Latest Investigations into dB_Sun Disturbance

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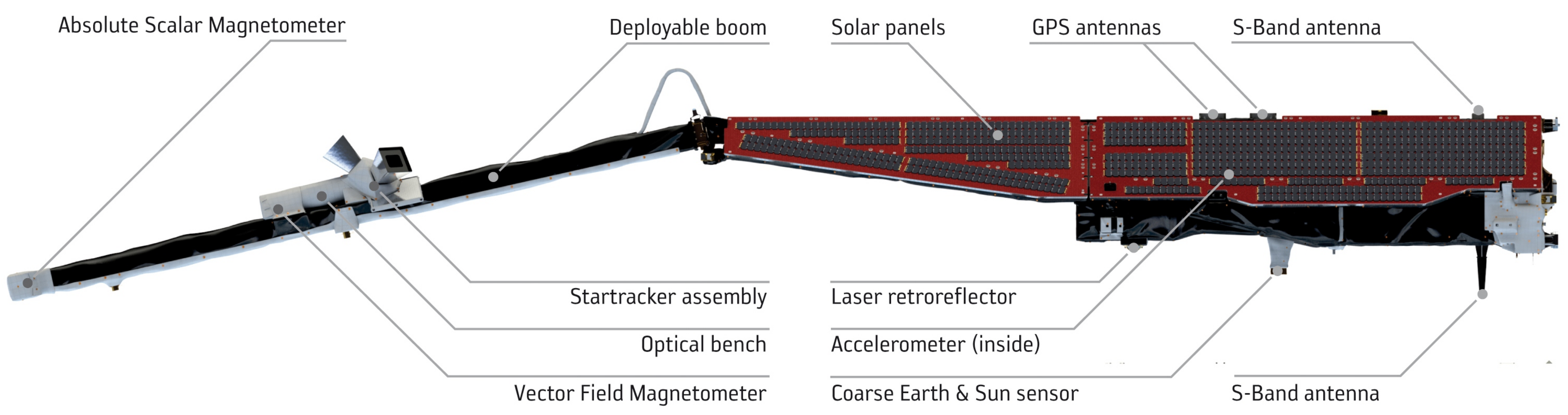
Introduction

The three Swarm spacecraft are built using world class magnetometers, the French optically pumped Helium magnetometer by CEA/Leti working both as an absolute scalar reference magnetometer and as a vector magnetometer though with less pointing accuracy as the Danish Vecor Field Magnetometer by DTU Space using the compact spherical coil sensor principle. Both magnetometers are mounted on the boom to reduce even further the magnetic disturbances from the spacecraft which by iself is designed to be very magnetically "clean", i.e. with as little magnetic disturbance as possible, and with careful characterisation of whatever magnetic disturbances remaining. Despite these efforts, it became clear early in the Mission that something was not performing as expected: the magnetic measurements from the two magnetometers could not be made to agree to the expected sub-nT level using traditional calibration and characterisation methods. Major efforts from both engineering and scientific side has been invested in analyses, investigations, and methods of characterizing and compensating the observed discrepancies eventually leading to a generally accepted physical explanation of the magneetic disturbance as well as a workable characterisation and compensation of the effect. In this poster, we accept the physical explanation to be the true cause of the disturbance. The disturbances are caused by thermo-electric currents (known as the *Seebech effect*) flowing in the thermal blankets around both magnetometer sensors as well as around parts of the boom. As the thermo-electric currents are primarely driven by the Sun, this magnetic disturbance has been denoted *dB_Sun*.
This poster gives a brief tour of the history of *dB_Sun*.

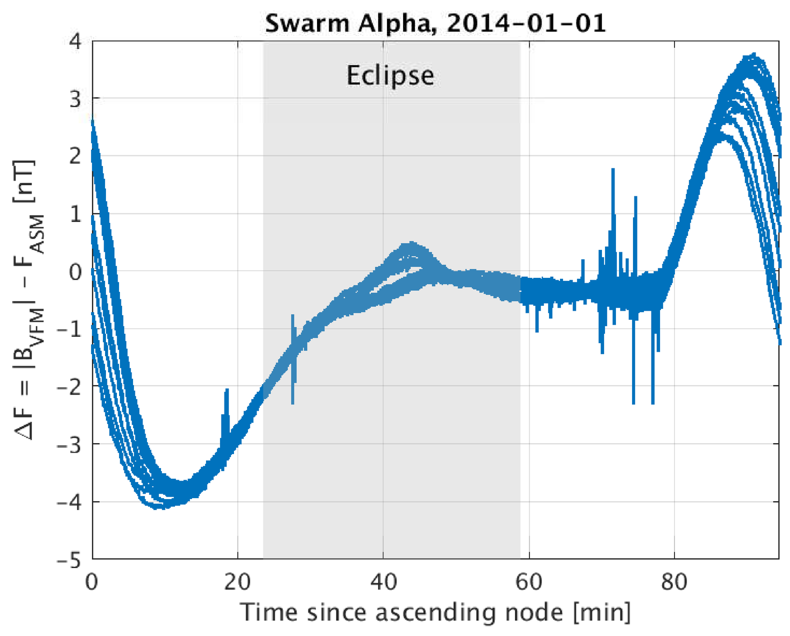
The Spacecraft



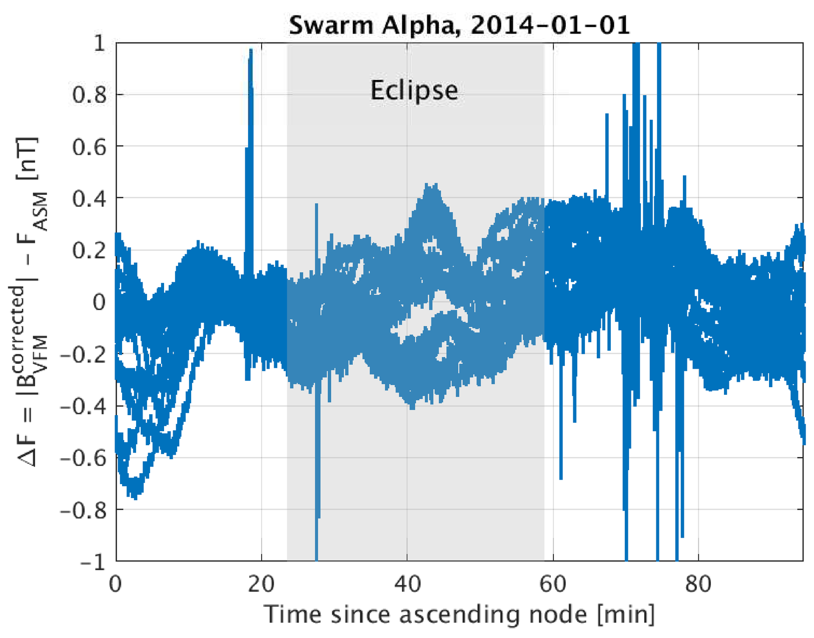
The two science magnetometers on Swarm are the Absolute Scalar Magnetometer (ASM) at the tip of the boom and the Vector Field Magnetometer (VFM) 1/3 inwards on the boom. Around both magnetometers are the white, thermal blankets made of an outer layer of betacloth and multiple aluminum layers beneath. Also noticeable is the thermal blanket on the bottom side of the boom, a.k.a. the "boom-blanket".

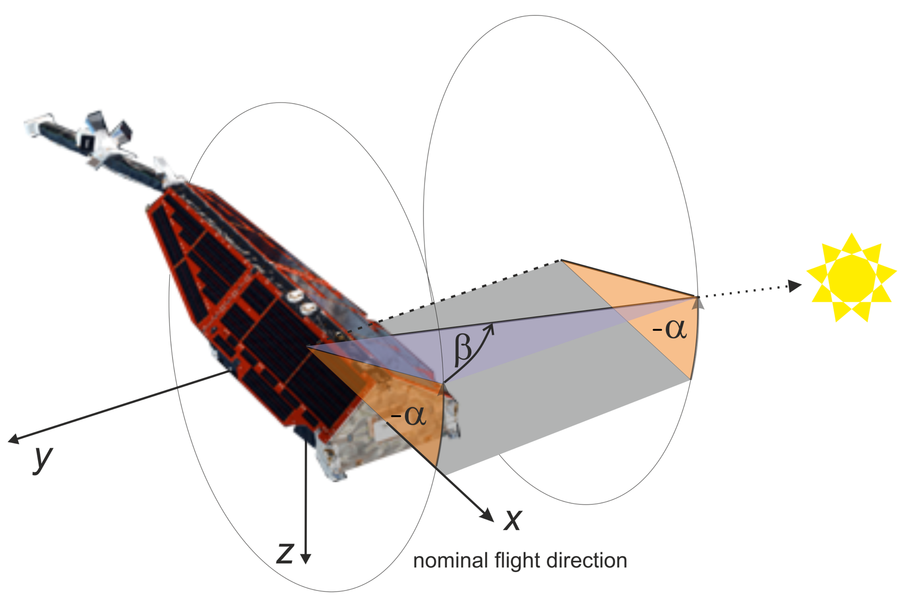
Early Analyses and Initial Correction

The plot to the right shows the "scalar residuals" of one day of Swarm Alpha data after a traditional *in-flight scalar calibration*, i.e. a calibration of the vector magnetometer, VFM, using the measurements of the absolute scalar magnetometer, ASM, as reference. The plot shows the difference between the modulus of the calibrated VFM vector measurements, $|\mathbf{B}_{VFM}|$, and the scalar measurements of the ASM, F_{ASM} as a function of the time since ascending node (northward pass of the Equator). From this plot it is clear, the scalar residuals are not in the expected sub-nT level, but it is also clear, the discrepancies are highly regular and it seems, they fade away when entering eclipse. Plots of data from Swarm Bravo and Charlie show similar though not identical behaviour.

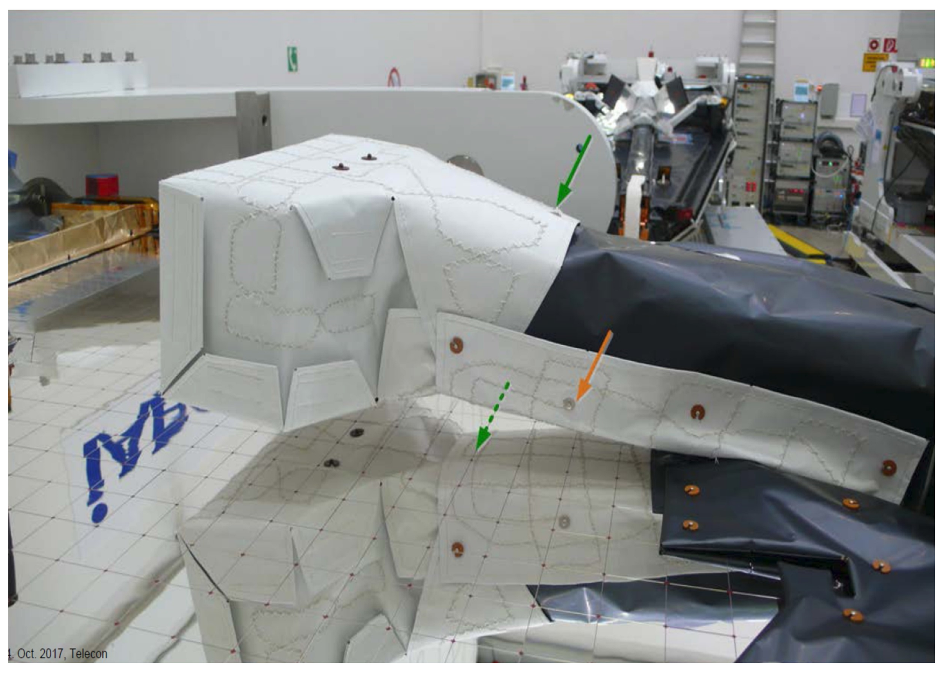


Based on this and many other investigations, Vincent Lesur (2015) devised a correction scheme where, for each satellite, a bias vector parameterized by the orientation of the Sun w.r.t. the spacecraft was estimated and applied in the corrections of the VFM vector measurements. This correction scheme proved very effective, see plot below left of the scalar residuals after applying the correction, and was adopted for the official Swarm Level 1b data, see Tøffner-Clausem (2016). The bias vector is denoted *dB_Sun*.
The orientation of the Sun w.r.t. the spacecraft is parameterised by the two angles, *alpha* and *beta* depicted in the figure below right. The axes of dB_Sun is described by three individual spherical harmonic expansions of degree and order 25.





Physical Model



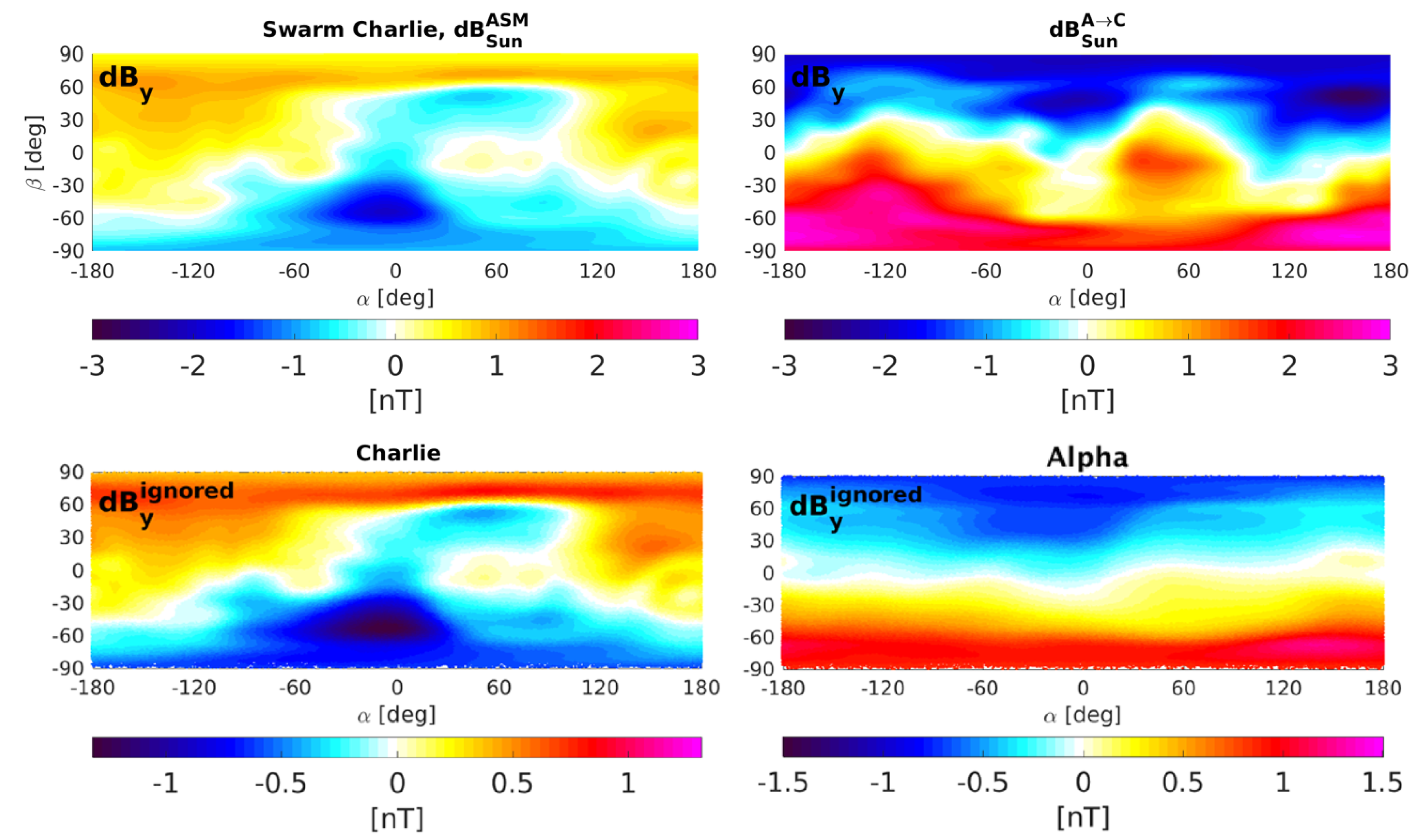
Despite the great success of the correction model devised by Vincent Lesur this is a heuristic model which does not provide any physical explanation of the disturbance. The description of the physical phenomena is provided by Peter Brauer, see the neighboring Poster 11. In short, the driving effect are thermo-electric currents between rivets in the thermal blankets around the magnetometer sensors. Each thermal blanket on Swarm is equipped with two rivets for electrical grounding purposes – two for redundancy – and these rivets are exposed to Sun illumination and hence to solar heating. See picture of the blanket around the ASM sensor to the right. This results in different temperatures of the rivets which causes electrical potentials between the rivets which are electrically connected both through the grounding network as well as through the thermal blankets, hence currents will flow in the blankets and grounding wires in close proximity to the magnetometers. The differences in the estimated *dB_Sun*'s (cf plots at the bottom of this poster) of the three spacecraft can be explained by differences in resistances, mainly contact resistances and resistances in the aluminum foils of the thermal blankets.

Further Investigations and Conclusions from the Physical Model

Besides the investigations of the discrepancies between the VFM and ASM, the IPGP team in France lead by Gauthier Hulot conducted detailed inter-satellite comparisons and analyses of ASM measurements durings spacecraft manoeuvres (cf. talk by Gauthier on Wednesday); this work reveals discrepancies which were not understood initially but are now explained by the physical *dB_Sun* model of Peter Brauer. This lead to a split of the iniital *dB_Sun* correction, which was originally only applied to the VFM measurements, into two parts: one applied to the VFM measurements and one applied to the ASM measurements. Please note, that from the in-flight characterisation of *dB_Sun* it is mathematically impossible to distinguish disturbances at the VFM sensor from any at the ASM sensor, **hence the physical model is crucial for making this separation**.

Latest Investigations into *dB_Sun*

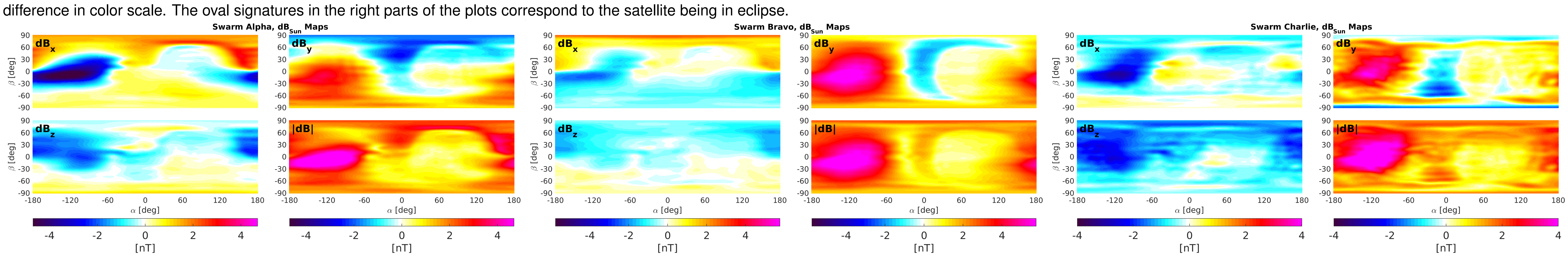
The introduction of the *dB_Sun, ASM* correction into the Swarm Level 1b data did help to resolve some small issues of residual distributions when performing main field modeling with Swarm data. However, there were still features present which did not conform with the magnetic field around the Earth. This lead to a correction of the Baseline 06 magnetic data known as "dB_y^{ignore}". There were no physical explanation for this correction, but the modeling results were compelling. Recent analysis of the y-component of *dB_Sun* estimated from in-flight calibrations of Swarm Alpha and Charlie has lead to the maps shown below. Top-left: dB_y on Charlie estimated from the first year of ASM measurements on Charlie Top-right: dB_y on Charlie estimated from ASM measurements on Alpha mapped to Charlie Bottom: The dB_y^{ignore}'s from Charlie respectivel Alpha which were introduced in Baseline 06. Notice the similarity between top and bottom plots.



As the basic difference between the left and right plots is whether the ASM on Alpha or Charlie is used as reference, the current conclusions from these plots are, there is a contribution to y of *dB_Sun* which seems to be related to the ASM measurements and to have opposite sign on Swarm Alpha respectively Charlie. Furthermore, this contribution seems to be quite anti-symmetric with the Sun beta angle. The working hypothesis is, that the thermal blanket beneath the boom is generating currents which – via the grounding wires – flow into the blanket around the ASM. The positions of the rivets on the boom blanket could account for the beta-asymmetry. The change in sign between Swarm Alpha and Charlie is believed to be due to different mounting of the ASM blanket grounding wires onto the grounding network of the boom.

Maps of *dB_Sun*

These are maps of the original *dB_Sun*'s, i.e. before the separation into VFM and ASM parts. The three components as well as the total length of *dB_Sun* are plotted versus the Sun incident angles, *alpha* and *beta*. Notice the slight difference in color scale. The oval signatures in the right parts of the plots correspond to the satellite being in eclipse.



References

Lesur, V., et al.. *Parent magnetic field models for the IGRF-12 GFZ-candidates, Earth, Planets and Space, 67*(1) (DOI: 10.1186/s40623-015-0239-6), 2015
Tøffner-Clausen, L., et.al., *In-flight scalar calibration and characterisation of the Swarm magnetometry package, Earth, Planets and Space, 68*1 (DOI: 10.1186/s40623-016-0501-6), 2016