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

Daniel J. Lea, Isabelle Mirouze, Matthew J. Martin, Robert R. King, Adrian Hines, David Walters and Michael Thurlow

Oct 2015
Outline

This presentation covers the following areas

• Why coupled NWP?
• Coupled data assimilation approaches
• Met Office weakly coupled DA
• Plans/future work
Why coupled NWP?

(see T. Johns’ talk)

Potential benefits include:

• Improved modelling of lower boundary (diurnal cycle and mean fluxes, sea breezes, …)

• Improved modelling of strongly coupled phenomena (e.g. TCs, MJO)

• Better for “non-ocean” components that are difficult to model in atm-only (e.g. sea ice)

• Already running forced ocean forecast models (1 way coupling)
Coupled modelling with the UM
GC2.0 and its components

Coupled NWP
GloSea seamless EPS
Decadal Prediction
Climate Change studies

GC2.0
Global Coupled modelling configuration

Oasis

Global Atmosphere 6.0
N06 (~135km) → 12km

Global Ocean 5.0
NEMO
ORCA225 (0.25)

Global Ice 6.0
CICE
ORCA225 → ORCA (1)
Coupled data assimilation
Uncoupled DA

- Straightforward ... use existing ocean and atmosphere analysis systems to initialise coupled forecasts
- No guaranteed consistency between initial states

Fully (strongly) coupled DA

- Should give improved analysis and forecast because of more consistent initial conditions
  - Potentially less initialisation shock
- Less compartmentalised – have to understand the atmosphere and ocean if there are problems
- Work required to develop coupled DA compt
Weakly coupled DA

- Build system with existing components
- Still gives a more consistent initial state
The weakly coupled DA system
## Model components

<table>
<thead>
<tr>
<th>Atmos</th>
<th>Models</th>
<th>Observations</th>
<th>Data assim system</th>
<th>Initialisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UM (N216) ~60km/L85</td>
<td>AIRS, IASI, ATOVS, GPSRO, SSMI, Aircraft, Sondes, Surf-Scat</td>
<td>4D-Var ~120km</td>
<td>Instantaneous (T-3)</td>
</tr>
<tr>
<td></td>
<td>GA4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>JULES ~60km/4 layers</td>
<td>3D-Var Screen, ASCAT, NESDIS</td>
<td>Nudging Analysis</td>
<td>Instantaneous (T+3)</td>
</tr>
<tr>
<td></td>
<td>GL4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>NEMO ~25km/L75</td>
<td>In situ SST, T/S profiles, AATSR, AVHRR, AMSRE, Jason 1+2, ENVISAT</td>
<td>3D-Var FGAT</td>
<td>IAU</td>
</tr>
<tr>
<td>Sea Ice</td>
<td>CICE ~25km 5 categories</td>
<td>SSMI</td>
<td>3D-Var FGAT</td>
<td>IAU</td>
</tr>
</tbody>
</table>

Increased coupling frequency to 1 hour
Coupled DA components

- Observations Data Base
- VAR
  - 3D-VAR screen
  - 4D-VAR atmosphere
- NEMOVAR
  - 3D-VAR FGAT
- NEMO
  - Ocean: 25 km (equator) on 75 levels
- CICE
  - Sea Ice: 25 km (equator)
- SURF
  - Soil moisture content nudging and soil wetness blending
  - Snow analysis
  - Snow obs.
  - Once a day
- UOASIS
  - Atmosphere: 60 km on 85 levels
- Snow
  - Once a day

Connections:
- Soil wetness
- Atm. inc.
- Smc
- Ocean and Sea Ice inc.
Experimental setup

13 month coupled DA run Dec 2011 to Dec 2012

Focus on the impact of the coupled initialisation strategy

• on the performance of the data assimilation
• on the performance of short-range coupled forecasts.

Compare to separate ocean and atmosphere DA runs with configurations the same as the coupled model equivalents.

Initial results – analysis runs
Ocean impact on atmosphere analysis (Dec 2011 average)

Ocean zonal current

Zonal wind: coupled control difference
Monthly mean increments of surface air temperature (top) & ocean surface temperature (bottom) Dec 2011 – indication of model bias

Coupled

Abs(coupled) minus abs(ctl)

Blue good for coupled

Air

-1.5 °C/6hrs

-1.5

Ocean

-0.05 °C/6hrs

-0.05

0.0125 °C/6hrs

0.0125
Ocean comparison to observations (obs-bkg RMS) coupled vs ocean control

<table>
<thead>
<tr>
<th></th>
<th>Coupled RMS</th>
<th>Ocean control RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST in situ / deg C</td>
<td>0.4147</td>
<td>0.3984</td>
</tr>
<tr>
<td>SSH / m</td>
<td>0.0746</td>
<td>0.0730</td>
</tr>
<tr>
<td>Sea ice concentration</td>
<td>0.0296</td>
<td>0.0295</td>
</tr>
<tr>
<td>Profile T / deg C</td>
<td>0.6250</td>
<td>0.6199</td>
</tr>
<tr>
<td>Profile S / psu</td>
<td>0.1243</td>
<td>0.1243</td>
</tr>
</tbody>
</table>

- Not too bad given the coupled model has not been used in ocean data assimilation previously
- Would like to understand the reasons for the degraded statistics in particular:
  - SST
  - SSH
Why are SST stats degraded in coupled model?

Diurnal cycle of a drifter (30cm depth) in the South Pacific

- Both coupled and uncoupled models lack an explicit diurnal model
- Ocean control errors lower but possibly compensating errors
Monthly mean differences (coupled minus control) of sea surface salinity

Month 1

Month 13

Increasing differences in surface salinity between the coupled and control.

Not clear from comparison to salinity obs which is correct (sampling sparse)
River Plate
Evaporation minus precip and runoff (freshwater flux out of the ocean)

Ocean control

Runoff difference

kg m$^{-2}$ s$^{-1}$
Forecast results
CPLD DA Forecasts versus Control DA Forecasts

Large scale regional bias and RMSE

- Generally only a small impact on f/c errors
- Positive impact on 9-10 day air-temperature f/c in NH in FC_CPLD_DA (significant?)
- Impact on NH SST bias
- Small impact on SH RMS SST errors (not shown)

10-day forecasts for 26 August -15 September 2012
Two forecasts per day (00z and 12z)
Forecast results summary


Performance of the atmosphere forecasts is very similar in coupled and control DA

Performance of the ocean forecasts:

- Month 1 (Dec 2011) similar in coupled and control (SST diurnal error does not affect the forecasts)
- Later (e.g. Aug/Sep/Oct) the coupled forecast performance is hampered by the drift in the ocean analysis (described earlier).
Conclusions & future work
Conclusions

• Coupled and un-coupled DA compared in one-year trials.

• Reasonable results given this is the first time these coupled model and data assimilation systems are put together

• Impact of the ocean currents visible in the atmosphere.

• Some issues of the coupled model are highlighted by coupled DA:
  • The amplified diurnal cycle probably leads to the innovation statistics for SST and upper temperature profiles being slightly worse, although mean increments are smaller
  • Problem with the river run off. This may stem from P-E errors
  • Demonstrates that the demands of coupled DA can highlight issues with the coupled model that might not be otherwise noticed. Such improvements should then feed back into improved climate modelling.
Ongoing and future work

- Implement a GC2 demonstration operational system for coupled DA in 2016
- Upgrade system in-line with operational NWP/FOAM
- Continue research on inter-fluid error covariances, modelling diurnal cycle and freshwater errors in DA
- Work towards operational coupled NWP (and retirement of uncoupled systems) on timescale of 2-4 years?
Questions?