Characterization of onset durations for early VLF scattering events

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Ionospheric disturbances produced by lightning discharges are capable of scattering sub-ionospherically propagating VLF waves, leading to amplitude and/or phase perturbations of the received VLF signal. A specific class of these types of perturbations occur within ∼20 msec of the causative lightning discharge, known as "early" VLF events, indicating a direct and immediate impact on the overlying ionosphere. Event onset durations, defined as the time between the start of the event to the occurrence of the maximal amplitude/phase perturbation, have been used to further classify early events as "fast" (<20 msec) or "slow" (∼0.5 to ∼2.5 seconds). Recent literature have cited onset durations to suggest underlying physical mechanisms. For example, early/slow events have been associated with the secondary ionization that results from subsequent lightning return strokes. Additionally, VLF sprite scattering has been predicted to have an ∼65 msec onset duration, outside the current definition of "fast."

We demonstrate here that onset durations are best categorized by the normalized scattered field magnitude and not by the resulting amplitude or phase perturbation. Experimental observations of VLF events are used to demonstrate that a "fast" scattered field can lead to a slow amplitude or a slow phase perturbation, due to the phasor addition of the ambient and scattered fields. Since the scattered field magnitude is most directly related to the conductivity changes within the disturbed region of the ionosphere, to classify such an event as slow based on amplitude-only/phase-only observations could be physically misleading. As such, the categorizations of VLF scattering events using only amplitude/phase perturbations are incomplete, and may possibly lead to an incorrect or inconsistent characterization of events. Finally, we find that the current definition of "fast" may be too restrictive, in that many VLF events exhibit onset durations between 20 msec and 200 msec, yet are clearly distinguishable from classically "slow" events.