FROM RESEARCH TO INDUSTRY

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On the in-flight calibration of the experimental Absolute Scalar Magnetometer vector mode on board the Swarm satellites

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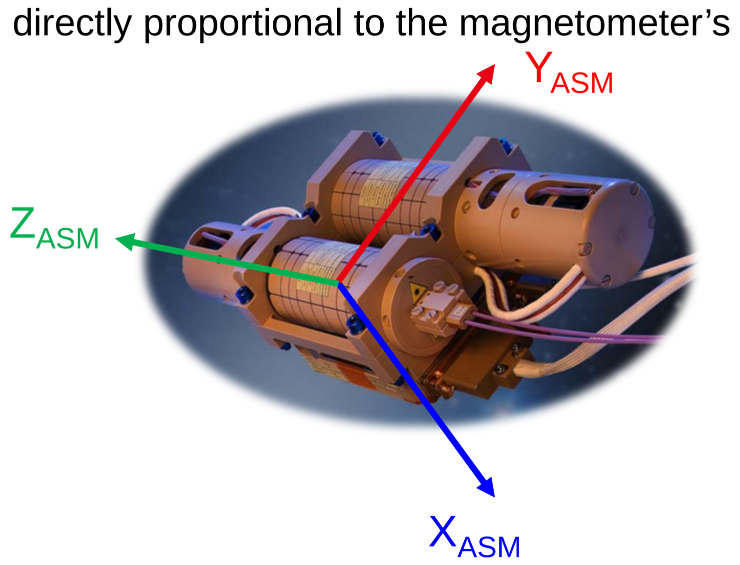
ASM OPERATING PRINCIPLES

As the magnetic reference of the ESA Swarm mission, the ASM provides continuous absolute measurements of the Earth's magnetic field strength B_0, with unequaled and constant performance over field modulus, spatial position and orientation [1]. The ASM is a **magnetic field to frequency converter** based on atomic spectroscopy of the ^4He in its metastable level 2^3S_1. It exploits the Zeeman effect, with the signal being amplified by optical pumping. The magnetic field modulus B_0 is directly proportional to the magnetometer's resonance Larmor frequency f_{Larmor} :



$$B_0 = \frac{f_{Larmor}}{\gamma_{^4He}} \text{ with } \gamma_{^4He}/2\pi \approx 28 \text{ GHz/T}$$

$$\|\overrightarrow{B_{tot}}(t)\| = \left\|\overrightarrow{B_0}(t) + \sum_{i=X,Y,Z} \overrightarrow{b_{mi}}\cos(\omega_i t)\right\|$$

Using 3 orthogonal coils, 3 low frequency AC modulations $\overrightarrow{b_{mi}}$ are superimposed (amplitude ≈ 50 nT, frequencies ≈ 8 Hz, 11 Hz and 13 Hz) on the static field $\overrightarrow{B_0}$: a real time analysis of the resulting scalar measurement then simultaneously provides a direct estimation of the magnetic field projections on the 3 modulation directions, in addition to the unaffected static field determination [2].

Both nominal high performance scalar and optional demonstrative vector measurements are provided at the same time and location

ASM VECTOR CALIBRATION STRATEGY

ASM vector L0 data

Parallel tracks

Daily ASM vector calibration with ASM CCDB generation
(daily calibration with a 3 days sliding window scheme)
+
Additional ASM flags files generation pointing out: noise outliers, ASM sensor motor activations and HF magnetic perturbations from ASM sensor bracket heater

ASM-V data production
(self-consistent ASM scalar and vector product with additional information recovered from L1B products)

OBJECTIVE n°1 :
Assessment of the ASM vector performance w.r.t the nominal VFM vector product
IGRF models generation by IPGP with standalone ASM-V data or ASM scalar + VFM vector data
+
Swarm satellite boom stability assessment (ASM-V vs VFM alignment)

Single long term vector calibration algorithm evaluation

Addition of external corrective parameters:
daily sensor heater duty-cycle, daylight duration, satellite orientation w.r.t. to the sun, external TRP gradients,…

many of these parameters are inter-correlated in orbit

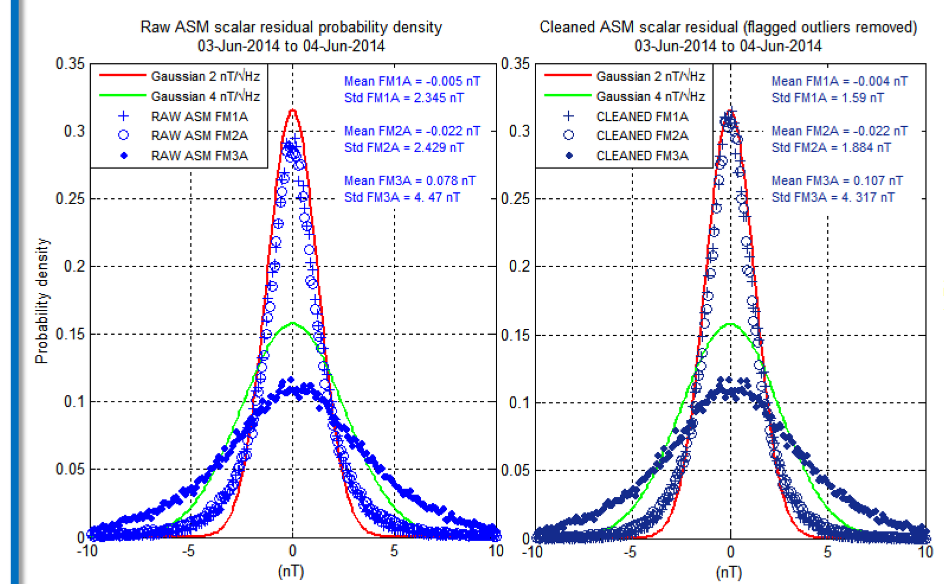
A parallel analysis between physical and empirical model corrections has to be constantly and carefully achieved in order to implement representative corrections

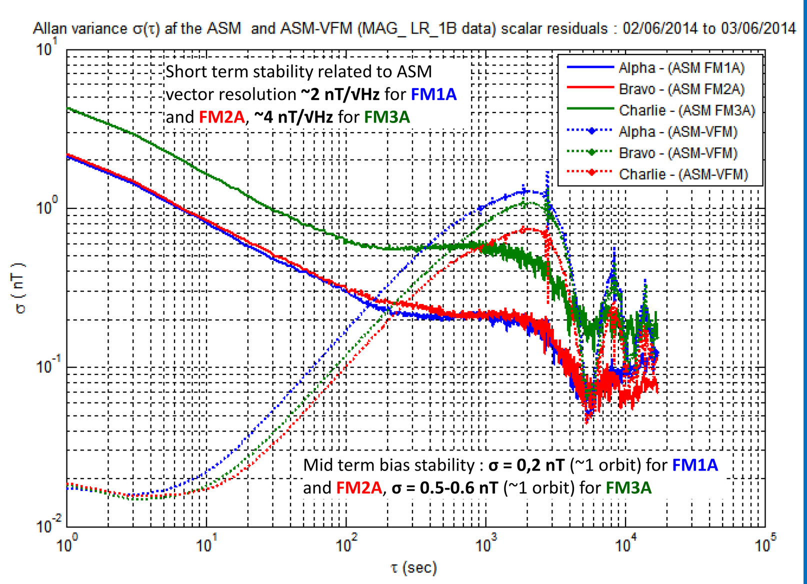
OBJECTIVE n°2 :
Better in-flight behavior characterization of the ASM instrument

OBJECTIVE n°3 :
Ways forward for the improvement of the next generation of the ASM sensor design

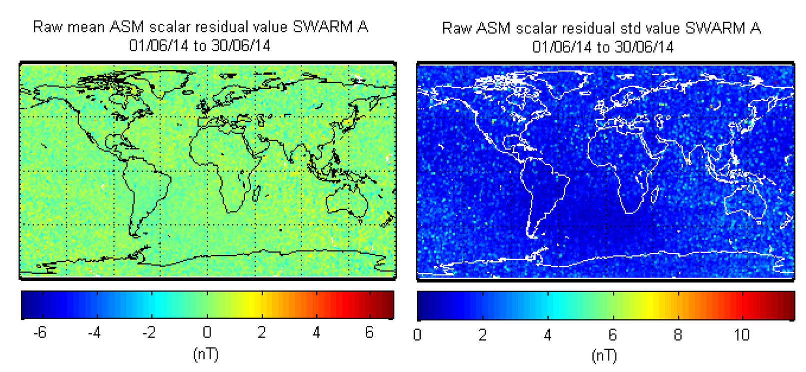
ASM VECTOR CALIBRATION PERFORMANCES

Short & Mid term (1 day - 1 week):

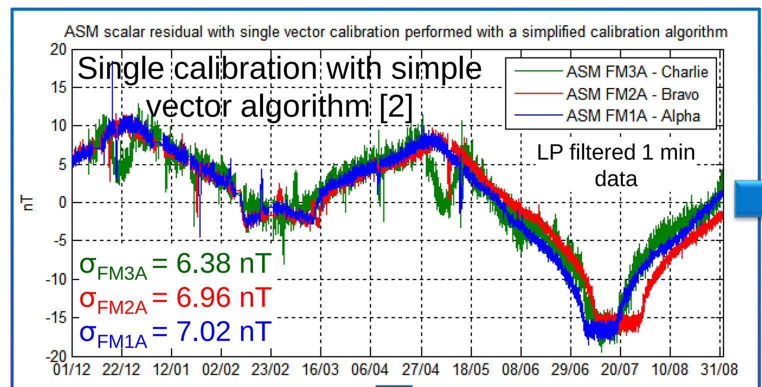


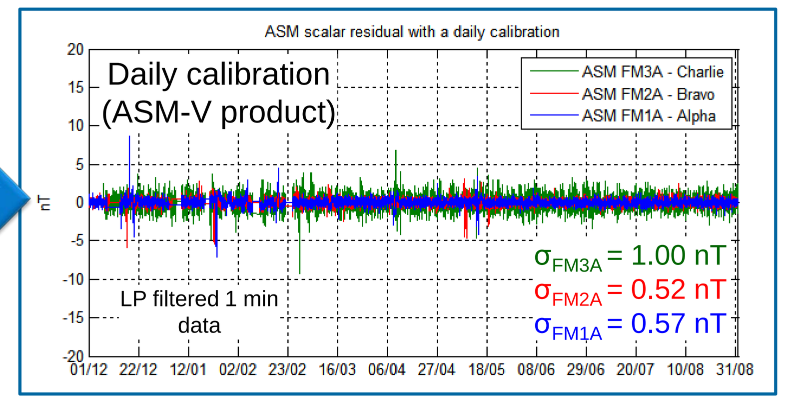


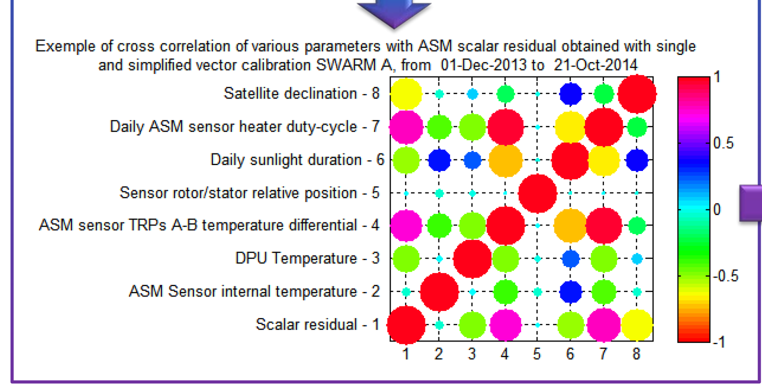
- ASM vector performances in complete agreement w.r.t on-ground characterizations
- No orbital signature
- Short term ASM vector measurements stability driven by intrinsic noise level characteristics
- Better mid term stability (orbital periods > 200 s, i.e. λ > 1600 km / S.H. orders < 30) w.r.t. to the current data from MAGx_LR_1B product

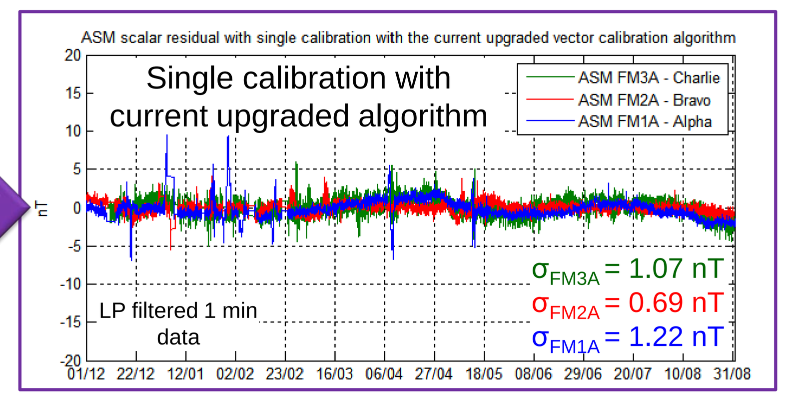


Long term (months - year):

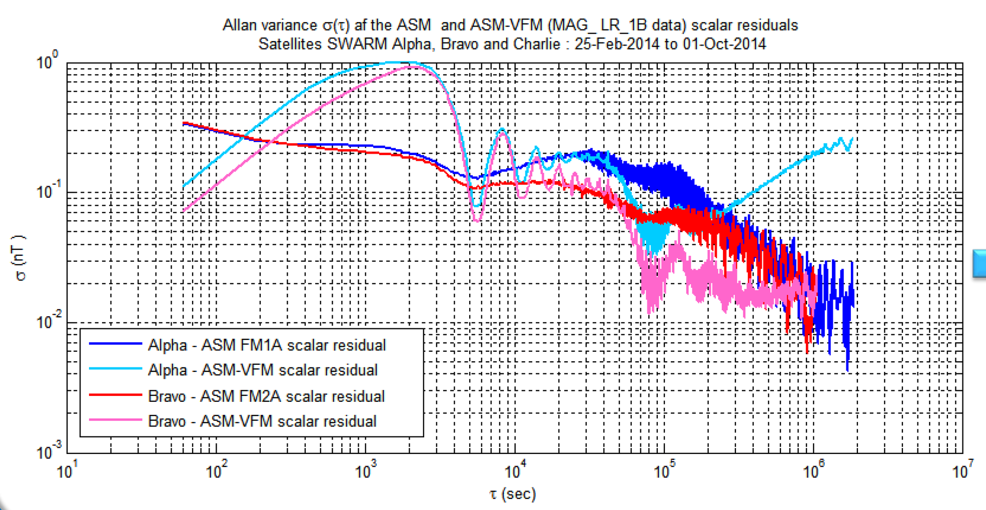








- Most of the daily evolutions/drifts in daily CCDB parameters are shown in the vector coils scale factors which are corrected thanks to a daily calibration (ASM-V product)
- Promising single upgraded vector calibration results, still under improvement



The long term ASM vector measurements stability is lower than 0.1 nT which allows to assess with good accuracy the relative orientation stability between ASM and VFM reference frames and thus the satellite boom mechanical stability over time between the two instruments

ASM PERFORMANCE SUMMARY

	Characteristics	Swarm Alpha ASM FM1A	Swarm Beta ASM FM2A	Swarm Charlie ASM FM3A
SCALAR	Scalar resolution (pT/√Hz)	1.1	1.0	1.4
	Scalar bandwidth & sampling (Scalar 1 Hz/ Burst mode 250 Hz)	[DC-0.4 Hz] / [DC-100 Hz]	[DC-0.4 Hz] / [DC-100 Hz]	[DC-0.4 Hz] / [DC-100 Hz]
	Accuracy of ASM scalar L1B products (σ_{max} in pT)	65	65	65

	Characteristics	Swarm Alpha ASM FM1A	Swarm Beta ASM FM2A	Swarm Charlie ASM FM3A
VECTOR	Vector resolution (nT/√Hz)	~2	~2	~4
	Mean daily scalar residual (pT)	+/- 20	+/- 20	+/-40
	Daily raw scalar residual Std (nT)	2.6	2.7	5.3
	Daily scalar residual Std – Cleaned from flagged outliers (nT)	1.5-1.8	1.9-2.3	5-6
	Detected orbital signature	NO	NO	NO
	Orbital scalar residual stability (nT)	0.2	0.2	0.6
	Long term scalar residual stability (nT)	<0.1	<0.1	<0.3

CONCLUSIONS & PERSPECTIVES

- In addition to high performance scalar nominal data, ASM instruments are able to provide robust vector data at the same location and time with a long term stability σ lower than 0.1 nT and other performances characteristics in agreement with on ground characterizations
- A self-consistent ASM scalar and vector product (ASM-V) has been successfully used as input for IGRF model determination and other studies (cf IPGP work [3-5] also presented at AGU 2014)
- A single ASM vector calibration seems achievable but still needs further improvements

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