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Comparison between solar electron and ion path lengths traveled during the Ground-Level Enhancement events in solar cycle 23

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The inconsistency of electron and ion path lengths during Solar Energetic Particle (SEP) events remains an open issue. In order to investigate the difference between the electron and ion path lengths during the Ground-Level Enhancement (GLE) events in solar cycle 23, electron and ion data from the WIND/3DP/SST and WIND/EPACT/LEMT instruments respectively have been used. The electron path lengths were determined for the GLEs in solar cycle 23 assuming that the solar release time of non-relativistic electrons is well represented by the onset time of metric type II or decametre-hectometric (DH) type III radio bursts. The values estimated for low-energy electrons ($\sim$ 27 keV) were compared to the ion path lengths deduced by Reames for the GLEs in solar cycle 23 based on the onset-time analysis and consistency within an error range of 10% was found. In addition, the electron path lengths were found to increase with increasing electron energies, with the increasing rate of path lengths corresponding to broader position angle distribution (PAD) of electrons, which suggests that electron path length enhancement is due to interplanetary scattering experienced by first-arriving electrons. Furthermore, the solar longitude distribution and IMF topology of the GLE events examined support that the non-relativistic electrons observed have been accelerated in shocks driven by CMEs. Finally, it should be stressed that the observed path length consistency leads to stability of magnetic flux tubes along which particles travel, with a maximum stability time of $\sim$ 4.8 hours, which could be very important for forecasting since, based on the observed onset time of the electron event, it is possible to observe the arrival and duration of the proton event.