Swarm Expert Support Laboratories

Swarm Corrected Mag-L Preliminary Data Release Notes

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)

Doc. no: SW-RN-DTU-GS-002, Rev: 1, 2015-03-19

Prepared:		Approved:	
Lars Tøffner-Clausen	Date 2015-03-19	Poul Erik Holmdahl Olsen	Date 2015-03-19
ESL System Manager		ESL Project Manager	

Record of Changes

Reason	Description	Rev	Date
Initial vers.	Released	1dA	2015-03-17
Review	Added various clarifications in Sections 3 and 5.	1dB	2015-03-18
	Added validation of scalar mapping methodology, Figure 3-1 in Section 3.1.1		
Finalized	Added results for Swarm Charlie, Figure 5-3 in Section 5.	1	2015-03-19
	Added Table 5-1 of VFM calibration parameters.		
	Removed reference to previous data set version (Table 4-1).		

Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Purpose and Scope

The purpose of this document is to provide notes on the release of preliminary corrected Swarm magnetic vector field measurement data.

2 Applicable and Reference Documentation

2.1 Applicable Documents

[AD-1] SW-RS-DSC-SY-0002, Swarm L1b Processor Algorithms

[AD-2] SW-TN-DSC-SY-0005, Swarm L1b Processor CCDB

[AD-3] SW-RS-DSC-SY-0007, Swarm Level 1b Product Definition

2.2 Reference Documents

[RD-1] The Swarm Initial Field Model for the 2014 geomagnetic field, Olsen et.al., Geophysical Research Letters, 2015.

[RD-2] The CHAOS-4 geomagnetic field model, Olsen et.al., Geophysical Journal International, Vol. 197, No. 2, 2014, p. 815-827.

2.3 Abbreviations

Acronym ***or abbreviation***	***Description***
ASM	Absolute Scalar Magnetometer
BGS	British Geological Survey, GB
CCDB	Characterisation and Calibration Data Base
CIRES	Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, US
CUP	Charles University Prague, CZ
DTU	Technical University of Denmark, DK
DUT	Delft University of Technology, NL
ESA	European Space Agency
ESL	Swarm Expert Support Laboratories
ETH	Eidgenössische Technische Hochschule Zürich, CH
GFZ	Helmholtz Centre Potsdam – German Research Centre for Geoscience, DE
GSFC	NASA Goddard Space Flight Center, US

Acronym ***or abbreviation***	***Description***
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)
PDGS	Payload Data Ground Segment
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)
STR	Star Tracker
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
VFM	Vector Field Magnetometer
UoC	University of Calgary, CA
VZLU	Výzkumný a zkušební letecký ústav, or Aerospace Research And Test Establishment, CZ

3 Corrected Level 1b Mag-L Data Overview

This release note describes the preliminary Swarm Level 1b corrected Mag-L magnetic data product.

Early in the Swarm Mission it was recognized that the vector measurements on-board the Swarm spacecrafts suffered from an unexpected magnetic disturbance of varying strength and direction. The disturbance has been modelled as described in Section 3.1, and this model has then been used to produce the corrected Mag-L data as described in Section 3.2.

3.1 Magnetic Vector Disturbance Model

The magnetic disturbances of the Swarm vector measurements are highly correlated with the Sun incident angle w.r.t. the spacecraft. Vincent Lesur of GFZ in Potsdam, Germany, proposed to model the vector disturbance using a general spherical harmonic model in the Sun incident angles, and this model has proven to provide very satisfactory results (see Section 5).

The magnetic vector disturbance is denoted $\mathbf{dB}_{\mathrm{Sun}}$ and is modelled as:

$$\mathbf{dB}_{\mathrm{Sun}} = \sum_{n=1}^{N}\sum_{m=0}^{n}\left(\vec{g}_n^{\,m}\cos m\alpha + \vec{h}_n^{\,m}\sin m\alpha\right)P_n^m(\cos\beta) \qquad \text{(Eq. 1)}$$

where α and β are the Sun incident angles w.r.t to the spacecraft: β is the angle w.r.t. the $-\mathbf{y}_{S/C}$ axis, α is the angle from the $+\mathbf{x}_{S/C}$ axis in the $(\mathbf{x}_{S/C},\mathbf{z}_{S/C})$ plane. In the actual model, *N* is set to 25.

The parameters of (Eq. 1), $\vec{g}_n^{\,m}$ and $\vec{h}_n^{\,m}$, are estimated using an iteratively re-weighted least-squares fit of the calibrated and corrected scalar field measurements of the ASM and VFM* instruments. The full model is however over-determined hence the degrees of freedom in the estimation is reduced to ~600. Individual parameters are estimated for each satellite as the disturbances are not identical across the spacecrafts. Best results are obtained by co-estimation of small corrections to the VFM pre-flight calibration parameters, cf. Section 6.3.4 of [AD-1].

3.1.1 Lack of ASM Data on Swarm Charlie

The ASM instrument on Swarm C(harlie) stopped providing data on 5th November 2014. Magnetic scalar reference measurements for the disturbance model characterisation and VFM calibration described above have successfully been generated using the ASM measurements on Swarm Alpha using a magnetic mapping:

$$F_{A\rightarrow C\,\mathrm{map}} = F_A(t_A) - F_{\mathrm{model}}(t_A, \mathbf{r}_A) + F_{\mathrm{model}}(t_C, \mathbf{r}_C) \qquad \text{(Eq. 2)}$$

where $F_A(t_A)$ are the ASM measurements on Swarm Alpha; t_A, $\mathbf{r}_A$, t_C, and $\mathbf{r}_C$ are times and positions of Swarm Alpha and Charlie respectively chosen such that $|t_A - t_C| < 50$ seconds and $\mathbf{r}_A$ and $\mathbf{r}_C$ are at the same geographical latitude. F_{model} is a main field model of the Earth's core (SIFM+, cf. [RD-1]) and crust (CHAOS4b, cf. [RD-2]) up to degree and order 85 for the static part and degree and order 13 for the secular variation. A validation of this method is demonstrated in Figure 3-1 below, showing the difference between $F_{A\rightarrow C\,\mathrm{map}}$ and

* The *scalar*field of the VFM is the modulus of the VFM vector measurement.

F_C, the scalar field measurements of the ASM on Swarm Charlie ('$F_{ASM,C}$' in the figure). The overall rms of the differences is 835 pT.

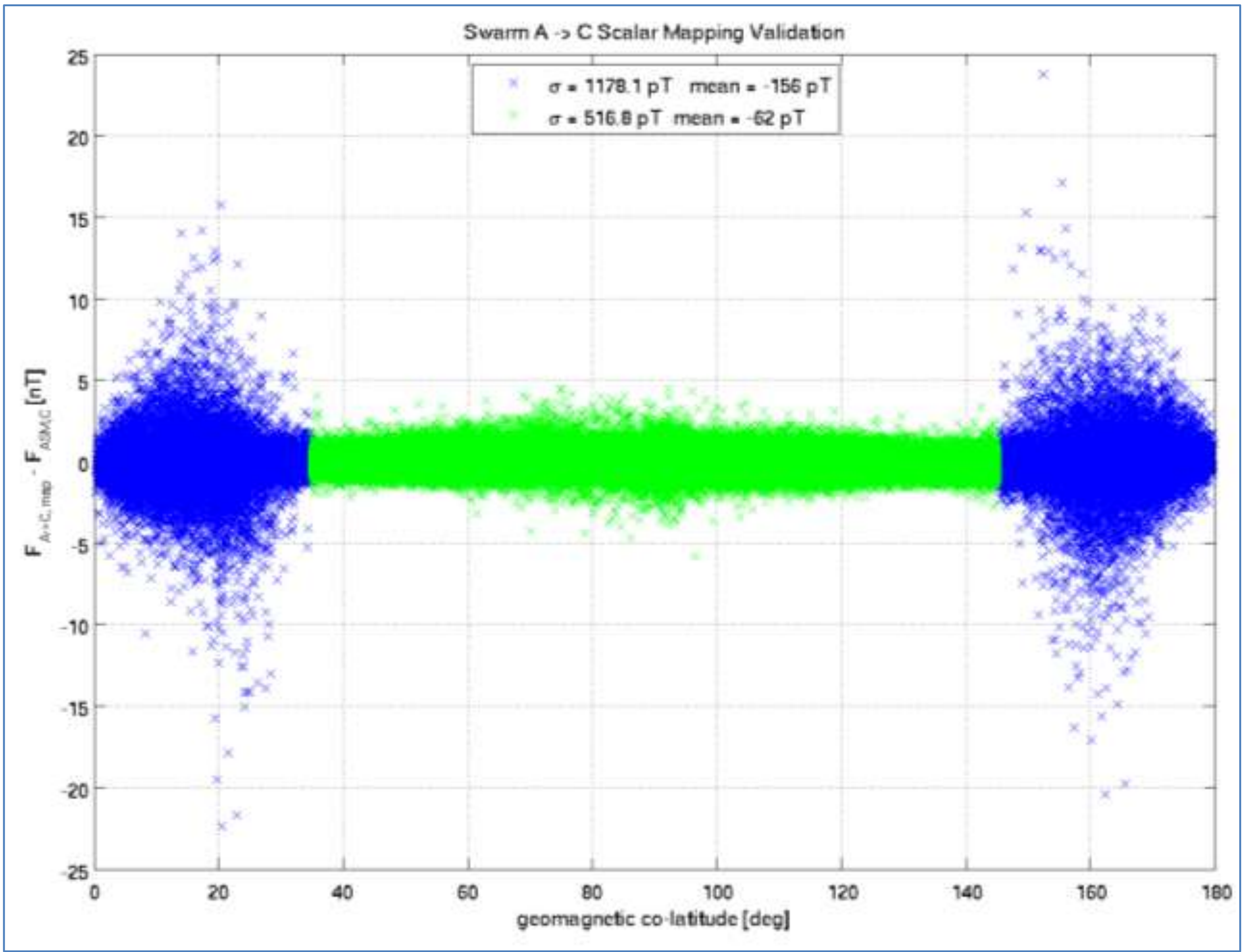

Figure 3-1 Difference of $F_{A \rightarrow C\ map}$ and F_C

3.2 Magnetic Vector Data Processing

The corrected magnetic vector data are based on the official Level 1b Mag-L products, MAGx_LR_1B, from the operational Level 1b Processor. The calibration parameters for the vector measurements estimated on a daily basis (denoted VFM TCF) are replaced by the co-estimated correction parameters (see Section 3.1), and the magnetic vector disturbance, $\mathbf{dB}_{Sun}$, is applied. The complete list of Mag-L product elements updated in this data set is given in Table 3-1.

Table 3-1 Updated Level 1b Mag-L Elements

Element	Change
B_VFM	Daily calibration (VFM TCF parameters) replaced by the co-estimated calibration parameters, and then corrected for $\mathbf{dB}_{Sun}$
B_NEC	As for B_VFM

Element	Change
Flags_B	Bit 3 (value 8) updated: indicates discrepancy between calibrated and corrected ASM and VFM measurements
Flags_F	Bit 4 (value 16) updated: indicates discrepancy between calibrated and corrected ASM and VFM measurements
dB_Sun	Added element containing $\mathbf{dB}_{Sun}$, VFM frame

4 Dataset Release Notes

The released versions of the corrected Mag-L Level 1b datasets are listed in Table 4-1 below. The main difference between the datasets is the time span of the data used for the estimation of the calibration and characterisation parameters.

Table 4-1 Corrected Mag-L Dataset Versions

Dataset version	Time span used for estimation	IDs		
		A	B	C
0403	2013-11-26 – 2015-02-28	1502c	1502f	1502d

5 Results

5.1 Effect of Correction

The effect of the correction for dataset 0403 is shown in Figure 5-1, Figure 5-2 and Figure 5-3 below. The plots show the difference in scalar measurements from the ASM and VFM instruments; in blue the difference without the correction for $\mathbf{dB}_{Sun}$, in green with the correction applied. The occasional spikes still present in the corrected data correspond to periods of specific satellite manoeuvres; the model described here is not able to fully correct data from such periods. Investigations into the data from periods of such manoeuvres are ongoing.

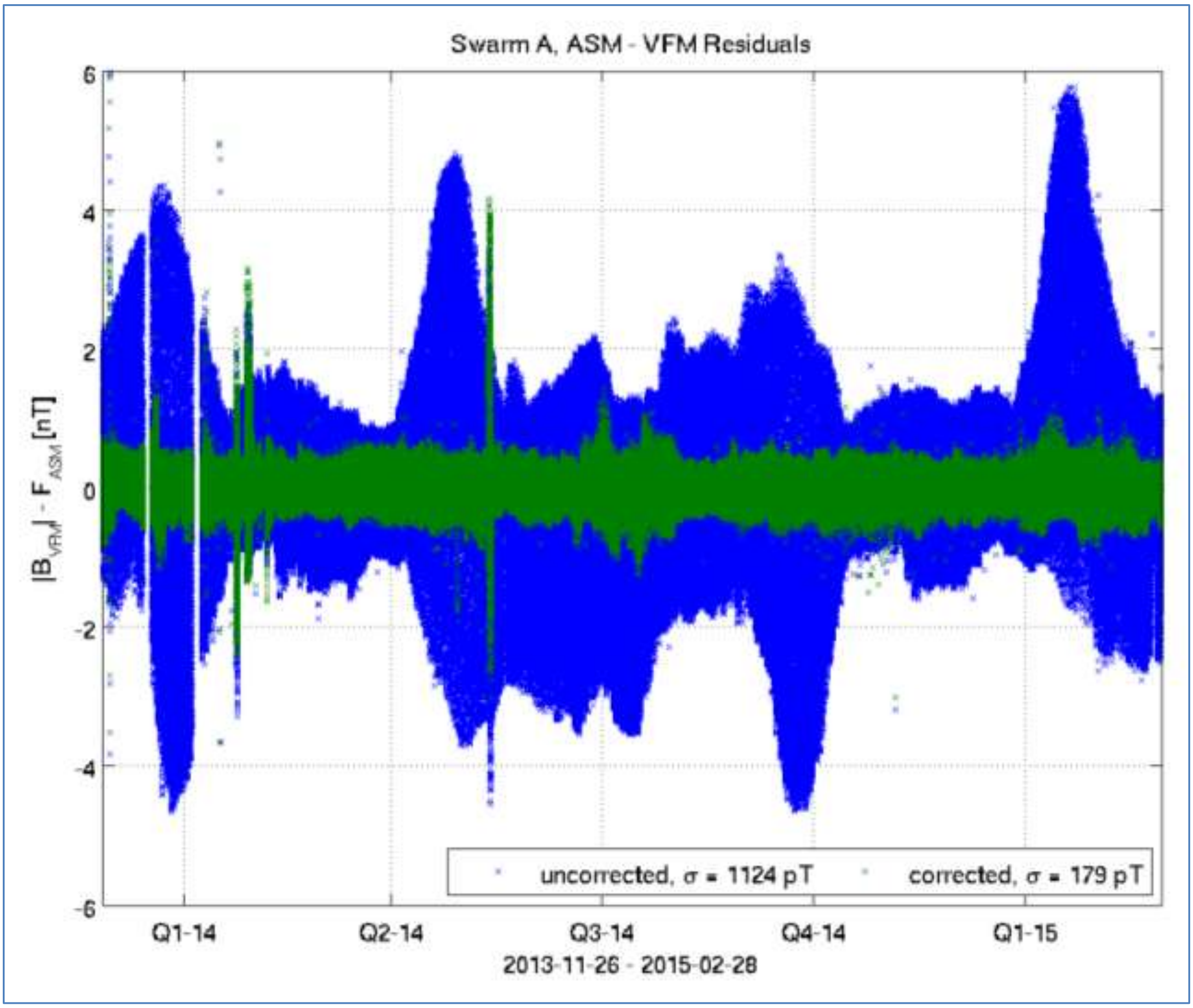

Figure 5-1 Swarm Alpha Scalar Residuals

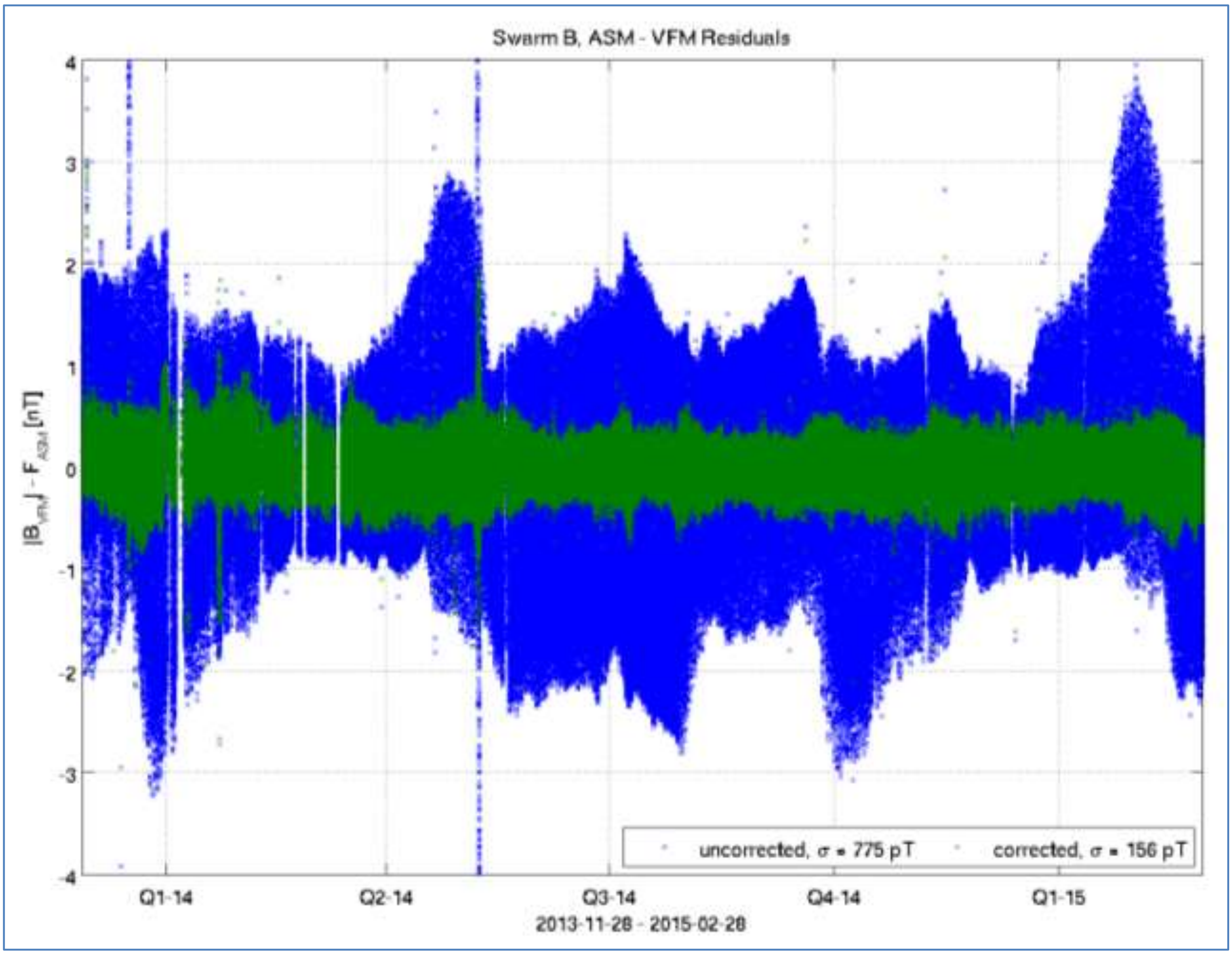

Figure 5-2 Swarm Bravo Scalar Residuals

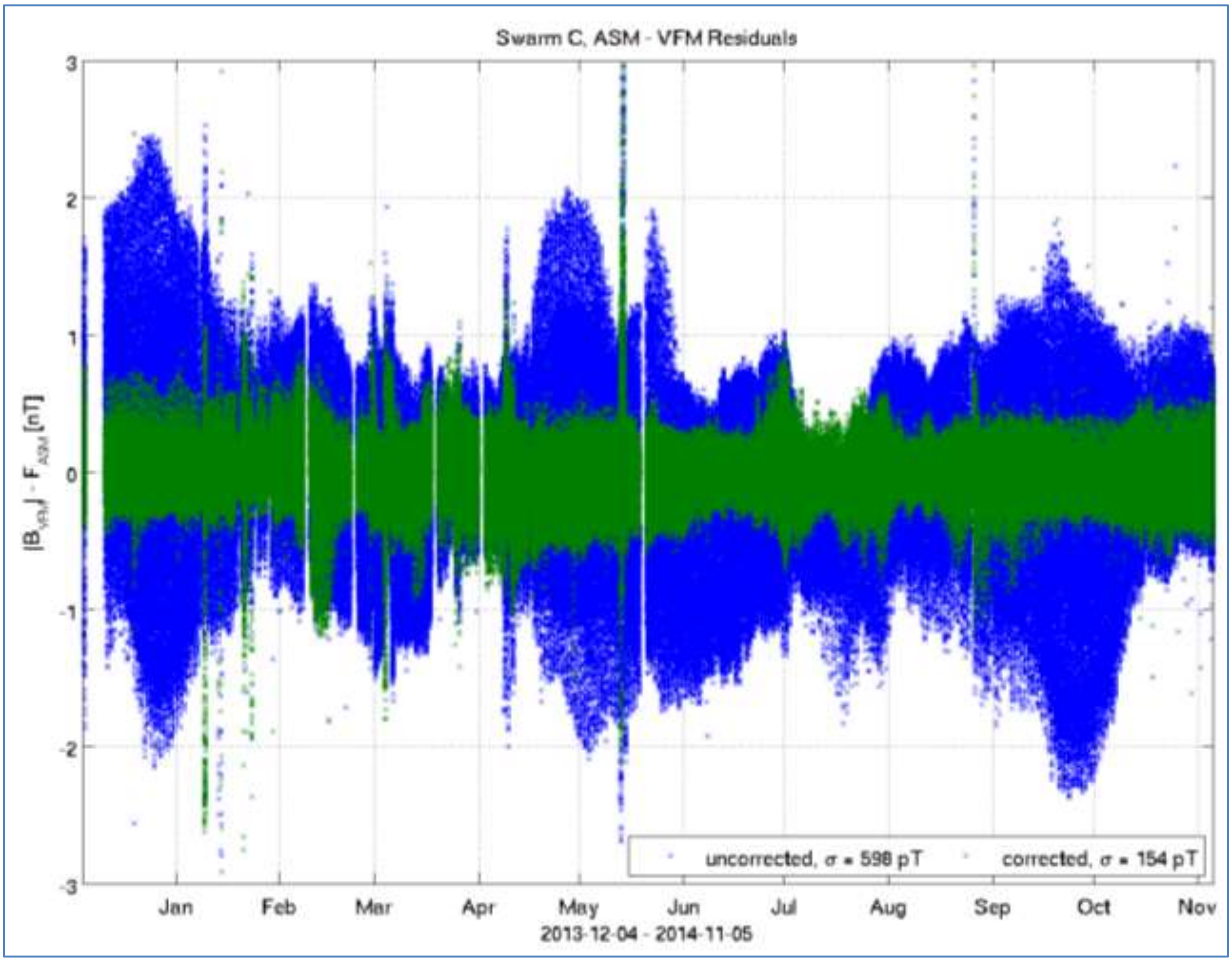

Figure 5-3 Swarm Charlie Scalar Residuals

5.2 VFM Calibration Parameters

The co-estimated adjustments of the VFM calibration parameters together with their pre-flight values are listed in Table 5-1 below.

Table 5-1 VFM Calibration Parameters

Sat	Sensitivity/sensor temperature, $s_{T,sensor}$ [10^{-6}/nT °C]		Sensitivity/electronics temperature, $s_{T,elec}$ [10^{-6}/nT °C]		Non-orthogionalities [arc-seconds]	
	Pre-flight	Adjustment	Pre-flight	Adjustment	Pre-flight	Adjustment
A	28.5 28.8 28.3	0.651 0.019† 1.003	-5.899 -3.854 -2.037	0.735 0† -0.173	102.386 217.403 -179.318	-0.948 -3.983 -0.265
B	28.3 29.0 28.8	1.094 0.022† 1.668	-4.598 -4.934 -5.440	0.885 0† 0.797	350.880 62.432 -147.060	-1.111 -2.550 -1.888
C	27.7 29.1 28.4	1.483 0.006† 1.112	-4.112 -3.994 -6.731	0.722 0† 1.247	139.140 -248.890 -109.960	0.179 1.059 1.451

† It is difficult to estimate Swarm VFM parameters related to the y-axis, hence they are inhibited in the estimation