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Coupled Data Assimilation at DWD: Use of satellite observations for the ocean

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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 ICON-O for the ocean and ICON-NWP for the atmosphere. It is part of the ICON-Seamless development theme of the ICON Consortium, developing an integrated model framework for weather and climate applications. In the beginning the data assimilation will be a weakly coupled system using the operational DA in the atmosphere and a 3Dvar method in the ocean. On this poster, first results of assimilating satellite observations of temperature and salinity into the ocean component are presented.

I. Satellite Observations – OSTIA SST

The Operational Sea Surface Temperature and Ice Analysis[1)] (OSTIA) is a level 4 product generated by the GHRSST project and distributed through the Copernicus service. It combines observations from various satellites in both the infrared and microwave spectrum with some in situ observations to provide a gap-free global SST on a daily basis on a regular 0.05° grid. The OSTIA analysis is generated using a 2D variational assimilation within NEMOVAR. A combination of the analysis of the previous day and climatological data is used as a first guess. The OSTIA SST is therefore not influenced by a forecast model.

OSTIA attempts to determine the foundation SST, *viz.* the SST from which the diurnal cycle has been removed. This corresponds approximately to the in situ measurement of the water temperature at sunrise. The SST is provided together with a pointwise estimate of the observation error, with a mean absolute error of about 0.35K. The sea ice fraction is provided on the same grid.

II. Satellite Observations – SMOS SSS

The ESA Soil Moisture and Ocean Salinity (SMOS) mission observes the sea surface salinity using passive microwave measurements in the L-band (1.4GHz) from a sun synchronous orbit of about 758km in height. The satellite covers the whole earth approximately every 3 days.

A level 3 product is produced every day[2)] and also distributed over the Copernicus service. The product contains two variables: "practical sea surface salinity" and "practical sea surface salinity corrected from rain instantaneous freshening effect". Both variables are supplemented with error estimates and a quality control flag. The data is provided on a cylindrical grid with a horizontal resolution of about 25km at 30°N/S.

III. Assimilation Method

A variational method that compares the surface observations to the model forecast at a single model level was implemented. A 2-dimensional minimization is performed to find the model increment in observation space. A post-multiplication using both the horizontal and vertical B matrix is performed to obtain a 3D analysis increment.

$$(R + HB_{hor}H^T)w = y - Hx_b$$
$$\delta a_{inc} = B_{vert}B_{hor}H^T w$$

As a first test, the horizontal B matrix is a simple Gaussian correlation matrix and will be later replaced by an ensemble B. The vertical B matrix is constructed from the globally averaged correlations measured in forecasts without ocean DA.

In contrast to the SSS, the SST has a significant diurnal cycle – both in reality and in our forecast model. The OSTIA product provides the so-called foundation temperature which corresponds approximately to the *in-situ* temperature at sunrise. Therefore, the first guess at approximate time (FGAT) method was implemented to calculate the departures $y - Hx_b^{FGAT}$ at each point around sunrise (local time).

The observations are filtered based on the provided quality flags and error estimates and using the sea ice product of OSTIA. Furthermore, a superobbing/thinning method is applied to remove spatial correlations in the satellite data.

Setup of Assimilation Experiment

Time period: 2022-01-01 00UTC – 2022-01-15 00UTC

Data Assimilation

Ocean DA:
- 3D-VAR DA method
- Assimilation of OSTIA SST / SMOS SSS data

Atmospheric DA:
- 3D-VAR method
- Assimilation of conventional data, SYNOP, and satellite data

Model

- Ocean model ICON-O
  - ~40km resolution
- Atmospheric model ICON-NWP
  - ~80km resolution
- Both models are coupled with YAC

IV. Results of Experiment

The assimilation cycle experiments are verified against ARGO float *in-situ* observations of temperature and salinity. This data set is an independent data set as they are neither part of the OSTIA nor the SMOS product.

Fig. 1 shows the difference $first\ guess - obs$ for the SST on the first and last day of the experiment. The error is greatly reduced and large systematic model biases (e.g. in the southern ocean) are removed.

In *Fig. 2* the time series of the RMSE of temperature and salinity in different depths in the upper ocean are shown. We remark that the vertical correlation in B_{vert} is decreasing with depth and zero below 200m. The RMSE is reduced by up to 30% for temperature and 50% for salinity in the top layers and to a lesser degree deeper below the surface.

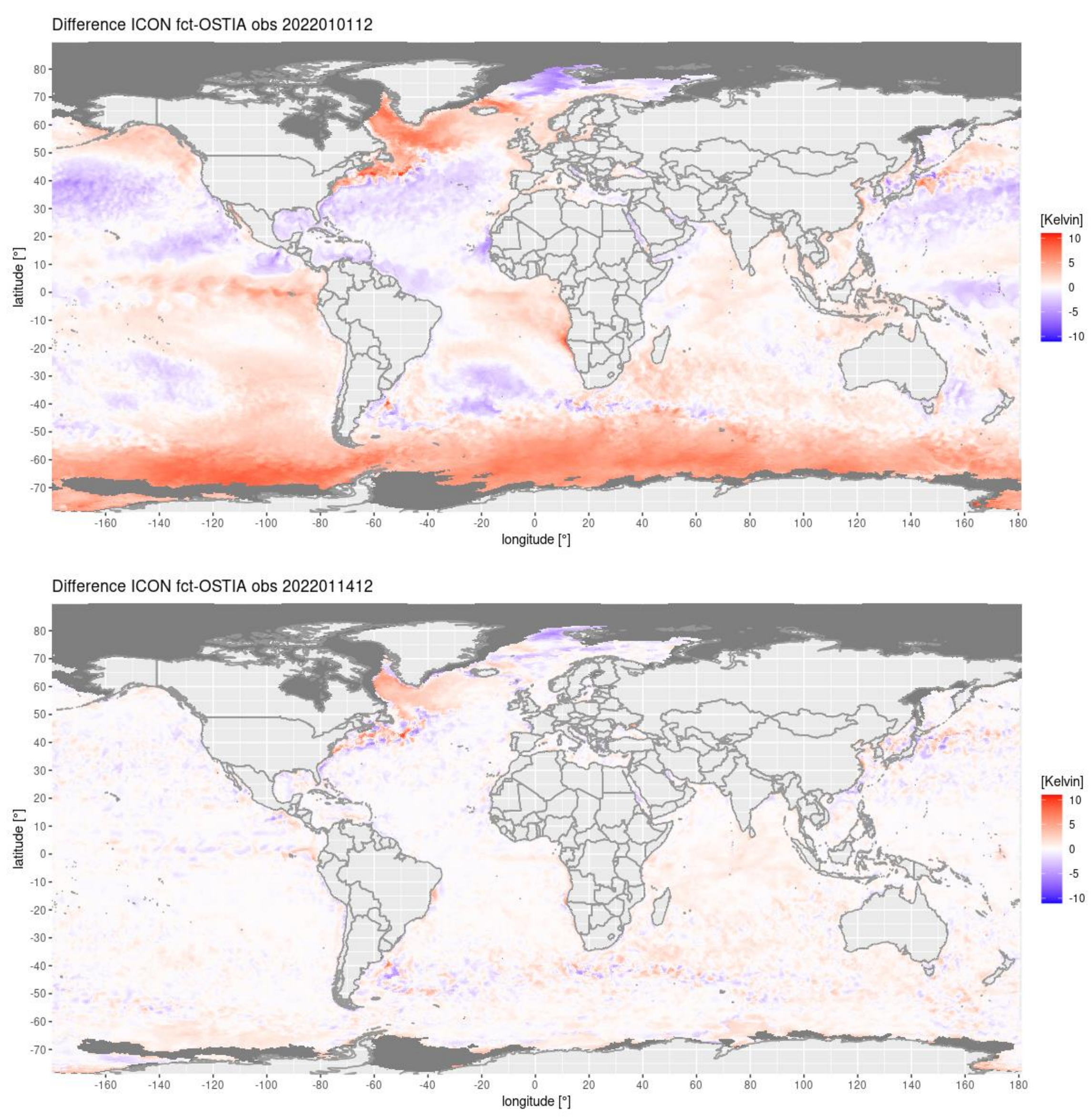

Figure 1: Difference of model first guess minus OSTIA obs. Top: first day, bottom: day 14

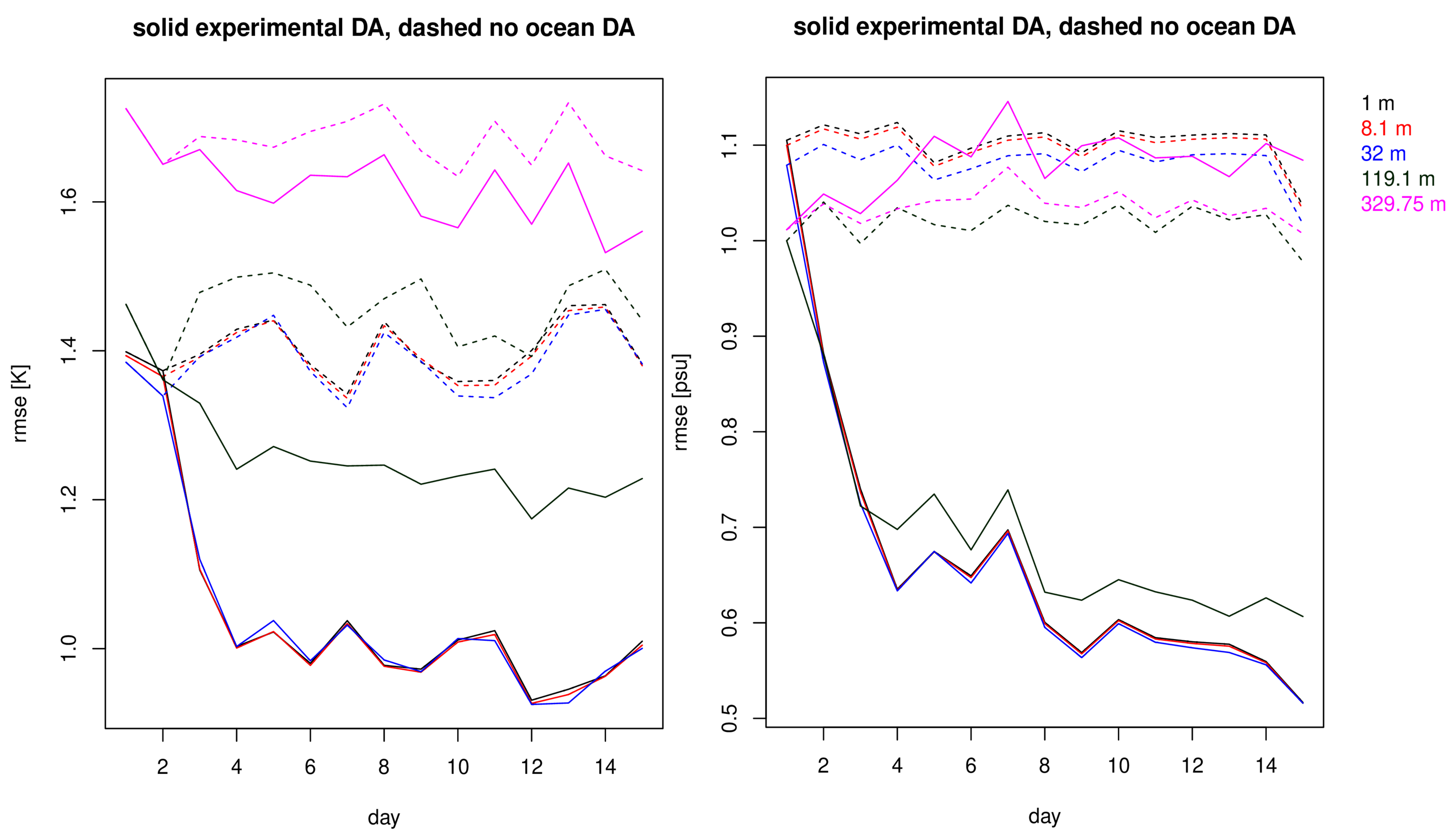

Figure 2: Time series of the RMSE of model first guess against ARGO floats for 2022-01-01 to 2022-01-15 for different depths. Left: temperature; right: salinity.

Conclusion

- A weakly-coupled data assimilation system was set up using extant NWP DA for the atmosphere and a 3D-Var scheme for satellite observations of the ocean.
- Both OSTIA SST and SMOS SSS DA have been tested in a 15 day experiment.
- Verification against independent ARGO data shows significant improvement of the RMSE for both observation systems.

Next steps

- Implement a 3D -Var for the ocean that can 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.

1) Good et al, The Current Configuration of the OSTIA, (2020) https://doi.org/10.3390/rs12040720
2) Boutin et al, New SMOS Sea Surface Salinity (2018) https://doi.org/10.1016/j.rse.2018.05.022

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