The Met Office operational global ocean forecasting system at 1/12th degree resolution

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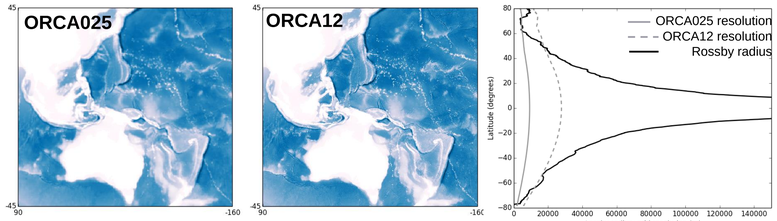
1. INTRODUCTION

The Met Office's operational Forecasting Ocean Assimilation Model (FOAM) global system has recently been upgraded from an eddy permitting 1/4° resolution (FOAM-ORCA025) to an eddy resolving 1/12° resolution (FOAM-ORCA12).

The increase in resolution allows mesoscale processes to be resolved at a much larger range of latitudes, representation of finer resolution bathymetric features and coastlines and a larger number of resolved islands which can play an important role in ocean circulation.

We provide a description of the new FOAM system and results which demonstrate the impact of the change in model resolution.



Bathymetry for the Western Tropical Pacific

Zonally averaged grid resolution and Rossby radius

2. FOAM SYSTEM DESCRIPTION

Model

- NEMOv3.6 ocean model (GO6) with 75 vertical levels, CICE sea-ice model (GSI8.1).

Data Assimilation

- NEMOVAR: 3D-VAR FGAT scheme with a 24 hour assimilation window (Waters et al., 2015).
- State vector: temperature (T), salinity (S), sea surface height (SSH), velocities, sea ice concentration (SIC) .
- Variational sea surface temperature (SST) and sea level anomaly (SLA) bias correction schemes.
- Background error covariances modelled by the diffusion operator.
- Multivariate balance specified through linearised balance relationships (Weaver et al., 2005).
- Two horizontal background error correlation scales for T & S – a shorter Rossby radius dependent scale and a longer 4° scale.
- Unbalanced SSH background error correlation scale 4°, SIC background error correlation scale 25km.
- Vertical background error correlations are parametrised based on the mixed layer depth.
- Background error variances, ratio between two length-scales (for T and S) and observations error variances are seasonally varying.
- Incremental Analysis update (IAU)

Observations

- Assimilate satellite and *in-situ* SST, altimeter SLA, *in-situ* temperature and salinity profiles and satellite sea ice concentration

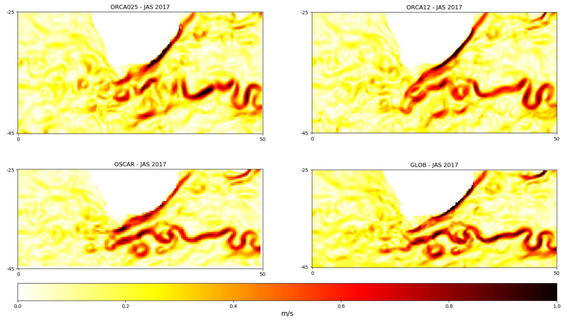
FOAM-ORCA025

- Model on 1/4° ORCA grid, Data assimilation on 1/4° ORCA grid

FOAM-ORCA12

- Model on 1/12° ORCA grid, Data assimilation on 1/4° ORCA grid
- Common for high resolution systems to perform the data assimilation inner-loop at lower resolution than the model resolution in NWP and in operational oceanography
- Significantly lower cost to perform assimilation at 1/4°.

3. SURFACE VELOCITY COMPARISON



Qualitatively, the Agulhas current is more coherent with a well defined retroflection in FOAM-ORCA12 and is more consistent with the OSCAR and GLOB-current observation products.

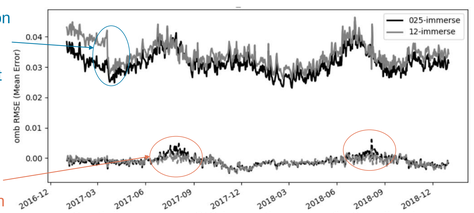
Surface Agulhas Current: June-July-August 2017

4. INNOVATION STATISTICS

The innovation (observation minus background) statistics generally show an increase in root mean square difference (RMSD) for FOAM-ORCA12 relative to FOAM-ORCA025. The RMSD increases by 3% for in-situ SST, 3.6% for temperature profiles and 4.5% for salinity profiles. The innovation statistics for SIC are shown below.

Fix to the observation costal filtering by OSI_SAF. Larger RMSD improvement in FOAM-ORCA12 due to the higher resolution coastline

Mean error reduced in FOAM-ORCA12 in July-August. Due to a reduced bias in the Arctic during the melt season.

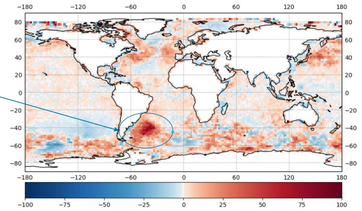


Spatially-averaged SIC innovation mean (bottom lines) and RMSD (top lines) for the global ocean, ORCA025 in black and ORCA12 in grey.

More small scale features are represented in higher resolution models, there is an increased likelihood for these to be offset from real features in space and time, resulting in the so called "double-penalty" effect. The increases in innovation RMSD for T, S and SIC in FOAM-ORCA12 are attributed to this double penalty effect and demonstrates the limitations of this type of assessment when comparing different resolution systems.

There is a larger increase of 6.5% for the SLA RMSD. Some of this increase is probably related to the double penalty effect, however, the spatial plot of innovation percentage differences in RMSD for the 2 year hindcast period shows particularly large errors in the Zapiola region.

Investigation showed erroneous stationary eddies in this region in FOAM-ORCA12. Because these eddies are persistent they are seen as a bias and therefore are not corrected by the assimilation.
One theory is that these stationary eddies are caused by the mismatch in the bathymetry resolution between the model and data assimilation step.

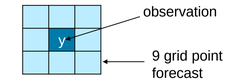


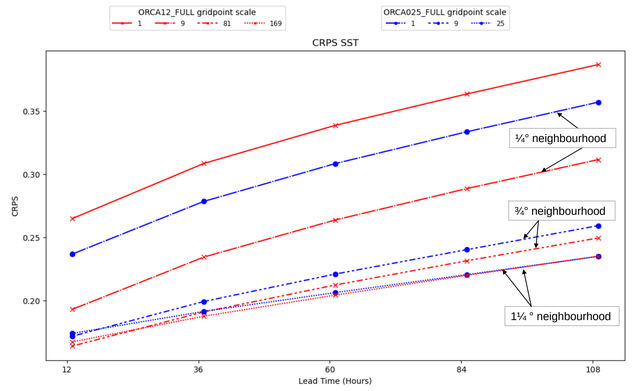
Innovations percentage differences in RMSD between FOAM-ORCA025 and FOAM-ORCA12. Blue means FOAM-ORCA12 RMSD is lower, red means it is higher.

5. RESOLUTION INDEPENDENT METRICS

With the limitation of standard assessment techniques for high resolution systems, new methods such as the High-Resolution Assessment (HiRA) method are being developed for use with FOAM (Crocker et al., 2020).

- HiRA uses increasing sized neighbourhoods to generate a pseudo ensemble which can then be compared to an observed value
- HiRA assumes that the observation is a true value at its location and also representative of the characteristics of the surrounding area.





Continuous Ranked Probability score (CRPS) for drifters' SST as a function of forecast (lead) times, averages for the global ocean and over a six-month period Jun-Dec 2018.

The matching line styles represent equivalent neighbourhood sizes that should be compared for FOAM-ORCA12 and FOAM-ORCA025. The CRPS tends to zero for a perfect forecast, therefore lower CRPS score indicates a lower error. At the grid scale (i.e when the neighbourhood is size 1), the CRPS is equivalent to Mean Absolute Error. The higher resolution FOAM-ORCA12 consistently has lower errors than FOAM-ORCA025 when equivalent neighbourhood extents are compared. This supports our argument that the SST innovation statistics for FOAM-ORCA12 are penalized by a double penalty effect. We intend to extend this validation method to other variables in the near future.

6. SUMMARY AND FUTURE WORK

- The FOAM-ORCA12 system became operational in December 2020.
- Traditional statistical verification methods suggest that the new system performs slightly worse than the pre-existing FOAM-ORCA025 configuration, while preliminary results from HiRA show an improvement in SST prediction.
- Neighbourhood verification methods provide a fairer way of comparing different resolution systems and will be extended to other variables.
- Recent developments to the modelling of background error covariances in NEMOVAR substantially reduce the cost of running the data assimilation at 1/12°. We plan to trial a FOAM-ORCA12 system with data assimilation at 1/12° and assess the impact of increased resolution in the assimilation.

7. REFERENCES

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