The Astrophysical Journal, 647:648–653, 2006 August 10


# ON THE RATES OF CORONAL MASS EJECTIONS: REMOTE SOLAR AND IN SITU OBSERVATIONS

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*Received 2006 March 3; accepted 2006 April 25*

## ABSTRACT

We compare the rates of coronal mass ejections (CMEs) as inferred from remote solar observations and interplanetary CMEs (ICMEs) as inferred from in situ observations at both 1 AU and *Ulysses* from 1996 through 2004. We also distinguish between those ICMEs that contain a magnetic cloud (MC) and those that do not. While the rates of CMEs and ICMEs track each other well at solar minimum, they diverge significantly in early 1998, during the ascending phase of the solar cycle, with the remote solar observations yielding approximately 20 times more events than are seen at 1 AU. This divergence persists through 2004. A similar divergence occurs between MCs and non-MC ICMEs. We argue that these divergences are due to the birth of midlatitude active regions, which are the sites of a distinct population of CMEs, only partially intercepted by Earth, and we present a simple geometric argument showing that the CME and ICME rates are consistent with one another. We also acknowledge contributions from (1) an increased rate of high-latitude CMEs and (2) focusing effects from the global solar field. While our analysis, coupled with numerical modeling results, generally supports the interpretation that whether one observes a MC within an ICME is sensitive to the trajectory of the spacecraft through the ICME (i.e., an observational selection effect), one result directly contradicts it. Specifically, we find no systematic offset between the latitudinal origin of ICMEs that contain MCs at 1 AU in the ecliptic plane and that of those that do not.

*Subject headings:* solar wind — Sun: activity — Sun: corona — Sun: coronal mass ejections (CMEs) — Sun: magnetic fields

## 1. INTRODUCTION

In this report we compare the rates of coronal mass ejections (CMEs) observed at the Sun with the rates of interplanetary CMEs (ICMEs) inferred from in situ measurements. To our knowledge, this is the first time such a direct comparison has been made. We distinguish those ICMEs that also contain a flux rope and those that do not. Our goals are twofold: first, to understand the similarities and differences between CME and ICME rates; and second, to assess whether distinct classes of CMEs can be discerned from this analysis.

Over the years a number of studies have quantified the occurrence rates and properties of CMEs and ICMEs. Hundhausen (1993) used *Solar Maximum Mission* (*SMM*) coronagraph/polarimeter measurements of the solar corona in 1980 and from 1984 to 1989 to study the statistical properties of 1300 CMEs. He found that (1) the average (median) angular width (in the plane of the sky) was 47° (44°); (2) there was no systematic trend in angular width during the course of these observations; (3) the distribution in central latitude of the CME was approximately symmetric with respect to the heliographic equator; (4) the spread in central latitude showed a strong dependence on solar cycle, with the rms average latitude being $\sim$13° at solar minimum and $\sim$40° at solar maximum; and (5) the changes in the distribution of central latitudes corresponded to large-scale magnetic structures, such as prominences and bright coronal regions, and not to small-scale structures, such as sunspots, active regions (ARs), or H$\alpha$ flares.

Webb & Howard (1994) studied the occurrence rates of CMEs over more than a solar cycle using data from *Skylab*, *SMM*, Solwind, and the *Helios* zodiacal light photometers. They found that the CME rate tended to track the solar activity cycle in both amplitude and phase. Moreover, no particular class of solar activity (e.g., H$\alpha$ flares, metric type II bursts, interplanetary shocks, disappearing filaments, and erupting prominences) appeared to notably better correlated than any other.

St. Cyr et al. (2000) studied the properties of CMEs using data from the LASCO instrument on board *SOHO*. They found that the rate of CMEs and distribution of apparent locations of CMEs was generally consistent with these previous studies. One notable difference, however, was that the average apparent size of the CMEs was significantly larger. This was attributed to the detection of a significant population of partial and full halo CMEs.

Yashiro et al. (2004) compiled the most complete catalog of CMEs to date. Using nearly 7000 events, they found that the average width of normal CMEs (that is, CMEs for which $20° <$ width $< 120°$) rose from 47° at solar minimum to 61° during the early phase of solar maximum, and back to 53° during the late phase of solar maximum. Gopalswamy (2004) compared the CME rate determined from this catalog with sunspot number. He found two clear peaks (in 2000 and 2002) in the CME rates that had corresponding peaks in sunspot number. However, the CME

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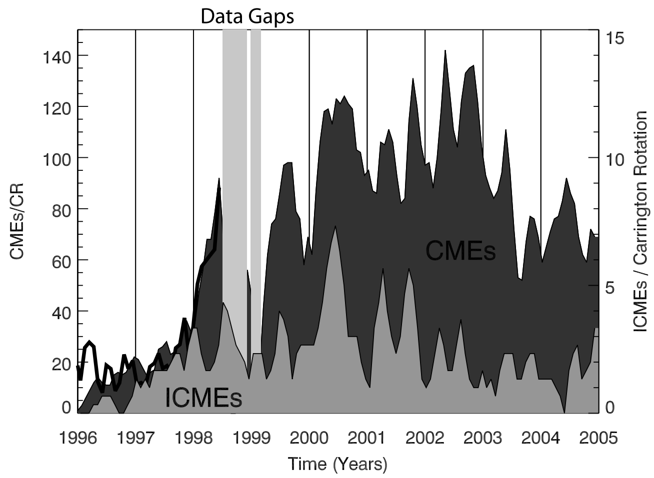


FIG. 1.—Running means (3-rotation) of CME (*dark gray*) and ICME (*light gray*) rates as a function of time, normalized to one Carrington rotation. As indicated by the vertical panels, no *SOHO* LASCO data were available during the second half of 1998 and in 1999 January. The black line running from 1996 through mid-1998 is the CME rate as determined by St. Cyr et al. (2000).

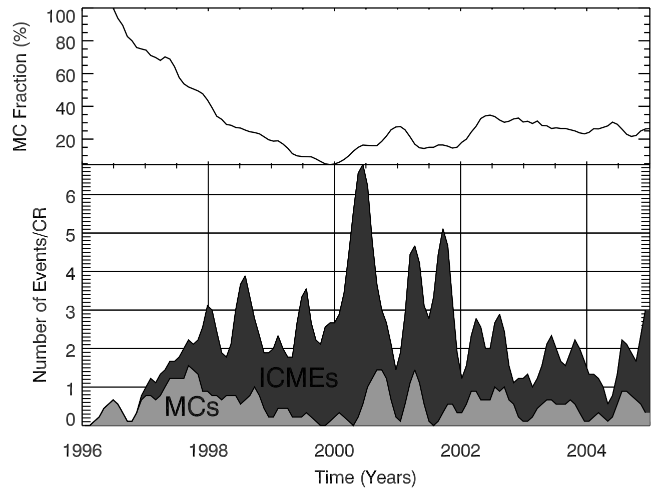


FIG. 2.—Running means (3-rotation) of magnetic cloud fraction (*top*) and non-MC ICME (*dark gray*) and MC (*light gray*) rates (*bottom*) as a function of time, normalized to one Carrington rotation.

rate peaks occurred some 2–3 months following the sunspot peaks. He attributed this to the fact that CMEs originate from quiescent filament regions that may not be associated with sunspots.

Cane & Richardson (2003) conducted a detailed survey of ICMEs at 1 AU from 1996 through 2002. They reported on the basic physical properties for over 200 events and found that the ICME rates increased by an order of magnitude between solar minimum and maximum. They also noted a periodic variation with a timescale of ~165 days, as well as other nonperiodic enhancements that were correlated with high solar activity levels (see also Richardson & Cane 2005). By distinguishing those ICMEs that were also magnetic clouds (MCs) they deduced that the "MC fraction" ranged from 15% at solar maximum to 100% at solar minimum (Richardson & Cane 2004). Richardson & Cane (2005) extended this survey through 2004. They interpreted the ICME rate as being composed of a background rate of ~1–2 ICMEs/rotation, upon which is superimposed a modulating component, associated with the presence of major ARs and present from 1997 through 2004. They also noted that the MC fraction, which decreased from ~100% in 1996 to ~10%–20% by 1999, remained approximately flat through 2004.

The aim of this report is to describe, compare, and interpret the inferred rates of CMEs at the Sun and their counterparts in the solar wind (ICMEs) at 1 AU and beyond. In § 2 we discuss the CME and ICME rates. We distinguish between ICMEs that contain flux ropes (MCs) and those that do not (non-MC CMEs). We also summarize *Ulysses* ICME rates during this same time period. In § 3 we describe several solar parameters, including photospheric observations of the magnetic field and the source latitude of CMEs. Finally, in § 4 we summarize the main results from this study and, with the aid of a simple geometric argument, demonstrate that the computed ICME rates are consistent with the CME rates. We discuss these results within the context of the relationship between MCs and ICMEs in general.

## 2. CME AND ICME RATES

The inferred rates of CMEs and ICMEs (in units of number per Carrington rotation [CR]) from the beginning of 1996 through the end of 2004 are summarized in Figure 1. The CME rates were derived from the *SOHO* LASCO online CME catalog.[3] They have not been corrected for *SOHO* LASCO downtimes; however, these effects are modest (compare with Fig. 4 of Gopalswamy et al. 2005) and do not affect our results. The ICME rates were obtained from an ongoing study described by Cane & Richardson (2003), and in particular, their Figure 2. They represent the best estimate of ICMEs in the near-Earth solar wind during this period, based on data from all available spacecraft and using a broad range of ICME signatures to identify events. Also superimposed is the CME rate as determined by St. Cyr et al. (2000). Although these results terminate in 1998 June, they provide independent verification that the identification criteria for CMEs in the online catalog, and hence the inferred CME rates are reliable. Several features from the figure are worth commenting on. First, the three profiles track one another reasonably well during the period following solar minimum (1996 January–1997 December), showing a gradual rise from ~10 CMEs/CR to ~30 events/CR (or 0.5–3 ICMEs/CR). Second, at the beginning of 1998, the CME and ICME rates diverge significantly, with the ICME rate maintaining an approximate value of 2–3 ICMEs/CR and the CME rate climbing to ~90–100 CMEs/CR at solar maximum. Third, superimposed on this solar-cycle-scale variation are perturbations in both the CME and ICME rates with periods of approximately 1/2 and 1 yr. These are particularly visible in the CME rates, which show midyear peaks in 1998, 1999, and 2000.

Cane & Richardson (2003) and Richardson & Cane (2004) also identified the subset of ICMEs that were also MCs. In Figure 2 we have separated the ICME rates into MCs and non-MC ICMEs. The MC rate is essentially flat throughout the entire period between 1996 and the end of 2004, showing a slight peak in late 1997 and a minimum just prior to solar maximum. We emphasize that variations on a timescale of a year or less should be viewed with caution given the small number of events observed. The non-MC ICME rate, on the other hand, rises from 1996 to early 1998, maintains a higher value during 1998–2002, and displays the biannual and annual peaks present in Figure 1. Viewed as a percentage, the fraction of ICMEs that were also MCs declined from ~100% in 1996 to zero in 2000, increasing slightly and remaining roughly constant (~25%) through 2004.

[3] See http://cdaw.gsfc.nasa.gov/CME_list.

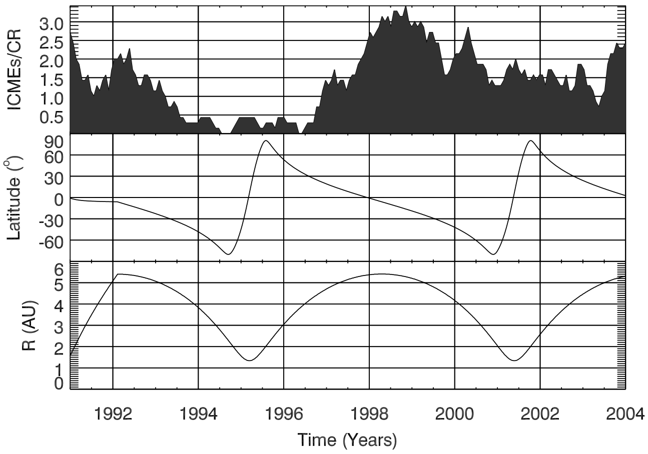


Fig. 3.—Running means (3-rotation) of ICME rate at *Ulysses* normalized to one Carrington rotation (*top*), latitude of *Ulysses* spacecraft (*middle*), and heliocentric distance of the *Ulysses* spacecraft (*bottom*) as a function of time.

Encompassing this time period, the *Ulysses* spacecraft was sampling the heliosphere over a range of latitudes and heliocentric distances (Smith & Marsden 2003). Figure 3 summarizes the ICME rate as determined from a variety of plasma and magnetic field signatures for more than one complete solar cycle. Our identification criterion was similar to that of Phillips (1997) and Gosling & Forsyth (2001); however, during the period from 1990 through 2002, we identified 33% (60) more events. A list of these events will be reported elsewhere; however, we note that the rates shown here do not differ qualitatively from the rates determined from the original ICME list.[4] Data gaps starting in 2004 preclude us from computing meaningful ICME rates beyond this point. Given the low number of events, we must take care in interpreting the results. On the largest scales, we infer that the ICME rate rose from 1996 onward, peaked in 1998, and subsequently declined. The peak ICME rate coincided with the spacecraft's traversal through the solar equatorial plane, which occurred while the spacecraft was located at its farthest distance from the Sun. The low ICME rates from mid-2000 to early 2001 occurred while *Ulysses* was at high latitudes. Interestingly, during the rapid latitude scan in 2001, the ICME rate remains approximately constant at all latitudes. On smaller scales, there is again the indication of episodic enhancements to the CME rate on the timescale of ~1 yr. It is also worth noting that the average ICME rates derived from the *Ulysses* data are similar to those at 1 AU (~1 per CR), despite differences in the heliocentric distance and latitude of the spacecraft as well as potential differences in the criteria used to identify the events.

## 3. SOLAR OBSERVATIONS

To relate these rates to solar observations, in the top panel of Figure 4 we have computed the $m = 0$ azimuthally symmetric part of the radial component of the magnetic field from Kitt Peak synoptic maps, for a period of ~30 yr (or almost 3 solar cycles). Blue indicates inward polarity, and red indicates outward polarity. These patterns describe the emergence of ARs and their associated magnetic flux at midlatitudes (initially at $|\lambda| \sim 25°$), their transport and diffusion, and their eventual annihilation. In addition, flux from the trailing parts of ARs can be seen to migrate steadily poleward. Below this, we show the monthly averaged sunspot number (SSN). The bottom panel

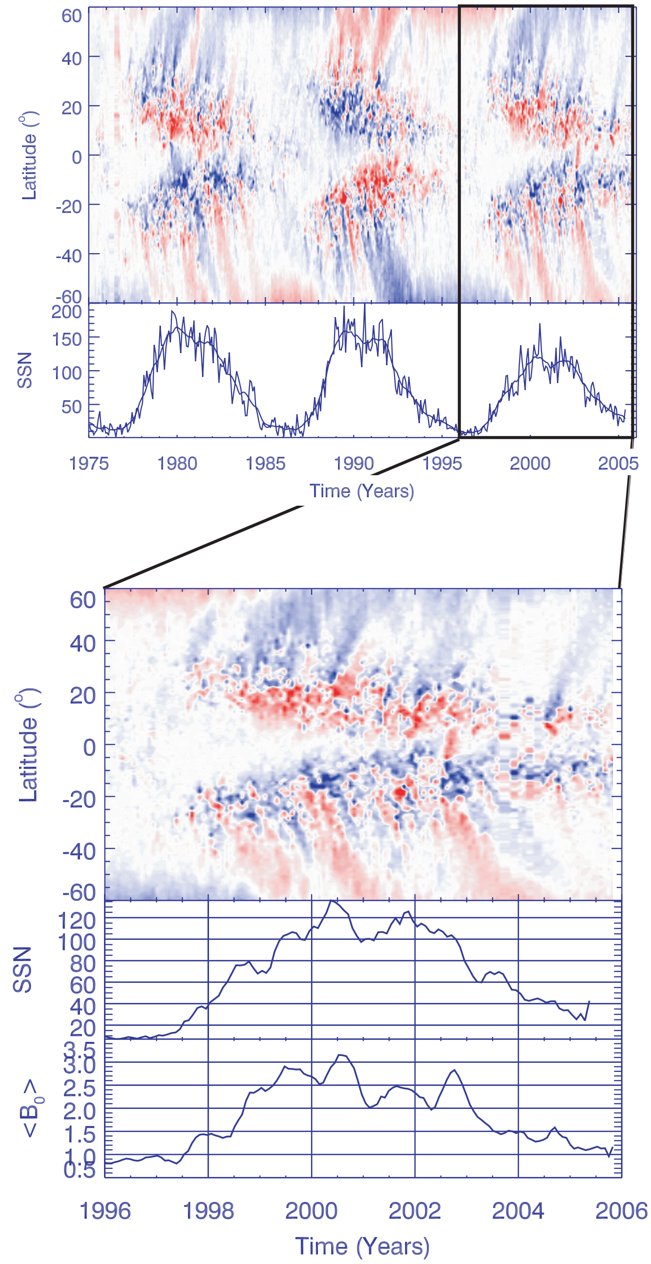


Fig. 4.—*Top:* Variation of the $m = 0$ azimuthally symmetric part of the radial component of the magnetic field (as inferred from Kitt Peak synoptic maps) and the monthly averaged and smoothed sunspot number (SSN) as a function of time. *Bottom:* Blowup of the data covering 1996 through 2002, and adding the average value of the $m = 0$ azimuthally symmetric part of the radial component of the magnetic field. Red (blue) indicates outwardly (inwardly) directed magnetic field.

replots these parameters for the range 1996–2005 and, in addition, shows a running mean of the latitudinally averaged absolute value of the $m = 0$ magnetic field. This then is a measure of the strength of the ARs present at that time. Several features are noteworthy. First, the midlatitude ARs appeared at the beginning of 1998, corresponding to the time when (1) the CME and ICME and (2) the non-MC ICME and MC rates diverged. Second, the SSN and $\langle B_0 \rangle$ profiles track each other well and, moreover, show localized maxima coincident with the approximately yearly peaks observed in the CME, ICME, and non-MC ICME rates, particularly at mid-1999, mid-2000, and mid-2001.

To complete our statistical description of these events, in Figure 5*a* we show the evolution of the source latitude of halo

[4] See http://swoops.lanl.gov/cme_list.html.

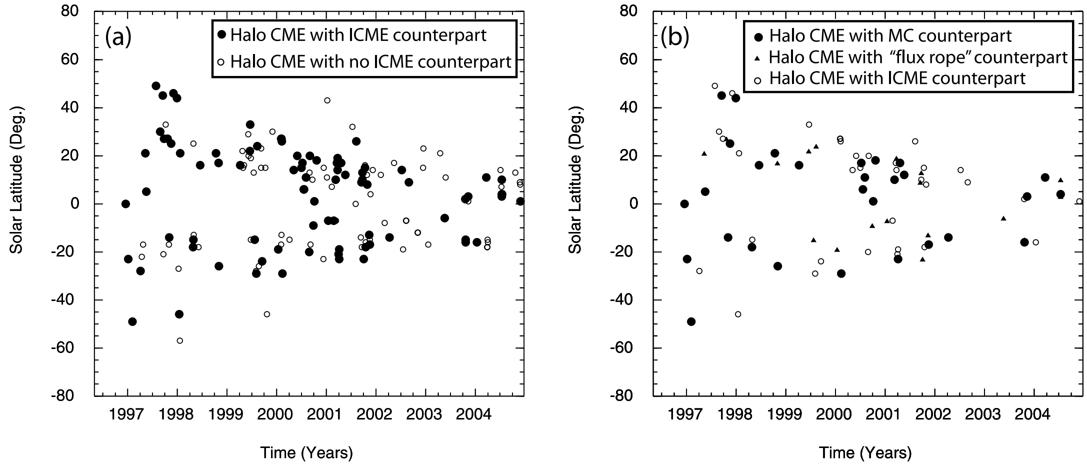


FIG. 5.—(*a*) Source latitude of all halo CMEs from 1997 through the end of 2004, categorized into those for which an ICME could be identified in 1 AU, in-ecliptic data (*filled circles*) and those for which one could not (*open circles*). (*b*) Source latitude of those CMEs that intercepted Earth for which: a MC could be identified (*filled circles*); a flux-rope-like structure could be identified (*filled triangles*); and no obvious rotations in the magnetic field were present (*open circles*).

CMEs (based on the location of an associated H$\alpha$ flare or disappearing filament), from 1997 through the end of 2004. They have been further divided into those for which a corresponding ICME could be identified in 1 AU inecliptic data (*filled circles*) and those for which one could not (*open circles*). Thus, these latter events probably did not intercept Earth. The main trend during this interval is the equatorward migration of the source latitudes, which flattens out by 2002, and the general pattern is similar to the AR evolution summarized in Figure 4. This profile appears to have begun in late 1997, with events early in that year clustering closer to the equator. Interestingly, there appears to be no systematic difference between the source latitude of CMEs that intercepted Earth, and those that did not. Figure 5*b* reproduces the source latitudes of those ICMEs that intercepted Earth but now distinguishes between those events for which a "classic" MC could be identified (*filled circles*), those that contained flux-rope-like features (*filled triangles*), and those ICMEs that had no obviously organized magnetic features (*open circles*).

## 4. SUMMARY AND DISCUSSION

In this report we have analyzed the inferred rates of coronal mass ejections (CMEs) from remote solar observations (*SOHO* LASCO) and the interplanetary counterparts of CMEs (ICMEs, from multiple spacecraft at 1 AU and at *Ulysses*) during the period from 1996 through 2004. We found that these rates diverged at the beginning of 1998, during the early ascending phase of the solar activity cycle. A similar divergence was found between ICMEs that are also magnetic clouds and those that are not. In addition, we noted several peaks in the occurrence rates of both CMEs and ICMEs reoccurring on quasi-biannual and -annual timescales. These were reproduced in the occurrence rate of ICMEs that were not identified as MCs, but not in the occurrence rates of MCs. Counterparts to the yearly peaks were noted in both time series of sunspot number and the observed mean absolute radial photospheric magnetic field. The divergence in CME and ICME rates was coincident with the appearance of midlatitude ARs, which occurred during the early ascending phase of the solar cycle.

There are a number of effects that could have contributed to the divergence between the CME and ICME rates. In the simplest terms, it can be attributed to the documented spread in the distribution in latitude of the inferred source location of CMEs during the rise toward solar maximum (Hundhausen 1993; St. Cyr et al. 2000). More specifically, given the well established association of many CMEs with ARs, we suggest that this divergence results from the appearance of midlatitude ARs, further suggesting a distinct new source of events. Thus, prior to 1998, most CMEs were presumably associated with large-scale eruptions of the streamer belt (although some AR-associated events were undoubtedly present). However in early 1998, the majority of CMEs were produced from AR eruptions at midlatitudes.

High-latitude CMEs, associated with the disappearance of polar crown filaments, undoubtedly also contributed to this divergence. From mid-1998 and through solar maximum, this subset of CMEs contributed 20%–25% to the total CME rate (Gopalswamy et al. 2003a) and, in particular, showed the same increase in early 1998. In fact, while the rate of lower latitude CMEs increased by a factor of $\sim$4 from 1997 to 2000, the corresponding increase in the high-latitude CME rate was almost an order of magnitude.

The strength and structure of the global coronal field may also have played a role in modulating differences between CME and ICME rates. Using case studies (Gopalswamy et al. 2000), statistics (Gopalswamy et al. 2003b), and analytic theory (Filippov et al. 2001), it has been shown that the global dipolar field exerts some control on the path of CMEs. The argument made is that during the ascending phase of the solar cycle, the polar field strength weakens, which in turn suggests that CMEs are no longer "guided" by the global magnetic field. Thus, fewer CMEs are intercepted by Earth.

Using simple geometric arguments, we can assess whether the CME and ICME rates at different epochs of the solar cycle are consistent with the relatively robustly measured property of CME angular width. Consider the simplified picture of a CME that evolves such that it maintains a constant angular width and circular cross section with increasing distance from the Sun. On the basis of global simulations (e.g., Riley et al. 2003), this is probably a reasonable assumption beyond several solar radii. If the CME is launched from the solar equator, but at a random longitude, then, neglecting differences between the ecliptic and solar equatorial planes, the probability that the CME will intercept the Earth is simply

$$P_1 = a/(2\pi), \qquad (1)$$

where $a$ is the (full) angular width of the CME. On the other hand, if the CME is launched from a completely random point on the Sun (i.e., an arbitrary latitude and longitude), then the probability that the CME will intercept the earth can be shown to be

$$P_2 = [1 - \cos(a/2)]/2. \quad (2)$$

These probabilities, $P_1$ and $P_2$, roughly correspond to solar minimum and maximum conditions, respectively, and can be used to relate the CME and ICME rates ($R$) to one another:

$$R_{\rm ICME} = PR_{\rm CME}. \quad (3)$$

For example, using the data in Figure 1, at solar minimum ($\sim$1996), $R_{\rm ICME}/R_{\rm CME} = 0.092$. Solving equation (1) for $a$ leads to an average CME angular width or 33°. In contrast, at solar maximum ($\sim$2001) $R_{\rm ICME}/R_{\rm CME} = 0.039$, and equation (2) yields an average angular width of 45°. These results are qualitatively consistent with the values obtained by Yashiro et al. (2004).

The ICME rates observed by the *Ulysses* spacecraft are more difficult to interpret because of its continual motion in both heliocentric distance and latitude. On the largest scales, the variations seem to be modulated primarily by latitudinal effects; i.e., *Ulysses* saw the highest ICME rates while located near the ecliptic plane. In addition, solar cycle trends are clearly present, as indicated by the near-zero rates from 1994 through mid-1996. There are no obvious trends with heliocentric distance, although it is possible that such an effect is present but masked: such an effect might be anticipated as ICME signatures becoming more difficult to discern at larger heliocentric distances. It is intriguing that episodic peaks on the timescale of $\sim$1 yr are also present. The low number of events does not allow us to speculate about variability on shorter timescales than this.

The relationship between ICMEs and MCs is not well understood. In particular, why do only a fraction of all ICMEs contain a MC (Gosling 1990; Richardson & Cane 2004)? There are several possible explanations. First, it could be an observational selection effect. That is, the magnetic cloud is a smaller scale structure embedded within the ICME. Whether or not the spacecraft detects a MC structure depends on its trajectory through the event (Marubashi 1997). During the ascending phase of the solar cycle as magnetic clouds are launched at higher latitudes, glancing impacts in the ecliptic plane may emphasize the non-flux-rope characteristics of the ejecta. There is evidence from multispacecraft observations that MCs may be smaller scale structures embedded within an ICME (e.g., Cane et al. 1997). Second, there could exist two (or more) distinct classes of CMEs, one that contains a MC and one that does not. Over the years, a number of attempts have been made to classify CMEs into distinct classes. The earliest, due to MacQueen & Fisher (1983) and revisited by Sheeley et al. (1999), was based on an apparent segregation of CMEs that were either (1) fast and typically associated with flares or (2) slow and typically associated with prominences. While these studies were suggestive, they were not, by any means, conclusive. Counterexamples were readily available. For example, fast CMEs that were obviously associated with a prominence have been found (Sheeley et al. 1999). From a modeling standpoint, it has been argued (Low & Zhang 2002) that two fundamental mechanisms can yield distinct classes of CMEs. Again, however, there is not a consensus view. Linker et al. (2001) have argued that the observations currently do not allow us to differentiate between potential competing mechanisms and that, in fact a single mechanism could reproduce the observed speed variations within CMEs. Chen & Krall (2003) also concluded that one mechanism could explain both prominence- and flare-related events. And, perhaps most importantly, none of these classifications directly address the presence or absence of flux ropes within the ICME. In fact, even the most sophisticated numerical models are incapable of producing a CME without an embedded flux rope. Third, whether or not one observes a MC could be a direct or indirect solar cycle effect (Richardson & Cane 2004). In the direct case, the initial structure of the erupting CME becomes increasingly complex from solar minimum to maximum. In the indirect case, interactions with other ICMEs and ambient solar wind structure could break up the simple flux-rope-like structure. CMEs interact strongly with the ambient solar wind (e.g., Riley et al. 1997; Odstrcil & Pizzo 1999a, 1999b, 1999c) and with other CMEs both close to the Sun (Gopalswamy et al. 2001, 2002a, 2002b) and in the solar wind (e.g., Burlaga et al. 2001). The coherence of the ICME's structure may depend on the conditions of the medium surrounding the ejecta. This phenomenon would increase as the rate of occurrence of CMEs increased. Richardson & Cane (2004) have argued that ICME-ICME interactions would be unlikely to explain these results, since the CME rate is not high enough to produce sufficient merging of MCs by 1 AU. Fourth, the MC/ICME relationship could be an evolutionary phenomena. On one hand, MCs could "age" with increasing heliocentric distance from the Sun (Osherovich & Burlaga 1997). In this scenario, the field strength of the flux rope decreases as the ICME moves away from the Sun to the point where the MC is not longer detected, and the MC fraction would decrease with increasing distance from the Sun. On the other hand, initially complex structures might "relax" into simpler flux rope configurations, such that the MC fraction increases with distance from the Sun (J. T. Gosling 1996, private communication). Richardson & Cane (2004) studied *Helios* data together with near-Earth observations and found no evidence for this evolutionary argument, at least between 0.3–1 AU.

The results described here are broadly consistent with the "selection effect" interpretation for the relationship between MCs and non-MC ICMEs, for the following reasons. First, near solar minimum, when many CMEs were launched near the solar equator, spacecraft located at 1 AU intercepted them close to their center. If all (I) CMEs contained a flux rope embedded in their center, then we would predict that all events were also MCs, as observed. Second, in early 1998 when the CME and ICME rates diverged, the rates of non-MC ICMEs and MC ICMEs also diverged, consistent with the idea of the Earth-based spacecraft intercepting the structure farther from its center and outside of the embedded flux rope. Third, the quasi-biannual and quasi-yearly periodicity in the CME rates is mirrored in the total and non-MC ICME rate profiles, but not the MC rate (although the poor statistics make this inference tentative). These variations are also visible in the $\langle B_0 \rangle$ and SSN profiles. Thus, the collective effect of the increasing CME rate from solar minimum to maximum, combined with the latitudinal spread in their source longitude resulted in an approximately constant MC rate during this period.

There are several aspects of our analysis that do not readily fit with the conclusions we have drawn here. First, concerning the divergence of the CME and ICME rates, why are the sources of events in late 1997, on average, at higher latitudes than in 1998, while the CME and ICME rates do not diverge significantly until the beginning of 1998? This may reflect a statistical limitation but could, in principle, be explained by the time lag between appearance of higher latitude CMEs in late 1997 and the increase in their occurrence rate at the beginning of 1998. In addition, we have expected the CME and ICME rates to agree better in 2002 and subsequent years, as the latitudes of emerging ARs flattened out to solar minimum values. In fact, this convergence is present due to the relative constancy of ICME rates and the general decline in CME rates starting in 2002. This issue may be resolved when we have completed a complete cycle through solar minimum, which should occur within the next year or two. Second, concerning relationship between MCs and ICMEs, if MCs are embedded within ICME structures, then as the ARs move to lower latitudes (Fig. 4), why do we not see the fraction of MCs increase? What we do see (Fig. 2) is that the MC fraction increases from 2000 through 2002 and remains relatively constant thereafter. Moreover, as shown in Figure 5*b*, there is no obvious difference in source latitude between those ICMEs that contain MCs (or flux-rope-like structures) and those that do not. However, given the errors associated with the identification of the source latitudes of these events as well as the limited number of events, we should be cautious in weighting these results.

As a final point, we note that all theories of CME initiation (and their numerical implementation) require either the presence or formation of a flux rope as an integral part of the eruption process. In fact, modelers have not yet been able to conceive of a process that could produce a CME without the presence of a flux rope. This is, in large part, due to the dominant role that the magnetic field plays in the eruption process through the conversion of magnetic energy into kinetic energy: stressing and energizing the field naturally leads to the formation of helical field lines. Simulations of ICME evolution in the solar wind (e.g., Riley et al. 2003) also support the idea that the presence or absence of a flux rope is sensitive to the spacecraft's trajectory through the disturbance. In fact, it is likely that fast CMEs produce disturbances that propagate sufficiently far in latitude that a spacecraft may never intercept the original ejecta yet time series of speed, density, and temperature may suggest the presence of an ICME (Riley et al. 1997). Conversely, it may even be possible for disturbances to alter the ambient magnetic field to the extent that a coherent structure mimicking a partial rotation of the magnetic field is produced.

P. R. gratefully acknowledges the support of the National Aeronautics and Space Administration (LWS and SECT Programs) and the National Science Foundation (SHINE Program) in undertaking this study.

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