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Magnetic Field Line Path Length Variations and Effects on Solar Energetic Particle Transport

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Modeling of time profiles of solar energetic particle (SEP) observations typically considers transport along a large-scale magnetic field with a fixed path length from the source to the observer. Chhiber et al. (2021) pointed out that the path length along a turbulent magnetic field line is longer than that along the large scale field, and that the path along the particle gyro-orbit can be substantially longer again; they also considered the global variation in these quantities. Here we point out that variability in the turbulent field line path length can affect the fits to SEP data and the inferred mean free path and injection profile. To explore such variability, we perform Monte Carlo simulations in representations of homogeneous 2D MHD + slab turbulence in spherical geometry and trace trajectories of field lines, particle guiding centers, and full particle orbits, considering ion injection from a narrow or wide angular region near the Sun, corresponding to an impulsive or gradual solar event, respectively. We analyze our simulation results in terms of path length statistics within and among square-degree pixels in heliolatitude and heliolongitude at 0.35 and 1 AU from the Sun. For a given representation of turbulence, there are systematic effects on the path lengths vs. heliolatitude and heliolongitude. Field line path lengths relate to the fluctuation amplitudes experienced by the field lines, which in turn partly relate to the local topology of 2D turbulence. Particles from an impulsive event that arrive at a distant angular separation (up to ~25 degrees from the mean field connection) generally have longer path lengths, not because of the angular distance *per se* but because of strong magnetic fluctuations experienced to drive the guiding field lines to such angular distances and because of the associated scattering of the particles. We describe the effects of such path length variations on observed time profiles of solar energetic particles, both in terms of path length variability at specific locations and motion of the observer with respect to turbulence topology during the course of the observations. This research was partially supported by Thailand Science Research and Innovation grant RTA6280002 and the Parker Solar Probe mission under the ISOIS project (contract NNN06AA01C) and a subcontract to University of Delaware from Princeton University (SUB0000165). Additional support is acknowledged from the NASA LWS program (NNX17AB79G) and HSR program (80NSSC18K1210 & 80NSSC18K1648).