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Swarm Level 2 Processing Facility

SW_TEST_MCO_SHAi2D

Intermediate validation of Swarm Level 2 Product: MCO_SHAi2D

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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 MCO_SHAi2D product. The detailed product name under inspection is: SW_TEST_MCO_SHAi2D

This product uses data acquired from MJD -546.81 to MJD 1095.50 and is valid over the period MJD -546.81 to MJD 1095.50, i.e. approx. 1998.5 to 2003.0. This is version 01 of the product.

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 product MCO_SHAi2D has undergone a series of validation and checks by partner XXX.

The SIL's opinion is that the MCO_SHAi2D is validated and is therefore suitable for release as the intermediate MCO_SHAi2D.

2 Applicable and Reference Documentation

2.1 Applicable Documents

The following documents are applicable for this document:

[AD-1] SW-RS-ESA-GS-0178: Development of the Swarm Level 2 Algorithms and Associated Level 2 Processing Facility – Technical Requirements, 2009-07-17

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] 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

2.3 Abbreviations

Acronym	*Description*
CAT-1	Category 1 products
EUL	Euler Angle
L2PS	Level 2 Processing Segment
SHA	Spherical Harmonic Analysis
SIL	Scientist in the Loop
PDGS	Payload Data Ground Segment
VAL	Validation

3 Intermediate 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 outputs are 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 outputs and (b) to give non-expert users confidence that the products released have been thoroughly inspected.

Many products are computed using different algorithms and data selection methods from the Swarm Level 1b data.

3.2 Validation Process for the Core Field Products

The magnetic core field product is describing a spherical harmonic model of the main (core) field and its temporal variation up to degree 20.

Two intermediate Core field products are derived through separate processing chains:

- MCO_SHAi2C is derived from the from Comprehensive Inversion product chain
- MCO_SHAi2D is derived from the Dedicated Core Field chain.

The following steps are undertaken to validate the SLOW lane core field model of the Dedicated Core Field chain:

- An intermediary L2 product is produced by an Level 2 Processing Segment (L2PS) processing chain (for MCO_SHAi2D)
- An internal validation of the product by the chain is produced in the form of an intermediary product validation report (for MCO_SHAi2D, the intermediary validation report is MCO_VALi2D)
- The intermediary product including its internal validation is distributed via PDGS to the L2PS
- The British Geological Survey will perform an independent validation of the product and produces a report, which will include the internal validation.

3.3 Role of Scientist in the Loop

The validation of the product is actively undertaken by a scientist in the loop (SIL)

- The SIL checks the product conforms to scientific expectations using a series of tests and also checks the product is correctly formatted for release.
- The SIL produces an intermediate validation report and releases the product back to the ESA PDGS for further independent validation.

The role of the SIL is to ensure that the output meets the criteria of being a valid scientific product and fulfilling the quality requirements.

4 Intermediate Validation Report of MCO_SHAi2D

The Core field models of the Earth's magnetic field describe the large scale spatial and temporal features of the magnetic field generated in the core. The models are used in a large number of research and commercial applications. The products consist of a series of so-called Gauss coefficients of degree n = 1 to N, which can be used to derive any component of the magnetic field using spherical harmonic. The value of N shall be at least 14, progressing to 20 during the mission.

There are a number of internationally agreed core field models available for comparison including (a) the International Geomagnetic Reference Field (IGRF) model and (b) the World Magnetic Model (WMM). These models are auxiliary data AUX_IGR_2_ and AUX_COR_2_, though note there are other available core field models.

The IGRF and WMM models describe the large-scale magnetic field up to degree 13 for the time epoch 2010.0 with a prediction of secular variation up to degree 8, valid for five years (until 2015). The Gauss coefficients for both IGRF and WMM are freely available for use.

The following validation tests can be made using the Gauss coefficients from MCO_SHA_2D and MCO_SHA_2C (a) with each other (when available).

4.1 Input products and data

The following products were used in the assessment of the MCO_SHAi2D

Table 4-1: Input products used for validation

Product	Type	Valid from/to	Comment
SW_TEST_AUX_COR_2__19980101T000000_20030101T000000_0001.DBL	Core field model, Reference!	Jan 1998 – Jan 2003	Independent model; derived from satellite and ground observatory data
SW_TEST_MCO_SHAi2D_19980101T000000_20030101T000000_0001.DBL	Dedicated Core Field Inversion model	Jan 1998 – Jan 2003	Derived from Swarm Level 1 data
SW_TEST_AUX_LIT_2__00000000T000000_99999999T999999_0001.DBL	Lithospheric model	N/A	

4.2 Output Products

The output product from this validation report are:

Swarm Level 2 Magnetic field Product:

SW_TEST_MCO_SHAi2_19980701T000000_20030101T000000_0001.DBL

Swarm Level 2 Intermediate Validation Product:

SW_TEST_MCO_VALi_19980701T000000_20030101T000000_0001.DBL

4.3 Validation Results

The tests were conducted using data between 1998.5 and 2003.0.
The following tests have been applied to the data.

4.3.1 Mean square vector field difference per spherical harmonic degree

The mean square vector field difference between models per spherical harmonic degree (*n*) is diagnostic of how closely the models match on average across the globe. The difference between Gauss coefficients g_n^m of model *i* and model *j* can be defined as:

$$ {}_{i,j}R_n = (n+1)\left(\frac{a}{r}\right)^{(2n+4)} \sum_{m=0}^{n} \left[{}_i g_n^m - {}_j g_n^m \right]^2 $$ Equation 4-1

where *n* is the degree, *m* is the order, *a* is the magnetic reference spherical radius of 6371.2 km which is close to the mean Earth radius, and *r* is the radius of the sphere of interest, which is taken as r = a for comparisons at the Earth's surface and r = 3480 km for comparisons at the core-mantle boundary. See Figure 4-7 for plot of R from equation 4-1.

The error measure we calculated for checking the quality requirements is the RMS difference between the secular variations of two models averaged over the spherical surface and in time (cf. [AD-1]):

$$ E = \sqrt{\frac{1}{\Delta T}\sum_{l=2}^{16}(l+1)\sum_{m}\int (\dot{g}_l^m - \tilde{\dot{g}}_l^m)^2\, dt} $$

Equation 4-2

In Figure 4-1 we plot the temporal evolution of the SV per degree in the period where the model is valid.

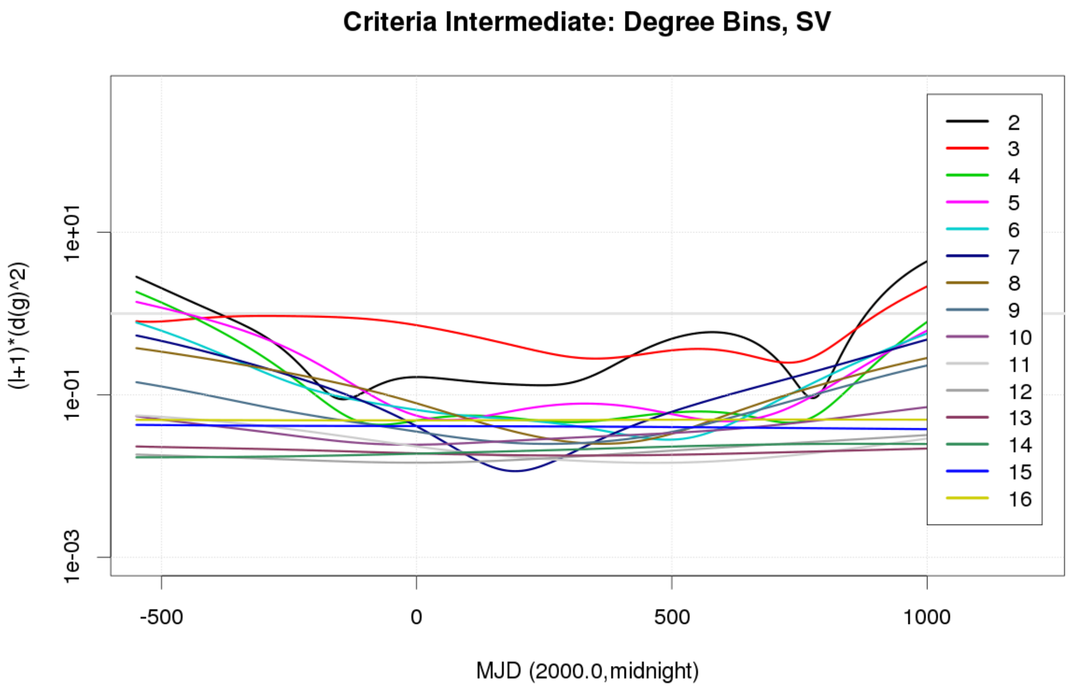

Figure 4-1: Temporal evolution of the model misfit compared to the reference model per SH degree for the SV.

In Figure 4-2 we show the histograms of the data residua for the horizontal components of low latitude data and all components of high latitude data. In Figure 4-3 and Figure 4-4 we show the histograms for each satellite separately. In Figure 4-5 we plot the differences of power spectra for the inverted model and the reference model, as well as a correlation coefficient between both models. The latter is close to 1 till degree 13 and falls off afterwards. In Figure 4-6 we show the power spectra for five snapshots in the model period for the core field and the secular variation. All these plots look reasonable and pass the visual inspection. For the quality criteria that need to be fulfilled see section 4.4.

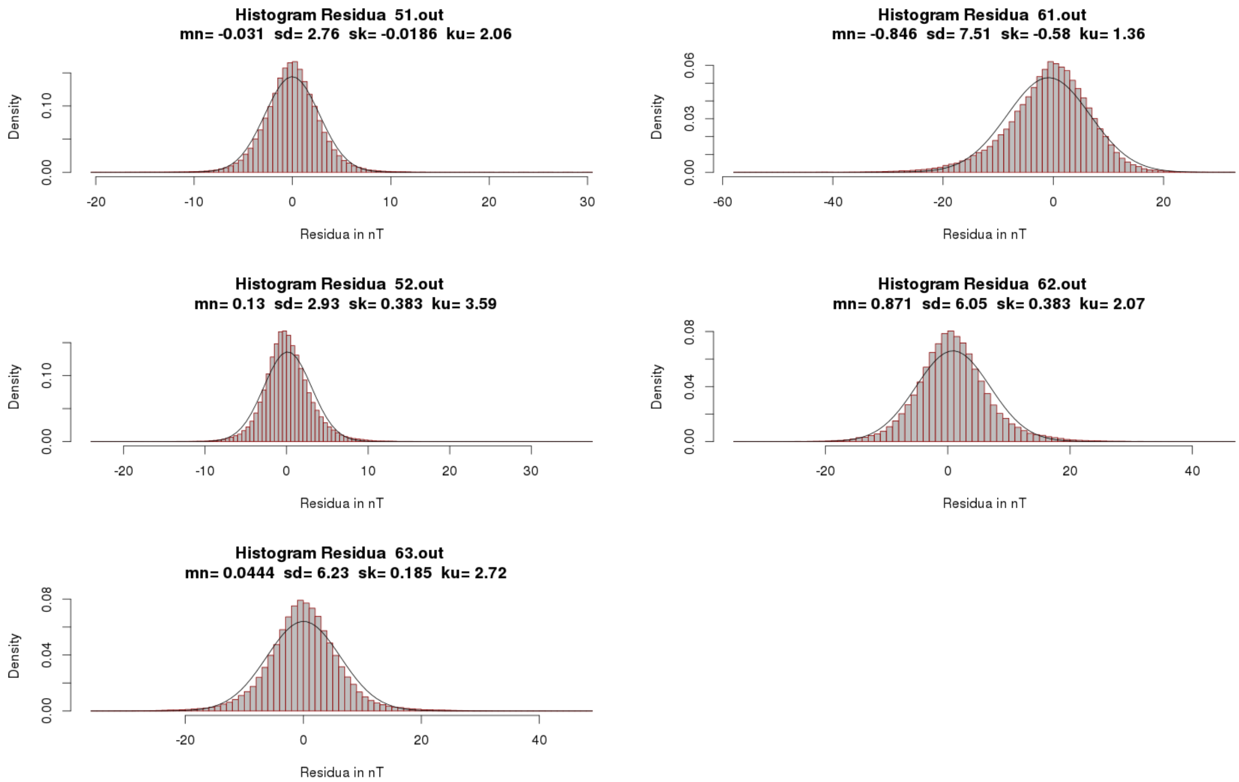

Figure 4-2: Histograms of data residua; for low latitudes (51 and 52) and for high latitudes (61, 62, and 63).

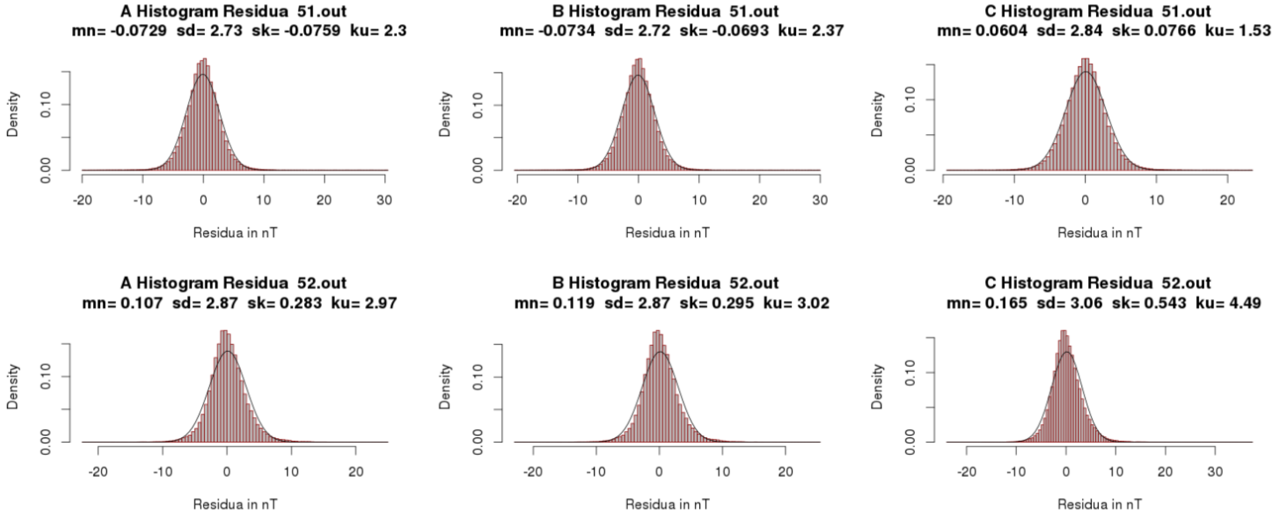

Figure 4-3: Histograms for data residua, low latitudes only, split by satellite (A,B,C).

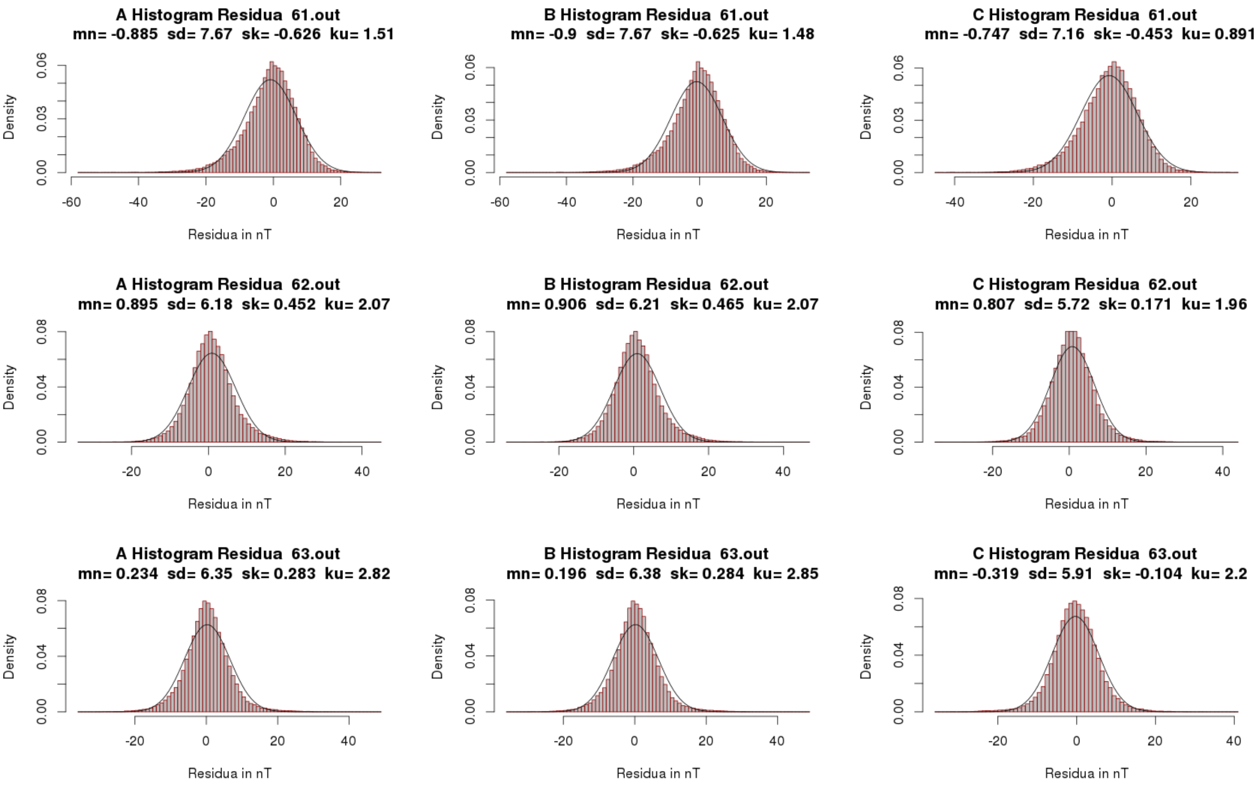

Figure 4-4: Histograms for data residua, high latitudes only, split by satellite (A,B,C).

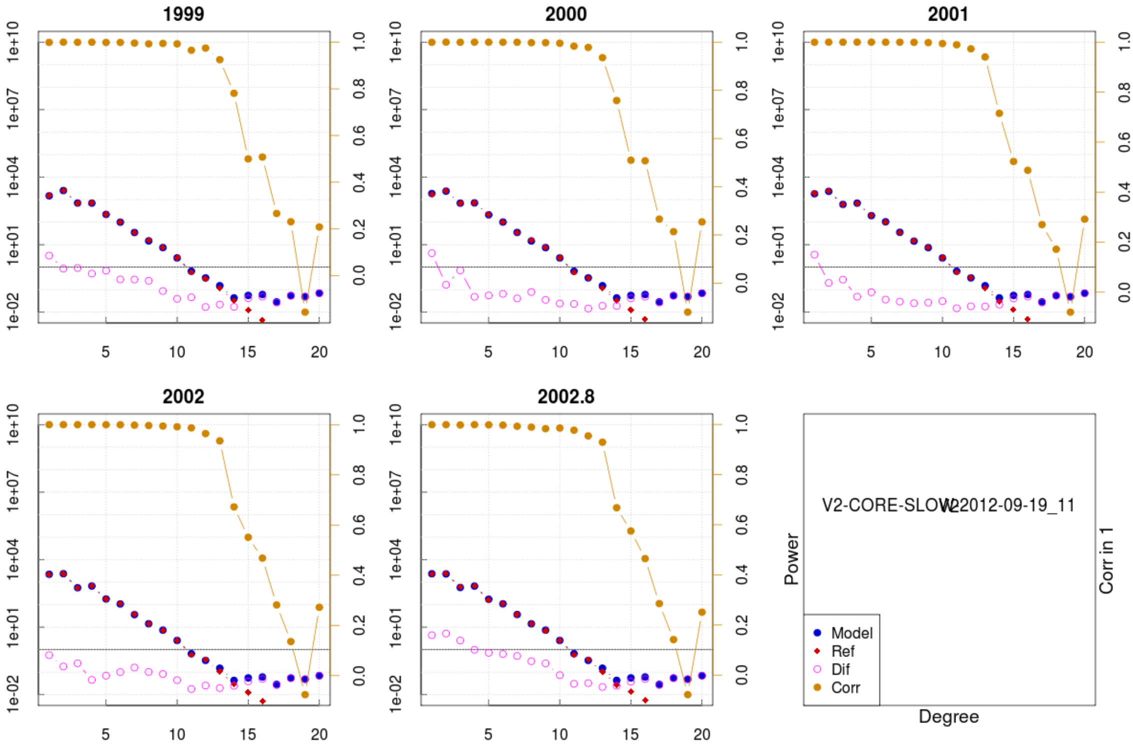

Figure 4-5: Power of difference (open circles) and correlation of evaluated model and reference model per spherical harmonic degree.

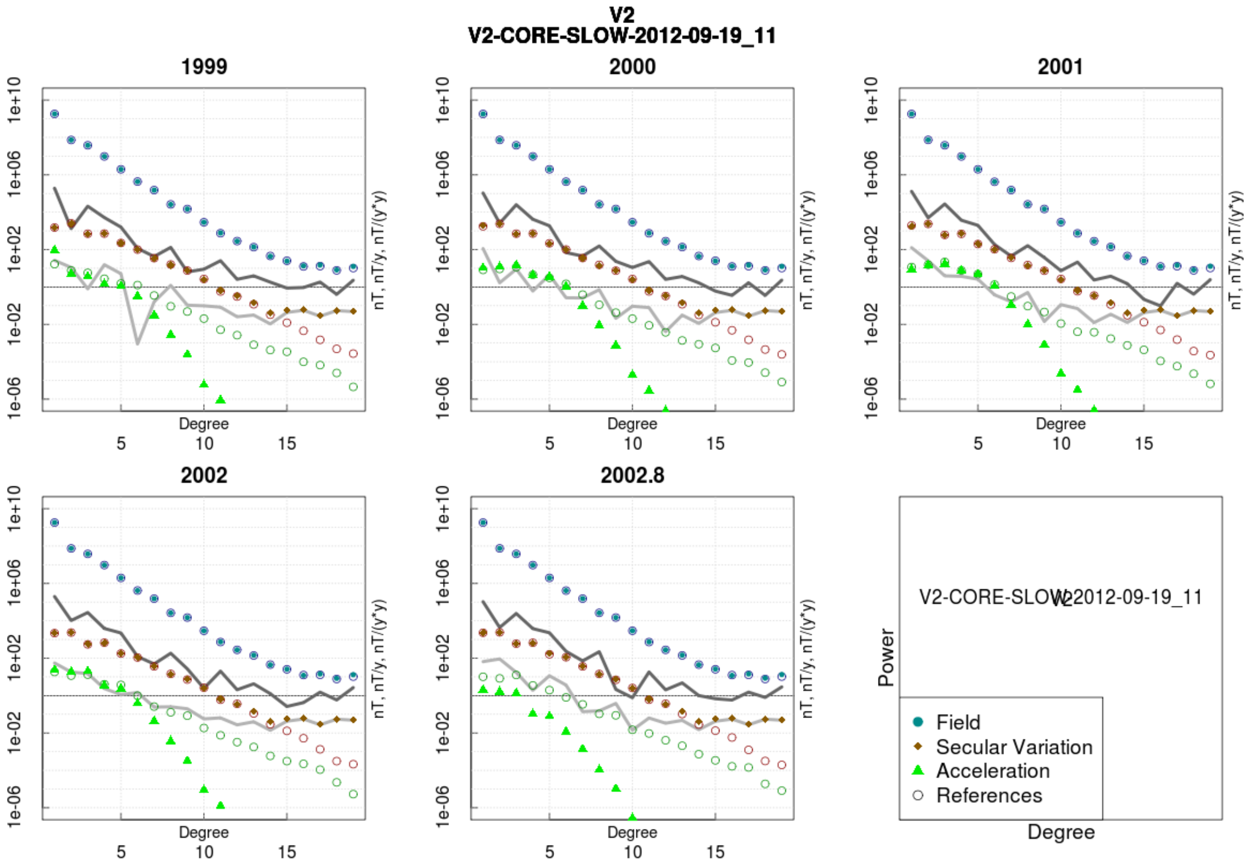

Figure 4-6: Power spectra for five different snapshots of the inverted slow core lane model.

4.3.2 Correlation per spherical harmonic degree

Analysis of spherical harmonic spectra is a powerful way to diagnose differences in amplitude between models but tells us little about how well they are correlated. The correlation per degree between two models again labelled by the indices *i* and *j* can be studied as a function of spherical harmonic degree using the quantity: ${}_{i,j}\rho_n$

$$
{}_{i,j}\rho_n = \frac{\sum_{m=0}^{n} \left({}_i g_n^m \; {}_j g_n^m \right)}{\sqrt{\left(\sum_{m=0}^{n} \left({}_i g_n^m \right)^2 \right) \left(\sum_{m=0}^{n} \left({}_j g_n^m \right)^2 \right)}} \qquad \text{Equation 4-3}
$$

Ideally, the correlation should be close to 1 for all models, indicating that they have equivalent features and coefficients. If the correlation falls below 0.5, for degrees 1-9, then the models should be examined in more detail. Coefficients from degree 10-13 in IGRF and WMM are less well-determined (e.g. due to noise) and also change more rapidly so are not expected to be well correlated by the launch of the Swarm mission.

See Figure 4-5 for correlation per spherical harmonic degree.

4.3.3 Visualisation of coefficient differences

A final method of visualising the differences in Gauss coefficients is to plot the differences ${}_i g_n^m - {}_j g_n^m$ as a triangular plot, with the zonal coefficients lying along the centre of the triangle, the sectorial coefficients along the edges and the tesseral coefficients filling the central regions. These plots will illustrate which, if any, coefficients are strongly divergent between models.

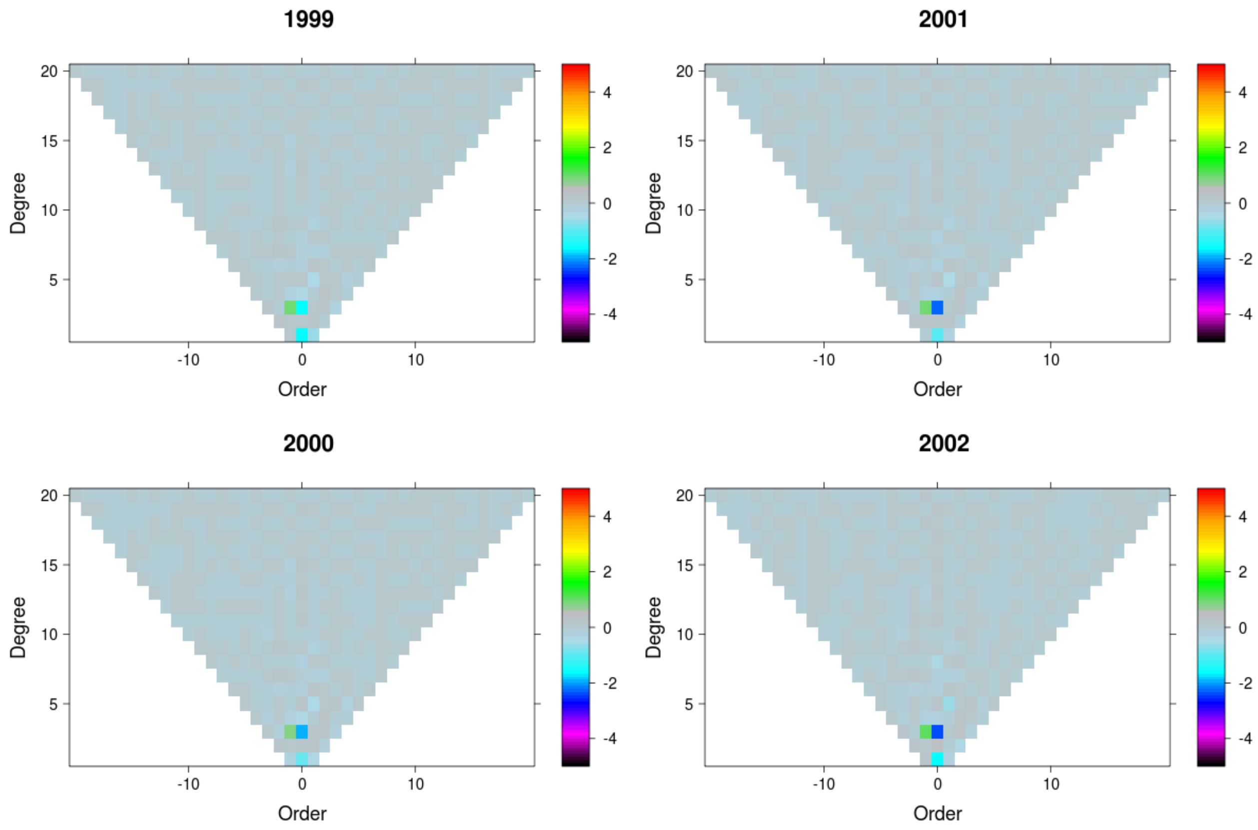

Figure 4-7: Visualisation of field differences between inverted model and reference field in a triangular order over degree scheme.

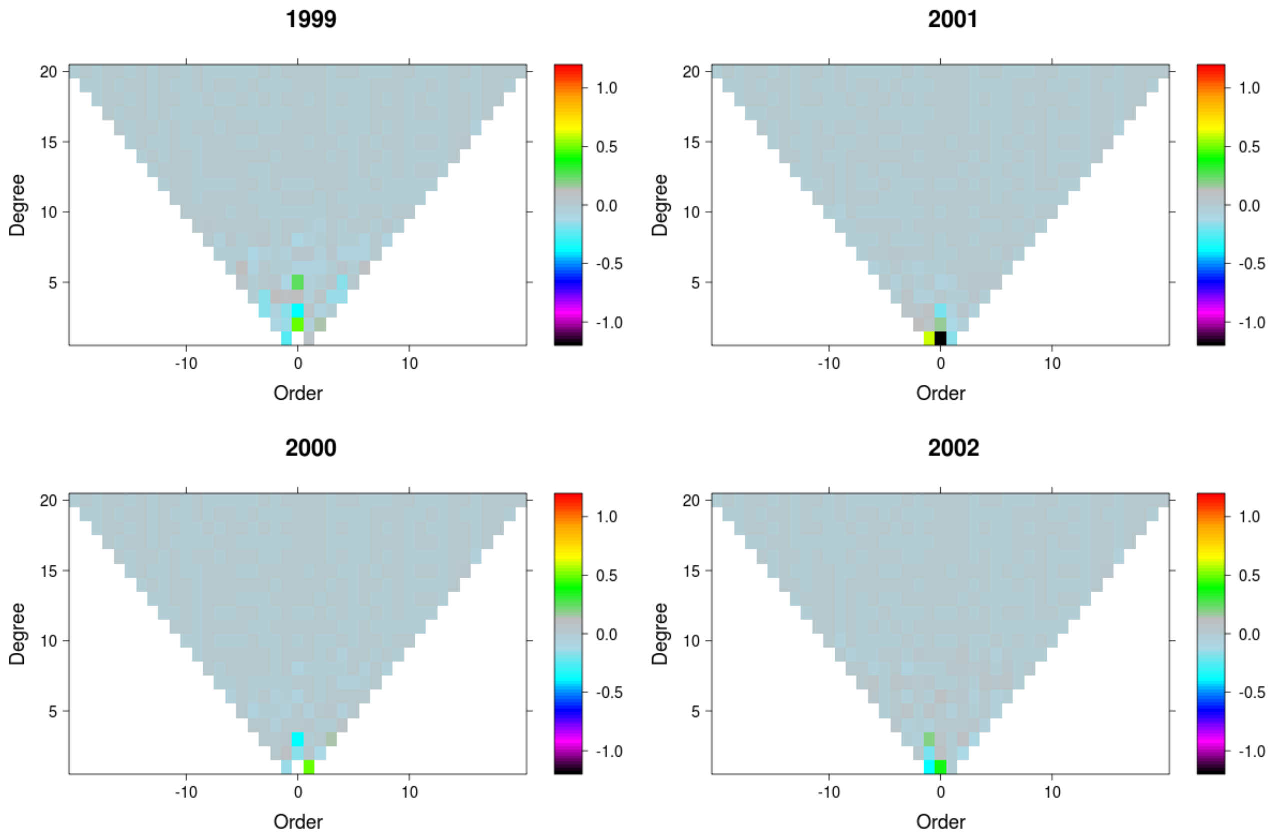

Figure 4-8: Visualisation of secular variation differences between inverted model and reference field in a triangular order over degree scheme.

4.3.4 Visualisation of spatial differences

A geographical investigation of the model fit is made by plotting the X-component residuals for high and low latitudes. The resulting plot is given an overview about the spatial distributions of the unfitted signals and where the disparities are located -- and may lead to the origin of that unfitted signals: if it's a residual lithospheric signal or of other origin (i.e. external fields at polar regions).

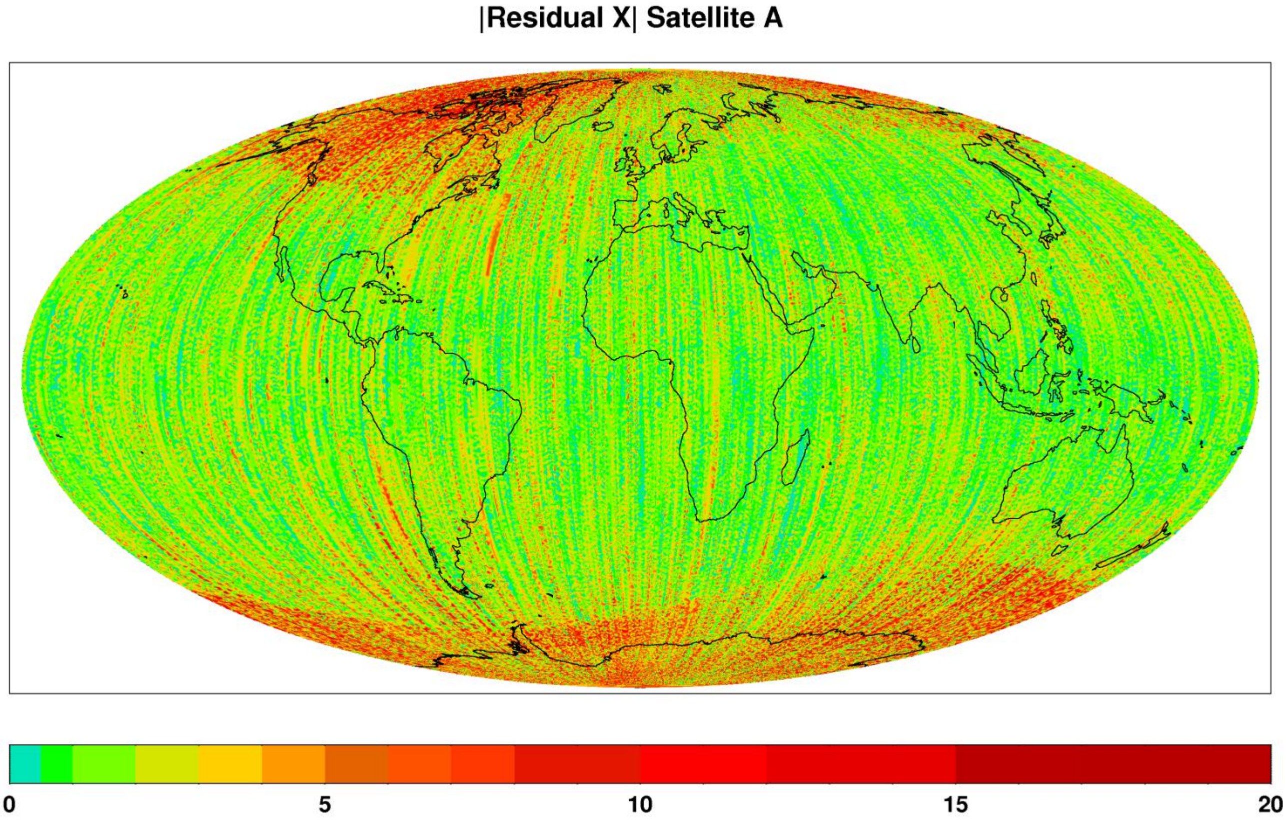

Figure 4-9: Spatial visualisation of residuals as an irregular contour plot (here: X component for high and low latitudes, as there are data residuals, given at satellite altitude)

4.3.5 Comparison of computed field values to ground-based observatory data

Ground-based observatory data (AUX_OBS_2_) can be used to check the values computed from the core field models.

For V2 tests no comparisons of the DCO SLOW CORE model estimate with observatory data is performed

4.3.6 Plotting time series

A series of plots of time versus computed Gauss coefficients will be derived to search for anomalous or periodic behaviour which might indicate underlying issues.

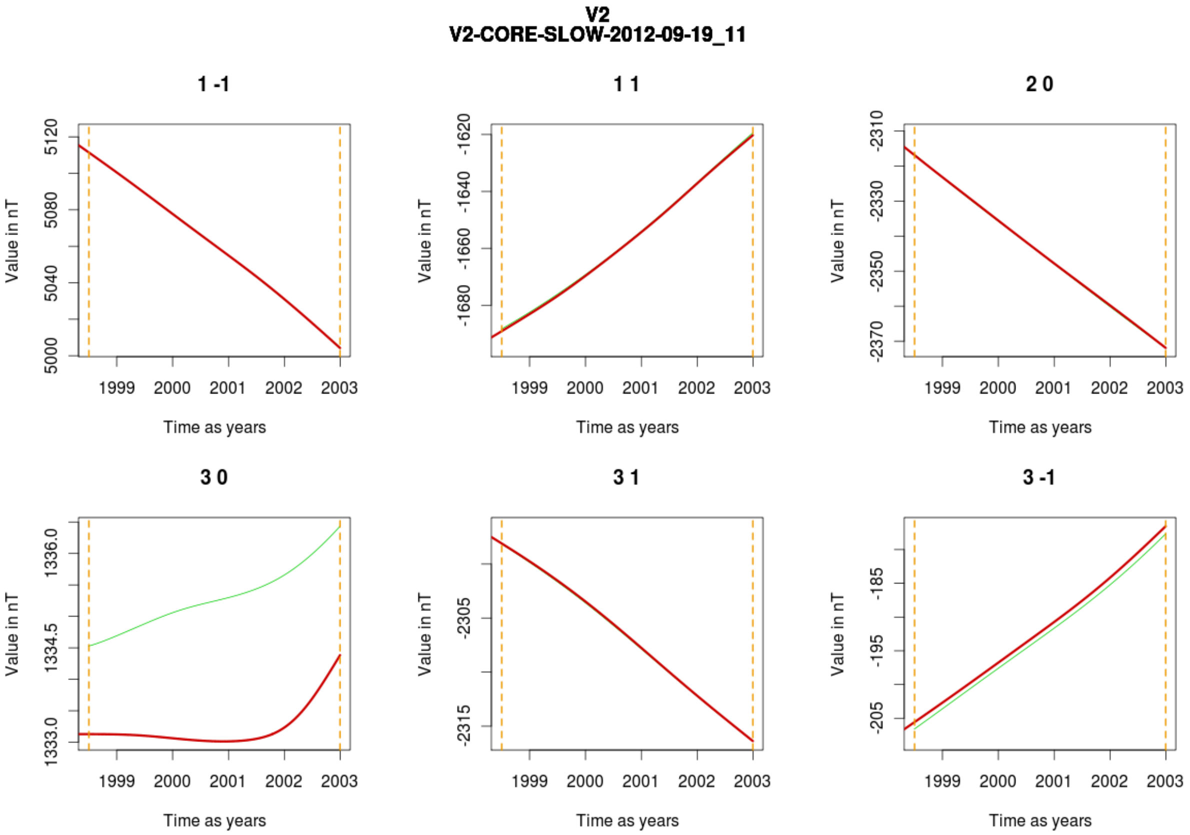

Figure 4-10: Time series of Gauss coefficients, the thin line is the behaviour of the reference model over the full time span, the thick solid line is the data period covered used for model estimation, the vertical dashed lines are indicating the data period covered.

4.4 Criteria

The following criteria are used to check the validity of the products:

The value of the error measure from Equation 4-2 must be smaller than 3 nT/yr. In our inversion during the V2 test we reached a value of **1.87 nT/yr**.

5 Comments from Scientist in Loop

The following comments and observations are given by the SIL:

1. The first attempt to run a SLOW CORE lane showed after one day, that the time required for four years of data coverage and full complexity (spline order, segmentation in external field) will not fit well into the scheduled week available. Ideally the DCO attempt requires several consecutive runs, to have a decent core field estimate, before the external field estimation is going to be finalized. Inside the overall processing time, a single iteration should not extend much more then something like a full day.
2. The reference model is the merged model of the core field and lithospheric field model, as this is the true result in the production phase.

3. The last step of the slow core chain was restarted in order to add more iterations to the inversion with varying damping parameters. Further iterations and fine-tuning of the damping parameters, unfortunately terminated by the product delivery schedule, are expected to improve the model, in particular at the boundaries of the data period.

6 Conclusions

The model we obtained in the inversion process fulfils the quality requirements (cf. section 4.4).

Nevertheless, trade-offs with time granted for the SLOW lane test and subsequent limitations in the particular data set used for the final version allows only to deliver a current snapshot of the inversion. With more processing time we can set less strict selection criteria, resulting in a larger data base that would allow to compute a better model, provided the data are weighted correctly.