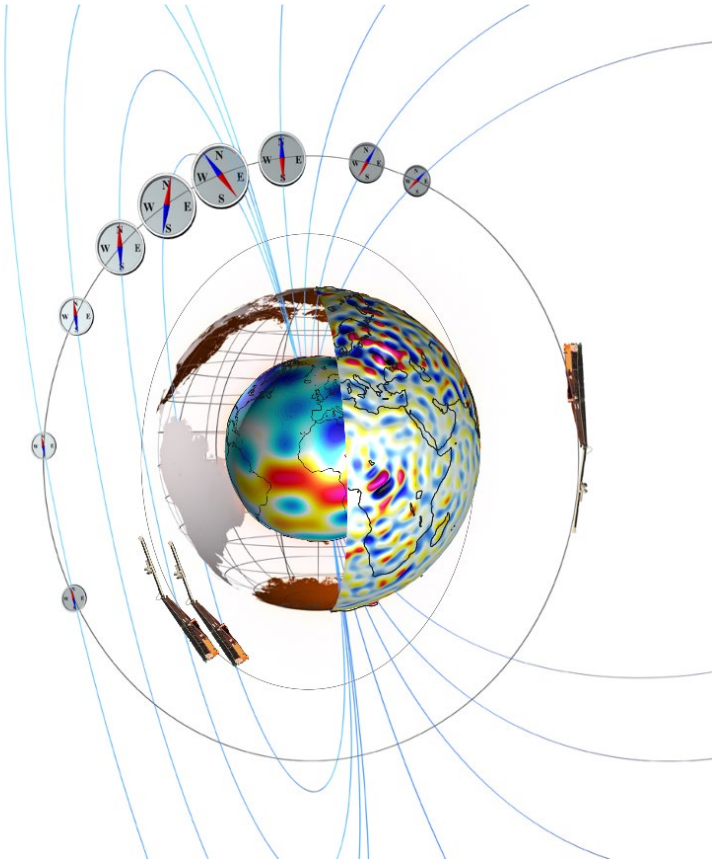
Statement of Work

Swarm DISC ITT 6.2

"Data Fusion Toolbox for Regional High-Latitude Ionospheric Electrodynamics"



Doc. no: SW-SW-DTU-GS-132, Rev: 1 dB

Record of Changes

Reason	Description	Rev	Date
Initial version	Draft template	1 dA	3 June 2024
Final version	Approved for publication	1 dB	2 July 2024

Table of Contents

List of Figures

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 6.2 – "Data Fusion Toolbox for Regional High-Latitude Ionospheric Electrodynamics".

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] Matsuo, T., & Richmond, A. D. (2008). Effects of high-latitude ionospheric electric field variability on global thermospheric Joule heating and mechanical energy transfer rate. Journal of Geophysical Research, 113 (A07309). doi:10.1029/2007JA012993

[RD-3] Zhu, Q., Deng, Y., Richmond, A., & Maute, A. (2018). Small-scale and mesoscale variabilities in the electric Field and particle precipitation and their impacts on Joule heating. Journal of Geophysical Research: Space Physics, 123, 9862- 9872.

[RD-4] Lu, G., A. D. Richmond, J. M. Ruohoniemi, R. A. Greenwald, M. Hairston, F. J. Rich, and D. S. Evans (2001), An investigation of the influence of data and model inputs on assimilative mapping of ionospheric electrodynamics, J. Geophys. Res., 106, 417–433, doi:10.1029/2000JA000606.

[RD-5] Hsu, C.-T. , Matsuo, T. , Maute, A. , Stoneback, R. , & Lien, C.-P. (2021). Data-driven ensemble modeling of equatorial ionospheric electrodynamics: a case study during a minor storm period under solar minimum conditions. Journal of Geophysical Research: Space Physics, 126, e2020JA028539. https://doi.org/10.1029/2020JA028539

[RD-6] Thomas, E. G., & Shepherd, S. G. (2018). Statistical patterns of ionospheric convection derived from mid-latitude, high-latitude, and polar SuperDARN HF radar observations. Journal of Geophysical Research: Space Physics, 123, 3196–3216. https://doi.org/10.1002/2018JA025280

[RD-7] Anderson, B., Korth, H., Waters, C., Green, D., Merkin, V., Barnes, R., & Dyrud, L. (2014). Development of large-scale Birkeland currents determined from the active magnetosphere and planetary electrodynamics response experiment. Geophysical Research Letters, 41(9), 3017–3025. https://doi.org/10.1002/2014GL059941

[RD-8] Ozturk, D. S., Meng, X., Verkhoglyadova, O. P., Varney, R., Reimer, A. S., & Semeter, J. L. (2020). A new framework to incorporate high-latitude input for mesoscale electrodynamics. Journal of Geophysical Research: Space Physics, 125, e2019JA027562. https://doi.org/10.1029/2019JA027562

[RD-9] Laundal K. M., Reistad J. P., Hatch S. M., Madelaire M., Walker S., Hovland A. Ø., et al. Local Mapping of Polar Ionospheric, Electrodynamics. J Geophys Res [Space Phys]. 2022;127, doi:10.1029/2022JA030356

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

At high latitudes, the thermosphere-ionosphere (TI) is coupled to the solar wind and the magnetosphere. The energy input into the TI system can vary significantly depending on the solar wind and geomagnetic conditions. Associated with high-latitude coupling are field-aligned currents which close through the ionosphere generating magnetic field perturbations observed in space and on the ground. The field-aligned and horizontal current flow, the ionospheric conductivities and the electric field/ion convection are all connected via the ionospheric electrodynamics, and variations in one quantity influence the others. It was shown that small-scales and meso-scales in the high latitude coupling are important to capture the effect on the TI coupling [e.g., Matsuo et al. 2008; Zhu et al., 2018].

Studying and describing the high-latitude electrodynamics is important for capturing TI variations but also for understanding magnetospheric processes. Data assimilation methods like AMGeOs and AMIE use ground and space-based observations e.g., magnetic perturbations, ion drift, and particle precipitation [e.g., Lu et al., 2001] to describe global, large-scale ion-convection and current flow. SuperDARN provides fitted global convection patterns based on the measured SuperDARN ion drifts [e.g., Thomas et al., 2018]. AMPERE derives the signal of high-latitude field-aligned current from a satellite constellation and provides the global electric potential for selected periods using either constant ionospheric conductances or derive them from FACs [e.g., Anderson et al, 2014]. Regional, mesoscale variations are considered by the High-Latitude Input for Mesoscale Electrodynamics (HIME) [Oztuerk et al., 2020] using regional observations e.g., PFISR. The Local Mapping of polar ionospheric electrodynamics (LOMPE) [Laundal et al., 2022] framework can include ground- and space-base magnetic perturbations and ion drift observations with a given ionospheric conductance pattern to describe the regional convection and current. Due to limited availability of data, most methods use models with various levels of sophistication to represent certain parameters. For example, the contribution of neutral winds is often ignored. In addition, the high-latitude ionospheric conductivities can be highly dynamic and have contributions from solar EUV and auroral particle precipitation.

The Swarm mission has provided in-situ information on the magnetic and electric field, as well as densities of the thermosphere and ionosphere, for more than a decade. Swarm provides high resolution observations along the satellite tracks. However, a lack of contextual information in the areas surrounding those tracks often hinders their full scientific interpretation. This project looks for an easy-to-use toolbox that can help gather information from Swarm and various other data sources and provides a regional reconstruction of the ionospheric electrodynamics through data fusion. This would considerably help in the scientific interpretation of Swarm in-situ observations and could lead to new scientific insights.

The mission objectives of Swarm, as well as already existing Swarm products are disseminated and described through https://earth.esa.int/eogateway/missions/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 products as part of the Level 2 product family (see Figure 1, and the applicable document [AD-1]).

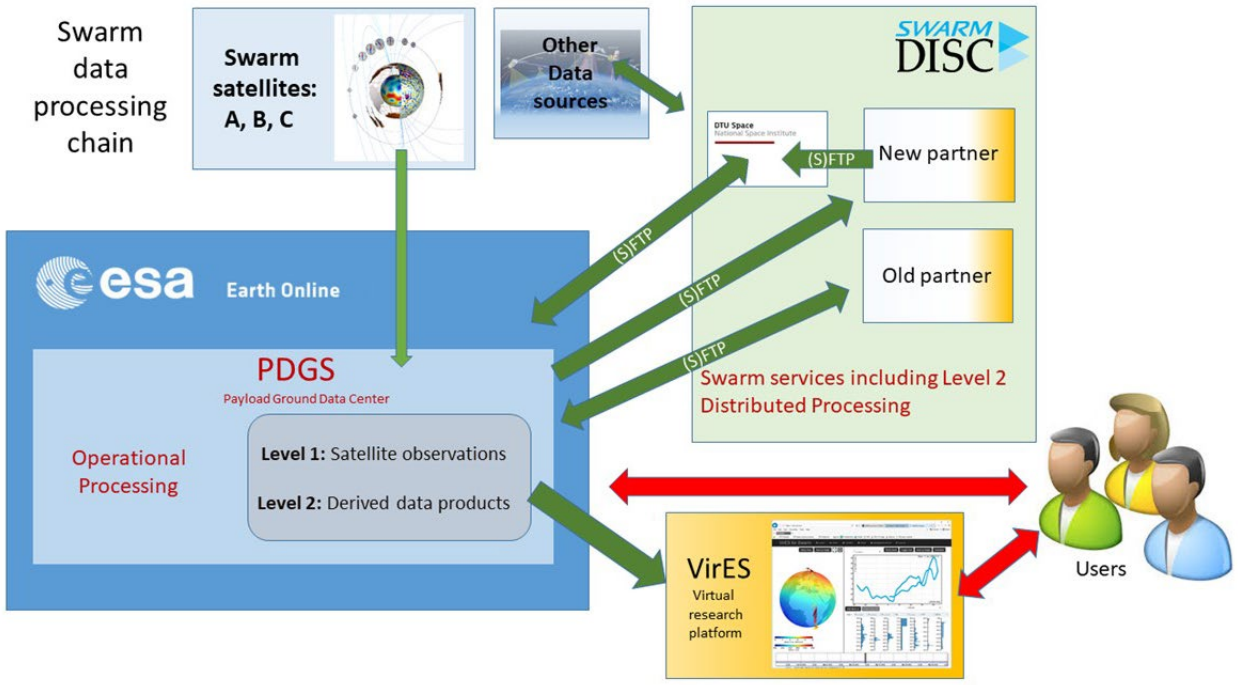


Figure 1 - Swarm data processing chain

3.2 Objectives of the Activity

The main objective of this activity is to develop and provide a toolbox to analyse the local ionosphere electrodynamics around LEO satellite paths at high latitudes. The contractors shall apply Swarm and other ionospheric data and demonstrate the toolbox's value in enhancing Swarm data exploitation.

This activity *shall*:

- implement an algorithm for regional reconstruction of ionospheric electrodynamics which is based on high-latitude observations, aimed at providing context to measurements made by the Swarm satellites
- develop a tool box that
    - allows the user to define region and time of the reconstruction
    - assists in the download of Swarm and other ground or space-based data e.g., of magnetic field and electric field
    - ingests and assimilates the downloaded data
    - applies the reconstruction of the at least 2D region of electrodynamic quantities, and generates output files and images for further analysis
    - provides a summary of data included in the requested reconstruction to allow the user to assess the coverage
- provide instructions for users on how to acquire input data

- perform sensitivity analyses with respect to the spatial/temporal data coverage on the output of the reconstruction and validate the output of the reconstruction
- deliver at least one publication for peer review and one presentation to a Swarm Data Quality Workshop or similar event.

This activity *should*:

- consider potential visualisation use cases for implementation in VirES or similar.

The toolbox developed during this activity *should*:

- offer automated download of input data, wherever possible, and provide instructions for manual downloading where needed
- include format adaptation of the input data to be ready for use in the toolbox
- offer options for different ionospheric conductivity models used in the reconstruction.

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.

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: Development and definition of the toolbox including documentation, validation and sensitivity analyses, as well as preparing a plan for the continued maintenance of the toolbox. 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 definition and work plan

4.2.1.1 *Input*

- Statement of Work (this document)
- Scientific literature
- Existing software
- Proposal (includes a first iteration of product definition and work plan)

4.2.1.2 *Task description*

The Contractor shall carry out a survey of the literature, as well as documentation of relevant data products, models and existing software tools.

This shall result in an update of the product definition and work plan, with respect to the version in the proposal. In particular, the product definition should indicate:

- a description of the algorithm to be used for data fusion, based on (reference to) an existing implementation and/or modifications for the current project
- which data products, models and/or assumptions will be used in the data fusion, and which input data formats will be supported
- which outputs (metadata such as variable descriptions, data types, units) will be provided by the toolbox (input data summary and output files), and in which data formats these will be supplied to users.

The work plan shall include details on the tasks of the projects and interdependencies between these tasks. For each task it should include inputs, outputs, subtasks, responsible key personnel, scheduled start times, and completion times.

4.2.1.3 *Deliverables*

- Literature survey (TN-03)
- Survey of existing data and tools (TN-04)
- Product definition document (TN-01)
- Work plan (updated) (TN-02)

4.2.2 Task 2: Development of data collection tools and documentation

4.2.2.1 *Input*

- Product definition
- Survey of existing data and tools

4.2.2.2 *Task description*

The Contractor shall develop and/or collect the necessary software tools and provide documentation that allows users to gather input data for the data fusion process for a specified time period and region. Use can be made of existing tools, such as the VirES Python Client module, HAPI client or scripts provided by other data portals, etc. The tools and documentation should allow users to inform themselves about which time periods and regions have available data products. The documentation shall include instructions on registration and authentication procedures, for datasets for which this is required. Wherever possible, the tools should allow for automated data retrieval.

The Contractor shall also make available a complete sample data set that can serve as input to the data fusion, so that users can test the data fusion software (developed during Task 3). The documentation shall include detailed instructions on the collection of the sample data set from the source archives, so that users can learn how to use the tools and documentation, check whether they get the correct results, and then adapt this approach for different time periods and regions of interest.

4.2.2.3 *Deliverables*

- Data collection tool(s) (DL-01)
- Data collection documentation for users (DL-02)
- Sample input data set for testing the data fusion (DL-03)

4.2.3 Task 3: Development of the data fusion and regional reconstruction tool

4.2.3.1 *Input*

- Product definition
- Literature survey
- Sample input data set for testing the data fusion

4.2.3.2 *Task description*

The contractor shall develop a software tool that implements the algorithm, specified during the product definition in task 1, for data fusion and regional reconstruction. The tool will be delivered with accompanying instructions for users (user documentation). The tool should take care of ingesting the input data, as it is made available after using the data collection tools and documentation from Task 2. The tool should make

all relevant options (e.g. regularisation, grid resolution, weights, etc.) of the data fusion and regional reconstruction available for modification by users via a user interface. Next, it should perform the data fusion and regional reconstruction of the ionospheric electrodynamics, and produce output files.

The output shall encompass numerical data files according to the product description, as well as (quick-look) plots for easy inspection of the algorithm input, output, and at least errors / uncertainty characteristics of the data fusion product.

As part of the documentation, the Contractor shall describe running the tool using the sample input data set. The Contractor shall also make available the output data files (data and plots) based on the sample input data set, so that users who are getting started using the data fusion software can get acquainted with the outputs and compare their own results with it.

4.2.3.3 *Deliverables*

- Data fusion and regional reconstruction tool (DL-04)
- User documentation for the data fusion and regional reconstruction tool (DL-05)
- Sample output files from the data fusion and regional reconstruction tool (DL-06)

4.2.4 Task 4: Validation and sensitivity analysis

4.2.4.1 *Input*

- Tool(s) and data

4.2.4.2 *Task description*

The Contractor shall test the proper functioning of the tool, and validate and test the sensitivity of the outputs as a function of different inputs, for example by using synthetic data or changing weights of input data. The output of the activity shall be documented in a validation report, which shall also include a description of the datasets used in the validation and sensitivity analysis.

The Contractor shall consider to include the relevant experience gained during this part of the work in the user documentation.

4.2.4.3 *Deliverables*

- Validation report (TN-05)
- Updated user documentation

4.2.5 Task 5: Transition to users

4.2.5.1 *Input*

- Data collection tool(s)
- Data collection documentation for users
- Sample input data set for testing the data fusion
- Data fusion and regional reconstruction tool
- User documentation for the data fusion and regional reconstruction tool
- Sample output files from the data fusion and regional reconstruction tool

4.2.5.2 *Task description*

After testing and validation, the Contractor shall make the tools and documentation available to end users via a website (for examle under the Swarm DISC GitHub Organisation).

The Contractor shall prepare a plan for how continued operational provision of the tool could be supported beyond the end of the contract. This plan shall describe the support needed for maintaining updated versions of the tool and include answering user questions received by ESA EO helpdesk (second line support) in the event that a future operational phase is to be negotiated. The contractor shall consider potential use cases for integration with existing tools and products for visualisation and analysis, in particular those that have previously been developed in the framework of Swarm DISC (e.g. VirES, Swarm-PAL, Swarm VRE Jupyter Notebooks, Space Weather Timeline Viewer). The Contractor shall provide recommendations about such integration.

4.2.5.3 *Deliverables*

- Website providing the tool(s) and documentation for download by users (DL-07)
- Plan for continuation and integration (TN-06)

4.2.6 Task 6: Final presentation

4.2.6.1 *Input*

- All outcomes from the project

4.2.6.2 *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 and Validation Report will be made publicly available on the Swarm web page.

4.2.6.3 *Deliverables*

- One publication submitted for peer review (DL-08)
- Presentation of project achievements at Swarm DQW or similar event (DL-09)
- Final project documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format (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 toolbox. 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 reserves 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	Product Definition Document (PDD)
TN-02	Work plan
TN-03	Literature survey
TN-04	Survey of existing data and tools
TN-05	Validation report
TN-06	Plan for continuation and integration

5.5 Other Deliverables

DL-01	Data collection tool(s)
DL-02	Data collection documentation for users
DL-03	Sample input data set for testing the data fusion
DL-04	Data fusion and regional reconstruction tool
DL-05	User documentation for the data fusion and regional reconstruction tool
DL-06	Sample output files from the data fusion and regional reconstruction tool
DL-07	Website providing the tool(s) and documentation for download by users
DL-08	One publication submitted for peer review
DL-09	Presentation of project achievements at Swarm DQW or similar event

DL-01	Data collection tool(s)
DL-10	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** • Literature survey (TN-03) • Survey of existing data and tools (TN-04) • Product definition document (PDD) (TN-01) • Work plan (updated) (TN-02)	KO+2
MIL-03	**Delivery 2 – Mid-Term Review** Near final version of: • Data collection tool(s) (DL-01) • Data collection documentation for users (DL-02) • Sample input data set for testing the data fusion (DL-03) Preliminary versions of: • Data fusion and regional reconstruction tool (DL-04) • User documentation for the data fusion and regional reconstruction tool (DL-05) • Sample output files from the data fusion and regional reconstruction tool (DL-06)	KO+7
MIL-04	**Delivery 3 – Final delivery** • Validation report (TN-05) • Website providing the tool(s) and documentation for download by users (DL-07) • Plan for continuation and integration (TN-06)	KO+11
MIL-05	**Final Presentation** All technical notes (updated if necessary), presentations, publications, and other relevant documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format (DL-10)	KO+12