CNR ISMAR
ISTITUTO DI SCIENZE MARINE

Regione Lazio
POR FESR 2014-2020

ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Towards coupled air–sea data assimilation in a regional model

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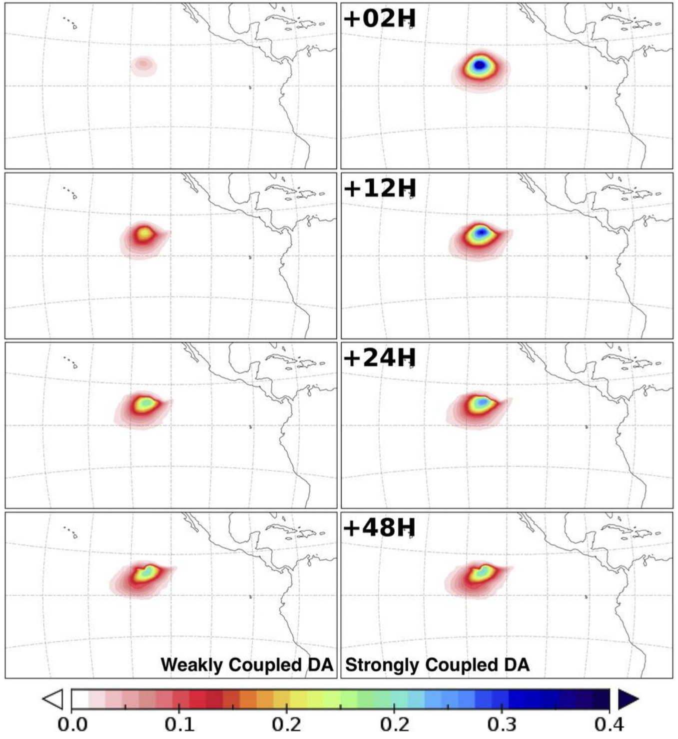
Outline

- *Motivation*
- *Strongly coupled DA in a coupled single–column model*
- *Extension within a real 3D model*

Motivation: Coupled Data Assimilation

T2M increments from a single SST assimilation



Storto, et al. 2018 *Monthly Weather Review, 146*

- It can be foreseen that future DA systems will be fully coupled, in order to:
  - Minimize imbalances and initial shocks
  - Enhance the exploitation of observations through cross-medium propagation
  - Enhance the use of satellite data through coupled observation operators

<u>Short-range (weather) applications:</u>

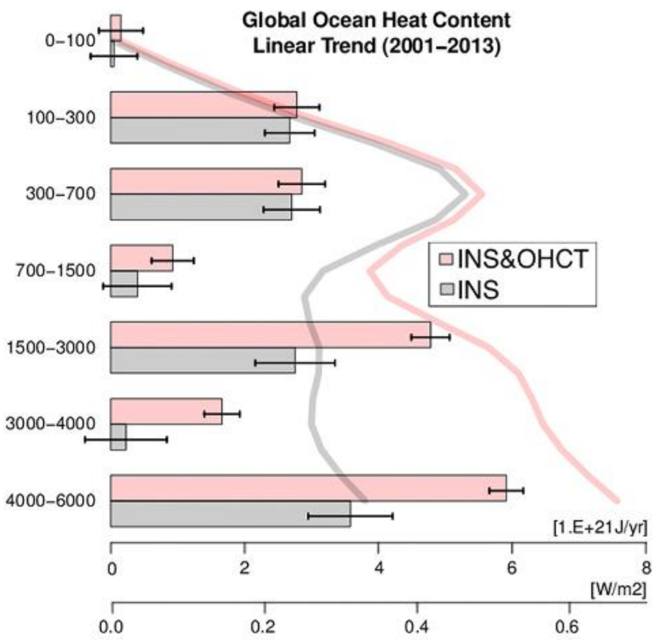
Potential for strongly coupled events (hurricanes, heavy precipitation events, etc.)

<u>Long-range (climate) applications:</u>

Potential for coupled reanalyses, predictability gain in subseasonal to decadal (e.g. precipitation/SST feedback effects, the MJO, the AMOC and NAO, ENSO, etc.)

Motivation: Coupled Data Assimilation

Impact of assimilating TOA–EEI on the global ocean warming



Storto, et al. 2017 *Geophys. Res. Lett., 44*

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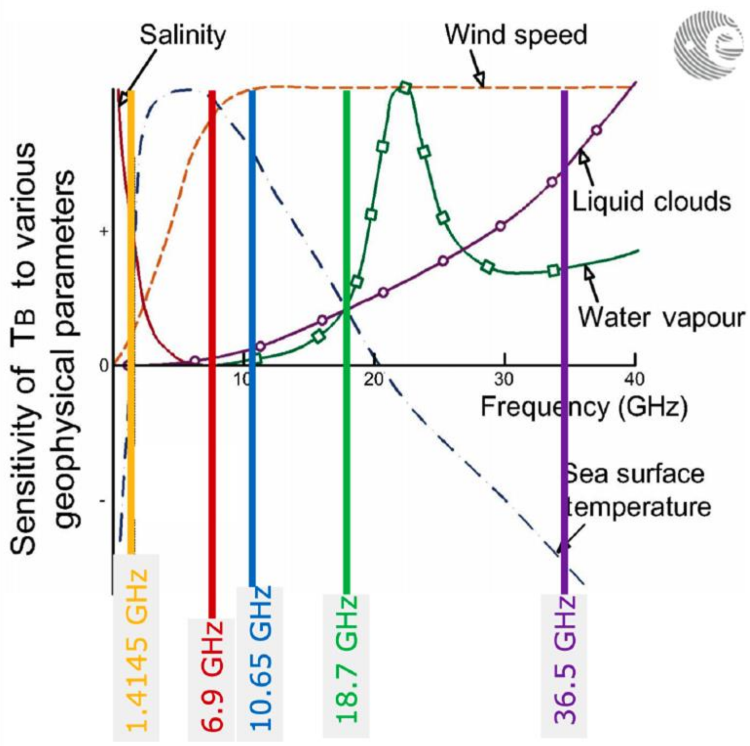
Motivation:
Coupled Data Assimilation

The Copernicus Imaging Microwave Radiometer (CIMR)



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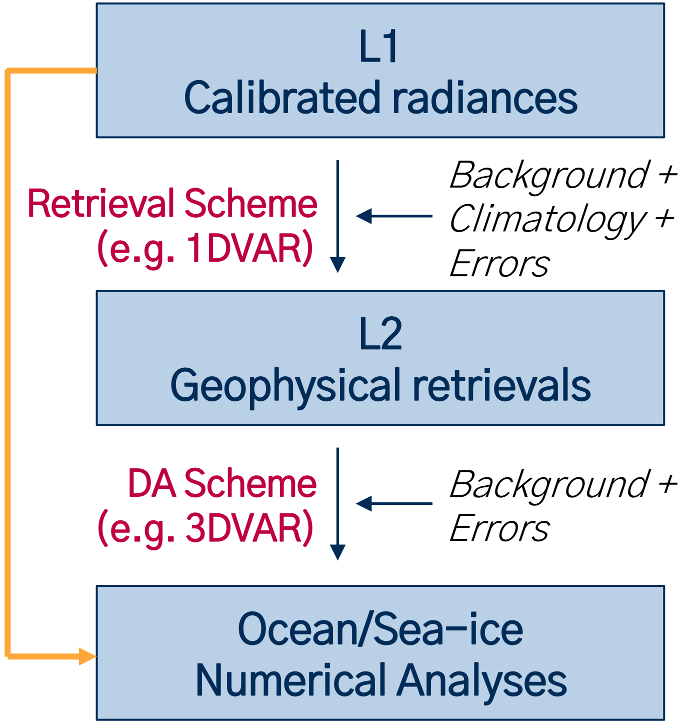
T_B from CIMR channels are sensitive to both oceanic (SST, SSS), atmospheric (wind speed, cloud liquid water) and sea-ice (SIC, SIT) variables -> intrinsically coupled information

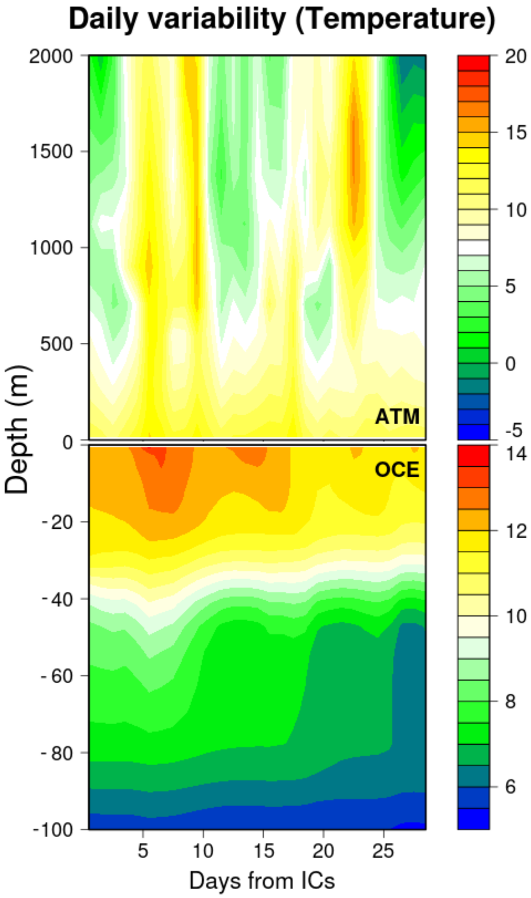
CIMR is an ideal sensor to test coupled data assimilation algorithm

Motivation: T_B Assimilation

- Most ocean data assimilation systems ingest retrievals (e.g. SST, SSS, L2/L3/L4) rather than T_B observations (L1)
- Long-standing experience in Numerical Weather Prediction proved that this approach is rather suboptimal, because retrieval algorithms:
  - Use several assumptions and requires an additional step
  - Introduce error cross-covariances between background and retrievals
  - Difficulty in estimating retrieval uncertainty
  - Possible non-gaussianity of retrievals
- **As CIMR will provide multi-variate oceanic retrievals (SST, SSS), the assimilation of T_B may be particularly advantageous**



Assimilation component: Coupled 1DVAR



- NEMO 3.6, 75 depth levels + OpenIFS Cy40r1, 60 vertical levels
- LIM3 multi–category sea–ice model, 5 categories
- OASIS3–MCT coupler
- Location: PAPA station (Pacific Ocean, 50°N; 145°W)
- Incremental 3DVAR scheme with control variable transformation
- State vector seamlessly includes:
  - Atmosphere: U, V, T, Q
  - Ocean: T, S
- Background–errors as multi–variate EOFs, calculated from anomalies w.r.t. the monthly long–term mean, ensemble mean, etc.
- Simple background quality check; Vertical super–obbing for in–situ
- Limited–memory quasi–Newton minimizer L–BFGS. Coded in R.

Physical fields and Tb ensemble spread

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Ensemble system:

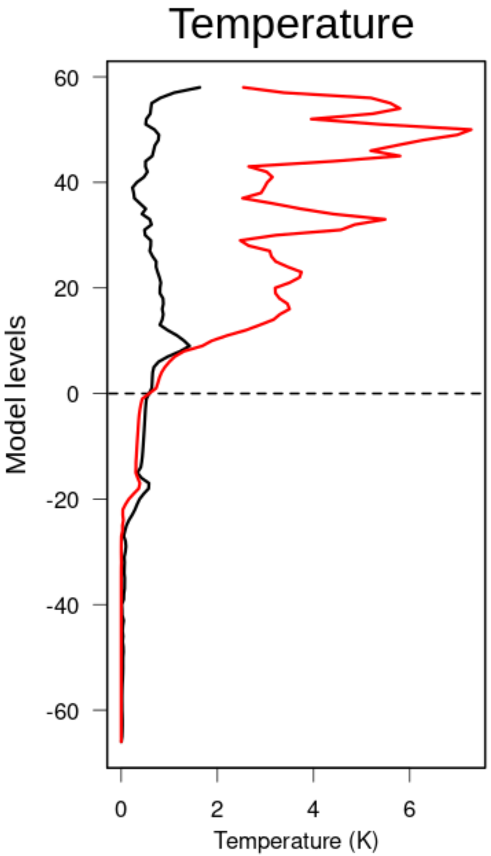
3 ocean model physics
5 atmospheric model physics
6 ocean initial conditions
11 atmospheric initial conditions

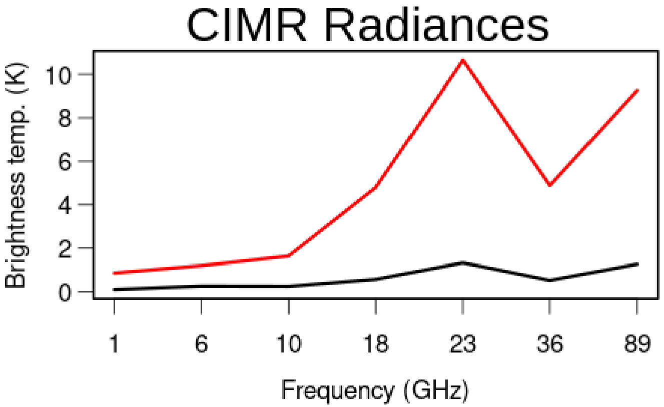
990 members

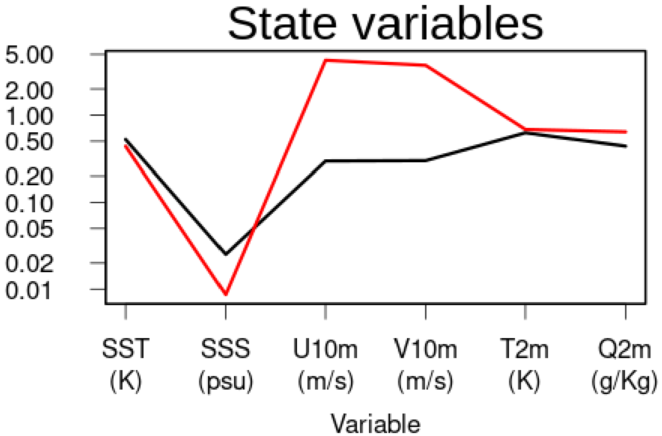
This ensemble is used for:

- Observation operator formulation
- Hybrid ensemble-variational data assimilation

Ensemble St. Dev. vs Temporal St. Dev.







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Experiments: Configuration of OSSEs

Nature Run
Atmospheric ICs from ERA5 ensemble,
Oceanic ICs from GLORYS ocean reanalysis
Nudging to ERA-Interim T/Q (atmosphere)
Nudging to GREP T/S (ocean) and SWR perturb.

↓

Synthetic observations:

Air: T and Q (radiosonde profile)
Sea: T and S (Argo float profile)
CIMR T_B (all channels)
CIMR retrievals (SST, SSS, wind vector 10m)

1-month simulations
with 12-hourly assimilation time-windows
2 CIMR passeges per day (50°N)
2 observations per day also for in-situ

Initial experiments performed to assess the impact of different observing networks

Observational Errors:

Radiosonde: as in ECMWF/IFS

Argo: as in CNR-ISMAR 3DVAR

CIMR T_B: as CIMR ensemble standard dev.

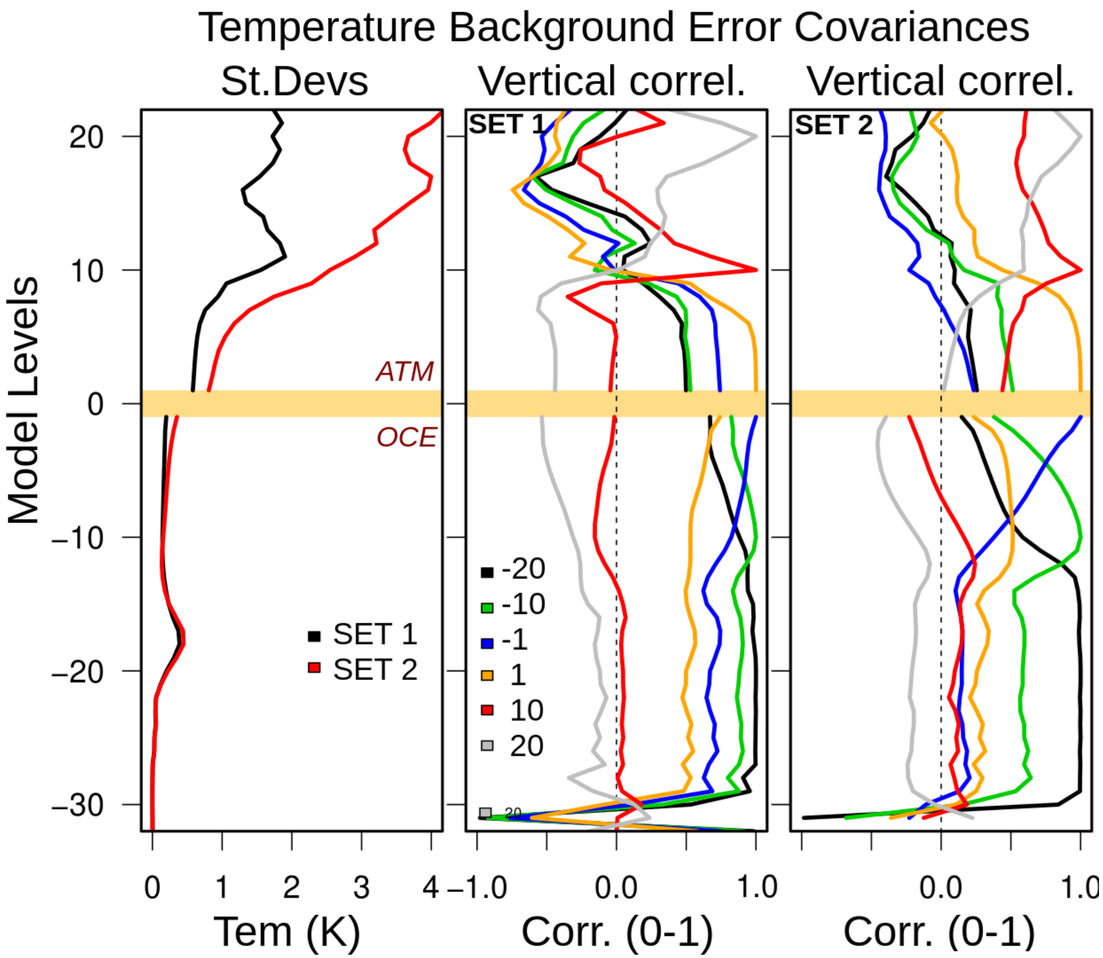
CIMR retrievals: as mission target accuracy at ~50°N (0.3°C|0.55psu|2m/s)

Sets of BECs

<u>**BECs setup is particularly relevant for coupled DA**</u>

<u>**SET1:**</u>
Differences between CTRL and TRUTH (Nature Run)

<u>**SET2:**</u>
6−hourly anomalies of CTRL run



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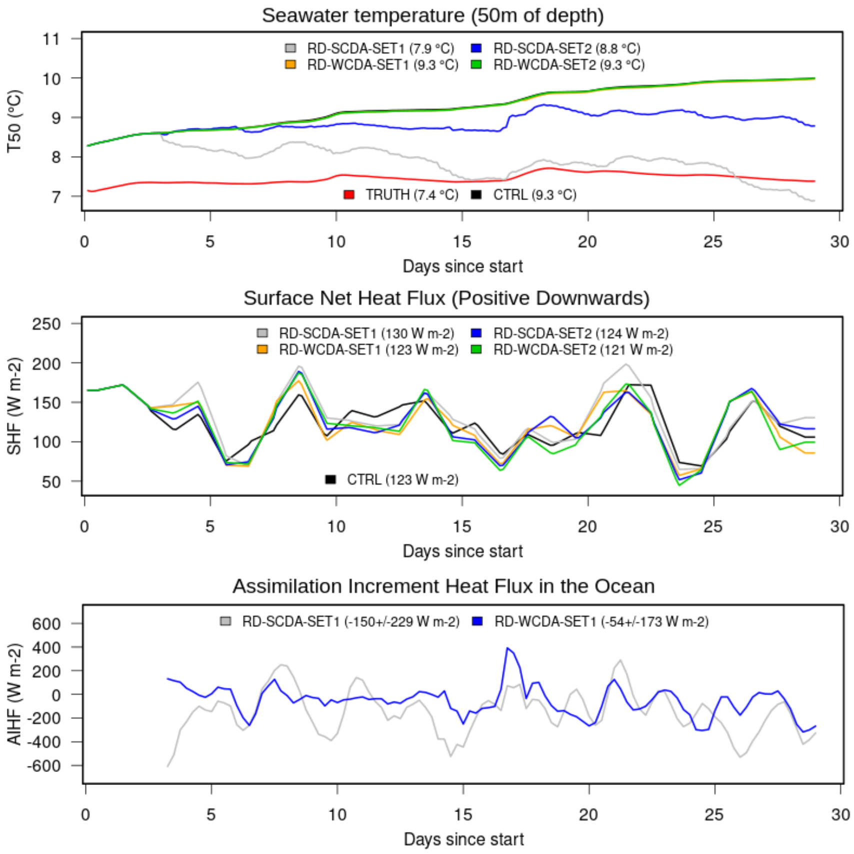
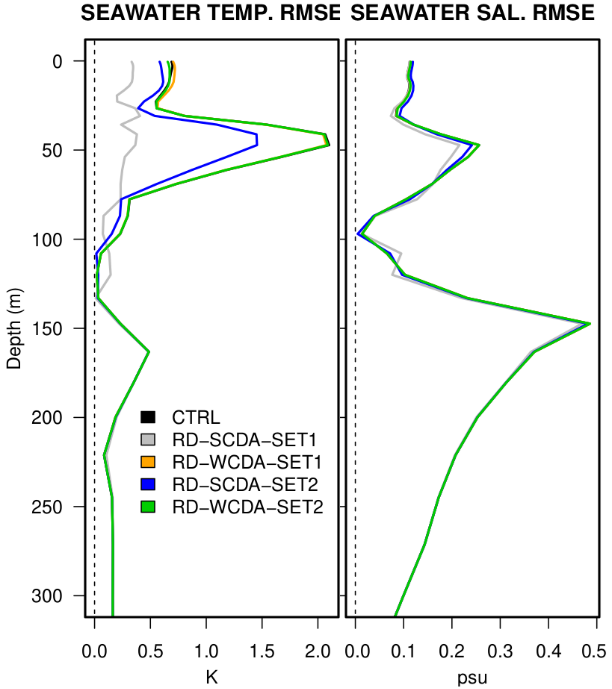
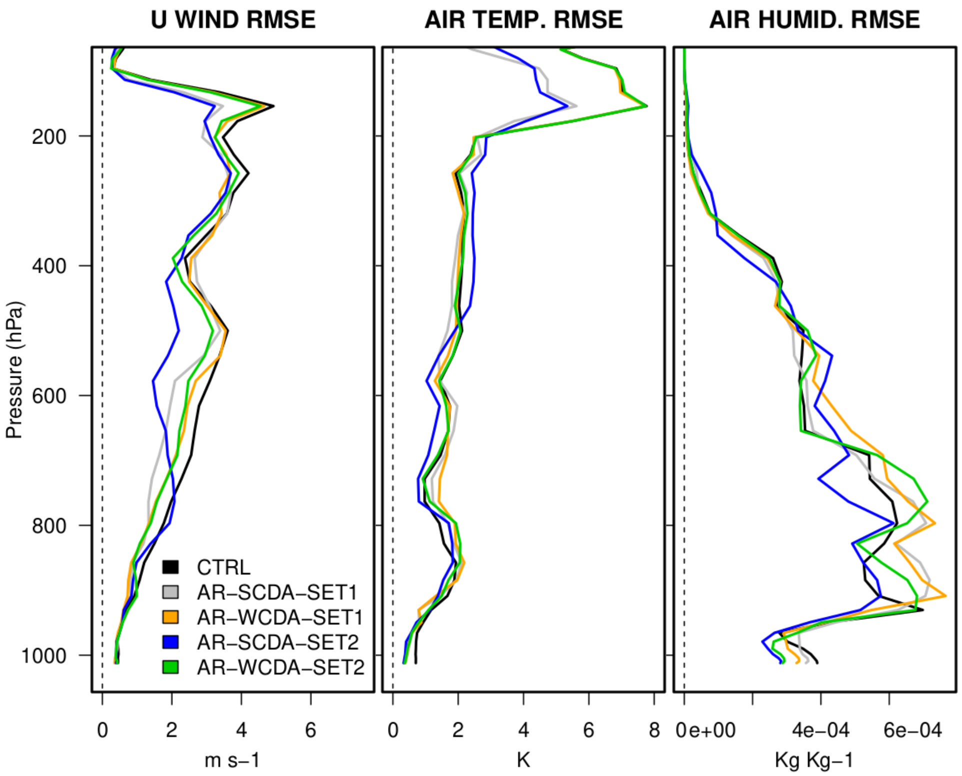
Weakly vs Strongly Coupled DA

Radiosonde DA	Seawater Tem (0–60m)	Salinity (0–60m)
Weakly DA	~0%	~0%
Strongly DA	**20–60%**	**1–10%**



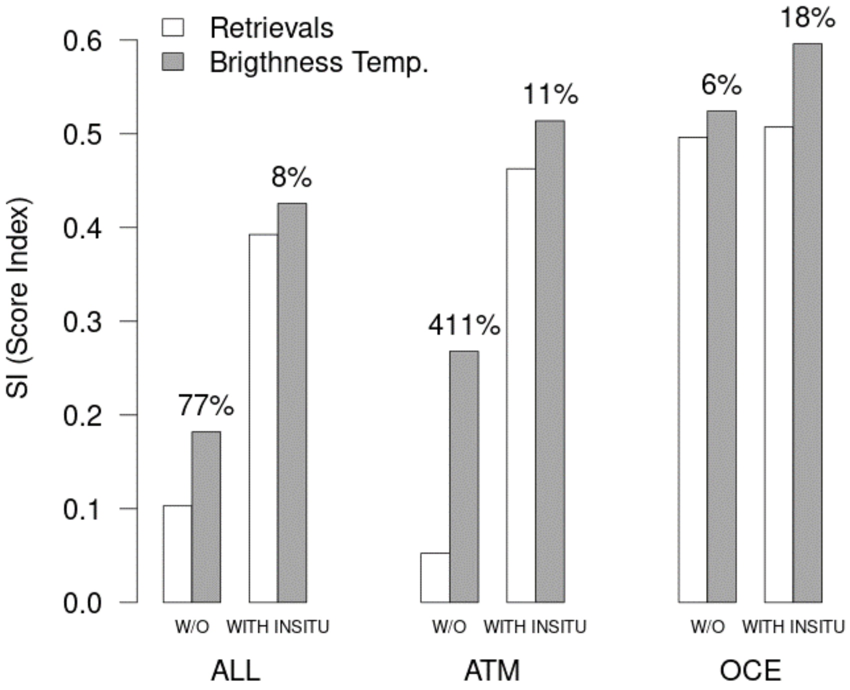


Weakly vs Strongly Coupled DA



Argo DA	U wind (troposph.)	Air Tem (troposph.)
Weakly DA	10−15%	2−4%
Strongly DA	**22−30%**	**2−12%**

Preliminary results



Score Index: *RMSE decrease (%) averaged over multiple verifying parameters*

- Tb assimilation consistently improves the geophysical retrieval data assimilation, both in ATM and OCE, and both with/without synergy of in-situ observations

Limitations

Limitations of the 1D approach

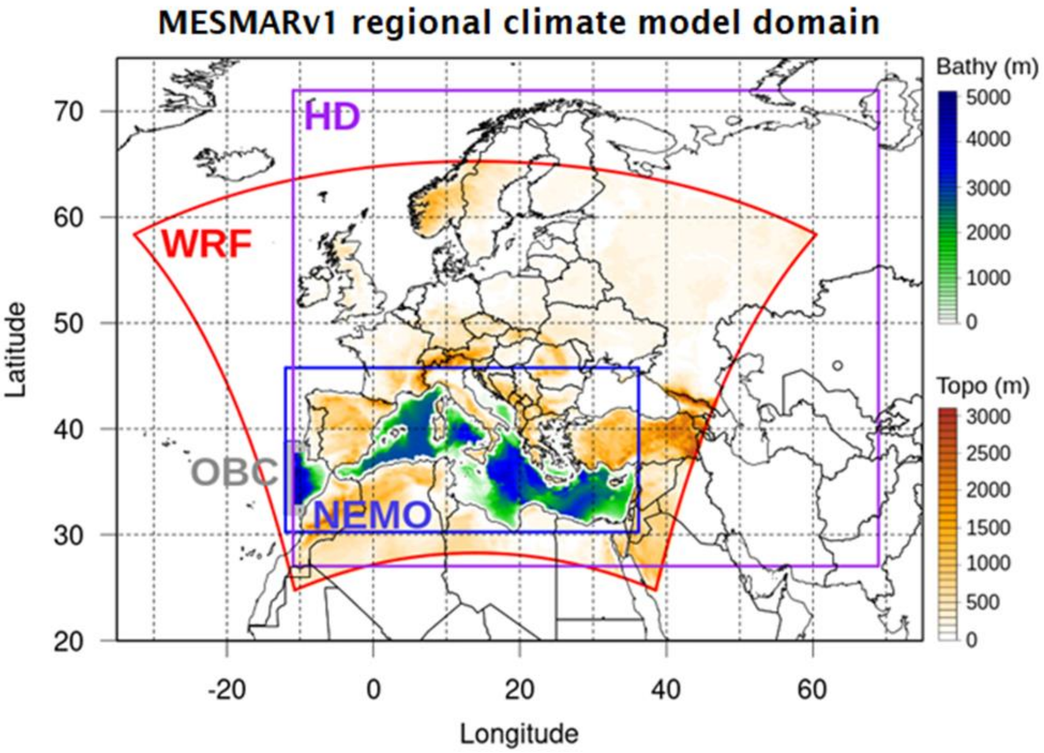
- The 1D framework intrinsically lacks realism for what concerns:
    - Only thermodynamics / vertical mixing are relevant
    - In-situ observation sampling is not realistic
    - Neglecting the horizontal physics may amplify the memory of the system and thus the observational impact

- Challenging the coupled DA problem requires a fully 3D state-of-the-art system

Regional coupled model

WRF model (4.3.3)
Resol.: 15km L40
LBCs: ERA5 (6h)
ICs: ERA5
SBCs: (OSTIA)
Radiation: RRTMG
Surface layer: MM5
Microphys.: Morrison
Land: Noah
Cumulus: Betts–Miller–Janjic
PBL/SBC: MM5

Coupler
OASIS3–MCT4
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 (5.0.1) River Discharge
1/12° Resolution
European Basins

Storto, A., et al., MESMAR v1: a new regional coupled climate model for downscaling, predictability, and data assimilation studies in the Mediterranean region, Geosci. Model Dev., 2023.

Coupled Model code: https://doi.org/10.5281/zenodo.7898938

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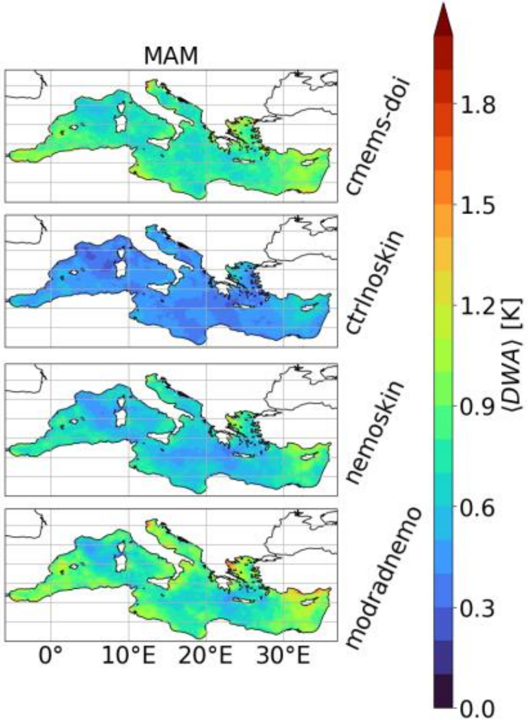

Improving the skinSST scheme in the NEMO-WRF coupled system

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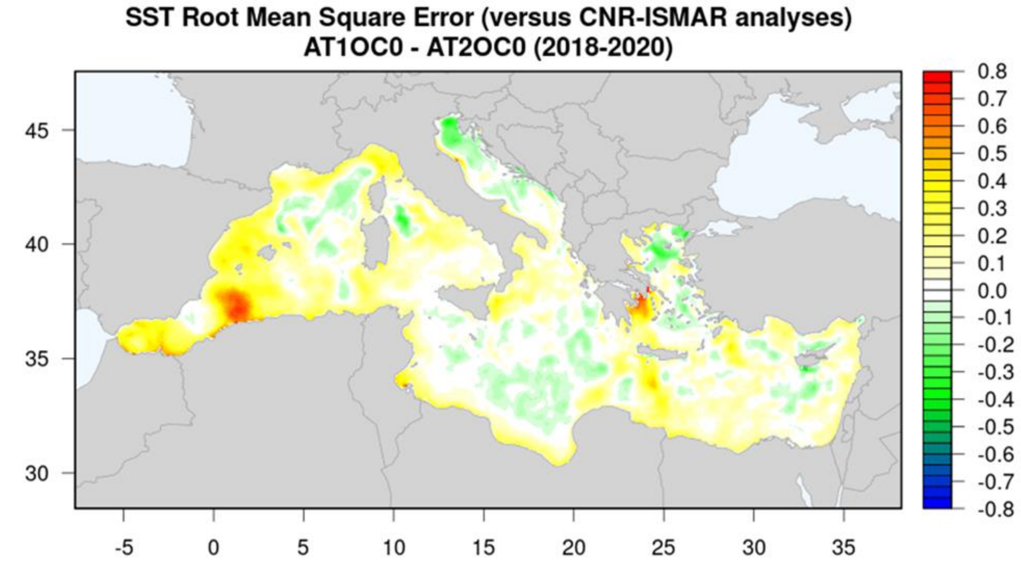
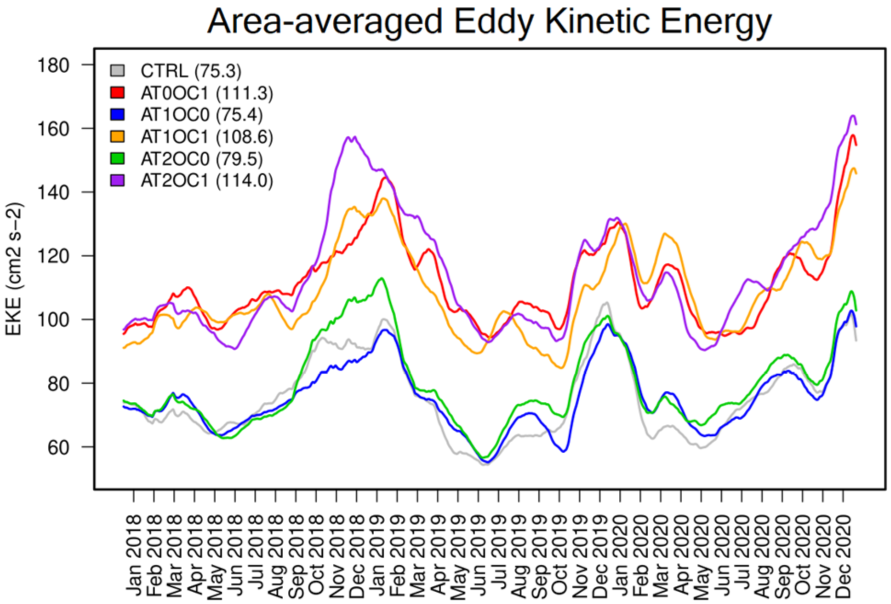
Weakly Coupled DA experiments

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

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





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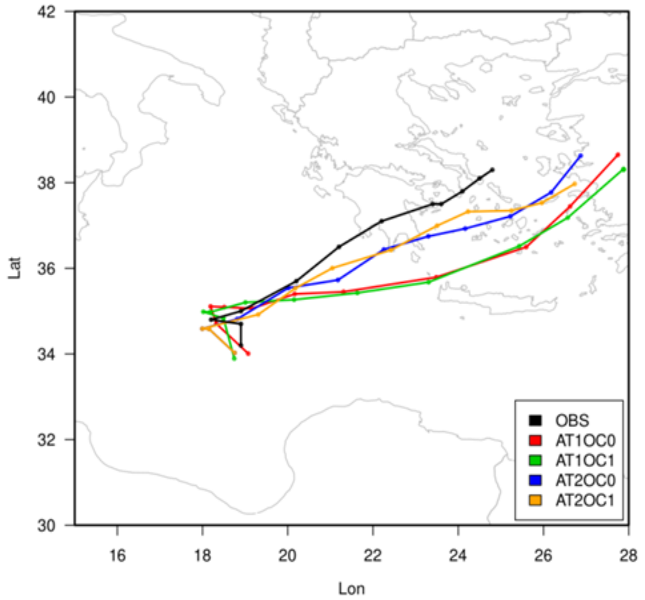
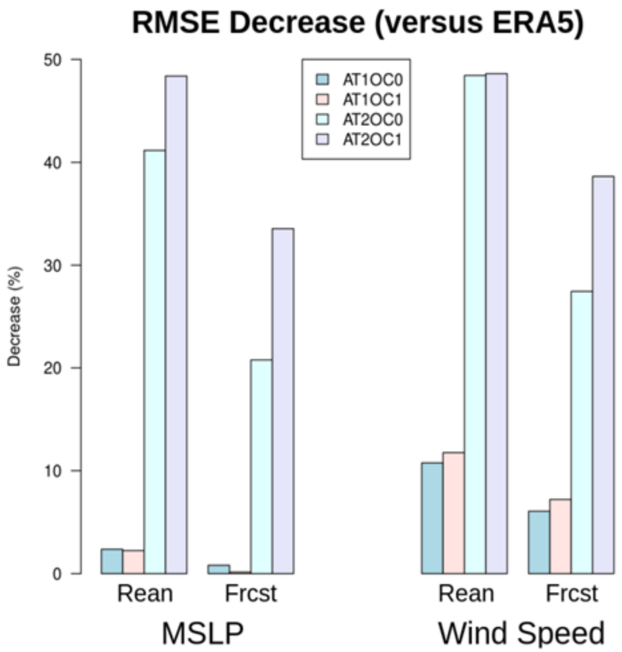
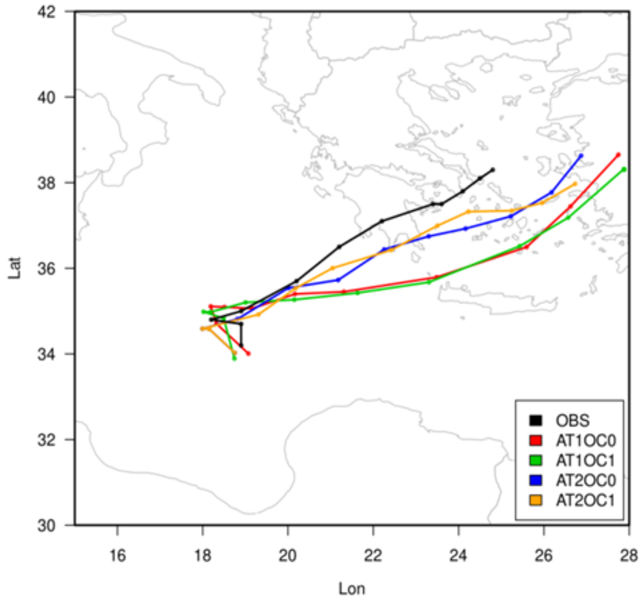


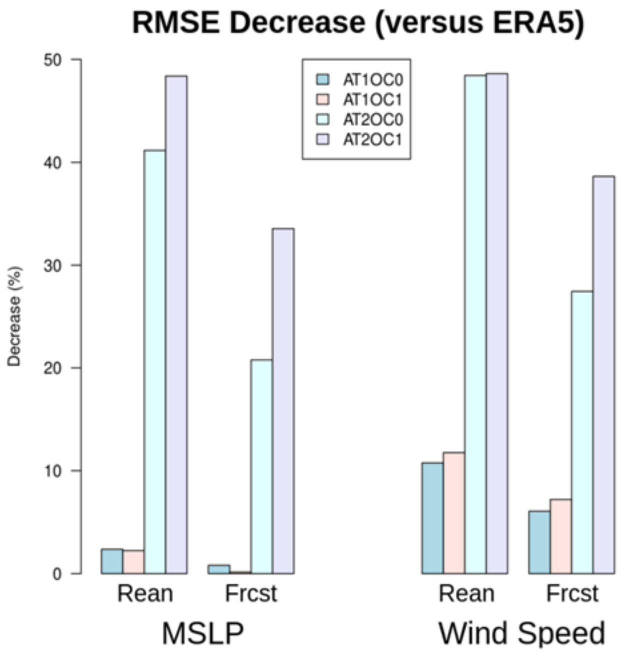


Medicane track captured well when the spectral nudging is used. No significant impact of ocean DA

Intensity (minimum MSLP; maximum wind) of medicane is improved when subsurface ocean DA is used

Weakly Coupled DA experiments





Completed: a weekly coupled reanalysis 1998–2022 of the Mediterranean region

Ongoing: seamlessly extend the DA system to include atmospheric parameters and observations

Technical developments + scientific experiments to identify optimal cross-medium (hybrid) covariances

Outlook

- Large potential from coupled data assimilation at all scales:
  - Maximization of observations' impact
  - Coupled observation operators (better satellite data assimilation)
  - Reduction of ICs imbalance/shocks
  - Better closure of e.g., energy budget

- Relatively straight-forward for short-range predictions.
  - Benefits still need to be quantified systematically
    - Implied fluxes to be evaluated

- Beside reanalyses, climate applications (from sub-seasonal to decadal) may benefit as well (for the reasons above, for seamless predictions, etc.)
  - Challenge is the temporal scale [filtering, representativeness, etc.] (long-window 4DVAR, time-averaged observations for decadal predictions, ...)

Thank you

Questions?