New NICMOS Flat-fields

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Abstract. The A-to-D conversion, or gain, of the NICMOS detectors depends on a combination of detector temperature and bias voltage. The response of the three NICMOS detectors changed slightly due to changes in the A-to-D conversion over both the era before the installation of the NICMOS Cooling System (NCS) 1997-1998 and after the installation 2002-2008. This change can be expressed as a change in an effective temperature (or equivalently A-to-D conversion) referred to as biastemp, which is calculated directly from the bias level of the science exposures. Here we discuss the creation of new flat-field reference files used to correct for changes in the structure of flat-fields caused by the change in A-to-D conversion. These reference files (*.tdf.fits) populate the keyword TDFFILE in the headers of pre-NCS data retrieved from the OTFR after January 23, 2009 and post-NCS data retrieved after November 19, 2008 and are used by the FLATCORR step in calnica version 4.4 and later. Each *_tdf.fits file consists of five different extensions each valid at a different biastemp range. During calibration, the pipeline calculates the biastemp of the science image and then uses the flat-field extension with the best matching biastemp. For consistency check we also created epoch dependent flat-fields for post-NCS data and compared them with the biastemp dependent flat-fields.

1. Introduction

The detector quantum efficiency (DQE) of NICMOS detectors varies both on pixel-to-pixel scale and on large scale across the chip. This causes the science data to have large spatial variations even for a case with uniform illumination. Before 2008 static flat-fields were used to correct pixel-to-pixel and large scale DQE variations by multiplying the science data by inverse flat-field image normalized to unity. One flat-field was used for each camera and filter combination.

The response of the three NICMOS detectors changed slightly due to (1) variation in detector temperature in the pre-NCS era, 1997-1998 and (2) changes in the A-to-D conversion due to a varying bias voltage after the installation of NCS in 2002. Both (1) and (2) can be expressed as a change in an effective temperature (or equivalently A-to-D conversion) referred to as biastemp, which is calculated directly from the bias level of the science exposures. This variation was noticed in 2008-2009. Variation in biastemp affects the pixel response (hotter pixels are relatively more affected than cooler) causing biastemp dependent changes in the structure of flat-fields even after normalizing to unity.

Throughout Cycle 7 and 7N (pre-NCS era, operating temperature 62K) and in Cycle 11 and beyond (post-NCS era, operating temperature 77K) the variation was approximately 2K as measured by biastemp. To correct for biastemp dependent changes in the structure of flat fields, we have created new flats-fields for all filters in NIC1, NIC2 and NIC3. These reference files each consist of five different flat-field extensions, each valid at a different biastemp range. Calnica, version 4.4 and later now uses these reference files

587
to choose the flat-field extension appropriate for the biastemp of the file that is being reduced. The effect of this on the photometry is at most 1% and depends on the position on the detectors. Users who use data retrieved earlier than 2008 and for whom this effect is significant, should re-calibrate the data with calnica version 4.4 (or later) and the latest reference files or retrieve the data again from the archive using the OTFR.

In this report we discuss the creation of new temperature dependent flat-field reference files for all three NICMOS cameras, for both the pre-NCS and post-NCS eras. The term temperature refers to the bias-derived temperature (biastemp) calculated by PyRAF task CalTempFromBias. This temperature populates the keyword TFBTEMP in primary headers. Note again that this is not a true "physical" temperature, but an "effective temperature" used to quantify changes in the detector A-to-D conversion. For more details about the CalTempFromBias code and biastemp measurements please refer to Dahlen et al. 2009 NICMOS ISR-2009-002, Pirzkal et al. 2009 NICMOS ISR-2009-007 and NICMOS Data Handbook version 8.0.

2. Data

Table 1 shows the data that was used to create the new flat-fields.

<table>
<thead>
<tr>
<th>Program ID</th>
<th>Program Title</th>
<th>Program PI</th>
<th>Cameras</th>
<th>Date Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>7957</td>
<td>Lamp Flats II: NICMOS Pointed Flats</td>
<td>A. Schultz</td>
<td>1, 2, 3</td>
<td>03/8/1998 - 05/19/1998</td>
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<tr>
<td>7961</td>
<td>FLATs: Warming Up</td>
<td>D. Calzetti</td>
<td>1, 2, 3</td>
<td>11/9/1998 - 12/13/1998</td>
</tr>
<tr>
<td>8083</td>
<td>FLATs: Warming Up - continuation</td>
<td>D. Calzetti</td>
<td>1, 2, 3</td>
<td>12/14/1998 - 01/10/1999</td>
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<td>8974</td>
<td>NICMOS Flats and temperature dependence of the DQE</td>
<td>T. Boeker</td>
<td>1, 2, 3</td>
<td>04/20/2002 - 05/7/2002</td>
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<td>8985</td>
<td>NICMOS Internal Flats</td>
<td>A. Schultz</td>
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<td>03/13/2002 - 19/5/2002</td>
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<td>9326</td>
<td>NICMOS Cycle 10 Early Calibration Monitor</td>
<td>A. Schultz</td>
<td>1, 2, 3</td>
<td>05/30/2002 - 18/9/2002</td>
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<td>9327</td>
<td>NICMOS Flats: narrow filters for NIC1 + NIC2, NIC3 in parallel</td>
<td>S. Arribas</td>
<td>1, 2, 3</td>
<td>26/7/2002 - 28/7/2002</td>
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<td>9557</td>
<td>NICMOS flats: Camera 3 narrow filters and grisms</td>
<td>S. Arribas</td>
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<td>9640</td>
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<td>10379</td>
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<td>10728</td>
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<td>1, 2, 3</td>
<td>28/10/2005 - 8/6/2006</td>
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<tr>
<td>11016</td>
<td>NICMOS Flats: narrow and broad filters for NIC1 + NIC2, NIC3 in parallel</td>
<td>N. Pirzkal</td>
<td>1, 2, 3</td>
<td>10/12/2006 - 22/09/2007</td>
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<td>11059</td>
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<td>1, 2, 3</td>
<td>17/11/2006 - 26/08/2007</td>
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<td>11321</td>
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<td>02/05/2008 - 23/07/2008</td>
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<td>11532</td>
<td>NICMOS Cycle 16 Time</td>
<td>T. Dahlen</td>
<td>1, 2, 3</td>
<td>14/06/2008 - 25/07/2008</td>
</tr>
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</table>

- Pre-NCS: The data obtained during the NICMOS flat-field calibration programs during 1997-1998 were used to generate static pre-NCS flat-fields. Data from program 8083 were used to calculate the pixel-to-pixel response as a function of temperature.
• Post-NCS:-The data obtained during the NICMOS flat-field monitoring from 2002 to 2008 were used to regenerate biastemp dependent flat-fields. These programs represent the full span of post-NCS flat monitor programs.

3. Creating Flat-field images

3.1. Pre-NCS flat-fields

These flat-fields are created as follows.

1. First we determine the temperature of the existing static pre-NCS flat-field images by calculating the mean temperature of the individual exposures that were used to produce the flat-fields. We use the bias-derived temperature given by the TEBTEMP keyword in the image header of each file.

![Response in electrons/s as a function of temperature, normalized at T=63K.](image)

Figure 1: Response in electrons/s as a function of temperature, normalized at T=63K. Curves are shown for wave-lengths 1.1, 1.6 and 2.2 micron. Shorter wave-lengths have steeper slopes.

2. We thereafter calculate the pixel-to-pixel response as a function of temperature and wave-length using flat-field images in F110W and F160W (and also including F222M for NIC3) taken during the end-of-life warm-up monitoring in January 1999. Adding to these a few images taken at lower temperatures earlier in the pre-NCS era, the available flat-fields span over the temperature range 55-70K. The first fit of the pixel-to-pixel response in electrons/s vs. temperature for each pixel is made at the particular wave-lengths of the available filters using an IDL script makefits written by Eddie Bergeron. Another script makewavefits is thereafter used to make wave-length fits to the output from above. The end products from these scripts are arrays with coefficients relating the response in electrons/s of each camera with temperature and wave-length. New flat-fields at desired temperature and wavelength are created using these relations and existing static flat-fields. An example of the response on
electrons/s as a function of temperature for NIC3 at wave-lengths 1.1, 1.6, and 2.2 microns is shown in Figure 1. The symbols are measured points and the lines are fits to these points. Shorter wave-lengths have steeper temperature gradient. Curves are normalized to unity at 63 K.

For each filter and camera, flats are calculated at the following five different output temperatures: 61.2 K, 61.6 K, 62.0 K, 62.4 K, and 62.8 K. This approximately divides the temperature range used in the pre-NCS era in five equally spaced bins. For consistency with previously created flat-fields, each flat-field is normalized to unity in [*,36:256] for NIC1 and NIC2 and in [*,56:256] for NIC3. The flat-fields are thereafter inverted. Each flat-field, having an extension '*.df.fits, consists of a stack of five flats for the above mentioned temperatures. When applying flat-field correction, the bias temp, TFBTEMP, is used to choose the flat closest in temperature, which is thereafter used for the flat-field correction.

3.2. Post-NCS flat-fields

Figure 2: Temperature from bias for NIC1, NIC2 and NIC3 data
In Figure 2 we show the temperature variation of individual flat-field images taken during the NICMOS flat-field monitoring programs 2002-2008. From the figure it is clear that there is a strong evolution in temperature-from-bias with time and we therefore should expect that the shape of the post-NCS flat-fields will also change over this period. We therefore create new flat-fields also for the post-NCS era, where each flat-field consists of a data-cube with five separate flat-fields extensions, each valid for a specific biastemp range.

To do this we first create single exposure flat-field images by subtracting pairs of calibration images taken first with the NICMOS internal flat-field lamp on then off. This is done for all filters and all cameras using the available monitoring data taken 2002-2008. In total there are about 800-900 single exposure images per camera divided among the different filters. We thereafter use the temperature (TFBTEMP) of these images to divide the flat-fields into five temperature bins so that approximately the same number of exposures falls in each bin for each camera. The limits for the temperature bins for each camera are given in Section 5.

We finally combine the single exposure images in each temperature bin to create a median flat-field image. Each image is thereafter normalized to unity (using \([*,36:256]\) for NIC1 and NIC2 and \([*,56:256]\) for NIC3) and inverted.

For filters monitored regularly, like F110W, F160W and F222M, there are enough single exposure flat-fields to create final images in all five temperature bins. For some less observed filters, mostly narrow band filters, images are not available in all five temperature bins. In those cases final images are generated by interpolating. We also generate a pedigree file that includes information on all individual images going into each final flat-field together with S/N for all the combined images. This pedigree file is available on the NICMOS web page, www.stsci.edu/hst/nicmos.

4. Epoch Flat-fields

Figure 2 shows that the biastemp changes close to linearly with time and an alternative approach to create flat-fields would therefore be to divide the flat-fields in temporal bins as discussed in Dahlen et al. 2007 NICMOS ISR-2007-002. For consistency check epoch dependent flat-fields were also created using a method similar to that of biastemp dependent flat-fields. Instead of temperatures the flat-fields were divided into bins for different epochs.

4.1. Comparison of Epoch and Temperature flat-fields

To quantify the difference between the epoch and temperature flat-fields, the signal-to-noise ratio for flat-fields in all temperature bins was compared with signal-to-noise ratio for flat-fields in all epoch bins (not including bins for which interpolated flat-fields were created). Table 2 shows the median S/N for biastemp dependent and epoch dependent flat-fields for all three NICMOS cameras.

The median of the S/N for biastemp dependent flat-fields is higher than for the epoch dependent flat-fields. Note also that the total number of different temperature images created is larger than the number of epoch images. This means that on average fewer single flat-field images were used to produce the temperature dependent flat-fields. Despite that, the S/N for the temperature flat-fields are higher, assuring us that the temperature dependent flat-fields are a better choice to use.
Table 2: Comparison of post-NCS epoch and temperature flat-fields.

<table>
<thead>
<tr>
<th></th>
<th>Number of Images</th>
<th>median S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIC1 temperature flat-fields</td>
<td>64</td>
<td>733.510</td>
</tr>
<tr>
<td>NIC1 epoch flat-fields</td>
<td>52</td>
<td>722.210</td>
</tr>
<tr>
<td>NIC2 temperature flat-fields</td>
<td>67</td>
<td>728.600</td>
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<tr>
<td>NIC2 epoch flat-fields</td>
<td>57</td>
<td>713.710</td>
</tr>
<tr>
<td>NIC3 temperature flat-fields</td>
<td>63</td>
<td>823.690</td>
</tr>
<tr>
<td>NIC3 epoch flat-fields</td>
<td>55</td>
<td>772.180</td>
</tr>
</tbody>
</table>

5. Structure of new flat-field reference files

Each flat-field image (*.tdf.fits) consists of five individual images (imsets) each having five extensions: SCI, ERR, DQ, SAMP, and TIME. The *.tdf.fits images therefore consist of 25 extensions with the SCI images, i.e., the flat-fields, in extensions 1, 6, 11, 16, and 21. Keywords TFBLOW and TFBHIGH show the temperature range for each extension. The full temperature range covered by all five bins is given by the TFBLOW and TFBHIGH keyword in the primary header (EXT=0). The extension for which TFBLOW < TFBTEMP < TFBHIGH, where TFBTEMP is the temperature from science data header, is used for the flat-fielding.

The temperature ranges (in Kelvin) are:

Pre-NCS NIC1, NIC2, NIC3 flat-fields
extension 0: TFBLOW=52.0, TFBHIGH=70.0
extension 1: TFBLOW=52.0, TFBHIGH=61.4
extension 6: TFBLOW=61.4, TFBHIGH=61.8
extension 11: TFBLOW=61.8, TFBHIGH=62.2
extension 16: TFBLOW=62.2, TFBHIGH=62.6
extension 21: TFBLOW=62.6, TFBHIGH=70.0

Post-NCS flat-fields
NIC1
extension 0: TFBLOW=64.95, TFBHIGH=86.85
extension 1: TFBLOW=64.95, TFBHIGH=74.95
extension 6: TFBLOW=74.95, TFBHIGH=75.55
extension 11: TFBLOW=75.55, TFBHIGH=76.25
extension 16: TFBLOW=76.25, TFBHIGH=76.85
extension 21: TFBLOW=76.85, TFBHIGH=86.85

NIC2
extension 0: TFBLOW=64.65, TFBHIGH=86.80
extension 1: TFBLOW=64.65, TFBHIGH=74.65
extension 6: TFBLOW=74.65, TFBHIGH=75.30
extension 11: TFBLOW=75.30, TFBHIGH=76.15
extension 16: TFBLOW=76.15, TFBHIGH=76.80
extension 21: TFBLOW=76.80, TFBHIGH=86.80

NIC3
extension 0: TFBLOW=65.60, TFBHIGH=87.05
extension 1: TBFLOW=65.60, TFBHIGH=75.60
extension 6: TBFLOW=75.60, TFBHIGH=76.08
extension 11: TBFLOW=76.08, TFBHIGH=76.56
extension 16: TBFLOW=76.56, TFBHIGH=77.05
extension 21: TBFLOW=77.05, TFBHIGH=87.05

Figure 3: Panels 1 to 5 show the ratio images obtained by dividing a flat corresponding to each temperature bin in the biastemp dependent flat by the static flat for pre-NCS NIC3, F110W data.

Figure 4: Panels 1 to 5 show the ratio images obtained by dividing a flat corresponding to each temperature bin in the temperature dependent flat by the static flat for post-NCS NIC3, F110W data.

Figures 3 and 4 show the ratio images obtained by dividing each SCI extension in NIC3, F110W temperature dependent flat by the SCI extension in the static flat file, for pre and post-NCS data respectively. The temperature goes up as we go from panel 1 (top left) to panel 5 (bottom right). Panel 3 in figure 3 and panel 4 in figure 4 are relatively flat due to the fact that the temperature range of SCI[11] image is close to the temperature of the static flat file. From both the figures we can conclude that the biastemp dependent
flat-fields do have some structure as compared to the static flat-field and the structure of flat field does depend upon temperature. The evolution of the pre-NCS flats is due to a true change in detector temperature, while the change in post-NCS flats is due to a drift in bias voltage.

6. FLATCORR

The new flat-fields populate the header keyword TDFFILE. This reference file contains the flat-field image for a given detector and filter (or polarizer) combination. As explained above this file contains five imsets, each with a flat-field image valid for a particular temperature range. In the FLATCORR step, calnica reads the bias-derived temperature from the TFBTEMP keyword in the science data header and selects the appropriate imset from the TDFFILE. The imset used is written to the TDFGROUP keyword in the header of the calibrated (*.cal.fits) files. See figure 5

The new flat fields were delivered to the archive on November 19, 2008 (updated NIC3 flat-fields delivered on May 27, 2009) for Cycle 11 and later observations and on January 23, 2009 for data taken during Cycles 7 and 7N. There is no TDFFILE listed in the header for the data retrieved prior to these dates. In this case, the FLATFILE reference file which is a single static (non-temperature dependent) flat-field image is used instead. If both TDFFILE and FLATFILE reference files are given in the header, calnica chooses the TDFFILE. FLATFILE is used instead of TDFFILE in the cases where TFBTEMP keyword is missing or TFBTEMP lies outside the range given by TFBHIGH and TFBLOW keywords in the primary header. Error estimates and DQ flags contained in the TDFFILE/FLATFILE are propagated into the processed images. The difference between the new flat-fields and the static flat-fields is small but it can affect the photometry on a 1% level.
7. Summary

Data from NICMOS calibration programs during 1997-1998 and 2002-2008 are used to generate new pre-NCS and post-NCS flat-fields. Variations in the A-to-D conversion in the NICMOS detectors, as quantified by the bias-derived effective temperature (given by header keyword TFBTEMP), affects the pixel-to-pixel response and the structure of the flat fields for all detectors. The new flat-fields (*_tdf.fits) correct for this effect in the FLATCORR step of calnica version 4.4 and later. The *_tdf.fits files populate the keyword TDFFILE in the headers of data retrieved after November 19, 2008 for post-NCS flat-fields and January 23, 2009 for pre-NCS flat-fields.

Acknowledgments. We would like to thank L. Bergeron for providing the scripts to create pre-NCS temperature dependent flat-fields.

References

Dahlen, T., Barker, E., Bergeron, E., & Smith, D. NICMOS ISR-2009-002, STScI, Temperature Dependent Dark Reference Files: Linear Dark and Amplifier Glow Components