# Merging observations and Earth system models

Coupled ensemble data assimilation for Earth system models

T. Jung, Q. Tang, L. Mu, L. Nerger, Alfred Wegener Institute Helmholtz Center for Polar and Marine Research

## In Short

- Earth system models simulate different compartments like the ocean and the atmosphere
- Data assimilation merges models with real observations to improve the model predictions
- Of particular interest is the question of how to optimally transfer the information in data assimilation between different compartments
- Ensemble data assimilation methods use an ensemble of model state realizations to estimate the uncertainty but also the cross-correlations between different compartments

This project considers the problem of data assimilation in coupled models of Earth system compartments. These model systems usually consist of separate models for different compartments, like the ocean and the atmosphere, which are coupled through a coupler software that performs the information exchanges at the interface of the compartments and can interpolate between different model grids. While the data assimilation into single compartment models, in particular circulation models of the ocean or atmosphere, is well established, the assimilation into coupled models is at a rather early stage. Of particular interest is the so-called 'strongly-coupled' data assimilation in which the assimilation of observations of one compartment are directly used to correct the model state of another compartment. For example, this concerns satellite observations of the ocean like sea surface temperature.

In the project we use the coupled atmosphereocean model ECHAM6-FESOM (AWI-CM, Sidorenko et al., 2015) to examine data assimilation for a coupled atmosphere-ocean model. The data assimilation is implemented using the Parallel Data Assimilation Framework (PDAF, Nerger et al., 2019, Nerger and Hiller 2013), which is an open-source software for ensemble data assimilation developed at the Alfred Wegener Institute. A particular focus of the project is the strongly-coupled data assimilation, i.e. we focus on the question of how we can utilize, e.g., oceanic observations to directly improve the model state in the atmosphere.

In the first phase of the project we simultaneously assimilate satellite observations of the sea surface temperature (SST) and profile observations of temperature and salinity, i.e. observations that have been measured in the oceans below the surface at depths down to 5000 m and update only the ocean state in the coupled model. This is an extension of the weakly coupled data assimilation from the previous project. Both data types are assimilated daily over the year 2016. About 1000 profiles are available each day with measurements at different depths. The daily satellite SST data has several gaps which are caused by clouds. Results are evaluated for both the ocean and the atmosphere variables.

Figure 1 shows the 10-month average SST difference between the model simulation and the observations. The difference is strongly decreased in all assimilation scenarios. The global area-weighted 10-month average over the absolute SST difference is only 0.31°C if both of the two types of observations are assimilated, which is the lowest among the three assimilation runs. If only profile data are assimilated, the difference is higher with 0.7°C, which is still only half the difference of 1.41°C in the free run. Below the surface, the RMSE of subsurface temperature is reduced by 20% when assimilating only the SST observations (not shown). As expected this influence is larger when assimilating profile data. The reduction reaches 65% if only profile observations are assimilated.



**Figure 1:** Average difference of SST between the model simulation and the observations over months March to December for different simulation scenarios: a) 'Free\_run' with no assimilation, b) 'DA\_SST' with assimilation of SST, c) 'DA\_proTS' with assimilation of profiles and d) 'DA\_all' with assimilation of both the two types of observations.

The impact of the DA into the ocean on the atmosphere through the model dynamics is also evaluated by comparing with the ERA-interim reanalysis data. Figure 2 shows the mean difference for the months March to December of temperature at 2m above surface between the model simulation and the ERA-Interim reanalysis data for the different simulation scenarios. The free run shows rather large biases of both signs and the average bias is -0.24 degree. In general, the three assimilation runs result in an overall more homogeneous and smaller bias. However, a positive bias is visible everywhere over the oceans except in the Arctic Ocean and parts of the Southern Ocean.



**Figure 2:** Average difference of temperature at 2m above surface between the model simulation and the ERA data over months March to December for different simulation scenarios.

The 10-month average difference of the wind velocity field and the wind strength at 10m above the surface is shown in Figure 3. In the free run, the velocity magnitude at the equator is overestimated in the Pacific Ocean and underestimated in the Atlantic Ocean. The data assimilation strongly reduces these large differences (by 21.4 % in the region from 10°S to 10°N when assimilating SST), but the overall flow pattern is maintained. In addition, the bias of wind strength is reduced in the Southern and Northern Pacific. In the Southern Indian Ocean, the bias is slightly increased due to an eastward flow induced by the DA. The effects are very similar for all assimilation scenarios, but slightly smaller if assimilating only the profiles. Over land, the 10-m wind velocities in the free run and the three data assimilation runs are rather similar. The assimilation does not give rise to significant influence on the velocities there.



Figure 3: Average difference of wind speed at 10m above surface between the model simulation and the ERA data over months March to December for different simulation scenarios.

In the second phase of the project we assimilate satel-

lite SST observation to jointly update the ocean and atmosphere. This is a starting point for the strongly coupled assimilation. In the atmosphere, air temperature, divergence, vorticity, surface pressure, humidity and wind velocity are included in the state vector and hence directly updated by the assimilation. Results are compared with the free run as well as the weakly coupled run DA SST that assimilates also only the SST. Compared to the free run, the difference patterns of SST for the SCDA and WCDA are guite similar. Differences between the SCDA and WCDA are large at some regions like the Gulf stream, west of South Africa, and east of Japan. For the air temperature, at 2m and at pressure levels 300, 500, 1000hPa, SCDA performs slightly worse than the WCDA. However, at levels 850hPa and 925hPa, SCDA is slightly better than the WCDA.

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## **More Information**

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## Funding

Impuls- und Vernetzungsfonds of the Helmholtz Association of Germany Research Centers, Project 'Advanced Earth System Modeling Capacity'