The marine and coastal hazards of Mediterranean cyclones

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Modelling the Mediterranean cyclones

- **Extreme sea levels** (surge + tide) and **waves** induced by cyclones strongly affect Med costal communities
- Med has a very **complex coastline** characterized by the presence of several low-land **coastal environments** (lagoons, bays, deltas, estuaries, …) and subjected to many **anthropogenic pressures**
- We aim at characterizing the **cyclone hazard** using **numerical modelling**.

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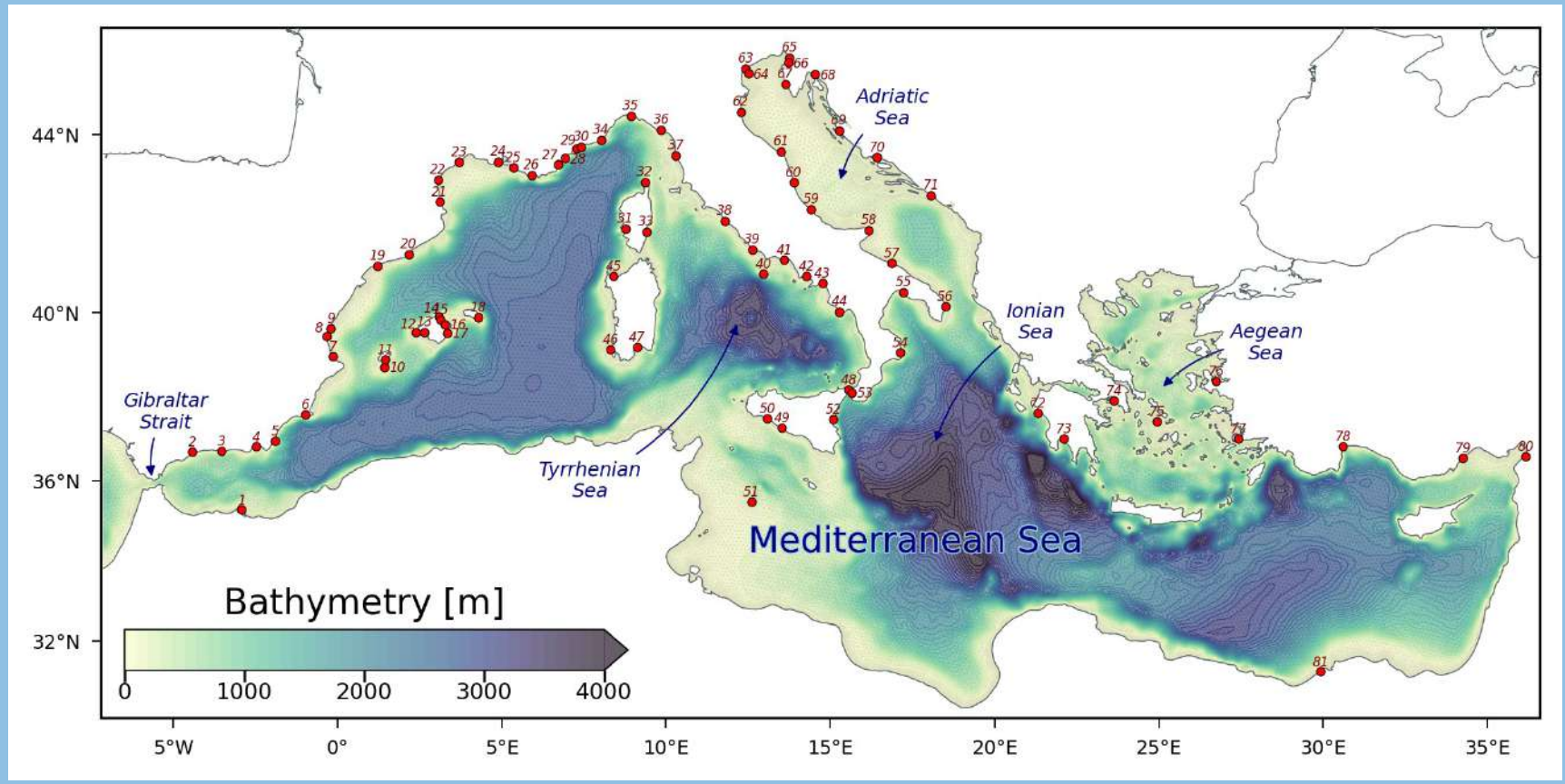
A multi-scale modelling approach

In the context of **ocean modelling**, the **Mediterranean Sea** represents a challenge, as this regional sea is strongly affected by **air-sea**, **land-sea**, and **coastal-offshore** interactions.

Simulations were performed with **SHYFEM-WW3** hydrodynamic-wave coupled model (1994-2020) forced by:

- sea levels at the **Atlantic Oc.**
- surface **wind and MSLP**
- internal **tidal potential**



TIDE ↔ SURGE ↔ WAVE interactions

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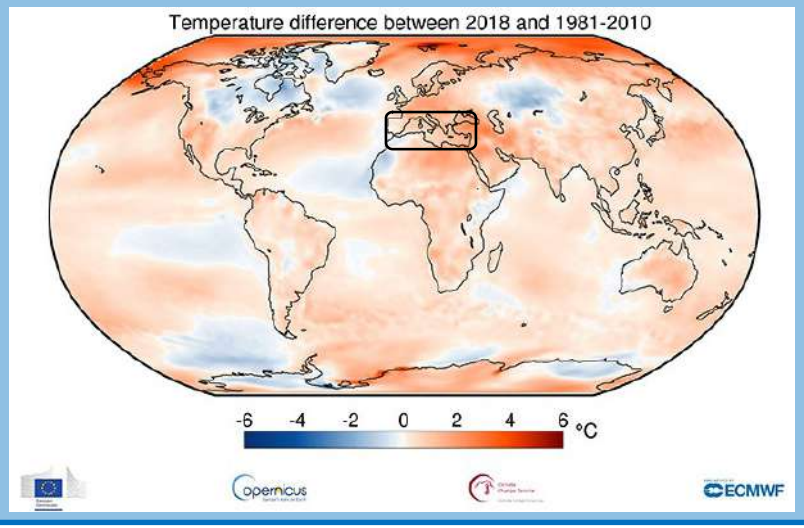
The atmospheric forcing

Most of the **uncertainty** associated with the simulation of **sea storms** resides in the **atmospheric forcing**.
We considered **two reanalysis** datasets (https://climate.copernicus.eu/):

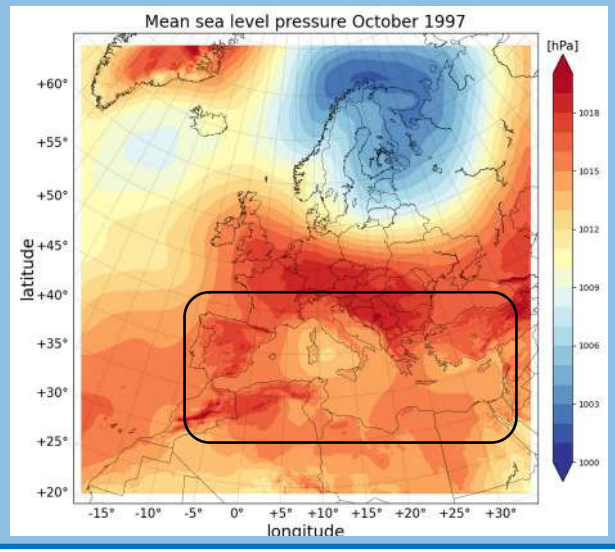
ERA5

- global
- available from 1940 onwards
- hourly frequency
- resolution of 0.25° (~30 km)



CERRA

- regional (Europe) nested in ERA5
- available from 1984 to April 2021
- 3-hourly frequency
- resolution of 5.5 km



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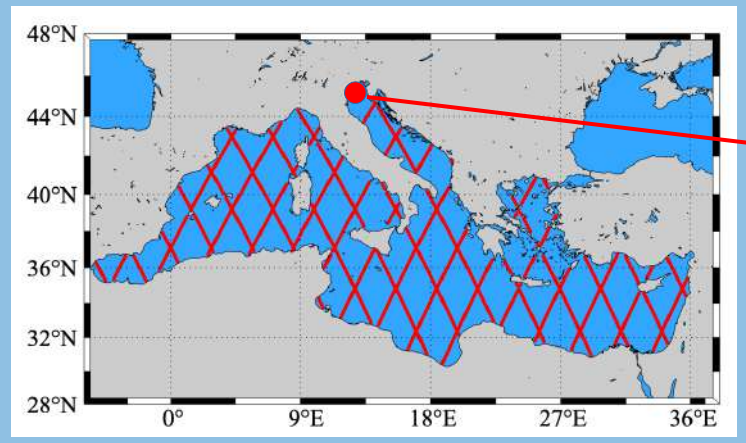
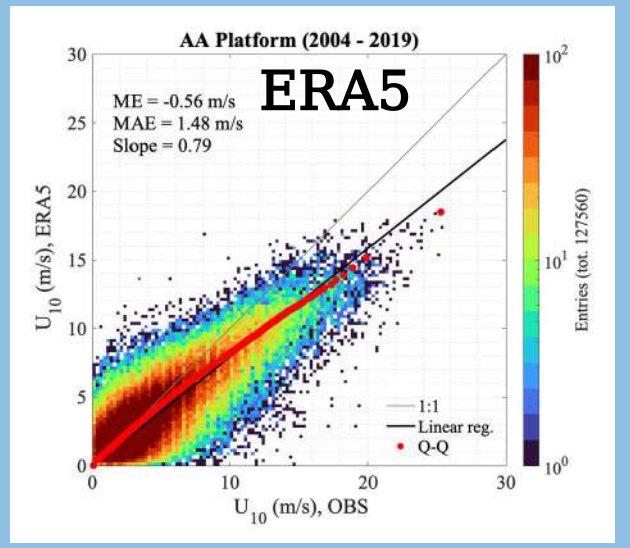
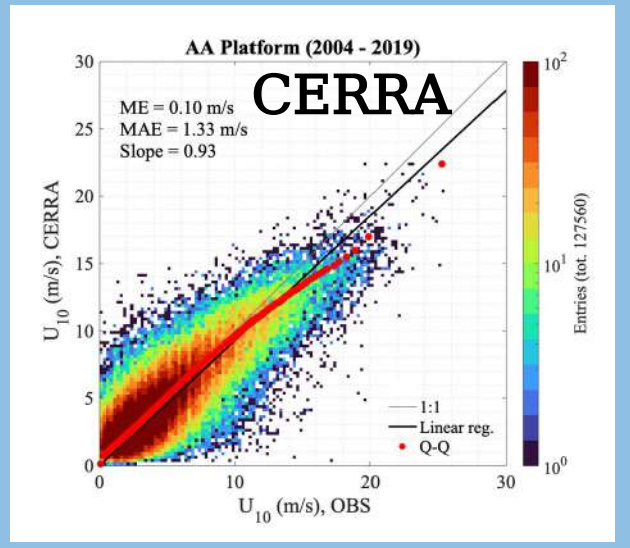
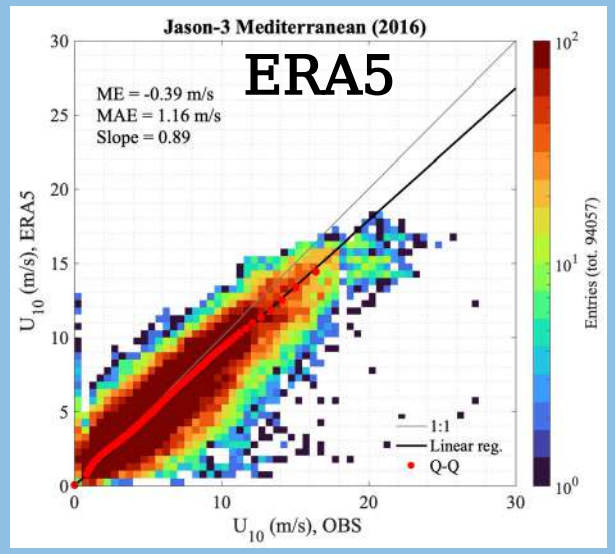
Wind validation

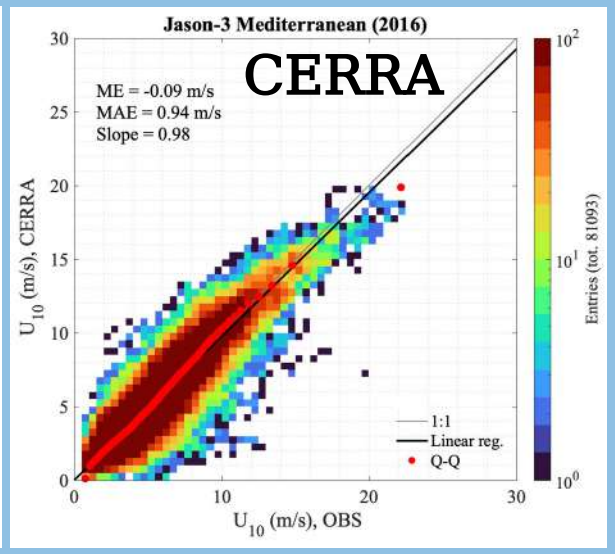


Acqua Alta Oceanographic station in the Northern Adriatic Sea (Pomaro et al., 2017)









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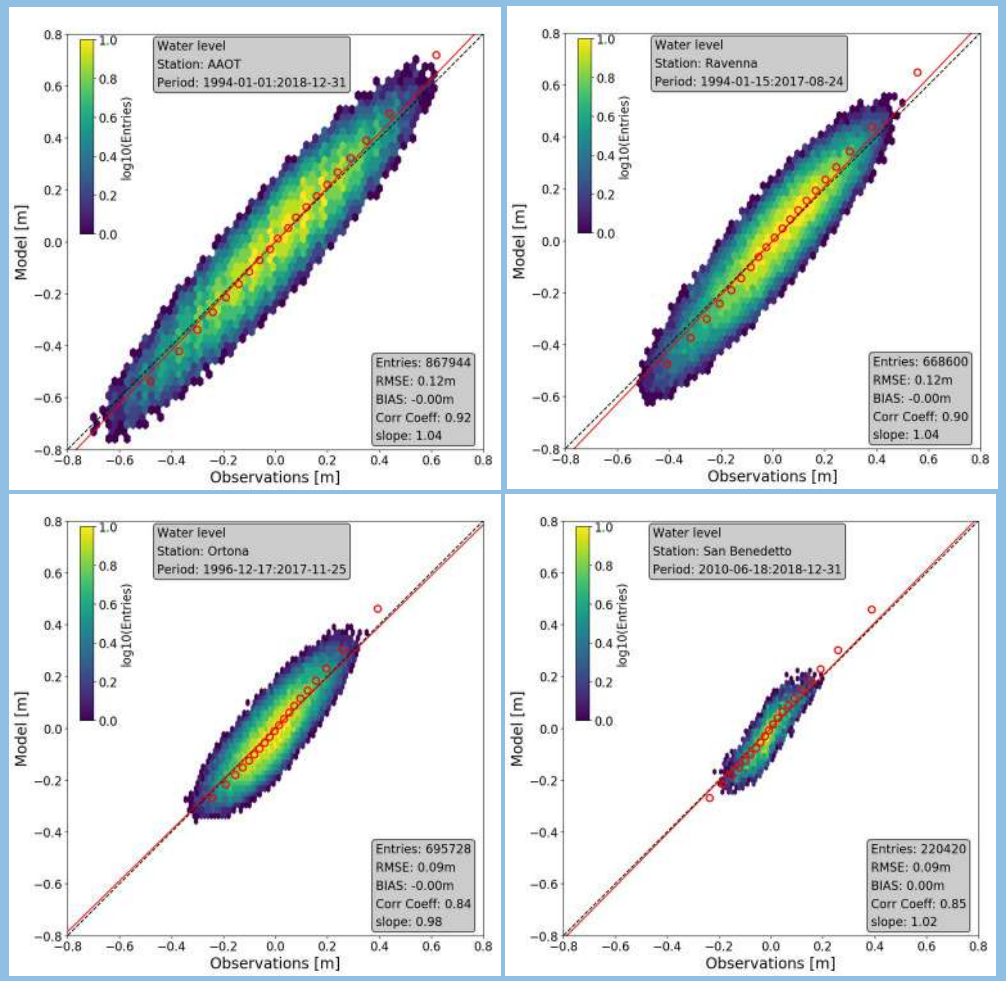
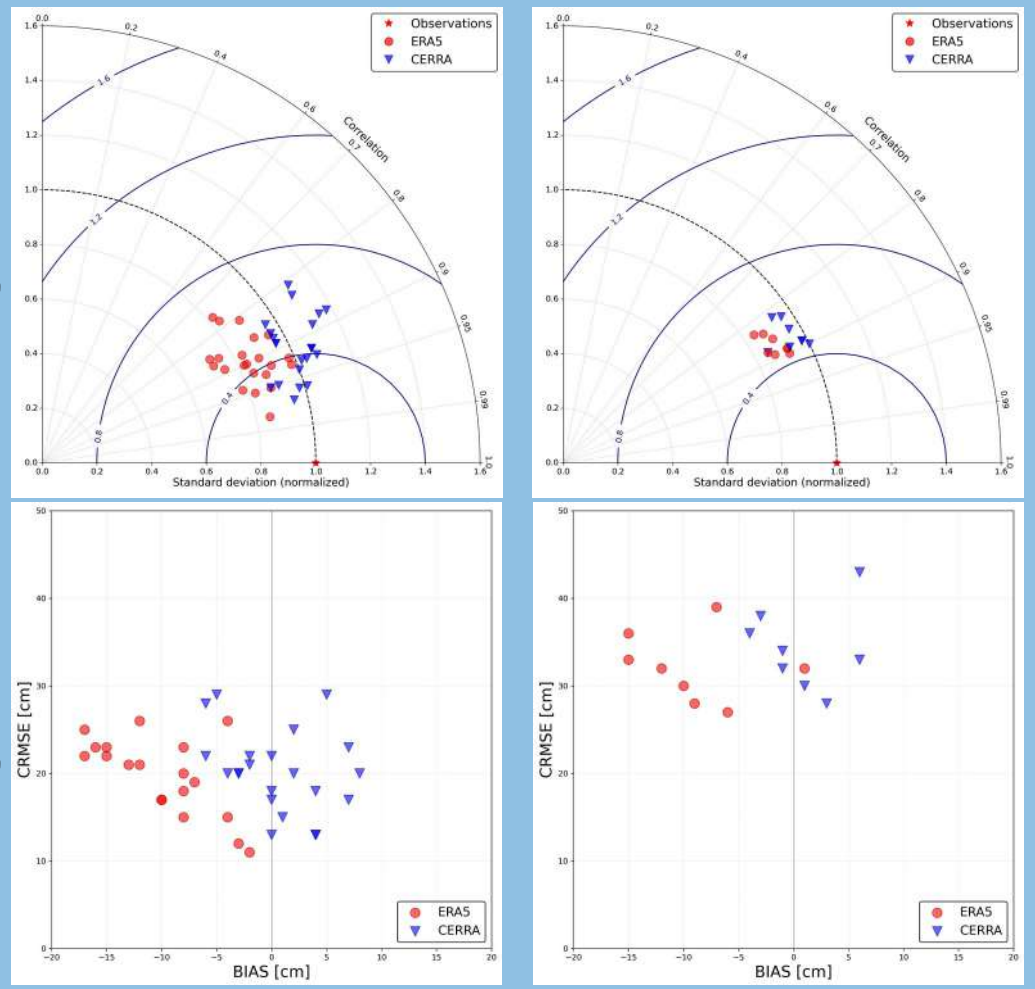
Sea level and wave validation

Total sea level



Sign. wave height



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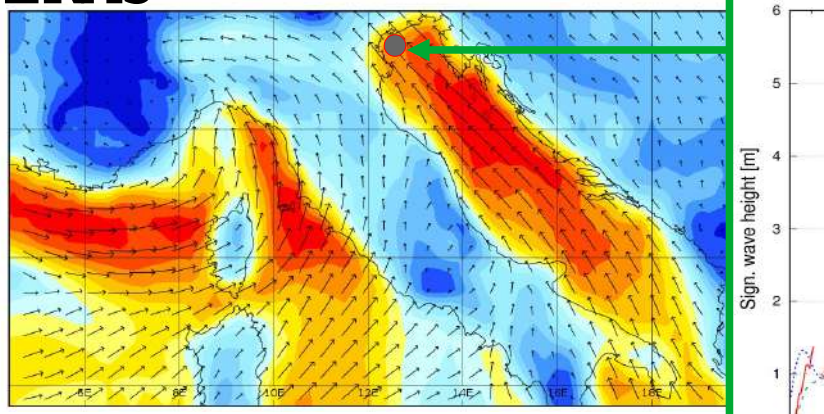
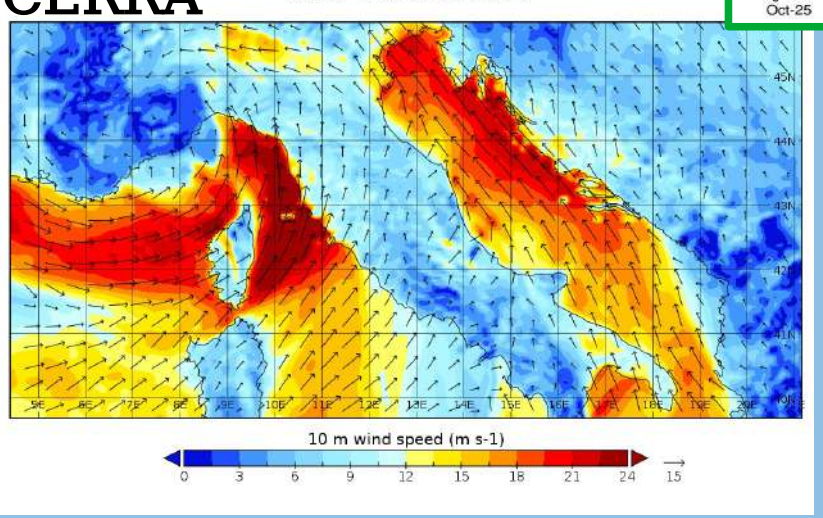
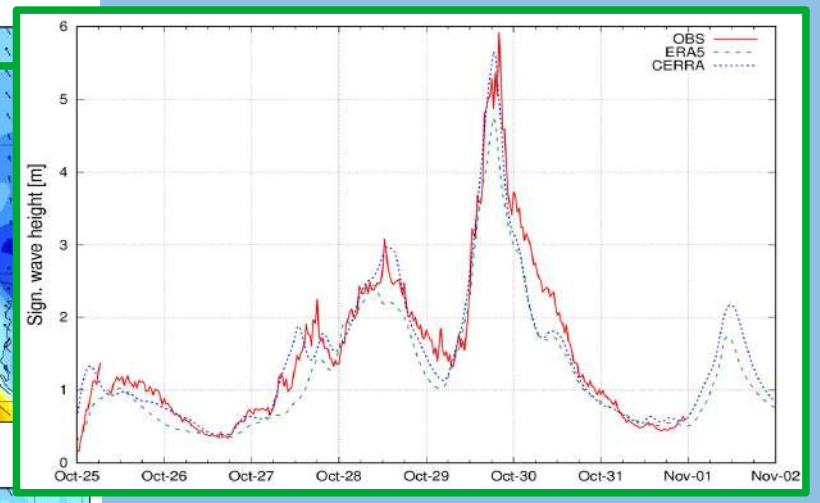
Storm Vaia, Oct 2018

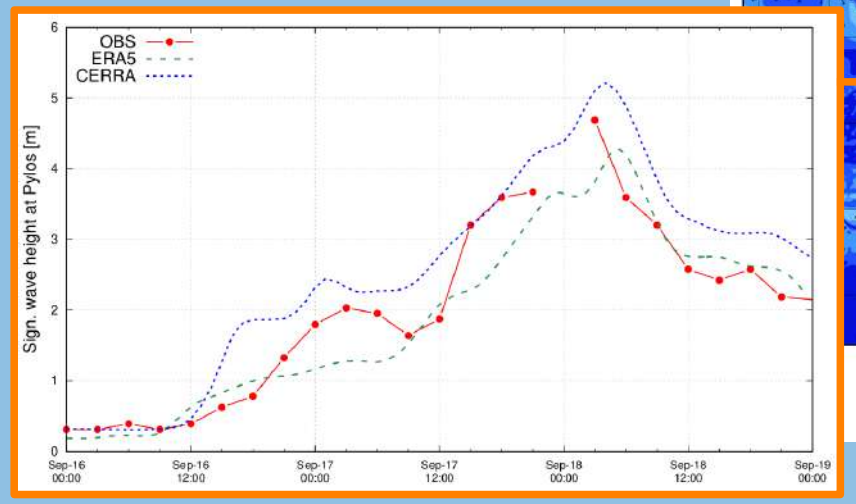
ERA5



CERRA



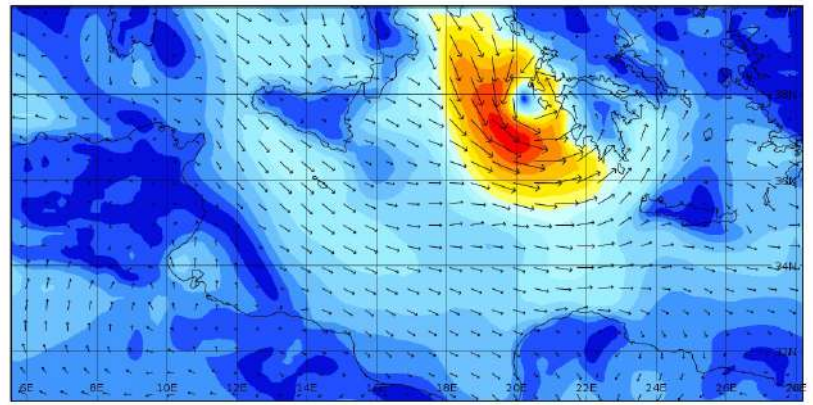




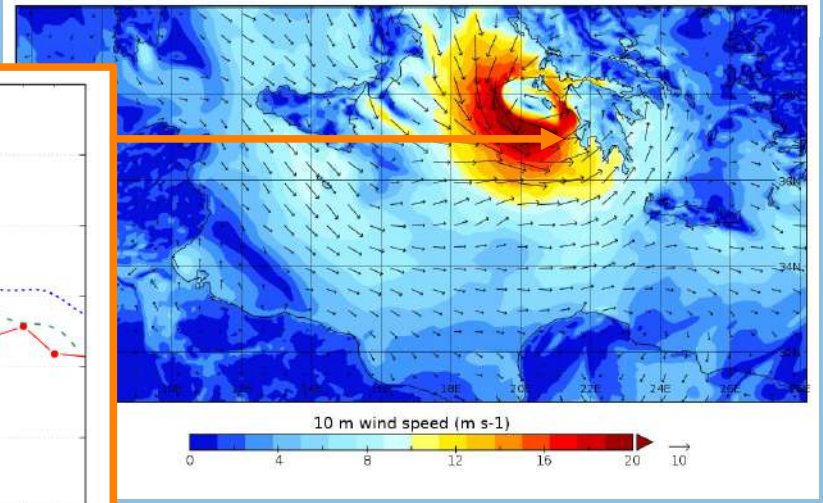
Cavaleri et al. Prog. Oc., 2019

Medicane Ianos, Sep 2020

ERA5



CERRA



Ferrarin et al. NHESS, 2023

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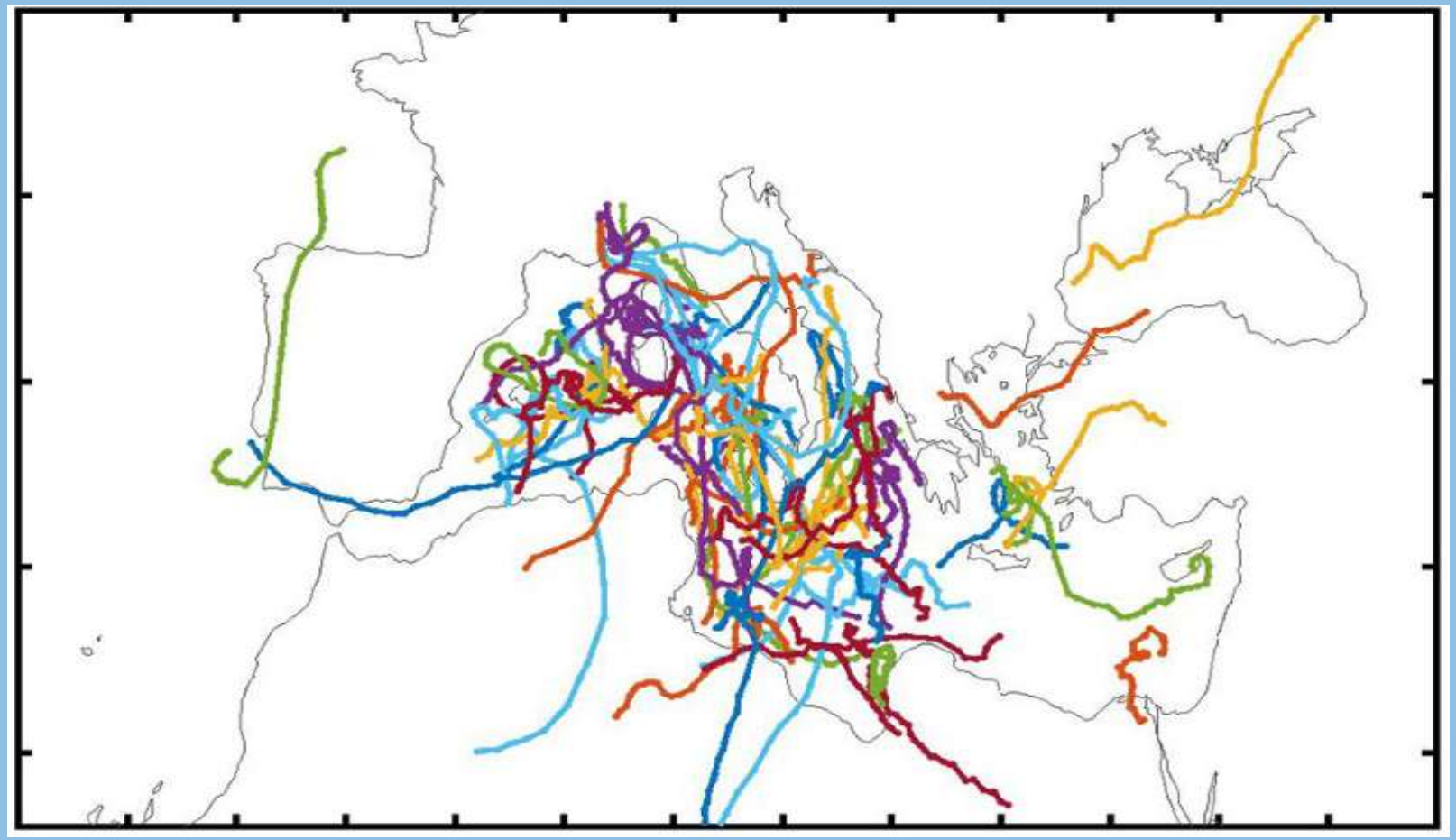
Cyclone detection

Sea storm events are defined from the **meteorological** point of view.

Cyclone track and duration are detected according to Flaounas, et al (2023) by using a **composite cyclone tracks** based on different detection and tracking methods.

About **1100 cyclones** identified from 1994 to 2020



Flaounas, et al. Weather Clim. Dynam, 2023

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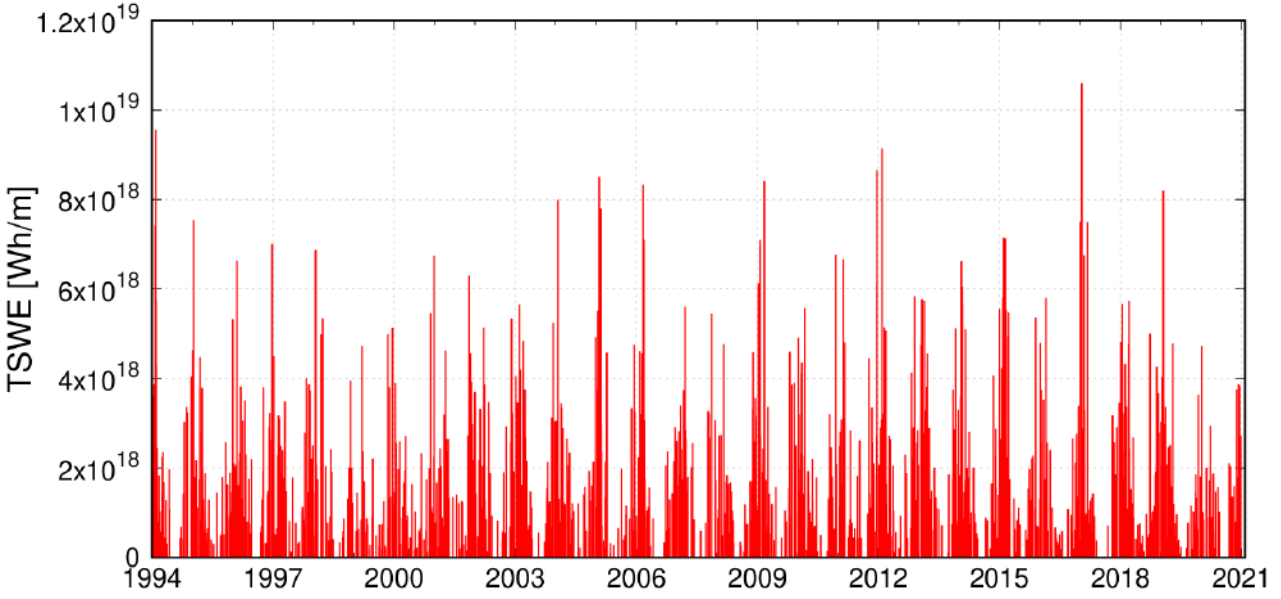
Cyclone hazard estimation

To evaluate the **cumulative hazard** of each cyclone, we computed the **total storm wave energy** (**TSWE**) by integrating the **wave power** contribution of each sea state over the storm duration.



n	cyclone_id	Initial time	Final time	duration [h]	TSWE [Wh/m]
1	1553	2017-01-16::08:00:00	2017-01-26::03:00:00	236	1.06E+19
2	615	1994-02-05::08:00:00	1994-02-09::14:00:00	103	9.56E+18
3	1346	2012-02-05::17:00:00	2012-02-10::01:00:00	105	9.14E+18
4	1335	2011-12-21::12:00:00	2011-12-29::00:00:00	181	8.66E+18
5	1057	2005-01-31::06:00:00	2005-02-06::08:00:00	147	8.51E+18
6	1213	2009-03-05::17:00:00	2009-03-09::06:00:00	86	8.42E+18
7	1099	2006-03-05::17:00:00	2006-03-09::05:00:00	85	8.33E+18
8	1642	2019-01-24::02:00:00	2019-01-27::20:00:00	91	8.20E+18
9	1014	2004-01-22::08:00:00	2004-01-25::12:00:00	77	7.99E+18
10	1059	2005-02-14::01:00:00	2005-02-17::11:00:00	83	7.80E+18
11	646	1995-01-13::00:00:00	1995-01-18::12:00:00	133	7.55E+18
12	1551	2017-01-06::09:00:00	2017-01-12::01:00:00	137	7.51E+18
13	1561	2017-03-06::15:00:00	2017-03-12::22:00:00	152	7.50E+18
14	614	1994-01-28::14:00:00	1994-01-31::20:00:00	79	7.43E+18
15	1475	2015-02-08::22:00:00	2015-02-14::10:00:00	133	7.14E+18
16	1477	2015-02-23::20:00:00	2015-02-28::20:00:00	121	7.13E+18
17	1101	2006-03-11::04:00:00	2006-03-14::23:00:00	92	7.11E+18
18	1209	2009-01-25::12:00:00	2009-01-31::18:00:00	151	7.10E+18
19	732	1996-12-24::18:00:00	1996-12-30::09:00:00	136	7.00E+18
20	1207	2009-01-24::05:00:00	2009-01-26::05:00:00	49	6.93E+18
21	778	1998-01-20::04:00:00	1998-01-23::18:00:00	87	6.87E+18
22	1291	2010-12-10::09:00:00	2010-12-13::09:00:00	73	6.77E+18
23	1555	2017-02-05::13:00:00	2017-02-09::13:00:00	97	6.75E+18
24	880	2000-12-30::07:00:00	2001-01-02::18:00:00	84	6.74E+18
25	1301	2011-02-17::12:00:00	2011-02-21::01:00:00	86	6.67E+18
26	697	1996-02-08::15:00:00	1996-02-11::10:00:00	68	6.64E+18
27	1431	2014-01-22::13:00:00	2014-01-28::08:00:00	140	6.62E+18
28	914	2001-11-10::00:00:00	2001-11-13::03:00:00	76	6.30E+18
29	1334	2011-12-20::03:00:00	2011-12-24::03:00:00	97	6.14E+18
30	1205	2009-01-12::02:00:00	2009-01-15::01:00:00	72	6.13E+18

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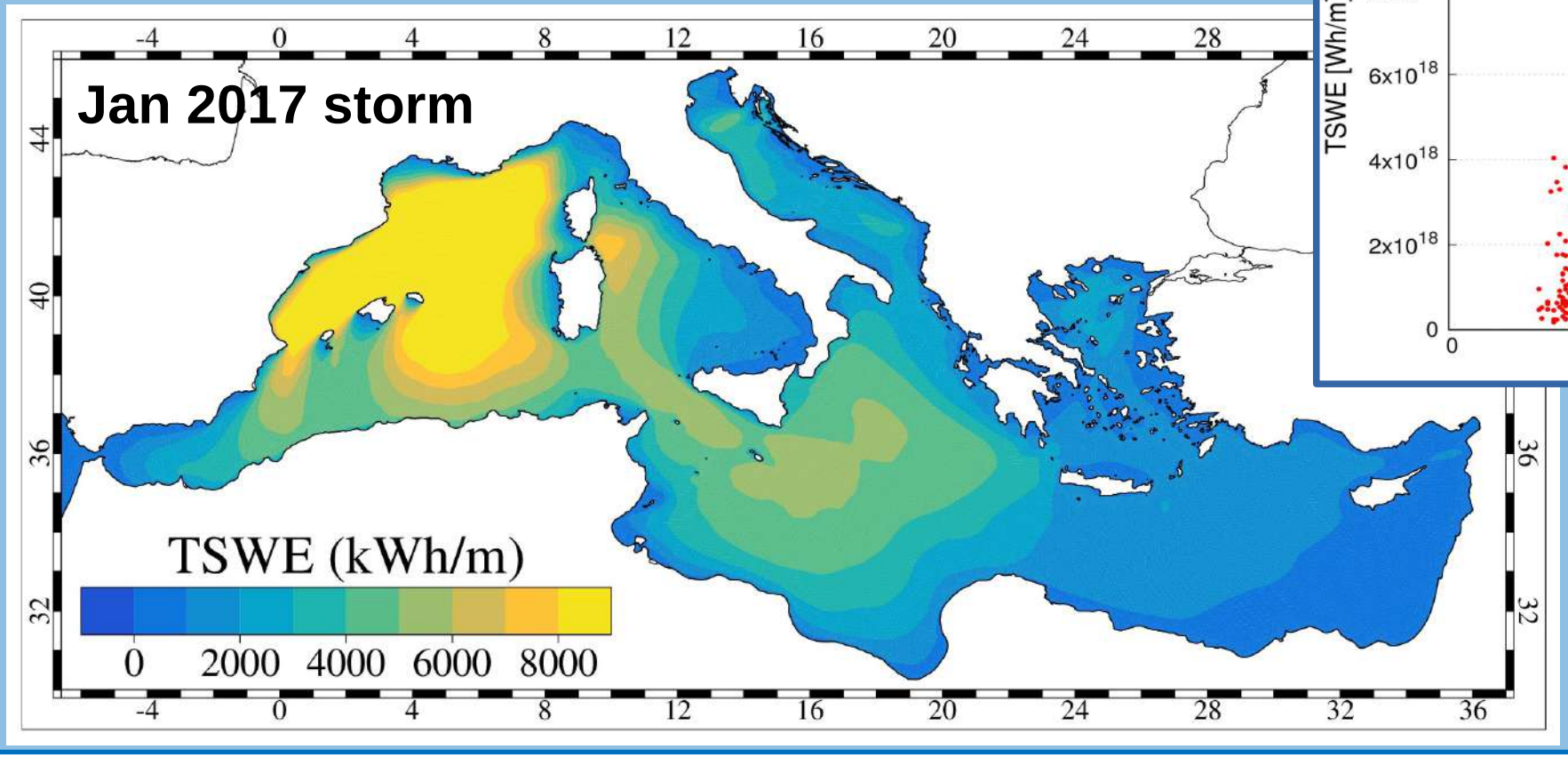
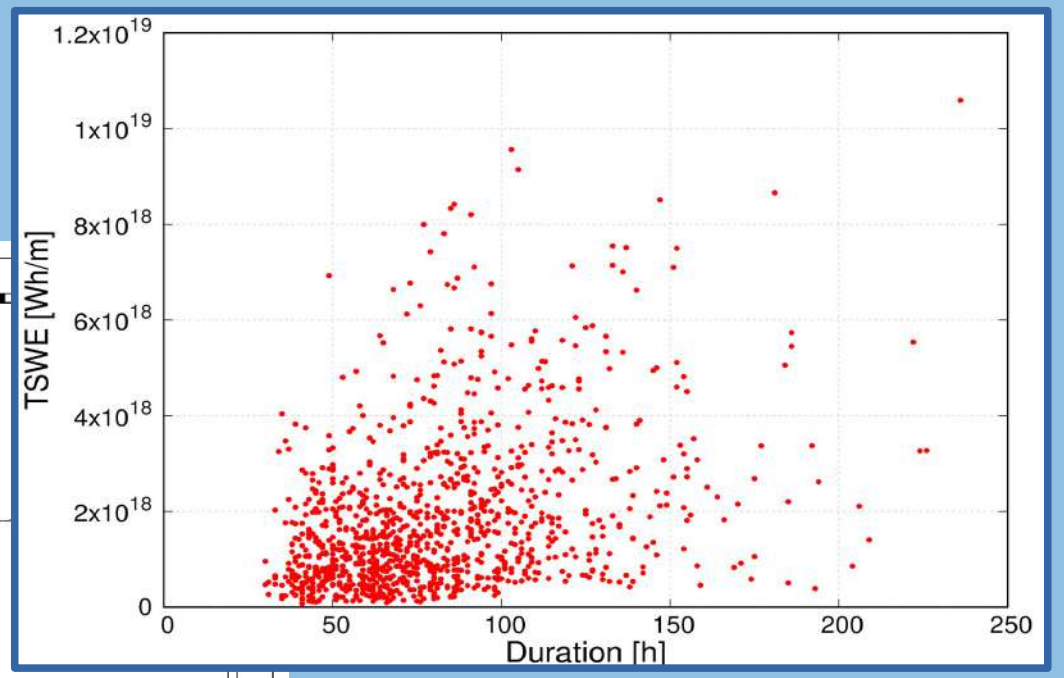
Cyclone hazard estimation

Space/time characterization of each cyclone.
Definition of storm climatologies in the Med Sea.





Cyclone analysis and clustering in progress.

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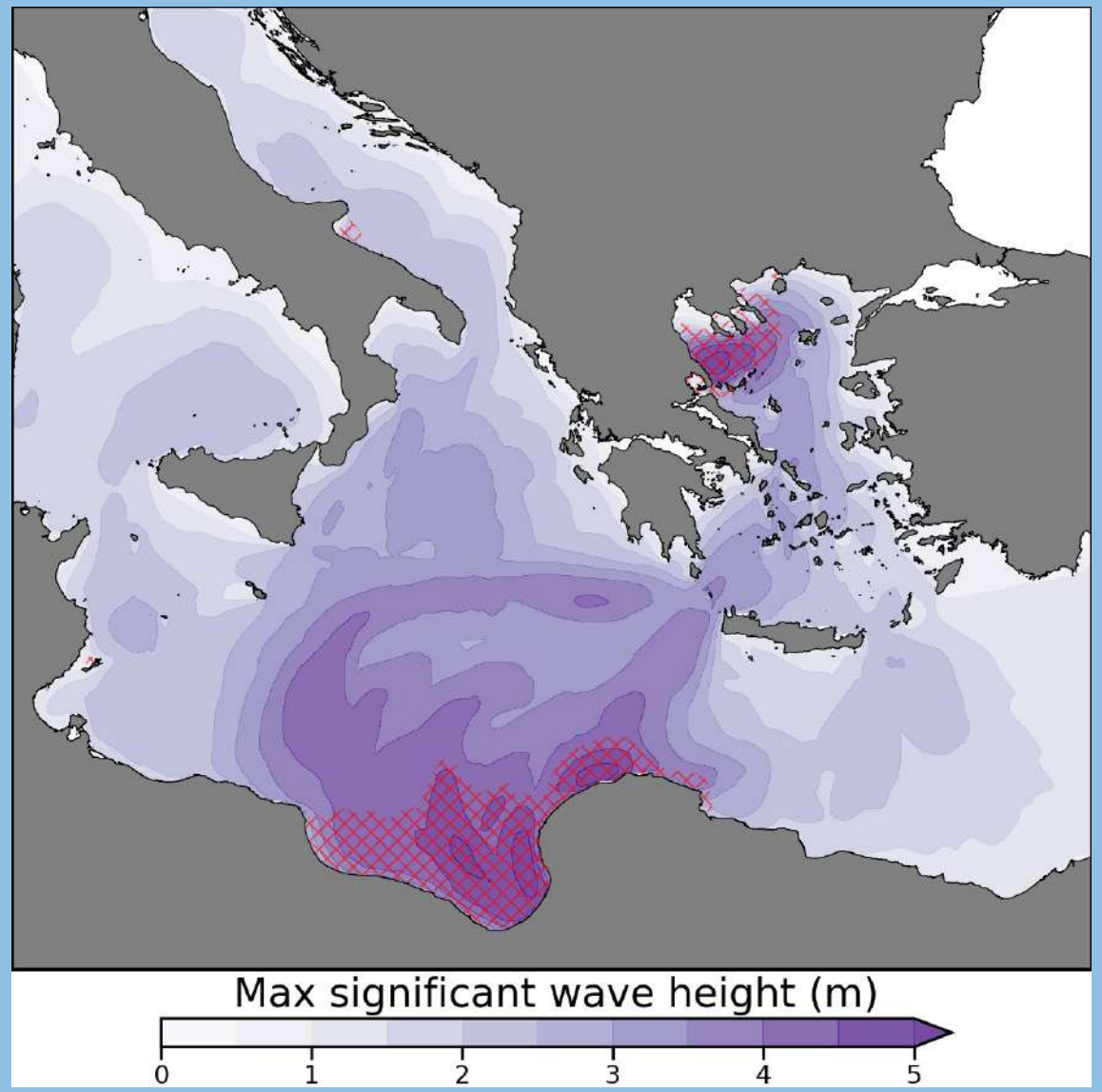
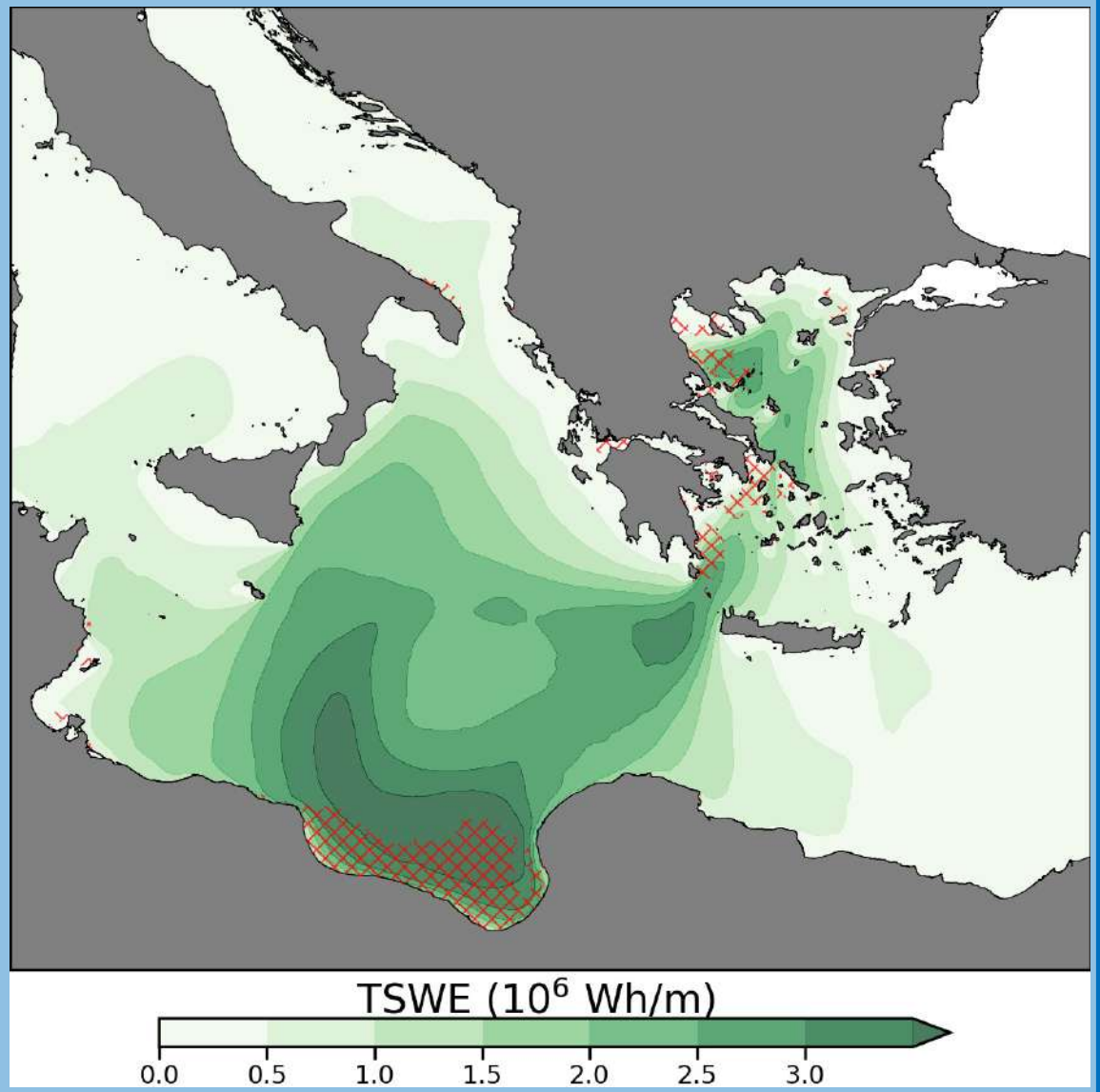
Storm Daniel (Sep. 2023)

Max. **SWH** (99th percentile)



TSWE (99th percentile)



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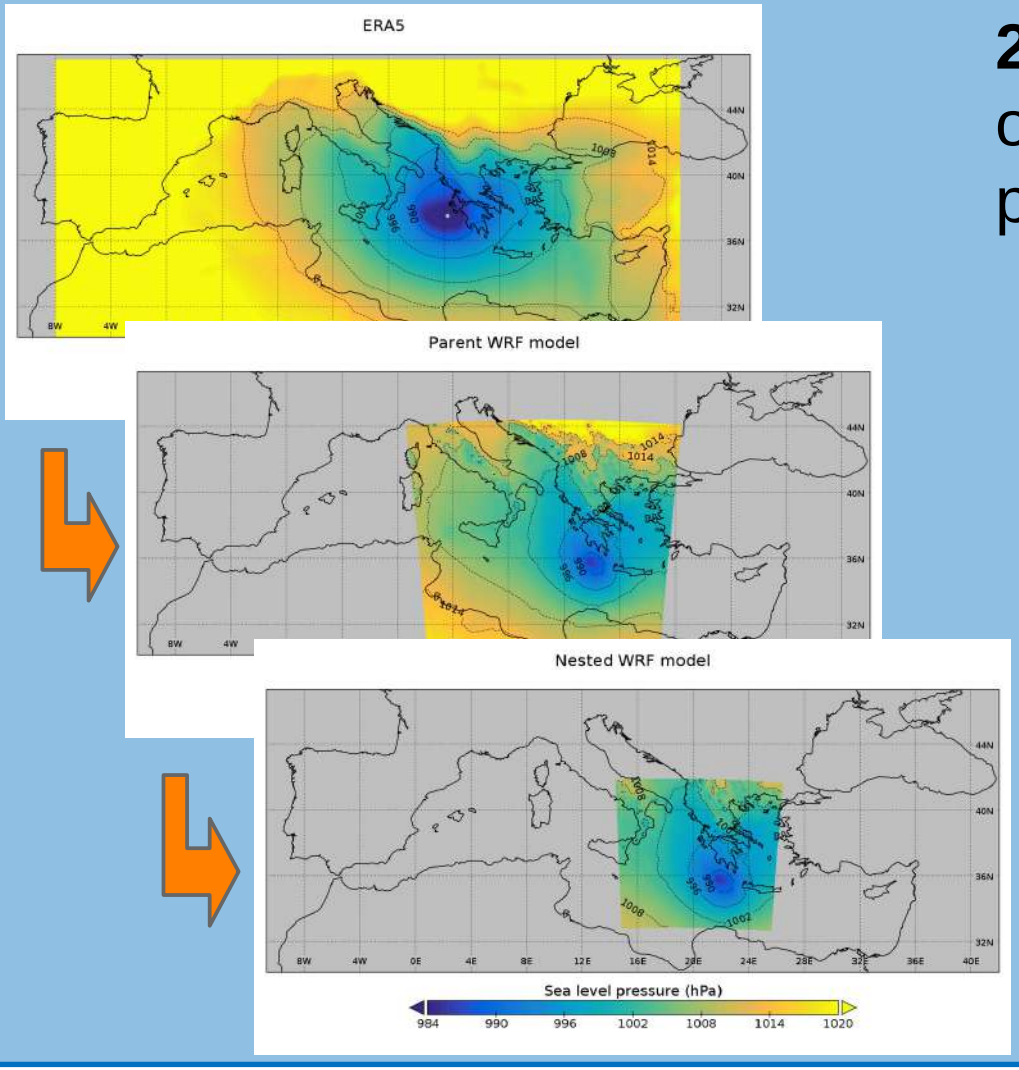
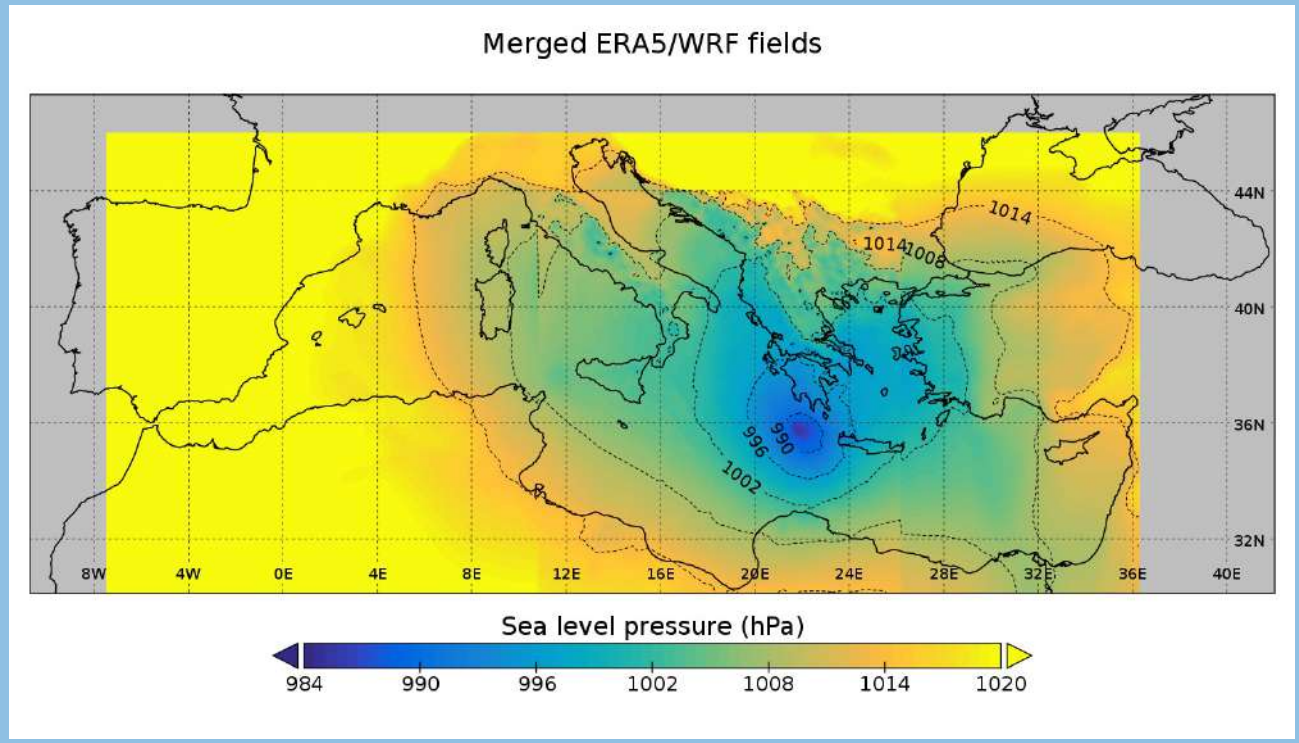
High-resolution cyclone simulations

2.8 km WRF downscaling of ERA5 with **30 min** output over a 100x100 km domain (nested in a 8km parent WRF) **moving along the cyclone track**.





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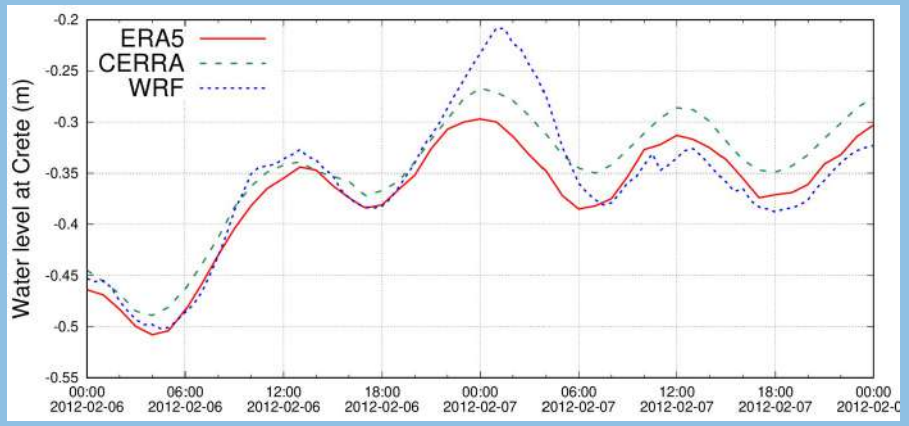
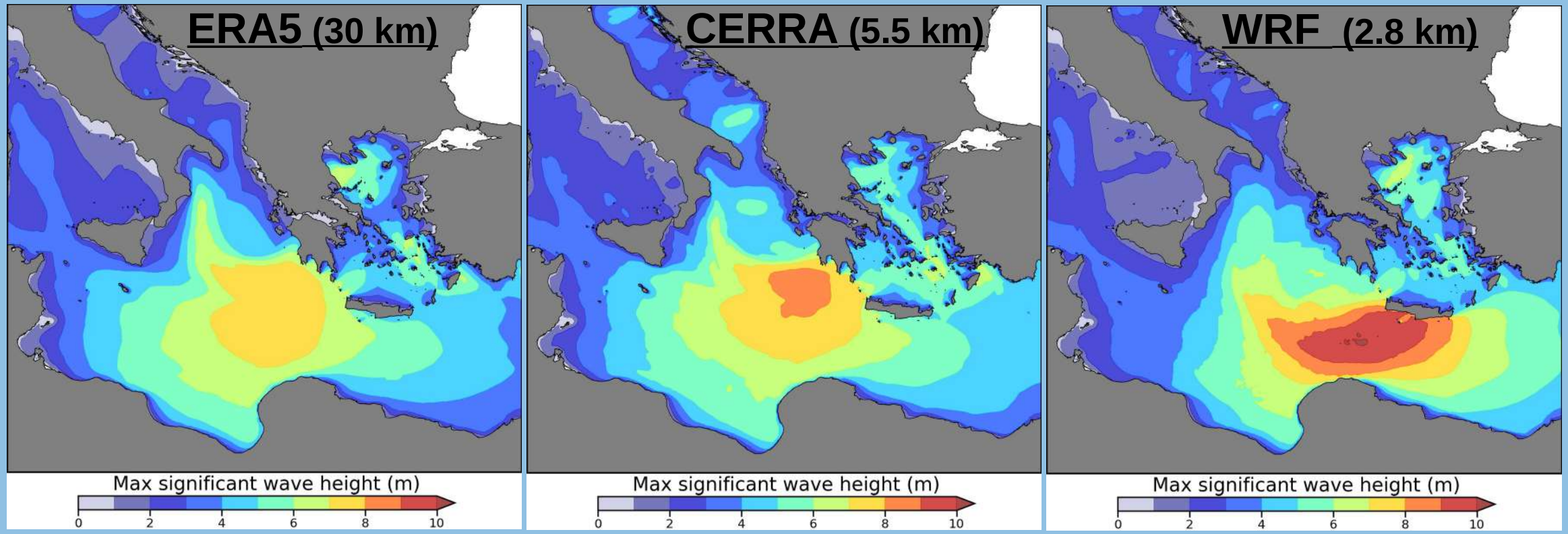
Wave and sea level results



WRF forcing provides a **more severe** open sea and coastal conditions with respect to ERA5 and CERRA.
Results are under validation.



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Conclusions and planned follow-up activities

- CERRA winds and the derived sea levels and waves perform better than ERA5, especially for the most extreme cyclones.
- 1994-2020 model outputs and derived indicators (TSWE and others, SPI) form a precious dataset for evaluating the cyclone hazard in the Mediterranean Sea

- Hazard-based cyclone classification will be performed and compared with meteo-based clusters (Kotsias et al., 2023; Givon et al., 2023)
- Future developments towards fully coupled meteo-wave-ocean modelling systems.

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Thank you for your attention

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MEDcyclones

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COST action

Ferrarin et al (2023), Assessing the coastal hazard of medicane Ianos through ensemble modelling, Nat. Hazards Earth Syst. Sci., 23, 2273–2287, doi: 10.5194/nhess-23-2273-2023
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Givon et al. (2023), Process-based classification of Mediterranean cyclones using potential vorticity, doi: 10.5194/egusphere-2023-1247
Kotsias et al. (2023), Objective climatology and classification of the Mediterranean cyclones based on the ERA5 …, Theo. App. Clim, doi: 10.1007/s00704-023-04374-8

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