Regional Reanalysis and Global Data Assimilation Activities at the Met Office

Richard Renshaw, Dale Barker, Peter Jermey, and many others
Outline

Global DAE Operational Upgrades
Coupled (Ocean-Atmosphere DA) Status and Plans
Progress with global 4DEnVar.
Forecast Sensitivity to Observations (FSO).
Regional Reanalysis
Our 2020 vision: a 10km coupled global ensemble and a 1km coupled UK ensemble.
DAE Contributions to PS31 Global Operational Upgrade (16 Jan 2013):

- **Short-range global ensemble (MOGREPS-G)** resolution increased from N216 (~60km) to N400 (~33km).
- MOGREPS-G ensemble size for hybrid 4D-Var/ETKF data assimilation increased from 22 to 44 members.
- Mix of climatological/ensemble covariances in hybrid tuned.
- Large impact of DAE and SA upgrades in PS31 from trials: ~1-3pts on the global (deterministic) NWP index.
DAE Contributions to PS32 Global Operational Upgrade (30 Apr 2013):

- Extended Kalman Filter (EKF) land DA scheme.
- Assimilation of SEVERI/MODIS aerosol optical depth (AOD).
- ODB for observation monitoring
- Aircraft temperature bias correction.
- Small impact of DAE and SA upgrades in PS32: \(~0.3\text{pts}\) on the global (deterministic) NWP index.
Technical change only:

Rose suite scheduling system based on Cylc (Hillary Oliver, NIWA)

Configured by text files
More flexible and adaptable
Observation Ingest: ODB, MetDB/MOODS

Previous scenario

Adam Maycock

MetDB
Database

BUFR (O)
Merge-back (O,B,A)

OPS
Observation processing system

varobs/var_cx

VAR
Variational analysis

Analysis

UM
Unified model

Bespoke files (O,B)

Bespoke files (e.g. FSO)

MASS
Data archive

Existing Monitoring / verification (including VER)

Fields files

BUFR

Adam Maycock
Observation Ingest: ODB, MetDB/MOODS

Since 2013

Adam Maycock

- ODB archive to MASS replaces both MetDB merge-back and (over time) other bespoke monitoring formats produced directly from OPS
- Move towards OBSTAT for monitoring and verification
- Convert to ODB for OPS ingest

BUFR (O)

BUFR to ODB

ODB (O)

BUFR (O,B)

vars/vars_cx

MetDB
Database

OPS
Observation processing system

VAR
Variational analysis

UM
Unified model

OBSTAT+VER++
Monitoring / verification

Mass Data archive

Bespoke files (e.g. FSO)

Fields files
Observation Ingest: ODB, MetDB/MOODS

Future Scenario

- MetDB replaced by MOODS
- Could convert to ODB as data arrives within MOODS rather than as separate one-off task.
- Could replace varobs and var_cx with ODB (not yet agreed).
- ODB output from VAR providing additional information for monitoring and verification
- Further progress to use of OBSTAT, unlikely to replace all existing tools
- VERSUS replaces VER

Fields files

Adam Maycock
Coupled data assimilation: Current And Planned System

Current GloSea5 initialisation

Planned GloSea5 initialisation

Matt Martin
Global Atmospheric DA Strategy: Ensemble-Variational Methods

- In short-term, perform refactoring/optimizing current VAR code.
- Also continue to develop hybrid in short/medium-term.
- Develop En4DEnVar (further integration of DA/MOGREPS) as a potential alternative to 4D-Var/ETKF.
Comparison of 4DEnVar to 4DVar

Neill Bowler

4DEnVar Advantages:

• Cheap
  • Allows cost to be recycled into larger ensemble or outer loop
  • Can do DA at high-res
• No linear model
  • No maintenance
  • No concerns over neglected physics schemes

4DEnVar Disadvantages:

• Large memory and I/O requirement
• No propagation of static covariances
• Localisation may need to follow the flow
• No Jc term
4DEnVar Initial Trial Results

<table>
<thead>
<tr>
<th>Control</th>
<th>Experiment</th>
<th>RMSE</th>
<th>NH</th>
<th>Tropics</th>
<th>SH</th>
</tr>
</thead>
<tbody>
<tr>
<td>hybrid-3DVar(^4^4)</td>
<td>4DEnVar(^4^4)</td>
<td>-0.9%</td>
<td>10/113/0</td>
<td>0/123/0</td>
<td>7/112/4</td>
</tr>
<tr>
<td>4DVar(N108)</td>
<td>4DEnVar(^4^4)</td>
<td>+0.47%</td>
<td>10/111/2</td>
<td>1/106/16</td>
<td>6/90/27</td>
</tr>
<tr>
<td>hybrid-4DVar(^2^2)</td>
<td>4DEnVar(^4^4)</td>
<td>+2.4%</td>
<td>1/118/4</td>
<td>0/103/20</td>
<td>0/52/71</td>
</tr>
<tr>
<td>hybrid-4DVar(^4^4)</td>
<td>4DEnVar(^4^4)</td>
<td>+2.7%</td>
<td>0/100/23</td>
<td>0/102/21</td>
<td>0/44/79</td>
</tr>
</tbody>
</table>

Better/neutral/worse results ±2% RMSE thresholds

- Preliminary results: very little tuning, low-resolution.
- 4DEnVar beating hybrid-3DVar.
- Comparable with 2011 MetO system (4DVar), but way off 2012 system (22 member hybrid-4D-Var)
Leading order: 1) AMSUA, 2) IASI, 3) TEMP, 4) Aircraft, 5) Surface, etc.
Total impact shown, could also show impact/observation.
Major collaboration between MetO and KMA (Sang-Won Joo)
The Statistical Nature of Observation Impact

- Only just over 50% of observations reduce forecast error.

- Toy model results in Lorenc and Marriott (2012) show this is due to random observation error, imperfect verifying analysis, imperfect DA (e.g. covariances), analysis projecting onto growing and decay modes in forecast.

- Estimate: need 6 months time series to assess impact for single observing site.
EUROPEAN REANALYSIS AND OBSERVATIONS FOR MONITORING
Tracking changes in European climate

• EU-project, April 2010 – March 2014, 9 partners

• Goal: LONG-TERM CLIMATE DATASETS + ASSESSMENTS OF CHANGE
  ...describing climate variability and change at the European scale
  ...placing high-impact extreme events in a historical context
Uncertainties in Ensembles of Regional Re-Analyses 2014-2017

Met Office reanalysis:
- Satellite era 1978 - present
- Ensemble variational reanalysis
WP2.1 “Building capacity for advanced regional data assimilation”

reanalysis period 2008 - 2009
Model forcing

Surface fields

• SST and sea-ice from OSTIA
• Soil moisture and snow from Met Office operational Global

Initial and lateral boundary conditions

• 6-hourly ERA-Interim global analyses
model orography

ERA-Interim
Model T255 (80km)
Var T159 (125km)

Met Office
Model 12km
Var 24km
ERA-Interim vs EURO4M

- **T255 (80km), 60 levels**
- **T159 (125km) 4D-Var**
- **12-hour analysis window**
  - using:
    - conventional obs
    - satellite radiances

- **12km, 70 levels**
- **24km 4D-Var**
- **6-hour analysis window**
  - using:
    - conventional obs
    - satellite radiances
    - GPS (ground-based & RO)
    - visibility
    - cloud
    - precipitation
Observations

- Surface (SYNOP, buoy, etc)
- Upper air (sonde, pilot, wind profiler)
  - Aircraft
  - AMV (‘satwinds’)
- GPS-RO and ground-based GPS
  - Scatterometer winds
  - ATOVS
  - AIRS
  - IASI
- MSG clear sky radiances
Getting more from surface obs...

• Visibility
• Cloud
• Rainfall
Visibility assimilation

Visibility = f( aerosol concentration, humidity )
Cloud assimilation

Operational NAE assimilates 3D cloud fields from nowcasting system (combines satellite imagery + surface reports)

EURO4M reanalysis uses surface reports directly
Cloud from SYNOP report

Wattisham, 00Z 2012/03/13
AAXX 13004 03590 11238 83504 10064 20060 30240 40352 53002 60001 71022
886// 92350 333 55/// 20411 84703 86706 88708

84703  4 oktas Stratus from 90m
86706  6 oktas Stratus from 180m
88708  8 oktas Stratus from 240m

Pete Francis
Precipitation assimilation

- Operational UK models assimilate radar rainrate (latent heat nudging)

- For IMDAA, aim to assimilate raingauge accumulations
Precipitation assimilation

E-Obs gridded daily precipitations
Precipitation assimilation

Target

Use E-Obs gridded daily precipitations

System to disaggregate 24hr accumulations to 6hrs

Use Var outer loop
Collaboration – Cross-Validation

Compare our reanalysis against:

- SMHI/HIRLAM 22km 3D-Var
- ERA-Interim
- Obs climatologies

Peter Jermey
At low thresholds models over-represent
At high thresholds models under-represent, but …
… bias is reduced by increased resolution & 4DVAR assimilation
Climate Statistics

Monthly Means

Compare with ECA&D statistics from observations

Correlation ERA and EURO4M MEAN of T2 in 200801 with E-Obs

ERA $R_{XY} = 0.9324$

EURO4M $R_{XY} = 0.9514$

using 1532 Observations, rejecting 0 Observations
Indian Monsoon Data Assimilation and Analysis (IMDAA)

A collaboration between NCMRWF, IMD and the Met Office, 2014-2017

Funded under the MoES National Monsoon Mission

E. Rajagopal, D. Barker
The IMARR project will:

- leverage the massive effort undertaken to develop UM internationally.
- leverage UM regional reanalyses efforts performed in the EURO4M European regional reanalysis.
- be developed in parallel with, and contribute to, NCMRWF’s regional UM NWP application.
- Perform a 35yr deterministic reanalysis, and a shorter ensemble reanalysis (IMARR-E) to demonstrate reanalysis uncertainty.
4 Parallel Streams

A

B

C

D

with 1 month overlap for spin-up
How long to spin up?

RMS difference screen temp

day

How long to spin up?

RMS difference screen temp

day

0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
Var Resolution

4DVar run time:

- 36km  1 node hour
- 24km  3 node hours
- 12km  20 node hours

UM T+24  1.5 node hours
Var Resolution: 24 vs 36 km

Temperature (Kelvin) at Station Height: Surface Obs
Unknown rotated lat / long area
Equalized and Meaned from 1/2/2009 00Z to 28/2/2009 18Z

Cases: EURO4M  EURO4M 36km
Observations from ECMWF

- Surface (SYNOP, buoy, etc) incl visibility
- Upper air (sonde, pilot, wind profiler)
  - Aircraft
  - AMV (‘satwinds’)
  - ATOVS
  - AIRS
  - IASI
  - GPSRO
- MSG clear sky radiances
Observations from MetDB

- Ground-based GPS
- Scatterometer winds
Observation processing
ODB – obs monitoring database

- ODB stores observations + qc + O-B + O-A + ...
  - Established ECMWF database + utilities
    - Array of tools available “for free”
      - Metview macros (quick look)
      - Obstat (detailed stats / graphics)
Bias correction of satellite radiances

Initial reanalysis:
Radiances processed, not assimilated

Final reanalysis:
Radiances assimilated

monthly bias statistics
Any Questions?
## PS31: estimated impacts

<table>
<thead>
<tr>
<th>Component</th>
<th>Key items</th>
<th>NWP index</th>
<th>Costs in global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid</td>
<td>MOGREPS size (44)</td>
<td>+0.6</td>
<td>Reduction in VAR costs (optimisation). [Costs significant in MOGREPS]</td>
</tr>
<tr>
<td></td>
<td>MOGREPS N400</td>
<td>+0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modes weights</td>
<td>+0.1</td>
<td></td>
</tr>
<tr>
<td>Satellite</td>
<td>Satwind thinning</td>
<td>+0.6</td>
<td>Minor extra OPS</td>
</tr>
<tr>
<td></td>
<td>Rest of package</td>
<td>+0.4</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>OSTIA</td>
<td>+0.5</td>
<td>Nil</td>
</tr>
</tbody>
</table>
Currently the GloSea system uses initial conditions generated separately from ocean-only (FOAM), and atmosphere-only (NWP) model/assimilation systems.

We plan to develop coupled data assimilation, to begin with using a “weakly” coupled data assimilation approach (see next slide).

This development is being done using the GloSea5 model components with their associated DA schemes:

<table>
<thead>
<tr>
<th>Model components</th>
<th>Resolution</th>
<th>DA scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM atmosphere</td>
<td>N216L85 (~60km)</td>
<td>4DVar</td>
</tr>
<tr>
<td>UM land</td>
<td>N216 (~60km)</td>
<td>Soil moisture nudging + ASCAT</td>
</tr>
<tr>
<td>NEMO ocean</td>
<td>ORCA025L75 (~25km)</td>
<td>3DVar-FGAT</td>
</tr>
<tr>
<td>CICE sea-ice</td>
<td>ORC025 (~25km)</td>
<td>3DVar-FGAT</td>
</tr>
</tbody>
</table>
Forecast Sensitivity to Observations (FSO)

Energy-weighted forecast error norms

Observation impact is quantified as the difference in forecast error norm

$\delta e = e_a - e_b$

Observation assimilated

$e$  
$x_a$  
$x_b$  
$x^f$

Adjoint Model

Adjoint of NWP model/DA system used to derive analysis/observation sensitivity.

- FSO technique can estimate individual contribution of every observation.
- Reduces need for expensive data denial experiments.
- Assists optimal design of observation networks.
Comparison of En-4DEnVar with En-4DVar and EnKF

<table>
<thead>
<tr>
<th>En-4DVar (ECMWF)</th>
<th>En-4DEnVar (MetO)</th>
<th>EnKF (Env. Canada)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ensembles of 4D-Var (EDA)</td>
<td>• Ensembles of 4DenVar</td>
<td>• Highest maintenance cost</td>
</tr>
<tr>
<td>• Ideal, update mimics data assimilation</td>
<td>• Close to data assimilation</td>
<td>• Update algorithm relatively simple</td>
</tr>
<tr>
<td>• Very expensive</td>
<td>• Fairly expensive</td>
<td>• Quickest to run</td>
</tr>
<tr>
<td>• Uses static covariances in ensemble update?</td>
<td>• Some things come for free</td>
<td>• Possible (difficult) to do hybrid</td>
</tr>
<tr>
<td></td>
<td>• Parameter transform</td>
<td>• May need a linear observation operator</td>
</tr>
<tr>
<td></td>
<td>• Localisation in model space</td>
<td></td>
</tr>
</tbody>
</table>
Hybrid 4D-Var/ETKF DA

\[ y_n = H(x_n^f), \sigma_o, \ldots \]

\[ x_n^a = x^a + \delta x_n^a \]

MOGREPS-G

Adam Clayton on 2-year secondment to KMA to implement/improve hybrid

Deterministic
A weakly coupled data assimilation (WCDA) system has been set up by combining HadGEM3, VAR, SURF, OPS, NEMOVAR into a single Rose suite.

The system runs on a 6-hour cycle (the impact of using this time-window on the ocean has been investigated).

Two one-month trial periods are now being run (Dec 2011 and June 2012) in order to assess the impact of the WCDA system on the short-range forecasts:

1. Weakly coupled DA
   - 5-day coupled forecasts set 1

2a. Atmosphere only DA (forced by OSTIA SSTs/sea-ice)
2b. Ocean only DA (forced by fluxes from 2a)
   - 5-day coupled forecasts set 2
Medium-range Ensemble and ‘Seamless’ Forecasting

• Before PS31, medium-range ensemble (MOGREPS-15) based on short-range MOGREPS-G (N216/60km 70-level), but run to 15 days using UK member-state computer time at ECMWF.

• **Change in strategy**: Hold-off resolution upgrade (->33km) to uncoupled MOGREPS-15, and instead merge with monthly to seasonal (GloSea5) in a common N216 (60km) 85-level configuration:
  
  • Initial condition perturbations from ETKF and, in longer term, Ensemble Data Assimilation System;
  
  • Coupled model to better represent ocean-atmosphere interactions.

• A more comprehensive comparison of MOGREPS-15 and GloSea5 ensembles is currently underway, at N216L85 resolution.
Schematic of possible coupled medium-range/monthly/seasonal EPS

Richard Swinbank
Main changes in the use of satellite data in NWP: 2012-13

John Eyre

- Metop-B added – ATOVS, IASI, ASCAT, GRAS  (Dec 12 – Apr 13)
- IASI - correlated obs errors introduced  (Jan 13 – PS31)
- OSCAT winds added (scatterometer on India's Oceansat-2)  (Jan 13)
- AMVs - revised thinning (6 hours → 2 hours)  (Jan 13)
- Suomi-NPP added – ATMS and CrIS  (Apr 13 – PS32)

- Overall, satellite data volume assimilated has increased by ~50%

- Other changes:
  - Locally-received AIRS data (more timely regional data)  (Jan 12)
  - Ground-based GPS - now in global (was in NAE and UKV)  (Mar 12)
  - Updated radiative transfer model (RTTOV version 9)  (Sep 12)
  - ATOVS - variable obs errors (with scan angle, surface type, …) (Jan 13)
  - GPS-RO - new satellite (CNOFS); revised obs errors  (Jan 13)
  - Geo clear-sky radiances – GOES-13, GOES-15, MTSAT-2 added  (Jan-Apr 13)
  - MODIS aerosol optical depth assimilated  (Apr 13)
Satellite data: plans for 2013

- RTTOV-v11 released (Jun 13)
- ROPP-v7 released (Sep 13)

- Assimilation of near-surface MW sounder channels over land
- Improved treatment of obs errors for AMSU, ATMS, SSMIS
- System for processing FY-3 MW sounder data

- Improved modelling of clouds in IR radiance assimilation
- IASI data in UKV

- Assessment of VarBC for key satellite data types

- High-resolution AMVs in UKV
- Enhanced aerosol optical depth assimilation
- System to verify UM forecasts using simulated imagery

- Report on winds from MTG-IRS (EUMETSAT fellowship)
Cloud-RH diagnostic

Smith scheme
QJRMS 1990

aircraft data
Wood & Field, JAS 2000
Bias correction of satellite radiances
(based on Harris and Kelly, 2001)

\[ bias = c_{\text{scan}} + \sum_{i=1}^{n} c_{i}^{\text{air}} f(x_b) \]

VarBC allows Var to analyse \{c\}