Open Call for Ideas for

New data products, tools and services for Swarm

Template

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In order to facilitate 'cross pollination' between ideas and research groups, the Proposer(s) declare in submitting this idea, that the Swarm DISC may publish the name(s) of the proposer(s) and the title of the idea. Please indicate below (select Yes or No) whether DISC can also publish the entire content of the submitted idea:

Publish the entire content *Yes*

Product/Tool/Service Idea

Title: **Extension of GeospaceLAB software package to support Swarm mission**

Product/Tool/Service Description (2 pages maximum)

- **Description of proposed product/tool/service**

Research projects in space physics and space weather are typically based on several kinds of measured and/or modelling data. Processing and combining those data are demanding tasks because they are often provided from different data sources and in different formats. Even one satellite mission, such as Swarm, may include tens of data products. The diversity of data adds an unnecessary complexity to the data analysis in research projects. It often takes a lot of time for a researcher to collect and manage the data before the data are processed for a further analysis and interpretation. To improve the productivity in data access and analysis, the open-source Python package GeospaceLAB is developed [URL1, RD1].

GeospaceLAB provides a unified process for data access, management, and visualization that connects the data provider and the space physics researchers. Using the package, researchers can progress their research in a quick manner and focus more on the data interpretation and research results. The package has been applied in the study of Magnetosphere-ionosphere-thermosphere coupling. The package got 29 stars in GitHub and was included in Python in Heliosphysics Community (PyHC) in 2022.

In this proposal, we want to extend GeospaceLAB to support the Swarm mission. The main tasks include:

T1. Support all Swarm Level 1, Level 2, and advanced data products.

T2. Communication with Swarm VirES client and HAPI service.

T3. Specialized functionalities for analyzing the low-Earth-orbit satellite measurements, e.g., conjunction event finder and module for data grouping and gridding.

- **Description of current state of the art and level of maturity of proposed algorithm**

Python has become the fastest-growing programming language in scientific research during the last 2 decades. GeospaceLAB takes advantage of the programming language Python and its built-in and external open-source packages. GeospaceLAB can complete multiple tasks that are required for a scientific data analysis, instead of using different programming languages or software. Since the framework in the core modules is well structured, the package is highly extendable for multiple purposes in space research. It is timely to make a full support for the Swarm mission.

For the Swarm mission, the "Dataset" classes of GeospaceLAB will be customized for each data product. Currently, the "Dataset" classes support to download and load several Swarm data products, including MAG, EFI_LP, FAC, EFI_TCT, and DNS_ACC with the functions to check data availability, version, and query of parameters. The same techniques can be applied to other swarm data products.

In addition, the Dataset classes can be used as a wrapper for the VirES for Swarm data service. With the implementation, users can directly communicate with VirES for Swarm and use the functionality of

GeospaceLAB to visualize the data provided from VirES. There is also the opportunity to connect to SwarmPAL to add more visualisation capabilities to that package.
The Visualization toolbox in GeospaceLAB manages the time-series and geospatial plots for Swarm data. In the toolbox, the Dashboard classes have been optimized for low-Earth orbit data. For time-series plots, it can add additional tick labels for satellite position (e.g., GLAT, GLON, MLAT, MLT). The geo-Dashboard classes provide different map projections, so that users can view the LEO data in different maps with different coordinate systems. These functions let users easily identify various ionospheric signatures with corresponding locations.

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

GeospaceLAB aims to support all Swarm Level 1, Level 2, and advanced data. The Dataset classes can check the data availability and version, read data with flexible time range, scan data gaps and outliers, and load auxiliary information as dataset attributes. All the Swarm data are retrieved from ESA's Swarm Data Access.

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

The expected output is the modules to access and visualize different Swarm data products. The package will provide ready-to-use example codes and documentation. As a result, users can get a quick start to use the package. The package is maintained in the GitHub repository. Special functionality will be developed for analysing the LEO data, such as a conjunction finder to identify conjunctions events between satellites and ground instruments and toolbox for data grouping and gridding according to satellite orbits. Regular updates will be made to fix bugs add new functionality.

- **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.**

GeospaceLAB is typically used in magnetosphere-ionosphere-thermosphere coupling studies. For example, there are several published papers on the topic of polar cap aurora [RD2], ionospheric conductance [RD3], ion outflow [RD4], thermospheric wind [RD5], and polar cap patches [RD6]. Users can also use it to check space weather events (e.g., storms and substorms) with the solar wind parameters from the OMNI database and various geomagnetic indices. The GeoDashboard and GeoPanel classes can be used for a global view of the key parameters in the ionosphere-thermosphere system. Combined with the TSDashboard for time series plots, users can easily identify the regional/local responses. So far, the package supports more than 25 data products from different online/local data sources, including OMNI solar wind and IMF, geomagnetic indices (SuperMAG, AE, Kp, Hp, SYM/ASYM, Dst, and F10.7 indices), GNSS TEC, incoherent scatter radars, magnetometers, DMSP, GRACE, and GRACE-FO measurements, and a few Swarm data products as mentioned above. A conjunction event finder would enhance the joint analysis of these datasets. With the full support of the Swarm mission, users can investigate any scientific objectives related to the mission and create new research topics by exploring Swarm data and other data in space physics. The package can be developed to interact with other Python packages, such as ESA-funded VirES for Swarm and SwarmPAL, so that users can easily switch to use different functions in those packages.

- **Expected user community**

The expected user community includes but is not limited to the researchers in space physics, space weather, and geophysics.

References

[URL1] GitHub repository for GeospaceLAB: https://github.com/JouleCai/geospacelab
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[RD3] Wang et al. (2024). Ionospheric conductances due to electron and ion precipitations: A comparison between EISCAT and DMSP estimates. Journal of Geophysical Research: Space Physics, 129, e2023JA032354. https://doi.org/10.1029/2023JA032354
[RD4] Venugopal et al.(2024). Enhanced Oxygen Ion Outflow at Earth and Mars due to the Concurrent Impact of a Stream Interaction Region. The Astrophysical Journal, 966(1), 126. Doi:10.3847/1538-4357/ad307a.
[RD5] Oyama et al. (2024). Thermospheric wind response to March 2023 storm: Largest wind ever observed with a Fabry-Perot interferometer in Tromsø, Norway since 2009. Space Weather, 22, e2023SW003728. https://doi.org/10.1029/2023SW003728
[RD6] Cai et al. (2024). Effect of polar cap patches on the high-latitude upper thermospheric winds. Journal of Geophysical Research: Space Physics, 129, e2024JA032819. https://doi.org/10.1029/2024JA032819