Multigrid Beta Filter Scheme for Modeling Background Error Covariance in 3DRTMA

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1. Parallel multigrid beta filter

This report describes a novel technique for modeling of the background error covariance that is under development at EMC.

Until now, the data assimilation system at EMC was using recursive filters (RF) (e.g., Wu *et al*., 2002; de Pondeca *et al.*, 2011) as a quasi-Gaussian approximation of covariances. Despite some nice properties, RF are essentially sequential operators, exceedingly difficult to successfully parallelize, preventing them to scale well with an increasing number of processing elements.

The Three-Dimensional (3D) Real-Time Mesoscale Analysis (RTMA) system is a project with the goal to provide analyses at remarkably high horizontal resolutions (~2.5 km) at frequent time intervals (~15 min). For the success of such computationally demanding enterprise, the key prerequisite is a vastly improved efficiency, in which scenario the RF represents one of the main hurdles.

Our solution to this problem is the development of a new filter based on the beta distribution, incorporated within a parallel multigrid structure (MGBF).

The new technique has ability to better describe covariances across various scales, to include cross-correlations and to provide negative side lobes, which realistic covariances may possess. Most importantly, the beta filter has a finite support and is therefore more readily parallelizable, which should yield much better scaling.

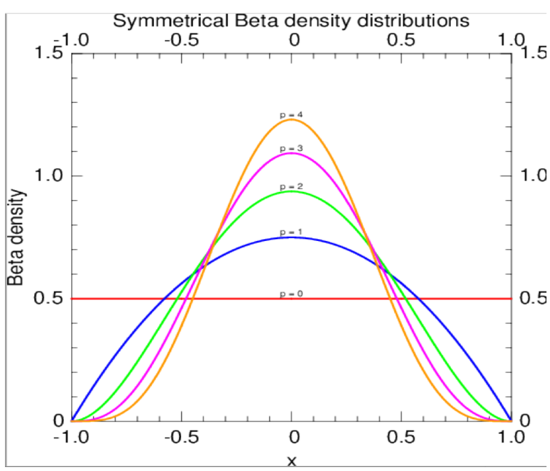

Fig. 1: Examples of beta filter (From Purser *et al.* 2021).

The multigrid method is usually used for solving of elliptic problems based on the idea that the solutions derived at lower and higher resolutions can be combined in an overall more efficient numerical scheme.

In our case, we apply the multigrid by simultaneously calculating quasi-Gaussian approximations by the beta filter over various spatial scales (grid generations), and then combining them together by giving appropriate scale weights to contributions from various grid generations.

An efficient version of the code is developed that allows integration over a wide range of domain decompositions among processing elements.

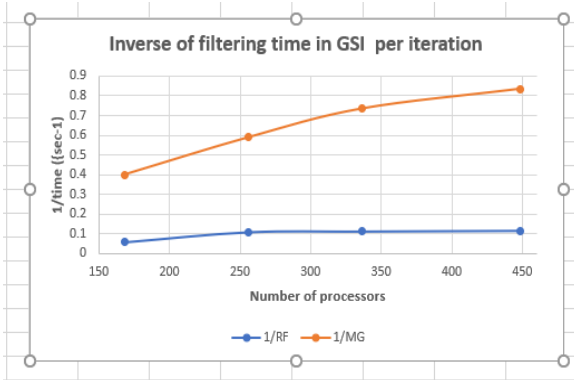

Fig. 2: Scaling derived in single observation tests with RF and MGBF in GSI (Rancic *et al.* 2021).

2. Preliminary test results

Preliminary scaling derived in a single observation test within GSI (Grid-point Statistical Interpolation), the present data assimilation system at EMC, are shown in Fig. 2. With the increase of number processors, MGBF keeps improving generally better performance, which RF cannot match any longer.

3. Concluding remarks

The MGBF is a multifaceted project, with many attractive features, such as:

- Generation of negative side lobes of covariances through application of a Helmholtz operator
- Introduction of a multivariate option
- Formulation of an efficient, line version of beta filter
- The code is generalized so that it can perform across a wide range of processor decompositions

A preliminary application in GSI confirms a potentially exceptionally large speed up in comparison to RF.

Plans for further development include:

- An updated definition of aspect tensor
- Formulation of a novel, computationally efficient technique for normalization of covariances
- Inclusion of a line version of beta filter
- Further exploration of the multivariate option
- Implementation of MGBF into the JEDI, a new data assimilation system, and formulation of a generalized version for the cubed sphere.

In addition, the line beta filter has a four-dimensional version which opens interesting possibilities for applications in nowcasting. A strategy for application of machine learning to judicially define MGBF scale weights is also formulated, in an effort to further polish estimate of the background error covariance.

References

De Pondeca, M. S., and Coauthors, 2011: The Real-Time Mesoscale Analysis at NOAA's Na-tional Centers for Environmental Prediction: Current status and development. Wea. Forecasting, 26, 593–612.

Purser, R. J., M. Rancic, and M. S. De Pondeca, 2021: The Multigrid Beta Function Approach for Modeling of Background Error Covariance in the Real Time Mesoscale Analysis (RTMA). Mon. Wea. Rev. (under review).

Rancic, M., R. J. Purser and M. Pondeca, 2021: Multigrid beta filter scheme for modeling background error covariance in 3DRTMA: Generalization, Helmholtz operator, and line filters. 25IOAS. 101thAnnual Meeting of American Meteorological Society, 9-15 January 2021.

Wu, W.-S., R. J. Purser, and D. F. Parrish, 2002: Three-dimensional variational analysis with spatially inhomogeneous covariances. Mon. Wea. Rev., 130, 2905–2914.