Ground-based measurements of atmospheric discharges detected on Swarm

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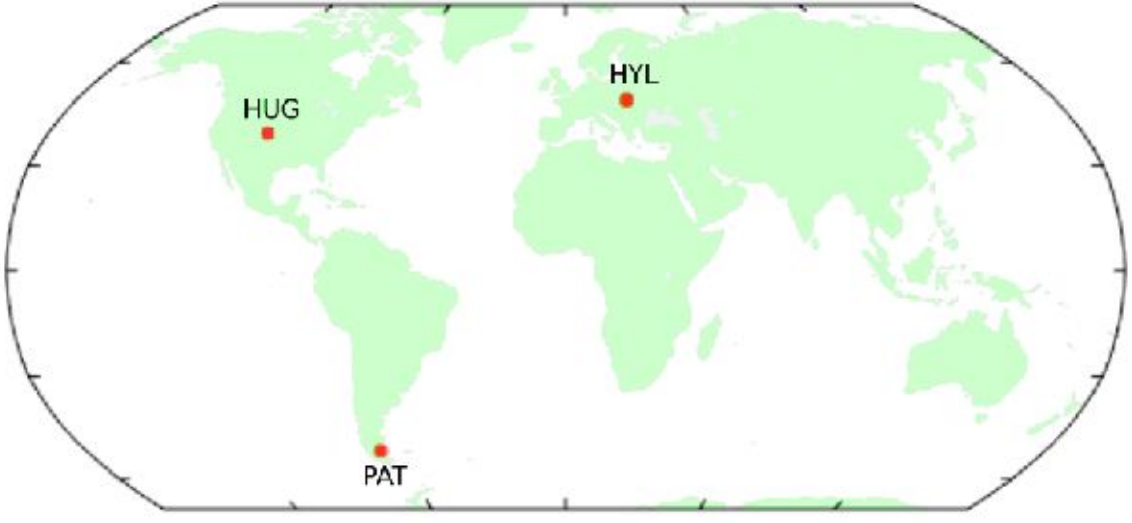
Source of ground-based ELF data

The ELF data was 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 Argentina (installed on March 26, 2016)

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



The stations are fully automated and perform continuous recording

Ground-based measurements in the ELF range

At each station we measure two magnetic field components: north-south (NS) and east-west (EW)

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

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

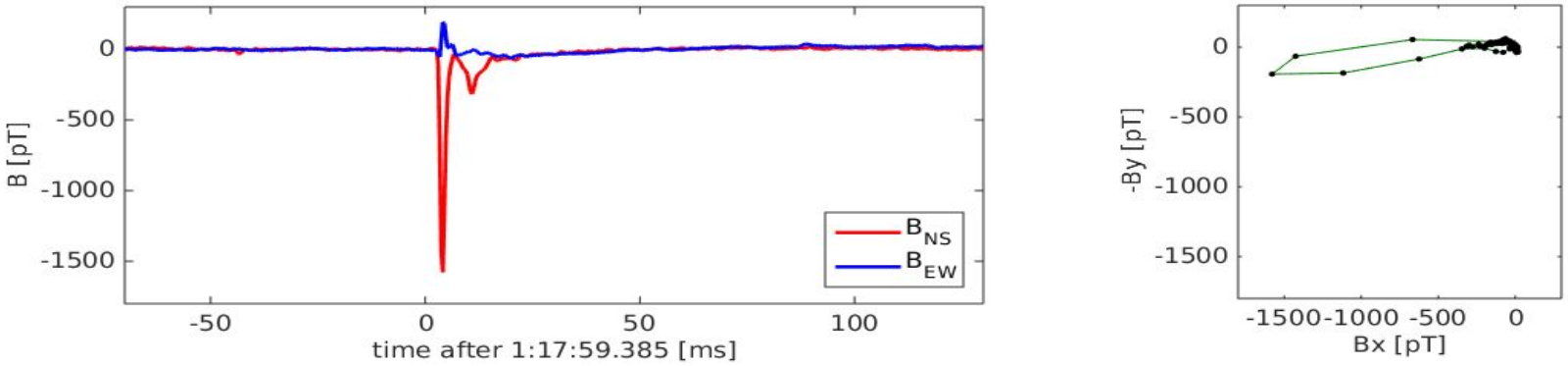
Installation of the Patagonia ELF station in Patagonia, Argentina, March 2016

Ground-based TLE data

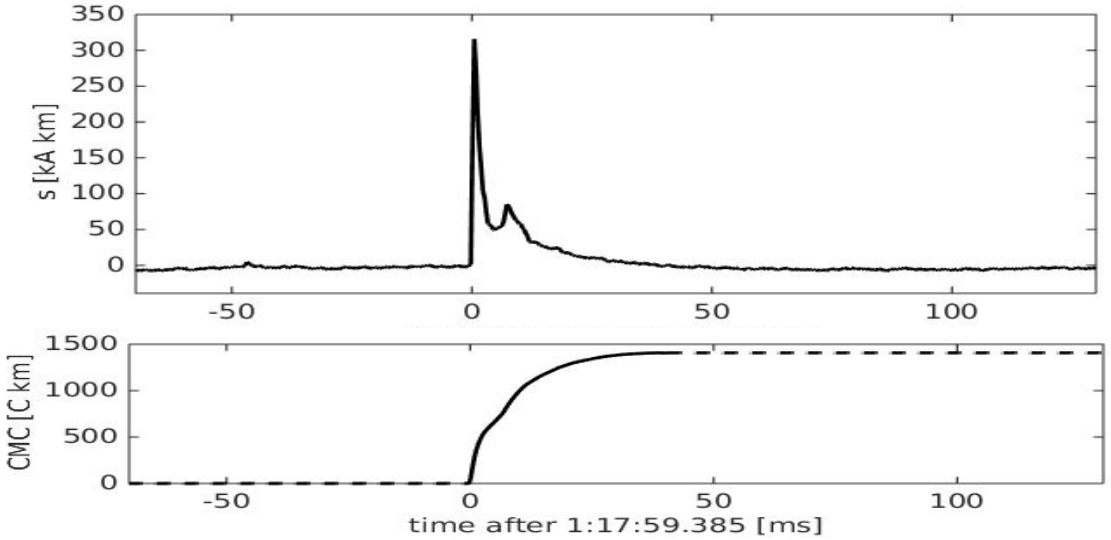
- The main source of TLE data for Europe was an observation site located in Nydek, Czech Republic (49.6682N, 18.7692E, 475m a.m.s.l.)

System specifications
Four cameras Watec 910hx
Lens Computar 3,5-10/1,0, Computar 4,5-12/1,2 and Goyo 3-8/0,95
Zoom lens Tevidon 25/1,4, Sigma 35/1,4 and Super Takumar 50/1,4
Time information: Internet time (TimeMemo) and GPS time (TIM-10)
Analog-to-digital converter:Dazzle DVC100(107)
Camera position: manually controlled
Observer: Martin Popek

A video frame showing a sprite that occurred on 16 August 2017 at 01:17:59 UT,
The video was recorded in Nydek, Czechia, from the distance of 467 km

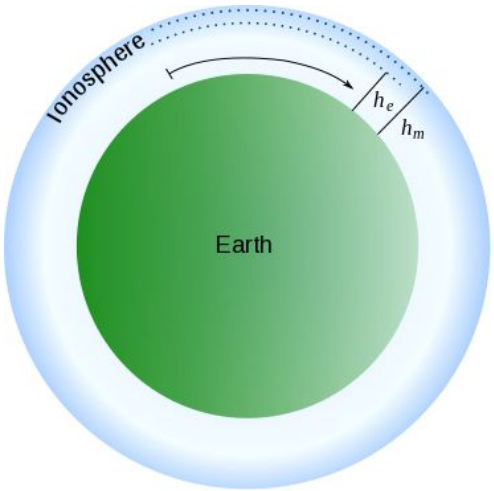


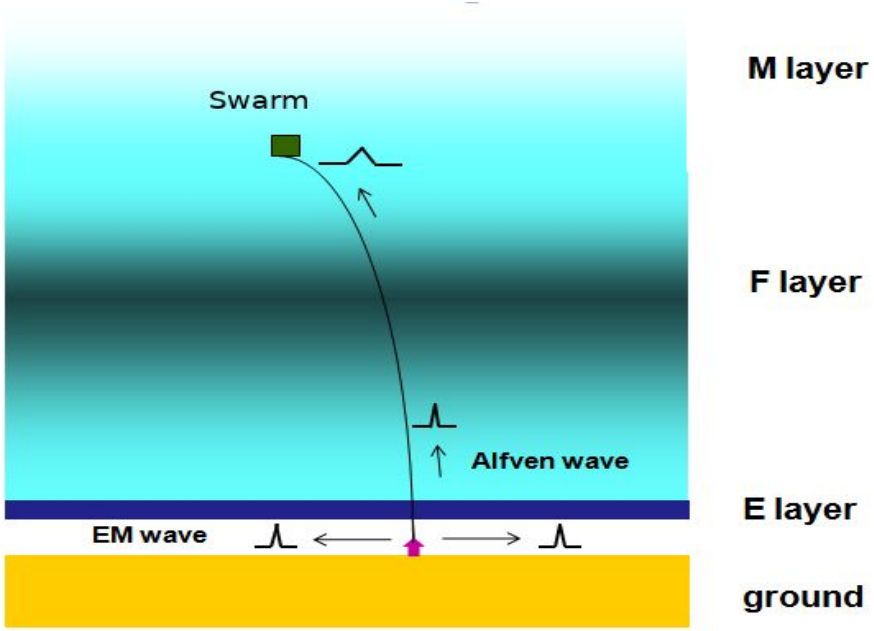
The north-south and east-west magnetic field components associated with this sprite event.
The distance from the ELF station was of 733 km.



Reconstructed current moment waveform associated with the sprite event (top) and the charge moment change (bottom).

Searching for coincidence between ground-based observations of atmospheric discharges and Swarm measurements





The amplitude of the ELF wave recorded on the ground is proportional to the charge moment of the discharge:

$$B_{peak} = C\,p \quad [\mathrm{pT}]$$

The coefficient C depends on the propagation channel, the distance from the source, and the receiver transfer function.

The amplitude spectral density measured on Swarm is proportional on the charge moment of the discharge:

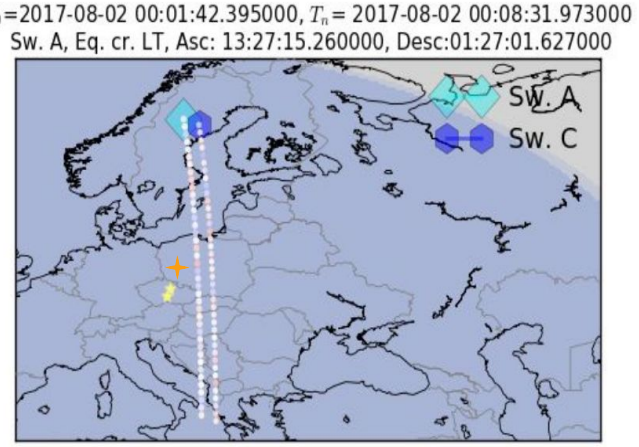
$$B_A(p) = \beta \cdot p \quad [\mathrm{pT}/\sqrt{\mathrm{Hz}}]$$

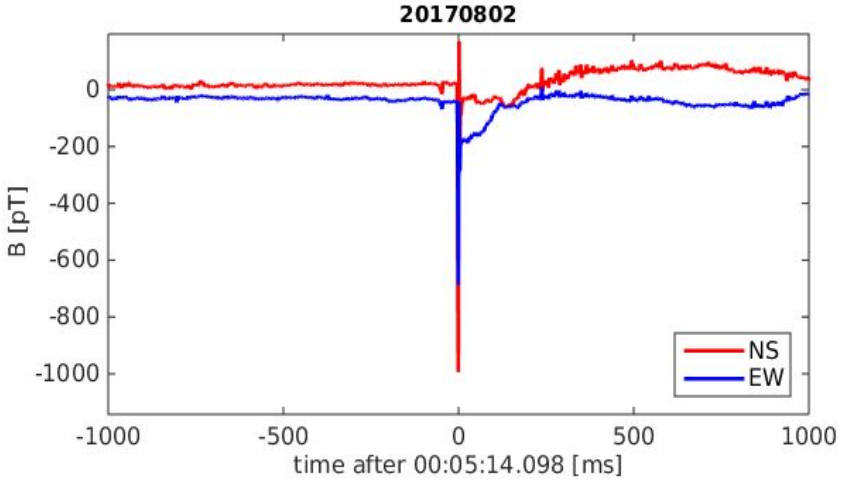
The efficiency of the atmosphere-ionosphere wave coupling is determined by Hall and Pedersen conductivities at the altitude of E layer.
The conversion coefficient β is smaller during the day than at night.

- During the project Martin Popek recorded 2000 TLEs.
- We found coincidence with Swarm location in only a few cases, and in only one case Swarm was close enough to record a convincing signal.
- The recorded signature allowed us to use a sattelite-to-ground approach to find a large number of similar signatures and verify with the ground instruments that they coincide with lightning.
- The most interesting events were used in case studies.

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

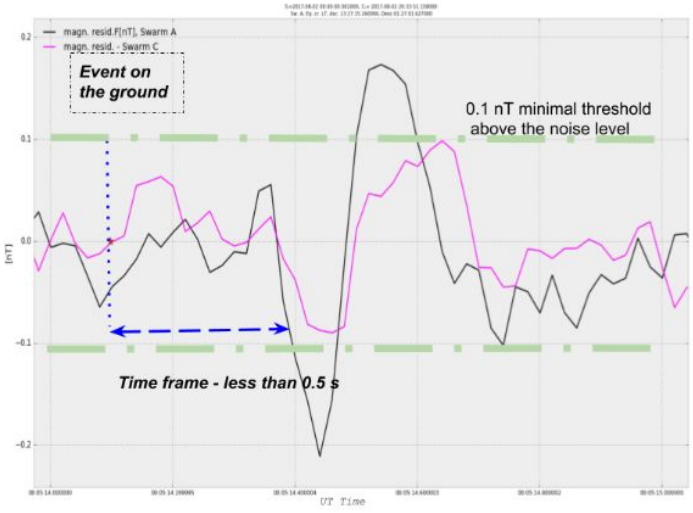
A sequence of sprites recorded by Martin Popek





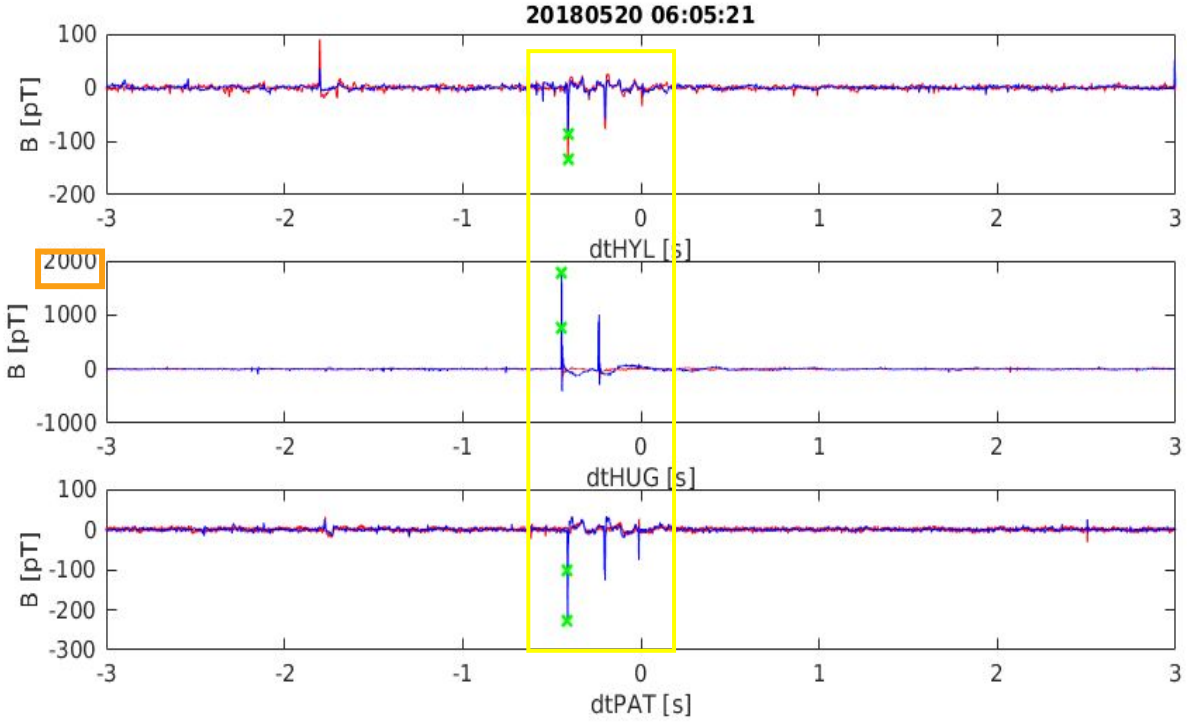
The north-south and east-west magnetic field components associated with the TLE, recorded by the Hylaty ELF station on 2 August 2017.

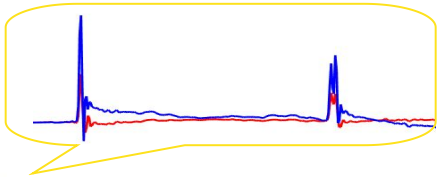
CMC=4870 C km, iCMC=400 C km

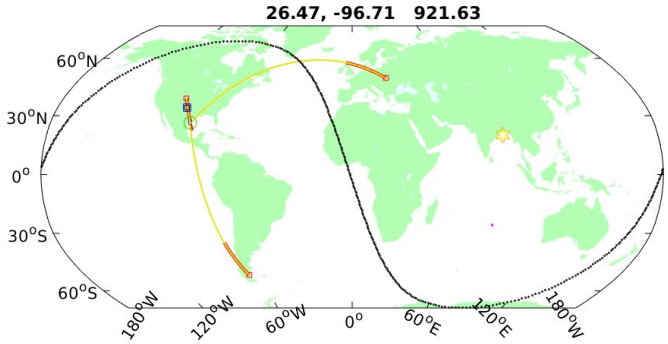


Signature of the discharge on Swarm A & C

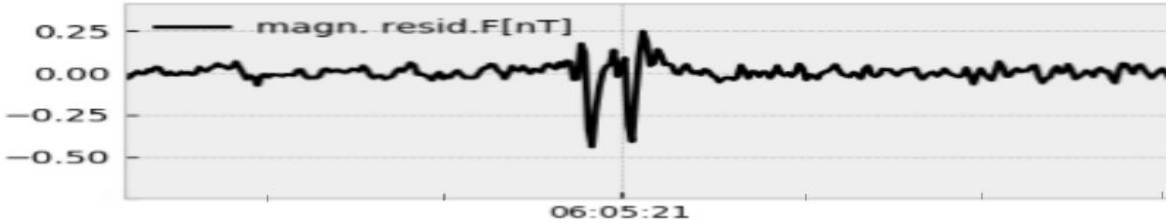
Strong lightning discharges in Oklahoma detected on Swarm





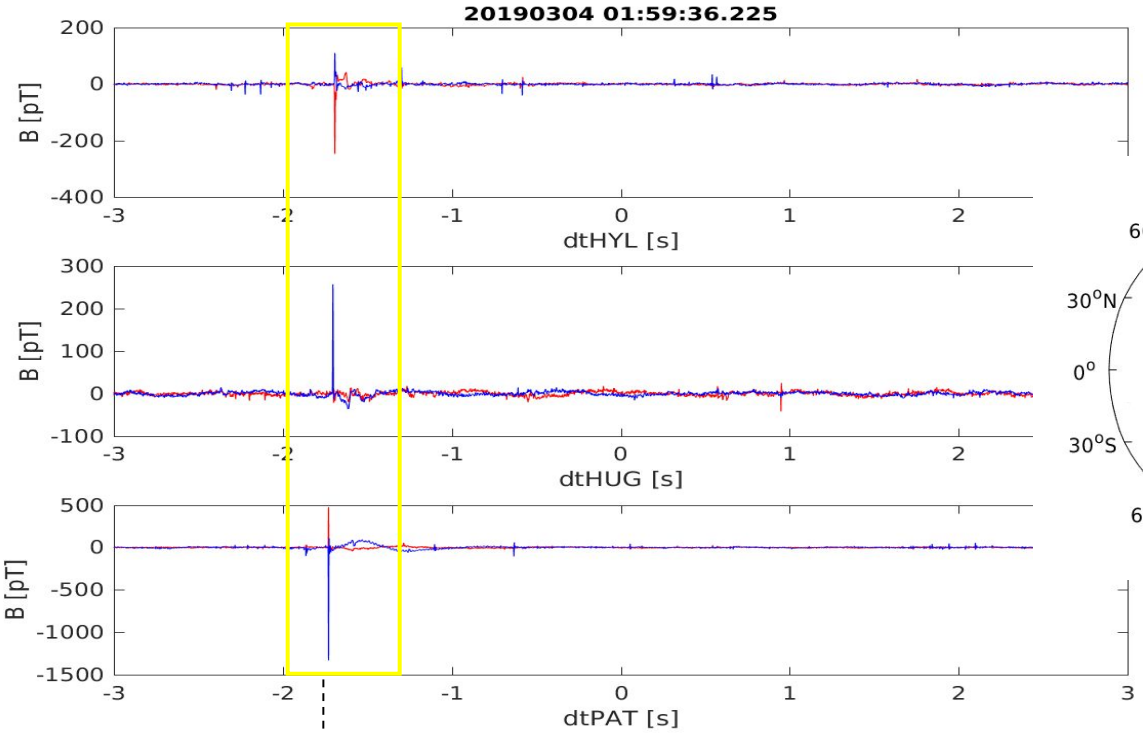


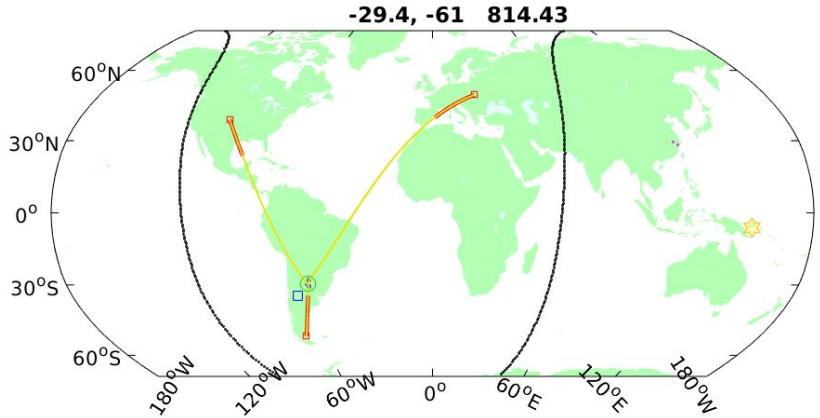
Magnetic field component recorded by the Hylaty, Hugo, and Patagonia stations
(first: iCMC=~700 C km, second: two discharges each with iCMC of about 350 C km)



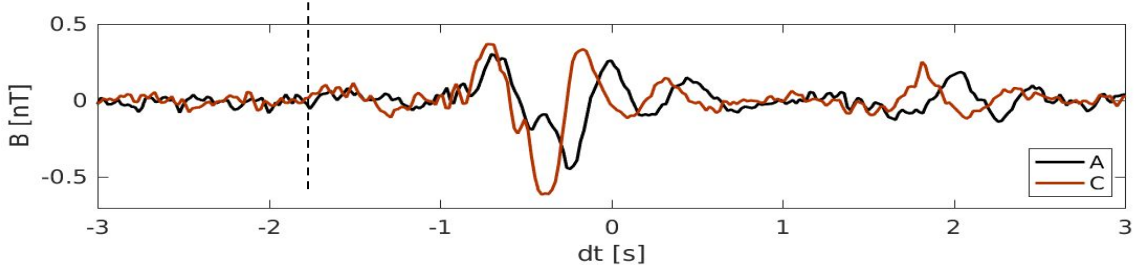
Magnetic field recorded on Swarm

Strong lightning in South America detected on Swarm



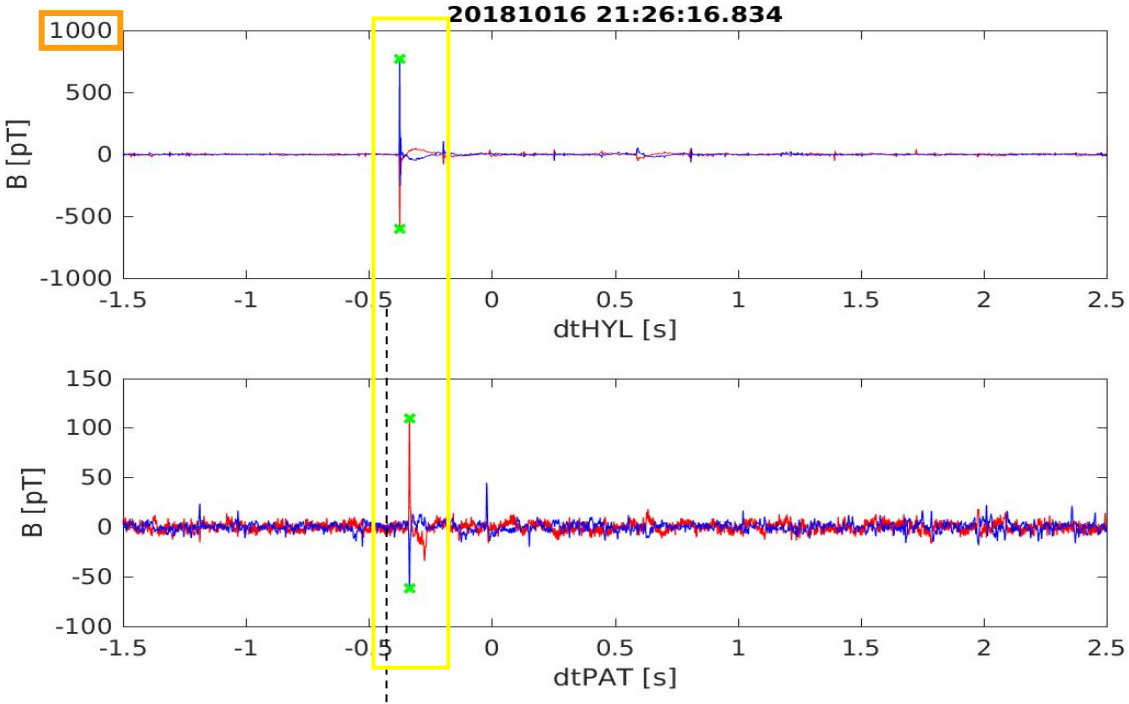


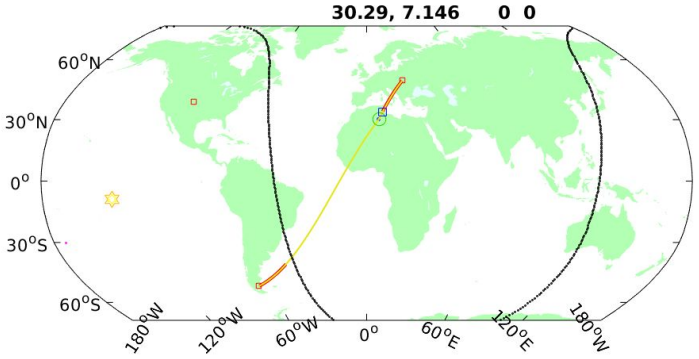
Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC~=1500 C km)



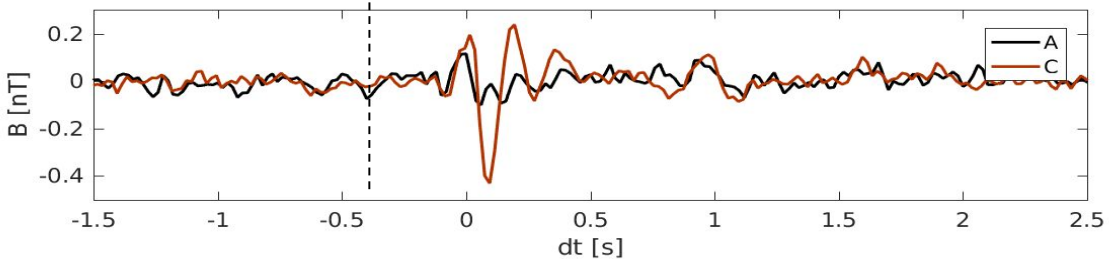
Magnetic field recorded on Swarm A and C

Strong lightning in North Africa detected on Swarm



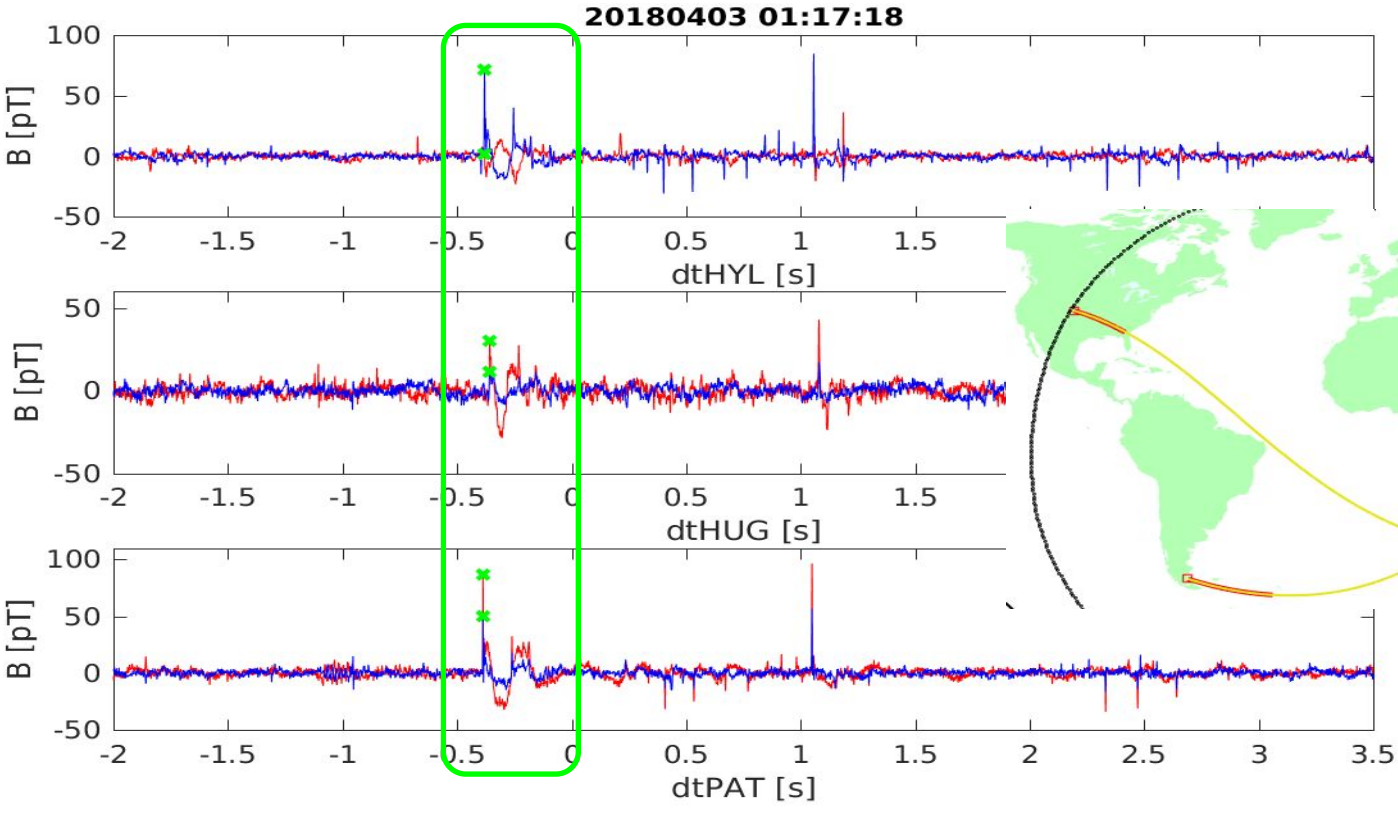


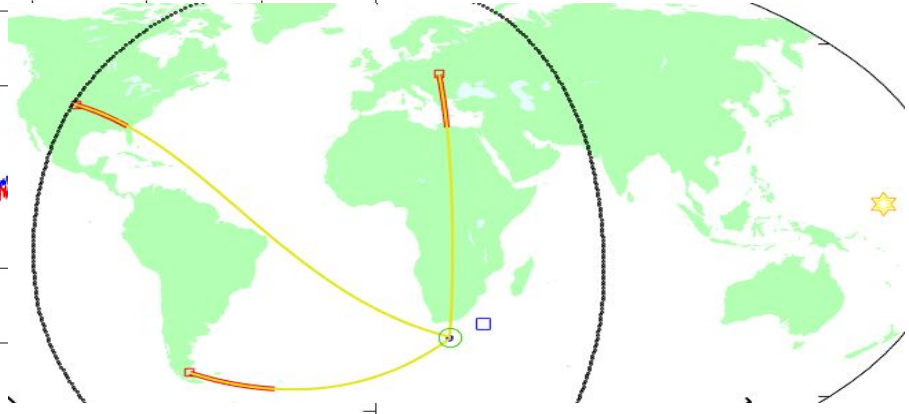
Magnetic field component recorded by the Hylaty and Patagonia stations (iCMC~=1000 C km)



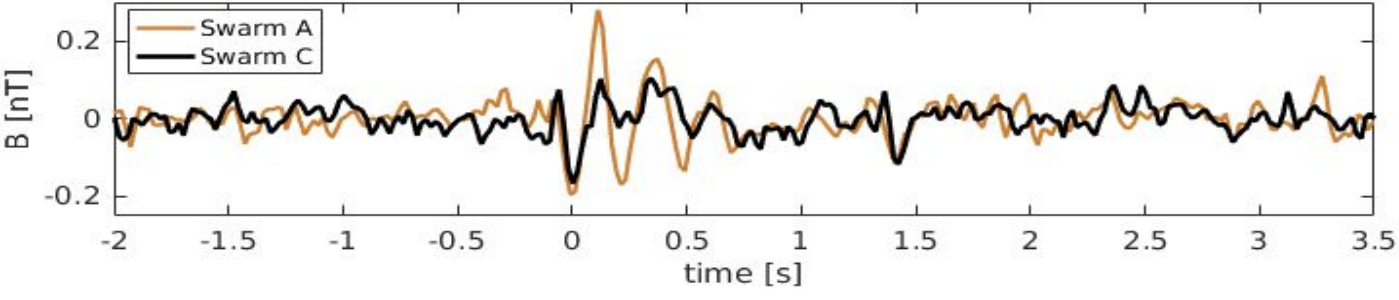
Magnetic field recorded on Swarm A and C

Strong lightning in Africa detected on Swarm

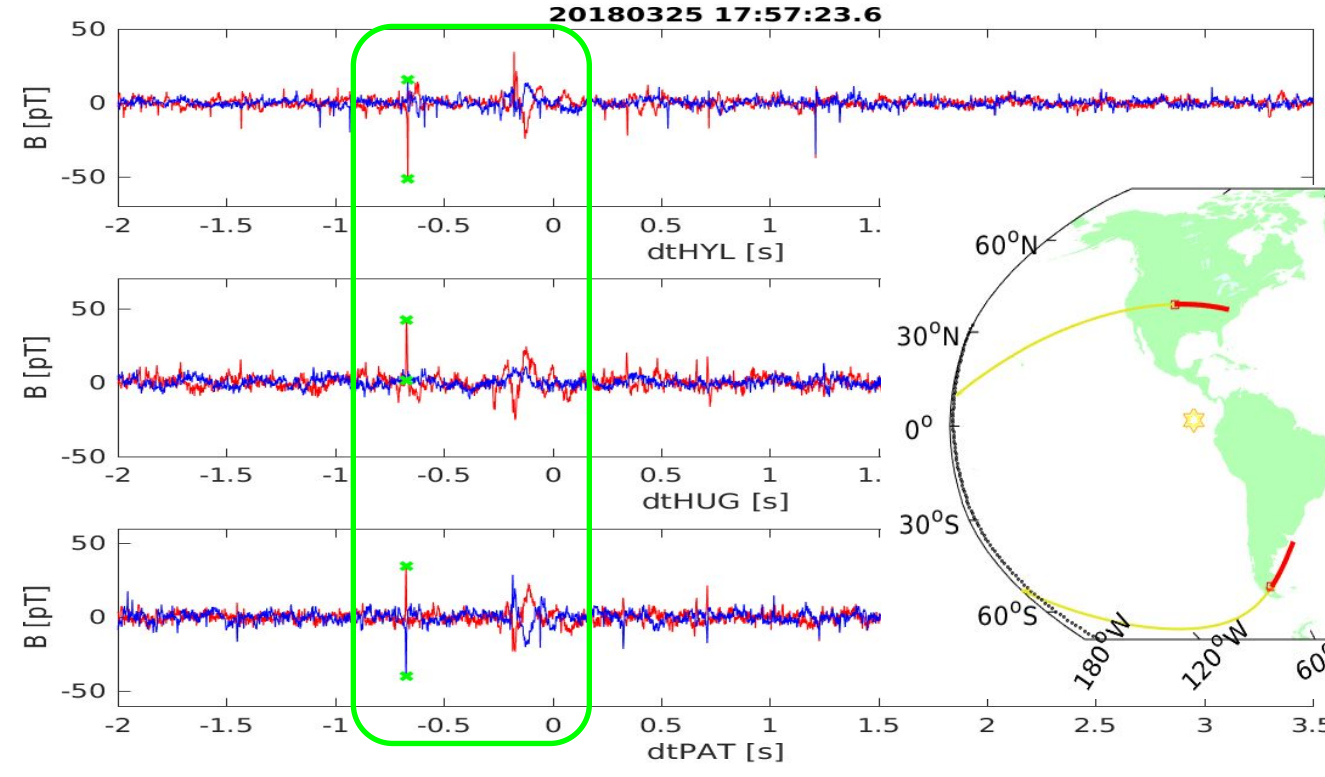


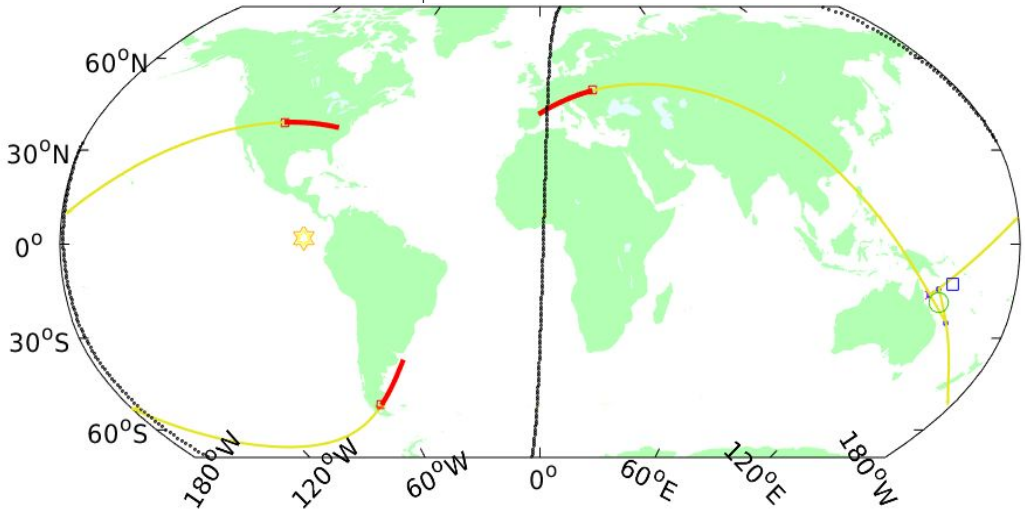


iCMC = 500 Ckm

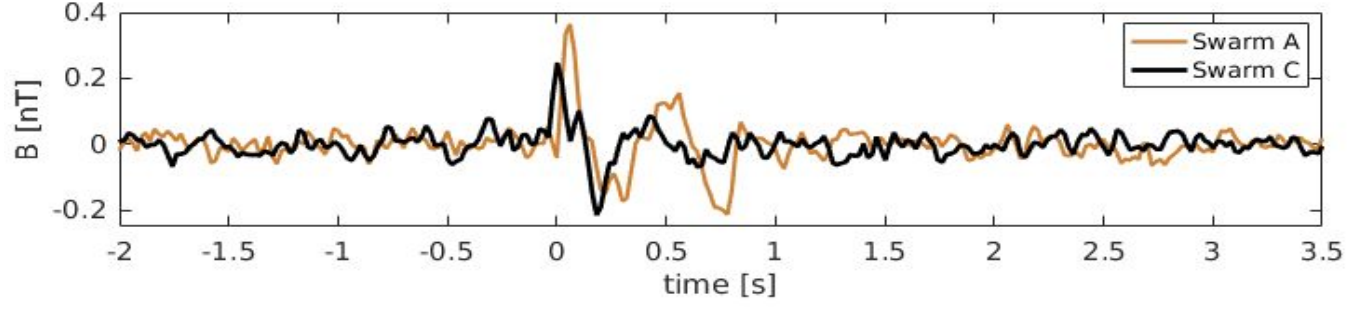


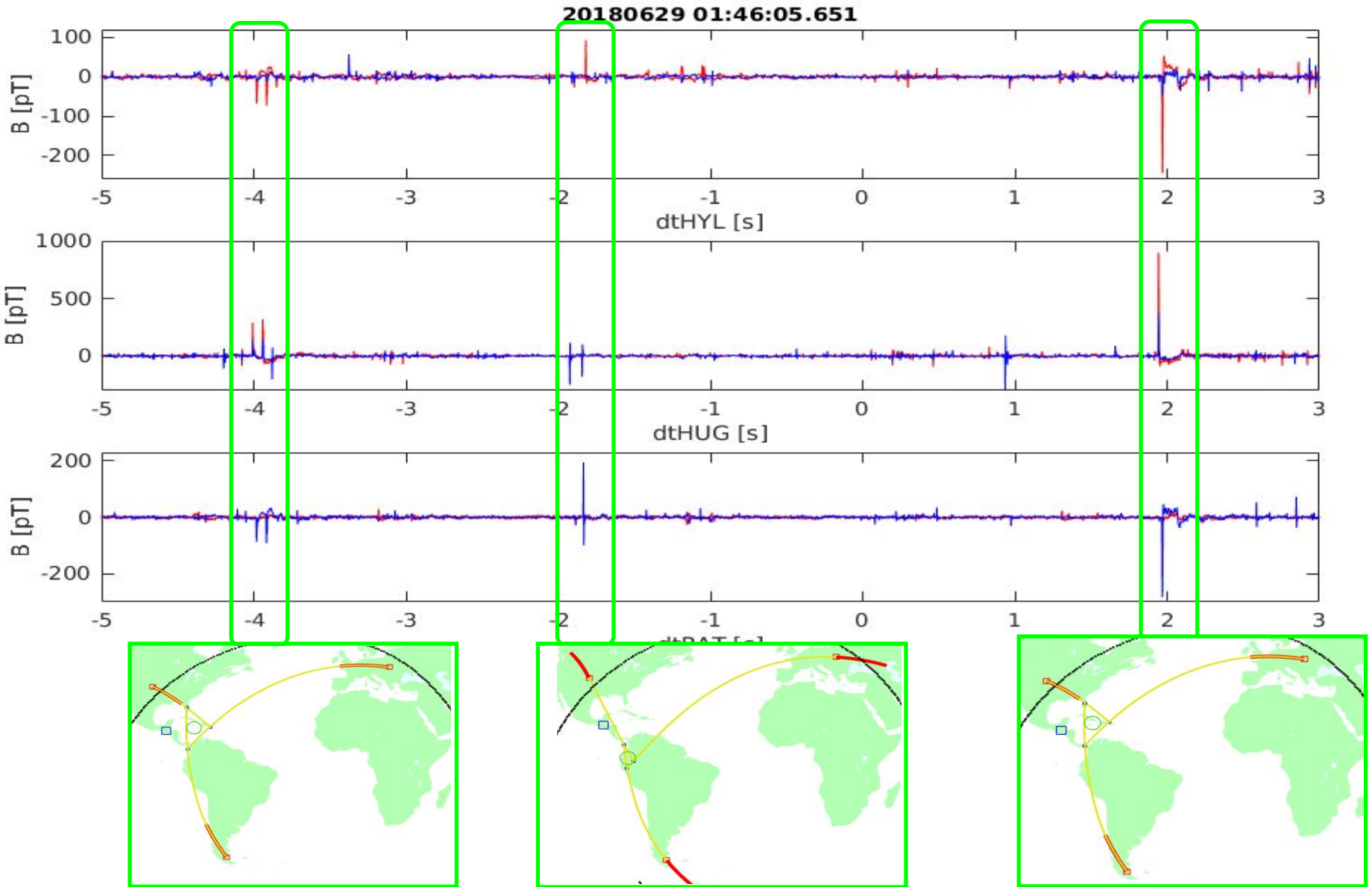
Strong lightning in Oceania detected on Swarm





iCMC = 530 Ckm




20180629 01:46:05.651
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-2
-1
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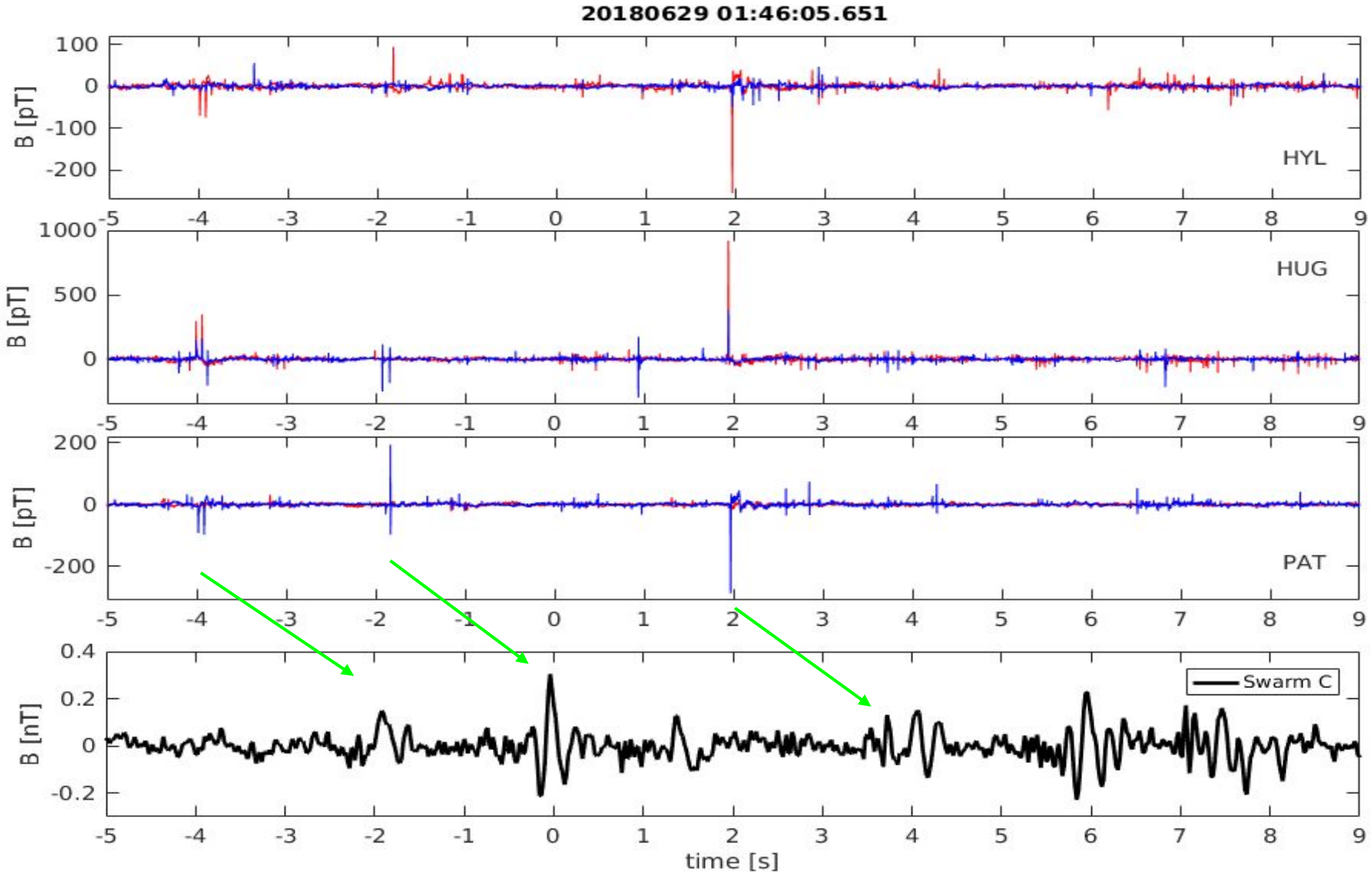
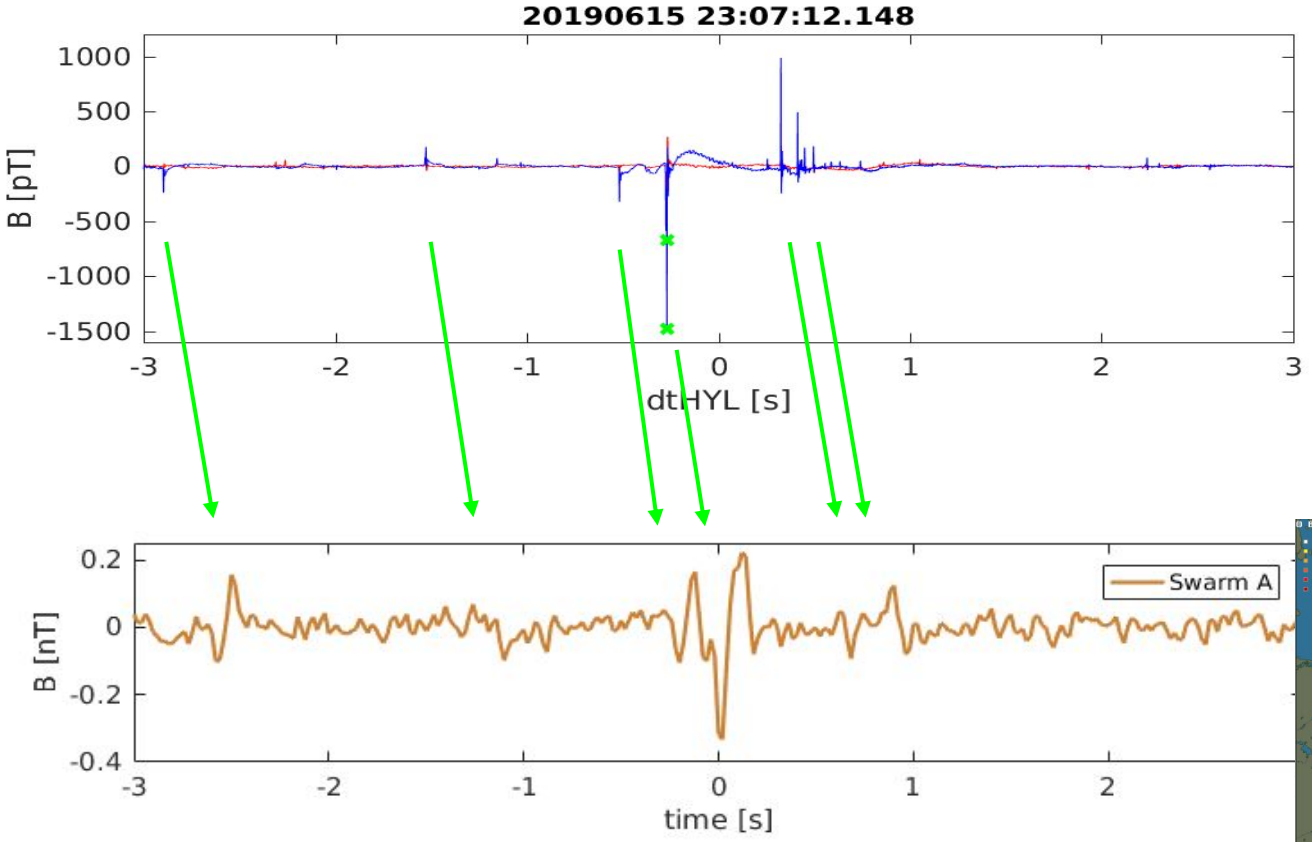
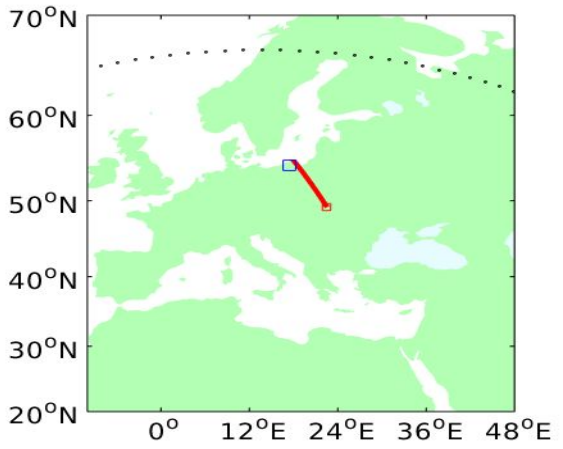
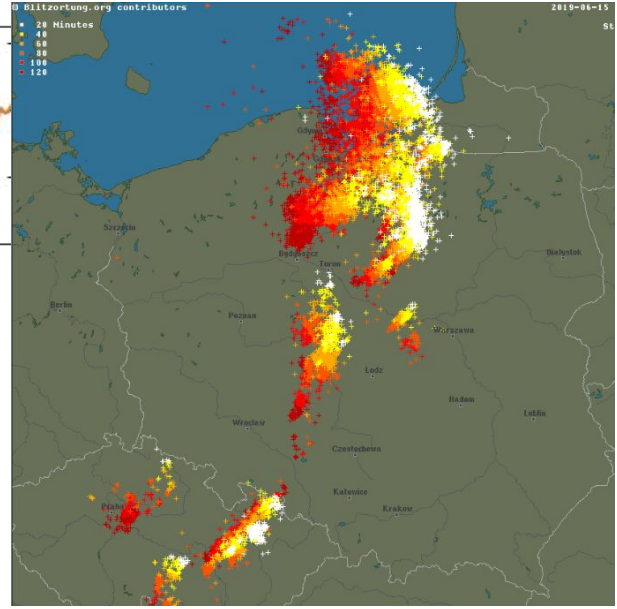
A powerful lightning in Central America detected on Swarm



Lightning discharges in Poland detected on Swarm

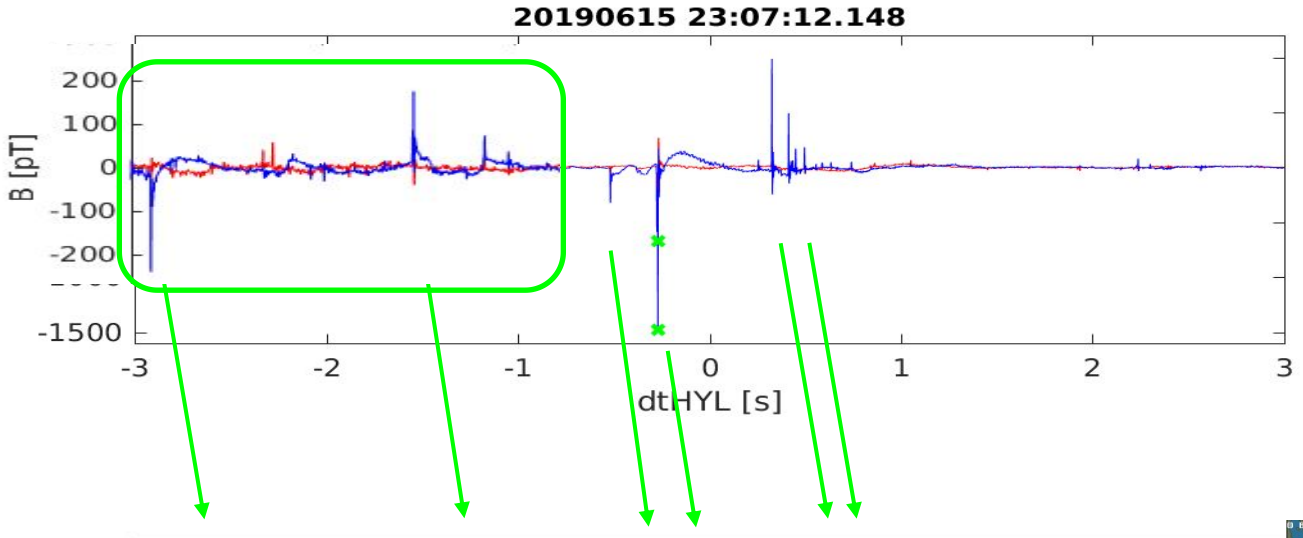


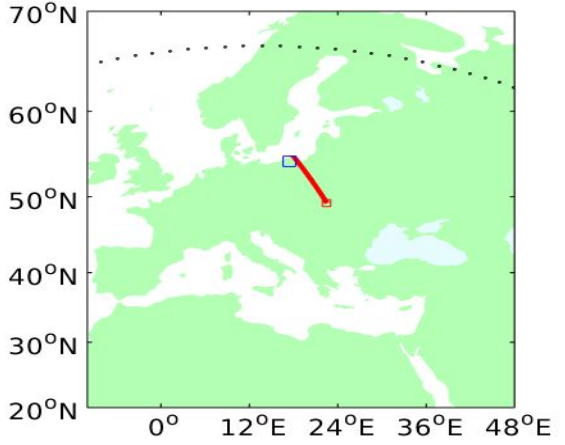


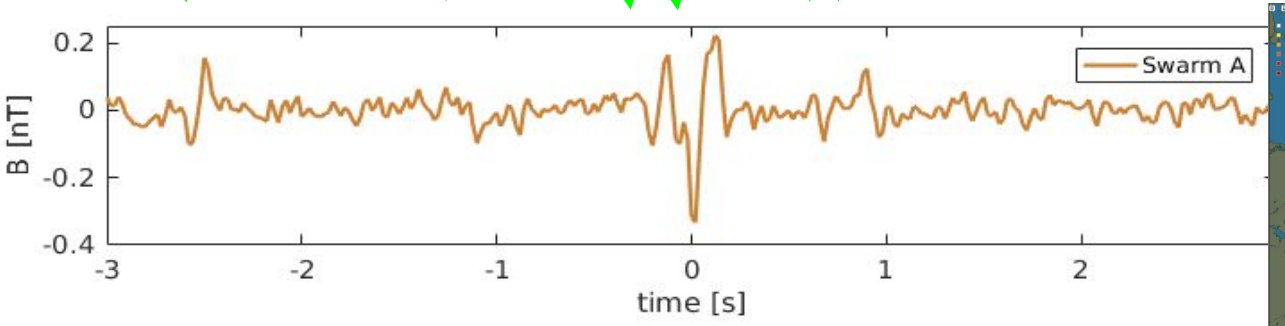


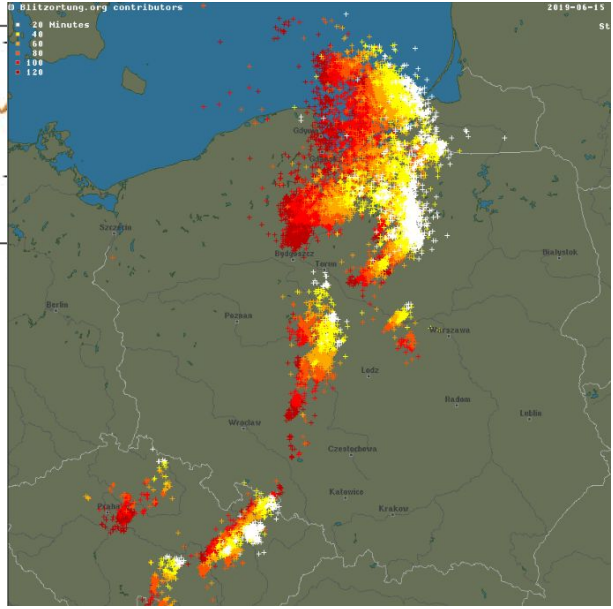
iCMC of the strongest discharge ~= 530 Ckm

Strong lightning in Poland detected on Swarm



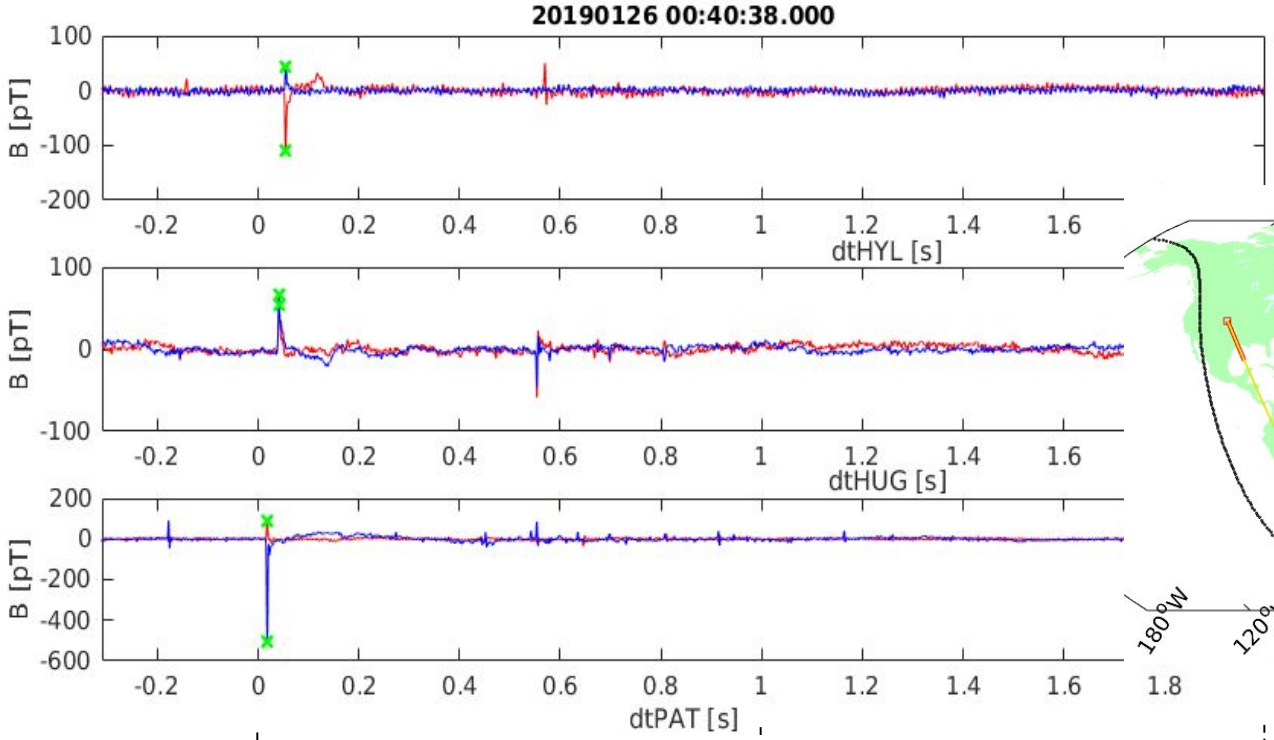


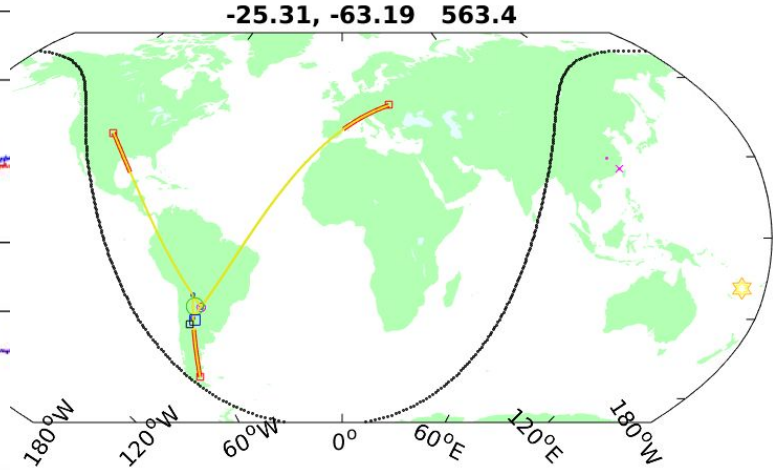




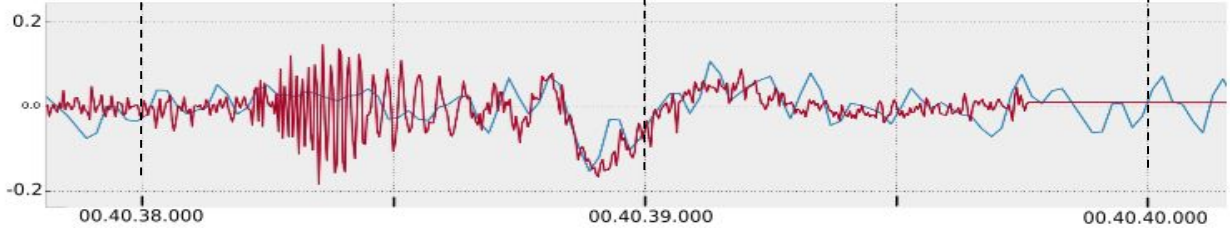
iCMC of the strongest discharge ~= 530 Ckm

Vector magnetometer vs. scalar magnetometer on Swarm





Magnetic field component recorded by the Hylaty, Hugo and Patagonia stations (iCMC~=480 C km)



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