Block methods for solving an ensemble of data assimilations

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In numerical weather prediction systems, the initialization of the state is made through data assimilation, which determines the best initial state of the atmosphere using notably a background state (a previous short range forecast) and a set of observations. This implies an accurate representation of background error statistics, which can be estimated by running Ensembles of variational Data Assimilations (EDA). This consists in a set of data assimilation experiments with perturbed backgrounds and observations, and also allows to initialize ensemble prediction systems. Running EDA leads to the minimization of a set of cost functions. However, these systems have very large dimensions (state vector size around 10^8 together with 10^4 – 10^5 assimilated observations for the limited area model of Météo France, AROME-France), so the computational cost of EDA generally limits the ensemble size.

We propose a new class of algorithms for speeding up the minimizations of an EDA. It consists in using block Krylov methods to perform simultaneously the minimization for all members of the ensemble, instead of performing each minimization separately. We have developed preconditioned block versions of the Full Orthogonal Method both in primal and in dual spaces. The latter works in observation space that is usually of smaller dimension than the state space, giving thus an advantage in terms of memory requirements and computational cost. Those developments have been implemented in the Oriented Object Prediction System (OOPS), a framework for data assimilation implementations developed by the European Centre for Medium-Range Weather Forecasts, Météo France and their partners. Parallelization strategies have also been developed for accelerating the minimization and limiting the amount of communications.

These algorithm has been applied to the EDA system of AROME-France, both in its standard version (1 – 25 members) and in an extended version simulating future instrumental and computational developments (1 – 75 members, 10^5 – 10^6 observations). The experiments performed show that the number of iterations needed to converge is drastically reduced when using the block Krylov approaches, with a relative further reduction when the condition number of the Hessian of the problem increases. Moreover, working in dual space allows to reduce the computational time of the minimization by a factor of 1.5 – 3 (with 25 members) compared to non-block methods, making our approach attractive for operational use.