
OSIRIS

Optical, Spectroscopic, and Infrared Remote Imaging System

OSIRIS calibration pipeline OsiCalliope

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1 General aspects

1.1 Scope

This document describes the calibration pipeline for the images acquired by both OSIRIS cameras onboard the ROSETTA spacecraft: the Wide Angle Camera (WAC) and the Narrow Angle Camera (NAC). The document describes the implemented procedures and algorithms in OsiCalliope v1.12 and higher.

The previous versions of the pipeline were implemented as IDL scripts, and documented by the “*OSIRIS Calibration Pipeline Manual - RO-RIS-MPAE-MA-005_D_c*”. The current pipeline version is written in C++ and compiled as a standalone application.

1.2 Applicable Documents

no.	document name	document no, Issue./Rev.
AD1	OSIRIS Experiment Data Record and Software Interface Specification (EDR/SIS)	RO-RIS-MPAE-ID-018
AD2	Rosetta-OSIRIS to Planetary Science Archive Interface Control Document	RO-RIS-MPAE-ID-015

1.3 Reference Documents

no.	document name	document no, Issue./Rev.
RD1	OSIRIS user manual	RO-RIS-MPAE-UM-004, D/s
RD2	Shutter parameters for exposure time calculation	RO-RIS-MPAE-TN-073
RD3	CCD Readout Board – (CRB)	RO-RIS-MPAE-SP-020
RD4	OSIRIS Calibration Report	RO-RIS-MPAE-RP-147, 1/b
RD5	OSIRIS Calibration Pipeline Manual	RO-RIS-MPAE-MA-005, D/c
RD6	Low Level Software Interface between CRB and DPU	RIS-MPAE-ID-008, 2/k
RD7	Transfer function between the encoder measurement and the blades position of the FM WAC SHM	RO-RIS-UPD-TN-W333-219
RD8	Transfer function between the encoder measurement and the blades position of the FM NAC SHM	RO-RIS-UPD-TN-N333-213
RD9	OSIRIS camera linearity and saturation level	RO-RIS-MPAE-TN-078
RD10	OSIRIS camera bad pixel list	RO-RIS-MPAE-TN-080
RD11	OSIRIS camera bias levels	RO-RIS-MPAE-TN-079
RD12	Acquisition and processing of flat field images for OSIRIS calibration	RO-RIS-MPAE-TN-075
RD13	Determination of the absolute calibration coefficients	RO-RIS-MPAE-TN-074



	to radiometrically calibrate OSIRIS images	
RD14	Osiris camera distortion correction parameters	RO-RIS-MPAE-TN-081

1.4 Introduction

The pipeline has been developed to calibrate OSIRIS images. The pipeline software “OsiCalliope” is part of the complete OSIRIS scientific data processing pipeline. This system contains different components that are responsible for:

- Downloading the data from the Data Delivery System (DDS)
- Generating raw images, with actual instrument hardware readouts (PDS Level 0)
- Generating raw images, with calibrated hardware parameters, and spacecraft position and pointing (PDS Level 1)
- Creating calibrated images for scientific analysis (PDS Level 2, 3 and 3B)
- Producing additional image formats (JPEG, FITS, etc.)
- Generating reports and notifications

The current document defines the requirements and procedures to create calibrated images for scientific analysis, from the raw image data, hardware (imaging) configuration, and spacecraft pointing data.

1.5 Processing levels of the images

The OSIRIS data levels are^{RD2}:

- **Level 0:** PDS format, raw header (proprietary, non-standard labels), raw binary with 16 bit unsigned integer image data.
- **Level 1:** PDS format, calibrated header, (standard labels), raw binary with, 16 bit unsigned integer image data.
- **Level 2:** PDS format, calibrated header, radiometric calibrated 32 bit float image data (in $W\ m^{-2}\ sr^{-1}\ nm^{-1}$ units).
- **Level 2B:** (Optional) PDS format, calibrated header, radiometric calibrated 32 bit float image data (IOF reflectance units).
- **Level 3:** PDS format, calibrated header, radiometric calibrated 32 bit float image data, corrected for the camera optical distortion (in $W\ m^{-2}\ sr^{-1}\ nm^{-1}$ units).
- **Level 3B:** PDS format, calibrated header, radiometric calibrated 32 bit float image data, corrected for the camera optical distortion (IOF reflectance units).

The OSIRIS data levels correspond to CODMAC (Committee on Data Management, Archiving, and Computing) levels:

$$\text{OSIRIS level } n = \text{CODMAC level } n+1$$

Thus, the listed OSIRIS data levels correspond to CODMAC levels 1-4, respectively.

The full image processing pipeline contains several software components:

- “**OsiDrone**” oversees the generation and archiving up to level 1.



- It pulls the raw spacecraft data from the servers at ESA and calls “**OsiTrap**” to generate level 0 and level 1 images in the primary archive.
- In the next step “**Getty**” determines where each of the images should be copied in the secondary archive and “**OsiDrone**” copies the images to the indicated location.
- A Python script finds the level 1 images in the secondary archive and calls a number of software components:
 - Level 2 (optional 2B), level 3, and level 3B images are generated by “**OsiCalliope**”.
 - The “**Pds2Legacy**” application is used for the creation of additional formats from the PDS, such as JPEG and FITS.

The structure of the secondary archive is shown in Figure 1.

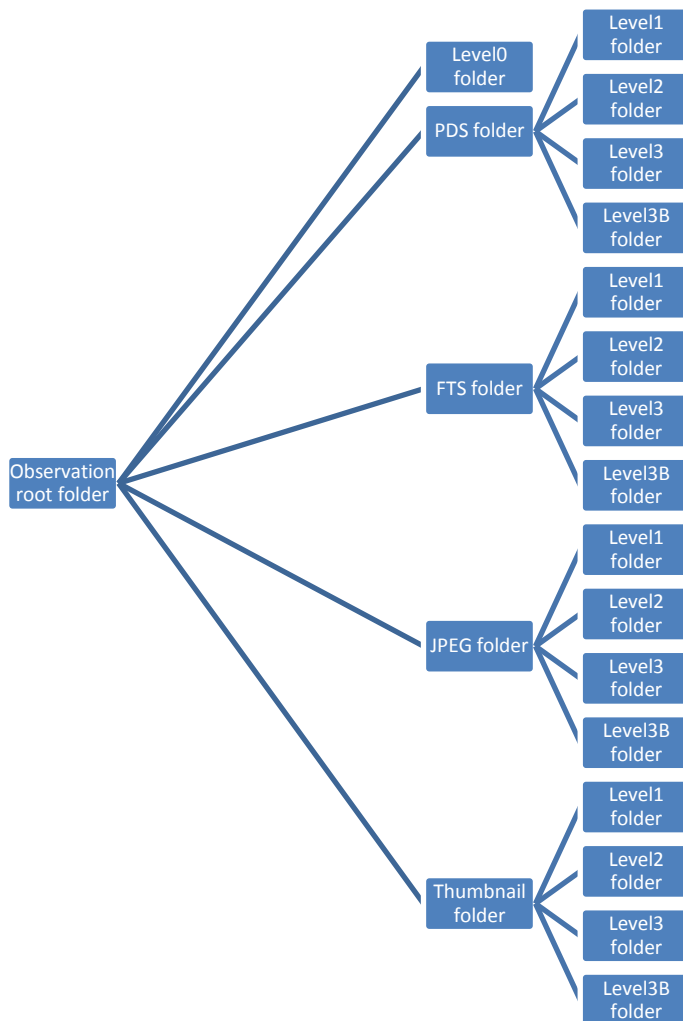


Figure 1 Structure of the secondary archive



1.6 Osiris cameras^{RD1}

Both the NAC and the WAC use a 2k x 2k pixel backside illuminated CCD ^[RD1] as an image sensor. The OSIRIS CCD has 2048 columns and 2052 lines (2 + 2048 + 2). The serial register contains 2148 pixels (2 + 48 + 2048 + 48 + 2). A sketch of the CCD is shown in Figure 2.

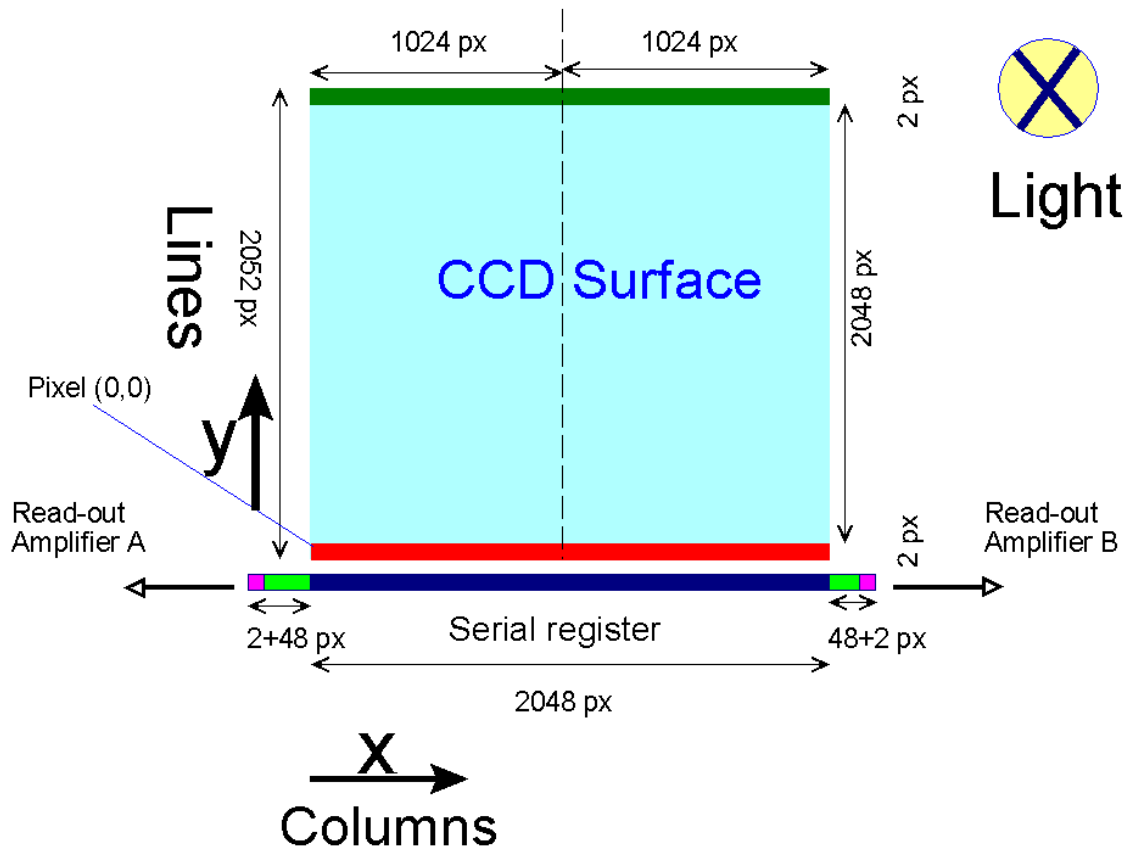


Figure 2 Structure of the OSIRIS CCDs

The two extra lines at the bottom of the CCD (colored in red in Figure 2) are generally discarded. The two extra lines at the top of the CCD (colored in green in Figure 2), which are read out after the image data, are called overlocking lines.

The first two extra pixels in the serial register (colored in fuchsia in Figure 2) are ignored, thus 48 extra pixels (colored in light green in Figure 2) appear at both ends of the serial register. These pixels, which are read out before or after the image data, are called pre-clocked pixels and post-clocked pixels, respectively. Pre-clocked and post-clocked pixels do not represent physical pixels of the CCD.

Overlocking lines are used to determine the charge transfer efficiency, while pre-clocked and post-clocked pixels are used to estimate the bias and the electronic noise level of the image.

The cameras use a dual 14 bit Analogue to Digital Converter (ADC) configuration, providing a nominal 16 bit ADC system^{RD3}. The imaging can use the low 14 bit (ADC-LOW), the full range



14 bit (ADC_HIGH) shifted up by 2 bits, and both ADCs (ADC-TANDEM), providing quasi 16 bit resolution (at least in the low DN range).

The CCD readout is equipped with two amplifiers (A and B) which can be used individually or in parallel, for faster readout. The two amplifiers have slightly different operational parameters.

During the imaging, neighboring pixels can be handled together, forming a larger virtual pixel. This technique is called binning, and is able to reduce the photon noise and increase the sensitivity. Binning can be used to connect 1, 4, 16 or 64 pixels (1x1, 2x2, 4x4 and 8x8)

Besides the full-frame imaging, which uses the full CCD area, windowing can reduce the image size, by transmitting only a smaller area of the CCD. This can drastically reduce the data volume through the communication channel. The OSIRIS cameras can do this either by hardware or by software. Software windowing acquires the full CCD area, and the on-board processor cuts out the required pixels for transmission. Hardware windowing reads out only a sub-frame of the CCD, which can also speed up the imaging sequence. However, hardware windowing has side effects on the bias and gain values.

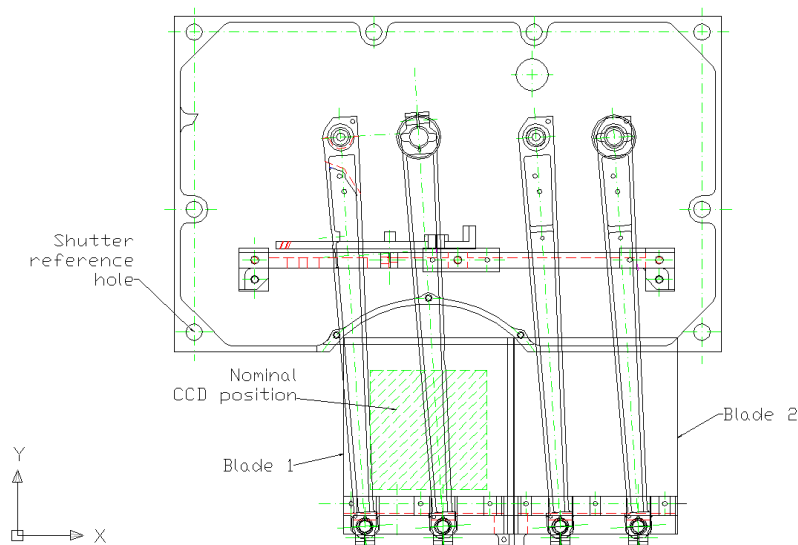


Figure 3 Shutter mechanism

The OSIRIS detectors are so called “full frame CCD”, which means that a mechanical shutter is necessary to control the exposure, and, during the image readout, the shutter must remain closed. The shutter blades are operated by motors, and the shafts are equipped by optical encoders that give feedback about the blade positions and timings. These values are necessary to accurately control the exposure time nonlinearities.

Both the NAC and the WAC are equipped with a dual filter wheel set, each wheel consisting of 8 positions. These wheel positions are used to select a transmission band for the WAC and a combination of band-pass, neutral density, or focusing optics for the NAC.

The main optical system of the cameras is off axis telescopes. A 3-mirror-system is used for the NAC and a 2-mirror-system for the WAC. The transmission and distortion of these optical systems have major impact on the image calibration.



2 The structure of the pipeline

The OSIRIS calibration pipeline application is the “OsiCalliope.exe”. The software can be used either in interactive or in command line mode. In the second mode it must receive the root folder of the observation (which contains the “pds\level1” folders) as parameter. The software generates level 2, level 2B, level 3, and level 3B images from the level 1 data. The storage location of the calibrated images is also controlled by the parameters.

The pipeline software loads the (level 1) images to be calibrated, one after the other, and executes the required calibration steps sequentially on the data. A HISTORY section is inserted after the PDS header of each image and the completed calibration steps are marked there with the applied parameters (and references) so that the process is transparent and repeatable.

The “OsiCalliope.exe” also uses a configuration file. This file is a PDS label format text file, listing all the input parameters and binary file references for the calibration process. The OsiCalliope configuration file is located in the \OSICALLIOPE\DATA\ folder, where “OSICALLIOPE” is the folder containing the “osicalliope.exe” file. The DATA folder contains additional data files and folders used by the calibration processes. The keys in the label are non-standard PDS keys using the namespace identifier WAC: and NAC: as reference to the specific OSIRIS camera.

All calibration files used by OsiCalliope to calibrate OSIRIS images are listed in Section 4.

“OsiCalliope” performs the following steps to calibrate the raw images:

1.	Separation of the various frame elements: image, pre-clocked and post-clocked pixels, overclocking lines	
2.	Convert image data to “double” format.	
3.	Correction of the tandem ADC offset and gain	
4.	Subtraction of bias	
5.	Removal of coherent noise (under development)	
6.	Removal of dark current (optional)	
7.	High spatial frequency flat fielding	
8.	Removal of bad pixels and bad columns	
9.	Correction of ghost and stray light (under development)	
10.	Low spatial frequency flat fielding	
11.	Normalization to exposure time	
12.	Conversion to radiometric units (absolute calibration)	
13.	Generate sigma map and quality map	Level 2, 2B output
14.	Correction of geometric distortion	Level 3, 3B output



3 Pipeline procedures and algorithms

3.1 Separation of the various frame elements

Each frame is composed of different elements: the actual image, pre-clocked and/or post-clocked pixels and overclocking lines. The pre-clocked, post-clocked pixels and overclocking lines are separated by “OsiTrap” and stored in the level 0 and level 1 files, as separate image objects.

For level 2 and higher images, pre-clocked and post-clocked pixel and overclocking lines images are not present.

3.2 Convert image data to “double” format.

The binary section of the PDS file is converted to PC_DOUBLE (64 bits) format for further processing. This format is used only internally by the pipeline; the final storage format is PC_REAL (32 bits).

3.3 Removal of Tandem ADC offset

Both NAC and WAC are equipped with two 14 bits ADCs for each readout channels (ADC-LOW and ADC-HIGH) to digitize the CCD pixel signal. The readout electronics can use the ADCs separately (either ADC-LOW or ADC-HIGH) or together in a dual 14 bits ADC configuration (ADC-TANDEM). The latter option gives a quasi-16bits dynamical range, which is resolved using a sub-ranging technique. The signal is split between the two ADCs as follows (RD3):

Where $0 \leq DN \leq ADC_SW_DN$ \implies ADC-LOW is used

Where $ADC_SW_DN < DN \leq 2^{16} - 1$ \implies ADC-HIGH is used.

and ADC_SW_DN is the switch-over value, set to 16383 (0x3FFF).

The two ADCs are adjusted to cover a continuous range linearly however, there is a few DNs offset between them. To correctly handle this, the calibration process must determine the readout channel (A or B) and the corresponding ADC unit (ADC-LOW or ADC-HIGH). Then the following correction is applied for pixels having a DN value ADC_SW_DN or greater:

$$DN_C = DN_O - ADC_{offset}$$

DN_C : is the corrected pixel intensity

DN_O : the original pixel intensity

ADC_{offset} : the offset value of the matching ADC

The correction constants are determined during the ground campaign and stored in the OsiCalliope configuration file under the following keys:



Amplifier A (single channel)	Amplifier B (single channel)
ADC_OFFSET_A	ADC_OFFSET_B
Amplifier A (dual channel)	Amplifier A (dual channel)
ADC_OFFSET_DA	ADC_OFFSET_DB

Note that the values are different for single channel (A or B) readout and dual channel (A and B) readout! The applied ADC correction values for the left and right half (A and B amplifier) of the image is stored in the image header HISTORY section:

ADC_OFFSET_VALUES = (44.000, 48.000) (example)

3.4 Subtraction of bias^{RD1}

Ground calibration and in-flight tests indicated that the actual bias value of the OSIRIS cameras depends on the operation mode and the AD converter operating temperature. The following correction is applied:

$$DN_C = DN_O - BIAS_{OM_T_0} + (T_{ADC} - T_0) * C_T$$

Where:

- DN_C : is the corrected pixel value
- DN_O : the original pixel value
- $BIAS_{OM_T_0}$: bias constant for the specific operational mode, at T_0 temperature of the AD converter.
- T_0 : bias constant reference temperature.
- C_T : bias temperature dependency factor

According to current knowledge, the bias is constant for all software windowing and binning modes. The value changes by hardware window size, binning and amplifier channel. The bias is also slightly temperature dependent. The $BIAS_{OM_T_0}$ values are therefore individually determined for the frequently used operational modes^{RD1}:

- Hardware window sizes: 2048x2048, 1024x1024, 512x512, 256x256, 128x128, 64x64
- Binning modes: 1x1, 2x2, 4x4, 8x8
- Optimized sync modes for the respective binning

For the operational modes with no $BIAS_{OM_T_0}$ value, the default bias is used, but it may result a small residual error.

The bias data files used by OsiCalliope are listed in Sec. 4.

The correction constants are determined during inflight calibration campaigns, and stored with the following key schemes:

$BIAS_W_n_B_n_A_n_S_{nn}$ for single channel readout

$BIAS_W_n_B_n_D_n_S_{nn}$ for dual channel readout



where: W : Windowing mode, n = 0 software windowing, n = 1 hardware windowing,

B : Binning mode n = 1 '1x1', n = 2 '2x2', n = 4 '4x4' or n = 8 '8x8'

A or D : Amplifier or dual channel n = A or n = B

S : CRB to power converter synchronization mode nn = 00-31

The bias error, (standard deviation) is also stored similarly:

SDEV_Wn_Bn_An_Snn for single channel readout

SDEV_Wn_Bn_Dn_Snn for dual channel readout Bias errors.

For the removal of the bias-temperature dependence, a linear correction is used.

For this reason the nominal temperature of the bias calibration constants is stored in Kelvins as well as the temperature coefficient [DN/K]:

BIAS_A_TEMPERATURE	=	281.1	(example)
BIAS_A_TEMP_FACTOR	=	0.7	

The actual bias correction is calculated as:

$$\text{BIAS} = \text{BIAS_Wn_Bn_An_Snn} + (T_{\text{ADC}} - \text{BIAS_TEMPERATURE}) * \text{BIAS_DELTA_TEMP}$$

Where the T_{ADC} is the temperature of the AD converter read from PDS header. The applied bias correction values for the left and right half (A and B amplifier) of the image is stored in the image header HISTORY section:

BIAS_VALUES	=	(240.742, 240.742)	(example)
BIAS_TEMP	=	(297.7, 298.9)	
BIAS_TEMP_DELTA	=	(0.000, 0.000)	

3.5 Removal of coherent noise

The removal procedure is currently not implemented.

The NAC and WAC signal chains are exposed to noise generated in the CCD readout board (CRB) power converter modules and in the data processing unit (DPU) power converter module. The CRB power converter modules are considered the dominant noise source.

Both, NAC and WAC CRB power converter modules are synchronised with the corresponding pixel readouts. The converters contain two primary switches in push-pull, where one switch is active for the even pixels while the other switch is active for the odd pixels. Both switches produce different noise effects. Thus, we have different coherent noise on odd and on even pixels, which produces a black-and-white pattern upon the image data with amplitudes of up to 25 DN. This pattern is vertically structured if extra pixels are not included, while it is diagonally structured if the extra pixels are included.



Possible noise removal algorithms are currently under evaluation. If for readout the two amplifiers are used in parallel, the two parts of the CCD are processed separately (RD4).

3.6 Removal of dark current

The procedure is currently not implemented.

Dark frames with exposure times between 1 s and 1200 s have been acquired to investigate the dark current behavior. Between May and December 2014, the CCD temperature was in the range 148-150 K; the measured dark charge is $< 0.006 \text{ e}^-/\text{s}$ that correspond to $< 0.002 \text{ DN/s}$. Even for long coma exposures (up to 300 s long) the dark current is much smaller than the readout noise at the current operational temperature; therefore no dark current correction is necessary.

3.7 High spatial frequency flat fielding^{RD1}

The flat field corrects for the non-uniform sensitivity of the camera across the image plane. Two main forms of non-uniformities are present:

- A pixel-to-pixel sensitivity variation across the image, due to the size difference and electrical characteristics of the individual CCD pixels and to dust particles on the CCD chip surface;
- A lower spatial frequency variation that is caused by the optical properties of the camera and the filters.

To correct the OSIRIS images, we have introduced a new technique that consists in correcting the two types of non-uniformities in two steps. First the pixel-to-pixel sensitivity variations are removed and then the lower spatial frequency variations.

Currently, the high spatial frequency flat fields correspond to artificial frame with constant intensity equal to 1.

The high spatial frequency flat fielding is done by multiplying the original image with the "FLAT_HI" image. The procedure is noted in the HISTORY:

```
FLAT_HI_FILE = "NAC_FM_FLATHI-22.IMG" (example)
```

The high spatial frequency flat fields used by OsiCalliope are listed in Sec. 4.

3.8 Removal of bad pixels^{RD11}

Logically bad pixel removal should precede the flat-fielding, but since its algorithm relies on the corrected neighboring pixel values, the high spatial frequency flat field correction is done first.

Bad pixels are areas of the CCD surface that provides invalid DN values. They can be individual pixels, or group of pixels (lines, rows, or areas). Bad pixels can be handled by the on-board spacecraft software, by the calibration pipeline, or both. An up-to-date bad pixel list is used by the pipeline to avoid double processing^{RD1}. The calibration pipeline can provide more sophisticated correction methods than the on-board software, however a certain level of processing is unavoidable on-board to reach higher compression ratios. The PDS header flag: "BAD_PIXEL_REPLACEMENT_FLAG" in the group "SR_PROCESSING_FLAGS" indicates the presence of the spacecraft processing.

The bad pixel lists for the NAC and WAC used by OsiCalliope are listed in Sec. 4.



The list indicates the position of the bad pixels, and the correction method in the following form:

area_type = (x, y, method)

For single pixels: **PIXEL = (10, 10, MEDIAN_CORR)** (example)

where: 10, 10 is an example of the column and row coordinates, and MEDIAN_CORR or AVERAGE_CORR is the correction method: median or average of the neighboring 8 pixels.

For columns: **COLUMN = (994, 0, SHIFT_L_CORR)** (example)

where: 994, is the column number, MEDIAN_CORR or AVERAGE_CORR replaces each pixel of the column with the median or average of the neighboring 6 good pixels. SHIFT_L_CORR or SHIFT_R_CORR handles hot or dim columns, by shifting its DN values to have the same median as the Left or Right neighbor's.

Hot pixels, columns and rectangular areas are also marked as **PIXEL**, **COLUMN** or **REGION_R**. The **NO_CORR** key indicates no correction method, just an indication in the quality map.

Bad column number 995: The neighboring columns are also slightly affected by the higher charge of this bad column. The following correction method shifts the affected neighboring columns, than corrects the bad one.

COLUMN = (994, 0, SHIFT_L_CORR) (example)

COLUMN = (996, 0, SHIFT_R_CORR)

COLUMN = (995, 0, MEDIAN_CORR)

Rectangular areas, such as the 9x9 pixels (blob) area close to the physical center of the NAC, are also handled:

REGION_R = (915, 970, 20, 20, NO_CORR) (example)

The applied bad pixel list is noted in the HISTORY:

BAD_PIXEL_LIST = "NAC_FM_BAD_PIXEL_LIST.LBL" (example)

3.9 Correction of ghost and stray light

Procedure is currently not implemented.

A deconvolution based ghost removal method is under development.

3.10 Low spatial frequency flat fielding

Low spatial frequency flat fielding is used to remove sensitivity non-uniformities in the image plane that are caused by the filters and the optical system itself. Currently, the low-spatial frequency flat fields correspond to the ground flat-fields, thus this calibration step correspond to a high- and low- special frequency flat fielding of the images.

The low spatial frequency flat fielding is done by multiplying the original image with the "FLAT_LO" image. The procedure is noted in the HISTORY:

FLAT_LO_FILE = "NAC_FM_FLAT-22.IMG" (example)



The low spatial frequency flat fields used by OsiCalliope are listed in Sec. 4.

3.11 Normalization of the exposure time

Each image is normalized to 1 second exposure time. The normalization is done by first calculating the “**MEAN_EFFECTIVE_EXPOSURETIME**”:

$$\text{exp_time}_{\text{mean_effective}} \equiv \text{exp_time}_{\text{commanded}} + \Delta t.$$

The Δt is a correction of the actual shutter blade velocity variation during the exposure.

If the image data contains the shutter pulse information, it will be used to calculate the correction value. Otherwise $\Delta t = -0.0027$ s for the NAC and $\Delta t = -0.0025$ s for the WAC. These values are calculated from the in-flight linearity test.

The accurate exposure time calculation is based on the shutter pulse information and uses the following algorithm:

- The shutter pulse array contains the number of clock pulses (2.1MHz) at certain encoder (angular) positions of the shutter blade arm.
- The encoder positions are transformed into shutter blade positions by the shutter blade transfer functions.
- The blade position – time function is calculated
- The difference of the above functions for the two blades at a certain CCD position gives the actual exposure time, for a given pixel. The average of these values is the **MEAN_EFFECTIVE_EXPOSURETIME**

The image is divided by the exposure time (**MEAN_EFFECTIVE_EXPOSURETIME**). The **HISTORY** section notes the applied correction values:

```

EXPOSURE_CORRECTION_TYPE           = SHUTTER_PULSES           (example)
MEAN_EFFECTIVE_EXPOSURETIME       = 0.0973 <s>

```

3.12 Conversion to radiometric units (absolute calibration)

The last step to achieve radiometric calibrated images is the conversion from DN/s to $\text{W m}^{-2} \text{sr}^{-1} \text{nm}^{-1}$ and reflectance.

The calibration constants for the absolute calibrations are obtained from the observation of standard stars (usually Vega)^{RD1}.

The applied absolute calibration factor is listed in the **HISTORY**:

```

ABSCAL_FACTOR = 1.233e+008           (example)

```

The radiometric calibration coefficients used by OsiCalliope are listed in Sec. 4.

3.13 Generate sigma map and quality map

In addition to the calibrated frame, the pipeline also creates for each image a map with error estimates and quality indicators.

The **ERROR ESTIMATE MAP** is a float image with the same dimension as the image itself. For each pixel its error is determined by the Poisson error E_p , and the (bias) readout noise E_B :



$$error_{i,j} = \sqrt{E_P^2 + E_B^2}$$

$$E_P = \frac{\sqrt{N_{i,j}}}{N_{i,j}}$$

where $N_{i,j}$ is the intensity of the pixel with coordinates (i, j) in number of electrons. Since the Poisson statistics are done using the intensity in number of electrons, the image intensity has to be converted from DN to number of electrons and this is done using:

$$I_{e^-} = I_{DN} \cdot gain$$

where I_{e^-} and I_{DN} are the intensity in number of electrons and DN, respectively, and gain is the number of electrons per DN (for OSIRIS WAC and NAC gain = 3.1 e⁻/DN in HIGH gain mode and gain = 15.5 e⁻/DN in LOW gain mode).

$$NB: N_{i,j} = I_{e^-, (i,j)}, \sum_{i,j} N_{i,j} = I_{e^-}$$

The PIXEL QUALITY MAP is an 8-bit image with the same dimension as the image itself and contains a quality estimate of each pixel. The quality map exists for data level 2 and higher.

The quality estimate values stored in the quality map are generated by setting a given bit to value 1 for specific effects. If more than one effect is present in the data several different bits can be set. The following values are possible:

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Value	128	64	32	16	8	4	2	1
Effect	BAD	SAT	DIM	WARM	LOSSY	NLIN	-	VALID

BAD: Pixel is marked as bad

SAT: Pixel was saturated during the exposure

DIM: Pixel is marked as dim (low sensitivity)

WARM: Pixel is marked as warm (increased or varying sensitivity) use with caution

LOSSY: Lossy image compression applied on pixel

NLIN: Pixel was exposed into the nonlinear DN range of the CCD

VALID: Pixel is valid. Invalid or non-existing (0) can be due to packet loss, or distortion correction.

Some flags have been removed from quality map (they are valid for the full image area):

CONV: (bit 1) Pixel has seen gauss convolution filtering as part of the image compression

SQRT: (bit 0) Pixel has seen sqrt filtering as part of the image compression



3.14 Geometric distortion^{RD1}

Both the NAC and WAC optical layouts are off-axis mirror systems, which provide high transmittance and near diffraction limited performance, with low geometrical optical aberrations. However, this layout has a significant geometrical distortion which must be corrected for the correct image registration.

The correction is performed by resampling the images according to the nonlinear distortion function of the relevant camera, as if it would be acquired by a distortion free camera. The image resampling is done by the bi-linear algorithm, and since the original image is in radiance or reflectance unit, the result is also considered radiometrically corrected on the large scale.

The resampling is based on a two dimensional third-order polynomial fit:

$$X_i = \sum_{i,j} kx_{i,j} \cdot X_0^j \cdot Y_0^i$$

$$Y_i = \sum_{i,j} ky_{i,j} \cdot X_0^j \cdot Y_0^i$$

Where (X_i, Y_i) , the undistorted coordinates are expressed as a function of the actual image coordinates (X_0, Y_0) . The coefficients for distortion removal (kx and ky) are the coefficients of the third-order polynomial fit. To obtain the corrected level 3 images, the level 2 images are wrapped according to the tabulated kx and ky distortion removal coefficients.

The geometric distortion correction files used by OsiCalliope are listed in Sec. 4.

4 Calibration files used by OsiCalliope

The calibration files used by OsiCalliope to calibrate OSIRIS images are listed in Table 1.

Calibration step	Calibration File	Reference Document
ADC offset removal	OSICALLIOPE_??.TXT	
Bias subtraction	NAC_FM_BIAS_V??.TXT WAC_FM_BIAS_V??.TXT	RD11
High spatial-frequency flat fielding	NAC_FM_FLATHI_00_V??.IMG WAC_FM_FLATHI_00_V??.IMG	RD12
Bad pixels correction	NAC_FM_BAD_PIXEL_V??.TXT WAC_FM_BAD_PIXEL_V??.TXT	RD10
Low spatial-frequency flat fielding	NAC_FM_FLAT_??_V??.IMG WAC_FM_FLAT_??_V??.IMG	RD12
Exposure time normalization	For ballistic mode: NAC_FM_EXP_BAL_V??.TXT WAC_FM_EXP_BAL_V??.TXT WAC_FM_EXP_20160323_V??.TXT	RD2



	WAC_FM_EXP_20160405_V??.TXT	
Radiometric calibration	NAC_FM_ABSCAL_V??.TXT WAC_FM_ABSCAL_V??.TXT	RD13
Geometric distortion correction	NAC_FM_DISTORTION_V??.TXT WAC_FM_DISTORTION_V??.TXT	RD14

Table 1 Calibration files used by OsiCalliope to calibrate OSIRIS images and reference document where the files are described.