Ensemble Estimation of Background-Error Variances in a Three-Dimensional Variational Data Assimilation System for Global Ocean Analysis

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Objective

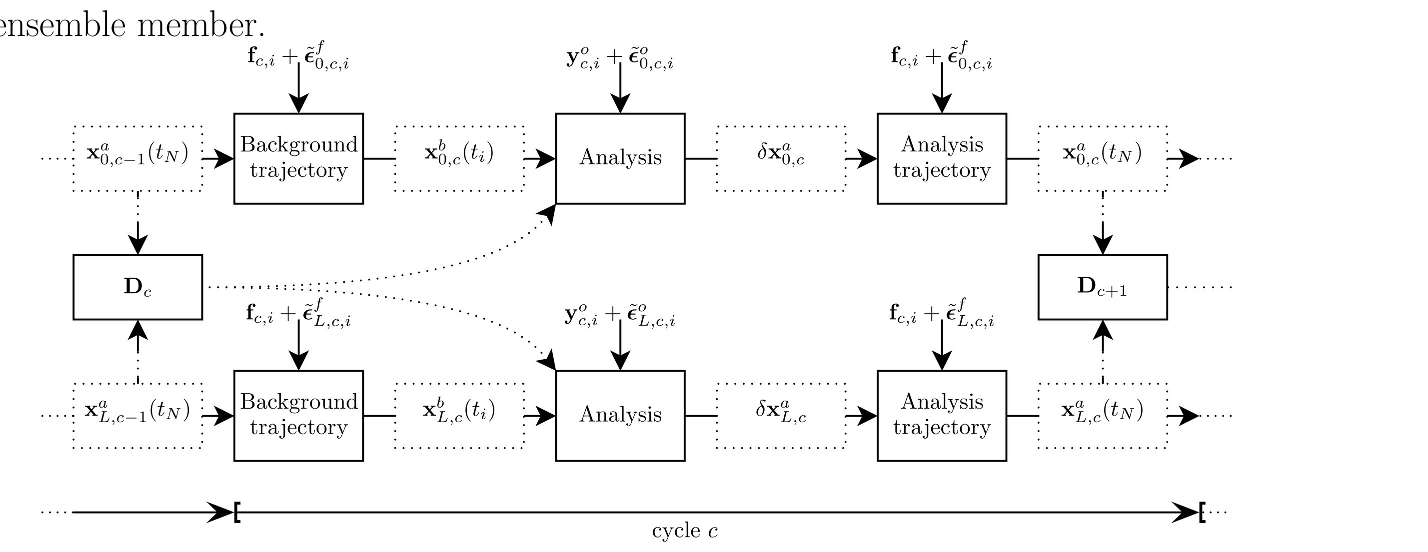
- This study aims at testing the senstivity of global ocean analyses to two flow-dependent formulations of the background-error standard deviations (σ^b).
  - The first formulation employs an empirical parameterization of σ^b in terms of the vertical gradients of the background temperature and salinity fields (experiment **B1R2**).
  - The second formulation derives σ^b from the spread of an ensemble of analyses (experiment **B2R2**).
  - Reference experiments include one without data assimilation (**CTL**) and one that employs the parameterized σ^b but an alternative observation-error standard deviation (σ^o) formulation (**B1R1**).

The Assimilation System and Experimental Design

- The ocean model is the global ORCA2 configuration of OPA8.2 (Madec *et al.* 1998).
- The assimilation method is a multivariate 3D-Var version of OPAVAR (Weaver *et al.* 2005).
- The data are quality-controlled temperature and salinity profiles from EN2v1 (Ingleby and Huddleston 2007).
- The observation-error variances are estimated using the Fu *et al.* (1993) method.
- The surface forcing fields are derived from ERA40 (Uppala *et al.* 2005).
- The experimental design follows the common procedures used in the ENSEMBLES and ENACT projects (Davey *et al.* 2006).
- The experiments are performed for the period 1 January 1993 to 31 December 2001, using a 10-day assimilation cycle.

The Ensemble 3D-Var Cycling Procedure

- On each 3D-Var cycle, an analysis increment ($\delta\mathbf{x}^a$) for temperature, salinity, SSH and horizontal velocity is computed and used to update the model background trajectory.
- In the ensemble 3D-Var, the model integration and analysis increment computation are done separately for each ensemble member.



- A 9-member ensemble is produced by perturbing the surface forcing fields (heat flux, fresh-water flux, wind-stress), the profile observations and the background state.
  - The forcing perturbations are derived from different forcing products (Balmaseda *et al.* 2008).
  - The observation perturbations are Gaussian with covariance matrix $\mathbf{R}$.
  - The background state is perturbed implicitly via the cycling procedure.
- The sample variance matrix computed from ensemble differences is used to update the background-error variance matix ($\mathbf{D}$).
- A 90-day sliding window is used to reduce sampling error, giving an effective ensemble size of 81 on each cycle for estimating $\mathbf{D}$.

Results: Assimilation Statistics I

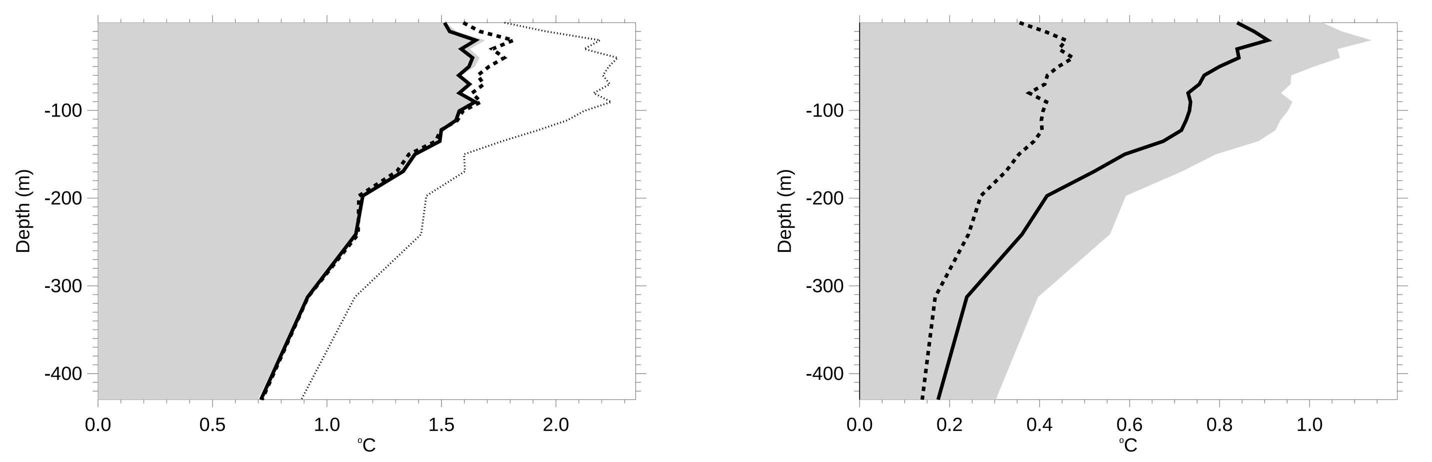
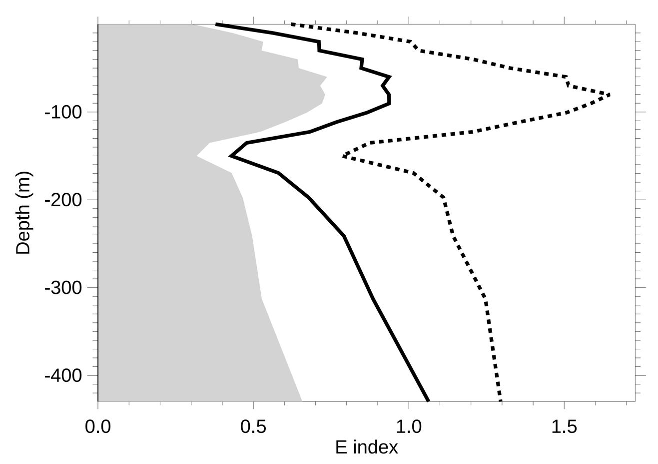


Fig. 1: Vertical profiles of the 1994-2000 global mean standard deviation of the innovation ($\mathbf{d}$; left panel) and root-mean square of the analysis increments ($\mathbf{H}\delta\mathbf{x}^a$; right panel) for temperature in B1R1 (grey shade), B1R2 (solid) and B2R2 (dashed). The thin-dotted curve (left panel) is $\mathbf{d}$ for CTL.



An "efficiency" (E-)index:

$$E = \frac{\mathrm{rms}(\mathbf{d}_{\mathrm{CTL}}) - \mathrm{rms}(\mathbf{d})}{\mathrm{rms}(\mathbf{H}\delta\mathbf{x}^a)}$$

$$= \frac{\text{10-day forecast error improvement wrt CTL}}{\text{work done by assimilation method}}$$

Fig. 2: Temperature E-index for B1R1 (grey shade), B1R2 (solid) and B2R2 (dashed).

Results: Assimilation Statistics II

- The innovations and analysis increments generated by the data assimilation system can be used to diagnose *a posteriori* the covariances of observationn and background error (Desroziers *et al.* 2005).

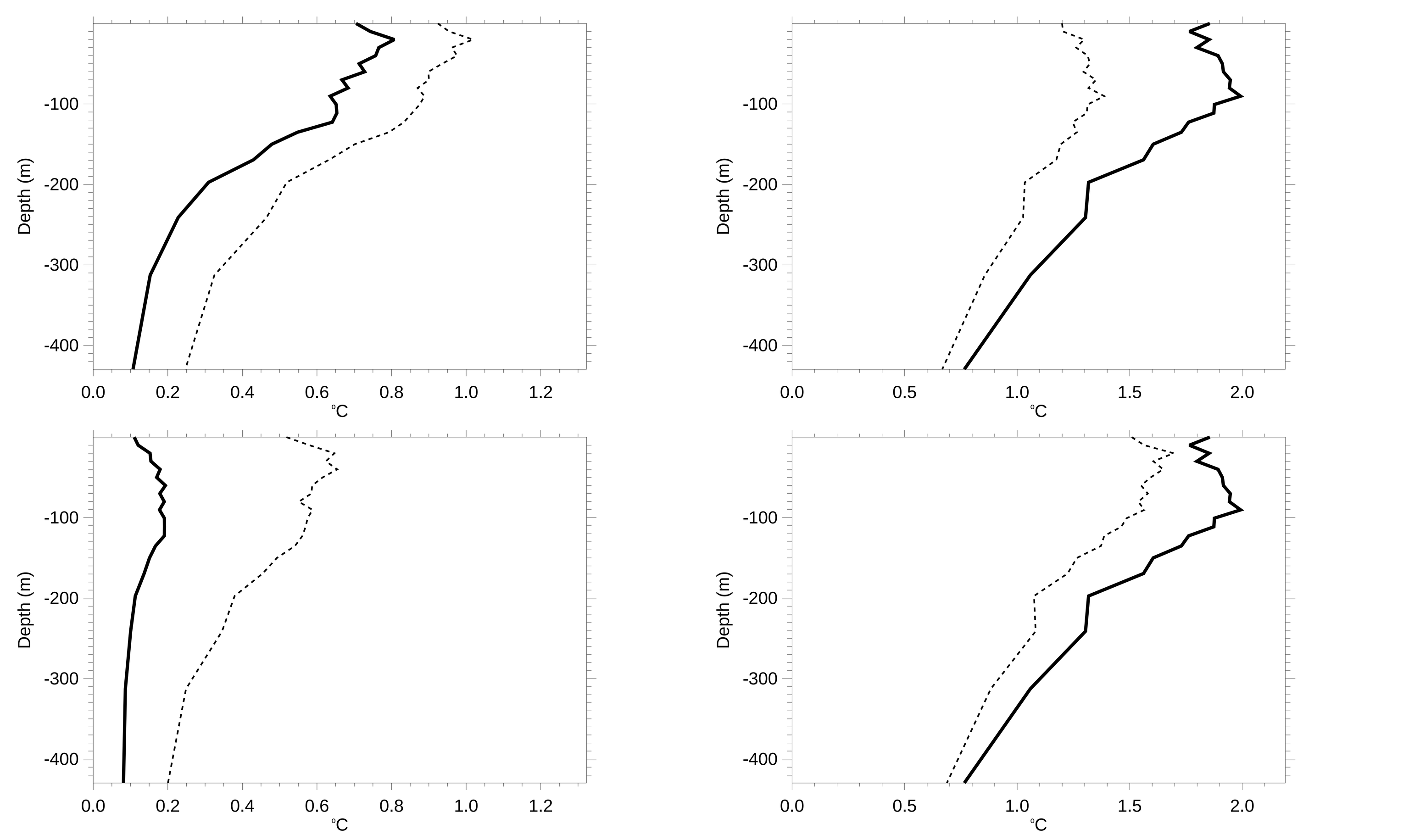


Fig. 3: Vertical profiles of σ^b (left panel) and σ^o (right panel) for temperature in B1R2 (upper panels) and B2R2 (lower panels). Solid curves correspond to the σ^b and σ^o that were *specified* in the assimilation experiment; dashed curves correspond to the σ^b and σ^o that were *diagnosed a posteriori*.

Results: Independent Data Comparisons

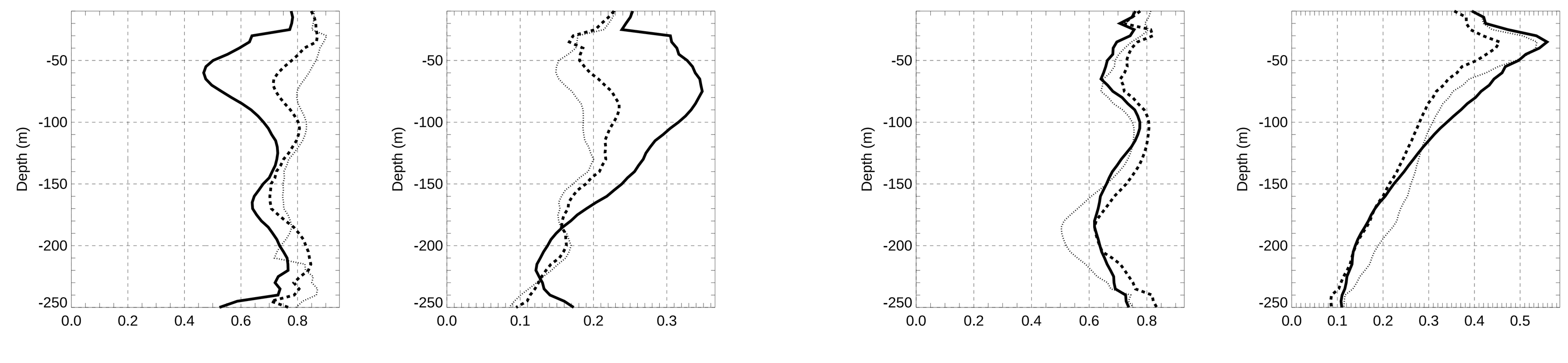


Fig. 4: Correlation (panels 1 and 3) and rms error (m s^{-1}; panels 2 and 4) between equatorial zonal currents from TAO data and those from CTL (dotted), B1R2 (solid) and B2R2 (dashed) over the 1993-2000 period at 165°E (panels 1 and 2) and 110°W (panels 3 and 4).

	NW.EXTROP.ATL		NINO3.4	
Experiment name	Correlation	Rms error (m)	Correlation	Rms error (m)
CTL	0.97	0.012	0.98	0.022
B1R1	0.62	0.040	0.99	0.012
B1R2	0.73	0.033	0.99	0.012
B2R2	0.87	0.023	0.99	0.013

Tab. 1: Correlation coefficient and rms error (in metres) in the northwest extratropical Atlantic (75°W-40°W, 30°N-60°N) and NINO3.4 region of the tropical Pacific (170°W-120°W, 5°S-5°N) between SSH anomalies from T/P data and those from the model in the various experiments.

Summary and Future Directions

- Both the parameterized and ensemble σ^b formulations produce a significant reduction in the rms of the innovations, with the parameterized σ^b slightly better above 150 m.
- The ensemble σ^b analyses are better "balanced" and closer to independent data than those produced with the parameterized σ^b.
- Statistical consistency checks suggest that the ensemble σ^b are underestimated and the σ^o are overestimated. The parameterized σ^b are also underestimated but to a lesser extent.
- The ensemble method will be improved by including explicit model-error perturbations.
- The ensemble method will be used to estimate background-error correlation length scales as well as variances.

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