

Dalla scala globale al Mediterraneo: evoluzione storica del concetto di global warming e impatti nella regione mediterranea

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Dynamics of Ecosystems and Computational Oceanography © OGS National Institute of Oceanography

Understanding and quantitatively representing the dynamics of marine, coastal and lagoon ecosystems, through the development and use of numerical analysis methods and models of different complexity that describe and integrate physical, biogeochemical and ecological dynamics at different spatial and temporal scales, also using artificial intelligence and supercomputing technologies.

https://www.ogs.it/en/dynamics-ecosystems-andcomputational-oceanography







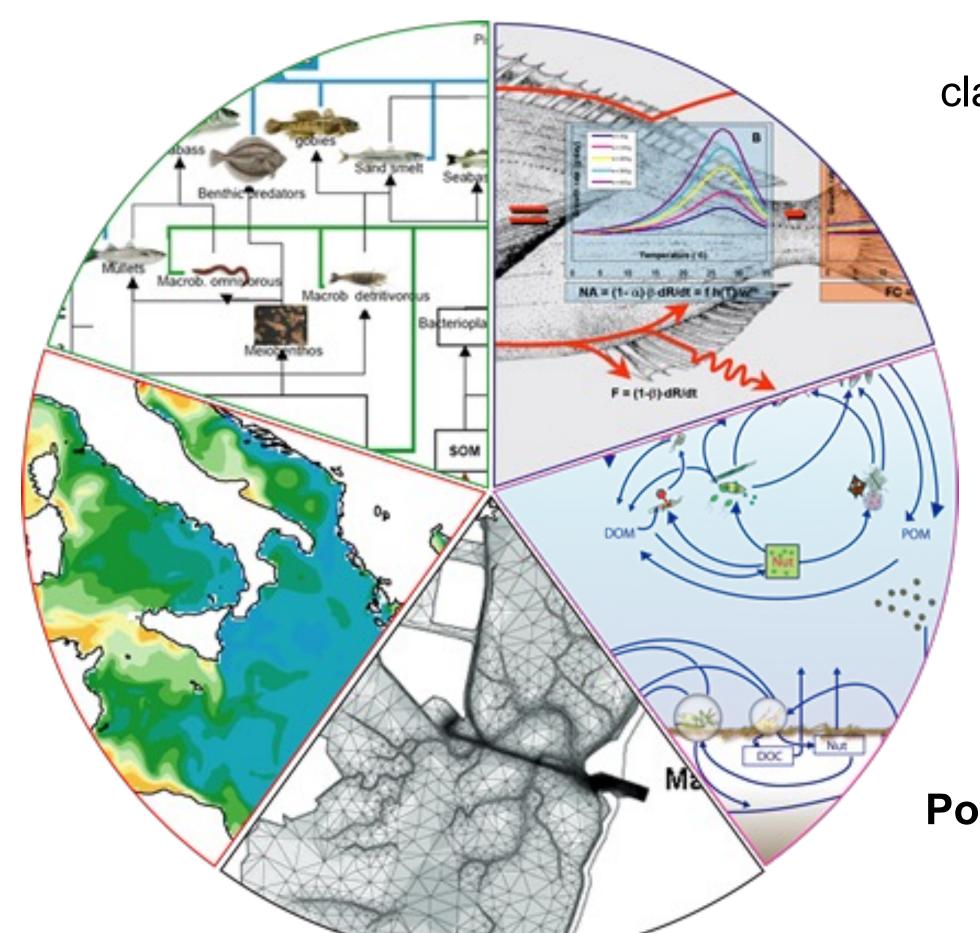
The ECHO research group develops and uses a wide set of methods and models, according to the specific problem to be solved:

Food web / network models ECOPATH, ECOSIM, ECOSPACE

Habitat suitability models
LTRANS+behaviour

Hydrodynamic models

finite differences: OGSTM finite elements: SHYFEM finite volumes: MITgcm



Individual Based Model & population dynamics

clams, mussels, fish, jellyfish, plancton, macroalgae

Biogeochemical models
BFM, TDM

Bio-optics models OASIM

Pollutant dispersion and bioaccumulation SERAFM, MERCURY, CUSTOM

Integrated physical-biogeochemical-ecological models



Take home messages

- Fattori antropici (emissioni gas serra) sono responsabili della transizione climatica in atto. Ci sono sicuramente degli altri fattori (naturali) che potrebbero avere un qualche ruolo nel cambiamento climatico. Ma attualmente la loro azione è dimostrata come trascurabile
- Gli strumenti che usiamo per studiare il clima (i modelli climatici frutto della ricerca di due generazioni di scienziati) sono validi e affidabili (anche unico strumento a disposizione)
- Se non facciamo nulla il clima delle prossime decadi sarà sostanzialmente diverso da quello scorso secolo con impatti significativi nell'area Mediterranea



The Mediterranean climate

- "Mediterranean climate" is one the different types of climate on Earth according to the qualitative classification of Koeppen (Koeppen, 1936)
- It is used to define the climate of other (generally smaller) regions besides that of the Mediterranean region itself.
- It may occur on the west side of continents between about 30 and 40 latitude (like California, Southern Africa)
- "Mediterranean" climate is essentially characterized by : a) mild wet winters and b) warm to hot, dry summers



The Mediterranean climate





The Mediterranean Region(*) has several morphological, geographical, historical and social characteristics, which make its climate scientifically interesting *no universal definition of the land boundaries of the Mediterranean region



What are the characteristics making this climate quite different from the others?

- the presence of a relatively large mass of water (Mediterranean Sea) in a(n) (almost) closed basin with an area 2.5 million km², 3700 km in longitude, 1600 km in latitude, average depth is 1500 m, maximum value of 5150 m in the Ionian Sea.
- Meridional gradient with a transition from hot and arid regions to humid mountain climate and permanent glaciers in about 2,000 km.
- albedo differences South-North Strong in directions



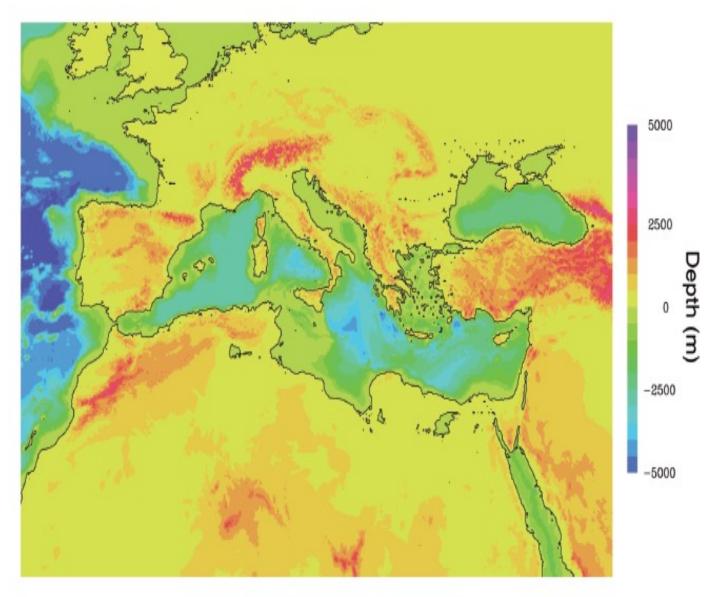
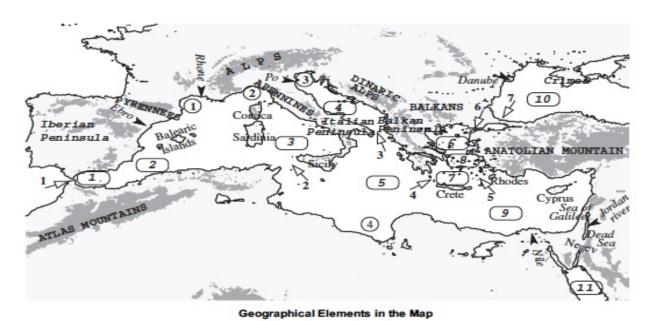


Figure 1: Orography and Sea-depth of the Mediterranean region.



-Cyprus

-Rhodes

-Sardinia

Peninsulas

-Balkan peninsula

-Iberian peninsula

-Italian peninsula

-Sicily

-Crimea

Mountains

-Anatolian mountain Apennines -Atlas mountair -Balkans -Dinaric Alps -Pyrennees

Lakes -Sea of Galilee -Dead Sea

8-Cyclades Plateau 9-Levantine basin 10-Black Sea 11-Red Sea

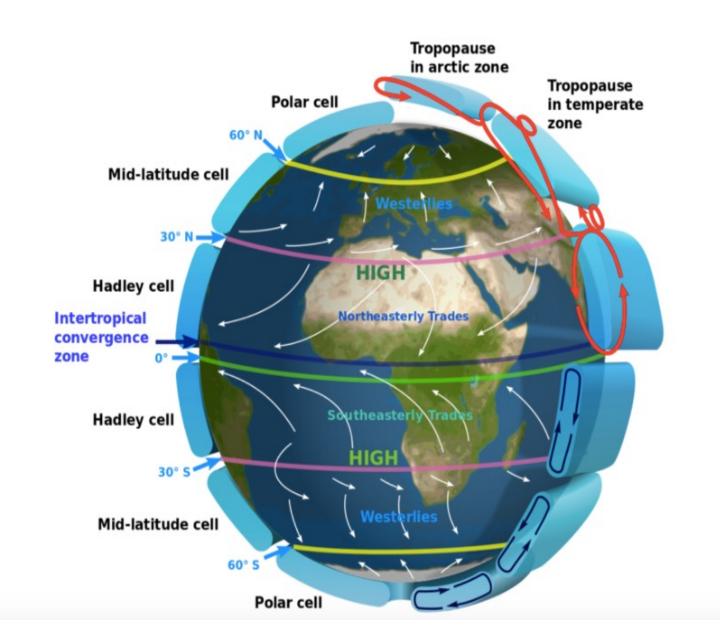
Rivers (mouths are denoted with black arrows)

-Danub -Jordan

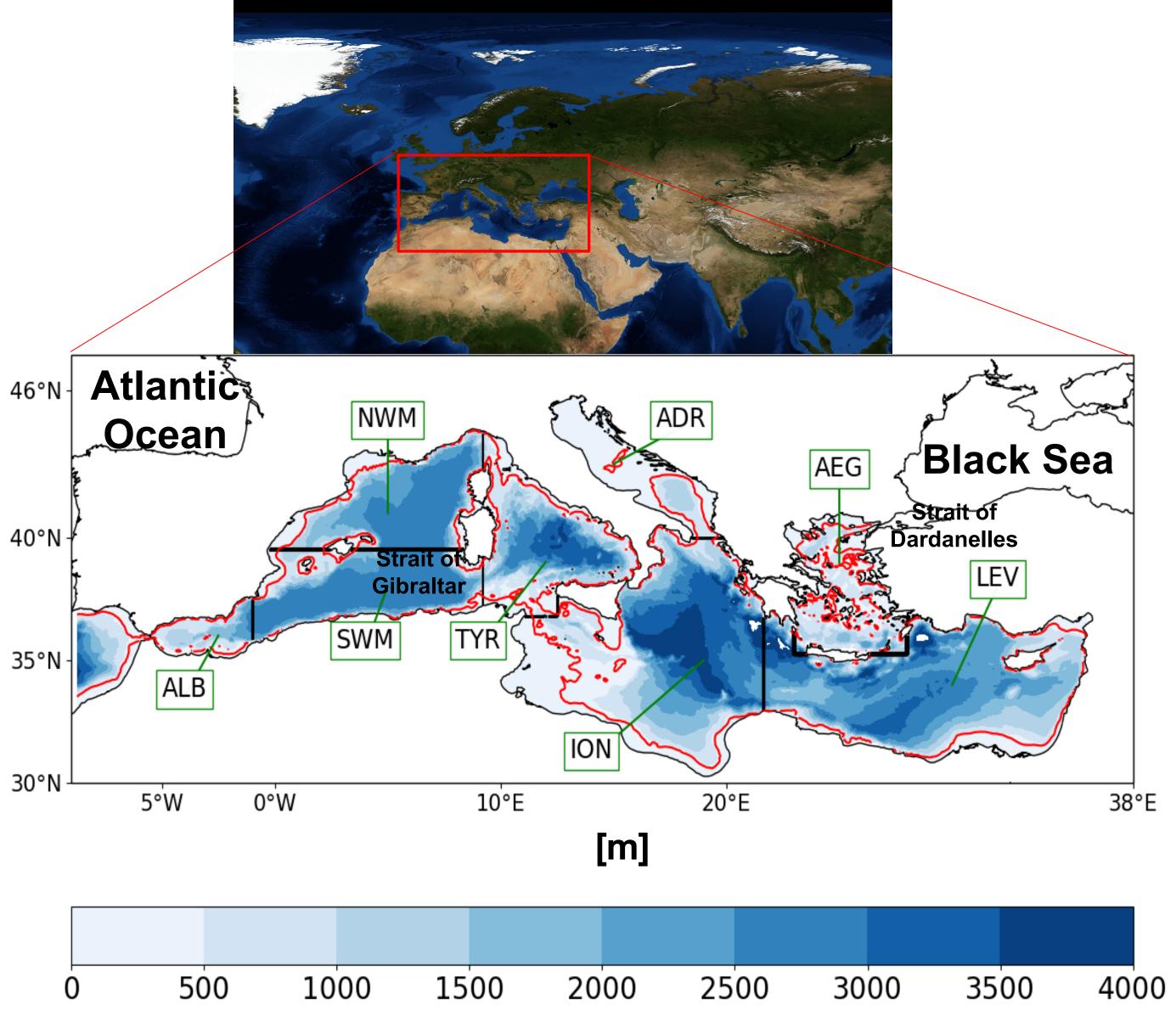
Others -The Negev desert

What are the characteristics making this climate quite different from the others?

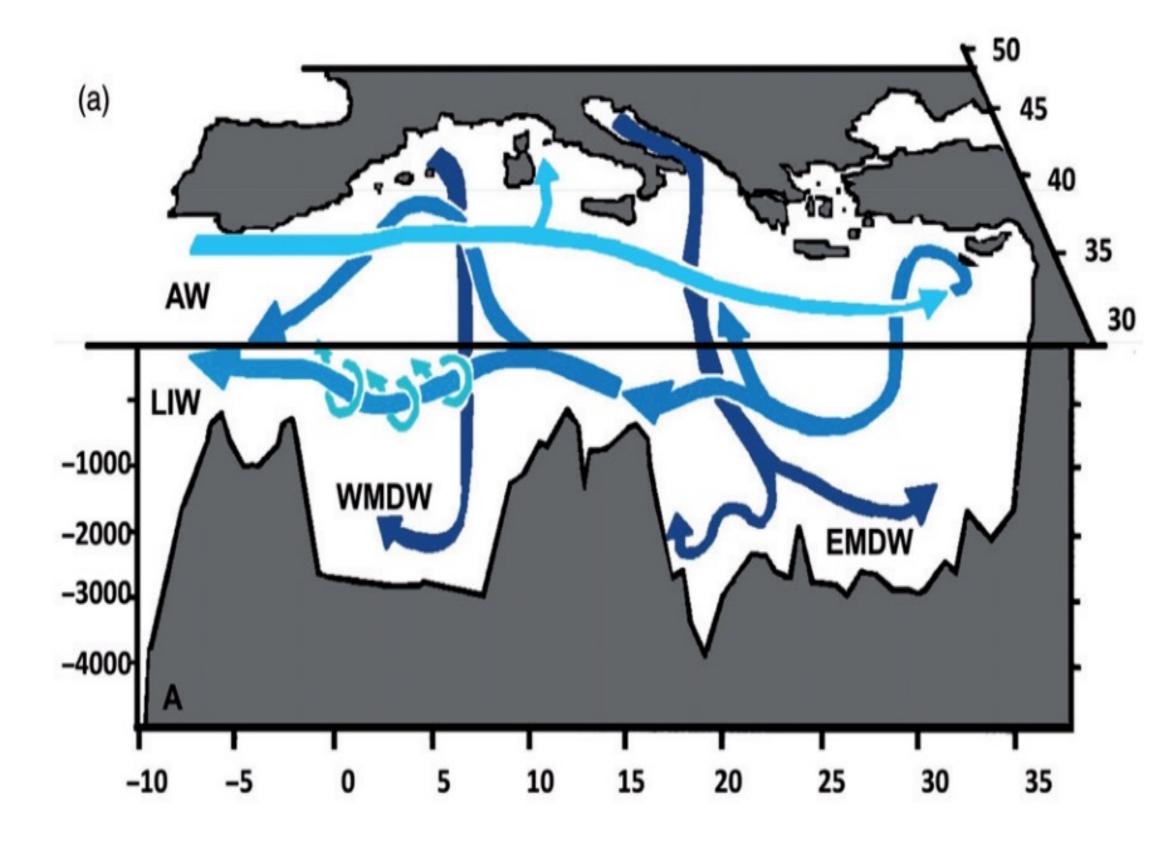
- It is located in a transitional zone, where mid-latitude and tropical variability are both important and compete
- Because of the presence of highly populated and technologically advanced societies since, at least, 2000 BC it is possible to observe important patterns of land use change and important anthropic effects on the environment together with a huge amount of climate information from past centuries
- 400 million people live in the countries around the Mediterranean Sea and about 145 million (that is 34% of total) people live in the coastal region.
- Huge availability of observational and reanalyses datasets for the region
- Strong socioeconomic differences between north and south part of the region: difference in pro capita gross domestic product, pro capita energy supply, CO₂ emissions, more tourist arrivals, water availability, population growth, agriculture production



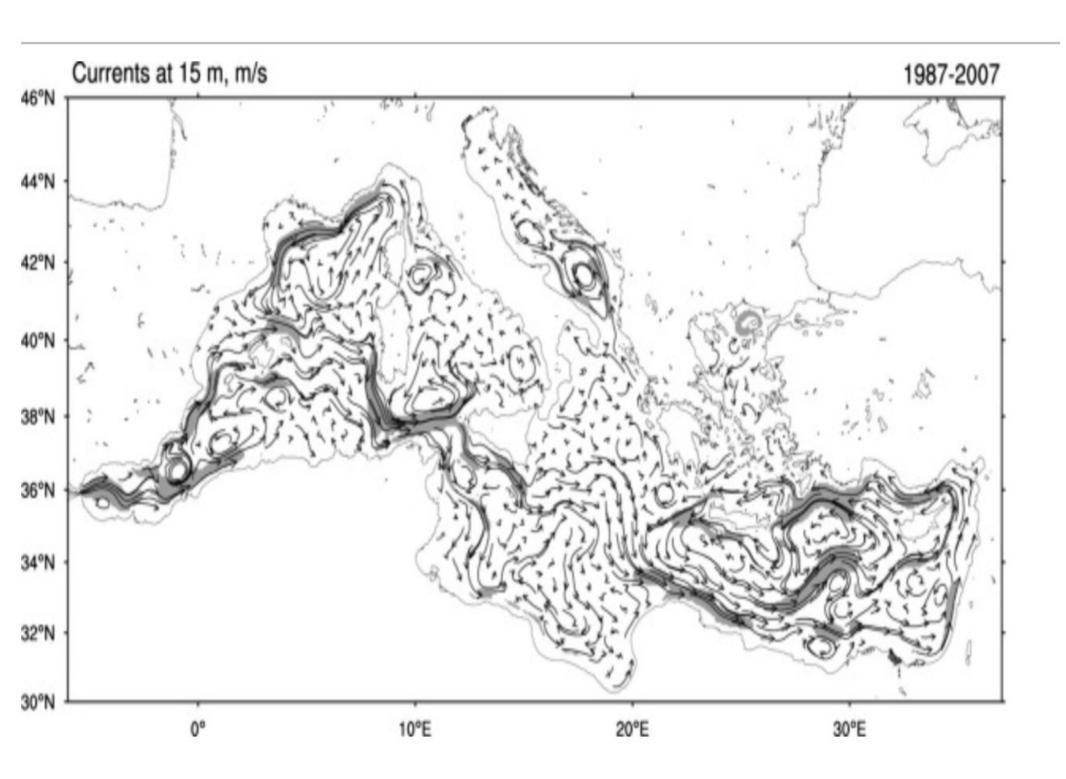
The Mediterranean Sea



Mediterranean thermohaline circulation (MTHC, from Bergamasco and Malanotte-Rizzoli, 2010)

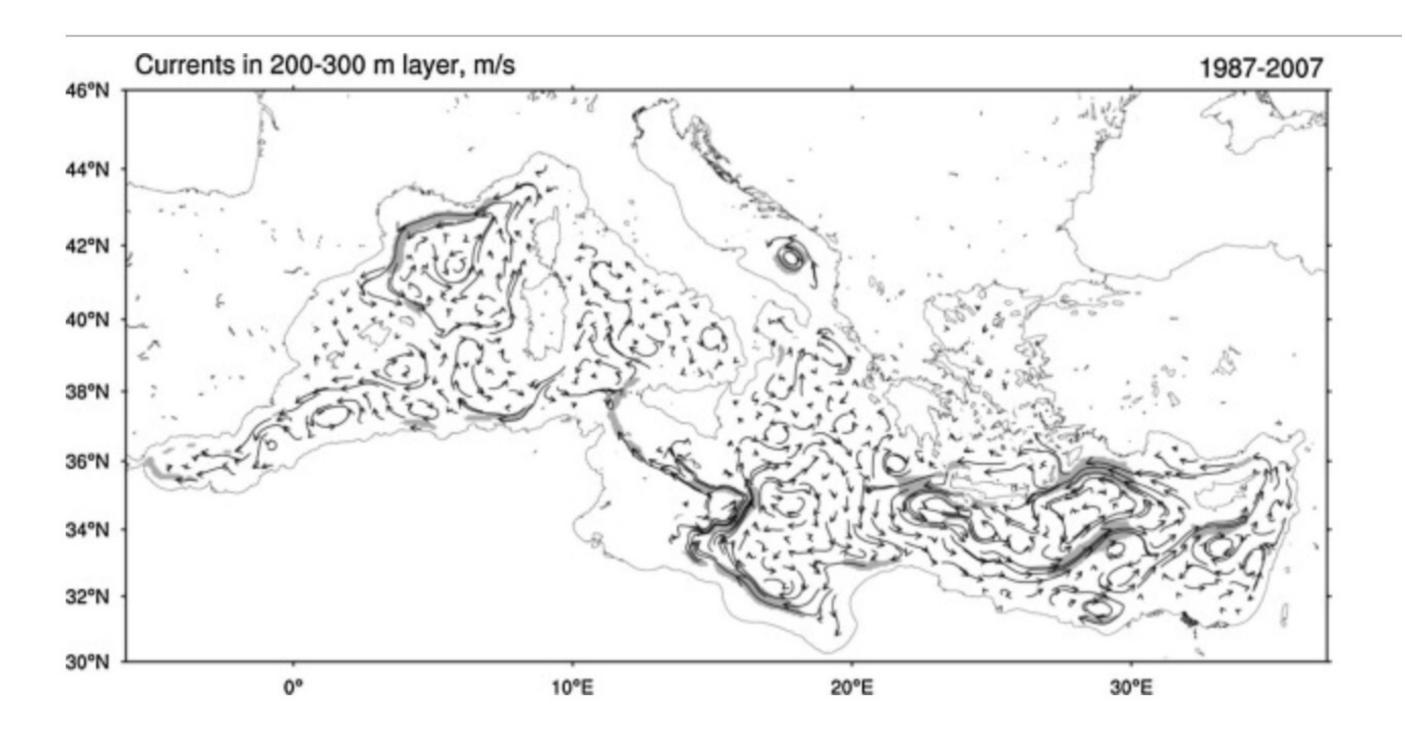


The Mediterranean Sea



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Fig. 3. The 1987–2007 time-mean circulation at 15m depth from the reanalysis: gray areas indicate velocity amplitudes greater than 0.1 ms⁻¹.

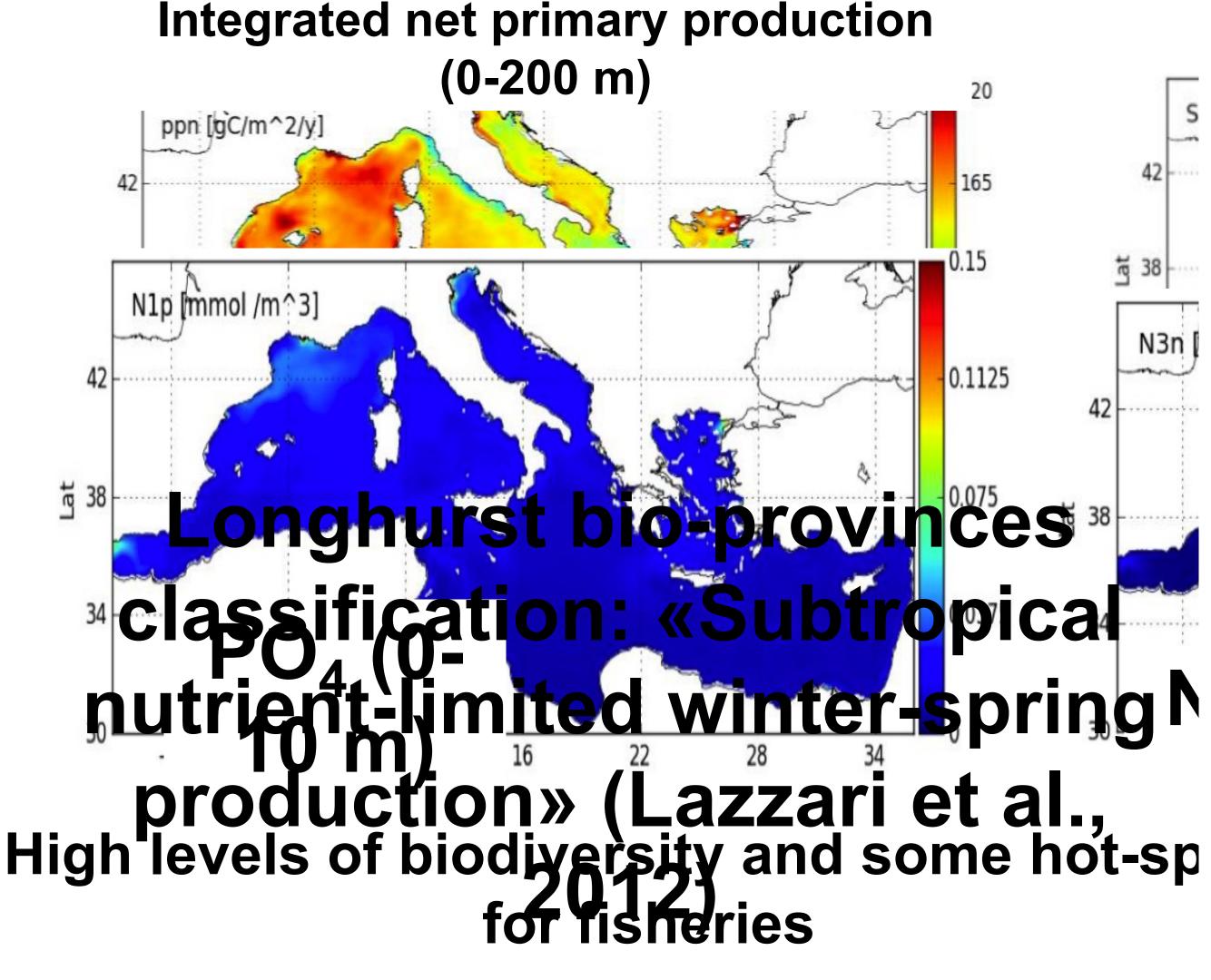


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Fig. 4. The 1987–2007 time-mean circulation, averaged in the layer between 200 and 300m, from the reanalysis: gray areas indicate velocity amplitudes greater than 0.05 ms⁻¹.

The Mediterranean Sea

Bianchi and Morra (2000)



High impacts due to pollution and overexploitation of marine resources

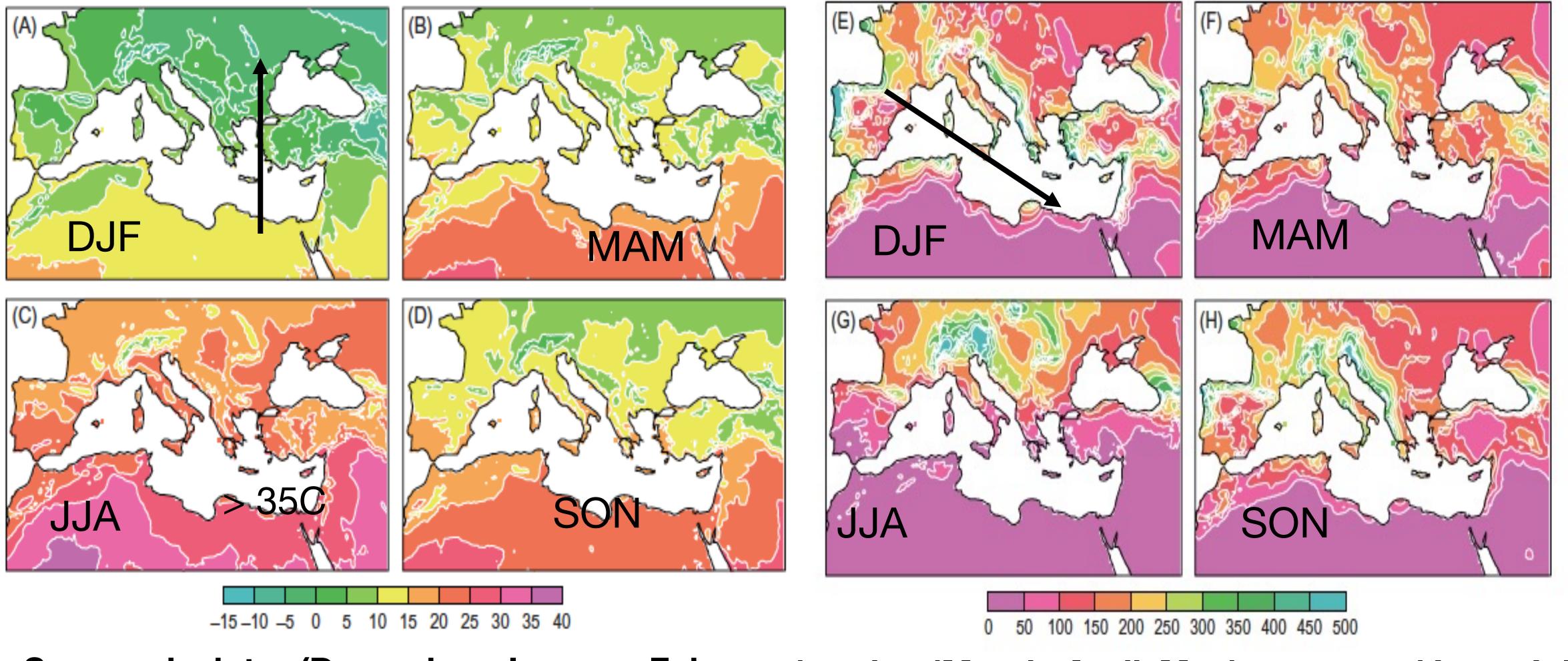
Numbers of species of macroscopic marine organisms in the world ocean and in the Mediterranean Sea.^a

Taxa	World	Mediterranean	Medit/ World (%)	
Red algae	5250	867	16.5	
Brown algae	1500	265	17.7	
Green algae	1200	214	17.8	
Sea grasses	50	5	10.0	
Total plants	8000	1351	16.9	
Sponges	5500	600	10.9	
Cnidarians	11 000	450	4.1	
Bryozoans	5000	500	10.0	
Annelids	8000	777	9.7	
Molluscs	32 000	1376	4.3	
Arthropods	33 600	1935	5.8	
Echinoderms	6500	143	2.2	
Tunicates	1350	244	18.1	
Other invertebrates	~13 550	~550	4.1	
Total invertebrates	~116 500	~6575	5.6	
Cartilagineous fishes	850	81	9.5	
Bony fishes	11 500	532	4.1	
Reptiles	58	5	8.6	
Mammals	114	21	18.4	
Total vertebrates	12 522	639	5.1	
Grand total	~137 000	~8565	6.3	

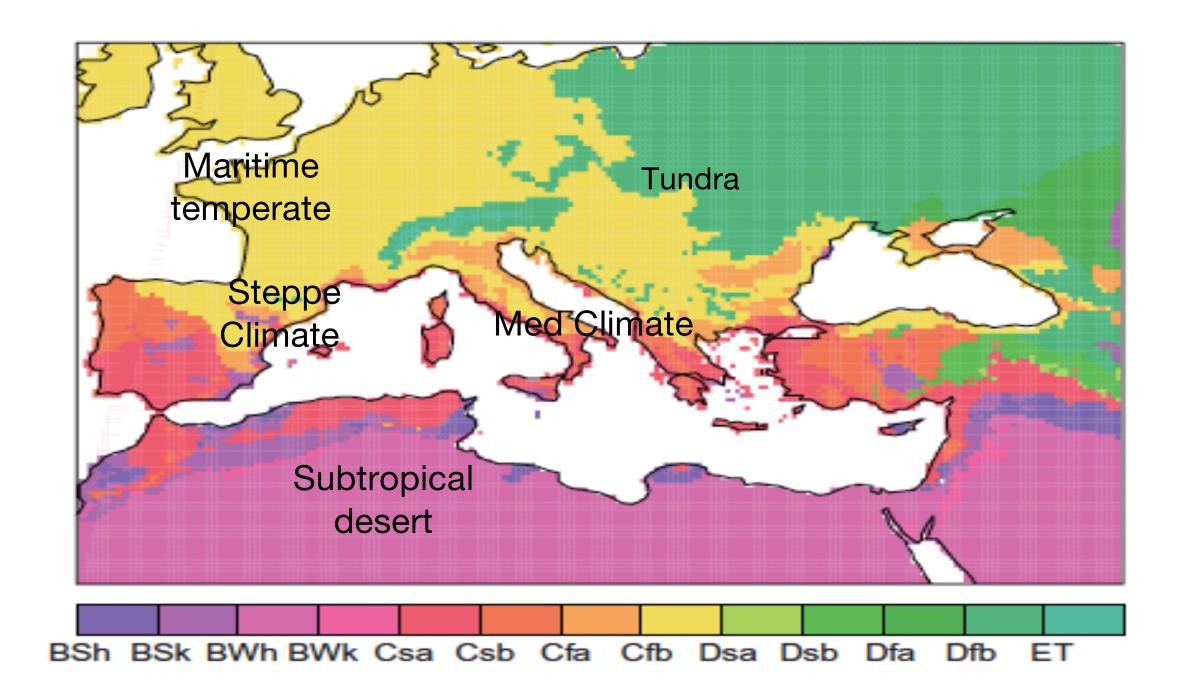
^a Based on several sources (see text).

Temperature

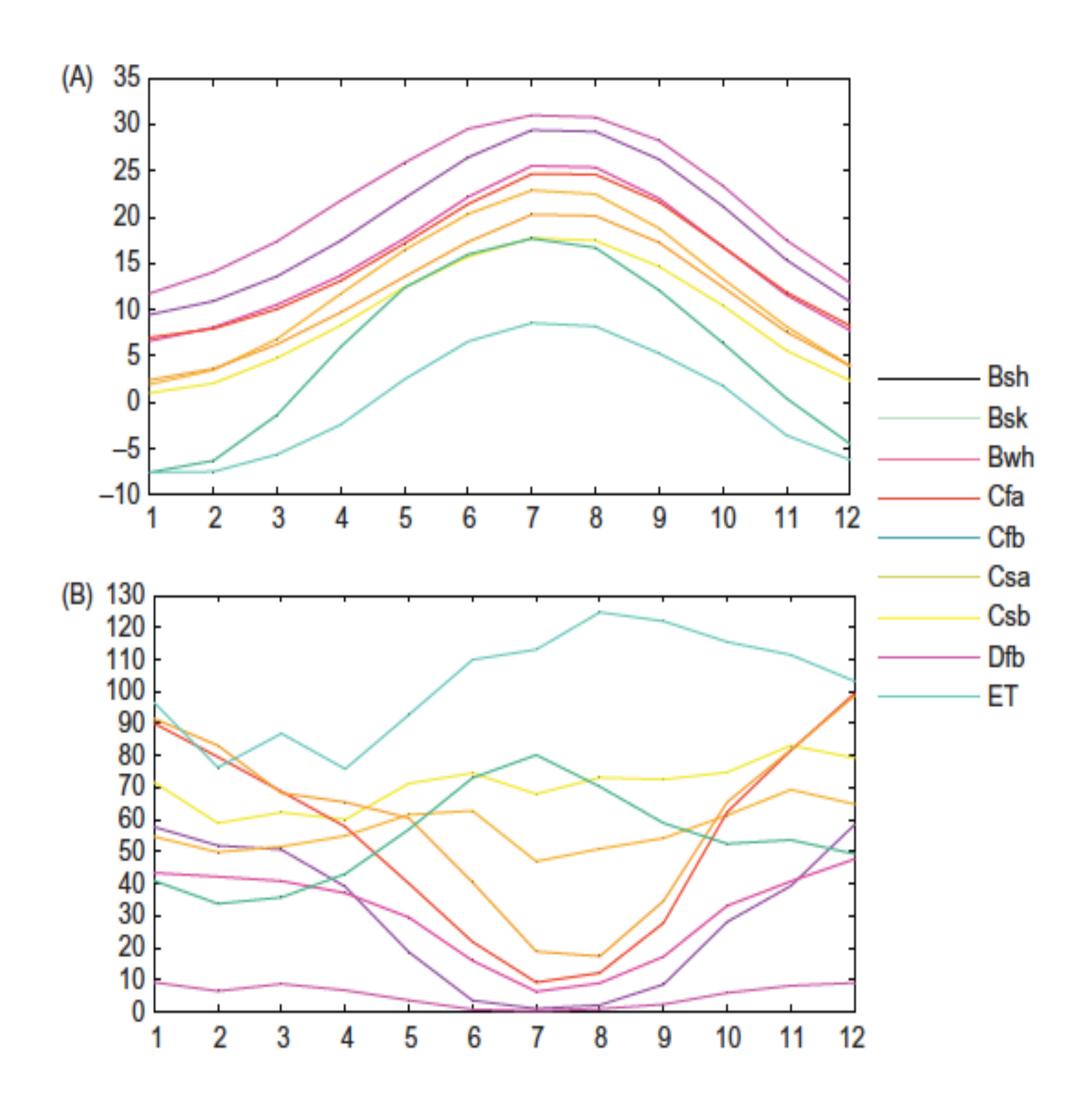
Precipitation



Seasonal winter (December–January–February) spring (March–April–May), summer: (June–July–August) autumn (September–October–November),mean temperature (°C, panels A–D) and total precipitation (mm per season, panels E–H) maps for the period 1961–1990 based on CRU data. (from Lionello et al.,2012a)

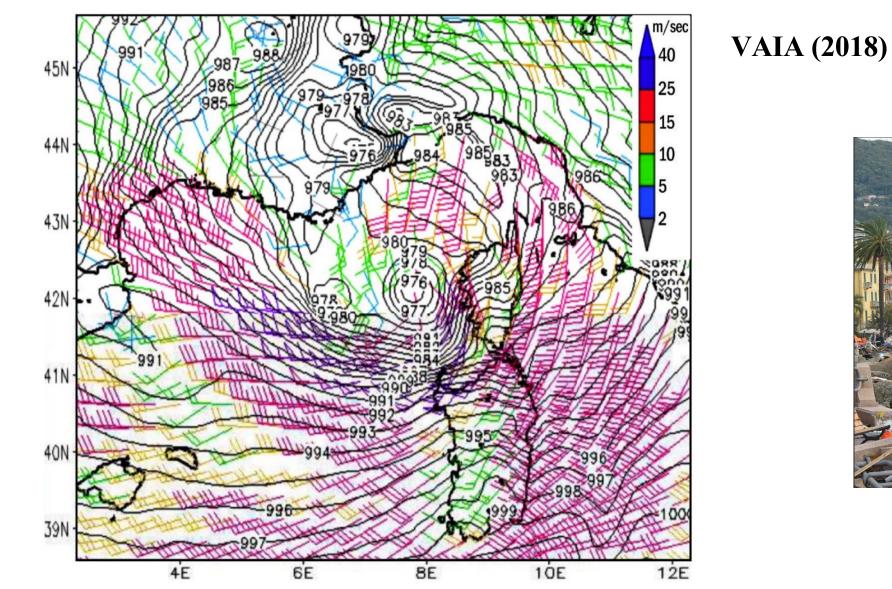


Köppen climate types in the Mediterranean region: subtropical steppe (BSh), midlatitude steppe (BSk), subtropical desert (BWh), midlatitude desert (BWk), Mediterranean climate with hot/warm summer (Csa/b), humid subtropical with no dry season (Cfa), maritime temperate (Cfb), humid continental with hot/warm summer (Dfa/b), continental with dry hot/warm summer (Dsa/b), and tundra (ET). This figure is based on Climatic Research Unit (CRU) temperature and precipitation gridded data (New et al., 2000). From Lionello et al,2012a



Mean annual cycles of temperature (A, monthly average temperature, °C) and precipitation (B, mm/month) of the Köppen climate types in the Mediterranean.

...It is better to talk about different Koeppen climate types in the Mediterranean than a »single» Mediterranean climate



PORTOFINO



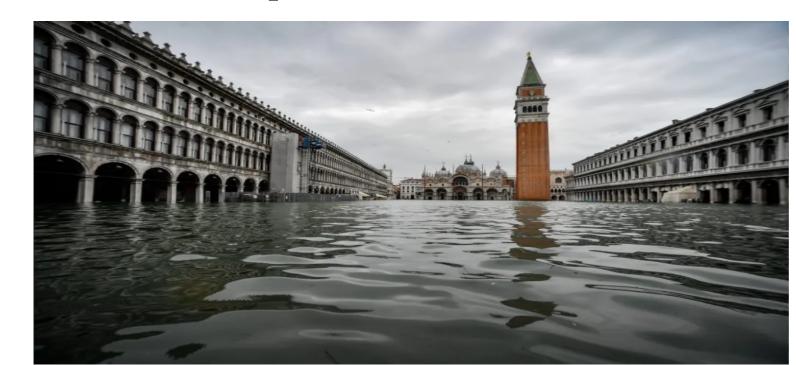
DOLOMITES



MEDICANE IANOS (GREECE)



"Aqua alta" in Venice



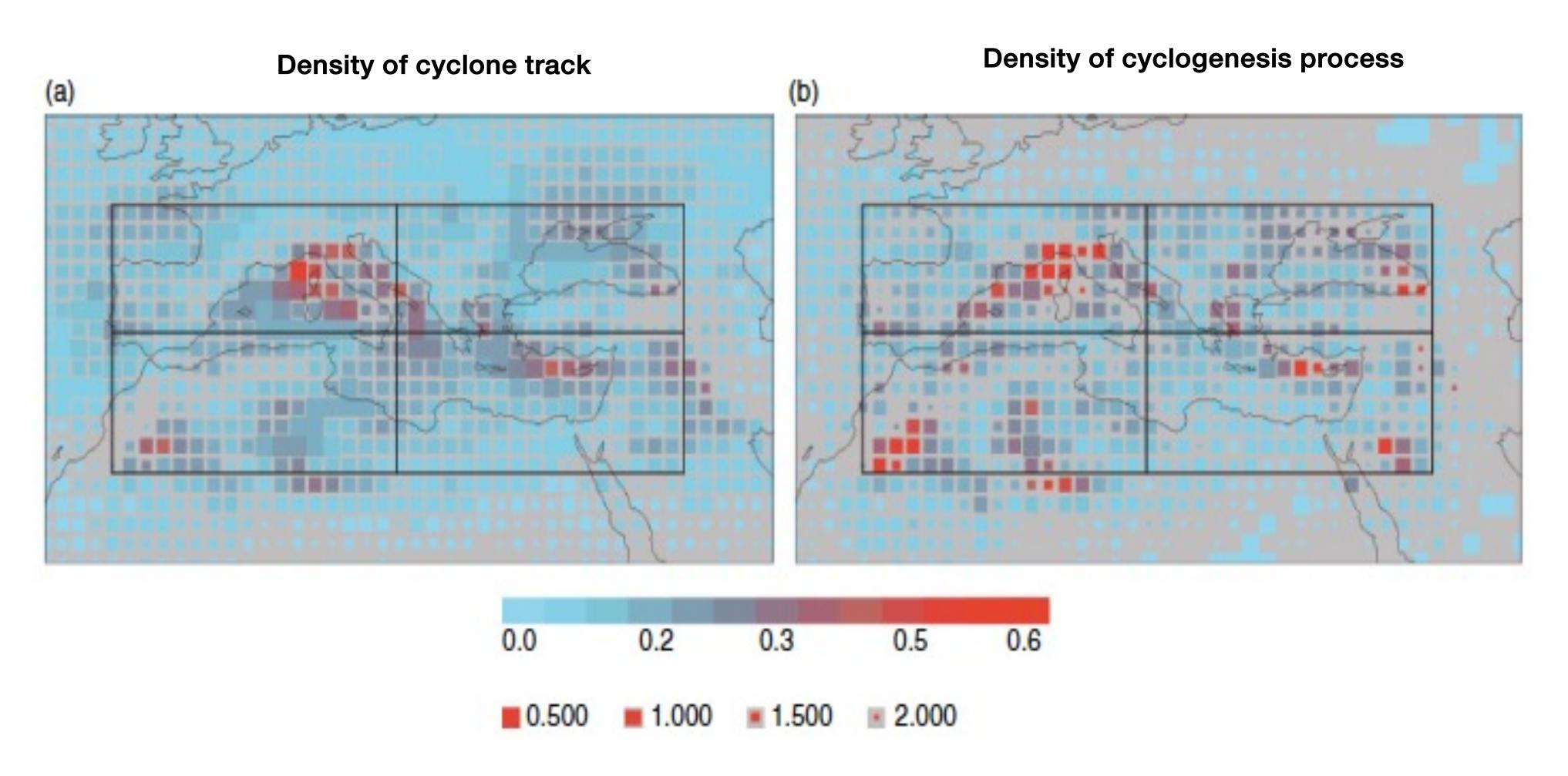
Ferrando, I.; Brandolini, P.; Federici, B.; Lucarelli, A.; Sguerso, D.; Morelli, D.; Corradi, N. Coastal Modification in Relation to Sea Storm Effects: Application of 3D Remote Sensing Survey in Sanremo Marina (Liguria, NW Italy). *Water* 2021, *13*, 1040. https://doi.org/10.3390/w13081040

The Mediterranean region (MED) is one of the most active region in the Northern Hemisphere in terms of cyclone activity (Lionello et al., 2016; Flaounas et al., 2022).

Cyclones plays a fundamental role in the:

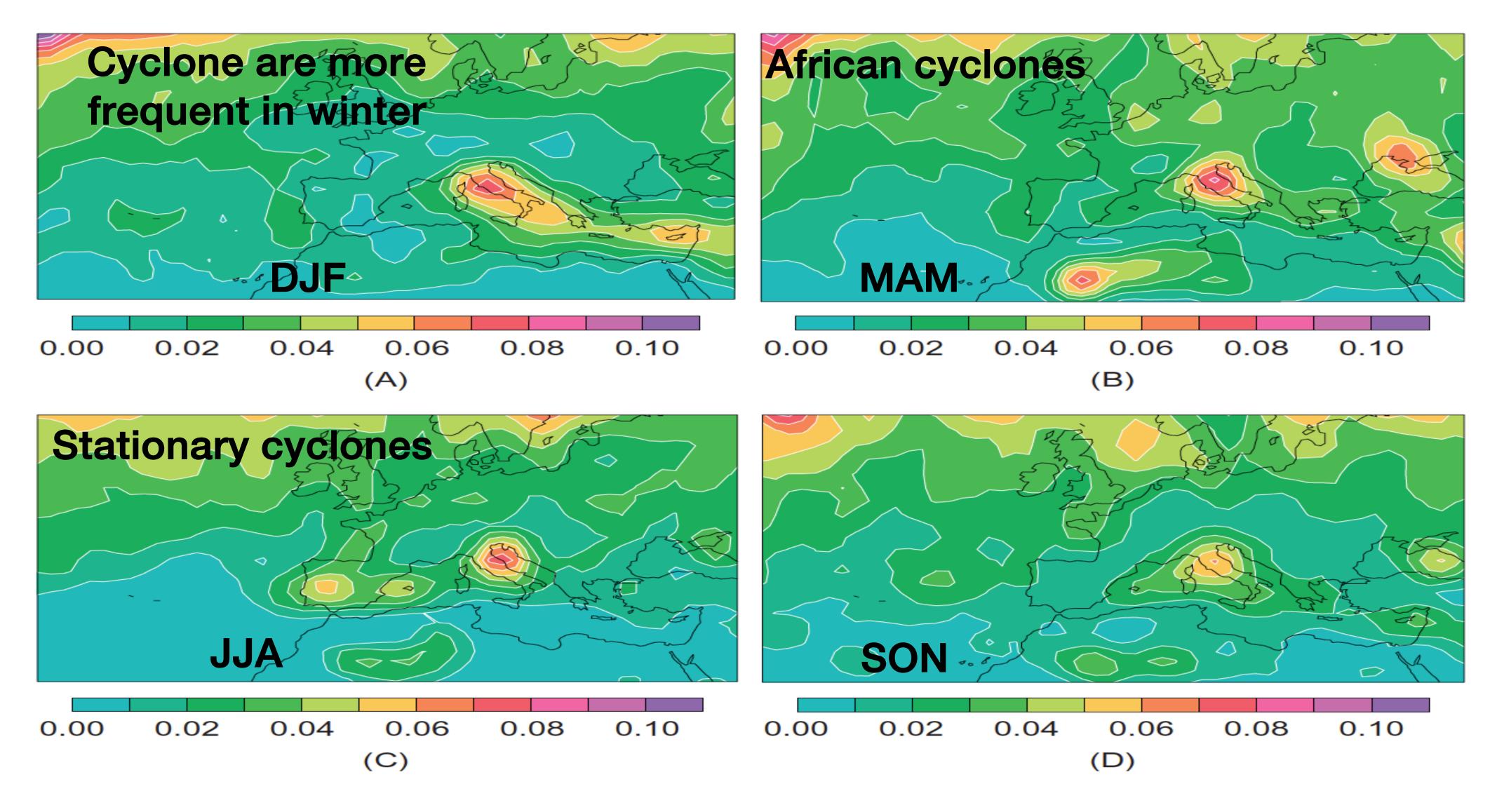
- . Water and Energy budget
- Location and magnitude of weather events and their extreme (heavy precipitation, windstorms, storm surges, marine storminess, landslide,....)

Cyclones in the Mediterranean region



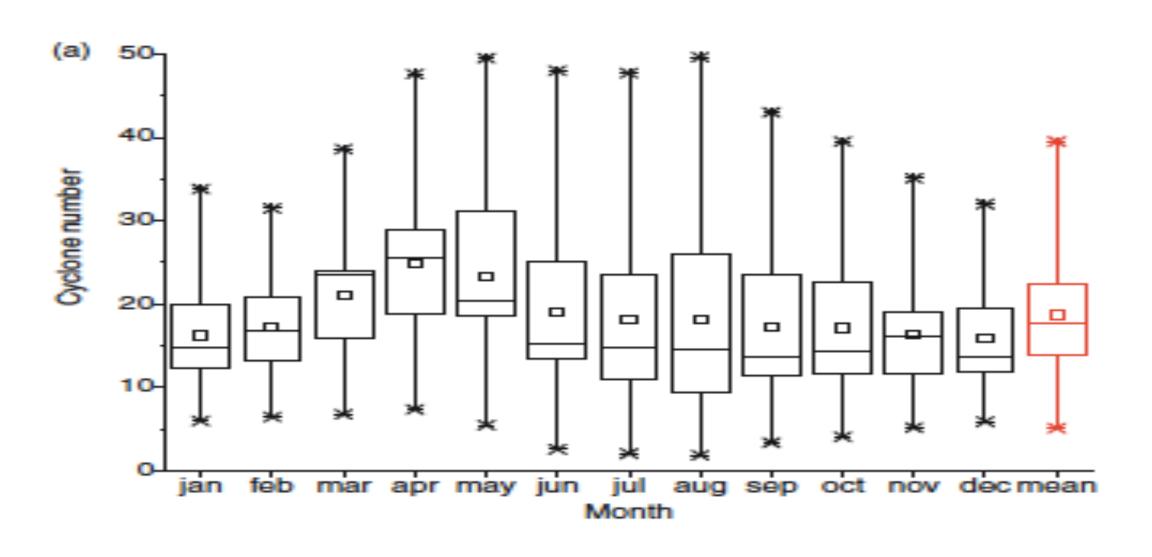
Cyclone tracks and cyclogenesis in the Mediterranean region. (a) Track density according to the multi-methods mean. Colours represent the probability (%) that a cyclone track crosses each 1.581.58 cell of the domain in the 6-hourly field (values according to the label bar below the panels). (b) Probability (%) that cyclogenesis occurs in each cell in the 6-hourly field. In both panels, only cyclones whose track crosses the Mediterranean region are considered. The filled fraction of each cell corresponds to the level of agreement (given by the normalised standard deviation) among methods as annotated below the panels. The large rectangle denotes the Mediterranean region with its subdivision in four sectors

Cyclones in the Mediterranean region

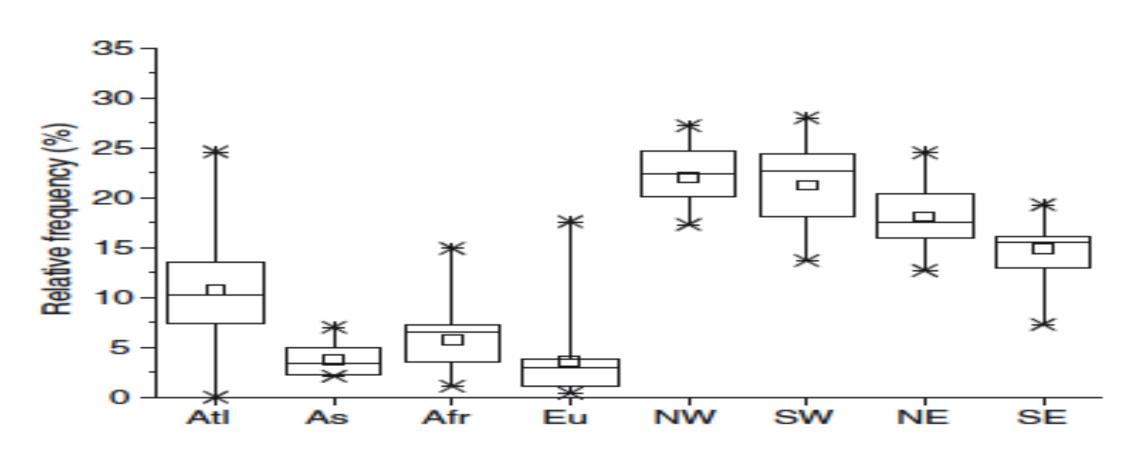


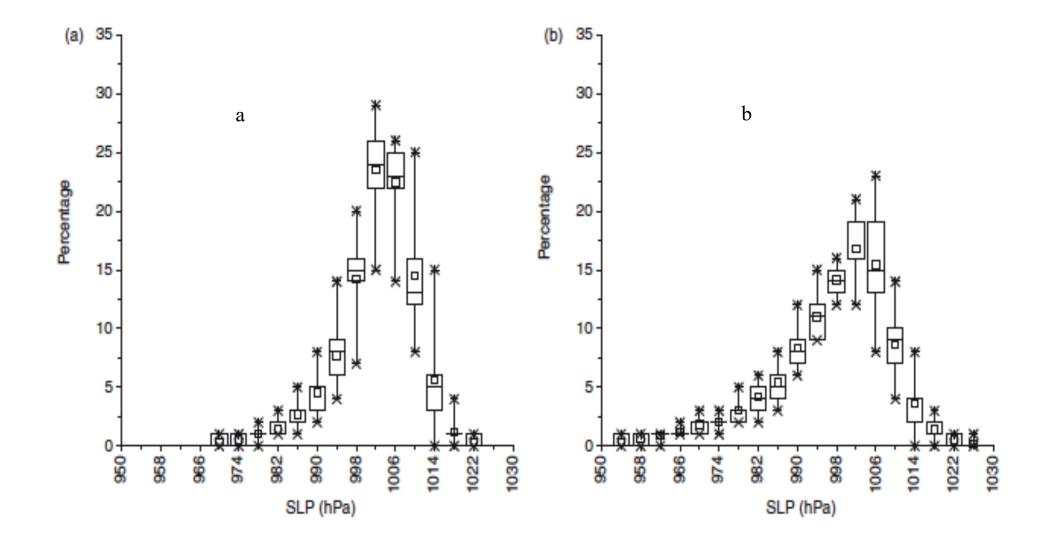
Seasonal average density track (seasonal frequency/degree2) according to ERA-Interim 1989–2009 in winter (A), spring (B), summer (C), and fall (D). Only cyclones with a minimum duration of 1 day and 5 hPa depth with respect to the background are included.

Cyclones in the Mediterranean region



Inter-monthly variation of total number of Mediterranean cyclones



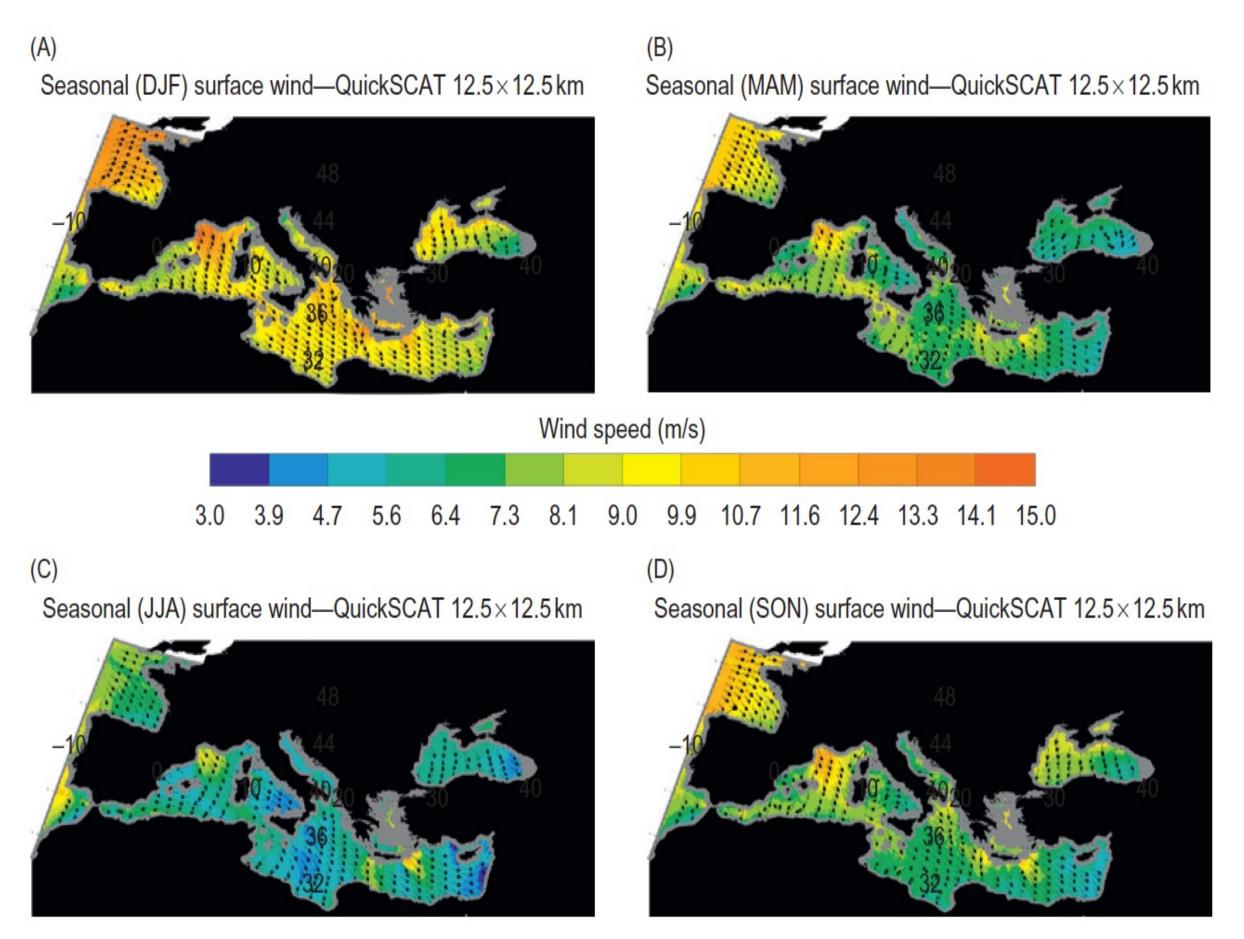


Relative frequency (%) of cyclones as function of their lifetime MSLP minimum considering 4 hPa wide bins and covering the range from 930 to 1030 hPa illustrated by box plots: (a) Mediterranean cyclones and (b) the NH cyclones

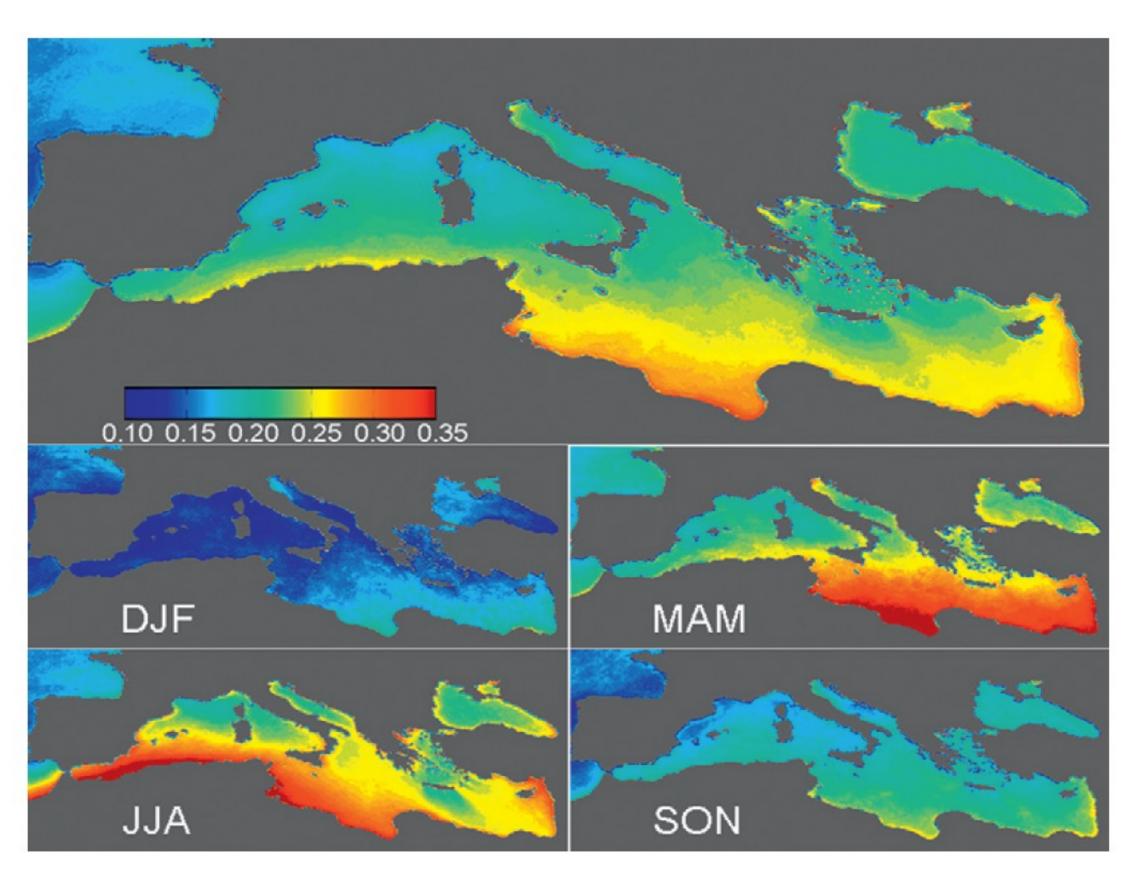
From Lionello et al.,2016

Relative frequency (%) of cyclogenesis occurring in the four sectors marked in Fig. 1 (NW, NE, SW, SE) and outside of the MR: Atlantic (Atl), Asia (As), Africa(Afr), Europe (Eu).

Environmental patterns in the Mediterranean region



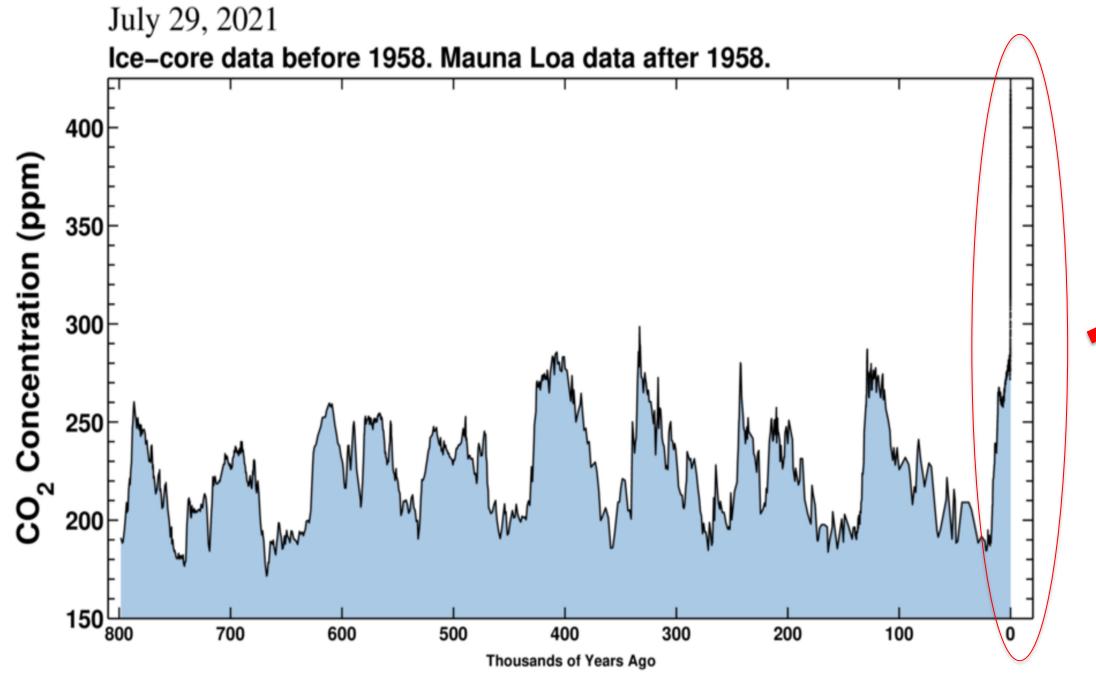
Seasonal mean (2000–2008) wind magnitude/direction from QuickSCAT for (A) Winter (DJF), (B) spring (MAM), (C) summer (JJA), and (D) fall (SON). The gray color relates to grid points that did not pass the quality filtering (i.e., coastal areas).

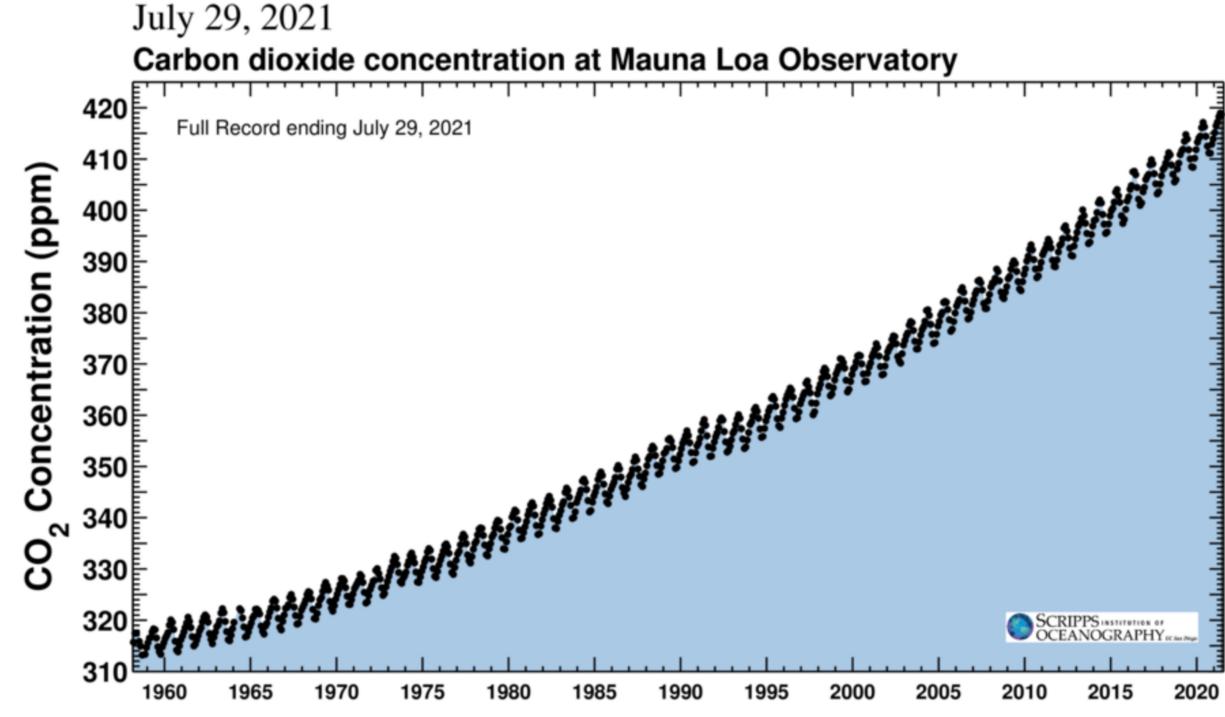


Map of the mean aerosol optical depth at 550 nm (AOD) for the 5-year period from June 2005 to May 2010 and corresponding seasonal averages as derived from MSG/SEVIRI

From Lionello et al.,2016

Temporal evolution of the atmospheric CO₂





https://keelingcurve.ucsd.edu/



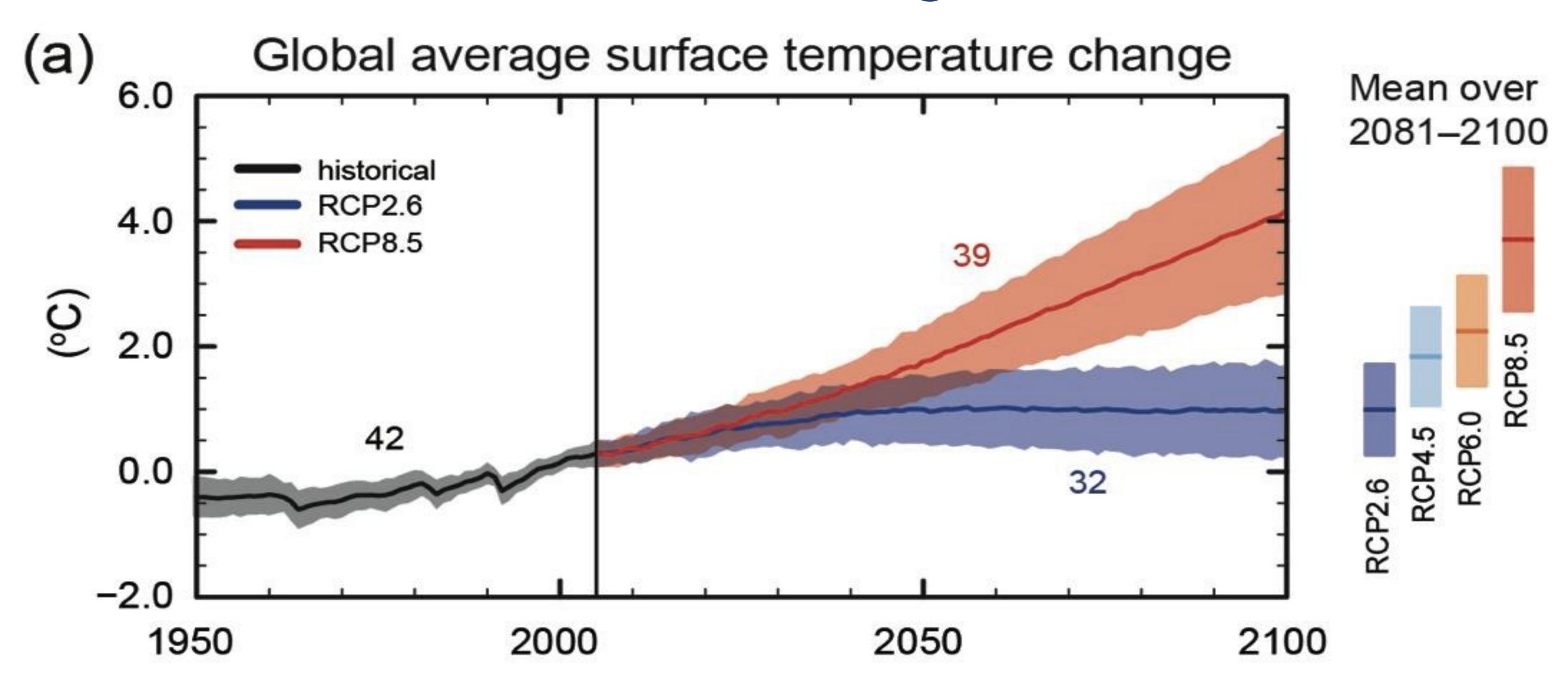
Global warming

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) b) Change in global surface temperature (annual average) as observed and as reconstructed (1-2000) and observed (1850-2020) simulated using human & natural and only natural factors (both 1850-2020) °C °C 2.0 2.0 Warming is unprecedented in more than 2000 years 1.5 1.5 Warmest multi-century observed period in more than simulated 100,000 years 1.0 1.0 human & natural observed 0.5 0.5 - 0.2 simulated natural only (solar & volcanic) reconstructed -0.5 -0.5 2000 **2020** 500 1850 1900 1950 1000 1500 **1850 2020**

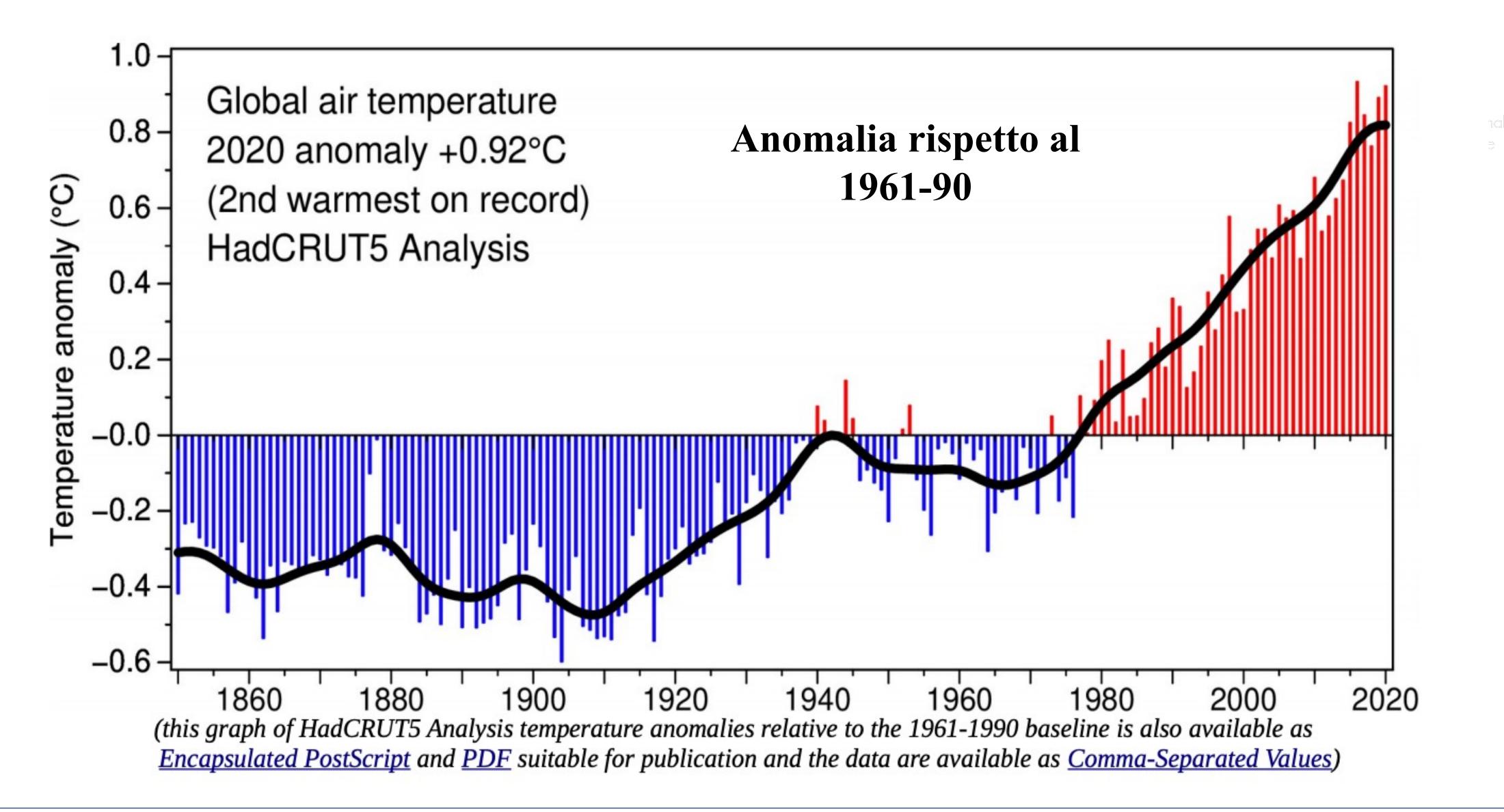
IPCC, 2021: Summary for Policymakers

Global warming





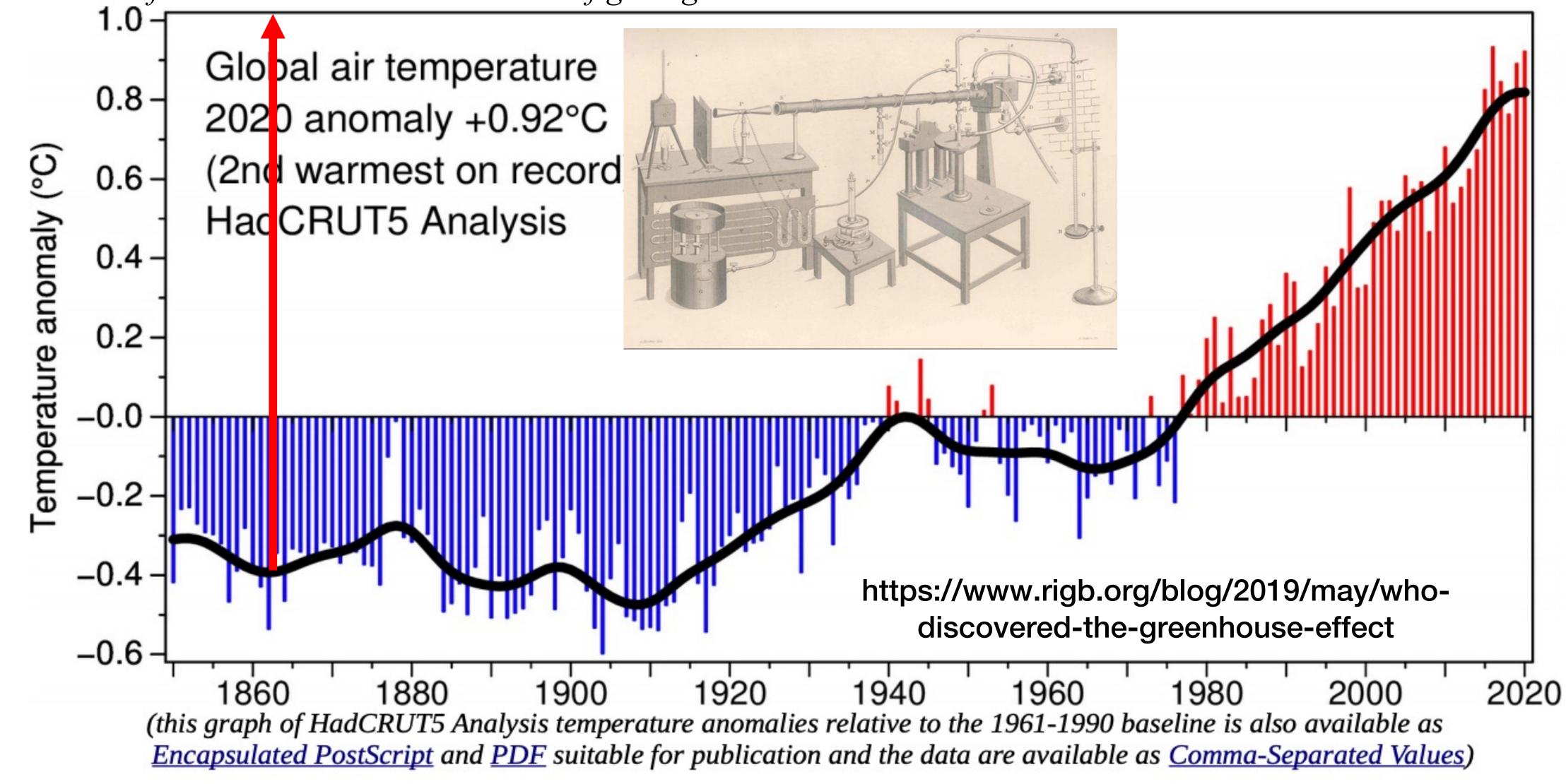
Temperature media globale della superficie terrestre: serie temporale dei dati strumentali





22

John Tyndall (1829-1893) effettua le prime misurazioni dell'asssorbimento della radiazione termica da parte dei gas e descrive l'effetto serra : "Thus the atmosphere admits of the entrance of solar heat; but checks its exit, and the result is a tendency to accumulate heat at the surface of the planet...If, as the above experiments indicate, the chief influence be exercised by aqueous vapour, every variation of this constituent must produce a change of climate. Similar remarks would apply to the carbonic acid [carbon dioxide] diffused through the air'... 'Such changes may in fact have produced all the mutations of climate which the researches of geologists reveal"



Eunice Newton Foote (1819-1888)



«Circumstances affecting the heat of the Sun's rays" from the *American Journal of Science* (1857)

«An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature... must have necessarily resulted» (Foote, 1856).

82 On the Heat in the Sun's Rays.

ART. XXXI.—Circumstances affecting the Heat of the Sun's Rays; by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

My investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Several results have been obtained.

First. The action increases with the density of the air, and

is diminished as it becomes more rarified.

The experiments were made with an air-pump and two cylindrical receivers of the same size, about four inches in diameter and thirty in length. In each were placed two thermometers, and the air was exhausted from one and condensed in the other. After both had acquired the same temperature they were placed in the sun, side by side, and while the action of the sun's rays rose to 110° in the condensed tube, it attained only 88° in the other. I had no means at hand of measuring the degree of condensation or rarefaction.

The observations taken once in two or three minutes, were as follows:

Exhau	Exhausted Tube		Condensed Tube.	
In shade.	In sun.	Is shade,	In sun.	
75	80	75	80	
76	82	78	95	
80	82	80	100	
83	86	82	105	
84	83	85	110	

This circumstance must affect the power of the sun's rays in different places, and contribute to produce their feeble action on the summits of lofty mountains.

Secontly. The action of the sun's rays was found to be greater in moist than in dry air. In one of the receivers the air was saturated with moisture—

in the other it was dried by the use of chlorid of calcium.

Both were placed in the sun as before and the result was as

Dry	Dry Ale.		mp Air.
In shade.	In sun.	In shade.	I In our.
75	75	76	75
78	88	78	90
82	102	82	106
82	104	82	110
82	105	82	114
88	108	92	120

Marcou's Geological Map of the United States.

The high temperature of moist air has frequently been observed. Who has not experienced the burning heat of the sun that precedes a summer's shower? The isothermal lines will, I think, be found to be much affected by the different degrees of moisture in different places.

moisture in different places.

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

In Common Air.		- L	In Carbonic Acid Gas.		
In shade.	In wan.	1	In shade.	In sun.	300
80	90	-	80	90	
81	9-4		84	100	
80	99	-	84	110	
81	100	OF ENGINEERS	85	120	

The receiver containing the gas became itself much heated very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

ent, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

ART. XXXII.—Review of a portion of the Geological Map of the United States and British Provinces by Jules Marcou; by WIL-LIAM P. BLAKE

Geological maps of the United States published in Europe and widely circulated among European geologists, are necessarily regarded by us with no small degree of attention and curiosity. This is more especially true, when such maps embrace regions of which the geography has only recently been made known and the geology has never before been laid down on a map with any approach to accuracy.

The recent geological map and profile by M. J. Marcou, which has appeared in the Annales des Mines and in the Bulletin of

* Carte Géologique des Etats-Unis et des Provinces Anglaises de l'Amérique du Nord par Jules Marcou. Annales des Mines, 54 Série, T. vii, p. 329. Published also with the following:

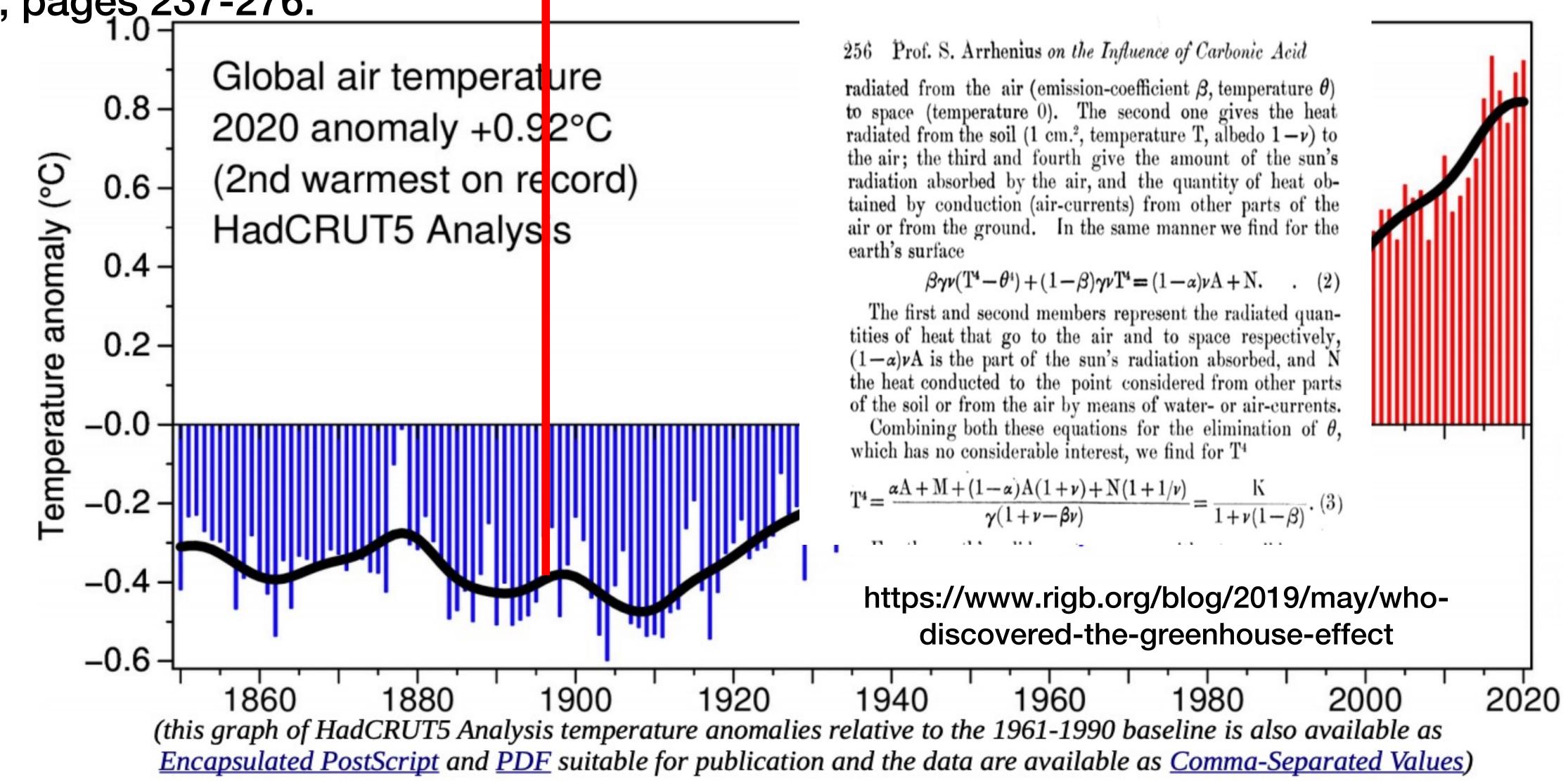
Résumé explicatif d'une carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord, avec un profil géologique allant de la vallée du Mississippi aux côtes du Pacifique, et une planche de fossiles, par M. Jules Marcou Bulletin de la Société Géologique de France. Mai, 1855, p. 813.

https://www.climate.gov/news-features/features/happy-200th-birthday-eunice-foote-hidden-climate-science-pioneer

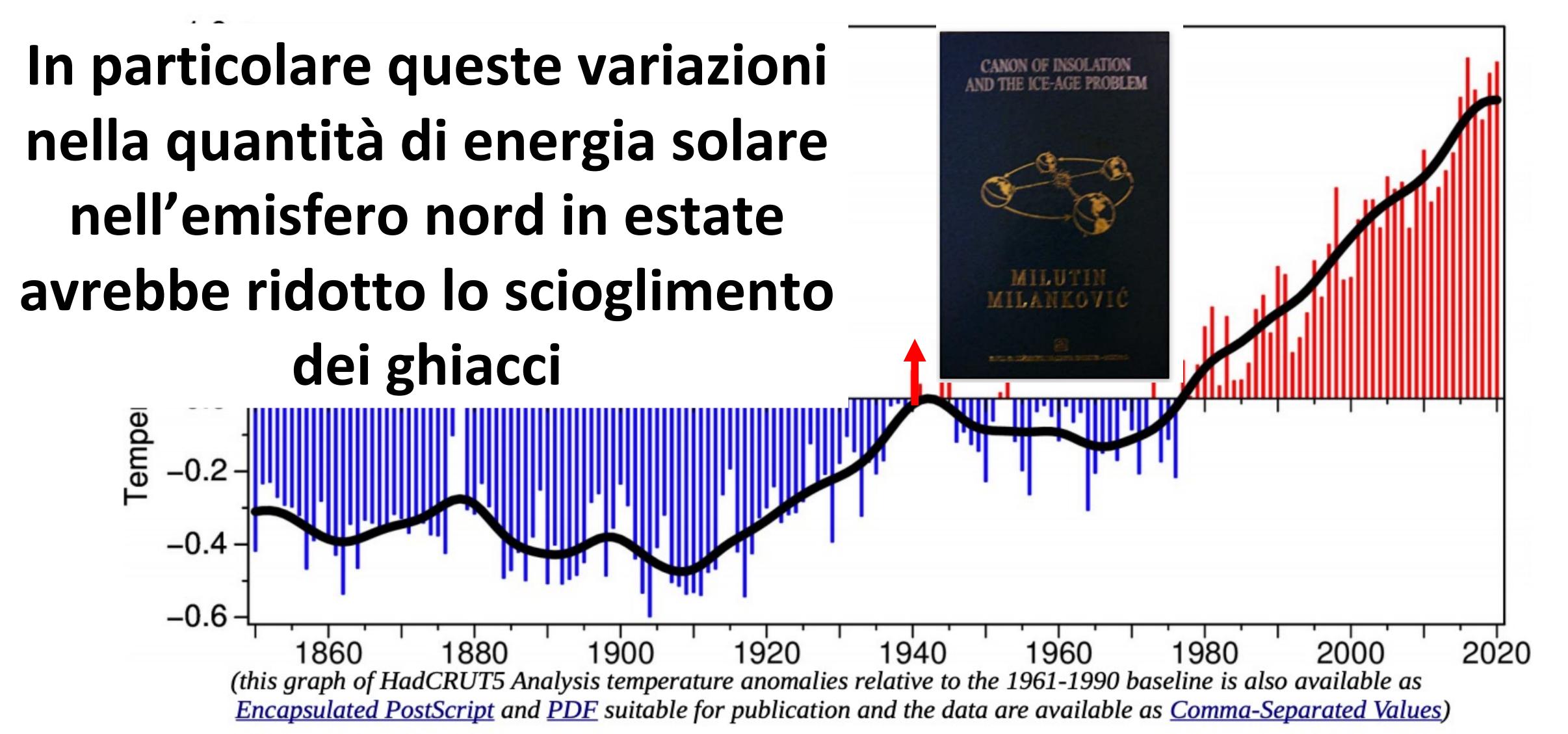


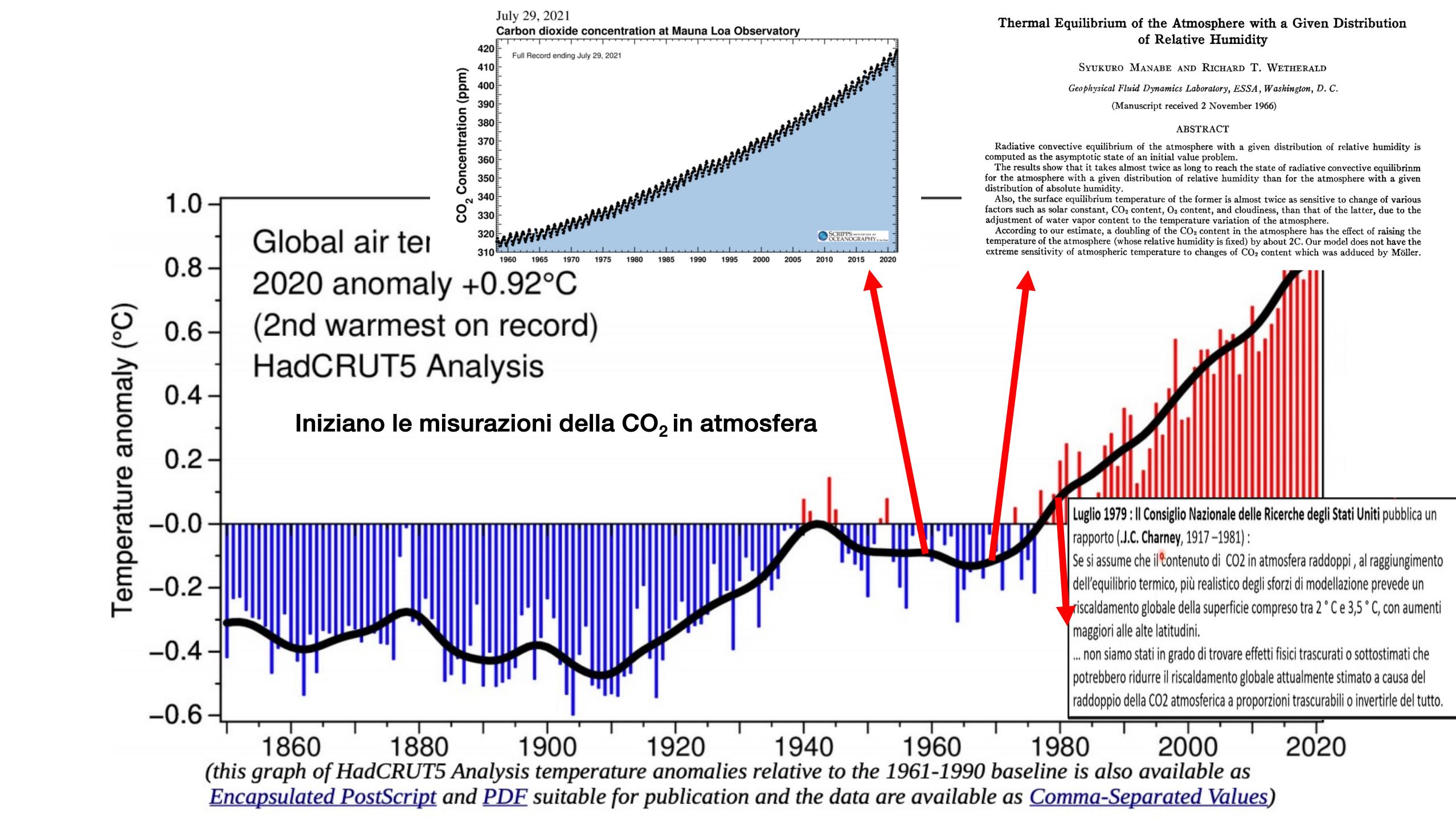
Svante Arrhenius (1859-1927) utilizza i principi della chimica per calcolare l'aumento della temperature superficiale della Terra causato dall'aumento della CO₂ nell'atmosfera:

On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground Svante Arrhenius Philosophical Magazine and Journal of Science Series 5, Volume 41, April 1896, pages 237-276.



Milutin Milanković (1879-1951) : legò i cambiamenti climatici a cambiamenti nelle caratteristiche geometriche dell'orbita terrestre



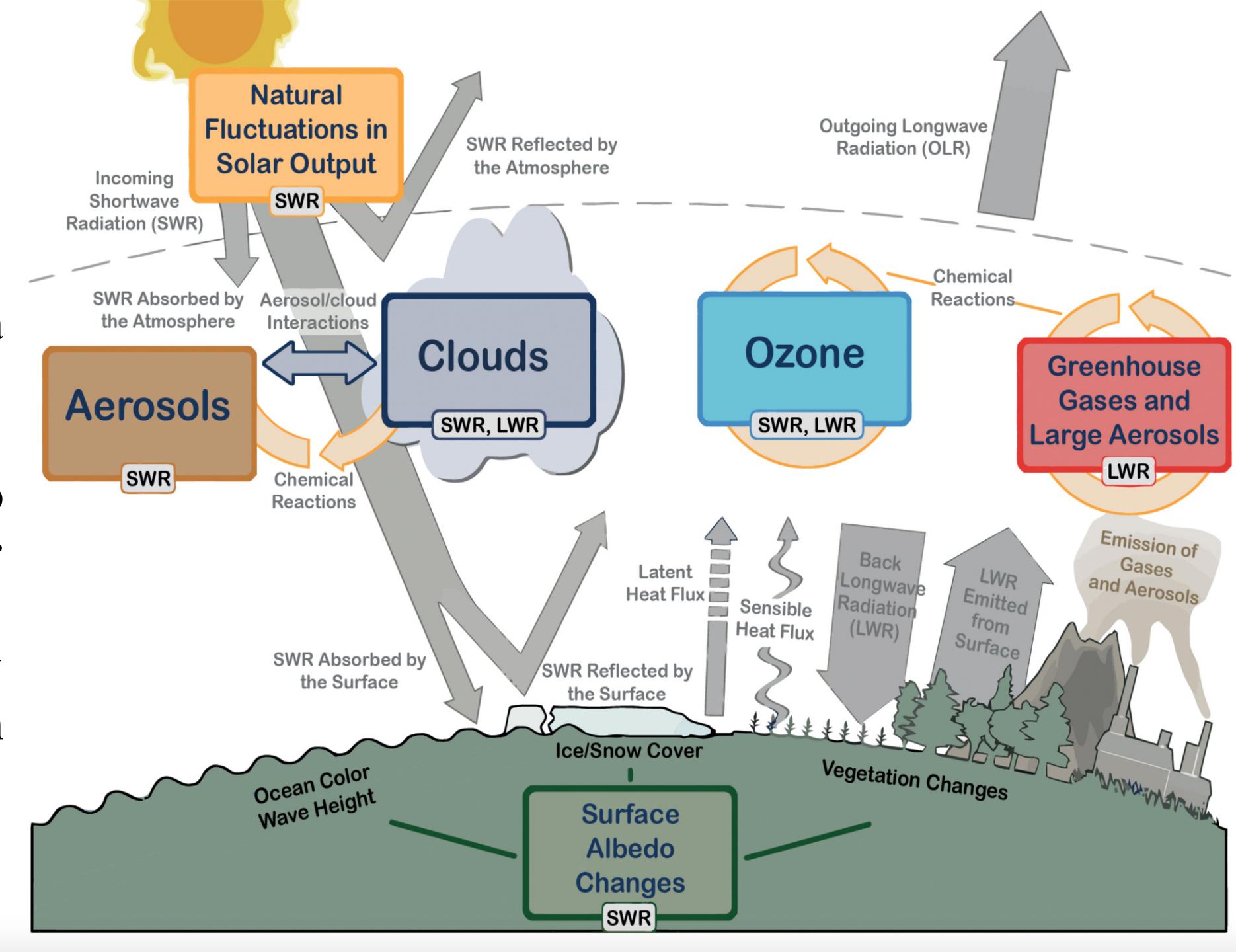


The climate system

Source:

http://www.atmos.a lbany.edu/facstaff/ brose/classes/ATM 623 Spring2015/No tes/Lectures/Lectur e04%20--%20Climate%20sy stem%20componen ts.html





Fattori che influenzano il bilancio radiativo terrestre

2.7 (0.016)

Table 1. Simplified Expressions for Radiative Forcing of CO₂, CH₄, and N₂O, Where C Is the CO₂ Concentration (in ppm), M Is the CH₄Concentration (in ppb), and N Is the N₂O Concentration (in ppb)^a

GAS SERRA

Gas Simplified Expression

Coefficients

Maximum Absolute Error Relative to Line-by-Line Model % (Wm⁻²) $CO_{2} \begin{bmatrix} a_{1}(C-C_{0})^{2} + b_{1}|C-C_{0}| + c_{1}\overline{N} + 5.36 \end{bmatrix} \times \ln(^{C}/c_{0})$ $a_{1}=-2.4\times10^{-7} \text{Wm}^{-2} \text{ppm}^{-1}$ $b_{1}=7.2\times10^{-4} \text{Wm}^{-2} \text{ppm}^{-1}$ $c_{1}=-2.1\times10^{-4} \text{Wm}^{-2} \text{ppm}^{-1}$ $a_{2}=-8.0\times10^{-6} \text{Wm}^{-2} \text{ppm}^{-1}$ $b_{2}=4.2\times10^{-6} \text{Wm}^{-2} \text{ppb}^{-1}$

 $c_2 = -4.9 \times 10^{-6} \text{Wm}^{-2} \text{ppb}^{-3}$

 $a_3 = -1.3 \times 10^{-6} \,\mathrm{Wm}^{-2} \mathrm{ppb}^{-1}$

 $b_3 = -8.2 \times 10^{-6} \text{Wm}^{-2} \text{ppb}^{-1}$

Si può calcolare l'effetto dei gas serra sul bilancio radiativo

Attraverso calcoli complicati (ma universalmente accettati)

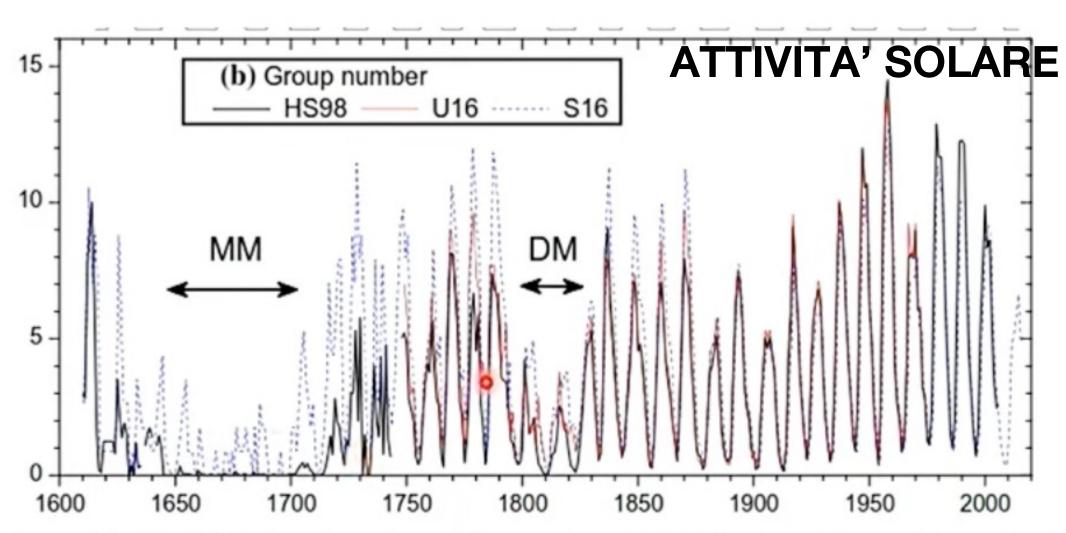
CO₂: 1.95 Wm⁻²

CH₄: 0.62 Wm⁻²

 $N_20: 0.18 \text{ Wm}^{-2}$

Attività Solare: 0.25 Wm⁻²

mated to be 10% for CO₂ and N₂O and 14% for CH₄ (see section 3.4). https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2016GL07



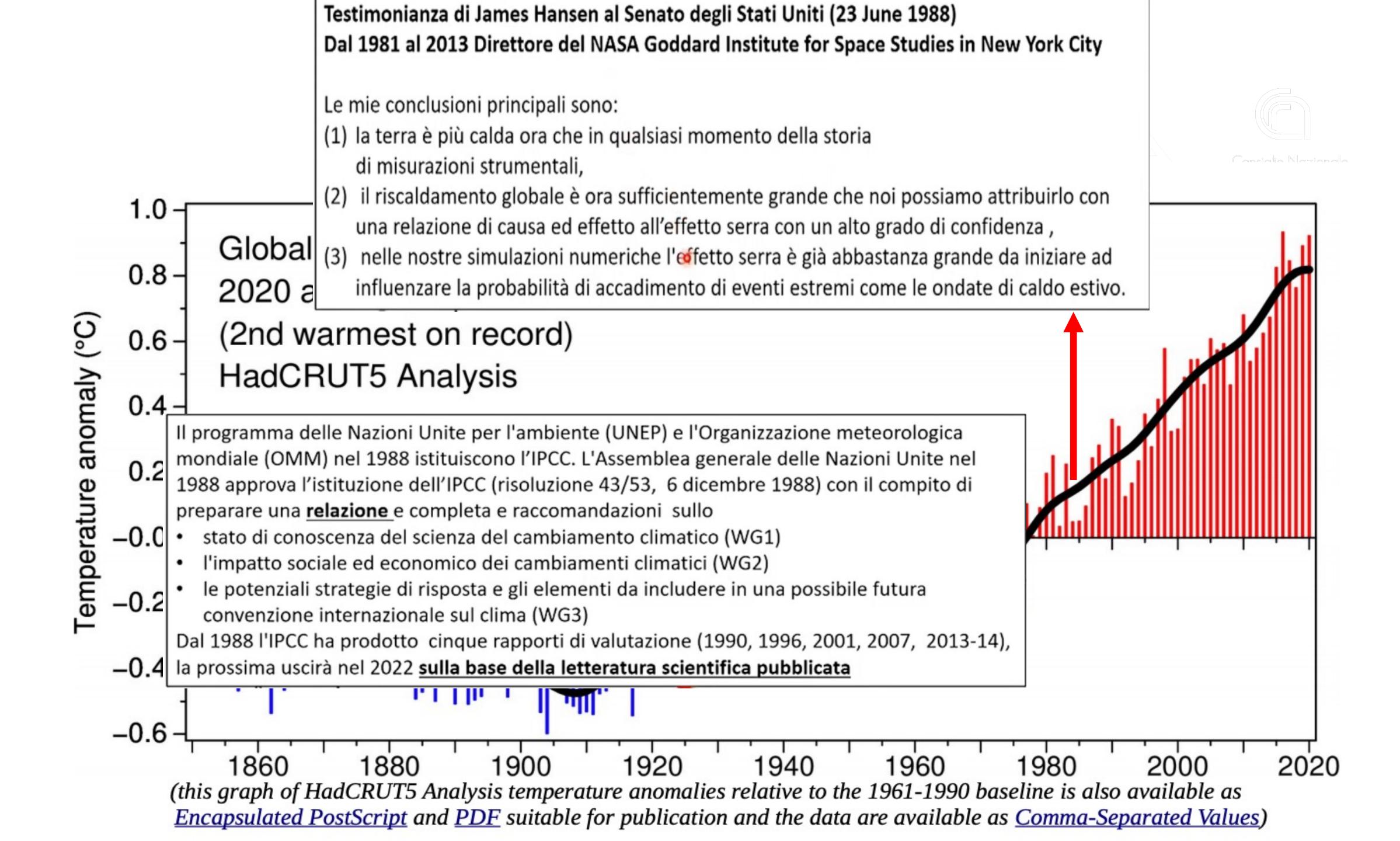
 $[a_3\overline{M} + b_3\overline{N} + 0.043](\sqrt{M} - \sqrt{M_0})$

 CH_4

Qualcuno ha anche parlato di effetti del ciclo dello ozono ed di effetti dei raggi cosmici (effetto Svensmark) sulla copertura nuvolosa.. Ma per adesso nessuna relazione statisticamente significative è stata trovata.

Lean, J. L. (2018). Estimating solar irradiance since 850 CE. Earth and Space Science, 5, 133–149 Lean, J. (2017). Sun climate connections. Oxford Research Encyclopedia. https://doi.org/10.1093/acrefore/9780190228620.013

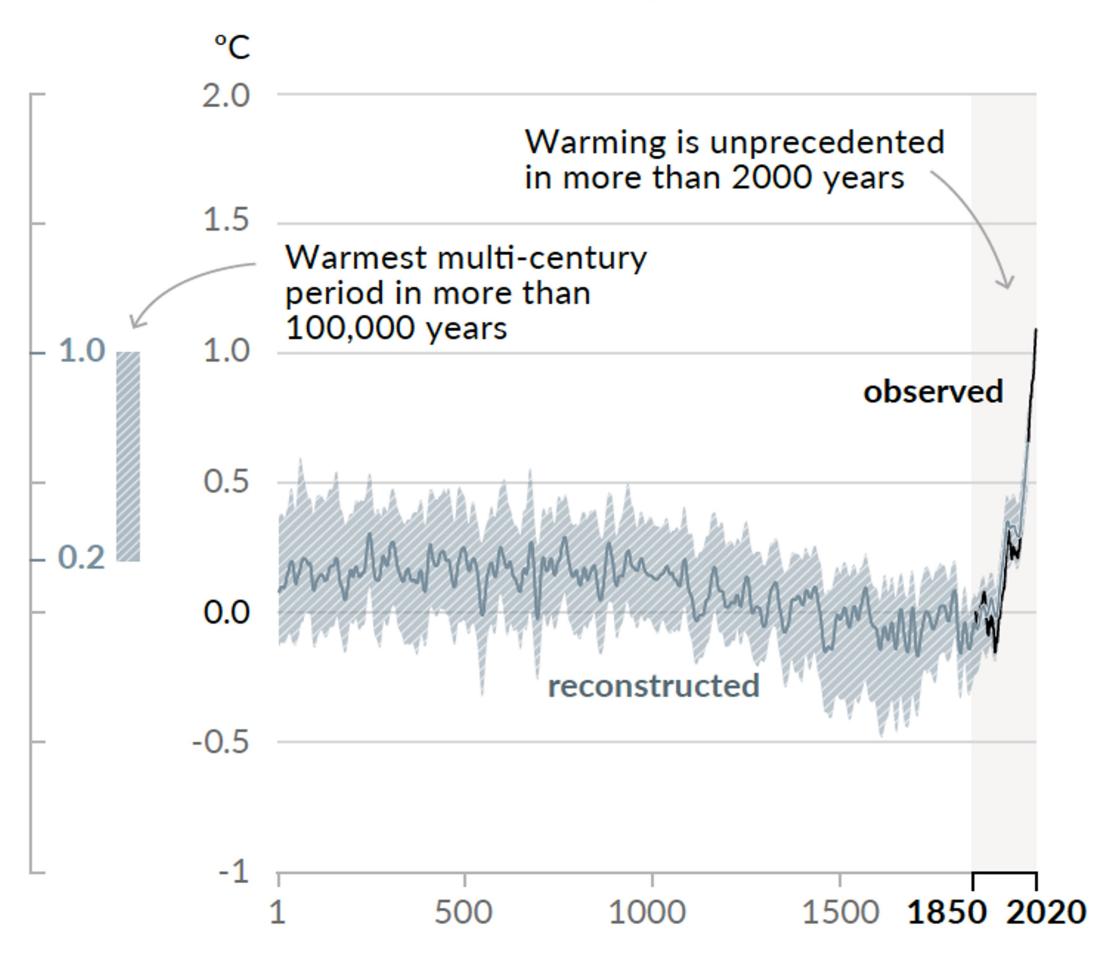
 $^{^{}a}$ C, M, and N are concentration at the time at which the forcing is required, and $C_{\underline{o}}$, M_{o} and N_{o} are the initial concentrations. For terms within the square brackets, the gas concentrations are the mean of the initial and final concentrations (e.g., $\overline{M} = 0.5(M + M_{o})$) for methane) when the concentrations of those overlapping gases are also changing. The expressions are valid in the ranges 180–2000 ppm for CO_{2} , 200–525 ppb for $N_{2}O$, and 340–3500 ppb for CH_{4} . The maximum absolute error, relative to the OLBL (in % and, in parentheses, in Wm^{-2}), is shown in the final column. Note that the absolute uncertainty in the OLBL calculations is esti-



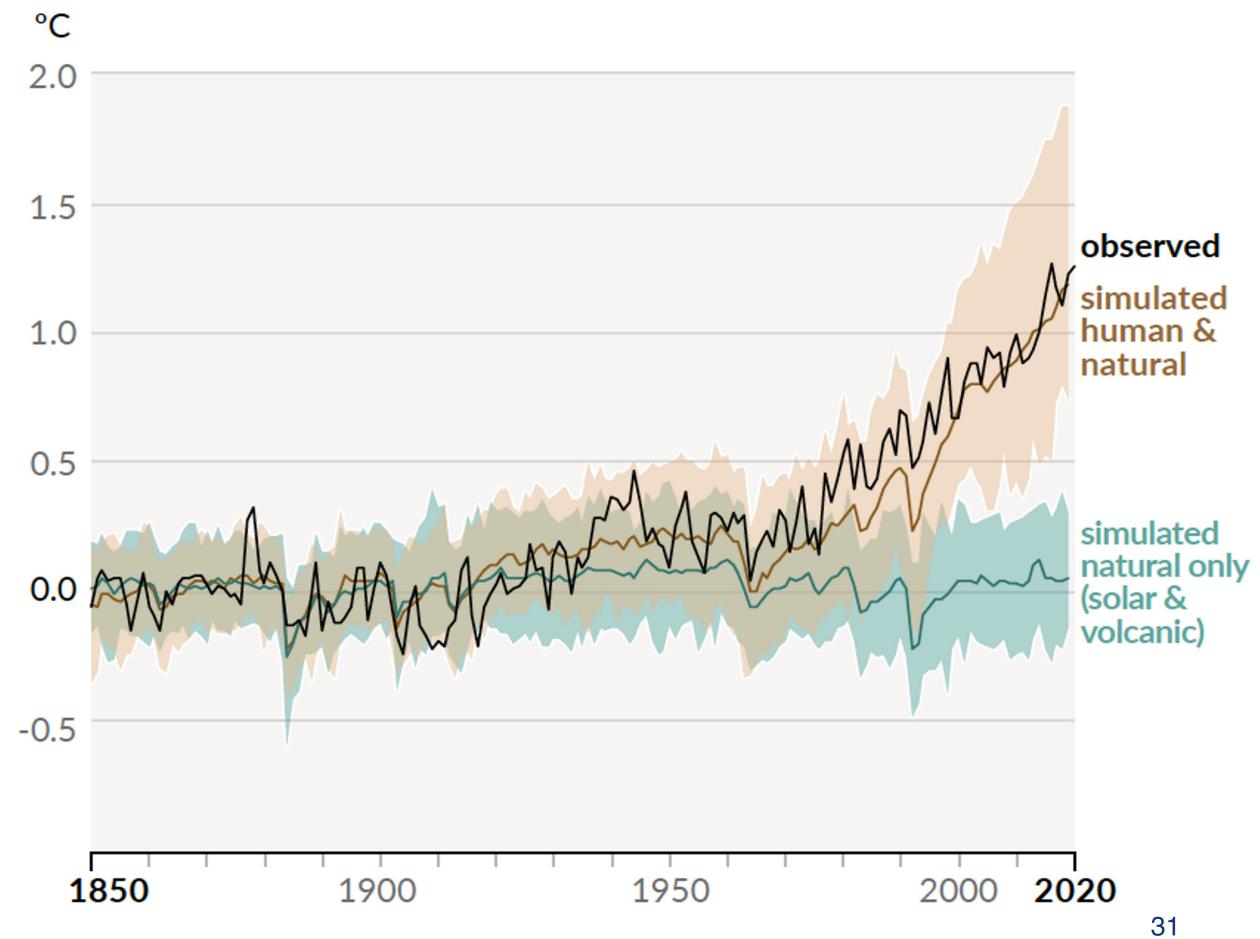
Global warming

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)



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



IPCC, 2021: Summary for Policymakers

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate



Type of observed change in hot extremes

Increase (41)

Decrease (0)

Low agreement in the type of change (2)

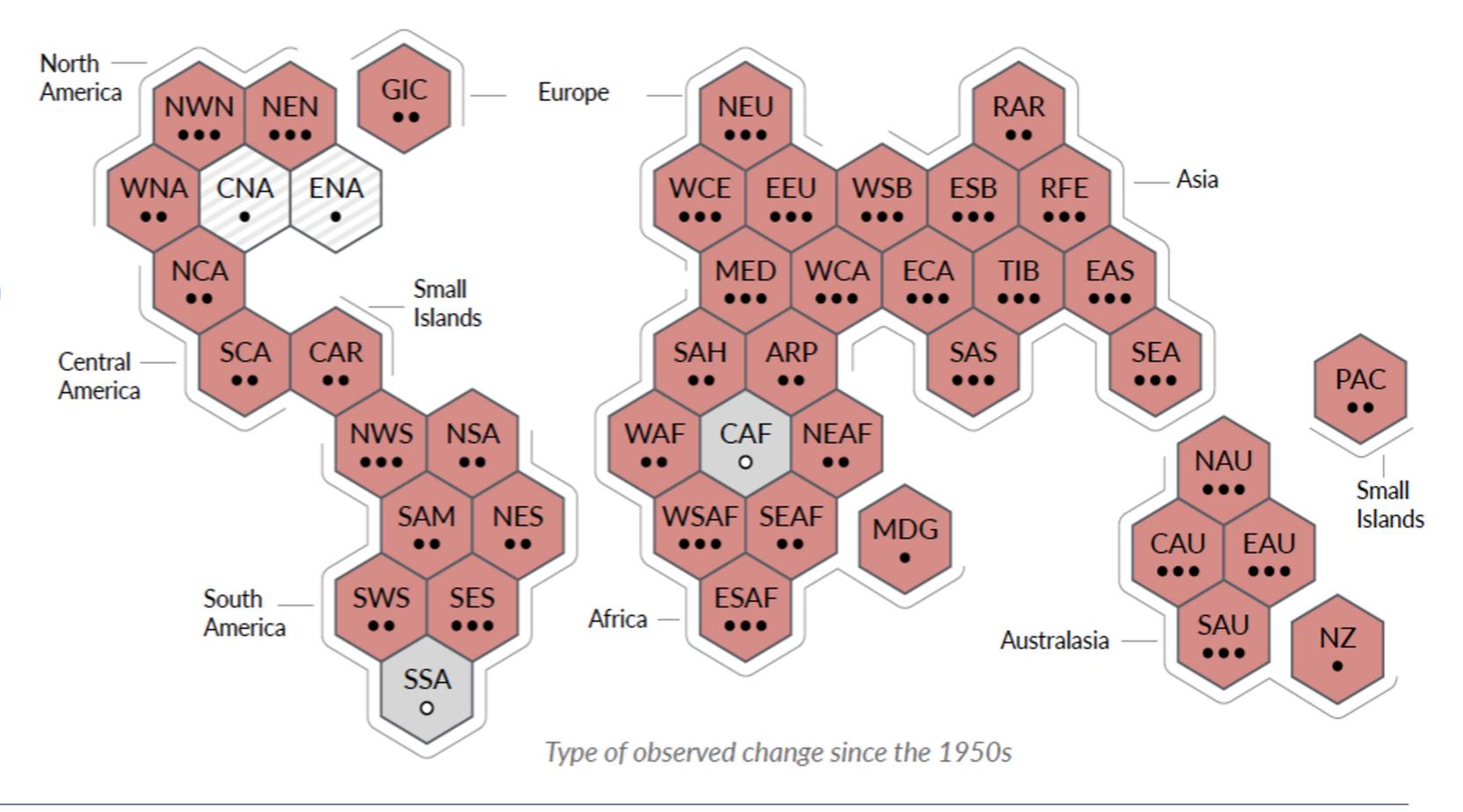
Limited data and/or literature (2)

Confidence in human contribution to the observed change

- ●●● High
 - Medium
 - Low due to limited agreement
 - Low due to limited evidence

IPCC, 2021: Summary for Policymakers

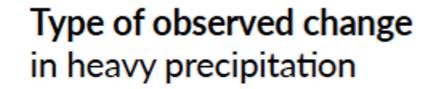
a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions





Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions



Increase (19)

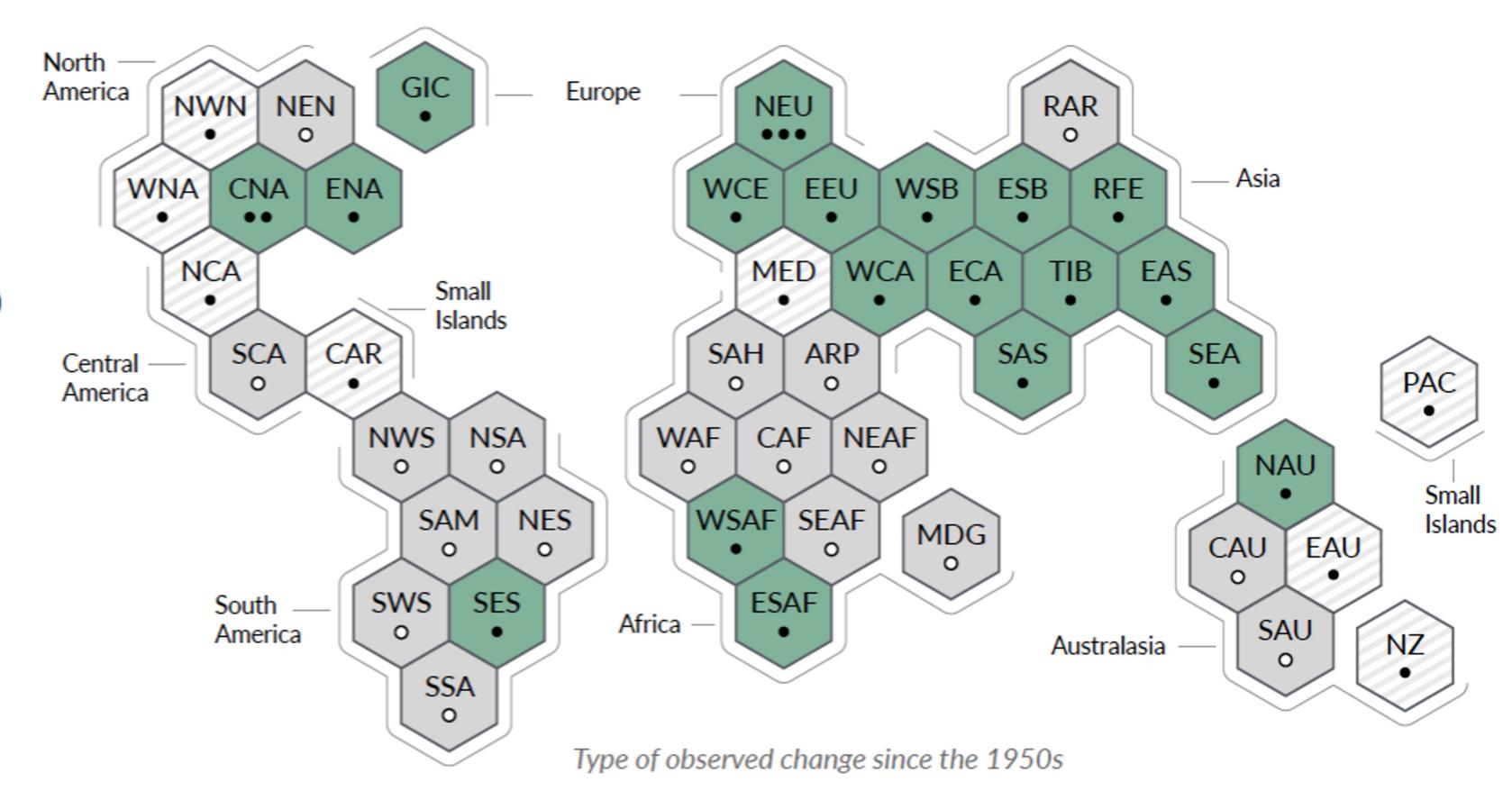
Decrease (0)

Low agreement in the type of change (8)

Limited data and/or literature (18)

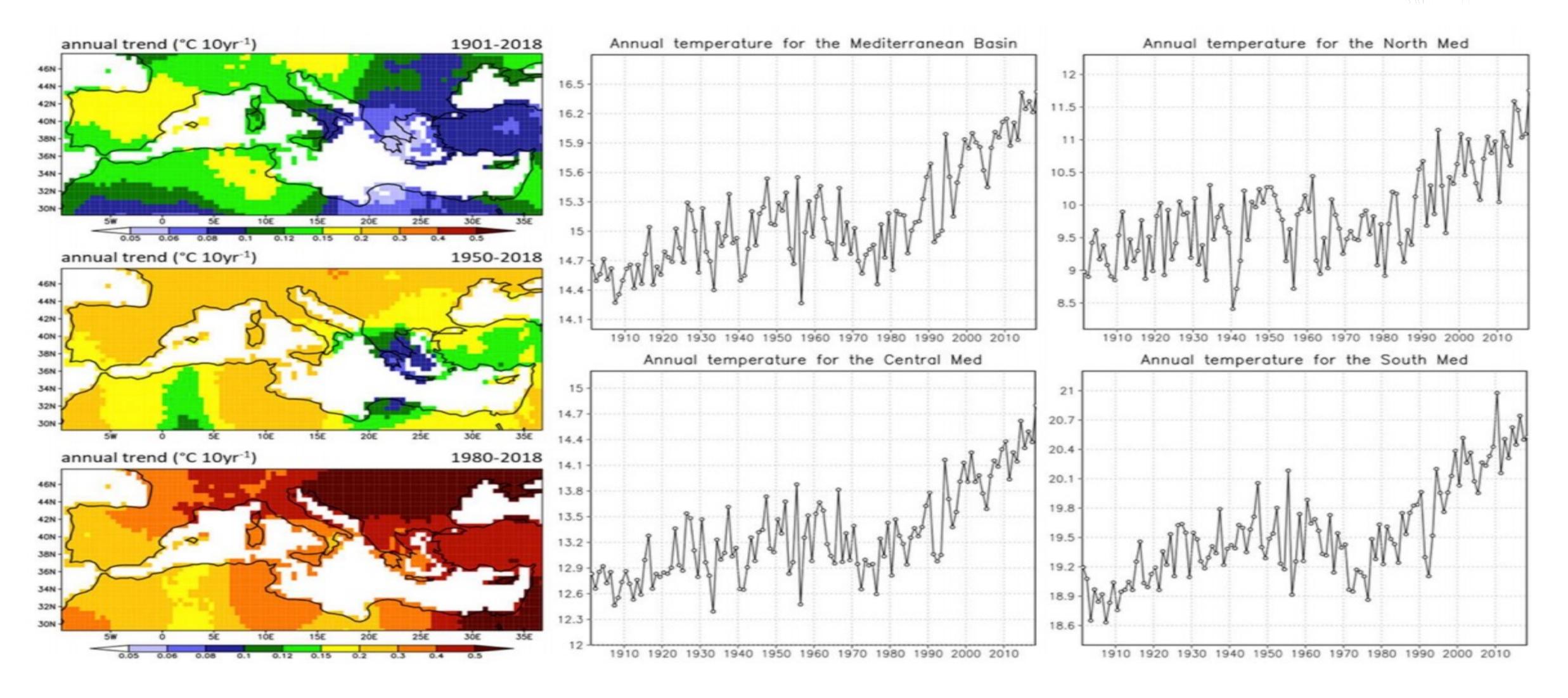
Confidence in human contribution to the observed change

- ●●● High
 - • Medium
 - Low due to limited agreement
 - Low due to limited evidence





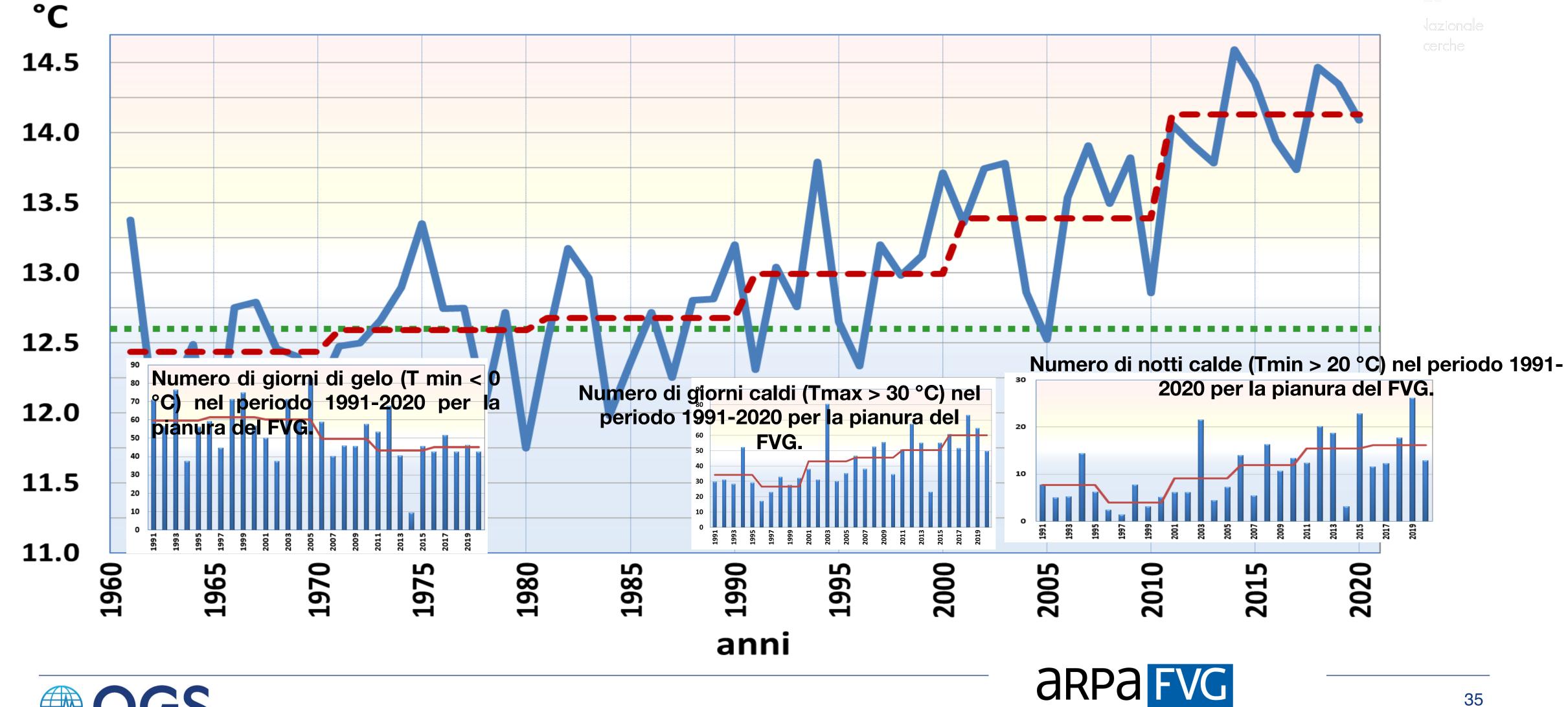
Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes



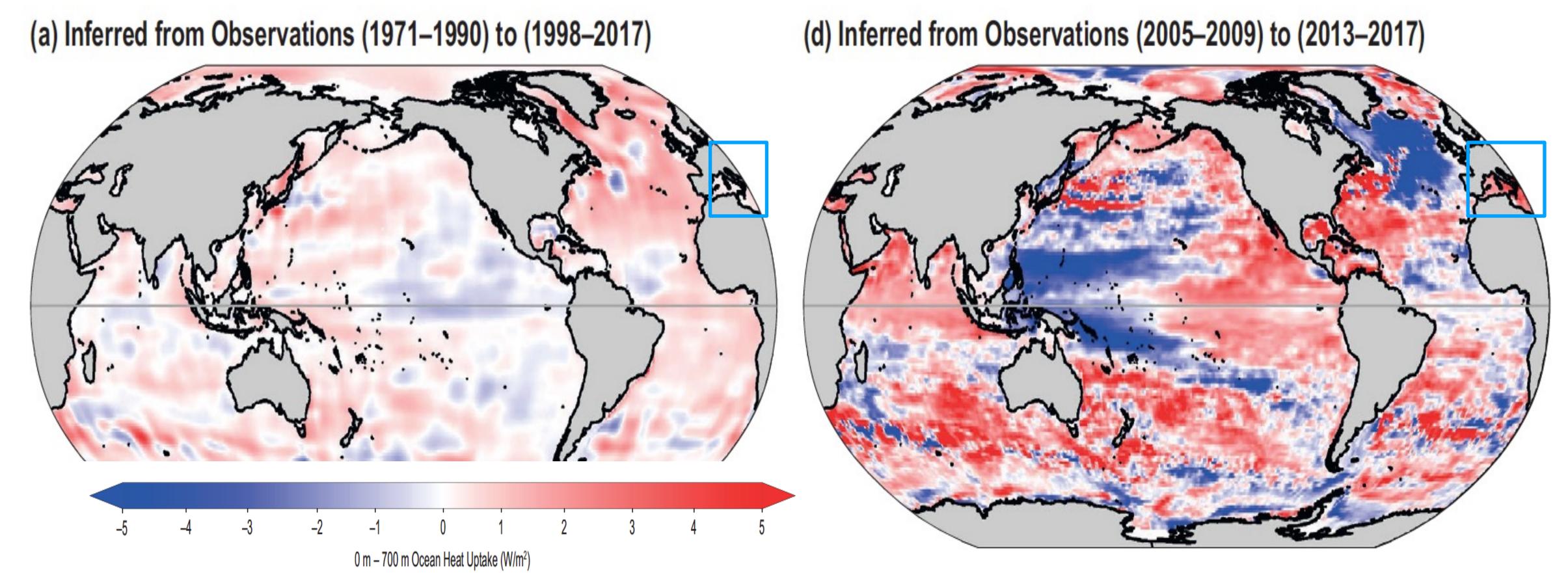
Observed temperature trends (left panels) and time-series of temperature over land for the Mediterranean based on the Climatic Research Unit (CRU) (Harris et al. 2020, MedECC, 2021) gridded observations. Time-series refer to the whole Mediterranean as defined in the left panels and for three Mediterranean sub-regions (Fig. 2.1): north (FR, ALBA), central (IB, CM, AN) and south Mediterranean (WM, EM, LE).

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate





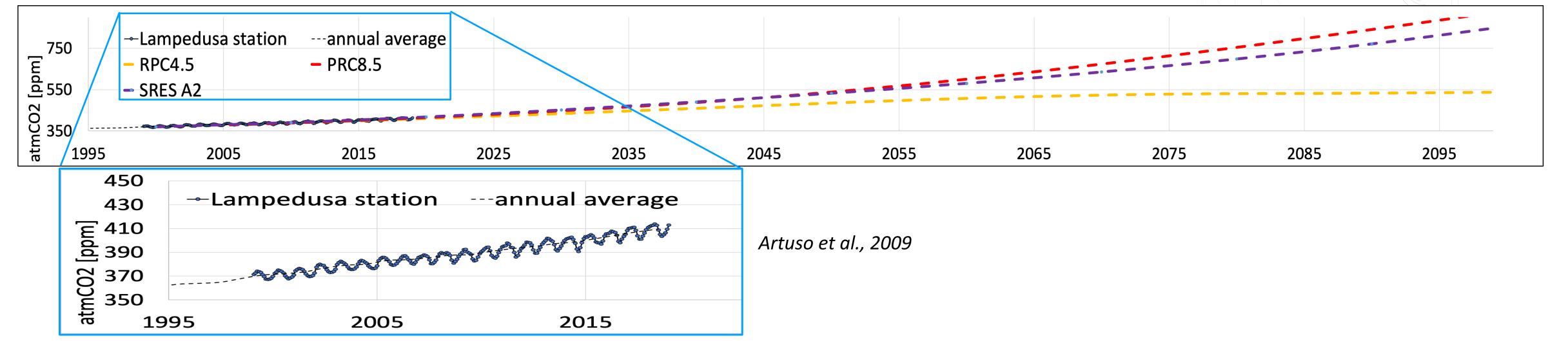
Increase of atmospheric CO₂ and overall warming of the ocean

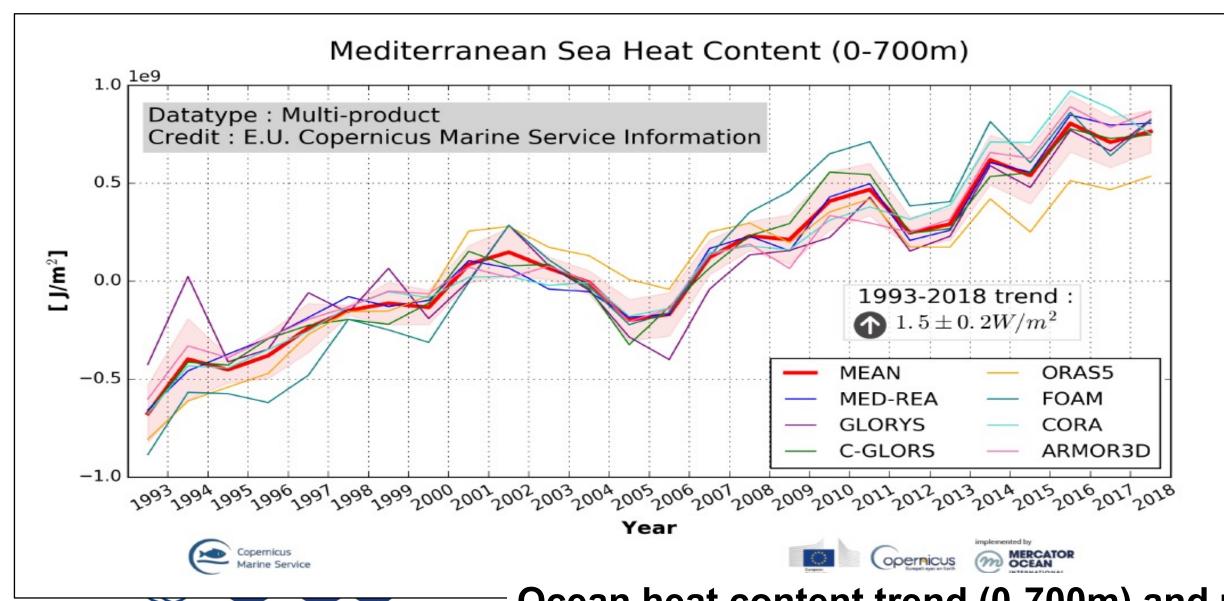


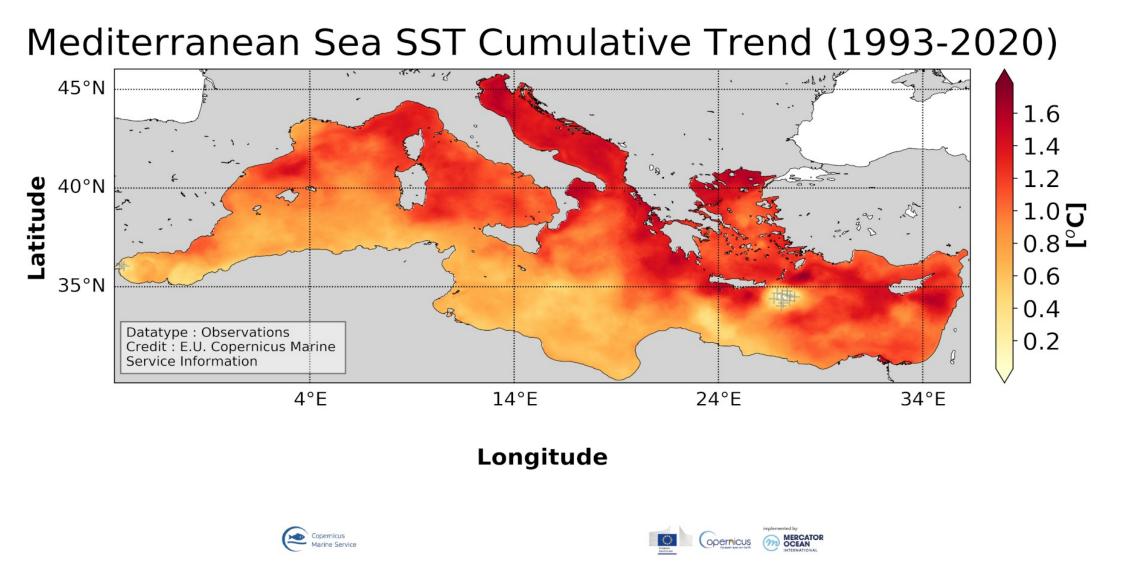
Ocean warming has contributed to:

- -observed changes in biogeography of organisms and community composition
- -alter interactions between organisms
- -changes in spatial distribution, abundance, growth, survival of fish stocks (from IPCC AR5, 2019)

Increase of atmospheric CO₂ and overall warming of the Mediterranean Sea







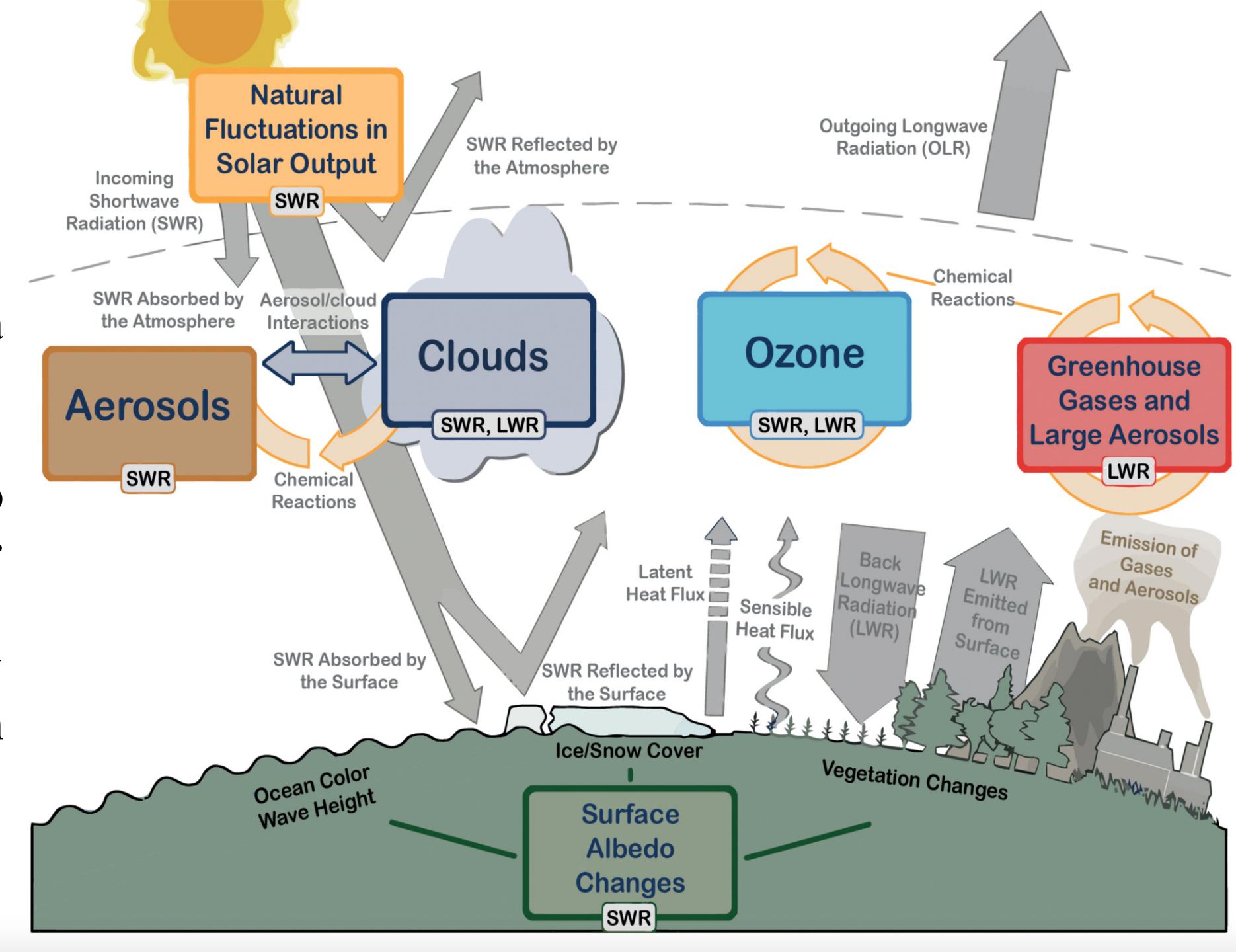
Ocean heat content trend (0-700m) and map of cumulative trend of temperature in the last 30 years from Marine Copernicus Service

The climate system

Source:

http://www.atmos.a lbany.edu/facstaff/ brose/classes/ATM 623 Spring2015/No tes/Lectures/Lectur e04%20--%20Climate%20sy stem%20componen ts.html





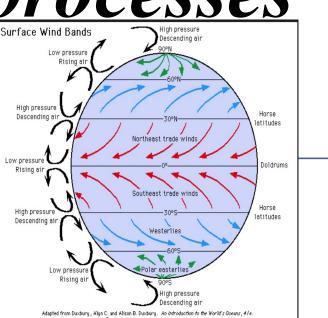
Modelli climatici

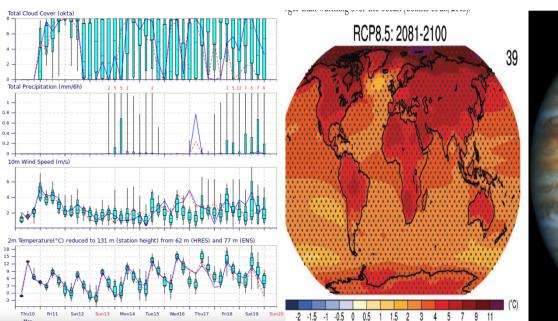
- "A climate model is a (simplified) mathematical representation of the physical processes that determine climate"
- Developed to understand and to study the general circulation of the atmosphere
- To produce <u>Short-Term Forecasts</u> (Numerical Weather Predictions or NWP), <u>Long-term Climate Projections</u> or to do <u>Paleoclimate research</u>
- <u>To do experiments on the Earth system</u> (drivers of the climate and weather) but also on <u>exoplanets</u> (Jupiter, Titan)

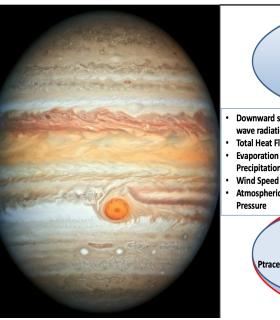
They underwent a progressive increase in their complexity by the inclusion of the coupling with the ocean and the cryosphere (Earth System models)

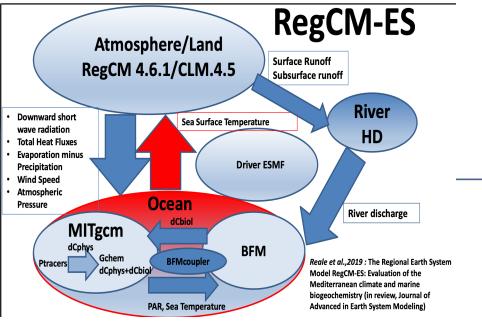
and the regional processes

OGS









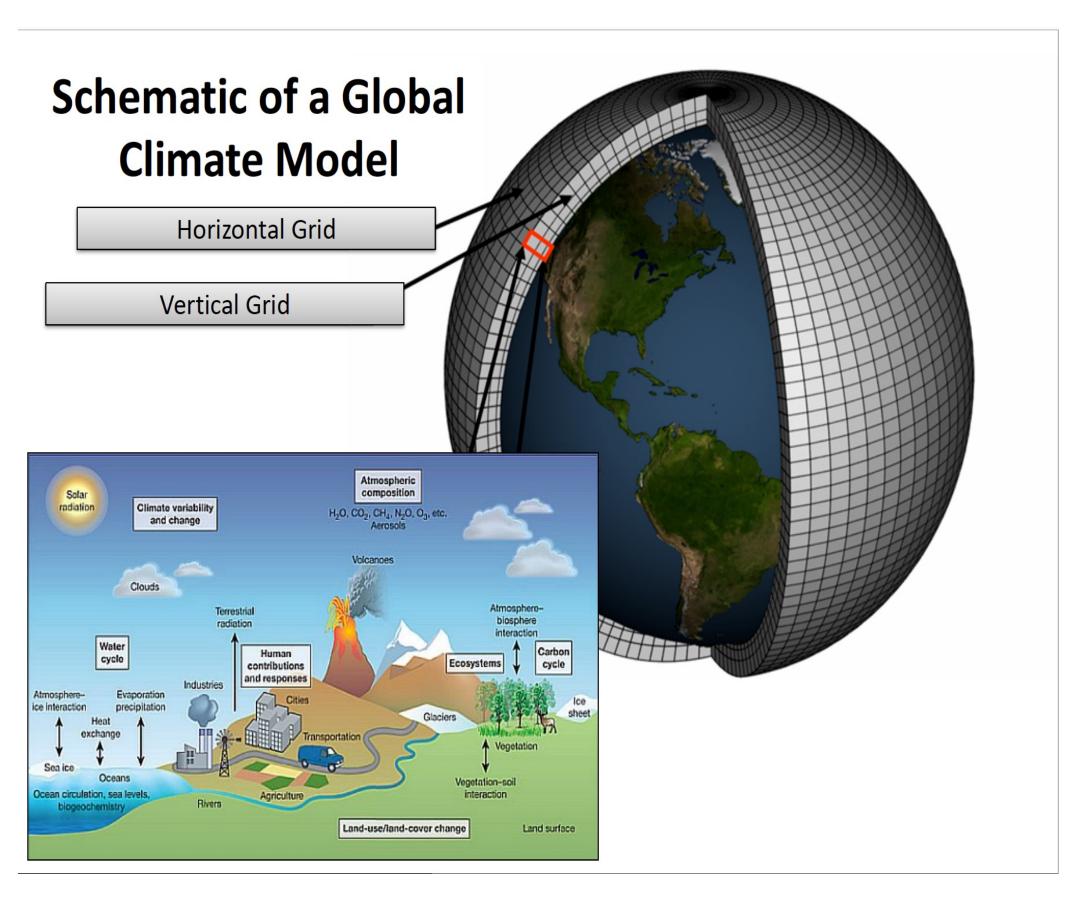
39

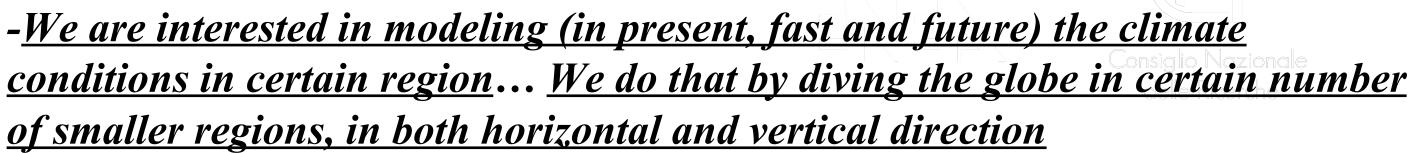
Climate models vs Numerical Weather Predictions (NWP)

- Climate models are different from NWP (as they are motivated by different needs)
- Climate models includes processes which operates on long time scales (energy budget and greenhouse gases emissions) and coarse resolution due to the need to simulate on longer time-scale
- NWP needs higher spatial resolution and does not need to include some physical processes
- The differences are faded out in the recent years (research centers used the same model to do climate projections and NWP)
- A further development among climate models has been the introduction of Regional climate models



Modelli climatici





- -In each of these smaller region we can capture and analyze different processes:
- Atmospheric fluxes
- Solar radiation
- Greenhouse gases emission
- River and precipitation
- Ecosystems dynamics..

Limitazioni pratiche e strutturali dei modelli

- Finite risorse computazionali → limiti sulla risoluzione spaziale del modello. In generale all'aumento della risoluzione corrisponde una maggiore accuratezza numerica e capacità di includere processi a piccola scala
- 2. Finite risorse computazionali e insufficiente conoscenze strutturali >> necessità di rappresentare in modo semplificato alcuni processi (parametrizzazione e tuning)
- 3. Insufficiente conoscenza delle condizioni iniziali e variabilità interna del sistema climatico → Una singola simulazione rappresenta solo uno dei possibili percorsi che il sistema climatico potrebbe seguire (asincronia di variabilità multi-decadale reale € singola simulazione, media fra le varie simulazioni per separare le tendenze climatiche dalla variabilità)

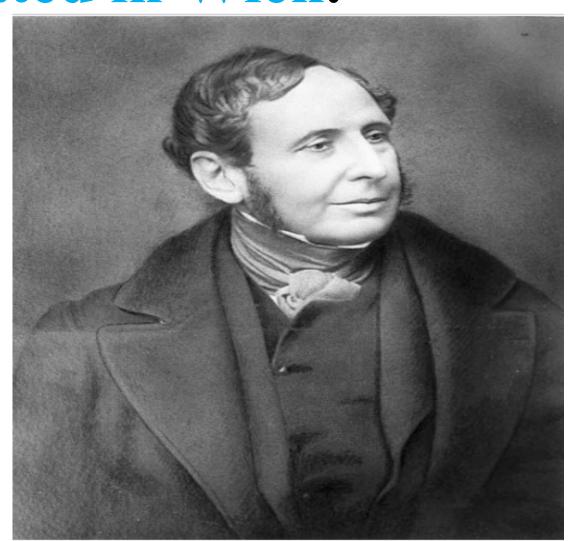


- a) Before the invention of meteorological devices, weather forecast were based on the observation of sky ("tempo rosso di sera, buon tempo si spera"-high pressure moving from the west)
- b) 1600-1700: Evangelista Torricelli introduces the Barometer (he also observed that high pressure is usually correlated with nice weather) while Francesco Folli introduces the Hygrometer to measure the humidity
- c) 1700-1800: Daniel Fahrenheit introduces the thermometer while Antoine de Lavoisier began to make daily measures of the temperature, air pressure and wind direction and speed.

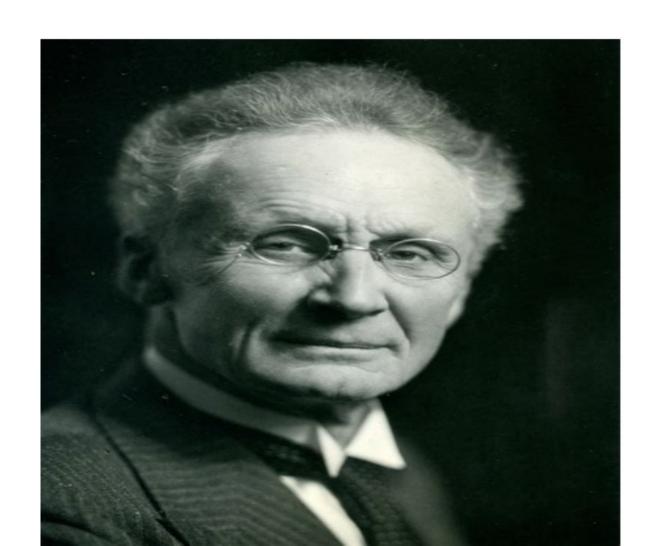


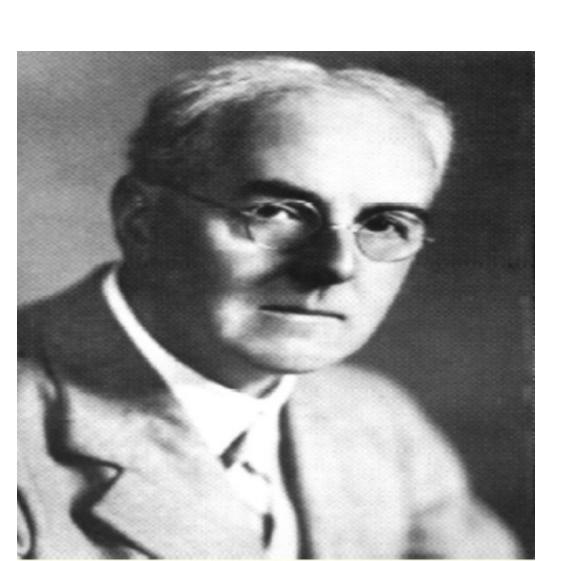
- a) 1837: Invention of the telegraph. There is the possibility of communicate the weather conditions and patterns among vast different areas
- b) 1849: The Smithsonian institute first established an observation network across USA
- c) 1854: A French warship and 38 other vessels sank in a violent storm. Urbain Le Verrier (director Paris Observatory) has sent to investigate and he found that the storm formed two days before. It is clear the need for a storm warming system which is established one year later in France
- d) 1860: Robert Fitzroy produced the first synoptic chart of England using the telegraph and use the term weather forecast. He is the founder of the Met Office
- e) 1873: The International Weather Organization is created in Wien.





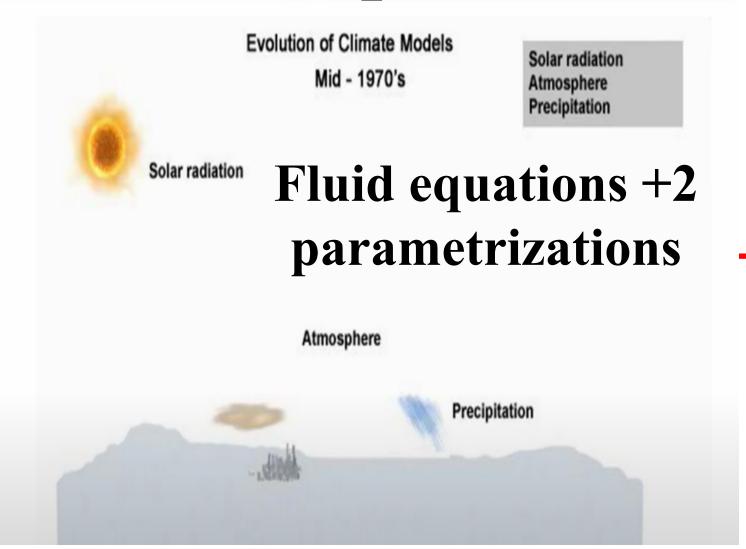
- a) 1916: The "great" Vilhelm Bjerknes introduces the «primitive» equation of fluid motions (momentum and mass conservations and thermodynamics)
- b) 1922: Lewis Fry Richardson uses these equations and proposed some mathematical tecniques in his publication "Weather predictions by Numerical processes" to produce some weather forecasts. He tried to produce the forecast for a single day (May, 10th 1910) at 1pm using as initial conditions the data taken at 7am. The calculation required 3 months (not a nowcasting) and predicted an increase in the air pressure of approximately 145 mbar (while, in reality, the pressure was costant). There was an error in the numerical tecniques adopted (instability). This problem was fixed and the value was accurate

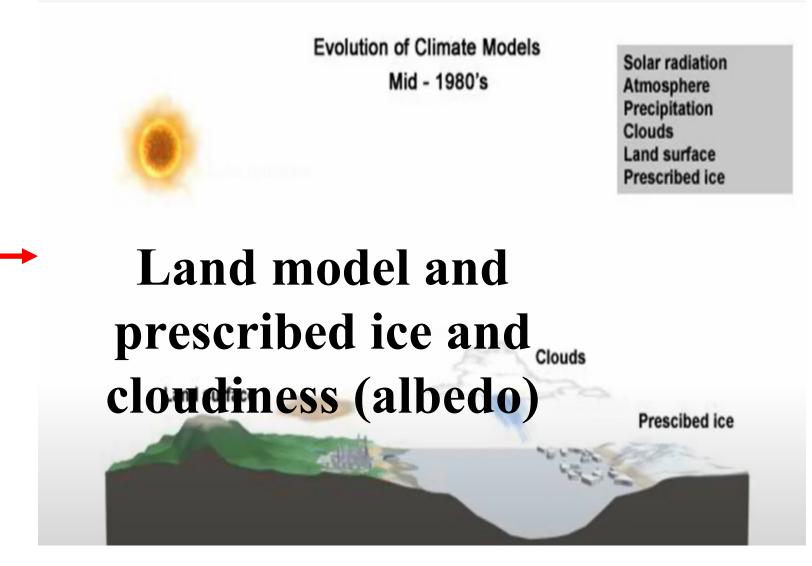


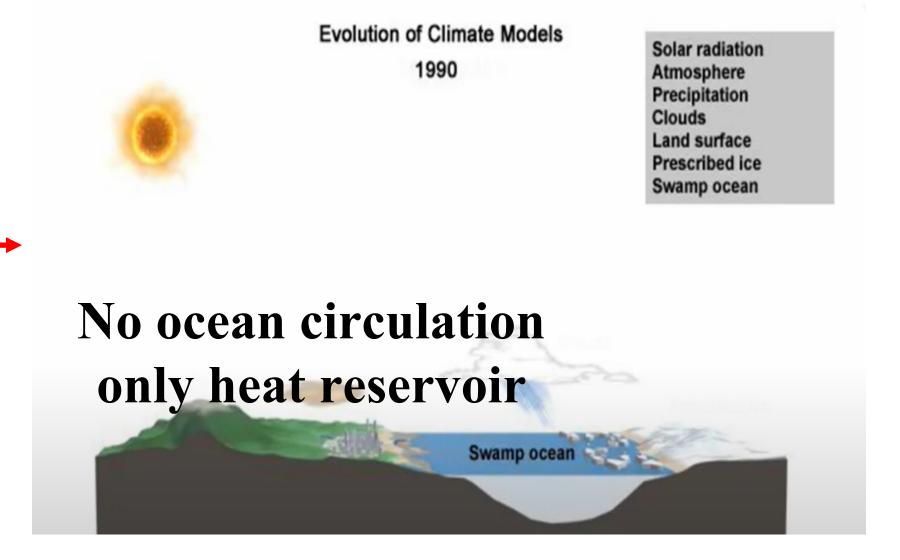


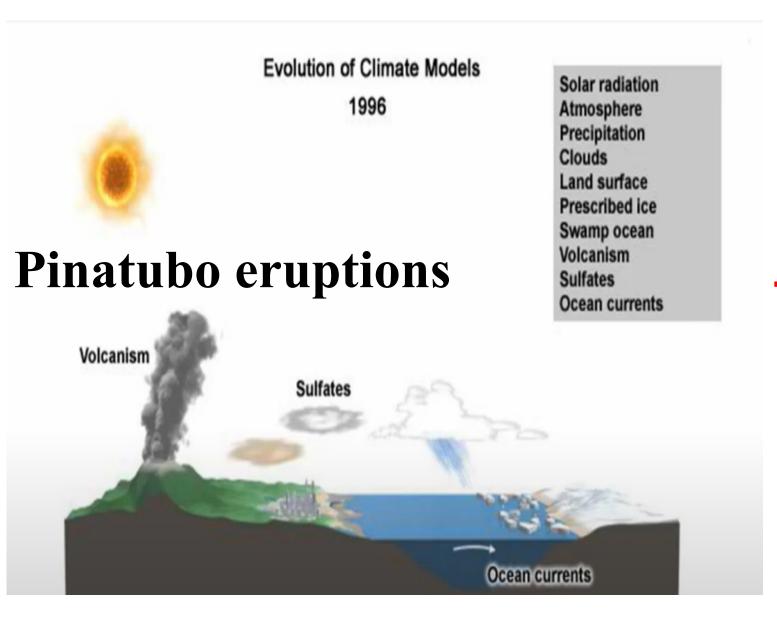
- a) 1940-1950: John von Neumann (working with nuclear explosion) and Jule Charney (who worked with Carl Rossby in Chicago) developed the first numerical framework for weather prediction and produced the first successful weather forecast in Princeton in the "supercomputer" ENIAC
- b) 1955: First General Circulation Model developed by Norman Philips (Princeton University). The "discretized" domain was represented by two layer atmosphere on a cylinder of 17 cells high and 16 cells in circumference. The supercomputer has only 5KB of memory+10KB of memory
- c) 1958-1965: J. Smagorinsky and Syukuro Manabe (2021 Nobel prize) developed the first 3D model of the atmosphere using the primitive equations
- d) 1956-1964: Y.Mintz and A.Arakawa developed a two layer model with realistic topography
- 1970-onwards: Dramatic explosions in the number and complexity of available atmospheric models

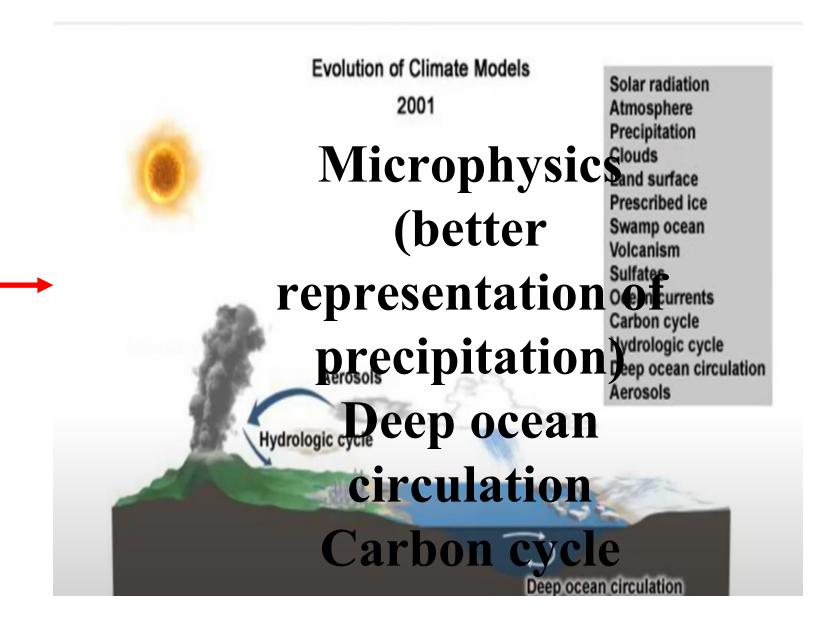
Temporal evolution of climate models

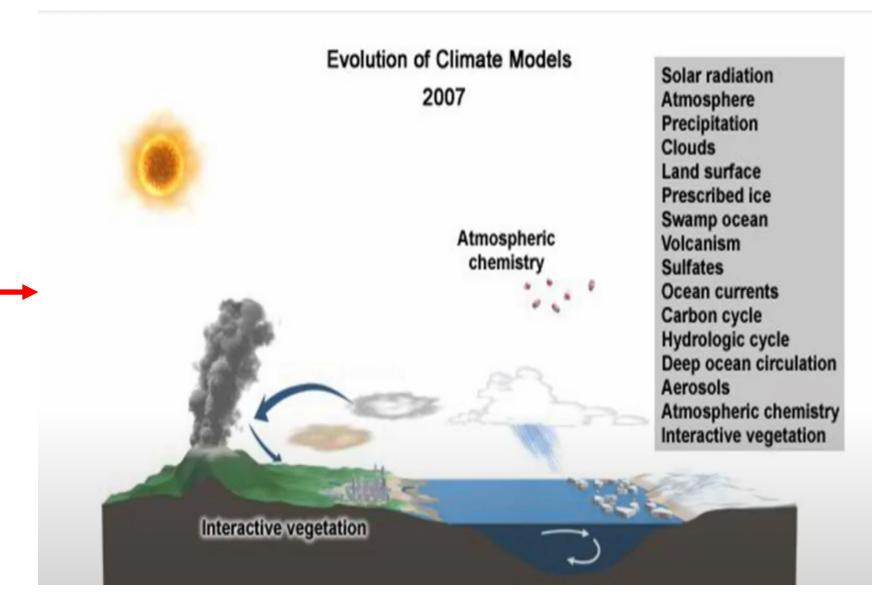












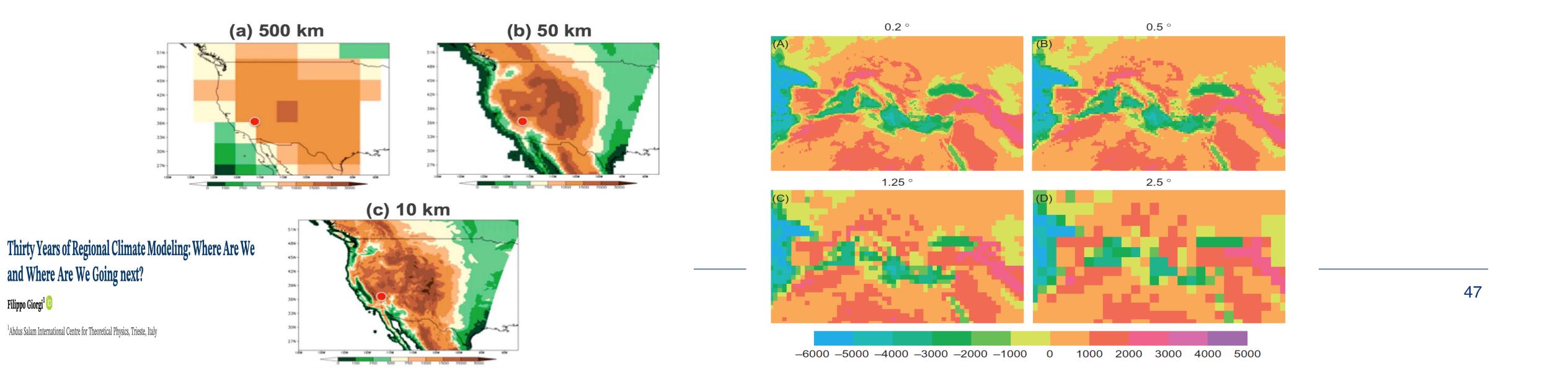
© the comet program/Paul Ulrich

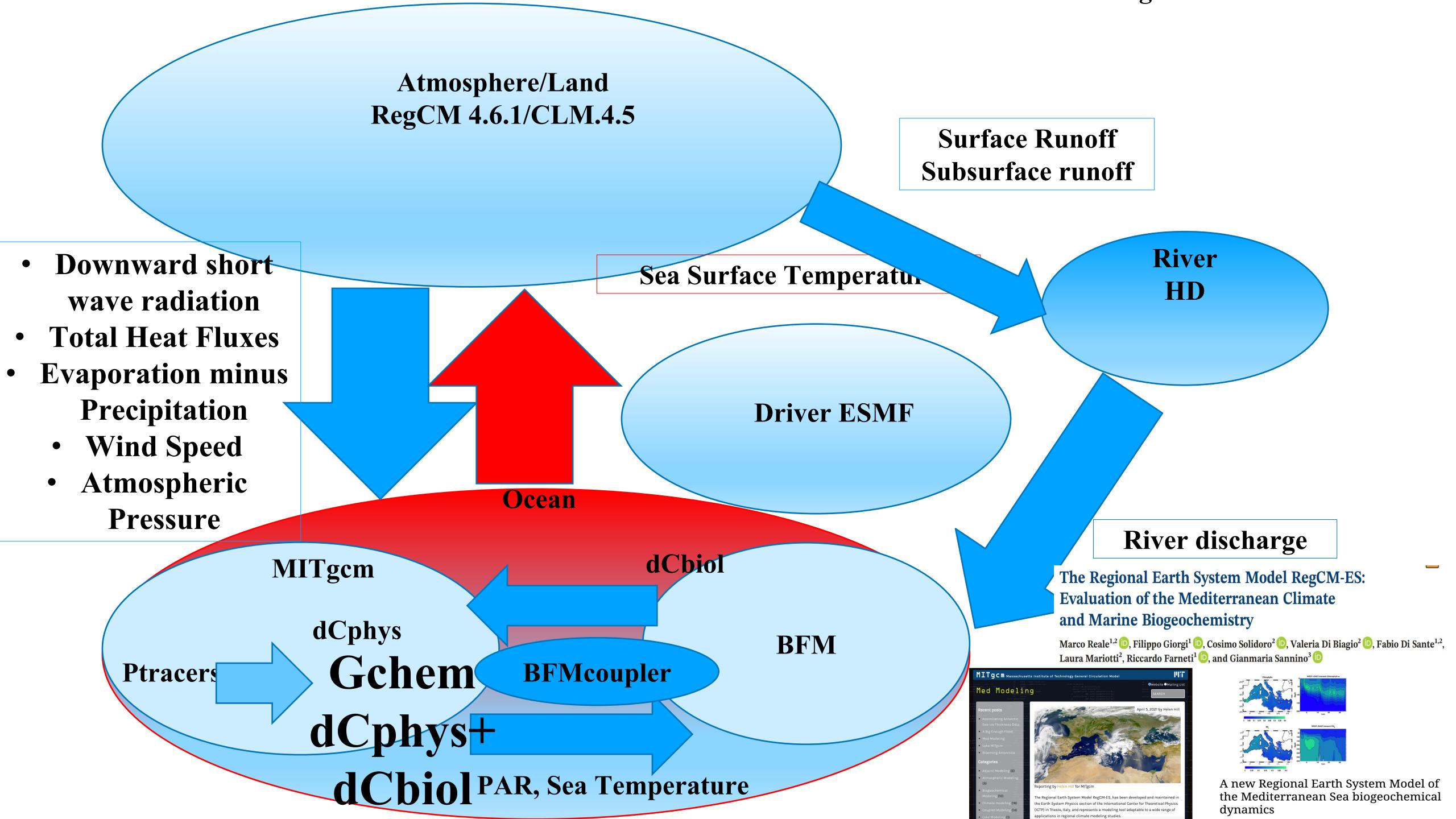
Modelli climatici

•Great improvements into resolution, computational methods and parametrizations, and additional processes (e.g., interactive aerosols)

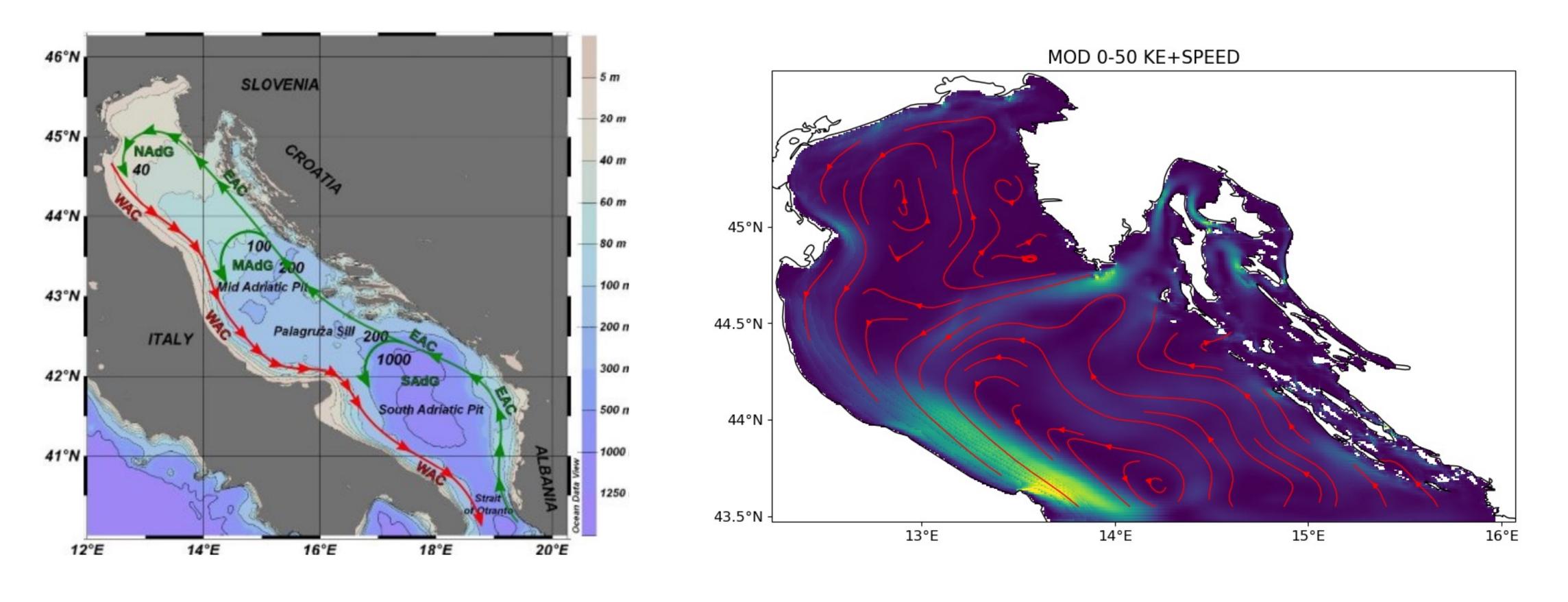


- •Progress in the simulation of important modes of climate variability (ENSO) has increased the overall confidence in the models' representation of important climate processes.
- •Greater ability of AOGCMs to simulate extreme events, especially hot and cold spells.
- •Improvements in the simulation of extratropical and tropical cyclones.

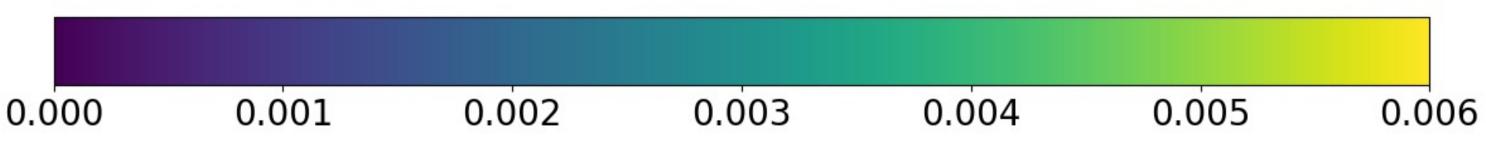




Some preliminary results: surface circulation of the Northern Adriatic

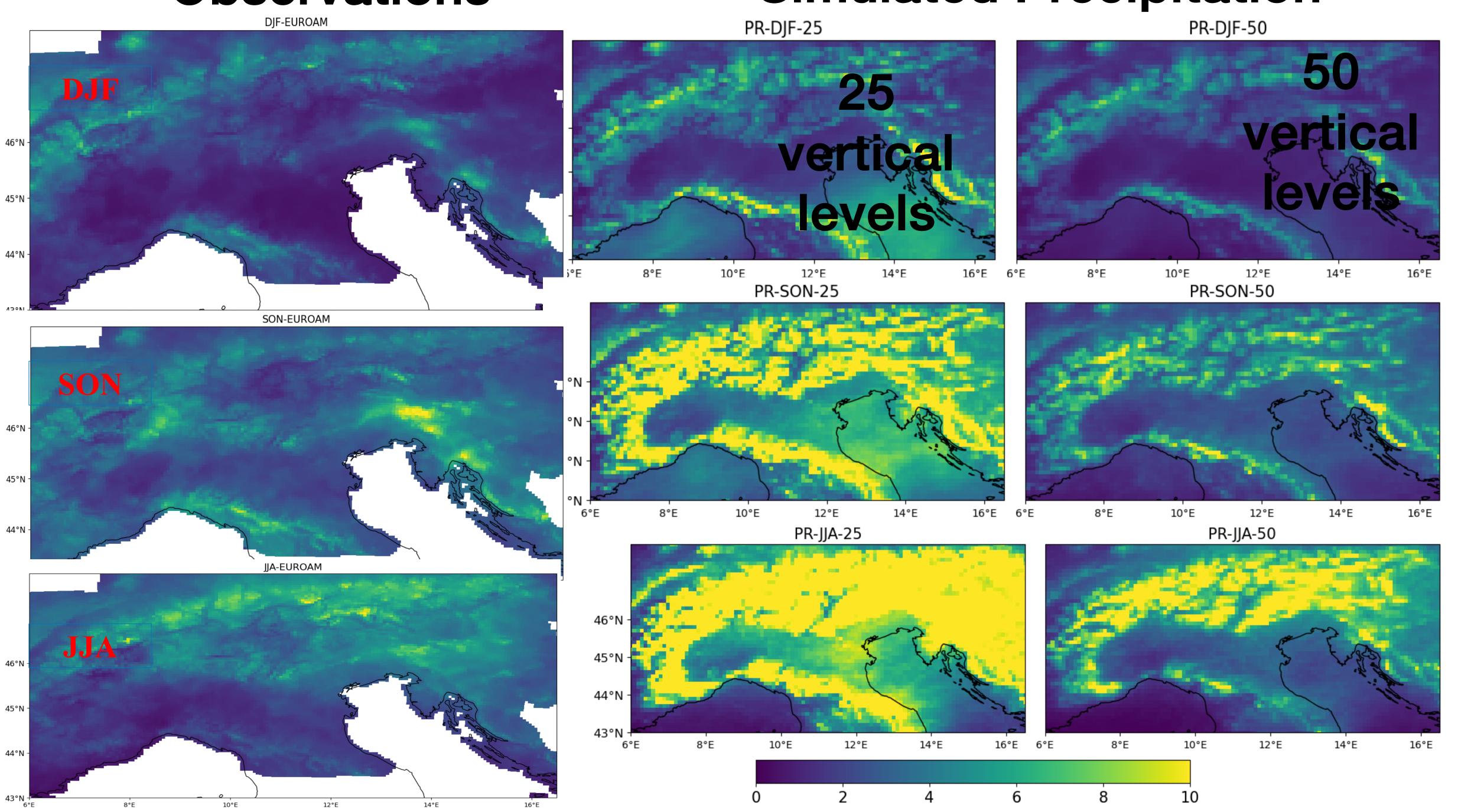


Lipizer et al., 2014

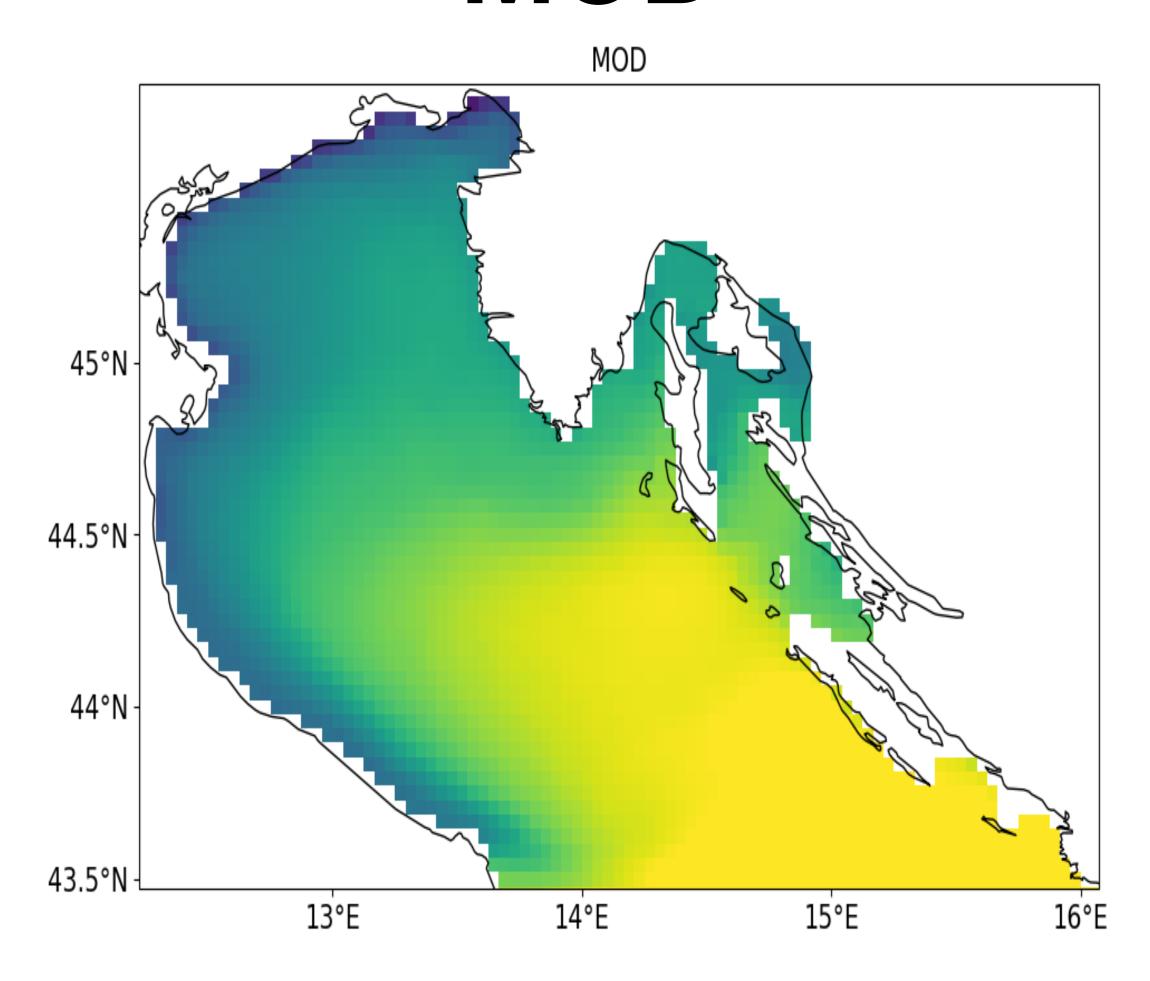


Observations

Simulated Precipitation

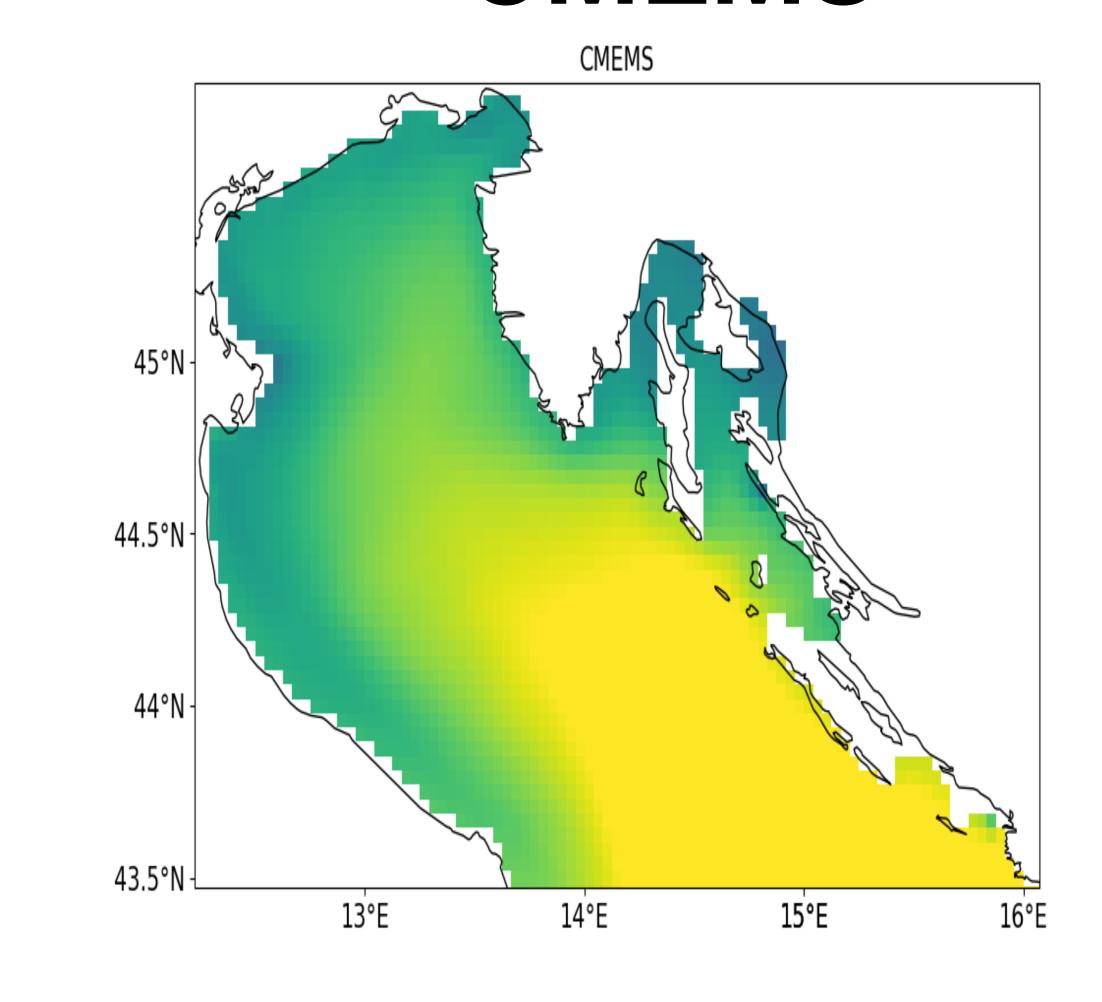


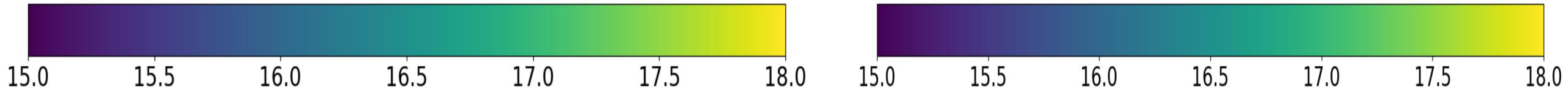
MOD



SST

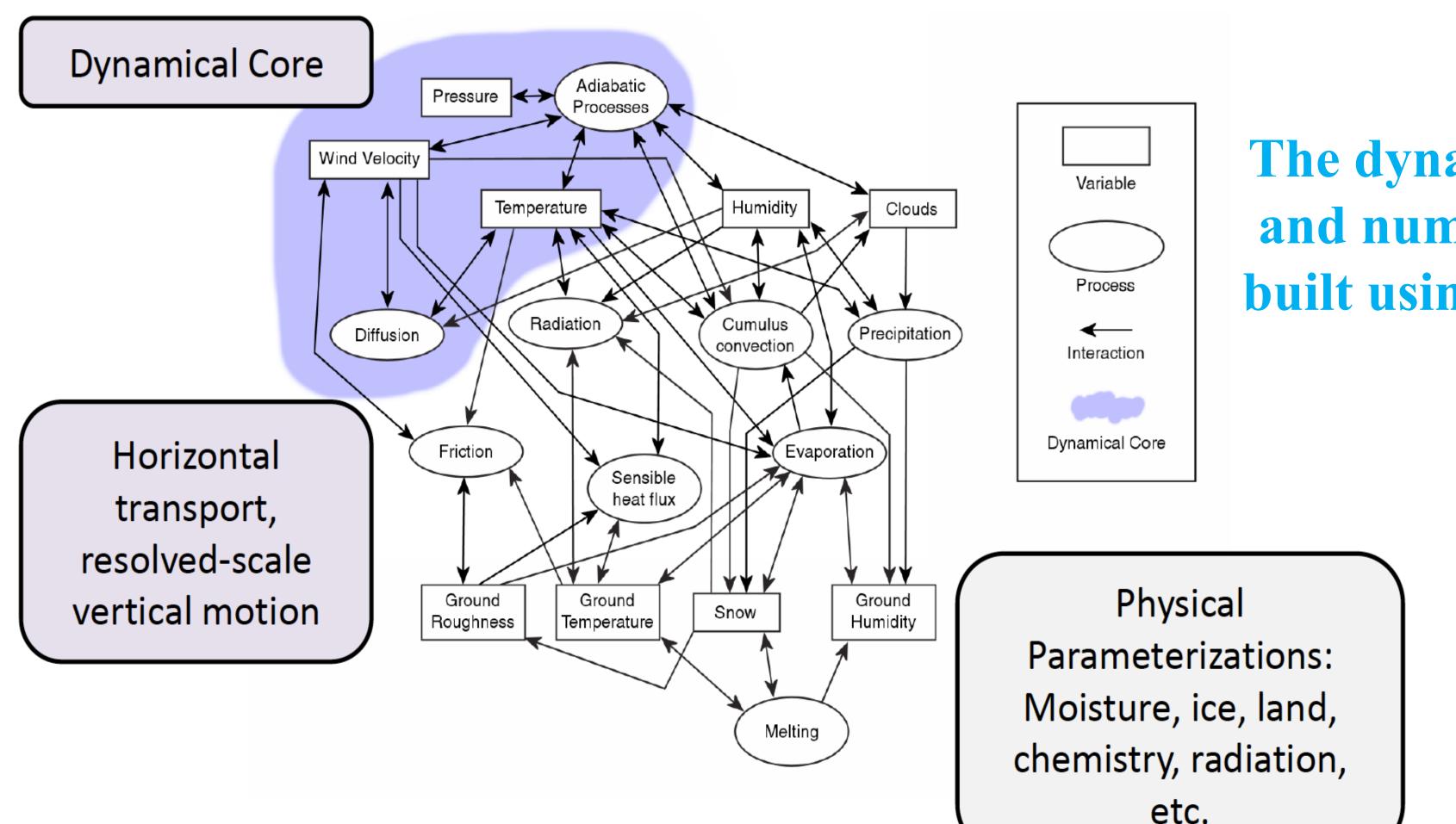
CMEMS





Anatomy of an atmospheric model

You can divide an atmospheric model in two components:



The dynamical cores of climate models and numerical weather prediction are built using the same set of fundamental equations

etc.

ulrich

• Equation of motion
$$\frac{\mathbf{Equations set}^*}{\frac{D\mathbf{u}}{Dt}} = \frac{d\mathbf{u}}{dt} + \mathbf{u}.\nabla \mathbf{u} = -\frac{1}{\rho} \Delta p - f\mathbf{k} \times \mathbf{u} - g\mathbf{k} + F \leftarrow \text{Viscous Force}$$

Pressure gradient

Equation of state

$$p = \rho RT$$

• Thermodynamic Equation $dq = c_p dT - v dp$,

$$dq = c_p dT - v dp$$

* Simplified representation of the equations...see Pedlosky, different available versions using different coordinates.. Temporal and spatial derivative involved

Mass continuity

$$\frac{D\rho}{Dt} = -\rho \nabla .\mathbf{u}$$

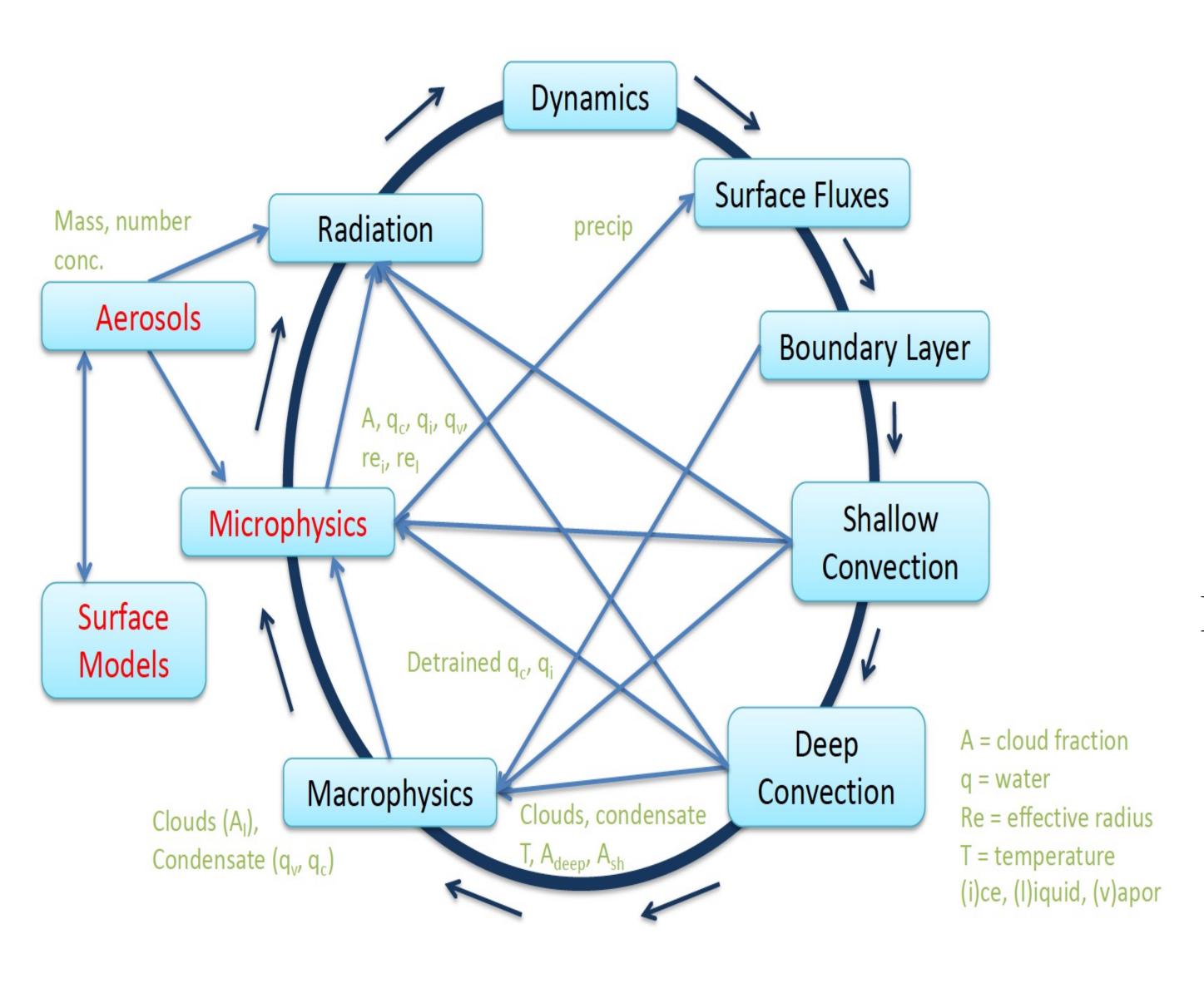
Water continuity

$$\frac{Dr_i}{Dt} = S_i$$

u wind, f Coriolis parameter,p pressure, R gas constant, T temperature, q is diabiatic heating, C_p heat capacity at constant pressure, v specific volume, rho density, r_i is the mixing ration of water species i (snow, rain, cloud droplets) while S_i is the source/sink

- -This equation set cannot be solved analytically, only numerically
- -We are not interested the resolving the dynamics of each molecule in the atmosphere
- -We do not have enough space to store data
- -We do not have enough computational power

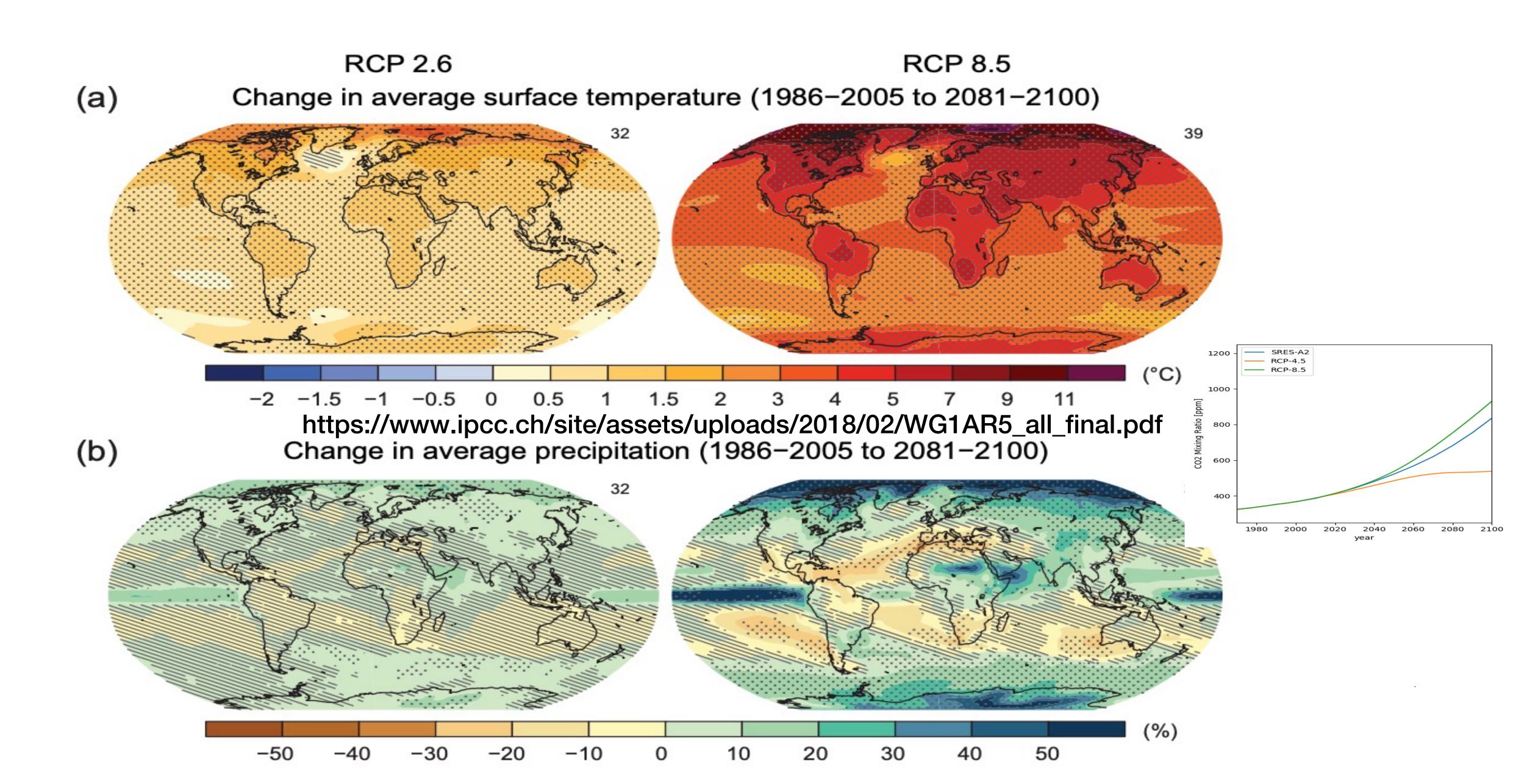
Parametrizations



-Inputs and effects are considered in single column -Calculations are instantaneous (not the same timescale of the large scale)

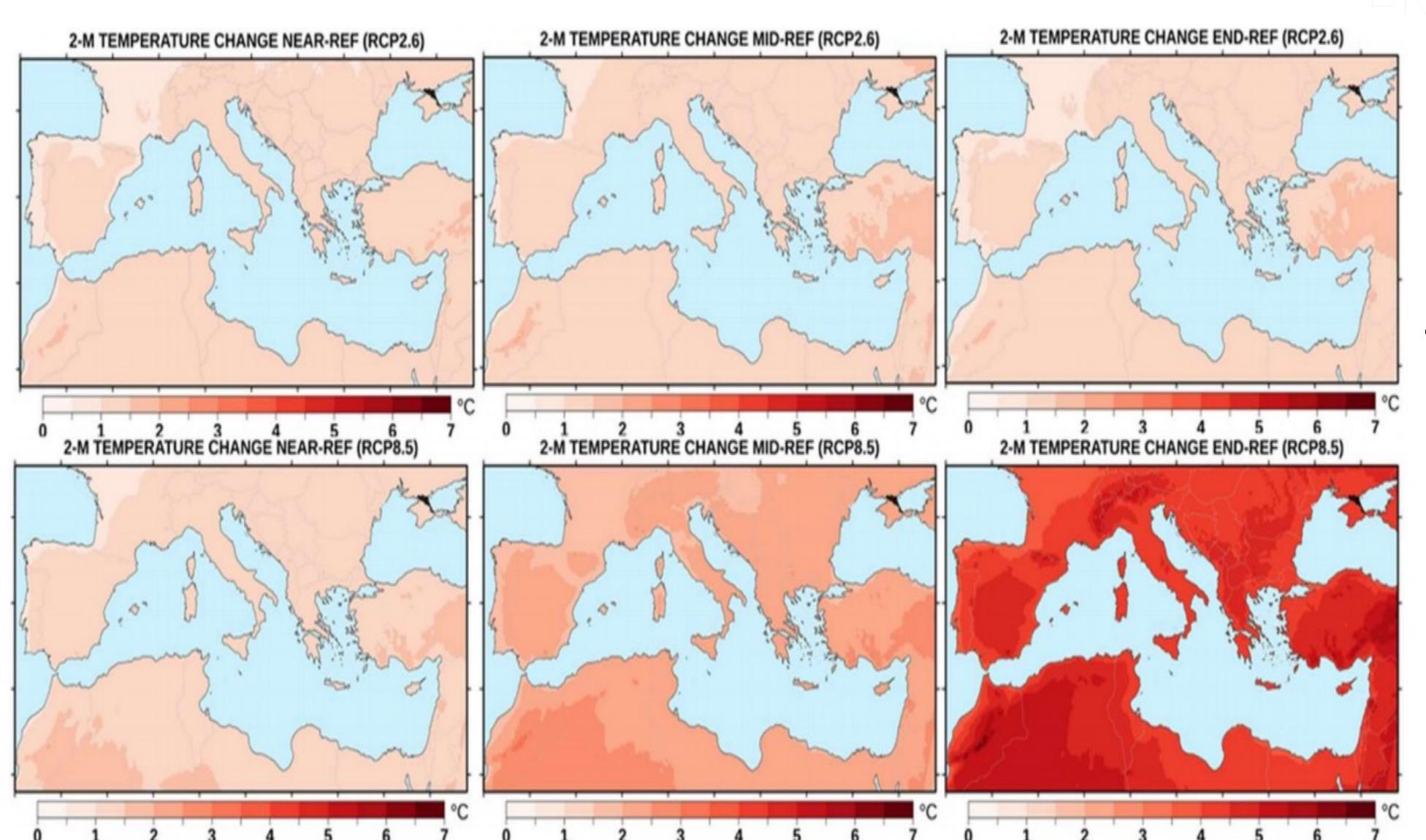
Both points give problems with increasing resolution and smaller time steps

Proiezioni per la temperatura e le precipitazioni



Proiezioni nella temperatura nell'ensemble Euro-





Consiglio Nazionale delle Ricerche

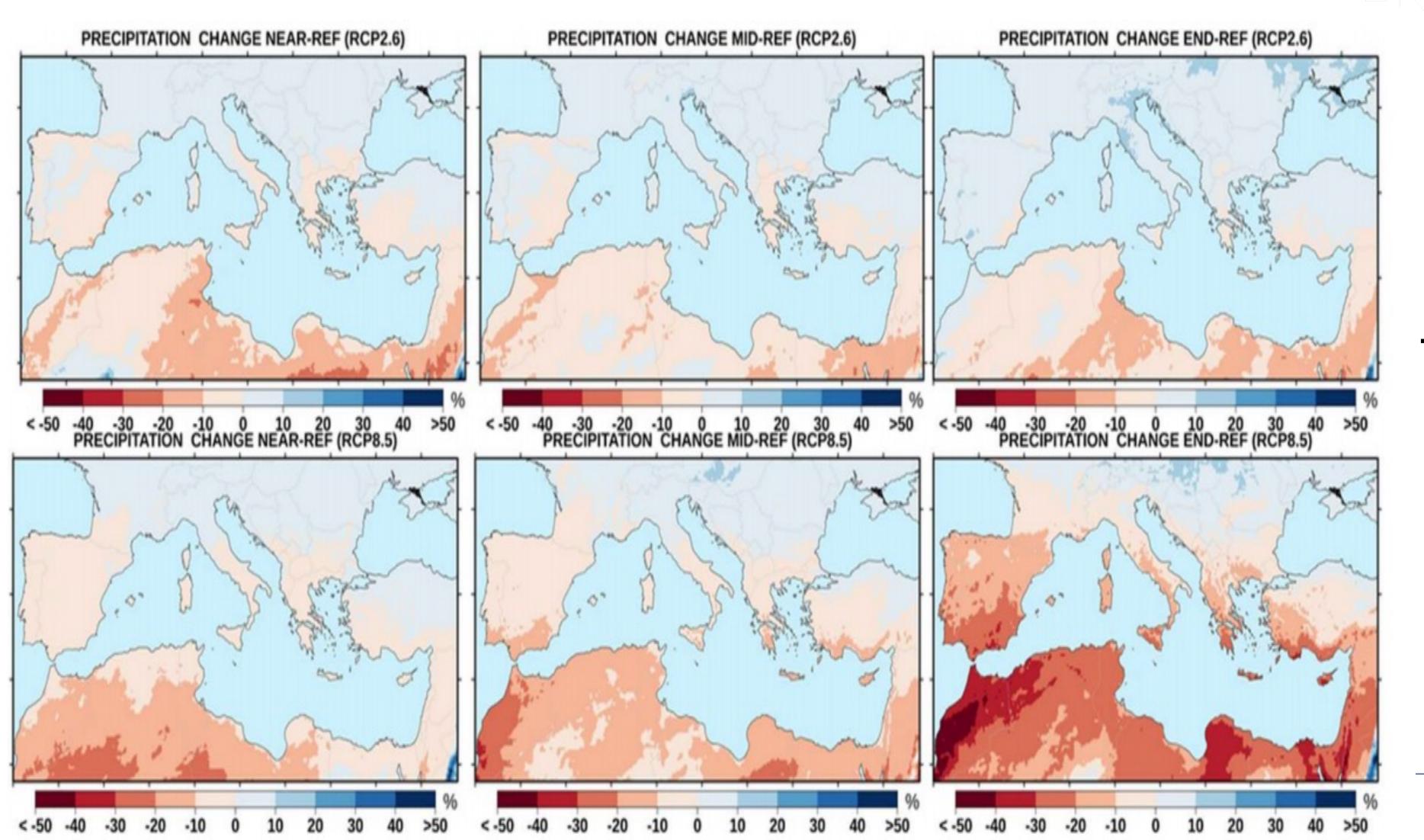
MedECC(2021)

The intensity of the signal depends on the emission scenarios!

Proiezioni delle precipitazioni nell'ensemble





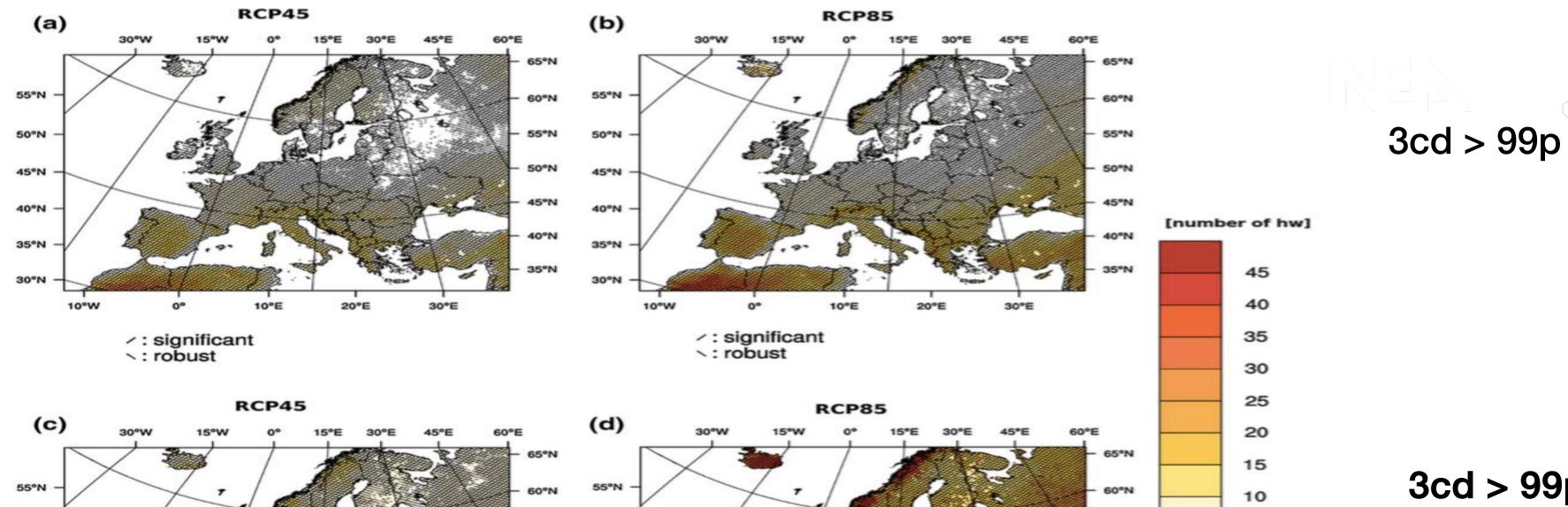


MedECC(2021)

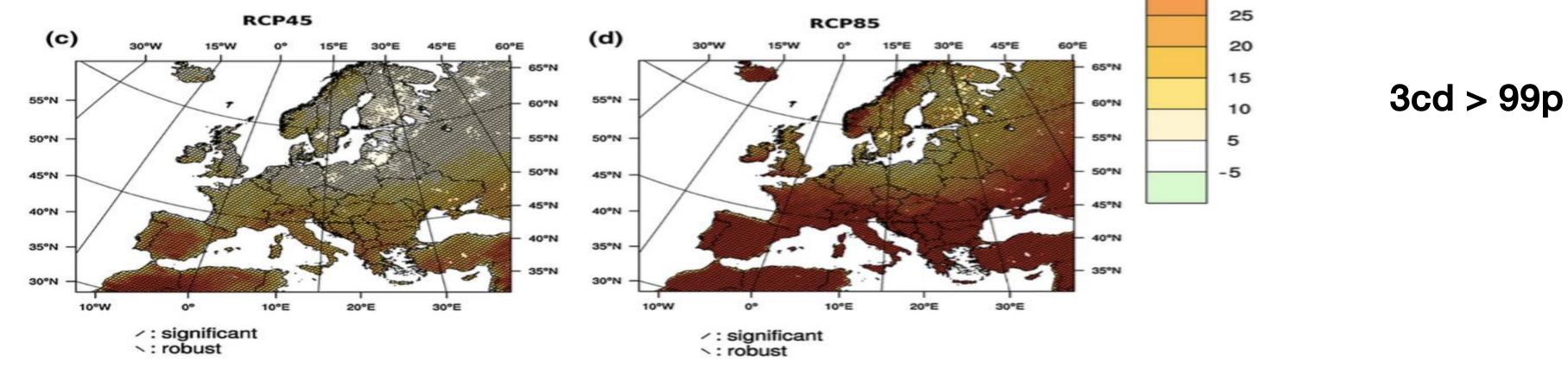
The intensity of the signal depends on the emission scenarios!

Proiezioni per le ondate di calore

2021-2050 minus 1971-2000

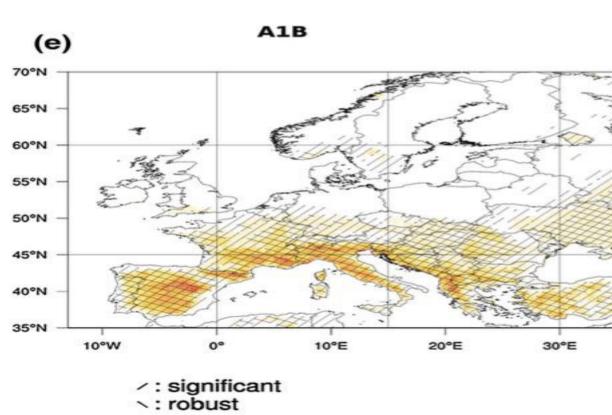


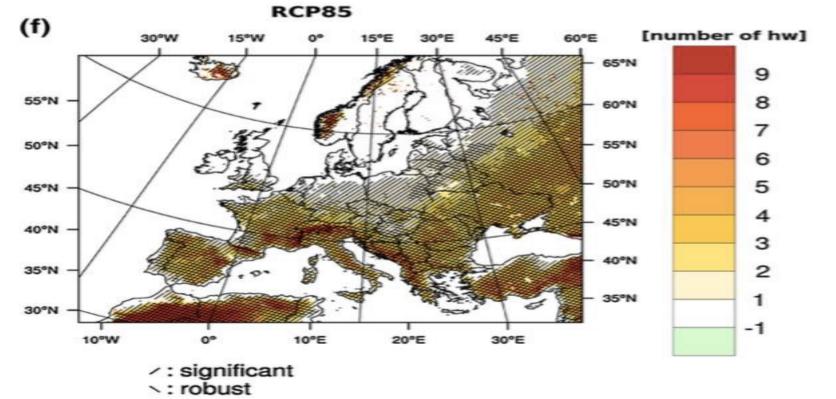
2071-2100 minus 1971-2000



2071-2100 minus 1971-2000





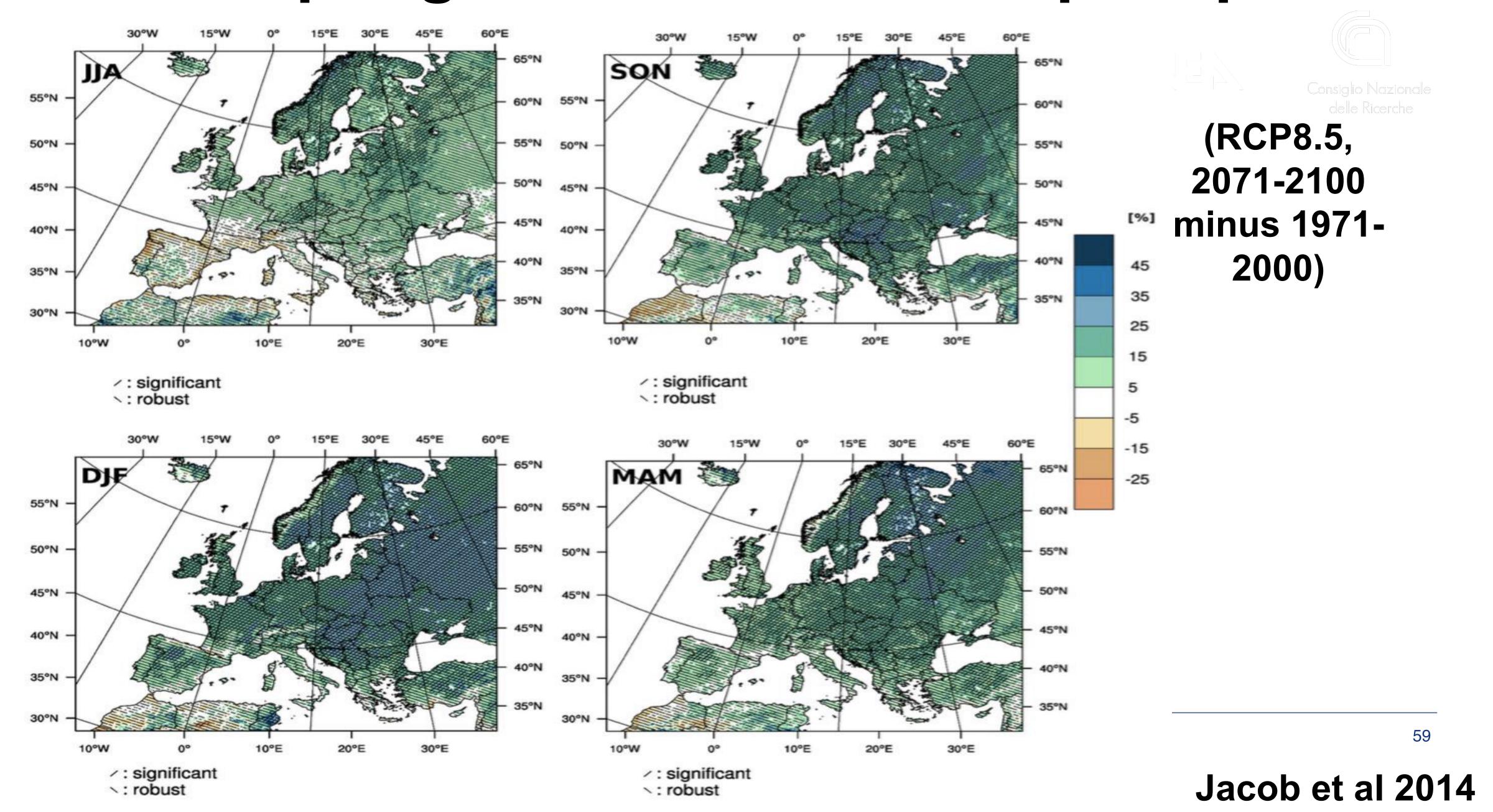


5cd > 5C

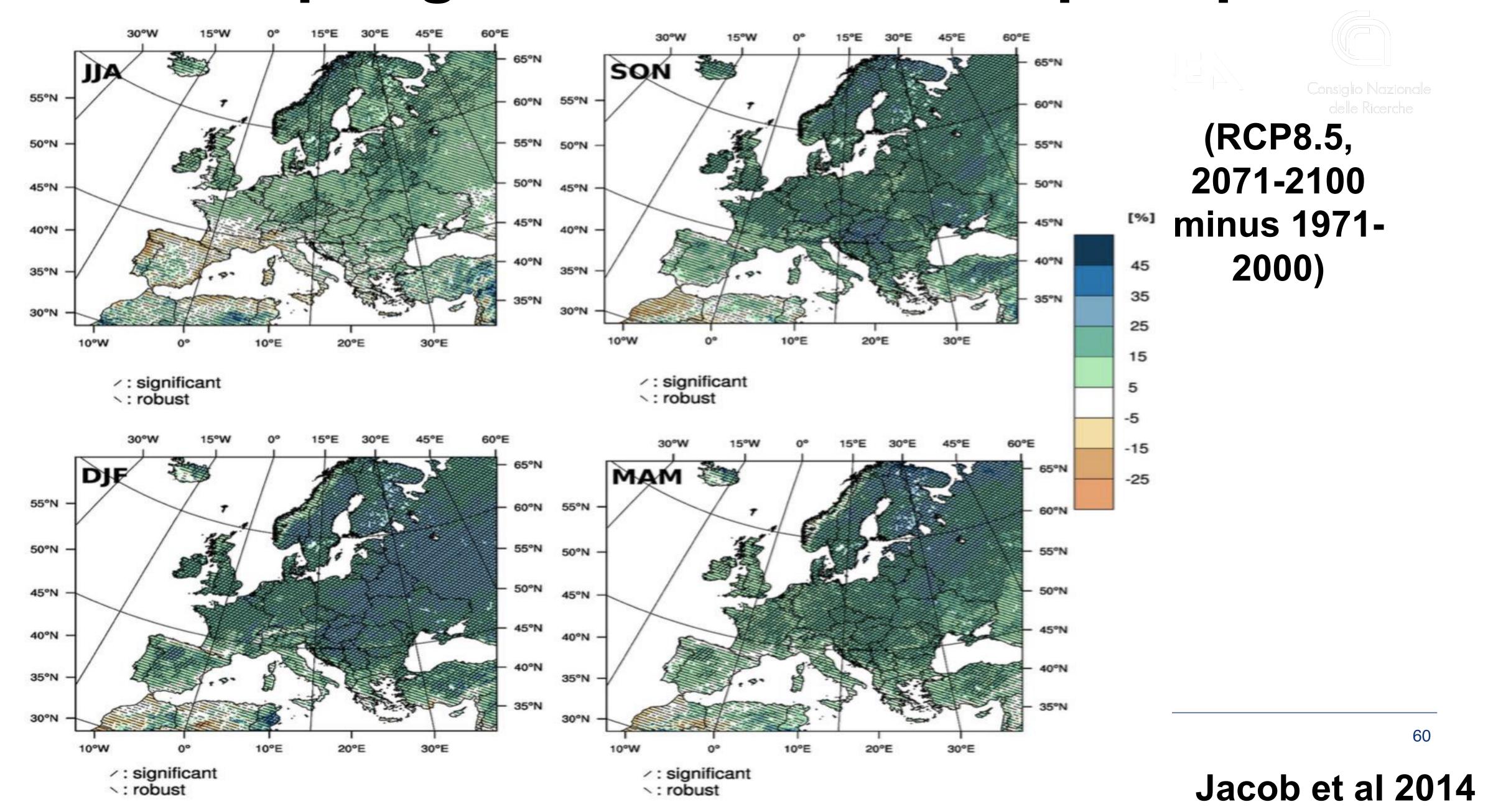
58

Jacob et al 2014

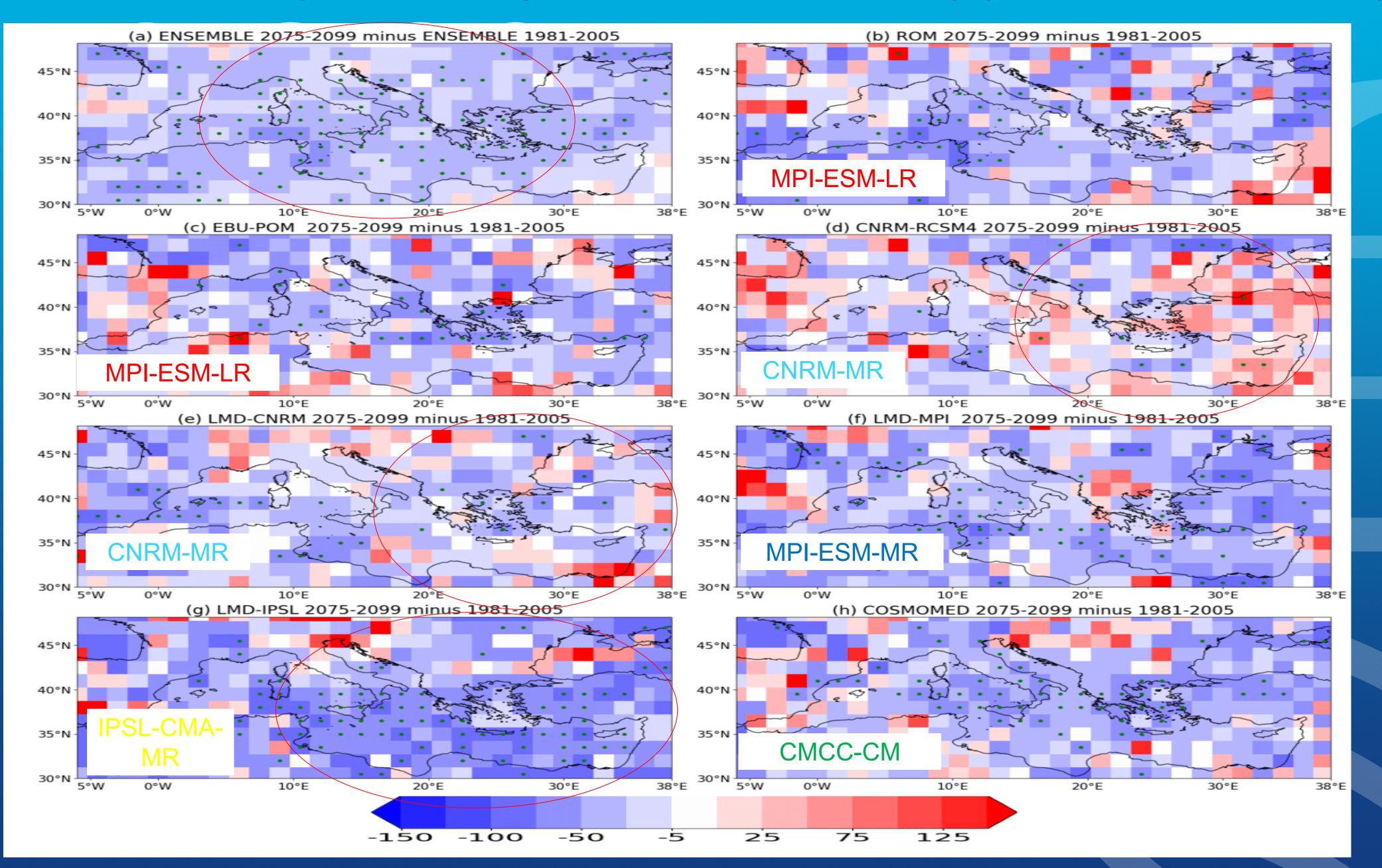
Proiezioni per gli eventi estremi di precipitazione



Proiezioni per gli eventi estremi di precipitazione



Cyclone activity at the end of 21st century (RCP8.5 scenario-CTRL)

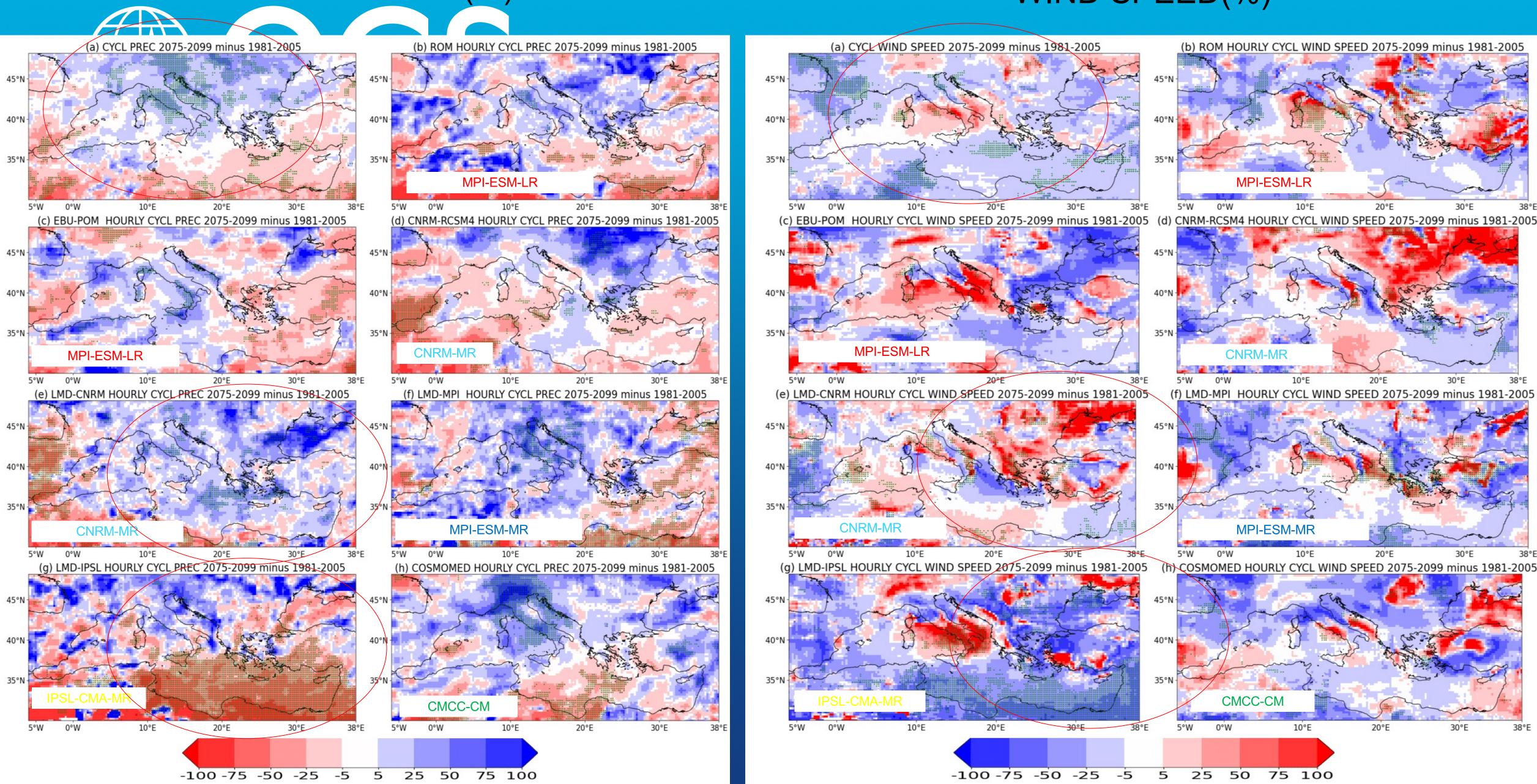


Spatial distribution of the relative changes (in %) with respect to the period 1981-2005 of the annual number of cyclone tracks in the period 2075-2099 in the

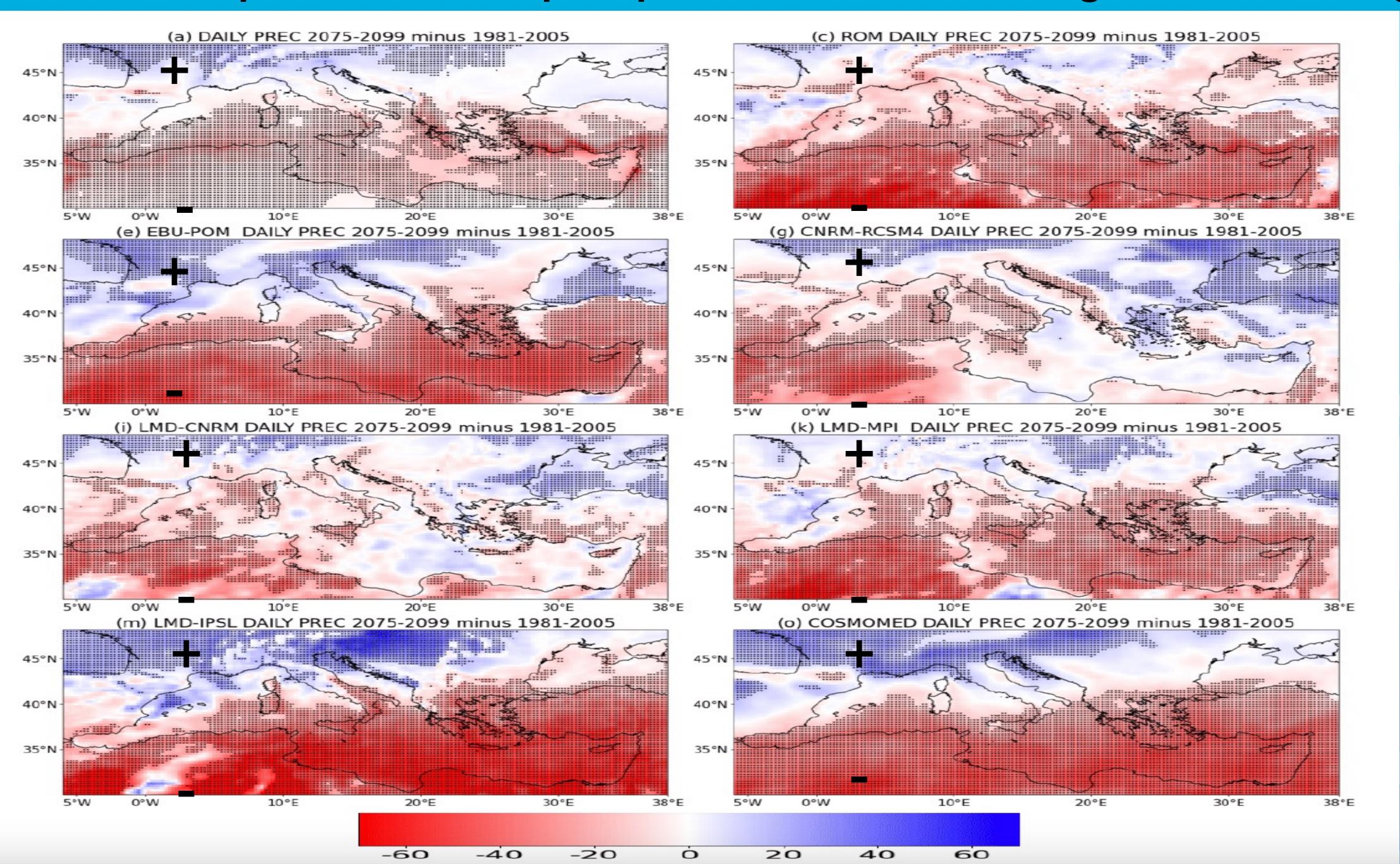
multi model means (ENSEMBLE, a), ROM (b), EBU-POM (c), LMD-IPSL and COSMOMED Green the multi-model means panel (a) shows the the climate where robust among the RCSMs Green dots in the panels b-h mark difference in the density of tracks between the period 2075-2099 and 1981-2005 is statistically significant with p<0.05.

Cyclone activity at the end of 21st century (RCP8.5 scenario)

RAIN (%) WIND SPEED(%)



Simulated response of winter precipitation to climate change in the Med Region

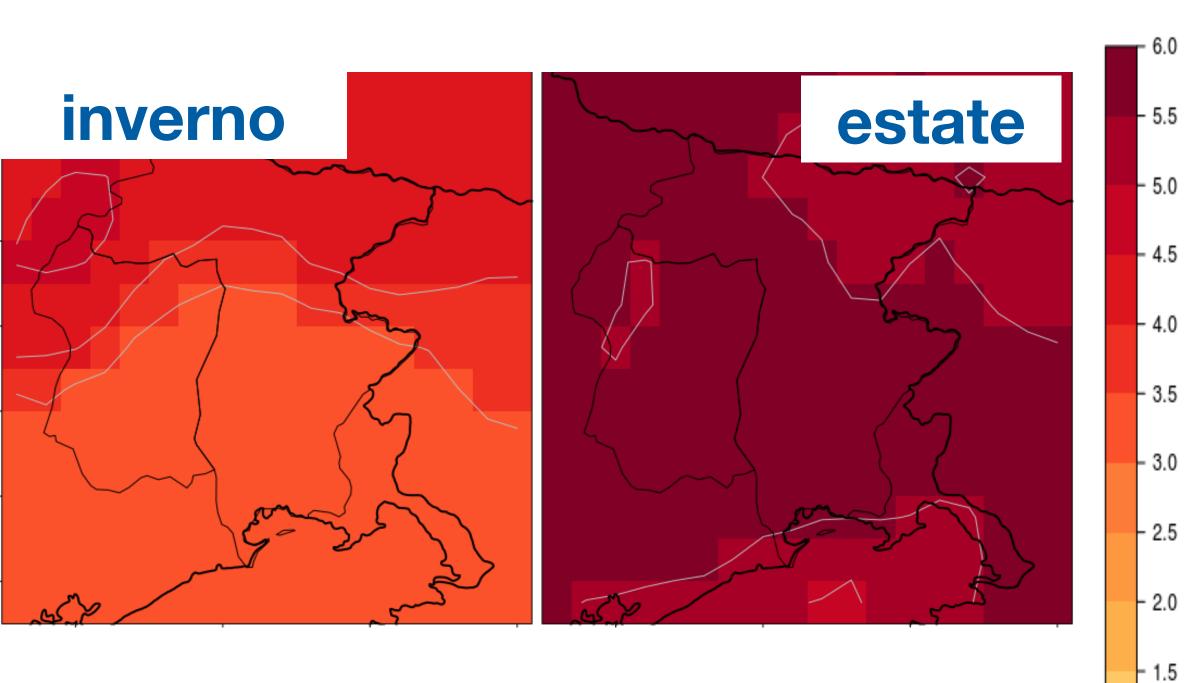


..e in Friulia Venezia Giulia..?

- 1.0

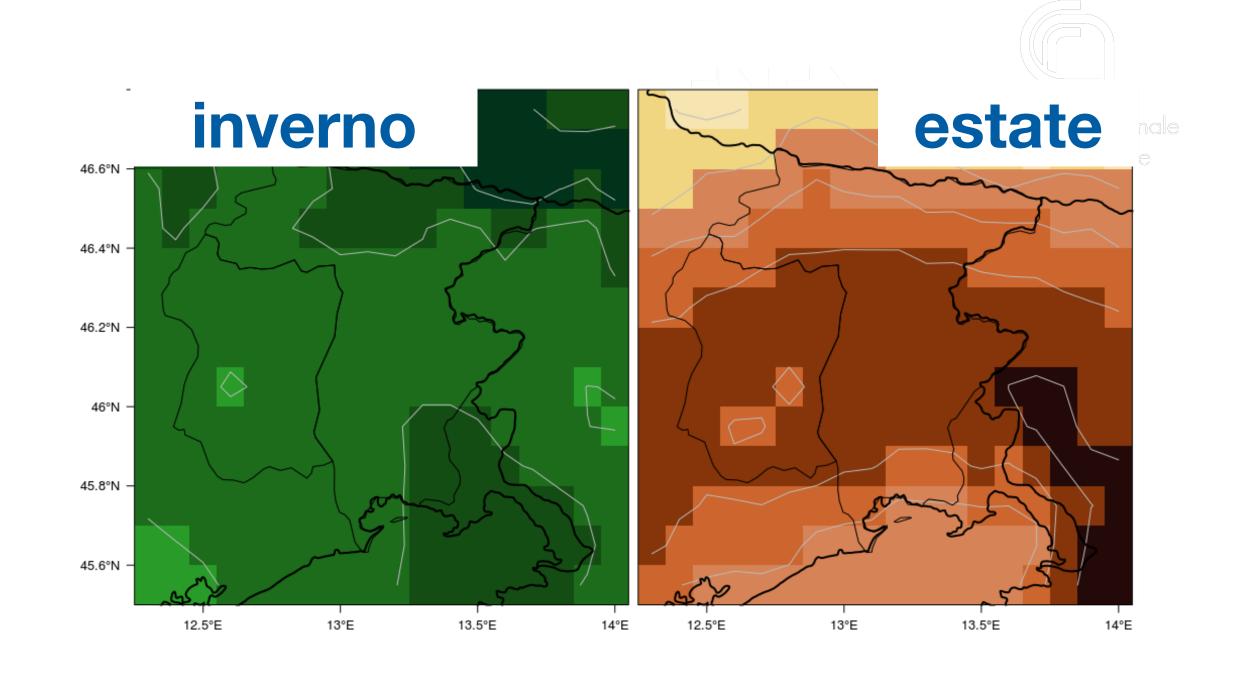
- 0.5

- 0.0



temperature

2071-2100



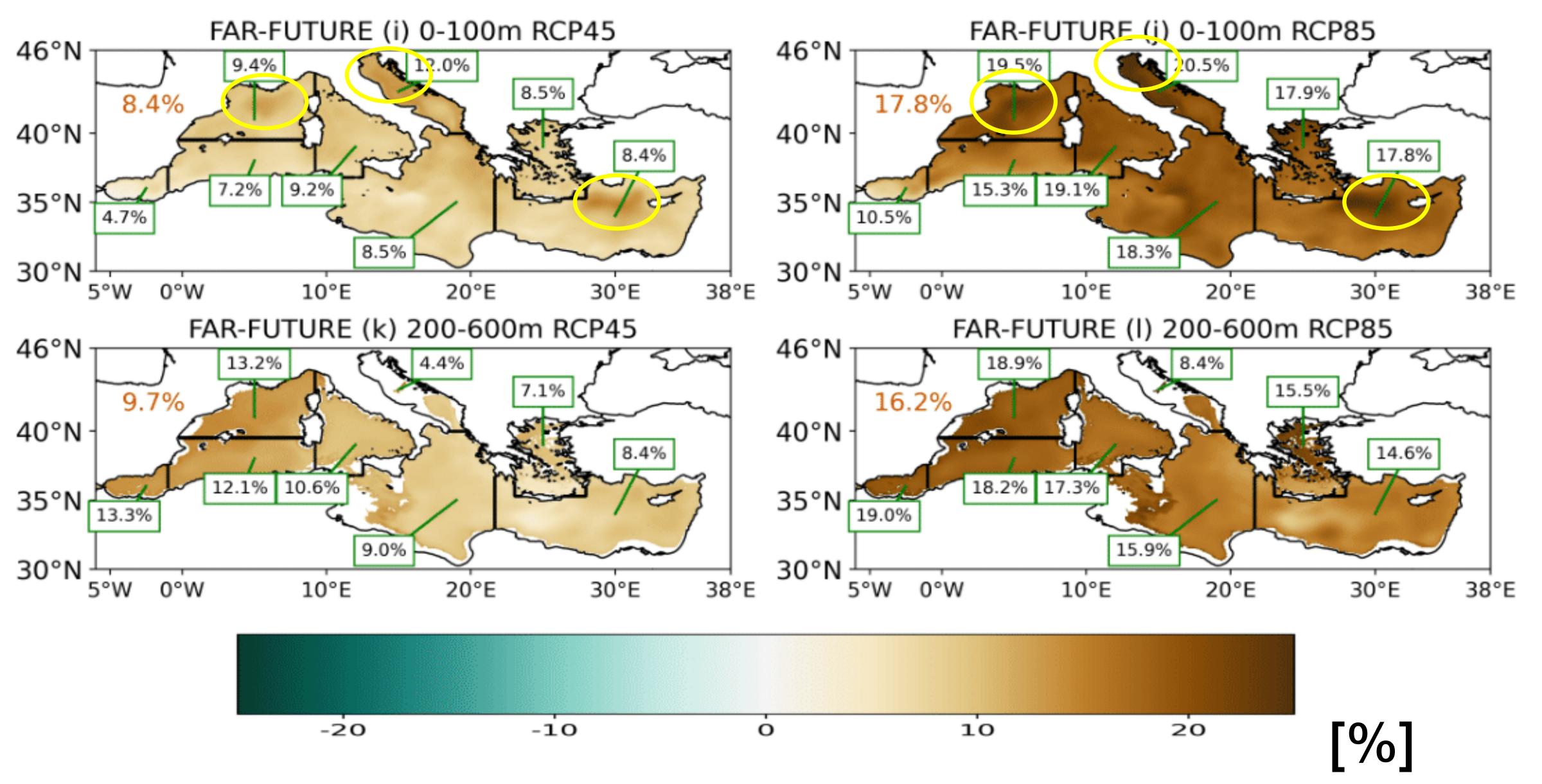
precipitazioni



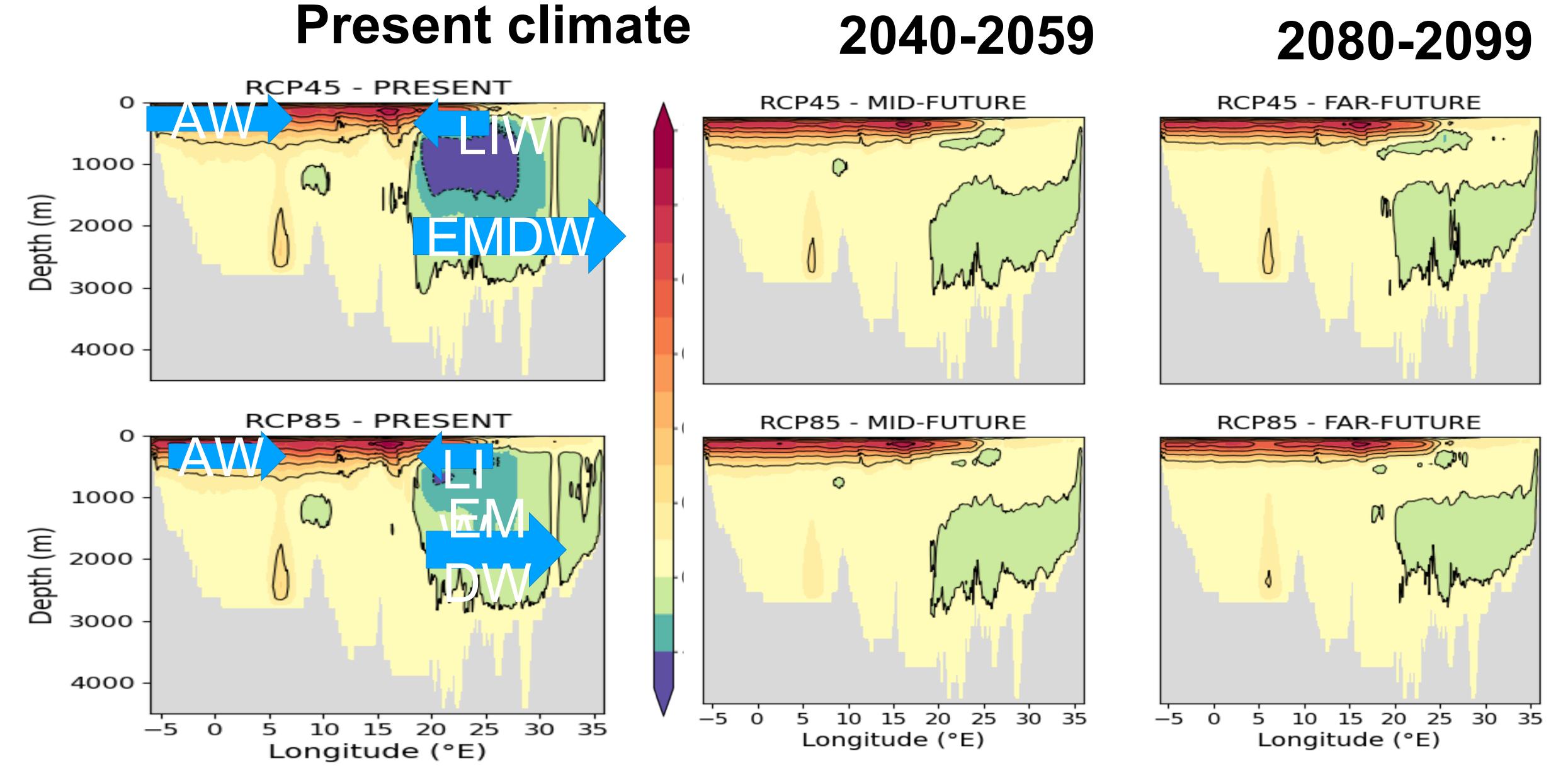
2071-2100



Future projections for the Mediterranean Sea: Physics

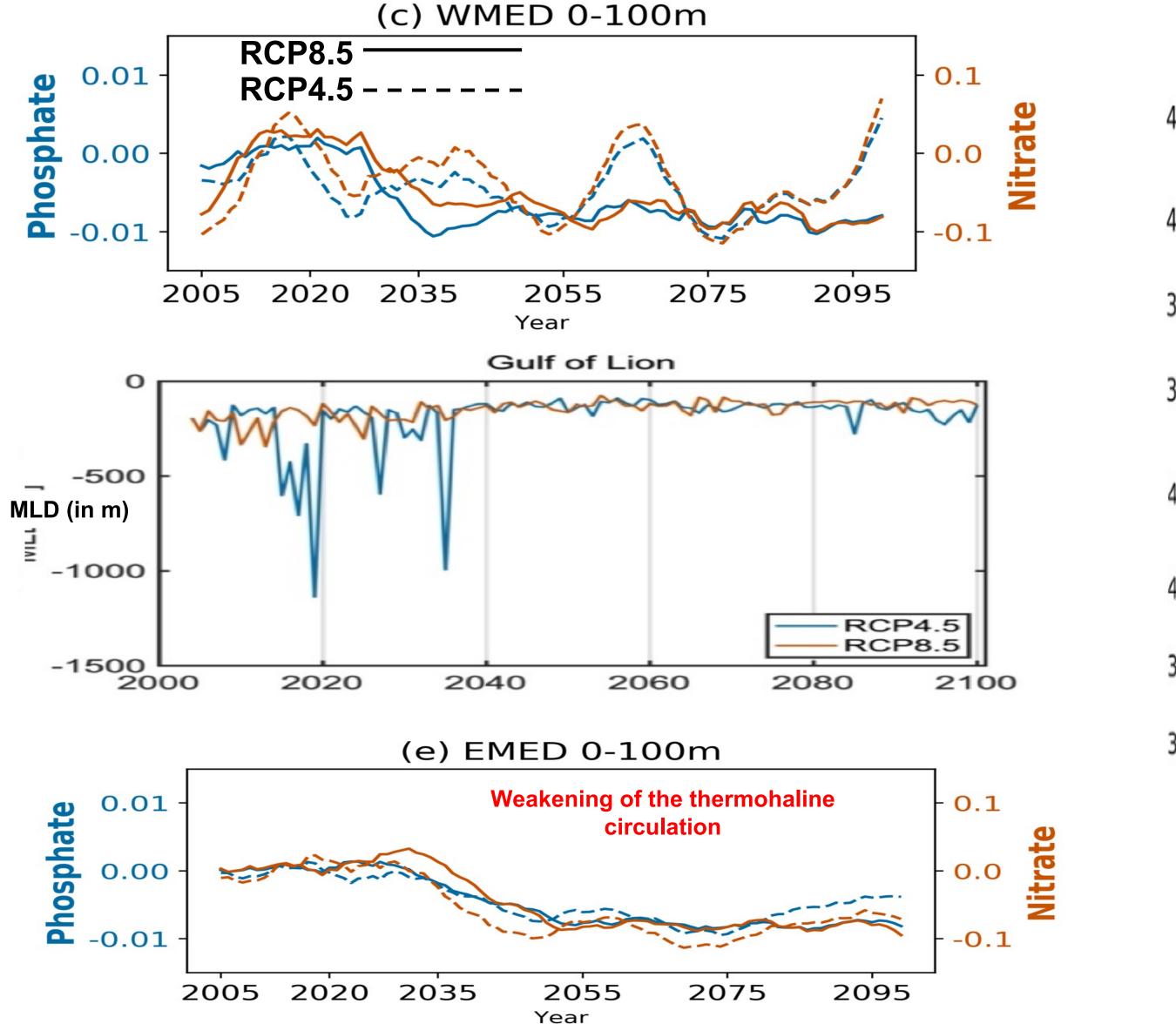


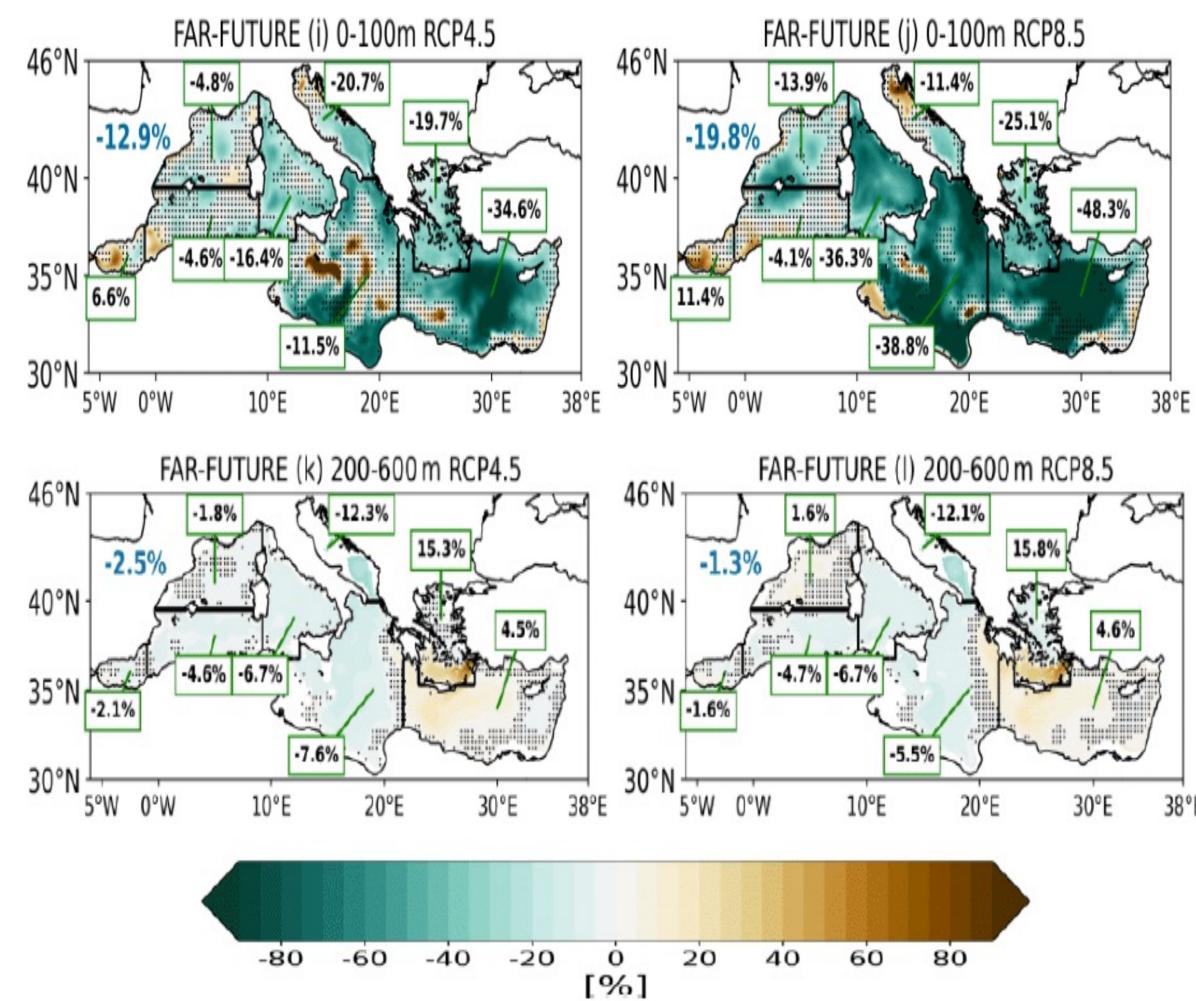
Future projections for the Mediterranean Sea: Physics



Mediterranean Sea zonal stream function annual mean (in Sv) averaged over the PRESENT (2005-2020), MID-FUTURE (2040-2059) and FAR-FUTURE (2080-2099) periods for RCP4.5 and RCP8.5 scenarios.

Future projections for the Mediterranean Sea: Biogeochemistry

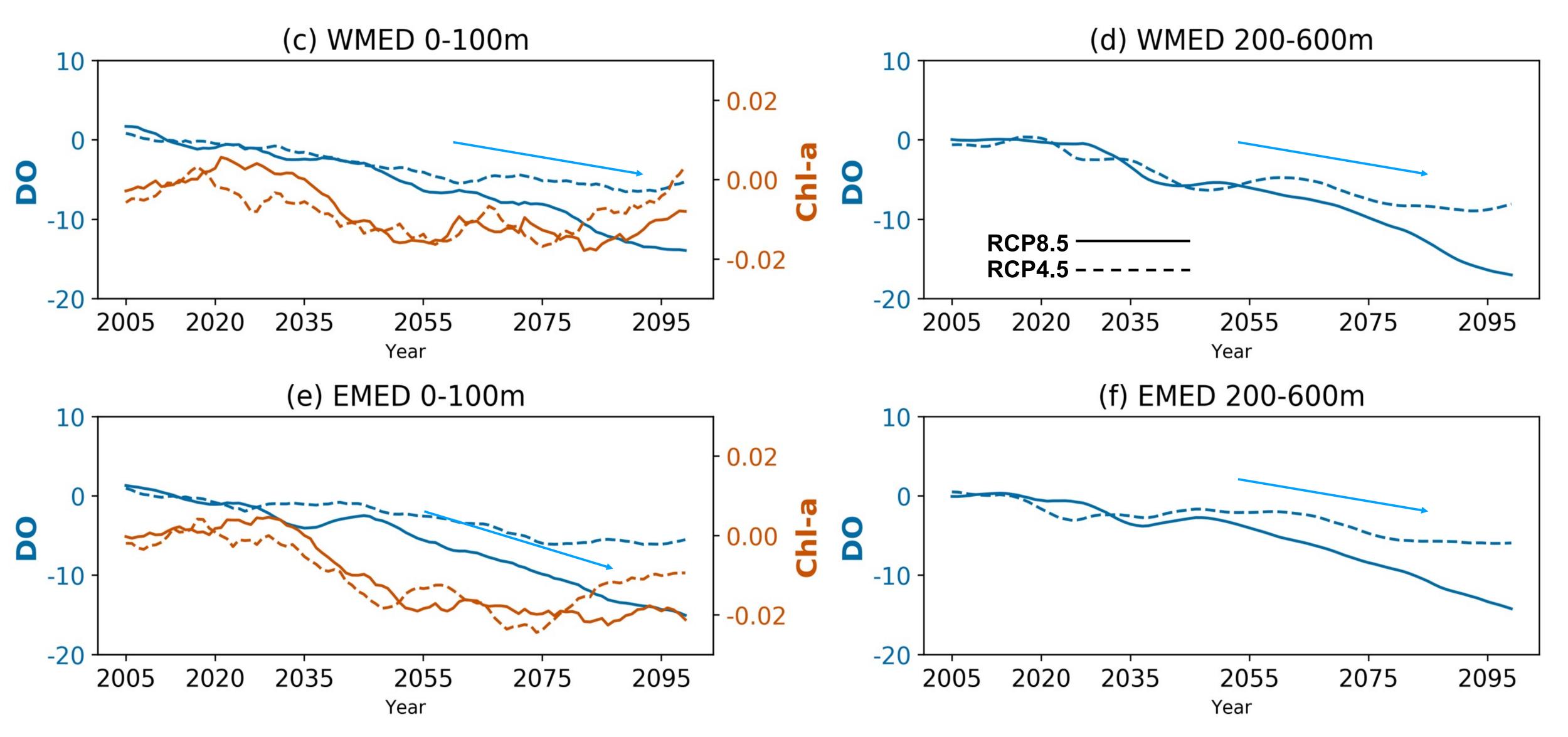




Spatial gradient within the same sub-basin affecting the sign and the statistical significance of the projected changes

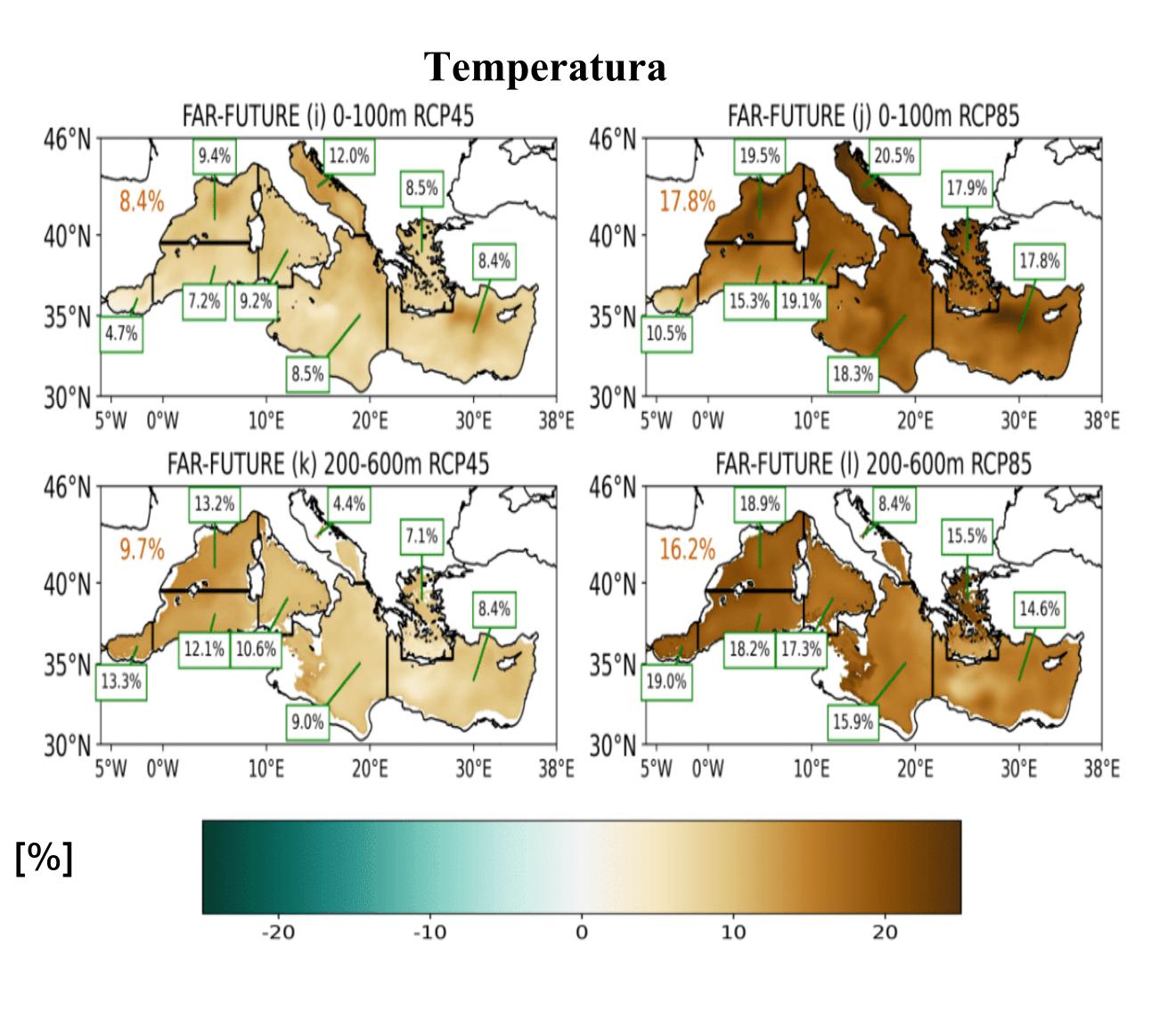
Yearly timeseries for the emission scenario RCP8.5 (solid line) and RCP4.5 (dashed line) in the Mediterranean Sea (MED, a-b), Western Mediterranean (WMED, c-d) and Eastern Mediterranean (EMED, e-f) for the layer 0-100m (left column)

Future projections of the Mediterranean Sea: Biogeochemistry

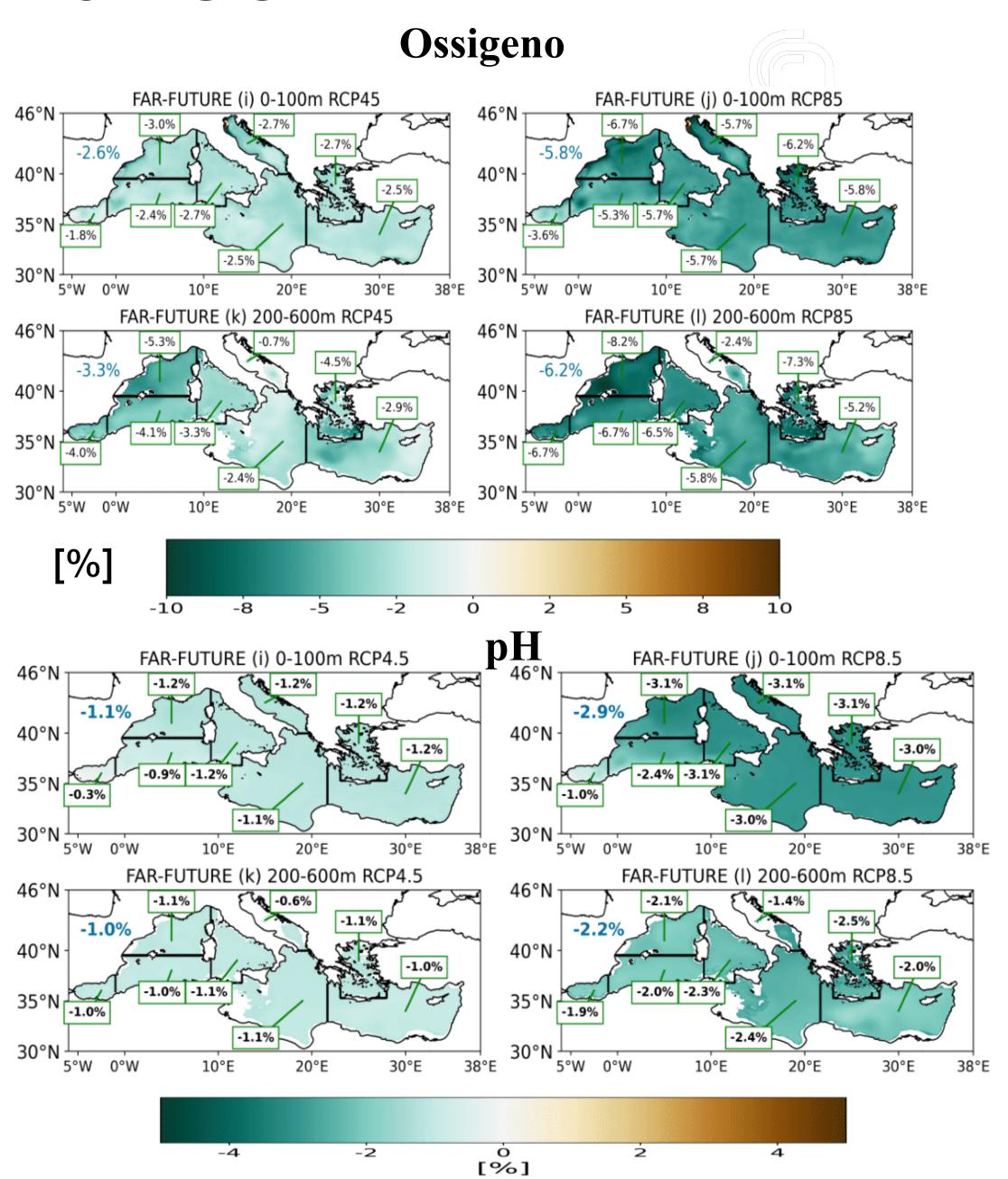


Yearly timeseries for the emission scenario RCP8.5 (solid line) and RCP4.5 (dashed line) in the Mediterranean Sea (MED, a-b), Western Mediterranean (WMED, c-d) and Eastern Mediterranean (EMED, e-f) for the layer 0-100m (left column) and 200-600m (right column) for the 2005-2099 period.

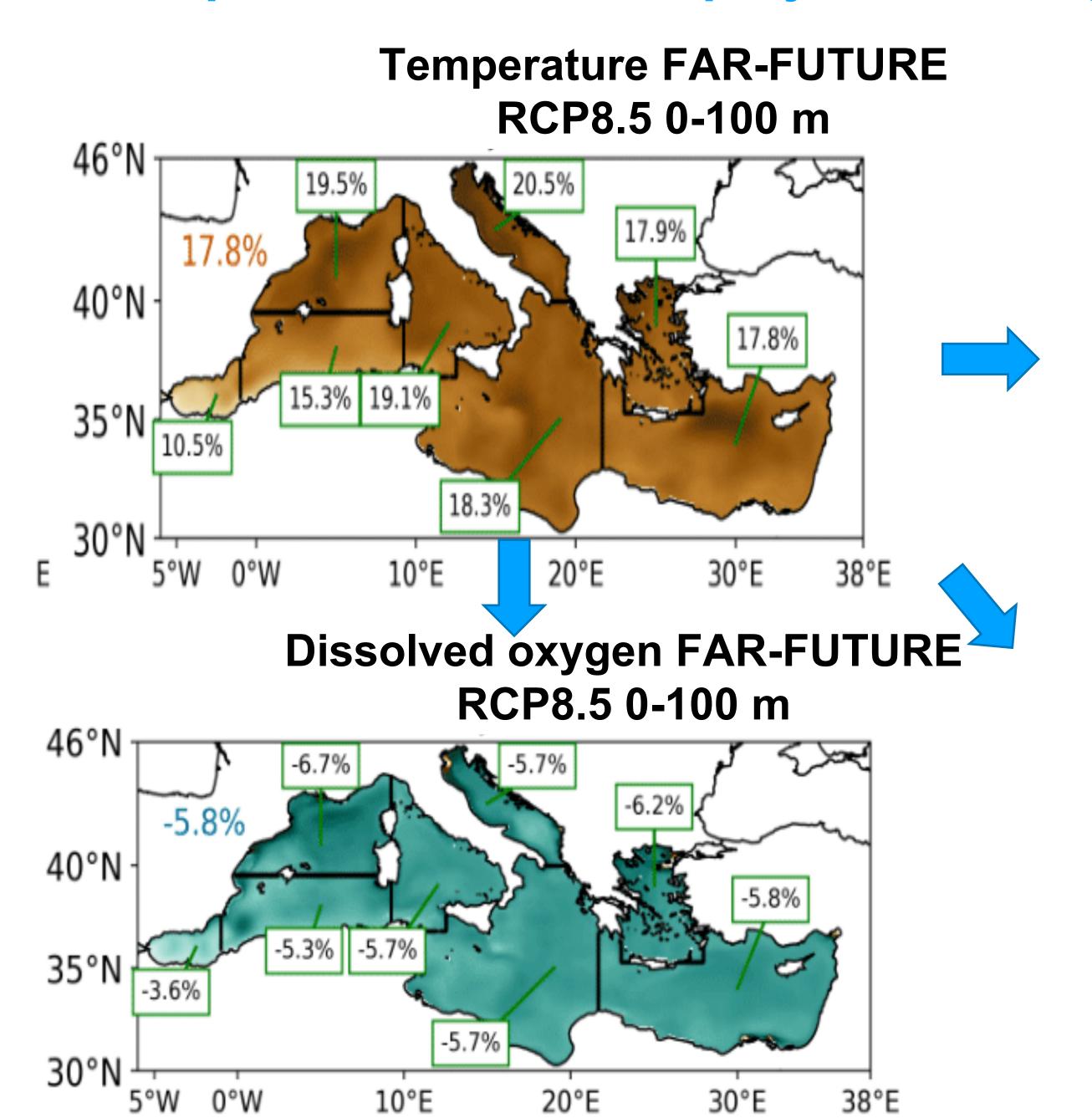
Mar Mediterraneo



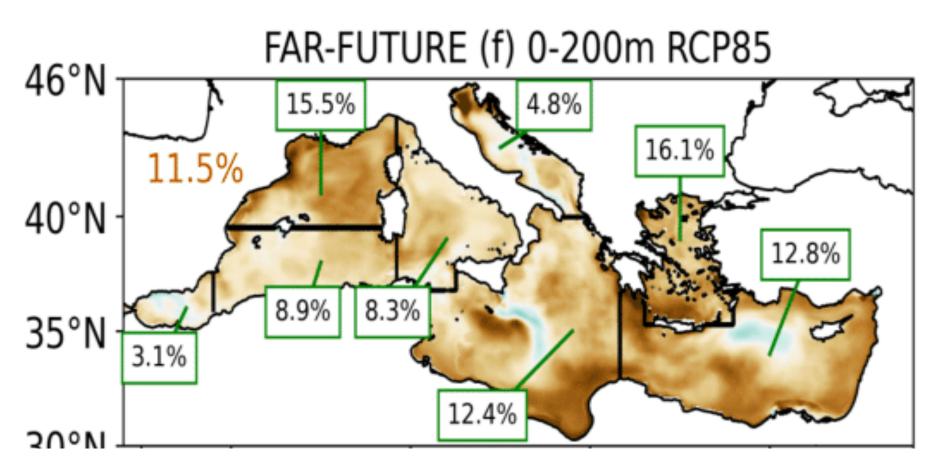
Reale, M., Cossarini, G., Lazzari, P., Lovato, T., Bolzon, G., Masina, S., Solidoro, C., and Salon, S.: Acidification, deoxygenation, and nutrient and biomass declines in a warming Mediterranean Sea, Biogeosciences, 19, 4035–4065, https://doi.org/10.5194/bg-19-4035-2022, 2022



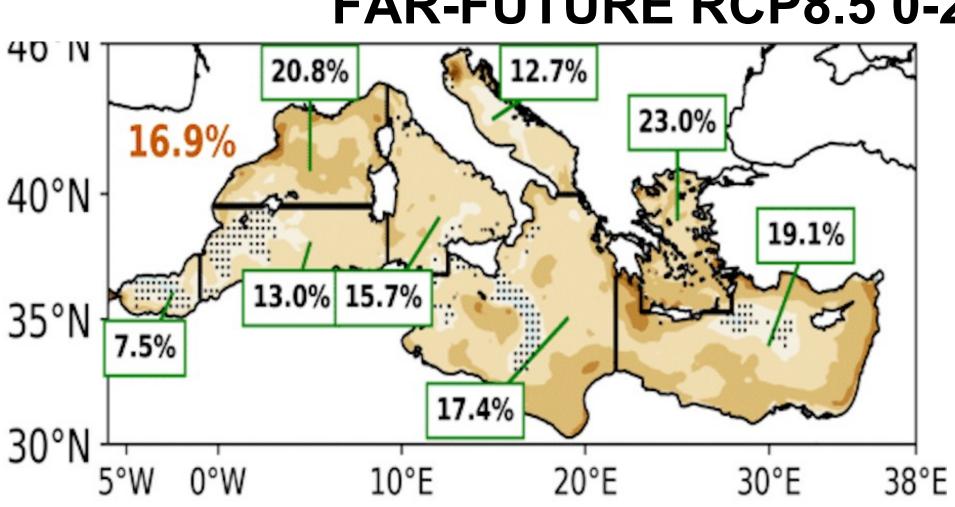
Correspondence between projected changes in the physics and biogeochemistry



Phyto Respiration FAR-FUTURE RCP8.5 0-200 m

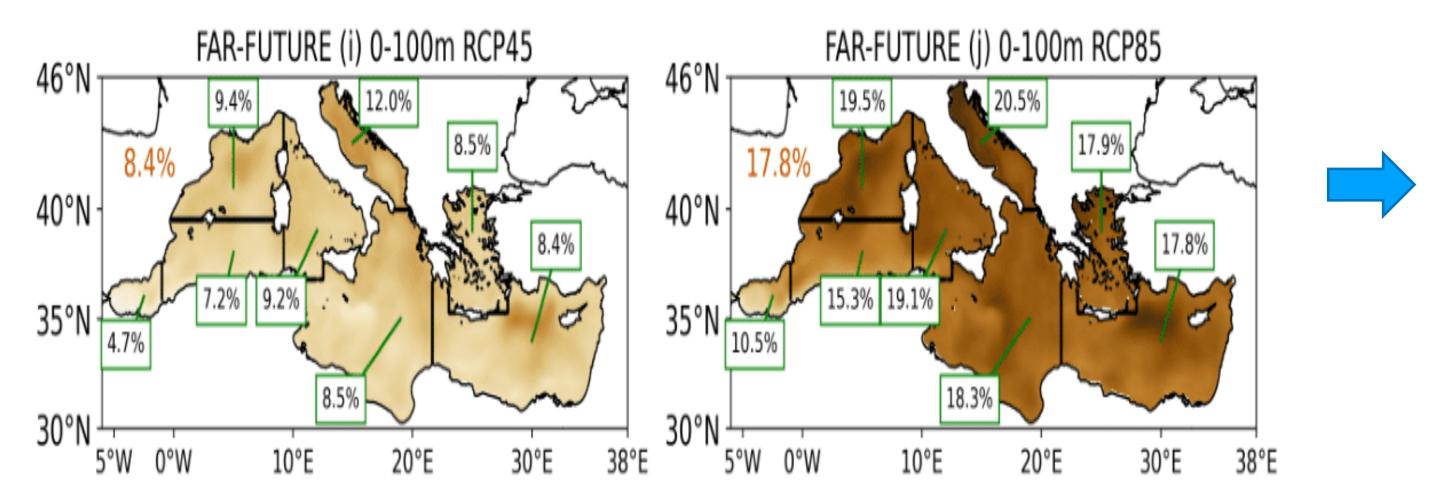


Integrated net primary production FAR-FUTURE RCP8.5 0-200 m

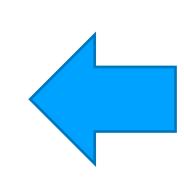


Correspondence between projected changes in the physics and biogeochemistry Temperature

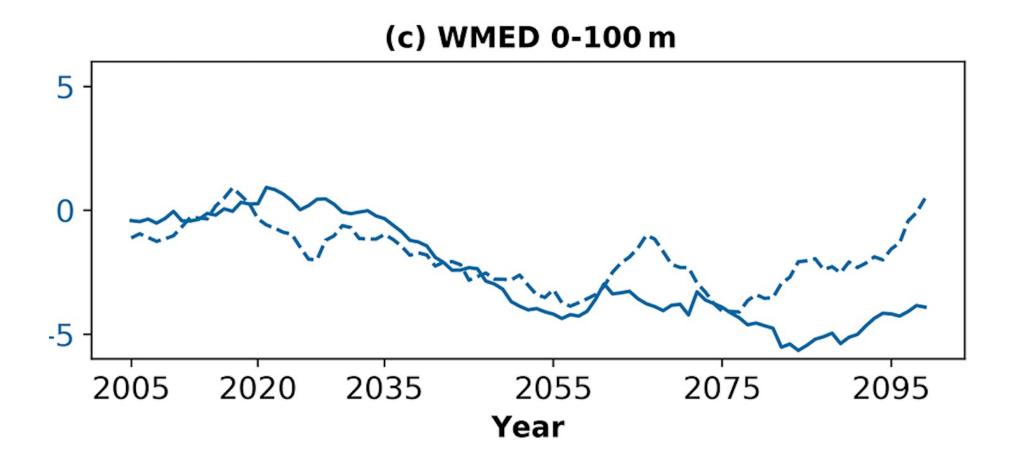
Temperature FAR-FUTURE RCP 4.5/8.5 0-100 m

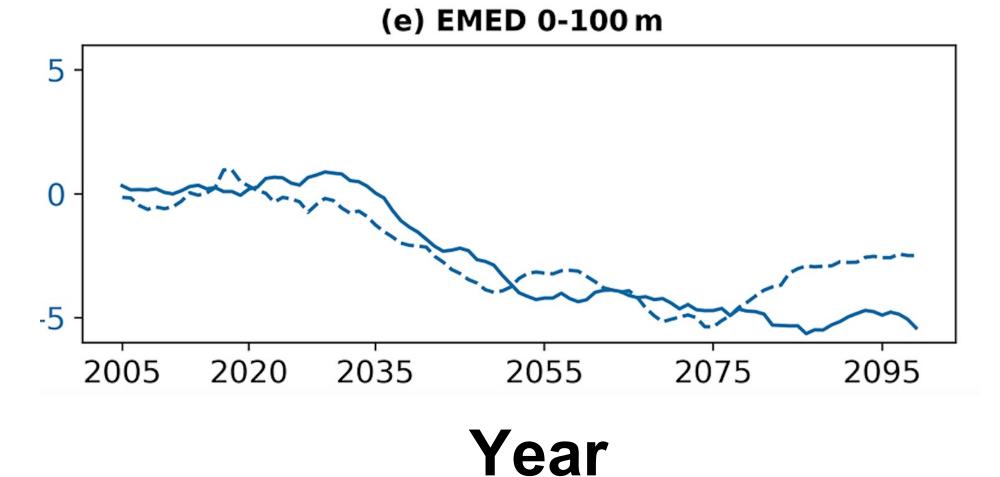


The same behavior has been observed for both Zoo and Phytoplankton and Bacterial Carbon biomass



Organic Matter (mg m⁻³)





Take home messages

- Fattori antropici (emissioni gas serra) sono responsabili della transizione climatica in atto. Ci sono sicuramente degli altri fattori (naturali) che potrebbero avere un qualche ruolo nel cambiamento climatico. Ma attualmente la loro azione è dimostrata come trascurabile
- Gli strumenti che usiamo per studiare il clima (i modelli climatici frutto della ricerca di due generazioni di scienziati) sono validi e affidabili (anche unico strumento a disposizione)
- Se non facciamo nulla il clima delle prossime decadi sarà sostanzialmente diverso da quello scorso secolo con impatti significativi nell'area Mediterranea





Grazie per l'attenzione!!!

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