Calibration Report of the **STAFF** Measurements in the Cluster Active Archive (CAA)

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Content

1 Introduction

In the first part, this document briefly describes the STAFF experiment, the calibration method used, and the delivered products.

In the second part, a large number of cross-calibration studies are given, especially those with FGM, and summarizes the efforts done on this subject since last years. The measurements by two common STAFF-SC and STAFF-SA frequency bands are also compared.

The cross-calibration results presented here are based on the talks given between the first cross-calibration workshop in ESTEC in February 2006 and the 15th CAA Cross-Calibration meeting, in London, 17-19 April 2012.

Both old and new results are summarized here.

A number of authors have been involved in this work, including L Mirioni, V. Bouzid, P. Canu, Y. De Conchy, C. Lacombe, B. Grison, O. Santolik, O. Alexandrova and D. Attié.

2 Instrument Description

The CLUSTER STAFF experiment comprises a tri-axial search coils magnetic sensor (0.1 Hz – 4 kHz frequency range) and two on-board wave analyzers, a magnetic waveform unit (STAFF-SC) and a wave spectrum analyzers (STAFF-SA) that calculates the complete matrix for the 3xB + 2xE components; the electric waveform data are received from the EFW sensors. For more detail of the experiment, see references [1-2]

2.1 STAFF-SC

- The magnetic waveform unit delivers 3 waveforms (B_x, B_y, B_z) from the pre-amplifier filtered in either of the two low-pass bandwidths, 0.1 - 10 Hz (Normal Bit Rate: NBR) and 0.1 - 180 Hz (High Bit Rate: HBR). Sampling rates are 25 and 450 Hz, respectively.

- The filtered signals are digitized by three 16 bits sampling and hold devices synchronised by DWP and sent to the DWP experiment.

- The A/D converters are the same for STAFF and EFW and synchronized by DWP in order to facilitate further combined wave analysis. The low pass filters are identical too.

- Due to the telemetry limitation, a compression from 16 to 12 bits is performed inside DWP for STAFF wave form data.

- The coordinate system of the level 1 (L1) data is the Spinning Sensor System (SSS, STAFF Sensor Reference Frame); this is a spinning frame. x and y axis are parallel to the EFW axis and z is parallel to the spacecraft spin axis.

2.2 *STAFF*-SA

- The spectrum analyzer is designed to calculate the complete cross spectral matrix for the 5 available components, 3xB + 2xE, in the 8 Hz-4 kHz frequency range. The electric field components come from EFW sensors.

- The analysis band is divided into 3 logarithmically distributed frequency sub-bands of 9 frequencies each.

- For each sub-band there are 3 automatic gain control (AGC): one for Bx channel (parallel to the spacecraft spin axis) and one for each couple of spinning components (B_y, B_z and E_y, E_z respectively). Note that here, x,y,z correspond to the Body Build coordinate system, where x is the spin axis. In this document, general convention for science data set z as the spin axis.

- The different modes are the combination of 3 parameters: the time resolution, the number of frequencies computed (2 or 3 bands), the number of wave components considered.

- The coordinate system used for the delivery products is the ISR2 (inverse of SR2, close to GSE).

3 Measurement Calibration Procedures

3.1 Calibrations procedures

This term overlaps different aspects:

- The calibration methods used to transform L1 data (waveform or spectra) into level 2 (L2) calibrated data.

The corresponding software (see [3] and [4]), that take for input L1 data files and calibration files, and produce L2 data files.

- The calibration files take into account the whole transfer function, including the sensors, the pre-amplifiers and eventually the filters. These files can be regularly updated by the exploitation of calibrated signals recorded during the on board calibration mode executed once per orbit and kept in the L1 and CWF data files. Up to now, the use of these calibrated signals has allowed to verify that the STAFF experiment performances have not changed since the commissioning phase. Nevertheless a more refined cross calibration study has shown the need to validate the on-ground calibration performed before launch. A detail study of the ground equipment together with detailed cross calibrations has allowed to valid new transfer functions. As it will be shown, the correction factor is about 10 % for frequencies less that 8 Hz for SC1 with respect to the 3 other spacecraft. Another 10% correction is to be applied to the whole frequency range to the 4 S/C transfer functions.

3.2 Cross - calibration procedures

There are several possibilities for cross-calibration activities:

- The STAFF-SC NBR mode delivers magnetic waveform up to 10 Hz. So, comparison with FGM data can be done at two levels:
    - The Doppler effect due to the STAFF sensor rotation into the DC magnetic field provides a strong sine signal in the spin plane. On this strong sine signal are superimposed the very low amplitude magnetic fluctuations. Once the sine signal is extracted, its amplitude and phase are determined and corrected by the transfer function. These X and Y calibrated components of the DC magnetic field in the spin plane can be directly compared with FGM data.
    - The 3 STAFF-SC calibrated waveforms, from about spin frequency (0.25 Hz) up to 10 Hz, can be compared to the FGM high resolution waveform in any coordinate system.
    - To check a possible dependency with frequency, the corresponding spectra can be also compared. This provides additional information on each instrument, sensitivity versus frequency.

- The STAFF-SC HBR mode delivers magnetic waveform up to 180 Hz, and so permits an overlap with the low part of the STAFF-SA frequency range (usually 64 Hz-4 kHz in HBR, but some dedicated mode may allow a comparison from 8 Hz). Thus, the spectra level and the spectra continuity of the two sub-experiments can be checked.

- For STAFF-SA, in addition to the cross-calibration mentioned above, it is possible to check the spectral continuity of the magnetic fluctuations with:
  - WBD (between 25 Hz and 4 kHz)
  - The spectral continuity of the electric fluctuations with EFW in the same conditions as for the magnetic components as described above for STAFF SC and STAFF SA.
  - WHISPER (between 2 kHz and 4 kHz)

4 Measurement Processing Procedures

4.1 Cleaning waveform procedures

As explained in 3.2, the Doppler effect due to the STAFF sensor rotation into the DC magnetic field provides a strong sine signal on the components perpendicular to the spin axis (X and Y). This sine amplitude is equal to the perpendicular DC magnetic field (from a few nT up to 2000 nT, value above which the STAFF signal saturates). On this strong sine signal are superimposed the very low amplitude magnetic fluctuations (~a few nT or less).

First, before the FFT procedure, it is necessary to remove this strong sine signal. Then, the FFT will be applied on the remaining useful signal. This process consists of fitting the signal with a pure sine signal, whose frequency is known (the spin frequency). The dedicated process, based on a harmonic analysis applied on a single spectral component, provides the fitted sine signal amplitude and phase. Note that those two parameters are useful for FGM DC field comparison. Finally, this pure sine signal is subtracted from the original one to retrieve the fluctuations. This process is very efficient in terms of rejection performance and CPU time. But it requires at least a minimum duration of two spin periods, where the DC field is supposed to be constant. For long-time windows, only a DC field average value is subtracted, and so the efficiency of the rejection is decreased. In any case, all frequencies are preserved, but the spin frequency. As we can see, one has to choose the best compromise between a not too short and a not too long window duration.

Another process called “detrend” process can be applied also for long-time windows. A “smoothed” signal, containing only lower frequencies is estimated. This signal is then subtracted to the original one, to obtain the magnetic fluctuations. As this method takes into account the DC field slow variations, it is possible to apply it on long-time windows. This method can still be applied on less than one spin period time windows. But it also removes all lower frequencies below the spin frequency.

Generally, the first method is applied. When short-time windows are required, “detrend” method is used. In the case of DC magnetic field fast variations, both methods are applied.

4.2 Classical calibration method for STAFF - SC

This method operates in up to 5 steps depending on the desired final product, steps that are given below:

4.2.1 Get Level 1 waveform (in Volts) <u>as a series of successive windows</u>.

→ *Selecting window time length (Δt) determines the frequency resolution (Δf) as Δt.Δf =1.*
→ *TM count [065535] to Volt [-5V, +5 V].conversion.*

—► Calibration step # **1**: Volts, spinning sensor system, with DC field.

4.2.2 "Cleaning" raw waveforms in the Spinning Sensor System (SSS).

→ *Remove the spin tone signal (~ 1 nT up to ~ 5600 nT) high compared to the useful signal (~1 nT or less). This is done using a specific harmonic analysis process. There are then 2 data sets, waveform in TM volts without DC components and DC components XY kept for further use. Those XY spin plane components are calibrated for step 5 processing and future FGM comparisons.*

—► Calibration step # **2**: Volts, spinning sensor system, without DC field.

4.2.3 Calibration of each component in a given window.

→ *Signal Centering, trapezoidal windowing, FFT, complex transfer function including conversion from Volt to nT, correction by *1/G(f),*

- ➔ *At this step one gets the complex calibrated spectra in the spacecraft spinning reference frame*
- ➔ *To go back to time domain :cutoff at low frequency*
  - o *0.1 Hz for further transformation into SR2/ISR2 reference frame,*
  - o *0.5 Hz for further transformation into GSE*

Then apply an FFT^{-1}.

—► Calibration step # **3**: nTesla, spinning sensor system, without DC field.

4.2.4 Get calibrated time series data in nT, in a fixed reference frame.

→ *Apply the appropriate matrix, but it requires accurate spin phase computation from the Sun pulse.*
→depending on the desired reference frame, use the data set produced after either one of the filtering (see above)

—► Calibration step # **4**: nTesla, fixed SR2 system, without DC field, [Fmin,Fmax].

→ *Change coordinate system possibility from SR2 to GSE, or other (GSM, MAG, GEO...) with RCL & Rocotlib software (see [4], [5], [6]). Isr2 is inverse SR2 opposite sense for z axis)*

4.2.5 Add DC field values on X and Y

—► Calibration step # **5**: nTesla, fixed SR2 system, with previous calibrated X-Y DC field.
This permits to compare STAFF and FGM spin plane components data.

The DC field is not added on the Z axis since it is very weak and not significant, due to the very low difference (below 0.5°) between the Z and spin axis.
Note that this method is well adapted to compute calibrated spectra, but does not allow getting a continuous calibrated waveform, because edges of calibration window are disturbed by the weighting function. A new method has thus been developed and is applied now(see 4.3), after that satisfactory preliminary results have been obtained and shown at the *10th CAA Cross-Calibration meeting, Paris, 2-4 November 2009.*

The full processing line of STAFF data and output products is given in the next section.

4.3 New CLUSTER STAFF - SC continuous calibration method

The method described hereafter replaces now the classical method to produce calibrated wave form data. Indeed, this last one is well adapted to produce calibrated spectra, but does not deliver a continuous waveform. As a Fourier transform is applied on successive windows, the calibrated signal is affected by edge effects. Various test has been done to check the validity of this method with respect to the classical one (see *10th CAA Cross-Calibration meeting, Paris, 2-4 November 2009* and 11th *CAA Cross-Calibration meeting, Goslar, 7-9 April 2010*).

The continuous calibration method is based on the classical method. Data are processed as a series of successive windows but now spaced by one or a few TM count (at 25 or 450 Hz), that implies an overlapping of 2 successive windows. Then a Gaussian windowing is applied, and only the central point (or a few central points), corresponding to the Gaussian maximum, are kept. The next window is taken by a time shift of only one (or a few) TM count.

The diagram hereafter summarizes this method:

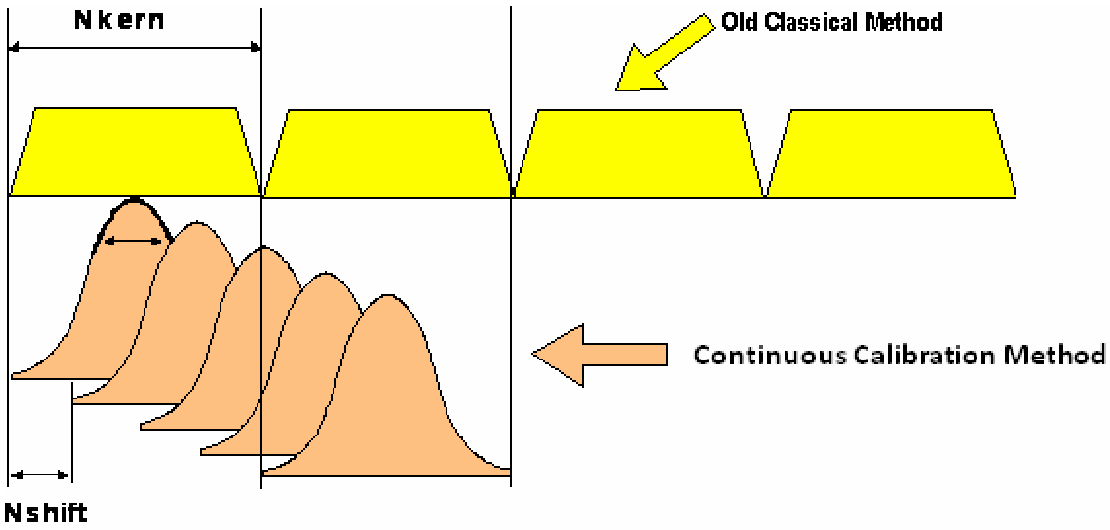

Figure 1: The schematic drawing of the two methods used for the production of continuous waveforms

This method avoids the discontinuity on each window edge and a continuous calibrated waveform is also obtained. Nevertheless, it requires much CPU time.

Nkern must be chosen to - do a correct despin (> 2Ts, but not too long, ex: 512 points)
- have a high enough frequency resolution (not too short)

Nshift can be - the shortest possible (ex : 2 pts)
- -could be extended to reduce CPU time without damage for the calibration quality (could be 6-8 pts)

The parameters chosen for NBR data are: Nkern = 1024, Nshift = 2

Note 1: In a first approach, the classical method has already been improved by a more efficient despin, (and so a better calibration), which is used in the new method. In particular, the phase continuity of the spin signal has been imposed.

Note 2: This method, working in the frequency domain, is comparable to the one chosen for Themis SCM data, where we remain in the time domain, and perform a convolution between the signal and the inverse of the impulse response of the transfer function. This is the same thing in term of mathematical approach, but different in term of coding. The choice of the frequency domain enables a more straightforward coding, and benefit of pieces of code already existing.

4.4 Full processing line

The logical flow diagram hereafter describes the full processing from the raw data until the level3 (L3) products.

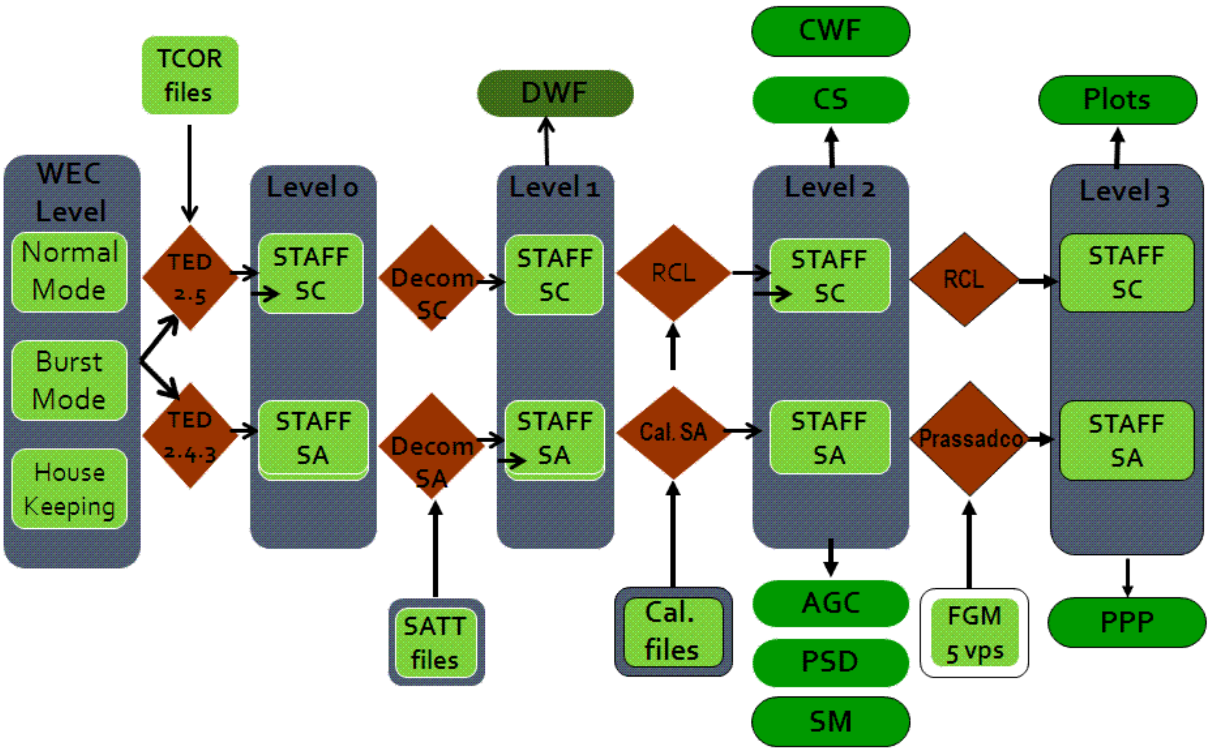

Figure 2: Processing chain for the data production.
The data products in green are delivered to the CAA.

Remarks:

- The TED software version used to process datation is different for STAFF-SC and STAFF-SA. For details, see UG or ICD.
- The STAFF-SC L1 data files, also called Decommuted Waveforms (DWF) are delivered to CAA because it is the only data pack containing all initial data (information about block data format, datation, compression quality, etc.), before any transformation such as calibration or change of reference frame.
- STAFF-SA calibration is done by dedicated software [7].

- STAFF-SC calibration is done using a part of RCL software (see [4]). RCL (Roproc Command Language) is a set of commands allowing many different data processes required for spatial experiment. This is an overcoat of the Roproc software (P. Robert's procedures, see [3]), initially developed for CLUSTER. RCL software allows the processing of CLUSTER data as well as data issued from any project/experiment, on any platform and Operating system (tested on SUN/Solaris, Linux, windows).

- The L2 to L3 processing is done by RCL for STAFF-SC and PRASSADCO for STAFF-SA (see [4 & 8]).

5 Results of Calibration Activities

There has been a problem on the calibration of STAFF-SC data for S/C #1.

- Problem identified after launch: the perpendicular DC-field measured by the spinning spacecraft at the spin frequency is not the same from S/C #1 than the other S/C: Difference is ~ 10 %. For an example, see the left-hand plot of Figure 3.

- S/C# 1 gives always lower values than other S/C for the DC field estimation from the spin signal.

- This difference is confirmed by FGM data.

This discrepancy has been identified thanks to coming back to old files of ground measurements of the transfer function: the current loop used was not the same as for other spacecraft and has been shown to have different characteristics. This has been shown to affect only the frequency range below 8 Hz. This is solved now by using for SC1 a transfer function that is the mean fo the transfer functions of the 3 other spacecraft. The results are shown in section 6.

As will be seen in the description of the cross calibration activities, apart SC1, when comparing SC2, 3 and 4 DC field and waveform in NBR (f< 10 Hz) with FGM, an additional difference of about 10 % was evidenced. This point together with the issue on SC1 led to review the ground equipment.
The above differences have been understood and the transfer functions updated accordingly.

Main conclusions are given in section 6.

6 Results of Cross-Calibration Activities

Plots hereafter have been presented at various Cross Calibration meetings. All main results have been summarised and put in next sections.

6.1 Comparison of STAFF-SC Spin plane DC field with FGM

6.1.1 Case studies

The STAFF/FGM comparison plots below have be presented at the *1tst Cross-Calibration Workshop, 2006, ESTEC*, and at the 8th *Cross-Calibration Workshop, Kinsale, Ireland, 28-30 October 2008*.

A first problem was identified after launch: the perpendicular DC-field measured by the spinning spacecraft at the spin frequency was not the same from S/C #1 than from the other S/C: The difference was of ~ 8 to 20 % with respect to FGM. S/C# 1 gave always lower values than other S/C by ~10%, and the difference was confirmed by FGM.

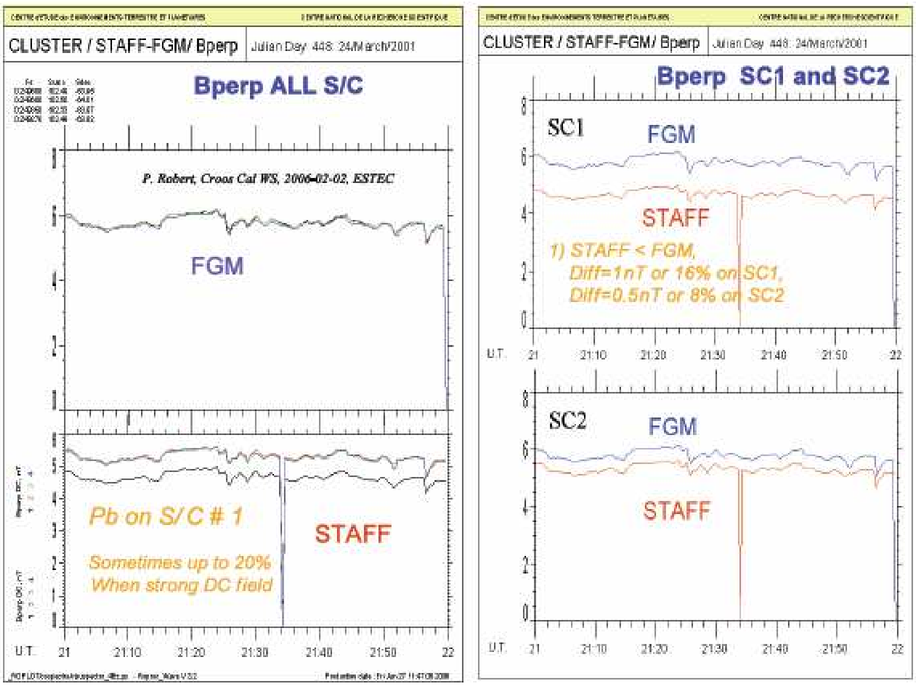

Figure 3-a. Comparisons of the modulus of the DC filed in the plane perpendicular to the spin axis. Left: comparison of the perpendicular components between the four spacecraft. Top panel is for FGM and bottom for STAFF-SC. Right: comparison of FGM and STAFF-SC for C1 and 2.

After correction of the transfer functions, the FGM/STAFF comparison gives the following results, shown on Figure 3-b. Now the agreement is good on this case study for the modulus of the DC field perpendicular to the spin axis.

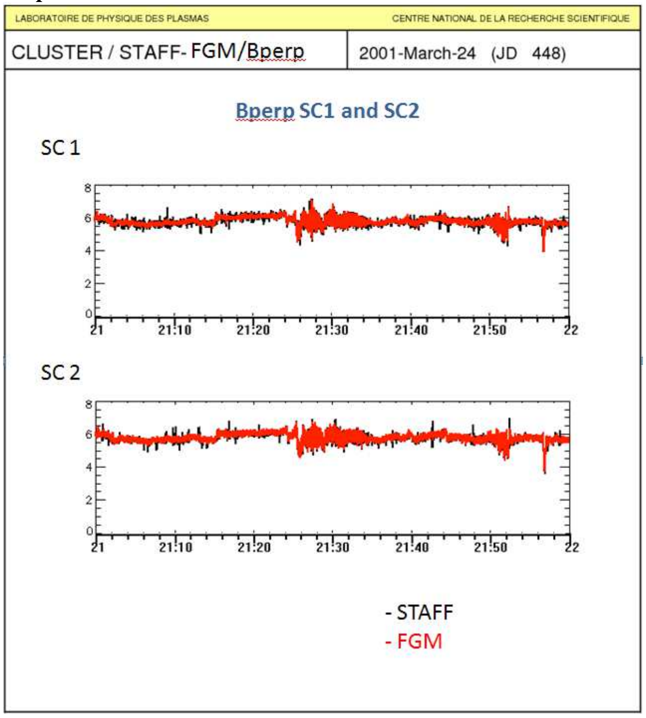

Figure 3-b: same as right panel of figure 3-a, with the corrected transfer function. This plot has been done with high resolution data. One can see the good agreement between STAFF and FGM data.

Results of a detailed study showing the components of the DC field in the spin plane for both STAFF and FGM, before and after the transfer function correction are given on figure 4, for S/C 1 and S/C2.

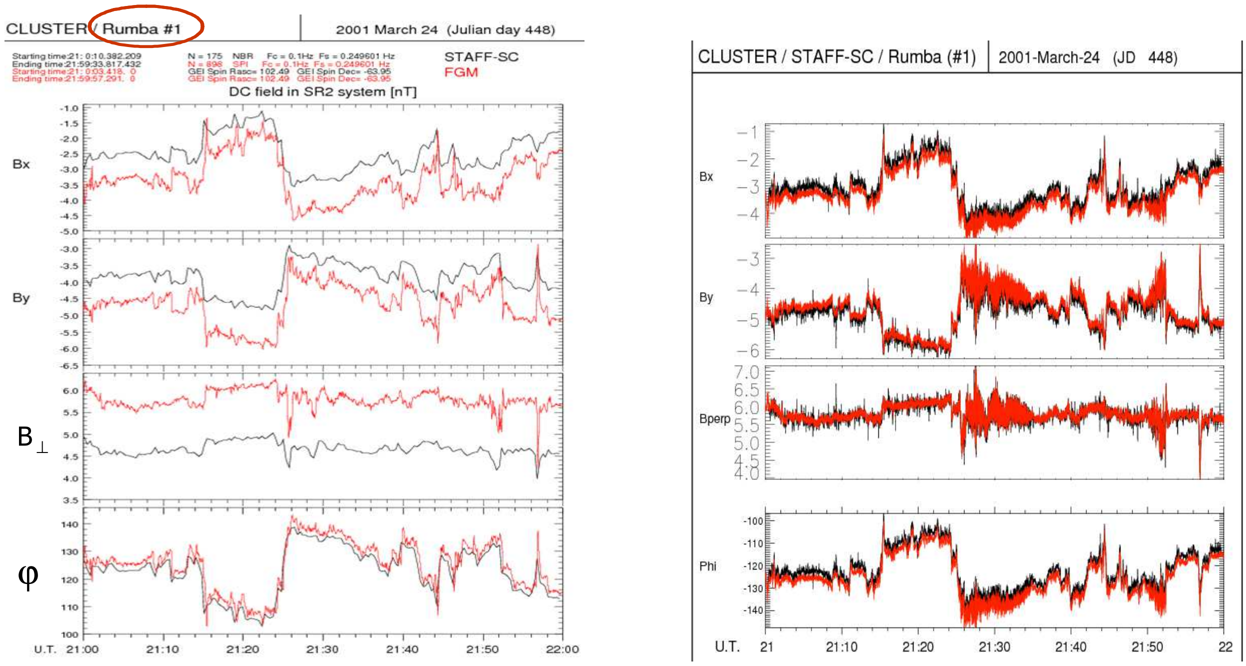

Figure 4: STAFF (black) and FGM (red) comparisons with the old(left) and the corrected transfer function (right), for Bx, By, Bperp and ϕ components. The good agreement for the corrected transfer function is clear; This new plot has been done with the high resolution FGM data and the new continuous CWF STAFF-SC data.

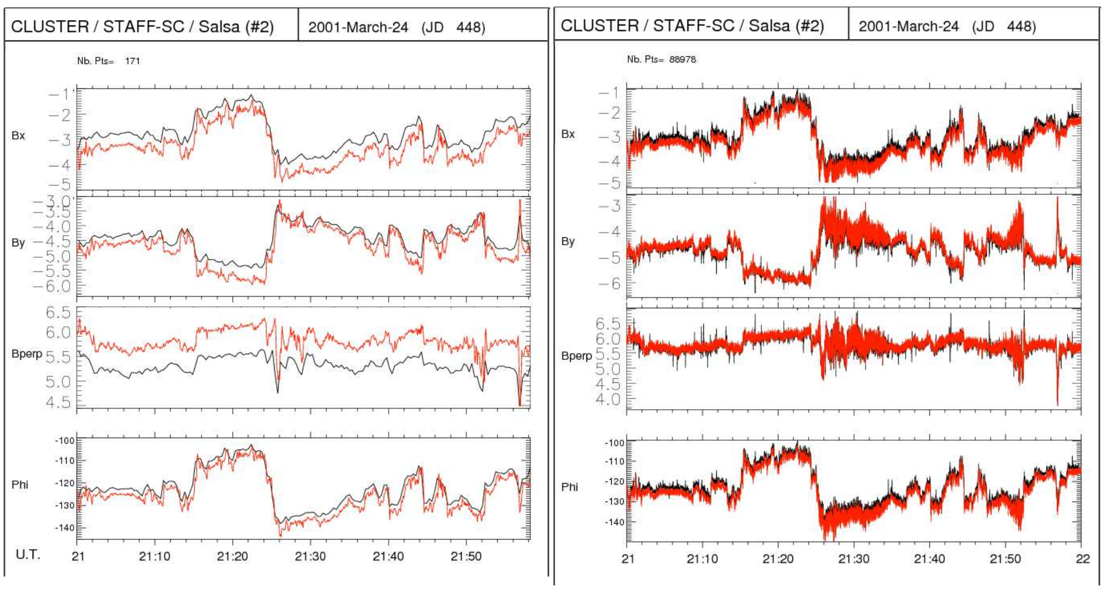

Figure 5: same as figure 4, for S/C 2

6.1.2 Statistical study for all S/C

To confirm the above results, a statistical study has been done on more than 30 cases, covering 6 years of cluster mission, in various conditions. Results are shown below (S/C#1,2,3,4 in Black, R,G,B).

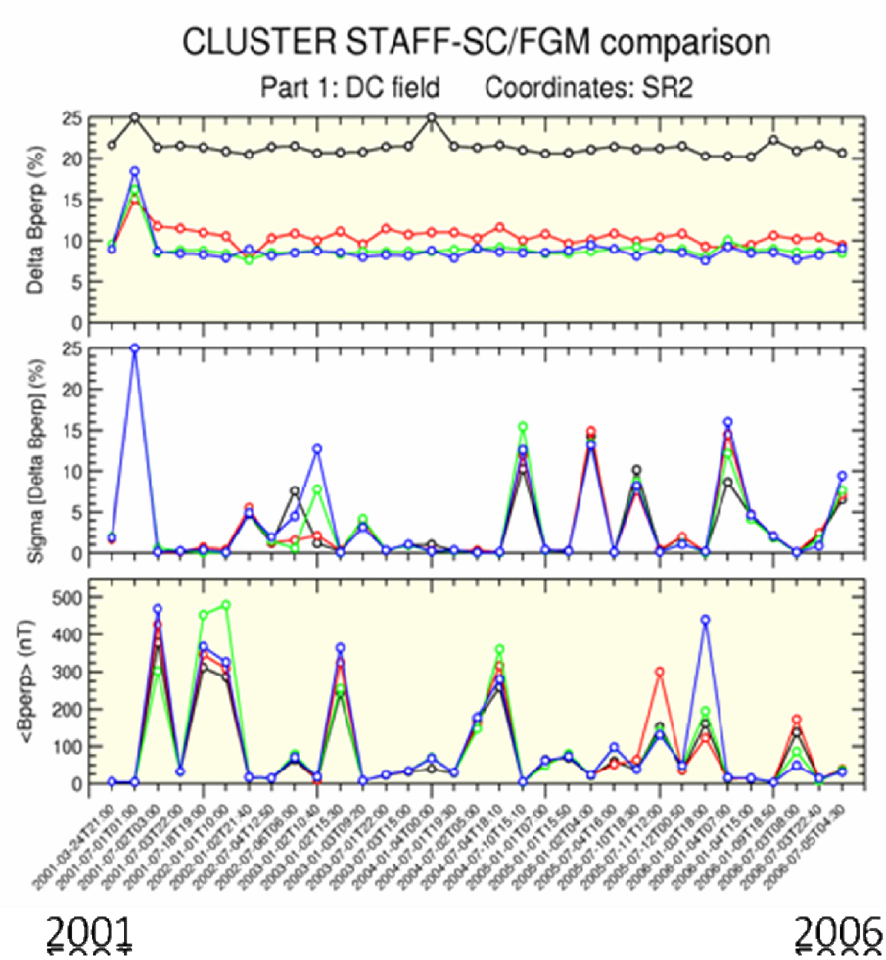

Figure 6: Evolution with time of STAFF and FGM comparison for DC field data in the spin plane obtained with the old transfer function

⇒ ***These results show that the difference on the DC fields was always ~21% for S/C#1 (with STAFF lower than FGM), and ~10% for S/C#2,3 and 4.***

This series of results have led to go back to the old calibration files and to the ground calibration facility.

This has led to two different results. First spacecraft 1 had been calibrated with a different courant loop that the other spacecraft. Measurements of the 2 different loops characteristics explained the difference of about 10 % at 0.25 HZ, the difference decreasing progressively with increasing frequency, being null at 8 HZ. It has been decided to apply to SC1 data the mean transfer function of SC1, 2 and 3.

Second, looking at the equipment, it was found that the calibration loops are no longer a perfect circle; new tests have been done with new and accurate sensors. A further correction of about 7 db to apply to the previous measurements has been identified. The results of the use of the new transfer functions are shown in what follows.

When applying the corrected transfer functions to the same data set, one finds the results given in figure 5-b.

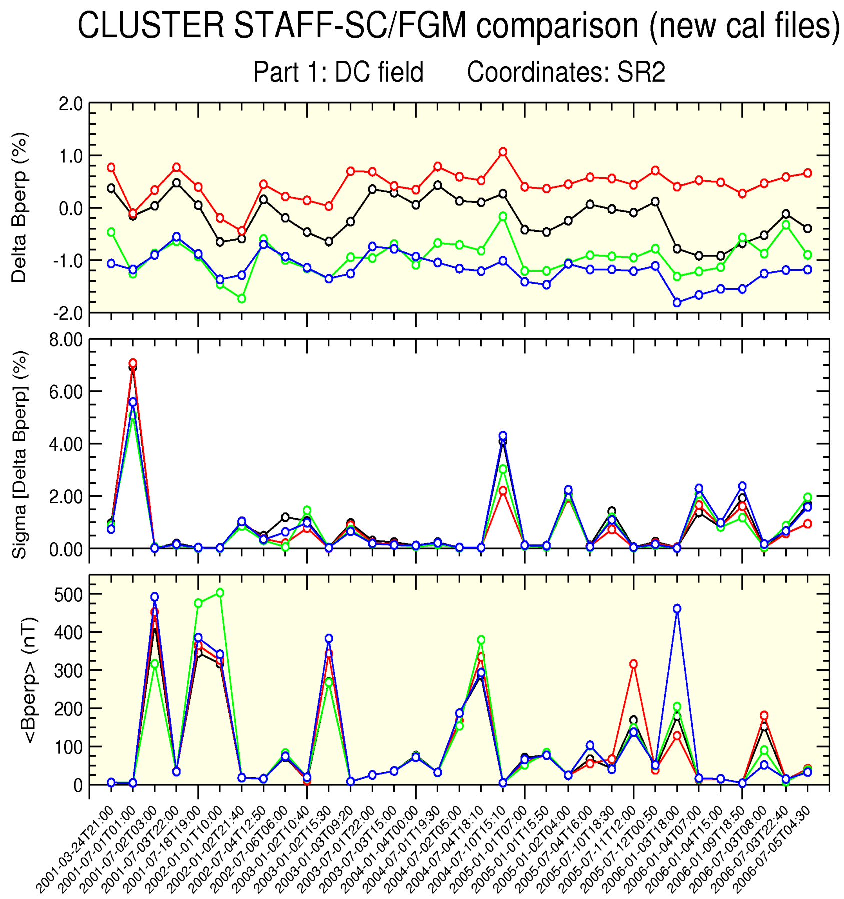

Figure 7b: Same as figure 6, with the corrected transfer functions. The difference between FGM and STAFF are now of the order 1%

⇒ **In conclusion**, these new results show that the new transfer functions give results quite comparable to FGM ones, for strong and weak signals and for six years of Cluster data.

⇒ Independently of the transfer function issue, one should notice the stability of the instrument performances with time.

6.2 Comparison of STAFF - SC spectra with FGM

6.2.1 Strong and low noise levels

Plots hereafter show comparisons between STAFF and FGM spectra during a high amplitude large frequency band event (top panel), and very low ULF wave activity (bottom panel); for the latter case, the noise level corresponds to the instrument sensitivity (*1tst Cross-Calibration Workshop, 2006-02-02, ESTEC)*.

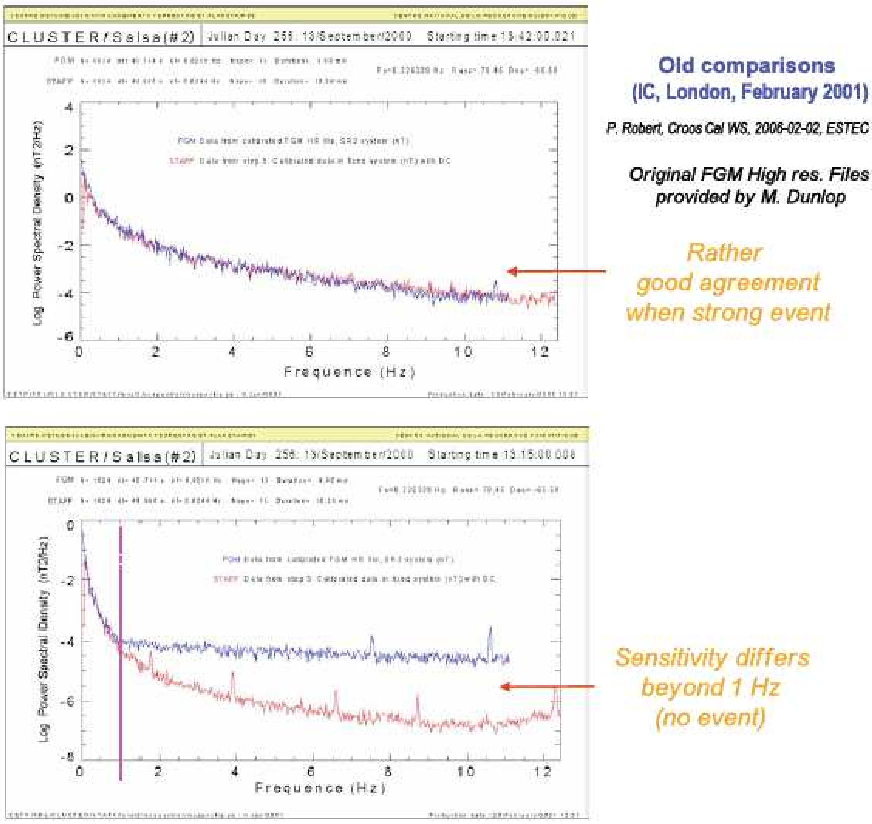

Figure 8:: Comparison of power spectra between FGM and STAFF-SC. The example on the bottom shows a case of low-amplitude waves that cannot be observed by FGM due to its higher noise level above 1 Hz

⇒ Main conclusion is that the sensitivity of the two instruments are equivalent around 1 Hz. Below 1 Hz, FGM is better and reach the real DC (STAFF stops at ~ 0.1 Hz and has some troubles around spin frequency), and beyond 1 Hz, STAFF is more sensitive.

6.3 Comparison of STAFF - SC waveform with FGM

6.3.1 Classical method and old transfer function

Plots below directly compare the STAFF-SC calibrated waveform (NBR) with FGM data, in the SR2 system (*1tst Cross-Calibration Workshop, 2006-02-02, ESTEC)*.
STAFF spin plane components are differently affected by the spacecraft spin. SR2 frame has been also chosen as it does not mix the XY spin plane components, and the parallel Z component. To remove the remaining spin effect, waveforms (STAFF and FGM) are filtered between 1 and 6 Hz.

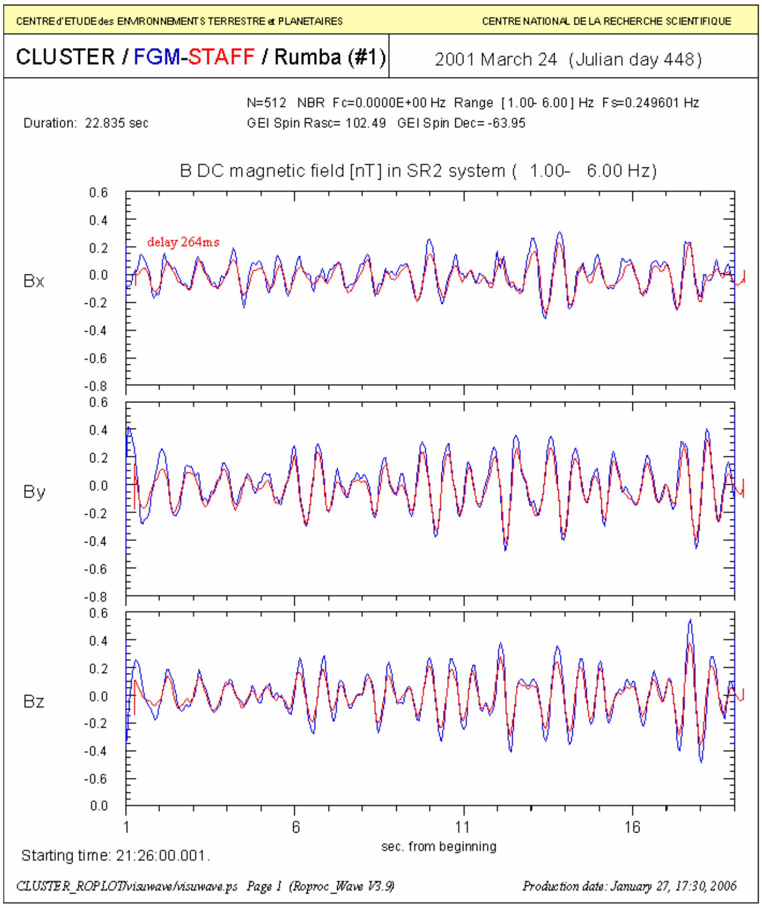

Figure 9: STAFF/FGM comparisons at waveform level

Results are rather satisfactory, particularly concerning the shape of the waveform, which correspond to a wave at ~ 2 Hz.

For another example, there is a zoom on the phase comparison, which has not changed with the updated transfer function~~,~~, see figure 10.

⇒ In this event using the old transfer function, we found the same difference of ~ 20 % on the amplitude for S/C#1. Conclusions remain the same for other S/C.

It is also possible with STAFF to obtain the no filtered waveforms in the spin plane, including DC part. This is the example above, where we apply an arbitrary offset to a better visibility:

Bx = - 4.5 By = - 5. Bz = +0.5

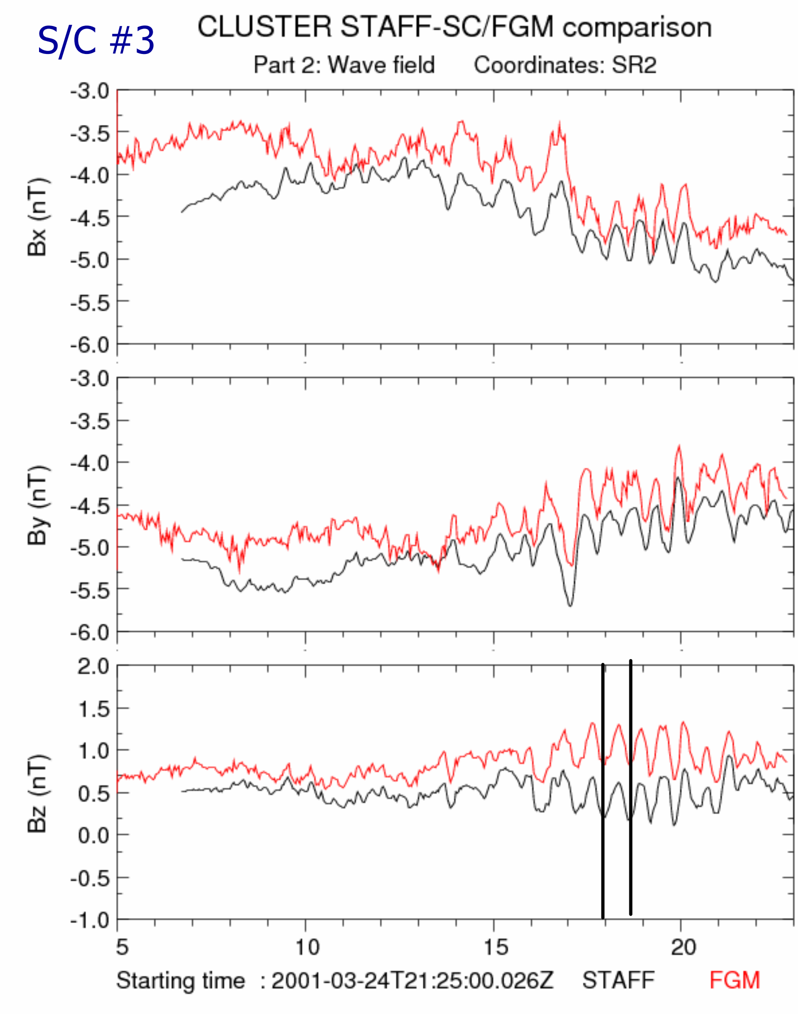

Figure 10: Same as figure 9 for another event.

Results show a very similar shape, and STAFF fluctuations amplitude at ~1 Hz are always ~10-12% lower than the one of FGM.

⇒ ***Once again, we got the same conclusion at 1 Hz than for the DC field.***

6.3.2 New continuous calibration method and new transfer function

Results given below have been shown in *15th CAA Cross-Calibration meeting, London, April 2012.*

The Calibrated Wave Forms (CWF) using the new (corrected) transfer function are delivered to CAA in both GSE and ISR2 frames. An example of the CWF product is given below. In this example the data are in GSE frame, filtered above 0.5 Hz to avoid all spin effect and have a range where sensitivity is good. Note that in SR2 system the 2 DC components in spin plane are also delivered.

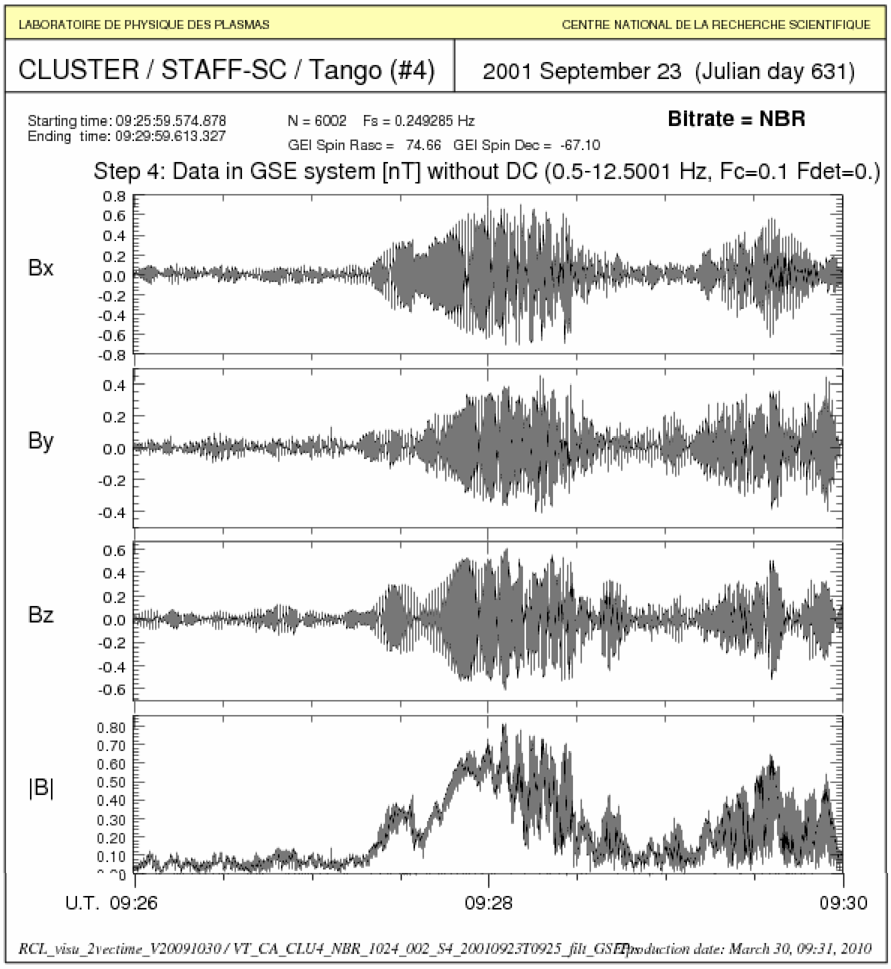

Figure 11: example of the continuous calibration method results.

The figure below present a further example of comparison between the newly calibrated waveform delivered to CAA and FGM data. One can see that the results are satisfactory now.

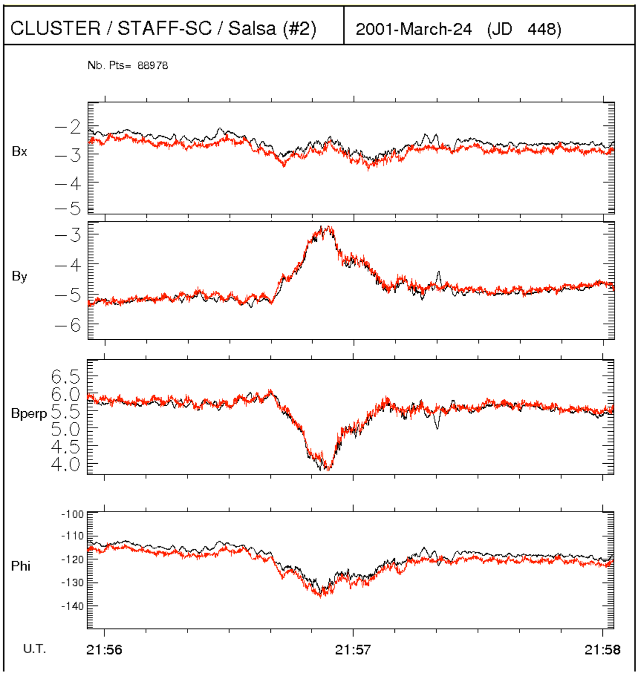

Figure 12: comparison STAFF/FGM for a short time scale event.

6.4 Spectra continuity between STAFF and FGM

Plots hereafter plots come from [9], and show a rather good agreement between the slope of the STAFF-SC spectra (NBR) and FGM, within a common frequency range of about 0.6 to 3 Hz. Plots show also an abrupt change of the slope around 1 Hz, but the spectra continuity between STAFF and FGM is clearly visible. Logarithmic scale does not allow the estimation of the differences with accuracy as previously, but this is also a significant result which be worth to be said.

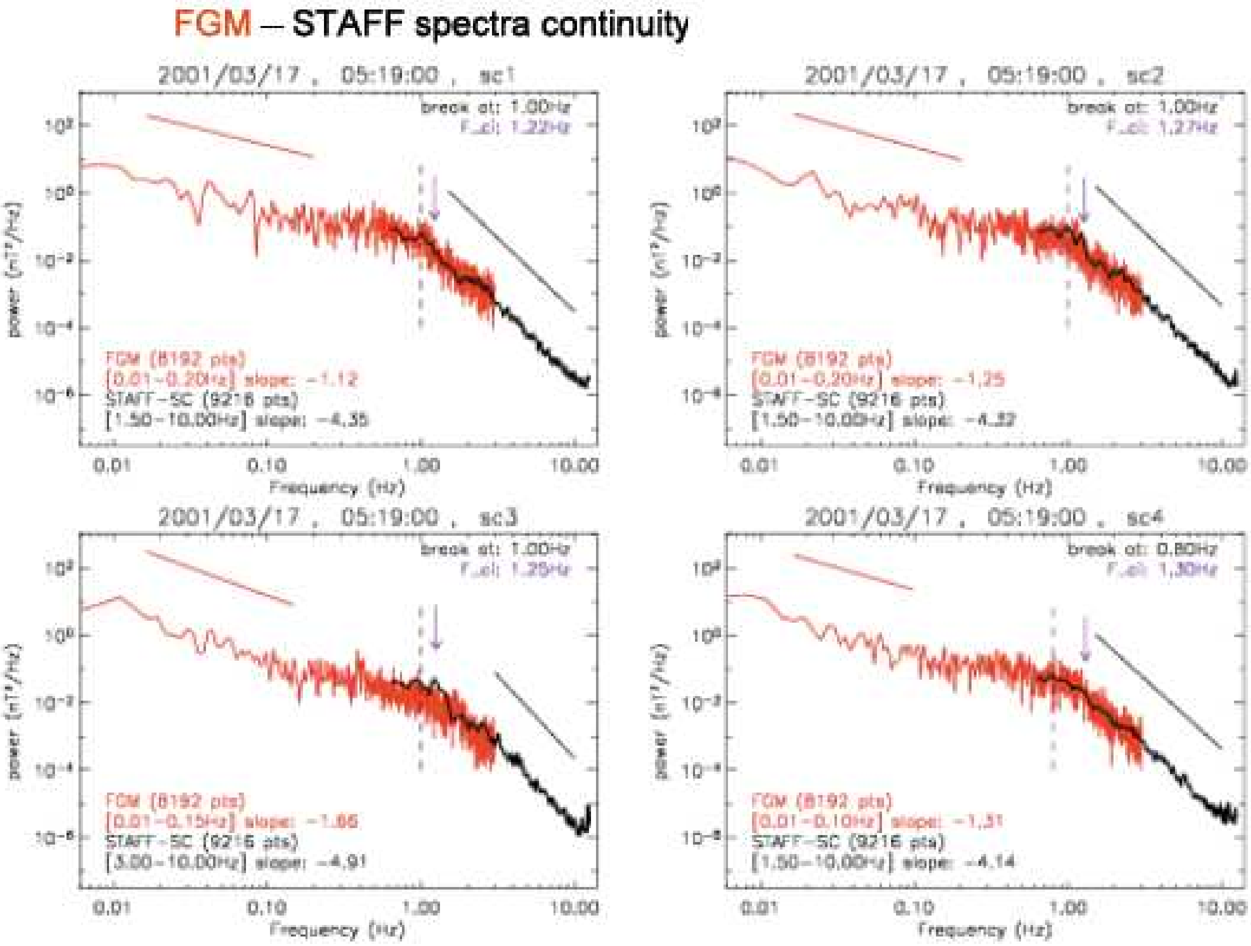

Figure 15: Comparisons of spectra coming from FGM (red) and Staff-SC (black)

6.5 Conclusions on STAFF-FGM comparison

6.5.1 Main conclusions

All the previous differences observed between STAFF-SC and FGM have mostly disappeared with the correction of the search coil transfer functions. There is no longer a difference between S/C 1 and the other spacecraft. The residual difference between STAFF SC and FGM is now of the order of 1 – 2 % in amplitude and about 2-3 ° in phase. It is not expected to reach a better agreement in the future.

6.5.2 Limitation of STAFF-FGM comparison at low frequency

The DC part of the magnetic field can be estimated by STAFF-SC thanks to the Doppler effect, as seen previously. But since the transfer function is null at zero frequency, there is a gap in the observed spectrum, depending on the wave polarization.

So, a right-handed polarized wave at spin frequency cannot be recorded by the STAFF sensor. It is seen at F=0 by the spinning sensor coordinate system because we have $F_{SR2}= F - F_{spin}$

But a left-handed polarized wave at any frequency, including DC, is recorded by the STAFF sensor because its frequency is $F_{SR2}= F + F_{spin}$

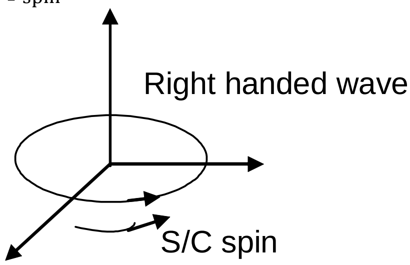

Figure 17.

In conclusion, at low frequency, near the spin frequency, we cannot expect a full agreement between STAFF and FGM, except for left-handed polarized wave. This is why the CWF will be filtered below 0.5 Hz, to get data with a good accuracy.

6.6 Spectra continuity between STAFF - SC and STAFF - SA

6.6.1 General continuity

Plots below illustrate the connection between STAFF-SC spectra upper frequency band and STAFF-SA spectra lower frequency band. Level and slope are rather good, except a small discrepancy for S/C #3. Further investigations should be done..

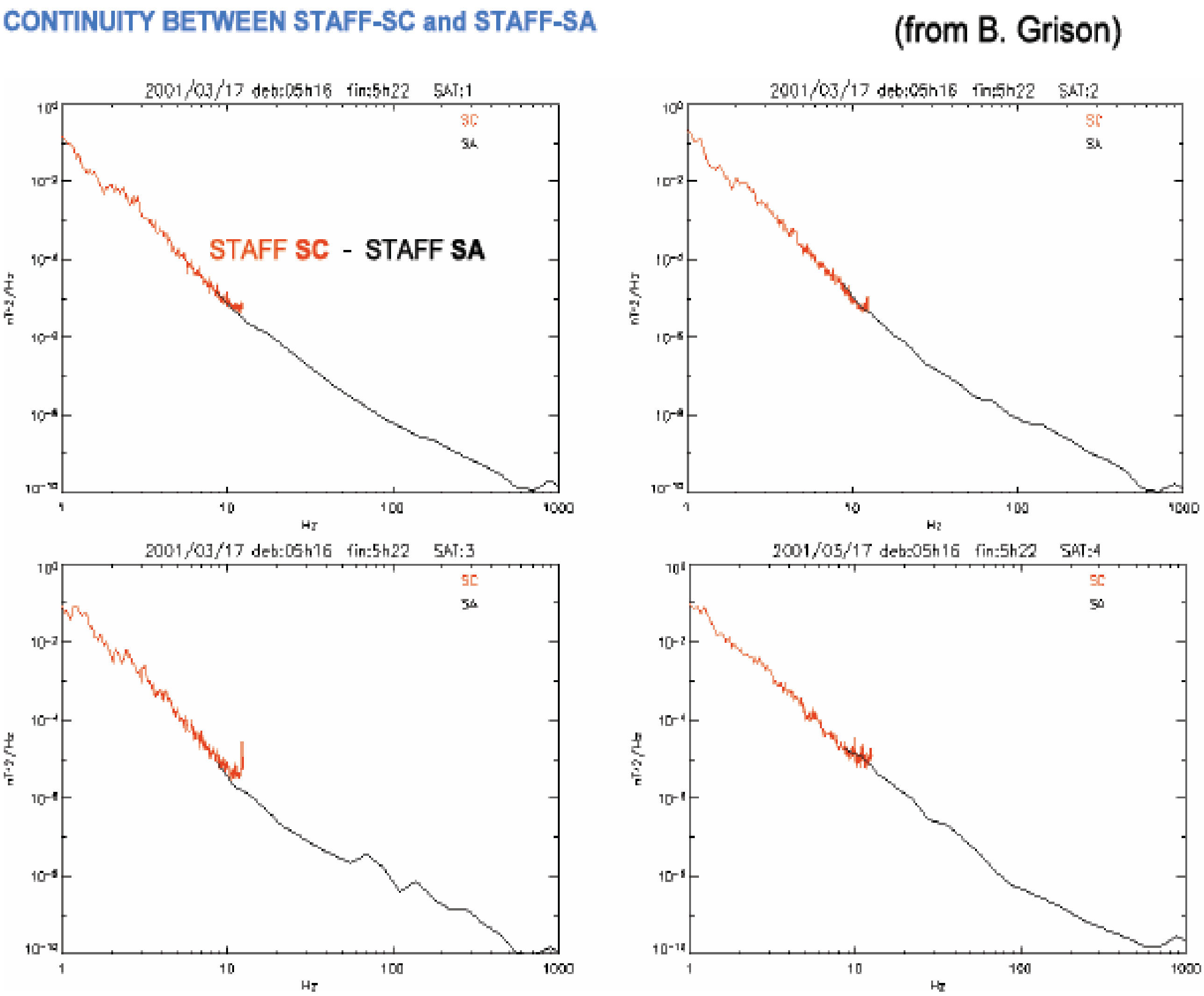

Figure 18: Staff-SC spectrum (red) and SA (back)
Courtesy of B. Grison

6.6.2 Instrumental effect at low frequency on Staff-SA

If the continuity between both analyses is generally good, one can on some events find, when looking in details to the data, a small apparent difference at low frequency. Figure 19, shows, for SC 1& 4, a comparison between STAFF SC and STAFF SA for turbulent like wave spectra: SC in the 1 -10 Hz frequency range and SA in the 8 - 300 Hz frequency range (continuous lines). One can see that the 2 sub experiments give a similar slope behaviour joined by the dotted line. But a small instrumental effect is visible, minimizing the data values of SA, between 8 and 18 Hz on S/C 1 and from 8 to 35 Hz for S/C4,. S/C 2 and 3. This is under study. (See also UG § 6.3.). The 3 spectra are respectively the power perpendicularly to the main field, the power parallel to the main field and the total power.

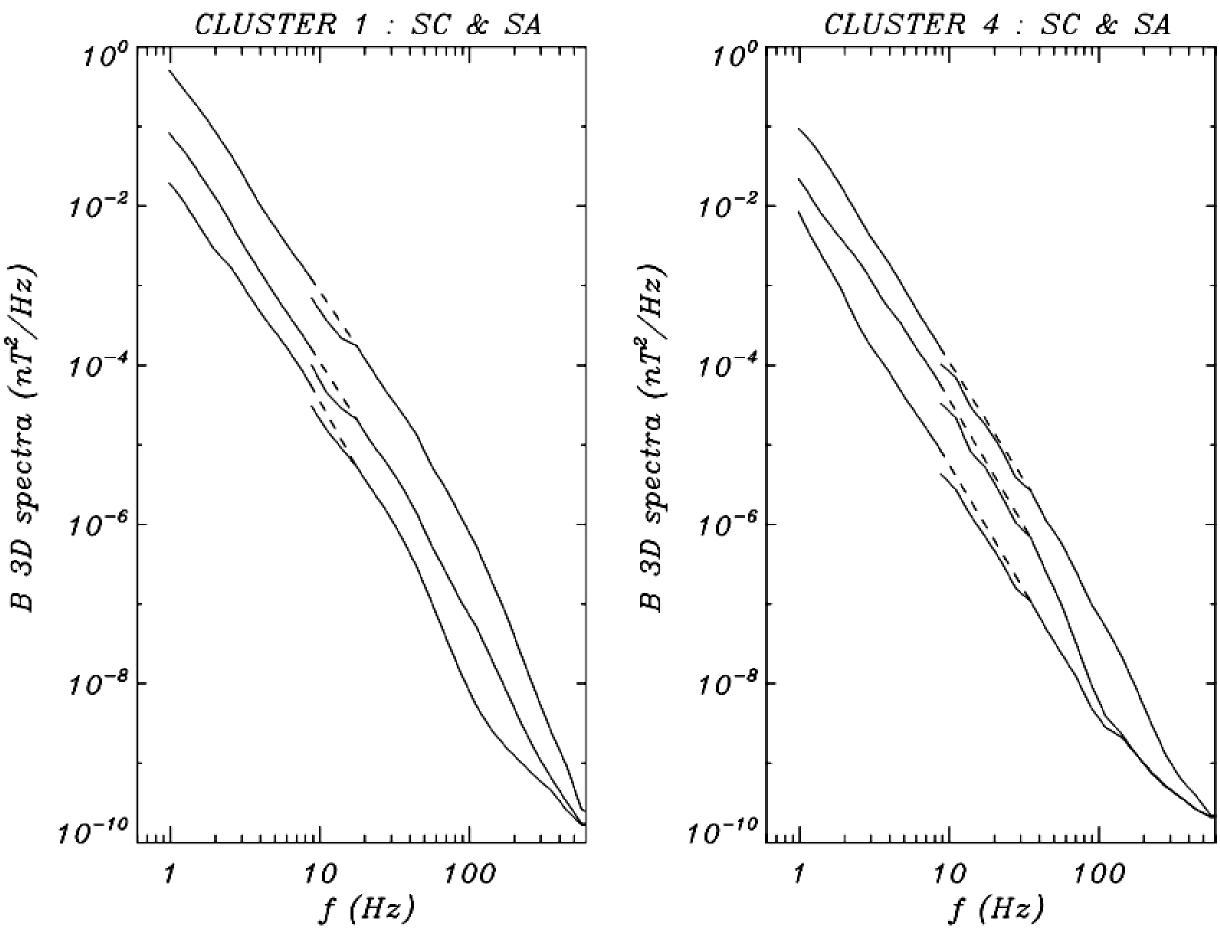

Figure 19: Evidence of small discrepancies between Sc and SA at small frequencies Courtesy of C. Lacombe and Y. De Conchy.

6.6.3 Comparison using special mode of SC and SA

We can extend this comparison to higher frequencies, when SC, in HBR mode, cover the frequency range up to 180 Hz. Figure 20 (for SC1) and 21 (for SC4) show a comparison between STAFF SC and STAFF SA taking benefit of a special mode commanded to get a maximum frequency overlap between the 2 analysers. The spectrum analyser has been commanded in a normal bit rate mode during a period of high telemetry rate, having then a frequency overlap between 8 and 180 Hz. The crosses are for the spectrum analyser frequencies, the continuous line for the result of a wavelet analysis performed on the SC calibrated waveform. The 4 plots are for the 3 magnetic components and the total power. Both behaviours are globally similar, taking into account - as in the previous figure - the underestimation of STAFF SA at low frequency (see above).

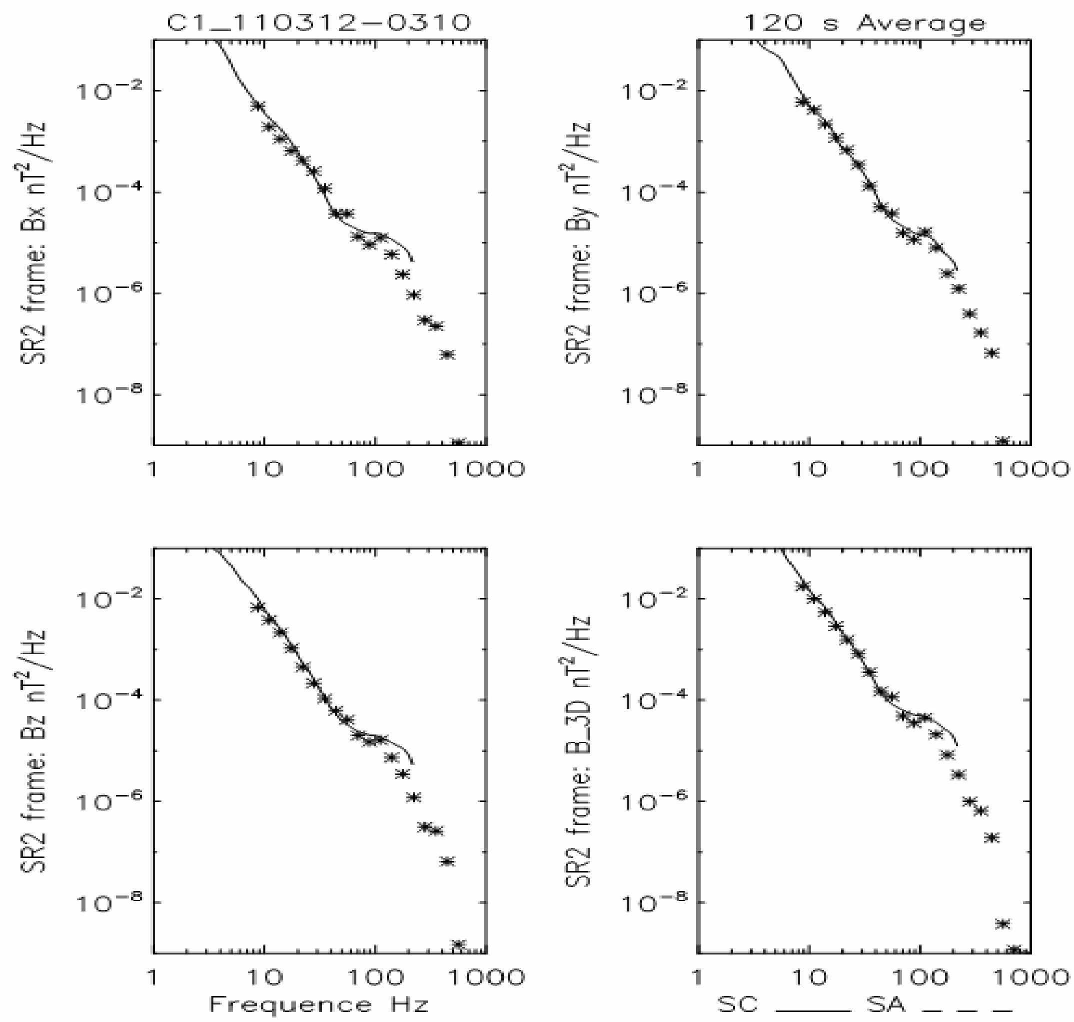

Figure 20: Combined spectra between Staff-SC (line) and SA (cross) for SC1

Courtesy of C. Lacombe and Y. De Conchy

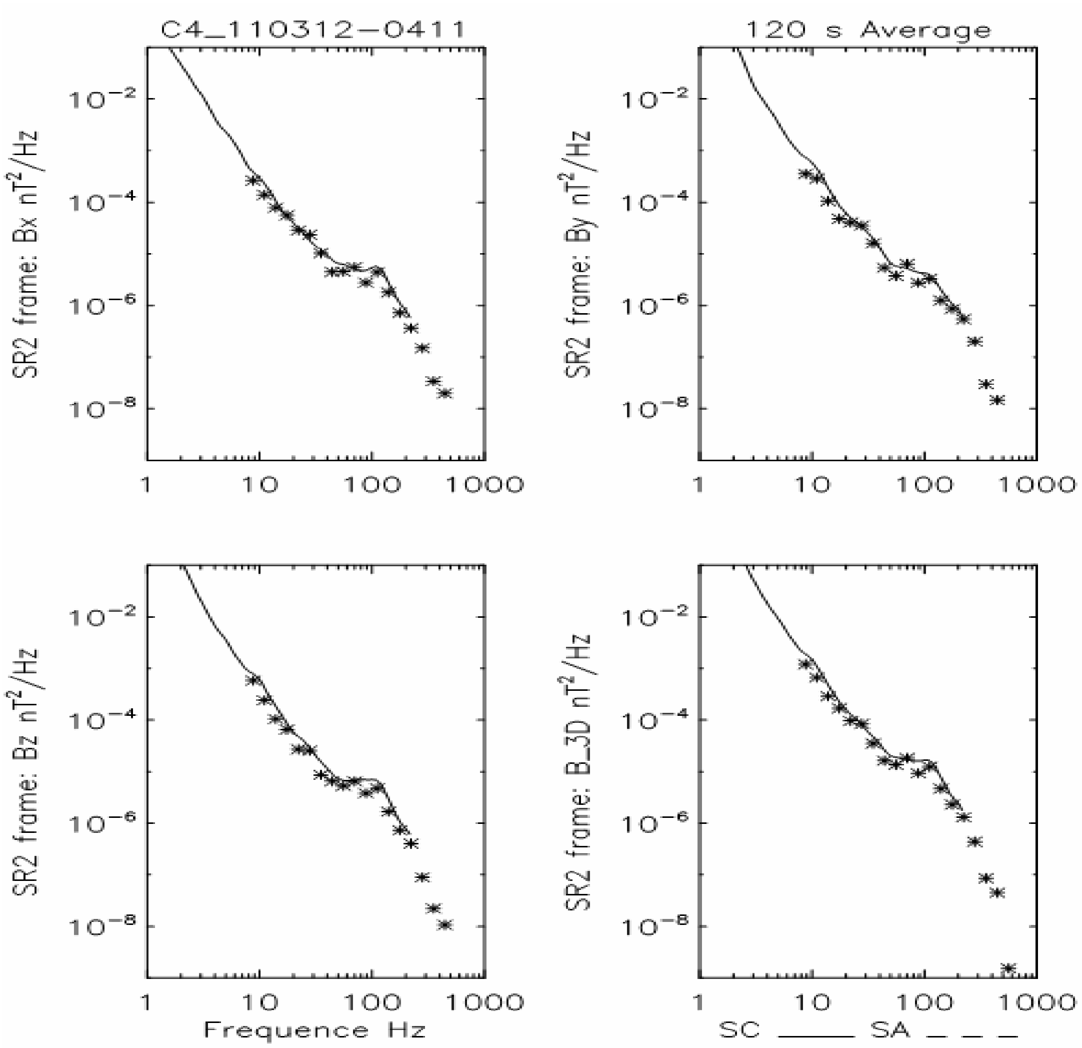

Figure 21: Same as figure 20 for SC4.

6.7 Continuity between FGM, STAFF-SC and STAFF-SA

Figure 22 below shows a combination of FGM, STAFF-SC and SA data for magnetic and Staff-SA and EFW for electric components. A good continuity is observed between the data sets, acquired during a magnetopause crossing, with a rather constant slope until 200 Hz. Small discrepancies between STAFF-SC and STAFF-SA has been corrected since this work. The STAFF sensitivity is also plotted.

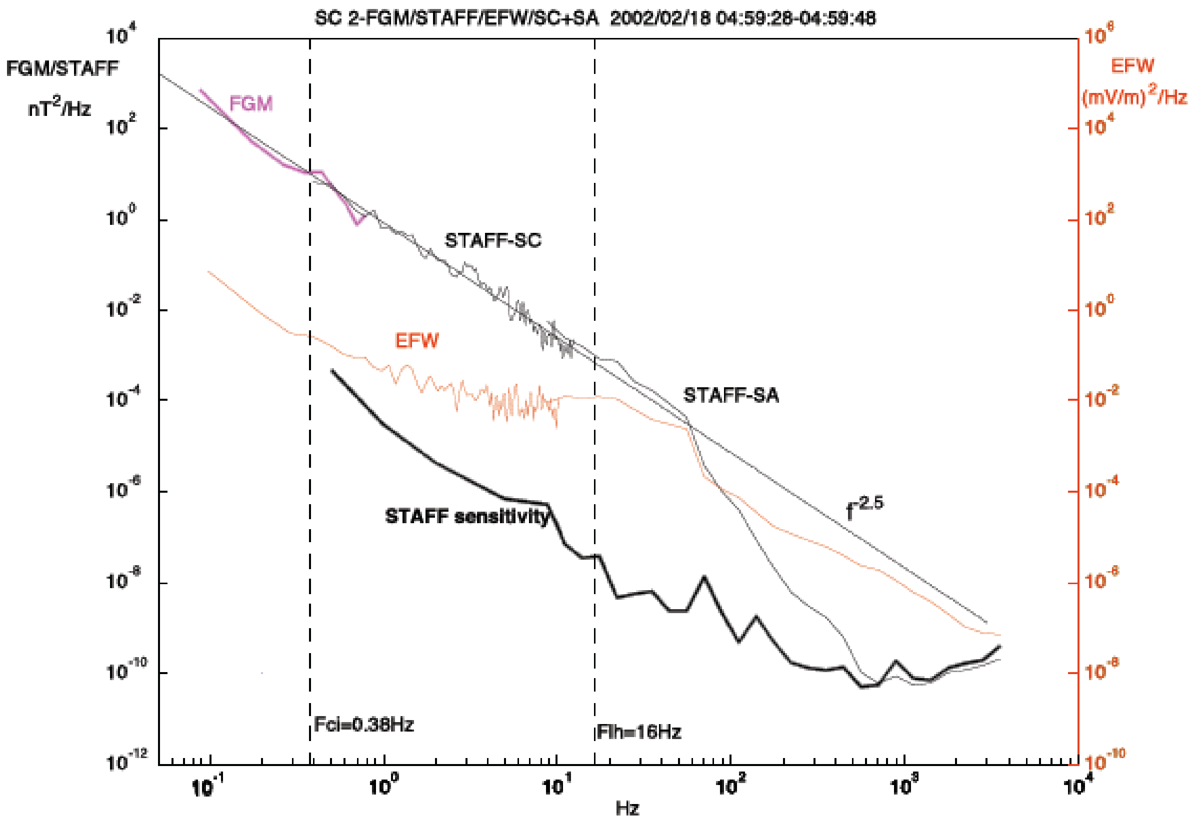

Figure 22: Combination of FM, STAFF-SC and SA spectra

6.8 Statistical comparisons between STAFF-SC and STAFF-SA

For these comparisons, data from several periods have been used to widely cover the possible magnetic fluctuation intensities range. The intervals are:

- 16/12/2001 from 05:30 to 06:30 (high intensity fluctuations in the magnetosheath).

- 19/12/2001 from 02:40 to 03:40 (low intensity fluctuations in the magnetosheath).
- 03/02/2001 from 17:00 to 18:00 (very low intensity fluctuations in the solar wind).
- 19/02/2002 from 01:00 to 02:00 (low intensity fluctuations in the solar wind).

For each of these intervals, the data have been divided into 20 seconds length sub-intervals. On each of those sub-intervals, the average values have been computed around 8.8 Hz for both the STAFF-SA (SA) and the STAFF-SC (SC) fluctuations. These average values are called respectively *<sa>* and *<sc>*. Practically, the following procedure has been used:~~.~~

For SA, the time resolution of each channel is one second. Therefore, *<sa>* is the average of the 20 consecutive spectral values at the first SA frequency channel, that is at 8.8 Hz. As indicated previously, the 27 SA frequency channels are distributed logarithmically in the frequency range between 8 Hz to 4 kHz. Each of these 27 channels measures fluctuations in a band Δf around a central frequency f_0 with $\Delta f/f_0 \approx 0.26$. Therefore, for the first SA frequency channel, the fluctuations are recorded over the frequency range ~7.6 to ~9.9 Hz. For SC, the PSDs spectra of the whole waveform signal are first computed on each 20 seconds sub-interval. Then, *<sc>* is the average PSD in the frequency band ~7.6 to ~9.9 Hz.

In the figures below, for each of the three components, for Cluster 1 and for all the 20 seconds subintervals, *<sc>* is plotted as a function of *<sa>*. On these figures the magnetic fluctuations are displayed in nT_2/Hz. The diamonds represent the magnetosheath high intensity fluctuations, the stars represent the magnetosheath low intensity and the crosses represent the solar wind data. Note that the plots and the following conclusions are very similar for all the other Cluster spacecrafts. Two main conclusions arise from this study:

- Globally the agreement between *<sc>* and *<sa>* is good while the fluctuations intensity is larger than $\sim 10^5\ nT^2/Hz$ (diamonds). For intensities lower than this threshold (stars), there is no agreement. Only an extensive physically based study would provide us the fluctuations absolute level to determine which experiment (SC or SA).gives the true measurement. Note that this threshold value ($10^5\ nT^2/Hz$) is close to the search coils (SC) sensitivity level at this frequency ($10^6\ nT^2/Hz$).

- For all spacecraft, the agreement is better on the Z-component fluctuations than on the X and Y. It is probably due to the despin procedures applied to both SA and SC. For SA, the pairs of spin-plane magnetic field components are despun aboard the spacecraft. For SC, the despin is performed on ground. For SC the despin procedure has noticeable effects on the X and Y components around the spin frequency (0.25 Hz) and almost no effects on the Z component.

In summary, the agreement between STAFF-SA and STAFF-SC is good, while the magnetic fluctuation level around 8.8 Hz is larger than $10^{-5}\ nT^2/Hz$. Consequently, the magnetic PSD data around this frequency, with values smaller than this threshold should be used with caution.

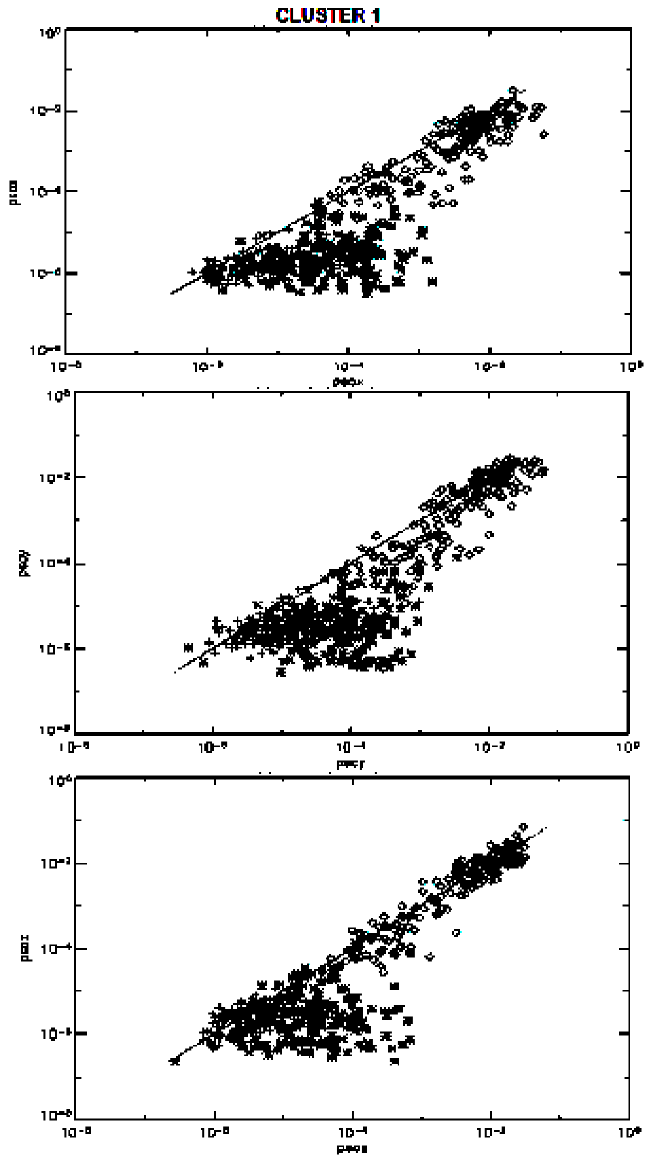

Figure 23: Comparison of magnetic fluctuations levels between SC and SA at 8.8 Hz, for low and high intensity values

6.9 Comparison of STAFF - SA with other WEC instrument

Here are presented cross-calibration results between STAFF and other WEC instruments, first comparisons of magnetic fluctuations between STAFF SA and WBD, then between STAFF-SA electric field fluctuations and EFW WHISPER and WBD. Since the comparisons between

STAFF-SA and WBD have been done on a reduced data set, they are probably not fully representative and further comparisons should be done.

6.9.1 Magnetic fluctuations comparisons between STAFF-SA and WBD

This comparison is done first on a specific event. A chorus type event detected when WBD and STAFF SA were both operating has been chosen (see below figure 24)

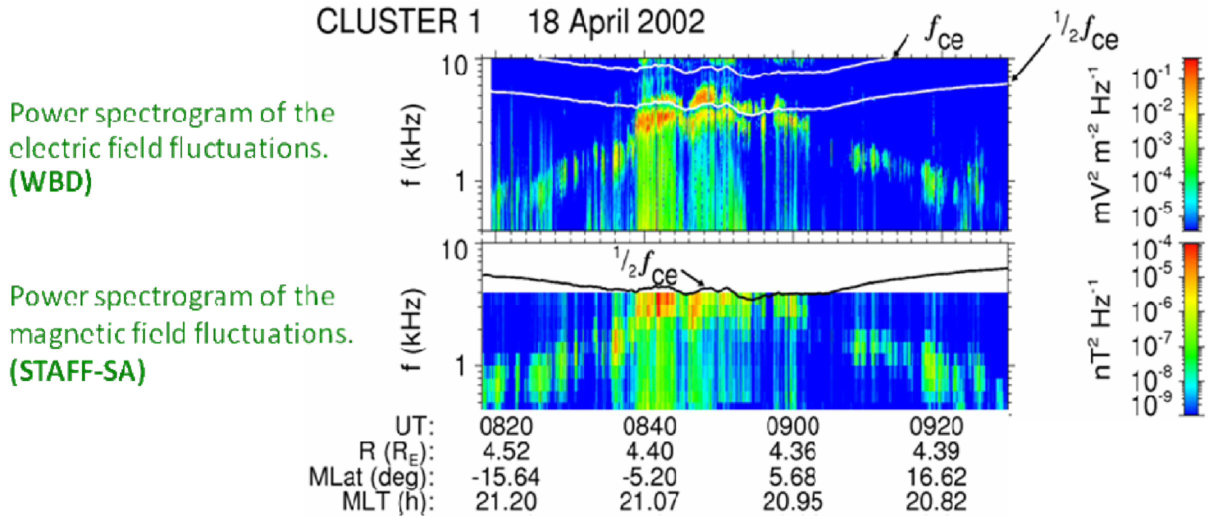

Figure 24: event chosen for comparing STAFF SA and WBD

The analysis has been done during the most intense part of the event, between 08:44:55 and 08:53:48. The WBD magnetic spinning component By is acquired 10 s over 50 s of data (covering periods where Whisper is active). A FFT is applied to the time series samples corresponding to the 4 s STAFF SA analysis intervals and the power is averaged over frequency intervals corresponding to the 27 STAFF SA frequency bins. The STAFF-SA data are despun and analyzed onboard. Figure 25 shows the results of the comparison, for the whole frequency range and for the 3 STAFF-SA bandwidths.
The best fit is for C band (500-4000 Hz), which corresponds to the frequency range of the maximum wave power (see figure 24).

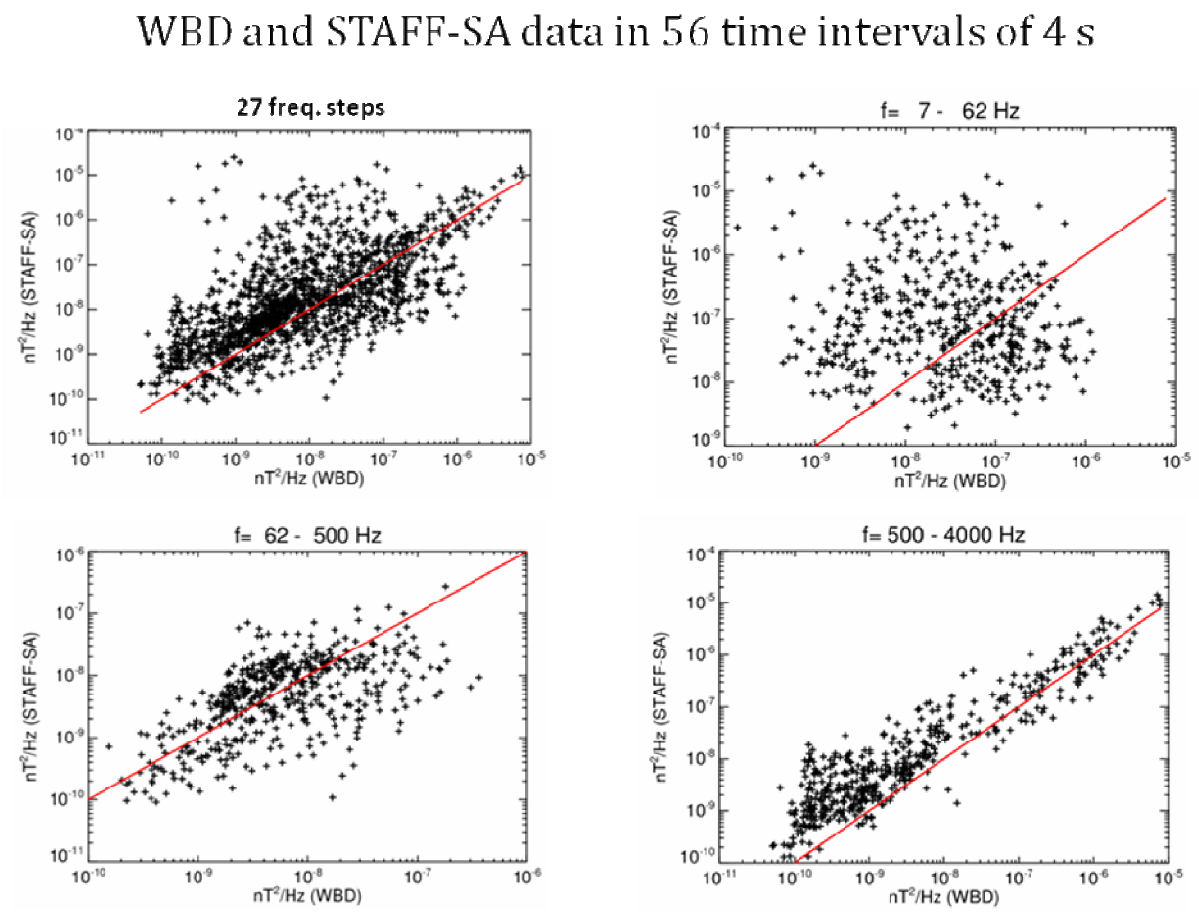

Figure 25: comparison of STAFF-SA and WBD power density of magnetic fluctuations (in nT²/Hz) for the whole frequency range (top-left) and for the different STAFF SA frequency bands A, B, C.

The median power ratio (STAFF-SA/WBD) is shown in Figure 26. For strong waves the ration is about 4 in C band, about 1 for low amplitude waves (B band). The behavior in A band, where the signal is at noise level, seems to be linked to the WBD high pass filter.

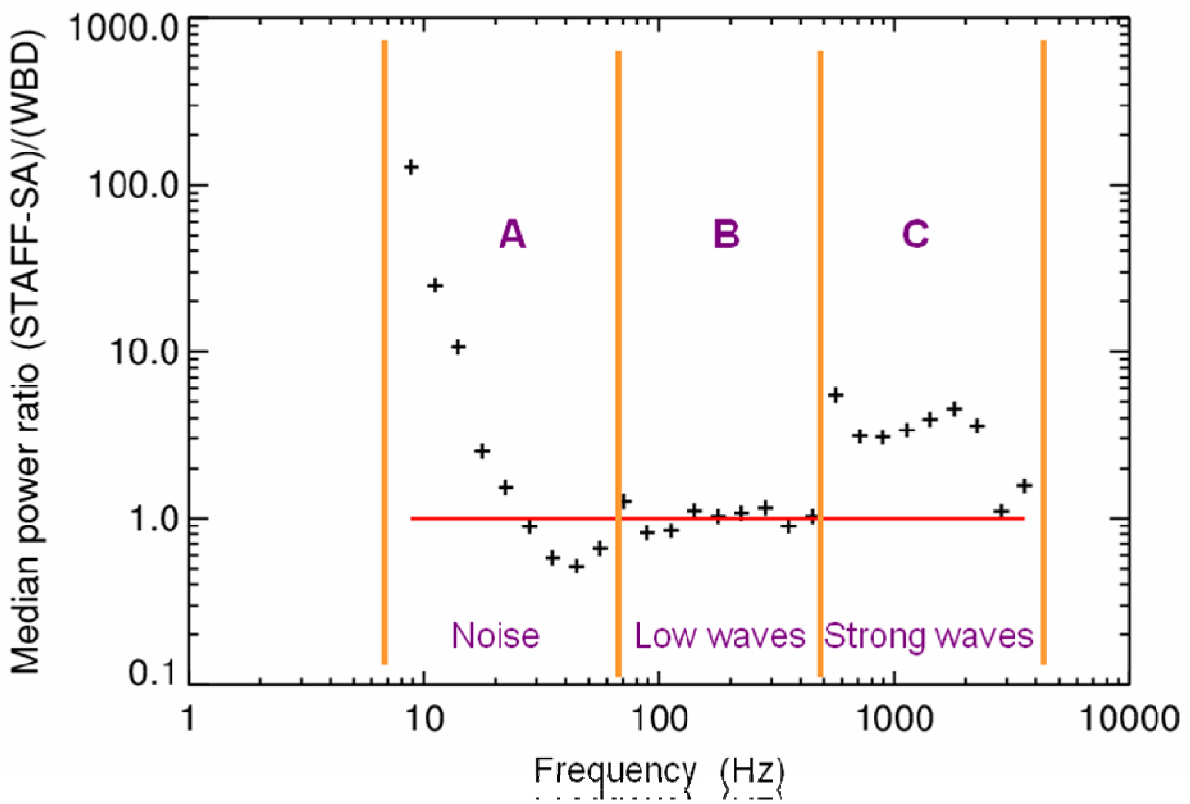

Figure 26 : Plot of the median power ratio between STAFF-SA and WBD power calculated in frequency bins similar to those of STAFF-SA and calculated over similar time periods. For the lower frequency band A in which there was no wave signal for the studied event, one sees the effect of the WBD high pass filter.

The above differences between the two experiments can be partly explained by the differences in the data acquisition and processing. The behavior of the background noise is explained by the WBD high pass filter. The different between band B and C is still to be understood. For the higher signal, the ratio of 4 in power (then 2 in amplitude), should be corrected with the revised transfer functions to be applied on the different on board analysers.

6.9.2 Electric fluctuations comparisons between STAFF-SA and EFW

For these comparisons, we have used data of two different periods, one when the spacecraft were in normal bit rate and one in high bit rate. This allows to make the comparison for two different frequency ranges, around 8 Hz and around 70 Hz.

The first period, in NBR, is for the period 16/03/2002 from 05:00 to 08:00, which corresponds to a cusp traversal. The EFW waveforms have been retrieved using the ISDAT software. For this period, data (using the P1234 parameter on ISDAT) were available only for Cluster 3 & 4.

For the SA/EFW comparison, the analysis procedure approach used for magnetic component and described in the previous section has been adopted for the electric component. On the two next Figures, for each of the two electric components, for Cluster 3 and for all the 20 seconds sub-intervals the SA electric fluctuations have been plotted as a function of the EFW ones in the range 7.6 to 9.9 Hz.

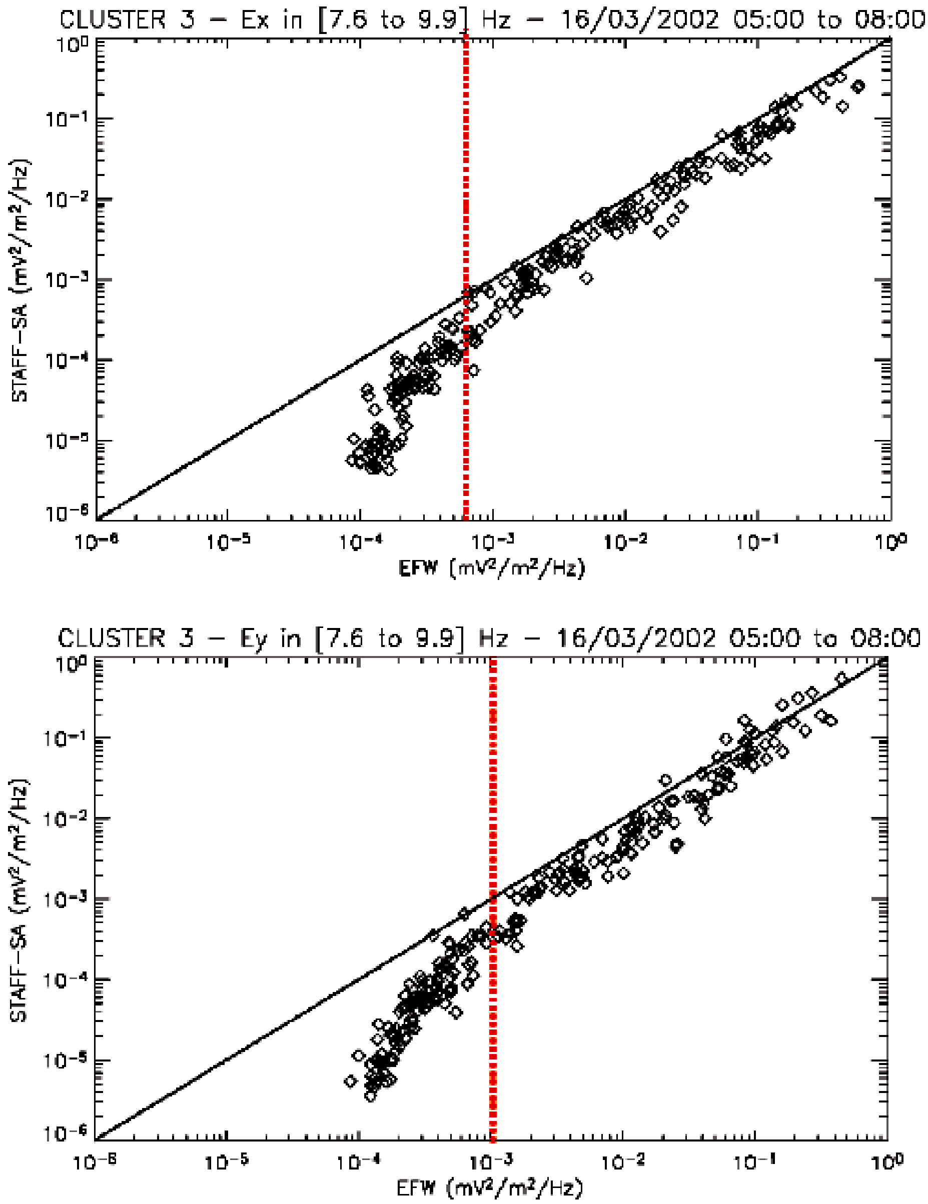

Figure 27: Comparison between STAFF-SA and EFW of electric field power at frequency ~ 8.8 Hz in NBR mode for the Ex (top) and Ey component (bottom.

For the second period, in HBR, the results plotted in Figure 28 correspond to an hour of data for S/C2 on 19 April 2001.

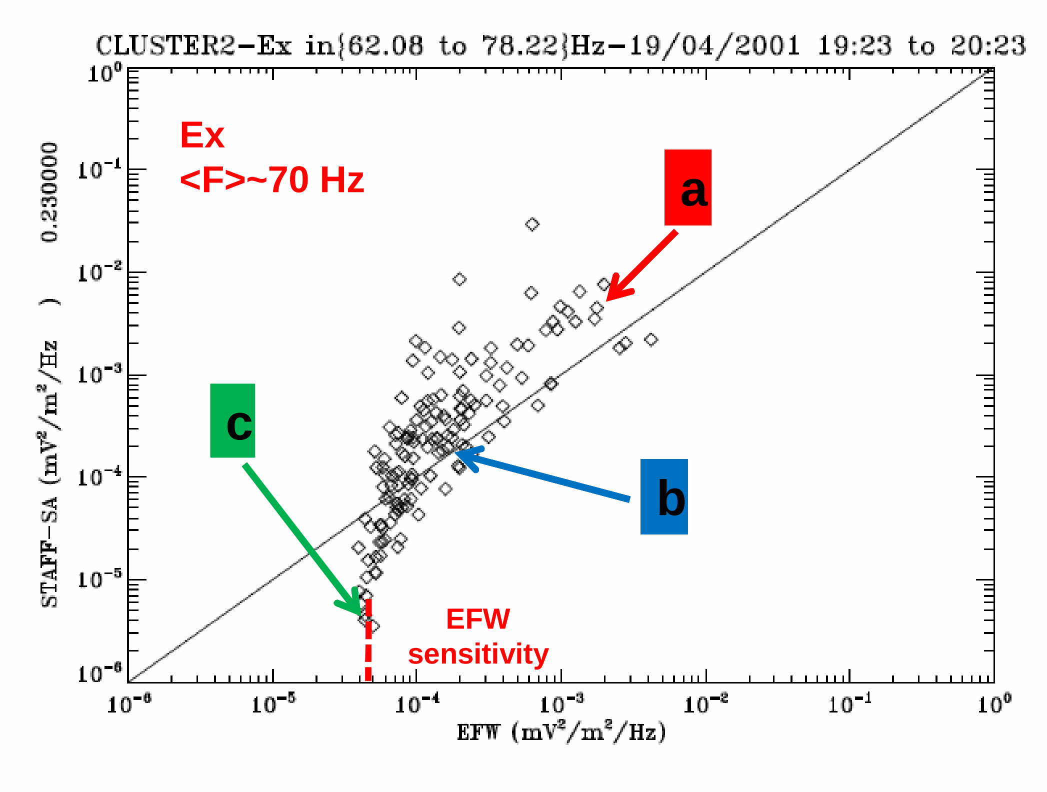

Figure 27: Comparison between STAFF and EFW electric components in HBR mode

On these three figures the electric fluctuations are displayed in $(mV/m)^2/Hz$. The data are globally in good agreement when the intensity of the fluctuations is larger than a given threshold. For the four spacecraft, this threshold is about $10^{-3}(mV/m)^2/Hz$ around 8 Hz and 10^{-4} $(mV/m)^2/Hz$ around 70 Hz. Below these threshold, the two experiments disagree. It is probably due to the EFW experiments sensitivity level which reaches those value at these frequencies [A. Ericksson, private communication].

Conclusion of comparisons between STAFF-SA and EFW: the agreement is good while the electric fluctuations level around 8.8 Hz is larger than *6 to 10 x* 10^{-4} *$(mV/m)^2/Hz$*. As this latter value is known to be close to the EFW experiment sensitivity, the electric PSD data, around this frequency, should be retrieved preferentially from the STAFF-SA experiment. In the same way, in high bit rate if the fluctuation level around 70 Hz is below *6 to 10 x* 10^{-5} *$(mV/m)^2/Hz$*, one should preferably use SA data.

6.9.3 Electric fluctuations comparisons between STAFF - SA , WHISPER and WBD

A first comparison between those three instruments measurements is given in Figure 28. On this figure are displayed electric field fluctuations measured at the same time by STAFF-SA, WHISPER and WBD. For WHISPER, the data are retrieved with ISDAT with the calibration files updated on 2001-02-28 and named C1234_CT_WHI_20010504_V002.cal. The selected parameter is "WHISPER NATURAL" For WBD the PSDs were provided by Jolene Pickett and Ondrej Santolik, using the calibration coefficients produced by Rich Huff on 09 July 2001. Depending on the frequency overlaps, the agreement is more or less good between the three experiments.

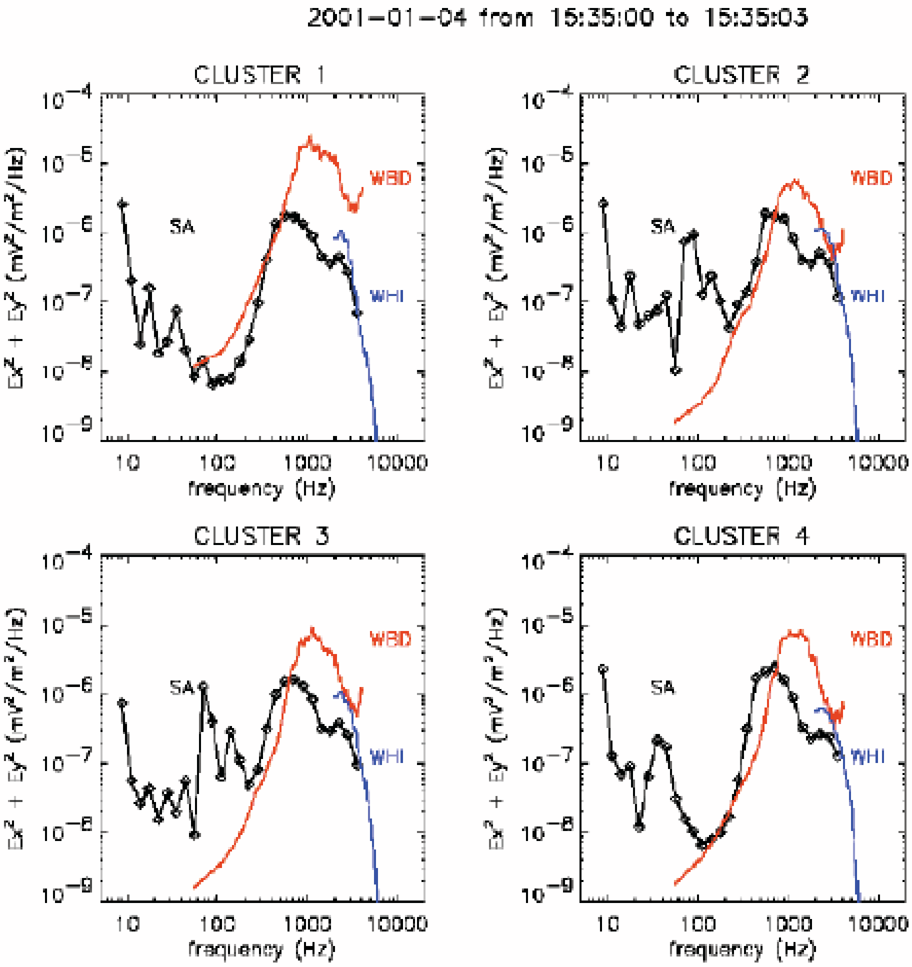

Figure 28: a first comparison between results from the STAFF-SA, Whisper and WBD instruments on a single event for the 4 spacecraft. Significant discrepancies are observed

Whereas there seems to be good agreement between Whisper and WBD (except on S/C 1), the WBD/STAFF comparison shows discrepancies to be solved. The understanding of these significant differences will have to take into account the differences between these instruments in collecting their data.

A final comparison is done using Staff-SA and Whisper data, obtained on a longer time interval

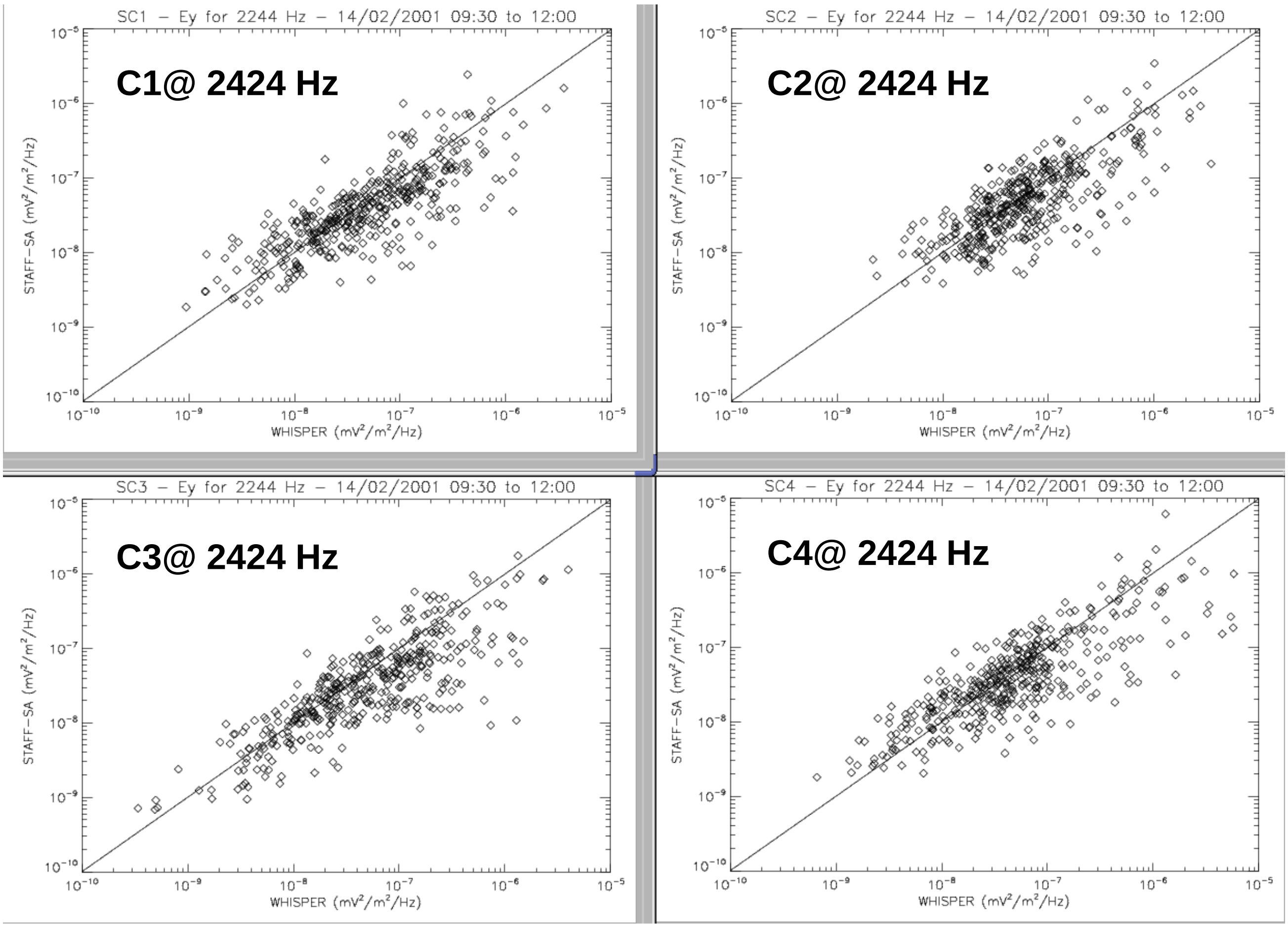

Figure 29: Comparison between Staff-SA and Whisper (medium intensity).

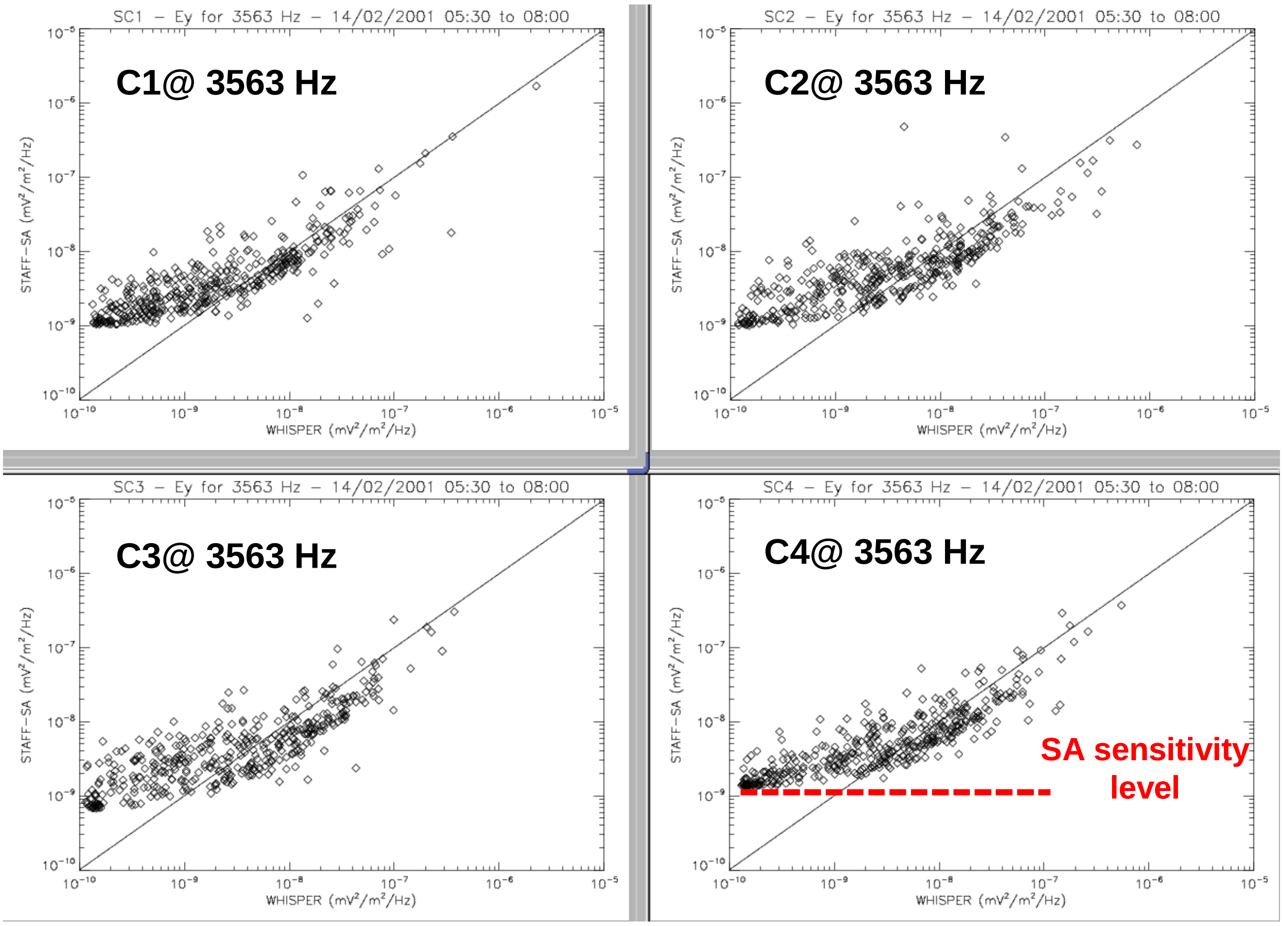

Figure 30: Comparison between Staff-SA and Whisper (low intensity)

This comparison is done on 2 different frequencies channels and different regions. Figure 29 displays data collected close to the magnetopause with medium wave intensities, while figure 30 shows data collected in the plasmathrough with lower level intensities. The agreement between the 2 instruments is rather good on the first example, and presents a significant difference for the lower level intensities, which can be attributed to reaching the sensitivity level for Staff-SA.

In conclusion, the agreement between SA and WHISPER is quite good. Nevertheless, at high frequency (around 3 500 Hz) the sensitivity level of STAFF SA, not as good as the Whisper one, is evidenced.

7 Summary

The calibrations and cross calibrations results presented here illustrates the improvements obtained between the initial STAFF products delivered to the CAA and the data which will be available in the final archived obtained by the new calibration functions.
In particular the significant discrepancies found for Staff-SC between SC1 and the other spacecraft and between STAFF-SC and FGM has been well understood and corrected, the residual differences (less than 1% in intensity and 3° in phase) being more than satisfactory.

The previous calibration error on S/C1 has no influence on the other instruments using STAFF magnetic search coil, as it affected only frequencies below 8 Hz.

Although some coherence has been evidence between the wave instruments collecting data in the overlapping frequency range (Staff, EFW, Whisper, WBD), significant discrepancies have been found, depending on the frequency and the waves intensity. The users should then take care of the differences identified so far, particularly when data are analyzed close the instruments respective sensitivity levels. Efforts are on going to understand better these discrepancies, taking into account, in particular, the different modes of operations and data collections

8 References

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