

Creation and Testing Procedures for STIS CCD Bias Reference Files

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ABSTRACT

We describe the procedures that are (and have been) used to create STIS CCD Bias Reference files during HST Observing Cycles 7 and 8, as well as the testing procedures that are performed by the STIS team prior to delivering the Bias Reference files to the operational HST/STIS pipeline system (OPUS) and the HST archive. Currently (i.e., in HST Cycle 8), Bias Reference files in the nominal CCDGAIN=1, unbinned mode are delivered weekly, while less often used modes (CCDGAIN=1: 1x2 binning, 2x1 binning, 2x2 binning; CCDGAIN=4: 1x1 binning) are delivered biweekly. This high delivery frequency of Bias Reference files is needed to ensure a proper correction for the changing number and location of hot columns.

1. Introduction

STIS CCD Bias reference files are used in the **calstis** pipeline calibration to subtract the two-dimensional structure present in bias (zero-exposure time) images from CCD data, prior to cosmic ray rejection, dark subtraction and flatfielding. In the context of the **calstis** software, this calibration step is called **BIASCORR**, which is performed in the *calstis1* module (described in STIS Instrument Science Report¹ 98-26, Hodge, Baum & Goudfrooij 1998). Within the IRAF/STSDAS package **stdas.hst_calib.stis**, the *calstis1* module is performed by means of task **basic2d**, the use of which is described in STIS ISR 98-14 (Katsanis et al. 1998).

This document presents to the HST user community the issues relevant to creating proper STIS CCD bias reference files. Details of the procedures used to create the reference files are also described. Finally, an outline of the tests performed prior to their delivery to the STIS pipeline system is given.

1. Hereafter referred to as ISR

2. The Structure of STIS CCD Bias Files and its Evolution in Time

In this Section, we briefly describe the structure of STIS CCD bias files and discuss the need for updates to the bias reference files on a rather short time scale to enable a proper basic CCD reduction.

2.1. The Two-Dimensional Structure of STIS CCD Bias Files

The global two-dimensional structure of STIS CCD bias files has been extensively described and illustrated in STIS ISRs 97-09 (Goudfrooij & Walsh 1997) and 98-31 (Goudfrooij 1998). A summary of the different structures is itemized below.

1. **A global ramp (i.e., of low spatial frequency) along the columns**, which is (at least partly) due to accumulative spurious charge, which starts to accumulate at row #512 (in unbinned images). This effect is more pronounced in CCDGAIN=4 than in CCDGAIN=1 images. The ramp along columns in the sensitive region of the CCD is *NOT* present in the leading (i.e., left-hand² side) serial overscan region (which is used for bias level correction within the STIS pipeline, represented by the BLEVCORR step in *calstis1*), which is one of the main reasons why an additional 2-D bias correction is necessary. However, the ramp does not show any variation with time (see STIS ISR 98-31).
2. **A global ramp along the rows**, which is consistent with that found in the parallel overscan, so that it is corrected for in the BLEVCORR step in *calstis1*.
3. **A “roll-off” at the right-hand edge of the sensitive region of the CCD**, which is *not* corrected for in the BLEVCORR step in *calstis1*.
4. **Hot columns** which are due to charge traps caused by hot pixels during read out. The locations and the relative intensities of many of these hot columns have been found to change with time (see below). This is due to the fact that the number of hot pixels has been increasing with time (see STIS ISR 98-06, Hayes, Christensen & Goudfrooij 1998) and that the locations of hot pixels on the CCD change with time (e.g., after CCD anneals).

2.2. Science Requirements for STIS CCD Bias Reference Files

2.2.1. Signal-to-Noise Ratio Requirement

Due to the structures enumerated as 1), 3) and 4) above, a two-dimensional bias image correction is necessary for a proper reduction of STIS CCD data (Goudfrooij & Walsh 1997). As such, the bias reference files used within the STIS pipeline should have a signal-to-noise ratio (hereafter S/N) per pixel that is high enough so as to render its influence to the effective noise of the output pipeline product negligible. We emphasize that achieving this goal is not as trivial as it may seem. In the case of unbinned CCDGAIN=1 data, for

2. Orientations/coordinates are given with respect to the coordinate system of in-flight images.

instance, the read-out noise is $4.0 \text{ e}^-/\text{pixel}$ (e.g., Kimble et al. 1998; Goudfrooij 1998), while the median level of a two-dimensional superbias image (after overscan subtraction) is $\sim 0.40 \text{ ADU}$. Thus, in order to render the effective RMS noise per pixel in such a superbias to equal its intensity level and thus raise the effective noise of CCD data by a negligible amount only, one needs to combine at least $(4.0/0.40)^2 \sim 100$ bias frames together. As the opportunities for taking STIS CCD bias frames are limited and the structure of bias images is different for different binning factors and gain settings (i.e., bias reference files have to be produced for all different supported gain and binning settings; cf. Goudfrooij & Walsh 1997), this obviously sets a constraint on the frequency of bias reference file updates. We list the number of bias files to be combined together to achieve this S/N requirement in Table 1 for all supported gain and binning settings.

Table 1. Number of STIS CCD bias frames to be combined together in order to obtain $S/N = 1$ per pixel for superbias images taken in all supported gain and binning settings.

CCDGAIN setting	Binning	Read-out Noise Per Pixel (ADU)	Median Intensity Level in Bias Frame (ADU)	Number of Frames needed to obtain $S/N = 1$ per Pixel
1	1x1	4.0	0.40	100
1	1x2	4.0	0.64	39
1	2x1	4.0	0.65	38
1	2x2	4.0	1.19	11
1	4x1	4.0	1.19	11
1	4x2	4.0	1.86	5
4	1x1	1.89	1.45	2

2.2.2. The Need for Frequent Bias Reference File Updates

The hot columns (item 4 in Section 2.2 above) change with time in a way similar to that of the “hottest” hot pixels, which are the ones that cause the charge traps. In the following, we define the term “hot pixels” to mean “pixels with a dark current $> 10 \text{ e}^-/\text{s}$ ”. The rate at which the number of these hot pixels grows *between CCD anneals* is about 0.5 per day for the STIS CCD (Hayes, Christensen, & Goudfrooij 1998). Thus, one can expect new hot columns to appear at a rate of $\sim 3\text{-}4$ per week between anneals. Furthermore, the monthly anneals anneal out 15 (± 5)% of these hot pixels. With this in mind, the decision was taken (early in Cycle 7, a few months after STIS science verification) that reference files which correct for hot pixels and columns be produced with a frequency of once a week. During Cycle 7 operations, this correction was performed by means of weekly deliveries of *dark* reference files³ rather than biases, which is similar to the solution devised by the

WFPC2 instrument team (see, e.g., Burrows 1994; Holtzman et al. 1995). The bias reference files were produced by averaging an adequate number of bias files together (cf. Table 1), and eliminating any hot pixels and columns present in the averaged superbias (using the “basebias” procedure; the procedures/algorithms used to produce bias reference files are detailed in Section 3. See also Goudfrooij 1998). However, it has recently become apparent that this solution produces significant residuals at the locations of hot columns in pipeline-calibrated STIS CCD data, especially in case of short exposures. After analysis of a suite of CCD images and spectra taken using a suitable range of exposure times and instrument configurations, we have concluded that there are two main reasons for these “hot column residuals”:

1. The “hottest” hot pixels actually saturate in dark exposures, so that those hot pixels and the hot columns they produce are not well corrected for in case of science images with exposure times shorter than those of the dark files⁴.
2. The structure of hot columns is different for different gain and binning settings, whereas dark exposures have only been taken in the CCDGAIN=1, unbinned mode⁵.

With this in mind, we recently (May/June 1999) decided to investigate the alternative solution: Using *weekly bias* reference files to correct for hot columns during **calstis** pipeline reduction. As an illustration of the changing appearance of hot columns in bias frames with time, we depict two superbias (cosmic-ray-rejected averages of ~100 biases) taken in the CCDGAIN=1, 1x1 binning mode in Figure 1: One constructed from bias frames taken during September - November 1997, and one constructed from bias frames taken during July 1999. *The result of using weekly bias and dark reference files (instead of only weekly darks) turned out to improve the cosmetic appearance of pipeline-reduced images and spectra quite significantly.* This is illustrated in Figure 2, which shows a comparison between a STIS 50CCD image of a region in the outskirts of the globular cluster ω Cen reduced using (a) a weekly superdark only, and (b) a weekly superbias and a weekly superdark. Notice the improvement in the correction of the hot columns.

3. An ISR on the creation and testing of STIS CCD Dark Reference Files is in preparation.

4. One way to avoid this problem might seem to be the use of “daily darks”, which are taken daily with a short exposure time (these can be retrieved by the user from the HST archive to make daily updates to the hottest pixels in STIS CCD darks. To this end, a STSDAS task **daydark** is available in the **stdas.hst_calib.stis** package. See the STIS instrument WWW pages for details). However, these daily darks have a S/N that is insufficient for use in the *regular pipeline* processing.

5. We will take CCD darks in 2x2 binning mode as well within the STIS Cycle 8 calibration program.

Figure 1: Greyscale comparison of an unbinned superbias frame taken in CCDGAIN=1 during September - November 1997 (top) with one taken during July 1999 (bottom). Grey-scale cuts were set at 90% (white) and 700% (black) of the median bias level, using a linear stretch. Notice the significant change in appearance of the hot columns.

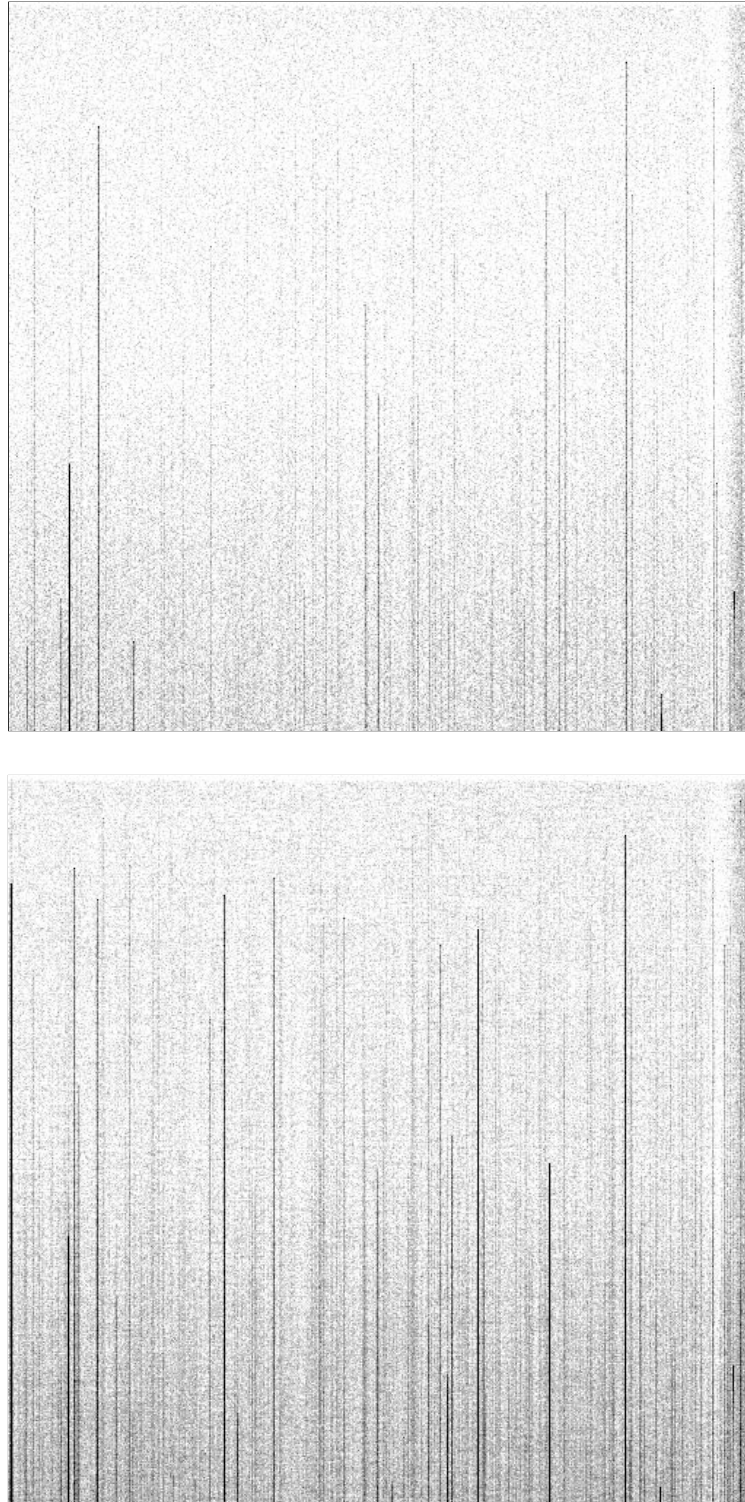
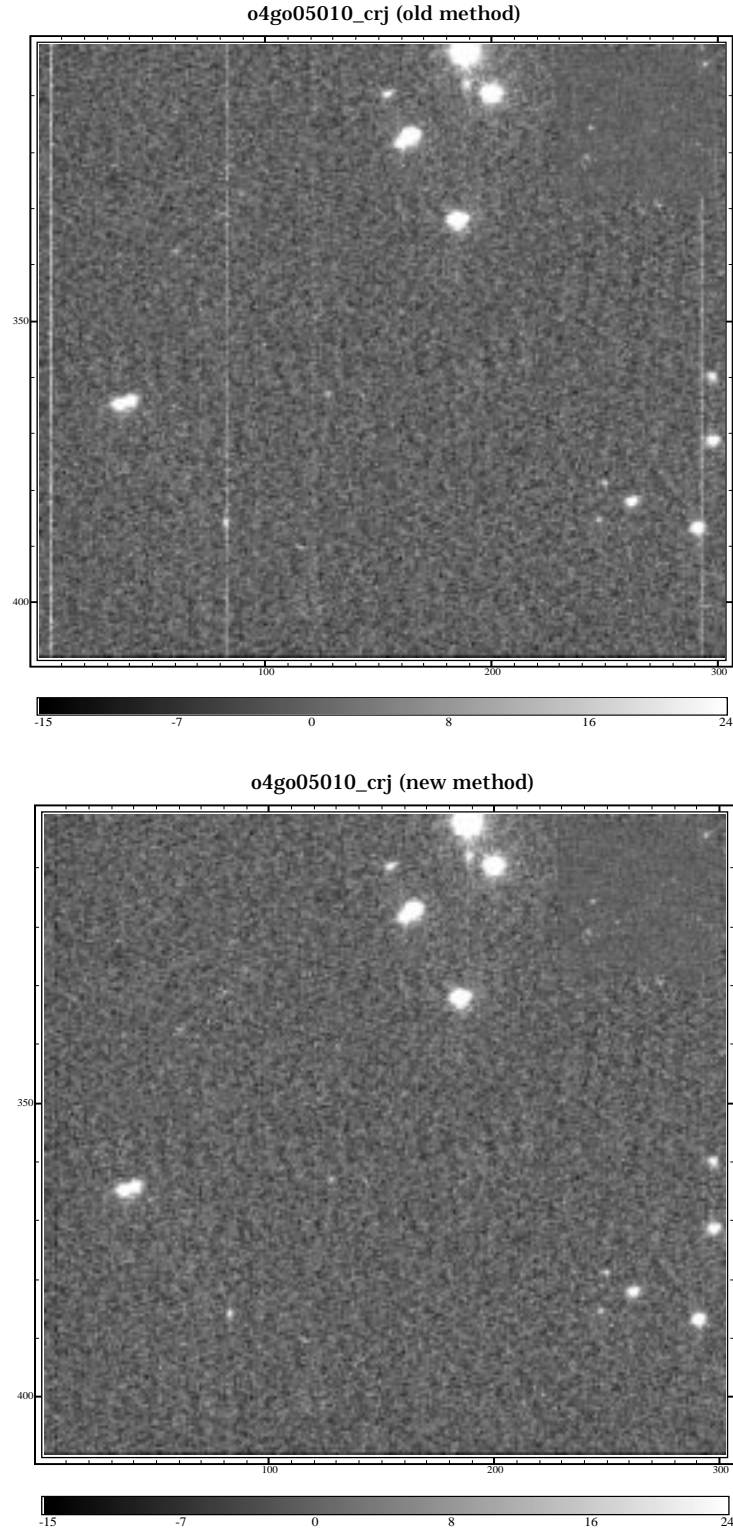


Figure 2: Comparison of (part of) a STIS CCD image of a sparse star field in the outskirts of the globular cluster ω Cen reduced (a, upper) using a weekly dark reference file, and (b, lower) using both weekly bias and dark reference files. Notice the significant improvement in cosmetic appearance resulting from the use of weekly bias reference files.



The number of bias frames taken per week during Cycles 7 and 8 are listed below in Table 2 for supported gain and binning settings. Examination of Table 2 shows that prior to July 1999 (i.e., the start of HST Cycle 8), the number of bias frames taken per week is clearly insufficient to create weekly superbias with a S/N per pixel high enough for use in the standard pipeline (cf. Table 1), which is the reason why the STIS group decided to increase significantly the frequency of CCD bias frames taken per week in Cycle 8 (see Table 2). This difference in bias-taking frequency causes the need for different strategies for weekly superbias production, which are described in the next section.

Table 2. Number of bias frames taken per week in bias monitoring programs during HST Cycles 7 and 8 for supported gain and binning settings.

CCDGAIN setting	Binning	Proposal ID	Execution Dates	Number of Bias Frames taken per Week
1	1x1	7092	03/1997 - 06/1997	5
		7601	06/1997 - 12/1997	5
		7926	02/1998 - 05/1998	5
		7948, 7949	05/1998 - 06/1999	14
		8409, 8439	07/1999 - 07/2000	98
1	1x2	7930	04/1998 - 05/1999	31 every 80 days
		8409, 8439	07/1999 - 07/2000	14
1	2x1	8409, 8439	07/1999 - 07/2000	14
1	2x2	8409, 8439	07/1999 - 07/2000	14
4	1x1	7092	03/1997 - 06/1997	2
		7601	06/1997 - 12/1997	2
		7926	02/1998 - 05/1998	2
		7948, 7949	05/1998 - 06/1999	14
		8409, 8439	07/1999 - 07/2000	21

3. The Creation Procedures for STIS CCD Bias Reference Files

The creation of STIS CCD bias reference files involves the use of a number of procedures which are provided in the form of IRAF CL scripts (which are for STScI internal use only). The script names involved in the process as a function of observing date, gain and binning is summarized below in Table 3.

Table 3. Listing of IRAF CL scripts used for creation of bias reference files, as a function of CCDGAIN, observing date, and binning, for supported gain/binning combinations.

CCDGAIN setting	Binning	Observing Date	CL Scripts used for creating Bias Reference File	Reference File Delivery Frequency
1	1x1	03/1997 - 06/1999	weekbias	weekly
		07/1999 -	refbias^a	weekly
1	1x2	03/1997 - 06/1999	refbias	3-monthly
		07/1999 -	refbias	biweekly
1	2x1	03/1997 - 06/1999	refbias	6-monthly
		07/1999 -	refbias	biweekly
1	2x2	03/1997 - 06/1999	refbias	6-monthly
		07/1999 -	refbias	biweekly
1	4x1	03/1997 -	refbias	6-monthly
1	4x2	03/1997 -	refbias	6-monthly
4	1x1	03/1997 - 06/1999	refbias	6-monthly
		07/1999 -	refbias	biweekly

a. Sometimes **weekbias** is used instead of **refbias** for this mode, namely in case an anneal occurs within a certain week so that fewer bias frames are taken during that week. See Section 4 for more information on this issue.

Notice that starting in July 1999 (i.e., Cycle 8), the frequency of bias reference file deliveries has become weekly or bi-weekly for all CCDGAIN and binning settings. This frequency is appropriate to sample the typical timescale within which the number of hot columns changes, as mentioned before. However, since the different CCDGAIN/binning combinations require different numbers of bias frames averaged together to form reference files with high enough S/N (cf. Table 1), the *choice of procedures/scripts to be used* to create those reference files for a given CCDGAIN/binning combination depends on the bias-taking frequencies, cf. Table 2.

The descriptions of the three scripts used for bias reference file creation are detailed below.

The REFBIAS script

This script represents the simplest procedure to create STIS superbias files. The input parameter set for this script is shown below.

```
inbiases = ""           Input bias(es) to be combined
(reffile = "refbias_bia") Name of output reference bias frame
(maxiter = 30)         Maximum number of iterations for imstat
  (lower = INDEF)      Initial lower limit for imstat
  (upper = INDEF)      Initial upper limit for imstat
(verbose = no)         Show results of imstat iterations?
  (print = no)         Print final results of imstat iterations?
(imglist = "")         Internal use only, do not edit
(Version = "15Oct99") Date of Installation
  (mode = "al")
```

The **refbias** procedure works as follows. After joining the raw input bias files (parameter **inbiases**) together into a multi-imset file, overscan subtraction is performed for every individual bias frame. The bias frames in the multi-imset file are then combined using **ocr-reject**, which performs a three-step iterative cosmic-ray rejection with rejection thresholds of 5, 4, and 3 sigma, respectively. After cosmic ray rejection, the combined bias is divided by the number of frames combined (**ocrreject** adds images instead of averaging them), using the **msarith** task in the **stdas.toolbox.imgtools.mstools** package. Subsequently, hot pixels (and columns) are identified as follows. A median-filtered version of the averaged bias is created (kernel = 15 x 3 pixels) and subtracted from the averaged bias, leaving a "residual" image containing hot pixels and columns. The pixels hotter than 5 sigma of the effective RMS noise in the residual bias image are then identified, and flagged as such in the Data Quality (DQ) extension of the output reference bias file. Finally, the main header of the output file is made compatible with use in the operational HST/STIS pipeline (OPUS) and filled with the appropriate keywords. For quality control purposes, the following extra output files are created:

- Three ASCII text files containing the statistics of the full image: one for the science [SCI] extension, one for the error [ERR] extension, and one for the DQ extension;
- Two PostScript plots showing (1) the structure of the bias frame averaged along columns, and (2) the structure of the bias frame averaged along rows. The plotting ranges are fixed for any combination of CCDGAIN and binning factors to ease comparisons with the plots of superbias frames created previously.

The other input parameters of the script (**maxiter**, **lower**, **upper**, **verbose**, **print**) are included to allow the user to override the defaults used in the iterative statistics that are performed within the script to neglect hot pixels and columns in the calculation of the mean level and standard deviation (σ) of the (averaged) superbias file(s). The default settings for these parameters typically do not need adjustment, however.

The **refbias** script is intended for creating bias reference files for CCDGAIN/binning combinations that are taken with a high enough frequency to render the S/N per pixel high enough at the median intensity of the bias. It is currently used to create weekly bias reference files for the CCDGAIN=1, 1x1 binning case, and biweekly bias reference files for the CCDGAIN=1, 1x2, 2x1, and 2x2 binning cases.

The BASEBIAS script

This script⁶ is used to create high signal-to-noise superbias frames from which hot pixels or columns are removed. The resulting superbias frames are *not* delivered as reference files (hence the fact that this script is not mentioned in Table 3 above). Instead, they are used as a “baseline” into which hot columns are inserted by means of the **weekbias** script (cf. below). This procedure is typically run every month to average together bias files taken during that month. Then each 6 months, the six monthly superbias are averaged together to create a “baseline” superbias for the next 6 months. The input parameter set for the **basebias** script is shown below.

```

inbiases = ""           Name of input bias image(s)
(reffile = "baseref_bia") Name of output reference bias frame
(maxiter = 30)         Maximum number of iterations for imstat
  (lower = INDEF)      Initial lower limit for imstat
  (upper = INDEF)      Initial upper limit for imstat
(verbose = no)         Show results of imstat iterations?
  (print = no)         Print final results of imstat iterations?
(imglist = "")         Internal use only, do not edit
(Version = "15Oct99")  Date of Installation
  (mode = "al")

```

The way this script works is quite similar to the **refbias** script described above, with one important difference: The hot pixels and columns are not only identified and flagged as such in the DQ extension, but their values are actually *replaced* by the corresponding pixel values in the median-filtered superbias. This allows one to average several output superbias together (over time) in order to create very high S/N superbias that represent the structure of the bias frames *underlying the hot pixels and columns*.

The **basebias** script is intended to create such high S/N “baseline” superbias for the CCDGAIN/binning combinations that need their bias reference files created using the **weekbias** script, i.e., those that are taken with a frequency not high enough to provide S/N = 1 per pixel at the median intensity of the bias after averaging the biases taken during 1-2 weeks together (see below for more information on the **weekbias** script).

6. NOTE: This script was actually called **refbias** prior to our re-vamping of the reference file-creating procedures in July 1999 (see, e.g., Goudfrooij 1998).

The WEEKBIAS script

This script was heavily used prior to July 1999, to create weekly biases for the CCD-GAIN=1, 1x1 binning case. It is currently only occasionally used to create weekly bias reference files, namely during weeks in which an anneal occurs (see Sect. 4). Its input parameter set is shown below.

```
inbiases = ""           Input bias(es) to be combined
basebias = ""          Name of baseline superbias
(reffile = "weekbias_bia") Name of output reference bias frame
(hotcolfile = "hotcols.dat") Name of output file to contain the hot columns
(maxiter = 30)         Maximum number of iterations for imstat
(lower = INDEF)        Initial lower limit for imstat
(upper = INDEF)        Initial upper limit for imstat
(verbose = no)         Show results of imstat iterations?
(print = no)           Print final results of imstat iterations?
(imglist = "")         Internal use only, do not edit
(Version = "15Oct99")  Date of Installation
(mode = "al")
```

The **weekbias** procedure works as follows. After joining the raw input bias files (parameter **inbiases**) together into a multi-imset file, overscan subtraction is performed for every individual bias frame. The bias frames in the multi-imset file are then combined using **ocrrreject**, which performs a three-step iterative cosmic-ray rejection with rejection thresholds of 5, 4, and 3 sigma, respectively. After cosmic ray rejection, the combined bias is divided by the number of frames combined (**ocrrreject** adds images instead of averaging them), using the **msarith** task in the **stdas.toolbox.imgtools.mstools** package. Subsequently, hot columns are identified as follows. A median-filtered version of the averaged bias is created (kernel = 15 x 3 pixels) and subtracted from the averaged bias, leaving a "residual" image containing hot pixels and columns. The lower 20% of the rows in this residual image (i.e., the rows that are furthest away from the read-out amplifier in use and thus harbor most of the hot columns) were subsequently averaged together into a 1-D image from which the columns hotter than 5 sigma above the effective RMS noise on the averaged bias were identified (the hot columns are mentioned in an output ASCII file (parameter **hotcolfile**)). Finally, the pixel values in those identified columns of the "residual" image are added into a "baseline" superbias image (parameter **basebias**), from which the hot columns had been eliminated using the **basebias** script (which was described above).

4. Avoiding Anneals in Creating STIS CCD Bias Reference Files

All bias reference files that are delivered weekly are created from bias files taken *between CCD anneals* (which occur monthly). The reason for this is that the CCD anneals cause a significant drop in the number of hot pixels (and columns). The (minor) disadvantage of this policy is that there will be fewer bias frames taken during the week in which an anneal

occurs than during other weeks, so that the S/N per pixel may become too low when using **refbias** to create bias reference files for the anneal-impacted weeks. Under these circumstances, **weekbias** is being used instead of **refbias** to ensure high S/N.

5. Testing Procedure for STIS CCD Bias Reference Files

Prior to delivering bias reference files to the operational HST/STIS pipeline system (OPUS) and the HST archive, the following tests are performed on the to-be-delivered files:

1. The iterative statistics of the SCI, ERR, and DQ extensions are checked against each other and against those of previously delivered bias reference files;
2. The image headers are checked for the occurrence of any unwanted strings (using unix command **less**);
3. The values of the FITS keywords in the main image header are checked for correctness.;
4. FITS compatibility is verified;
5. The FITS file is checked for *formal* compatibility with the OPUS pipeline system;
6. The FITS file is run as if it already were a reference file in the pipeline to verify (a) its compatibility and (b) the scientific correctness of the results.

These tests are performed by means of automatic procedures. To ease the process of evaluating the correctness of the files to be delivered to OPUS, all reference bias image statistics mentioned above are appended to files (one file for each CCDGAIN/binning combination) that contain such information for all STIS CCD bias reference files delivered to date.

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