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# Day-time seeing observations at Kodaikanal Tower Telescope

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**Abstract.** A limb monitor was fabricated and used for the observation of seeing conditions at the Solar tower telescope of Kodaikanal observatory. We describe the instrument and report the results obtained on image stability, intermittency of good moments, their durations and utility in adopting a frame selection technique at the telescope. We discuss the observed clustering of moments with good image steadiness and use it to estimate the cell size range of a dominant scale of atmospheric turbulence during the observations.

*Key words:* solar seeing conditions—limb monitor—atmospheric turbulence

## 1. Introduction

The spatial resolution attainable with a ground-based solar telescope is largely limited by the atmospheric conditions at the site and by the perturbations within the telescope itself. Significant efforts have gone into the development of techniques for the optimal utilization of the prevalent seeing conditions at a given site. The quantitative measurement of solar 'seeing' holds the key to these developments.

Further, through a better understanding of the image degrading processes in the atmosphere and the telescopes, and also due to significant improvements in mirror control and computational techniques, it has become possible to successfully attempt various methods of compensating the wavefront deformations (von der Luhe 1988; Dunn & Smartt 1991). It is hence necessary to obtain information on the distorting elements in the atmosphere and the perturbations in the telescope.

At the Solar Tower Telescope of Kodaikanal observatory (Bappu 1967), instruments are being developed to monitor the wavefront distortions introduced by the atmosphere and by the telescope. A photoelectric limb monitor has been fabricated and used for observing the image stability. Details of the monitor are described in Section 2 and the observational results obtained such as the intermittency, the durations etc. are presented in Section 3. Recurring periods of image steadiness attributable to the atmospheric conditions are observed, and these are used to estimate the size of a dominant scale of atmospheric turbulence during the period of observations.

## 2. The limb monitor

The visual examination of solar limb at the image plane has for long been a quick method of qualitative assessment of seeing conditions. 'Limb boiling' under poor sky conditions and a steady limb under good skies are therefore very familiar to the solar observer. In fact, it turns out that the eye estimates of seeing on the image agree well with the rms values of quantitative measurement of seeing (Roddier 1981).

Bray et al. (1959) fabricated and used a photoelectric limb monitor for the quantitative estimation of seeing. They used a pair of arc shaped slits at opposite limbs with photo cells as sensors to monitor the intensity fluctuations; the ac component of the sum of the signals, displayed by a meter, gave a measure of seeing. Brandt (1969) used a radial slit at the limb and studied the frequency spectra of image motion. Colgate & Moore (1975) used radial slits and monitored the uncorrelated motion of opposite limbs to estimate the seeing. Brandt et al. (1987) showed that a single radial slit could be used conveniently to calibrate and measure the seeing, provided that the telescope is free from any shake and guiding errors or that errors are identified and substracted out.

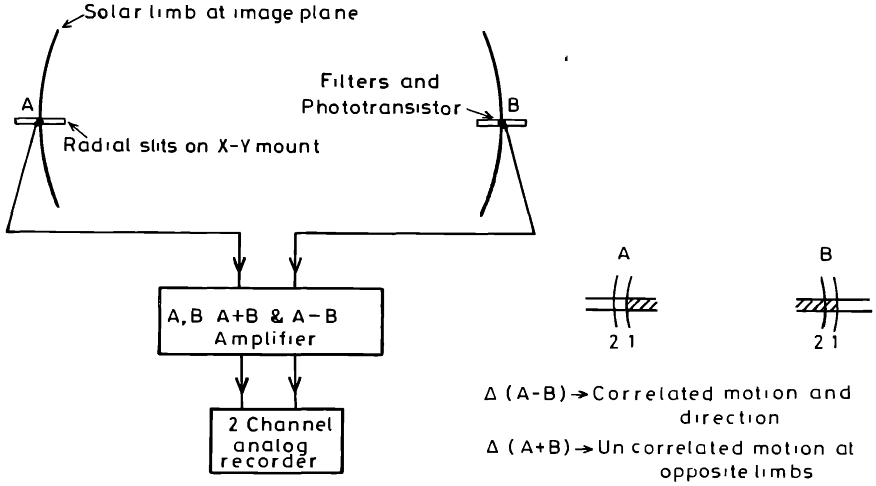

**Figure 1.** Schematic diagram of the simple limb monitor used. The image motions derived are illustrated.

In order to meet our dual purpose of assessing the image stability due to the telescope shake in wind, tracking errors etc. and to monitor the atmospheric seeing conditions at the telescope, we adopted the simple technique of using two phototransistors behind radial slits at opposite limbs, as shown in Fig. 1. The monitor on an x-y mount was used at the f/90, 17 cm image of the Solar Tower Telescope at

Kodaikanal. The radial slits were 600 $\mu$m (6.5 arc sec) in width and 10 mm in height. A filter combination of BG 18 and VG 9 was found to be appropriate with the matched pair of phototransistors. The individual outputs, their sum and substracted values, say A, B, A + B, and A – B, could be separately amplified and recorded in the analog mode.

The departure of A – B from a dc level gave the full image motion and direction while the ac component of A + B gave the uncorrelated image motion at limbs. The time constant of analog recorder allowed a measurement of signals at frequencies of around 3 Hz. The image motion was calibrated by moving the monitor in steps of 100 $\mu$m on either side of an artificial limb obtained using a limb template at about 5 arc sec inside the solar limb. The calibration was verified and corrected on the actual solar limb during short periods of image steadiness. The effect of limb darkening on the calibration was found to be within 1 to 2% of the corresponding steps. Simultaneous observations of A – B and A + B components were obtained on five days under clear sky conditions. The results of these observations are presented in Section 3.

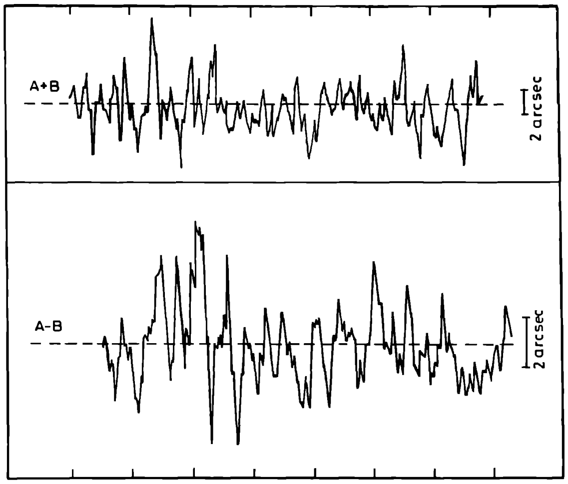

**Figure 2.** Sample portion of the analog scan. The ticks are of 10 seconds duration each.

A sample of the observations recorded is illustrated in Fig. 2. The dc level of A + B remained uniform during an image drift of up to ± 4 arcsec, to within 10% of the ac component. The upper estimates for errors in the evaluated image motion are found to be about 7% around 3 arcsec and about 5% around 2 arcsec, which are satisfactory for the purpose of this study.

## 3. Results and discussion

The limb monitor was first used to check the stability of image tracking at the telescope using the solid state coelostat drive system developed by Srinivasan et al. (1989). It was found that the image can be held steady to within ±1 arc sec of the set position for durations of about 1.5 minutes, without guiding. Further increase in stability can be attempted by adjusting the frequency of the drive subject to the limit imposed by the component of the varying diurnal Dec motion which is not compensated for. A limb monitor with phototransistor pairs along RA and Dec will hence be useful for online autoguiding of the image.

Observations with the monitor were obtained during 20-28 February 1992. On these days, an average of about two hours was used for other observational programs on the main spectrograph. Out of the total 23 hours of observations obtained with the monitor, an average seeing of 4 arc sec or better prevailed for 305 minutes. There were ten spells of 10 to 40 minutes duration each, at different epochs. This data has been used to examine the details of image motion. The intermittency of good moments of seeing is immediately evident from the observations. Single durations of less than 3 seconds are not taken into account as they are not likely to be useful in an automated frame selection at focal plane.

Seeing conditions: Typical seeing conditions represented by the image motion are illustrated in Fig. 3. Four of 15 minute spells on 21 February 1994 are compared with the 15 minute average of the total 305 minute data obtained. An image steadiness of within 1 arcsec is observed for 12% of the period in one case and it is practically nil in another spell, while the overall average is about 2% of the total period.

The general conditions on the days of observations were as follows; Image steadiness of around 1 arcsec was recorded for 5 ± 2% of the time in uncorrelated motion (distortion), 15 ± 3% of the time in correlated image motion, and 2 ± 0.5% of the time in both, simultaneously. Under good to excellent conditions, the corresponding values increased to 16 ± 3%, 25 ± 5%, and 8 ± 2% respectively. During an outstanding period of about 30 minutes on 27 February, the image was steady to within 0.5 to 0.7 arc sec for a total duration of about 7.5% of the time.

Fried parameter: A convenient measure of the atmospheric seeing quality, the Fried parameter $r_0$, is defined by the expression (Roddier 1981),

$$r_0 = [0.423\, k^2 \sec z \int_0^\infty C_n^2(h)\, dh]^{-3/5} \tag{1}$$

where $C_n^2(h)$ is the structure coefficient of the refractive index fluctuations as a measure of height $h$, $k = 2\pi/\lambda$, with $\lambda$ being the wavelength, and $z$ the zenith angle of observation. The parameter $r_0$ represents the coherence length of the wavefront deformation at the entrance pupil of the telescope. It can also be visualized as the diameter of a fictitious diffraction limited telescope which yields the same resolution as that of a much larger telescope observing through the turbulence characterized by $\int C_n^2(h) dh$.

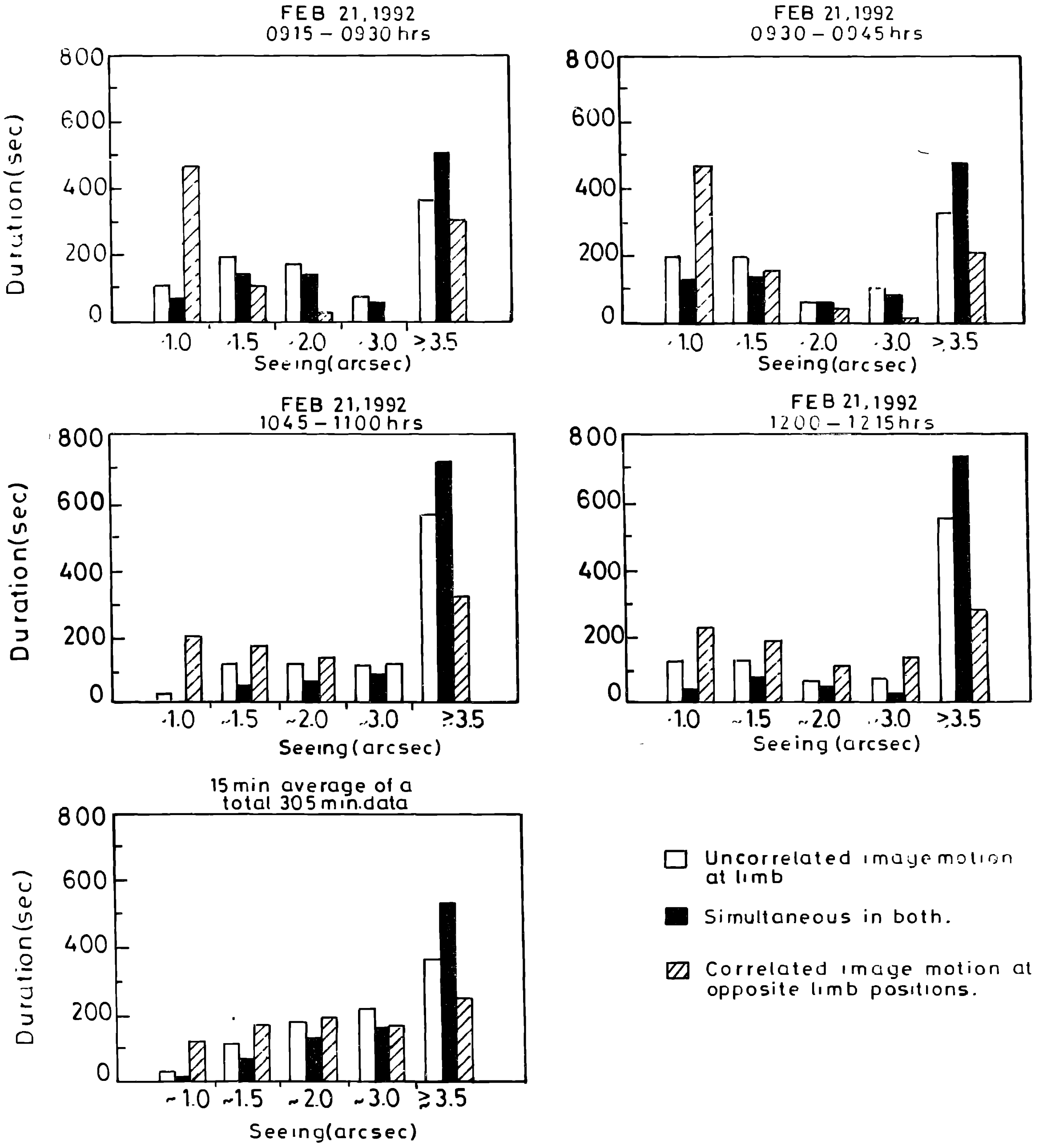

**Figure 3.** Illustrations of four 15 minute spells of observed image motion on the same day compared with corresponding mean values obtained from a total of 305 minute observations on different days.

Borgnino et al. (1979) have shown that $r_0$ can be expressed in terms of the aperture of the objective $D$ and the angle of arrival fluctuations $\sigma_\alpha$ in arcsec as :

$$r_0 = 8.25.10^5\, D^{-1/5} \lambda^{6/5} \left(\sigma_\alpha^2\right)^{-3/5} . \tag{2}$$

Using the above data on image motion at the focal plane, we evaluate the rms Fried parameter $r_0$ for the observed good spells to be ~ 4.0 cm. Hence for the 20 cm aperature of the objective used, the value of $D/r_0$ is around 5. As pointed out by Roddier (1981), therefore, a frame selection procedure becomes necessary at the telescope. The probability of getting a short exposure of one arcsec or better frame turns out to be around 1/200. It is much less (around 1/1000) for obtaining sub arcsec frames of short exposures or one arcsec frames of longer exposures.

The best of seeing conditions at Kodaikanal are generally prevalent in the early mornings, one to two hours after sunrise. However, during the days of the above observations the sky remained thick during early hours and improved later. The rms $r_0$ evaluated above can thus be taken as a representative value for an average day in winter and not for the best days at Kodaikanal.

Clustering of good moments: We observed an interesting phenomenon of clustering of good moments of seeing. Such 'clustering' occurred at intervals of 3 to 6 minutes during periods of good to excellent sky conditions. The durations of improved seeing conditions and the average periods of intervals between successive spells varied inversely with the observed average wind velocity. A typical event has the following features:

a) The image steadiness improves in correlated motion at opposite limbs.

b) After about a minute, the localized image steadiness as seen in uncorrelated motion also improves significantly for a duration of about 1 to 4 minutes (~ 1 minute during winds of around 4 $\mathrm{ms}^{-1}$ and ~ 3 to 4 minutes when it is about 2 $\mathrm{ms}^{-1}$).

c) Condition returns to that of (a) above.

d) Average image motion returns to pre-clustering values.

During the period (b), the image is steady to around one arc for 20 to 40% of the time. This period can be used to obtain 'burst-shot' sequences of frames. Also, the fact that the image becomes steady first in correlated motion will be useful for triggering such a sequence.

Atmospheric turbulence: It is well known that the scaling down of energy due to temperature fluctuations in the atmosphere follows the Kolmogorov spectrum from the largest cells where the turbulence is generated ($L_u$) to the smallest ones ($L_l$) where it is dissipated by molecular friction. There is substantial controversy about the size of $L_u$ although it may not be a unique quantity. The values estimated from various observations are in the range of a few to 15 meters, 100 to 1000 meters, or even kilometers in the case of stellar wavefront phases incident on telescopes (Coulman & Vernin 1991; Major 1993; Colavita et al. 1987).

We observe that the intermittent periods of 'clustering' of good moments can be understood as periods of quiet between turbulent cells. Further, the frequency of our observations at around 3 Hz is well within the range of 0.001 to 100 Hz over which the response of the atmosphere is known to have a good correspondence with the Kolmogorov spectrum. Therefore, using the data on intervals between clusters of steady moments and the prevailing average wind velocities measured at the observatory for the nearest hours, we obtain the range of values for the dominant scale to be 100 to 700 meters. We do not notice evidence for larger cell sizes in our individual continuous monitoring of over 40 minutes each. It is hence perhaps reasonable to suggest that this could be the outer scale $L_u$. This range is in agreement with the reported values of 100 to 1000 meters cited above, for the day skies. The much higher values reported are essentially for the night skies.

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