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How does ocean-wave-atmosphere interaction affect Medicane intensity? A coupled model study based on Ianos (2020)

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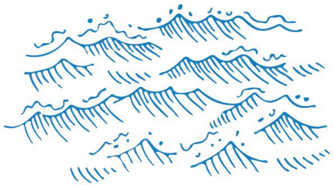
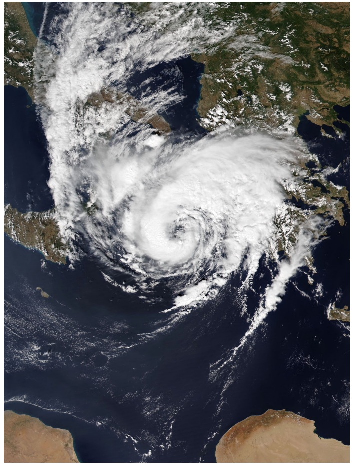


Ocean

Ocean provides heat energy to the cyclone (enthalpy heat fluxes)

Cyclone provides mechanical energy to the ocean (wind forcing)



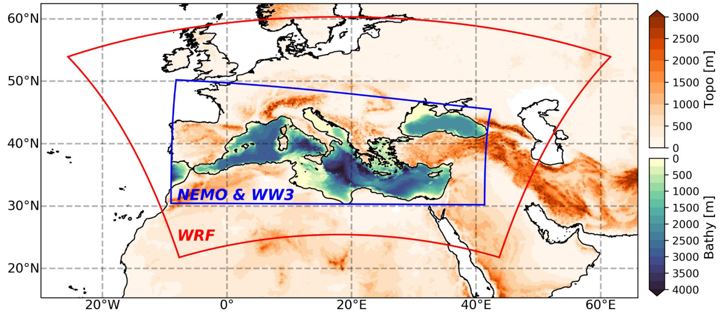
Medicane Ianos (2020)

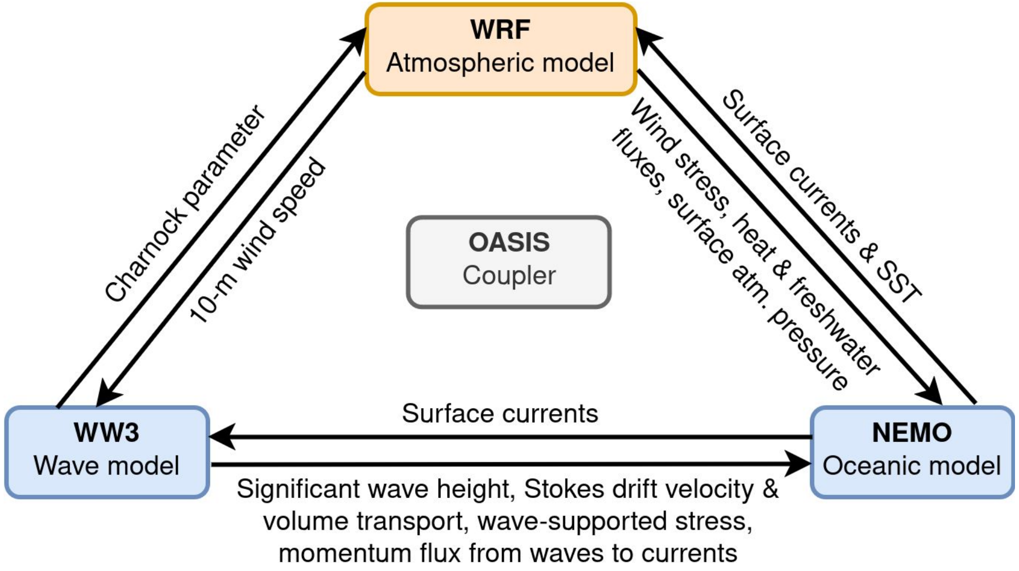
Source: EOSDIS Worldview

1. The cyclone causes strong vertical mixing in the ocean
2. Cooling of the Sea Surface Temperature (SST)
3. Reduction of available energy in the cyclone
4. **Negative feedback between cyclone and SST**

Coupled model set-up *(Karagiorgos et al., 2024)*:

- **WRF**: Δx, Δy = 9 km / Δt = 30 s
  IC/BC: 3-h ECMWF IFS forecasts
- **NEMO**: Δx, Δy = ~7-9 km / Δt = 360 s
  IC/BC: GLORYS12 daily reanalysis
- **WaveWatch 3**: Common mesh with NEMO | Δt = 720 s
- **Coupler OASIS**: WRF ↔ NEMO: 6 min; WW3: 12 min





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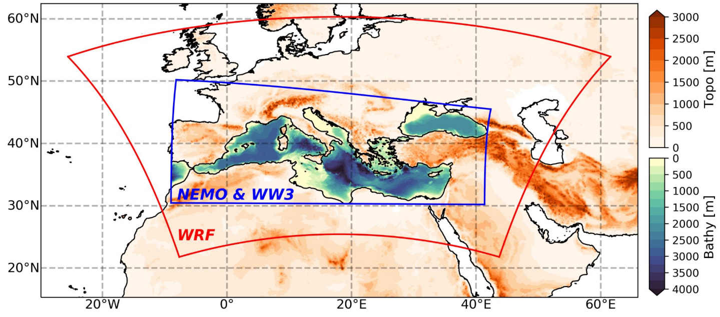
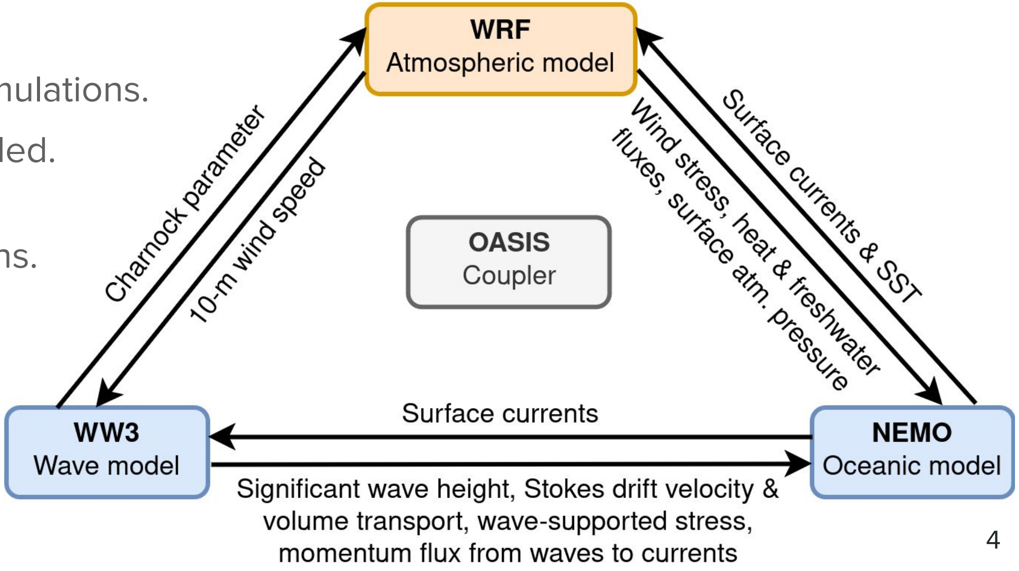


Medicane Ianos (15-20 Sep 2020):

- **Atm-only**: Fixed initial SST throughout the simulations.
- **OA**: WRF and NEMO models are 2-way coupled.
- **OWA**: Added WW3 to OA; Wave effects on surface roughness & wave-current interactions.

Sensitivity runs to initialization time:
16/00 UTC and 17/00 UTC.



Regarding wave coupling processes

Wave-atmosphere

- Momentum roughness length:

$$z_0(sea) = \frac{\alpha_{ch} u_*^2}{g} + \frac{0.11\nu}{u_*}$$

Charnock parameter α_{ch}:

Atm-only & **OA**: α_{ch} = 0.0185.

OWA: α_{ch} from WaveWatch 3.

- Transfer coefficients for momentum and turbulent heat fluxes are functions of $\mathbf{z_0}$ (Jimenez et al., 2012), thus the sea-state.

Wave-ocean

- Sea-state dependent ocean-side momentum flux:

$$\tau_{oc} = \tau_a - (\tau_{in} + \tau_{ds})$$

τ_{in} ~ wave growth

τ_{ds} ~ wave dissipation

τ_a: from WRF

$\tau_{in} + \tau_{ds}$: **OWA**: from WaveWatch 3

- Stokes Drift-Related processes.

- Wave-height dependent ocean roughness length:

$$z_0^{ocean-side} = 1.3H_s$$

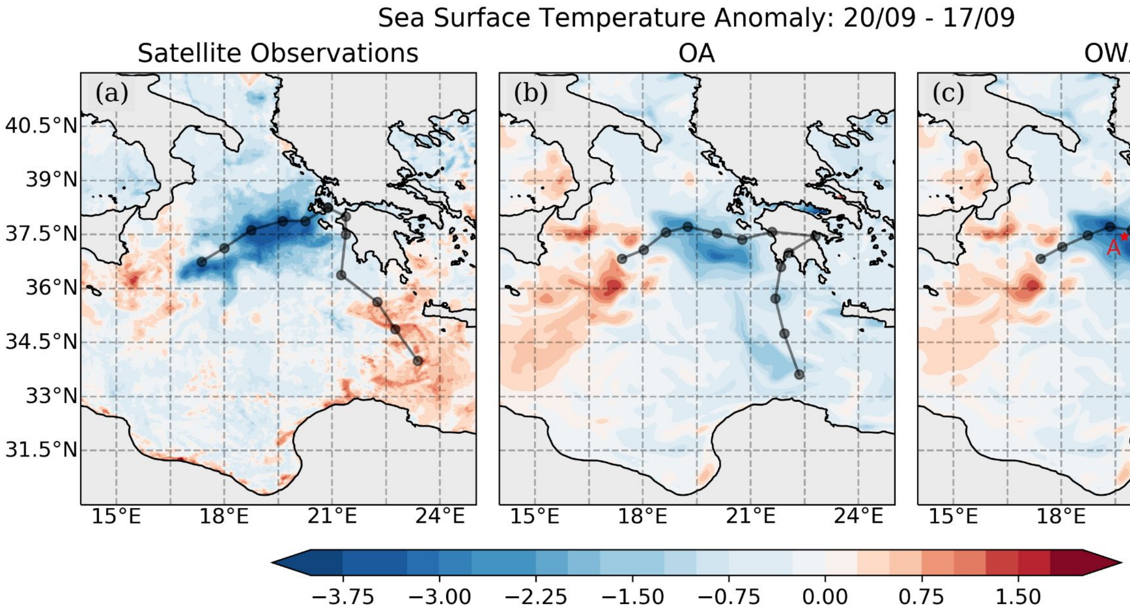
Significant wave height H_s:

Atm-only & **OA**: H_s following Rascle et al. (2008).

OWA: H_s from WaveWatch 3.

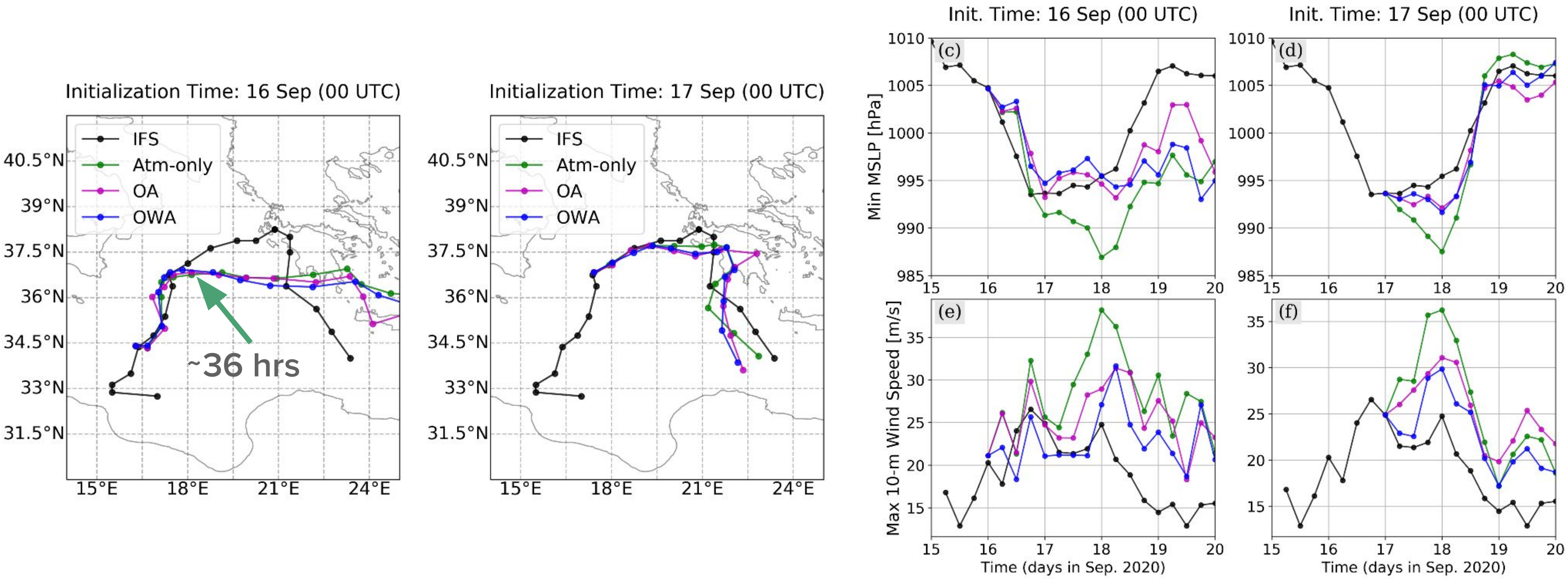
More details in publication: *Karagiorgos et al., 2024*

Sea Surface Temperature response



- **(OA):** SST cooling up to ~3.7 ◦C.
- **(OWA):** Wave-related processes further enhance the SST cooling by ~1.2 ◦C, reducing the cooling bias compared with the satellite L4 SST.

Impact on the cyclone's track & intensity

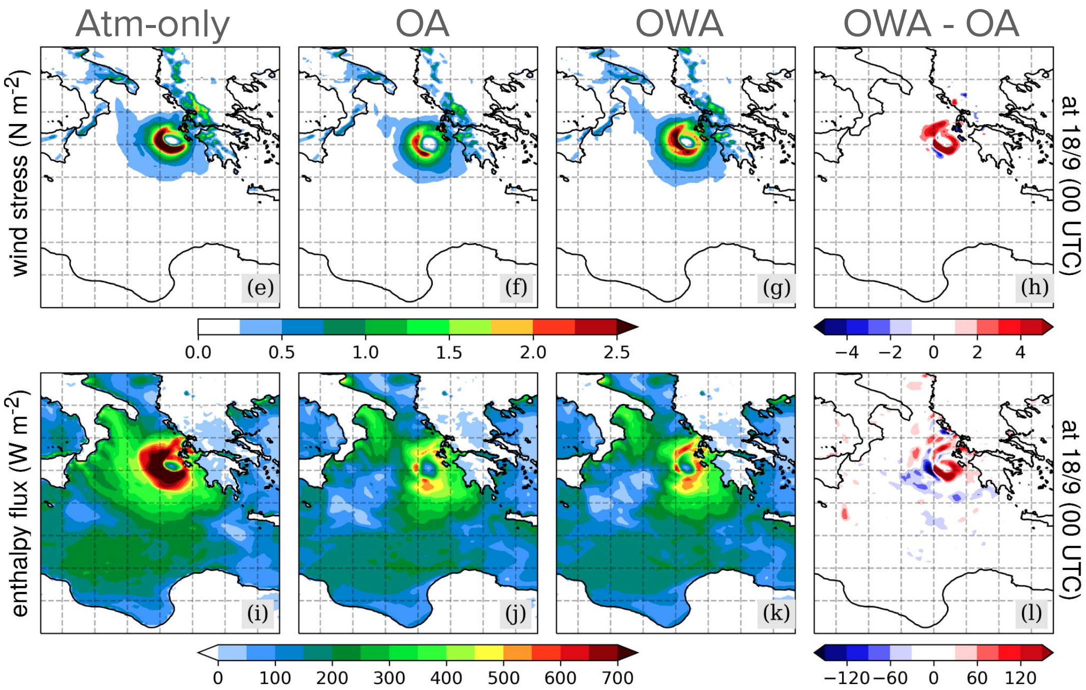


- Simulated trajectories depend mainly on the initial conditions of the models *(or the development phase of the cyclone)*; Improved tracks for init. at 17/00 vs 16/00.
- The coupling reduces the cyclone intensity (in terms of min. MSLP & max. 10-m winds), closer to the ECMWF IFS analysis.

Effects on air-sea momentum & heat fluxes

- Ocean coupling **(OA)** reduces both momentum and enthalpy (latent + sensible) fluxes, which is directly linked to SST cooling.
  → **negative** feedback on cyclone.

- Wave coupling **(OWA)** increases air–sea fluxes due to increased surface roughness length, despite enhanced SST cooling in OWA.



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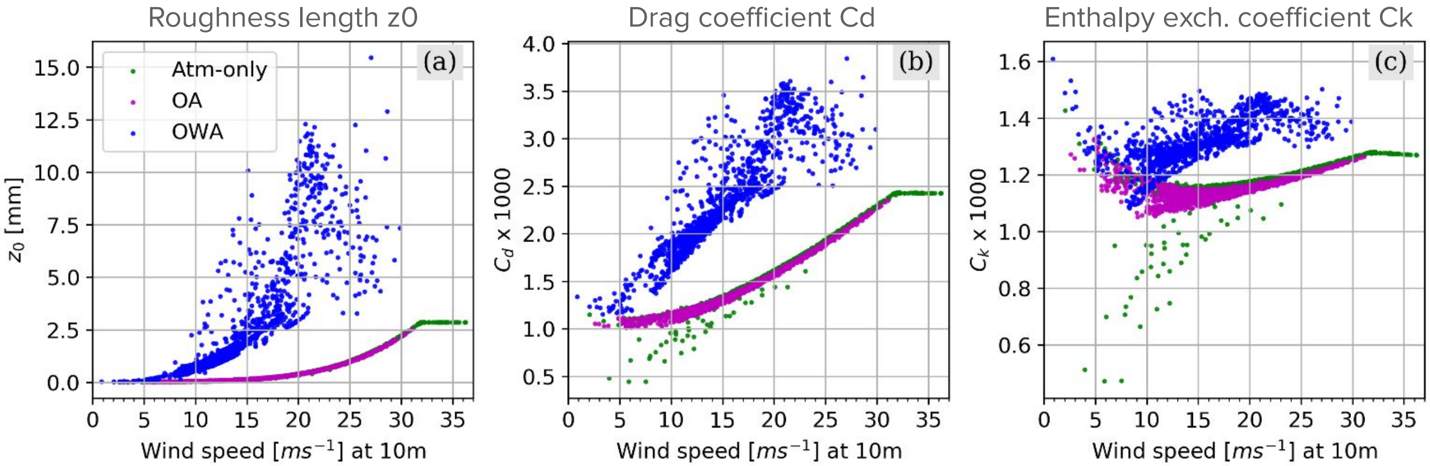
Competing effects on cyclone intensity:

negative feedback via increased momentum flux and
positive feedback via increased enthalpy flux.

Impact of wave coupling on surface roughness & air-sea exchange coefficients



- Wave-induced interactions **(OWA)** significant increases the surface roughness values (z_0), particularly noticeable at winds exceeding value of 10 ms^{-1}.
- Consequently, both the Cd and Ck coefficients increase with a large range of values, leading to the enhancement of both momentum and enthalpy fluxes.

Conclusions

- Incorporating both ocean and wave processes improved the accuracy of cyclones' intensity and their underlying SST.
- The coupling feedback controls the deepening of the cyclone, while the models's initial conditions affects the track forecasts.
- Sea-state effects on surface roughness have competing effects on cyclone intensity.

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More details in the publication:

Karagiorgos et al., 2024
"Ocean-wave-atmosphere coupling effect in Medicane forecasting"

https://doi.org/10.1016/j.atmosres.2024.107418

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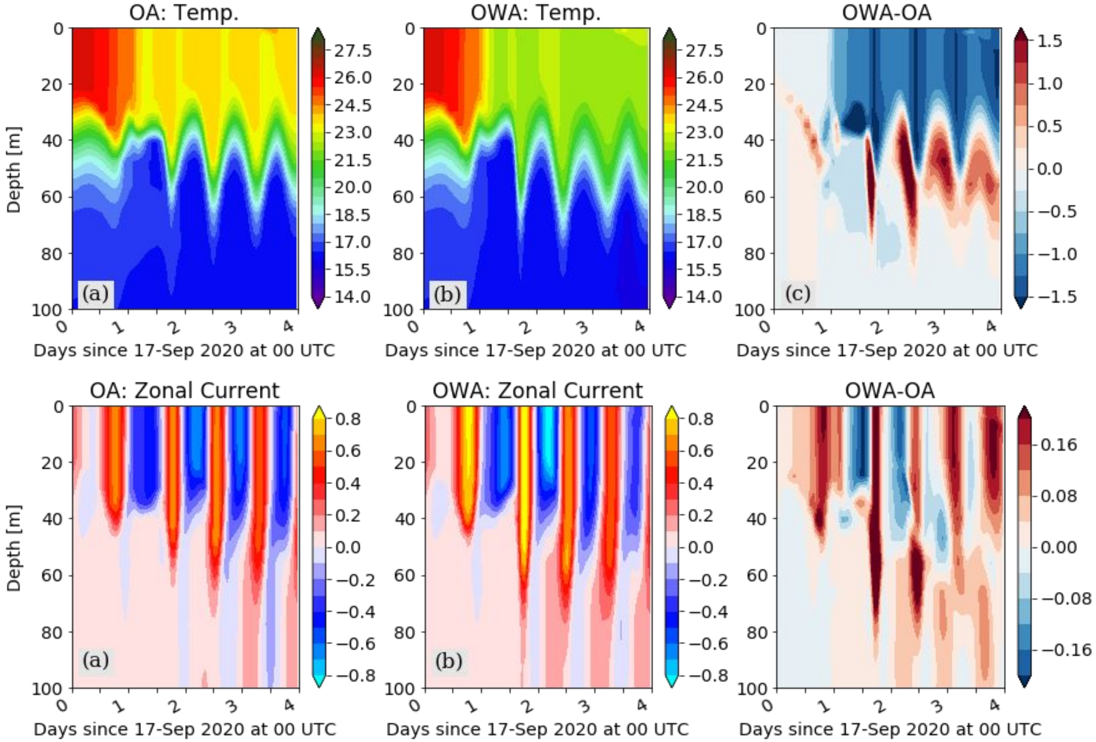
Supplementary material

Upper-ocean response

Temperature

Zonal Current



- Upper-ocean cooling for at least 3 days after the cyclone's passage.
- Inertial oscillation of the thermocline behind the cyclone (period ~ 1 day), similar to tropical cyclones cases.