Spatial and spectral characteristics of ionospheric perturbations over regions of major thunderstorm cells

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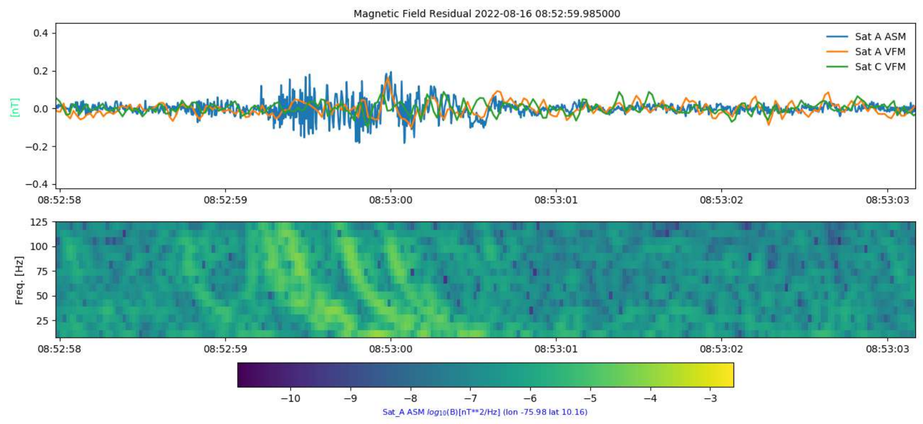
Motivation - Hunting for "sprites" with Swarm

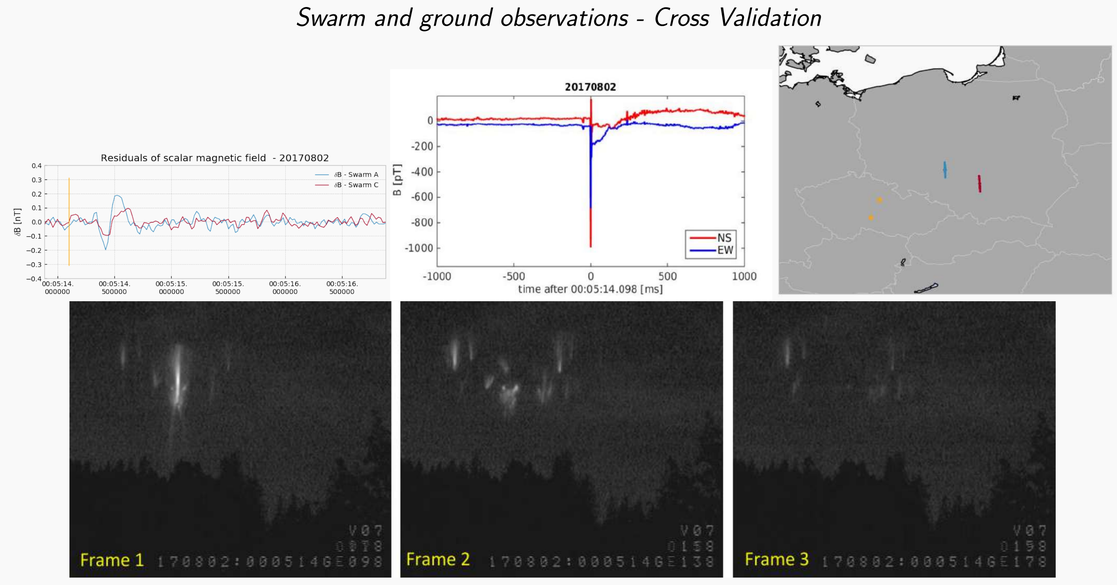
- Lightning around the Earth are known to generate EM fluctuations in a broad range of frequencies that propagate in the lower atmosphere.
- The highest power content is typically at frequencies of the order of kHz (VLF range), but some discharges maintain a continuing current of and luminous activity on larger time scales corresponding to the ULF of several Hz.
- Converted into Alfven waves at ionosphere-mesosphere boundary, portion of these waves can be detected at the altitude of Swarm (with ASM (250 Hz) and VFM (50 Hz) instruments) as small scale fluctuations of the **B** - field.
- Transient Luminous Emissions (TLEs) - Special class of manifestation of lightning activity was of particular interest for Swarm



Alpha and Charlie passing over the thunderstorm regions - VFM is less sensitive to ordinary lightning activity, and unlike ASM only allows for detection of special class of lightning activity, called Transient Luminous Events (TLEs)

From the first case to global distribution of detected TLEs - Verification with ground based data

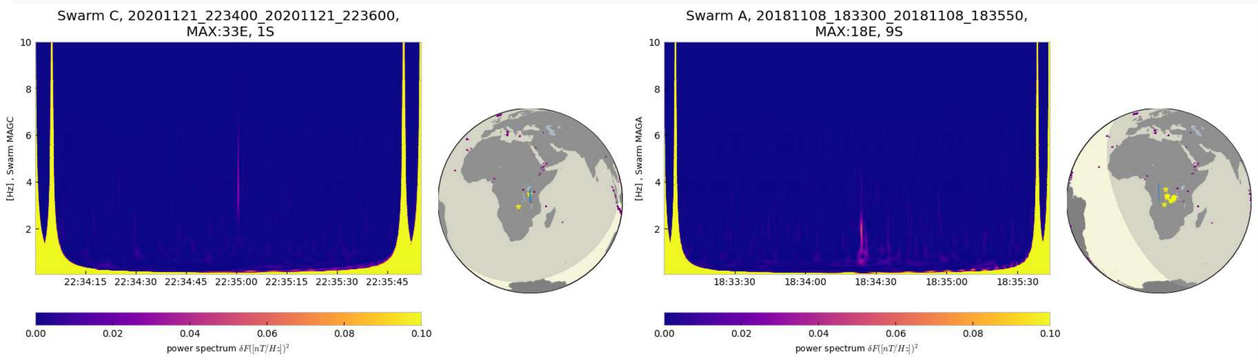
Swarm and ground observations - Cross Validation



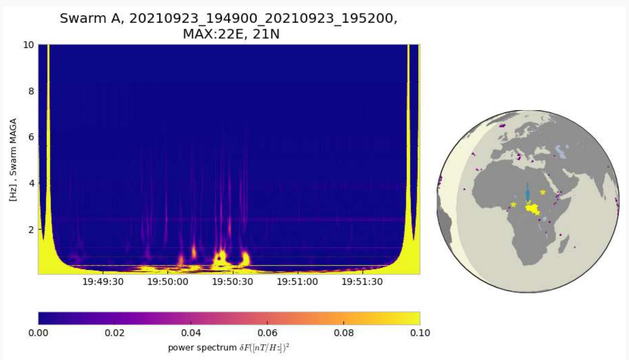
August, 2, 2017 Swarm was passing over Poland, where ground station in Hylaty registered strong magnetic field fluctuations, caused by powerful discharges with estimated charge moment reaching **4870** C km. The event was also captured by the ground-based observer in Nydek (Czech Republic). From the comparison between Alpha and Charlie it was obvious that the distance between the satellite and the event plays a crucial role. Successful detection of magnetic field perturbations with the VFM instrument strongly depends on the distance between satellite track and lightning source can not be greater than 500 km.

African "chimney" - Source of intense thunderstorms and ionospheric fluctuations - Examples of three typical signals in the detection algorithm

Typical CG+ events

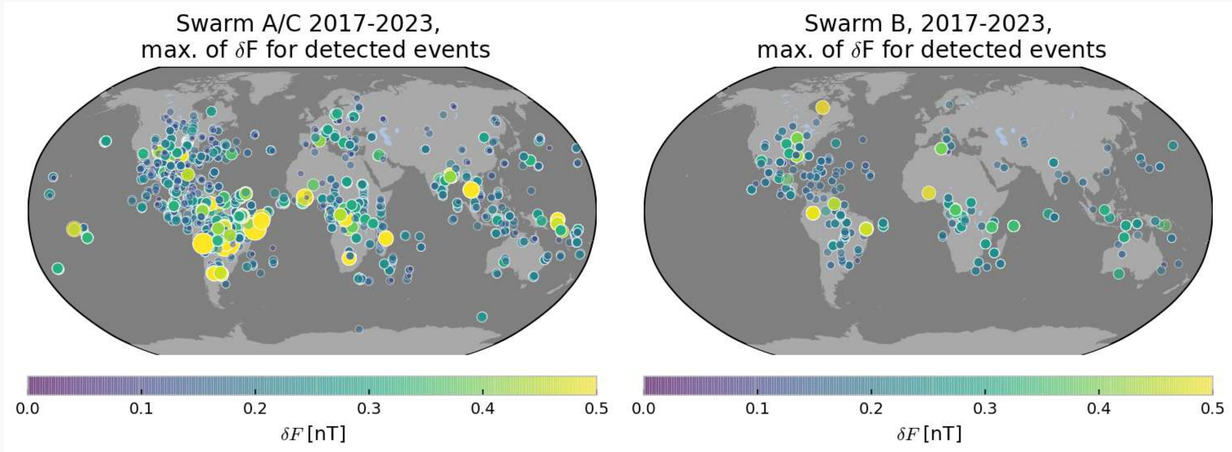


"False detection case" which may originate from plasma bubbles occurring in the region



- VFM 50 Hz data were used for the study. $\delta B_i = B_i^{obs} - B_i^{approx}$ - Local **B** trend is removed, with the 4^{th} order polynomial approximation applied over 5 second periods.
- Fitting procedures are used to localize sharp peaks. Signal triggered by lightning has a form of differentiated Gaussian signal.
- Threshold: $\delta F > 0.16$ nT
- Wavelet spectral analysis revealed, that such simplified detection tends to produce "false detection cases" especially in regions where plasma fluctuations occur (equatorial regions).

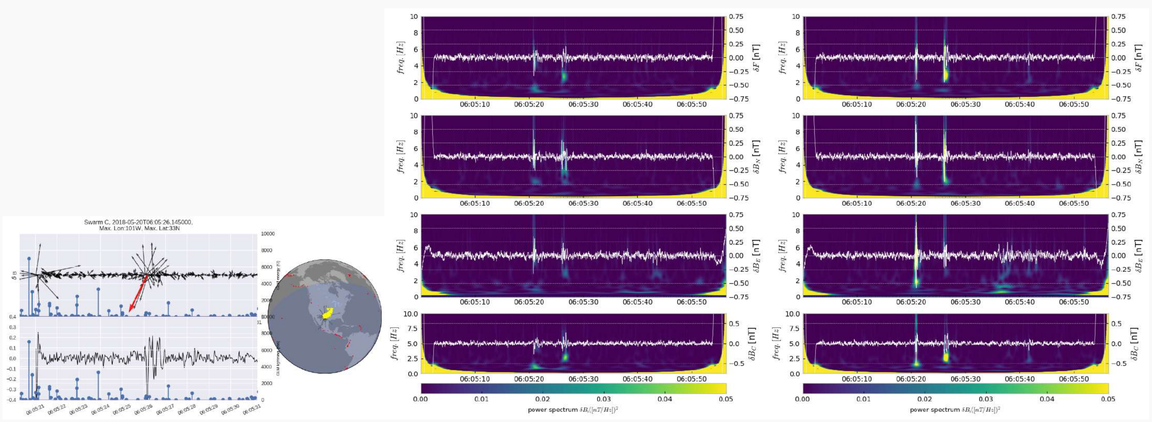
Global distribution of identified cases



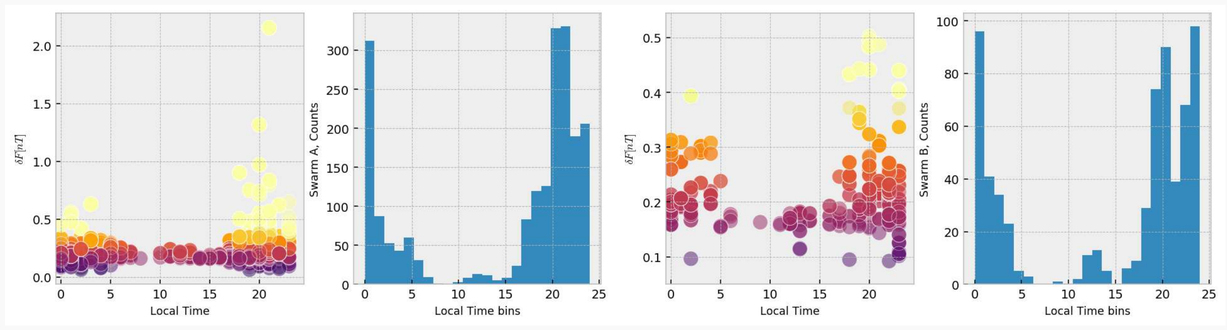
Global distribution of detected TLEs. Number of cases identified by VFM: Alpha/Charlie: 1896/1723, Bravo: 672

Swarm VFM & Lightning Imager GLM

Lightning Imagers data from the GEOS series of satellite, allowed to verify what kind of lightning activity triggers such perturbations that can be detected on-board Swarm



Local time dependence



- Global distribution of identified magnetic field fluctuation is consistent with location of major thunderstorm cells. Patagonian region and Central Africa are recognized as the the source of most powerful magnetic fluctuations.
- There is noticeable altitudinal dependence, resulting in reduced number of successful cases for Bravo.
- **Gathered statistics showed that Swarm will not allow to monitor thunderstorm activity on regular basis in a such way as VLF stations, however Swarm provides first direct experimental confirmation of leakage of electromagnetic fluctuations caused by lightning events into the upper ionosphere, at the ULF frequencies.**

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