Measurements and Implications of the Relationship Between Lightning and TGFs

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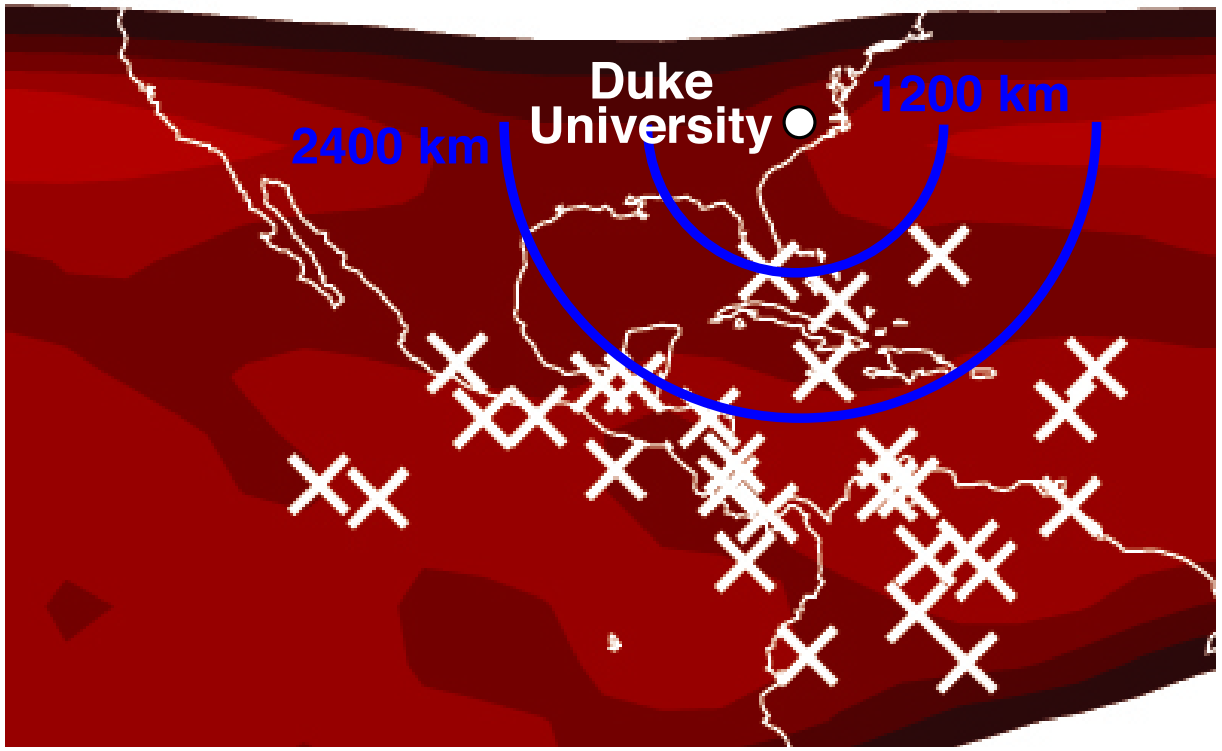
- **Goal: quantify lightning-TGF correlation and measure associated lightning parameters to test our understanding.**

Event Selection

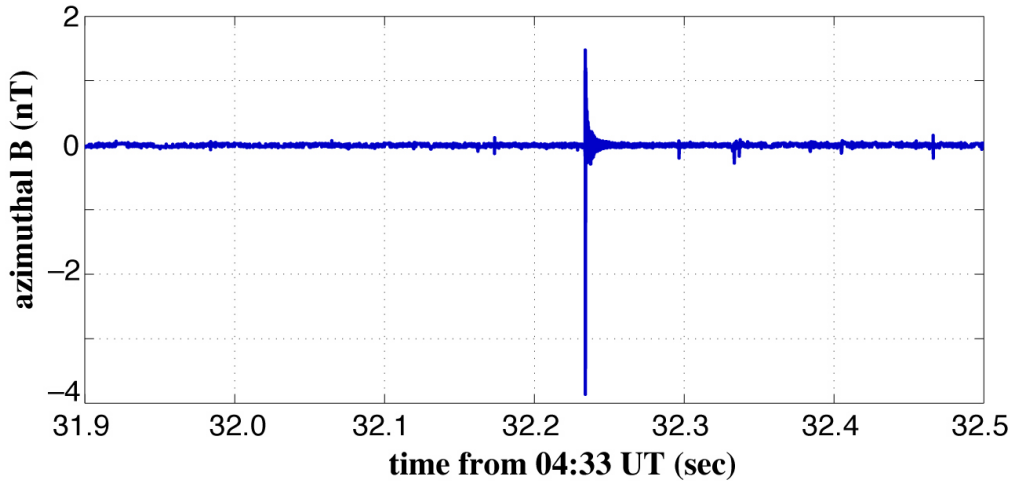


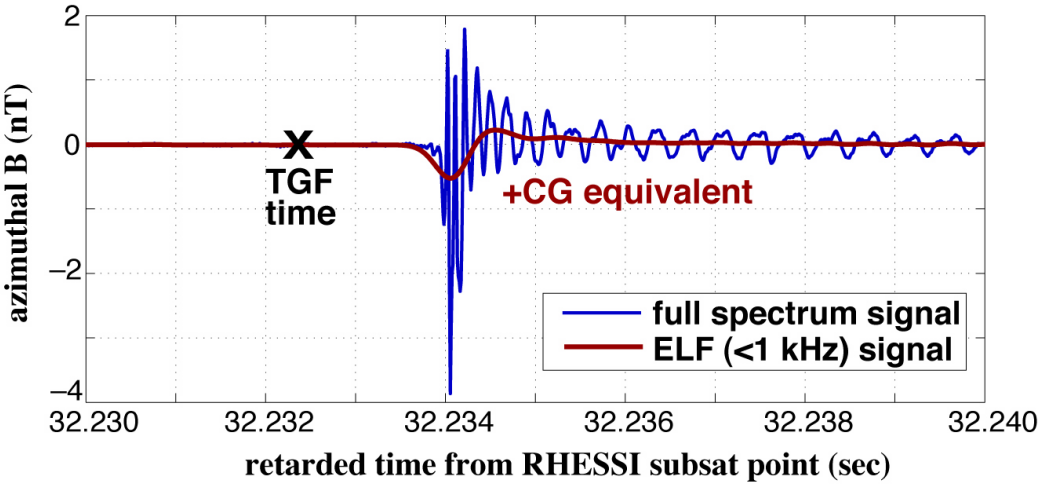
- **Duke Sensors:**
  - **VLF-ELF (50 Hz–30 kHz)**
  - **ELF-ULF (<0.1 Hz–400 Hz)**
  - **Both sets continuously recorded July through October 2004**
- **RHESSI TGFs:**
  - **Americas and Caribbean events (not more than ~4000 km)**
  - **26 TGFs during continuous mag data**

Example #1

- Only one signal from right direction, big and obvious.
- VLF signal looks like that from a big but ordinary CG stroke.
- Close look: TGF happens 1.7 ms before lightning.
- Vertical charge motion in lightning is equivalent to +CG.

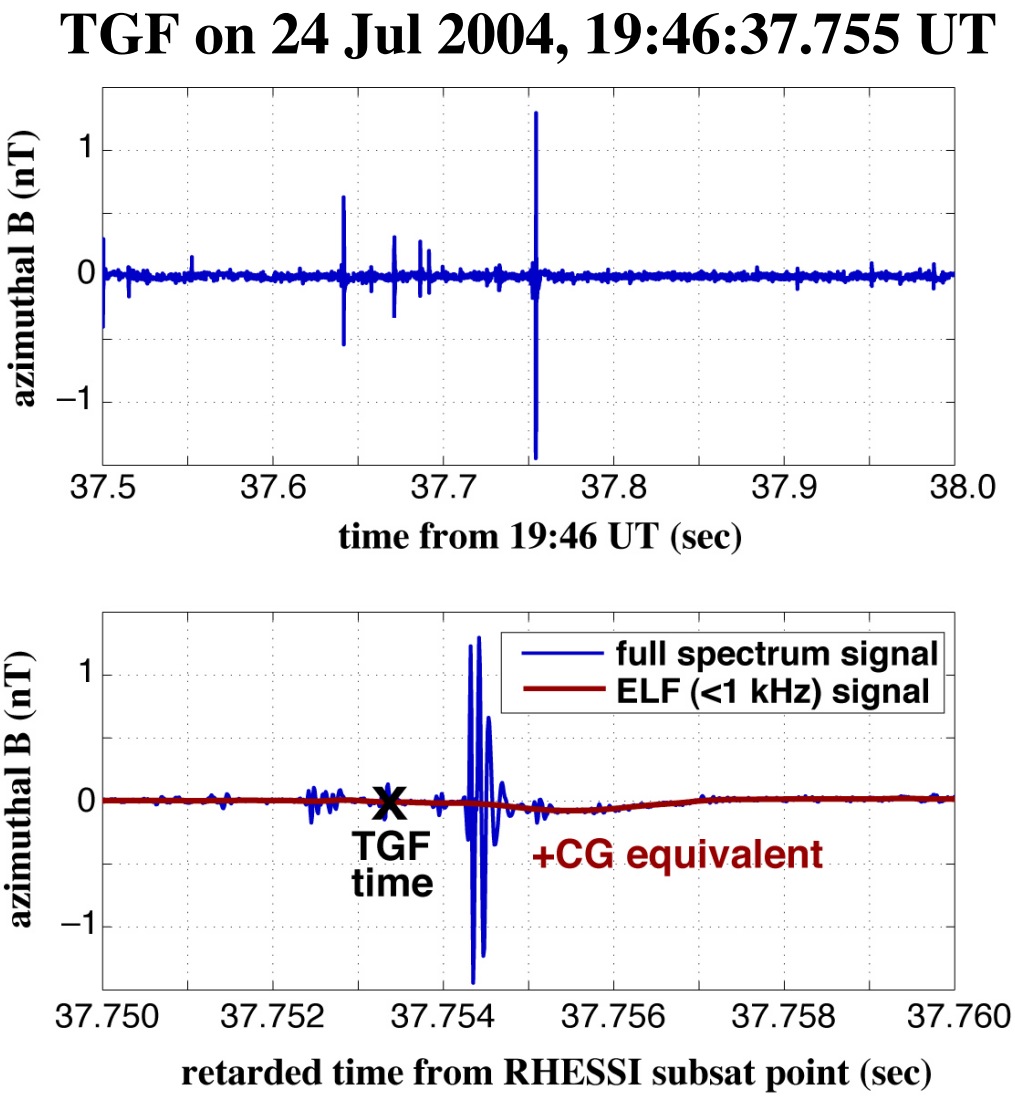
TGF on 22 Oct 2004, 04:33:32.234 UT





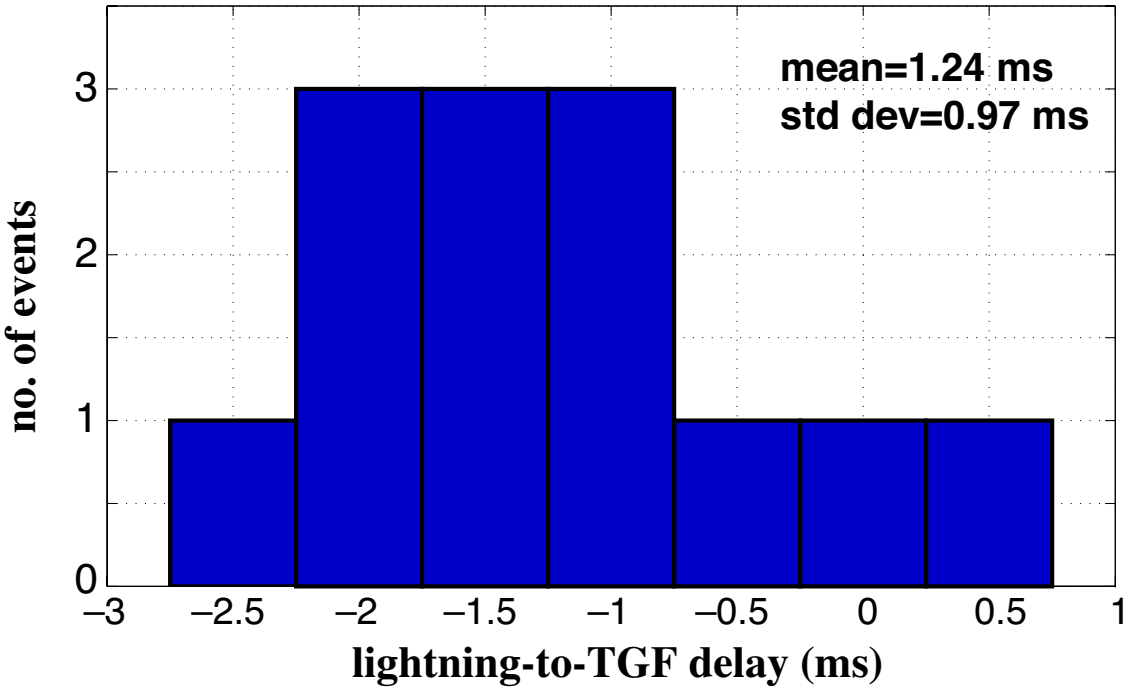
Example #2

- Still one clear signal near TGF time from right direction.
- VLF signal more complex than that from an ordinary CG stroke.
- Close look: TGF happens 1.1 ms before lightning.
- Vertical charge motion in lightning is equivalent to +CG.



Time Correlation Summary

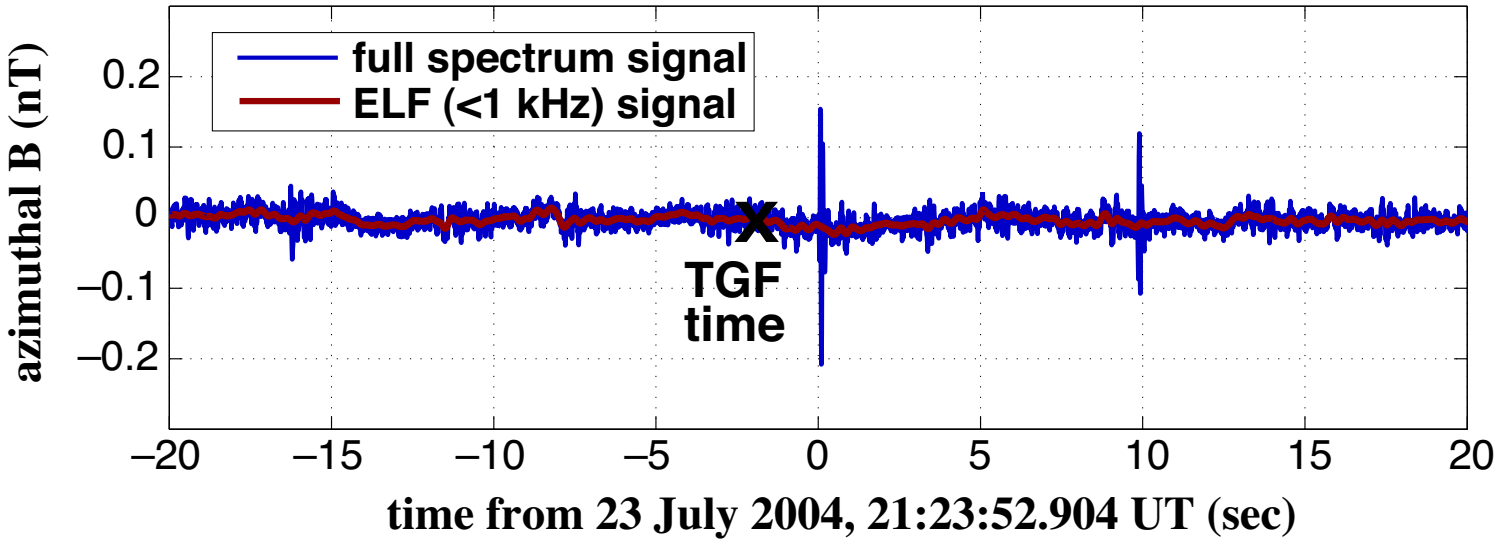
- Searched ±500 ms around TGF for closest lightning time correlation.
- In 13 out of 26,
  - time correlation is +0.5/–2.5 ms
  - all but 1 within ±6° of expected direction
  - all +CG equivalent
- Tied closely in time to stroke time (unlike sprites).
- TGFs on average 1.24 ms *before* lightning. Why?



- RHESSI has a systematic timing offset of around 1 ms.
- Lightning strokes on average 400 km farther from Duke than subsat point (south of TGF: wrong direction).
- TGFs originate before lightning stroke.

Remaining 13 Events?

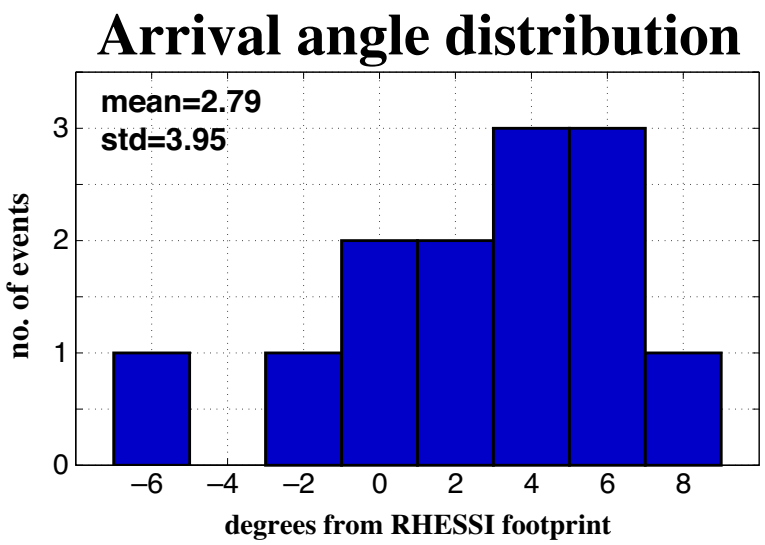
- 8 events ambiguous.
  - 6 time correlated with lightning strokes from right direction but too small to determine polarity (5 C km charge moment change max).

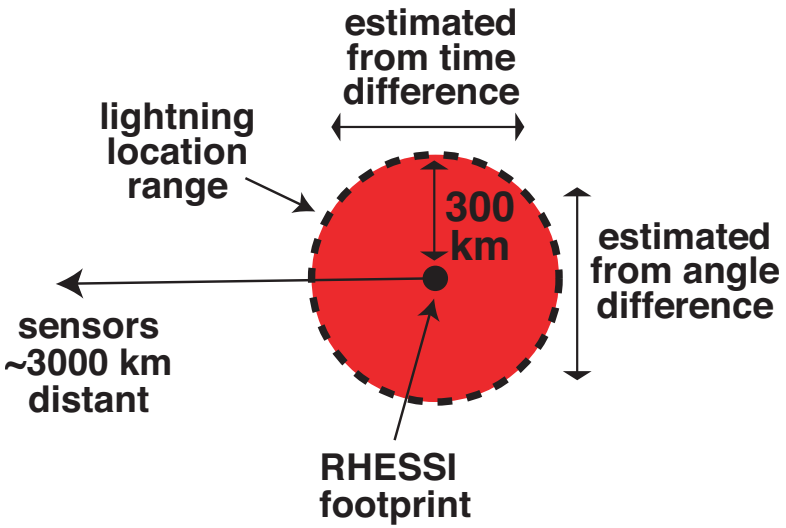


  - 2 are overlapped by larger sferics from other directions.
- 5 events: no discernable lightning stroke within ±500 ms.
  - From 2000–4000 km range, a CG would have to be tiny for us not to see it.
  - These are a puzzle.

Detailed Lightning/TGF Spatial Relationship

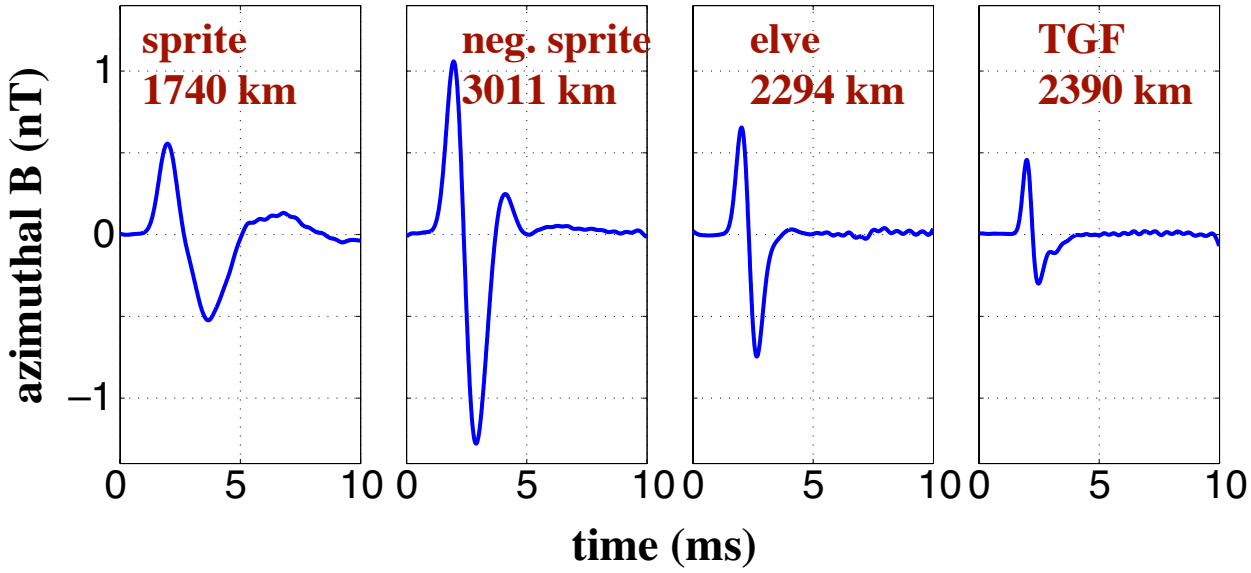
- **Assume early TGFs are due to RHESSI timing or pre-stroke process.**
- **Narrow spread (std=0.97 ms) of lightning timing around TGF time constrains TGF detection/lightning *radial* distance to ±300 km.**
- **Similarly narrow spread in arrival angle difference from RHESSI footprint (std=4.0°) projected along distance constrains *azimuthal* distance to approx. ±300 km.**
- **This circle is in good agreement with ~160 km distance of Dallas TGF from NLDN location.**





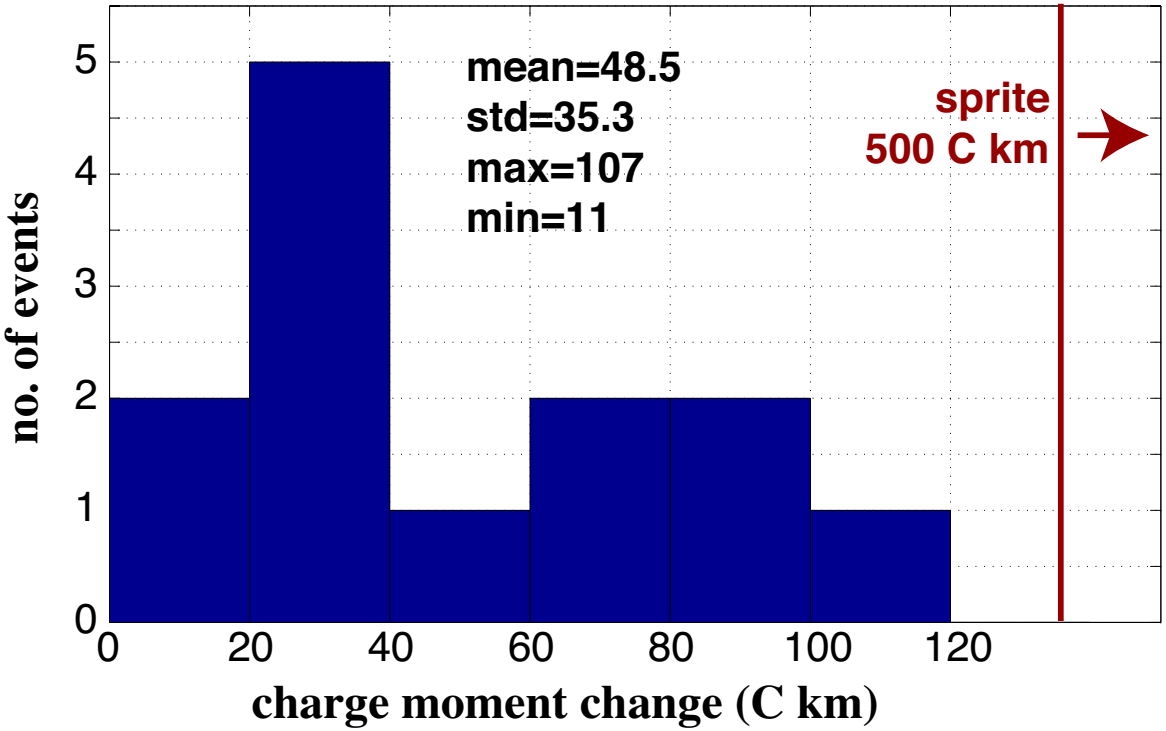
Are The TGF Lightning Strokes As Big As Expected?

- **<1 kHz signal closely linked to charge moment change, in turn linked to above-cloud electric field: we have a lot of experience in solving this inverse problem.**
- **Waveform comparison from the *same* sensors during *same* period:**



- **Biggest TGF-associated lightning not nearly as big as a sprite.**
- **Lower frequency data shows that slower currents not significant, as expected from timing.**

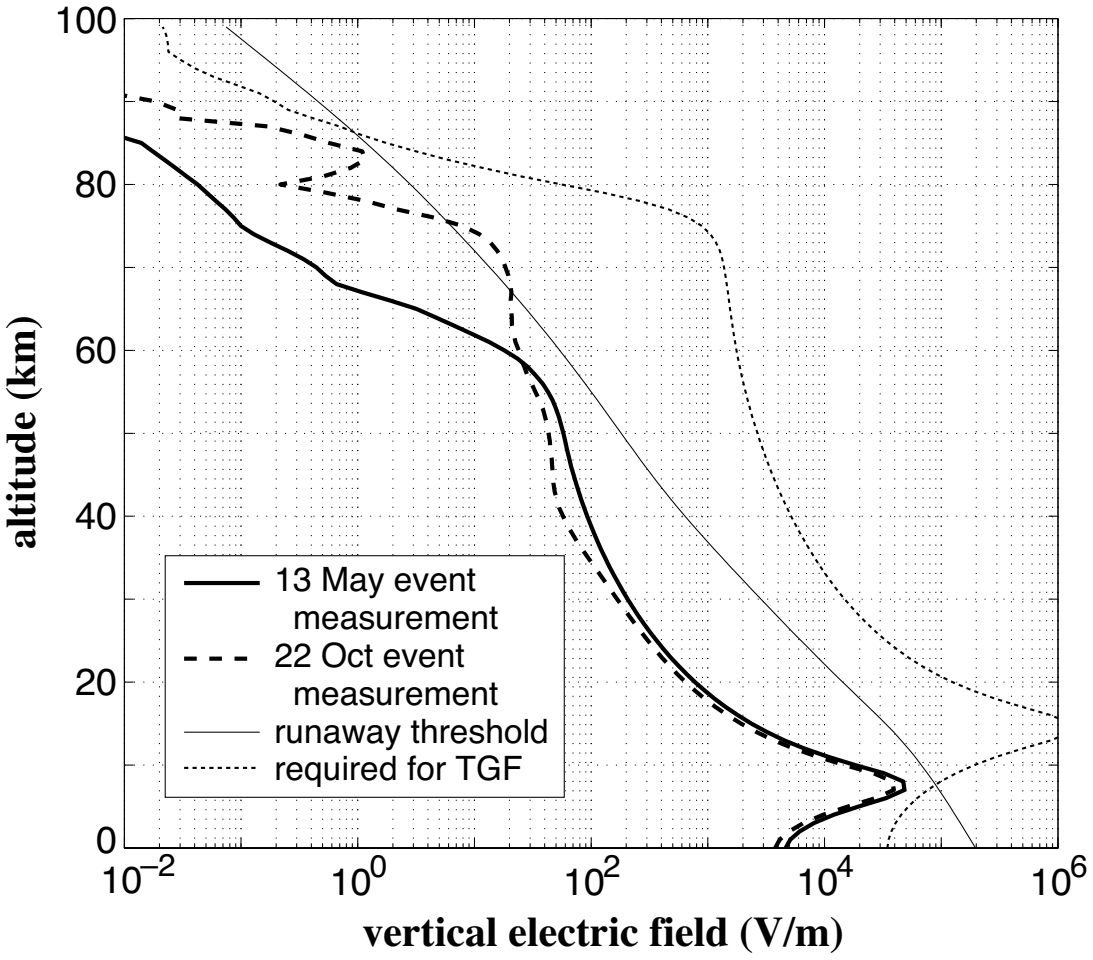
TGF-Associated Charge Moment Changes



- These 13 strokes have 5–50 times smaller charge moment change than a typical sprite (500 C km).
- Runaway breakdown simulations indicate ~6000 C km required to generate a TGF [*Lehtinen et al., JGR*, 2001].

Above-Thunderstorm Electric Fields

- Can estimate above-cloud fields from by using measured charge moment change as model input.
- Clearly shows that even the biggest TGF-associated strokes are smaller than theory by ~100.
- These strokes are all way too small to generate the expected runaway breakdown between 30 and 50 km.
- Perhaps no-lighting TGFs not that unusual.



Discussion and Other Possibilities

- What could produce sufficient field at 30–50 km altitude?
  - Not slow vertical charge motion: field relaxation times are <1 sec and, given the amount of charge that must be moved, this would be visible in our low frequency data.
  - Vertical intercloud discharge would produce even smaller fields.
  - Slow rise time horizontal charge motion? 500 C over tens of km in <1 sec would be unprecedented.
- Other possibilities?
  - Runaway breakdown occurs at lower altitudes closer to charge motion. Details of charge distribution in cloud important.
  - Charge injection from thundercloud into higher altitudes. Less charge required to make localized high fields.
  - Other mechanisms?

Conclusions

- In 13 of 26 events, TGFs clearly linked to a process that radiates like a medium to small +CG return stroke.
- TGF and discharge occur within 2 ms of each other (different from sprites). Cannot rule out possibility that TGF occurs before stroke.
- Based on timing and direction finding, TGFs are detected within 300 km of lightning location and clearly not skewed to south of lightning.
- Measured lightning charge moment changes ~100 times smaller than that suggested by runaway theory. Seems very unlikely that lightning-generated fields at 30–50 km are responsible for TGFs.
- Other possibilities: lower altitude (<30 km), upward charge injection, other mechanism.