User Guide to the **STAFF** measurements in the Cluster Science Archive (CSA)

Version 4.0

updated by Patrick Canu, Rodrigue Piberne, Veronique Bouzid, Ralph Katra
Nicole Cornilleau-Wehrlin, C. Lacombe and STAFF team.

DOCUMENT CHANGE RECORD

Issue	Date	Details
1.0	2009-02-01	
2.0	2010-05-21	Major update
3.0	2011-04-26	Revision/ PPP description/EFW failure effects
3.1	2012-05-03	Revision/ CWF description
3.2	2012-10-29	Correction STAFF-SA level 2: reference frame (SR2)/ SM units/ HK plots description/
3.3	2013-05-10	General update/ CWF update/ Special operations
3.4 3.5 3.6	2014-05-12 2015-09-04 2017-04-26	Revision Revision Revision / Addition of Appendix E (Definitions of Coord. Systems used by STAFF) / Update of the "Use of CWF data" section.
4.0	2025-04-30	Major Revision. Include examples of data problems, anomalies and limits, addition of Flight calibration results and description of the calibration reports in the archive. Add some details on operations. Correction of some errors

Content

1 Introduction

This document provides a brief outline of the data archiving from the STAFF experiment on Cluster in the ESA Cluster Science Archive (CSA).

First, the CLUSTER STAFF (Spatio Temporal Analysis of Field Fluctuations) experiment is briefly described, including its operations and limits, as well as the calibration and processing procedures of the measurements. Afterwards the key science measurements and datasets are described including some general warnings and recommendations for the users of the STAFF datasets. All STAFF datasets available on the CSA are listed in appendix B.

2 Instrument Description

The CLUSTER STAFF instrument comprises a tri-axial search coil magnetic sensor (0.1Hz- 4 kHz frequency range), and two on-board wave analysers: a magnetic waveform unit (STAFF-SC) and a wave spectrum analyser (STAFF-SA). The latter calculates the complete spectral matrix for the 3xB (magnetic field) + 2xE (electric field) wave components. The wave electric fields, measured by the four spherical EFW (Electric Field and Wave) experiment sensors, are transmitted to and analysed by the STAFF-SA electronics. STAFF is one of the 5 Cluster wave experiments which form the WEC (Wave experiment Consortium). For more details about STAFF instrument description, see documents [1], [2], [3] and [4].

2.1 The Magnetic Waveform Unit

The magnetic waveform unit (STAFF-SC) is made of various subunits to perform different filtering and waveform digitalisation, output interface and on-board calibration (for the whole STAFF experiment).

The three magnetic components of the magnetic field (B_x, B_y and B_z), at the output of the search coil preamplifiers are simultaneously low pass filtered at either 10Hz or 180Hz depending on the spacecraft telemetry mode (NBR Normal Bit Rate and HBR High Bit Rate, respectively – see Table 1 in section 3). Then, the three components are simultaneously digitised by 16 bits sampling at 25 or 450 Hz according to the telemetry mode (see above). STAFF and EFW waveforms are sampled simultaneously and synchronized by the Digital Wave Processor (DWP). Before the transmission to the ground, the DWP compresses the STAFF measurements

to 12 bits (see Appendix E). Note that EFW and STAFF filters have been identically designed for further combined electromagnetic waveform data analysis.
From the spinning of the spacecraft, one can get the amplitude of the DC magnetic field component in the spin plane, extracted from the signal at the spin frequency (about 0.25 Hz).

2.2 The Spectrum Analyser

The Spectrum Analyser (STAFF-SA) is designed to perform the complete auto- and cross-correlation matrix of 5 wave components (B_x, B_y, B_z, E_y, E_z) over the frequency range 8Hz–4kHz. The "front-end" of the analyser is analogue, consisting in 15 anti-aliasing filters and 9 automatic gain controllers (AGC), dividing the frequency band into 3 logarithmically distributed frequency sub-bands (A: 8-64Hz, B: 64-512Hz and C: 512-4096Hz). The AGC amplifiers normalise the output signal to an optimum level for digitisation. The digital processor divides each sub-band into 9 frequency channels. The analysis band is therefore divided into 27 frequency bands, logarithmically spaced. The total dynamic range is then (analogue plus digital processor) 120 db.

2.3 Instrument and data Coordinate Systems

The STAFF-SC level 1 waveform (DWF) data are given in the instrument reference frame, in order to keep all available information. This reference frame is the Data Sensor System (DSS), a variant of the Spin Reference System (SRS) (see Figure 1 and Appendix E: Ancilliary data), and has been chosen to be the same as EFW instrument coordinate system in the spin plane (at 45° of the satellite body built reference frame); the third component, orthogonal to the 2 others, is parallel to the spacecraft spin axis, at the first order of precision. There is ~0.5º difference between spacecraft spin axis and the axial component which is small enough that no correction is needed. This small angle is seen as a weak spin modulation on Bz component when the B field is very strong (e.g., close to perigee). The three sensors are so close to orthogonality that no correction is needed.
STAFF level 2 (calibrated data) and level 3 (value added products) products are given in de-spun coordinate systems, as detailed below.

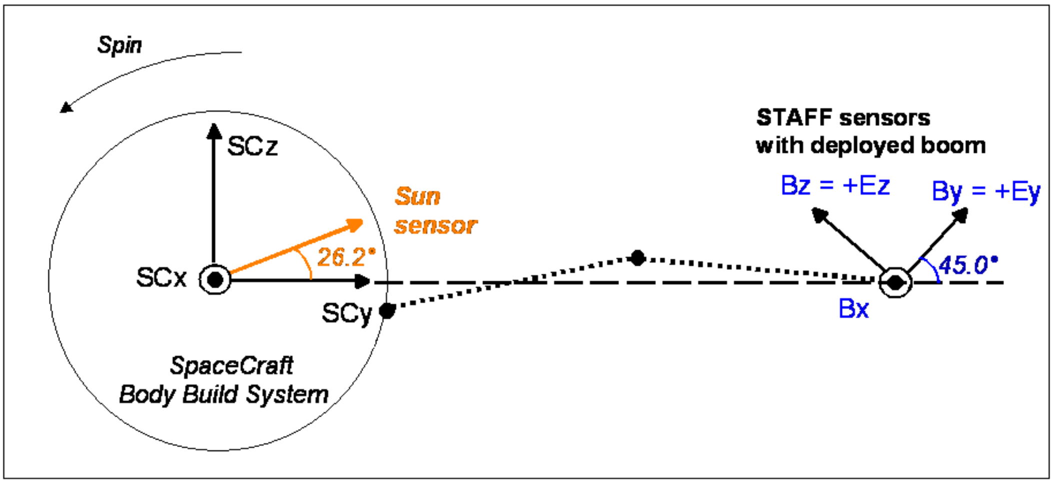


Figure 1 : STAFF antenna reference frame SCS

STAFF-SC level 2 data products derived from the waveform data include Calibrated Waveform data (CWF) and Calibrated Complex Spectra (CS). CWF datasets - NBR and HBR datasets being merged - are delivered both in GSE (Geocentric Solar Ecliptic) and in ISR2 (inverse of SR2: Spin Reference 2). CS datasets are in GSE.

For STAFF-SA data, the full resolution datasets (level 2 Power Spectral Density and Spectral Matrix) are given in SR2. SR2 has been chosen instead of GSE usually used, as there are only 2 electric components. Any transformation to a coordinate system which is not in the satellite spin plane needs to do the hypothesis E.B=0. We decided not to apply this assumption as the STAFF-SA level 2 data are the most complete dataset of this part of the experiment to be kept in CSA. **ATTENTION** SR2 reference frame, fixed frame in the spacecraft coordinate system, is NOT close to GSE, as the spacecraft spin axis points toward South. X axis is in the direction of the SUN, the Y axis is towards dawn.

In the case of STAFF-SA Polarization and Propagation Parameters the coordinate system is MFA (Magnetic Field Aligned). There is no risk to lose information, as it is always possible to recalculate these parameters, starting from Spectral Matrix data.

For the definition of GSE, ISR2, SR2, see Appendix E: Coordinate systems used by STAFF definitions and for MFAs see also Figure 5 in § 5.5.

3 Instrument Operations

Different operational modes have been applied, mainly depending on the bit rate, either normal (NBR-spacecraft modes NM1, 2 or 3) or high (HBR- S/C BM1 and BM2). The complete description of the different possible modes is given in [1], [2] and [4]. Specific use of BM2 and BM3 modes by STAFF is specified in Appendix F, §13.3. The main characteristics of the most common modes for the waveform and the spectrum analyser are given in Table 1 and Table 2. The magnetic (STAFF-SC) and electric (EFW, see the user guide of the EFW experiment) waveform frequencies are low-pass filtered in the same way and are sampled simultaneously as commanded by the DWP experiment. Other modes are nearly never run, at the exception of the commissioning phase at the beginning of the mission, or special tests. A calibration mode is also run after the BM3 mode of operation, at least once per orbit (see Appendix F STAFF Special Operations).

	STAFF-SC (Waveform)		STAFF-SA (Spectrum Analyser)		
Bit Rate	Frequency Range	Sampling rate	Frequency Range	Data	Resolution
Normal Bit Rate (NMs)	0.1-10 Hz	25 Hz	8 Hz-4 kHz	PSD SM	1s 4s
High Bit Rate (BM1or2)	0.1-180 Hz	450 Hz	64 Hz – 4kHz	PSD SM	0.125 or 0.25s 1s

Table 1: STAFF modes main characteristics as a function of Telemetry mode. PSD: Power Spectral Density and SM: Spectral Matrix.

The content of STAFF-SA data depends both on the bit rate (frequency range and time resolution, cf. Table 1) and the Whisper mode (cf. Table 2). The Whisper active sounding mode lasts for a few seconds (about 3 seconds) usually every 52 or 104 seconds. This mode triggers interferences on the electric field measurements, which are then not useful, but has no impact on the magnetic field measurements. DWP synchronises perfectly STAFF-SA and Whisper operational modes so that the sounding effect (whisper sounder on) is always within one sample only for 4s resolution STAFF-SA spectral matrix. There is no calculation of the spectral elements comprising electric field data during those 4 seconds. There are no electric field data when Whisper is active; only magnetic field date, this is why one can see white lines or data gaps on electric dynamic spectra (see e.g. Figure 4).

WHISPER MODE	STAFF-SA components
active	3 x B
passive	3 x B + 2 x E

Table 2: Availability of STAFF-SA data as a function of Whisper experiment mode, active or passive.

STAFF-SA electric components may be affected by the EFW preamplifier failure on some of the spacecraft probes. Even if only one over 4 EFW probes on a given spacecraft has failed, the 2 STAFF-SA electric components are affected: the onboard despin processing of STAFF-SA data combines the 2 spinning components. After a failure, the electric antenna may be saturated, but once EFW team has commanded the failed probe into density mode, i.e. set the potential to V=0, the data quality is good again, but the sensitivity is decreased. This is detailed in section §6.5.5.

4 Measurement Calibration and Processing Procedures

For details about the data processing the user should refer to the STAFF ICD [1] and the Calibration Report [5]. Only some warnings are given here.

4.1 Some warnings about calibration

To summarise, in what concerns **magnetic field data:**

- The state of the instrument (STAFF magnetic sensors and preamplifiers) has not varied with time during the whole mission.
- The difference between STAFF-SC (CWF dataset) and FGM data over their common frequency range is marginal and satisfactory.
- STAFF-SA electric components were impacted by various EFW probe failures during the mission .

In what concerns **electric field calibration**, see also document [5]. Some corrections may have to be applied to the STAFF-SA electric field values after EFW probe failures. This is detailed in § 6.5.5 of the present document.

TCOR and the Timing accuracy of Waveform data: The time precision provided through the spacecraft telemetry - which initially is 2ms – is not sufficient for some studies using the Calibrated Wave Form(CWF), more specially those using the High Bit Rate, then on ground timing re-calibration is performed when possible. The information provided by JSOC and fine-tuned by DWP team is used to recalibrate the UT time at the data decommutation level, through the use of the TCOR (Time CORrection) Files provided by the DWP team. The achieved accuracy, when the TCOR file correction exists, is about 20 μs.

The information on TCOR activation is given in the header of the file ("TCOR option" in the FILE_CAVEATS metadata) and corrected data records (if some) are flagged using the 12th character of the status word (see

10 Appendix C: Description of the STAFF status word).
When comparing data from the different S/C, it might be useful to check this. The same correction is applied to STAFF and EFW level 1 (uncalibrated) waveform data. Example of impact of TCOR corrections is given in § 6. For more details see [8].

4.2 Level 2 and Level 3 Products

Details can be found in the ICD and in the Calibration Report (references [1] and [5]) and in [9]). Details on the different products are given in the next section, as well as some needed information for the use of these products.

5 Key Science Measurement and Datasets

For information concerning the datasets reference frames, the user may refer to paragraph 2.3.

5.1 STAFF-SC CWF (Continuously Calibrated Waveform)

This dataset provides waveforms of the three components of the magnetic field, sampled either at 25 Hz (normal mode) or 450 Hz (burst mode). These datasets are provided both in ISR2 and GSE coordinate systems. Due to the transfer functions and filters of the STAFF search coil, the operational frequency ranges of these datasets are 0.1-10Hz and 0.1-180 Hz respectively. For the lowest significant frequencies, see below the details concerning each dataset (ISR2 or GSE). The calibration of these waveforms is detailed in the STAFF calibration report [5].

For both datasets, NBR and HBR data files are merged to ensure a time continuity.

For general warnings and caveats about CWF, please refer to the § 6.3 "Use of CWF data", in the "Recommendations and caveats" section. [6.2]

General warnings and caveat: the 3 wave components given in nT unit are complemented by a number of information given either in the header or in a status word at each time step. The status word is described in

10 Appendix C: Description of the STAFF status word. The main points to look at in the status are:

- **In flight calibration:** This happens once, sometimes twice, per orbit for 6 minutes. The corresponding data have been suppressed from both ISR2 and GSE CWF files. Those periods are indicated in the caveat C? _CQ_STA_CALIBRATION_CAVEATS.
- **No Reference Pulses:** The absence of CWF data when the Sun Reference Pulse is missing for more than 600 seconds (10 minutes), e.g. eclipses. The absence of Sun Reference Pulse is flagged by the NOTSRP caveat. The sun pulse is needed to calculate the phase, which is in return needed in the software calibration process. The phase status (11th character of the STAFF status word) gives information about the Sun Pulse quality (nominal, interpolated or suspect) used in the phase calculation. (cf. Appendix C, Phase status). For more details see § 6.2
- **Eclipses:** Data were collected while the spacecraft were in eclipses during the first phase of the mission. This acquisition was no more possible after the end of life of the spacecraft on board batteries, beginning in 2006.
- **WEC anomaly in 2011 on C3**: A malfunction occurred on the whole WEC set of instruments on C3 on March 5th 2011, which prevent any data acquisition for WEC hence for STAFF. The operations and data acquisition were fully restored on June 1st, 2011.
- **Time accuracy:** see above. The information on TCOR activation is given in the header; absence of correction is indicated in character 12 of the status word (See § 6.3 for the impact of absence of TCOR).

5.1.1 Advantages of ISR2 dataset

There are remnants of the spin signal at 0.25 Hz and 0.5 Hz in the spin plane. But the Bz component parallel to the spin axis is nearly always free of spin signal (see section § 2.3) which is one advantage of this reference frame.

The other advantage of this dataset is that together with the waveform, the component of the DC magnetic field in the spin plane is also given. It is extracted from the spin signal.

The key metadata for Calibrated Waveform dataset in ISR2 are (see ICD [1] for the complete description):

Name	Calibrated Magnetic Field Waveform in ISR2
Property	Vector
Sizes	3
Components	Bx, By, Bz
Units	nT
Name	Components of the DC Magnetic Field in the Spin Plane
Property	Vector
Sizes	2
Components	BDCx, BDCy
Units	nT

5.1.2 Advantage of GSE dataset

The waveform dataset in GSE is filtered from effects of the spin signal; thus, the minimum meaningful frequency is 0.6 Hz. In this reference frame, data are more directly comparable with other datasets.

The key metadata for Calibrated Waveform dataset in GSE are (see ICD [1] for the complete description):

Name	Calibrated Magnetic Field Waveform in GSE
Property	Vector
Sizes	3
Components	Bx, By, Bz
Units	nT

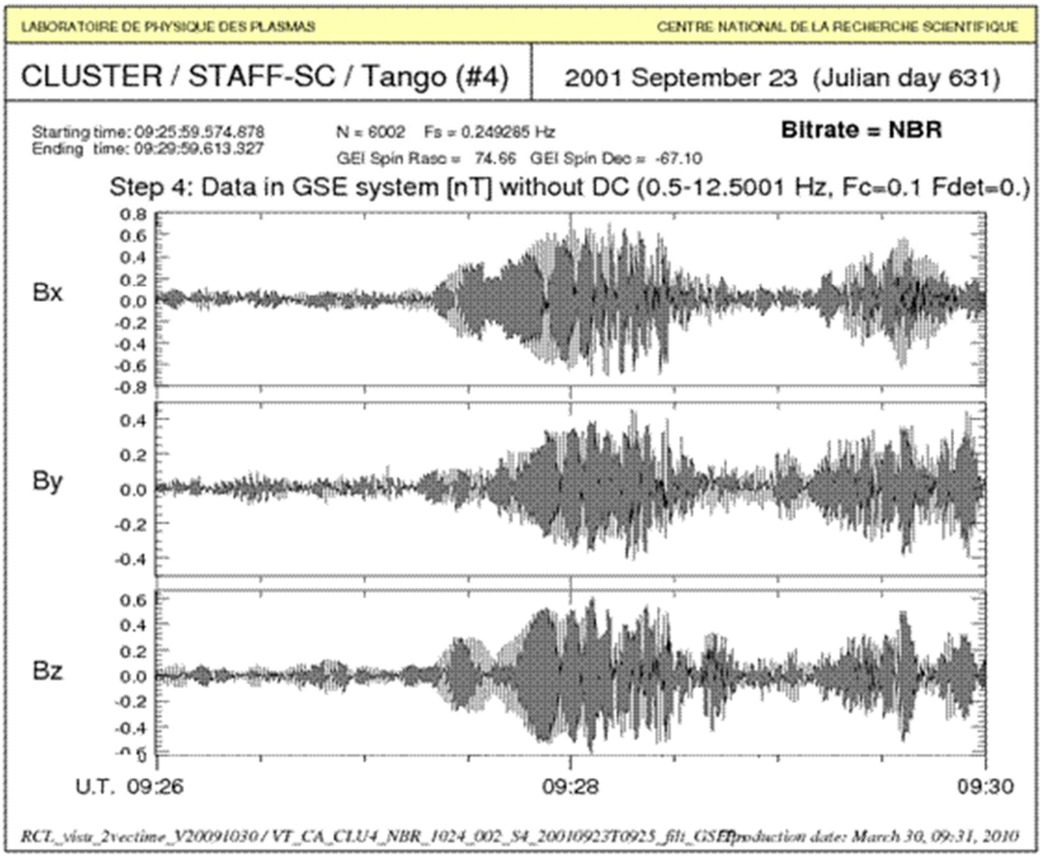


Figure 2: Example of waveform plot, in GSE reference frame

5.2 STAFF-SC CS (Complex Calibrated Spectra)

These spectra data are given in nT in the GSE frame of reference. The calibrated complex spectra have the following frequency and time resolutions ~0.098Hz and 10.24s respectively in NBR (0.1 Hz-12.5Hz) and ~0.109Hz and 9.10s in HBR (0.1 Hz – 225 Hz) i.e. $\Delta t.\Delta f = 1$. As the spectra are complex, Inverse Fourier Transform can be performed without loss of information. With some appropriate wave analysis dedicated software, the polarisation and propagation parameters can be obtained in the M. F. A. (Magnetic Field Aligned) frame of reference using the FGM data that are available at CSA (5VPS or SPIN datasets). An example of plot obtained with CS data is given on Figure 3. Note that the STAFF-SC magnetic waveform data at low frequency (around 0.25 Hz) may contain some remnant of the spin signal which can become very strong around perigee, in strong magnetic fields (see § 6).

The key variables are

- Time (refers to the beginning of the time interval)
- Frequency (128 or 2048 frequency bins in NBR/HBR respectively)
- Complex spectra (that depend on both time and frequency)

The key metadata for Complex Spectra are (see ICD for the complete description):

Name	Components of the Magnetic Field Complex Spectrum
Property	Vector
Sizes	128, 2, 3 (NBR) or 2048,2,3 (HBR)
Components	Re, Im
Units	nT

Associated caveat:

There is one major caveat that the data are provided also during eclipse when data acquisition was possible during the first year of the mission and when the spin angle is not well known and therefore the data are not correct. The users will receive a caveat file (C*_CQ_STA_NOTSRP) indicating the intervals when the sun reference pulse is not available (i.e. during eclipse).

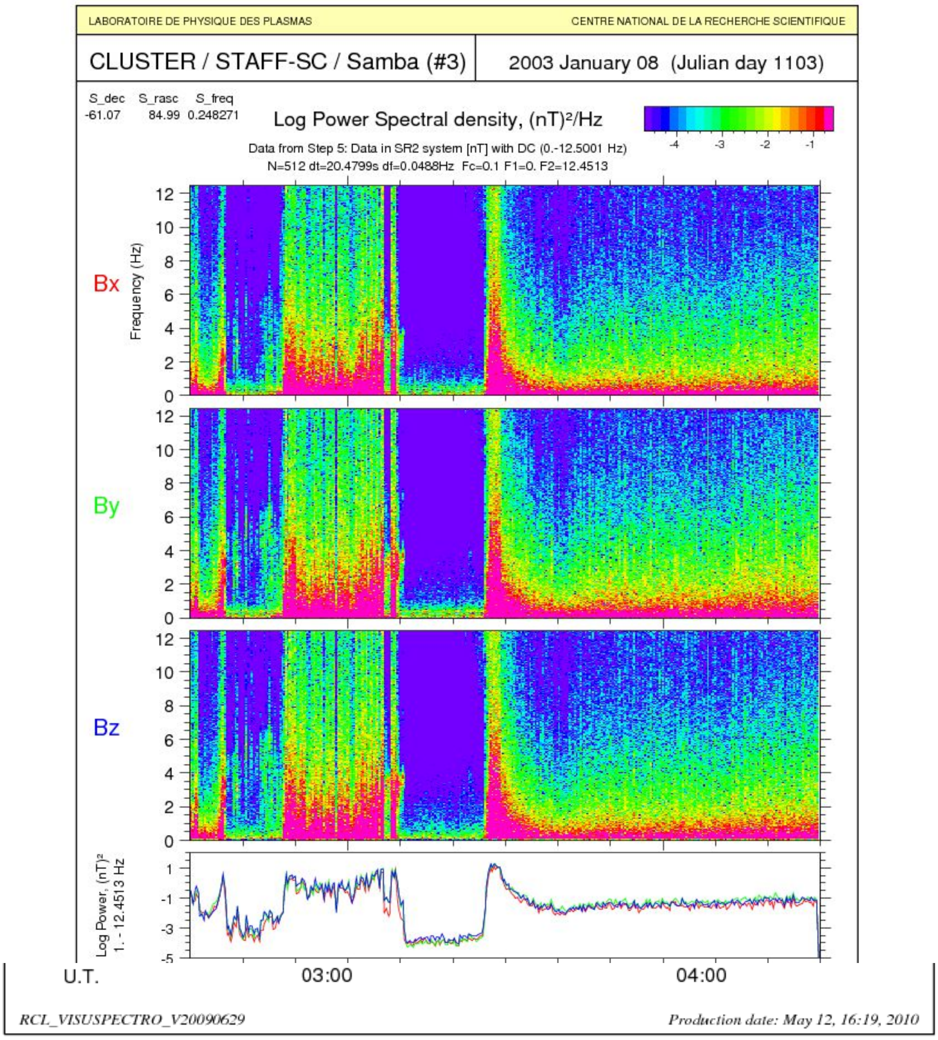


Figure 3 : Example of plot for 3 components obtained from CS data

5.3 STAFF-SA PSD (Power Spectral Density)

The Power Spectral Densities values for the magnetic and the electric field are the diagonal term of the Spectral Matrix:

$$\begin{pmatrix} B_x^2 & B_x.B_y^* & B_x.B_z^* & B_x.E_x^* & B_x.E_y^* \\ B_y.B_x^* & B_y^2 & B_y.B_z^* & B_y.E_x^* & B_y.E_y^* \\ B_z.B_x^* & B_z.B_y^* & B_z^2 & B_z.E_x^* & B_z.E_y^* \\ E_x.B_x^* & E_x.B_y^* & E_x.B_z^* & E_x^2 & E_x.E_y^* \\ E_y.B_x^* & E_y.B_y^* & E_y.B_z^* & E_y.E_x^* & E_y^2 \end{pmatrix}$$

Those parameters are given in nT^2Hz^{-1} for the magnetic components (B_x^2, B_y^2 and B_z^2) and in $mV^2m^{-2}Hz^{-1}$ (E_x^2 and E_y^2) for the electric ones. Dynamic spectra can thus be deduced for any component of the electromagnetic or electrostatic waves in the 8 Hz – 4 kHz frequency range. The electron gyrofrequency is covered by the STAFF frequency range on the complete orbit or a major part of it (i.e. except close to the perigee).

Note that the time resolution is better for the PSD than for the complete Spectral Matrix elements (see Table 1), varying from 0.125 or 0.25 s in HBR to 1 s in NBR. The data, delivered to CSA in SR2 reference frame, can be transformed into any reference frame, with no hypothesis for the magnetic field components, and with the hypothesis E.B=0 for the electric components. Figure 4 gives an example of dynamic spectra of E and B field for the 4 Cluster.

Sometimes, mainly when the signal level is very low, there are negative PSD values in the raw data. Those have been replaced by fill values (see § 6).

The key supporting variables are:

- Frequency (central frequency, 27 frequency bins)
- Time (which refers to the beginning of the time interval)
- Frequency_BHW (bin half width - 27 frequency ranges)

The key metadata are :

Data are given by the following two variables:

- BB, for the magnetic components (depend on both frequency and time):

Name	Power Spectrum 8-4000 Hz of the B-field components in SR2 coordinate system
Property	Vector
Sizes	27, 3
Components	B_x^2, B_y^2, B_z^2
Units	nT^2Hz^{-1}

- EE for the electric components (depend on both frequency and time):

Name	Power Spectrum 8-4000 Hz of the E-field components in SR2 coordinate system
Property	Vector
Sizes	27, 2
Components	E_x^2, E_y^2
Units	$mV^2m^{-2}Hz^{-1}$

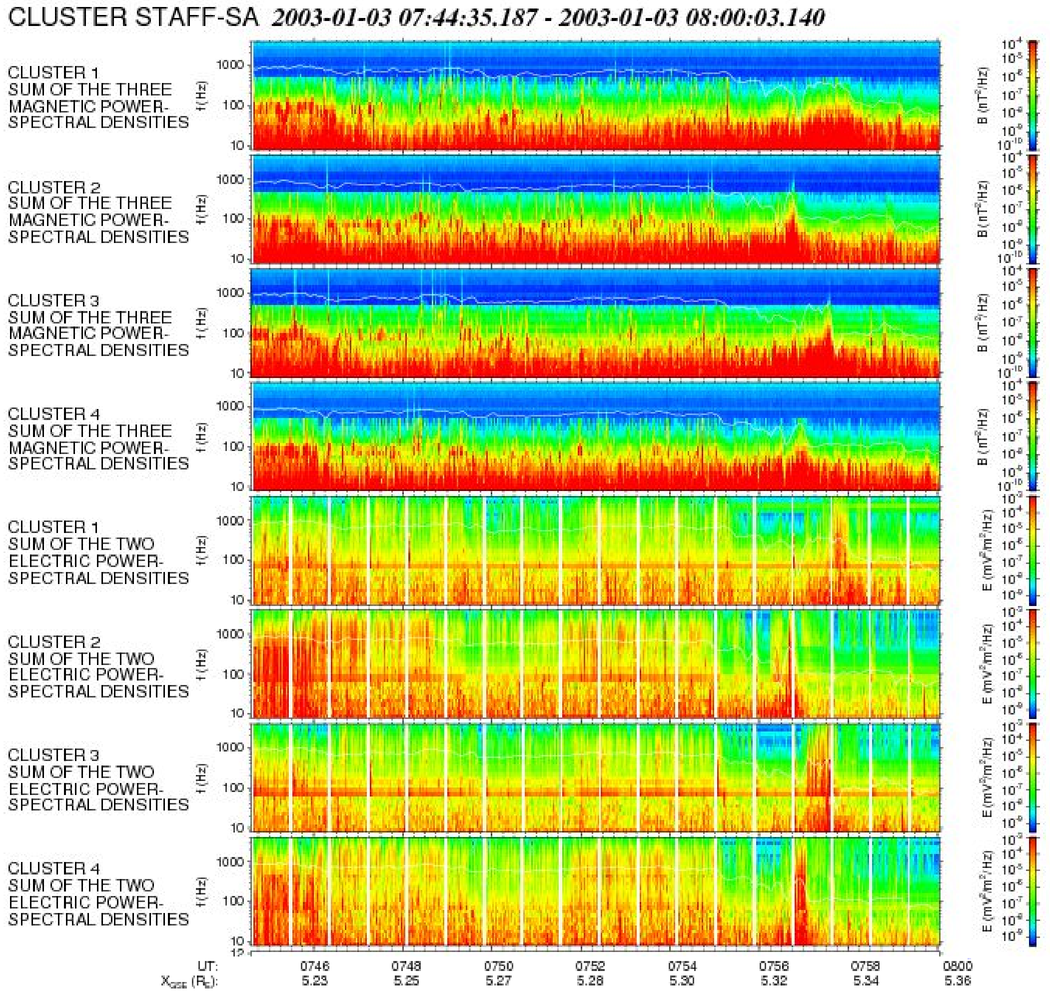


Figure 4 : Example of plots of data derived from PSD in the magnetosheath. B and E power density for the 4 spacecraft. Experiment mode varies from 5 components matrix) to (3 x B) mode when Whisper experiment is active. This explains the white lines on E data

5.4 STAFF-SA SM (Spectral Matrix)

The Spectral Matrix components are:

$$\begin{pmatrix} B_x^2 & B_x.B_y^* & B_x.B_z^* & B_x.E_x^* & B_x.E_y^* \\ B_y.B_x^* & B_y^2 & B_y.B_z^* & B_y.E_x^* & B_y.E_y^* \\ B_z.B_x^* & B_z.B_y^* & B_z^2 & B_z.E_x^* & B_z.E_y^* \\ E_x.B_x^* & E_x.B_y^* & E_x.B_z^* & E_x^2 & E_x.E_y^* \\ E_y.B_x^* & E_y.B_y^* & E_y.B_z^* & E_y.E_x^* & E_y^2 \end{pmatrix}$$

For the sake of homogeneity, all terms are expressed in $mV^2m^{-2}Hz^{-1}$. To do so, the hypothesis made is that the index n=c B/E =1, c being the light velocity. It is from this dataset, once transformed from SR2 reference frame to MFA, Magnetic Field Aligned reference frame, that wave characteristics (polarisation, ellipticity, direction of propagation etc…) can be determined (see next §).

The key supporting variables are, as for PSD:

- Frequency (central frequency, 27 frequency bins)
- Time (which refers to the beginning of the time interval)
- Frequency_BHW (bin half width - 27 frequency ranges)

Data are separated into three variables, one for the magnetic components (BB), one for the electric components (EE), and one for the cross-products (BE):

The key metadata are:

BB depend on time and frequency:

Name	Cross-Spectral matrix of the magnetic field at 27 frequencies from 8 Hz to 4 kHz in SR2 reference frame.
Property	Vector
Sizes	27, 2, 3, 3 !27frequency bins x 2 (Re + Im) parts x (3x3) matrix
Units	$mV^2m^{-2}Hz^{-1}$

EE depend on time and frequency

Name	Cross-Spectral matrix of the electric field at 27 frequencies from 8 Hz to 4 kHz in SR2 reference frame.
Property	Vector
Sizes	27, 2, 2, 2 !27frequency bins x 2 (Re + Im) parts x (2x2) matrix
Units	$mV^2m^{-2}Hz^{-1}$

BE depend on time and frequency

Name	Electromagnetic Cross-Spectral ExB products at 27 frequencies from 8 Hz to 4 kHz in SR2 reference frame.
Property	Vector
Sizes	27, 2, 3, 2 !27frequency bins x 2 (Re + Im) parts x (3x2) matrix
Units	$mV^2m^{-2}Hz^{-1}$

Note that the diagonal terms values of the matrix are the result of an average over 4 or 8 successive PSD values. That is why the user should refer to the **PSDNEG caveat.**

5.5 STAFF-SA PPP (Polarization and Propagation Parameters)

The PPP dataset gives some polarisation and propagation parameters for electromagnetic waves. They are derived from singular value decomposition (SVD) of the cross-spectral matrix (SM) using the PRASSADCO program [6] at 27 (or 18 in HBR) logarithmically distributed frequencies between 8 Hz (or 64 Hz in HBR) to 4 kHz. The time resolution is telemetry mode dependant, 1 or 4 s (see Table 1). The SVD method is described in [7].

The parameters derived from the three magnetic components are THSVD, PHSVD, ELLSVD, POLSVD and BSUM. BSUM is the sum of the three magnetic auto-power spectra. **When BSUM is less than 1.0E^{-09} nT^{2}/Hz, the calculation** of the other magnetic dependant parameters **is meaningless.** The THETA and PHI variables are respectively the **wave vector** polar and azimuthal angles in Magnetic Field Aligned (MFA) coordinate system. For MFA, THETA and PHI definition, see Figure 5 below. POLSVD and ELLSVD stand for the degree of polarisation (between 0 and 1) and the ellipticity (between -1 and +1), respectively. The sign of EELSVD indicates whether the waves are right-handed (positive) or left-handed (negative) polarised. The degree of polarisation is the ratio of the polarized wave power to the total wave power.

The parameters **that require the electric components** are ESUM and PVSIGN. ESUM is the sum of auto-power spectra of the two electric antennae. PVSIGN is the Poynting vector component parallel to the magnetic field, normalised by its standard deviation. Positive (negative) values correspond to a parallel (anti-parallel) Z-component of the Poynting vector. The calculation of PVSIGN is meaningless if BSUM is inferior to 1.0E^{-09} nT^{2}Hz^{-1}, and ESUM to 3.0E^{-09}mV^{-2}m^{-2}Hz^{-1}.

An example of PPP parameters plot is given in Figure 6.

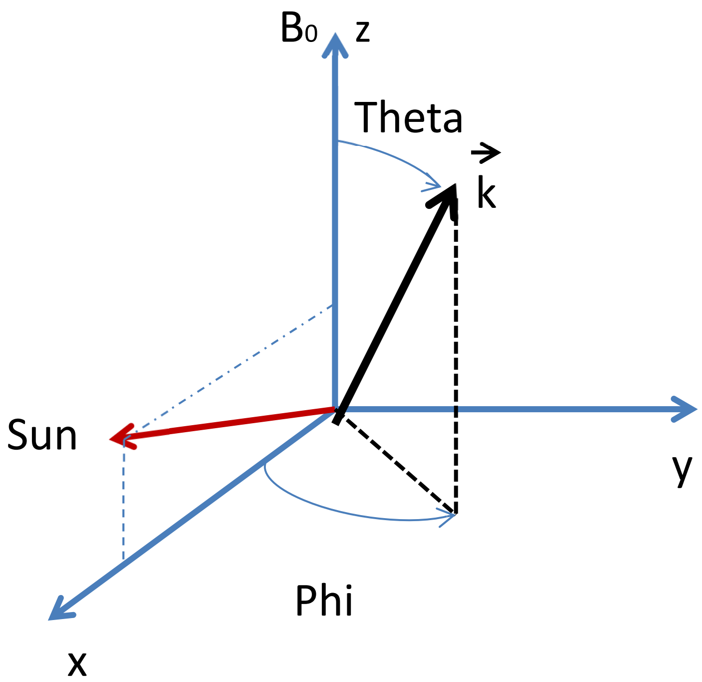


Figure 5 : Scheme of angles that characterise the wave vector direction in the MFA reference frame. MFA: the z axis is along the DC magnetic field B0, x direction is defined so that the Sun direction be in the x, z plan.

The change of coordinate system has been done using FGM 5VPS data (See FGM user guide for explanation) that is available at CSA. The FGM 5VPS dataset is the magnetic field vector at the resolution of 0.2s (5 Vectors Per Second). Before performing the change of coordinate system, PRASSADCO calculates the mean field direction by averaging the 5PVS data on the time interval relevant to the given SM measurement (1 or 4 s). Then **the time attributed to the considered PPP measurement is the time corresponding to the middle of the interval.**

The user should not be surprised finding a time difference from SM by half a measurement duration (0.5 or 2 s). For SM, the timestamp refers to the start time of the measurement interval.

Key Supporting variable are:

- Frequency (central frequency, 27 frequency bins)
- Time (refers to the middle of the time interval)
- Frequency (bin half width - 27 frequency ranges)

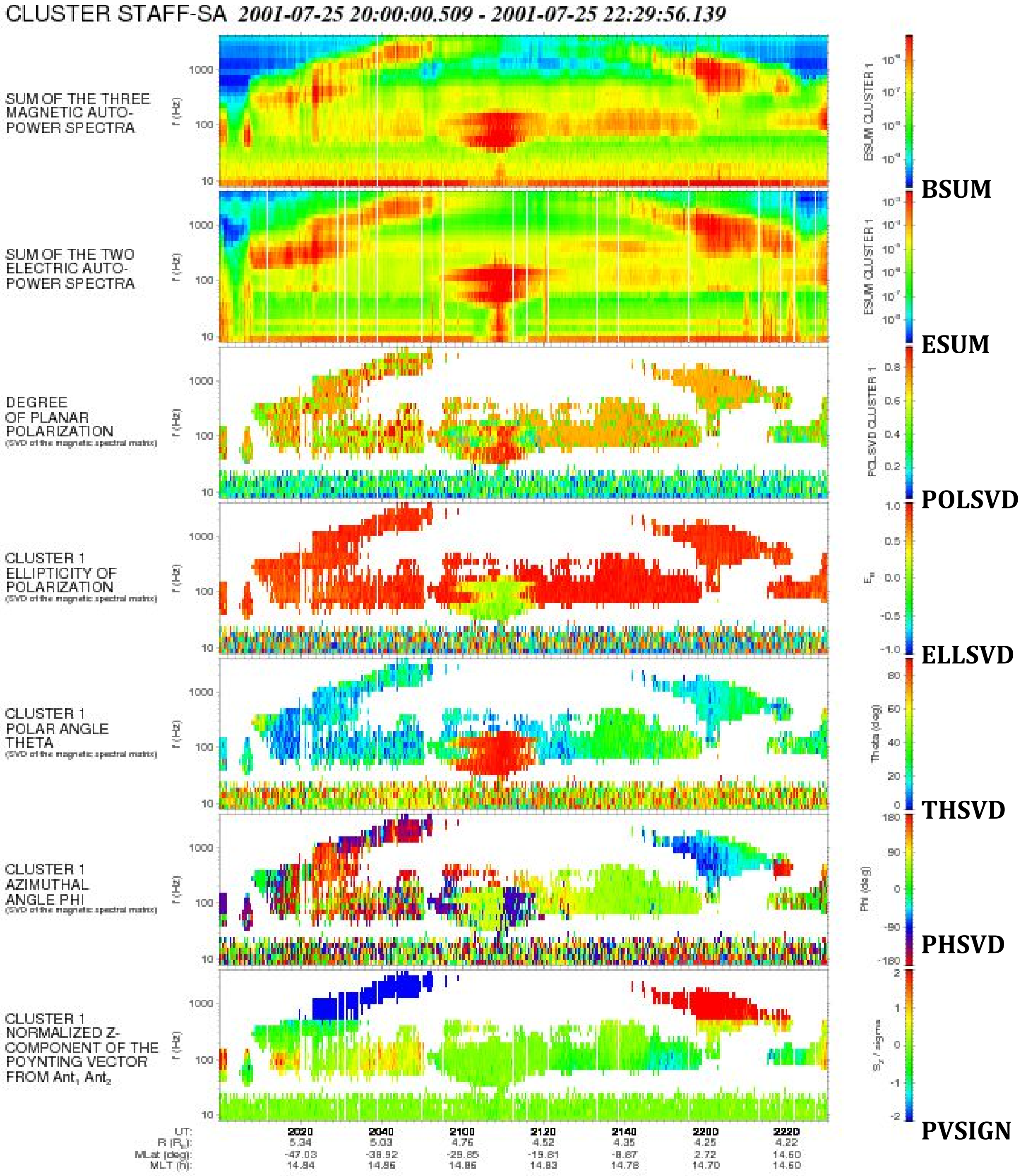


Figure 6 : Example of Polarization and Propagation Parameters (PPP) plot. Below a certain power density value PPP are not plotted to help interpretation (here the threshold is 1.0.E-07 nT2Hz-1)

The key metadata are:

THSVD:

Name	Polar angle of the direction of propagation in MFA coordinate system (SVD).
Components	THSVD
Units	Degree

PHSVD:

Name	Azimuthal angle of the direction of propagation in MFA coordinate system (SVD).
Components	PHSVD
Units	Degree

ELLSVD:

Name	Ellipticity of the polarization (SVD).
Sizes	27
Components	ELLSVD
Units	Unitless

POLSVD:

Name	Degree of polarization in the polarization plane (SVD).
Components	POLSVD
Units	Unitless

BSUM:

Name	Sum of the three magnetic auto-power spectra.
Components	POLSVD
Units	nT^2Hz^{-1}

ESUM:

Name	Sum of the two electric auto-power spectra.
Components	ESUM
Units	$mV^2m^{-2}Hz^{-1}$

PVSIGN

Name	Parallel component of the Poynting vector normalized by its standard deviation.
Components	PVSIGN
Units	Unitless

The associated **caveats** are: **UNDEFINED_MFA** (no magnetic field) and **NOTSRP** (no sun pulse).

5.6 STAFF-SC SPECTRO (3 hours routine plots) – QUICKLOOKS

Routine plots produced at LPP are delivered to CSA for browsing purposes. Each one contains dynamic spectra of the Bz component parallel to the spin axis, for the 4 spacecraft, for 3 hours of data. Below the integrated power is given and the very bottom plot gives the modulus of the B field in the spin plane derived from the CWF calibration process. Data in NBR and HBR telemetry mode are on different plots. They can help selecting a shorter time period to analyse or plot. An example in NBR mode is given in Figure 7 below.

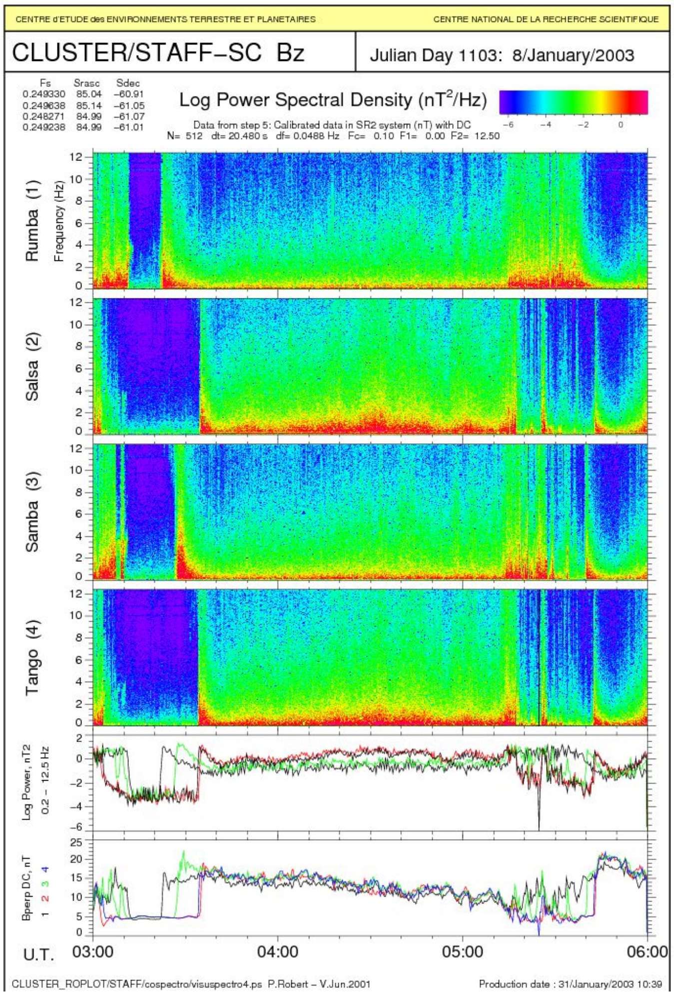
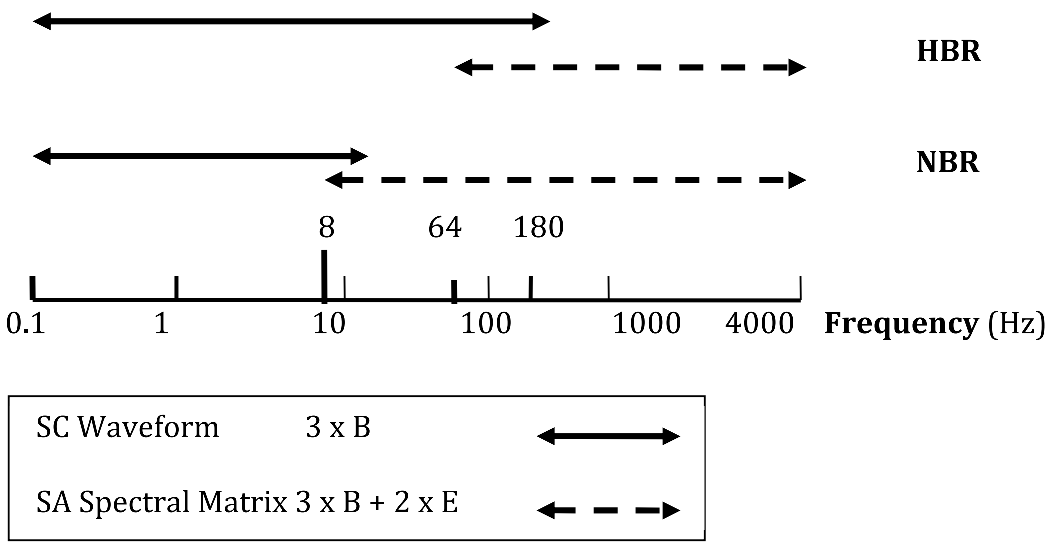


Figure 7: Example of quicklook plot (successive crossings of the bow shock)

6 Recommendations and caveats

The scheme below shows the data availability as a function of telemetry mode and should help **choosing a STAFF dataset**.



6.1 Choice between different Cluster datasets

Results of cross-calibration studies (see [5]) give the following indication for the choice of a given experiment, when performing similar measurements.

Magnetic fluctuations

Frequency range / Instrument	0.1-0.5 Hz	0.5-1 Hz	1 – 10 Hz B < 10 -4 $nT^2 Hz^{-1}$	1 – 10 Hz B > 10 -4 $nT^2 Hz^{-1}$	> 10 Hz
FGM	X	X		X	
STAFF-SC		X	X	X	X in HBR
STAFF-SA					X

STAFF at frequencies around spin doesn't despin the data as well as FGM. Above ~1Hz the sensitivity of STAFF instrument is better than FGM one. For more details on instrument choice and on combining both data sets, see the Calibration Report [5].

WBD and STAFF

Those experiments are complementary in the frequency range 25 Hz to 4 kHz, when WBD operates in its default mode (25Hz – 9.5 kHz frequency coverage). WBD has a much higher frequency and time resolution in the bandwidth of STAFF (respectively ~3 to 20Hz and ~5 to 36 microseconds). However, WBD has also strong limitations compared to STAFF: it is operated only up to a few hours per orbit and provides only one component of the Electric or the Magnetic field, hence not enabling the derivation of polarization parameters.

Conclusion of comparisons between STAFF-SA and EFW (see CR ref [5])

The agreement is good while the electric fluctuations level around 8.8 Hz is larger than 6 to 10 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. At 70 Hz, the threshold is 10^{-4} $(mV/m)^2/Hz$.

6.2 Data Availability and Quality

General Remark: Various in-flight situations can prevent the availability and good quality of some or all STAFF Data. Since the SC and SA data are provided by two different sub-instruments, the data can be present and correct in one of them and not on the other.

Interferences seen in routine operations

Some weak interferences can be seen on a routine basis during periods of no significant wave activities. They are due to internal STAFF, WEC or spacecraft induced noise and can vary in amplitude with time, but with a very narrow bandwidth. They can be seen on spectrogram as horizontal lines. Examples for both SCM and SA data are given in the figures below. Figure 8 display ~20 minutes of C1 SCM data obtained in HBR mode during a quiet period. The low-level interferences are evident as numerous horizontal lines, with the Bz components ones being the most numerous because of the lower noise with respect to the spin plane components. Figure 9 (electric) and Figure 10 (magnetic) present the interferences observed on routine over the frequency range of the Spectrum Analyser. The C3 SA data have a significantly higher noise level around F ~100 Hz due to calibration issue.

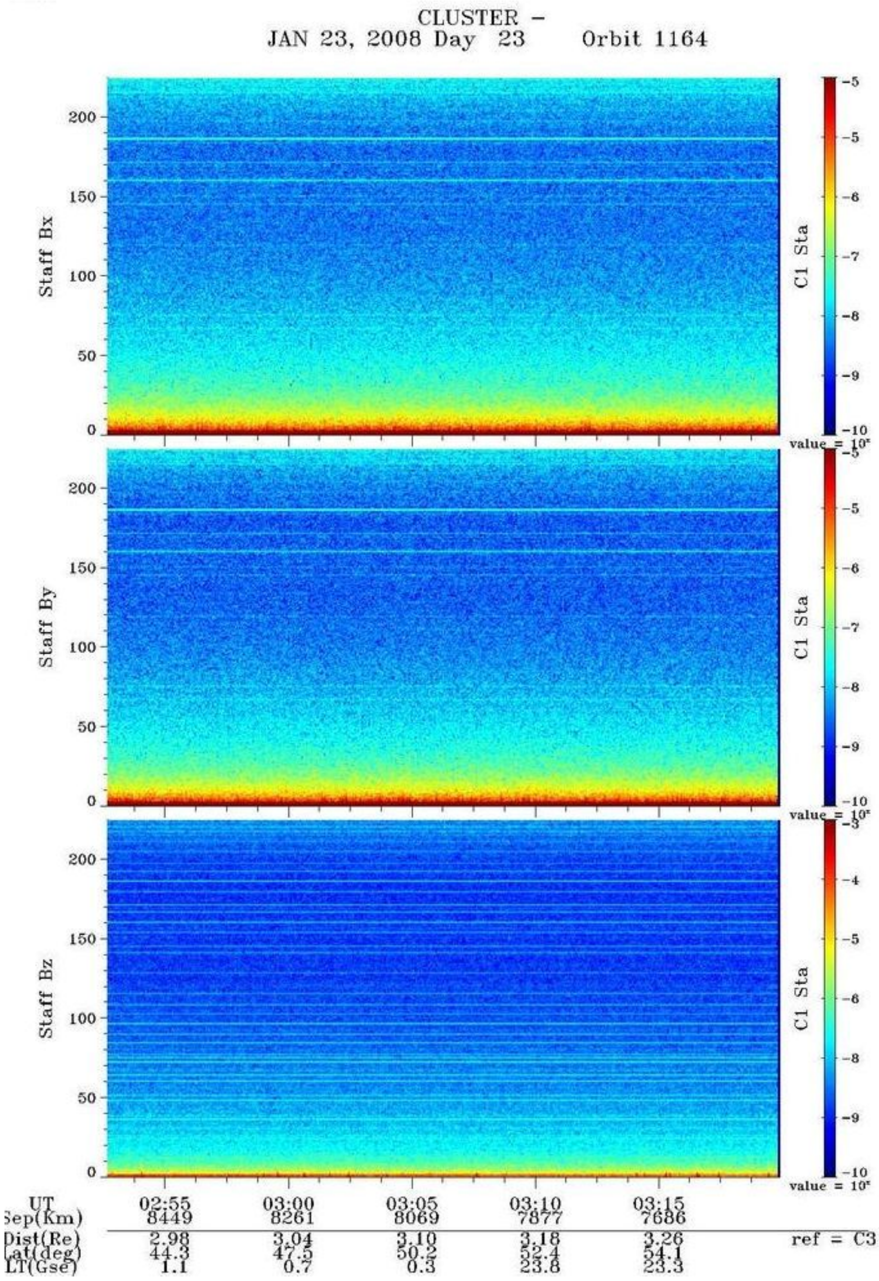


Figure 8: Interferences seen in SCM C1 data in Burst mode

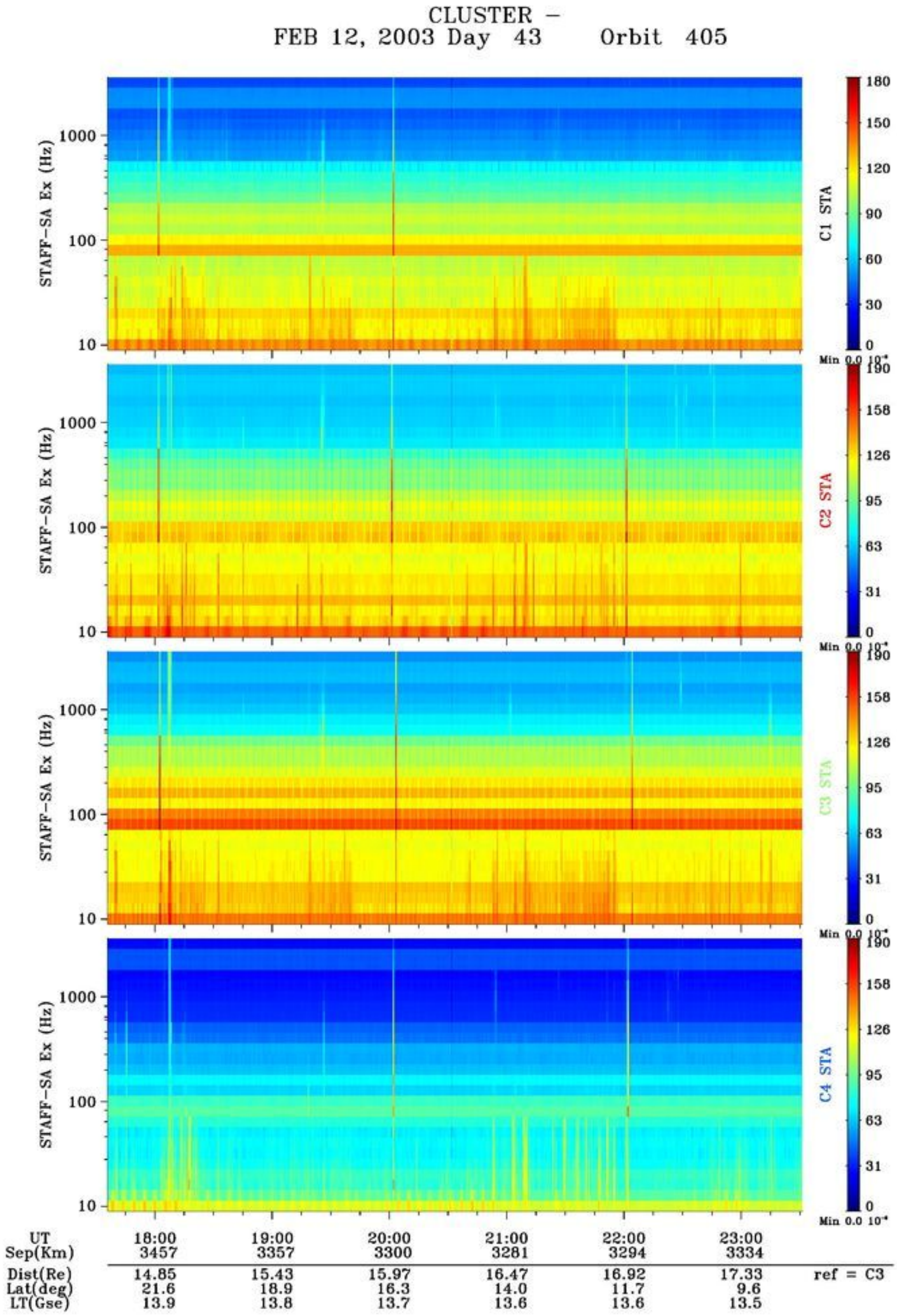


Figure 9: Interferences seen on routine on SA Electric component

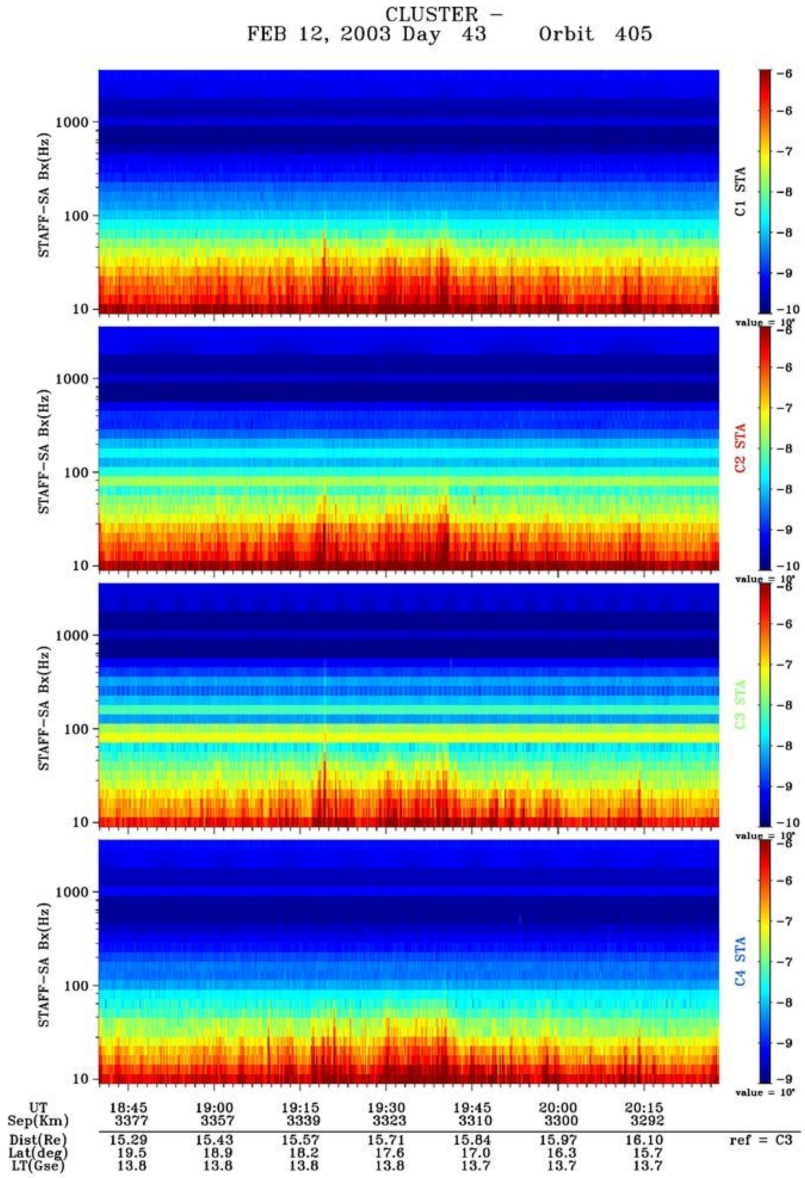


Figure 10: Interferences seen on routine in SA Magnetic components

Because the on-board data commands, acquisition and packaging in the spacecraft telemetry are highly depending on software which can be corrupted by events (i.e.: Single Event Upset), there can be bad or poor-quality data, even no data, not all fully identified, in the STAFF data sets, for example:

- DWP anomaly (i.e.: SEU) which induce
  One, two or all SC data to be corrupted
  Good SC data and no SA data (due to lack of synchronisation with DWP)
- Telemetry overflow which induces non-continuous data stream
- Saturation of B components (mainly on SC, above its range) due to low perigee, not expected in the baseline mission for which the instruments were design

If some STAFF data seems to deviate from good quality products, the user should consider the information found in the file headers, caveats or in the House Keeping plots where the most useful anomaly status can be found (TM overflow, Application Overflow, SC Error, SA Error, …).
The most significant anomalies of the standard operating modes that can be found and the possible limitations of their use are presented below through examples found in the STAFF data products:

6.3 Use of CWF Data

The calibrated waveform data are produced with the best calibration files. See the Calibration Report [5] for the method and the STAFF-FGM crosscalibration results. The user should keep in mind the following caveats:

On-board calibrations periods:

- To be not confused with scientifically usable waveforms or spectra, the on-board calibration data are removed from CWF files, which corresponds then to a data gap (about 6 minutes in NBR, 1.5 minute in HBR) in the CWF. This **generally** happens once, sometimes twice, per orbit, during the so-called BM3 mode. These calibration periods are listed in the CALIBRATION caveats (C?_CQ_STA_CALIBRATION_CAVEATS).

Absence of Sun Pulse:

- The CWF calibration software needs to find in DWF at least one valid phase value per calibration window. With one or more valid phase values, the calibration software can interpolate to deduce the phase values of the whole current calibration window. If so, the invalid phase values of the window being calibrated will change from "-500.00" in DWF to a valid value in CWF (calculated by interpolation). The phase status of these records will also be changed from 'N' in DWF to 'R' (for recovered) in the CWF. An example of this phase 'recovery' can be found for example by comparing C1 DWF and CWF data from 21:47:06.386660Z to 21:47:26.786190Z.

But, if not a single valid phase value is found in a calibration window, the CWF has filled values (for phase and components). This will prevent from further polarisation or propagation characteristic determination. Only the component parallel to the spin axis or the total wave power is meaningful. A bad phase value is often due to the Sun Reference Pulse missing for more than 600 seconds (so mainly in eclipse periods). The absence of Sun Reference Pulse is flagged by the NOTSRP caveat (C?_CQ_TSA_NOTSRP_CAVEATS_). If the sun pulse is missing for less than 600 seconds and Φ_{SC} (Φ_{SC}: spacecraft's phase) is the same before and after the gap, then we deduce the Sun Reference Pulse by interpolation. The sun pulse is needed to calculate the phase, which is in return needed in the software calibration process. So, during long periods of absence of sun pulse no CWF (nor CS) are produced. The phase status (11th character of the STAFF status word) holds information about the Sun Pulse quality (nominal, interpolated or suspect) used in the phase calculation. (cf. Appendix C, Phase status).

Time accuracy:

- The lack of TCOR data (§4.1) to improve the timing of samples from 2 ms to 50 µsec can have significant impacts when using the HBR data, when comparing data from different spacecraft. The impact of non-corrected data on successive blocks can also introduce discontinuities and artefacts. See Figure 10 below where CWF data obtained in HBR over a 0.5s timeframe for C3, shows the differences in Bx and By when TCOR is used (in red) or not (in black). The user should then carefully check in the CWF header and on character 12 of STAFF status word (Annex C) if the TCOR correction has been applied or not.

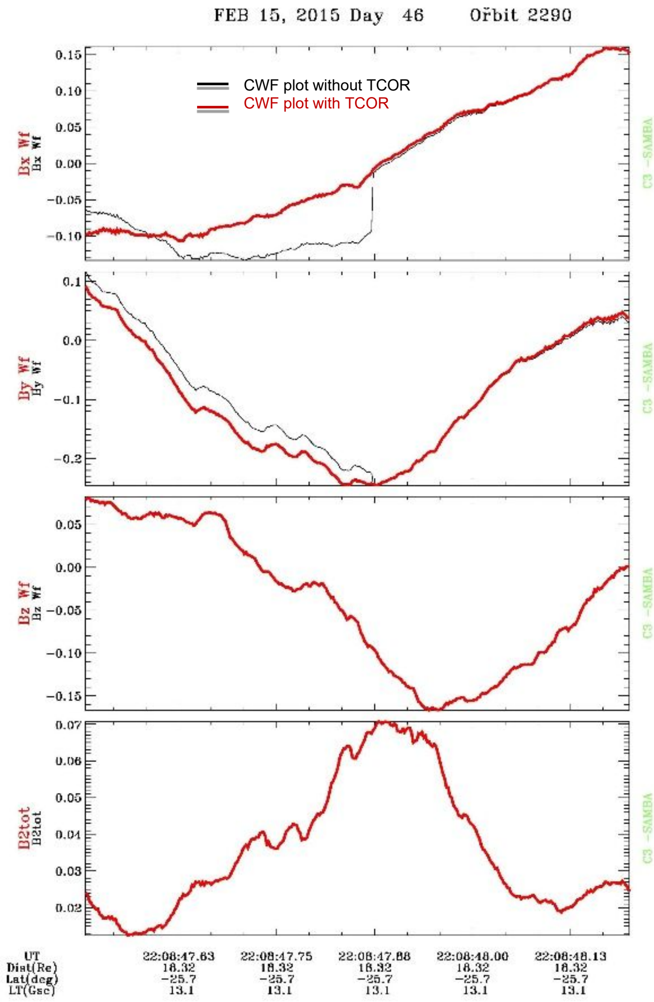


Figure 11: Example of impact of TCOR data on the 3 components in a CWF file

In case of simultaneous use of EFW and STAFF waveforms:

- Timing:
  Check the status of the TCOR option in both datasets. See "Timing accuracy of Waveform" in the section [4.1] for details.
  While both datasets have the same time at level 1, once calibrated the timing is different for both datasets, due to the two different calibration processing for both experiments. The low pass filter effect is translated in EFW data by the addition of a constant time shift, whereas

in STAFF data it results in a frequency-dependent phase shift at the time of the data acquisition. This explains why for the products available at CSA, the time is different.

- Analysis of events at frequencies > filter frequency cut off/2:
  The procedure used by EFW considers the effect of the low pass filter is exact as long as one considers frequencies < fmax filter/2. Above this frequency it is no longer true and the shift is different in STAFF data, as STAFF incorporates the filter transfer function in its processing chain. Information can be found on EFW documentation.

Limits of the calibration method in CWF

- The method of calibration using FFT, the need to despin the raw data over a time window greater than the spin period, have necessarily unavoidable compromises. This has obvious impacts when the SC time series to be calibrated (DWF) are not continuous due to bad telemetry, which induced missing spectra when the number of missing samples exceeds the size of the sample in the window use to calibrate the raw data (see [5] for examples). Therefore, DWF samples may exist while no calibrated CWF data is available. Since the calibration method used is different to produce CWF and CS data, the number of missing calibrated spectra from the same period may be different between those from CWF and CS. For some specific studies, it is appropriate to restart the calibration processing from the raw DWF data, see [5].

6.4 Use of CS Data

Those data are calibrated, and can be used with nearly no restriction, the calibration being stable over time. The quality of calibrated spectral measurements is generally good, except in certain specific situations:

- ***Saturation at perigee***

The perigee has changed during the mission. In the period end 2007-2011 and in 2023-2024 (end of 2022-2024 for C2), the low perigee induced a saturation of the waveform on the 2 spin plane components, when the DC field seen by these search coil axes is above about 1200nT, a value which was not expected in the baseline mission and for which the hardware was not designed. These saturated values, present in the CWF and CS have not been eliminated from these files. But they can be easily identified using the value of the B field provided by FGM. The impact is more limited on the Bz component. It is not visible for CS files available in the ISR2 frame. However, it may be present for a strong B field for CS files produced in the GSE frame, which are impacted by the spin plane components. Note that for this reason, saturation effects are almost not visible in the CS_plots available at the CSA in the GSE frame, since these plots contain only Bz values. The periods corresponding to saturation at perigee were eliminated from these archived plots. The effect of the spin signal and of saturated data can be seen on Figure 12 and Figure 13. In that example, the Bz component is not affected.

Associated caveats:
C?_CQ_STA_NOTSRP_CAVEATS
C?_CQ_STA_CALIBRATION_CAVEATS

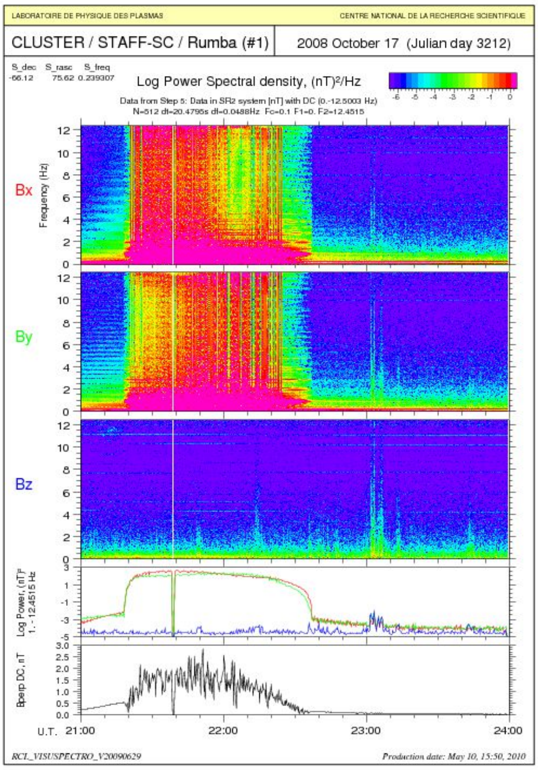


Figure 12: Plot of CS data during a waveform saturation period (DC field > 2000nT)

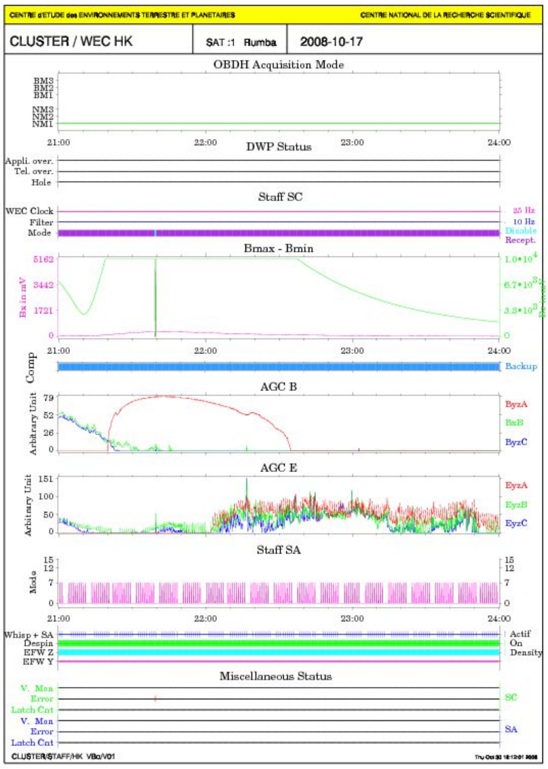


Figure 13: House Keeping data for the same time interval as on Figure 8. The parameter Bmax-Bmin, amplitude of the analog waveform is above 10 V. Note that the STAFF-SA AGC is saturated too. Search coil data are invalid between 21:20 and 22:40

These two Figures show the effect of waveform saturation at perigee. On Figure 13 are displayed the Housekeeping data, the fourth panel from top, Bmax-Bmin, saturates and the Bx and By components of the dynamic spectra show clearly saturation. We suggest then to the users, to check the quality of non-standard data by looking at the House Keeping plots at CSA.

- ***Bad Telemetry and missing data in CWF and CS***

During poor communications between the spacecraft and the ground station, the received telemetry can be non-continuous and can induce data gaps in the SC received samples. This situation can also occur with a bad WEC command due to a DWP error or corruption which can result in oversubscription of the WEC telemetry allocation and subsequently missing data. The data gaps in the DWF files will induced missing CWF data points and CS spectra (see [5] for details). An example is shown in the CS plot used in Figure 14 below, during a bad TM period encountered by C1, with irregular/missing spectra, while the other spacecraft had good TM.

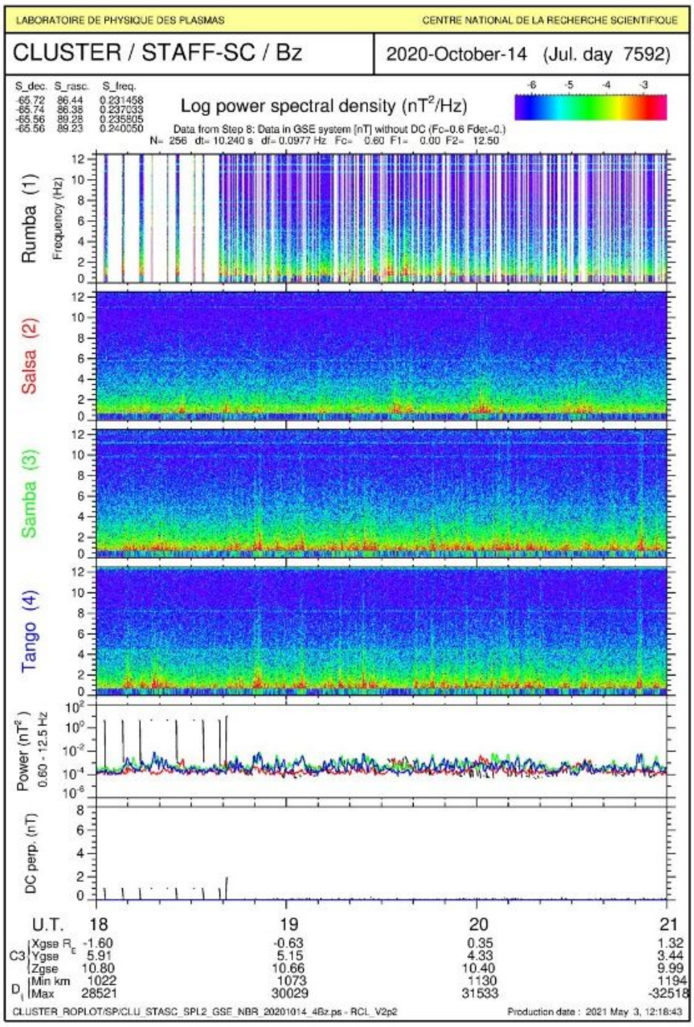


Figure 14: Bz spectra during a bad TM episode encountered by C1

- ***Corrupted telemetry packets***

These events can occur when TM packets are corrupted by an anomaly in the onboard DWP processing, due for example to an SEU or a bit error, and provide data unusable for STAFF or for the entire WEC instrumentation. Figure 15 below shows such an event where a bit error occurred on C2 at ~16:25 UT, while data for other spacecraft are correct.
The corrupted values can occur on all data (including SA data) or part of STAFF measurements, a single component for example and can present different forms of corrupted data. These anomalies, as well as the TM overflow situation, usually stop at the next BM3 mode (at least one per orbit) when the DWP is systematically reboot. The bad data are then observed for a duration less than one orbit. For more severe software malfunctions, a power cycling of the instrument or DWP can be requested and the bad data period can cover many orbits.

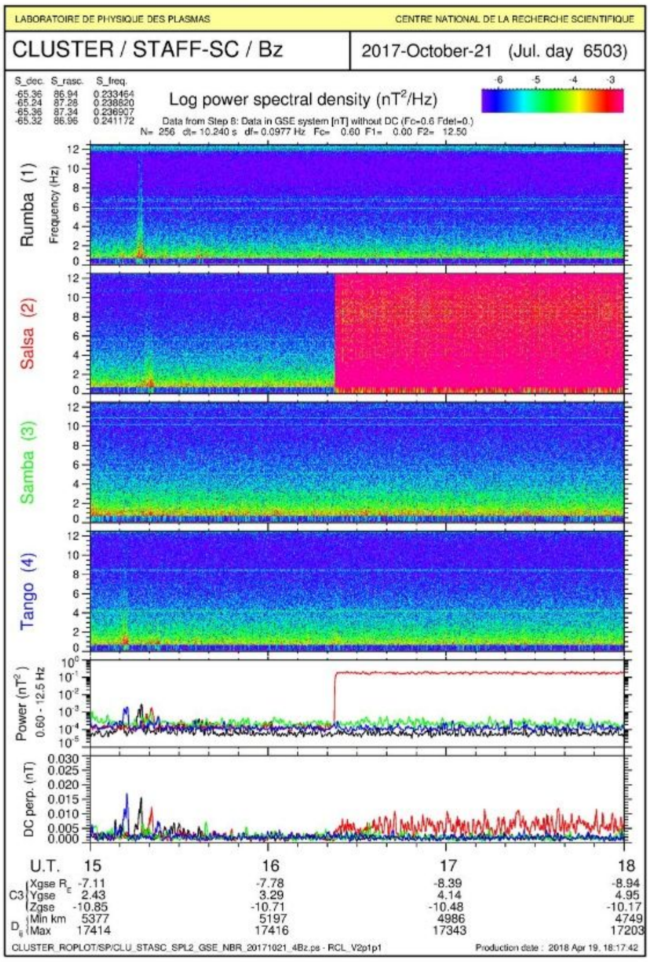


Figure 15: Bad data on C2 due to corrupted telemetry packets

6.5 Use of STAFF-SA products

6.5.1 General considerations applicable to all STAFF-SA products

Concerning the use of the parameters calculated from the measurement of magnetic fluctuations, for SM and PSD level 2 products, there are some warnings:

- a possible saturation of the waveform at perigee, which occurs when perigee is low (L≤ ~2). This case has not been flagged and the user must be aware of this. The AGC can be saturated in a very high B field.

- The Spectral Matrix coefficients are given in a fixed frame of reference onboard, considering the sun pulse for despinning the data. This constitutes an issue on the validity of the calculation when the sun pulse is not available. This mainly occurs during eclipse periods. That is why a caveat file has been produced as explained below, NOTSRP files.

- Low values in the on SA measurements leading to negative values.

Caveat 1: NOTSRP
This dataset contains caveats for the PPP, PSD and SM datasets. This caveats dataset provides the users with time intervals when no Sun pulse (TSRP) was recorded in the S/C housekeeping data. Note that it can be in eclipse period but not only. During those time intervals only, the total power density is meaningful. In particular no PPP data should be used.

Caveat 2: PSDNEG
As already mentioned, there can be PSD negative values at time of very low amplitude signal that have been replaced by fill values in PSD, and put in this caveat. PSDNEG are caveat files for the SM an PPP datasets. The caveats consist of the PSD negative values that have been replaced in the PSD data product by a fill value for a given time and frequency. It permits to evaluate the validity of the SM power density value including those negative PSD in its calculation.

6.5.2 Timing issues

As mentioned in §5.3, one shouldn’t worry about a difference of timing between STAFF-SA SM (or PSD) and PPP. For a given time interval (1 s or 4 s depending on bit rate mode), SM are dated at the beginning of the interval whereas PPP are date at the middle of the time interval. PPP are time stamped either 0.5 s or 2 s later. With Version V07 of this data set, the insertion of a delta t information in the dataset solves this point.

6.5.3 Use of magnetic field measurements

Continuity between STAFF-SC and STAFF-SA spectra is rather good (see CR [5]).
There are interferences, seen mainly on S/C2 and 3, that are internal to STAFF-SA at 70, 140 and 280 Hz, and an interference at 900 Hz seen an all 4 S/C, coming from DWP Clock. Interferences are hidden for strong enough signal (see e.g. interference at 70 Hz).
When using STAFF-SA spectra, the user shall consider the above facts to not misinterpret STAFF-SA spectra.

6.5.4 Bad Intercalibration between SA Frequency bands

When strong, large band, fast varying emissions are encountered, the intercalibration between each of the 3 frequency bands of the SA (see §2.2) can be of very poor quality, there is no continuity in frequency of the spectra and peaks can occur at the edge between the frequency bands. This problem occurred mainly for the electric field components, but can be also observed on the magnetic ones. The common origin of these anomalies is presented in more details in the CR [5]. No solution is available now to provide a better calibration. Figure 16 presents an example of such bad intercalibrations.

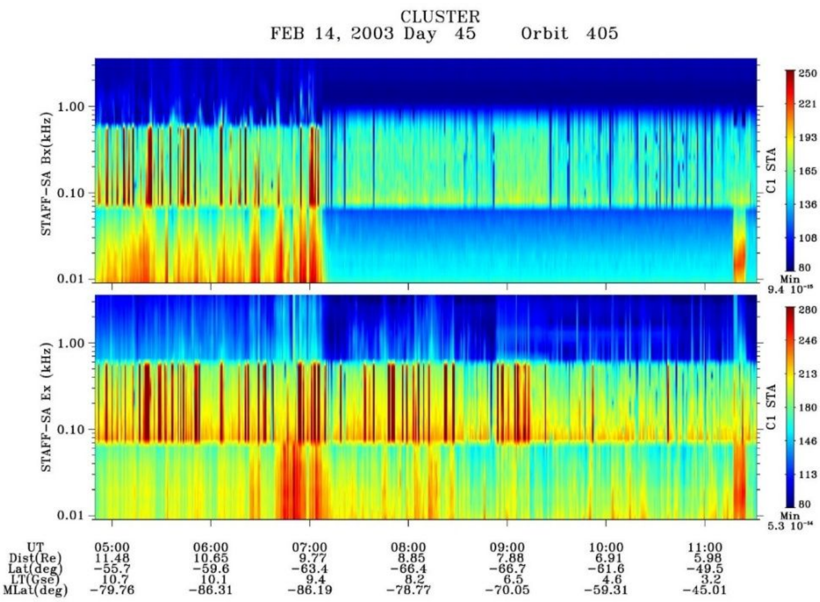


Figure 16: Bad intercalibration between SA bands observed on Magnetic(top) and Electric(bottom)

6.5.5 Use of electric field measurements and related parameters

- ***EFW probe failures***

For the use of parameters calculated from the measurement of **ELECTRIC FIELD**, the main concern is the partial failure of EFW booms as mentioned in section 3. Table 3 gives periods of potentially invalid measurements. Some details are given below. For further information on the various problems with probes, see EFW User's Guide and Calibration Report.

STAFF-SA electric components may be affected by the EFW probe failures on some of the spacecraft (see Table 3). After the failure, the electric antenna may be saturated, but once EFW has commanded the failed probe into density mode, i.e. set the potential to V=0, the quality is good again, but the sensitivity is decreased. Due to the onboard de-spin processing, the failure of one probe affects the same way the 2 STAFF-SA calculated electric field components.

Note 1: Some EFW probe failures will prevent the measurements of the DC electric field, but will have no impact on the measurement of electric fluctuations observed by STAFF-SA.
For one probe failure, the underestimation of the electric power is about one third of the total power, whereas for 2 probes failures the power is underestimated by a factor of 2. Example of a probe failure is shown in Figure 17 (left) with sudden saturation on C1 and the result of recovery is shown in Figure 17 (right) when the failed probe is set into density mode, i.e. the potential is set to V=0.

Note 2: The impact on STAFF-SA electric field power has not been corrected in the corresponding calibrated data, which assumed full antenna length during the whole mission. While it is possible to consider the true antenna length in the electric PSD values, this is far more complicated for the Spectral Matrix (SM) values. To avoid the delivery of different calibrated values for the electric components in both PSD and SM, it has been decided to not correct the PSD value from the effective electric antenna length.

The following table gives the details of EFW operations following probe failures and data quality.

S/C	Failed probe	Failure date	Density mode implementation	Time interval	STAFF-SA E data quality
C1				2001-01-01 - 2001-12-27	4
	P1	2001-12-28 03:02:57		2001-12-28 - 2002-01-27	0
			2002-01-27	2002-01-27 - 2007-06-12	2 a
				2007-06-13	XX
				2007-06-14 - 2009-04-18	2a
	P4	2009-04-19 07:29:00		2009-04-19 - 2009-05-10	0 *
				2009-05-10 - 2009-10-14	2a
	P4	2009-10-14 07:00:00		2009-10-14 - 2009-11-28	0
			2009-11-28	2009-11-28 - End of mission	2b
	P3	2018-12-10 03:00			
C2				2001-01-01 - 2007-05-13	4
	P1	2007-05-13		2007-05-13 - 2007-06-23	0
			2007-06-23	2007-06-23 - 2024-07-16	2a
	P2	2015-12-10 19:38			
	P3	2022-08-23 12:08			
C3				2001-01-01 - 2002-07-28	4
	P1	2002-07-29 09:06:59		2002-07-29 - 2002-08-09	0
			2002-08-09	2002-08-09 - End of mission	2a
	P3	2011-06-01			?
	P3&P4 OFF	2024-04-28 18:43			
	ON	2024-09-28 00:00			
C4				2001-01-01 – End of mission	4

4 : good quality
2 : no saturation - caution to absolute values :
2a :one probe is set to zero (density mode, V=0) ; power underestimated : ~0.625 of the power in $mV^2\ m^{-1}\ Hz^{-1}$
2b : 2 probes are set to zero : power underestimated by a factor of 2 (~0.5 of the power in $mV^2\ m^{-1}\ Hz^{-1}$)
0: one component saturates; do not consider using STAFF-SA electric component or E field deduced parameters (Poynting Vector component)
0* : many successive operations
XX : special tests; be cautious

Table 3: EFW Operations and STAFF E component quality

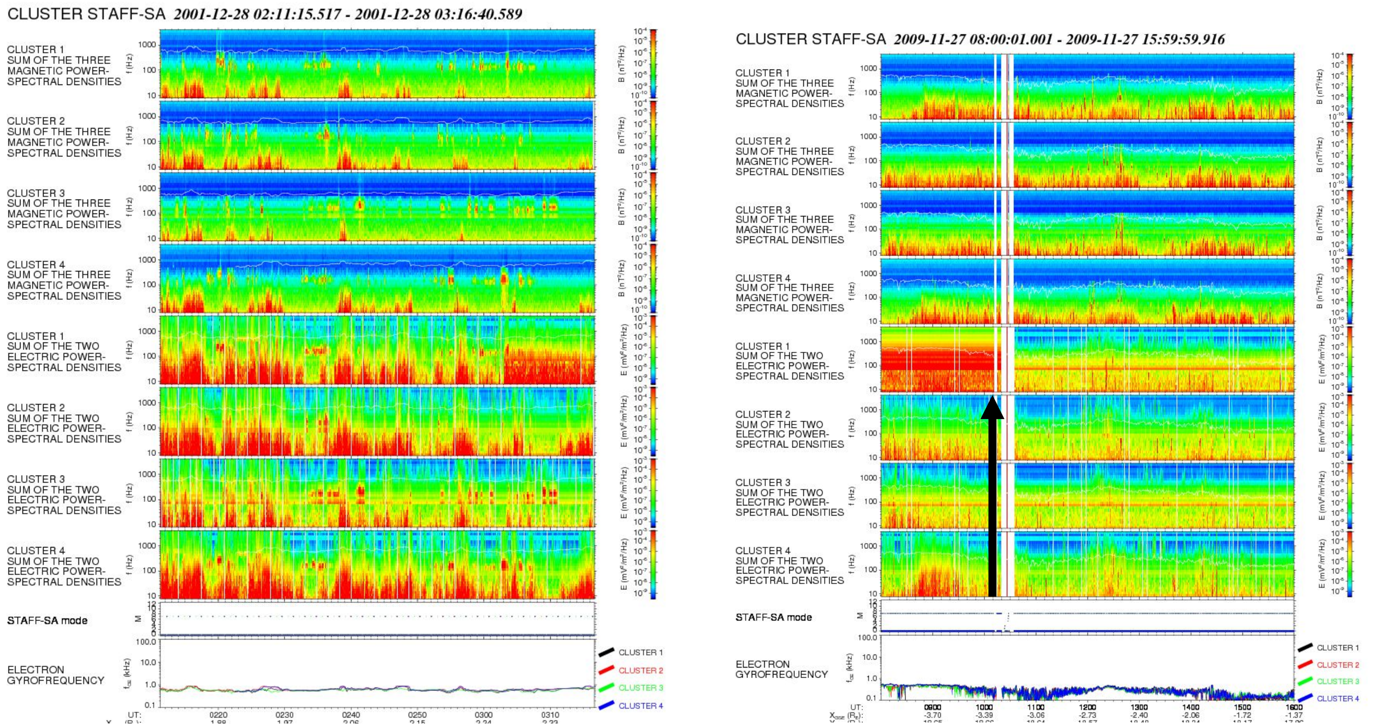


Figure 17: Example of EFW probe failure (left), seen as a saturation on Dec 28, 2001 at ~03:02 and recovery (right) of E field measurements after a similar failure in 2009 by putting the failed SC 1 probe in density mode (V=0). SC1 E data change after 10:20 from saturated to behaviour comparable to other S/C

- ***Interferences from Solar Aspect Angle (SAA) close to 90°***

To save fuel to increase the mission lifetime after 2014, it was decided not to change the attitude of the spacecraft every 3 months to cope with the variation in the angle of the booms relative to the direction of the sun.

This regular change in attitude was designed to avoid, in particular, any shadow on the electric sensors, which can be source of spiky interferences.

This induced short duration strong electric spikes each time an EFW probe was in the sunlight. If these spikes can be eliminated from time series measurements (like EFW ones), they stimulated the AGC of SA for periods close to their integration times (960 ms for A band) and greatly overestimate the measured electric fields which appears as strong interferences in the SA data. The fixed attitude, close to the sun direction perpendicular to the spin axis (SAA ~90°), and hence the beginning of strong electric interferences seen by SA was effective in May 2014 and kept until end of the mission.

Figure 18 shows an example of such interferences, for which the form and duration depends on each spacecraft (due to different EFW probe failures and SAA).

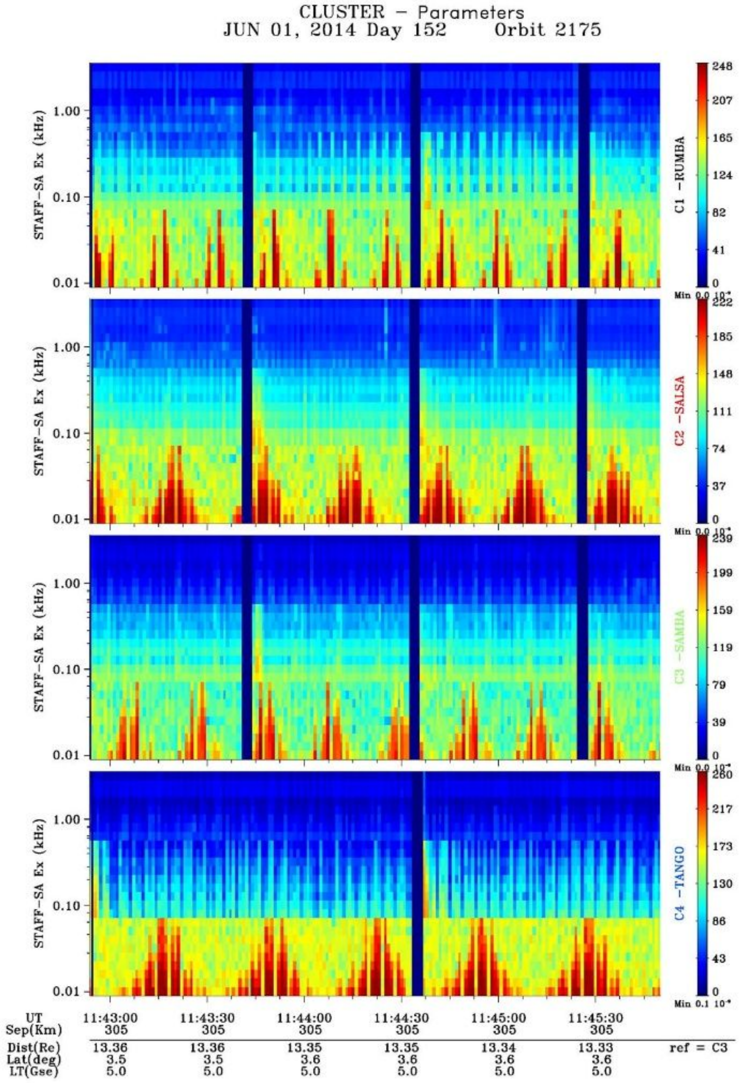


Figure 18: Interferences induced by SAA~90° on EFW probes seen by SA-Electric on the spacecraft

- ***Electric interference coming from the EDI experiment***

The CLUSTER-EDI experiment injects pulsed electrons beams in the plasma surrounding the spacecraft. This generates electric fluctuation disturbances which are seen on the two electric components of the STAFF Spectrum Analyser (SA). These disturbances appeared as an increase of the background noise over the frequency range of the instrument. The magnetic components are not affected. Figure 19 below shows an example of this disturbance on C1, with the increased of background noise over the full frequency range, in the period ~12:20-16:10 UT on the 2 electric components (2 bottom plots). The saturation seen on the electric components below 100 Hz is due to the interference SAA ~90° (see above) The level of interferences changed with time and spacecraft depending on the evolution of hardware of the EDI instrument. There is no interference on C4 since EDI was not operational on the spacecraft.

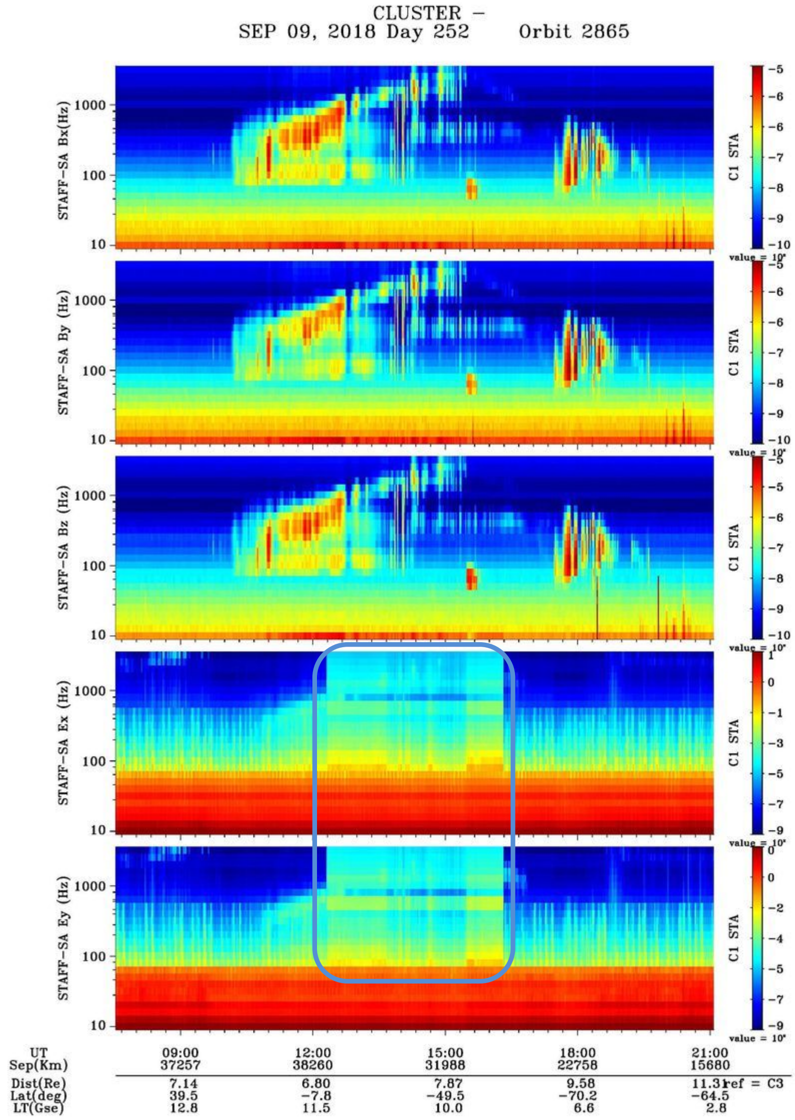


Figure 19: Electric Disturbances (in blue rectangle) induced by the EDI inst rument

- ***Interferences following Whisper active mode***

Because of potential interferences, there is no data capture of electric components of SA during the active mode of the Whisper instruments which transmits short duration pulses, typically ~1ms duration, during a few seconds. However, there may be significant interferences observed on a few SA electric spectra, mainly on the B frequency band (64-512 Hz) following this active mode. This cannot come directly from Whisper transmitter which is Off at this time, and the origin of these interferences, variable between the spacecraft and the period has not been investigated. An example is shown on Figure 20 below. The vertical black lines (no data) on the figure correspond to the periods of Whisper active mode. Note that on this example, if the interferences (in red circle) are visible with different forms on C2, C3 and C4 (shorter duration), no interference is visible on C1.

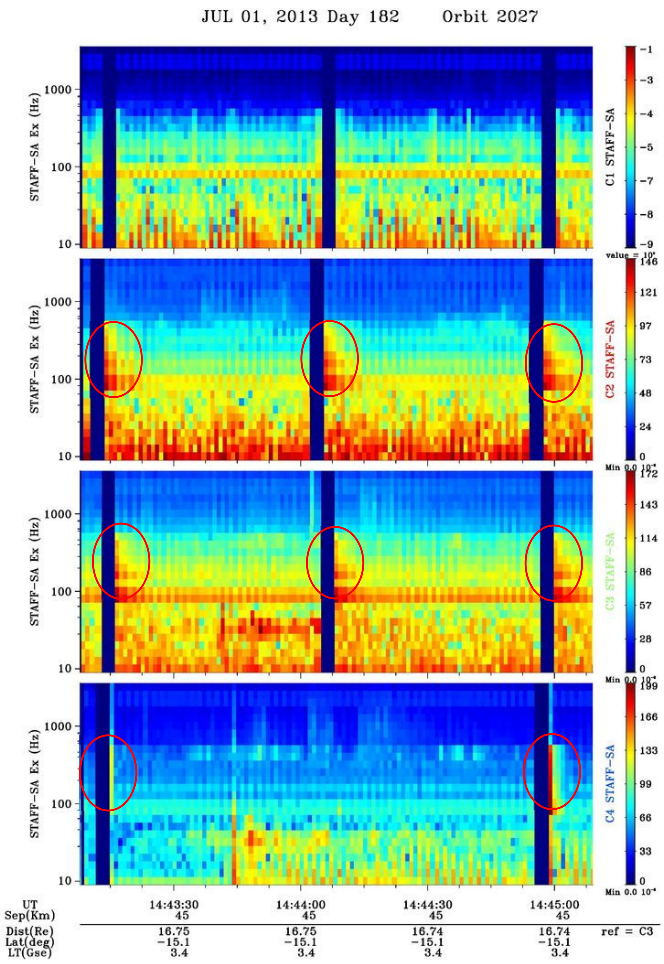


Figure 20: Interference (red circle) on SA electric spectra following Whisper active mode

6.2.6 Use of STAFF-SA PPP (Polarization and Propagation Parameters)

Warnings given above, in particular in what concerns electric field measurements, are applicable. One shoufor data validity. Quality 2 seems to be good enough in what concerns the direction of the Poynting vector.

For the PPP use, some more caution has to be taken. The validity of the results depends on the amplitude of signal. Thus, a **threshold on the total wave power density** (Magnetic or electric or both), point by point, should be used (e.g. BSUM threshold for the example presented on Figure 4 is 1.0.E-07 nT^2Hz^{-1}).

Since the electric field measurements calibrations have not been modified to account for the various probe failures affecting C1, C2 and C3 over the whole mission, the users have to use the corresponding EB cross-products in the matrix and hence the derived parameters with some caution.

Another issue is the validity of the change of frame of reference. When there is either no attitude or no FGM data available, the PPP are not calculated, the change in MFA frame of reference being not possible. PPP data are replaced by fill values. The description of these fill values is included a **caveat, called UNDEFINED_MFA.**

7 References

[1] Bouzid, V. , Cornilleau-Wehrlin, Burlaud, C.; Mirioni, L. ; N.; Maksimovic, M.; Robert, P. ; Piberne, R. : **Cluster Active Archive: Interface Control Document,** CSA-STA-ICD-0001,V5.6, 2025, http://caa.estec.esa.int/caa/ug_cr_icd.xml

[2] Cornilleau-Wehrlin, N.; Chauveau, P.; Louis, S.; Meyer, A.; Nappa, J. M.; Perraut S.; Rezeau, L.; Robert, P.; Roux, A. and C. De Villerdary: **The cluster spatio-temporal analysis of field fluctuations (STAFF) experiment.** *Space Science Review,* **79**: 107-136, 1997.

[3] Cornilleau-Wehrlin N., Chanteur G., Perraut S. , Rezeau L. , Robert P. , Roux A. , Villedary C. de, P. Canu, Maksimovic M., Conchy, Y. de, Hubert D. , Lacombe, Lefeuvre, F., Parrot M., Pinçon, J.L. , Décréau P.M.E., Harvey C.C., Louarn Ph., Santolik, O., Alleyne H.St.C., Roth M., Chust T., Le Contel O. and STAFF team, **First results obtained by the Cluster STAFF experiment***, Ann. Geophys.,* **21**, 437-456, 2003.

[4] **WEC Instrument User Manual**, CL-WEC-UM-002. http://caa.estec.esa.int/caa/dwp_docs.xml

[5] **Calibration Report of the STAFF measurements in the Cluster Science Archive (CSA),** CAA-EST-CR-001, V5.0, 2025**.** http://caa.estec.esa.int/caa/ug_cr_icd.xml

[6] Santolik O., **"Propagation Analysis of STAFF-SA Data with Coherency Tests (A User's Guide to PRASSADCO)",** LPCE/NTS/073.D, Lab. Phys. Chimie Environ./CNRS, Orleans, France, 2003. (http://os.matfyz.cz/PRASSADCO/guide.pdf)

[7] Santolik O., M. Parrot, and F. Lefeuvre, **"Singular value decomposition methods for wave propagation analysis",** *Radio Sci.,* 38 (1), 1010, doi:10.1029/2000RS002523, 2003.

[8] Yearby, K.H., S.N. Walker and M.A. Balikhin, **Enhanced timing accuracy for Cluster data, Geosci. Instrum. Method. Data Syst**, 3, 515-531, 2013

[9] Robert, P., N. Cornilleau-Wehrlin, R. Piberne, Y. de Conchy, C. Lacombe, V. Bouzid, B. Grison, D. Alison and P. Canu, **Cluster STAFF search coils magnetometer calibration – comparisons with FGM,** Geosci. Instrum. Method. Data Syst, 3, 679-751, 2013

8 Appendix A: Acronyms

AGC	Automatic Gain Control
BSUM	Sum of the three magnetic auto-power spectra
CETP	Centre d'études des Environnements Terrestre et Planétaires
CS	Calibrated Spectra
DWF	Decommutated Waveform
DWP	Digital Wave Processor experiment, member of the WEC
EFW	Electric Field and Wave experiment, member of the WEC
ELLSVD	Ellipticity of the polarization
ESUM	Sum of the auto-power spectra of the two electric antennae
GSE	Geocentric Solar Ecliptic
ISR2	Inverse of SR2
LPP	Laboratoire de Physique des Plasmas
MFA	Magnetic Field Aligned
PHSVD	Azimuthal Angle Value of the wave vector
POLSVD	Degree of Polarization in the polarization plane
PPP	Polarization and Propagation Parameters
PSD	Power Spectral Density
PVSIGN	Direction of the Poynting Vector component parallel to the magnetic field
SA	Spectrum Analyser
SC	STAFF Waveform data (from Search Coils only)
SEU	Single Event Upset
SM	Spectral Matrix
SR2	Spin Reference 2
STAFF	Spatio Temporal Analysis of Field Fluctuations experiment, member of the WEC
SSW6RF	STAFF Sensor WEC6 Reference Frame
TCOR	Time CORorrection
TED	Software to extract instrument data from WEC science data packages and to time the data using HK data
THSVD	Polar Angle Value of the wave vector
WEC	Wave Experiments Consortium

9 Appendix B: The STAFF datasets stored in the CSA

Dataset name	Dataset title[1]
Science datasets	
C?_CP_STA_CWF_GSE	Calibrated Magnetic WaveForm in GSE (NBR up to 12.5 Hz and HBR up to 225 Hz merged)
C?_CP_STA_CWF_ISR2	Calibrated Magnetic WaveForm in ISR2 (NBR up to 12.5 Hz and HBR up to 225 Hz merged)
C?_CP_STA_CS_NBR/HBR	Magnetic Field Spectra in GSE (up to 12.5 Hz (NBR)/225 Hz (HBR))
C?_CP_STA_PSD	Power Spectral Density (8 Hz - 4 kHz)
C? _CP_STA_SM	Spectral Matrix (8 Hz - 4 kHz)
C?_CP_STA_PPP	Polarization and Propagation Parameters (8 Hz - 4 kHz)
Science quicklook plots	
CL_CG_STA_SC_SPECTRO_NBR CL_CG_STA_SC_SPECTRO_HBR	Plot - Bz Spectral Density for all spacecraft (burst; up to 225 Hz)
Ancillary datasets	
C?_CP_STA_DWF_NBR/HBR	Magnetic Field Waveform - uncalibrated (25 or 450 Hz sampling)
C?_CP_STA_AGC	Automatic Gain Control
CL_CG_STAFF-HK	Plot STAFF House Keeping parameters and relevant WEC HK
C?_CE_STA_IFCReport	Text report of in-flight calibration sequence
Caveats	
C?_CQ_STA_NOTSRP_CAVEATS	Provides the users time interval when no Sun pulse (TSRP) was recorded in the S/C housekeeping data. Note that it can be in eclipse period but not especially
C1_CQ_STA_SA_PSDNEG_CAVEATS	For a given time and frequency are given the PSD negative values that have been replaced in the PSD data product by a fillvalue
C1_CQ_STA_SA_UNDEFINED_MFA_CAVEATS	Here are given times where there are either low coverage FGM data or low auxiliary data time coverage to transform SM data in MFA coordinate system
C1_CQ_STA_CALIBRATION_CAVEATS	Indicates when the STAFF instruments are in calibration mode

[1] This is the title visible in the CSA web GUI for downloading

10 Appendix C: Description of the STAFF status word

There is in fact two status word in STAFF data:

- STAFF-SA status word: 1 to 9 characters described below.
- STAFF-SC status word: 1 to 14 characters described below.

STAFF-SC status word

STAFF-SA status word

1	2	3	4	5	6	7	**8**	9	10	**11**	12	**13**	**14**
Step in cal	EFW Y	EFW Z	Mode SA	Mode SC	Despin SA	WHISPER Actif	**Calibration**	EFW sweep	Compression Mode	**Phase**	Tcor	**Time quality**	**Compression Quality**

The 14 characters of the status word included in the STAFF-SC products.

Detailed description is given below:

<table>
<tr><th rowspan="2">Description</th><th colspan="2">Values</th></tr>
<tr><th>Min-max</th><th>Meanings</th></tr>
<tr><td>Step in cal</td><td>0-n</td><td>0: science mode
<table>
<tr><th>Step</th><th>Mode</th><th>Attenuation (dB)</th></tr>
<tr><td>1</td><td>CAL4</td><td>0</td></tr>
<tr><td>2</td><td>CAL4</td><td>0</td></tr>
<tr><td>3</td><td>CAL4</td><td>0</td></tr>
<tr><td>4</td><td>CAL4</td><td>0</td></tr>
<tr><td>5</td><td>CAL4</td><td>-13</td></tr>
<tr><td>6</td><td>CAL4</td><td>-26</td></tr>
<tr><td>7</td><td>CAL4</td><td>-39</td></tr>
<tr><td>8</td><td>CAL4</td><td>-52</td></tr>
<tr><td>9</td><td>CAL4</td><td>-65</td></tr>
<tr><td>a</td><td>CAL4</td><td>-78</td></tr>
<tr><td>b</td><td>CAL4</td><td>Gnd</td></tr>
<tr><td>c</td><td>CAL3</td><td>0</td></tr>
<tr><td>d</td><td>CAL3</td><td>-26</td></tr>
<tr><td>e</td><td>CAL1</td><td>0</td></tr>
<tr><td>f</td><td>CAL2</td><td>0</td></tr>
<tr><td>g</td><td>CAL1</td><td>-26</td></tr>
<tr><td>h</td><td>CAL2</td><td>-26</td></tr>
<tr><td>i</td><td>CAL1</td><td>-52</td></tr>
<tr><td>j</td><td>CAL2</td><td>-52</td></tr>
<tr><td>k</td><td>CAL2</td><td>Gnd</td></tr>
<tr><td>l</td><td>CAL OFF redundant</td><td></td></tr>
<tr><td>m</td><td>CAL2</td><td>-26</td></tr>
<tr><td>n</td><td>CAL Off/On satellite</td><td></td></tr>
</table>
o: after calibration, till reset or new calibration</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>EFW Y boom pair</td><td>0-1</td><td>0: density mode off
1: density mode on</td></tr>
<tr><td>EFW Z boom pair</td><td>0-1</td><td>0: density mode off
1: density mode on</td></tr>
</table>

<table>
<tr><td>STAFF-SA mode description</td><td>0-f</td><td>
<table>
<tr><th>Value</th><th>Mode</th></tr>
<tr><td>0</td><td>NM1</td></tr>
<tr><td>1</td><td>NM2e</td></tr>
<tr><td>2</td><td>NM2b</td></tr>
<tr><td>3</td><td>Illegal</td></tr>
<tr><td>4</td><td>Emergency</td></tr>
<tr><td>5</td><td>Special</td></tr>
<tr><td>6</td><td>NM1’e</td></tr>
<tr><td>7</td><td>NM1’b</td></tr>
<tr><td>8</td><td>FM1</td></tr>
<tr><td>9</td><td>FM3e</td></tr>
<tr><td>a</td><td>FM3b</td></tr>
<tr><td>b</td><td>Illegal</td></tr>
<tr><td>c</td><td>FM2</td></tr>
<tr><td>d</td><td>Illegal</td></tr>
<tr><td>e</td><td>Illegal</td></tr>
<tr><td>f</td><td>Passive</td></tr>
</table>
</td></tr>
<tr><td>STAFF-SC mode</td><td>0-1</td><td>0: SC bandwidth 10 Hz
1: SC bandwidth 180 Hz</td></tr>
<tr><td>On-board despin (STAFF-SA)</td><td>0-1</td><td>0: despin on
1: despin off</td></tr>
<tr><td>WHISPER transmitter</td><td>0-1</td><td>0: off
1: active</td></tr>
<tr><td>Calibration</td><td>0-1</td><td>0: off
1: active</td></tr>
<tr><td>EFW sweep progress</td><td>0-2</td><td>0: no scanning
1: scanning
2: non-synchronised block</td></tr>
<tr><td>Compression Mode</td><td>0-2</td><td>0: nominal
1: backup
2: no compression</td></tr>
</table>

Phase	0-Z	0: True sun pulse used in phase calculation. 1: Interpolated sun pulse used in phase calculation. 2: Suspect sun pulse used in phase calculation. N: Phase = -500. due to invalid sun pulse status or unable to find satisfactory sun pulse. R: Recovered phase value (Phase with 'N' status in DWF but recovered by interpolation by the calibration software. Used in CWF and CS but only seen in CWF). Z: Phase = -500. (Can't open the interpolated sun pulses' file). In all cases, if the reference phase is not found in SATT, a default mean value is used.
Tcor	0-1	0: No (No Tcor correction available) 1: Yes (Tcor corrected)
Time Quality	0-1	0: interpolated time 1: block time
Compression quality	0-7	0 = no compression error 1 – 7 = error on 1 to 3 components in instrument frame 1 error on Bx 2 error on By 3 error on Bx and By 4 error on Bz 5 error on Bx and Bz 6 error on By and Bz 7 error on the 3 components

11 Appendix D: Description of the Compression Error

Waveform data is sampled into 16 bits for the first record of each block, but for other records only the difference is kept, coded in 12 bits. If the difference between two records is too big, we may encounter compression errors. Fortunately, we know on which bit the error occurs, which allows us to maximise it.

Three compression modes are available (see Status word character #10), and may lead to one or another bit to be wrong. The maximum error is then known, see the following table (where Delta is the difference between the current record and the previous one):

	Delta (16 bits)	Maximum Compression Error (TM counts)	Maximum Error (mV)
No Compression	0-65535	0	0
Normal Compression	0-2015	0	0
	2016-65535	1024	150
Backup compression	0-511	0	0
	512-1535	1	0.15
	1536-3587	2	0.3
	3588-7447	4	0.6
	7448-65535	1024	150

The normal and backup compression are used respectively when we expect to measure "low" and "high" amplitude signals including large spin signals.

Details of the compression error are given in the DWF datasets (one word per component).

In CWF a compression quality is given (see status word, character # 14) in the status word. This compression quality is calculated the following way:

Q = 4*Bx_error + 2*By_error + 1*Bz_error

With Bx, By and Bz being the components in the STAFF Search coil reference frame DSS (see § 2.3) and the error set to 0 no error, 1 an error

12 Appendix E: Ancilliary data

12.1 Level 1 STAFF-SC DWF (Decommutated Waveform) - Ancillary data

The decommutated waveform data (DWF), given in telemetry counts in the Data Sensor System (DSS) frame, are stored in the archive as reference data for the case of any further reprocessing. This dataset contains the maximum of information needed for the calibration process. The data sets contain all data present in the telemetry including non scientifically usable periods as the calibration periods, saturated measurements, or corrupted data coming from wrong behaviour of the STAFF application in DWP packaging. DWF are stored as ancillary dataset at CSA.
DWF are processed at LPP from RFF files (different from DWF only by their header) used to produce calibrated waveform (CWF) and complex spectra (CS) dataset.

12.2 STAFF–SA AGC (Automatic Gain Control) ancillary data

Those parameters are mainly given for control purpose as they are derived from an analogue signal. Nevertheless, it can be useful for plotting large-scale data to study the evolution of the wave global power as a function of any parameters. The user would find them in the STAFF ancillary data at CSA. The AGC parameters are the average power spectral density in the analogue receivers pass-band derived from the AGC signal. This is measured in the three large pass-band with the same time resolution as PSD.
A parallel (Bz) and a perpendicular (Bxy) component to the spin axis are measured for the magnetic field while only the perpendicular one (Exy) is measured for the electric field. There are three AGC values that are given in nT^2Hz^{-1} for the two magnetic AGC (Bz, Bxy) and in $mV^2m^{-2}Hz^{-1}$ for one electric AGC (Exy). There is one value per frequency band of the analyser (A: 8-64Hz, B: 64-512Hz and C: 512-4096Hz).

Here is a description of the STAFF-SA Automatic Gain control (AGC) parameter dataset
Supporting data and data are time series data depending on the variable Time__C?_CP_STA_AGC

Supporting Data describe the three frequency bands (A, B, C). Each band is defined with the interval centred frequency and the frequency bin half width.

Frequency__C?_CP_STA_AGC

Name	Interval centred frequency tag
Sizes	3
Units	Hz

Frequency_BHW__C?_CP_STA_AGC

Name	Frequency bin half width
Sizes	3
Units	Hz

Data are separated into two variables, one for the magnetic AGC, one for the electric AGC:
B_C?_STA_AGC_ depend on time and frequency

Name	Magnetic AGC
Property	Vector
Sizes	3, 2
Components	B_z, B_{xy}
Units	nT^2Hz^{-1}

E_C?_STA_AGC_ depend on time and frequency

Name	Electric AGC
Property	Vector
Sizes	3
Components	E_{xy}
Units	$mV^2m^{-1}Hz^{-1}$

12.3 STAFF House Keeping data plots - ancillary data

These plots (Figure 21) show a summary of housekeeping data extracted from WEC HK telemetry. There is one plot per S/C, of 3 hours duration each. HK time resolution is 5.15 seconds.

The plotted parameters allow verifying the mode of operation and the health of STAFF experiment, in the context of WEC and satellite mode of operation.

It permits in particular to understand data gaps.

On those plots (see below) are plotted from top to bottom:

1-The S/C telemetry mode

2- STAFF relevant DWP status (as Application or TM overflow)

3-4-5 STAFF-SC (3- mode; 4- maximum amplitude of the waveform; 5- compression mode)

6-7-8 STAFF-SA (6 and 7- AGC level; 8-mode)

9 and 10 various WEC and STAFF status

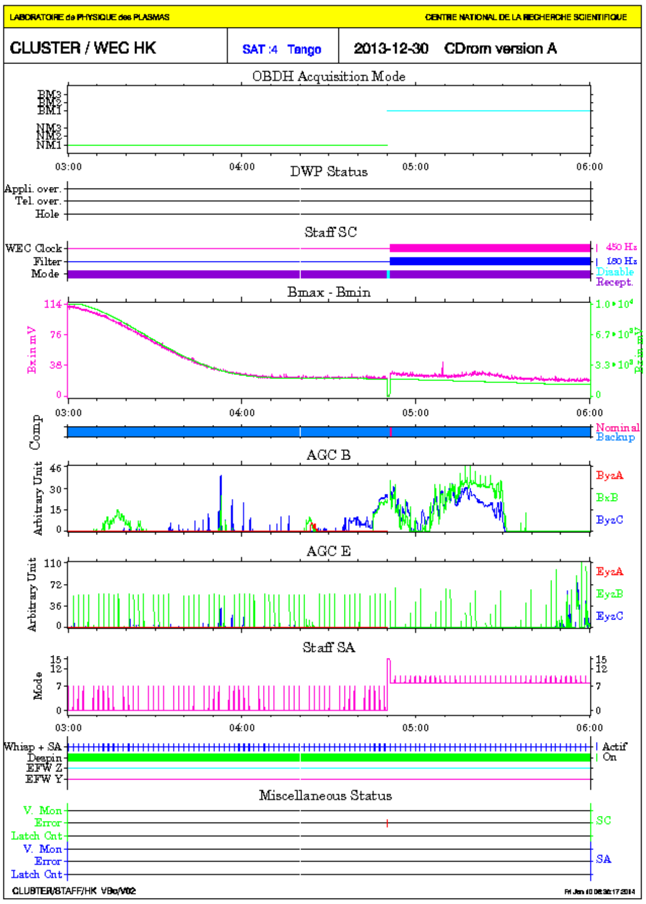


Figure 21: Example of routine plot of STAFF and relevant WEC Housekeeping data

13 Appendix F STAFF Special Operations

13.1 Introduction

There are very few STAFF specific special operations, the main differences being between Normal bit rate mode and High bit rate mode, also called burst mode, this being applicable to the whole spacecraft (see e.g. Table 1 of the present User Guide document).

Nevertheless, there are some special operations, which are of two kinds, recurrent and very seldom. The recurrent one is the in-flight STAFF calibration mode of 6 minutes duration, run once per orbit after the so-called BM3 mode. An example is given hereafter. A specific period, before the beginning of Cluster operations, is the commissioning phase during which the instruments were switched on and tested. Other special operations have been run for special tests. A list of those is given below.

13.2 Instruments Commissioning Phase

After the spacecraft launch in summer 2000 and before the beginning of the scientific operations on February 1st, 2001, the instruments were switched on by pair, first C1&C2 end of August 2000, then C3&C4 beginning of October 2000. Various modes were tested, usually for very short periods. The EFW booms were deployed by steps of increasing length before reaching their operational extension. These periods up to December were barely of scientific interests relative to the Cluster objectives because the instruments were generally not in an operational mode, run for very short period of time and there were no simultaneous operations of the instruments and spacecraft. However, these data can have interest of their own. For example, the deployment of the EFW electric booms was design to eventually study the electrostatic emissions with short wavelength. Then all STAFF products have been archived at CSA except the PPP, which required the FGM data for production, not available simultaneously. For use of these commissioning phase data, the users should carefully check the instrument modes and context at this time. Although not part of the main Cluster operation phase, the January 2001 data are very close to full operations and can be used as such.

13.3 Special BM modes

- **BM2 Mode**

Telemetry from each Cluster WBD instrument is typically downloaded directly to NASA's DSN ground station. BM2 mode was designed to allow this data to be stored in the Cluster Solid State Recorder (SSR) for later download to ESA's ground station. This mode was rarely used during the primary mission. However, after NASA's financial support for Cluster ended in 2015, which stopped the use of DSN, this mode has been more widely run. Although WBD uses most of its telemetry capabilities, Cluster's other instruments, including STAFF, then operate in NBR mode.

- **BM3 mode**

The Burst Mode 3 (BM3) is a short duration mode (~20 min) during which the on-board memories of some instruments (FGM, EFW) are downloaded. This mode is run one or twice per orbit. STAFF has no on-board memory, but some data can be collected prior to the calibration sequence. The STAFF-SA instrument is run in a mode compatible with the Normal Bit Rate Telemetry. No SCM scientific mode is activated.

13.4 In flight calibrations

In order to check the quality of the magnetic field fluctuations measurements and its possible evolution during the mission, an in-flight calibration mode is run once, sometime twice, per orbit and nearly always just after a spacecraft Burst Mode 3 (BM3). During this mode, a small generator is used to send a known current in the counter reaction loop of each magnetic axis. The calibration mode was run in NBR mode most of the time, and was run in HBR mode a few times during the mission. There are 23 steps, which can be obtained with a sine wave (~7.3 Hz in NBR, ~ 102 Hz in HBR) or a white noise (0.1 Hz- 4000 Hz). This white noise can be attenuated by steps (0 to 52 dB). Each step definition can be found in the STAFF Status Word-1 (10 Appendix C: Description of the STAFF status word). There are 400 samples collected for each step in NBR and 1800 samples in HBR, for a total calibration sequence of 6min08s in NBR and 1min32 s in HBR. The duration is the same for SA but the number of samples in each step depends on the mode run. See the Calibration Report (5] for more details. The corresponding data are not included in the science data. They can be accessed in the DWF files. Occurences of Calibration mode can be recognised on Housekeeping data plots (Figure 22) that are provided by STAFF at CSA as ancillary data (see § 5.9). Their timing is listed in the **CALIB_YTR_CAVEATS** files, which contains the beginnings and ends of all the calibration sequences during a given year of the mission.
A short analysis of these in-flight calibration is routinely performed on ground for each calibration sequence and the results are written in a short report. For the most significant steps, a comparison is done between the in-flight CAL measurements and reference values obtained on ground. An anomaly line is written each time a CAL value differs by more than 50% from the reference value. These reports are archived at CSA as **C?_CE_STA_IFCReport**. Their full description is provided in the STAFF Calibration Report [5]

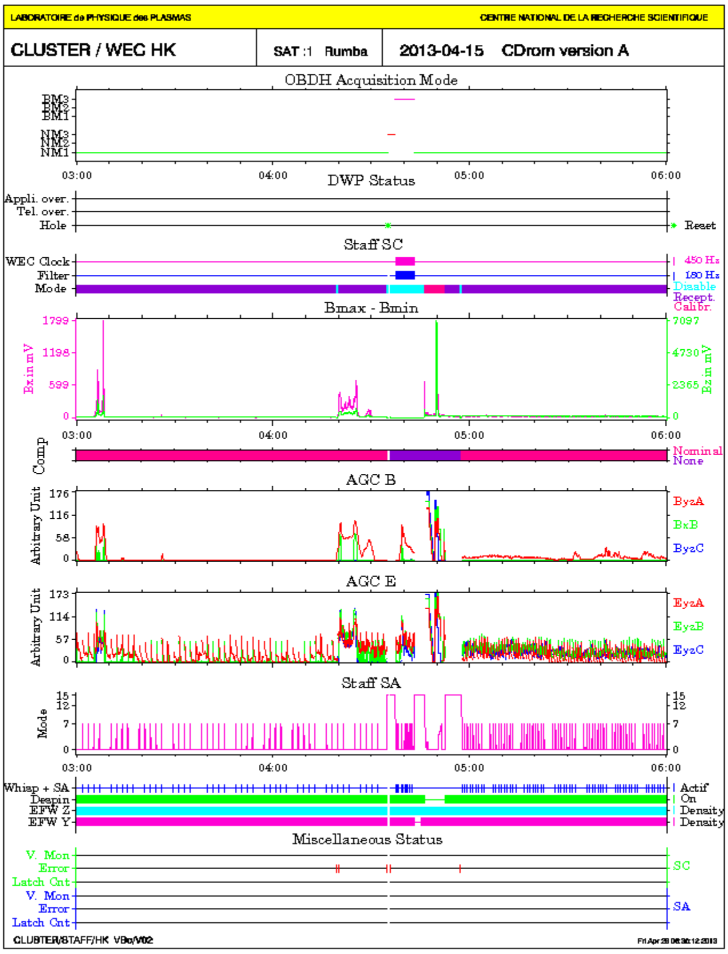


Figure 22: The calibration sequence is identified in the mode line of the HK plots AGC values are specific during the calibration sequence

13.5 Special operation modes

13.5.1 STAFF spectrum Analyser without onboard despin (despin OFF)

The purpose of this test was to look at the influence of an EFW probe failure on STAFF-SA data.

Dates:
SC1 21/06/2010 05:39 -> 22/06/2010 04:32
SC4 20/06/2010 03:59 -> 21/06/2010 07:46

13.5.2 STAFF-SA in normal mode and spacecraft in High Bit Rate mode

The purpose of the test was to have the biggest possible frequency overlap between the 2 parts of the experiment, i.e. between 8 Hz and 180 Hz (see e.g. §6.6 and figures 23 and 24 of STAFF Calibration Report). This can be also further used to compare EFW waveform and STAFF-SA data.

Dates:

SC 1,2,4 12/03/2011 03:03 -> 12/03/2011 04:25 (SC are in Solar Wind)
SC 1,2,4 15/03/2011 16:00 -> 15/03/2011 17:20 (SC are in Solar Wind)
SC 1,2,4 16/03/2011 12:20 -> 16/03/2011 13:45 (SC are in magnetosheath)

SC 3 03/07/2011 03:42 -> 03/07/2011 05:06 (SC are mainly in magnetosheath)
SC 3 05/07/2011 10:29 -> 05/07/2011 11:51 (SC are skimming the boundary layer)

14 Appendix E: Coordinate systems used by STAFF definitions

To transform telemetry data into significant physical units we need to convert the data from the sensor coordinate system into one or another system, and in particular to transform from the spinning system into a fixed one, with respect to Sun and Earth for instance. The following sections are dedicated to define all intermediate coordinate systems required for this operation. Notice than these definitions can be used for other experiment of the same type, one any other mission.
All transformation matrixes are named as: A_to_B where A and B are two different coordinate systems. To convert a vector given in the A system to the same vector expressed in the B system, the following expression is used:

$$\begin{pmatrix} x \\ y \\ y \end{pmatrix}_B = A\_to\_B \begin{pmatrix} x \\ y \\ y \end{pmatrix}_A$$

For general computation of this kind of matrix.

14.1 The Sensor Coordinate System (SCS)

This is the system where the original signal is measured (see Figure 23 below). This system could be a non-perfect orthogonal system.

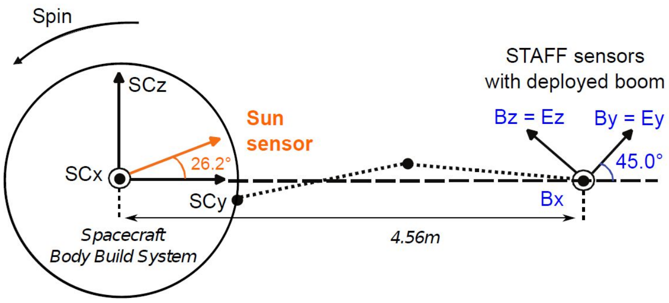


Figure 23: Position of the STAFF antennas in the "Body Build" reference frame linked to the satellite

14.2 The Orthogonal Sensor System (OSS)

This is a Cartesian orthogonal coordinate system. The original sensor system can be a non-orthogonal system. The first step is to transform the data vector in an orthogonal coordinate system: Z axis being the reference of the new Orthogonal Sensor System. The corresponding matrix, called "SCS_to_OSS", close to a unit matrix, is required and must be applied: values are supposed to be constant in time. Nevertheless, in a first time, considering the low deviation of the sensor to an orthogonal system for CLUSTER/STAFF (~0.2°), this correction is not applied and the matrix is set to unity matrix.

$$SCS\_to\_OSS \cong \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

14.3 The Data Sensor System (DSS)

The Body Build System (BBS, see next section) is a system fixed to the geometry of the spacecraft, and is used as the spacecraft system reference for all the experiments. Generally, for most of spacecraft missions, the Z axis is close to the maximum principal inertia axis also called the spin axis (for spin stabilized spacecraft). Nevertheless, for CLUSTER, this axis has been defined as the X axis

In all our data, the convention taken is Z=spin axis. It means that we have an intermediate coordinate system, called Data Sensor System (DSS) which corresponds to the previous OSS, but where the axes are permuted, to make Z close to the spin axis.

By respect to the Fig. 1, X_{OSS}, Y_{OSS}, Z_{OSS}, becomes Y, Z, X in DSS.

This permutation is obtained by the following matrix:

$$OSS\_to\_DSS = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

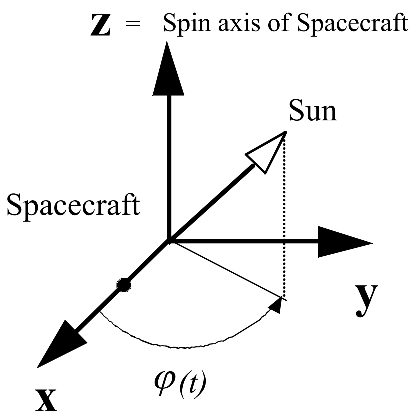
14.4 The Body Build System (BBS)

In the case of CLUSTER, the Z axis of the Data Sensor System is close to the X axis of the BBS system, but the misalignment angle is not easy to determine. It is also true for the small angle between this X_{BBS} and the true spin axis (precession and nutation motions). Nevertheless, an estimate of the cumulative angle is done in next subsection. Here, we neglect this small misalignment and assume $Z_{DSS} = X_{BBS}$. In all cases, 2 others axes may be rotated by an important angle (see Figure. 23). The corresponding matrix is required, called "DSS_to_BBS": values are supposed to be constant. Practically, for the STAFF search coils of CLUSTER, this matrix is a rotation matrix of $\alpha = 45°$.

$$DSS\_to\_BBS = \begin{pmatrix} 0 & 0 & 1 \\ \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \end{pmatrix}$$

14.5 The Spin Reference System (SRS)

The Spin reference system has its Z axis parallel to the spin axis. This is a spinning system, rotating at the spin frequency. As mentioned above, there is a small misalignment between the X_{BBS} axis and the Z_{SCS} axis, as there is another slight misalignment between the X_{BBS} axis and the Z_{DSS} axis (see Figure 24).



This is a spinning local system close to the measurement antenna of a spacecraft.

The Z-axis is the spin axis of the spacecraft.

The X-axis and Y-axis are perpendicular to the spin axis, and rotate at the spin frequency of the spacecraft.

The definition of the SR system needs the knowledge of the spin axis in a fixed frame of reference as the GEI inertial system, and the value of the spin phase φ at a given time

Figure 24: Definition of SR system

This is not easy to separate the two previous angles, but it is possible to estimate the small angle between the Z_{SCS} axis and the true spin axis which define Z_{SRS}. This angle θ could be estimated by the measurement of the low spin signal on the Z_{SCS} component.
If B_{xs}, B_{ys}, B_{zs}, are the amplitudes in nT of the spin sine on the 3 x, y, z components of the SCS system, this angle is estimated by:

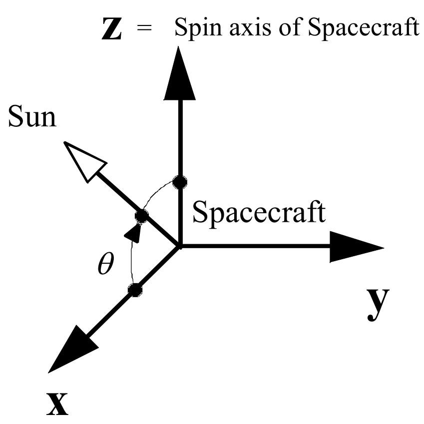
$$\sin\tilde{\theta} = \frac{B_{zs}\sqrt{2}}{\sqrt{B_{xs}^2 + B_{ys}^2 + B_{zs}^2}}$$

This angle could be constant, but can have also small variations during operations on the spacecraft (trajectory modifications, etc.). It has been estimated to an average value of ~0.5°, and, in a first time, has not been taken into account. So, the “BBS_to_SRS” matrix is a simple circular permutation set to:

$$BBS\_to\_SRS \cong \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

14.6 The spin reference2 system (SR2)

The SR2 system, also called “SSS” for Spacecraft-SUN System, or “DS” for despun, is derived from the SRS system by a *despin* operation. The spinning Spacecraft is “stopped” just at the time where the X axis is in the plane containing the Z spin axis and the direction of the Sun. The rotation angle required is derived from the Sun pulse or any other quantity to compute the spin phase angle φ_s (see Figure 25).



This is a fixed system useful for the spacecraft data processing. It is also called SCS, as "Spacecraft-Sun system", or DS system (Despun Satellite).

The Z-axis is the spin axis of the spacecraft.
The X-Z plane contains the direction of the Sun.

The X-axis is towards the day side.
The Y-axis is perpendicular to the spacecraft-Sun line.

The SR2 system rotates with the same period than the orbital period of the spacecraft with respect to the inertial system, while the declination θ varies continuously.

Figure 25: Definition of SR2 system (Despun)

This spin phase angle φ_s, and the corresponding time measurement, is required to build the "SRS_to_SR2" matrix. Terms of this matrix are fast varying with time. The phase angle φ_s is calculated for each time tag of the data thanks to the sun pulse signal. This gives, where f_s is the spin frequency:

$$SRS\_to\_SR2 = \begin{pmatrix} \sin(2\pi f_s t + \varphi_s) & \cos(2\pi f_s t + \varphi_s) & 0 \\ \cos(2\pi f_s t + \varphi_s) & -\sin(2\pi f_s t + \varphi_s) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

14.7 The Inverse SR2 system (ISR2)

This is equivalent to the SR2 system (or SSS) where the Z and Y axis has inverse sign. This system is useful for CLUSTER, where the Z axis of ISR2 system is close to the Z axis of the GSE system, so ISR2 is a rather good approximation of the GSE system, and does not requires knowledge of spin direction in GSE system.

$$SR2\_to\_ISR2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

14.8 Simplification of the cumulative matrix products

Cumulative matrix product requested to transform original data given in SCS coordinate to a fixed coordinate system such as SR2 can be strongly simplified if we neglect all small misalignment angles mentioned above. By the way, the first mass processing on the STAFF-SC data was to produce a data base for the level 1 data (telemetry data) in the DSS system, which is delivered to the CSA. The only difference between the DSS with the SCS sensor coordinate is a circular permutation of the components to get the Z axis close to the spin axis, since we assume that the SCS is orthogonal and equal to the OSS.
So to transform data expressed in DSS into the "fixed" SR2 we have to apply the cumulative matrix product:

$$\begin{pmatrix} x \\ y \\ y \end{pmatrix}_{SR2} = [SRS\_to\_SR2][BBS\_to\_SRS][DSS\_to\_BBS]\begin{pmatrix} x \\ y \\ y \end{pmatrix}_{DSS}$$

Assuming all small misalignment angles close to zero, we get:

$$[BBS\_to\_SRS][DSS\_to\_BBS] = \begin{pmatrix} \cos\alpha & -\sin\alpha & 1 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Using expression of SRS_to_SR2 given in section 5.6, with $\omega_s = 2\pi f_s$ after some calculus we get:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{SR2} = \begin{pmatrix} \sin(\omega_s t + \varphi_s + \alpha) & \cos(\omega_s t + \varphi_s + \alpha) & 1 \\ \cos(\omega_s t + \varphi_s + \alpha) & -\sin(\omega_s t + \varphi_s + \alpha) & 0 \\ 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{DSS}$$

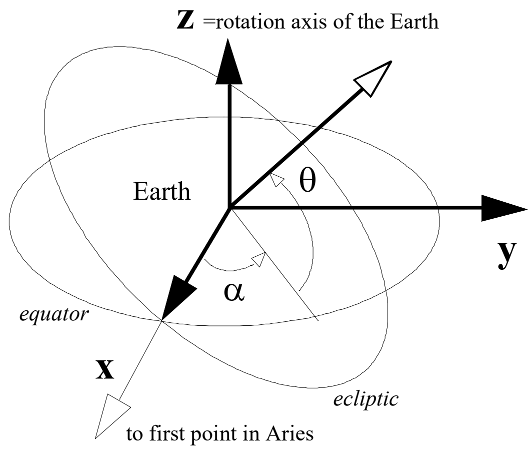
By neglecting all the small misalignment angles, the transformation from the Data Sensor System to the fixed SR2 system is simply reduced to a rotation in the spin plane of the fast-varying angle:

$$\psi = (\omega_s t + \varphi_s + \alpha).$$

This simplification is used for CLUSTER/STAFF calibration, but cannot be used for spacecraft or rocket having precession or nutation, or a non-constant direction of the spin axis. In this case, the full computation must be done.

14.9 The Geocentric Equatorial Inertial system (GEI)

The GSE system is a well-known system, with the Z axis perpendicular to the Ecliptic plane, and the X axis toward the Sun. To do the transformation of the SSS to the GSE, the direction of the spin axis in the GSE system is required. Due to the gyroscopic effect of a spinning spacecraft, the spin axis is ~constant in an inertial system, and so has a yearly variation in the GSE system, excepted during spacecraft operations (see Figure 26).



The Z-axis is parallel to the rotation axis of the Earth. The X-axis is defined by the intersection of the equator plane and the ecliptic plane, and is pointing towards the first point of Aries (Sun position at the vernal equinox). One can define the ***right ascension α*** *and the* ***declination θ*** *as:*

right ascension: $\alpha = \tan^{-1}(V_y/V_x)$

with α *in [0°,180°] for* $V_y>0$

α *in [180°,360°] for* $V_y<0$

declination $\theta = \sin^{-1}(V_z/V)$

with θ *in [-90°,90°]*

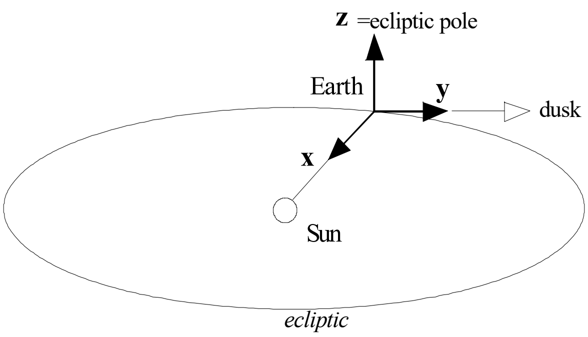
Figure 26: Definition of GEI system:

The Cartesian GSE coordinates of the direction of spin axis is required, as the corresponding time measurement. Those angles are also available in the auxiliary files available at CSA (latitude and longitude angles of the spin axis direction in GSE).

Note that in GSE system, each component mixes both parallel and perpendicular components to the spin axis. Because sensitivity is strongly different at low frequency on the parallel and perpendicular components in SR2 system, it is recommended to filter the date below ~0.6Hz before coordinate transformation. This is done for CSA Complex Spectra products.

14.10 The Geocentric Solar Ecliptic system (GSE)

Well-known and Widely used system (see Figure 27).



The X-axis is pointing from the Earth towards the Sun.

The X-axis and the Y-axis are included in the ecliptic plane.

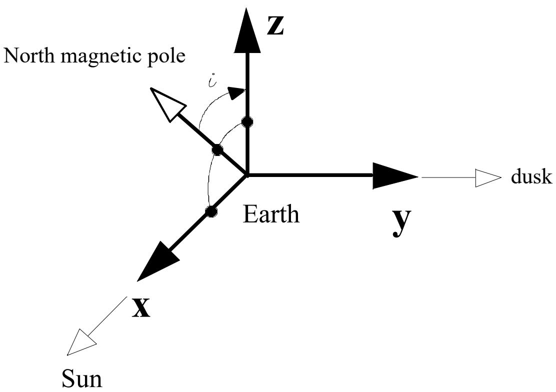
The Y-axis is pointing toward the dusk, opposing to the planetary motion.

The Z-axis is parallel to the ecliptic pole. The GSE system has a yearly rotation with respect to the inertial system.

Figure 27: Definition of GSE system

14.11 Geocentric Solar Magnetospheric system (GSM)

This system is known in space physics to properly organize the data, insofar as it reconciles the direction of the sun and the plane of the Earth magnetic meridian (see Figure 28).



The X-axis is pointing from the Earth towards the Sun.

The X-Z plane contains the dipole axis.

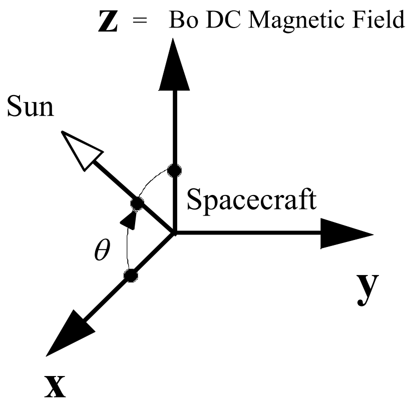
The Y-axis is perpendicular to the Earth's magnetic dipole, towards the dusk and include in the magnetic equator plane.

Figure 28: Definition of GSM system

The positive Z-axis is chosen to be in the same sense as the northern magnetic pole: the dipole tilt angle ***i*** is positive when the north magnetic pole is tilted towards the Sun. In addition to a yearly period due to the motion of the Earth about the Sun, the GSM system rocks about the Solar direction with a 24 h period.

14.12 Magnetic Field Aligned system (MFA)

This system is essential to study the polarization of waves. Indeed, most of the plane waves are characterized by their direction of rotation around the magnetic field, and by the angle between the normal to the wave plane and the main field (see Figure 28: Definition of MFA system). It has therefore been introduced for this purpose.



This is a system useful for physic, but the meaning of the Bo DC magnetic field must be known, as its time variation.
The Z-axis is the DC magnetic field vector.
The X-Z plane contains the direction of the Sun.

The X-axis is towards the day side.
The Y-axis is perpendicular to the spacecraft-Sun line.

The MFA system move continuously with the time variation of the DC magnetic field.

Figure 28: Definition of MFA system