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Swarm, SMILE & Geospace combined multi-scale data set

1. Description of proposed product/tool/service

We propose a set of visualisation tools, supported by corresponding analysis techniques, to combine Swarm field-aligned current (FAC) and polar electrojet (AEJ) products with both ground and outer spacecraft data that will help provide a shift change in our understanding of magnetospheric-ionospheric coupling, driven by external space weather. The data focusses around that expected from the upcoming Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission, to be launched in 2025, and the wealth of available Cluster/MMS data. SMILE (a joint European Space Agency and Chinese Academy of Sciences mission) has a nominal lifetime of 3-7 years. From its 50-hour, high apogee polar orbit, SMILE will provide **never-before-seen images** of the magnetosheath using the Soft X-ray Imager (SXI) whilst **simultaneously observing the response** of the northern hemisphere ionosphere using an Ultraviolet Imager (UVI). SMILE will also fly with two *in situ* experiments; a magnetometer (MAG) and a light-ion analyser (LIA). SXI will derive magnetopause and cusp boundaries, using variable integration times (from 5 minutes to 15 minutes), depending on prevailing solar wind and interplanetary magnetic field conditions, and UVI will produce Lyman-Birge-Hopfield wide band greyscale images every 60s or less, at ~150 km or better resolution. The SMILE mission has significantly matured since our last submission to Swarm DISC. This includes simulated data products. This is especially important for SXI, given the data analysis steps required to derive magnetosheath or cusps boundaries from 2D X-ray images. We have also made important progress with the SMILE Data Fusion Facility (DFF, https://www.smile-fusion.le.ac.uk/), see the example in Fig. 1.

2. Description of current state of the art and level of maturity of proposed algorithm

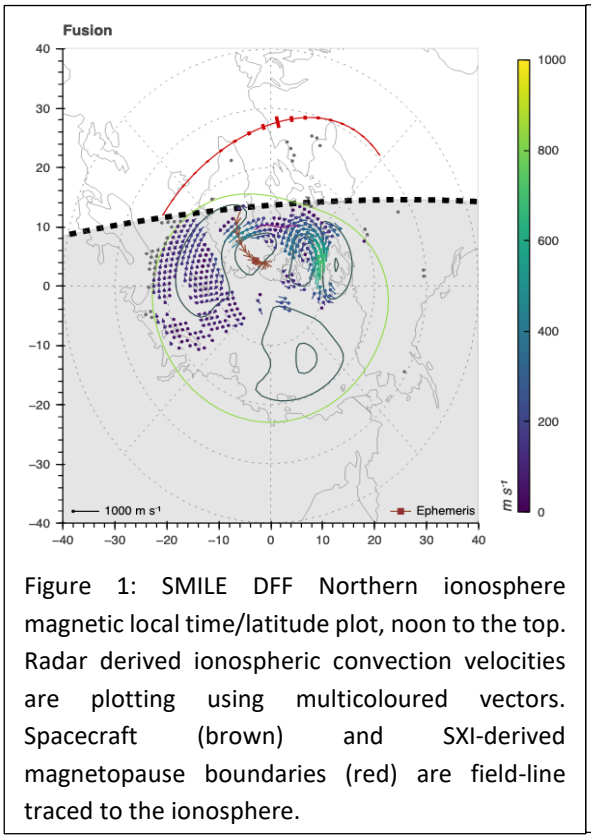


Figure 1: SMILE DFF Northern ionosphere magnetic local time/latitude plot, noon to the top. Radar derived ionospheric convection velocities are plotting using multicoloured vectors. Spacecraft (brown) and SXI-derived magnetopause boundaries (red) are field-line traced to the ionosphere.

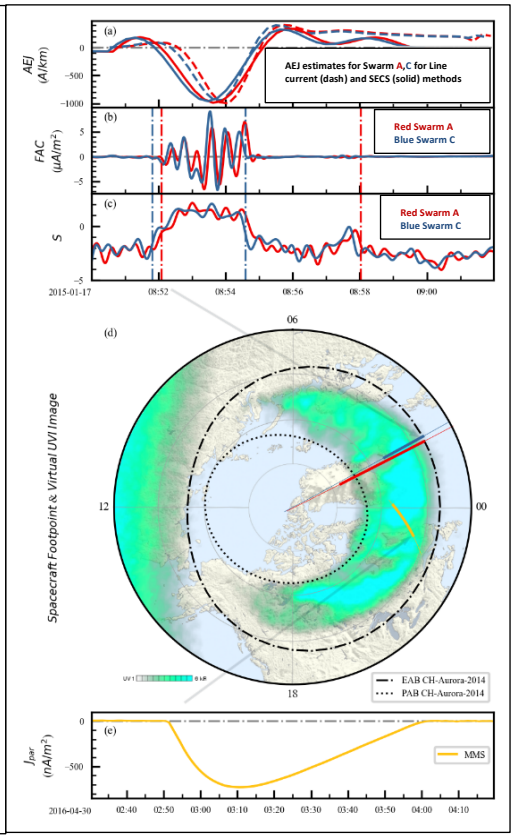


Figure 2: An example from Wei et al. to show how signatures of Swarm FACs & AEJ calculations can be combined with model auroral boundaries (Swarm-AEBS), emissions, and together with outer spacecraft (MMS). An array of ground magnetometers (not shown) also lie under the spacecraft footprints.

The existing Swarm level 2 (L2) data products use both single and dual spacecraft estimates of FACs sampled by Swarm at the high cadence of the magnetometer measurements, but often filtered to 10-20s and AEJ estimates can be obtained through existing Swarm algorithms (see Swarm-AEBS), as shown in Figure 2.

The SXI simulator, using magnetohydrodynamic or kinetic code input, is now able to explore scenarios driven by differing ambient solar wind conditions and explore various driving phenomena. For UVI, LIA, and MAG simulations, we rely on previous missions, such as NASA's IMAGE. SMILE instrument teams are currently discussing quick look data products to be hosted by ESA, including images, keograms, and spectral products.

For example, a 'cause-and-effect' measure for comparing SXI with UVI quickly, e.g., total SXI counts versus auroral brightness in a restricted nightside magnetic-local-time wedge from UVI, versus time for tracking substorm phenomena, with context provided by Swarm and ground-based magnetometers.

3. Data input needs (e.g., type of data from Swarm and/or other, frequency, auxiliary information)

The data used will be the L1B and L2 data from Swarm, expected at 1s or lower cadence. Depending on the timing of any project, the initial focus will be to produce a set of tools to combine Swarm FAC and AEJ products with simulated or actual SMILE-SXI and UVI data products, in timely preparation for SMILE operations; adding Cluster, MMS (and SMILE) *in situ* products. The combined data set will include products such as magnetopause location, mapped to the ionosphere, and auroral boundaries, with satellite footprints; extending to other data sets, e.g., ground data, UVI aurora and AMPERE FACs where feasible. This will allow effective & efficient tracking of FAC response to dayside driving at the magnetopause. An up-to-date SMILE ephemeris from the SMILE Science Working Team, and Swarm ephemerides will be required. The proposed work will require the efforts of a dedicated software engineer, at an anticipated level of 0.5 to 1.0 FTE.

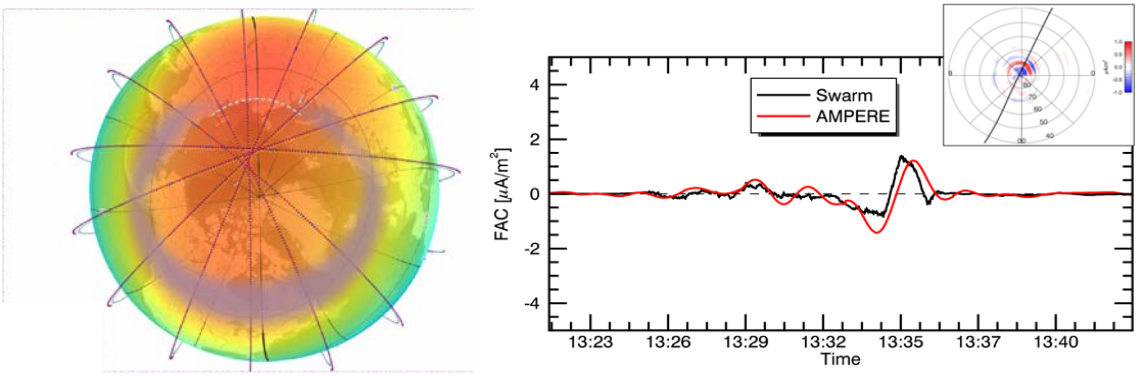


Figure 3: (Left) Mocked-up VirES-style global plot, with Swarm FACs (red=up, blue=down), UVI auroral oval (grey shaded area), and SXI-derived mapped magnetopause position (light green, dashed line). (Right) AMPERE/Swarm time series comparison with inset showing the Swarm spacecraft track on the AMPERE model currents.

4. Expected output (e.g., frequency of delivery, suggested strategy for data delivery)

We anticipate output from the data products and tools developed here to be ingested into existing Swarm platforms, e.g., VirES or Swarm-Aurora, as well as into SMILE DFF, plus any subsequent platform to visualise Swarm with SMILE & Cluster data in a global geospace context. One potential mock up image is shown in Fig. 3, left. We will make AMPERE-Swarm-SMILE & Cluster compared products, e.g., AMPERE-Swarm R1 currents compared to UVI open-closed boundaries, and scaling comparisons between AMPERE and Swarm (see Fig. 3, right). FAC orientations obtained from the dual Swarm spacecraft will be compared with the aurora, a method that is currently being explored by the FACTOR project, which we can extend to FAC R1/R2 boundaries and the Champ/Swarm auroral boundary model (Xiong et al. 2014). Additionally, the cusp location, as determined by Swarm & Cluster, can be used in SXI processing to constrain boundary detection methods. All Swarm-Cluster-SMILE products will follow mission metadata standards to allow ease of portability.

5. Scientific/application benefits, complementarity with other relevant ESA and non-ESA activities including opportunities for new scientific activities based on implementation of the proposed product / service

Rarely are solar-terrestrial experimental data presented in isolation. These data require the context provided by a multiscale approach that considers the Earth's magnetosphere and ionosphere as an integrated system, with multiple routes for feedback and influence across wide ranging spatial and temporal scales. There are increased efforts by ESA and the wider international heliospheric community (e.g., the recent ESA hosted meeting (https://www.cosmos.esa.int/web/esa-heliophysics/heliophysics-in-europe-2024), to take a holistic view of the Earth's system. This project aligns well with these efforts.

6. Expected user community

The data products proposed here will extend and diversify the current Swarm user base, by providing data visualisation and analytic tools that explore the Earth's magnetosphere at multiple spatial scales and at multiple cadences. The tools will be presented to those ground-based facilities who are actively supporting SMILE, including SuperDARN, SuperMAG, and EISCAT 3D. The use of these tools across multiple platforms to present this data will expose Swarm to new communities enabling Swarm to extend its reach.