Investigations into ATSR-1 1.6 & 3.7µm channel switching

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Change Record

Issue	Date	Description
0.1	11-Nov-2016	First complete draft
0.2	16-Nov-2016	Checked by Space Connexions. Changes accepted, version updated.
0.3	25-Nov-2016	Minor update to caption of reflectance comparison figure used for validation, following confirmation of information regarding plotted data. Added new information regarding operations on 13-Sep-1991 and modified conclusion.
1.0	29-Nov-2016	Finalised Issue 1. Accepted all recent changes and added Hugh Kelliher as "Checked by".

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1 Scope of Document

This Technical Note describes work performed by RAL Space to investigate processing of the ATSR-1 1.6µm channel data for the period from mid-Sept 1991 to late May 1992 where the blackbody data are missing. This work is performed as Work Package 4.4 of the proposal described in [AD 1].

2 Terms, Definitions and Abbreviations

2.1 Acronyms

APP	Archive Product Processor
ATSR	Along-Track Scanning Radiometer
CRC	Cyclic Redundancy Check
IDL	Interactive Data Language
NEODC	NERC Earth Observation Data Centre
NERC	Natural Environment Research Council
SADIST-2	Synthesis of ATSR Data Into Sea-surface Temperatures (ATSR data processing software based on DEC/VMS environment)
SCP	Signal Channel Processor
SUPPLE	SADIST UBT Product Processor Linux Environment (Linux port of SADIST software)
TOA	Top Of Atmosphere
UBT	Ungridded Brightness Temperature (SADIST ATSR data product)

3 Documents

3.1 Applicable Documents

Ref	Title	Document code	Version	Date
AD 1	ATSR Satellite Dataset Supporting Activities, 2014 - 2017	Proposal 2014-07-001 (response to DECC ITT : TRN 829/06/2014)	2	28-Jul-2014
AD 2	ERS Ground Stations Products specification	ER-IS-EPO-GS-0201	Issue 3/1	23-Nov-2004
AD 3	ATSR-1 anomaly log	http://www.atsr.rl.ac.uk/satellite/logs/anomaly/archive/ers-1/index.shtml	N/A	N/A
AD 4	ATSR Operations Log Book	N/A (hand-written notebook)	N/A	1991-1999
AD 5	SADIST-2 v100 Products	ER-TN-RAL-AT-2164	N/A	06-Sep-1995
AD 6	ATSR Digital Electronics Unit Requirement Specification	ER/RS/BAe/PL/0001	6c	March 1991

[AD 2] can be obtained by searching the ESA Earth Online site at https://earth.esa.int/

[AD 4] is stored at RAL by the current (A)ATSR team

3.2 Reference Documents

Ref	Title	Document code	Version	Date
RD 1				

4 Overview

The standard mode for data collection and downlink from the ATSR-1 1.6µm and 3.7µm channels was to record data from only one of the channels at any given time, switching between the two depending on a signal threshold. Restricted bandwidth meant that the data from 4 channels (4 * 12 bits) needed to be compressed to 31 bits. The most common compression mode was:

- 12bit 11µm
- 8bit 11-12µm difference
- 11bit 1.6µm or 3.7µm depending on 1.6um signal threshold being exceeded.

This mode was employed up to the point when the 3.7µm channel failed at 19:12 UTC 27-May-1992. From 13-Sep-1991 until the 3.7µm failure, the 1.6µm earth-view calibrated data are flagged as "calibration unavailable" in the corresponding UBT products because the blackbody data necessary for calibration are flagged as "missing/unavailable".

Checks performed on the existing data archive have demonstrated that the earth-viewing (uncalibrated) signal is indeed present in the telemetry for both channels and switching does occur as planned. This can be seen clearly in 'SADIST-2' processor Ucounts images.

The existing data archive was generated by the SADIST-2 processor, which ran on a VAX/VMS system. In 2008 a partial port of the SADIST software was performed to support continued processing of ATSR-2 data in a Linux environment. The ported SADIST software is known as SUPPLE. The SUPPLE software could potentially be extended to process ATSR-1 Level 0 to UBT.

ESA have recently performed a "re-transcription" of the archive of data from Matera to generate a new archive of L0 data from ATSR-1&2, which is available on disk rather than on tape. ATSR-1 L0 data for the affected period is therefore available in a format which is relatively easy to process.

This work package therefore breaks down into the following tasks.

- Adapt the SUPPLE processor to cope with data from ATSR-1
- Investigate the available data and attempt to define an algorithm to derive the missing blackbody detector counts
- Incorporate the new algorithm into the SUPPLE software; test and validate
- Process L0 data to UBT for the affected period

5 Investigations

5.1 Extension of SUPPLE to process ATSR-1 data

Note that the information in the following paragraphs may appear extremely detailed given that the work is not particularly complex. It is considered useful to record the information for future reference, due to the delays caused by the loss of expertise due to staff changes and the difficulty experienced in obtaining information due to the age of the relevant documentation.

The SUPPLE processor consists of a pre-processor coded in IDL and a main processor (called SUM) coded in C. The pre-processor is a minimal implementation compared to the original SADIST-2 pre-processor, which handled a range of input data formats including tapes and which was responsible for the scheduling of jobs for the main "slave" processor.

The SUPPLE pre-processor reads Level 0 data from "EATC2" files only. For details of the EATC2 file format and contents see [AD 2]. The job of the pre-processor is essentially to strip out parts of the Level 0 data into separate "generic" files used as input to the main SUM processor: e.g. the source packets are written to one file, minus the EATC2 file headers; the clock calibration and state vector data are written out to separate files.

It was suggested that the main change required so that the SUPPLE processor would accept ATSR-1 data would be to the pre-processor. Jack Abolins, who had developed the SUPPLE processor, was able to take some pre-processed Level 0 data files generated by the old SADIST-2 VMS pre-processor, and process them successfully on a Linux machine using an old "SUM" executable.

The ATSR-1 source packet is effectively the same as the L-rate ATSR-2 packet. The SUPPLE pre-processor was updated to extract packets of 4000 bytes if the instrument is ATSR-1.

Although the required update to the pre-processor was relatively straightforward, the work took some time since all the original developers had left RAL and the documentation available was in the form of hardcopies, e.g. of the original SADIST-2 system documents from 1995, which did not reflect more recent changes to the software. Considerable effort was expended in trying to find documentation on the ATSR-1 source packet definition, e.g. to find suitable header values for use in validity checks. Information on the contents of the EATC2 / Level 0 data files is available in [AD 2], which was found by searching the ESA EO web pages.

As noted above, it had been shown in ~2014 that it was possible to take pre-processed ATSR-1 Level 0 data files from VMS and process them on a Linux system using SUM. Following the pre-processor update above, processing by SUM on the latest development server was attempted but failed. The SUM executable had not been re-compiled for several years and by early 2015 the system was being run on new hardware with a current version of Linux and current gcc compiler and libraries.

Changes to gcc and the libraries meant that in order to compile the software on the current system a new "ERSorb" library was needed. The ERSorb library software was originally written in Fortran. Compilation and linking of C code with Fortran library code requires certain gcc compiler flags and a supporting library. This gcc library had changed since the porting work was done in 2008, hence the existing ERSorb library was not compatible with the current gcc compiler version.

An updated ERSorb library was found via the ESA EO help desk. The software was developed at ESTEC by Berthyl Duesman and a new copy was supplied by Montserrat Pinol Sole.

Once built with the new ERSorb library and with a couple of minor bug fixes applied it was possible to run SUM on ATSR-1 data on Linux.

Attempts to run SUM on ATSR-2 data for validation purposes failed due to a problem with the CRC check, which identified all packets as null. Initial attempts to solve the CRC problem were unsuccessful and it was left unsolved, on the basis that the priority for intended use of SUPPLE was to process ATSR-1 data. It is thought that the CRC check algorithm currently implemented may be different from the one in the SADIST VMS code, and that it uses a system function which was adopted on the basis of faster performance. The CRC problem was solved in 2016 when it was found to result from a discrepancy in the data types used. The CRC stored in the ATSR-2 packet is a 2-byte value, whereas the result of the checksum calculation was a long value which overflowed 2 bytes. The code was updated so that the values compared are of consistent types and the checksum result is masked to remove the higher-order bytes.

Once ATSR-1 Level 0 data could be processed to UBT, comparisons were made between a small number of new and archived UBT products by visual inspection of scene images.

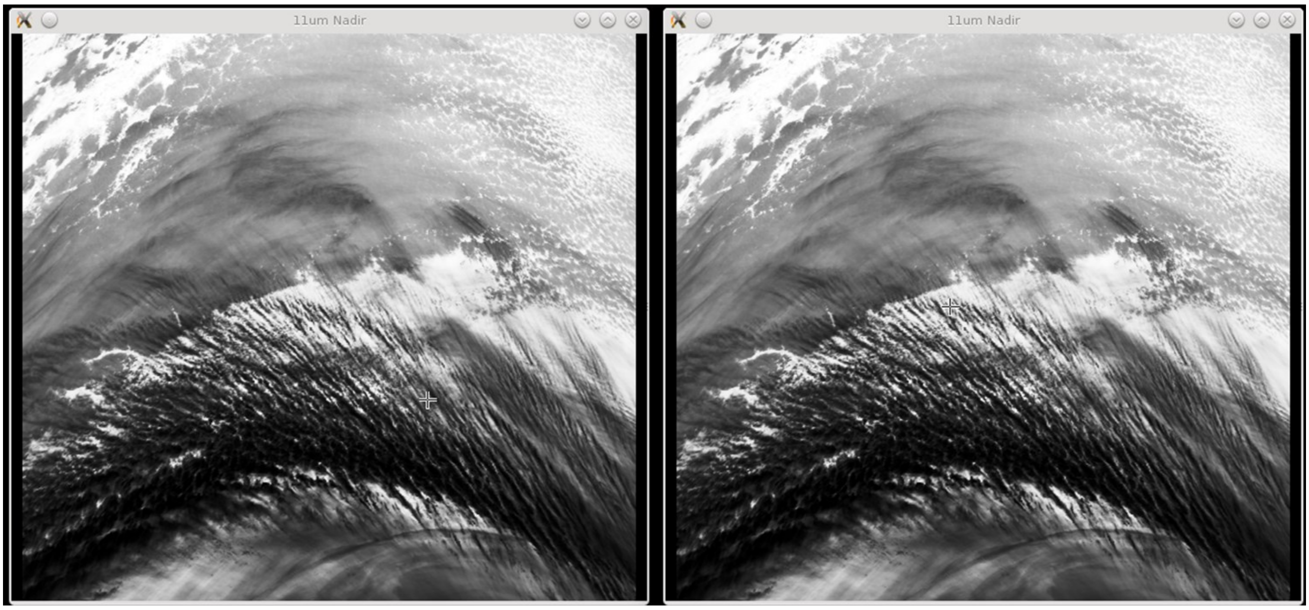

Figure 1: comparison of UBT products from the NEODC archive and from the SUPPLE processor, running on Linux. Left: archived product ralubt-9403150020-05325-041001-1av356, version 356 processed 01-Oct-2004. Right, ralubt-9403150020-05379-150629-1v401, version 401 (temporary version number set to indicate new software) processed 29-Jun-2015.

Figure 1 shows two versions of the same UBT scene, one from the archive and one generated by the newly-compiled software. Note that the two scenes appear to be identical despite an apparent difference in the along-track distance denoted by the second numeric value in each filename: 05379 in the v356 product and 05325 in the new product. **The assignment of the along-track distance value by the SUPPLE software has not been investigated**. If the value corresponds exactly to the first scan in the image, an offset of approximately 10% might be expected.

5.2 Investigation of blackbody data in the UBT archive

IDL tools were written and run on UBT data extracted from the NEODC archive, in order to determine

- On what dates and times the 1.6µm blackbody data are present or missing
- What are "typical" values for the blackbody detector counts when present
- What associated values can be extracted to aid derivation of a detector counts algorithm, e.g. gains, offsets and detector temperatures

Each scan record in a UBT product contains 36 +BB (warm blackbody) and 36 –BB (cold) pixel detector counts in each channel. The detector views of the blackbody fall in the centre pixels of these arrays, with blank pixels at either end of the arrays. The –BB value is required to calibrate the 1.6µm channel.

Inspection of sample UBT products from September 1991 showed that the 1.6µm blackbody data are present up until approximately 08:35 on 13-Sep-1991. At 19:12 on 27-May-1992 the 3.7µm channel failed. From the time of the failure the 1.6µm blackbody data are once again present. Typical values in

Sept 1991, as shown in Figure 2, are around 190 to 200 counts with a small variation within an orbit. “Stepping” of values is seen at intervals of 512 scans due to the instrument auto-gain and offset adjustment. Figure 3 shows an example of the 1.6µm blackbody counts from a partial orbit on 13-Sep-1991, a few hours after the data become unavailable. When the values return in May 1992 (Figure 4) the counts are higher than in early September 1991 but the same general patterns of variation remain.

The ATSR-1 anomaly log [AD 3] does not record sufficient detail to show what changes to the instrument configuration were made on 13-Sep-1991. It is noted that on 14-Sep-1991, large sections of several orbits contain no valid pixel data in any channel; these pixels are flagged with value -7: “calibration parameters unavailable for pixel”.

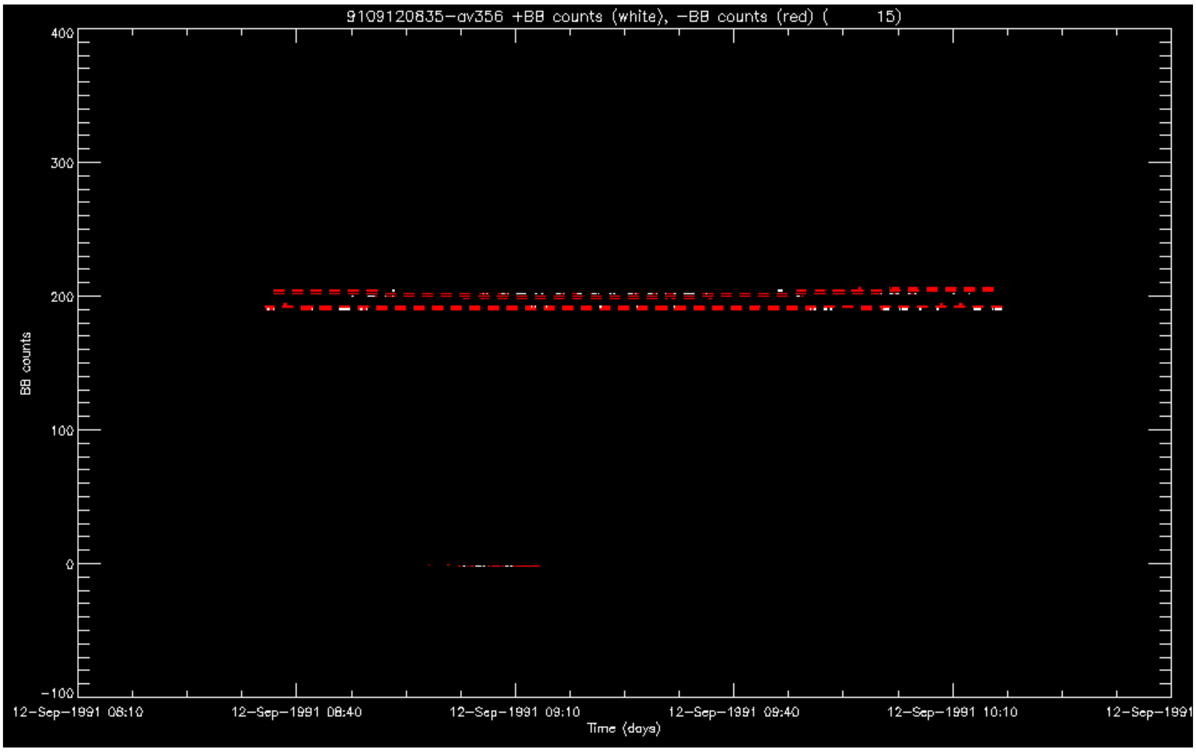

Figure 2: Typical 1.6µm blackbody values from 12-Sep-1991, 1 orbit with ascending node crossing time 08:35UTC.

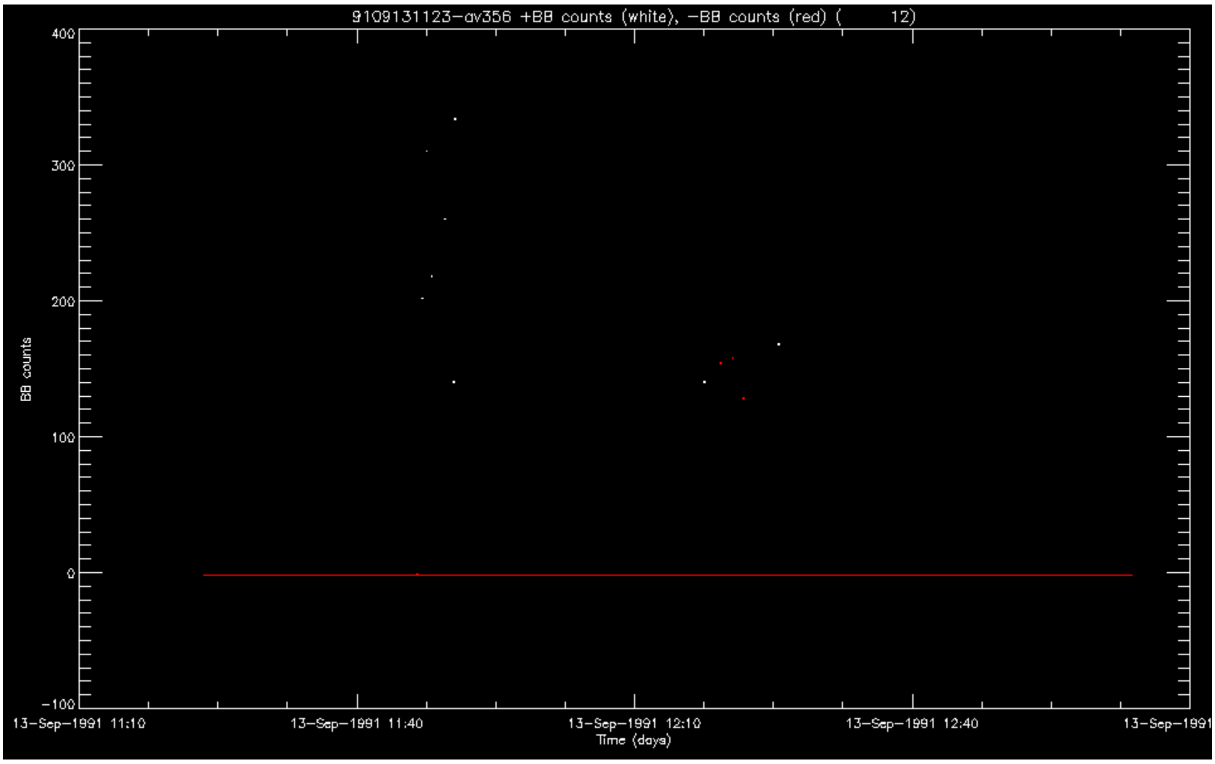

Figure 3: 1.6µm blackbody counts from 13-Sep-1991 (partial orbit)

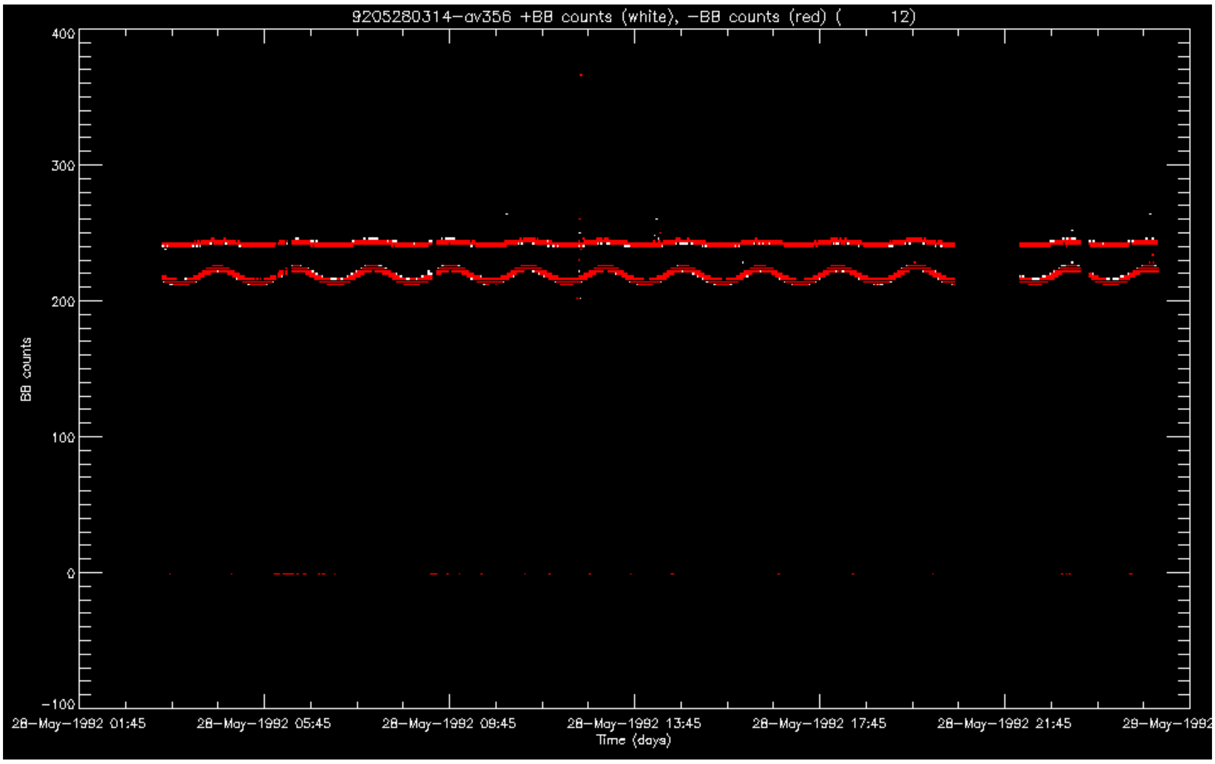

Figure 4: 1.6µm blackbody counts from 28-May-1992, whole day's data

Also included here for reference, but outside of the period of missing blackbody data, Figure 5 shows that by 19-Jun-1992 further changes to the instrument configuration had resulted in lower blackbody detector count values and no "stepping" due to the auto-gain and offset adjustment.

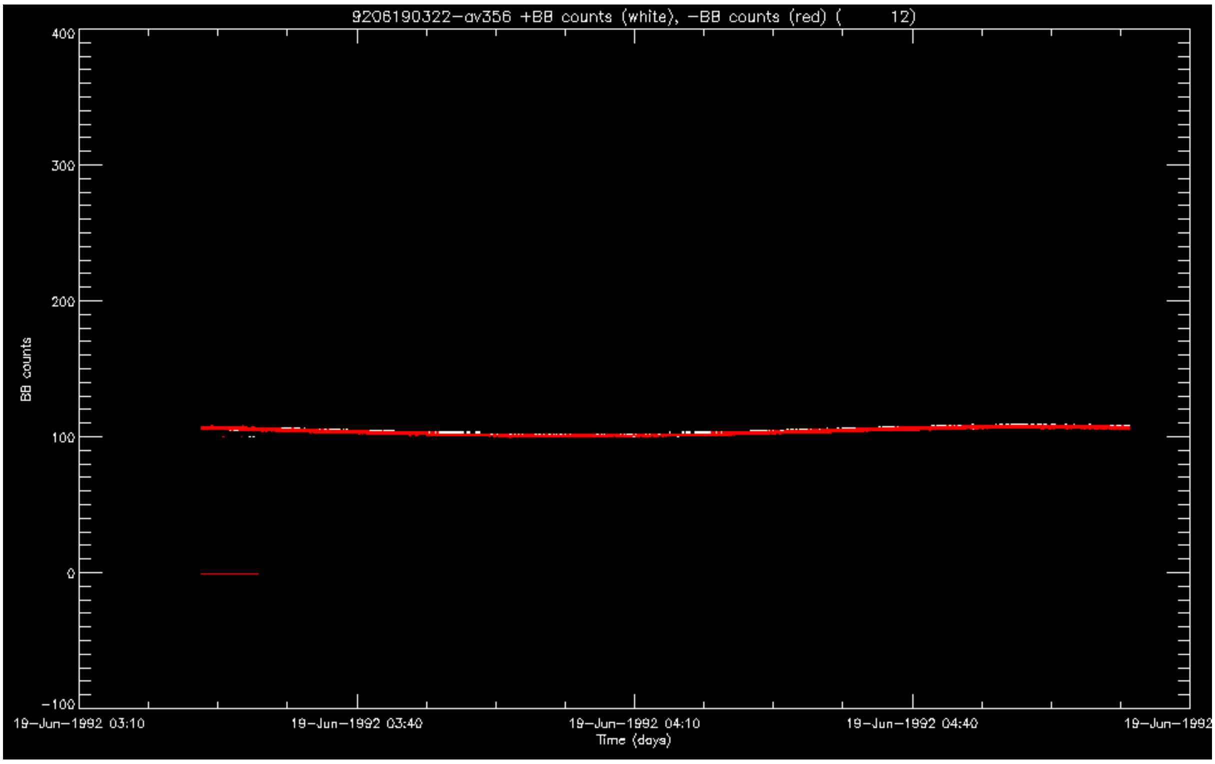

Figure 5: 1.6µm blackbody counts from 19-Jun-1992, 1 orbit.

Values for the blackbody counts, gains, offsets and detector temperatures from sample orbits in September 1991 and May 1992 were supplied to Dave Smith, who derived an algorithm to calculate the blackbody counts in the gap period.

The digital signals are converted to voltage at the input to the Signal Channel Processor (SCP) amplifier using the SCP Gain and Offset values from housekeeping data. The relationship between detector counts, gain, offset and detector voltage is:

Vdet = (10.0 / 4095.0 * DN) / (23.3 * Gain * 2.2) - 0.01685 * Offset

where Vdet is the detector voltage.

Vdet also depends on detector temperature, as shown in Figure 6 and Figure 7. A derived fit shows that the voltage dependence on temperature is as follows:

$V_{new} = a_0 + a_1 T_{det} + a_2 T_{de} t^2$

Where the fitted coefficient values are:
a0 = 0.032595740
a1 = -0.00073488893
a2 = 4.1961275e-06

The derived "dark signal" or cold blackbody detector counts are then given by

$DN_{new} = 4095.0 / 10.0 * ((V_{det,new} + 0.01685 * \text{offset}) * (23.3 * \text{gain} * 2.2))$

Figure 8 shows that the derived values typically agree with the measured blackbody counts to within +/-2 in general, for the available sample days.

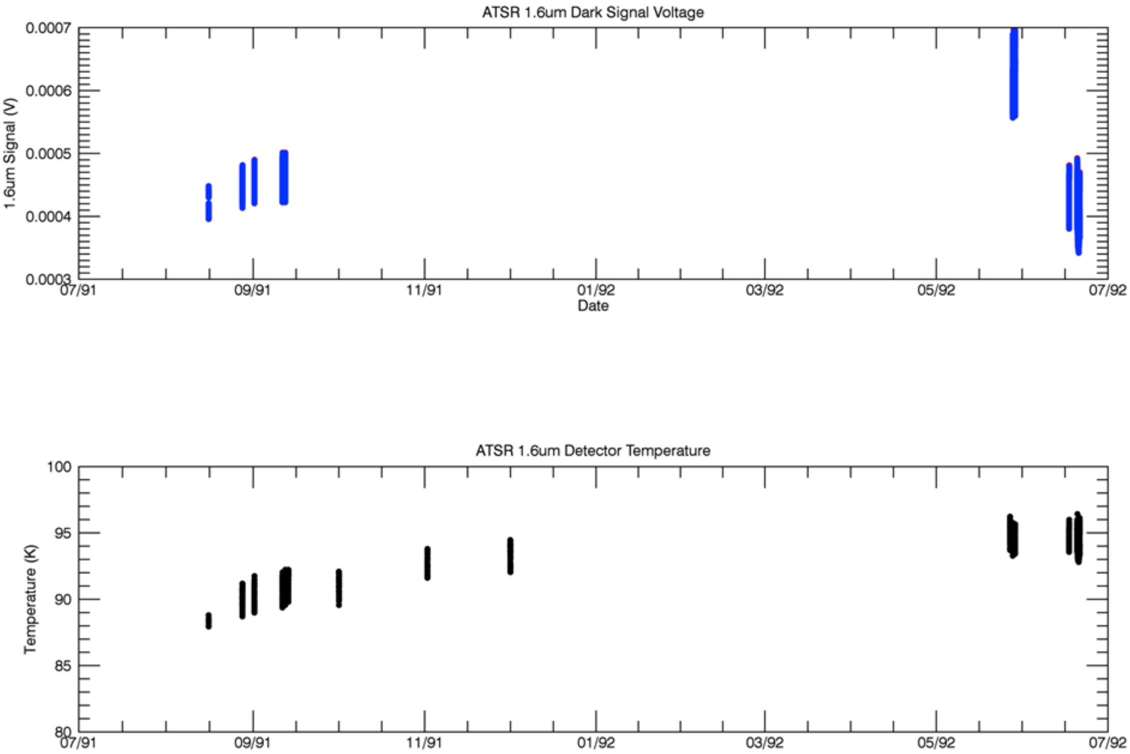

Figure 6: 1.6µm blackbody detector counts from sample days (top panel) and variation with detector temperature

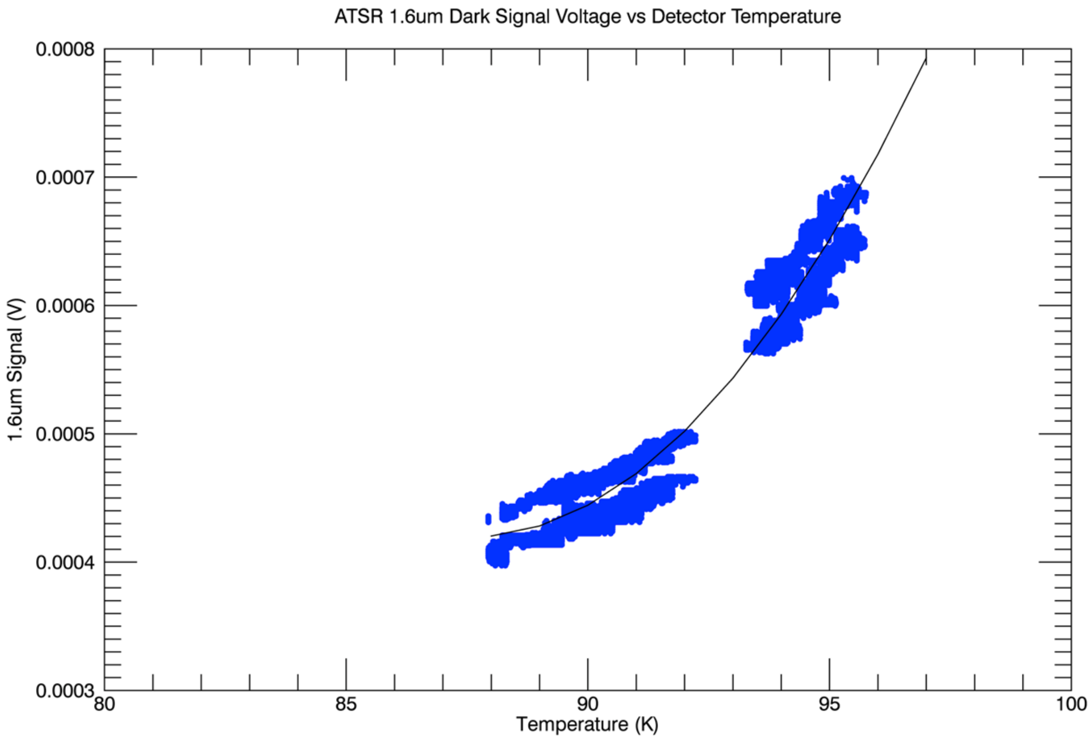

Figure 7: Detector voltage dependence on temperature, from sample 1991 data

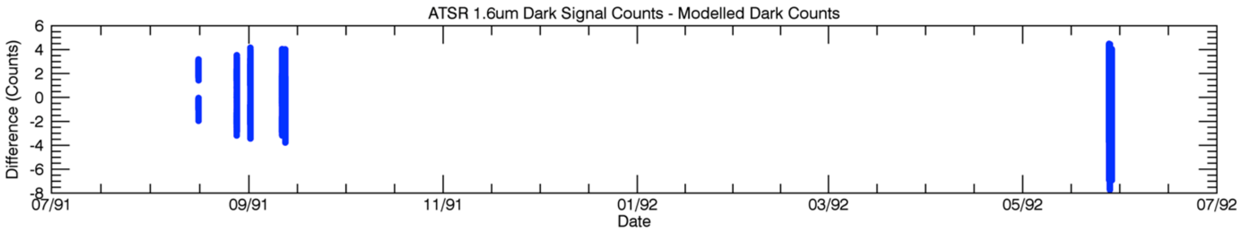

Figure 8: difference between derived and actual 1.6µm blackbody counts for sample days in 1991 and 1992

The SUPPLE code therefore needs modification to include the algorithm above, using the following telemetry values:

TM.Z562 – AT 1.6µm Det Temp
TM.Z258 – AT 1.6 Gain
TM.Z262 – AT 1.6 Offset

5.3 Modifications to SUPPLE and initial results

As an initial test, a constant value for the cold blackbody counts was inserted into the SUPPLE code to demonstrate that the resulting UBT product contained valid 1.6µm Earth-view data. From this test it was concluded that the blackbody counts were being inserted at the correct point in processing and that no additional values were needed.

The derived algorithm described above was then added to the SUPPLE processing code in a new function. The function includes a test on the source packet time so that 1.6µm cold blackbody values are replaced only within the affected period. For testing, the packet time test was omitted so that the derived blackbody data values would be output regardless of date, overwriting the measured values where present. The derived counts for 01-Sep-1991 and 28-May-1992 shown in Figure 9 and Figure 10 demonstrate that the algorithm reproduces the original count values well where the blackbody data are present, i.e. the derived cold blackbody values (red) closely match the measured warm blackbody values (white).

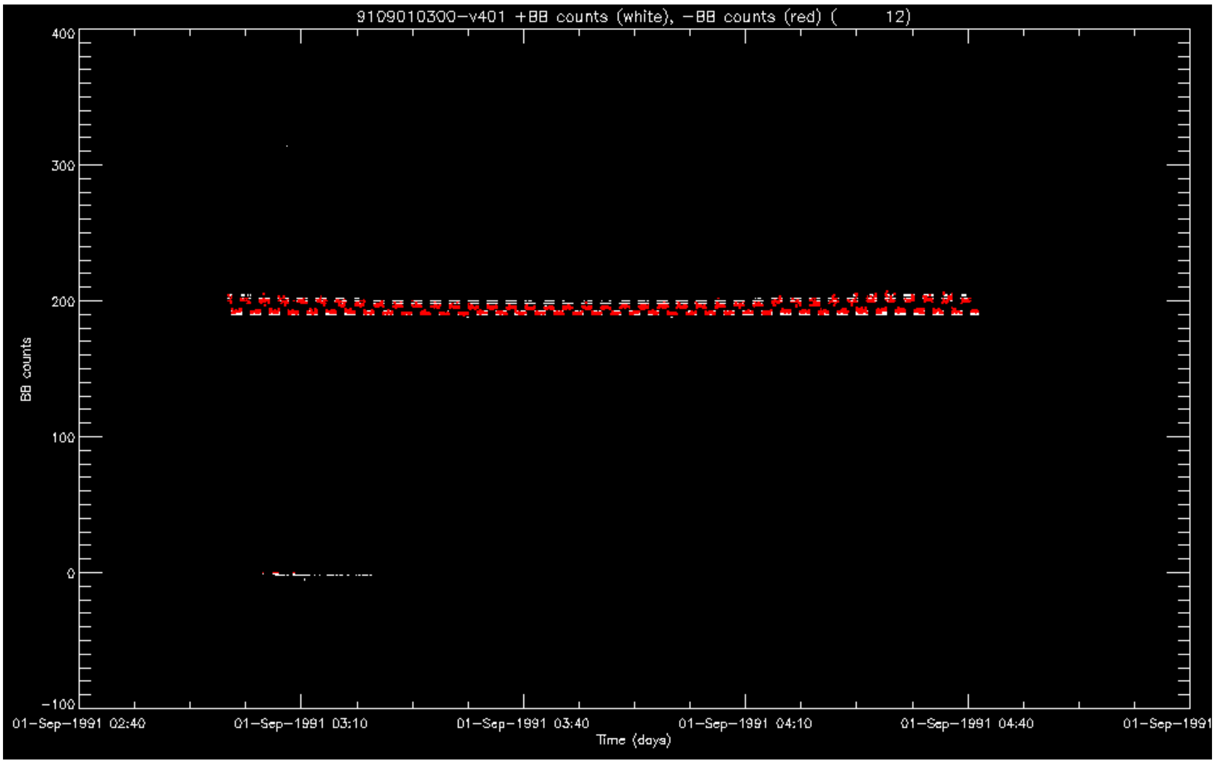

Figure 9: Derived 1.6µm cold blackbody counts (in red) from 01-Sep-1991 (1 orbit). Measured +BB values are shown in white. Processed by v401 development code; all cold blackbody values are derived.

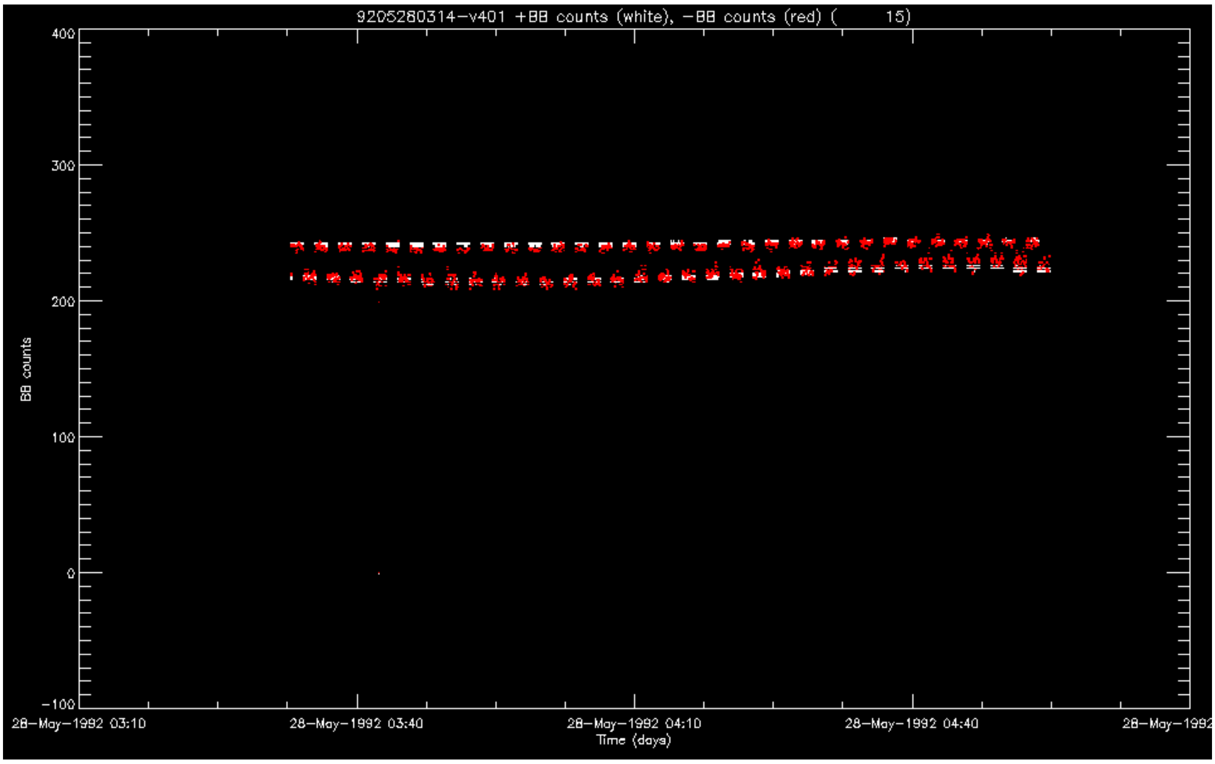

Figure 10: Derived 1.6µm cold blackbody counts (in red) from 28-May-1992 (1 orbit). Measured +BB values are shown in white. Processed by v401 development code; all cold blackbody values are derived.

In the period where measured cold blackbody counts are missing, the derived values are noticeably different from the earlier or later values, as shown by the data from 13-Sep-1991 in Figure 11. For the first part of the day measured blackbody values are present and the derived values are in the expected range. For the latter part of the day the warm blackbody values are missing, as shown by the points in white with small negative (flag) values, while the derived cold blackbody values are considerably lower than the previous points. As shown by Figure 12 the derived counts remain low throughout the missing data period, with another step change at the point where the measured counts data become available again in May 1992.

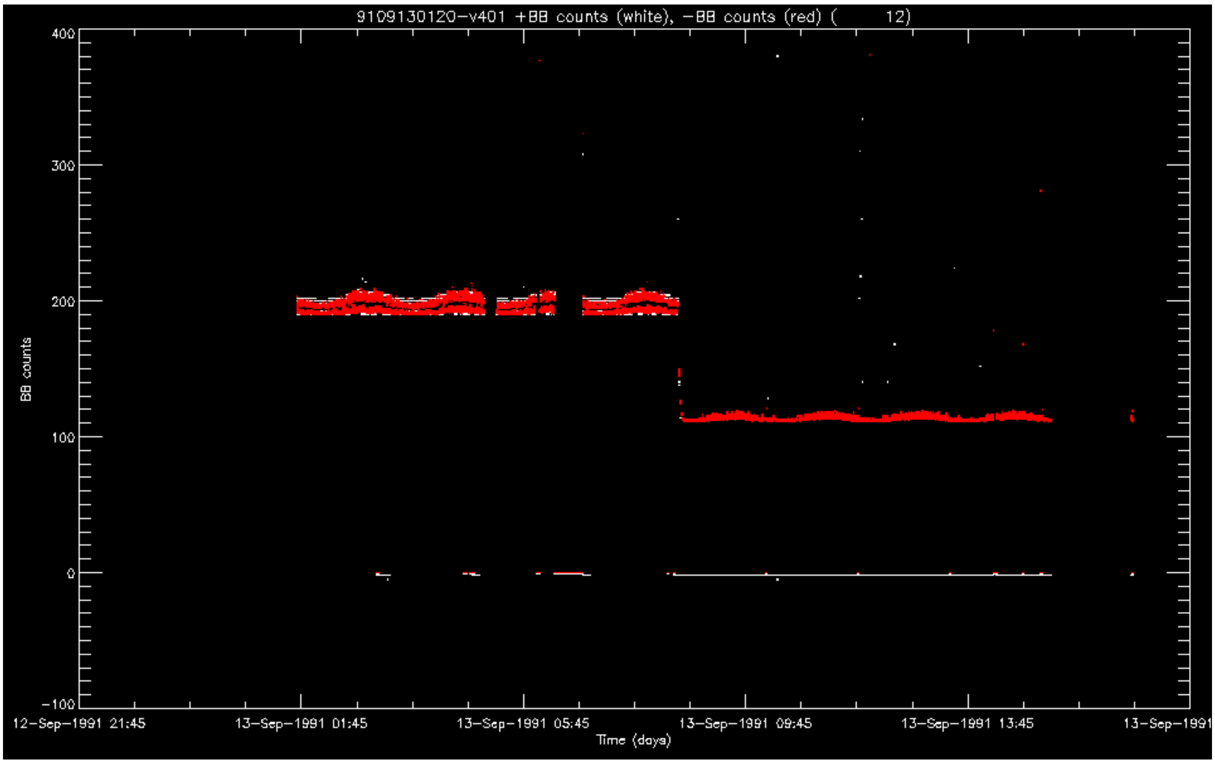

Figure 11: Derived 1.6µm cold blackbody counts (in red) from 13-Sep-1991 (full day). Measured +BB values are shown in white. Processed by v401 development code; all cold blackbody values are derived.

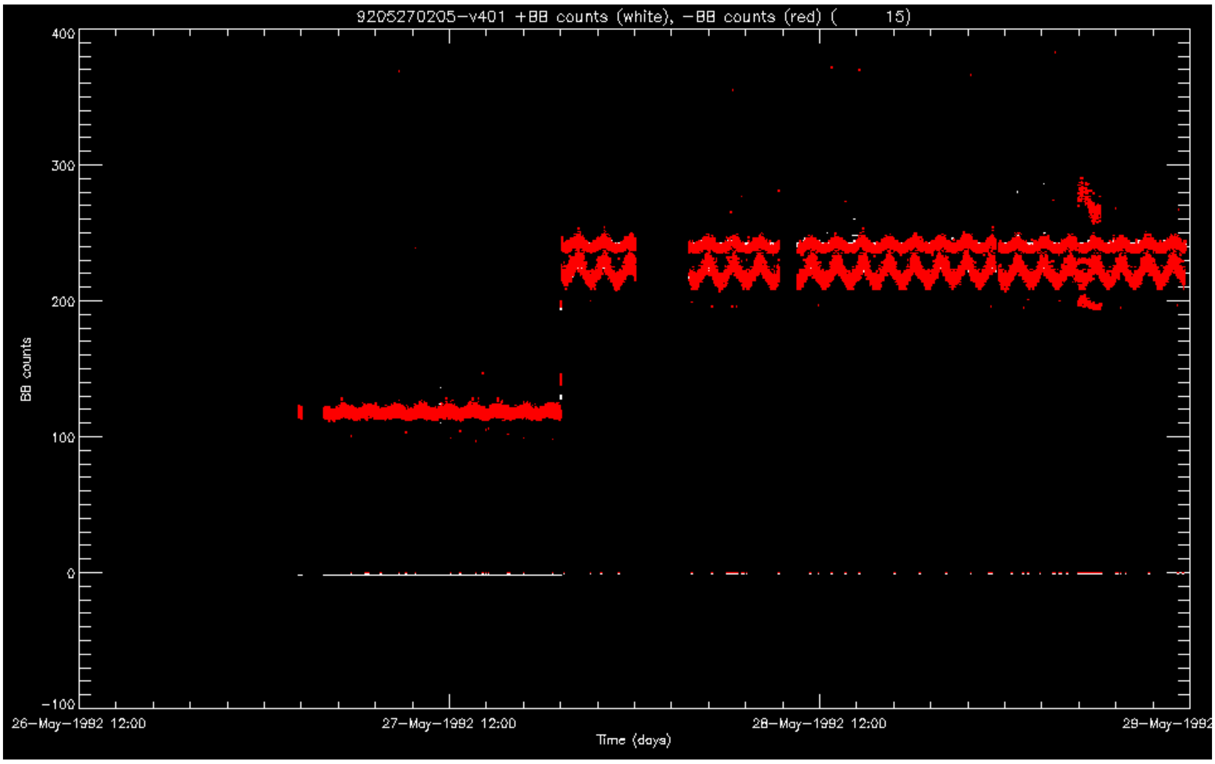

Figure 12: Derived 1.6µm cold blackbody counts (in red) from 27 to 29-May-1992. Measured +BB values are shown in white. Processed by v401 development code; all cold blackbody values are derived.

The gains and offsets for the two transition days were examined to try to determine the cause of the change in derived values during the gap period. The values are plotted in Figure 13 and Figure 14. Coincident with the change in derived blackbody counts on each day is a change in the gains, apparently indicating a switch from the auto-cal gain and offset setting (two traces for gains) to a fixed gain and offset.

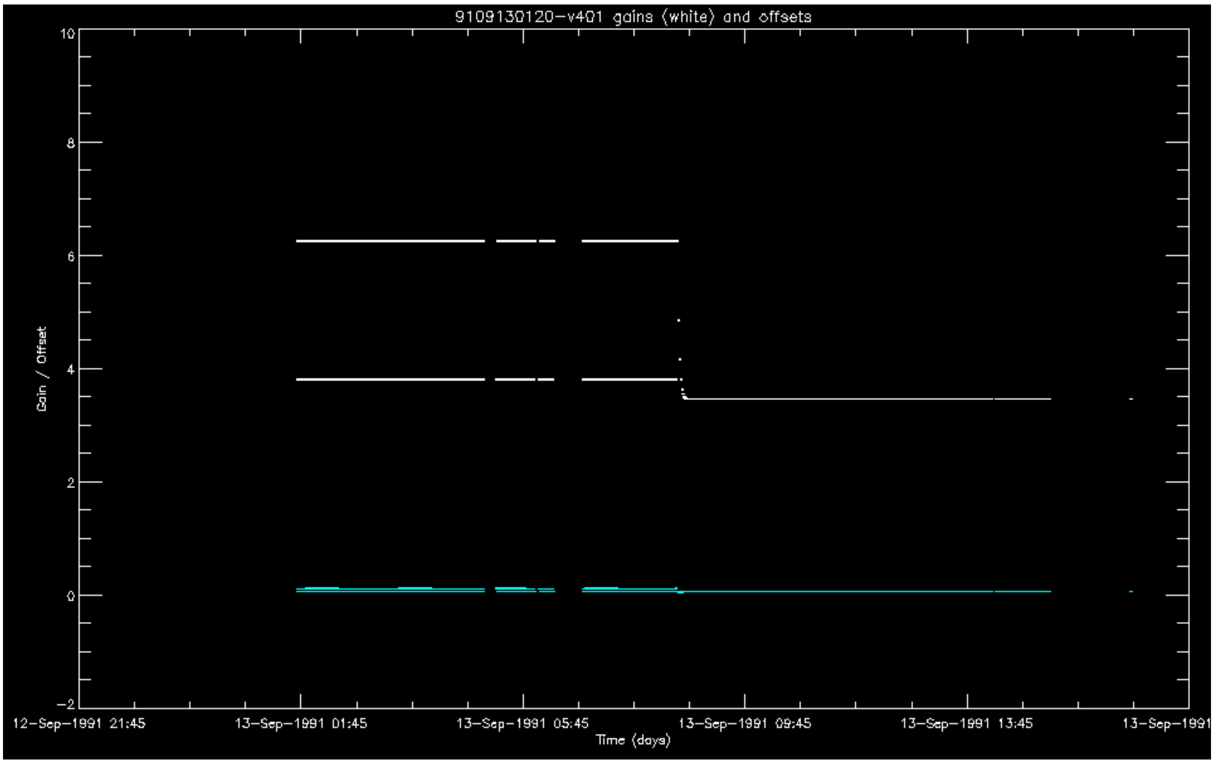

Figure 13: 1.6µm channel SCP gains (white) and offsets for 13-Sep-1991

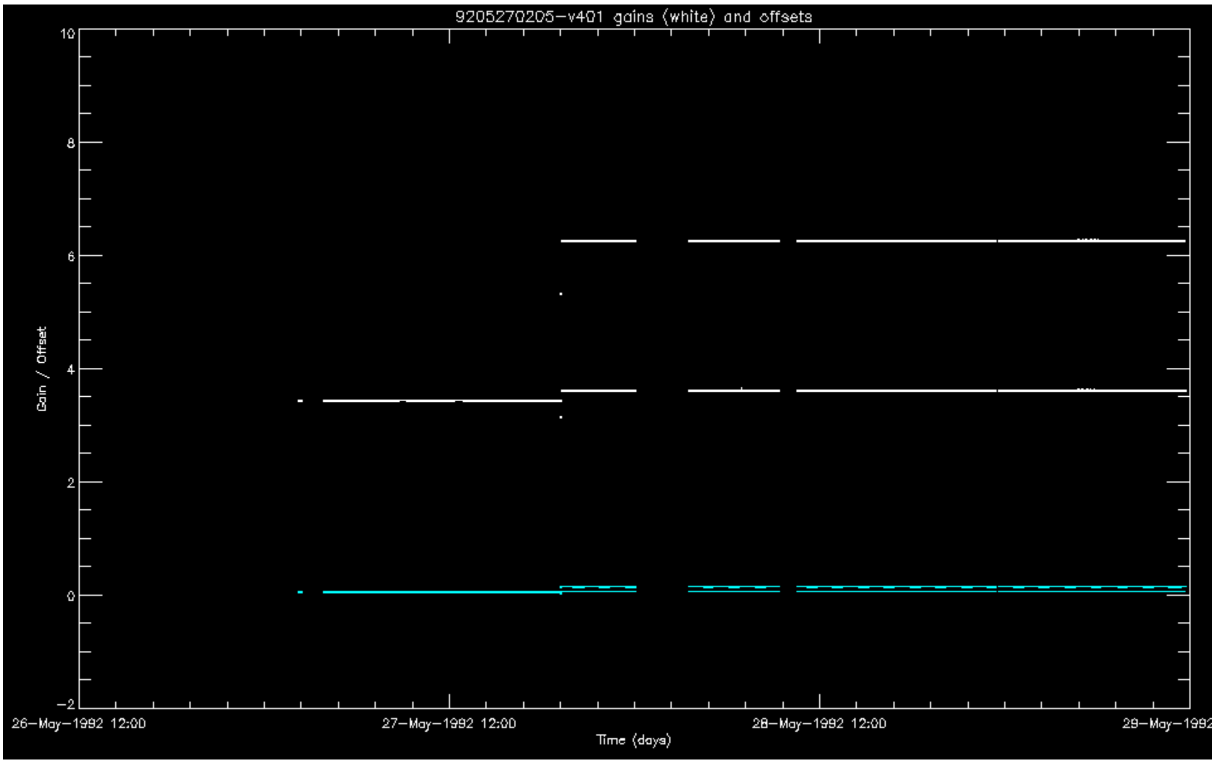

Figure 14: 1.6µm channel SCP gains (white) and offsets for 27 & 28-May-1992

The ATSR operations log book [AD 4] was subsequently located. Information noted on 13-Sep-1991 shows that work was being done on the 1.6µm and 3.7µm channels during this period. The following excerpts have been transcribed from the hand-written notes from 13-Sep-1991.

"John Delderfield concerned that when gain offset commands sent on 2 Aug (orbit 233) resulted in all signal channels given 0 counts in all channels.

Following deck of commands on TM sheets concluded that values given as decimal should have been hex."

(Followed by a summary of Gains and Offsets in the 3.7µm, 11µm and 12µm channels)

"Investigation of continuing IRRAD offscale history messages found that they are caused by auto-cal attempting to set 1.6 gain at a value < 100H. In this case auto-cal creates a history message and sets the gain to the default. Current configuration 3.7 gain 11, scaling factor 0.125.

To avoid anomaly" (followed by a calculation of a new minimum 1.6µm scaling factor)

"Command sent e:31:57

Scaling factor to 0.3125"

The timing of these commands is not recorded.

"Note, also high 1.6 gain (sent as default) caused background 1.6 counts to be ≈$204_{DEC,}$ higher than 1.6/3.7 threshold of 110. This means no 3.7 data getting through.

After command sent BB average count returned to normal 99 count. Should now be getting 3.7 data."

The following entry is "16:42 ERS-1 payload sent to STANDBY". The timing of this entry places an upper limit on the time of the commands above.

The two log lines above, which refer to background 1.6µm counts of approximately 204 and the average blackbody count "returned to normal" at approximately 99 counts appear to support the change seen in Figure 11. The "BB average count" referred to is presumably the mean cold blackbody radiance value, which is extracted directly from the telemetry item ICU 23 [AD 6] and written into each UBT detector record [AD 5]. Sample UBT products were checked and it was found that the mean cold blackbody radiance value is still present in the UBT data at times when the 1.6µm blackbody counts are absent from the pixel arrays. For sample orbits on 13-Sep-1991 the maximum and mean of the mean cold blackbody radiance values over an orbit were 204 and 196.24 at 06:21UTC and 101 and 99.47 at 09:42 UTC. N.B. the values do not appear to be present in the 06:21UTC orbit after approximately 07:10, whereas the blackbody pixel data are available until approximately 08:00. Nonetheless, this average count in telemetry varies in the same way as the derived counts and gives confidence that the step change in derived values is valid.

Further sample data checked on 27-May-1992, from the orbit at 18:51UTC shows that the mean cold blackbody radiance changes again from values close to 100, to approximately 240, with stepping of values as seen when the auto-cal is active.

The resulting UBTs generated with the synthesized blackbody counts are, of course, uncalibrated. It was therefore necessary to process to L1B products and compare the resulting values against existing, calibrated reflectances for known calibration sites.

5.4 Validation of derived reflectance values

A number of orbits in early January 1992 which include overpasses of known desert sites were selected. For these 16 orbits, the Level 0 data were processed to UBT using SUPPLE and the resulting UBT products were processed to Level 1B TOA products using the APP.

From the resulting Level 1B products it is possible to extract reflectance values over stable calibration sites used for ATSR calibration. Dave Smith, ATSR calibration scientist, has extracted top-of-atmosphere reflectance for two of these sites using RAL's vicarious calibration tools. The extracted reflectances were compared against corresponding data from the ATSR-1 archive that were used in earlier calibration analysis. There was good agreement between the derived and archived values, giving confidence in the update to SUPPLE, as shown in Figure 15.

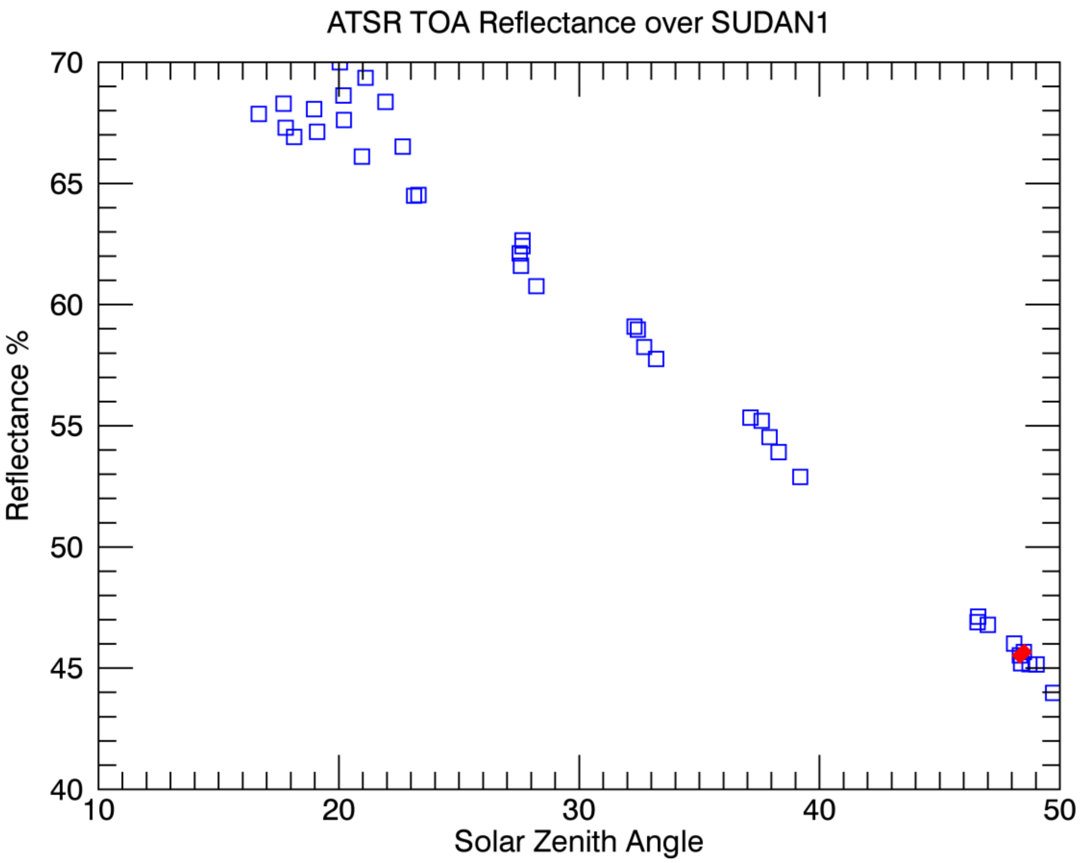

Figure 15: Comparison of derived ATSR-1 reflectance values over the “Sudan 1” calibration site in January 1992 (red points) with archived values for the same scene (blue squares).

5.5 Final updates to SUPPLE

Following validation of the reflectance values above, the change in the SUPPLE processor was finalised. The time range check before applying the blackbody count derivation algorithm was re-introduced. Smoothing was added in the derivation of missing blackbody counts, by checking validity flags and excluding packets for which the required temperatures, gains or offsets were 0 (during testing, cases were found where values of 0 within the source packet data were not flagged in the associated validation values). Figure 16 shows an example of the resulting derived blackbody counts for 27 to 29-May-1992, covering the end of the missing data period.

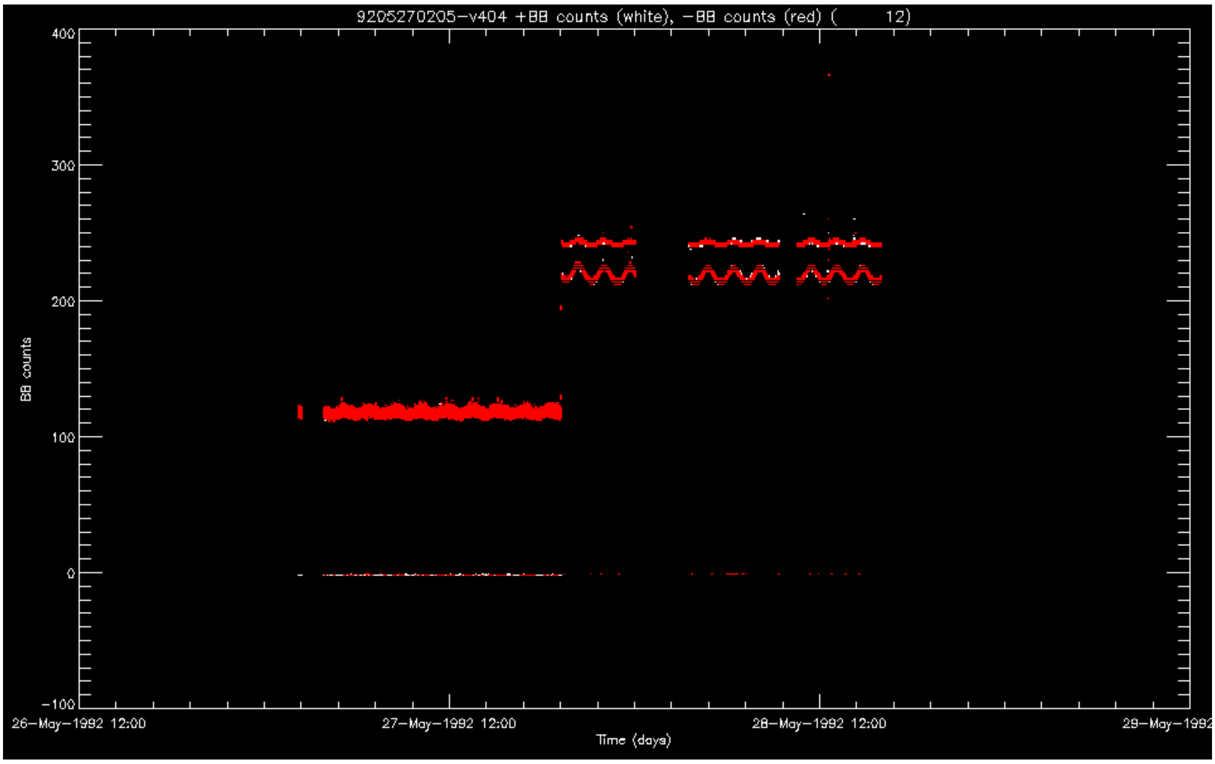

Figure 16: Derived and measured warm (white) and cold (red) blackbody counts from the final v404 update of the SUPPLE processor, for 27-29-May-1992.

Figure 17 shows an example of 11µm and 1.6µm nadir view images from a UBT product in January 1992, which falls during the gap period.

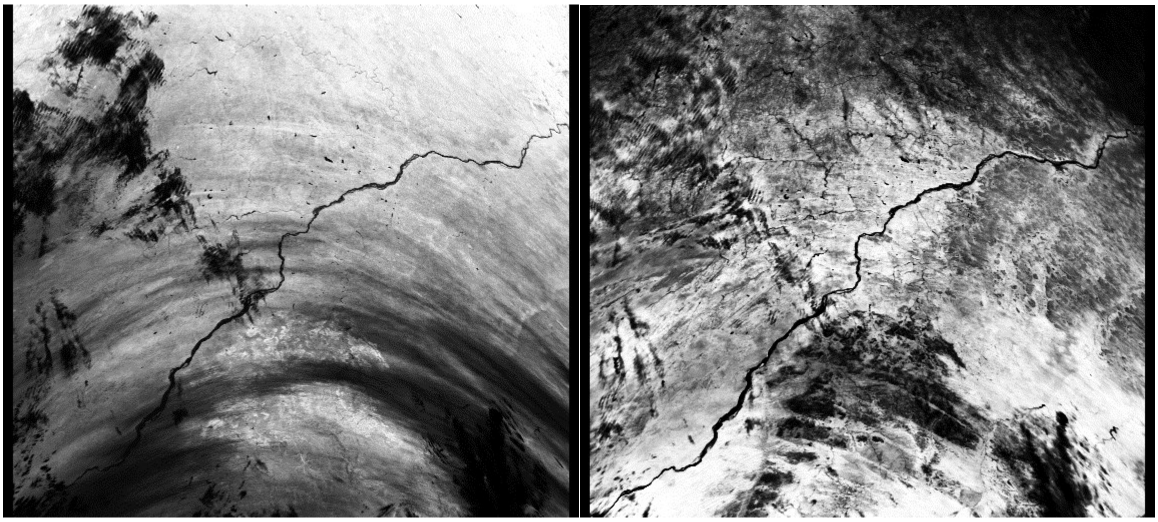

Figure 17: 11µm and 1.6µm nadir scenes from UBT product ralubt-9201020949-18159-161110-1v404.ubt-tl

6 Conclusions

An algorithm has been found which successfully reproduces measured cold blackbody values where they are available, before and after the missing data period. For the period within the data gap, a step change in derived cold blackbody counts is seen. Plots of gains and other data from this period suggest that there was a change in instrument configuration. The operations log [AD 4] confirms that commands were sent on 13-Sep-1991 to change the 1.6µm channel settings. The mean cold blackbody count telemetry values available from UBT products show a similar change to the derived counts, which gives further confidence in the derived values.

Reflectance values in Level 1B products generated from the derived blackbody counts have been validated and are in good agreement with measured values from other periods.

The algorithm has been integrated into the SUPPLE processor so that replacement cold blackbody values are derived within the missing data period, 08:35 13-Sep-1991 to 19:12 27-May-1992.

Level 0 data are available for this period from the ESA re-transcription performed in 2015-16. The Level 0 data set will be reprocessed to generate new UBT products.