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: Toolbox for creating a neutral mass density scale height data product from satellite coplanar events.

Product/Tool/Service Description (2 pages maximum)

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

Different precession rates of two low-Earth-orbit (LEO) satellites make it possible that the two satellites are coplanar during a certain period. When two satellites are coplanar, the ionospheric and thermospheric parameters measured from the two satellites can be compared. One of the parameters estimated from coplanar measurements is the H_ρ in the upper atmosphere [e.g., RD2]. In the ESA funded project "Joule heating effects on ionosphere-thermosphere coupling and neutral density (JOIN)" (ESA AO/1-11878/23/I-EB ending by 01.2026, URL1) Work Package 3, we are analysing the neutral mass density scale height during nine coplanar periods in 2014-2023 for the Swarm, GRACE, and GRACE-FO missions (Figure 1). Based on this work, we propose to develop a new toolbox and data product for the LEO satellite missions. The main tasks include:

T1. Developing and publishing a Python toolbox for analysing coplanar events, which can be integrated to the ESA-funded SwarmPAL (https://swarmpal.readthedocs.io/en/latest/acknowledgements.html) ecosystem.

T2. Data product of the neutral mass density scale height with an extension for the missions prior to Swarm, including CHAMP, GRACE, and GOCE before 2014 and continued analysis for the Swarm and GRACE-FO missions after 2023.

T3. Supplementary data and quicklook plots.

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

The coplanar events of CHAMP and GRACE satellites were studied during the solar minimum between Solar Cycles 23 and 24 [RD1 and RD2]. In Thayer et al.'s work [RD2], the averaged scale height was estimated and they found that the presence of helium plays a dominant role in determining the CHAMP-to-GRACE density ratio in the winter hemisphere during extreme solar minimum. The behaviour of the density ratio at two altitudes, or in terms of the height-averaged reciprocal of density scale height, during active solar and geomagnetic activity conditions are poorly understood.

Combining the neutral density measurements from Swarm, GRACE, and GRACE-FO missions, we have found nine coplanar periods (see Figure 1) during the years 2014-2023 in the WP3 of the JOIN project. The averaged neutral mass density scale height can be estimated by

$$\langle H_\rho \rangle = \frac{1}{z_A - z_B} \ln \frac{\rho_A}{\rho_B}, \qquad \text{(Eq. 1)}$$

where ρ and z are neutral mass density and altitude, respectively and the subscripts A and B represent the two coplanar satellites.

We have developed the procedures for the scale height analysis. The main procedures include: (1) Low-band-filtering of the along-track measurements of the neutral mass density for the two coplanar satellites; (2) Grouping the along-track data into two trajectory sectors: centered at the ascending phase and centered at the descending phase; (3) Gridding the grouped data in evenly distributed universal time (UT)-Latitude grids; and (4) Using the gridded neutral mass density and altitude data to estimate the averaged scale height as shown in Equation 1.

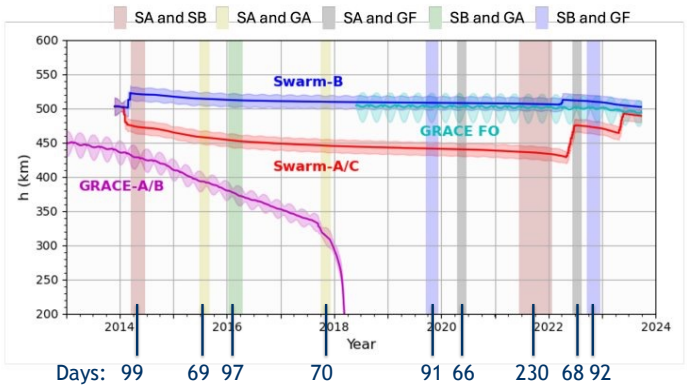


Figure 1 The time spans for the three missions between 2013 and 2023. The vertical shadings indicate the co-planar periods of two satellites with a local time (LT) difference of 1 h (SA: Swarm-A, SB: Swarm-B, GA: GRACE-A, and GF: GRACE FO).

The progress in the current scale height analysis drives us to extend the analysis for all the LEO missions providing neutral density measurements and to develop a toolbox for analysing coplanar events and providing the neutral mass density scale height data product. Furthermore, the neutral mass density from MSIS or DTM models can be processed in the same way as shown above. As a result, the scale height based on models will be provided for comparison.

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

For this work, we will use the neutral density measurements from the CHAMP, GOCE, Swarm, GRACE, and GRACE-FO missions. As shown in Figure 1, the number of days during each coplanar period varies between 60-230 days. Swarm mission provides two data products of neutral density: DNS_POD and DNS_ACC. The former neutral density is estimated from the GPS receiver with a time resolution of 30 s and the latter from both GPS and ACC with a time resolution of 10 s. Other satellite missions provide DNS_ACC data only.

To estimate the modeled scale height, we need to run MSIS and DTM models with the input of solar radiation and geomagnetic activity indices.

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

First, we will develop a Python toolbox for analysing coplanar events, including the functionality to search coplanar events, retrieve satellite orbit and measurement data, group and grid data, and produce output and visualization. The toolbox may be integrated to the ESA-funded SwarmPAL package. Second, we will provide the data product of the neutral mass density scale height as a function of UT and latitude. The scale heights are estimated from both measurements and empirical models. The data will be stored in NETCDF format with a daily period. Third, we will provide supplementary data and plots in the scale height data product, including associated auxiliary information such as quality flag, satellite orbit parameters and quicklook plots.

- **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.**

Users may use the data product of neutral mass density scale height to study its dependence on altitude, local time, latitude, solar activity, and geomagnetic activity. Since scale height in the upper thermosphere indicates the change in neutral temperature and composition, one of the two parameters may be inferred if assuming the other is invariant for a condition. In addition, the data product may be used for validating the output from either empirical or first-principles models. The toolbox for analysing coplanar events can also be used for comparing other key parameters measured by different satellites, such as electron density, electric field and currents, to reveal small scale variations in the ionosphere-thermosphere.

- **Expected user community**

The expected user community includes but is not limited to the researchers in space physics and space weather, especially for the topic of the ionosphere-thermosphere coupling.

References

[URL1] JOIN project: https://www.oulu.fi/en/projects/joule-heating-effects-ionosphere-thermosphere-coupling-and-neutral-density-join

[URL2] SwarmPAL: https://swarmpal.readthedocs.io/en/latest/acknowledgements.html

[RD1]Bruinsma et al. (2010). Anomalous behavior of the thermosphere during solar minimum observed by CHAMP and GRACE. Journal of Geophysical Research: Space Physics, vol. 115.A11. doi: https://doi.org/10.1029/2010JA015605.

[RD2] Thayer et al. (2012). The impact of helium on thermosphere mass density response to geomagnetic activity during the recent solar minimum. Journal of Geophysical Research: Space Physics, vol. 117.A7. doi: https://doi.org/10.1029/2012JA017832 .