

Interactive Visualizations of Space Weather Data

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Background

Space weather is a common description of the environmental conditions in our solar system and the heliosphere, involving phenomena such as solar flares, high-speed solar winds and coronal mass ejections (CME, massive plasma cloud). Though Earth's magnetosphere serves as a shield for charged solar particles and protects life on Earth from radiation, much modern technology is highly dependent on our planet's atmosphere and sensitive to unpredicted changes due to space weather events.

At the Community Coordinated Modeling Center (CCMC) lab at NASA Goddard Space Flight Center (GSFC) solar observation data is used as input for global heliosphere simulation runs. The simulations generate high resolution models that are an important part of space weather forecasting at NASA and which are publicly available on the CCMC website. Among the space-time continuum models are ENLIL that contains data on the solar wind and CME interaction, and BATS-R-US containing global magnetosphere data.

Open Space is a collaboration project between Linköping University (LiU), NASA GSFC, and American Museum of Natural History (AMNH), developing new tools for interactive, multi scale, and multi display environments to explore our current understanding of Universe. The ultimate goal is a general open source visualization software to be maintained at LiU and developed further through an open ended masters level thesis program, enabling synchronized presentations in dome theaters across the globe, including the Hayden Planetarium in New York and the Visualization Center C in Norrköping.

This paper describes and presents select results of the first master thesis iteration, which focuses mainly on initial research, prototype building and defining requirements for the final software. The prototyping includes code development that can later be reused during the main software development.

Introducing volumetric rendering

The tools that are currently used by space weather researchers often generate two-dimensional, non-interactive cut planes, see figure 1. Due to the multi-dimensional nature of the data, there has been a request to introduce volumetric rendering to visualize space weather events. In the scope of Open Space a custom module has been developed for volumetric rendering engine Voreen, that loads and interpolates ENLIL and BATS-R-US models onto three-dimensional grids and lets the user interact with the data in all dimensions.

The ENLIL model is used to study the interaction between the solar wind and CMEs and contains data for the global heliosphere. The interaction is of great interest for the scientists to study, but for pure visualization purposes it is desired to separate the CME data from the background solar wind.

The solar wind is successfully rendered for several of the modeled variables by defining a low pass transfer function, see figure 2a in which mass density $N \cdot r^2$ is visualized. A variable dp is derived for visualizing CME iso-surfaces in ENLIL models, and successfully filters away the background solar wind. It is, however, a combination of several modeled variables and makes little sense to describe any true physics. When volumetrically rendered it suggests physical properties that are not

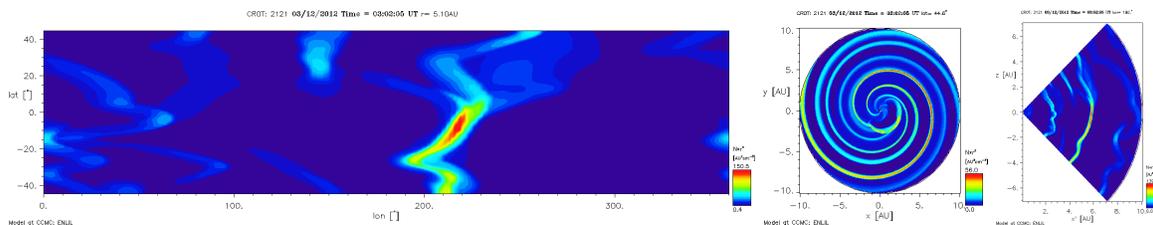


Figure 1: CCMC's online tool Runs on Request outputs two-dimensional, non-interactive cut planes.

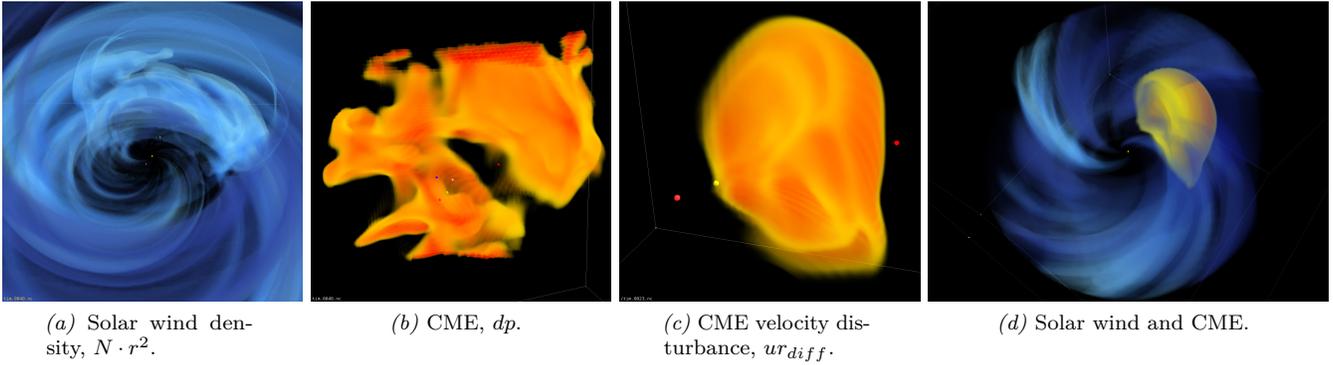


Figure 2: To successfully visualize a CME event the solar wind and plasma cloud data need to be separated.

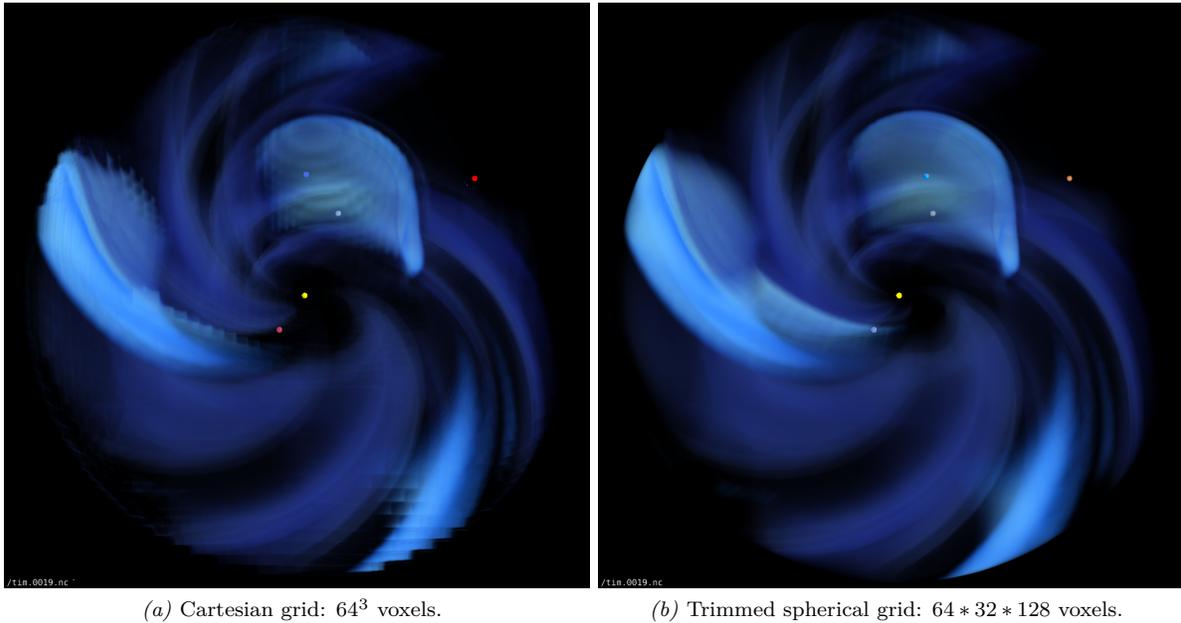


Figure 3: By defining a spherical model on an equidistant Cartesian grid a large amount of the voxels become empty, and can result in distinct interpolation artifacts (a). By defining a trimmed spherical grid all voxels contain valid values and no interpolation artifacts are introduced due to coordinate transformations (b).

believed to be correct, i.e. fractal structures and "holes" as seen in figure 2b. Instead, a new approach has been introduced in which a second model, containing the solar wind alone, is subtracted from the full model. This enables the CME data to be successfully separated for most modeled variables, including radial velocity u_r , as seen in figure 2c and 2d. This approach has not been taken before, and has for the first time been introduced in the scope of the Open Space project.

Ray casting in spherical coordinates

The ENLIL model is a spherical model. By transforming it to Cartesian coordinates and defining it on an equidistant cuboid grid (as in traditional ray casting) a large amount of the voxels become empty and will not contribute to the final rendering. These voxels are essentially "waste" of memory and band width, and also decrease the model's voxel density. The transformation can also introduce distinct interpolation artifacts at rendering time, see figure 3a.

By defining the volume's voxel array in spherical coordinates $\{r, \theta, \varphi\}$ the model does not need to be transformed to Cartesian space at loading time. Instead each ray's sampling points are transformed to spherical space during rendering, using a shader program. This approach minimizes the amount of empty voxels (from 63% to 0% empty voxels for an ENLIL sub-sphere model), maximizes the effective resolution, and introduces no interpolation artifacts due to coordinate transformations, compare figure 3a and 3b. It also enables straightforward shader calculations related to the spherical nature of the data e.g. spherical cut planes and adaptive sampling rates and opacity levels.

There is no known published paper that describes volumetric rendering for non-Cartesian volumes. Thus, all results are due to original research in the scope of the Open Space project.