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Euclid Near-Infrared Imaging Reduction Pipeline – Resampling

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DOCUMENT HISTORY

Version	Date	Modification
1.0	19/07/2018	first version

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ACRONYMS

ESA	European Space Agency
LODEEN	Local Development Environment
NIR	Near Infrared
NISP	Near Infrared Spectrometer and Photometer
LE1	Level 1 data product format
OU	Organization Unit
OU-NIR	Organization Unit for Near Infrared Imaging
OU-SIM	Organization Unit for Simulation
PSF	Point Spread Function
SC	Scientific Challenge
SGS	Science Ground Segment

APPLICABLE DOCUMENTS

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[AD1] Addendum n. 2014-049-R.2-2017 all'Accordo Attuativo 2014-049-R.0 dell'Accordo Quadro ASI/INAF ("Realizzazione di attività tecniche e scientifiche presso lo SSDC nel periodo 2018-2020")

REFERENCE DOCUMENTS

[RD1] Relazione sull'attività del primo semestre 2015 del gruppo Euclid, protocollo ASDC-PRR-EUC-001-2015

[RD2] Relazione sull'attività del secondo semestre 2015 del gruppo Euclid, protocollo ASDC-PRR-EUC-002-2015

[RD3] Relazione sull'attività del primo semestre 2016 del gruppo Euclid, protocollo ASDC-PRR-EUC-001-2016

[RD4] Relazione sull'attività del secondo semestre 2016 del gruppo Euclid, protocollo ASDC-PRR-EUC-002-2016

[RD5] Relazione sull'attività del primo trimestre 2017 del gruppo Euclid, protocollo ASDC-PRR-EUC-001-2017

[RD6] Relazione sull'attività del secondo trimestre 2017 del gruppo Euclid, protocollo ASDC-PRR-EUC-002-2017

[RD7] Relazione sull'attività del terzo trimestre 2017 del gruppo Euclid, protocollo ASDC-PRR-EUC-003-2017

[RD8] Relazione sull'attività del quarto trimestre 2017 del gruppo Euclid, protocollo ASDC-PRR-EUC-004-2017

[RD9] Relazione sull'attività del primo semestre 2018 del gruppo Euclid, protocollo SSDC-PRR-EUC-001-2018

[RD10] Relazione personale sull'attività svolta da giugno 2015 a maggio 2016

[RD11] Relazione personale sull'attività svolta da giugno 2016 a maggio 2017

[RD12] Relazione personale sull'attività svolta da giugno 2017 a maggio 2018

[RD13] Technical Document: "Euclid Near-Infrared Imaging Reduction Pipeline – Astrometric Calibration", prot. SSDC-TSR-EUC-001-2018

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1. INTRODUCTION

The near-infrared (NIR) imaging reduction pipeline is responsibility of the NIR Organization Unit (OU-NIR), one of the sub-projects of the Science Ground Segment (SGS) in the Euclid ESA survey mission. Starting from Level 1 (LE1) raw frames produced by the Near Infrared Spectrometer and Photometer (NISP) instrument in photometric mode, the NIR pipeline shall produce individual and stacked images in Y, J, and H bands accounting for instrumental effects, subtracting the sky background, performing the astrometric and photometric calibrations, and providing all the information needed for catalogue production such as the Point Spread Function (PSF), variance, weights, and quality flags. In particular, an intermediate task of the NIR processing function is to perform the resampling of the images. After being pre-processed by the first steps of the pipeline, the astrometrically and photometrically calibrated images are realigned, rotated, and projected on a common grid, in preparation to a subsequent task of image combination. For more details on the description of the NIR pipeline, see the technical document on the astrometric calibration (RD13).

Here I present the current status of the NIR processing function but focusing on the results obtained from the Image Resampling module applied to simulated frames produced by the OU responsible for the simulations (OU-SIM). Based on data simulated for the Scientific Challenges (SC) 2 and 3, I discuss the different tests and settings performed in order to fulfill specific requirements as well as the implementations planned for future challenges.

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2. DESCRIPTION

NIR_Resampling Software

The goal of this processing element is to realign, rotate, and project on a common grid the 16 detectors of the input dithers containing the astrometrically and photometrically calibrated images produced by the initial steps of the NIR image reduction pipeline, in preparation to the task of image combination.

The image resampling is performed using SWarp (Bertin et al. 2002), one of the packages of the AstrOmatic software[1].

SWarp uses the technique of "inverse mapping" to project input images into the output frame space. In this procedure, the output frame is scanned pixel-per-pixel and line-by-line. Using the inverse projection, to each output pixel center is associated a position in the input frames to which the image is interpolated.

As detailed in the SWarp documentation, the procedure of resampling is settled by a few parameters set in a configuration file passed as input. One of these parameters is the RESAMPLING_TYPE, which allows the user to choose among several interpolation functions, such as the nearest-neighbor (NEAREST), bi-linear (BILINEAR), or Lanczos of different window sizes (LANCZOS2, LANCZOS3, and LANCZOS4).

Requirements

[1] http://www.astromatic.net/software

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There is no specific requirement stablished for the NIR_Resampling software. The functionalities currently included have been developed aiming at fulfilling general requirements settled by the Euclid SGS NIR Requirements Specification Document and also at maintaining the accuracy achieved by the previous image processing steps, in particular the astrometric and photometric calibrations.

Inputs and outputs

The input files required by this module are:

- The four dither exposure files of a given pointing and a given filter after being processed by the pre-reduction steps and after the (relative and absolute) photometric and astrometric calibration.
- One configuration file, used by SWarp, which must be in the `auxdir` directory.

The output files created by this module are:

- One 3-layer file for each input dither containing the realigned, rotated, and resampled scientific, variance, and data-quality frames. The output frames are resampled on a grid common to all the input dithers.

List of executables

a) `NIR_DoresamplProgram.py` is the executable that is run in the science pipeline. In the current version of the pipeline, this command accepts the following arguments:

`--caldither1 to --caldither4:` Input dither exposure files with astrometric solution.

`--resampledmef1 to --resampledmef4:` Output dither exposure files that will contain the resampled images written in the 3-layer structure (scientific data, variance, and data-quality flags).

`--workdir:` Working directory.

`--logdir:` Logging directory.

b) SWarp is installed on the Euclid Local Development Environment (LODEEN) and the `swarp` command is run to perform the image resampling. The default values of all the

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parameters used by SWarp are stored in a configuration file (`swarp_resampl.conf`) put in the `auxdir` directory. Parameters with values different from default are defined inside the code, as is the case of the following parameters:

`-IMAGEOUT_NAME:` Name of a temporary file that will contain the resampled and coadded scientific image (not used by the resampling module).

`-WEIGHTOUT_NAME:` Name of a temporary file that will contain the resampled and coadded weight-map image (not used by the resampling module).

`-RESAMPLE_DIR:` Path of the directory where resampled images are written.

`-WEIGHT_THRESH:` Threshold below or above which input weights are defined equivalent to zero (infinite variance, i.e., a bad pixel).

The temporary files aforementioned have to be defined but they will not be created by SWarp in case of resampling only. SWarp is also used to combine the resampled images, which is done by another module of the NIR pipeline, so such files will be created and used later on in the reduction processing.

To each input dither SWarp also expects an input file containing the weight-maps. Such files are temporarily created by the NIR_Resampling software and are based on the variance and data-quality layers present in the input dithers. In order to be retrieved by Swarp, the weight filenames must have a specific suffix that is define by means of the WEIGHT_SUFFIX keyword (by default it is defined as .weight.fits). The format of the input weights is defined by the WEIGHT_TYPE keyword, which was set to MAP_VARIANCE.

Concerning the outputs, to each detector of each input dither will be associated two temporary files, one that will contain the resampled image and another one that will contain the related weights. In the NIR_Resampling software, these temporary files are put together in one single file written in the 3-layer structure. In the current version of the software, the weight files are used to reconstruct the variance and the data-quality layers, but for future versions the data-quality layer will be resampled separately (see next section).

More details on the input parameters can be retrieved in the SWarp user's manual[2].

[2] https://www.astromatic.net/pubsvn/software/swarp/trunk/doc/swarp.pdf

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3. DISCUSSION

Scientific Challenge 2 and 3

I tested different interpolation functions applied to the data simulated for SC#2 and SC#3 by comparing the differences in magnitude and in position of extracted sources before and after the image resampling procedure. The source extraction is done using SExtractor (Bertin & Arnouts 1996), another AstrOmatic package. Figures 1 and 2 show the results of the comparison using SC#3 simulated images (similar results were obtained for SC#2 simulated images).

On the one hand, as shown in Figure 1, the NEAREST interpolation function is clearly the one having less impact on the magnitude of the extracted sources after applying the resampling. On the other hand, in Figure 2 we can see that the same function is the one causing the largest dispersion in both right ascension (RA) and declination (DEC) coordinates. The LANCZOS2 function seems to be a good compromise. It provides:

- small systematic differences in magnitude (0.003 mag);
- small systematic differences in position (within 0.005″) for both RA and DEC;
- dispersions in magnitude that are on the order of (or smaller than) the error estimated for the magnitude of a given source (see Figure 3);
- dispersions in position that are an order of magnitude smaller than the 0.2″ accuracy required by the Requirements Specification Document;

and at the same time introduces less artifacts around image discontinuities, as discussed in the SWarp user's manual (see Figure 6 therein).

It is worth noticing that, as seen in Figure 3, the errors after applying the image resampling are systematically smaller when the BILINEAR and LANCZOS functions are used, and remain practically unchanged in the case of the NEAREST function. This means that, for all these interpolation functions, the resampling procedure does not introduce additional uncertainties in the magnitude estimation.

Nevertheless, it should be noticed that the BILINEAR function is still a good option. Despite the systematic difference seen in Figure 1, the dispersions in magnitude are even smaller than in the LANCZOS2 case. Also, as seen in Figure 2, the dispersions in position are the smallest among all functions, at least for the brightest sources. Moreover, in Figure 3 we can see that the BILINEAR case is the one having the smallest errors in magnitude after the image resampling. Therefore, the behavior of this function should be tested again using new simulations.

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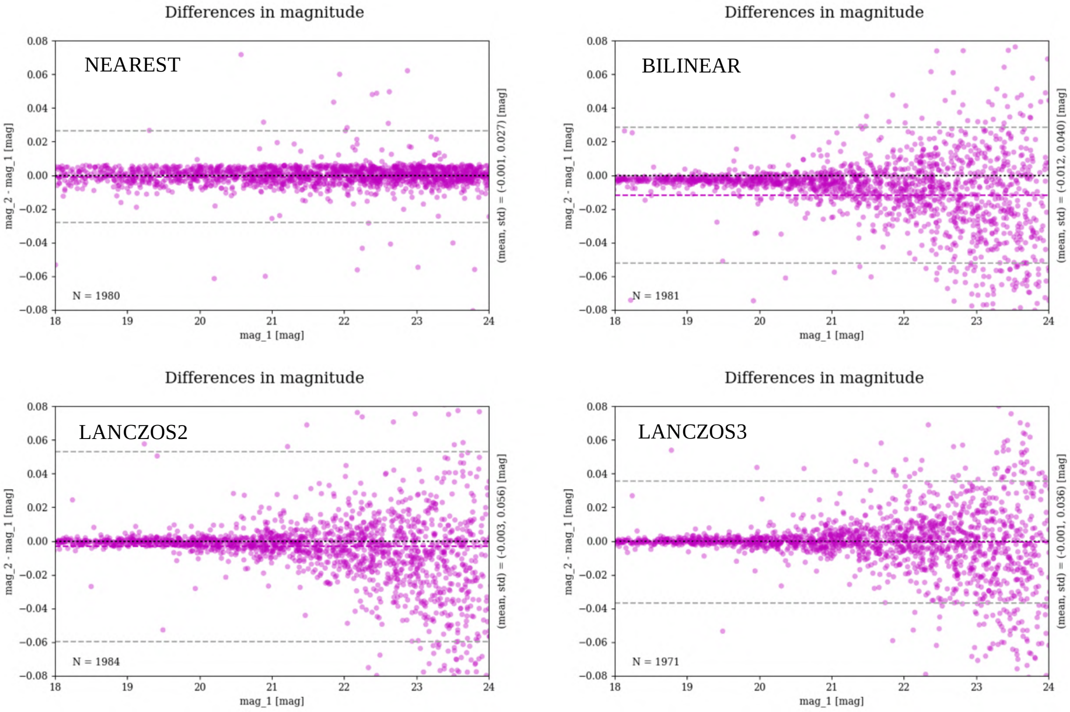

Figure 1: Differences in magnitude before and after resampling as a function of the magnitude for different interpolation functions. The dashed lines indicate the mean (magenta) and the 1σ standard deviation (light grey).

The errors in Figure 3 are provided by SExtractor and are computed using Eq. 61 of the SExtractor user's manual[3]. This equation depends on the area over which the total flux of a given source is summed, on the standard deviation of the noise estimated from the background, and on the detector gain. The BILINEAR and LANCZOS2 functions are in some way reducing the background noise, thus reducing the errors in magnitude. It is not clear if this is an improvement (considering the reduction of the noise) or if the errors are just being underestimated and the magnitude incorrectly measured (considering the systematic differences observed in Figure 1 for the BILINEAR case). Additional tests are clearly required.

[3] https://www.astromatic.net/pubsvn/software/sextractor/trunk/doc/sextractor.pdf

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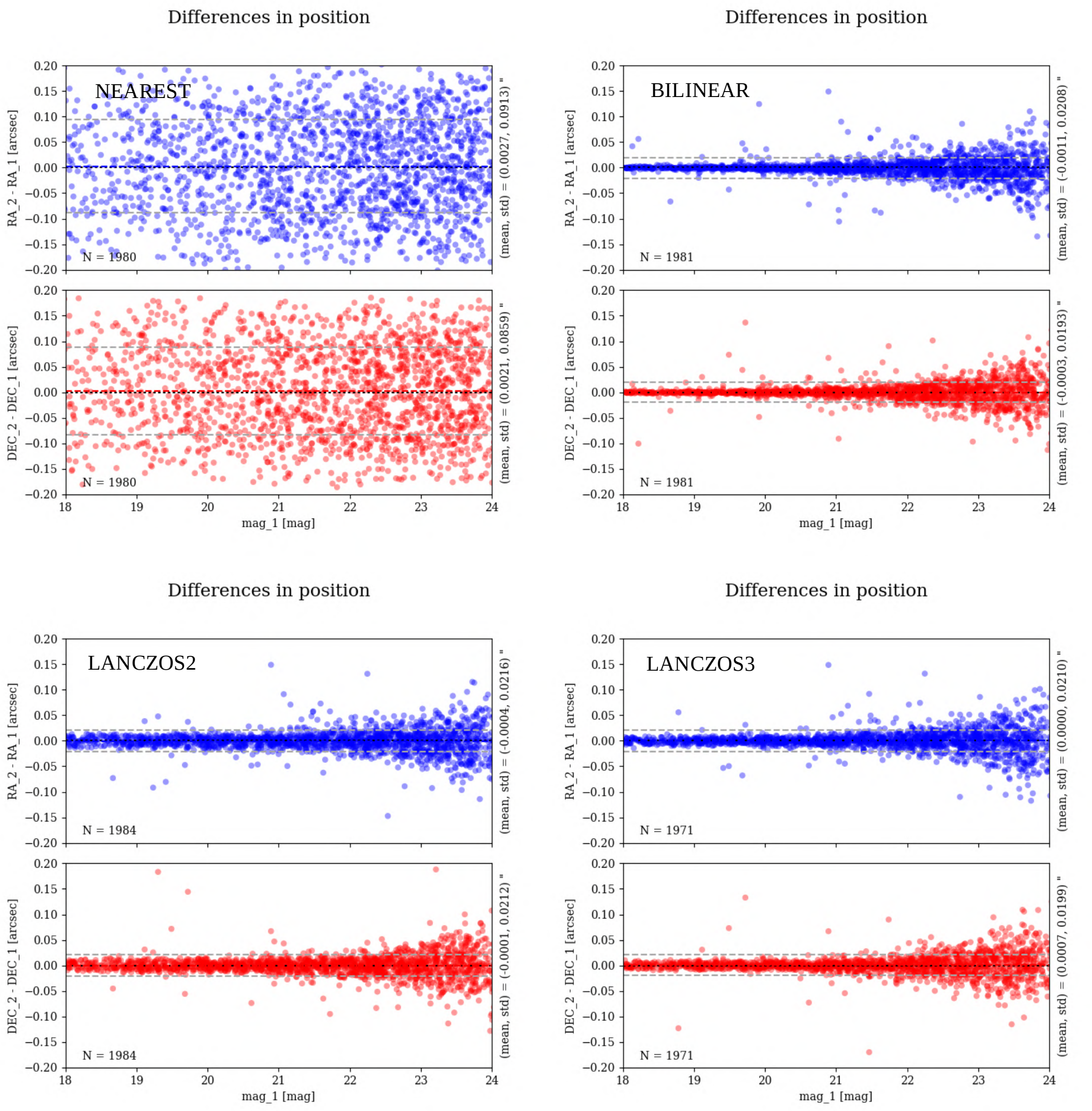

Figure 2: Differences in RA (blue) and DEC (red) positions before and after the resampling as a function of the magnitude for different interpolation functions. The dashed lines indicate the mean and the 1σ standard deviation (light grey).

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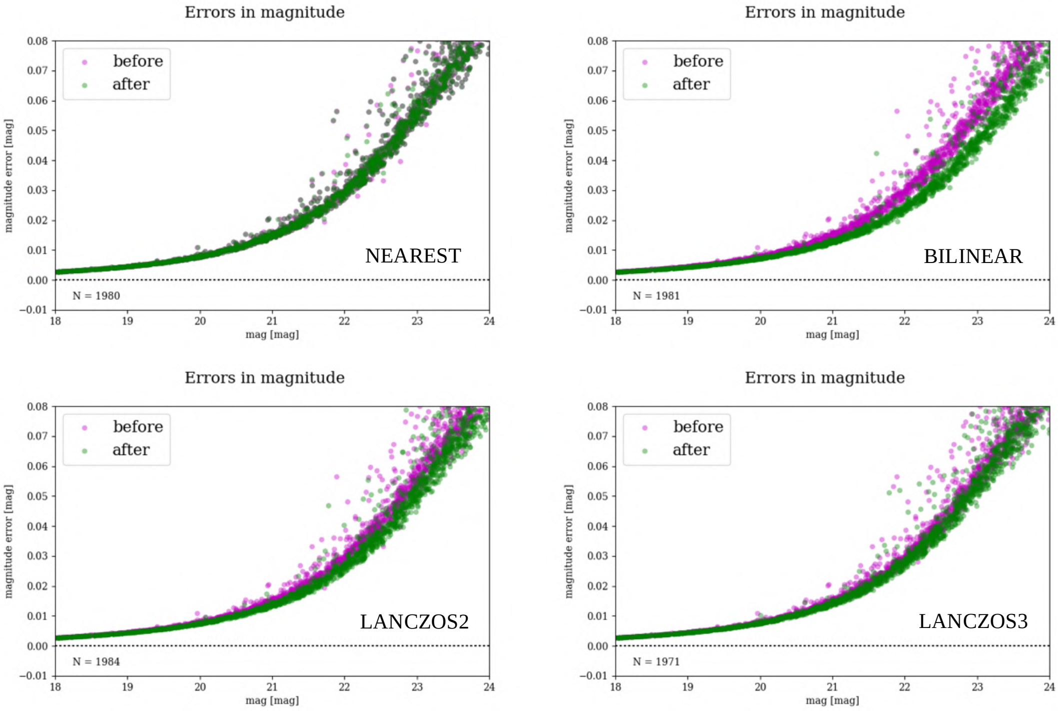

Figure 3: Errors in magnitude as a function of the magnitude before and after applying the image resampling procedure.

Scientific Challenges 4, 5, and 6

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New simulations are planned to be delivered soon in the occasion of the scientific challenges 4, 5, and 6. These challenges, being related to the production of data for different OUs (OU-SHE: measurements of galaxy shapes; OU-PHZ: production of photometric redshifts; OU-SPE: production of spectroscopic redshifts), will be executed in parallel (SC#4,5,6) and end at the same time. The main improvements that are planned to be implemented in the NIR_Resampling software for these new challenges can be described as follows:

1) *List of input dithers*

In case of reprocessing the scientific images, or in case of processing images produced for the self-calibration field (tens of exposures required for the creation of a large scale flat-field), there might be a need of performing the resampling of several dither exposures. In such cases, the images of more than one pointing should then be passed as input in order to be resampled on a grid common to all pointings. The software will thus be modified to accept a list of dithers instead of the four individual dithers of one given pointing.

2) *Propagation of flags*

Another feature that is planned to be implemented for SC#4,5,6 is the propagation of the flags stored in the data-quality layer of each input dither. Figure 4 shows an example before and after applying the resampling procedure, and also comparing the current version of the software that has been applied to SC#2 and SC#3 data with what is planned for SC#4,5,6. The left panel of this figure shows flagged pixels before the resampling. On the middle panel we can see the same pixels resampled using the LANCZOS2 interpolation function (with this function each pixel is spread over 16 pixels in the resampled grid, as discussed in the SWarp's manual), but the information on the flag type has been lost: good pixels remain unflagged and set to zero, but flagged pixels are all set to unit. On the right panel, the flagged pixels are also spread over 16 pixels but the previous flag types are kept. After the resampling, possible intersection between adjacent pixels are managed with the OR operator: if the flag type of both pixels are equal, the type will remain the same; if the flag types are different, the resulting pixel will be the sum of the two types.

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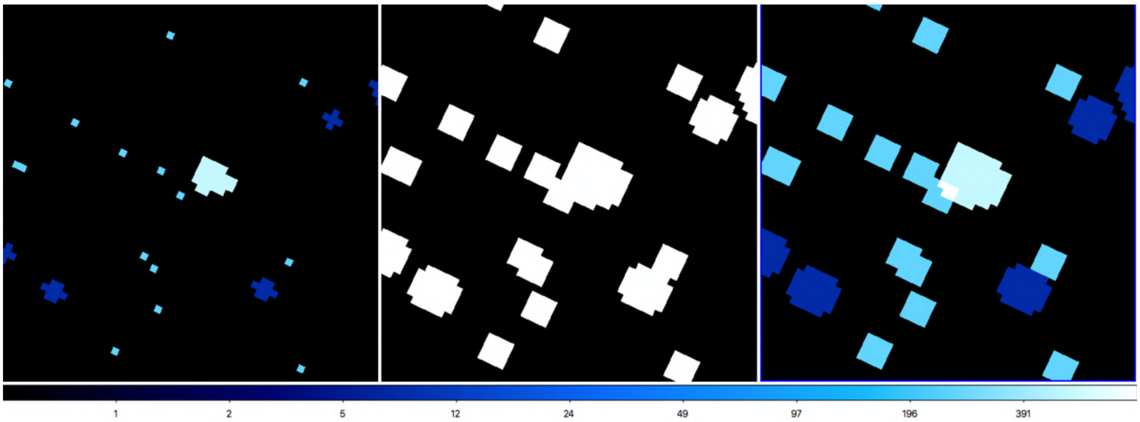

Figure 4: A section of the data-quality layer before and after the resampling procedure showing the possibility of propagating the image flags, a functionality planned for SC#4,5,6. In the left and right panels the color coding represents different flags (dark blue: cosmic rays; cyan: bad pixels; light blue: non-linear pixels; white: an OR operation between bad and non-linear pixels). In the middle panel black and white mean unflagged and flagged pixels, respectively.

The propagation of the flags is a functionality useful to the next step of the NIR pipeline, i.e., the identification of cosmic rays based on multiple frames. That module will use the information stored in the data-quality layer of several dithers with the aim at identifying pixels wrongly flagged by the module of cosmic ray identification based on one single frame. The flag maps can also be propagated until the step of image combination and then be stored as a coadded data-quality layer. It might be useful to keep track of the different flags associated to a pixel that was created from several dithers.

The implementation of the flag-map propagation required a modification of the source files of SWarp, because in its current version this functionality is not available. Therefore, I modified a few source files by adding a new interpolation function, which I named LANCZOS2_FLAGS. This allows the resampling of the data-quality layer using the same interpolation function applied to the scientific layer, thus having both the same interpolation grid. For the moment, the NIR_Resampling software uses the C version of SWarp available as one of the AstrOmatic packages. A new C++ version of the code is under development exclusively for Euclid, and the inclusion of the flag propagation functionality has been requested. In the upcoming challenges, other functions such as BILINEAR_FLAGS or LANCZOS3_FLAGS might also be implemented if needed.

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4. ACKNOWLEDGEMENTS

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