Swarm4Anom - Final review

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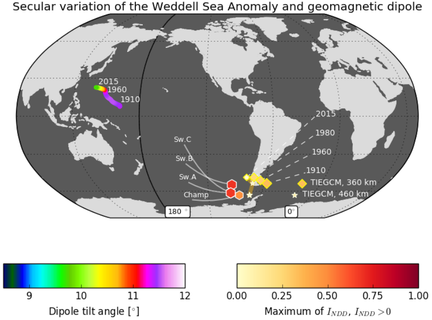
J. Blecki[2], Slominski[2], M. Strumik[2], J. Mlynarczyk[3], K. Martynski[3], A. Kulak[3]

1. Obsee, 2. CBK, 3. AGH

December 24, 2020

Swarm4Anom

I - dedicated to macro-scale features (Cont. of the previous studies) in the Earth's ionosphere and long-term analysis
(CBK/ OBSEE)
Key findings published in JGR
Analysis of the Impact of Long-Term Changes in the Geomagnetic Field on the Spatial Pattern of the Weddell Sea Anomaly
`https://doi.org/10.1029/2019JA027528`

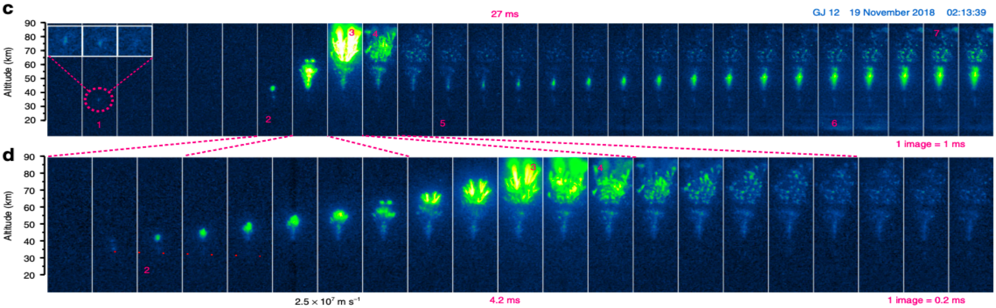


II - dedicated to small scale perturbations originating from thunderstorm activity (AGH/ CBK/ OBSEE)
Results submitted to GRL

- E. Slominska: - Swarm4Anom - Project overview and key findings:
  Global distribution of magnetic field fluctuation related to strong lightning activity - Output product description and recommendations for further analysis
- M.Strumik - Experimental evidence of a link between lightning and magnetic field fluctuations in the upper ionosphere observed by Swarm
- Mlynarczyk - Ground-based measurements of atmospheric discharges detected on Swarm
- Strumik - Ionosphere in TIEGCM simulations: visualizations and comparison with Swarm measurements
- Blecki - Selection of additional results based on Swarm data, but not directly related to main topic of project.

Main question:

Does the VFM instrument onboard Swarm, allow to detect signals triggered by strong lightning activity, and in particular by transient luminous events (TLEs)?

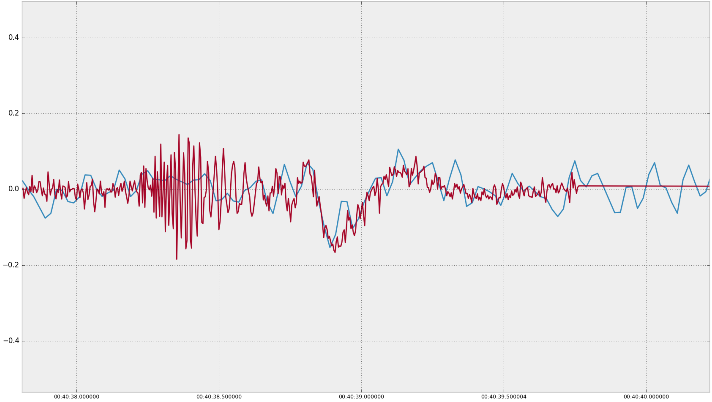


Source: Gigantic jet discharges evolve stepwise through the middle atmosphere -https://doi.org/10.1038/s41467-019-12261-y

- Sprites are the most spectacular among TLEs. Characterized by large luminous body above an active thunderstorm, developing vertically upward between 40 and 80 km.
- They last from several milliseconds to a few tens of milliseconds.
- 20 ms time resolution of the VFM instrument should allow to investigate effects of slowly varying (continuing) currents following the impulsive and dynamic +CG return strokes.

Is it possible to monitor lightning activity with Swarm? - ASM 250 Hz vs. VFM 50 Hz

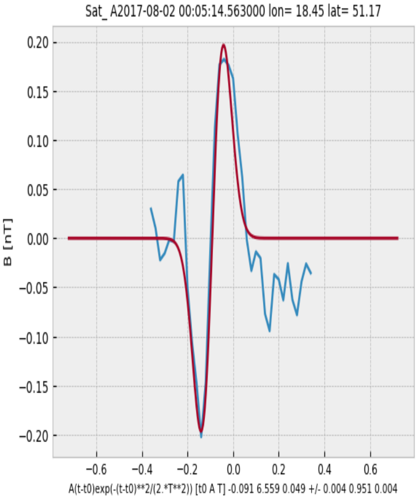
ASM Burst mode data provide evidence of whistler-type emission - triggered by relatively weak lightning event



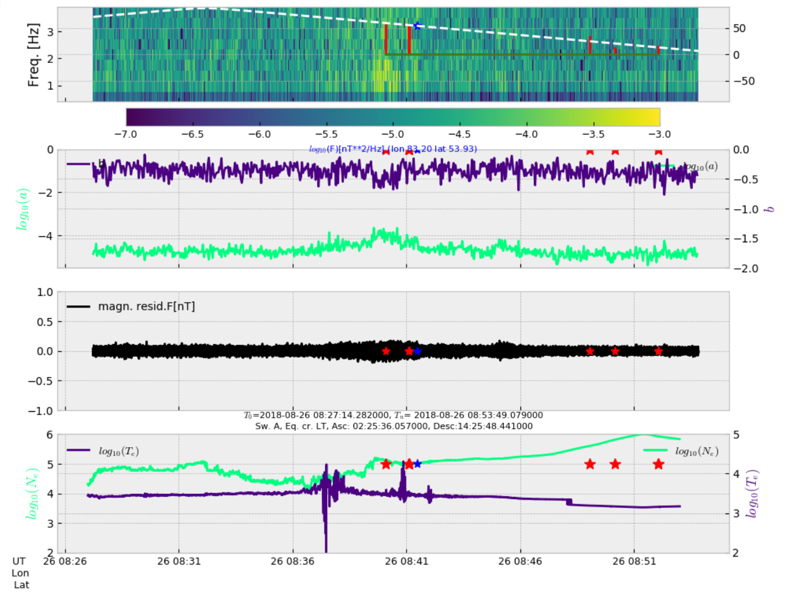
Response to the lightning event on the VFM instrument is expected to occur at frequencies below 10Hz

Methodology

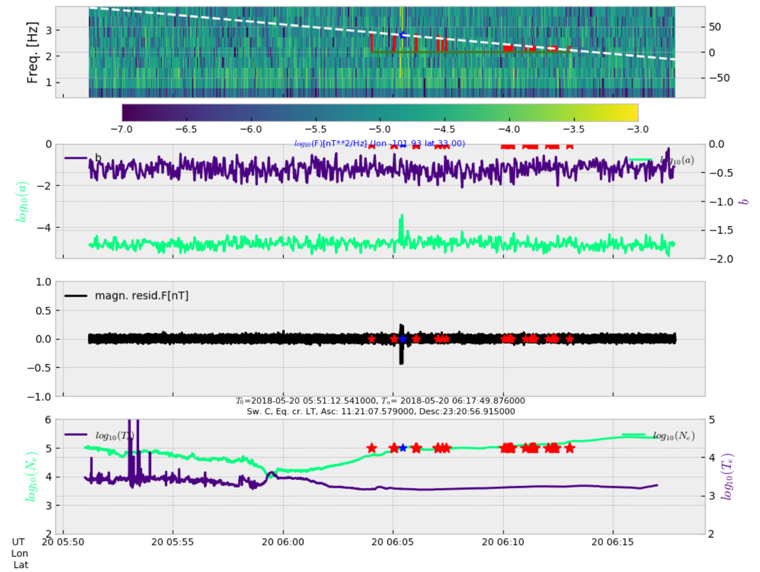
- Powerful discharges (CG+ type) may generate strong currents which will lead to small-scale fluctuations in the **B** field.
- $\delta B_i = B_i^{obs} - B_i^{approx}$ - Local **B** trend is removed, with the 4^{th} order polynomial approximation applied over 5 second time periods.
- Fitting procedures used to localize sharp peaks. Expected signal triggered by lightning has a form of differentiated Gaussian signal.
- Analysis concentrates on residual signal and sudden peaks which have magnitude higher than assumed threshold ($\delta F > 0.17$ nT).
- WWLLN dataset is used to provide verification of lightning activity in the certain region



Sample spectrum of irregularities



Thunderstorms in Oklahoma - 2018.05.20



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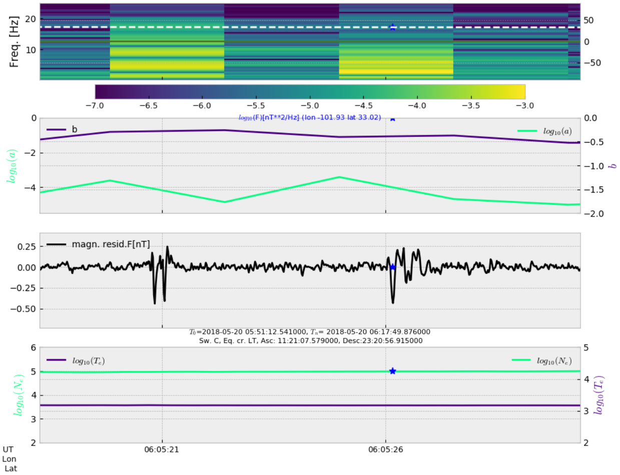
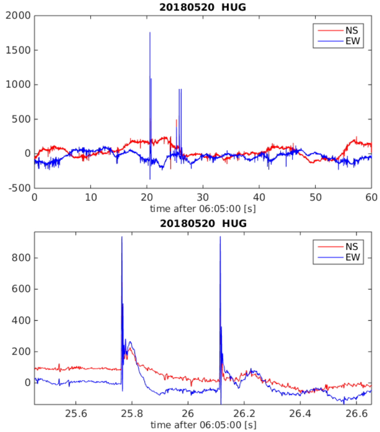
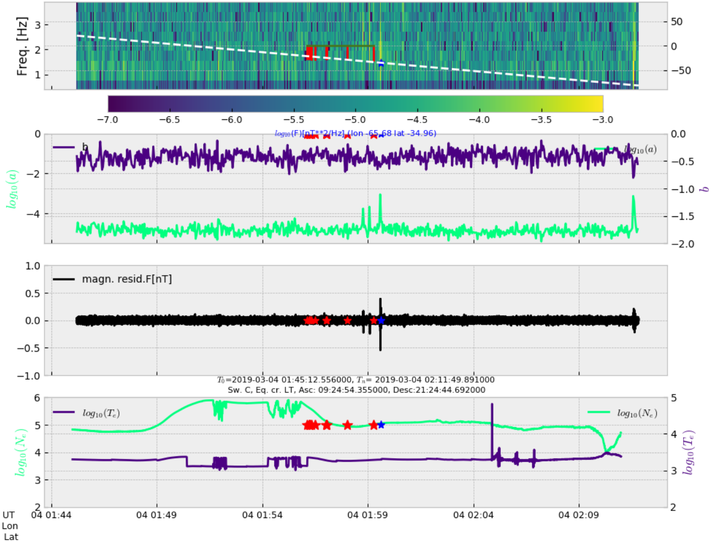


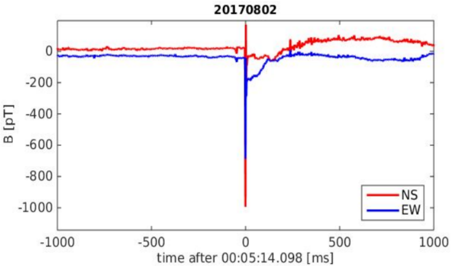


Thunderstorms in Patagonia - 20190304 - UTC 01:58:00



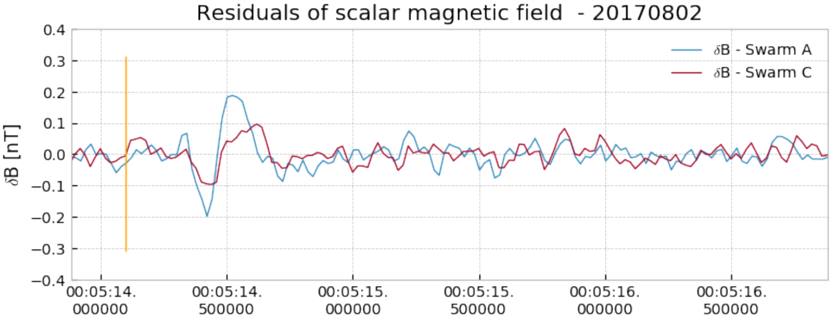
- Swarm passes through a series of prominent plasma depletions and enters the region of strong thunderstorm.
- Location and time of flashes derived from the GLM imager.

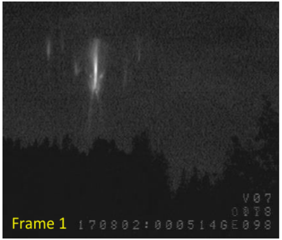
Basic conditions for effective detection

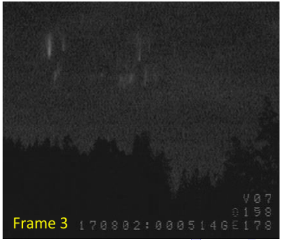


August, 2, 2017 Swarm was passing over Poland, where ground station in Hylaty registered strong magnetic field fluctuations, caused by powerful discharges with estimated charge moment **4870** C km. The event was also captured by the ground-based observer in Nydek (M. Popek)

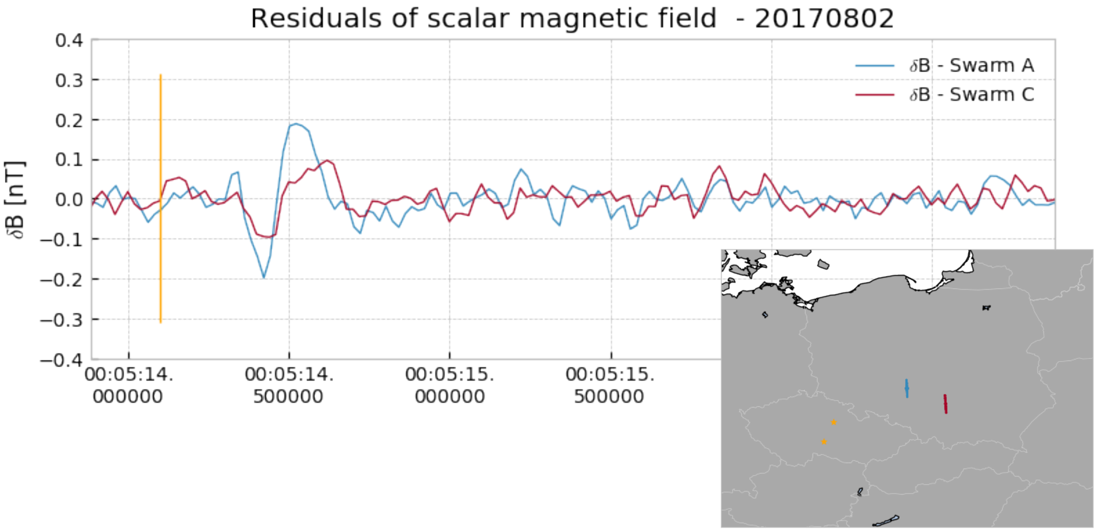
Basic conditions for effective detection - Cross validation with ground observations



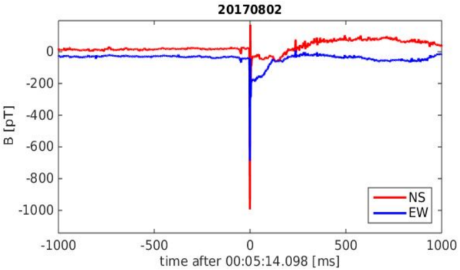


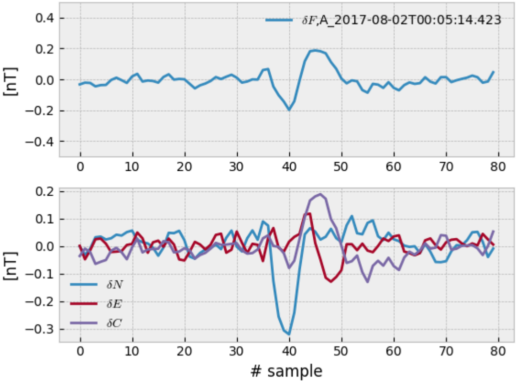


Conjunction between Swarm A/C and TLE (I)



Conjunction between Swarm B and TLE (II)





Detection algorithm relied on the analysis of scalar field fluctuations δF and not components.
Less noise on δF, easier to detect sharp peaks

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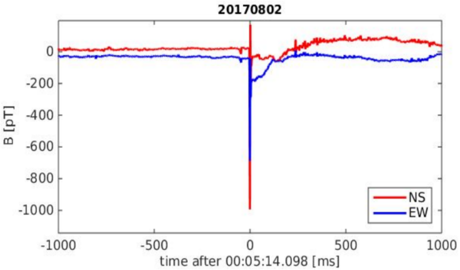

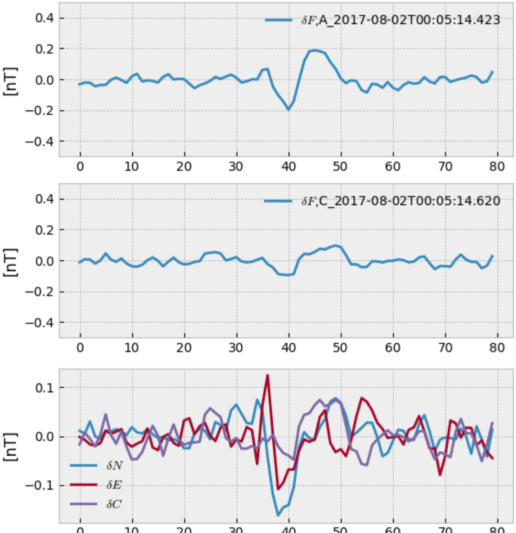

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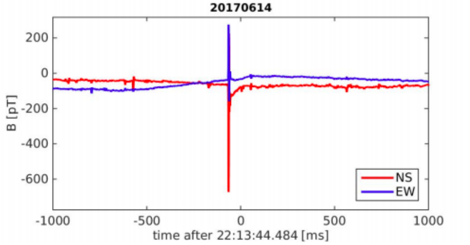
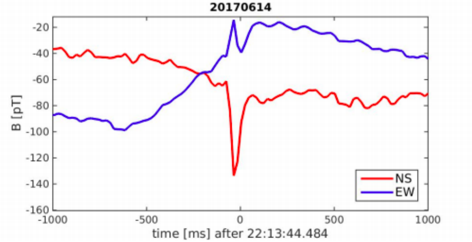
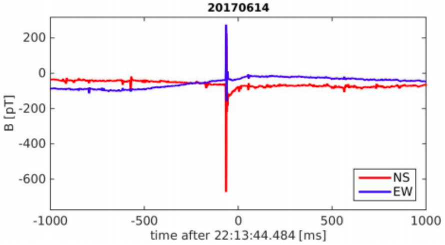


The north-south and east-west magnetic field components associated with the sprite event. Distance 972 km.



Assuming that Swarm should detect signal in a same way as ground-based station we should be able to detect this particular case TLE

Less evident example - Swarm B



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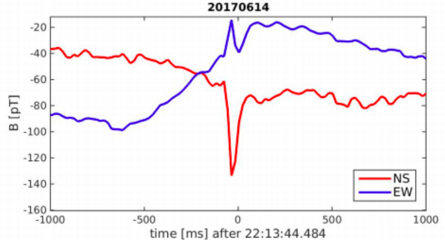

Swarm B, 2017-06-14T22:13:39.585000

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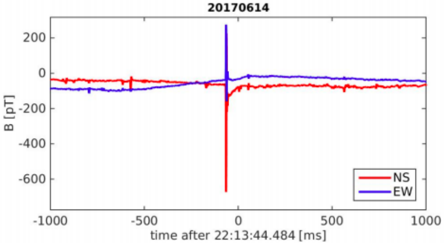

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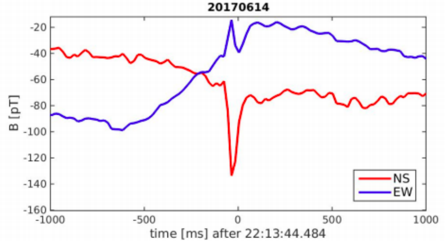
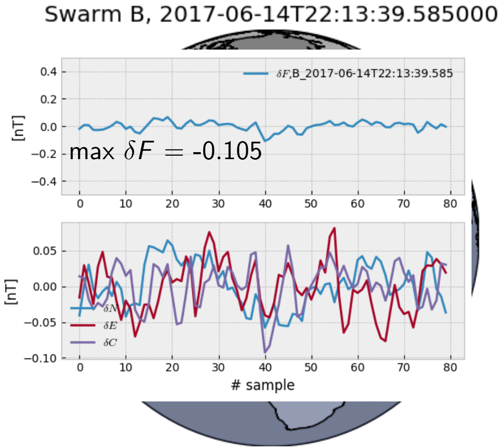
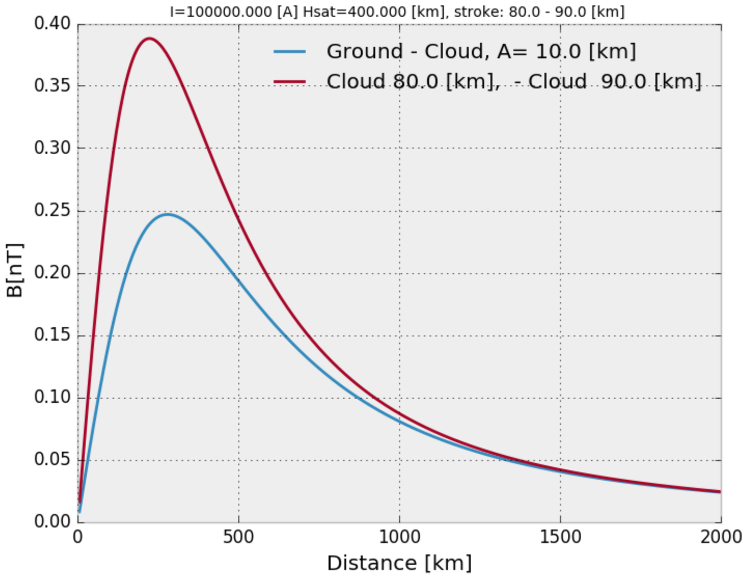




Geometrical condition for detection

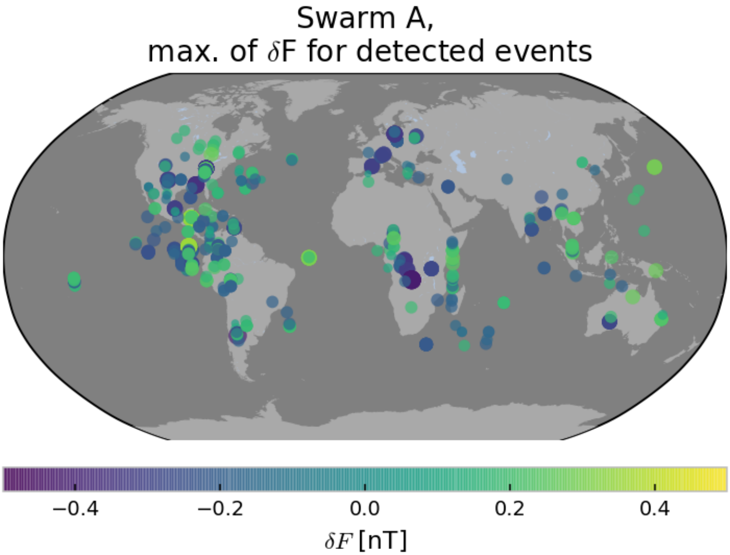
Course approximation: In the **near zone the fields have the character of static fields** with radial components and variation with distance which depends in detail on the properties of the source. In the far zone, on the other hand, the fields are transverse to the radius vector and fall off as r^{-1}, typical of radiation fields.



Global representation of lightning-triggered fluctuations detected by Swarm

Total number of detected cases between 2017 - 2020

- Alpha: 125
- Bravo: 38
- Charlie: 93



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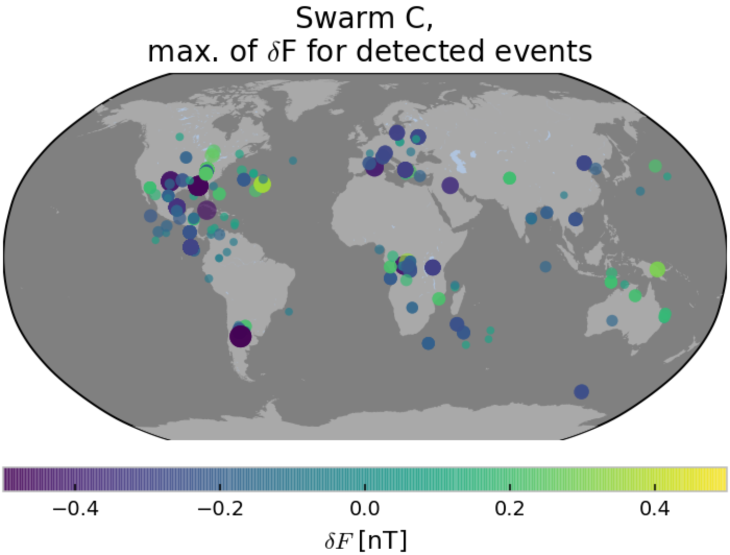

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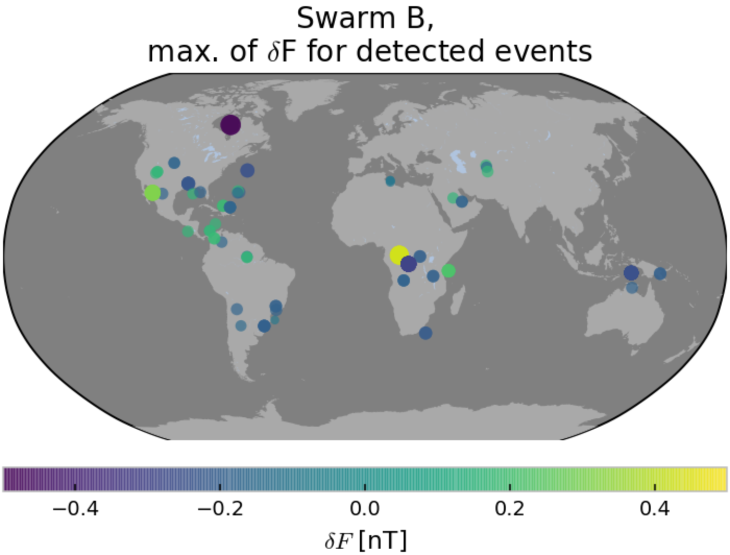


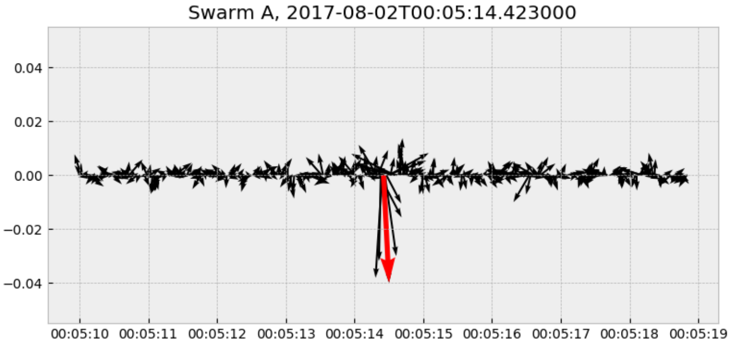
Structure of lightning triggered disturbances

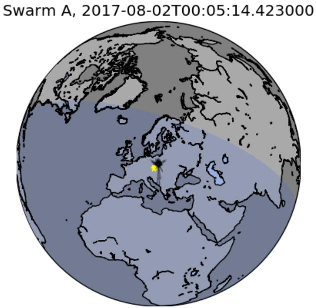
Next step: **What further information can be deduced from Swarm observations about the character of disturbances?**

- *Bosinger, T., A . Mika, S. L. Shalimov, C. Haldoupis, and T. Neubert (2006), Is there a unique signature in the ULF response to sprite-associated lightning flashes?, J. Geophys. Res., 111, A10310, doi:10.1029/2006JA011887.* - The evidence shows no unique and identifiable ULF signature relating to the sprite causative discharges.
- Examined the response measured by a pulsation magnetometer located in southern Finland, to selection of the +CG events from central France.
- Analysis of two magnetic field components showed that when one component maximizes, minimizing in the other.
- The affected component was characterized by a sharp, fast unipolar pulse followed by a slower decay (a tail) lasting typically 0.5 to 1.0 s. There were observations, however, with only a sharp unipolar pulse without a gradual decay (without a tail). In both cases the pulse had a duration of typically 0.1 s. Rather frequently the pulse triggered some damped oscillations superimposed on the tail. These oscillations persisted sometimes still beyond it.

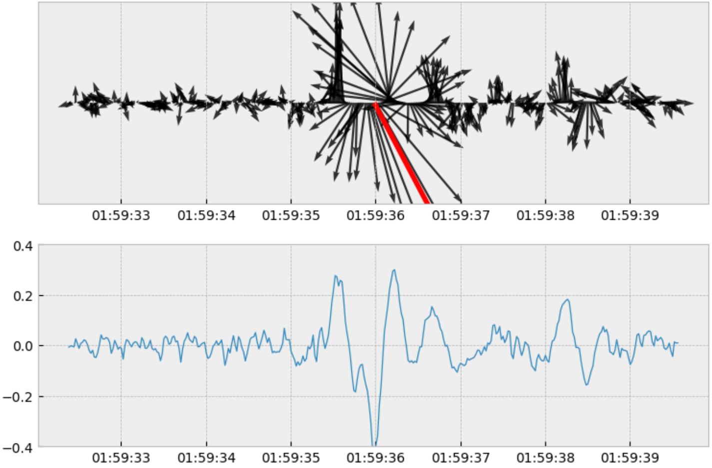
Structure of disturbances - I

- Fluctuations of δF provide general indication that intensified lightning activity triggered perturbations in the magnetic field.
- Analysis of components δB_i allows to analyze how the perturbation propagates.

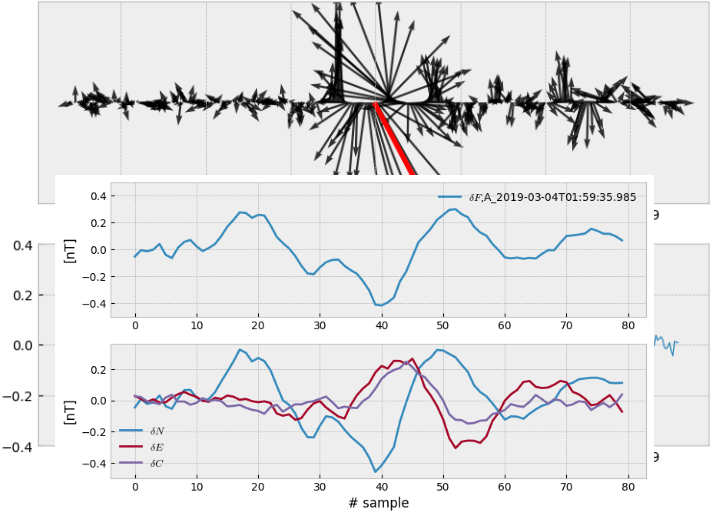




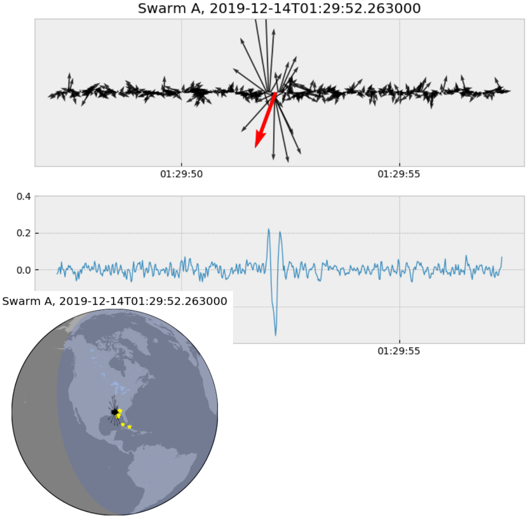
Structure of disturbances - II

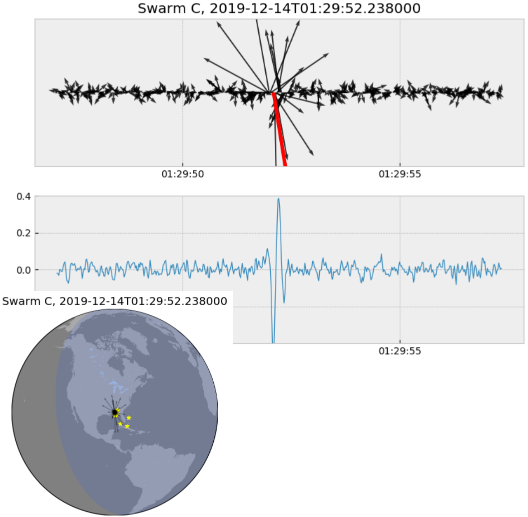


Structure of disturbances - II



Structure of disturbances - location of source and satellite





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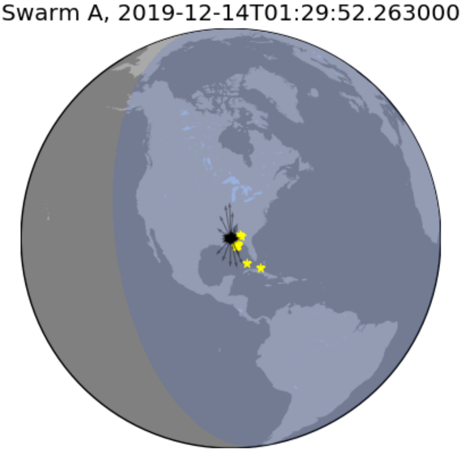
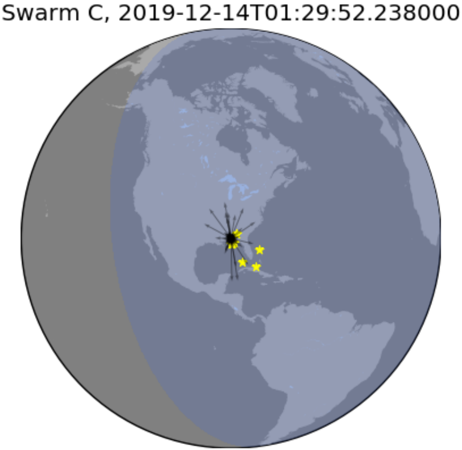
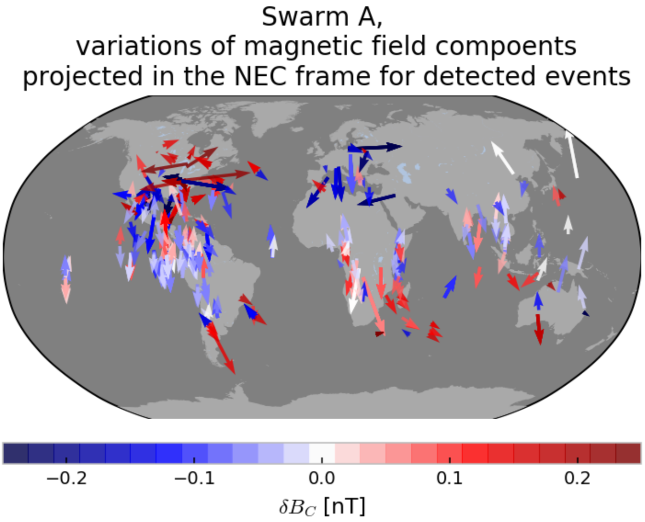


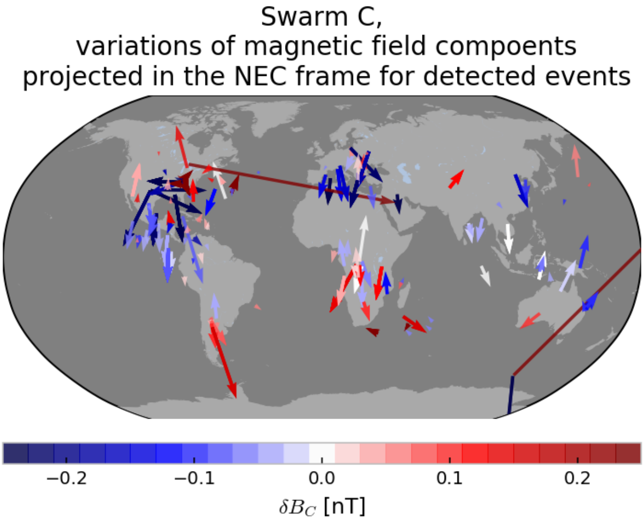


Defining the structure



- For majority of events, fluctuations of magnetic field propagate across N-S component (projection in the NEC frame)
- Using Swarm magnetometers we are able to determine how the fluctuation propagates with respect to the main field.

Defining the structure



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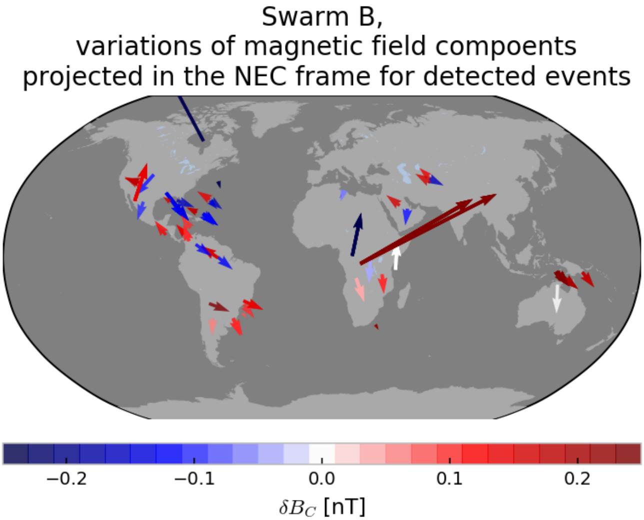

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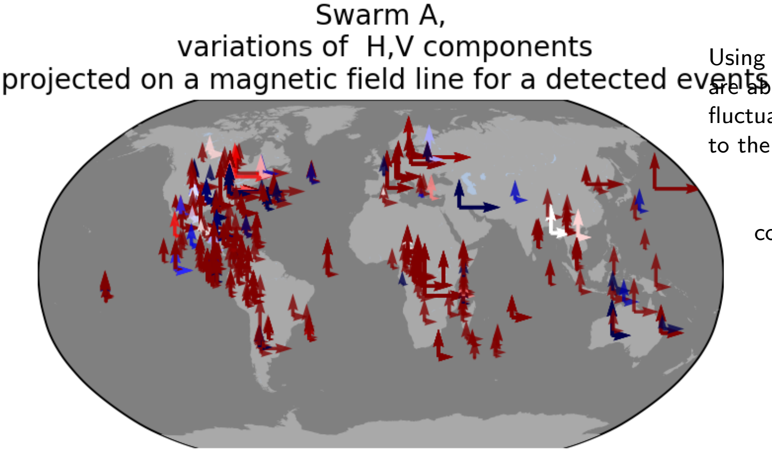
Direction of disturbance propagation with respect to the main field



Using Swarm magnetometers we are able to determine how the fluctuation propagates with respect to the main field.

$$\cos f = \frac{\delta B_i(t) \cdot B_i^{app}(t)}{\|\delta B_i(t)\| \|B_i^{app}(t)\|}$$

$$b_{\|} = \|\delta B_i(t)\| \cos f$$

$$b_{\perp} = \|\delta B_i(t)\| - b_{\|}$$

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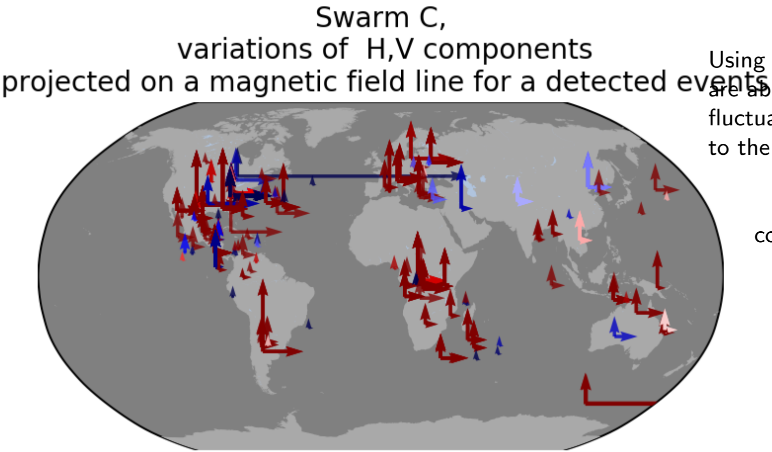

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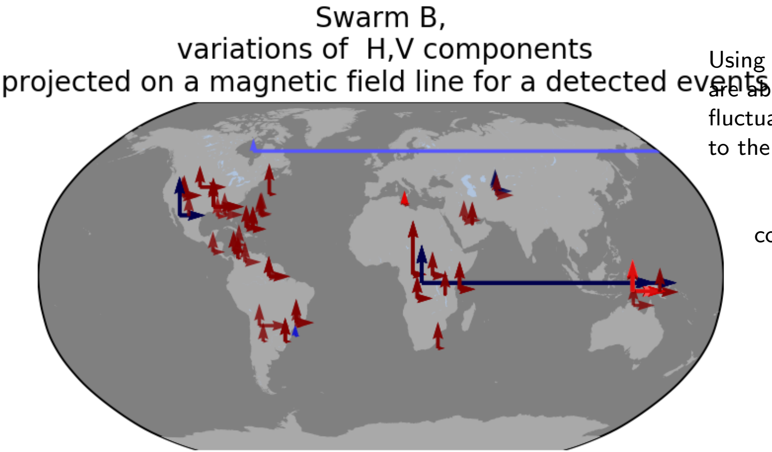

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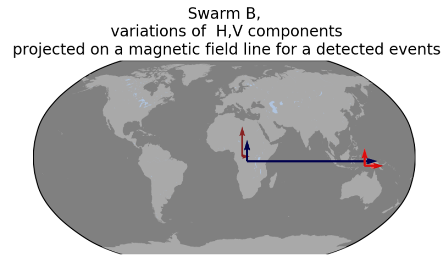
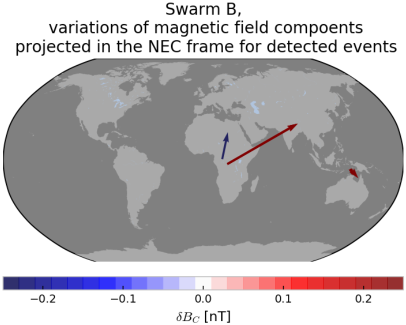
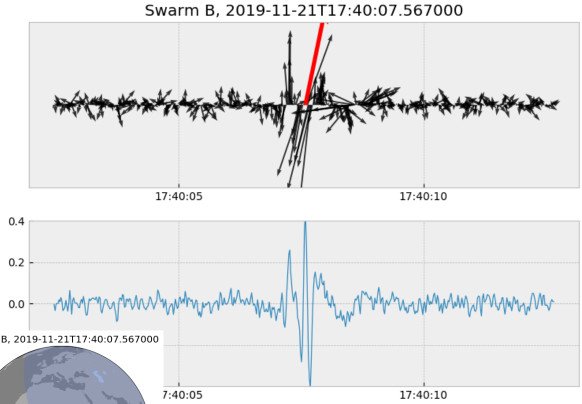
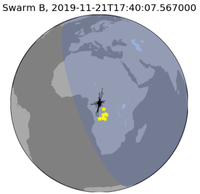

Swarm B,
variations of H,V components
projected on a magnetic field line for a detected events


Swarm B,
variations of magnetic field compoents
projected in the NEC frame for detected events
−0.2
−0.1
0.0
0.1
0.2
δB_C [nT]


Swarm B, 2019-11-21T17:40:07.567000
17:40:05
17:40:10
0.4
0.2
0.0
7:40:05
17:40:10


Swarm B, 2019-11-21T17:40:07.567000

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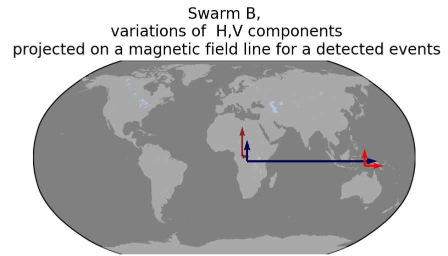
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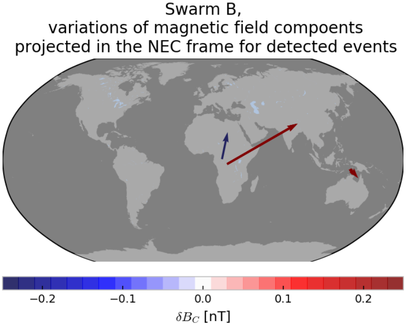
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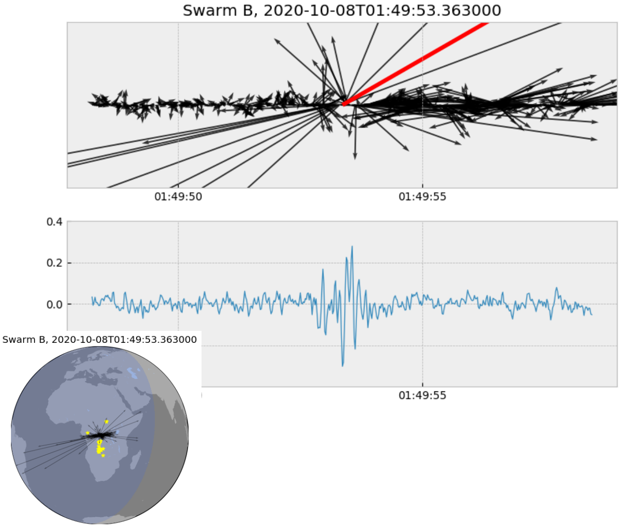
Swarm B, 2020-10-08T01:49:53.363000
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01:49:55
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0.2
0.0
01:49:55
Swarm B, 2020-10-08T01:49:53.363000

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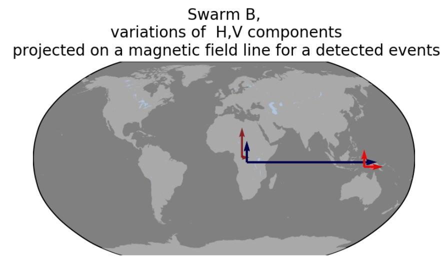
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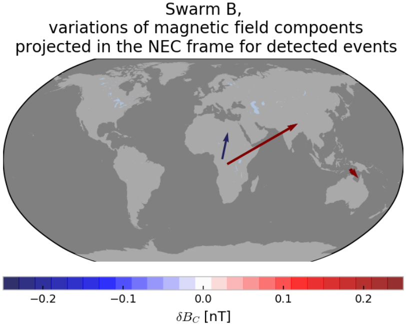
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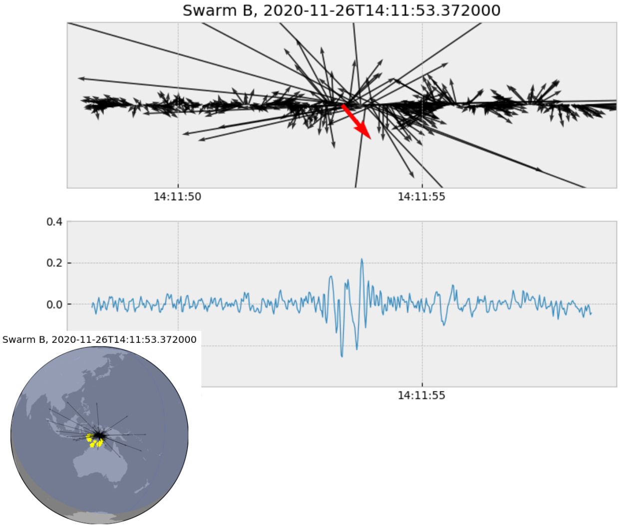
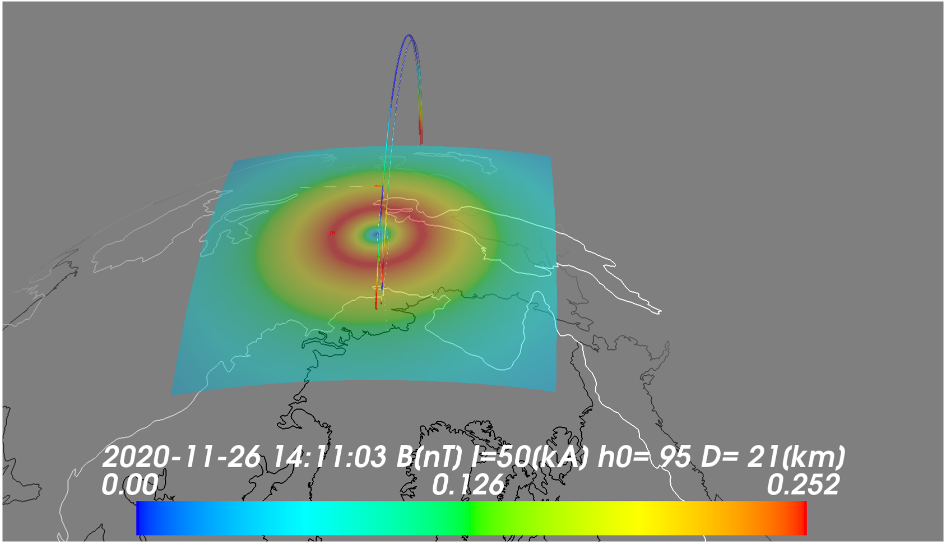
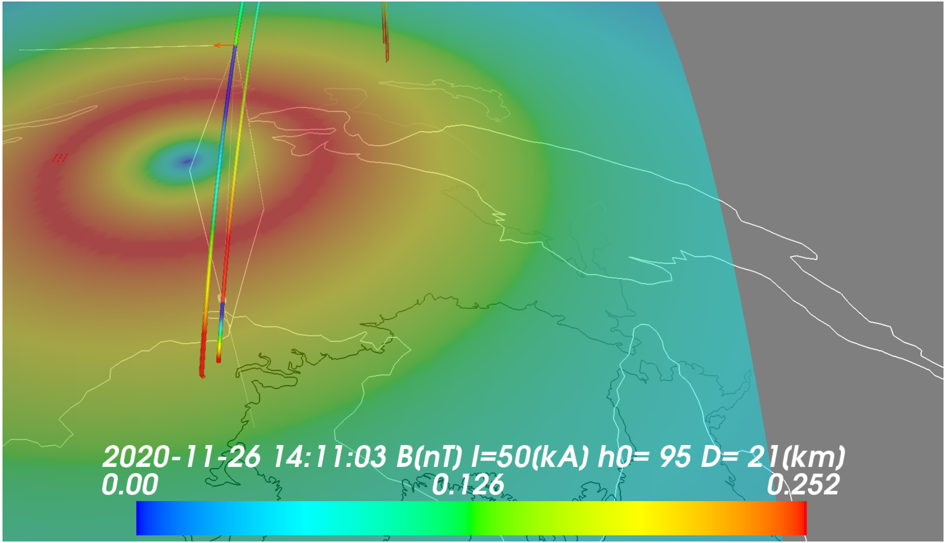
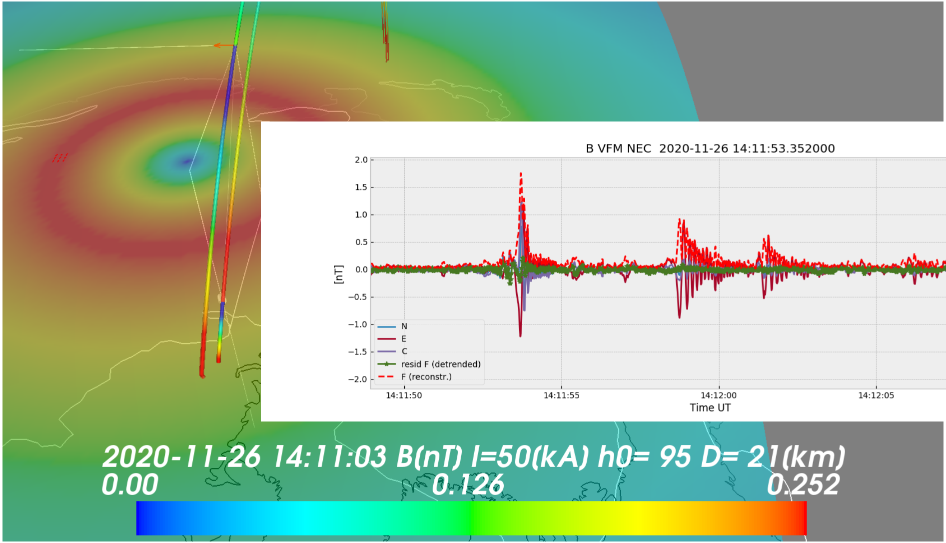
0.2
δB_C [nT]


Swarm B, 2020-11-26T14:11:53.372000
14:11:50
14:11:55
0.4
0.2
0.0
14:11:55
Swarm B, 2020-11-26T14:11:53.372000


2020-11-26 14:11:03 B(nT) I=50(kA) h0= 95 D= 21(km)
0.00
0.126
0.252


2020-11-26 14:11:03 B(nT) I=50(kA) h0= 95 D= 21(km)
0.00
0.126
0.252


B VFM NEC 2020-11-26 14:11:53.352000
[nT]
Time UT
14:11:50
14:11:55
14:12:00
14:12:05
14:12:10
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
N
E
C
resid F (detrended)
F (reconstr.)
2020-11-26 14:11:03 B(nT) I=50(kA) h0= 95 D= 21(km)
0.00
0.126
0.252

Main findings from the project

- VFM allows to detect lightning-triggered fluctuations, under Detection of lightning-triggered magnetic field fluctuations onboard Swarm is possible when the distance between Swarm and active thunderstorm region is not greater than 700 km.
- The response on the VFM instrument does not only depend on the strength of the lightning event, but additionally is highly determined by the configuration in which satellite and source of disturbances occurs.

Output of the project

Successful cases are stored in the CDF format. The naming convention is as follows: SIG_[A/B/C]_YYYY-MM-DDTHH:MM:SS.SS0000__xxxxx_????_25(

- xxxxx - record number
- ???? - denotes maximum amplitude of the detected peak
- vvv - denotes version of the algorithm. and the structure of the file is provided below:

Data are accessible through the web server
Simple python code is provided for quick reading and visualization of data

Name of Variable	***Description***
Timestamp_light	Timestamp of the lightning event
light_lon	Lightning longitude
light_lat	Lightning latitude
light	Lightning event description [longitude, latitude, longitude_projected_onto_magnetic_field_line, latitude_projected_onto_magnetic_field_line, distance_to_the_satellite(km)]
Tim_resid	Timestamp of magnetic field residuals
T	Time in seconds around the detected spike
Lon_resid	Longitude of residuals along the satellite track
Lat_resid	Latitude of residuals along the satellite track
Trend	Three components and scalar field of the main trend [N,E,C,F] based on polynomial approximation
B_NEC	Three components [N,E,C] of the main trend based
SIG	Residuals of three components of magnetic field [∂N,∂E,∂C]
B_SIG	Residuals of the scalar magnetic field [∂F]
Radius	Radius from the Earth Center