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High Speed Solar Wind Forecast Model from the Solar Surface to 1AU Using Global 3D MHD Simulation

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Abstract. Emanating from coronals holes (CHs), high speed streams (HSSs) cause recurrent geomagnetic disturbances in the Earth's magnetosphere. For this reason being able to predict the occurrence and timing of the high speed solar wind is one of the more important issues in space weather forecasting. Currently, it is still difficult to estimate the effect of a CH in case that it extends from high latitudes to lower ones. To monitor the global solar wind condition we have therefore developed a three-dimensional MHD simulation code, the REProduce Plasma Universe (REPPU) code, that is driven by the solar magnetic field from the solar surface to 1AU. The connectivity of magnetic field lines from CHs to Earth's orbit via HSSs has been investigated. Simulation results are presented and the usefulness of our model is discussed.

Keywords. Space weather, MHD, methods: numerical, Sun: corona (Sun:) solar wind, solar-terrestrial relations

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1. Introduction

Coronal holes (CHs) are the origin of high speed streams (HSSs) and generally occur near the minimum of the 11-year solar activity cycle. When they interact with slow speed streams, it can result in co-rotating interaction regions that can cause temporary disturbances in Earth's magnetosphere. Thus, being able to reproduce the global solar wind structure is one of the important issues for space weather to consider when forecasting the space weather.

Several MHD models have been developed to simulate the solar wind structure ranging from the outer region of the sun (about 20 - 50 solar radii) to a distance of several AU (e.g., Shiota and Kataoka 2016, Odstrcil *et al.* 2005) or from the photosphere to interplanetary space (e.g., Nakamizo & Tanaka *et al.* 2009, Toth *et al.* 2005, Riley *et al.* 2001).

The REProduce Plasma Universe (REPPU code), developed by Tanaka (Tanaka 1994, Nakamizo & Tanaka *et al.* 2009) extends from the solar surface to about 200 solar radii. One of the distinguishing features of this simulation model is the grid structure used for the spherical surface, which has no polar singularity or no seam. This can avoid congested fine grids around the poles. In this way, we are able to reproduce both CHs and the global solar wind structure, thus allowing us to identify the connectivity of a CH and the associated HSS. It is expected that our results will be useful for assessing the potential severity of a CH. Our model is now being used for solar wind forecasting at our institute and provides a solar wind forecast every day. In this paper, we briefly describe the REPPU code and present several simulation results.

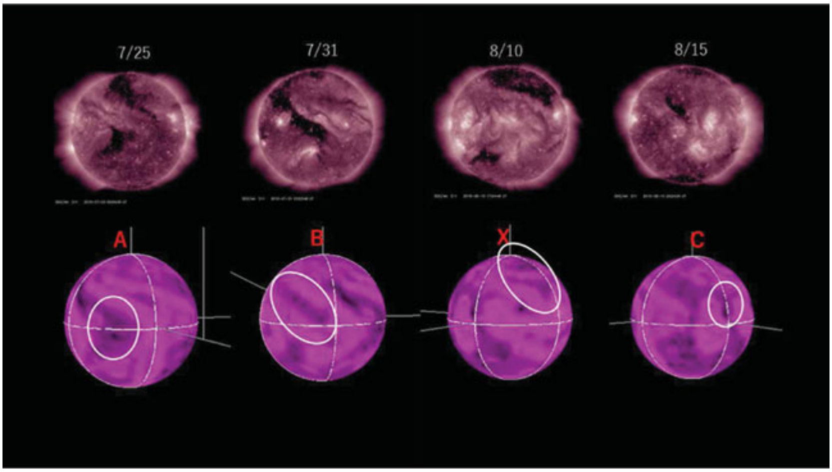

Figure 1. CH observations using SDO AIA211 data (upper panels) and corresponding color contour maps of CH plasma temperature obtained by simulation (lower panels).

2. Method

The simulation method and the model used in this work are described in Den *et al.* (2015) and Nakamizo & Tanaka *et al.* (2009). Here we depict different points from our previous papers. The simulation region extends to 217 solar radii. The number of grid points is 217 in the radial direction with a minimum resolution of 0.02 solar radii and a maximum resolution of 2.7 solar radii. We start by calculating the potential magnetic field of the solar corona using GONG observational data of the photospheric magnetic field and obtain a steady state representation of the solar wind.

We solve three dimensional MHD equations with heating terms including a volumetric heating function and Spitzer-type thermal conduction. Our heating function consists of the expansion factor of the solar magnetic field, the e-folding decay, and the intensity of the heating function. The decaying scale is here tuned to 0.7 solar radii.

3. Simulation Results

The period of GONG data used here is 2017/7/14-8/19. Figure 1 presents the CHs that occurred in this period on four different days. In Figure 1 (In the upper panels of Figure 1), CHs are observed as dark images in the SDO AIA211 data, and the lower panels present the corresponding simulation results as color contour maps of the plasma temperature. We label each simulated CH as A, B, X, and C to clarify the source of the solar wind observed at the L1 point. The CH in the third column (X) crossed the central meridian on Aug. 7: however, there are not observational data for the period Aug 7 - 9, so we used the data obtained on Aug. 10 instead. In each of the four cases, the simulation results reproduce almost all the features of the CHs.

In the upper panel figures of Figure 2 magnetic field lines are drawn starting from the identified CHs, and the same lines are mapped on the color contour plots of the solar wind speed on Earth's orbital plane (lower panels). It can be seen that the extended field lines correspond to the HSS region. These results present the magnetic connectivity between the CHs and the high speed solar wind region.

Figure 3 presents a plot of the simulated solar wind speed at the L1 point (top panel), the real-time solar wind velocity data observed by DSCOVR (middle panel) and the local geomagnetic K index, which quantifies the impact of space weather phenomena

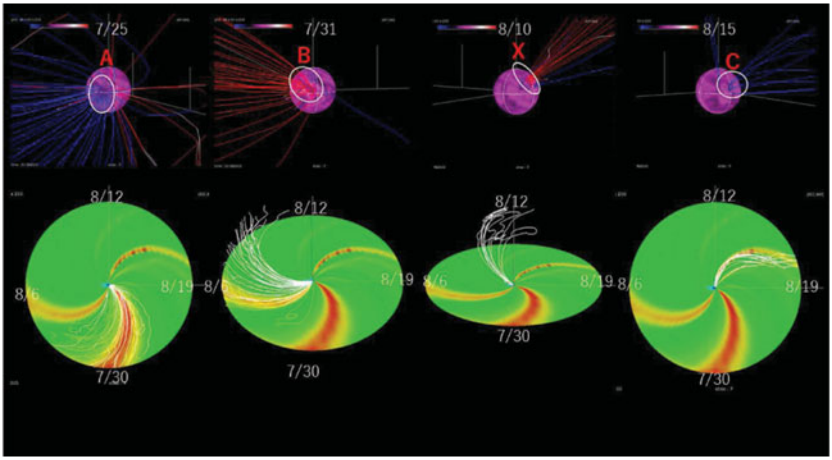

Figure 2. Magnetic field lines are drawn starting from the CHs (upper panel figures), where the red and blue lines represent an away and a toward direction respectively. The same field lines (in white) are also shown with the color contour of the solar wind speed on Earth's orbital plane (lower panel figures).

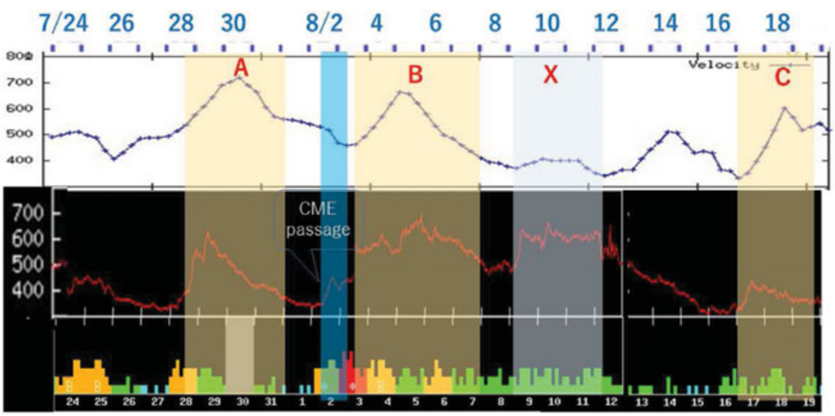

Figure 3. Simulated and measured solar wind velocity at the L1 point (upper and middle panels) and corresponding geomagnetic K-index (bottom panel) for the four cases.

on the Earth's magnetic field (bottom panel). The yellow and red bars of the K index imply significant disturbances in the horizontal component of Earth's magnetic field. The three yellow transparent vertical bars present high stream regions having corresponding simulated CHs (labeled A, B, C in Figures 1 and 2). The blue transparent bar represents the time interval when a CME passed, which is not an object of our study in this paper. The grey transparent bar also shows a high stream region: however, the simulated solar wind was not found to be high. This observed stream is thought to originate from the CH labeled X in Figures 1 and 2. The simulated magnetic field moved to a high latitude region and did not reach Earth's orbital plane (Figure 2). This discrepancy may be due to the evaluation of the expansion rate of the magnetic field, which is one of the problems of our model. It is interesting that the CH labeled C cannot be seen in the SDO data (Figure 1), but the simulation result and data observed by DSCOVR show that a medium speed solar wind originated from it (Figure 3).

4. Concluding Remarks

We developed a 3D MHD simulation model, the REPPU code, for simulating CHs and the global solar wind structure. We showed that our simulation can reproduce both CHs and associated HSSs in the solar wind and additionally identify the connectivity of magnetic field lines in HSSs to CHs. It is still difficult to assess the effect of a mid-latitude CH since this needs more precise modeling of the CHs, which is one of our future works.

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