Simultaneous seeing measurements at Atacama

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ABSTRACT

Institute of Astronomy, University of Tokyo is now planning to build a 6.5-m optical-infrared telescope in Atacama, Chile. This project is called "Univ. Tokyo Atacama Observatory (TAO)", and the site evaluation is now under way. As a part of this evaluation process, we started an investigation to compare the astronomical seeing at Atacama with that at Mauna Kea. Here, we report preliminary results of seeing measurements at several sites in Atacama, carried out on October 2003. In order to separate the temporal and site-to-site variation of the seeing, we used two sets of Differential Image Motion Monitors (DIMMs), each of which has two pairs of 7.4 cm sub-apertures with 20.5 cm separation. Three sites were investigated; the point near the TAO weather station (4,950m), the summit of Cello Chico (5,150m) and the point at 5,430m altitude on Cello Toco. Simultaneous measurements were carried out for three half nights out of four half nights measurements. Although the amount of our data is very limited, the results suggest following: 1) Seeing becomes better and more stable as time passing to midnight (eg. From $0.''7$ to $0.''4$ at V-band). 2) Higher altitude sites show better seeing than lower altitude sites.

Keywords: Site survey, Seeing, DIMM, Atacama

1. INTRODUCTION

Demands for investigation of next astronomical observation sites have been growing after the saturation of telescopes on Mauna Kea. One of the sites to be investigated is Atacama, mountain region located at the northern part of Republic of Chile. The targeted area for this investigation is the plateau at 5,000m altitude around Cello Chajnantor (Llano de Chajnantor), 60km distance eastward from Atacama Desert. Institute of Astronomy, University of Tokyo is now planning to build a 6.5 meter optical-infrared telescope on a peak in this region. This project is called "University of Tokyo Atacama Observatory"[1] (TAO: project leader is Yuzuru Yoshii), and the site evaluation is now under progress. Giovanelli reported[2] that peaks in this area have high potential to become an excellent site in terms of good optical seeing as well as high infrared transparency. Therefore, we have been particularly interested in the summit of Cello Chajnantor as a candidate site of TAO, and started a site survey at Llano de Chajnantor. The seeing measurements have been carried out as a part of this survey.

For the seeing evaluation at Atacama, a differential image motion monitor (DIMM) is useful because its portability is an advantage especially in an unexplored area. However, a measurement with a DIMM has uncertainty in absolute calibration, and it is difficult to make a precise measurement with only one DIMM. Therefore, we decided to use two sets of DIMMs and carry out simultaneous observations to measure the

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relative seeing variation between two observation points. In this paper, we report preliminary results of seeing measurements carried out at several point in Llano de Chajnantor on October 2003.

2. SYSTEM DESCRIPTION

The DIMM system we used is called "University of Tokyo DIMM[3] (UT-DIMM), based on a MEADE LX200 12 inch aperture telescope. Table 1 summarizes the specification of UT-DIMM. An aperture mask has two pairs of 7.4 cm sub apertures, which are defined diagonally with 20.5 cm separation. A detector is a consumer CCD camera, Neptune 100, manufactured by WATEC. Using this CCD camera, the pixel scale is $0.''667$ (Horizontal) $\times$ $0.''629$ (Vertical) /pixel. Thanks to its high sensitivity and low readout noise, exposure time of 0.5 msec is possible for 1 magnitude star. This will be enough to reduce finite exposure-time effect.[4] Data acquisition system is based on Linux PC with a video capture card, employing Video4Linux library. This system can process video capturing and centroid calculation at 30 frames per second, thus seeing value is obtained every 4 seconds by using 120 data for variance calculation. Also, remote control of the telescope via RS-232C communication is available. This reduces activities around the telescope to correct tracking error, which may result in measurement errors caused by heat of human bodies.

Table 1. UT-DIMM system specification

Telescope	Meade LX200 $12''$
Sub aperture layout:	Two pairs diagonal
Sub aperture diameter	7.4 cm
Sub aperture separation	20.5cm
Detector	WATEC Neptune 100, Consumer CCD
Pixel scale	$0.''667$ (Horizontal) $\times$ $0.''627$ (Vertical) / pixel
Exposure time	0.5ms for 1 mag star
Realtime data aquisition	Linux based PC
Sampling rate	30 frames / second

3. SITES

We chose three sites to be investigated in Llano de Chajnantor area; a point near the TAO weather station located between Cello Chajnantor and Cello Chascon, the summit of Cello Chico and a point at 5,430m altitude on Cello Toco. Figure 1 shows the locations of sites on a map and Figure 3 shows photos of preparations at each site.

For a reference, we recorded wind speeds at height of about 2 m from the ground with handy-anemometers. As Figure 2 shows, the wind speed exceeded 10 m/s in daytime, started decreasing after sunset, finally settled to about 5 m/s around 2:00 UT. The averaged wind speed at Cello Chico was higher than that at Cello Toco during our measurements. Although wind directions were not measured quantitatively, they were approximate west during the whole measurement. We explain each site in the following.

3.1. TAO weather station

The TAO weather station is placed between Cello Chajnantor and Cello Chascon. We set up the DIMM near this station. The observation point was located at $-22°59'50''$ latitude, $-67°43'9''$ longitude and 4,950m altitude.

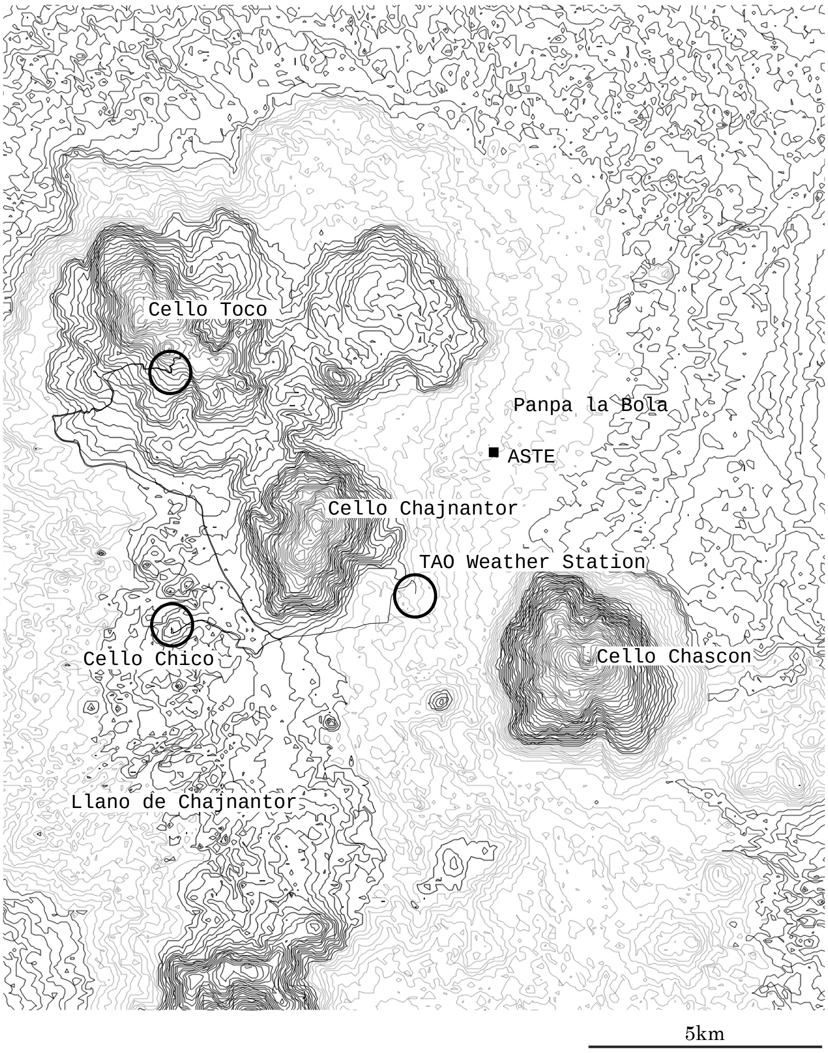

Figure 1. The Map of Atacama plateau area including Llano de Chajnantor and Panpa la Bola. This map is based on the data provided by Earth Remote Sensing Data Analysis Center (ERSDAC). Three circles indicate the sites.

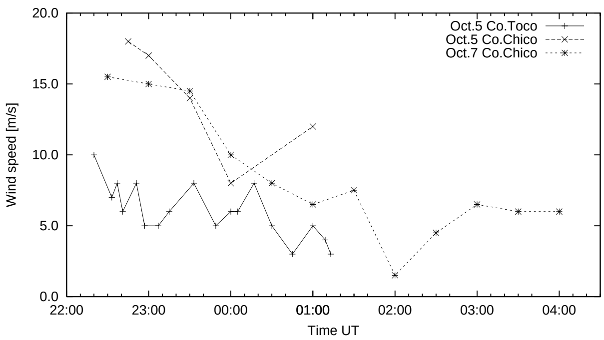

Figure 2. Wind speeds at 2 m from the ground measured by handy-anemometer.

3.2. Cello Chico

Cello Chico is an isolated peak in Llano de Chajnantor and located in southwest of Cello Chajnantor. We set up the DIMM at the west edge of the summit of Cello Chico to avoid the wake, which seemed to be generated by the landform around the peak. The observation point was located at $-23°00'18''$ latitude, $-67°46'14''$ longitude and 5,150m altitude.

3.3. Cello Toco

Cello Toco is at the northern area in Llano de Chajnantor and is accessible up to about 5,440m altitude by vehicles. We set up the DIMM on the unpaved road facing Llano de Chajnantor. The observation point was located at $-22°57'20''$ latitude, $-67°46'13''$ longitude and 5,430m altitude.

4. IMAGE MOTION AND SEEING

Seeing values are calculated from image motions by the following procedures.[5] An image motion is defined to be a variance of image centroids. The centroids are obtained in every captured frame and accumulated up to 120 data points to calculate the variance σ^2. The relation between the Fried's seeing parameter r_0 and the variance of the differential longitudinal image motion σ_l^2 is given by

$$\sigma_l^2 = 2\lambda^2 r_0^{-5/3}[0.179D^{-1/3} - 0.0968d^{-1/3}] \tag{1}$$

Also the relation between r_0 and the variance of the differential transverse image motion σ_t^2 is given by

$$\sigma_t^2 = 2\lambda^2 r_0^{-5/3}[0.179D^{-1/3} - 0.145d^{-1/3}] \tag{2}$$

Here, λ is wavelength, D is a diameter of sub apertures and d is a distance between sub apertures. In case of our system, 0.5μm for λ, 7.4cm for D and 20.5cm for d are adopted. FWHM θ is estimated numerically with λ and r_0,

$$\theta = 0.98 \times \frac{\lambda}{r_0} \tag{3}$$

Finally, the zenith distance correction is applied,

$$\theta(0) = \theta(z) \times (\cos z)^{3/5}\,, \tag{4}$$

where z is a zenith distance, $\theta(z)$ is the observed seeing and $\theta(0)$ is the seeing at zenith.

5. OBSERVATIONS AND RESULTS

We carried out a half-night measurement on Oct. 2, 4, 5 and 7, 2003. The first night was used for calibration of two DIMMs and the other three nights for simultaneous measurements. Table 2 summarizes the whole observations.

5.1. Calibration of DIMMs

The calibration of two DIMMs, assigned DIMM1 and DIMM2, is carried out on Oct. 2. DIMM1 and DIMM2 are set up with a distance of 3 m in order not to affect each other. Windshields are used to reduce telescope vibration. Figure 4 shows correlation of measured seeings between DIMM1 and DIMM2. Because our DIMMs have two pairs of sub apertures, we obtain seeing data in four directions, parallel and perpendicular image motion to the sub aperture separation in both horizontal and vertical pairs. Dotted lines indicate regression lines, which are obtained with Geometric Mean regression. Table 3 shows the confidence level on various condition. For example, $\pm 0.''2$ difference on a condition of $1''$ seeing can be discussed with 95% confidence level.

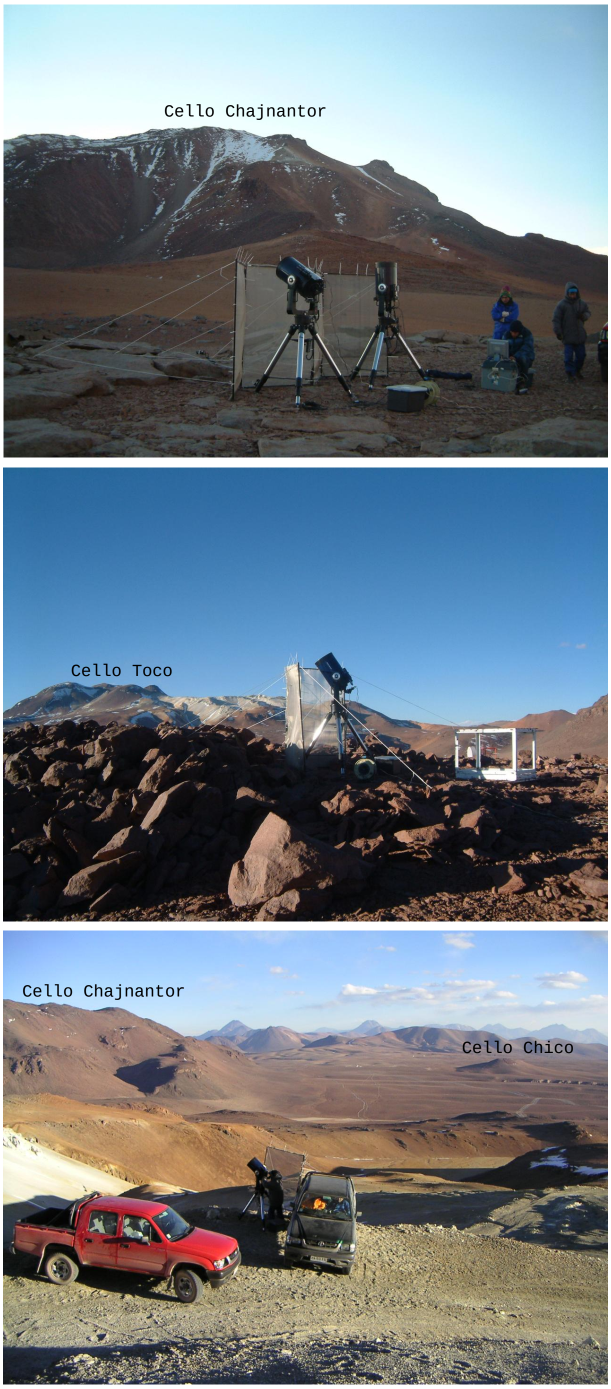

Figure 3. (top) The point near the TAO weather station. Cello Chajnantor is seen at the back of DIMMs.
(middle) The summit of Cello Chico. The DIMM was installed at the west edge of the summit.
(bottom) The point on Cello Toco. The whole area of Llano de Chajnantor can be viewed from this point.

Table 2. Summary of the whole observations

Start time, UT	End time, UT	Site	Purpose
02/10/2003 23:55	03/10/2003 0:55	TAO weather station	Calibration
04/10/2003 23:40	05/10/2003 4:00	TAO weather station and Cello Chico	Simultaneous measurement
05/10/2003 23:50	06/10/2003 1:20	Cello Toco and Cello Chico	Simultaneous measurement
07/10/2003 23:10	08/10/2003 4:10	Cello Toco and Cello Chico	Simultaneous measurement

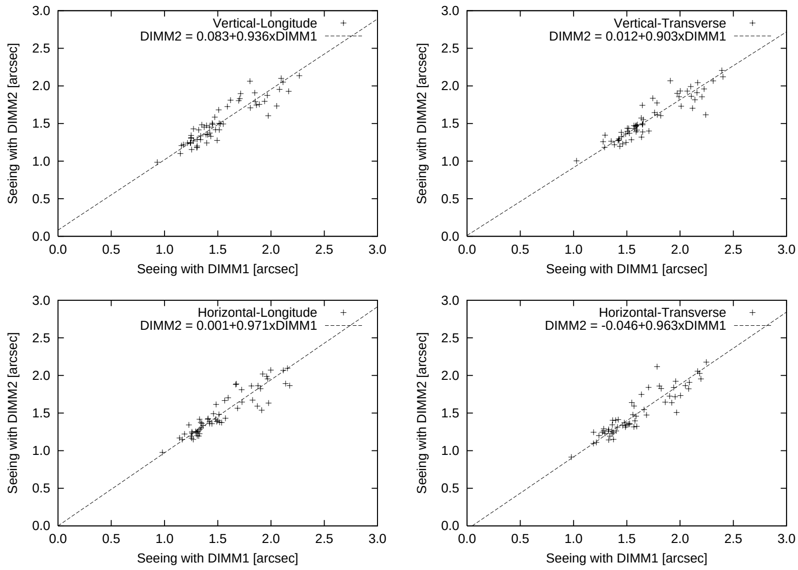

Figure 4. Scattered plots, which show correlation between the measurements of DIMM1 and DIMM2 in directions of longitudinal (left) and transverse (right) data for vertical (top) and horizontal (bottom) pairs of apertures.

5.2. Simultaneous Observations

We carried out simultaneous seeing measurements on Oct. 4, 5, and 7 with following configurations.

- Configuration (1) : TAO weather station and Cello Chico
- Configuration (2) : Cello Toco and Cello Chico

A same star, α PsA, was observed with the same exposure time of 0.5 msec during the whole measurement. The star was not changed once the measurement had started because re-pointing of the telescope would be a loss of time. Table 4 summarizes the results.

5.2.1. TAO weather station and Cello Chico

The first observation was carried out with the configuration (1), at the TAO weather station and the summit of Cello Chico on Oct.4. Total time of the observation was 5 hours including 176 minutes of simultaneous measurement. Figure 5 shows a temporal variation and a distribution of the measured seeing. The seeing at Cello Chico was better than that at the TAO weather station. It became better and more stable for later measurements, and finally, reached about $0.''4$ around midnight.

Table 3. Confidence level of the simultaneous measurement

$\pm 0.''20$ on $1''$ seeing condition:	95%
$\pm 0.''10$ on $1''$ seeing condition:	69%

Table 4. Summary of the simultaneous observations

Date	Site	Median	Mode	80 percentile points
04/10/2003	Weather Station	$2.''24$	$1.''6$	$2.''96$
	Cello Chico	$0.''67$	$0.''8$	$0.''85$
05/10/2003	Cello Toco	$0.''67$	$0.''7$	$0.''76$
	Cello Chico	$0.''95$	$1.''0$	$1.''15$
07/10/2003	Cello Toco	$0.''71$	$0.''7$	$0.''91$
	Cello Chico	$0.''98$	$0.''8$	$1.''32$

5.2.2. Cello Toco and Cello Chico (1)

The second observation was carried out with the configuration (2), at Cello Toco and Cello Chico on Oct.5. Total time of the observation was 1.5 hours including 14 minutes simultaneous measurement. Figure 6 shows a temporal variation and a distribution of the measured seeing. Due to malfunction of the detector, little data was obtained by the DIMM at Cello Chico. Seeing at Cello Toco was stable and 54% of data were within the range from $0.''6$ to $0.''7$.

5.2.3. Cello Toco and Cello Chico (2)

The third observation was carried out with the configuration (2), at Cello Toco and Cello Chico on Oct.7. Total time of the observation was 5 hours, including 181 minutes simultaneous measurement. The seeing at Cello Toco is better than that at Cello Chico as shown in table 4. Figure 7 shows a temporal variation and distribution of the measured seeing. The temporal variation shows that the seeing at Cello Toco was stable like the previous measurement on Oct.5, and that at Cello Chico became stable after 1:10 UT.

6. DISCUSSION

6.1. Temporal variation

On Oct. 4, seeing at Cello Chico started from $0.''8$, got worse up to $1.''2$ around 2:00 UT (22:00 Local time), and then got better to $0.''4$. Seeing at the TAO weather station started from $3.''5$, went down to $1.''5$ around 2:00 UT, and then got worse to $3.''5$. On Oct. 5, seeing at Cello Toco started from $0.''8$ and got slightly better to $0.''6$ around 1:00 UT. Seeing at Cello Chico could not be obtained properly. On Oct. 7, seeing at both Cello Chico and Cello Toco started with $1.''0$, got worse up to $2.''0$ around 1:00 UT, got worse again at only Cello Chico around 1:50 UT, and then got better around 3:30 UT.

Two patterns of temporal variation of seeing were observed on Oct. 4 and Oct. 7, one was getting better around 2:00 UT, and the other was getting worse around 2:00 UT. The TAO weather station showed the former pattern, and Cello Chico and Cello Toco showed the latter pattern.

The reason why seeing changed around 2:00 UT is expected to be the changes of a weather condition. However we could not make strong arguments for it, due to the very limited meteorological data at Atacama. Information of weather condition, temperatures of ground surface and wind directions, as well as simultaneous seeing data are required to understand the detail of temporal seeing variation.

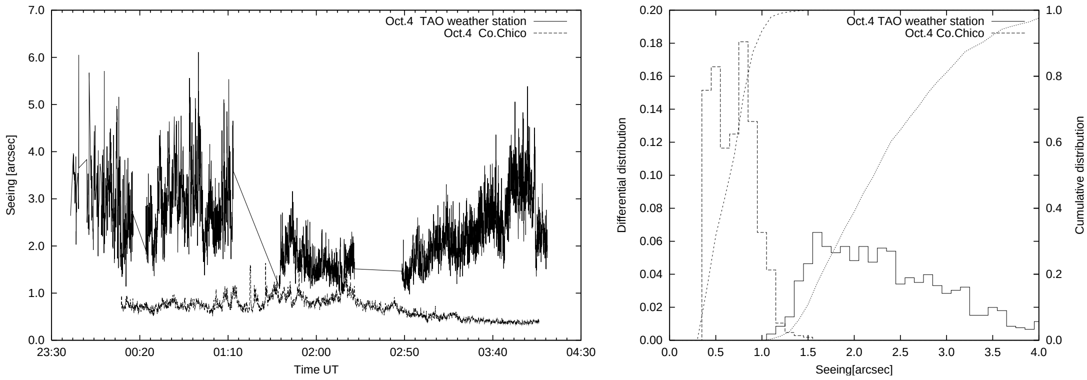

Figure 5. Seeing at the TAO weather station and Cello Chico on Oct.4. A temporal variation (left), a differential distribution (histogram in right panel) and a cumulative distribution (lines in right panel) are shown. 10 second averages of all four data (longitudinal and transverse motion for vertical and horizontal pair of apertures) are used for plots in Figure 5 $\sim$ Fig 7.

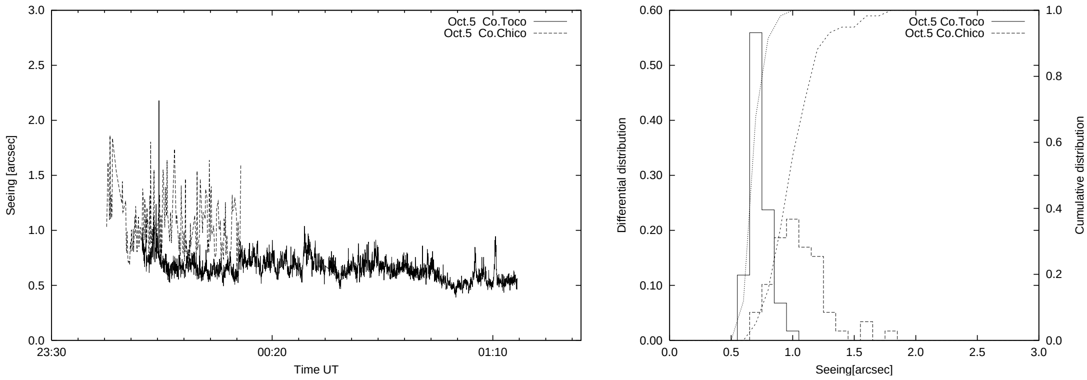

Figure 6. Seeing at Cello Toco and Cello Chico on Oct.5. A temporal variation (left), a differential distribution (histogram in right panel) and a cumulative distribution (lines in right panel) are shown.

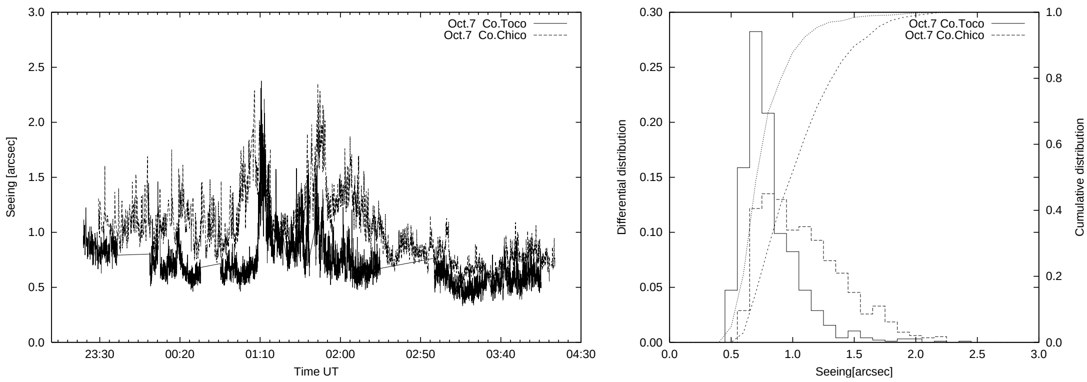

Figure 7. Seeing at Cello Toco and Cello Chico on Oct.7. A temporal variation (left), a differential distribution (histogram in right panel) and a cumulative distribution (lines in right panel) are shown.

6.2. Site-to-Site variation

Data on Oct.4 shows that the median seeing at the TAO weather station was $2.''24$ while that at Cello Chico was $0.''67$. What is the cause for such difference? At the TAO weather station, seeing was possibly affected by downstream, which was generated by radiative cooling at the surface of Cello Chajnantor and blown toward east by the wind.

Another difference is the median seeing at Cello Toco and that at Cello Chico which were $0.''67$ and $0.''95$ on Oct. 5, and $0.''71$ and $0.''98$ on Oct. 7. These $\sim 0.''27$ differences of seeing are significant compared with the accuracy of the calibration. The differences of seeing between two sites seemed to be caused by the difference in altitudes, because the sites chosen for the configuration (2) did not have any obstacles at windward. The observation point at Cello Toco is about 300 m higher than that at Cello Chico, thus each site might belong to a different layer of the atmosphere. This characteristic that a higher altitude site shows better seeing is quite similar to the measurements by Giovanelli. Although the area where we carried out the simultaneous measurements was not so wide, the significant difference was observed. This means that the cause of the difference is possibly not the free atmosphere but the local effect. We are now planning to carry out a seeing measurement at the summit of Cello Chajnantor, where seeing is expected to be better than any current observation points.

7. CONCLUSIONS

We report preliminary results of the simultaneous seeing measurement carried out at Atacama on October 2003. Three sites were investigated; the point near the TAO weather station between Cello Chajnantor and Cello Chascon, the summit of Cello Chico and the point at 5,430m altitude on Cello Toco. The results suggest following: 1) Seeing becomes better and more stable as time passing to midnight. 2) Higher altitude sites show better seeing than lower altitude sites, which is consistent with the measurements by Giovanelli.

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