§4. Simulations of Coronal Mass Ejection with Structured Ambient Solar Wind


In order to more accurately model the propagation of a coronal mass ejection (CME), one of energetic solar phenomena, we reproduced the structure of the ambient solar wind and simulated a CME propagation using 3D hydrodynamical simulation code. In the previous work, our solar wind model is set artificially. Solar wind consists of fast and slow region. Wind velocity input into inner boundary takes minimum on a geodesic line, and smoothly connects to fast wind with \( \tanh^2 \) profile. In this work, we use observational data of the magnetic field on the solar surface and obtain structured solar wind velocity by adopting appropriate solar wind heating model. Solar wind velocity at a latitude \( \theta \) and a longitude \( \varphi \) on the solar surface is determined from Wilcox Solar Observatory photospheric field, \( B_{\text{Ph}} \), and source surface field, \( B_{\text{SS}} \), by following equation1):

\[
V(\theta, \varphi) = \begin{cases} 
267.5 \left( f < 1 \right) \\
267.5 + 451 \cdot f(\theta, \varphi)^2 \left( f \geq 1 \right)
\end{cases}
\]

Corona heating model is given by

\[ Q = \rho q_v (T(\theta, \varphi) - T_0) \exp \left( - \left( \frac{r - R_s}{\sigma_v} \right)^2 \right) \]

where \( q_v = 1.0 \times 10^6 \text{ erg/g/s/K} \), \( \sigma_v = 4.5 R_s \), \( R_s \) : solar radii

\[ T(\theta, \varphi) = \begin{cases} 
T_0(\theta, \varphi) + 1.1 \times 10^6 \left( \frac{\pi}{50} \right) \left( \frac{\xi}{2} \right) \left( B(\xi) \right) \left( 0 \leq t < 10 \text{min} \right) \\
V_{\text{max}} \left( \frac{t}{10 \text{min}} \right) + V_{\text{min}} \left( 10 \text{min} \leq t < 20 \text{min} \right) \\
V_{\text{max}} \left( \frac{80 \text{min} - t}{60 \text{ min}} \right) + V_{\text{min}} \left( 20 \text{ min} \leq t < 60 \text{ min} \right) \\
V_{\text{max}} \left( \frac{80 \text{min} - t}{60 \text{ min}} \right) + V_{\text{min}} \left( 20 \text{ min} \leq t < 80 \text{ min} \right)
\end{cases} \]

where \( t \) is a time from the CME initiation and \( V_{\text{max}} \) and \( V_{\text{min}} \) are maximum input velocity, 1220 km/s based on observational data, and minimum one we assumed respectively. Figures 2 present the distribution of the solar wind velocity on the horizontal plane illustrated by color contour. It can be seen that the CME associated shock wave passed through the earth orbit, and complicated structure is formed behind the shock. Most refined mesh size in the CME propagation simulation is \( 1/10^{14} \times \) simulation box size in the corresponding region. Thus our simulation is highly resolved, however, the right panel of Figs. 2 shows that the shock wave passed about 1 day earlier than the observation, which suggests that models adopted here are needed to be improved.


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Fig. 1. The distribution of the ambient solar wind on the horizontal plane (left panel) and the velocity plot at the ACE satellite orbit during June 1 and 22 (right panel).

Fig. 2 Snap shot of the distribution of the solar wind velocity on the horizontal plane at 107 hours after the CME occurred (left panel) and the velocity plot at the ACE satellite orbit around the shock wave passage time (right panel).