Atmosphere-Waves Coupling in the Mediterranean with ICON-CLM

Danny Risto, Bodo Ahrens
Goethe University Frankfurt, Germany
risto@iau.uni-frankfurt.de

CLM Assembly 2026

Motivation

- Vb-cyclones and medicanes cross the Mediterranean and bring heavy precipitation to Central Europe (Krug et al., 2022)
- Wind-driven evaporation over the basin supplies that moisture
- Wave-dependent surface roughness modulates wind, evaporation and storm intensity (Batibeniz et al., 2025)
- Regional climate models can benefit from two-way atmosphere–wave coupling

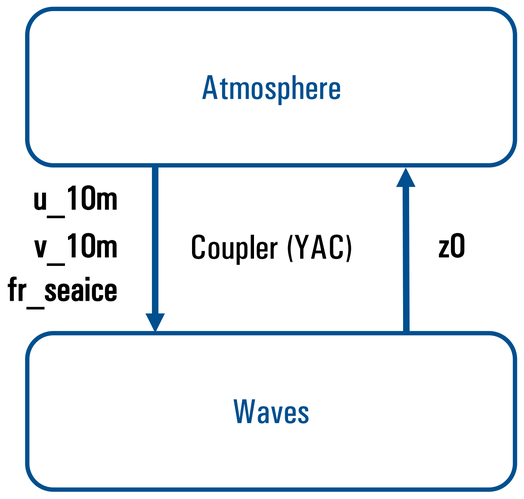
Abstract

Within Med-CORDEX we implement two-way atmosphere–wave coupling in ICON-CLM, coupling ICON-NWP-LAM with ICON-WAVES-LAM at 3.9 km over the Mediterranean through the YAC coupler.

During the test runs in January–March 2011, the waves increase mean sea-surface roughness length by a factor of 1.62, slow the 10 m wind by 1.5 % and increase the upward latent heat flux by 2.5 %, with almost all of the signal above 8 m s^{-1}. Coupling costs about 5.5 % extra runtime; evaluation and optimisation are still in progress.

Model Setup

- Atmosphere: ICON-NWP-LAM, 3.9 km
- Waves: ICON-WAVES-LAM, 3.9 km, 24 directions, 30 frequencies
- Coupler YAC: atmosphere passes u_10m, v_10m, fr_seaice; waves return roughness length z0
- Time steps: atmosphere 36 s, waves 72 s, coupling 144 s
- Wave component adds about 5.5 % runtime



Implementation & Experiments

- ICON-WAVES as limited-area model, from the ICON-NWP feature branch with local fixes: boundary data applied only at the open boundary, not along every coastline, and read per restart chunk so monthly chains work
- Wave grid: ocean-only grid cut from the 3.9 km atmosphere grid, isolated cells and unconnected basins removed; additional ExtPar file with bathymetry
- Wave lateral boundaries: analytic JONSWAP spectrum (30 frequencies × 24 directions) derived from the hourly near-surface wind of the atmospheric boundary files; frame cells mapped through the shared grid index, no interpolation
- 32 nodes, 224 ranks for the wave component, exchange every 144 s via YAC
- Atmosphere initialised and hourly forced by ERA5; waves cold-started from JONSWAP
- Coupled run (CPL) against uncoupled reference (REF) under identical forcing, Jan–Mar 2011
- Limitations: three months only, more are coming; no swell at the wave boundaries

Coupling roughens the sea surface

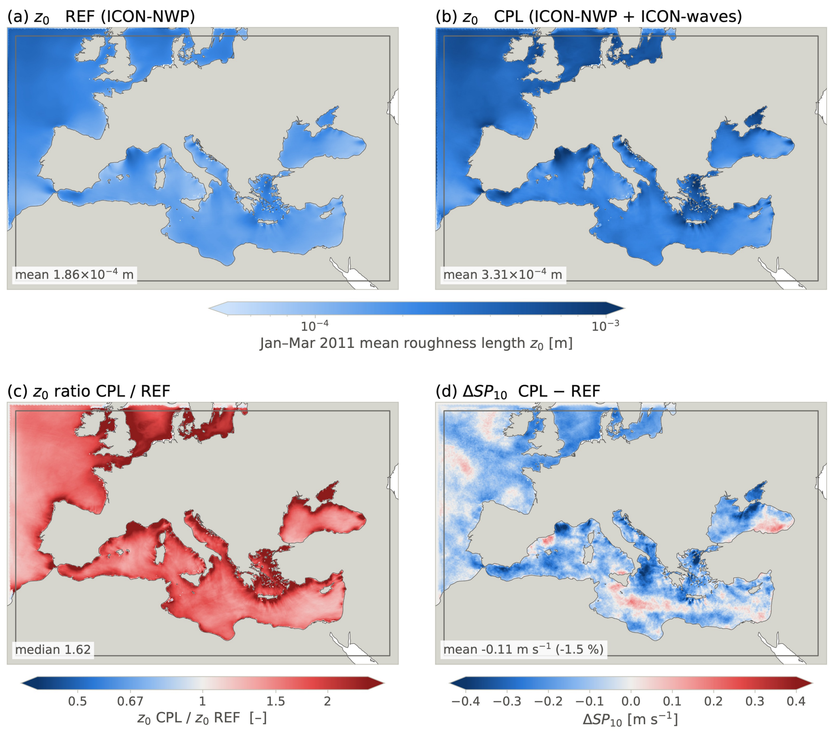


Fig 1: Roughness length and wind-speed change. Mean z0 in (a) REF and (b) CPL, (c) the z0 ratio CPL/REF and (d) the difference in wind speed between CPL and REF.

- Jan–Mar 2011 means: z0 rises from 1.9 to 3.3 × 10^{-4} m, median ratio 1.62
- Roughening is strongest in the windy costal areas
- The rougher surface slows the 10 m wind by 0.11 m s^{-1} (– 1.5 %, domain mean)

Roughness and wind speed

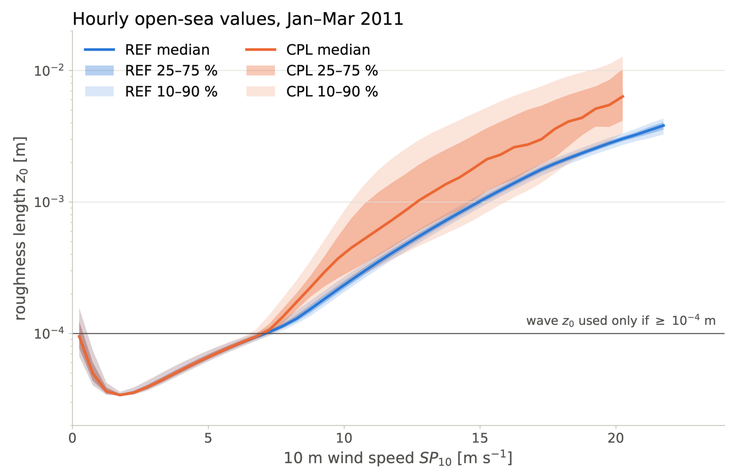


Fig 2: z0 versus wind speed. Hourly z0 against SP10 of the same run, in 0.5 m/s bins. Lines show the median; bands show the 25–75 % and 10–90 % ranges. Classes with fewer than 2000 samples are not shown.

- Wave z0 is used only where it exceeds 10^{-4} m, reached near 7–8 m s^{-1}
- Below that threshold CPL and REF are identical by construction
- Above it the coupled median z0 grows to about 1.7–1.8× the reference and spreads far more widely

Latent and sensible heat fluxes

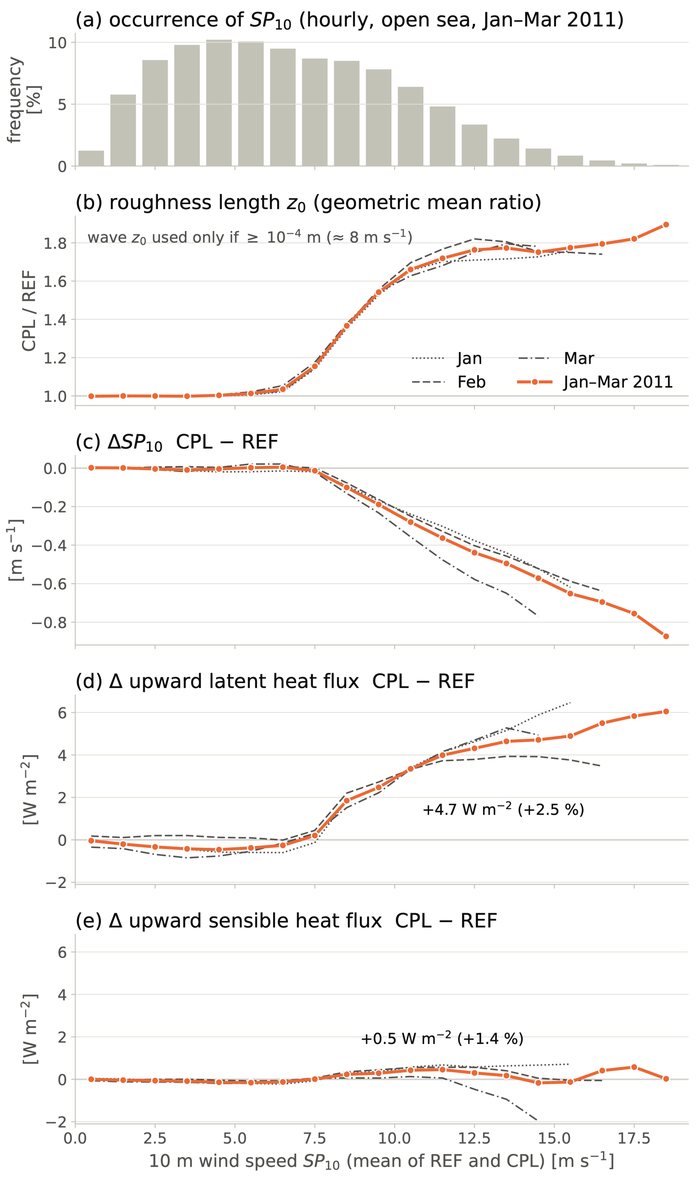


Fig 3: Response versus wind speed, by month and binned to 1 m/s wind speeds. Orange: Jan–Mar 2011 mean; grey: each month separately. Panels: (a) how often each bin occurs; (b) z0 ratio CPL/REF (geometric mean); CPL − REF differences in (c) SP10, (d) upward latent heat flux and (e) upward sensible heat flux.

- Hourly open-sea values binned by 10 m wind speed
- z0 ratio saturates near 1.7–1.9 above 10 m s^{-1} (b)
- Wind speed drops by up to 0.9 m s^{-1} in the strongest winds (c)
- Upward latent heat flux gains 4.7 W m^{-2} (+2.5 %), sensible heat flux 0.5 W m^{-2} (+1.4 %) (d, e)
- Winds above 8 m s^{-1} are rare (a), which keeps the domain mean effect small

Case study: Gulf of Lion

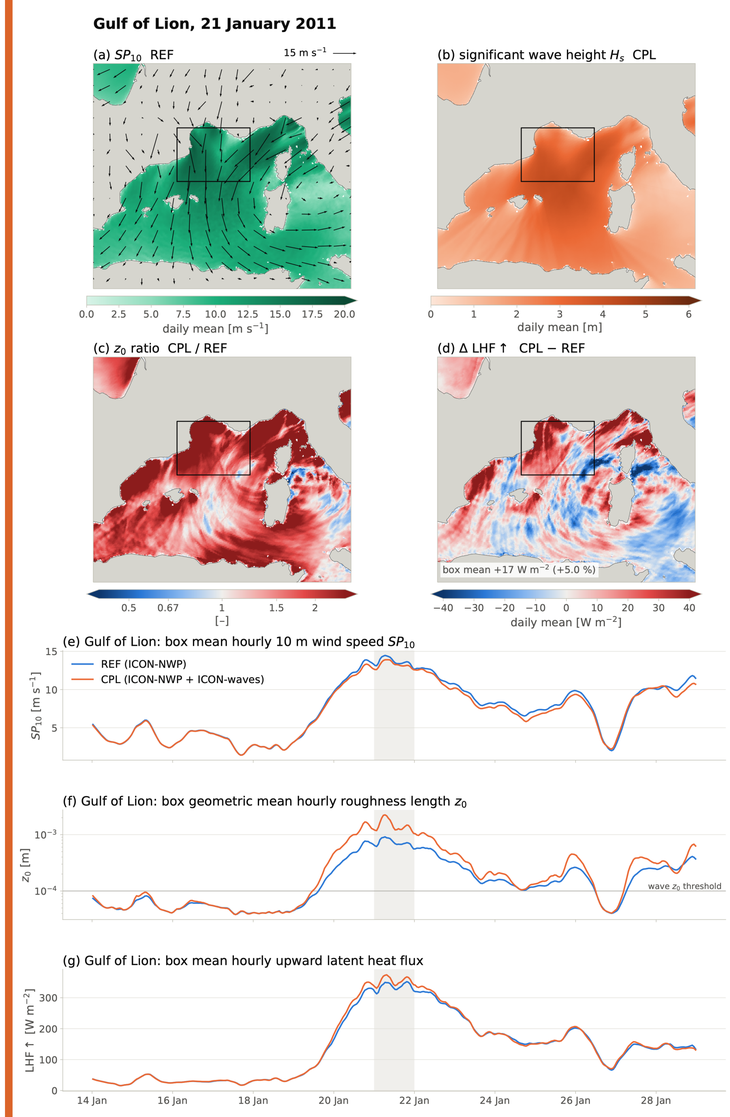


Fig 4: Gulf of Lion on 21st January 2011. Northerly Mistral–Tramontane (box mean SP10 13.6 m/s). Maps show daily means: (a) REF SP10 with wind directions, (b) CPL significant wave height (box mean 3.3 m), (c) z0 ratio CPL/REF (box median 2.25), (d) change in upward latent heat flux. (e–g) Box-mean hourly SP10, z0 and upward latent heat flux over ±7 days, with the case day shaded grey.

- Mistral event of 21 January 2011, box mean over the Gulf of Lion
- Box-mean significant wave height 3.3 m and z0 about 2.3× the reference (b, c, f)
- Box-mean 10 m wind speed changes little, but the upward latent heat flux rises by 17 W m^{-2} (+5.0 %) (d, g)
- Coupling matters in windy/stormy conditions

Summary & Conclusions

- Two-way atmosphere–wave coupling runs technically in ICON-LAM at 3.9 km for about 5.5 % extra cost
- Waves roughen the sea surface (z0 × 1.62), slow the 10 m wind by 1.5 % and raise the upward latent heat flux by 2.5 %
- The signal is confined to winds above about 8 m s^{-1} and is largest in storms
- Evaluation and optimisation in progress
- Open question: lateral wave forcing: zero vs JONSWAP (no swell) vs global wave spectrum
- Next: full-year runs, medicane cases, and atmosphere–wave–ocean coupling in limited-area mode

Acknowledgements

Thanks to Daniel Reinert and Mikhail Dobrynin (DWD) helping to setup the model and the ocean waves grid.
This work used resources of the Deutsches Klimarechenzentrum (DKRZ) granted by its Scientific Steering Committee (WLA) under project ID 1064.
We used ERA5 as forcing data (ECMWF, Hersbach et al. 2017, 10.24381/cds.143582cf, Data distribution by the German Climate Computing Center (DKRZ)).

References

Batibeniz, F., Önol, B., Turuncoglu, U. U., & Raible, C. C. (2025). Air–sea interaction in medicanes with atmosphere–ocean–wave coupled regional climate simulations. Quarterly Journal of the Royal Meteorological Society, 151(772), e5040.
Krug, A., Aemisegger, F., Sprenger, M., & Ahrens, B. (2022). Moisture sources of heavy precipitation in Central Europe in synoptic situations with Vb-cyclones: A. Krug et al. Climate dynamics, 59(11), 3227-3245.