Generalization of constant-alpha force-free cylindrical flux rope model

Nobuhiko Nishimura[1]; Katsuhide Marubashi[2]; Munetoshi Tokumaru[3]
[1] ISEE, Nagoya Univ.; [2] NICT; [3] ISEE, Nagoya Univ.

The interplanetary flux rope (IFR) is a transient magnetic field structure expelled from the Sun. The magnetic field structure of IFR consists of helical field lines whose pitch angles change with the distance from the axis. These properties are often compared with those at the Sun. For example, the tilt angle of the axis is compared with that of the magnetic polarity inversion line on the photosphere or the elongation direction of coronal mass ejection (Yurchyshyn et al., 2007; Marubashi et al., 2015). This comparison should help us to understand the dynamics of IFR propagation and lead to improvement of space weather forecasting. On the other hand, helical field lines relate to the poloidal magnetic flux inside the IFR and the magnetic flux is compared with that of the eruption region. This comparison gives us hint on how reconnection contributes to the formation of the poloidal magnetic flux of the flux rope at the Sun (Hu et al. 2014). Thus, understanding the axis orientation and helical field lines of IFR is important. IFR structure has been analyzed by many model fitting methods and reconstruction methods. A widely used model is the cylindrical constant-alpha force-free model (Burlaga, 1988; hereafter, we call it the traditional model). This model is based on the Lundquist solution and the pitch angle of the helical field line becomes 90 deg at the boundary. This boundary condition has been used since many IFRs show 180 deg rotation of observed magnetic field direction. However, IFRs exhibiting considerably small rotations of the magnetic field (for example less than 60 deg) are often observed suggesting that the pitch angle of the helical field line at the boundary may not be 90 deg. Therefore, we relax the restriction that the pitch angle should be 90 deg at the surface and try to fit the observational data to this generalized flux rope model. It can be done by taking the pitch angle at the surface as an additional free parameter in addition to the traditional model. It is known that this new model satisfies the force-free condition. The selection of the pitch angle at the boundary should affect the model fitting result; the structure of the helical field lines and the axis orientation. Therefore, it is expected that the new model changes our understanding of the relationship between IFRs and flux ropes at the Sun. In this presentation, we introduce the new model and show the difference between results from our new model and those from the traditional model. We analyze 87 magnetic obstacles (MOs) listed in Linkcat (https://www.helcats-fp7.eu/catalogues/wp4_cat.html) between 2008 and 2013. The term magnetic obstacle is introduced by Nieves-Chinchilla et al. 2018 in order to signify the possibility of more complex IFR configurations. Thus, MOs are allowed for departures from idealized IFR configurations. The new and traditional cylindrical models are fitted to in situ observations of MOs by Wind, STEREO-A or STEREO-B. 38 out of 87 MOs are fitted well using the new model (cf. 35 out of 87 MOs for the traditional model). The remaining MOs (49 out of 87 MOs) may not be structures suitable for cylindrical flux rope models; toroidal or highly distorted shape and so on. The difference of tilt angles between the new model and the traditional model is found to be small (less than 15 deg) except for one event. Therefore, the selection of the pitch angle at the boundary little affects tilt angles. However, the large difference of axis orientations (greater than 30 deg) is shown for about 30% events although the tilt angles are maintained. The pitch angle of the new model at the boundary significantly changed from that of the traditional model for the non-negligible number of events (about 40% events). The results show that the new cylindrical model should be taken into account especially in examining the helical field line structure of IFR.