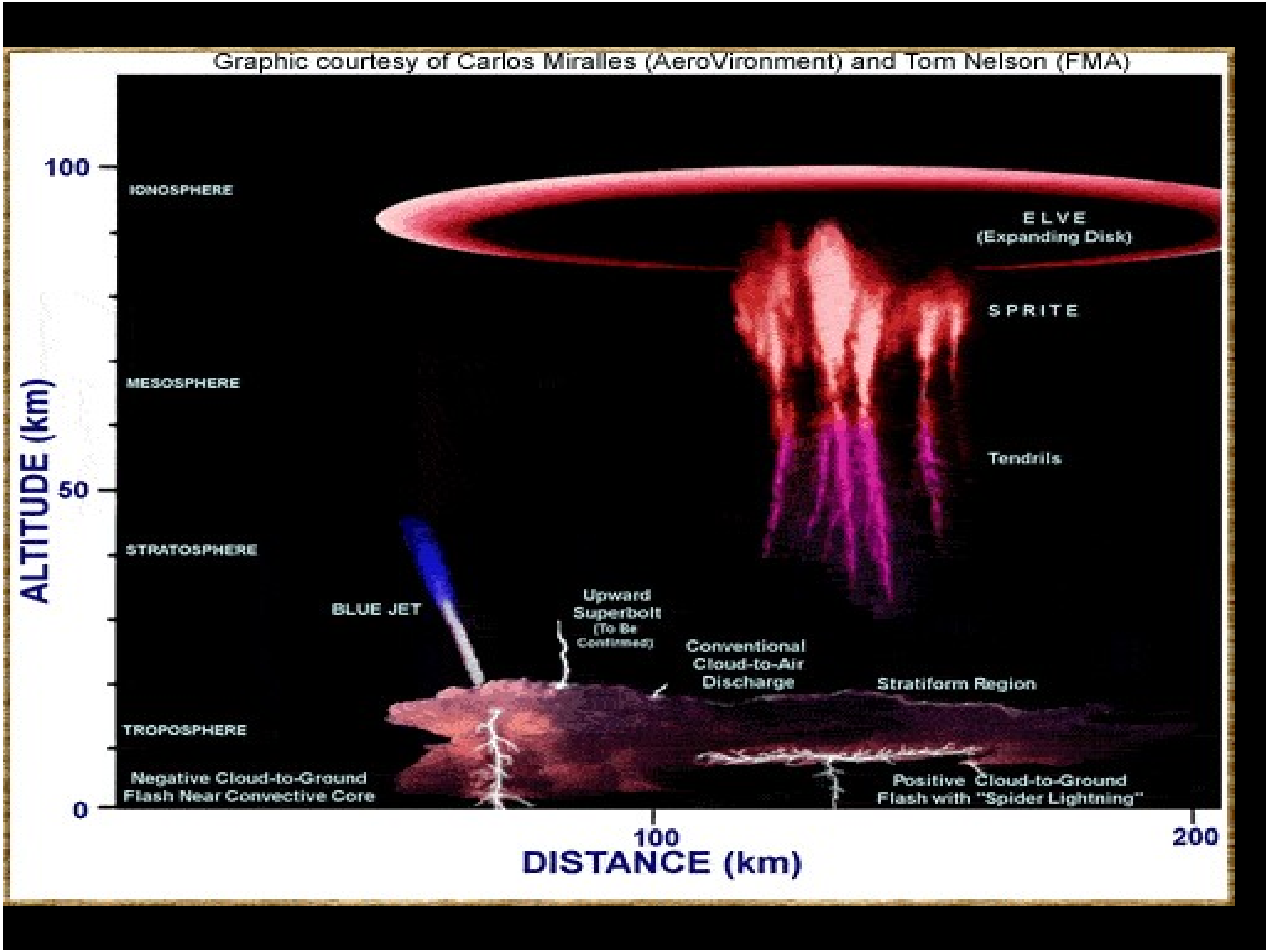
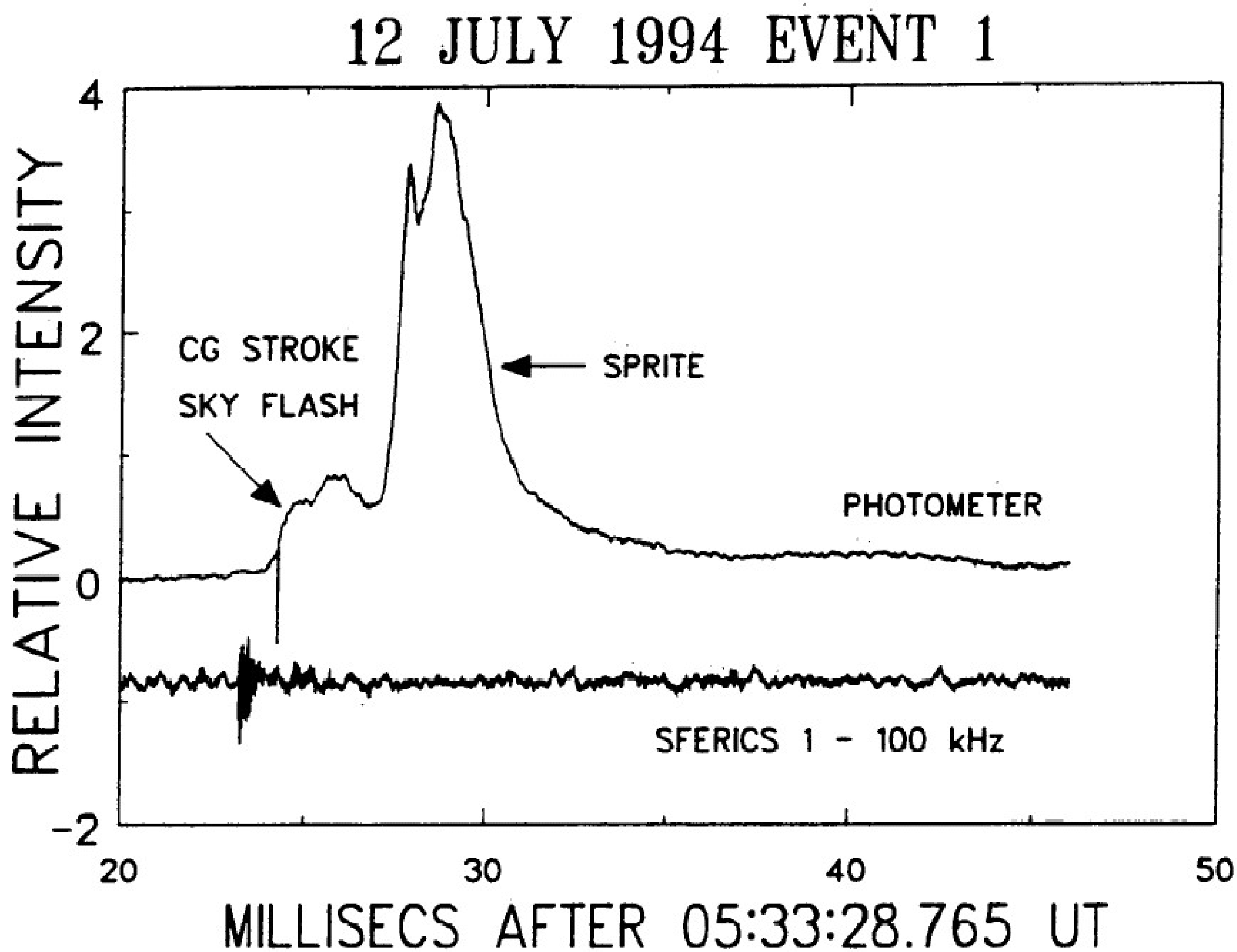
Intro to TLEs

- TLE: Transient Luminous Events
- See ISS   video (next)
- Sprites, Jets, Elves, Halos …
- Current Experiments: RHESSI, Fermi TGFs
- Lightning transients – whistler waves into Magnetosphere

From the International Space Station ISS


Graphic courtesy of Carlos Miralles (AeroVironment) and Tom Nelson (FMA)
ALTITUDE (km)
100
50
0
IONOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
ELVE
(Expanding Disk)
SPRITE
Tendrils
BLUE JET
Upward
Superbolt
(To Be
Confirmed)
Conventional
Cloud-to-Air
Discharge
Stratiform Region
Negative Cloud-to-Ground
Flash Near Convective Core
Positive Cloud-to-Ground
Flash with "Spider Lightning"
100
200
DISTANCE (km)

Winckler, et al



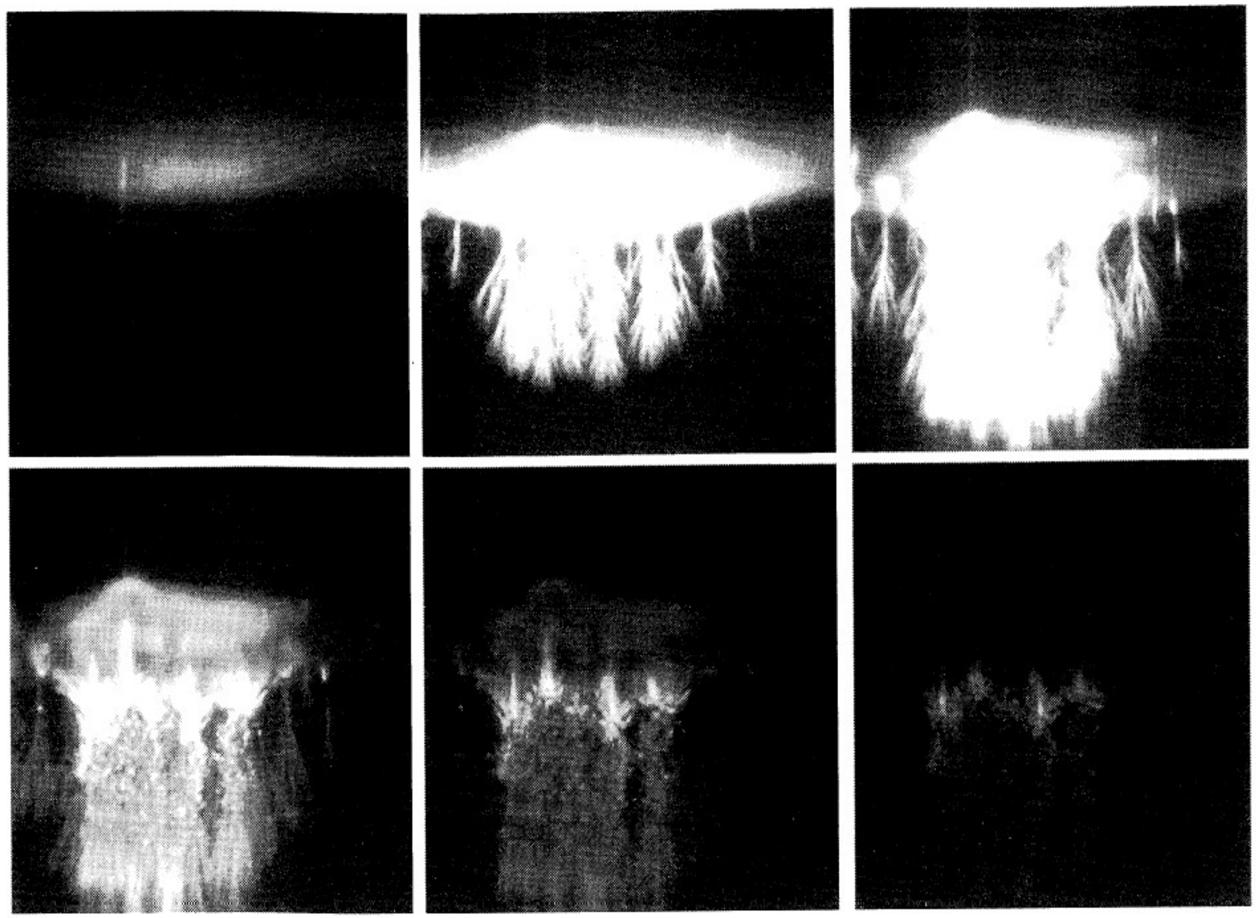
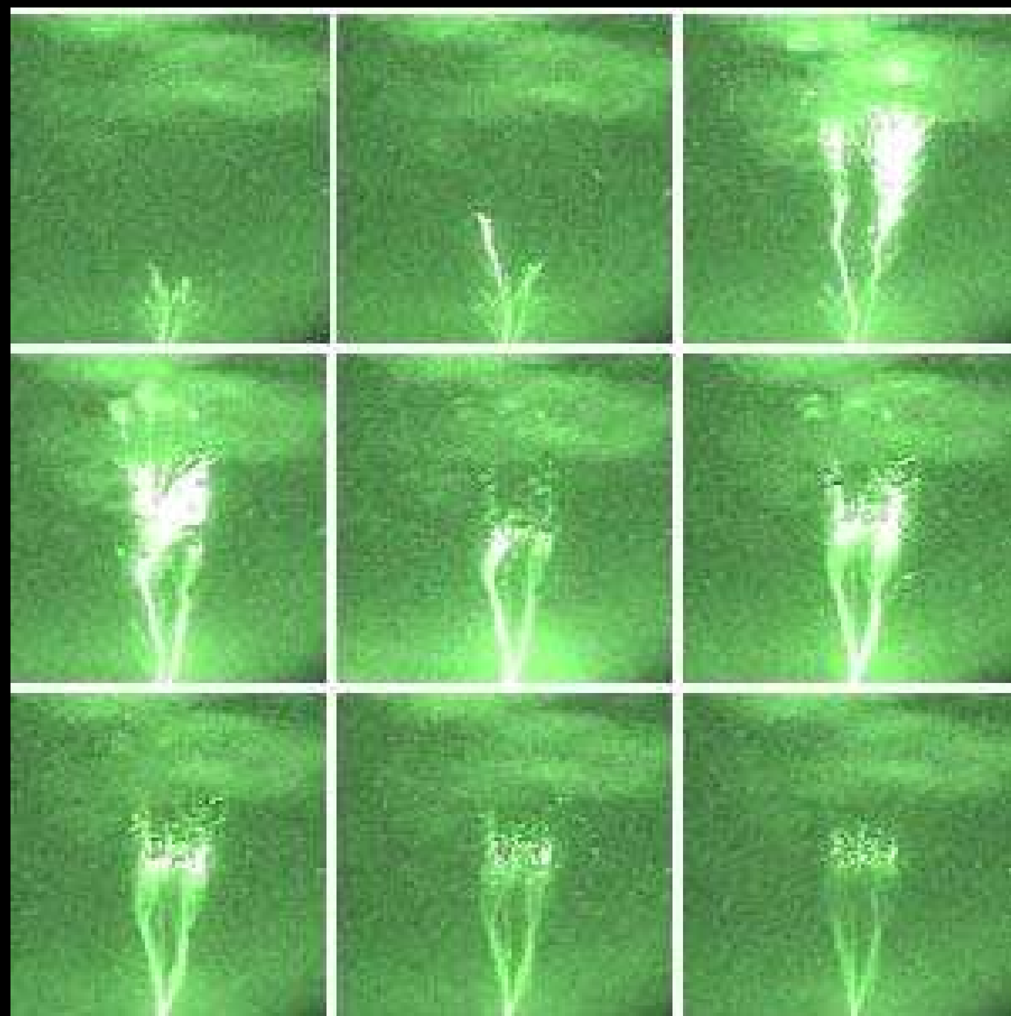


Figure 1. 6 high-speed images, each 1 ms apart, of a large sprite 06:15:07.67 UT on 18 August 1999. The examp illustrates some of the typical sprite features: The large horizontal, fairly featureless structure prominent in the two fi images is the sprite halo. It often precedes the sprite event. The sprite then develops from an altitude near that of the ha with tendrils going down and branches going up. In this example most of the activity is in the tendrils.



Hardman, et al, GRL, 2000

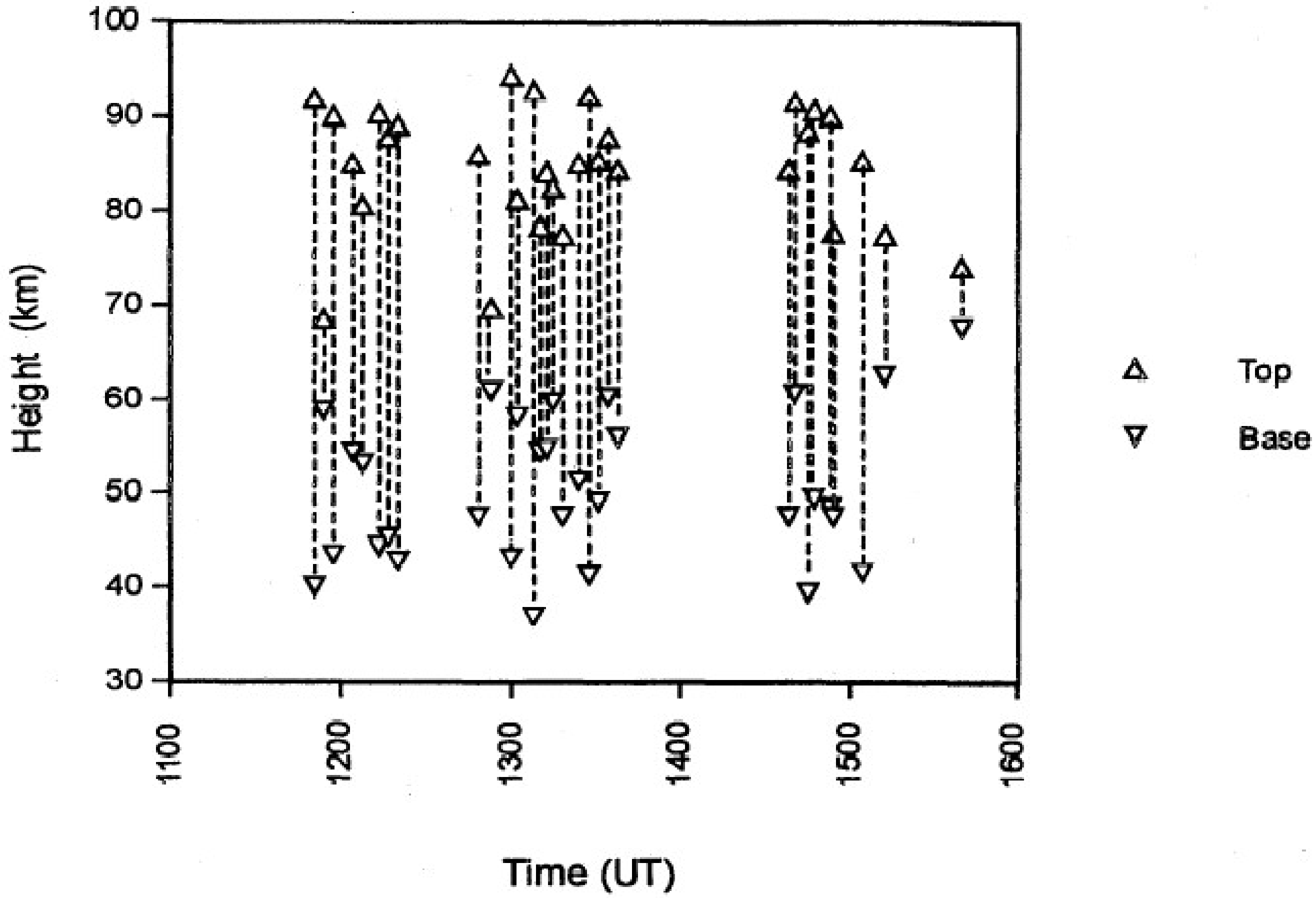
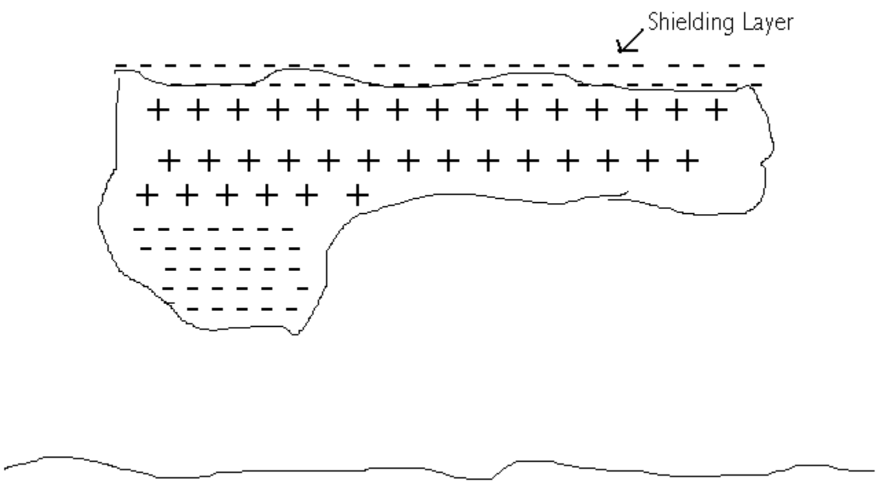
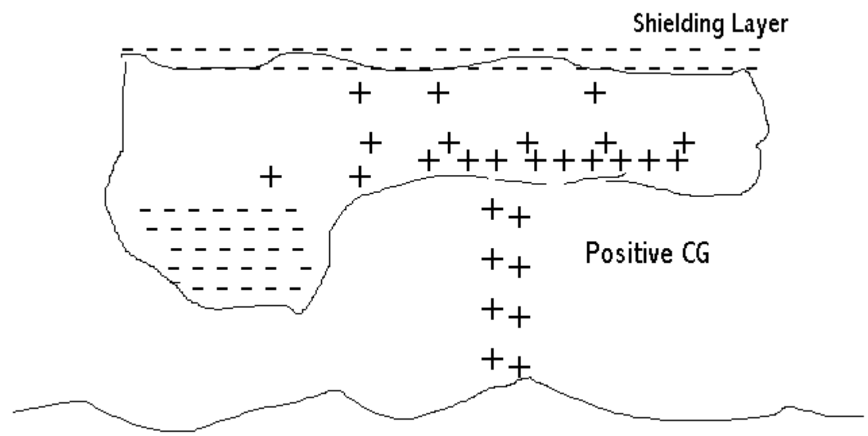


Figure 7. Heights of the lowest (base) and highest (top) visible portions of sprites observed on November 26.

The Quasi-Electrostatic Field Model

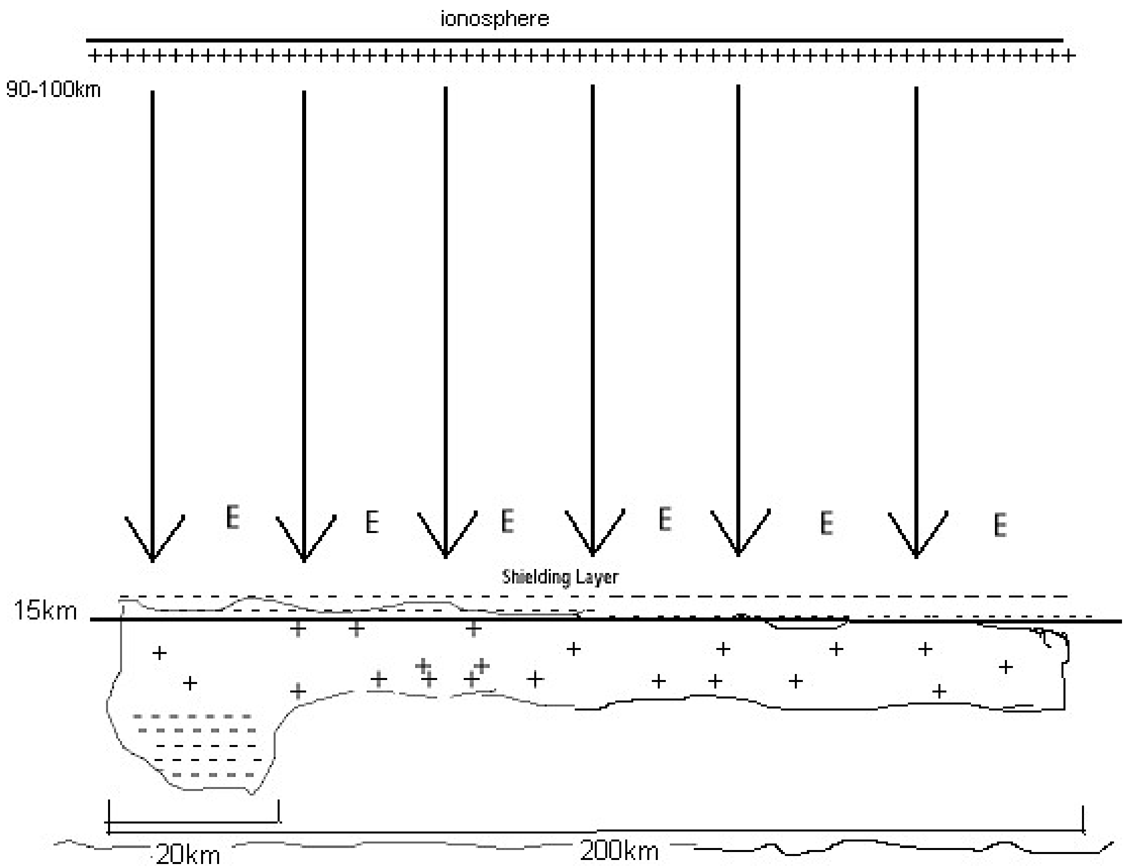


1. The cloud charges up before the lightning discharge inducing a negative shielding layer



2. The positive CG removes positive charge but the negative shielding layer remains over a much longer time scale

The Quasi-Electrostatic Field



3. The negative shielding layer remains after the discharge causing polarization in the atmosphere and a quasi-static E-field. This can me likened to a giant parallel plate capacitor as shown above. This strong E-field causes electrical breakdown producing sprites.

Problems with the models, as shown by Cummer & Stanley:

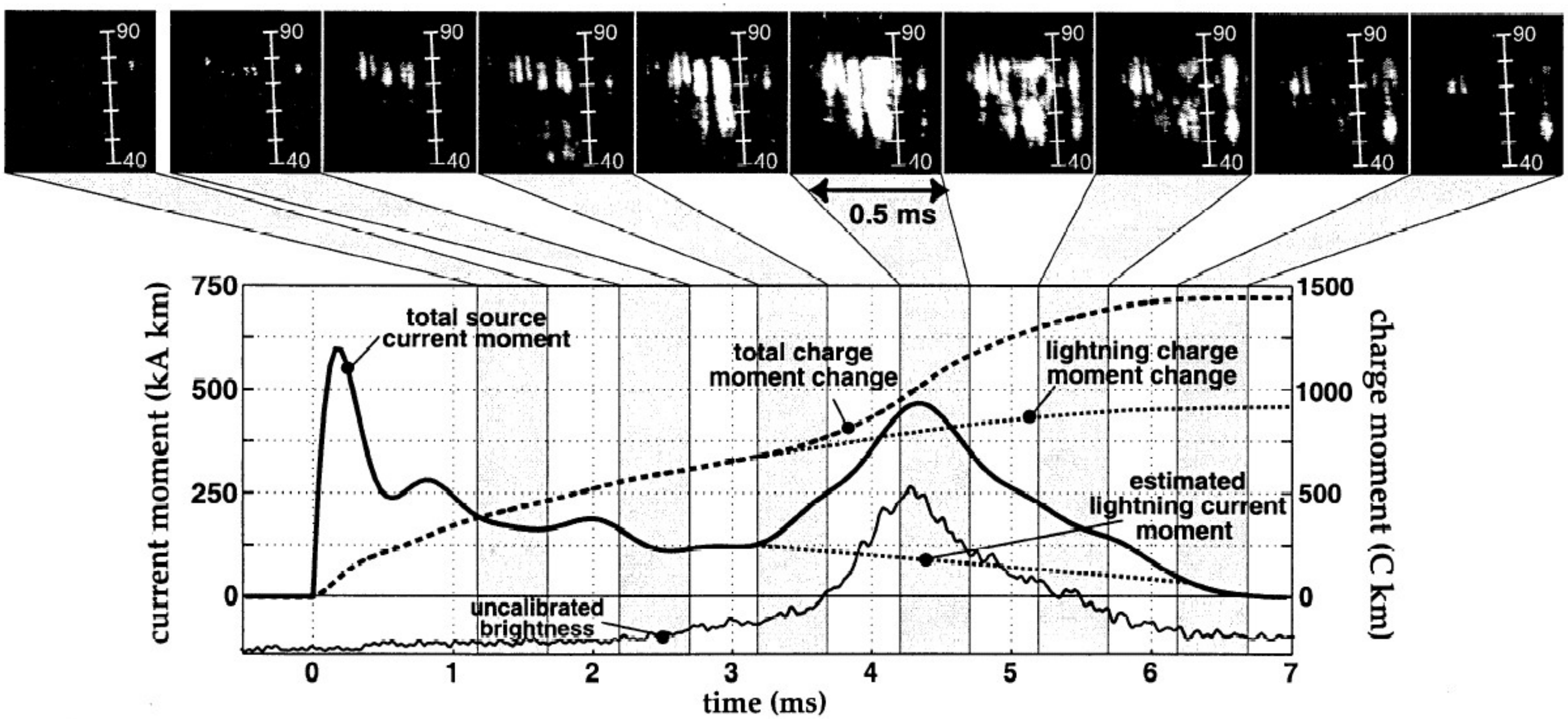


Figure 1. Time-aligned high speed video images, photometer-observed brightness, lightning and sprite current moment waveform, and cumulative charge moment change from a sprite cluster on 6 Oct 1997, 04:45:59.10691 UT. The contrast of the first two images is enhanced to highlight the optical emissions.

Cummer and Stanley, GRL, 99

The data (previous slide) show that vertical charge moment changes of 800 – 1100 CKm in 2 – 4 ms are associated with sustained emissions at altitudes as low as 50 km. This is a factor of 2 to 10 times smaller than the vertical lightning charge moment changes required to produce runaway and conventional breakdown at 50 km, respectively.

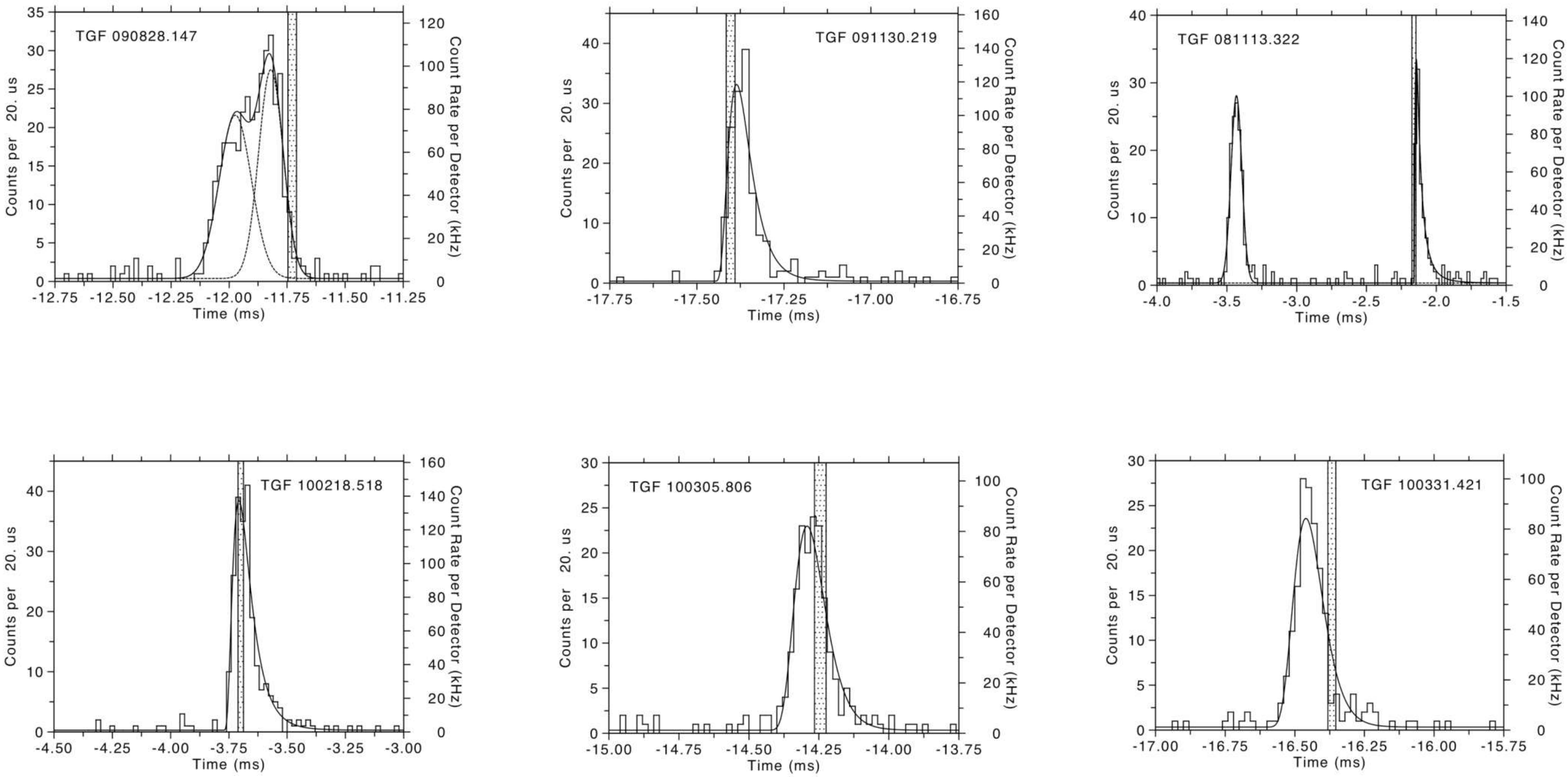
These observations are consistent with the generation of significant mesospheric electric fields by horizontal currents in some sprites, but we cannot rule out other processes as the explanation for the observations

(Cummer et al, 1999)

Next:

- TGFs (Terrestrial Gamma Flashes) (antimatter in Lightning: http://www.wired.com/wiredscience/2009/11/antimatter-lightning)
- Lightning in the ionosphere: unpredicted
- Significant lightning whistler wave amplitude all the way to the magnetopause
- NASA video of TGFs http://www.youtube.com/watch?v=S64RjPinpIs&feature=player_embedded
- Better:
- http://www.nasa.gov/mission_pages/GLAST/news/vision-improve_prt.htm

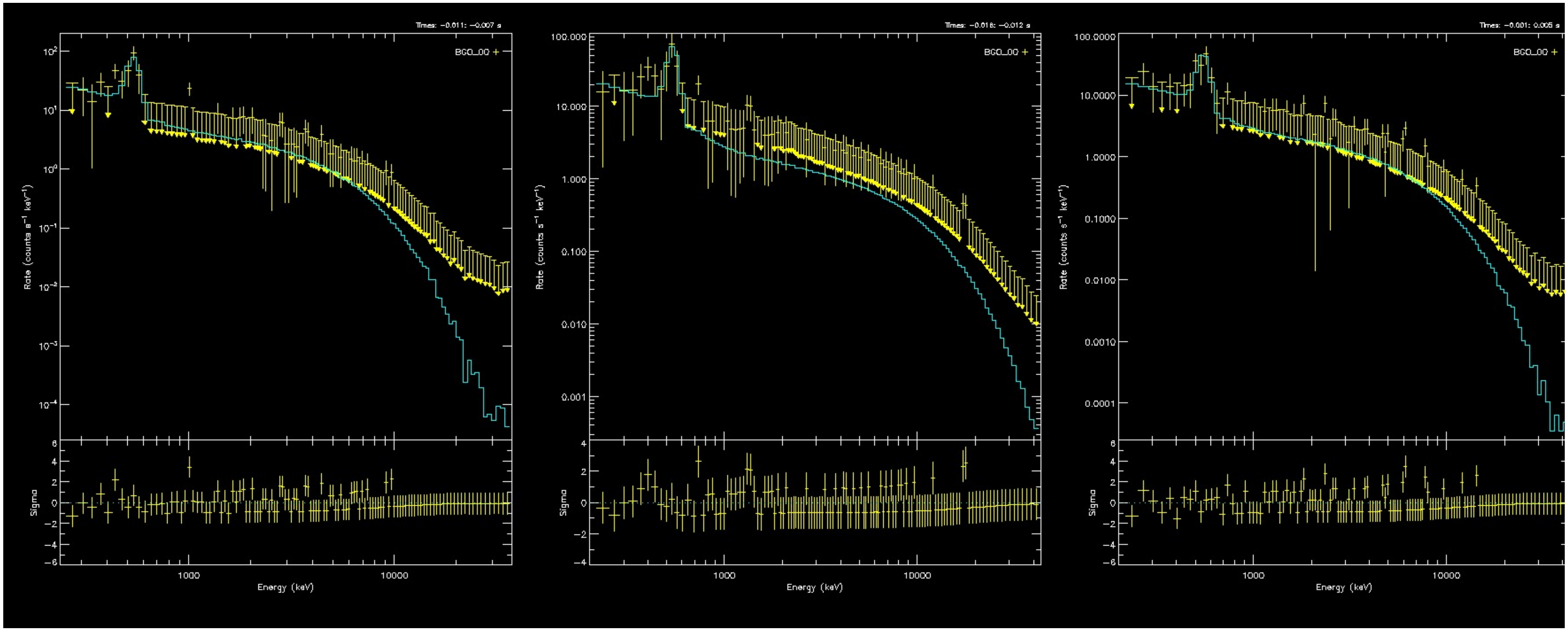
TGF-lightning are Simultaneous!



- GBM light curves corrected for light travel time and clock drift (histogram)
- WWLLN stroke time and uncertainty band (dotted vertical bar)

Positron Features Detected with GBM

TGF 080807 TGF 090813 TGF 091214



- Spectra fitted by separately simulating electrons and positrons along the field lines.
- Fits require both electron and positron components
- Exponential continuum spectrum with Ecutoff=2-4 MeV.

ESO, SUBARU/NATIONAL ASTRON. OBS. OF JAPAN

Sign of antimatter seen in lightning

Gamma-ray flash energies indicate presence of positrons

By Ron Cowen

WASHINGTON — Designed to scan the heavens thousands to billions of light-years beyond the solar system for gamma rays, the Fermi Gamma-ray Space Telescope has also picked up a shocking vibe from Earth. During its first 14 months of operation, the flying observatory has detected 17 gamma-ray flashes associated with terrestrial storms — some containing a surprising sign of antimatter.

During two recent lightning storms, Fermi recorded gamma-ray emissions with an energy that could have been produced only by energetic positrons, the antimatter equivalent of electrons. The positron observations are the first of their kind for lightning storms. Michael Briggs of the University of Alabama in Huntsville announced the findings November 5 at the 2009 Fermi Symposium.

The 17 flashes Fermi detected occurred just before, during and immediately after lightning strikes, as tracked by the World Wide Lightning Location Network.

During lightning storms previously observed by other spacecraft, energetic electrons moving toward the craft slowed down and produced gamma rays. The unusual positron signature seen by Fermi suggests that the normal orientation for an electric field associated with a lightning storm is somehow reversed, Briggs said. Scientists are now working to figure out how the field reversal could have occurred. But for now, he said, the answer is up in the air.

Recording terrestrial gamma-ray flashes isn't new. The first were found by NASA's Compton Gamma-ray Observatory in the early 1990s. NASA's RHESSI satellite, which primarily looks at X-ray and gamma-ray emissions from the sun, has found some 800 terrestrial gamma-ray flashes, Briggs noted. ■

Next: Common Lightning effects in the ionosphere

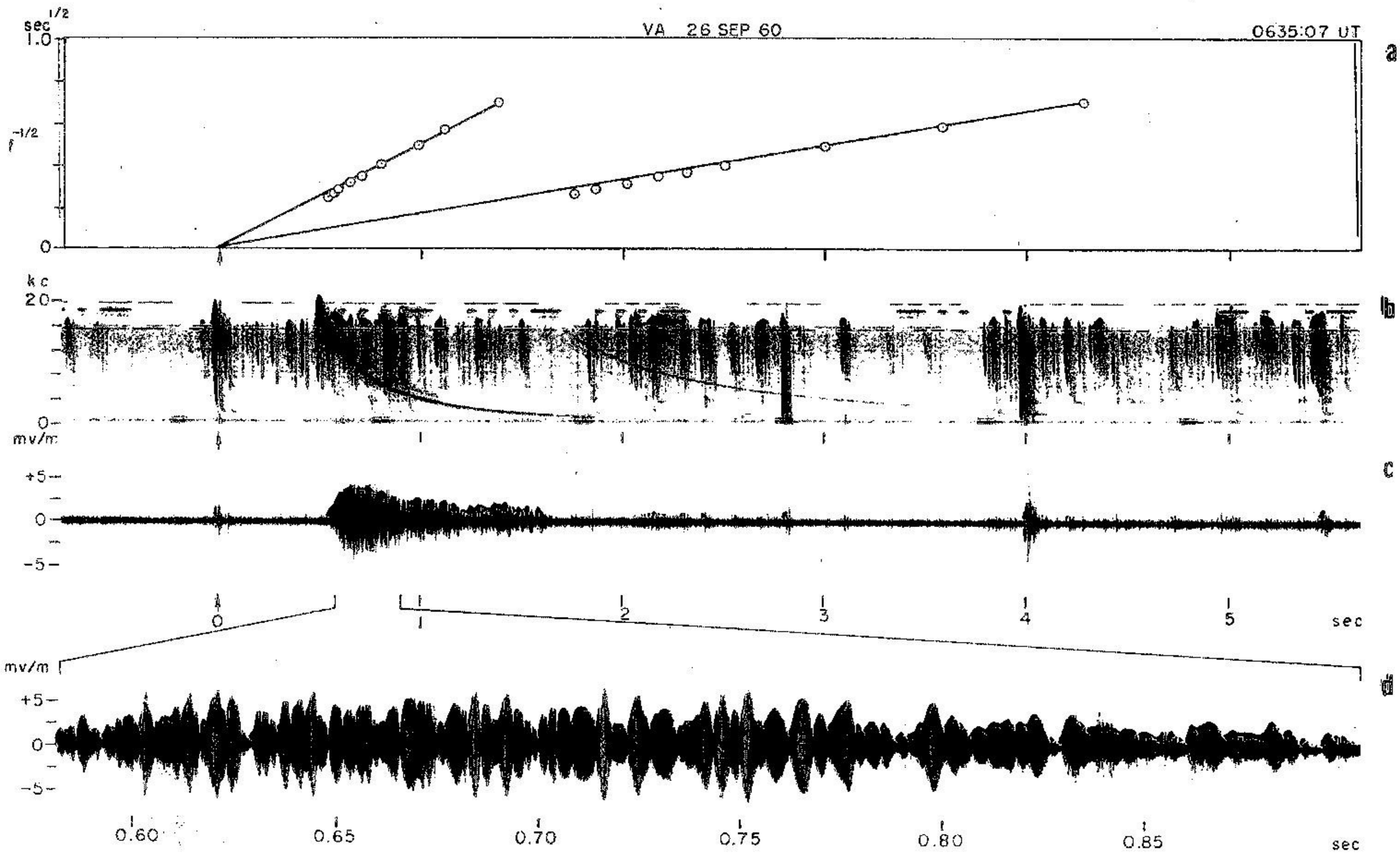


FIG. 4-3. One-hop whistler of high amplitude with three-hop echo. *a*, Curve of $1/\sqrt{f}$ versus *t*. *b*, Dynamic spectrum. *c*, Corresponding oscillogram of wide-band amplitude. *d*, A section of *c* expanded in time by a factor of 20. In parts *c* and *d*, filter passband was 600 cps to 15 kc/s.

Ground based measurements

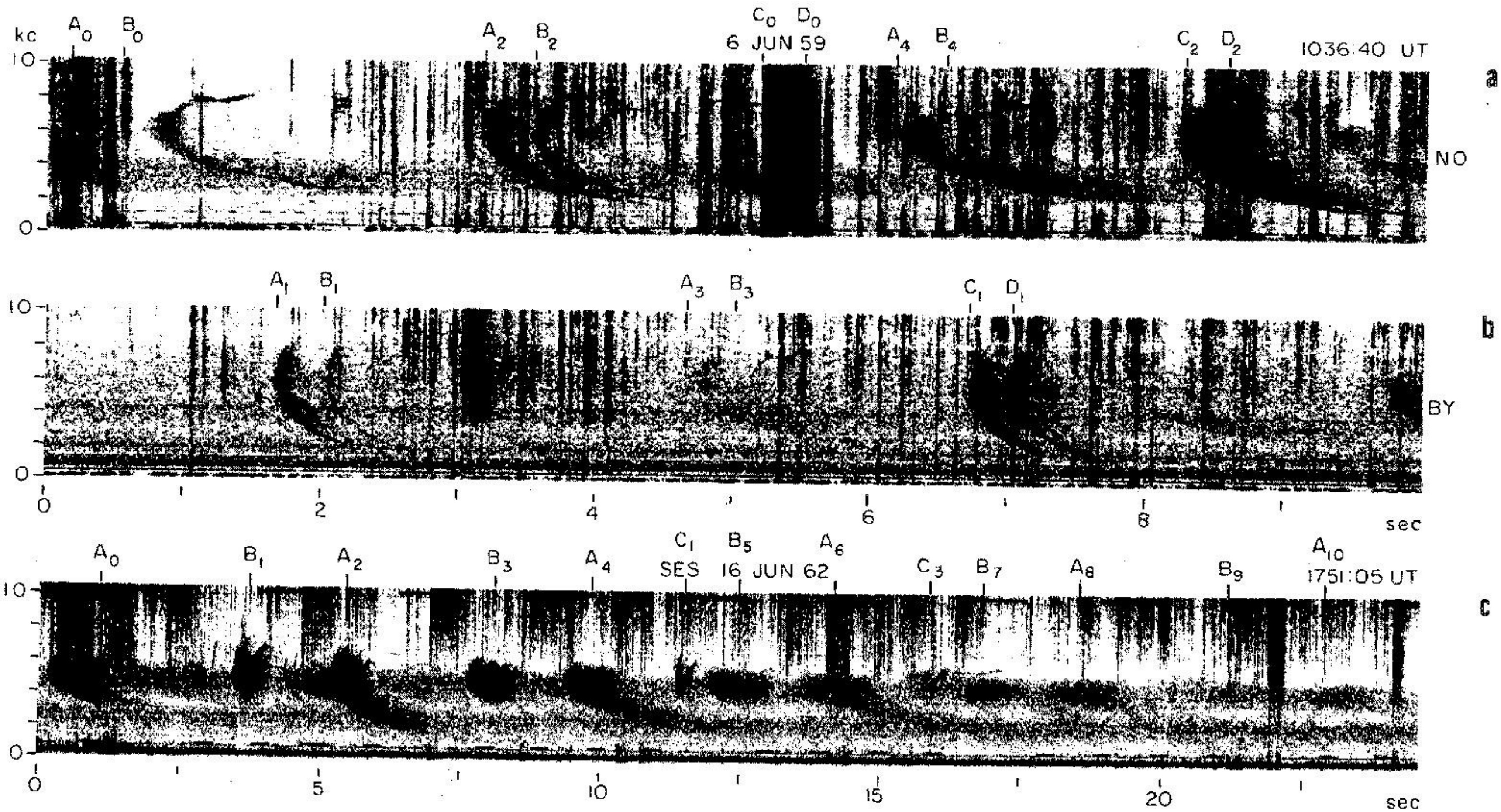


FIG. 4-20. Echoing nose whistlers. *a*, Even-order echo trains; four sources marked; first whistler is a four-hop echo of a preceding whistler (dot shown). Note emissions triggered above nose. *b*, Odd-order echoes of same whistler; $f_n = 6.0$ kc/s, $t_n = 1.52$ sec. Station NPG provides relative timing. *c*, Odd-order echo trains, marked B_1 to B_9 and C_1, C_3; even-order echo train, marked A_0 to A_{10}; nose frequencies range from less than 4.4 kc/s to 5.3 kc/s ($t_n = 2.0$ sec); echoes show path mixing, with average period between echo groups of 2.19 sec.

Ground based measurements

Prediction by Dejnakarintra and Park:

Lightning E-field ~10^{-4} V/m in ionosphere

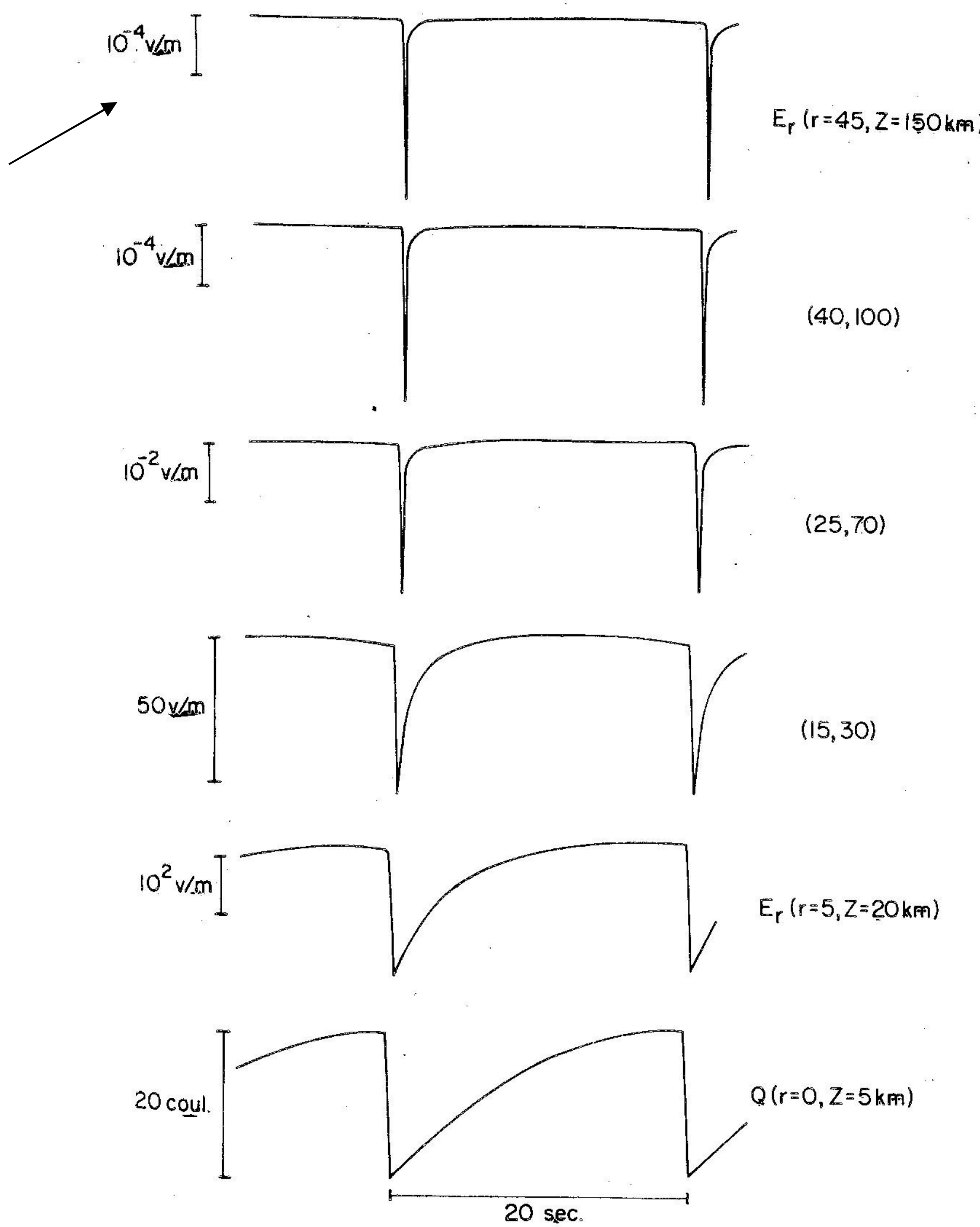


FIGURE 5-23. PLOTS OF E_r AT SELECTED VALUES OF r AND z. The waveform of the monopole source is shown at the bottom.

Ionospheric fields 10s of mV/m

NASA WALLOPS IS

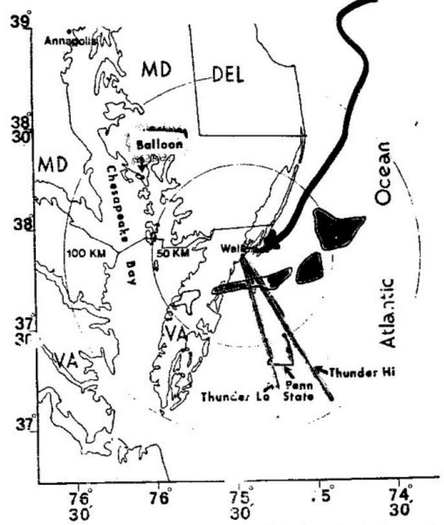


Fig. 1. Map showing the location of the four thunderstorm cells and the balloon at the launch time of Thunder Lo. The trajectories of Thunder Lo, Thunder Hi, and the Pennsylvania State University parachute payload (after deployment) are also indicated.

this to be the location of the cloud tops. It should be noted that there is a positive correlation between cloud height and electrical activity [*Shackford*, 1960].

In this paper an overview of the experimental results of the thunderstorm campaign is presented but with emphasis upon the new and exciting observations of lightning-related transients in the ionosphere. A detailed presentation of the "dc" (quasi-static) electric field data can be found in paper 2. Also found in paper 2 is an analysis comparing the quasi-static electric field data with earlier work. A more complete theoretical analysis of the ionospheric results is under way and will be presented in subsequent publications.

Data Presentation

Simultaneous data from the two ballistic rockets, the balloon-borne VLF sensor and a ground-based 2-MHz receiver located at Wallops Island, are presented in Figure 2 for a 6-s interval. The smoothly varying sinusoidal signals in the top panels are due to the response of the rotation dc coupled antenna to the sum of the ambient electric field and the **V × B** electric field (the electric field induced by the motion of the rocket moving at a velocity **V** across the magnetic field **B**). The sinusoidal signals are interrupted by nearly simultaneous excursions of the order of several tens of millivolts per meter measured on both rockets. For this event one rocket was located at an altitude of 142 km, and the other at an altitude of 88 km. Higher time resolution presentations show that the signal at high altitudes is delayed from that detected on the lower payload by a time consistent with a propagation speed equal to the speed of light.

The event just prior to 0210:40 consisted of a set of five or six excursions separated by about 0.05 s, each of which was detected on the three airborne platforms and the ground receiver. Such a sequence is characteristic of the multiple strokes which make up a single lightning flash. The magnitude of the electric field pulse at 142 km (top panel) due to the first stroke was comparable to the signal detected at 88 km. The signals at high altitude from subsequent strokes of the same flash were much smaller than those registered in the meso-

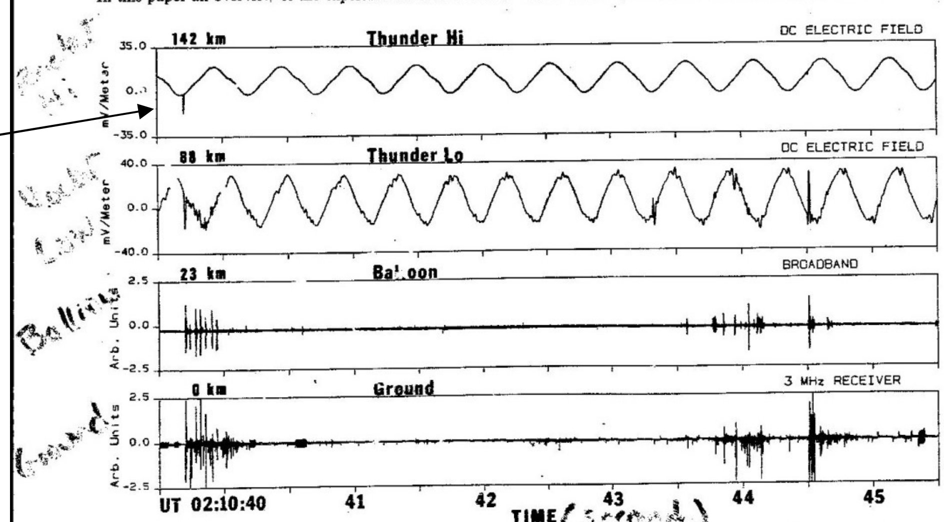


Fig. 2. Simultaneous data from ionospheric rocket, the mesospheric rocket, a VLF receiver on the stratospheric balloon, and a ground-based 3-MHz receiver. Notice the signals due to lightning strokes just before 0210:40 UT and at 0210:44.5 UT.

2.17

Kelley et al, 1985

Discovery paper

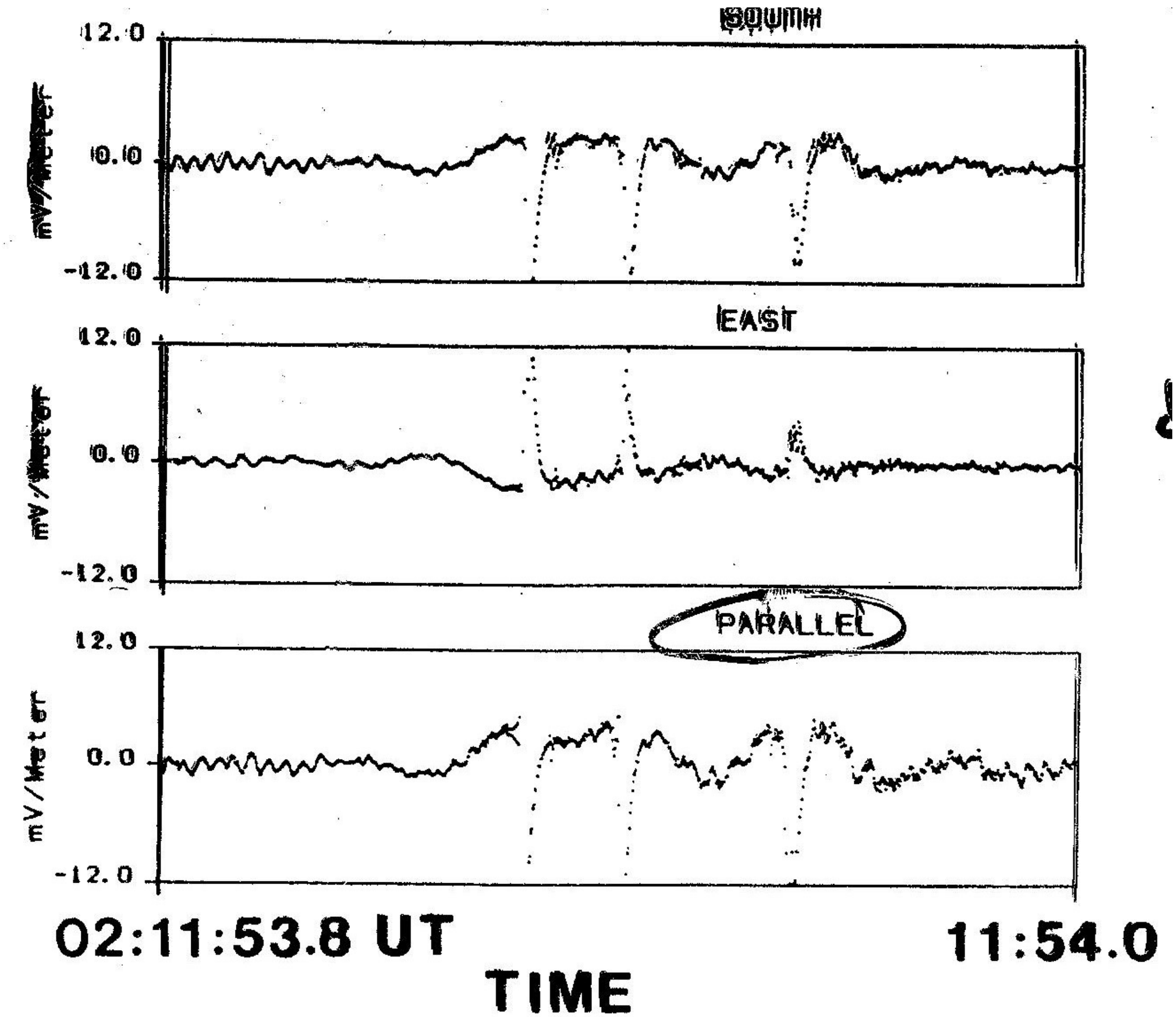
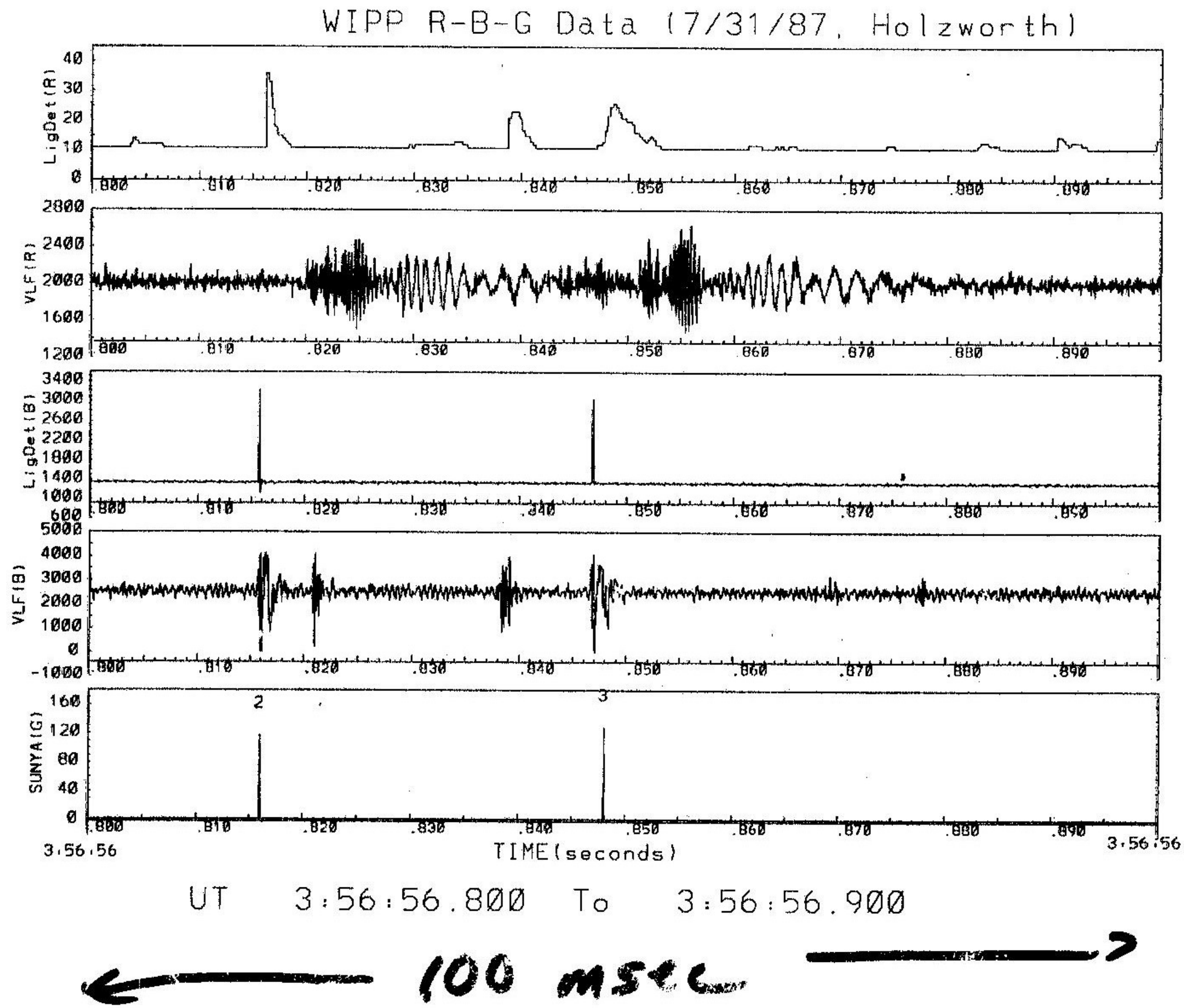


Figure 4.4 Ionospheric electric field data which have been transformed into geomagnetic coordinates. Notice that the lightning transients have a significant electric field parallel to the Earth's magnetic field.

← 200 MSEC →


WIPP R-B-G Data (7/31/87, Holzworth)
LigDet(R)
VLF(R)
LigDet(B)
VLF(B)
SUNYA(G)
2
3
.800 .810 .820 .830 .840 .850 .860 .870 .880 .890
3.56.56
3.56.56
TIME(seconds)
UT 3:56:56.800 To 3:56:56.900
100 msec

Geophysical
Research
Letters

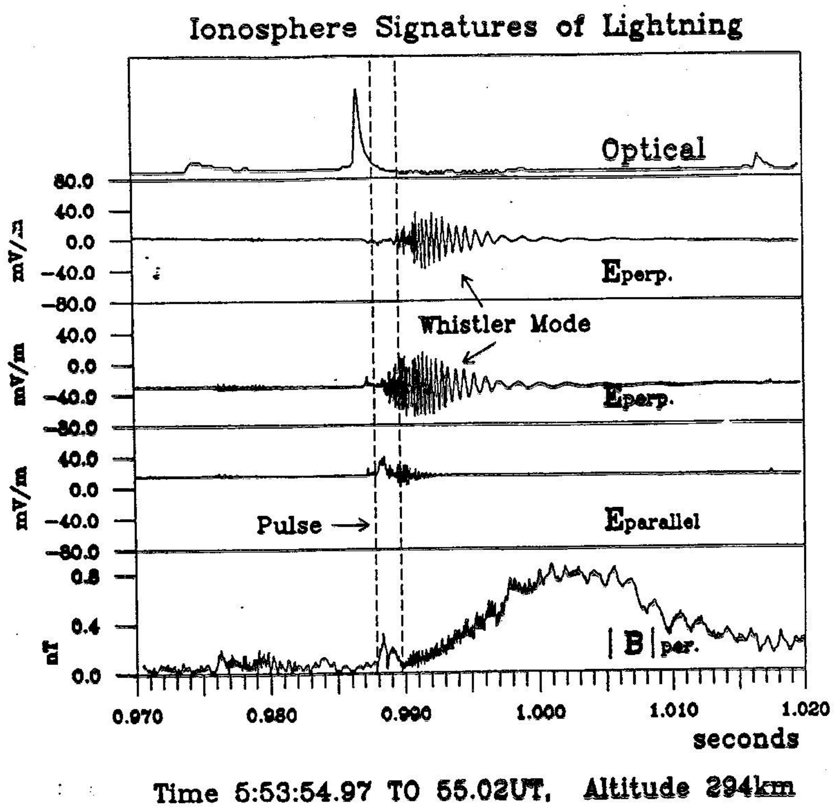


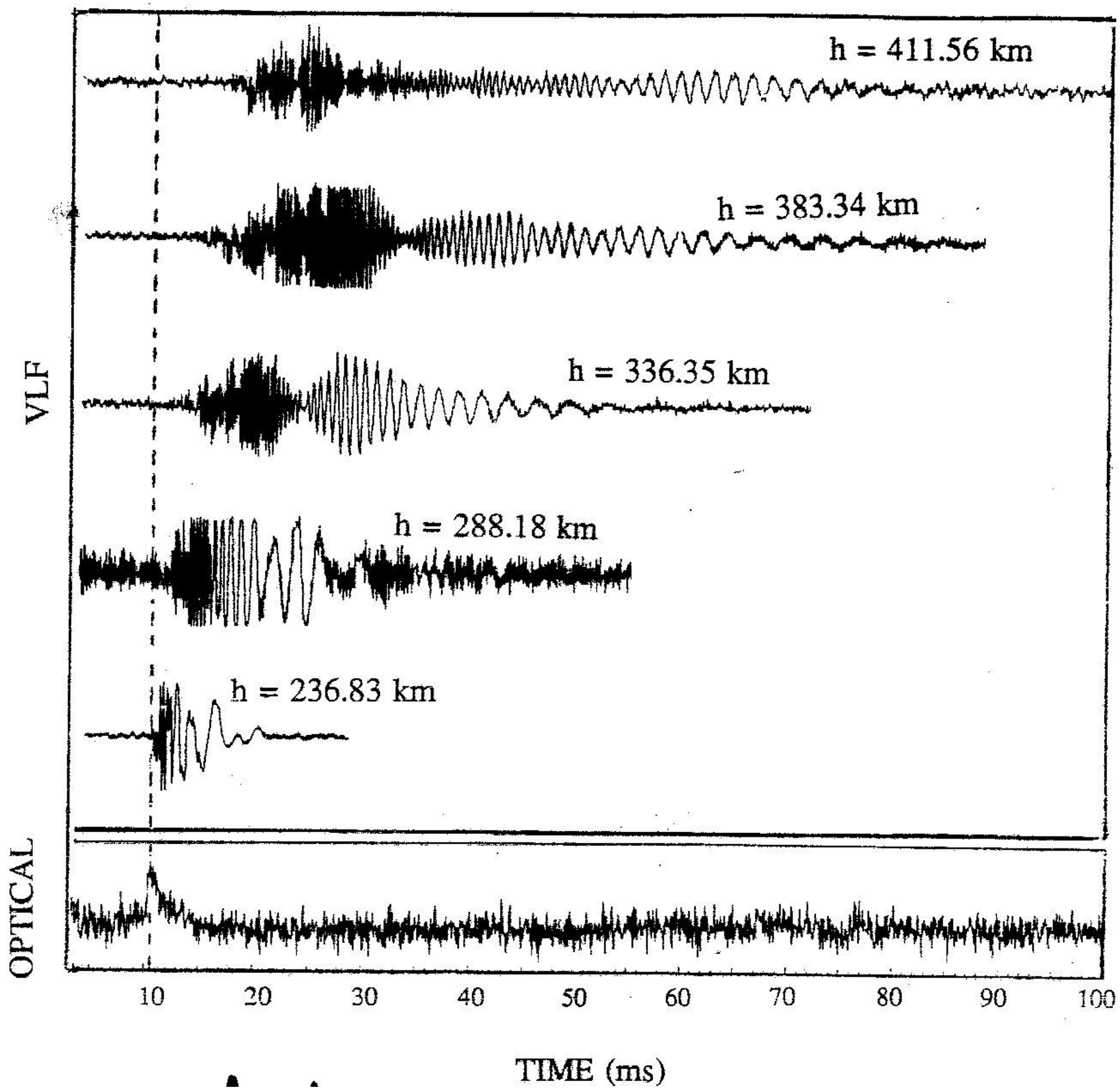
Figure II.A.1 50 msec of electric and magnetic field and optical data in the ionosphere during a lightning stroke

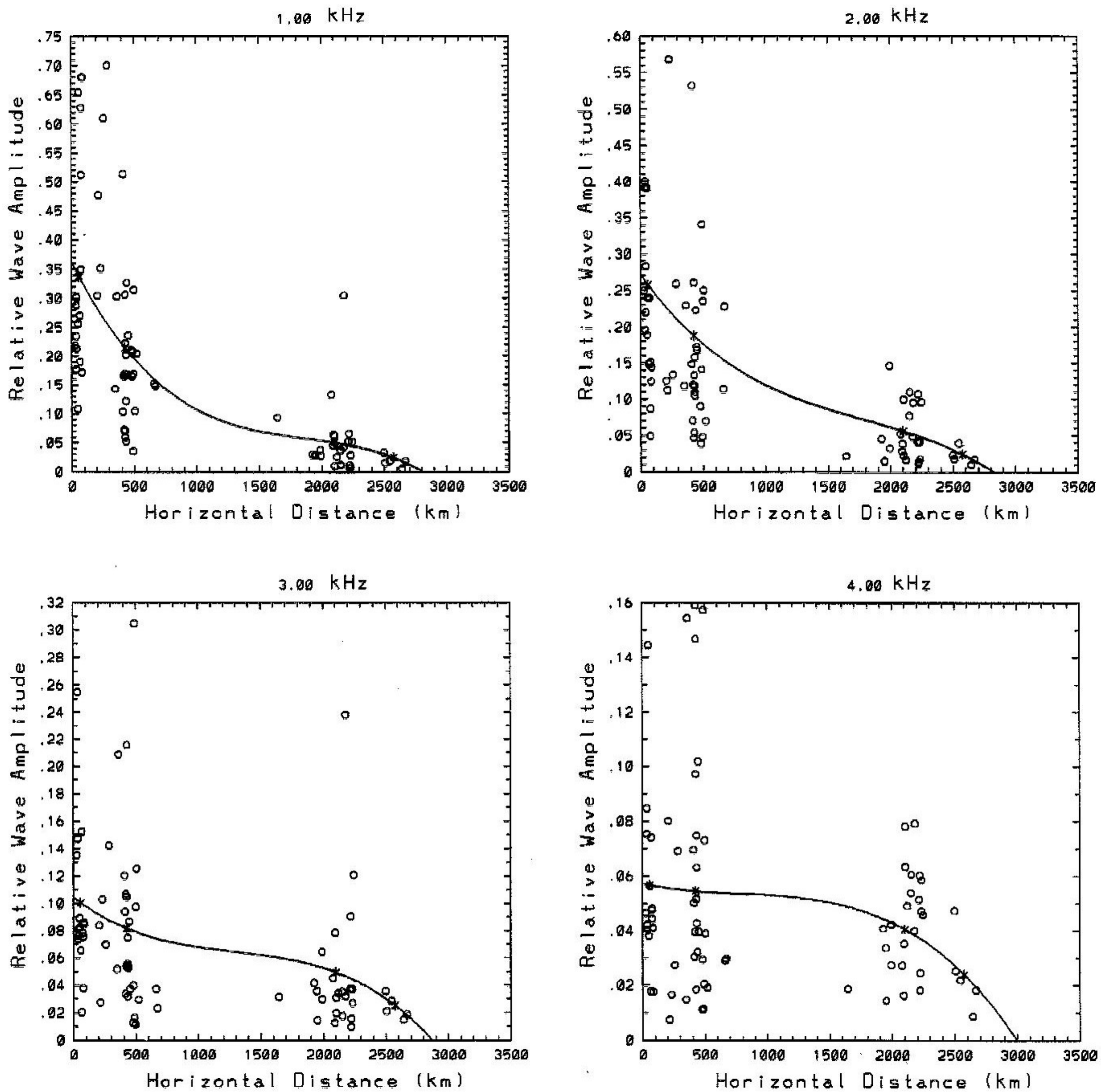
NOVEMBER 1990

Volume 17 Number 12

AMERICAN GEOPHYSICAL UNION

WIPP ROCKET DATA (July 31, 1987)




1.00 kHz
2.00 kHz
3.00 kHz
4.00 kHz
Relative Wave Amplitude
Horizontal Distance (km)

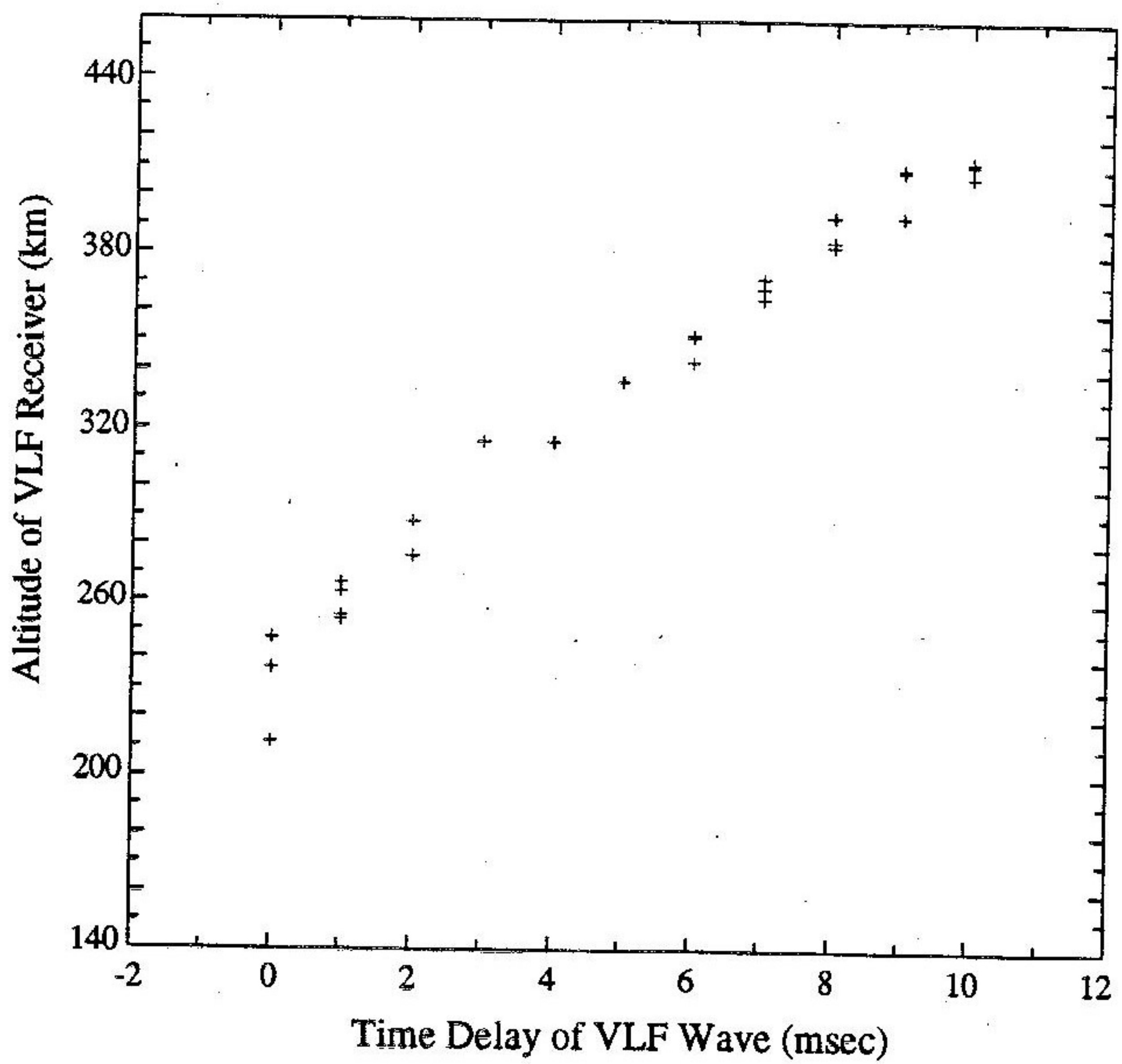
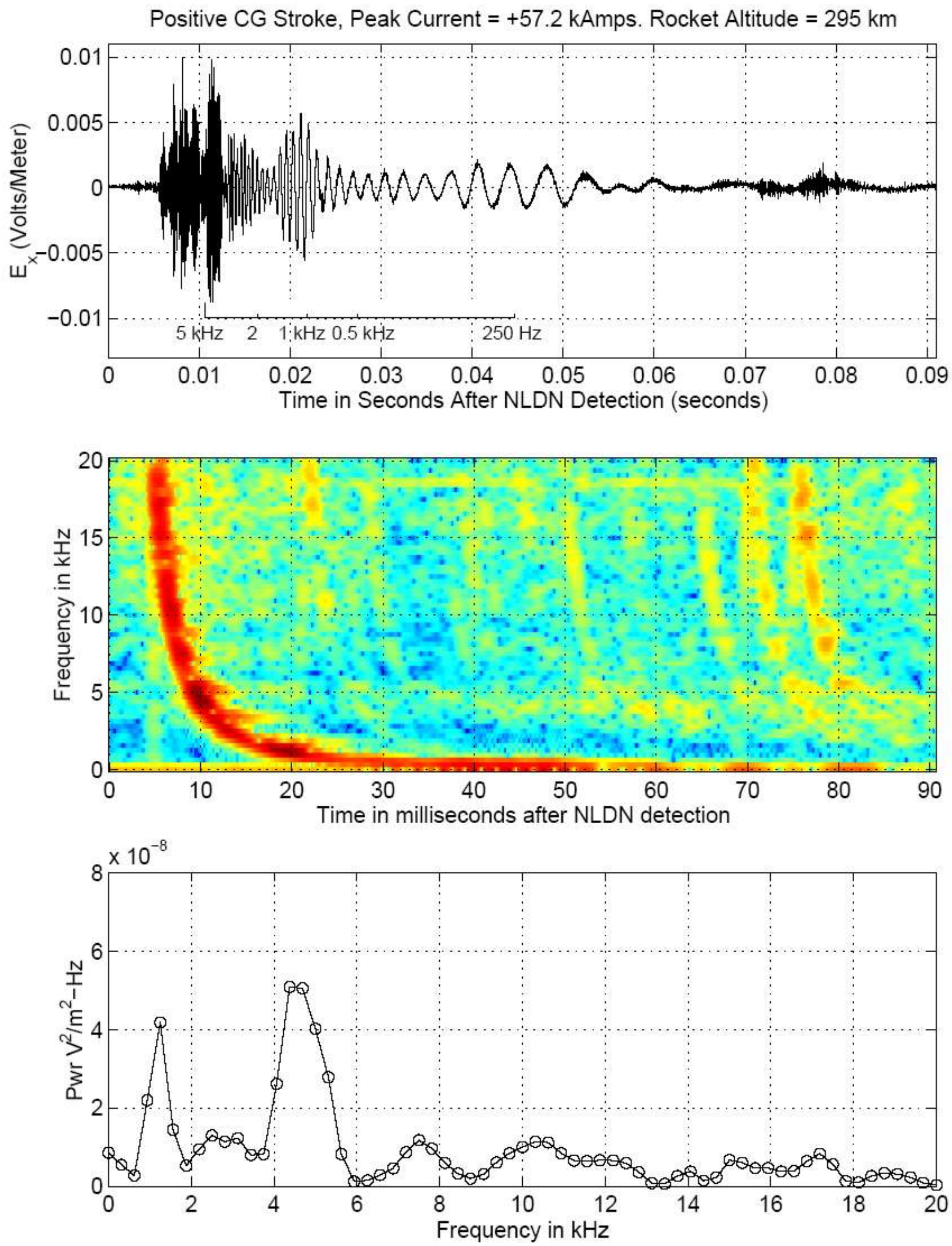
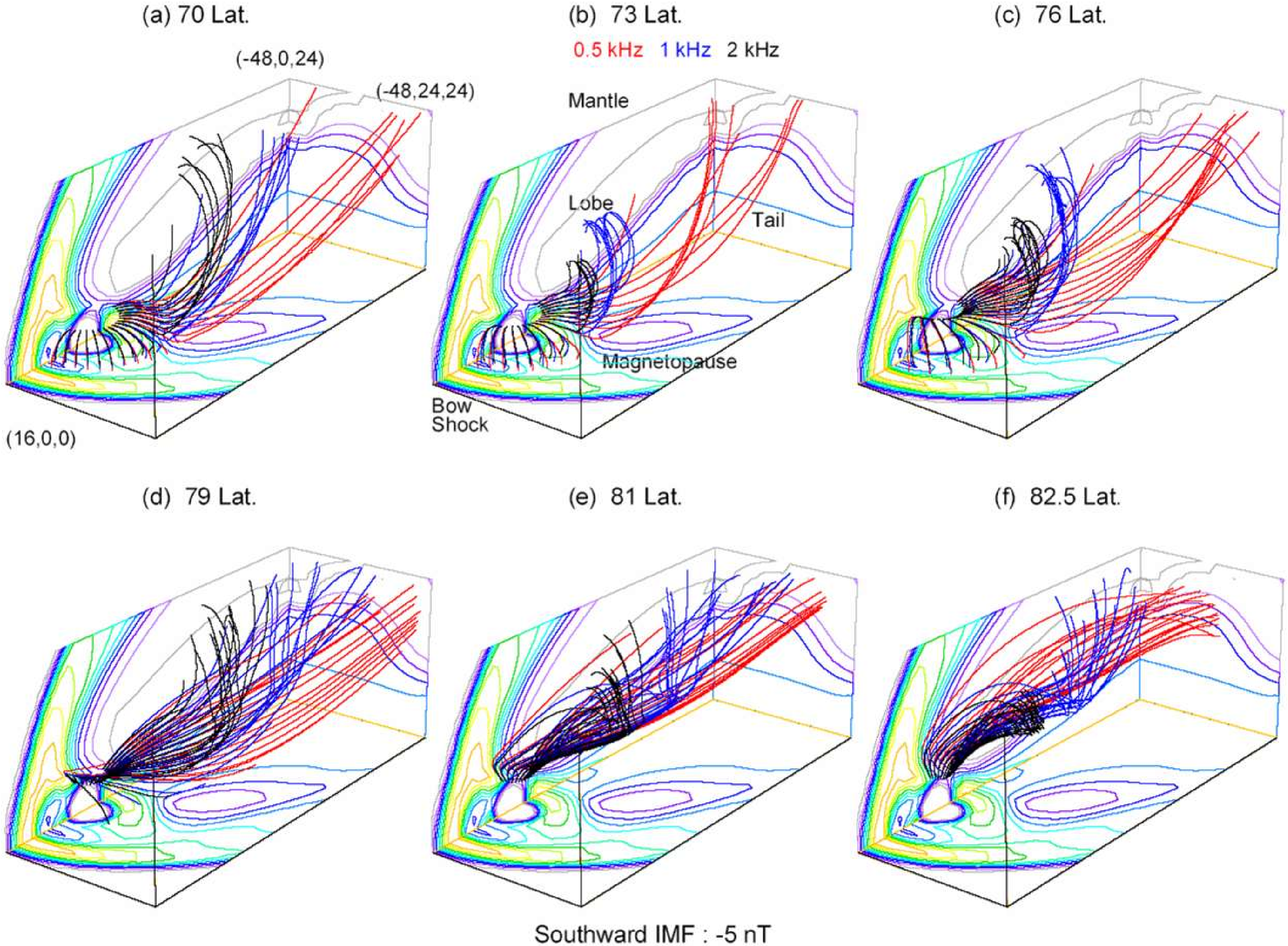


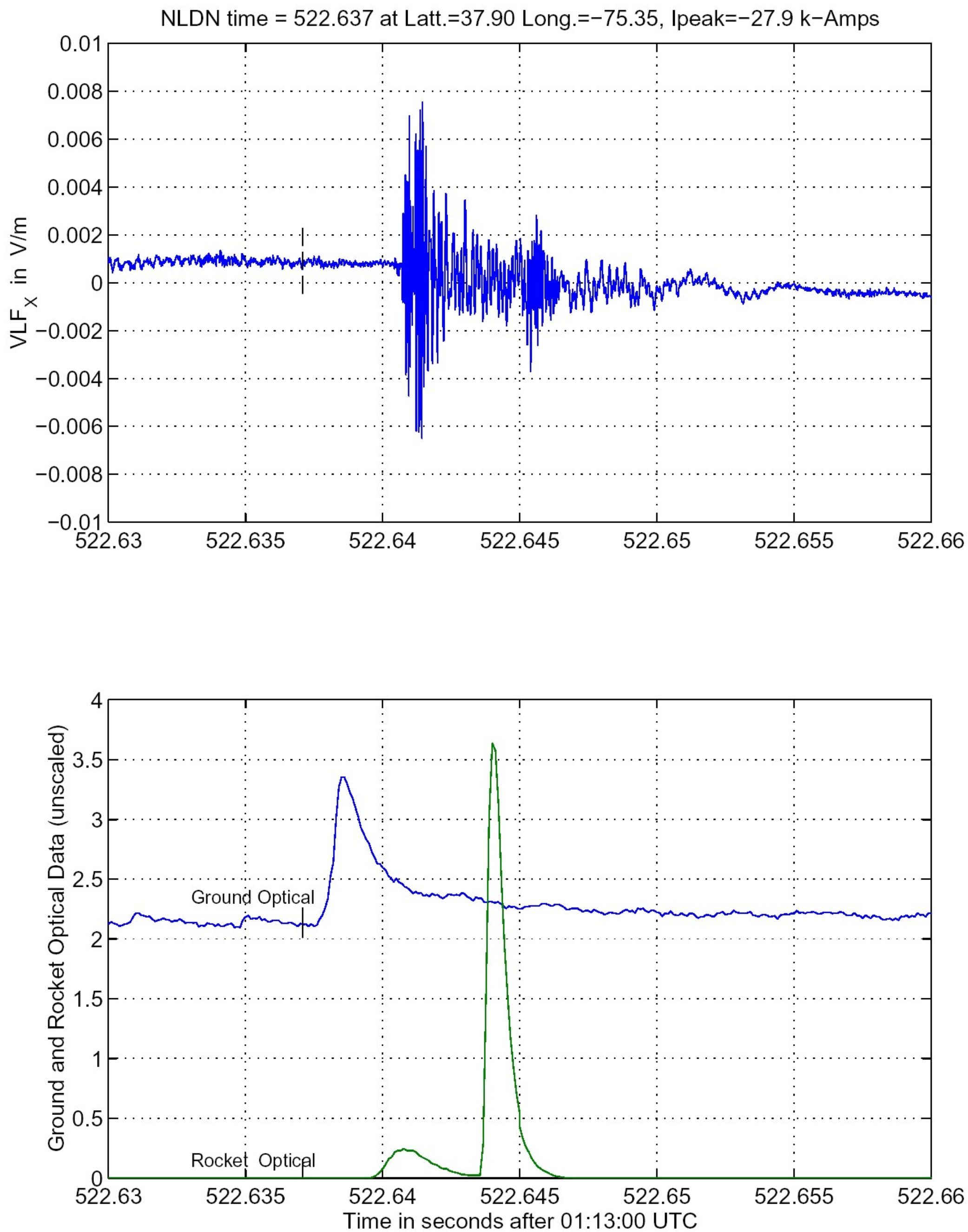
Figure 5.3: Relation between the time delay of 24 kHz waves and the altitude of the rocket. Lightning events in this figure are the same events shown in Figure 5.2.


Positive CG Stroke, Peak Current = +57.2 kAmps. Rocket Altitude = 295 km
0.01
0.005
0
−0.005
−0.01
E_x (Volts/Meter)
5 kHz
2
1 kHz
0.5 kHz
250 Hz
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
Time in Seconds After NLDN Detection (seconds)
20
15
10
5
0
Frequency in kHz
0
10
20
30
40
50
60
70
80
90
Time in milliseconds after NLDN detection
x 10^-8
8
6
4
2
0
Pwr V^2/m^2−Hz
0
2
4
6
8
10
12
14
16
18
20
Frequency in kHz



(a) 70 Lat.
(b) 73 Lat.
(c) 76 Lat.
0.5 kHz
1 kHz
2 kHz
(-48,0,24)
(-48,24,24)
(16,0,0)
Mantle
Lobe
Tail
Magnetopause
Bow
Shock
(d) 79 Lat.
(e) 81 Lat.
(f) 82.5 Lat.
Southward IMF : -5 nT

efield pulse + optical



T-III whistlers