Searching for correlations between magnetic field variation on Swarm and atmospheric discharges observed by ELF ground stations

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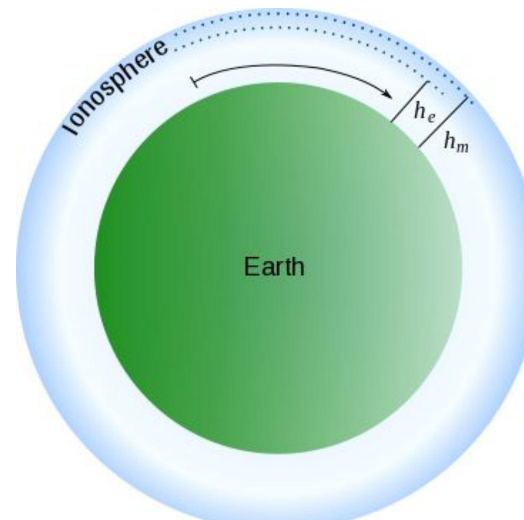
Source of ground-based ELF data

The data is provided by our system called World ELF Radiolocation Array (WERA), which consists of three ELF stations:

1. The Hylaty station in Poland (installed in 2005, upgraded in 2013)
2. The Hugo station in Colorado, USA (installed in 2015)
3. The Patagonia station in southern Patagonia, Argentina (installed on March 26, 2016)

-> Use of three stations on different continents allows us to measure strong atmospheric discharges occurring anywhere on Earth.



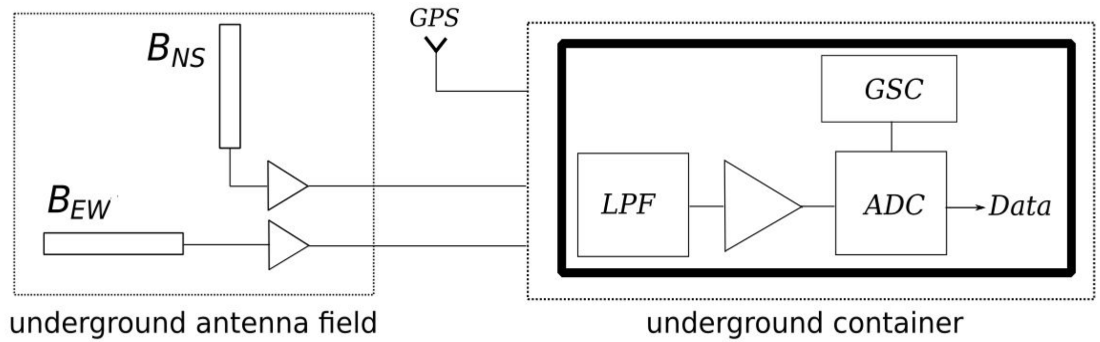
unimodal up to ~1.5kHz
very small attenuation rate

- Each station is equipped with a broadband magnetometer, composed of a receiver and two magnetic antennas
- The stations are fully automated and perform continuous recording

Ground-based measurements in the ELF range

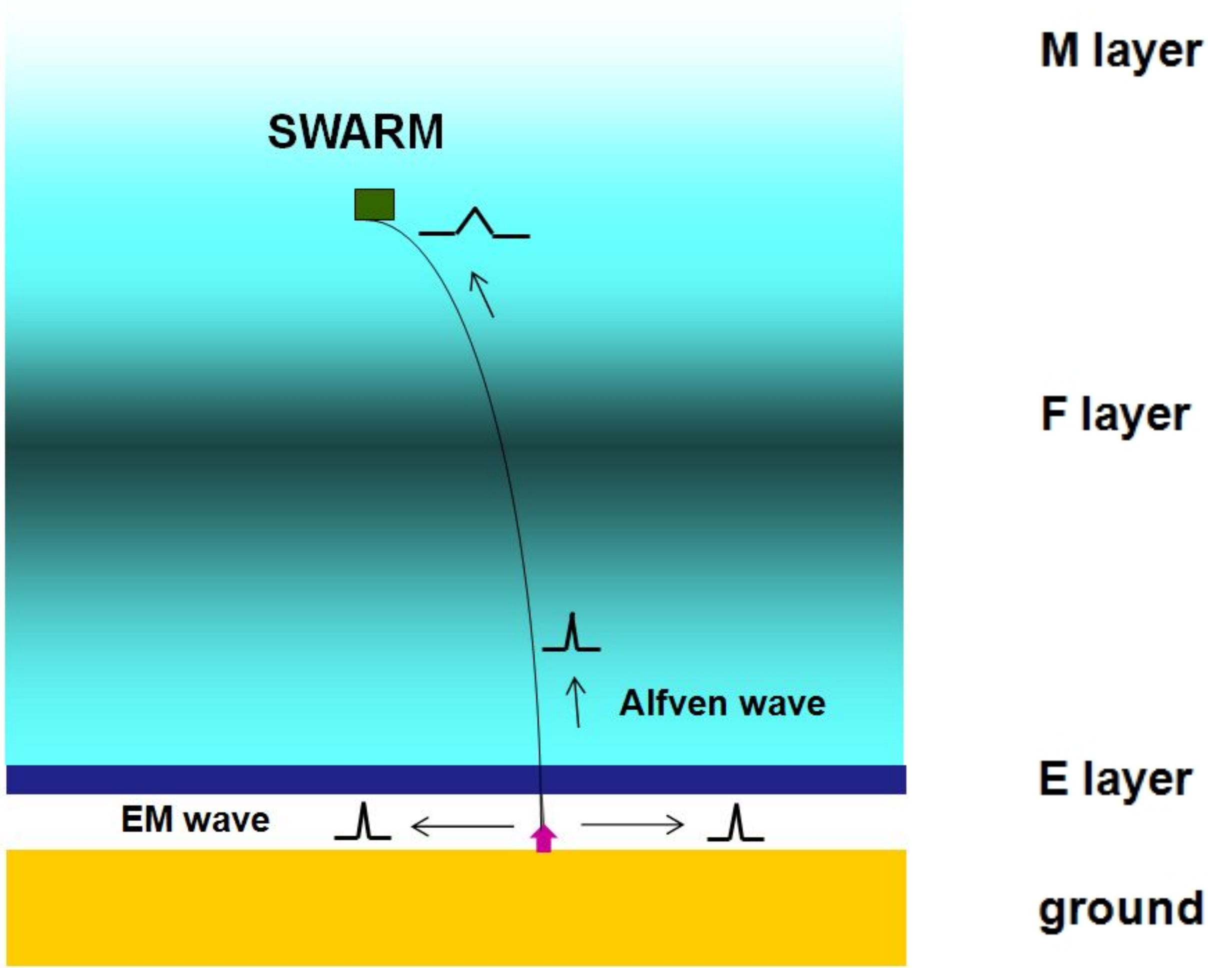
- Two magnetic antennas, NS and EW, and an ELF receiver,
- A remote area with low power line noise, and low noise in the lowest part of the spectrum (f<1 Hz)

Parameters of the WERA system
- frequency range 0.03 - 300 Hz
- sampling frequency 887 Hz
- sensitivity 0.04 pT/sqrt(Hz) at 10 Hz
- battery powered



Installaton of the Hugo ELF station in Colorado, USA, in May 2015

Wave phenomena associated with an atmospheric discharge



Model of Alfven wave generation by an atmospheric discharge

The waves are generated due to discontinuity of the parameters at the border of the atmosphere and the ionospheric E layer

The efficiency of the atmosphere-ionosphere wave coupling is determined by Hall and Pedersen conductivities at the altitude of E layer.

The existing models are based on full-wave solution of a set of equations describing the electromagnetic fields in the atmosphere and the field of magnetosonic and Alfven waves in the ionosphere $B_{\phi}(z,\rho,t)$

The model predicts the impulse amplitude of Alfven wave based on the charge moment of the discharge *p* [C m]

Due to non-uniformity of F layer (steep gradient of electron concentration at the altitudes of the order of 500 km), some portion of energy reflects back. The mechanism of penetration of the ionosphere-magnetosphere boundary strongly depends on frequency (the wave-reflection ratio reaches 0.9). Waves that return to E layer are reflected almost completely. Multiple reflections between the boundary regions lead to ionospheric Alfvena wave resonance (IAR). It can be observed at the frequencies up to a few Hz.

References

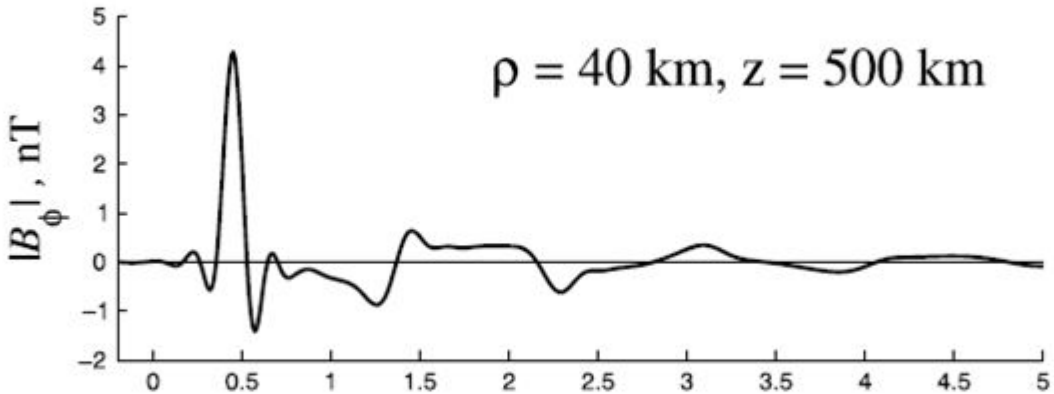
Surkov et al., 2005 – model based on a simplified layered ionosphere

Plyasov et al., 2012 – analytical model – layered ionosphere

Mazur et al., 2018 – generalization – full numerical model that uses IRI

Predictions of the model for mid lattitudes based on Mazur et al. 2018

1 – an atmospheric discharge generates the first impulse of Alfven wave



2 – the delay of the impulse is about 0.45 s

3 – the following waveform results from the waves reflected in the Ionospheric Alfven Resonator

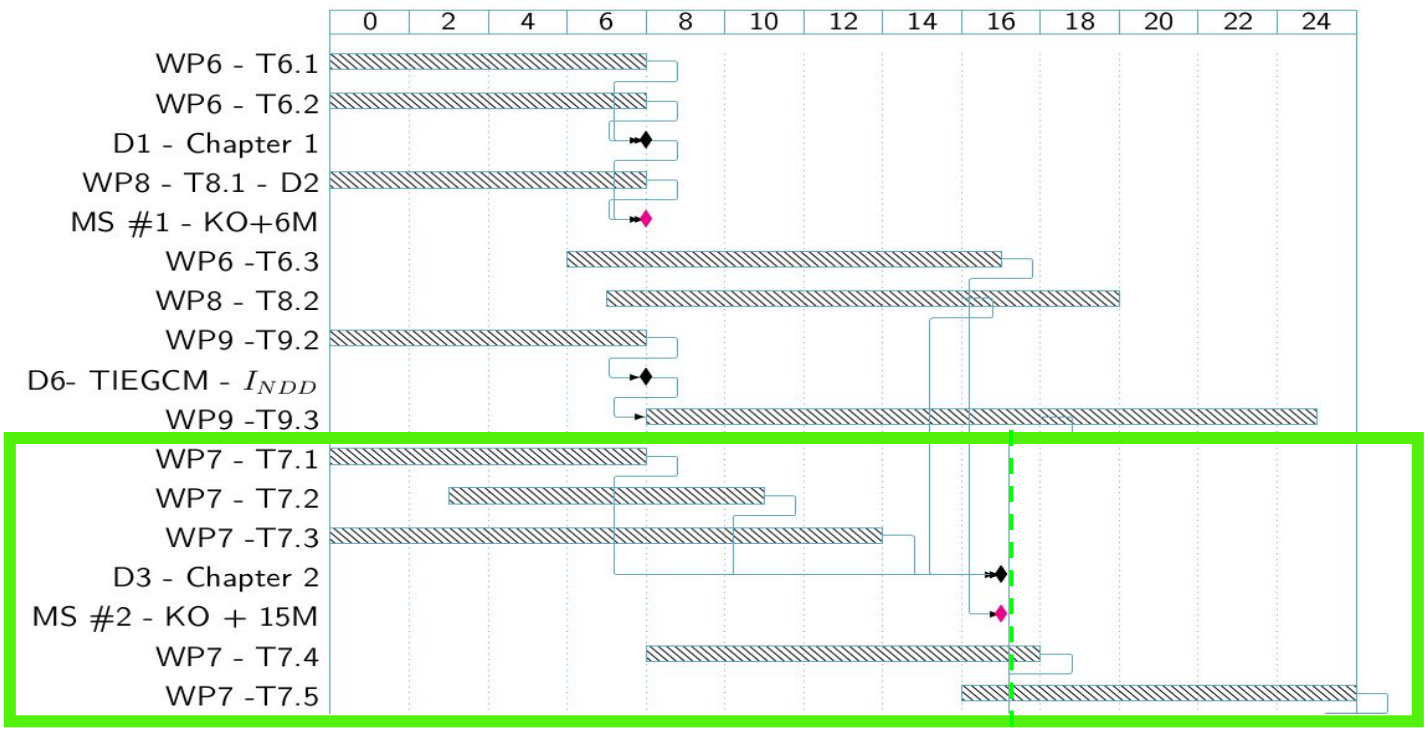
4 – field distribution inside the magnetic tube is proportional to the $exp(r/r_c)$ where r_c is the radius of the tube

5 – the radius of the tube depends on the wavelength of Alfven wave.

6 – during the night the radius of the tube it is about 3 times longer than during the day (at 10 Hz ~100 km and ~30 km, respectively)

WP7: Searching for coincidences and correlations between ground-based observations of atmospheric discharges and Swarm measurements.

T 7.1 Creating the first database of TLE events documented optically and electromagnetically with ground-based instruments
T 7.2 Searching for coincidence with Swarm locations
T 7.3 Mapping thunderstorm activity using ELF measurements
T 7.4 Analyzing thunderstorm activity in time windows corresponding to Swarm locations
T 7.5 Updating the database of TLE events and searching for coincidence with Swarm locations (>900 TLEs)



Schedule for WP7 presented in the proposal

WP7: Searching for coincidences and correlations between ground-based observations of atmospheric discharges and Swarm measurements.

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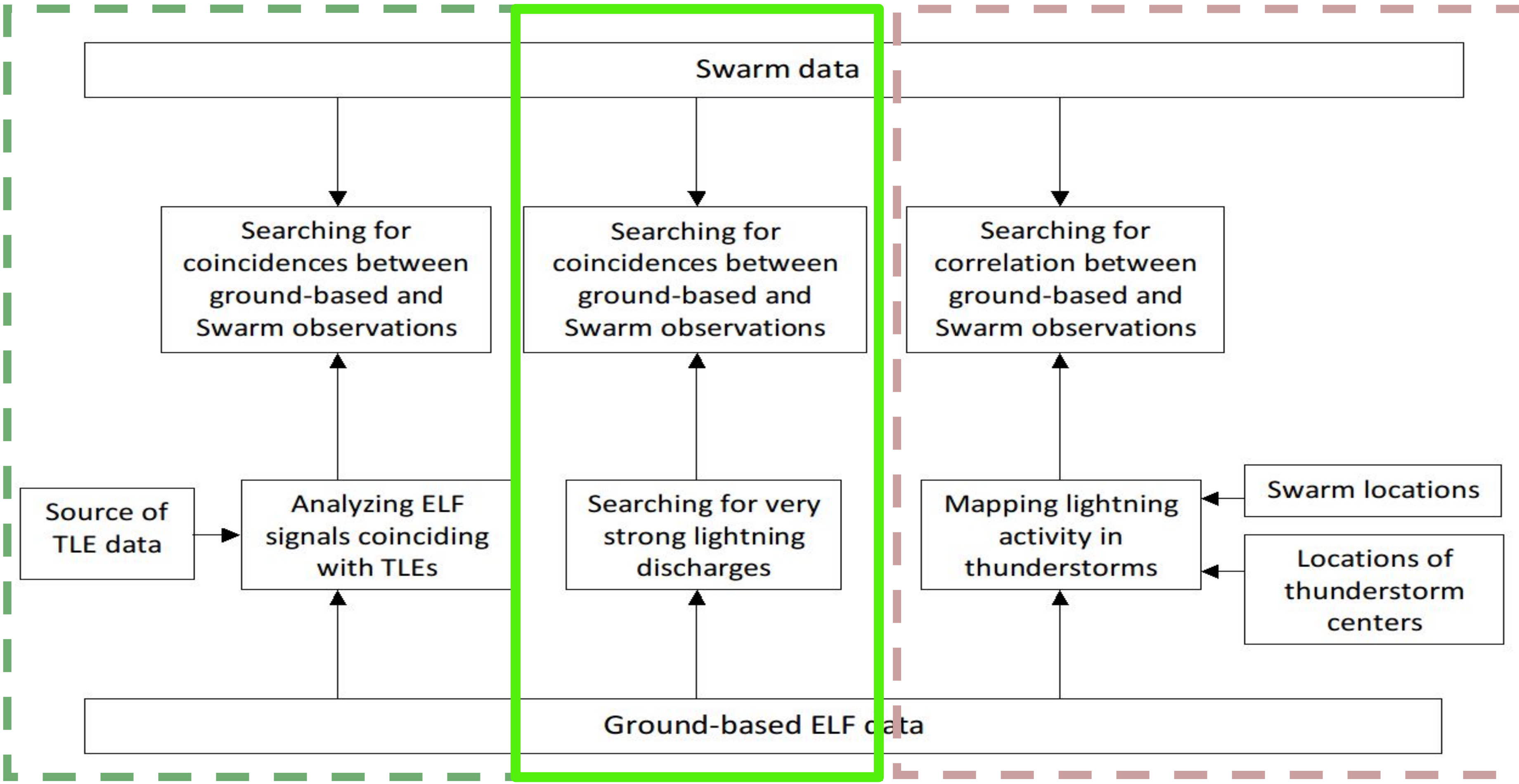
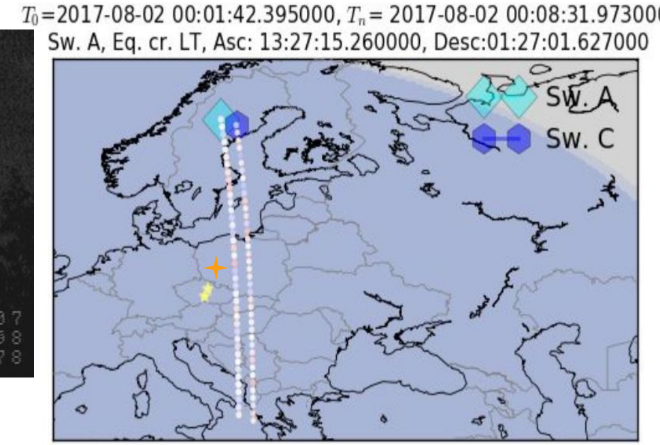
- Within T 7.1 we created a database of 700 TLEs that were documented in video. Each event was associated with an ELF signature and the location.
- Within T 7.2 we were looking for coincidence with Swarm locations and found it in several cases.
- For the strongest discharge, we found a very clear signal on Swarm. This was an important step forward in the project, because it allowed us to confirm the signature associated with lightning and run an automated search for such signatures
- Within T 7.3 we implemented an algorithm for mapping thunderstorm activity using ELF measurements. The algorithm has been debugged and optimized. It has been used in T 7.4 to analyze thunderstorm activity in time windows corresponding to Swarm locations

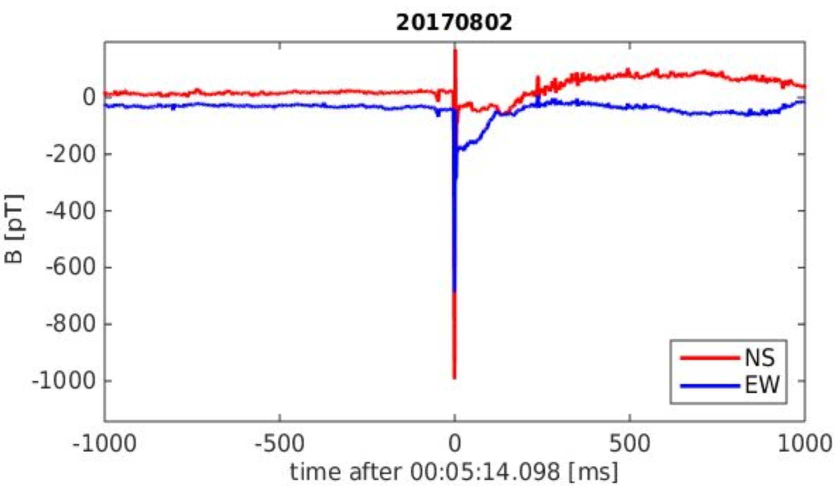
WP7: Searching for coincidences and correlations between ground-based observations of atmospheric discharges and Swarm measurements.



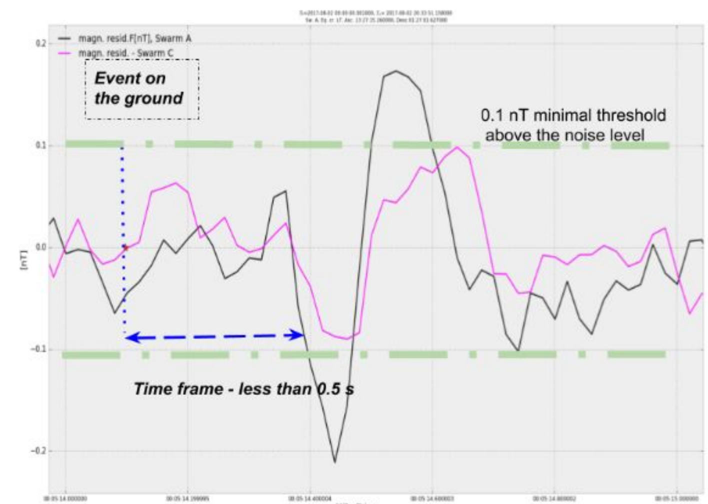
Our first successful detection of lightning associated with a TLE on Swarm

A sequence of sprites recorded by Martin Popek



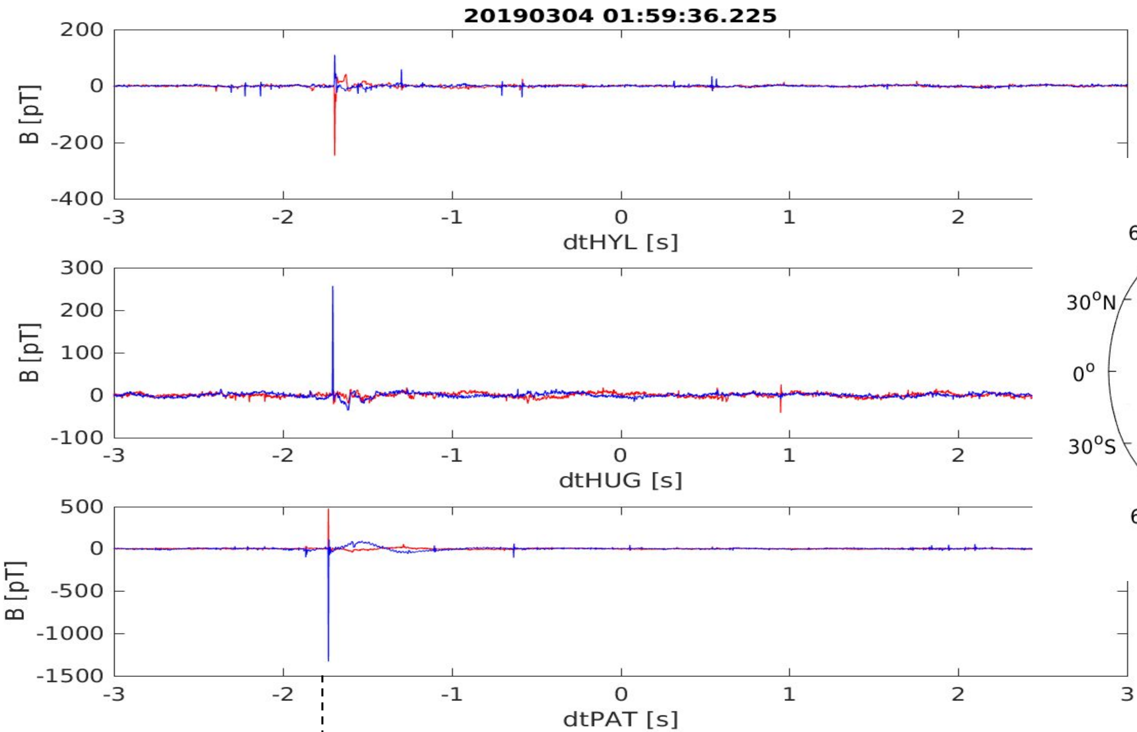


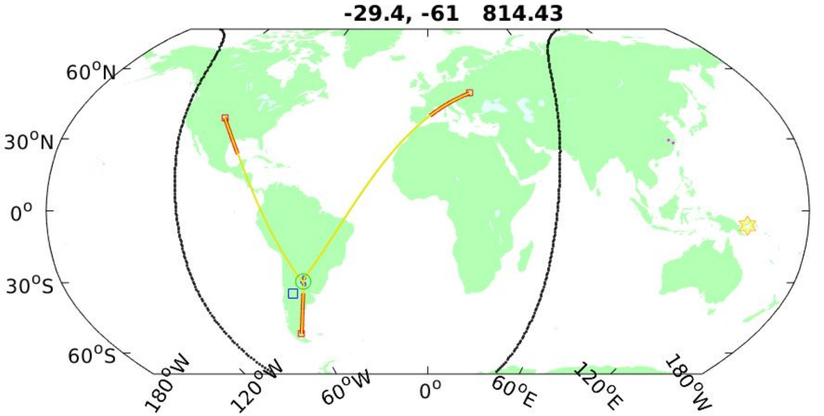
The north-south and east-west magnetic field components associated with the TLE, recorded by the Hylaty ELF station on 2 August 2017.
CMC=4870 C km, iCMC=400 C km



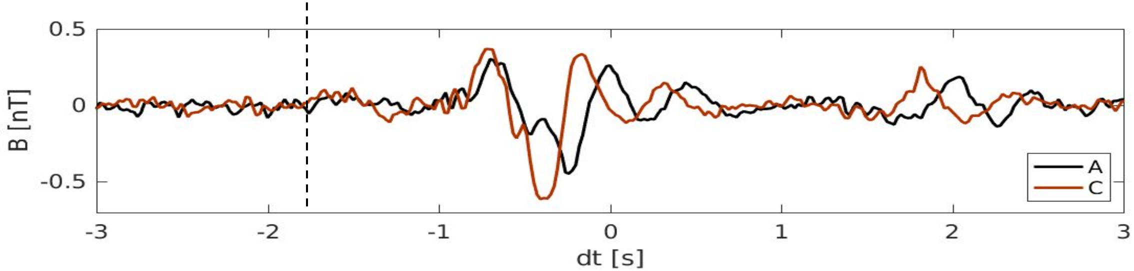
Signature of the discharge on Swarm A & C

Another strong lightning in Patagonia detected on Swarm



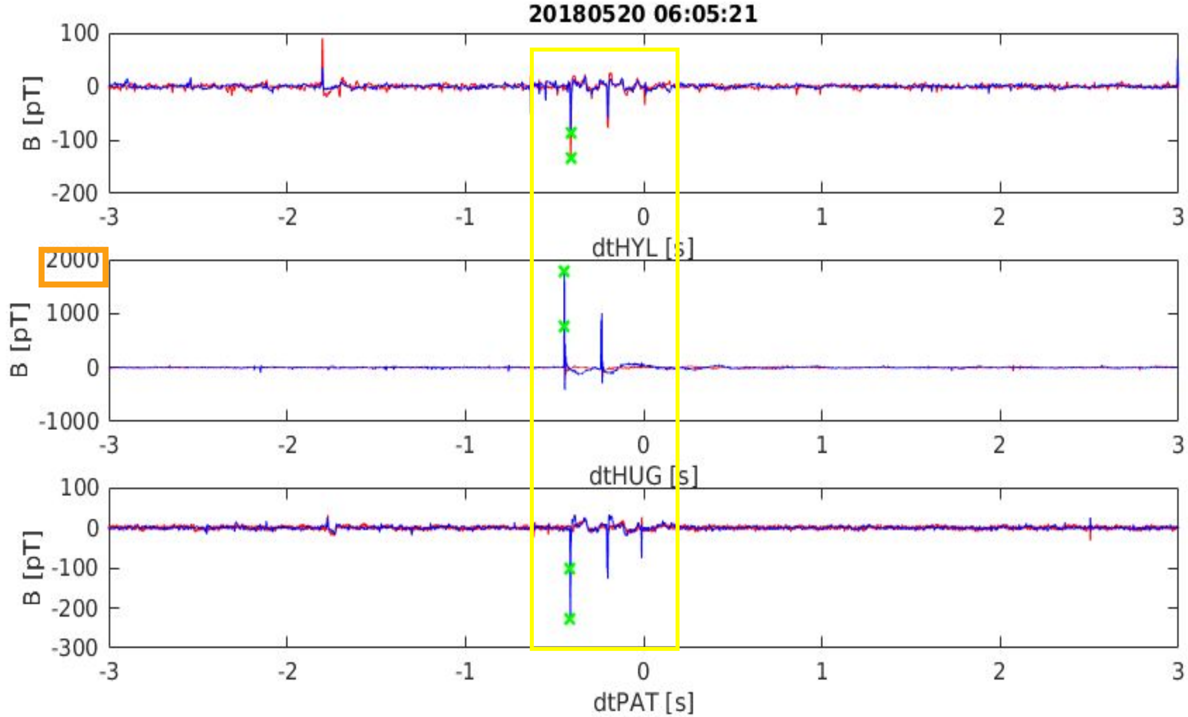


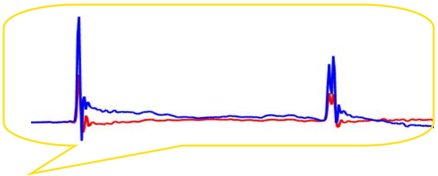
Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC close to 1500 C km)

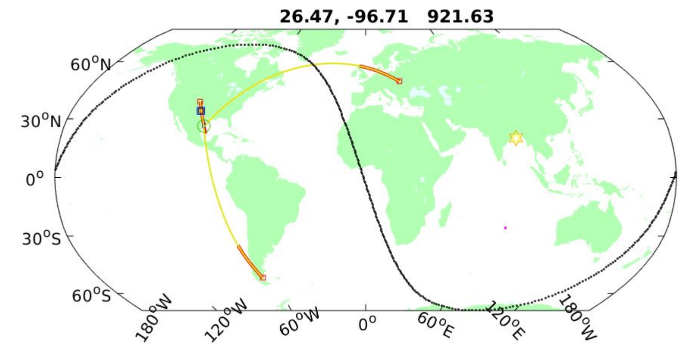


Magnetic field recorded on Swarm A and C

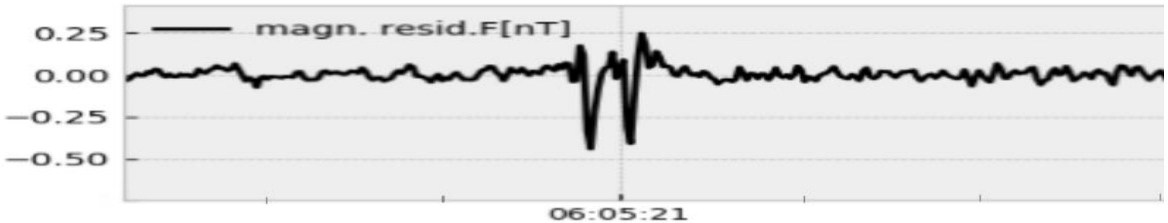
Strong lightning discharges in Oklahoma detected on Swarm





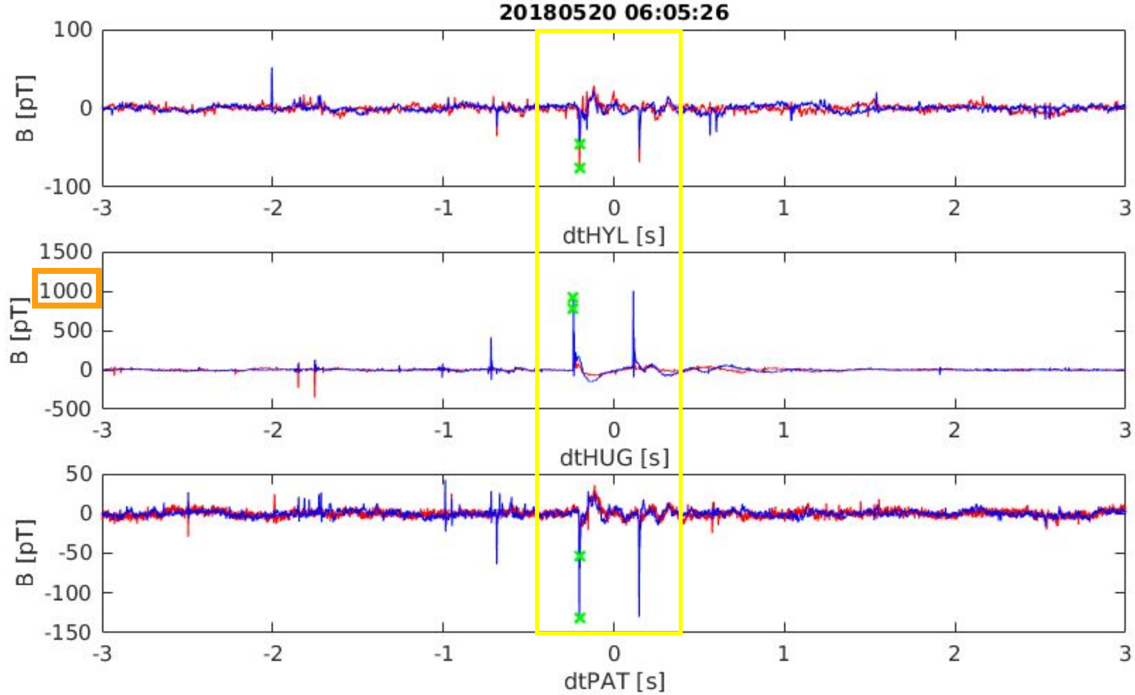


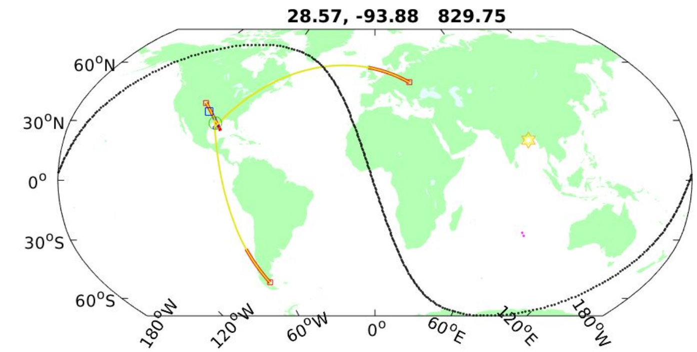
Magnetic field component recorded by the Hylaty, Hugo, and Patagonia stations
(first: iCMC> 500 C km, second: two discharges each with iCMC < 500 C km)



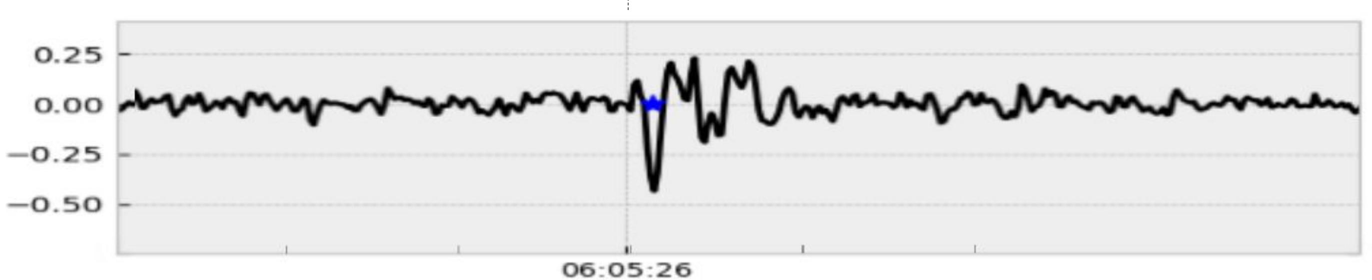
Magnetic field recorded on Swarm C

Strong lightning discharges in Oklahoma detected on Swarm



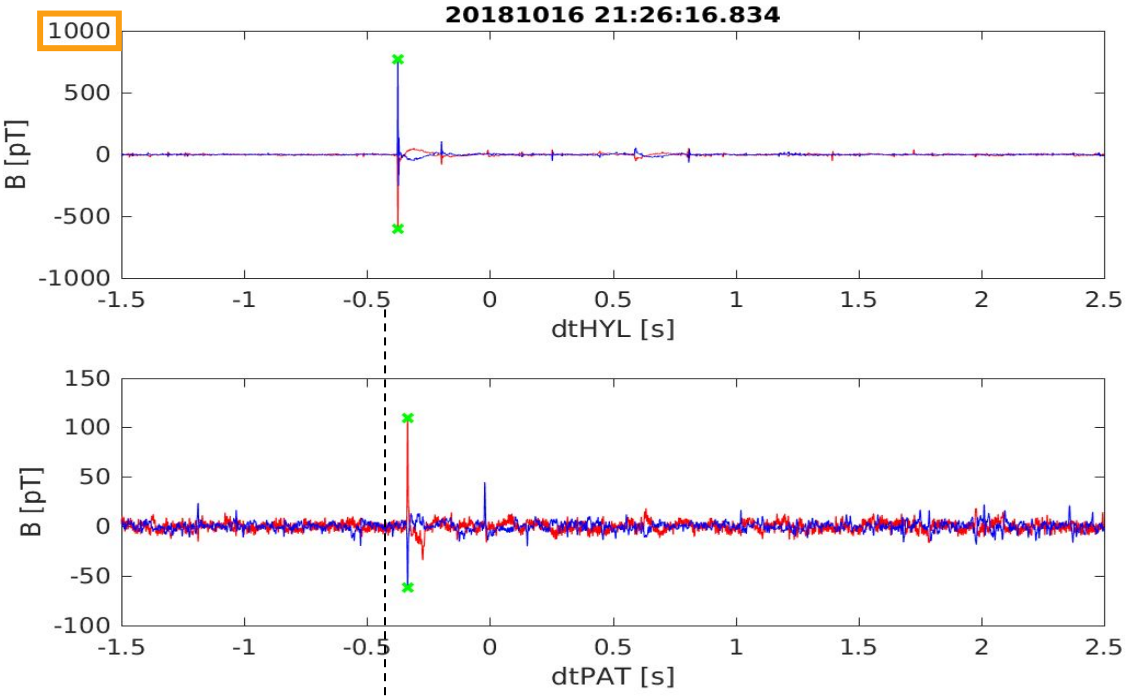


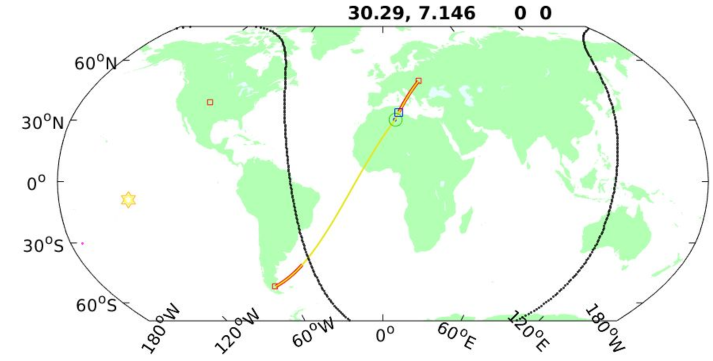
Magnetic field component recorded by the Hylaty, Hugo, and Patagonia stations
(iCMC in both cases close to 500 C km)



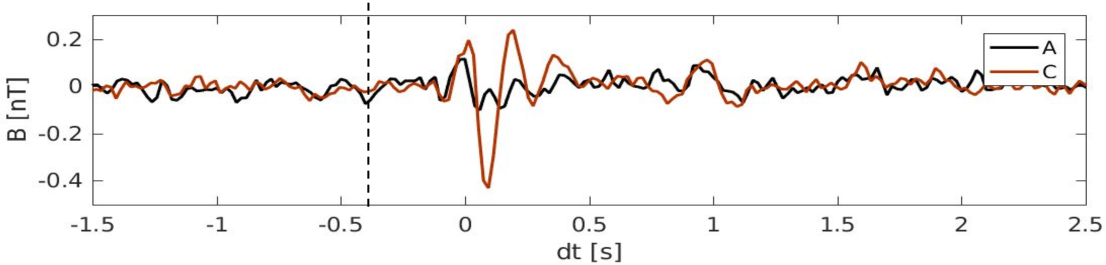
Magnetic field recorded on Swarm C

Strong lightning in the Mediterranean detected on Swarm



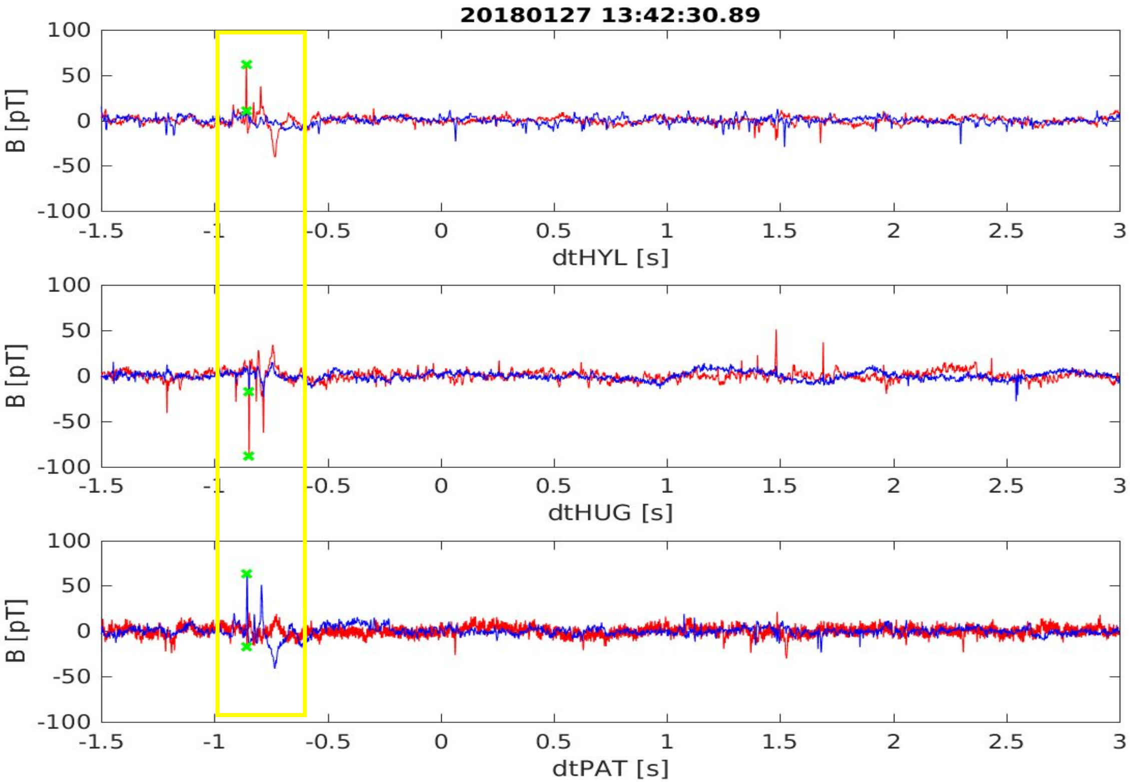


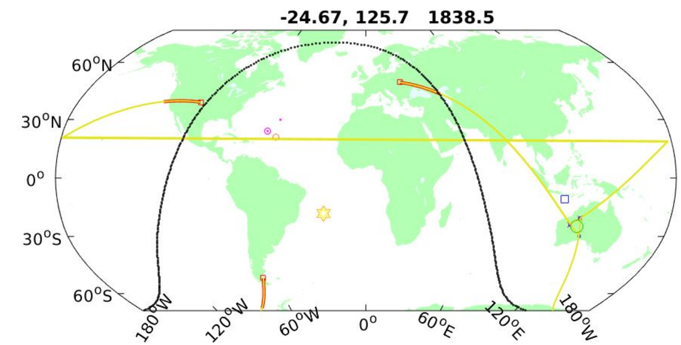
Magnetic field component recorded by the Hylaty and Patagonia stations (iCMC close to 1000 C km)



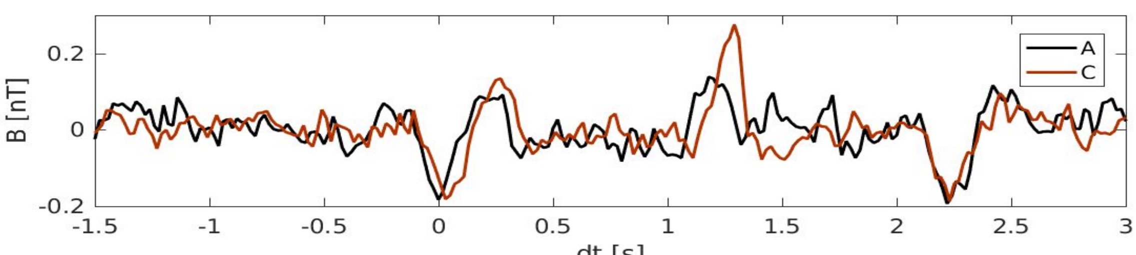
Magnetic field recorded on Swarm A and C

A sequence of lightning discharges in Oceania



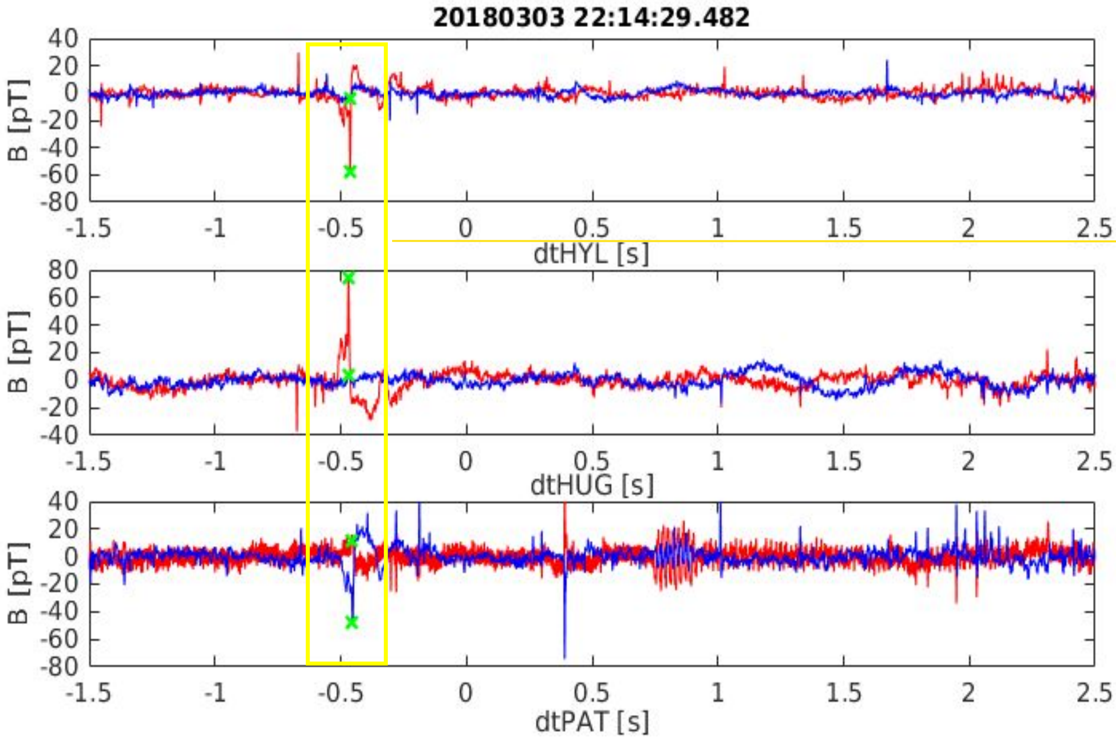


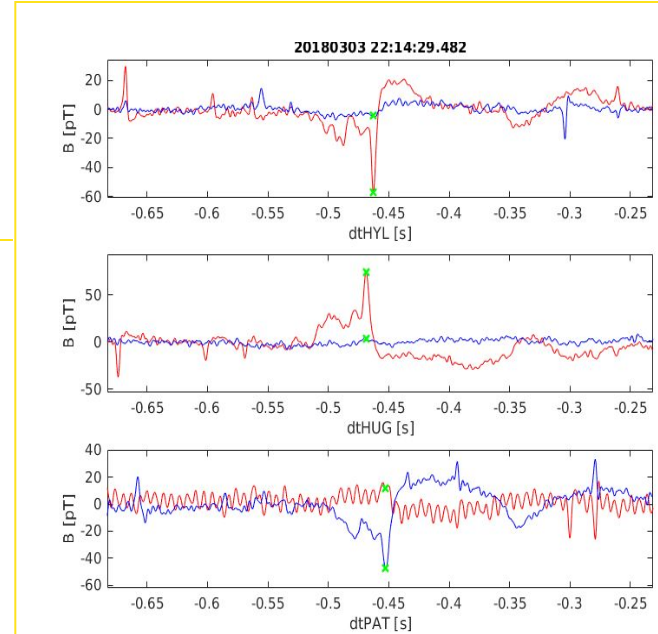
Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC of the first discharge > 500 C km)



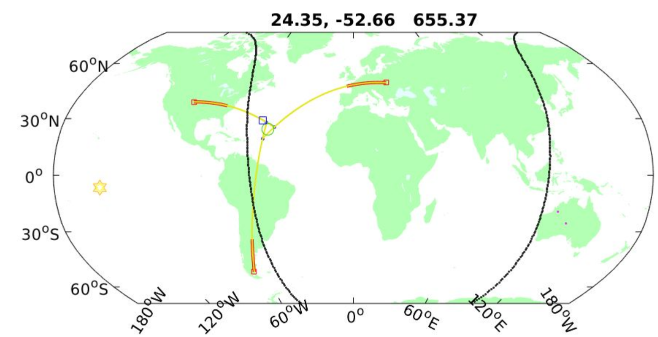
Magnetic field recorded on Swarm A and C

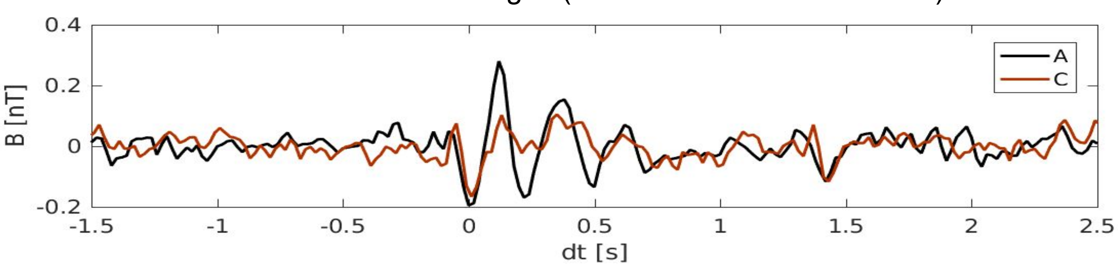
A sequence of lightning discharges in central America





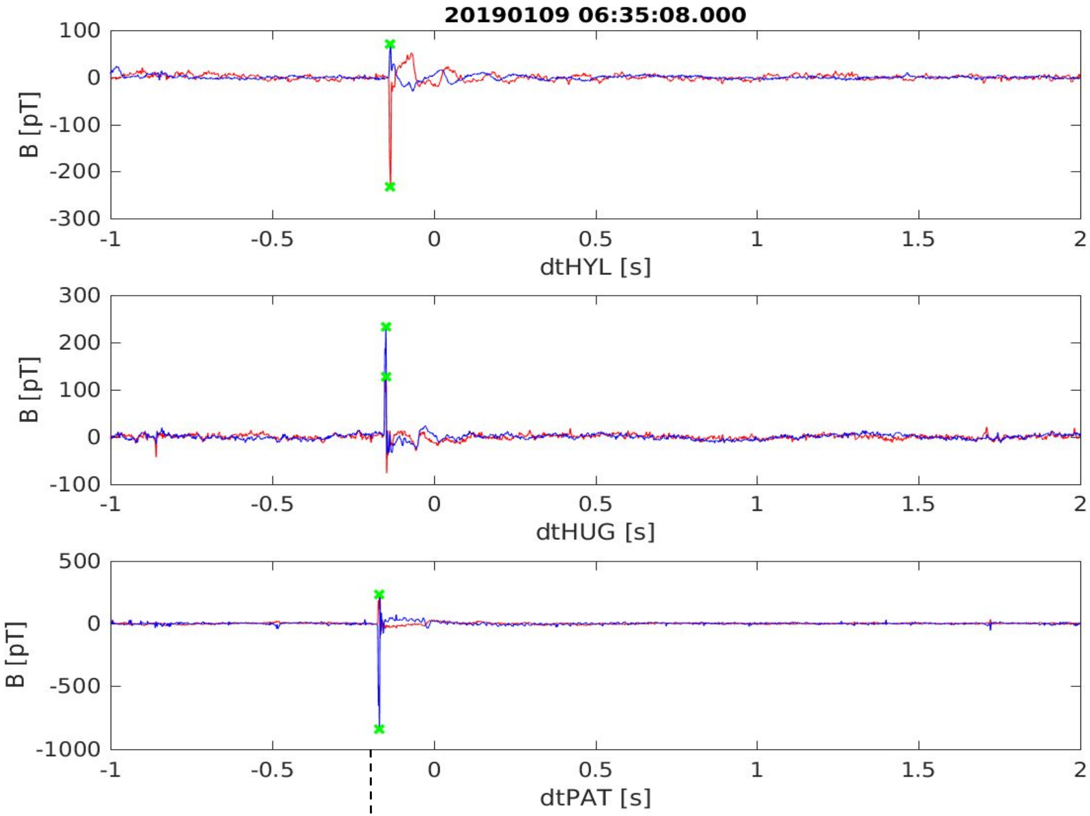
Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations after a series of weak discharges (each with iCMC < 200 C km)

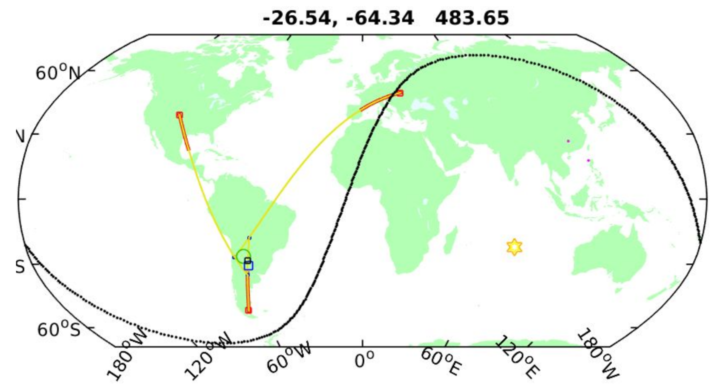




Magnetic field recorded on Swarm A and C

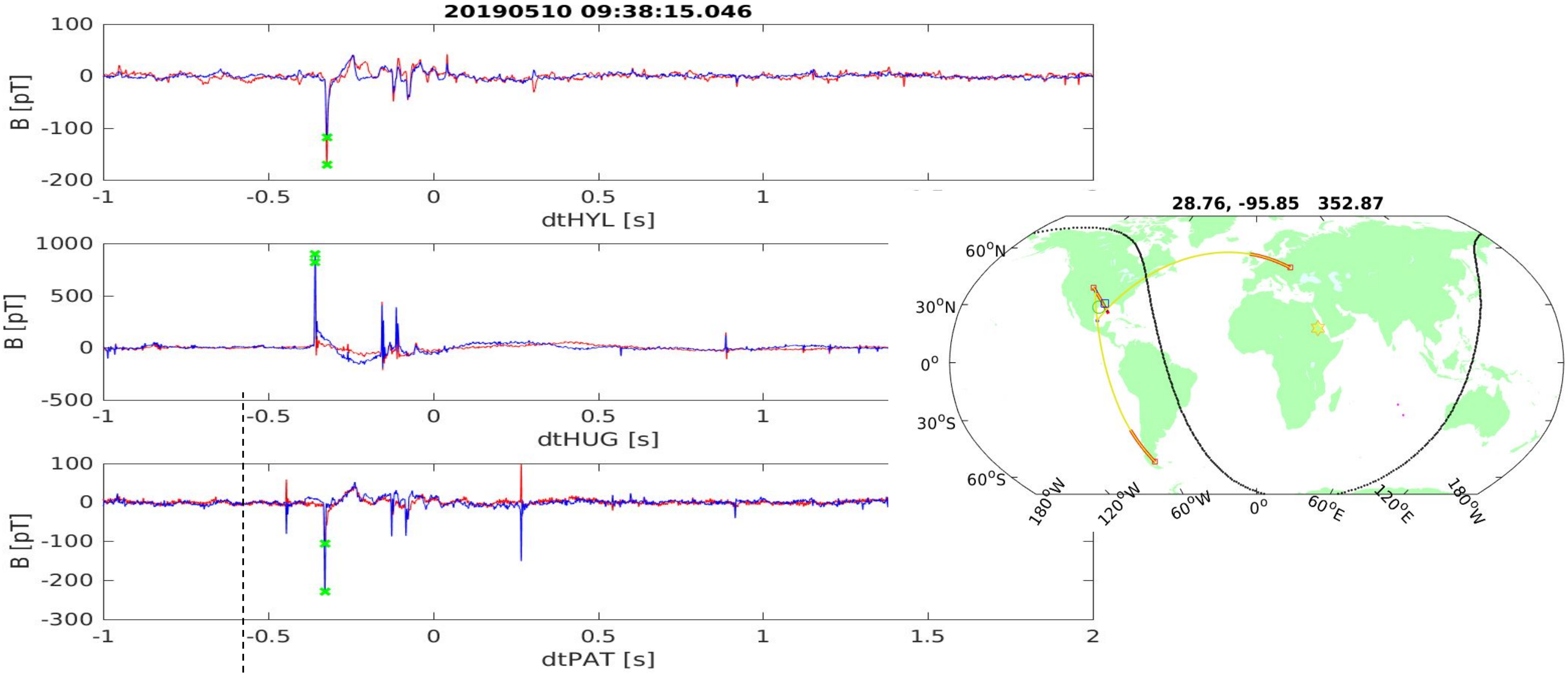
Strong lightning discharge in Patagonia detected on Swarm



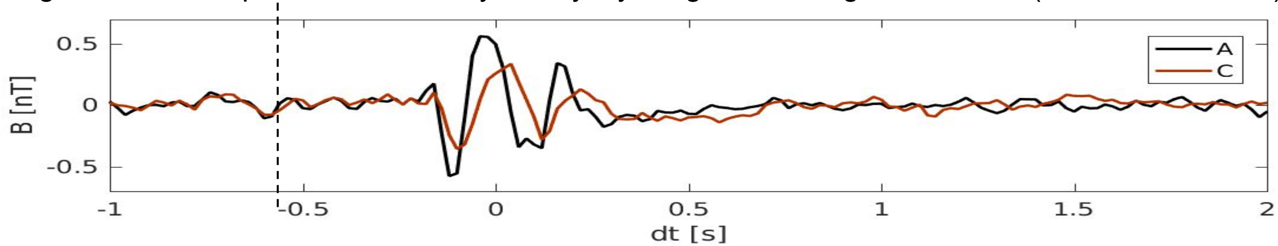


Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC close to 1000 C km)

A sequence of lightning discharges in North America detected on Swarm

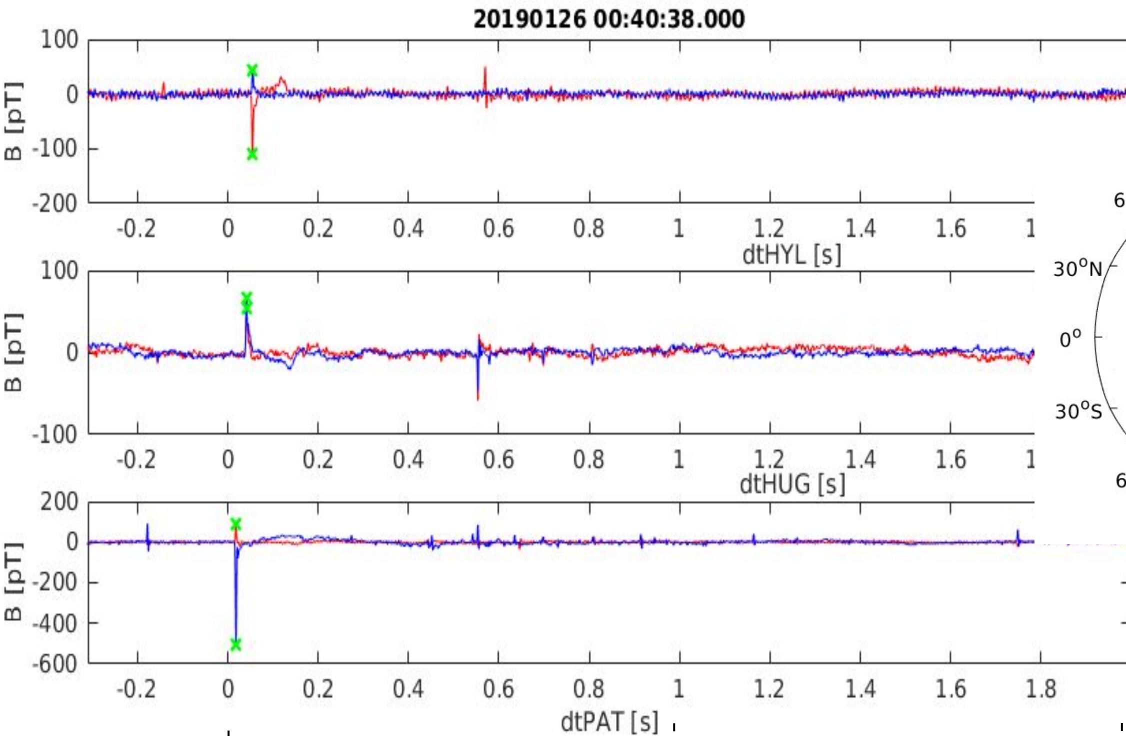


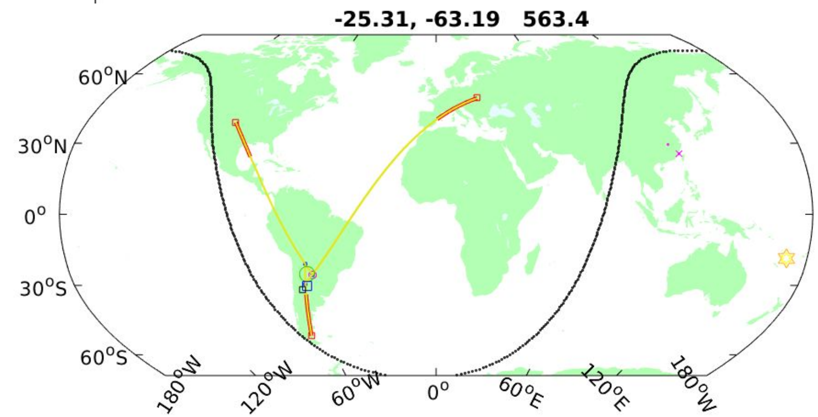
Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC > 500 C km)



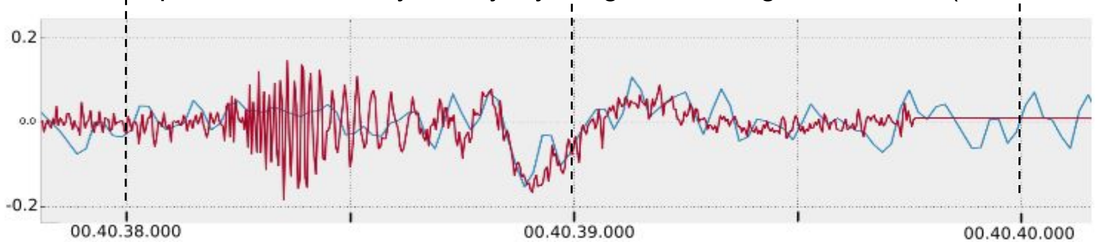
Magnetic field recorded on Swarm A and C

Vector magnetometer vs. scalar magnetometer on Swarm





Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC close to 500 C km)



Signal associated with lightning recorded on Swarm by the **scalar** and **vector** magnetometer

Conclusions

- A strong lightning that triggered a TLE over Poland allowed us to define a response expected on Swarm in the magnetic field recording
- Using automated search, a large number of similar signatures has been found.
- An initial threshold of 0.1 nT led to many false detections triggered by noise and signals not associated with lighting
- With the threshold of 0.2 nT we were able to find coincidence in most cases.
- The most interesting events will be used in case studies.
- The database will also be updated with 900 new cases of TLEs documented in video