VISUALIZATION OF FLUX ROPE GENERATION PROCESS USING LARGE QUANTITIES OF MHD SIMULATION DATA

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ABSTRACT

We will present a new concept of analysis by using visualization of large quantities of simulation data. The time development of 3D object with high temporal resolution provides the opportunity of scientific discovery. We visualize large quantities of simulation data using visualization application 'Virtual Aurora' based on AVS and the parallel distributed processing at "Space Weather Cloud" in NICT based on the Gfarm technology. We introduce two results of high temporal resolution visualization which are magnetic flux rope generation process and dayside reconnection using a system of magnetic field line tracing.

Keywords: visualization, cloud computing system, parallel distributed processing, space weather, reconnection

1 INTRODUCTION

According as super computer's ability increases we can treat high precision simulation data while we need to visualize the big simulation data. We progress the technique of 3D visualization. Matsuoka et al. (2008) analyzed 3D structures of magnetic flux rope in terrestrial magnetosphere by using 3D visualization techniques. However they visualized simulation data in the specific time and space region in which we need to see physical interest because the computational resource has limit. We succeeded to visualize all time and space by using big storage and parallel distributed processing (Murata et al., 2011). The visualization technique provides the opportunity of scientific discovery because we can see small and large scale structures at the same time. We performed two type visualizations in difference of how to draw magnetic field lines. One is that start points of magnetic field lines are fixed in time. The other is that start points of magnetic field lines move with stream elements following the velocity. 'Frozen-in' concept is that magnetic field line moves on stream elements except magnetic diffusion region. The later visualization means magnetic field line tracing. In chapter 2, we describe how to visualize all step data. In chapter 3, we introduce the visualization result of magnetic flux rope generation in fixed start points and dayside magnetic reconnection by using magnetic field line tracing.

2 3D OBJECT WITH HIGH TEMPORAL RESOLUTION

2.1 Global MHD simulation data

We use the data generated by an MHD (magnetohydrodynamic) simulation of the interaction between the solar wind and the terrestrial magnetosphere. The number of data points is 450×300×300 in the Cartesian coordinates. The simulation covers the time interval of 2 hours with a time resolution of 0.5 sec. Namely the number of simulation steps is 14400. The space grid interval is $0.2R_E$ where R_E is earth radius length. Total data size is about 18TB. The data of ACE satellite with 5 minute interval at Galaxy15 (2010/4/5) event is used as the solar wind input. The outer boundary is that the variables are fixed for upstream and the variables are free for downstream. The inner boundary is that the variable is the same of initial condition in radius of $4R_E$. In the range from $4R_E$ to $5R_E$, the simulation values are smoothly combined with the initial values.

2.2 Visualization techniques using parallel distributed processing

In order to treat the big data, we use the parallel distributed processing at “Space Weather Cloud” in NICT based on the Gfarm technology. The number of processor is above 100 cores. We visualized the simulation data of Galaxy event as drawing the number of above 1000 field lines using visualization application 'Virtual Aurora' developed based on AVS. The work flow of visualization is shown in Figure 1. First we convert the simulation data to HDF format data for Virtual Aurora. Second we visualize the HDF format data using ‘Virtual Aurora’. Third we output the result as each time step 3D object file. Last we combine each time step 3D object into the high temporal resolution 3D object which has a large amount of information volume. In case of magnetic field line tracing, we need to read all files in order to trace the streak line. These work flows are complex for the parallel distributed processing. In order to describe the work flow in program, we use Parallel Workflow extension for Rake (Pwrake), which is a tool for the parallel distributed processing. We describe the flexible work flow by using Ruby. In order to look the time development of 3D object, e.g. a file size of 2000 step GFA is 3GB, we developed the 64bit 3D object player in NICT which can zoom the objects and change the view-direction easily.

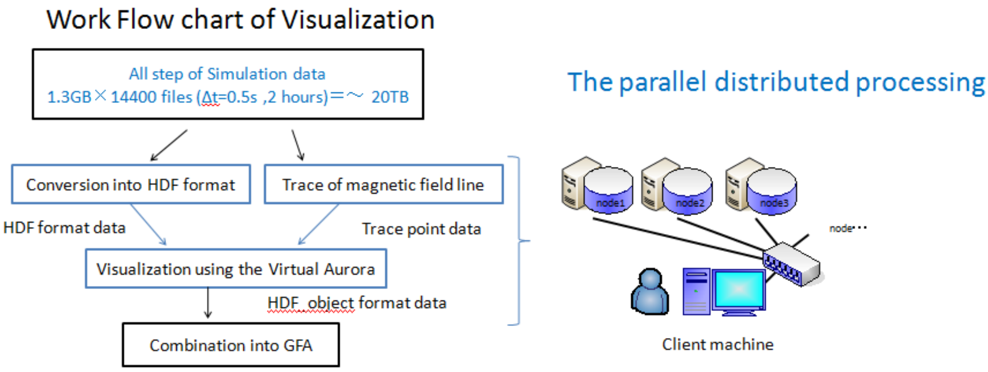

Figure 1. Work Flow chart of Visualization using the parallel distributed processing

3 Visualization of simulation results

First visualization using the high temporal resolution visualization system with fixed start points is about the generation process of a flux rope, which is a small structure and begins from a spiral field line by magnetic reconnection, related with a release of the solar wind energy at the magnetotail. This knowledge can be acquired by the looking at small and large scale structures with high temporal resolution. Second visualization using the system of magnetic field tracing is about the dayside reconnection. In order to visualize reconnection region, we need to trace the magnetic field lines. We visualized the reconnection region.

3.1 Visualization of magnetic flux rope

We show a result of galaxy event simulation and observation for two hours. Figure 2 shows that four snapshots of simulation, the solar wind magnetic data observed by ACE satellite and tail magnetic data observed by GOSE11 satellite. The snapshots show pressure color contours of equatorial and meridian cross section and magnetic field line divided into open line (red), closed line (green) and detached line (yellow) according to topology of field line. Intensity of solar wind negative Bz increases at 8:00 UT as shown in ACE magnetic data. Intensity of magnetic field observed by GOSE11 increases at 9:00 UT. This increase indicates dipolarization. In the MHD simulation, topology of magnetic field lines changes open into detached line because field lines reconnect at about 8:36 UT and a flux rope generates. The flux rope releases to interplanetary space at 8:41 UT. There is a difference of timing about 30 minutes between observational dipolarization and flux rope release in simulation. This difference arises because this simulation does not include ionosphere effect as boundary condition and a magnetic diffusion coefficient is uniform anywhere in the simulation, that is, reconnection is easy to occur in the simulation. The simulation is consistent with the observation except the difference of timing.

We are interested in flux rope generation process. We investigate this process in high time resolution because we visualized this simulation using all step data. Figure 3 shows that topology of magnetic field lines at flux rope generation. We visualized first reconnection, that is, closed field line reconnects and changes into open field lines at 8:35:38.500 UT as shown in Figure (c) and enlargement figure. The open field line is spiral structure and generates flux rope after 10 seconds as shown in Figure (e). The open field lines reconnect and change into detached field line after 10 seconds and the flux rope is released as shown in Figure (f). Topology of magnetic field lines change during 1 minute for flux rope generation.

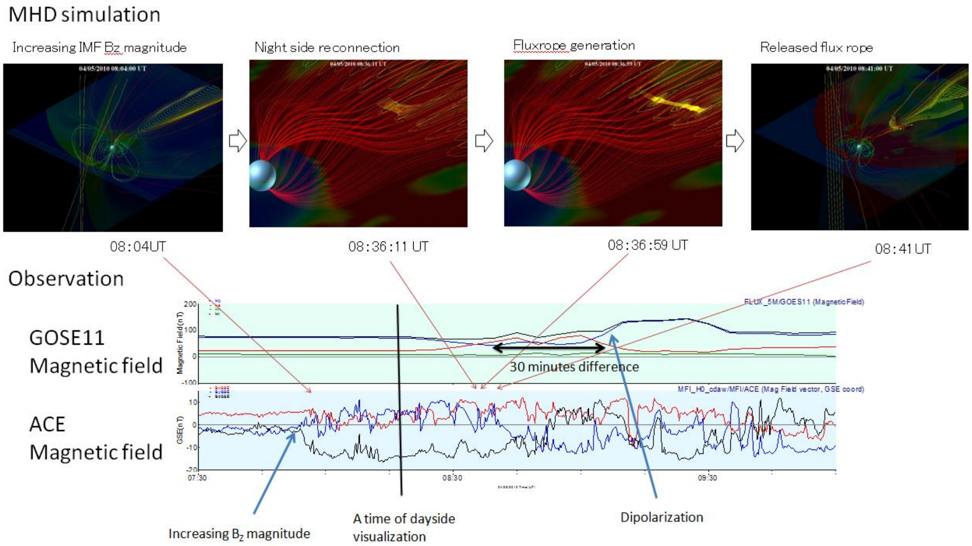

Figure 2. Comparison between MHD simulation and GOSE11 observation at galaxy event.

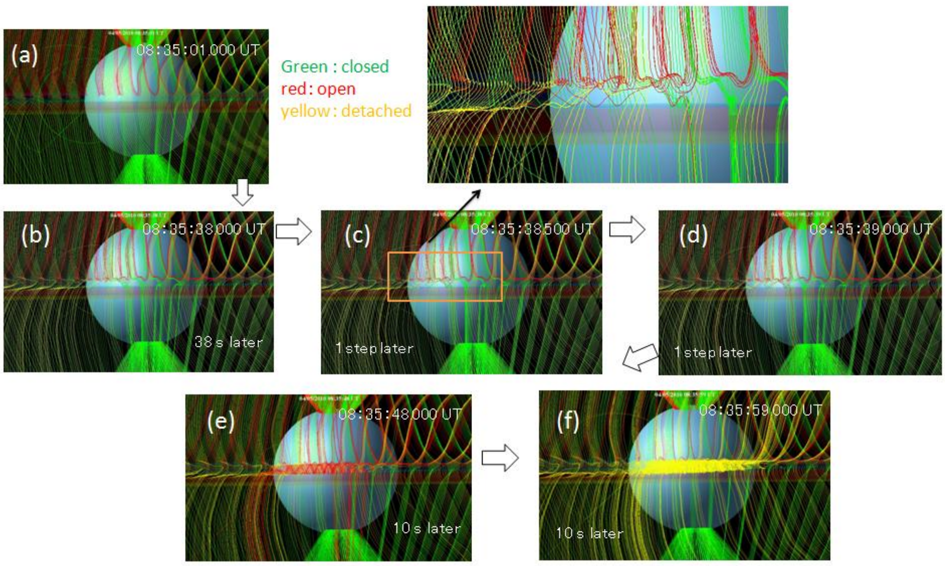

Figure 3. Topology of magnetic field lines during 1 minute when the flux rope generates.

3.2 Visualization of dayside reconnection using a system of magnetic field line tracing

Dayside magnetic reconnection is a main mechanism that transports solar wind energy into the magnetosphere. We visualize the reconnection region between interplanetary magnetic field (IMF) and terrestrial magnetic field by tracing the IMF. As a first result, we trace the IMF when the IMF is southward (Bz=-12nT, By=5nT) at 8:20 UT. Figure 4 shows dayside reconnection region. We view in the direction from solar to earth. The blue sphere is earth. The yellow lines and the red lines are magnetic field lines. The topology of field lines is indicated by the same color as section 3.1. The yellow points are start points to draw the magnetic field line. Start points are 11point (down to dusk) × 11point (north to south) and an interval is $2R_E$. Figure (a) shows that the magnetic field lines starting from two red circles are bended in the dawn-dusk direction in order to diffuse between the solar wind and terrestrial field. The red square indicates a diffusion region. Diffusion region is from subsolar point to $\pm 5R_E$ in the dawn-dusk direction. After 0.5 seconds, the field lines first reconnect with terrestrial field line as shown in Figure (b). Solar wind field lines reconnect with terrestrial field through this diffusion region. After 10 seconds, the magnetic field lines in the region from the subsolar point to $\pm 5R_E$ in the dawn-dusk directions reconnect with the terrestrial field lines at the dayside magnetopause as shown in Figure (c). In region of flank sides over ±5R_E, magnetic field lines do not reconnect and are transported through the sheath region to the downstream.

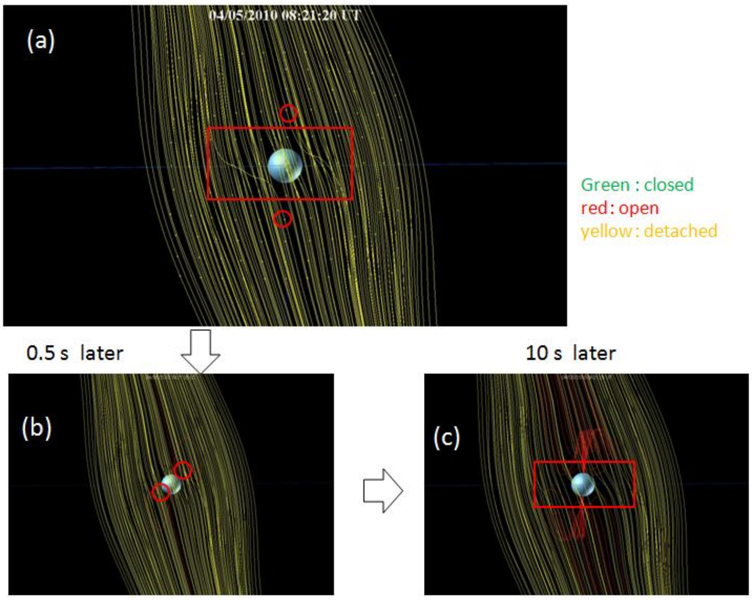

Figure 4. Visualization of the dayside reconnection region

4 CONCLUSION

We have visualized MHD simulation result in two type methods, which have a difference in start points treatment, in high temporal resolution by using parallel distributed processing. First we visualized generation of flux rope for galaxy event. We find that topology of flux rope's magnetic field lines changes during 1 minute. Second we succeeded in visualizing magnetic field line tracing to MHD simulation data. We find that the magnetic field lines in the region from the subsolar point to ±5R_E in the dawn-dusk direction reconnect at the dayside magnetopause and transport the nightside magnetosphere. In region of flank sides over ±5R_E, magnetic field lines do not reconnect and are transported through the sheath region to the downstream.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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