The spectral dependence of TGFs on source distance and other insights into RHESSI TGFs from geolocated sferic data

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The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) has detected over 800 Terrestrial Gamma-ray Flashes (TGFs) since its launch in 2002, providing a large database for statistical studies of TGFs. TGFs are thought to be produced by relativistic runaway electrons inside of thunderclouds, and relativistic runaway models have been successful in modeling the combined spectrum of all RHESSI TGFs (J. R. Dwyer and D. M. Smith, Geophys. Res. Lett., 32, L22804, 2005). However, some details of TGF source beaming and altitude cannot be constrained by the combined spectrum because it averages over important differences among individual TGFs, including the horizontal distance from the TGF source to the sub-satellite point. In this paper we use lightning flash locations from the World Wide Lightning Location Network (WWLLN) to identify thunderstorm locations, indicating possible TGF sources, near 362 RHESSI TGFs. TGFs with lightning flashes within 300 km of the sub-satellite point have a much harder spectrum than TGFs with no close lightning flashes. The spectral dependence of TGFs on source distance is compared with Monte Carlo simulations of relativistic runaway breakdown to constrain TGF source altitude and geometry. Models with vertical and tilted beams and with various beam widths and altitudes are considered. We also use TGFs associated with sferics that have been geolocated to positions more than 300km from the sub-satellite point to show that models with narrow, vertical beam sources at $\geq$ 21 km are unlikely to produce the number of high-energy photons detected in distant TGFs. Finally, we examine the timing of TGF events with respect to the storm evolution, estimating the development stage of the storm from the time series of WWLLN sferics, and the relative geographic distribution of TGFs compared with WWLLN lightning locations.