Terrestrial Gamma-ray Flashes and Lightning

by

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Terrestrial Gamma-ray Flashes (TGFs)

- *Fishman et al. [1994]* first reported phenomena:
  - BATSE instrument on CGRO satellite observed gamma-rays coming from the Earth
  - Subsat point of detects correlated with storm regions

- *Inan et al. [1996]* found coincident lightning:
  - Coincidences found for two TGFs
  - One of the TGFs clearly moved positive charge downward. It was claimed to be a positive cloud-to-ground (+CG).
RHESSI overview

- **RHESSI**: Reuven Ramaty High Energy Solar Spectroscopic Imager
- **Orbital parameters:**
  - Orbit inclination: 38°
  - Altitude: ~600 km
- **TGF detection:**
  - Sub-second duration
  - 12-sigma above noise
- **Photon detectors:**
  - ~60 keV to ~20 MeV
RHESSI: global distribution of TGFs

Expected Distribution of Observed TGFs if Globally Uniform

Global Lightning Frequency (OTD LIS)

Adapted from Smith et al. (2005)
Los Alamos Sferic Array (LASA) Sensor

- Detects electric field changes from lightning (known as “sferics”)
- Inverted flat-plate sensor
  - Salad bowl shields sensor from rain
- Frequency: ~200 Hz – 500 kHz
  - RC time constant: 1 ms
  - Low-pass filter at ~500 kHz
- 4'x4' grounded base
LASA data acquisition hardware

- Linux-based PCs
- Measurement Computing PCI-DAS4020/12 digitizer:
  - 20MHz @ 12-bit resolution
  - 4 input channels
- Synergy G-SynQ/T GPS units:
  - ±50 ns accuracy
LASA data acquisition software

- **2MHz sample rate:**
  - 10 pt sum @20 Mhz: ~15-bit resolution

- **Floating DC threshold:**
  - Floats on 2 or 4 kHz average

- **No dead-time** between trigs!
LASA station locations

2004: Florida Network

+2005: Great Plains Network

Four Station Sensitivity Pattern
Florida sensor locations

Building dimensions and surroundings vary, so electric field intensification (gain) will too
Florida sensor relative gains

- Compared sferic amplitudes for 85 events at >2000 km range from multiple storms in different directions
Eight geolocated strokes which struck triggered lightning launch pad at Camp Blanding:

- **Jun 23 16:11:06.390**
  - **Time**: 116 m
  - **16:29:30.704**: 156 m

- **Jul 24 19:11:00.758**
  - **Time**: 586 m
  - **+0.350**: 131 m
  - **+0.264**: 139 m
  - **+0.200**: 37 m
  - **+0.058**: 38 m
  - **+0.031**: 20 m

**Geolocation error: 153 m**
TGFs: Ground-based analogs

- *Moore et al. [2001]* documented X-rays from stepped leaders
- *Dwyer et al. [2003]* detected X-rays from dart-leaders in triggered lightning (up to ~250 keV)
- *Dwyer et al. [2004]* detected gamma-rays during the initial stage of triggered lightning, possibly originating from inside the cloud

*Note: difficult to detect high energy photons in space originating from near ground level!*
TGFs: Thunderstorm tops?

- Dwyer and Smith (2005): used a Monte Carlo method to match the observed RHESSI energy spectrum (integrated over many TGFs) with a source at 15-21km altitude

- Williams (2006): Noted that the concentration of TGFs near the equator is consistent with higher thunderstorm tops there (>15km).
TGFs: sprite connection?

- Sprites are electrical discharges at high altitude (40-90km) above large thunderstorm complexes
- Sprites associated with +CGs (*Boccippio et al.*, 1995...) with very few exceptions (*Barrington-Leigh et al.*, 1999)
- Runaway breakdown could be occurring for sufficiently large +CG charge moments
  - *Lehtinen et al.*, 1999: beam follows magnetic field lines
- Runaway electrons generated in energetic streamer tips?
  - *Pasko et al.*, 1998: Can generate X-rays, but hard to generate gamma-rays

- Positive polarity
  - Close enough to discern that it is likely an intracloud (IC), not a CG
- Only LANL station saw it, but have NLDN sky-hop geo
  - RHESSI TGF: 13:49:47.202 UT
  - TGF plan position: 130 km to south-southeast of RHESSI
June 18, 2004  21:03:11 UT

- Intracloud sferic waveform (positive-polarity)
  - Multiple peaks on leading edge
  - Rise time: 74 µs (>10 µs of CGs)

- TGF sferic geolocated 128 km from subsat point
2004, June 18   Altitudes

- Determine altitudes from Ionosphere reflections:
  - Peaks B & C: 13.6 km (±2 km)
  - Peak A: Similar altitude (14.5 km), but larger uncertainty
2004, June 18  Storm history

- Narrow Bipolar Events (NBES) and TGF altitudes:
  - NBES in blue, +NBES in red, and TGF A-C events in black
- TGF occurs during 1st overshooting top:
  - Storm reaches up to ~17km based on NBE altitudes around time of TGF
2004, June 18    Radar data

- NEXRAD radar Level II data
- Storm top is above highest horizontal scan at ~13 km
- TGF and -NBE are in or above 30-35 dBz region
- Storm is <20 min old!
2005, August 11  22:48:01 UT

- **+NBE sferic waveform**
  - *Important, since it's been suggested that NBEs are produced by runaway breakdown (see Gurevich (2004), and references therein)*

- TGF sferic geolocated 117km from subsat point
2005, August 11  Photons vs. Sferic

- +NBE occurs at or near onset of normal IC flash (consistent with earlier VHF studies)
- Photons lead +NBE by ~3ms!
- TGF is broad, unlike +NBE sferic
2005, August 11   Altitudes

- Storm capped at ~14km altitude
- Source is likely lower than 15-21km modeled by Dwyer and Smith (2005)

- +NBE: 11.5 km
- +IC pulse: 13.1 km (part of normal IC)
Summary of events within 1100km

- All detected events were +ICs
- Detected +IC sferics were big
  - Range-normalized peak E within upper 5% of all IC flashes
- TGFs either led or were coincident with sferics *(when corrected for ~2ms timing error)*

Within ~1100 km, can reliably discern between ICs and CGs (ocean propagation helps since attenuation less over salt water)
Broad or beamed source?

- TGFs correlated with coldest (-65° C) cloud tops
- TGFs offset from RHESSI subsat by ~390km! (source is either broad or non-vertical beamed)

GOES images obtained from:  http://squall.sfsu.edu/crws/archive/satimgs_month_arch.html
Summary

- TGFs appear to be primarily associated with positive intraclouds (electrons accelerated upwards, as expected)
- TGF intraclouds are high (11-15km), but not as high as the 15-21km predicted by models
- TGF intracloud sferics are unusually energetic (upper 5% of all ICs detected)