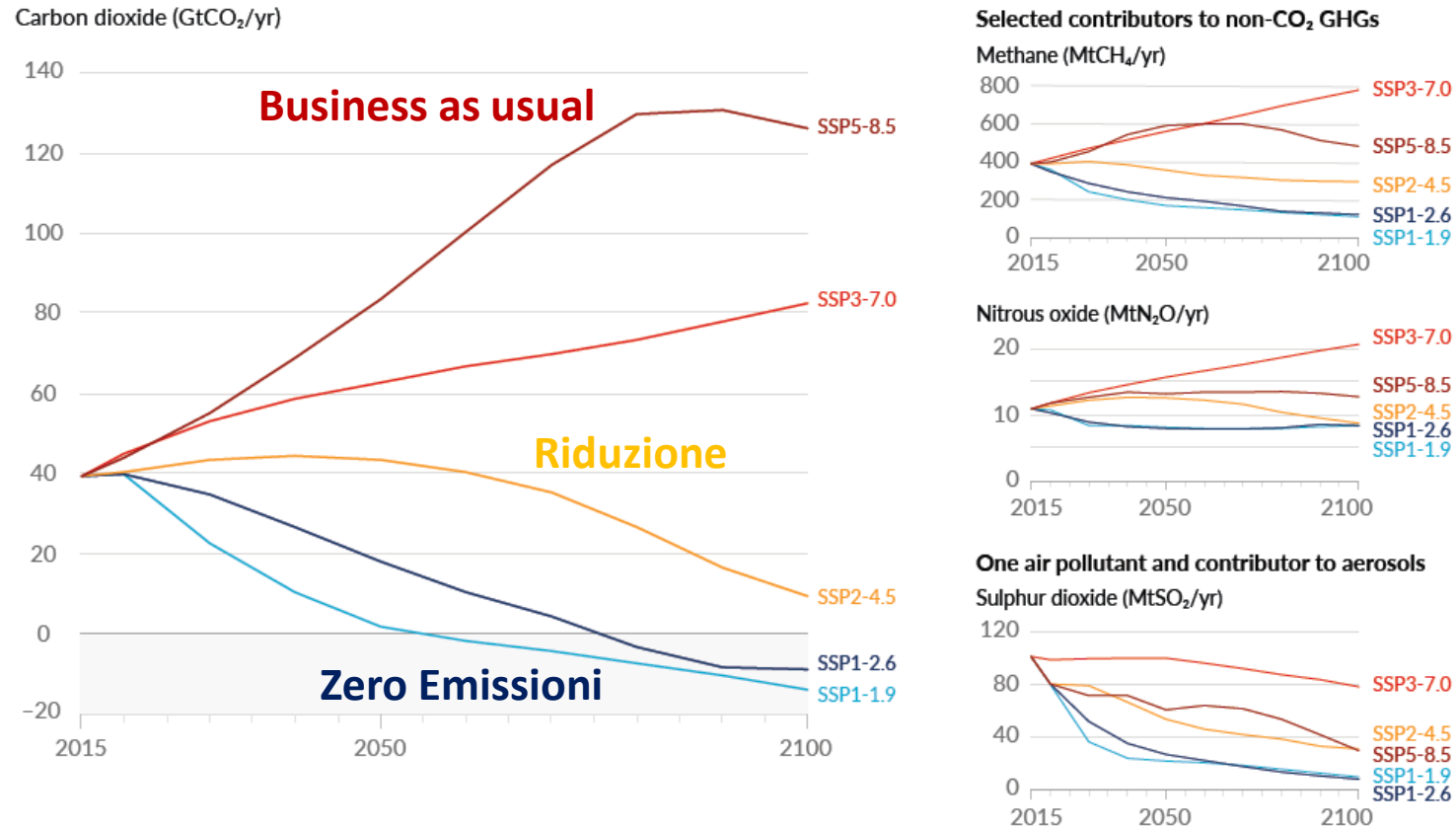
[<https://www.ipcc.ch/assessment-report/ar6/>]



Scenari di emissione

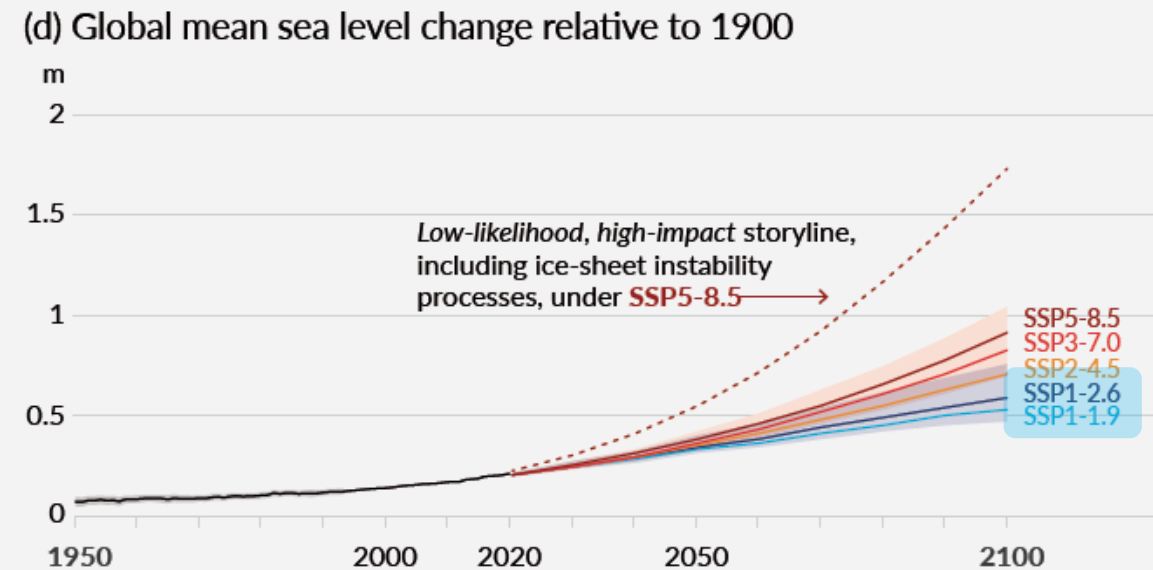
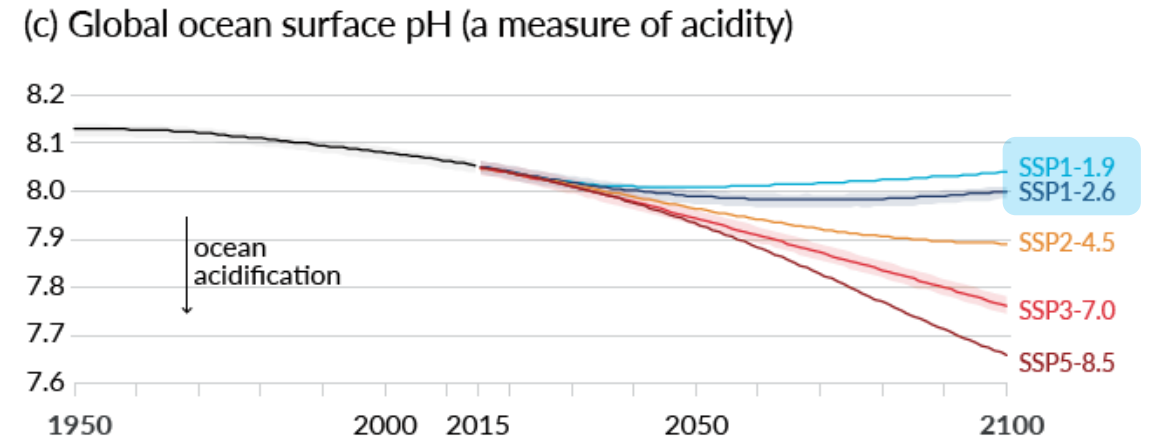
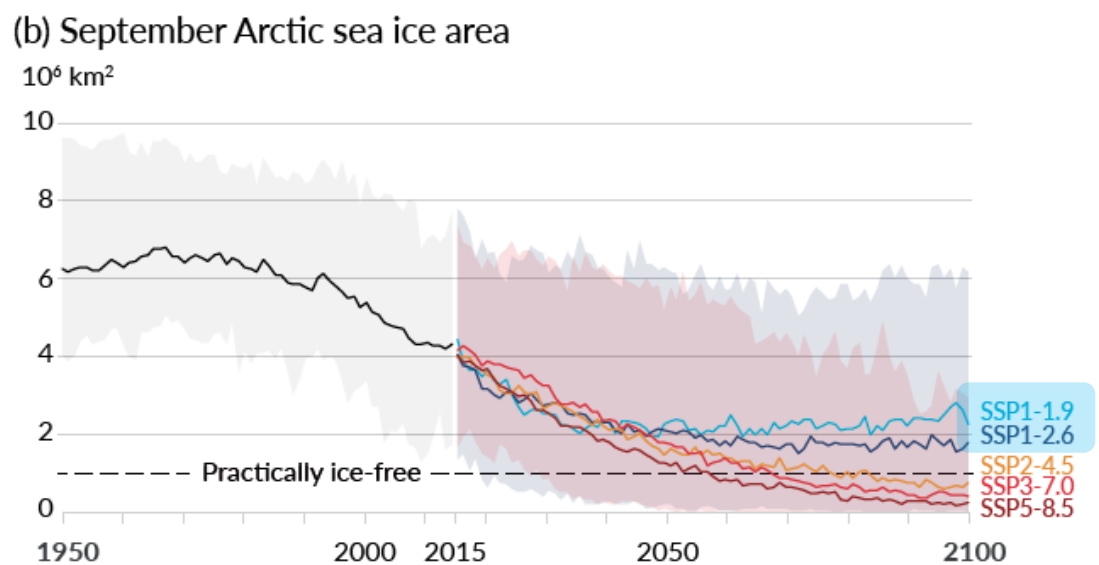
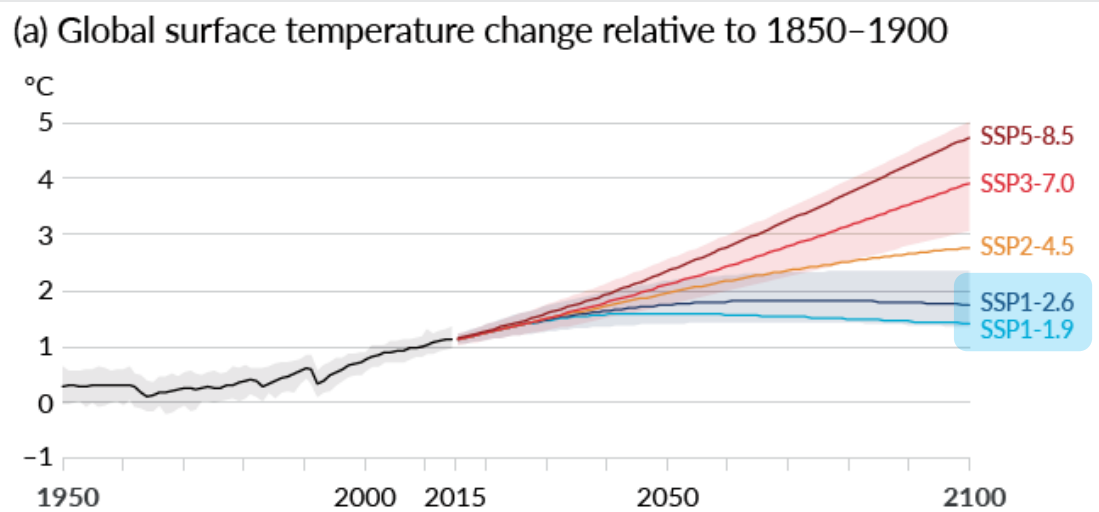
Future emissions cause future additional warming, with total warming dominated by past and future CO₂ emissions

(a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios



[<https://www.ipcc.ch/assessment-report/ar6/>]

Proiezioni climatiche



<https://www.ipcc.ch/assessment-report/ar6/>



Proiezioni climatiche

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	<i>Very likely</i> range (°C)	Best estimate (°C)	<i>Very likely</i> range (°C)	Best estimate (°C)	<i>Very likely</i> range (°C)
Zero nel 2050 SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
Zero nel 2075 SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

[<https://www.ipcc.ch/assessment-report/ar6/>]

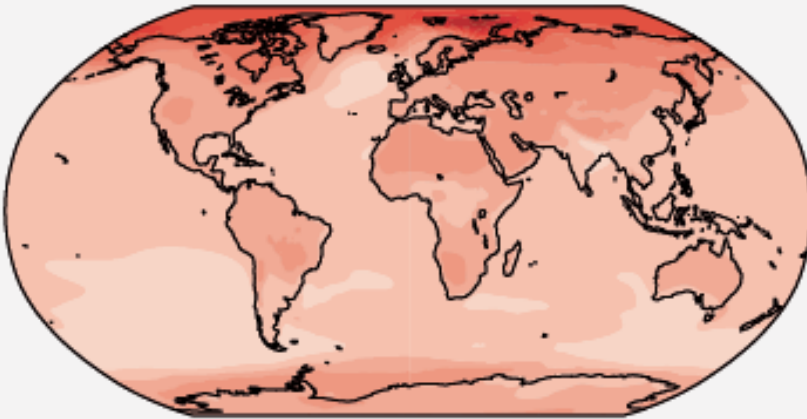


Proiezioni climatiche

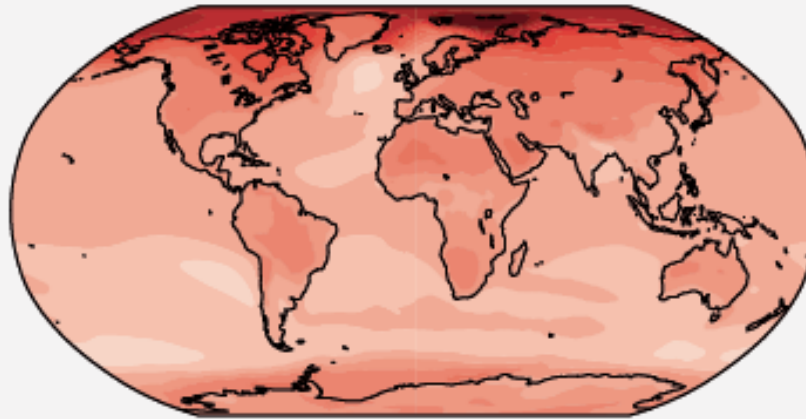
(b) Annual mean temperature change (°C)
relative to 1850–1900

Across warming levels, land areas warm more than ocean areas, and the Arctic and Antarctica warm more than the tropics.

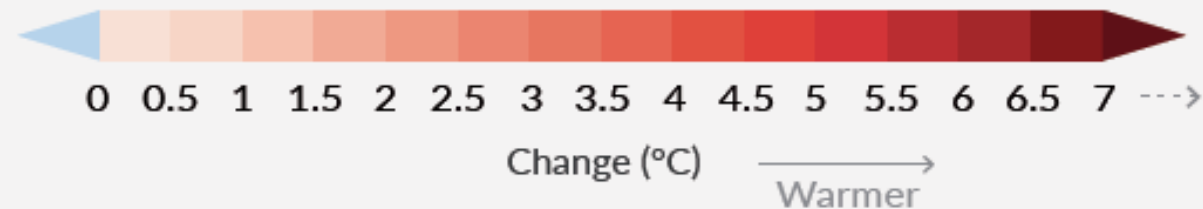
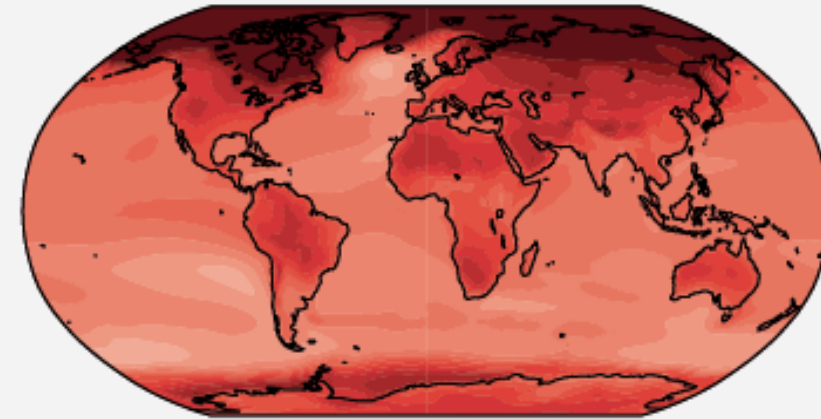
Simulated change at 1.5°C global warming



Simulated change at 2°C global warming



Simulated change at 4°C global warming



[<https://www.ipcc.ch/assessment-report/ar6/>]

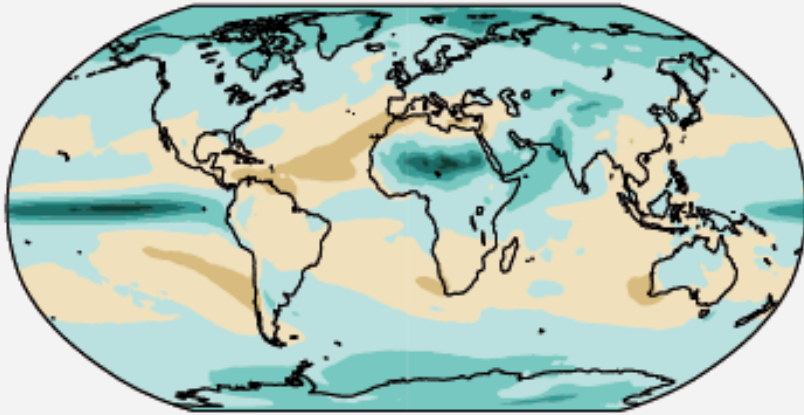


Proiezioni climatiche

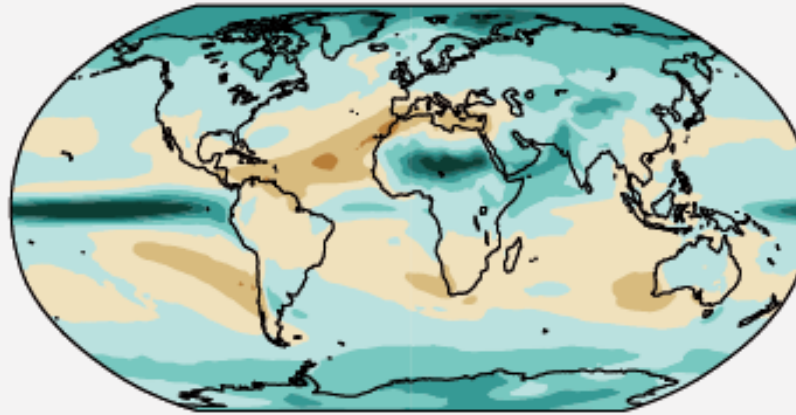
(c) Annual mean precipitation change (%) relative to 1850–1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

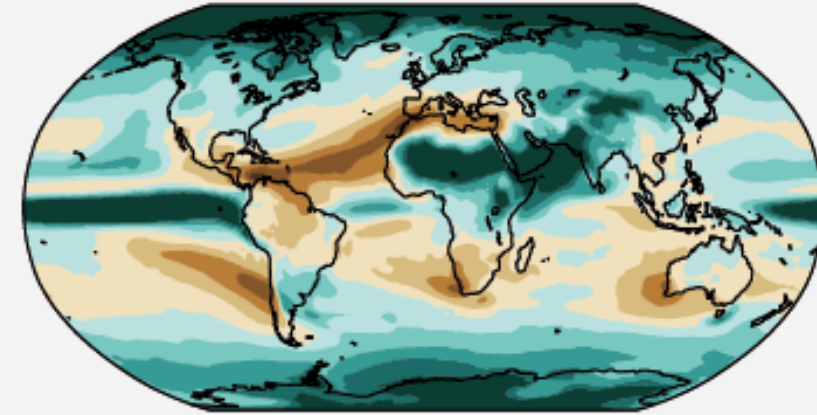
Simulated change at 1.5°C global warming



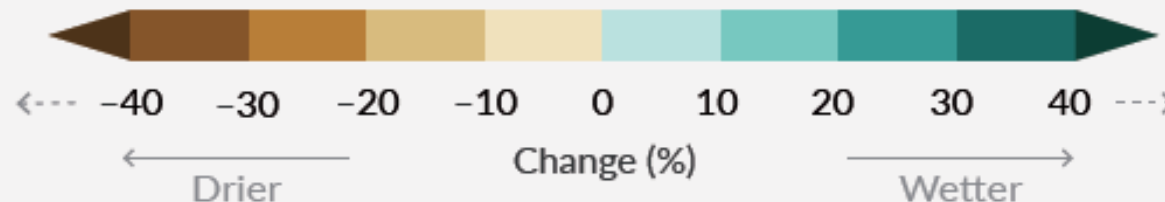
Simulated change at 2°C global warming



Simulated change at 4°C global warming



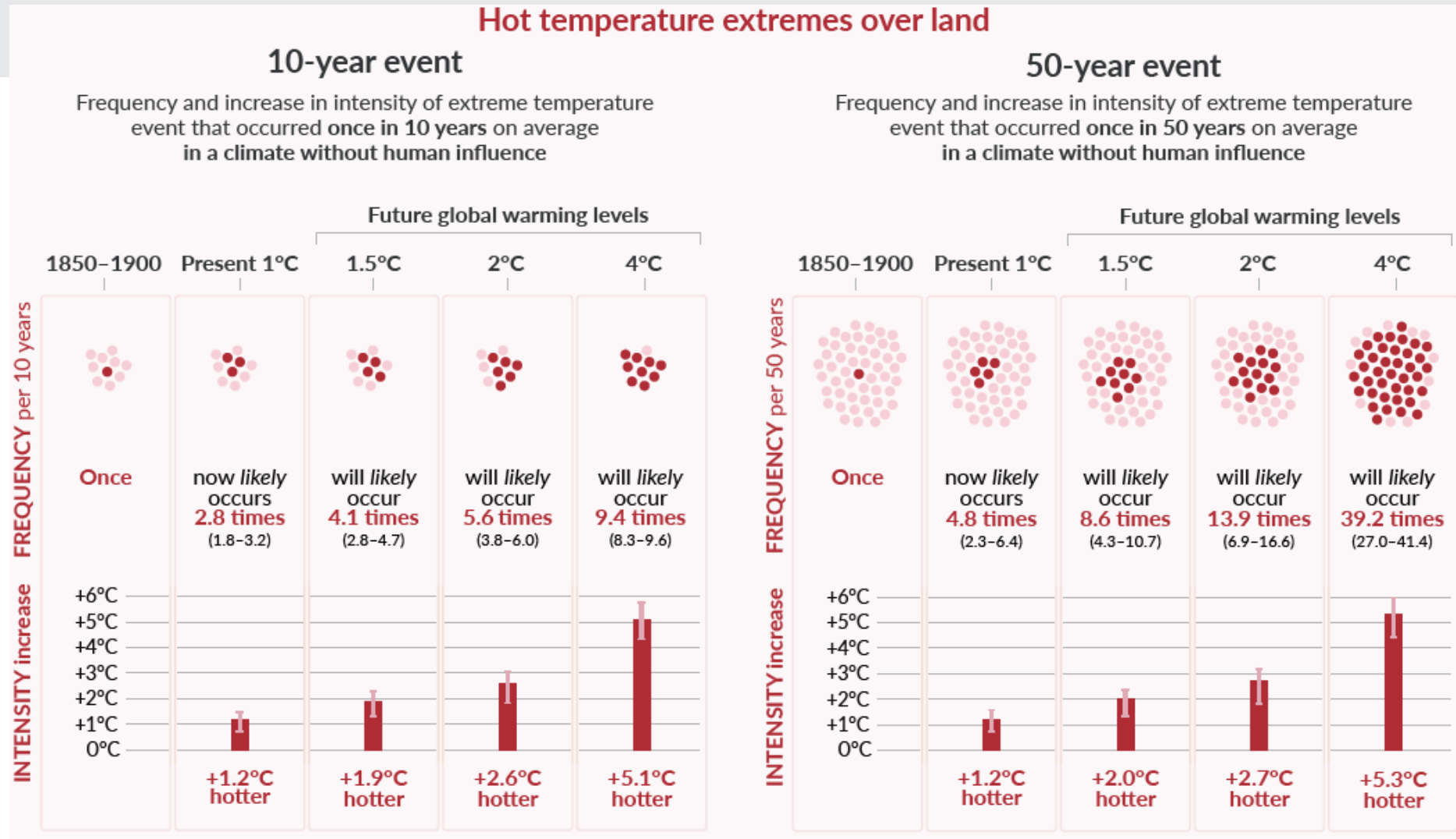
Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions.



[<https://www.ipcc.ch/assessment-report/ar6/>]



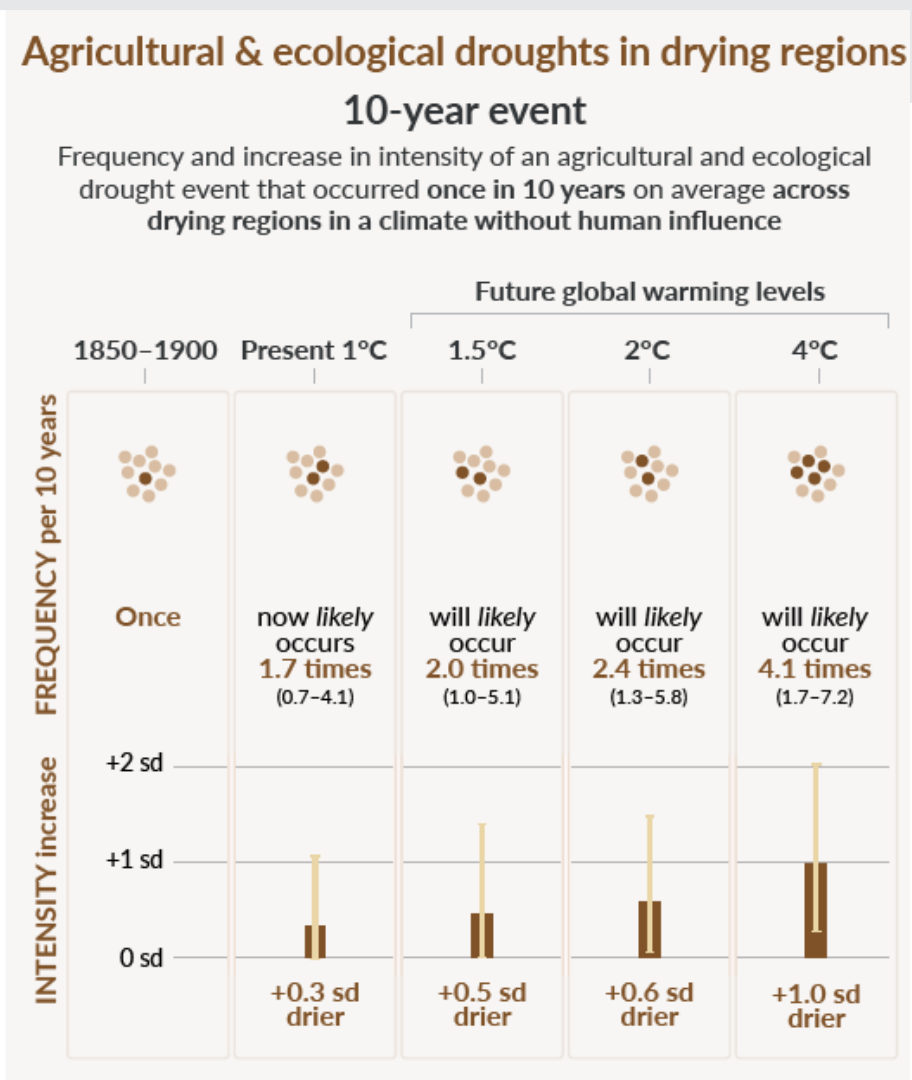
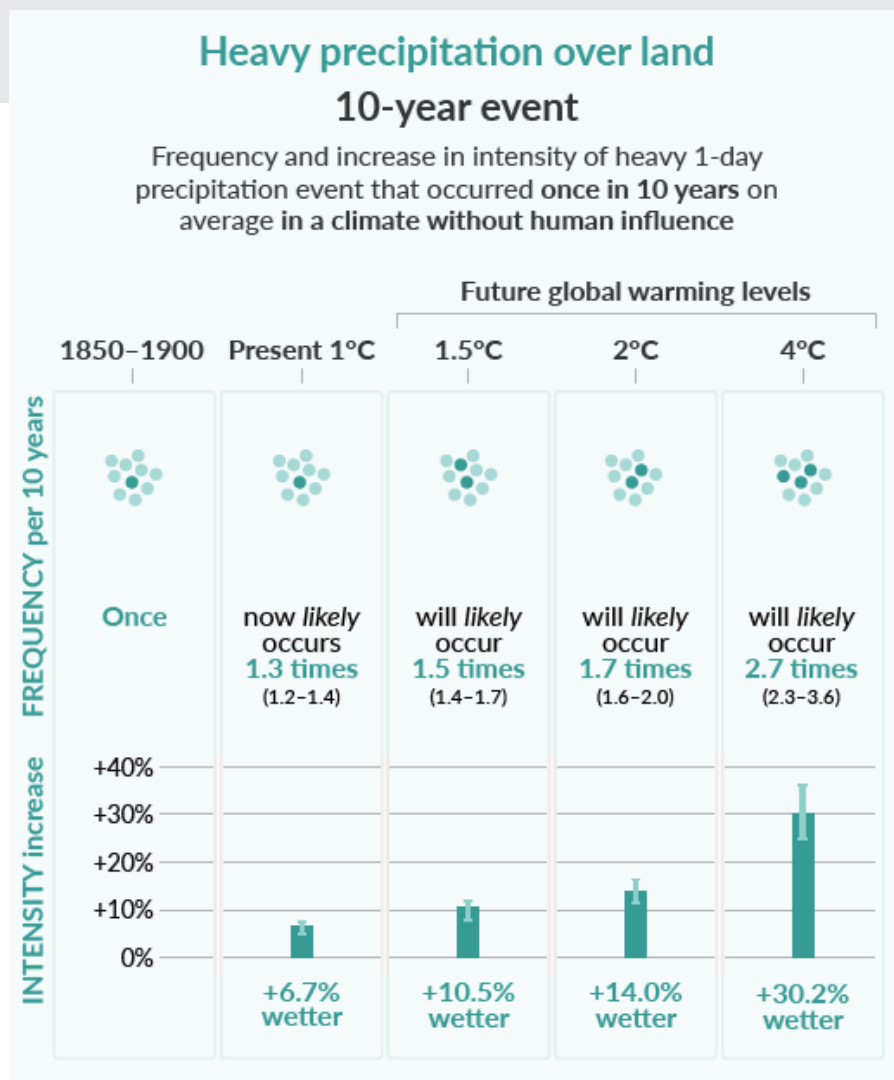
Proiezioni climatiche, in pratica



[<https://www.ipcc.ch/assessment-report/ar6/>]



Proiezioni climatiche, in pratica

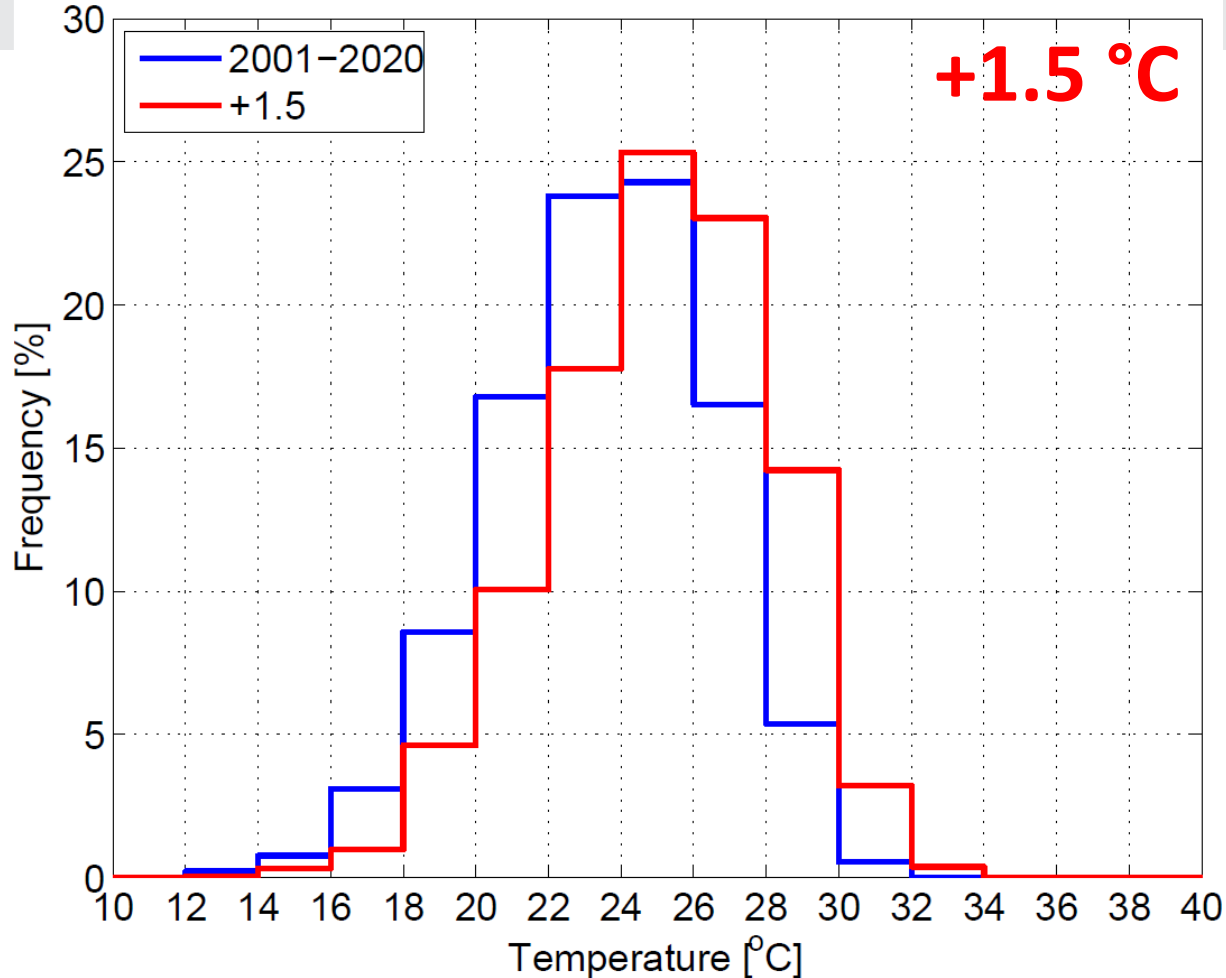


[<https://www.ipcc.ch/assessment-report/ar6/>]

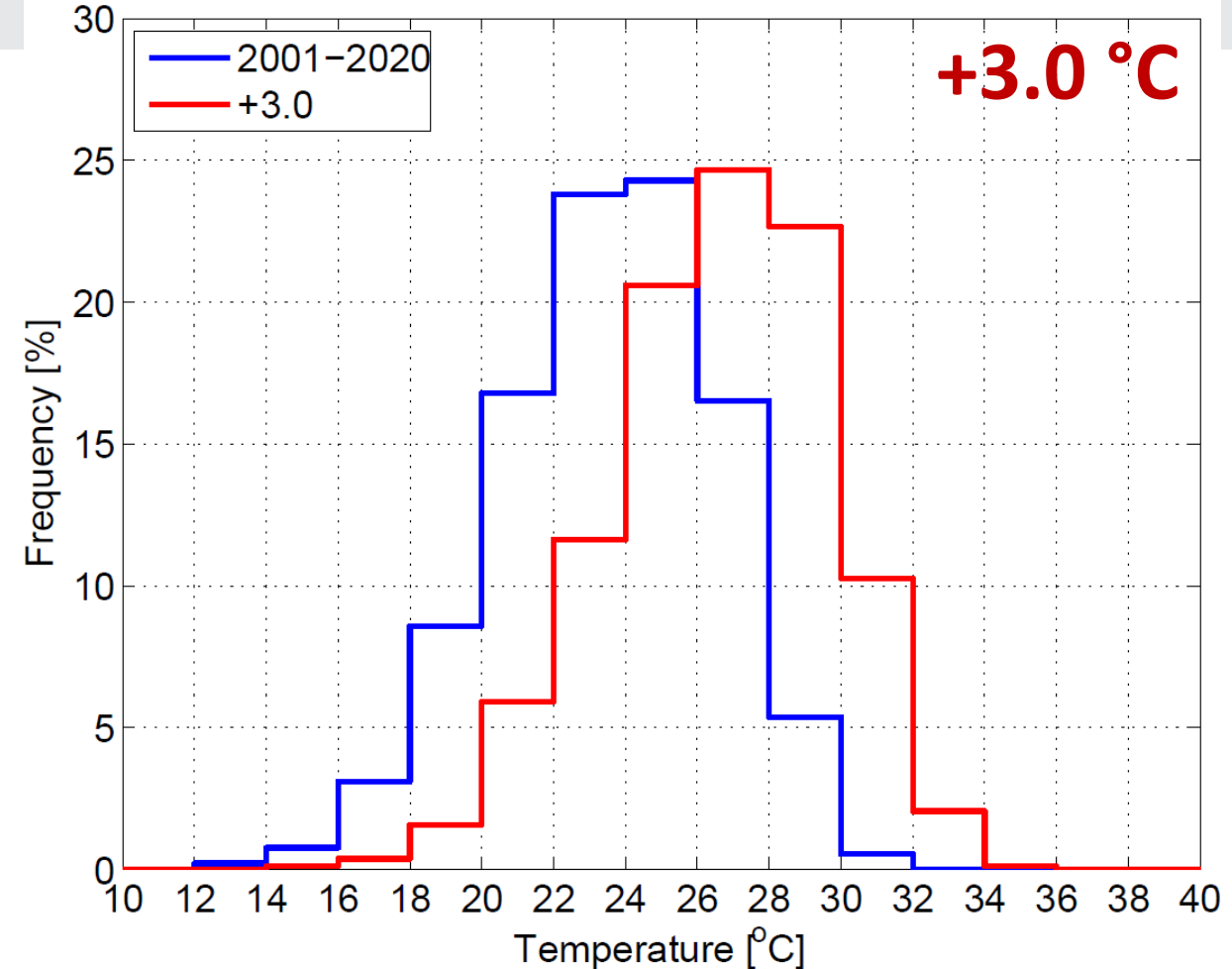


Proiezioni climatiche, a Foligno

[E-OBS] Tmean | Foligno (Jun-Jul-Aug)



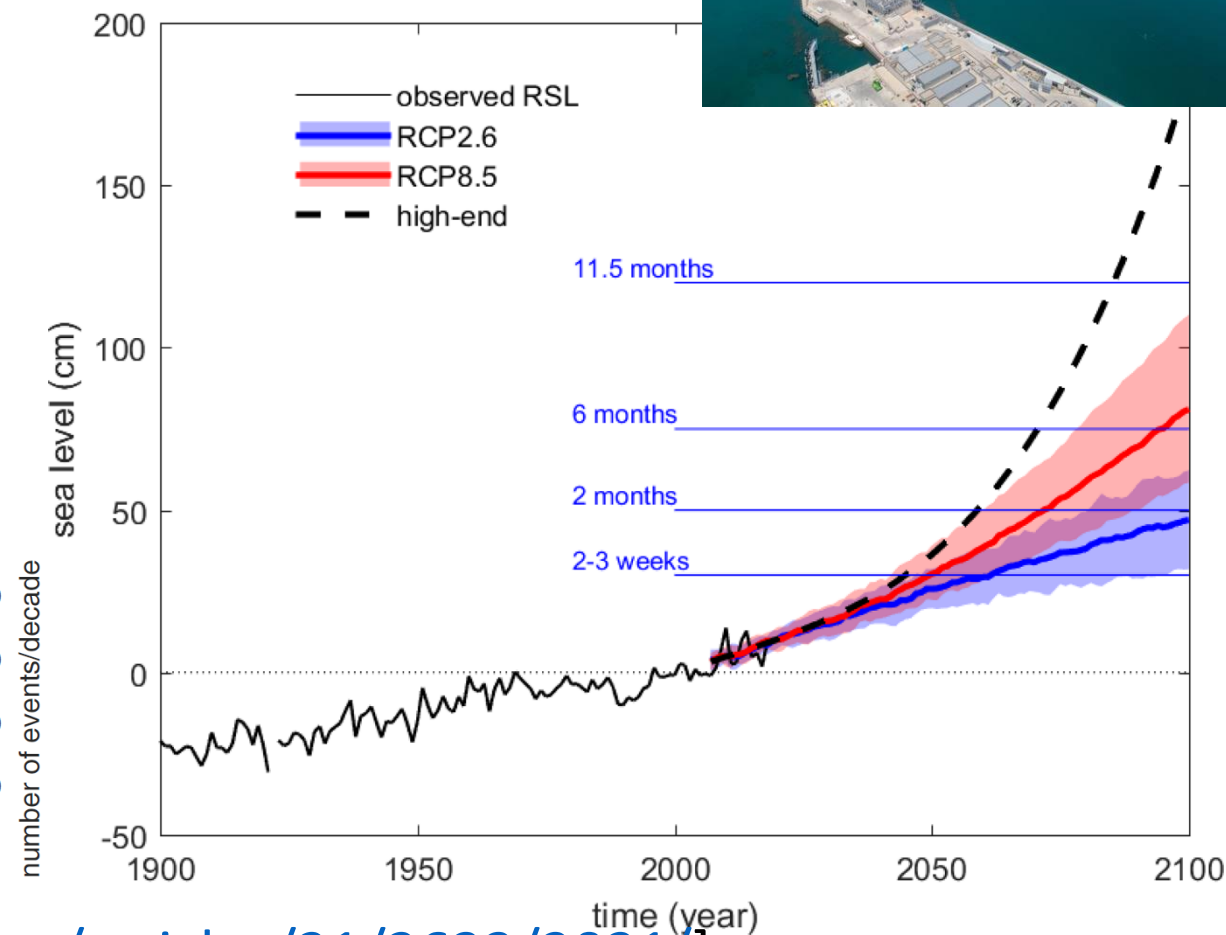
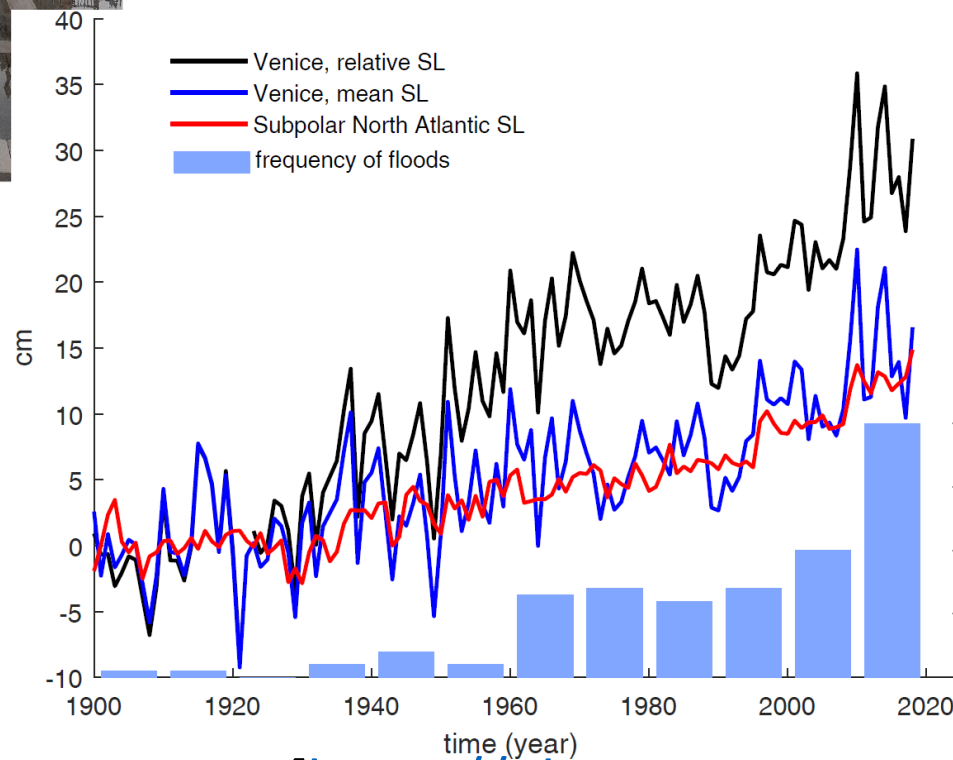
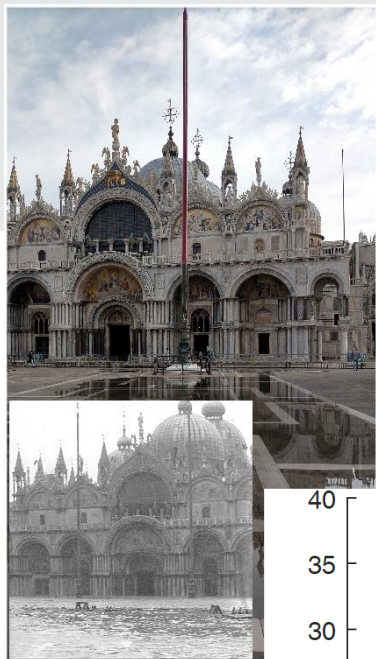
[E-OBS] Tmean | Foligno (Jun-Jul-Aug)



→ ***Don't try this at home! This is not a climate prediction! ☺***



Proiezioni climatiche, a Venezia



[<https://nhess.copernicus.org/articles/21/2633/2021/>]



Proiezioni climatiche, Mediterraneo

HEAT AND COLD	
Mean surface temperature	↗ High confidence of increase
Extreme heat	↗ High confidence of increase
Cold spell	↘ High confidence of decrease
Frost	↘ High confidence of decrease
WET AND DRY	
Mean precipitation	↘ High confidence of decrease
River flood	↘ Medium confidence of decrease
Heavy precipitation and pluvial flood	↗ Medium confidence of increase
Aridity	↗ High confidence of increase
Hydrological drought	↗ High confidence of increase
Agricultural and ecological drought	↗ High confidence of increase
Fire weather	↗ High confidence of increase

[<https://interactive-atlas.ipcc.ch/>]



Proiezioni climatiche, Mediterraneo

WIND 	
Mean wind speed	✓ High confidence of decrease
Severe wind storm	^ Medium confidence of increase
SNOW AND ICE	
Snow, glacier and ice sheet	✓ High confidence of decrease
Permafrost	✓ High confidence of decrease
Lake, river and sea ice	✓ High confidence of decrease
COASTAL 	
Relative sea level	^ High confidence of increase
Coastal flood	^ High confidence of increase
Coastal erosion	^ High confidence of increase
Marine heatwave	^ High confidence of increase
Ocean acidity	^ High confidence of increase

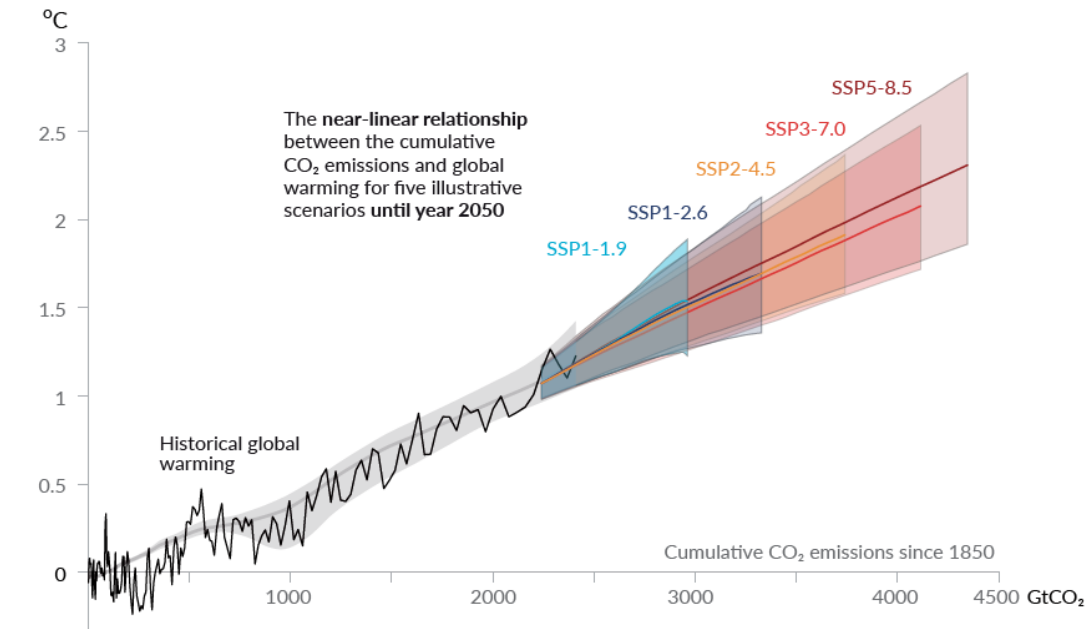
[<https://interactive-atlas.ipcc.ch/>]



Soluzioni (per un clima a +2.0 °C)

Every tonne of CO₂ emissions adds to global warming

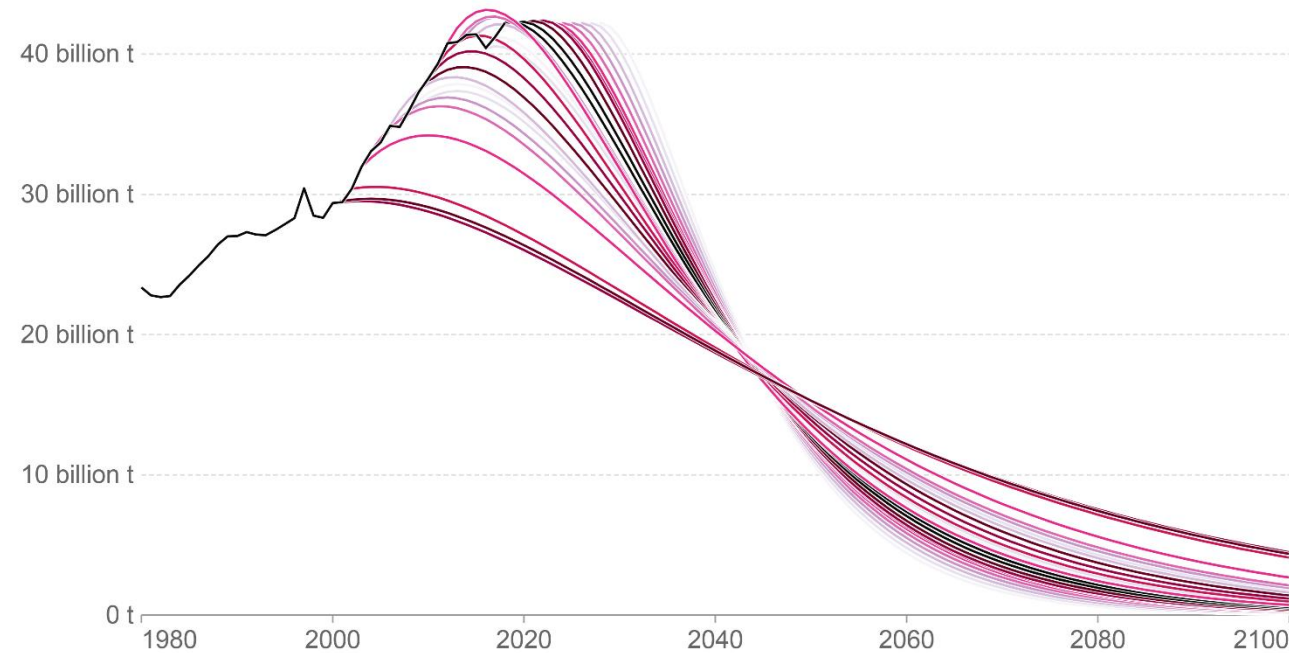
Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



CO₂ reductions needed to keep global temperature rise below 2°C

Annual emissions of carbon dioxide under various mitigation scenarios to keep global average temperature rise below 2°C. Scenarios are based on the CO₂ reductions necessary if mitigation had started – with global emissions peaking and quickly reducing – in the given year.

Our World
in Data

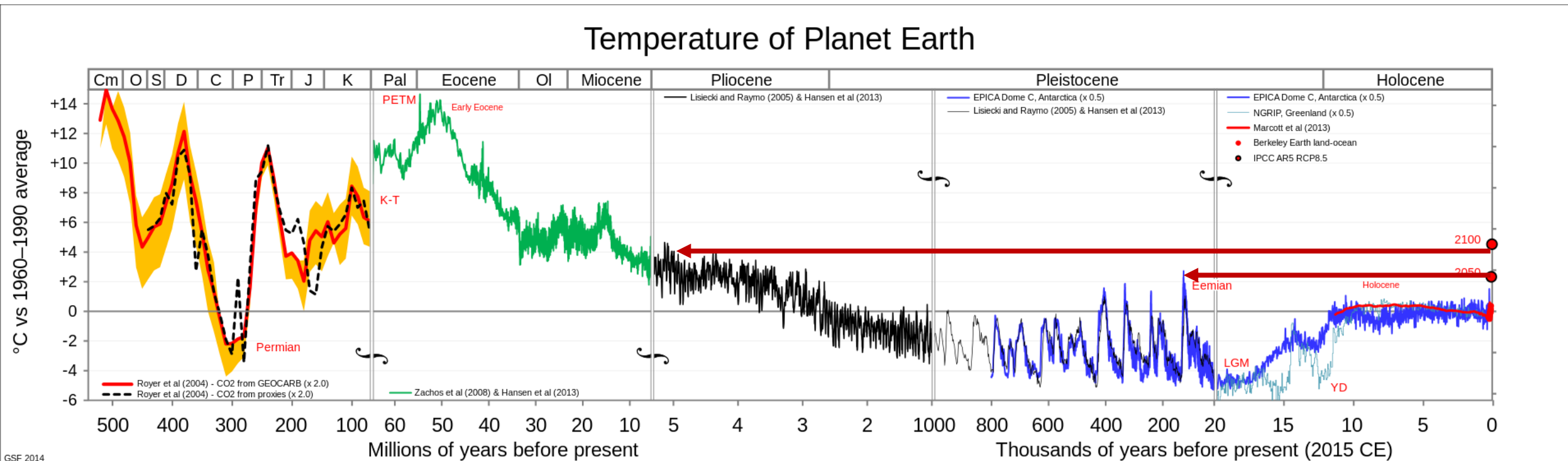


Source: Robbie Andrews (2019); based on Global Carbon Project & IPCC SR15
Note: Carbon budgets are based on a >66% chance of staying below 2°C from the IPCC's SR15 Report.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

[<https://www.ipcc.ch/assessment-report/ar6/>]



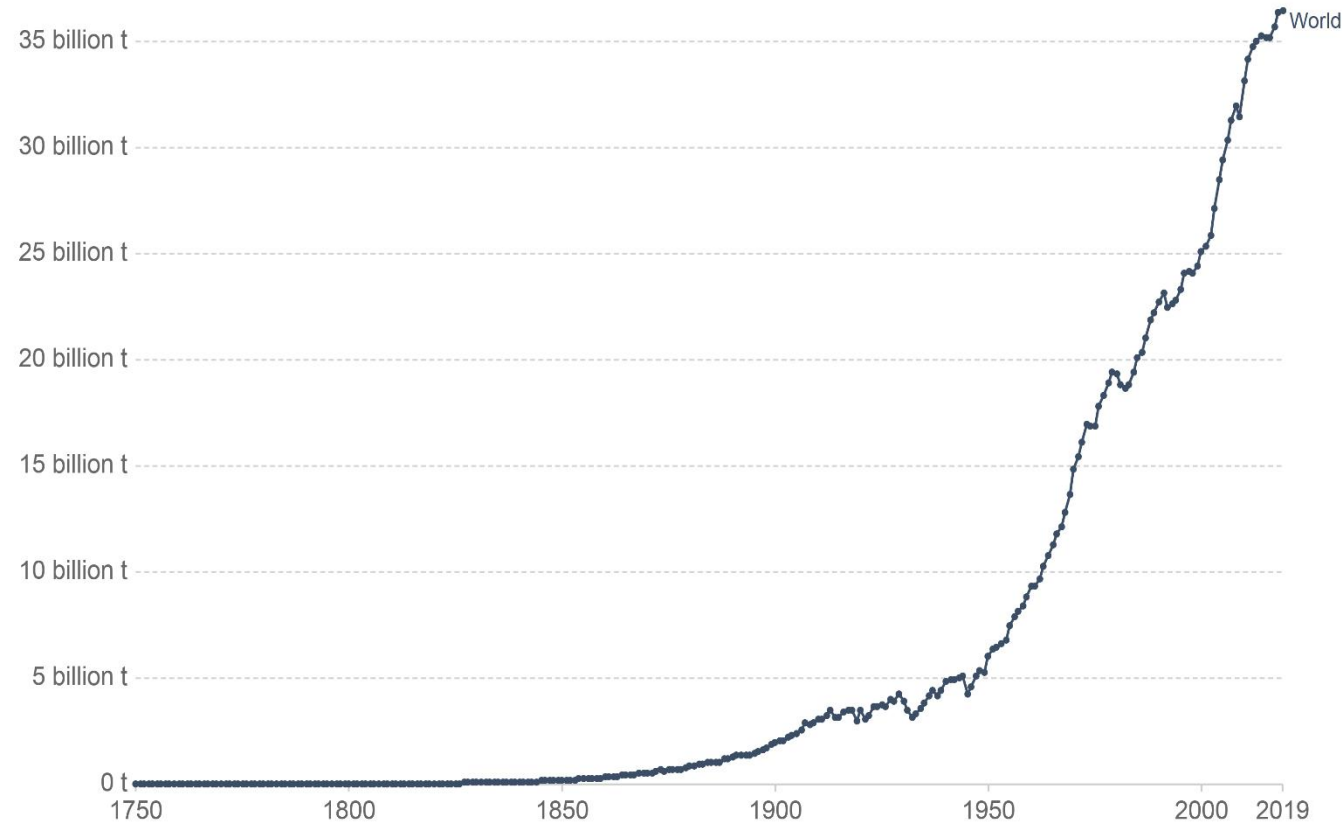
Scenari futuri che guardano al passato (remoto)



Emissioni di gas serra

Annual CO₂ emissions

Carbon dioxide (CO₂) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.



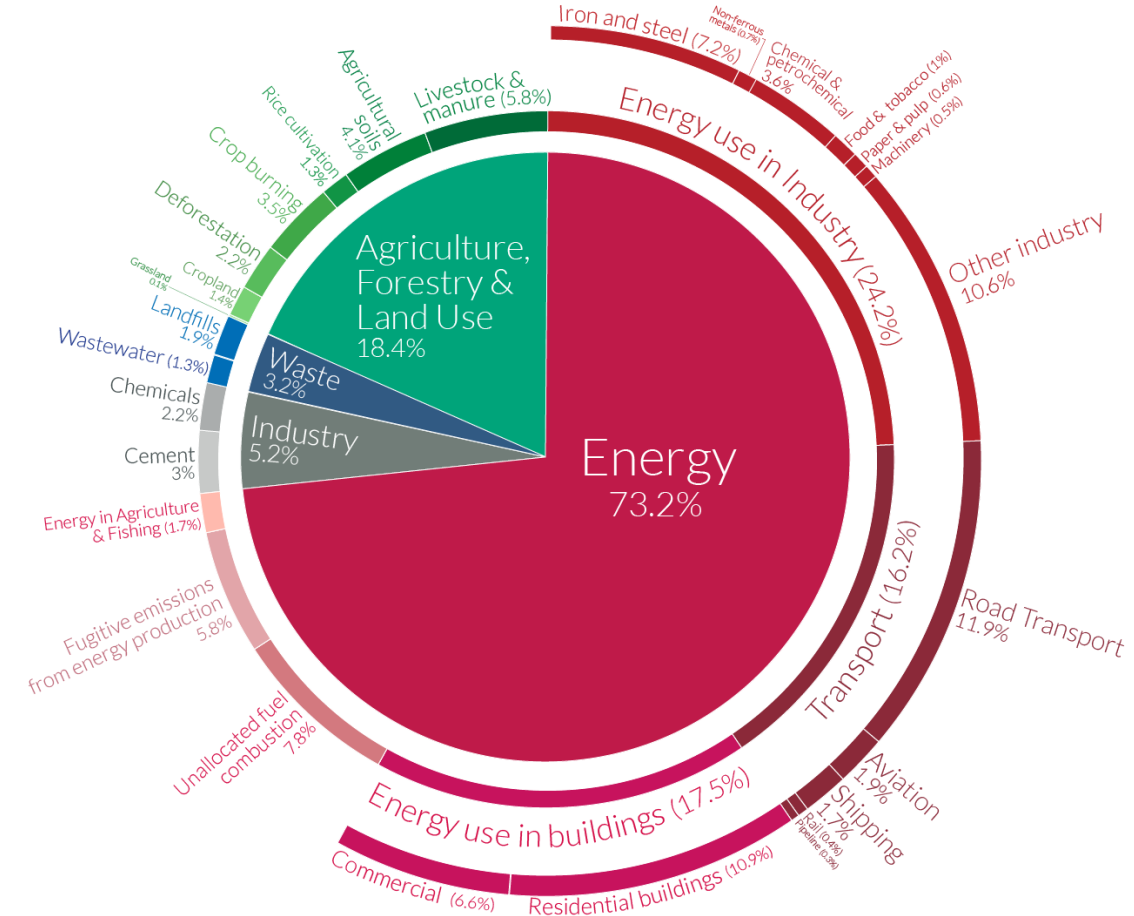
Source: Global Carbon Project; Carbon Dioxide Information Analysis Centre (CDIAC) OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY
Note: CO₂ emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.

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Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO₂eq.

Our World
in Data



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020).

Licensed under CC-BY by the author Hannah Ritchie (2020).

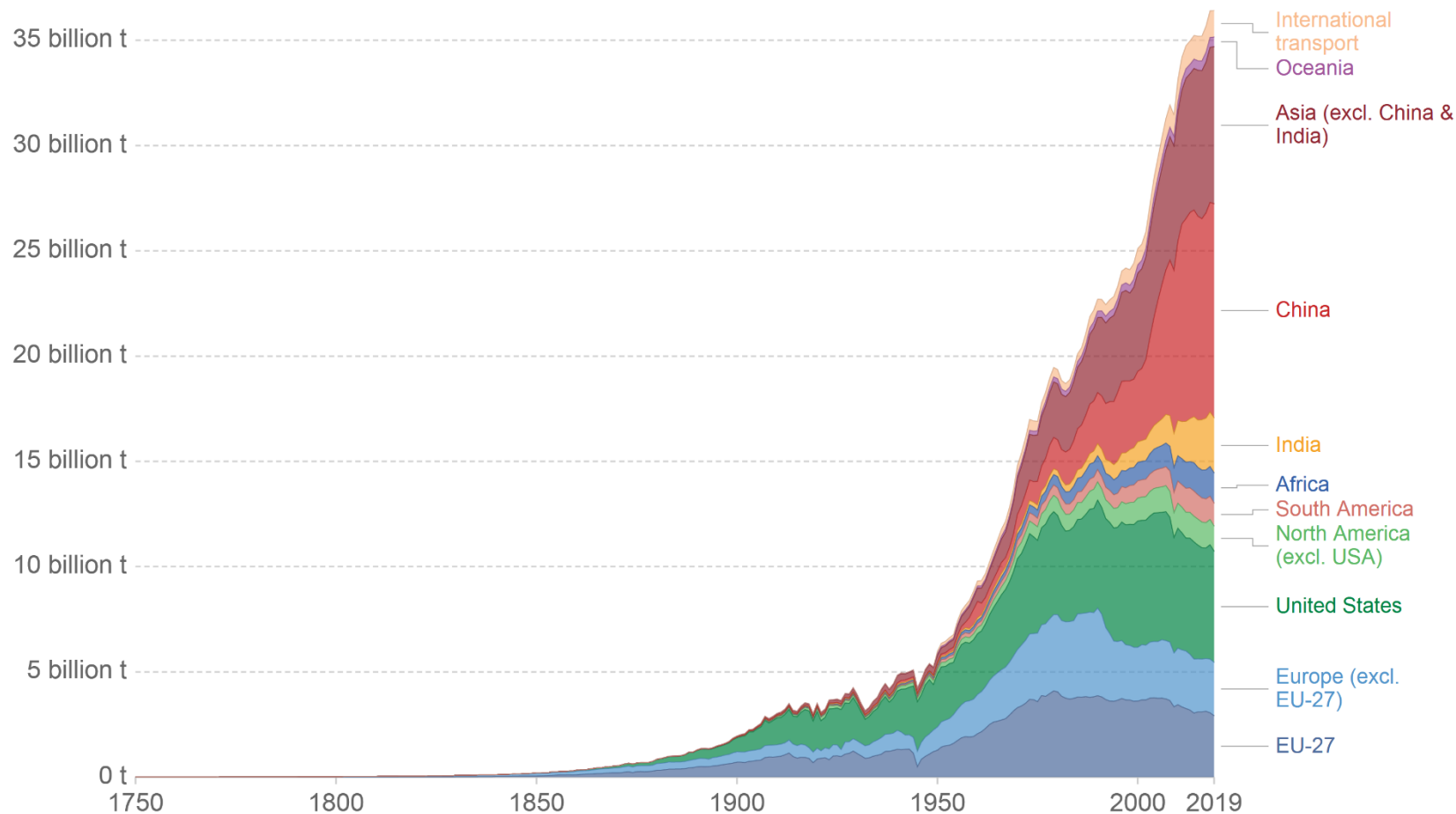
[<https://ourworldindata.org/>]



Emissioni di gas serra

Annual total CO₂ emissions, by world region

Our World
in Data



Source: Our World in Data based on the Global Carbon Project

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

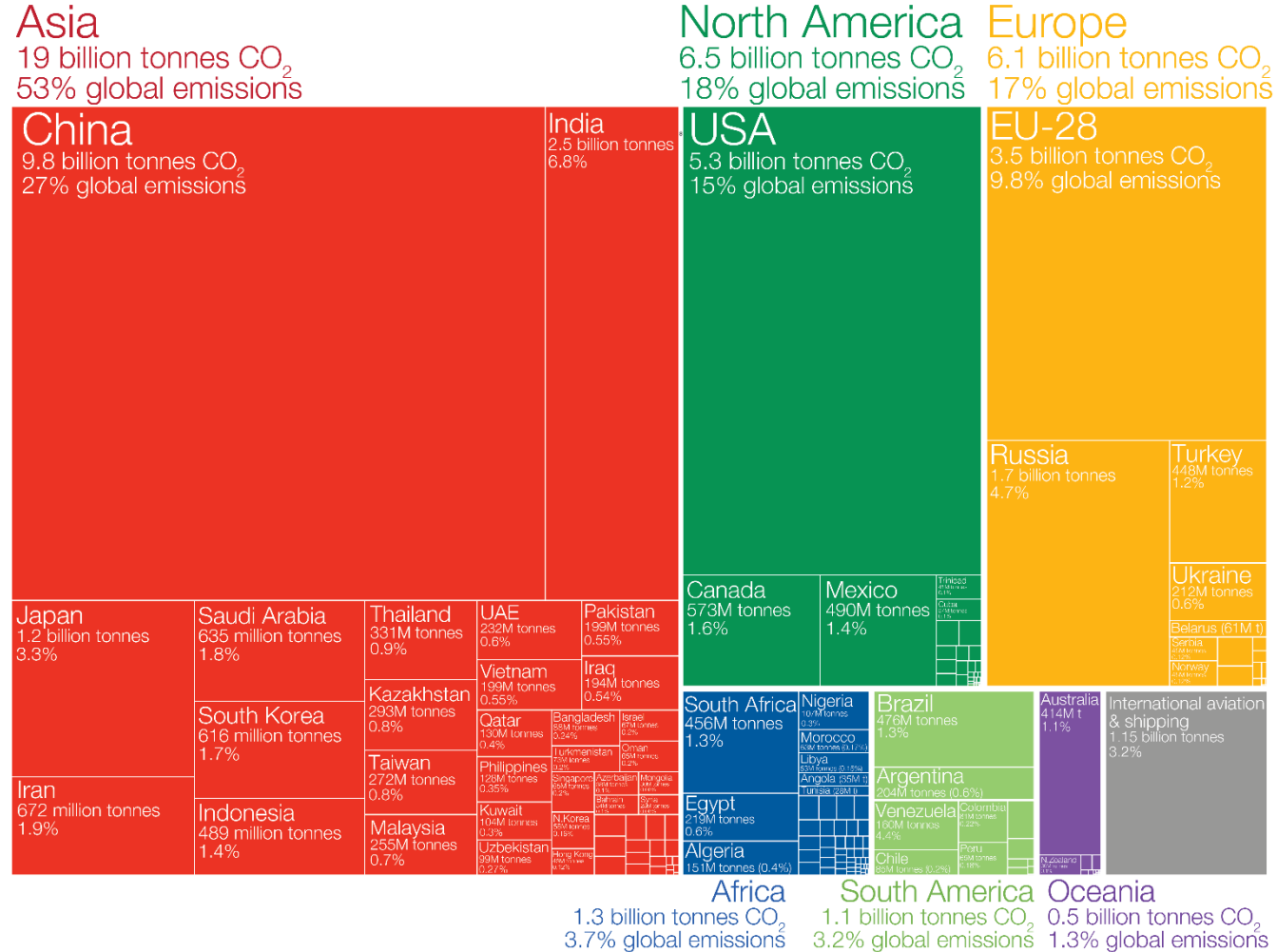
Note: This measures CO₂ emissions from fossil fuels and cement production only – land use change is not included. 'Statistical differences' (included in the GCP dataset) are not included here.

Emissioni di gas serra

Who emits the most CO₂?

Global carbon dioxide (CO₂) emissions were 36.2 billion tonnes in 2017.

Our World
in Data



Shown are national production-based emissions in 2017. Production-based emissions measure CO₂ produced domestically from fossil fuel combustion and cement, and do not adjust for emissions embedded in trade (i.e. consumption-based).

Figures for the 28 countries in the European Union have been grouped as the 'EU-28' since international targets and negotiations are typically set as a collaborative target between EU countries. Values may not sum to 100% due to rounding.

Data source: Global Carbon Project (GCP).

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

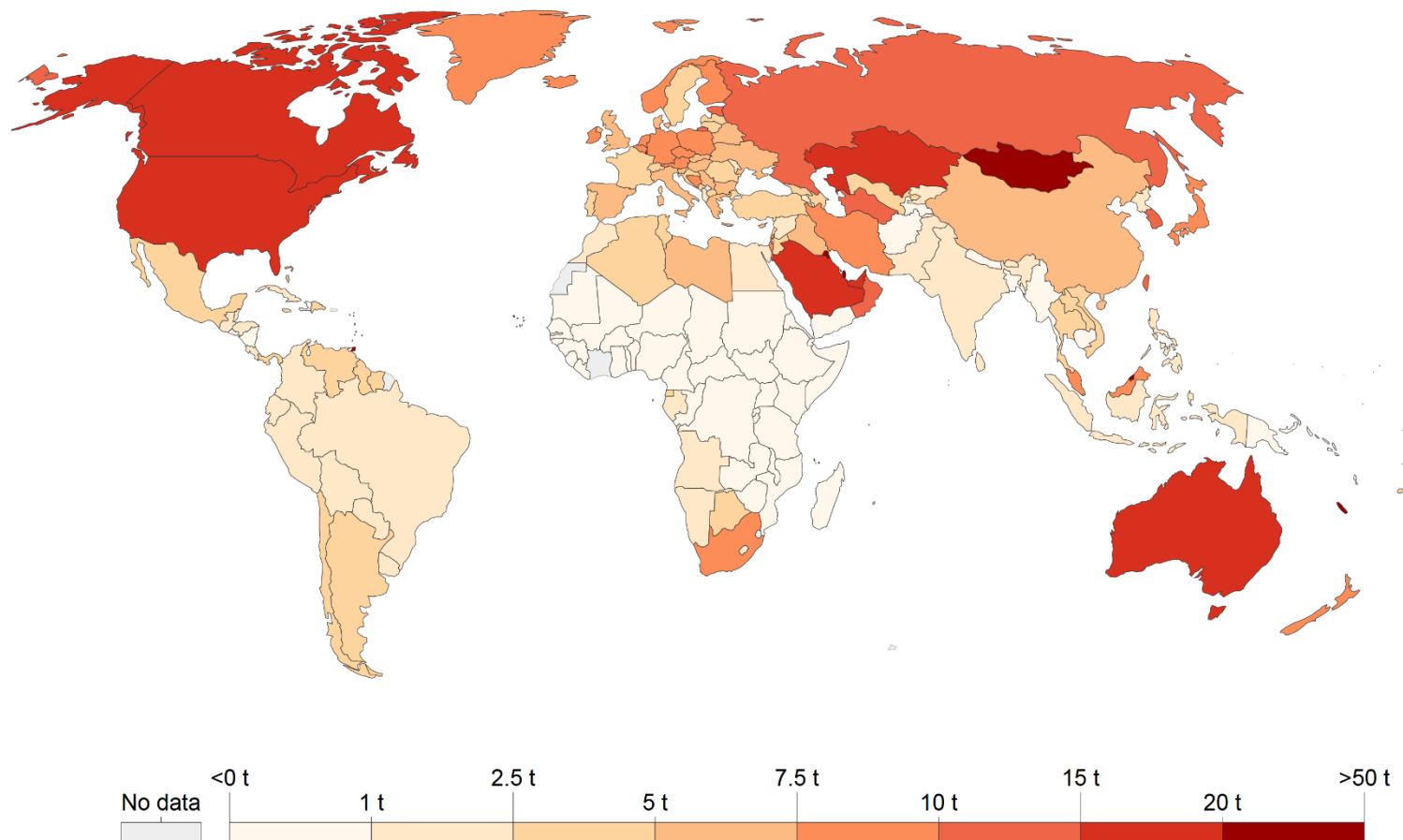
Licensed under CC-BY by the author Hannah Ritchie.

Emissioni di gas serra

Per capita CO₂ emissions, 2019

Carbon dioxide (CO₂) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Our World
in Data



Source: Our World in Data based on the Global Carbon Project; Gapminder & UN
Note: CO₂ emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.

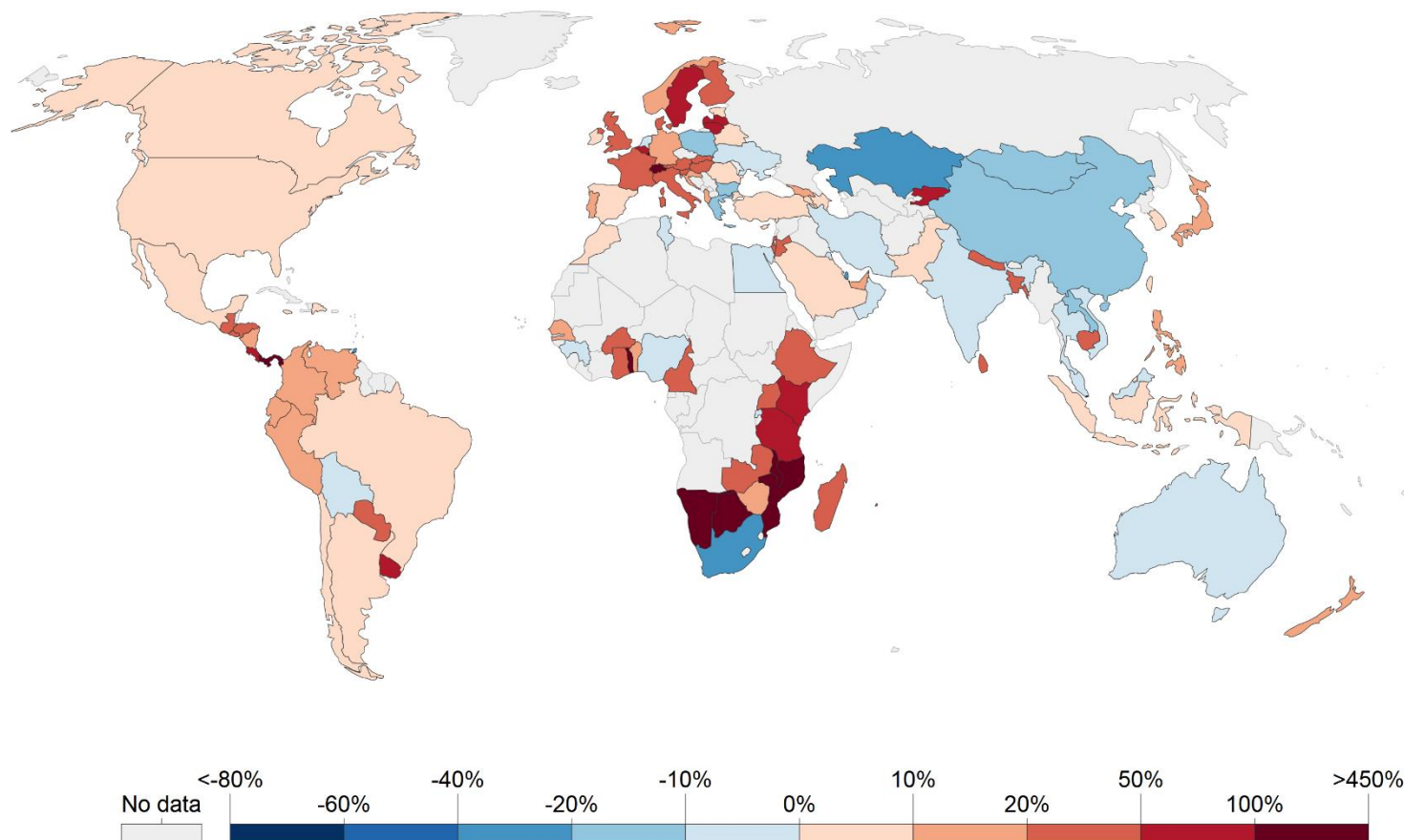
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

Emissioni di gas serra

CO₂ emissions embedded in trade, 2018

Share of carbon dioxide (CO₂) emissions embedded in trade, measured as emissions exported or imported as the percentage of domestic production emissions. Positive values (red) represent net importers of CO₂ (i.e. "20%" would mean a country imported emissions equivalent to 20% of its domestic emissions). Negative values (blue) represent net exporters of CO₂.

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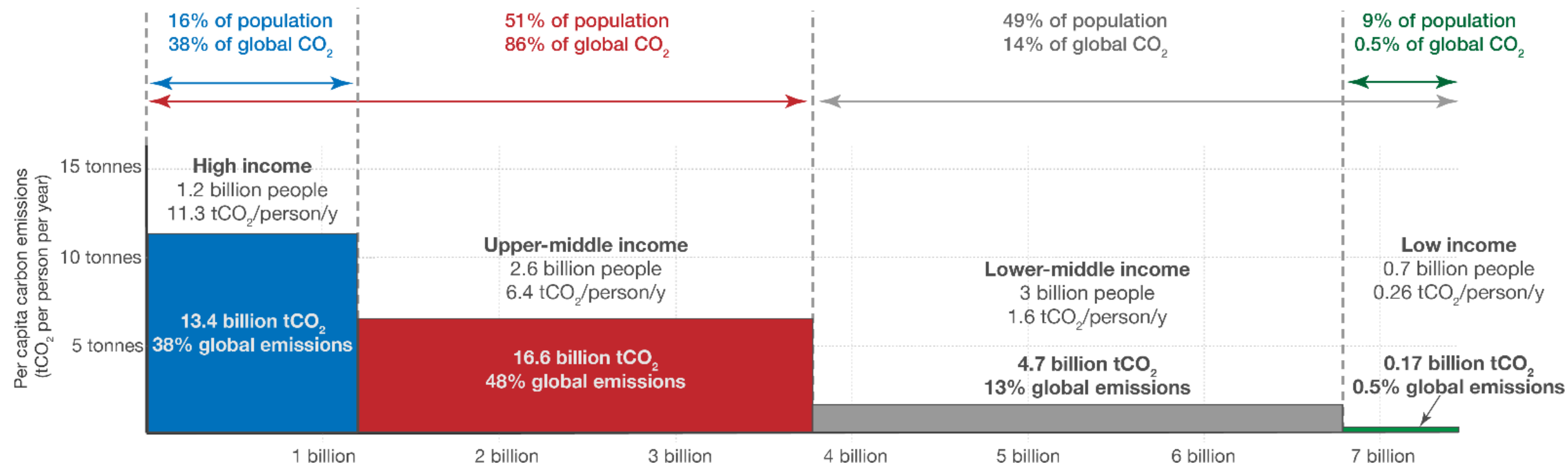
Source: Peters et al. (2012 updated); Global Carbon Project

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY



Emissioni di gas serra

By Income Group

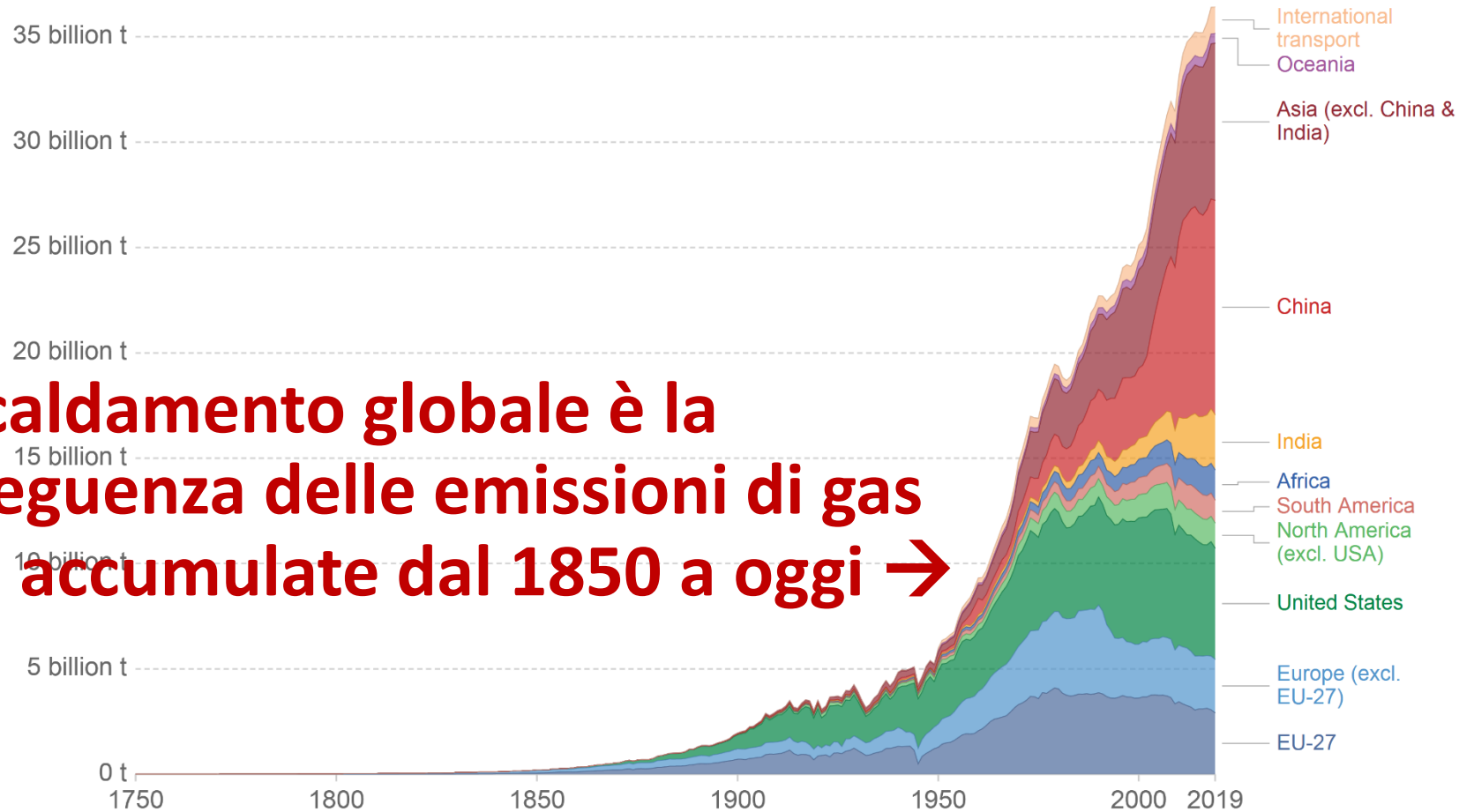


Emissioni di gas serra

Annual total CO₂ emissions, by world region

Our World
in Data

**Il riscaldamento globale è la
conseguenza delle emissioni di gas
serra accumulate dal 1850 a oggi →**



Source: Our World in Data based on the Global Carbon Project

Note: This measures CO₂ emissions from fossil fuels and cement production only – land use change is not included. 'Statistical differences' (included in the GCP dataset) are not included here.

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Emissioni di gas serra

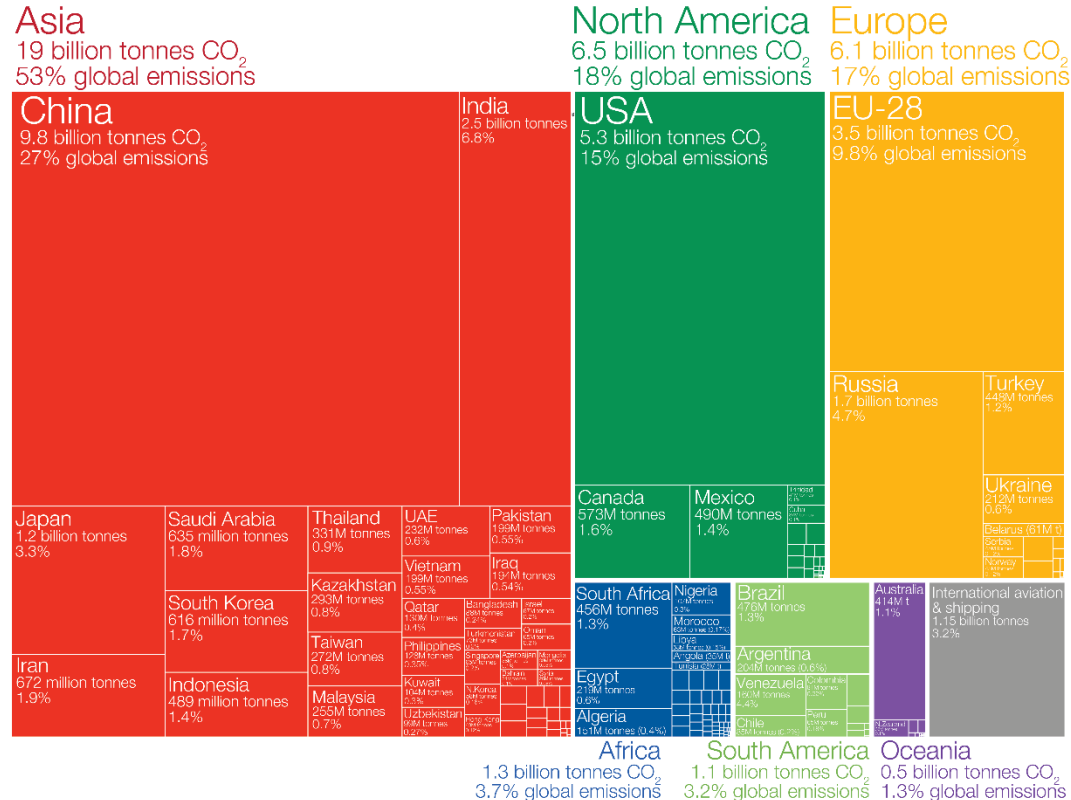
1751-2017

2019

Who emits the most CO₂?

Global carbon dioxide (CO₂) emissions were 36.2 billion tonnes in 2017.

Our World
in Data



Shown are national production-based emissions in 2017. Production-based emissions measure CO₂ produced domestically from fossil fuel combustion and cement, and do not adjust for emissions embedded in trade (i.e. consumption-based).

Figures for the 28 countries in the European Union have been grouped as the 'EU-28' since international targets and negotiations are typically set as a collaborative target between EU countries. Values may not sum to 100% due to rounding.

Data source: Global Carbon Project (GCP).

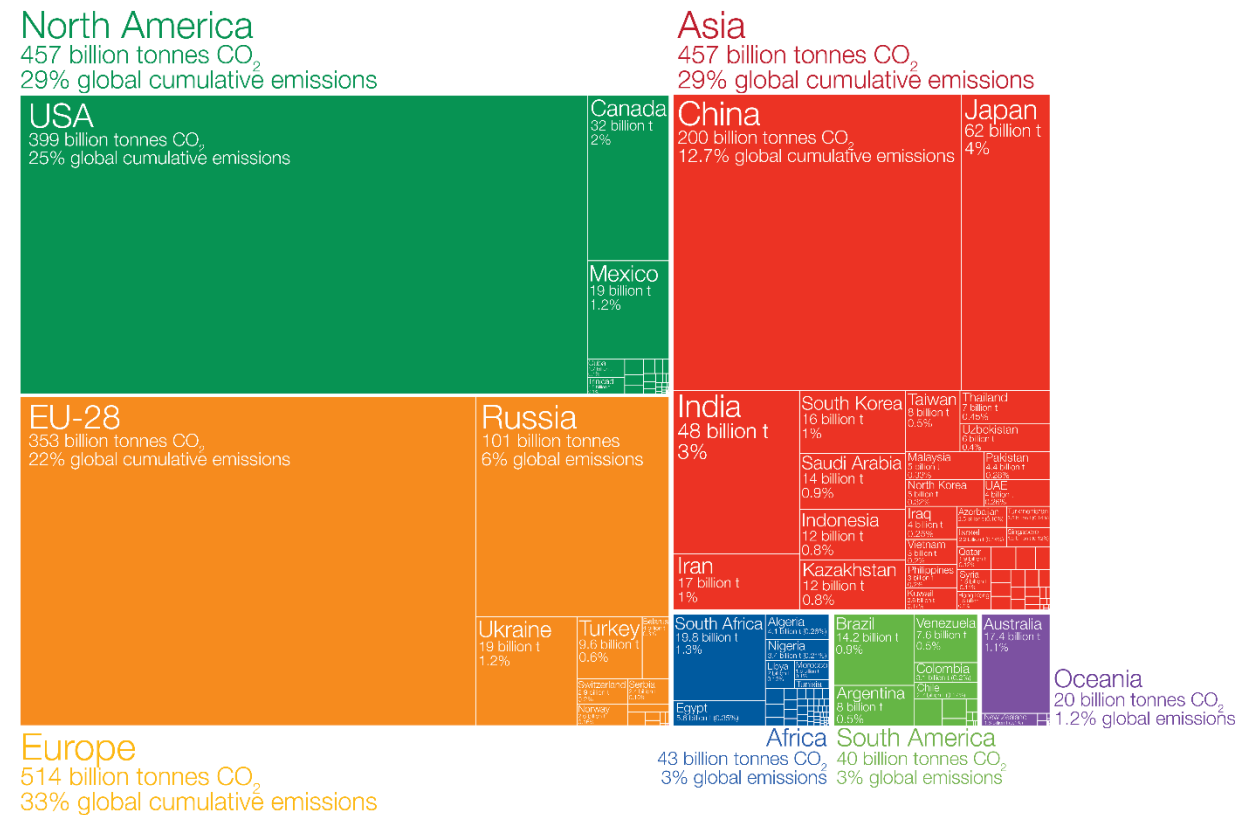
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Who has contributed most to global CO₂ emissions?

Our World
in Data

Cumulative carbon dioxide (CO₂) emissions over the period from 1751 to 2017. Figures are based on production-based emissions which measure CO₂ produced domestically from fossil fuel combustion and cement, and do not correct for emissions embedded in trade (i.e. consumption-based). Emissions from international travel are not included.



Figures for the 28 countries in the European Union have been grouped as the 'EU-28' since international targets and negotiations are typically set as a collaborative target between EU countries. Values may not sum to 100% due to rounding.

Data source: Calculated by Our World in Data based on data from The Global Carbon Project (GCP) and Carbon Dioxide Analysis Center (CDIAC). 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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