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Swarm Level 2 Processing System

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University of Colorado (CIRES)
Charles University Prague (CUP)

Intermediate validation of Swarm Level 2 Products

SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101
SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101

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Record of changes

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Contents

1 Introduction

1.1 Purpose

The purpose of this document is to describe and illustrate the processes and tests applied to the intermediate validation of the MIN_1DMi2_ and MCR_1DMi2_ products generated in the V2 test. The detailed product names under inspection are:
SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101,
SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101.
For the purpose of the V1 and V2 tests, the products use a simulated dataset covering the period from 1998/07/01 00:45 to 2002/12/31 23:15. The products are valid at any time (time-independent). The version number 0101 refers to the products generated in V2 testing (version number 0001 was used for V1 tests).

1.2 Scope

The document applies to the development phase and to the implementation and operational phases of the project.

1.3 Executive Summary

The Swarm products
SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101,
SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101.
have undergone a series of validations and checks by partner ETH. The ETH SILs' opinion is that the products are validated and therefore suitable for release as the intermediate products.

2 Applicable and Reference Documentation

2.1 Reference Documents

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

[RD-1] Swarm Level 1b Product Definition, SW-RS-DSC-SY-0007

[RD-2] Product Specification for L2 Products and Auxiliary Products, SW-DS-DTU-GS-0001

[RD-3] Earth Explorer File Format Standards Doc. No: PE-TN-ESA-GS-0001 ESA ESTEC, Noordwijk, The Netherlands

[RD-4] Swarm Level 2 Product Data Handbook, SW-HB-DTU-GS-0001

[RD-5] Swarm Level 2 Processing System, ETH Sub-System Acceptance Test Report V2, SW-TR-ETH-GS-0004_SS_ATR_V2.

2.2 Abbreviations

Acronym	Description
CAT-1	Category 1 products
CUP	Charles University in Prague
ESA	European Space Agency
ETH	Eidgenössische Technische Hochschule Zürich
FD	Frequency domain
L2PS	Level 2 Processing Segment
SIL	Scientist in the Loop
PDGS	Payload Data Ground Segment
TD	Time domain
V1	Version 1
V2	Version 2
VAL	Validation
1-D	One-dimensional
3-D	Three-dimensional
1DI	1-D inversion

Table 1: List of abbreviations.

3 Validation of Swarm Level 2 products

3.1 Objective

The objective of this document is to verify and validate the Level 2 CAT-1 intermediate product output. The next stage of verification is carried out using auxiliary data from independent sources to confirm that the output is scientifically valid and feasible. The purpose is

(a) to ensure that no obvious mistakes or errors have been made in the production of the Level 2 output, and

(b) to give non-expert users confidence that the product released have been thoroughly inspected.

3.2 Validation Process for the 1-D Mantle Induction Products

The 1-D inversion (1DI) is an existing software package, which contains a number of programs that have been developed and used for many years by ETH. It therefore constitutes a re-use of software in the context of the Swarm mission. The products of the 1DI, `MIN_1DMi2_` and `MCR_1DMi2_`, contain the recovered 1-D mantle conductivity model of the Earth (which has been corrected for the ocean effect) and the set of complex-valued C-responses computed at discrete frequencies, respectively.
The following steps are undertaken to validate, then promote the products for release to the ESA Payload Data Ground Segment (PDGS):

(a) Intermediate L2 products `MIN_1DMi2_` and `MCR_1DMi2_` are produced by the L2PS processing chain.

(b) An internal validation of the products is produced in the form of intermediate product validation reports `MI1_VALi2_` and `MC1_VALi2_`. As only a combined validation of the products is scientifically meaningful, both reports have the same content.

The intermediate products including their internal validation are distributed via PDGS to the L2PS. The British Geological Survey performs an independent validation of the products and produces a report, which will include the internal validation.

3.3 Role of Scientist in the Loop

The validation of the products is actively undertaken by the scientists in the loop (SIL) at ETH. The SILs check that the products conform to scientific expectations using a series of tests and also check that the products are correctly formatted for release. The SILs produce a validation report and release the products back to the ESA PDGS for further independent validation. The role of the SILs is to ensure that the outputs meet the criteria of being valid scientific products.

4 Intermediate Validation Report

The main objective of the 1DI is to recover the depth dependence of electrical conductivity in Earth. In the production phase, the main task of validation will be to compare the product `MIN_1DMi2_` to the previously published 1-D model `AUX_MCM` based on CHAMP/Ørsted/SAC-C satellite data.
For the purpose of V1 and V2 testing, simulated data in the TDS-1 dataset were prepared using a known, artificial target conductivity model. Therefore, the 1-D conductivity product `MIN_1DMi2_` can be compared directly against this model. Naturally, this will not be possible for models based on actual satellite data.
1-D mantle conductivity is obtained by inverting complex-valued C-responses, thereby accounting for the known, laterally variable conductance of the surface layer representing crust and oceans. The product `MCR_1DMi2_` is thus complementary to `MIN_1DMi2_`.

4.1 Input products and data

The following products are used in the assessment of the `MIN_1DMi2_` and `MCR_1DMi2_`:

Product	Type	Comment
`SW_TEST_AUX_MCM_2__00000000T000000_ 99999999T999999_0002.DBL`	Mantle conductivity model	Independent 1-D model from CHAMP satellite data
`target.DBL`	Mantle conductivity model	Known 3-D target conductivity model (V1, V2 tests only)

Table 2: Input products used for validation

4.2 Output Products

The output products from this validation report are:

Swarm Level 2 Magnetic field Products:
`SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101`,
`SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101`,

Swarm Level 2 Validation Products:
`SW_TEST_MC1_VALi2__00000000T000000_99999999T999999_0101`.

4.3 Validation Results

The tests were conducted between 2012/07/02 and 2012/07/10.

Validation of 1-D mantle conductivity and C-response products

The 1-D inversion is an iterative process. Within each iteration, the dominant internal (induced) coefficient i_1^0, in the following just referred to as i, is corrected for the ocean effect in the following way:

$$i^{exp,\,corr} = i^{exp} + i^{1-D} - i^{3-D}, \tag{1}$$

where i^{1-D} and i^{3-D} are the internal coefficients obtained from simulated induction in the current 1-D and 3-D (1-D + ocean) models, respectively. The ratio between internal and external coefficients is used to compute the C-responses. Convergence is based on the weighted difference between C-responses computed from i^{exp} (named C^{exp}) and C-responses computed from i^{3-D} (named C^{3-D}) according to the formula

$$\frac{1}{N_\omega}\sqrt{\sum_{\omega=1}^{N_\omega}\left|\frac{C^{exp}(\omega)-C^{3-D}(\omega)}{\delta C^{exp}(\omega)}\right|^2} \le \varepsilon, \tag{2}$$

where $\omega = 1..N_\omega$ is the range of frequencies considered, δC^{exp} are uncertainties, and ε is a threshold value. The C-responses computed from $i^{exp,\,corr}$ are used as data in the actual inversion for mantle conductivity.

For the V2 test, C-responses at 24 logarithmically spaced periods between 14 hours and 103 days were used to recover the average conductivity of totally 44 layers at depths between 1 km and 2891 km (core-mantle boundary). Layers up to a depth of 1500 km had a thickness of 50 km each, those below had a thickness of 100 km each. The known conductance of the surface layer representing crust and oceans (surface conductance map) was scaled to a thickness of 1 km and fixed. The conductivity of the core was fixed as well (to 10^5 S/m).

Inversion was initiated with constant mantle conductivity of 1 S/m. The 1DI converged within 5 iterations for a threshold value of $\varepsilon = 5.0$. Figure 1 shows the convergence of the C-responses. The bottom right panel in Figure 1 compares C^{exp} and C^{3-D} (both computed from the ratio between dominating internal and external coefficients of the spherical harmonic expansion of the magnetospheric field) with C-responses computed directly from the (laterally averaged) 3-D target conductivity structure. The agreement is good, especially when considering that the direct computation does not take into account 3-D effects from the surface thin layer. This validates the C-response product `MCR_1DMi2_`.

Starting model and recovered model (after 5 iterations) are compared to the laterally averaged target model in Figure 2. Although the conductivity of the starting model is very different from the target conductivity structure, good recovery of the target model is obtained. The difference between target and recovered conductivity is fairly below one order of magnitude in all depth ranges. This validates the 1-D mantle conductivity product `MIN_1DMi2_`. Due to the applied smoothing, the recovered model does not comprise the large jumps in conductivity that are apparent in the target model at depths of 400 km and 700 km. Such large jumps in conductivity are, however, not expected for real data.

Format compatibility

The product
`SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101`

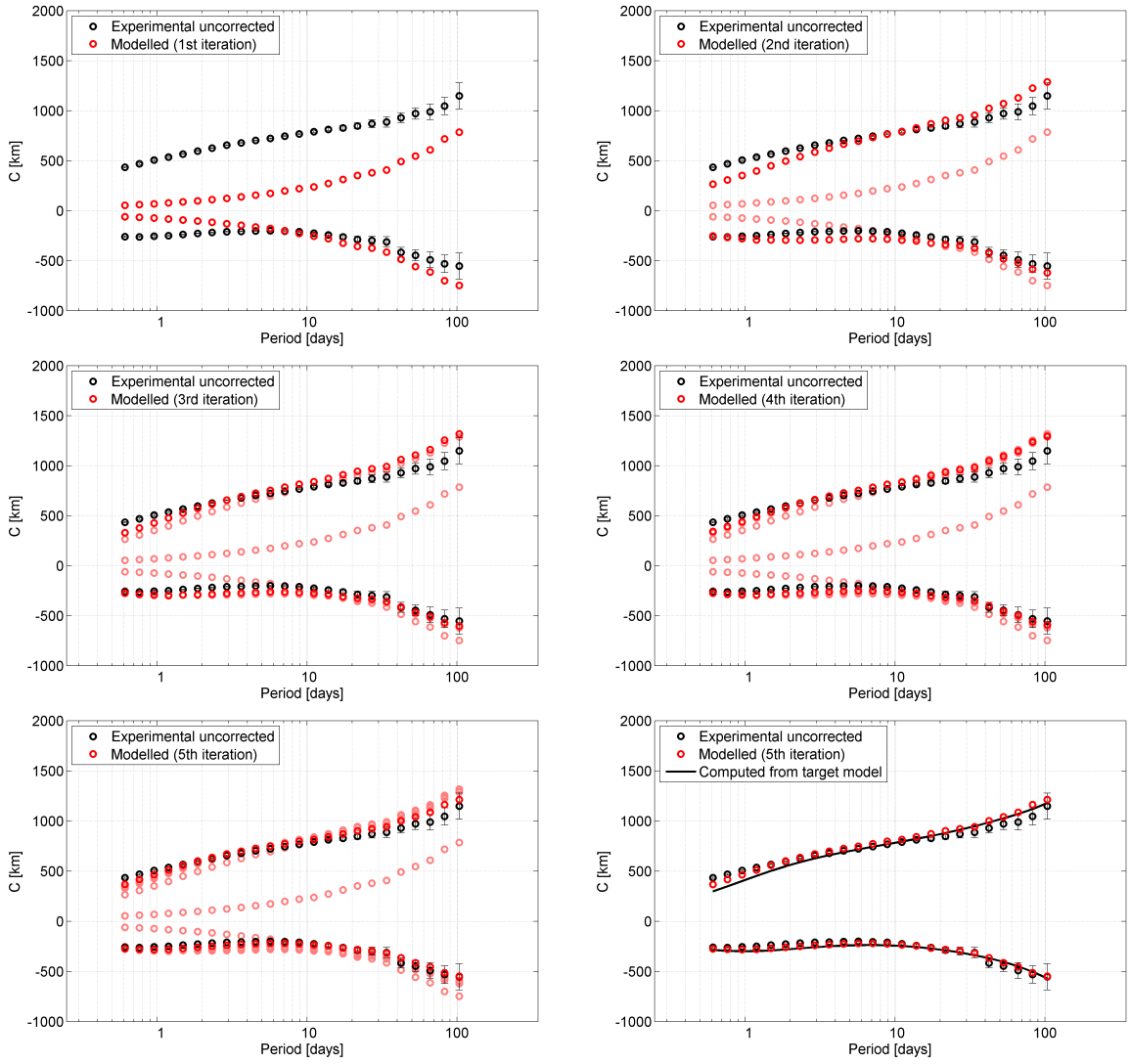

Figure 1: Iterative convergence of C^{exp} (black) and C^{3-D} (red). Modelled C-responses of previous iterations are indicated in light red. The bottom right picture repeats for clarity the comparison between experimental and modelled C-responses of the final iteration and compares both to an alternative computation of (1-D) C-responses based the target conductivity structure.

has been successfully written and subsequently read using the subroutines from the `MantleConductivityIO.f90` module.
The product
`SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101`
has been successfully written and subsequently read using the subroutines from the `CResponsesIO.f90` module (see `SwarmL2/smarth-eth/eth-internal/IO_subroutines` in the `svn`) as documented in [RD-5].
Conformance to the format was also checked visually against specifications (in particular: header comments, number and indexing of layers/periods).)

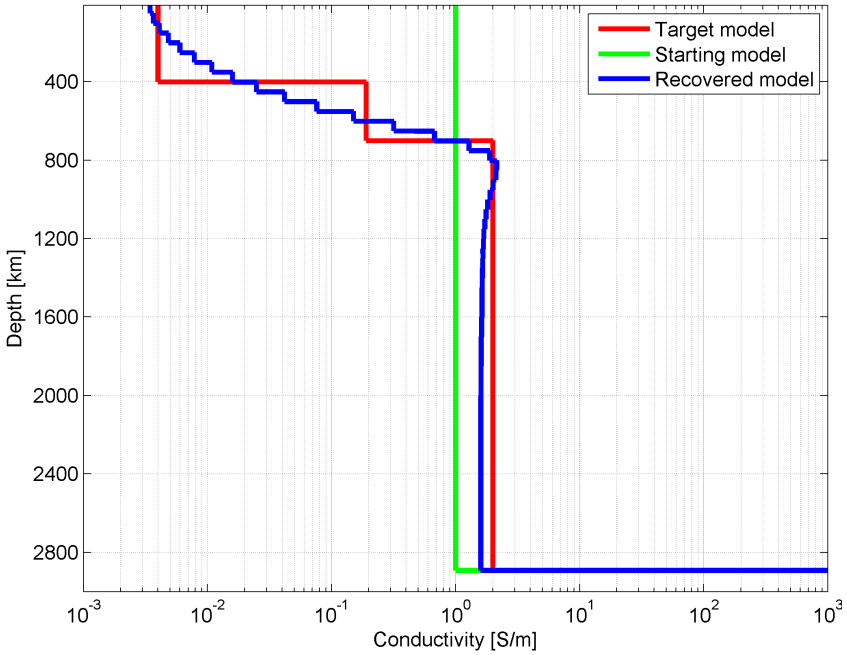

Figure 2: Comparison between the (laterally averaged) conductivity of the target model and conductivities of the starting model and the final recovered model.

4.4 Criteria

The following criteria are suggested to cross-check the validity of the products.

Product	**Test**	**Criteria**	**Pass**
`MIN_1DMi2_`	comparison with laterally averaged TDS-1 target model	difference within 1 order of magnitude	Yes (V1, V2 only)
`MIN_1DMi2_`	Read using `MantleConductivityIO`	Successfully read	Yes (see [RD-5])
`MIN_1DMi2_`	comparison with 1-D model `AUX_MCM_`	difference within 1 order of magnitude	N/A for V1, V2 tests
`MCR_1DMi2_`	comparison with C-responses computed from laterally averaged TDS-1 target model	difference $<$ 200 km	Yes (V1, V2 only)
`MCR_1DMi2_`	Read using `CResponsesIO`	Successfully read	Yes (see [RD-5])

Table 3: Validation criteria

5 Conclusions

The Swarm products
SW_TEST_MIN_1DMi2__00000000T000000_99999999T999999_0101,
SW_TEST_MCR_1DMi2__00000000T000000_99999999T999999_0101,
have undergone a series of validations and checks by partner ETH. In particular:

(a) The products have been found to conform to the format specification.

(b) The (laterally averaged) TDS-1 target conductivity model has been recovered within 1 order of magnitude accuracy.

The ETH SILs opinion is that the products are validated and therefore suitable for release as the intermediate product.