



Statement of Work

Swarm DISC ITT 7.2

“Empirical model of ionospheric electrodynamics during substorms”



Doc. no: SW-SW-DTU-GS-135, Rev: 1



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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 7.2 – Empirical model of ionospheric electrodynamics during substorms.

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] Weimer, D. R. (2005), Improved ionospheric electrodynamic models and application to calculating Joule heating rates, *J. Geophys. Res.*, 110, A05306, doi:10.1029/2004JA010884.

[RD-3] Cousins, E. D. P., and S. G. Shepherd (2010), A dynamical model of high-latitude convection derived from SuperDARN plasma drift measurements, *J. Geophys. Res.*, 115, A12329, doi:10.1029/2010JA016017.

[RD-4] Laundal, K. M. et al. (2018) 'Solar Wind and Seasonal Influence on Ionospheric Currents From Swarm and CHAMP Measurements', *Journal of Geophysical Research: Space Physics*. John Wiley & Sons, Ltd, 123(5), pp. 4402–4429. doi: 10.1029/2018JA025387.

[RD-5] Hatch, S. M., Vanhamäki, H., Laundal, K. M., Reistad, J. P., Burchill, J. K., Lomidze, L., Knudsen, D. J., Madelaire, M., & Tesfaw, H. (2024). Does high-latitude ionospheric electrodynamics exhibit



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hemispheric mirror symmetry? *Annales Geophysicae*, 42(1), 229–253.
<https://doi.org/10.5194/angeo-42-229-2024>.

[RD-6] Lomidze, L., Burchill, J. K., Knudsen, D. J., Kouznetsov, A., & Weimer, D. R. (2019). Validity Study of the Swarm Horizontal Cross-Track Ion Drift Velocities in the High-Latitude Ionosphere. *Earth and Space Science*, 6(3), 411–432. <https://doi.org/10.1029/2018EA000546>.

[RD-7] Swarm Product Data Handbook at <https://swarmhandbook.earth.esa.int/>

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](#).

AMPS	Average Magnetic field and Polar current System
Swarm Hi-C	Swarm High-latitude Convection model
SWIPE	Swarm Ionospheric Polar Electrodynamics model



3 Background and Objectives

3.1 Background

Substorms triggered in the magnetotail are transient events in magnetospheric dynamics that significantly alter the Geospace current system, magnetic field configuration, and overall behaviour of the coupled magnetosphere-ionosphere system. Understanding substorms is essential for comprehending space weather phenomena and their potential impacts on satellite operations, communication systems, and technological infrastructure on Earth.

The electrodynamics of the high-latitude ionosphere involves a complex interplay of various physical processes. The solar-wind-induced electric field is one of the most critical drivers of dynamics in the magnetosphere, driving global convection in the magnetosphere and the magnetically conjugate high-latitude ionosphere. During substorms, mesoscale electric potentials are superimposed onto the global-scale electric potential, leading to modifications in the overall convection pattern.

Magnetospheric, field-aligned, and ionospheric currents that form a global current system are also significantly affected throughout the substorm evolution. The most prominent manifestation of this process is the formation of the substorm current wedge. As a consequence of these current variations, the magnetic field also experiences substantial changes.

Current empirical models of high-latitude ionospheric dynamics (such as the Weimer2005 [RD-2], Cousins&Shephard2010 model [RD-3], AMPS [RD-4], Swarm Hi-C or SWIPE [RD-5]) lack a comprehensive characterisation of all these substorm-related processes. An empirical model of the high-latitude ionosphere would effectively enable further studies of these complex processes, based on Swarm observations.

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 in 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 product as part of the Level 2 product family (see Figure 1, and the applicable document [AD-1]).

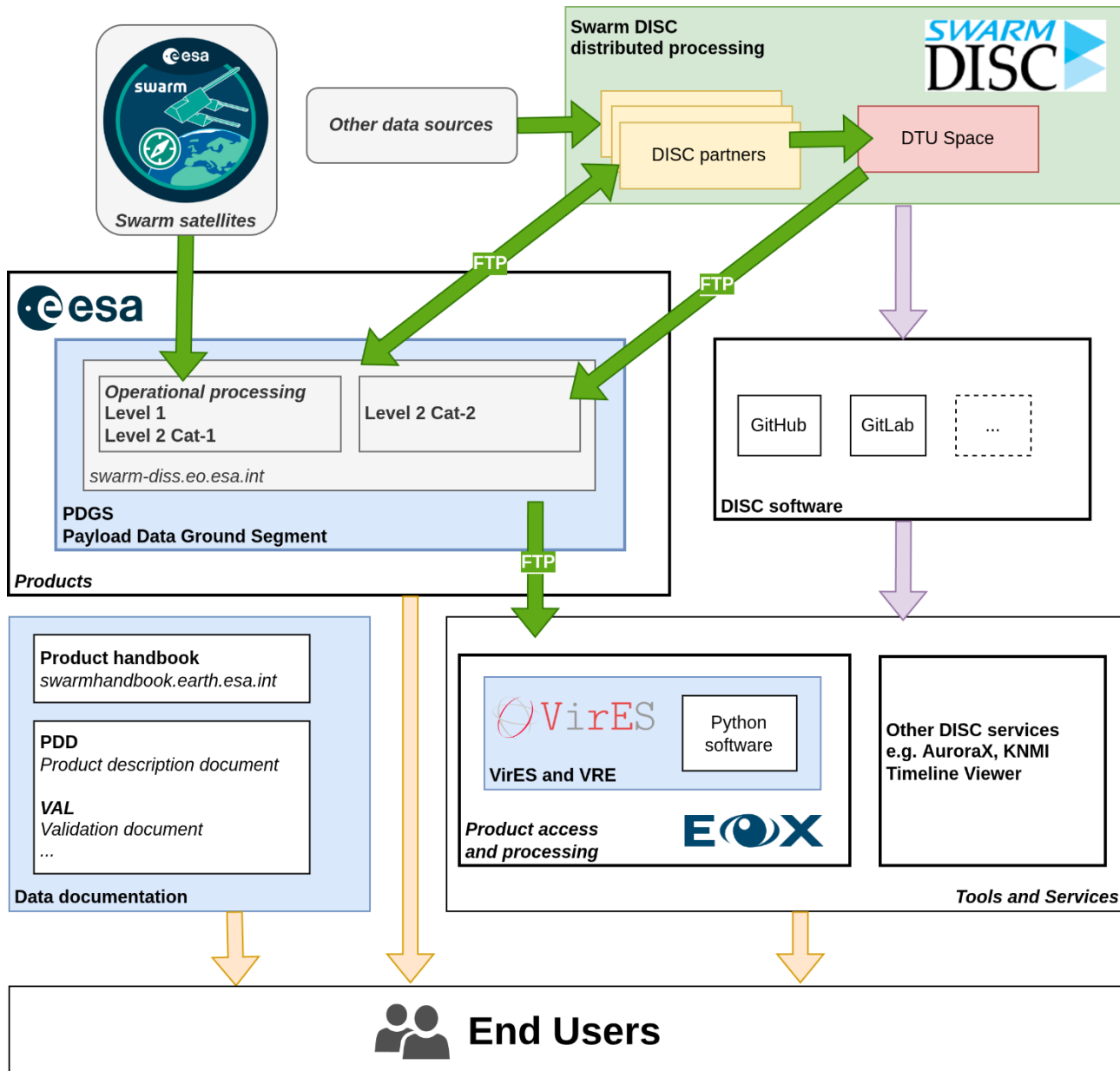


Figure 1 - Swarm data processing chain

3.2 Objectives of the Activity

The main objective of this activity is the development of an empirical model of ionospheric electrodynamics during geomagnetic substorms.

This activity shall:

- Develop an empirical model of ionospheric electrodynamics during geomagnetic substorms.
- The model shall be primarily based on data obtained by the Swarm satellite mission.
- Validate the performance of the model output in terms of typical temporal and spatial scales and magnitude during geomagnetic substorms against independent data.
- Discuss the assumptions taken during model development.



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- Provide a Swarm data product to be distributed through ESA's dissemination server (<https://swarm-diss.eo.esa.int>), e.g., the coefficient files to run the model forward code.
- Deliver model forward code in an open-source programming language, for example Python, including documentation as open source on community platforms, such as GitHub.
- Export the output/results of the model in a commonly used data format.

This activity *should*:

- Identify potential limitations of the model due to the substorm classification method.
- Study the suitability of the input Swarm data for the purpose of model development for substorms, such as expected limitations and validity ranges of the model due to the quality of the input data, seasonal/local time distribution, etc.
- Deliver the model inversion code including documentation as open source on community platforms, such as GitHub.
- Provide tools for visualisation of the model output.

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 could be suitable for generation on a repeated basis pending availability of the required input products.

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 tasks listed under 4.2. The tender shall present an applicable Work Plan to implement them in the proposal.

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: Model definition and tool specification

4.2.1.1 Input

- Statement of Work (this document)
- Swarm data products and their documentation
- Scientific literature
- Supporting (e.g. ground based) data
- Supporting models
- Proposal (should include a first iteration of the model definition and work plan)

4.2.1.2 Task description

Based on a review of the existing scientific literature and the documentation of Swarm products (see <https://swarmhandbook.earth.esa.int>) and other relevant products and data sets, the Contractor shall provide a description of the model definition (e.g. model parameters, coefficients etc) and the tools to be developed. That would include descriptions of:

- Survey of data and existing tools and models
- The Swarm data products and other data sets to be used, with their temporal and spatial coverage.
- The quantities to be modelled (e.g. ionospheric currents, magnetic field perturbations, electric potentials, and related quantities) and description of the parametrization to be used.
- The methods to be used, the assumptions made and the data processing procedures to be applied, with information about employed models e.g., to describe the substorm-related variations, and a plan for assessing the quality of the resulting electrodynamic model.
- The tools (e.g. software) to be developed and the output to be generated of inversion and forward models (e.g. coefficients with units, name).

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4.2.1.3 Deliverables

- Model Definition Document, including specifications of input data and tool specifications (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 Model Definition and work plan)
- Model Definition Document (TN-01)

4.2.2.2 Task description

The Contractor shall propose an updated work plan for the implementation, testing, documentation, and operation of the tool.

The work plan should include details about the project's tasks, their timeline, and identify key personnel.

4.2.2.3 Deliverables

- Updated work plan (TN-02)

4.2.3 Task 3: Data collection and quality assessment

4.2.3.1 Input

- Statement of Work (this document)
- Model Definition Document (TN-01)
- Swarm data and other data sets

4.2.3.2 Task description

At the data preparation stage, the Contractor shall also

- provide details on the data collection procedure (e.g., identification of substorms, datasets to be used, time intervals, intensity) and adopted model input
- select an independent data set to be used for model validation.

The suitability of the input Swarm data for the purpose of model development for substorms should be assessed

4.2.3.3 Deliverables

- Data sets prepared as input for the model development (DL-01)
- Data sets for model validation (DL-02)
- Reporting on the data collection procedure and quality assessment (DL-03)

4.2.4 Task 4: Development of the empirical model

4.2.4.1 Input

- Model Definition Document (TN-01)
- Data sets prepared as input for the model development (DL-01)

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4.2.4.2 *Task description*

Development of the empirical model. The inverse and forward codes shall be properly tested and submitted to an open-source repository. Example plots of the model output during testing of the model should be provided.

4.2.4.3 *Deliverables*

- Description of the processing algorithm (TN-03)
- Model code (DL-04)
- Example plots based on the test data set and model output (DL-05)
- Model coefficients (DL-06)

4.2.5 **Task 5: Model validation**

4.2.5.1 *Input*

- Model code (DL-04)
- Data sets for model validation (DL-02)

4.2.5.2 *Task description*

The empirical model shall be tested using an independent data set to assess its performance. A report is expected on the limitations and validity ranges (spatial and temporal resolution, magnitude, etc.) of the model due to the quality of the input data and assumptions based on these tests.

4.2.5.3 *Deliverables*

- Full validation report including validation plots based on the test data (TN-04)

4.2.6 **Task 6: Transitions to users and documentation to ESA**

4.2.6.1 *Input*

- All deliverables from Tasks 1-5

4.2.6.2 *Task description*

- Transfer of model code, model coefficients, potentially the visualisation code, and the corresponding documentation to Swarm DISC.
- Provide potential updates on the brief summary of the project published on the Swarm mission [web-site](#) and link to model code repository.
- Proposal for continued operation beyond project closure.

4.2.6.3 *Deliverables*

- Final project documentation, e.g. model and algorithm description, delivered electronically to the Swarm DISC Project Office in searchable PDF format (DL-07)
- Description of model output data transfer functionality and proposal for continued operation beyond project closure (TN-05)
- Final data set (DL-08)



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.

4.2.7.3 *Deliverables*

- One publication submitted for peer review (DL-09)
- Presentation of project achievements at Swarm DQW or similar event (DL-10)



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 intervals 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.	
GR-04	The Contractor shall consider public outreach opportunities that may arise from this project. Ideas should be reported to the DISC Project Office who will liaise between the project team and ESA’s communications team.	

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-09) 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 reserve the right to call up ad hoc meetings at any time for justified reasons.
ME-05	The Contractor shall provide minutes of the meetings. The DISC Project Office shall provide a template.

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. Submitting parts of the Project Report as journal publications is also acceptable.

TN-01	Model Definition Document
TN-02	Work plan
TN-03	Description of the Processing Algorithms (DPA) and preferably submission of inversion code to open-source repository
TN-04	Validation report
TN-05	Description of model output data transfer functionality and proposal for continued operation beyond project closure

5.5 Other Deliverables

DL-01	Data sets prepared as input for the model development
DL-02	Data sets for model validation
DL-03	Reporting on the data collection procedure and quality assessment
DL-04	Model code



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DL-05	Example plots based on the test data set and model output
DL-06	Model coefficients
DL-07	Final project documentation, e.g. model and algorithm description, delivered electronically to the Swarm DISC Project Office in searchable PDF format
DL-08	Final data set
DL-09	One publication submitted for peer review
DL-10	Presentation of project achievements at Swarm DQW or similar event

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	If 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"> Model Definition Document - incl. survey of data and existing tools and models Work plan (updated) 	KO+2
MIL-03	Delivery 2 – Review <ul style="list-style-type: none"> Working version of forward code with functional example Coefficients (close to final) Validation report (interim) 	KO+9
MIL-04	Delivery 3 – Final delivery <ul style="list-style-type: none"> Fully validated model Validation report (final) Submission of model code plus documentation Description of model output data transfer functionality and proposal for continued operation beyond project closure 	KO+11
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+12