Analysis of Plasma Irregularities and Electromagnetic Signals Based on Swarm Absolute Scalar Magnetometer Burst Mode Sessions

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Introduction

The commissioning phase of Swarm satellites provided opportunities to acquire measurement during special acquisitions sessions. The Absolute Scalar Magnetometer (ASM) instrument of each satellite were operated in *burst mode*: the recording frequency of the instruments were risen from the nominal 1 Hz to 250 Hz.

A total of seven burst mode sessions, covering between 3 and 48 hours of continuous recording, were realized between December 2013 and February 2014. During that time, the local time of Swarm satellites orbits shifted from midnight-noon to post sunrise-post sunset. The last burst mode session occurred during the recovery phase of a geomagnetic storm. Therefore these data allow to investigate both quiet and geomagnetic active periods.

The analysis of burst mode data was focused on phenomena that can be investigated only using this higher sampling rate, providing insight in the frequency band between few Hz to 125 Hz. From the analysis of the magnetic field data we could observe typical signals related to different geomagnetic phenomena, showing distinct features at low, mid and high latitude.

We were able to detect fast magnetic field fluctuations with a typical pattern, associated with low-latitudes irregularities in the ionospheric plasma during the development of post-sunset plasma bubbles.

We also present results of the analysis of short electromagnetic signals that were detected mostly in the mid-to-low latitudes evening sector, investigating their correlation with the occurrence of lightning on the ground.

Over the high latitudes, we detected fast variations of magnetic field intensity during the active periods and analyse their correlations with plasma irregularities.

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.

Automatic detection of events

- To select candidate events we analyzed one minute of data at a time.
- We pre-processed the data in order to remove most of the instrumental artefacts (piezo-electric motor transient perturbations, sensor heaters perturbations, spikes).
- We subtracted to B0 a 4th degree polynomial.
- 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%

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 characterization.

Plasma bubbles

Swarm magnetic and electron density detection of 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.

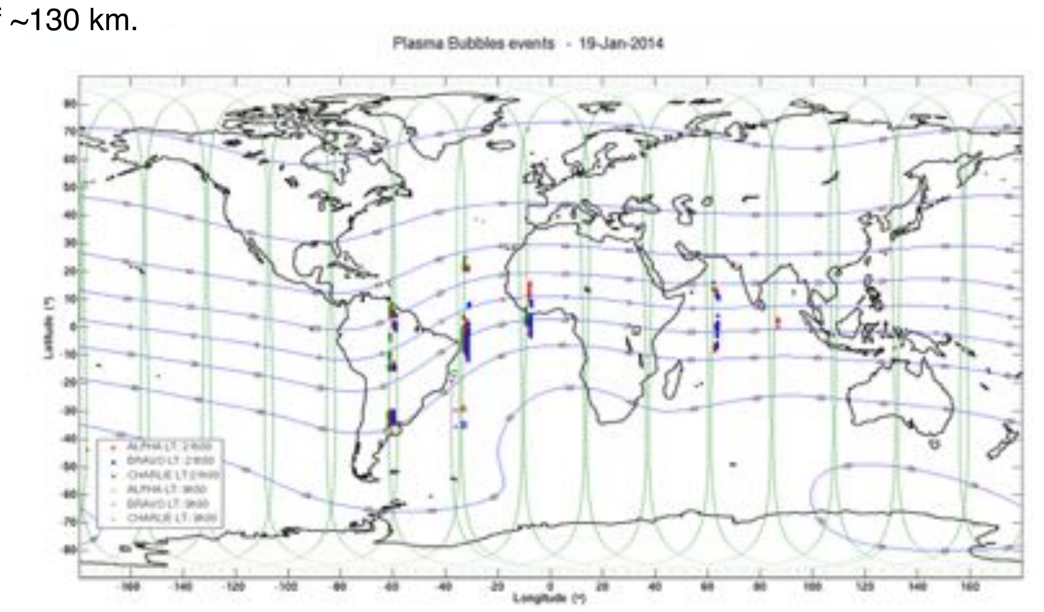

Figure 1: Map of the bubble events detected on 19 January 2014 using the detection algorithm, cross-checked with EFI data. Swarm satellites B, A, C were following each other.

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.

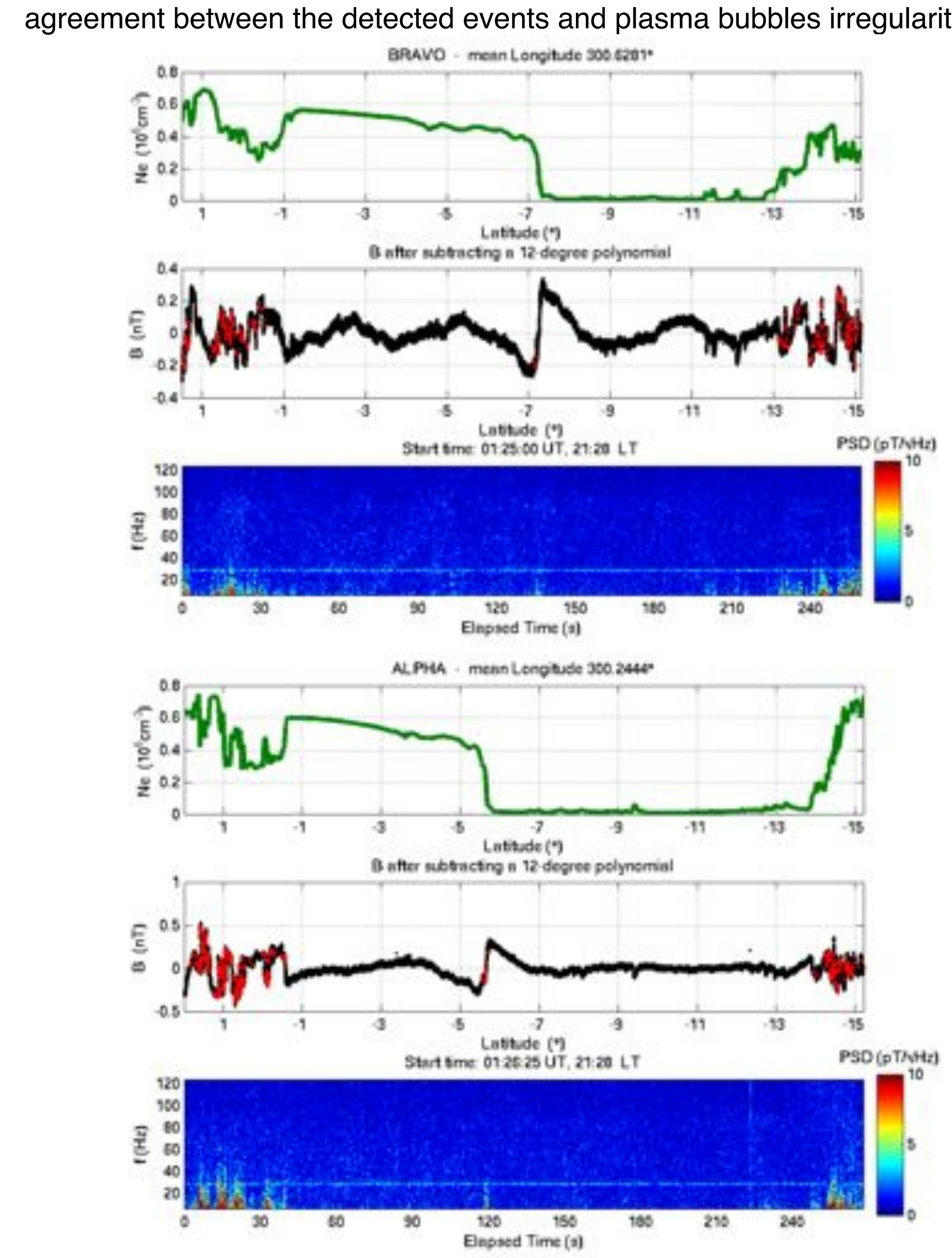

Figure 2: Comparison between EFI electron densities (top) and burst mode ASM magnetic field (middle) and corresponding spectrogram (bottom) while Swarm satellites crossed a plasma bubble on 19/01/2014 (B and A are shown).

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.

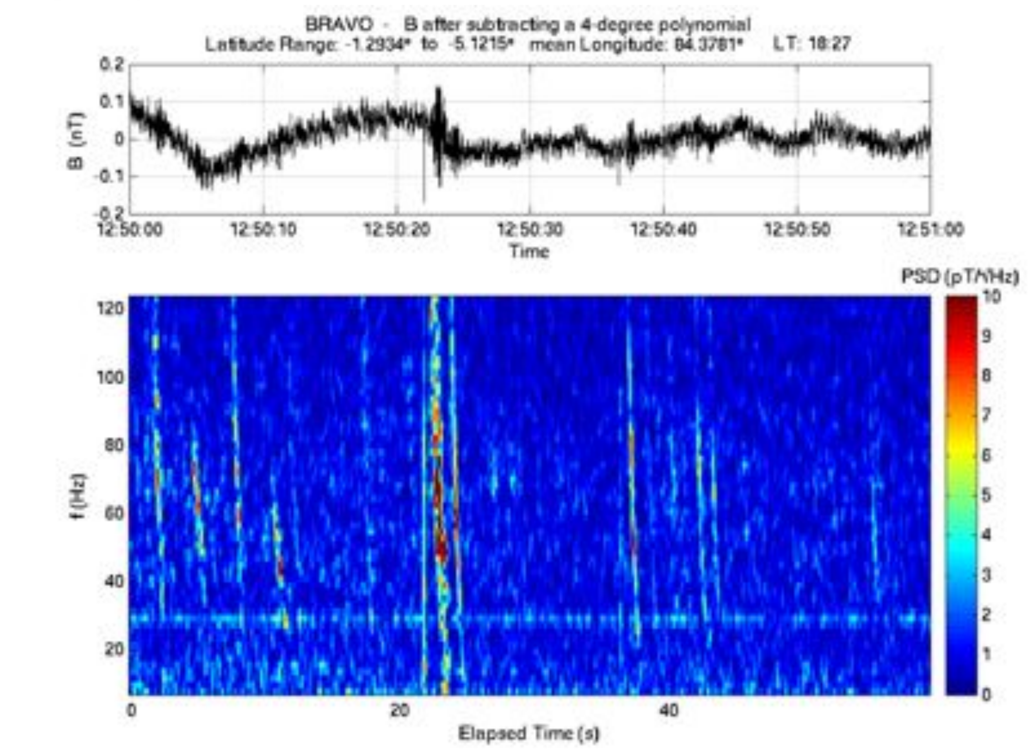

Figure 3: Electromagnetic signals detected on 22/2/2015 during the minute starting at 12:50 UT. Both Swarm B and C detections are simultaneous (397 km distance).

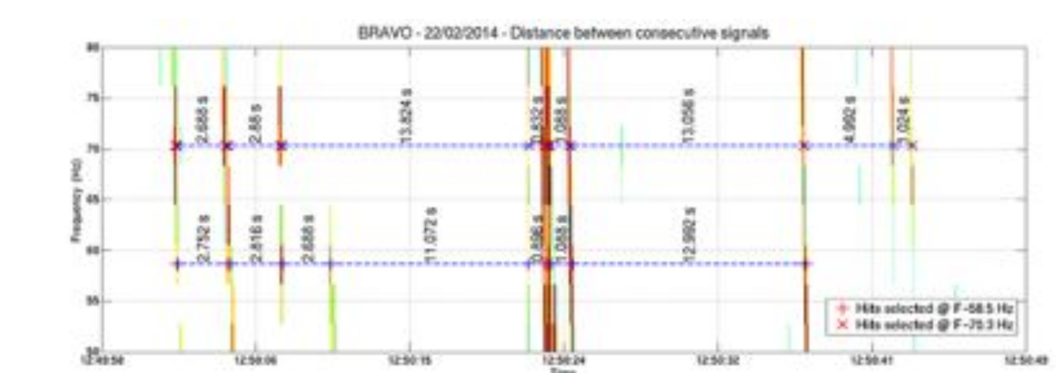

Figure 4: Time separation between successive signals detected during the minute shown in Figure 4 at the frequency levels of 58.5 Hz and 70.3 Hz.

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 are comparing with lightning data from the World Wide Lightning Location Network (WWLLN).

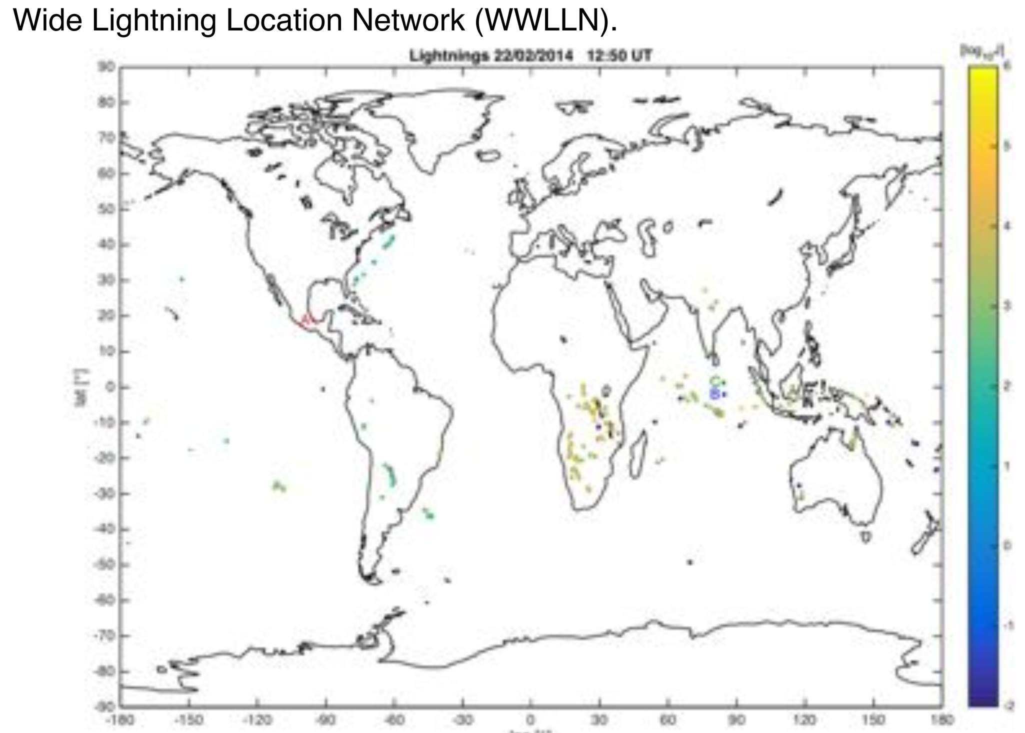

Figure 5: Map of lightning strokes occurred on 22 February 2014 during the minute starting at 12:50 UT. Satellites B and C were flying above the Indian Ocean. The strongest lighting occurred at 12:50:22.18 in that region, most likely producing the large signal seen in Figure 3.

High latitudes irregularities

During geomagnetic active periods, in the high latitudes, we detected strong signals in the burst data.

The electron density at the altitude of Swarm satellites shows small-scale irregularities covering the whole polar region.

We observe in the magnetic field an increased noise level between 10 and 20 Hz and peaks that can reach 100 Hz associated with strong gradients of electron density.

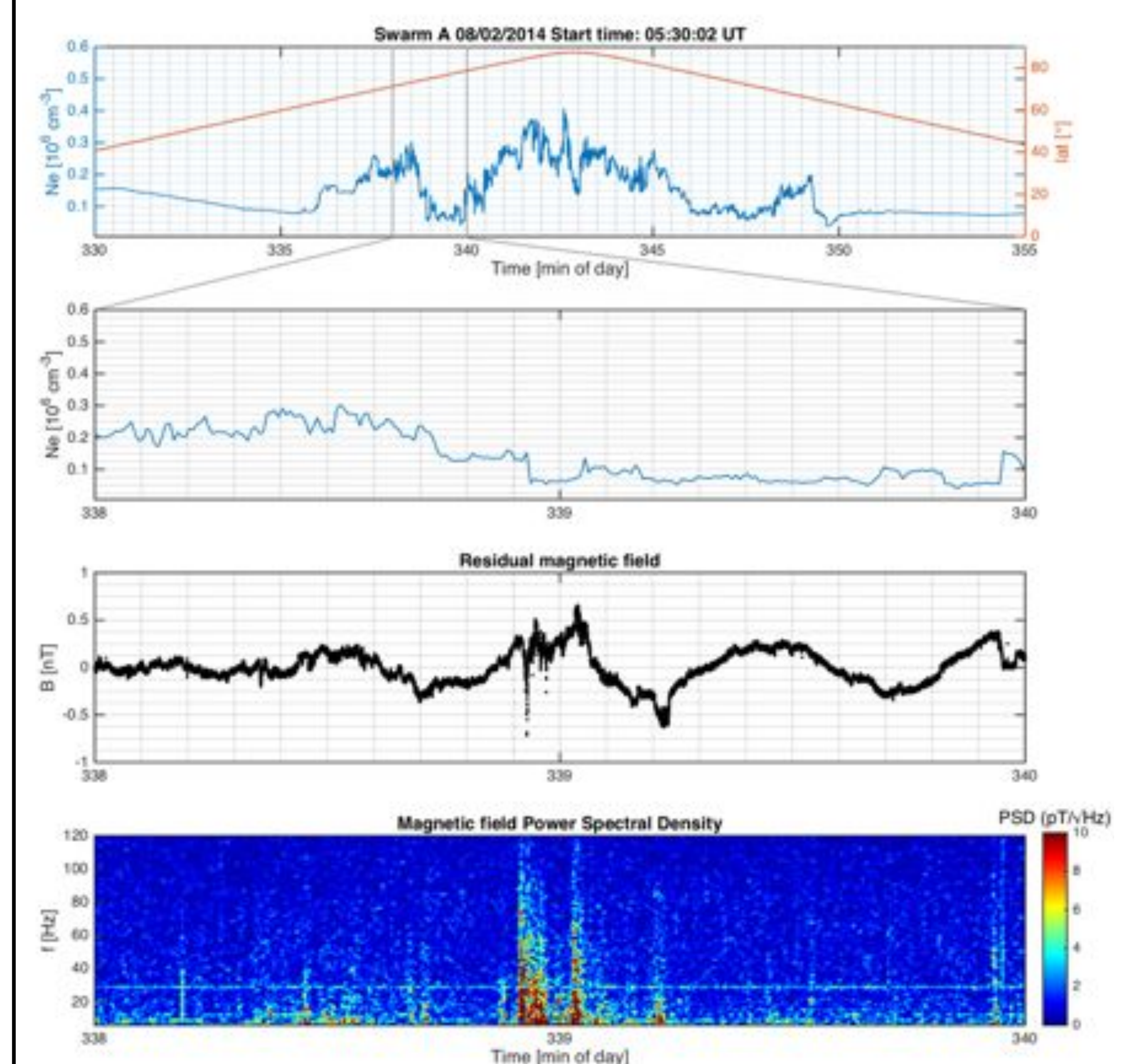

Figure 6: Electron density irregularities and associated magnetic field intensity fluctuations at high latitudes during a geomagnetic active period on 8/2/2014.

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

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

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Acknowledgments

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