Precise reconstitution of the Spacecraft Event Time (SCET)

Notes by Keith Yearby, 2004 July 7

Contents

1 Introduction

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 is 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 +/- 2ms. However for inter-spacecraft comparisons of EFW and STAFF waveform data a much higher accuracy is needed. It is proposed to achieve this by preparing files containing time corrections.

1.1 ESOC time correlation

During each pass the HK data is time stamped at the Ground Station with the Earth Reception Time (ERT) and this is used to generate the SCET by taking into account the on-board delay, the Ground Station delay and the propagation delay. The Time Correlation process uses a 'least squares' algorithm to derive the SCET from the OBT using the equation:

SCET = TICK * OBT + SCETo

The control system compares the time of each incoming frames with the time which would be obtained using the current time correlation:

DIFF = | (ERT – Delays) – (TICK * OBT + SCETo) |

When the difference (DIFF) is greater than 2 milliseconds a new time correlation is required. The HK and science data available to the CDDS and delivered on the CD-ROM are time stamped with SCET using the current time correlation.

At present the ESOC supplied DIFF measurements are the absolute value of the difference, so an independent measurement of the sign is required.

1.2 Accuracy of correlation of VC0 reset pulse and OBT

The VC0 reset pulse occurs every 5.15222168 seconds, that is 84414 slots with 1024 OBT counts per slot. Therefore the OBT should increment by 86439936 between each format, or equivalently OBT modulo 86439936 should be constant. In the rest of this document we refer to the quantity OBT modulo 86439936 as OBTM or 'OBT mod VC0'.

Although the OBT itself is not included in the data released to experimenters, it can be determined from the SCET by applying the time correlation backwards. The limited precision of the SCET means the OBT cannot be determined exactly by this method, but we expect OBTM to remain constant within +/- 17 counts (+/- 1 microsecond).

The width and jitter of the VC0 reset pulse is specified as 3.81 and < 2 micro-seconds respectively. The accuracy of the onboard time correlation between the reset pulse and OBT is not specified, but we would expect this to be accurate within one bit time, that is 3.81 micro-seconds (64 OBT counts) at the highest bit rate (262144 bps). This appears to be true for TDA modes 7, 8 (WBD data only), 9 and 10.

However, if we look at TDA mode 4 (21845 bps) SSR playback data we find the OBTM can be anywhere in the range +/- 180 micro-seconds from real time value. For TDA mode 6 (131072 bps) this range is +/- 30 micro-seconds. This is based on the observation that deviations of this size occur in OBTM, with no associated phase change of the VC0 reset pulse. In both cases the range is +/- 4 bits at the relevant bit rate. The deviation usually changes at each TDA mode change.

Therefore for accurate timing of playback data, the OBT should be adjusted so that OBTM is equal to the real time value. In this document this correction will be termed the OFFSET.

It is possible for TDA modes 4 and 6 data to be taken in real time at the same time as it is recorded to the SSR. In this case the OBTM is the same as for the SSR data, and for the purpose of applying time corrections this data should be treated the same as playback data.

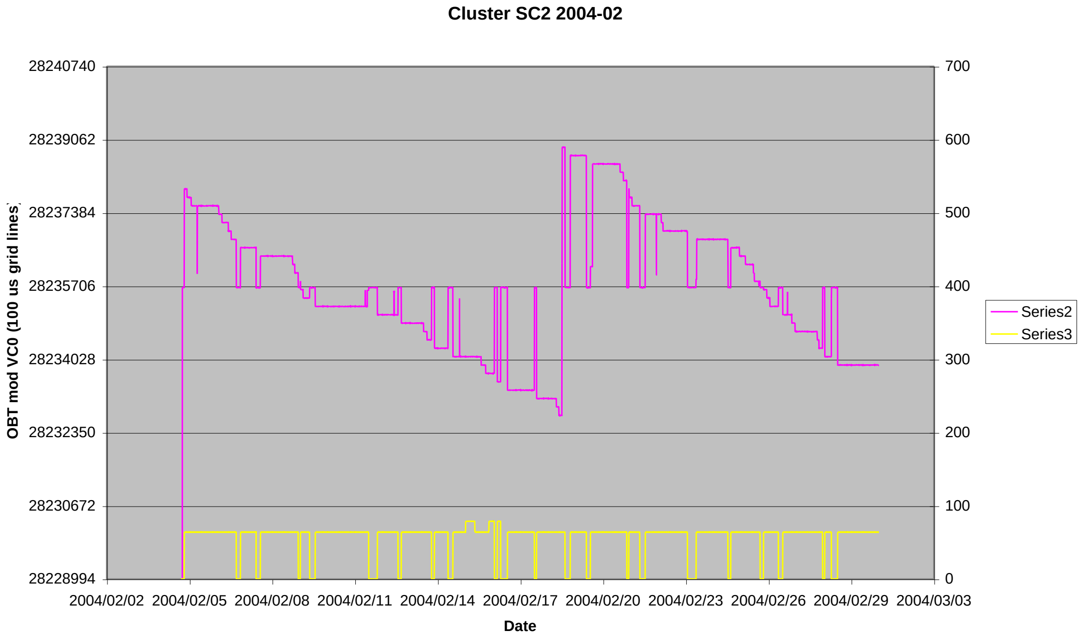

Figure 1. OBTM for SC2 WEC HK data (series 2) during February 2004. The ‘stream’ byte from the DDID header is also shown (series 3). This is zero for real time data. The grid lines are at intervals of 1678 OBT counts which is approximately 100 microseconds. It is observed that OBTM always returns to the same value (28235680) for real time data, but for playback data may be anywhere in the range +/- 180 microseconds from this value.

1.3 Stability of VC0 reset pulse

Although we see deviations in the OBTM for playback data, the OBTM often returns to the same value for each period of real time only data. This implies that the VC0 cycle onboard has continued uninterrupted on board, with no deviations from the nominal period. During the periods studied this was always true for SC2 and SC4, usually for SC3, but rarely for SC1.

The WEC HK parameter EW5SSOFF measures the phase of the WEC 900 Hz master clock relative to the VC0 reset pulse. Although the WEC clock is not that stable, careful observations reveals that when the real time OBTM changes, one or more phase jumps have occurred in the VC0 cycle at some time between the two periods of real time telemetry.

From observations so far, it appears that when jumps in the VC0 phase occur, they are always in units of 125.8 micro-seconds, that is 2112 OBT counts. Using this assumption it is much easier to identify the location and size of the jumps.

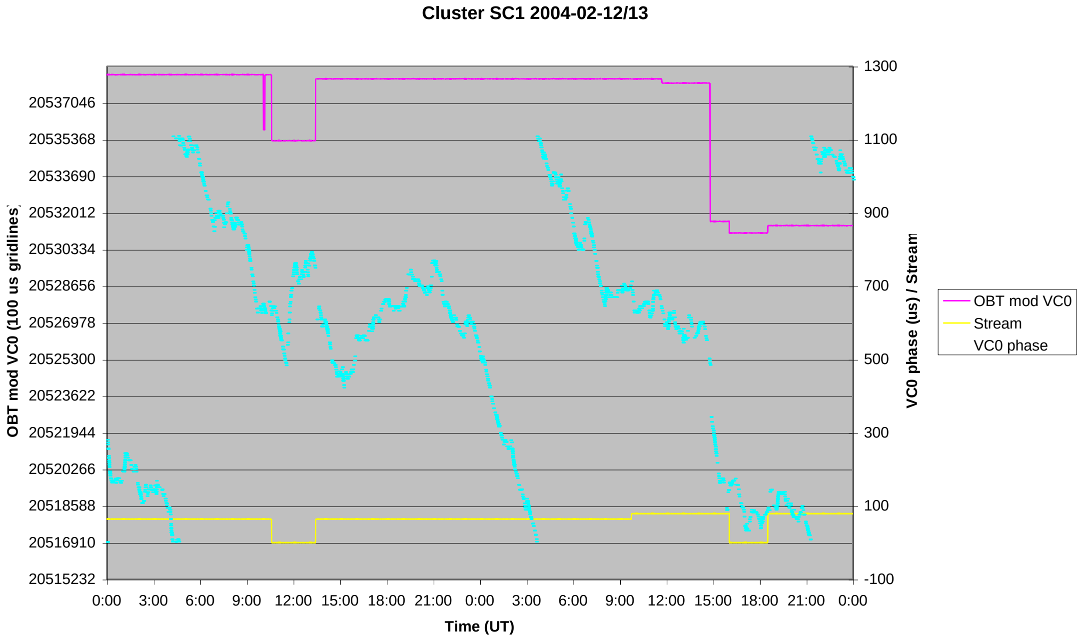

Figure 2. OBTM for SC1 WEC HK data for 12 and 13 February 2004. The VC0 phase determined from the WEC HK parameter EW5SSOFF is also shown. It is observed that OBTM changes from 20535310 to 20531080 between the two periods of real time TM, a jump of -4230 or -252 micro-seconds. Two separate VC0 phase jumps are seen in the WEC HK, -119 microseconds at 2004-02-12 13:26, and -132 microseconds at 2004-02-13 14:48.

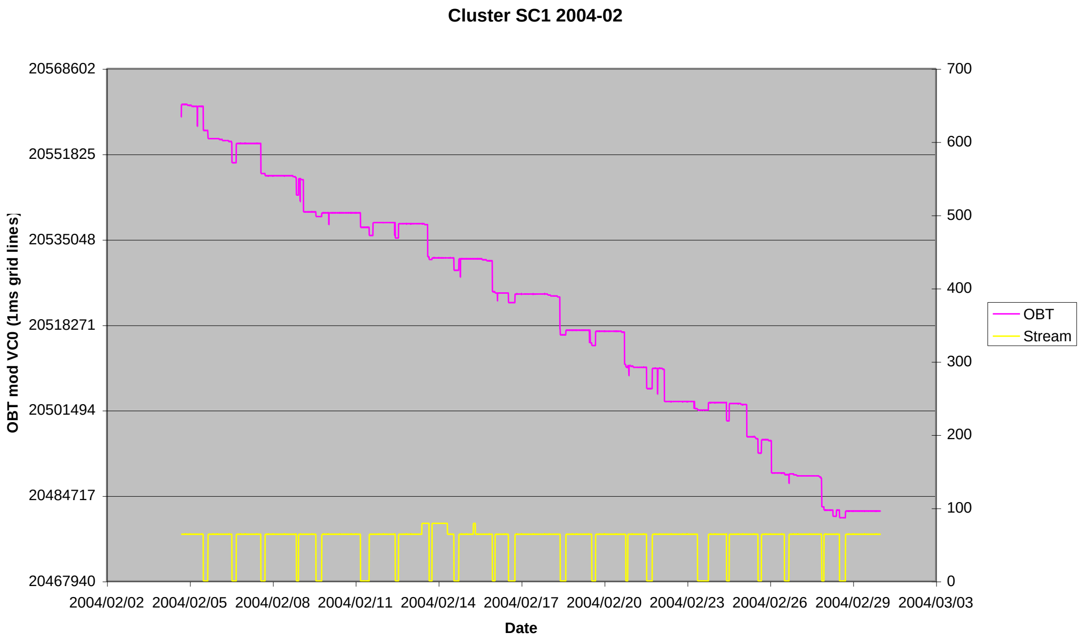

Figure 3. OBTM for SC1 WEC HK data (OBT mod VC0) during February 2004. The 'stream' byte from the DDID header is also shown (series 3). This is zero for real time data. The grid lines are at intervals of 16777 OBT counts which is approximately 1 millisecond. Unlike SC2, it is observed that OBTM does not return to the same value for real time data, but decreases every time.

1.4 Which ESOC time correlation is applied to each period of data?

It is necessary to know this so that the correct DIFF can be applied to data taken at around the time of a new time correlation. The answer would seem to be obvious: 'When a new time correlation is performed this applies to all data from that point onwards'. This is almost true for real time data.

For example a time correlation was performed on SC1 at: 2004/02/04 09:54:53, and was used for real time data from 2004/02/04 09:59:16 onwards.

However, for SSR data, the new time correlation is applied to all data *downlinked* after the time of the new time correlation. This data may have been acquired onboard up to 48 hours earlier. The time of downlink is not included in the data released to the experimenters, so there is no direct way to determine which time correlation was used.

An indirect method is to look at the OBTM calculated using an assumed time correlation. If this differs by more that +/- 3072 (180 micro-sec) from the real time value, or shows a continuous gradual change, then the time correlation is probably the wrong one. This is not foolproof as the difference between two time correlations may be small.

1.5 WBD data

The WBD data is useful for two purposes for improving the accuracy of WEC timing. Firstly it provides an independent DIFF measurement, including the sign, to complement those provided by ESOC. Secondly it provides the real time value of OBTM during the WBD observation.

Usually the WBD DIFFs agree well (within 20 µs) with those from ESOC.

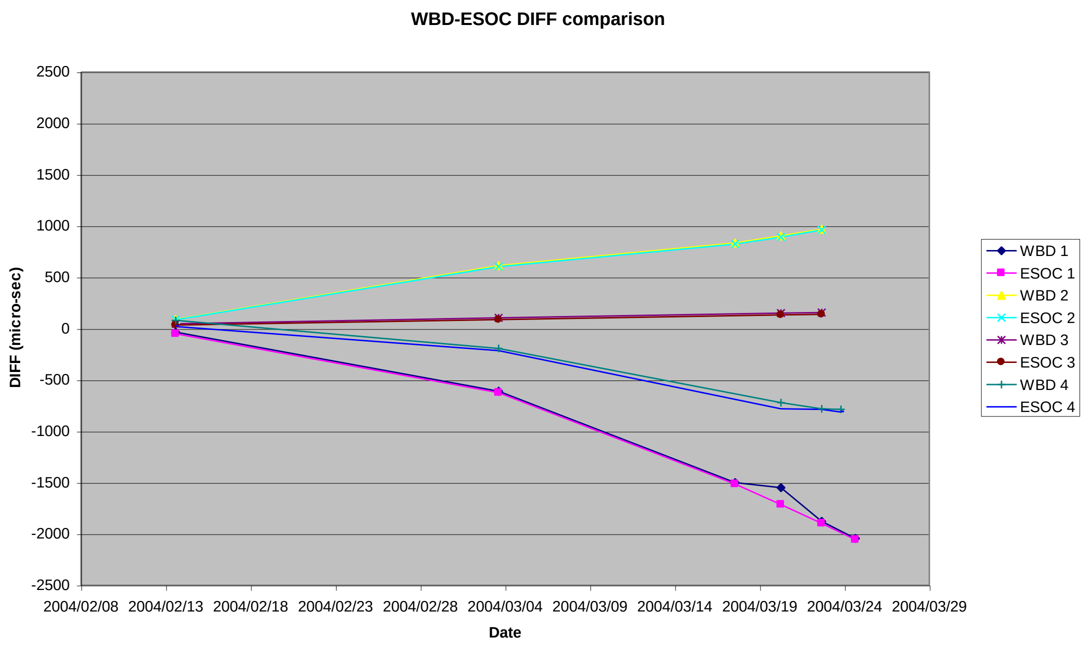

Figure 4. Comparison between WBD and ESOC DIFF measurements.

2 Preparation of the WEC time correction files

2.1 Point Valid DIFF measurements

Firstly the a file of Point Valid DIFF measurements must be prepared, in the format specified in section 3.1.

The DIFF values in these files will be based on data from three sources.

1) The DIFF measurements received quarterly from ESOC. Presently the absolute value of the DIFF (ie. without the sign) is provided, but the sign may be included in future. The data is received as Excel files, one for all spacecraft for three months. A manual procedure for extracting the relevant data is given in the next section.

2) The TCAL files when a new time correlation is done. The DIFF, and rate of change of DIFF is zero by definition at the time of a new time correlation. Using that fact, the DIFF and rate of change that would apply at that time using the old time correlation can be estimated. The command line tool 'readtcal' will extract the DIFF measurements from these files.

3) The WBD data DVDs. DIFF measurements can be extracted from the WBD level one data. The software tool 'wbddiff' will automatically process all necessary level one data (probably one 10 minute data file per observation period is sufficient) on one DVD and write the DIFF measurements to a text file.

Next, the sign must be added to the ESOC DIFF, probably by assuming it is the same as that for the nearest WBD DIFF or the following TCAL DIFF. Problems could still arise when the DIFFs are close to zero, hence the request for ESOC to provide signed DIFFs if possible.

Both ESOC and WBD DIFFs are occasionally subject to errors of 100 micro-seconds or more, so the measurements must be validated before use. At the end of this process we will have a list of DIFFs valid at specific times, and for a specific time correlation.

2.2 Extracting DIFF values from Excel files from ESOC

The ESOC DIFF measurements for SC1 and SC2 are normally well behaved, and can be used more or less directly, if the sign is known. The data can be converted to a WEC DIFF format text file using the procedure below.

For SC3 and SC4 it is more difficult, as one of the two receiver chains is not correctly calibrated and this leads to a discrepancy of around 44 micro-seconds. There is also no indication of which receiver chain was used. One option is to select only the values which agree well with the WBD DIFFs.

The Excel workbooks received from ESOC cover a three month period, and have a separate worksheet for each spacecraft. The date/time and the unsigned DIFF in nano-seconds are provided in columns B and C respectively. The measurements are given for every format during the first minute of each hour during a real time pass. Normally there should be at least 11 measurements in each minute, and it seems sensible to average them.

The data columns B and C, for all measurements between two successive time correlations, should be copied and pasted into Sheet1 of a new workbook, starting at column A, row 4.

In column C enter the formula:

```
=IF(AND(A4-A3 > 0.01, A14-A4 < 0.01), A9, "")
```

This says: if a new minute has just started, and the following 11 rows all have that minute, then set the cell value to that at middle of the 11 rows. Otherwise set the cell to blank.

In column D enter the formula:

=AVERAGE(B4:B14)/1000

This sets cell value to the average DIFF of the 11 rows, and converts to micro-seconds. If it is known that the sign should be minus, multiply the value by -1.

Put these formulae in row 4 to start with and use Edit, Fill, Down to copy them into all rows where there are values in columns A and B.

Next select column C and use the Data, Filter, Autofilter menu to select only rows with non-blank cells.

Select columns C and D, then copy and paste the selected data into a new worksheet (Sheet2) in columns A and B, starting at row 4.

In the new worksheet, put the spacecraft ID (1, 2, 3 or 4) in column C, and -1 in columns D and E (for antenna and OBTM = unspecified).

Select column A, and enter the Format, Cells menu. Set the custom format yyyy-mm-ddThh:mm:ss. Adjust the width of A column to about 20 units, and the others to 10 units.

Enter suitable titles and headers in rows 1 to 3, making sure that the first character in column A in each row is a # so that these lines will be treated at comments.

At this stage it is convenient to insert a chart of the data on Sheet2 to check that the measurements appear well behaved. Any obviously bad value should be deleted.

Save the whole workbook in Excel format using a name like yymmdd_s_esocdiff.xls, where yymmdd are the year, month and day of the time correlation that applies to this period, and s is the spacecraft ID.

Then save Sheet2 in Formatted Text (Space delimited) format using a name like "yymmdd_s_esocdiff.txt". Note that the whole name should be enclosed in double quotes to stop Excel forcing a .prn extension. The resulting text file should be a valid WEC DIFF file according to the specification in section 3.1.

See example files: 040204_1_esocdiff.xls, 040204_1_esocdiff.txt

2.3 Making a WEC TCOR file

Having obtained a WEC DIFF file which contains DIFF measurements valid at specific times, the next stage is to scan the series of HK files covering the time period to determine each time interval that requires a separate OFFSET correction, and to interpolate the DIFF measurements to get the DIFFs for each interval.

The command line tool 'maketcor' will perform this task.

First it is necessary to prepare a text file containing the path of each HK data file during the period (one per line). Either the full absolute path of each file may be specified, or a relative path from the current directory, or if the files are in the current directory, just the name. The file can be prepared (for example) using the DOS DIR /b command or the Unix find command.

Then enter the command:

maketcor -f file_list -c tcal_file -d diff_file >tcor_file

where:

file_list is the text file containing the list of HK file names created above, tcal_file is any TCAL file from the DDS or CDROM valid for the period,

[Note added 2005-08-02: If possible, the TCAL file should be the one for the end of the period, that contains the time correlations both for this period and the following one. It will be 60 bytes in size rather than the normal 30 bytes.]

diff_file is file containing the point valid DIFF measurements,

tcor_file is the new TCOR file.

This software tool scans the all the WEC HK files during the validity of the time correlation to determine:

1) Each separate period that a linear time calibration can be applied to. This can be done by looking for changes in OBTM larger that about 35 counts (TBC).

2) The size and time of any phase jumps in the VC0 cycle, and hence what the real time OBTM should be for each period identified in (1). For a given series of files, these can be estimated from the first to the last period of real time data.

For each period the OFFSET correction applying to the whole of that period is determined by taking the difference between the estimated real time OBTM and the actual OBTM. Then the DIFF at the start and end of the period is determined by linear interpolation between the preceding and following entries in the DIFF file.

The output file should be manually edited to remove any records (and associated comments) outside of the period. These will typically be for the first day before the time correlation, and for the last day after the new time correlation. Then check carefully for any remaining warning or error messages.

See example file: 040204_1_tcor.txt

2.4 Converting the TCOR file to binary format

Once the ASCII TCOR file has been validated, it may be converted to binary format using the command line tool 'convtcor'.

One or more ASCII files may be converted to a single binary file using the following command:

maketcor -f file_list -t ascii_tcor_file -o binary_tcor_file

where:

file_list is a text file containing a list of ASCII TCOR file names,
ascii_tcor_file is a single ASCII TCOR file name,
binary_tcor_file is the name for the binary TCOR output file.

Normally only one of -t or -f would be specified, though if both are specified the single file will be processed first followed by the list (no matter what order -t and -f are specified).

2.5 WEC time correction web site

Initially the WEC time correction files and associated documents and software will be available on part of the WEC operations web site at URL:

http://www.acse.shef.ac.uk/wec-ops/timing/

The username and password are the same as for the rest of the site.

3 Proposed time correction file formats

3.1 Point valid DIFF measurements

These are ASCII format files that specify the signed DIFF at specific points in time, that is when real time data is acquired either by ESOC or DSN. These files will be prepared manually using as input the ESOC DIFF measurements received as Microsoft Excel sheets, and DSN DIFF measurements extracted from the WBD data on DVD. They will be used as input to the software tool that generates the WEC time correction (TCOR) files.

The file will contain a number of records in the following format:

DATE/TIME The date and time at which the measurements apply specified in CCSDS ASCII time format, ie. yyyy-mm-ddThh:mm:ss.

DIFF The signed DIFF in micro-seconds.

SCID A number identifying the spacecraft this measurement applies to.

ANT An optional number specifying the antenna and/or receiver chain used to receive the real time data on which the DIFF measurement is based. This is only available for WBD data at present, and for ESOC data will be set to -1 for not specified.

OBTM For WBD data this specifies the OBTM for the real time data. This is extracted directly from the WBD level one files, and should match the estimated or assumed real time OBTM for the ESOC data. For ESOC data it will be -1 for not specified.

Each field will be separated by one or more spaces, and the records will be separated by new lines. Any line starting with # is a comment.

3.2 ASCII TCOR files

These are ASCII format files that specify the corrections (OFFSET and DIFF) for each period during which a linear correction applies. The records will not span TDA mode changes, new ESOC time correlations, or any other abrupt change in the corrections required. Probably there will be separate files for each spacecraft.

Each record contains:

START_DATE/TIME END_DATE/TIME SC OFFSET DIFF1 DIFF2

START_DATE/TIME and END_DATE/TIME specify the date and time of the first and last packet to which the corrections apply in standard CCDSD ASCII time format, ie.: yyyy-dd-mmThh:mm:ss.

SC is the ID for the spacecraft the corrections apply to, as 1, 2, 3 or 4.

OFFSET is the offset as a signed integer number of micro-seconds to be added to the SCET for SSR data to get the time of the VC0 reset pulse on board. It will be zero for real time data, and constant for each interval of SSR data in the same TDA mode.

DIFF1 and DIFF2 are the clock correction as signed integer micro-seconds that applies at the start and end of the interval respectively.

Each item in a record will be separated by one or more spaces, and records will be separated by newlines. Any line starting with # is a comment.

To correct the SCET in WEC HK data it is necessary to find the record in the calibration file corresponding to the time of the data, and with matching SC, interpolate between the two DIFFs to get the DIFF for the time of the data, then add OFFSET and DIFF to the SCET.

3.3 Binary TCOR files

These specify the same information as the ASCII TCOR files, but in a binary format using the same DDS packet header as the HK and science files.

START DATE/TIME and SC are included in the standard DDS packet header. START DATE/TIME uses the standard SCET format, but may be given to 1 second precision only. Therefore, it may not match exactly the time of the first data packet of the interval the correction applies to.

END DATE/TIME also uses the standard SCET format and will be in bytes 0 to 7 of the DDS packet data field. Again this may be given to 1 second precision only.

OFFSET is given as a 32 bit signed integer (most significant byte first) in bytes 8 to 11.

DIFF1 is given as a 32 bit signed integer (most significant byte first) in bytes 12 to 15.

DIFF2 is given as a 32 bit signed integer (most significant byte first) in bytes 16 and 19.

TBD additional fields may be included to assist with the verification of this data, but may be ignored by the software that applies the time corrections. The comment lines are used for this purpose in the ASCII version.

3.4 WEC HK files with time correction applied

If time corrections are applied by pre-processing the WEC HK files to create new files with corrected times, there should be a clear indication that the files have corrections applied. It is proposed to add 4 to the 'Time Quality' in byte 14, bits 0..3, making it 4, 5, or 6 (all presently unused).

4 Verification of timing accuracy

It is difficult to independently verify the absolute timing accuracy, but unexpected time jumps can easily be observed. WEC waveform data is acquired in packets at 1s intervals timed using a crystal oscillator independent of the spacecraft clock. The times on the following chart are modulo 0.1s, and are adjusted for the average rate of drift of the WEC clock. The uncorrected time shows jumps due to the change in offset between OBT and the VC0 reset pulse at TDA mode changes, and due to a new time correlation. These jumps are removed when the corrections are applied.

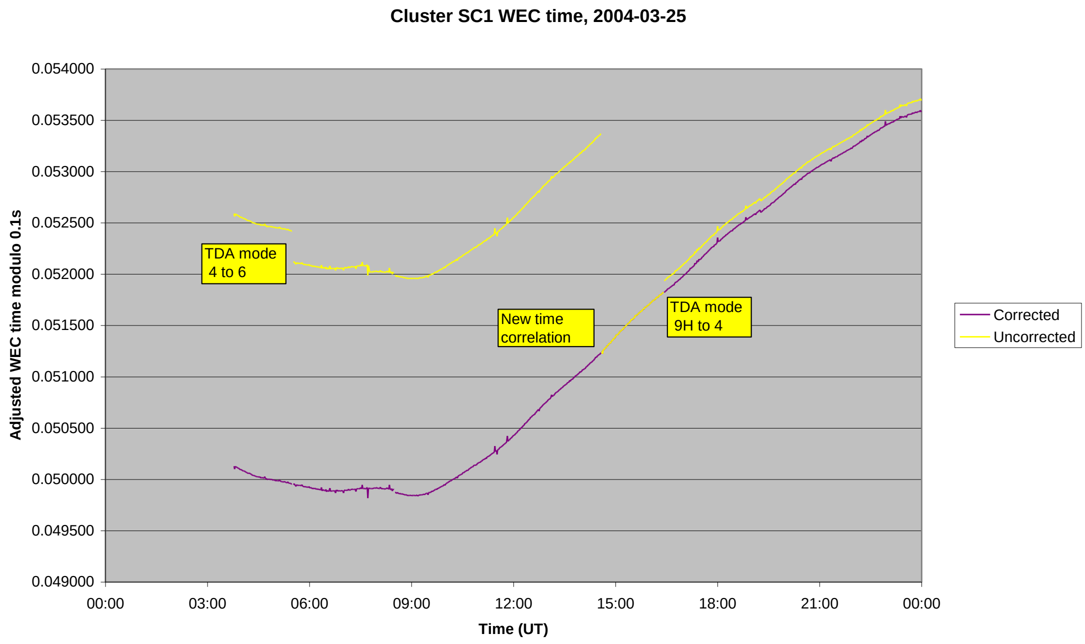

Figure 5. WEC waveform data timetags, before and after correction of the SCET using a TCOR file.

5 List of abbrievations

ANT A number identifying the DSN antenna used to receive WBD data.

DIFF The difference between the SCET measured in real time and that obtained from the onboard time using the current time correlation. When the DIFF is signed, this is $SCET_{rt}$-$SCET_{obt}$.

OBT Onboard time measured using a binary counter. This consists of a 32 bit count of the number of seconds, and a 20 bit sub-second counter. The latter is stored left justified in three bytes, that is four zero bits are appended on the right. In this document the whole OBT is considered as one 56 bit counter that increments at 2^{24} counts per second.

OBTM The 56 bit OBT modulo 86439936 (the period of the VC0 reset pulse in OBT counts).

OFFSET The different between the actual OBT count at the time of the VC0 reset pulse, and the OBT count that is recorded in the HK data on the SSR.

SCET Spacecraft event time. Nominally the UTC time that the VC0 reset pulse was issued onboard.

SSR Solid state recorder.

STREAM Byte 13 of the DDS packet header that indicates the source of the data and real time or SSR. Note that when the OBDH is in TDA mode 4 or 6 (when data is recorded on the SSR), it is also possible to simultaneously take the data in real time. In this case the stream parameter will indicate real time, whilst the OBTM will be as for SSR data.

TCAL Time calibration file. An auxiliary data file provided on the DDS and CDROMs that specifies the transformation from OBT to SCET using the current time correlation.

TCOR WEC time correction files.

TDA Telemetry data acquisition.

VC0 Virtual channel zero. This channel contains the housekeeping data, and one frame is generated nominally every 5.15222168 seconds (exactly 86439936 OBT counts). A ‘reset pulse’ is generated onboard that is correlated with the transmission of the first bit of this channel.