Geophysical Research Abstracts
Vol. 13, EGU2011-5325-1, 2011
EGU General Assembly 2011

Occurrence Frequency of Interplanetary Magnetic Flux Ropes

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We surveyed the solar wind data to identify magnetic field structures which can be well described by flux rope models. Here we call them interplanetary magnetic flux ropes rather than magnetic clouds, because we include such structures in which magnetic field rotation angles are relatively small, whereas in the original definition of the magnetic cloud (Burlaga et al.) large angles of filed rotation are required. The survey period is 15 years from 1995 to 2009, the data from WIND/MFI and SWE being used for the period from January 1995 to February 1998, and the data from ACE/MAG and SWEPAM for the period from March 1998 to December 2009.
Our criteria for flux rope selection are: (1) the durations are equal to or longer than 7 hours, and (2) the observed magnetic field variations are well fitted to force-free flux rope models. (square root of chi-squares normalized by maximum field intensity should be 0.3.) The fitting was done with both models of cylinder and torus flux rope models when necessary.
As a result we could identify over 400 flux rope structures in the 15-year solar wind data. This number is much larger than the numbers of magnetic clouds identified by previous studies. Take results of 1999 for example, 51 flux ropes were identified in this survey, whereas the number of magnetic clouds (MCs) identified in the previous studies are: 14 MCs (Lynch et al., JGR 2005); 9 MCs (Huttunen et al., Ann. Geophys., 2005); 4 MCs and 16 MC-like structures (Lepping et al., Ann. Geophys., 2006). The list of interplanetary coronal mass ejections (ICMEs) includes 33 ICMEs in 1999 (Richardson and Cane, level 3 data in the ACE Science Center website). The number of flux ropes we identified is large enough to suppose that essentially all the ICMEs should contain embedded flux rope structures. There are two reasons for this large number of flux rope identification. First, there exist some cases for which only the torus model can explain the observations. Secondly, more flux ropes are detected at larger impact parameters (the closest approach distance of the spacecraft from the flux rope axis normalized by flux rope radius). The previous studies did not pay much attention to such cases of spacecraft encounters with flux ropes at large impact parameters because the field rotation angles are small. We argue that this increase in occurrence frequency of flux ropes for larger impact parameters is consistent if the uniform angular distribution is assumed for the orientation of flux rope axis.