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Whistlers detected in the Extremely Low Frequencies by Swarm satellites and their seasonal and solar activity variations

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One-week campaigns of magnetic field intensity measurements at 250 Hz have been realized on Swarm Alpha and Bravo satellites every month since the last solar minimum, from 2019. This has been possible because the Absolute Scalar Magnetometers (ASM) have the capability to run in *burst* mode providing high-quality data [1], while nominal operations provide 1 Hz measurements. Swarm satellites fly on polar orbits: Alpha at about 450 km height and Bravo at about 500 km. Both slowly drift in local time; this allowed to progressively acquire *burst* mode data under different conditions, with the long-term aim of covering all local times for all seasons.

We analyzed fractional-hop whistlers detected in the Extremely Low Frequencies (EF) during these campaigns. Most whistlers occurred at low latitudes, with the highest concentrations over Africa, the Carribeans and Indonesia. The strong day-to-day variability in the number of detections is related to the variability of lightning activity on the ground. The largest amounts of whistlers were always recorded during evening and night while the morning hours present the lowest whistler activity. A correlation with the solar cycle appears in Swarm detections: the number of detected whistlers increased with the increase of solar activity.

The ELF component of powerful lightning strikes can propagate at very far distance in the waveguide between the ground the lower ionosphere, producing whistlers that can be detected at Swarm altitudes several thousands of km away from the strike location. We were also able to conduct joint acquisition campaigns on both Alpha and Bravo satellites and identified several cases of whistlers detected by both satellites having been generated by the same lightning strike. We used data from the World Wide Lightning Location Network (WWLLN) and the World ELF Radiolocation Array (WERA) to identify the strikes that originated remarkable whistlers.

The dispersions of fractional-hop whistlers depend on their propagation path and on the ionospheric plasma distribution. We developed a new technique to obtain an ionospheric measurement from the arrival time of two frequency components of these whistlers [2]. We called it Total square Root Electron Content (TREC). This measurement opens new applications of whistlers to obtain information on the ionospheric plasma, particularly important on regions where there are limited data available.

1. J.M. Léger, T. Jager, F. Bertrand, G. Hulot, L. Brocco, P. Vigneron, X. Lalanne, A. Chulliat and I. Fratter, "In-flight performance of the Absolute Scalar Magnetometer vector mode on board the Swarm satellites", *Earth Planets and Space* **67**, 1, doi: 10.1186/s40623-015-0231-1, 2015.

2. M. Jenner, P. Coïsson, G. Hulot, D. Buresova, V. Truhlik, L. Chauvet, "Total Root Electron Content: A New Metric for the Ionosphere Below Low Earth Orbiting Satellites" submitted to *Geophysical Research Letters*, 2023.