Met Office

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Biases at the base of the mixed layer induced by 3DVar assimilation of sea surface temperature observations.

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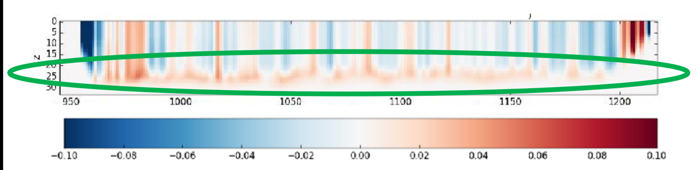
(A) Overview

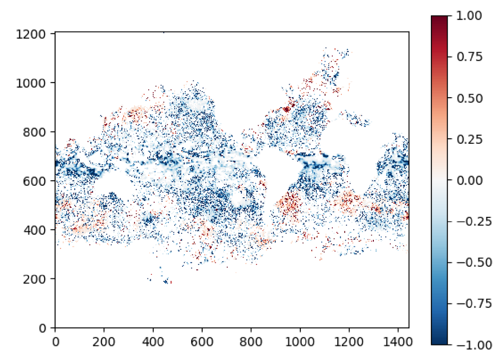


When assimilating SST data at the Met Office a positive bias in the temperature increments is often observed at the base of the mixed layer. This is a particular problem when only SST data are available.

The left plot shows the mean increments around the ACC when only SST data were assimilated.

While this issue happens in general, it is easier to study when only SST data are assimilated. In such a case, the dipole structure illustrated above is seen over most of the globe. Although in some regions an inverse dipole is seen.

The plot to the right shows the relative dipole for a month of mean increments.



relative dipole = sign(surface increment) * | subsurface peak increment / surface increment |

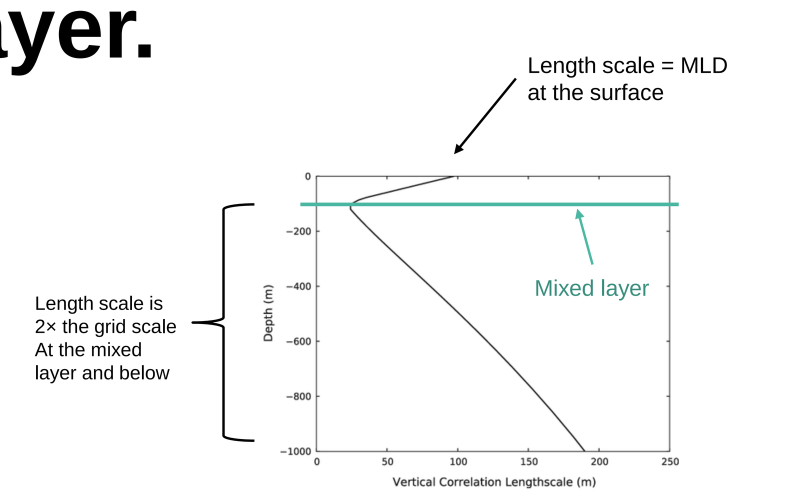
The above problem has been investigated using both 1D and 3D systems (described below).

A significant number of possible solutions to the problem have been tested. Most had limited effect and are not discussed here.

Two methodologies have been found to have a significant impact and these are discussed in panels (E) and (F).

(B) A mechanism for bias generation at the base of the mixed layer.

In ocean data assimilation at the Met Office, the vertical spreading of information is parameterised based on the mixed layer depth:

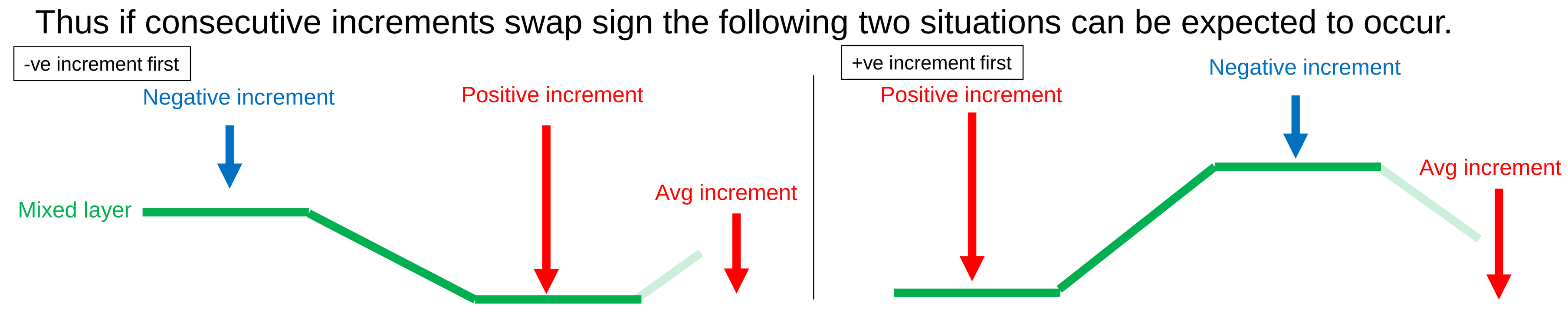


However, assimilation affects the evolution of the mixed layer through changes to the vertical density gradient.

Thus there is a feedback between the assimilation and the evolution of the mixed layer.

A positive increment will shallow the mixed layer reducing the vertical extent on the next assimilation cycle. Conversely a negative increment will deepen the mixed layer increasing the extent.

Thus if consecutive increments swap sign the following two situations can be expected to occur.



Therefore, because of the response of the mixed layer, the average increment is positive below the shallowest part of mixed layer, regardless of which increment comes first. This is a particular problem for the right plot as the effects of the positive increment can become trapped below the mixed layer

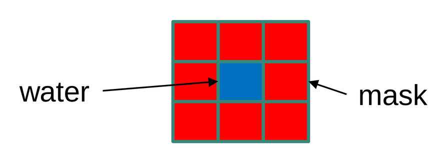
In reality the situation is more complex for a number of reasons including:

- The evolution of the mixed layer has a complex inverse relationship to the density gradient. Consequently the magnitude of the response will differ between positive and negative increments.
- Intrinsic biases in the ocean model, or the applied fluxes, could have an impact on the response of the mixed layer to the increments.

(C) 1D ocean column system

1) For reasons of cost, the vertical propagation problem has mostly been investigated using a single column model

The model uses the NEMO[1] Vn3.6 model in a 3x3 configuration with 72 levels. Only the middle column is unmasked.

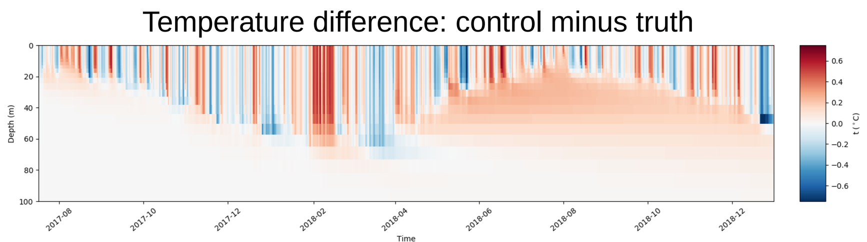


Atmospheric forcing is taken from Met Office NWP forcing fields, interpolated to the column's location.

3DVar data assimilation of SST is done using NEMOVAR[2].

3) Comparing the truth to a control, which assimilated observations, shows that positive biases are formed beneath the mixed layer

Temperature difference: control minus truth



Occasionally negative biases form, but these are less common and shorter lived.

2) We have been running the 1D model in a perfect twin setup, with a free run taken as the 'truth'. Experiments were done at station PAPA:

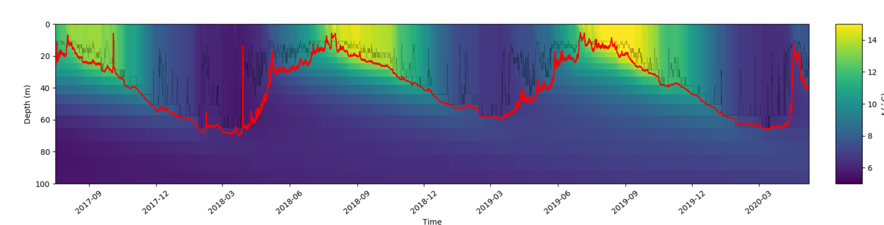
Each assimilating cycle (1 day) one observation of SST is drawn from the truth and perturbed with 0.5 ˚C Gaussian noise

The assimilating run is identical to the free run, except for the data assimilation.

=> If everything is ideal, the assimilating run should randomly bounce around the truth within the analysis error, but **should not** become biased.

In all experiments both the observation and background errors were set to the same value (0.1˚C).

The free running experiment shows a seasonal cycle in mixed layer depth and surface temperature:



Red line:- Kara MLD

(D) 3D Ocean system

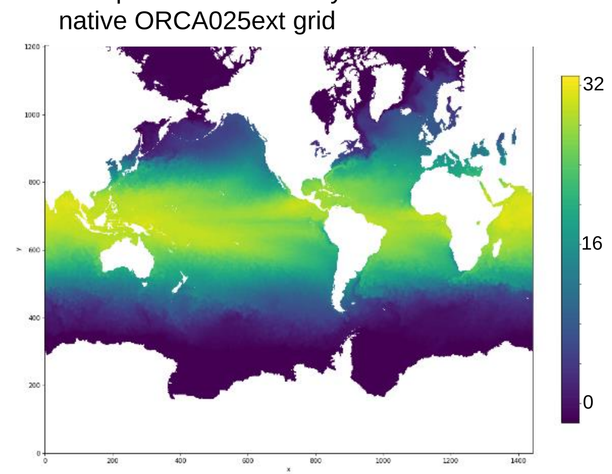
3D experiments were done using a modified version of the FOAM[3] operational ocean system:

- NEMO[1] Vn3.6 ocean model
- ORCA025ext ¼ degree resolution model grid, 75 vertical levels
- 3DVar NEMOVAR[2] data assimilation.
- Fluxes taken from the Met Office NWP atmospheric model.

Unlike in the operational version of FOAM, we only assimilated SST observations in the tests described in this poster. All other parameters were the same as FOAM.

All runs discussed in this poster started in February 2015, with results presented valid for March 2015.

Snapshot of surface temperature from the operational FOAM system on the native ORCA025ext grid



(E) Filtering the mixed layer.

Given the description given in panel (B), it is expected that having a temporally smoothed mixed layer will reduce the bias that has been found.

This has been tested in both 1D and 3D by temporally filtering the mixed layer depth seen by the assimilation (the true mixed layer was unchanged). Filtering was done using a forward pass exponential filter which has the form:

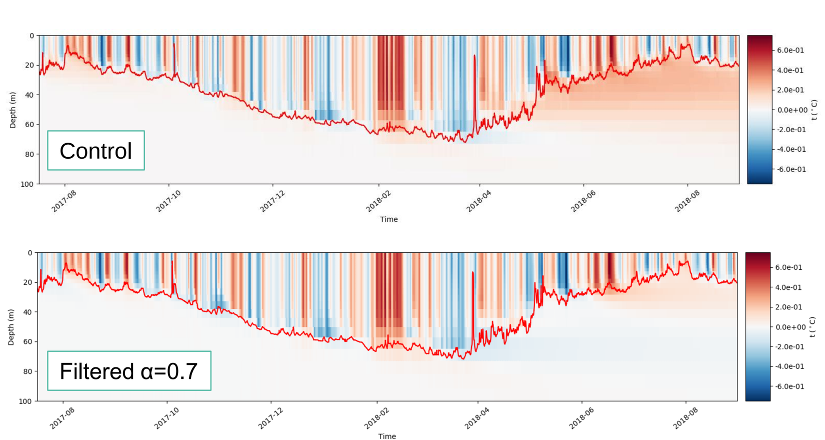
$$\bar{M}_t = \alpha M_t + (1-\alpha)\bar{M}_{t-1}$$

$\bar{M}_t$:- Mean mixed layer at time-step t
M_t:- Mixed layer at time-step t
α:- Weighting factor, must be between 0 and 1.

After numerous 1D experiments a value of α=0.7 (corresponding to a time-scale of 2.8 days) was found to give the best results

1D

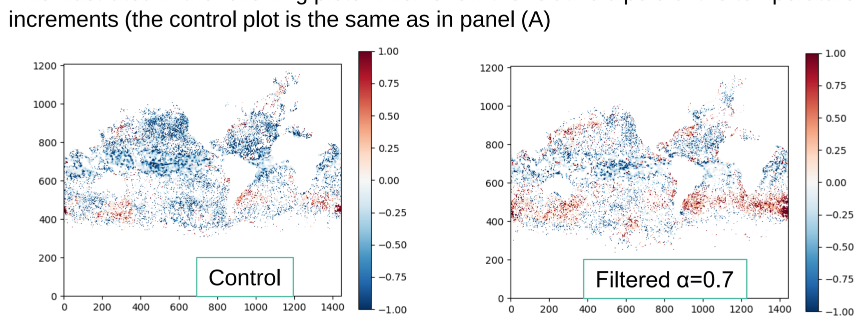
Filtering in 1-D worked well, reducing the biases below the mixed layer. This is seen in the plots below, which show the difference to the truth



3D

Unfortunately, in 3D filtering the mixed layer reduced the positive biases, but at the cost of increasing the negative biases.

This illustrated in the following plots which show the relative dipole of the temperature increments (the control plot is the same as in panel (A)



It is not clear why this has happened, but may be due to model biases that were not simulated in the 1D case.

(F) Balancing salinity to minimise the density gradient change.

Another possibility is preventing the assimilation changing the density gradient (and thus the mixed layer) by compensating for temperature gradient changes by applying increments to salinity.

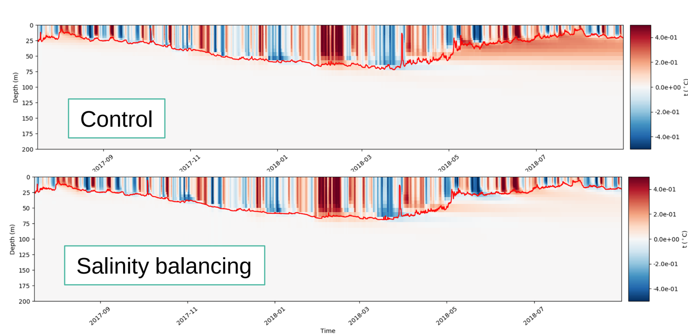
After a number of 1D experiments it was found that balancing the temperature gradient between 0.7 and 1.3 times the mixed layer depth worked well. Note that this necessitated adding a constant salinity increment shallower than 0.7 times the mixed layer depth to prevent adding an artificial density gradient in the near surface.

All density calculations were performed using a linearised equation of state.

1D

As expected, using salinity balancing significantly reduced the biases in temperature.

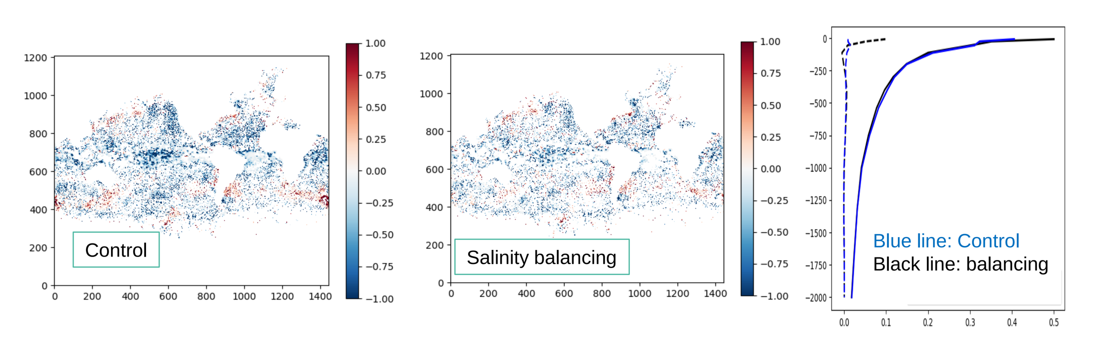
However, salinity is degraded (not shown).



3D

Unlike the filtering method, minimising the change in the density gradient reduces dipolar structures in the increments everywhere.

Unfortunately, salinity is significantly degraded. This is shown on the 3rd plot below, which shows the RMS (solid lines) and bias (dashed lines) between the model and unassimilated salinity profiles.



(G) Future work

So far, no method tested has been shown to reduce the bias problem without degrading other aspects of the system.

Ensemble data assimilation provides a means to remove the parameterised length scale described in panel B. Thus, it is planned to investigate if ensemble DA can reduce the bias problem.

Explicitly controlling the evolution of the mixed layer with the data assimilation is another possibility to be investigated.

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References

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