26-DAY ANALYSIS OF ENERGETIC ION OBSERVATIONS AT HIGH AND LOW HELIOLATITUDES: *ULYSSES* AND ACE

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Abstract. We present observations of energetic (0.34–8 MeV) ions from the *Ulysses* spacecraft during its second ascent to southern high latitude regions of the heliosphere. We cover the period from January 1999 until mid-2000 as *Ulysses* moved from 5.2 AU and 18° S to 3.5 AU and 55° S. In contrast to the long-lived and well-defined ∼26-day recurrences that were observed throughout *Ulysses*' first southern pass, energetic ion fluxes during the first portion of the *Ulysses*' second polar orbit are highly irregular. Although corotating interaction regions (CIRs) are clearly present in solar wind and magnetic field data throughout the first half of 1999, their effects on energetic ion intensities are quite different from what they were in 1992–1993. No dominant strictly recurrent ion flux increases are observed in association with the arrival of these CIRs. Correspondingly, there is no stable structure of large polar coronal holes during the same period. Isolated transient solar energetic particle (SEP) events are observed at low and high latitudes. We compare energetic ion observations from the ACE and *Ulysses* spacecraft during the first half of 1999 to determine the influence of these SEP events in the observed recurrent CIR structure. Such SEP events occurred only occasionally during 1992–1993, but when they occurred, they obscured the recurrences in a manner similar to that observed in 1999–2000. We therefore conclude that the basic differences in the behavior of energetic ion events between the first and second southern passes are due to the short life of the corotating structure and the higher frequency of SEP events occurring in 1999–2000.

From January 1999 to May 2000 *Ulysses* moved south from a heliolatitude of 18° S to 55° S. The same range of latitudes was covered in its first polar orbit from the end of 1992 through early 1994. While the first polar orbit spanned the declining phase of the solar cycle 22, the second orbit coincided with the rising phase of the solar cycle 23. Energetic ion observations over the first portion of *Ulysses*' second polar orbit were remarkably different from those taken at similar latitudes in its first orbit. Figure 1 shows energetic ion intensities and solar wind speed as measured by *Ulysses* instrumentation throughout this range of heliolatitudes [18°–55° S]. In the first orbit (top panel), before reaching ∼36° S, solar wind flows from both the streamer belt (at ∼400 km s^{-1}) and from the polar coronal hole (at ∼800 km s^{-1}) were observed in each solar rotation. Strong and recurrent corotating interaction regions (CIRs), mostly bounded by forward and reverse shock pairs (FS–RS), were observed up to a latitude of ∼36° S. Rotation 15 was the last rotation where a corotating FS–RS pair was observed. From then on, the spacecraft was immersed in the flow from the polar coronal hole and only

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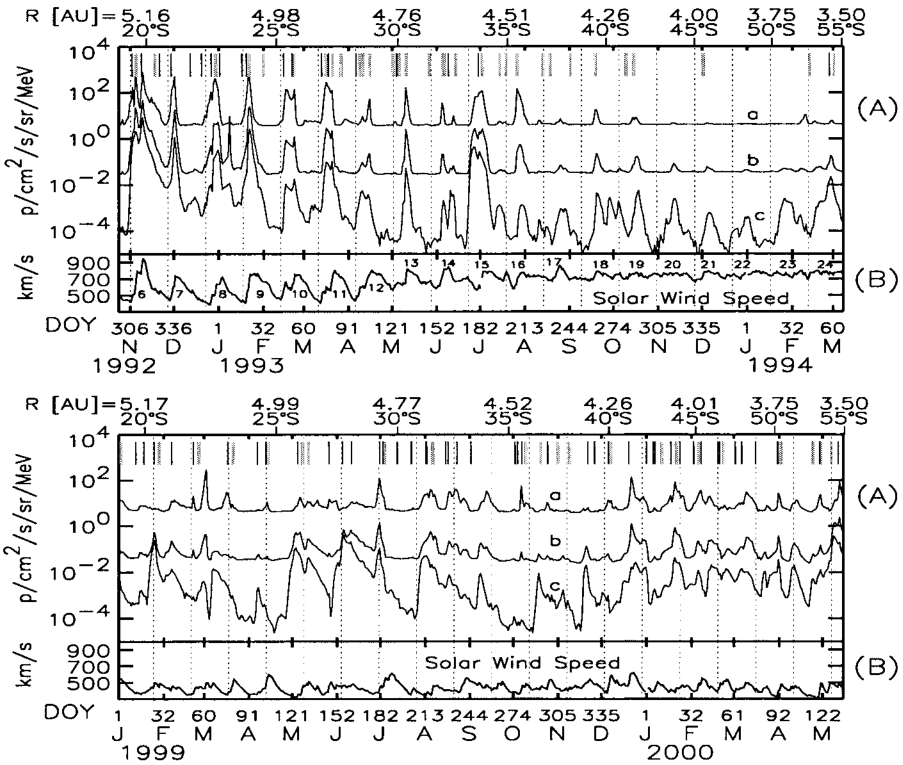

Figure 1. (A) One-day averages of (a) 0.34–0.60 MeV and (b) 1.87–4.80 MeV ion fluxes as observed by HISCALE/LEMS120 (Lanzerotti *et al.*, 1992) and (c) 3.80–8 MeV proton flux as observed by COSPIN/LET (Simpson *et al.*, 1992). (B) One-day averages of the solar wind speed as measured by SWOOPS instrument (Bame *et al.*, 1992). The vertical dotted lines are spaced 26 days apart. Small solid and gray vertical bars show the arrival at *Ulysses* of forward and reverse shocks, respectively.

reverse shocks were regularly observed. Above ~42° S, CIR reverse shocks were observed only sporadically (Gosling *et al.,* 1995).

A regular pattern of particle increases during the first southern pass was observed in association with those CIRs. Before the disappearance of recurrent CIR shocks, peaks in the ion intensity were observed close to both the forward and reverse shocks. Even after no corotating shocks were seen (poleward of ~42° S), the recurrent peaks in the particle intensities were still observed, although the intensity decreased with increasing latitude. This pattern of events was disturbed by the occurrence of transient events. Example of such transient events were seen at peaks 6, 15, 18, 24 and between 23 and 24. These transient events produced a rise in the intensity of the peaks, suggesting that energetic solar particles provided a seed particle population for the recurrent CIRs to accelerate (Sanderson *et al.*, 1995).

The first portion of the second southern pass shows a completely different pattern. *Ulysses* observed both slow solar wind and an irregularly structured intermediate-speed (<650 km s^{-1}) wind. Numerous CIRs (many of which were bounded

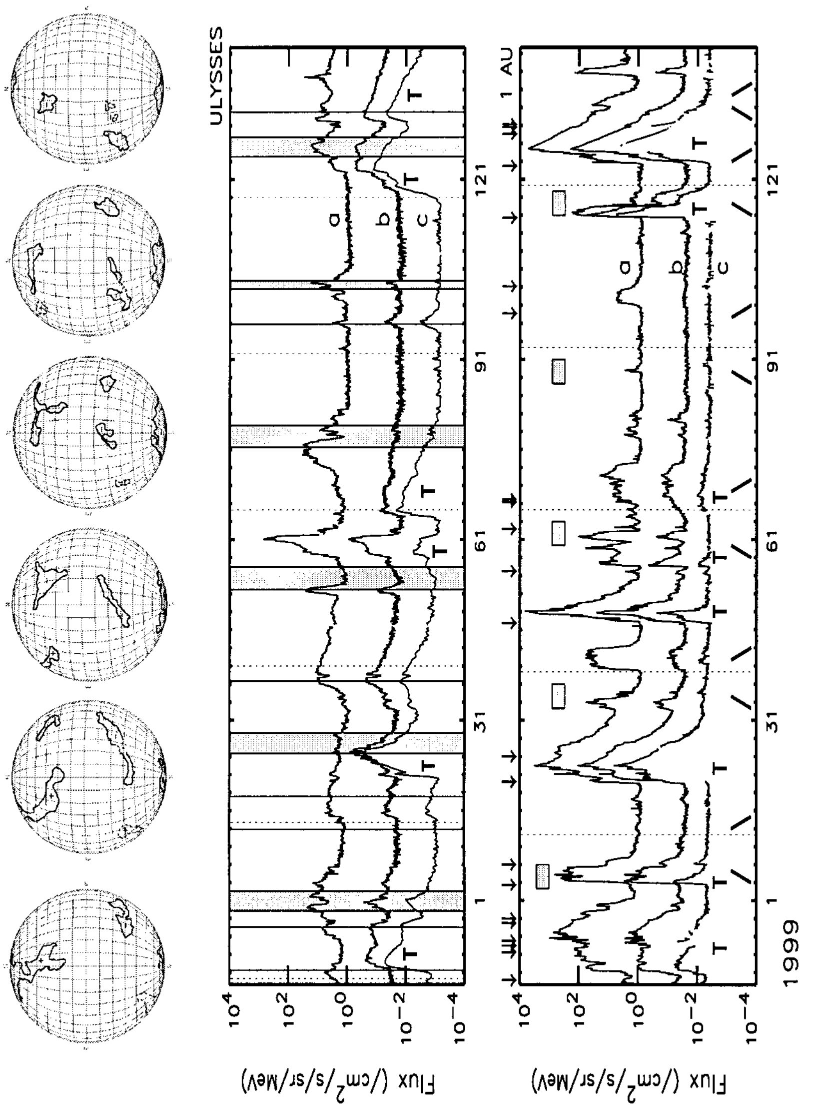

Figure 2. Top panel: coronal hole 1083 nm maps provided by the National Solar Observatory at Kitt Peak (*Solar Geophysical Data*, 1999) taken, from left to right, on day 348 in 1998, and on day 9, 34, 61, 89 and 115 in 1999. *Middle panel:* 1-hour averages of (a) 0.34–0.60 MeV and (b) 1.87–4.80 MeV ion fluxes from HISCALE/LEMS120 and (c) 3.80–8 MeV proton flux from COSPIN/LET from 24 December 1998 to 24 May 1999. Vertical solid lines show the arrival of interplanetary shocks, and the vertical gray bars the recurrent CIRs observed when *Ulysses* was, from left to right, at W60°, W35°, W7°, E15°, E41° and E65° with respect to the Sun-Earth line. *Bottom panel:* 1-hour averages of (a) 0.31–0.58 MeV and (b) 1.90–4.80 MeV ion fluxes from ACE/EPAM (Gold *et al.*, 1998) and (c) 4.60–15 MeV from IMP8/CPME (Sarris *et al.*, 1976) for the same period. Slash and back-slash lines identify the change of magnetic sector at ACE from positive to negative polarity (/) and from negative to positive polarity (\). Gray rectangles identify the particle flux enhancement observed with the change of the magnetic sector. Small vertical arrows mark the occurrence of the main solar events as noted in LASCO/CME lists and Boulder Preliminary Reports. **T**s indicate transient particle events.

by FS–RS pairs) were observed without any limit in heliolatitude (McComas *et al.*, 2000). While several of these interaction regions reappeared at roughly the solar rotation period over a few consecutive rotations (e.g., the first five rotations of 1999), they were much less periodic than in 1992–1993. In contrast to the first polar orbit, energetic ion intensities fluctuated without any real pattern, even when CIRs were recurrently observed at *Ulysses*. The reason of this may be twofold: the increasing level of solar activity throughout this second orbit and/or the associated evolution of the solar corona which might distort any stable corotating structure.

To study the effects of the increasing level of solar activity on the lack of a recurrent pattern in the particle intensity profiles, we analyze the first five rotations of 1999 when CIRs were recurrently observed. Figure 2 shows energetic ion observations from *Ulysses* at $\sim$5 AU and from ACE and IMP-8 at 1 AU. The top panel shows six coronal images of the Sun for different solar rotations. We identify the origin of the solar wind stream causing the recurrent CIR at *Ulysses* with the small-scale negative coronal hole in the southern hemisphere. Ballistic projection of the solar wind and the change of magnetic polarity within these CIRs supports our identification. Transient events (labeled **T**) were observed at 1 and 5 AU in a close relation with the occurrence of large solar events. This behavior suggests that such solar events were responsible for filling the heliosphere with energetic particles at different longitudes and latitudes. The arrival of FS–RS pairs at *Ulysses* caused an increase in the low-energy ion intensities, however the overall flux profile was dominated by the occurrence of SEP events. At 1 AU two magnetic sectors were observed in each solar rotation (except for the last rotation when coronal structure was already distorted). Gray rectangles identify the entrance into the negative magnetic field sector containing the coronal hole origin of the CIR observed at *Ulysses*. The arrival of this sector at 1 AU did not always correspond to an increase in the solar wind speed since the coronal hole did not reach low latitudes. The crossing from one magnetic sector to another produced an increase of the low-energy fluxes, but the flux profile was dominated by the occurrence of SEP events.

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