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Spectral characteristics of VLF sferics associated with TGFs

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A detailed analysis of RHESSI TGFs is performed in association with WWLLN sources and VLF sferics recorded at Duke University. The analysis of the TGF-WWLLN matches allowed to evaluate RHESSI clock systematic offsets [1], which allows to perform a more precise timing analysis involving TGF data comparisons with the VLF sferics recorded at Duke University.

In this work we analyzed the energy spectra of 35 VLF sferics, which were identified as candidates to be emitted by the TGF source, based on the simultaneity and location coincidence between the TGF and radio sources. 20 events have WWLLN detections, which provides a reliable source location of the event. For the other 15 events several selection criteria were used:

- source location should be consistent with the simultaneity of the TGF and VLF sferic within ± 200 μs uncertainty;
- source location should lay within the azimuthal $\pm 4°$ cone defined by the ratio of the radial and azimuthal magnetic field components of the VLF sferic;
- source location should lay within 800 km circle around the RHESSI foot-point;
- source location should lay within a cluster of a current lightning activity validated by WWLLN (or any other lightning detection network).

The energy spectra of 35 VLF sferics related to TGFs were analyzed in the context of the TGF radio emission model developed in [2]. Proposed model represents a TGF at source as a sequence of N_p seeding pulses of energetic particles which develop into runaway avalanches in the strong ambient field. These relativistic electrons ionize air along their propagation path which results in secondary currents of low energy electrons and light ions in the ambient electric field. These secondary currents produce radio emissions that can be detected by the ground based sensors.

Proposed model allows to express the TGF source current moment energy spectrum using the T_{50} TGF duration measured by RHESSI. This gives the opportunity to establish and validate empirically the functional link between the satellite measurements and radio recordings of TGFs. Distances from the analyzed TGF sources to the Duke VLF receiver range from 2000 to 4000 km. This involves the consideration of the propagation effects in the Earth-ionosphere wave guide (EIWG). The EIWG transfer function was calculated for each event using the full wave propagation method. Thus, the modeled energy spectrum of the TGF source current moment can be transformed into how it would look like for the Duke VLF receiver.

Comparative analysis of the energy spectra of modeled TGF radio emission and associated VLF sferics for 20 events with WWLLN confirmed location and 15 events without WWLLN detection shows that 31 of these 35 events exhibit a good fit between the modeled and observed spectra, with only 4 exceptions, that look inconsistent with the proposed model.

The second cutoff frequency f_{B} with the number of avalanches N_p define the shape of the observed energy spectrum of the sferic emitted by a TGF. Multiplicity of the TGF serves as another important discriminative factor that shows the consistency between the modeled and observed spectra.

The results show that the number of avalanches N_p should be relatively small, of the order of 30-300, to make the modeled TGF radio emission consistent with the observed VLF sferics. These small values of N_p give an argument in favor of the leader model of the TGF production, and also might refer to streamers in the streamer zone of the leader tip, as candidates, producing initial seeding pulses that develop into RREAs, generating a TGF.

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[2]. Dwyer, J. R., and S. A. Cummer (2013), Radio emissions from terrestrial gamma ray flashes, J. Geophys. Res., 118, doi:10.1002/jgra.50188.