Multiscale FGAT data assimilation in OceanMAPS (v3.4) forecasting system

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Introduction

The *Ocean Model, Analysis and Prediction System (OceanMAPS)* is the ocean forecasting system implemented at the Bureau of Meteorology. OceanMAPS provides 7-day forecasts on daily basis in near global eddy-resolving horizonal grid. The system is based on Modular Ocean Model (MOM 5) and data assimilation is using Enkf-C software in Ensemble Optimal Interpolation (EnOI) mode. An efficient, two-stage, multiscale FGAT (First Guess at Appropriate Time) EnOI data assimilation is used in OceanMAPSv3.4. First stage EnOI data assimilation is done using a static ensemble of climatological anomalies constructed using a coarse, 1°global ocean model. This followed by an FGAT EnOI data assimilation based on intraseasonal anomalies from a free run of the eddy-resolving ocean model (same as the OceanMAPS Ocean Model configuration). The coarse-resolution ensemble is aimed to correct broad-scales, and high-resolution ensemble is used to correct the eddy-scales. Corrections from the coarse steps are more effective at reducing the biases in the subsurface ocean whereas the high-resolution steps largely restricted to vertically uniform corrections that are associated with mesoscale eddies. Implementation of FGAT sees more observations are assimilated into the system, especially in the form of satellite-derived sea surface temperature, that gives closer fit to observation in surface and near-surface temperature.

Multi-scale data assimilation in OceanMAPSv3.4

Multiscale data assimilation used in OceanMAPSv3.4 is based on EnOI method. The method utilizes the covariances of a stationary ensemble based on anomalies from a previous free-running model simulation that are typically multi-variate. In EnOI-DA, observation-model differences are projected onto ensemble members to construct a weighted averaged that becomes the correction to the ocean state.

The DA system here is developed by adding a coarse-resolution step to the DA component, before the high-resolution data assimilation used in previous versions, making it a twostep process. The high-resolution data assimilation is also converted to asynchronous FGAT mode (from a 3-day centred synchronous assimilation used in earlier versions) to allow more observations are assimilated. This multiscale DA workflow is summarised in Figure 1.

The initial background is the ocean model restart at end of the ocean model run from the previous cycle. The background is regridded onto the coarse grid and the coarse DA is calculated (DA-L) using the ensemble from the coarse ocean model. Observations in DA-L are also averaged onto the coarse grid in the process of building "super-observations" (Sakov, 2014). The correction, or increment, from DA-L is interpolated back to the OFAM grid and added to the initial backgrounds from the restart for the new high resolution DA background. In this way, broad scale corrections get incorporated into the background without losing the important mesoscale features from initial background. The second, FGAT high-resolution DA cycle produces analysis that now includes low- and high-resolution corrections. The analysis from this cycle becomes the initial condition for the next ocean model integration. The ocean model integrates the ocean state forward in time and restart becomes the background to the next DA cycle. A `clean' forecast statistics is then calculated in the next cycle using restarts before any DA steps are involved.

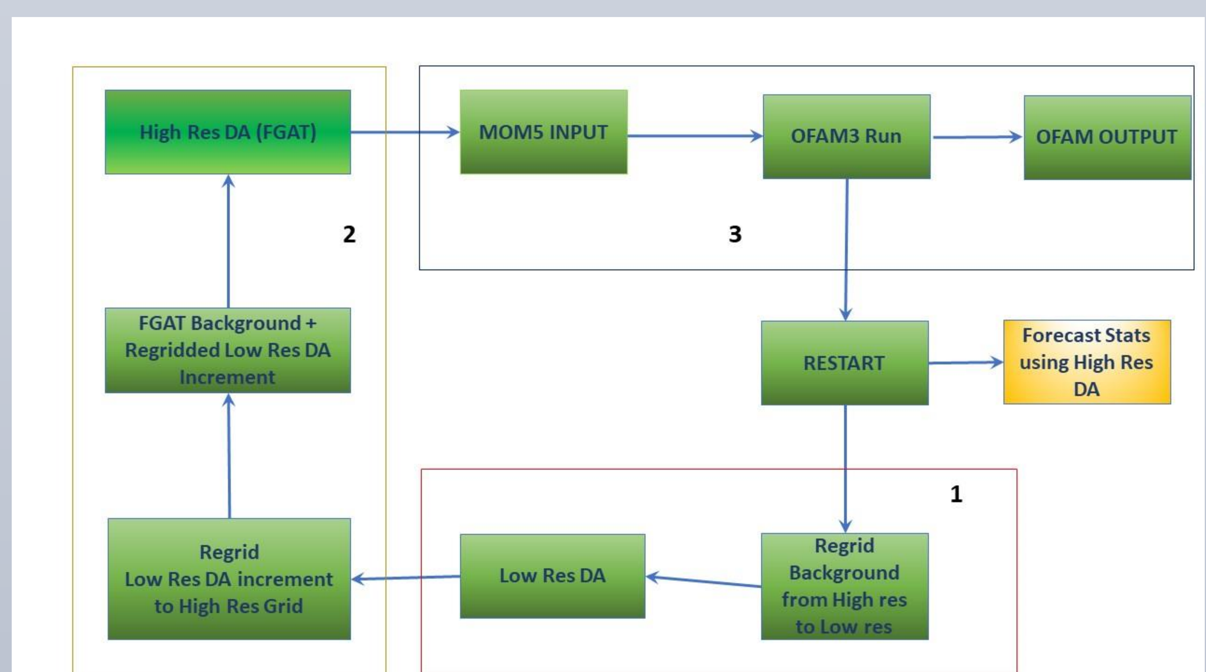

Figure 1. Schematic diagram of Multiscale Data assimilation in OceanMAPSv3.4

1. Low mode data assimilation (DA-L)
2. High resolution data assimilation (DA-H)
3. MOM model run

Forecast statistics

To compare the performance of OceanMAPSv3.3 (operational version) and OceanMAPSv3.4, timeseries of the global mean absolute deviations and global biases, for temperature and salinity, for the full year of 2020 are shown in Figure 2. There are substantial reductions in forecast deviations and biases of subsurface temperatures and salinity in OceanMAPSv3.4 compared to the operational version. New system shows over 15% reduction in mean absolute errors in temperature and approximately 23% reduction in errors in salinity. Global forecast bias in temperature and salinity in the new system is also performing better than the operational system, with more stability over the period and closer to the zero mark.

Global forecast statistics for sea surface temperature and upper ocean temperature (<50m) are shown in Figure 3. Influence of asynchronous (FGAT) assimilation that allow to assimilate observations closer to the observed time, is evident in the SST and upper ocean statistics. Notable stable bias in SST is seen in the new version, compared to the seasonal fluctuations observed in the operational version. FGAT capability increases the number of observations that can be assimilated into the system, especially in the form of SST observations, and influence the upper ocean temperature. Upper ocean temperature bias and MAE also performs better in the new version compared to OceanMAPSv3.3. SLA forecast errors are similar for both OceanMAPSv3.4 and OceanMAPSv3.3.

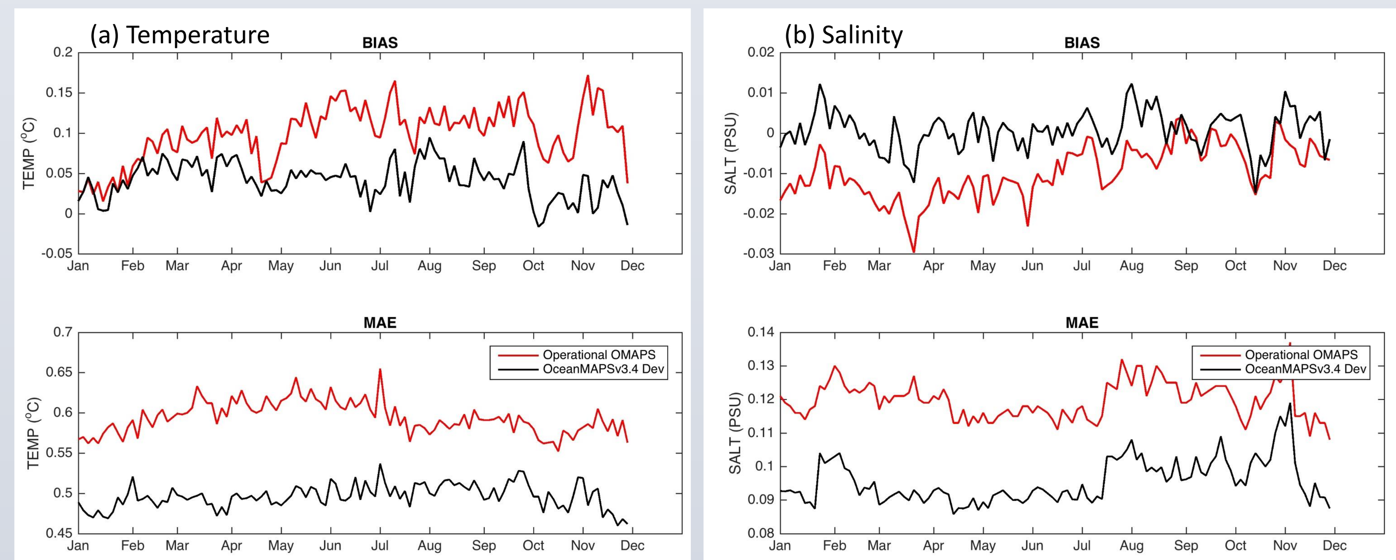

Figure 2. Forecast statistics for temperature and salinity (full profile depth) from OceanMAPS Operational version (v3.3) and OceanMAPSv3.4.

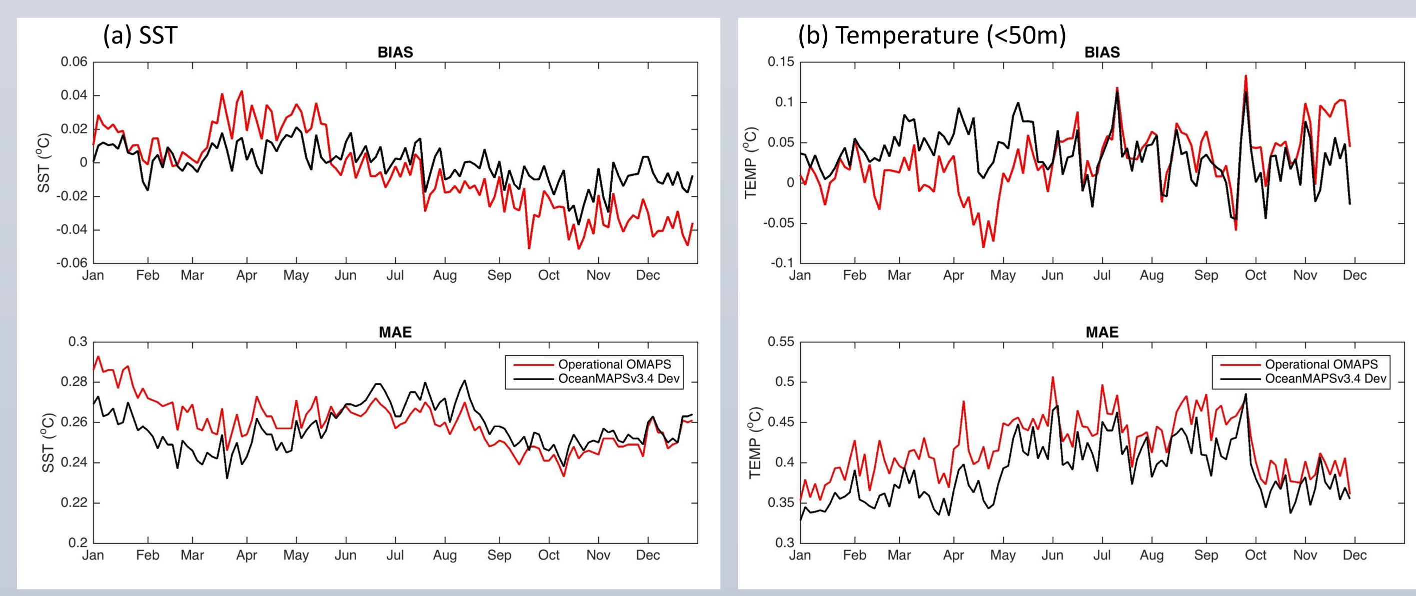

Figure 3. Forecast statistics for sea surface temperature and temperature in the upper 50m from OceanMAPS Operational version (v3.3) and OceanMAPSv3.4.

Sub-surface Temperature and salinity profiles

Figure 4 represent the error (model - observations) spread in best estimates (analysis day model fields) for temperature and salinity profiles for OceanMAPSv3.3 and OceanMAPSv3.4. The general behaviour is to have larger errors in the upper ocean associated with both the mixed layer and thermocline/pycnocline, and then a gradual decrease in errors with depth in line with a decrease in variability of the deeper ocean. However, in OceanMAPSv3.3 we find the system errors (especially in temperature) are not decreasing with depth as expected, possibility due to greater bias in temperature and salinity in the deeper model domain. This issue is greatly reduced by the implementation of multi-scale data assimilation in OceanMAPSv3.4. The profile errors in OceanMAPSv3.4 are much narrower and tighter to the median, especially in temperature at mid-depth and near surface. Similar improvements are notable in salinity profiles in OceanMAPSv3.4 as well.

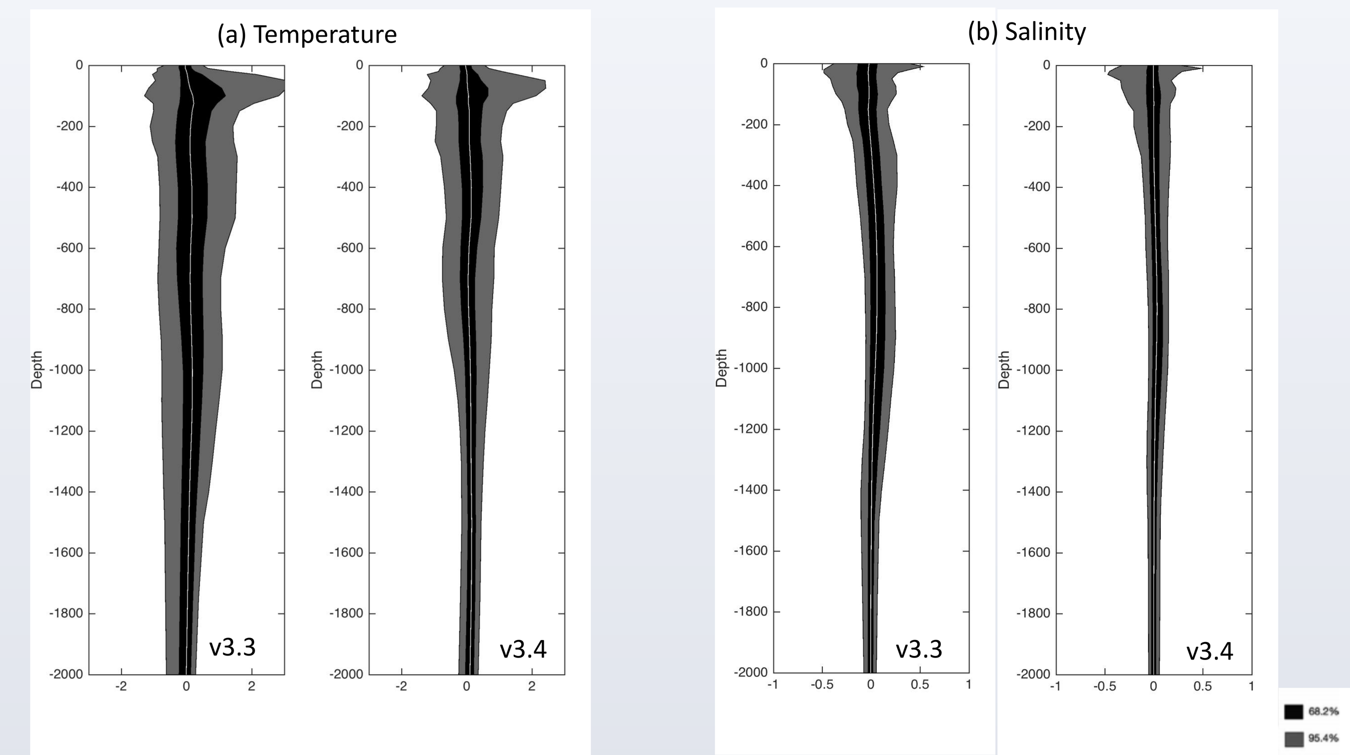

Figure 4. *Temperature and salinity profile error spread in percentiles for June 2020, OceanMAPSv3.3 and OceanMAPSv3.4. Errors are calculated as difference between model fields and Argo observations.*

Mean data assimilation increments

Mean increment fields from the data assimilation for OceanMAPSv3.3 and OceanMAPSv3.4 are shown in Figure 5. Mean absolute field gives indications on the amount of work data assimilation does to correct the model. Over long period a better system has less mean increment values. SST mean increment fields show that the OceanMAPSv3.4 system has comparatively less errors to OceanMAPSv3.3, especially in northern high-latitudes and along the equator. Similarly, in depth-averaged temperature increments, there is less discontinuous increments in the equatorial regions in the newer version.

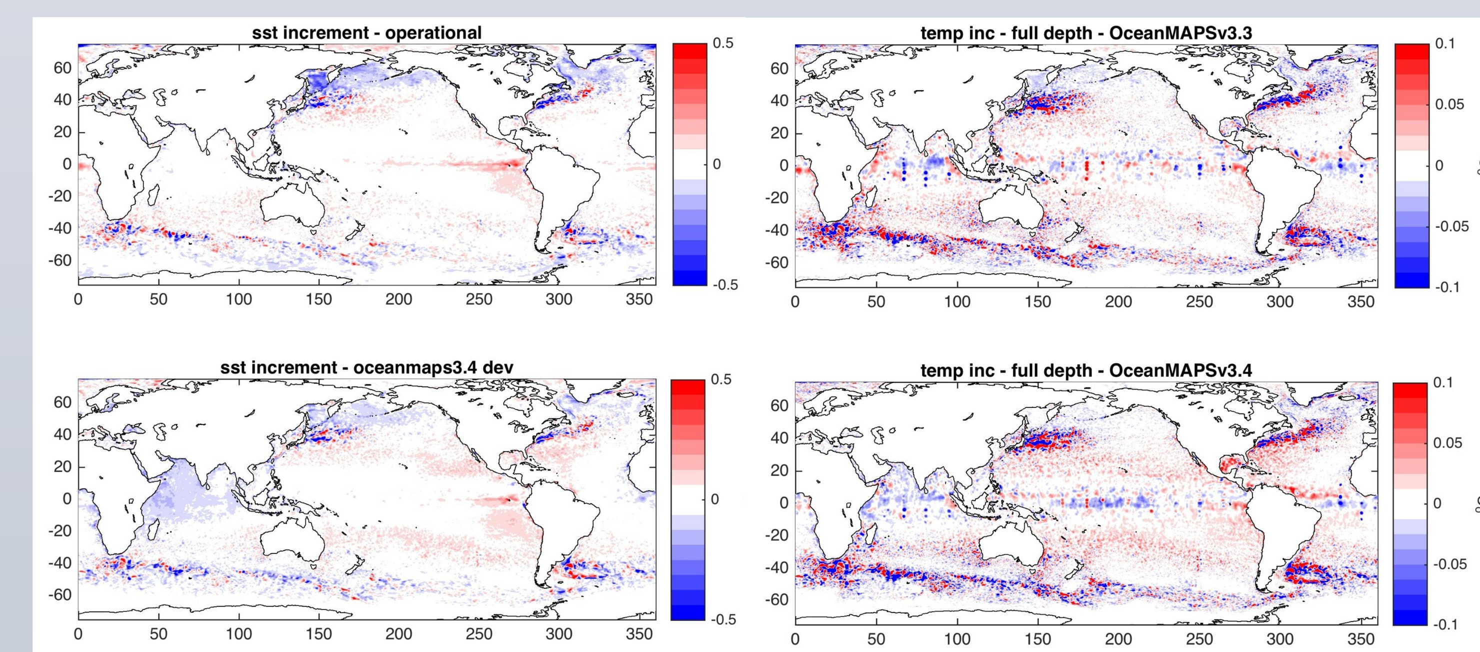

Figure 5. *Mean data assimilation increments for 2020, (a) SST and (b) depth-averaged temperature for OceanMAPSv3.3 (top) and OceanMAPSv3.4 (bottom).*

Summary

Forecast errors are significantly reduced in OceanMAPSv3.4 with multiscale FGAT DA compared to OceanMAPSv3.3. Mean absolute deviations of forecasts in subsurface temperature (salinity), from all depths, are reduced by ~16% (~23%) compared to OceanMAPSv3.3. Improvements are greater at depth, with OceanMAPSv3.4 show tighter fit with observation, with less spread in errors. Overall performance of OceanMAPSv3.4 is better, with less mean-corrections are applied over the period.

Reference:

- Huang, X., **Divakaran, P.**, Sakov, P., Brassington, G., Beggs. H., Zhong, A., Entel, M.,Charles, S., Matthews, L., 2021. Operational upgrade to OceanMAPS version 3.4. Operations Bulletin xxx. xx May 2021. Bureau of Meteorology .
- Chamberlain M, A., Oke, P. R., Fiedler A, R, S., Beggs H, Brassington G B., **Divakaran, P.**, Sakov, P., 2021, Next generation of Bluelink ocean reanalysis with multiscale data assimilation: BRAN2020, Journal of Marine Systems (submitted).
- Chamberlain M, A., Oke, P. R., Brassington G B., Sandery, P., **Divakaran, P.**, Fiedler A, R, S., 2021, Next generation of Bluelink ocean reanalysis with multiscale data assimilation: BRAN2020, Ocean Modelling (submitted).
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