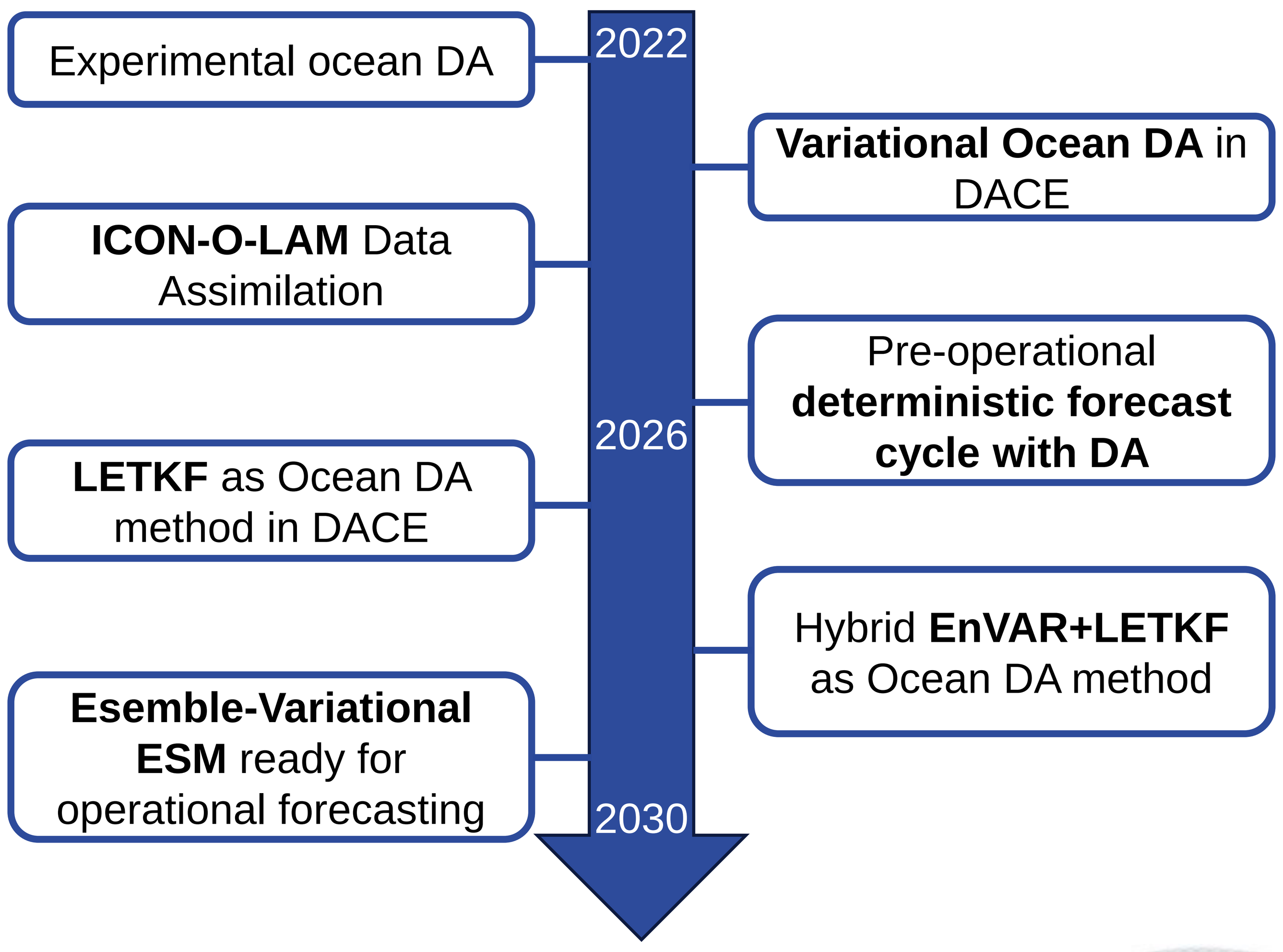
Coupled Data Assimilation at DWD: Development of an Ocean Data Assimilation System

N. Schenk, M. Sprengel, R. Williams

The new project "Earth System Modelling at the Weather scale" (ESM-W) by DWD in cooperation with GeoInfoDienst BW aims to develop a coupled ocean-atmosphere forecasting system based on the ocean model ICON-O and the atmospheric model ICON-NWP.

The initialization of the coupled model is based on the operational DA system of DWD (hybrid EnVAR+LETKF) for the atmosphere combined with a newly developed 3DVAR method for the ocean applied to ARGO float data as well as sea surface products derived from satellite measurements. Following the weakly-coupled assimilation approach, both states are updated separately for the moment. We present the components of the coupled system with focus on the ocean data assimilation which is a prototype for a general system to allow for future extensions to ensemble based methods in the ocean and strongly coupled data assimilation.



I. Earth System Model

At the beginning, we focus on a global coupled model while a regional ICON-O-LAM is under development. We use ICON-NWP, the global atmospheric model in numerical weather prediction at DWD. This is coupled to the ocean model ICON-O via the YAC (Yet Another Coupler) exchanging conservation variables.
Currently, a mean resolution of 80km is used for the atmospheric model and 40km for the ocean model. In future, we aim to run the operational atmospheric resolution with an ocean model of resolution between 5 and 10 km.

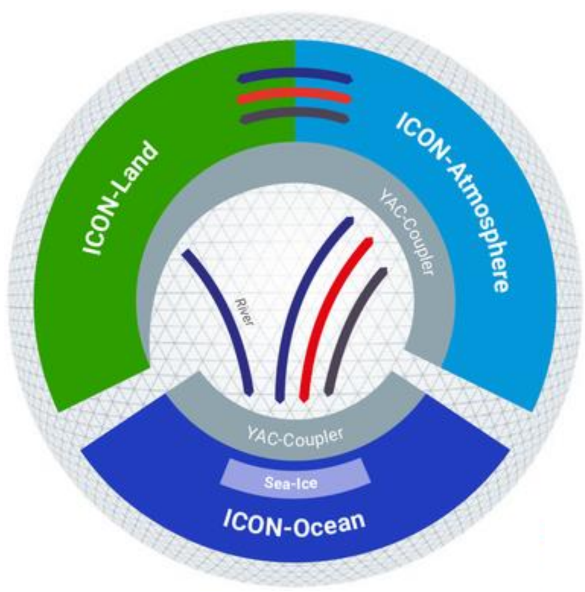


Figure 1: Schematic structure of coupled model system and interaction between the different components through the YAC (Korn et al.[1]).

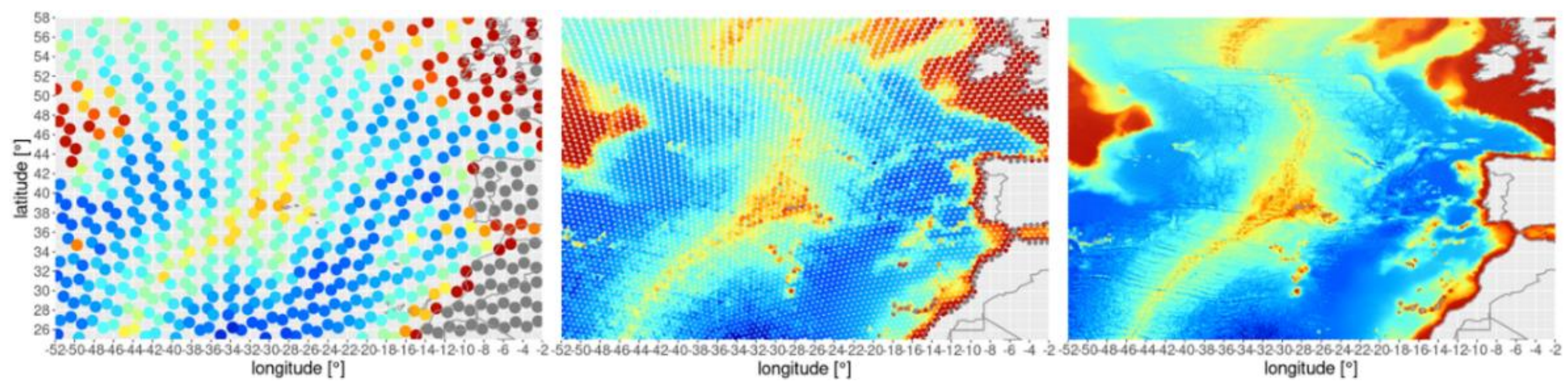


Figure 2: ICON-O bathymetry with resolution of 160km (left), 40km (middle) and 10km (right).

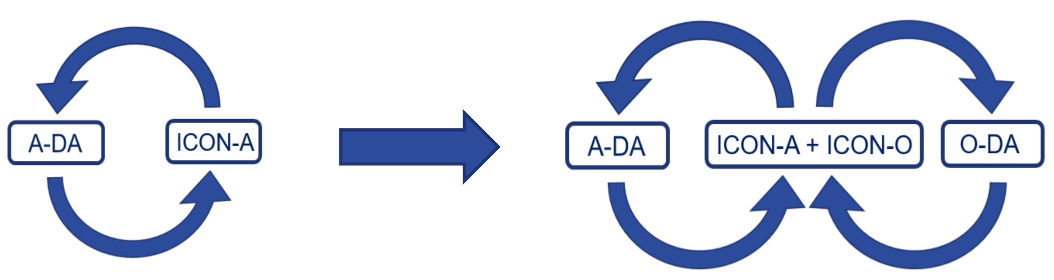


Figure 3: Presently, a weakly-coupled data assimilation approach is used within the ESM-W project.

Conclusion

- ESM-W works with a coupled NWP-system within the ICON-framework
- Restructuring of DACE is in progress and needed to carry out ocean DA
- A weakly-coupled data assimilation system was set up using extant NWP DA for the atmosphere and a 3DVAR scheme for ARGO observations in the ocean.

Next steps

- Improve the 3DVAR for the ocean in DACE to assimilate both satellite and in situ observations at the same time.
- Coupled experiments combining ARGO and OSTIA/SMOS data.
- Run long assimilation cycle to spin-up the coupled ocean.

II. Data Assimilation Coding Environment (DACE)

DACE is the *Data Assimilation Coding Environment* at DWD. Presently, DACE is designed to process atmospheric observations and to carry out different data assimilation methods for the atmosphere. To be able to assimilate not only ocean variables but also surface variables and greenhouse gases, for example, there is the need to restructure DACE. This ongoing work will also enable us to work on strongly coupled data assimilation regarding atmosphere and ocean.

III. Atmospheric Data Assimilation in DACE

There are different DA methods available to be applied to various atmospheric observation systems. For the global system *PSAS/3DVAR* and a hybrid *EnVAR + LETKF* method can be used. In the regional system the pure *LETKF* method is used. For DA cycles with the global coupled ICON-ESM model, we mainly use the 3DVAR for technical tests and the spin-up phase. Later, we will use the full hybrid method to get the best results.

IV. Ocean Data Assimilation in DACE

Presently, we focus on the assimilation of ARGO[2] float data as conventional observation system as well as sea surface products derived from satellite measurements (e.g. OSTIA[3] SST and SMOS[4] SSS).
In the current version of the 3DVAR method the observation processing is excluded and done beforehand. The core of the DA method follows the PSAS scheme. The minimization problem

$$x^a = argmin_x(\|y - Hx\|^2_{R^{-1}} + \|x - x^b\|^2_{B^{-1}})$$

is solved in two steps. First, the matrix $(R + HBH^T)$ is inverted by solving the following equation with the conjugate gradient (CG) method (linear case),

$$(R + HBH^T)z = y - H(x^b).$$

Second, the post-multiplication is performed, i.e.

$$x^a - x^b = BH^T z.$$

In the application of this method to ARGO data, there is no need to account for nonlinearities which would be handled by the iterative application of the CG method and a line search.
In a first setup, the observation error covariance R is assumed to be diagonal and the model error covariance B is chosen as a Gaussian matrix with a factor to adapt the variance. The observation operator H is only an interpolation operator since the ARGO observations are converted to depth in meters and potential temperature beforehand.

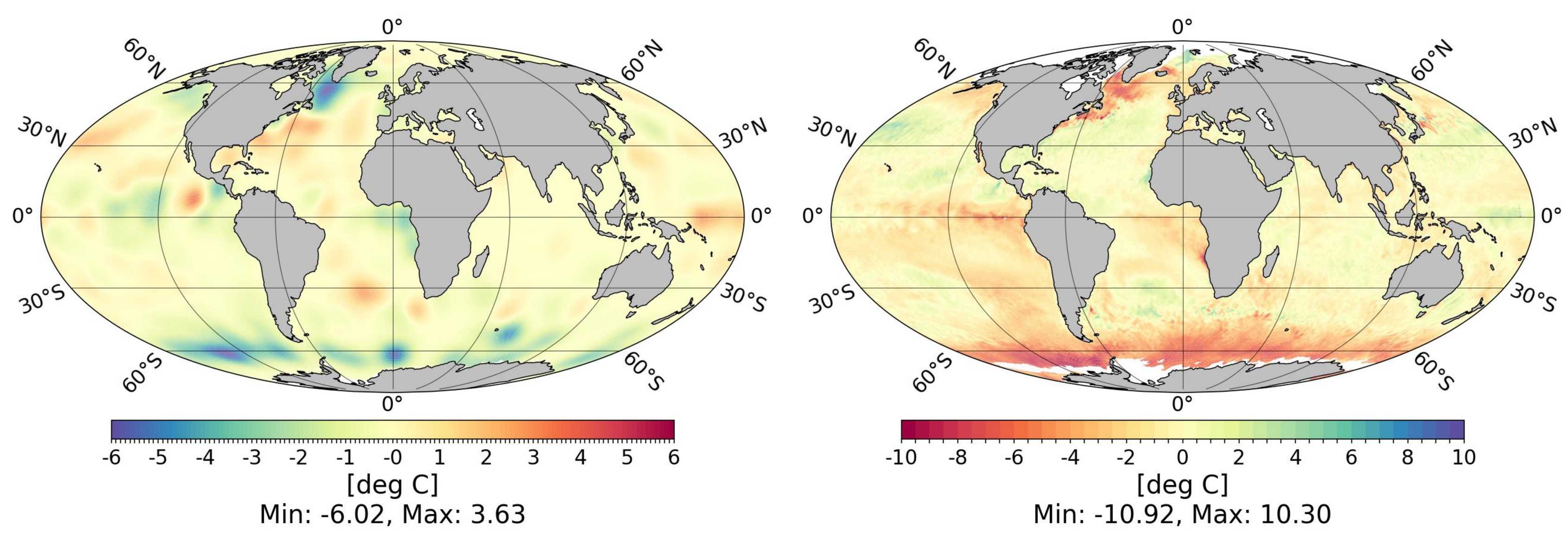


Figure 4: Analysis increment for sea water temperature in 8m depth generated with 3DVAR approach applied to ARGO temperature (left). Temperature bias with respect to OSTIA foundation SST data (right).

V. Results for Cycled Weakly-Coupled Assimilation Experiments

The previously described coupled assimilation system is applied for several weeks. The results with respect to assimilation of temperature and salinity measured by ARGO floats in the ocean are described on the poster by *R. Williams et al*.
Outcomes for the assimilation of OSTIA SST data and SMOS SSS data in the ocean within the coupled system using a 3DVAR approach with FGAT are shown on the poster by *M. Sprengel et al*.

1) „ICON-O: The Ocean Component of the ICON Earth System Model—Global Simulation Characteristics and Local Telescoping Capability", IAMES, Volume 14, Issue10, 2022, https://doi.org/10.1029/2021MS002952
2) Argo (2000). Argo float data and metadata from Global Data Assembly Centre (Argo GDAC). SEANOE. https://doi.org/10.17882/42182
3) Good et al, The Current Configuration of the OSTIA, (2020) https://doi.org/10.3390/rs12040720
4) Boutin et al, New SMOS Sea Surface Salinity (2018) https://doi.org/10.1016/j.rse.2018.05.022

Deutscher Wetterdienst, Offenbach am Main, Germany
Contact: Nora.Schenk@dwd.de

Zentrum für Geoinformationswesen der Bundeswehr