Analysis of spatio-temporal correlations between GOES-16/17 GLM observations of lightnings and magnetic field fluctuations measured by Swarm

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ESA Swarm4Anom project

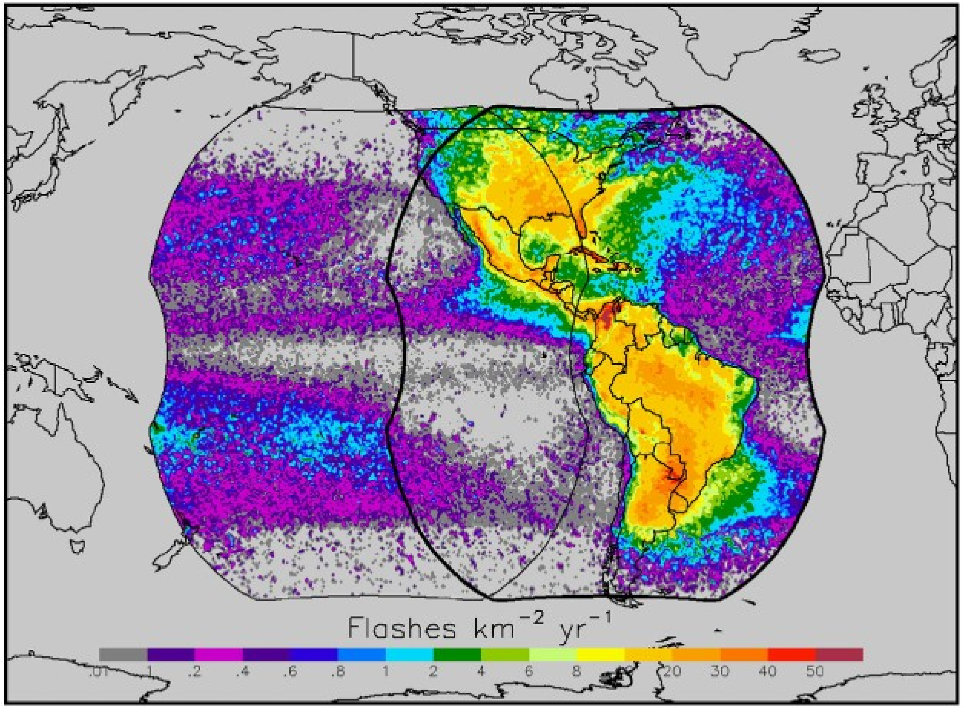
Progress meeting, 23 April 2020

Outline

- Study based on the list of cases provided by Ewa & Jan
- Analysis of cases covered by the field of view of GOES-16/17 GLM instrument: North and South America, adjacent oceanic regions
- Focus on spatio-temporal correlations between GLM observations and Swarm magnetic-field measurements
- Theoretical context: Mazur et al. 2018 model and simple considerations based on the Biot-Savart law

GOES-16/17 (R series) GLM

Goodman et al. 2013



field of view of GOES-16/17 GLM instrument: North and South America, adjacent oceanic regions

Geostationary satellites

GLM is mapping the total lightning activity during day (more difficult) and night

pixel FOV (nadir): 8 km
pixel FOV (corner): 14 km

wavelength: 777.4 nm

frame rate: 2 ms

GLM data and algorithms

Goodman et al. 2013

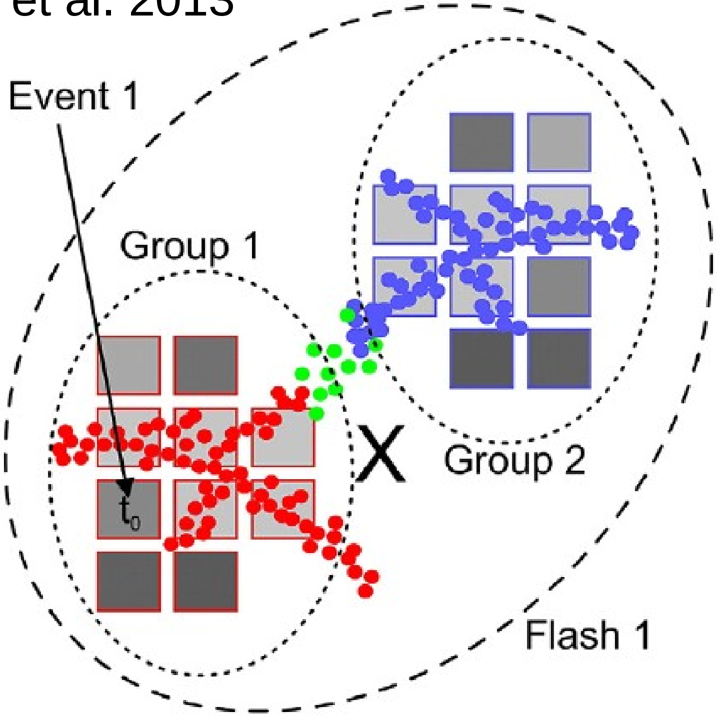
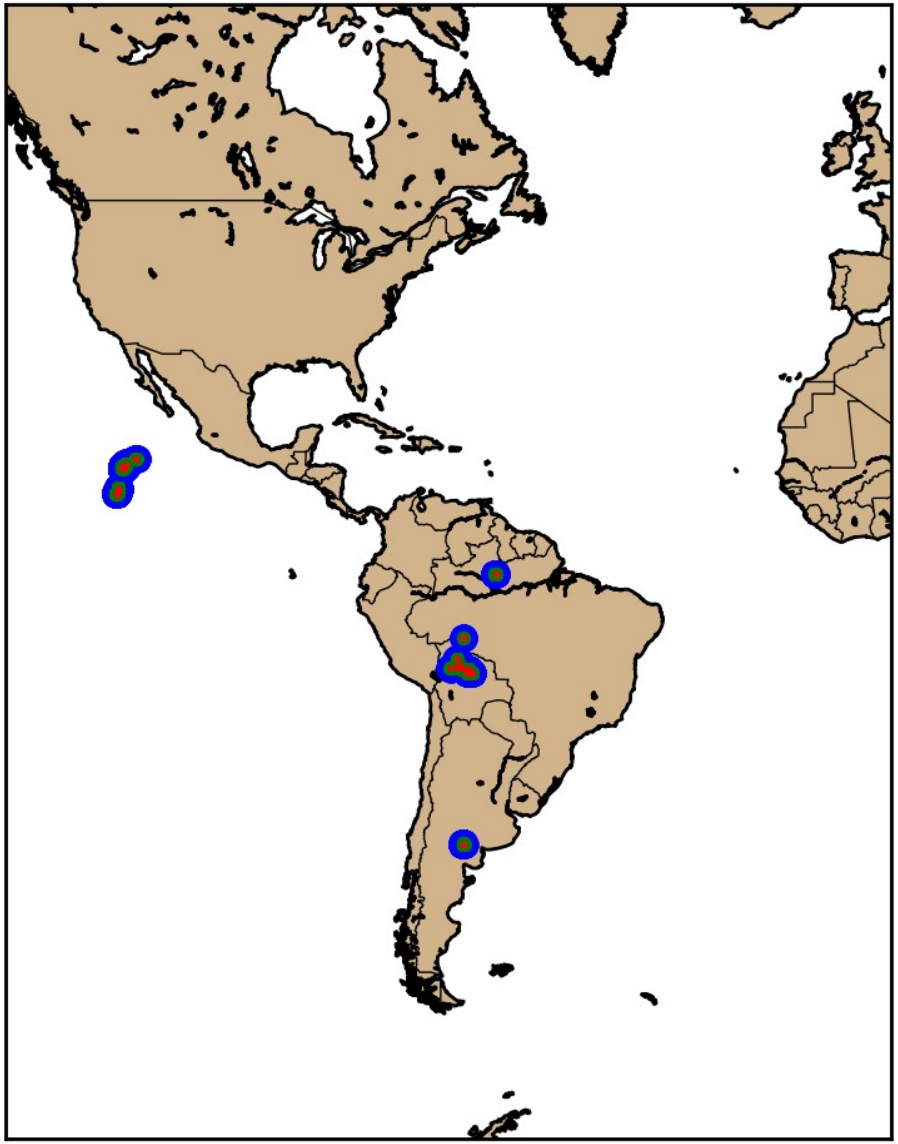


Illustration of the GLM algorithm with heritage from NASA Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD)

- Event (hot pixel exceeding a threshold)
- Group (set of adjacent events at the same time)
- Flash (set of groups sequentially separated in time by 330 ms or less and in space by no more than 16.5 km – two pixels)

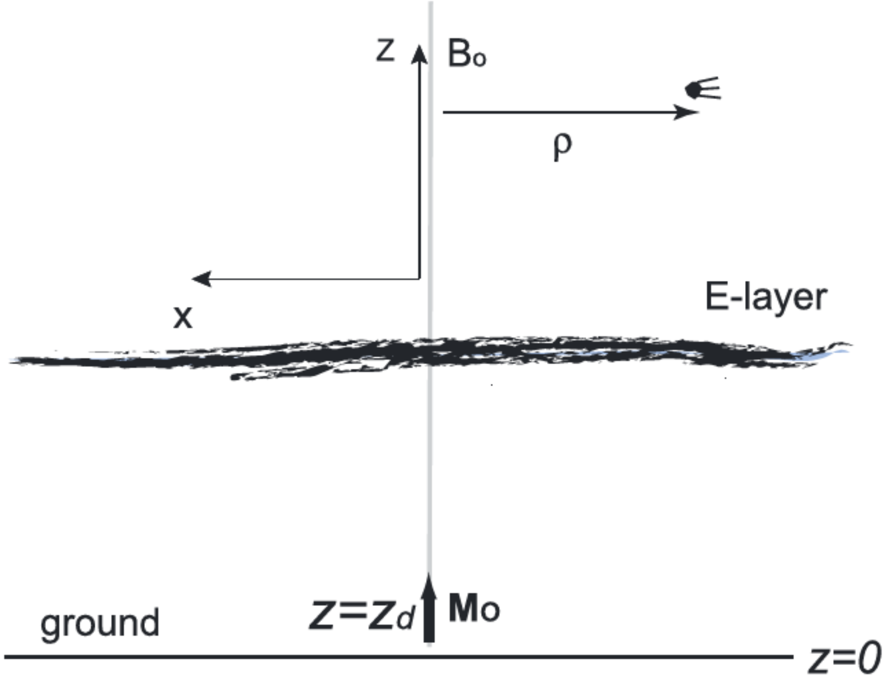


GLM data

- Events show hot pixels (attributes: time, location, energy)
- Groups (attributes: time, location of the center, energy, area, quality flag)
- Flashes (attributes: time interval, location of the center, energy, area, quality flag)

All the three „objects” include interesting information for studies

Modeling ULF/ELF range



Mazur et al. 2018

Discharge/current at some height above the ground

Propagation of the perturbation in the atmosphere with the light speed

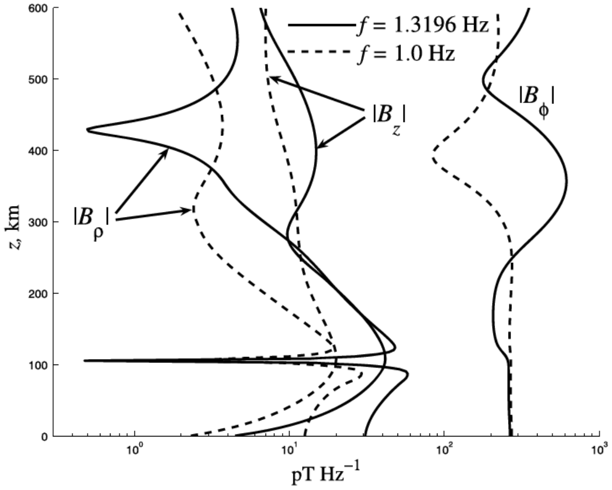
Conversion to a plasma wave in the E-layer

Propagation of the plasma wave with a smaller speed in the ionosphere

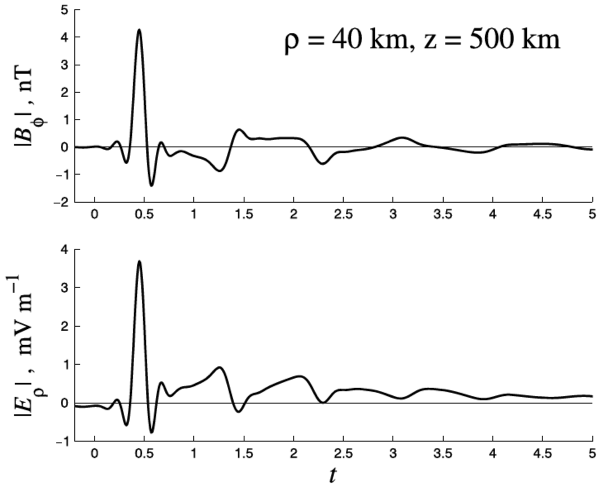
Remark: both current and magnetic field are vertical (radial) in the model by Mazur et al. 2018

Modeling ULF/ELF range

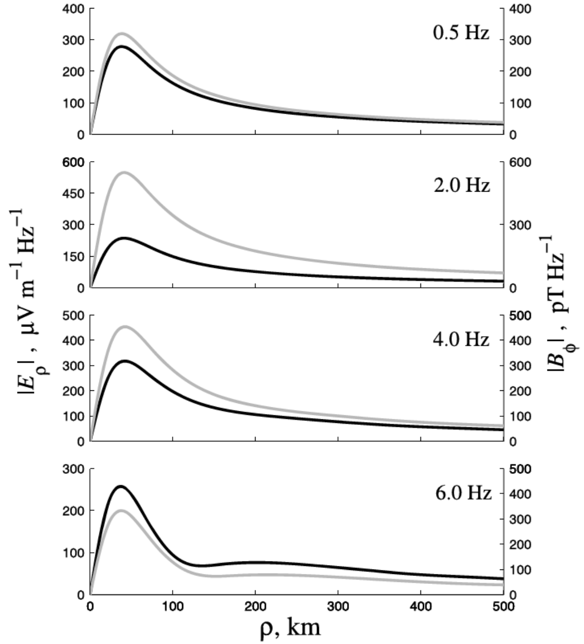
Mazur et al. 2018



B_φ dominates over B_z and B_ρ

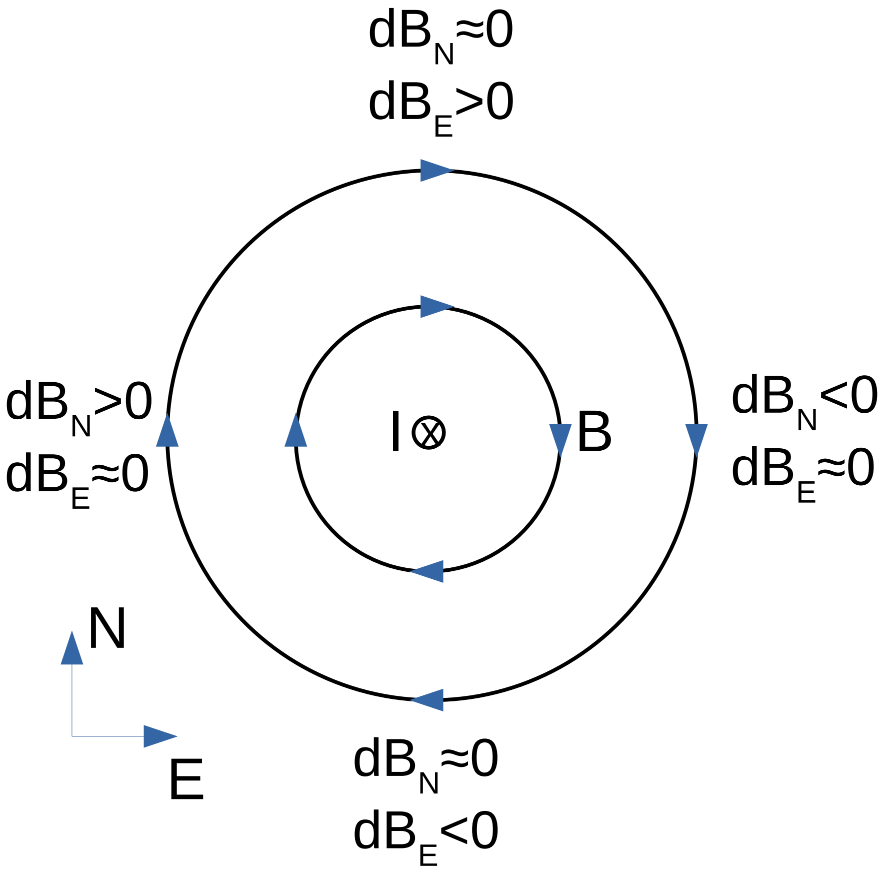


Example of a waveform seen by a satellite:
amplitude ~4 nT,
time lag ~0.45 s,
echo lag ~1 s



Amplitude modulation dependent on ρ

Magnetic field lines around a discharge



A simpler model gives also some insight: magnetic field from a finite conductor based on the Biot-Savart law (plasma wave not included)

ULF/ELF-range frequency problem can be solved if we have +CG with continuing current

C (center) component should be small for vertical/radial discharges (possibility of testing)

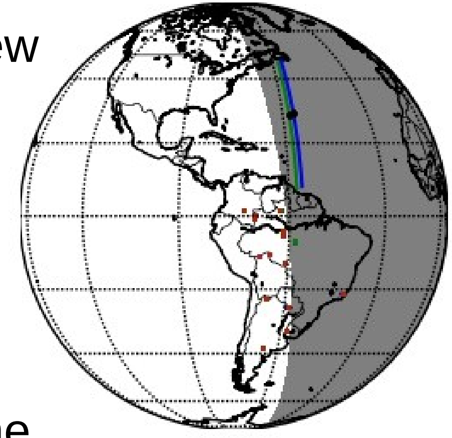
Case study

GLM observations and Swarm magnetic field fluctuations, time evolution

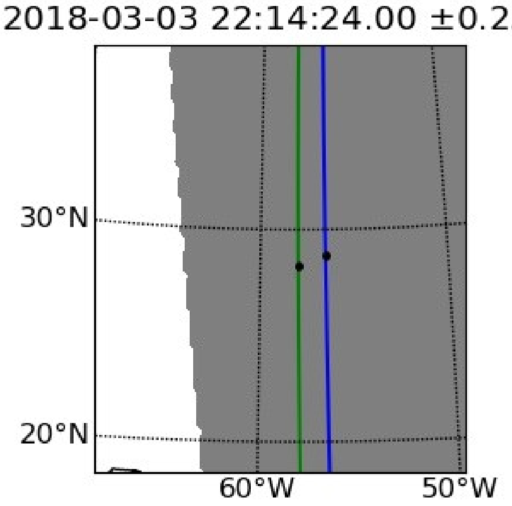
2018-03-03 22:14:29

54.3° W, 28.5° N

Global-view map

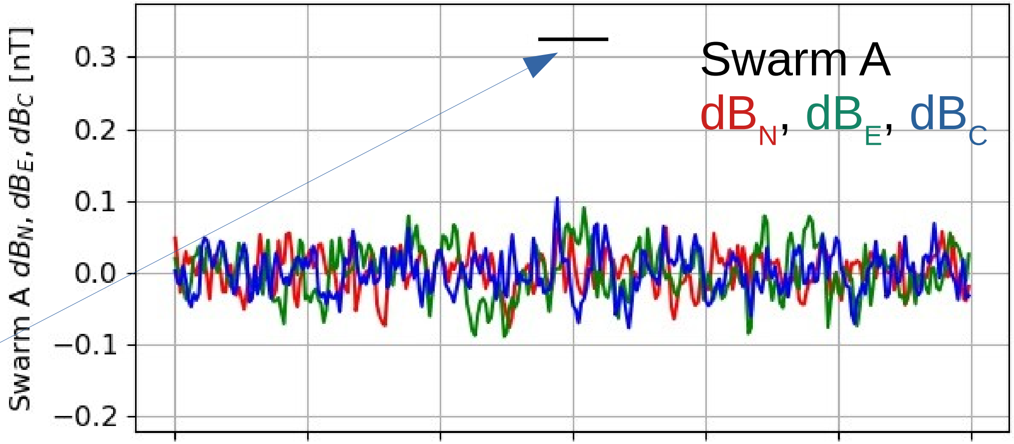


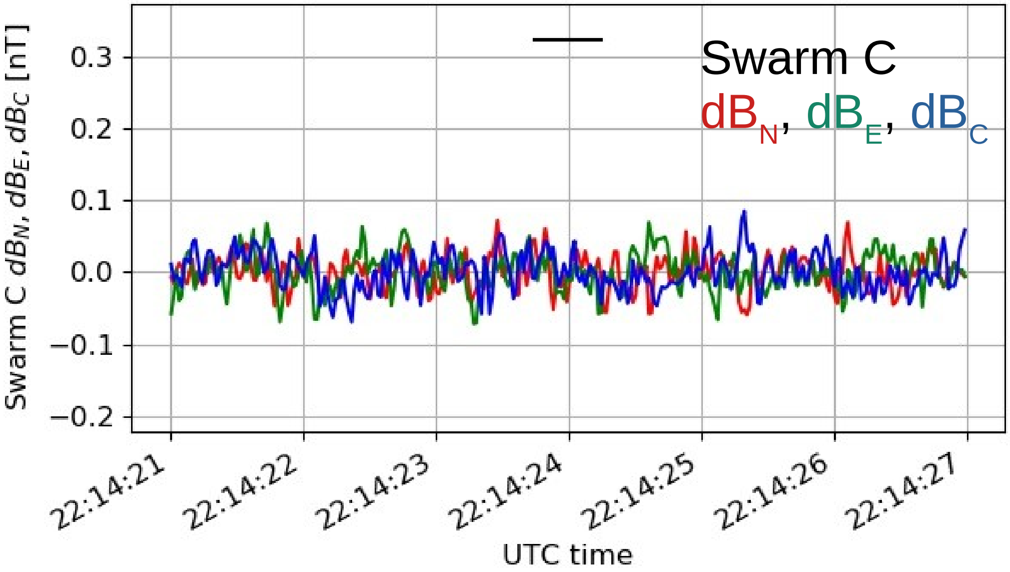
Maps contain lightnings for this time interval

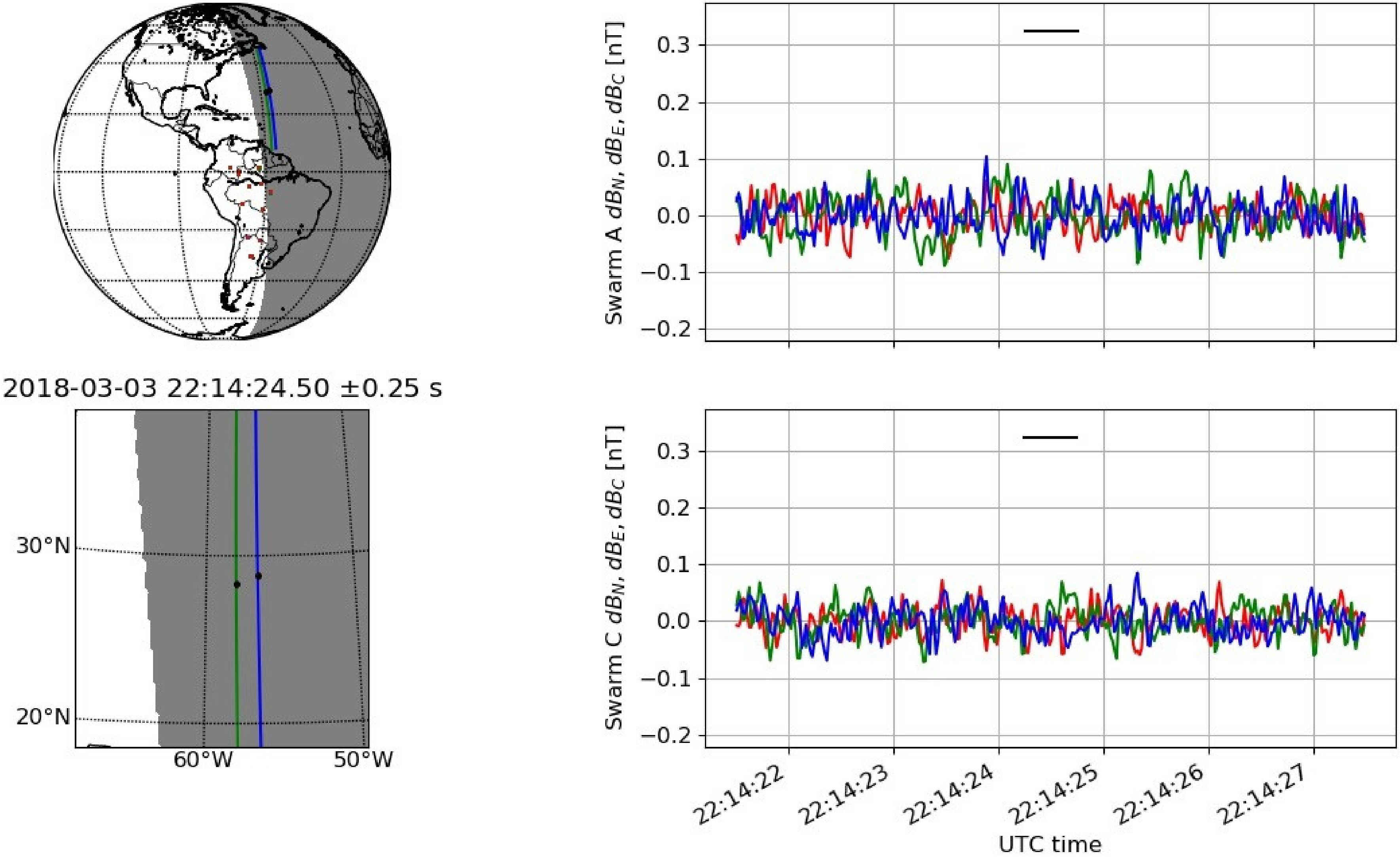


Local-view map

Time step: 0.5 s







2018-03-03 22:14:24.50 ±0.25 s
30°N
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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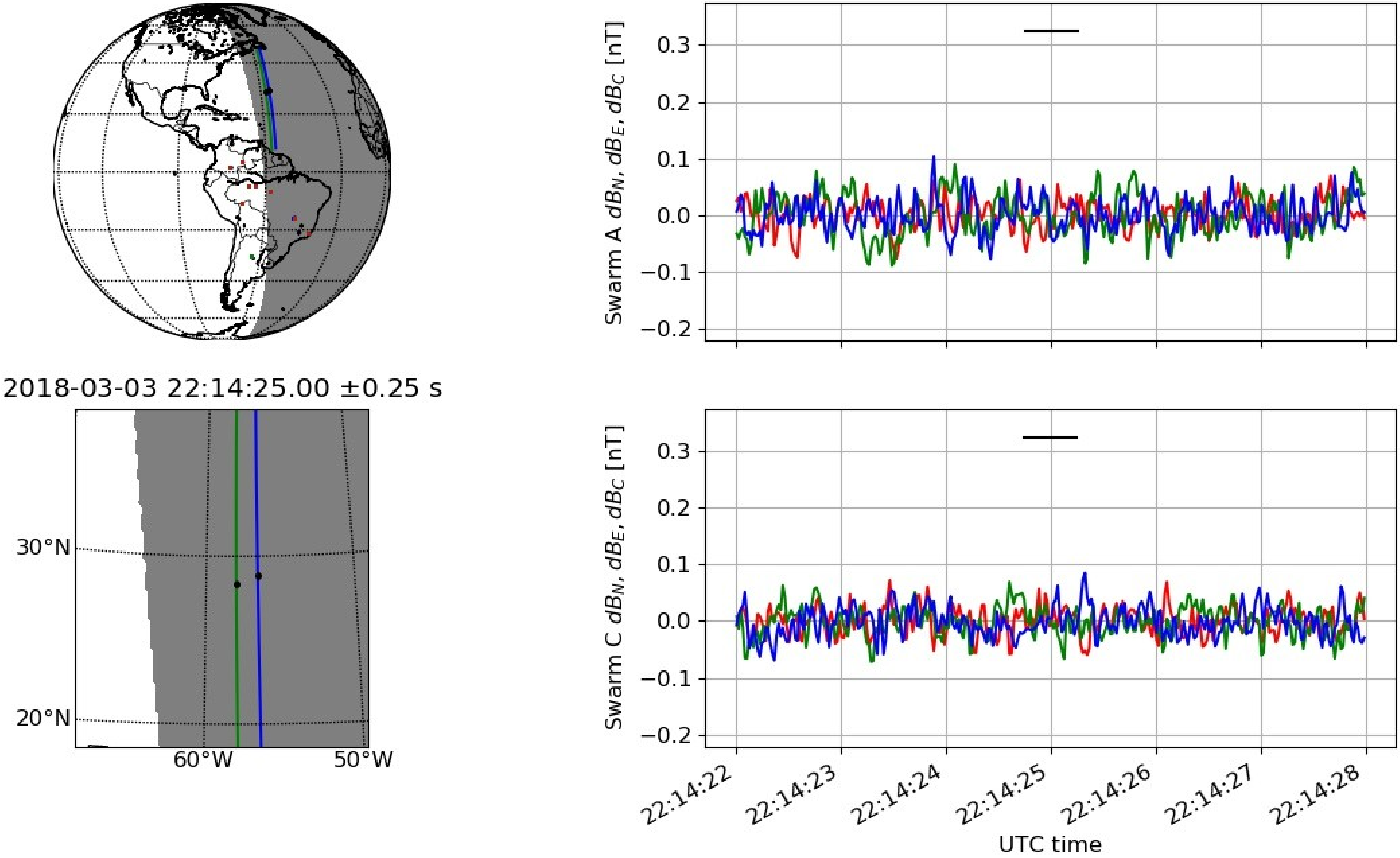
UTC time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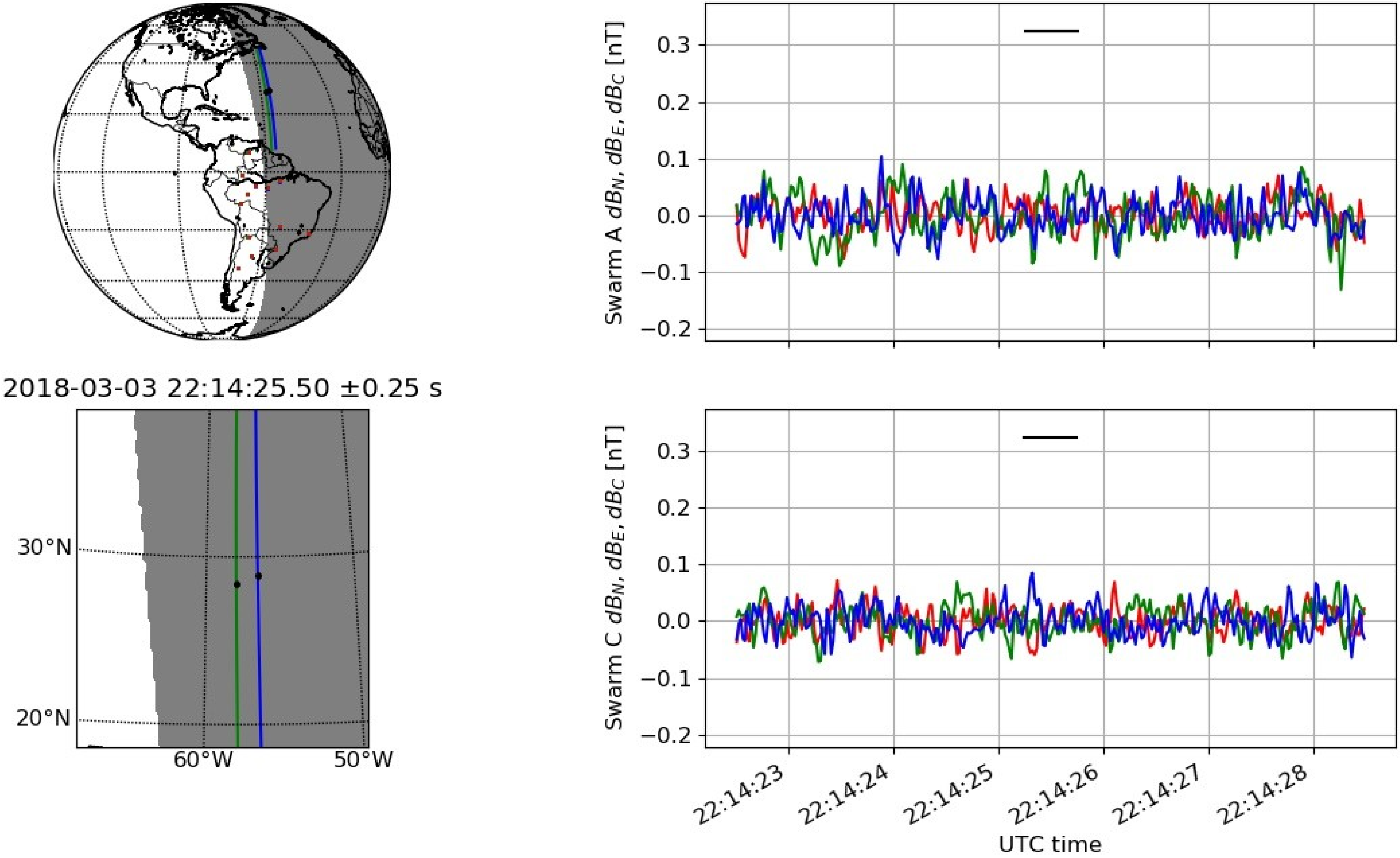
UTC time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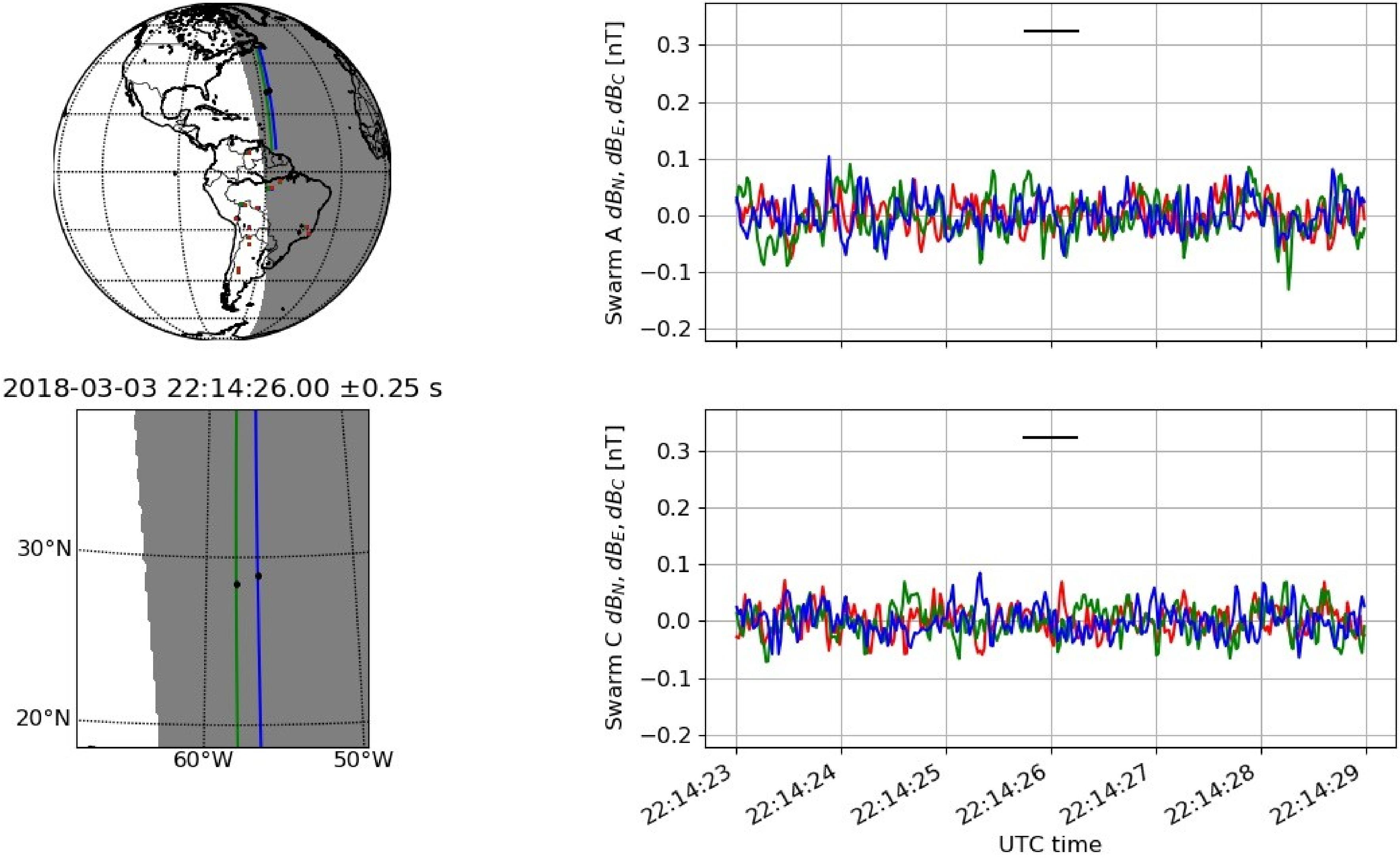
UTC time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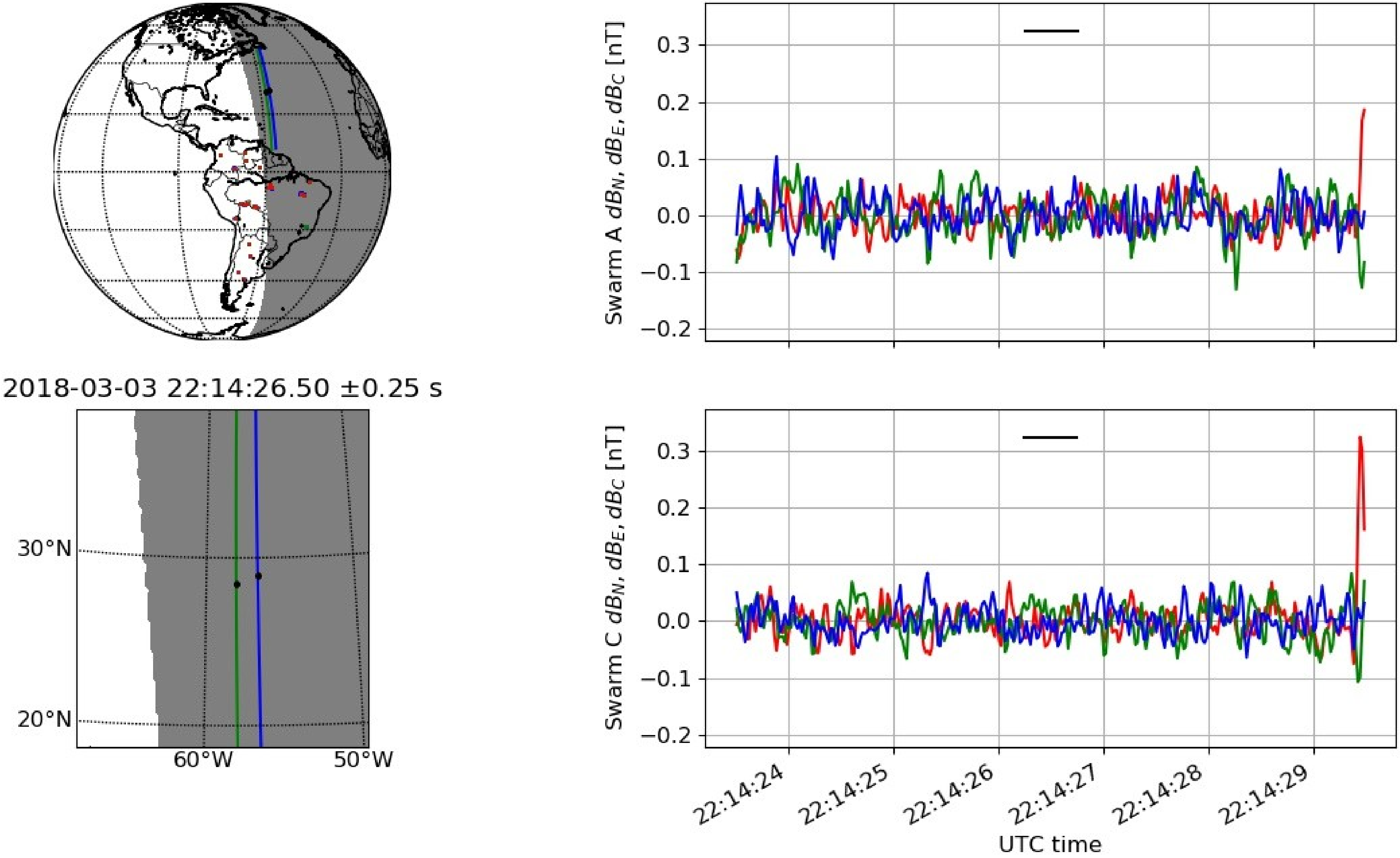
UTC time



2018-03-03 22:14:26.50 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
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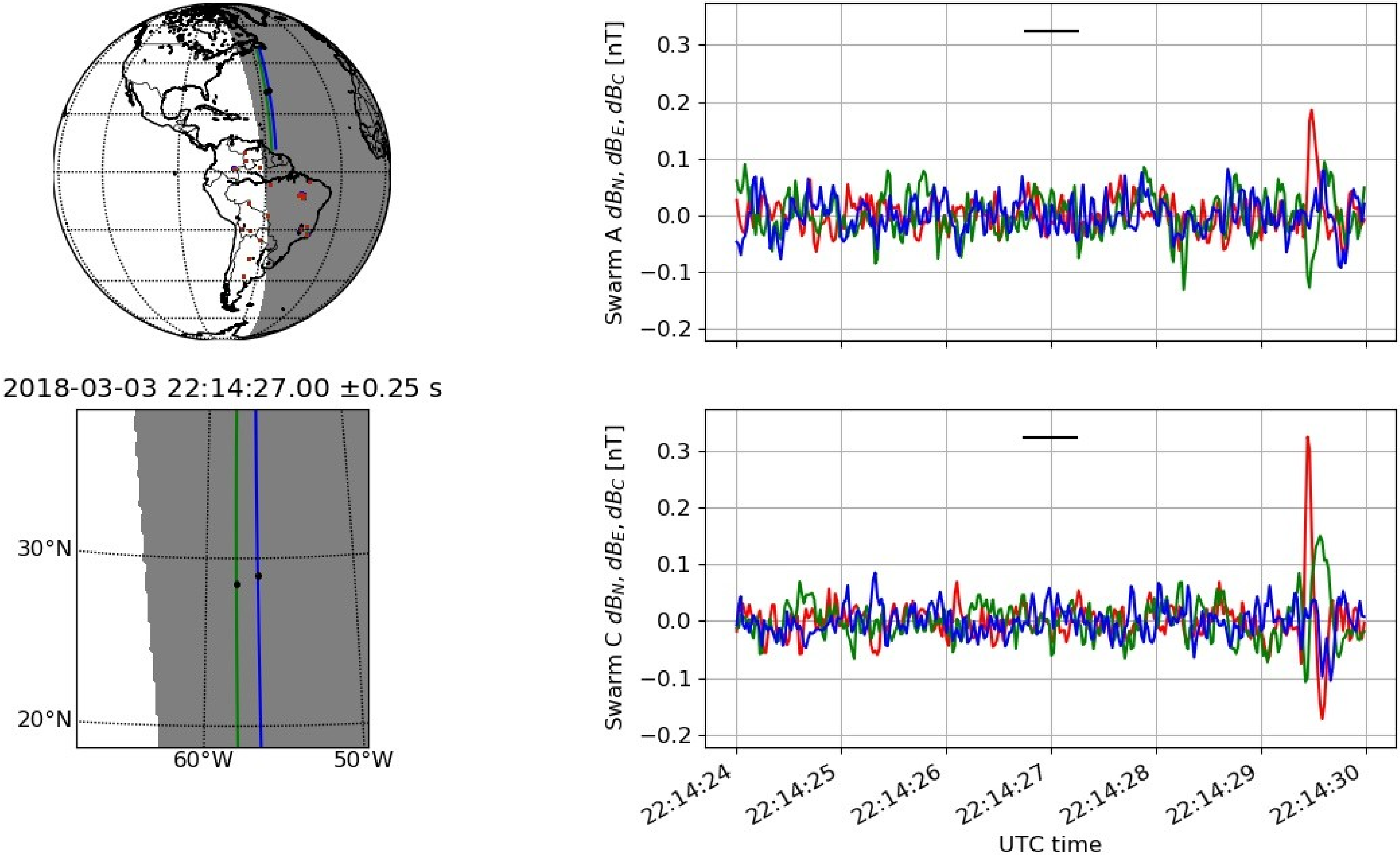
UTC time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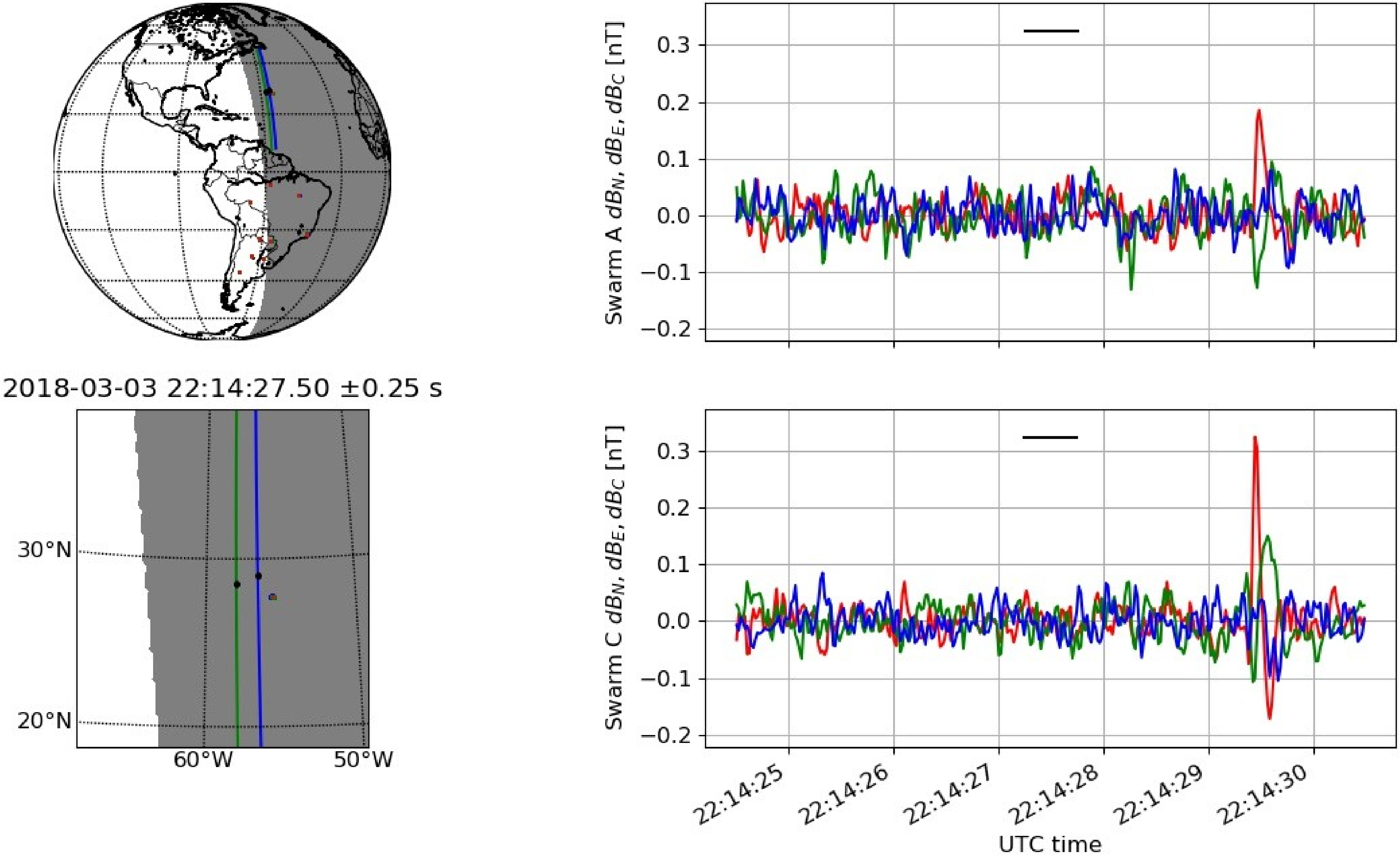
UTC time



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Swarm C dB_N, dB_E, dB_C [nT]
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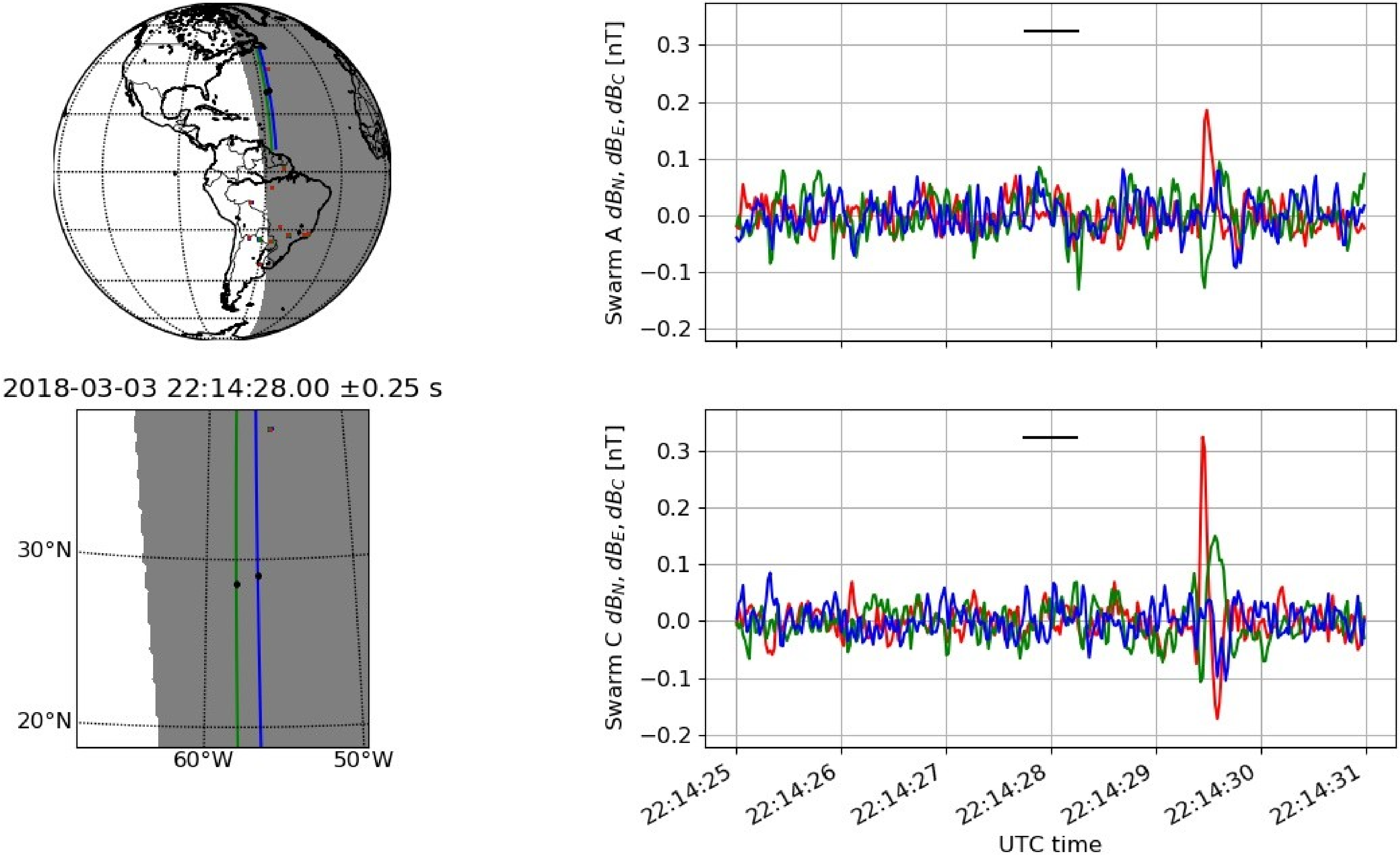
UTC time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Swarm C dB_N, dB_E, dB_C [nT]
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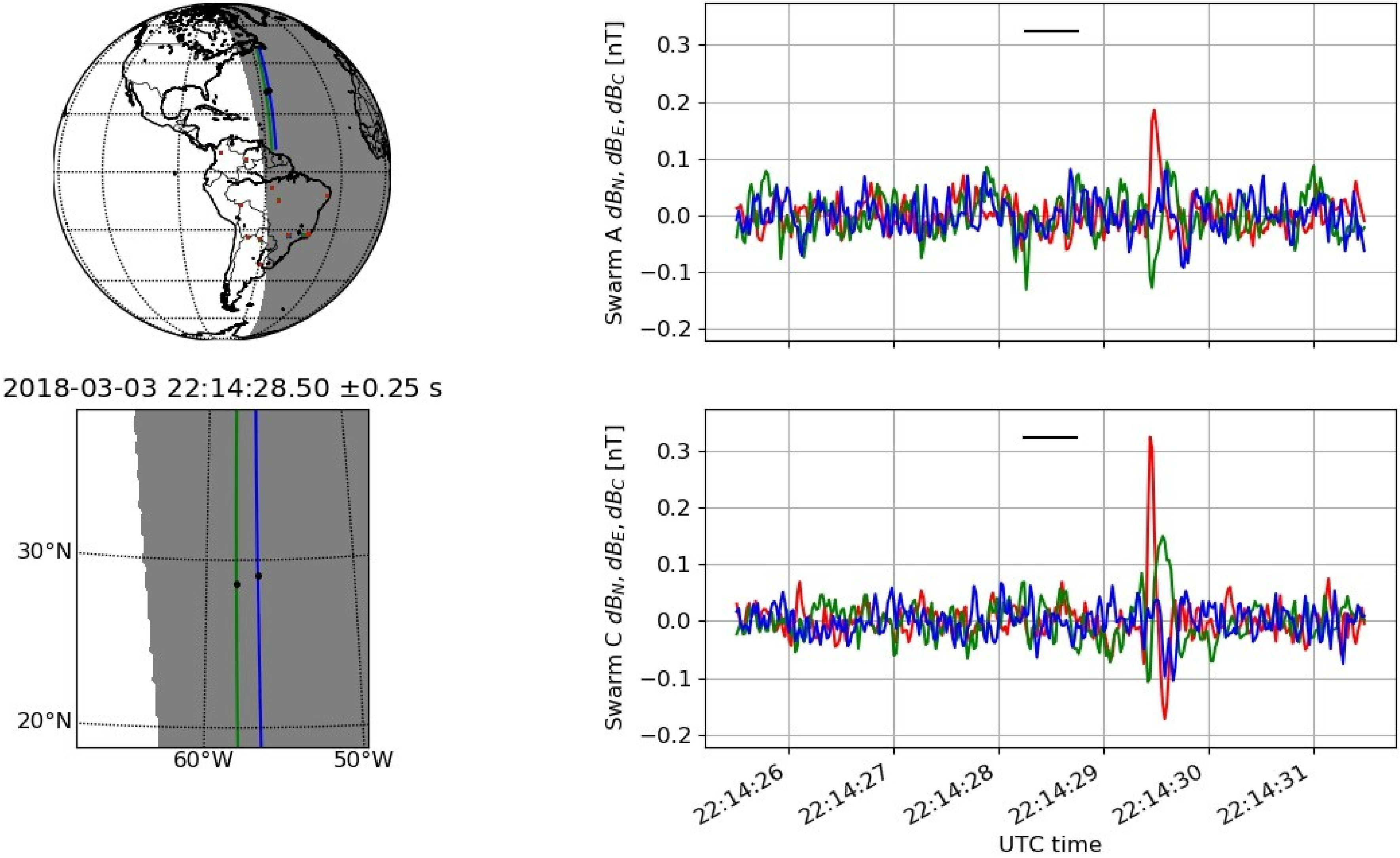
UTC time



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Swarm A dB_N, dB_E, dB_C [nT]
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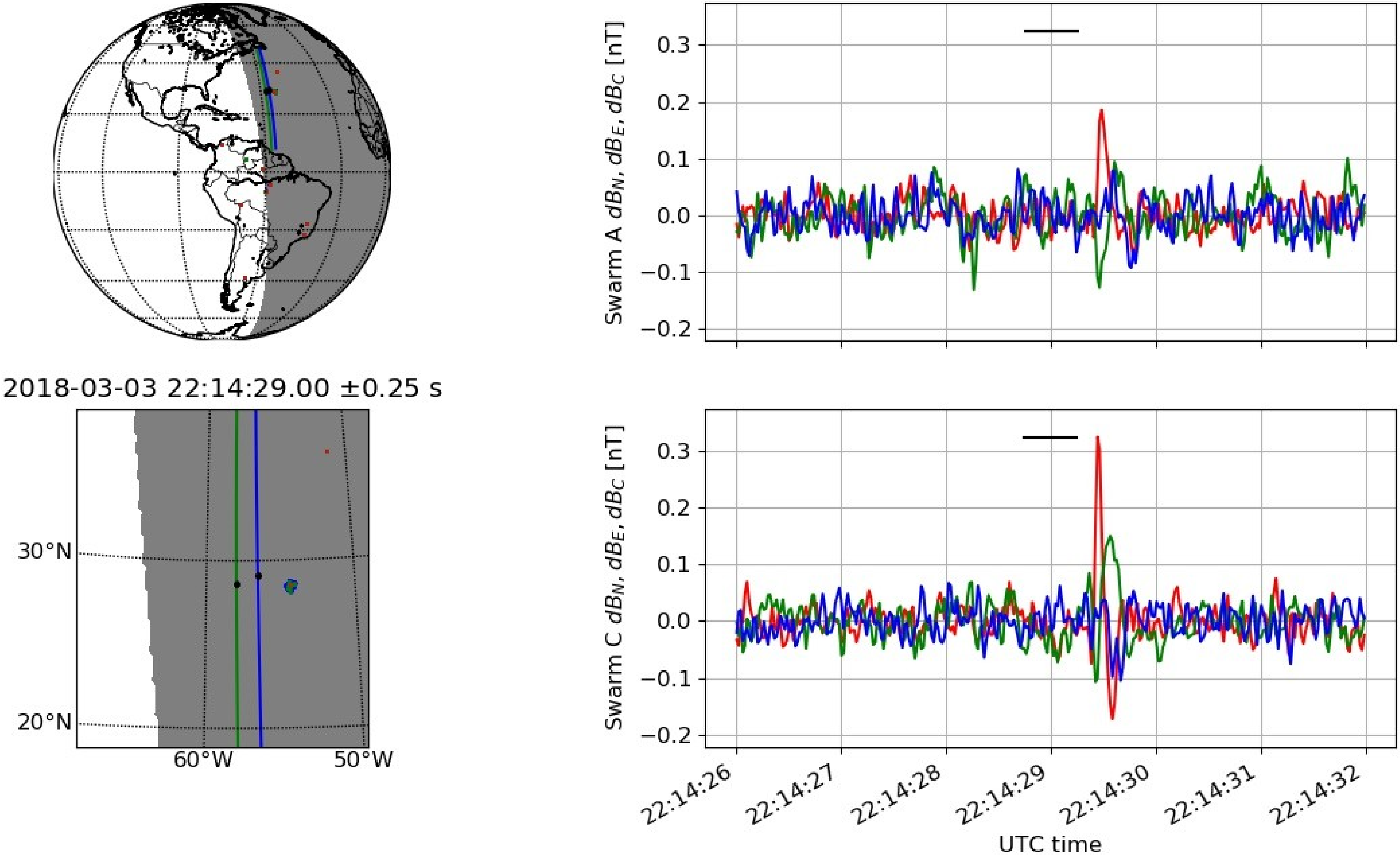
UTC time



2018-03-03 22:14:29.00 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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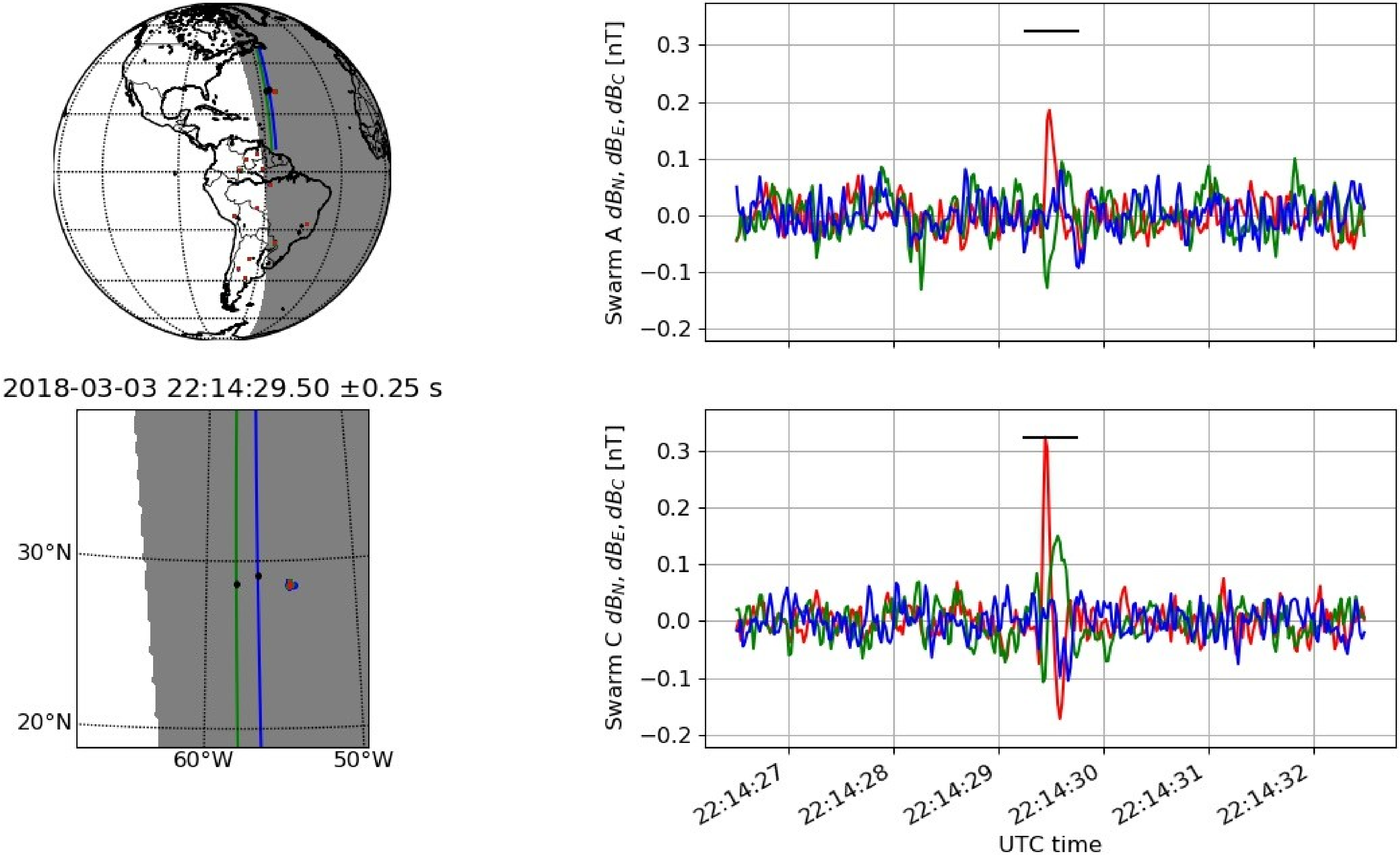
UTC time



2018-03-03 22:14:29.50 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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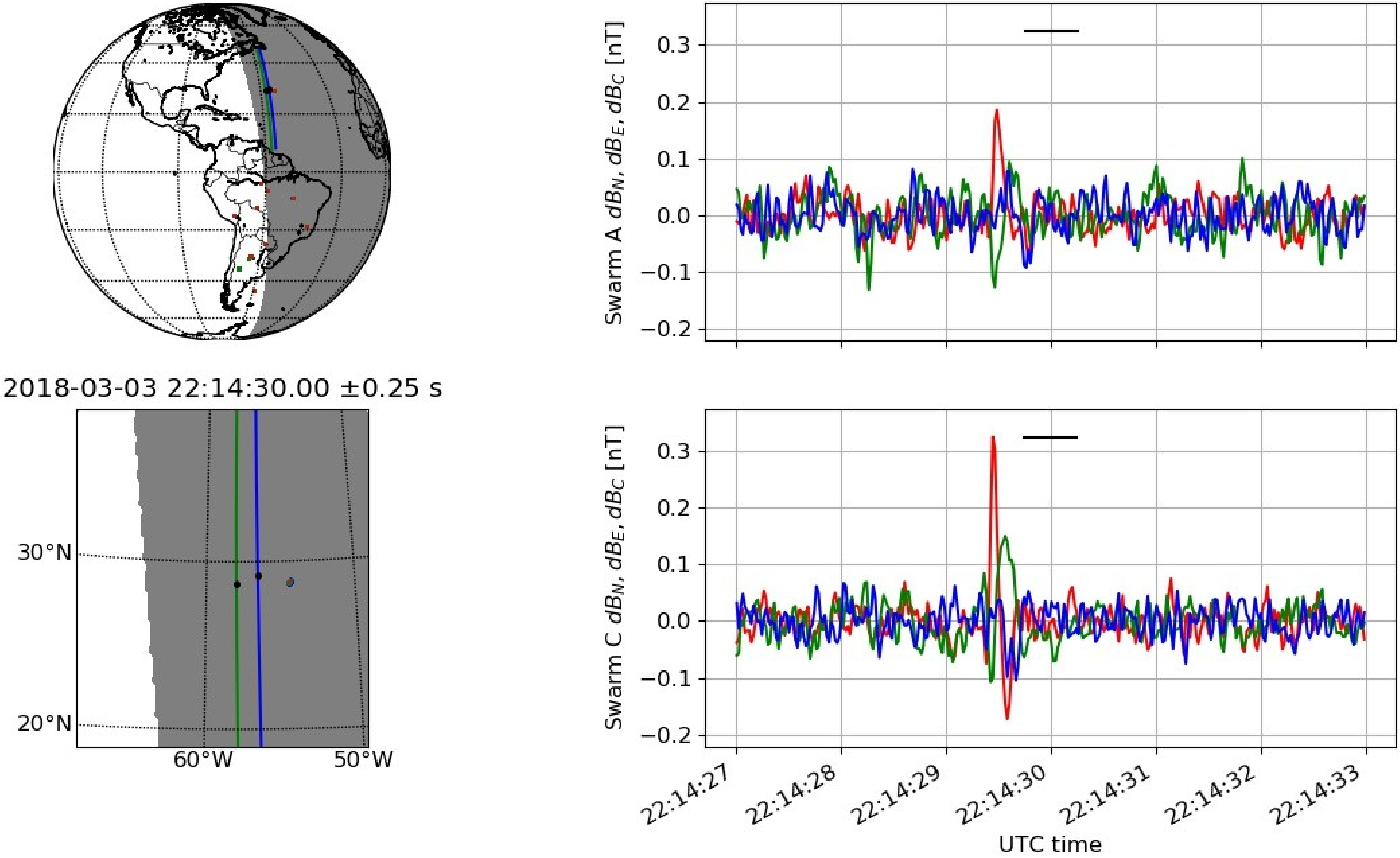
UTC time



2018-03-03 22:14:30.00 ±0.25 s
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Swarm C dB_N, dB_E, dB_C [nT]
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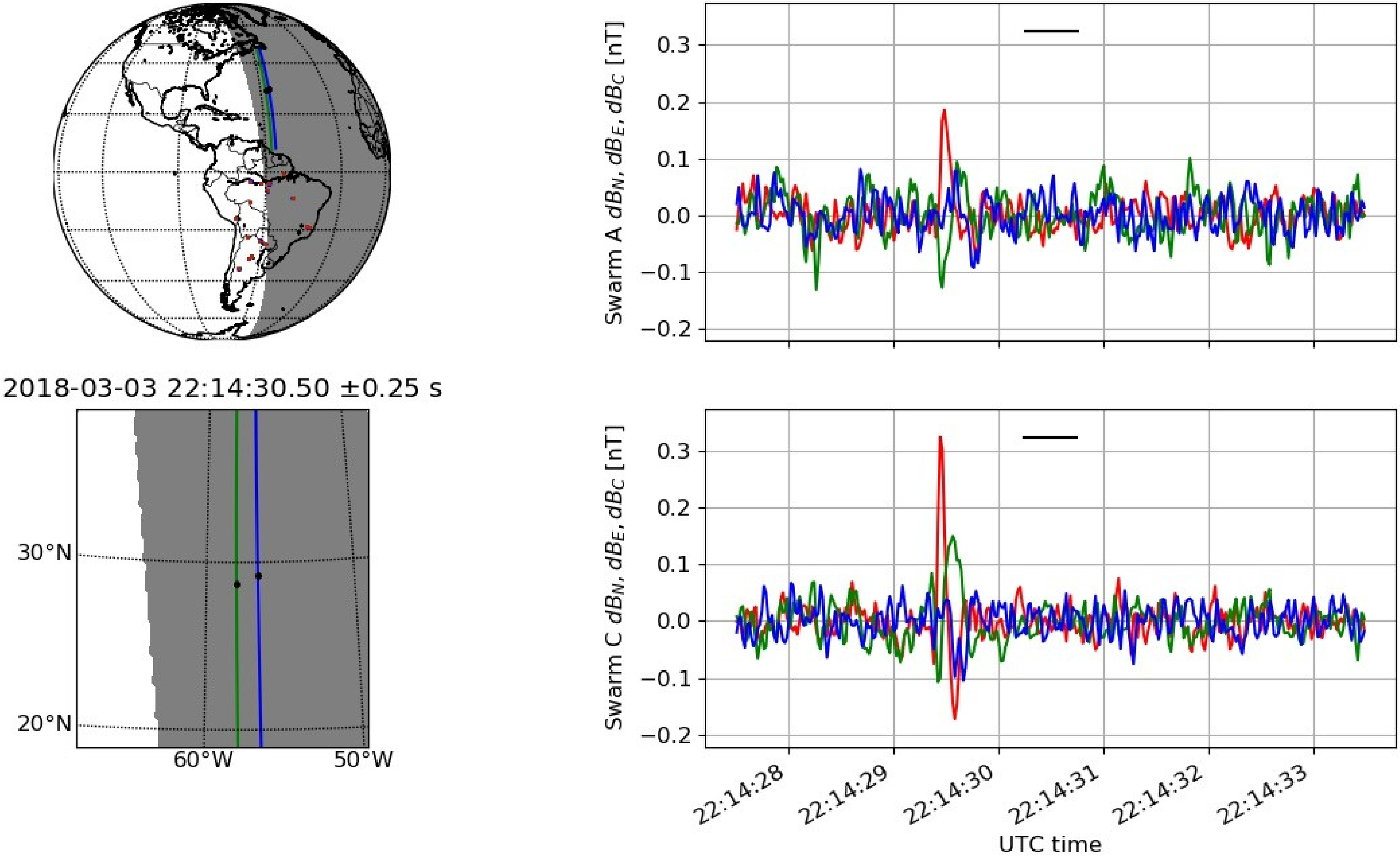
UTC time



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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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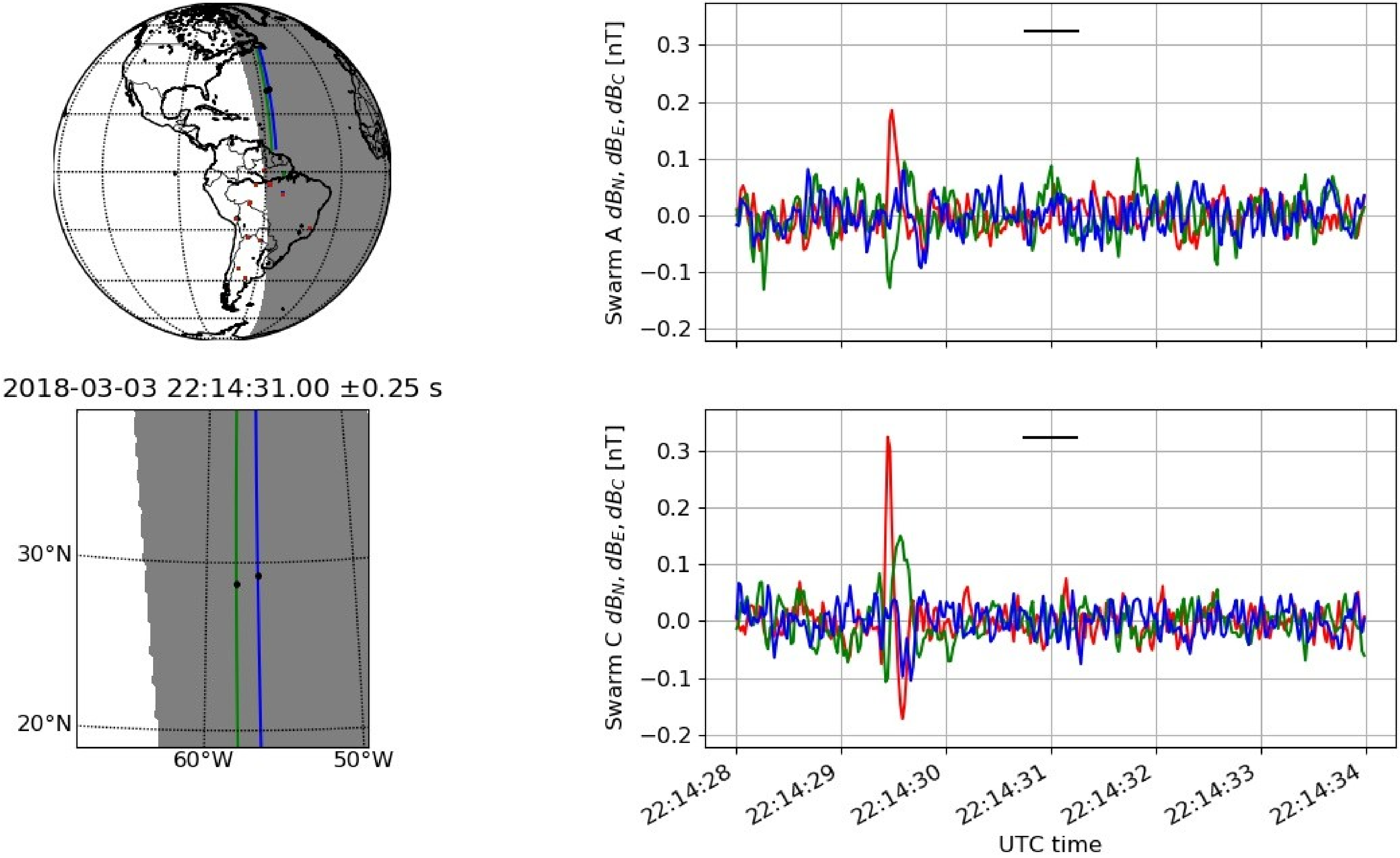
22:14:33
UTC time


2018-03-03 22:14:31.00 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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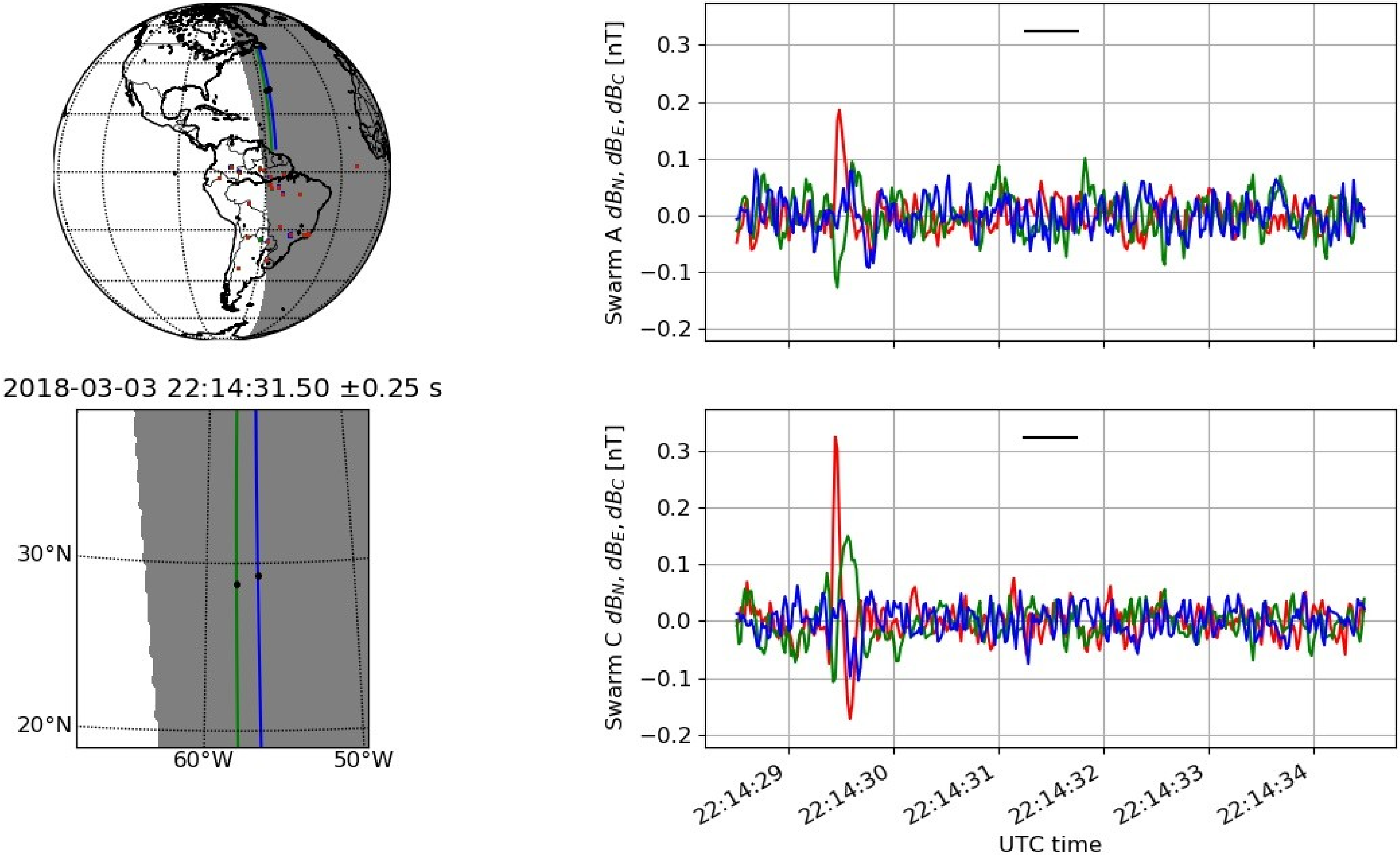
UTC time



2018-03-03 22:14:31.50 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
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22:14:29
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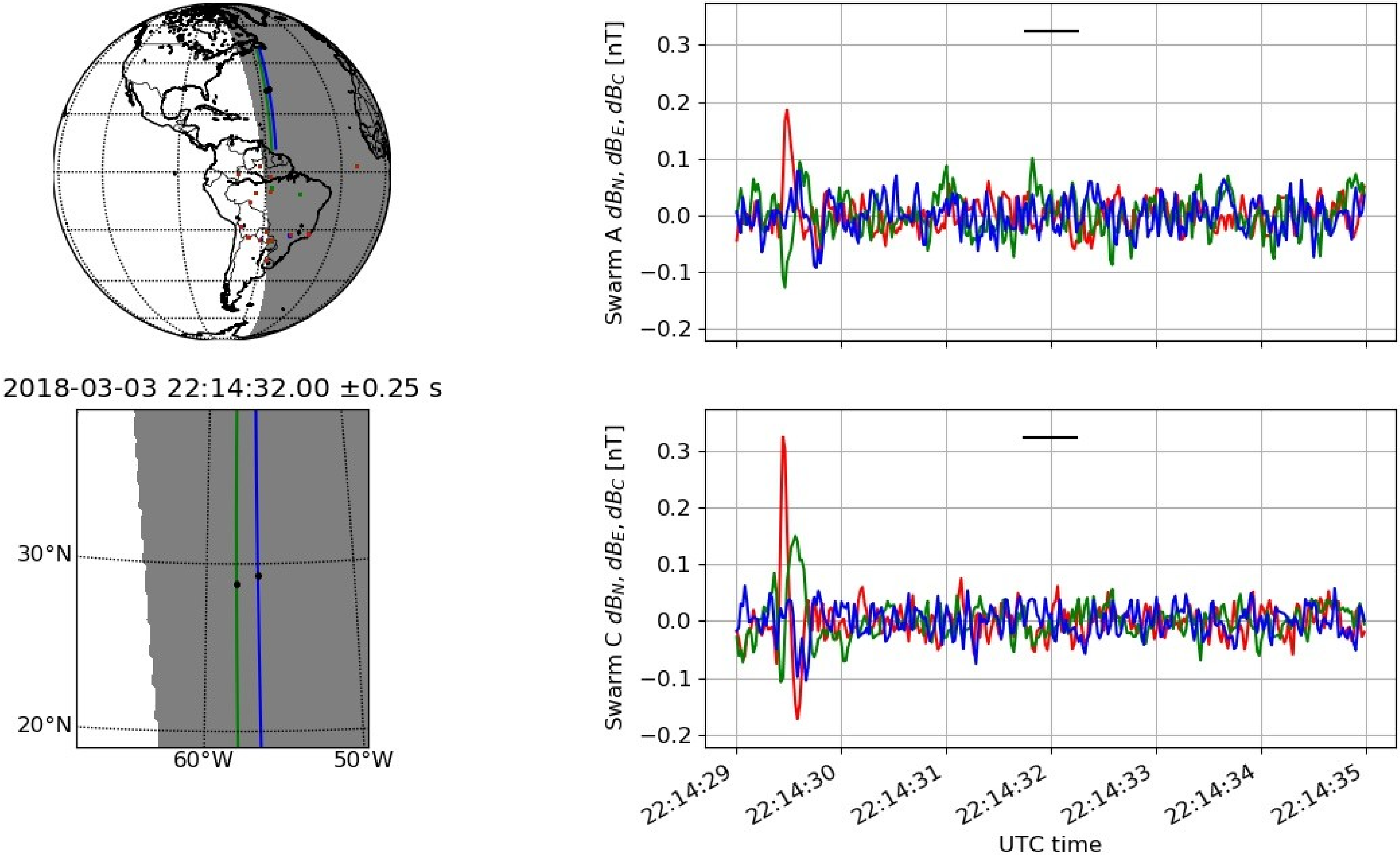
22:14:34
UTC time


2018-03-03 22:14:32.00 ±0.25 s
30°N
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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22:14:29
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22:14:34
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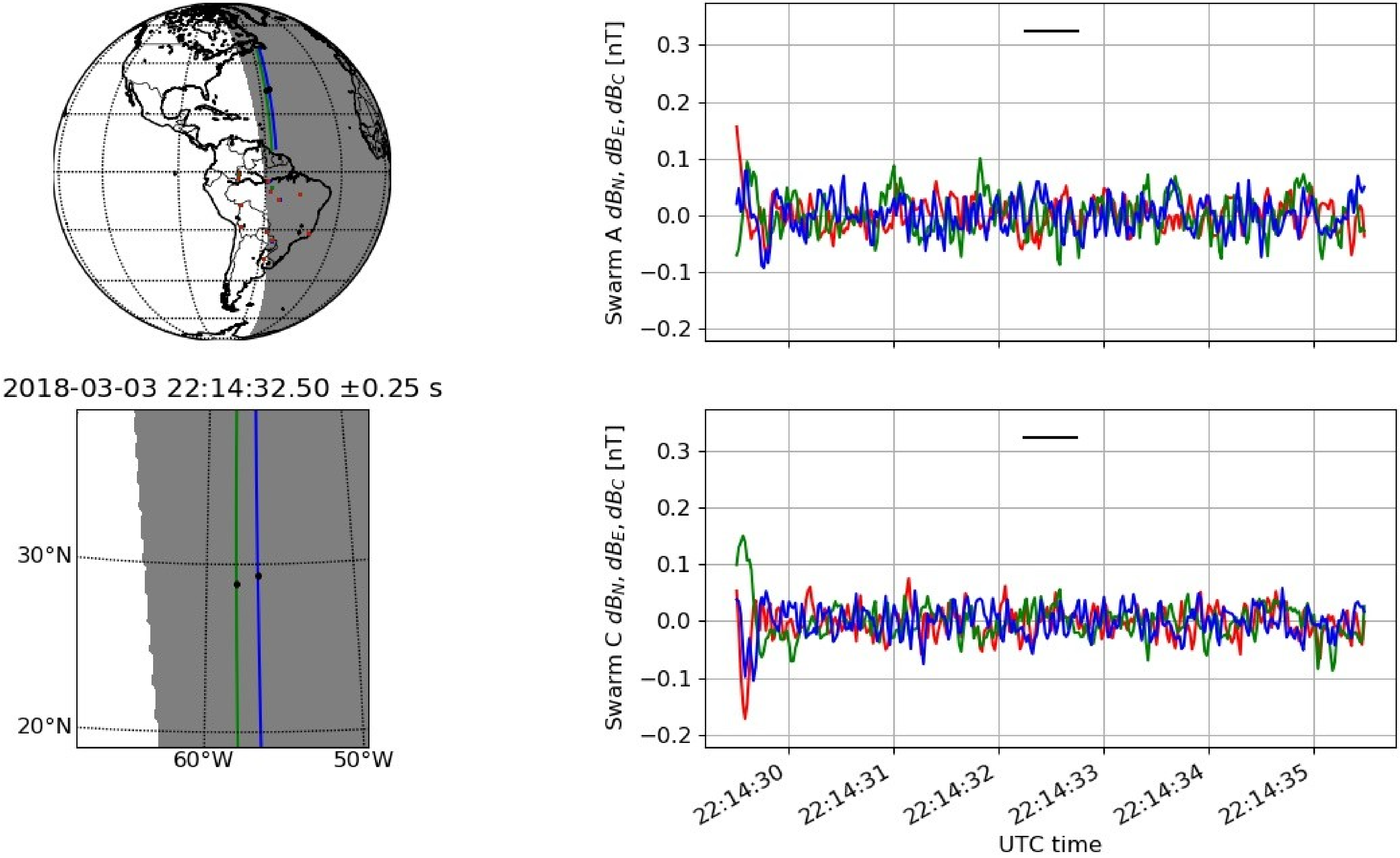
UTC time


2018-03-03 22:14:32.50 ±0.25 s
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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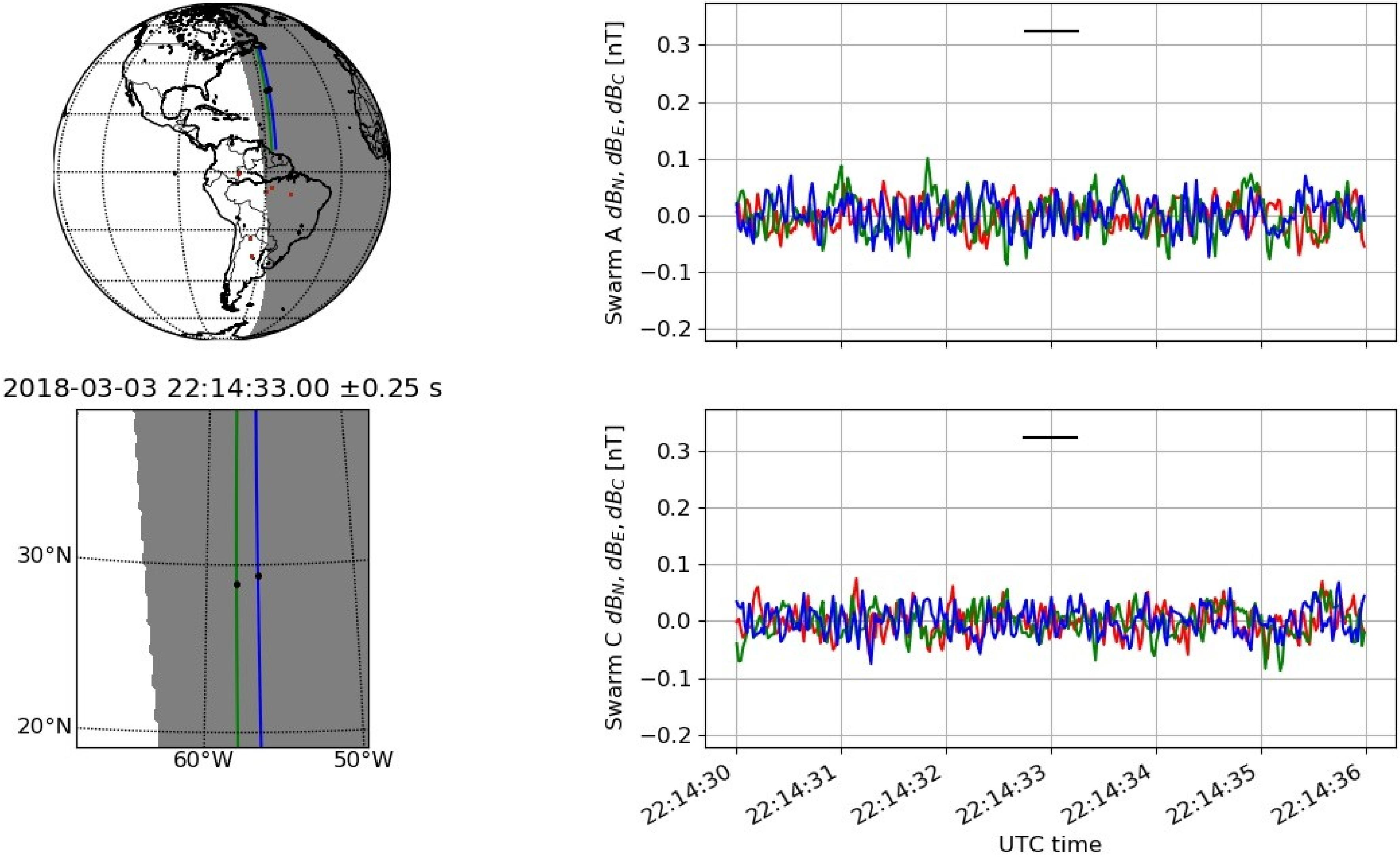
22:14:35
UTC time



2018-03-03 22:14:33.00 ±0.25 s
30°N
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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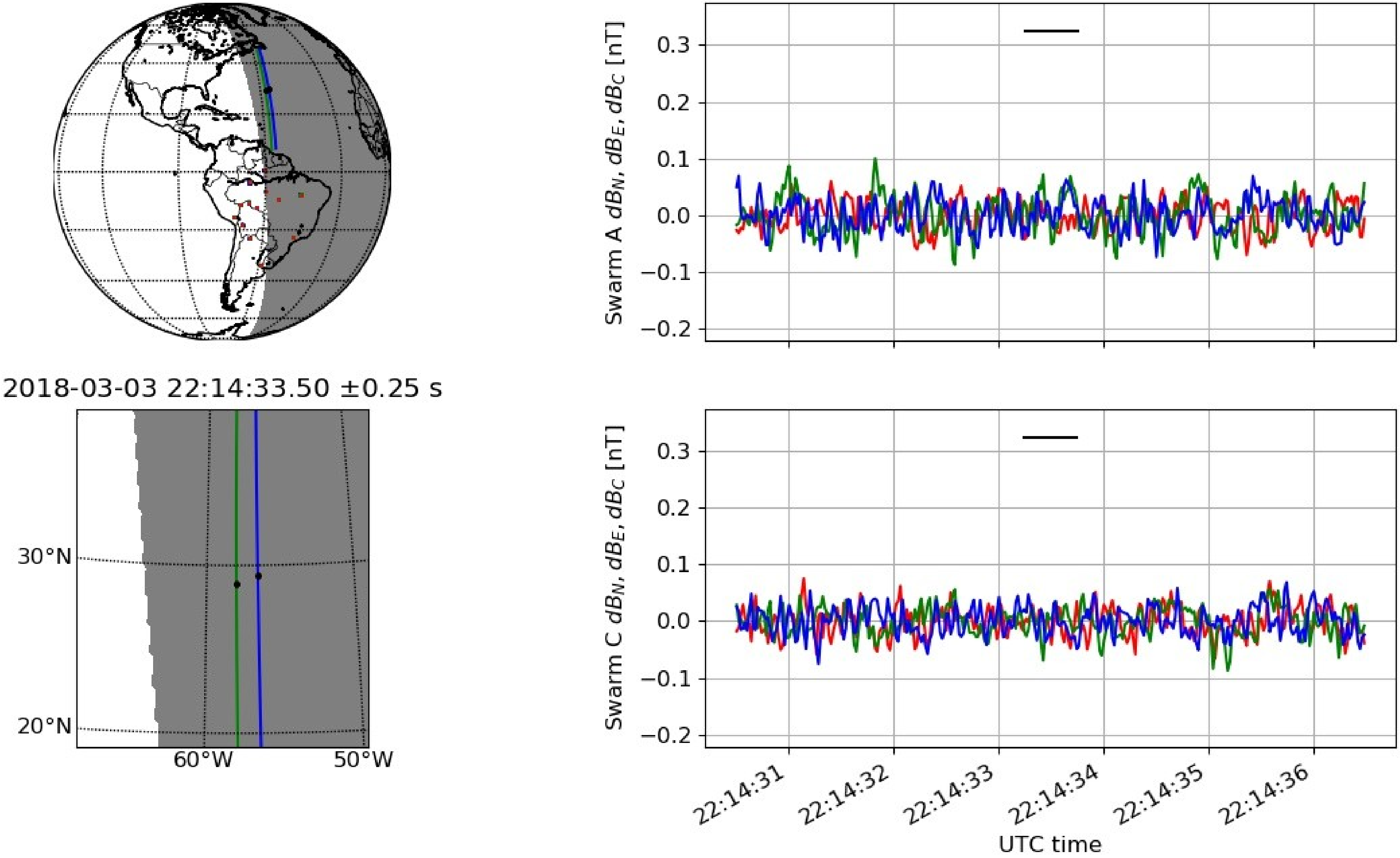
UTC time



2018-03-03 22:14:33.50 ±0.25 s
30°N
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Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
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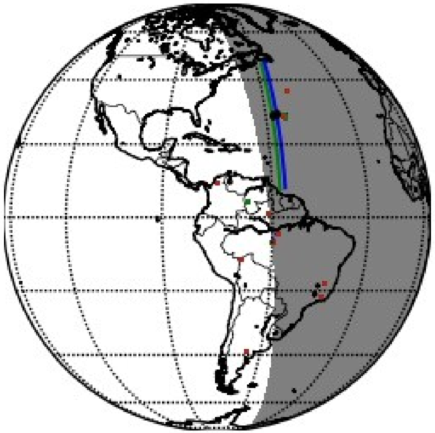
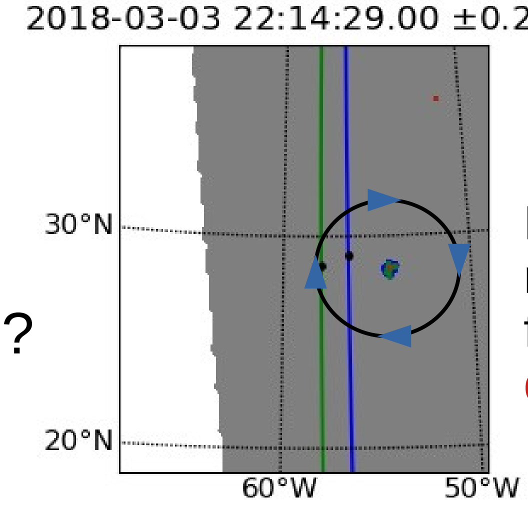
UTC time

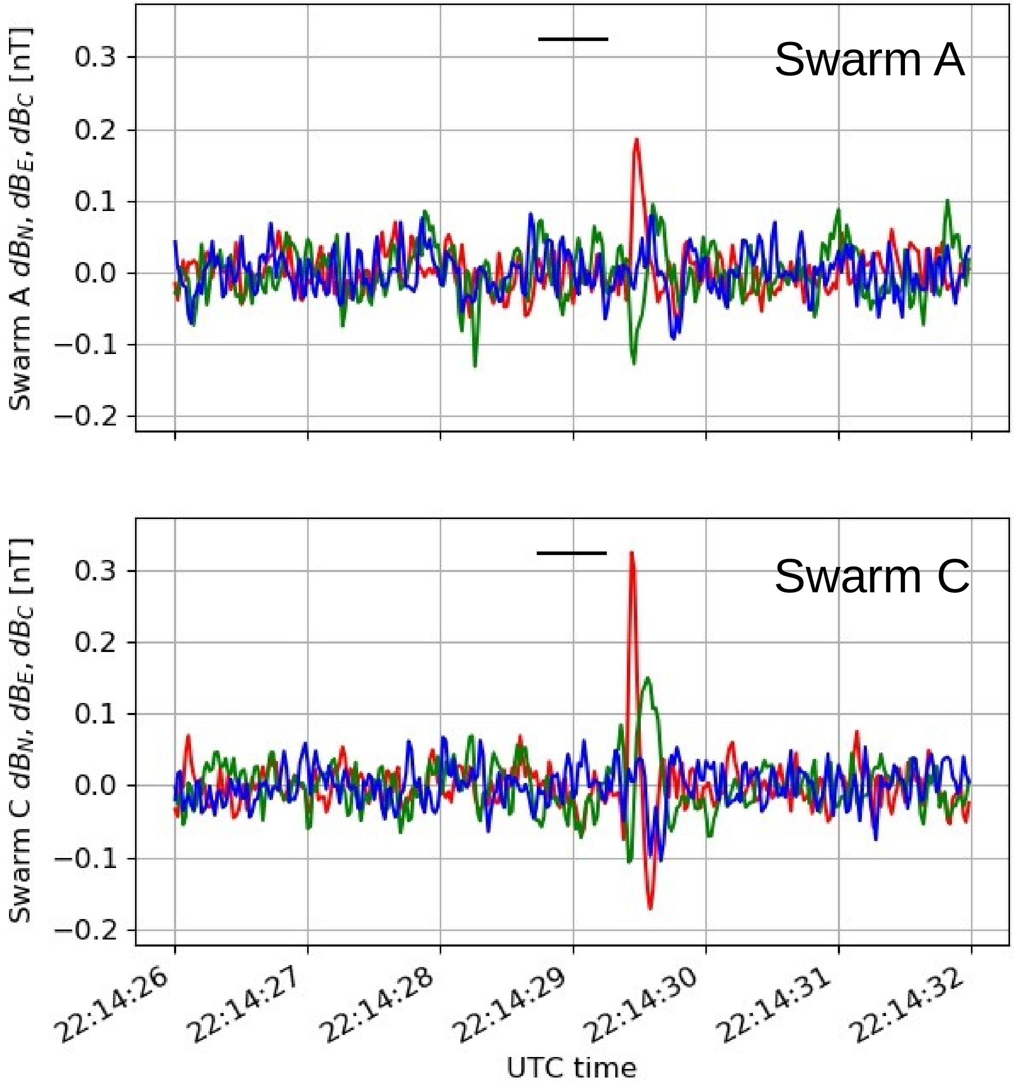
Return to frame 11





+CG?

Expected magnetic field lines $dB_N > dB_E$



Swarm C closer to the flash than Swarm A, which is seen in amplitudes

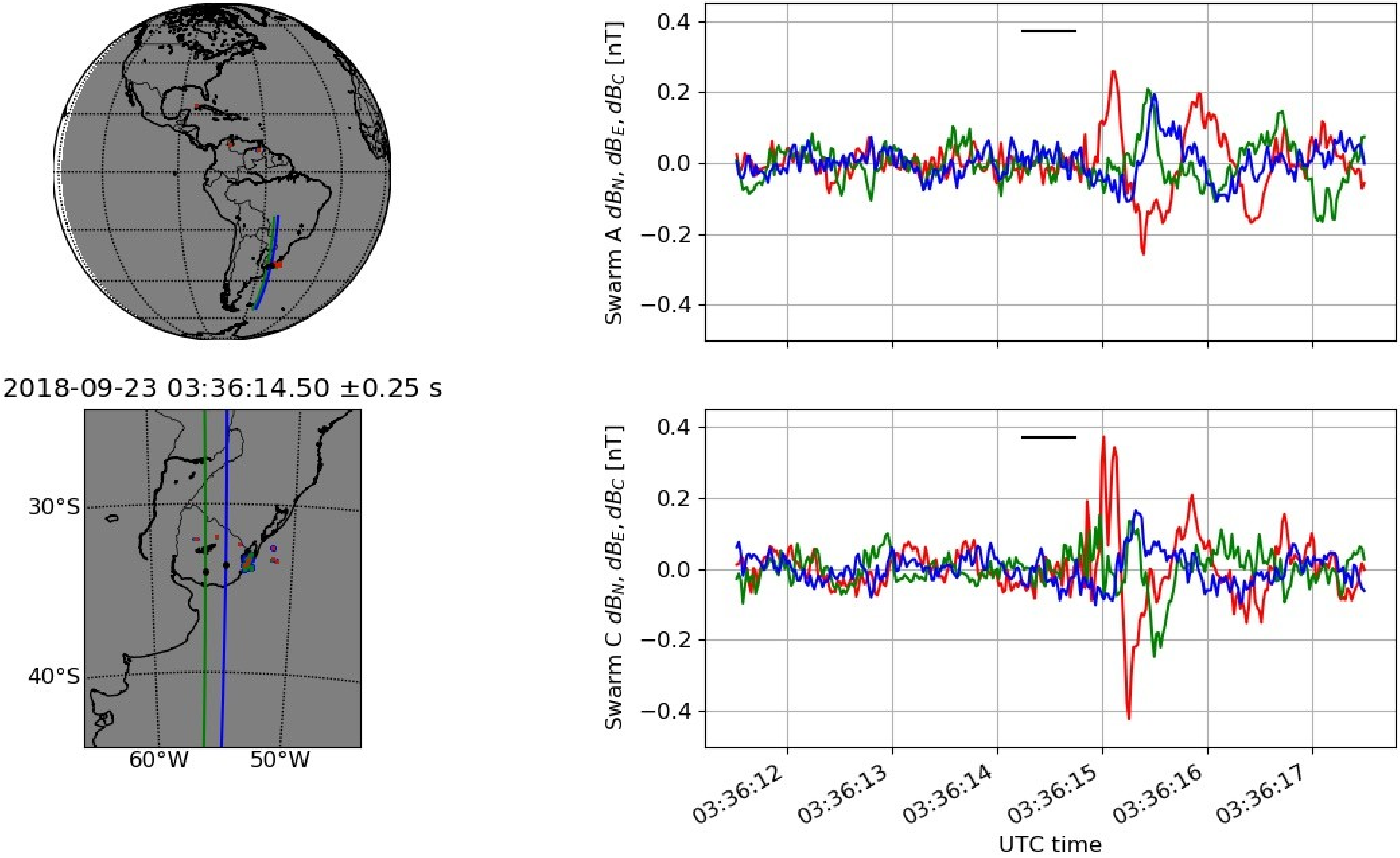
12 similar cases were found (including the first one) in Ewa & Jan list, where similar scenario was observed

1. 2018-03-03 22:14:29, 54.3° W, 28.5° N (shown in previous slides)
2. 2018-09-23 03:36:15, 53.1° W, 33.2° S
3. 2018-10-06 06:10:05, 106.5° W, 19.5° N
4. 2018-11-01 03:03:24, 98.2° W, 20.5° N
5. 2019-05-10 09:38:15, 95.1° W, 30.6° N
6. 2019-06-05 02:57:35, 30.9° W, 31.0° S
7. 2019-06-18 05:26:11, 80.1° W, 25.2° N
8. 2019-06-20 05:41:36, 93.1° W, 33.5° N
9. 2019-06-20 05:42:05, 89.2° W, 34.2° N
10. 2019-10-31 01:25:21, 30.1° W, 35.5° N
11. 2019-11-28 02:57:28, 89.5° W, 18.4° N
12. 2019-12-14 01:29:52, 85.0° W, 32.3° N

Next slides show these cases, two frames for each case

If a flash is seen in more than two consequtive frames (0.5s each), it is presumably caused by continuing current

2a


2018-09-23 03:36:14.50 ±0.25 s
30°S
40°S
60°W
50°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.4
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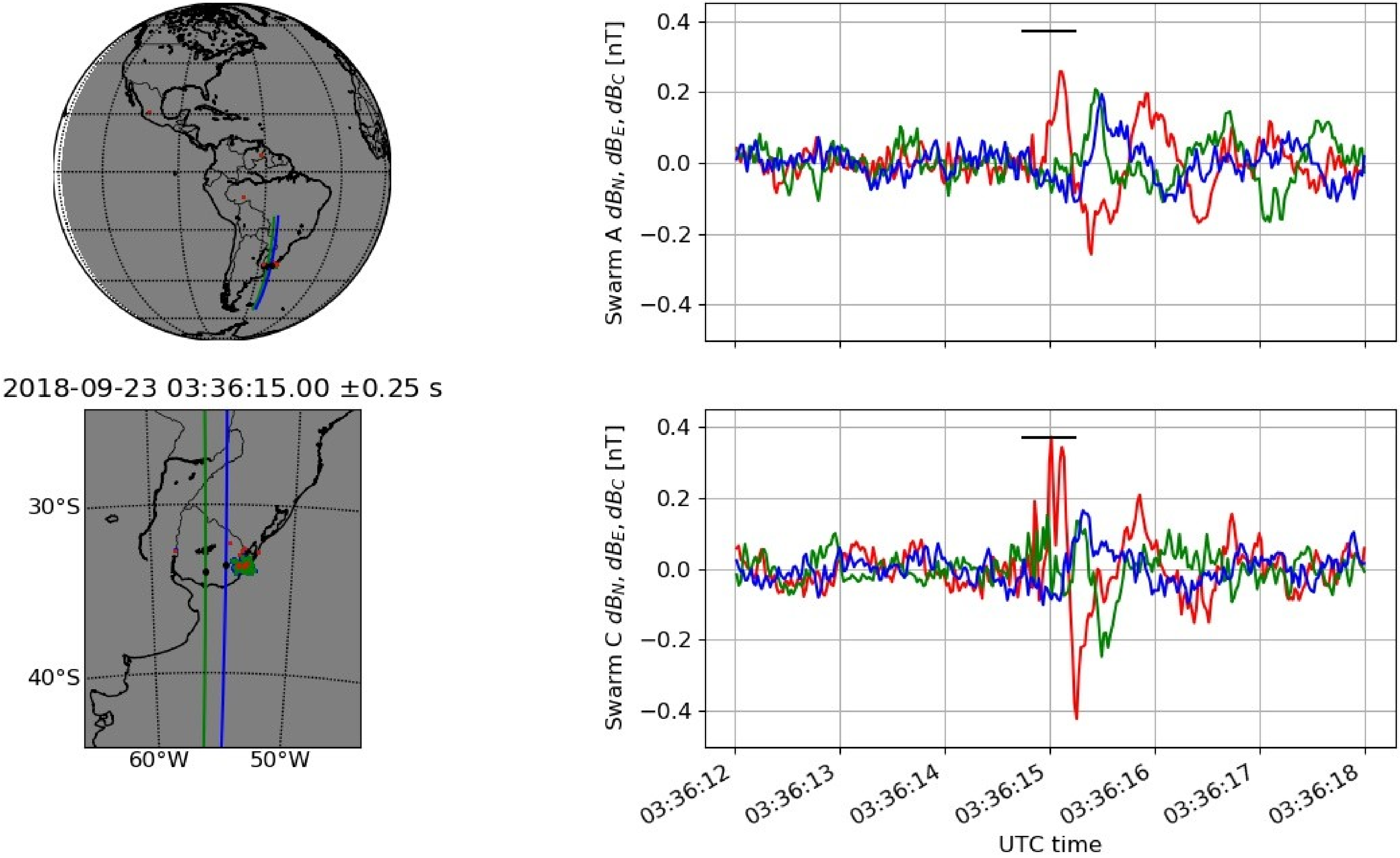
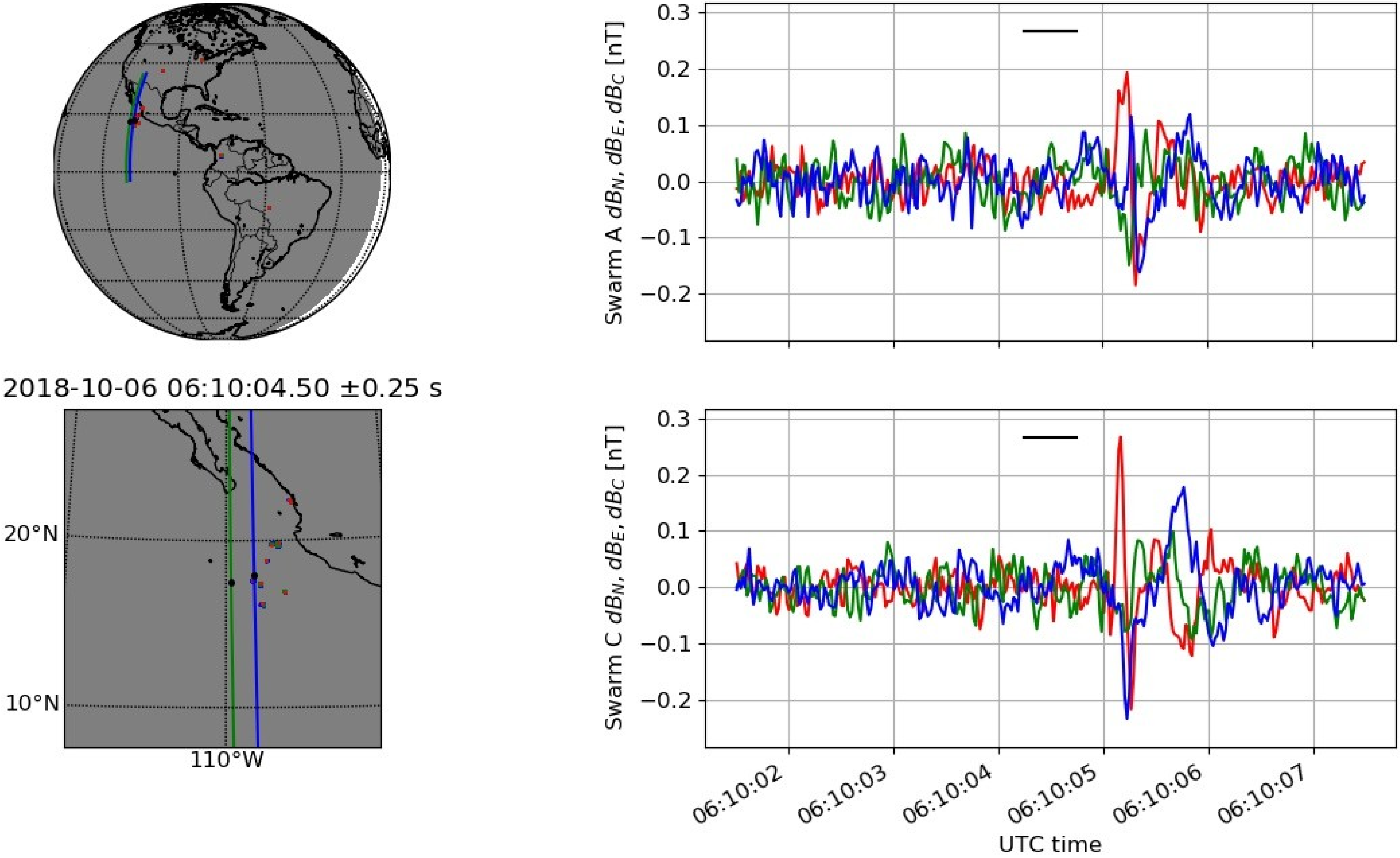
03:36:12
03:36:13
03:36:14
03:36:15
03:36:16
03:36:17
UTC time

2b

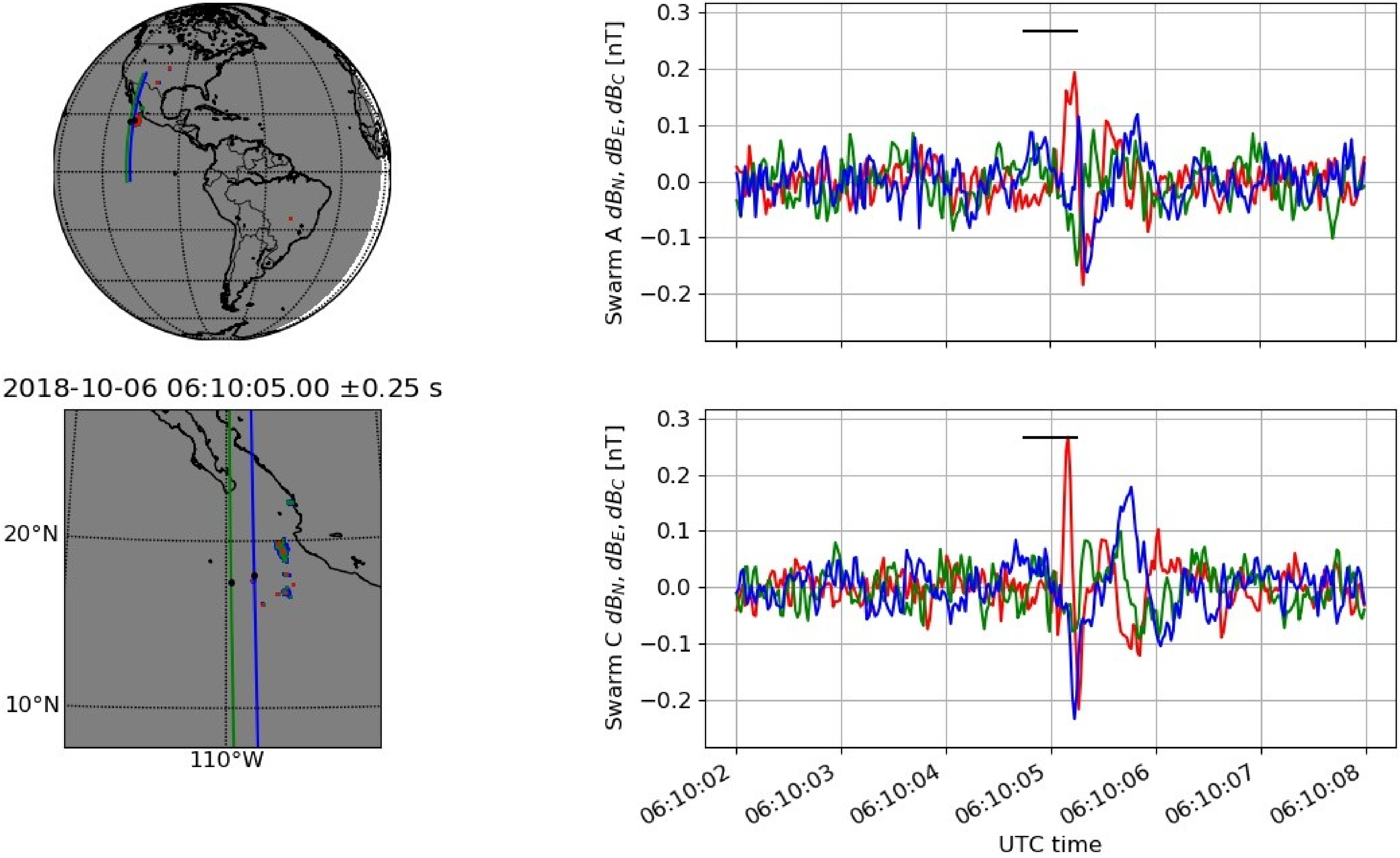


2018-09-23 03:36:15.00 ±0.25 s
30°S
40°S
60°W
50°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.4
0.2
0.0
−0.2
−0.4
03:36:12
03:36:13
03:36:14
03:36:15
03:36:16
03:36:17
03:36:18
UTC time

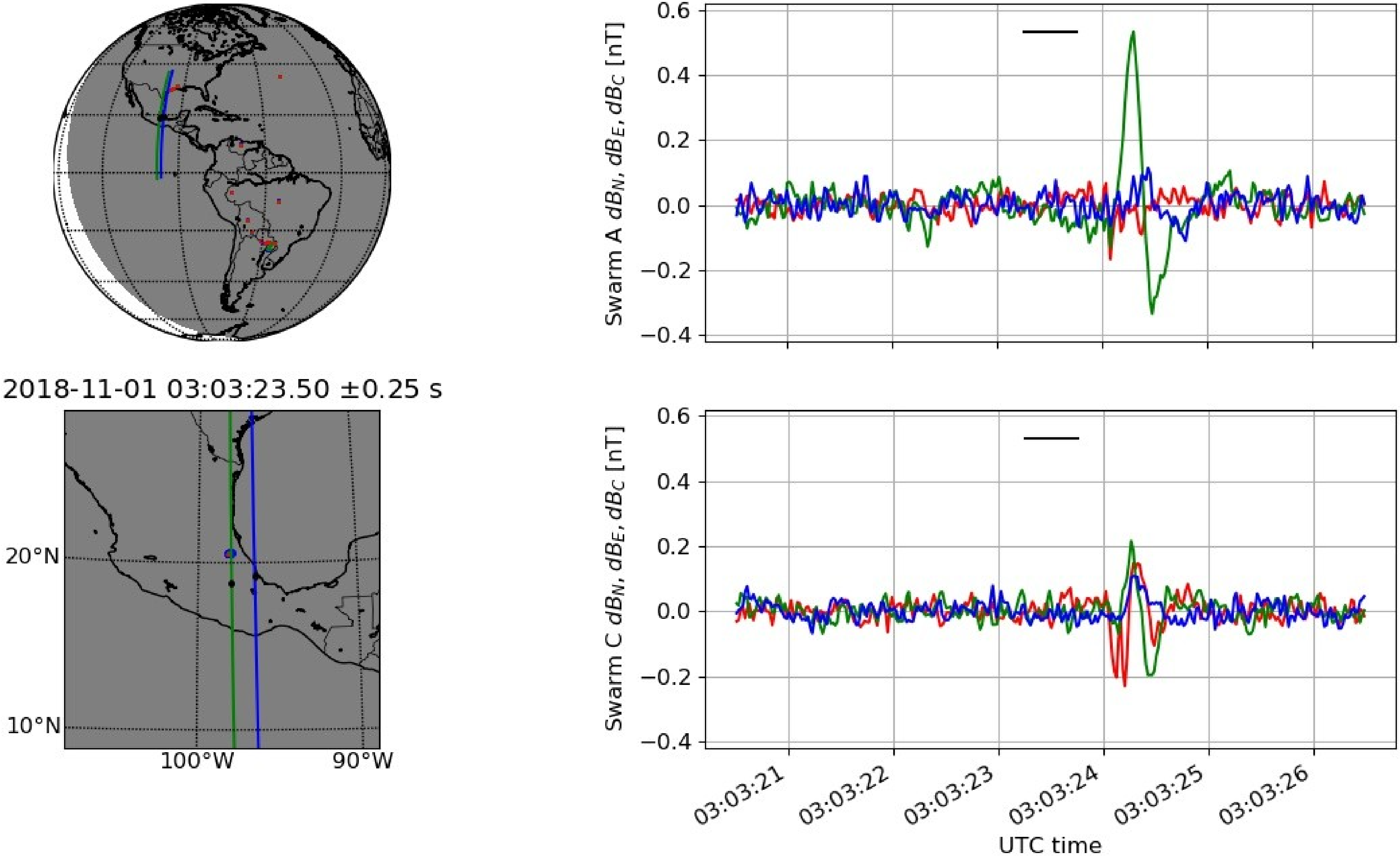
3a


2018-10-06 06:10:04.50 ±0.25 s
20°N
10°N
110°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.3
0.2
0.1
0.0
−0.1
−0.2
06:10:02
06:10:03
06:10:04
06:10:05
06:10:06
06:10:07
UTC time

3b

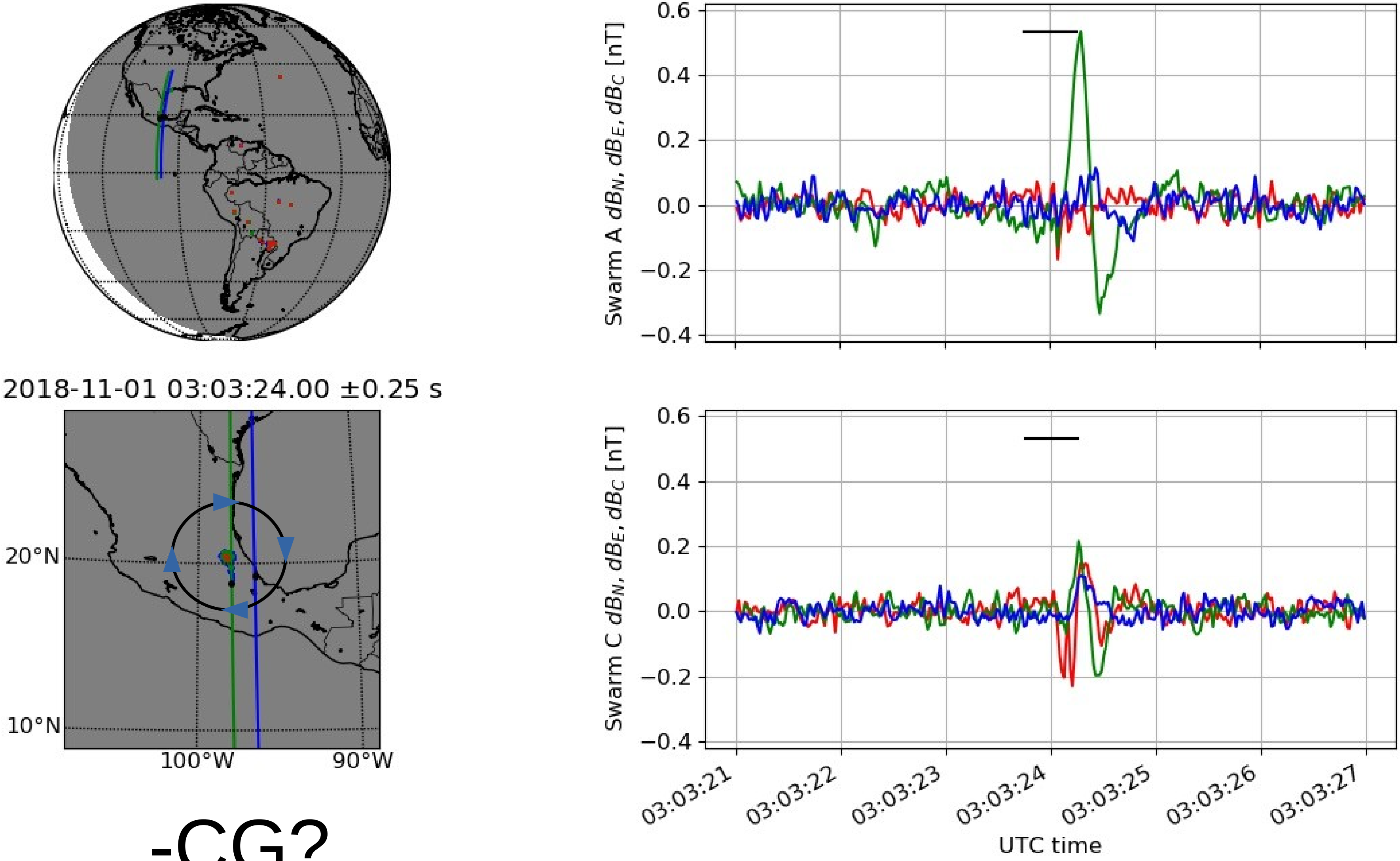

2018-10-06 06:10:05.00 ±0.25 s
20°N
10°N
110°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.3
0.2
0.1
0.0
−0.1
−0.2
06:10:02
06:10:03
06:10:04
06:10:05
06:10:06
06:10:07
06:10:08
UTC time

4a



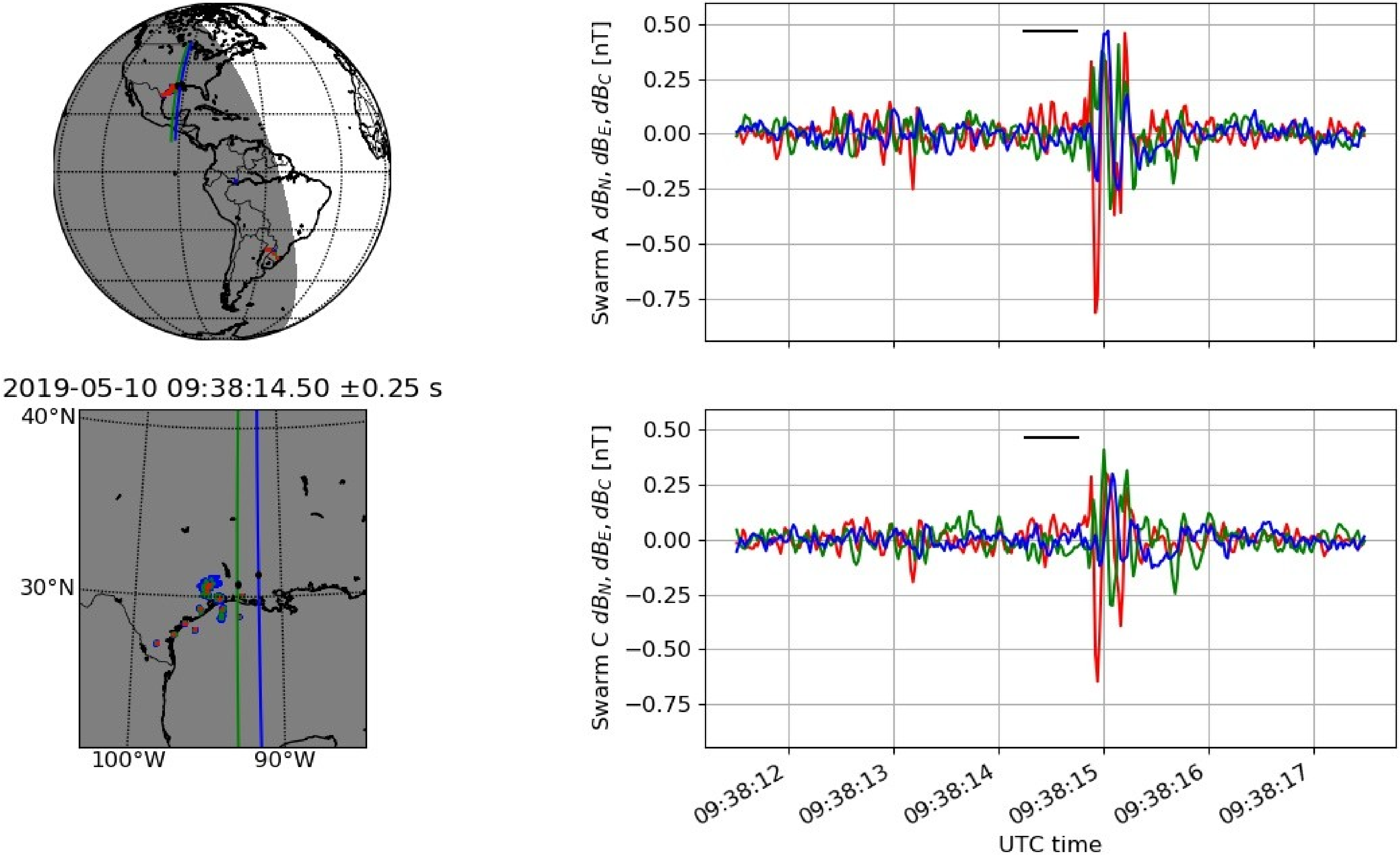
2018-11-01 03:03:23.50 ±0.25 s
20°N
10°N
100°W
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.6
0.4
0.2
0.0
−0.2
−0.4
03:03:21
03:03:22
03:03:23
03:03:24
03:03:25
03:03:26
UTC time

4b

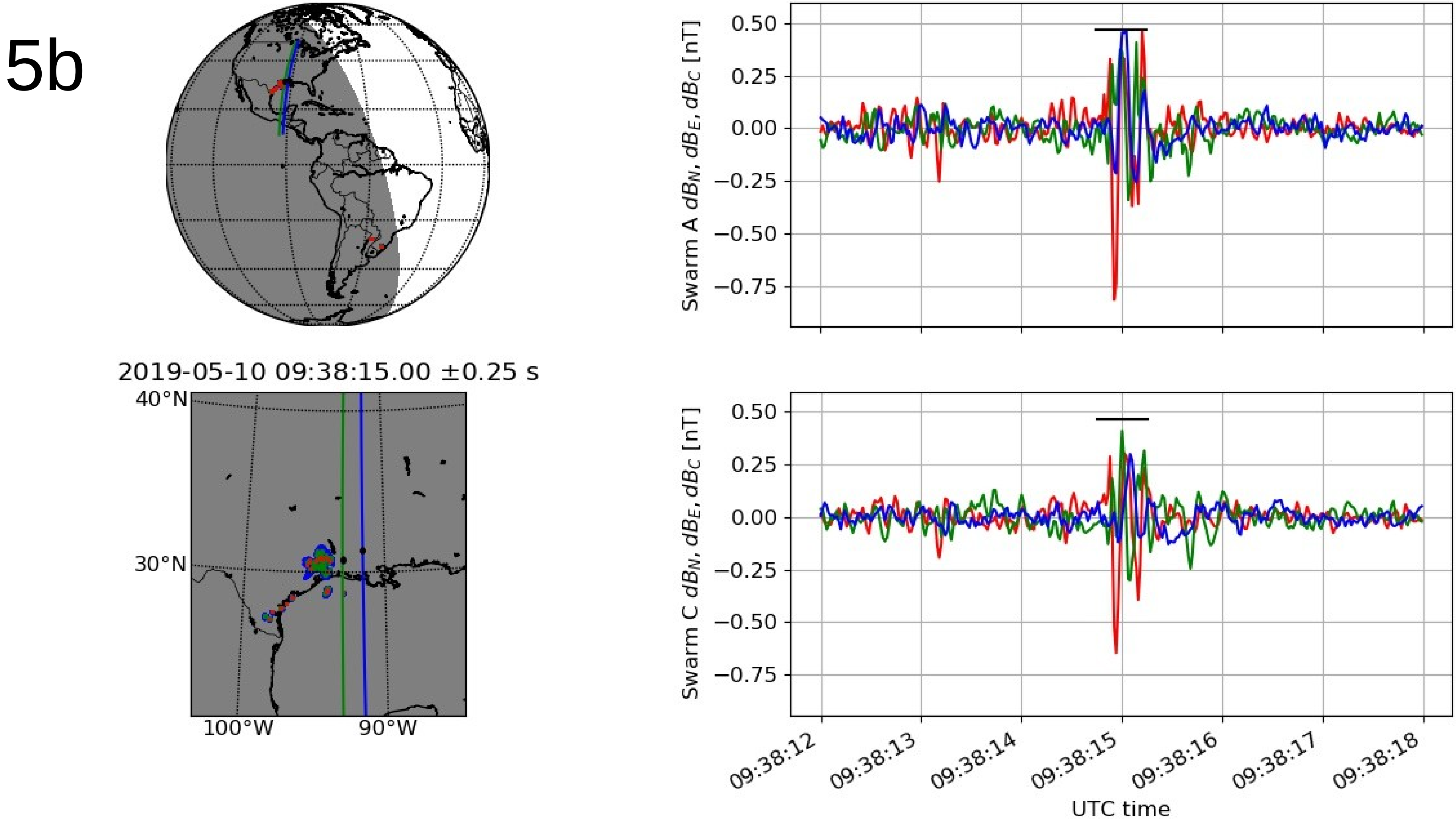

2018-11-01 03:03:24.00 ±0.25 s
20°N
10°N
100°W
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.6
0.4
0.2
0.0
−0.2
−0.4
03:03:21
03:03:22
03:03:23
03:03:24
03:03:25
03:03:26
03:03:27
UTC time

-CG?

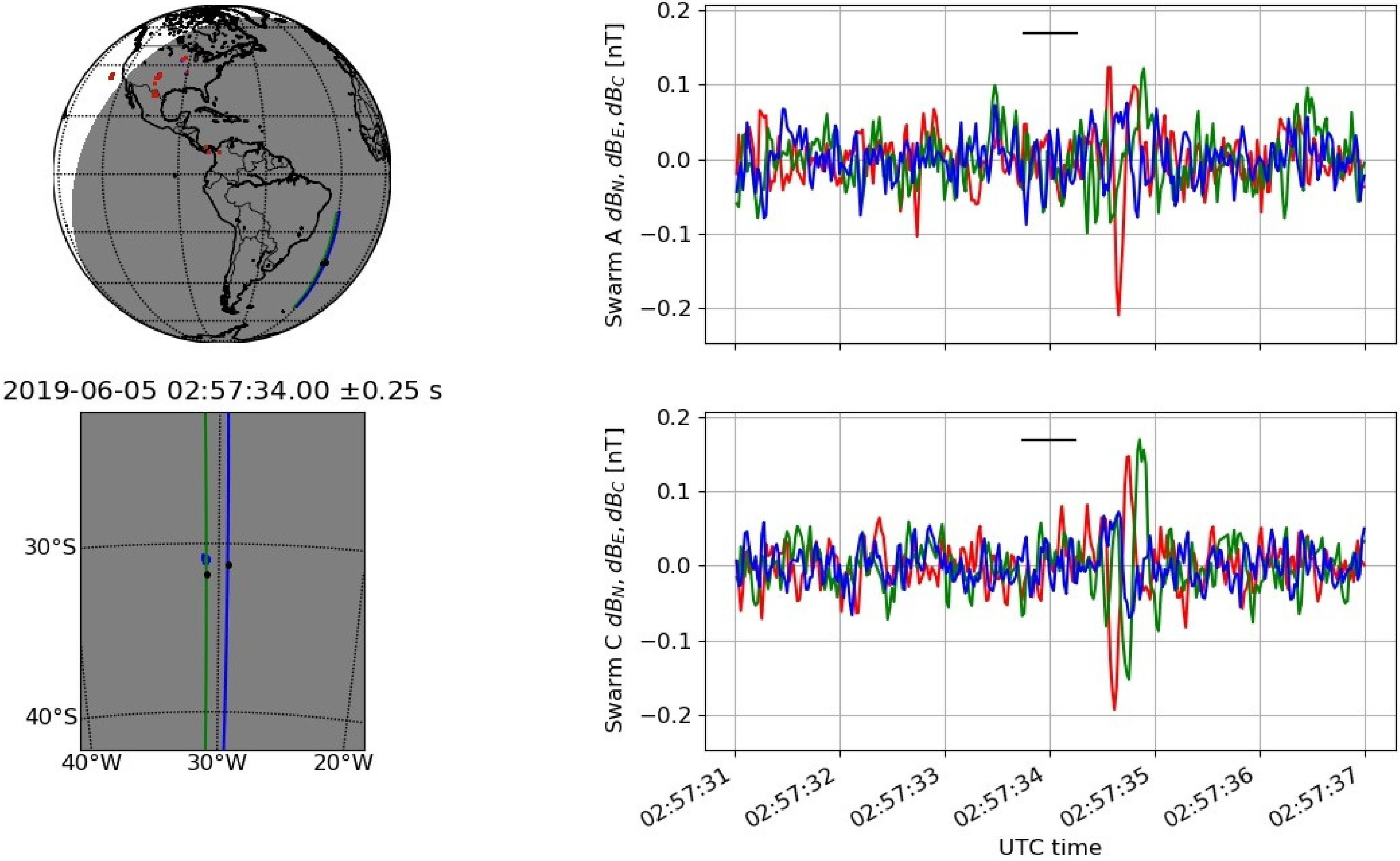
5a



2019-05-10 09:38:14.50 ±0.25 s
40°N
30°N
100°W
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.50
0.25
0.00
−0.25
−0.50
−0.75
09:38:12
09:38:13
09:38:14
09:38:15
09:38:16
09:38:17
UTC time

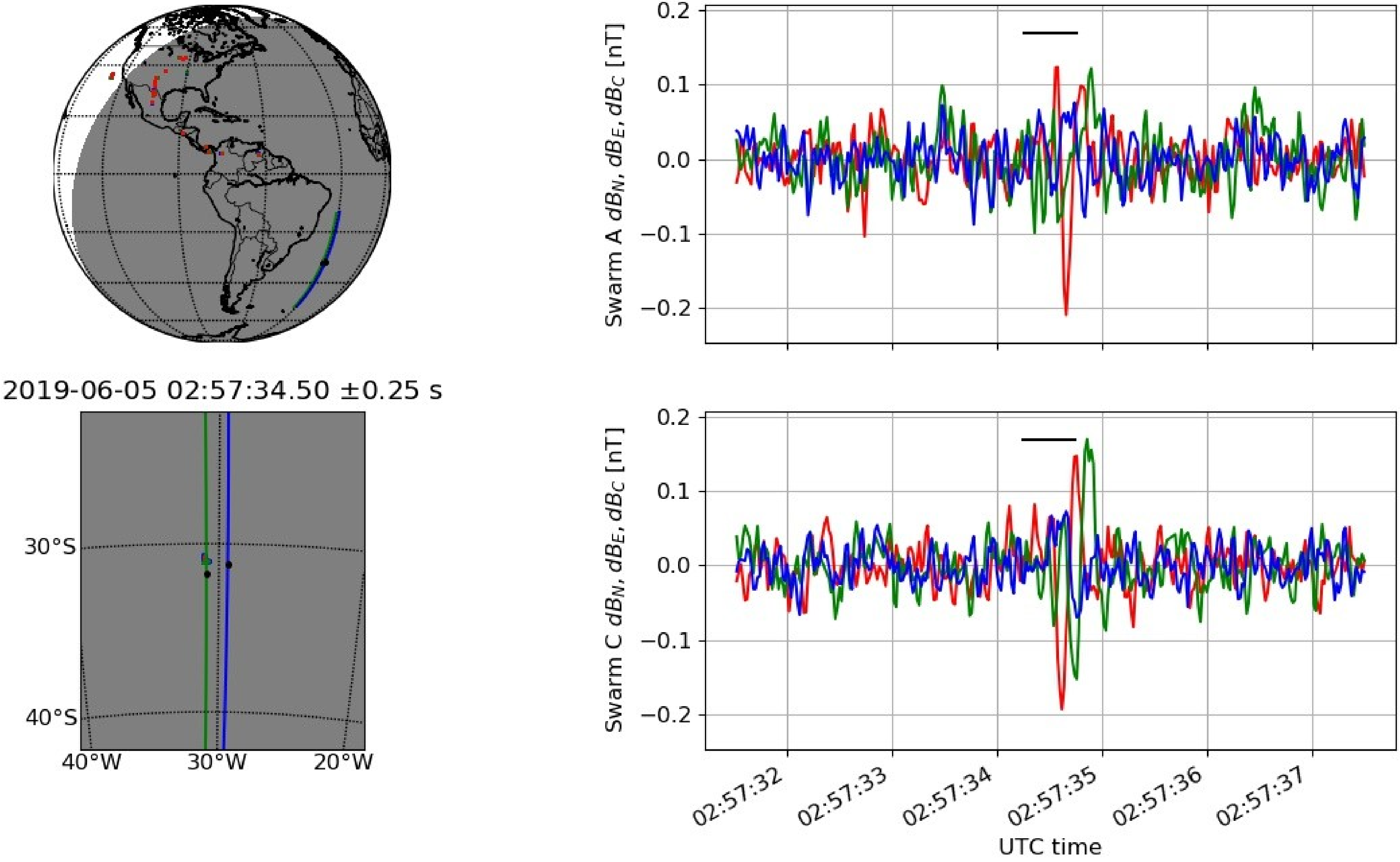

5b
2019-05-10 09:38:15.00 ±0.25 s
40°N
30°N
100°W
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.50
0.25
0.00
−0.25
−0.50
−0.75
09:38:12
09:38:13
09:38:14
09:38:15
09:38:16
09:38:17
09:38:18
UTC time

6a



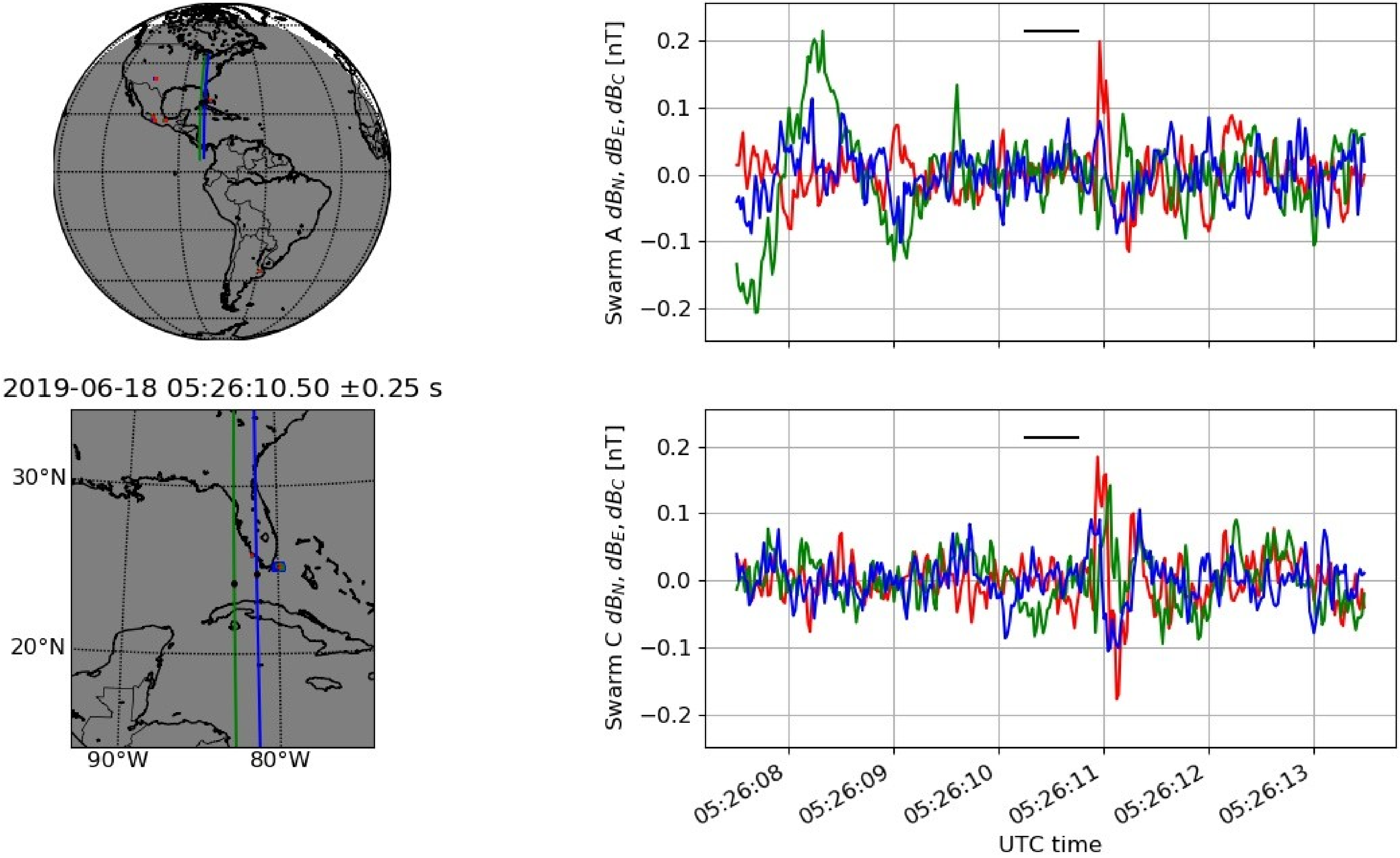
2019-06-05 02:57:34.00 ±0.25 s
30°S
40°S
40°W
30°W
20°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.1
0.0
−0.1
−0.2
02:57:31
02:57:32
02:57:33
02:57:34
02:57:35
02:57:36
02:57:37
UTC time

6b

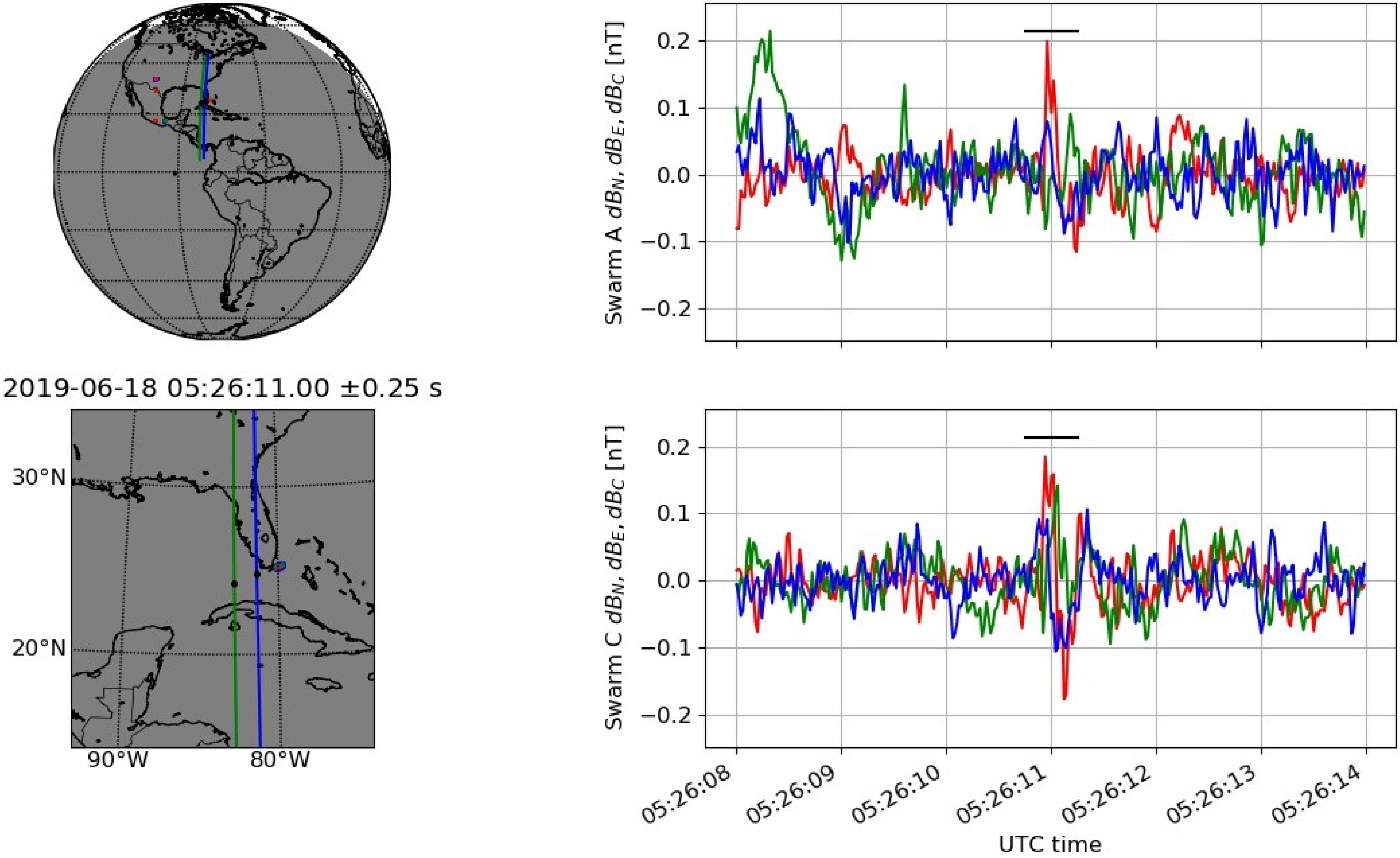


2019-06-05 02:57:34.50 ±0.25 s
30°S
40°S
40°W
30°W
20°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.1
0.0
−0.1
−0.2
02:57:32
02:57:33
02:57:34
02:57:35
02:57:36
02:57:37
UTC time

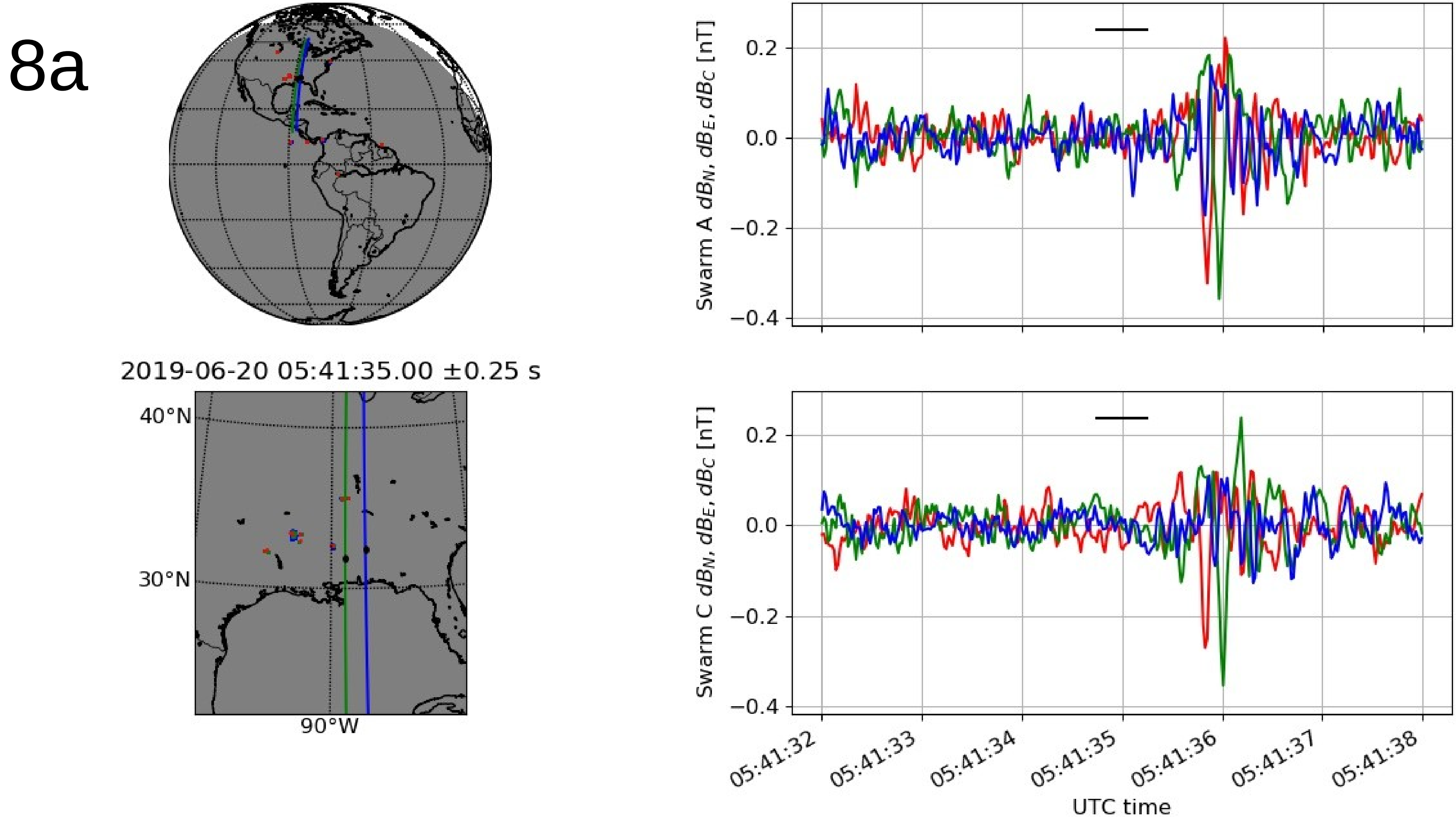
7a


2019-06-18 05:26:10.50 ±0.25 s
30°N
20°N
90°W
80°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.1
0.0
−0.1
−0.2
05:26:08
05:26:09
05:26:10
05:26:11
05:26:12
05:26:13
UTC time

7b

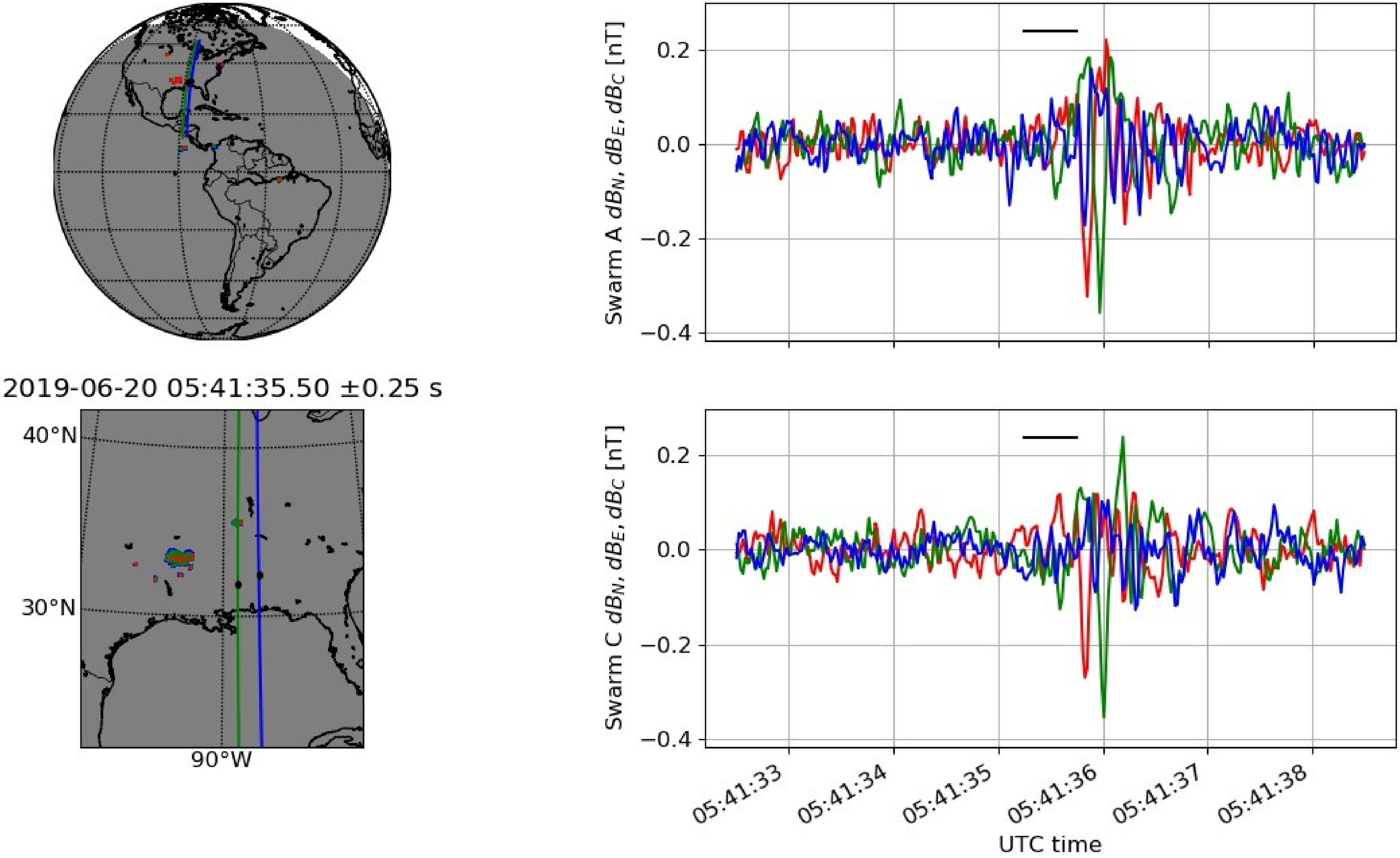


2019-06-18 05:26:11.00 ±0.25 s
30°N
20°N
90°W
80°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.1
0.0
−0.1
−0.2
05:26:08
05:26:09
05:26:10
05:26:11
05:26:12
05:26:13
05:26:14
UTC time

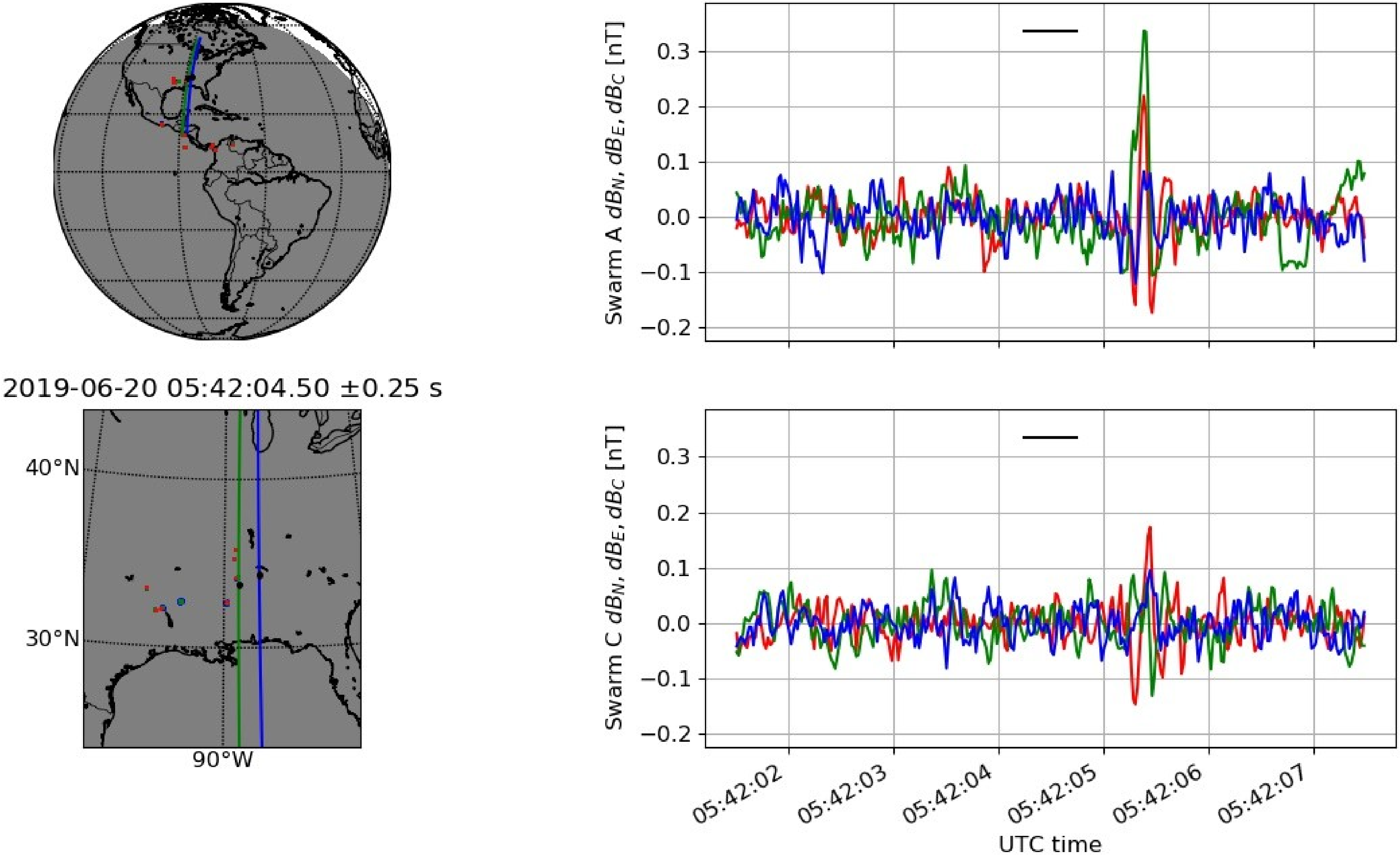


8a
2019-06-20 05:41:35.00 ±0.25 s
40°N
30°N
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.0
−0.2
−0.4
05:41:32
05:41:33
05:41:34
05:41:35
05:41:36
05:41:37
05:41:38
UTC time

8b

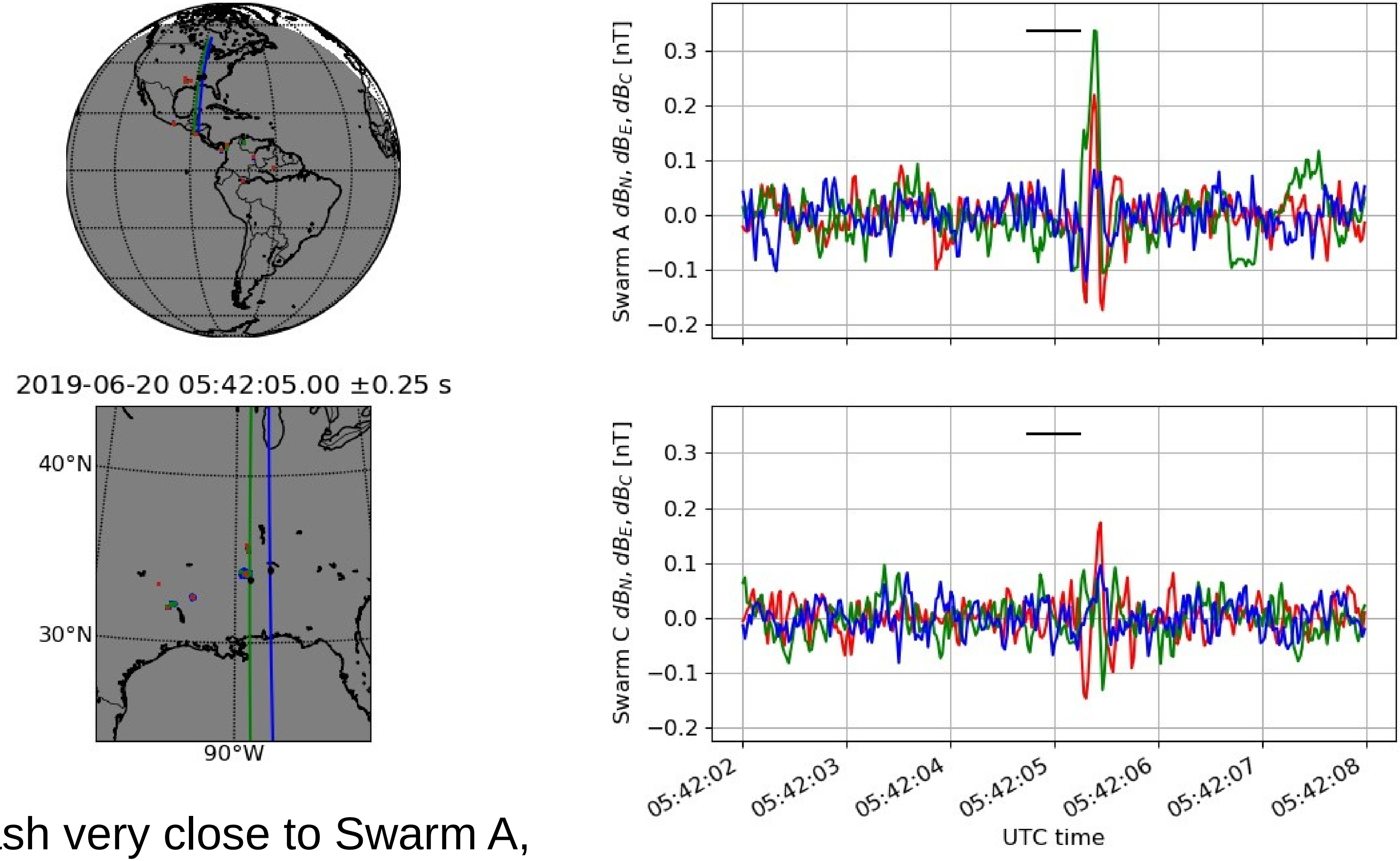

2019-06-20 05:41:35.50 ±0.25 s
40°N
30°N
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.2
0.0
−0.2
−0.4
05:41:33
05:41:34
05:41:35
05:41:36
05:41:37
05:41:38
UTC time

9a



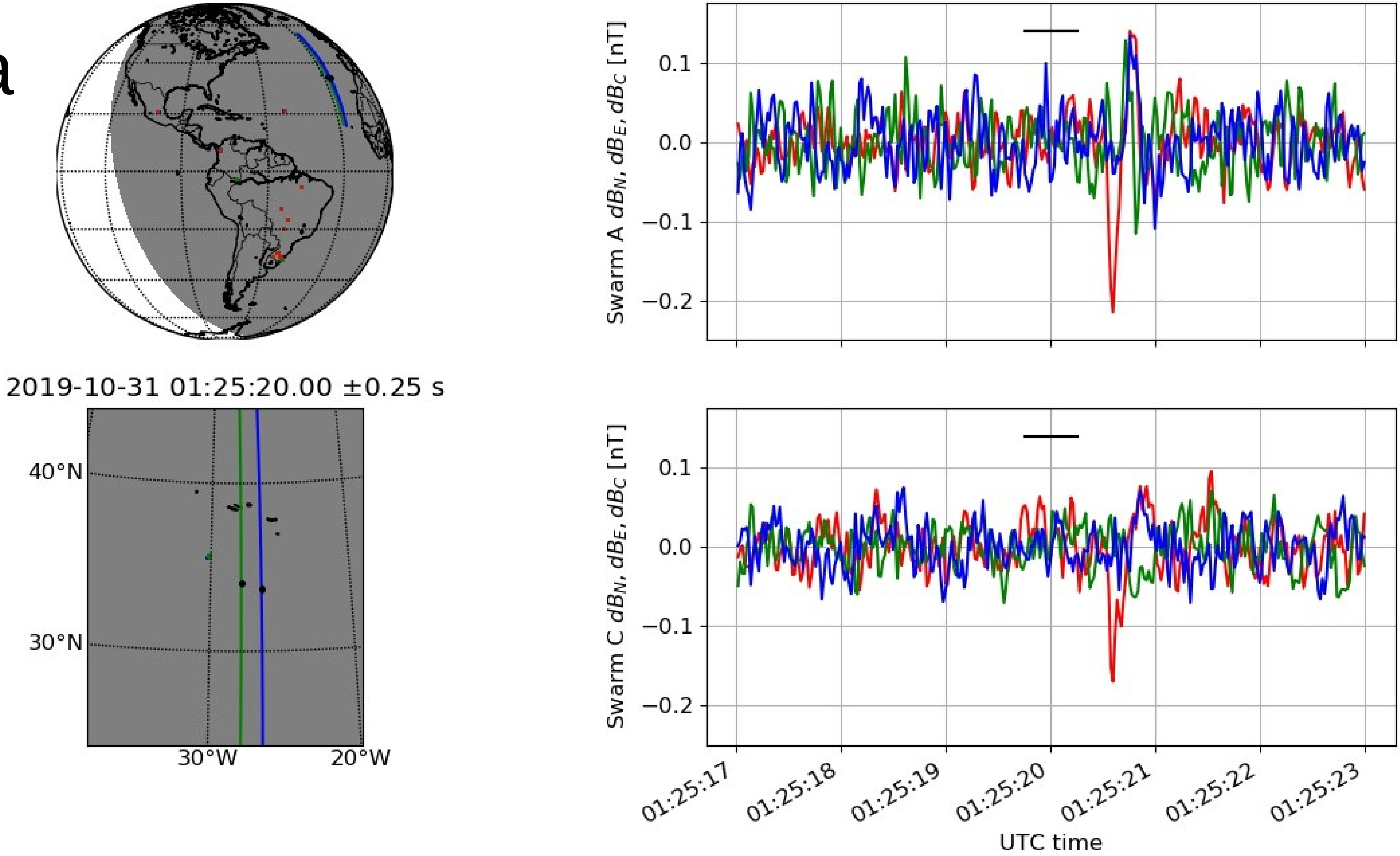
2019-06-20 05:42:04.50 ±0.25 s
40°N
30°N
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.3
0.2
0.1
0.0
−0.1
−0.2
05:42:02
05:42:03
05:42:04
05:42:05
05:42:06
05:42:07
UTC time

9b

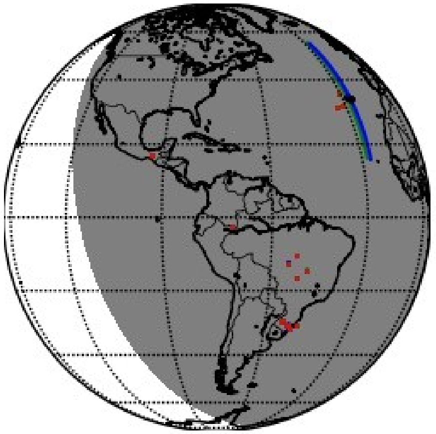


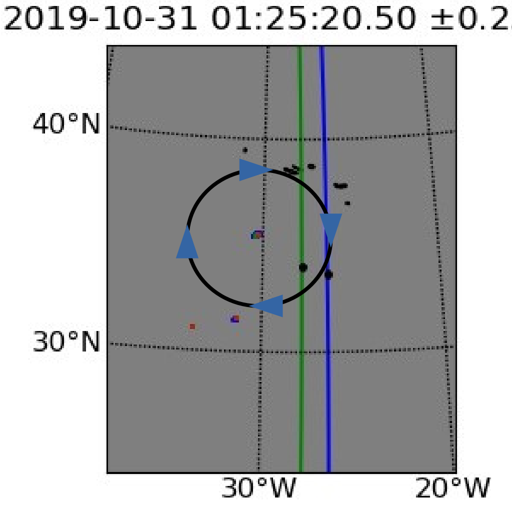
Flash very close to Swarm A,
which is seen in the amplitudes

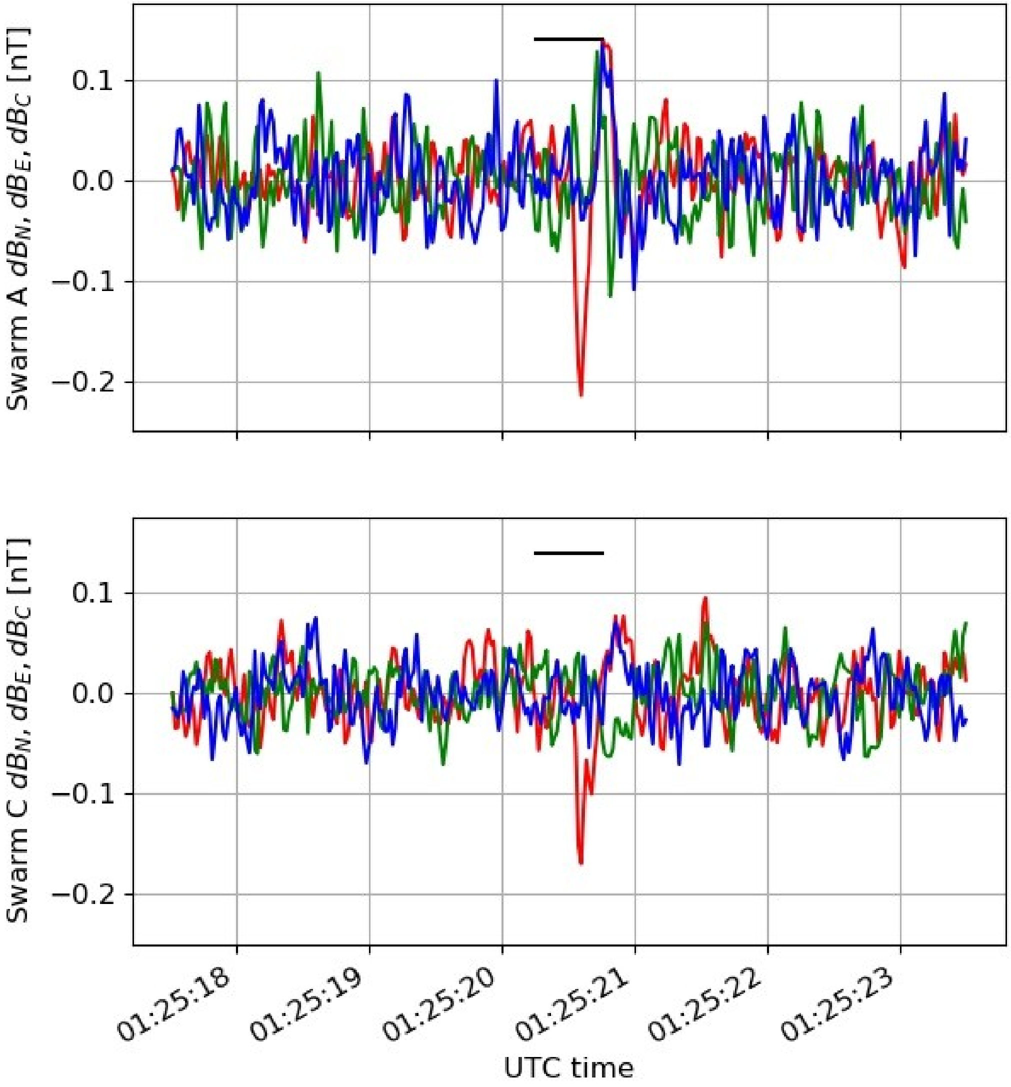
10a


2019-10-31 01:25:20.00 ±0.25 s
40°N
30°N
30°W
20°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.1
0.0
−0.1
−0.2
01:25:17
01:25:18
01:25:19
01:25:20
01:25:21
01:25:22
01:25:23
UTC time

10b

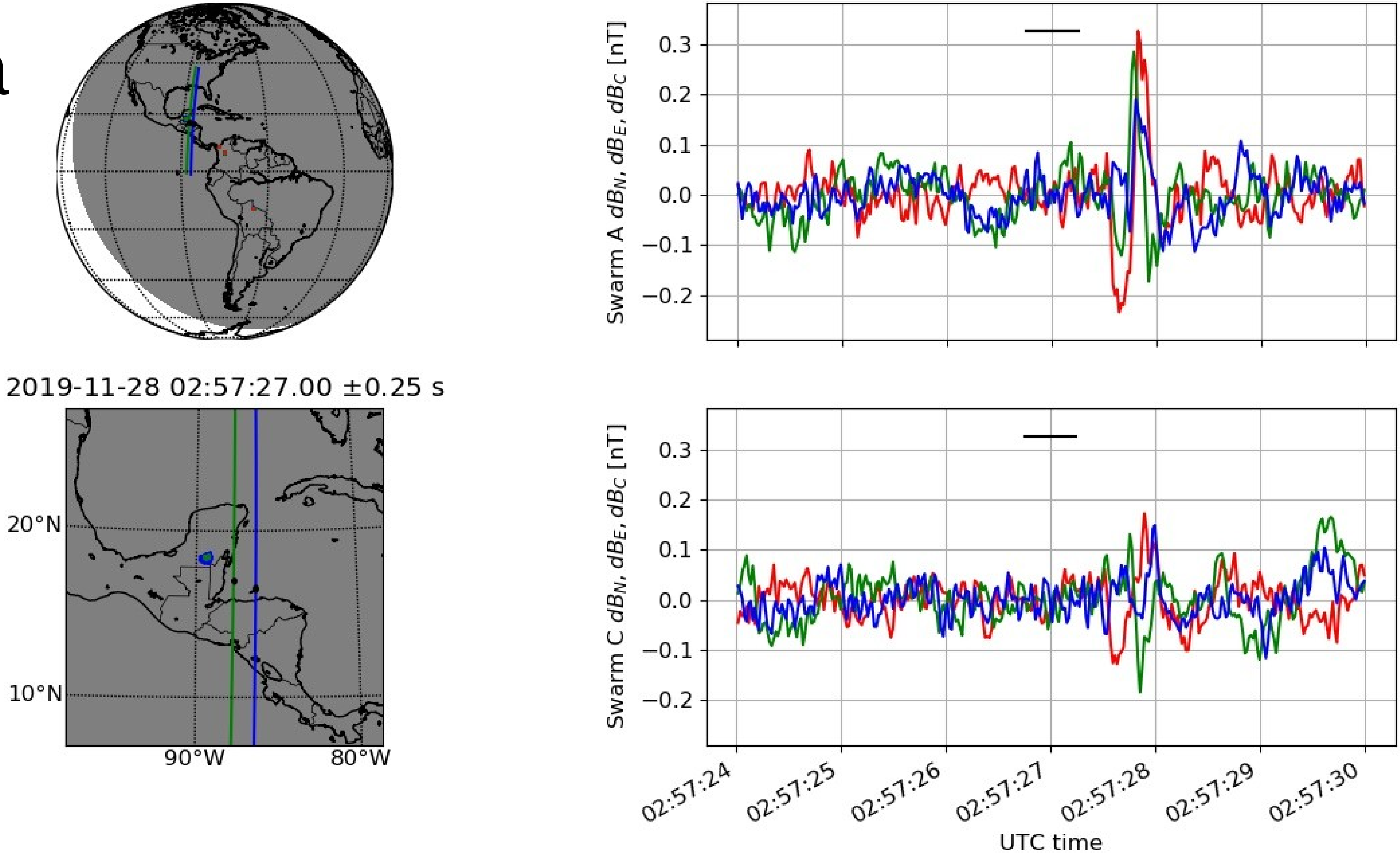




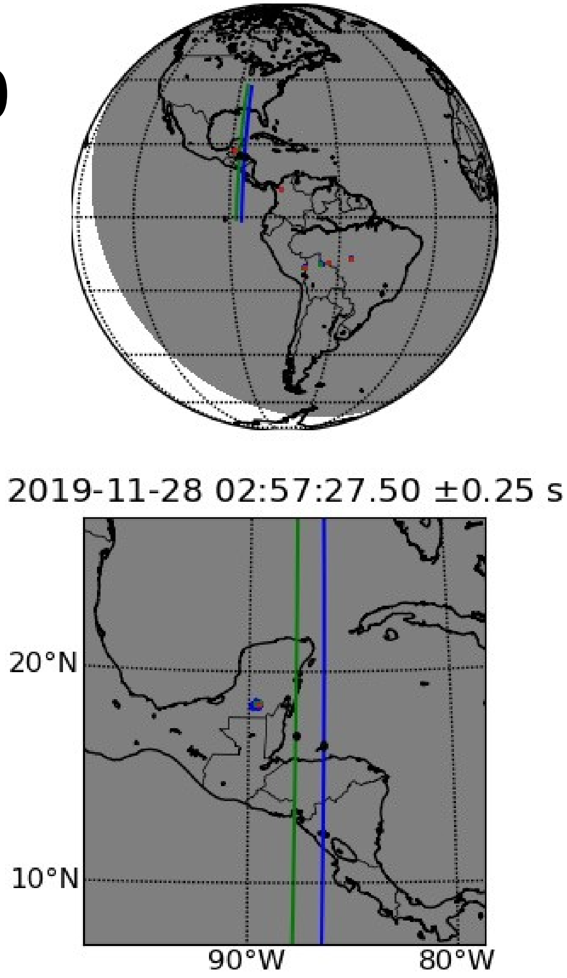


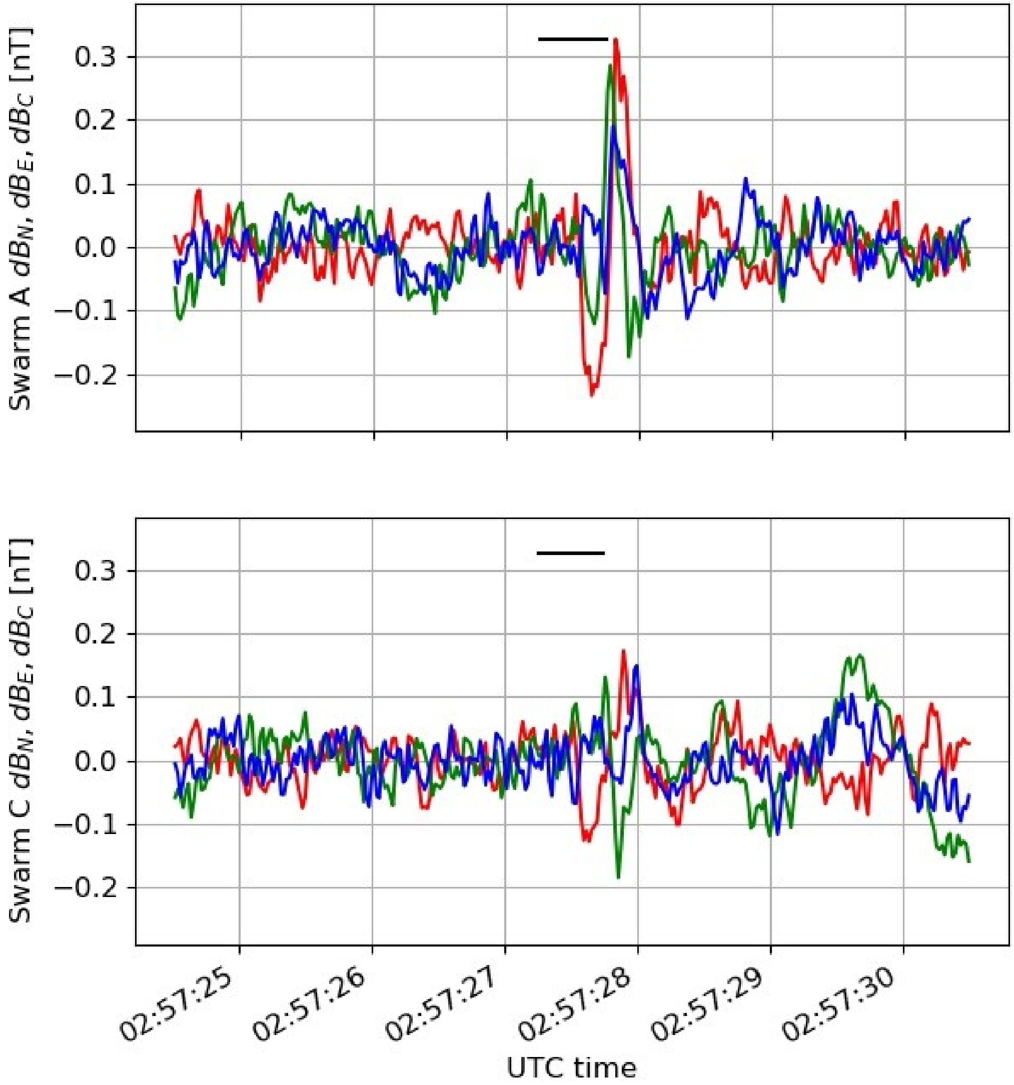
Leading dB_N is negative,
we are on the other side

11a


2019-11-28 02:57:27.00 ±0.25 s
20°N
10°N
90°W
80°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.3
0.2
0.1
0.0
−0.1
−0.2
02:57:24
02:57:25
02:57:26
02:57:27
02:57:28
02:57:29
02:57:30
UTC time

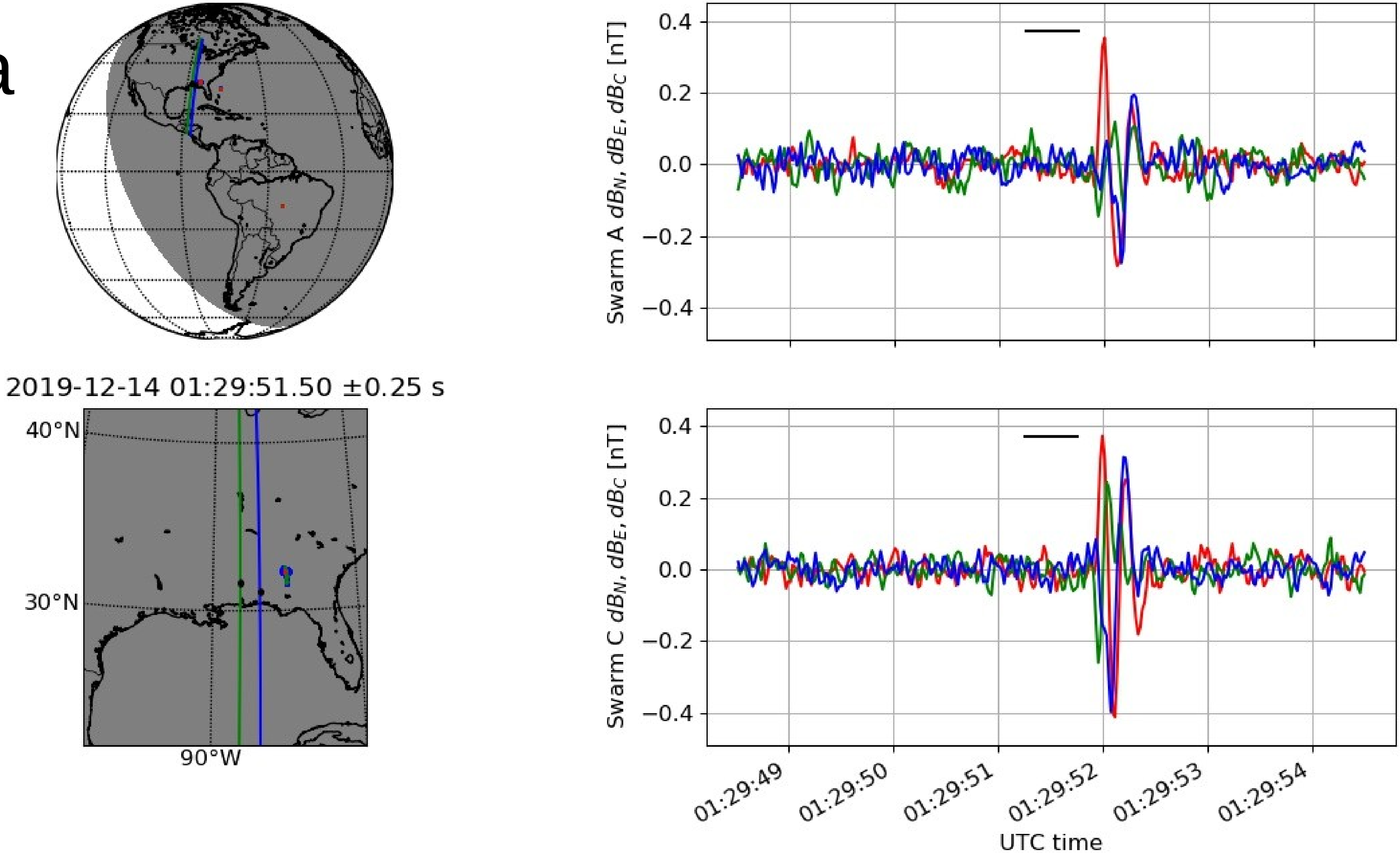
11b





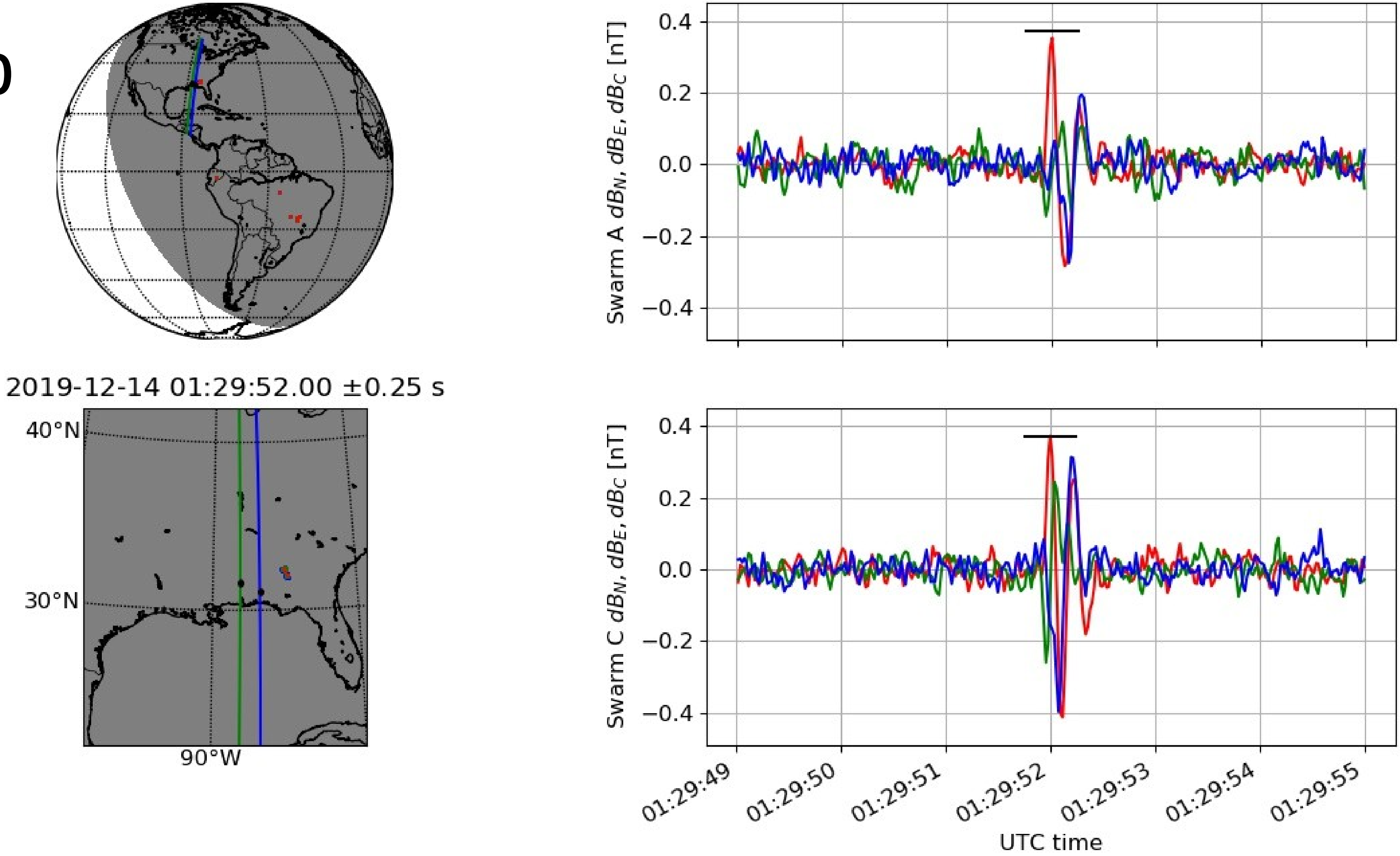
Leading dB_N is negative,
we are on the other side

12a



2019-12-14 01:29:51.50 ±0.25 s
40°N
30°N
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.4
0.2
0.0
−0.2
−0.4
01:29:49
01:29:50
01:29:51
01:29:52
01:29:53
01:29:54
UTC time

12b

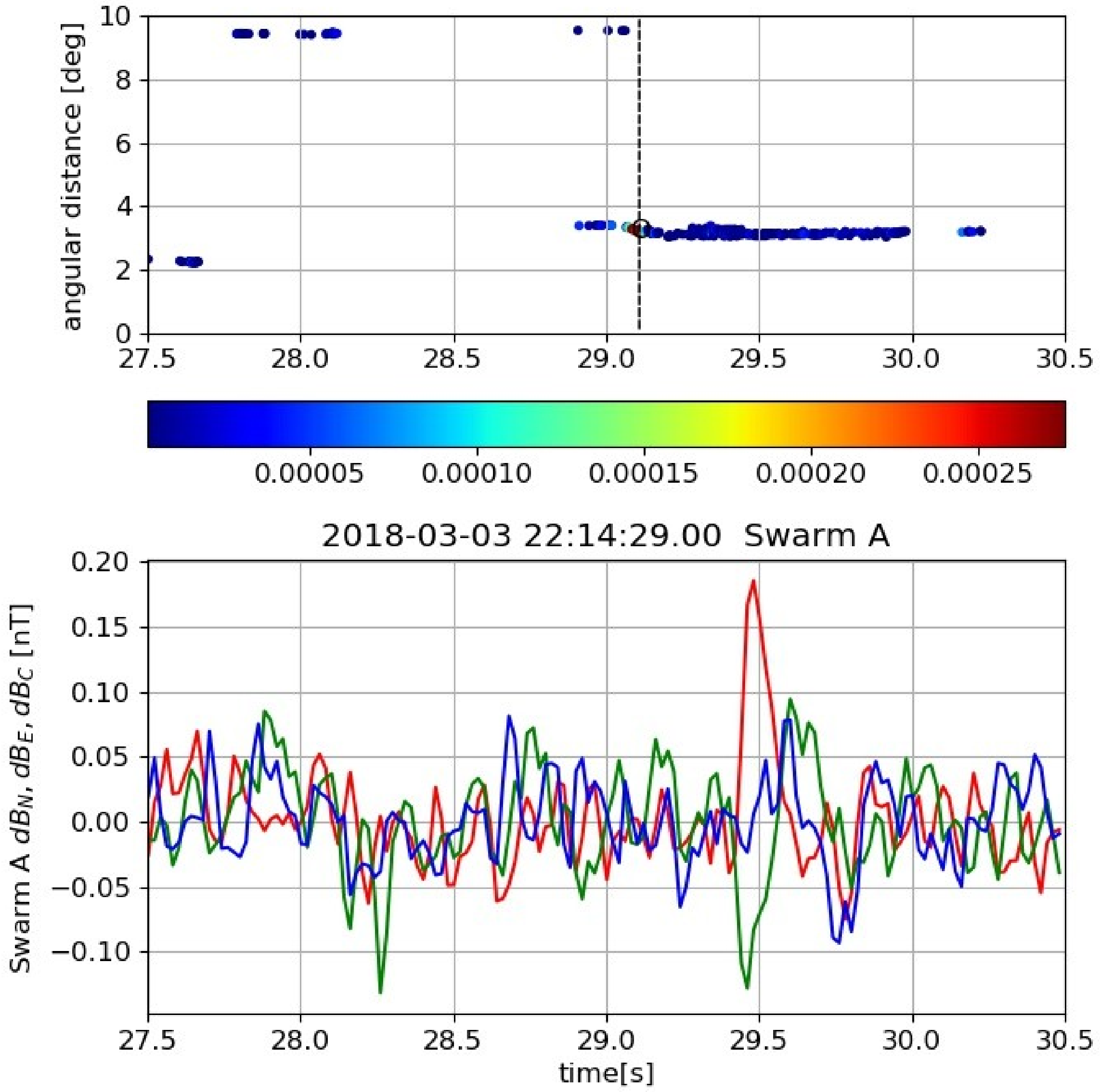


2019-12-14 01:29:52.00 ±0.25 s
40°N
30°N
90°W
Swarm A dB_N, dB_E, dB_C [nT]
Swarm C dB_N, dB_E, dB_C [nT]
0.4
0.2
0.0
−0.2
−0.4
01:29:49
01:29:50
01:29:51
01:29:52
01:29:53
01:29:54
01:29:55
UTC time

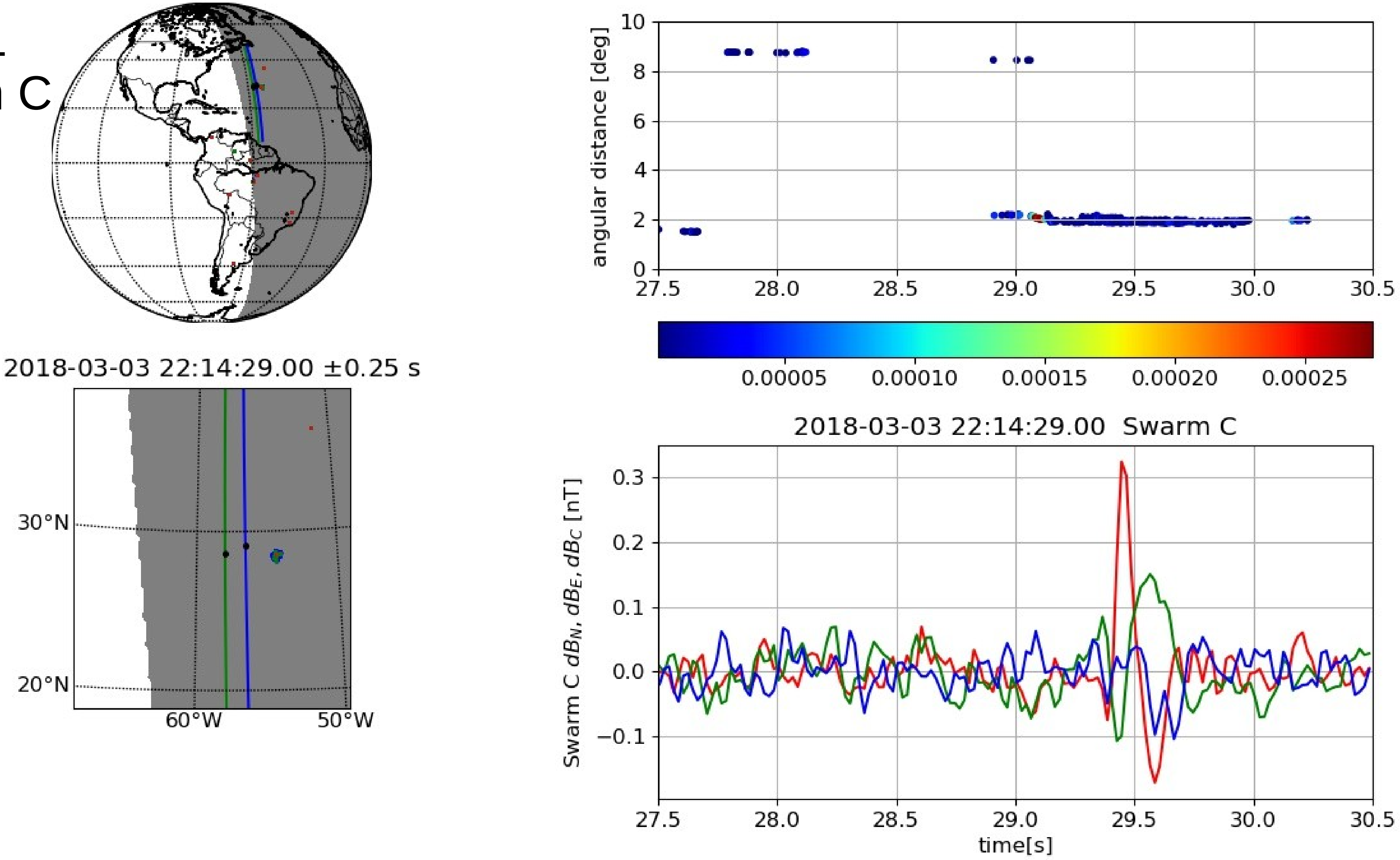
Case 1, Swarm A

Time-distance-energy plot

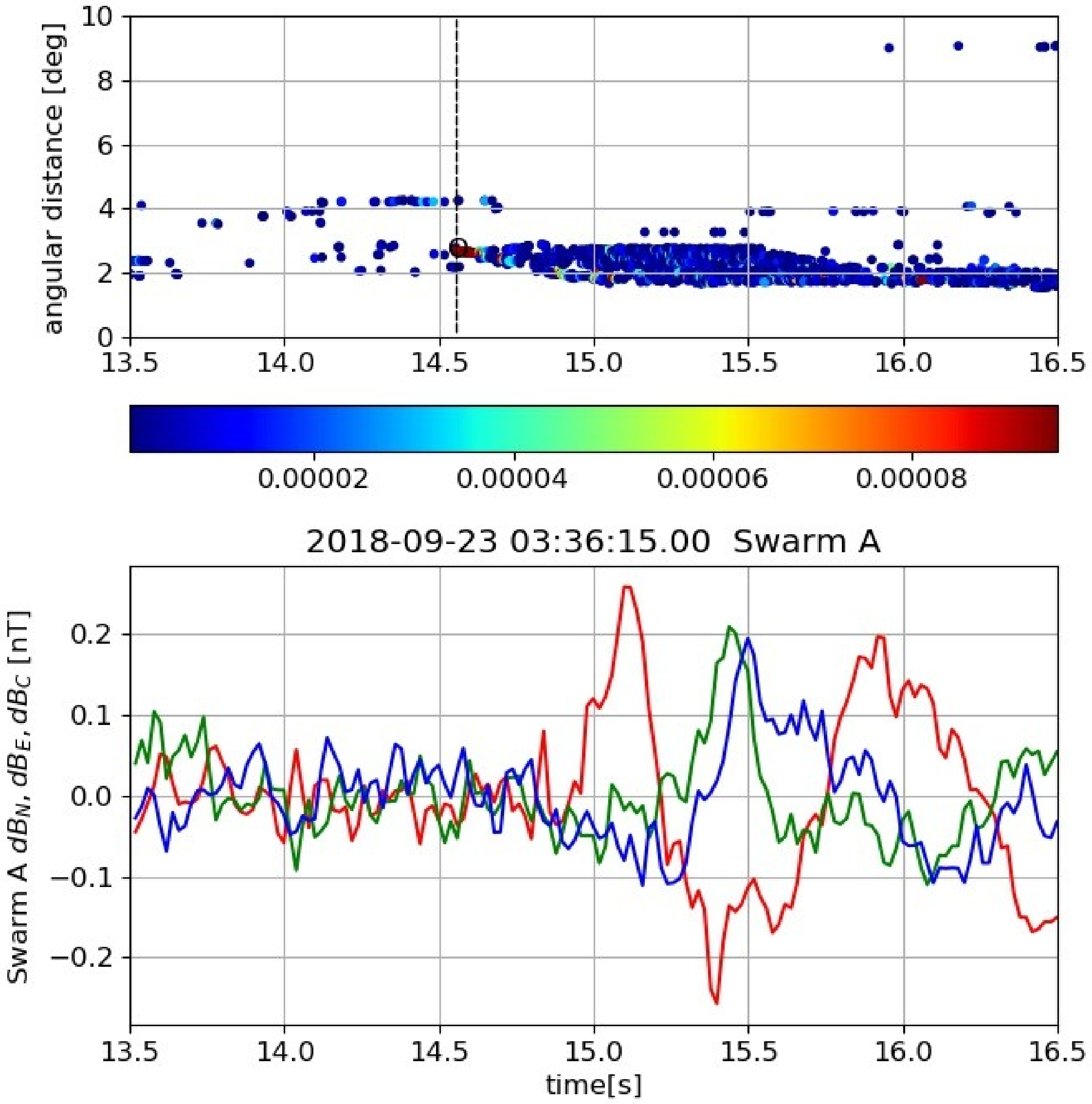
- based on groups
- allows to determine time lag between a flash and a Swarm fluctuation
- we can determine time interval for the flash
- we can estimate size of the flash
- shows the angular distance between the flash and Swarm



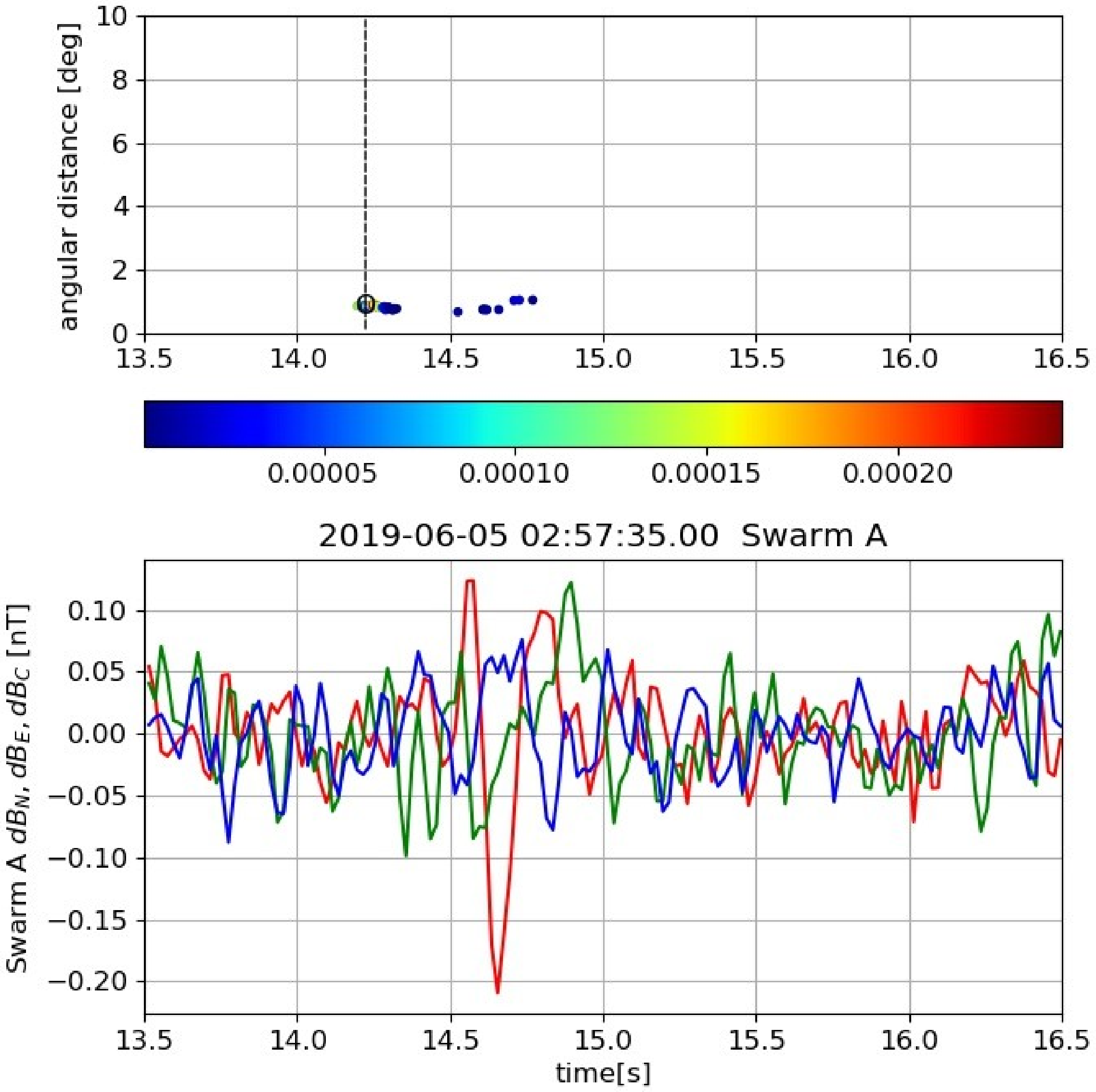
Case 1
Swarm C



Case 2
Swarm A



Case 6
Swarm A



Conclusions

- Correlations between GLM and Swarm reveal a picture that is consistent with Mazur et al. 2018 model, but amplitudes are significantly smaller (by factor ~0.1) and observed waveforms are more complicated
- If $\Delta t>0.5s$ is set for flash selection process, then the study naturally focuses on continuing-current flashes, possibly TLE's
- After selecting flashes with $\Delta t>0.5s$, it turned out a posteriori that the flashes are spatially extended which is physically consistent
- All analyzed cases were observed during local nighttime
- Most cases are +CG, at least one is -CG, as inferred from the leading part of magnetic field fluctuations
- Time-distance-energy plots were proposed as a useful tool in investigations of spatio-temporal correlations between GLM observations and Swarm measurements
- Cases from 2020 still remain in the fridge to be analyzed soon ...