Storm surge modelling and forecasting of Mediterranean tropical-like cyclone

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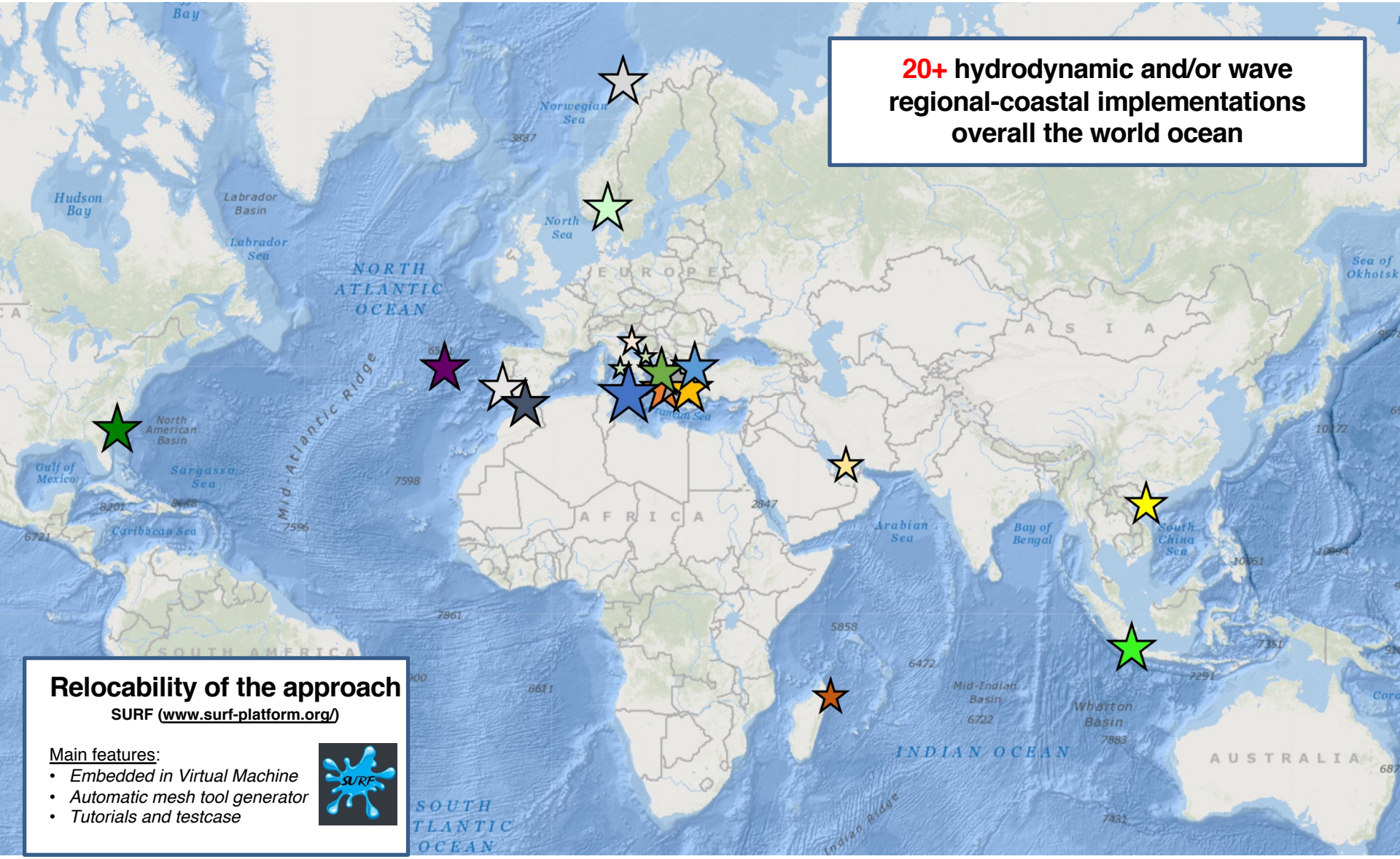
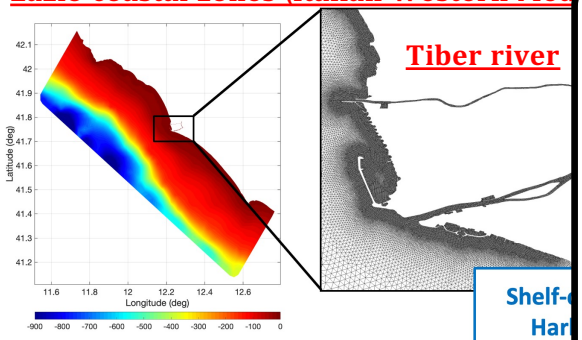
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Coastal modelling at CMCC: downscaling from CMEMS, operational forecasting, on-demand relocability



Coastal modelling at CMCC: downscaling from CMEMS, operational forecasting, on-demand relocability

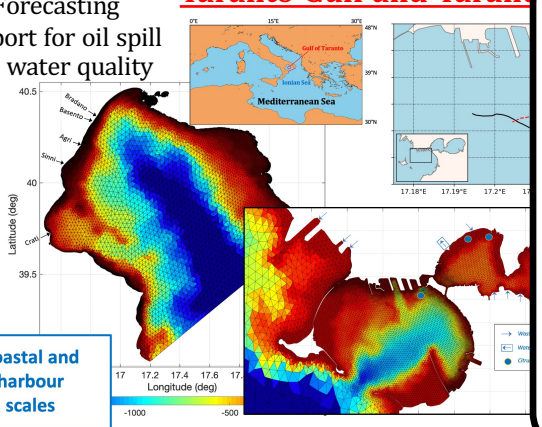
Lazio coastal zones (Italian Western Med



Operational Forecasting
Support for sediment transport dynamics

Taranto Gulf and Tarant

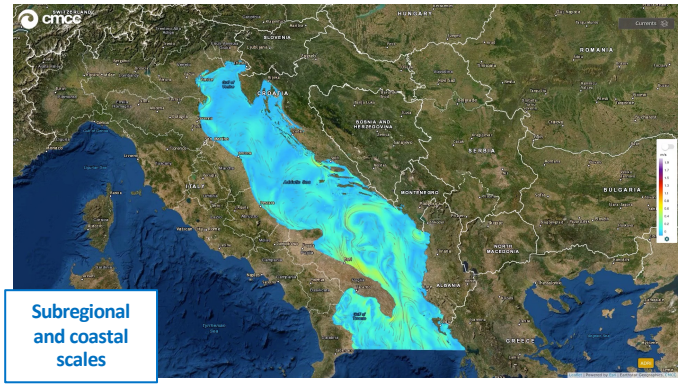
Forecasting
Support for oil spill and water quality



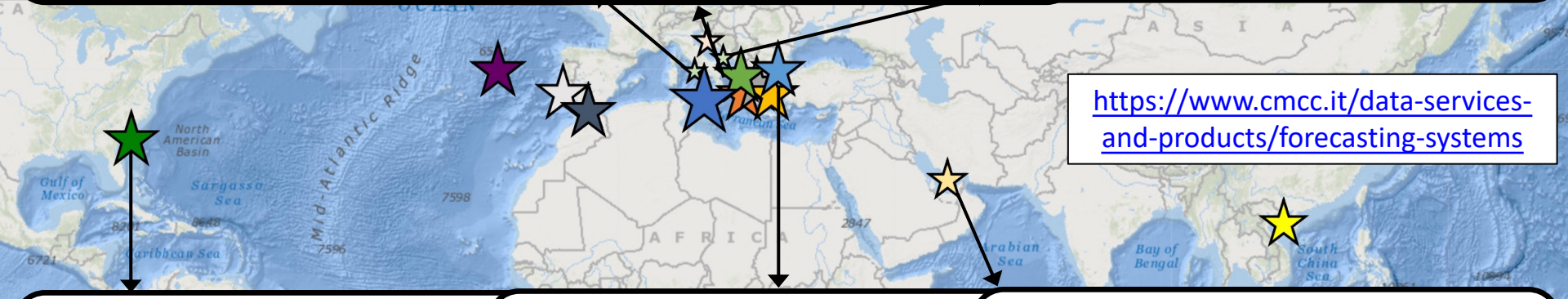
Coastal and harbour scales

Adriatic Sea

Operational Forecasting
Storm surge modelling

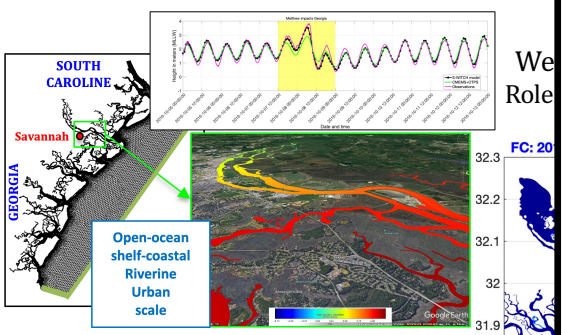


Subregional and coastal scales



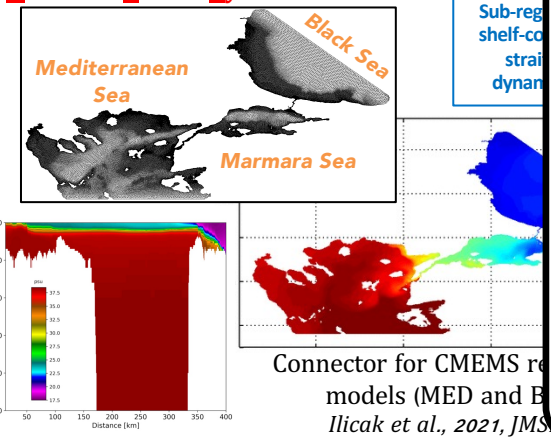
https://www.cmcc.it/data-services-and-products/forecasting-systems

South Atlantic Bight (Savannah, Georgia,



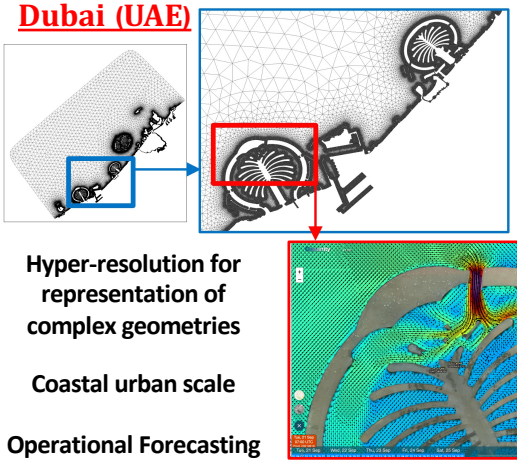
Storm surge induced by Matthew and Dorian Hurricanes (Park et al., 2022, Ceng)

Turkish Strait System



Connector for CMEMS re
models (MED and B
Ilicak et al., 2021, JMS

Dubai (UAE)



Hyper-resolution for representation of complex geometries

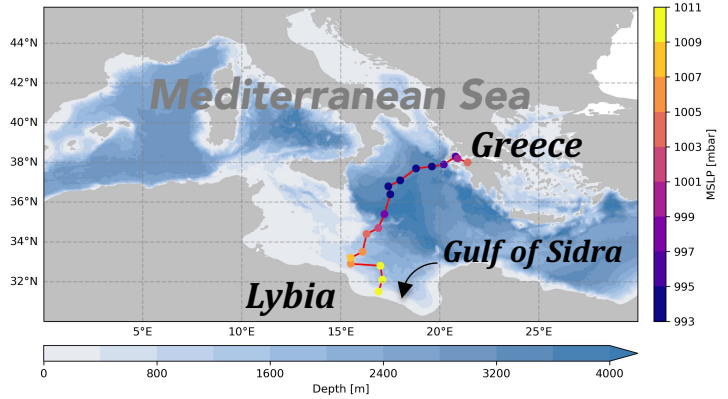
Coastal urban scale

Operational Forecasting

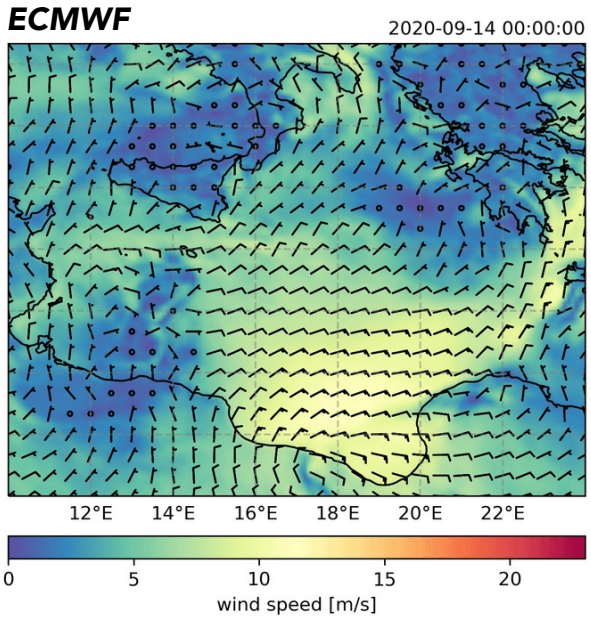
The Medicane "Ianos" in September 2020

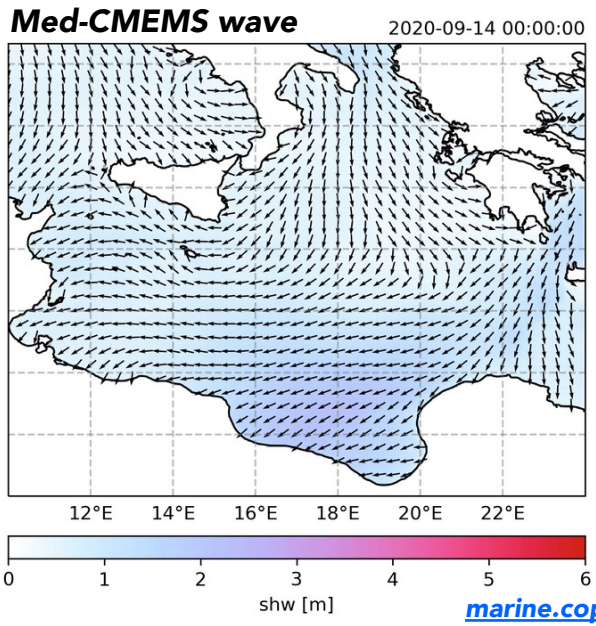
Medicanes ('Mediterranean-Hurricanes') are intense **cyclonic** systems resembling **tropical** storms that form over the **warm waters** of the **Mediterranean sea**, mostly during the **autumn and early winter** months (Smart, 2020).

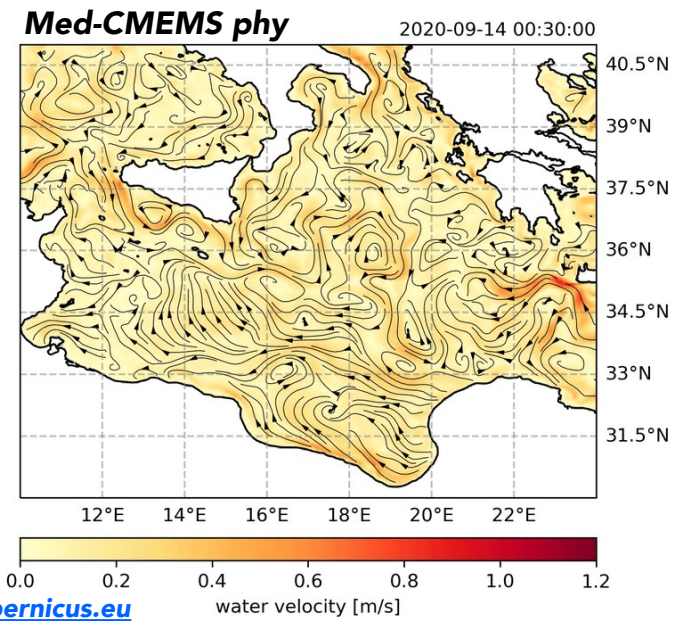
Medicane Ianos is one of the **strongest storms recorded since 1969** (in terms of duration and intensity), causing **wind gusts reaching 110 km/h**, heavy rainfall, **storm surge and flooding**, damages and death (Zekkos et al., 2019).



OBJECTIVE: investigation via high-resolution hydrodynamic and wave numerical ocean models on:
- **remote open-ocean pattern** and Ianos medicane fingerprints
- local **coastal features** and **storm surge**
- contribution of **wave-induced surface stress to the storm surge**







marine.copernicus.eu

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Wave and hydrodynamic ocean modelling set-up

Waves

WAVEWATCH-III model

Third-generation wave model (NOAA/NCEP), solving the random phase spectral action density balance equation for wavenumber-direction spectra. V6.07 version based on unstructured meshes and sources/sinks terms for coastal processes. Boundary forcing via Med-CMEMS wave model (marine.copernicus.eu)

Hydrodynamics

SHYFEM model

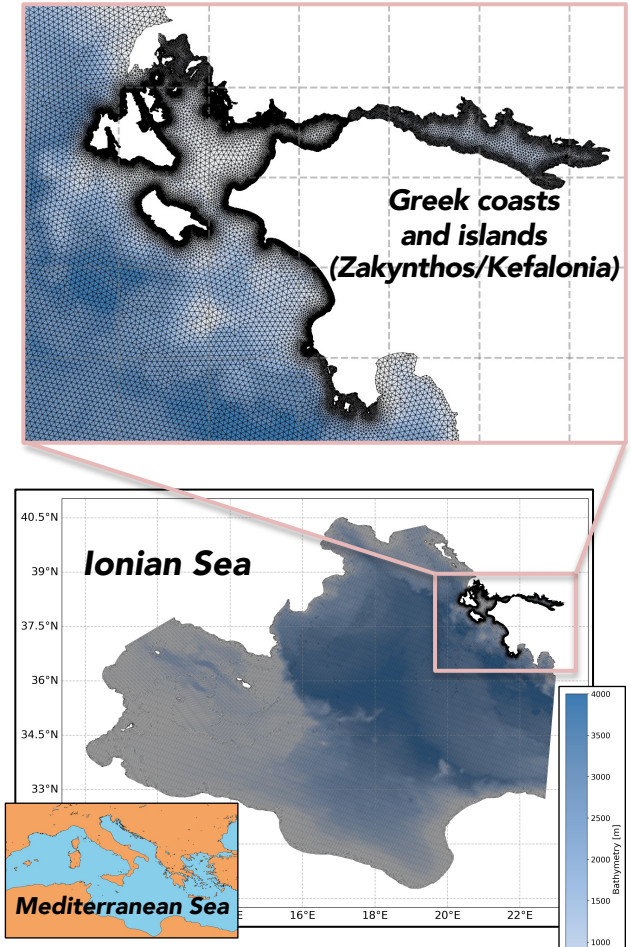
Unstructured-grid 3D fully-baroclinic hydrodynamic model (Umgiesser et al., 2004). Operational forecasts for coastal zones (Federico et al., 2017). Relocability in several world ocean coastal areas (Trotta et al., 2021). Already applied for hurricanes in SAB (Park et al., 2022). Boundary forcing via Med-CMEMS phy model (marine.copernicus.eu)

Atmospheric forcing

ECMWF 0.10°

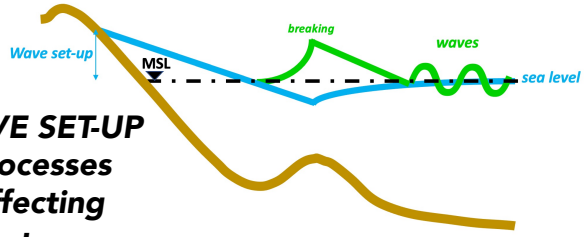
Analyses (with 6h-freq) provided by European Centre for Medium-Range Weather Forecasts.
Variables: wind speed at 10m, mean sea level pressure, air and dew point temperature, precipitation and cloud cover.

Wave and hydrodynamic models on the same horizontal unstructured grid, with resolution ranging from 2km in open sea to 50m in coastal zone



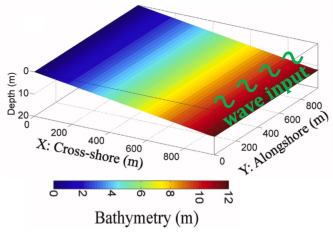
Coupling

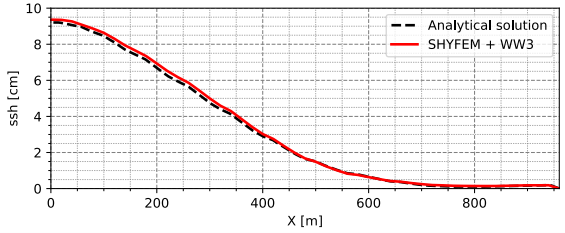
Waves-to-currents forcing via Radiation Stress theory of Longuet-Higgins and Stewart



WAVE SET-UP processes affecting coastal storm surge

Verification with idealized testcase: planar beach

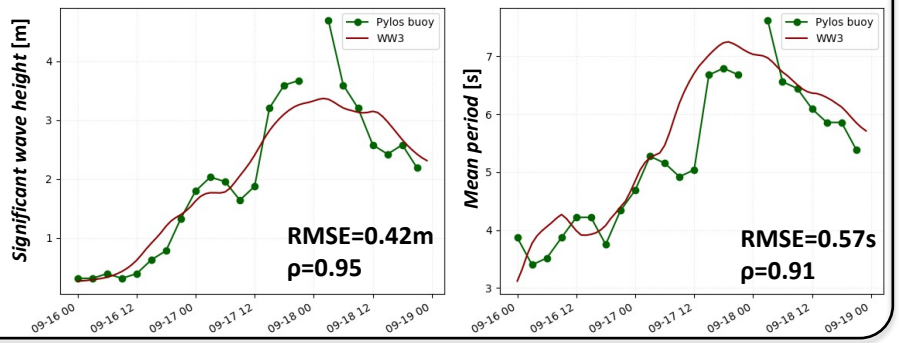


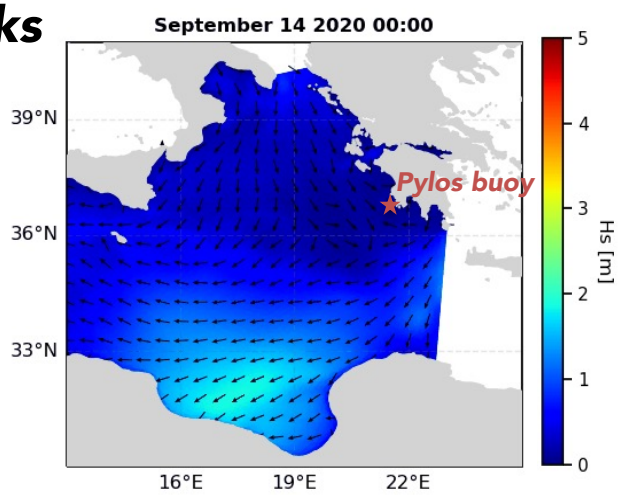


Waves: model validation with buoy and satellite tracks

Validation against moored wave buoy at Pylos station

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.*



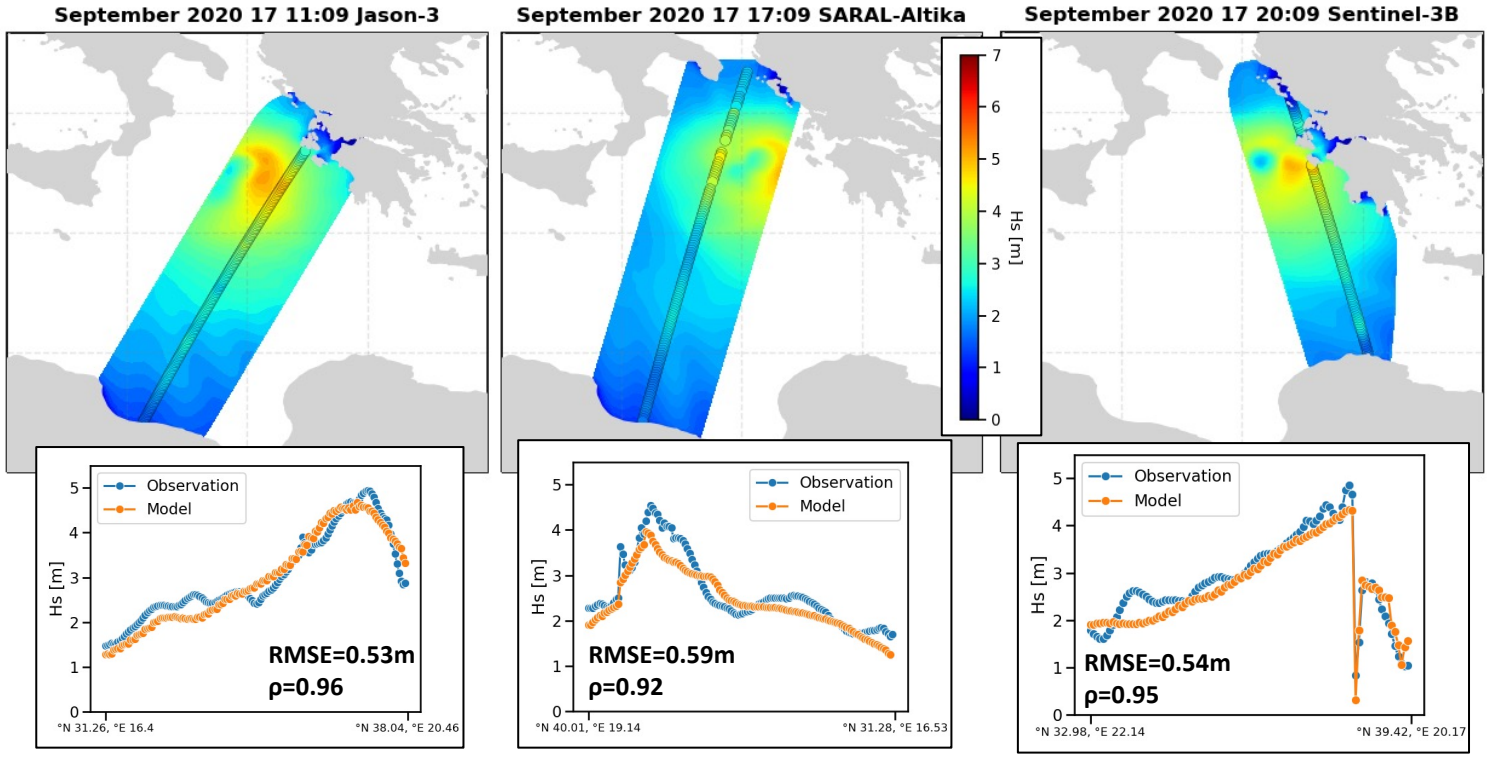


Validation against satellite tracks

Satellite altimeters (Jason3, Saral-Altika, Sentinel-3b) available in CMEMS catalogue. ***Maximum wave heights around 4.5 m****.*

Good agreement with RMSE up to 0.53m 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.*



Hydrodynamics: open-ocean patterns, coastal wave-induced stress and storm surge

The fingerprint of the Medicane Ianos on the sea surface temperature.

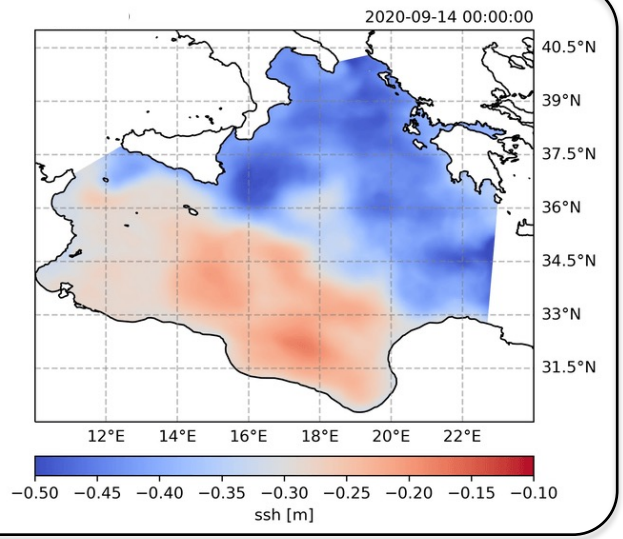
Analysis against the pre-storm condition.

*Between 2020/09/14 and 2020/09/19, an SST decrease due to Medicane Ianos (**up to -4.0 °C**) was simulated by the model, with slight overestimation of the cooling in comparison with the **satellite L4 SST** dataset available in CMEMS catalogue.*

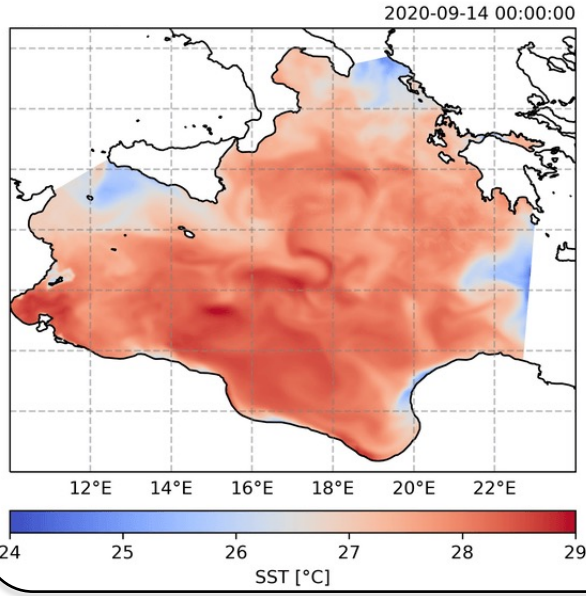
Sea surface height

Clear pattern of the Medicane Ianos on sea surface height**. The strongest signal on sea surface height occurred between the 2020-09-16 12:00 and 2020-09-17 12:00. **Total sea level (surge and tides) reached 0.7m.

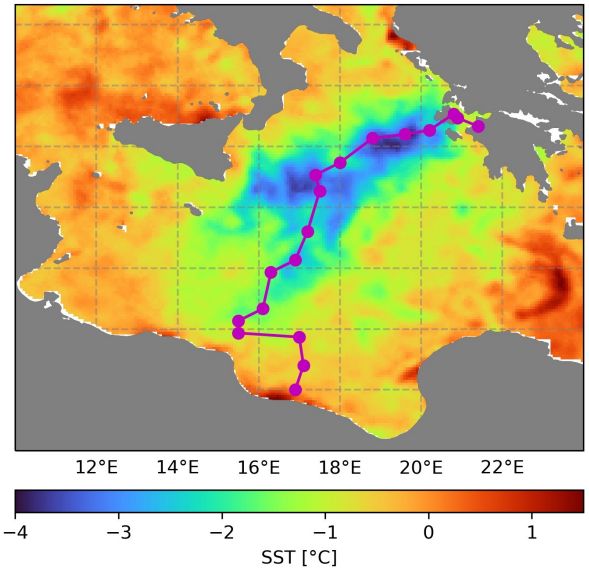
*Then, the cyclone moved eastwards. **On 2020-09-18 00:00-06:00, the Medicane Ianos hit the coasts of the Ionian Greek islands and coasts.***



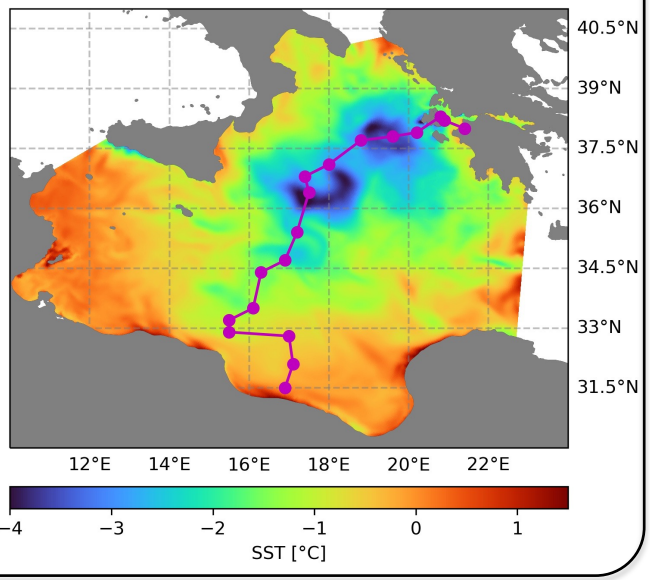
Sea surface temperature model



SST satellite difference 2020/09/19 – 2020/09/14



SST model difference 2020/09/19 – 2020/09/14



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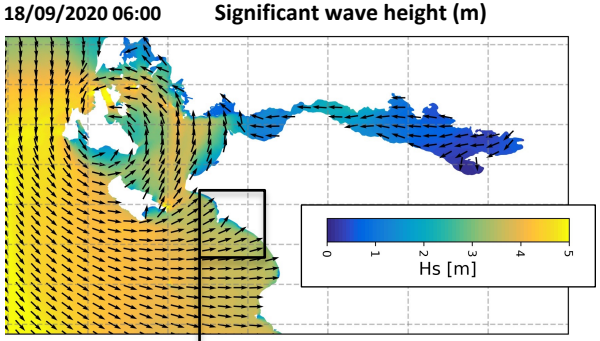
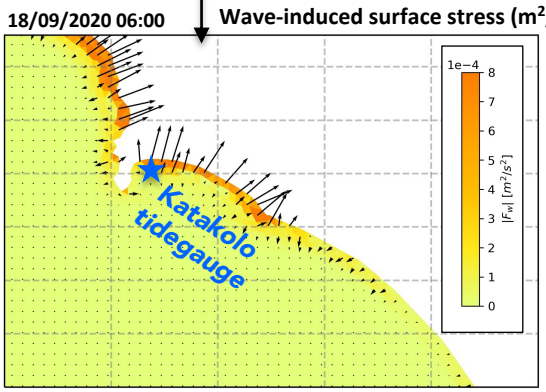
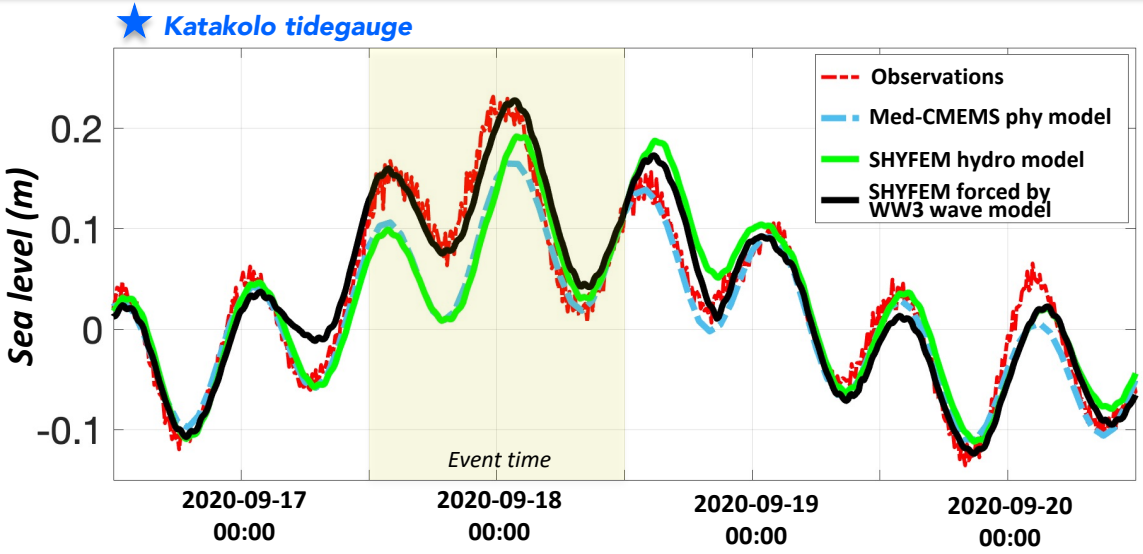
Hydrodynamics: open-ocean patterns, coastal wave-induced stress and storm surge

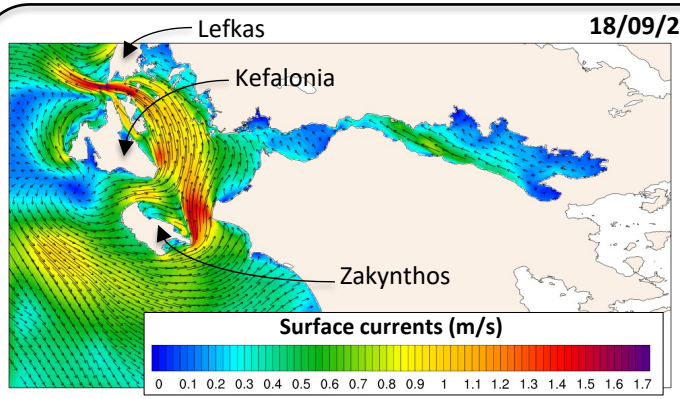


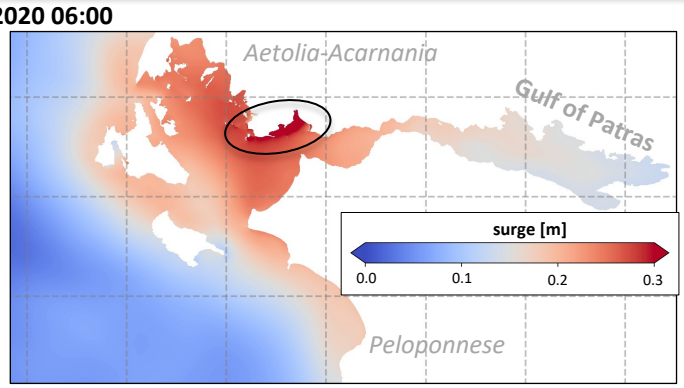




Comparison between **Med-CMEMS phy** model, **SHYFEM (only) hydrodynamic** model and **SHYFEM hydrodynamic model forced by radiation stress of WW3 wave model**, against tidegauge observation in Katakolo station.

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.

Conclusions

- **High-resolution seamless (from open- to coastal- scale) modelling of ocean conditions during the passage of Medicane Ianos**
- **The validation in open ocean, the remote forcing and the fingerprint of the Medicane**
- **The role of wave contribution in storm surge representation (up to 20%) and the validation with in-situ coastal observations**

Next steps

- **Two-way wave-current coupling: radiation stress and drag coefficient from-waves-to-hydro; sea level and currents from-hydro-to-waves.**
- **Methodology could be further enhanced by means of specific downstream applications and decision support systems, oriented to provide early waning and rapid alert in case of extreme sea level short-term forecasts.**

Thank you!

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