



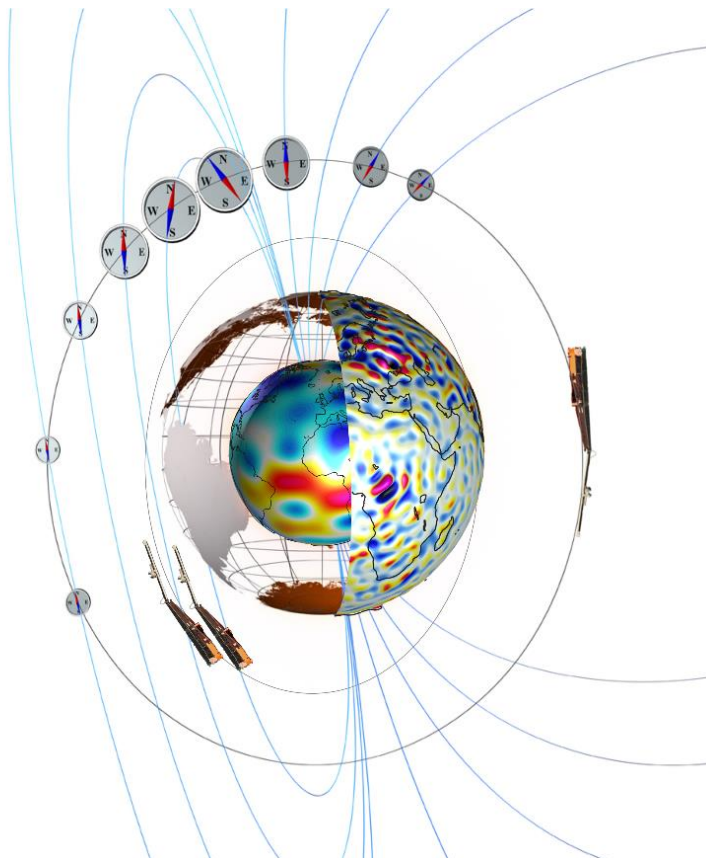
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# Statement of Work

## Swarm DISC ITT 1.1

### “Swarm as a gravity field mission”

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### Record of Changes

Reason	Description	Rev	Date
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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 1.1 – “Swarm as a gravity field mission”.

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-0008 Swarm PDGS to SDPC Interfacing Control Document version 1.0](#)

[AD-2] ICGEM format 2011 <http://icgem.gfz-potsdam.de/ICGEM/documents/ICGEM-Format-2011.pdf>

### 2.2 Reference Documents

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

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

### 2.3 Terminology

In this document the term ‘*shall*’ indicates requirements which the products must meet, while ‘*should*’ indicates a desirable product features and ‘*may*’ is used to indicate a suggested feature.

### 2.4 Abbreviations



<b>Acronym or abbreviation</b>	<b>Description</b>
CDM	Configuration and Data Management
DTU	Technical University of Denmark, DK
Cat-1 / -2	Category-1 products are data products generated at a Swarm DISC partner, outside the PDGS, but published via the PDGS. Category-2 products are generated at the PDGS.
ESA	European Space Agency
GUT	GOCE User Toolbox: <a href="https://earth.esa.int/documents/10174/1500266/GUT3_brochure.pdf">https://earth.esa.int/documents/10174/1500266/GUT3_brochure.pdf</a>
ITT	Invitation To Tender
PDGS	Payload Ground Data Segment
SLA	Service Level Agreement
SVN	SVN Repository with server located at DTU. Presently, the following URLs apply: <a href="https://smart-svn.spacecenter.dk/svn/smart/SwarmESL-All">https://smart-svn.spacecenter.dk/svn/smart/SwarmESL-All</a> <a href="https://smart-svn.spacecenter.dk/svn/smart/SwarmL2">https://smart-svn.spacecenter.dk/svn/smart/SwarmL2</a> (heritage from the L2PS Project)
Swarm	Constellation of 3 ESA satellites, <a href="http://www.esa.int/es-aLP/ESA3QZJE43D_LPswarm_0.html">http://www.esa.int/es-aLP/ESA3QZJE43D_LPswarm_0.html</a>
Swarm Data Handbook	<a href="https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/data-handbook">https://earth.esa.int/web/guest/missions/esa-eo-missions/swarm/data-handbook</a> New documentation site for Swarm Data Products
Swarm Wiki	<a href="http://swarm-wiki.spacecenter.dk/mediawiki-1.21.1/index.php/Main_Page">http://swarm-wiki.spacecenter.dk/mediawiki-1.21.1/index.php/Main_Page</a> (Previous documentation site for Swarm data products and activities – currently being migrated to Swarm Data Handbook)
TBC	To Be Confirmed
TBD	To Be Defined
TDS	Test Data Set
TTO	Transfer To Operation
VirES	Virtual research platform <a href="https://vires.services">https://vires.services</a>
WBS	Work Breakdown Structure
WPD	Work Package Descriptions

## 3 Background and Objective(s)

### 3.1 Background

Global gravity field models and specifically its variability in time are of interest to numerous geophysical studies. The static and time variable gravity field is the only quantity capable to quantify systematically the spatial mass distribution and its variability in time. Mass distribution and its variability are mainly caused by the global water cycle and density variations in the Earth's crust. By making use of satellite observations, global fields of mass distribution for specific periods in time can be computed, which in the sequel can be analyzed in the time domain in order to derive mass redistribution. By separating the integrated observations into signals for individual geophysical domains, like the continental hydrosphere, polar ice sheets, ocean mass and solid Earth, parameters of the system Earth and its changes due to global change can be determined.

The Swarm mission with its three satellites and their instrumentation is capable to provide information about the Earth gravity field by analyzing orbit perturbations caused by gravity field anomalies applying the high-low satellite-to-satellite tracking (hl-SST) approach. This approach by far is not as sensitive to mass variabilities as it is the case for the low-low satellite-to-satellite tracking (ll-SST) approach. The latter has been successfully realized by the Gravity Recovery And Climate Experiment (GRACE) mission, which delivered since more than a decade high quality estimates of the monthly time variable gravity field and which is still in operation, but slowly reaching its end of life with some interrupts in observations. In early 2018 the GRACE Follow-On mission (GRACE-FO) will be launched, which applies the same observation principle, but makes use of improved instrumentation. Due to the not continuous GRACE data flow and the possible gap until GRACE-FO will be in full operation the Swarm hl-SST data provides an opportunity to bridge a potential gap between both missions, although the spatial resolution would be worse than GRACE due to the less sensitive hl-SST concept.

In addition to dedicated single-pair satellite missions such as GRACE and GRACE-FO, the three Swarm satellites, due to their different orbits, theoretically provide a higher temporal sampling of the gravity field. This could result in gravity field models, which are less disturbed by temporal aliasing. By combining observations from all three Swarm satellites also denser spatial sampling is possible, which could also be beneficial to the accuracy of the low degree coefficients. In addition to that, relative observations between each of the three satellites in the sense of inter-satellite range variations, which can be determined from joint analysis of GPS observations, might be an additional observation quantity, which is similar to a ll-SST measurement, but in different directions. In conclusion, it is expected, that the Swarm constellation can deliver information about the time variable gravity field specifically by a joint analysis of all three satellites in the hl-SST mode, and by making use of derived ll-SST observations between the Swarm satellites.

As a result of this activity 'Swarm as a gravity field mission' shall deliver gravity field models on a regular basis as a new product in the Swarm data processing chain (see Figure 1), and upload them via FTP to the Payload Data Ground Segment (PDGS) at ESA. All Swarm related data products are available to users through the PDGS. Swarm data products available are described on the Swarm Data Handbook (previously known as Swarm Wiki) and visualizations of most Swarm data products are available via the interactive 'VirES' Virtual research platform (<https://vires.services>). However, since extensive work has already been provided to enable visualization of Gravity Field Models in the GOCE User Toolbox (GUT), this new gravity field model product will not be implemented in VirEs.

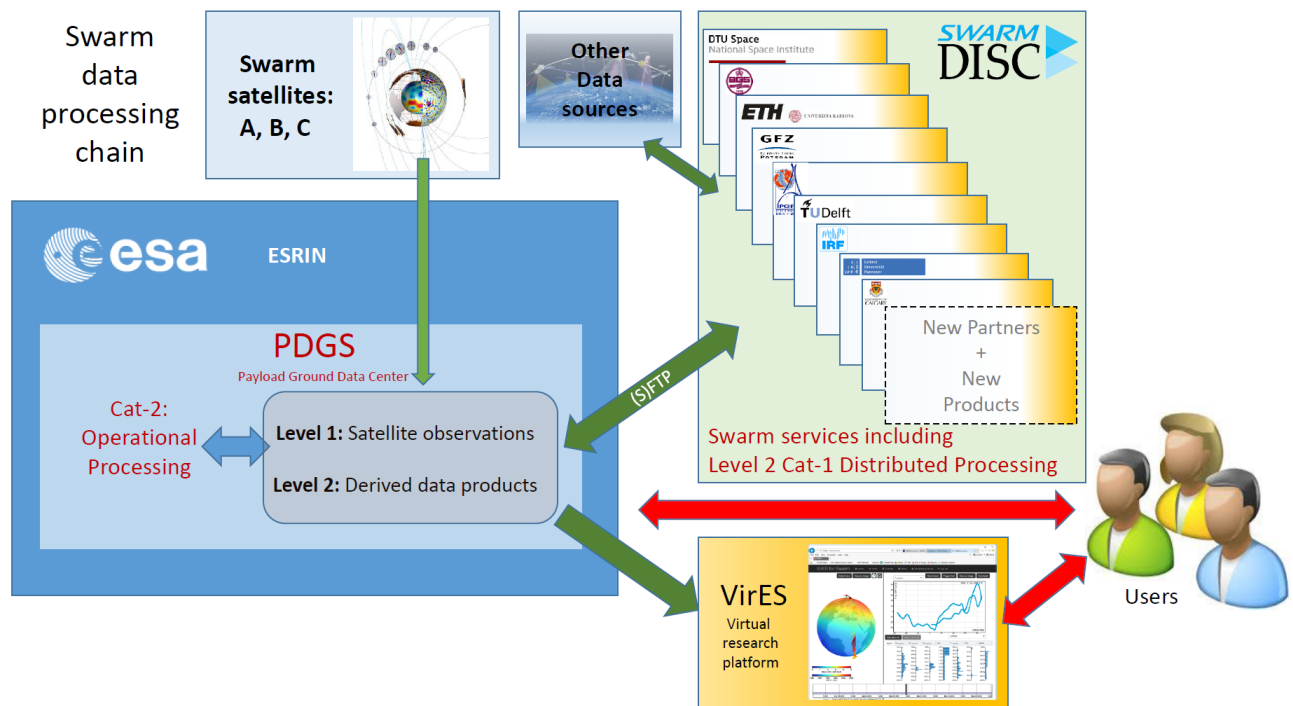


Figure 1 - Swarm data processing chain

### 3.2 Objective(s) of the Activity

The main objective of this activity is to produce and deliver time variable gravity field models at least on a monthly base with maximum possible spatial resolution, which are compatible to GRACE monthly fields in terms of processing standards and background models. These fields shall be capable of bridging data gaps in the GRACE time series until the GRACE-FO mission will be in full operation.

In particular ‘Swarm as a gravity field mission’ shall deliver:

- Production of monthly snapshot gravity field models from Swarm (and other data, if applicable) with maximum possible spatial resolution (degree and order of 12 is regarded as a minimum). Higher time resolution models may be considered, but are not requested.
- Two categories of models shall be delivered:
  - 1) Validation models where GRACE is in full operation in order to compare Swarm and GRACE monthly models.
  - 2) Monthly operational models from Swarm data.
- Gravity field products shall be delivered in the ICGEM format [AD-2], which is the standard format of the International Centre for Global Earth Models (ICGEM) of the International Association of Geodesy (IAG).
- A technical note describing the Swarm specific adaptations used in the gravity field processor and the standards and background models applied.
- A technical note with a description of Swarm data to be used and related data pre-processing steps to be applied. In particular it shall be specified if at all or to what extent Swarm accelerometer data are applicable for the gravity field processing as they do not perform as expected. Note: the accelerometer performance is most critical to the determination of the long wavelengths of the time variable gravity field. In addition it should be investigated if range-rate observations between the Swarm satellites as they can be derived from GPS data/orbits are applicable as additional type of information in a II-SST concept. A description of possible other satellite data, which might support the Swarm gravity field processing shall be added as well.

- A technical note describing the monthly Swarm gravity field models (content and format), their validation procedure and an assessment of internal and external accuracy of these models.
- In case that sub-monthly gravity field models will be generated they shall be assessed for information content and quality.
- The final presentation shall contain visualizations of the gravity field models for the last six months of the project duration, based on the tools in the GOCE User Toolbox.
- During the project at least one peer reviewed publication and one presentation at a Swarm Data Quality Workshop are expected. Public Outreach opportunities that the Tenderer anticipate to arise from this new product shall be described in the Tender, and included in the proposed work plan.
- During Swarm operations, the processors will be enhanced and improved triggering the reprocessing of the full mission data and the subsequent release of such 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 data products with an updated file counter. Your proposal shall describe which steps you will take in both the reprocessing or re-generation scenarios in order to ensure the data quality of your output products.

### 3.3 Assumptions and Constraints

Only official Swarm products made available by the Swarm PDGS shall be used by the project. In case data from other sources are needed for processing purposes these products need to be defined and described in detail.

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. Approval will be provided with the monthly progress report (mid month), to match the payment approval cycle of Swarm DISC.

## 4 Work to be performed

### 4.1 Work Logic

The work to be performed shall be divided into:

- An Implementation phase
- A Model generation phase

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

### 4.2 Implementation

#### 4.2.1 Task 1: Swarm Gravity Field Processor

##### 4.2.1.1 Input

- Existing gravity field processor
- Swarm product specifications
- GRACE & GRACE-FO standards and background models

##### 4.2.1.2 Task Description

- Description of Swarm specific adaptations of gravity field processor
- Adapt gravity field processor to Swarm L1 products
- Description of standards and background models
- Implement GRACE and GRACE-FO standards in gravity field processor

##### 4.2.1.3 Deliverables

- TN-01: Swarm gravity field processor, standards and background models

#### 4.2.2 Task 2: Swarm Data Pre-processing

##### 4.2.2.1 Input

- Swarm L1 Products and Descriptions
- Other satellite or ancillary data

##### 4.2.2.2 Task description

- Definition of Swarm GPS data pre-processing procedure
- Implementation of Swarm GPS pre-processing algorithm
- Analysis of Swarm accelerometer data
- Trade-off analysis of accelerometer data versus models of non-gravitational accelerations
- Implementation of procedure for non-gravitational accelerations
- Analysis of range-rate observations between Swarm satellites as additional II-SST observation type in various directions and impact on Swarm gravity field
- Algorithms for determination of II-SST range rate observations between Swarm satellites
- Description of non-Swarm satellite data to be used in addition and related pre-processing steps to be applied.

## 4.2.2.3 Deliverables

- TN-02: Swarm and external data pre-processing description

## 4.2.3 Task 3: Validation of Swarm Gravity Field Processor

### 4.2.3.1 Input

- TN-01, TN-02
- GRACE monthly gravity field models

### 4.2.3.2 Task description

- Identification of overlapping validation period for Swarm gravity field model using high quality GRACE model(s) as reference
- Processing of Swarm gravity field models for the validation period
- Comparison of Swarm versus GRACE monthly models and quality assessment of signals and errors of Swarm validation fields (also assessment of achievable spatial and temporal resolution).

### 4.2.3.3 Deliverables

- TN-03: Validation report for Swarm gravity field models

## 4.3 Model Generation and Release

### 4.3.1 Task 4: Swarm Gravity Field Models

#### 4.3.1.1 Input

- Swarm L1 products
- External/other data
- TN-01, TN-02, TN-03

#### 4.3.1.2 Task description

- Detailed description of products to be published on Swarm Data Handbook
- Processing of monthly (or higher time resolution) Swarm models with implemented and validated approach
- Preparation of Swarm gravity field products in ICGEM format [AD-2]. The contractor shall be fully responsible for the data content quality before any data transfer.
- Delivery of Swarm gravity field products to PDGS via (S)FTP, in accordance with [AD-1]. The Swarm DISC System Manager will offer Unix scripts that exemplifies generation of header and dissemination files.
- Second levels support - responding to user questions that the ESA helpdesk cannot answer in relation to Swarm gravity field products, via e-mail on a best effort basis.

#### 4.3.1.3 Deliverables

- TN-04: Product description of Swarm gravity field models published on Swarm Data Handbook
- DL-01: Time series of Swarm gravity field models including quality parameters, delivered at PDGS, from beginning of Swarm mission until end of project

- DL-04: E-mail replies to 2<sup>nd</sup> level support questions forwarded from ESA EO helpdesk

### **4.3.2 Task 5: Final presentation**

#### **4.3.2.1 Input**

- Swarm gravity field models
- TN-01, TN-02, TN-03, TN-04

#### **4.3.2.2 Task description**

- Preparation and submission of peer reviewed publication about 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

#### **4.3.2.3 Deliverables**

- DL-02: One Peer reviewed publication submitted
- DL-03: A presentation of project achievements made during a Swarm DQW.
- DL-05: All project documentation delivered electronically to the Swarm DISC Project Office in searchable PDF format.

## 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

#### 5.1.1 General

MG-01	The contractor shall assign a responsible project manager as point of contact with the DISC project office / the Agency.
MG-02	A point of contact shall be assigned for subcontractors, if any, but generally any correspondence with the project will be via the project manager assigned in MG-01

#### 5.1.2 Communications

MC-01	<p>All correspondence between the project and the Agency must be via – or if agreed by DTU in copy to – the Swarm DISC project office:</p> <p>Swarm DISC Project office  DTU Space, Building 371  Diplomvej  2800 Kgs. Lyngby  Denmark  Fax: +45 4525 9701</p>
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### 5.2 Reporting

#### 5.2.1 General reporting requirements

GR-01	The contractor shall submit all documents to the DISC Project Office in searchable, non-protected PDF format, as well as their native format (MS Word 2010 or compatible format).
GR-01	The contractor shall ensure that electronic documents do not contain any harmful code (e.g. virus)

#### 5.2.2 Minutes of Meeting

MM-01	The contractor shall produce short minutes of meeting, recording participants and any decisions made during the Kick Off meeting as well as status report meetings, and send a copy of these to the Swarm DISC project office, not later than two days after these meetings.
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### 5.2.3 Progress Reports

PR-01	The contractor shall produce a short monthly progress report, which is sent via e-mail to the Swarm DISC project office.
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## 5.3 Technical Documentation

TN-01	Swarm gravity field processor, standards and background models
TN-02	Swarm and external data pre-processing algorithms
TN-03	Validation report for Swarm gravity field models
TN-04	Product description of Swarm gravity field models published on Swarm Data Handbook

## 5.4 Meetings

ME-01	The Contractor shall organize a kick off meeting via WebEx where key persons are introduced and the project schedule is presented.
ME-02	The contractor shall bimonthly present the status report to the Swarm DISC project office via WebEx. The status report shall be provided to DTU one week before the teleconference. The Agency reserves the right to participate.
ME-03	The Contractor shall prepare a presentation of the final result (DL-03) 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 the Agency reserves the right to call up ad hoc meetings at any time for justified reasons.

### 5.5 Other Deliverables

DL-01	Time series of Swarm gravity field models including quality parameters, delivered at PDGS, from beginning of Swarm mission until end of project.
DL-02	One Peer reviewed publication submitted.
DL-03	Presentation of project achievements to Swarm DQW.
DL-04	E-mail replies to 2 <sup>nd</sup> level support questions forwarded from ESA EO helpdesk
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, Milestones and Deliverables

### 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 and reported to the DISC project office with justification.
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	Event timeline (months)
MIL-01	Project Kick Off	KO
MIL-02	Delivery 1: TN-01, TN-02	KO+4
MIL-03	Delivery 2: TN-03	KO+6
MIL-04	Delivery 3: TN-04, DL-01 (until KO+9)	KO+10
MIL-05	Final Delivery: DL-01 (until at least KO+11), DL-02, DL-03, DL-04, DL-05	KO+12