User Guide to the DWP Measurements in the Cluster Science Archive (CSA)

prepared by

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Version 1.15

Table of Contents

Reference Documents

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Acronyms

ACF	Auto-Correlation Function
BM1	Burst Mode 1 - Cluster high resolution science operational mode
CAA	Cluster Active Archive
CEF	Cluster Exchange Format - Cluster data format
CSA	Cluster Science Archive
DWP	Digital Wave Processor - Cluster instrument
EFW	Electric Fields and Waves - Cluster instrument
ESOC	European Satellite Operations Center
FFT	Fast Fourier Transform
HAR	High Angular Resolution - PEACE operational mode
HEEA	High Energy Electron Analyser - PEACE sensor
IEL	Inter-Experiment Link
LAR	Low Angular Resolution - PEACE operational mode
LEEA	Low Energy Electron Analyser - PEACE sensor
MAR	Medium Angular Resolution - PEACE operational mode
MCP	Micro-channel plate - PEACE detector
NM	Normal Mode - Cluster nominal science operational mode
OBDH	Onboard Data Handelling
PEACE	Plasma Electron And Current Experiment - Cluster instrument
RT	Real Time - Data telemeted as soon as collected
SSR	Solid State Recorder - Used to store data between ground station passes
STAFF	Spatio-Temporal Analysis of Field Fluctuations - Cluster instrument
TCAL	Time Calibration - calibration of clock count into UT
UT	Universal time
WBD	WideBand Data - Cluster instrument
WEC	Wave Experiment Consortium
WHISPER	Waves of HIgh frequency and Sounder for Probing Electron density by Relaxation - Cluster instrument

1 Introduction

This User Guide provides some basic background information about the Cluster Digital Wave Processor (DWP) instrument and the particle correlator software application regarding their operation and the data produced. This guide also provides an information source regarding the use and interpretation of the data files produced by the DWP and that are available from the Cluster Science Archive (CSA).

This User Guide describes the science related data products generated by the DWP instrument, namely those related to the particle correlator application (PCOR[1]) and the time correction files (TCOR). Details of the operations of DWP and WEC (see next section) may be found in the operations (DWP_LOG) and commanding (UT_PIOR) data sets that are described in Section B.1 and Section B.2 respeectively.

2 Instrument Description

The Cluster DWP instrument is described in detail by *Woolliscroft et al.* [1997]. In brief, the DWP instrument is responsible for the commanding, synchronisation and mode control, and data processing for the Cluster Wave Experiment Consortium (WEC) that comprises EFW, STAFF, WHISPER, WBD, and DWP. A full description of WEC may be found in the WEC User Manual [*Willis et al.*, 2000]. DWP forwards configuration commands to the instruments and controls their mode of operation using a series of onboard macros. Data is then collected from the instruments and any application processing requested is performed e.g. data compression, before the data is formatted into a single stream and forwarded to the spacecraft telemetry data stream.

As well as handling science data from the various instruments, DWP also collects and stores in its housekeeping data stream various data that may be used to monitor the health of WEC and that may be used to troubleshoot any problems that may occur. These values represent a snapshot of the operational status of WEC at the time of the onboard reset pulse.

The DWP does not possess any sensors that are used to perform scientific measurements. However, as part of its application processing packages DWP contains a software correlator instrument. This application takes raw count values from the PEACE HEEA sensor via an onboard Inter-Experiment Link (IEL) and calculates the auto-correlation function for a short time series of counts.

3 Instrument Operations

DWP operations fall into one of two categories, namely those related to the commanding of and data collection from the WEC instruments, and those related to the operation of the software particle correlator.

During normal operations, the experimenter data sets are time stamped by ESOC. However, the accuracy of these time stamps is of the order of 2 ms. To improve this situation, a time correction data set is also generated, improving the accuracy of the time stamps to around 20 μs. These tasks are outlined in the following subsections.

3.1 Commanding Related Operations

DWP is responsible for the commanding of and data collection from the other WEC instruments. This includes

- forwarding of instrument configuration commands to the appropriate instrument,
- control of the instrument modes during the cycling of operations that involve periods of active sounding measurements by WHISPER,

[1] The particle correlator data set contents and name have evolved over the lifetime of CAA/CSA, see Section 5.2.1

- collection of analogue and digital parameters to evaluate the health, operation, and aid troubleshooting of problems that occur within WEC,
- collection of data from the WEC instruments,
- application processing, e.g. data compression,
- formatting of WEC data for its insertion into the spacecraft telemetry stream

There are two DWP data sets within the CAA that are related to these activities, namely UT_PIOR and DWP_LOG. For the details of these datasets, see Appendix B.

During it's period of operations, the set of macros used to implement the various WEC operational modes has been modified to take into account the various probe failures as well as the addition of patches to update and implement new operational macros.

The processors and memory used within the DWP instruments have occasionally shown themselves to be susceptible to Single Event Upsets (SEU) caused by the passage of high energy particles. The occurrence of such events has been studied and reported in *Yearby and Alleyne* [2003] and *Yearby et al.* [2014].

3.2 Particle Correlator

The particle correlator is a software application that forms autocorrelation functions (ACFs) of short time series of particle counts measured in one of the PEACE HEEA sensor polar zones. The PEACE instrument and its operations are described in detail in *Johnstone et al.* [1997] and also in the PEACE CAA User Guide [*Fazakerley and the PEACE Operations Team*, 2015]. In order to describe the operation of the particle correlator it is important to understand the basics of operation of the PEACE instrument.

The PEACE electron analyser measures the three-dimensional velocity distribution of electrons in the energy range 0.59 eV to 26.4 keVusing two hemispherical, top hat style electrostatic energy analysers. Although both analysers may cover the complete energy range, their design features mean that one sensor, the Low Energy Electron Analyser (LEEA) is more specialised to cover the lower portion of electron energies (0.59-9.45eV) whilst the High Energy Electron Analyser (HEEA) is more specialised to cover the upper end of the electron spectrum. Since the particle correlator takes counts from the HEEA sensor only, the rest of this description will refer to the HEEA sensor.

The HEEA sensor is mounted on the side of the Cluster spacecraft at an azimuth of 330°from the YBuild axis as shown in the upper section of Figure 1. The spin of the spacecraft is defined as the period between two events recorded by the spacecraft sun sensor, located at 26.2°counterclockwise from the YBuild axis. Thus the azimuthal offset of the HEEA sensor at the start of the spin is 303.8°. The field of view of the instrument is divided up into 12 polar zones that sample the direction of incoming electrons with respect to the satellite spin axis as shown in the lower section of Figure 1 (taken from the PEACE CAA User Guide CAA_EST_UG_PEA_v24).

The sampling of the PEACE instrument is synchronised with the spin of the spacecraft, performing either 16, 32, or 64 full energy sweeps covering up to 60 of the possible 88 energy levels per spin. Each energy level is sampled for a period TACC=TSPIN/1024 $\sim$ 3.9ms. PEACE operates in one of three basic sweep patterns, namely LAR, MAR, HAR (Low, Medium and High Angular Resolution) that provide different azimuthal resolution; notice that the longer the energy sweep, the poorer the angular resolution. In LAR mode each energy level is sampled from the highest to lowest, i.e. the measured energy is reduced by one step between each sampling period. In MAR and HAR mode the measured energy is reduced by two steps between consecutive sampling periods. The difference between MAR and HAR is that HAR mode covers only half of the energy range of MAR mode. For a more detailed explanation, the reader should see Section 5.2.1 and is also recommended to read the CAA PEACE User Guide.

Due to constraints of the processing and telemetry, the correlator application can only analyse the counts from one of the 12 polar zones. The polar zone from which the counts are taken is kept constant for the

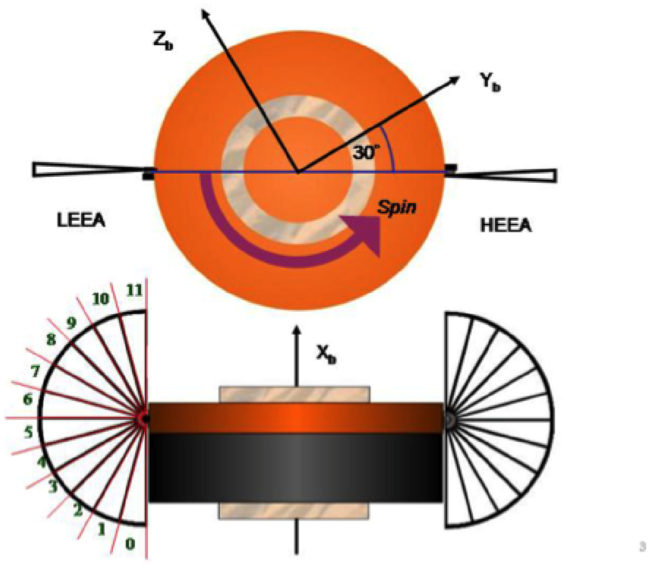

Figure 1: PEACE HEEA location

period for a whole spin (4 sec). The strategy of selecting which polar zone to use has changed during the mission. At the beginning of the mission the polar zone was selected such that at one point in the spin, the magnetic field vector (measured during the previous spin) was expected to be parallel to the look direction of the polar zone. Later in the mission, starting from 2002-06-09, the correlator cycled through all polar bins in sequence at the rate of one polar bin per spin.

The individual particle detections from HEEA are passed to DWP via the IEL. The correlator application within DWP counts the number of detections as a function of time. This short time series is then used to calculate an ACF. The process of calculating the ACF is illustrated in Figure 2. The time series of counts is first duplicated, creating a second, identical time series. The first value of the ACF or 'zero lag' is calculated by multiplying the two arrays on an element by element basis and then summing the products. The first lag value is generated by shifting one of the time series by one bin to the right and the element wise products are summed to generate the lag value. The process continues by shifting one series and then summing the element wise products to create other lag values.

Individual ACFs are constructed within separate 1.111 millisecond periods defined by the DWP master clock (900Hz). During one clock period, the individual counts from the PEACE HEEA sensor are binned according to their arrival times into 61 time bins of 12 μs duration, producing a snapshot of the electron counts covering a period of 0.732 ms i.e. a 66% duty cycle.

ACFs are constructed using counts corresponding to one of 15 correlator energy bands. One correlator energy band corresponds to either 2 or 4 adjacent PEACE energy levels. This results in the formation of 6 ACFs per PEACE accumulation period. The actual energy range of the correlator energy bands depends upon the PEACE HEEA sensor preset energy value and the sweep mode. These are included in the correlator datasets and are determined on the ground from an analysis of the PEACE science telemetry data.

Constraints on the processing and telemetry allow only two of the 15 possible correlator energy bands to be processed during a particular spin period. One of these energy bands is preselected using telecommands in an attempt to target certain scientific phenomena, for example, reflected electrons in the foreshock or resonant electrons in the equatorial plasmasphere. The other energy band steps sequentially through the remaining 14 levels at the rate of one energy level per spin.

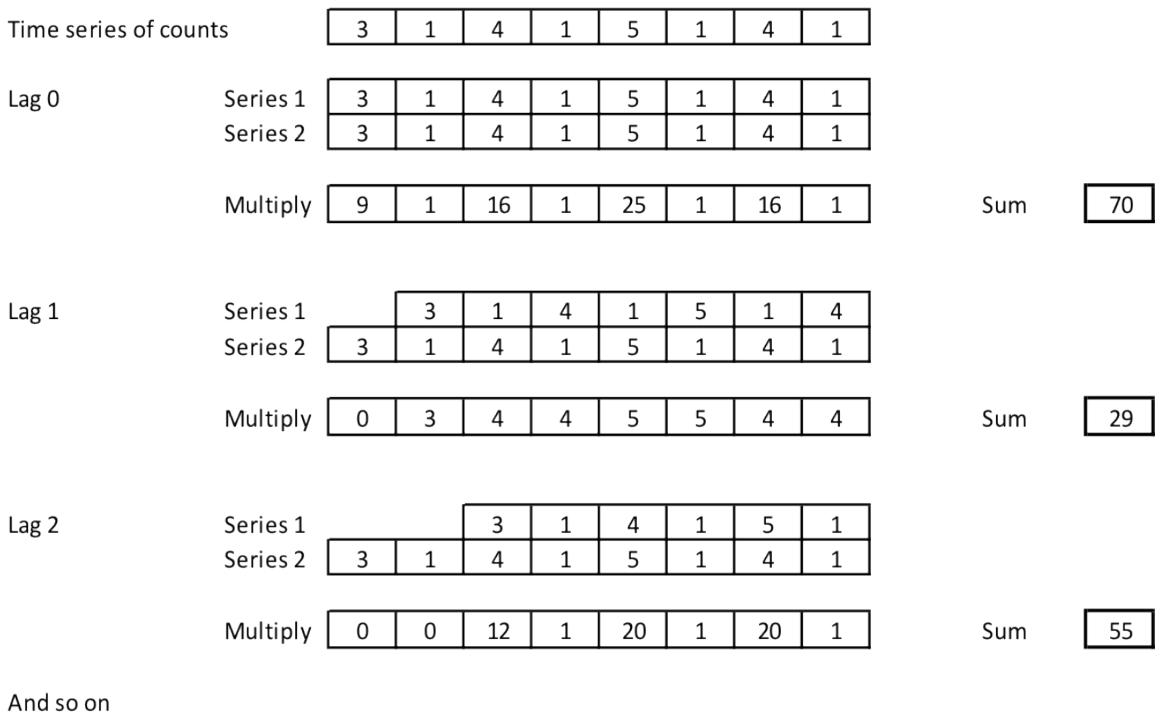

Figure 2: Calculation of the ACF.

The correlator calculates the first 32 lags of the ACF during each 1.111ms sampling period. When converted into the frequency domain, these lag values cover the frequency range 1.4-41.6 kHz.

In order to gain better statistics, the individual component ACFs (each is based on data from 1.1 ms interval) are summed on a lag by lag basis to improve the signal to noise ratio and also ensure that the data fits into the correlator telemetry allocation. In normal science mode, this results in one ACF per spin and the loss of any azimuthal information, temporal resolution, and a wide pitch angle coverage. For burst science modes, the correlator may be configured to generate 4, 8, or 16 ACF's per spin, resulting in a much narrower range of pitch angles and azimuths. The summed ACFs are downlinked in the spacecraft telemetry together with the number of individual ACF summed. On the ground these data are processed to determine the average of the summed ACFs. These data, which are not normalised, are then written into the CEF file.

There are two methods that may be used to estimate the PEACE count rate for the particular energy/polar bin being analysed. The first may be reconstructed from the non-zero lags of the ACF i.e. lags in the range 1-31 as follows:

$$count\_rate\_estimate = \sqrt{\sum_{l=1}^{31} lag(l)/31} \qquad (1)$$

This is the method that has been used to calculate the estimated count rates that exist in the PCOR CEF data files. This data was not included in the original COR data sets.

The second assumes that the electron count rate has a Poisson distribution. In this case, an estimate of the count rate may be obtained from the zero lag value (zl) as follows:

$$count\_rate\_estimate = (\sqrt{zl + 1/4}) - 1/2 \tag{2}$$

In both cases, the units of the count rate will be counts per 12μs time bin. In order to convert these values into counts per second they are multiplied by 83333 (i.e. 1/12e^{-6}).

4 Measurement Calibration and Processing Procedures

The only calibrations used in the production of DWP CAA data parameters involve the interpretation of digital values using lookup tables. The values in the lookup tables were determined during ground testing before launch. For further details, see the WEC User Manual [*Willis et al.*, 2000] or the DWP Calibration Report [*Walker and Yearby*, 2014a]. The latter document also provides details of the processing procedures.

5 Key Science Measurements and Datasets

5.1 Time Correction

5.1.1 Data

The time stamps that are issued with the Cluster data sets are only accurate to ±2 ms. When combining data WEC burst mode science data (from EFW or STAFF SC that are sampled at 450Hz) this implies a phase error of up to 260°. Fortunately there is a method which may be applied to the time stamps, improving their accuracy to 20 μs, or less than 2°phase error. The methodology used, together with its implementation are described in *Yearby* [2004] and in the accompanying CAA DWP Calibration Report [*Walker and Yearby*, 2014a], whilst this User Guide concentrates upon the usage and caveats of these parameters. In addition to these documents there are more detailed reports on the production of these parameters for each year of the mission available from CAA (see https://www.cosmos.esa.int/web/csa/documentation/ and follow the links for DWP TCOR documentation).

To achieve the improved accuracy, it has been determined that two parameters are required. The first parameter, called OFFSET, is related to the satellite telemetry mode and represents the delay between the time at which the OBDH reset pulse is issued and the time at which it was written into the data packets. The second parameter, DIFF, represents the drift of the satellite clock with respect to UT.

Table 1: Contents of the DWP TCOR data files.

Parameter	Description
Time	Interval centred time tag
Offset	The "Offset" is the difference in microseconds between the reference time for the packet and the onboard time stamp for that packet. It is only applicable to data recorded via the Solid State Recorder, and is zero during real time data acquisition. The "Offset" is not applicable to WBD data acquired via DSN. The FILLVAL for the "Offset" parameter is $-1.0e1$.
Diff	The "Diff" is the difference in microseconds between the onboard time and UTC. For all data except WBD DSN data, the Offset and Diff should be added to the UTC packet times to get the accurate reference time of the packet. For WBD DSN data only the Diff should be used. The FILLVAL for the "Diff" parameter is $-1.0e1$.

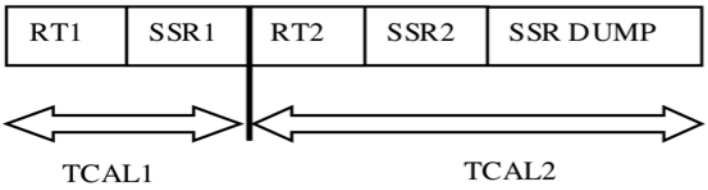

Figure 3: Real time and solid state recorder operations scenario.

These time correction parameters are provided at the start and end of each period of the same telemetry mode. The OFFSET term is constant throughout each period, and the same value will be written in the records at the start and end of the period. The DIFF value at a particular time may be obtained by linear interpolation of the DIFF values that bracket the time of interest. However, there are limitations on the use of OFFSET and DIFF. These are listed Section Section 5.1.2.

The values OFFSET and DIFF, found in the TCOR files, are used to correct the time stamps with which ESOC label the science and housekeeping data in order to achieve a higher timing accuracy. To apply these corrections, the user needs to determine the values of OFFSET and DIFF that correspond to the data period in which the user's data point lies. Simply add the value of OFFSET. The value of DIFF to be added is determined by linear interpolation between the two records that span the time of interest (see the example below).

Users of the time correction dataset should be aware of its limitations. Most importantly, TCOR data is not available at all times. Occasionally, values of OFFSET and/or DIFF cannot be computed due to some ambiguity in the data sets on which it is based. This usually occurs around the time that a new time calibration is computed by ESOC. The ambiguity arises for periods of data that are measured and then stored on the solid state recorder and downlinked at a later date. For example consider the operations scenario outlined in Figure 3.

Initially TCAL1 is in operation. The satellite is collecting data and transmitting directly to the ground station in real time RT1. The time tags of the data collected in this period will be calibrated using TCAL1. At the end of this acquisition period, the satellite loses its link with the ground station. Any data collected are sent to the onboard solid state recorder (SSR1). During the next real time pass of the satellite (RT2) a new time calibration TCAL2 is calculated and is applied to data collected during RT2. This is then followed by a second period when data is dumped to the onboard recorder (SSR2). At the next contact period with the ground station the satellite downloads data stored in the onboard recorder. The data collected by the ground station were collected during the periods SSR1 and SSR2 for which time calibrations TCAL1 and TCAL2 were in operation respectively. However, once downlinked the current TCAL is used to calibrate the time tags i.e. TCAL2 for both data periods. This implies that the calibrated time tags for SSR1 are incorrect and so any values of DIFF for this period will be incorrect. Hence the value of DIFF for periods such as SSR1 would be undefined.

In the first issue of the dataset, any data that fails validation is simply deleted from the files and replaced by a FILLVAL. TCOR coverage is typically around 90%. This is due to the following reasons:

- Until the end of 2004, the DIFF values calculated by ESOC were unsigned and so it could be unclear whether the value is positive or negative (see caveats below).
- During power down eclipses (see caveats below).

Applications requiring accurate timing should confirm that TCOR data is available at the relevant time. Details of the calculations of the time corrections parameters for individual years may be found in the set of technical notes describing their production that are available of CAA.

2007-01-01T18:00:26Z, 0.0, 60.0
2007-01-01T20:34:49Z, 0.0, 60.0
2007-01-01T20:34:59Z, -1.0e31, -1.0e31
2007-01-01T20:35:00Z, -260.0, 60.0
2007-01-02T07:49:56Z, -260.0, 63.0
2007-01-02T07:50:11Z, -1.0e31, -1.0e31
2007-01-02T07:50:12Z, -248.0, 63.0
2007-01-02T08:50:49Z, -248.0, 64.0
2007-01-02T08:51:09Z, -1.0e31, -1.0e31
2007-01-02T08:51:10Z, -363.0, 64.0

Figure 4: Extract from the TCOR file for the beginning on 2007.

For example, downloading a TCOR CEF file covering the first few days on 2007 yields the data values for time, OFFSET and DIFF shown in Figure 4.

To determine the correction required at 2007-01-02T00:00:00Z we can see from Figure 4 that the values of OFFSET and DIFF that bracket the required time are not fill values and so a correction can be calculated. At this time, the value of OFFSET is -260 μs (the values of OFFSET are the same in the entries that bracket the time at which we are calculating the correction). The value of DIFF is determined using linear interpolation and is 60.9 μs. Therefore the total correction to be applied is-260+60.9=-199 μs.

Fill values prevent any corrections being calculated for intervals such as 2007-01-01T20:34:49Z to 2007-01-01T20:35:00Z.

It should be noted that these time corrections are NOT applied to any of the DWP data products. The reason for this is that none of the data products require microsecond accuracy timing. They may, however, have been applied to other data sets within the CSA when available. The potential user should consult the User Guide for the appropriate data set to determine whether these corrections have been applied.

5.1.2 Caveats

The following general caveats apply to this data set. For caveats that apply to specific time intervals, please see the caveat files and caveat information supplied in the data files.

Use data with caution.

If published results depend critically on timing accuracy it is recommended that the user should re-verify the TCOR data in question and consult the technical notes that accompany their production [Yearby].

Data before 2005.

Until the end of 2004, the DIFF measurements provided by ESOC as excel TCAL spreadsheets for each pass were unsigned. The sign was determined by comparison with the WBD DIFF or the DIFF calculated from TCAL. However, when the DIFF was small, it was difficult to be sure that the sign has been determined correctly. This typically occurs when a new TCAL calibration has been issued by ESOC and so the value of DIFF will be small. This could introduce an error of less than 50 μs.

TCOR data is not available at all times.

Applications requiring accurate timing should confirm that TCOR data is available at the relevant time and that its values are not equal to the FILLVAL.

Possible erroneous data.

In this first release, data that fails validation is simply deleted from the files and FILLVAL inserted. In some cases, it may be possible to calculate the TCOR values manually, based on the methods described in *Yearby* [2004]. Gaps tend to occur mainly around the times at which a new time correlation is performed. Until 25 October 2007, in the 2 days prior to a new time correlation, it is not certain whether the old or new time correlation applies to a particular period of data. Incorrect determination of which time correlation was used could result in an error of 2ms or more in the corrected time. In most cases, any erroneous data should have been removed during the validation process, but there is a small chance some may remain.

OFFSET should be constant.

The OFFSET is constant throughout each data acquisition interval, and the same value will be written in the records at the start and end of the period. If the OFFSET values before and after the required time are different, or either has been set to the fill value (-1e31) then OFFSET is not available for that period.

Interpolation between TCOR records

Interpolation between TCOR records in CEF files is only permitted in limited circumstances. The time corrections are provided at the start and end times of each period of the same telemetry mode.

Do not interpolate between values of OFFSET.

No interpolation between different OFFSET values is allowed.

Interpolation of DIFF

The DIFF may be obtained by linear interpolation of the DIFF values before and after the required time. However, if either DIFF is set to the fill value (-1e31), then DIFF is not available for that period. It is not allowed to interpolate over a fill value.

Power down eclipses

During power down eclipses even the spacecraft clock has to be turned off to preserve what little power exists. Once powered up following the eclipse it may take a couple of days for the spacecraft clock to stabilise.

5.2 Particle Correlator

5.2.1 Data

Since its initial introduction into the CAA/CSA, the contents of the Particle Correlator data set has evolved, with each evolution introducing more parameters in an effort to make the data set more user friendly. This change in contents has also meant that the data set name has changed from COR to CORR to PCOR. Since this change represents the addition of extra data fields the older datasets have been superseded and so the COR and CORR data sets are no longer available from CSA.

The data fields available in the DWP Correlator data sets (both fixed and stepped energy) are listed in Table 2.

Table 2: The data fields present in the PCOR data sets.

Parameter	Description
Time	Interval centred time tag. Note that the TCOR timing corrections have not been applied to this data field.
Half_Interval	Half interval for data accumulation
Look_Angle_Azimuth	PEACE azimuthal look direction for which ACF has been calculated. In normal science mode, data are spin averaged in which case the data values are -1. The reference frame is SR2.
Half_Azimuth	Half azimuth angle over which ACF accumulated. In normal science mode, data are spin averaged in which case the data values are -1.
Look_Angle_Polar	PEACE polar look direction for which ACF has been calculated. The correlator processes data from one polar bin per spin. See caveat section for further information. The reference frame is SR2.
EnergyBinNumber	Correlator energy band (number) in which the electrons are correlated.
Energy	PEACE energy for which ACF has been calculated. This is the centre energy of the 2 or 4 PEACE energy bands that are used to construct the ACF.
MCP_level	The PEACE HEEA MCP high voltage level setting. Note that if this value is zero, HEEA is not operating.
NumberACFsummed	Number of PEACE sweeps summed in this accumulation.
Lag_Time	ACF lag times associated with the individual ACF lags.
ACF	Electron count auto-correlation function.
CntRateEst	An estimate of the PEACE electron count rate deduced from the ACF using (1) for the energy and polar/azimuthal bin combination.
MinPitchAngle	Estimate of the minimum value for the electron pitch angle encountered during the current azimuthal sector.
MaxPitchAngle	Estimate of the maximum value for the electron pitch angle encountered during the current azimuthal sector.
fish_T	Maximum Fisher T statistic for the ACF.
fish_F	Frequency at which Maximum Fisher T statistic occurs.
fish_S	Percentage significance of Fisher T statistic.
iDisp	Measurement of dispersion of counts.
Peace_mode	PEACE sampling mode. 0 - fixed energy, 1 - LAR mode, 2 - MAR mode. 3 - HAR mode

The values contained in the ACF represent the number of counts squared per interval in which the counts were collected, i.e. units of counts. No effort has been made to normalise the ACF such that the zero lag value is unity. The conversion from these units into SI requires multiplication of the ACF values by a factor 8.3333e4 (as specified above and in the ICD).

The ACFs are best inspected in the frequency domain. Hence, each ACF should be reflected around the zero lag value to create a series of values that can be passed to an FFT routine to convert the data into the frequency domain.

The PEACE MCP level is included within the correlator data sets as an indication of the current operation of PEACE, e.g. a value of zero indicates that HEEA was not operating. Since these data sets contain a record of the changes in the PEACE count rate, the results do not depend upon the MCP or gain settings. However, changes in the MCP level will affect the count rate estimate. It was decided that it was not feasible to include the PEACE gain settings and that nothing would be gained by converting the count rate to fluxes. Users interested in this information should consult the PEACE data files within CAA.

Using the estimated count rate it is possible to reconstruct the electron distribution as a function of particle energy, polar zone, and/or azimuthal zone. Note, however, that when constructing the energy distribution it is preferable to use the ENERGY (PEACE energy) parameter rather than the Energy-BinNumber (correlator energy bin). The reason for this is that the correlator is usually set up to receive PEACE HEEA data in MAR mode. If PEACE uses HAR mode, the HEEA sensor only sweeps over half of the energy range used in MAR mode but makes twice the number of complete energy sweeps. Thus, one correlator energy sweep contains data from two PEACE energy sweeps. It is possible for the DWP correlator processing software to recover the PEACE energy for all correlator energy bins except for the central one which corresponds to the period when the PEACE energy fly-back occurs (as the PEACE sensor resets itself to begin another energy sweep). This is illustrated in Figure 5 which shows the correlator energy bins in relation to the HEEA energy in MAR (top) and HAR (bottom) mode. The yellow stripe represents the fixed energy whilst the cyan and green show the stepped energies used and the correlator energy channel is listed at the bottom of the Figure. In both MAR and HAR modes, correlator energy bin 0 contains the PEACE flyback and so is not used. In HAR mode, correlator energy bin 8 also contains the PEACE energy flyback. Within the data file, the ACF resulting from the HEEA counts collected in this period have the PEACE energy set to a fill value as it is undefined.

The pitch angle data fields MinPitchAngle and MaxPitchAngle contain the minimum and maximum limits for the pitch angle of the electrons detected during one azimuthal zone. In NM operations measurements the ACFs are averaged over data collected from one spin (one azimuthal zone), and so normally the pitch angle range is very wide. In BM1 operations, there are either 4, 8, or 16 azimuthal zones per spin depending upon operational mode and the data represent the average angle between the magnetic field (based upon the 5VPS dataset) and the PEACE HEEA polar zone from which the data were collected. The precision is limited due to the fact that each polar zone has an angular width of 15°(as is shown in Figure 1).

To provide information on the quality of the ACF's, the PCOR files include four parameters that are intended to highlight the significance of any periodicities in the HEEA electron count rate. These parameters are:

fish_T The Fisher T statistic is the ratio of the maximum power spectral density of the power spectrum divided by the total power of the power spectrum (not including the DC component). The power spectral density is calculated using the periodogram method (MATLAB routine periodogram).

fish_F This value is the frequency at which the maximum power occurs.

fish_S This is the percentage probability that the observed power spectrum is not the result of a Gaussian white noise process. It is calculated from the Fisher G statistic as follows.

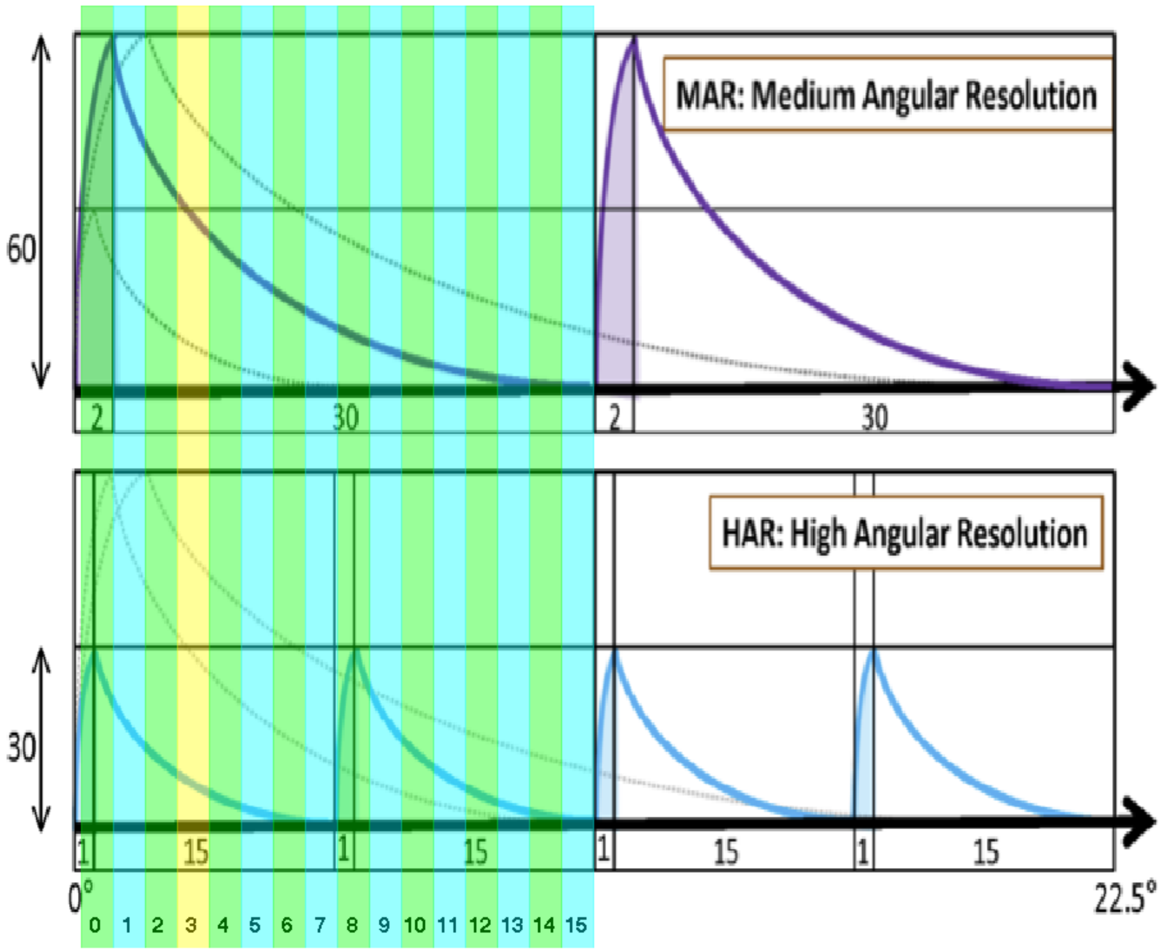

Figure 5: Relation between the correlator and PEACE energies in MAR and HAR modes.

1. The maximum power in a frequency channel as a proportion of the total power is determined.

$$g = max(power)/sum(power)$$

$$m = floor(1/g)$$

2. For each ACF with a finite value of M

$$FisherG = \sum_{k=1}^{m} -1^{k-1} * N!/k!(N-k)! * ((1-k*g)^{N-1})$$

where N is the length of the ACF.

3. The significance is then defined as:

$$Fishersignificance = 100 * (1 - FisherG)$$

iDisp This value provides a measurement of the variance of the count rate and is calculated as

$$(ZL - \langle NZL \rangle)/count\_rate\_estimation$$

where ZL is the ACF zero lag value and $\langle NZL \rangle$ is the average value of the non-zero lab values. For a purely Poissonian process, this value is unity.

In addition, the PCOR files also contain a flag related to the PEACE operational mode. The values used in the data sets are listed in Table 2.

Figure 6 shows an overview of the correlator ACF data (one minute averages) measured on 20th December, 2007 by Cluster 1; these plots are available from the CAA. The panels show (top to bottom) the FFT of the stepped energy ACFs, the FFT of the preselected fixed energy ACFs, all ACFs, the electron energy distribution (the white line indicates the energy used for the fixed energy ACFs), distribution with respect to polar look angle (fixed energy only), and distribution with respect to azimuth look angle (in normal mode measurements are spin averaged, in burst modes, there are either 4, 8, or 16 azimuth bins depending upon telemetry allocation). These electron distributions are reconstructed from the raw counts available from the ACF data.

A glance at this plot shows:

- Between 04:30 and 12:15 the PEACE HEEA sensor worked in HAR mode (restricted energy range in energy distribution). During this period, the count rate was low (nothing is shown in the energy distribution panel) which results in flat ACFs that contain sporadic peaks.
- From 12:15 until the end of the day, PEACE HEEA is operating in MAR mode which covers a larger energy range and so has been able to capture a portion of the electron population.
- Between 12:15 and 15:00 a strong band is seen in the FFT of both the stepped and fixed energy ACFs. The exact frequency of this band varies from spacecraft to spacecraft, but is typically 28kHz. During this period the ACF exhibits a strongly banded structure. Such bands occur due to the transfer of WHISPER data within DWP affecting the timing of the bins used to accumulate the electron counts from PEACE. This results in one of the time bins being longer than the others and accumulating more counts. This effect becomes most obvious during periods of high electron counts as indicated by the red regions in the lower three panels.
- In NM there is no azimuthal binning and so the azimuthal distribution is set to an angle of -1 (see the bottom panel of Figure 6).
- The grey areas in the top two panels between 4-12UT indicate when no counts were measured.

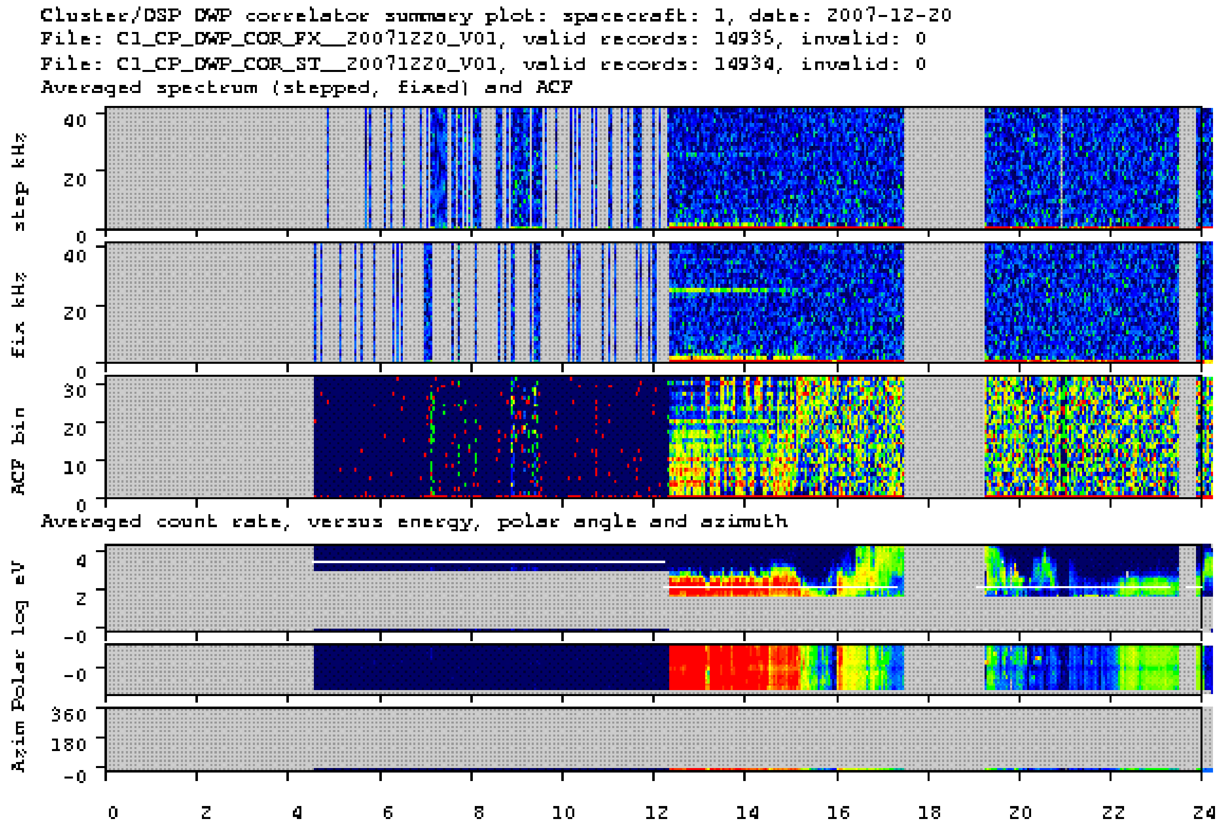

Figure 6: Correlator data validation plot.

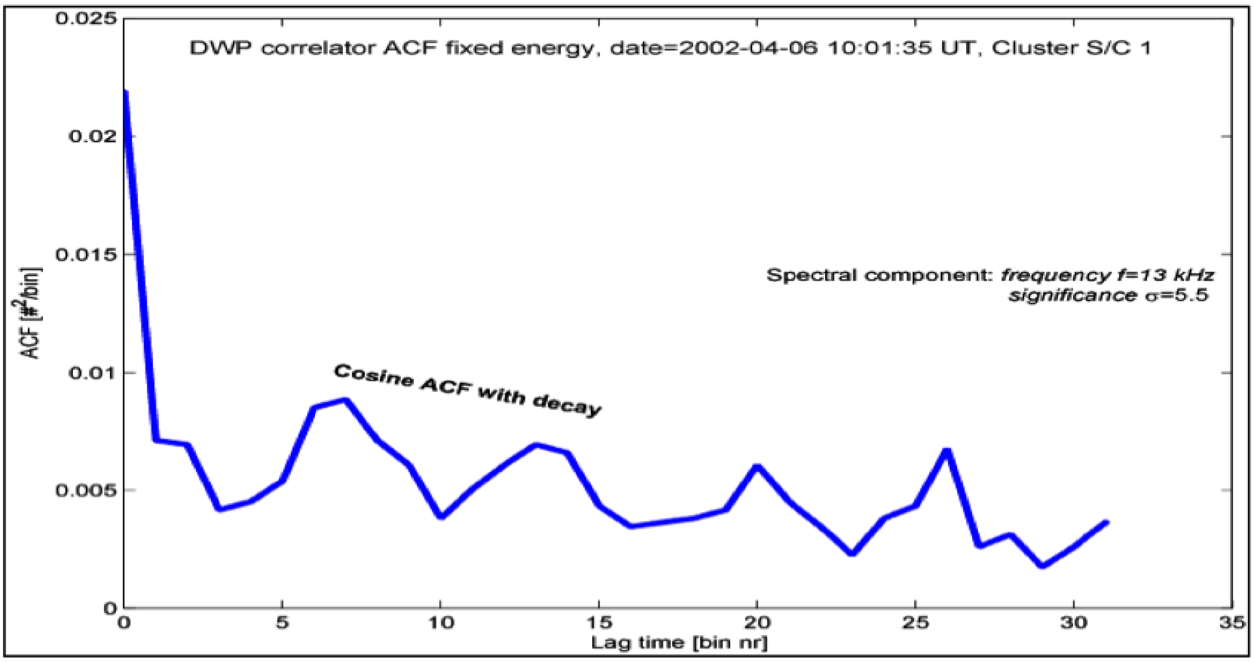

Figure 7: Autocorrelation function measured in the inner magnetosphere. Peaks of the non-zero lags occur typically in every 6-7th bin.

A good example of an ACF is shown in Figure 7, which was measured by the Cluster 1 spacecraft during the crossing of the radiation belts on April 6th, 2002. This ACF was computed using counts from energy bin 15 (48.8eV) looking in the direction (polar bin) -22.5°(in the SR2 coordinate system). A total of 192 individual ACFs measured over one spin were averaged. The ACF amplitude of the lag values varies as a decaying cosine function. The peaks of the non-zero lags occur typically in every 6-7th bin. Since each bin corresponds to a period of 12μs there appears to be a correlation period of around 72-84μs which implies a frequency of around 12-14 kHz.

Figure 8 shows (from top to bottom) plots of the count rate, the Fisher T statistic, its frequency, and significance together with the count rate dispersion that includes the time (2002-04-06 10:01:35) when the ACF shown in Figure 7 was observed. At this time, the Fisher T statistic is extremely high, peaking at ~ 0.28. This shows that around 30% of the power in the spectrum of oscillations occurs at one specific frequency. In addition, the significance is extremely high, almost 100%, providing evidence that this occurrence is most probably the result of natural process rather than a random occurrence in the data stream.

One cause of this correlation in the electron count rate could be the result of the interaction of plasma waves with the electron distribution. To check this out we can look at the WHISPER electric field spectra recorded around this time. Figure 9 shows the appropriate electric field spectra. It can be seen that there is indeed a jump in the amplitude of the electric field spectrum in the frequency range 12-14kHz, as indicated by the ACF. Thus it appears that waves observed in the vicinity of the plasma frequency are responsible for the observed modulation in the electron count rate.

5.2.2 Caveats

The following general caveats apply to this data set. For caveats that apply to specific time intervals, please see the caveat files and caveat information supplied in the data files.

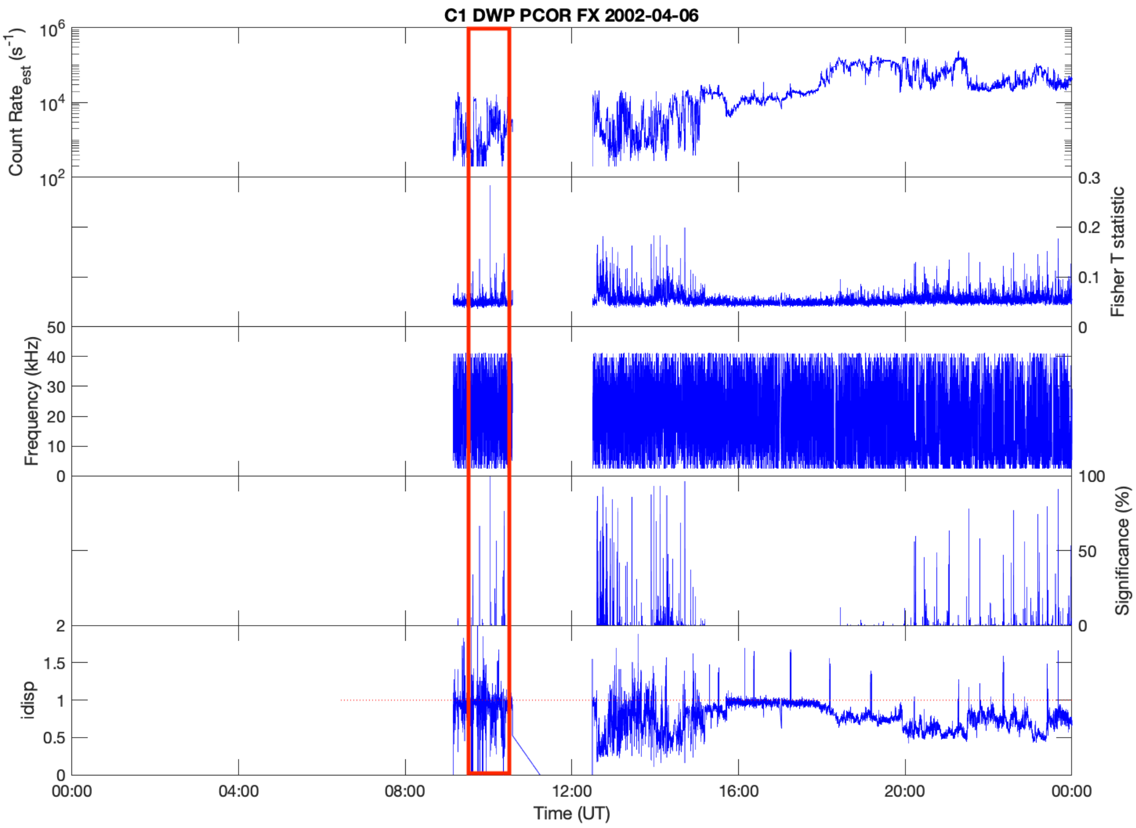

Figure 8: Fisher statistics of the ACF shoewn in Figure 7

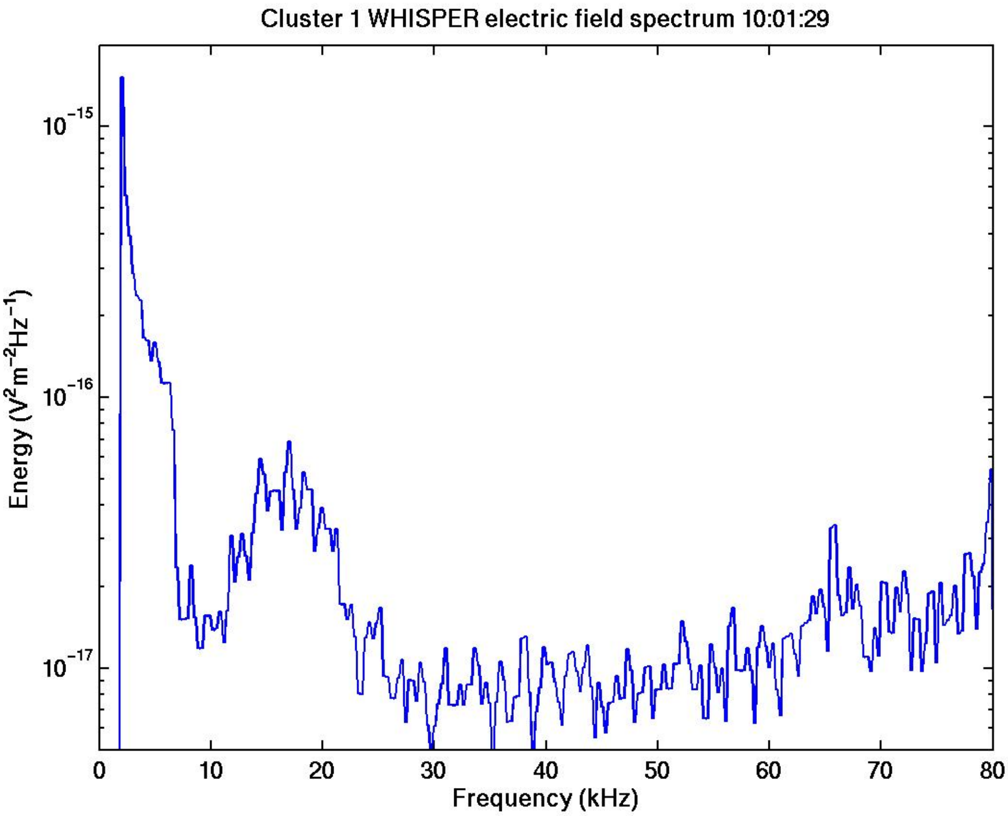

Figure 9: WHISPER spectrum measured at the same time as the ACF shown in Figure 7.

Table 3: PEACE sweep modes.

Sweep mode	PEACE mode	Comments
0	HEEA is off or in fixed energy mode	No correlator data.
1	HEEA LAR mode	DWP cannot determine the PEACE energy of particles analysed.
2	HEEA MAR mode	
3	HEEA HAR mode	Possible low count rates because the higher energies may miss the majority of the electron distribution, resulting in a flat ACF.

Effects of PEACE Operations

Correlator data is present only when the PEACE HEEA sensor is in use. This is indicated either by the PEACE sweep mode available in the Prime Parameter data set (see table below to interpret the data values) or the MCP level written to the CAA Correlator data files (level zero indicate that HEEA is not operating) [*Johnstone et al.*, 1997].

Between 2013-04-27 and 2013-05-22 the PEACE instrument was disabled on SC3 due to operational problems.

From early 2012 onwards there has been a severe reduction in the sensitivity of the PEACE instrument on Cluster 3. This is evident in the energy spectra overview plots.

For more details on the operations of PEACE HEEA sensor the user is recommended to consult the PEACE operational logs at http://www.mssl.ucl.ac.uk/missions/cluster/about_operations/PEACE_ops_history.php.

Quality issues of the ACF

Low count rates. Flat spectra containing random peaks can result from a low count rate. This may occur if PEACE is operating the HEEA sensor with a reduced energy range (e.g. HAR mode) such that the count rate is low because most particles are at lower energies (see Figure 6 which shows that between 04:30 and 12:15 UT the HEEA energy range was too high to observe large numbers of particles).

High count rates. High count rates can result in the appearance of a signal at around 28 kHz in the frequency spectrum. This line results from interference within the DWP instrument caused by the internal transfer of WHISPER data.

Selection of polar zone. The behaviour of the polar angle depends on how PEACE selects the polar zone for the correlator. Early in the mission, until June 9th, 2002, the polar zone was selected according to the magnetic field direction measured on the previous spin and so the polar angle tends to stay on a single value for long periods. After this date the zone stepped through the 12 possible zones, at one step per spin. However, there are rare occasions during which the correlator used the field direction to select the polar zone. This usually occurs for short periods when the HEEA instrument in switched into HAR mode. The azimuth angle is averaged over a spin in normal modes (indicated by an azimuth look angle of -1). In burst modes there are either 4, 8, or 16 summed ACFs output per spin.

A sloping ACF. This is due to steep edges in the energy spectrum causing a rapid change in count rate with time during the energy sweep.

Interferences

WHISPER. Many periods show a weak correlation at ∼36 μs period or ∼28 kHz (the exact value is different on each S/C) and associated high frequency interference line. This effect is present whenever the count rate is very high, and is believed to be due to Whisper data transfer interfering with correlator sampling.

WHISPER. When looking at the 1-minute averaged overview plots it is observed that the energy spectrum may occasionally show that the maximum flux rises in energy over the period of a gee minutes. This effect can be understood in terms of a beating between the 1-minute averages displayed and the 52 second WHISPER sounding cycle.

EDI. Spurious lines in the dynamic spectra may result from operations of EDI.

Limitations of DWP Operations

NM operations. From the start of the mission until 2007-05-27 the correlator was always operating during normal mode operations. After this date, there are periods of normal mode operations during which the correlator is turned off. The correlator is always working during burst mode periods. Details of these periods during which the correlator was not operating may be found in the associated caveat files.

C4 NM operations. From 2008-04-25 operations with the correlator on spacecraft 4 during normal science mode operations were halted completely. The correlator is still operated in periods of burst science. However, since the beginning of the Cluster 4 WEC/HPA power sharing scheme on 2010-08-06, WEC4 may be reactivated with the correlator operating until the next WEC reset/mode change. These data are OK to use.

C1 NM operations. From 2013-09-10 operations with the correlator on spacecraft 1 during normal science mode operations were halted completely. The correlator is still operated in periods of burst science. This is due to the increase in upsets suffered by DWP when the correlator is running.

In some circumstances, the correlator may be turned on but receive no setup commands. As a result, the full energy range of the PEACE data may not be used and the reconstructed energy distribution is incomplete, with data only at certain (constant) energies as shown in the CORR_PLOT graphical summary plots. This data should have been removed during the validation process.

This is caused by the correlator operating in its default mode (expecting PEACE HEEA LAR mode data). HEEA will more than likely be running in MAR or HAR mode which are not compatible with this correlator mode. As a result, the energy distribution will be incomplete. This situation may arise in the following circumstances: WEC is operating in its Emergency/Default mode. (during which the correlator is normally turned off) and scheduled commands for EFW burst/sweep operations are executed in a period in which the correlator was expected to be operating. No correlator configuration commands are received between a BM3 reset and the time the correlator is activated, either during a normal or burst science mode macro sequence.

PEACE Operation Anomalies

Broken PEACE anodes. Since 2005-08-22 anode 2 of the HEEA sensor on spacecraft 3 has not been operating correctly. This implies that the measured flux of electrons arriving from one particular polar look direction will be greatly reduced. Anode 2 corresponds to a polar look direction P9 centred on -52.5°(see Figure 1). Thus, any ACFs generated when the correlator receives its count data from this particular polar bin will be invalid.

Energy bin number. Occasionally, although the energy bin number lies in the correct range (1-15) the energy listed in the data file is set to the fill value of -1.0. This may indicate that there was no PEACE information regarding the actual energy being sampled. If this is the case, the MCP level will also be set to the fill value.

MAR/HAR mode. The normal setup for the correlator assumes that PEACE is operating in MAR mode. If PEACE is switched in to HAR mode there are two PEACE energy sweeps per correlator energy sweep. As a result, counts corresponding to the same PEACE energy level appear to originate from two different correlator energy levels (separated by 8 energy levels). Hence, for reconstruction of the energy spectra it is recommended to use the data in the ENERGY (PEACE energy) parameter rather than the EnergyBinNumber (correlator energy bin).

March - November 2005 attempts were made to optimise the correlator operations to match the current HEEA operational mode, i.e. if HEEA was operating in HAR(LAR) mode the correlator should be configured to process HAR(LAR) mode data. However, during this period it was found that HEEA switched modes more often than expected and that if the correlator was to follow suit every time the overall operations of WEC would be disrupted. As a result, within this time period there are a significant number of intervals during which HEEA operated in one mode whilst the correlator was configured to operate in the other. Problems arise when HEEA switches to MAR mode whilst the correlator expects HAR mode data. The result is that the ACFs are processed incorrectly and the final data files contain long periods when the Energy is undefined. When this occurs, the correlator data should not be used. Caveats have been added to the data files to indicate such periods and the data for these periods should have been deleted. Periods when the correlator operated in MAR mode and HEEA collected data in HAR mode do not have this problem as the data may be processed without problems. As a result, after this date the correlator was always configured to operate assuming the data from HEEA were collected in MAR mode.

Beat Interference. During early operations (between June 9th, 2002 and November 8th, 2003) the PEACE energy level that was used for the fixed energy ACF was set as the lowest value in the currently operating HEEA energy range. An example of these operations is shown in Figure 7. Between 15 and 23UT there are a series of diagonal bands visible in the polar angle plot. These bands result from a beat between the rate at which the polar bin scans (4sec*12bins=48 seconds) and the WHISPER sounder cycle of 52 seconds. The WHISPER pulse puts energy into the plasma, increasing the particle energy enough to cause an increase in the counts registered in the energy channel currently being sampled.

5.3 Particle Correlator Plots

5.3.1 Data

The PCOR_PLOT data set is a graphical product that shows a summary of the data available from the DWP Particle Correlator. These plots are generated as part of the Correlator data generation process and are used by the DWP team to validate the data sets. This multi-satellite graphical product shows correlator data from all satellites on each plot. An example of the data is shown in Figure 10. The data shown are one minute averages.

For each satellite two sets of panels are displayed. The upper three panels show (top to bottom) the FFTs of the stepped energy ACFs, the FFTs of the fixed energy ACFs, and the individual ACFs (1 minute averages). These panels show if there is any periodicity in the arrival times of the electrons in the HEEA sensor and its frequency. Periodicities in the electron count rate may result from the interaction of the electron population with waves and can be confirmed by inspecting the wave spectra recorded by WHISPER.

The lower three panels show reconstructions of the electron energy distribution, the distribution with respect to polar look angle (fixed energy only) and azimuthal distribution. It should be noted that in normal mode, the ACFs are averaged over one spin and so any azimuthal information is lost in which case the values of the data parameter Look_Angle_Azimuth is set to -1.

In burst modes, there are either 4, 8, or 16 azimuth bins depending upon correlator operational mode and telemetry data allocation.

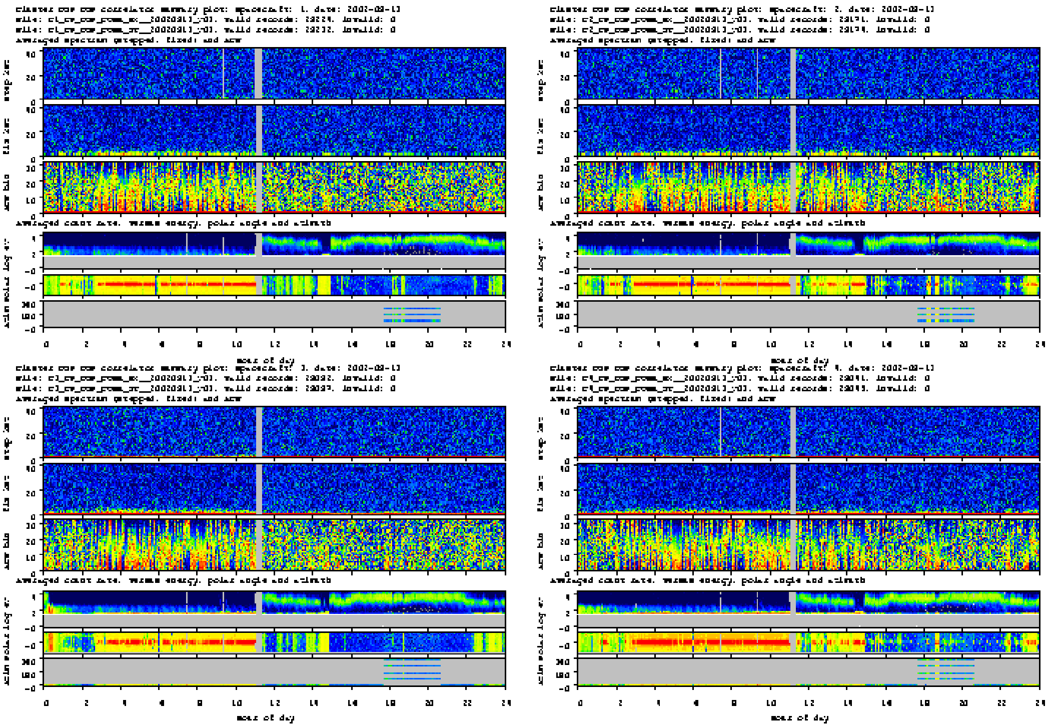

Figure 10: Example DWP correlator overview plot.

Table 4: Interpretation of the status variables.

Parameter	Description
Time_tags	Centre time of data interval
Half_interval	Half of interval averaging length
Status_DWP	DWP status
Status_Acf	Correlator status
Status_Heea	Status of PEACE HEEA sensor
Status_Heea	Status of PEACE HEEA sensor
Status_B	Magnetic field direction
State_wec	Status of WEC instruments as recorded in the WEC housekeeping data files
Status_wbd	More details regarding the setup of the WEC WBD instrument
Correl_signif	Percentage significance of any sinusoidal oscillation measured on ACF
Correl_freq	Frequency of sinusoidal oscillation
Correl_P	Energy of particles
CorrelCrEst	Estimation of count rate from lag values
Correl_Ivar	Index of variation in the electron count rate

Table 5: Contents of the Summary Parameter files.

Parameter	Description
Time_tags	Centre time of data interval
Half_interval	Half of interval averaging length
Status_DWP	DWP status
Status_Acf	Correlator status
Status_Heea	Status of PEACE HEEA sensor
Status_B	Magnetic field direction
State_wec	Status of WEC instruments as recorded in the WEC housekeeping data files
Status_wbd	Further details regarding the setup of the WEC WBD instrument
Correl_signif	Percentage significance of any sinusoidal oscillation measured on ACF

5.3.2 Caveats

On a few occasions, the energy distribution plots show what appear to be a number of gaps in the distribution. The source of this was traced to a rounding error in the correlator plotting software. A solution to this problem was implemented in January 2011.

5.4 Prime/Summary parameters

5.4.1 Data

The set of DWP Prime and Summary Parameter files are produced by the UK Cluster Data Centre using software provided by the PI group. In keeping with other Prime/Key Parameter data sets, the Prime Parameter files contain spin resolution (≈4 sec) data while the Summary Parameter fits contain 1 minute averages of these data. Originally, these data sets were designed to provide an overview of the full resolution data sets such as that now contained in the PCOR and DWP_LOG data files. The quality of these data sets is lower than that of the high resolution data sets that are currently available. The following data descriptions have been included here for completeness.

Table 4 and Table 5 list the parameters available in these files.

5.4.2 Caveats

In using the Prime and Summary parameters it should be noted that:

- Before December 1st, 2008 the contents of each CDF file were inspected and validated by the DWP PI group prior to ingestion into the Cluster Data System. After this date, files are no longer validated by the DWP team.
- The parameters Status_DWP, Status_Acf, Status_Heea, and Status_B contain one value per data word.
- The parameters status_wec and status_wbd should be interpreted in a bitwise fashion. Their interpretation is outlined in Table 6.

Table 6: Interpretation of the status related variables in the Prime and Summary Parameter files

PARAMETER	DESCRIPTION
Status_DWP	Correlator status – 5 data words
Status_DWP[0]	Reserved for CSDS use
Status_DWP[1]	Indicates whether correlator is on or off Bits used: MSB - - - - - - - x LSB 0 = correlator off 1 = correlator on
Status_DWP[2]	Amplitude count from zero lag Bits used: MSB x x x x x x x x LSB Amplitude of count value deduced from ACF zero lag
Status_DWP[3]	Significance test used Bits used: MSB x x x x x x x x LSB 0 = Fisher 1 = Schuster 2 = Chebyshev
Status_DWP[4]	Whisper sounding mode (if known) Bits used: MSB x x x x x x x x LSB Type of WHISPER sounding mode (0 = unknown)
Status_Acf	Correlator status – 4 data words
Status_Acf[0]	Use of preselected of stepped energy bin Bits used: MSB x x x x x x x x LSB 0 = ACF used in CSDS is pre-selected (fixed) energy 1 = ACF used in CSDS is stepped energy
Status_Acf[1]	Correlator bit rate Bits used: MSB x x x x x x x x LSB Correlator bit rate switch (ACF output rate)
Status_Acf[2]	Number of ACFs summed Bits used: MSB x x x x x x x x LSB Number of onboard summed ACF components
Status_Acf[3]	Amplitude of zero lag Bits used: MSB x x x x x x x x LSB Amplitude of zero lag in units of 1.1
Status_Heea	Status of PEACE HEEA sensor – 4 data words
Status_Heea[0]	Availability of calibration Bits used: MSB x x x x x x x x LSB 0 = PEACE HEEA calibration file values available 1 = PEACE HEEA calibration file values not available

Status_Heea[1]	Energy sweeps per spin Bits used: MSB x x x x x x x x LSB PEACE HEEA energy sweep mode
Status_Heea[2]	PEACE HEEA preset energy level Bits used: MSB x x x x x x x x LSB PEACE HEEA energy preset level
Status_Heea[3]	Total PEACE HEEA electron counts Bits used: MSB x x x x x x x x LSB PEACE HEEA recorded total count number (all polar zones/all energies) per spacecraft spin period in log units of 1.1
Status_B	Magnetic field direction – 4 data words
Status_B[0]	HEEA polar zone from which correlator data is taken Bits used: MSB x x x x x x x x LSB HEEA polar zone sup[plying correlator data for this spin period.
Status_B[1]	HEEA polar zone containing magnetic field Bits used: MSB x x x x x x x x LSB HEEA polar zone containing magnetic field as deduced from previous spin
Status_B[2]	Azimuthal offset of magnetic field Bits used: MSB x x x x x x x x LSB Spacecraft azimuthal offset of magnetic field in units of 5.625 degrees
Status_B[3]	Source of magnetic field data Bits used: MSB x x x x x x x x LSB 0 = magnetic field from FGM via IEL 1 = magnetic field from REACE symmetry calculation
State_wec	Status of WEC instruments as recorded in the WEC housekeeping data files – 5 data words
State_wec[0]	EFW parameters Bits used: MSB x - - - - - - - LSB 0 = EFW working 1 = EFW not working Bits used: MSB - x - - - - - - LSB 0 = Unit 1 in E-field mode 1 = Unit 1 in density mode Bits used: MSB - - x - - - - - LSB 0 = Unit 2 in E-field mode 1 = Unit 2 in density mode Bits used: MSB - - - x - - - - LSB 0 = Unit 3 in E-field mode 1 = Unit 3 in density mode Bits used: MSB - - - - x - - - LSB 0 = Unit 4 in E-field mode 1 = Unit 4 in density mode Bits used: MSB - - - - - x - - LSB 0 = EFW not in interferometric mode 1 = EFW in interferometric mode Bits used: MSB - - - - - - x x LSB 0 = EFW in normal mode 1 = EFW in split sampling mode

	2 = EFW in HX sampling mode 3 = null
State_wec[1]	STAFF parameters Bits used: MSB x - - - - - - - LSB 0 = STAFF SA working 1 = STAFF SA not working Bits used: MSB - x - - - - - - LSB 0 = STAFF MWF working 1 = STAFF MWF not working Bits used: MSB - - x - - - - - LSB 0 = STAFF not in calibration mode 1 = STAFF in calibration mode Bits used: MSB - - - x x x x - LSB 0 = STAFF normal 1 mode 1 = STAFF normal 2e mode 2 = STAFF normal 2b mode 3 = STAFF Illegal 4 = STAFF not in emergency mode 5 = STAFF in special mode 6 = STAFF in normal 1e mode 7 = STAFF in normal 1b mode 8 = STAFF SA in FAST mode 1 mode 9 = STAFF SA in FAST mode 3e mode 10 = STAFF SA in FAST mode 3b mode 11 = Illegal 12 = STAFF SA in FAST mode 2 mode 13 = STAFF in standby mode 14 = Illegal 15 = Illegal Bits used: MSB - - - - - - - x LSB 0 = STAFF MWF bandwidth 10Hz 1 = STAFF MWF bandwidth 180 Hz
State_wec[2]	WHISPER parameters Bits used: MSB x x x - - - - - LSB 0 = WHISPER not working 1 = WHISPER Calibration mode (quiet) 2 = WHISPER Calibration mode (Sounding) 3 = WHISPER Natural model 4 = WHISPER Sounding - normal mode 5 = WHISPER Sounding - gliding mode 6 = WHISPER Sounding - synchronous mode 7 = not used Bits used: MSB - - - x - - - - LSB (Sounding modes) 0 = Receiving antenna Ez 1 = Receiving antenna Ey Bits used: MSB - - - - x x - - LSB (Sounding modes) 0 = No emission 1 = Pulse level 50 V peak to peak 2 = Pulse level 100 V peak to peak 3 = Pulse level 200 V peak to peak Bits used: MSB - - - - - - x x LSB (Sounding modes)

	0 = Pulse duration 13 ms 1 = Pulse duration 26 ms 2 = Pulse duration 40 ms 3 = Pulse duration other Bits used: MSB - - - x x - - - LSB (Natural modes) 0 = 64 FFT bins used 1 = 128 FFT bins used 2 = 256 FFT bins used 3 = 512 FFT bins used Bits used: MSB - - - - - x x x LSB (Natural modes) 0 = 32 spectra averages 1 = 16 spectra averages 2 = 16 spectra averages 3 = 8 spectra averages 4 = 4 spectra averages 5 = 2 spectra averages 6 = 64 spectra averages 7 = 1 spectra averages
State_wec[3]	DWP parameters Bits used: MSB x - - - - - - - LSB 0 = correlator working 1 = correlator disabled Bits used: MSB - x x x x - - - LSB Energy level Bits used: MSB - - - - - x - - LSB 0 = Sample clock 25 Hz 1 = Sample clock 450 Hz Bits used: MSB - - - - - - x x LSB 0 = Normal mode 1 = Burst mode 1 2 = Burst mode 2 3 = Burst mode 3
State_wec[4]	WBD parameters Bits used: MSB x - - - - - - - LSB 0 = WBD working 1 = WBD not working Bits used: MSB - x x - - - - - LSB 0 = Base band 0 kHz 1 = Base band 125 kHz 2 = Base band 250 kHz 3 = Base band 500 kHz Bits used: MSB - - - x x x - - LSB 0 = 9.5 kHz 8 bit 1 = 9.5 kHz 8 bit 2 = 19 kHz 4 bit 3 = 19 kHz 8 bit 4 = 77 kHz 8 bit 5 = 77 kHz 1 bit 6 = 77 kHz 4 bit 7 = 77 kHz 8 bit

Status_wbd	More details regarding the setup of the WEC WBD instrument – 4 data words
Status_wbd[0]	For CSDS use
Status_wbd[1]	WBD parameters Bits used: MSB x - - - - - - - LSB 0 = WBD working 1 = WBD not working Bits used: MSB - x - - - - - - LSB Not used Bits used: MSB - - x x - - - - LSB 0 = Base band 0 kHz 1 = Base band 125 kHz 2 = Base band 250 kHz 3 = Base band 500 kHz Bits used: MSB - - - - x x - - LSB 0 = LV0 1 = LV1 2 = LV2 3 = LV3 Bits used: MSB - - - - - - x x LSB 0 = UV0 1 = UV1 2 = UV2 3 = UV3
Status_wbd[2]	WBD parameters Bits used: MSB x - - - - - - - LSB 0 = WBD working 1 = WBD not working Bits used: MSB - x - - - - - - LSB 0 = HK not via DWP 1 = HK via DWP Bits used: MSB - - x - - - - - LSB 0 = Auto gain set 1 = Manual gain set Bits used: MSB - - - x x x x - LSB Digitised gain setting Bits used: MSB x - - - - - - - LSB 0 = Primary interface 1 = Redundant interface
Status_wbd [3]	WBD parameters Bits used: MSB x - - - - - - - LSB 0 = WBD working 1 = WBD not working Bits used: MSB - x - - - - - - LSB Not used Bits used: MSB - - x - - - - - LSB 0 = VXO locked 1 = VXO not locked Bits used: MSB - - - x x x - - LSB 0 = 9.5 kHz 8 bit 1 = 9.5 kHz 8 bit

	2 = 19 kHz 4 bit 3 = 19 kHz 8 bit 4 = 77 kHz 8 bit 5 = 77 kHz 1 bit 6 = 77 kHz 4 bit 7 = 77 kHz 8 bit Bits used: MSB - - - - - - x x LSB 0 = Ez antenna 1 = By antenna 2 = Bx antenna 3 = Ey antenna

6 Recommendations

Since no parameters are replicated or calibrated using more than one method all parameters within the DWP CAA data files are unique and so there is no confusion over when it is in appropriate to use them. However, care does need to be taken with their interpretation. When in doubt, consult the caveat section for the appropriate data set in the previous sections of this User Guide and the online data caveat files.

The Summary and Prime Parameter files have been superseded by the PCOR and DWP_LOG files and so their use is not recommended.

7 DWP time line

Table 7 lists the notable events in the operation of the DWP instruments.

Table 7: Significant events in the operation of the Cluster DWP Particle Correlator

Date/period	Satellite	Event
2001-02-01	1234	Science operation begin
2002-06-09 to 2003-11-08	1234	Lowest PEACE energy bin used for fixed ACF
2002-06-09 to 2003-11-08	1234	Before this date, the correlator polar zone was selected by PEACE depending upon the magnetic field direction. After this date the sleeked zone steps through all possible zones, changing every spin.
2004-01-18	3	Due to overheating problems operation of WBD instrument is limited to 10 minutes per hour.
2005-03 to 2005-11	1234	Attempts to coordinate correlator and PEACE operational modes
2005-08-22	3	Anode 2 of HEEA sensor stops working correctly. It yields an extremely low count rate.
2007-05-27	1234	Before this date the correlator was always operating. After this date there are periods when the correlator is turned off. For a list of these off periods see the PCOR caveat file.
2008-04-25	4	Normal science mode operations halted
2013-04-27 to 2013-05-22	3	PEACE instrument disabled due to operational problems
2013-09-10	1	Normal science mode operations halted

Appendices

A DWP Datasets

Table 8 shows the names of all of the DWP datasets for the Cluster spacecraft, where in Dataset names [n] = 1-4 . Note that the last two datasets, starting with "CM", are multi-satellite datasets that contain data for all four spacecraft.

Table 8: DWP data set names in CSA.

Dataset Name	Dataset title
Science datasets	
C[n]_CP_DWP_PCOR_FX	Particle Correlator Data, fixed energy band
C[n]_CP_DWP_PCOR_ST	Particle Correlator Data, stepped energy band
Operations datasets	
C[n]_CP_DWP_LOG	Wave Consortium operations log
CM_CP_DWP_UT_PIOR	Wave Consortium Commanding
Caveat datasets	
C[n]_CQ_DWP_PCOR_FX	Caveats for Particle Correlator, fixed energy band
C[n]_CQ_DWP_PCOR_ST	Caveats for Particle Correlator, stepped energy band
C[n]_CQ_DWP_TCOR	Caveats for Time corrections
C[n]_CQ_DWP_LOG	Caveats for Wave Consortium operations log
CM_CQ_DWP_UT_PIOR	Caveats for Wave Consortium Commanding
Auxillary datasets	
C[n]_CP_DWP_TCOR	Time corrections
C[n]_PP_DWP	Prime Parameter Particle Correlator data (spin resolution)
CL_SP_DWP	Summary Parameter Particle Correlator data (1 minute resolution)
Graphical datasets	
CM_CG_DWP_PCOR_OVERVIEW_PS	Overview plot containing 1 min averaged PCOR data from both FX and ST data streams.
C[n]_CG_DWP_PCOR_FX_OVERVIEW2_PNG	Overview plot of Fisher statistical parameters from the FX data stream.
C[n]_CG_DWP_PCOR_ST_OVERVIEW2_PNG	Overview plot of Fisher statistical parameters from the ST data stream.
C[n]_CG_DWP_LOG_OVERVIEW_m	Operational overview pots generated from the DWP_LOG data set. There are 8 separate plots.

B DWP Operational Datasets

B.1 DWP_LOG

B.1.1 Data

The DWP_LOG data set contains a record of the actual instrument setup commands as recorded in the DWP housekeeping data file. The data validity is for the time interval specified during which a particular

WEC mode was in operation. The parameters contained in this data set are listed in Table 9. The DWP housekeeping parameter pneumonics from which they are derived correspond to the parameter names used in chapter 2 of the WEC User Manual [*Willis et al.*, 2000]. The WEC User Manual should be consulted if more information regarding the parameters is required.

The operational modes of WEC are driven by sets of macros which switch the individual instrument modes depending upon the current part of the macro cycle being executed. Full details of these macro operations may be found in the WEC User Manual [*Willis et al.*, 2000].

For all macros, the WHISPER and STAFF instruments have two different sets of parameters that configure them. One set are used during periods when the WHISPER transmitter is active whilst the second set are used when the WHISPER transmitter is not working, i.e. passive mode.

The WBD instrument has two distinct modes of operation (that are unrelated to WHISPER being active or passive). The first configures WBD to operate using a fixed bandwidth/conversion frequency setting. The second consists of a pair of macros that allow the instrument to cycle between either three specified conversion frequencies or taking signals from both the electric and magnetic antennae alternately.

Table 9: Parameters contained in the DWP LOG data sets and their origin

Parameter	Interpretation
Time tags	
Time	Interval (data acquisition interval) during which a particular WEC mode was executed. They are generated from the RDM time stamps. Note that the TCOR time corrections have NOT been applied.
DWP Configuration	
Format_Count	Number of formats (data frames) in interval
Clock_Freq	WEC Master Clock Frequency. WEC parameters: EW5RSCNT, EW5SSOFF
DWP_MODEL_TAG	DWP instrument model number WEC parameter: EW5MOTAG
LOG_EVENT	Event causing this log entry. "MACRO" - A predefined macro was in operation "Gap" - The period contains no data "CONFIG" - DWP is in the process of configuring the WEC instruments "CAL" - WEC was operating a calibration mode "WATCHDOG" - A watchdog reset occurred "POWER" - DWP was switching on the WEC instruments
DWP_CONFIG_0 DWP_CONFIG_1 DWP_CONFIG_2	Configuration of the individual transputers processors. The transputers may be powered "OFF", or run at "HALF" or "FULL" speed. WEC parameter: EW5P0CFG WEC parameter: EW5P1CFG WEC parameter: EW5P2CFG
DWP_SEU_count	Number of DWP single event upsets. SEU's are detected by looking for changes in the memory check sums between successive data formats. WEC parameters: EW5MLEC1-EW5MLE15
DWP_Chk_Sum	Checksum of DWP memory at the end of the interval. This value is calculated from the DWP memory dumps that occur during execution of the macro. WEC parameters: EW5MLEC1-EW5MLE15

Table 9: continued

Errors detected by the WEC instruments	
STAFF_SA_Zero_Count	Average number of STAFF SA zeros. WEC parameter: EW1ZCNTR
DWP_error_count	Number of DWP errors reported. This counts the number of times any of the WEC parameters listed below are non-zero, indicating an error. EW5DMAFL, EW5EITCM, EW5EITEW, EW5ELINT, EW5ESTMR, EW5EAPOV, EW5ENRDY, EW5ETMOV, EW5TIWME, EW5ATSNP, EW5CORDS, EW5WDWPO, EW5WPOWD
STA_SA_error_count	Number of STAFF SA errors reported. This is a count of the number of times the WEC parameter EW1EWORD was non-zero. WEC parameter: EW1EWORD
STA_SC_error_count	Number of STAFF SC errors reported. This is a count of the number of times the WEC parameter EW2EWORD was non-zero. WEC parameter: EW2EWORD
WHI_error_count	Number of WHISPER errors reported. This is a count of the number of times the WEC parameter EW3IFST was non-zero. WEC parameter: EW3IFST
TM_Overflow	Number of Telemetry Overflows detected. WEC parameter: EW5ETMOV
AP_Overflow	Number of Application Overflows detected. WEC parameter: EW5EAPOV
WEC Operational Modes	
TM_Mode_Name	Telemetry mode name indicates the satellite operational mode eg NM - normal science mode, BM1 - Burst science mode, BM3 - Burst mode 3 operations.
Mode_Name	WEC mode name. This is the name of the WEC mode that was in operation
Mode_Desc	WEC mode Description. A more descriptive mode name. Full descriptions of the operational modes may be found in the WEC User Manual chapter 6.
WEC Instrument Configuration	
STA_SA_Mode_Passive	STAFF SA mode in passive part of mode cycle
STA_SA_Mode_Active	STAFF SA mode in active part of mode cycle
WHI_Mode_Passive	WHISPER mode is passive part of mode cycle
WHI_Mode_Active	WHISPER mode in active part of mode cycle
WBD_Mode_1	Wideband mode in first part of mode cycle
WBD_Mode_2	Wideband mode in second part of mode cycle
WBD_Mode_3	Wideband mode in third part of mode cycle
COR_OUTPUT_MODE	Correlator output mode.
COR_SWEEP_MODE	Correlator sweep mode. WEC parameter: EW3PCFBS
COR_FIX_LEVEL	Correlator fixed energy level. WEC parameter: EW5PRCTL
Instrumental Voltages and their Standard Deviations	
These analogue measurements contain the average value of the parameter measured during the acquisition interval together with its standard deviation as an indication of the variation of the parameter during this period. The expected nominal values and their calibrations may be found in the WEC Instrument Manual (chapter 2).	
WEC_Current_Average	Average WEC current WEC parameter: EW5WECCS
WEC_Current_Std_Dev	Standard deviation of WEC current

Table 9: continued

DWP_5V_Average	Average DWP voltage (5V) WEC parameter: EW5VMON
DWP_5V_Std_Dev	Standard deviation of DWP voltage (5V)
STA_SA_6V_Average	Average STAFF SA voltage (6V) WEC parameter: EW1VMON0
STA_SA_6V_Std_Dev	Standard deviation of STAFF SA voltage (6V)
STA_SA_M6V_Average	Average STAFF SA voltage (-6V) WEC parameter: EW1VMON1
STA_SA_M6V_Std_Dev	Standard deviation of STAFF SA voltage (-6V)
STA_SA_5V_Average	Average STAFF SA voltage (5V) averaged WEC parameter: EW1VMON2
STA_SA_5V_Std_Dev	Standard deviation of STAFF SA voltage (5V)
STA_SC_M9V_Average	Average STAFF SC voltage (-9V) WEC parameter: EW2VMON0
STA_SC_M9V_Std_Dev	Standard deviation of STAFF SC voltage (-9V)
STA_SC_M6V_Average	Average STAFF SC voltage (-6V) WEC parameter: EW2VMON1
STA_SC_M6V_Std_Dev	Standard deviation of STAFF SC voltage (-6V)
STA_SC_9V_Average	Average STAFF SC voltage (9V) WEC parameter: EW2VMON2
STA_SC_9V_Std_Dev	Standard deviation of STAFF SC voltage (9V)
STA_SC_6V_Average	Average STAFF SC voltage (6V) WEC parameter: EW2VMON3
STA_SC_6V_Std_Dev	Standard deviation of STAFF SC voltage (6V)
WBD_6V_Average	Average Wideband voltage (6V) WEC parameter: EW4VMON0
WBD_6V_Std_Dev	Standard deviation of Wideband voltage (6V)

A set of monthly overview plots, created from the DWP_LOG file and summarising WEC operations, are available from CSA. There are a set of 8 plots per month per satellite that show the following information. The values pertain to each individual acquisition interval.

OVERVIEW_1 - Error flags Indicate the value of error flags in the WEC housekeeping data.

OVERVIEW_2 - Analogue values These are the average and standard deviations of various instrument voltages, the DWP current, and instrument temperature values.

OVERVIEW_3 - Telemetry rates The used telemetry allocation for each of the WEC instruments.

OVERVIEW_4 - Correlator mode The operational mode of the DWP particle correlator application.

OVERVIEW_5 - STAFF mode The STAFF operational mode words.

OVERVIEW_6 - WBD mode The WBD operational mode words broken down into their constituent parameters.

OVERVIEW_7 - WHISPER mode I The WHISPER operational mode words (active) broken down into their constituent parameters.

OVERVIEW_8 - WHISPER mode II The WHISPER operational mode words (passive) broken down into their constituent parameters.

Further descriptions of the parameters may be found in the Table 9, the DWP ICD [*Walker and Yearby*, 2014b] and the WEC User Manual [*Willis et al.*, 2000].

Table 10: DWP instrument model numbers

Satellite	HEX	Dec
Cluster 1	0xCD06	52486
Cluster 2	0xCD07	52487
Cluster 3	0xCD08	52488
Cluster 4	0xCD05	52485

The top panel on each page contains the DWP instrument model number. This parameter should take the values shown in Table 10. If DWP is not operational, the model number is either zero or 0xFFFF (65535) and the period is marked by a grey shaded region.

B.1.2 Caveats

The following general caveats apply to this data set. For caveats that apply to specific time intervals, please see the caveat files and caveat information supplied in the data files.

From 2003-12-13 the WBD instrument on Cluster 3 began to draw large currents and as a consequence overheat. As a result, commanding and operational strategies were changed from 2004-01-18 such that the instrument is only powered on for periods of 10 minutes at a time. As a result, the average voltage within an acquisition period is around zero.

During periods when DWP is configuring WEC or powering up the instruments the voltage averages may be zero and the STAFF_SA temperature is set to 200.

B.2 UT_PIOR

The UT_PIOR data sets contain a UT time tagged list of the commands that were generated as part of the Cluster commanding activities. As such it contains a record of the commands uplinked to the satellites. The data fields available are listed in Table 11.

Table 11: Parameters contained in the DWP UT_PIOR data sets

Field	Value
Time	Time tag for event/command
Tag	Type of entry EVT = event e.g. shock crossing, radiation belt entry/exit etc ORS = Start of operational sequence (acquisition interval) ORE = End of operational sequence (acquisition interval) REM = Comment added during revision SEQ = Operational command sequence used
Mask	Spacecraft number to which the entry applies
Label	Acquisition interval tag
Content	Command macro/event/comment etc

Table 12 below shows an example of a typical set on entries in the UT_PIOR data set:

The first line contains event information, in this case a crossing of the auroral oval by the reference Cluster spacecraft (mask=" 0"). All other entries in this table are for spacecraft 4 only. The second line indicates the end of one data acquisition interval whilst the third line indicates the beginning of the next interval. The Content corresponding to the Tags "SEQ" provide the WEC command that was executed and its parameters (if any).

Table 12: Example of the contents of the UT_PIOR data set

Time	Tag	Mask	Label	Content
2014-07-06T00:27:01Z	"EVT"	" 0"	"————"	"Q3_191_O Auroral oval"
2014-07-06T01:44:00Z	"ORE"	" 4"	"01_NM102B000"	"U1_191_1 +00:23:00 NM1 1 —"
2014-07-06T01:44:00Z	"ORS"	" 4"	"01_WB103A000"	"U1_191_1 +05:42:00 WB1 2"
2014-07-06T01:44:00Z	"REM"	" 4"	"01_WB103A000"	"IBMD used : wec_1234_wbd_mode VAL file used : wec_wbd_090_ez "
2014-07-06T01:44:00Z	"SEQ"	" 4"	"01_WB103A000"	"SWECJ022, X'00';"
2014-07-06T01:44:02Z	"REM"	" 4"	"01_WB103A000"	"PMRQ 02: WBD 77kHz bandwidth 500kHz conversion"
2014-07-06T01:44:02Z	"SEQ"	" 4"	"01_WB103A000"	"SWECJ009, X'00', X'70';"

B.2.1 Caveats

There are currently no general caveats for this data set. For caveats that apply to specific time intervals, please see the caveat files and caveat information supplied in the data files.