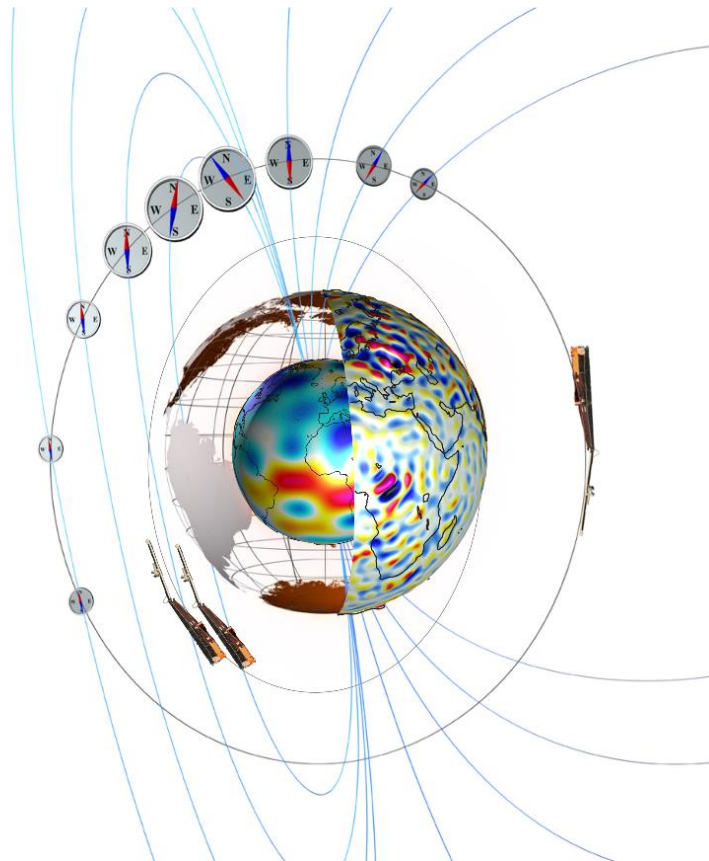

Statement of Work

Swarm DISC ITT 4.3

“Satellite derived thermospheric data products in support of Swarm science”



Doc. no: SW-SW-DTU-GS-129, Rev: 1

Record of Changes

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1 Introduction

This Invitation to Tender is issued by the Swarm DISC consortium on behalf of ESA within the reference frame of ESA contract 4000109587/13/I-NB, under the Swarm DISC Procurement Procedure described [RD-1].

1.1 Scope and Applicability

This document describes the activity to be executed and the deliverables required under the Swarm DISC ITT 4.3 – “Satellite derived thermospheric data products in support of Swarm science”.

It will become part of the contract and shall serve as an applicable document throughout the execution of the work (with possible amendments recorded during the negotiation meeting).

The document is structured as follows:

- Chapter 2 quotes applicable and reference documents (including applicable standards).
- Chapter 3 introduces the background and main objectives of the work, and presents the constraints on the system to be produced.
- Chapter 4 defines the work to be performed in the contract to produce the required output.
- Chapter 5 contains the requirements on deliverables and on general project management aspects.
- Chapter 6 contains schedule and milestones.

2 Applicable and Reference Documentation

2.1 Applicable Documents

The following documents are applicable to the definitions within this document.

[AD-1] [ESA-EOPG-MOM-IF-17 Swarm SDPC to PDGS Interfacing Control Document \(ICD\)](#)

2.2 Reference Documents

The following document contains supporting and background information to be taken into account during the activities specified within this document.

[RD-1] [SW-RS-DTU-GS-003 rev. 2, Swarm DISC Procurement Procedure](#)

[RD-2] Bruinsma, S. L., & Forbes, J. M. (2010). Anomalous behavior of the thermosphere during solar minimum observed by CHAMP and GRACE. *Journal of Geophysical Research: Space Physics*, 115(A11). <https://doi.org/10.1029/2010JA015605>

[RD-3] Doornbos, E., van den IJssel, J., Luehr, H., Foerster, M., & Koppenwallner, G. (2010). Neutral Density and Crosswind Determination from Arbitrarily Oriented Multiaxis Accelerometers on Satellites. *Journal of Spacecraft and Rockets*, 47(4), 580-589. <https://doi.org/10.2514/1.48114>

[RD-4] Sutton, E. K. (2011), Accelerometer-Derived Atmospheric Density from the CHAMP and GRACE Satellites, AFRL Tech. Rep., DTIC# ADA537198, Defense Technical Information Center (DTIC), Fort Belvoir, VA. <http://www.dtic.mil/docs/citations/ADA537198>

[RD-5] Doornbos, E. (2012), Thermospheric Density and Wind Determination from Satellite Dynamics, Springer Theses, Springer, Berlin, doi:10.1007/978-3-642-25129-0_2

- [RD-6] Mehta, P. M., Walker, A. C., Sutton, E., & Godinez, H. C. (2017). New density estimates derived using accelerometers on board the CHAMP and GRACE satellites. *Space Weather*, 15(4), 558-576. <https://doi.org/10.1002/2016SW001562>
- [RD-7] Vielberg, K., Forootan, E., Lück, C., Löcher, A., Kusche, J., & Börger, K. (2018). Comparison of accelerometer data calibration methods used in thermospheric neutral density estimation. *Annales Geophysicae*, 36(3), 761-779. <https://doi.org/10.5194/angeo-36-761-2018>
- [RD-8] G. March, E.N. Doornbos, P.N.A.M. Visser (2019). High-fidelity geometry models for improving the consistency of CHAMP, GRACE, GOCE and Swarm thermospheric density data sets. *Advances in Space Research*, 63(1), 213-238. <https://doi.org/10.1016/j.asr.2018.07.009>
- [RD-9] Panzetta, F., Bloßfeld, M., Erdogan, E. et al. (2019). Towards thermospheric density estimation from SLR observations of LEO satellites: a case study with ANDE-Pollux satellite. *Journal of Geodesy* 93, 353-368. <https://doi.org/10.1007/s00190-018-1165-8>
- [RD-10] Vielberg, K., and Kusche, J. (2020). Extended forward and inverse modeling of radiation pressure accelerations for LEO satellites. *Journal of Geodesy*, 94 (Article 43). <https://doi.org/10.1007/s00190-020-01368-6>
- [RD-11] Krauss, S., Behzadpour, S., Temmer, M., & Lhotka, C. (2020). Exploring Thermospheric Variations Triggered by Severe Geomagnetic Storm on 26 August 2018 Using GRACE Follow-On Data. *Journal of Geophysical Research: Space Physics*, 125(5). <https://doi.org/10.1029/2019JA027731>

2.3 Terminology

In this document the term ‘*shall*’ indicates requirements which the proposed effort must meet, while ‘*should*’ indicates a desirable feature.

2.4 Abbreviations

A frequently updated Acronyms and Abbreviations list for Swarm and related projects can be found [here](#) in the Swarm Data Handbook.

3 Background and Objectives

3.1 Background

The GRACE and GRACE-FO missions (designated simply as GRACE below) have been designed for mapping temporal gravity variations from the analysis of relative orbital motion. The very precise instrument suites on-board of these satellites contain measures to mitigate the influence of space weather in the thermosphere-ionosphere on gravity recovery: dual-frequency signals are used to mitigate ionospheric path delay on inter-satellite range measurements, while accelerometers are used to mitigate the effects of atmospheric drag. The GRACE satellites have therefore proven to be very useful for the delivery of in-situ data on the thermosphere and ionosphere as well.

Routinely processed GRACE data for thermosphere parameters would be of great additional value to existing Swarm data. The GRACE missions (first launch in 2002, follow-on launched in 2018) are overlapping in time with Swarm, and have already been providing data in the decade before the launch of Swarm. The pairs of GRACE satellites have similar orbital characteristics as the lower Swarm satellites. Therefore, GRACE is very well suited to extend and add value to the Swarm data base.

GRACE accelerometer data processing for the derivation of thermosphere data has been investigated e.g. in the publications listed as Reference Documents (2.2). However, the validation and documentation of the derivation methodology as well as the continued production and provision of easy access to end users of a full, well-documented and regularly updated data set have not been established.

For this call, it is proposed to leverage the publicly available GRACE L1 data products, and generate data products related to the thermospheric density and winds, complementing Swarm DISC products. While the call is focused on utilizing GRACE data, proposals based on similar observations from other LEO satellites are also welcome.

The mission objectives of Swarm, as well as already existing Swarm products are disseminated and described through <https://earth.esa.int/swarm> and included links.

Current Swarm data products are described on the [Swarm Data Handbook](#) and visualizations of most Swarm data products are available via the interactive '[VirES for Swarm](#)' client. Tenderers are encouraged to visit VirES, to get an impression of the capabilities available.

This project shall deliver its products as part of the Level 2 distributed processing network, as a new product in the Swarm data processing chain (see Figure 1, and the applicable document [AD-1]). The products shall be suitable for generation on a regular basis pending availability of the required input products.

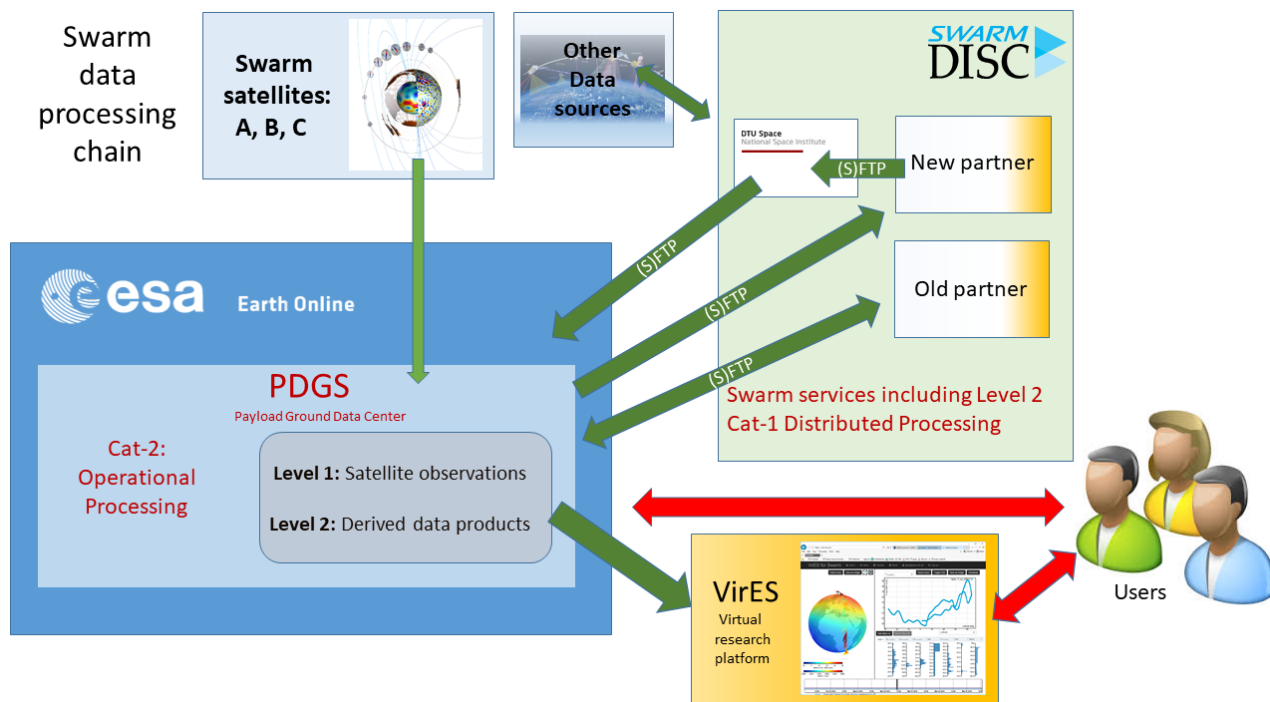


Figure 1 - Swarm data processing chain

Category-2 products are generated at PDGS. Category-1 products are generated by Swarm DISC partners, and published via the PDGS.

3.2 Objectives of the Activity

The main objective of this activity is to enhance and supplement the Swarm thermospheric dataset.

This activity *shall*:

- Develop and define products for thermosphere parameters such as thermosphere density and crosswind data, from GRACE accelerometer and GPS tracking data (crosswind data processing is feasible at high density levels only)
 - The definition shall ensure compatibility and complementarity with existing and foreseen Swarm data products
 - The definition shall include information that enables the identification of conjunctions between several spacecraft (including between the Swarm satellites), such as relative spatial and temporal distance of the thermosphere observations.
 - The definition shall address comparability of the defined products between the various satellites, including the three Swarm satellites.
- Validate the products by comparison to Swarm data as well as other data sources as applicable.
- Prepare a technical note describing the possible science use case of this new data set in combination with existing Swarm data.
- Provide visualization use cases, sample data sets and assist the operator of VirES in specifying and testing relevant web visualization(s).
- During the project, deliver at least one publication for peer review and one presentation to a Swarm Data Quality Workshop or similar event.

- Take into account that during satellite operations, the data processors may be enhanced and improved, triggering the reprocessing of the full mission data and the subsequent release of new product baseline. Furthermore, data quality assessment processes may reveal anomalies that could lead to the re-generation and replacement of a specific group of already existing products with an updated file counter. Therefore, the Contractor shall describe which steps they will take in both the reprocessing or re-generation scenarios in order to ensure the data quality of their output products.

This activity *should*:

- Develop and define additional related products based on data from GRACE or other LEO satellites.
- Explore the development of products that harness the possibilities of multiple satellites.
- Harness public outreach opportunities that may arise from this new product.

3.3 Assumptions and Constraints

Approval of deliverables will normally require 14 days for review by Swarm DISC Project Office. Approval of payment milestones is subject to approval of the related deliverables.

The tenderer shall show that they have access to the input data and that the project products preferably can be distributed in accordance with the [ESA data policies](#).

The products shall be suitable for generation on a regular basis pending availability of the required input products. The new products are expected to be distributed through PDGS, but the tenderer may suggest using an alternative similar system for distribution as appropriate.

4 Work to be Performed

All deliverables described here will require an informal review – reviewer to be appointed by the Swarm DISC technical representative – and subsequent written approval.

The following sections describe the tasks anticipated to complete this project. Required output deliverables are listed in chapter 5.

4.1 Work Logic

The work to be performed shall cover the following tasks: Definition and development of the products including validation of the input data and study of limitations to model assumptions, a scientific validation of the developed products, the implementation of the products for ESA PDGS or other data system and verification and validation of the products performance, as well as preparation of the products for provision in an operational setting. The work shall also include the presentation of the results on international conferences and the compilation into a scientific publication.

The Contractor is expected to provide a brief summary of the project (about 200 words) to be published on the Swarm mission [website](#) a week after Kick Off at the latest.

4.2 Implementation

4.2.1 Task 1: Product development and definition

4.2.1.1 Input

- Statement of Work (this document)
- Scientific literature
- Satellite data products and product documentation
- Supporting data and models
- Proposal (should include a first iteration of the product definition and work plan)

4.2.1.2 Task description

Based on a review of the existing scientific literature and documentation of existing or recent Swarm products (see <https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/data-handbook>), the Contractor shall define a new high-level product such as thermosphere densities and cross-track winds from other similar LEO satellites.

The Contractor shall document the definition of the product. In addition to the consideration listed in the above section 3.2, the product definition shall include information on the required input products, a definition of the data fields and metadata to be contained in the output product, information on the expected accuracy, time representation, temporal sampling and data volume of the product, as well as latency for availability of the product.

4.2.1.3 Deliverables

- Product Definition Document (PDD) including specification of input data (TN-01)

4.2.2 Task 2: Work plan

4.2.2.1 Input

- Statement of Work (this document)
- Proposal (should include a first iteration of the product definition and work plan)

4.2.2.2 Task description

The Contractor shall propose a work plan for the implementation, validation and operation of the processor that is to be developed for producing the new product. The proposed work plan shall be supported by preliminary analysis results. The work plan shall include the identification of the satellite data and meta-data required for the analysis, as well as independent data or models to be used for validation. One or more representative periods for initial testing and validation of the processor and resulting product shall be defined in the work plan. Satellite input data from sources other than existing Swarm products shall be described in the work plan, along with information on how to access this data.

4.2.2.3 Deliverables

- Updated work plan (TN-02)

4.2.3 Task 3: Science case

4.2.3.1 Input

- Product Definition Document including specification of input data (TN-01)
- Statement of Work (this document)
- Scientific literature

4.2.3.2 Task description

Prepare a technical note describing the possible science use case of this new data set in combination with existing Swarm data.

4.2.3.3 Deliverables

- Description of possible science use case (TN-07)

4.2.4 Task 4: Processor implementation

4.2.4.1 Input

- Product Definition Document (TN-01)
- Work plan (TN-02)
- Input data products

4.2.4.2 Task description

The Contractor shall implement the processor at its premises, according to the work plan. The processor shall be implemented to produce the data set, in accordance with the Product Definition Document. The

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Contractor shall document the algorithms that are applied in the processor in a technical note. The Contractor is strongly encouraged to adopt an open source approach for the code development. The Contractor shall collect all necessary input data to run the processor for a test period, and generate and deliver a first test data set.

4.2.4.3 Deliverables

- Description of the Processing Algorithms (DPA) and preferably submission of code to open source repository (TN-03)
- First test data set (DL-01)

4.2.5 Task 5: Product validation**4.2.5.1 Input**

- Product Definition Document (TN-01)
- Work plan (TN-02)

4.2.5.2 Task description

The Contractor shall compare the new product with data from Swarm and other data sources as applicable, to demonstrate the validity of the data set, and to the extent possible assess the accuracy of the data. The output of the activity shall be documented in a validation report, which shall include a description of the dataset used in the validation.

In order to assist the visualisation of the new data set in VirES, the Contractor shall develop visualization use cases and test data sets. The Contractor is encouraged to interact as early as possible with the VirES team in support of their implementation of the product visualization.

4.2.5.3 Deliverables

- Validation report (TN-04)
- Visualisation use cases, including test data and format specification (TN-06)

4.2.6 Task 6: Preparation and transfer of data to PDGS or alternative data system**4.2.6.1 Input**

- Product Definition Document (TN-01)
- Work plan (TN-02)
- Interface Control Document (ICD) [AD-1]

4.2.6.2 Task description

The Contractor shall produce the output data in the final product format compliant with [AD-1] and distribute it via PDGS or via an alternative similar system as appropriate.

The final output data should cover the full mission and be delivered by the Final Presentation.

The Contractor shall prepare a plan for how continued operational provision of the data product could be supported beyond the end of the contract. This plan shall describe the support needed for maintaining operational production including answering user questions received by ESA EO helpdesk (second line support) in the event that a future operational phase is to be negotiated.

4.2.6.3 *Deliverables*

- Description of data transfer functionality and proposal for continued operation beyond project closure (TN-05)
- Full mission data delivered to PDGS or other data system (DL-02)

4.2.7 **Task 7: Final presentation**

4.2.7.1 *Input*

- All outcomes from the project

4.2.7.2 *Task description*

- Preparation and submission of publication for peer review on the outcome of this project
- Presentation of project achievements at a Swarm Data Quality Workshop or similar event to be agreed with the Swarm DISC Project Office towards the end of the project.
- Delivery of all documentation to Swarm DISC. Note that the PDD, DAP, and Validation Report will be made publicly available on the Swarm Data Handbook.

4.2.7.3 *Deliverables*

- One publication submitted for peer review (DL-03)
- Presentation of project achievements at Swarm DQW or similar event (DL-04)
- Final project documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format (DL-05)

5 Requirements for Management, Reporting, Meetings, and Deliverables

The following are the requirements for management, reporting, meetings and deliverables applicable to the present activity.

5.1 Management

MG-01	The Contractor shall assign a responsible project manager as point of contact with the DISC Project Office / ESA.	
MG-02	A point of contact shall be assigned for each subcontractor, if any, but generally any correspondence with the project will be via the project manager assigned in MG-01	
MG-03	All correspondence between the project and ESA must be via – or if agreed by DTU in copy to – the Swarm DISC Project Office, with attention to the DISC project manager by email or letter post: Klaus Nielsen klausn@space.dtu.dk:	Swarm DISC Project Office DTU Space Centrifugevej, Building 356 DK-2800 Kgs. Lyngby Denmark Fax: +45 4525 9701

5.2 Reporting

GR-01	The Contractor shall submit all documents to the DISC Project Office in a searchable, non-protected PDF format, as well as their native format.
GR-02	The Contractor shall ensure that electronic documents do not contain any harmful code (e.g. virus)
GR-03	The Contractor shall produce a short quarterly progress report (or at other interval as agreed), communicated to the Swarm DISC Project Office via SVN and email. This report shall contain highlights of recent achievements, status on work progress, references to publications or presentations, new challenges, etc. Swarm DISC will provide a reporting template.

5.3 Meetings

ME-01	The Contractor shall organize a Kick Off meeting via telecon where key persons are introduced and the project schedule is presented.
ME-02	The Contractor shall at the Mid Term Review present highlights of recent achievements, status on work progress, and plan for the remaining part of the project to the Swarm DISC Project Office via telecon. The presentation should preferably be comprised of a limited number of slides provided to DTU one week before the telecon. ESA reserves the right to participate.
ME-03	The Contractor shall prepare a presentation of the final result (DL-04) and present it to the Swarm DISC community at a suitable event (Data Quality Workshop or conference) in Europe to be agreed with the Swarm DISC Project Office.

ME-04	The Swarm DISC Project Office and ESA reserves the right to call up ad hoc meetings at any time for justified reasons.
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5.4 Technical Documentation

The individual deliverables referred to in the task descriptions above and listed below can be submitted either as individual documents (technical notes) or as sections in a combined project report. The latter will take the form of a living document to be submitted in revisions according to the schedule outlined in section 6.2 below.

TN-01	Product Definition Document (PDD)
TN-02	Work plan
TN-03	Description of the Processing Algorithms (DPA) and preferably submission of code to open source repository
TN-04	Validation report
TN-05	Description of data transfer functionality and proposal for continued operation beyond project closure
TN-06	Visualisation use case, including test data and format specification.
TN-07	Description of possible science use case

5.5 Other Deliverables

DL-01	First test data set
DL-02	Full mission data delivered to PDGS or other data system
DL-03	One publication submitted for peer review
DL-04	Presentation of project achievements at Swarm DQW or similar event
DL-05	All technical notes, presentations, publications and other relevant project documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format.

6 Schedule and Milestones

6.1 Schedule

SC-01	The Contractor shall establish a schedule that is consistent with the planned start of work and the milestones in section 6.2. Any deviation shall be identified and duly justified.
SC-02	The Contractor shall during execution monitor the major milestone schedule. Deviations shall be reported with justification to the DISC Project Office as soon as identified.
SC-03	In the event that delays to milestone deliveries are anticipated, this shall be reported to the Swarm DISC Project Office as soon as possible.

6.2 Milestones

Milestone	Description	Suggested timeline (months)
MIL-01	Project Kick Off	KO
MIL-02	Delivery 1 <ul style="list-style-type: none"> Product Definition Document (TN-01) Updated work plan (TN-02) 	KO+2
MIL-03	Delivery 2 – Mid Term Review <ul style="list-style-type: none"> Description of possible science use case (TN-07) First test data set (DL-01) Draft visualization use case, including test data and format specification (TN-06) 	KO+6
MIL-04	Delivery 3 – Final delivery <ul style="list-style-type: none"> Updated Product Definition Document (TN-01) Description of the Processing Algorithms (TN-03) Validation report (TN-04) Description of data transfer functionality and proposal for continued operations beyond project closure (TN-05) Updated visualization use case, including test data and format specification (TN-06) Full mission data delivered to PDGS or other data system (DL-02) One peer reviewed publication submitted (DL-03) 	KO+12
MIL-05	Final Presentation All technical notes, presentations, publications, and other relevant documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format.	KO+14