IUSS
Scuola Universitaria Superiore Pavia

CLIMA: Cosa ci aspetta?

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CARISMA Centre

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

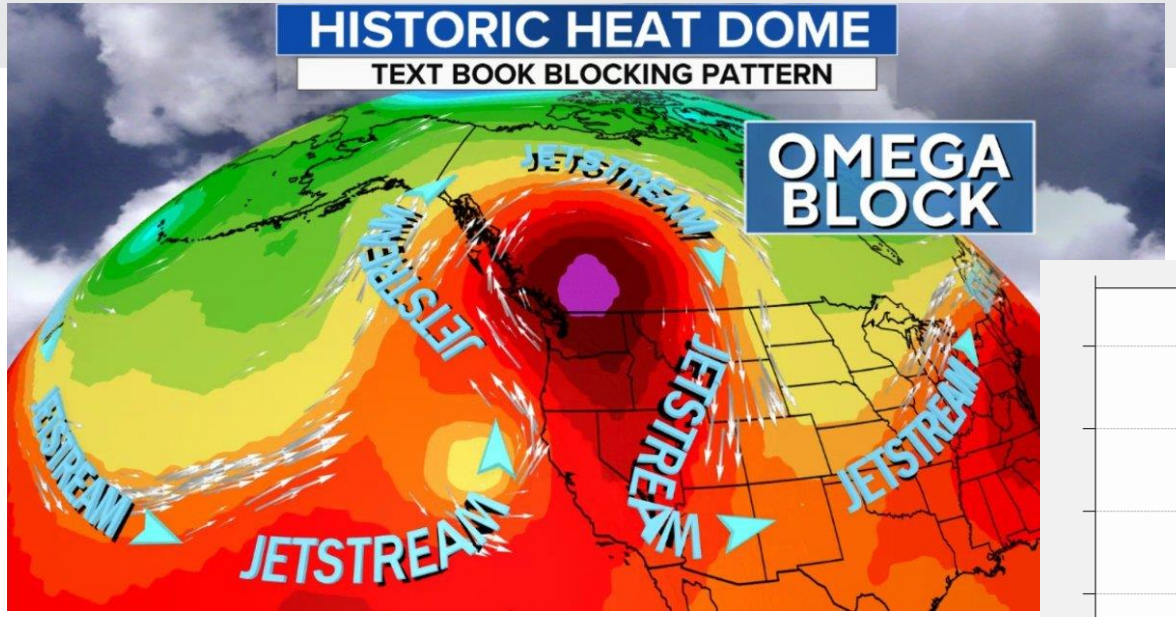
[https://www.bbc.com/news/world-us-canada-57678054]

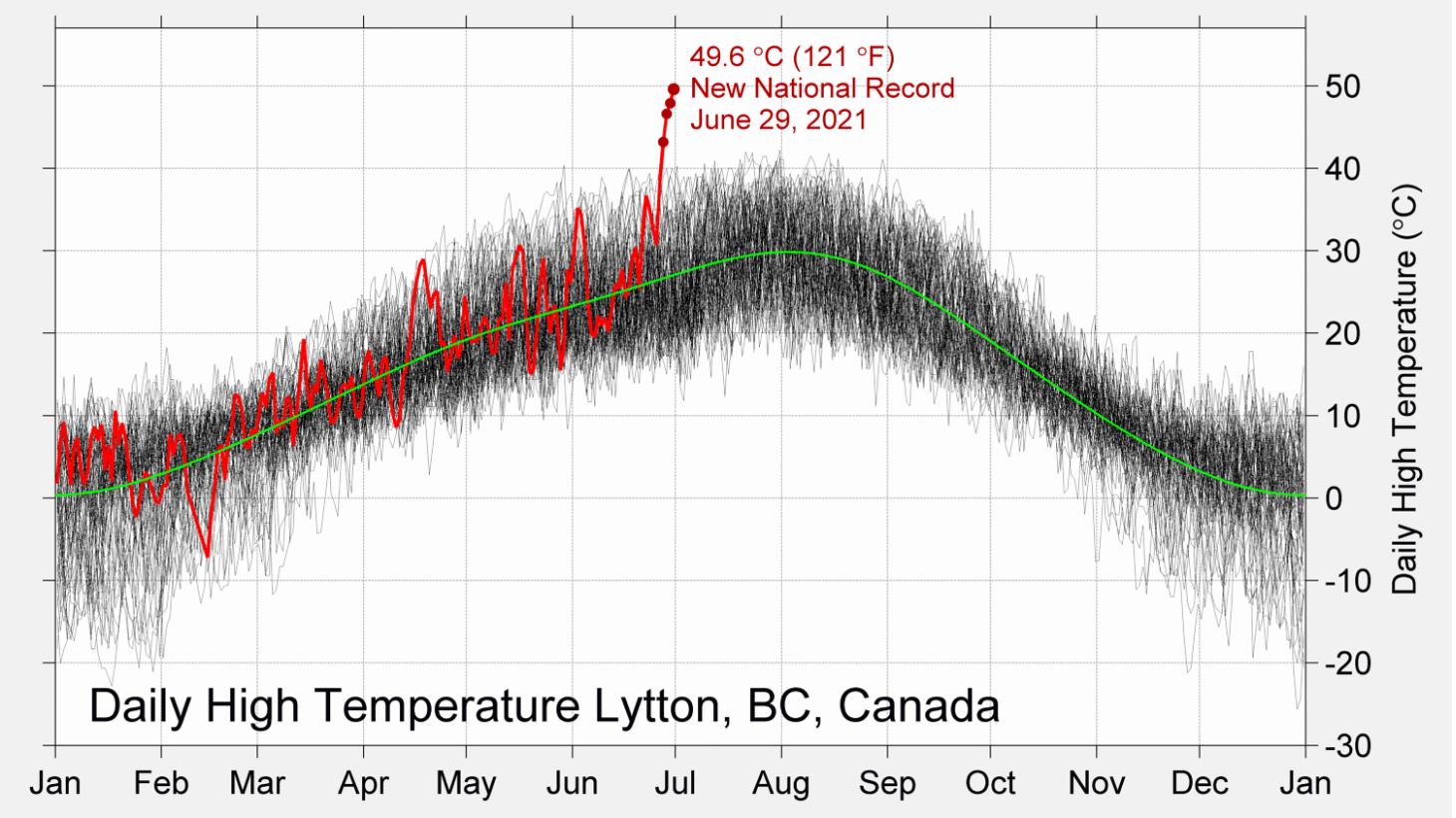
Record heatwave may have killed 500 people in western Canada

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]

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



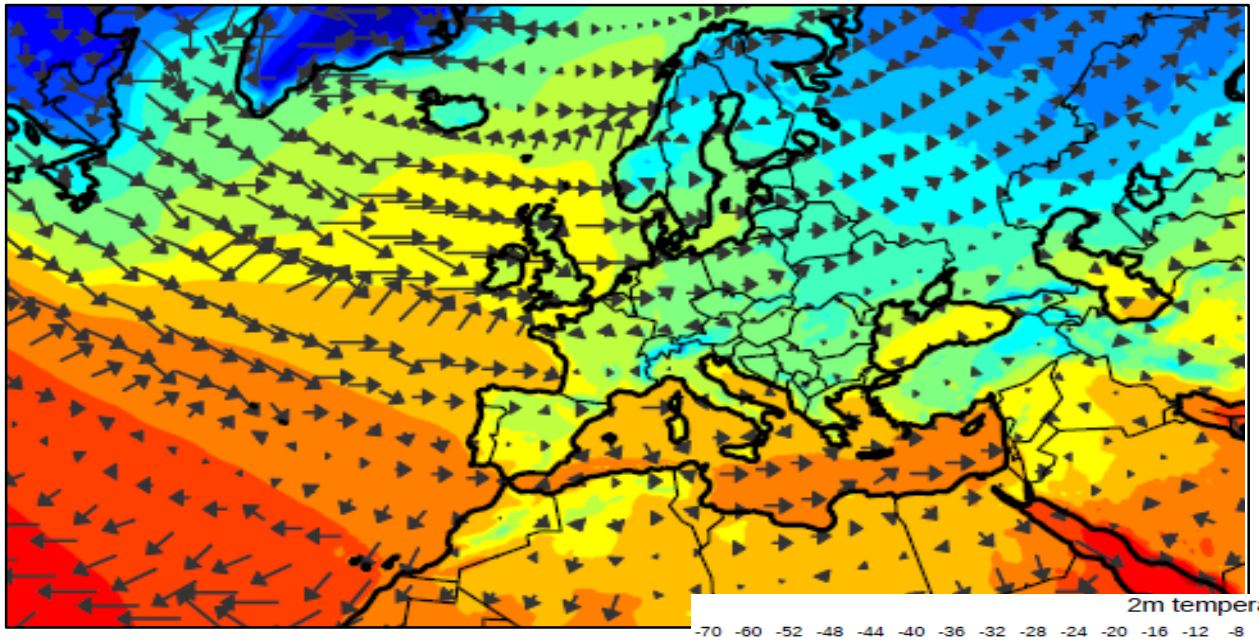


Cos’è il clima? Quale relazione con il meteo?

Meteo: stato dell’atmosfera in questo momento.

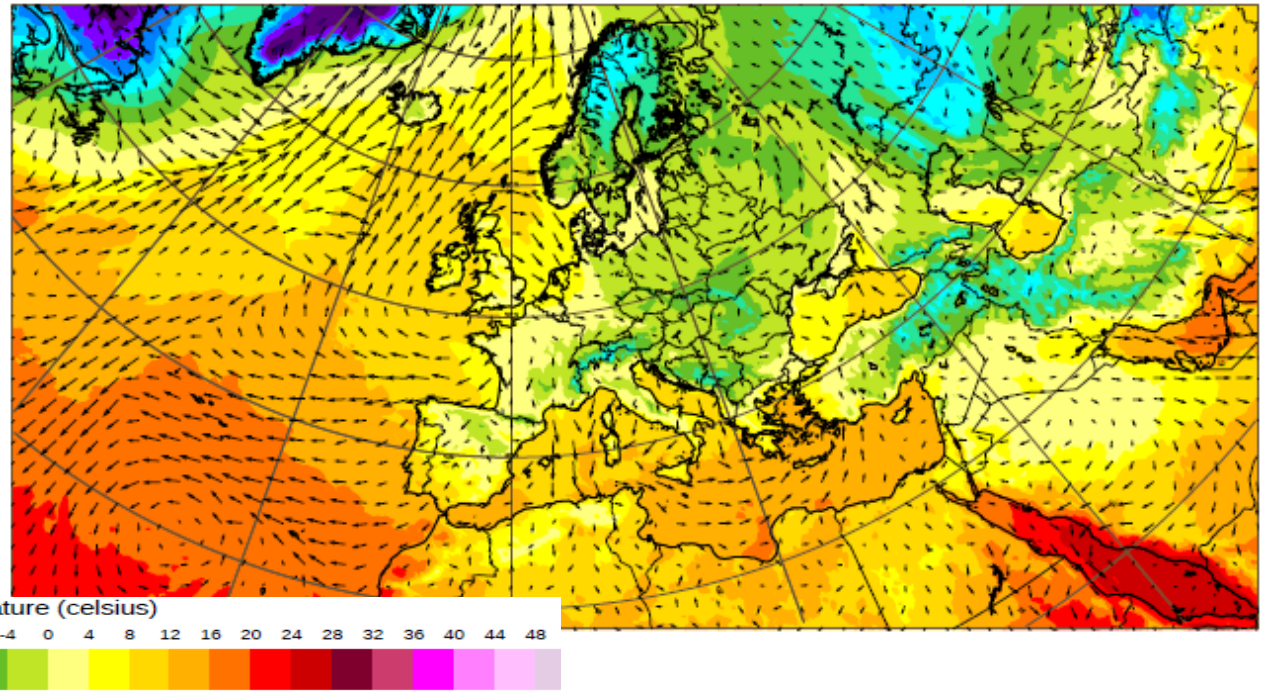
Clima: stato medio dell’atmosfera su lunghi periodi (30 anni).

[dati ERA5] climatologia di gennaio



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

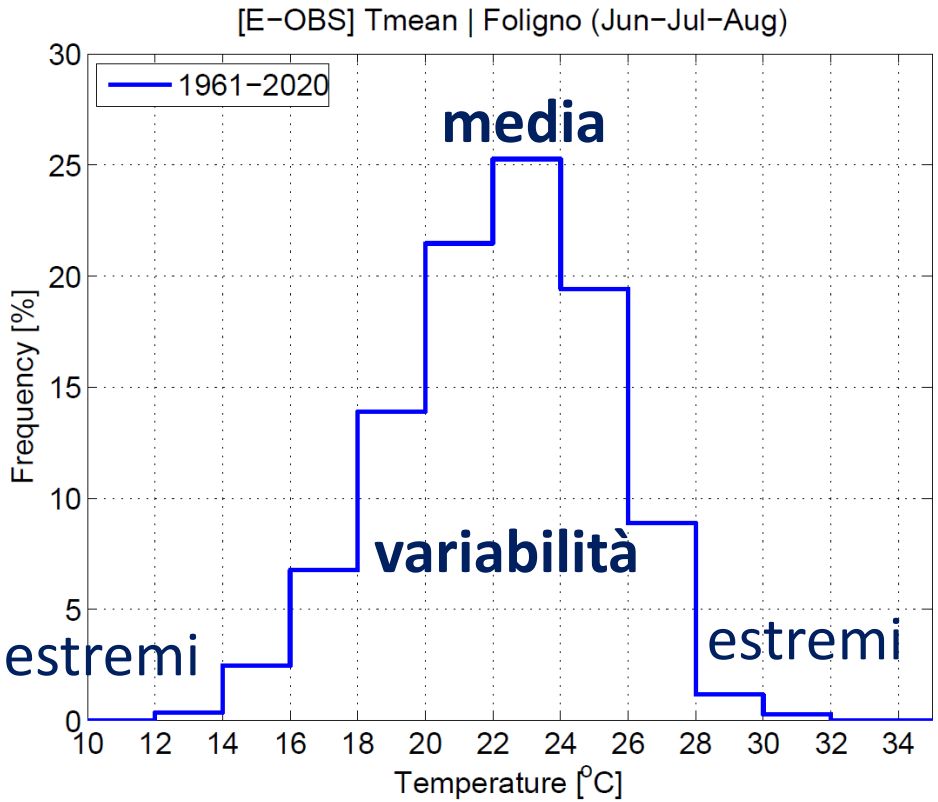
[previsioni ECMWF] 21 gennaio 2022



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

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

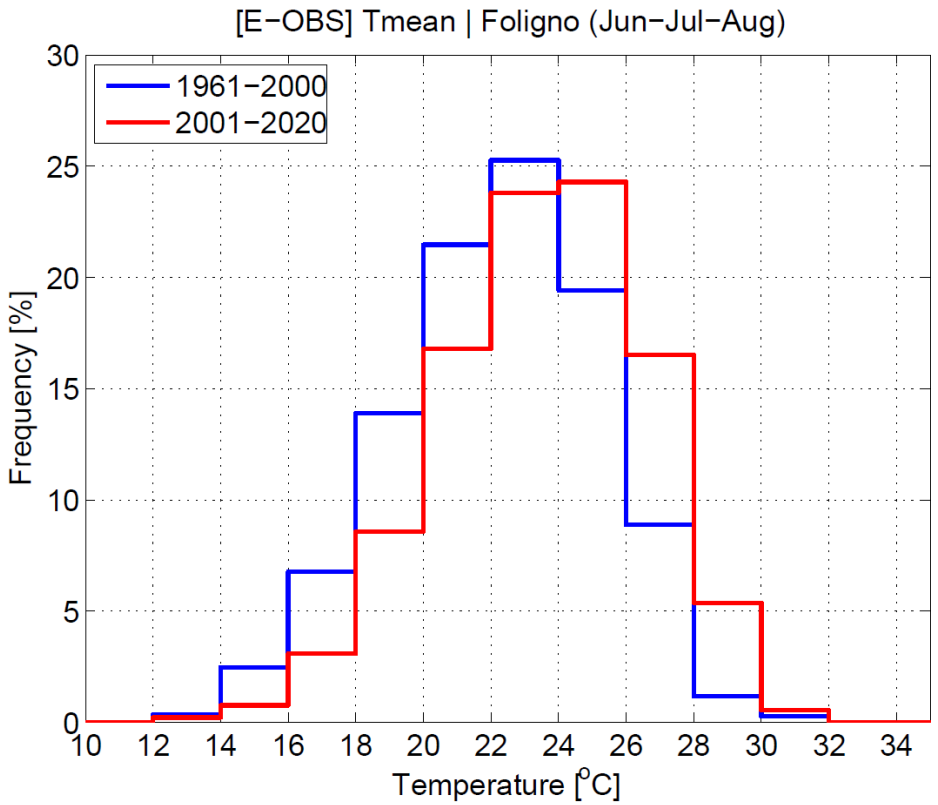
Definizione statistica: il clima è definito dalle caratteristiche (es. media, variabilità) della distribuzione di probabilità delle variabili climatiche (es. temperatura, precipitazione) → il clima è la probabilità di osservare il meteo.



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

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

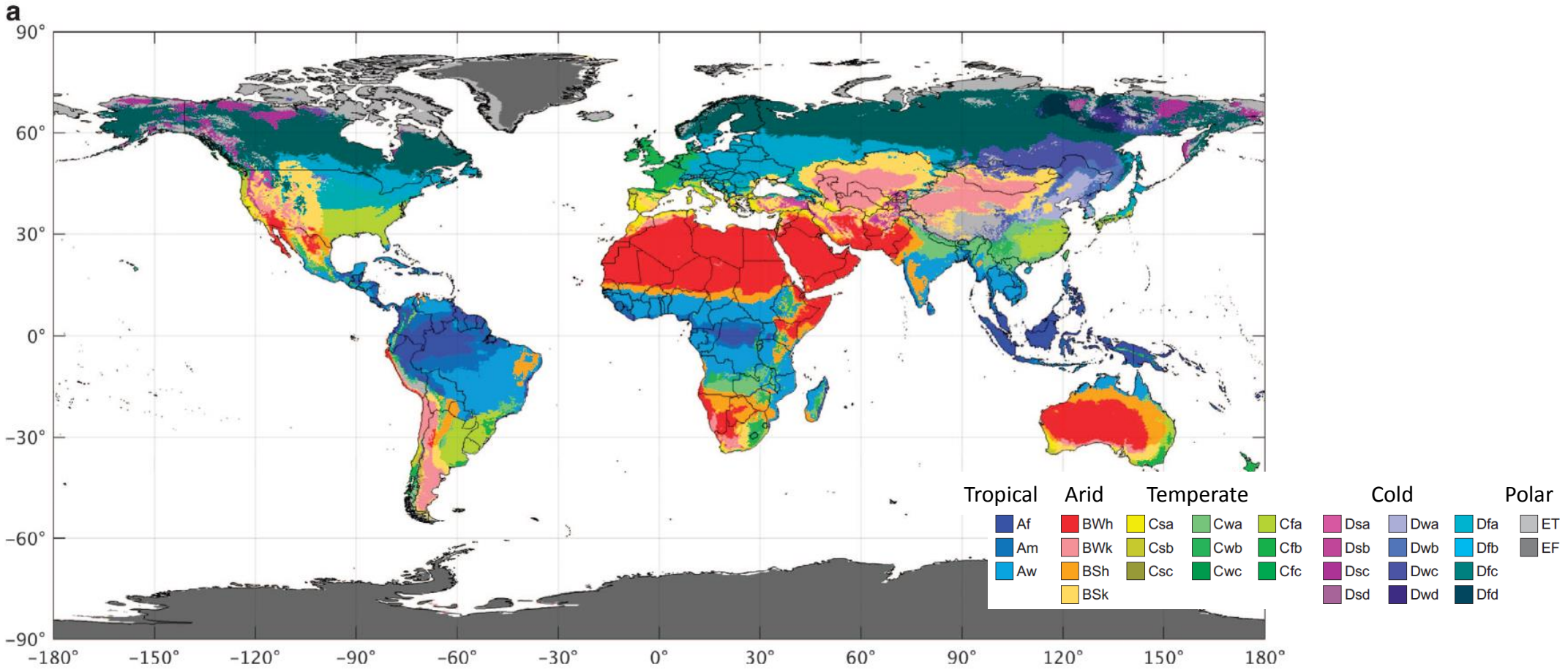
Cambiamento climatico: cambiamento statisticamente significativo nella distribuzione di probabilità delle variabili climatiche.



[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

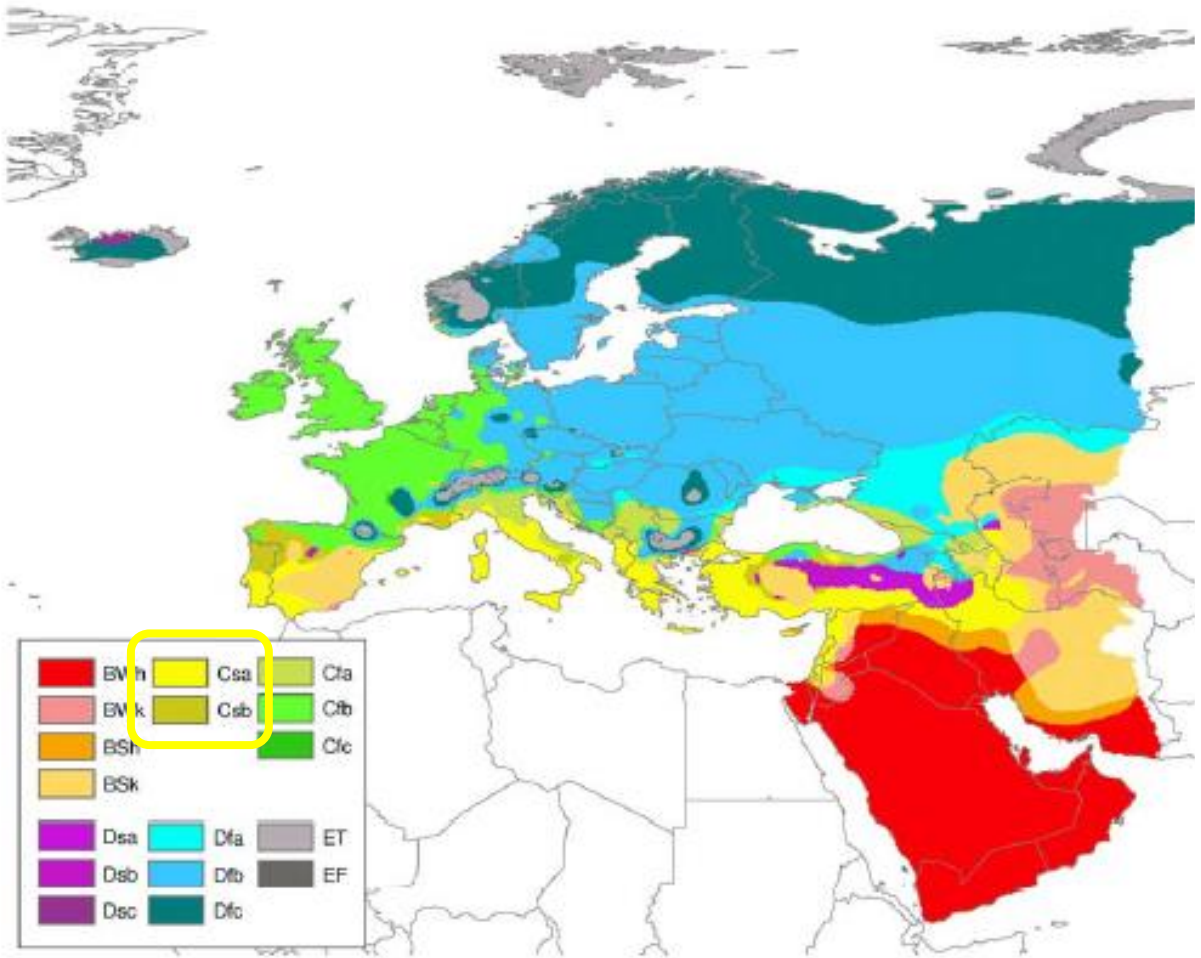


Fig. 8. Köppen-Geiger climate type map of Europe.

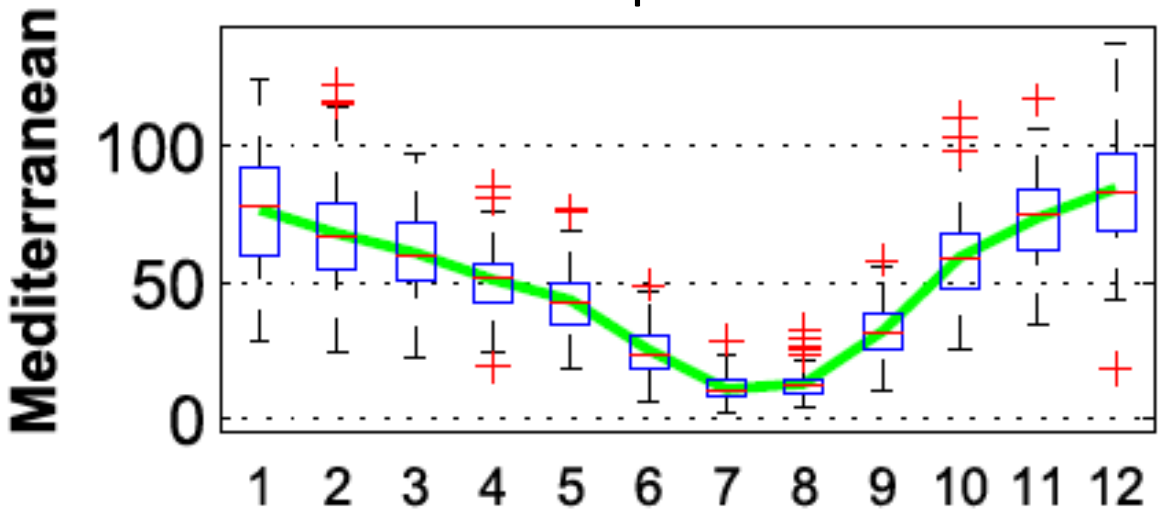
Table 1. Description of Köppen climate symbols and defining criteria.

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

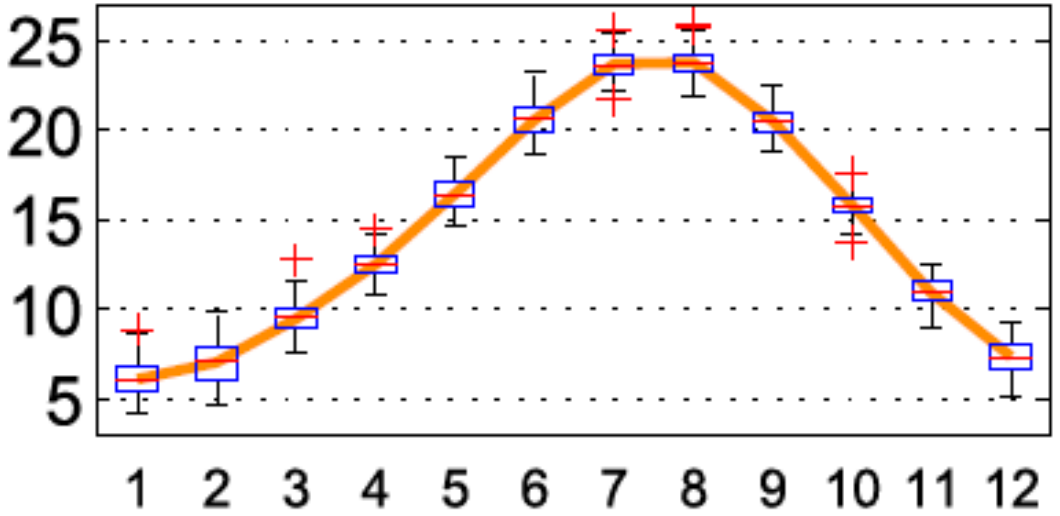
[Peel et al. 2007, www.hydrol-earth-syst-sci.net/11/1633/2007/]

Clima Mediterraneo

Precipitazione



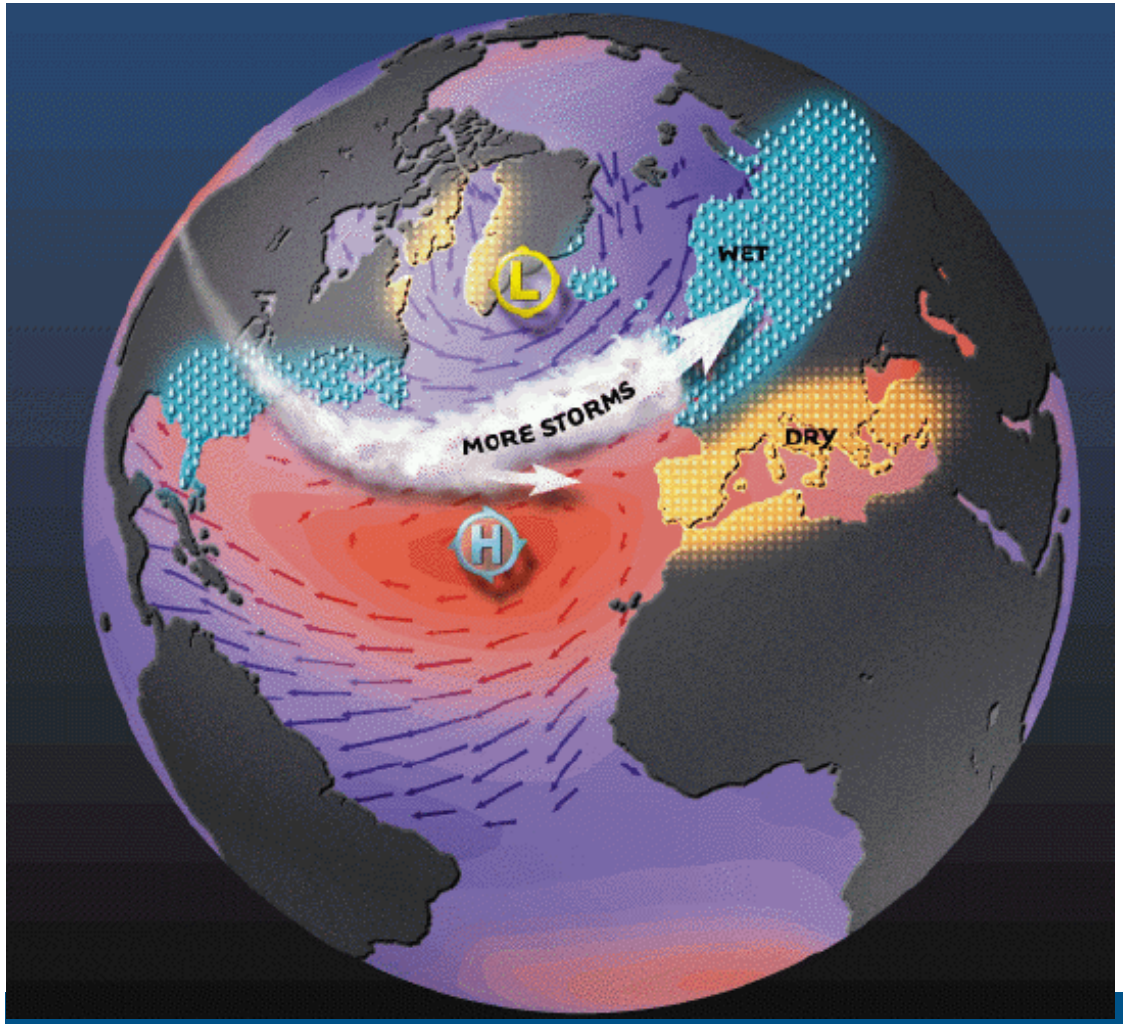
Temperatura

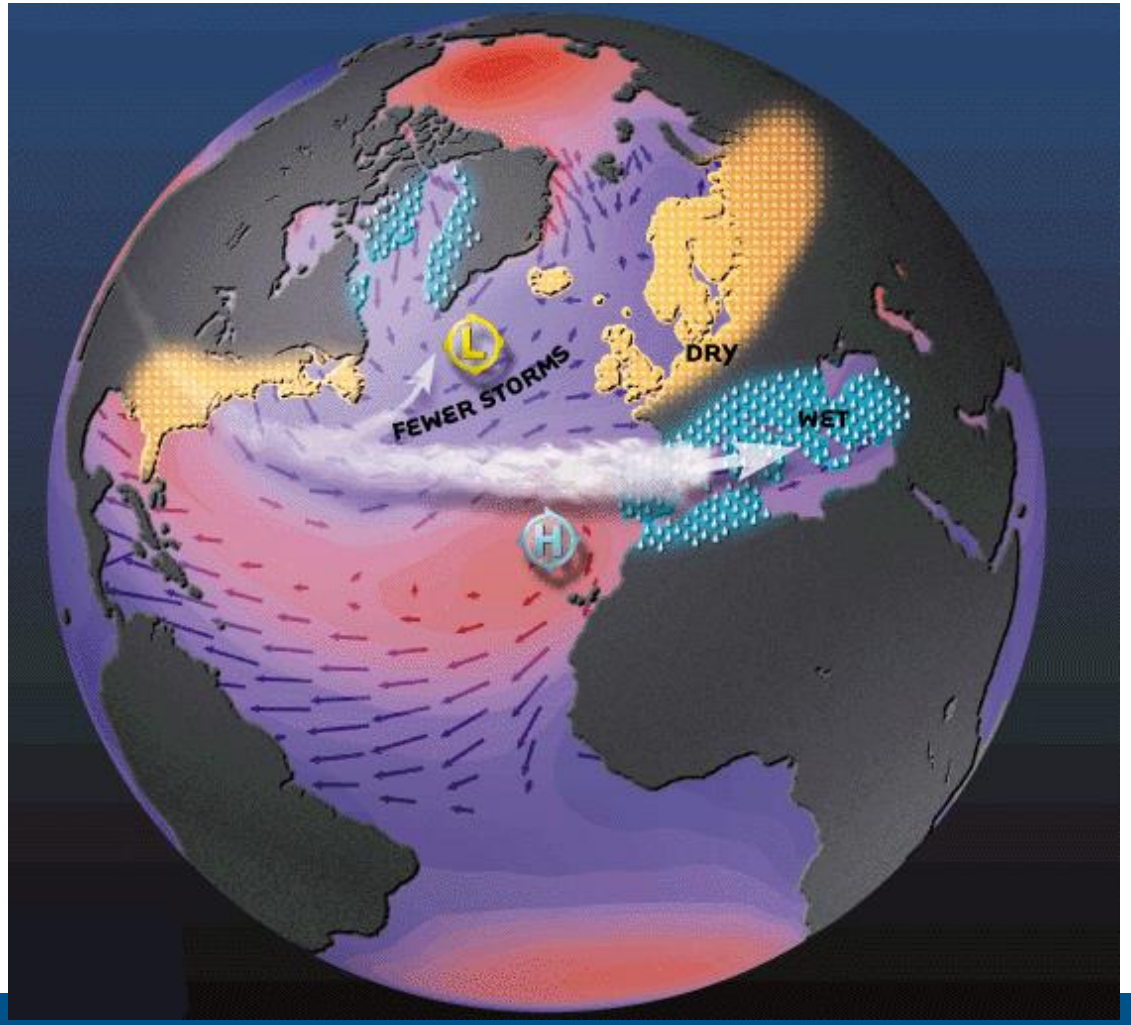


[Seager et al. (2019) https://journals.ametsoc.org/view/journals/clim/32/10/jcli-d-18-0472.1.xml]

Clima Mediterraneo

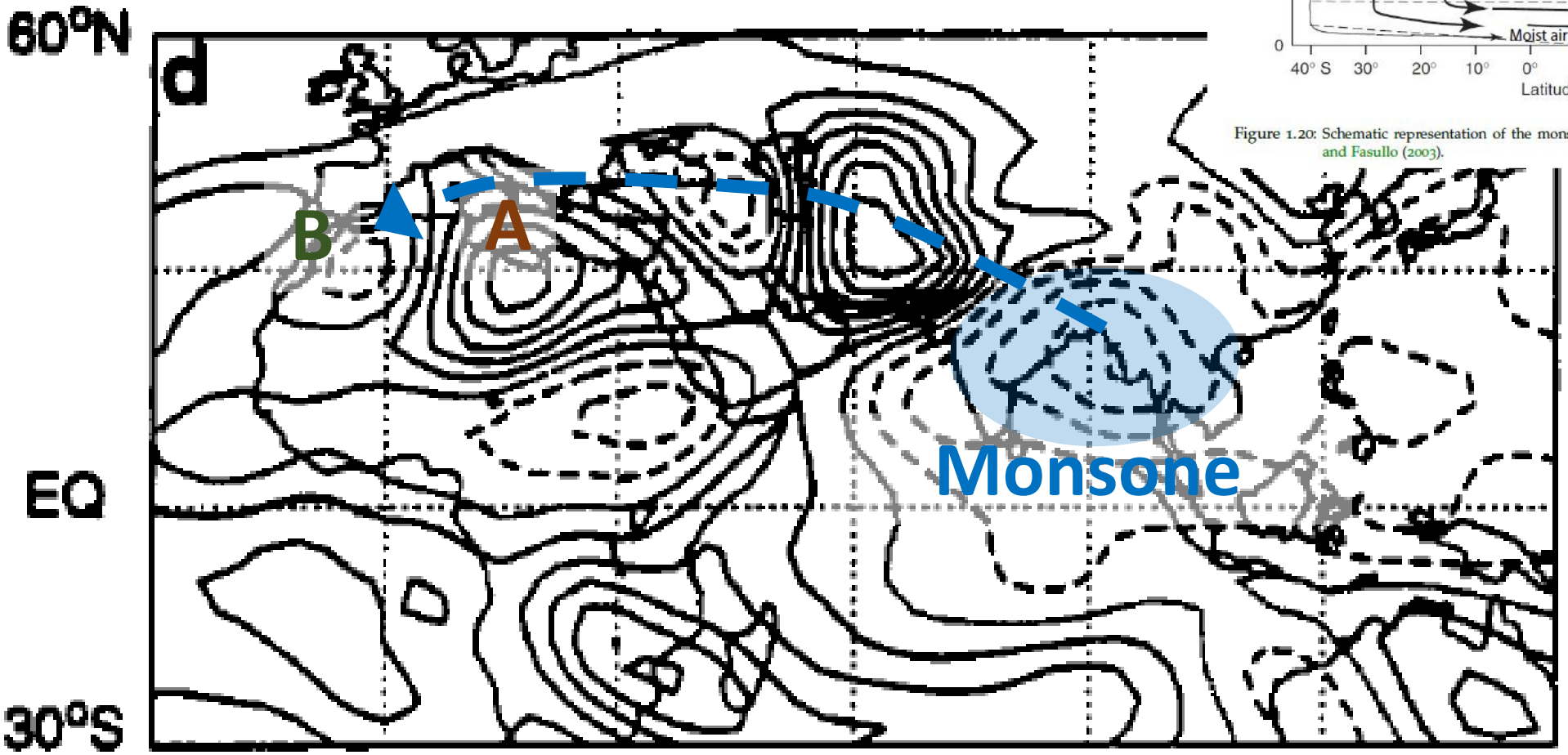
North Atlantic Oscillation





Clima Mediterraneo

Indian Monsoon



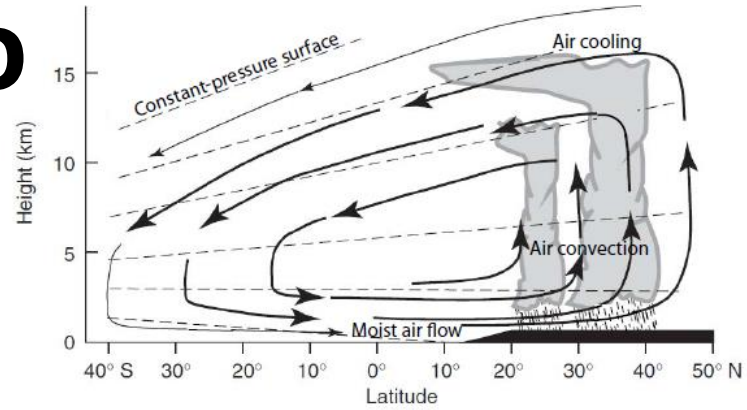
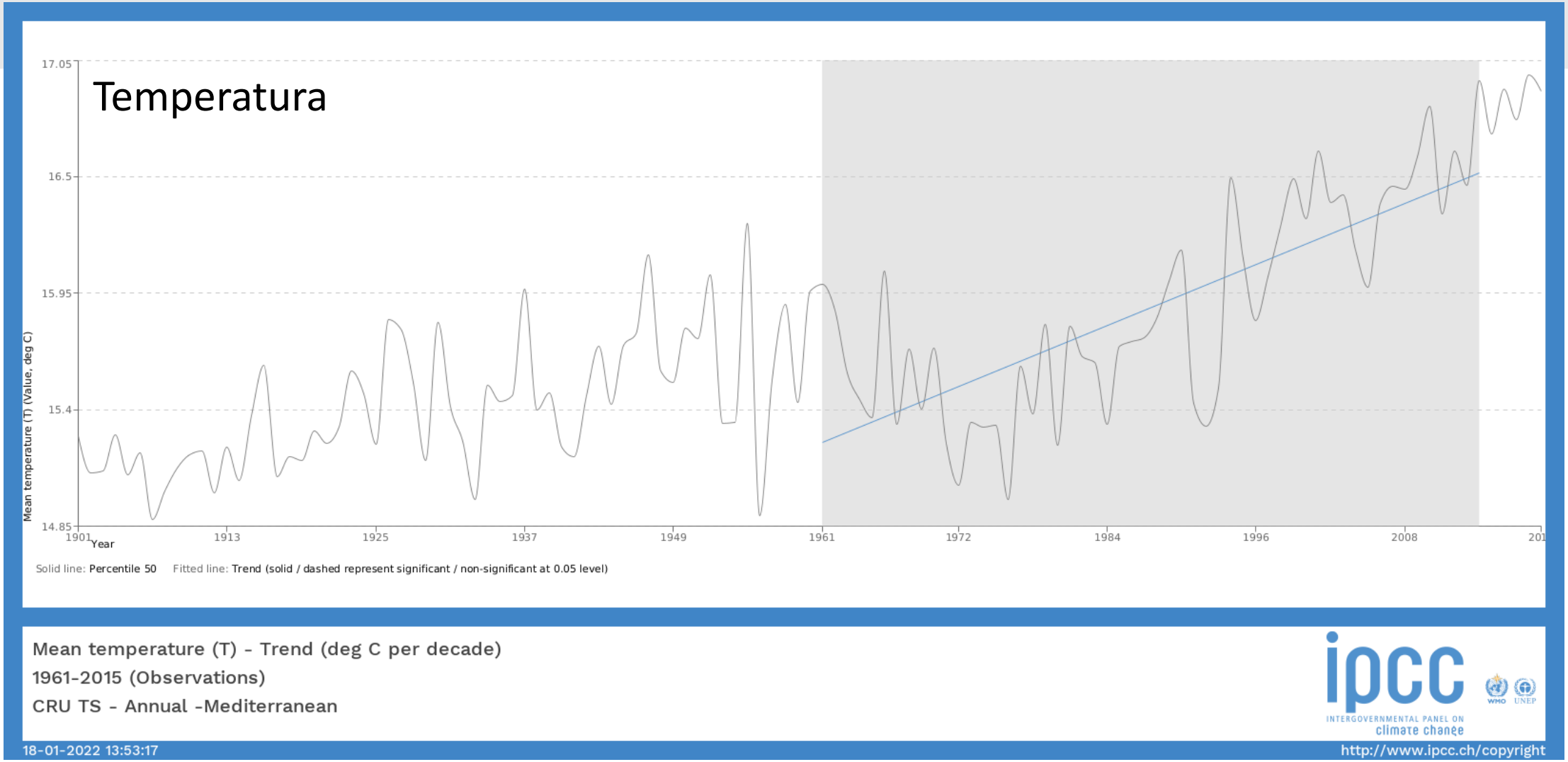


Figure 1.20: Schematic representation of the monsoon circulation. Adapted from Webster and Fasullo (2003).

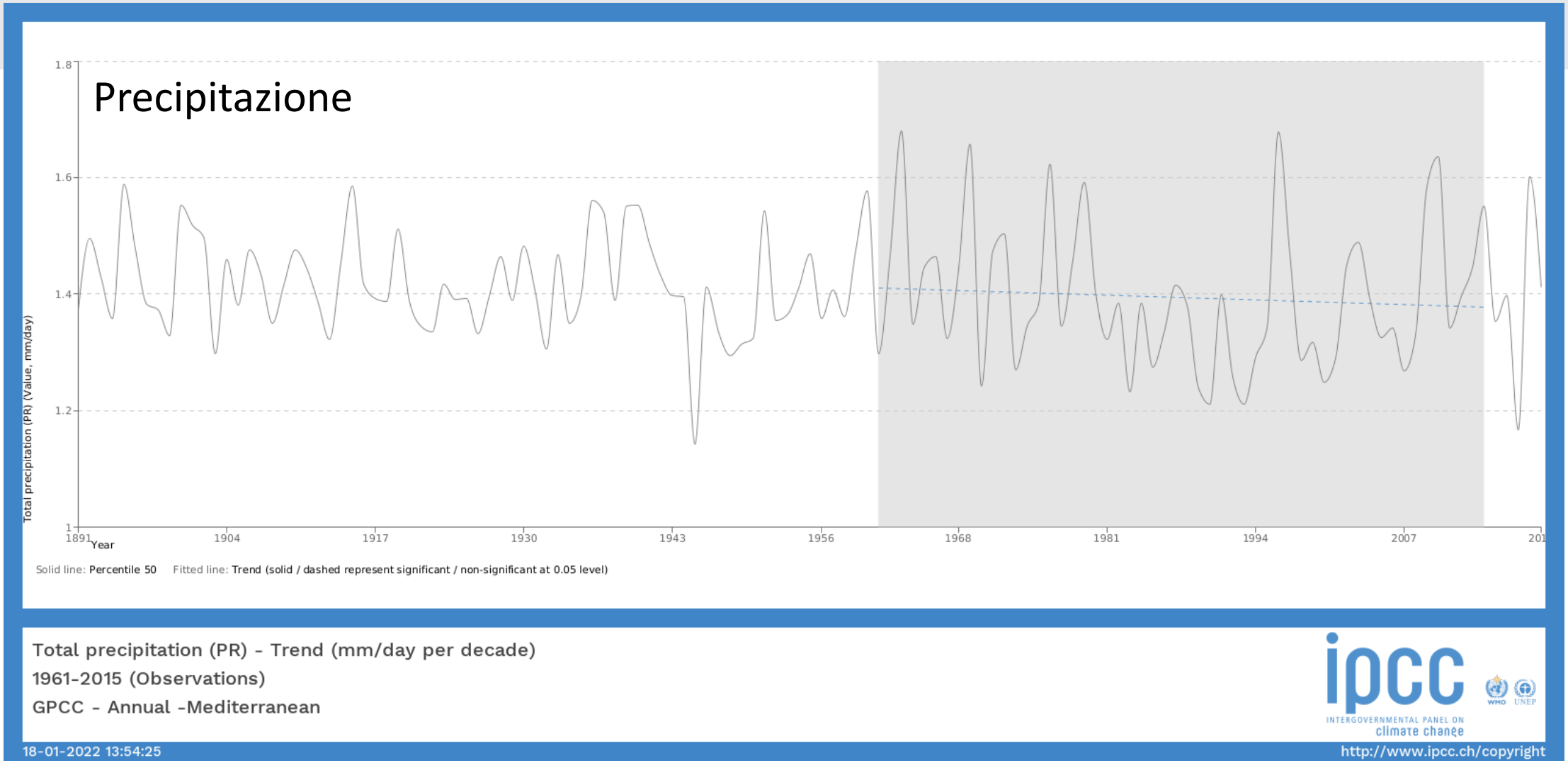
Rodwell & Hoskins 1996 [https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.49712253408]

Clima Mediterraneo, in evoluzione



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

Clima Mediterraneo, in evoluzione



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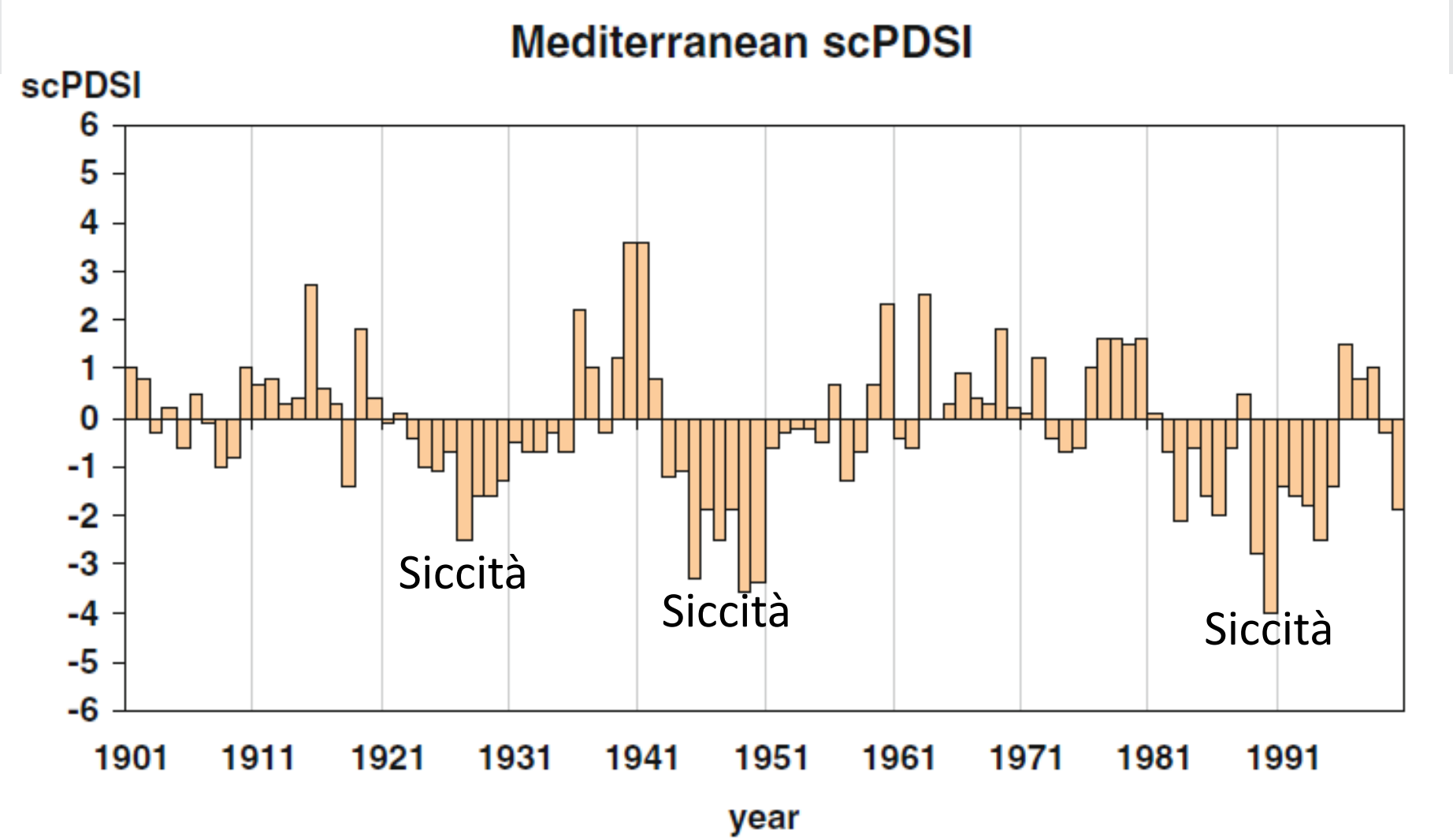
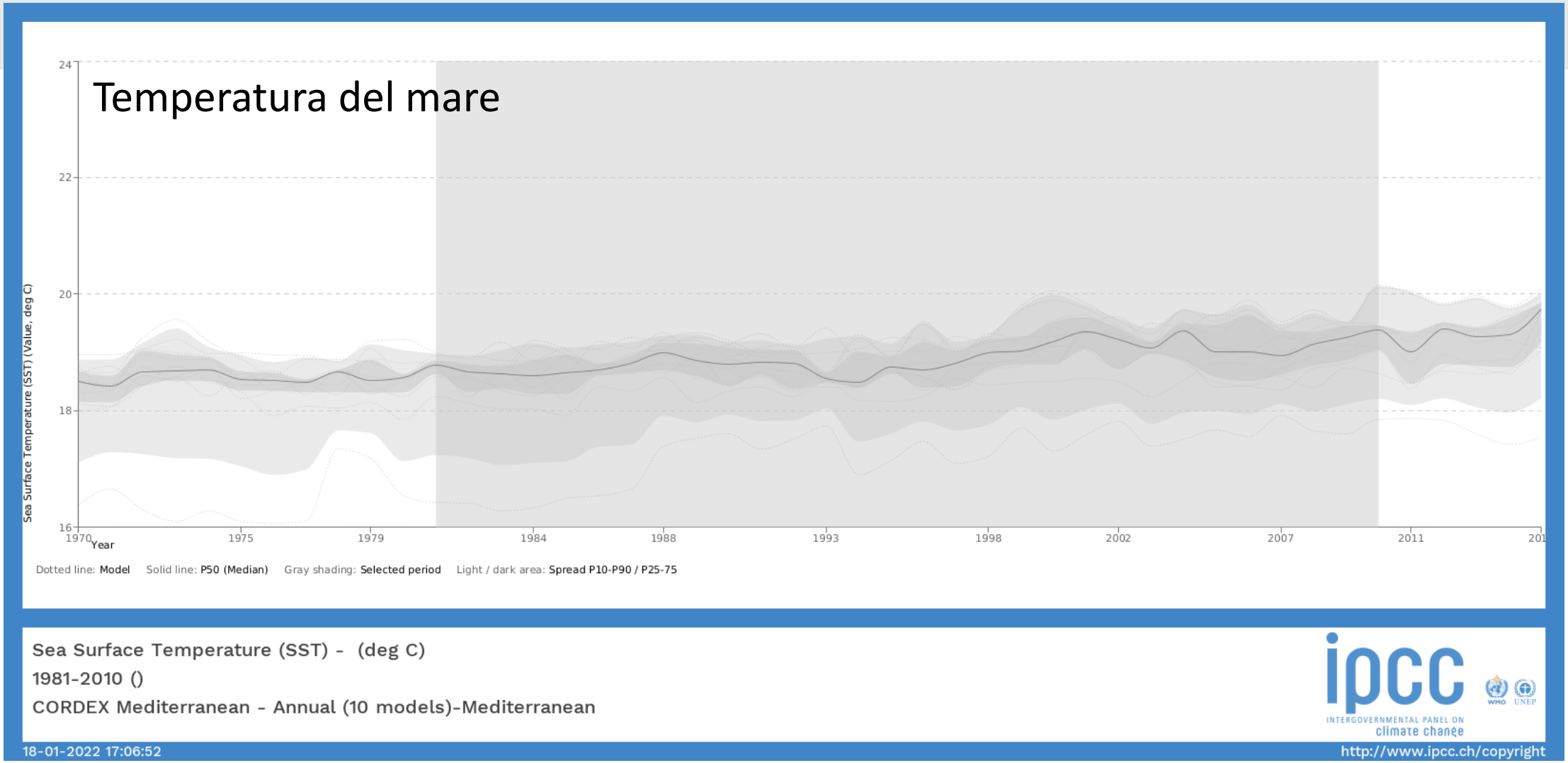


[Ulbrich U. et al. (2013) https://doi.org/10.1007/978-94-007-5781-3_2]

Clima Mediterraneo, in evoluzione



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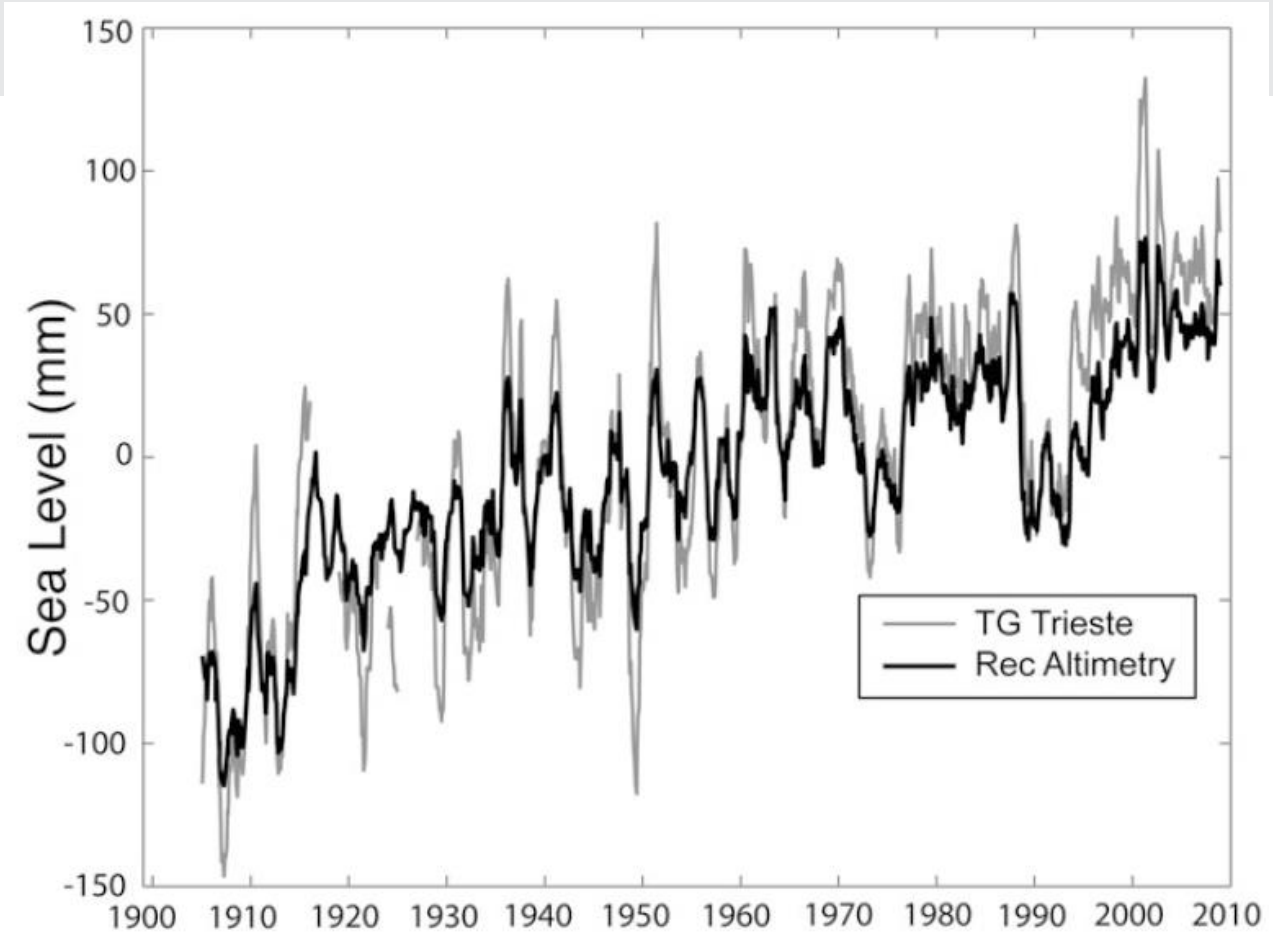
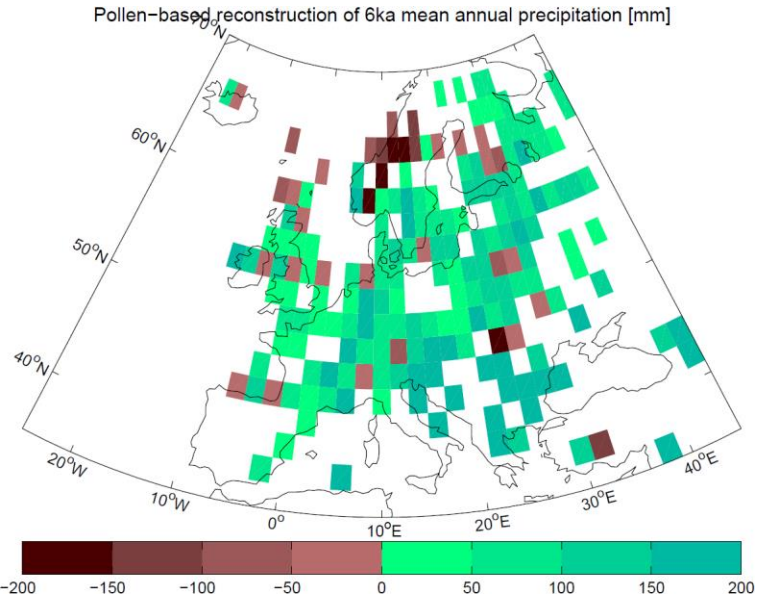


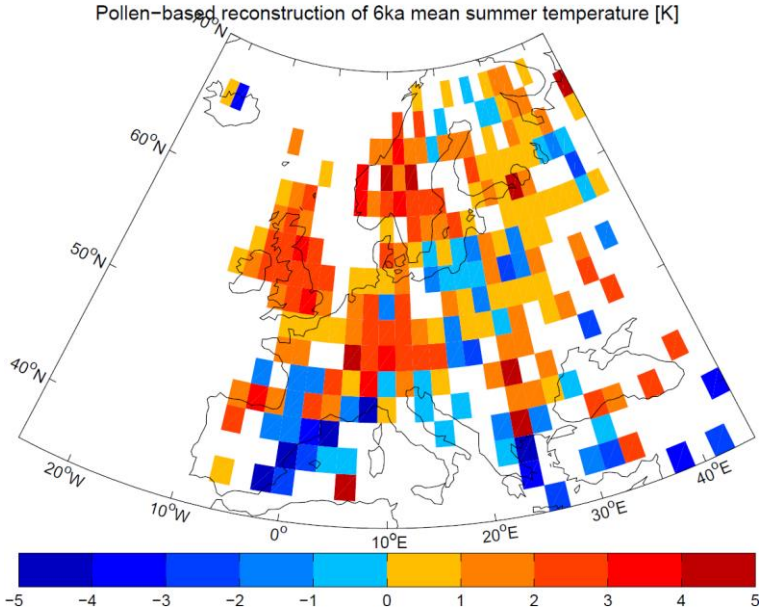
Fig. 2.7 Sea level rise in the Mediterranean from the tide-gauge in Trieste (corrected for atmospheric pressure and glacio-isostatic rebound) (*gray line*); and reconstruction of basin wide sea level from altimetry and tide gauges (*black*)

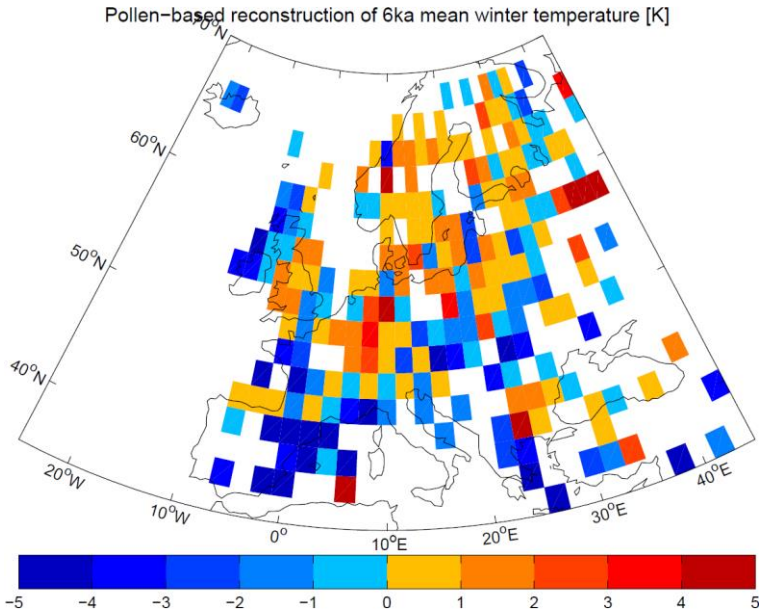
[Ulbrich U. et al. (2013) https://doi.org/10.1007/978-94-007-5781-3_2]

Cambiamenti climatici

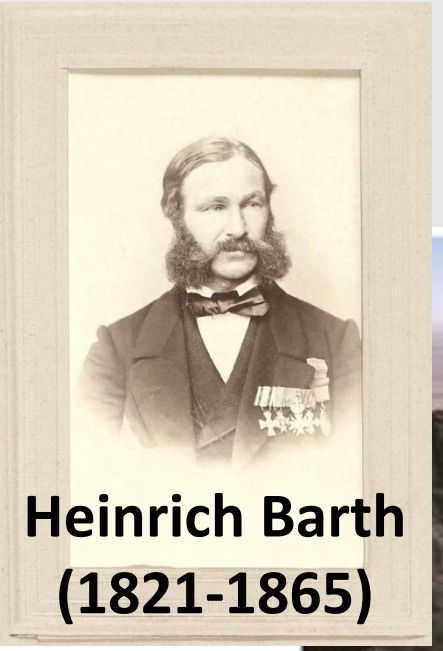
Medio Olocene (10-5 mila anni fa)



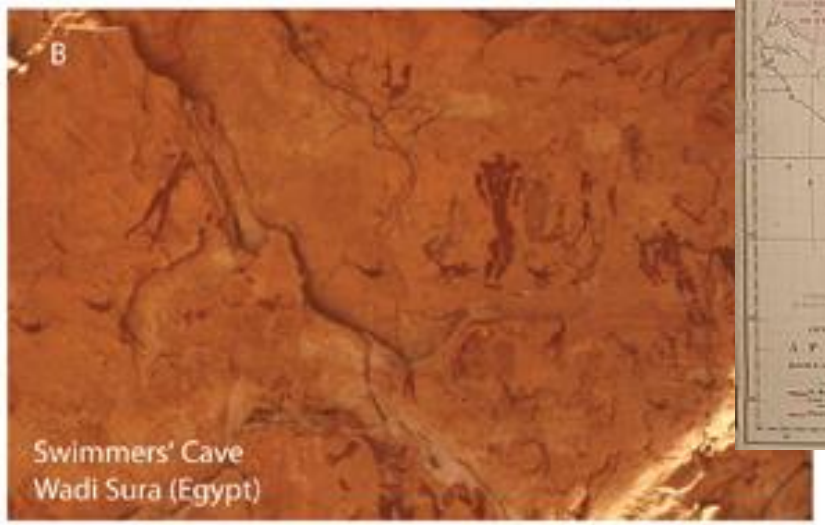


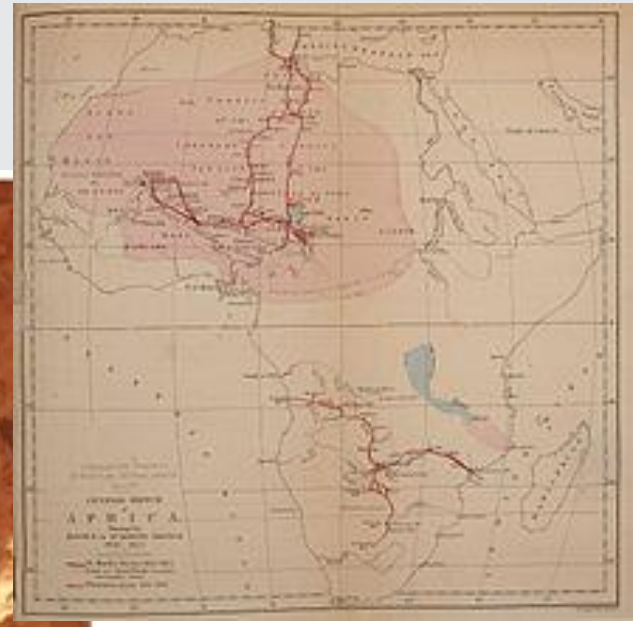


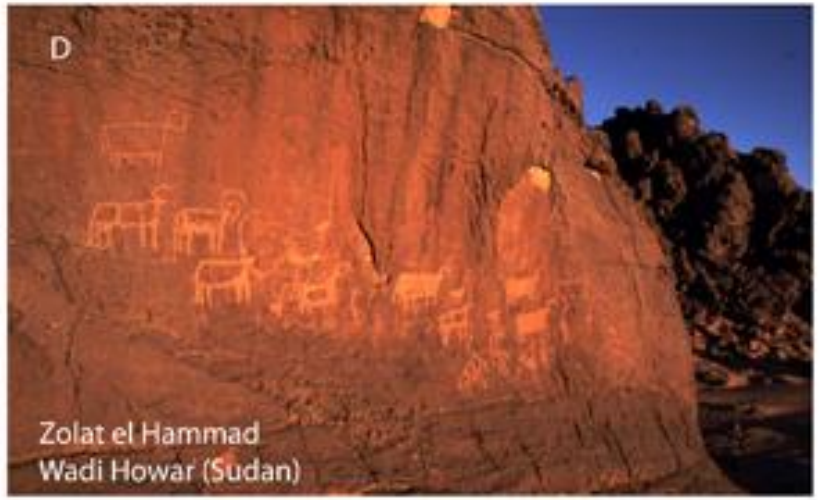
Cambiamenti climatici



Heinrich Barth
(1821-1865)







Cambiamenti climatici

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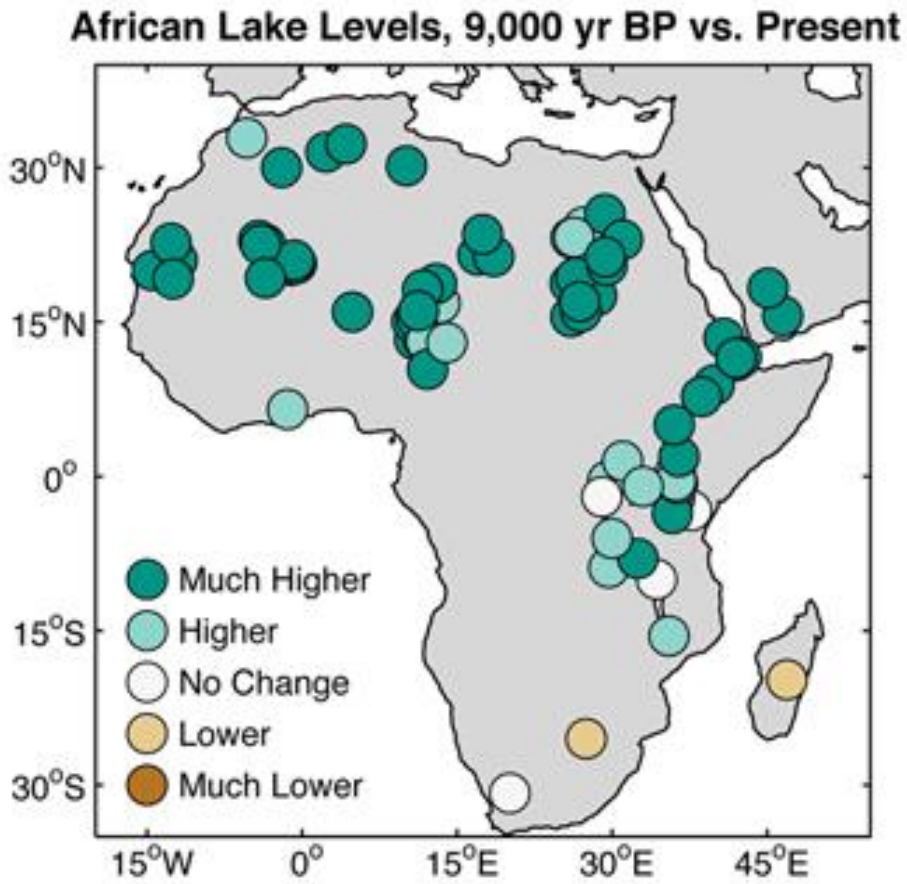
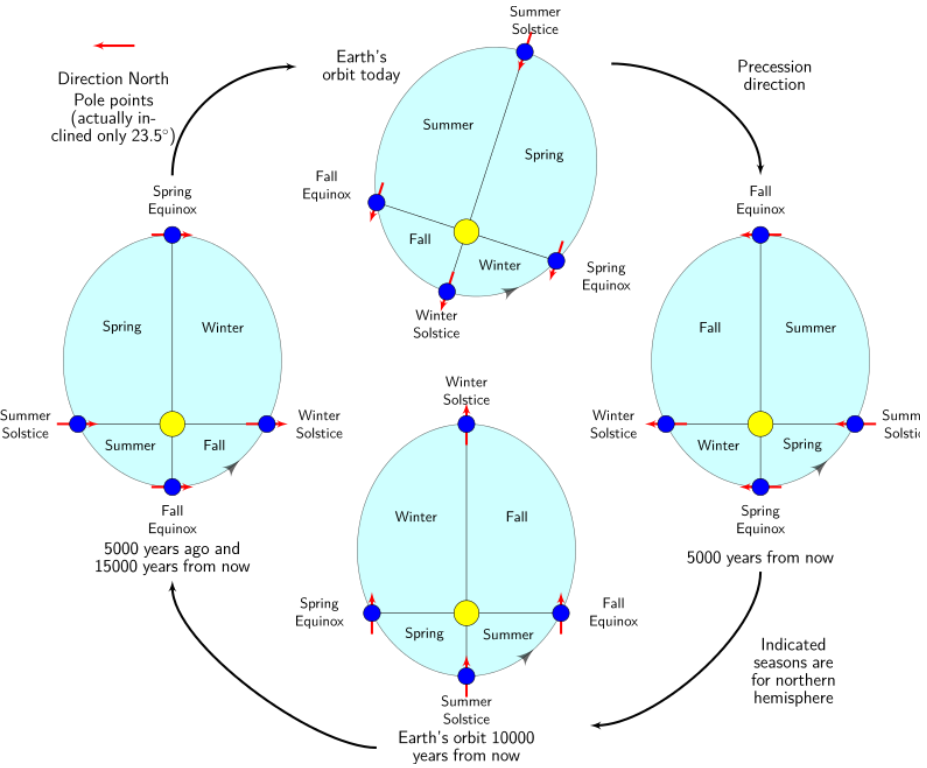
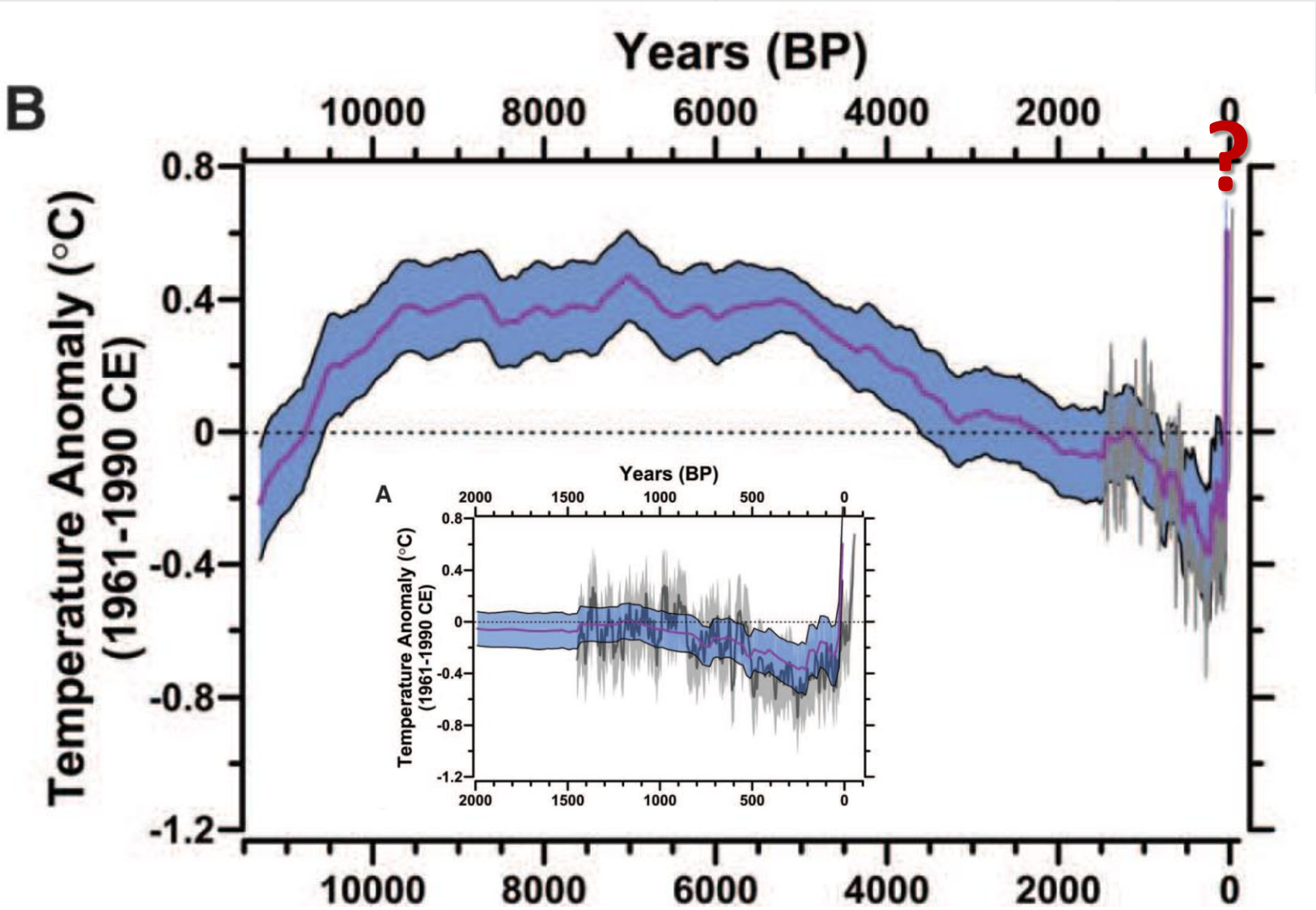


[https://www.nature.com/scitable/knowledge/library/green-sahara-african-humid-periods-paced-by-82884405]

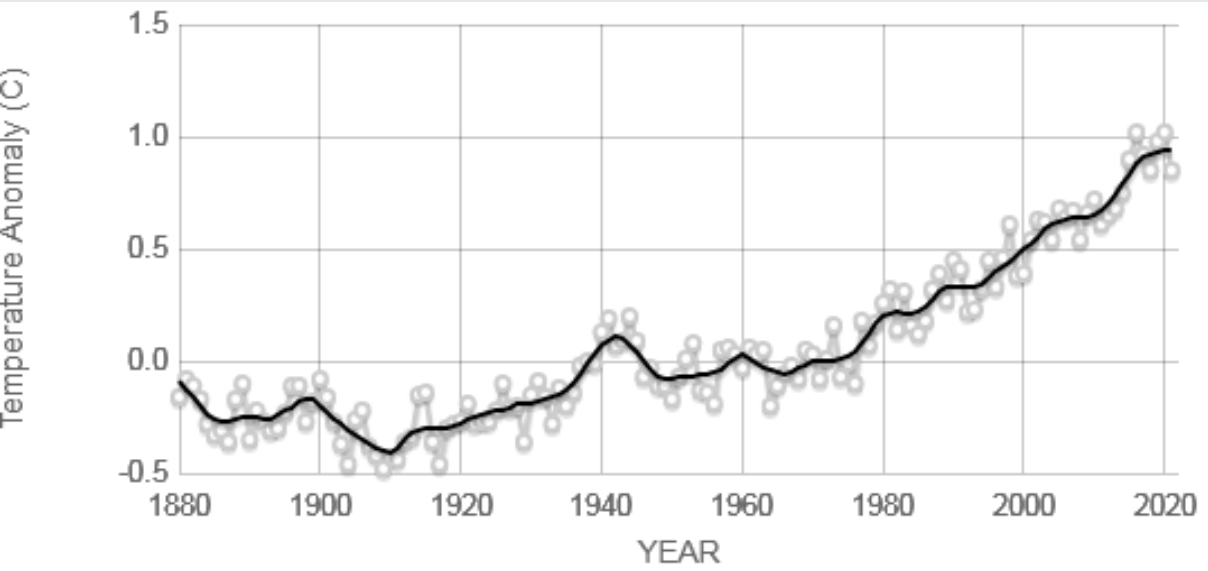
Cambiamenti climatici, cause (naturali?)



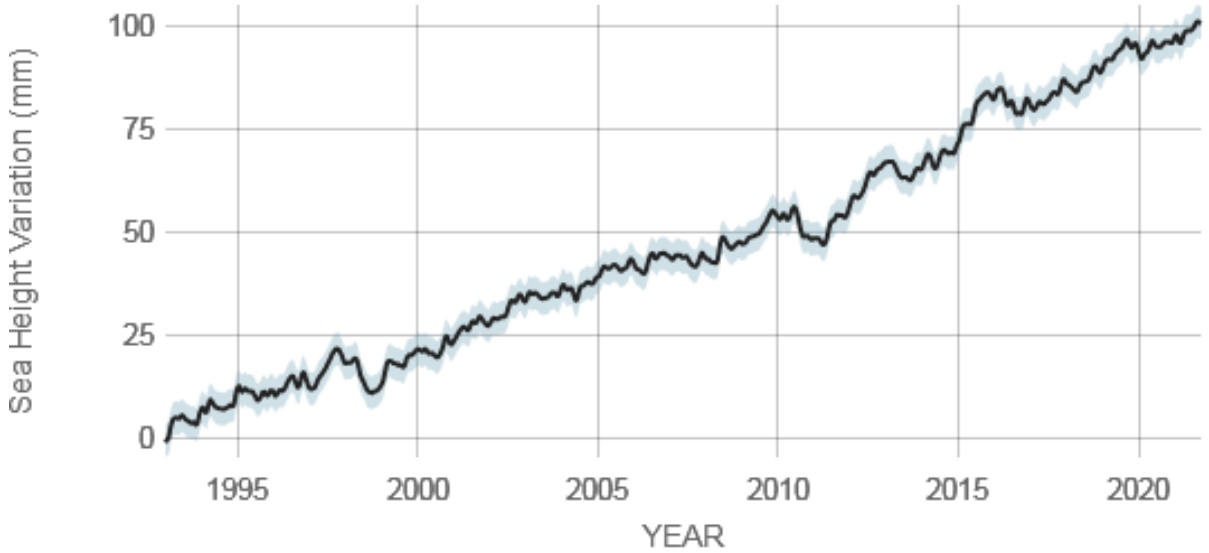


[Marcott et al. 2013, https://www.science.org/doi/10.1126/science.1228026]

Cambiamenti climatici, cause (naturali?)



Source: climate.nasa.gov



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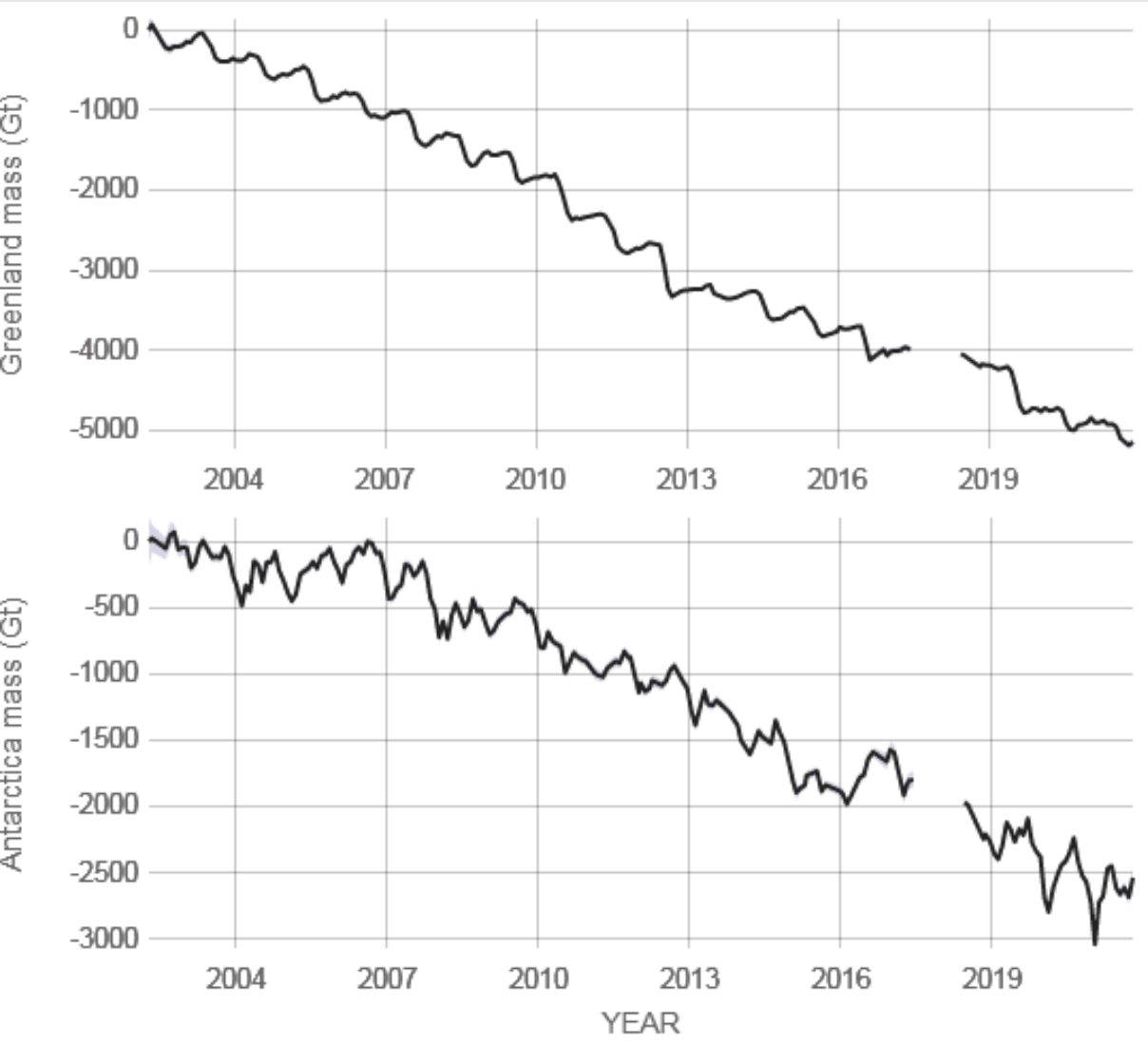
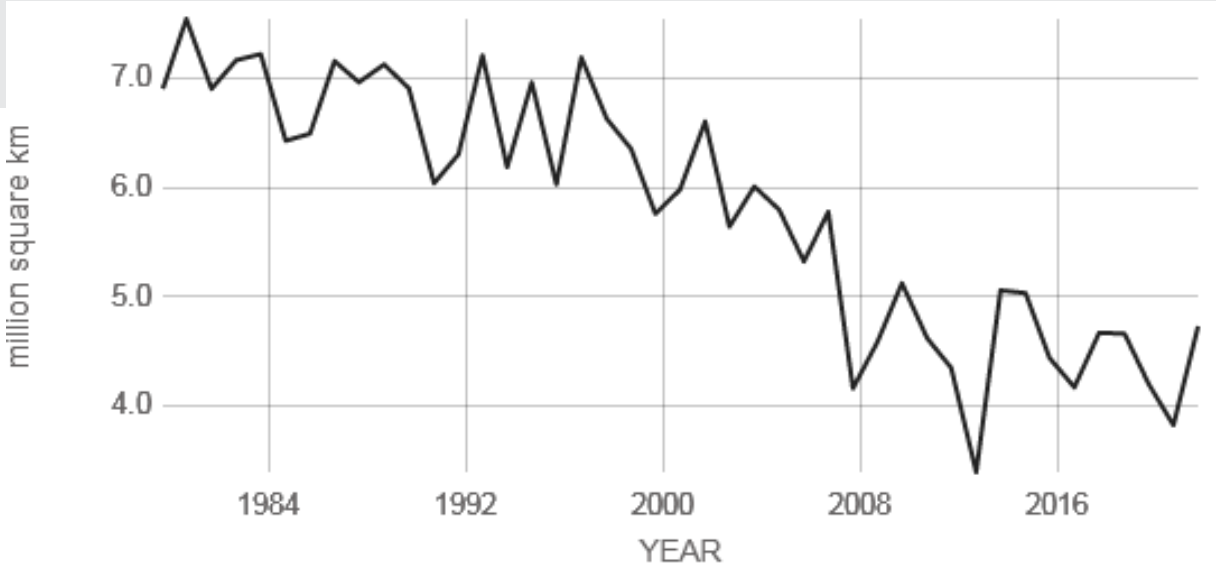
Cambiamenti climatici, cause (naturali?)

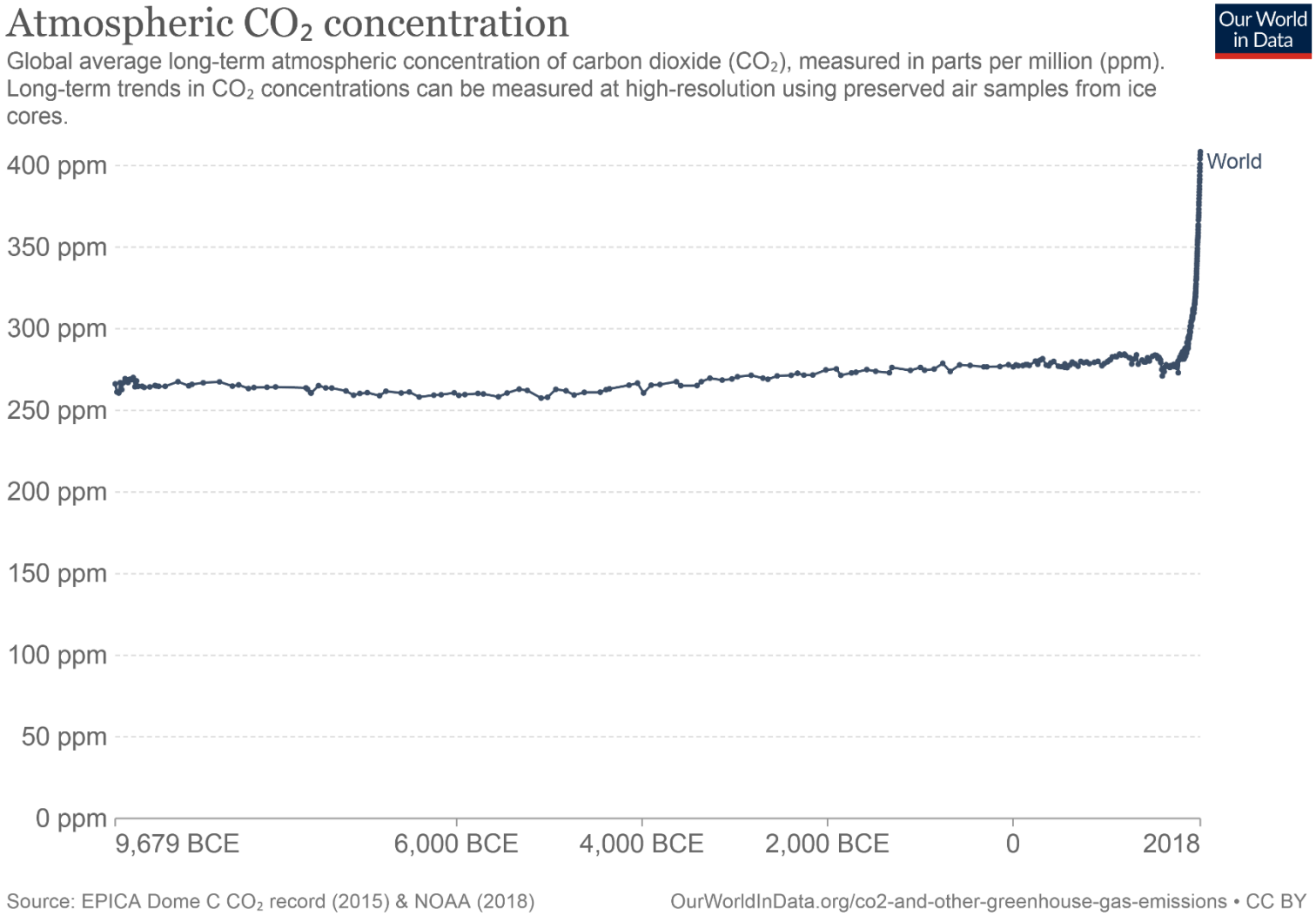


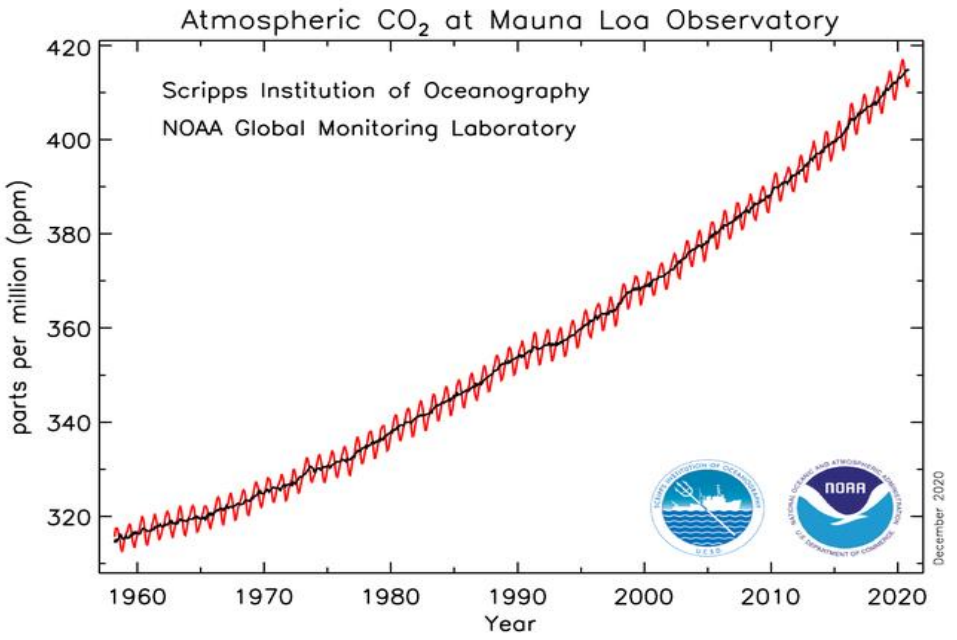
Source: climate.nasa.gov



Source: climate.nasa.gov

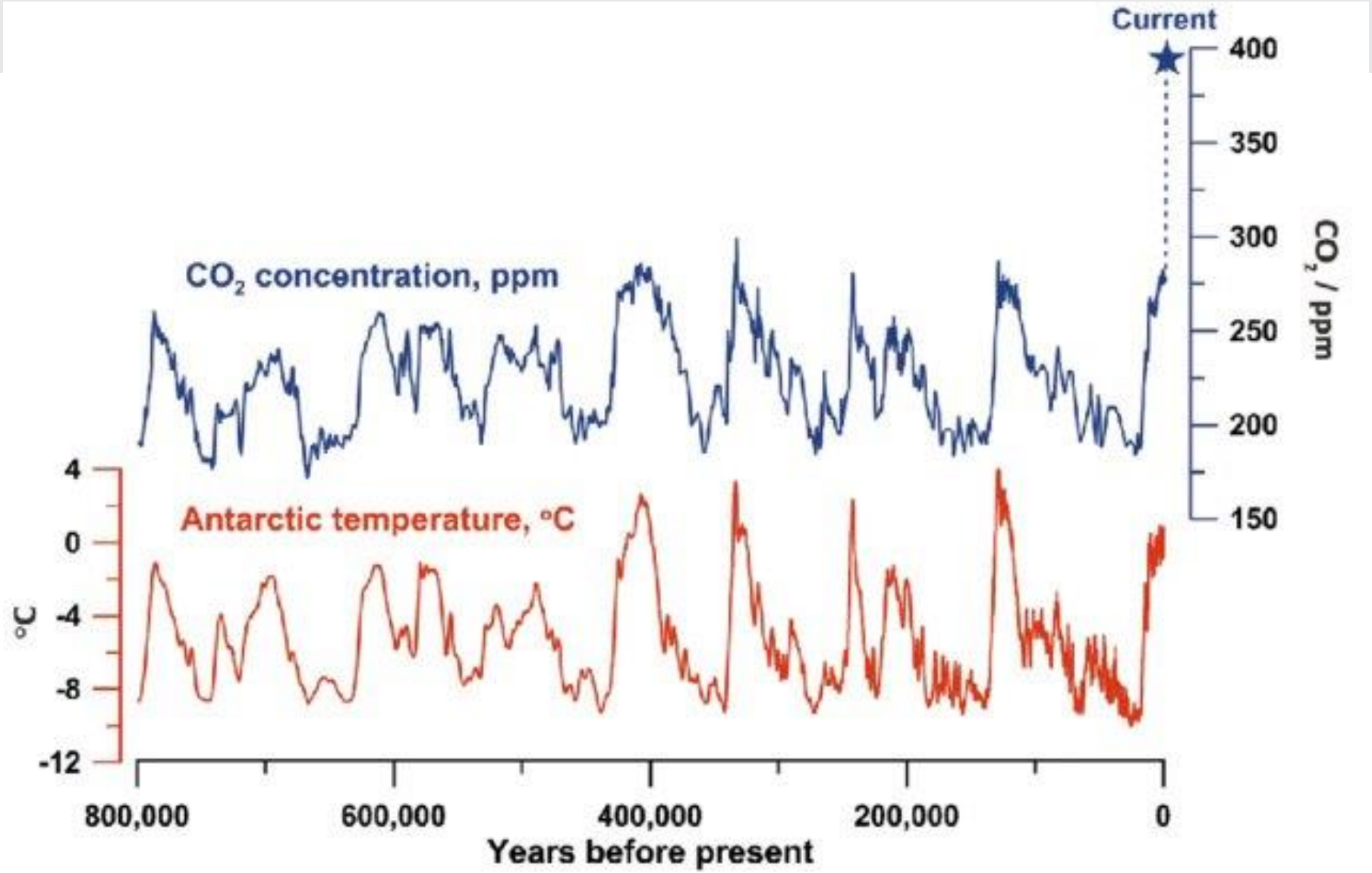
Cambiamenti climatici, cause (naturali?)



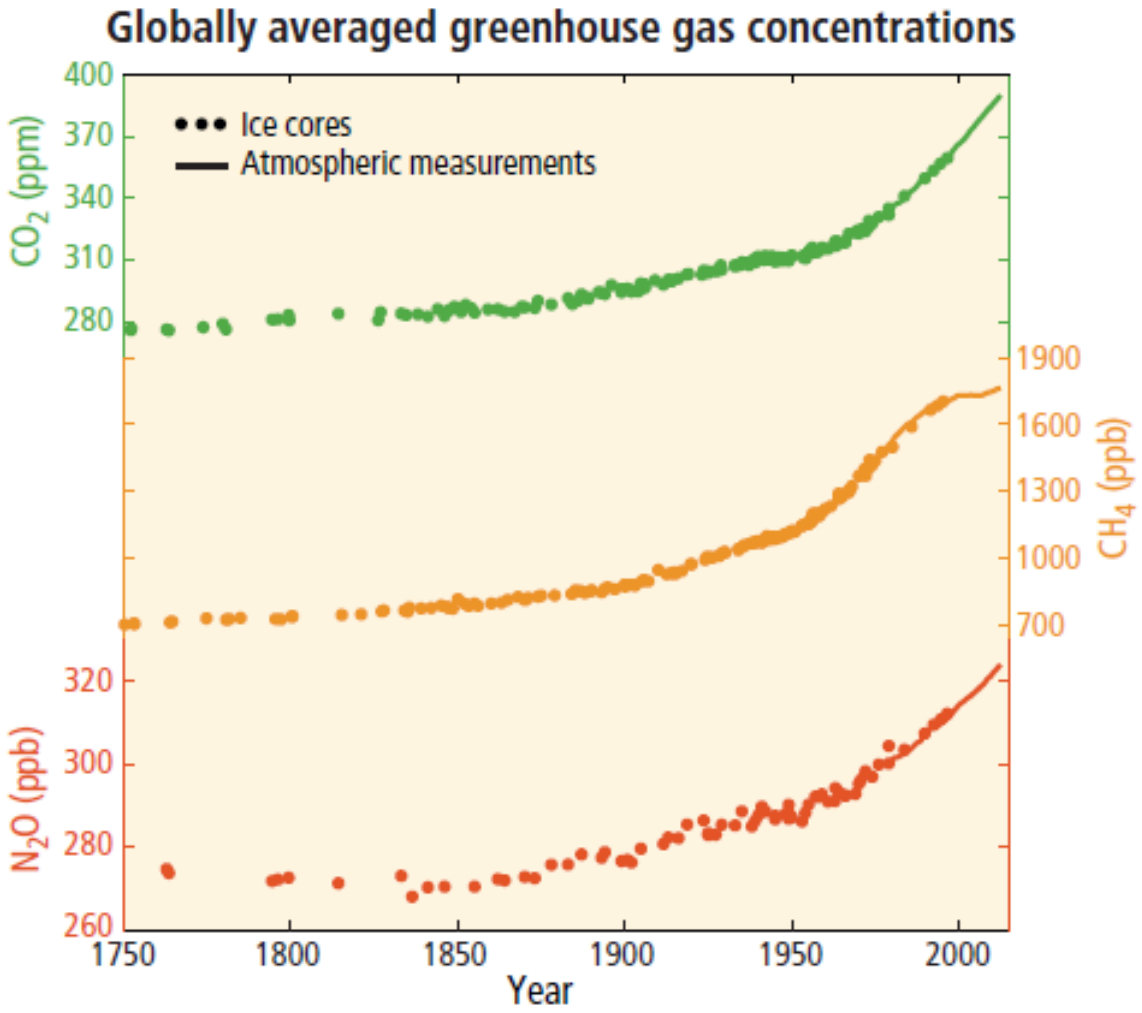


[https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions]

Cambiamenti climatici, cause (naturali?)

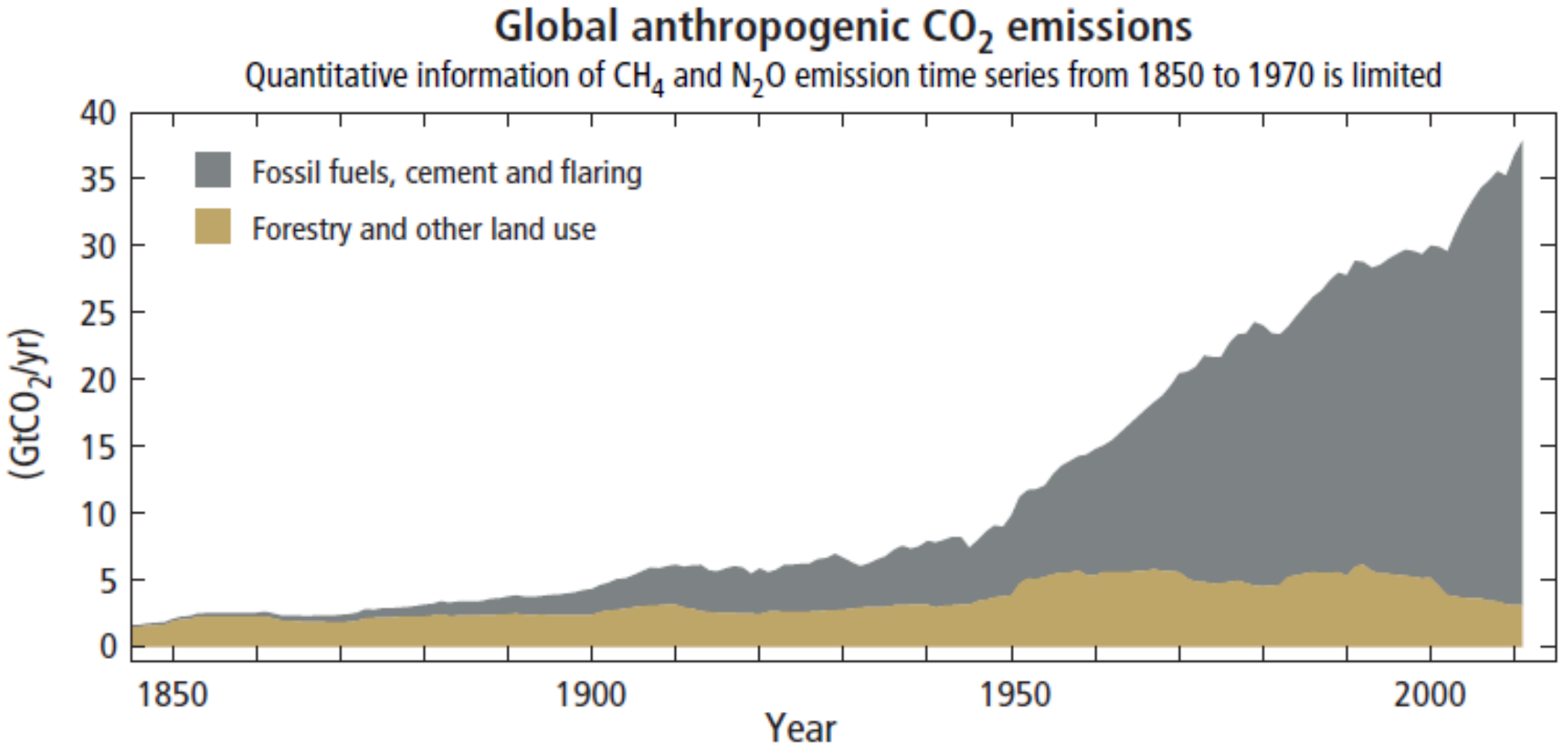


Cambiamenti climatici e attività umane



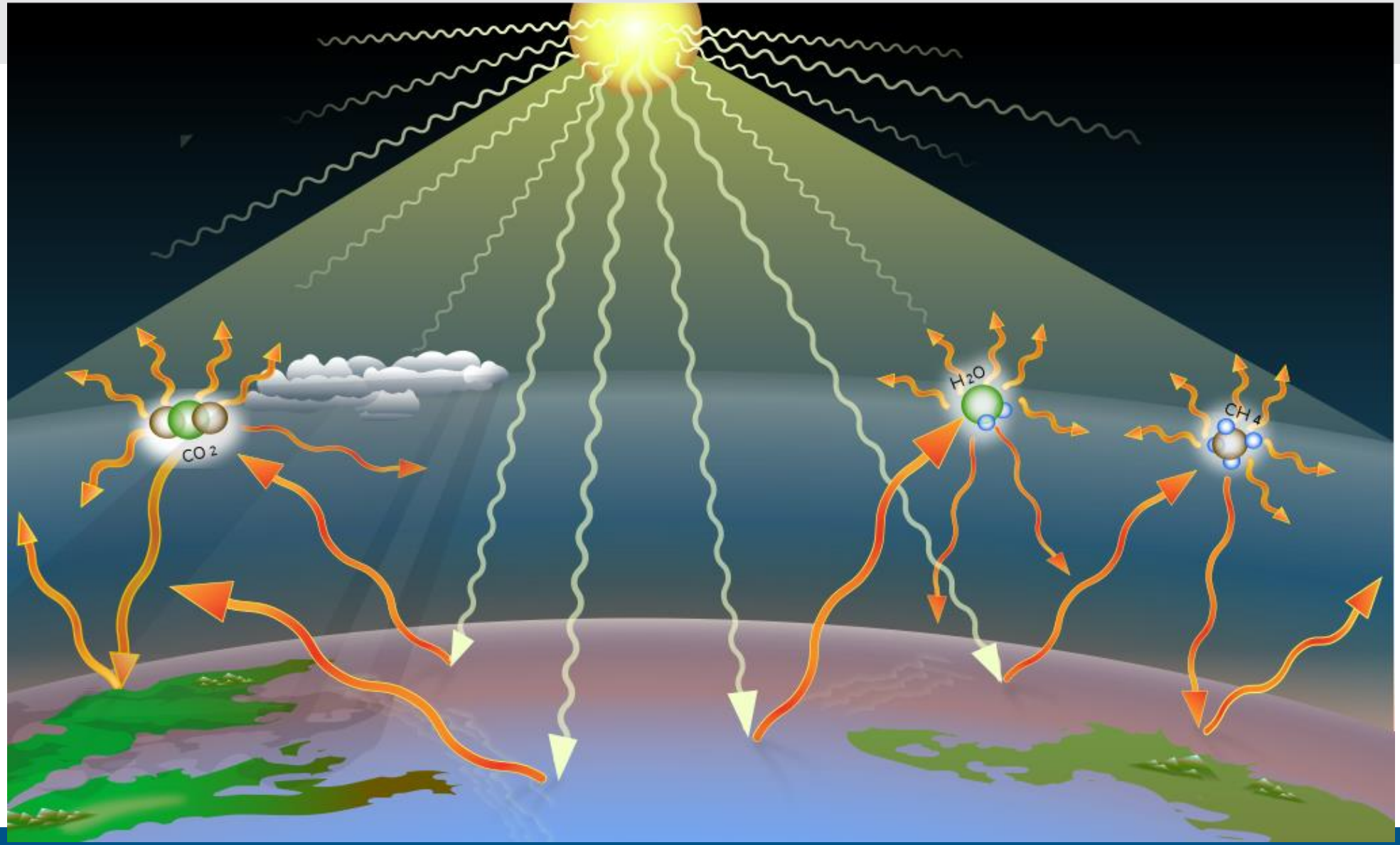
[https://www.ipcc.ch/report/ar5/syr/]

Cambiamenti climatici e attività umane

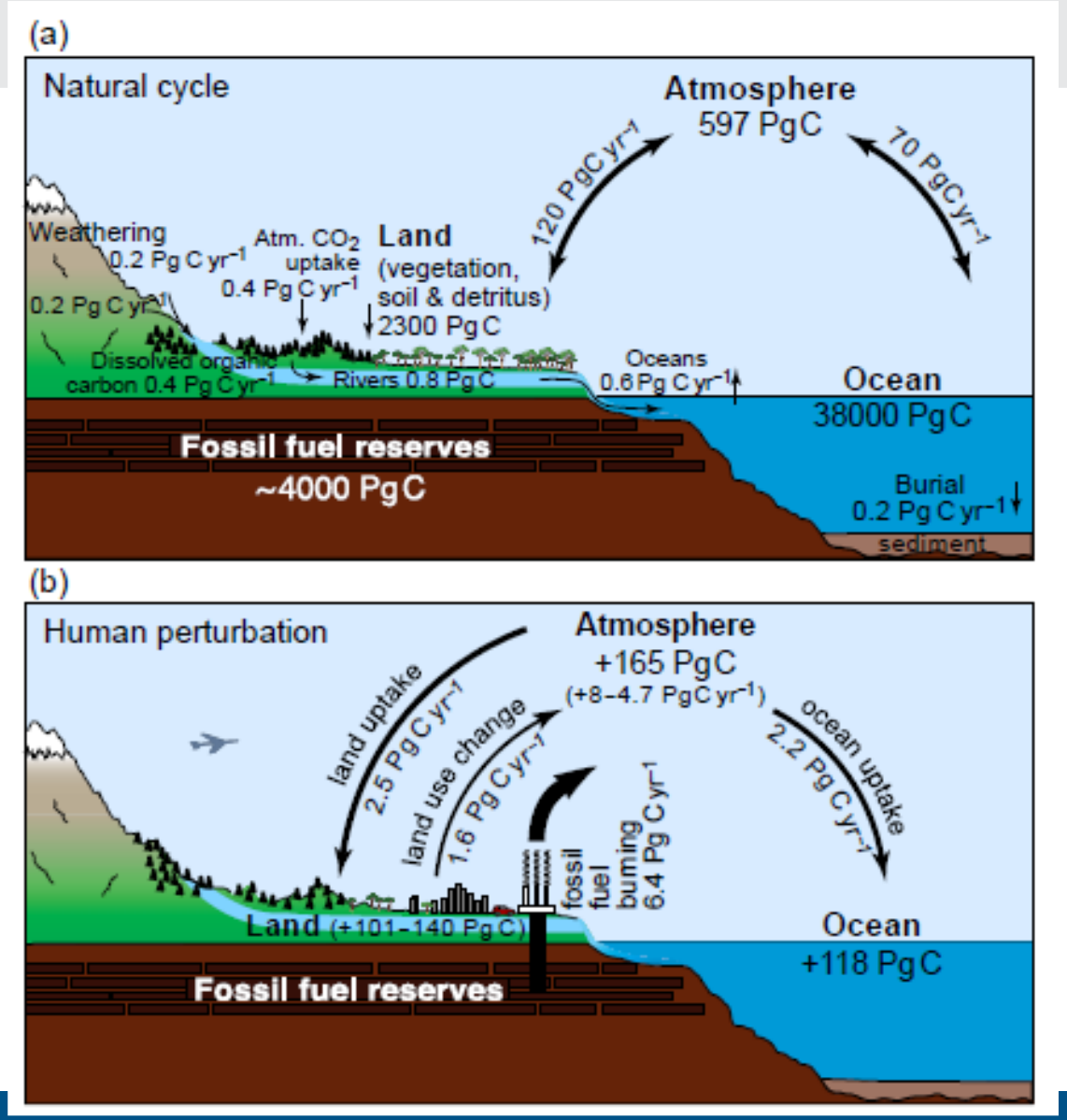


[https://www.ipcc.ch/report/ar5/syr/]

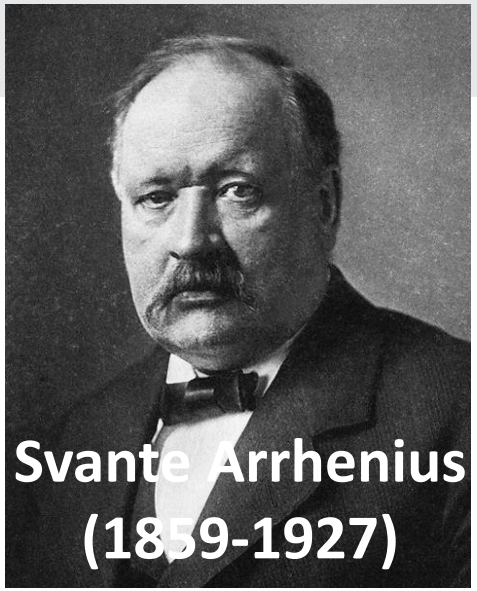
Effetto Serra



Ciclo del carbonio ed effetto serra

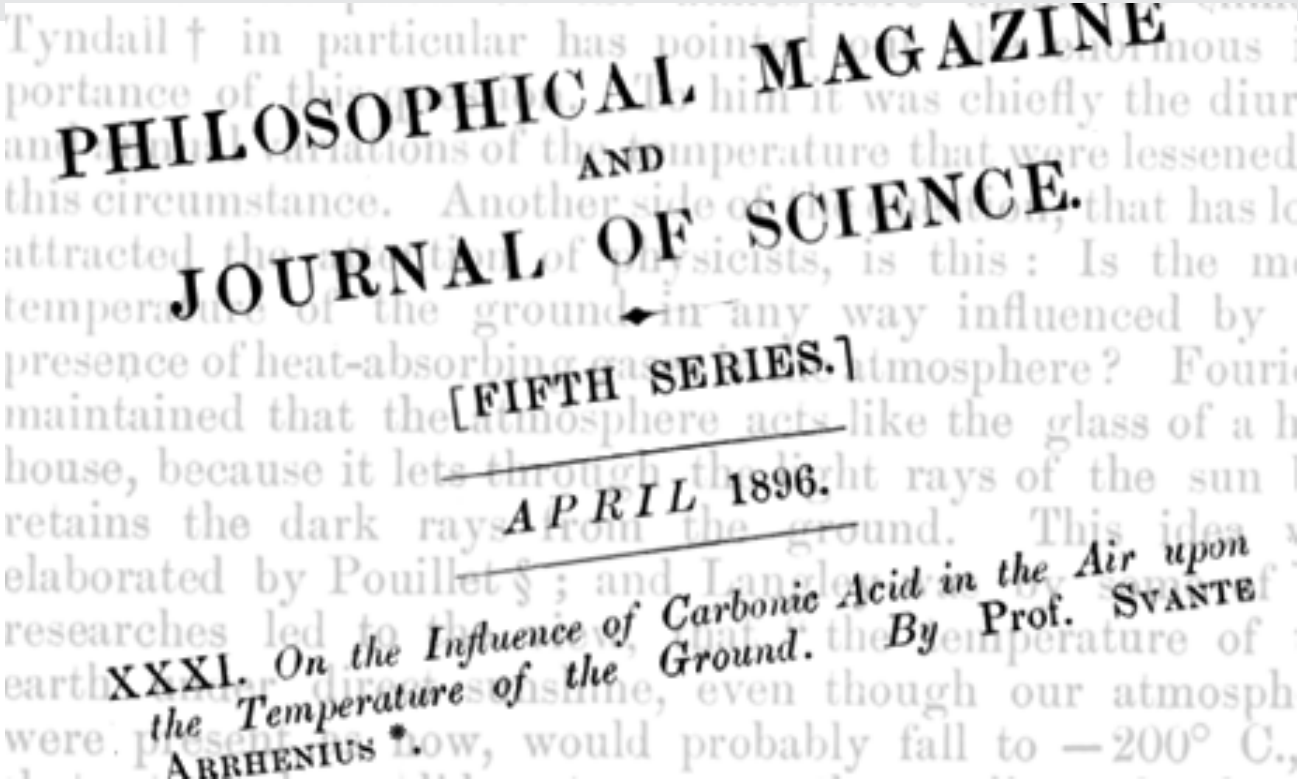


Effetto serra, una vecchia storia



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

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


PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.
[FIFTH SERIES.]
APRIL 1896.

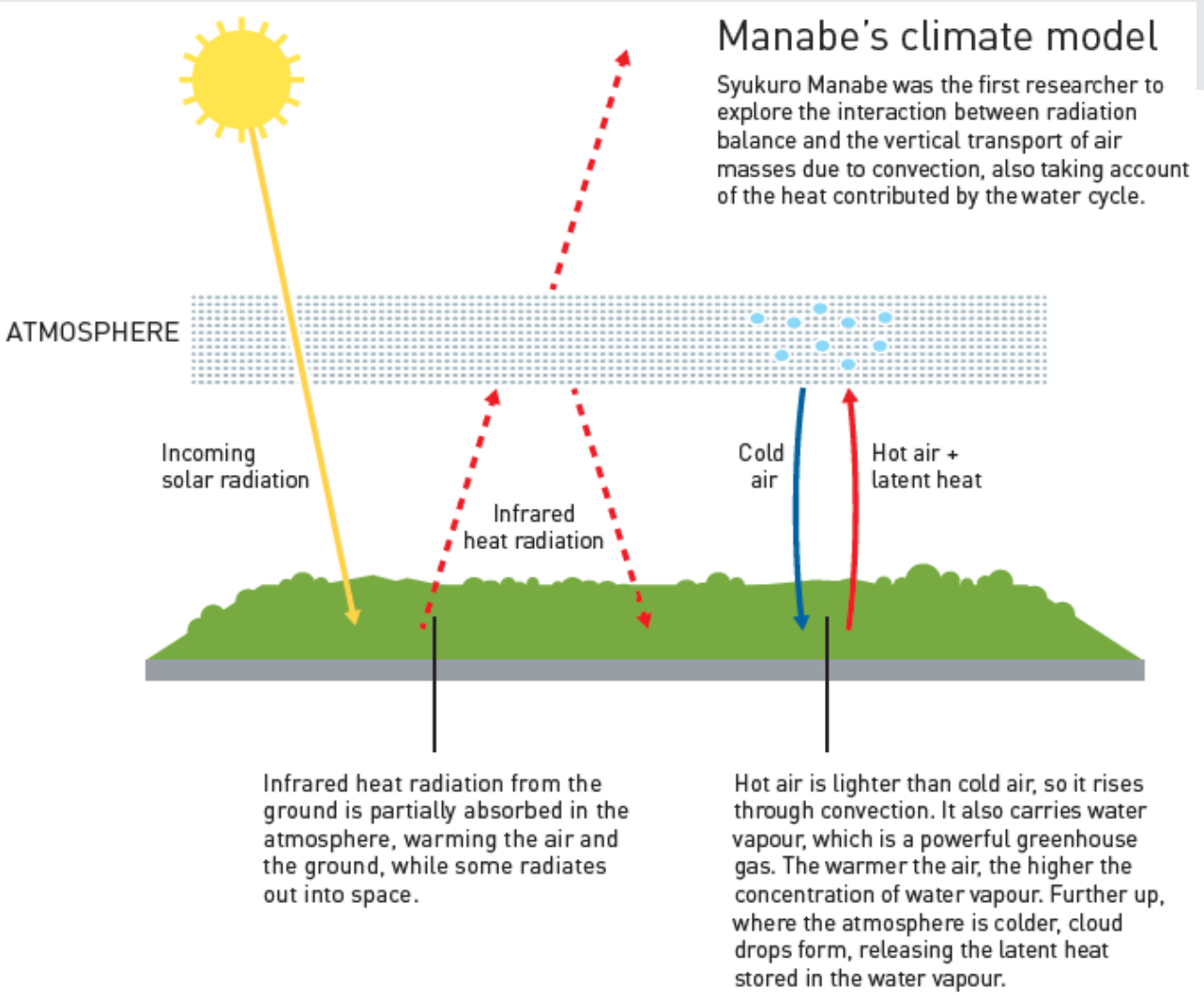
XXXI. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. By Prof. SVANTE ARRHENIUS *.

Legge di Stefan-Boltzmann

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

Effetto serra, una vecchia storia

Syukuro Manabe
[Nobel per la Fisica 2021]



[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

CO_2 GREENHOUSE EFFECT

A TECHNICAL REVIEW

PREPARED BY THE

COORDINATION AND PLANNING DIVISION

EXXON RESEARCH AND ENGINEERING COMPANY

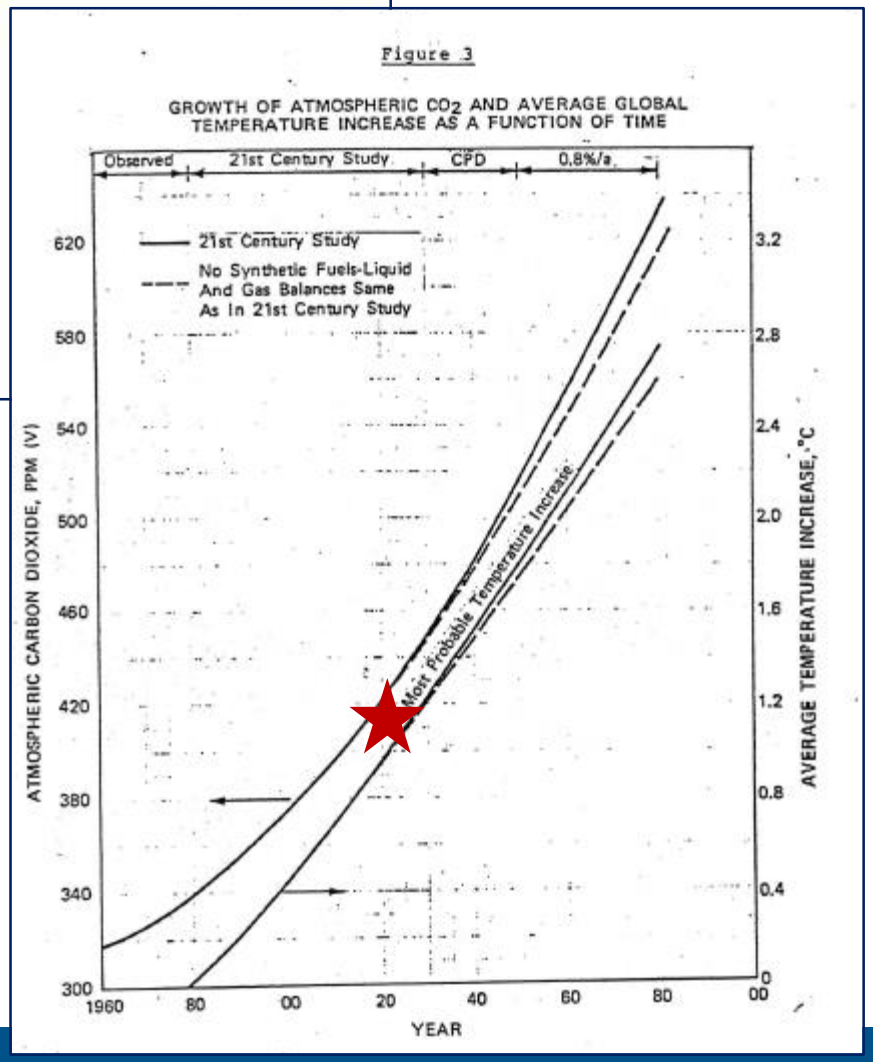
APRIL 1, 1982

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

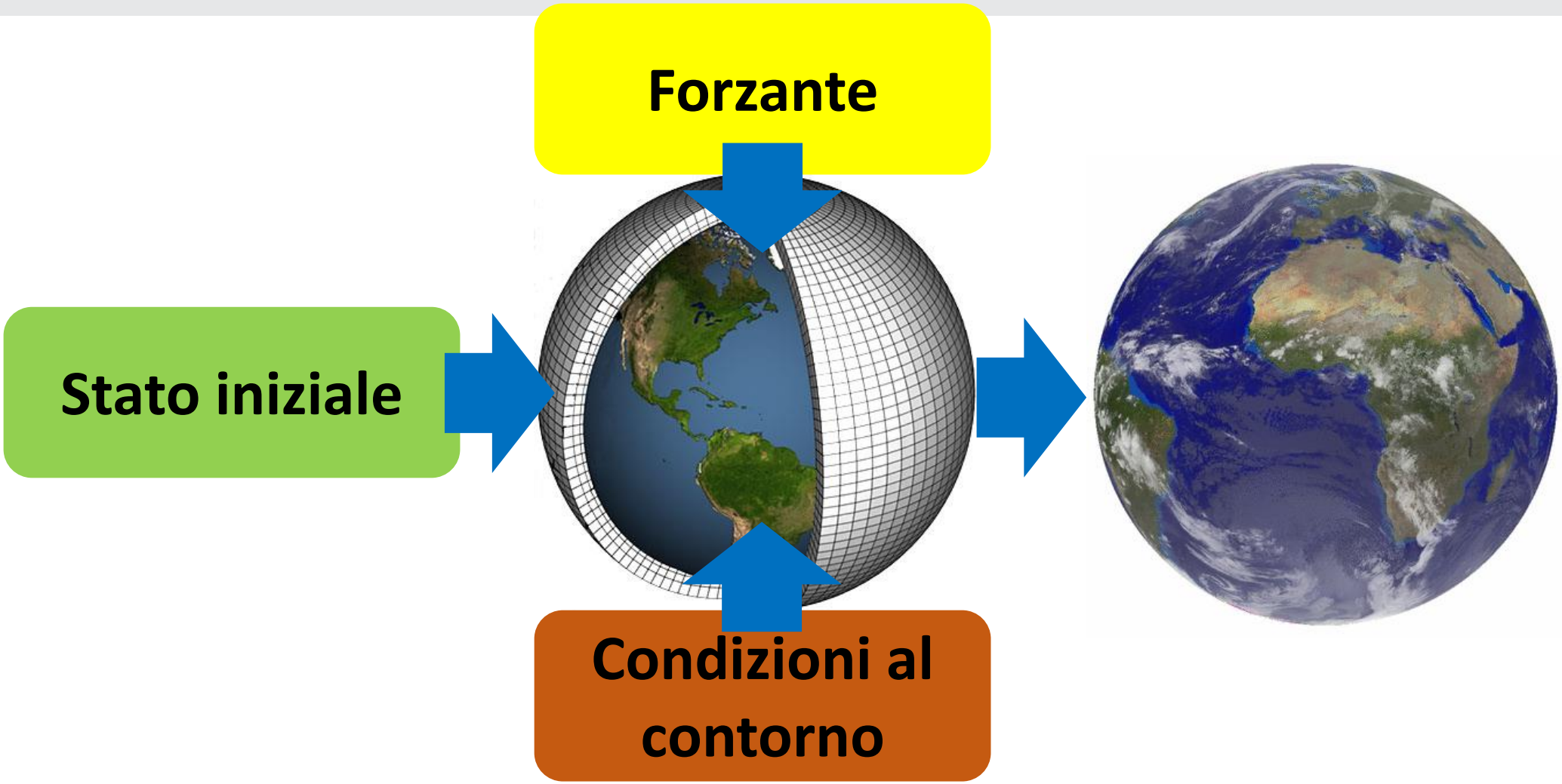
$$\rho = \frac{p}{RT}$$ Stato

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

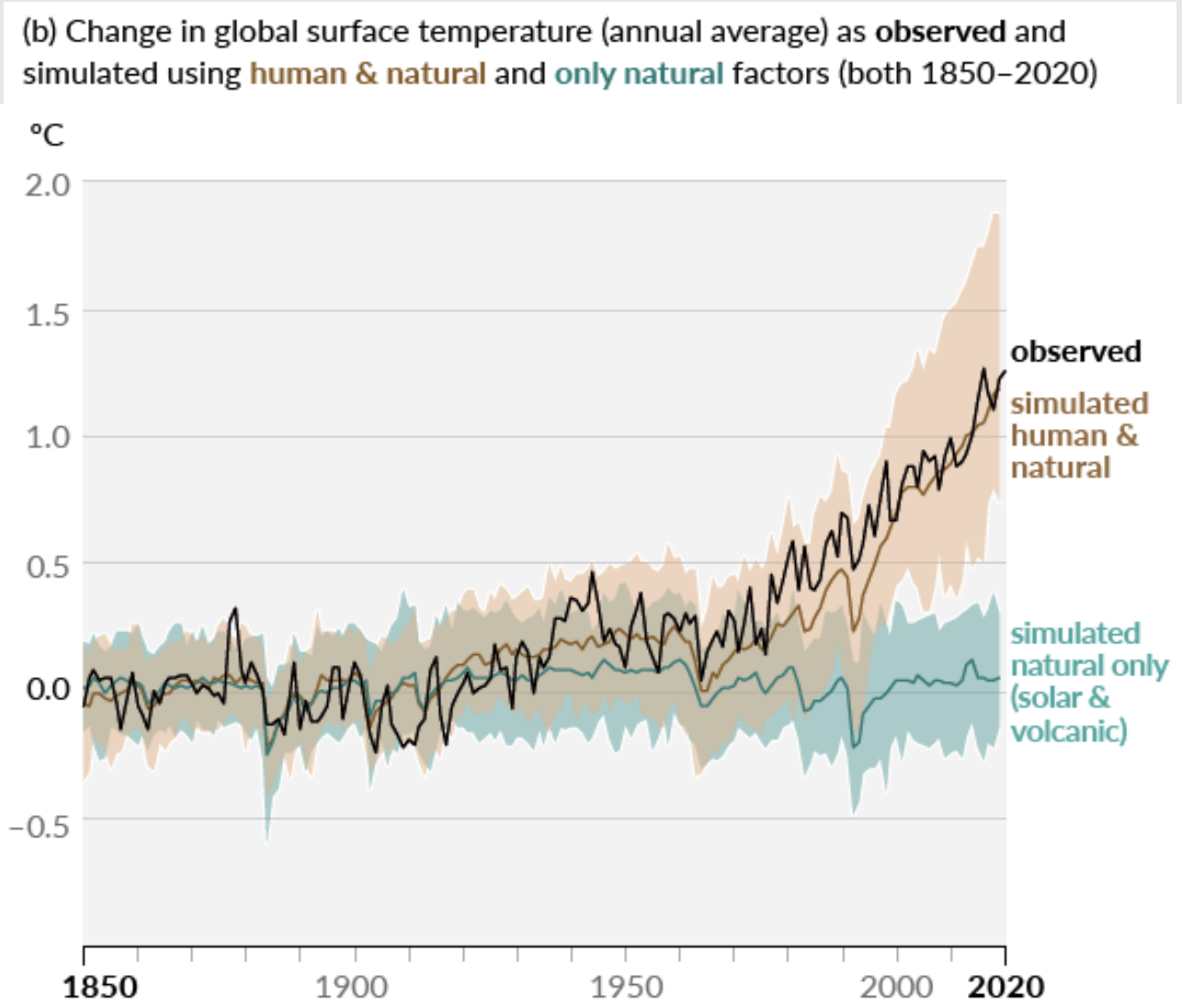
$$c_p \frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt} = Q$$ Temperatura

$$\frac{dm}{dt} = S$$ Umidità/Salinitá

Modelli climatici

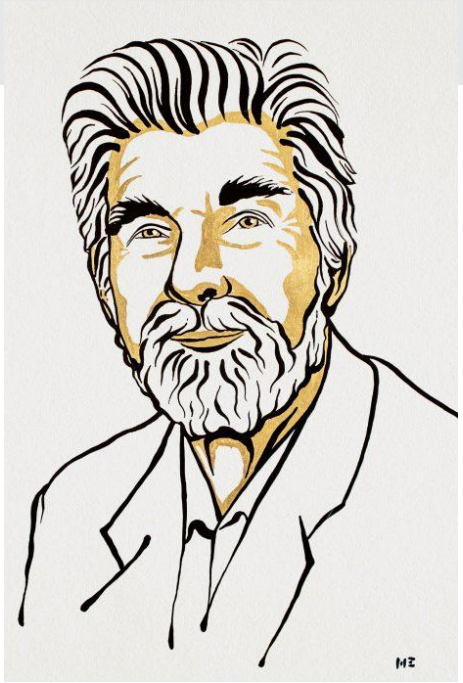


Attribuzione del cambiamento climatico

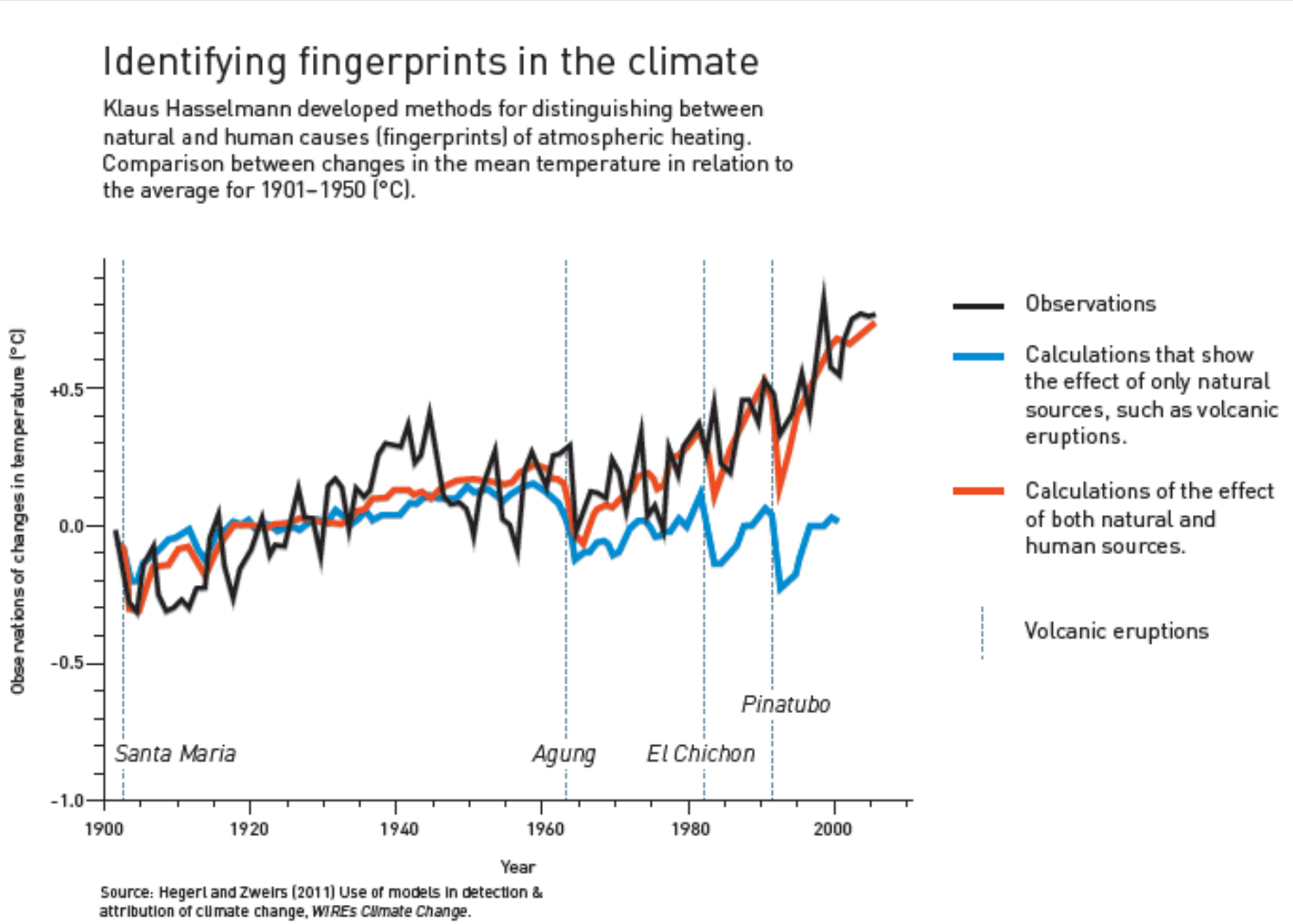


[https://www.ipcc.ch/assessment-report/ar6/]

Attribuzione del cambiamento climatico

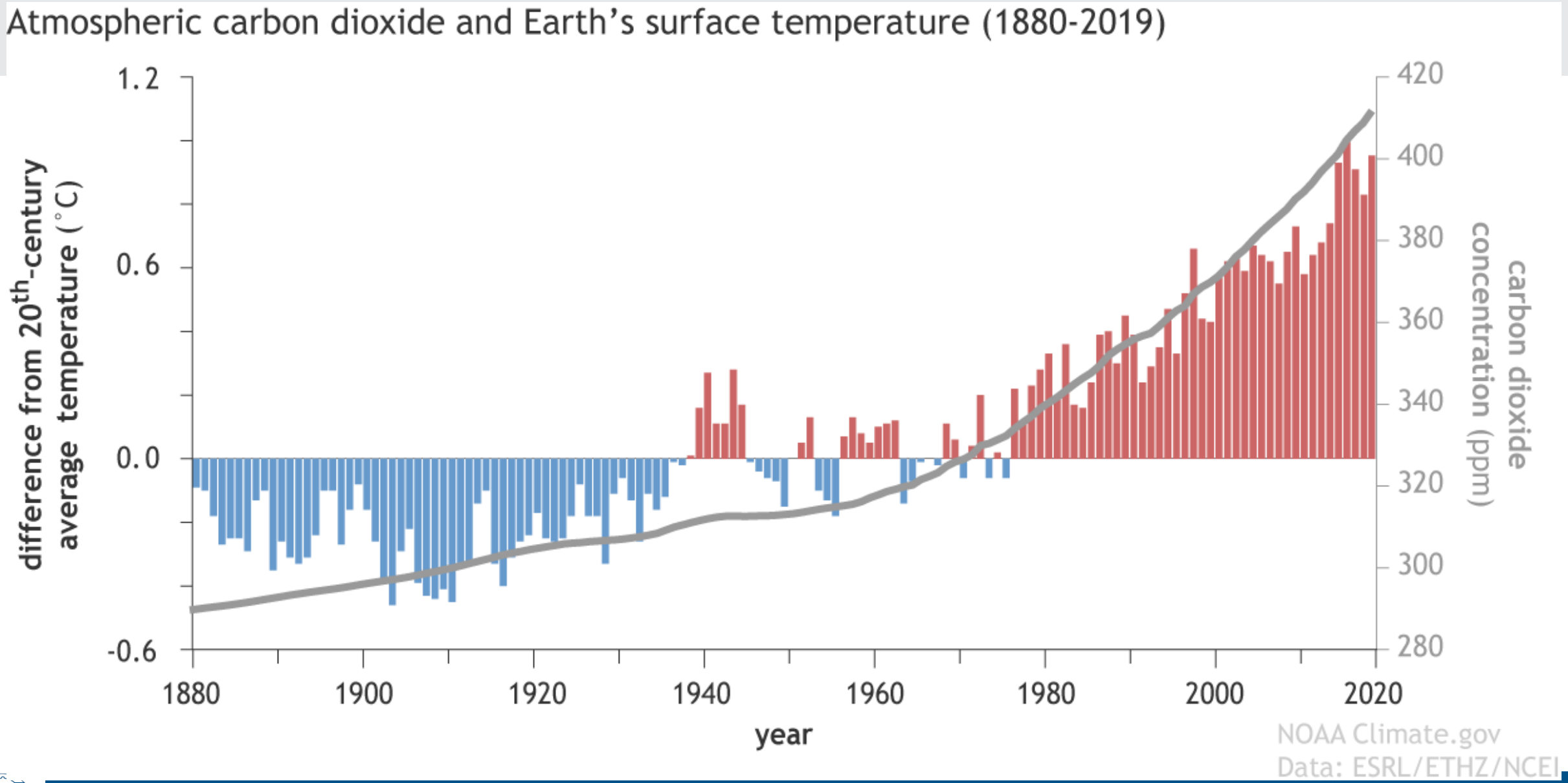


Klaus Hasselmann
[Nobel per la Fisica 2021]

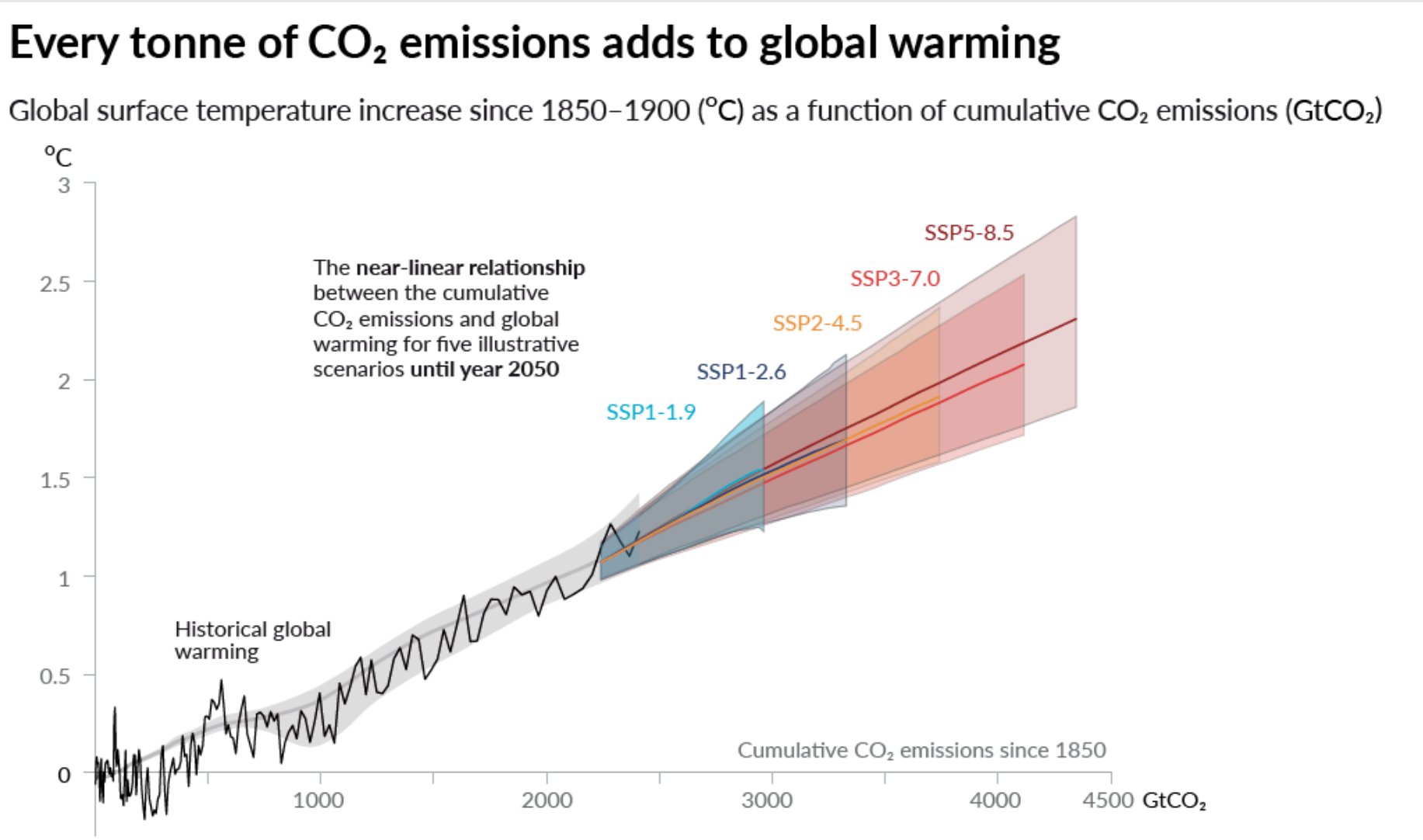


[https://www.nobelprize.org/uploads/2021/10/sciback_fy_en_21.pdf]

Attribuzione del cambiamento climatico



Sensibilità climatica

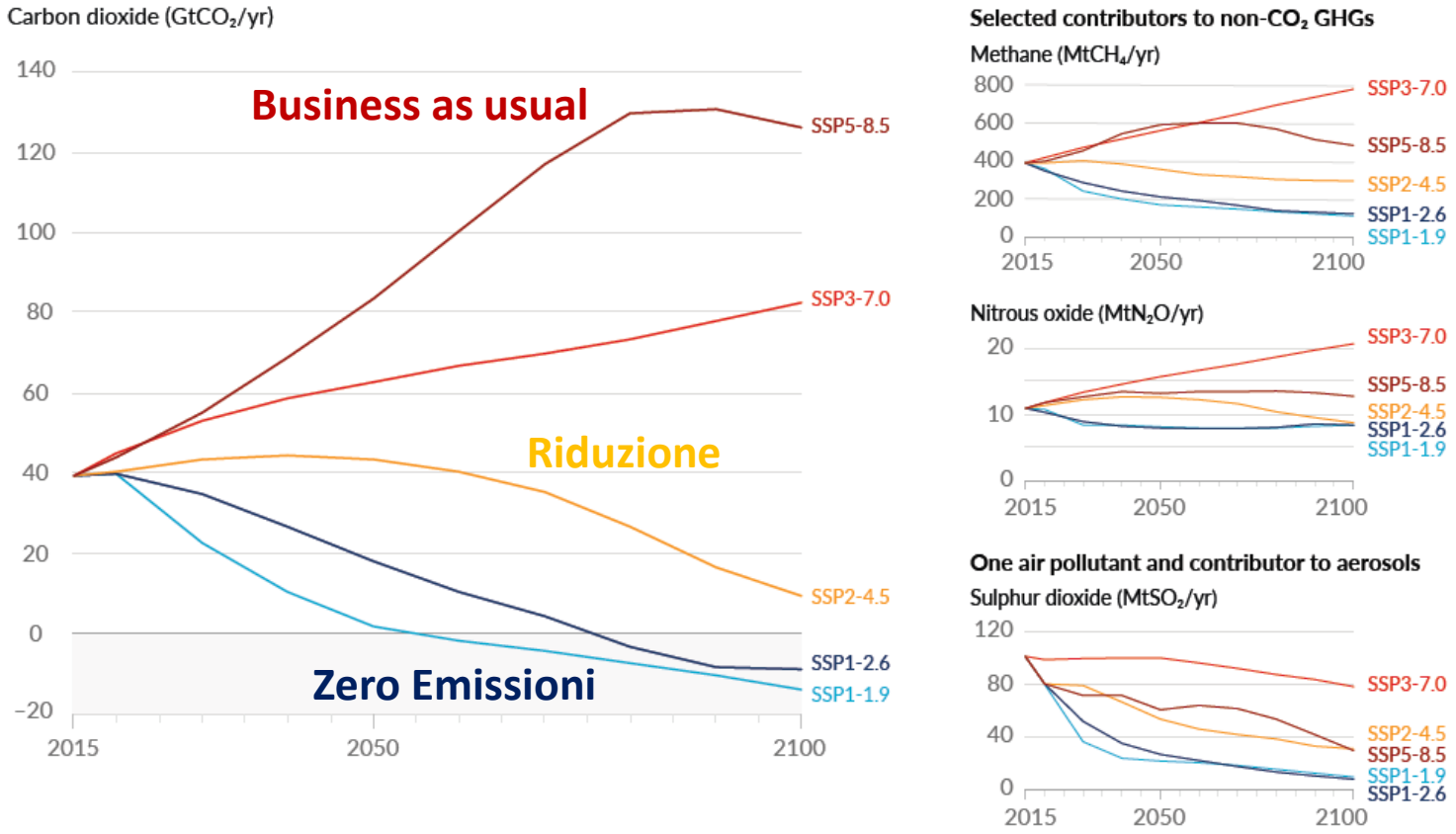


[https://www.ipcc.ch/assessment-report/ar6/]

Scenari di emissione

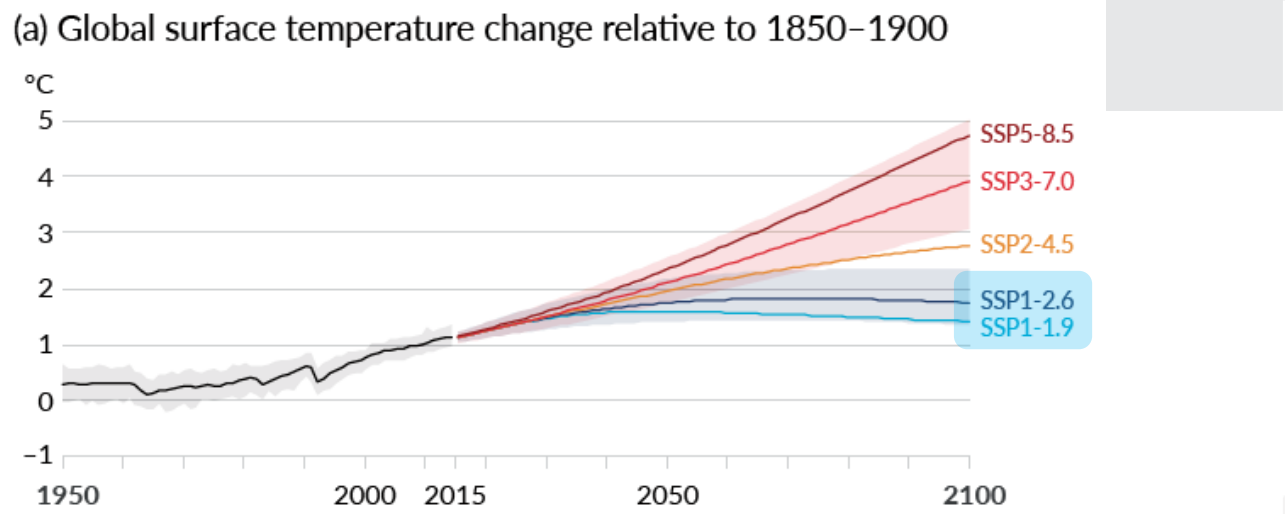
Future emissions cause future additional warming, with total warming dominated by past and future CO_2 emissions

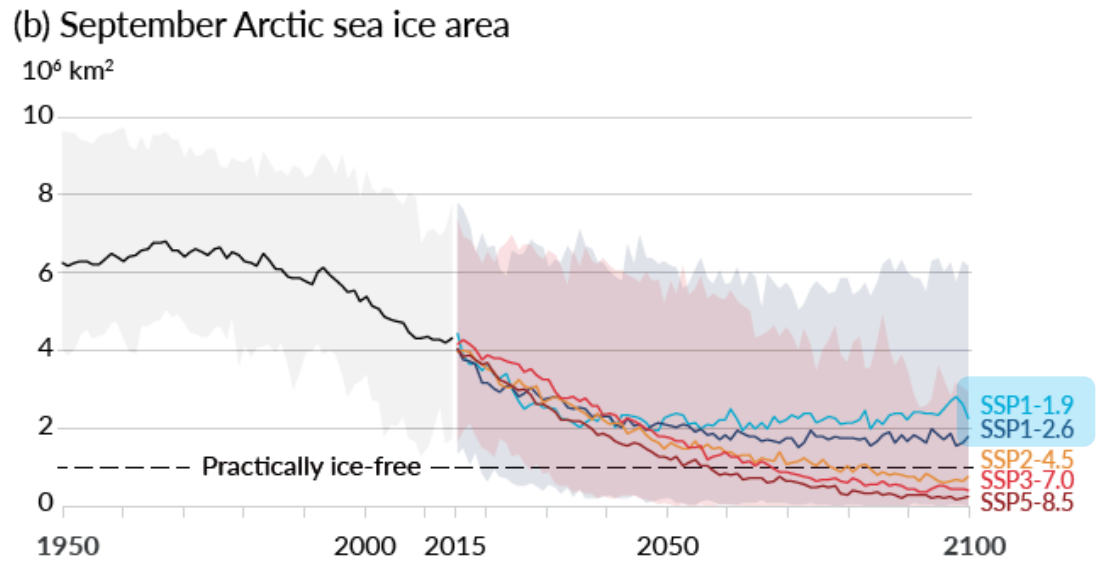
(a) Future annual emissions of CO_2 (left) and of a subset of key non-CO_2 drivers (right), across five illustrative scenarios

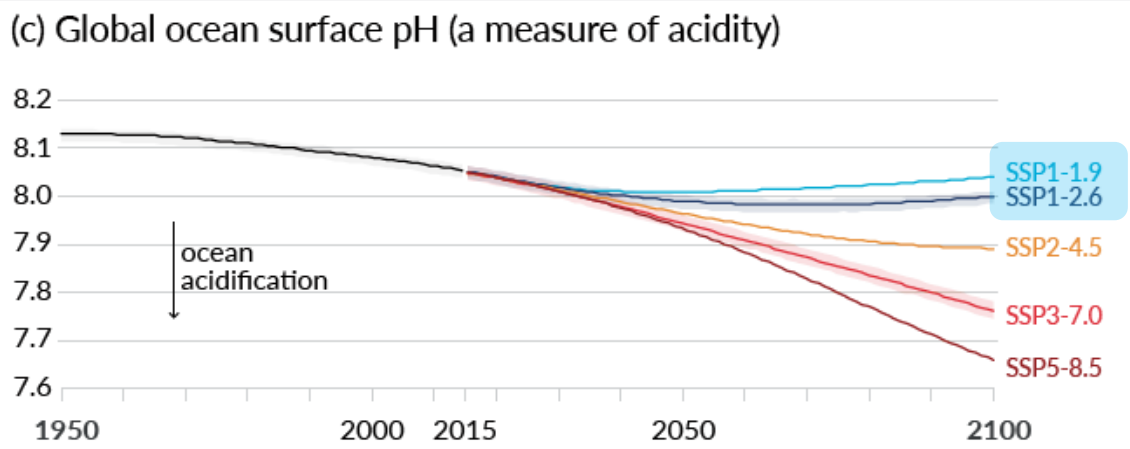


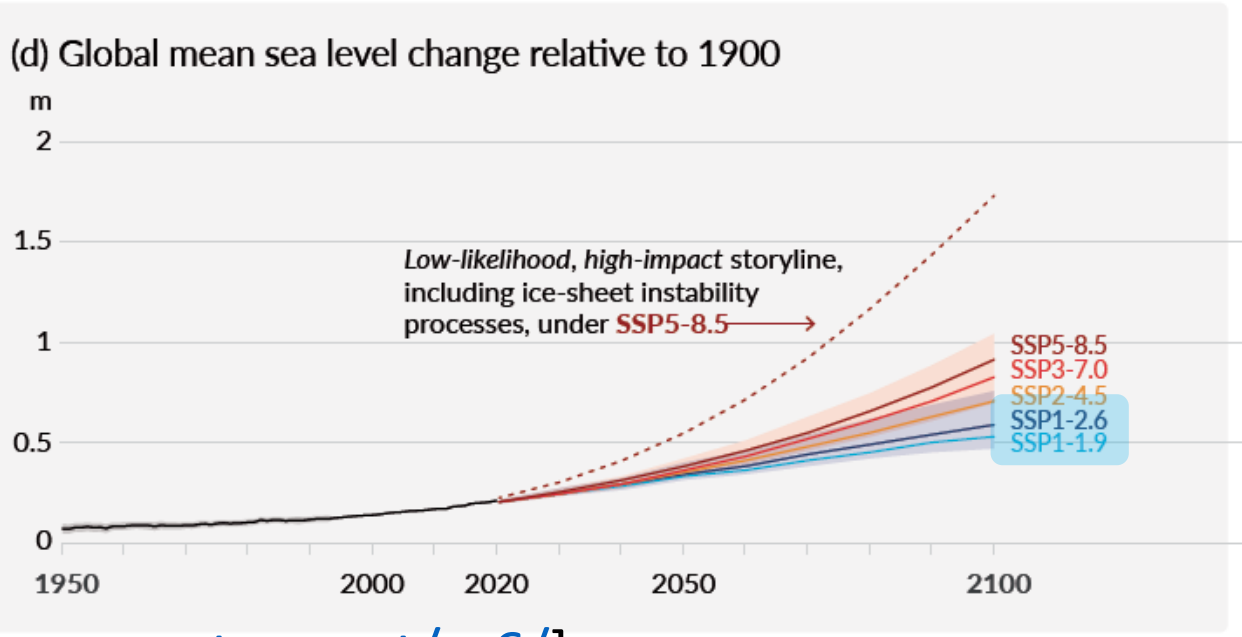
[https://www.ipcc.ch/assessment-report/ar6/]

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)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
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

Zero nel 2050

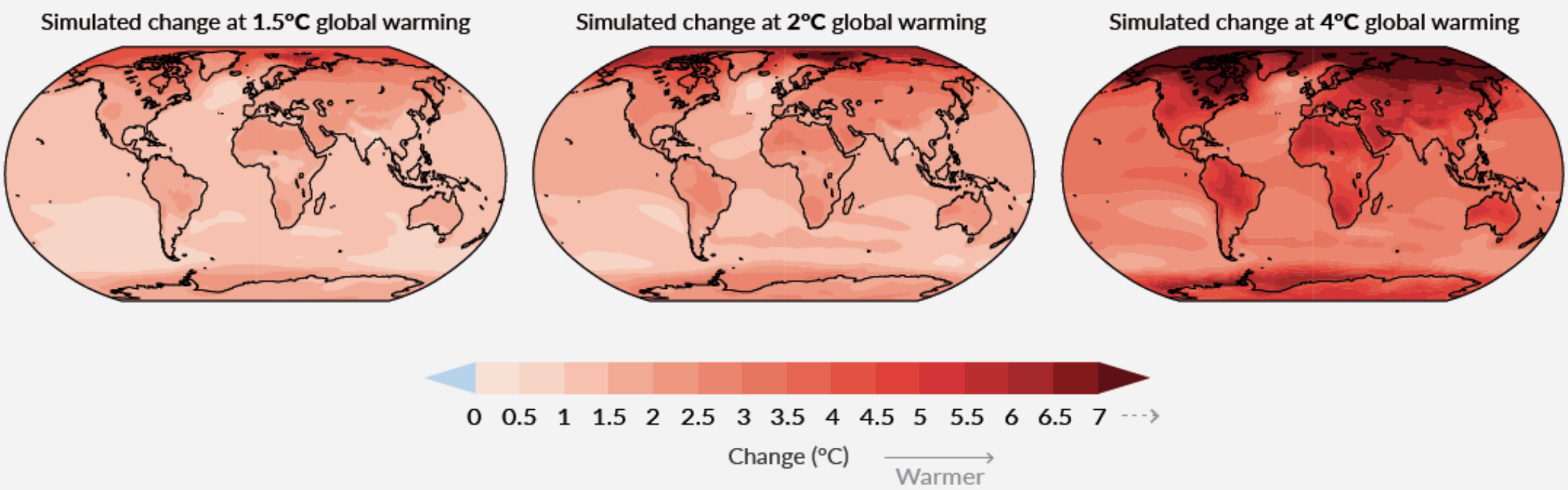
Zero nel 2075

[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.

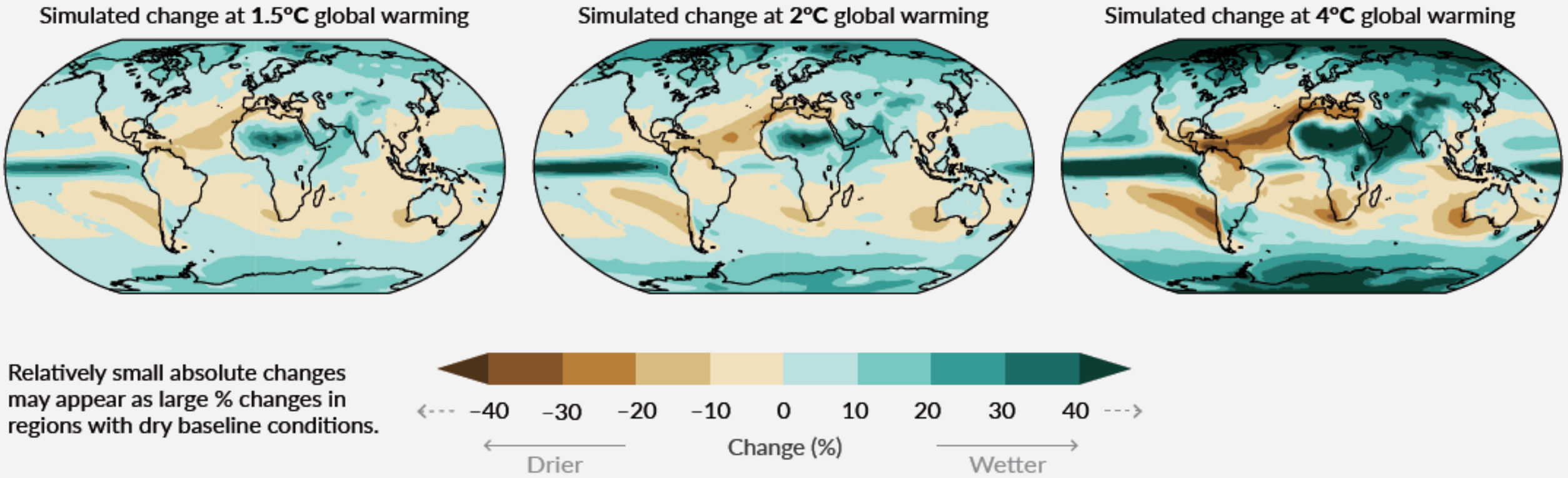


[https://www.ipcc.ch/assessment-report/ar6/]

Proiezioni climatiche

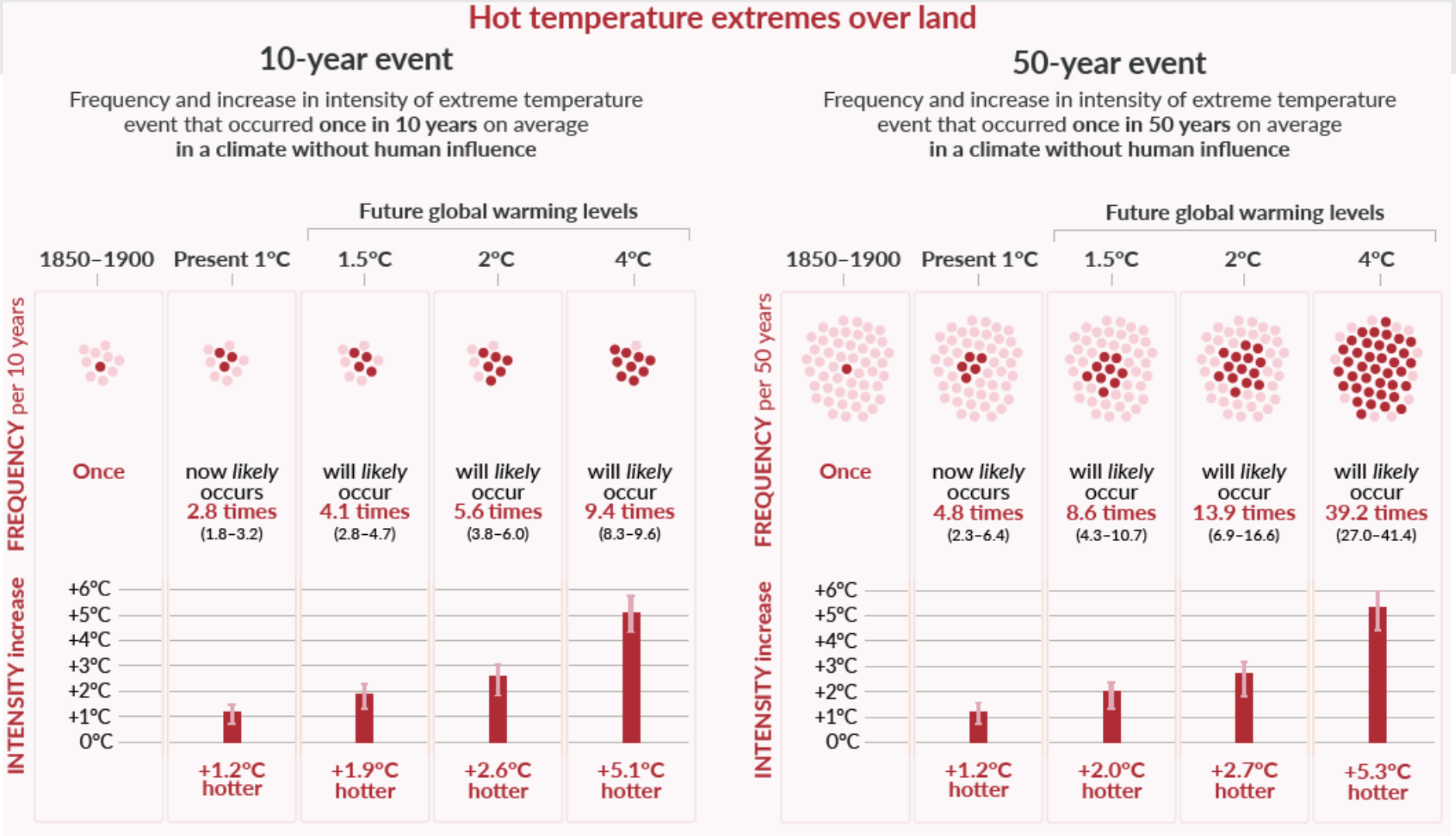
(c) Annual mean precipitation change (%) relative to 1850–1900

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.



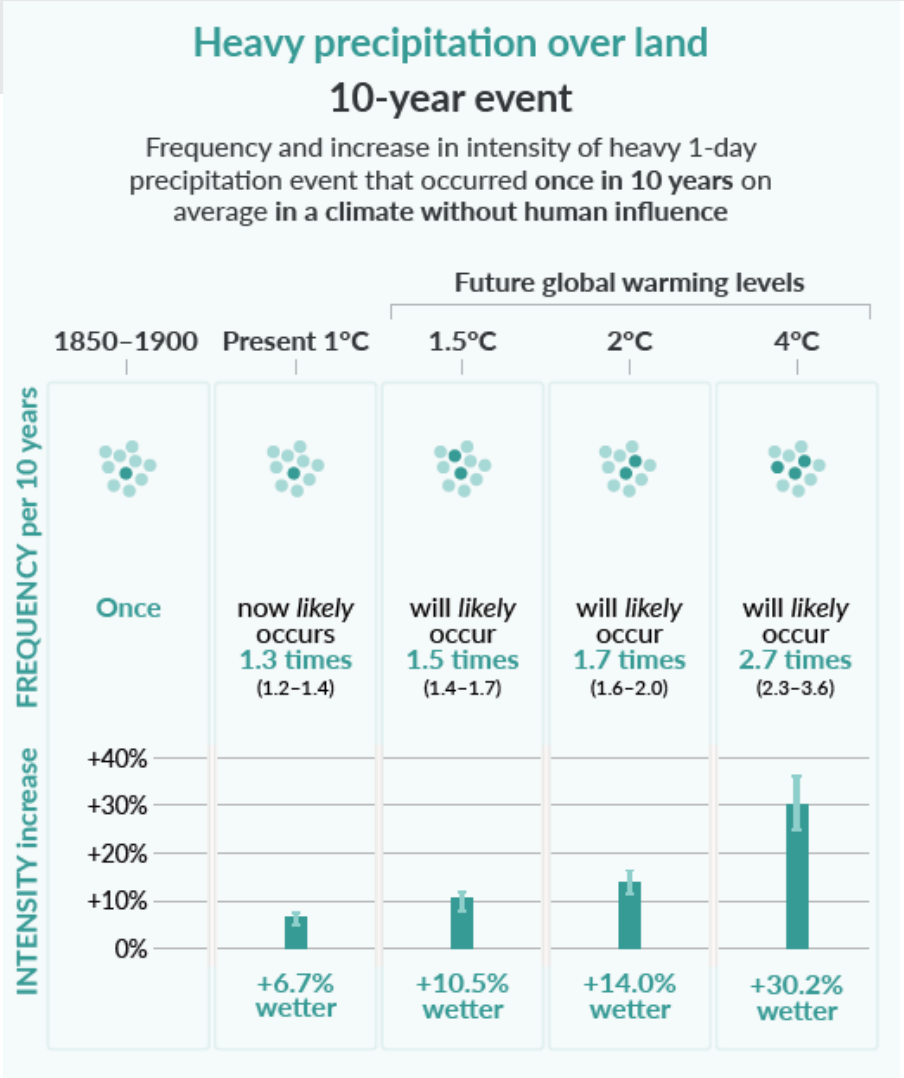
[https://www.ipcc.ch/assessment-report/ar6/]

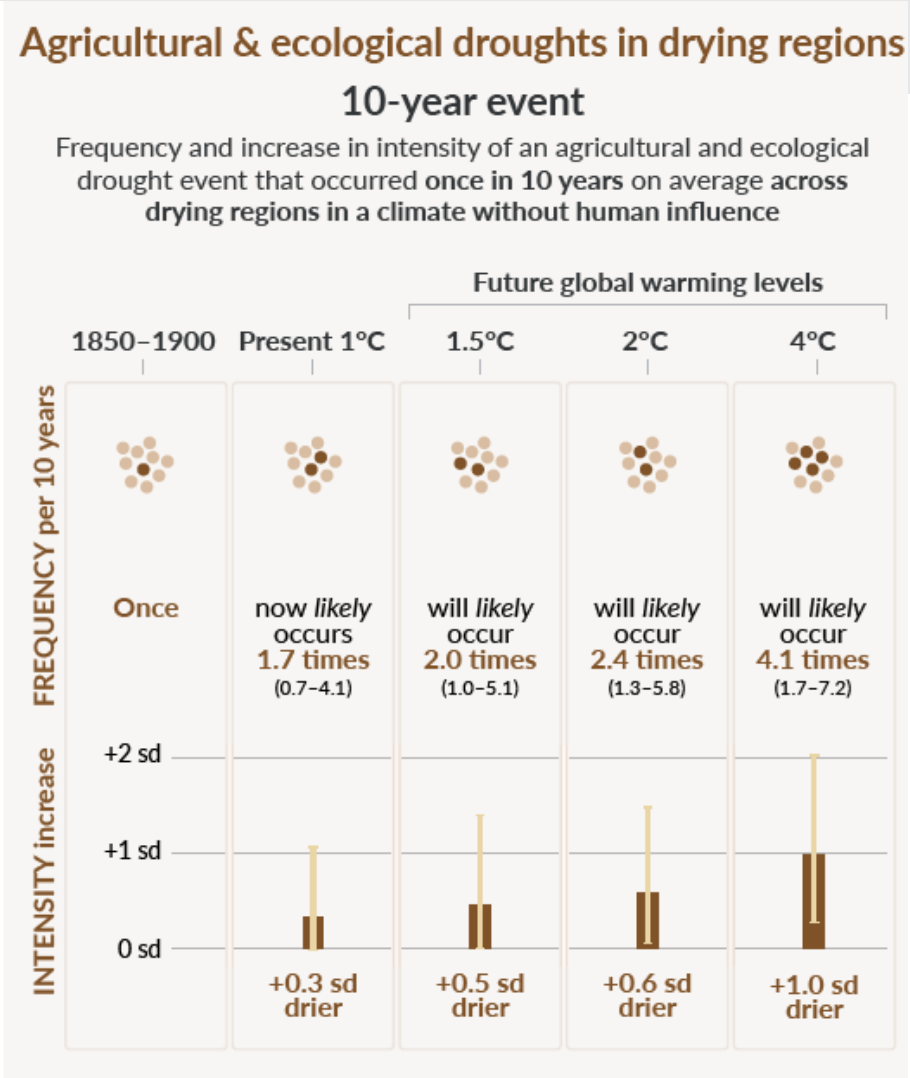
Proiezioni climatiche, in pratica



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

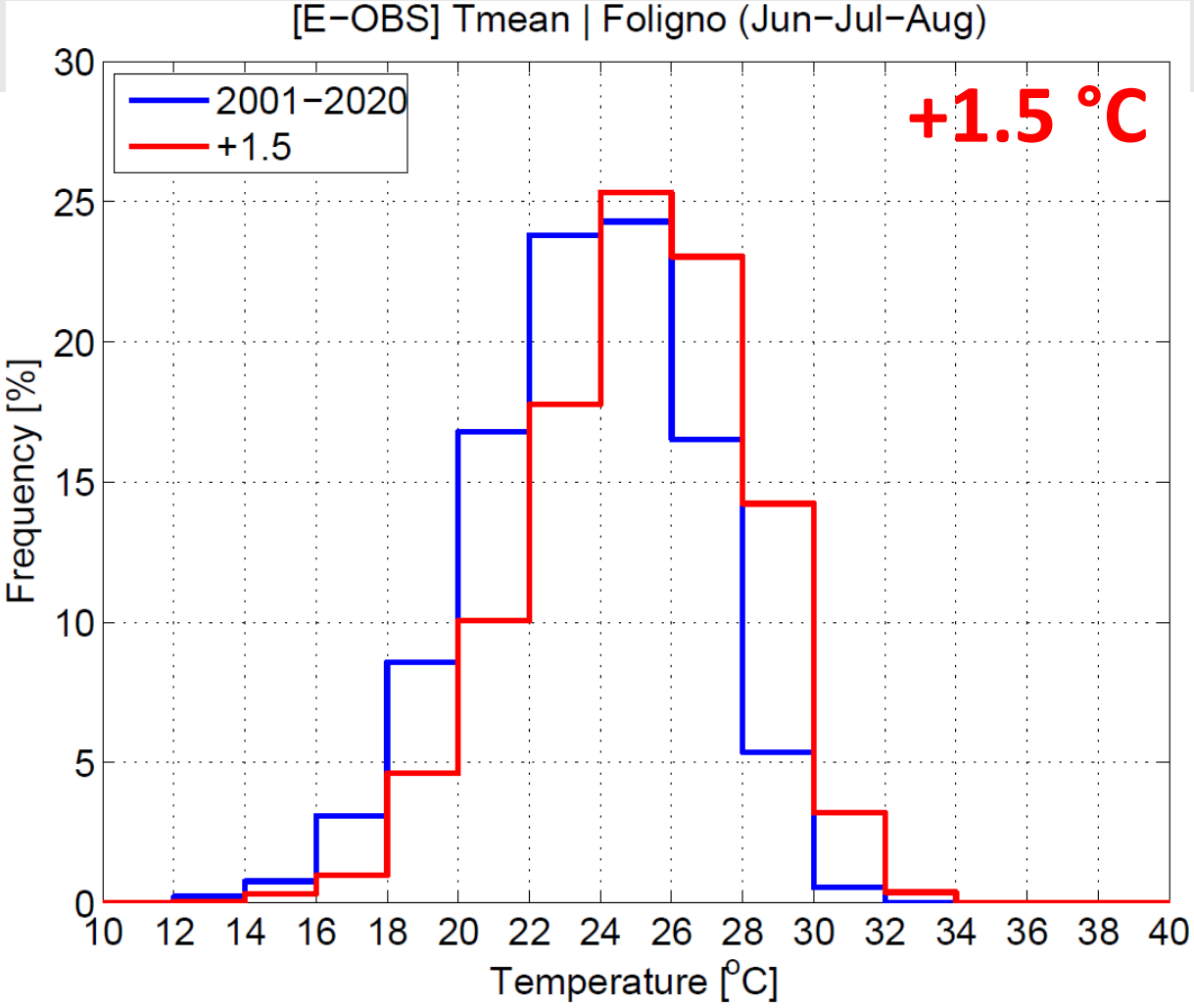
Proiezioni climatiche, in pratica

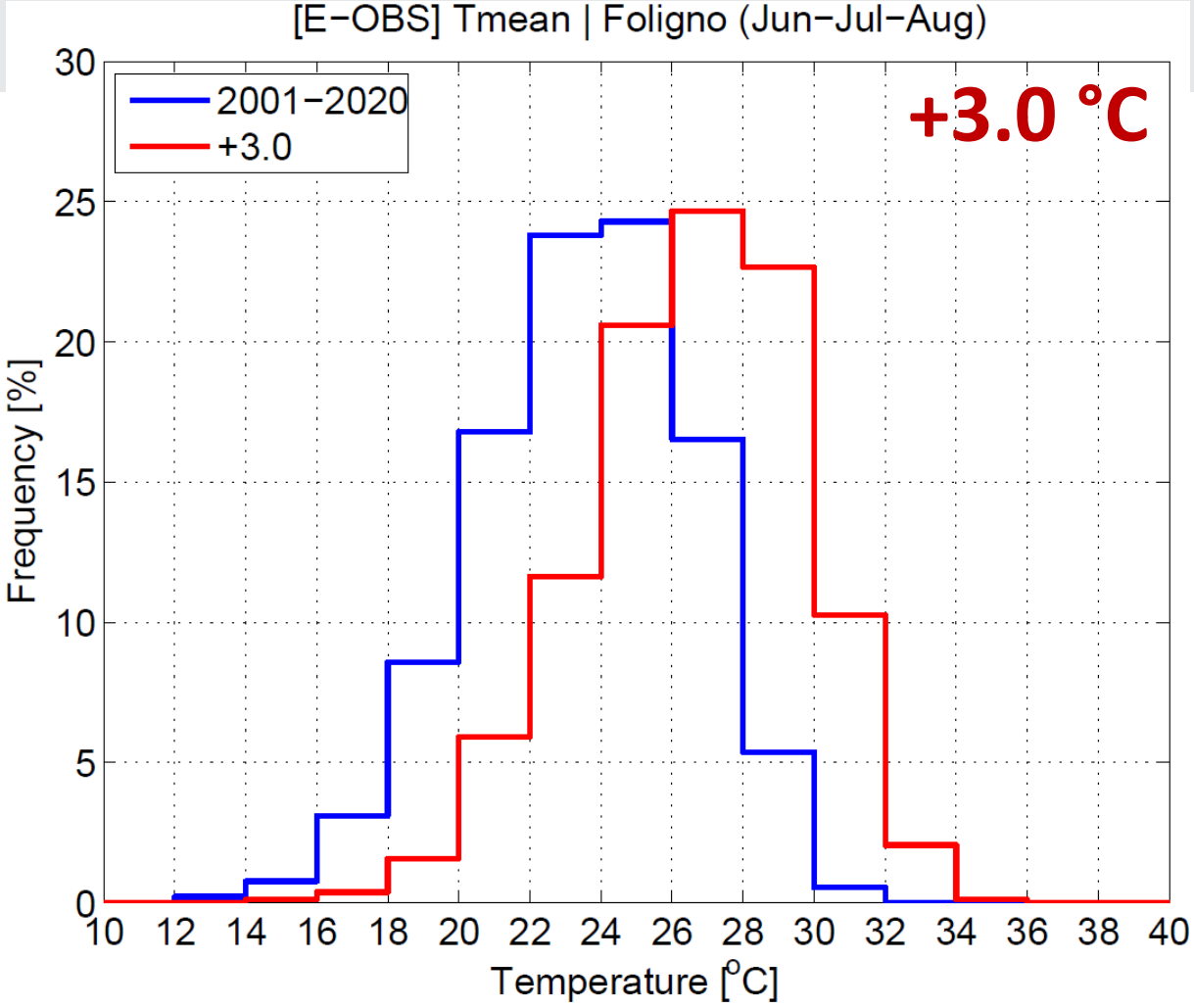




[https://www.ipcc.ch/assessment-report/ar6/]

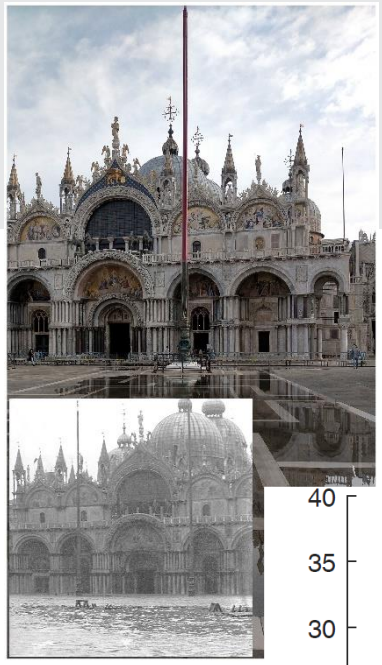
Proiezioni climatiche, a Foligno

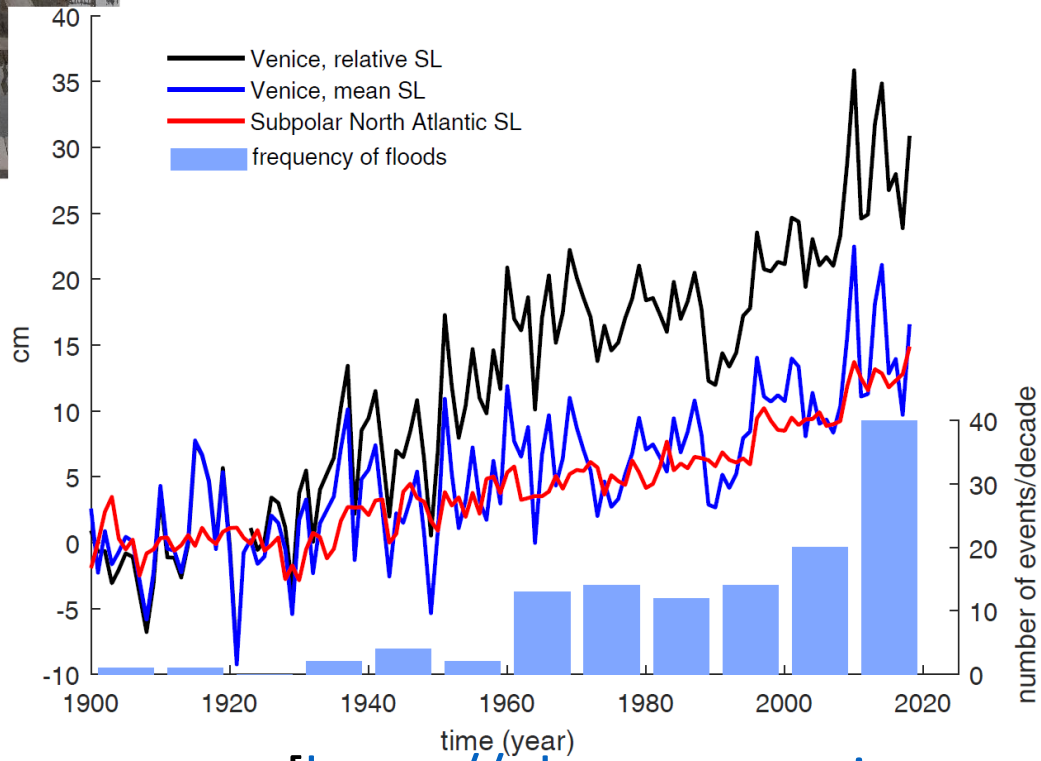


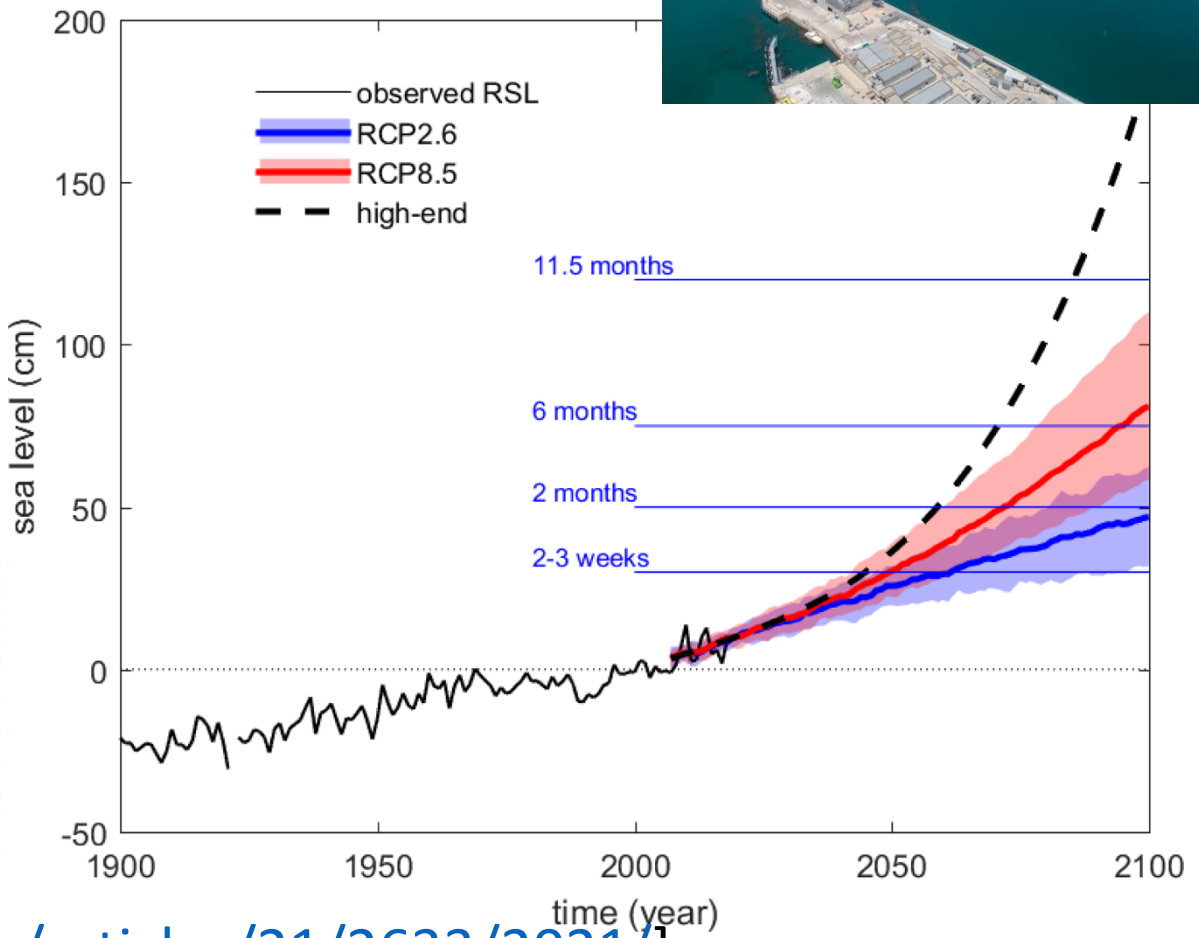


→ ***Don't try this at home! This is not a climate prediction!*** ☺

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	v High confidence of decrease
Frost	v High confidence of decrease
WET AND DRY	
Mean precipitation	v High confidence of decrease
River flood	v 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

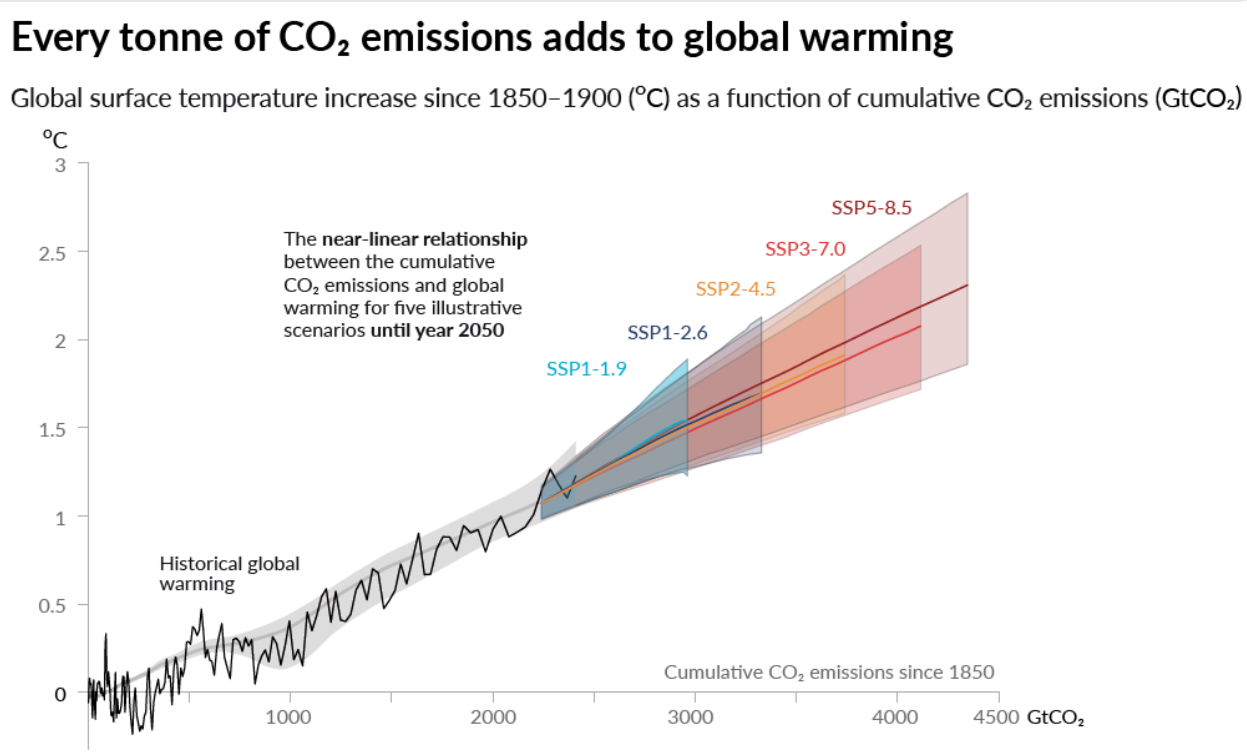
[https://interactive-atlas.ipcc.ch/]

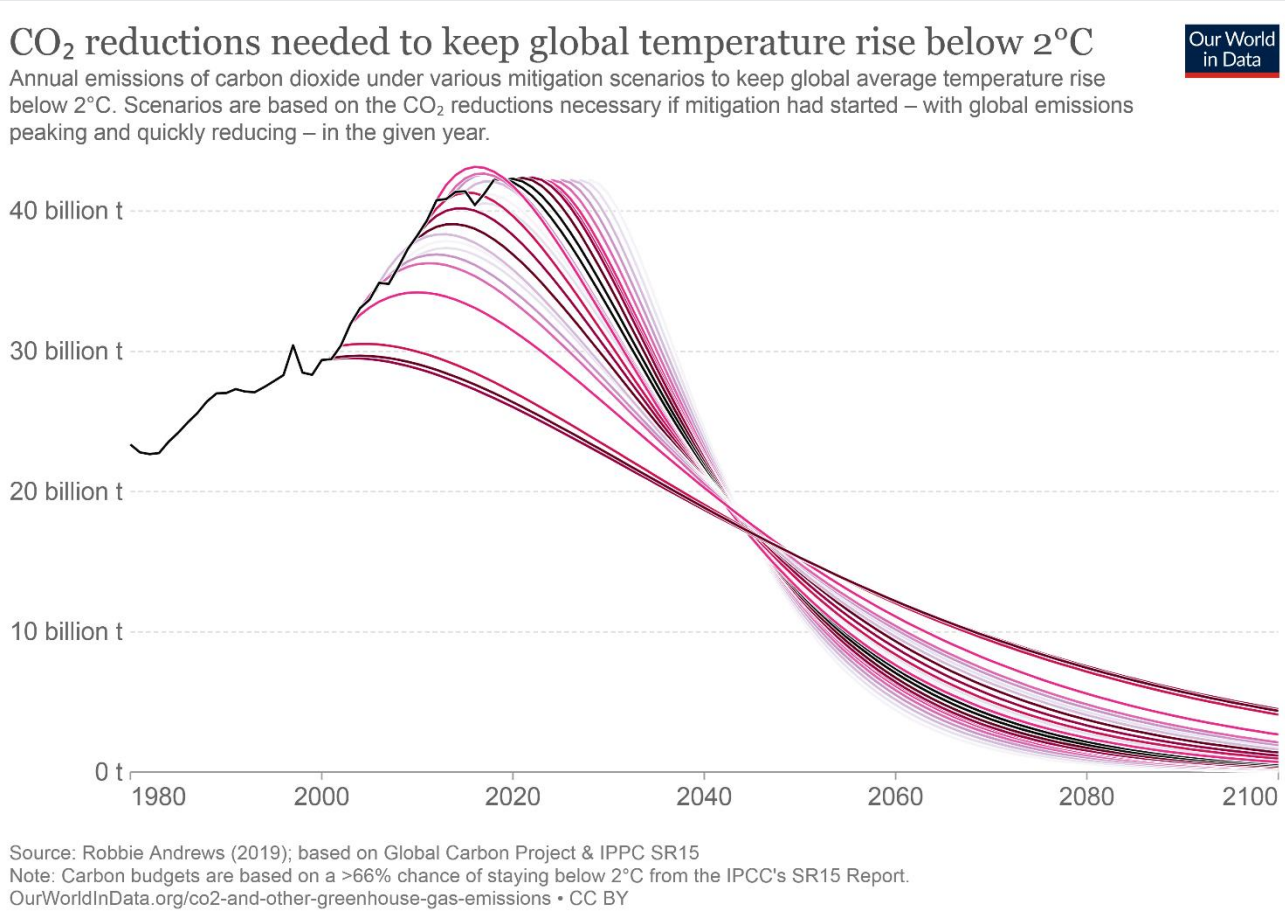
Proiezioni climatiche, Mediterraneo

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/]

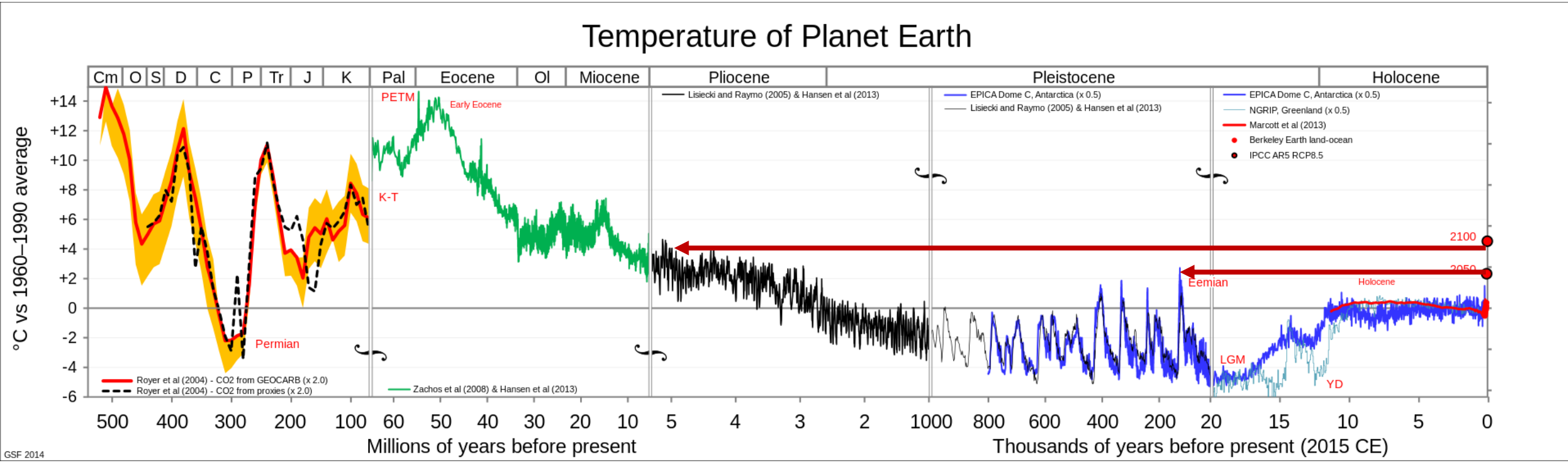
Soluzioni (per un clima a +2.0 °C)



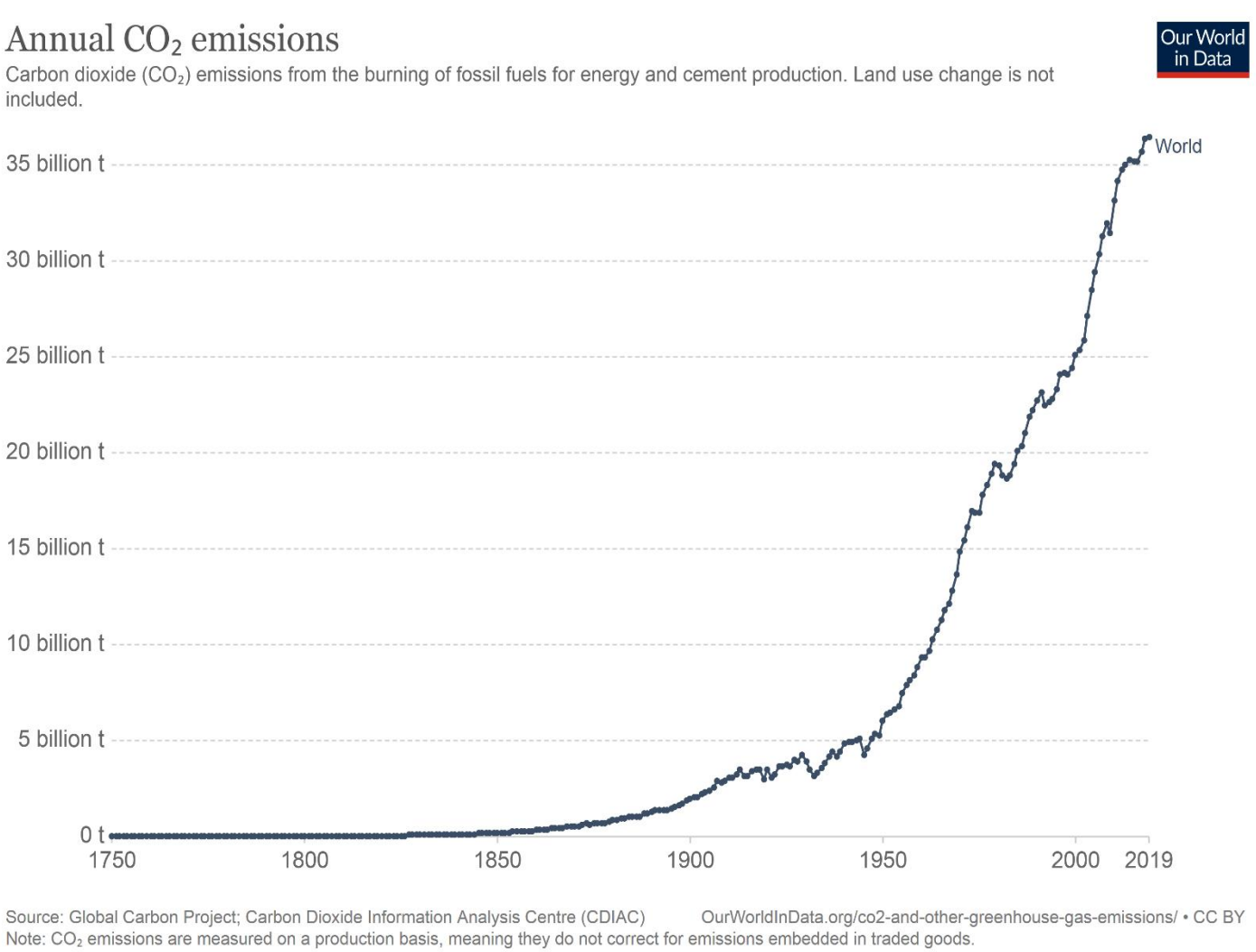


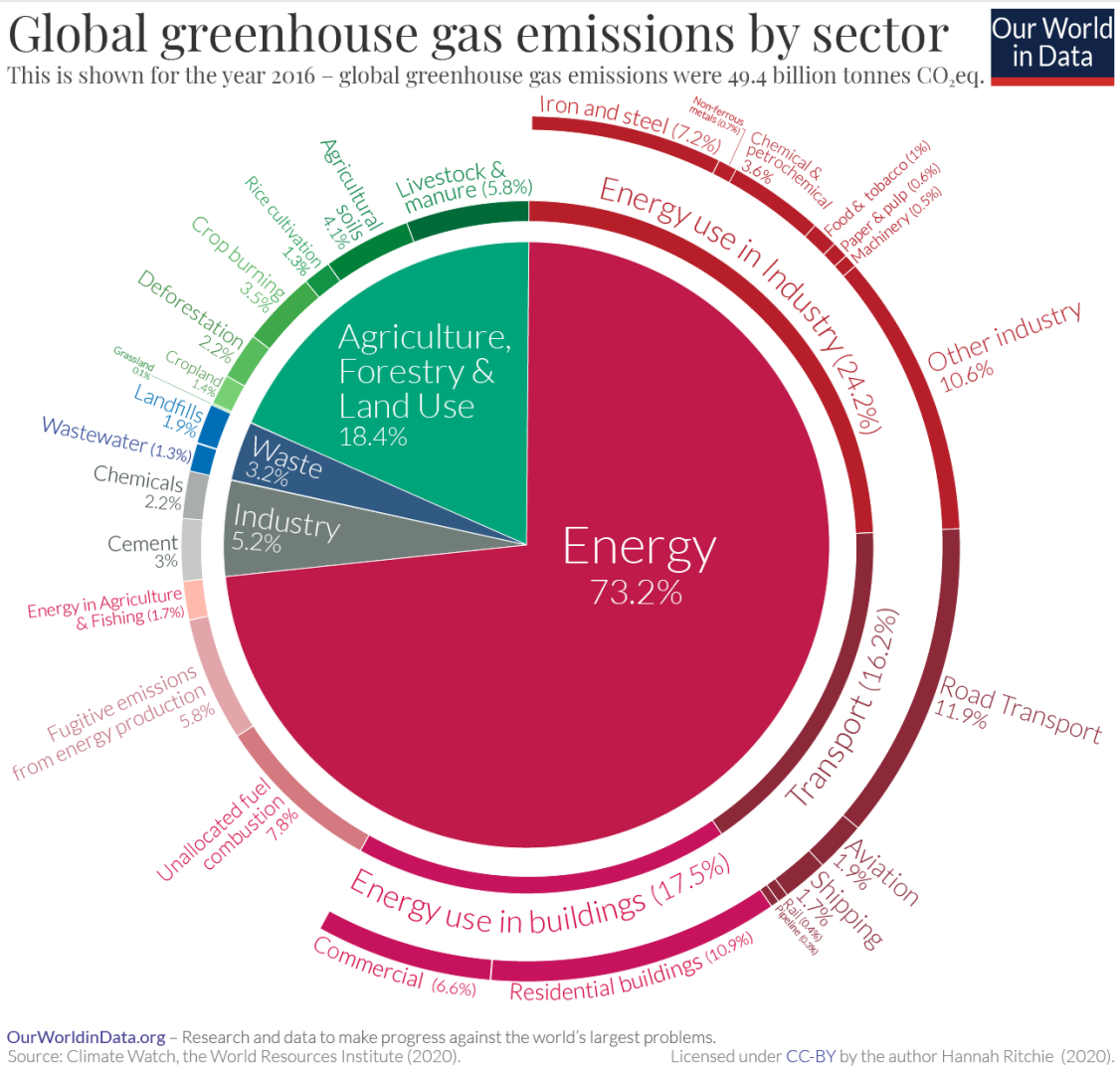
[https://www.ipcc.ch/assessment-report/ar6/]

Scenari futuri che guardano al passato (remoto)



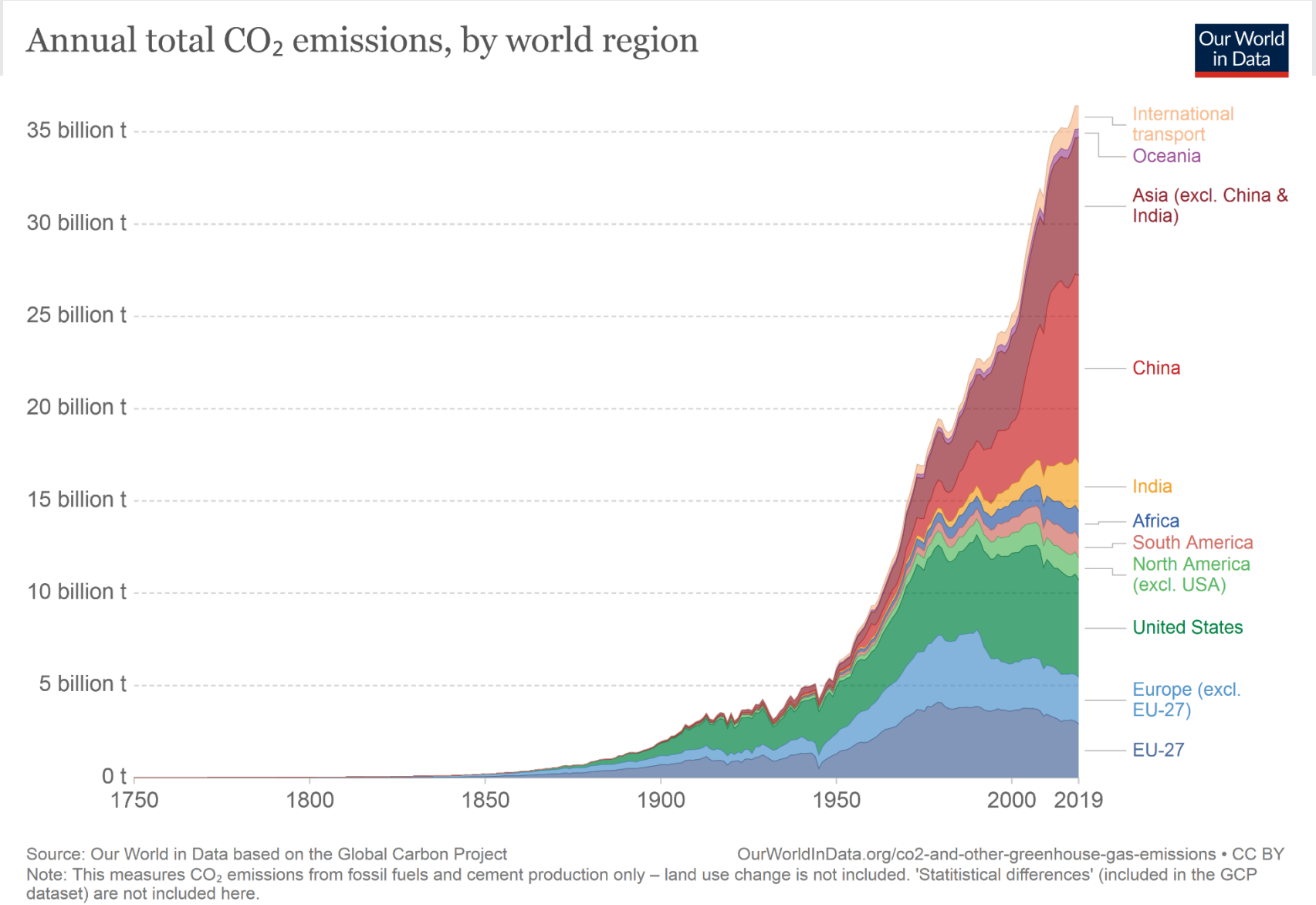
Emissioni di gas serra



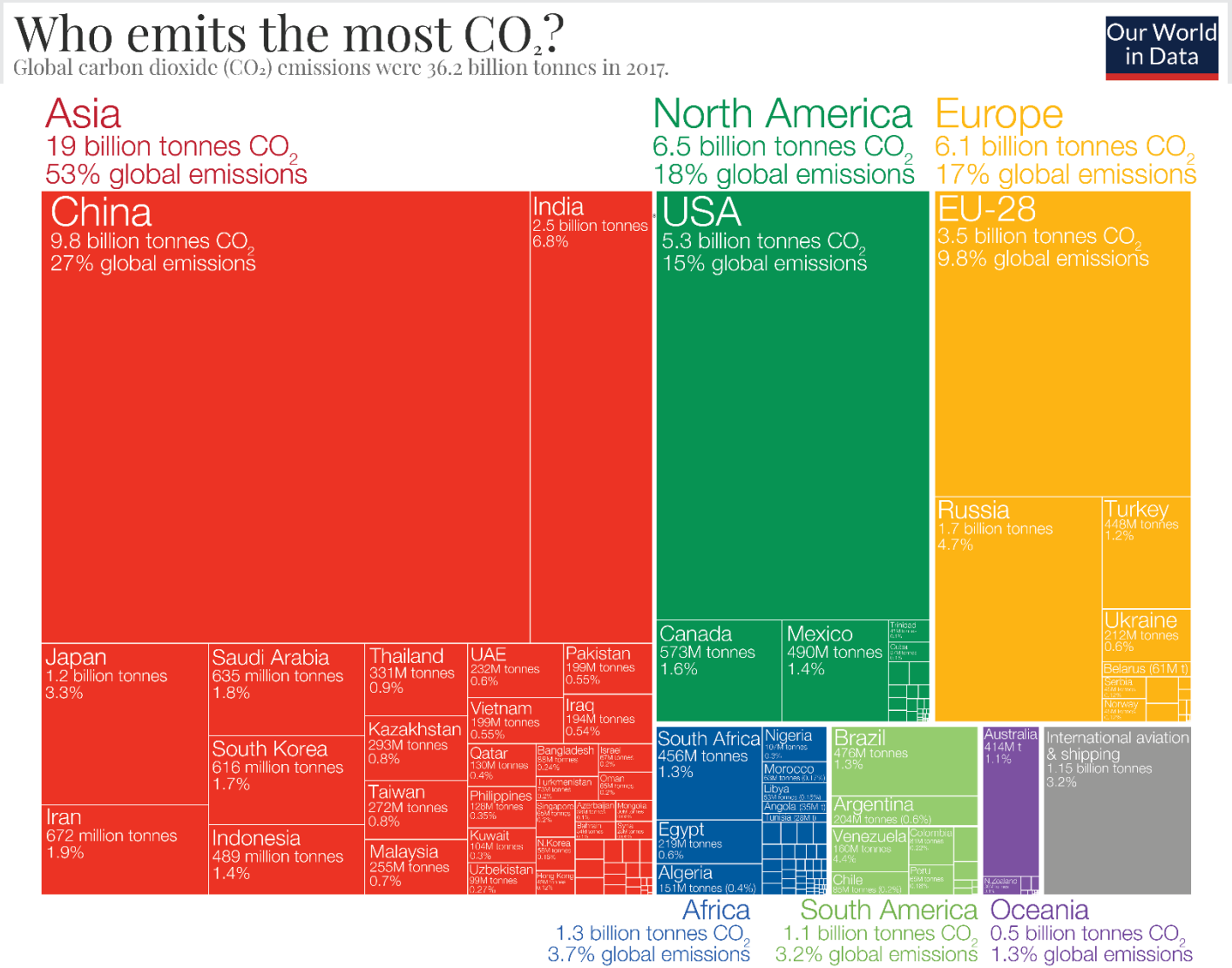


[https://ourworldindata.org/]

Emissioni di gas serra



Emissioni di gas serra

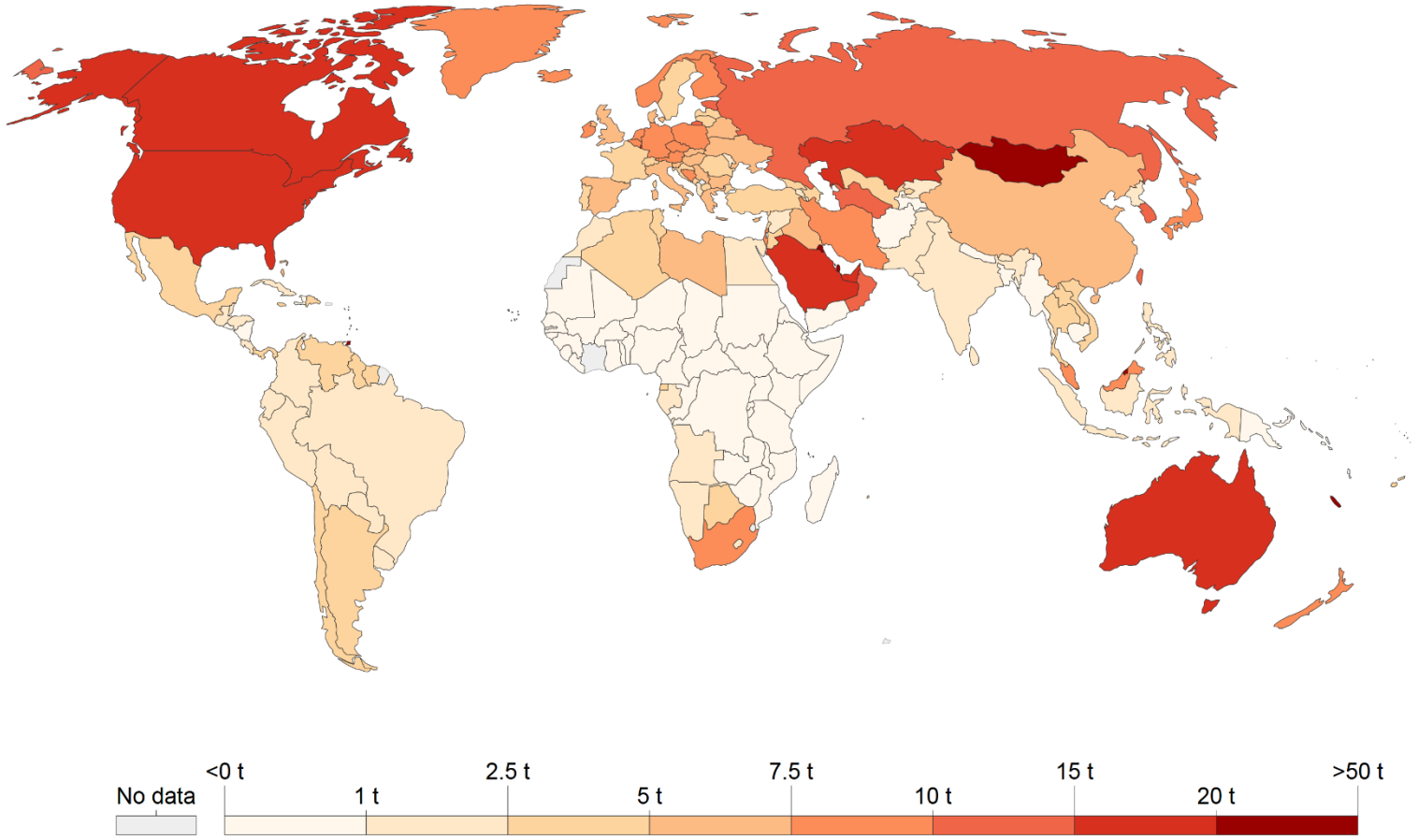


Emissioni di gas serra

Per capita CO_2 emissions, 2019

Carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Our World in Data

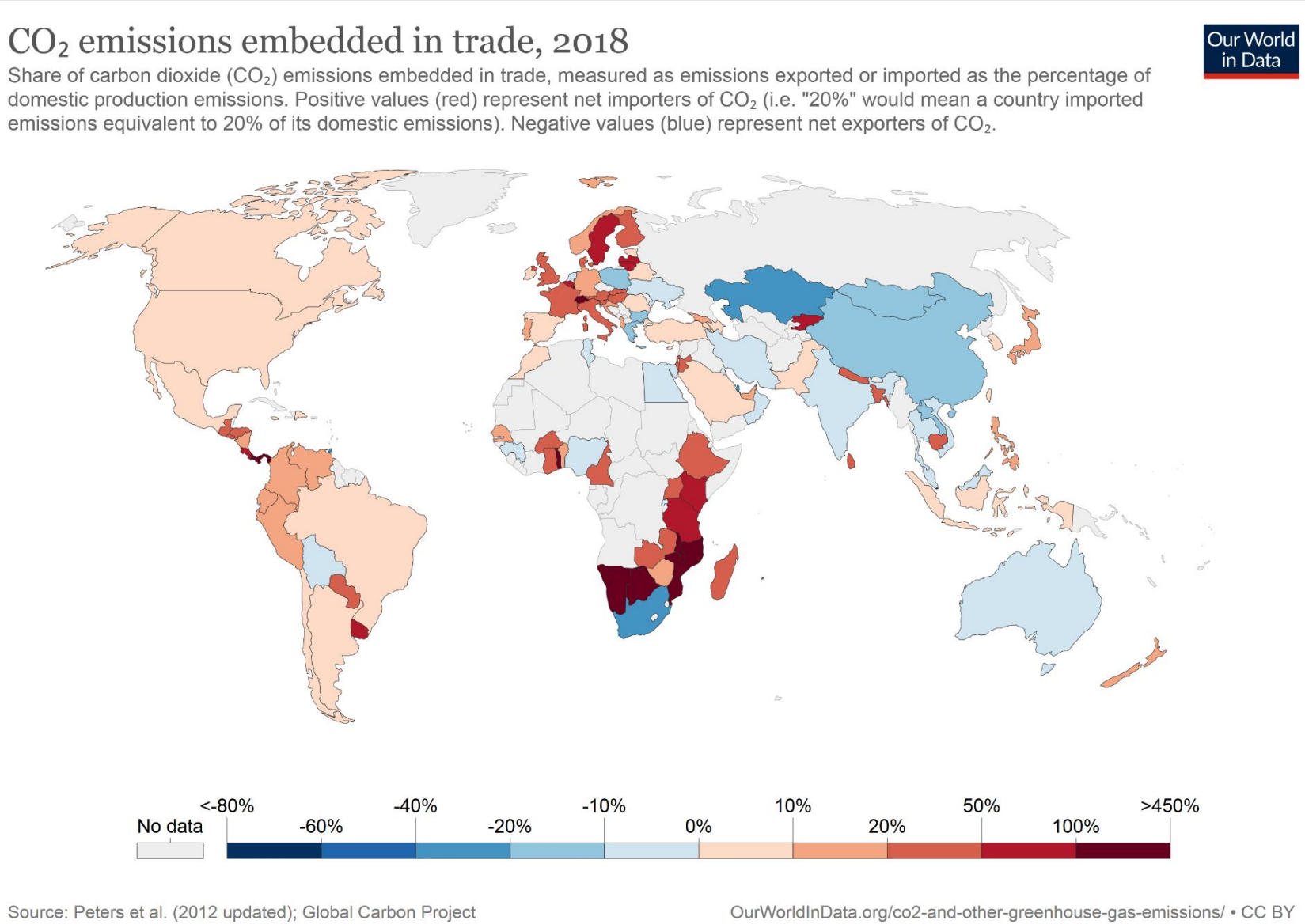


Source: Our World in Data based on the Global Carbon Project; Gapminder & UN

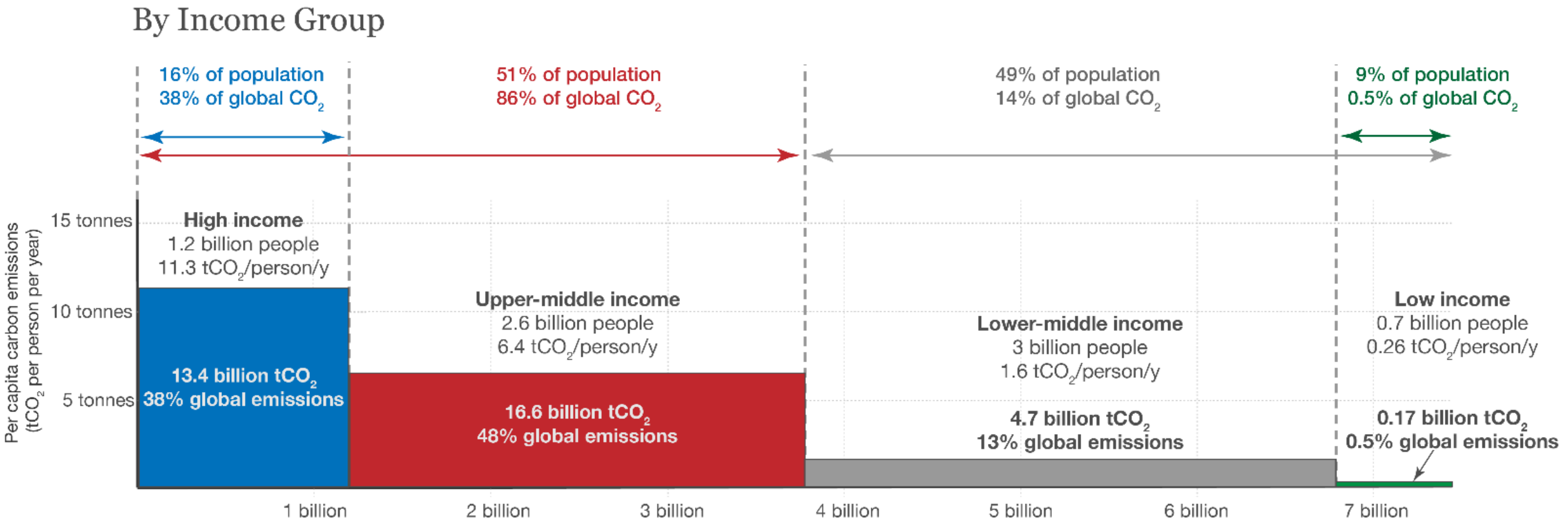
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

Note: CO_2 emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.

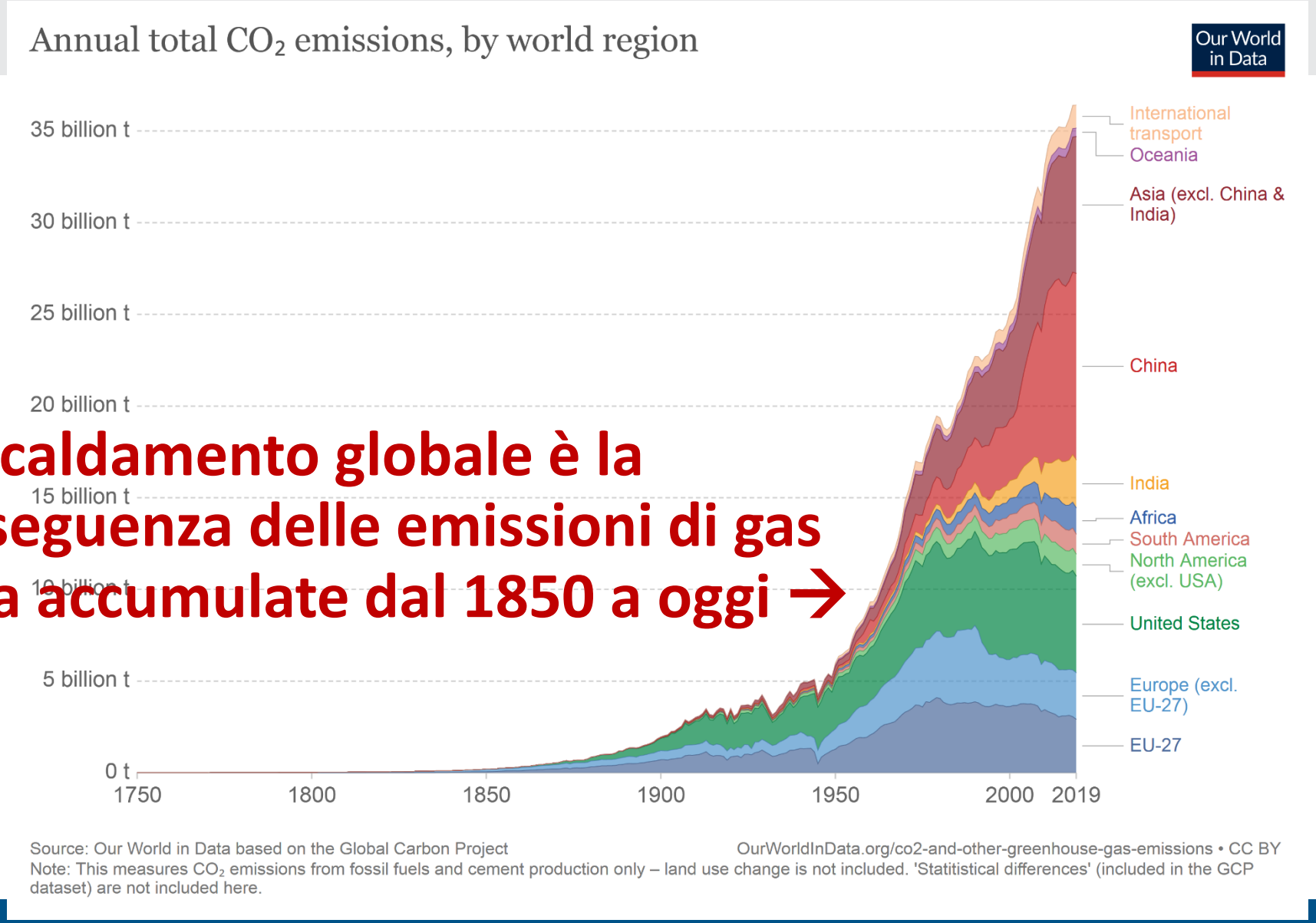
Emissioni di gas serra



Emissioni di gas serra



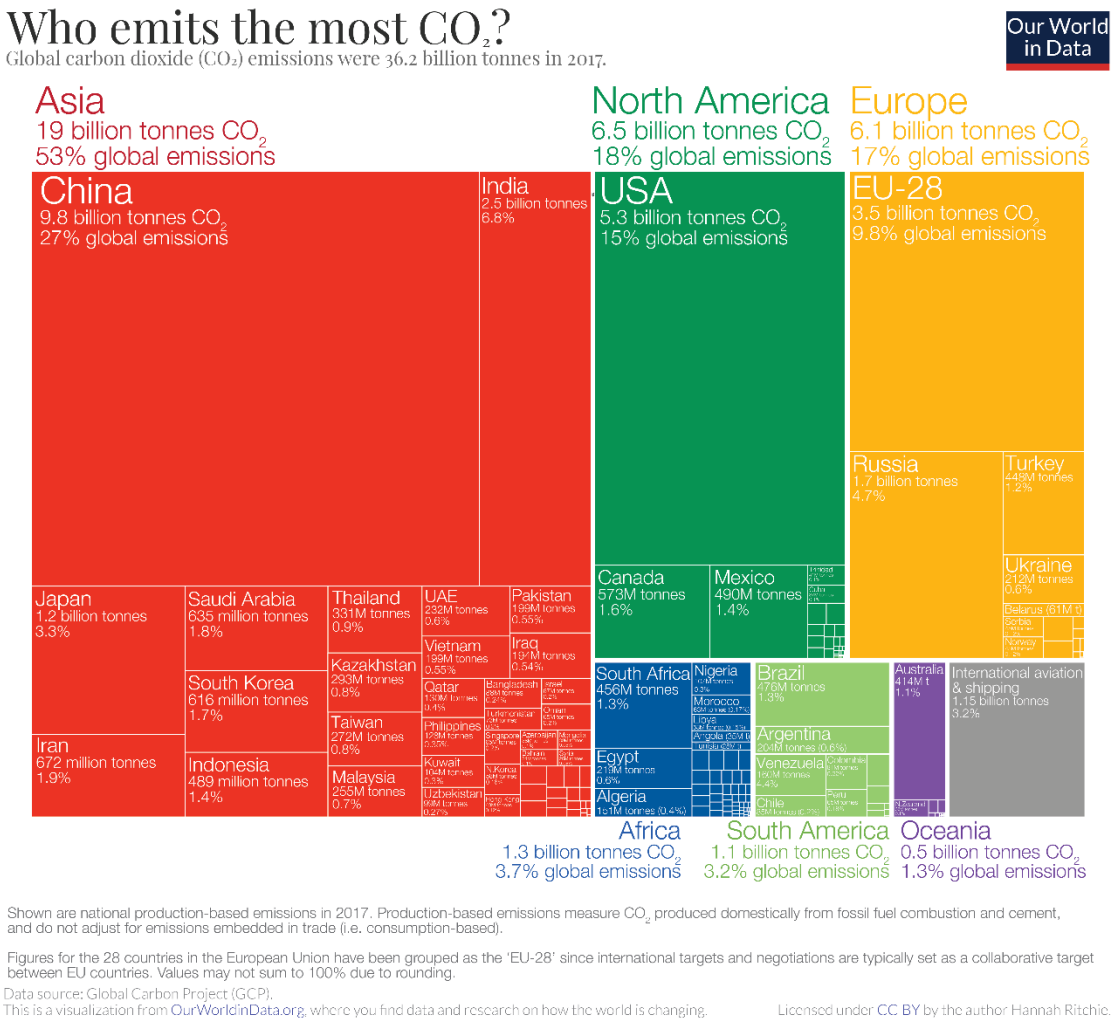
Emissioni di gas serra



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

Emissioni di gas serra

2019



Shown are national production-based emissions in 2017. Production-based emissions measure CO_2 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, where you find data and research on how the world is changing.

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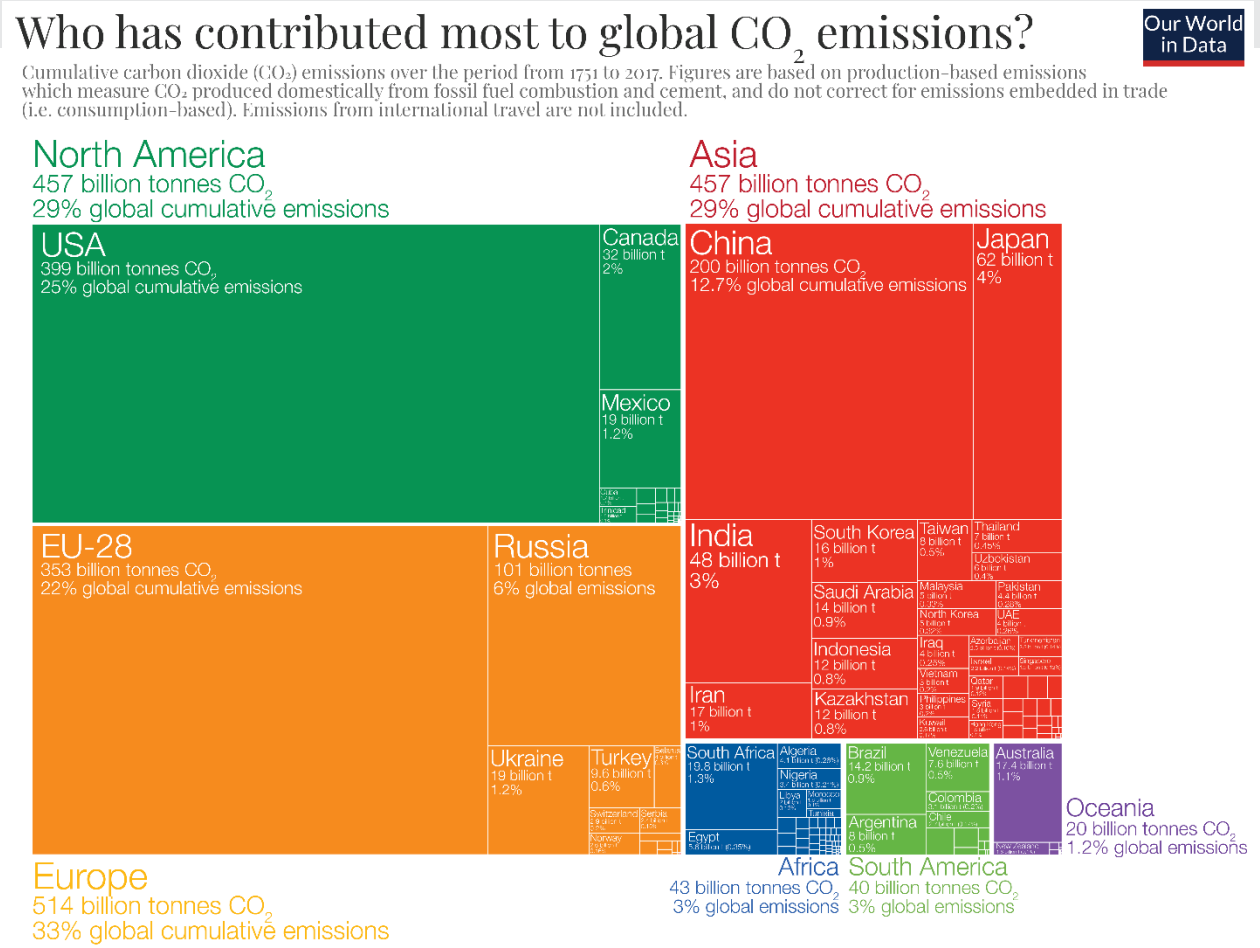
1751-2017



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