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Seeing and microthermal measurements near Devasthal top

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Abstract. Results of the seeing measurements carried out near Devasthal top on 43 nights during March to April 1999 are presented. Open air seeing measurements were carried out with a differential image motion monitor (DIMM) using a 38 cm telescope with the mirror about 2 m above the ground. This, in combination with our earlier reported measurements carried out during October to November 1998 on 37 nights show a median seeing of 1.″1 and 35% of the time seeing is better than 1.″0. A trend in the seeing evolution is noticed with better seeing towards the later part of the night. By analysing the temporal evolution of seeing for seeing fluctuations it is found that the mean ratio of two seeing values separated by a time interval of Δt grows with a time constant of about 17 minutes. To quantify the optical image degradation caused by atmospheric turbulence very near to the ground, microthermal measurements were also simultaneously performed with DIMM observations. Microthermal measurements show that most of the contribution to seeing comes from the 6 – 12 m slab of the atmosphere with a mean value of 0.″86. A significant decrease in turbulence over the height of the mast is noticed with a mean value of 0.″22 for the 12 – 18 m slab. A seeing of ~ 0.″6 can be achieved by locating the telescope at a height of ~ 13 m above the ground.

Key Words : Seeing - atmospheric turbulence - site testing

1. Introduction

With modern earth based atronomical instruments, it is still predominantly the image transmitting properties of the Earth's atmosphere that limit performance to a level well below that of which the instruments are theoretically capable (Coulman 1985). The effects of the atmosphere is manifested in the size of the image (referred to as seeing; the FWHM of the stellar image expressed in arcsecond) formed at the focus of the telescope. The stellar image is degraded in such a way that its size depends mostly on the turbulence integrated throughout the atmosphere. Therefore for the optimal use of modern astronomical facilities, characterization of the atmosphere at the site is mandatory. It may be mentioned that the quality of seeing depends significantly on the local topography and it is hence imperative that measurements are conducted at few candidate locations at a given site before the location for installing the telescope is chosen.

In an effort to install a modern 3 m class optical telescope an extensive site survery was carried out by U.P. State Observatory (UPSO) in Kumaon and Garhwal regions of Shivalik Himalayas in 1980s. This initial site survey work came up with Devasthal as a potential astronomical site, based on the criteria such as logistics, altitude, approachability, number of clear (cloud free) nights and local topography conducive to good seeing. Details of the preliminary investigations can be found in Sagar et al. (2000 a,b). As a follow up of the site survey measurements carried out in 1980s and to characterise Devasthal site for astronomical uses more precisely, site survey measurements were carried out at two places in Devasthal namely Site 1 and Site 2 during 1997-98. (cf. Sagar et al. 2000 a,b). DIMM measurements were carried out at both sites whereas microthermal measurements (Pant et al. 1999) and meteorological measurements were carried out at Site 1. This study led Sagar et al. (2000 a,b) to conclude that, for astronomical observations, Site 2 is better than Site 1. Therefore to characterise Site 2 (hereinafter called Devasthal top) additional seeing measurements were carried out during March–April 1999. In order to quantify seeing degradation due to surface layer near Devasthal top and thus to estimate the gain in seeing with height microthermal measurements were also carried out simultaneously with DIMM. In the section to follow DIMM seeing measurements are described. Section 3 describes the microthermal measurements, Section 4 the seeing characteristics near Devasthal top and the conclusions are given in Section 5.

2. Seeing measurements

This section describes the DIMM seeing measurements which were carried out near Devasthal top. Measurements could not be performed at the actual peak due to the existence of a Hindu temple. The instrumental setup is that of a 38 cm telescope with single pier mounting having a plate scale of 36″/mm at the f/15 Cassegrain focus. The front portion of the tube is covered by a mask having two circular holes each of 5 cm in diameter and separated by 24 cm. One of the holes contains a prism which deviates the incoming parallel light of a star by about 30″ in the direction joining the line of the centers of the two holes so that two images of the same star are formed on the CCD detector. The telescope is equipped with a PC which controls the Santa Barbara Instruments Group ST4 autoguiding CCD camera and thus accumulates image motion data and analyse them online to provide seeing measurements in two mutually perpendicular directions. One pixel of the CCD corresponds to 0.″50 x 0.″58. The details of the instrumental setup, theory and the method used in determining seeing can be found in Sagar et al. (2000a). Previous seeing measurements carried over 37 nights (October to December 1998) show a median seeing value of 1.″07 and reported by Sagar et al. (2000a).

Additional seeing measurements were carried out on 43 nights during March–April 1999. Among the two independent estimates of seeing namely longitudinal and transverse we have considered only the longitudinal component as the seeing of the site. The nightly variation of

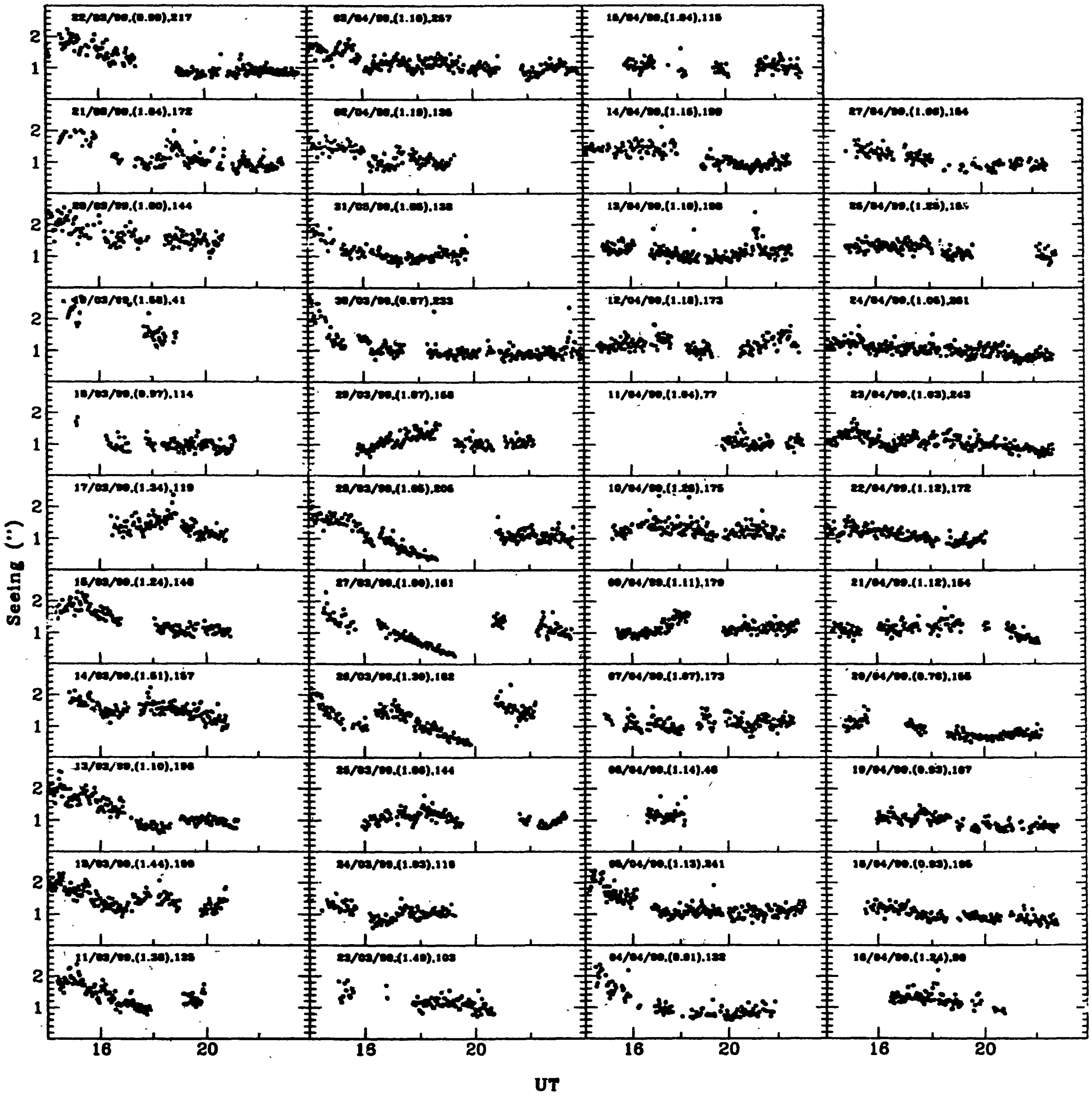

Figure 1. DIMM seeing measurements plotted against UT. The date of observation along with the median seeing value (inside bracket) and the number of points are indicated sequentially on each panel.

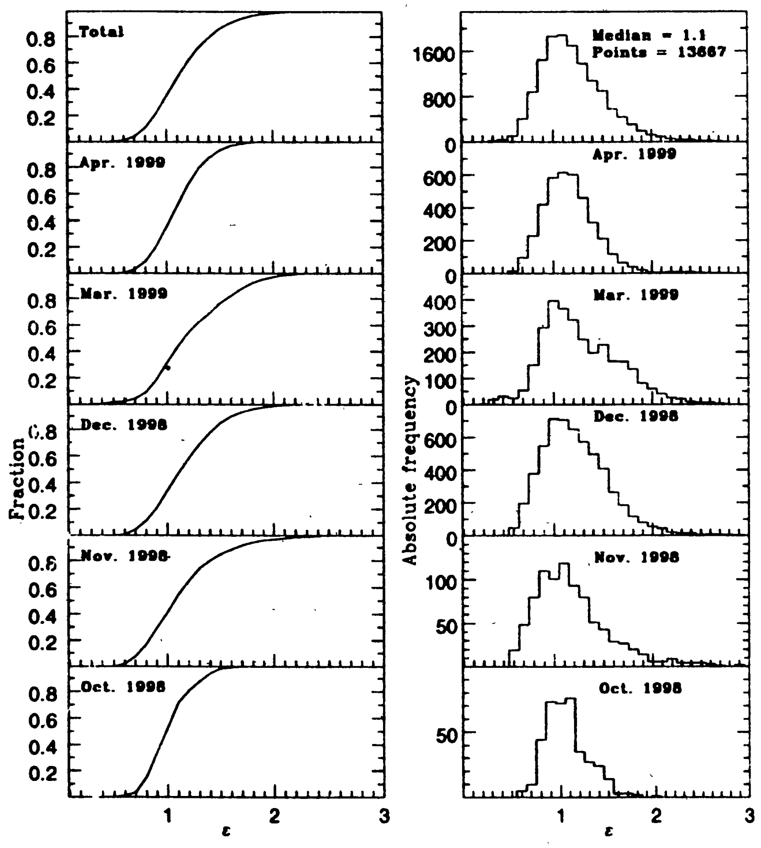

Figure 2. Histogram and cumulative distribution of seeing measured using DIMM.

seeing against UT is shown in Fig. 1. Fig. 2 shows the histogram and cumulative distribution of seeing near Devasthal top monthwise and for the whole campaign. The monthwise statistics of seeing values such as mean, median and the total number of observations are given in Table 1. Table 2 gives the overall statistics of the seeing values obtained near Devasthal top. It is found that for about 35% of the observing time seeing remains < 1.″0.

The instrumental noise which is the uncertainty in the determination of the centroid of an image due to detector noise was estimated to be 0.09 pixels. This system noise when taken into account improves the seeing values by 0.″03. The statistical error in the seeing measurements which was calculated using the formalism given by Frieden (1983) turns out to be 12%. In the absence of any directional dependent errors, both longitudinal and transverse seeing estimates have the same accuracy. Generally the best estimate of the current image size is given by the average and in such cases the final statistical error comes to about 9% for each individual result. The details of these are given in Sagar et al. (2000a).

Table 1. Results of DIMM seeing measurements.

Month	No. of observations	No. of nights	seeing in arcsecond Mean	Std.dev	Median
10–98	389	5	1.0	0.2	1.0
11–98	873	6	1.1	0.4	1.1
12–98	5536	26	1.2	0.3	1.1
03–99	3050	20	1.2	0.4	1.2
04–99	3819	23	1.1	0.3	1.1

Apart from the atmospheric turbulence, local man made turbulence will also affect the image quality obtained at the telescope focus. As our DIMM measurements were carried out in open air there may not be any appreciable contribution of the so called dome seeing to the seeing values reported here. At the same time the difference in the temperature between primary mirror and ambient medium (cause of mirror seeing) may have its contribution in our measured values. No corrections have been made for these effects and instrumental noise and moreover as the measurements are carried out close to ground, the seeing values reported here are indeed upper limits.

There is an appreciable degradation in seeing due to turbulence introduced by the surface layer of the atmosphere (Avila et al. 1998, Pant et al. 1999, Vernin & Muñoz-Tuñón 1994). Considerable improvement in image quality can be achieved by locating the telescope at a higher level as has been reported by Pant et al. (1999). To have an estimation of the gain in seeing achieved by locating the telescope at a higher level microthermal measurements were also carried out simultaneously with DIMM and the details of the measurements are given in the next section.

3. Microthermal measurements

The detection of the local source of seeing which occurs in levels of the atmosphere very near the ground within a few tens of meter above the ground is of great importance for evaluating the seeing conditions of an astronomical site. To have a good assessment of the quality of an astronomical site it is not sufficient to measure only the optical turbulence integrated over the whole atmosphere, but also to evaluate the relative contribution to the smearing of the image from intervening slabs of the atmosphere (Vernin & Muñoz-Tuñón 1992). It is an established fact that the average value of the seeing is correlated directly with the amplitude and frequency of occurrence of the temperature fluctuations. Hence microthermal measurements carried at various heights above the atmosphere can provide us with an estimate of the contribution of various slabs of the atmosphere to seeing. This information can also be used to decide the height for locating the telescope so as to achieve better seeing.

Microthermal measurements were made using pairs of microthermal sensors made from Nickel wire of 25 μ in diameter separated by a distance of 1 m and mounted at three different levels on a mast situated respectively at 6, 12 and 18 m above the ground. The instrumental set up is the same as that used earlier during site survey measurements at Devasthal

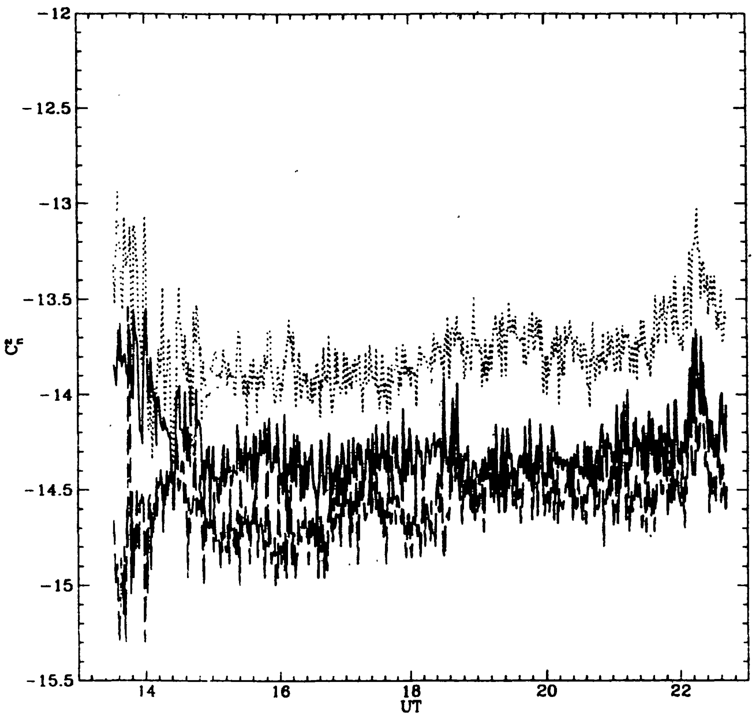

Figure 3. Temporal evolution of C_N^2 during the night of 23 March 1999. Dots represent the 6 m level, solid line represents the 12 m level and long dashes the 18 m level.

Site 1, and hence the instrumental details, theory and the methods employed in deducing the seeing estimates from microthermal measurements can be found in Pant et al. (1999). Microthermal measurements were successfully recorded on 11 nights simultaneously with DIMM seeing measurements during March–April 1999. The results of the measurements for three levels along with the simultaneous DIMM measurements are given in Table 3. A look into the table shows that major contribution to seeing comes from the 6-12 m slab of the atmosphere. Figure 3 shows the temporal evolution of C_N^2, the refractive index structure constant, observed on 23 March 1999 from where a rapid decline of microthermal fluctuations from 6 to 18 m height is seen. In Fig. 4 is shown the derived values of C_N^2, Δh on the night of 23 March, 1999 for the two slabs. The solid curve indicates the contribution of turbulence to seeing between 6 and 12 m, whereas the dotted curve indicates the contribution between 12 and 18 m slab. This figure, and also the values given in Table 3 show that significant contribution of microthermal turbulence to seeing comes from the lower 6–12 m slab of the atmosphere. Figure 5 shows the statistics of seeing derived from both microthermal and DIMM for the 11 nights where simultaneous measurements were available. The mean values of seeing are $0.''86$, $0.''22$ and $0.''91$ respectively for the 6–12, 12–18 and 6–18 m respectively. Corresponding DIMM measurements give a mean

Table 2. DIMM seeing statistics.

Total no. of nights observed (datapoints)	80 (13667)
Minimum seeing (″)	0.3
Average seeing (″)	1.2 ± 0.3
Median seeing (″)	1.1
Percentage of data with seeing ≤ 1″.0	35
Percentage of data with seeing 1″.0 – 1″.2	26
Percentage of data with seeing 1″.2 – 1″.4	18
Percentage of data with seeing 1″.4 – 1″.6	11
Percentage of data with seeing 1″.6 – 1″.8	6
Percentage of data with seeing 1″.8 – 2″.0	2
Percentage of data with seeing > 2″.0	2

value of 1″.21. It is not unexpected that the major contribution to seeing comes from the 6–12 m slab, as thermal disturbances affect this layer most compared to the higher layers since it is located very near to ground. Also since the surface of the earth acts as a heat sink during day and heat source during night, the magnitude of microthermal fluctuations within turbulent layers are usually maximum near the ground (Erasmus & Thompson 1986). Microthermal measurements carried out at Devasthal Site 1 also shows that the major contribution to seeing comes from the 6–12 m slab of the atmosphere (see Pant et al. 1999). A comparison of the microthermal measurements carried out at Devasthal Site 1 and Devasthal top along with the corresponding DIMM measurements are given in Table 4.

The local value of seeing is considered to be zero arcsec at a height of ~ 100 m from the ground and it increases as the starlight passes through the turbulent boundary layers of the atmosphere below 100 m (Echevarria et al. 1998). Also above 100 m only the turbulent layers of the free atmosphere (FA) which mostly reside at a height of 10 km or so degrades the stellar image. The total value of seeing is given by

$$S_T = \left(S_L^{5/3} + F\,A^{5/3}\right)^{3/5} \tag{1}$$

where S_L gives the local value of the seeing measured for a particular slab. Adopting a value of FA contribution to seeing as 0″.52 (Cromwell et al. 1998) the total seeing S_T estimated for Devasthal top is 1″.11 which is in agreement with the value of 1″.21 obtained from simultaneous DIMM measurements. Using the value of the seeing contribution deducted from

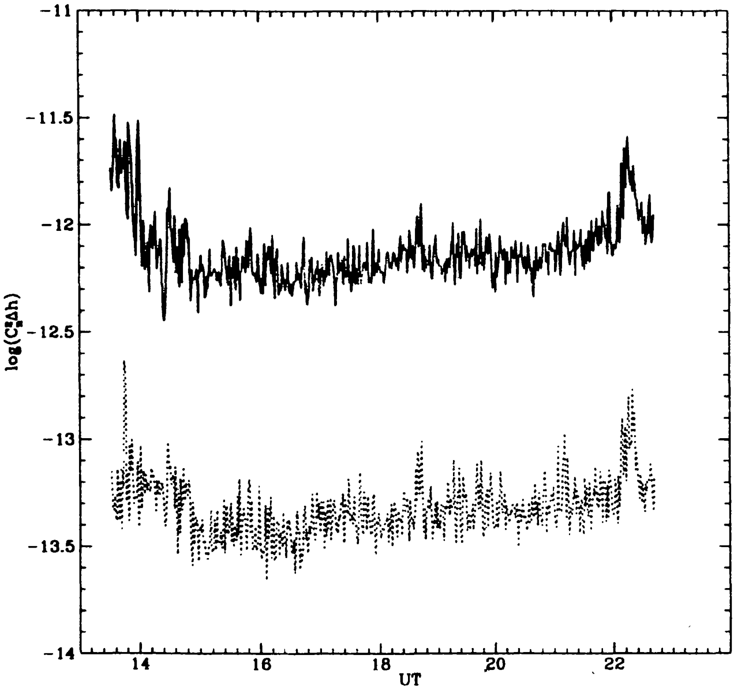

Figure 4. Turbulence in the surface layer measured from microthermal sensors on the 18 m high mast on 23 March 1999. The solid line gives the 6–12 m contribution whereas the dots refer to the 12–18 m contribution.

the 12 – 18 m slab of 0″.22 as the local seeing, we estimated the value of S_T at 0″.59 using Eq. (1). This indicates that if the telescope is located at a height of about 13 m from the ground one can achieve sub arcsecond seeing of the order of S_T evaluated (ie. ~ 0″.6) for a significant fraction of the observing time.

4. Seeing characteristics near Devasthal top

4.1 Stability of seeing

Stability of seeing is yet another important factor which tells of the quality of a site. To get a knowledge of the seeing stability, we carefully looked into individual nights having more than 6 hours of continuous seeing data. Among 80 nights of observations covering 5 months, we have 53 nights satisfying this criterion. The time during which seeing is less than 1″.0 in a stretch for > 4 hour, 2 to 4 hour and < 2 hour are found to be 11%, 25% and 64% respectively.

4.2 Temporal evolution of seeing

A random phenomenon like seeing (x) is assumed to follow a log-normal distribution. In Fig. 6 is shown the distribution of the measured seeing (solid line) along with the deduced log-normal distribution function (filled circles) using the measured second moment. As can be seen

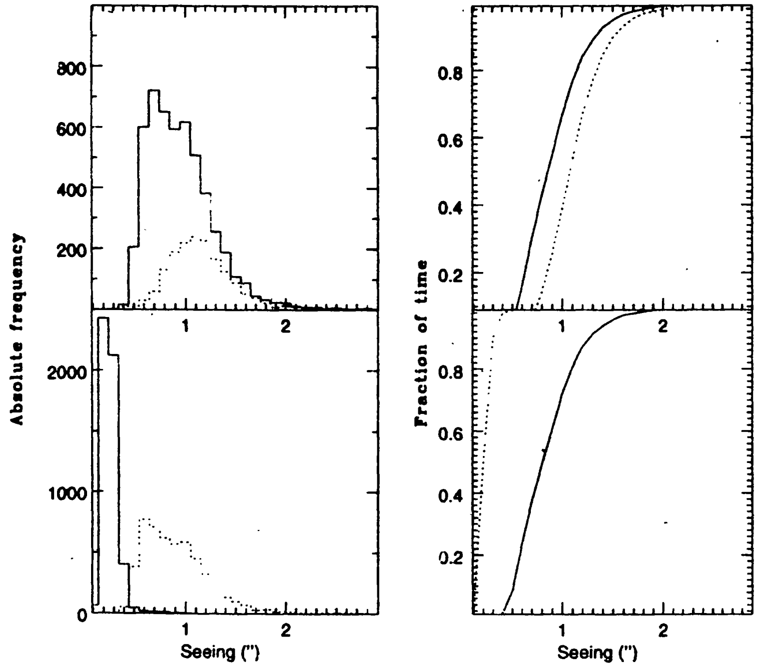

Figure 5. Seeing probability and associated cumulative distribution function : (top) solid line is for the 6–18 m slab and the dotted line is that of the DIMM measurements, (bottom left) solid line is for the 12–18 m slab and the dotted line is for the 6–12 m slab, (bottom right) solid line is for the 6–12 m slab and dotted line is for the 12–18 m slab.

from the top panel of Fig. 6, the deduced log-normal distribution function does not match well with the observed seeing probability density function f(x). As the measurement error (y) in x has a Gaussian distribution with zero mean and variance σ^2, the result of the measurement is the value (u) having a probability density function f(u), where

$$u = x + y \tag{2}$$

To get f(x) a simple deconvolution is made of the noise and we have shown in the bottom panel of Fig. 6 the deduced log-normal distribution of seeing after deconvolution of the noise. A significant improvement in the fit is seen.

To have further insight into the seeing quality of the site it is useful to have a characterization of the temporal evolution of seeing i.e., the variation of seeing quality with time. In Fig. 7 is shown against UT the results of all observing nights averaged in 30 min bin. The data exhibits a correlation, such that seeing is poorer in the begining of the night and improves towards the later part of the night.

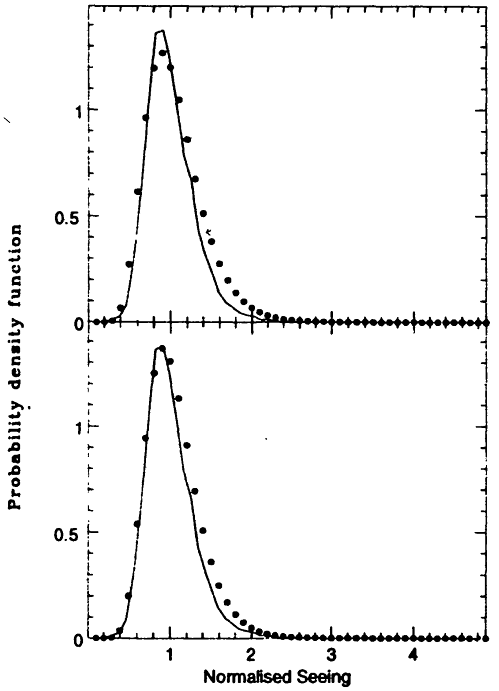

Figure 6. Distribution function of the measured seeing at Devasthal top (shown as continuous line). The filled circle at the top is the deduced log-normal distribution using the measured second moment and the same at the bottom is the log-normal distribution after deconvolution of the noise.

Also, seeing is known to vary over a large range of timescales such as minutes, hours, days, seasons and years. This is due to the physical processes which give rise to atmospheric instabilities and the generation of optical turbulence (Vernin & Muñoz-Tuñón 1998). Astronomers generally talk of good or bad seeing nights as if seeing varied over time scales of days and site testing campaigns also focus on average seeing distributions. This is possibly because at most astronomical telescopes, man made seeing which vary over a time scale of hours or days significantly contribute to the image spread. In the new generation of astronomical facilities extreme care is taken to eliminate man made seeing to provide good image quality of what the atmosphere only has to offer. In good sites seeing better than 0″.3 and as bad as 0″.8 can occur during the course of the night. Queue scheduling of astronomical observations is planned in most observatories to take advantage of the excellent seeing conditions and this requires a knowledge of the, characteristic time scale of seeing fluctuations. We also tried to look for any peculiar behaviour in the temporal evolution of seeing in our data. Following Racine (1996) we have computed the fractional change in seeing over a time interval Δt defined as

$$f_{\omega}(\Delta t) \equiv \frac{|\omega(t + \Delta t) - \omega(t)|}{\omega(t + \Delta t) + \omega(t)} \qquad (3)$$

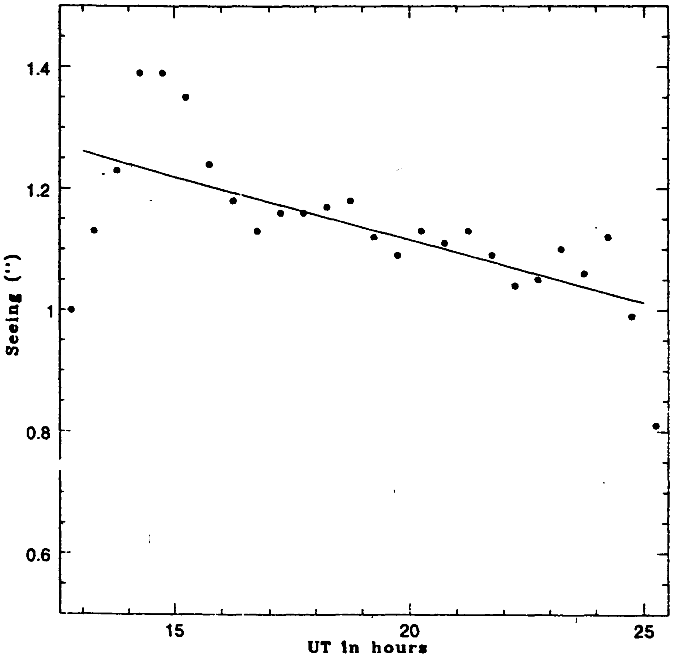

Figure 7. Average seeing for the entire observing run plotted against UT. The data are binned in 30 min interval. The data is best fit with seeing = -0.02 (± 0.005)*UT + 1.53 (± 0.10)

Only nights with more than 6 hours of continuous seeing measurements without any break in between is used in the computation of f_ω (Δt). Assuming a log-normal distribution of seeing with dispersion σ and a finite seeing correlation time, the mean value $\langle f_{\Delta t} \rangle$ should grow from $\langle f(0) \rangle = 0$ to a saturated value $\langle f(\infty) \rangle$. Therefore

$$\langle f_\omega(\Delta t) \rangle = \{f_\omega(\infty)\} \left[1 - exp\left(-\frac{\Delta t}{\tau} \right)^\gamma \right] \tag{4}$$

where τ and γ are the time constant and growth rate respectively. Best fit of Eq. 4 to the data is shown in Fig. 8 and is obtained with $\langle f(\infty) \rangle = 0.09 \pm 0.01$, $\tau = 16.85 \pm 2.7$ min and $\gamma = 0.86 \pm 0.13$. This value of time constant τ is in good agreement with that found by Raccine (1996) for Mauna Kea (τ = 17 min), but lower than that given by Vernin & Muñoz-Tuñón (1998) for the Roque de los Muchachos Observatory (ORM) site at La Palma (τ = 1.2 hr). The data in Fig. 8 suggest the presence of quasiperiodic residuals about the best fit using the relation of Eq. 4. This may be due to the modulation of gravity driven atmospheric waves with seeing.

5. Conclusions

DIMM seeing measurements carried out on 80 nights yield a median seeing value of 1.″1. The fraction of time seeing < 1.″0 is 35%. Moreover, as no correction has been applied for the instrumental noise, mirror seeing and as the observations are carried out close to ground, the

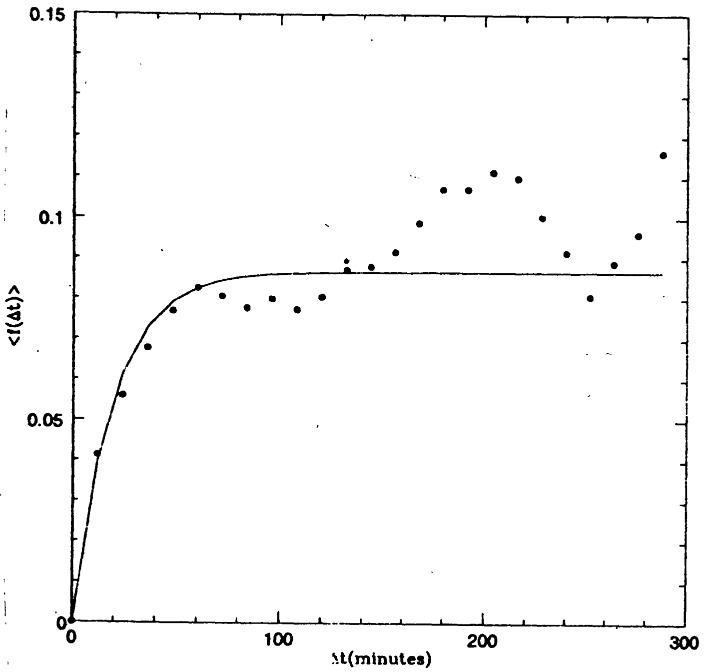

Figure 8. The average normalized difference between two seeing samples plotted as a function of the time interval between the samples.

reported values are only upper estimates. Dome seeing may not have an appreciable contribution as the DIMM was operated in open air. Estimation of surface layer contribution to seeing using microthermal measurements show that the surface layer upto about 12 m above the ground significantly deteriorates the stellar image. The contribution to seeing due to 6–12 m and 12–18 m slabs of the atmosphere are $0.''86$ and $0.''22$ respectively. It is also found that a seeing of ~ $0.''6$ can be achieved for most of the time by locating the telescope at a height of about 13 m above the ground. Seeing shows a correlation with time such that it is poorer in the begining of the night and improves towards the later part of the night. The mean ratio of two seeing values separated by a time interval Δt grows with an e-folding time of about 17 min. This study shows that Devasthal top is a good choice for locating the proposed 3 m UPSO-TIFR optical telescope.

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Table 3. Seeing values in arcsecond from microthermal and DIMM measurements.

Date	Microthermal Height range (in m) 6 - 12	 12 - 18	 6 - 18	DIMM
17-03-99	0.79	0.28	0.87	1.34
19-03-99	0.94	0.22	0.99	1.58
20-03-99	1.07	0.27	1.13	1.60
23-03-99	1.09	0.21	1.13	1.49
26-03-99	1.14	0.22	1.18	1.30
16-04-99	0.95	0.18	0.99	1.24
21-04-99	0.72	0.20	0.77	1.12
22-04-99	0.58	0.17	0.63	1.12
23-04-99	0.72	0.20	0.76	1.03
24-04-99	0.74	0.23	0.80	1.05
25-04-99	0.82	0.24	0.88	1.25
Mean	0.86	0.22	0.91	1.21

Table 4. Comparison of microthermal and DIMM seeing measurements in arcsecond made at Site 1 and Devasthal top.

Date	Microthermal Height range (in m) 6 - 12	 12 - 18	 6 - 18	DIMM
Site 1	1.28	0.32	1.36	1.51
Devasthal top	0.86	0.22	0.91	1.21

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