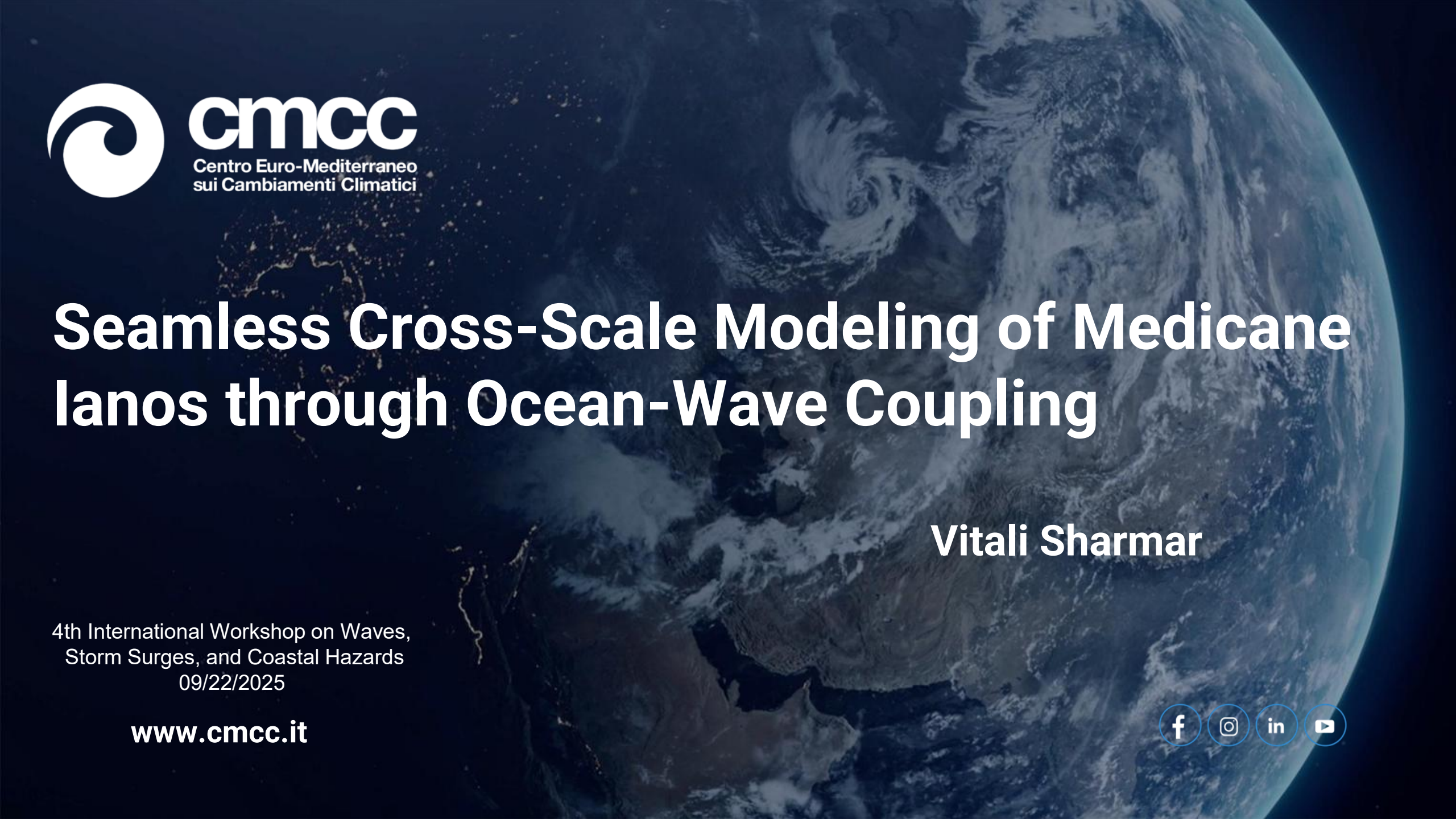

Seamless Cross-Scale Modeling of Medicane Ianos through Ocean-Wave Coupling

Vitali Sharmar

4th International Workshop on Waves,
Storm Surges, and Coastal Hazards
09/22/2025

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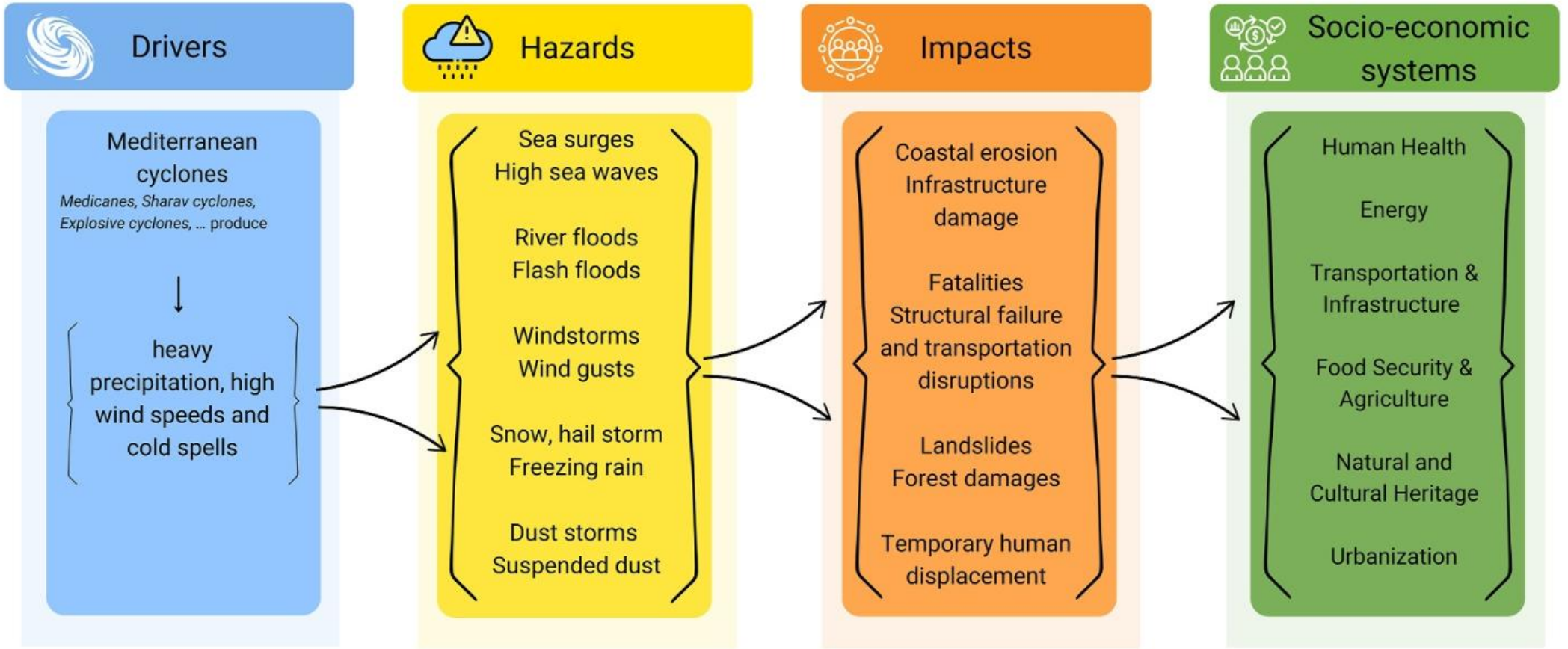
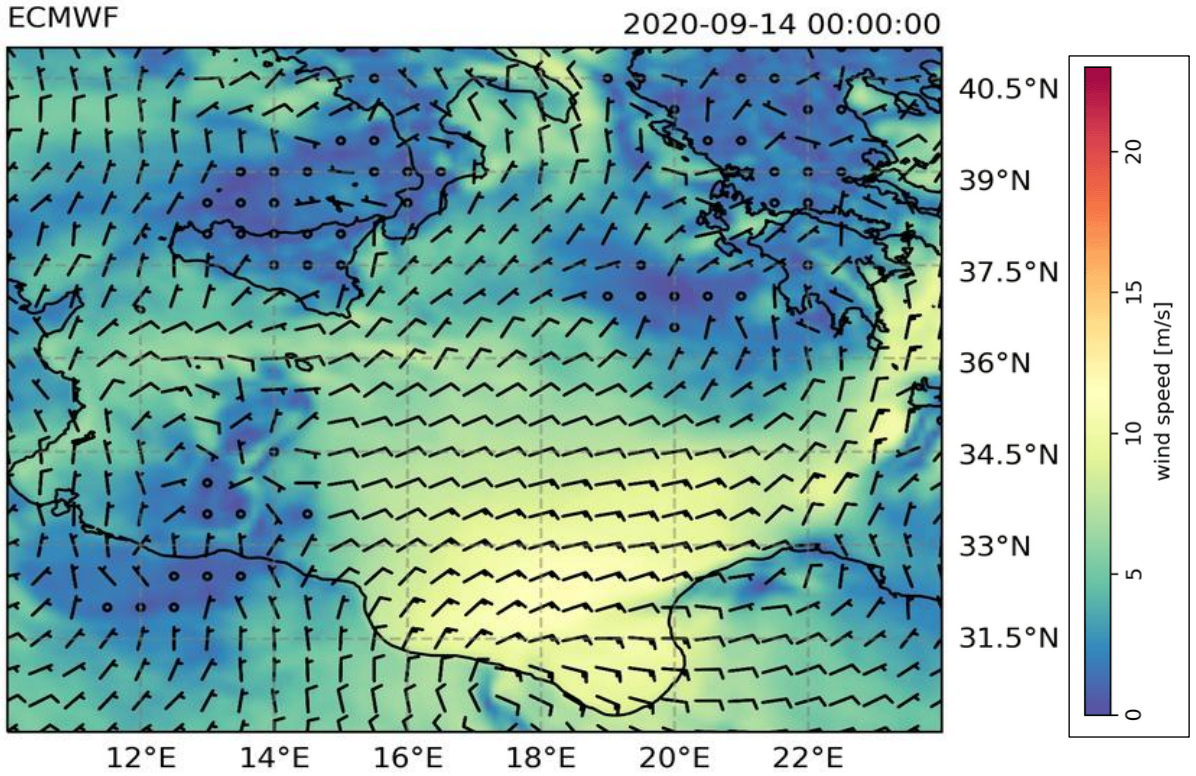
Motivation


Drivers
Mediterranean cyclones
Medicanes, Sharav cyclones, Explosive cyclones, ... produce
heavy precipitation, high wind speeds and cold spells
Hazards
Sea surges
High sea waves
River floods
Flash floods
Windstorms
Wind gusts
Snow, hail storm
Freezing rain
Dust storms
Suspended dust
Impacts
Coastal erosion
Infrastructure damage
Fatalities
Structural failure and transportation disruptions
Landslides
Forest damages
Temporary human displacement
Socio-economic systems
Human Health
Energy
Transportation & Infrastructure
Food Security & Agriculture
Natural and Cultural Heritage
Urbanization

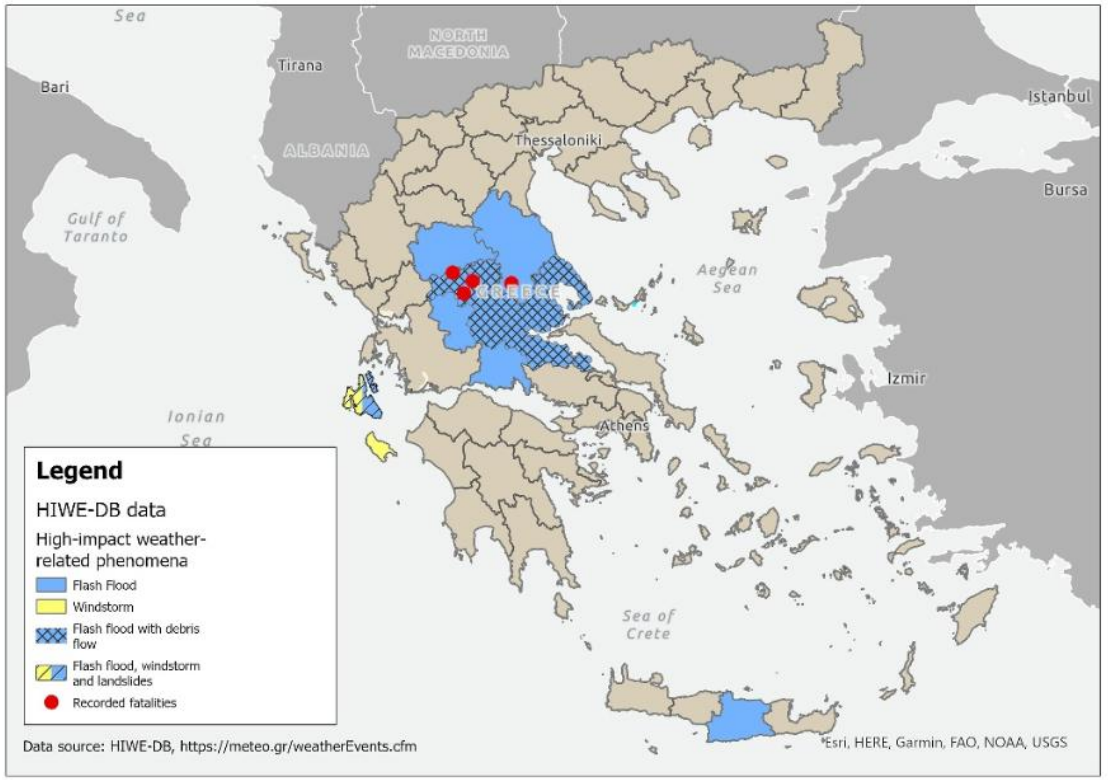
Aim of this study

To provide investigations through high-resolution circulation and wave modeling of:

- **remote open-ocean** pattern and the Medicane fingerprint
- **wave-induced surface stress and** contribution of **wave setup to coastal storm surge**



10 m wind during Medicane Ianos



The hazards and the impacts

Modeling framework

Circulation and wave models domains are based on downscaling of unstructured grids (2km in open sea to 50m in coastal zone), which have the advantages to set a multi-resolution in the same domain in a seamless fashion

Atmospheric forcing

Analyses (with 6h-freq) provided by European Centre for Medium-Range Weather Forecasts.
Variables: wind speed at 10m, mean sea level pressure, air and dew point temperature, precipitation and cloud cover.

Open lateral boundary conditions

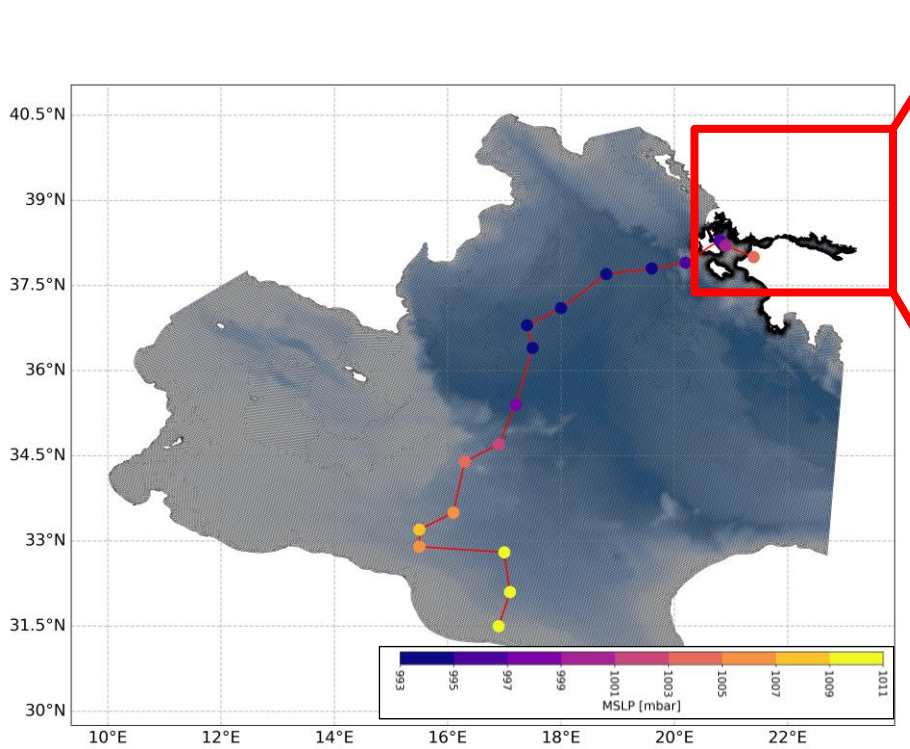
MED/MFC Copernicus for the ocean field
Bathymetric data come from the European Marine Observation and Data Network (EMODnet) http://www.emodnet.eu/bathymetry) and are interpolated onto the computational grid.

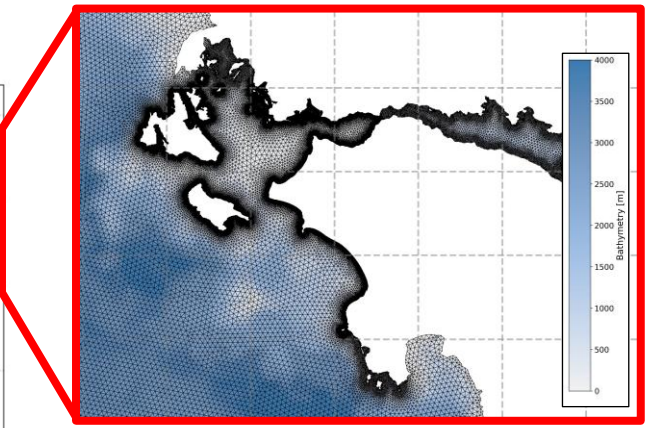
WW3 v6.07 model

- ST4 physics package T741 physics from Ardhuin et al. (2010)
- Spectral resolution: 30 frequencies (0.05–0.7932 Hz), 24 directions
- DIA for non-linear wave interactions
- BETAMAX = 1.43

***SHYFEM-MPI* model**

- Unstructured-grid 3D fully-baroclinic hydrodynamic model
- Applied in operational forecasts for coastal zones (Federico et al., 2017, Micaletto et al., 2022).



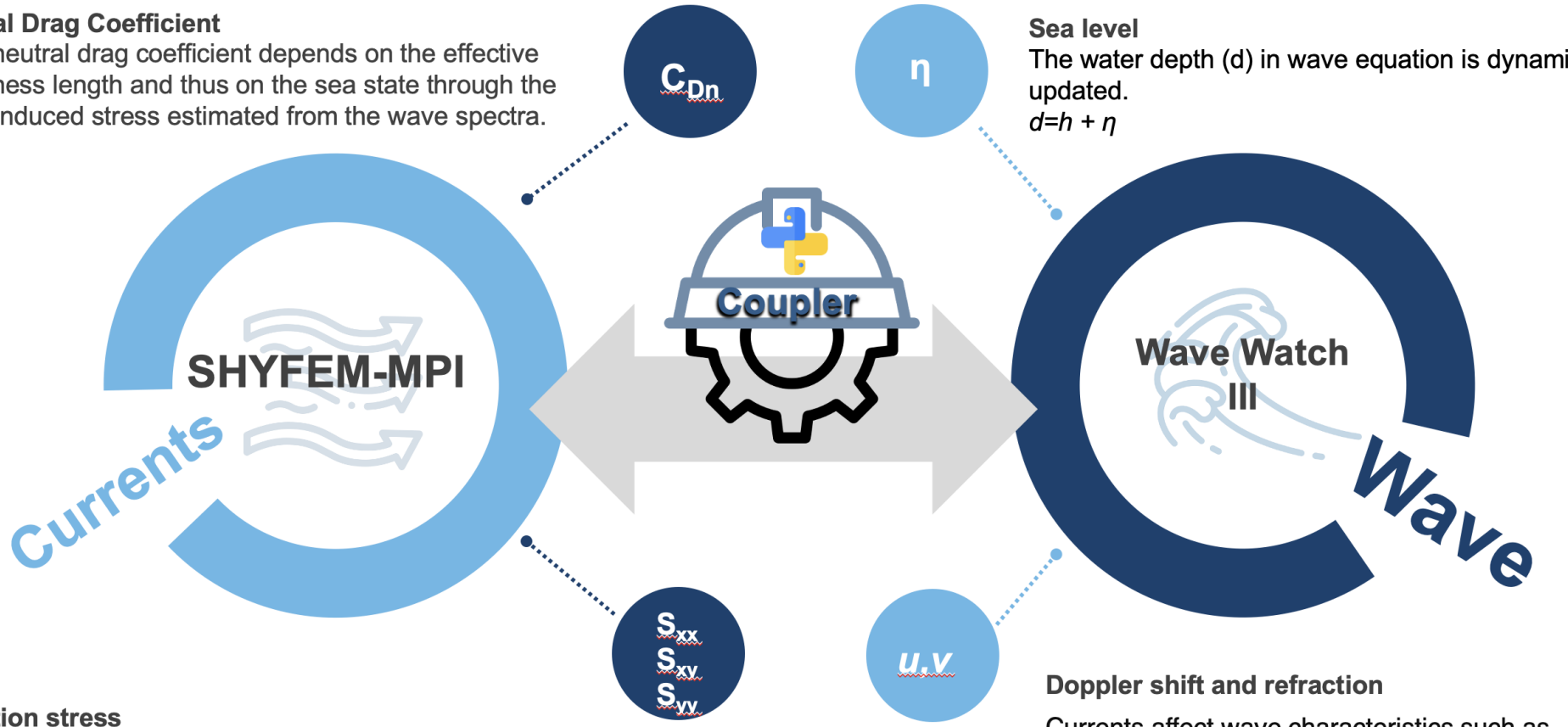


Numerical domain and bathymetry

Coupling tool

Two-way wave-currents coupling

Neutral Drag Coefficient
Wind neutral drag coefficient depends on the effective roughness length and thus on the sea state through the wave-induced stress estimated from the wave spectra.



Sea level
The water depth (d) in wave equation is dynamically updated.
$d=h+\eta$

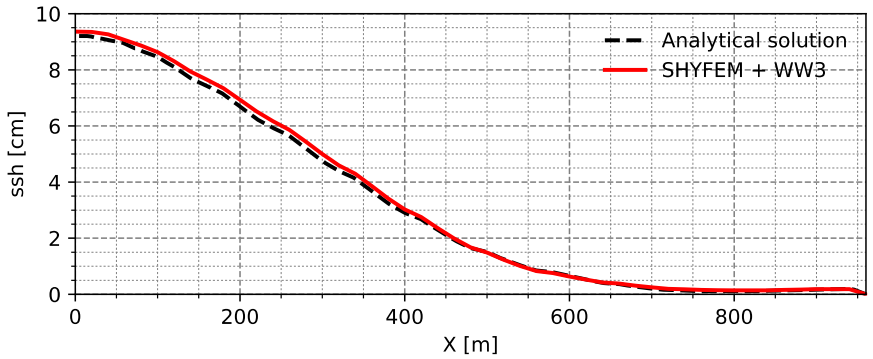
Radiation stress
Waves exert a net force on the water body directed along the wave propagation direction. Excess of momentum flux due to the presence of waves

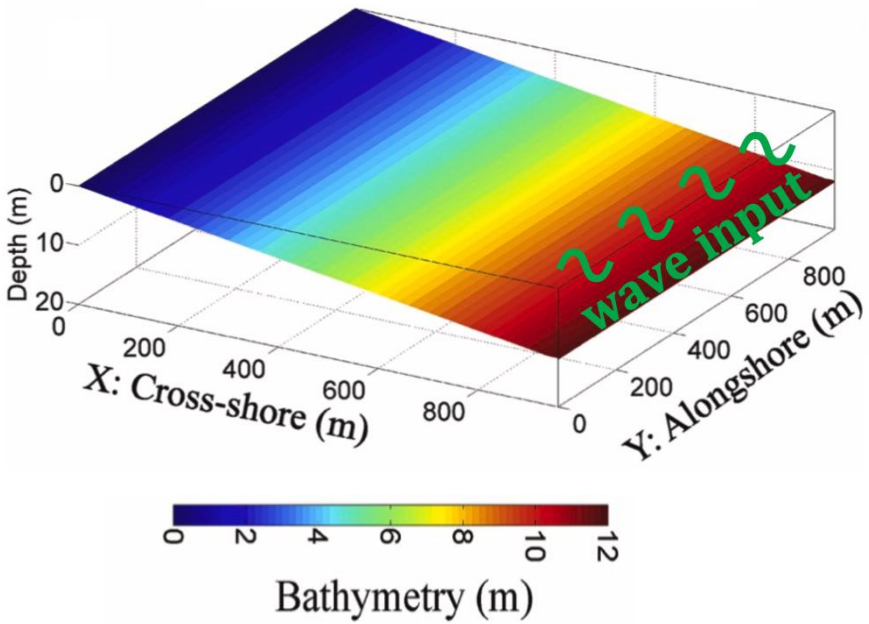
Doppler shift and refraction
Currents affect wave characteristics such as wavelength, amplitude, wavenumber and direction

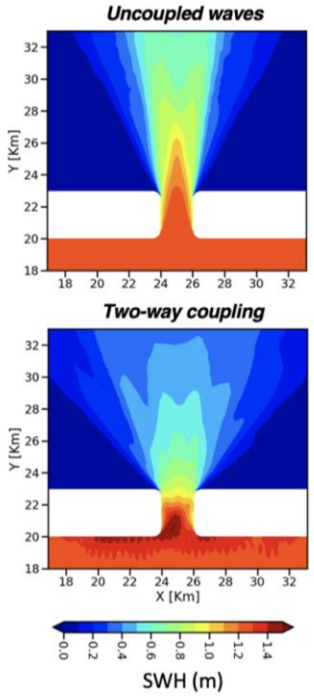
Validation of coupled physics

We adopted to idealized test cases coupled model's physics

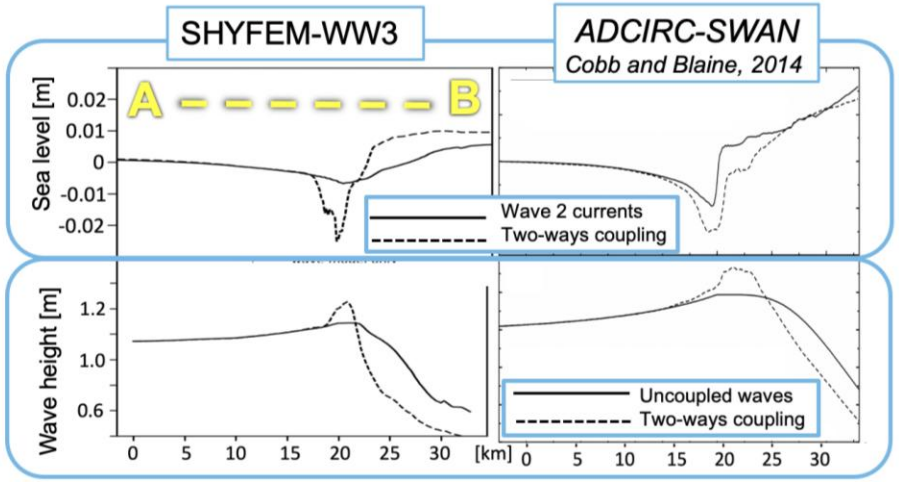
Planar beach

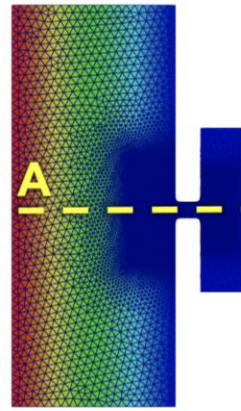






Tidal Inlet





Abbreviation	Description
W-0	Standalone wave model
C-0	Standalone circulation model
W-C	Two-way coupled system wave–circulation
C-WF	Circulation model forced by wave

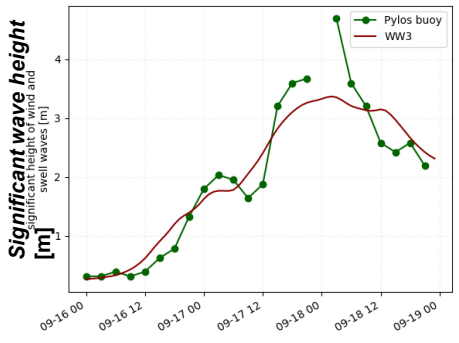
Wave height highest and sharper, which shoals earlier because of an opposing current, as found in literature

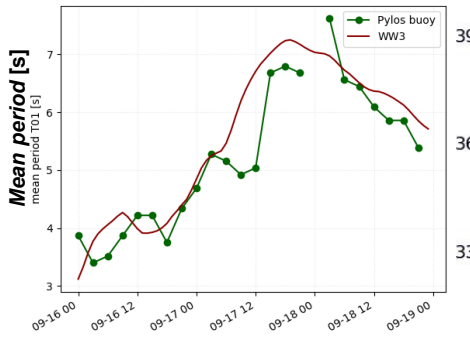
The **wave-induced set-down** and **set-up** are well defined in the two-way coupled case

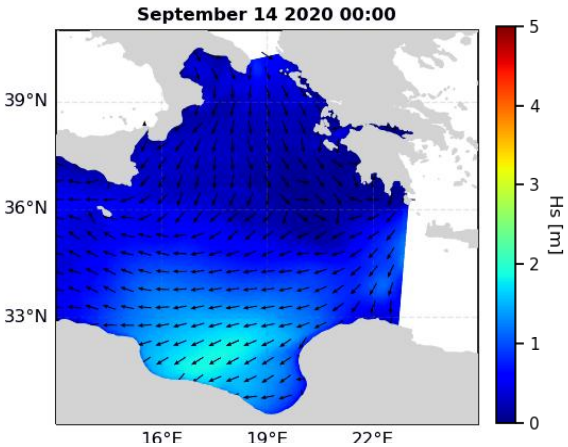
Validation: WW3 vs buoy and altimeters

Validation against buoy

- Multiparametric moored buoy in Pylos managed by HCMR (GR).
- General good agreement (correlation up to 0.95).
- Underestimation of SWH at peak event. Location south-eastern with respect to the event.

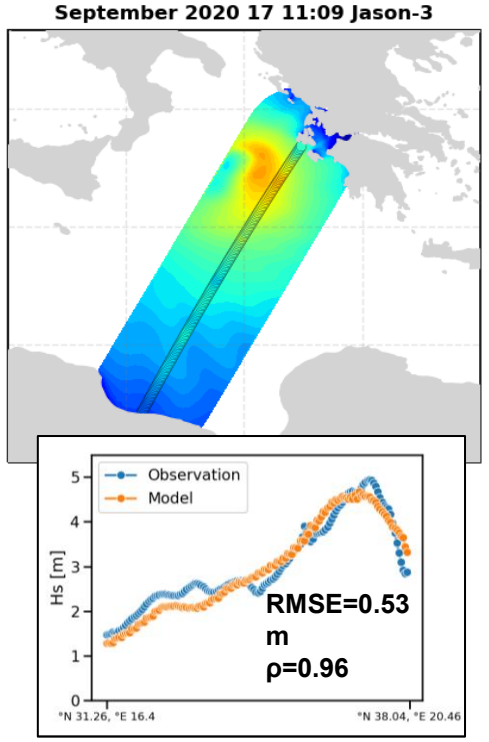


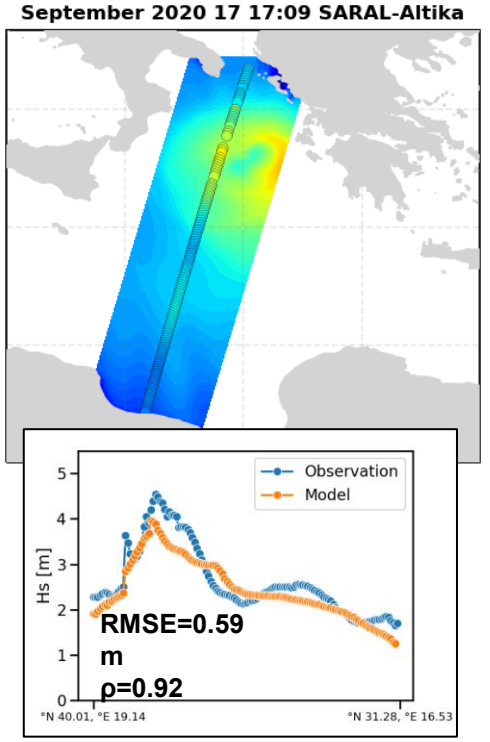


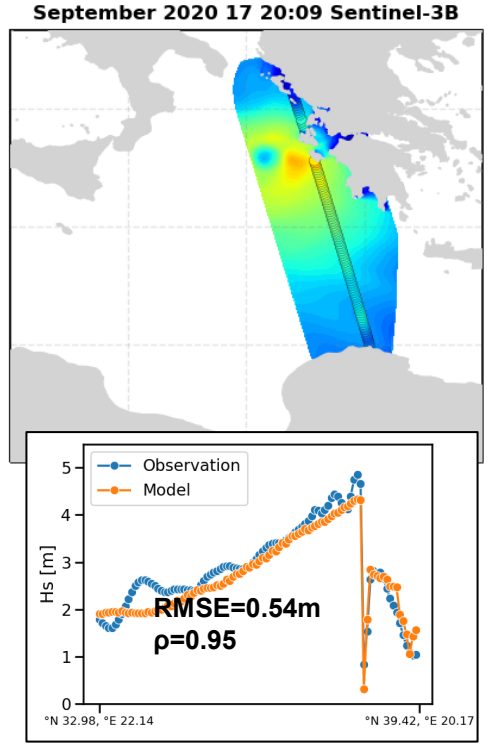


Validation against satellite tracks

- Satellite altimeters (Jason3, Saral-Altika, Sentinel-3b) available in CMEMS catalogue. **Maximum wave heights around 4.5 m**.
- **Good agreement with RMSE up to 0.5m and correlation to 0.96 for Jason-3**. Underestimation of peak for Saral-Altika up to 0.75m.
- **Normalized RMSE shows an error of 14%.** No data assimilation is performed in the modelling system.

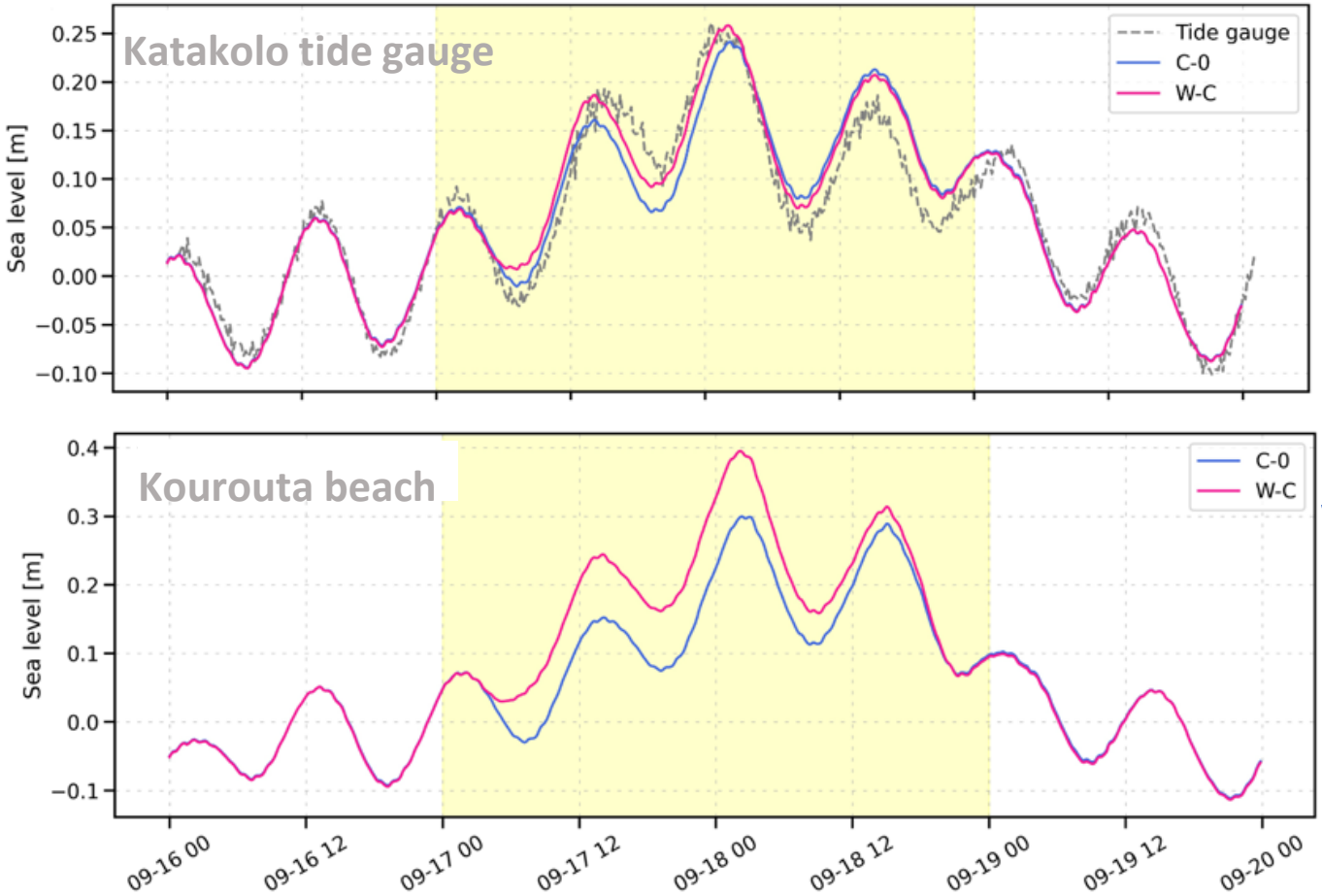




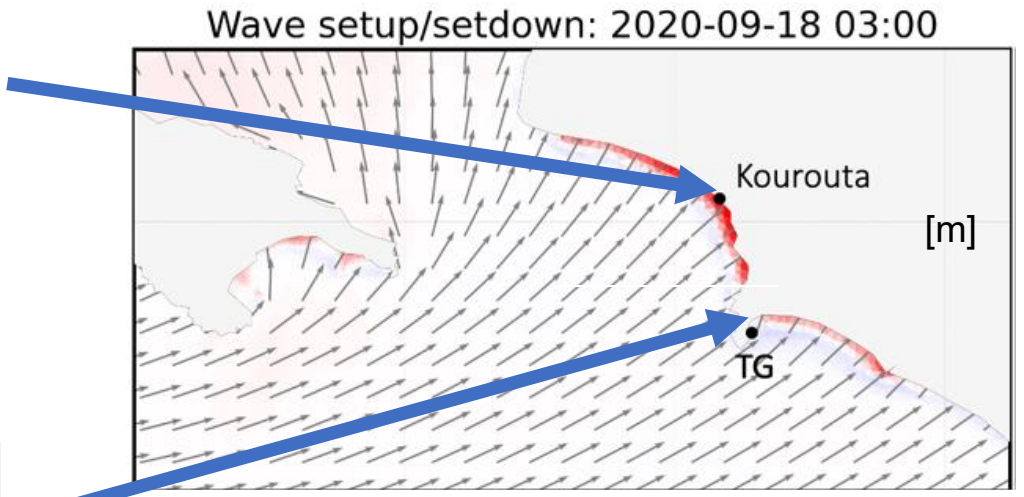


Coastal wave-induced stress and storm surge

Total water level for coupled (W-C) and free run (C-O) are compared with Katakolo tide gauge -TG (gray). Coupling improved the the model accuracy in describing the event. In the bottom panel, the model configurations are compared at the Kourouta beach.



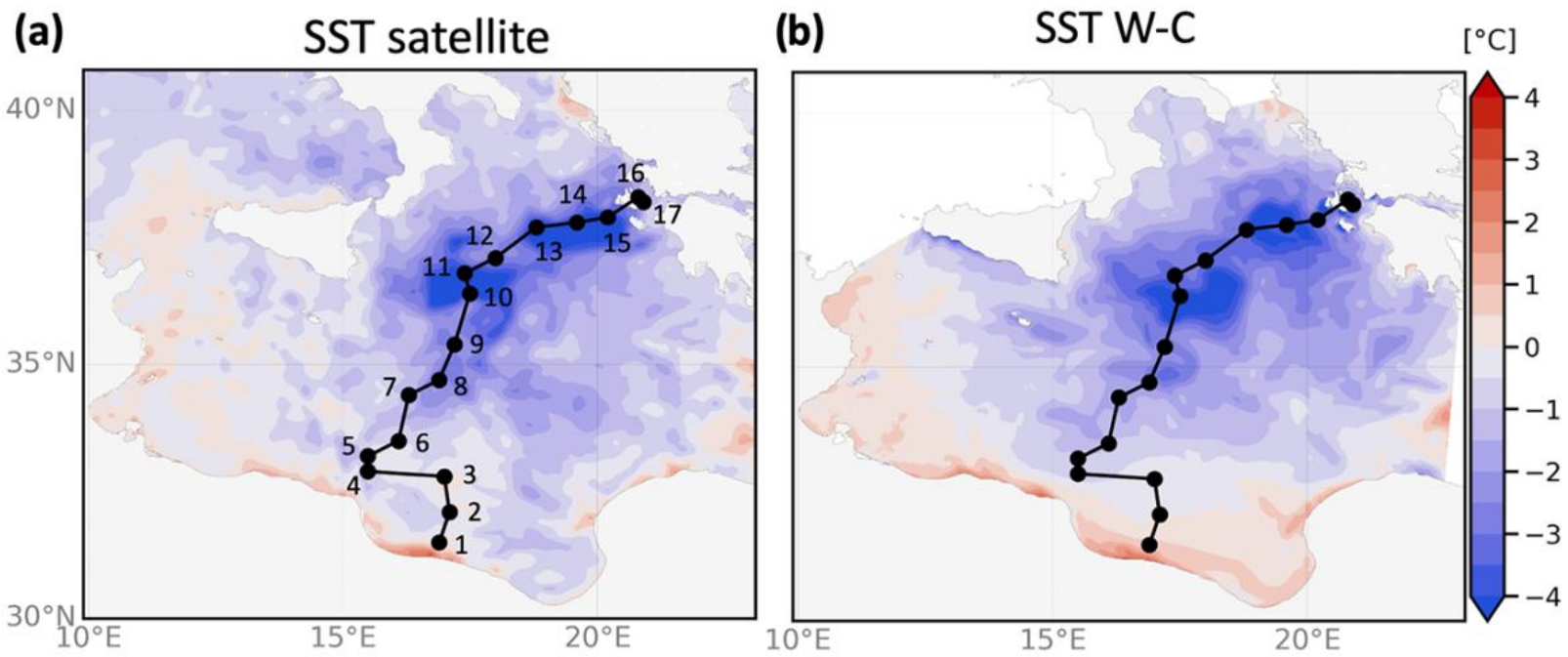
Storm surge during Medicane Ianos



Wave setup and setdown

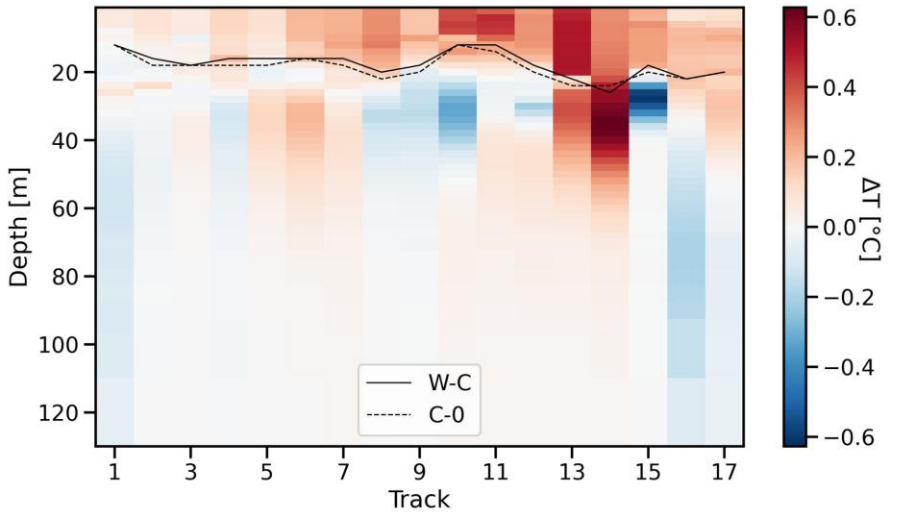
TWL difference between free and coupled runs. Vectors show the mean wave direction. The variability of TWL, considering the wave contribution, could reach 30%.

Coastal wave-induced stress and storm surge



The fingerprint of the Medicane Ianos against the pre-storm condition.

SST decrease due to Medicane Ianos (up to -4.0°C). Slight overestimation of the cooling in comparison with the satellite L4 SST.



Conclusions

- The real-case simulation and comparison of coupled versus uncoupled configurations highlight the added value of incorporating the wave component in storm surge simulations, particularly for coastal applications.
- Notably, during Medicane Ianos, wave setup contributes to approximately 10 % of the sea level variation at the Katakolon tide gauge, with a significantly greater impact – around 30 % – in nearshore areas.
- The impact of circulation on wave dynamics is appreciable, as coupling reduces bias by approximately 6 % and overall error by around 3 % in the wave model.
- Next step will include various physical processes that can modify wave-current interactions (vertical mixing, additional turbulent mixing and etc.)

Causio, S., Shirinov, S., Federico, I., De Cillis, G., Clementi, E., Mentaschi, L., and Coppini, G.: Coupling ocean currents and waves for seamless cross-scale modeling during Medicane Ianos, Ocean Sci., 21, 1105–1123, https://doi.org/10.5194/os-21-1105-2025, 2025.

Acknowledgements

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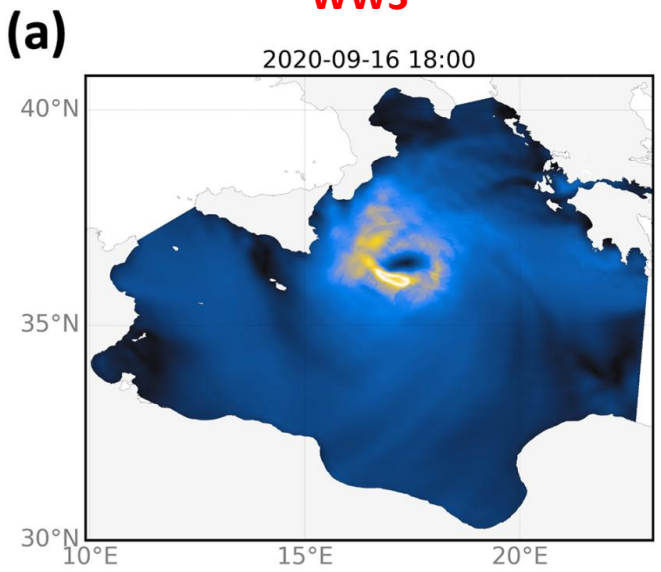
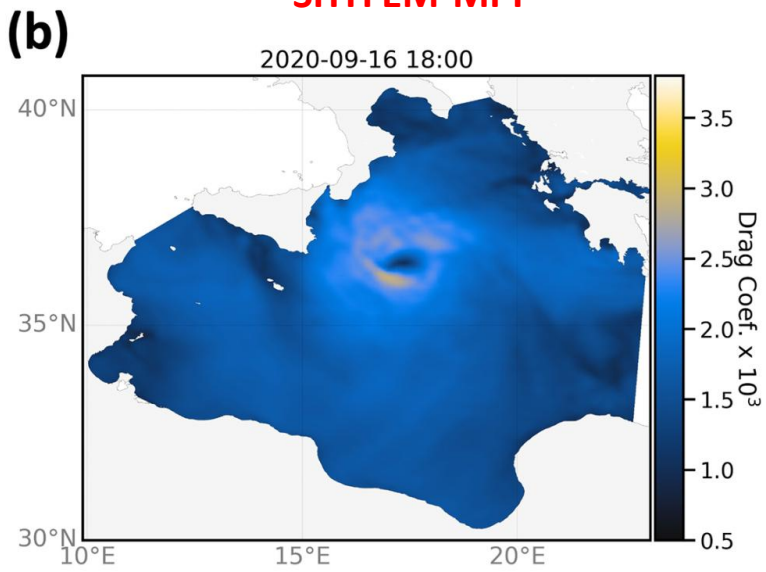
Thanks

Coastal wave-induced stress and storm surge

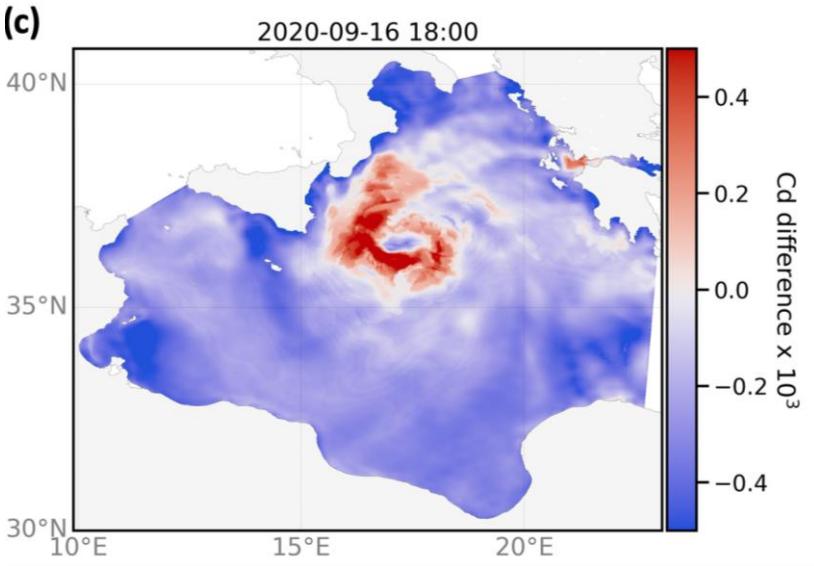
WW3



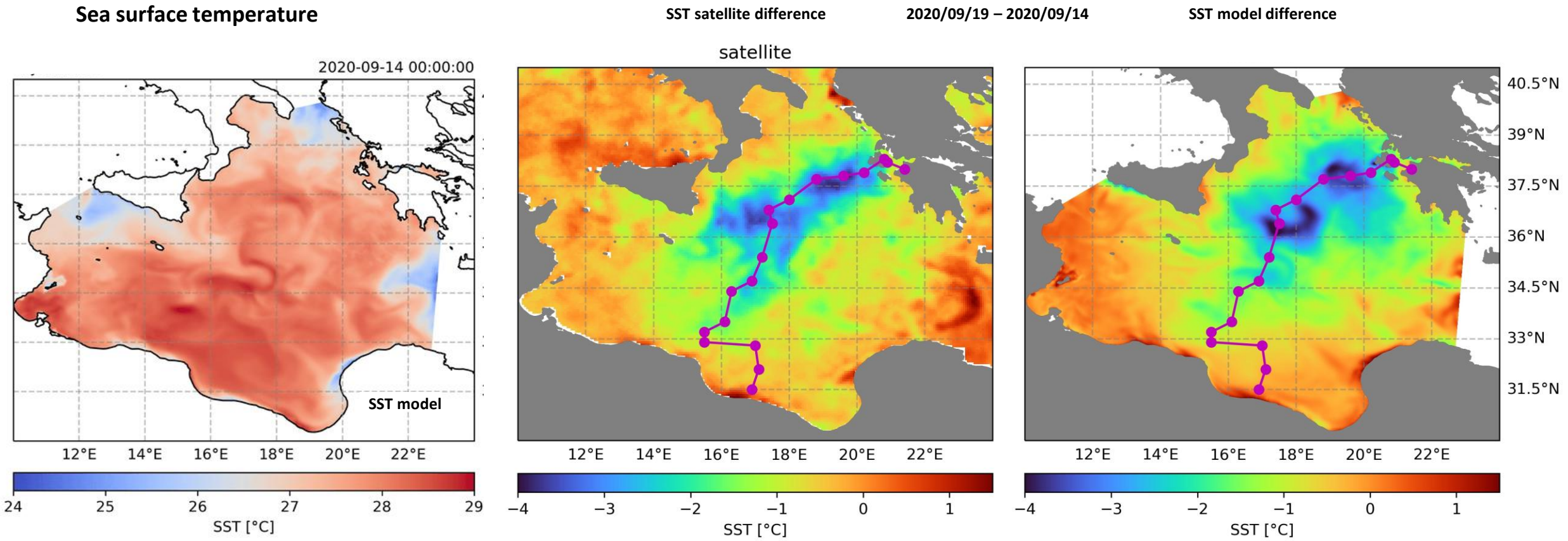
SHYFEM-MPI



WW3 -- SHYFEM-MPI



Validation: circulation model vs satellites



The fingerprint of the Medicane Ianos against the pre-storm condition.

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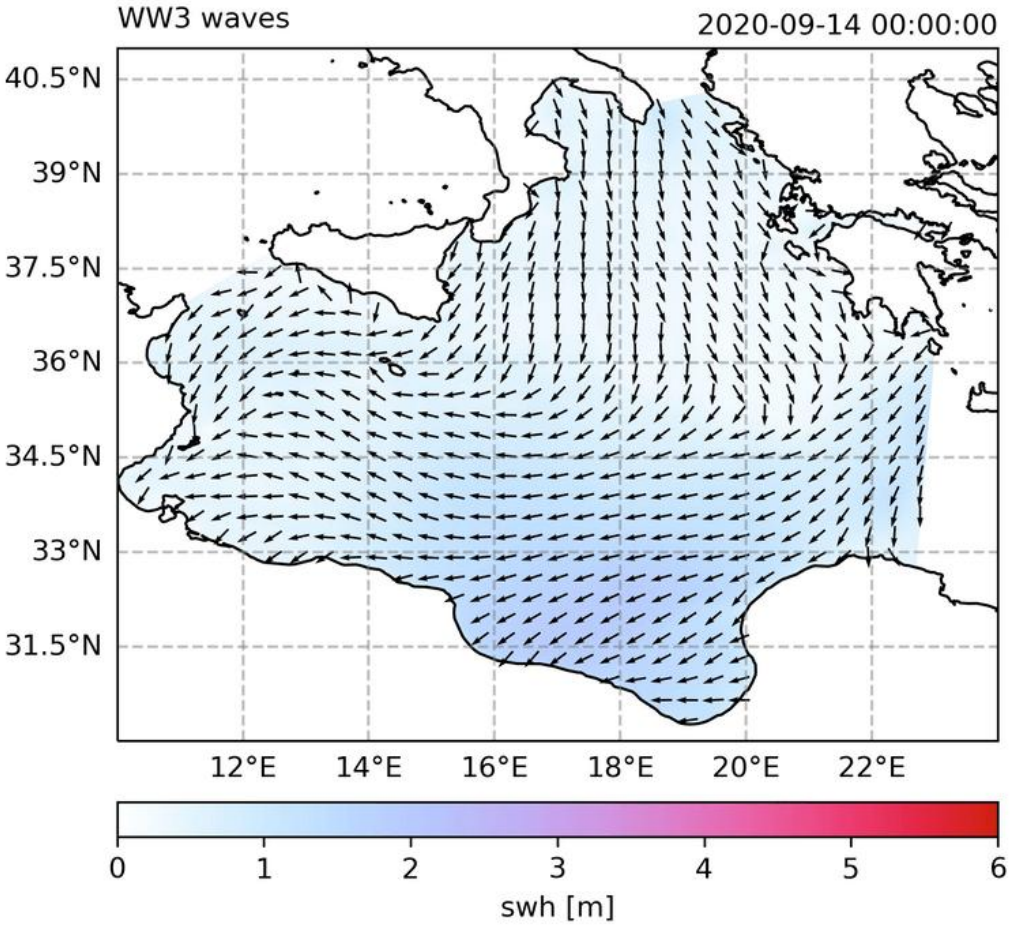
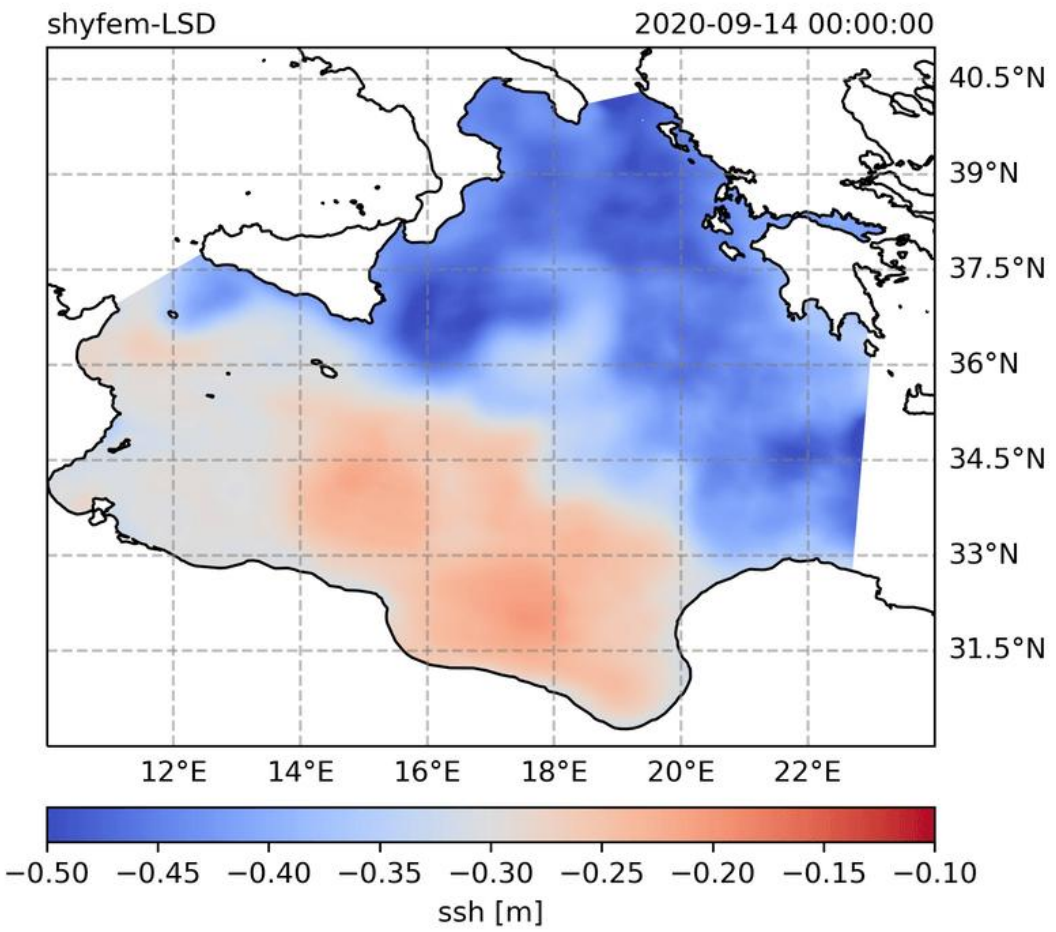
Results

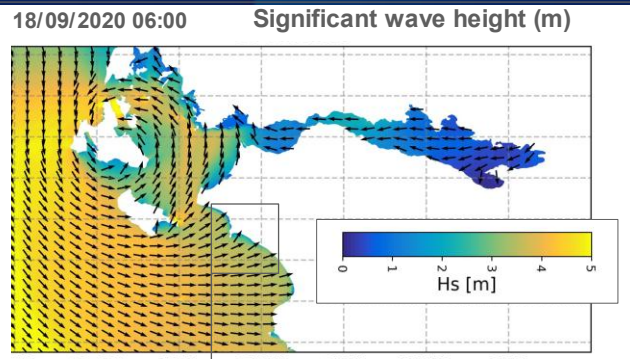
WW3 significant wave height

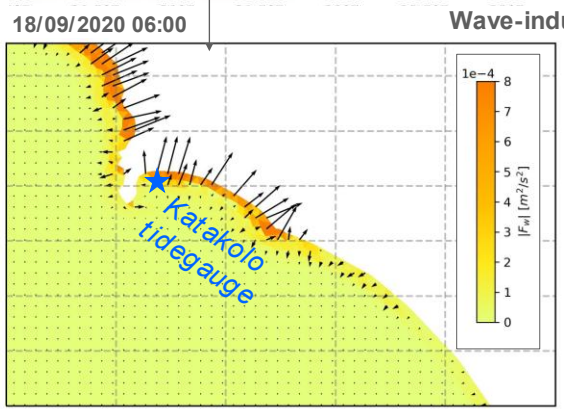


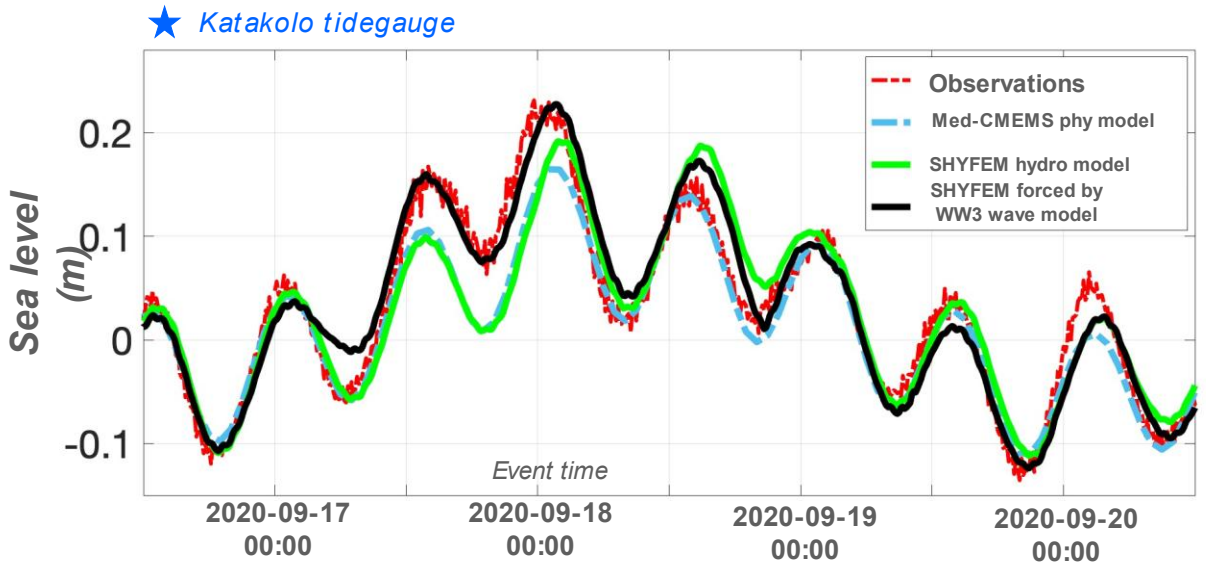
SHYFEM sea surface height



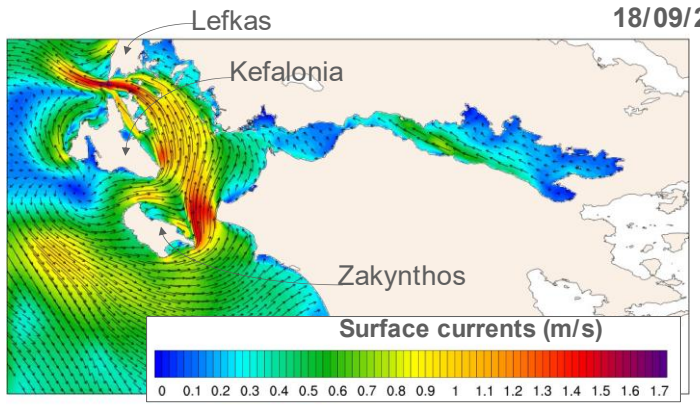
Coastal wave-induced stress and storm surge

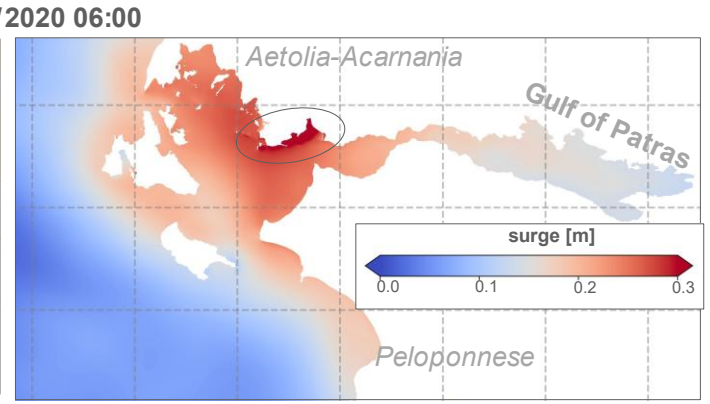






Comparison between **Med-CMEMS phy** model, **SHYFEM (only) hydrodynamic** model and **SHYFEM hydrodynamic model forced by radiation stress of WW3 wave model**, against tidegauge observation in Katakolo station.
High resolution coastal model improves capability in **capturing the peak event**, well highlighted by the system including **wave contribution** (~20% of total sea level) both in terms of sea level peak and phase.
Worsening accuracies of coastal models in forming and decaying of the event need to be investigated.





Coastal circulation resembles the cyclonic pattern of the hurricane, with **highest intensity** between Kefalonia and Lefkada, and in eastern waters of Zakynthos.

Maximum surge levels are evident in coastal zone of southern part of Aetolia-Acarnania at the entrance of the Gulf of Patras.