

Highly-Scalable Algorithms for Ensemble Data Assimilation

Jeffrey Anderson, Nancy Collins, and Helen Kershaw

*Institute for Mathematics Applied to Geophysics,
National Center for Atmospheric Research, USA, Email: jla@ucar.edu.*

A complete ensemble data assimilation algorithm can be composed into three basic computational tasks: advancing an ensemble of model forecasts, computing ensembles of forward operators for available observations, and assimilating the observations to modify the ensemble of model states. Each of these tasks requires a fundamentally different pattern of communication when implemented on current generation supercomputers.

Large geophysical forecast models are usually parallelized by decomposing the domain into a number of physically contiguous subdomains. Typically, communication is only to adjacent subdomains and is generally facilitated by associating a halo of redundant state variables around the boundaries of each subdomain. The ensembles are independent for the purposes of the forecasts, which makes their calculation embarrassingly parallel.

Computing the forward operators for in situ observations like a radiosonde temperature generally requires a spatial (and possibly temporal) interpolation between spatially contiguous state variables. The communication patterns here are similar to those required for the forecast. However, some observations, for instance a radio occultation phase delay, are functions of many state variables that span large distances in the horizontal and vertical, potentially far beyond any halo region. The communication required to compute these forward operators is not compatible with the haloed subdomains used for the forecast.

Finally, the assimilation requires two additional communication patterns. Sample means, variances and covariances must be computed for model state variables and observation priors, all of which require communication across different ensembles. In addition, information from each observation must be distributed so that all related state variables (most commonly those within a given distance) can be updated.

We begin by describing currently implemented algorithms in which global data transposes and broadcast communication are used to facilitate the different communication patterns [1]. Algorithms that avoid transposes for particular applications are also reviewed [2]. We then describe several novel algorithms that can avoid global transposes. The first will decompose the entire ensemble assimilation problem into a set of physically contiguous subdomains. A second will use data flow methods for the assimilation part of the computation. The computation, communication, and memory requirements of the existing and proposed algorithms as a function of model size, ensemble size, and processor count will be discussed. Implications for implementation on machines with computational accelerators will also be noted.

References:

- [1] Anderson, J. and N. Collins. "Scalable implementations of ensemble filter algorithms for data assimilation," *J. Atmos. Oceanic Technol.*, **24**, 1452–1463, 2007.
- [2] Wang, Y., Y. Jung, T. Supinie and M. Xue. "A Hybrid MPI/OpenMP Parallel Algorithm and Performance Analysis for an Ensemble Square Root Filter Designed for Multi-scale Observations," To appear in *J. Atmos. Oceanic Technol.*, doi: <http://dx.doi.org/10.1175/JTECH-D-12-00165.1>, 2013.