Influence of solar photospheric magnetic field distributions on the estimation of interplanetary magnetic fields

*Minami Yoshida[1,2], Toshifumi Shimizu[2], Shin Toriumi[2]

1. The University of Tokyo, 2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

The estimation of the magnetic field extending from the solar surface to the heliosphere is important for understanding how solar activity influences on the heliosphere and interplanetary space. Magnetic fields extending from the sun's photosphere can be classified into two types: open and closed. The open magnetic field is mainly originated on the coronal holes and it’s connected to the interplanetary magnetic field (open flux). The open flux density can be estimated by a coronal magnetic field model with the photospheric magnetic synoptic maps. It is, however, known to be by a factor of 2-4 smaller than the radial flux density by in-situ measurement near the Earth (Linker et al., 2017, Wallace et al., 2019; The open flux problem).
In this study, we investigated the possibility that the open flux problem is caused by the insufficient amount of magnetic flux estimated on the solar surface (photosphere) to understand the root cause of the open flux problem, by deriving the amount of the open flux at different phases over a solar activity cycle. The potential field source surface (PFSS) model was used with the SDO/HMI synoptic maps as the lower boundary. The source surface was set at 2.5 solar radii. Assuming that the magnetic field lines are in the radial direction at the source surface and that there is no dependence of heliospheric latitude at 1 AU from the Sun (Smith et al., 1995), we calculated the open flux density $|B_{r\ 1AU}|$ for about 11 years from 2010. The results show that on average, $|B_{r\ 1AU}|$ estimated by the PFSS model is underestimated to a level of 24% in solar minimum, 29% in solar maximum, and 26% during the entire period of the in-situ measurement. Even when we artificially increase the magnetic flux at the polar regions twice, the estimated $|B_{r\ 1AU}|$ is still at a level of about 30%. The magnetic flux density distribution on the source surface shows similar to the large-scale structure of the magnetic field on the solar surface. In the solar minimum, the solar magnetic field is a dipole, and the magnetic flux is primarily concentrated to the polar regions. In the solar maximum, the magnetic field is distributed in the mid and low latitudes where several active regions appear. In summary, we found that the average of the estimated $|B_{r\ 1AU}|$ varies only by about 5% over the solar activity cycle, although the magnetic flux distribution changes significantly both in the polar regions and in low and mid latitudes. In addition, even if the magnetic flux on the polar regions increases, $|B_{r\ 1AU}|$ slightly increases in solar minimum and hardly increase in the solar maximum. Therefore, the poor observations of the photosphereric magnetic field is not the main contributor to the open flux problem.

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