Radial and longitudinal dependence of solar 4-13 MeV and 27-37 MeV proton peak intensities and fluences: Helios and IMP-8 observations

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We study the radial and longitudinal dependence of the 4-13 MeV and 27-37 MeV proton peak intensities and fluences measured during intense solar energetic particle events of solar cycle 21 by the Interplanetary Monitoring Platform-8 (IMP-8) and the Helios -1 and -2 spacecraft. We analyze 77 events and compute the total event fluence and the peak intensity, distinguishing between maximum intensities reached during the prompt component of the event or associated with the passage of traveling interplanetary shocks. Simultaneous measurements of individual events by at least two of these three spacecraft show that the dominant parameter that determines the peak intensity and fluence of the events is the longitudinal distance (designated as ϕ) between the parent active region and the footpoint of the magnetic field line that connects the spacecraft with the Sun, but not the heliocentric radial distance (which we designate as R). We perform a multiparameter fit to the radial and longitudinal distributions of peak intensities and fluences for those events whose solar origin has been identified and that produce intensity enhancements observed by at least two spacecraft. This fit allows us to determine radial variations of peak intensities that, on average over the ensemble of events, range from $R^{-2.5}$ to $R^{-1.6}$ for proton energies of 4-13 MeV and 27-37 MeV, respectively, whereas event fluences range from $R^{-1.9}$ to $R^{-0.9}$ for proton energies of 4-13 MeV and 27-37 MeV, respectively. These radial dependences are weaker than those inferred from diffusion transport models (i.e., $\mathrm{R}^{-3.3}$ for peak intensities and $\mathrm{R}^{-2.1}$ for event fluences). The longitudinal distributions of peak intensities and fluences are approximated by a functional form $e^{-k\left(\phi-\phi_0\right)^2}$ where ϕ_0 is the centroid of the distribution and k is $\sim$1/rad^2. Longitudinal distributions are not centered around the footpoint of the magnetic field line connecting the observers with the Sun, but toward the east with an angular distance with respect to the observer's magnetic footpoints that decreases with the energy of the particles. Individual events observed by two spacecraft with close nominal magnetic connection but at different radial distances show peak intensities and fluences that follow radial dependences less steep than the guidelines given to extrapolate peak intensities and fluences from 1 AU to inner radial distances (Shea et al., 1988). These recommended radial dependences (i.e., R^{-3} and $\mathrm{R}^{-2.5}$ for peak intensities and fluences, respectively) lead to an overestimation of peak intensities and fluences at heliocentric radial distances $R<1$ AU.