An Optimal Ensemble Interpolation Scheme for Assimilation of Argo Profiles into HYCOM

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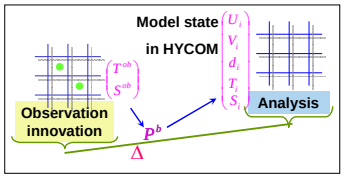
Problems with the Straightforward EnOI Scheme

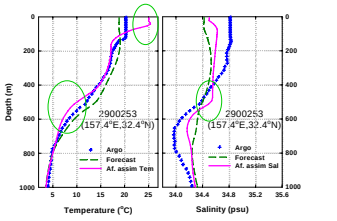
EnOI: $A' = (A - \bar{A})$ $\quad P^b = \alpha A' A'^T/(N-1)$ $\quad K = P^b H^T (H P^b H^T + R)^{-1}$

$$X^a = X^f + K(Y^o - HX^f)$$



Sketch of analysis with straightforward scheme

An example using the straightforward EnOI scheme at Argo float: 2900253



EnOI analysis:

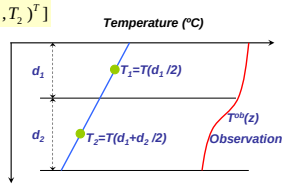
$$(d_1^a, d_2^a, T_1^a, T_2^a)^T = (d_1, d_2, T_1, T_2)^T + K[(T^{ob}(z))^T - H(d_1, d_2, T_1, T_2)^T]$$

Optimal analysis:

$$X^a = Arg^{-1} J(X):$$
$$= (X - X^b)^T P^{b-1} (X - X^b) + (Y^o - HX^b)^T R^{-1} (Y^o - HX^b)$$

Strong nonlinear Observation operator

$$H(d_1, d_2, T_1, T_2) = [T_1(d_2 + 2d_1 - 2z) + T_2(2z - d_1)]/(d_1 + d_2)$$



Only one iteration cannot assure its optimality.

New EnOI Scheme for Argo Profiles

i) **Converting Argo profiles into the observations at model layers.**

ii) **Assimilating the "observed" thickness, and only adjusting the model states as current components and layer thickness.**

$$(d_1^a, d_2^a, ,)^T = (d_1, d_2, ,)^T + K[(d^{ob}(i))^T - H(d_1, d_2, ,)^T]$$

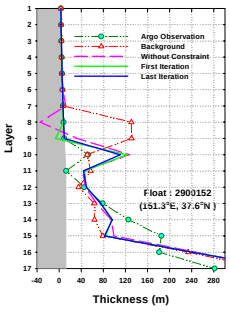
iii) **Reanalyzing the layer thickness with minimal thickness constraint as Thacker(2007)**

iv) **With fixed layer thickness, respectively assimilating the "observed" temperature and salinity, and only adjusting itself.**

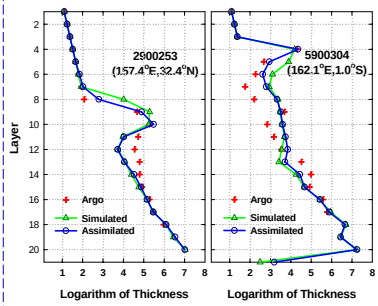
$$(, , T_1^a, T_2^a)^T = (d_1^a, d_2^a, T_1, T_2)^T + K[(T^{ob}(i))^T - H(d_1^a, d_2^a, T_1, T_2)^T]$$

Now, the observation operator is uncorrelated with layer thickness so that it can ensure the final optimality.

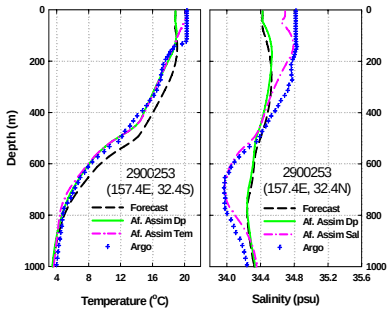
An Example with Constraint Analysis for Thickness



Examples of Analyzed Layer Thickness



Example of applying the new EnOI scheme at float: 2900253



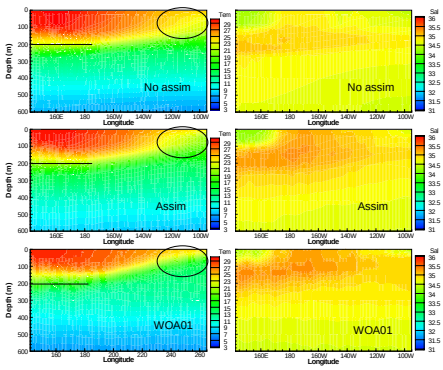
Continuous assimilation experiments in Pacific

HYCOM Model

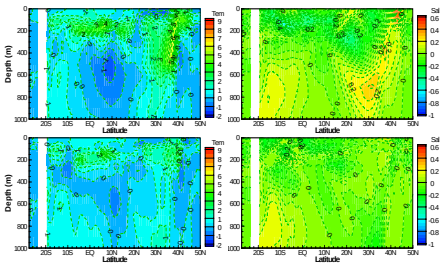
Domain: 95ºE~70ºW, -28ºS-52ºN; Horizontal: 42~72 km; Vertical: 22 layers, potential density from 18.0 to 28.84; Forcing: ECMWF with 6h; Lateral boundary: GDEM relaxation

Table 1 summary of experiment design

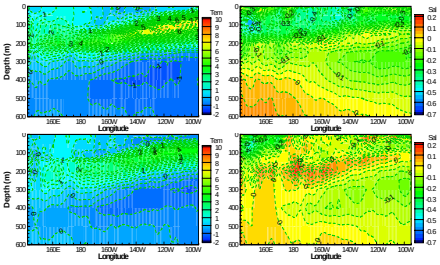
Expt.	Running time	Assim. window	Influence radius (km)	Horizontal Localization	Vertical Localization	Output Forecast
No_assim	1 year	-	-	-	-	Every 3 days
Assim	1 year	3 days	800	Yes	No	Every 3 days
Assim_local	1 year	3 days	800	Yes	Temp, Salt	Every 3 days



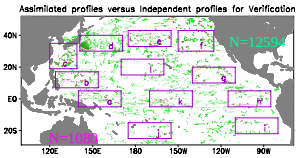
Maps showing mean Temp (left) and Salt (right) along Equator over 2004: no assim, assim, and WOA01.

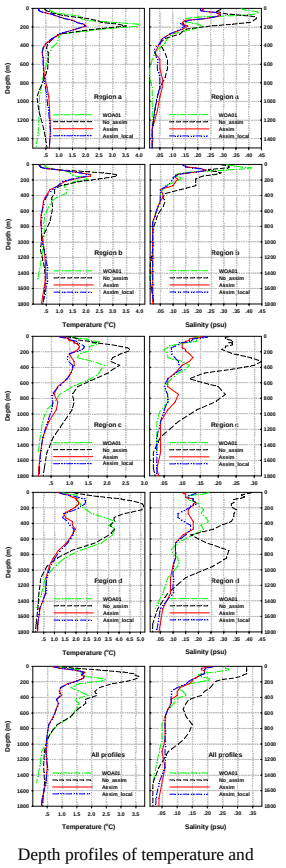


The difference of mean Temp (left) and Salt (right) along 165ºE over 2004 between: no assim (top), assim (bottom) and WOA01.



The difference of mean Temp (left) and Salt (right) along Equator over 2004 between: no assim (top), assim (bottom) and WOA01.





Depth profiles of temperature and salinity RMSEs for no assim (Black), assim (Red) and assim_local (Blue), and climatolgy (WOA01, green).

Conclusions

- **Using the straightforward EnOI scheme may result in some problems which are related with the layer thickness as model variable in HYCOM.**
- **To overcome this problem, a new EnOI scheme is proposed: first assimilate the layer thickness and adjust the model variables as thickness, velocity components, then the temperature and salinity are respectively assimilated. Its validity is checked by single points experiment.**
- **Continuous assimilation experiment in 2004 suggests that the model states in upper ocean can be remarkably improved by Argo profiles using this EnOI scheme.**

Reference

1.Bertino L., G. Evensen and H. Wackernagel, 2003: Sequential data assimilation techniques in oceanography. *International Statistical Review*, V. 71, No 1, pp. 223-242.

2.Bleck, R., 2002: An Oceanic General Circulation Model Framed in Hybrid Isopycnic-Cartesian Coordinates. Ocean Modelling, 4, 55-88.

3.Chassignet, E.P., Hurlburt, H.E., Smedstad, O.M., Halliwell, G.R., Hogan, P.J., Wallcraft, A.J., Baraille, R., Bleck, R., 2007: The HYCOM(Hybrid Coordinate Ocean Model) data assimilative system. *J. Marine. Syst.*, 65, 60-83.

4.Evensen, G., 1994: Sequential data assimilation with a nonlinear quasi-geostrophic model using montecarlo methods to forecast error statistics. J. Geophys. Res., 99, 10143-10162.

5.Evensen, G., 2003: The ensemble Kalman filter: theoretical formulation and practical implementation. Ocean Dynamics, 53, 343-367.

6.Gaspari, G., Cohn, S.E., 1999: Construction of correlation functions in two and three dimensions. Q. J. Roy. Met. Soc., 125, 723-757.

7.Hamill, T.M., Whitaker, J.S., Snyder, C., 2001: Distance-dependent filtering of background error covariances in an ensemble Kalman Filter. Mon. Weath. Rev., 129, 2776-2790.

8.Houtekamer, P.L., Mitchell, H.L., 2001: A sequential ensemble Kalman filter for atmospheric data assimilation. Mon. Weath. Rev., 129,123-137.

9.Mitchell, M.J., Houtekamer, P.L., Pellerin, G., 2002: Ensemble size, balance, and model-error representation in an ensemble Kalman filter. Mon. Weath. Rev., 130, 2791-2808.

10.Oke, P.R., Brassington, G.B., Griffin, D.A., Schiller, A., 2008: The Bluelink ocean data assimilation system (BODAS). *Ocean Modelling*, 21, 46-70.

11.Oke, P.R., Sakov, P., Corney, S.P., 2007: Impacts of localization in the EnKF and EnOI: experiments with a small model. *Ocean Dyn.*, 57, 32-45.

12.Thacker, W.C., 2007: Data assimilation with inequality constraints. *Ocean Modelling*, 16, 265-276

13.Thacker, W.C., Esenkov, O.E., 2002: Assimilating XBT data into HYCOM. *J. Atmos. Oceanic Technol.*, 19, 709-724