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Validation of Reduced Operate Anneal Mode in the Advanced Camera for Surveys Wide Field Channel

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Abstract

Since installation aboard the Hubble Space Telescope (HST) in 2002, the Advanced Camera for Surveys (ACS) undergoes a monthly annealing process that is effective in reducing dark current in the Wide Field Channel (WFC) pair of CCD detectors. After failing to return to operate mode following two completed anneals in early 2019, ACS suffered back to back safing events. As a result, a new Reduced Operate Anneal (ROA) mode was implemented in October 2019 to avoid future reboot failures. In this report, we investigate the effects of the newly instated ROA mode through an analysis of two different sets of pre- and post-anneal dark frames: those from the CCD Hot Pixel Annealing and Daily Monitor calibration programs. We conclude that ROA mode is similar or more effective than the previous anneal mode in reducing the global dark current and the percent CCD coverage of hot and warm pixels in the ACS/WFC.

1 Introduction

The ACS anneal has occurred, with variations, approximately every four weeks since the installation of ACS in March 2002, and changes based on instrument functionality and performance (Desjardins et al., 2018). The main purpose of the anneal is to temporarily reduce dark current (i.e., excess thermal charge trapped in the silicon lattice of CCD detectors) in the WFC CCDs that increases linearly as the detector ages. While the dark current of a single pixel can vary over time (McDonald et al., 2020), a pixel with elevated dark current is categorized as 1) "warm" if 0.06 $e^-/s \leq$ dark current < 0.14 e^-/s or 2) "hot" if dark current ≥ 0.14 e^-/s. Warm and hot pixels can be falsely perceived as signal from a source when taking science observations, and therefore must be accurately identified, flagged and calibrated out.

Under normal annealing circumstances, a majority of ACS electronics are powered off and the WFC CCDs are heated from the operating temperature of -80°C to the annealing temperature of +20°C for a 12-hour duration. Following the completion of the 28 February 2019 and 3 April 2019 anneals, ACS experienced back-to-back safing events upon rebooting back to operate mode from anneal mode. HST engineers at NASA Goddard Space Flight Center (GSFC) traced these safing events to a malfunction with an unused memory chip, triggered only when the memory board, which is separate from the CCD, is colder in anneal mode than it is in normal operations; i.e., when ACS electronics are too cold during an anneal.

To avoid future reboot failures, the ACS Operations team at GSFC formulated a new Reduced Operate Anneal (ROA) mode that keeps more ACS components operating during an anneal, maintaining power to the memory boards and eliminating thermal cycling, thus preventing the memory chip malfunction from occurring. Implementation of ROA mode began with the 17 October 2019 anneal and has since warranted a rapid investigation into the efficacy of this new anneal method. In this report, we extend and improve on previous methods used in McDonald et al. (2020) to measure the global dark current and percent CCD coverage of warm and hot pixels in pre- and post-anneal dark frames in order to validate the effectiveness of ROA mode in healing ongoing CCD damage in the ACS/WFC.

2 Data and Analysis

This analysis consists of using pre- and post-anneal dark exposures from eight proposals in two different calibration programs: 1) The CCD Hot Pixel Annealing Program (HST proposals 14951, 15524 and 15762; PI: Desjardins) and 2) The Daily Monitor program (HST proposals 14948, 15519, 15520, 15521 and 15757; PI: Desjardins). As required through the CCD Hot Pixel Annealing program, a set of four, 1040 second un-flashed dark exposures are taken within 12 hours before and 6-18 hours after each anneal (McDonald et al., 2020). The Daily Monitor program requires a set of four, 1000.5 second post-flashed dark exposures to be taken every Monday, Wednesday and Friday of each week. The differences between the darks taken with each program are detailed in Table 1.

The most significant difference between these two sets of dark frames is the presence, or absence, of post-flash. Since January 2015, all Daily Monitor dark frames are post-flashed; i.e., a LED-illumination procedure is applied to the exposures to mitigate the effects of Charge-Transfer-Efficiency (CTE) loss. By applying post-flash illumination to each exposure (Miles, 2018), the background is artificially increased, filling many of the charge traps that reduce the incidence of warm pixels in dark exposures (Ogaz et al., 2015). Because the ACS/WFC has a large population of warm pixels, using post-flashed, Daily Monitor darks

Table 1: Dark exposure comparison by ACS program

	CCD Hot Pixel Annealing	Daily Monitor
Frequency	Before and after each anneal	Monday, Wednesday, Friday each week
Number of exposures	4	4
Duration (s)	1000-1040	1000.5
Post-flashed?	No	Yes

are ideal when trying to accurately quantify the number of hot and warm pixels in the WFC CCDs. On the same note, given the un-flashed nature of the darks in the CCD Hot Pixel Annealing program, these exposures are ideal for measuring the raw accumulation of dark current in the ACS/WFC.

To measure the global dark current in the ACS/WFC, we collected 128 raw dark frames from the CCD Hot Pixel Annealing program over the 16-month period from the 27 October 2018 anneal (∼1-year prior to the implementation of ROA mode) to the 03 February 2020 anneal (four months after the implementation of ROA mode). Eight post-anneal dark frames of this type were lost during this time period because of the safe-mode events that occurred following the 28 February 2019 and 3 April 2019 anneals. Much like the data calibration described in the McDonald et al. (2020) analysis, the CALACS tasks `acsccd` and `acsrej` were used to subtract the bias level from each dark frame, combine the bias-subtracted files based on their corresponding anneal dates, sort into 'before' and 'after' anneal groups, and cosmic ray reject each group. The final data sample contained 17 pre-anneal and 15 post-anneal stacks of CCD Hot Pixel annealing darks from which we measure the global dark current of the entire WFC detector along with the change in global dark current with respect to each anneal.

To measure the percent CCD coverage of hot and warm pixels in the ACS/WFC, we collected 124 raw dark frames from the Daily Monitor program over the same 16-month time span as described for the previous dark set. Four pre-anneal dark frames of this type were withdrawn preceding the 27 October 2018 anneal and eight post-anneal dark frames were lost following the safe-mode events that took place after the 28 February 2019 and 3 April 2019 anneals. Because these dark exposures were post-flashed and in need of CTE-correction, each file was run through the CALACS pipeline in its entirety to subtract the bias level, flag pixels in the Data Quality (DQ) array, perform pixel-based CTE-corrections, and subtract the applied post-flash for each image. The calibrated flc.fits files that resulted were then combined based on their corresponding anneal dates, sorted into 'before' and 'after' anneal groups, and cosmic ray rejected via the CALACS task `acsrej`. The final data sample consisted of 16 pre-anneal and 15 post-anneal stacks of Daily Monitor darks from which the percent coverage of hot pixels and hot plus warm pixels in the ACS/WFC were measured along with the percent change for each anneal.

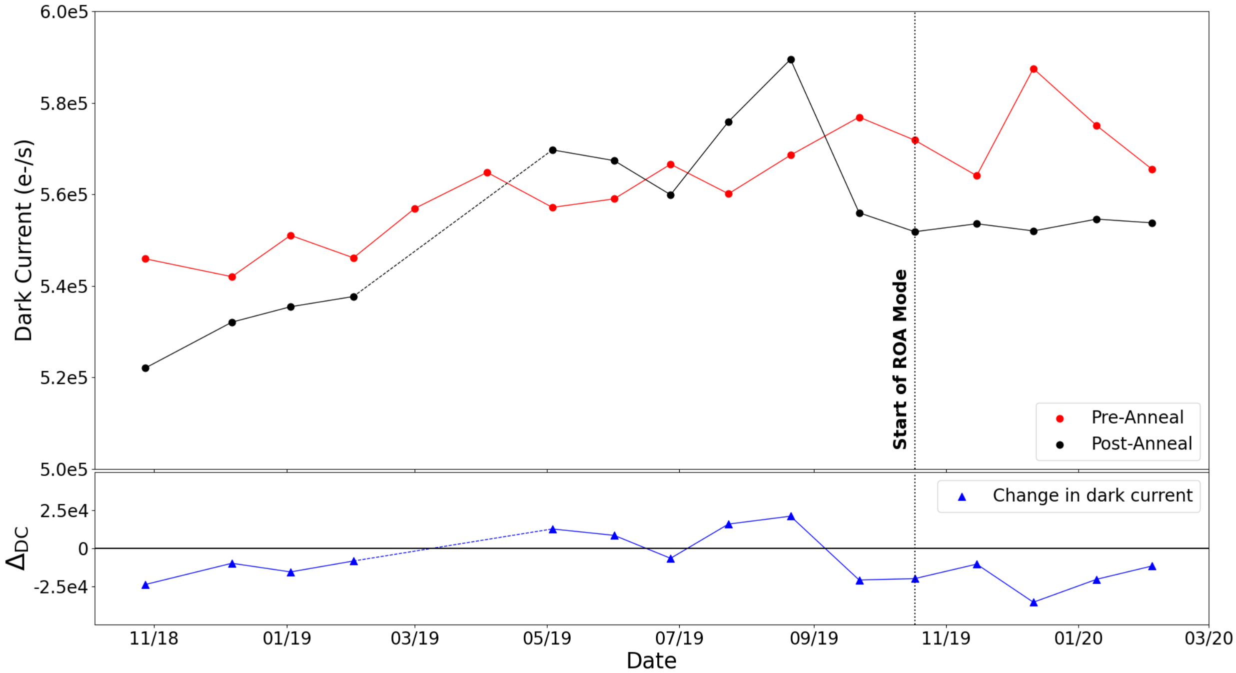

Figure 1: The global dark current pre- and post-anneal are measured alongside the change in global dark current (Δ_{DC}) with respect to each anneal. Each data point represents a set of calibrated and combined set of four darks from the CCD Hot Pixel Annealing program. The vertical dotted line indicates the start of ROA mode, while dashed lines connecting data points represent where data is missing.

3 Results

The pre- and post-anneal global dark current in the ACS/WFC is displayed in Figure 1. Each data point is representative of a calibrated and combined set of darks from the CCD Hot Pixel Annealing program. We observe a steady increase in the global dark current over the year leading up to ROA mode, with several fluctuations in pre- and post-anneal measurements revealing four instances in 2019 (03 May, 31 May, 23 July, and 20 Aug) in which the dark current post-anneal was greater than its pre-anneal value.

The change in global dark current is also featured in Figure 1, and more clearly highlights the four, nearly consecutive instances in which the change in global dark current is positive. After the implementation of ROA mode in October 2019, the change in global dark current is observed to be consistently negative for the five anneals that followed. We also note that the post-anneal global dark current measurements for the five anneals performed with ROA mode appear to nearly stabilize, hovering around 553,000 e^-/s.

To determine the effectiveness of ROA mode in reducing the hot and warm pixel populations in the ACS/WFC, the percent CCD coverage of hot pixels and hot plus warm pixels were measured and plotted in Figures 2 and 3, respectively. Here, each measurement is representative of a calibrated and combined set of darks from the Daily Monitor program. The change in percent coverage with respect to each anneal is also plotted in each figure.

In Figure 2, we observe that all the anneals over the 16-month period had a negative change in percent coverage; i.e., there were fewer hot pixels measured after each anneal, than before. We see a similar trend in Figure 3, with the exception of the 26 June 2019 anneal

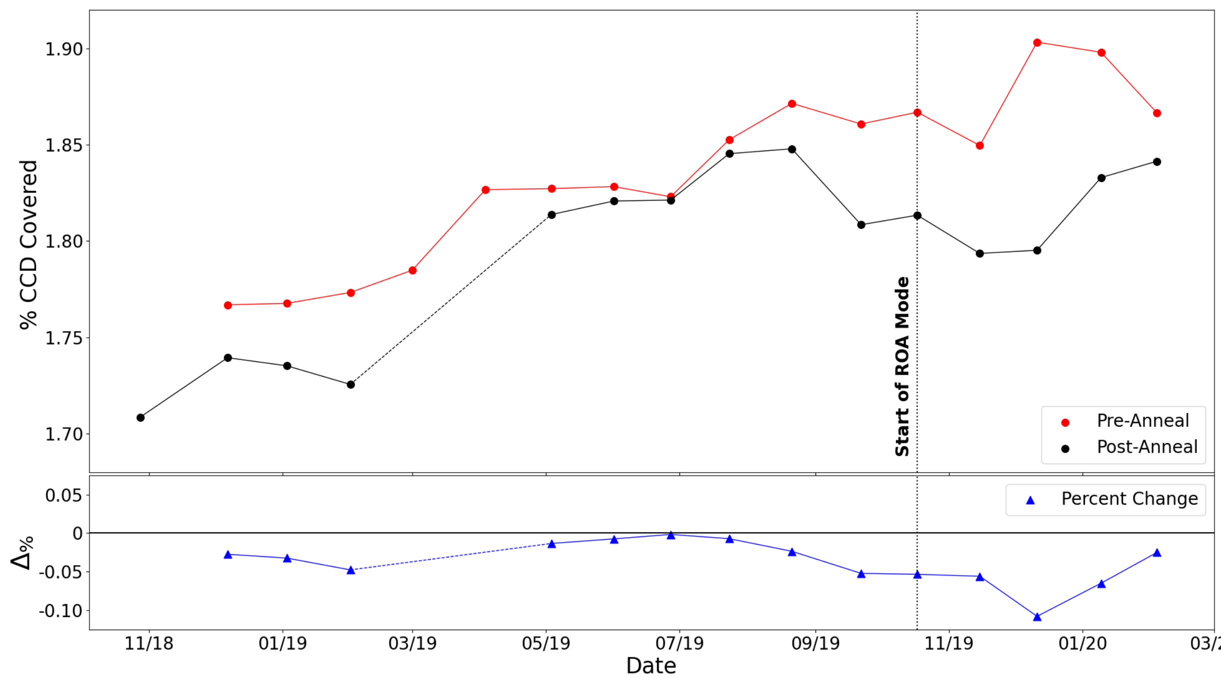

Figure 2: The percent CCD coverage of hot pixels pre- and post-anneal are measured alongside the change in percent coverage ($\Delta_{\%}$) with respect to each anneal. Each data point represents a set of calibrated and combined set of four darks from the Daily Monitor program. All line features are the same as described in Figure 1.

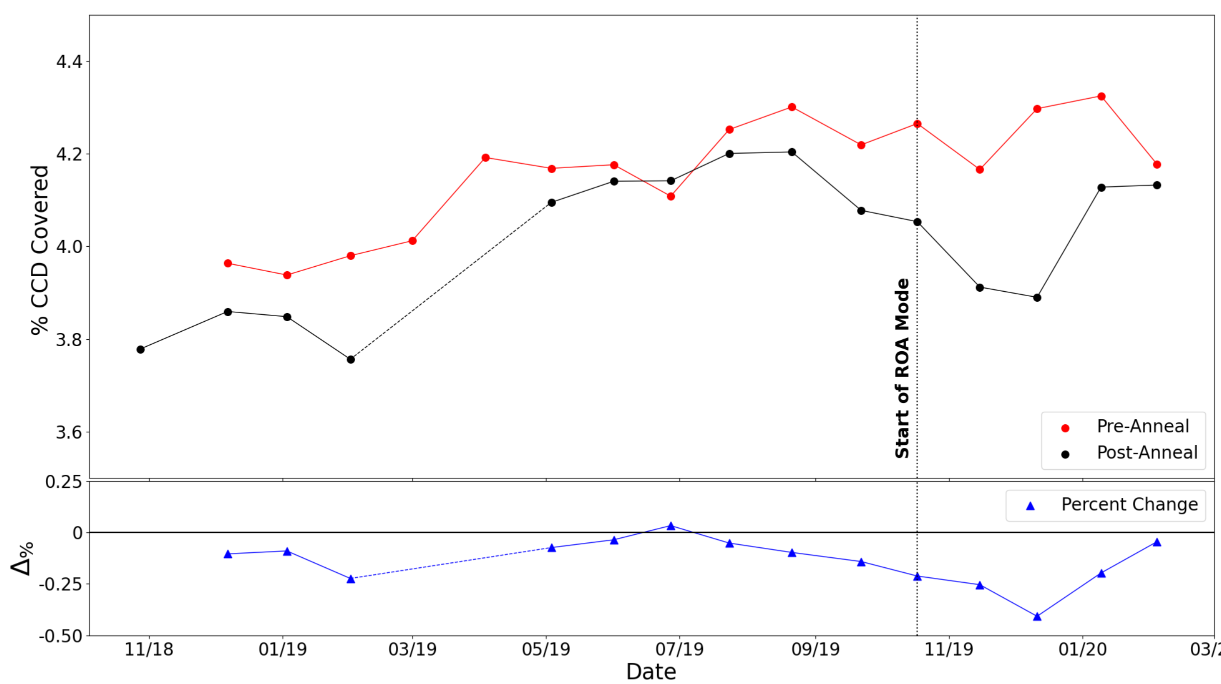

Figure 3: The percent CCD coverage of hot plus warm pixels pre- and post-anneal are measured alongside the change in percent coverage ($\Delta_{\%}$) with respect to each anneal. Each data point represents a set of calibrated and combined set of four darks from the Daily Monitor program. All line features are the same as described in Figure 1.

that boasts a greater percentage of hot and warm pixels covering the CCD post-anneal, than pre-anneal. Both figures show that since implementation of ROA mode, the change in percent coverage of each metric has remained largely negative. In fact, the change in percent coverage in both measurements hits a minimum for the entire 16-month period with the anneal executed on 10 December 2019.

For comparison purposes, the mean change in global dark current, percent coverage of hot pixels, and percent coverage of hot plus warm pixels are measured for the anneals executed before and after the implementation of ROA mode. Although our sample indicates 12 anneals occurred before ROA mode was instated, only some anneals in each set of darks retained both pre- and post-anneal measurements due to data losses explained in Section 2. Thus, the mean statistics for before ROA mode comprised 10 anneals for the global dark current measurement and nine anneals for both the hot pixel coverage and hot plus warm pixel coverage measurements. The mean statistics for after ROA mode comprised five anneals for each measurement. Refer to Table 2 for these comparison statistics.

Table 2: Comparison of Mean Statistics from Before and After ROA mode

	$\Delta_{globalDC}$ (e^{-}/s)	$\Delta_{\%_{hp}}$ (%)	$\Delta_{\%_{hp+wp}}$ (%)
Before ROA Mode[a]	-2788	-0.0237	-0.0871
After ROA Mode[b]	-19631	-0.0615	-0.2231

[a] Data taken from October 2018 to September 2019.
[b] Data taken from October 2019 to the February 2020.

4 Discussion

When examining the behavior of the global dark current over the 16-month period from October 2018 to February 2020 (Figure 1), it appears that anneals performed with ROA mode show consistent and effective dark current reduction. Of the 10 anneals performed in the year prior to ROA mode that possess both pre- and post-anneal measurements, four exhibit higher global dark currents post-anneal than pre-anneal. This indicates that 40% of anneals during this time were ineffective.

In contrast, all five anneals carried out since the implementation of ROA mode in October 2019 have shown consistent, and in some cases increased, levels of efficacy in reducing global dark current. An inspection of the comparison statistics in Table 2 reveals a mean change in global dark current that is roughly seven times more negative for ROA mode anneals than for pre-ROA mode anneals; an indication that ROA mode anneals were seven times more effective in reducing the global dark current. Moreover, the post-anneal global dark current for the five ROA mode anneals appears to even stabilize, when a linear increase is expected over several anneal periods. Despite the relatively short timescale over which the data was taken, these findings lead us to believe that ROA mode is just as effective, if not more effective, than the previous anneal mode in reducing the global dark current in the ACS/WFC.

The percent hot pixel coverage measurements (Figure 2) show a different pattern, with all anneals in the sample (excluding those missing pre- or post- anneal measurements) having post-anneal values less than their pre-anneal counterparts. The percent coverage of hot plus warm pixels (Figure 3) exhibits near identical behavior, with the exception of the 26 June 2019 anneal having higher percent coverage after the anneal, than before. While this implies that all, or most, of the anneals performed within the 16-month time frame were effective in reducing the hot and warm pixel populations, some anneals appear to achieve a greater level of efficacy than others.

Throughout much of the year prior to ROA mode, the change in percent CCD coverage, pre- and post-anneal, for both hot pixels and hot plus warm pixels often approached zero; i.e., many of the anneals executed during this time had little to no effect on the hot and warm pixel populations. After ROA mode was instated, the change in percent coverage for each measurement remained largely negative, even reaching a minimum with the 10 December 2019 anneal. Moreover, by examining Table 2, we find that the mean change in percent CCD coverage for both hot pixels and hot plus warm pixels is nearly 2.6 times more negative for the anneals executed with ROA mode than those executed before. From these observations, it is evident that ROA mode has demonstrated equal, or even increased levels of efficacy in reducing the incidence of hot and warm pixels in the ACS/WFC.

5 Conclusion

The introduction of Reduced Operate Anneal (ROA) mode in October 2019 provided a solution to a recurring instrument malfunction that occurred when ACS electronics became too cold during the annealing process. This new ROA mode required rapid validation and prompted the launch of an investigation to determine its efficacy in reducing the dark current and hot and warm pixel populations in the ACS/WFC. Two sets of dark exposures from two different ACS programs were used to measure the global dark current, percent CCD coverage of hot pixels, and percent CCD coverage of hot plus warm pixels over the 16-month time frame from October 2018 to February 2020.

The analysis of CCD Hot Pixel Annealing, pre- and post-anneal dark frames showed that 40% of anneals executed within the year prior to the implementation of ROA mode were ineffective in reducing the global dark current. Conversely, the five anneals executed with ROA mode exhibited consistent and highly negative changes in dark current, indicating that ROA mode anneals were highly effective in reducing global dark current. Examination of additional pre- and post-anneal dark frames from the Daily Monitor program showed that most all anneals executed within the 16-month period were effective, to varying degrees, in reducing the percent hot pixel coverage and percent hot plus warm pixel coverage in the WFC CCDs. Anneals performed with ROA mode, however, demonstrated a higher degree of effectiveness, with the mean percent change in CCD coverage for both metrics to be 2.6 times more negative for ROA mode anneals.

Based on these findings, we can conclude that ROA mode is just as effective, if not more effective, than the previous anneal mode in reducing the global dark current and hot and warm pixel populations in the ACS/WFC. ROA mode has proven to be a valid and effective anneal mode and will continue to be used as the standard for the foreseeable future. Further monitoring of ROA mode over longer timescales is recommended to assess long-term performance and ensure optimal instrument functionality.

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References

Desjardins, T. D., Miles, N. D., Ryon, J. E., & Borncamp, D. C. 2018, ACS/WFC Superbias, Superdark, and Sink Pixel File Generation, Tech. Rep. ACS TIR 2018-01, STScI

McDonald, M. C., Desjardins, T. D., & Miles, N. D. 2020, Anneal Efficacy in the Advanced Camera for Surveys Wide Field Channel, Instrument Science Report ACS 2020-5

Miles, N. 2018, Updates to Post-Flash Calibration for the Advanced Camera for Surveys Wide Field Channel, Instrument Science Report ACS 2018-02

Ogaz, S., Anderson, J., & Golimowski, D. 2015, Post-Flash Calibration Darks for the Advanced Camera for Surveys Wide Field Channel (ACS/WFC), Instrument Science Report ACS 2015-03