EUROPEAN SOUTHERN OBSERVATORY

VERY LARGE TELESCOPE

NAOS-CONICA Calibration Plan

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78	June 12, 2006	First page	Putting into the correct format
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Contents

Acronyms

DIT	Detector Integration Time
FP	Fabry-Perot
IB	Intermediate Band
ISAAC	Infrared Spectrograph And Array Camera
LW	Long Wavelength
NAOS	Nasmyth Adaptive Optics System
NB	Narrow Band
NDIT	Number of DITs
OB	Observing Block
RMS	Root Mean Square
RON	ReadOut Noise
SDI	Simultaneous Differential Imager
SN	Signal-to-Noise
SW	Short Wavelength
TBC	To Be Confirmed
TBD	To Be Determined
TCS	Telescope Control System
UT4	Unit Telescope 4 (Yepun)
WFS	WaveFront Sensor
ZP	Zero Point

1 Introduction

1.1 Scope and Limitations

NAOS-CONICA is a very versatile instrument. Dichroics, masks, filters, polarizers, grisms, cameras and other more exotic elements can be combined together to yield an extremely large number of observing configurations. For imaging in the broad-band H-band filter alone, one could in principle choose among 4×3×2 = 24 different configurations (4 NAOS dichroics, 3 CONICA cameras and two readout modes) and this does not include the possibility of polarimetric and coronographic configurations.

The basic aim of the calibration plan is to provide the community with darks, flat fields, arcs, zero points and telluric reference observations which enable the effective removal of instrumental and atmospheric features.

This document lists the templates that are used to take calibration data and it describes the recipes which convert the raw data into calibration products, whether they be calibration frames or numbers.

The determination of instrumental aberrations, distortion maps, detector characteristics, etc. are carried out as part of maintenance activities. The present document relates only maintenance activities related to the CONICA detector (linearity & gain). It may contain in the future more information about the NAOS maintenance activities, that are performed regularly.

Additional information about calibrations can be found in the NAOS-CONICA user manual.

1.2 Template Naming Convention

Templates are named via the following convension:

NACO_*mode*_*type*_*mnemonic*

where:

mode is `img` for imaging or polarimetry with the wire grids, `spec` for grism spectroscopy, `pol` for polarimetry, `coro` for coronography, `fpi` for FP imaging, `sdi` for imaging with SDI and `all` for templates applying to all modes.

type is `acq` for acquisition, `obs` for observation, `cal` for calibration, and `tec` for maintenance.

mnemonic describes the main function of the template.

2 Calibration Plan

2.1 Introduction

This section gives an overview on all calibrations that are carried out at regular intervals in order to guarantee the calibration of scientific data. Data products resulting from the calibration observations are archived, and available for science calibration, quality control and monitoring of instrument performance.

2.2 Darks

Template: `NACO_all_cal_Darks`

Purpose: Remove zero level offset and check RON.

Description: Dark frames are obtained at the end of the night for each detector setting (readout mode, detector mode, DIT and camera) that was used during the previous night. Three darks are taken for each setting. These frames can be used to estimate the zero level offset (dark) and the RON. They should not be used to measure instrumental background and detector dark current. These are measured as part of a maintenance procedure.

Observing Conditions: Daytime, upper dome lights off.

CONICA state: Dark position

NAOS state: Ignore

TCS state: Ignore

Frequency: Daily

Duration: Up to 2 hrs

Required data: None

Pipeline Procedure:

- median frames with the same DIT, detector mode, readout mode and camera.
- compute RON and median
- produce hot, cold and deviant pixel maps

Accuracy: 5% in the readout noise, 2 ADU in the median level

Products: Dark frames, RON, median level. as well as hot, cold and deviant pixel maps.

2.3 Flat Fields

2.3.1 SW twilight flats

Template: `NACO_img_cal_TwFlats`

Purpose: Flat field SW imaging, polarimetric and coronographic data.

Description: Given the small pixel scale, twilight flats have to be started 20 to 50 minutes before sunset, and given the slow change in the sky brightness at this time, the template cycles through one or more broad filters and one or more NB or IB filters. Depending on the cameras and filters involved, the template requires between 15 minutes and 1 hour to run, takes 5-20 exposures in each filter and must end between 5 to 8 minutes after sunset.

The NB and IB filters are split into four groups: IB filters, K-band NB filters, H-band NB filters and J-band NB filters. The number of NB and IB filters that can be done with broad band filters depends on the camera and the filters.

All twilight flats will be obtained with the telescope pointing at Zenith and with the visual dichroic. There is no difference between flats taken with the visual, N20C80, N90C10 and K dichroics.

The sequence for evening twilight flats is currently defined as follow, but is adapted to meet the needs (e.g. many twilights with the S27 might be taken if many filters have been used, whereby data with the S54 might be taken only once a month).

day1: Cycle through H, Ks and one or more IB or NB filters, then J-band. Both with the S54 camera and the VIS dichroic
day2: Cycle through H, Ks and one or more IB or NB filters, then J-band. Both with the S27 camera and the VIS dichroic
day3: Cycle through J, H, and Ks and one or more IB or NB filters, S13 camera and the VIS dichroic

Thus it normally takes 3 days to cycle through the broad band filters and one readout mode.

Twilight flats with the neutral density filters, the Wollastons, the Fabry-Perot (FP), the wire grids and/or the coronographic masks are **not** supported. For broad band filters, the flats are taken with the readout mode set to `Double_RdRstRd`. For NB and IB filters, the flats are taken with the readout mode set to `FowlerNsamp`. Other combinations are generally not done in service mode. In visitor mode, we may use other readout modes at the request of the visitor, but visitors should note that some combinations of filter, objective and readout mode may be very difficult to do. If twilight flats for a particular setup are not available, lamp flats are an adequate substitute. Since this (internal lamp flat) is not possible with the half-wave plate, upon request in visitor mode, twilight flats can be taken with the half-wave plate in the beam.

Twilight flats with the SDI (Simultaneous Differential Imager) are supported for visitor mode; however, given the unique nature of this mode, we have created a special template called `NACO_img_cal_SDITwFlats`. These flats are taken with the complete SDI set_up, i.e. special SDI field mask, SDI double Wollaston, H broad-band filter and SDI objective present in the lightpath.

The count level in twilight flats taken in Double_RdRstRd and with DITs shorter than 60 seconds starts with an average count level of 6000 ADU and this decreases with deepening twilight to a few hundred ADUs. The count level in twilight flats taken in FowlerNsamp or for flats with DITs greater than 60 seconds start with an average count level of 2000 ADUs and decrease to several tens of ADU as twilight deepens. Generally, there are 5-20 images for each filter in a twilight sequence.

Observing Conditions: Late afternoon and early twilight - Clear sky.

CONICA state: Online

NAOS state: Online

TCS state: Ignore, pointing at Zenith.

Frequency: Daily.

Duration: 30 - 60 minutes

Required data: Dark frame (optional)

Pipeline Procedure: Identical to ISAAC twilight flats.

- Reject frames with counts above 6800 ADU.
- Subtract a dark with the same DIT and camera (optional)
- Compute the linear regression factors on every pixel.
- Extract the bad pixel map
- Normalize
- Issue a warning if the number of frames per filter is less than five or if the range of fluxes in the frames for any one filter is less than a factor of three.

Accuracy: SN > 100, < 2% Illumination error.

Products: SW flatfield, bad pixel map

2.3.2 LW sky flats

Template: `NACO_img_cal_SkyFlats`

Purpose: Flat field LW imaging, polarimetric and coronographic data.

Description: The skyflats are taken by imaging the sky at three airmasses (1.03, 2.0 and 2.40). These flats, taken as required, must be taken after the TCS status has changed from ignore to normal, which usually occurs after the J-band sky flats, i.e. after sunset.

Valid evening sky flats sequences are:

M_prime with the L27 objective and the VIS dichroic
L_prime with the L27 objective and the VIS dichroic
NB_3.74 with the L27 objective and the VIS dichroic
NB_4.05 with the L27 objective and the VIS dichroic
NB_3.74 with the L54 objective and the VIS dichroic
NB_4.05 with the L54 objective and the VIS dichroic

All twilight flats are taken with the visual dichroic, as there is no difference between flats taken with the visual and JHK dichroics.

Skyflats flats with the Neutral density filters, Wollastons, wire grids or coronographic mask substrates are **not** supported.

Flats with the M_prime filter are windowed.

Observing Conditions: Late twilight

CONICA state: Online

NAOS state: Online

TCS state: Online

Frequency: As required.

Duration: 15 minutes

Required data: None.

Pipeline Procedure:

- Median the frames taken at the same airmass.
- Subtract a dark taken with the same DIT, camera and window from all the frames
- extract the bad pixel map
- Normalize

Accuracy: SN > 100, < 2% Illumination error.

Products: LW flatfield

2.3.3 Imaging lamp flats

Template: `NACO_img_cal_LampFlats`

Purpose: Flat field SW imaging, polarimetric and coronographic data.

Description: Imaging flatfields are obtained in the morning with the halogen lamp in the calibration unit for the setups that were used during the previous night. Three lamp-on and lamp-off frames are taken for each setup.

All readout modes are supported. "Imaging" lamp flats with the Neutral density filters and coronographic masks are **not** supported and are **impossible** with the LW filters and the half-wave plate.

Lamp flats with the SDI mode are supported; however, given the unique nature of this mode, we have created a special template called `NACO_img_cal_SDILampFlats`. These flats are taken with the complete SDI set_up (field mask, double Wollaston, H band filter & SDI-objective).

Lamp flats with the FP are also supported, and they are also taken with a special template, which is called `NACO_fpi_cal_LampFlats`. These flats are taken in the morning for the setups (IB filter, FP setting and detector readout mode) that were used during the previous night.

Observing Conditions: Daytime, upper dome lights off.

CONICA state: Online, lamp mirror in

NAOS state: Ignore

TCS state: Ignore

Frequency: Daily at present.

Duration: Up to 2 hours.

Required data: None.

Pipeline Procedure:

- Median the frames with lamp on and median the frames with the lamp off
- Subtract the resulting off-frame from the resuling on-frame
- Normalise

Accuracy: SN > 100, <5% over the largest scales

Products: Imaging lampflat frames.

2.3.4 Polarimetric lamp flats

Template: `NACO_pol_cal_LampFlats`

Purpose: Flat field polarimetric data.

Description: Polarimetric flatfields are obtained in the morning, with the halogen lamp present in the CONICA calibration unit, for the setups that were used during the previous night. Three lamp-on and lamp-off frames are taken for each setup.

All readout modes are supported. Lamp flats with the neutral density filters are **not** supported and **not** possible both for the LW filters and the half-wave plate.

Polarimetric lamp flats have either the wollaston (together with the wollaston mask) or one of the wire grids in the light path. Imaging lamp flats without the wire grids or the wollaston are also taken and are an adequate alternative.

Observing Conditions: Daytime, upper dome lights off.

CONICA state: Online, lamp mirror in

NAOS state: Ignore

TCS state: Ignore

Frequency: Daily at present.

Duration: Up to 2 hours.

Required data: None.

Pipeline Procedure:

- Median the frames with lamp on and median the frames with the lamp off
- Subtract the resulting off-frame from the resuling on-frame
- Normalise

Accuracy: SN > 100, <5% over the largest scales

Products: Polarimetric lampflat frames.

2.3.5 Spectroscopic flats

Template: `NACO_spec_cal_LampFlats`

Purpose: Spectroscopic flatfields for calibration of pixel-to-pixel variations.

Description: Spectroscopic flatfields are obtained in the morning, with the halogen lamp present in the CONICA calibration unit, for the setups that were used during the previous night. Three lamp-on and lamp-off frames are taken for each setup. Flats for slitless spectroscopy will be take with the mask that is used for slitless spectroscopy.

Observing Conditions: Daytime, upper dome lights off

CONICA state: Online, lamp mirror in

NAOS state: Ignore

TCS state: Ignore

Frequency: Daily at present.

Duration: Up to 2 hours

Required data: None.

Pipeline Procedure: Not implemented.

- Median the frames with lamp on and median the frames with lamp off
- Subtract resulting off-frame from the resulting on-frame
- Normalise

Accuracy: SN > 100, <5% across the spatial axis

Products: Spectroscopic lampflat frames.

2.4 Wavelength Calibration

2.4.1 Spectroscopic arcs

Template: `NACO_spec_cal_Arcs`

Purpose: Wavelength Calibration.

Description: Spectroscopic arcs are obtained in the morning with the penray lamp in the calibration unit for the setups that were used during the previous night. One lamp-on and one lamp-off frame are taken for each setup. LW setups are **not** supported. For slitless spectroscopy, arcs with the 86 mas slit will be provided.

Observing Conditions: Daytime, upper dome lamps off

CONICA state: Online, lamp mirror in

NAOS state: Ignore

TCS state: Ignore

Frequency: Daily at present.

Duration: Up to 2 hours.

Required data: None.

Pipeline Procedure: Not implemented.

- Subtract the off-frame from the on-frame
- Determine 2-d wavelength solution

Accuracy: 0.5 pixels relative and 2 pixels absolute.

Products: 2-D wavelength calibration co-efficients.

2.4.2 Nighttime spectroscopic arcs and flatfields

Users can choose to take nighttime spectroscopic arcs and flat fields. Usually, these calibrations are not required if you wish to do spectrophotometry to an accuracy of 5% or less. If the option to take lamp flats is selected, *n* pairs of frames, where *n* is a number between one and three, with the lamp on and off will be taken. Likewise, if the option to do arcs is selected, one frame with the arc lamp on and one frame with the arc lamp off will be taken. Alternatively, one can select to do both lamp flats and arcs, in which case $n + 1$ pairs of frames will be taken.

2.4.3 Nighttime coronographic flatfields

We recommend that users take nighttime flatfields with the semi-transparent Lyot and 4QPM coronographs. Only the SW filters are supported. LW lamp flats are **not** possible. For the LW filters, the only alternative is to use a sky frame to flat field the data. If the option to take lamp flats is selected, *n* pairs of frames, where *n* is a number between one and three, with the lamp on and off will be taken. Lamp flats with the opaque masks are not required and are **not** supported.

2.4.4 Nighttime FP arcs

Since we have observed drifts of about 1 nm in the setting of the FP over a 24 hour period, it is mandatory that users attach the `NACO_fpi_cal_Arcs` template at the beginning of every OB that uses the FP.

The purpose of this template is to determine the transformation between x,y (detector coordinates) and z (FP plate distance) and x,y versus λ. Additional details are given in the NACO User Manual.

Currently, this template is not run during the morning calibrations.

2.5 Detector Calibrations

2.5.1 Detector Linearity

Template: `NACO_img_cal_Linearity`

Purpose: Determine non-linearity co-efficients

Description: Under stable illumination from the halogen lamp in the calibration unit, measurement of the number of counts versus DIT for each detector mode.

Observing Conditions: Daytime

Frequency: Once a year

Special conditions: None.

Duration: 1 hr

Required data: None.

Pipeline Procedure: To be defined.

Accuracy: 1% in the corrected flux.

Products: Fit coefficients, saturation level, bad pixel map.

2.5.2 Detector Gain

Template: `NACO_img_cal_Gain`

Purpose: Determine detector gain.

Description: Under illumination from the halogen lamp in the calibration unit, measurement of the noise as a function of flux for each detector mode.

Observing Conditions: Daytime

Frequency: Once a year

Special conditions: Stable source

Duration: 1 hour

Required data: None.

Pipeline Procedure: To be defined.

Accuracy: 10%

Products: Gain.

2.6 Photometry

2.6.1 Photometric calibration - Imaging

Template: `NACO_img_cal_StandardStar`

Purpose: Photometric calibration for the broad band filters (J,H,Ks, L_prime and M_prime).

Description: A star is imaged at the center and in the four corners of the array.

For J, H and Ks, the ZPs are measured with the readmode set to `Double_RdRstRd`. For the LW filters, the ZPs are measured with the readmode set to `Uncorr`. M_prime images are windowed. Standards are taken with the appropriate dichroic.

ZPs with the NB, IB or neutral density filters, the FP, the wire grids, the Wollastons, the half-wave plate and/or the coronographic masks are **not** taken as part of the observatory's calibration plan. Users should submit OBs if they wish standards to be observed with these elements.

Observing Conditions: Photometric

CONICA state: Online

NAOS state: Online, closed loop

TCS state: Online

Frequency: Nightly with S27 and Visual WFS. Other objectives and wavefront sensors as required.

Duration: 30min

Required data: Twilight flat

Pipeline Procedure:

- Subtract images in pairs and divide by the twilight flat (skyflat for LW) if available
- Aperture photometry of the standard star at five positions.
- Mean zeropoint and associated RMS
- Strehl ratio

Accuracy: <5% on ZPs and Strehl ratios

Products: ZP, RMS and Strehl Ratios for broad band filters (J,H,Ks and Lp).

2.6.2 Telluric Standards - Spectroscopy

Template: `NACO_spec_cal_StandardStar`

Purpose: Remove telluric lines from science spectra.

Description: A star of known spectral type is imaged either immediately after the science target it is meant to calibrate.

Observing Conditions: Clear

CONICA state: Online

NAOS state: Online, closed loop

TCS state: Online

Frequency: As required (for each spectroscopic setting observed)

Duration: 30min

Required data: Dark, Flats and Arcs.

Pipeline Procedure: Not supported by the pipeline.

Accuracy: An airmass difference of less than 0.2.

Products: None

3 Decision Tree for Pipeline Calibration

The time delay between calibration frames and the frames they calibrate should always be kept to a minimum. For quick look reduction at the telescope, calibration frames are not necessary.

3.1 Darks

Defining parameters:

- DIT
- Readout mode
- Detector mode
- Camera
- Image size (windowed or not)

Quality control and monitoring:

- RON
- Median level
- Issue a warning if the RON differs by more than 25% or if the median level differs by more than 10% from the long term trend.

Selection criteria for data that require darks. I.e everything that is not a dark

1. Choose daily dark with the same set of defining parameters.
2. Choose archive dark with same set of defining parameters.
3. Choose dark with closest DIT. Readmode and detector mode must remain the same.
4. No dark subtraction

3.2 Flatfields

3.2.1 Imaging

Defining Parameters

- Mask (FLM_13, FLM_27, FLM_54)
- Filter
- FP setting if used.
- Camera
- Readmode
- Detector mode
- Image size (windowed or not)

Quality control/Trend analysis:

- Divide the flat with a recently obtained flat and issue a warning if the pixel-to-pixel RMS in the divided image is greater than 2% or if the large scale illumination differs by more than 5%.

Selection criteria for all imaging, polarimetric and coronographic data:

1. Choose twilight flat (SW) or skyflat (LW) with the same set of defining parameters.
2. Choose archive twilight flat (SW) or skyflat (LW) with the same set of defining parameters.
3. Choose lampflat (SW only) with the same camera, filter, FP setting if used, readmode and detector mode.
4. Choose archive lampflat (SW only) with the same camera, filter, FP setting if used, readmode and detector.
5. No flat

3.2.2 SDI Flats

SDI flats are done with special SDI templates: `NACO_img_cal_SDITwFlats` and `NACO_img_cal_SDILampFlats`.

Defining Parameters

- Camera
- Readmode
- Detector mode

Quality control/Trend analysis:

- Divide the flat with a recently obtained flat and issue a warning if the pixel-to-pixel RMS in the divided image is greater than 2% or if the large scale illumination differs by more than 5%.

Selection criteria for all SDI data:

1. Choose twilight flat SW with the same set of defining parameters.
2. Choose archive twilight flat with the same set of defining parameters.
3. Choose lampflat with the same camera, readmode and detector mode.
4. Choose archive lampflat with the same camera, readmode and detector.
5. No flat

3.2.3 Spectroscopy

Defining Parameters

- Grism
- Order Sorting Filter
- Slit
- Camera

Quality control/Trend analysis:

- Divide the flat with a recently obtained flat and issue a warning if the pixel-to-pixel RMS in the brightest regions of the divided image is greater than 2% or if the large scale illumination differs by more than 5%.

Selection criteria for all spectroscopic data:

1. Choose a lamp flat with the same set of defining parameters.
2. Choose an archive lamp flat with the same set of defining parameters.
3. No flat

3.3 Wavelength Calibration

Defining Parameters

- Grism
- Order Sorting Filter
- Slit
- Camera

Quality control/Trend analysis:

- Measure the dispersion and compare the coefficients with the long term trend. Issue a warning if the central wavelength shifts by more than 0.5 pixels.

Selection criteria for all spectroscopic data:

1. Choose an arc with the same set of defining parameters.
2. Choose an archived arc with the same set of defining parameters.
3. No dispersion solution.

For slitless observations, use arcs with the 86mas slit.

3.4 Flux Calibration

3.4.1 Imaging Standards

Defining Parameters

- Mask (FLM_13 or other)
- Filter
- Camera
- Readmode
- Detector mode
- NAOS Dichroic
- Lyot stop

Quality control/Trend analysis:

- Compare ZPs with recently obtained values. Issue a warning if the difference is greater than 5%, or if the RMS is greater than 5

Selection criteria:

1. Choose nightly zero point with the same set of defining parameters.
2. Choose archive zero point with the same set of defining parameters.
3. No flux calibration

3.4.2 Telluric Standards

Defining Parameters

- Grism
- Order Sorting Filter
- Slit
- Camera

Quality control/Trend analysis:

- None

Selection criteria:

1. Choose standard with the same set of defining parameters, the same date and with an airmass difference < 0.2.
2. Choose standard with the same set of defining parameters and with an airmass difference < 0.2.
3. Choose standard with the same set of defining parameters.
4. No standard.

4 Summary

Table **??** summarizes the calibration templates and activities.

Table 1: NaCo calibration templates

template name	description of activity	time required	Time and Frequency
NACO_all_cal_Darks	Darks	Up to 2 hours	Daytime, daily
NACO_img_cal_TwFlats	Twilight Flats	70 minutes	Twilight, daily
NACO_img_cal_SDITwFlats	Twilight Flats	70 minutes	Upon request
NACO_img_cal_SkyFlats	Sky Flats	15 minutes	Twilight, as req.
NACO_img_cal_LampFlats	Imaging lamp flats	Up to 2 hours	Daytime, as req.
NACO_img_cal_SDILampFlats	SDI lamp flats	Up to 2 hours	Daytime, as req.
NACO_fpi_cal_LampFlats	FPI lamp flats	Up to 2 hours	Daytime, as req.
NACO_pol_cal_LampFlats	Pol. lamp flats	Up to 2 hours	Daytime, as req.
NACO_img_cal_StandardStar	Photometric Stds	20 minutes	Nighttime, nightly
NACO_spec_cal_LampFlats	Spec. lamp flats	Up to 2 hours	Daytime, as req.
NACO_spec_cal_Arcs	Arcs	Up to 2 hours	Daytime, as req.
NACO_spec_cal_StandardStar	Telluric Standard	20 minutes	Nighttime, as req.
NACO_img_cal_Linearity	Array Linearity	1 hour	Daytime, six monthly
NACO_img_cal_Gain	Gain	1 hour	Daytime, six monthly

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