Ocean data assimilation of profile data on density levels in FOAM

Daniel Lea[1], Keith Haines[2], Greg Smith[2] and Matt Martin[1]

[1] UK Met Office
[2] ESSC, Reading University

We modify the UK Met Office FOAM (NEMO) OI ocean data assimilation system to assimilate profile data (including Argo) on density levels. The model background field is converted to spiciness on a set of specified density levels and the depths of those density levels are calculated. The profile observations are also converted to spiciness and density level depth for the same set of specified density levels. We perform two analyses, first of spiciness on density levels with the data being spread over large spatial scales, and second of density level depth with smaller spatial scales. The order of the analyses is not important. The resulting increment fields are converted back to temperature and salinity on model z-levels. The results of this are compared to the standard FOAM assimilation on z-levels over a 1 year period assimilating the same observations.

The model used in the assimilation is a 40 level NEMO version of the 1/3 degree North Atlantic FOAM system run at the Met Office. The spiciness definition is a simplified function of temperature and salinity which is designed to be orthogonal to density, $\pi = 3[T/20 + S/10]$ (units kg m^{-3}).

Part 1 introduces density level assimilation with the assimilation of one profile observation. In part 2 we assimilate multiple observations and use the PV filter to control the spreading of information across fronts. Part 3 shows the results of running the density level assimilation system for 1 year compared to the z-level assimilation system. In part 4 we use the Hollingsworth and Lönnberg (1986) method to try to improve the error covariances.

1. Assimilation of one profile observation

To test the density assimilation system we assimilate a single Argo profile observation. To do this both the observation temperature and salinity are converted to spiciness on specified density surfaces, $\pi(\rho)$, and the depth of those surfaces, $z(\rho)$, is calculated by linear interpolation. This takes advantage of a natural split between slow water mass changes in $\pi(\rho)$ and faster changes in $z(\rho)$. The assimilation analysis is performed in density level space so the increments spread along density surfaces. There are 101 evenly spaced density levels ranging from 1021 kg m^{-3} to 1031 kg m^{-3}.

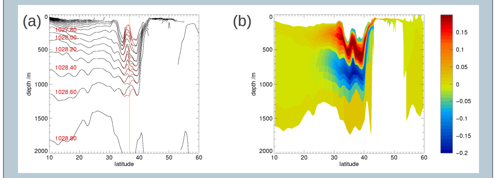

Fig 1: South – North section at 52.3°W. (a) Assimilation of density level depth. The density levels before assimilation are shown as black lines and after assimilation in red. Only every second density level is plotted. The yellow line shows the observation location (36.8°N, 52.3°W). (b) Assimilation of spiciness on the background density surfaces. Correlation widths are 60 km and 400 km for $\pi(\rho)$ and $z(\rho)$ respectively.

The assimilation increments must be converted back to temperature and salinity on z-levels to be inserted into the model.

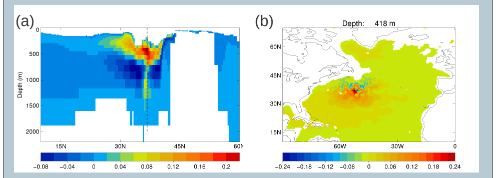

Fig 2: Results of converting the increments in Fig 1 back to z-levels. (a) South – North section at 52.3°W of salinity increments (psu). Note the contribution of large scale spiciness changes and the local effect of the change in the density level are of opposite signs at ~1000 m. (b) Increment of salinity at 418 m (model level). The structure of the increment reflects the background density structure.

2. Potential vorticity filtering

It is generally advantageous to spread spiciness information over large distances along density surfaces in most cases, except in regions such as the Gulf Stream where the potential vorticity (PV) gradient is high. Therefore, we introduce a dependence on the PV gradient into the horizontal recursive filter which spreads the increments. This is implemented by reducing the correlation width where the PV gradient is high, where PV is defined as $f\Delta\rho/\Delta h$, f is the Coriolis parameter and h is the density layer thickness. The width is proportional to 1+k(grad.PV) with the widths in the x and y directions treated separately. The k value ($k=10^{12}$ kg^{-1}m^{5}s) is tuned to give a range of correlation widths typically from 400 km to 40 km.

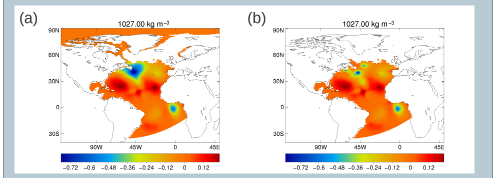

Fig 3: Increments of spiciness on a density surface with (a) no PV filtering and (b) with PV filtering. The spreading of the increments is much reduced near the Gulf Stream while elsewhere it is largely unaffected.

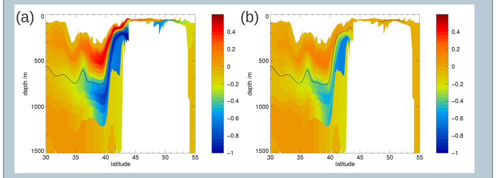

Fig 4: South – North section at 52.3°W. (a) no PV filtering and (b) with PV filtering. The solid line shows the 1027 kg m^{-3} density surface (see Fig 3). With the PV filter the negative spiciness increment which propagated onto the shelf (where the spiciness is already low) no longer does so. The increment size is reduced elsewhere because the increments from nearby observations are spread less far.

3. Comparison of z-level and ρ-level assimilation

The ρ-level assimilation gives better results near the surface (at low density) but worse results at depth. There are fewer observations at low density, therefore on average the z-level assimilation gives the best results. This is surprising given that density level assimilation should be more physically realistic than z-level assimilation. One possibility is that the background and observation variances for the preliminary ρ-level assimilation are quite crude. In contrast, the z-level covariances have been developed and tuned over a number of years. Initial estimates of the background variance of the spiciness were assumed to be 1 everywhere which may be too high. The spiciness observation errors were calculated from the z-level errors and are approximately 0.1. We can use this initial integration to improve the results using the Hollingsworth and Lönnberg method (1986). See section 4.

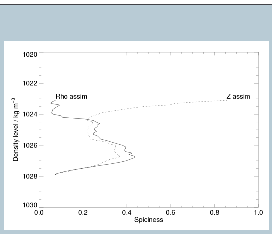

Fig 5: Observation minus background RMS of spiciness on density levels. Comparing z-level and ρ-level assimilation.

4. Calculating error covariances

The Hollingsworth and Lönnberg (1986) (HL) method is a standard way to improve the background error and estimate the observation error (including represention error). It was used in the original FOAM system – the difference here is that we examine spiciness and density level instead of salinity and temperature. HL requires an initial assimilation run which produces the background values at the observation locations. Then the covariance of observation minus background (O-B) values are plotted and a covariance (SOAR) function is fitted. The improved correlation scales and variances can be used in a subsequent assimilation.

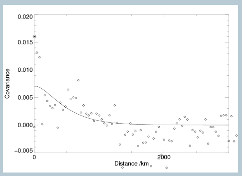

Fig 6: Covariance of O-B (excluding the Gulf Stream region) in 40 km bins (diamonds). The solid line shows the fitted SOAR function with a width of ~300 km and peak value of 0.007. The star shows the variance of O-B (0.016). The difference between the variance and peak value is the estimated observation error (0.009).

Spatially varying background variances can be found by binning the results in 10 by 10 degree bins. Getting stable statistics is difficult due to the relative sparseness of profile data. Assuming a uniform correlation width (400 km) gives reasonable variance results, however. The main result is that the spiciness background error is much lower than that used previously.

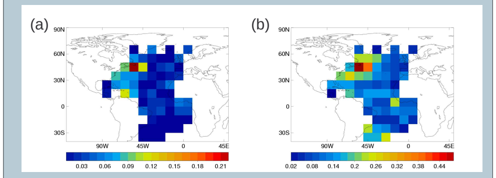

Fig 7: (a) Spiciness background variance estimate using the HL method. (b) Spiciness observation error estimate.

Given the difficultly in obtaining stable statistics another method of calculating covariance statistics may be required, for example the NMC method, to complement HL (not yet done). A run with statistics calculated from the above HL only analysis produced little improvement on the results in section 3. Further investigation is planned on how to improve the results. I have developed an IDL program (“dataplot”) to examine the observation and model values which may help identify potential problems.

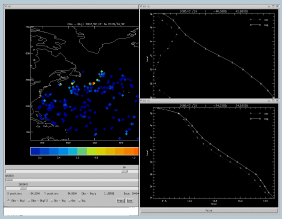

Fig 8: Example screenshot of “dataplot”. Shows a map of observation minus background values. Overlaid are selected profile plots of observation and background values.

5. Discussion

- A system of assimilating observations on density surfaces has been developed. This has the potential to improve the horizontal spreading of observation information.
- The background and observation errors may need further improvement, however, to gain maximum advantage from this assimilation method.
- The FOAM system has been transitioned to a ¼ degree ORCA025 configuration. Experiments with density level assimilation are planned using the observation operator framework with this new system.

Reference

Hollingsworth, A. and P. Lönnberg, 1986. The statistical structure of short range forecast errors as determined from radiosonde data. Part I: The wind field., *Tellus*, **38A**, 111-136.

Ocean Forecasting Research and Development
Met Office FitzRoy Road Exeter Devon EX1 3PB
United Kingdom
Tel: +44 (0)1392 884854 Fax: +44 (0)1392 885681
Email: daniel.lea@metoffice.gov.uk