ESL SWARM

Swarm Expert Support Laboratories

Swarm ASM-VFM Residual Task Force: Test Dataset Description

British Geological Survey (BGS)
National Space Institute – DTU Space (DTU)
Delft Institute of Earth Observation and Space Systems (DUT)
Helmholtz Centre Potsdam - German Research Centre for Geosciences (GFZ)
Eidgenössische Technische Hochschule Zürich (ETH)
Institut de Physique du Globe de Paris (IPGP)
The Swedish Institute of Space Physics (IRF)
Laboratoire d'électronique des technologies de l'information (Leti)
University of Calgary (UoC)
Aerospace Research And Test Establishment (VZLU)

with additional contributions from

NASA Goddard Space Flight Center (GSFC)
University of Colorado (CIRES)
Charles University Prague (CUP)

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Record of Changes

Reason	Description	Rev	Date
Initial vers.	Released	1 dA	2014-08-29
Intern review	Corrected document location on the svn in section 1.1	1 dB	2014-09-01
	Removed abbreviations not used in section 2.3.		
	Section 3 renamed.		
	Clarified that the difference in the data set is with respect to the original L1b Mag-L data (not to previously released ASM-VFM investigation data sets) (Section 3.2.2.2).		
	Corrected type of time-stamps from CDFepoch to MATLAB epoch (Section 3.2.2.2)		
	Figures 2, 3, 4, 8 and 9 resized.		
Added datafiles	Added description of Solar illumination data files (Section 3.2.2.2).	1 dC	2014-09-10
	Removed versions and dates of applicable and reference documents (Sections 2.1 and 2.2)		
Clarification	Clarified reference frame for Solar illumination angles (Section 3.2.2.2).	1	2014-09-10
New release of data	Reorganized to accommodate description of new releases of test data sets. Supporting information moved to Annexes.	2dA	2014-10-13
	TDS 3 (new) described in Section 3.2.1		
Internal review	Clarified preservation of pre-flight VFM calibration and stray field correction (Sections 3.1 and 3.2.1.1).	2	2014-10-15
	Moved TDS into separate subdirectories on DTU ftp server.		
	Minor clarifications.		

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1   Introduction

1.1   Scope and applicability

This document describes the L1b data sets produced and released by ESL to the ASM-VFM residual task force group.

This document is available on the SVN, https://smart-svn.spacecenter.dk/svn/smart/SwarmESL-All/L1b_Technical/Reports/SW-TN-DTU-GS-006_ASM_VFM_Task_Force_DS_Delivered.pdf.

2   Applicable and Reference Documentation

2.1   Applicable Documents

The following documents are applicable to the definitions within this document.

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

[AD-2]   SW-RS-DSC-SY-0002, Level 1b Processor Algorithms

[AD-3]   SW-TN-DSC-SY-0005, Level 1b Processor Characterization and Calibration Data Base

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]   PE-TN-ESA-GS-0001, Earth Explorer Ground Segment, File Format Standard

[RD-2]   SW-TN-ESA-GS-0074, Tailoring of the Earth Explorer File Format Standard for the Swarm Ground Segment

[RD-3]   SW-ID-GMV-GS-0006, CDF Data Format Swarm L1B

2.3   Abbreviations

Acronym or abbreviation	Description
ASM	Absolute Scalar Magnetometer
Aux	Auxiliary
BGS	British Geological Survey, GB
CCDB	Characterisation and Calibration DataBase
CIRES	Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, US
CUP	Charles University Prague, CZ
DTU	Technical University of Denmark, DK

Acronym or abbreviation	Description
DUT	Delft University of Technology, NL
ESA	European Space Agency
ESL	Swarm Expert Support Laboratories
ESRIN	European Space Research Institute, Frascati, IT
ESTEC	European Space Research and Technology Centre, Noordwijk, NL
ETH	Eidgenössische Technische Hochschule Zürich, CH
FTP	File Transfer Protocol
GFZ	Helmholtz Centre Potsdam - German Research Centre for Geoscience, DE
GSFC	NASA Goddard Space Flight Center, US
IPGP	Institut de Physique du Globe de Paris, FR
JIRA	Atlassian JIRA internet based tool for tracking issues with server located at DTU https://jira.spacecenter.dk/
L0	Level 0 (satellite data)
L1	Level 1 (satellite data)
L1b	Level 1b (satellite data)
L2	Level 2 (satellite data)
L2PS	Level 2 Processing System, comprising 12 chains, located at six institutes in CH, DE, DK, FR, NL and UK.
MPPF	Mission Planning and Performance Facility
PDGS	Payload Data Ground Segment
PP	Prototype Processor
QWG	Quality Working Group
SCARF	Satellite Constellation Application and Research Facility. Same as L2PS.
SFTP	Secure File Transfer Protocol
STR	Star Tracker
SVN	SVN Repository with server located at DTU. Presently, the following URLs apply: https://smart-svn.spacecenter.dk/svn/smart/SwarmESL-All https://smart-svn.spacecenter.dk/svn/smart/SwarmL2 (heritage from the L2PS Project)

Acronym or abbreviation	*Description*
SVT	Swarm Validation Team
SW	Software
Swarm	Constellation of 3 ESA satellites, http://www.esa.int/esaLP/ESA3QZJE43D_LPswarm_0.html
TBC	To Be Confirmed
TBD	To Be Defined
TDS	Test Data Set
UoC	University of Calgary (CA)
VFM	Vector Field Magnetometer
VZLU	Výzkumný a zkušební letecký ústav, or Aerospace Research And Test Establishment (CZ)

3   Test Data Set for ASM-VFM Residuals Investigation

3.1   Input Data

The input data have been selected from L1b MAGx_LR_1B data version 0301 (same as 0302 since B_NEC is ignored) using CCDB version 0008, and based on the following criteria:

Table 3-1 - Data selection criteria

Flags_F < 32	No gaps in ASM data
Flags_B < 16	No gaps in VFM data
Flags_q < 50	At least two camera heads used for attitude
Flags_Platform < 64	S/C telemetry available for stray field corrections
F > 0	ASM data available

The main difference between the test data sets being released and the original Level 1b data, is the estimation of the VFM calibration parameters. The test data sets use a fixed set of calibration parameters instead of using the daily estimation of the parameters (cf. Annex A). The VFM calibration process applied to the test data set described here consisted in the following steps:

1. Undo the daily calibration estimates by calculating and applying the inverse values – this leaves the pre-flight determined calibration parameter application as well as the stray field correction
2. Apply a constant set of VFM calibration parameters; see Sections 3.2.x.1 for details.

3.2   Output Data

3.2.1   Data Set 3 Produced 2014-10-10

3.2.1.1   *VFM calibration parameters*

These test data sets are produced using only one scaling for each satellite common for the three axes (on top of the pre-flight calibration, cf. above), i.e. $B = s * B_{pre\text{-}flight}$. The values for s are determined using all data (day- and night-side), they are stored in the TDS files, and the values 1/s – the sensitivities – are listed in Table 3-2 below.

Table 3-2 - Fixed set of VFM Parameters, TDS 3

Sat	Sensitivity
A	1.000271182
B	1.000172801
C	1.000194444

3.2.1.2   *Data Files*

The test data sets are available at ftp://ftp.space.dtu.dk/data/magnetic-satellites/Swarm/SCARF/ASM_VFM_Task_Force/TDS-3 and consist of the following files

    SwA_MagCL_131126_140930.mat
    SwB_MagCL_131128_141001.mat
    SwC_MagCL_131204_141001.mat

In addition to these files containing 1 sec data we also provide downsampled versions containing 1 min values:

    SwA_MagCL_131126_140930_1min.mat
    SwB_MagCL_131128_141001_1min.mat
    SwC_MagCL_131204_141001_1min.mat

Each of these files contain the following parameters available from the beginning of the mission (23 November 2013) until the 30th of September/1st of October 2014:

- Magnetic field vector in the VFM frame (B_{VFM}): B(:,3)
- Magnetic field intensity (F_{ASM}): F(:)
- Quaternions (q_NEC_CRF): q(:, 4)
- Position of VFM sensor, ITRF, spherical coordinates
  (radius, co-latitude, longitude): r(:), theta(:), phi(:)
- Timestamp:t(:) as MATLAB Epoch
  Note: to obtain time in MD2000 use t-datenum(2000,1,1);;
- Solar elevation angle - elevation above x-y plane, i.e. positive upwards[1]: elev_Sun(:)
- Solar azimuth angle from x-axis, positive towards left[1]: azim_Sun(:)
- Satellite in Earth's eclipse? (approximate): Eclipse(:)
- VFM scaling parameter: s(1)

Please note that the theta provided in the test data sets is colatitude as opposed to latitude as given in the L1b CDF files.

The next 3 plots present the ASM-VFM Residuals for Swarm A, B, and C.
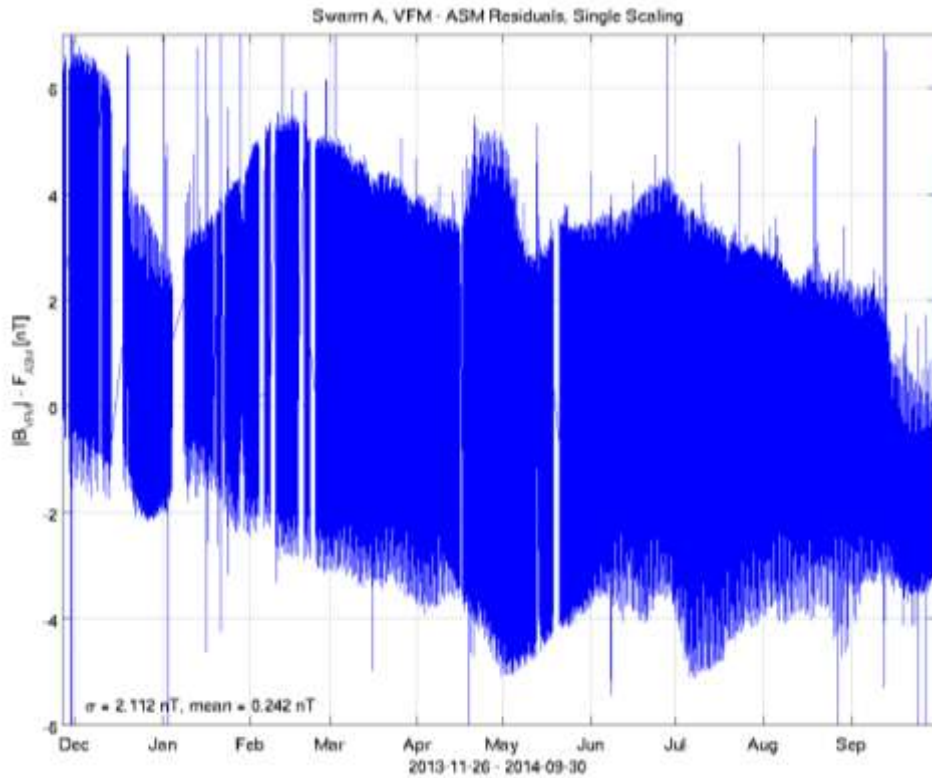
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[1] In nominal flight configuration.

Swarm A, VFM - ASM Residuals, Single Scaling

Figure 3-1 Swarm A Residuals, TDS 3

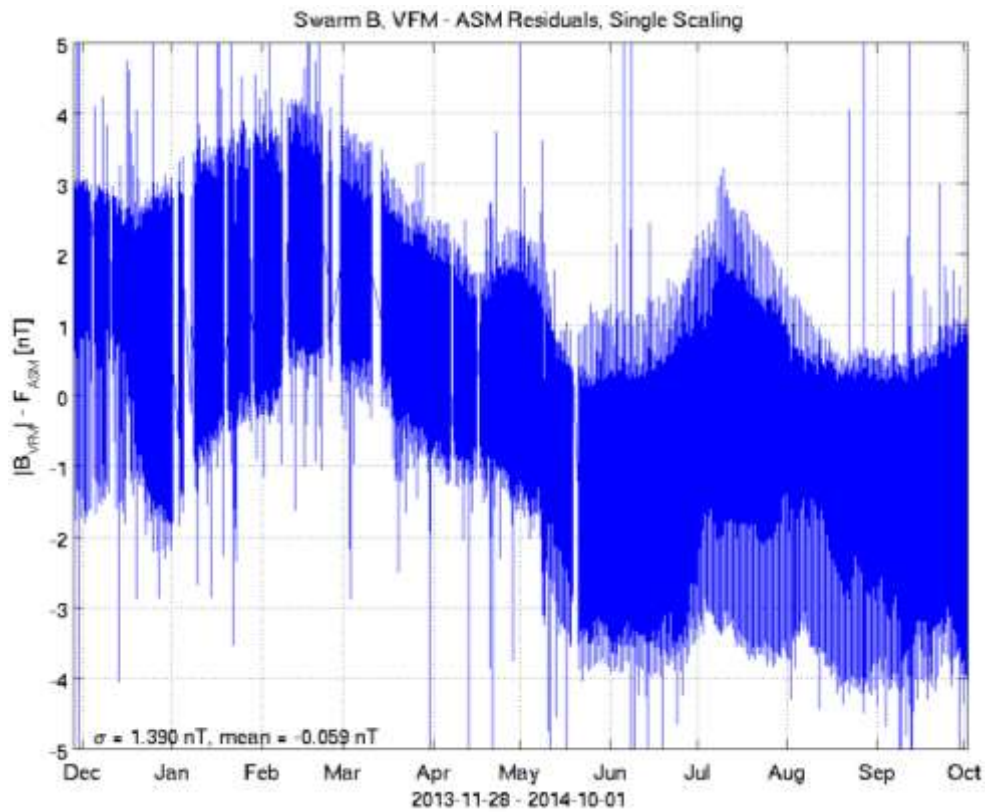Swarm B, VFM - ASM Residuals, Single Scaling

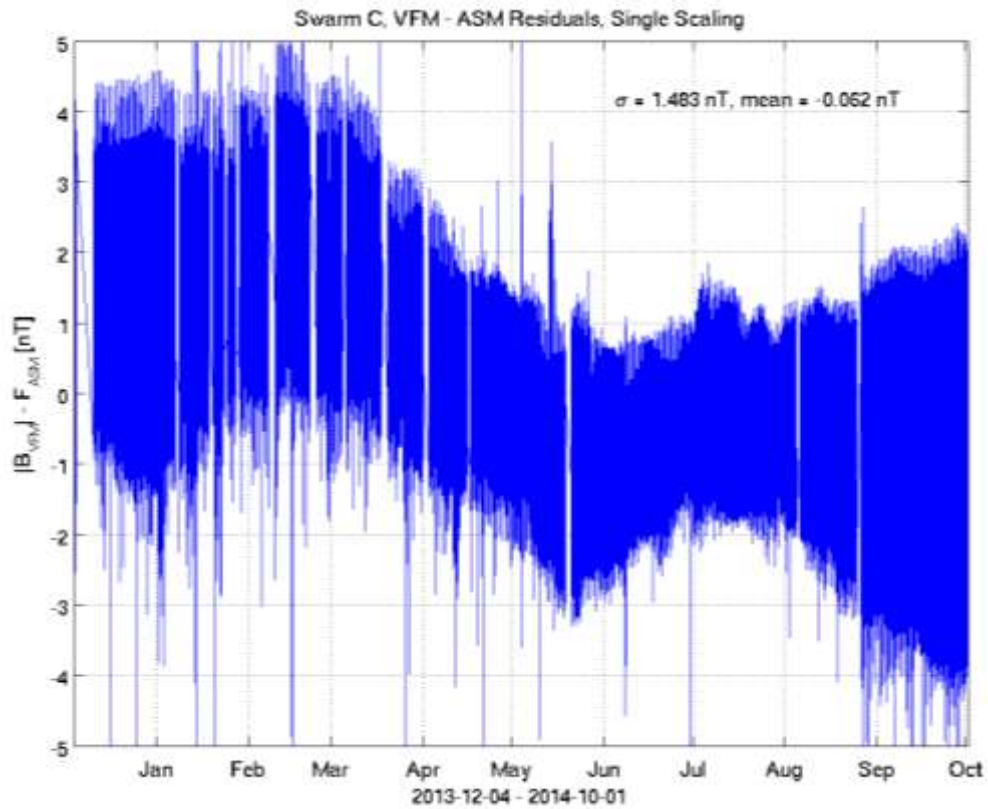**Figure 3-2 Swarm B Residuals, TDS 3**

Figure 3-3 Swarm C Residuals, TDS 3

3.2.2   Data Set 2 Produced 2014-08-28

3.2.2.1   *VFM calibration parameters*

These test data sets are produced using VFM parameters estimated from data with the Sun at least 23.5 degrees below the orbit-horizon, yielding the following sets of 6 parameters (the non-orthogonalities are the preflight same as for the L1b official data) for each satellite which has been applied in step 2 to calibrate the data:

Table 3-3 - Fixed set of VFM Parameters, TDS 2

Sat	Param	x	y	z
A	bias	1.2055	-3.0231	0.8768
	scale	1.00031278	1.00025234	1.00021227
B	bias	0.2369	-3.5129	1.3158
	scale	1.00015709	1.00015651	1.00021198
C	bias	0.7346	-0.2541	1.7123
	scale	1.00018291	1.00022022	1.00024723

3.2.2.2 *Data Files*

The data sets produced for the ASM-VFM task force are available at ftp://ftp.space.dtu.dk/data/magnetic-satellites/Swarm/SCARF/ASM_VFM_Task_Force/TDS-2 and consist of the following files

> SwA_MagCL_131126_140815.mat
> SwB_MagCL_131126_140815.mat
> SwC_MagCL_131126_140815.mat

In addition to these files containing 1 sec data we also provide downsampled versions containing 1 min values (i.e. every 60th data point):

> SwA_MagCL_131126_140815_1min.mat
> SwB_MagCL_131126_140815_1min.mat
> SwC_MagCL_131126_140815_1min.mat

Each of these files contain the following parameters from the beginning of the mission (23 November 2013) until the 15th of August 2014:

- Magnetic field vector in the VFM frame (B_{VFM}): B(:,3)
- Magnetic field intensity (F_{ASM}): F(:)
- Quaternions (q_NEC_CRF): q(:, 4)
- Position of VFM sensor, ITRF, spherical coordinates
  (radius, co-latitude, longitude): r(:), theta(:), phi(:)
- Timestamp:t(:) as MATLAB Epoch
  Note: to obtain time in MD2000 use t-datenum(2000,1,1);;

Please note that the theta provided in the new data sets is colatitude as opposed to latitude as given in the L1b CDF files.

The new B_{VFM} provided is calculated from magnetic field vector in the L1b files by applying a fixed set of VFM calibration parameters as described in Section 3.2.

In addition to the files listed above, files containing Solar illumination information in a frame fixed to the spacecraft with x-axis in the nominal forward direction and z-axis pointing upwards are available in the same ftp server directory. The filenames are:

> SwA_MagCL_Sun_131126_140815.mat   SwA_MagCL_Sun_131126_140815_1min.mat
> SwB_MagCL_Sun_131126_140815.mat   SwB_MagCL_Sun_131126_140815_1min.mat
> SwC_MagCL_Sun_131126_140815.mat   SwC_MagCL_Sun_131126_140815_1min.mat

Each of these files contain the following parameters at the same time-instants as the corresponding data files:

- Solar elevation angle - elevation above x-y plane, i.e. positive upwards: elev_Sun(:)
- Solar azimuth angle from x-axis, positive towards left: azim_Sun(:)
- Earth eclipse indication (approximate): Eclipse(:)

The next 3 plots present the ASM-VFM Residuals (F_{ASM} -$|\mathbf{B}_{VFM}|$) for Swarm A, B and C, for deep eclipse (green) and non- or low-eclipse (red). Only deep eclipse data have been used for obtaining the 9 calibration parameters listed in Table 3-3 (Section 3.2.2.1).
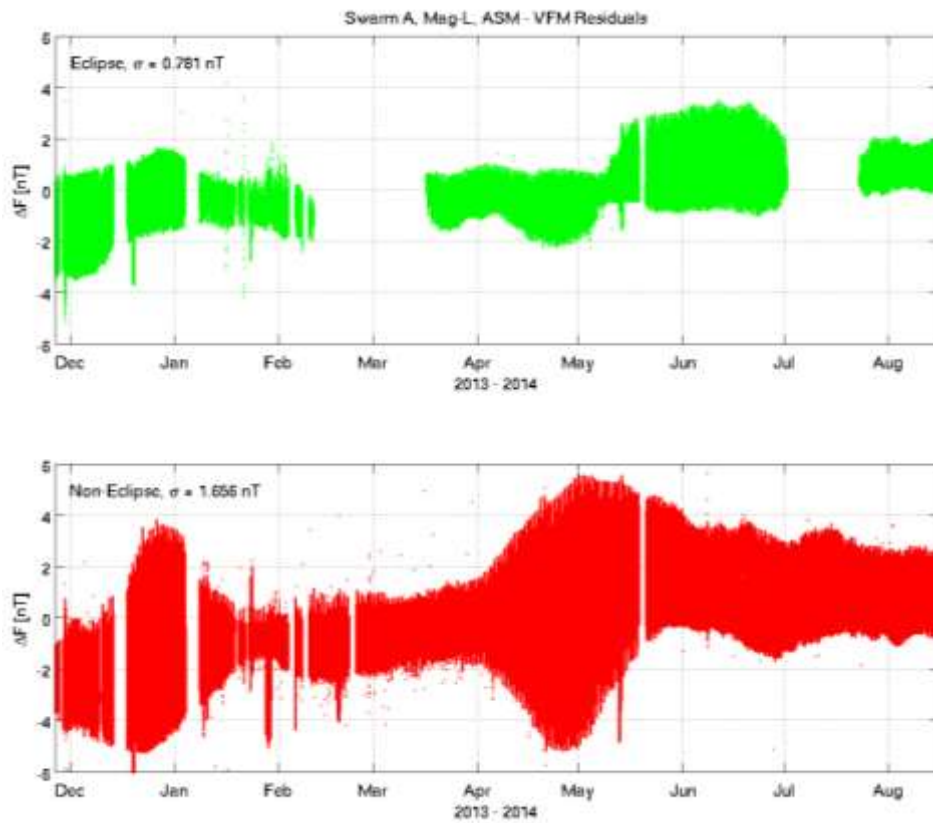
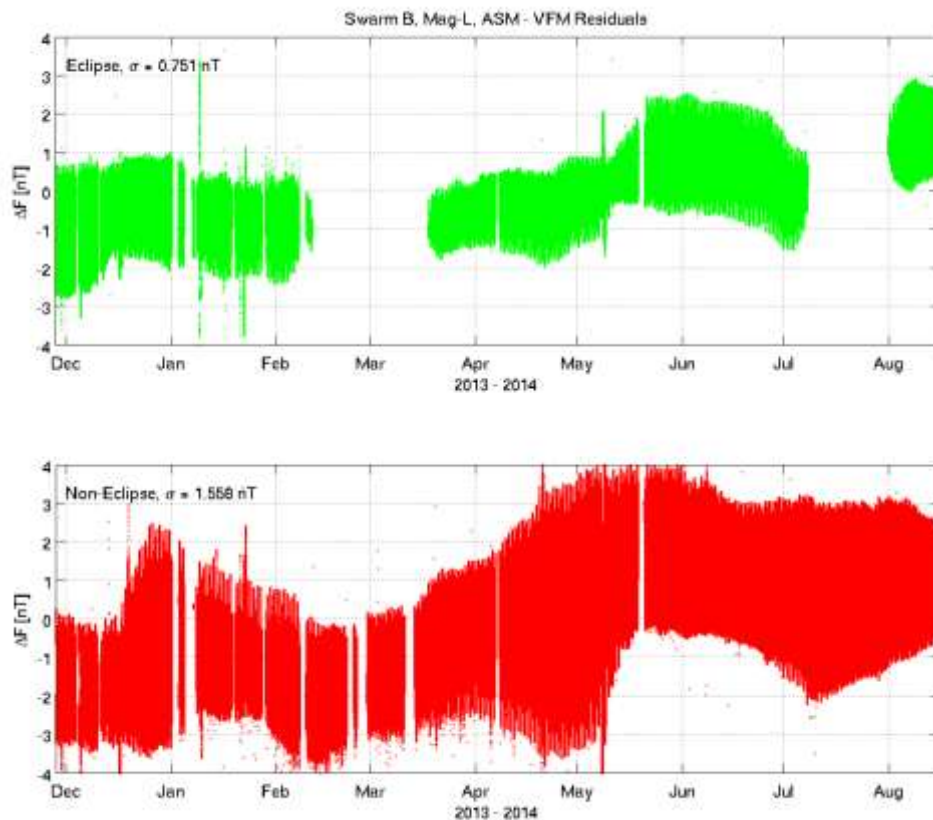**Figure 3-4 Swarm A Residuals, TDS 2**
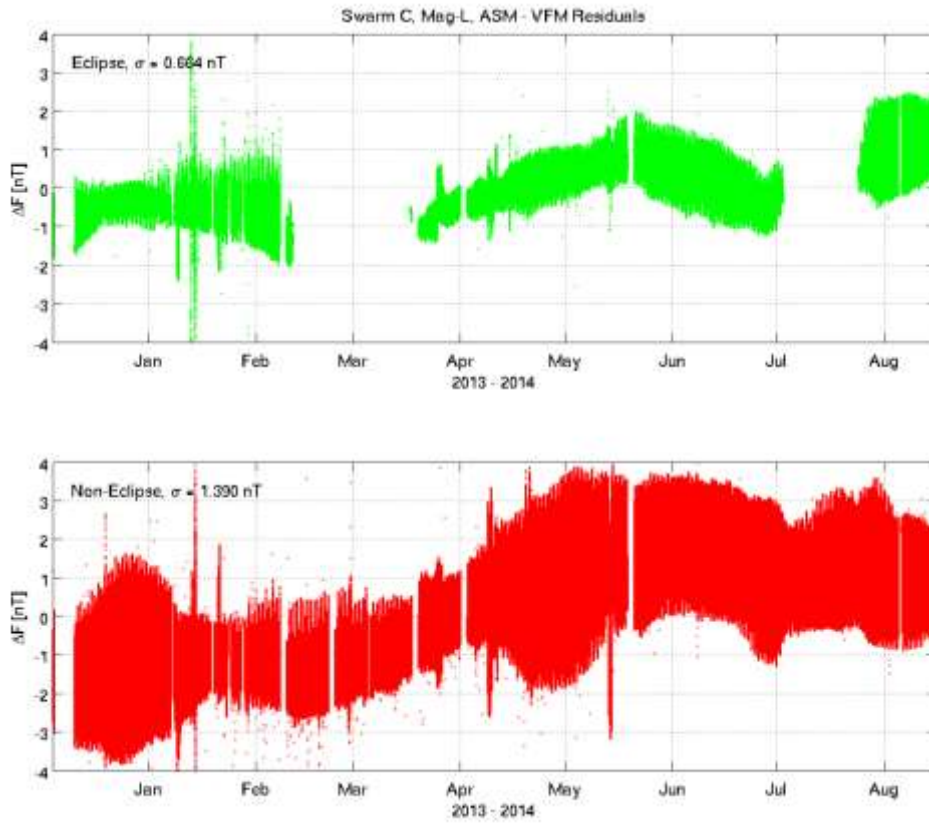

Figure 3-5 Swarm B Residuals, TDS 2

Figure 3-6 Swarm C Residuals, TDS 2

A   VFM TCF Parameter Evolution

The evolution of the parameters that have been estimated in the operational L1b processor and applied for calibrating B_VFM in the L1b files version 0301 (and 0302) can be found in the plots below. Please recall, for the ASM-VFM test data set these parameters have been replaced by fixed parameters as described in Section 3.2.

These parameters are estimated daily (using the data from the full day) with the constraint not to deviate significantly from the parameters of the previous day. They are usually referred to as "VFM Temporal Calibration File" (VFM TCF).

The VFM TCF plot evolution shown below (for Swarm A, B and C), since mid May, illustrate that the Swarm data impose a clear trend in the biases (though, still below 0.35 nT). Furthermore, the somewhat expected decrease in the residuals (in the "rms") in the second dawn-dusk orbit phase in June/July seems to be absent or even resulted in an increase in the rms. Please recall, in the second dawn-dusk orbit phase, the Swarm satellites were facing with the opposite side towards the Sun compared to the first dawn-dusk phase - this seems to make a significant difference.
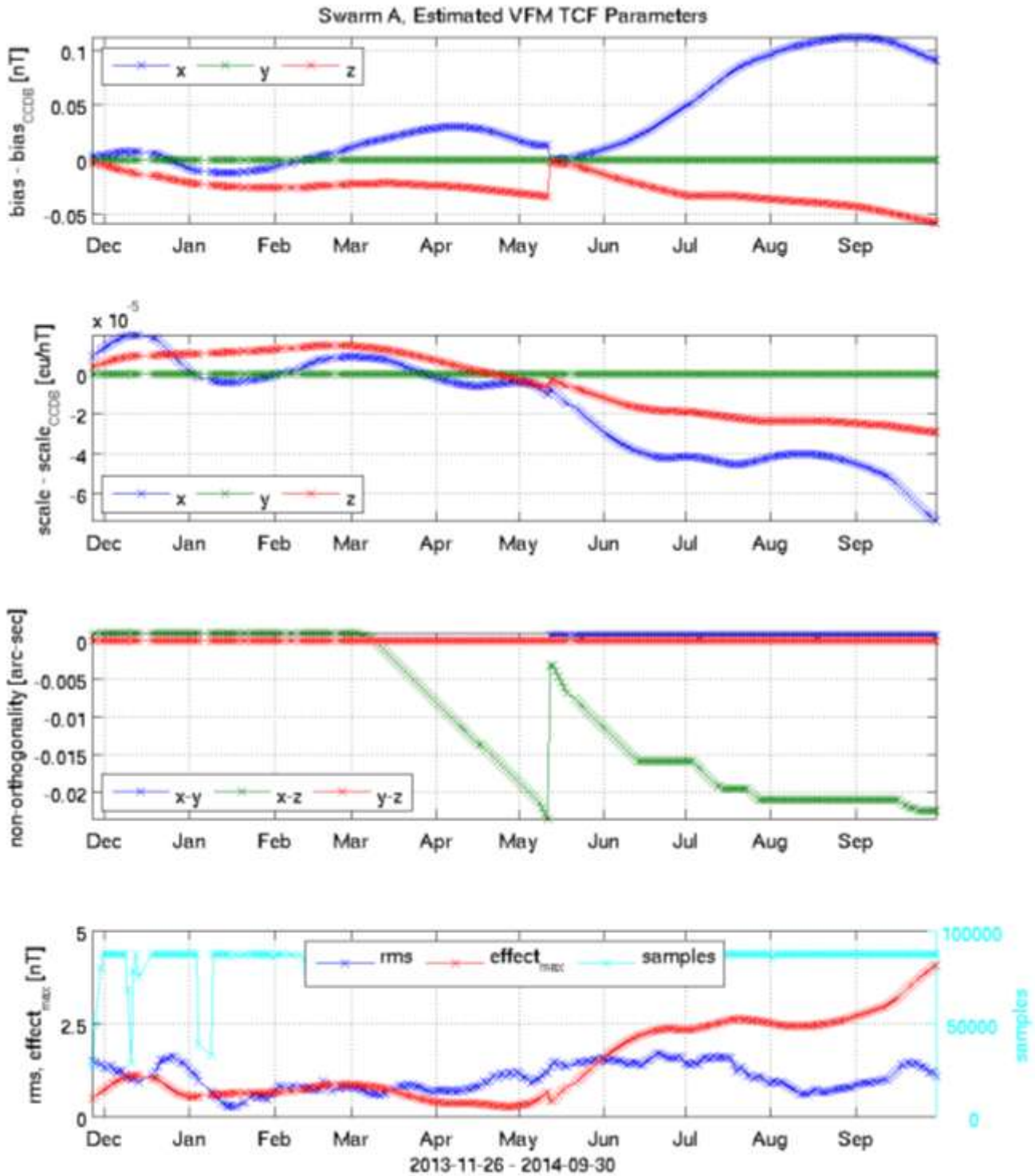
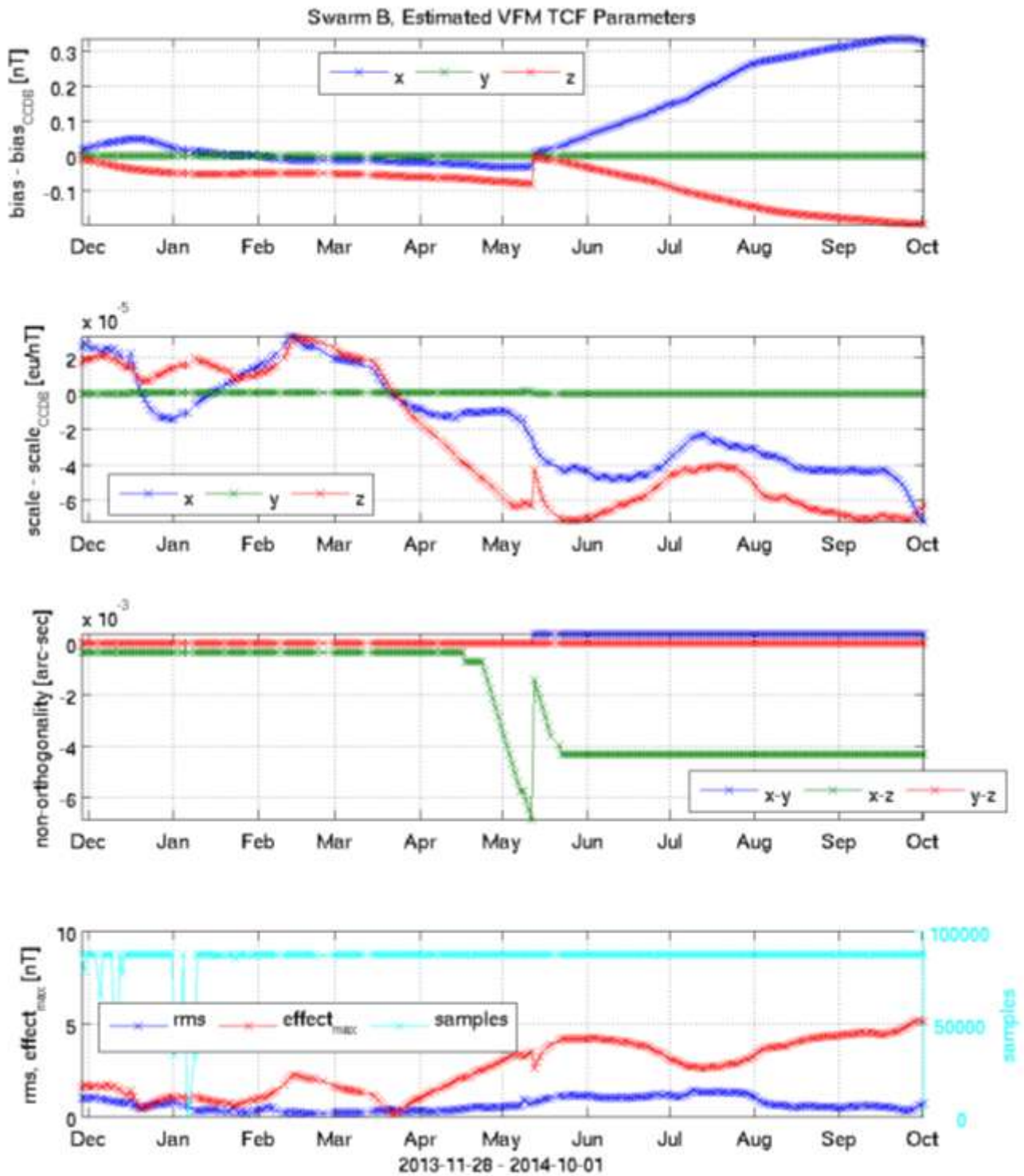**Figure A. A-1 Swarm A, Estimated VFM TCF Parameters**
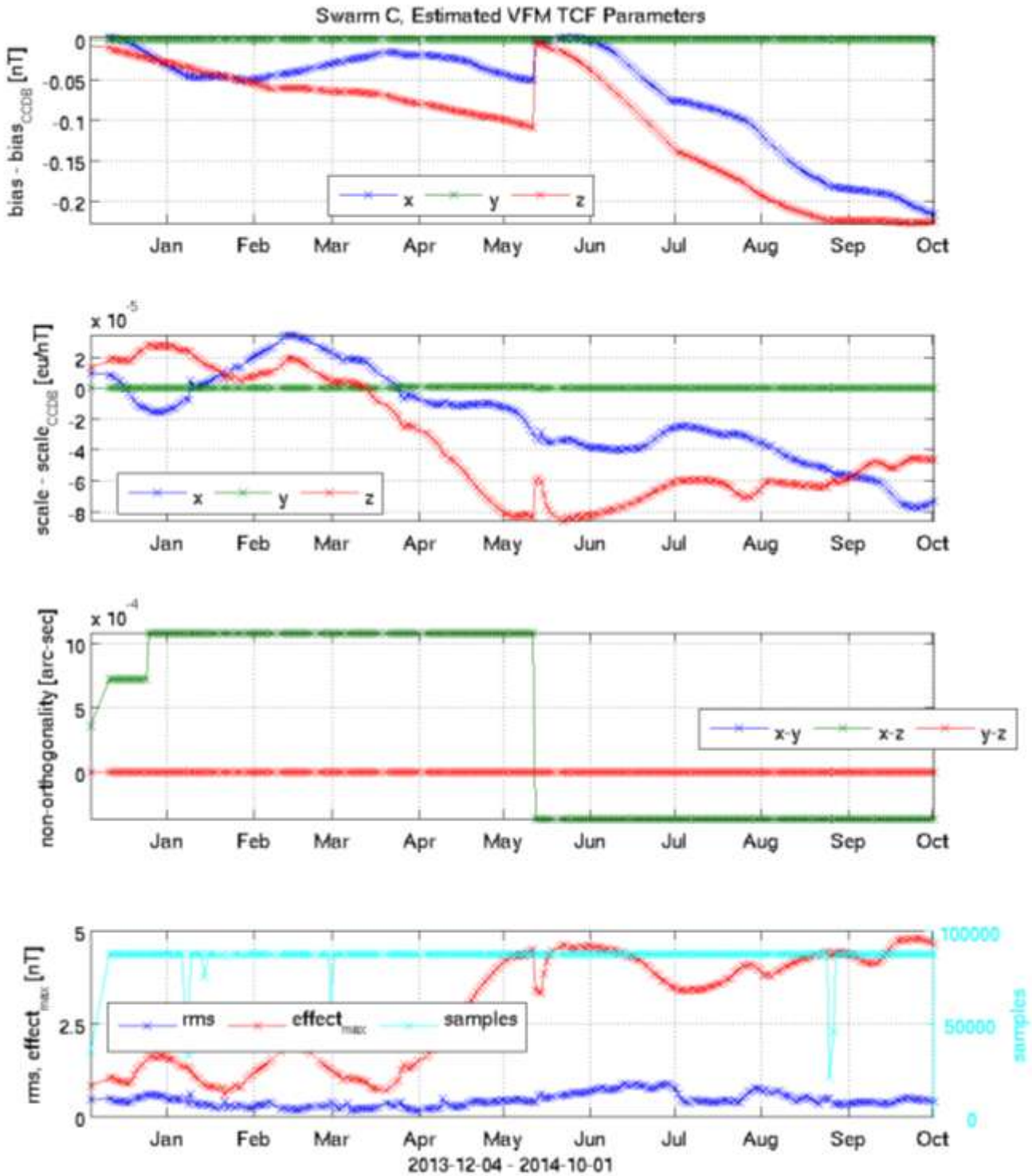
Figure A. A-2 Swarm B, Estimated VFM TCF Parameters

Figure A. A-3 Swarm C, Estimated VFM TCF Parameters

B Comparison between the TDS B$_{VFM}$ and Original L1b B$_{VFM}$

Using Swarm C as an illustration of the comparison between the new magnetic field vector and the official L1b magnetic field vector, we can see that the difference is very small and not visible when we first plot one day of data points.
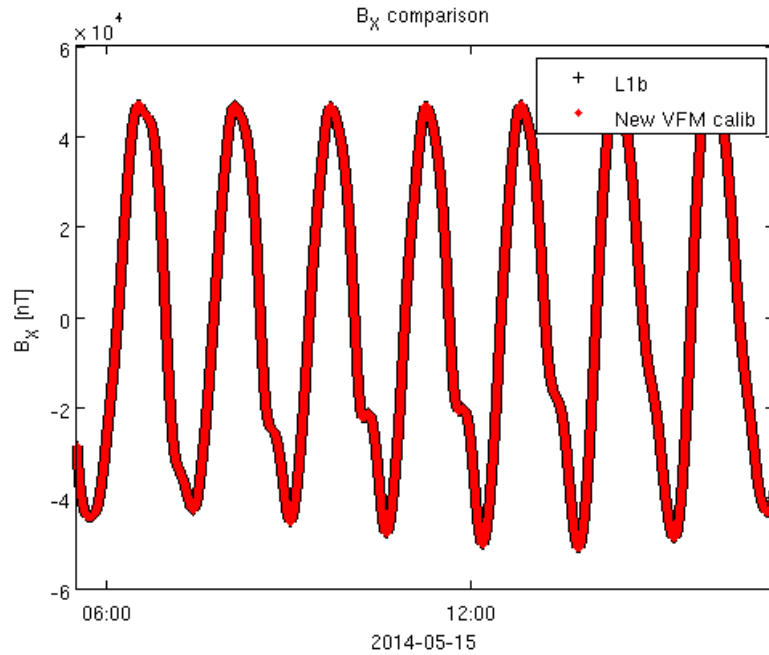

Figure A. B-1 Swarm C, Bx comparison

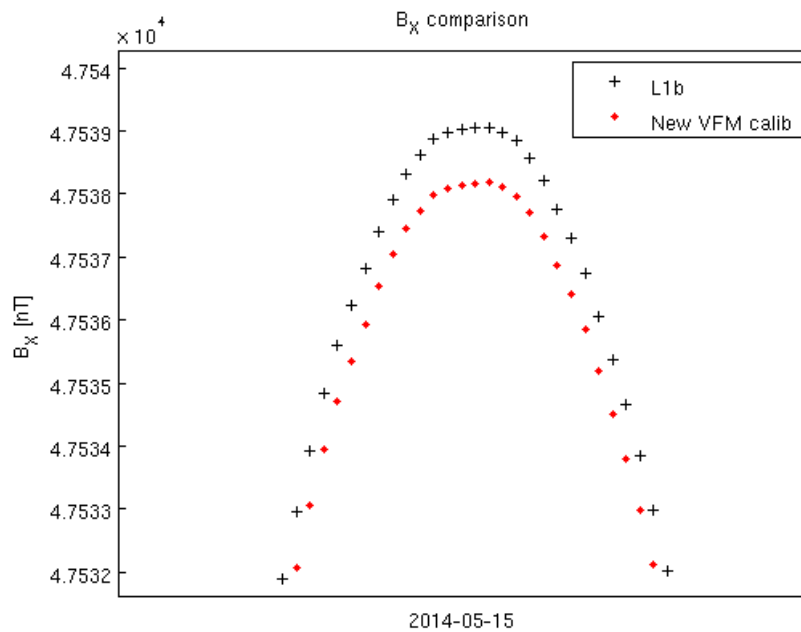By zooming into the plots, we find difference of the order of a few nT.

Figure A. B-2 Bx comparison zoom

C Mag-C Calibration Data

The test data sets produced in May 2014 for the ASM-VFM residual investigations were based on the Mag-C calibration data in which the ASM instrument filter has been accounted for by filtering the scalar response of the 50 Hz VFM measurements (plus additional schemes to account for e.g. stray fields). In this respect, these data sets were only suited for this specific analysis whereas comparisons with other Swarm data and estimations of main field models were not straightforward.

In order to expand the potential analyses the new data sets described above were generated based on the 1 Hz, official L1b Mag-L products. As for previous test data sets, the daily set of parameters for the VFM is replaced by a fixed set of coefficients. The only foreseen deficiency of such a data set is the handling of the ASM filter effect, which is accounted for by a static time-shift. However, the analysis presented in the plot below, showing the difference between applying a filter and time-shifting the scalar VFM responses, suggests this effect is at or below the VFM instrument noise level (around 30 pT).
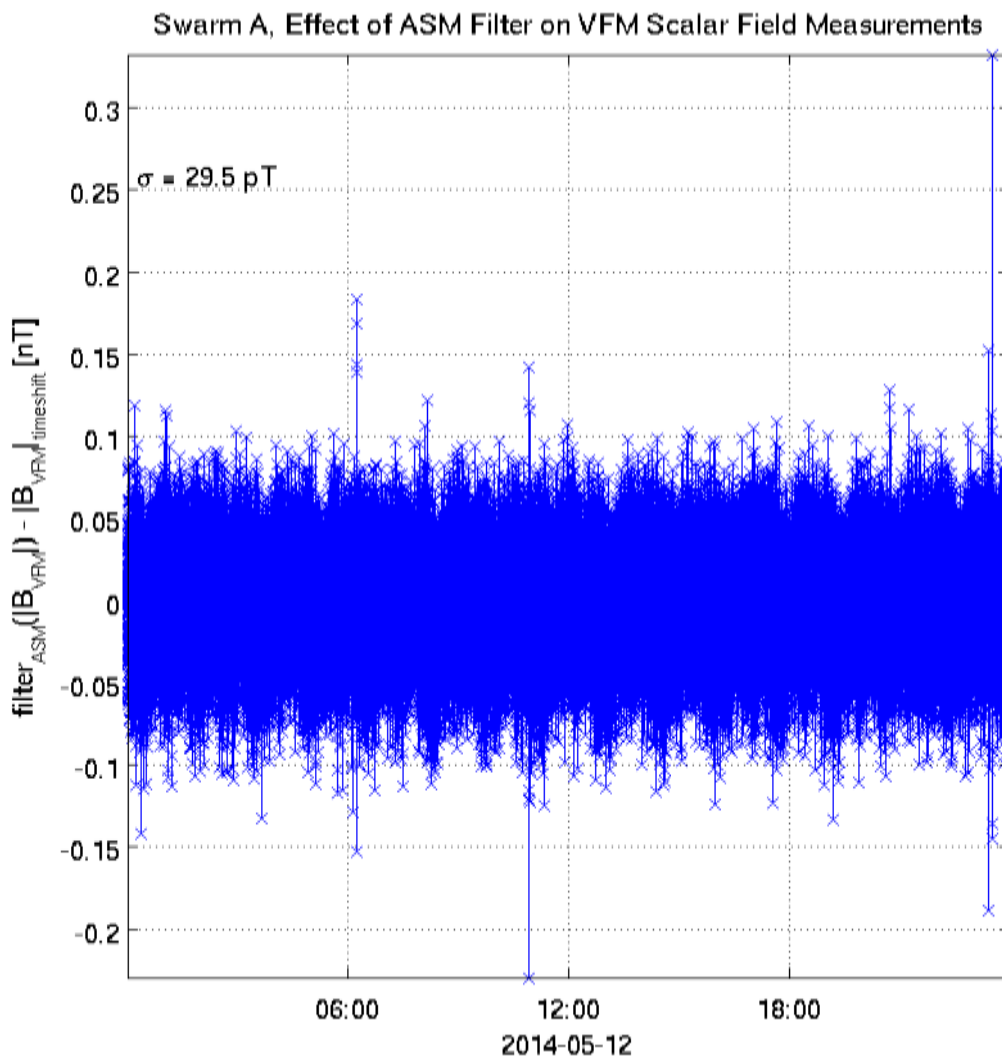

Figure A. C-1 ASM Filter effect on the VFM Scalar Field Measurements