Climate Change for Mediterranean Cyclones

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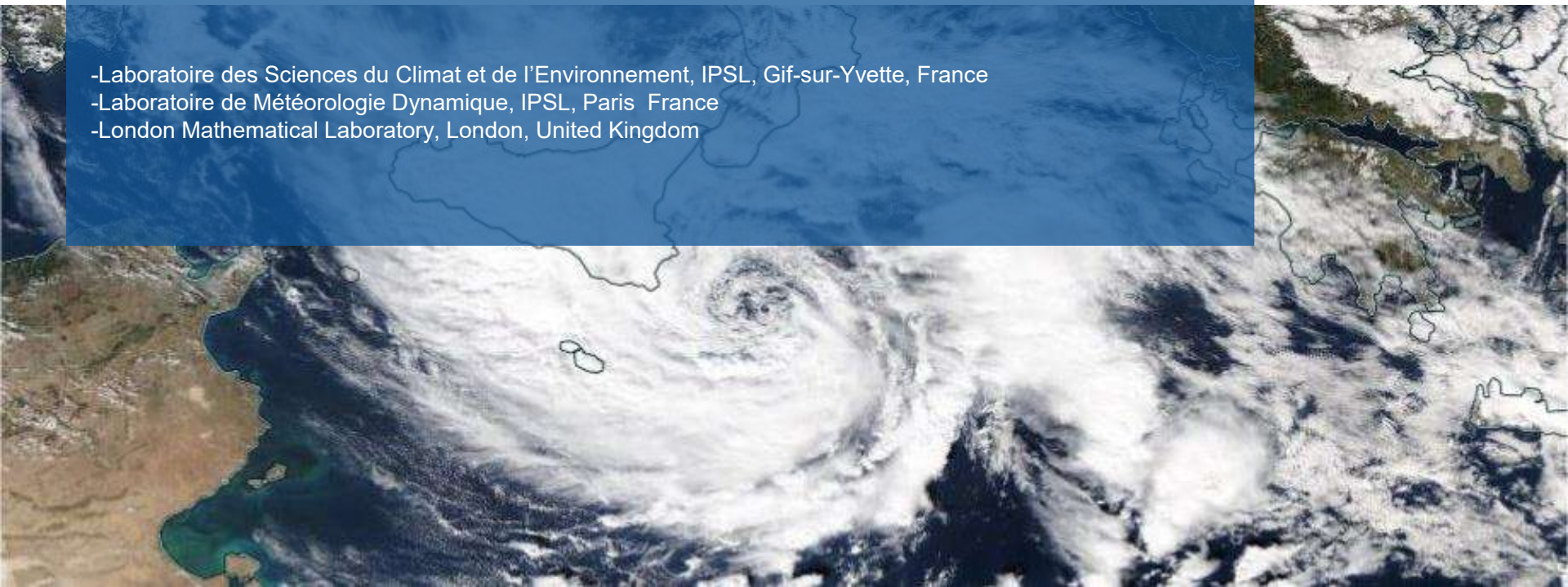

OUTLINE

1. Climate Change in the Mediterranean Basin
2. Background on Mediterranean Cyclones and Medicanes
3. Climatology of Mediterranean Cyclones and Medicanes
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5. Future projections
6. Implications for the society, impacts, adaptation

THE FIRST MEDITERRANEAN CYCLONE?

« I 'll give that man his swamping fill of trouble!' [said Poseidon]
With that he rammed the clouds together—both hands
clutching his trident—**churned the waves into chaos,** whipping
all the gales from every quarter, shrouding over in thunderheads
the earth and sea at once—**and night swept down from the sky—**
East and South Winds clashed and the raging West and North,
sprung from the heavens, roiled heaving breakers up—
and Odysseus' knees quaked, his spirit too;
numb with fear he spoke to his own great heart:
'Wretched man—what becomes of me now, at last?
I fear the nymph foretold it all too well—
on the high seas, she said, before I can reach
my native land I'll fill my cup of pain! And now,
look, it all comes to pass**. What monstrous clouds**—
King Zeus crowning the whole wide heaven black—
churning the seas in chaos, gales blasting,
raging around my head from every quarter—
my death-plunge in a flash, it's certain now »

Homer et al. The Odyssey: Book 5

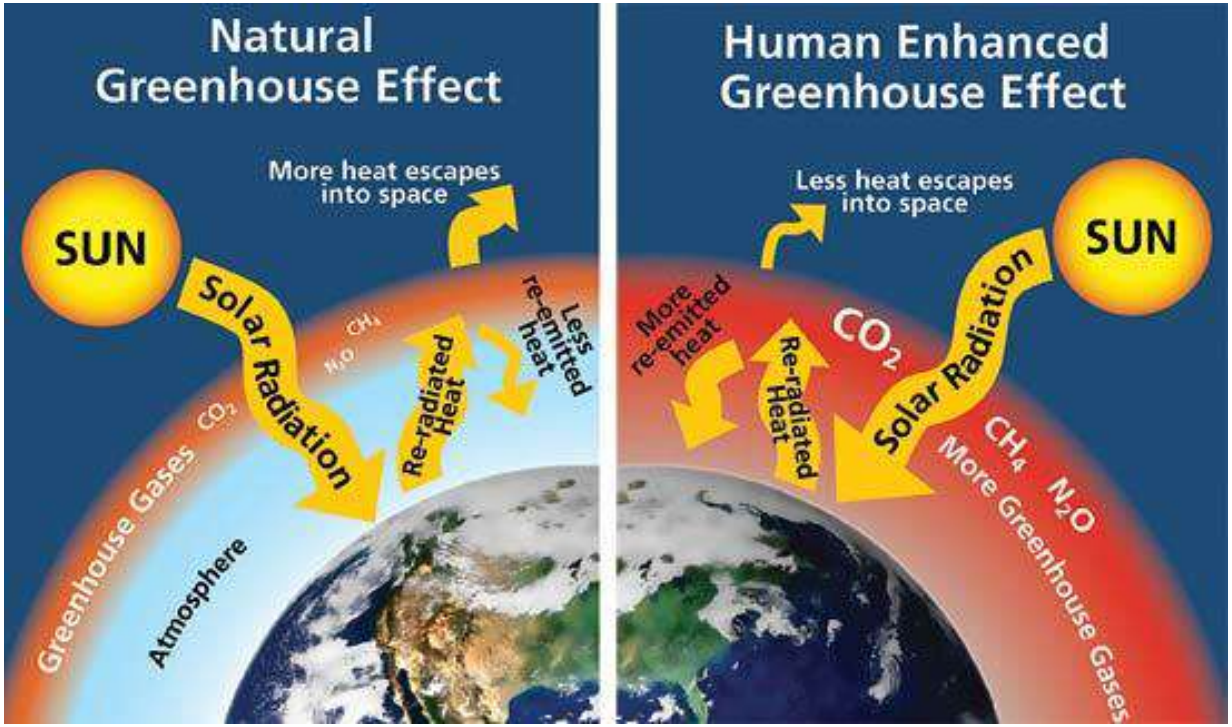
THE MEDITERRANEAN CLIMATE

A climate of hot 🌞 dry summers and humid, cool winters ☔ and a generally hilly landscape ⛰️, small and large islands 🏝️.

The Mediterranean is an area populated by an heterogenous mix of populations 🏛️ ⛪ with different wealth and an enormous cultural heritage.

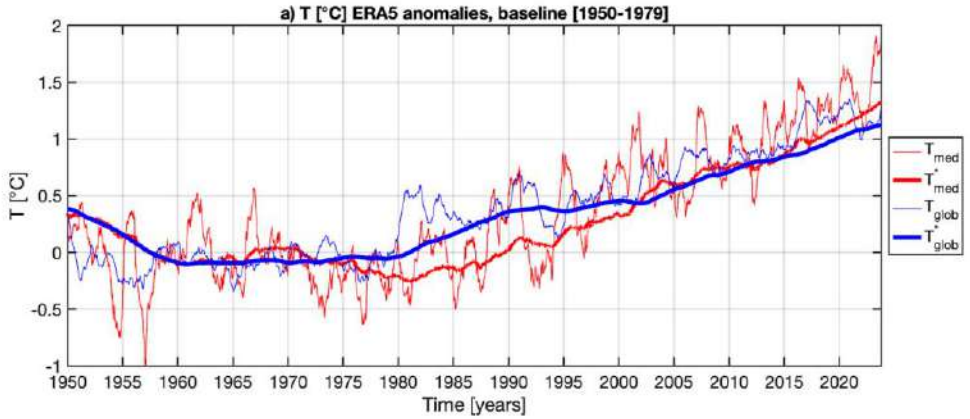
It has not only a very rich biodiversity 📣 but also a large number of species that do not exist anywhere else.

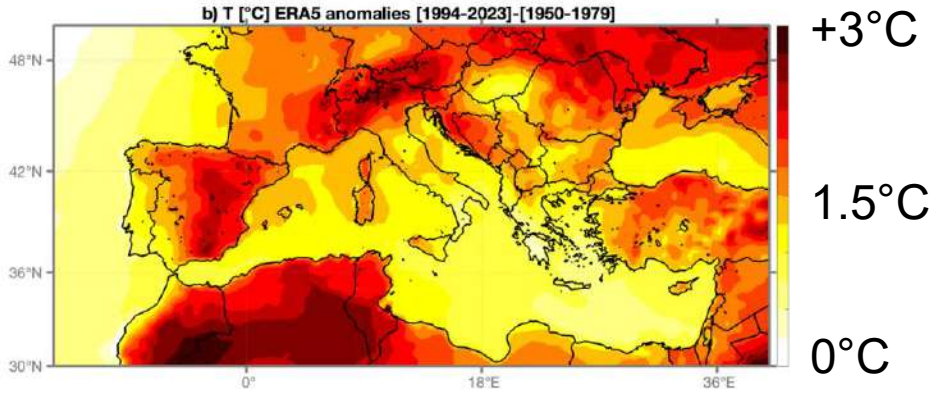
CLIMATE CHANGE, THE (VERY) BASICS



Source: W. Elder, NPS

OBSERVED CLIMATE CHANGE IN THE MEDITERRANEAN REGION





Jezequel et al. Submitted

a) Temporal distribution of mean air temperature anomalies for the period 1950-2023 with respect to the period 1950-1879, with the Mediterranean Basin (red) and the globe (blue). Ticker lines show smoothing for a window of 10 years running moving average.
b) Spatial distribution of anomalies between the recent period [1994-2023] and the past period [1950-1979]. Data are preprocessed by removing the seasonal cycle, computed by subtracting the calendar day average, at each grid point.

OBSERVED CLIMATE CHANGE IN THE MEDITERRANEAN REGION

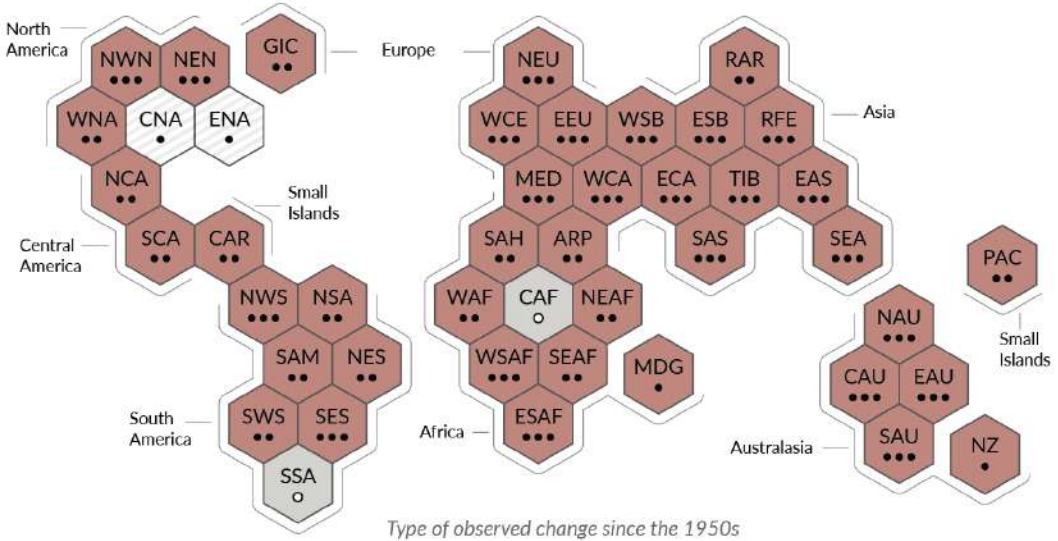
(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

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

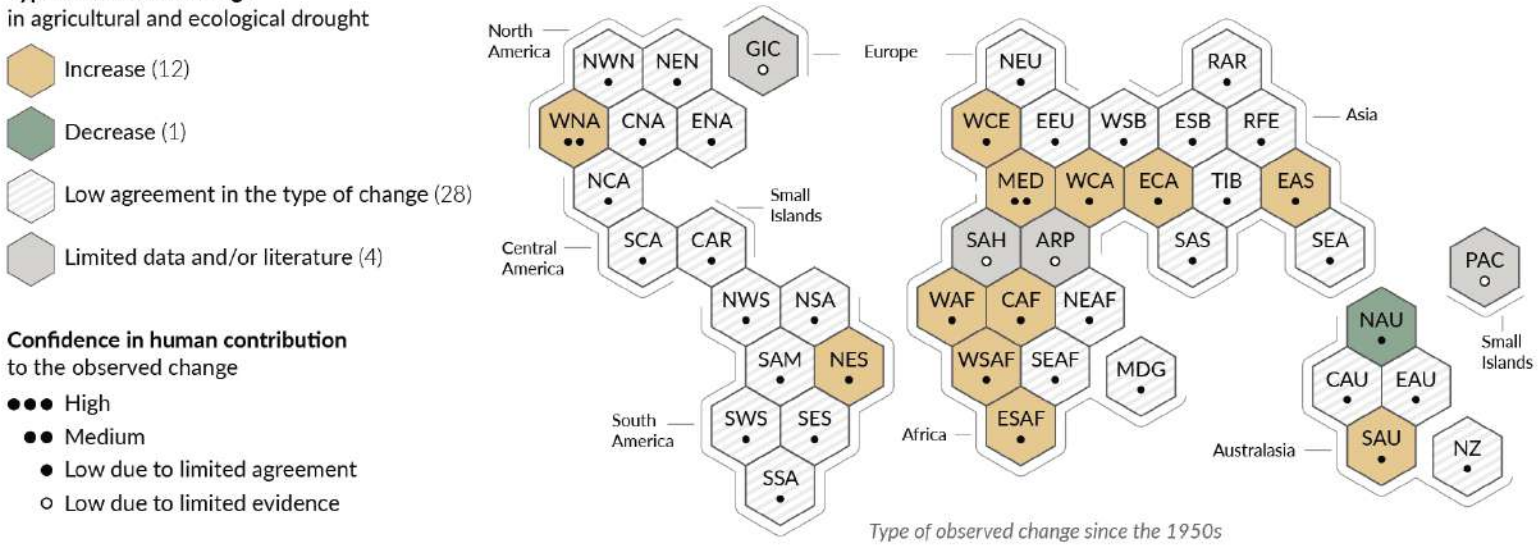
- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

OBSERVED CLIMATE CHANGE IN THE MEDITERRANEAN REGION

(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



OBSERVED CLIMATE CHANGE IN THE MEDITERRANEAN REGION

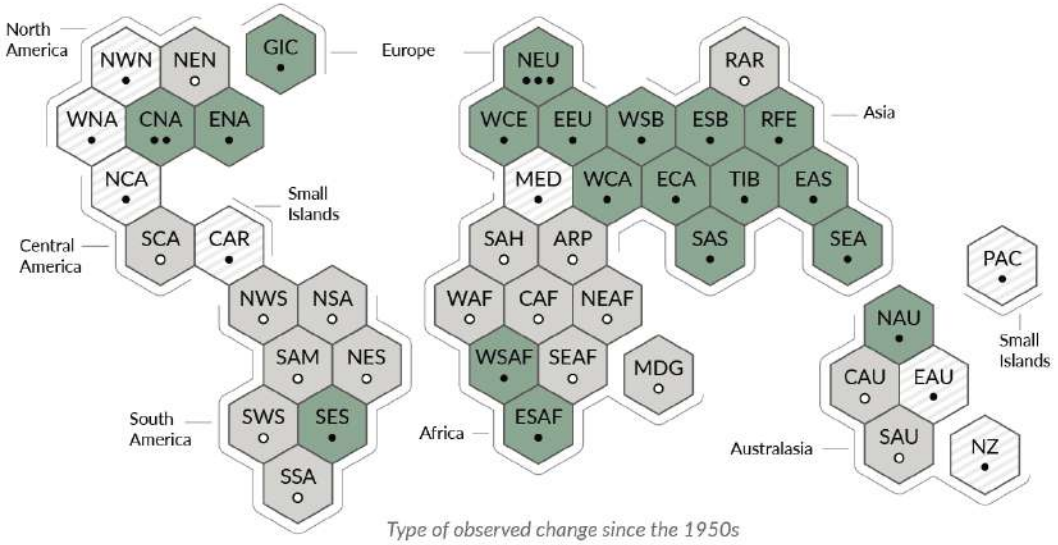
(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change
in heavy precipitation

- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

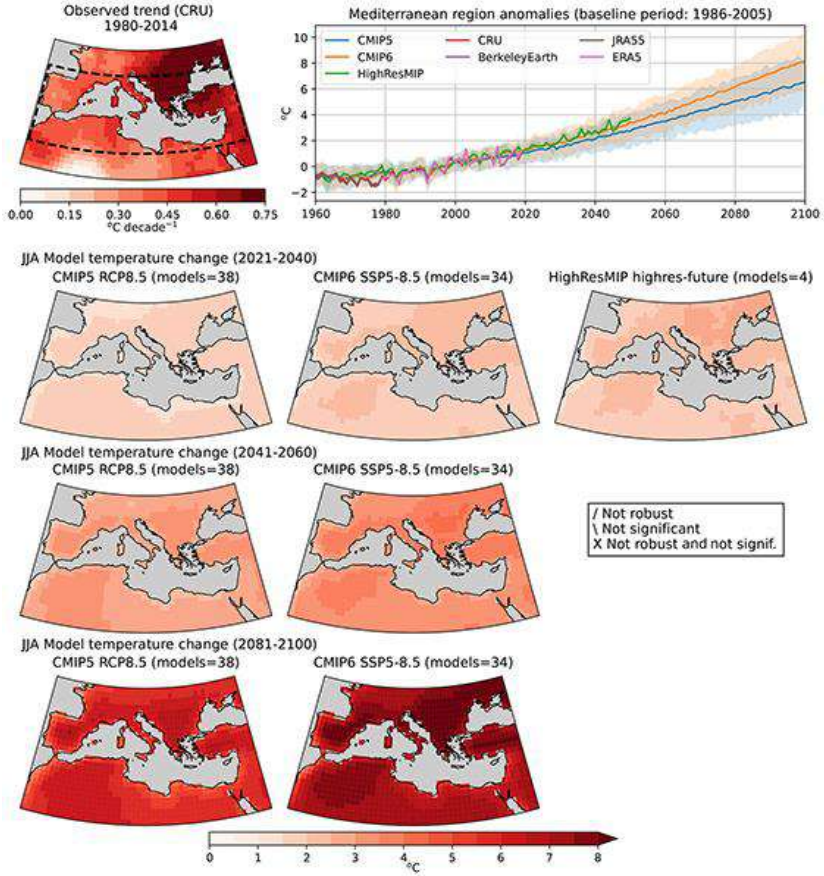
Confidence in human contribution
to the observed change

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



Type of observed change since the 1950s

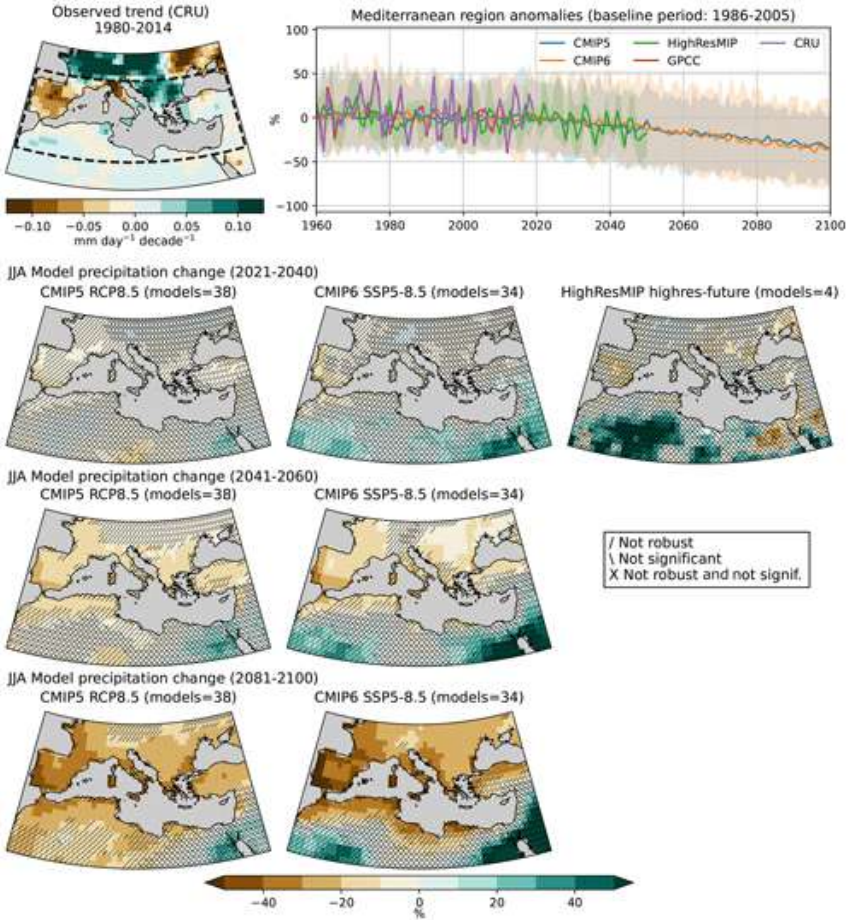
PROJECTIONS: CLIMATE CHANGE IN THE MEDITERRANEAN REGION



JJA ΔTAS according to CMIP5, CMIP6 and HighResMIP ensemble means (columns) for the three relevant future periods (rows), under the RCP8.5 and SSP5-8.5 scenarios. The time series plot shows the anomalies in the Mediterranean region with respect to the period 1986–2005 for the multi-model ensembles and the observational references. A solid line indicates the one-member-per-model ensemble mean and the shaded region indicates the 5th–95th percentiles range. The CRU trend for the period 1980–2014 is shown along with the dashed line, which bounds the Mediterranean region.

Cos et al. 2022

PROJECTIONS: CLIMATE CHANGE IN THE MEDITERRANEAN REGION ☔



As previous slide, but for precipitation

Cos et al. 2022

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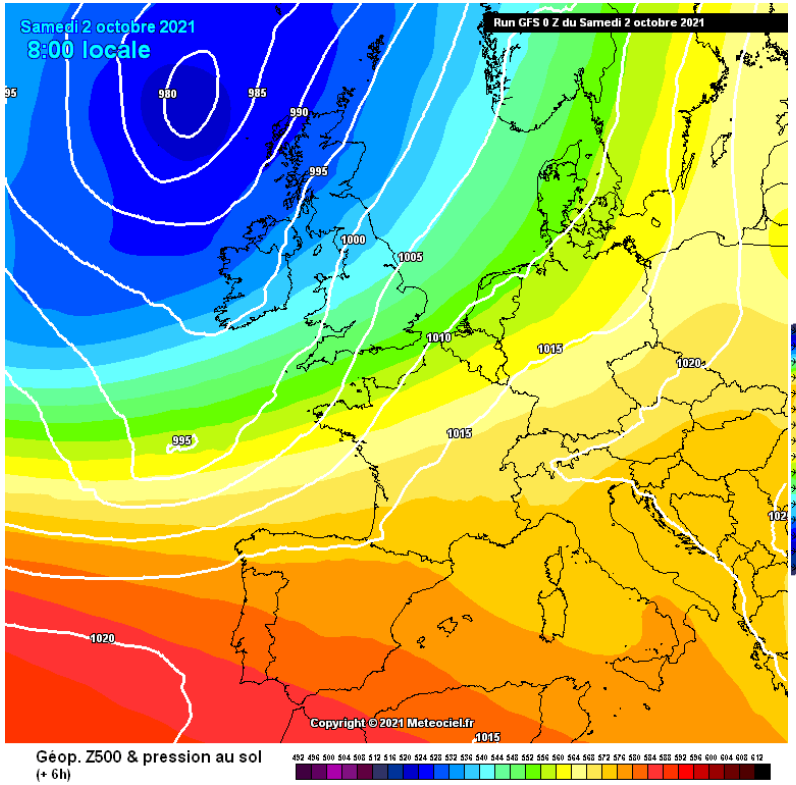
CYCLONES IN THE MEDITERRANEAN BASIN

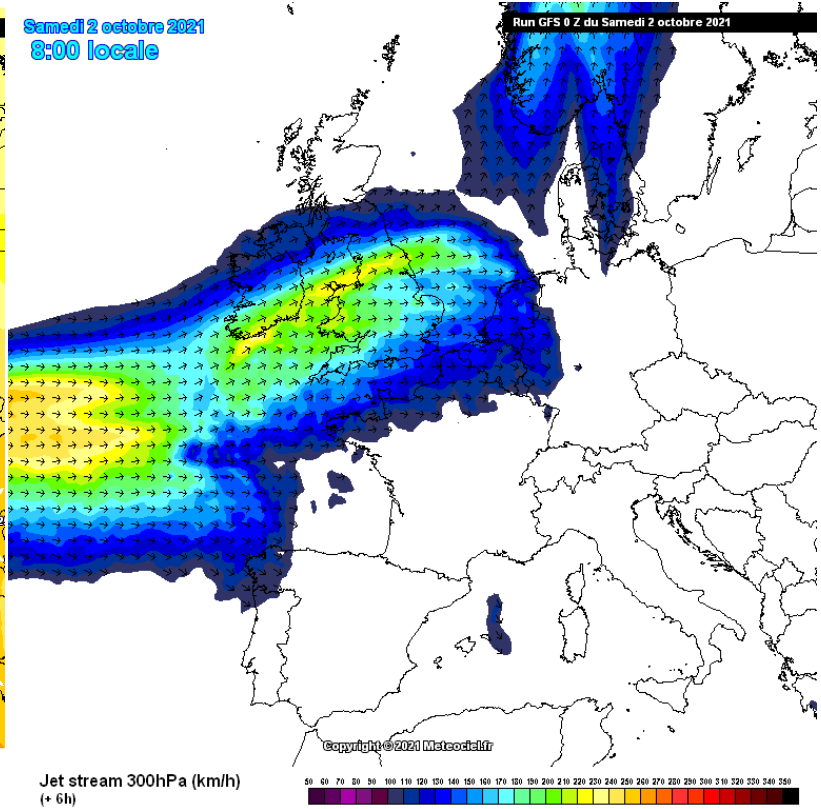
Mediterranean **cyclones typically form** as a result of interactions between cold/wet air masses from the north advected by the jet stream and warm, moist air from the Mediterranean Sea.

Sea surface temperatures, atmospheric instability, and topography play crucial roles in the cyclogenesis process in the Mediterranean region.

CYCLOGENESIS IN THE MEDITERRANEAN – A TYPICAL EXAMPLE

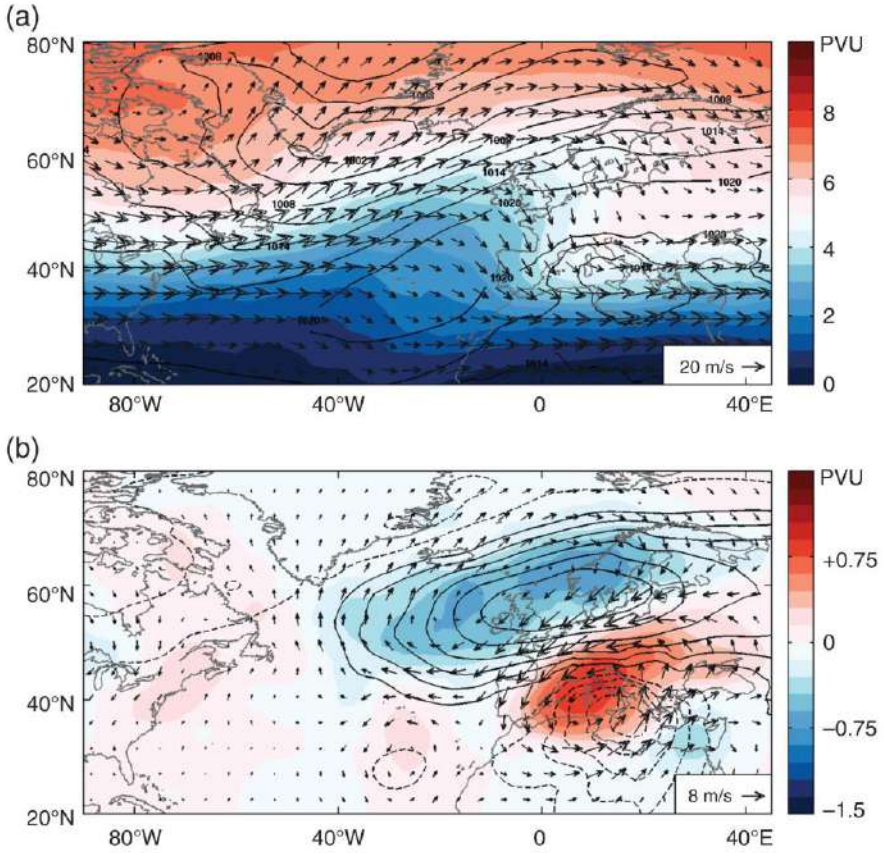


Géop. Z500 & pression au sol
(+ 6h)



Jet stream 300hPa (km/h)
(+ 6h)

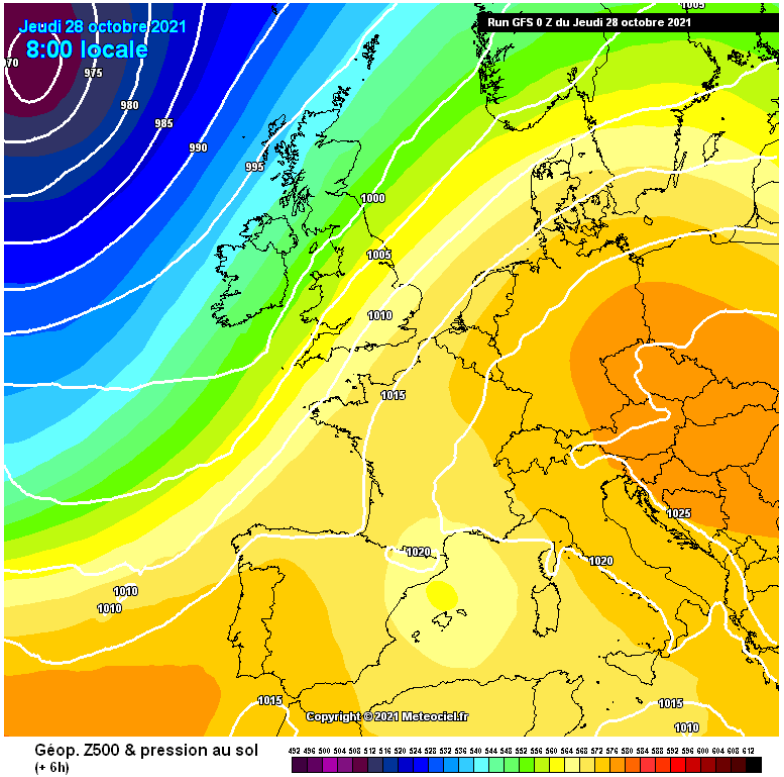
CYCLOGENESIS IN THE MEDITERRANEAN – SUMMARY



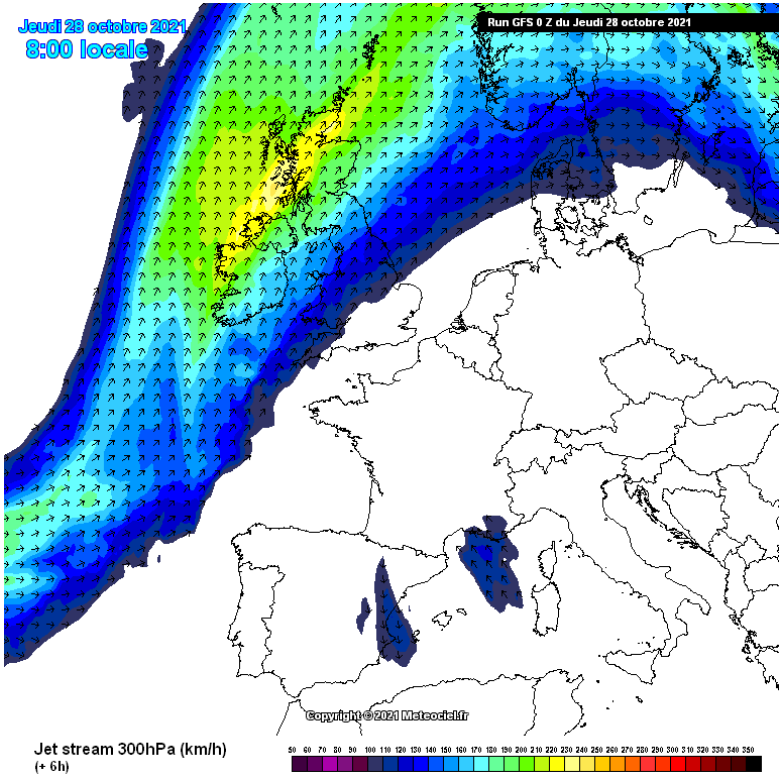
(a) ERA-Interim average fields of sea-level pressure (black contours), PV (shaded) and wind (arrows) on the 330 K isentropic surface, centred at the time of maximum intensity of the 200 Mediterranean cyclones. Panel (b) is like (a) but for monthly anomalies (contours every 1 hPa, dashed for negative and solid for positive values). Reprinted from Raveh-Rubin and Flaounas (2017).

Flaounas et al. 2022, WCD

CYCLOGENESIS IN THE MEDITERRANEAN – MEDICANE APOLLO



Géop. Z500 & pression au sol
(+ 6h)



Jet stream 300hPa (km/h)
(+ 6h)

A SHORT RECAP OF MEDICANE LIFECYCLE VS TROPICAL CYCLONES

Medicanes can occur in every season.

MEDICANES

- **Extratropical Cyclone** enters the Mediterranean Sea
- Strong vertical temperature gradients favor **convection**
- Convection is sustained and concentrate around a **warm core**
- **Complete dissipation**

TROPICAL CYCLONES

- Strong Organized **convection** reach mesoscale size
- Rotation starts to affect convective cells, a **warm core** creates.
- Convective cells organize in bands
- it can transform in **extratropical cyclones**

Hurricanes mostly occur from June to November

RECONSTRUCTING THE CLIMATOLOGY OF MEDITERRANEAN CYCLONES

☔ **Historical Meteorological observations:** Monitoring and analyzing atmospheric pressure patterns, wind speed and direction, precipitation, and temperature gradients can help identify the presence and development of Mediterranean cyclones.

🛰️ **Satellite imagery**: Use of satellites provides a tool for reliable detection and tracking cyclones in the Mediterranean since ~1979

=> Difficult to reconstruct tropical cyclones before satellites

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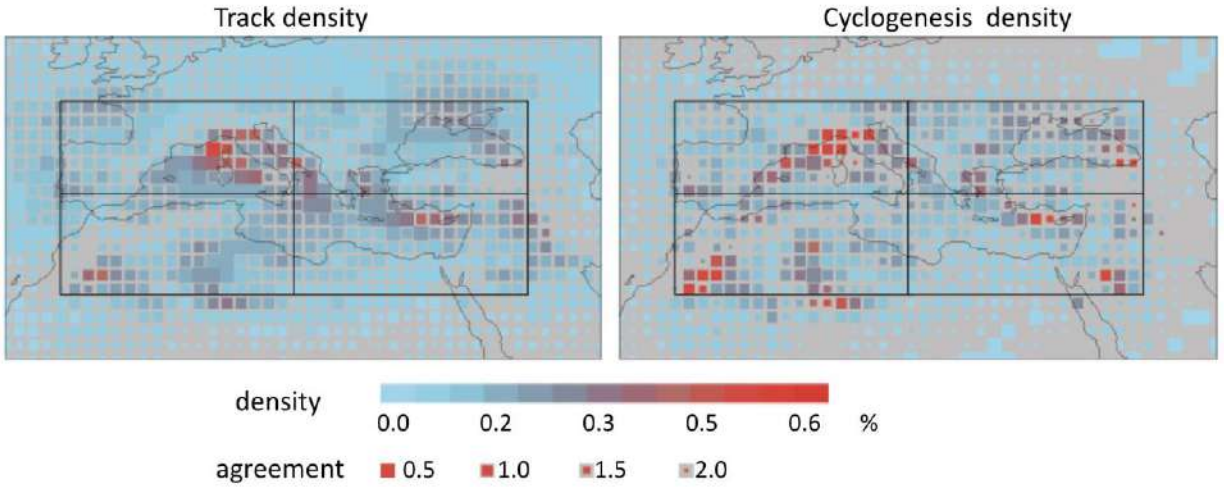
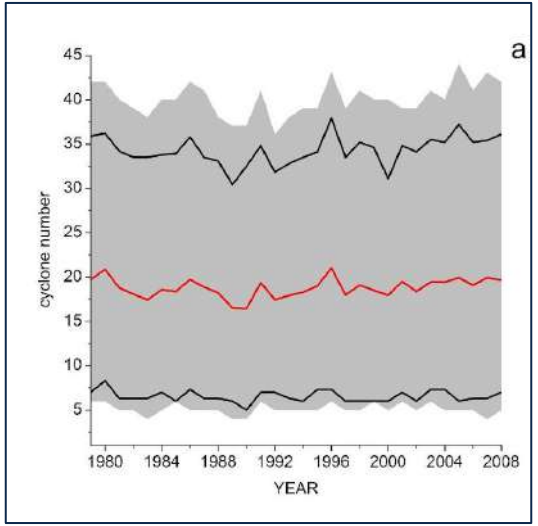
RECONSTRUCTING THE CLIMATOLOGY OF MEDITERRANEAN CYCLONES

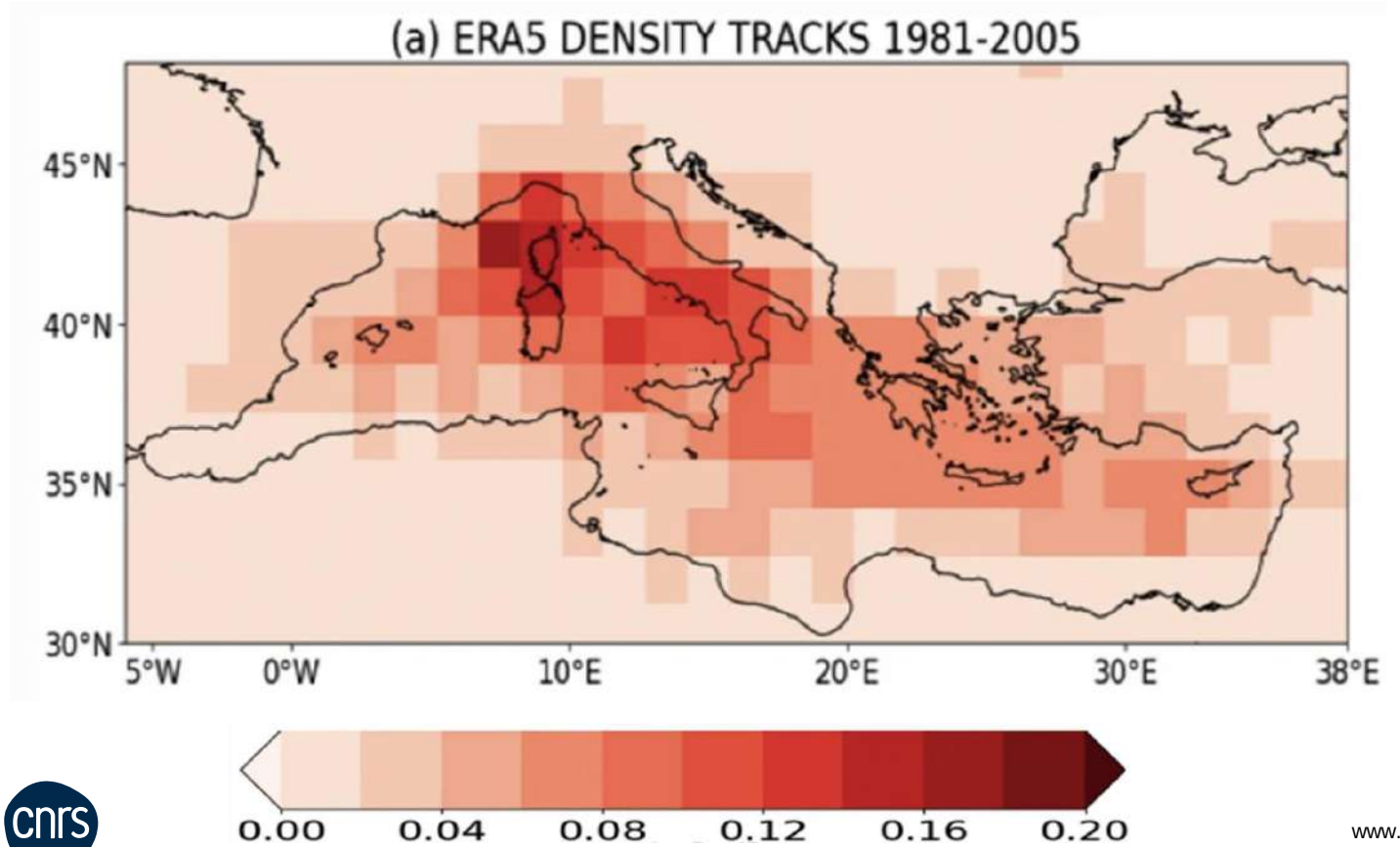




Colours represent the probability (%) that a cyclone track crosses or cyclogenesis occurs in each 1.5x1.5 cell of the domain in the 6-hourly fields. Only cyclones whose track crosses the Mediterranean region are considered. The filled fraction of each cell corresponds to the level of agreement (given by the normalised standard deviation/ mean value) among methods. The large rectangle denotes the Mediterranean region with its subdivision in four sectors.

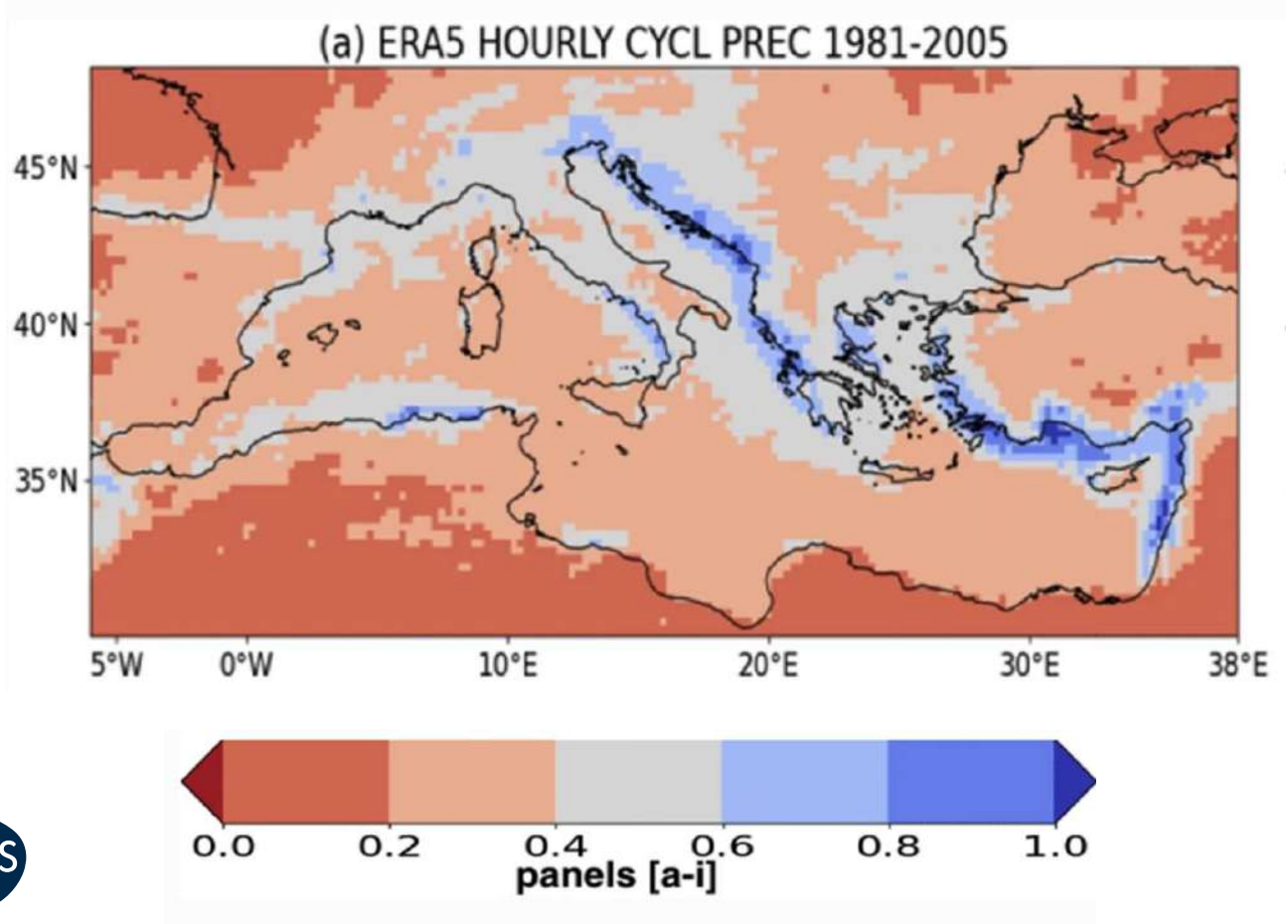
Lionello et al. 2016

RECONSTRUCTING THE CLIMATOLOGY OF MEDITERRANEAN CYCLONES



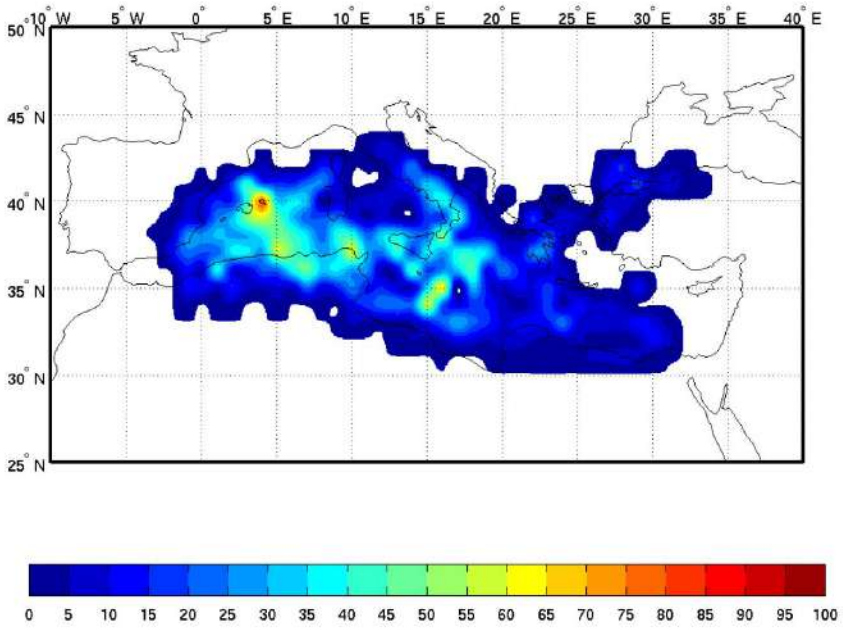
Reale et al. 2022
Climate Dynamics

RECONSTRUCTING THE CLIMATOLOGY OF MEDITERRANEAN CYCLONES



Reale et al. 2022
Climate Dynamics

MEDICANES CLIMATOLOGY



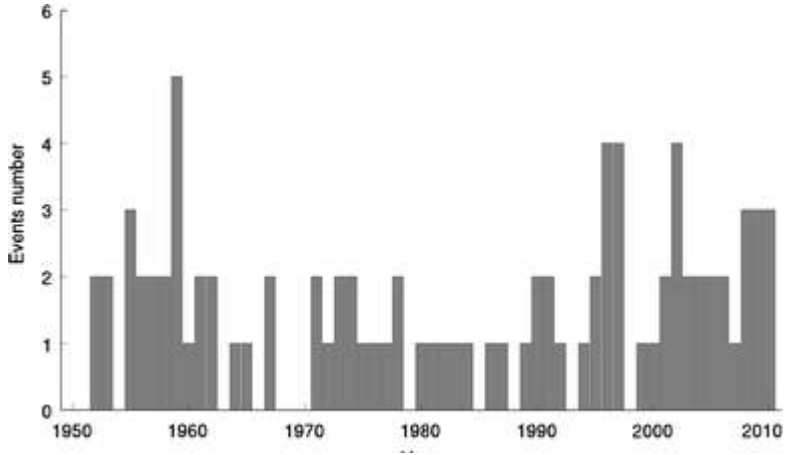


Figure 1: Locations of all the medicanes detected . Top: genesis density (first location in the track) per 2 ° x 2 ° box. Bottom: track density per 2 ° x 2 ° box.

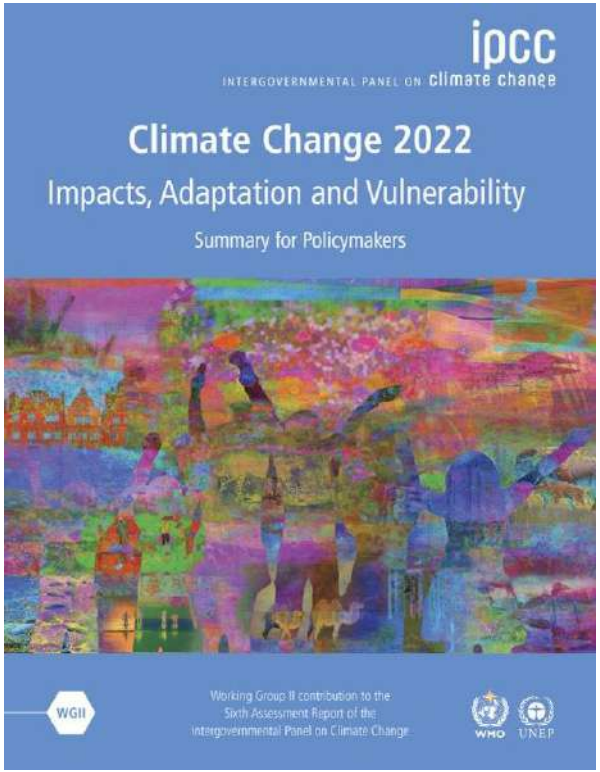
Cavicchia et al. 2013
Climate Dynamics

OBSERVED CHANGES IN MEDITERRANEAN CYCLONES?

AR6-WG1 Chapter 2: Changing state of the climate system
Chapter 2 concluded that in the NH there is overall low confidence in recent (since 1980s) likely increase of in the total number of ExtraTropical Cyclones and that there is medium confidence in a poleward shift of the storm tracks. Overall, there is also low confidence in past-century trends in the number and intensity of the strongest ExtraTtropical Cyclones due to the large interannual and decadal variability and due to temporal and spatial heterogeneities in the number and type of assimilated data in reanalyses, particularly before the satellite era

AR6-WG1 Chapter 11: Weather and climate extreme events in a changing climate
There is low confidence in past changes of maximum wind speeds and other measures of dynamical intensity of ExtraTropical Cyclones. Future wind speed changes are expected to be small, although poleward shifts in the storm tracks could lead to substantial changes in extreme wind speeds in some regions (medium confidence).

Chapter 12: Climate change information for regional impact and for risk assessment
A slightly increased frequency and amplitude of extratropical cyclones, strong winds and extra-tropical storms is projected for Northern, Central and Western Europe by the middle of the century and beyond and for global warming levels of 2°C or more (medium confidence). The frequency of Medicanes is projected to decrease (medium confidence), but their intensity is projected to increase.



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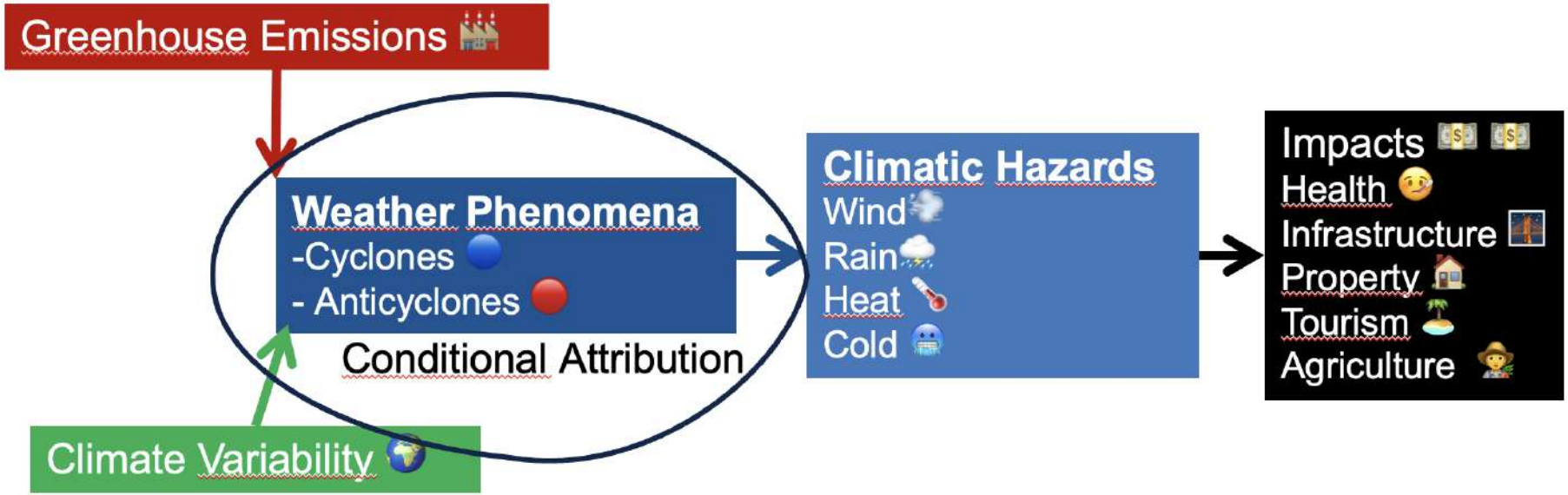
ATTRIBUTION OF MEDITERRANEAN CYCLONES

Attribution: The process of determining the causes of observed changes in a single climate extreme event in terms of natural climate variability or greenhouse gases emissions

"I wonder what would happen if I halved the global warming...?"

CONDITIONAL ATTRIBUTION PATHWAY



ANALOGUES METHOD FOR CONDITIONAL ATTRIBUTION

🌐 **Data**: gridded data from reanlayses MSWX (1979 Present)

🌀 **Event Definition**: Time averaged Surface Pressure Anomalies map in a lon-lat box

🔍 **Analogues Analysis**: Assess differences in Present vs. Past Analogues

⏰ **Periods**: Split into two periods

- 🏞️ Past: Barely affected by Climate Change
- 🌄 Present: Highly affected by Climate Change

📊 **Diagnosed Changes:** Pressure, Temperature, Precipitation, Winds

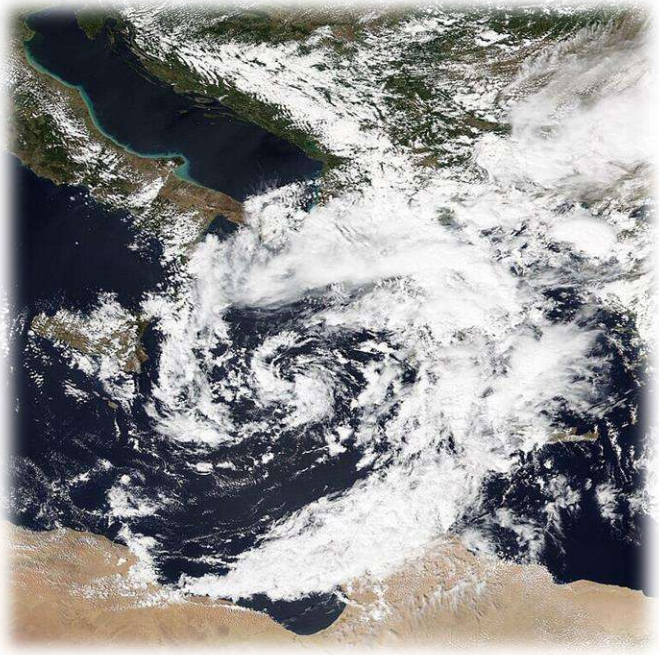
🌍 **Natural Variability Modes Change of phase in analogues:** ENSO, AMO, PDO

CASE STUDY 1: MEDICANE DANIEL

- 🌀 On September 10, Daniel made landfall near the Libyan city of Benghazi, and then moved to the East, heavily affecting the Libyan coast, including the cities of Tobruk and Darnah.

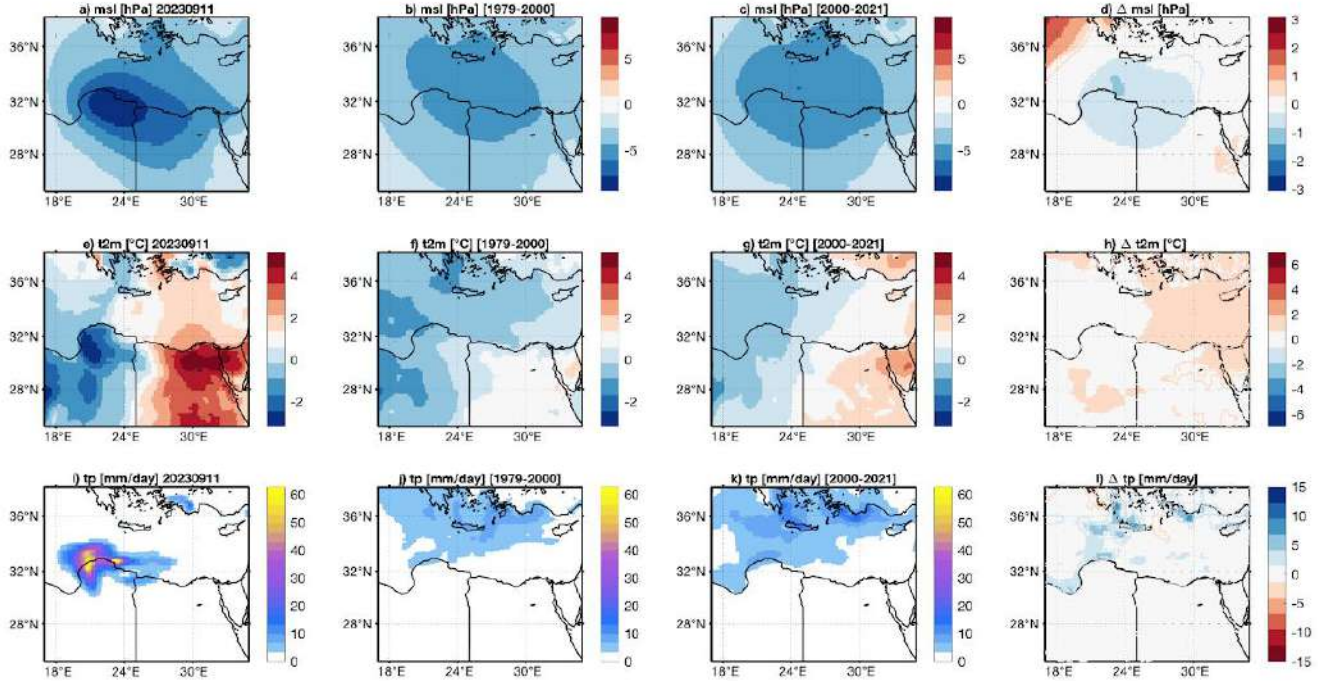
- 💧 **Precipitation totals reached 150-200 mm in several areas, peaking over 400 mm in Al-Bayda, an all-time record for the city.**

- 💥 Daniel's severe precipitations caused catastrophic flooding over the eastern Libyan coast, with **over 5000 fatalities.**

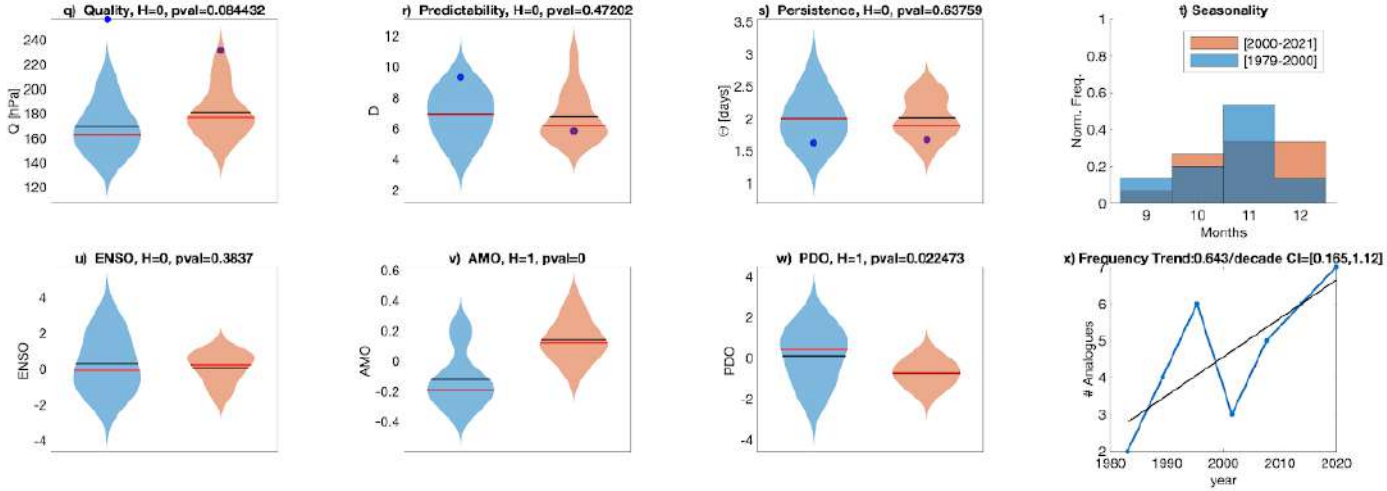


CASE STUDY 1: MEDICANE DANIEL

EVENT | PAST | PRESENT | Δ=PRESENT-PAST



CASE STUDY 1: MEDICANE DANIEL



Violin plots for past (blue) and present (orange) periods for Quality Q analogs (q), Predictability Index D (r), Persistence Index Θ (s), and distribution of analogs in each month (t). Violin plots for past (blue) and present (orange) periods for ENSO (u), AMO (v) and PDO (w). Number of the Analogues occurring in each subperiod (blue) and linear trend (black). Values for the peak day of the extreme event are marked by a blue dot. Horizontal bars in panels (q,r,s,u,v,w) correspond to the mean (black) and median (red) of the distribution

CASE STUDY 1: MEDICANE DANIEL : CLIMAMETER REPORT

« Heavy precipitation in Medicane Daniel mostly strengthened by human-driven climate change»

•Mediterranean depressions similar to Medicane Daniel are between 5 and 9 mm/day wetter in the present than they would have been in the past along the eastern Libyan coast.

•Medicane Daniel was a largely unique event: similar events are Mediterranean depressions which do not display the tropical characteristics typical of medicanes.

•Natural climate variability likely played a role in driving the pressure pattern linked to the landfall of Medicane Daniel.

IMPACTS ON COMMUNICATION

- 🇬🇷 02-10-2023 Συνεργάτης του Αστεροσκοπείου στο ethnos.gr: Πώς το «El Nino» σχετίζεται με την κακοκαιρία - Εξαιρετικά ασυνήθιστο καιρικά φαινόμενο 📰 Έθνος

- 🇸🇪 19-09-2023 Studier: Översvämningarna förvärrades av klimatförändringar 🎤 SverigesRadio

- 🇸🇦 15-09-2023 أعاصير المتوسط العنيفة.. خبير يكشف 📰 SkyNews Arabia 🇫🇷 15-09-2023 Libye, Grèce, Chine... le réchauffement climatique, fabrique de déluges ? 📰 le Parisien

- 🇫🇷 14-09-2023 Inondations en Libye : la chaleur de la Méditerranée à l'origine du phénomène 📺 TF1

- 🇳🇴 13-09-2023 20.000 kan være døde etter flom i Libya. Derfor ble det så ill? 📰 Aftenposten

- 🇮🇹 13-09-2023 ClimaMeter svela in tempo reale l'origine degli eventi climatici estremi 📰 Greenreport

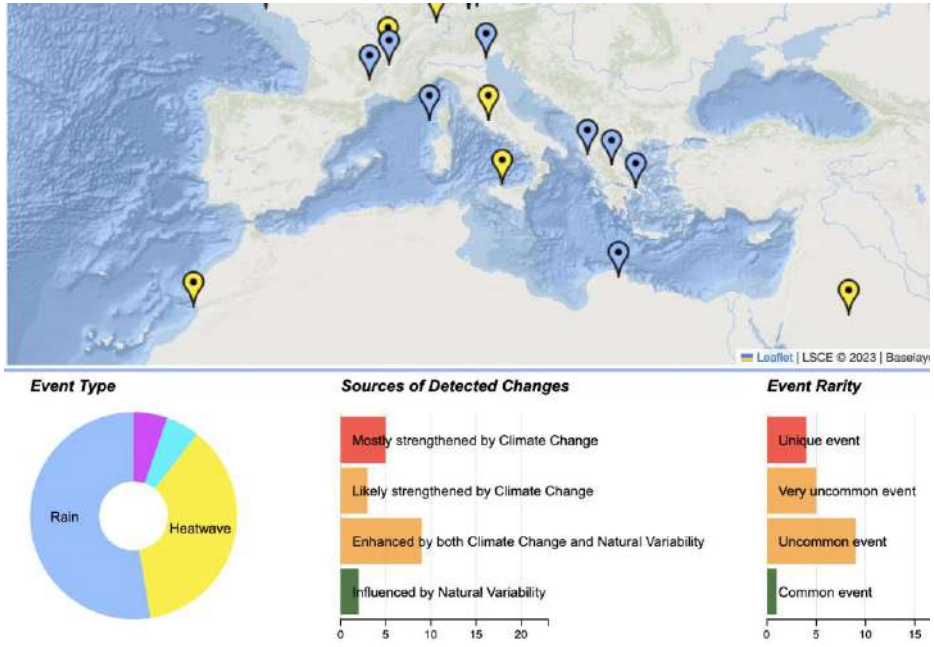
- 🇨🇭 13-09-2023 Les inondations en Libye ont fait plus de 3800 morts et 30'000 déplacés 🎤 RTS
- …

CLIMAMETER CONSORTIUM

ClimaMeter is a rapid attribution framework for putting weather extremes in a climate perspective, developed by IPSL-CNRS

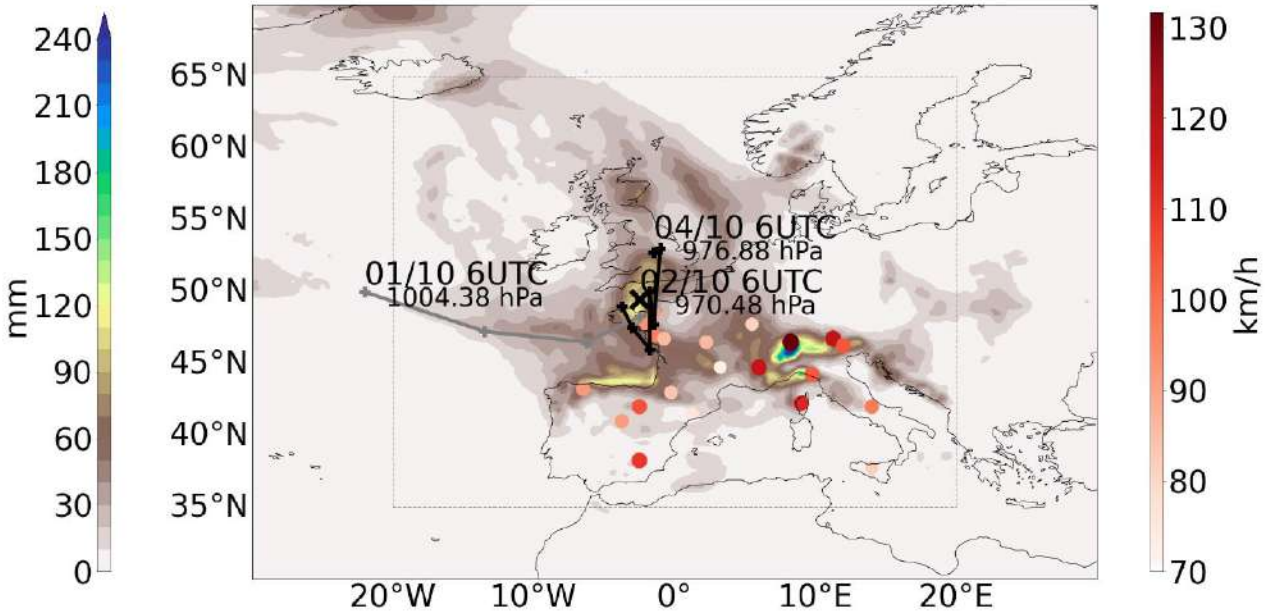
ClimaMeter is a consortium of scientists coming from several institutions: Columbia CSAG ETH HCMR ICTP INGV LML CCRS NOAA NUS MeteoGr UBC Uppsala University VU PIK Bern University Universiad EAFIT

Report ready ~48 hours after the event



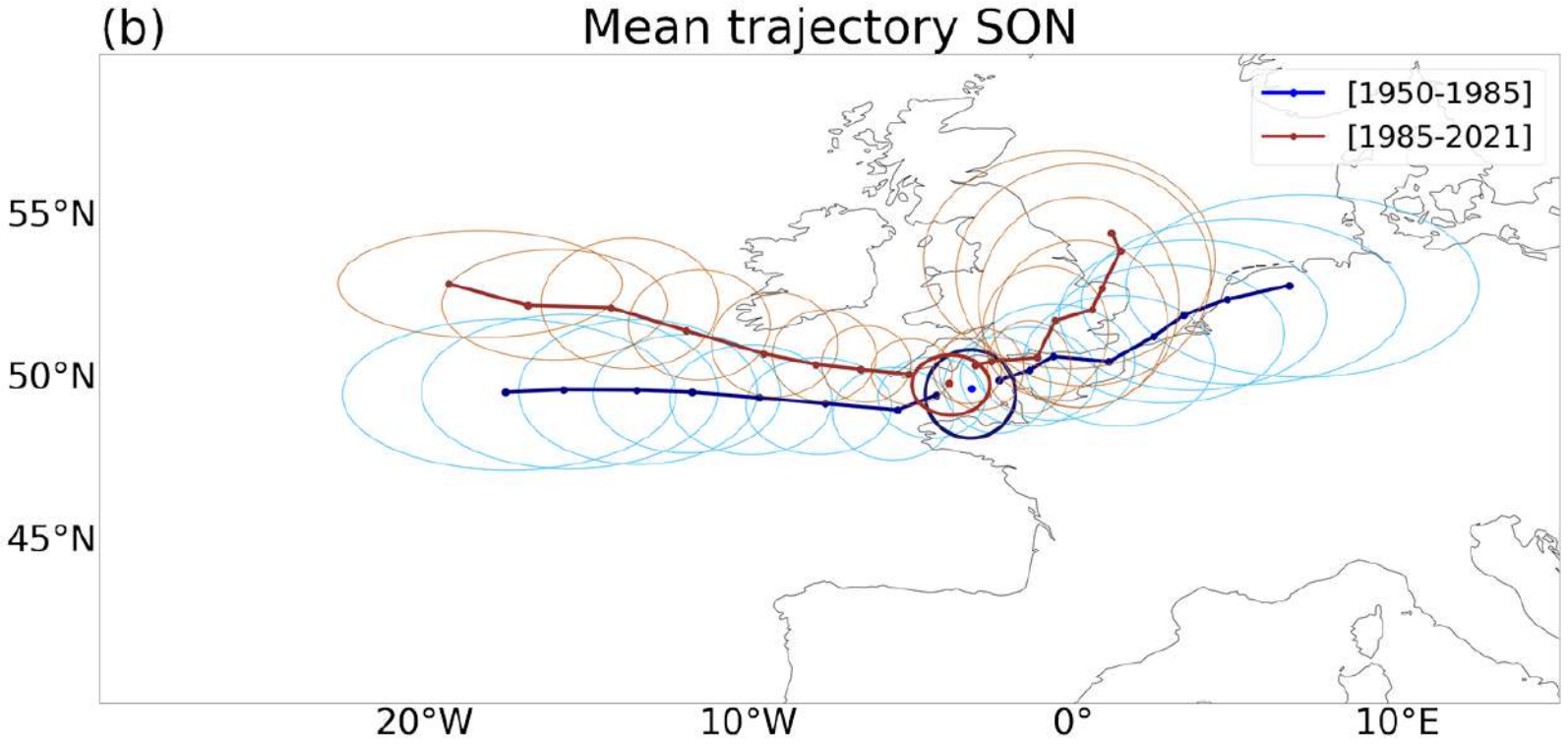
CASE STUDY 2: STORM ALEX

Extreme Event Attribution → ALEX, a high impact extratropical cyclone in October 2020



Ginesta et al. 2022

CASE STUDY 2: STORM ALEX



Ginesta et al. 2022

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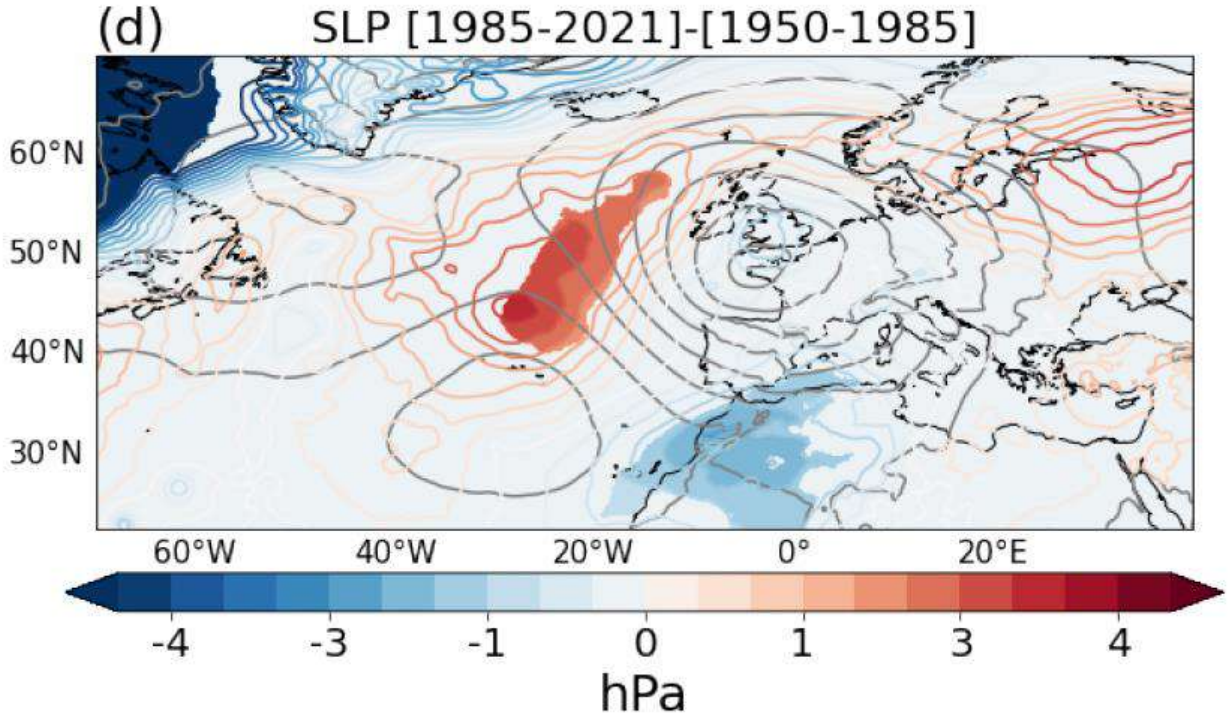

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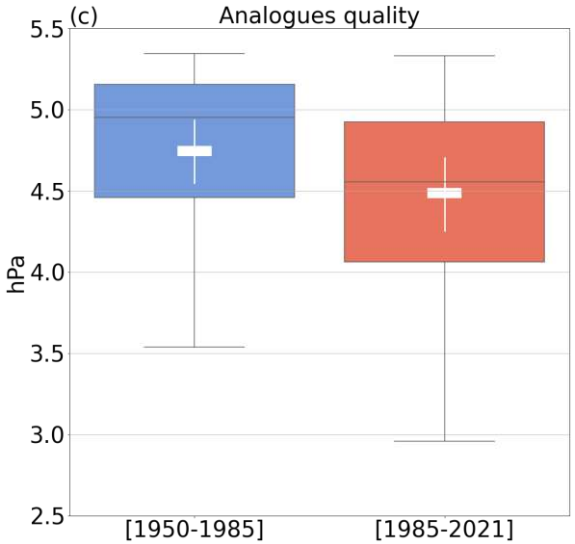

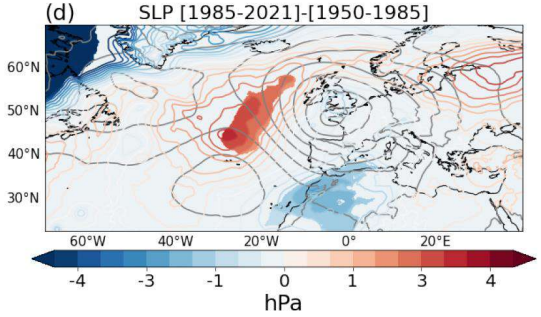

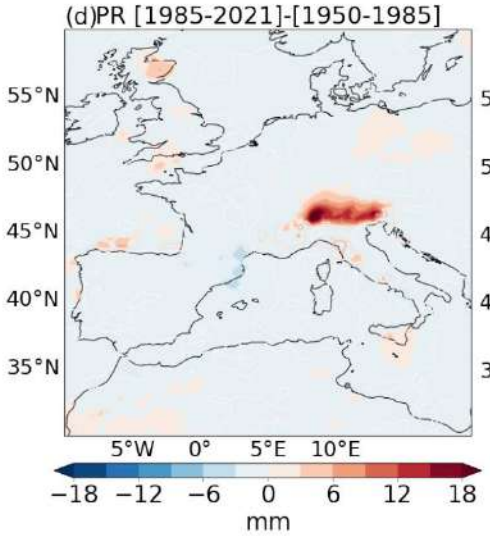

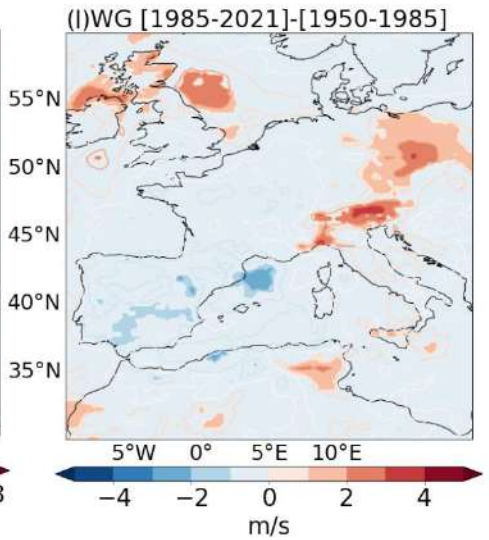

Ginesta et al. 2022

CASE STUDY 2: STORM ALEX

Alex-like storms in the factual period are ...

- **More persistent** → favours extreme events that result from prolonged weather conditions
- **More intense** and deep (specially in the autumn)
- **More frequent in autumn**
- They produce **more precipitation** → more severe flooding events

Ginesta et al. 2022

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THE CHALLENGE OF FUTURE MEDCYCLONES CLIMATE PROJECTIONS

1. Limited observational data

- Scarcity of comprehensive and long-term data on Mediterranean cyclones
- Challenges in historical records and monitoring system coverage

2. Complex interaction of factors

-Influence of multiple factors: sea surface temperatures, atmospheric dynamics, topography
-Difficulty in accurately capturing and modeling their interactions

3. Regional climate modeling limitations

-Coarse spatial resolution of regional climate models (RCMs)
-Limitations in simulating detailed dynamics of Mediterranean cyclones

A CONSENSUS IN THE DECREASE OF NUMBER OF MEDCYCLONES

•Lionello et al. 2008. The number of cyclones decreases in future conditions throughout Europe, except over the Central Europe and Mediterranean regions in summer (where it increases). The frequency of intense cyclones and the depth of extreme cyclones increase over the North-East Atlantic, decrease over Russia and show an irregular response over the rest of the domain.

•Raible et al 2010 winter : The Mediterranean cyclones, which are individually detected and tracked, decrease by 10% in the Western Mediterranean (WM) whereas no significant change is found in the Eastern Mediterranean

•Zappa et al., 2013 RCP4.5 RCP8.5 response is characterized by a tripolar pattern over Europe, with an increase in the number of cyclones in central Europe and a decreased number in the Norwegian and Mediterranean Seas.

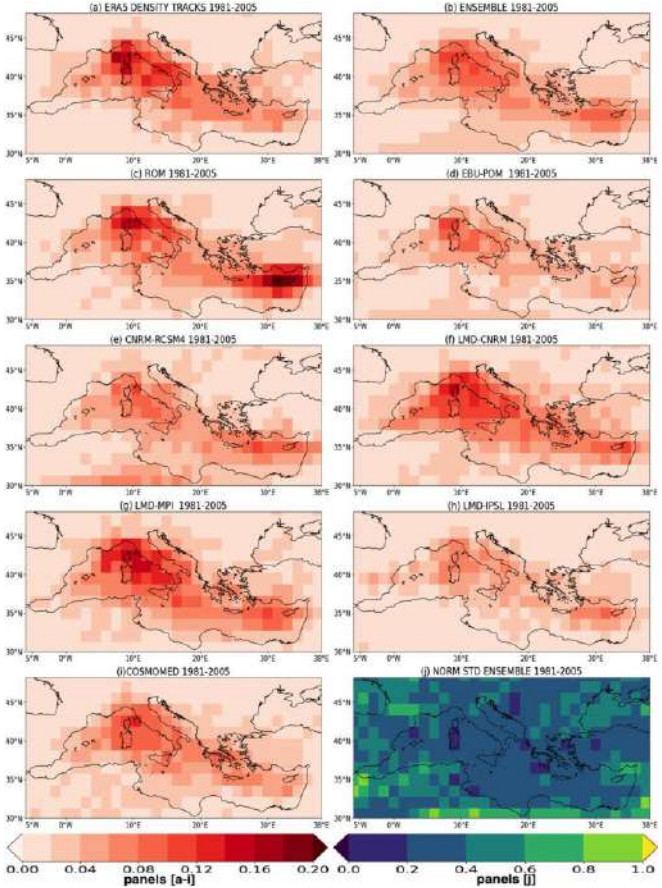
•Nissen 2014 All model simulations show a reduction in the total number of cyclones crossing the Mediterranean region under climate change conditions SRES A1B

•Zappa et al., 2015 The results show that the projected Mediterranean precipitation reduction in winter is strongly related to a decrease in the number of Mediterranean cyclones. However, the contribution from changes in the amount of precipitation generated by each cyclone are also locally important: in the East Mediterranean they amplify the precipitation trend due to the reduction in the number of cyclones, while in the North Mediterranean they compensate for it. S

•Hochman et al. 2020 decrease of cyprus low (east med) rcp8.5

•Reale 2022 RCP8.5 In general, the RCSMs show at the end of the twenty-first century a decrease in the number and an overall weakening of cyclones moving across the Mediterranean.

GREAT UNCERTAINTIES ON FUTURE MEDCYCLONES PROJECTIONS
How RCMs represent Mediterranean cyclones climatology?

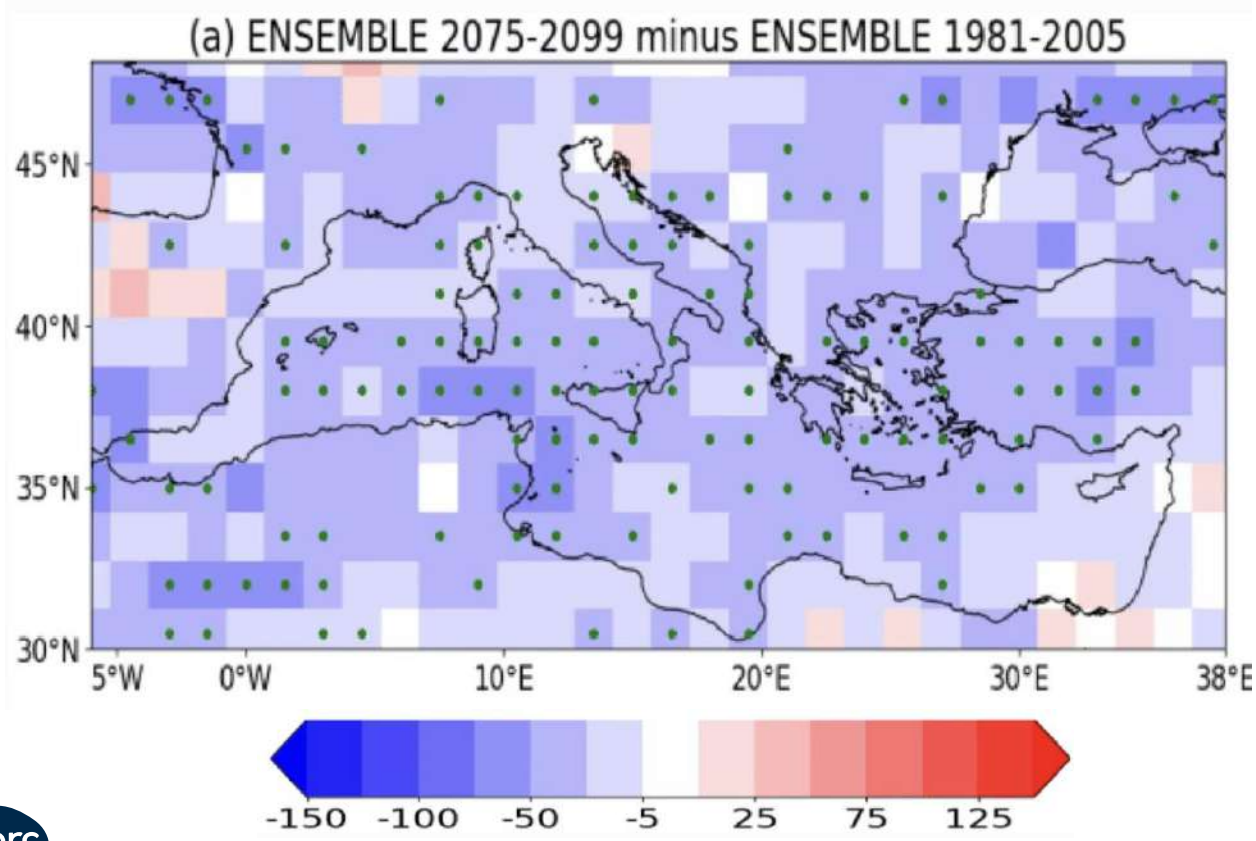


Spatial distribution of annual mean number of cyclone tracks in each cell of 1.5˚ in the period 1981–2005 for ERA5 (**a**), multi-model mean (ENSEMBLE, **b**), ROM (**c**), EBU-POM (**d**), CNRM-RCSM4 (**e**), LMD-CNRM (**f**), LMD-MPI (**g**), LMD-IPSL (**h**) and COSMOMED (**i**). Panel (**j**) shows the normalized standard deviation among all the RCSMs

⇒ RCMs show large biases in reproducing medCyclones frequencies

Reale et al. 2022
Climate Dynamics

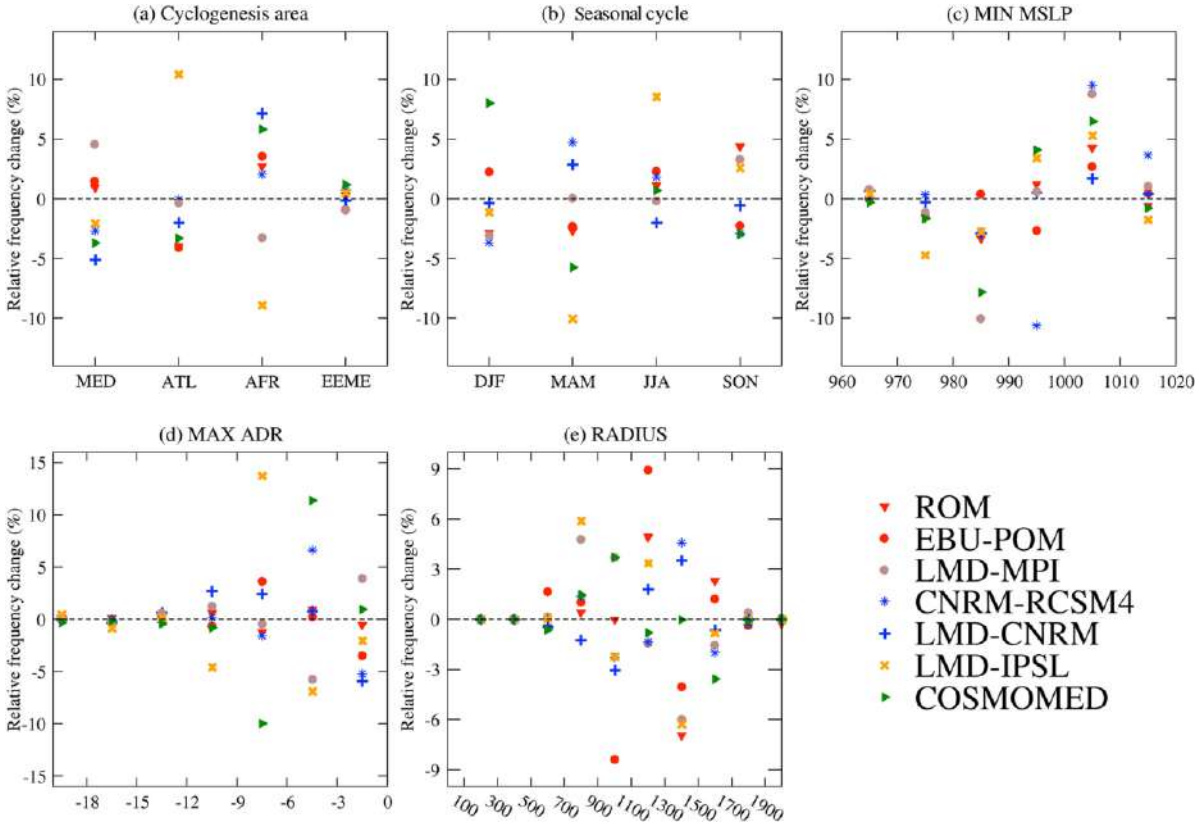
GREAT UNCERTAINTIES ON FUTURE MEDCYCLONES PROJECTIONS
A general consensus on the decrease in the number of cyclones



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**). Green dots in the multi-model means panel (**a**) shows the cells where the climate change signal is robust among the RCSMs

Reale et al. 2022
Climate Dynamics

GREAT UNCERTAINTIES ON FUTURE MEDCYCLONES PROJECTIONS



While there is consensus on the decrease in frequency all the fine details of Med Cyclones in the future heavily depend on the model

Reale et al. 2022
Climate Dynamics

MORE INTENSE BUT FEWER MEDICANES IN THE FUTURE

•Gaertner et al., 2007: increase in the extremes of cyclone intensity over the Mediterranean Sea under a climate change scenario.
•Romero and Emanuel 2013 Fewer medicanes but a higher number of violent storms
•Cavicchia et al., 2014: the projected effect of climate change on Mediterranean tropical-like cyclones is decreased frequency and a tendency toward a moderate increase of intensity.
•Walsh et al., 2014: The results indicate that the number of such systems decreases in a warmer world, particularly in winter.
•Tous et al., 2016 medicanes tend to decrease in number but increase in intensity
•Koseki et al., 2017: (pseudo global warming (PGW) approach) most of the medicane characteristics moderately intensify if climate changes are appled to all variables
•Romero and Emanuel 2017 Increased occurrence of medicanes in the western Mediterranean and Black Sea that is balanced by a reduction of storm tracks in contiguous areas, particularly in the central Mediterranean; however, future extreme events become more probable in all Mediterranean subbasins.
González-Alemán et al., 2019 despite a decrease in frequency, Medicanes potentially become more hazardous in the late century

PHYSICAL ARGUMENTS BEYOND THE PROJECTED CHANGES

1. 📉 Decrease in Frequency & 🧭 Northward Shift:

-Climate models project fewer Mediterranean cyclones with a northward shift in the storm track.
-Changes in atmospheric circulation patterns contribute to reduced cyclone formation in the region.

2. 🌀 Increase in Intensity:

-Despite decreased frequency, future scenarios indicate more intense Mediterranean cyclones.
-Warmer sea surface temperatures and increased moisture fuel stronger and extreme cyclonic events.

3. ⛈️ Altered Precipitation Patterns:

-Precipitation associated with Mediterranean cyclones may change.
-Distribution and intensity of rainfall could be modified, leading to concentrated and heavy rainfall during cyclone passages.

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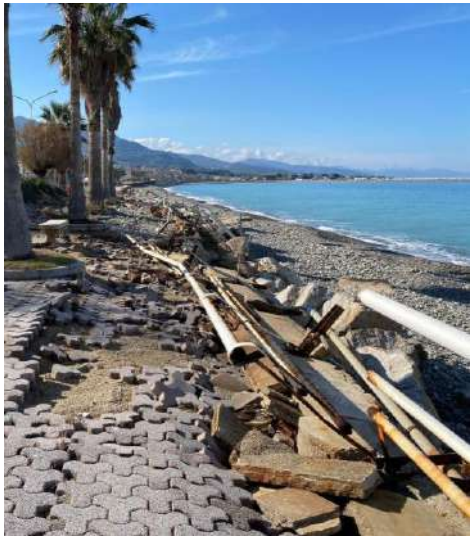
FUTURE IMPACTS OF MEDITERRANEAN CYCLONES (1/2)



S.Agata Militello beach destroyed by a storm, @AntonioCarcione

Flooding 🌊☔:

-The potential for intensified rainfall during Mediterranean cyclones can result in a higher risk of flooding.
-Heavy precipitation combined with urbanization and inadequate infrastructure may lead to flash floods and increased water-related hazards.

Coastal Erosion and Storm Surges 🏖️🌊:

-Rising sea levels and more intense cyclones can amplify the risk of coastal erosion and storm surges.
-Cyclone-induced storm surges can cause significant damage to coastal areas, including erosion, inundation, and damage to infrastructure.

FUTURE IMPACTS OF MEDITERRANEAN CYCLONES (2/2)

The destruction on pine forest produced by the cyclone Vaia in Trentino Alto Adige

Strong Winds and Structural Damage 🌬️🏢:
More intense cyclones are likely to generate stronger winds, posing a risk of structural damage to buildings, infrastructure, transportation and vegetation.

Agricultural and Ecological Impacts 🌾🌿:
Heavy rainfall and strong winds can damage crops, disrupt farming activities, and impact natural habitats

Human Health and Safety 😷🚑:
Increased risks of waterborne diseases, disruptions in healthcare services, and potential injuries or casualties during cyclone impacts are concerns.

CLIMATE CHANGE FOR MEDITERRANEAN CYCLONES
The floor is yours!

- Few established results in the literature, the most robust being the decrease in frequency and increase in intensity of the MedCyclones
- Impacts from MedCyclones could be enhanced in the future by sea-level rise, higher precipitation and temperatures.

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