Swarm's Absolute Scalar Magnetometers experimental vector field measurements: first conclusions from comparisons with 1 Hz nominal Swarm Level1b vector data.

Laura Brocco[1], Gauthier Hulot[1], Pierre Vigneron[1], Raul Crespo Grau[1,4], Xavier Lalanne[1], Olivier Sirol[1],

Jean-Michel Léger[2], Thomas Jager[2], François Bertrand[2], Axel Boness[2],

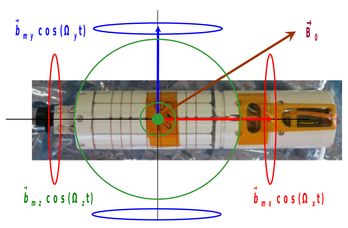
Isabelle Fratter[3]

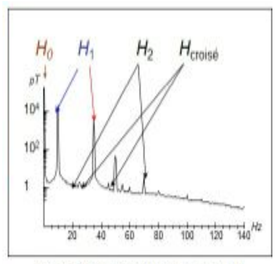
(1) Equipe de Géomagnetisme, Institut de Physique du Globe de Paris (IPGP), France (2) CEA-Leti Grenoble, France, (3) Centre National d'Études Spaciales (CNES), Toulouse, France (4) Observatorio Geofísico central, Instituto Geografico Nacional (IGN), Spain

Summary

Swarm's Absolute Scalar Magnetometers (ASM) provide absolute scalar measurements of the magnetic field with high accuracy and stability on the three satellites of the mission. These are used to produce the 1 Hz nominal Swarm Level1b scalar data and to calibrate the 1 Hz nominal Swarm Level1b vector data. In addition, and on an experimental basis, these ASM instruments can also, and simultaneously, provide independent vector field measurements. These appear to be of very stable quality, with no apparent biases, and can thus be used for comparison with readings from the Vector Field Magnetometer (VFM, located some distance away along the boom and used to produce the nominal Swarm Level1b vector data) for quality crosschecks, possible detection of undesired satellite signals, as well as assessment of the stability of the mechanical link between both instruments. Here, we will describe how such crosschecks and comparisons, which imply using appropriate synchronization and alignment procedures, can be carried out, and present conclusions from such comparisons. Most encouraging is the fact that the mechanical link between the ASM and VFM instruments appears to be very stable on all three satellites, suggesting that further more detailed comparisons could be made between ASM and VFM vector data to help investigate consistency issues that may remain between 1 Hz nominal Swarm Level1b vector and scalar data (e.g., possible time-varying differences between modulus of the vector data and the scalar data, even after implementation of the nominal VFM calibration procedure). Results from such on-going investigations are presented and discussed.

1 Principle of the ASM vector measurement





Real time analysis of the scalar output

$$|| \mathbf{B}_{tot} || = || \mathbf{B}_0 + \Sigma_{i=x,y,z} \mathbf{b}_{mi} \cos(\Omega_i t) ||$$

- Three perpendicular coils generate periodic magnetic fields with known amplitudes (~ 50 nT) and three different known (and adjustable) frequencies beyond 1 Hz (7.92 Hz, 10.98 Hz and 12.97 Hz) .
- Real time analysis (with 250 Hz sampling rate) of the scalar field measured by the (scalar) sensor makes it possible to measure the scalar field at 1 Hz (with nominal performance) together with all field components along the three coil axis.
- Some calibration is needed to scale the response to the three sets of coils and take into account the non-orthogonality of the three axes, the thermal impact and the position of the rotating sensor within the instrument (CCDB parameters).

2 L1A data production

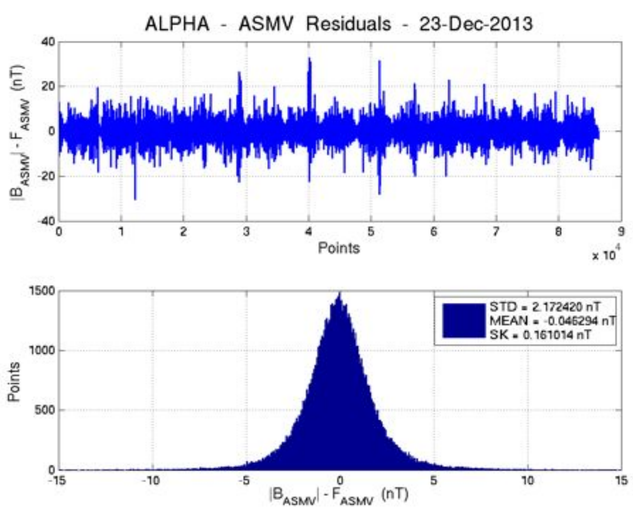
- The ASMV-L1A data are generated via a dedicated software. The inputs required by the software to produce 1 day of data are:
  - The Level-0 (L0) raw data
  - The auxiliary files with the stray fields measurements
  - The calibration parameters (CCDB). For each day a different CCDB is used. Each CCDB is built using three consecutive days data (the day of interest, the day before and the day after).
  - The nominal Swarm Level-1B (L1B) data (for auxiliary information)

This chain produces both scalar (F_{1A}) and vector field ($\mathbf{B}_{1A}$) values in the ASM (coils) reference frame at instrument times t_{ASM} with 1 Hz sampling rate.

- The L1A data are then synchronized at UTC time using a cubic spline interpolation. The estimated error on the interpolation is ~ 0.01 nT.

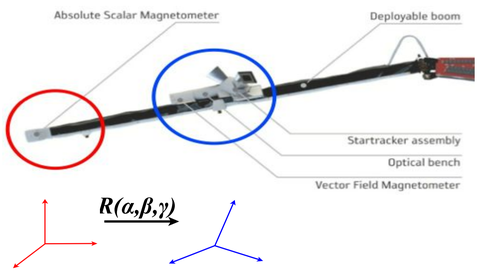
In this Poster are presented the results obtained using the L0 files *v.2.0* and L1B files *v.3.01*. One day (**December 23, 2013**). Residuals for the synchronized ASMV-L1A data of satellite **Alpha** are displayed below.

$$R_{1A} = || \mathbf{B}_{1A} || - F_{1A}$$



3 Alignment and comparison of the ASM vector measurements with respect to nominal L1B VFM vector data

- Using synchronized ASMV-L1A and nominal L1B (VFM) 1 Hz vector data
- We seek the best rotation R(α,β,γ) from the ASMV to the VFM instrument frames minimizing χ^2 (see below).

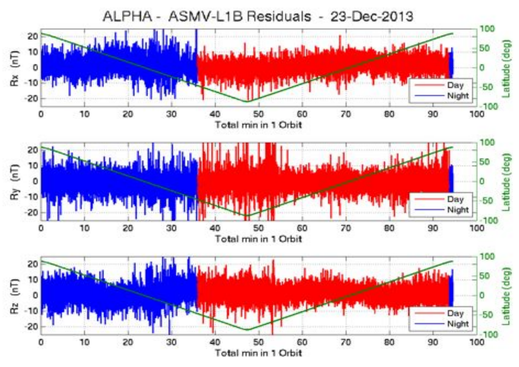


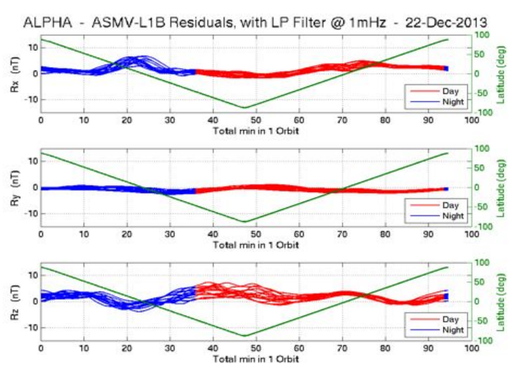
$$\chi^2 = \sum_{i=1}^{N} \left\| \vec{B}_{VFM_i} - R(\alpha,\beta,\gamma) \left(\frac{\left\| \vec{B}_{VFM_i} \right\|}{\left\| \vec{B}_{ASM_i} \right\|} \vec{B}_{ASM_i} \right) \right\|^2$$

- Residuals between the rotated ASMV and the VFM data for the three magnetic components (B_x, B_y, B_z) in the VFM frame are plotted below for satellite **Alpha**, on **December 23, 2013.**

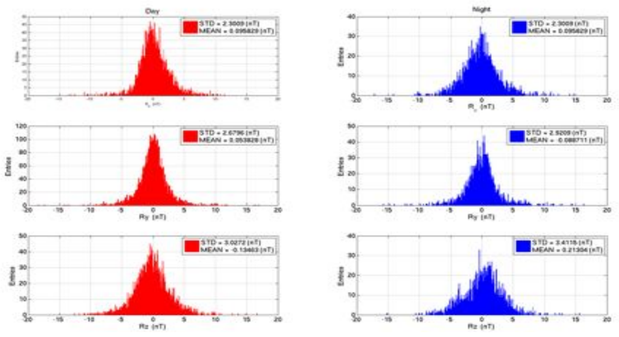
$$R_j = B_{j,ASM-V} - B_{j,1B} \qquad j=x,y,z$$

- Residuals along orbits are plotted as a function of the the time elapsed since descending from the North Pole (Figure below left). We distinguish between day (fully lighted, red) and night (dark, blue) segments of the orbit. Sun illumination of the satellite has been estimated from the Sun and satellite relative positions, updated every seconds. Latitude is also shown in green.
- The figure below on the right shows the same residuals filtered using a low pass 2nd order Butterworth filter, with $F_{cut\text{-}off}$ = 1 mHz, to remove instrument noise and highlight the pattern of the ASMV-L1B vector residuals.
- Note that on December 23, 2013 the ascending/descending local times are noon/midnight.



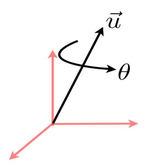


- Instrument noise is next recovered by subtracting the above systematic signal from the initial residuals (see figure below).

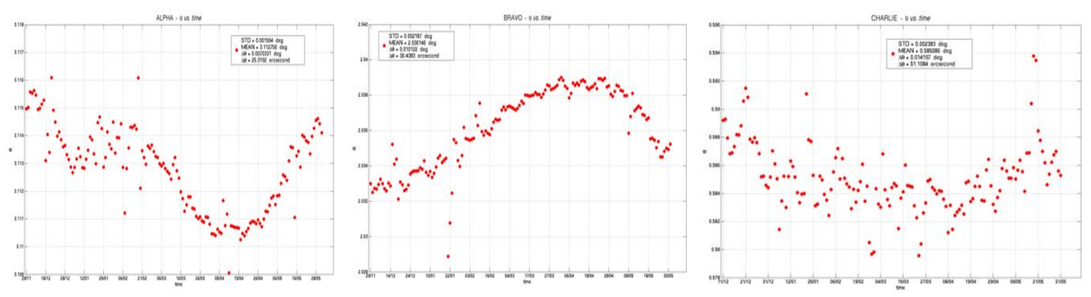


- This noise is consistent with the L1A-ASMV scalar residuals shown in panel 2.

4 ASMV – VFM alignment stability



- The recovered rigid rotation between the ASMV and VFM reference frames can be characterized by an angle θ and a unit vector **u**.
- Both quantities are evaluated on a day by day basis.
- For all satellites **u** is quasi-coincident with the z-axis of the VFM frame (coincident with the axes of the satellite) and constant over the six months; the behaviour of θ is displayed in the three figures below.



- Note the good overall stability, consistent with the residuals shown in panel 3.
- Note also the greater uncertainty on Charlie.

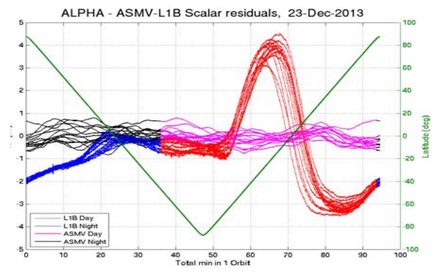
5 Comparison of ASMV and L1B-VFM scalar residuals

- L1B-VFM scalar residuals are defined as

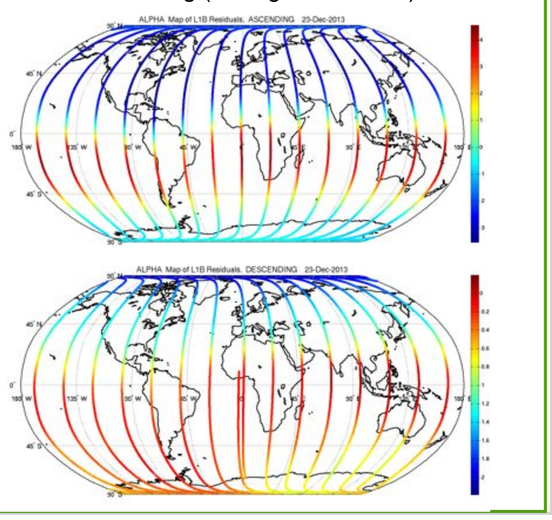
$$R_{1B} = || \mathbf{B}_{1B} || - F_{1B}$$

where F_{1B} is the nominal L1B scalar data, whereas ASMV scalar residuals are defined as stated in panel 2.

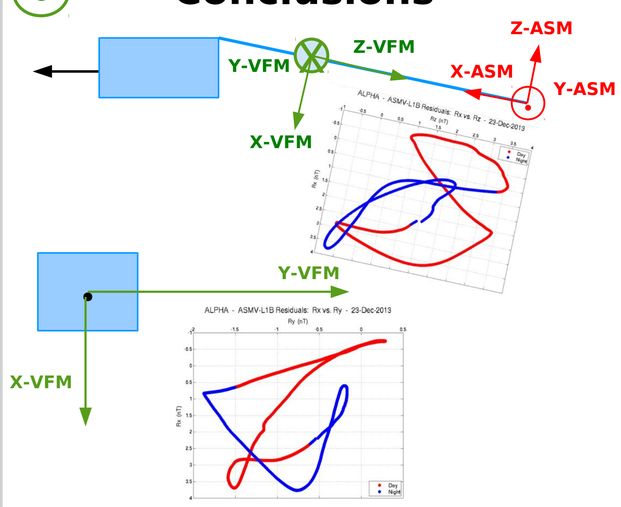
- To ease comparison and remove instrument noise, ASMV residuals are filtered using the same filter as described in panel 3.
- The figure below shows those residuals for satellite **Alpha**, on **December 23, 2013**.



- Note that the ASMV residuals are quite flat for all latitudes and do not change as a function of the Sun illumination, contrary to the L1B-VFM residuals.
- Maps of the L1B-VFM residuals (on ascending and descending orbits) are displayed below.
- Note that maximum L1B-VFM residuals are observed on ascending (noon local time) orbits, but that a significant signal is still to be seen at high Northern latitudes on descending (midnight local time) orbits.



6 Conclusions



- Vector components of the ASM experimental vector mode in the ASM frame of reference are close to their expected data quality.
- Alignment of these ASMV vector data with the nominal L1B-VFM data reveals a good mechanical stability between instrument frames.
- This stability can be used to investigate the origin of the inconsistency of the L1B-VFM data with the L1B scalar data (scalar residuals, discussed in panel 5).
- Plots of the corresponding vector residuals in the Alpha satellite reference frame (above, 1 mHz filtered and averaged over one day) reveal a complex (but repeatable, recall panel 3) pattern.