Building a Small-scale Magnetic Flux Rope Database via the Grad-Shafranov Reconstruction Technique

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INTRODUCTION

The magnetic flux ropes in the solar wind are an important type of transient and coherent structures. Their formation, propagation and evolution shed light on the big picture of the space plasma dynamic processes. The large-scale magnetic flux ropes are intensively studied in past decades, however, our understanding on the formation, propagation and evolution shed light on the big picture of the space plasma dynamic processes. The magnetic flux ropes in the solar wind are an important type of transient and coherent structures. Their formation, propagation and evolution shed light on the big picture of the space plasma dynamic processes. The large-scale magnetic flux ropes are intensively studied in past decades, however, our understanding on

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In Grad-Shafranov reconstruction technique [Hu and Sonnerup, 2001, 2002; Sonnerup et al., 2006], the magneto-hydrostatic equilibrium assumption is adopted to describe the magnetic field structures. Such a configuration is in static force balance between the plasma pressure gradient and the Lorentz force.

\[ \nabla \cdot B = 0 \]

(1)

There are two other conditions satisfied by the magnetic field which are \( \nabla \times B = 0 \) and \( \nabla \times E = -\mu_0 J \). In arcinclined flux rope, the variation along axial direction is much greater than that in the transverse direction. So we can assume that the magnetic field and plasma equilibrium has the translation symmetry along the axial direction (the z-axis), which is perpendicular to the transverse plane (the cross-section y-plane). The magnetic field vector is transformed into a co-moving frame of reference which is taken as the deHoffmann-Teller (HT) frame (deHoffmann, et al., 1950; Sonnerup, et al. 1967) where the electric field vanishes. Making use of the magnetic flux function (magnetic vector potential in y, z-plane) such that the magnetic field vector is

\[ B = [B_x, B_y, B_z] \]

(2)

one can reduce the Equation (1) to a scalar equation

\[ \frac{\partial^2 B_z}{\partial z^2} + 2 \frac{\partial B_z}{\partial y} + \frac{\partial^2 B_z}{\partial y^2} = \frac{\partial^2 B_y}{\partial y^2} = \frac{\partial^2 B_y}{\partial y^2} = -\frac{\partial^2 B_x}{\partial y^2} \]

(3)

The above Equation (3) is the so-called Grad-Shafranov (GS) equation.

The automated detection algorithm is based on the fact that the magnetic flux function Ay, z is a field line invariant [Sonnerup et al., 2006], and the transverse pressure P_y is a single-valued function of A. When a spacecraft passes through the cross-section of a magnetic flux rope, it firstly crosses some transverse magnetic field lines in its first half path, and then it crosses exactly the same set of transverse field lines, but in reverse order, in its second half path. Therefore, in the in situ data, calculated magnetic flux function A associated with the field lines shows a double-folded pattern. Since the transverse pressure P_y is a single-valued function of A, the two branches of the data points for P_y vs. A should coincide.

Select a detection window size
Find a co_moving frame of reference (HT frame)
Transform magnetic field vectors to HT frame
If the difference of the two branches of double-folded section of PT-A curve is small enough, label it as flux rope candidate.
Apply trial-and-error process to find optimal z-axis orientation, based on the requirement of PT-A being single-valued.
Check if the PT-A curve has double-folding feature. If it does, take the z-axis with best PT-A single-valued curve. If not, slide to next detection window.
Apply selection criteria such as minimum duration, maximum radius, minimum average magnetic field, etc., to refine the database.

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SOLAR-C OBSERVATION

MAGNETIC FIELD MEASUREMENTS

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CONCLUSION AND DISCUSSION

We developed a novel automated flux rope detection algorithm based on Grad-Shafranov reconstruction technique. The algorithm has been tested using in-situ data from WIND spacecraft from 1996 to 2015. A large number of small-scale magnetic flux ropes with time durations ranging from 8 minute to 60 minutes are detected.

Based on the detected events, we did some preliminary statistical analysis. The statistical results show that the occurrence of small-scale magnetic flux ropes has a strong correlation to solar cycle, which indicates that the origination of small-scale magnetic flux ropes relates to the solar activity. The results also show certain features different from large-scale magnetic flux ropes (magnetic clouds), e.g., relatively weak core magnetic field and high plasma beta value. Additional analysis needs to be done to answer the debatable questions concerning the origination and formation mechanism, and the relation to particle acceleration by small-scale magnetic flux ropes.

Currently, this database is still under development and is constantly updated. We need to expand the flux rope database to a new page that shows the detailed analysis result based on the GS method, which is shown to the right for one event. Later we will include more detailed information on the webpages such as the GS reconstruction maps and statistical results.

The current database includes the small-scale flux rope events with time durations from 8 minutes to 60 minutes during the time period 1996 - 2015 (20 years). Later we will expand the database to cover the time durations from several minutes to several hours.

The current database is built based on in-situ data from WIND spacecraft. Later we will use our algorithm to scan more data sources, such as the data from ACE or Ulysses to detect flux ropes in the broader space region.