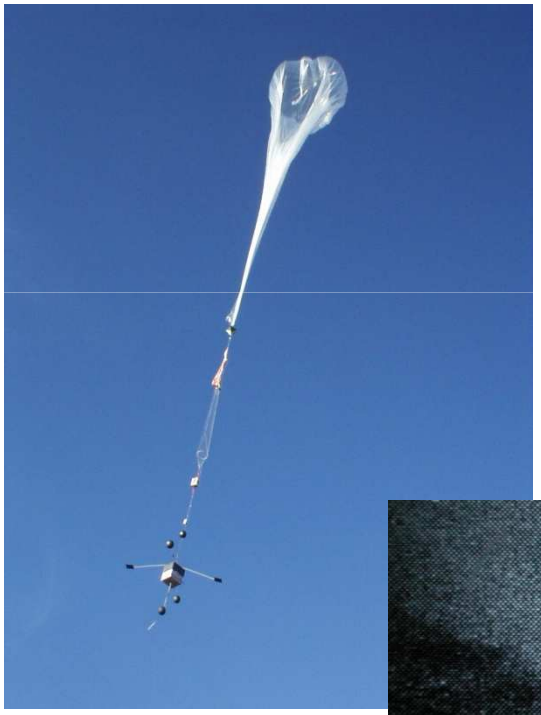
In Situ Measurements of Electrodynamics Above Thunderstorms: Past Results and Future Directions



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Outline

I. Motivation: Are there electric fields above thunderstorms large enough to generate TLEs?

II. Review of past experiments

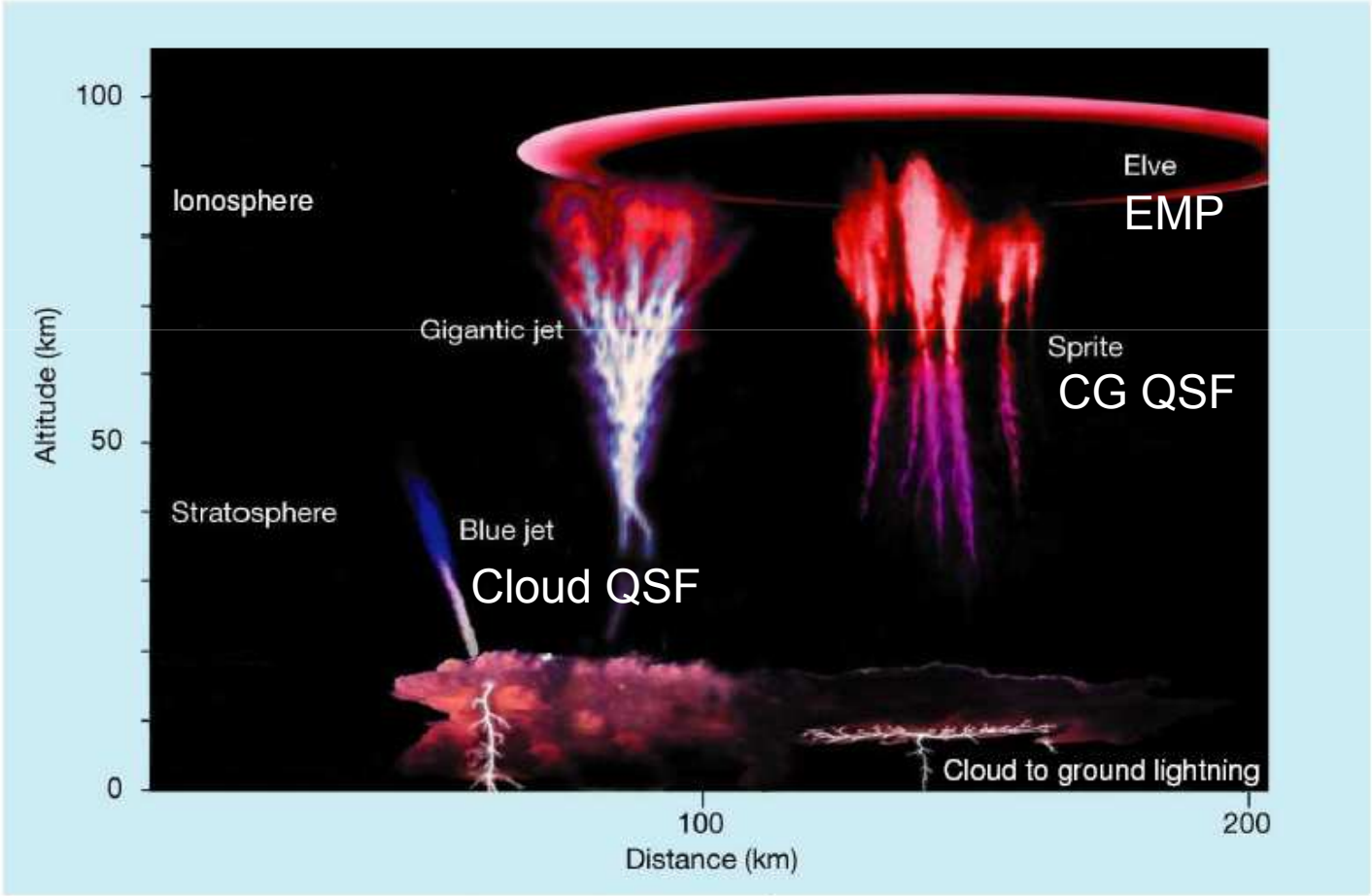
III. In situ balloon measurements – Brazil Sprite Campaign 2002-03

IV. In situ rocket measurements – Thunderstorm III Campaign 1995

V. New directions for in situ campaigns

What Causes TLES?

Lightning-Related Middle Atmospheric Transient Luminous Events



[Lyons et al., BAMS, 84, 445, 2003; Pasko, Nature, 423, 927, 2003]

Quick Review of Other In situ Experiments

Balloons:

•Gish and Wait, JGR, [1950] aircraft measurements of upward directed current of 0.5 A above thunderstorms at 12 km altitude

•Stergis et al., J. Atmos. Terr. Phys, [1957] balloon measurements of 1.3 A at 21- 27 km

•Holzworth J. Atmos. Terr. Phys, [1981], balloon

•Tohoku U. Japan, Yukihiro Takahashi et al., 2006, VLF electric fields and ELVES

Quick Review of Other In situ Experiments

Rockets

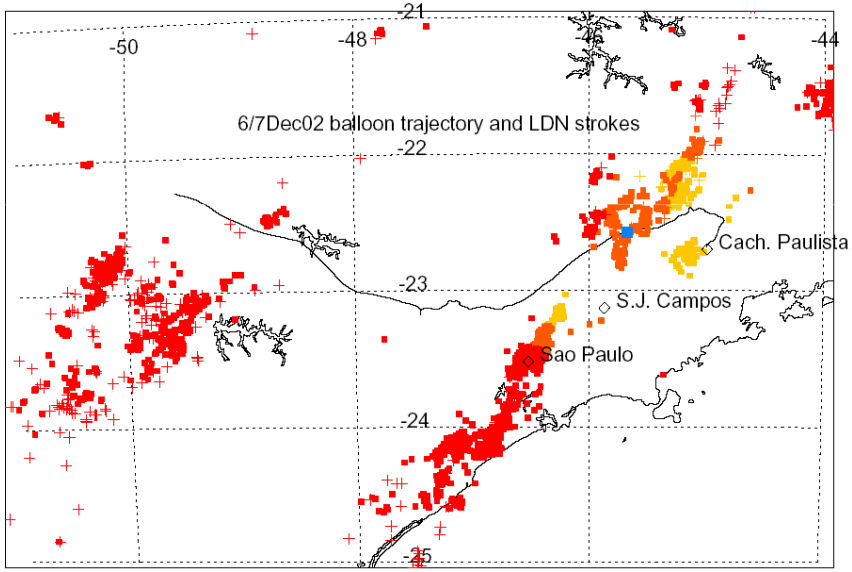
- ThunderLo/ThunderHi campaign from Wallops Island, VA in 1981 [*Kelley et al.* 1985; Holzworth et al. 1985]. Two rockets, a balloon and a rocket-borne parachute payload were flown simultaneously.
- The WIPP/Thunderstorm II Campaign, Wallops Island, VA 1987-88: Six stratospheric balloon flights and two ionospheric rocket flights (Kintner et al., [1987]; Arnoldy and Kintner, [1989])
- The Lightning Bolt Campaign, Wallops Island, VA, 2000 (NASA Flight 27-143, PI: Wygant): One ionospheric rocket flight measured dc to VLF and HF vector electric and magnetic fields, plasma density, fast electrons, and optical power (see Rowland et al., [2004]).

The Sprite Balloon Campaign
Brazil 2002-2003

DC/AC Vector E-field
(0 to 200V/m)
⌖ polar conductivity
DC/AC Magnetic Field
up/dn Optical Power
up/dn X-rays
External air Temperature
3MBPS digital telemetry

Nearby (< 75 km) Quasi-Electrostatic Field Changes due to Lightning

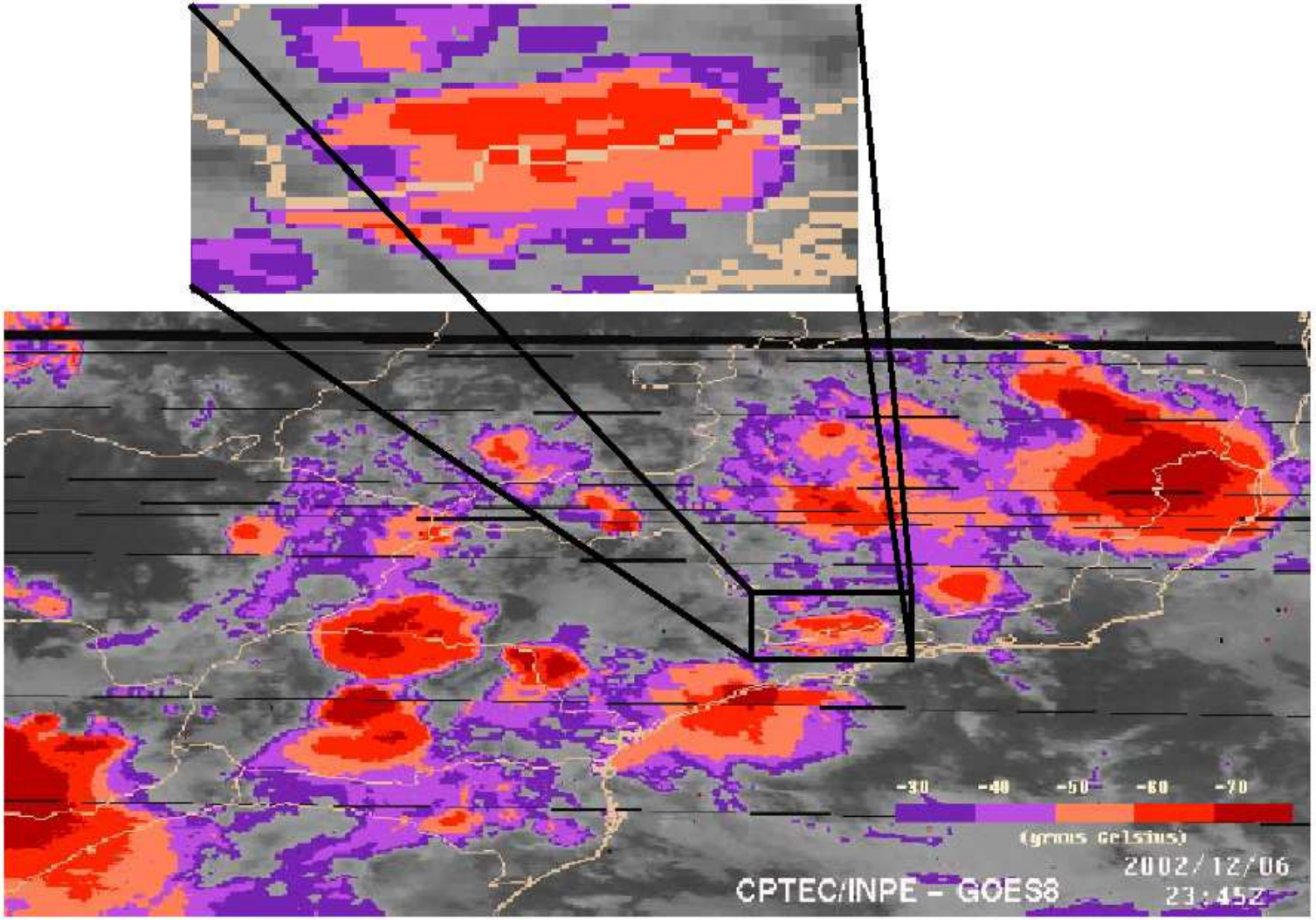
[Thomas et al., IEEE TGRS, 2004; Thomas et al. GRL, 2005; Holzworth et al. GRL, 2005; Thomas et al. Atm. Res., 2009]



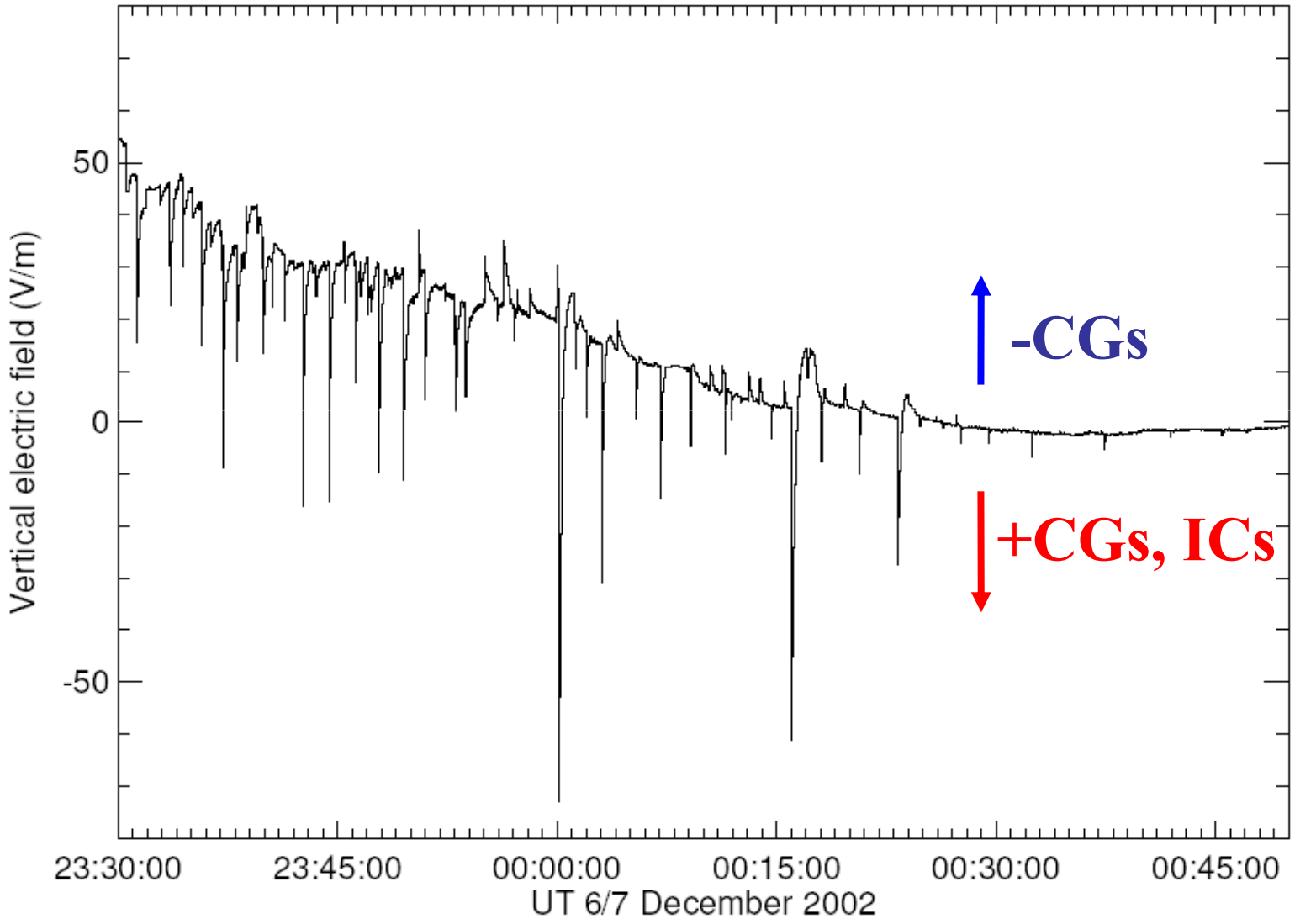
Flight 1 Trajectory and BIN CGs

- 38 electric field changes greater than 10 V/m were measured above 30km in alt.
- Location of strokes: Brazilian Integrated Ground Based Lightning Network (BIN)
- Sprites not ruled out, although none were confirmed optically

GOES8 Satellite IR image from 23:45 UT Dec. 6, 2002 for the southeast of Brazil

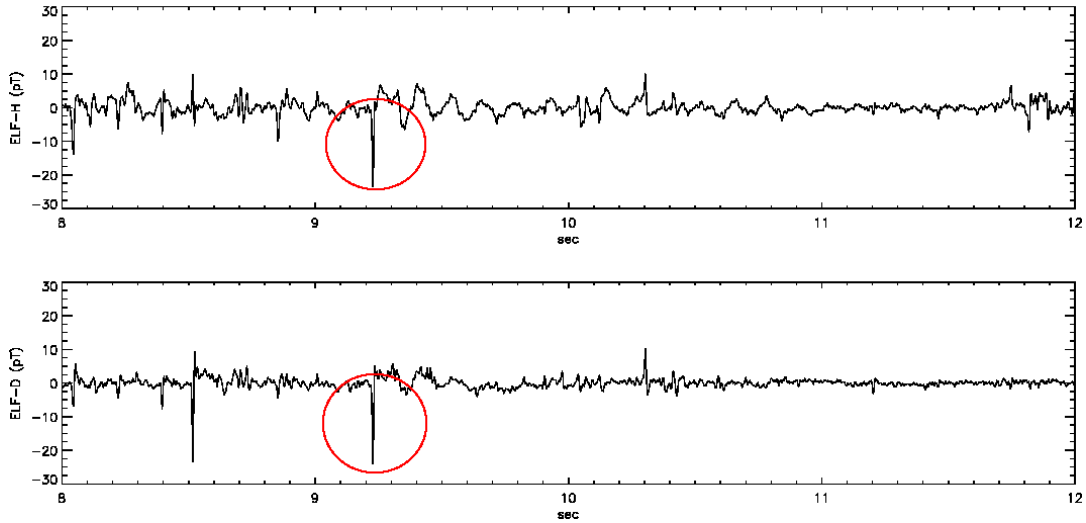


80 minutes of vertical dc electric field data during Flight 1



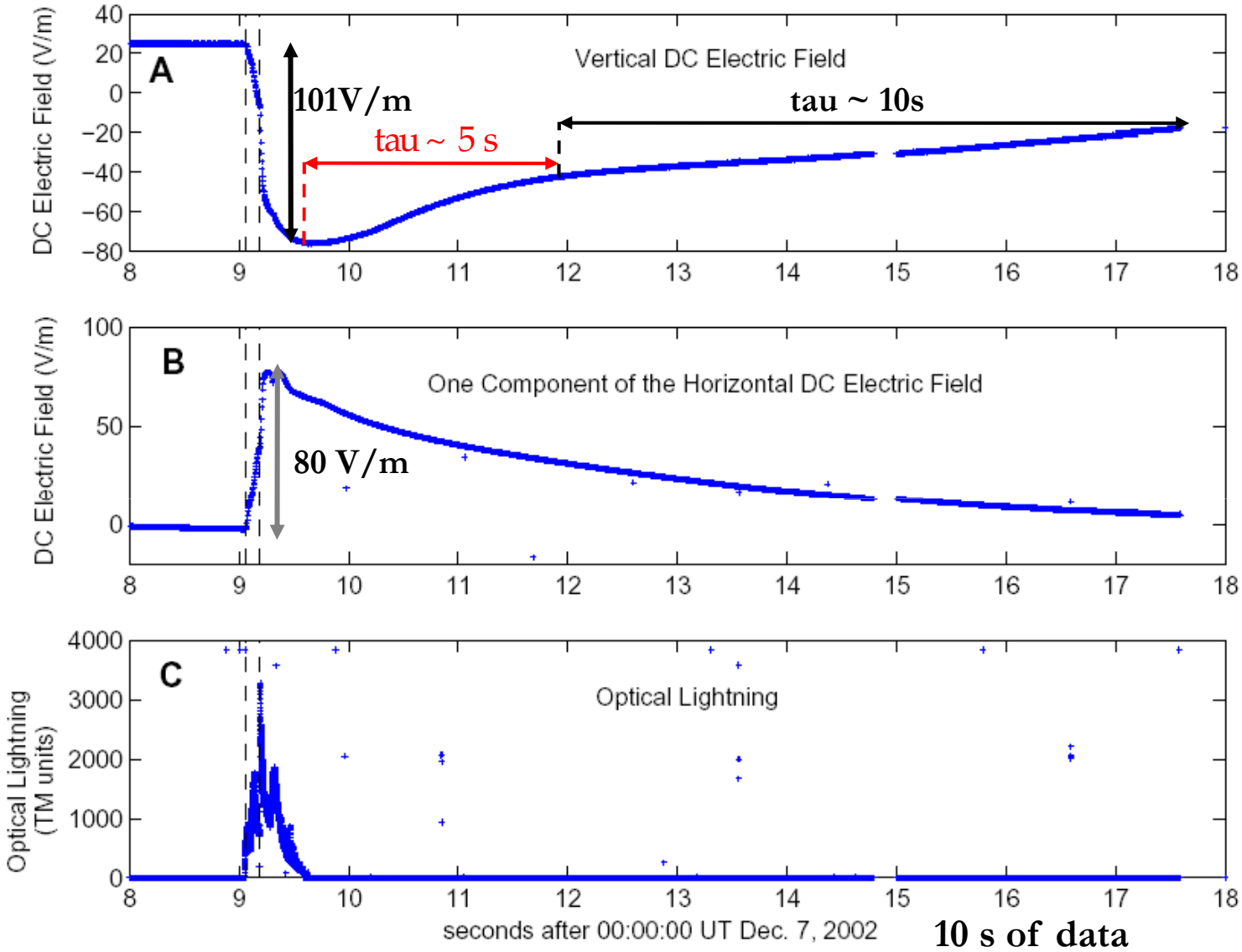
Case Study: A Large +CG Event

- Two positive cloud-to-ground (+CG) strokes 140ms apart 34 km hor. distance from the balloon payload (alt=34km)
- Charge moment: 329-1683 C-km estimated from remote ELF (extremely low frequency) magnetic field measurements (M. Sato)

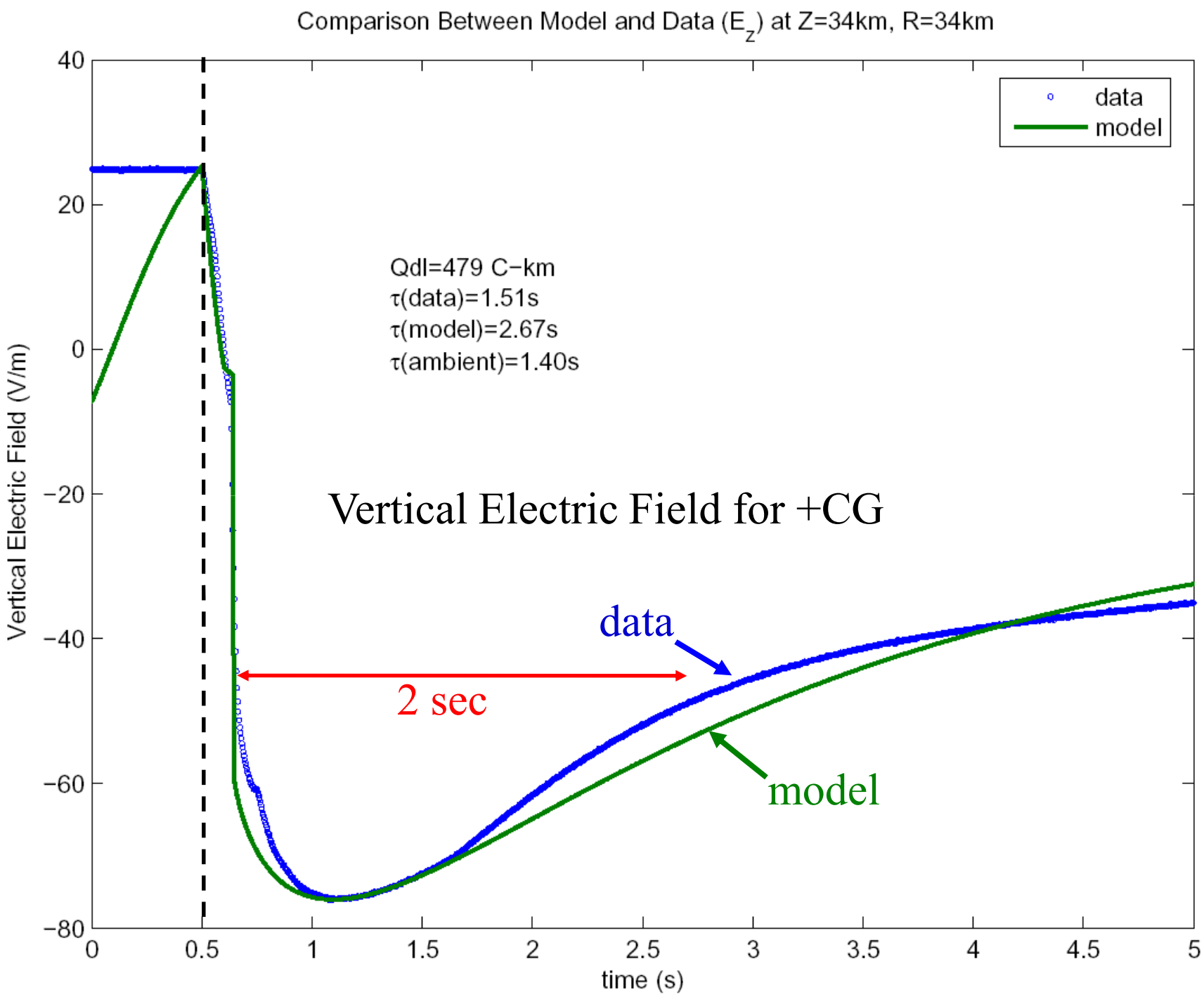


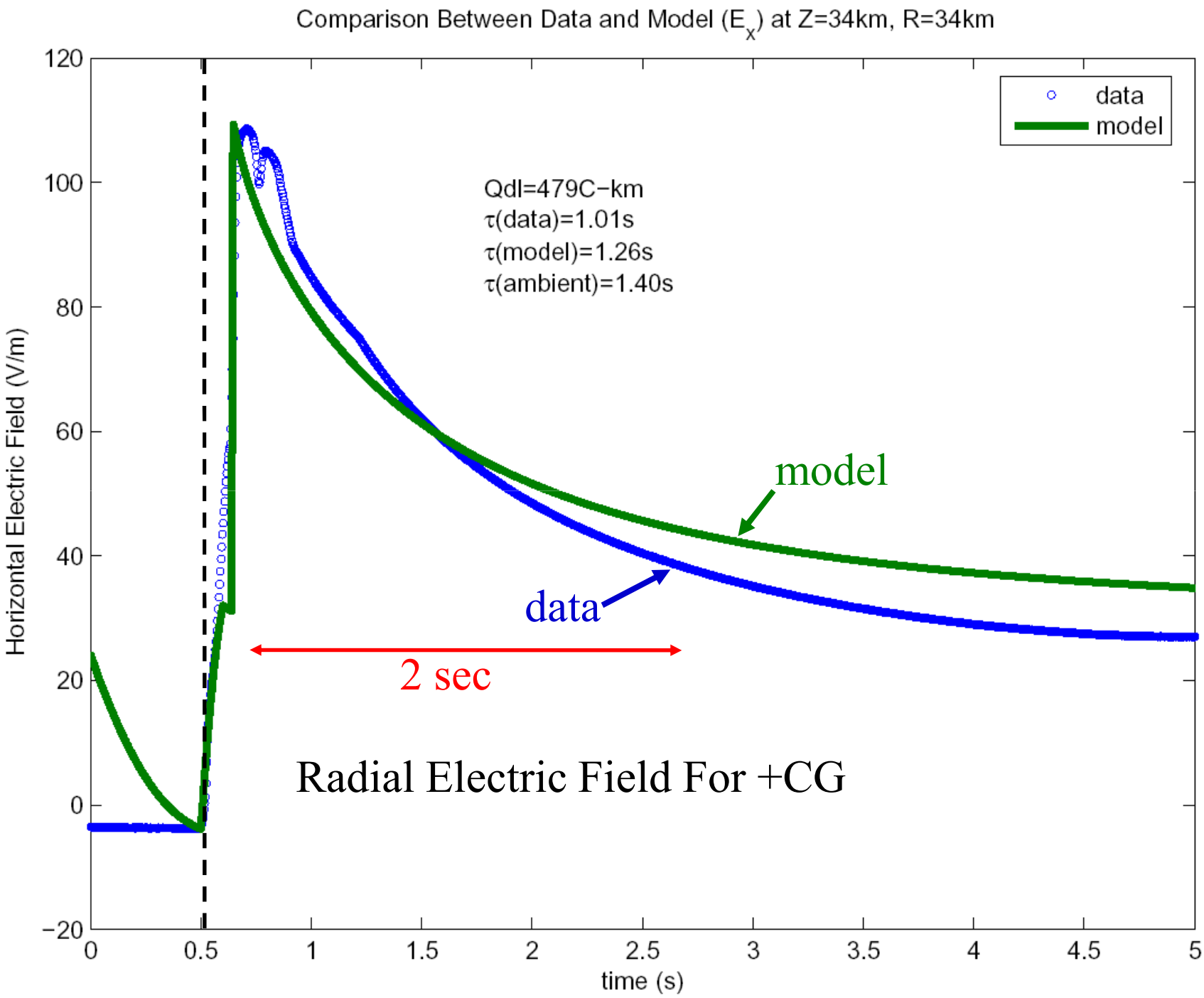
ELF Data from Syowa, Antarctica

DC Electric Field Change Driven by +CG (Possible Sprite Event)



In-situ data: Two lightning events, +15kA and +53kA (436 C-km), at ~00:00:09 UT Dec. 7 both less than 40 km from the balloon payload.


Comparison Between Model and Data (E_z) at Z=34km, R=34km
data
model
Qdl=479 C−km
τ(data)=1.51s
τ(model)=2.67s
τ(ambient)=1.40s
Vertical Electric Field for +CG
data
2 sec
model
Vertical Electric Field (V/m)
time (s)
40
20
0
−20
−40
−60
−80
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Comparison Between Data and Model (E_x) at Z=34km, R=34km
data
model
Qdl=479C−km
τ(data)=1.01s
τ(model)=1.26s
τ(ambient)=1.40s
model
data
2 sec
Radial Electric Field For +CG
Horizontal Electric Field (V/m)
time (s)
120
100
80
60
40
20
0
−20
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

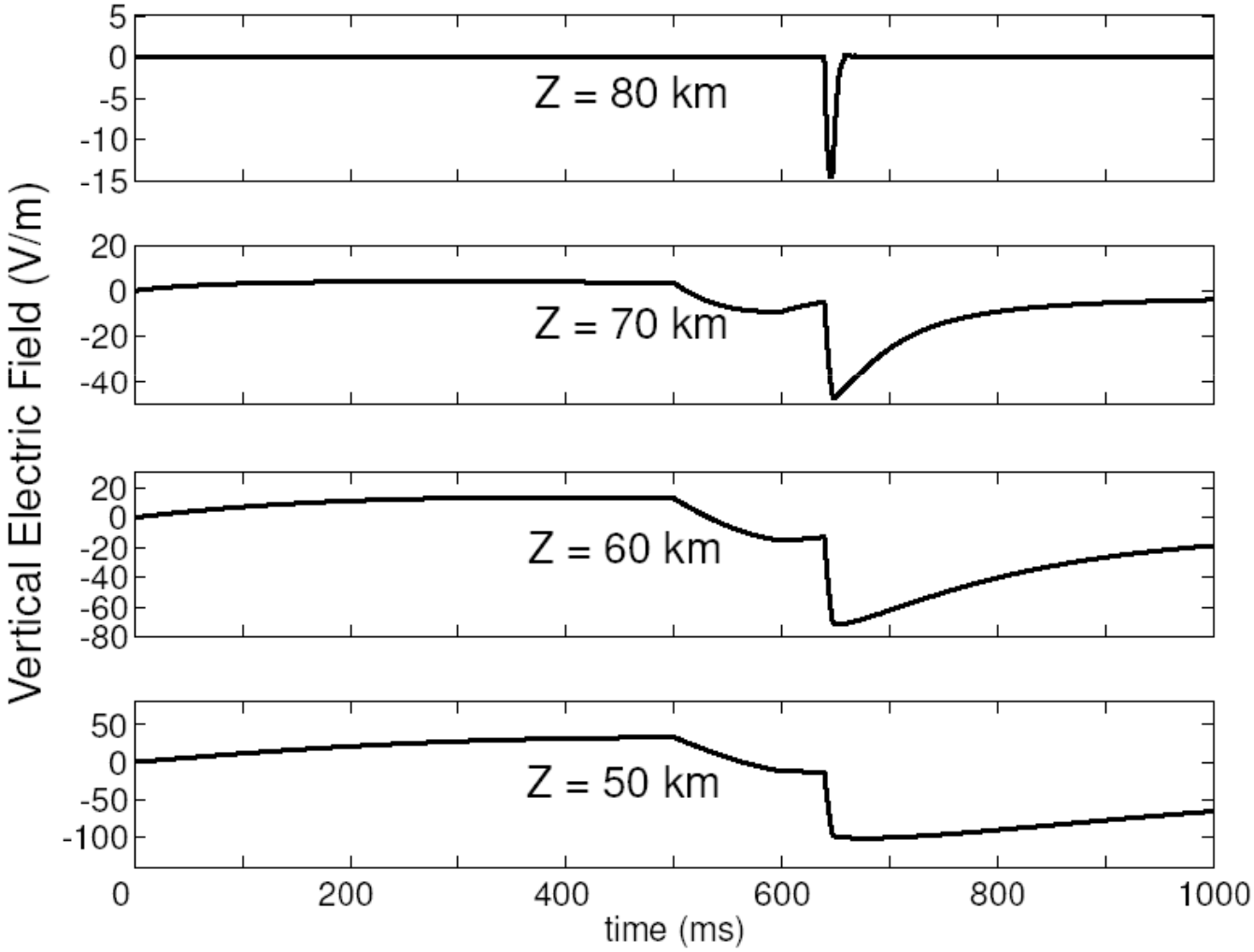
Breakdown Thresholds

•Conventional Breakdown (E_k): electric field magnitude when ionization rate surpasses the attachment rate, $E_k = 3.2 \times 10^6$ V/m at STP.

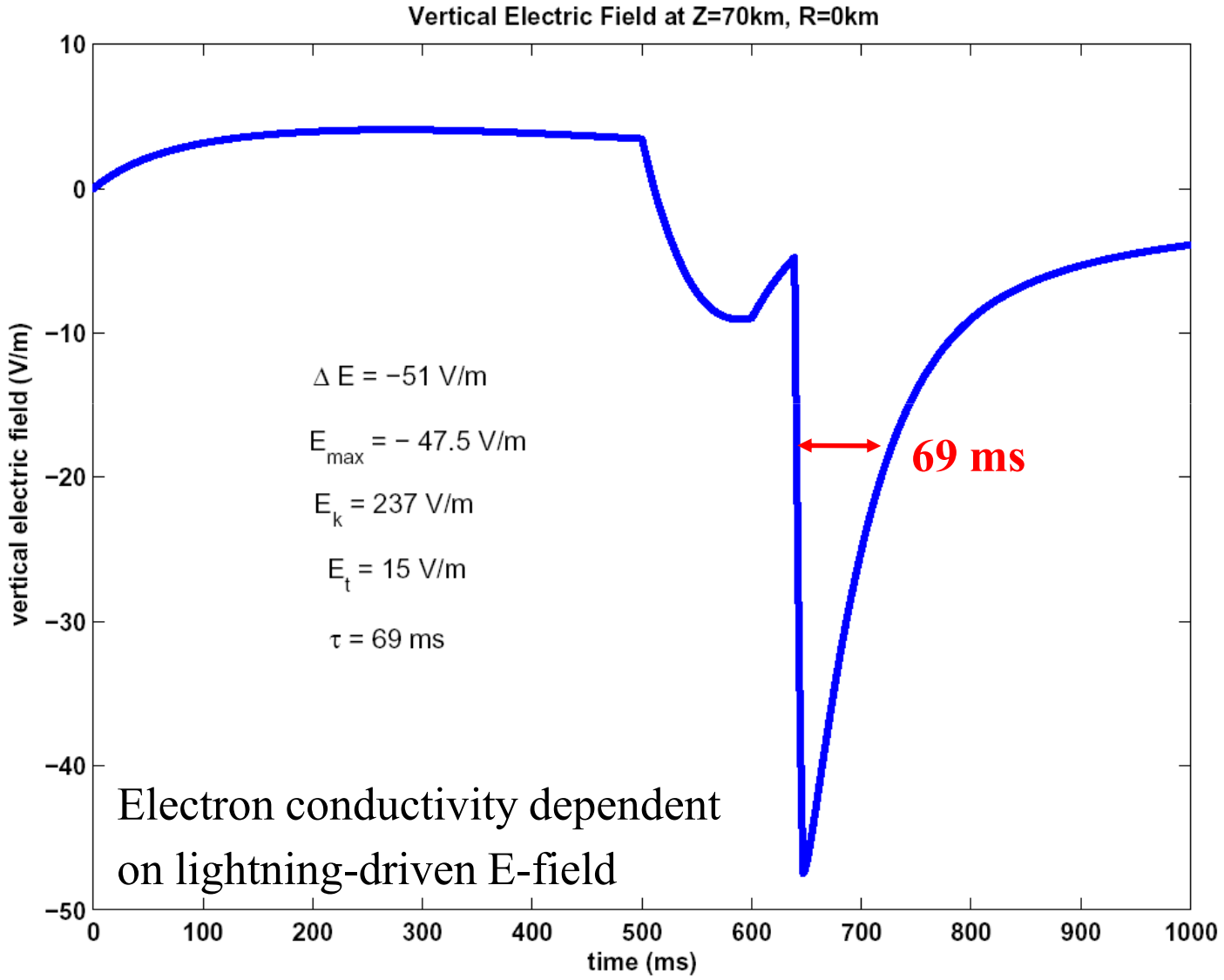
•Relativistic Runaway (E_t): electric field magnitude needed for a 1 MeV electron to initiate a electron avalanche, $E_t = 2 \times 10^5$ V/m at STP.

•Positive (Negative) Streamer Breakdown (E_{cr}^+, E_{cr}^-): electric field magnitude needed for an ionized filament to continue to propagate in the direction (opposite direction) of the field, $E_{cr}^+ = 4.4 \times 10^5$ V/m and $E_{cr}^- = -1.25 \times 10^6$ V/m at STP.

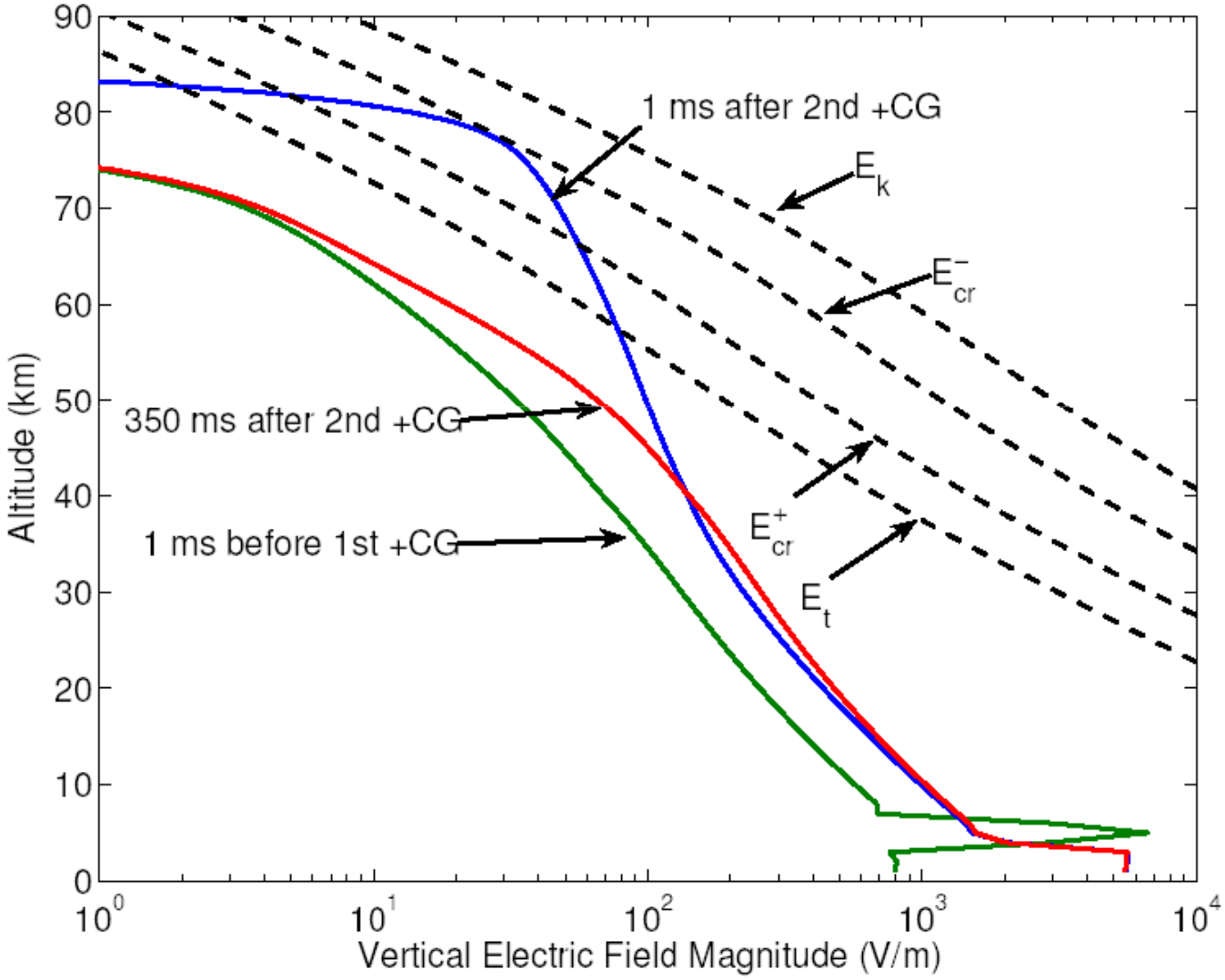
Model Output: Predicted lightning-driven electric fields at sprite altitudes (Z=50-80km)



Model Output: Predicted lightning-driven electric fields at sprite altitudes (Z=70km)

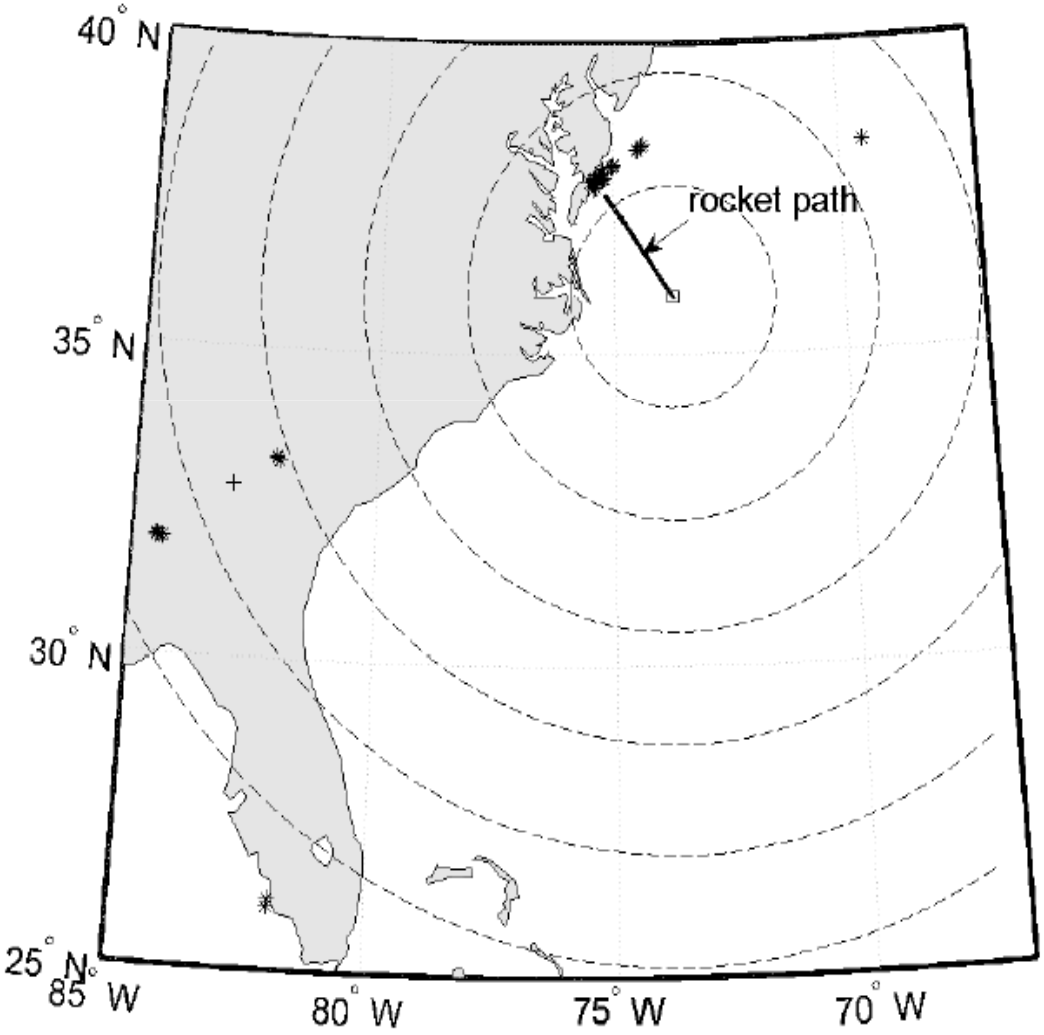


Model Output: Vertical electric field vs. altitude at R=0 km

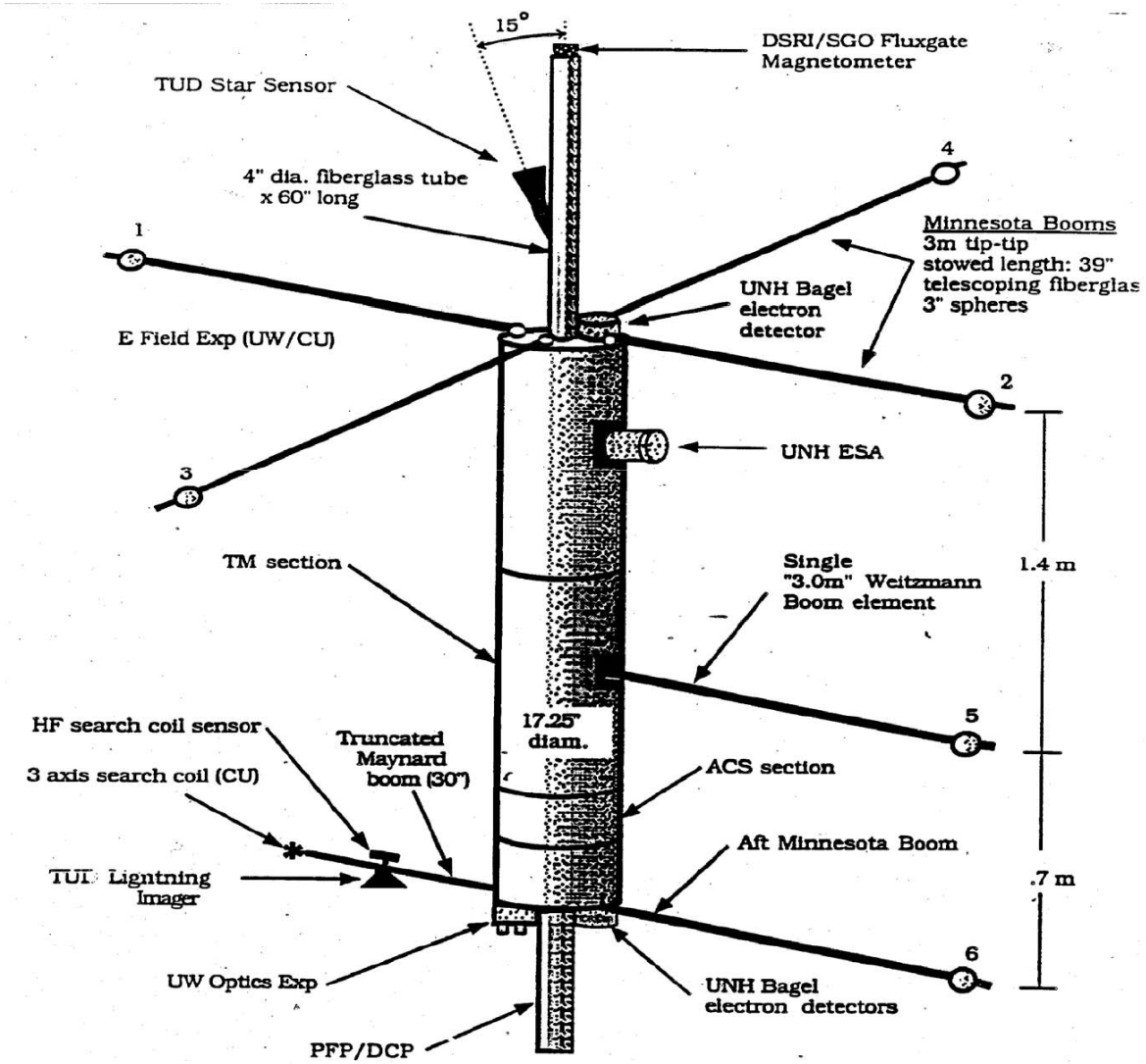


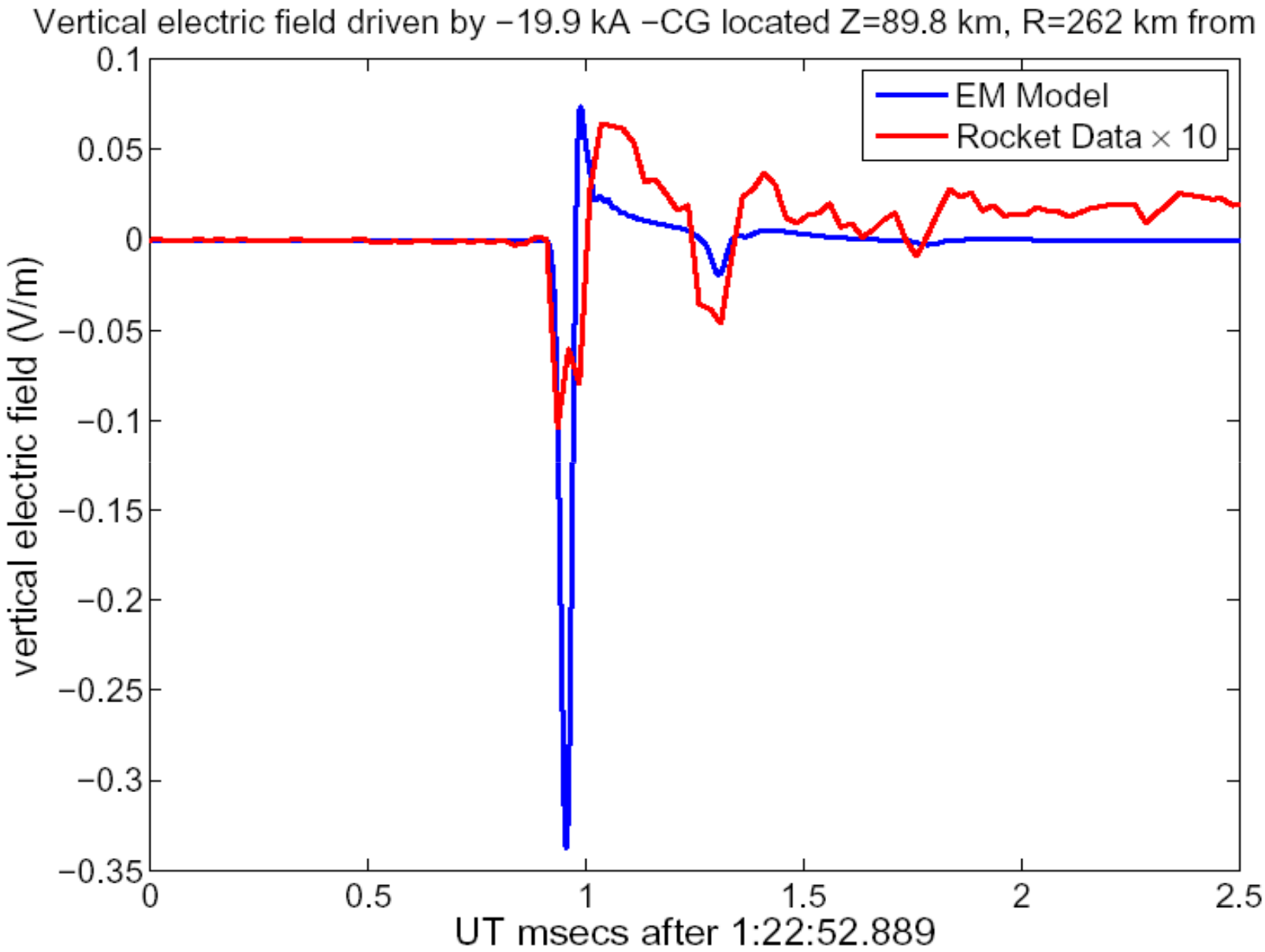
Thunderstorm-III Rocket Sept.1 1995

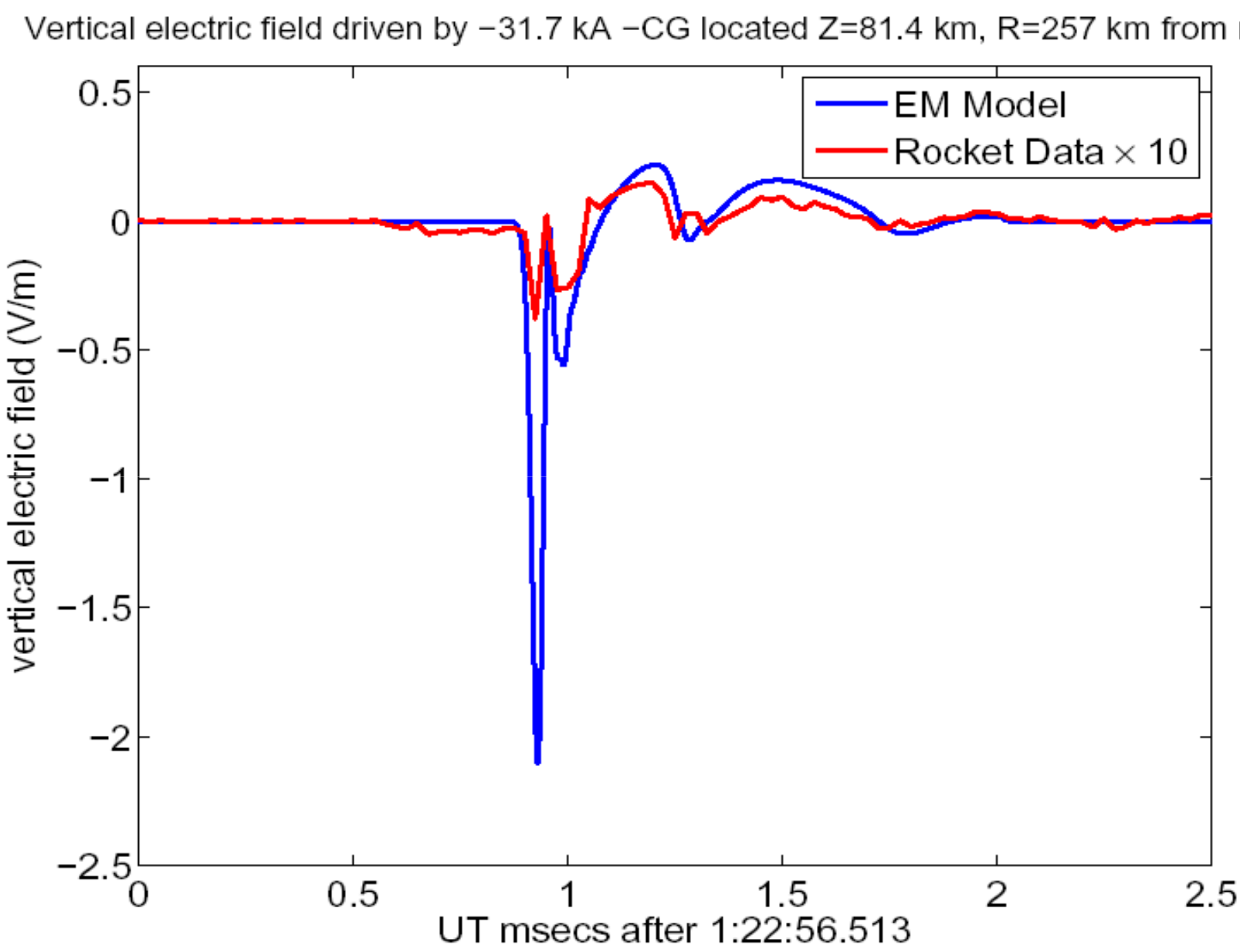
[Barnum, PhD Thesis,1999; Thomas et al., JGR, 2008]



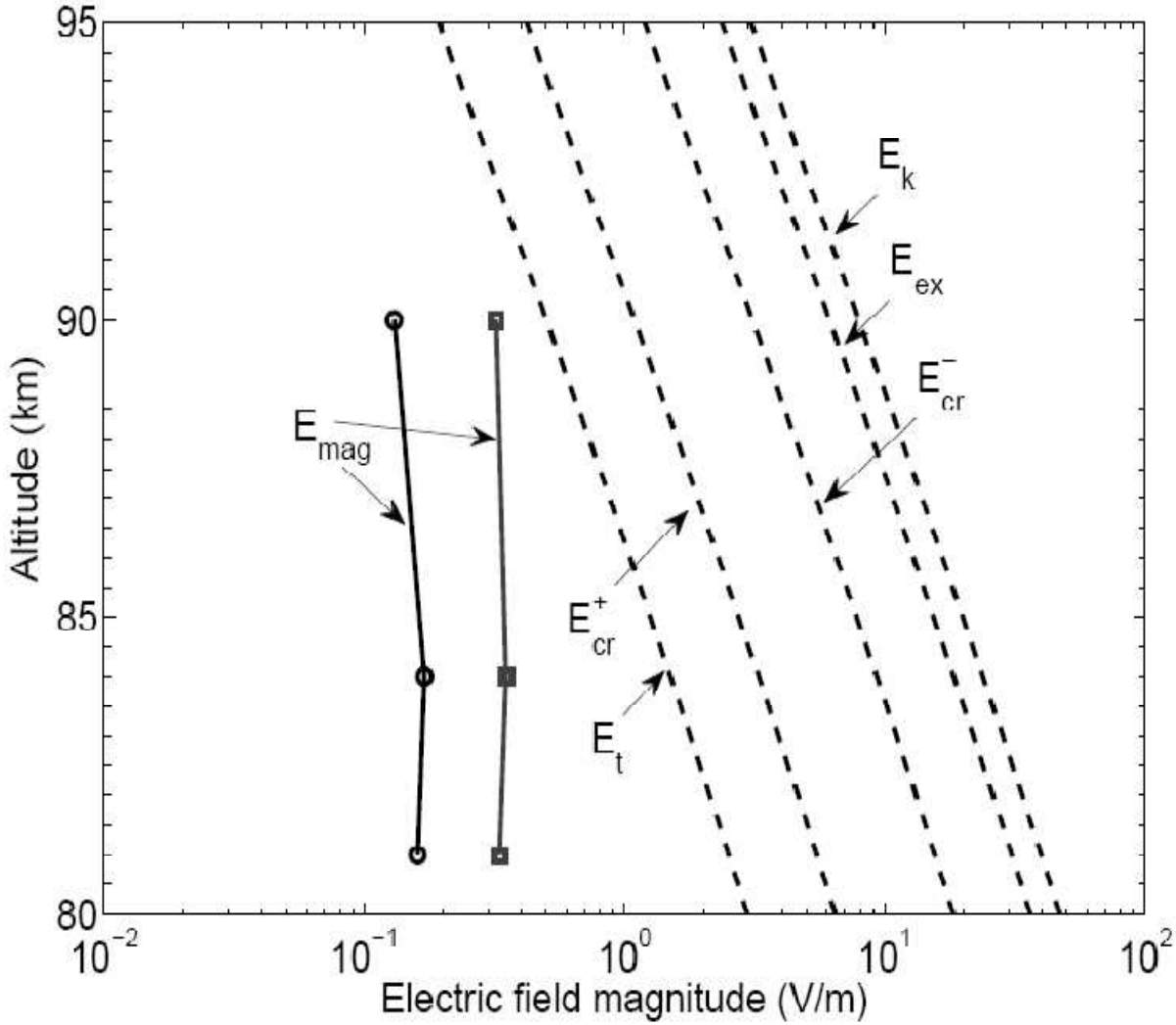
Thunderstorm-III Payload




Vertical electric field driven by −19.9 kA −CG located Z=89.8 km, R=262 km from rocket
EM Model
Rocket Data × 10
vertical electric field (V/m)
UT msecs after 1:22:52.889
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−0.3
−0.35
0
0.5
1
1.5
2
2.5

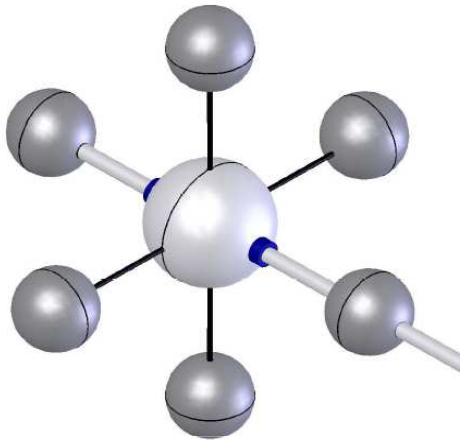

Vertical electric field driven by −31.7 kA −CG located Z=81.4 km, R=257 km from rocket
EM Model
Rocket Data × 10
vertical electric field (V/m)
UT msecs after 1:22:56.513
0.5
0
−0.5
−1
−1.5
−2
−2.5
0
0.5
1
1.5
2
2.5

Predicted Field at ELVE Altitudes for 100 kA CG

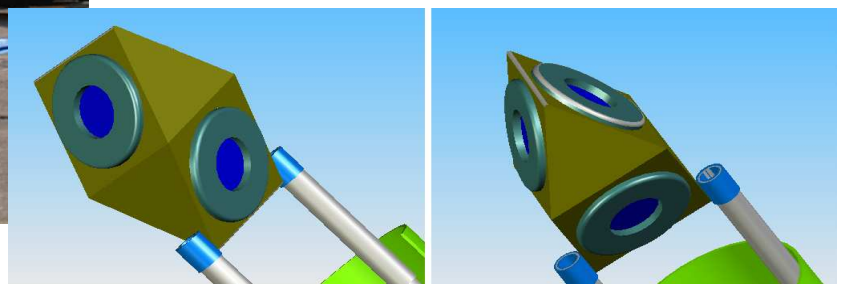


New Directions for in situ measurements: Lightweight Balloon Platforms

Student built balloon payloads launched from Moses Lake, WA



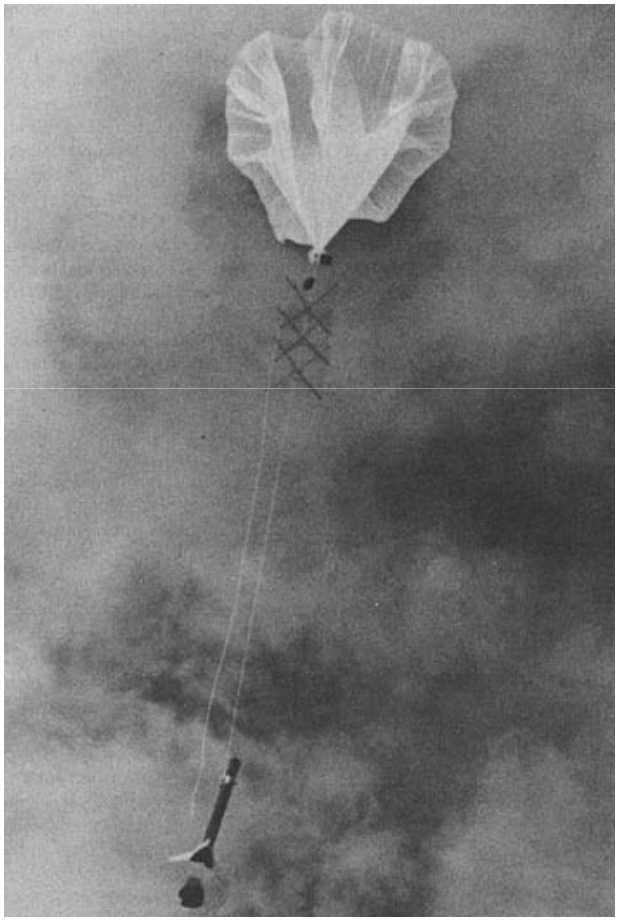
Double Langmuir probe vector electric field sensor.



A model of the speaker electric field mill.

New Directions for in situ measurements: Rockoon (Rocket Launched from Balloon)

- Rocket carried to middle atmosphere by balloon.
- Small and low-cost rocket launched from about 30 km and capable of reaching 60-70 km in altitude
- First flights – Van Allen 1949.



Courtesy of NASA

Conclusions: Brazil Balloons and Thunderstorm III Rocket

- Balloon measurements at 35 km generally agree with quasi-static electric field model for sprites
- Rocket measurements at 80-100 km are more than 10 times smaller than predicted by electromagnetic model for ELVEs
- Better understanding of conductivity in the middle atmosphere is central to understanding TLEs
- **Additional in situ measurements needed during confirmed sprite and elve events to verify generation mechanisms**