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Modeling the Penetration of the Barrier to Ultra-relativistic Electrons in the Outer Van Allen Belt during Extreme Magnetic Storms

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One of the most interesting observations made by the Van Allen Probes is the occurrence of an apparent impenetrable barrier to ultra-relativistic electrons at the inner edge of the outer zone. The ultra-relativistic electron flux drops sharply by orders of magnitude at this barrier, located at L$\sim$2.8, with no observations of flux enhancements reaching lower L-shells inside the barrier having been made during the Van Allen Probes era. However, during previous solar cycles, more extreme events such as the Halloween 2003 magnetic storm have resulted in ultra-relativistic electron penetration through the barrier, enhancing the flux in the slot region and inner zone. Simulating the outer radiation belt dynamics during these extreme events is challenging using existing radiation belt models, especially those based on statistical models for the wave amplitudes implicated in various acceleration and loss processes. For example, the ULF wave radial diffusion coefficients which determine how fast the electrons are transported inward and outward are typically based on ULF wave statistics expressed as a function of Kp, and are only valid for Kp values between 0 and 6. Here we use an alternative event-based observational characterisation of the ULF wave radial diffusion coefficients and examine both the generation of the apparent barrier in long-term simulations of the outer belt dynamics during the Van Allen Probes era (cf. Ozeke et al., Nature Comm. 2018), and the penetration of the barrier during the extreme Halloween 2003 magnetic storm. Instead of using statistical models for the radial diffusion coefficients, here we utilize ground magnetometer data to determine the event-specific radial diffusion coefficients required to simulate extreme events. Our results highlight the importance of using event specific radial diffusion coefficients, for example based on directly observed ULF wave power, to simulate the dynamics of the outer belt during extreme space weather events.