# Swarm Level 2 Processing System

# Intermediate validation of Swarm Level 2 Ionospheric Field Product

## SW_OPER_MIO_VALi2C_20131201T000000_20170101T000000_0201

**By: DTU**

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## Abstract and Conclusion


The processes and tests applied in the intermediate validation of the MIO_SHAi2C product

**SW_OPER_MIO_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 ionosphere ("MIO" 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 and the product is valid over the same period ("20131201T000000_20170101T000000" 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_MIO_SHAi2C_20131201T000000_20170101T000000_0201 product shows structures in good agreement with ionospheric field models.

**The DTU SIL's opinion is that the MIO_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 |
| MIO | Magnetic Ionospheric 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**


[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 MIO_SHAi2C

## 1.1 Input data products

The following input data products were used for the estimation of the MIO_SHAi2C ionospheric 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_0109<br>SW_OPER_AUX_OBS_2__20140101T000000_20141231T235959_0109<br>SW_OPER_AUX_OBS_2__20150101T000000_20151231T235959_0109<br>SW_OPER_AUX_OBS_2__20160101T000000_20161231T235959_0109 | Observatory hourly mean values | 2013-12-01 – 2016-10-31 | 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*_*yyyymmddTh2m2s2*_0501<br>SW_OPER_MAGB_LR_1B_*yyyymmddTh1m1s1*_*yyyymmddTh2m2s2*_0501<br>SW_OPER_MAGC_LR_1B_*yyyymmddTh1m1s1*_*yyyymmddTh2m2s2*_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 Magnetic ionospheric field Product:*

SW_OPER_MIO_SHAi2C_20131201T000000_20170101T000000_0201

*Swarm Level 2 Intermediate Validation Product:*

SW_OPER_MIO_VALi2C_20131201T000000_20170101T000000_0201

## 1.4 Validation Results

The tests were conducted between 2017-02-14 and 2017-03-02. The following tests have been applied to the ionospheric field model product.

### 1.4.1 Equivalent Current Function

The figures on the following pages show the equivalent current function of the primary ionospheric currents for the MIO_SHAi2C product and for the CM5 model [Sabaka, GJI, 2015] for four different epochs, for the equinoxes and the solstices. Each plot shows the current system for four different UT times, morning (06h), noon, evening (18h), and midnight. The blue line indicates the magnetic dip equator, which gives an indication of the separation between northern and southern current functions. Also shown are the 55°N and 55°S magnetic quasi dipole latitudes in red corresponding to the transition of the use of vector field information. The current function is shown as iso-lines with 10 kA separation.

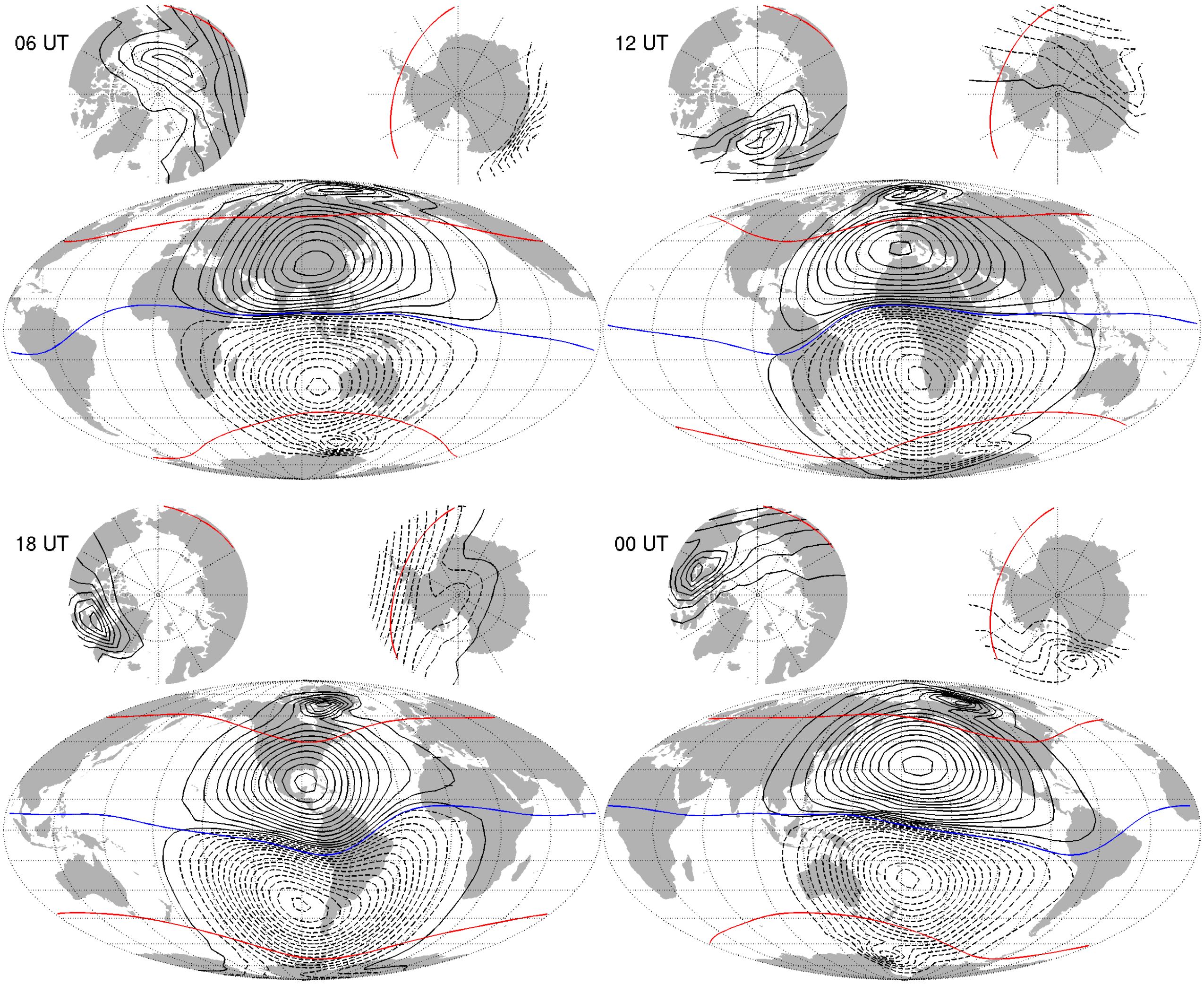


Figure 1-1: Equivalent current function, MIO_SHAi2C, March equinox

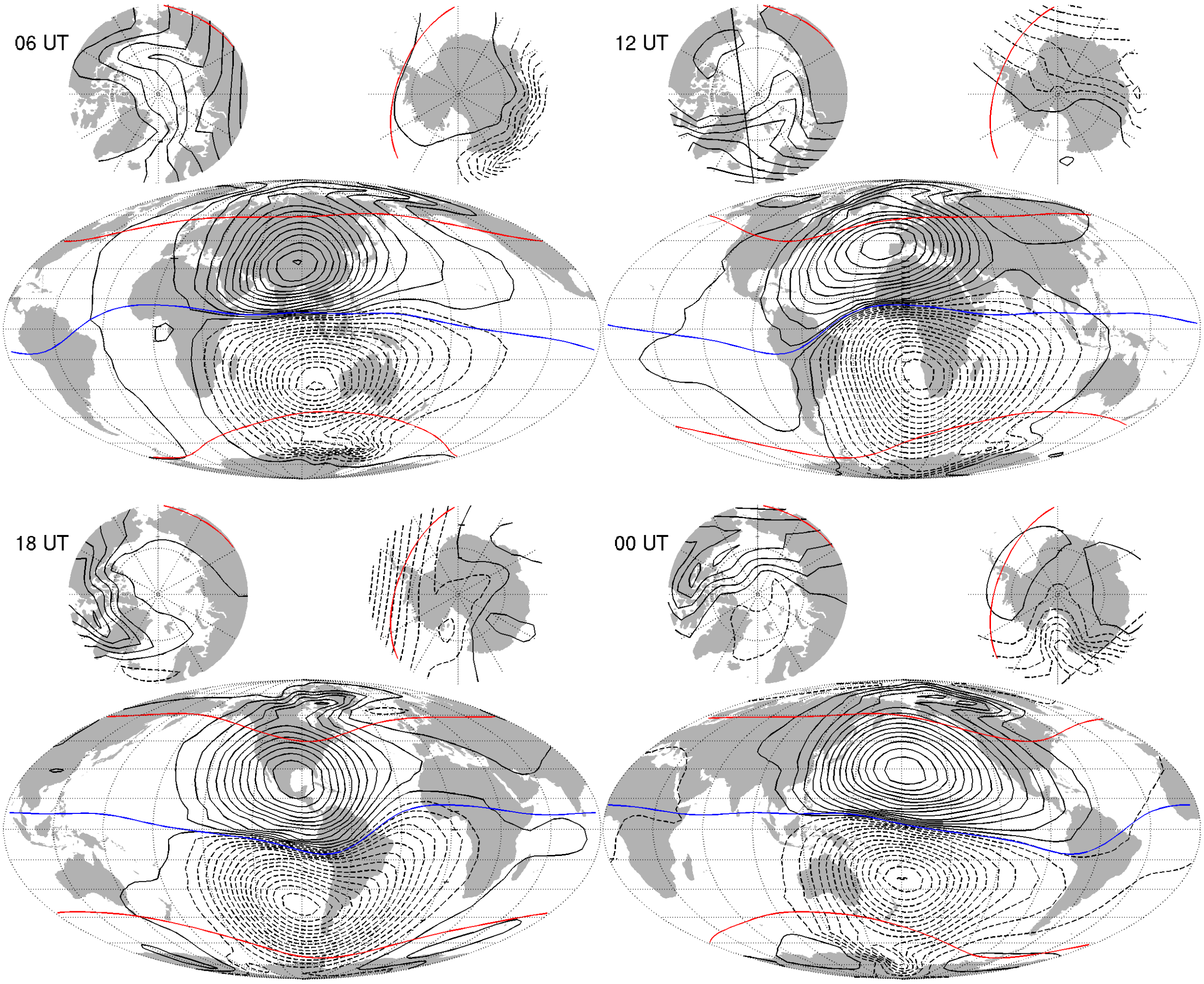


Figure 1-2: Equivalent current function, CM5, March equinox

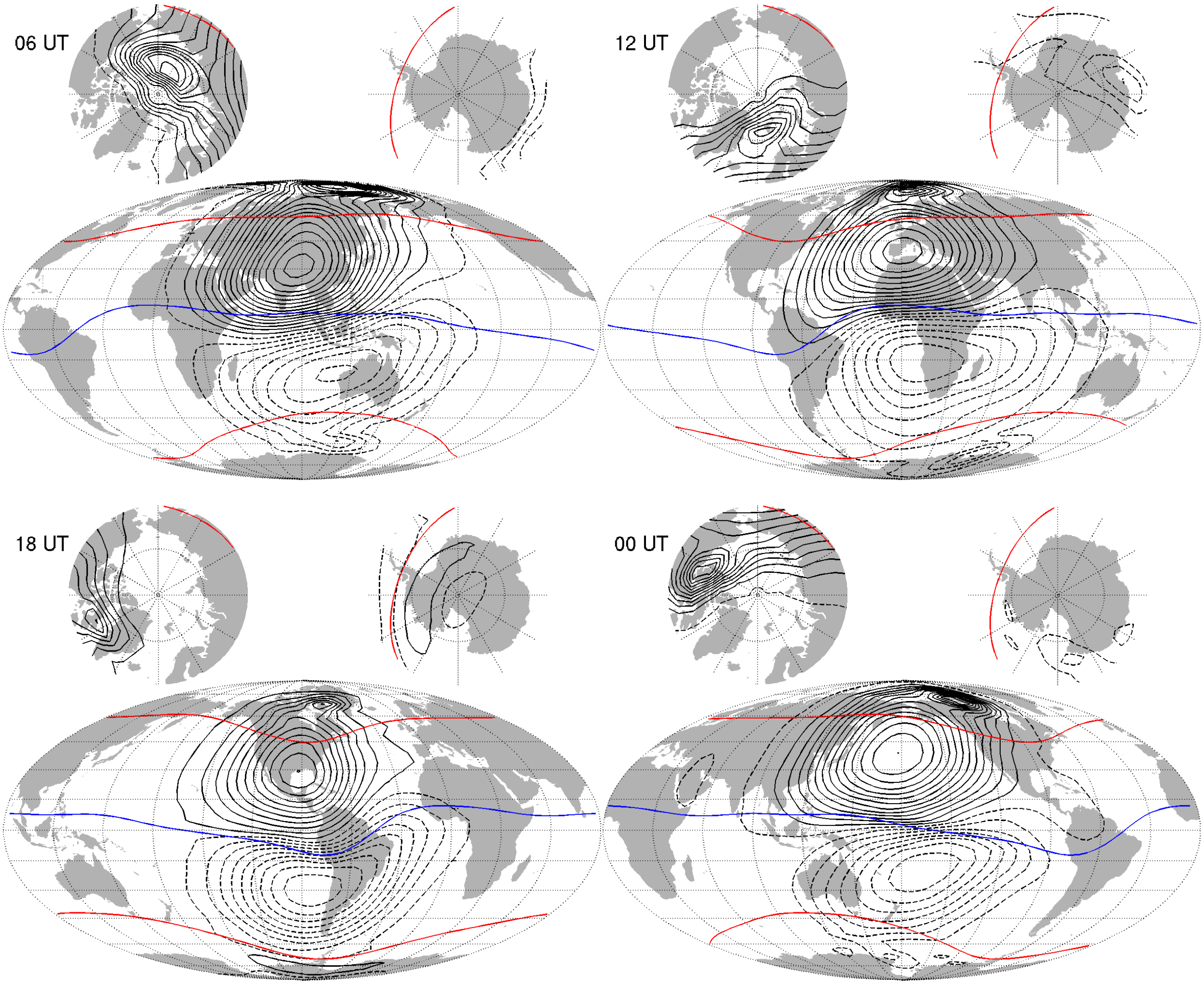


Figure 1-3: Equivalent current function, MIO_SHAi2C, June solstice

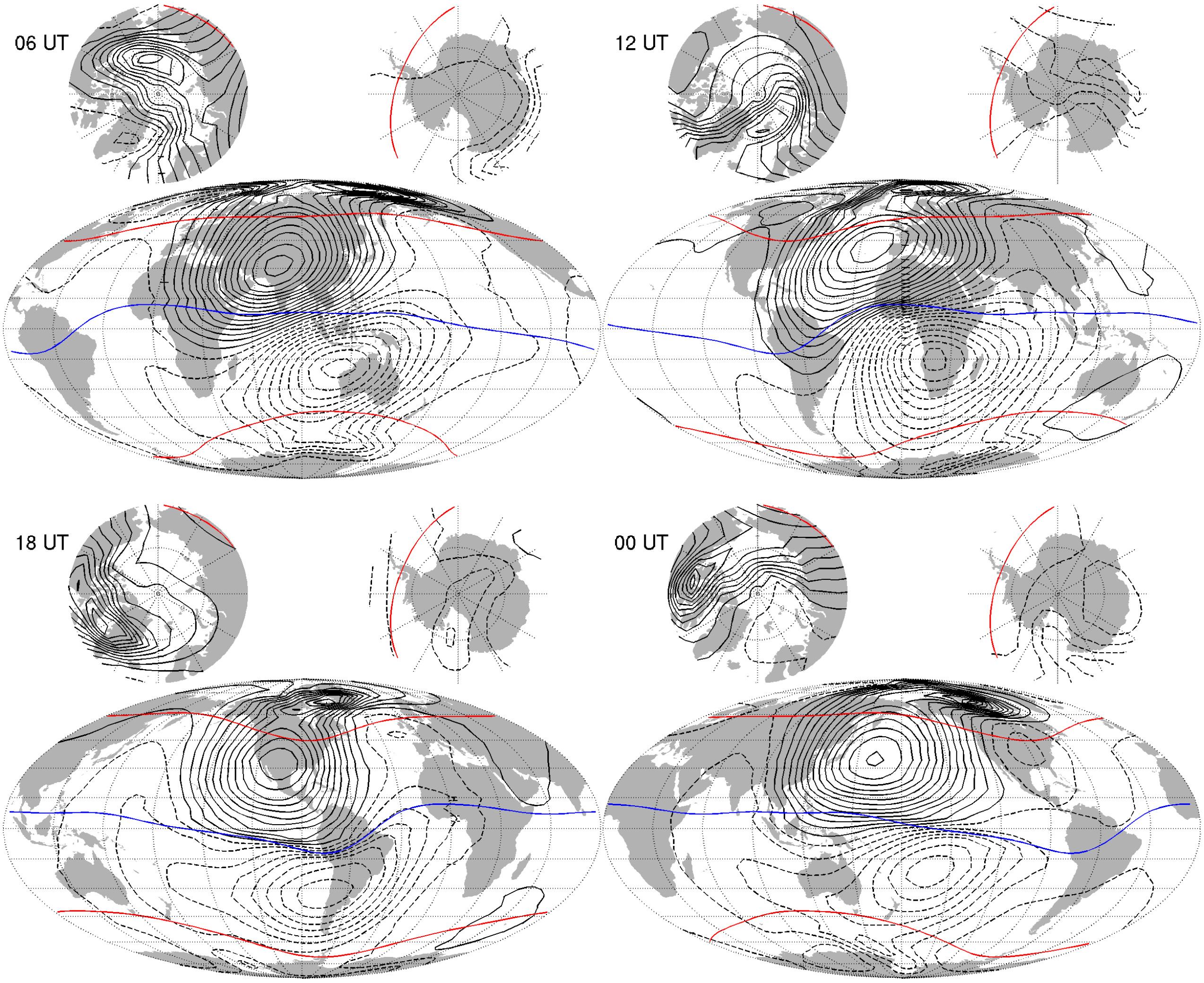


Figure 1-4: Equivalent current function, CM5, June solstice

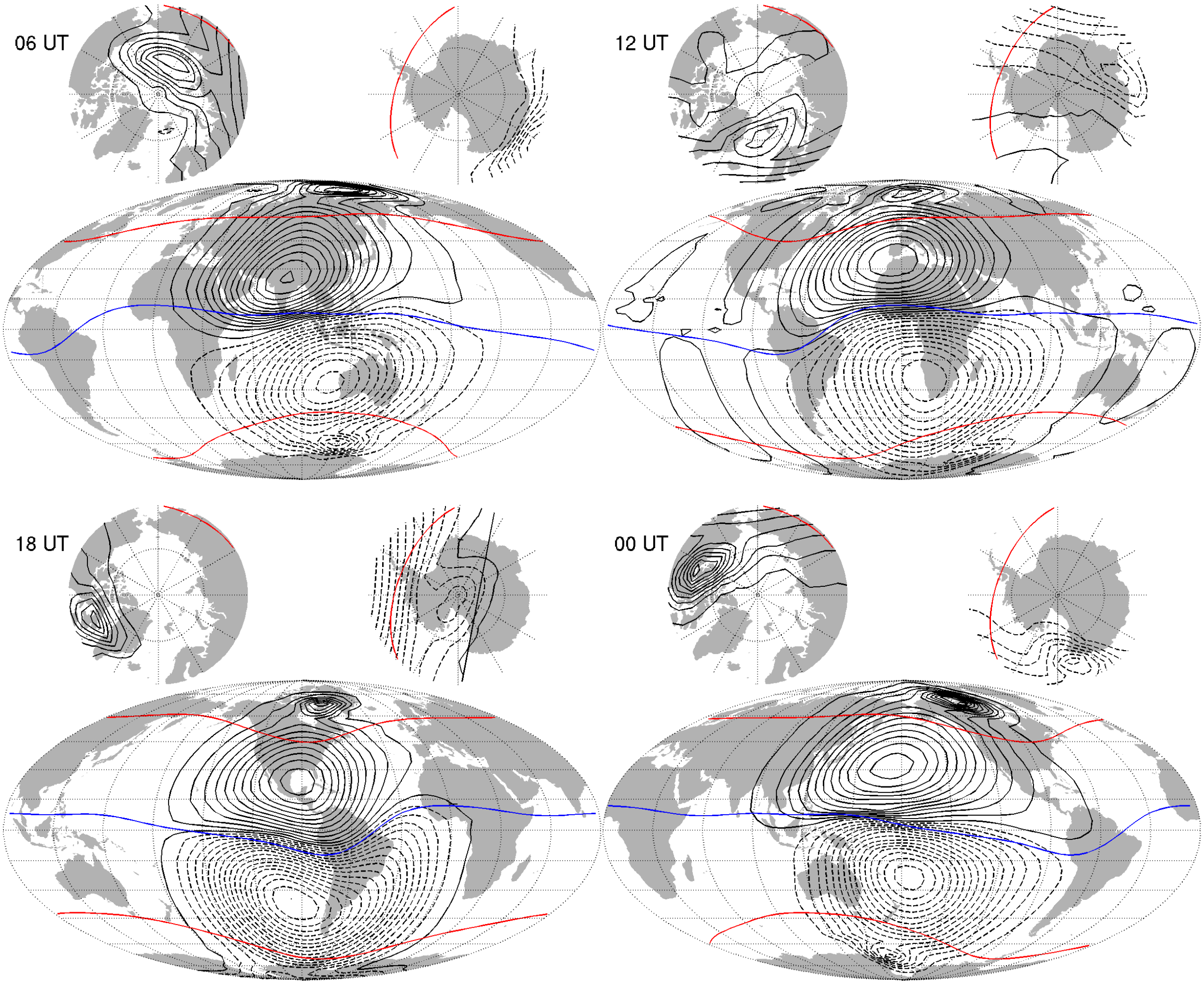


Figure 1-5: Equivalent current function, MIO_SHAi2C, September equinox

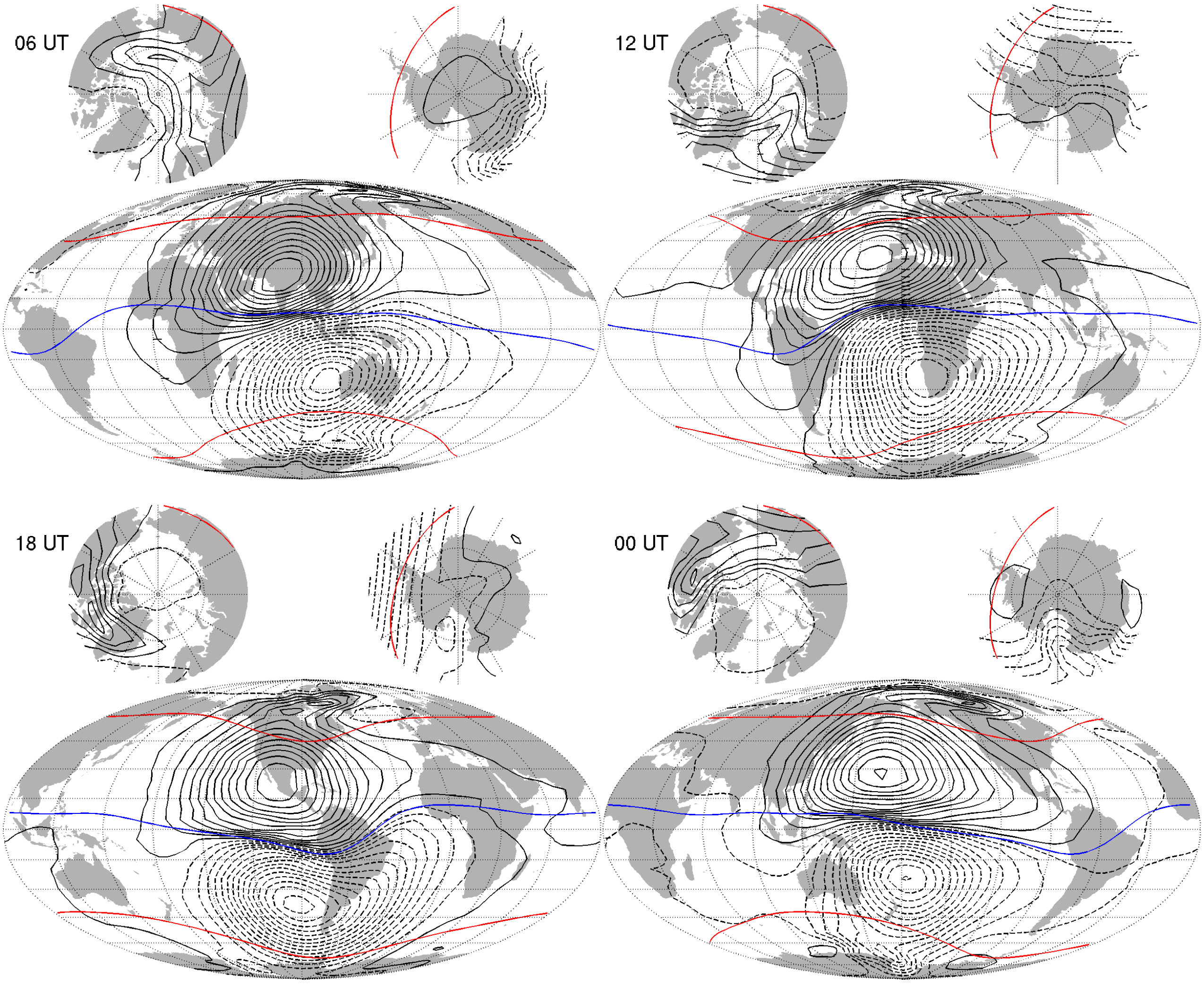


Figure 1-6: Equivalent current function, CM5, September equinox

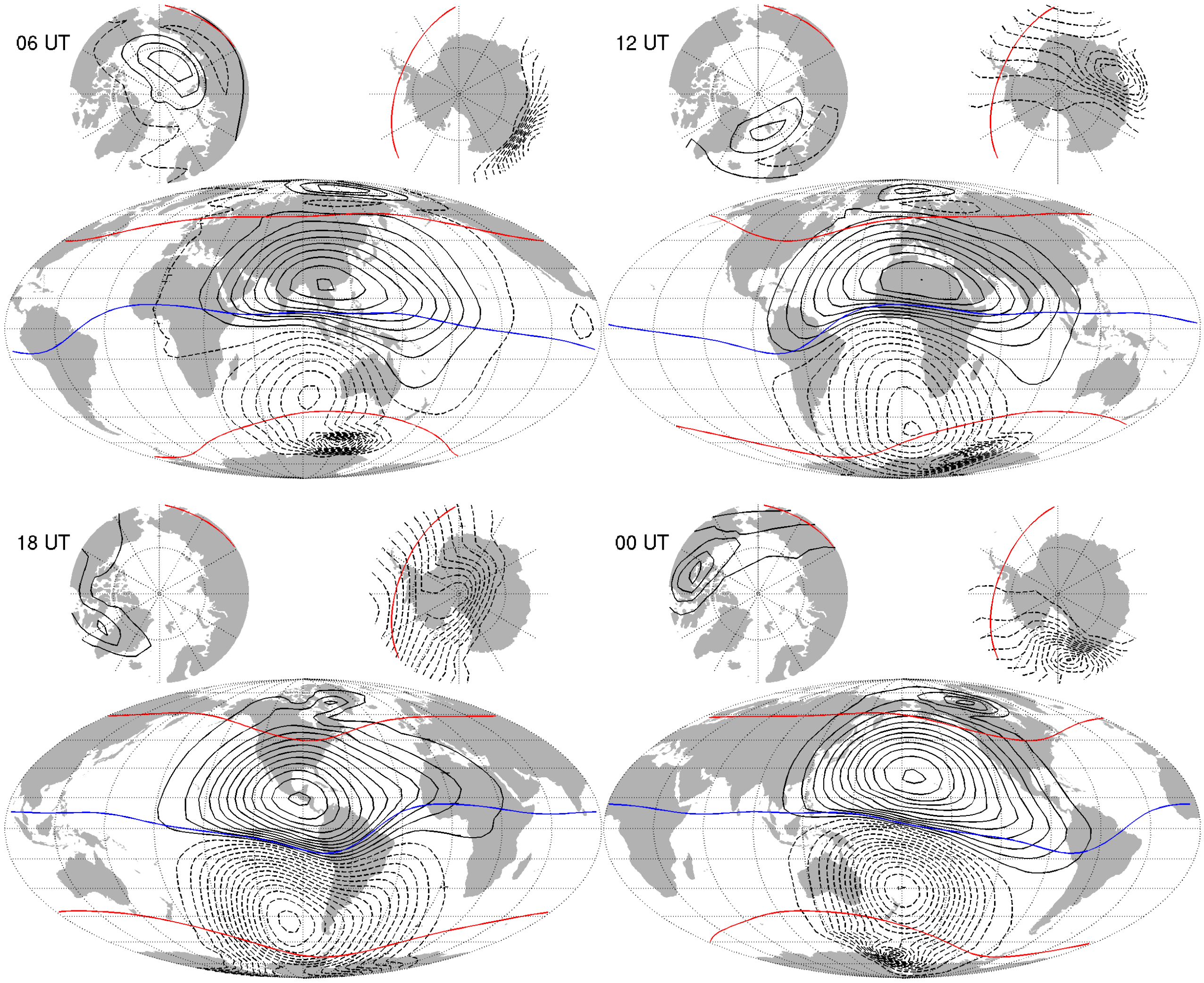


Figure 1-7: Equivalent current function, MIO_SHAi2C, December solstice

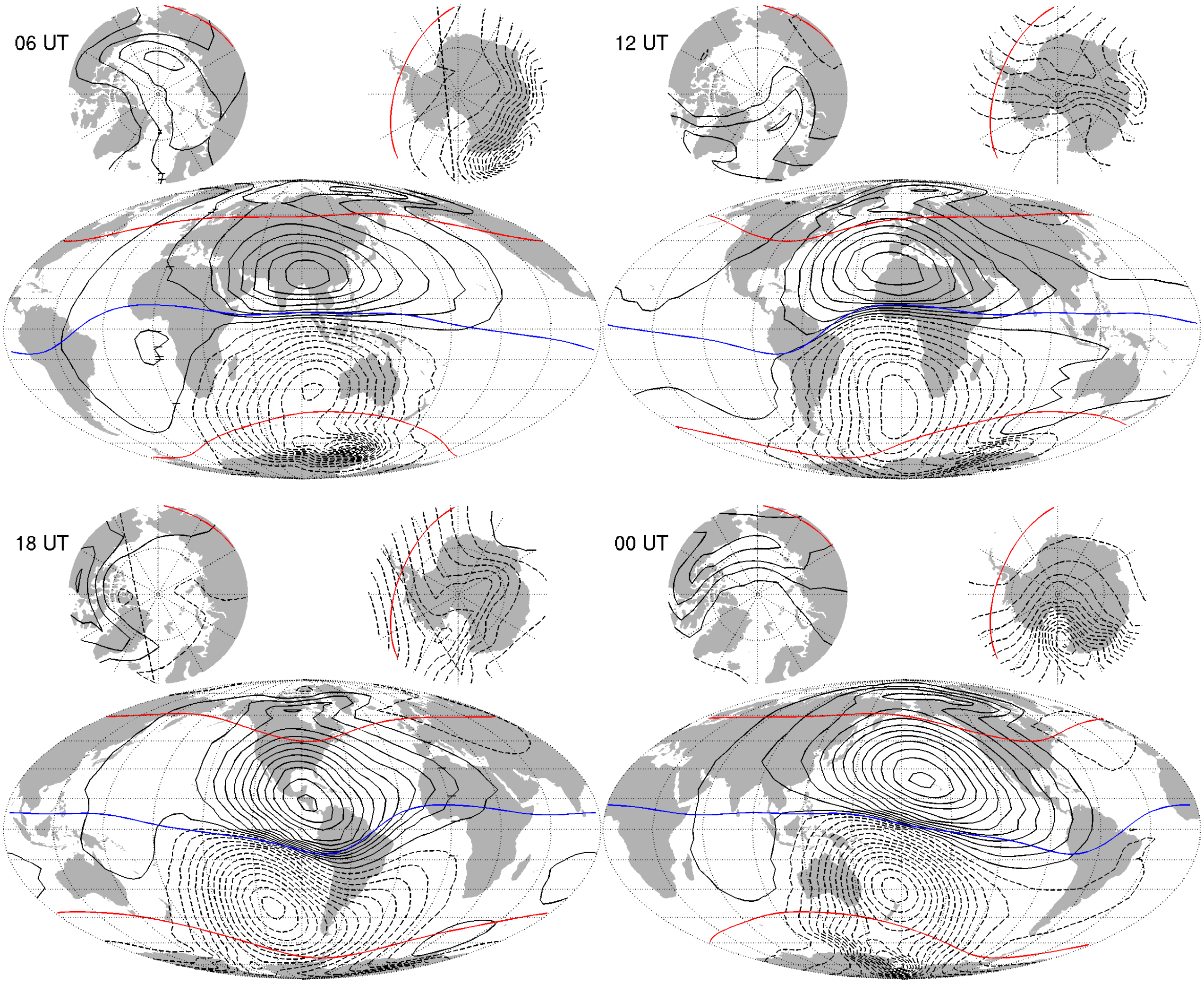


Figure 1-8: Equivalent current function, CM5, December solstice

### 1.4.2 Data Statistics

The statistics of the measurement data obtained by the CI modelling is given in Table 1-2 below. Grey cells indicate data from night side, white cells indicate data from sunlit regions. Crossed cells indicate data which are not used in the inversion process. “Field” indicate the pure vector and scalar measurements, whereas “NS diff” and “EW diff” indicate the North-South (along-track) respectively East-West differences. The standard deviations (of the residuals between the observations and the estimated model) of the differences are quite impressive; the standard deviations of the direct field measurements from the satellites are also quite excellent whereas the ground observatories show slightly higher residuals than previously recorded. Note also the expected similarity between Swarm A and C (side-by-side flying pair) and North-South differences for all three satellites. Swarm B shows slightly higher residuals in the Field components at low and mid latitudes and slightly lower residuals at high latitudes likely due to its higher altitude.

| Swarm/ Obs. | | Geomagnetic quasi-dipole latitude; Standard deviations of data residuals, Huber weighted, [nT] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low, ≤ 10° | | | | Mid, ]10°..55°] | | | | High, > 55° | | | |
| | | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ | $\sigma(F)$ | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ | $\sigma(F)$ | $\sigma(B_r)$ | $\sigma(B_\theta)$ | $\sigma(B_\varphi)$ | $\sigma(F)$ |
| A | Field | 1.77 | 3.30 | 1.98 | 3.21 | 2.73 | 3.62 | 2.86 | 2.06 | × | × | × | 5.97 |
| | NS diff | 0.38 | 0.18 | 0.37 | 0.19 | 0.26 | 0.33 | 0.39 | 0.20 | × | × | × | 1.84 |
| | | 1.30 | 0.98 | 1.20 | 0.85 | 0.61 | 0.72 | 1.27 | 0.33 | × | × | × | 2.59 |
| B | Field | 1.95 | 4.07 | 2.84 | 4.00 | 3.14 | 4.48 | 3.77 | 2.71 | × | × | × | 5.78 |
| | NS diff | 0.38 | 0.18 | 0.36 | 0.19 | 0.26 | 0.34 | 0.40 | 0.22 | × | × | × | 1.61 |
| | | 1.10 | 0.79 | 1.06 | 0.66 | 0.58 | 0.68 | 1.21 | 0.31 | × | × | × | 2.28 |
| C | Field | 1.78 | 3.33 | 2.02 | 3.27 | 2.79 | 3.66 | 2.83 | 2.11 | × | × | × | 5.98 |
| | NS diff | 0.40 | 0.19 | 0.38 | 0.19 | 0.28 | 0.35 | 0.41 | 0.21 | × | × | × | 1.85 |
| | | 1.30 | 0.98 | 1.21 | 0.89 | 0.63 | 0.74 | 1.29 | 0.33 | × | × | × | 2.59 |
| A-C | EW diff | 0.83 | 0.36 | 0.99 | 0.29 | 0.43 | 0.49 | 0.94 | 0.28 | × | × | × | 0.62 |
| | | 2.10 | 0.78 | 2.52 | 0.55 | 0.96 | 1.10 | 1.64 | 0.44 | × | × | × | 0.75 |
| Magnetic observatories | | 5.70 | 5.32 | 4.43 | 4.81 | 5.55 | 5.14 | 4.44 | 4.79 | 16.82 | 14.01 | 10.53 | 17.61 |
| | | 12.38 | 13.02 | 10.88 | 11.79 | 8.32 | 8.93 | 10.15 | 8.39 | 23.42 | 22.58 | 16.94 | 26.04 |

Table 1-2: Observation Statistics

## 1.5 Criteria

Table 1-3 below summarizes the criteria used to check the validity of the MIO_SHAi2C product:

| Input | Test | Criteria | Pass? |
|---|---|---|---|
| Observations | Residual statistics | Standard deviation of 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 MIO_SHAi2C product is obtained as a comprehensive co-estimation of the core, lithosphere, ionosphere, and magnetosphere field contributions including induced contributions similar to the method described in [Sabaka, GRL, 2016]. The complete model configuration used is given in Table 2-1 below; the MIO_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 (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 mantle + oceans") and infinite conductor at depth.<br><br>Regularisation of:<br><br>1. Mean-square current density J in the E-region within the night-side 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 θ is co-latitude. |

| Model Part | Maximum Degree/Order | Temporal Characteristics | Comment |
|---|---|---|---|
| Magnetosphere, external | 3/1 | One hour bins | |
| Magnetosphere, induced | 3/3 | One 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 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 shows good agreement with alternative models and exhibits very good data residual statistics (Table 1-2).

### 2.2.2 Conclusion

The estimated model is assessed to be of good quality with very good agreement with the general structures of the ionospheric field.