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Coupled satellite data assimilation in intermediate complexity coupled model experiments

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The Copernicus Imaging Microwave Radiometer (CIMR) mission

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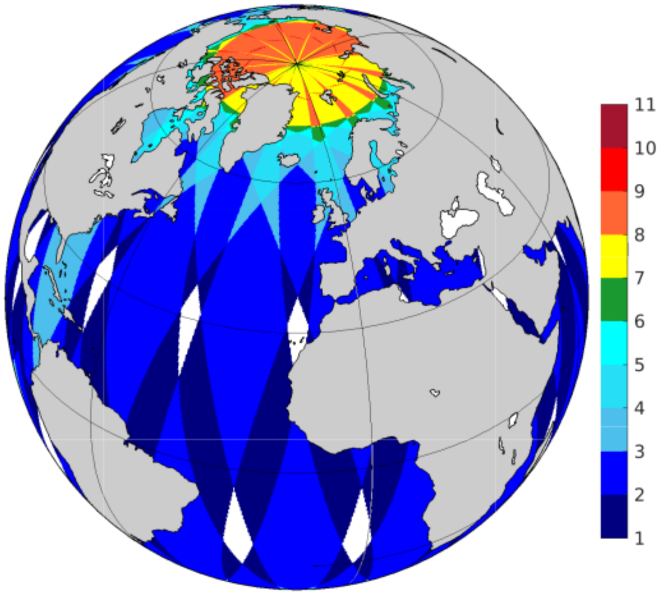
https://cimr.eu

A high priority candidate satellite mission within the European Copernicus Expansion program

Daily Coverage (obs per day)



- Global Coverage except small areas in the tropics
- No whole at the poles
- **> 2 obs per day from mid-latitudes poleward**

cimr.eu

HR SST and SSS from the same platform!

ESA **CIMR** 2026+ | JAXA **AMSR2 [A2]**, today)

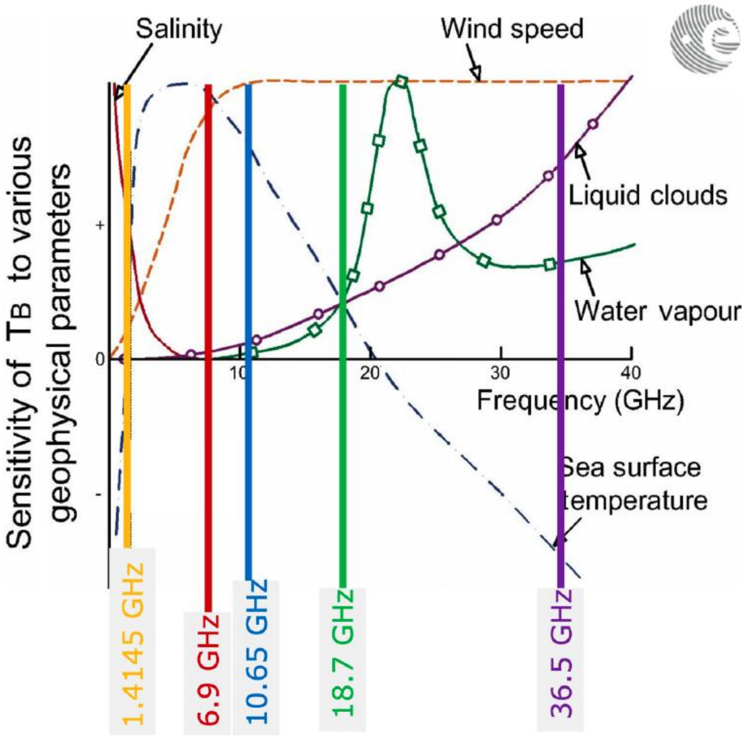
Beam centre frequency (GHz)	Beam Target resolution, L (km)		NEΔT (K)	
1.413	55	(x)	≤0.3	(x)
6.9	15	(48)	≤0.2	(0.3)
10.65	15	(33)	≤0.3	(0.6)
18.7	5	(18)	≤0.3	(0.7)
36.5	5	(9)	≤0.7	(0.7)

Sea Surface Salinity ~40 km
Sea Surface Temperature ~10 km

Sea Ice Thickness, Sea Ice Concentration, Sea Ice Extent, Ocean wind speed, Cloud Liquid Water

"ALL WEATHER", H-V Channels

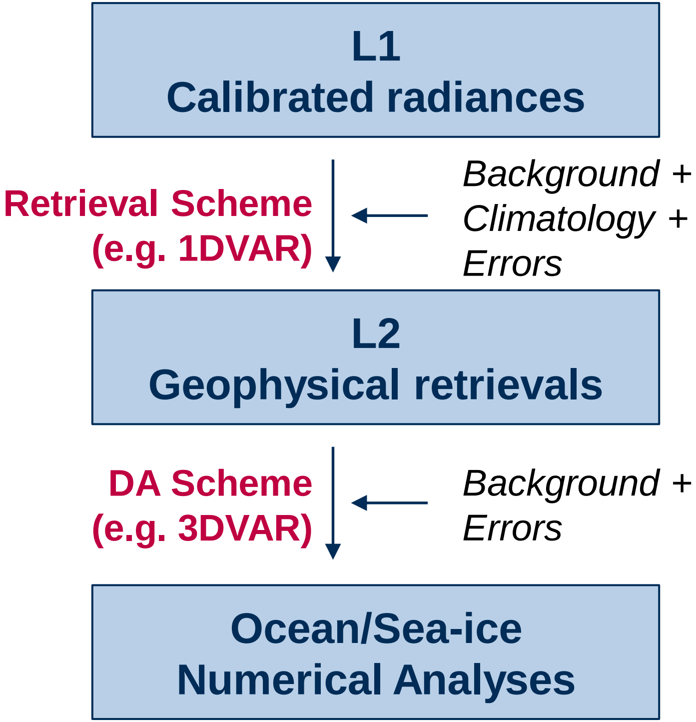
Motivation: Coupled Data Assimilation



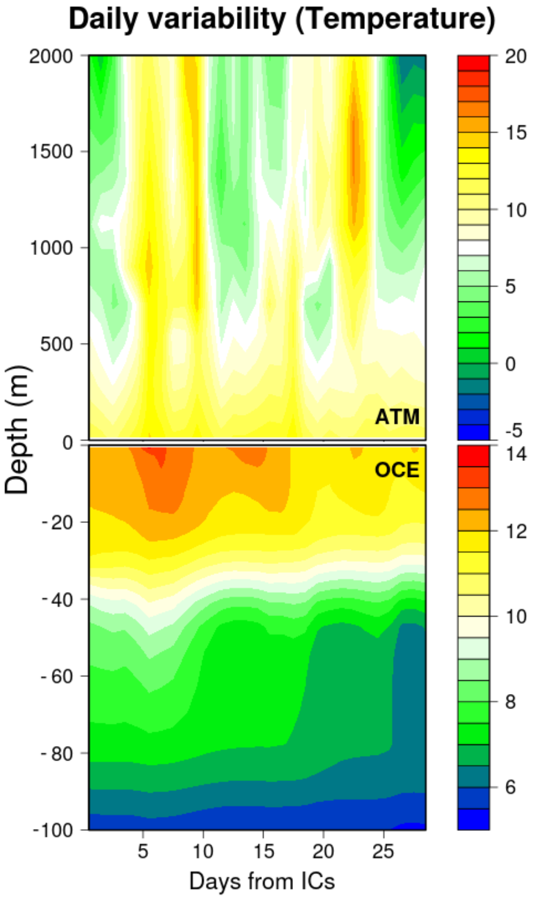
- It can be foreseen that future DA systems will be fully coupled, in order to:
  - Minimize imbalances and initial shocks
  - Enhance the exploitation of observations through cross-medium propagation
  - Enhance the use of satellite data through coupled observation operators
- T_B from CIMR channels are sensitive to both oceanic (SST, SSS), atmospheric (wind speed, cloud liquid water) and sea-ice (SIC, SIT) parameters
- 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, L3/L4) rather than T_B observations (L2)
- 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
- As CIMR will provide multi-variate oceanic retrievals (SST, SSS), the assimilation of T_B may be particularly advantageous



Modelling component: EC-Earth 1D (SCM) coupled model



- 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)
- Initialization: ERA-Interim and ORAS4 (ECMWF reanalyses)
- Maintained by Univ. of Stockholm within the EC-Earth consortium
- Timestep 900s (both atm and oce), 3-hourly outputs

Hartung, K., Svensson, G., Struthers, H., Deppenmeier, A.-L., and Hazeleger, W.: An EC-Earth coupled atmosphere–ocean single-column model (AOSCM.v1_EC-Earth3) for studying coupled marine and polar processes, Geosci. Model Dev., 11, 4117–4137, https://doi.org/10.5194/gmd-11-4117-2018, 2018.

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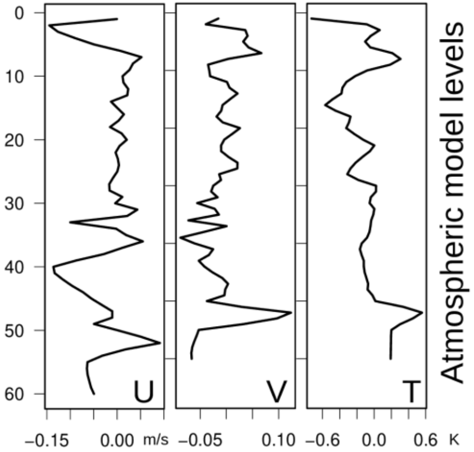
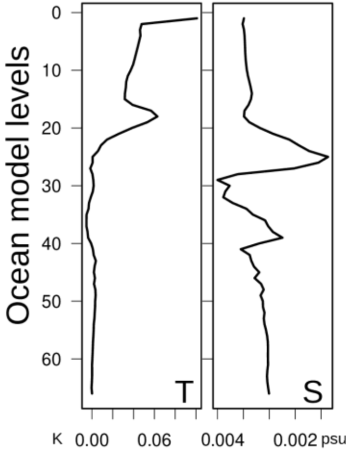
Assimilation component: Coupled 3DVAR





SST Single-obs experiment

- 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 (observations rejected when their square misfits exceed 3 times the sum of observation and background error variances)
- Vertical super-obbing for in-situ atmospheric and oceanic profiles
- Limited-memory quasi-Newton minimizer L-BFGS. Coded in R.

Physical fields and Tb ensemble spread

<u>Ensemble system:</u>

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

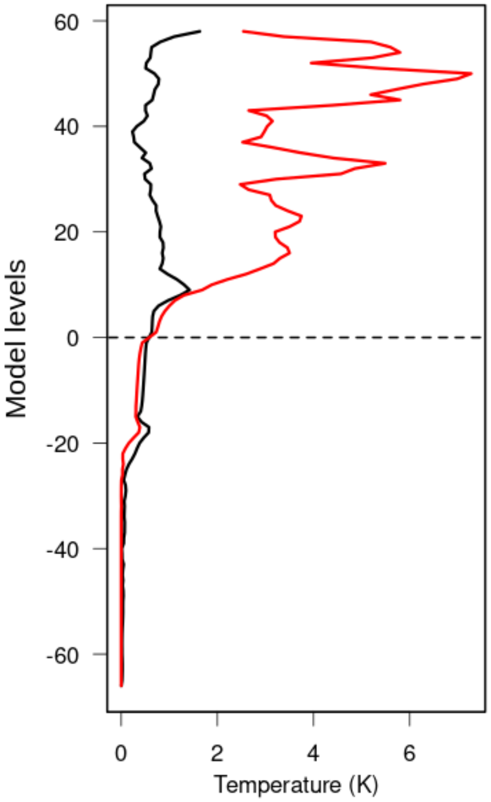
990 members

<u>This ensemble is used for:</u>

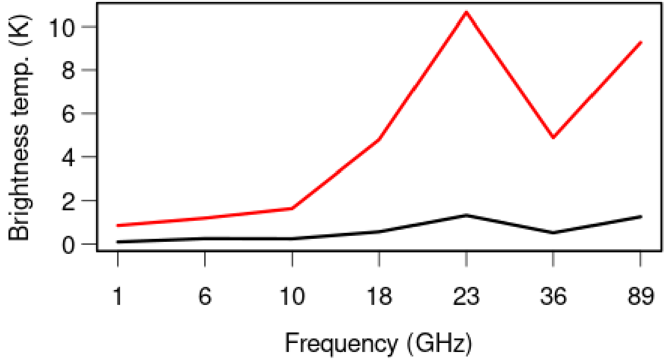
- Observation operator formulation
- Hybrid ensemble-variational data assimilation

Ensemble St. Dev. vs Temporal St. Dev.

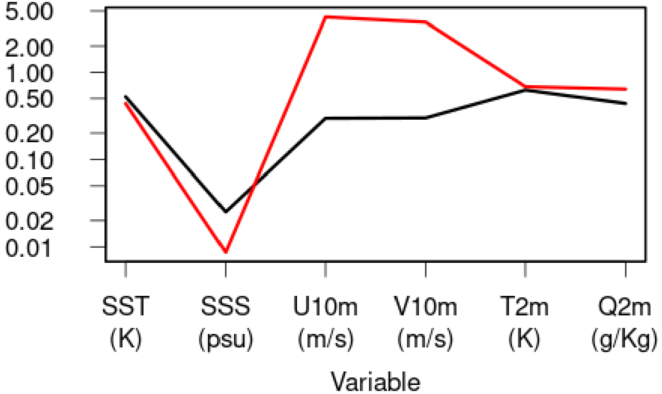
Temperature



CIMR Radiances



State variables



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.

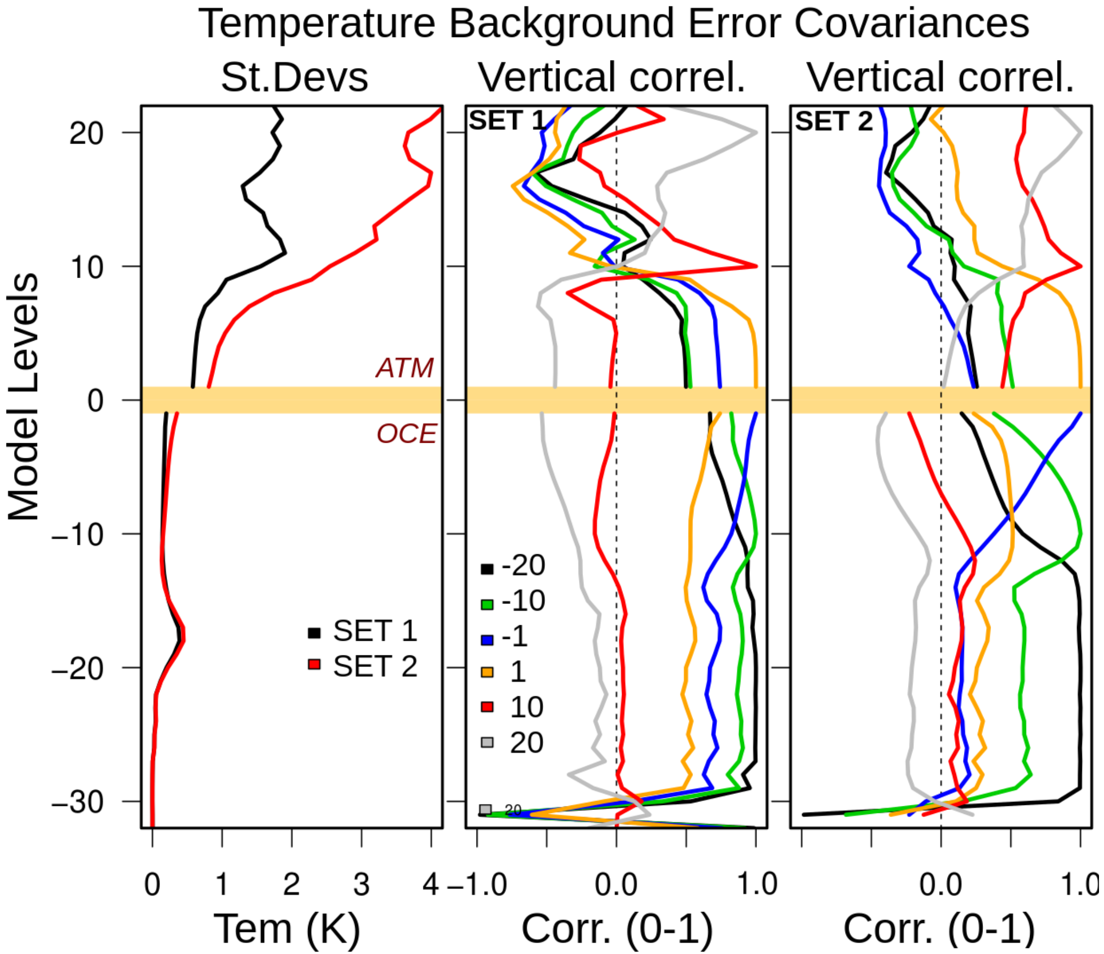
CIMR retrievals: as mission target accuracy at ~50°N (0.3°C|0.55psu|2m/s)

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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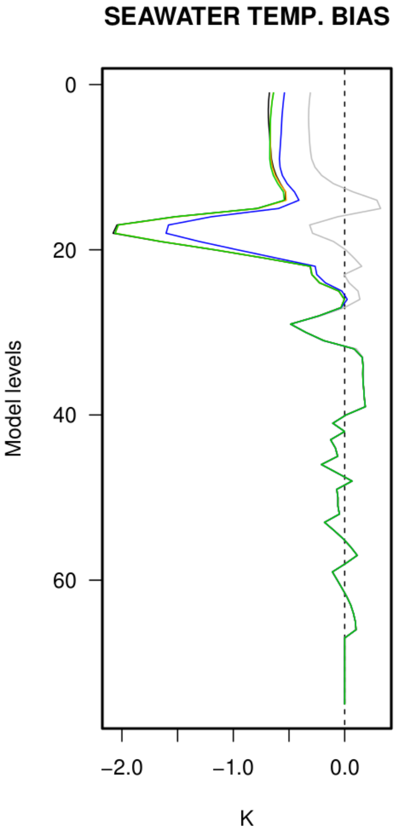
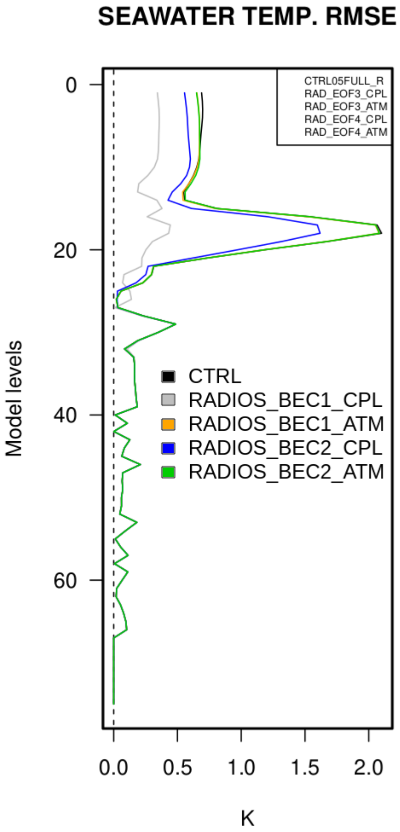
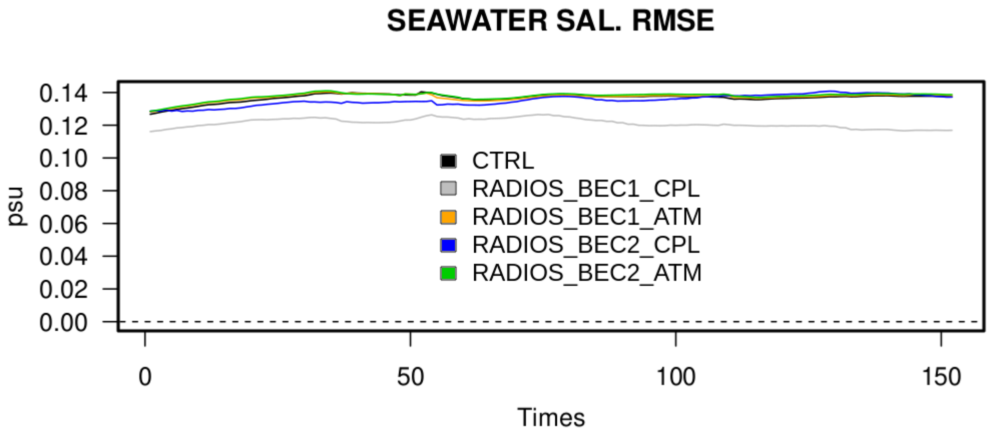
Weakly vs Strongly Coupled DA

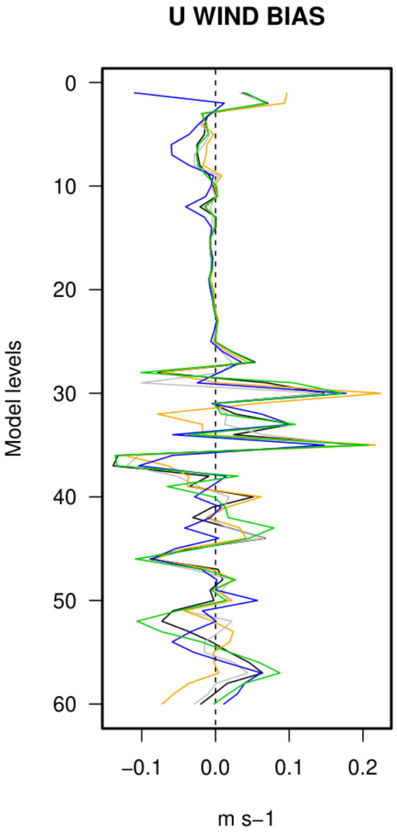


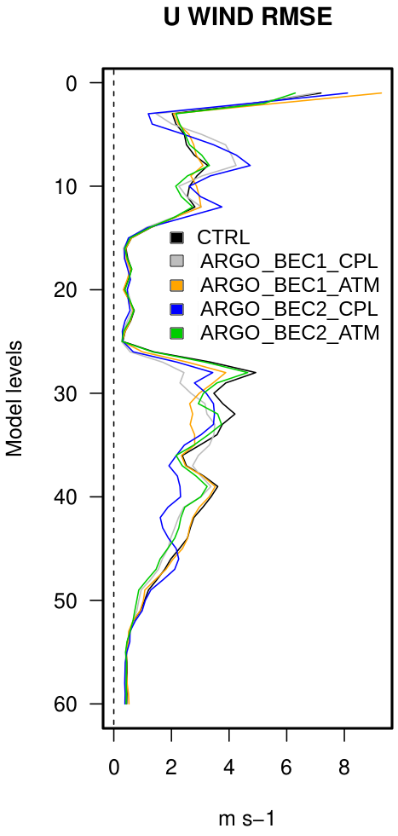


Radiosonde DA	Seawater Tem (0-60m)	Salinity (0-60m)
Weakly DA	~1%	~0%
Strongly DA	20-40%	1-11%

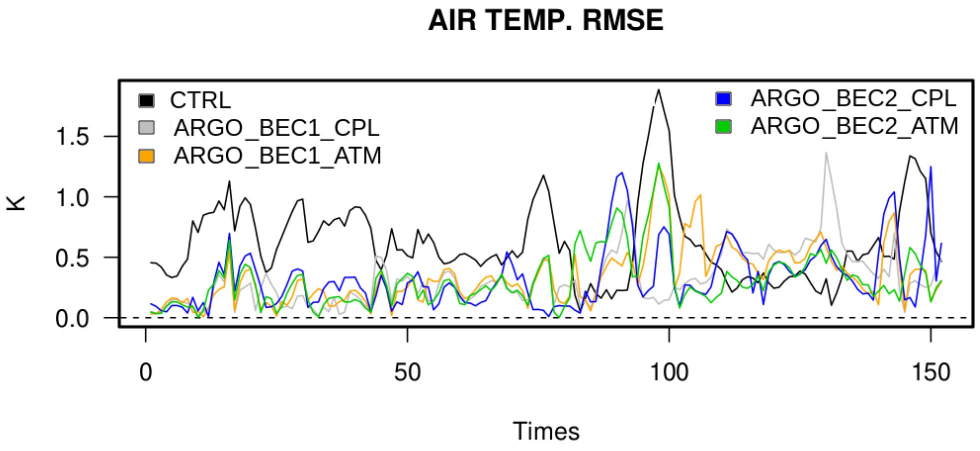


Weakly vs Strongly Coupled DA





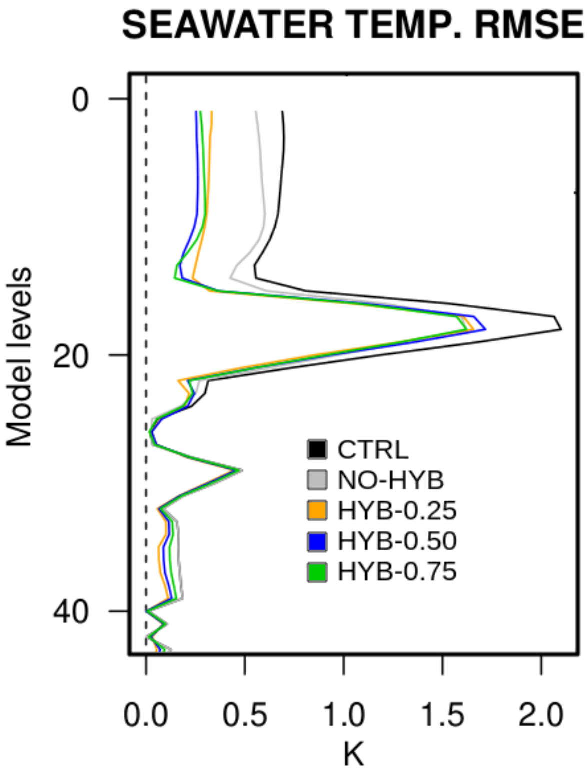
Argo DA	U wind (0-300m)	Air Tem (0-300m)
Weakly DA	0-6%	45-50%
Strongly DA	7-11%	64-67%

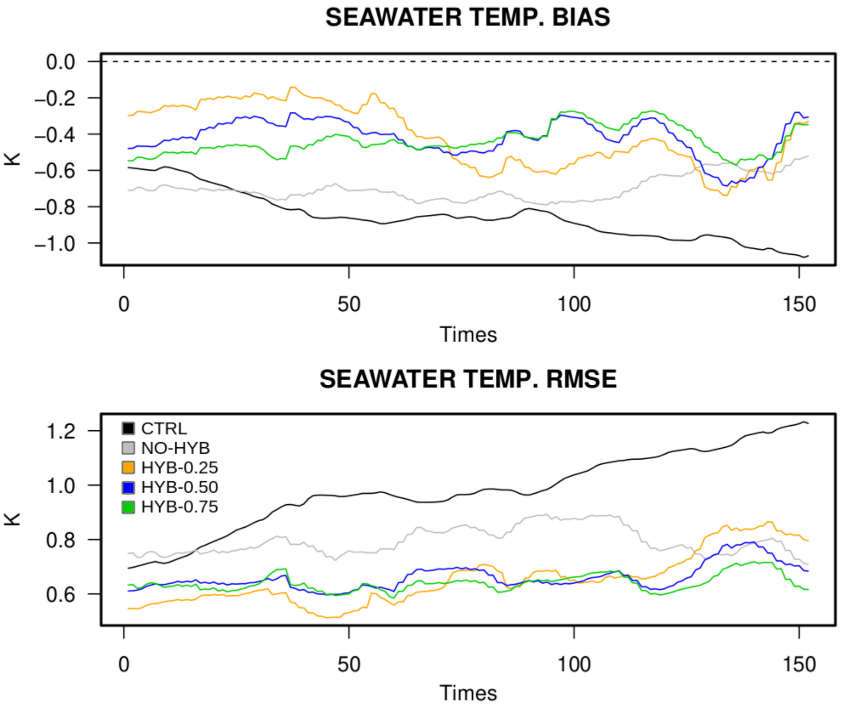


Impact of hybrid BECs

Strongly coupled DA: Verification of seawater Tem after assimilating radiosonde data

Hybrid covariances may particularly benefit Coupled DA





CIMR observation operator: Surrogate model from RTTOV13

- The observation operator for CIMR is taken from RTTOV13, merging T_B forward models from SMOS/MIRAS and Aqua/AMSR-E

- In order to avoid the coupling of the 3DVAR system with RTTOV for this idealized exercise, we formulate a

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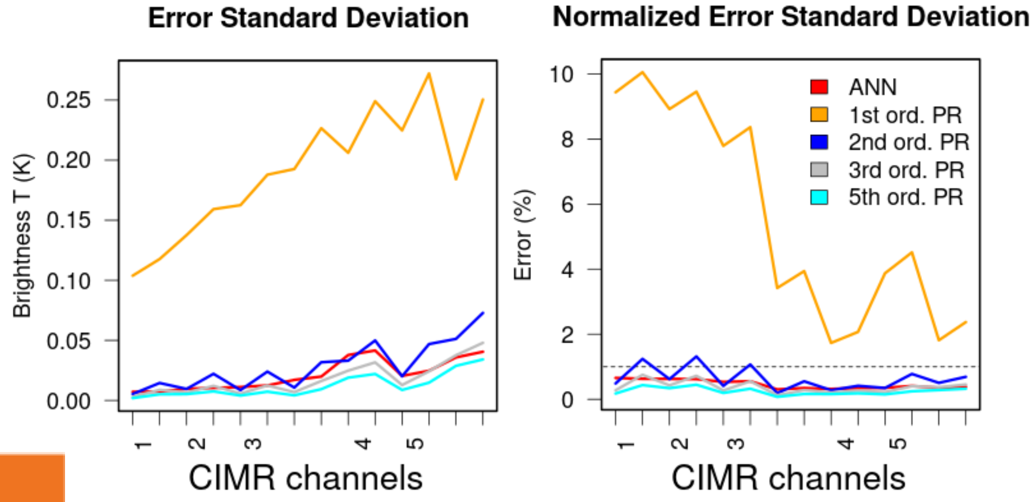


- Training data from the large ensemble of SCM fields and RTTOV outputs

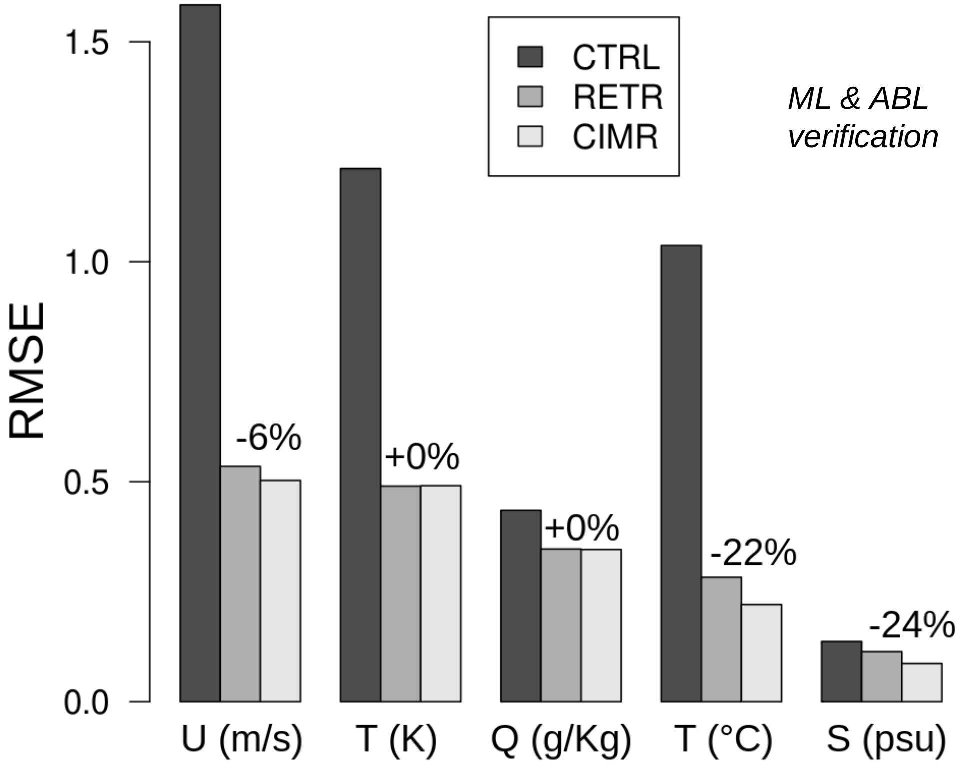
- Accuracy of Artifical Neural Network (ANN) and polynomial regression (PR) (order>3) is very high (error < 1% of T_B variability)

- For sake of simplicity 3rd ord. PR will be used

Experiments:
Comparing Tb vs Retrieval assimilation

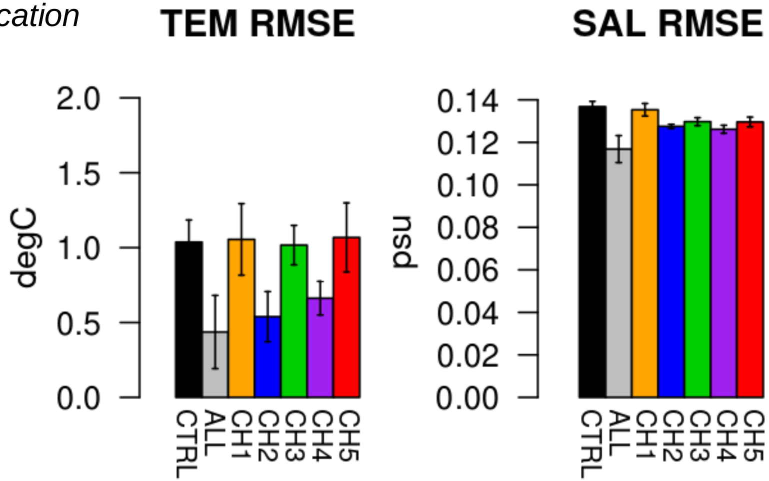
Comparing the impact of brightness temperature DA versus Retrievals DA

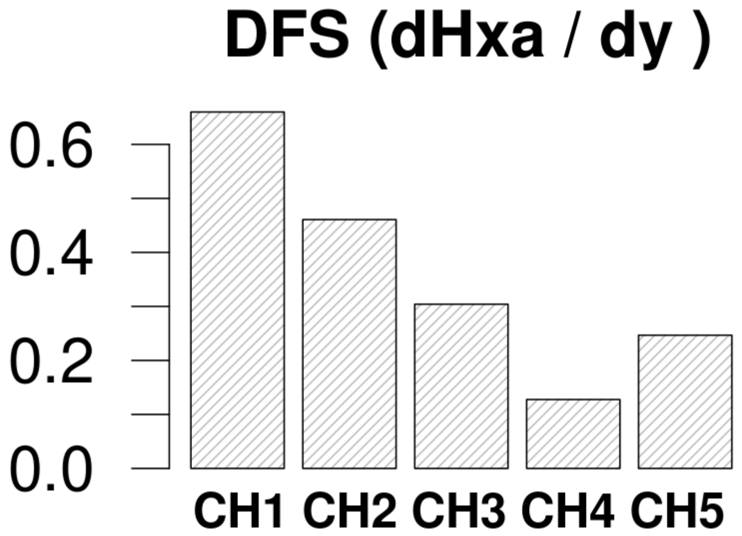
- Verification skill scores indicate that TB DA outperforms retrievals DA for ocean parameters and, partly, for wind, while the impact is neutral for atmospheric parameter verification
- Accuracy around the thermocline is particularly benefited by the TB data assimilation



Experiments: Preliminary results

Total column verification





- Data-denial experiments show that the assimilation of all channels always outperforms the ingestion of any individual channels
- Some results appear not completely intuitive, due to the role of atm-oce cross-covariances
- DFS (Degrees of Freedom for Signal) suggest that channels 1,2,3 impact the analysis at most

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Summary

- The CIMR mission fosters the rethinking of satellite data assimilation in the ocean (T_B vs retrievals) and calls for fully coupled (air-sea) data assimilation approaches
- A 1D strongly coupled analysis system based on EC-Earth and an atmosphere-ocean variational scheme has been setup to assess the benefits of strongly coupled DA and CIMR data assimilation
- Skill scores suggest that assimilating CIMR T_B outperforms retrieval assimilation in the verification of the ocean parameters (T, S)

Thank you for the attention

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