Quality Control of the ESO-VLT instruments
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ABSTRACT
Currently four instruments are operational at the four 8.2m telescopes of the European Southern Observatory Very Large Telescope: FORS1, FORS2, UVES, and ISAAC. Their data products are processed by the Data Flow Operations Group (also known as QC Garching) using dedicated pipelines. Calibration data are processed in order to provide instrument health checks, monitor instrument performance, and detect problems in time. The Quality Control (QC) system has been developed during the past three years. It has the following general components: procedures (pipeline and post-pipeline) to measure QC parameters; a database for storage; a calibration archive hosting master calibration data; web pages and interfaces. This system is part of a larger control system which also has a branch on Paranal where quick-look data are immediately checked for instrument health. The VLT QC system has a critical impact on instrument performance. Some examples are given where careful quality checks have discovered instrument failures or non-optimal performance. Results and documentation of the VLT QC system are accessible under http://www.eso.org/qc/.

Keywords: Quality control, data flow operations, trend analysis, data reduction pipelines, instrument performance

1 CONTROL QUALITY: WHY?

Like any other large observatory worldwide, the European Southern Observatory (ESO) has staff who permanently look into the performance of the instruments and check the quality of the data. ESO’s Very Large Telescope (VLT) on Paranal has the operational model of a data product facility. This goes beyond the day-to-day performance checks and means to deliver data of a defined and certified quality.

The Data Flow Operations Group at Garching Headquarters (DFO, also frequently called QC Garching), provides many aspects of data management and quality control (QC) of the VLT data stream. One of the main responsibilities is to assess and control the quality of the calibration data taken, with the goal to know and control the performance of the VLT instruments. Information about the results of this process is fed back to Paranal Science Operations and to the ESO User Community via QC reports and web pages.

The constant flow of raw data from the VLT instruments splits into data streams for the science data and the calibration data. The calibration data stream has two separate components:

- calibrations taken to remove instrument signatures from science data,
- calibrations taken for routine daily instrument health checks.

The focus of QC Garching is to process these data and extract Quality Control information. This process of course does not replace the on-site expertise of the Paranal staff. But it goes beyond the usual quick-look, on-the-spot checks and provides a permanent and in-depth knowledge of the instrument status. With QC parameters routinely collected over years, it is possible to control, predict, and often improve, the performance of the instruments.

This article describes the Quality Control process for the four presently operational VLT instruments: FORS1, FORS2, ISAAC and UVES. This process will be extended and refined for the next suite of instruments coming soon, VIMOS, NAOS/CONICA, and FLAMES, and ultimately expanded to all VLT instruments.

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2 HOW TO CONTROL DATA QUALITY

The term quality control, though often used, needs some definition. Quality control, as we understand it, implies the control of the following things:

- the quality of the raw data,
- the quality of products obtained from these raw data,
- the performance of the instrument component involved.

Quality control does generally not imply aspects like the control of ambient data (quality of a night), the proper format of FITS headers, or the tracking of programme execution. Responsible for these aspects, being part of Quality Control in a wider sense, are other groups, e.g. Paranal Science Operations, and the User Support Group.

2.1 Pipelines

Fundamental to the VLT Quality Control process is the use of automatic data processing packages, the pipelines. Without these, effective quality control of the huge amount of data produced by the Observatory would be impossible. In fact, the primary goal of the data reduction pipelines is to create calibration products and support quality control. Only after this comes the reduction of science data.

With the large-scale use of data processing pipelines, the Quality Control group has effectively also the function of assessing and improving the accuracy of the pipelines. As a by-product, we provide documentation about the pipeline functions from the user's point of view.

The usual day-to-day workflow of the QC scientists has as its primary components:

- process the raw data (calibration and science) using the instrument pipeline
- perform the quality checks
- select the certified products and distribute them.

One might say that the use of the pipeline, once the process has been set up properly, is mainly number-crunching, while the quality checks require expertise and brainwork.

2.2 The Quality Control process

There is a natural three-floor pyramid in the QC process (Figure 1):

- Check each data product.
- Derive and store a set of QC parameters per product.
- Look at the long-term behaviour of these parameters.

**Check each product.** The first, and most fundamental, step in the QC process is done on each pipeline product. Is the frame over/under-exposed? Is it different from the frame taken yesterday? A set of procedures creates displays and graphical information like cross-cuts and histograms. Frequently there is a comparison to a reference frame. Without these procedures, the QC scientist would be blind for data quality. The mere fact that a reduction job was executed without producing a core dump indicates nothing about data quality.

In practice, after some initial phase when indeed everything is inspected, one usually decides to switch to a confidence mode where, for example, only every third night is inspected in depth, while for the others the trending plots are consulted.

![Figure 1. The QC and trending pyramid](image-url)
This strategy is economic in case of very stable instrument performance, and mandatory with high data rates. Then the 'human factor', namely the possible level of concentration, ultimately limits complete product checks.

Figure 2 shows as an example the QC plot for the products of a UVES FORMATCHECK frame which is a technical calibration needed by the pipeline to find the spectral format. With an experienced eye, just a second is needed to know from this plot that everything is fine and under control.

QC checks are also done on Paranal, directly after frame acquisition. These on-the-spot inspections are of quick-look character and apply to both raw and product data. They are extremely important to check the actual status of the instrument, especially for those instruments like UVES which have no direct data transfer to Garching headquarters.

Derive QC1 parameters. Next step in the QC process is the extraction of QC parameters. These are numbers which characterize the most relevant properties of the data product in a condensed form. Since they are in most cases derived through some data manipulation (e.g. by the reduction pipeline), they are called QC1 parameters. This distinguishes them from the QC0 parameters which mainly describe site and ambient properties like seeing, moon phase etc.

Across the instruments, there are always QC1 parameters describing the detector status, i.e. the read noise, the mean bias level, the \( \text{rms} \) of gain variations etc. Other QC1 parameters specific to spectroscopic modes are resolving power, dispersion \( \text{rms} \), or number of identified lines. Imaging modes are controlled by QC1 parameters like zeropoints, lamp efficiency, and image quality.

Trending. The top level in the QC pyramid is the trending. Trending is a compilation of QC1 parameters over time, or a correlation of one QC1 parameter against another one. Trending can typically prove that a certain instrument property is stable and working as specified. It can do much more, however. For example, trending can discover the slow degrading of a filter, or aging effects of the detector electronics. Examples are given further below.

2.3 Outliers
Within the trending process, main attention focuses on two extremes: the outliers, and the average data points. Information theory says that outliers transport the highest information content. But not all outliers are relevant for QC purposes. We need to distinguish whether the outlier comes from a bad algorithm setup, from a bad instrument setup, or from a bad operational setup.
A bad algorithm may be e.g. a wrong code for \textit{rms} determination. Such outlier would help to improve the code. A bad instrument setup could be a stuck filter wheel with the filter vignetting the light path. A bad operational setup would be a frame claiming to be a flat, but the lamp was not switched on. Generally, the instrument setup outliers are the most relevant ones.

Finding that a certain QC1 value is stable over months or years may lead to relax the acquisition rate of the corresponding calibration data. This may be a good idea since we should avoid over-calibration. But one has to bear in mind that for proving stability, one needs a good coverage in time, so it's a good idea to have calibrations done more frequently than their typical variation timescale.

2.4 Certification

Once a product file has been QC checked, and its QC1 parameters have been verified to be valid entries, the data enter into the delivery channel, which involves ingestion into the master calibration archive, usage for science reduction and distribution to the end users (if taken in Service Mode). By definition, the data are then certified. Rejected data are deleted.

3 COMPONENTS CONTROLLED

In the following we provide an overview of the instrumental parameters which are presently controlled by the QC process.

UVES has been operational since April 2000 and was the first instrument with built-in QC procedures as part of the pipeline. So it was possible to measure and collect from the beginning a backbone set of QC1 parameters. This set has been expanded over the last two years. The two-year baseline forms an asset from which many valuable pieces of information about long-term behaviour can be extracted.

UVES QC monitors the following instrument components\(^3\) (see Figure 3):

<table>
<thead>
<tr>
<th>Component</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>detector</td>
<td>bias level, read noise, dark current; fringing</td>
</tr>
<tr>
<td>gratings</td>
<td>stability of spectral format; resolving power, precision of dispersion solution</td>
</tr>
<tr>
<td>slit</td>
<td>slit noise</td>
</tr>
<tr>
<td>lamps, filters</td>
<td>FF lamp stability, filter throughput</td>
</tr>
<tr>
<td>all components</td>
<td>efficiency</td>
</tr>
</tbody>
</table>

FORS1 and FORS2 have the following QC items\(^4\):

<table>
<thead>
<tr>
<th>Mode</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>bias level, read noise, dark current, gain, contamination</td>
</tr>
<tr>
<td>Imaging</td>
<td>zeropoints, colour terms, image quality</td>
</tr>
<tr>
<td>Long-Slit Spectroscopy</td>
<td>dispersion, resolution (FORS1 only)</td>
</tr>
<tr>
<td>Multi-Object Spectroscopy</td>
<td>to be added</td>
</tr>
</tbody>
</table>

ISAAC has the following QC items\(^5\):

<table>
<thead>
<tr>
<th>Mode</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>dark level, read noise</td>
</tr>
<tr>
<td>Imaging (short wavelength arm)</td>
<td>Zeropoints</td>
</tr>
<tr>
<td>Imaging (long wavelength arm)</td>
<td>to be added soon</td>
</tr>
</tbody>
</table>

\(^3\) access to the data under http://www.eso.org/qc/UVES/qc/qc1.html
\(^5\) http://www.eso.org/qc/ISAAC/qc/qc1.html
4 TRENDING

With the QC1 parameters stored in a database they become available for trending. There is a central QC1 database under development which will host all QC1 parameters and other related information like plots and trending results.

The QC1 database can be considered as the central memory about the status of each VLT instrument. The goal is to have available all quality information from the complete operational history of the instrument. This also includes information about interventions (e.g. mirror recoating) and replacements (optical components, detectors). Such information is vital for proper interpretation of the trending results. Moreover, with data collected over years, it becomes possible to detect slow degrading effects. Preventive interventions and maintenance can be scheduled properly.

5 WEB PAGES

As part of the QC process, these results are published on the web. Our Quality Control site is http://www.eso.org/qc/ which has, per instrument, a link to QC and trending results.

Under the URLs http://www.eso.org/qc/<INSTR>/qc/qc1.html (where INSTR is any of UVES, FORS1, FORS2, or ISAAC), you connect to the QC1 database. Here you may view trending plots and download ASCII data (see Figure 3). You also find detailed documentation about the QC1 parameters.

Our goal is to present knowledge, not just information. Take as an example the trending of the UVES spectral resolving power $R$. We do not just dump all available numbers per date, but provide a documentation of the measurement process, a selection of trending plots, a correlation with slit width and a comparison to User Manual values. Often there are also tutorial pages.

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6 http://www.eso.org/qc/UVES/qc/qc1.html
In the following section we provide some highlights from the QC and trending process. You will find more details in the papers Hummel et al. (2002) for the ISAAC instrument, and in Hanuschik et al. (2002) for the UVES case.

6.1 Compensation of UVES thermal drifts

The precision of the UVES spectrograph is limited by ambient temperature changes. A one degree difference causes an effective shift of the gratings by up to 1 pixel in cross-dispersion direction (Figure 4). The daily FORMATCHECK frames are compared to a reference frame and used to measure these shifts. Since the QC1 values proved a general stability and a linear slope of the thermal coefficients (left), a compensation for such drifts was successfully implemented in cross-dispersion direction (right). Meanwhile also the dispersion direction is corrected.

6.2 UVES filter degradation

The monitoring of the exposure level of the UVES flat-field lamps gives control over the lamp and filter status. The filter status is especially significant for the quality of science observations. In July 2001, the transmission of the blue CuSO4 filter dropped which was discovered in the trending plot (Figure 5). The replacement of the filter gave the blue efficiency of UVES a boost.

Figure 5. The transmission of the CuSO4 filter used for reducing scattered light in the blue arm of UVES dropped significantly in July 2001. This was only discovered in November 2001 when the corresponding trending procedure had been established. An inspection of that filter verified its poor state: its coating was partly destroyed by humidity. Its replacement in December 2001 has improved the efficiency considerably, which is clearly visible in the trending plot.
6.3 FORS1 image quality
Figure 6 combines input data from pipeline-processed SCIENCE images from FORS1. It demonstrates that in most cases FORS1 image quality is determined by the seeing and not degraded by potential errors like telescope guiding etc.

6.4 FORS1 photometric zeropoints
Figure 7 shows the complete history of FORS1 zeropoints in the V band, spanning three years. Zeropoints measure the efficiency of the overall system instrument plus telescope. There have been major interventions (see the caption for details), but maybe more interesting is the fact that there is a general loss of efficiency by about 8% per year, due to degrading of the mirror surface.

6.5 ISAAC photometric zeropoints
Figure 8 shows the zeropoints derived by the ISAAC pipeline for the period October 2001 until March 2002. The sharp jump around MJD-OBS = 52,200 is due to an intervention which included a re-alignment. This improved the instrument efficiency by up to 0.2 mags. The long-term trend is due to efficiency degrading, while the short-term scatter in most cases is due to fluctuations of the night quality.

7 SHARED QUALITY CONTROL

It is obvious that Quality Control must be a shared responsibility between QC Garching and Paranal Science Operations. There are always QC issues which require immediate reaction and intervention. These can only be properly handled on site. With the data airmailed to Garching (which today is the transfer mode for UVES, and soon for all VLT instruments), the typical reaction time on QC issues in Garching is about 7 days. This naturally leads to the concept of shared QC which means that part of the QC tasks are done on Paranal (in real time, by daytime astronomer), part in Garching (off-line, by QC scientist).
Three years of FORS1 zeropoints in the V band. Major interventions, causing steps in the slope, have been: mirror recoatings in February 2000 and March 2001, sudden degrading of main mirror due to rain in February 2001. The move to UT3/Melipal in August 2001 is virtually invisible in this plot. More details about FORS1/FORS2 zeropoints under 7.

7 On-site QC
Basic quality checks on the calibration data are performed by the Paranal daytime astronomer. Just after exposing the raw calibration data and pipeline-processing them into calibration products, the data are inspected visually. The on-line pipelines derive an essential set of QC1 parameters which is fed into a database. Essential are those QC1 parameters relating to fundamental instrument properties which, in case of failure, would jeopardize the usefulness of the science data. Such instrument health parameters are e.g. proper adjustment of gratings and filters, and proper CCD setup.

7.2 Off-line QC
The full set of quality checks is applied in Garching, anything which is not time critical, but requires in-depth analysis, pipeline or post-pipeline procedures. This applies also to complex trending analyses requiring extended data sets. Examples are photometric zeropoints which are determined from all standard star data of a night; colour and extinction terms being derived for a whole semester; efficiency curves; sky brightness etc.

7 http://www.eso.org/qc/FORS1/qc/zeropoints/zeropoints.html;
http://www.eso.org/qc/FORS2/qc/zeropoints/zeropoints.html
7.3 Feedback loops
The exchange of quality information between the two sites with QC activities is especially important. The main feedback channel from QC Garching to Paranal are the web-published trending plots which are updated daily. These monitor the proper function of all QC-checked components. Any anomalies are investigated in detail and reported directly to the Paranal instrument responsible.

7.4 Quick Updates
A new project to improve feedback timescales has been launched recently. It uses the daily health check calibrations which are pipeline-processed on Paranal by the quick-look pipelines. Instead of transferring the full data sets through the satellite link, only the processed QC1 parameters are put into the data stream. These parameters are automatically processed into updated trending plots. Refreshed versions are available on the web at about 09:00 Paranal time just in time when the daytime astronomers start their shift. Latest data are then less than one hour old. Anomalies in the trending are reported by automatic emails. This process provides both sides of the QC process (Paranal and QC Garching) with the same level of actuality.

8 FEEDBACK INTO CALIBRATION PLAN
Another example of successful feedback of the QC process and the instrument operations is the improvement of the Calibration Plan. In principle, calibration data are taken to remove instrumental signature from the science data ("calibrate the science"). In a more general sense, they are taken to know the instrument status ("calibrate the instrument"). Ideally, one would go for the latter goal since this provides the broader knowledge about the instrument while including the requirement to reduce the science data.
But in practice this is not even possible for simple instrument modes. For instance, the imaging mode of FORS1 has 5 standard filters with 4 CCD read modes and 2 different collimators. Obtaining a complete set of calibration frames, including twilight flats and standard stars, is practically not possible every night. As a more complex instrument, UVES has 12 standard setups, with roughly 20 different slit widths and 2 CCD modes, and the parameter space becomes forbiddingly large for routinely calibrating all settings.

Hence usually calibration data are triggered by the science setups actually used in the night before. To these are added the daily health check calibrations. On Paranal, an automatic tool is used which collects this information into the daytime calibration queue.

9 VISION

Our QC process is continuously evolving, to meet the current and future needs of our main customers: Paranal Science Operations and the ESO user community. Here are a few examples.

Although the QC1 parameters computed and controlled by QC Garching are available via our Web pages, they are not easily associated with the calibration products available from the ESO Science Archive. By the end of this year, we hope to have a new QC1 parameter database within the Archive domain. Once this database exists, it should be possible for users to retrieve the QC1 parameters associated with the calibration products they are retrieving from the Archive. This is particularly important in the context of Virtual Observatory development.

The calibration data flowing through QC Garching contains a rich but largely unexploited reservoir of information about Cerro Paranal as a site. QC Garching, in collaboration with other groups within ESO, has started several projects to process this information and make it available to our customers. For example, this year we will publish a high signal-to-noise, high resolution sky atlas extracted from many hours of UVES observations, as well as a study of optical sky brightness as a function of lunar phase, lunar distance, time after twilight, etc, derived from FORS data. Possible future projects include the creation of lists of faint, secondary photometric standards for FORS and ISAAC, in collaboration with Paranal Science Operations.

Of course, our main priority this year is to establish regular QC operations for the latest VLT instruments: NAOS/CONICA, VIMOS, and FLAMES, as well as extending our process to the VLT Interferometer complex. These instruments introduce many new and complex modes: optical interferometry, adaptive optic imaging, high density multi-object spectroscopy with slits and fibers, and integral field spectroscopy. The underlying, detector based health and wellness QC process are essentially extensions of our current process, but the development of a higher level QC process will be more challenging.

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