BIRKELAND CENTRE
FOR SPACE SCIENCE

Radio waves from lightning

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erc European Research Council

UNIVERSITAS BERGENSIS

UNIS The University Centre in Svalbard

NTNU Det skapende universitet

Lightning has electromagnetic nature, so the EM measurements is a natural very effective and informative tool to study lightning and other EM phenomena in the atmosphere.

Inside thunderclouds charge separation leads to very high electric fields, which are screened by the screening layer above the thundercloud. However, lightning discharges make a rapid redistribution of charges inside the cloud, which makes the whole system unbalanced and high fields escape the cloud. During their freedom period those fields give birth to a variety of transient events in the upper atmosphere, though quite quickly they will be killed by the re-formation of the screening layer.

In a simplistic way the lightning stroke can be represented as a discharge wave initially rolling through the conductive channel, which is followed by a slower lower current flow. The first current wave emits an impulsive radio wave which hits the ionosphere and produces an elve. The slower current transfers a large amount of charge which gives rise to a static electric field in the upper atmosphere and lead to formation of haloes and sprites.

Different components of the electrical discharge emit radio waves in different frequency ranges. Those frequency ranges are defined by the characteristic timescale of the process and by the characteristic size of the radiating volume.

Thus, we have three characteristic sizes in the system: the size of the radiating volume, distance to the observer, and the emitted wavelength. These parameters define what kind of processes we can observe, at which frequencies, and from which distance the observation will be most efficient.

A rule of thumb: characteristic size of the system defines the emitted wavelength (their ratio is a parameter of the multipole decomposition); the characteristic time scale defines the emitted frequency.

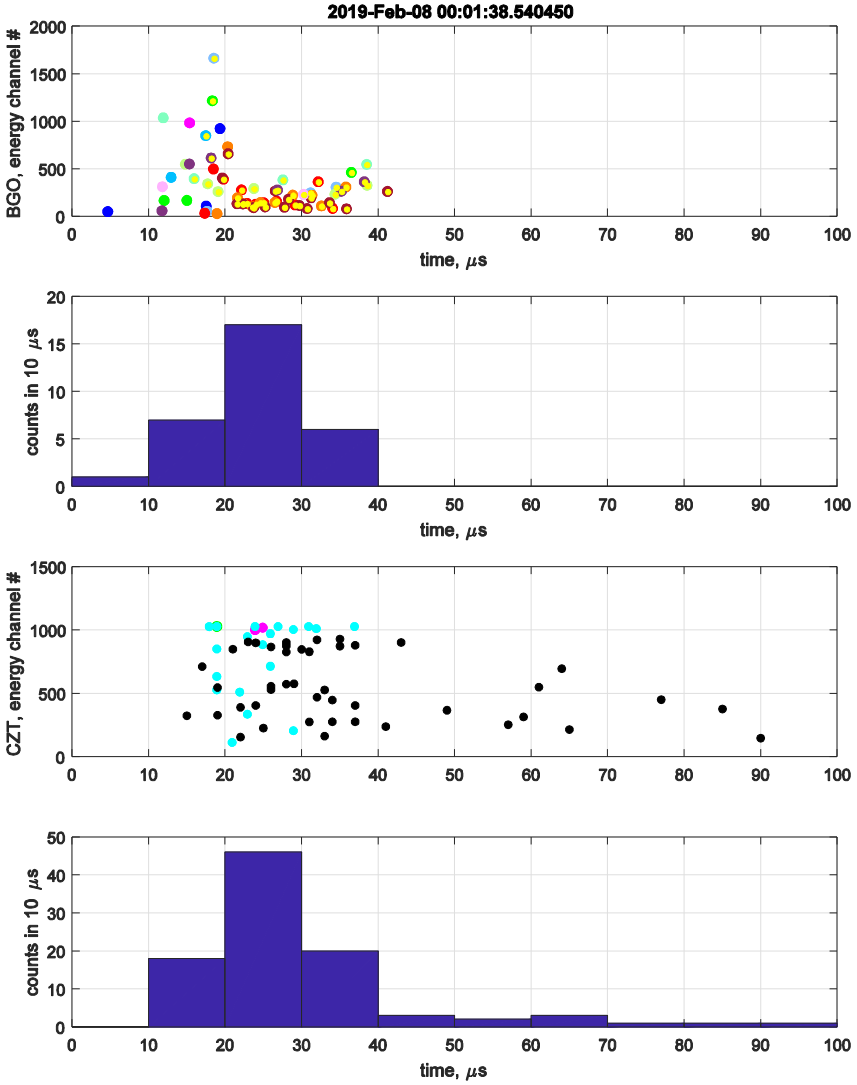
Also the ratio of the size of radiating system to the distance to the observer is supposed to be very small, so that all the corrections of that order can be neglected.

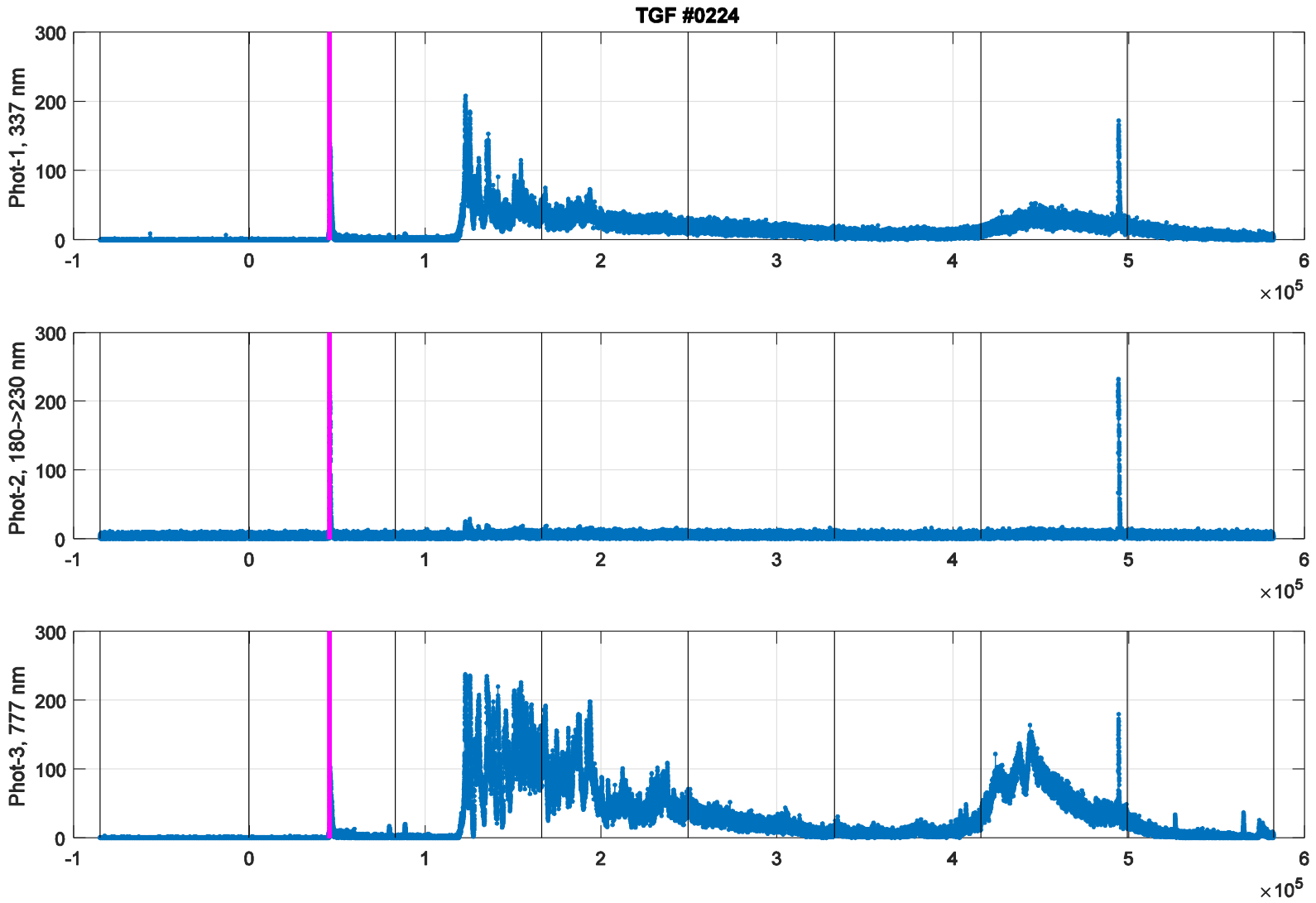
- ELF (3 ÷ 30 Hz) – Schumann resonances, monitoring global lightning activity
- ULF (0.3 ÷ 3 kHz) – long range (>10 Mm) lightning detection, slow currents (sprites, continuing currents, TGFs(?))
- VLF (3 ÷ 30 kHz) – lightning detection and location networks (few Mm)
- LF (30 ÷ 300 kHz) – location (<Mm); fine structure of the strokes, tricks with reflections, elevation angles; 3D tracking of the discharge (poor, <0.3 Mm)
- VHF (30 ÷ 300 MHz) – lightning mapping arrays, 3D tracking of the leaders (<0.2 Mm)
- Higher frequencies are required for studying the laboratory sparks (GHz for electron avalanches)

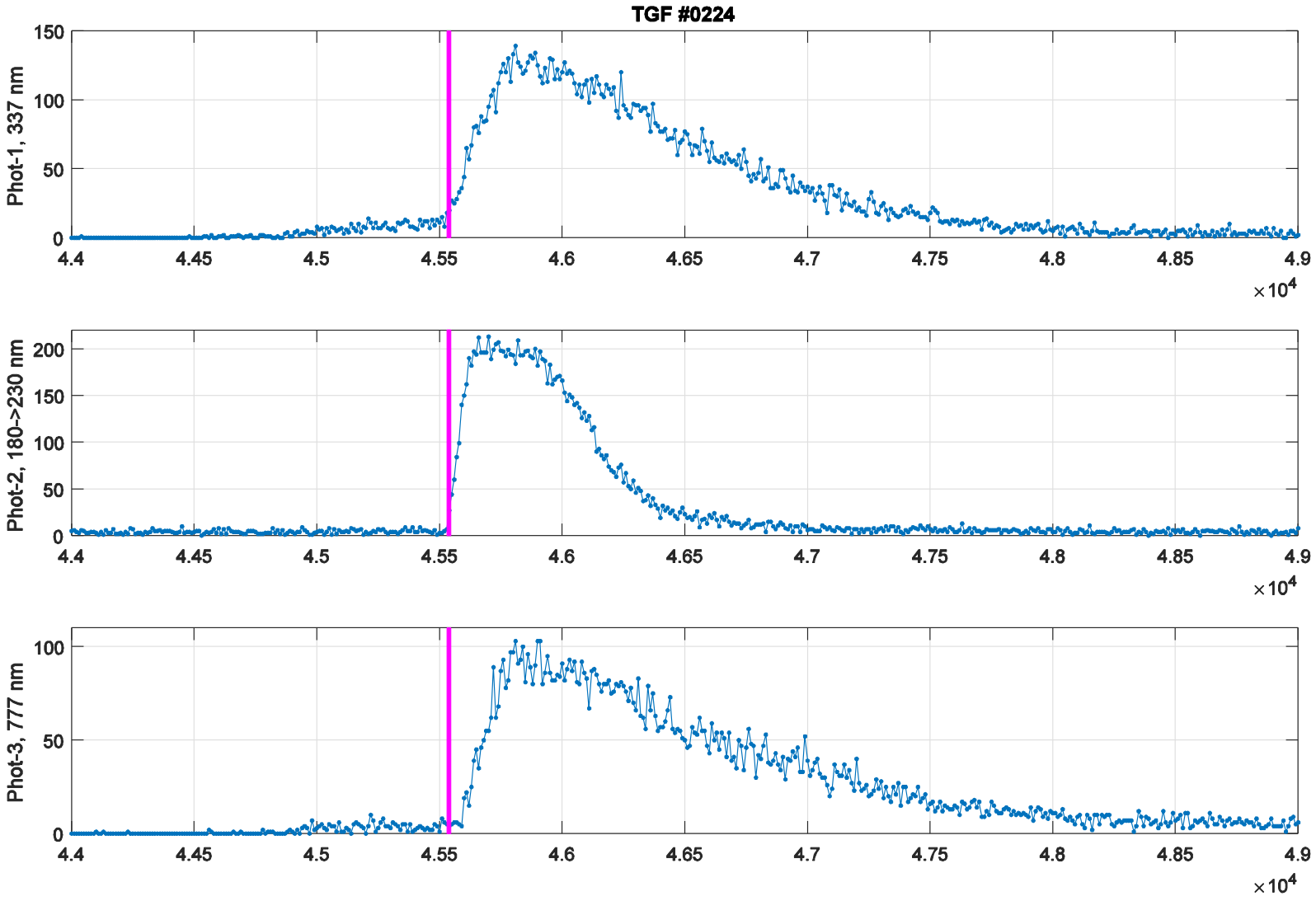
f	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz
λ	100 km	10 km	1 km	100 m	10 m	1 m	10 cm	1 cm	1 mm

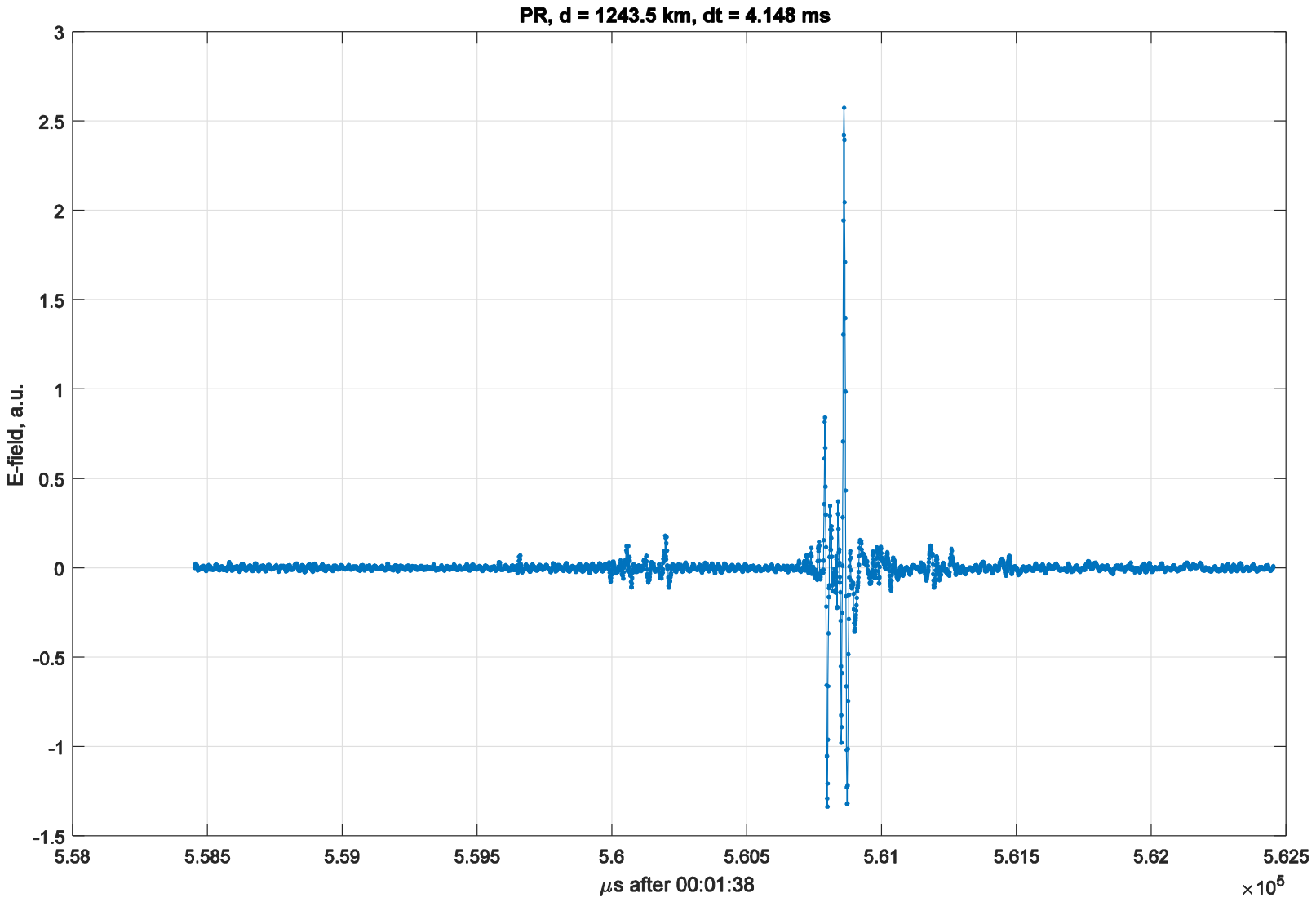
Instrument	Purpose
Single station	Events detection; event type identification; time evolution of the system; electrical characteristics of the discharge (current moment change, peak current, etc); general E-field monitoring
Array of stations	Location of the events; 3D tracking on the local scale
Network of stations	Location of events on the global scale

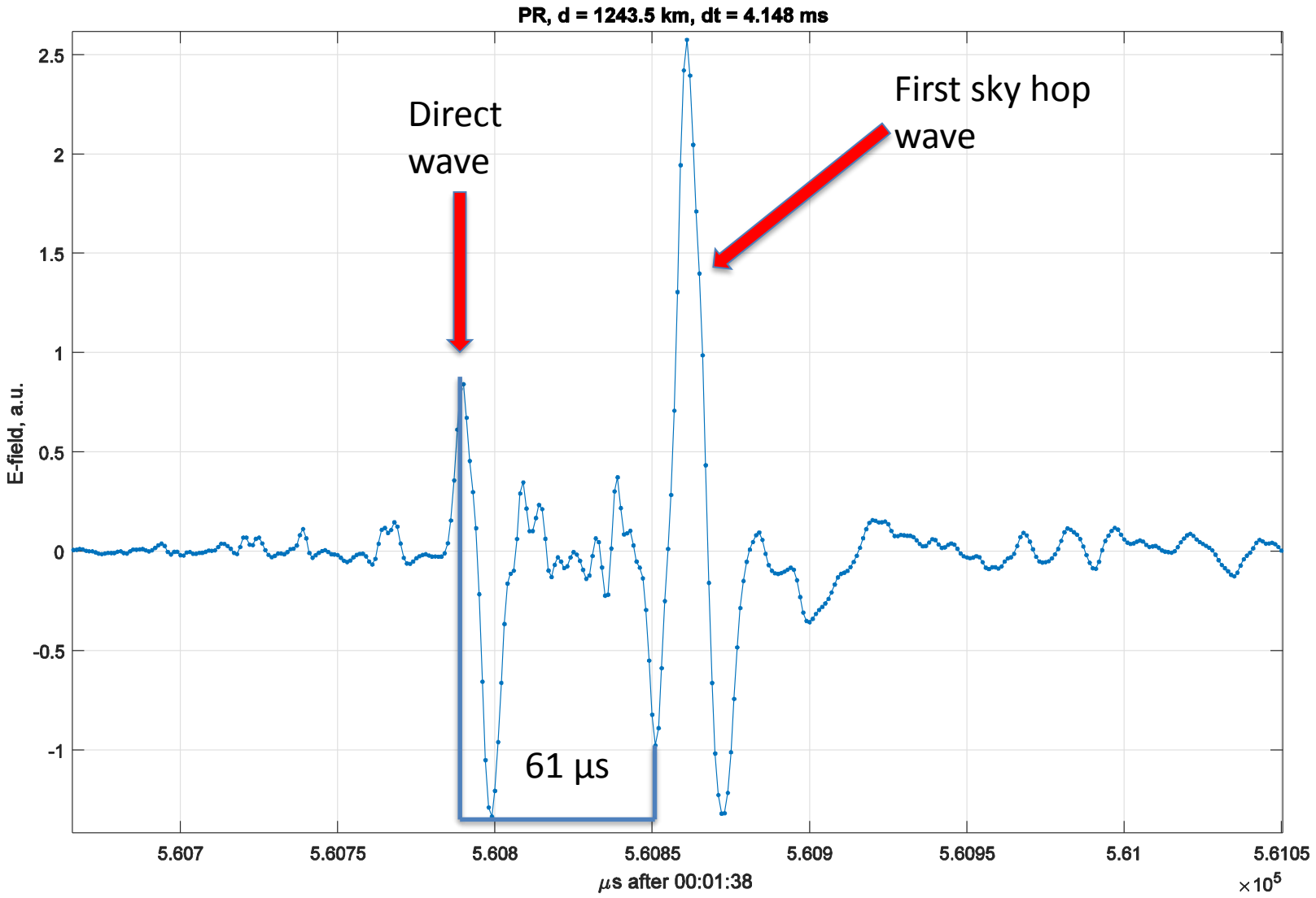
Sensor type	Purpose
E-field	E-field measurements; Ez near ground; only detection is possible with single station, no location possibility; tricks with reflections
B-field	Couple of coils for Bx and By near ground; direction finding with single station;


2019-Feb-08 00:01:38.540450
BGO, energy channel #
time, μs
counts in 10 μs
time, μs
CZT, energy channel #
time, μs
counts in 10 μs
time, μs


TGF #0224
Phot-1, 337 nm
Phot-2, 180->230 nm
Phot-3, 777 nm
300
200
100
0
-1
0
1
2
3
4
5
6
×10^5


TGF #0224
Phot-1, 337 nm
Phot-2, 180->230 nm
Phot-3, 777 nm
4.4
4.45
4.5
4.55
4.6
4.65
4.7
4.75
4.8
4.85
4.9
×10^4


PR, d = 1243.5 km, dt = 4.148 ms
E-field, a.u.
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
5.58
5.585
5.59
5.595
5.6
5.605
5.61
5.615
5.62
5.625
μs after 00:01:38
×10^5

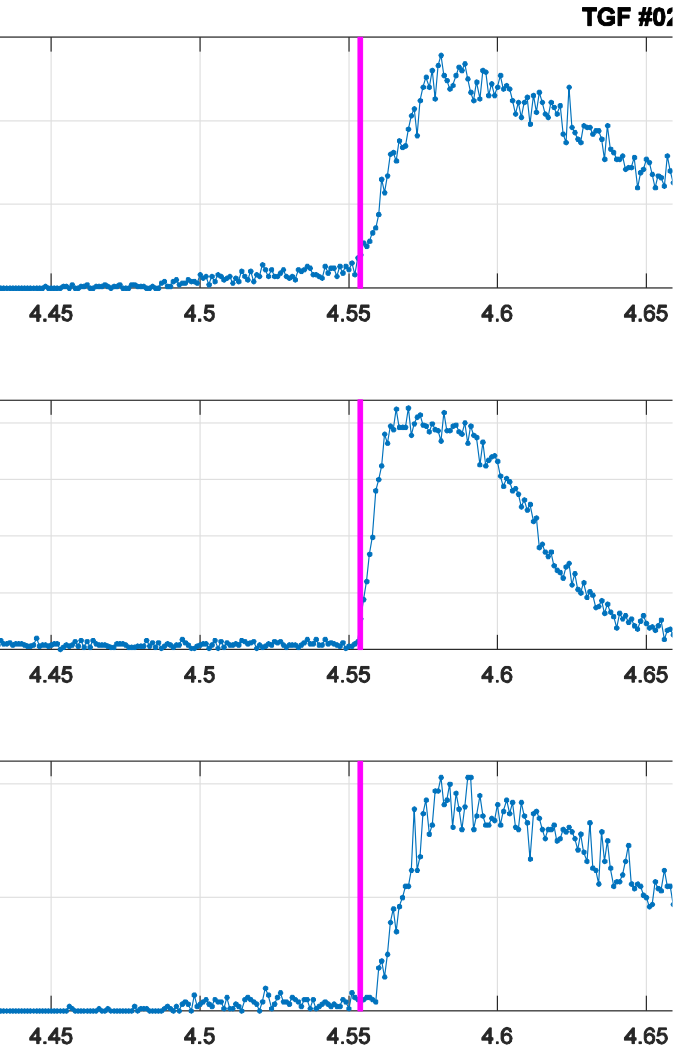

PR, d = 1243.5 km, dt = 4.148 ms
Direct wave
First sky hop wave
61 µs
E-field, a.u.
2.5
2
1.5
1
0.5
0
-0.5
-1
5.607
5.6075
5.608
5.6085
5.609
5.6095
5.61
5.6105
µs after 00:01:38
×10^5

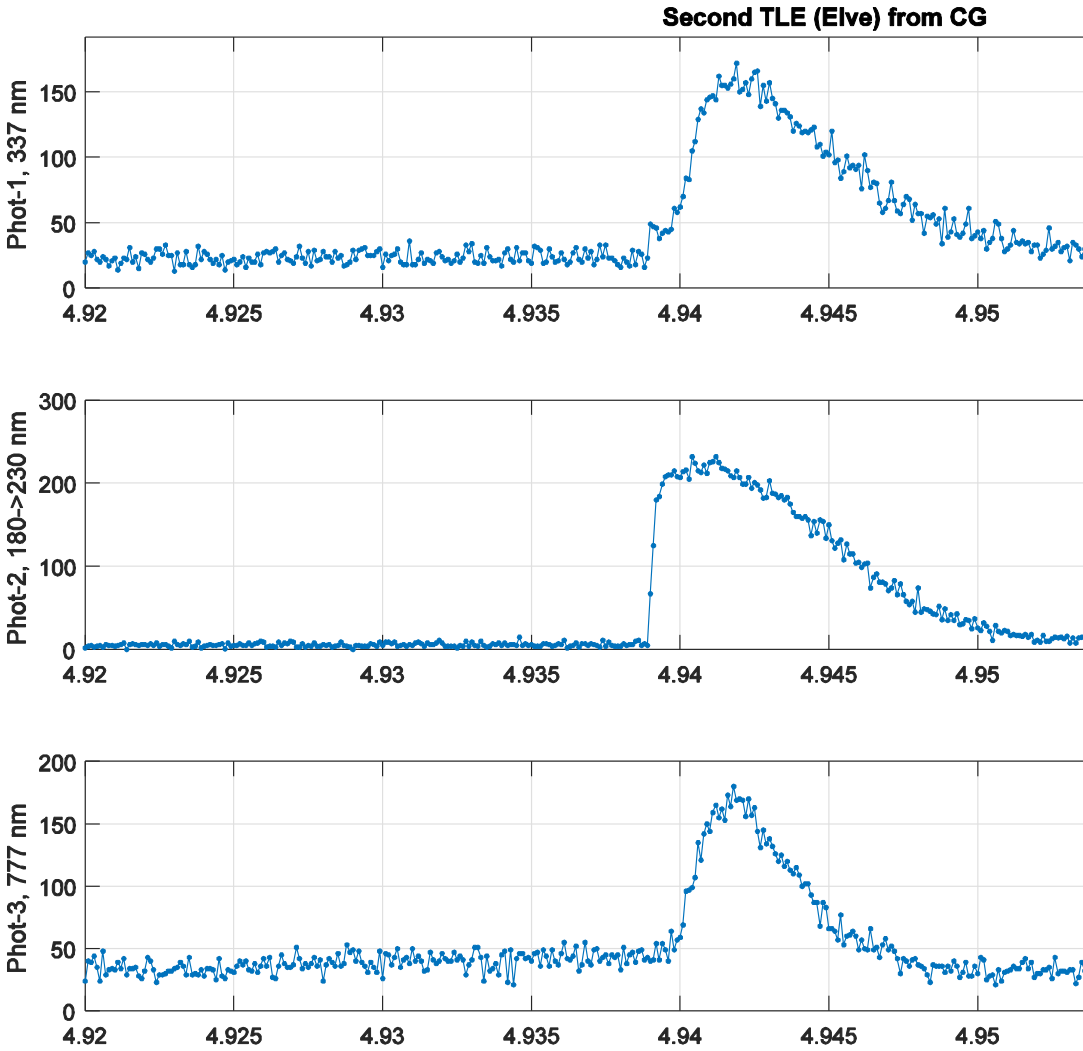
Should be 43 μs, but we observe 61 μs.

Accounting for the Earth curvature we would get 70 μs.

Assuming the source altitude to be 13 km gives 64 μs.

This convinces me that the two sferics that we observe are indeed the direct wave and the sky wave of the current pulse that we see in optical channels.


TGF #02
4.45
4.5
4.55
4.6
4.65

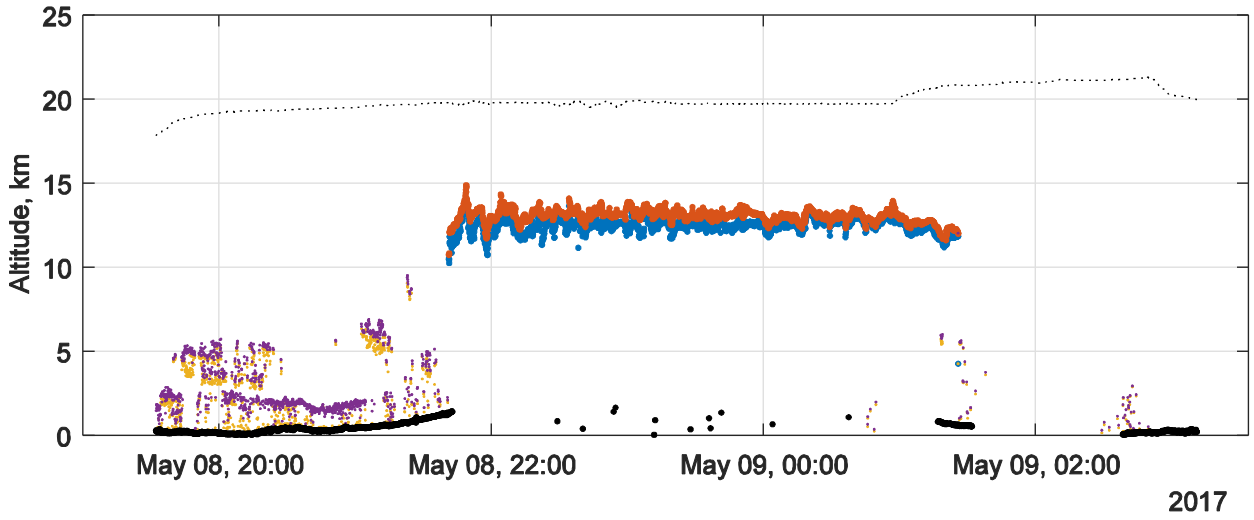

Second TLE (Elve) from CG
Phot-1, 337 nm
Phot-2, 180->230 nm
Phot-3, 777 nm
0
50
100
150
200
300
4.92
4.925
4.93
4.935
4.94
4.945
4.95

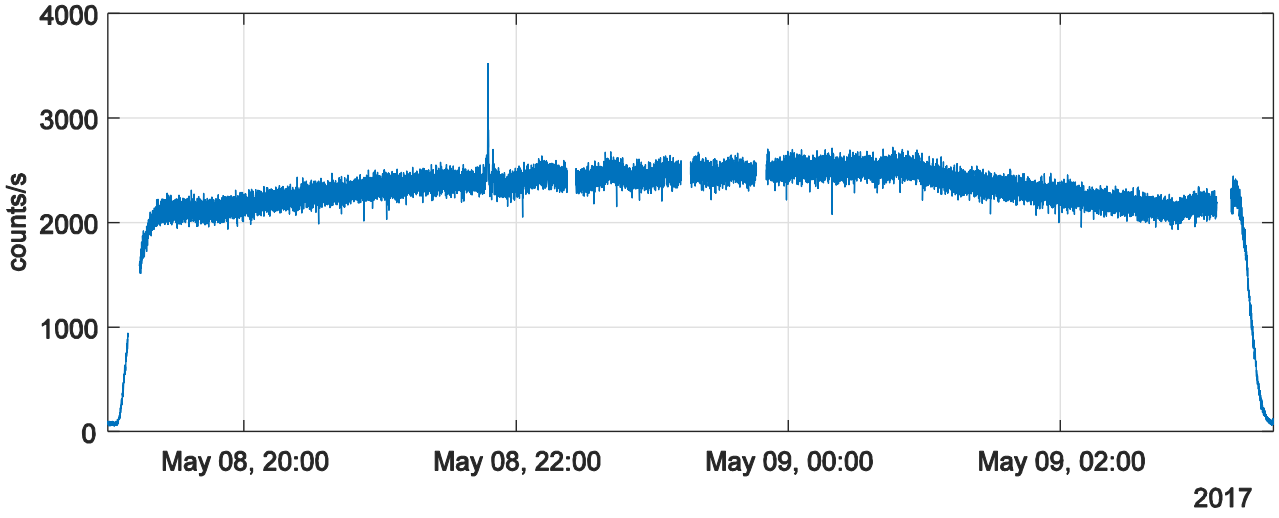
ALOFT campaign, gamma-ray glow detected over Colorado 8 May 2017.

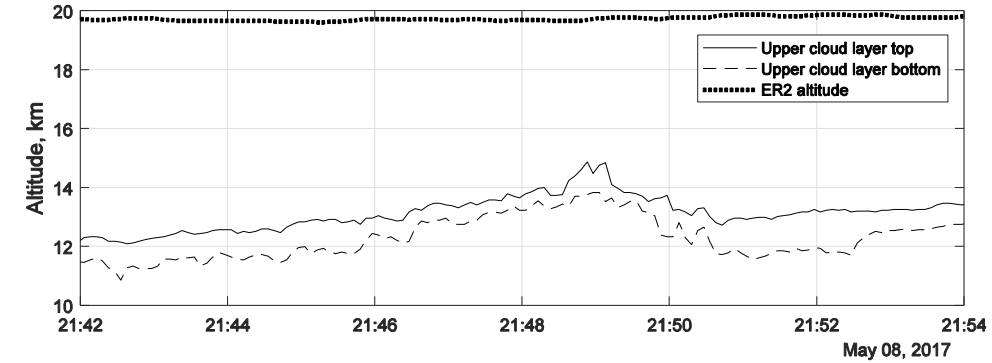
Onboard instrumentation:
- optical photometer array
- gamma-ray BGO detectors
- fast E-field antenna
- slow E-field antenna
- quasi-static E-field antenna
- IR radar

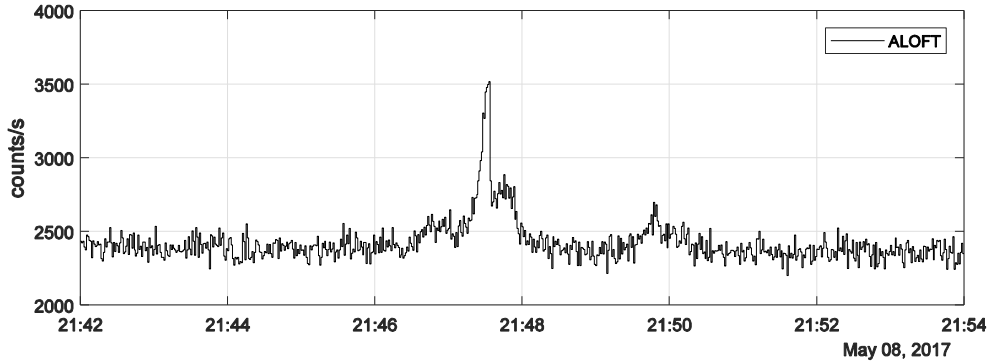
Ground support measurements:
- Colorado LMA
- ENTLN
- WWLLN

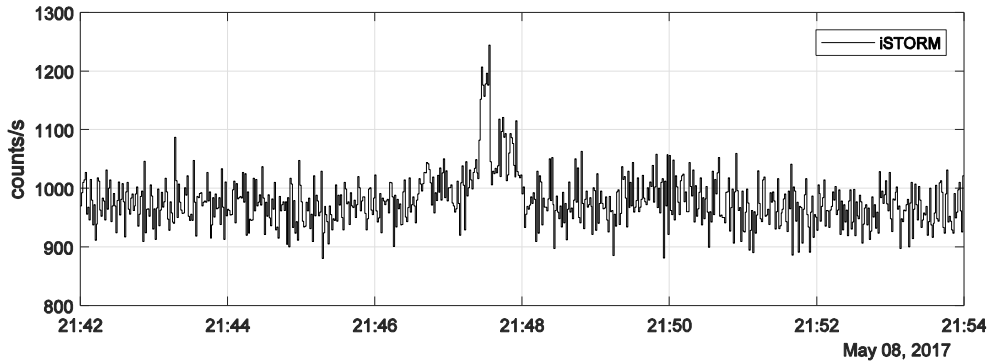
Satellite support:
- IR soundings for cloud tops

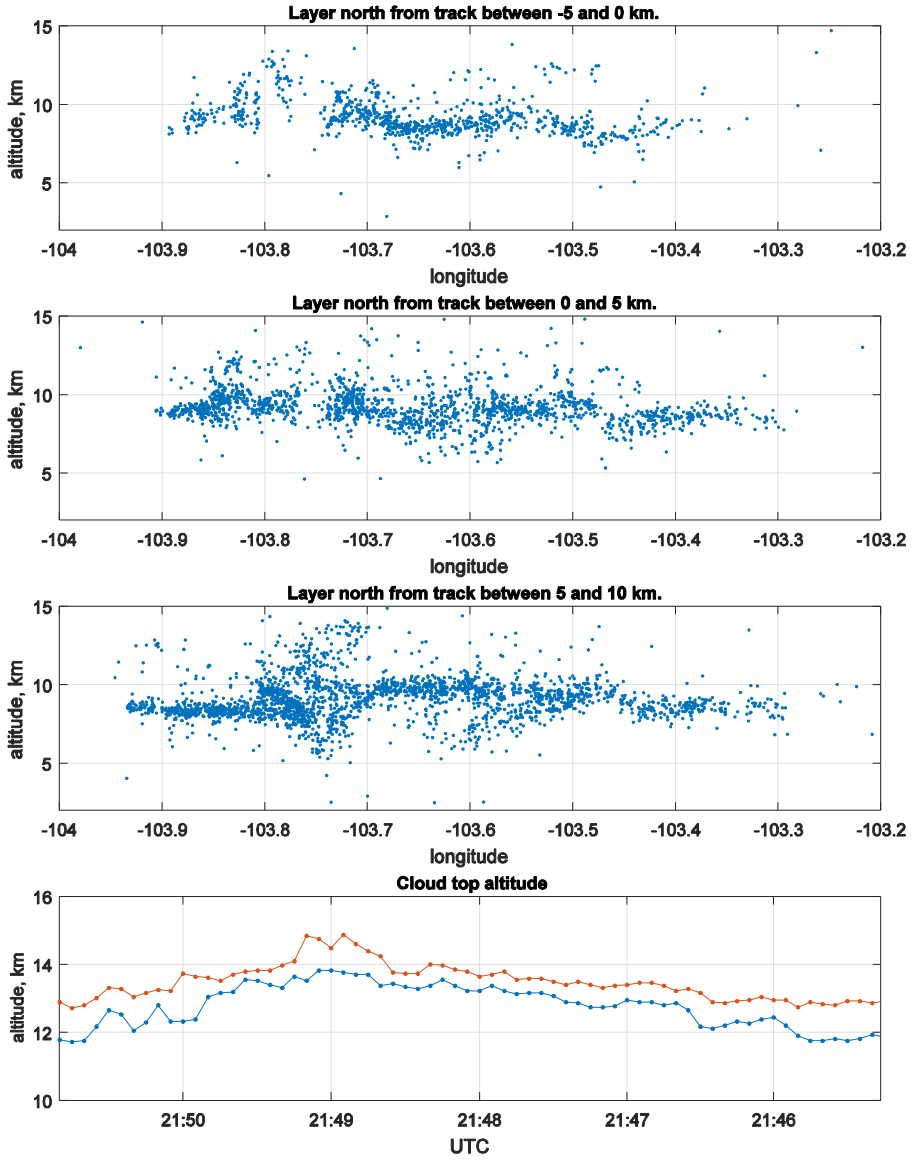

25
20
15
10
5
0
Altitude, km
May 08, 20:00
May 08, 22:00
May 09, 00:00
May 09, 02:00
2017

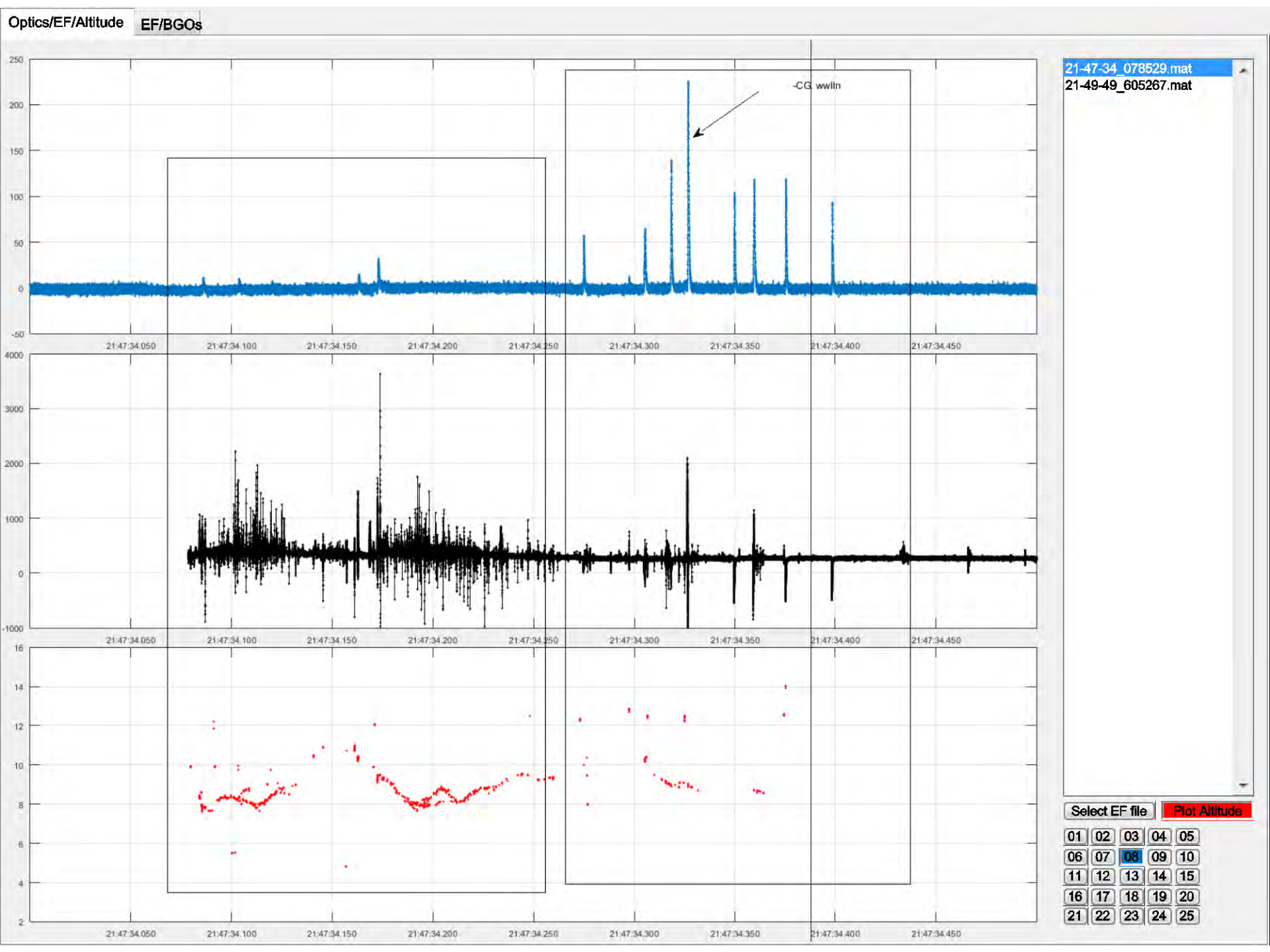

4000
3000
2000
1000
0
counts/s
May 08, 20:00
May 08, 22:00
May 09, 00:00
May 09, 02:00
2017

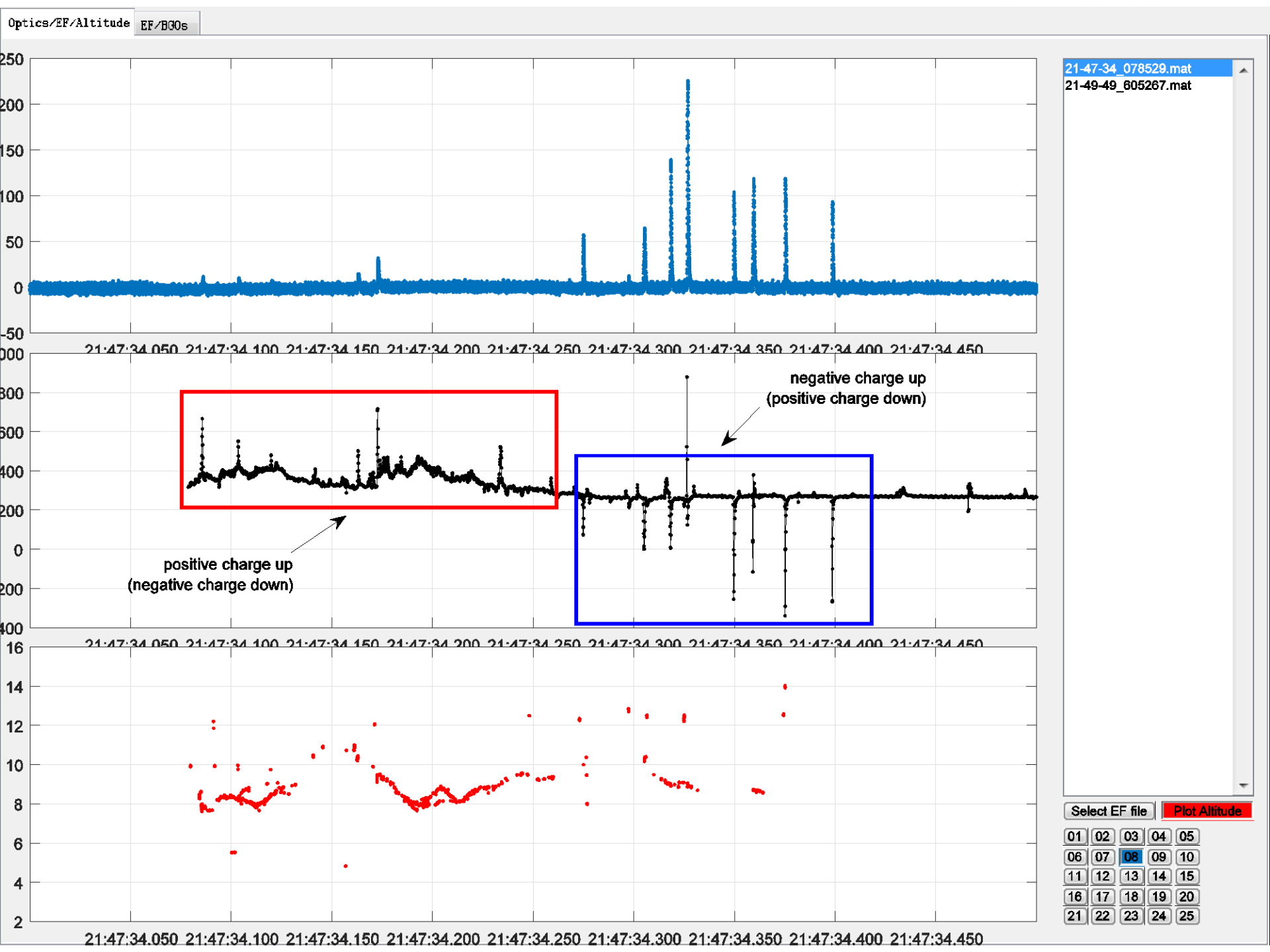

Upper cloud layer top
Upper cloud layer bottom
ER2 altitude
Altitude, km
20
18
16
14
12
10
21:42
21:44
21:46
21:48
21:50
21:52
21:54
May 08, 2017

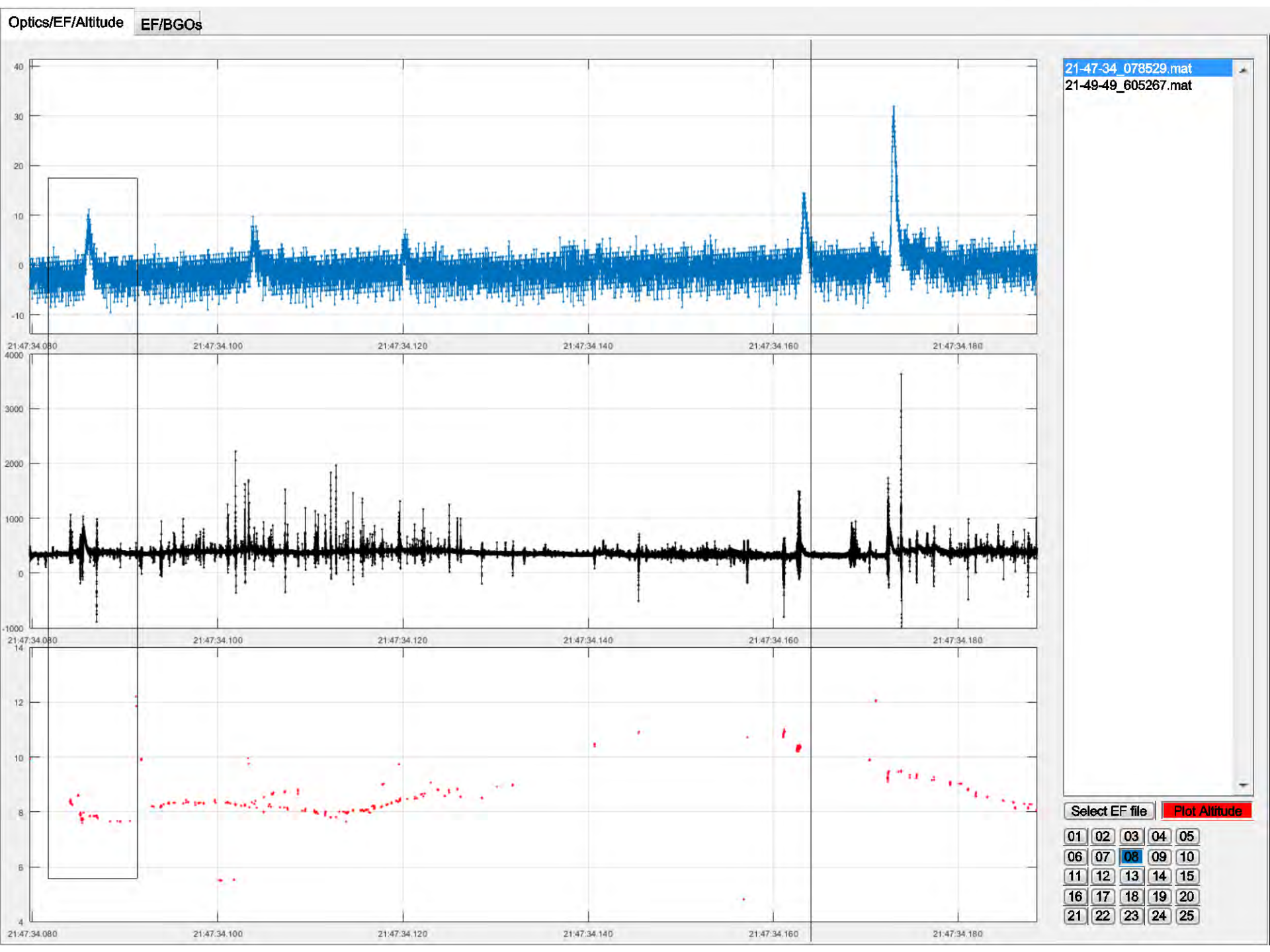

ALOFT
counts/s
4000
3500
3000
2500
2000
21:42
21:44
21:46
21:48
21:50
21:52
21:54
May 08, 2017

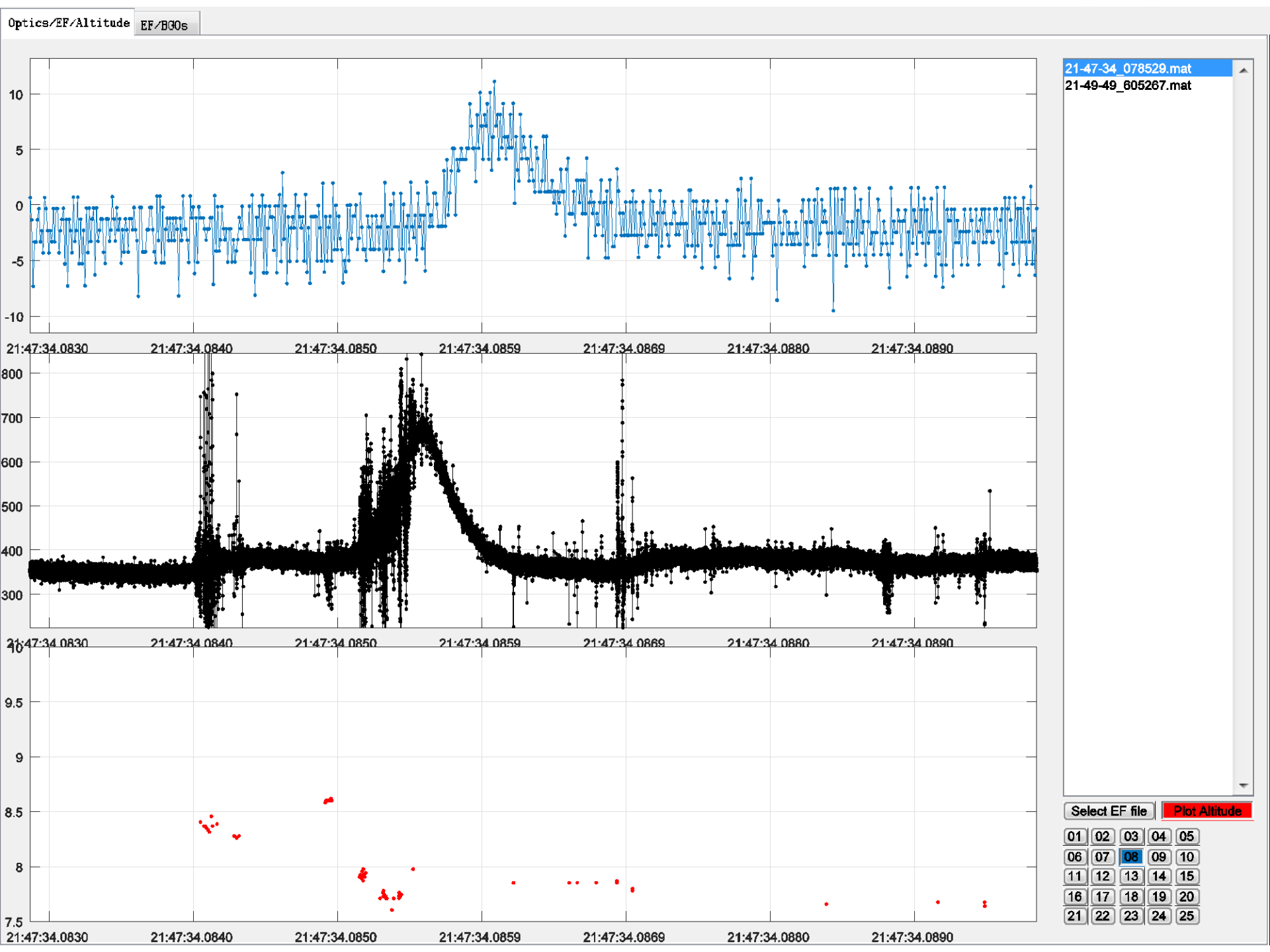

iSTORM
counts/s
1300
1200
1100
1000
900
800
21:42
21:44
21:46
21:48
21:50
21:52
21:54
May 08, 2017


Layer north from track between -5 and 0 km.
altitude, km
15
10
5
-104
-103.9
-103.8
-103.7
-103.6
-103.5
-103.4
-103.3
-103.2
longitude
Layer north from track between 0 and 5 km.
altitude, km
longitude
Layer north from track between 5 and 10 km.
altitude, km
longitude
Cloud top altitude
altitude, km
16
14
12
10
21:50
21:49
21:48
21:47
21:46
UTC


Optics/EF/Altitude
EF/BGOs
-CG wwlln
21-47-34_078529.mat
21-49-49_605267.mat
Select EF file
Plot Altitude
01 02 03 04 05
06 07 08 09 10
11 12 13 14 15
16 17 18 19 20
21 22 23 24 25
21:47:34.050
21:47:34.100
21:47:34.150
21:47:34.200
21:47:34.250
21:47:34.300
21:47:34.350
21:47:34.400
21:47:34.450


Optics/EF/Altitude
EF/BGOs
250
200
150
100
50
0
-50
21:47:34.050 21:47:34.100 21:47:34.150 21:47:34.200 21:47:34.250 21:47:34.300 21:47:34.350 21:47:34.400 21:47:34.450
000
800
600
400
200
0
200
400
negative charge up
(positive charge down)
positive charge up
(negative charge down)
21:47:34.050 21:47:34.100 21:47:34.150 21:47:34.200 21:47:34.250 21:47:34.300 21:47:34.350 21:47:34.400 21:47:34.450
16
14
12
10
8
6
4
2
21:47:34.050 21:47:34.100 21:47:34.150 21:47:34.200 21:47:34.250 21:47:34.300 21:47:34.350 21:47:34.400 21:47:34.450
21-47-34_078529.mat
21-49-49_605267.mat
Select EF file
Plot Altitude
01 02 03 04 05
06 07 08 09 10
11 12 13 14 15
16 17 18 19 20
21 22 23 24 25


Optics/EF/Altitude
EF/BGOs
21-47-34_078529.mat
21-49-49_605267.mat
Select EF file
Plot Altitude
01 02 03 04 05
06 07 08 09 10
11 12 13 14 15
16 17 18 19 20
21 22 23 24 25
21:47:34.080
21:47:34.100
21:47:34.120
21:47:34.140
21:47:34.160
21:47:34.180


Optics/EF/Altitude
EF/BGOs
21-47-34_078529.mat
21-49-49_605267.mat
Select EF file
Plot Altitude
01 02 03 04 05
06 07 08 09 10
11 12 13 14 15
16 17 18 19 20
21 22 23 24 25
10
5
0
-5
-10
800
700
600
500
400
300
10
9.5
9
8.5
8
7.5
21:47:34.0830
21:47:34.0840
21:47:34.0850
21:47:34.0859
21:47:34.0869
21:47:34.0880
21:47:34.0890