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

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1 Introduction

This report outlines the processing and calibration procedures for the following datasets of the Cluster Digital Wave Processor (DWP) instrument data files:

- **DWP_LOG** – Housekeeping information of WEC (Wave Experiment Consortium), including error counts, the configuration commands used by the individual WEC instruments, analogue measurement of the voltages and temperatures of the WEC instruments, and telemetry usage.
- **DWP_UT_PIOR** – This dataset contains a record of the commands sent to the WEC instruments.
- **DWP_TCOR** – A pair of parameters that may be used to correct the time tags supplied on the Cluster RDM and increase their accuracy from the standard 2ms to around 20 μs.
- **DWP_PCOR** – These data sets contain statistics of the PEACE electron count rate from the HEEA sensor.

2 Instrument Description

The Cluster DWP instrument is described in detail in Woolliscroft et al. (1997). In brief, the DWP instrument is responsible for the commanding, synchronisation, and data processing for the WEC. The WEC comprises of the instruments DWP, EFW, STAFF, WHISPER, and WBD. DWP acts as the central hub for WEC, forwarding configuration commands to the instruments and controls their mode of operation using a series of onboard macros.

There are two routes by which WEC data may be received on the ground:

- The first corresponds to the normal Cluster telemetry stream. Data is collected from the EFW, WHISPER, STAFF, DWP, and if specifically commanded, WBD. It should be noted that if data from WBD are to be put into this telemetry stream it is necessary to reduce the volume of WBD data by a factor 3 by performing digital filtering and resampling the output waveform. DWP then performs any application processing requested e.g. data compression, before the data is formatted into a single stream and forwarded to the spacecraft telemetry data stream.
- The second route applies only to the WBD instrument and is the normal telemetry route used by WBD. WBD has its own direct connection to the spacecraft data handling system and is thus able to dump its data independently of the other WEC instruments to a DSN ground station. In 2016, NASA discontinued funding the operations of WBD. From this date, data are either dumped to the ground station at Panska Ves, or, during planned BM2 operations the WBD data is downsampled and returned vis the normal WEC data path.

These two, independent telemetry channels each timestamp the data independently. A comparison of the results of these two time stamping mechanisms has highlighted small timing discrepancies in the spacecraft Command and Data System. These discrepancies can be calculated and applied to the data to increase the timing accuracy from 2ms to around 20μs. This time correction data may be found in the TCOR dataset.

As well as handling science data from the various instruments, DWP also collects various HK data that may be used to monitor the health of WEC and stores them in its housekeeping data stream.

In addition, DWP contains a software correlator application. This application takes raw count values from the PEACE HEEA sensor via an Inter-Experiment Link and computes their autocorrelation function of their arrival times.

3 Measurement Calibration Procedures

3.1 WEC HK data

The measurement calibration procedures performed by the DWP team relate to the analogue measurements of the WEC housekeeping (temperature, current, and voltages) that appear in the DWP LOG data sets. The DWP LOG data files provide an overview of the operations of WEC. As part of its health-checking role, DWP monitors the temperatures and voltages of itself and other WEC instruments. These analogue measurements are digitised before being placed into the telemetry stream. On the ground, the original analogue values are reconstructed using the digital to analogue calibration scales that were determined during ground testing on the instruments prior to launch. Details of these calibrations may be found in Chapter 2 WEC User Manual.

These values are not subjected to further ground calibrations and are not cross calibrated with any other measurements.

3.2 Time Correction

All calculations are based on the use of pre-calibrated but unvalidated measurements received from ESOC and WBD.

3.3 Particle Correlator

The count rates are not corrected to include any time varying changes in the sensitivity of the PEACE HEEA detector.

The determination of the PEACE energy is based upon the interpretation of the appropriate bits read from the PEACE NM/BM data files using a simple lookup table.

4 Measurement Processing Procedures

This section outlines the processing procedures performed in the production of the DWP data sets.

4.1 WEC HK data

The LOG data sets contain data extracted from the WEC housekeeping and science data files. The HK parameters are interpreted according to their definitions given in Chapter 2 of the WEC User Manual. The values record the operation of WEC for each acquisition interval during which a specified WEC mode operates. A change in the WEC operational mode results in a new entry. Analogue measurements (temperatures, voltages, and currents) that appear in each HK format[1] are averaged during the period being analysed. Their standard deviation is also recorded as a measure of their variability during this period. The science data files are used to calculate the telemetry rates used by each instrument during each operational period.

4.2 Particle Correlator

[1] A format corresponds to one time stamped packet of data.

The DWP particle correlator records the autocorrelation functions of the electron count rate obtained from the PEACE HEEA sensor. Because the DWP HK/Correlator data do not contain information about the PEACE instrument settings, the production of these parameters also uses the PEACE RDM files in order to determine the energy level of the particles that are used to compute the ACF, the polar zone of the detector from which counts are being taken, and the sweep mode being used.

4.3 Time Correction

For precise time stamping of Cluster science data it is necessary to accurately determine the UT time at which each VC0 reset pulse occurs onboard. This pulse is time correlated with the transmission of the first bit of the housekeeping virtual channel (VC0) and the contents of the onboard time counter at this time are recorded in the On-board Time (OBT) field of the VC0 transfer frame (EID-A section 3.3.1.3.1 and 3.3.7.2.2). The time of the pulse is called the Spacecraft Event Time or SCET, and is given to a standard accuracy of ±2 ms.

However, for inter-spacecraft comparisons of EFW, STAFF, and WBD waveform data a much higher accuracy is needed. Fortunately there is a method which may be applied to the time stamps, improving their accuracy to ~20 µs. To achieve this accuracy, it has been determined that two parameters, named DIFF and OFFSET, are required. This process is described in general in Yearby, (2004) and summarised here.

4.3.1 Determination of OFFSET

The first parameter, OFFSET, is related to the satellite telemetry mode. This value represents the delay between the time at which the On-Board Data Handling (OBDH) reset pulse is issued, signalling the creation of a new telemetry format, and the time encoded in the time stamp that was applied to the data packet. This value is constant during each acquisition interval in which a single spacecraft telemetry mode is in operation and will change when the spacecraft telemetry mode is changed. Changes in the spacecraft telemetry mode will result in a new value for OFFSET being determined for the new acquisition period.

The spacecraft internal clock operates at a frequency of 2^{24} Hz. This clock is used to issue the spacecraft reset pulse every 5.15222168 seconds (86439936 clock pulses) and hence coordinate the spacecraft tasks. Thus the value of the spacecraft clock counter, (OBT), should increment by 86439936 between consecutive formats and that OBT modulo 86439936 (henceforth known as OBTM) should be constant. Values of OBT are not released to experimenters but it is possible to reconstruct its value knowing SCET. An error of around 17 counts in OBT corresponds to a timing error of 1µs.

The width and jitter of the reset signal are specified as 3.81 and <2 µs respectfully. Therefore the timing accuracy would be expected to be of the order <5.81 µs. This is indeed the case for real time telemetry data. However, for some operational modes (e.g. solid state recorder playback) the value of OBTM can vary in the range ±180 µs for normal mode data and ±30 µs for burst mode. Therefore, values of OBT need to be adjusted so that they correspond to the real time value. It is possible that for some spacecraft telemetry modes real time telemetry data may be simultaneously written to the SSR. In this case, OBT requires correcting and the data should be treated as SSR playback data.

4.3.2 Determination of DIFF

The second parameter, DIFF, represents the drift of the satellite clock with respect to UT. DIFF values are routinely generated by ESOC by comparing the Spacecraft Event Time of the incoming data with that predicted using the current time calibrations.

During each pass, the Cluster data are stamped at the ground station with the Earth Reception Time (ERT). This value is then used to calculate the Spacecraft Event Time (SCET) by taking into account signal delays due to the propagation time and processing at the ground station. The Time Correlation process uses a least squares fitting procedure to derive SCET from OBT (measured as the number of counts of the onboard clock) since the last time calibration $SCET_0$.

$$SCET=TICK*OBT+SCET_0$$

where TICK is onboard clock rate. This correlation is then used to determine the difference between the frame times of the incoming data and the value of SCET from the current time correlation function.

$$DIFF=(ERT - Delays)-(TICK*OBT+SCET_0)$$

It should be noted that before 2005, ESOC provided only the absolute value for the value of DIFF. Therefore a method to determine its sign was therefore required. This was done by comparing the values of DIFF with similar values obtained from the WBD data set. However, when the value of DIFF was small, as it would have been just after a new time calibration had been issued it is difficult to assess the sign of DIFF accurately. From 2005 onwards ESOC produce a signed value of DIFF.

Prior to November 23rd, 2007, this DIFF parameter was allowed to build up to 2 ms at which point a new time correlation was performed. Since November 23rd, 2007, a new time correlation is performed by ESOC during every real time pass, resulting in smaller values of DIFF. As a result, DIFF values are usually less than 20 µs and so the phase error in burst mode data (OFFSET in the range ±30 µs) is around 60°.

The value of the DIFF parameter generated by ESOC (they are given in TCAL excel spreadsheets) may be verified independently using WBD data that are received by the NASA DSN. Usually, these two diff parameters agree well (within ±20µs). Before 2005, the DIFF measurements received from ESOC were unsigned, so the sign was determined by comparison with the WBD or TCAL DIFFs. The ESOC and WBD DIFF measurements are sometimes subject to errors so must be validated before use. The strategy used here is to regard the ESOC measurements as the primary measurement, and use the WBD data to validate it. For a further validation, the DIFF just prior to each new time correlation is determined by analysis of the TCAL files on the Cluster RDM.

The DIFF values that are written to the DWP_TCOR files are based on data from two sources.

- ESOC values of DIFF are delivered as an excel spreadsheet typically covering 3 months of data.
- WBD DVD's from which data can be extracted to calculate the WBD DIFF.

The ESOC Excel workbooks contain DIFF values for typically a 3 month period. Measurements are given for each format during the first minute of each hour during a real time pass. Normally, the 11 values of DIFF for each minute are averaged. This generates a list of DIFF values at specific times.

5 Results of Calibration Activities

5.1 WEC HK data

For the DWP_LOG data set, simple lookup tables are used to interpret data from the housekeeping data stream. This includes the calibration of analogue parameters. It should be noted that pre-launch calibration tables are used and no further ground calibrations are applied to these data. The calibration tables may be found in the WEC User Guide

5.2 Particle Correlator

Correct determination of the PEACE energy levels, sweep mode, preset energy, and polar/azimuthal sensor bins are performed by interpreting the appropriate PEACE housekeeping bits using values stored in lookup tables. These values are then used in the analysis and scientific interpretation of the correlator ACF's. The actual raw counts of the PEACE HEEA detector are used and no gain, geometrical factor, or sensitivity corrections are applied.

5.3 Time Correction

All value used in the computation of the DWP_TCOR data set use pre-calibrated values. The DWP team do not perform any calibration activities for this data set.

6 Results of Cross-Calibration Activities

The parameters contained within the DWP related data files are unique within Cluster and so cannot be quantitatively compared with the parameters generated by any other instrument.

However, in the case of the particle correlator it is possible to qualitatively compare the energy distributions obtained by the correlator with those measured by PEACE. The particle correlator takes the raw electron counts from the PEACE HEEA sensor and creates autocorrelation functions in order to study the time structure of the count rate. As outlined in the DWP User Guide, it is possible to take the autocorrelation functions and use them to estimate the actual count rate. Hence it is possible to build up a crude energy distribution of the local electron population.
Figure 1 shows the electron distribution recreated from the DWP particle correlator autocorrelation functions (top panel) and a PEACE energy spectrogram taken from the CSDSweb quicklook plot (bottom panel). The data were collected by Cluster 4 during the period 06-12UT on January 8th, 2005. The plots are qualitatively similar in nature, showing similar structure throughout this period. However, it should be noted that direct comparisons between the datasets are not possible since DWP only takes counts from one polar zone and one energy during each spin. There are obvious differences between the plots but these can be explained by the difference in operation between the two instruments. For instance, the correlator distribution only shows the counts at higher energies because it takes data from the PEACE HEEA sensor only. Changes in the PEACE sampling mode such as the transition between HAR and MAR modes (as seen in Figure 1 at 0725UT) can greatly influence the count rate received by the correlator. Other differences may arise due to the fact that the correlator only uses counts from only polar bin per spin.

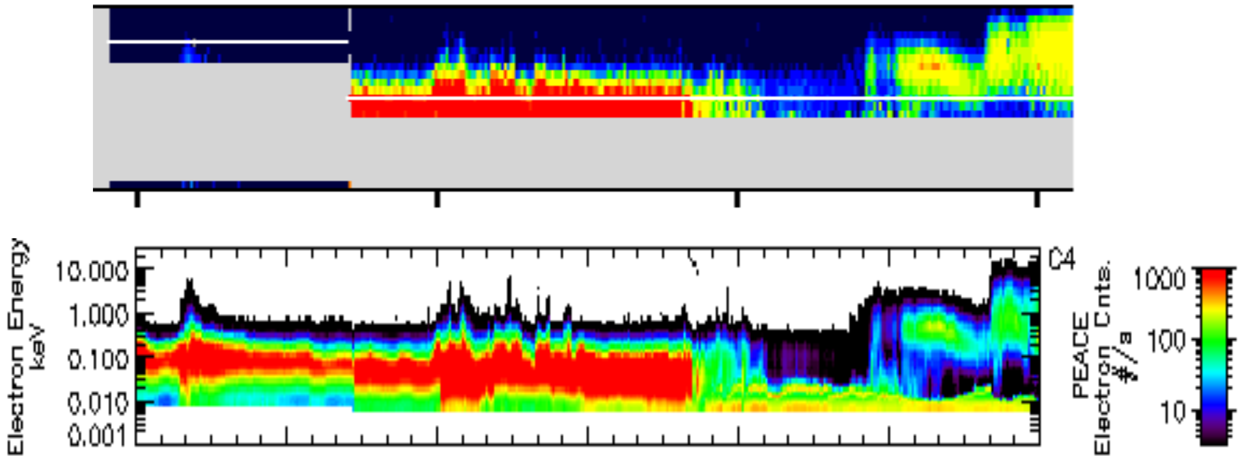

Figure 1: A comparison of the electron distribution function recreated using particle correlator data (top) with the measured PEACE distribution (bottom).

7 Summary

This document outlines the production and calibration activities of the DWP CAA data files. As mentioned above DWP uses pre-calibrated data to generate some of the data products. For those parameters that require calibration/interpretation, a simple lookup table provides the necessary conversion values.

8 References

WEC User Manual, Chapter 2 – Housekeeping telemetry

Woolliscroft, L. et al., The Digital Wave Processing Experiment on Cluster, Space Science Reviews 79, 209-231, 1997.

Yearby, K., Precise reconstitution of the Spacecraft Event Time. Technical note, 2004