SYMPOSIUM OP'24 ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Met Office

Equatorial Mixed Layer Depth Anomalies in a Global Ocean-Atmosphere Coupled System

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1. System

Operational global O-A coupled numerical weather prediction (NWP) system

- Atmosphere coupled to an interactive ocean and sea-ice component (**FOAM-GC**), see Guiavarc'h *et al.,* (2019).
- Weakly coupled data assimilation using NEMOVAR
- NEMO ocean at ¼˚ (ORCA025)
- Run 4x a day with 6 hr assimilation window
- 7 day forecast
- Data: www.metoffice.gov.uk/services/data/met-office-marine-data-service

2. Motivation

Mixed layer depths in the equatorial region in the Met Office operational coupled system were much **shallower** than those in a comparable ocean only system (**FOAM-GO**, see Barbosa Aguiar *et al.,* 2024), raising suspicions that the depths in the coupled system were incorrect. This equatorial region is also where a pressure correction is applied, suggesting the two may be linked.

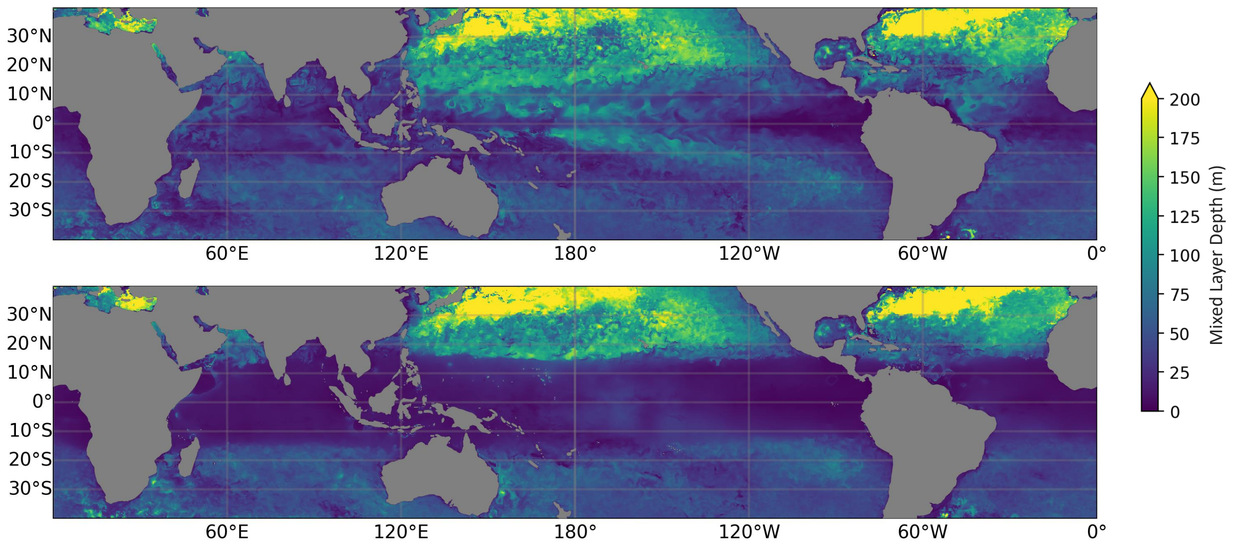

Figure 1 – Kara mixed layer depth on 15/03/2024 in the operational global ocean systems FOAM-GO (top) and FOAM-GC (bottom).

3. Background

Mixed Layer Depth

The main mixed layer depth diagnostic used in the system is based on the method of Kara *et al., (*2000).

- Uses vertical density gradients to identify mixed layer
- Settings: 3m reference depth, 0.8˚C (equivalent density) critical difference, 1/10th threshold fraction.

Pressure Correction

When temperature and salinity increments are added as part of data assimilation, they alter pressure gradient forces and cause spurious circulations in the equatorial region. To balance these changes an additional pressure term is added to the equations of motion (Bell *et al.,* 2004).

This 3D correction field evolves each cycle and is based on the temperature and salinity increments from that assimilation window, those from the last 90 days, and a decay term.

4. Method

Other than the coupling, the major difference between the coupled and ocean only systems is the assimilation window, 6 hr and 24 hr respectively.

In a research and development ocean only system these assimilation windows were replicated.

Experiment 1 – 24hr Assimilation Window
Experiment 2 – 6hr Assimilation Window

A third experiment was also undertaken to understand the impact of the pressure correction. In the generation of the pressure correction field, the weight given to the increments from the current assimilation window was reduced by half.

Experiment 3 – 6hr Assimilation Window & Reduced Increment Contribution to Pressure Correction

5. Results

- Average mixed layer depth in the equatorial region shoals in the 6 hr assimilation window experiment, but remains stable in 24 hr assimilation window experiment, replicating the differences seen between operational FOAM-GC and FOAM-GO.
- Reducing the influence of the current cycle's increments on the pressure correction reduced the rate of shoaling.
- The average magnitude of the pressure correction field remains stable in the 24 hr assimilation window experiment but increases in the 6 hr assimilation window experiment, again replicating what is observed in the operational systems.
- Reducing the influence of the current cycle's increments on the pressure correction reduces the growth of the pressure correction field's magnitude.

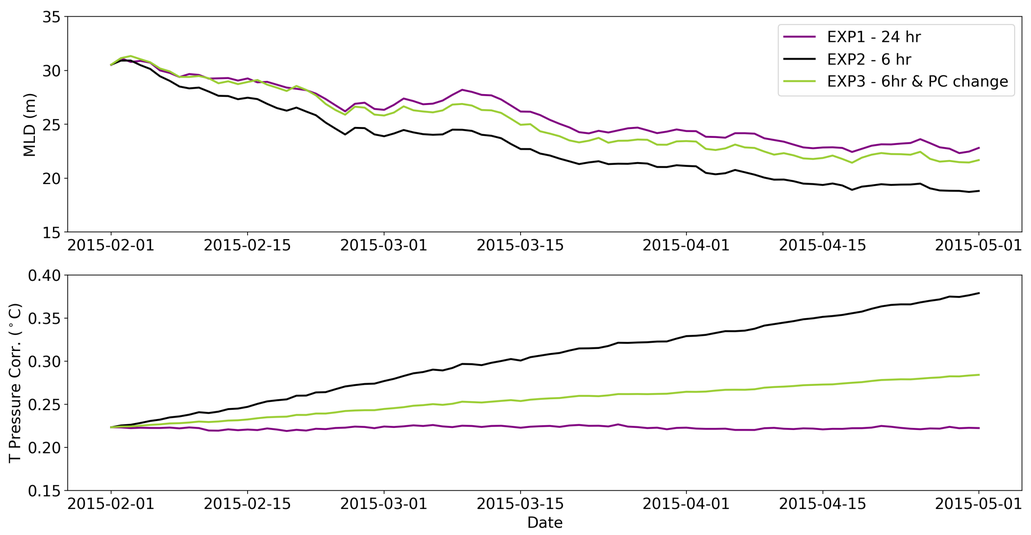

Figure 2 – Equatorial mean Kara mixed layer depth (top) and absolute mean of the temperature component of the pressure correction field in the top 150 m of the water column (bottom). All are averages between 10˚S - 10˚N.

6. Discussion & Conclusions

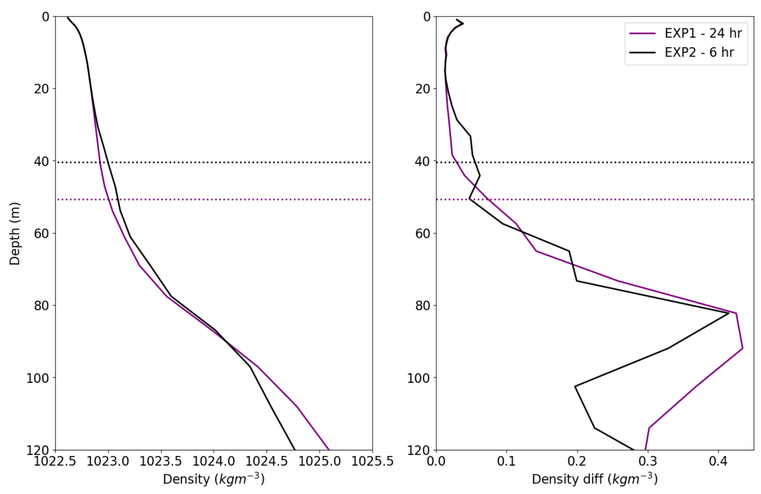

Figure 3 – Example profile (from 8˚S 137˚W at end of 3 month experiment period) of density (left) and density difference between adjacent depth pairs (right), to illustrate how the Kara MLD (dotted line) uses the density difference to identify the mixed layer depth.

The weighting of the current cycle's increment in the pressure correction field was too high for the 6 hr assimilation window, causing the magnitude of the field to grow over time.

How does the pressure correction link to mixed layer depth?

When the pressure correction field is too large it overcompensates for the changes in pressure gradient and acts to create spurious circulations similar to when no correction is applied. This perturbs the vertical density structure, altering the vertical density gradients which are used to identify the mixed layer depth. This leads to mis identification of the mixed layer depth.

Was the true mixed layer depth shallowing?

No, the diagnostic was misidentifying the mixed layer depth. Figure 3 demonstrates how small changes to the shape of the density profile cause mixed layer depth to be misidentified.

7. Future Work

- Investigate the magnitude of the increments in a 6 hr cycling system
- Recalculate data assimilation background error covariances for the 6 hr FOAM-GC system, currently those from the 24 hr FOAM-GO are used.
- Investigate which mixed layer depth diagnostic is most suitable for our users' requirements and best represents the true vertical structure of the model.

Barbosa Aguiar *et al.,* (2024). The Met Office Forecast Ocean Assimilation Model (FOAM) using a 1/12-degree grid for global forecasts, Quarterly Journal of the Royal Meteorological Society, 150(763), 3827-3852, https://doi.org/10.1002/qj.4798.

Bell *et al.,* (2004). Assimilation of data into an ocean model with systematic errors near the equator, Quarterly Journal of the Royal Meteorological Society, 130(598), 873-893, https://doi.org/10.1256/qj.02.109.

Guiavarc'h et al., (2019). Assessment of ocean analysis and forecast from an atmosphere–ocean coupled data assimilation operational system, Ocean Sci., 15, 1307–1326, https://doi.org/10.5194/os-15-1307-2019.

Kara *et al.,* (2000). An optimal definition for ocean mixed layer depth, Journal of Geophysical Research, 105 (C7), 16803-16821, https://doi.org/10.1029/2000JC900072.

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