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Ionospheric density perturbations and optical emissions due to horizontal in-cloud lightning EMP

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Optical emissions in the lower ionosphere due to cloud-to-ground lightning EMP, known as elves, have been observed in recent years from the ground and from space. Correlations between elves and ionospheric electron density perturbations known as "Early VLF" events show that elve-producing EMP may also cause significant electron density changes. Recently, in-cloud (IC) lightning discharges have been associated with sprites and with Early VLF events. It has also recently been shown that burst-like VLF activity is the signature of significant IC activity, and when associated with CG discharges, is likely the source of continuing current responsible for sprites. In this work, we investigate the potential for IC lightning EMP to cause measurable ionospheric density perturbations and optical emissions, using 3-dimensional modeling of the lightning EMP. We find that optical emissions should be detectable with modern photometers, and that electron density changes are primarily negative due to dissociative attachment to molecular oxygen, resulting in a density "hole" that persists for 10-100 seconds. We find that although larger amplitude IC pulses may cause ionization and thus increase the local electron density, the volumetric change in the electrons is still substantially negative in these cases. Furthermore, we show that perturbations caused by bursts of IC activity should be measurable as Early VLF events.