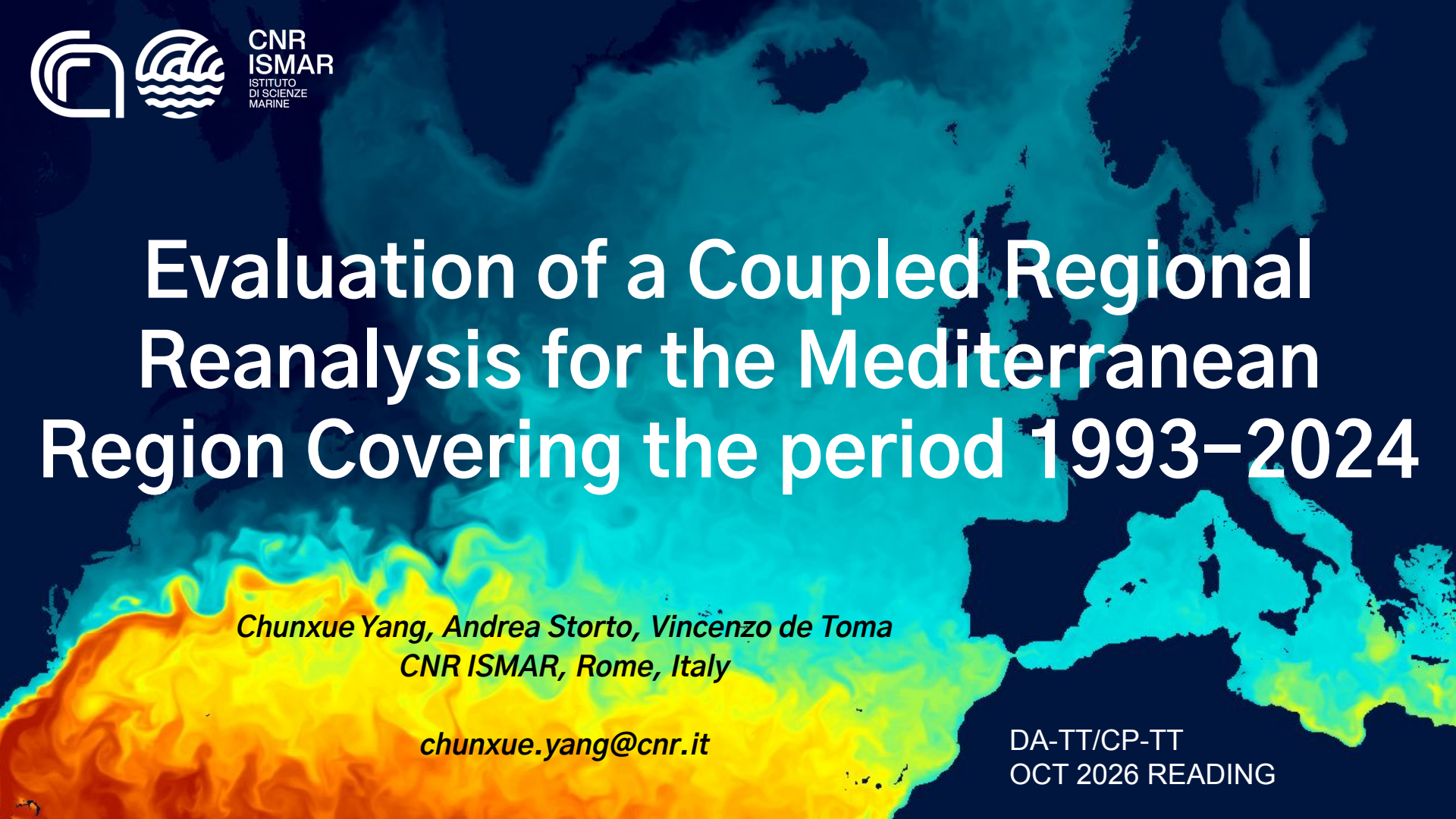


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Evaluation of a Coupled Regional Reanalysis for the Mediterranean Region Covering the period 1993–2024

Chunxue Yang, Andrea Storto, Vincenzo de Toma
CNR ISMAR, Rome, Italy

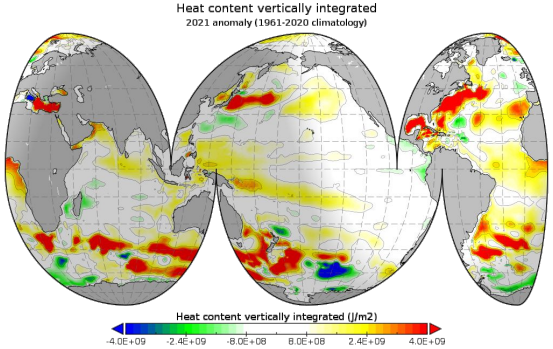
chunxue.yang@cnr.it

DA-TT/CP-TT
OCT 2026 READING

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NEMO-based models at ISMAR

Global Ocean models



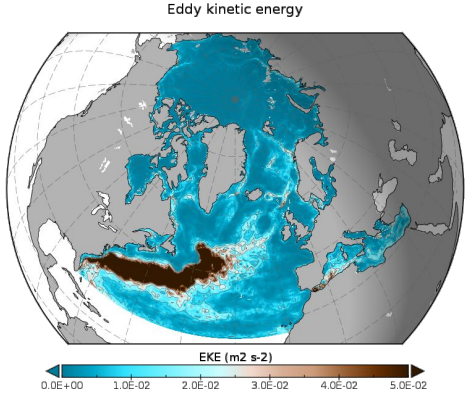
NEMO 4.0.7
ORCA1 (1°) L75
ORCA025 (1/4°) L75

Forced by ERA5 or 20CRv3

Data assimilation enabled:
Variational DA in the ocean
CIGAR reanalysis http://cigar.ismar.cnr.it/

Applications
Historical ensemble reanalyses
Land–sea coupling experiments

Regional models

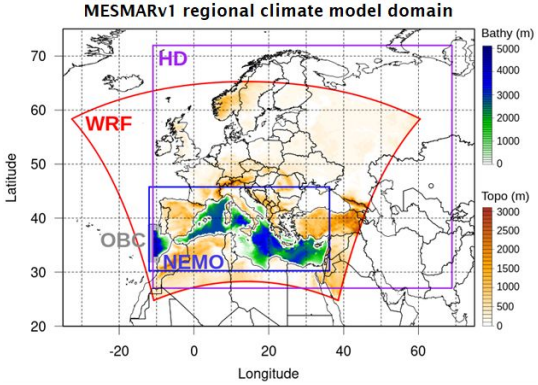


NEMO 4.0.7
CREG025 (1/4°L75) CREG12 (1/12°L75)
CREG36 (1/36°L75)

Forced by ERA5/GLORYS12

Data assimilation enabled:
Variational DA in the ocean

Applications
Interannual variability in the NA
Stochastic physics developments
DA developments (e.g. new obs types)



NEMO 4.0.7 (7kmL72)
WRF 4.3.3 (14kmL41)
HD 5.1 (1/12°) OASIS3-MCT 5.0

Forced by ERA5/ORAS5 laterally

Data assimilation enabled:
Variational DA in the ocean
Spectral nudging (~850km) in the atmosphere

Applications
Coupled DA
Air–sea interaction (skinSST schemes)

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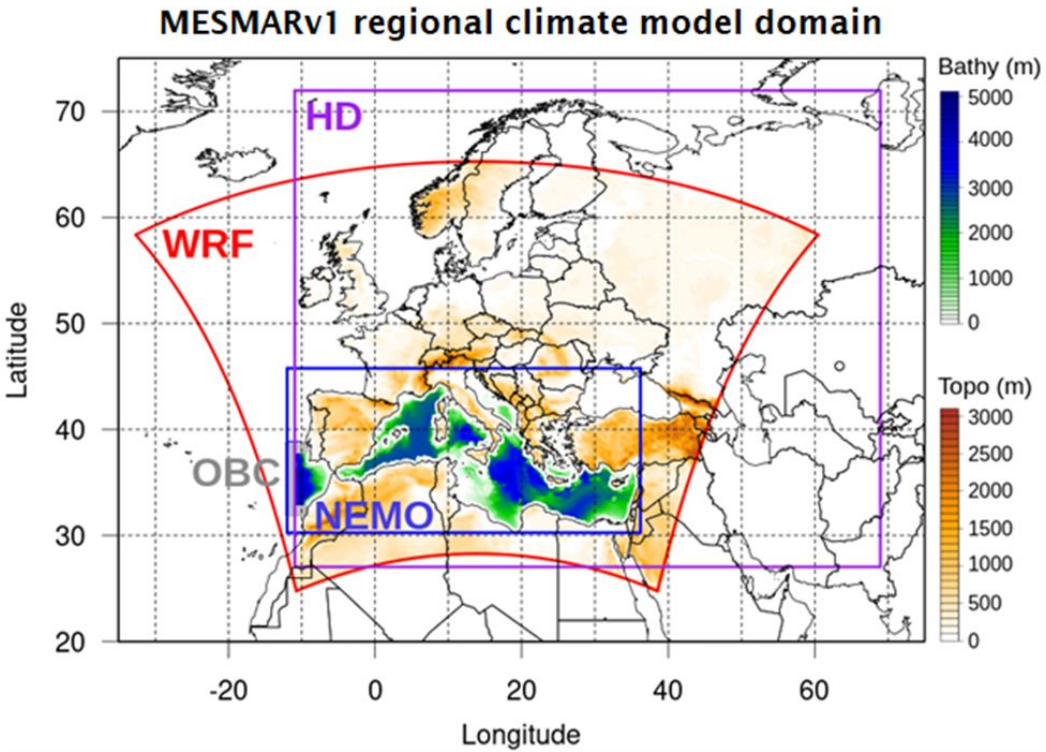
Regional coupled model

WRF model (4.3.3)

Resol.: 15km L40
LBCs: ERA5 (6h)
ICs: ERA5
SBCs: NEMO (OSTIA)
Radiation: RRTMG
Surface layer: Janjić
Microphys.: Thompson
Land: Noah-MP (4L)
Cumulus: Grell-Freitas
PBL: Mellor-Yamada (MYNN)

Coupler

OASIS3-MCT5
Coupling freq.: 1/2 hour
Interpol.: CONS. 1° ord



NEMO model (4.0.7)

Resol.: 7km L72
LBCs: ORAS5
ICs: GLORYS12
Sol Penetr.: RGB (CCI)
Mixing: MY+Canuto
BlackS: Climatol.

HD model (5.1) River Discharge

1/12° Resolution
European Basins

Funded by the Lazio Region under the EU Regional Operational Program and PNRR CN-HPC

https://doi.org/10.5194/gmd-16-4811-2023
https://doi.org/10.5281/zenodo.7898938

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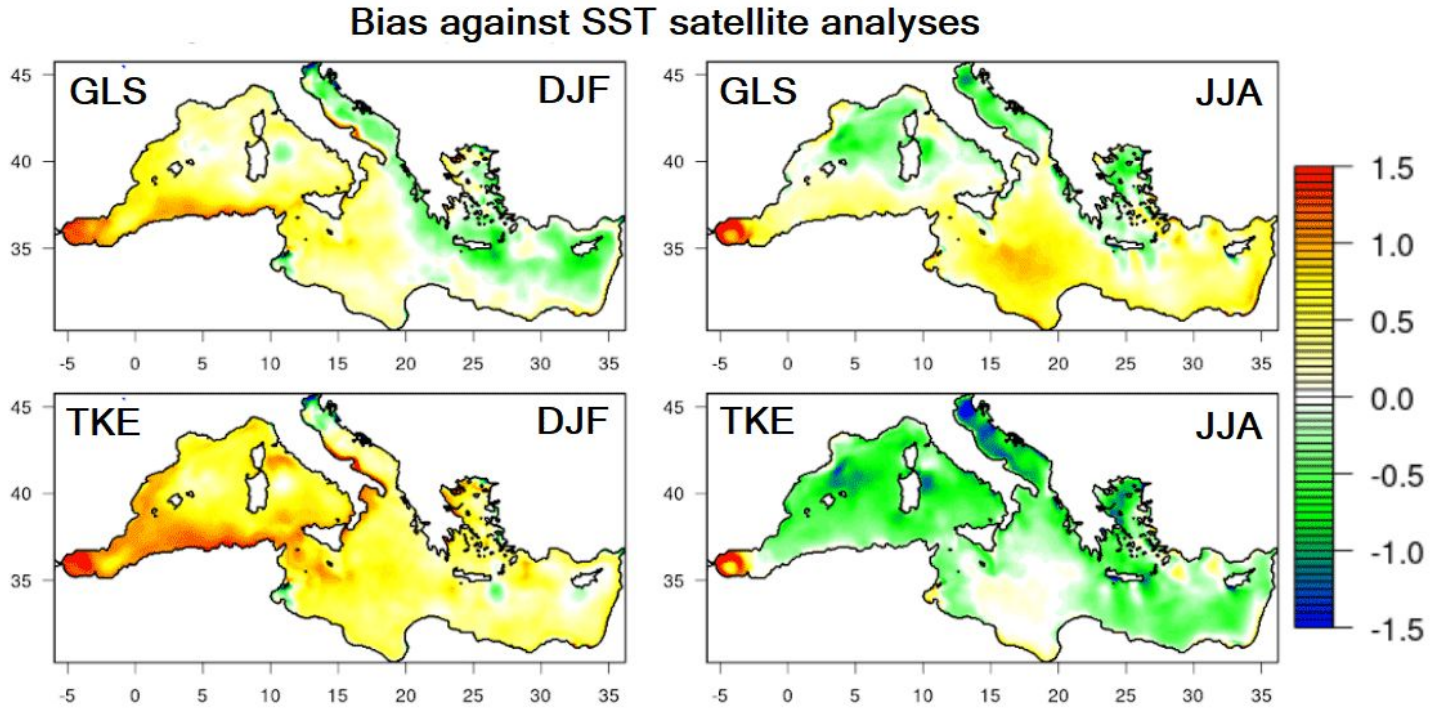
Regional coupled model

Field	From	To	Notes
Sea surface temperature	NEMO	WRF	Bulk temperature in NEMO at first ocean model level
Surface zonal current	NEMO	WRF	For use in the air–sea flux computations that consider the relative wind
Surface meridional current	NEMO	WRF	For use in the air–sea flux computations that consider the relative wind
Wind stress modulo	WRF	NEMO	–
Zonal wind stress	WRF	NEMO	–
Meridional wind stress	WRF	NEMO	–
Freshwater flux	WRF	NEMO	Given as evaporation minus precipitation
Solar heat flux	WRF	NEMO	Penetrative component of the air–sea heat flux
Non-solar heat flux	WRF	NEMO	Non-penetrative component of the air–sea heat flux
Atmospheric surface pressure	WRF	NEMO	For use to model the inverted barometer effect in NEMO
Surface runoff	WRF	HD	From the Noah-MP land model
Subsurface runoff	WRF	HD	From the Noah-MP land model
Runoff at the river mouth	HD	NEMO	Remapped and spread over the NEMO grid points

Funded by the Lazio Region under the EU Regional Operational Program and PNRR CN-HPC

https://doi.org/10.5194/gmd-16-4811-2023
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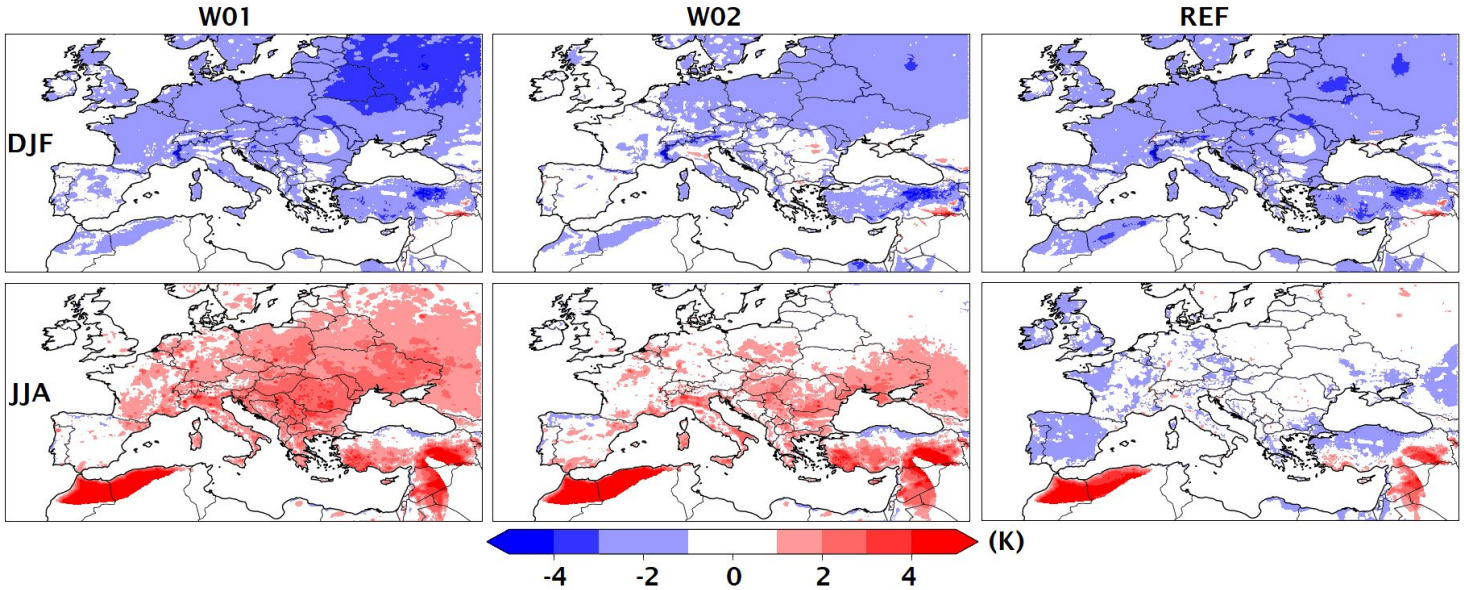
Sensitivity experiments and system tuning



1993–2020 sensitivity experiments

Impact of vertical mixing scheme: underestimated summer time stratification using the standard TKE scheme, then replaced by the GLS (Mellor–Yamada with Canuto closure)

Sensitivity experiments and system tuning

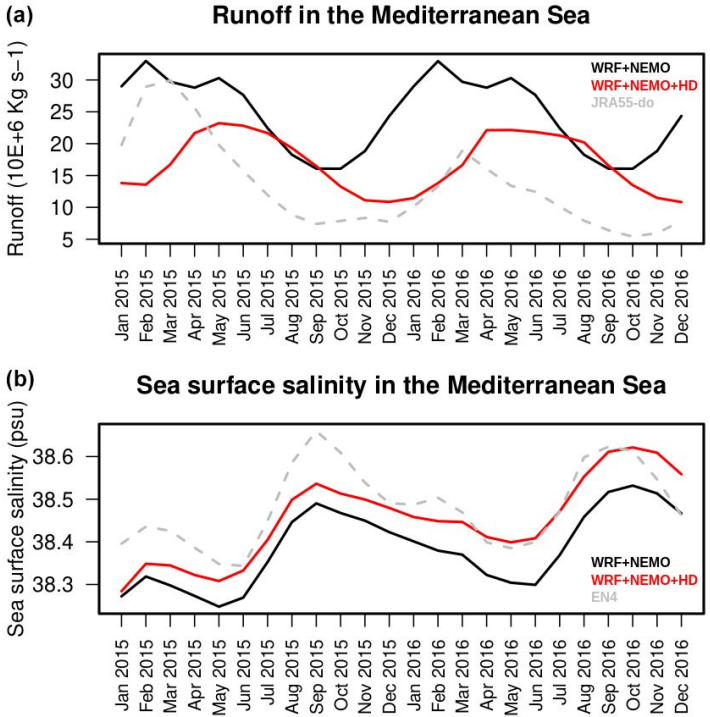


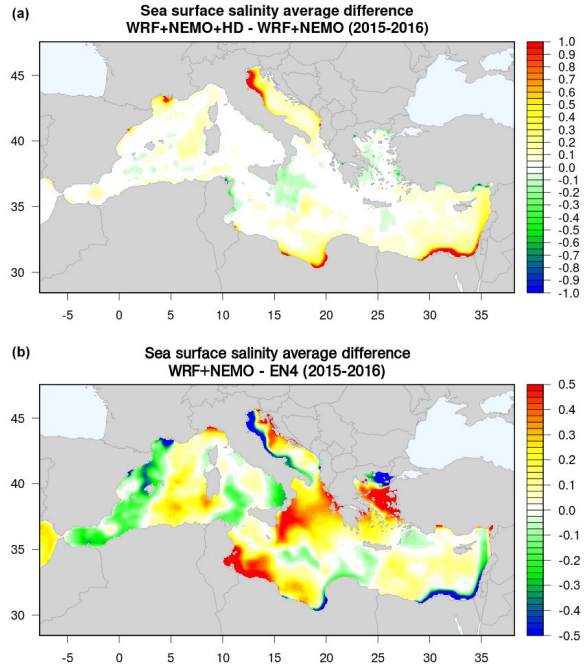
1993–2020 sensitivity experiments

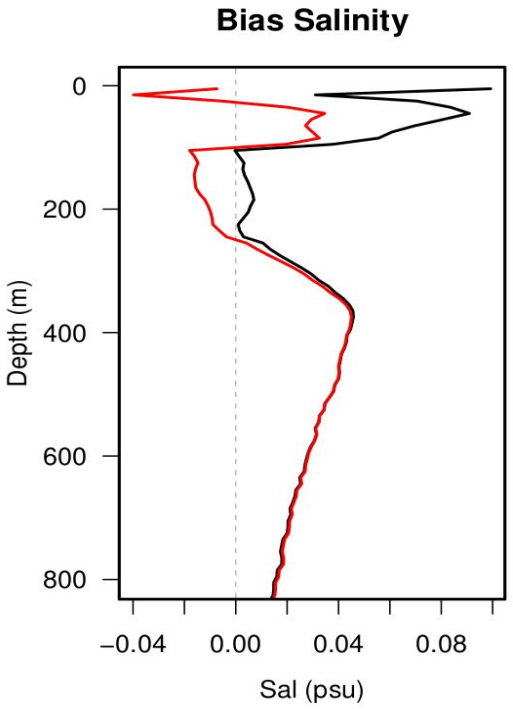
Impact of WRF physics/microphysics suites
Best T2M results with a configuration close to MED-CORDEX with some modifications from ENEA

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River discharge coupling







Rectification of the freshwater budget and cycle in the Med Sea
Positive impact on salinity skill scores (verification against external analyses and Argo floats)

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Weakly Coupled DA experiments

3DVAR in the ocean (Argo, altimetry, SST)

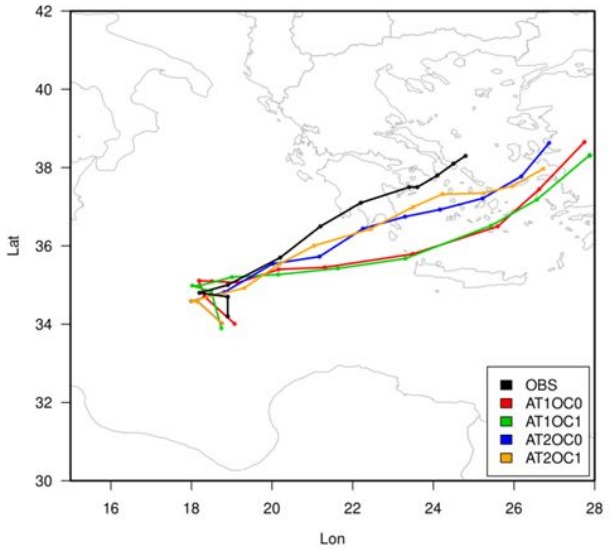
Spectral nudging (~850km, ERA5) in the atmosphere

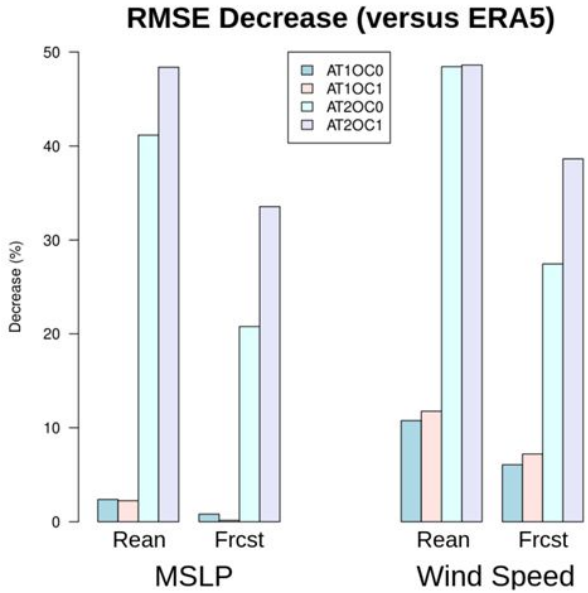
Experiment name	Atmospheric assimilation	Oceanic assimilation	RMSE					
			T850	WS 1000-850	Z500	SST	T0-50	S0-50
CTRL	No	No	2.07	3.58	29.5	0.63	1.13	0.32
AT0OC1	No	3DVAR+SRF	2.04	3.58	29.0	0.27	0.83	0.20
AT1OC0	Full-field nudging	No	0.82	2.08	10.7	0.71	1.10	0.32
AT1OC1	Full-field nudging	3DVAR+SRF	0.83	2.08	10.7	0.29	0.76	0.20
AT2OC0	Spectral nudging	No	1.0	2.77	10.7	0.63	1.11	0.29
AT2OC1	Spectral nudging	3DVAR+SRF	1.0	2.77	10.7	0.27	0.80	0.20
			3%		3%		3%	3%

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Weakly Coupled DA experiments

Medicane Zorbas





Medicane track: positive impact of atm. spectral nudging

Medicane intensity: significant impact of ocean DA

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Coupled Reanalysis **MESMAR-R**

Process-oriented coupled studies
Regional climate monitoring
Training dataset

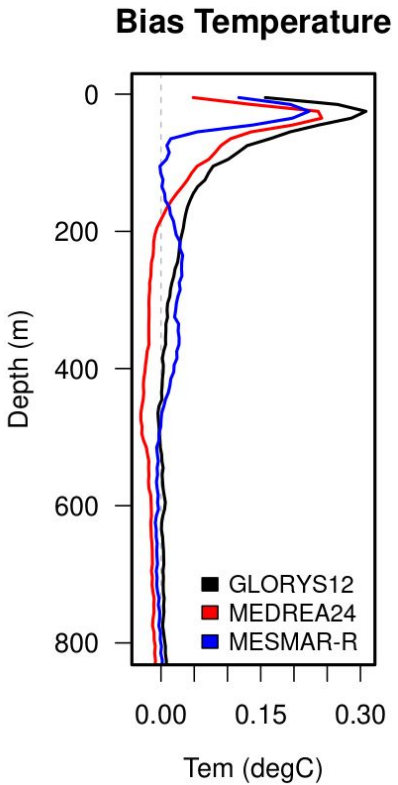
- 1993-2024
- Ocean 3DVAR (in-situ; SLA)
- Interface Nudging (SST, SSS)
- Atmospheric Spectral nudging (~850km)
- 3-day DA cycles
- Updated system: Altimetry assimilated, **B** from the previous iteration, deep-ocean bias correction

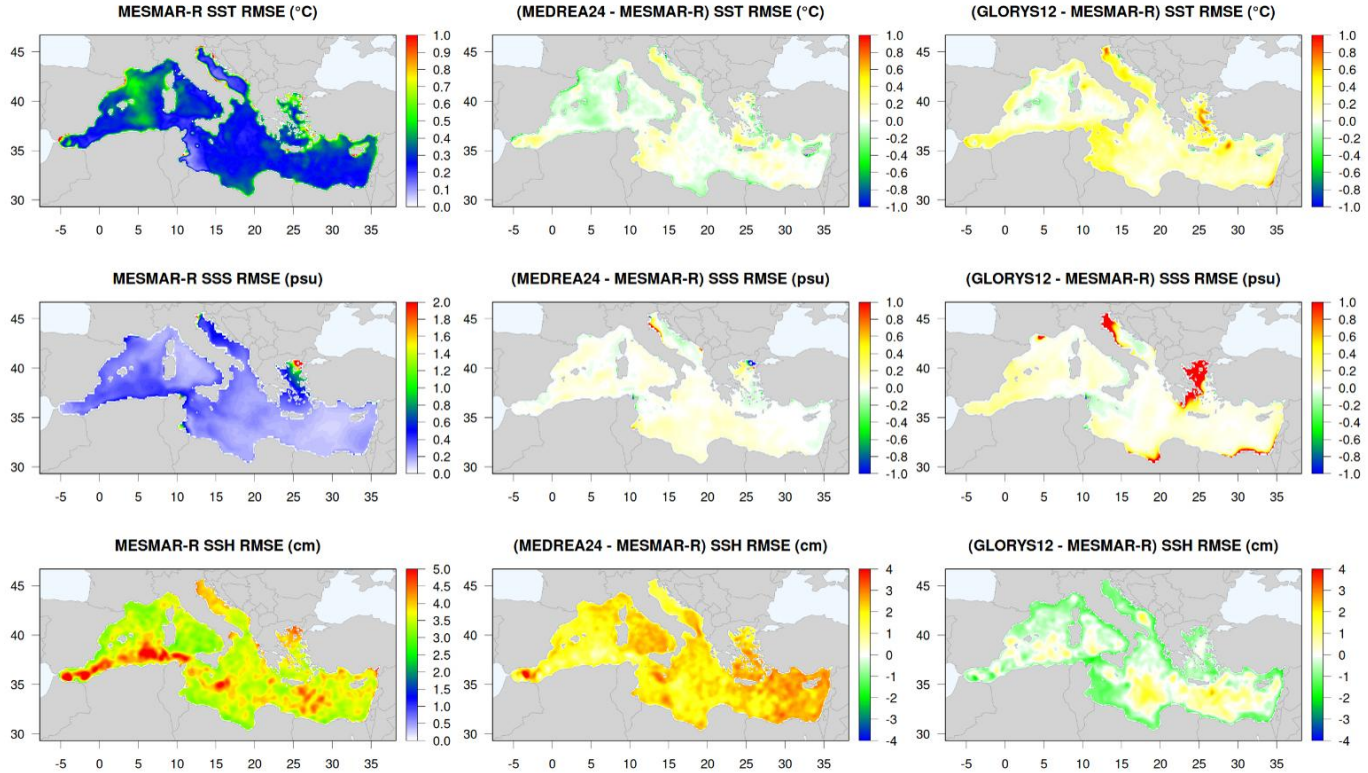
Data publicly available through Zenodo

Name	Atm	Oce	Purpose	Period
MESMAR-R	Data Assimilation	Data Assimilation	Coupled Reanalysis	1993–2024
COA	Simulation	Data Assimilation	Impact of atmospheric data assimilation	2000–2020
COS	Simulation	Simulation	Coupled Simulation	2000–2020
UOS	Not present	Simulation	Forced ocean Simulation	2000–2020
UOA	Not present	Data Assimilation	Forced ocean Reanalysis	2000–2020

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Selected results





Best sea-surface skill of the three; Upper ocean (0–210 m) T and S comparable to or better than MEDREA24; below 210 m MEDREA24 generally better. Smallest surface fresh bias; near-surface warm bias decays faster than in GLORYS12 and is near-zero below 200 m.

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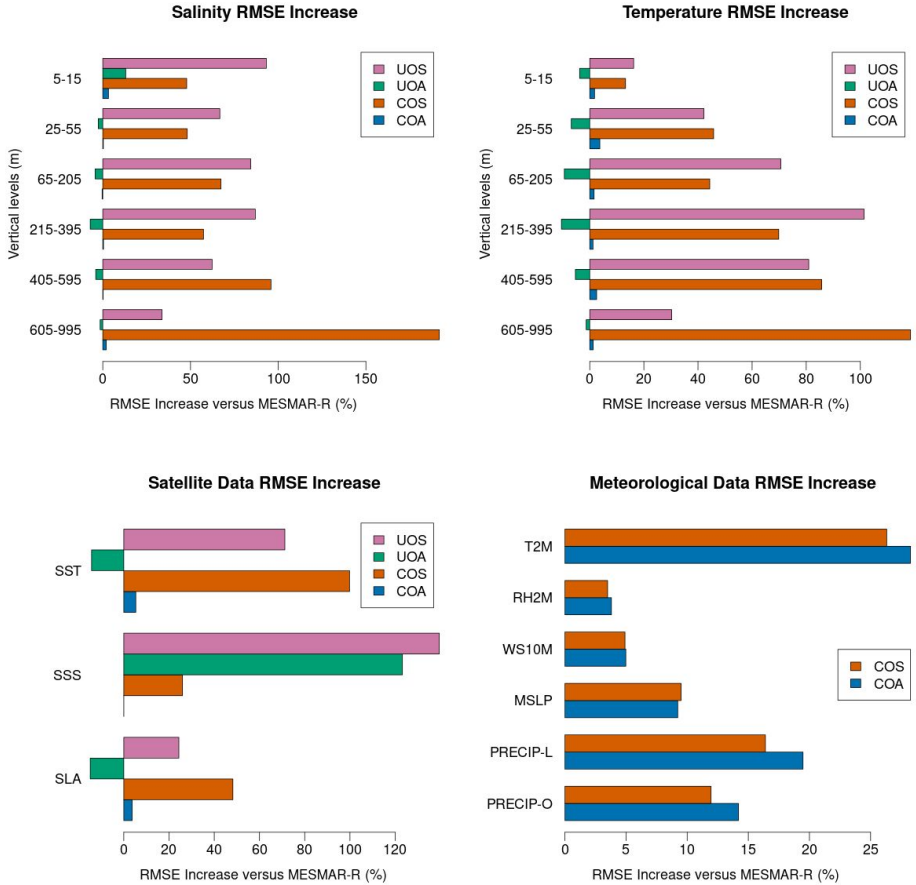
Selected results

Metric	MESMAR-R	ERA5	CERRA
T2M (°C)	1.38	1.24	1.14
RH2M (%)	7.63	7.26	6.61
MSLP (hPa)	2.61	2.35	2.38
WS10M ($m\,s^{-1}$)	0.91	0.64	0.67
PRECIP-LAND ($mm\,d^{-1}$)	1.37	0.89	–
PRECIP-OCE ($mm\,d^{-1}$)	1.17	1.06	–

Comparable skills (but clearly worse) than state of the art systems in atmosphere

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Selected results



COS (coupled, no DA) degrades most, with >100 % RMSE increase at depth;

UOS does better than COS, because ERA5 forcing acts as a weak atmospheric constraint;

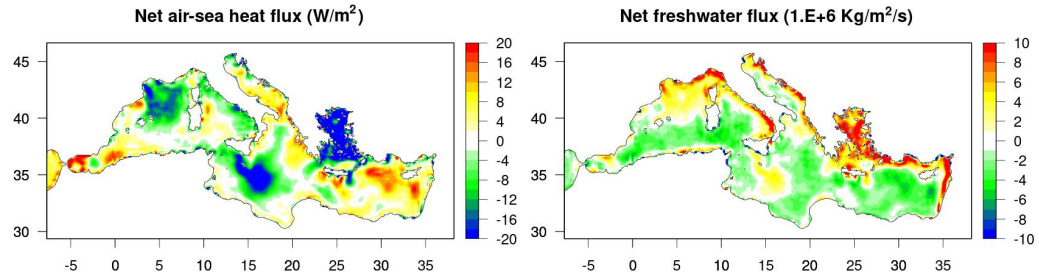
UOA is marginally better than MESMAR-R except for SSS and upper-ocean salinity

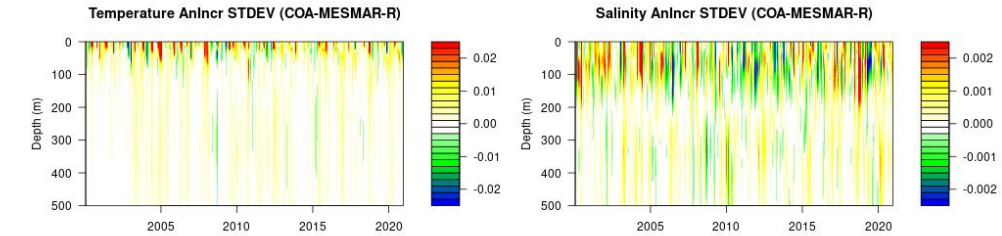
Atmospheric nudging also matters: removing it (COA) gives small but significant losses in SST, SLA and temperature near the mixed-layer base, and +20 % T2M / +15% land-precipitation RMSE.

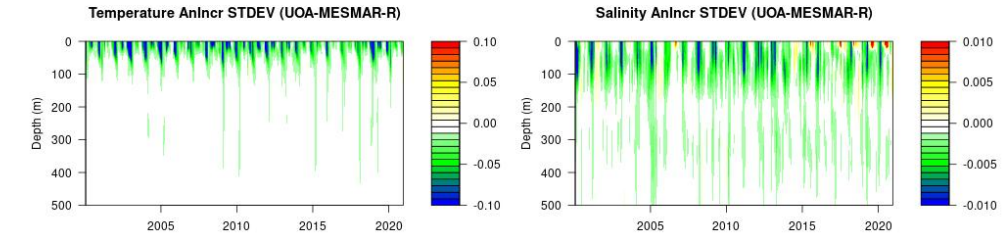
Coupling alone is not enough: DA in both media is needed

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Selected results







Coupling signature (COS-UOS): in the Aegean and south of Sicily, reduced downward heat flux and enhanced evaporation: cooler, saltier surface (SSS improves)

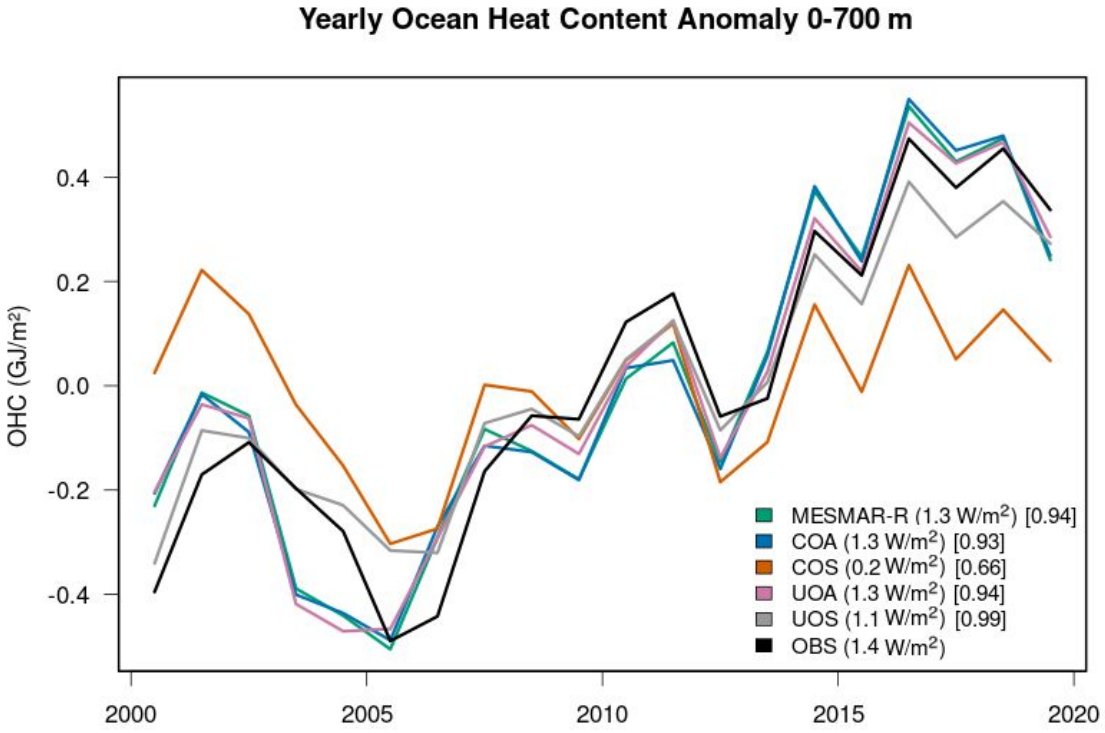
COA–MESMAR-R slightly positive → spectral nudging reduces the ocean corrections needed;

UOA–MESMAR-R negative in the top 50 m, peaking in winter: ERA5 near-surface forcing is still more accurate than the interactive coupling. Differences vanish below ~50 m

Goal is however to have consistent and synchronized atm-oce variability

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Selected results



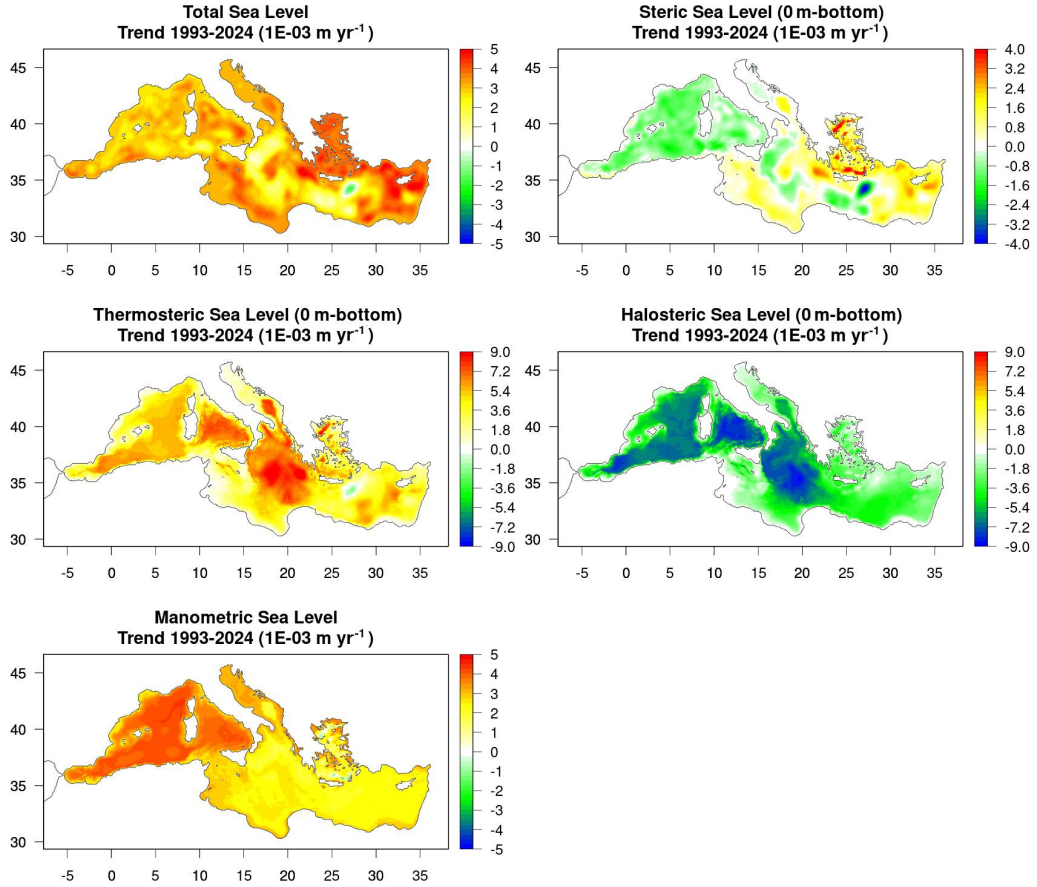
All DA-enabled configurations reproduce observed OHC:
rho = 0.93-0.94, trend 1.3 W m^{-2} vs 1.4 W m^{-2} observed

Without any DA the coupled system drifts: COS r = 0.66, trend 0.2 W m^{-2};
UOS reproduces variability (r = 0.99) but with damped amplitude and trend.

Ocean DA is the dominant source for correct basin-scale heat content representation.
The coupling modifies vertical mixing and winter convection, which is basically wrong in absence of DA

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Selected results



Total sea-level rise 3.06 mm yr^{-1} (3.61 over 1999–2024), in line with the Copernicus Marine indicator and literature (2.5 to 4.0 mm yr^{-1})

Mass-driven rise: manometric component 2.88 mm yr^{-1}, i.e. 94 % of the total because the basin follows the Atlantic Ocean variability

Thermo-halo compensation: thermosteric +4.03 vs halosteric −3.87 mm yr^{-1}; the strongest halosteric decline is in the western basin and Alboran (−5.0 mm yr^{-1}), consistent with basin-wide salinification

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Summary

- A new regional coupled reanalysis developed experimentally for climate monitoring, process-oriented studies (and possibly a resource for AI)
- The ocean component is comparable to other state-of-the-art reanalyses
- DA in both components is essential: coupling alone does not improve skill, but it rectifies the freshwater budget and amplifies gains when combined with assimilation
- Climate trends are physically coherent: mass-driven sea-level rise, thermo-halo compensation, salinification, near-surface warming and drying
- Strongly coupled DA: an unfunded wish!

Thank you

Questions?

Description and link for data release:

Storto, A., de Toma, V., and Yang, C.: Evaluation of a coupled regional reanalysis for the Mediterranean region covering the period 1993–2024, Ocean Sci., 22, 2809–2834, https://doi.org/10.5194/os-22-2809-2026, 2026.