Preparation and validation of WEC time corrections for leap second 2005/2006

Keith Yearby, 17 March 2009

Contents

1 Introduction

A positive Leap Second was introduced at the end of December 2005. Coordinated Universal Time (UTC) was retarded by 1.0s so that the sequence of times became:

2005-12-31 23:59:59
2005-12-31 23:59:60
2006-01-01 00:00:00

The Cluster mission operations systems at ESOC, and the WEC data analysis software (including TED), are not designed to handle leap seconds, and this leads to timing errors of one second during the last two days of 2005 and the first day of 2006. The situation is described in detail in the ESOC report CL-OPS-RP-1017-OPS-OFC.

The WEC time correction (TCOR) dataset is primarily intended to enhance the standard 2ms timing accuracy to 20μs, but the same mechanism can be used to correct the larger 1 second errors in the days before and after the leap second. This document describes the preparation of this special TCOR dataset. This dataset includes also the usual clock error corrections so the resulting corrected data should have 20μs accuracy.

Note that neither TED, APPTCOR, nor any other WEC software produced by the DWP team can correctly handle leap seconds, that is the time 2005-12-31 23:59:60 cannot be represented. Using the TCOR time corrections will ensure that the timing is correct in the days before and after the leap second. However, times in the immediate vicinity of the leap second (2005-12-31 23:59:54 to 2006-01-01 00:00:05) might still be incorrect by one second.

2 Data and references

Source data:

ESOC DIFF measurements for 2005, 2006.
Cluster RDM for 2005, 2006.

Documents:

Precise reconstitution of the Spacecraft Event Time (SCET), Keith Yearby, 2004 July 7
ESOC report "The effect of the Leap Second in 2005 on Cluster Data"
CL-OPS-RP-1017-OPS-OFC

Software:

maketcor3, version 3.10, 2006-03-03
veritcor, version 1.3, 2005-07-19
tcor2cef, version 1.6, 2006-03-02

3 Preparation of the Point Valid DIFF measurements

As part of the procedure to handle the leap second at ESOC, a new time correlation was performed on each spacecraft during the first pass on 2006-01-01. All data downlinked after the new time correlation is processed using the new time correlation, even that recorded up to two days before. Therefore, during the two days before the leap second, and the day after, we have a mix of data some processed using the old time correlation and some with the new. During this period we need to determine DIFF values with respect to both the old and new time correlations, and apply them as required.

Note that there is no direct indication of which time correlation was used for any data. This must be determined by manual inspection of the data. An additional field (Time Correlation Index - TCI) has been defined in the Point Valid Diff files to specify which time correlation was used.

The DIFF values for the old time correlation were determined using the standard ESOC measurements during the last real time passes of 2005, together with the value just before the new time correlation extracted from the TCAL files on the RDM. The latter values are determined by taking the difference between two successive TCAL records, and assuming that the DIFF just after the new time correlation must be zero (this is what the time correlation achieves). A linear interpolation is used to get DIFFs at intermediate times.

The DIFF values for the new time correlation are obtained by extrapolating back from the assumed zero DIFF at the time of the new time correlation, and the DIFF measured during the next real time pass one or two days later.

It was necessary to apply a correction for the drift of the reference clock at the Maspalomas ground station. See CLUSTER Mission Operations Report No. 289, annex 1. The Maspalomas reference clock error was estimated to be 33μs at this time. Note that Maspalomas was normally used only for SC3 and SC4, but the first time correlations of 2006 used Maspalomas for all spacecraft.

The Point Valid Diff files have been prepared manually as Excel spread sheets (eg. 05_ls_1_diff.xls), then exported as "Formatted Text (Space Delimited)". The files are listed below. The columns are:

1) The date and time at which the DIFF applies (as the spacecraft event time in the raw data files).
2) The DIFF in micro-seconds which should be added to the SCET of the raw data to get accurate times.
3) The Spacecraft the file applies to.
4) Whether the correction is referenced to the old (0) or new (1) time correlation (TCI). Note that 'old'and 'new' are defined for the case where only a few days data subject to only two time correlations are being processed. The value -1 may be specified for the more usual case where several months of data with many time correlations are processed, but prior to November 2007 will not always select the correct one.
5) Onboard Time Modulo - not used in this case.

DIFFs at intermediate times may be obtained by linear interpolation, except where there is a blank line in the file.

```
# Point valid DIFFs for 2005 December leap second
#  DATE/TIME        Final DIFF   SC     TCI     OBTM
 2005-12-30T17:00:25      -818       1       0      -1
 2005-12-30T18:00:27      -823       1       0      -1
 2005-12-30T19:00:28      -827       1       0      -1
 2005-12-30T20:00:30      -831       1       0      -1
 2005-12-30T21:00:26      -835       1       0      -1
```

```
 2005-12-31T00:31:00      -854       1       0      -1

 2005-12-31T00:32:00   1000000       1       1      -1
 2005-12-31T23:59:45   1000000       1       1      -1

 2006-01-01T00:00:15         0       1       1      -1
 2006-01-01T04:29:39         0       1       1      -1

 2006-01-01T04:30:22  -1001000       1       0      -1
 2006-01-01T05:01:01  -1001003       1       0      -1
 2006-01-01T05:04:11  -1001003       1       0      -1
```

```
# Point valid DIFFs for 2005 December leap second
#   DATE/TIME       Final DIFF   SC     TCI     OBTM
 2005-12-30T12:00:27      -216       2       0      -1
 2005-12-30T13:00:28      -216       2       0      -1
 2005-12-30T14:00:29      -216       2       0      -1
 2005-12-30T15:00:26      -216       2       0      -1
 2005-12-30T16:00:27      -216       2       0      -1
 2005-12-30T20:13:32      -214       2       0      -1

 2005-12-30T20:13:35   1000047       2       1      -1
 2006-01-01T00:00:00   1000037       2       1      -1

 2006-01-01T00:00:04        37       2       1      -1
 2006-01-01T09:09:55        33       2       1      -1

 2006-01-01T09:10:05  -1000200       2       0      -1
 2006-01-01T09:45:13  -1000200       2       0      -1
 2006-01-01T09:46:10  -1000200       2       0      -1

 2006-01-01T09:46:13        33       2       1      -1
 2006-01-03T07:00:30        17       2       1      -1
```

```
# Point valid DIFFs for 2005 December leap second
#       DATE/TIME   Final DIFF   SC     TCI     OBTM
 2005-12-30T18:00:27     -1232       3       0      -1
 2005-12-30T19:00:29     -1235       3       0      -1
 2005-12-30T20:00:30     -1237       3       0      -1
 2005-12-30T21:00:26     -1240       3       0      -1
 2005-12-30T22:00:28     -1243       3       0      -1
 2005-12-31T01:15:36     -1251       3       0      -1

 2005-12-31T01:15:38   1000034       3       1      -1
 2005-12-31T23:59:58   1000038       3       1      -1

 2006-01-01T00:00:01        38       3       1      -1
 2006-01-01T13:59:57        40       3       1      -1

 2006-01-01T14:00:06  -1001346       3       0      -1
 2006-01-01T14:35:55  -1001348       3       0      -1
 2006-01-01T14:36:53  -1001348       3       0      -1

 2006-01-01T15:00:28        40       3       1      -1
 2006-01-02T17:00:28        44       3       1      -1
```

```
# Point valid DIFFs for 2005 December leap second
#     DATE/TIME     Final DIFF   SC     TCI     OBTM
 2005-12-30T13:00:27        30       4       0      -1
```

```
2005-12-30T14:00:28        31       4       0      -1
2005-12-30T15:00:30        31       4       0      -1
2005-12-30T16:00:26        31       4       0      -1
2005-12-30T17:00:28        32       4       0      -1
2005-12-30T20:44:13        30       4       0      -1

2005-12-30T20:44:16    999996       4       1      -1
2005-12-31T23:59:59   1000022       4       1      -1

2006-01-01T00:00:03        22       4       1      -1
2006-01-01T18:09:56        39       4       1      -1

2006-01-01T18:10:06   -999988       4       0      -1
2006-01-01T18:45:01   -999988       4       0      -1
2006-01-01T18:48:10   -999988       4       0      -1

2006-01-01T19:00:30        40       4       1      -1
2006-01-02T14:00:25        58       4       1      -1
```

4 Generation of the ASCII TCOR files

The generation of the ASCII TCOR files is performed on the Sun network where direct access to the Cluster RDM is available.A list of the full path names of all HK and TCAL files for each spacecraft, for the period 2005-12-30 to 2006-01-03, is obtained using the Unix 'find' command, and various greps and sorts. The individual lists must be in chronological order. They are written to files named like 05_ls_*s*_hkla_files.txt.

```
find /data/disk2/cluster/RDM/051231* -name '*wh*' > scr.scr
find /data/disk2/cluster/RDM/051231* -name '*la*' >> scr.scr
find /data/disk2/cluster/RDM/060101* -name '*la*' >> scr.scr
find /data/disk2/cluster/RDM/060101* -name '*wh*' >> scr.scr
find /data/disk2/cluster/RDM/051230* -name '*wh*' >> scr.scr
find /data/disk2/cluster/RDM/051230* -name '*la*' >> scr.scr
find /data/disk2/cluster/RDM/060102* -name '*wh*' >> scr.scr
find /data/disk2/cluster/RDM/060103* -name '*wh*' >> scr.scr
~/CAA/weclog/purgedup scr.scr 05_ls_hkla_files.txt
grep cluster1 05_ls_hkla_files.txt | sort > 05_ls_1_hkla_files.txt
grep cluster2 05_ls_hkla_files.txt | sort > 05_ls_2_hkla_files.txt
grep cluster3 05_ls_hkla_files.txt | sort > 05_ls_3_hkla_files.txt
grep cluster4 05_ls_hkla_files.txt | sort > 05_ls_4_hkla_files.txt
```

A special version of Maketcor, maketcor3.10, has been prepared for making the TCOR files near the leap second, and has special features for using the TCI field in the Point Valid Diff files to establish which time correlation applies to each period of data. This version has not been validated for generating the usual year long TCOR files. Unlike previous versions, maketcor3.10 reads pre-processed time correlation information from text files, rather than processing the TCAL files itself.

```
../maketcor3.10 -c 05_ls_1_new_tcal.txt -d 05_ls_1_diff.prn \
   -f 05_ls_1_hkla_files.txt -w ../wbd/wbd_all_c1_ncd.txt \
   > 05_ls_1_tcor.txt
../maketcor3.10 -c 05_ls_2_new_tcal.txt -d 05_ls_2_diff.prn \
   -f 05_ls_2_hkla_files.txt -w ../wbd/wbd_all_c2_ncd.txt \
   > 05_ls_2_tcor_w.txt
../maketcor3.10 -c 05_ls_3_new_tcal.txt -d 05_ls_3_diff.prn \
   -f 05_ls_3_hkla_files.txt -w ../wbd/wbd_all_c3_ncd.txt \
   > 05_ls_3_tcor.txt
../maketcor3.10 -c 05_ls_4_new_tcal.txt -d 05_ls_4_diff.prn \
   -f 05_ls_4_hkla_files.txt -w ../wbd/wbd_all_c4_ncd.txt \
```

```
    > 05_ls_4_tcor.txt
```

5 Validation of the TCOR files

The software tool ‘maketcor3’ performs some automatic validation as the files are produced. Data that fails automatic validation is not included in the output files.

Further validation of the TCOR files is performed by generating version 0 CEF files, using these to apply time corrections, then analysing the time tags of the corrected data. Anomalies identified in the corrected data may then be related to errors noted in the TCOR file comments, and the TCOR records deleted or corrected. The process is then repeated until no anomalies are found. Comments in the ASCII TCOR files indicate where such corrections have been made.

The time tags are analysed using ‘veritcor’. This takes the time increment between each pair of records in the file, subtracts the nominal value of 5.15222168 seconds, and accumulates the minimum, maximum, mean and standard deviation over each 24 hour period. On SC1 and SC3 it is known that time jumps of -125.9 us occur occasionally. These are counted and removed before further analysis. Gaps in the file are allowed for, and by default ‘veritcor’ only processes records that are time corrected.

A typical 'veritcor' command is:

```
../veritcor -T . -v 4 -f 05_ls_3_kh_files.txt
```

```
#Date  Time  Formats  Jumps  Uncor  Min  Max  Mean  Stdev
# FILE LIST: 05_ls_1_kh_files.txt
2005/12/30 11:59:59.794460   4885      1      1 -3.3383  0.7148 -1.2470  0.6645
2005/12/31 11:59:56.010509  16763      1      0 -6.6762  0.7148 -1.2471  0.7839
2006/01/01 11:59:56.878776  16757      1      4 -3.3383  0.9532 -1.2472  0.7285

#Date  Time  Formats  Jumps  Uncor  Min  Max  Mean  Stdev
# FILE LIST: 05_ls_2_hk_files.txt
2005/12/30 11:59:58.749484   8377      0      0 -3.3383  2.1453 -0.6824  0.7901
2005/12/31 11:59:57.546434  16767      0      0 -3.3383  1.6685 -0.6832  0.7133
2006/01/02 11:59:59.792555  16770      0      0 -3.3383  1.9069 -0.6831  0.7376
2006/01/03 03:30:12.429557   4893      0  11850 -3.0999  1.6685 -0.6829  0.7536

#Date  Time  Formats  Jumps  Uncor  Min  Max  Mean  Stdev
# FILE LIST: 05_ls_3_kh_files.txt
2005/12/30 11:59:57.468616   4186      0      0 -3.0999  1.6685 -0.6499  0.7215
2005/12/31 11:59:56.265843  16767      0      1 -3.3383  1.6685 -0.6500  0.7186
2006/01/01 11:59:59.715291  16491      0    274 -4.1727  1.9069 -0.6502  0.7918
2006/01/02 08:30:11.636543  11880      0  21645 -3.3383  1.6685 -0.6498  0.7527

#Date  Time  Formats  Jumps  Uncor  Min  Max  Mean  Stdev
# FILE LIST: 05_ls_4_kh_files.txt
2005/12/30 11:59:58.315103   7679      1      1 -3.5767  0.7148 -0.9667  0.6523
2005/12/31 11:59:57.109611  16764      1      0 -3.0999  0.7148 -0.9668  0.6148
2006/01/01 11:59:57.980231  16621      2    143 -4.6496  0.7148 -0.9669  0.6644
2006/01/02 07:00:10.372230   9780      1  23738 -3.3383  0.9532 -0.9667  0.6744
```

It uses the same HK+TCAL file list file as 'maketcor3', although only the HK files are used. 'veritcor' includes the same code module used by TED to apply the TCOR corrections, and requires CEF TCOR files to be installed with the same index files. The '-T .' option specifies that the TCOR files (and the index files) are located in the default directory.

For the leap second time correction files an additional verification was performed by generating time corrected raw data files, then plotting the time stamps.

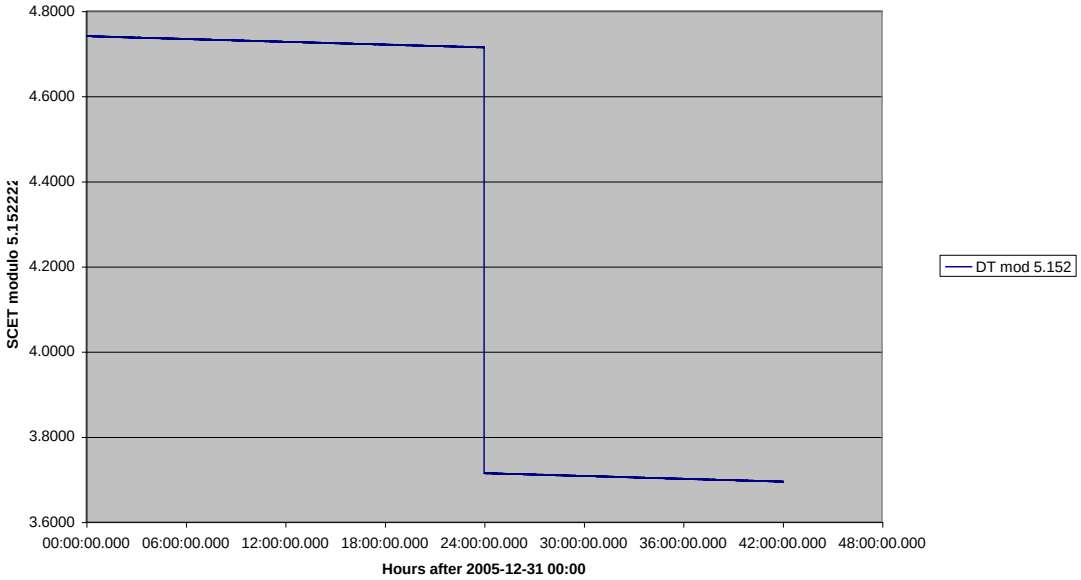
1) All WEC HK RDM files for 2005-12-30 to 2006-01-01 inclusive were concatenated (using Unix cat command) to produce one 3 day file for each spacecraft.
2) The time corrections were applied using apptcor. This works with the ASCII TCOR files rather than the CEF files.
3) TLMCHECK was used to obtain a list of time stamps to milli-second precision.

4) An Excel spread sheet was used to calculate the time stamp modulo 5.152222s (the interval between formats).

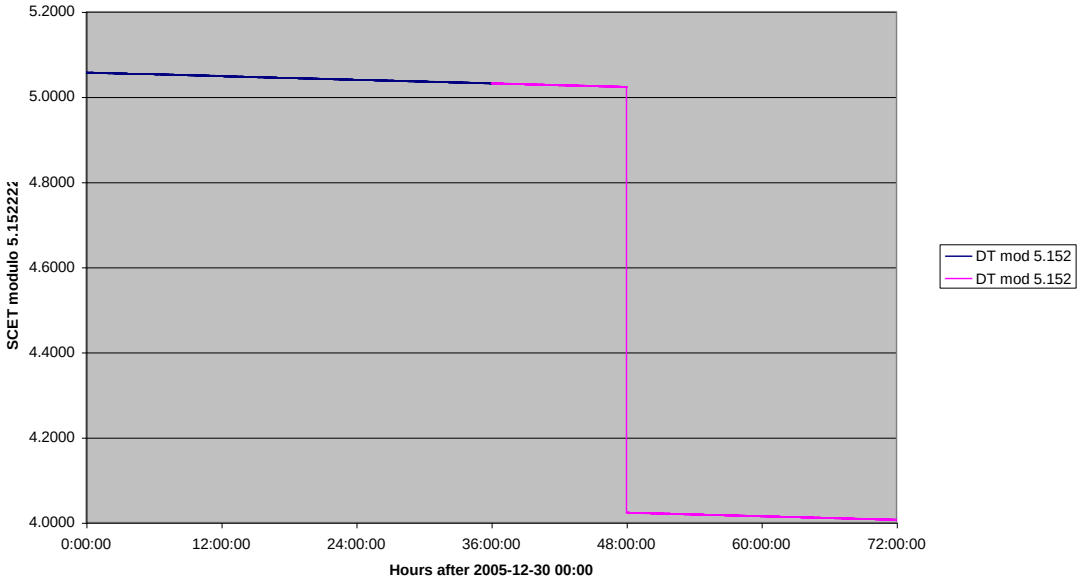
```
../apptcor -h 051230wh.na1 -o 051230wh.nt1 -t 05_ls_1_tcor.txt
../apptcor -h 051230wh.na2 -o 051230wh.nt2 -t 05_ls_2_tcor.txt
../apptcor -h 051230wh.na3 -o 051230wh.nt3 -t 05_ls_3_tcor.txt
../apptcor -h 051230wh.na4 -o 051230wh.nt4 -t 05_ls_4_tcor.txt
```

Note that Excel does not account for leap seconds, so we expect to see a one second jump in the modulo time at the time of the leap second itself, but there should be no jumps at other times. This is indeed the case in the following plots.

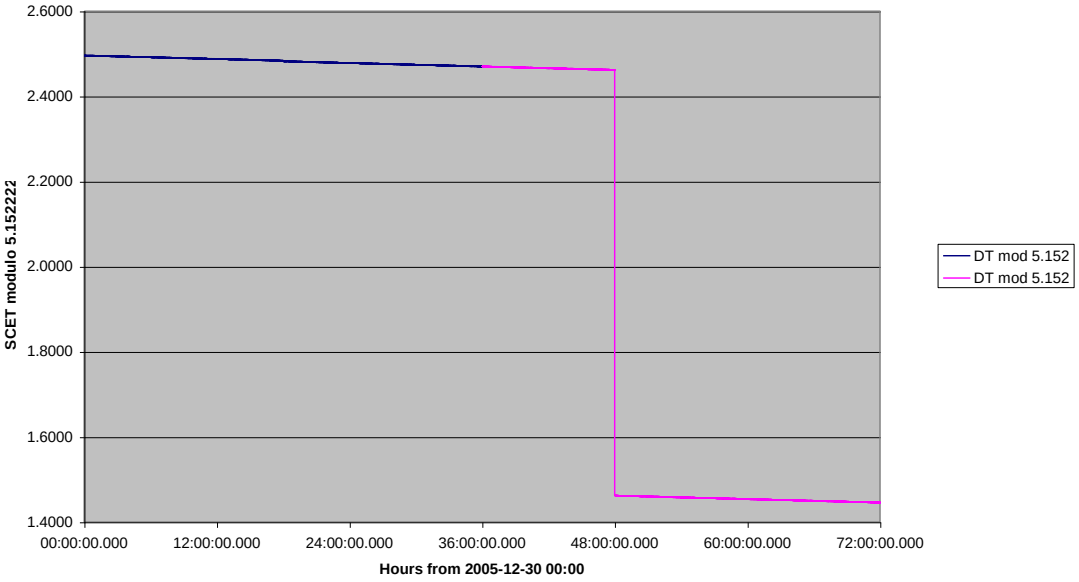
Cluster SC1, 2005-12-31 to 2006-01-01



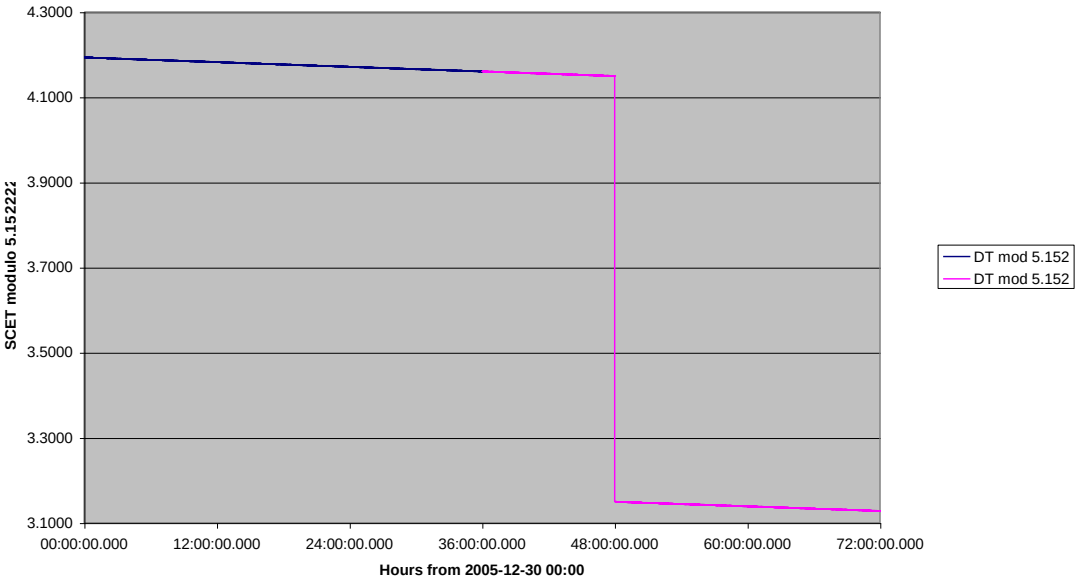
Cluster SC2, 2005-12-30 to 2006-01-01



Cluster SC3, 2005-12-30 to 2006-01-01



Cluster SC4, 2005-12-30 to 2006-01-01



6 Production of the CEF files

The final CEF files were produced by running TCOR2CEF on the validated ASCII format TCOR files, with version number 2 specified. The file comparison utility (diff) was used to check that the only changes between the version 0 files used for validation, and the final version, are in the filenames, version numbers, and generation date.

The CEF file name is generated automatically using information contained in the file (except for the version number which is specified). Note that the date included in the name is the date of the first data actually present in the file, which may not be the same as the start of the nominal period covered by the file.

```
../tcor2cef -t 05_ls_1_tcor.txt -v 2
TCOR2CEF, version 1.6
TCOR file:          05_ls_1_tcor.txt, s/c: 1, records: 15
Generated CEF name: C1_CP_DWP_TCOR__20051230_V02
Time range:         2005-12-30T17:00:25Z/2006-01-02T03:21:05Z
Finished, CEF size: 2867 bytes
Total duration:     210040 seconds
Corrected:          209919 seconds (99.9 %)

../tcor2cef -t 05_ls_2_tcor.txt -v 2
TCOR2CEF, version 1.6
TCOR file:          05_ls_2_tcor.txt, s/c: 2, records: 18
Generated CEF name: C2_CP_DWP_TCOR__20051230_V02
Time range:         2005-12-30T12:00:27Z/2006-01-03T07:00:25Z
Finished, CEF size: 3185 bytes
Total duration:     327598 seconds
Corrected:          327442 seconds (100.0 %)

../tcor2cef -t 05_ls_3_tcor.txt -v 2
TCOR2CEF, version 1.6
TCOR file:          05_ls_3_tcor.txt, s/c: 3, records: 17
Generated CEF name: C3_CP_DWP_TCOR__20051230_V02
Time range:         2005-12-30T18:00:27Z/2006-01-02T17:00:24Z
Finished, CEF size: 3061 bytes
Total duration:     255597 seconds
Corrected:          254079 seconds (99.4 %)

../tcor2cef -t 05_ls_4_tcor.txt -v 2
TCOR2CEF, version 1.6
TCOR file:          05_ls_4_tcor.txt, s/c: 4, records: 20
Generated CEF name: C4_CP_DWP_TCOR__20051230_V02
Time range:         2005-12-30T13:00:27Z/2006-01-02T14:00:21Z
Finished, CEF size: 3396 bytes
Total duration:     262794 seconds
Corrected:          261899 seconds (99.7 %)
```

```
diff C1_CP_DWP_TCOR__20051230_V00.cef C1_CP_DWP_TCOR__20051230_V02.cef
diff C2_CP_DWP_TCOR__20051230_V00.cef C2_CP_DWP_TCOR__20051230_V02.cef
diff C3_CP_DWP_TCOR__20051230_V00.cef C3_CP_DWP_TCOR__20051230_V02.cef
diff C4_CP_DWP_TCOR__20051230_V00.cef C4_CP_DWP_TCOR__20051230_V02.cef
```

The TCOR data in CEF format is available from the CAA as usual. In addition the following files are available from the WEC operations web site at URL:

http://www.acse.shef.ac.uk/wec-ops/timing/tcorfiles/2005_ls/

05_ls_1_diff.prn	Point valid DIFF text format
05_ls_2_diff.prn	
05_ls_3_diff.prn	
05_ls_4_diff.prn	
05_ls_1_diff.xls	Point valid DIFF Excel format
05_ls_2_diff.xls	
05_ls_3_diff.xls	
05_ls_4_diff.xls	
05_ls_1_tcor.txt	TCOR files text format
05_ls_2_tcor.txt	
05_ls_3_tcor.txt	
05_ls_4_tcor.txt	
C1_CP_DWP_TCOR__20051230_V02.cef	TCOR files CEF format
C2_CP_DWP_TCOR__20051230_V02.cef	
C3_CP_DWP_TCOR__20051230_V02.cef	
C4_CP_DWP_TCOR__20051230_V02.cef	

7 Caveats

The following general caveats apply to the 2005 leap second TCOR data:

Use with caution. If published results depend critically on timing accuracy it is recommended that the DWP team should re-verify the TCOR data in question. Times in the immediate vicinity of the leap second (2005-12-31 23:59:54 to 2006-01-01 00:00:05) might still be incorrect by one second.

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. The OFFSET is constant throughout each period, and the same value will be written in the records at the start and end of the period. If the OFFSET values before and after the required time are different, or either has the fill value of -1e31, then OFFSET is not available for that period. No interpolation between different OFFSET values is allowed. The DIFF may be obtained by linear interpolation of the DIFF values immediately before and after the required time. However, if either DIFF has the fill value of -1e31, then DIFF is not available for that period. It is not allowed to interpolate over a fill value.