JA04p-190 Geophysical signals detected during Swarm's Absolute Scalar Magnetometers burst mode sessions

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Introduction

Swarm satellites carry an Absolute Scalar Magnetometer (ASM) to measure the magnetic field intensity with high accuracy and stability (see poster JA04p-186). Nominal ASM data acquisition is at 1 Hz, but there is the possibility to acquire data in a so-called *burst mode* at 250 Hz. During the commissioning phase of the mission, seven burst mode acquisition campaigns have been run simultaneously for all satellites, obtaining a total of ten days of burst mode data.

We analysed the burst mode data to identify high frequency geomagnetic signals, developing a detection algorithm to identify the occurrence of events and characterise them, discriminating between geophysical signals and possible instrumental perturbations.

We found that during quiet time the detected events concentrate near the geomagnetic equator, showing a link with ionospheric irregularities and plasma bubbles. During geomagnetic active periods, these events are mostly observed in the auroral regions, related to polar region currents. Since these campaigns have been conducted during the initial months of the mission, the three satellites were still close to each other, allowing for an analysis of the spatial coherence of the observed signals.

Burst data pre-processing

We analysed the data files obtained combining the variables recorded in the SWARM L0 and SWARM L1A official products. We pre-processed the data in order to remove most of the instrumental artefacts.

1. **Piezo-electric motor transient perturbations**: when a spike is detected and is associated with an activation of the piezo-electric motor (located on the side of the ASM device and needed for maintaining the orthogonality conditions between the sensor and the ambient magnetic field B_0), we perform a linear interpolation of ± 10 points around the central value of the peak.
2. **Sensor heaters perturbations**: they are a consequence of resonances that occur when the heaters devices are ON and the measured magnetic field B_0 verifies the condition:

   $$B_0 = (2k + 1) \cdot B_{heater} \pm \varepsilon; \qquad k\text{=integer.}$$

   We set ε = 300 nT, and we removed all the magnetic samples when both conditions were simultaneously verified.
3. **Spikes**: We perform a general despiking to eliminate most of the glitches still contained in the data as well as the saturation steps that occur when the difference between two consecutive measurements is higher than 4 nT (these steps are a consequence of the size of the binary format record system).

Events selection

	ALPHA	BRAVO	CHARLIE
Total min processed	1440	1440	1440
Total min selected	28	27	30
Segments with Plasma Bubbles candidates	19 (68%)	18 (67%)	16 (53%)
Electromagnetic signals	3	6	2
Segments with noise events	6	5	13

% with respect to the selected events

Table 1: Events detected on 19/01/2014, a geomagnetically quiet day: Kp=1-. Swarm orbits were at 9:30-21:30 LST allowing the detection of ionospheric plasma bubbles.

To select candidate events we analysed one minute of data at a time.

1. We subtracted to B0 a 4th degree polynomial.
2. We computed the Power Spectrum Density (PSD) using the following parameters:
   - Sampling Frequency: 250 Hz
   - FFT (Fast Fourier Transform) order: 64
   - Covering percentage between two consecutive PSD: 75%
3. A selection algorithm is applied to the PSD time-frequency matrix:
   - Select all frequencies > 6 Hz (in order to exclude the known internal ASM RF modulation aliasing frequency peaks, at 3.05 Hz and harmonics).
   - Select all the hits with PSD amplitude > 5.6 pT/√Hz (in order to discard the internal RF frequency modulation aliasing at 30.1 Hz, whose amplitude is around 5 pT/√Hz).
   - Keep only the clusters of more than 6 consecutive hits that have time-coincidences with some hits in the above/below levels of frequency.

All the selected events are recorded with their time, frequency, amplitude and geographical coordinates for post-processing and characterisation.

Ionospheric Plasma bubbles

During the first part of the night at low latitudes plasma depletions can develop, mostly oriented in the North-South direction. On 19/01/2014 Swarm satellites were nearly following each other, the differences between their observations indicate the complexity of the ionospheric irregularities over an orbital distance of ~130 km.

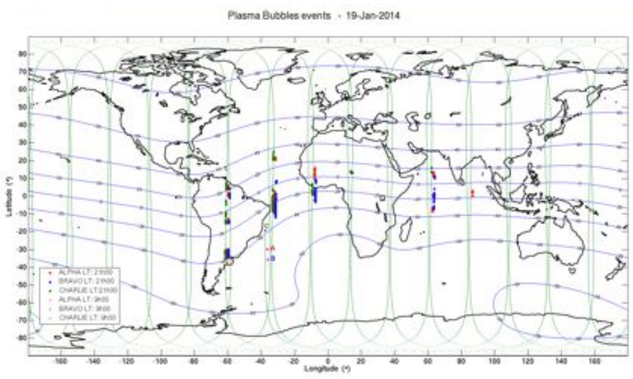

Figure 1: Map of the bubble events detected on 19 January 2014 using the detection algorithm, cross-checked with EFI data.

Between January 19 and February 23 Swarm satellites drifted from 21:30 LST to 18:30 LST. Therefore plasma bubbles detection was not possible in the last burst session.

Comparison with electron density data

Plasma bubbles are detected directly using Swarm satellites' EFI instrument that measure the ionospheric electron density at 2 Hz. We found a very good agreement between the detected events and plasma bubbles irregularities.

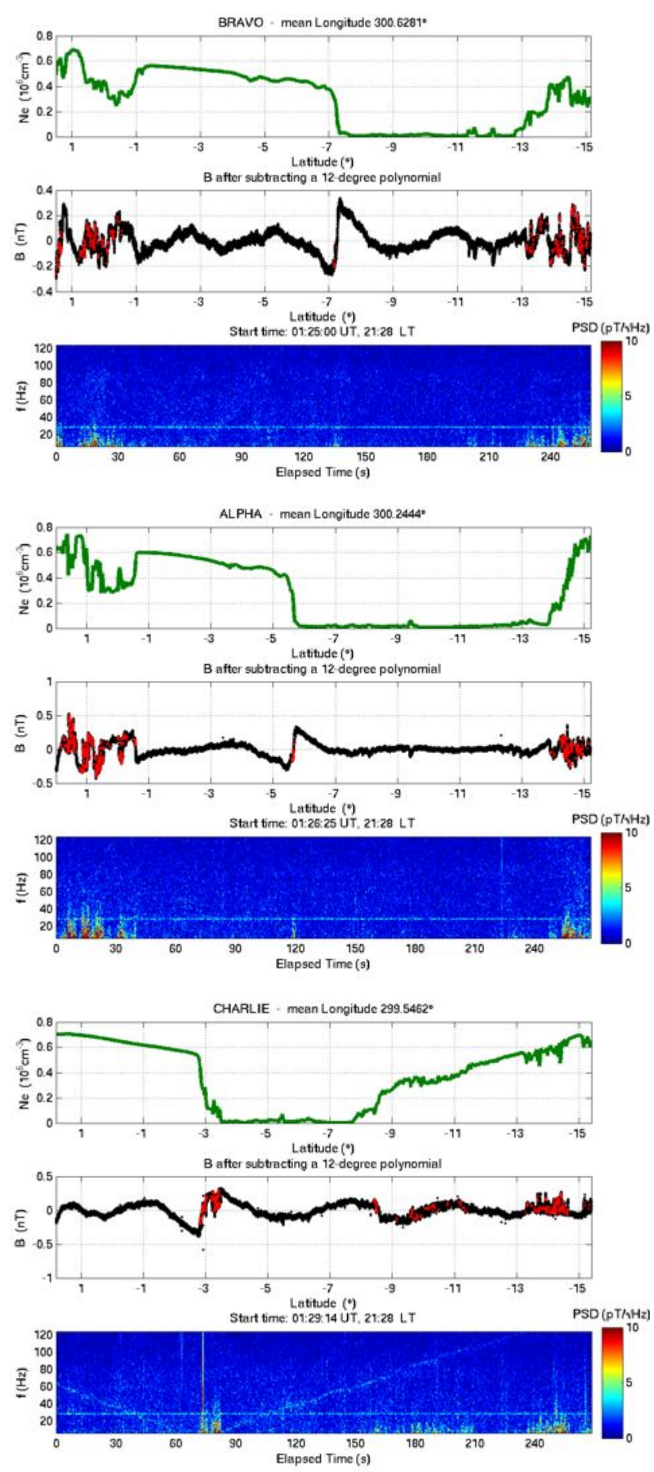

Figure 2: Comparison between EFI electron densities (top) and burst mode ASM magnetic field (middle) and corresponding spectrogram (bottom) while the three Swarm satellites crossed a plasma bubble on 19/01/2014.

In the middle panels the red dots indicate the events selected by the detection algorithm. There is a good agreement between the magnetic detections and the plasma irregularities.

Electromagnetic signals

Short signals with characteristic signature have been detected predominantly in the mid-to-low latitudes evening sector.

Their spectral signature covers the whole ELF frequencies observed during burst-mode sessions. Their duration is about 1 s. In all cases irregular trains of these signals are detected, that can last up to 6 minutes, while Swarm satellites cover distances of about 3000 km.

In some cases successive signals present similar patterns and a lower steepness in the spectrogram, suggesting analogy with ground-based observations of magnetospherically ducted whistlers.

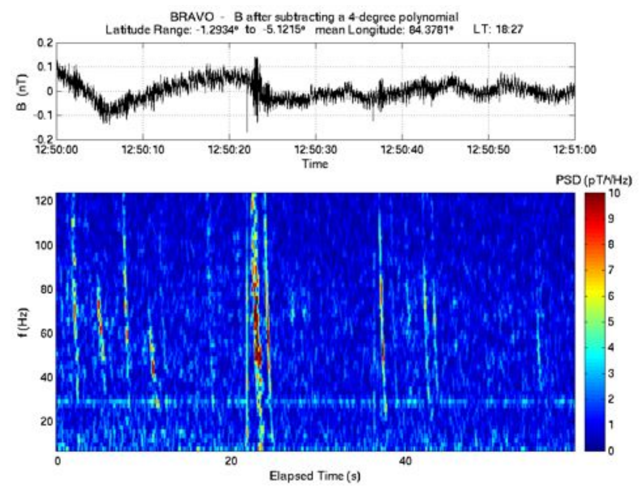

Figure 4: Electromagnetic signals detected during one minute. Both Swarm B and C detections are simultaneous (397 km distance).

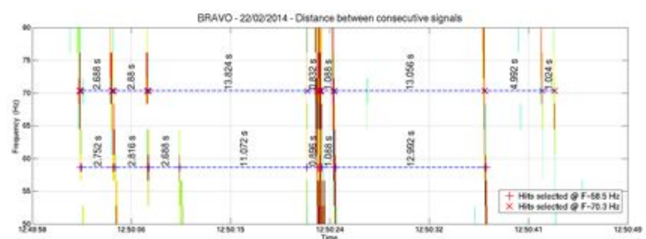

Figure 5: Time separation between successive signals detected during the minute shown in Figure 4 at the frequency levels of 58.5 Hz and 70.3 Hz.

Similarities between successive signals and their regular time separation suggest the possibility of multiple echoes of a phenomenon of common origin.

The ELF-SLF band (6-125 Hz) observed with burst data is below the usual ULF-VLF frequency range employed to record whistlers signals (1-20 kHz).

To understand the propagation modes and validate the hypothesis of lightning origin of these signals we will compare with lightning data from the World Wide Lightning Location Network (WWLN).

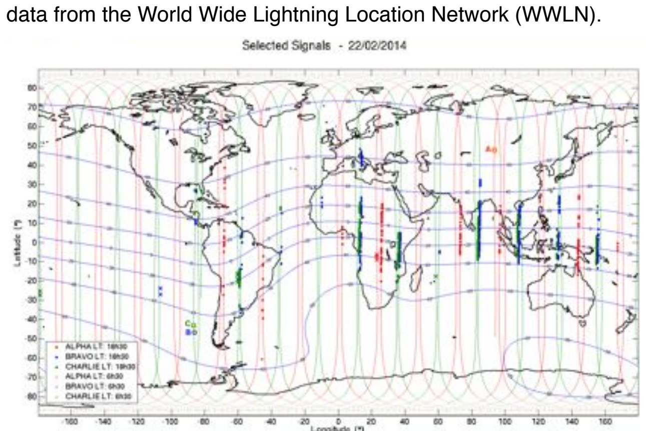

Figure 3: Map of electromagnetic events observed on 22 February 2014. Satellite B and C were nearby and detected the events simultaneously, while A was on the opposite side of the Earth.

Conclusions

Data collected during the burst-mode sessions of the three Swarm satellites show that in the frequency band between 10-120 Hz it is possible to detect the magnetic signature of:

- plasma bubbles irregularities in the early night sector
- electromagnetic signals similar to whistlers
- high latitudes irregularities (not shown here)

Further analysis is needed to understand the possible links between lightning activity and/or propagation of ELF signals from the ground or through the magnetosphere.

References

Hulot, G. et al. (2015), Swarm's absolute magnetometer experimental vector mode, an innovative capability for space magnetometry, GRL, 42, 1352–1359, doi:10.1002/2014GL062700.

Léger, J.-M. et al. (2015), In-flight performance of the absolute scalar magnetometer vector mode on board the Swarm satellites, EPS, 67(1), 57, doi:10.1186/s40623-015-0231-1.