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Ensemble Kalman Filter for Open GGCM

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We identified the prognostic and diagnostic variables in OpenGGCM which are suitable for data assimilation and for which sufficient data are available. Specifically, we use the ionosphere oxygen ion (O+) density as a proxy for ionospheric electron (e-) density as the primary prognostic variable. The ionosphere potential, magnetic perturbations on the ground and in near space, and a subset of space based plasma data, such as DMSP precipitation and density data were identified as suitable diagnostic data for the data assimilation.

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Final report for AFOSR grant "Ensemble Kalman Filter for OpenGGCM"

The overall goal of the project is to combine the NCAR Data Assimilation Research Testbed (DART) with the OpenGGCM geospace model to produce a data assimilation capable geospace model. DART is a software framework that implements an Ensemble Kalman Filter (EnKF) and has been used with some 30 different models, mostly from the atmospheric and oceanic domains. OpenGGCM is the first magnetosphere-ionosphere ever to be combined with DART.

As an initial step, we identified the prognostic and diagnostic variables in OpenGGCM which are suitable for data assimilation and for which sufficient data are available. Specifically, these include the ionosphere oxygen ion (O+) density as a proxy for ionospheric electron (e-) density as the primary prognostic variable. The ionosphere potential, magnetic perturbations on the ground and in near space, and a subset of space based plasma data, such as DMSP precipitation and density data were identified as suitable diagnostic data for the data assimilation. Prognostic data can be used in the assimilation process to modify fields in the simulation. Diagnostic data serve to estimate how the simulation deviates from reality.

In order to couple OpenGGCM with DART, a number of technical issues were solved. Both OpenGGCM and DART run on massive parallel computers with 100s to 1000s of processes. Synchronization and data exchange occur through file exchange. We developed, or adapted, as appropriate, `netcdf` based protocols and implemented them. These were first put in place only for O+/e- assimilation of COSMIC data. Since the O+ grid in the CTIM sub model of OpenGGCM is highly skewed, we needed to implement a new suite of interpolation routines. These have been developed and tested. Furthermore, we conducted so-called *hop tests*, where all data exchange and synchronization takes place, but no actual data assimilation is performed. In other words, DART returns unmodified fields to all OpenGGCM instances. The hop test is designed to reveal coding mistakes early. The coupled codes have passed the hop tests. We also prepared COSMIC data for assimilation runs. With these preparations we are now ready to produce a first assimilation experiment for the 2013 St. Patrick's day storm

Figure 1 shows a schematic that explains the data assimilation cycle, where an ensemble of models with variations of their input is run repeatedly. Each model run produces a projection of the observations, i.e., predicts what the observing system is expected to see. DART then computes the feedback to the model, i.e., modifications to the state vector. With the modified state vectors the ensemble of model runs is the advanced to the next assimilation step. In case of OpenGGCM and DART the data are COSMIC line of sight electron densities.

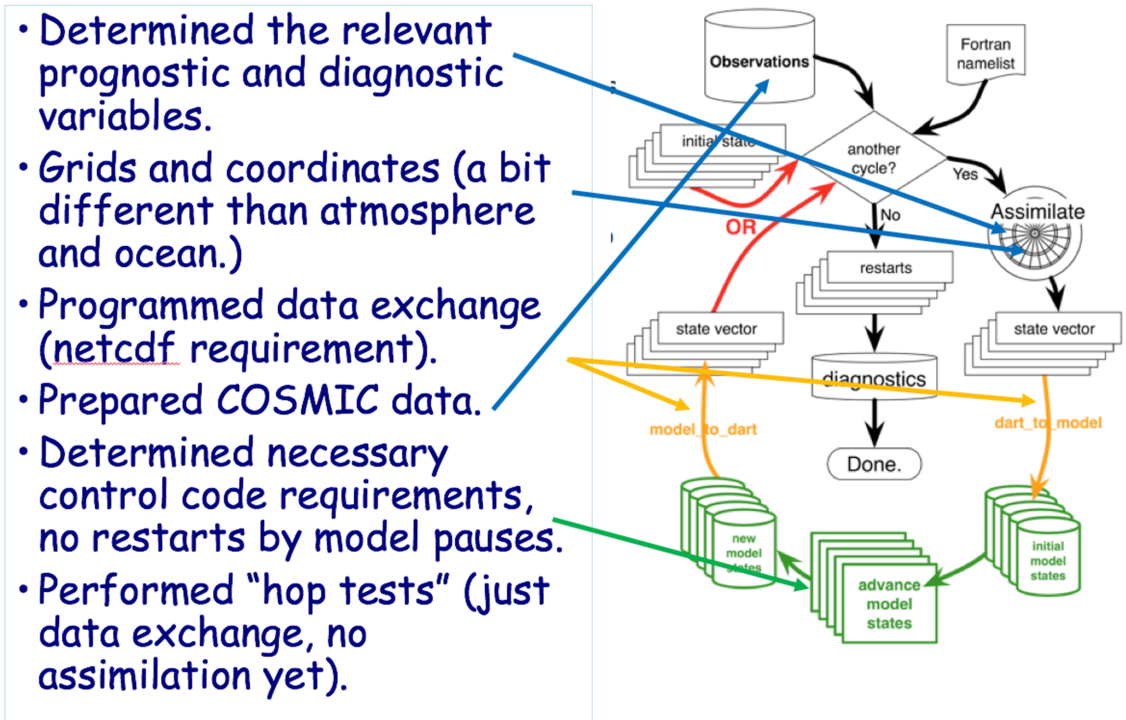

Figure 1: Showing a schematic of the data assimilation cycle with DART and OpenGGCM, and the work done so far.

Figure 2 illustrates the oxygen ion (O+) grid used in the CTIM part of OpenGGCM. The grid points are along dipole field lines, but in a geographic spherical coordinate system. Therefore, the grid becomes essentially irregular, but composed of "bricks." The data assimilation algorithm is required to interpolate within this kind of grid. The interpolation itself is straight-forward, but the problem lies in finding where within the grid the interpolation point is located, i.e., finding the right brick. An extensive search is computationally prohibitive. We thus developed a marching algorithm that successively marches through a list of neighbors to minimize the distance from the centers of gravity to the interpolation point.

Figure 3 illustrates the process. The bricks are first divided into tetrahedrons (tet4 elements), and lists are established for the center of gravity points, and the neighbors of for each tet4. From a starting point, one then marches to the neighbor that lies closest to the interpolation point. This process is repeated until one cannot get any closer. At that point one still needs an exhaustive search, because being closest the center of gravity does not yet imply one is in the right tet4. However, that search only needs to cover the immediate neighborhood and is computationally not very expensive.

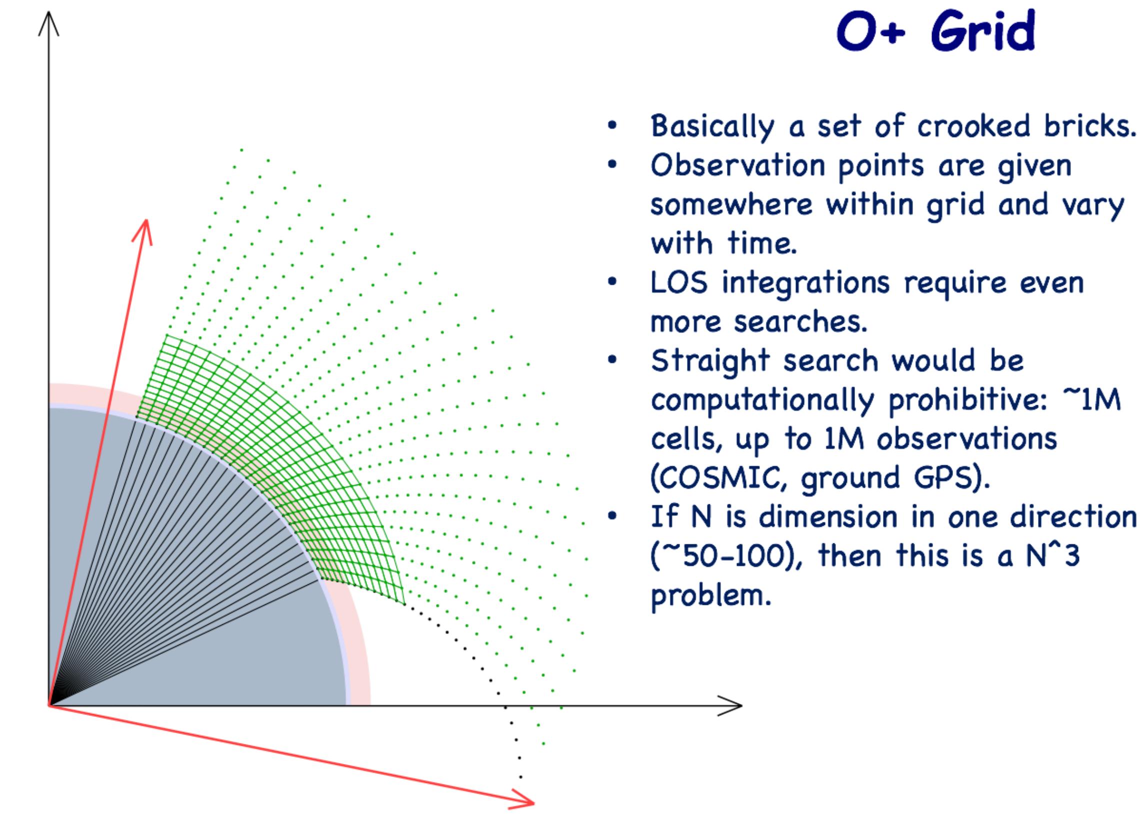

Figure 2: The O+ grid used in CTIM.

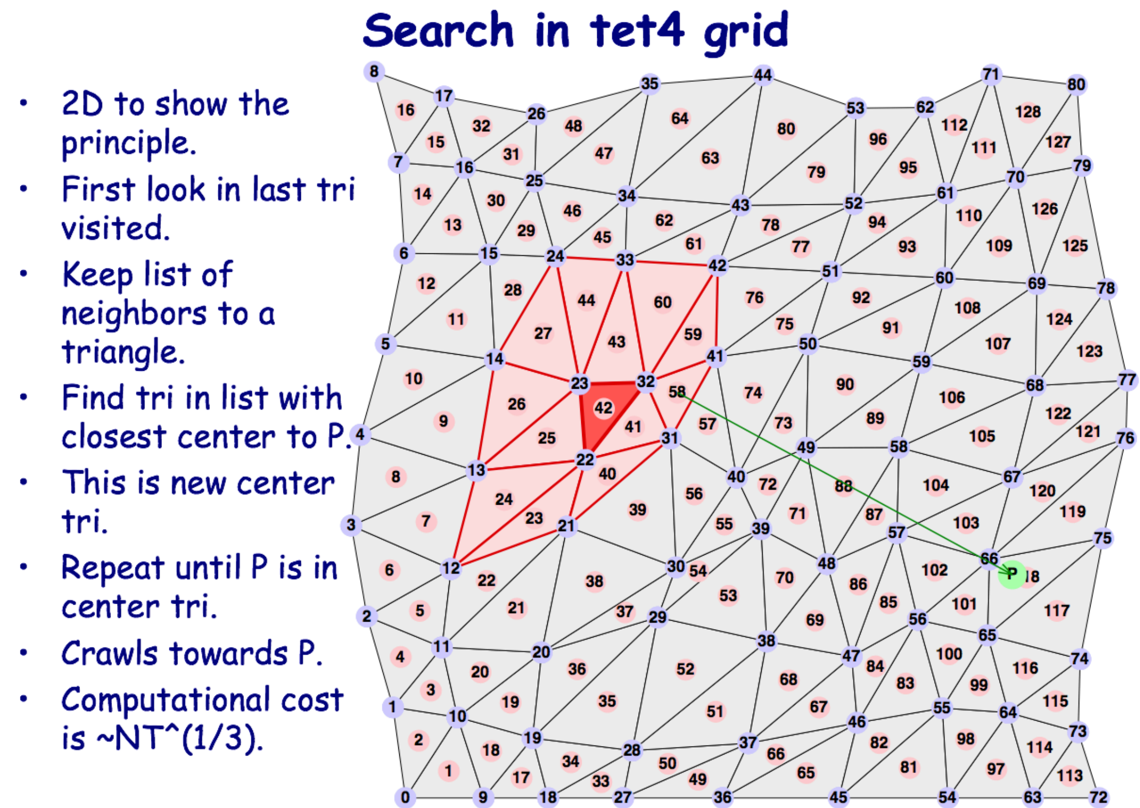

Figure 3: Schematic illustrating the search algorithm.