Recent developments in global ocean data assimilation using NEMOVAR at the Met Office

Matt Martin, Rob King, Dan Lea, Jonah Roberts-Jones, Martin Price, Jennie Waters, James While, Chris Harris, Ana Aguiar, Isabella Ascione, Catherine Guiavarch, Isabelle Mirouze

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Overview

- Introduction
- Global FOAM DA developments
- On-going work and summary
Introduction
• Forecasting Ocean Assimilation Model (FOAM) – global and regional ocean DA and forecasting. Focus here on global system (Rob King is talking about FOAM-Shelf).

• Runs operationally once per day:
  • Two one-day analysis windows from T-48-> T-24, T-24 -> T0.
  • 7-day ocean only forecasts forced by Met Office NWP surface fields.
  • It is used to initialise the ocean component of coupled seasonal forecasts (GloSea).

• The same model/DA system is used to produce ocean reanalysis, forced by ERA-Interim surface fields.

• Forecasts and reanalysis are provided to various customers including the UK Royal Navy and the European Copernicus Marine Environment Monitoring Service (CMEMS).

• We also run a separate Weakly Coupled DA (WCDA) system. Ocean/sea-ice DA component is the same set-up as for FOAM, except the DA time-window is 6 hours.
Introduction: Model and data assimilation scheme

• Ocean model is NEMO in the ORCA025ext configuration:
  • ~1/4° resolution with 75 vertical levels (1m resolution in the top 10m).
• Sea-ice model is CICE – multiple thickness categories.

• Data assimilation scheme is NEMOVAR which we develop jointly with CERFACS, ECMWF, INRIA.
  • 3DVar-FGAT scheme with a 1-day time window, with IAU over 1-day.
  • Implicit diffusion model for the background error correlations.
  • Two length-scale background error covariances, each with its own seasonally and spatially varying variances.
  • Multivariate balance relationships for ocean variables.
  • Observation bias correction for SST and SSH.
  • Equatorial model bias correction scheme (pressure correction).
Introduction: SST observations

- SST bias correction scheme calibrates the various satellite data types towards a reference/unbiased data-set (currently based on the in situ data).
- Near-surface vertical length-scales are based on the background mixed layer depth. Changing vertical length-scales requires a lookup table of normalisation factors for the background error correlation.
- Horizontal length-scales are reduced at high latitudes to avoid changing model SSTs under the sea-ice.
Introduction: *Altimeter observations*

- SLA observations are combined with Mean Dynamic Topography (MDT) to get SSH.
- MDT has errors and bias correction scheme is used to estimate these time-constant, spatially varying errors.
- SSH signal is split into barotropic and baroclinic signals.
- Baroclinic part is only applied where the top-to-bottom temperature difference is > 5°C.
- Barotropic part is applied at all latitudes.
• SSMIS Sea-ice concentration data is assimilated with only a short length-scale (~25km). The data is very dense (OSI-SAF gridded product).
• No updates are made to other ocean variables.
• The total sea-ice thickness in a grid-box is preserved during the DA.
• Where the model has zero ice, and the increments are adding in ice, the ice is added at 50cm thickness.
Introduction: *profile observations*

- Profile data: Argo, moored buoys, gliders, marine mammals (T only), XBTs.
- Background error standard deviations parameterised based on the vertical gradient of temperature in the background.
- Temperature-salinity balance relationship based on the background water masses below the mixed layer. Salinity data changes the unbalanced salinity, i.e. change the analysed water masses.

All T profile data (30th Sep 2017)

All S profile data (30th Sep 2017)
FOAM v14 developments
FOAM v14: Overview

• The current operational system is FOAM v13. A new system has been developed called v14.
• Trials of the new system are underway, and a reanalysis will be run soon.
• Operational implementation expected in Spring 2018.

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FOAM v14: NEMOVAR v4

Main technical changes:
- Changes to observation operator ($H_y$) for T/S profiles to deal with non-linear free surface.
- Changes to make sure that changes in SSH do not result in spurious fluxes of freshwater during IAU.
- Horizontal $B$ correlation model now 2D implicit diffusion: improvements near coastlines/islands.
- $\rightarrow$ computational cost is proportional to $[\text{length-scale} / \text{grid-size}]$. We limit the longer length-scale at high latitudes to make the diffusion model more efficient.
- SST and SSH observation bias terms now solved in the main minimisation.

\[
J(x,b) = (x-x^f)^T B^{-1} (x-x^f) + (b-b^f)^T O^{-1} (b-b^f) + (y-H_y(x+b))^T R^{-1} (y-H_y(x+b)) + (k-H_k(b))^T L^{-1} (k-H_k(b))
\]

- $J$: cost
- $y$: observations
- $B$: background error covariance
- $O$: observation bias error covariance
- $L$: matchup error covariance
- $H_y$: observation operator for observations
- $H_k$: observation operator for matchups

$x = [\text{SSH, T, S, u, v, SIC}] \Rightarrow \text{state vector}$

$b = [\text{SSH}_b, \text{SST}_b] \Rightarrow \text{obs bias vector}$

$k = [\text{SST}_\text{sat} - \text{SST}_\text{ref}] \Rightarrow \text{“obs-of-bias” matchups}$
FOAM v14: SST bias correction

• A new bias correction scheme combines a variational bias correction method with a correction based upon “observations-of-bias” (taken as the differences between standard observations and high-quality reference observations).

• The bias correction system is designed to give consistent results over long reanalysis, including periods where the amount of reference data is much less than it is now.

• Theoretical and idealised studies showed a combination of traditional variational bias correction, with the use of “observations-of-bias”, provides a more accurate and stable analysis.
FOAM v14: SST bias correction results

- 3 year experiments with FOAM v14 (Jan 2008 – Dec 2010)
- New scheme outperforms the matchup-based or variational-only schemes
- Further assessment of the impact of changing observing system on-going.

Global comparisons to in situ SST data prior to its assimilation
FOAM v14: *Incremental pressure correction*

- DA at the equator causes the generation of spurious vertical velocities (w).
- Scheme was devised by Waters et al. (2017) to reduce the impact of the DA on w.
- This scheme has been implemented in the FOAM v14 system and shows similar impact to the results of Waters et al (2017).

**Standard deviation of vertical velocities (m/s) at the equator for July 2011**
FOAM v14: Updated MDT and altimeter bias correction

- Currently using CNES-CLS09 MDT (ocean Mean Dynamic Topography) but now implemented an updated version CNES-CLS13 MDT
- The altimeter bias scheme has picked up some of the differences (note reverse sign due to definition of the bias).
FOAM v14: Updated MDT and altimeter bias correction

- Overall the new MDT significantly reduces the SSH and T profile innovations.
- Still an issue in the Med Sea – MDT error estimate perhaps under-estimated there?
Preliminary comparisons between FOAM v13 and v14 (Jul 2011 – Dec 2013)

- SST innovations overall similar (0.47 -> 0.46°C RMSE).
- SSH innovations overall similar (7.4 -> 7.3 cm RMSE), significant improvement in Tropical Pacific.

- Improvements in T profile innovations, particularly in the Tropical Pacific.
- Near surface S profile innovations degraded in the N. Atlantic.
On-going work and summary
On-going work – ocean DA developments

- Implementation of NEMOVARv4 in a global 1/12° resolution model (ORCA12) is being worked on.
- New observation types:
  - SSS assimilation – see talk later in the week
- Preliminary work on a global ensemble of 3DVars with perturbed obs and surface forcing.
- Planning to develop ensemble generation and test hybrid 3DVar/Ensemble DA.

![SST in Gulf Stream region](image1)

![SST in N.E. Atlantic region](image2)

[20111201T0000Z]
Summary

• New version of FOAM system (v14) is being tested for operational implementation in 2018:
  • Model changes: non-linear free surface; sea-ice model changes.
  • DA changes:
    • New version of NEMOVAR with 2D diffusion operator.
    • New MDT
    • Improved SST bias correction scheme
    • Incremental Pressure Correction scheme to improve assimilation at the equator.
  • Preliminary assessment of new system shows significant improvements in the Tropics
    (for SSH and T/S profiles).

• On-going work includes:
  • Implementing the latest version of the DA system in a 1/12° global configuration.
  • Testing new observing systems: satellite SSS, sea-ice thickness.
  • Improving weakly coupled DA system.
  • Starting work on generation and use of ensembles. More focus on this in the next years.
Questions?
On-going work - coupled data assimilation

- Weakly coupled data assimilation system running in operational environment.
- 4DVar atmosphere and 3DVar ocean/sea-ice with 6-hour window.
- ~40km resolution atmosphere/land and ¼° resolution ocean/sea-ice.
- Plan is to increase the atmospheric resolution of this system to be the same as the operational NWP system (~10km) over the next couple of years, and to assess its performance compared to the main NWP forecasts.
- Work on a coupled ensemble prediction system is also planned.

Impact of coupled DA on ocean forecasts

Global obs-minus-forecast statistics against surface drifters over 2015

Red – weakly coupled DA and coupled f/cs
Blue – uncoupled ocean DA (FOAM)
Green – coupled f/cs from uncoupled DA.