EFW DATA IN THE CLUSTER ACTIVE ARCHIVE

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ABSTRACT

The Cluster Active Archive is being assembled with the aim to hold high-quality, high-resolution Cluster instrument data for scientific use in both the near and the distant future. In this paper, the contributions to the archive from the Electric Field and Waves instrument are described. The archived data quantities are listed and explained, together with information on how they are computed and measures taken to ensure high scientific quality. Calibrating dc electric field data is a tedious process which involves both comparison with other data sets and theoretical as well as empirical modelling.

1. INSTRUMENT DESCRIPTION

1.1 Science objectives

The electric field and wave experiment (EFW) on Cluster is part of the Wave Experiment Consortium (WEC). The scientific objectives of WEC are

- Characterisation of non-linear electrostatic structures. This is achieved by high resolution time domain studies.
- Unambiguous determination of parameters which characterise plasma turbulence (distribution in the **k** vectors) and small-scale field-aligned current structures (geometry, current density,...) from inter-spacecraft correlations of field fluctuations.
- Evaluation of magnetic vorticity, charge separation voltages, etc.
- Assessment of the role played by electric and magnetic fluctuations in the "anomalous" behaviour of critical layers.
- Wave-particle interactions, via correlations performed onboard between wave and particle measurements.
- Determination of source locations from the wave vector measured at various spacecraft positions.
- Role of high frequency waves. Study of their fine structure and its bearings on non-linear wave particle interactions, from wide band data.
- Measurement of the quasistatic E field in the spin plane and of density fluctuations.
- Measurement of plasma density and assessment of its spatial variations.
- Evaluation of the spacecraft potential.

The EFW instrument is designed to measure the electric field and density fluctuations with sampling rates, on some occasions, up to 36000 samples/s in two channels. Langmuir sweeps are also made to determine the electron density and temperature. Among the more interesting objectives of the experiment is to study non-linear processes that result in acceleration of charged particles. Large scale phenomena where measurements from all four spacecraft are needed are also studied.

To meet the scientific objectives the electric field instrument is capable of measuring, in various modes:

- Instantaneous spin plane components of the electric field vector, over a dynamic range of 0.1 to 700 mV/m, and with variable time resolution down to 0.1 ms;
- The low energy plasma density, over a dynamic range of at least 1 to 100 cm^{-3};
- Electric fields and density fluctuations of both small and large amplitudes in electrostatic shocks or double layers, over dynamic ranges of 0.1 to 700 mV/m for the fields and 1 to 50% for the relative density fluctuations, and with a time resolution of 0.1 ms on some occasions;
- Waves, ranging from electrostatic ion cyclotron emissions having amplitudes as large as 60 mV/m at frequencies as low as 50 mHz, to lower hybrid emissions at several hundred Hz and with amplitudes as small as a few μV/m;
- Time delays between signals from up to four different antenna elements on the same spacecraft, with a time resolution of 30 μs on some occasions;
- The spacecraft potential.

1.2 Hardware overview

The detector of the instrument consists of four orthogonal spherical sensors deployed from 44 meter cables in the spin plane of the spacecraft, four deployment units, and a separate main electronics unit as shown in the block diagrams in Fig. 3-4 of [1]. The instrument has several important features. The potential drop between two opposing spherical sensors is measured to provide an electric field measurement. The instrument can also be operated as a Langmuir Probe and biased to provide the Langmuir current-voltage curve and, thus, the electron temperature and density. The potentials of the spherical sensor and nearby conductors relative to the plasma are controlled by the microprocessor in order to minimise errors associated with photoelectron fluxes to and from the spheres. The output signals from the spherical sensor preamplifiers are provided to the wave instruments (STAFF, WHISPER and WBD) for analysis of high frequency wave phenomena. The instrument has a 1-Mbyte burst memory and two fast A/D conversion circuits for recording electric field wave forms for time resolutions down to 0.03 ms. Data gathered in the burst memory are played back through the telemetry stream allocated to the electric field experiment by pre-empting a portion of the real time data gathered by the instrument. On board calculations of least square fits to the electric field data over one spacecraft spin period (4 seconds) provides a baseline of high quality two dimensional electric field components that are always present in the telemetry stream. Incoming data are continuously monitored using algorithms in software to determine if conditions are appropriate for triggering a burst data collection.

The current plan is that the only data provided to the CAA from the EFW instrument are electric field data and probe potential data as obtained regularly through the normal telemetry. Data collected at high time resolution to the internal EFW burst memory (the EFW internal burst data) are not included. Neither are the data from the Langmuir current-voltage sweeps described above. The spin-averaged data provided to the CAA are based on least-squares fits done on the ground on the full resolution data; the results from the on-board least-squares fits are not included.

1.3 Probes and filters

The EFW instrument has four probes configured in two orthogonal probe pairs in the spin plane on each spacecraft, as shown in Fig. 1. EFW measures individual probe potentials with a sampling frequency of 5 s^{-1}, as well as the potential difference between selected probe pairs with a sampling frequency of 25 s^{-1} or 450 s^{-1} depending on the telemetry mode. A schematic overview of the relevant signal paths is given in Fig. 2. The individual probe signals, p1 to p4, are always routed through 7-pole low-pass filters with a cut-off frequency of 10 Hz before sampling. The probe difference signals, p12, p34 and p32 are normally routed through 10 Hz low-pass filters if sampled at 25 s^{-1}, and through 180 Hz low-pass filters when sampled at 450 s^{-1}. More information on the instrument can be found in [1].

Normally, the full vector electric field is computed using the orthogonal signals p12 and p34. However, a failure occurred on probe 1 on spacecraft 1 (28 December 2001) and on probe 1 on spacecraft 3 (29 July 2002). After this time, it is not possible to use p12, but a workaround was implemented in the flight software to use p32 instead. This was fully implemented

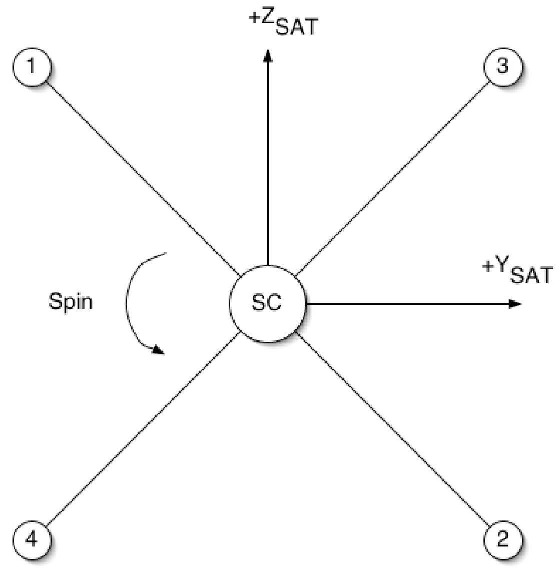

Fig.1 EFW probe configuration.

on 29 September 2003. In the intermediate period (Jan 2002 – Sep 2003 for SC1, and Aug 2002 – Sep 2003 for SC3), full resolution data will generally not be available. The spin resolution electric field data are not affected, since data from only one probe pair are used as input.

The filters are normally connected to the sampled quantities as indicated in Fig. 2. However, the 10 Hz filter on probe 3 on spacecraft 2 failed on 25 July 2001. As a workaround for this, we have instead used the 180 Hz filter for the difference signals sampled at 25 s^{-1},

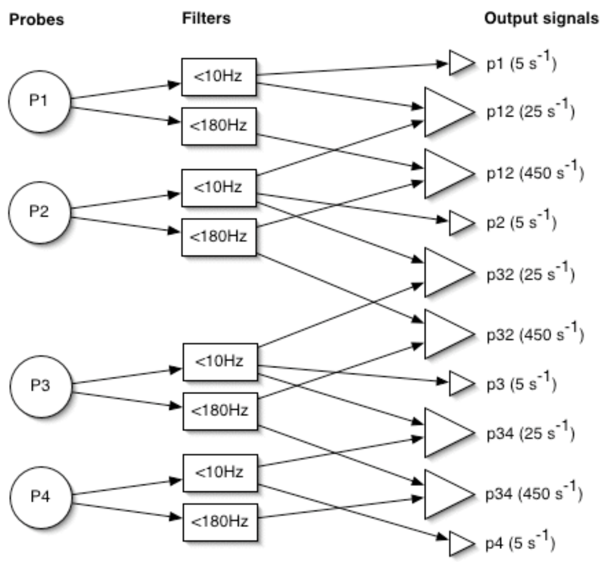

Fig.2 EFW probes and filters.

Table 1. Quantities delivered from EFW to CAA

Level	Quantity	Sampling rate	Data format	Description
L1	P1	5 s^{-1}	Time_tag P1 (scalar)	Potential probe 1
L1	P2	5 s^{-1}	Time_tag P2 (scalar)	Potential probe 2
L1	P3	5 s^{-1}	Time_tag P3 (scalar)	Potential probe 3
L1	P4	5 s^{-1}	Time_tag P4 (scalar)	Potential probe 4
L1	P12	25 s^{-1} or 450 s^{-1}	Time_tag P12 (scalar)	Potential difference probes 12
L1	P34	25 s^{-1} or 450 s^{-1}	Time_tag P34 (scalar)	Potential difference probes 34
L1	P32	25 s^{-1} or 450 s^{-1}	Time_tag P32 (scalar)	Potential difference probes 32
L2	P	5 s^{-1}	Time_tag Spacecraft_potential (scalar)	Average potential of selected probes, full resolution
L2	E	25 s^{-1} or 450 s^{-1}	Time_tag E_Vec_xy_ISR2 (vector)	Electric field, full resolution
L2	EF	25 s^{-1} or 450 s^{-1}	Time_tag EF_Vec_xy_ISR2 (vector)	Electric field, high-pass filtered, full resolution
L3	P	0.25 s^{-1}	Time_tag Spacecraft_potential (scalar)	Average potential of selected probes, spin resolution
L3	E	0.25 s^{-1}	Time_tag E_Vec_xy_ISR2 (vector) E_sigma (scalar)	Electric field and Standard deviation, spin resolution

which has no effect on the spin resolution data, and only a marginal effect on the full resolution data in those space environments where large amplitude electric field noise is present between 10 and 180 Hz.

2. DATA PRODUCTS

The EFW data products are grouped into three categories: level 1 (L1) data, which are essentially raw data unpacked from telemetry, level 2 (L2) data, which are full time resolution scientific data, and level 3 (L3) data, which are spin-averaged scientific data. The raw data contain both individuaal probe potential data and potential differences between probe pairs. The scientific data contain both the spacecraft potential and electric field data.

The electric field is calculated in the spin plane using P12 and P34 (or P32 and P34) and given in the spin-plane oriented coordinate system ISR2, which differs from GSE only due to the few degree tilt of the spacecraft (to avoid shadowing of the probes). The data are given in a reference frame moving with the spacecraft, i.e., the spacecraft-motion-induced electric field $\mathbf{v}_{sc}$ x $\mathbf{B}$ is not been subtracted before delivery to the CAA.

Table 1 lists the quantities delivered to the CAA from EFW. Note that:

- The Time_tag is given as ISO time.
- The electric field vectors are incomplete (the third component is zero).
- Raw sampling rates are 5 s^{-1} (independent of bitrate), 25 s^{-1} (in NM), and 450 s^{-1} (in BM).
- The sampling rate of 0.25 s^{-1} is a result of spin fits
- Potentials are in V, Electric fields and Standard deviation are in mV/m.
- The quantity EF is digitally high-pass filtered above 2 Hz to remove spurious effects on the data around or below the spin frequency, including unknown DC offsets.

Note also that Table 2 in section 3.3 lists 3 additional quantities, which are produced at the CAA.

3. PRODUCTION PROCEDURES

Generally, the EFW production can be divided into three steps: raw data (L1), products which involve individual probe potentials and products which involve the electric field.

3.1 Raw Data

For L1 data (full resolution raw data) the production procedures involve only decommutation and calibration into physical units.

The complete housekeeping data from EFW are not archived. Selected housekeeping data are used as the basis for information on instrument operations to be included in the instrument caveat files.

3.2 Individual Probe Potentials

The processing of the individual probe potentials from the raw data is straightforward. For the full resolution quantity L2_P an average of selected probes is computed. The average is generally taken over all probes which are operated in the electric field mode of the instrument (as opposed to the density mode). The spin resolution quantity L3_P involves time averaging of L2_P over 4 seconds. All these computations are done locally before delivery to the CAA.

3.3 Electric Field Products

The production procedures for electric field products can be split in two parts: local production of products which originate only from EFW data, and production of compound products (originating from more than one experiment) at the CAA.

3.3.1 Local production

The production procedures (local production) for electric field products are presented in Fig. 3. First, the spin resolution (L3) data are computed:

L3.1: spin fitting to raw data P12, P34 and/or P32, to obtain spin resolution E and ADC offsets.
L3.2: determine ISR2 offsets (sunward and duskward offsets) and correct for them.

As a result we have spin resolution electric field in the spacecraft spin plane ($\mathbf{Es_x}$, $\mathbf{Es_y}$). After this the full resolution (L2) data are computed:

L2.1: despin using corrections obtained in L3.1 (obtain full resolution E).
L2.2: correct for ISR2 offsets obtained in L3.2 (obtain full resolution corrected E).
L2.3: high-pass filter the data (obtain full resolution high-pass filtered EF).

As a result we have full resolution and high-pass filtered electric field in the spacecraft spin plane ($\mathbf{E_x}$, $\mathbf{E_y}$ and $\mathbf{E'_x}$ $\mathbf{E'_y}$). These data are final products which are made available to the CAA.

Data before high-pass filtering may be contaminated by offsets which are difficult to determine. In the case that the offsets are impossible to determine, these data will not be available in the CAA. The data after high-pass filtering will always be available.

The quantities $\mathbf{Es_x}$, $\mathbf{Es_y}$, $\mathbf{E_x}$, $\mathbf{E_y}$ and $\mathbf{E'_x}$ $\mathbf{E'_y}$ are delivered to the CAA.

3.3.2 Production at the CAA

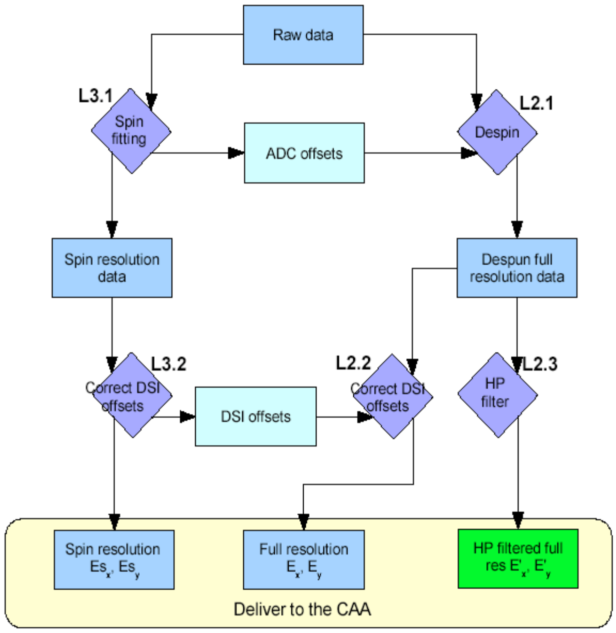

Fig. 3. Local data production (DSI = ISR2)

Production of final electric field products (except the high-pass filtered E-field) require additional data available at the CAA and will therefore be computed at the CAA. Pipeline for production of the EFW products at the CAA is presented in Fig. 4.

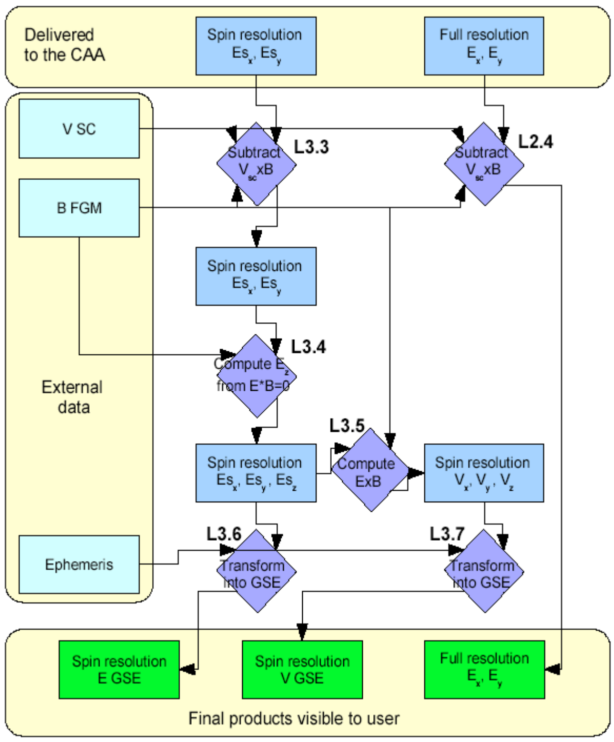

Fig. 4. Production at the CAA

Table 2. Quantities computed in CAA from EFW and other data

Level	Quantity	Sampling rate	Data format	Description
L2	EGSE	25 s^{-1} or 450 s^{-1}	Time_tag E_Vec_xy_GSE (vector)	Electric field, full resolution, inertial frame
L3	EGSE	0.25 s^{-1}	Time_tag E_Vec_xyz_GSE (vector)	Electric field, spin resolution, inertial frame
L3	VGSE	0.25 s^{-1}	Time_tag V_Vec_xyz_GSE (vector)	Convection velocity, spin resolution, inertial frame

L2.4, L3.3: Subtract the electric field induced by the spacecraft motion $\mathbf{v}_{sc}$ x $\mathbf{B}$ (obtain $\mathbf{E}$ in the inertial system). This operation requires the magnetic field $\mathbf{B}$ and the spacecraft velocity $\mathbf{v}_{sc}$.
L3.4: Compute E_z from the condition $\mathbf{E}*\mathbf{B} = 0$ (obtain the full vector of $\mathbf{E}$ in ISR2). This operation requires the magnetic field $\mathbf{B}$ and a condition telling in which situation such an operation is permitted (a condition on the angle between $\mathbf{B}$ and the spacecraft spin plane).
L3.5: Compute $\mathbf{v} = (\mathbf{E} \times \mathbf{B}) / \mathbf{B}^2$ (obtain the full vector of $\mathbf{v}$ in ISR2). This operation requires the magnetic field B.
L3.6, L3.7: Transform $\mathbf{E}$ and $\mathbf{v}$ into GSE This operation requires the spacecraft spin axis orientation in GSE, and is done only on the spin-averaged data.

As a result of the processing within CAA, the additional quantities listed in Table 2 are available to the user as EFW quantities, even though they are, in a strict sense, derived quantities using data from more than one instrument. Note that:

- The Time_tag is given as ISO time.
- The L2 EGSE electric field vector is incomplete (the third component is zero). Strictly speaking, this quantity is not in GSE but in the spin-plane oriented coordinate system ISR2.
- The L3 EGSE electric field vector is complete (all three components given), if the magnetic field is far enough from the spin plane that the condition $\mathbf{E}*\mathbf{B}=0$ can be used.
- Raw sampling rates are 25 s^{-1} (in NM), and 450 s^{-1} (in BM).
- The sampling rate of 0.25 s^{-1} is a result of spin fits.
- Electric fields are in mV/m, Velocity is in km/s.

Note that these are additional quantities where EFW data have been combined with other data. Table 1 in section 2 lists the main EFW quantities delivered to the CAA.

3.4 Quality Control Procedures

Quality control for EFW products can be divided into two levels:

1) control of raw data quality
2) comparison of final products with data from other instruments measuring the same quantities, such as EDI and CIS.

The first level of quality control on the raw data is done automatically, where obviously bad data are removed and never delivered to the CAA. Some types of spurious effects in the data are, however, not easily detectable by studying only the EFW data. Comparisons with data from other instruments, notably EDI and CIS, are necessary. In addition to data comparisons, theoreical and empirical modelling of the instrument and the measurement methods are done to understand the spurious effects and to be able to correct for them in a meaningful way. Both data comparisons and modelling are manpower-consuming tasks which are not easily automated. The output from the local data production (Fig. 3) is screened manually before delivery to the CAA.

4. DELIVERY SCHEDULE

In the original plan, the EFW products were to be delivered on the basis of magnetospheric region. The reason for this is that the quality of the electric field data is different in different regions and in order to maximise the amount and quality of delivered data it is most efficient to focus on one region at a time. The plan has since been slightly modified so that a first, preliminary, data set, using semi-automatic data correction algorithms, will be delivered in chronological order. After that, a refined data set with improved quality will be delivered by region,

5. REFERENCES

1. Gustafsson et al. The Electric Field and Wave Experiment for the Cluster Mission, *Space Sci. Rev.*, **79**, 137-156, 1997.