Contents

- Technical design
- First assessments
  - Analysis runs
  - Forecast runs
- Conclusion and future work
Positive impact of coupled models compared with un-coupled ocean or atmosphere models on medium-range forecasts has been shown (e.g. Johns et al., 2012).

Accurate coupled forecasts require accurate and consistent initial conditions.

Seasonal forecasting systems (GloSea5) carry out separate initialisation of ocean and atmosphere:
- **Atmosphere**: use fixed SST anomalies and sea ice from OSTIA.
- **Ocean**: use fluxes provided by the NWP.
Positive impact of coupled models compared with un-coupled ocean or atmosphere models on medium-range forecasts has been shown (e.g. Johns et al., 2012).

Accurate coupled forecasts require accurate and consistent initial conditions.

Coupled data assimilation could help improve both short-range and longer-range forecasts.

- Avoid initialisation shocks.
- Allow representation of coupled processes.
- Can let observations in the boundary layers influence both fluids.
Going from:

requires to tackle some difficult issues. Is this what we want to do? Let us begin with a "simple" framework:

Weakly-coupled data assimilation system
The weakly-coupled data assimilation design
Weakly coupled data assimilation

- Background trajectory produced by running the coupled model.
- Separate inner loops in ocean and atmosphere.

\[
\mathbf{z} = \begin{pmatrix} \mathbf{x}_{\text{atm}} \\ \mathbf{x}_{\text{ocn}} \end{pmatrix} \quad J_{\text{atm}}^{4D} = \frac{1}{2} \left\| \delta \mathbf{x}_{\text{atm}} \right\|_{\mathbf{B}_{\text{atm}}^{-1}}^2 + \frac{1}{2} \left\| \delta \mathbf{y}_{\text{atm}} \right\|_{\mathbf{R}_{\text{atm}}^{-1}}^2 \\
\mathbf{z}_{k}^{f} = \mathcal{M} \left[ \mathbf{z}_{k-1}^{a} \right] \quad J_{\text{ocn}}^{3D} = \frac{1}{2} \left\| \delta \mathbf{x}_{\text{ocn}} \right\|_{\mathbf{B}_{\text{ocn}}^{-1}}^2 + \frac{1}{2} \left\| \delta \mathbf{y}_{\text{ocn}} \right\|_{\mathbf{R}_{\text{ocn}}^{-1}}^2
\]

- Increments used to directly initialise atmosphere component of coupled model.
- Incremental Analysis Update (IAU) used in the ocean component of the coupled model.
# The different components

<table>
<thead>
<tr>
<th></th>
<th>Models</th>
<th>Observations</th>
<th>DA</th>
<th>Init.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmos.</td>
<td>UM</td>
<td>AIRS, IASI, ATOVS, GPSRO, SSMI, Aircraft, Sondes, Surf-Scat</td>
<td>4D-Var (~120 km)</td>
<td>Direct</td>
</tr>
<tr>
<td></td>
<td>JULES</td>
<td>3D-Var Screen, ASCAT, NESDIS</td>
<td>Nudging Analysis</td>
<td>T/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In situ SST, T/S profiles, AATSR, AVHRR, AMSRE, Jason 1/2, Envisat</td>
<td>3D-Var FGAT</td>
<td>Direct</td>
</tr>
<tr>
<td>Land</td>
<td>JULES</td>
<td>3D-Var Screen, ASCAT, NESDIS</td>
<td>Nudging Analysis</td>
<td>T/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In situ SST, T/S profiles, AATSR, AVHRR, AMSRE, Jason 1/2, Envisat</td>
<td>3D-Var FGAT</td>
<td>Direct</td>
</tr>
<tr>
<td>Ocean</td>
<td>NEMO</td>
<td>3D-Var Screen, ASCAT, NESDIS</td>
<td>Nudging Analysis</td>
<td>T/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In situ SST, T/S profiles, AATSR, AVHRR, AMSRE, Jason 1/2, Envisat</td>
<td>3D-Var FGAT</td>
<td>Direct</td>
</tr>
<tr>
<td>Sea Ice</td>
<td>CICE</td>
<td>SSMI</td>
<td>3D-Var FGAT</td>
<td>IAU</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The different components

<table>
<thead>
<tr>
<th>Models</th>
<th>Observations</th>
<th>DA</th>
<th>Init.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmos.</td>
<td><strong>UM</strong></td>
<td>4D-Var (~120 km)</td>
<td>Direct</td>
</tr>
<tr>
<td></td>
<td>∼60 km/L85 +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td><strong>JULES</strong></td>
<td>Nudging Analysis</td>
<td>T/2 Direct</td>
</tr>
<tr>
<td></td>
<td>∼60 km/4layers +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td><strong>NEMO</strong></td>
<td>3D-Var FGAT</td>
<td>IAU</td>
</tr>
<tr>
<td></td>
<td>∼25 km/L75 +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Ice</td>
<td><strong>CICE</strong></td>
<td>3D-Var FGAT</td>
<td>IAU</td>
</tr>
<tr>
<td></td>
<td>∼25 km</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

= HadGEM3 (OASIS: 1h coupling between Atmosphere and Ocean)
Atmosphere cycling:
6h + 6h, start T-3
Forecast at 00, 06, 12, 18 UTC
(Rawlins et al., 2007; Clayton et al., 2012)

Ocean cycling:
24h, start T+0
Forecast at 00 UTC
(Blockley et al., 2013)
Adapting the ocean and sea ice DA

(Waters et al., 2013)

Approach: to make ocean DA work with atmosphere DA cycling:

- Technical change to ordering of observation operator/IAU.
- NEMO/CICE made to run with sub-daily cycling.
- Time window changed from 24 hours to 6 hours.
- IAU changed from 24 hours to 3 hours.
Temperature 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 swath data

Ocean: from 24 hours to 6 hours
First results
Positive impact of coupled models compared with un-coupled ocean or atmosphere models on medium-range forecasts (e.g. Johns et al., 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 analysis results to operational FOAM and NWP.

One-month trials for 2 periods: Dec 2011 and June 2012.
- Forecast results for June 2012 not yet available.
- Focus on Dec 2011.
Experimental set-up

**Control runs**
- Atmosphere control DA.
- OSTIA SST anomalies and sea-ice
- Ocean control DA.

**Coupled DA runs**
- Weakly coupled DA

**F/c twice per day (00UTC, 12UTC)**
- Atmosphere model forecast
- Coupled model forecast

5 days
First results: analysis runs
Statistics for the Atmosphere (obs-anl) coupled vs atm. control vs NWP

- Statistics are consistent with operational NWP.
- 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.
Statistics for the Ocean (obs-bkg)  
coupled vs ocean control vs FOAM

- Statistics are slightly better than operational FOAM (6h vs 24h).
- SST slightly worse globally for coupled run, but better locally.
- Sea ice similar but times series show coupled run is better.

<table>
<thead>
<tr>
<th></th>
<th>Coupled</th>
<th>Ocean control</th>
<th>FOAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST in situ / °C</td>
<td>0.363</td>
<td>0.352</td>
<td>0.412</td>
</tr>
<tr>
<td>SST in situ (TP) / °C</td>
<td>0.324</td>
<td>0.314</td>
<td>0.335</td>
</tr>
<tr>
<td>SST AATSR / °C</td>
<td>0.430</td>
<td>0.409</td>
<td>0.409</td>
</tr>
<tr>
<td>SSH / m</td>
<td>0.071</td>
<td>0.070</td>
<td>0.070</td>
</tr>
<tr>
<td>Sea ice concentration</td>
<td>0.030</td>
<td>0.030</td>
<td>0.029</td>
</tr>
<tr>
<td>Profile T / °C</td>
<td>0.567</td>
<td>0.564</td>
<td>0.562</td>
</tr>
<tr>
<td>Profile S / psu</td>
<td>0.113</td>
<td>0.113</td>
<td>0.114</td>
</tr>
</tbody>
</table>
The impact of the ocean can be seen in the atmosphere fields.
Monthly mean increments for atmosphere surface temperature (left) and ocean temperature at first level (right).

Coupled run

Coupled run increments are smaller ⇒ better balance of the fluxes.
Monthly mean increments for atmosphere surface temperature (left) and ocean temperature at first level (right).

Control run

Coupled run increments are smaller ⇒ better balance of the fluxes.
First results: forecast runs
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.
Statistics for the Ocean (obs-fct) coupled vs control

- 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
Mean differences for $20^\circ$ isotherm depth
Rain fronts are forecasts in both runs but not as the same position.
Summary and conclusion

- Comparison between:
  - Coupled and un-coupled DA in one-month trials.
  - 5-day forecasts initialised by coupled or un-coupled DA.
  - Two periods: Dec2011 (finished) and June 2012 (not finished)

- Assessment so far show good results:
  - Global and regional statistics against observations
  - Monthly mean and std of surface fields and their differences
  - Binned innovations for the ocean fields
  - Forecast differences (e.g. precipitation)
  - Median Julian Oscillation (MJO) index calculation
  - Diurnal cycle of SST
    - J. While poster: an analysis system for diurnal SST

Our weakly-coupled data assimilation system works.
Impact of coupled DA:
- Rather small, but generally beneficial.
- More impact on the atmosphere than on the ocean (longer trials?).
- Potential issue with the surface wind speed in the coupled model.

Interesting features:
- The impact of the ocean is visible in the atmosphere.
- Differences south of Sahel, over India, . . .
- Dipoles in atmosphere forecasts suggest different positioning of events.
- Innovation SST statistics slightly worse but increments smaller.
- Sea ice concentration improvement.

Encouraging results: 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.
    - Strategy for developing 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.
Questions and answers
Precipitation forecast differences, example for 31/12/2011 1200 UTC
15-day hindcasts winter/summer
(Sean Milton’s group)
Atmosphere and Ocean coupled with OASIS (Valcke 20113)

Coupling needs to be frequent compared to the length of the assimilation window to ensure that the scales present in the observations are represented in the coupled model.

Max/min of the diurnal SST cycle at a TAO mooring 147E,0N (P. Sykes).

We are using 1-hour coupling frequency.