Coupled Data Assimilation Experiments at CNR ISMAR

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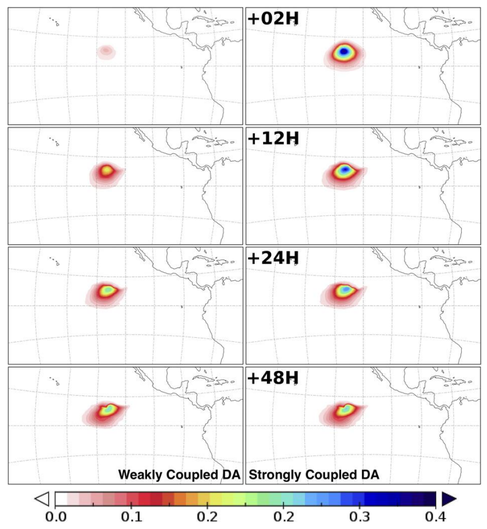
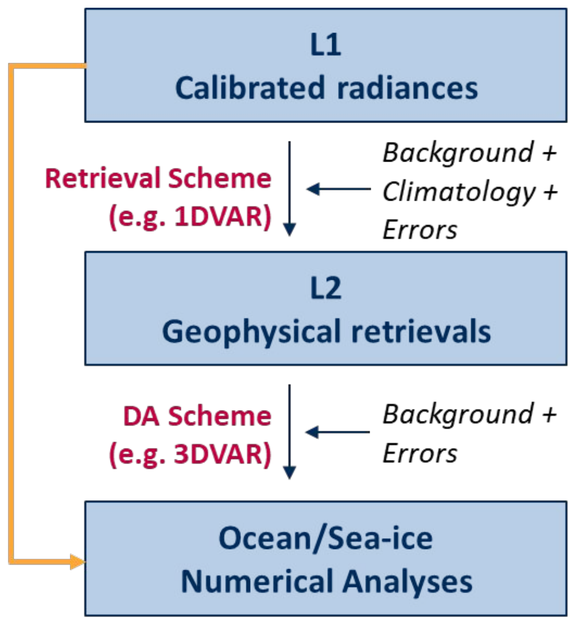
— Motivation —

- Future DA systems will be fully coupled, in order to:
  - Minimize imbalances and initial shocks (see example on the right)
  - Enhance the exploitation of observations through cross-medium propagation
  - Enhance the use of satellite data through coupled observation operators
- Brightness temperature data from e.g. channels that are sensitive to both oceanic (SST, SSS), atmospheric (wind speed, cloud liquid water) and sea-ice (SIC, SIT) variables provide intrinsically coupled information



Forecast model propagation of analysis increments (K) onto T2M increments at different forecast ranges for (left) weakly and (right) strongly coupled DA. The analysis increments come from single SST observation experiments. From Storto et al., 2018: Strongly Coupled Data Assimilation Experiments with Linearized Ocean-Atmosphere Balance Relationships. Mon. Wea. Rev., 146, DOI: 10.1175/MWR-D-17-0222.1.

- Additionally, 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
  - Possible non-gaussianity of retrievals (e.g. SIC)
- **An ideal sensor to test in this context is CIMR (Copernicus Imaging Microwave Radiometer) expected to be launched in 2029**



— Experiments with a single-column atm-oce model —

Model

We use the **single-column** (SCM) version of the EC-Earth 3 coupled model, which is made up of NEMO 3.6 (75 depth levels) and IFS cy40 (60 vertical levels), coupled through OASIS.

The model location is the PAPA station in the mid-latitude Pacific Ocean (50°N, 145°W).

The model is initialized through ERA-Interim and ORAS4 reanalyses from ECMWF.

Data Assimilation

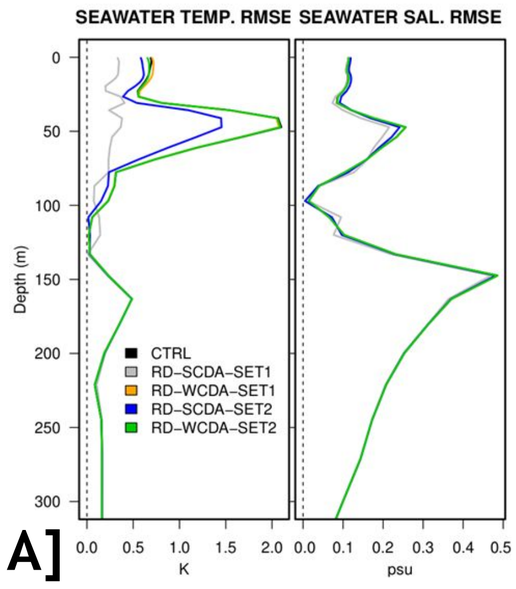
A coupled air-sea variational data assimilation system has been developed to assess the impact of observations within the coupled forecasts.

The coupled state vector includes wind vector, atmospheric temperature and humidity, oceanic temperature and salinity. Two different sets of coupled background-error covariances are tested. A simple quality check of observations and vertical *super-obbing* is embedded in the DA system.

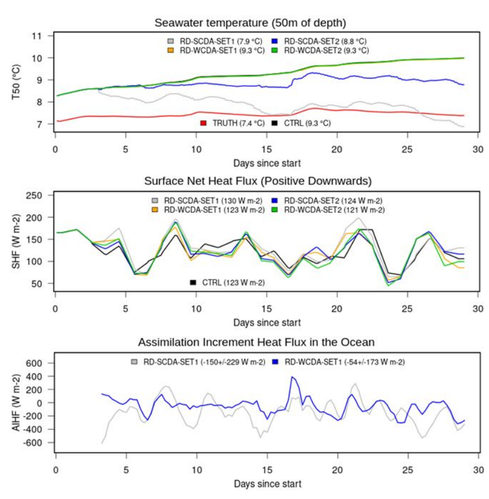
Methodology

Traditional OSSEs are used to test the algorithm and observation impact. The Nature Run uses different initial conditions and is nudged towards reanalysed fields.

The set of synthetic observations extracted from the Nature Run includes atmospheric profiles from radiosondes (12-hourly), oceanic profiles from Argo (24-hourly), CIMR retrievals and CIMR brightness temperature data (12-hourly), perturbed according to the nominal observation errors. 1-month experiments with 12-hourly assimilation windows are adopted.

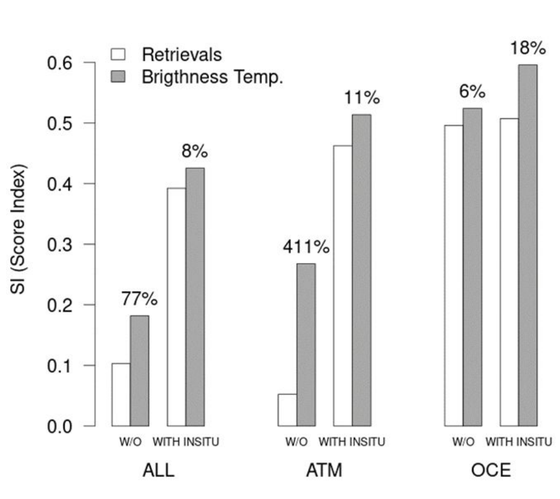


A]



B]

CTRL: no data assimilation
RD: Radiosonde data are assimilated
SCDA/WCDA: Strongly or weakly coupled DA
SET1/SET2: different sets of coupled covariances



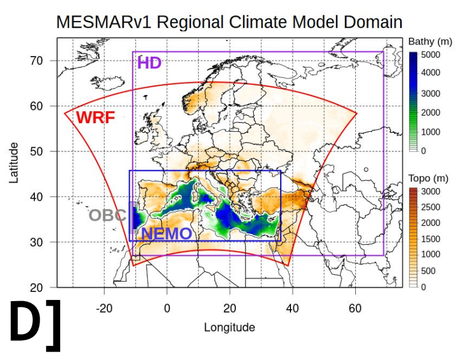
C]

The benefits of coupled DA are assessed in experiments where we assimilate radiosonde data and verify the forecasts against independent Argo data (Figures A, B).

Assimilating radiosonde profiles lead to significant improvements of the ocean temperature skill scores (up to 50%) when the strongly coupled DA is used. Weakly coupled DA does not provide improvements with respect to the control experiment. There is large impact of the set of coupled background-error covariances used. The effect of strongly coupled DA is dominant at analysis time, visible in the heat budget assessment (Figure B).

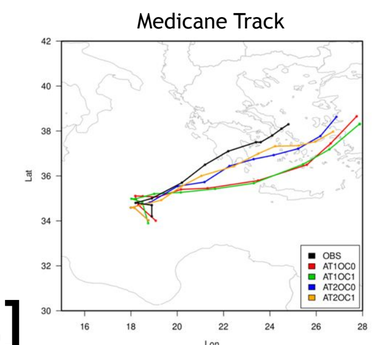
Preliminary results show that, compared to geophysical retrievals, assimilating brightness temperature from CIMR improves the skill scores (here the "Score Index" is used, which averages the fractional RMSE reduction over many verifying parameters, Figure C) in both atmospheric and oceanic verification, and also in both the cases where in-situ observations are assimilated together with CIMR or not. We conclude that the coupled assimilation of CIMR TB is promising for both (ocean) uncoupled and coupled applications, and outperforms the assimilation of retrievals.

— Experiments with a fully 3D model —



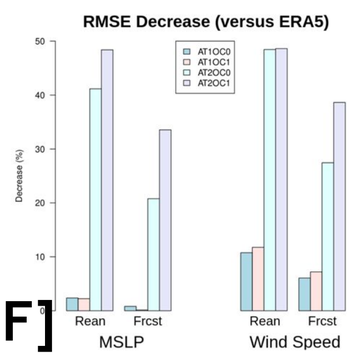
D]

NEMO 4.0.7 (7kmL72) + WRF 4.3.3 (14kmL40) + HD 5.0.1 (1/12°) + OASIS3-MCTv4
+ 3DVAR in the ocean + Spectral Nudging in atm



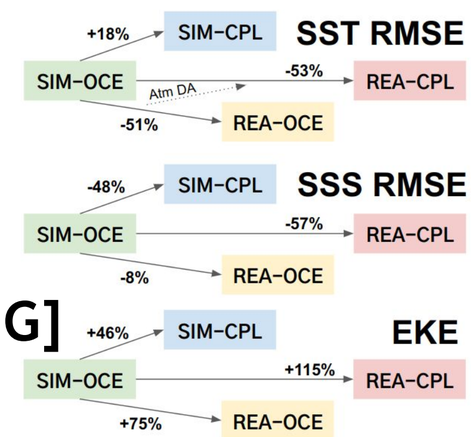
E]

Exp	MESREA	GLORYS	COPMED
SST	**0.25**	0.47	0.32
SLA	5.0	**3.3**	5.6
SSS	**0.25**	0.41	0.27



F]

Skill scores of a weakly coupled reanalysis (MESREA, 1998-2021) in the Med compared to CMEMS global (GLORYS) and regional (COPMED)reanalyses (SST in °C, SSS in psu, SLA in cm)



G]

Weakly coupled DA is configured in a regional atmosphere-ocean-hydrology coupled model over the Mediterranean basin.
Representation of medicanes (=hurricanes in the Mediterranean Sea) shows that atmospheric spectral nudging (AT2) outperforms full field nudging (AT1) while ocean observations do not show significant impact on the track trajectory (Figure E). However, skill scores about medicane intensity (along-track MSLP and wind, Figure F) show significant impact of ocean DA (AT2OC1 vs AT2OC0).

We also investigate the relative impact of coupling and DA on several ocean diagnostics (Figure G). SST accuracy is mostly benefited by ocean DA, while SSS mostly by the coupling. Higher (better) levels of EKE in the ocean are reached with significant contributions of both DA and coupling, in an almost additive way.

Next steps

- Finalize the CIMR assimilation studies in the single-column model through an enhanced observation operator formulated as neural network
- Add strongly coupled DA capability in the MESMAR 3D analysis and forecast system for regional reanalyses applications

Information on the forthcoming CIMR mission can be found at https://cimr.eu. Information on the SCM version of EC-Earth at http://www.ec-earth.org. Information on the regional coupled model is available from Storto et al., 2023: MESMAR v1: a new regional coupled climate model for downscaling, predictability, and data assimilation studies in the Mediterranean region, Geosci. Model Dev., https://doi.org/10.5194/gmd-16-4811-2023