

# Lightning spots as seen by Swarm

Spatial distribution and classification of Lightning-Induced magnetic field fluctuations detected by the Swarm constellation

AGH, CBK, OBSEE

Swarm4Anom PM4

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# Introduction

## TLEs(Transient Luminous Events) and magnetic field fluctuations

- ▶ J. Mlynarczyk - "Current progress on WP7"
- ▶ K. Martynski - "Analysing the African Storm Centre activity using the ELF data."
- ▶ K. Martynski - "Results of the 2D mapping of the African Storm Centre during Swarm flybys."
- ▶ E. Slominska - "Lightning spots as seen by Swarm - Spatial distribution and classification of Lightning-Induced magnetic field fluctuations detected by the Swarm constellation"
- ▶ M. Strumik - "Analysis of spatio-temporal correlations between GOES-16/17 GLM observations of lightnings and magnetic field fluctuations measured by Swarm"

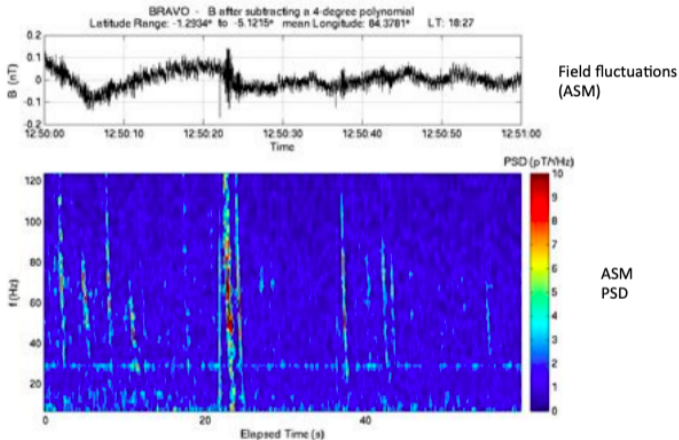
$I_{NDD}$  and Anomalies

# The WSA anomaly problem

- ▶ the index product is updated on a regular basis and is available
- ▶ the paper "Analysis of the impact of long-term changes in the geomagnetic field on the spatial pattern of the Weddell Sea Anomaly" [Paper #2019JA027528RR] has been accepted for publication in Journal of Geophysical Research - Space Physics.
- ▶ the paper contains the annotation about availability of the index product so it is possible that now the data will be used by wider community
- ▶ no DOI yet.

# Detection of lightning-related fluctuations - ASM 250 Hz vs. VFM 50 Hz

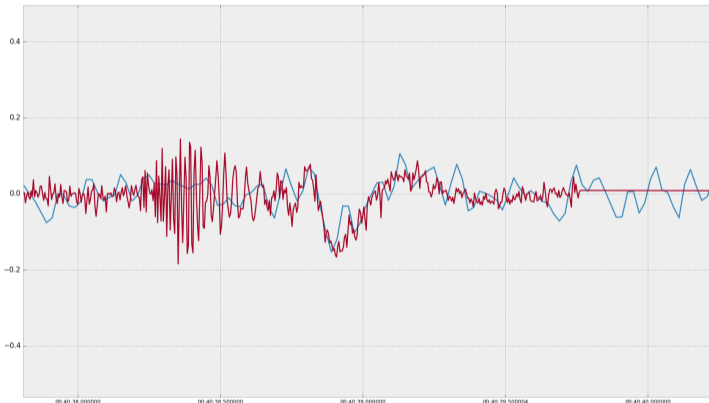
ASM Magnetometer on Swarm are able to detect signals triggered by lightning activity. Sensitivity of ASM allows to detect signals generated by moderate thunderstorms. Manifestation of lightning activity is in a form of so called Sferic-like emissions



*Image source: G. Hulot*

# Detection of lightning-related fluctuations - ASM 250 Hz vs. VFM 50 Hz

Ion-whistler emission -  
triggered by relatively  
weak lightning event:  
ASM (red line) vs VFM  
(blue line) Agreement  
in general trend, due to  
sampling we do not see  
small scale structures.  
**But ... VFM has an  
added value three  
components of the  
magnetic field**



# Extraction of fluctuations from Swarm MAGx\_HR - Processing steps

Powerful discharges (CG+ type) may generate strong currents which will lead to small-scale fluctuations in the **B** field

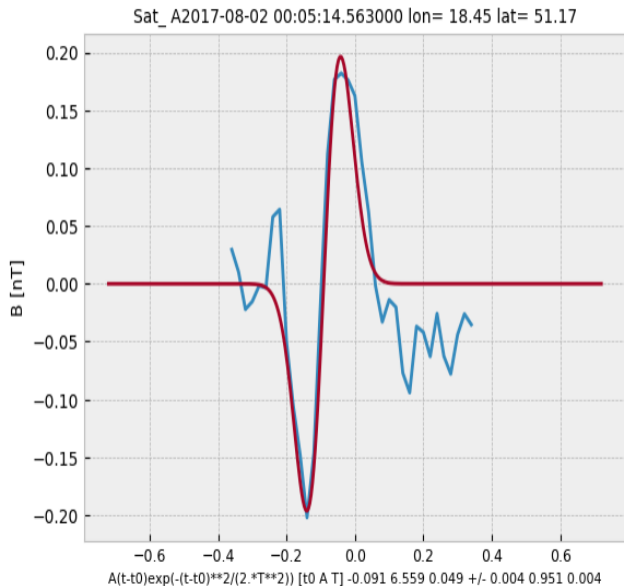
- ▶ Local **B** trend removal - Approximation based on 4<sup>nd</sup> order polynomial
- ▶ derive residuals

$$\delta B_i = B_i^{obs} - B_i^{approx}$$

- ▶ polynomial applied to 64/128/256 samples
- ▶ Analysis concentrates on residual signal and sudden peaks which have magnitude higher than assumed threshold ( $\delta F > 0.1$  nT).
- ▶ Analysis performed for three components and scalar of the magnetic field

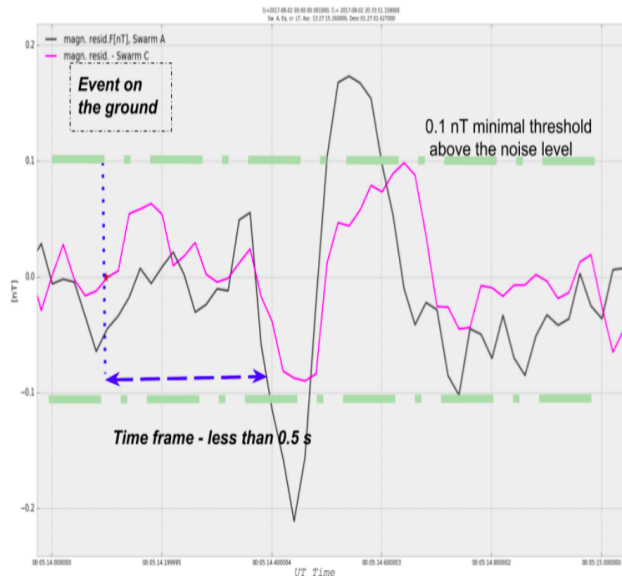
# Verification with ground based observations

- ▶ Expected signal - differentiated Gaussian signal
- ▶ minimal threshold for detection - above  $\pm .1nT$
- ▶ analysis of scalar field  $\delta F$  - not components
- ▶ looking for a source of currents
- ▶ automatic detection - quality of the fit determines, whether the spike is a good candidate for further analysis



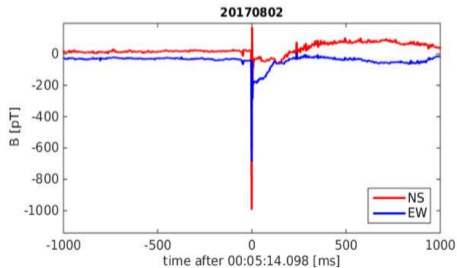
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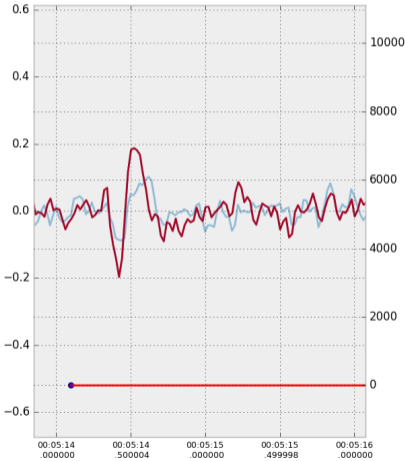


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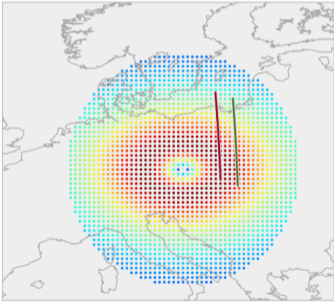


Strongest event, with charge moment **4870 C km**, should be seen on Swarm, if there is conjunction with the location of the satellite.

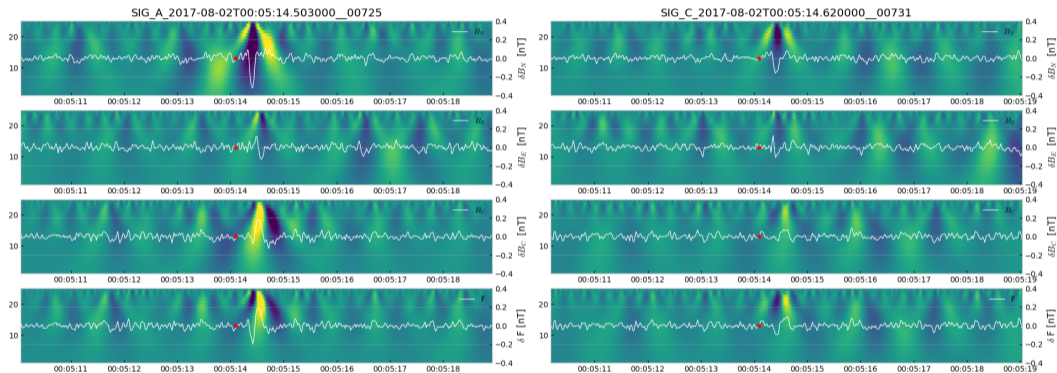
# Geometrical condition transformed on the Earth's surface around the location of the lightning event



Event time: 2017-08-02 00:05:14.098000



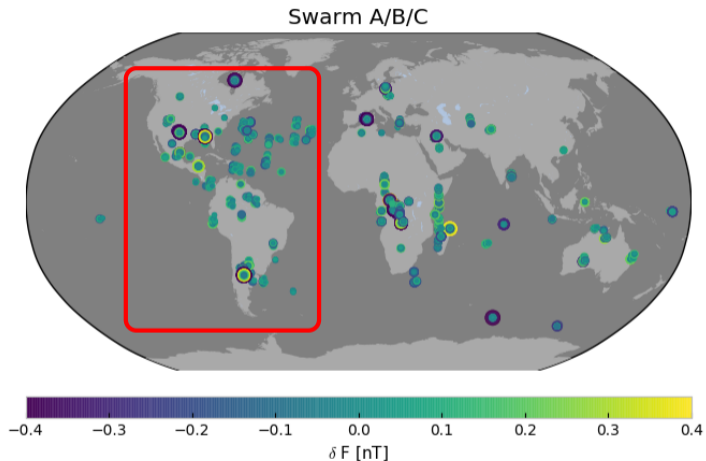
# Distance between Swarm and lightning source



Strong dumping of the signal between the lower pair for the same lightning source implies that we have to take into account the distance from the source.

# Detected cases

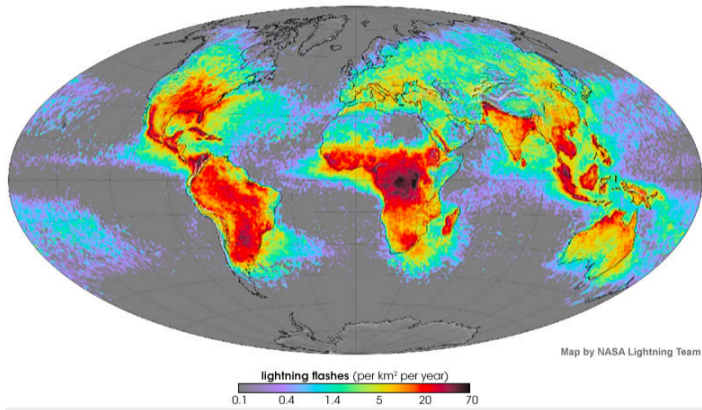
- ▶ **Simultaneous analysis with GLM**
- ▶ Remaining regions use low-resolution World Wide Lightning Location Network data, giving general overview of thunderstorm activity along the Swarm passes.
- ▶ Selected examples are derived with ground observations from the ULF stations



Database of analyses samples - from 2017 till current time, updated on daily basis: <http://swarm4anom.cbk.waw.pl/gauss/>

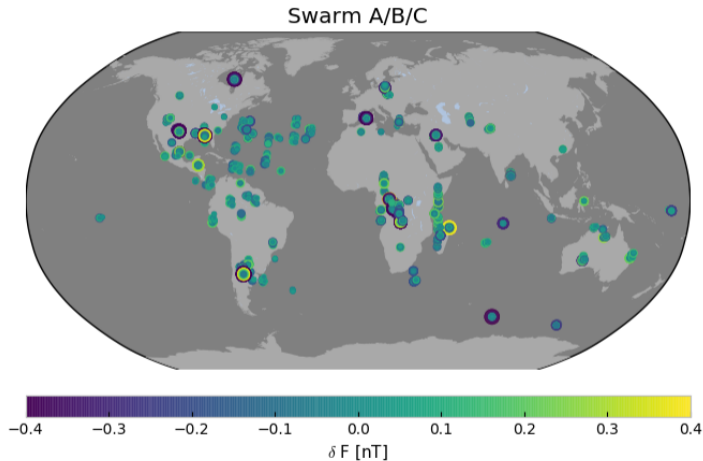
# Magnetic field fluctuations detected by Swarm

- ▶ **Fundamental criteria** for detection of signals triggered by lightning activity: close-proximity (up to 500 km) of Swarm to the active region
- ▶ Regions with detected fluctuations (2017 - 2020)



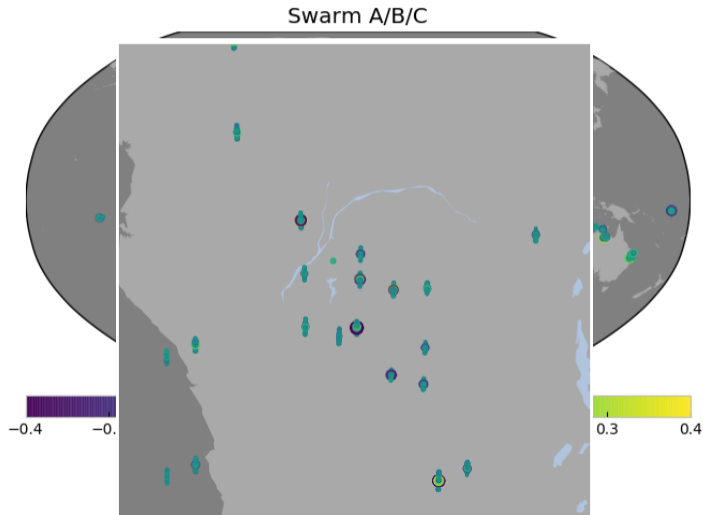
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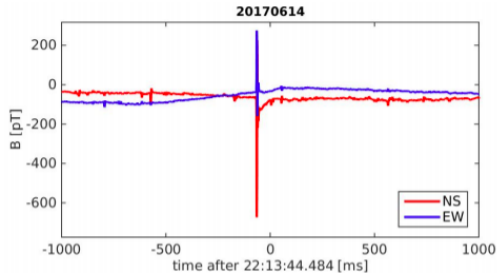


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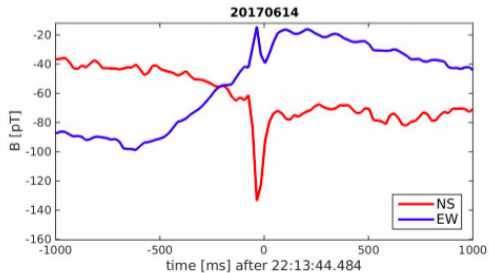
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# Distance between Swarm and the source of strong lightning



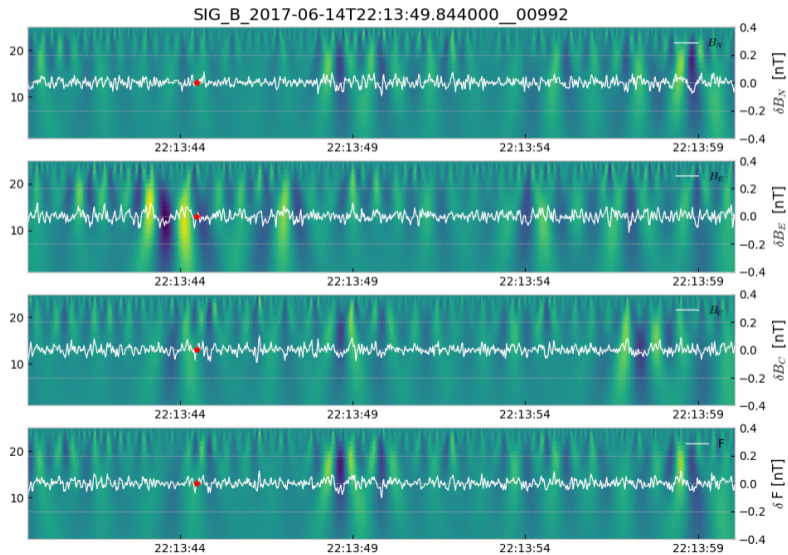
The north-south and east-west magnetic field components associated with the sprite event. Distance 972 km.



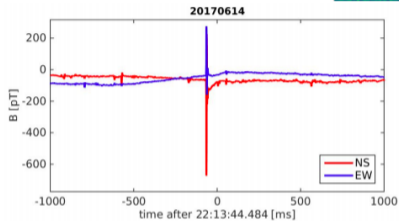
Assuming that Swarm should detect signal in a same way as ground-based station we should be able to detect this particular case TLE



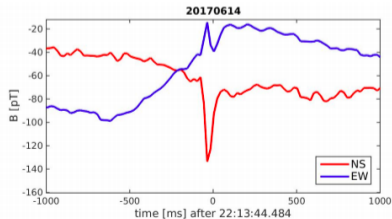
# Verification with ground based observations



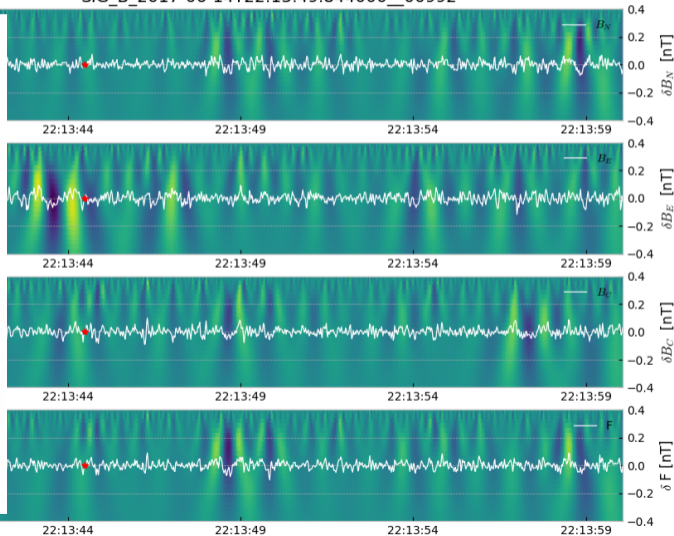
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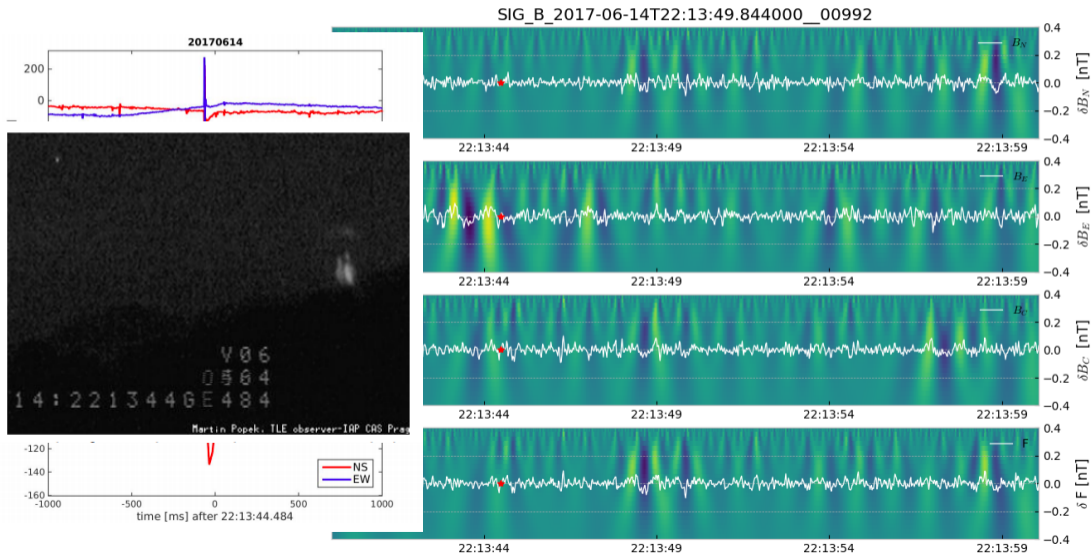
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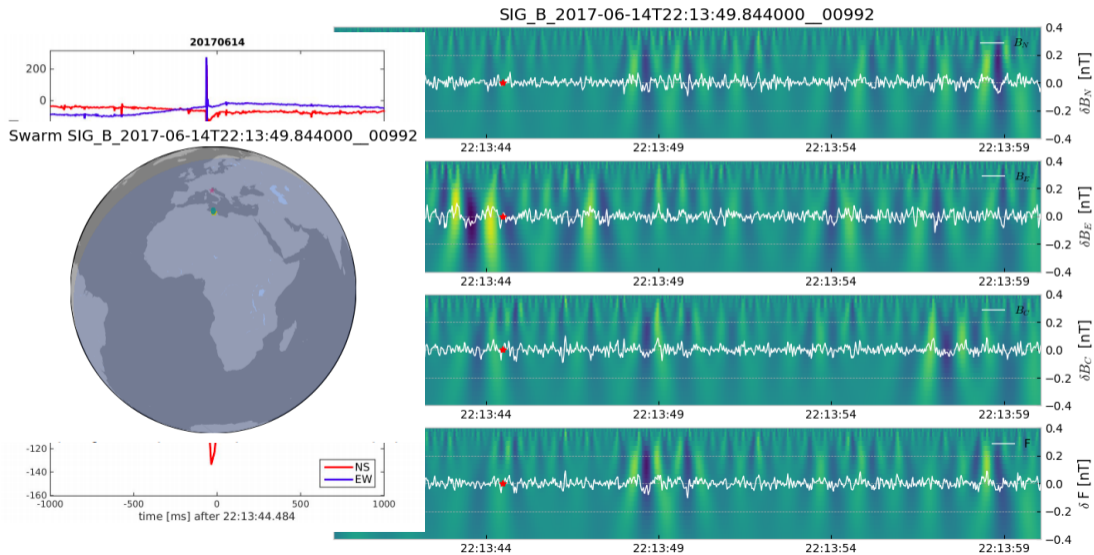
SIG\_B\_2017-06-14T22:13:49.844000\_00992



# Verification with ground based observations



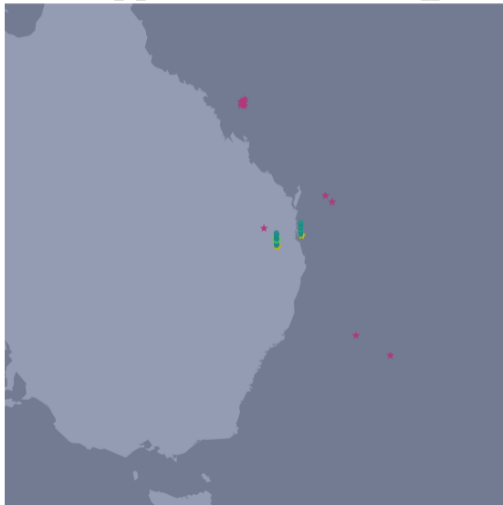
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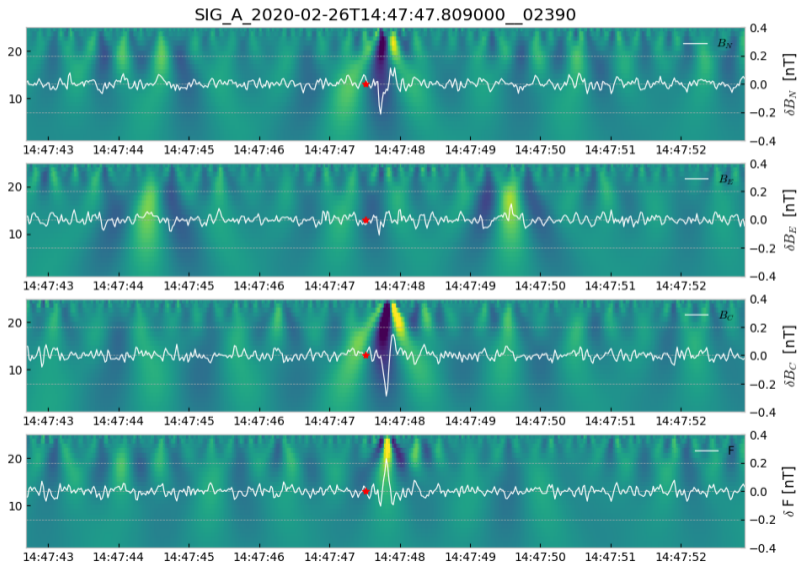
# Most recent examples

- ▶ A severe lightning storm swept across Australia in January/February 2020
- ▶ For the verification of this particular case prof. Rob Holzworth (University of Washington, WWLLN) provided precise timing for selected events (without energies)

Swarm SIG\_C\_2020-02-26T14:47:47.815000\_\_02390

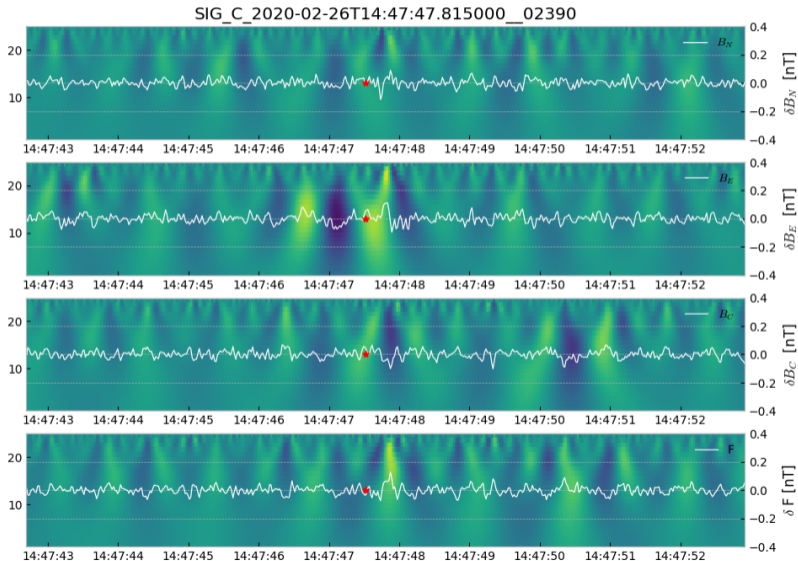


# Australian case 2020-02-26



- Modeling attempt to interpret such registrations - single lightning represented as an localized oscillating source

# Australian case 2020-02-26



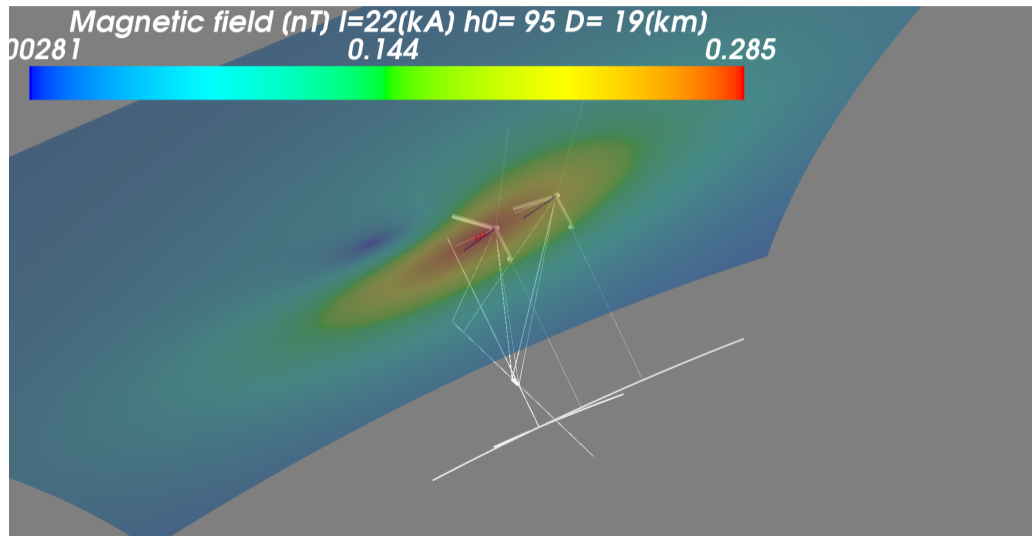
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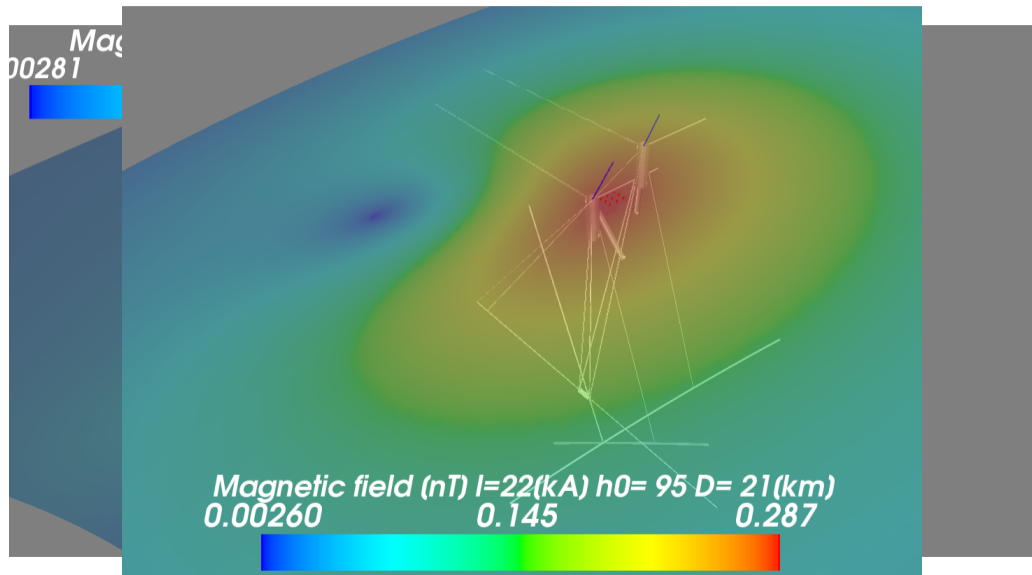




# Radiation of a Localized Oscillating Source - tilted source



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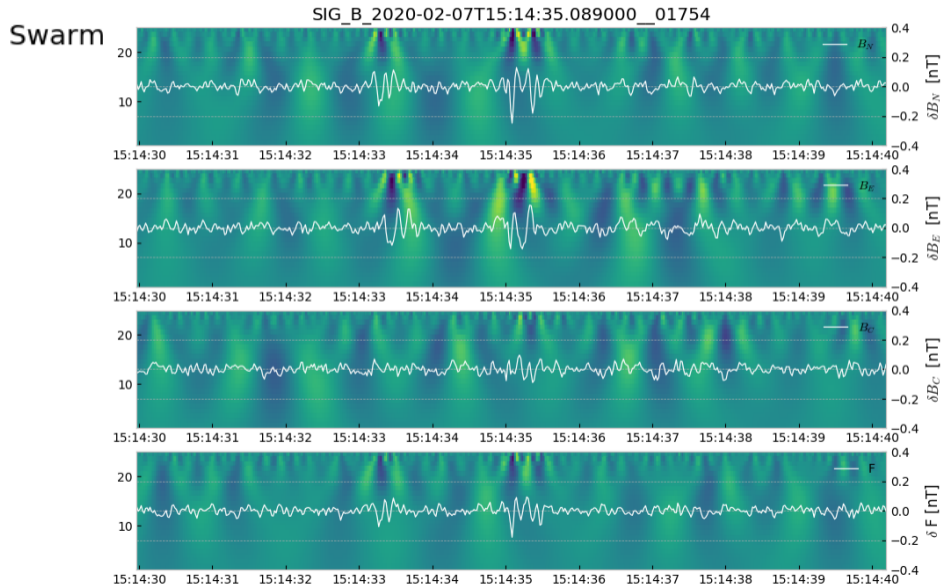


## Case II - Australia (low-res WWLLN)

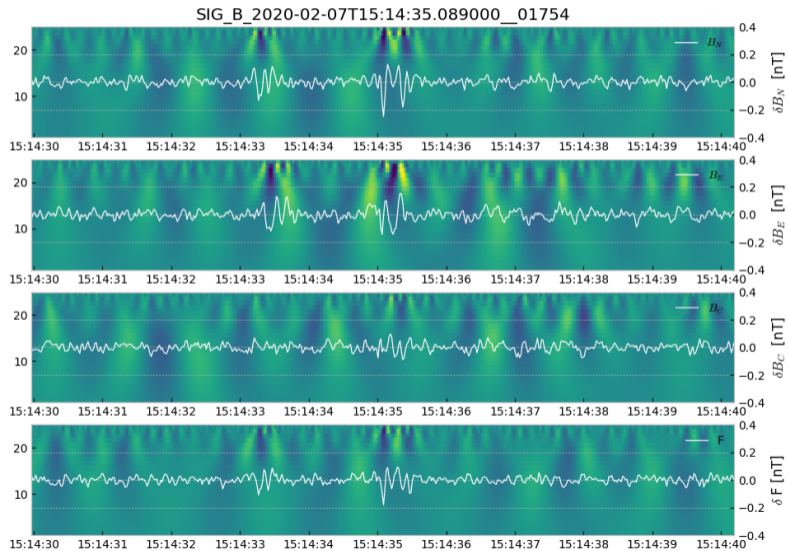
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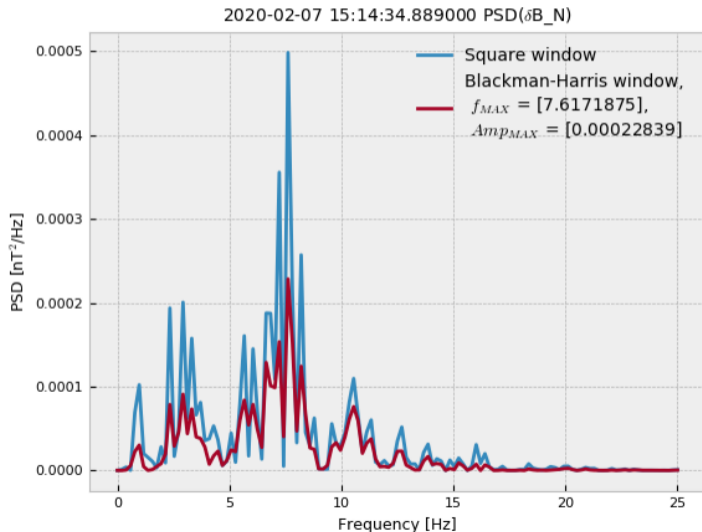
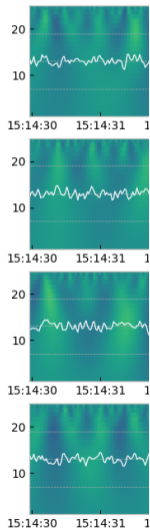
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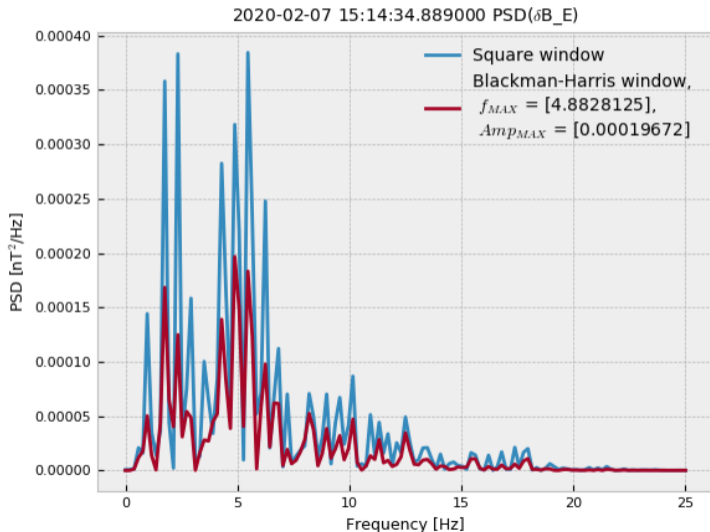
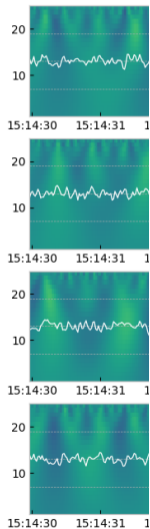
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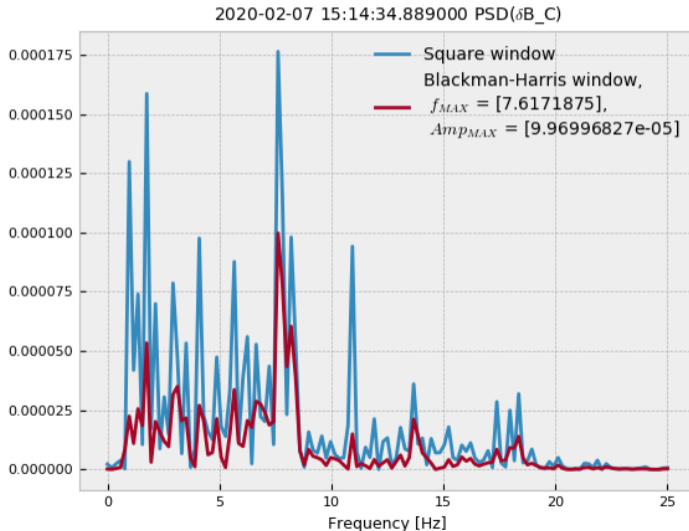
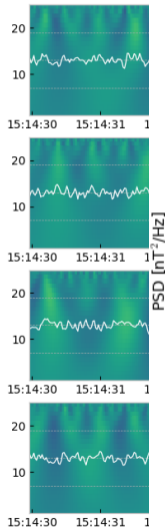


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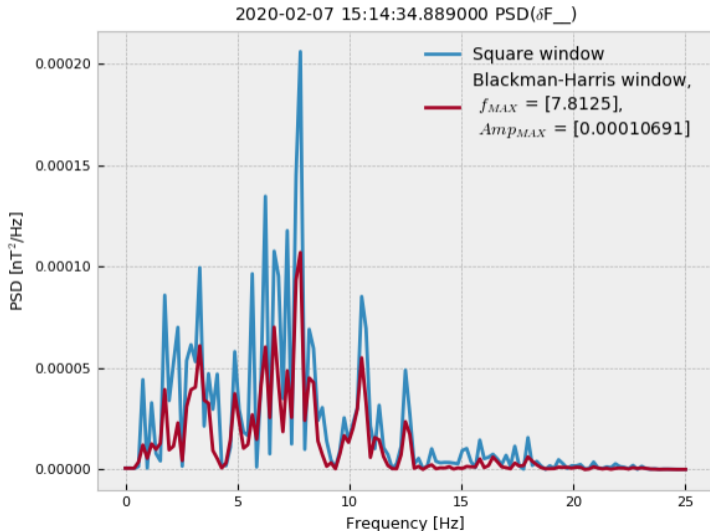
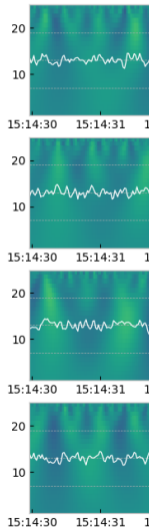




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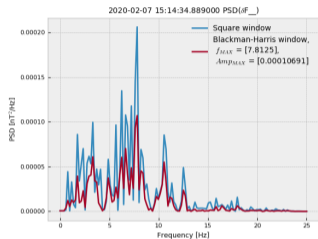
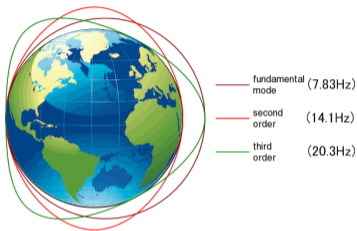


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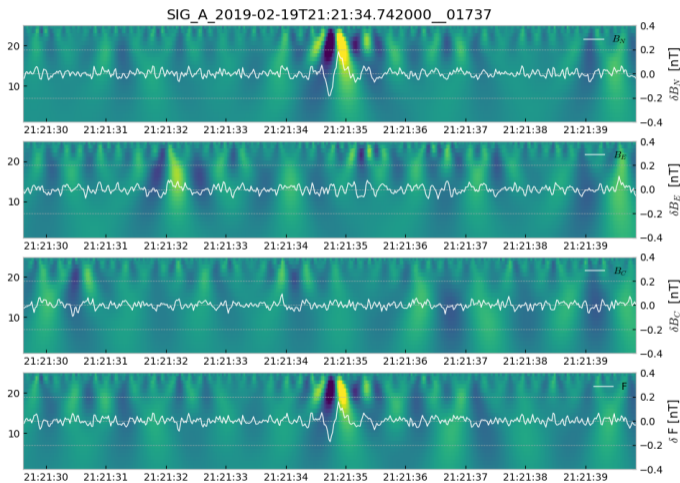
# Spectral characteristics - Is it a 1st mode of SR?

- ▶ The Schumann Resonances (SR) consist of a series of peaks in spectral power in the magnetic and electric field
- ▶ They arise from the continuous occurrence of equatorial lightning strikes
  - ▶ The SR are detectable on the ground using sensitive search-coil magnetometers.
  - ▶ Not confirmed with satellite magnetic field data.
  - ▶ So far detected only for one case on Swarm B.
  - ▶ For another series of events registered in the equatorial region in Africa on Alpha/Charlie no such confirmation.

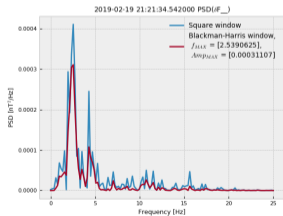
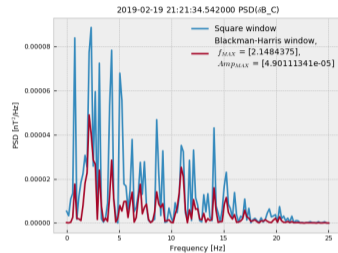
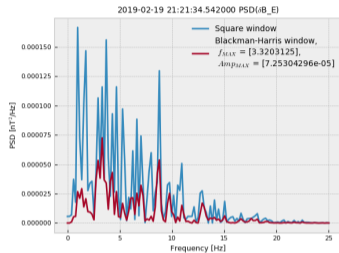
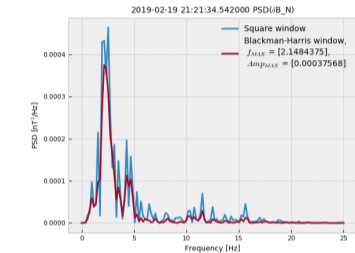


# Equatorial cases - African sector

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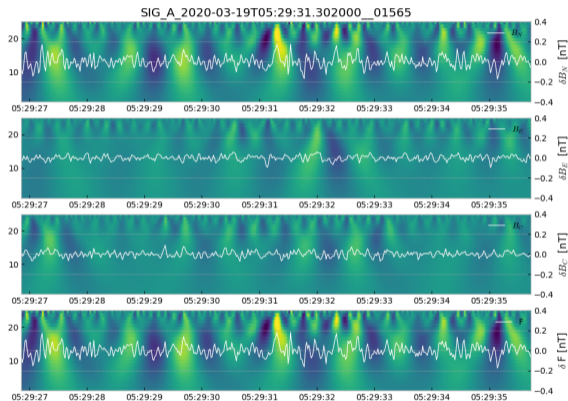


## Hypothesis:

Theoretical considerations suggest that the magnetic signature of SR may be detectable at satellite altitudes. Based on a series of examined cases, we should look for a signal that exhibits a sequence of spikes separated by 2-3 sec.

# Dayside registration

Swarm SIG\_A\_2020-03-19T05:29:31.302000\_\_01565



# Summary

- ▶ Detection of lightning signature with the VFM instrument is more probable when the satellite is passing through the active region - detection is more related to the source generating strong fluctuations (the concept of continuing current)
- ▶ Based on simplified model and defined geometrical conditions the distance between the source and the spacecraft projected on the ground should be around 400-600 km.
- ▶ Theoretical considerations suggest that the magnetic signature of SR may be detectable at satellite altitudes. The agreement between the maximum frequency and SR fundamental frequency seems to be a promising indicator for finding the confirmation.
- ▶ For a series of cases detected by Swarm more accurate verification of the origin of detected fluctuations can be obtained in a joint analysis with the Geo-stationary satellite GLM (Presentation by M. S.)