Adaptive optics quality metrics and the user constraint set for VLTI

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ABSTRACT

The ESO VLT Interferometer (VLTI) is a general-user facility and is operated in service mode (SM) for a large part of the available time. An important aspect of this SM observing mode is the definition of a set of critical observing conditions that must be met at the time of executing the requested observation. There are a number of observing constraints that are specific to interferometric observations, such as the choice of the array configuration and the hour angle at time of observation, which is processed during the scheduling. On the other hand, classical constraints such as the regular seeing or the lunar illumination are less critical for observations using VLTI instruments than for those using classical VLT instruments. In particular, the use of the adaptive optics system MACAO for VLTI observations employing the Unit Telescopes (UTs) ensures a very good image quality even for moderate environmental conditions. However, the exact dependence between environmental conditions, the performance of the MACAO systems, the wavefront quality at the interferometric instruments, and the accuracy of the final visibility, are not yet known in much detail. In order to investigate this dependence we have started to monitor routinely the environmental conditions, the quality of the MACAO systems, the quality of the acquisition images, and the final data product for all VLTI observations since June 2005. Here, we present the details of this study, as well as first statistics and results.

1. VLTI OPERATIONS

The VLT Interferometer (VLTI) has been operating on Paranal since 2001 with first fringes obtained at 2µm with VINCI, the VLTI commissioning instrument. Since Period 73 (April 2004), MIDI (the MID-infrared Instrument for the VLT), operating in the N Band between 8 to 12 µm is offered for Service Mode Observations (SM). For the past period (October 2005 to April 2006), MIDI was offered using the UT (Unit Telescopes 8.2m) or the AT (Auxiliary Telescopes: 1.8m).The second VLTI instrument AMBER (near-infrared/red focal instrument for the VLTI), operates in the bands J, H and K and has been offered for SM operations since P76 (October 2005) with 3 telescopes. Several sub-systems are also part of the VLTI; one of them is MACAO, the Multi-Application Curvature Adaptive Optics (see http://www.eso.org/projects/aot/macao_vlti/). For more information about the VLTI instruments during SM observations see ref. 1 to 5.

To get diffraction limited images with MIDI and AMBER on the UTs, MACAO is used during the observations. The MACAO systems guide on a target which could be different from the object observed by the VLTI instrument. For SM observations it is guaranteed that the MACAO loop is closed or the observation will be repeated. The operational conditions for a MACAO closed loop are a seeing less than 1.5 arcsec, a coherence time larger than 1.5ms, an air mass smaller than 2 and the distance between the science target and the AO target less than 57.5 arcsec.

We are investigating the dependence between the performance of the MACAO systems and the different seeing parameters recorded by the Astronomical Site Monitor (ASM). A further goal is to correlate these MACAO parameters with the VLTI QC parameters such as the quality of the MIDI acquisition image and the accuracy obtained on the AMBER or MIDI Visibility. We will present here comparison between the different MACAO systems involved in the same interferometric observation (2 telescopes with MIDI and 3 telescopes for AMBER), between the differential image motion monitor installed on Paranal (DIMM) and the MACAO data such as the Fried parameter R0 or the coherence time Tau0. Future studies will involve the comparison between the Strehl Ratio and the distance from the source and other atmospheric parameters such as the isoplanatic angle.

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2. THE VLTI ADAPTIVE OPTICS SYSTEM: MACAO

MACAO-VLTI is a set of Adaptive Optics systems dedicated to interferometry on the VLT Unit Telescopes (UTs). Four MACAO-VLTI systems are installed at the each UT Coudé focii feeding the VLTI delay lines with a corrected IR beam from 1000-13000nm with up to 50% Strehl @ 2.2microns (ref. 7). The most important requirement for the MACAO/VLTI system is to keep the piston variations over the pupil within the following specifications:

- < 25 nm RMS for a time window of 48ms
- < 125 nm RMS for 290ms
- < 2 µm Peak to Valley (PV) for a time window of 10mn

MACAO has been installed since 2003 and selected AO parameters are recorded in the MIDI and AMBER raw fits data since 2005 (table 1). The MIDI data used here are recorded since June 2005 while the AMBER data are recorded only since December 2005.

MACAO parameters	Description
STREHL_MEAN	Mean Strehl Ratio
STREHL_RMS	rms of the Strehl Ratio
WFE_MEAN	Mean squared wave front error (in rad) Ratio
WFE_RMS	rms of the squared wave front error (in rad) Ratio
ENC_MEAN	Normalized encircled energy
ENC_RMS	rms of the encircled energy
FWHM_MEAN	Mean delivered full width half maximum (in marcsec)
FWHM_RMS	rms of full width half maximum
L0_MEAN	Mean outer scale (in m)
L0_RMS	rms of the outer scale
R0_MEAN	Mean fried parameter (in m)
R0_RMS	rms of the Fried parameter
T0_MEAN	Mean AO coherence time (in ms)
T0_RMS	rms of the coherence time

Table 1: MACAO parameters logged in the MIDI and AMBER fits headers. Each parameter is calculated for the same duration than the fringe acquisition.

The mean and standard deviation values of the MACAO data are calculated by the MACAO Real Time Control (RTC) and are recorded over the same time interval as the corresponding time interval of the VLTI scientific data. The VLTI instrument sends a trigger to the MACAO RTC to start the data acquisition and to stop it; the measurement is appended to the fits headers of the MIDI or AMBER files.

3. COMPARISON OF THE MACAO SYSTEMS AT THE DIFFERENT UTS

Because VLTI can acquire fringes with up to 3 telescopes, we first compared the results obtained from the two or three MACAO systems during the fringe acquisition. All the MACAO systems involved in a VLTI observation use the same object for the AO correction. This object can be different from the VLTI target. The MACAO data and the MIDI/AMBER data are recorded at the same time. A regression fit of the form y=ax+b was performed, the values are given below.

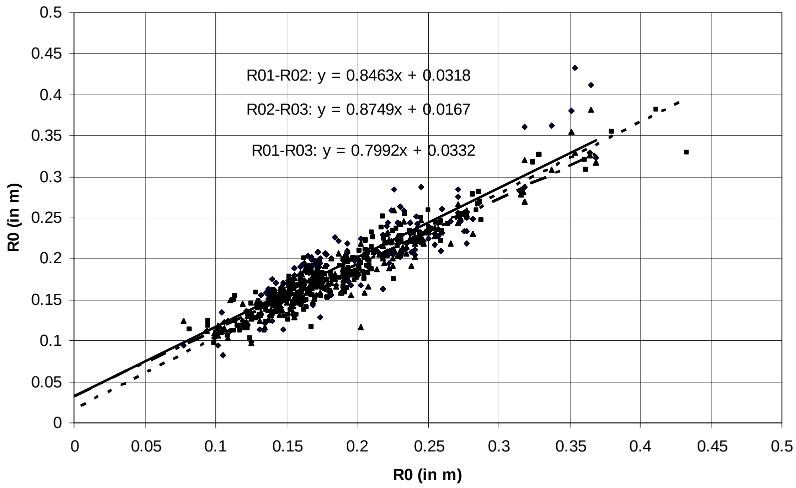

Fig 1: Comparison between the R0 (given in m and calculated at 500nm) retrieved from the operational MACAO systems installed on the UTs. This plot shows data taken with three telescopes with the instrument AMBER, the three sets of dots are respectively a comparison of R0 from MACAO1 and MACAO2 and from MACAO2 and MACAO3 and from MACAO1 and MACAO3. MACAOx is the MACAO system used with the telescope x, (MACAO1: UT1 or UT2, MACAO2: UT2, UT3 or UT4, MACAO3: UT3 or UT4). The regression fit gave values of respectively a=.85, b=.03 for the comparison between the sub-sytems 1-2, a=.87, b=.02 for the comparison of sub-sytems 2-3, a=.8, b=.03 for the comparison of the sub-systems 1-3.

The same comparison was done using the same data recorded with 2 MACAO systems during MIDI operations and the values of the regression fit are a=0.90 and b=0.02.

Tau0 is also calculated between the start and the end of the exposure and is logged in the fits headers. The fig. 2 shows a comparison between the coherence time calculated for MACAO1 and MACAO2, the second set of dots compare MACAO2 and MACAO3 and the third set of dots represents Tau0 for MACAO3 vs. Tau0 calculated by MACAO1. The regression fit value are respectively a=.66, b=0.75, a=.83, b=0.37 and a=.57, b=.95.

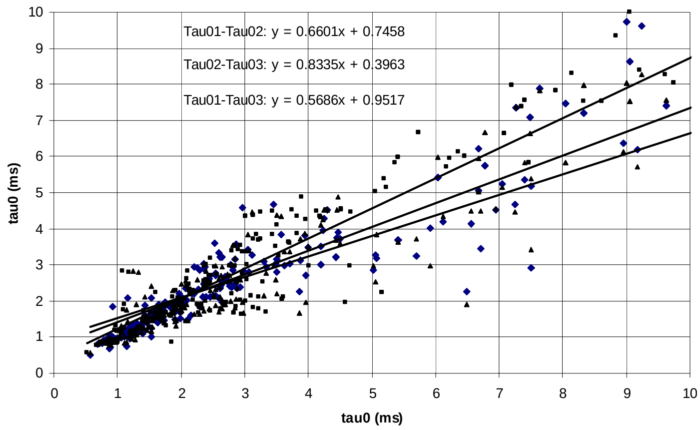

Fig 2: Comparison between the tau0 (at 500nm) measured by the different MACAO systems.

The R0 and Tau0 calculated by the two or three MACAO systems show some differences. There is also a certain spread of the data. A preliminary explanation could be that the systems are installed on the different UTs which are separated by several tens of meters (for example U1-U4 is 130m). Another explanation is that for the comparison between MACAO1 and MACAO2, we are comparing data taken on the UT1-UT2, UT1-UT3 and UT2-UT3 baselines. The same applies for the comparison between MACAO2 (UT1, UT2 or UT3) and MACAO 3 (UT3 or UT4). A more detailed study is under way to understand these differences.

4. COMPARISON OF MACAO AND DIMM PARAMETERS

The Astronomical Site Monitor (ASM) on Paranal is taking constant real-time measurements of the atmospheric conditions. The differential image motion monitor (DIMM) records data such as the Fried parameter R0 or the coherence time (Tau0). As shown in Sect. 3, these data are also calculated by the MACAO/VLTI systems. The following figures show the R0 calculated by the MACAO system vs. the R0 calculated by the DIMM (fig. 3) as well as the values of Tau0 (MACAO) vs. the values of Tau0 (DIMM).

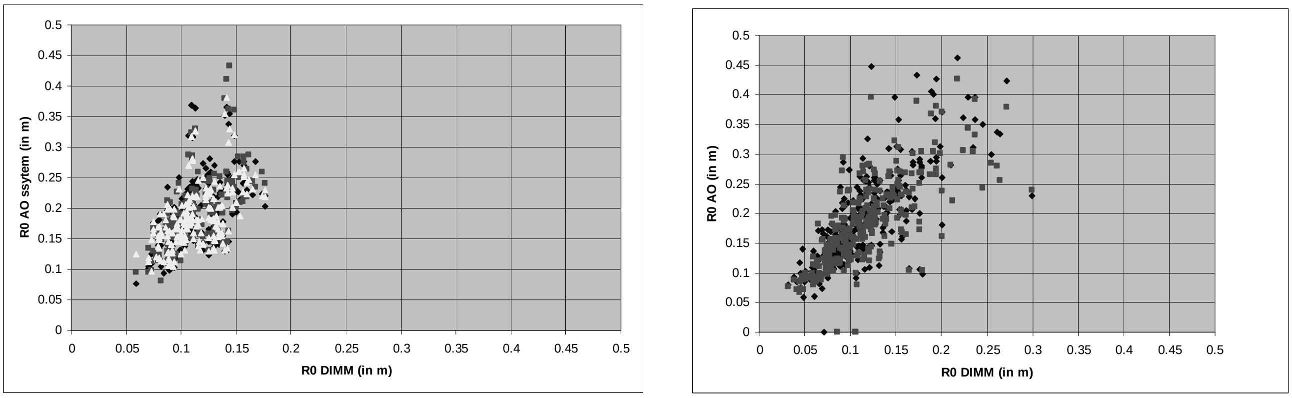

Fig3: R0 measured by the DIMM and the AO system. On the left the AMBER data (with up to 3 AO systems) on the right MIDI data with two AO systems.

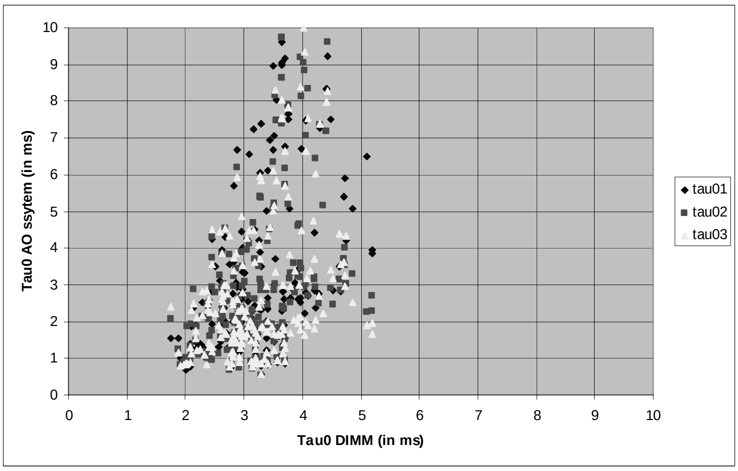

Fig 4: Coherence time Tau0 calculated by the DIMM and the MACAO systems. The deviation between the two systems is under investigation.

As shown on fig. 5, the DIMM is located north of the UTs and upwind. As with the differences between the MACAO units, this could explain that the DIMM data deviate from the MACAO data. The MACAO systems and the DIMM also use different stars to measure the atmospheric conditions. This could explain some of the differences between the DIMM and the MACAO measurements.

Fig. 5: Location of the 4 UTs and the differential image motion monitor DIMM on Paranal.

5. MACAO PERFORMANCE ON SKY

For most of the observations with MIDI or AMBER, the AO star is bright. As shown in the fig. 6, the slope of the curve Strehl ratio vs. V magnitude is not really steep up to 13th magnitude.

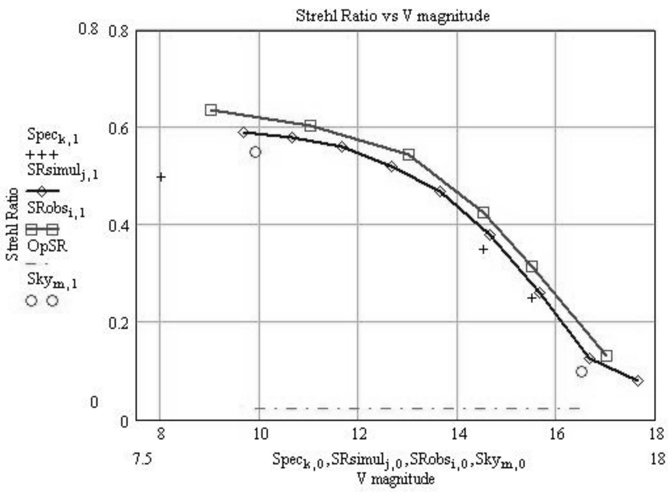

Fig. 6: Theoretical Strehl Ration vs. V magnitude of the AO star. For most of the VLTI observations, the target used by the MACAO system is bright (brighter than 12).

Using the MIDI data we plotted the measured Strehl Ratio vs. the V magnitude of the AO star (fig. 7). For these data, the magnitude of the AO star is mostly brighter than 12 and there is no strong correlation between the Strehl ratio and the magnitude of the AO star. When more measurements will be accumulated for fainter objects, we will try to reproduce the curve in fig. 6.

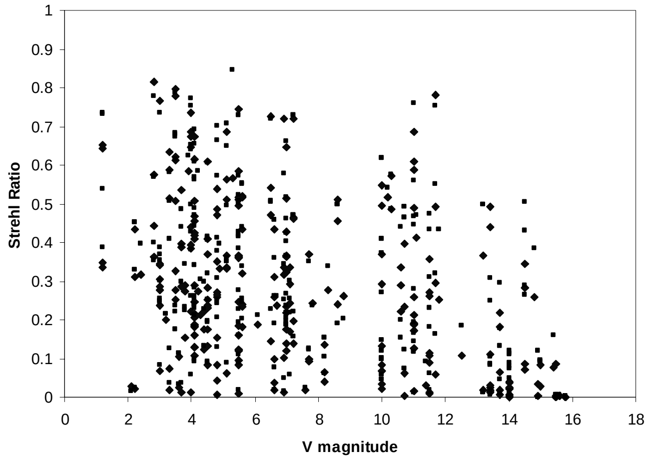

Fig 7: Strehl Ratio as a function of the magnitude of the AO star.

The fig. 8 shows the Strehl Ratio as a function of the R0 measured by the DIMM.

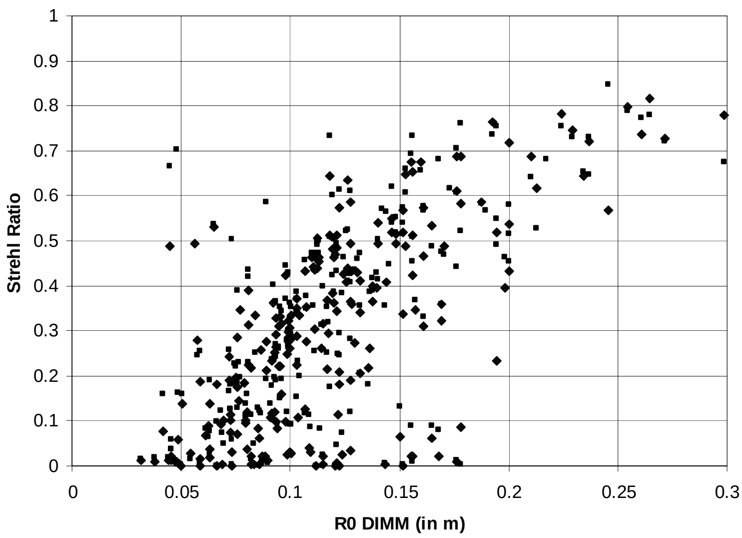

Fig 8: Strehl Ratio as a function of R0 (measured at 500nm, in m).

We further studied the correlations between the results of the AO systems and the atmospheric conditions. As shown before, the magnitude of the AO object (when brighter than 12-14) does not affect the quality of the AO correction. In the fig. 9 we also study the Strehl Ratio vs. the magnitude but for different R0 (top left: less than 10cm, top right between 10 and 20cm, bottom left between 20 and 30cm and bottom right more than 30cm).

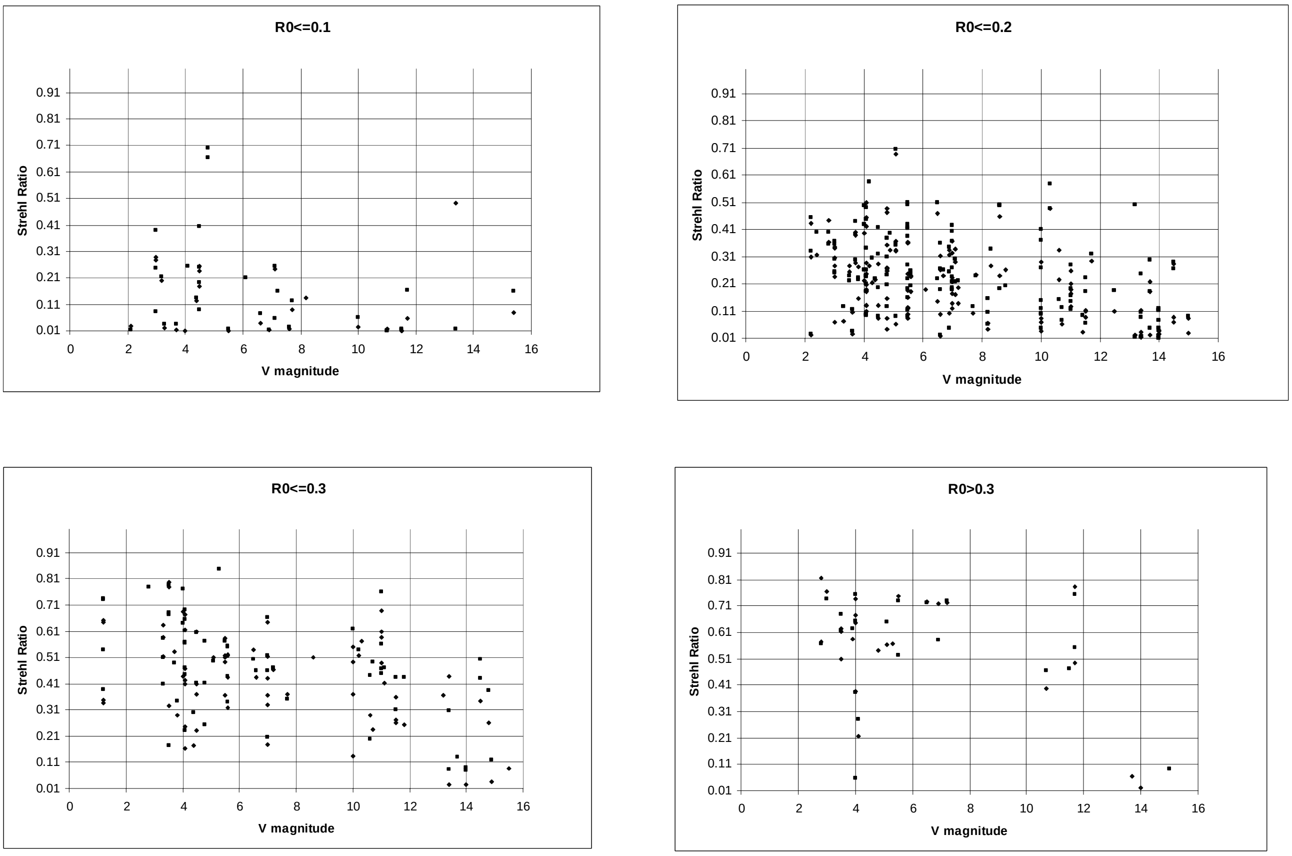

Fig 9: Strehl ratio function of the magnitude of the object. Each plot represents data taken with a certain range of R0, top left: R0<=10cm, top right R0 between 10 and 20cm, bottom left R0 between 20 and 30 cm, bottom right R0 >30cm. The scale is the same for each plot.

6. COMPARISON BETWEEN MACAO PARAMETERS AND THE RESULTS ON THE VLTI INSTRUMENTS

The final goal of this study is to compare the MACAO parameters with the QC parameters of the interferometric instruments such as the image quality, the position of the VLTI target or the accuracy on the fringe Visibility. We still need to understand some of the deviations between the different MACAO units and the DIMM. We are accumulating data which will be studied to understand better the different dependences.

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