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On the development of a 3D curvilinear hybrid model

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Abstract

We are developing a curvilinear (spherical and cylindrical) hybrid model, HYB-spherical/-cylinder, to study how the solar wind interacts with the solar system bodies. In this brief status report we illustrate the latest achievements of the curvilinear grids development and illustrate the usage of the new model by showing a preliminary test runs.

1. Introduction

A hybrid approach provides an efficient way to model how the cosmic plasma interacts with non-magnetized and magnetized planetary objects. In a hybrid model ions are treated as particles, while electrons form a massless, charge neutralizing fluid. The basic properties of the HYB hybrid model can be found at [1] and [2].

The HYB hybrid model family is being developed at the Finnish Meteorological Institute (FMI) during the last decade. The model has been used successfully to describe how the flowing plasma interacts with various solar system bodies such as Mercury, Venus, the Moon, Mars, Saturnian moon Titan and asteroids.

One geometrical limitation of the HYB model is, however, that it assumes cube shaped grid cells. In order to expand the usage of the HYB model we have initialized a project aiming to develop a curvilinear coordinate version of the model.

2. Spherical and Cylindrical grids in a hybrid model

In this section we briefly describe main advantages and challenges of the curvilinear grids when it is used in a hybrid model. Now we are developing spherical and cylindrical versions of HYB hybrid model simultaneously.

2.1 Advantages

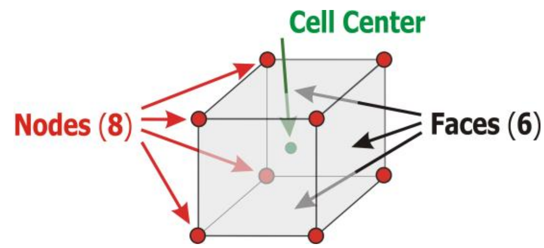

Figure 1: Cartesian cell shape.

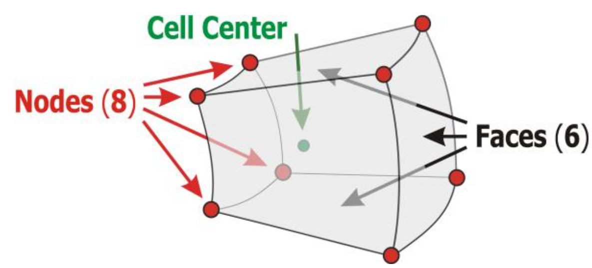

Figure 2: Spherical cell shape.

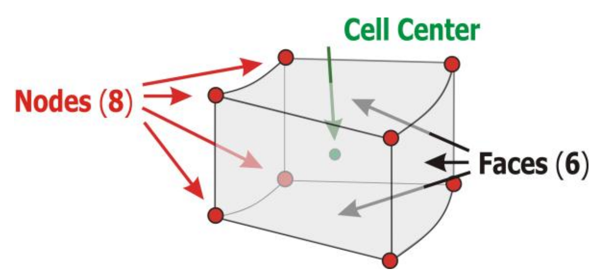

Figure 3: Cylindrical cell shape.

1. *Grid resolution*. In curvilinear coordinates there is "natural" grid refinement: the closer the cells are to the obstacle the smaller grid cells become. This property could be used for the introducing of a self-consistent ionosphere into the hybrid model, where we need to decrease the cell size at low altitudes.

2. *Obstacle boundary condition*. Another "natural" property of curvilinear (mostly spherical) coordinates is the geometrical interpretation of the obstacle. Planetary surface is covered by the r = constant

surface of the spherical grid, which simplifies the implementation of the boundary condition.

2.2 Modelling Challenges

1. Interpolations

Hybrid approach implies a number of vector and scalar value interpolations between different grid elements. As the curvilinear grids are not homogeneous, the realization of interpolation methods is not as straightforward as in the Cartesian coordinates.

2. Pole Region (only for spherical grid)

Spherical grid includes two singular points, poles, where the numerical values are not defined. Moreover, in circumpolar region numerical values "feel" singularities, because the spherical cell elements, edge lengths, face areas and cell volume become smaller when the cell is closer to the pole.

3. Examples of the test runs

Here we illustrate preliminary tests, which represent magnetized plasma propagation in empty (spherical and cylindrical) boxes. The results demonstrate uniform distribution of magnetic field, which is in a good agreement with expected value.

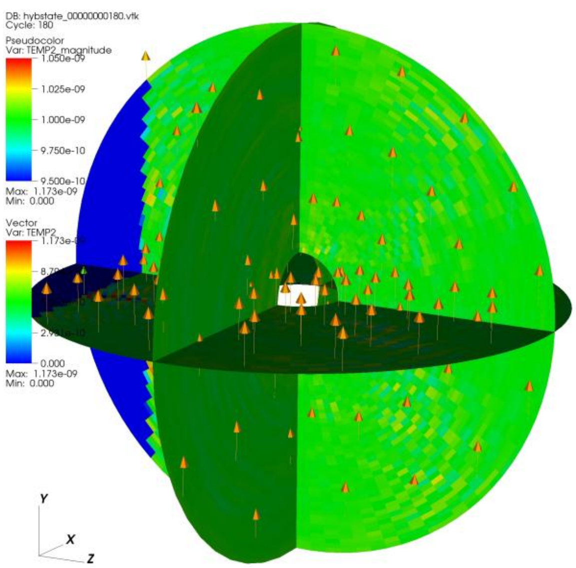

Figure 4: An example of magnetized plasma propagation in empty space using the spherical grid structure. The upper and lower values on the color bar represent scalar and vector magnitude of the magnetic field.

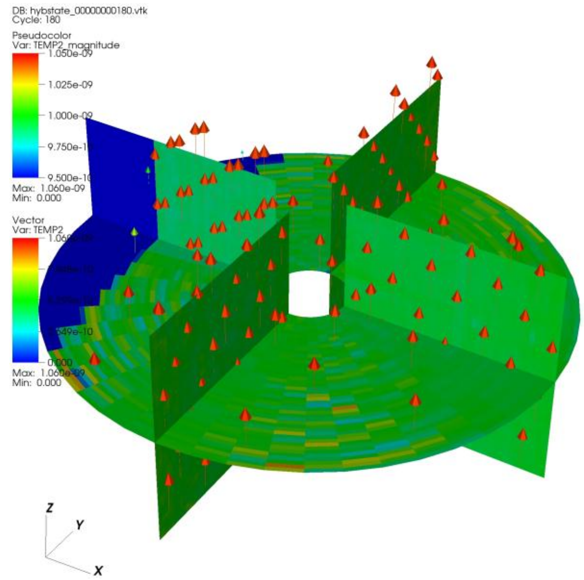

Figure 5: An example of magnetized plasma propagation in empty space using the cylindrical grid structure. The upper and lower values on the color bar represent scalar and vector magnitude of the magnetic field.

4. Conclusions

Developing a curvilinear hybrid model is a challenging task because of the complexity of the interpolation, the polar region of the grid and appropriate boundary conditions. Developing of such model is, however, anticipated to provide a powerful tool for self-consistent modeling of cosmic plasma interactions with various solar system bodies and exoplanets.

Reference

[1] Kallio, E., and Janhunen P., Modelling the Solar Wind Interaction With Mercury by a Quasineutral Hybrid Model, Annales Geophysicae, Vol. 21, p. 2133, 2003.

[2] Kallio, E. K. Liu, R. Jarvinen, V. Pohjola and P. Janhunen, Oxygen ion escape at Mars in a hybrid model: high energy and low energy ions, *Icarus, doi:10.1016/j.icarus.2009.05.015*, Vol. 206, Issue 1, pp. 152-163, 2010.