The Met Office Coupled Atmosphere/Land/Ocean/Sea-Ice Data Assimilation System

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Introduction

We have developed a weakly-coupled data assimilation (DA) system using the global coupled model HADGEM3 (Hadley Centre Global Environment Model, version 3). This model combines the atmospheric model UM (Unified Model) at 60 km horizontal resolution on 85 vertical levels, the ocean model NEMO (Nucleus for European Modeling of the Ocean) at 25 km (at the equator) horizontal resolution on 75 vertical levels, and the sea-ice model CICE at the same resolution as NEMO. The atmosphere and the ocean/sea-ice fields are coupled every 1-hour using the OASIS coupler. The coupled model is corrected using two separate 6-hour window data assimilation systems: a 4D-Var for the atmosphere with associated soil moisture content nudging and snow analysis schemes on the one hand, and a 3D-Var FGAT for the ocean and sea-ice on the other hand. The background information in the DA systems comes from a previous 6-hour forecast of the coupled model.

The aim of the work is to see whether the weakly-coupled DA system offers improvements over starting from separate atmosphere/ocean/sea-ice initial conditions. To assess the benefit of the weakly-coupled DA, one-month experiments have been carried out, including 1) a full atmosphere/land/ocean/sea-ice coupled DA run, 2) an atmosphere-only run forced by OSTIA SSTs and sea-ice with atmosphere and land DA, and 3) an ocean-only run forced by atmospheric fields from run 2 with ocean and sea-ice DA. In addition, 5-day coupled forecast runs, started twice a day, have been produced from initial conditions generated by either run 1 or a combination of runs 2 and 3.

Method

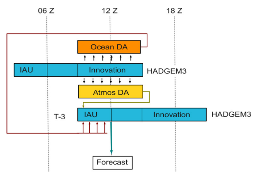
Positive impact has been shown of coupled models compared with un-coupled ocean or atmosphere models on medium-range forecasts (e.g. Johns et al., 2012). Accurate coupled forecasts require accurate and consistent initial conditions. However, existing seasonal forecasting systems (GloSea5) carry out, probably suboptimal, separate initialisation of ocean and atmosphere: Atmosphere using fixed SST anomalies and sea ice from OSTIA and ocean using fluxes provided by the NWP.

In the weakly-coupled framework the background trajectory is produced by running the coupled model. Separate inner loops are run in ocean and + atmosphere. Atmosphere Increments used to directly initialise atmosphere component of coupled model. Incremental Analysis Update (IAU) is used to initialise the ocean component of the coupled model.

	Models	Observations	DA	Initialisation
Atmos	UM ~60km/L85	AIRS, IASI, ATOVS, GPSRO, SSMI, Aircraft, Sondes, Surf-Scat	4D-Var ~120km	Direct
Land	JULES ~60km/4 layers	3D-Var Screen, ASCAT, NESDIS	Nudging Analysis	T/2 Direct
Ocean	NEMO ~25km/L75	In situ SST, T/S profiles, AATSR, AVHRR, AMSRE, Jason 1+2, ENVISAT	3D-Var FGAT	IAU
Sea Ice	CICE ~25km 5 categories	SSMI	3D-Var FGAT	IAU

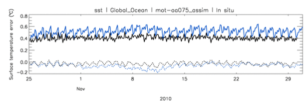
Atmosphere cycling: 6h + 6h, starting at T-3. Forecasts are run at 00, 06,12, 18 UTC (Rawlins et al., 2007;Clayton et al., 2012).
Ocean cycling: 24h, starting at T+0. A 7 day forecast is run at 00 UTC (Blockley et al., 2013).

Ocean DA adapted to atmosphere cycling: Fig ►



Required a technical change to ordering of observation operator/IAU. NEMO/CICE was changed to run with sub-daily cycling. Time window changed from 24 hours to 6 hours. IAU changed from 24 hours to 3 hours (for correct forecast initialisation).

Ocean: from 24 hours (Blue) to 6 hours (Black): Fig ►



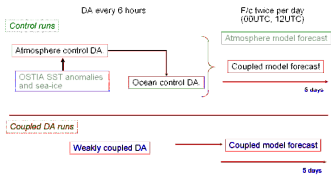
When changing from 24h to 6h temperature is worse in upper 400 m of tropical Pacific..SST improved: large amount of observations, model error has less time to grow. Sea ice worse: gridded product at 1200 UTC assimilated in 1 cycle out of every 4, model error allowed to grow in other cycles. Future development: assimilate level 2 sea ice concentration data. Temperature profile statistics and salinity profile statistics overall perhaps slightly worse, but more investigation required.

Experimental set-up

We focus on the impact of the coupled initialisation strategy on the performance of the data assimilation on the performance of short-range coupled forecasts. Benefits of coupled modelling already demonstrated.

We compare analysis results to control uncoupled runs and to operational FOAM and NWP. One-month trials for 2 periods: Dec 2011 and June 2012. Both the control and coupled DA runs are used to initialise sets of coupled Forecasts. Forecast results for June 2012 are not yet available. So initially focussing on Dec 2011.

NB the control results are somewhat preliminary as it turns out to be difficult to have an exact uncoupled analogue to the coupled atmosphere.



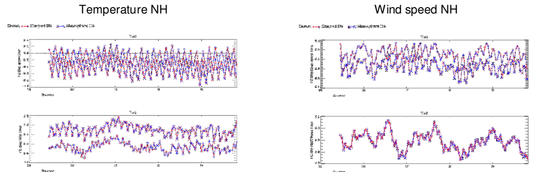
Statistics for the Atmosphere (obs-anl) coupled vs atm. control vs NWP : Dec 2011 Figs ▼

Statistics are consistent with operational NWP (not shown). Statistics are very similar for both coupled and control runs. Differences exist near the surface. Temperature: coupled run is less biased and has better RMSE. Relative humidity: coupled run has slightly better RMSE in NH. Wind speed: control run is less biased in NH and Tropics, has slightly better RMSE in Tropics.

Temperature NH — Wind speed NH

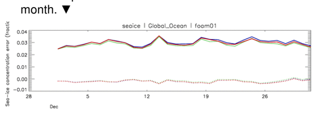
Bias

RMSE



Statistics for the Ocean (obs-bkg) coupled vs ocean control vs FOAM : Dec 2011 Fig ▼Table▼

Statistics are slightly better than operational FOAM (6h vs 24h). SST slightly worse globally for coupled run, but better locally. Sea ice similar but time series show coupled run is better towards the end of the month. ▼

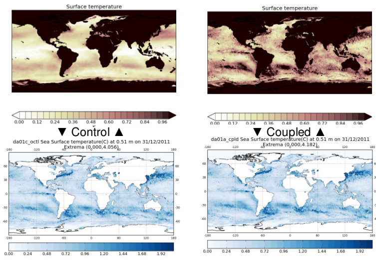


	Coupled	Ocean control	FOAM
SST in situ / deg C	0.363	0.352	0.412
SST in situ (TP) / deg C	0.324	0.314	0.335
SST AATSR / deg C	0.430	0.409	0.409
SSH / m	0.071	0.070	0.070
Sea ice concentration	0.030	0.030	0.029
Profile T / deg C	0.567	0.564	0.562
Profile S / psu	0.113	0.113	0.114

◄ Sea ice RMS (solid) and mean (dashed)

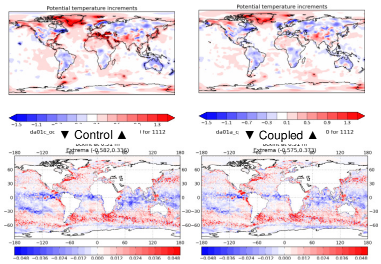
Monthly standard deviation of atmosphere surface temperature (top) and SST (bottom) Dec 2011: Figs ►

The impact of the ocean can be seen in the atmosphere fields. For example in the Gulf stream region which leads to greater surface temperature variability in the atmosphere.



Monthly mean increments for atmosphere surface temperature (top) and ocean temperature at first level (bottom) Dec 2011 : Figs ►

Coupled run increments are smaller indicating a better balance of the fluxes.



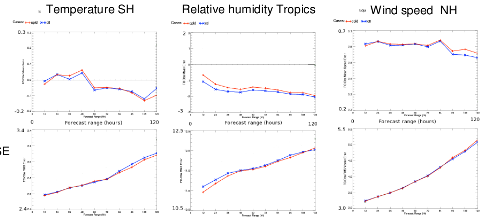
Forecast Statistics for the Atmosphere (obs minus fcst) Dec 2011 : Figs ▼ ►

Coupled vs control. Slight improvement in RMSE when initialising from coupled DA. Wind speed: slightly worse in NH, slightly better in Tropics. Differences in bias sometimes better, sometimes worse. Slight impact at higher altitudes at the end of the forecast.

Temperature SH — Relative humidity Tropics — Wind speed NH

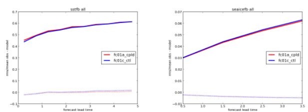
Bias

RMSE



Forecast Statistics for the Ocean (obs minus fcst) Dec 2011 : Figs ▼ ►

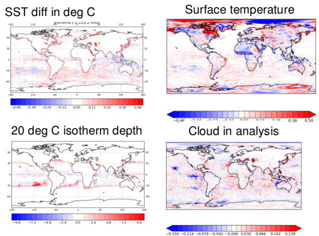
Statistics very similar for both forecasts. Interesting features: In situ SST control DA gain not maintained more than 1/2 day. Sea ice RMSE grows less fast when initialised by coupled DA



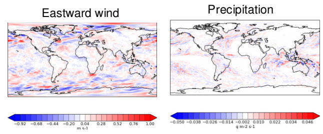
Mean differences for day 5 (cpld minus control) Dec 2011 : Figs ▼ ►

SST and atmosphere surface temperature impact. Unsurprisingly SST and surface atmosphere temperature correlate over the ocean, interesting land impacts however. 20 deg C Isotherm correlates with initial cloud differences.

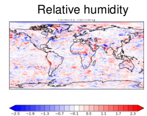
SST diff in deg C — Surface temperature — 20 deg C isotherm depth — Cloud in analysis



Eastward wind — Precipitation



Relative humidity



Precipitation dipoles indicating different frontal positions. See also wind difference in North Atlantic storm track. Differences in relative humidity near Sahel and India. At this time of year there is no precipitation impact.

Conclusions

We have compared coupled and un-coupled DA in one-month trials using 5-day forecasts initialised by coupled or un-coupled DA. Run for two periods Dec2011 (finished) and June 2012 (not finished).

The initial assessment so far shows good results in global and regional statistics against observations. Examinied were monthly mean and standard deviation of surface fields and their differences, binned innovations for the ocean fields. Also we looked at forecast differences (e.g. precipitation). The Median Julian Oscillation (MJO) index and the diurnal cycle of SST all showed the coupled DA system performing well.

Overall the impact of coupled DA is rather small, but generally beneficial. More impact on the atmosphere than on the ocean. Longer trials might show more ocean impact. Perhaps there is a potential issue with the surface wind speed in the coupled model
Some Interesting features: The impact of the ocean is visible in the atmosphere. Societally interesting differences south of Sahel, over India. Dipoles in atmosphere forecasts suggest different positioning of events. Innovation SST statistics slightly worse but increments smaller. Improvement in Sea ice concentration.

Encouraging results particularly as the system has not been tuned for coupled DA.

Future work

Short term: Finish the June 2012 period. Study more closely the interesting features. Run case studies for particular phenomena (hurricanes, monsoon).

Plans: Implement a demonstration operational system for coupled DA. Run OSEs and OSSEs for ocean (SST and Argo data). Estimate inter-fluid error covariances. Develop a strategy for more fully coupled DA. Investigation on initialisation shock and bias correction with University of Reading. General SST assimilation improvement. Implement higher resolution (~ 25 km) for the Atmosphere.

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