Final Progress Report for
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Solar Cycle Variation and Multipoint Studies of ICME Properties
P.I.: C. T. Russell

1. Introduction

The goal of the Living With a Star program is to understand the Sun-Earth connection sufficiently well that we can solve problems critical to life and society. This can most effectively be done in the short term using observations from our past and on-going programs. Not only can this approach solve some of the pressing issues but also it can provide ideas for the deployment of future spacecraft in the LWS program. The proposed effort uses data from NEAR, SOHO, Wind, ACE and Pioneer Venus in quadrature, multipoint, and solar cycle studies to study the interplanetary coronal mass ejection and its role in the magnetic flux cycle of the Sun.

ICMEs are most important to the LWS objectives because the solar wind conditions associated with these structures are the most geoeffective of any solar wind phenomena [Lindsay et al., 1995]. Their ability to produce strong geomagnetic disturbances arises first because of their high speed. This high speed overtakes the ambient solar wind producing a bow shock wave similar to the terrestrial bow shock. In the new techniques we develop as part of this effort we exploit this feature of ICMEs. This shocked plasma has a greater velocity, higher density and stronger magnetic field than the ambient solar wind, conditions that can enhance geomagnetic activity. The driving ICME is a large magnetic structure expanding outward in the solar wind [Gosling, 1996]. The ICMEs magnetic field is generally much higher than that in the ambient solar wind and the velocity is high. The twisted nature of the magnetic field in an ICME almost ensures that sometime during the ICME conditions favorable for geomagnetic storm initiation will occur.

To make early rapid progress in the objectives of the Living with a Star program we must exploit existing data sets and on-going space missions. To obtain data over the solar cycle we use the existing magnetic field and plasma data obtained by the Pioneer Venus spacecraft from 1978 to 1988 and the Wind magnetic field and plasma data from 1994 to 2004. To relate the structure of ICMEs to their causative CMEs on the Sun, we use the magnetic field data from the NEAR spacecraft in conjunction with SOHO images at times when NEAR is above the limbs of the Sun as seen from Earth (i.e. quadrature studies). To move away from overly simple models of ICME structure we exploit multipoint measurements of ICMEs using chance conjunctions of interplanetary spacecraft including Pioneer Venus and ISEE3, NEAR and Wind, as well as (on shorter baselines) the Wind-ACE pair. These multipoint studies allow us to prepare for the operation of the dual satellite STEREO mission as well as to give us direction for deploying follow-on multi-spacecraft missions.
Reference


2. Progress Report

Two quadrature studies were initiated, one with Chris St Cyr and one with Dave Rust. In the former study St Cyr measured the velocity of the CME in the corona and T. Mulligan calculated the transit speed to NEAR. These speeds agreed with no acceleration or deceleration of the ICME. The coronal speeds are shown in Figure 1. In the second study T. Mulligan inverted the properties of ICMEs and provided them to D. Rust for his comparison with solar magnetic structure. As part of this effort a dataset of NEAR magnetic measurements has been prepared and a website (http://www-ssc.igpp.ucla.edu/forms/polar/corr_data_new.html) provides plots and datasets to the community.

Next we have examined the ACE and NEAR data during the Bastille Day event and during the August 13, 2000 event. The former event is excellent for defining the expansion of ICME radii with heliocentric distance [3.1, 3.8, 4.2, 4.5, 4.6 and 5.1]. The second event is well suited for determining the bend in the axial field of a magnetic rope [3.8, 4.2, 4.5, 4.6, 5.1].

Then we examined the PVO observations of ICMEs over a solar cycle. We specifically examined how twisted the ropes were and the force-balance in the ropes. In most ropes the forces had a net outward component unless there was force balance, and there was some correlation of twistedness and this force imbalance. The ropes generally had a twist unlike that in a Bessel function flux rope [5.1]. This observation inspired an examination of the limitations of the Bessel function approach. These disadvantages were discussed at several conferences [4.3, 4.4, 4.7] and a published paper [3.8].

![Figure 1. Coronal speeds associated with CME later observed by NEAR above the same limb of the Sun.](attachment:chart.png)
As expected Tamitha Mulligan finished her dissertation, albeit a little later than expected [5.1]. Liz Jensen was able to begin work on the project with a new approach to determining flux rope orientation [4.16, 4.20, 4.22] and an undergraduate student Aniketa Shinde also assisted in identifying events and visualization of rope structure. Shinde’s work led to a method to identify ICMEs principally by their solar wind ion signatures [3.10, 4.11, 4.14, 4.15, 4.18]. She also completed a study that classified ICMEs by the strength of their signatures in different parameters and then contrasted her identification with those of other groups. This study has been slowed in the publication process by a referee who does not like what the comparison shows about his list [3.11, 4.23, 4.26]. After A. Shinde graduated this work was advanced by a new graduate student, L. Jian, who combined the plasma and magnetic field data to obtain the total pressure (perpendicular to the field). This parameter smoothly varies with occasional jumps due to shocks. The parameter provides diagnostics of ICMEs that are not obvious from the individual parameters and in addition can be used to characterize and identify stream interactions [4.27, 4.32, 4.33].

Finally, the grant supported the publication of the PVO-ISEE study [3.1] a tutorial on the solar wind and space weather [3.2] a discussion of why we use the term ICME [3.3] and an invited review on ICMEs [4.1] and a contributed review [3.9]. We have also initiated a study of the expansion of ICMEs as evidenced by the velocity variation in the solar wind plasma as the ICME passes [4.11, 4.14] and an ACE-Wind study of small scale structure [4.12]. L. Jensen who is taking over T. Mulligan’s efforts is also examining the solar coronal magnetic field via Faraday rotation using the Cassini spacecraft [3.12, 4.13, 4.30, 4.31]. The grant helped support our study of interplanetary field enhancements [4.17] and studies of the Halloween event [4.21, 4.24, 4.28].

3. Papers in Journals and Books (05/1/01 – 02/28/03)


4. Papers Presented at Meetings (05/1/01 – 02/28/03)


4.32 L. Jian, C. T. Russell, and J. T. Gosling, Using the total perpendicular pressure to diagnose corotating interaction regions and ICMEs, presented at Sun-Earth Connection Physics: The Geolmpact of CMEs, CIRs, and Ordinary Solar Wind, Merida, Mexico, November 2004.

5. Thesis