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Source Regions of the Interplanetary Magnetic Field and Variability in Heavy-Ion Elemental Composition in Gradual Solar Energetic Particle Events

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Gradual solar energetic particle (SEP) events are those in which ions are accelerated to their observed energies by interactions with a shock driven by a fast coronal mass-ejection (CME). Previous studies have shown that much of the observed event-to-event variability can be understood in terms of shock speed and evolution in the shock-normal angle. But an equally important factor, particularly for the elemental composition, is the origin of the suprathermal seed particles upon which the shock acts. To tackle this issue, we (1) use observed solar-wind speed, magnetograms, and the PFSS model to map the Sun-L1 interplanetary magnetic field (IMF) line back to its source region on the Sun at the time of the SEP observations; and (2) then look for correlation between SEP composition (as measured by Wind and ACE at $\sim$2-30 MeV/nucleon) and characteristics of the identified IMF-source regions. The study is based on 24 SEP events, identified as a statistically-significant increase in $\sim$20 MeV protons and occurring in 1998 and 2003-2006, when the rate of newly-emergent solar magnetic flux and CMEs was lower than in solar-maximum years and the field-line tracing is therefore more likely to be successful. We find that the gradual SEP Fe/O is correlated with the field strength at the IMF-source, with the largest enhancements occurring when the footpoint field is strong, due to the nearby presence of an active region. In these cases, other elemental ratios show a strong charge-to-mass (q/M) ordering, at least on average, similar to but less pronounced than that found in impulsive events. These results lead us to suggest that magnetic reconnection in footpoint regions near active regions bias the heavy-ion composition of suprathermal seed ions by processes qualitatively similar to those that produce larger heavy-ion enhancements in impulsive SEP events.