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

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In order to more accurate modeling of 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 hydro-dynamical 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 θ and a longitude φ on the solar surface is determined from Wilcox Solar Observatory photospheric field, B_{Ph}, and source surface field, B_{SS}, by following equation[1],

$$f(\theta,\varphi)=\left(\frac{R_{Ph}}{R_{SS}}\right)^2\frac{B_{Ph}(\theta,\varphi)}{B_{SS}(\theta,\varphi)}$$

$$\frac{V(\theta,\varphi)}{(km/s)}=\begin{cases}267.5 & (f<1)\\ 267.5+451\cdot f(\theta,\varphi)^{-\frac{2}{5}} & (f\geq 1)\end{cases}\quad . \qquad (1)$$

Corona heating model is given by

$$Q=\rho\, q_0(T_0(\theta,\varphi)-T)\exp\left[-\left(\frac{r-R_s}{\sigma_0}\right)^2\right]$$

$$q_0=1.0\times10^6\,\mathrm{erg/g/s/K},\quad \sigma_0=4.5R_s,\quad R_s:\text{solar radii}$$

where $T_0(\theta,\varphi)$ is a target temperature[2], which is between 1.1×10^6 K and 3.6×10^6 K so that $V(\theta,\varphi)$ determined in eq. (1) is reproduced. As for simulation method, we use adaptive mesh refinement (AMR) for grid formation and TVD method for flux calculation. Figures (1) show the simulation results of the ambient solar wind and we can see a good agreement qualitatively between the observational data and the simulation in the right panel. We modeled a partial halo CME occurred at 04:36:05 on 2nd June, 2012. A CME initiation model[3] is given by

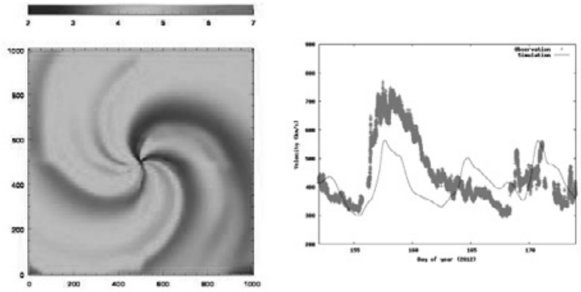

Fig. 1. The distribution of the ambient solar wind on the horizontal plane (left panel) and the velocity plot at the ACE satellite orbit during June 1 and 22 (right panel).

$$V(t,\xi)=V_{\max}\cos\left(\frac{\pi}{2}\cdot\frac{\xi}{50^\circ}\right)B(t)$$

$$B(t)=\begin{cases}(V_{\max}-V_{\min})\dfrac{t}{10\,\mathrm{min}}+V_{\min} & 0\leq t<10\,\mathrm{min}\\ V_{\max} & 10\,\mathrm{min}\leq t<20\,\mathrm{min}\\ V_{\max}\dfrac{80\,\mathrm{min}-t}{60\,\mathrm{min}}+V_{\min}\dfrac{t-20\,\mathrm{min}}{60\,\mathrm{min}} & 20\,\mathrm{min}\leq t<80\,\mathrm{min}\end{cases}$$

where t is a time from the CME initiation and $V_{\max}$ and $V_{\min}$ 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 the CME propagation simulation is $1/10^{14}$ x 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 1day earlier than the observation, which suggests that models adopted here are needed to be improved.

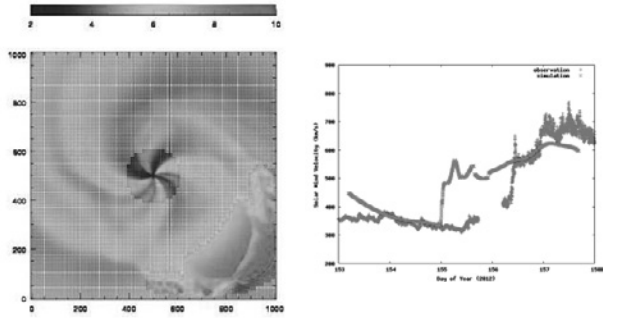

Fig. 2 Snap shot of the distribution of the solar wind velocity on the horizontal plane at 107 hours after the CME occurred (left panel) and the velocity plot at the ACE satellite orbit around the shock wave passage time (right panel).

1) Arge, C. N. and Pizzo, V. J. : J. Geophys. Res. **105** (2000) 10465.
2) Manchester, W. B., et al : J. Geophys. Res. **109** (2004) A02107.
3) Odstrcil, D. and Pizzo, V. J. : J. Geophys. Res. **104** (1999) 483.