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Three-dimensional evolution of ejected flux ropes from the Sun to 1 AU

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Studying the evolution of magnetic clouds entrained in coronal mass ejections using in-situ data is a difficult task since only a limited number of observational points is available at large heliocentric distances. Remote sensing observations can, however, provide important information for events close to the Sun. In this work we estimate the flux rope orientation first by studying the associated prominences and/or post-eruptive arcades using STEREO/EUVI and SOHO/EIT observations, then in the close vicinity of the Sun using forward modeling of STEREO/SECCHI and SOHO/LASCO coronagraph images of coronal mass ejections and, finally, in-situ using Grad-Shafranov reconstruction of the magnetic cloud at 1 AU. We show that it is possible to reconstruct the three-dimensional orientation and geometry of the flux rope in each of these three stages of its evolution. Thus, we are able to measure changes in the orientation of the erupted flux ropes as they propagate from the Sun to 1 AU. In contrast to past studies, our method allows one to deduce the evolution of the three-dimensional orientation of individual flux ropes rather than on a statistical basis. We study 15 magnetic clouds observed during the minimum following Solar Cycle 23 and the rise of Solar Cycle 24. The results of our analysis confirm earlier studies showing that the flux ropes tend to deflect towards the solar equatorial plane. We also find evidence of rotation on their travel from the Sun to 1 AU. We further compare the orientations of the studied flux ropes with the local orientation of the heliospheric current sheet using global MHD simulations of the solar corona.