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Efficient Computation of Matrix-vector Product in Data Assimilation

Recent studies have shown that some high-resolution remote-sensing observations exhibit spatial error-correlations, so the observation error covariance matrix should not be a diagonal matrix, but a dense matrix with nonzero off-diagonal entries. In this case, the multiplication of the inverse of this matrix with a vector in the solution of the variational minimization problem may be much more time-consuming, particularly if the parallel computation of the matrix-vector product requires a high degree of communication between CPUs. Efficiently computing this matrix-vector product is important if we want to assimilate a large volume of observational data within a short time interval, for example, when forecasting on convection-permitting scales. To this end, we apply a fast multipole method (FMM) to speed up the computation. The method improves the efficiency in two aspects. Firstly, it reduces the computational complexity. The direct computation of the matrix-vector product requires n^2 operations, with n being the number of observations, whereas by using the FMM we need $\mathcal{O}(n)$ works. Secondly, the FMM requires a low degree of communication between CPUs when we perform parallel computation. We explore a particular type of FMM that uses a singular value decomposition (SVD) and can be applied to any choice of observation error covariance matrix. We show that it can compute the matrix-vector product with a good accuracy, using only a few multipole terms. Moreover, reducing the condition number of observation error covariance matrix using appropriate reconditioning methods can improve the accuracy. In this study, we have shown the potential use of a well-known numerical technique to speed up the computation of matrix-vector products in data assimilation.

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