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**Objectives:** Evaluate Ensemble Variational Assimilation (EnsVAR) as a Bayesian estimator in nonlinear non-Gaussian situations. Numerical experiments of the twin type are performed on two small dimension chaotic systems. Comparison is made with the Ensemble Kalman Filter (EnKF) and the Particle Filter (PF).

**Main results:**
A number of identical-twin strong-constraint experiments have been performed on the 1996-Lorenz system. Since the Bayesian character of an ensemble, considered as a sample of a probability distribution, cannot be objectively checked, the weaker property of reliability (statistical consistency between predicted probabilities and observed frequencies) has been used instead.

A first series of experiments has been performed for reference purposes in a linear and Gaussian case, where theory says that EnsVAR is exactly Bayesian. Results obtained in the nonlinear (and/or non-Gaussian) case show as good a performance as in the case of exact Bayesianity. When assimilation is performed over long windows (up to 4 times the predictability time of the system as defined by the dominant Lyapunov exponent), it is necessary to resort to the **Quasi-Static Variational Assimilation** (QSVA), in which the length of the assimilation window is gradually increased (Fig. 1).

Similar results have been obtained with the Kuramoto-Sivashinsky equation. Comparison with EnKF and PF shows that EnsVAR produces results which are at least as good as those obtained with those two algorithms, and the more so in the forecast phase that follows the assimilation proper.

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Figure 1. Performance of strong-constraint EnsVAR on the 1996-Lorenz system, with an 18-day assimilation window. Top left: real and estimated (30 estimates) initial conditions (one set of observations). Top right: real and estimated temporal evolution of the model variable at three grid-points (id.). Middle row: statistical diagnostics of reliability; left: rank histogram (reliability implies a flat histogram; right: reliability diagram (reliability implies that diagram lies on the diagonal). Bottom left: Brier scores (reliability implies small value for quantity shown on the lower curve). Bottom right: estimation error along the assimilation window (dotted horizontal line shows magnitude of errors in observations).
Weak-constraint experiments have been performed in which the assimilating model is affected by errors. Because of the regularizing effect of the model error term in the objective function to be minimized, QSVA is no longer necessary, even over long assimilation windows. Otherwise, the results are globally very similar to those of the strong-constraint case (Fig. 2).

Figure 2. Diagnostics for the weak-constraint case, with an 18-day assimilation window (diagnostics performed on last 13 days of the window). Rows from top to bottom: rank histogram, reliability diagram, Brier score respectively. Columns from left to right: performance of EnsVAR, EnKF and PF respectively. The rank histogram shows a clear advantage for EnsVAR.

Future of the project: Experiments are now performed in a shallow-water oceanic model.

Publications

10 presentations in various meetings, including three invited ones, and one presentation in a Summer School.


O. Talagrand, Summer school on Uncertainty Quantification for Applied Problems, Basque Center for Applied Mathematics and Universidad de Valladolid, Bilbao, Spain, July 2016 (with M. Jardak).