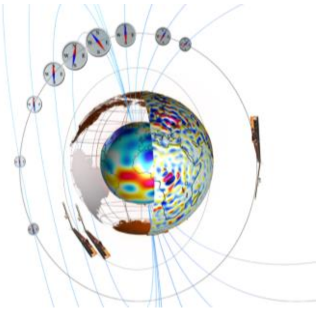

# Swarm Level 2 Processing System

# Intermediate validation of

# Swarm Level 2 Magnetospheric Field Product

**SW_OPER_MMA_VALi2C_20131201T000000_20170101T000000_0201**

**By: DTU**

**Date: 2017-04-10**

## Abstract and Conclusion


The processes and tests applied in the intermediate validation of the MMA_SHAi2C product

**SW_OPER_MMA_SHAi2C_20131201T000000_20170101T000000_0201**

and the conclusions on the product quality drawn herefrom are described in this document.

This product contains the representation of a model of the magnetic field of Earth's magnetosphere ("MMA" part of product name) using spherical harmonic coefficients ("SHA" part of product name). The model is estimated from Swarm and observatory data using the *Comprehensive Inversion* (CI) scheme within the Swarm Level 2 Processing system ("2C" part of product name). Operational Swarm Level 1b data version 0501, covering the period from 2013-12-01 to 2016-12-31 are used for the model estimation; the product is valid over the same period ("20131201T000000_20170101 T000000" part of product name). This is version 0201 of the product (last part of product name), i.e. same baseline (02) version as the previous CI product release and this is the first, minor version of the product. The format of the product is described in "Product Specification for L2 Products and Auxiliary Products", doc. no. SW-DS-DTU-GS-0001.

The assessment of the SW_OPER_MMA_SHAi2C_20131201T000000_20170101T000000_0201 product shows good agreement with the magnetic indices *Dst* and *RC*, and with existing mantle conductivity models.

**The DTU SIL's opinion is that the MMA_SHAi2C product is validated and is therefore suitable for release.**

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## Abbreviations

| *Acronym* | *Description* |
|---|---|
| AR-2 | Acceptance Review 2 |
| CI | Comprehensive Inversion |
| L2PS | Level 2 Processing System |
| MMA | Magnetic Magnetospheric field |
| PDGS | Payload Data Ground Segment |
| SHA | Spherical Harmonic Analysis |
| SIL | Scientist in the Loop |
| STR | Star Tracker |
| TDS | Test Data Set |
| VAL | Validation |
| VFM | Vector Field Magnetometer |

***References***

[Grayver, GRL, 2017] *Joint inversion of satellite-detected tidal and magnetospheric signals constrains electrical conductivity and water content of the upper mantle and transition zone*; Grayver, A. V.; Munch F. D.; Kuvshinov, A. V.; Khan, A.; Sabaka, T. J.; Tøffner-Clausen, L.; under review for Geophysical Research Letters, 2017.

[Sabaka, GJI, 2015] *CM5, a pre-Swarm comprehensive geomagnetic field model derived from over 12 yr of CHAMP, Ørsted, SAC-C and observatory data*; Sabaka, Terence J.; Olsen, Nils; Tyler, Robert H.; Kuvshinov, Alexey; in journal: Geophysical Journal International (ISSN: 0956-540X), doi: 10.1093/gji/ggu493, vol: 200, issue: 3, pages: 1596-1626, 2015.

[Sabaka, GRL, 2016] *Extracting Ocean-Generated Tidal Magnetic Signals from Swarm Data through Satellite Gradiometry*; Sabaka, Terence J. ; Tyler, Robert H. ; Olsen, Nils in journal: Geophysical Research Letters (ISSN: 0094-8276), doi: 10.1002/2016GL068180, 2016

# 1 Intermediate Validation Report of MMA_SHAi2C

## 1.1 Input data products

The following input data products were used for the estimation of the MMA_SHAi2C magnetospheric field model

| Products | Type | Period | Comment |
|---|---|---|---|
| SW_OPER_Q3D_CI_i2__00000000T000000_99999999T999999_0101 | Q-matrix of Earth's (1-D mantle + oceans) | - | Used for computing induced part of ionospheric field |
| SW_OPER_AUX_OBS_2__20130101T000000_20131231T235959_0110<br>SW_OPER_AUX_OBS_2__20140101T000000_20141231T235959_0110<br>SW_OPER_AUX_OBS_2__20150101T000000_20151231T235959_0110<br>SW_OPER_AUX_OBS_2__20160101T000000_20161231T235959_0110 | Observatory hourly mean values | 2013-12-01 – 2015-12-31 | A total of 143 observatories are included |
| SW_OPER_AUX_DST_2__19980101T013000_20170103T233000_0001<br>SW_OPER_AUX_F10_2__19980101T000000_20170101T000000_0001<br>SW_OPER_AUX_KP__2__19990101T023000_20161215T223000_0001 | Indices | As indicated by the file names | |
| SW_OPER_MAGA_LR_1B_*yyyymmddTh1m1s1*_*yyyymmdd*T*h2m2s2*_0501<br>SW_OPER_MAGB_LR_1B_*yyyymmddTh1m1s1*_*yyyymmdd*T*h2m2s2*_0501<br>SW_OPER_MAGC_LR_1B_*yyyymmddTh1m1s1*_*yyyymmdd*T*h2m2s2*_0501 | Swarm magnetic data, 1 Hz | 2013-12-01 - 2016-12-31 | Decimated to 15 second sampling |

Table 1-1: Input data products

## 1.2 Model Parameterization and Data Selection

See Section 2.1.

## 1.3 Output Products

The products of this validation report are:

*Swarm Level 2 Magnetospheric field Product:*

SW_OPER_MMA_SHAi2C_20131201T000000_20170101T000000_0201

*Swarm Level 2 Intermediate Validation Product:*

SW_OPER_MMA_VALi2C_20131201T000000_20170101T000000_0201

## 1.4 Validation Results

The tests were conducted between 2017-02-14 and 2017-03-17.

The following tests have been applied to the magnetospheric field output product.

### 1.4.1 Correlation with Dst Index

Figure 1-1 below shows the correlation between the main dipole coefficients of the external (inducing), $q_1^0$, and internal (induced), $g_1^0$, parts of the magnetospheric model and the respective parts, Est and Ist, of the geomagnetic index, Dst. The high correlation above 0.92 demonstrates a good estimation of $q_1^0$ and $g_1^0$.

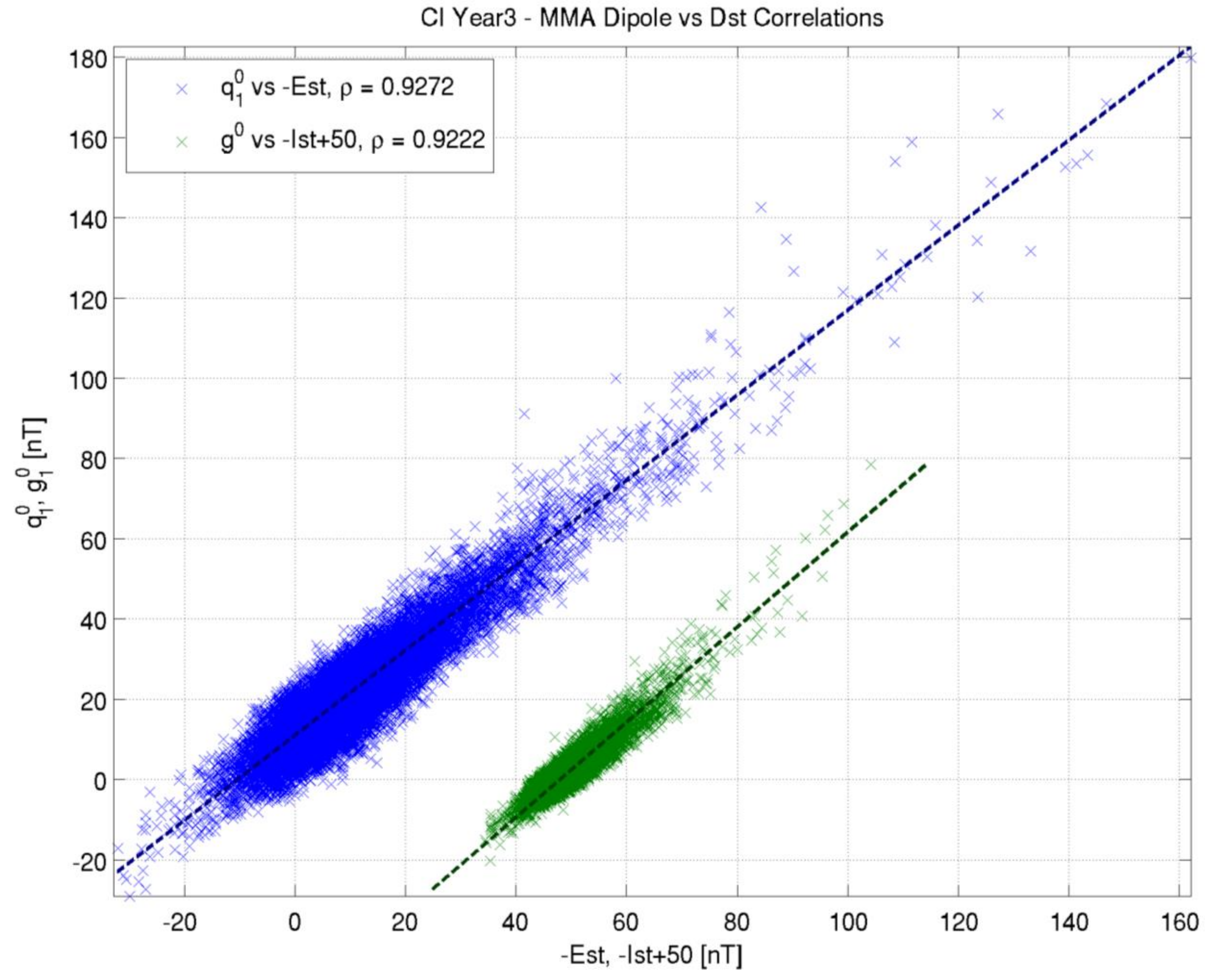


Figure 1-1: Correlation between $q_1^0$ and $g_1^0$ of MMA_SHAi2C and Dst index

### 1.4.2 Coherency with RC Index

In Figure 1-2 below, the squared coherences between the external and the induced dipole coefficients of MMA_SHAi2C, MMA_SHA_2F, and of the RC index are shown; in red $q_1^0$ vs $RC_e$, in blue $g_1^0$ vs $RC_i$, in purple $q_1^0$ vs $g_1^0$, and in cyan $q_1^0$ vs ${}^{FT}q_1^0$ of the *Fast-Track* magnetospheric product, MMA_SHA_2F. Coherencies are almost everywhere above 0.8 (except vs. RC for very short/long periods) with $q_1^0$ vs ${}^{FT}q_1^0$ showing the highest coherency despite the fact that they are derived in two quite distinct ways.

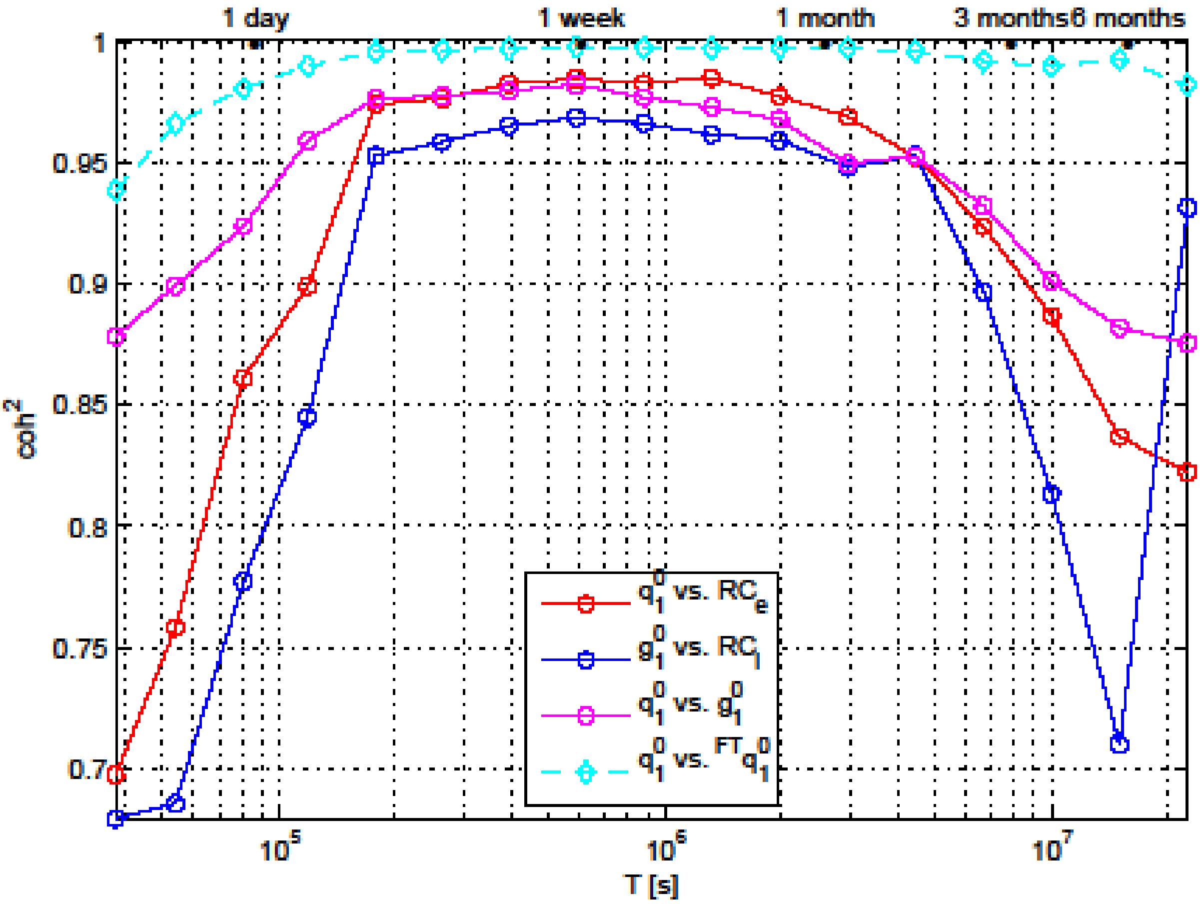


Figure 1-2: Coherency between dipole terms, RC index, and ${}^{FT}q_1^0$ of MMA_SHA_2F

### 1.4.3 C_Response

Figure 1-3 below shows the C-response estimates based on $q_1^0$ and $g_1^0$ in red circles with estimated error bars. The blue dashed curve shows theoretical values based on the conductivity model of Utada et al., whereas the green curves are based on a recent conductivity model of [Grayver, GRL, 2017]; both are in good agreement with the results from the CI MMA dipole terms.

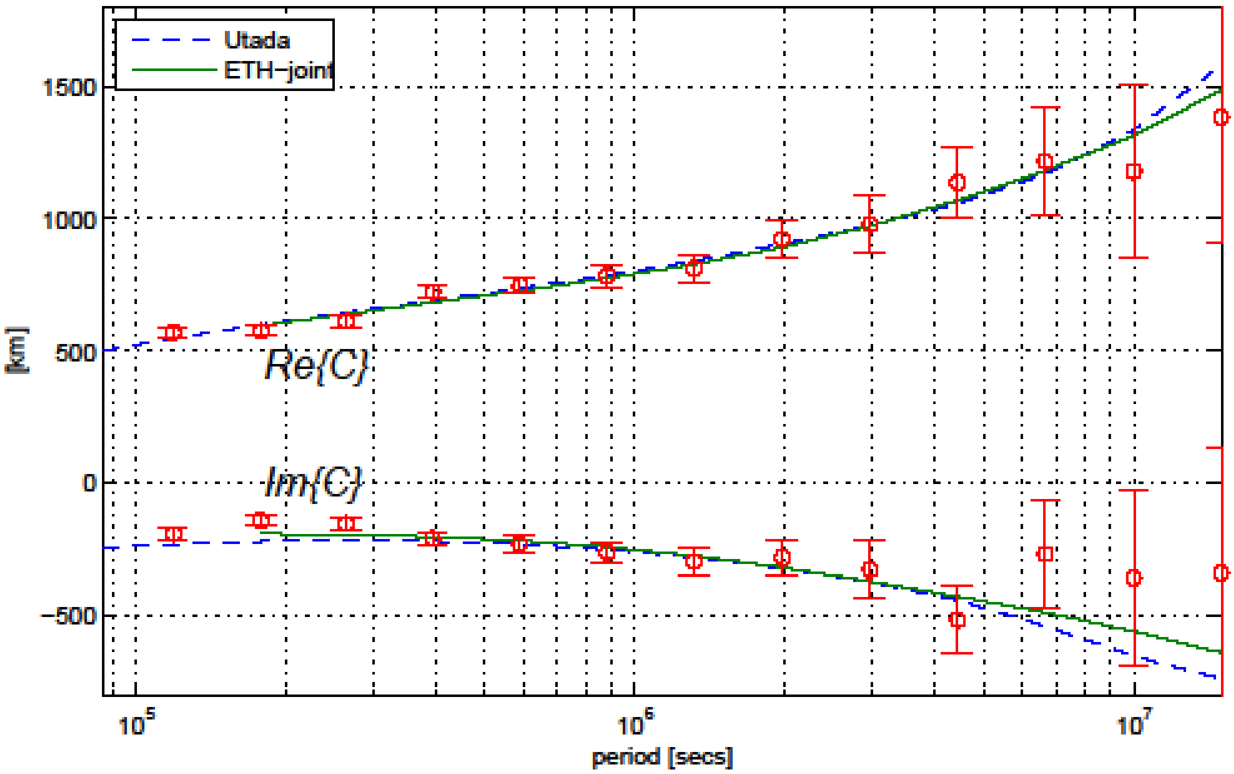


Figure 1-3: C-Response estimated from $q_1^0$ and $g_1^0$

### 1.4.4 Data Statistics

The statistics of the residuals between the measurement data and the complete CI model are given in Table 1-2 below. Note that the measurements encompass all data (quiet and disturbed) from both day (sunlit) and night side but only at low and mid latitudes.

| | Geomagnetic dipole latitude | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low, ≤ 10° | | | Mid, ]10°..55°] | | | High, > 55° | | |
| | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ |
| Swarm A | 5.03 | 6.12 | 7.78 | 4.74 | 7.85 | 7.68 | 26.12 | 56.71 | 62.47 |
| Swarm B | 4.62 | 5.93 | 7.60 | 4.13 | 7.65 | 7.57 | 24.58 | 55.69 | 62.11 |
| Swarm C | 5.64 | 6.19 | 7.76 | 5.22 | 7.95 | 7.71 | 26.30 | 56.87 | 62.69 |
| Observatories | 5.41 | 7.38 | 6.92 | 4.99 | 7.68 | 7.35 | 30.23 | 44.25 | 30.16 |

Table 1-2: Observation Statistics: standard deviations of data residuals, Huber weighted, [nT]

## 1.5 Criteria

Table 1-3 below summarizes the criteria used to check the validity of the MLI_SHAi2C product:

| **Input** | **Test** | **Criteria** | **Pass?** |
|---|---|---|---|
| Observations | Residual statistics | Standard deviation of quiet time vector data below 7 nT. | Ok |
| Alternative model | Comparison with model | CI model agrees with alternative model | Ok |

Table 1-3: Validation criteria

# 2 Additional Information

## 2.1 Model Configuration and Data Selection Parameters

The MMA_SHAi2C product is obtained as an estimation of the residual magnetic vector field after subtraction of a comprehensive co-estimated model of the core, lithosphere, ionosphere, and magnetosphere field contributions including induced contributions based on quite time data similar to the method described in [Sabaka, GRL, 2016]. The complete model configuration used is given in Table 2-1 below; the MMA_SHAi2C product is the green part:

| Model Part | Maximum Degree/Order | Temporal Characteristics | Comment |
|---|---|---|---|
| Core | 16/16 | Order 5 B-spline with knots every 6 months | Damping of the mean-square, second and third time derivatives of $B_r$ at the core-mantle boundary (at 3480 km radius). |
| Lithosphere | 90/90 | Static | Degree 17-90 purely determined by North-South differences from all satellites and East-West differences of lower pair satellite (A and C).<br><br>Damping of $B_r$ at the poles to reduce effect of lack of data at the poles ("*polar gap*") |
| Ionosphere | 45/5<br>(dipole coordinates) | Annual, semi-annual, 24-, 12-, 8- and 6- hours periodicity | Spherical harmonic expansion in quasi-dipole (QD) frame, underlying dipole SH $n_{max}$ = 60, $m_{max}$ = 12. Scaling by 3-months averages of F10.7 plus induction via a priori 3-D conductivity model ("1-D + oceans") and infinite conductor at depth.<br><br>Damping of:<br><br>1. Mean-square current density J in the E-region within the nightside sector (magnetic local times 21:00 through 05:00)<br><br>2. Mean-square of the surface Laplacian of J multiplied by a factor of $\sin^8(2\theta)$ over all local times, where $\theta$ is co-latitude. |

| Model Part | Maximum Degree/Order | Temporal Characteristics | Comment |
|---|---|---|---|
| Magnetosphere, quiet time, external | 3/1 | One hour bins | |
| Magnetosphere, quiet time, induced | 3/3 | One hour bins | |
| Magnetosphere, all data, external | 2/1 | Axial dipole term: 1½ hour bins<br>Other terms: 6 hour bins | Determined from vector (residual) data below 55° magnetic dipole latitude. |
| Magnetosphere, all data, induced | 3/3 | Axial dipole term: 1½ hour bins<br>Other terms: 6 hour bins | |
| M2 Tidal | 36/36 | Periodicity: 12.42060122 hr, phase fixed with respect to 00:00:00, 1999 January 1 GMT | |

Table 2-1: Model Configuration

The data selection criteria for the quiet time data are:

- Coarse agreement with CHAOS-6 field model: $\Delta B_c \leq 500$ nT for all components $c=r,\vartheta,\varphi$, and $\Delta F \leq 100$ nT.
- $Kp \leq 3^0$
- Time-derivative of Dst: $|dDst/dt| \leq 3$ nT/hour
- 15 second satellite sampling period
- Core and tidal fields determined from night-side data only, i.e. with Sun ≥ 10° below the horizon

## 2.2 Comments from Scientists in the Loop

### 2.2.1 Derivation of Model

The final Comprehensive Inversion model for the first three years of Swarm data show improved agreement with alternative models compared to previous CI models.

### 2.2.2 Conclusion

The estimated model is assessed to be of good quality with good agreement with the magnetic indices Dst and RC, with the MMA_SHA_2F product, and of the C-response of an alternative induction model.

Further analyses from the derivation of the 3-D mantle conductivity indicate some problems using the non-dipole terms for such studies. This will be pursued in future CI models.