

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

prepared by

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## Acronyms

|         |                                                                                                         |
|---------|---------------------------------------------------------------------------------------------------------|
| ACF     | Auto-Correlation Function                                                                               |
| BM1     | Burst Mode 1 - Cluster high resolution science operational mode                                         |
| BM2     | Burst Mode 2 - Cluster WBD measurements routed through DWP                                              |
| BM3     | Burst Mode 3 - Cluster EFW internal burst memory dump                                                   |
| CAA     | Cluster Active Archive                                                                                  |
| CDF     | Common Data Format - NASA ISTP standard data format                                                     |
| CEF     | Cluster Exchange Format - Cluster data format                                                           |
| CSA     | Cluster Science Archive                                                                                 |
| DWP     | Digital Wave Processor - Cluster WEC instrument                                                         |
| EFW     | Electric Fields and Waves - Cluster WEC instrument                                                      |
| ESOC    | European Satellite Operations Centre                                                                    |
| 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 WEC instrument                                 |
| TACC    | PEACE accumulation period                                                                               |
| TCAL    | Time Calibration - calibration of clock count into UT                                                   |
| UT      | Universal time                                                                                          |
| WBD     | WideBand Data - Cluster WEC instrument                                                                  |
| WEC     | Wave Experiment Consortium                                                                              |
| WHISPER | Waves of High frequency and Sounder for Probing Electron density by Relaxation - Cluster WEC 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 serves as 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, listed in Appendix A, generated by the DWP instrument, namely those related to the particle correlator application (PCOR<sup>1</sup>) 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 Appendix B.1 and Appendix B.2 respectively.

## 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  $\mu$ s. 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,

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

- control of the instrument modes during the cycling of operations that involve periods of active sounding measurements by WHISPER,
- 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 CSA that are related to these activities, namely `UT.PIOR` and `DWP.LOG`. For the details of these datasets, see Appendix B.

During its 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 CSA User Guide [*Fazakerley and the PEACE Operations Team*, 2025]. 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 keV using 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 (0.59-9.45 eV) 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  $330^\circ$  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  $26.2^\circ$  counterclockwise from the YBuild axis. Thus the azimuthal offset of the HEEA sensor at the start of the spin is  $303.8^\circ$ . 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 CSA User Guide).

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  $TACC = TSPIN/1024 \sim 3.9\text{ms}$ . 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 CSA PEACE User Guide.

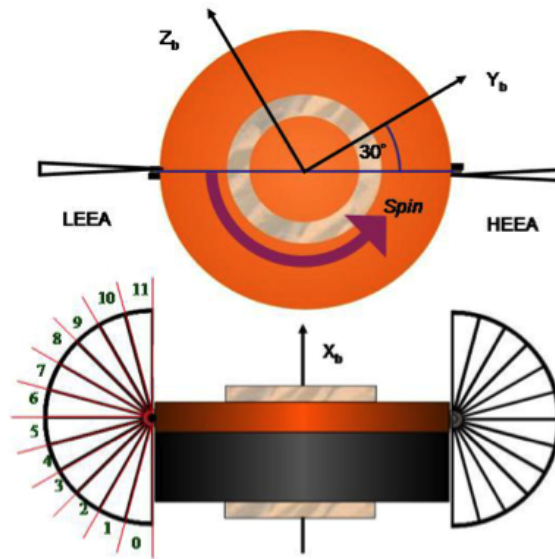


Figure 1: PEACE HEEA location

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 period of a whole spin ( $\sim 4$  seconds). 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  $12 \mu\text{s}$  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 fore-

|                       |          |                                                                                                             |   |    |    |    |    |   |    |   |     |                                     |    |
|-----------------------|----------|-------------------------------------------------------------------------------------------------------------|---|----|----|----|----|---|----|---|-----|-------------------------------------|----|
| Time series of counts |          | <table><tr><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td><td>1</td></tr></table>    | 3 | 1  | 4  | 1  | 5  | 1 | 4  | 1 |     |                                     |    |
| 3                     | 1        | 4                                                                                                           | 1 | 5  | 1  | 4  | 1  |   |    |   |     |                                     |    |
| Lag 0                 | Series 1 | <table><tr><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td><td>1</td></tr></table>    | 3 | 1  | 4  | 1  | 5  | 1 | 4  | 1 |     |                                     |    |
| 3                     | 1        | 4                                                                                                           | 1 | 5  | 1  | 4  | 1  |   |    |   |     |                                     |    |
|                       | Series 2 | <table><tr><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td><td>1</td></tr></table>    | 3 | 1  | 4  | 1  | 5  | 1 | 4  | 1 |     |                                     |    |
| 3                     | 1        | 4                                                                                                           | 1 | 5  | 1  | 4  | 1  |   |    |   |     |                                     |    |
|                       | Multiply | <table><tr><td>9</td><td>1</td><td>16</td><td>1</td><td>25</td><td>1</td><td>16</td><td>1</td></tr></table> | 9 | 1  | 16 | 1  | 25 | 1 | 16 | 1 | Sum | <table><tr><td>70</td></tr></table> | 70 |
| 9                     | 1        | 16                                                                                                          | 1 | 25 | 1  | 16 | 1  |   |    |   |     |                                     |    |
| 70                    |          |                                                                                                             |   |    |    |    |    |   |    |   |     |                                     |    |
| Lag 1                 | Series 1 | <table><tr><td></td><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td></tr></table>     |   | 3  | 1  | 4  | 1  | 5 | 1  | 4 |     |                                     |    |
|                       | 3        | 1                                                                                                           | 4 | 1  | 5  | 1  | 4  |   |    |   |     |                                     |    |
|                       | Series 2 | <table><tr><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td><td>1</td></tr></table>    | 3 | 1  | 4  | 1  | 5  | 1 | 4  | 1 |     |                                     |    |
| 3                     | 1        | 4                                                                                                           | 1 | 5  | 1  | 4  | 1  |   |    |   |     |                                     |    |
|                       | Multiply | <table><tr><td>0</td><td>3</td><td>4</td><td>4</td><td>5</td><td>5</td><td>4</td><td>4</td></tr></table>    | 0 | 3  | 4  | 4  | 5  | 5 | 4  | 4 | Sum | <table><tr><td>29</td></tr></table> | 29 |
| 0                     | 3        | 4                                                                                                           | 4 | 5  | 5  | 4  | 4  |   |    |   |     |                                     |    |
| 29                    |          |                                                                                                             |   |    |    |    |    |   |    |   |     |                                     |    |
| Lag 2                 | Series 1 | <table><tr><td></td><td></td><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td></tr></table>      |   |    | 3  | 1  | 4  | 1 | 5  | 1 |     |                                     |    |
|                       |          | 3                                                                                                           | 1 | 4  | 1  | 5  | 1  |   |    |   |     |                                     |    |
|                       | Series 2 | <table><tr><td>3</td><td>1</td><td>4</td><td>1</td><td>5</td><td>1</td><td>4</td><td>1</td></tr></table>    | 3 | 1  | 4  | 1  | 5  | 1 | 4  | 1 |     |                                     |    |
| 3                     | 1        | 4                                                                                                           | 1 | 5  | 1  | 4  | 1  |   |    |   |     |                                     |    |
|                       | Multiply | <table><tr><td>0</td><td>0</td><td>12</td><td>1</td><td>20</td><td>1</td><td>20</td><td>1</td></tr></table> | 0 | 0  | 12 | 1  | 20 | 1 | 20 | 1 | Sum | <table><tr><td>55</td></tr></table> | 55 |
| 0                     | 0        | 12                                                                                                          | 1 | 20 | 1  | 20 | 1  |   |    |   |     |                                     |    |
| 55                    |          |                                                                                                             |   |    |    |    |    |   |    |   |     |                                     |    |
| And so on             |          |                                                                                                             |   |    |    |    |    |   |    |   |     |                                     |    |

Figure 2: Calculation of the ACF.

shock 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.

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 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 and temporal resolution, resulting in a wide pitch angle coverage. For burst science modes, the correlator may be configured to generate 2, 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:

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

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 ( $z_l$ ) as follows:

$$\text{count\_rate\_estimate} = (\sqrt{z_l + 1/4}) - 1/2 \quad (2)$$

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

## 4 Measurement Calibration and Processing Procedures

The only calibrations used in the production of DWP CSA 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  $\pm 2$  ms. When combining WEC burst mode science data (from EFW or STAFF SC that are sampled at 450Hz) this implies a phase error of up to  $260^\circ$ . Fortunately there is a method which may be applied to the time stamps, improving their accuracy to  $20\mu\text{s}$ , or less than  $2^\circ$  phase error. The methodology used, together with its implementation are described in Yearby [2004] and in the accompanying CSA 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 CSA (<https://doi.org/10.5270/esa-ftdfdba>).

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 $-1.0\text{e}31$ . |
| 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 $-1.0\text{e}31$ .                                           |

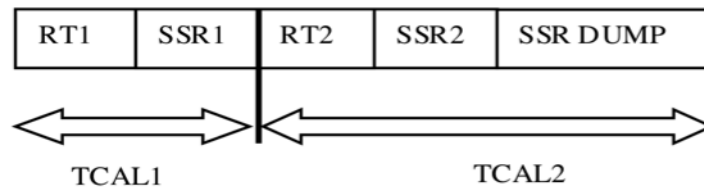


Figure 3: Real time and solid state recorder operations scenario.

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 in 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. The value of OFFSET is read directly from the TCOR data file. The value of DIFF is determined by linear interpolation between the two records that span the time of interest. The values of OFFSET and DIFF are then added to the value of the timetag (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, the time calibration 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 initial processing of the dataset, any data that failed validation was 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.

```
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.

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 from CSA.

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

Each TCOR correction is written as a set of three records, of which two contain valid values for OFFSET and DIFF, while the third contains fill values. Each triplet corresponds to one data acquisition interval during which the same spacecraft telemetry mode is in operation. Thus, when downloading the TCOR data sets it is advisable to bracket the target search time with sufficiently large end times, possibly several hours, to ensure that an appropriate complete set of records will be returned.

To determine the correction required at 2007-01-02T00:00:00Z we can see from Figure 4 that the records containing the values of OFFSET and DIFF that bracket the required time **do not contain fill values** and so a correction can be calculated. At this time, the value of OFFSET is  $-260\ \mu\text{s}$  (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  $60.9\ \mu\text{s}$ . Therefore the total correction to be applied is  $-260 + 60.9 = -199\ \mu\text{s}$ .

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, for example EFW and STAFF waveforms, 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 and the relevant Instrument User Manual to see if the time tags have already been corrected using TCOR.

### **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  $\mu$ s.

### **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.

### **Data around TCAL updates.**

In this first release, data that fails validation is simply deleted from the files and FILLVAL inserted. In some cases, however, 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. Any data identified as being erroneous has been deleted.

### **OFFSET should be constant.**

The OFFSET is constant throughout each data acquisition interval, and the same value will be written in the records corresponding to the start and end of the acquisition 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. This value is related to the spacecraft telemetry mode and will be constant during the acquisition interval.

### **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 (FX) and stepped (ST) energy) are listed in Table 2.

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 CSA.

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 FGM.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

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 Equation (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.                                                                                      |
| Correl_Fisher_T            | Maximum Fisher T statistic for the ACF.                                                                                                                                                          |
| Correl_Frequency           | Frequency at which Maximum Fisher T statistic occurs.                                                                                                                                            |
| Correl_Fisher_Significance | Percentage significance of Fisher T statistic.                                                                                                                                                   |
| Correl_Ivar                | Measurement of dispersion of counts.                                                                                                                                                             |
| Peace_mode                 | PEACE sampling mode.<br>0 - fixed energy, 1 - LAR mode, 2 - MAR mode. 3 - HAR mode                                                                                                               |

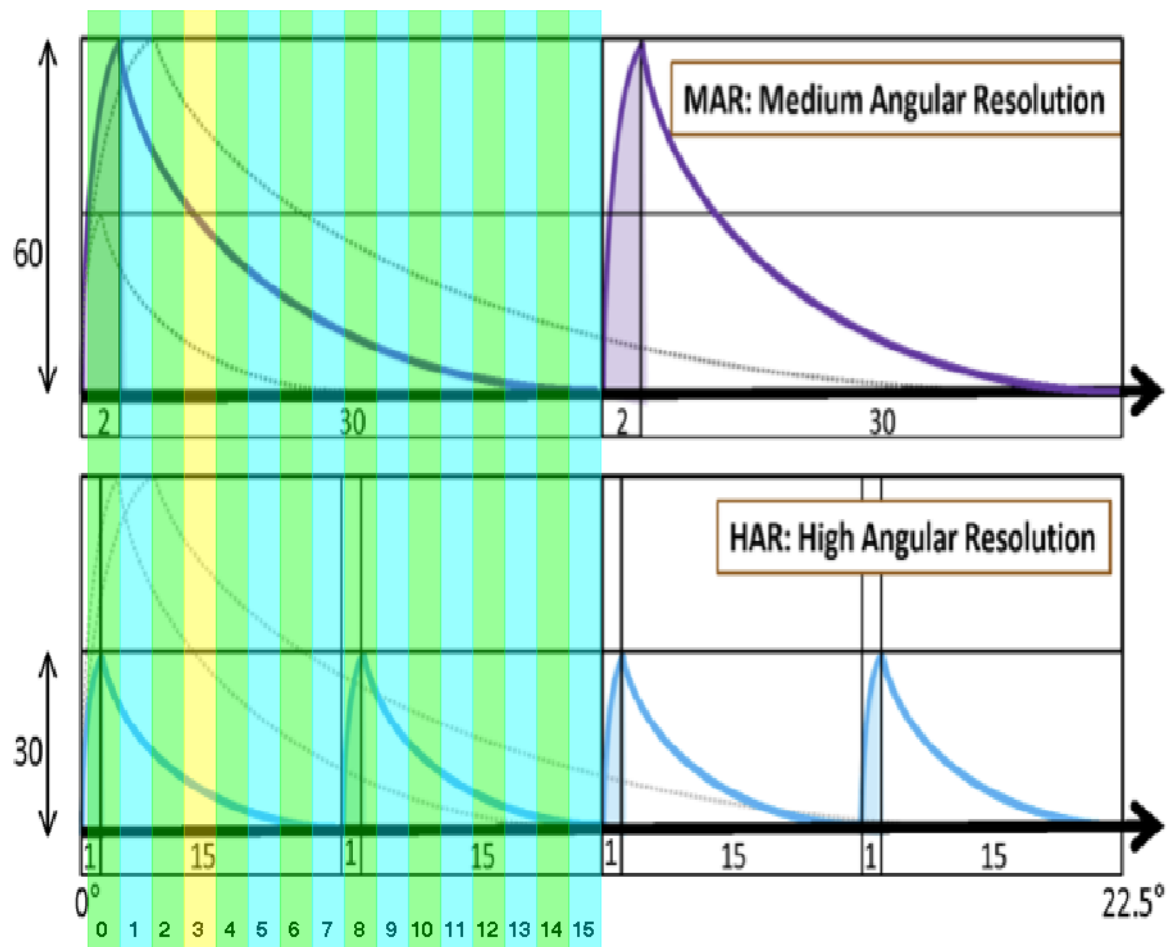


Figure 5: Relation between the correlator and PEACE energies in MAR and HAR modes.

intended to highlight the significance of any periodicities in the HEEA electron count rate. These parameters are:

**Correl\_Fisher\_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`).

**Correl\_Frequency** This value is the frequency at which the maximum power occurs.

**Correl\_Fisher\_Significance** 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.

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

$$g = \max(\text{power}) / \text{sum}(\text{power})$$

$$m = \text{floor}(1/g)$$

2. For each ACF with a finite value of  $m$

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

where  $N$  is the length of the ACF.

3. The significance is then defined as:

$$\text{Fishersignificance} = 100 * (1 - \text{FisherG})$$

**Correl\_Ivar** This value provides a measurement of the variance of the count rate and is calculated as

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

where  $ZL$  is the ACF zero lag value and  $\langle NZL \rangle$  is the average value of the non-zero lag 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 CSA (dataset `CM_CG_DWP_PCOR_OVERVIEW`). 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). 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.

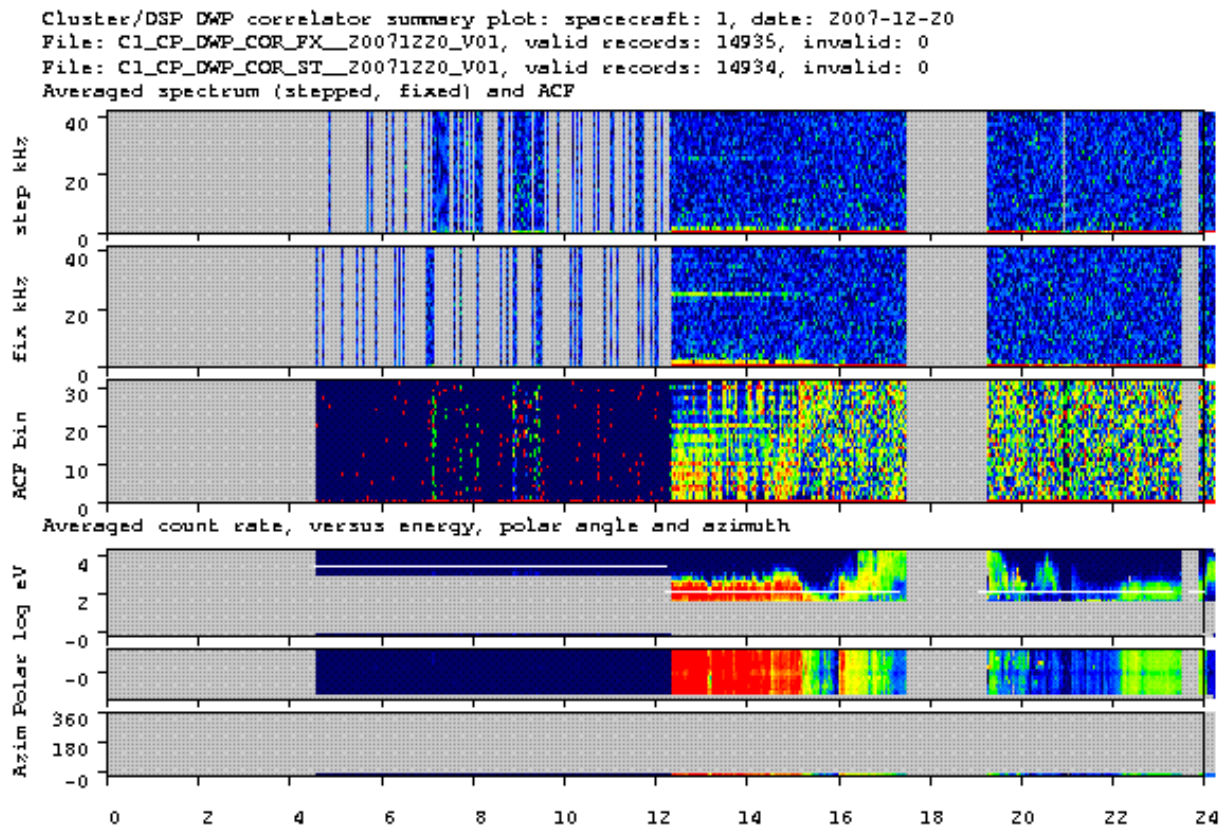


Figure 6: Correlator data validation plot.

- 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 28–32 kHz. 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.

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)  $-22.5^\circ$  (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  $12\mu\text{s}$  there appears to be a correlation period of around  $72\text{--}84\mu\text{s}$  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

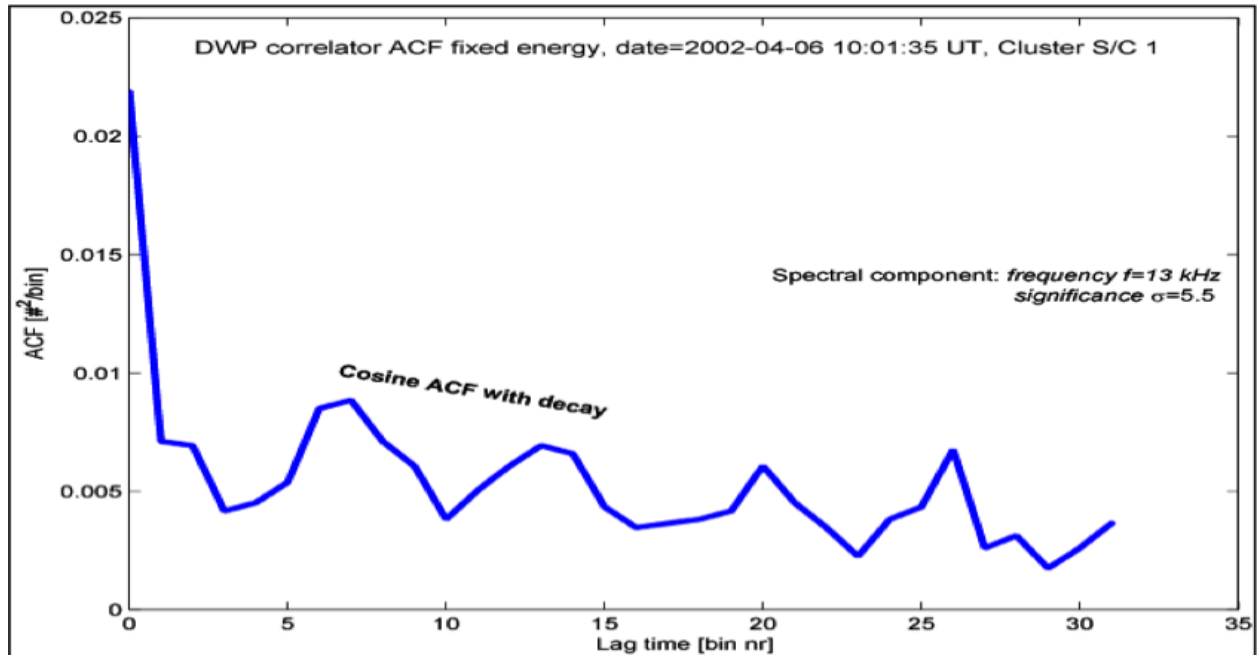


Figure 7: Autocorrelation function measured in the inner magnetosphere. Peaks of the non-zero lags occur typically in every 6-7th bin.

at  $\sim 0.28$ . 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. Correlator data is present only when

- the PEACE HEEA sensor is in use,
- the particle correlator application within DWP is activated.

The PCOR Caveat files contain information regarding

- Non-operational periods of the Correlator application,
- Periods considered as bad data,
- Operational caveats for the HEEA sensor determined by the PEACE team

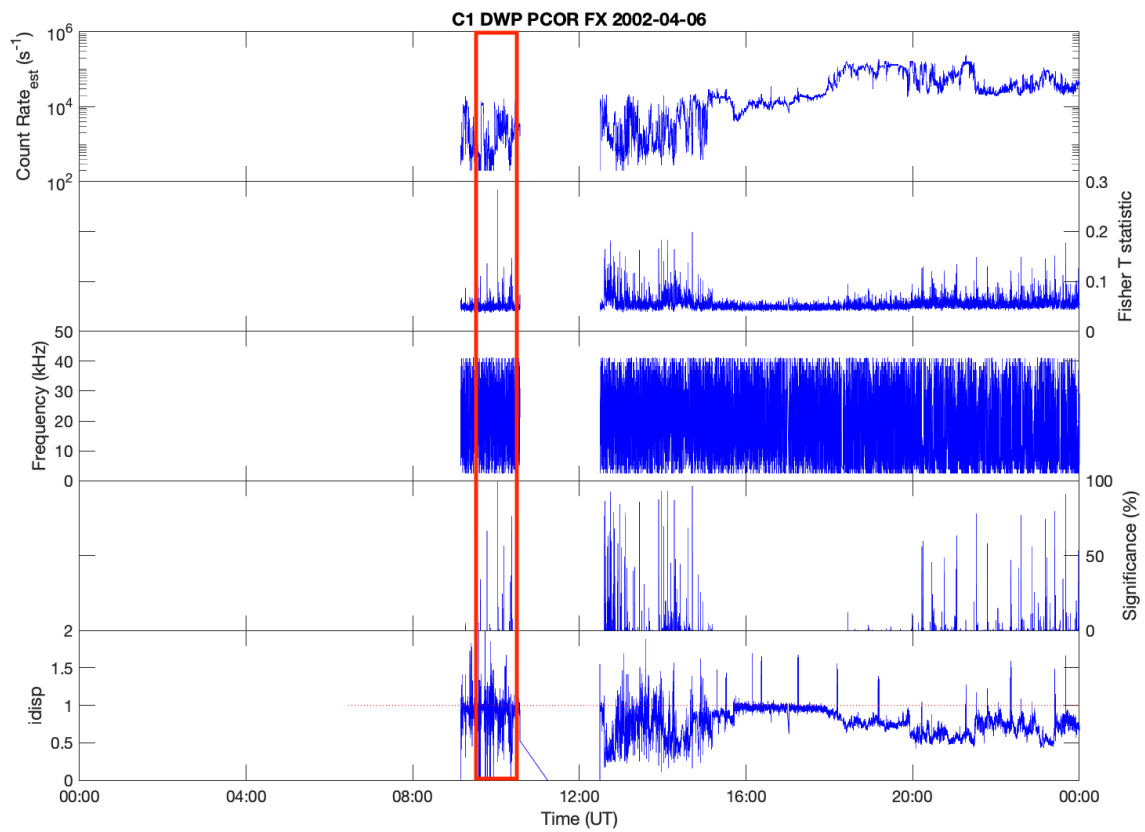


Figure 8: Fisher statistics of the ACF shown in Figure 7

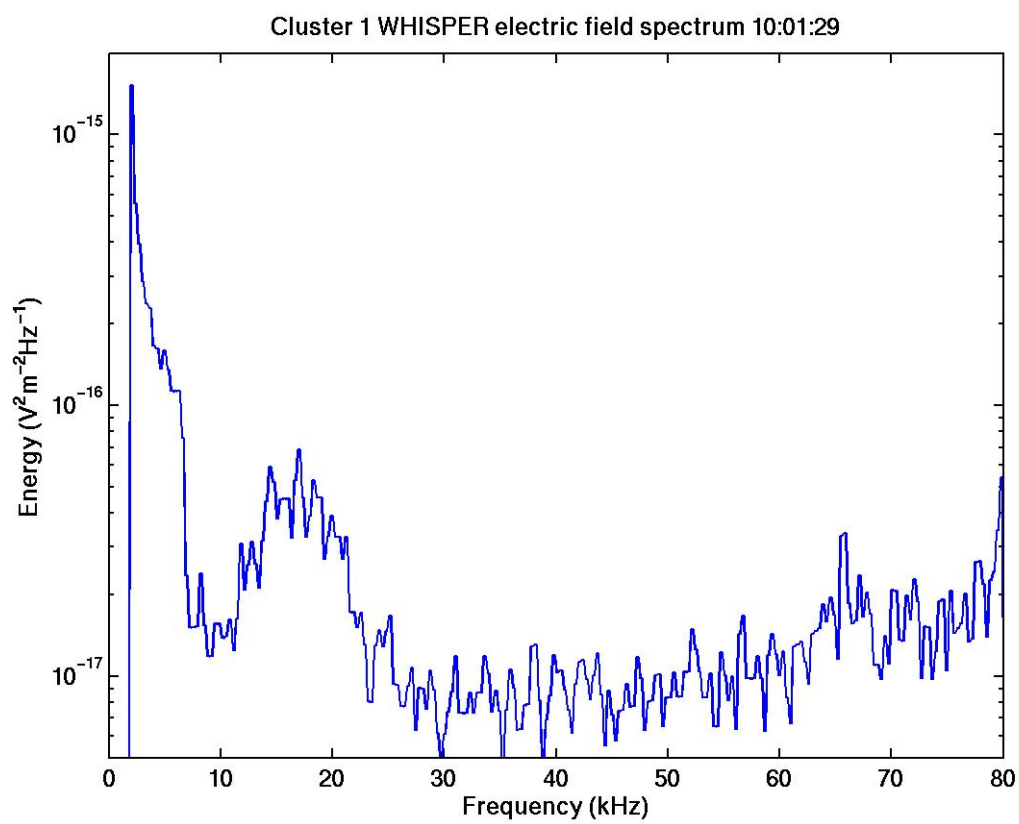


Figure 9: WHISPER spectrum measured at the same time as the ACF shown in Figure 7.

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. |

- Correlator data collection periods for which there are no corresponding FGM 5VPS measurements (pitch angle parameters are set to fill values).

### Effects of PEACE Operations

Periods in which the PEACE HEEA sensor is operational are indicated either by the PEACE sweep mode available in the Prime Parameter and PCOR sets (see Table 3 to interpret the data values) or the MCP level written to the CSA 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](#).

### 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 (variable LOOK\_ANGLE\_POLAR) 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 is 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  $\sim 36 \mu\text{s}$  period or  $\sim 28\text{--}32 \text{ kHz}$  (the exact value is different on each S/C), resulting in a high frequency interference line in the spectra (see the top two panels of Figure 6). 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 few 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.

**BM1 operations.** The correlators on all 4 spacecraft should be operational 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.

**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.

**Unintended correlator operations.** Occasionally the correlator may be activated in NM when the intention was not to operate it. This may occur when WEC enters standby, EFW undergoes a reset/mode change, and WEC is reactivated. These data are OK to use.

**Operations following WEC/HPA power sharing.** Following a period during which WEC/HPA power sharing occurs, the correlator may be activated during normal mode operations until the next WEC reset/mode change occurs. These data are OK to use.

**Incomplete startup commands.** 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 PCOR\_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 in which it expects 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  $-52.5^\circ$  (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 10. Between 15 and 23 UT 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 ( $4\text{sec} \times 12\text{bins} = 48$  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 CM\_CG\_DWP\_PCOR\_OVERVIEW\_PS data set is a graphical products that show 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

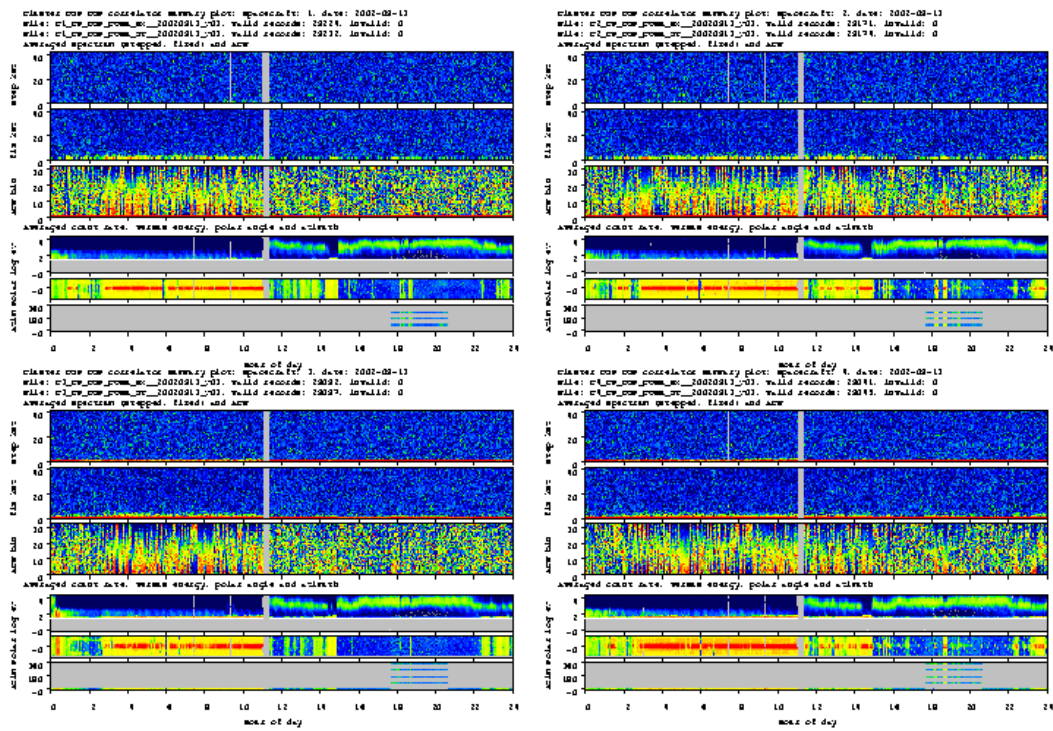


Figure 10: Example DWP correlator overview plot.

Table 4: Contents of the Cluster DWP PP data 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.Heea   | Status of PEACE HEEA sensor                                              |
| status.B      | Magnetic field direction                                                 |
| status.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                                                      |
| Correl.CRest  | Estimation of count rate from lag values                                 |
| Correl.Ivar   | Index of variation in the electron count rate                            |

## 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.

### 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

Prior to the inception of the Cluster Science Archive, the Cluster mission planned to distribute spin and 1-minute resolution data sets in a similar fashion to those datasets generated by other ISTP missions. The set of DWP Prime (PP) and Summary (SP) Parameter files were produced by the UK Cluster Data Centre using software provided by the PI team. In keeping with other ISTP Prime/Key Parameter data sets of the time, the Prime Parameter files contain spin resolution ( $\approx 4$  sec) data and Summary Parameters with a resolution of 1 minute. Originally, these data sets were designed to provide an overview of the full resolution data sets now contained in the PCOR and DWP\_LOG data files. The following data descriptions have only 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:

- The quality of the PP and SP data sets is lower than that of the PCOR and DWP\_LOG data sets that are currently available. It is therefore recommended that the user should

Table 5: Contents of the Cluster DWP SP data 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                                                 |
| status_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    |

access the PCOR and DWP\_LOG data sets. Within the CSA, the DWP SP files are now inactive i.e. not accessible.

- 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<br>Bits used: MSB - - - - - x LSB<br>0 = correlator off<br>1 = correlator on                                                          |
| status_DWP[2] | Amplitude count from zero lag<br>Bits used: MSB x x x x x x x x LSB<br>Amplitude of count value deduced from ACF zero lag                                                       |
| status_DWP[3] | Significance test used<br>Bits used: MSB x x x x x x x x LSB<br>0 = Fisher<br>1 = Schuster<br>2 = Chebyshev                                                                     |
| status_DWP[4] | Whisper sounding mode (if known)<br>Bits used: MSB x x x x x x x x LSB<br>Type of WHISPER sounding mode (0 = unknown)                                                           |
| status_Acf    | Correlator status – 4 data words                                                                                                                                                |
| status_Acf[0] | Use of preselected of stepped energy bin<br>Bits used: MSB x x x x x x x x LSB<br>0 = ACF used in CSDS is pre-selected (fixed) energy<br>1 = ACF used in CSDS is stepped energy |

|                       |                                                                                                                                                                                                                                |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>status_Acf[1]</b>  | Correlator bit rate<br>Bits used: MSB x x x x x x x LSB<br>Correlator bit rate switch (ACF output rate)                                                                                                                        |
| <b>status_Acf[2]</b>  | Number of ACFs summed<br>Bits used: MSB x x x x x x x LSB<br>Number of onboard summed ACF components                                                                                                                           |
| <b>status_Acf[3]</b>  | Amplitude of zero lag<br>Bits used: MSB x x x x x x x LSB<br>Amplitude of zero lag in units of 1.1                                                                                                                             |
| <b>status_Heea</b>    | Status of PEACE HEEA sensor – 4 data words                                                                                                                                                                                     |
| <b>status_Heea[0]</b> | Availability of calibration<br>Bits used: MSB x x x x x x x LSB<br>0 = PEACE HEEA calibration file values available<br>1 = PEACE HEEA calibration file values not available                                                    |
| <b>status_Heea[1]</b> | Energy sweeps per spin<br>Bits used: MSB x x x x x x x LSB<br>PEACE HEEA energy sweep mode                                                                                                                                     |
| <b>status_Heea[2]</b> | PEACE HEEA preset energy level<br>Bits used: MSB x x x x x x x LSB<br>PEACE HEEA energy preset level                                                                                                                           |
| <b>status_Heea[3]</b> | Total PEACE HEEA electron counts<br>Bits used: MSB x x x x x x x LSB<br>PEACE HEEA recorded total count number<br>(all polar zones/all energies) per spacecraft spin<br>period in log units of 1.1                             |
| <b>status_B</b>       | Magnetic field direction – 4 data words                                                                                                                                                                                        |
| <b>status_B[0]</b>    | HEEA polar zone from which correlator data is taken<br>Bits used: MSB x x x x x x x LSB<br>HEEA polar zone supplying correlator data for this<br>spin period.                                                                  |
| <b>status_B[1]</b>    | HEEA polar zone containing magnetic field<br>Bits used: MSB x x x x x x x LSB<br>HEEA polar zone containing magnetic field as deduced from previous<br>spin                                                                    |
| <b>status_B[2]</b>    | Azimuthal offset of magnetic field<br>Bits used: MSB x x x x x x x LSB<br>Spacecraft azimuthal offset of magnetic field in units of 5.625 degrees                                                                              |
| <b>status_B[3]</b>    | Source of magnetic field data<br>Bits used: MSB x x x x x x x LSB<br>0 = magnetic field from FGM via IEL<br>1 = magnetic field from REACE symmetry calculation                                                                 |
| <b>status_wec</b>     | Status of WEC instruments from the WEC housekeeping data files – 5 data<br>words                                                                                                                                               |
| <b>status_wec[0]</b>  | EFW parameters<br>Bits used: MSB x - - - - - LSB<br>0 = EFW working<br>1 = EFW not working<br>Bits used: MSB - x - - - - - LSB<br>0 = Unit 1 in E-field mode<br>1 = Unit 1 in density mode<br>Bits used: MSB - - x - - - - LSB |

|                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      | <p>0 = Unit 2 in E-field mode<br/> 1 = Unit 2 in density mode<br/> Bits used: MSB - - - x - - - - LSB<br/> 0 = Unit 3 in E-field mode<br/> 1 = Unit 3 in density mode<br/> Bits used: MSB - - - - x - - - LSB<br/> 0 = Unit 4 in E-field mode<br/> 1 = Unit 4 in density mode<br/> Bits used: MSB - - - - - x - - - LSB<br/> 0 = EFW not in interferometric mode<br/> 1 = EFW in interferometric mode<br/> Bits used: MSB - - - - - - x x LSB<br/> 0 = EFW in normal mode<br/> 1 = EFW in split sampling mode<br/> 2 = EFW in HX sampling mode<br/> 3 = null</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>status_wec[1]</b> | <p>STAFF parameters<br/> Bits used: MSB x - - - - - - - LSB<br/> 0 = STAFF SA working<br/> 1 = STAFF SA not working<br/> Bits used: MSB - x - - - - - - - LSB<br/> 0 = STAFF MWF working<br/> 1 = STAFF MWF not working<br/> Bits used: MSB - - x - - - - - - LSB<br/> 0 = STAFF not in calibration mode<br/> 1 = STAFF in calibration mode<br/> Bits used: MSB - - - x x x x - - - LSB<br/> 0 = STAFF normal 1 mode<br/> 1 = STAFF normal 2e mode<br/> 2 = STAFF normal 2b mode<br/> 3 = STAFF Illegal<br/> 4 = STAFF not in emergency mode<br/> 5 = STAFF in special mode<br/> 6 = STAFF in normal 1e mode<br/> 7 = STAFF in normal 1b mode<br/> 8 = STAFF SA in FAST mode 1 mode<br/> 9 = STAFF SA in FAST mode 3e mode<br/> 10 = STAFF SA in FAST mode 3b mode<br/> 11 = Illegal<br/> 12 = STAFF SA in FAST mode 2 mode<br/> 13 = STAFF in standby mode<br/> 14 = Illegal<br/> 15 = Illegal<br/> Bits used: MSB - - - - - - - x LSB<br/> 0 = STAFF MWF bandwidth 10Hz<br/> 1 = STAFF MWF bandwidth 180 Hz</p> |
| <b>status_wec[2]</b> | <p>WHISPER parameters<br/> Bits used: MSB x x x - - - - - LSB<br/> 0 = WHISPER not working<br/> 1 = WHISPER Calibration mode (quiet)<br/> 2 = WHISPER Calibration mode (Sounding)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

|                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      | <p>3 = WHISPER Natural model<br/> 4 = WHISPER Sounding - normal mode<br/> 5 = WHISPER Sounding - gliding mode<br/> 6 = WHISPER Sounding - synchronous mode<br/> 7 = not used</p> <p>Bits used: MSB - - - x - - - - LSB (Sounding modes)<br/> 0 = Receiving antenna Ez<br/> 1 = Receiving antenna Ey</p> <p>Bits used: MSB - - - - x x - - LSB (Sounding modes)<br/> 0 = No emission<br/> 1 = Pulse level 50 V peak to peak<br/> 2 = Pulse level 100 V peak to peak<br/> 3 = Pulse level 200 V peak to peak</p> <p>Bits used: MSB - - - - - x x LSB (Sounding modes)<br/> 0 = Pulse duration 13 ms<br/> 1 = Pulse duration 26 ms<br/> 2 = Pulse duration 40 ms<br/> 3 = Pulse duration other</p> <p>Bits used: MSB - - - x x - - - LSB (Natural modes)<br/> 0 = 64 FFT bins used<br/> 1 = 128 FFT bins used<br/> 2 = 256 FFT bins used<br/> 3 = 512 FFT bins used</p> <p>Bits used: MSB - - - - - x x x LSB (Natural modes)<br/> 0 = 32 spectra averages<br/> 1 = 16 spectra averages<br/> 2 = 16 spectra averages<br/> 3 = 8 spectra averages<br/> 4 = 4 spectra averages<br/> 5 = 2 spectra averages<br/> 6 = 64 spectra averages<br/> 7 = 1 spectra averages</p> |
| <b>status_wec[3]</b> | <p>DWP parameters</p> <p>Bits used: MSB x - - - - - LSB<br/> 0 = correlator working<br/> 1 = correlator disabled</p> <p>Bits used: MSB - x x x x - - - LSB<br/> Energy level</p> <p>Bits used: MSB - - - - - x - - LSB<br/> 0 = Sample clock 25 Hz<br/> 1 = Sample clock 450 Hz</p> <p>Bits used: MSB - - - - - x x LSB<br/> 0 = Normal mode<br/> 1 = Burst mode 1<br/> 2 = Burst mode 2<br/> 3 = Burst mode 3</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>status_wec[4]</b> | <p>WBD parameters</p> <p>Bits used: MSB x - - - - - LSB<br/> 0 = WBD working<br/> 1 = WBD not working</p> <p>Bits used: MSB - x x - - - - LSB</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|               |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               | 0 = Base band 0 kHz<br>1 = Base band 125 kHz<br>2 = Base band 250 kHz<br>3 = Base band 500 kHz<br>Bits used: MSB - - - x x x - - LSB<br>0 = 9.5 kHz 8 bit<br>1 = 9.5 kHz 8 bit<br>2 = 19 kHz 4 bit<br>3 = 19 kHz 8 bit<br>4 = 77 kHz 8 bit<br>5 = 77 kHz 1 bit<br>6 = 77 kHz 4 bit<br>7 = 77 kHz 8 bit                                                                                                                                             |
| status_wbd    | More details of the WEC WBD instrument – 4 data words                                                                                                                                                                                                                                                                                                                                                                                              |
| status_wbd[0] | For CSDS use                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| status_wbd[1] | WBD parameters<br>Bits used: MSB x - - - - - LSB<br>0 = WBD working<br>1 = WBD not working<br>Bits used: MSB - x - - - - - LSB<br>Not used<br>Bits used: MSB - - x x - - - LSB<br>0 = Base band 0 kHz<br>1 = Base band 125 kHz<br>2 = Base band 250 kHz<br>3 = Base band 500 kHz<br>Bits used: MSB - - - - x x - - LSB<br>0 = LV0<br>1 = LV1<br>2 = LV2<br>3 = LV3<br>Bits used: MSB - - - - - x x LSB<br>0 = UV0<br>1 = UV1<br>2 = UV2<br>3 = UV3 |
| status_wbd[2] | WBD parameters<br>Bits used: MSB x - - - - - LSB<br>0 = WBD working<br>1 = WBD not working<br>Bits used: MSB - x - - - - - LSB<br>0 = HK not via DWP<br>1 = HK via DWP<br>Bits used: MSB - - x - - - - LSB<br>0 = Auto gain set<br>1 = Manual gain set<br>Bits used: MSB - - - x x x x - LSB<br>Digitised gain setting<br>Bits used: MSB x - - - - - LSB<br>0 = Primary interface<br>1 = Redundant interface                                       |

|                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>status_wbd [3]</b> | <p>WBD parameters</p> <p>Bits used: MSB x - - - - - LSB</p> <p>0 = WBD working</p> <p>1 = WBD not working</p> <p>Bits used: MSB - x - - - - - LSB</p> <p>Not used</p> <p>Bits used: MSB - - x - - - - - LSB</p> <p>0 = VXO locked</p> <p>1 = VXO not locked</p> <p>Bits used: MSB - - - x x x - - LSB</p> <p>0 = 9.5 kHz 8 bit</p> <p>1 = 9.5 kHz 8 bit</p> <p>2 = 19 kHz 4 bit</p> <p>3 = 19 kHz 8 bit</p> <p>4 = 77 kHz 8 bit</p> <p>5 = 77 kHz 1 bit</p> <p>6 = 77 kHz 4 bit</p> <p>7 = 77 kHz 8 bit</p> <p>Bits used: MSB - - - - - x x LSB</p> <p>0 = Ez antenna</p> <p>1 = By antenna</p> <p>2 = Bx antenna</p> <p>3 = Ey antenna</p> |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 6 Recommendations

Since no parameters are replicated or calibrated using more than one method all parameters within the DWP CSA data files are unique and so there is no confusion over when it is 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 since:**

- The operations of WEC in general (PP/SP variables status\_wec), WBD (PP/SP variables status\_wbd), and particle correlator (PP/SP variables status\_Acf, status\_Heea, status\_B) are available in the DWP\_LOG file, and are summarised in plots associated with this data set.
- The correlator variables Correl.signif, Correl.freq, Correl.P, Correl.CrEst, and Correl.Ivar may refer to either the FX or the ST ACFs. These variables are now included within the PCOR\_ST and PCOR\_FX files.

## 7 DWP time line

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

It should be noted that the data gathered by DWP is not affected by the WEC probe failures since it does not make any wave measurements. The probe failures are listed in the EFW User Guide [*Lindqvist et al.*, 2026].

The data used by the particle correlator comes from the PEACE HEEA sensor. While an attempt has been made to include all PEACE HEEA caveats within the PCOR caveat files, it is recommended that the user inspect the PEACE caveat files to verify the operations of the HEEA sensor.

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               | 1234      | Before this date, the correlator polar zone was selected by PEACE depending upon the magnetic field direction. After this date the selected 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                                                                              |
|-----------------------------------|--------------------------------------------------------------------------------------------|
| <b>Science datasets</b>           |                                                                                            |
| C[n]_CP_DWP_PCOR_FX               | Particle Correlator Data, fixed energy band                                                |
| C[n]_CP_DWP_PCOR_ST               | Particle Correlator Data, stepped energy band                                              |
| <b>Operations datasets</b>        |                                                                                            |
| C[n]_CP_DWP_LOG                   | Wave Consortium operations log                                                             |
| CM_CP_DWP_UT_PIOR                 | Wave Consortium Commanding                                                                 |
| <b>Caveat datasets</b>            |                                                                                            |
| 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                                                     |
| <b>Auxillary datasets</b>         |                                                                                            |
| C[n]_CP_DWP_TCOR                  | Time corrections                                                                           |
| C[n]_PP_DWP                       | Prime Parameter Particle Correlator data (spin resolution)                                 |
| <b>Graphical datasets</b>         |                                                                                            |
| 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                                                                                                                                                                                                                                                                                                                                                          |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Time tags</b>                              |                                                                                                                                                                                                                                                                                                                                                                         |
| Time_Interval                                 | 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.                                                                                                                                                                           |
| <b>DWP Configuration</b>                      |                                                                                                                                                                                                                                                                                                                                                                         |
| Format_Count                                  | Number of formats (data frames) in interval                                                                                                                                                                                                                                                                                                                             |
| Clock_Freq                                    | WEC Master Clock Frequency.                                                                                                                                                                                                                                                                                                                                             |
| DWP_MODEL_TAG                                 | WEC parameters: EW5RSCNT, EW5SSOFF<br>DWP instrument model number<br>See Table 10 for values                                                                                                                                                                                                                                                                            |
| LOG_EVENT                                     | WEC parameter: EW5MOTAG<br>Event causing this log entry.<br>"MACRO" - A predefined macro was in operation<br>"Gap" - The period contains no data<br>"CONFIG" - DWP is in the process of configuring the WEC instruments<br>"CAL" - WEC was operating a calibration mode<br>"WATCHDOG" - A watchdog reset occurred<br>"POWER" - DWP was switching on the WEC instruments |
| DWP_CONFIG_0                                  | Configuration of the individual transputers processors. The transputers may be powered "OFF", or run at "HALF" or "FULL" speed.                                                                                                                                                                                                                                         |
| DWP_CONFIG_1                                  | WEC parameter: EW5P0CFG                                                                                                                                                                                                                                                                                                                                                 |
| DWP_CONFIG_2                                  | WEC parameter: EW5P1CFG<br>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.<br>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.<br>WEC parameters: EW5MLEC1-EW5MLE15                                                                                                                                                                                    |
| <b>Errors detected by the WEC instruments</b> |                                                                                                                                                                                                                                                                                                                                                                         |
| STAFF_SA_Zero_Count                           | Average number of STAFF SA zeros.                                                                                                                                                                                                                                                                                                                                       |

Table 9: continued

|                                                            |                                                                                                                                                                                                                                                                                                         |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DWP_error_count                                            | WEC parameter: EW1ZCNTR<br>Number of DWP errors reported. This counts the number of times any of the WEC parameters listed below are non-zero, indicating an error.<br>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.<br>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.<br>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.<br>WEC parameter: EW3IFST                                                                                                                                                             |
| TM_Overflow                                                | Number of Telemetry Overflows detected.<br>WEC parameter: EW5ETMOV                                                                                                                                                                                                                                      |
| AP_Overflow                                                | Number of Application Overflows detected.<br>WEC parameter: EW5EAPOV                                                                                                                                                                                                                                    |
| <b>WEC Operational Modes</b>                               |                                                                                                                                                                                                                                                                                                         |
| TM_Mode_Name                                               | Satellite telemetry mode name<br>NM - normal science mode,<br>BM1/BM2/BM3 - Burst science modes.                                                                                                                                                                                                        |
| 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.                                                                                                                                                           |
| <b>WEC Instrument Configuration</b>                        |                                                                                                                                                                                                                                                                                                         |
| 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.<br>COR0 – 136 bps<br>COR1 – 272 bps<br>COR2 – 544 bps<br>COR3 – 1088 bps<br>COR4 – 2176 bps                                                                                                                                                                                     |
| COR_SWEEP_MODE                                             | Correlator sweep mode.<br>FIXED – PEACE fixed energy sampling mode<br>LAR – PEACE sampling mode LAR<br>MAR – PEACE sampling mode MAR<br>HAR – PEACE sampling mode HAR<br>WEC parameter: EW3PCFBS                                                                                                        |
| COR_FIX_LEVEL                                              | Correlator fixed energy level.<br>WEC parameter: EW5PRCTL                                                                                                                                                                                                                                               |
| <b>Instrumental Voltages and their Standard Deviations</b> |                                                                                                                                                                                                                                                                                                         |

Table 9:

continued

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<br>WEC parameter: EW5WECCS                    |
| WEC_Current_Std_Dev              | Standard deviation of WEC current                                 |
| DWP_5V_Average                   | Average DWP voltage (5V)<br>WEC parameter: EW5VMON                |
| DWP_5V_Std_Dev                   | Standard deviation of DWP voltage (5V)                            |
| STA_SA_6V_Average                | Average STAFF SA voltage (6V)<br>WEC parameter: EW1VMON0          |
| STA_SA_6V_Std_Dev                | Standard deviation of STAFF SA voltage (6V)                       |
| STA_SA_M6V_Average               | Average STAFF SA voltage (-6V)<br>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<br>WEC parameter: EW1VMON2 |
| STA_SA_5V_Std_Dev                | Standard deviation of STAFF SA voltage (5V)                       |
| STA_SC_M9V_Average               | Average STAFF SC voltage (-9V)<br>WEC parameter: EW2VMON0         |
| STA_SC_M9V_Std_Dev               | Standard deviation of STAFF SC voltage (-9V)                      |
| STA_SC_M6V_Average               | Average STAFF SC voltage (-6V)<br>WEC parameter: EW2VMON1         |
| STA_SC_M6V_Std_Dev               | Standard deviation of STAFF SC voltage (-6V)                      |
| STA_SC_9V_Average                | Average STAFF SC voltage (9V)<br>WEC parameter: EW2VMON2          |
| STA_SC_9V_Std_Dev                | Standard deviation of STAFF SC voltage (9V)                       |
| STA_SC_6V_Average                | Average STAFF SC voltage (6V)<br>WEC parameter: EW2VMON3          |
| STA_SC_6V_Std_Dev                | Standard deviation of STAFF SC voltage (6V)                       |
| WBD_6V_Average                   | Average Wideband voltage (6V)<br>WEC parameter: EW4VMON0          |
| WBD_6V_Std_Dev                   | Standard deviation of Wideband voltage (6V)                       |
| <b>Instrumental Temperatures</b> |                                                                   |
| DWP_Temperature                  | DWP temperature                                                   |
| STA_SC_Temperature               | STAFF SC temperature                                              |
| STA_SA_Temperature               | STAFF SA temperature                                              |
| WHI_Temperature                  | WHISPER temperature                                               |
| WBD_Temperaure                   | WideBand temperature                                              |
| <b>Telemetry rates</b>           |                                                                   |
| WEC_TM_Rate                      | WEC telemetry rate                                                |
| EFW_TM_Rate                      | EFW telemetry rate                                                |
| STA_SC_TM_Rate                   | STA_SC telemetry rate                                             |
| STA_SA_TM_Rate                   | STA_SA telemetry rate                                             |
| WHI_TM_Rate                      | WHISPER telemetry rate                                            |
| WBD_TM_Rate                      | WideBand telemetry rate                                           |
| COR_TM_Rate                      | Correlator telemetry rate                                         |
| TM_Unused                        | Unused telemetry                                                  |
| TM_Overhead                      | Telemetry overhead                                                |

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 |

A set of monthly overview plots, created from the DWP\_LOG file and summarising WEC operations, are available from the 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*].

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<br>EVT = event e.g. shock crossing, radiation belt entry/exit etc<br>ORS = Start of operational sequence (acquisition interval)<br>ORE = End of operational sequence (acquisition interval)<br>REM = Comment added during revision<br>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 of entries in the UT\_PIOR data set:

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<br>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<br>500kHz conversion"                |
| 2014-07-06T01:44:02Z | "SEQ" | " 4" | "01_WB103A000" | "SWECJ009, X'00', X'70';"                                          |

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).

### 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.

## C Access to software/documentation

### C.1 Access to software/documentation at CSA

#### C.1.1 Telemetry Extraction and Decommuration (TED)

The WEC Telemetry Extraction and Decommuration, used by all WEC instrument teams, is available from the CSA home page (Home > Documentation > Instrument Team Documentation > DWP > Documents).

### C.1.2 WEC User Manual

The WEC User Manual, which describes the DWP HK file structure and operational modes, is available from the CSA home page (Home > Documentation > Instrument Team Documentation > DWP > Software).

### C.1.3 DWP documentation

The latest versions of the DWP User Manual, Interface Control Document, and Calibration report are available from the CSA (Home > Documentation > Cluster Instrumentation > User Guides, calibration reports, ICDs). These files are also mirrored in the Sheffield archive (see below).

## C.2 Access to software/documentation at Sheffield

The Cluster DWP data pipeline processing software for the generation of the Cluster DWP PCOR, UT\_PIOR, and DWP\_LOG data products are available from [the University of Sheffield on-line Research Data Archive \(ORDA\)](#). It also contains the documentation that outlines the pipeline processing and the usage of the data. Note that some of the routines use software modules that are only available as executables, compiled for Mac hosts.

### C.2.1 Documentation

These files contain the User Manuals, Interface Control Documents, Calibration reports, and information regarding the production pipelines.

**cluster\_documentation.tar.gz** Cluster related documentation

**double\_star\_documentation.tar.gz** Double Star related documentation

### C.2.2 Processing

These files contain the main data processing codes required to produce the DWP data sets available from CSA.

**caaget.tar.gz** Scripts to download and store the RDM files required for processing.

**cor.tar.gz** Scripts/codes required to extract the raw PCOR data from the RDM and preprocess it into its COR dataset form.

**MATLAB.code.tar.gz** Top level MATLAB routines to process the COR dataset into the PCOR product, and also create the DWP\_LOG and PCOR\_OVERVIEW2 plot files.

**ut\_pior.tar.gz** Scripts/code required to generate the UT\_PIOR data files from the RDM.

**wec\_log.tar.gz** Scripts/code to generate the DWP\_LOG data files from the RDM.

**caveats.tar.gz** Scripts/code required to generate the caveat files associated with the data sets.

**headers.tar.gz** An archive of the various DWP header files used by CAA.