Technical notes on Gamsberg Namibian site [1]

Seeing and Meteorology

Part III-b: Ground Level Turbulence

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[1] Belong to this series:
Part I: General Climatology, 11 pages, April 24, 1994
Part IIa: I.R. Quality, Upper-Air data, 14 pages, August 3, 1994
Part IIb: I.R. Quality, Water Vapour Monitoring, 4 pages, first issue September 23, 1994
Part IIIa: Seeing and Meteorology, Preliminary Results, 5 pages, last update September 21, 1994
Part IIIb: Seeing and Meteorology, Ground Level Turbulence, 8 pages, this issue September 28. 1994

1 Introduction

Seeing is measured with a telescope installed 2 m above ground on a cement platform. A fair comparison with other sites in terms of suitability for the VLT implies to subtract the fraction of image blurr occurring in the last 10 m of the lightpath.

This parameter can be estimated from the knowledge of the amount of thermal turbulence in the ground layer as explained in Section 2.

The thermal turbulence is monitored by means of cold wire thermometers with more than 10 Hz bandwidth and a few millidegrees resolution [Moresmau 86], Section 3 compares preliminary measurements at Gamsberg with earlier data obtained with the same sensors at various chilean sites.

The method used for the subtraction of the ground based turbulence from the optical path integrated seeing is explained in Section 4. A preliminary calculation of the amount of correction at Gamsberg is presented.

2 The physical meaning of astronomical seeing

Seeing is defined as the Full Width at Half Maximum of a long exposure image obtained at the focus of a large telescope limited by the atmosphere. For a given zenith angle γ, it can be written as a function of the refractive index structure coefficient along the path:

$$\mathrm{FWHM} = 0.976\frac{\lambda}{r_0} = 5.345\lambda^{-1/5}\left[(\cos\gamma)^{-1}\int C_n^2(z)\,dz\right]^{3/5} \text{; radians} \tag{1}$$

The index of refraction n of the atmosphere, restricted to the contributions of the continuum, for a wavelength λ, pressure P, absolute temperature T, and water vapor pressure e is, at visible wavelengths:

$$n - 1 \;=\; 77.6\,10^{-6}(1 + 7.52\,10^{-3}\lambda^{-2})(P + 4810\,e/T)/T \tag{2}$$

The fluctuations of the refractivity may be expressed as a function of the fluctuations in potential temperature, pressure and humidity along:

$$dn(T,P,e) = \left[\frac{\partial n}{\partial T}\right]_{(P,e)} dT + \left[\frac{\partial n}{\partial P}\right]_{(T,e)} dP + \left[\frac{\partial n}{\partial e}\right]_{(T,P)} de \tag{3}$$

The local variations of the index n are responsible for the perturbations induced on the optical wavefront. Most authors agree to neglect humidity fluctuations for optical wavelength [Andreas 88]. Considering local statistics only (i.e: at fixed height over land), pressure fluctuations may also be neglected and absolute temperature may be used in lieu of potential temperature. One may then define the local structure parameter for the index of refraction at $\lambda = 0.5\,\mu$m:

$$C_n^2 \approx \left(80\cdot 10^{-6}\frac{P}{T^2}\right)^2 C_T^2 \text{ ; m}^{-2/3} \tag{4}$$

where C_T^2 is the local isotropic temperature structure parameter defined as:

$$C_T^2(\mathbf{r}) = \frac{<(T(\mathbf{r}) - T(\mathbf{r}+\Delta\mathbf{r}))^2>}{\Delta\mathbf{r}^{2/3}} \text{ ; }^{\circ}\mathrm{C}^2\mathrm{m}^{-2/3} \tag{5}$$

3 Experimental Results

A 10 m high mast has been erected at Gamsberg, close to the seeing monitoring station. This mast is equipped since September 1st, with three sets of microthermal sensors at 3.5, 5.5 and 10 m above ground and with an anemometer, a thermometer and an hygrometer at the 3.5 m level.

The temperature structure parameter C_T^2 is computed every minute on the basis of 10 Hz samples of temperature microvariations, combined with the average windspeed during that period. The temporal method described thereafter permits to use one sensor (and its associated electronics) per level instead of two.

Because the turbulence features may be considered as moving horizontally at the wind speed in a frozen atmosphere hypothesis, the spatial autocorrelation in Equ. 5 has its equivalent in the time domain. One can define an equivalent time lag $\Delta t = \Delta r/\overline{u}$, where $\overline{u}$ is the short time average wind velocity. The temperature structure parameter measured at the height H with only one sensor is then:

$$C_T^2(t,H) = \frac{<(T(t,H) - T(t+\Delta t, H))^2>_\tau}{(\Delta t \cdot \overline{u})^{2/3}} \text{ ; in } \mathrm{C^2 m^{-2/3}} \tag{6}$$

Where $< \ . >_\tau$ means that the computation is made on time series long enough compared to Δt (typically $\tau = 1$ mn) and during which the wind velocity may be considered as constant.

As the same method was used in the past years, the Gamsberg results can be compared to those obtained at other sites [de Baas 91] as shown on Fig. 1. To correct seeing measurements made at 2 m above ground from the turbulence up to the VLT lower opening level, it is necessary to reconstruct the vertical profile of the temperature structure coefficient. For that reason Armazoni and Gamsberg were more thoroughly tested than the other sites which were all equipped with 5 m high towers for the telescope.

From Table 1, we remark that:

the ground thermal turbulence at Gamsberg is more than 6 times higher than at

Paranal (before levelling of the telescope area) **and 2.5 times more than at Armazoni** (which could be compared sizewise to the current Paranal telescope area).

height	C_t^2 ($C^2 m^{-2/3}$)				
	Paranal	Armazoni	La Silla	La Montura	Gamsberg
(m)					
10			0.003		0.010
8		0.005			
5.5					0.020
5	0.003	0.008		0.012	
3.5					0.024
2		0.012			

Table 1: Statistical summary of average C_t^2 data in function of height above ground for various types of mountains: Paranal (very narrow peak), Armazoni (narrow peak), La Silla (narrow ridge), Montura (soft double-peak) and Gamsberg (large table mountain).

4 Seeing data correction

Once the vertical profile of turbulence is known, it is possible to estimate the corresponding effect on the astronomical image of an air layer of thickness $H_0 - H_1$. First of all, Equ. 1 is easily expressed in arcsec at 0.5 μ and at zenith, measured from height H_0 above ground along:

$$\mathrm{FWHM}_{H_0} = 2.0\,10^7 \left[\int_{H_0}^{\infty} C_n^2(z)\,dz\right]^{3/5} \quad ;\mathrm{arcsec} \tag{7}$$

The ground related part of the integral can be isolated along:

$$\mathrm{FWHM}_{H_0} = 2.0\,10^7 \left[\int_{H_0}^{H_1} C_n^2(z)\,dz + \int_{H_1}^{\infty} C_n^2(z)\,dz\right]^{3/5} \quad ;\mathrm{arcsec} \tag{8}$$

Figure 2 shows the image size produced by the first part of the integral only, for H_1 values of 5, 10, and 20 m as a function of ground turbulence level, using Equ. 4 to convert temperature statistics into refractive index statistics. The results given in Table 2 show that the image spread due to ground turbulence is twice higher at Gamsberg than at Armazoni.

The atmospheric seeing measured by such a telescope can then be estimated along:

$$2.0\,10^7 \left[\int_{H_1}^{\infty} C_n^2(z)\,dz\right]^{3/5} = \left[\mathrm{FWHM}_{H_0}^{5/3} - (2.0\,10^7)^{5/3} \int_{H_0}^{H_1} C_n^2(z)\,dz\right]^{3/5} \quad ;\mathrm{arcsec} \tag{9}$$

Because of the non-linearity of the subtraction, the relative share of the ground layer depends on the global seeing quality. The correction to be expected is shown on Figure 3 for various initial conditions. Table 3 show that raising the telescope to 10 m brings noticeable improvements at Gamsberg for sub-arcsecond seeing (from 10% at 1 arcsec to 30% at 0.5 arcsec), while virtually no gain is obtained at Paranal (before levelling) down to 0.5 arcsec.

We thus conclude that

a telescope at Gamsberg should have its lower air inlet at more than 10 m above ground to benefit of the best seeing conditions.

bottom-top (m)	Average C_t^2 ($C^2 m^{-2/3}$) Gamsberg	Average C_t^2 ($C^2 m^{-2/3}$) Armazoni	FWHM (arcsec) Gamsberg	FWHM (arcsec) Armazoni
2-5	0.024	0.010	0.19	0.11
2-10	0.020	0.007	0.31	0.17
2-20	0.011	0.004	0.36	0.19

Table 2: Seeing due to the turbulence in the ground layer only, as a function of its thickness and for two different sites. The average C_t^2 is computed over the actual profiles. A linear height dependency is assumed for computing the integrals.

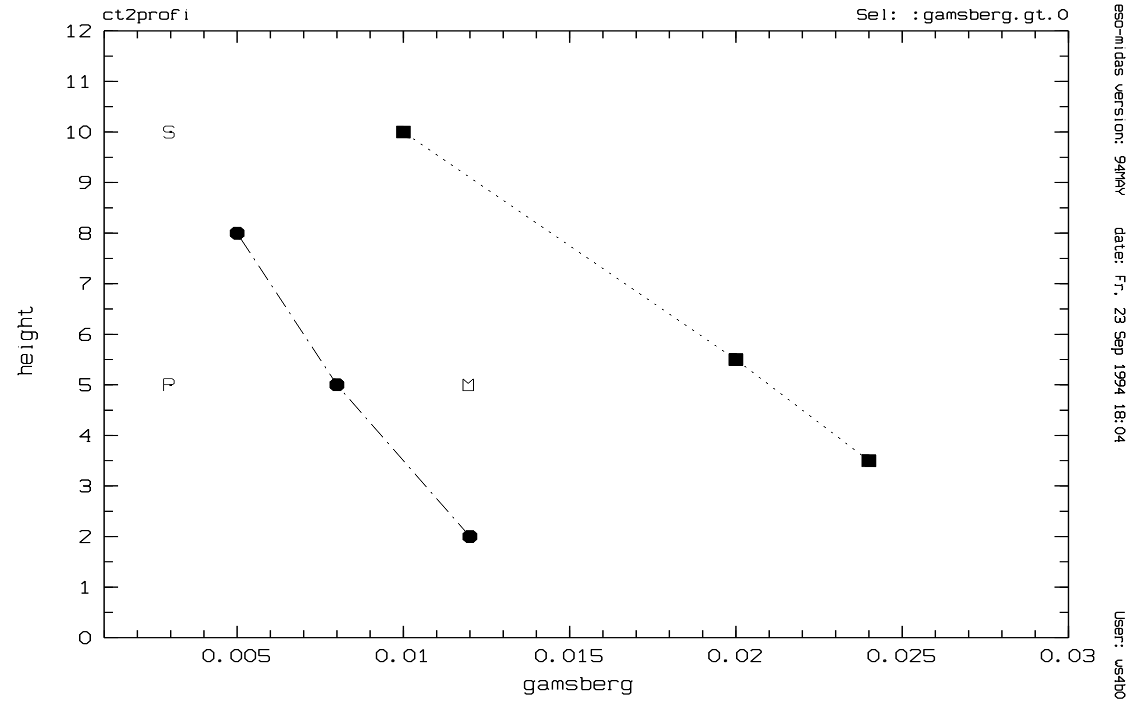

Figure 1: Average level of microthermal activity at nighttime during several weeks as a function of height above ground on several sites: Paranal (P, very narrow peak), Armazoni (filled circles, narrow peak), La Silla (S, narrow ridge), Montura (M, soft double-peak) and Gamsberg (filled squares, large table mountain).

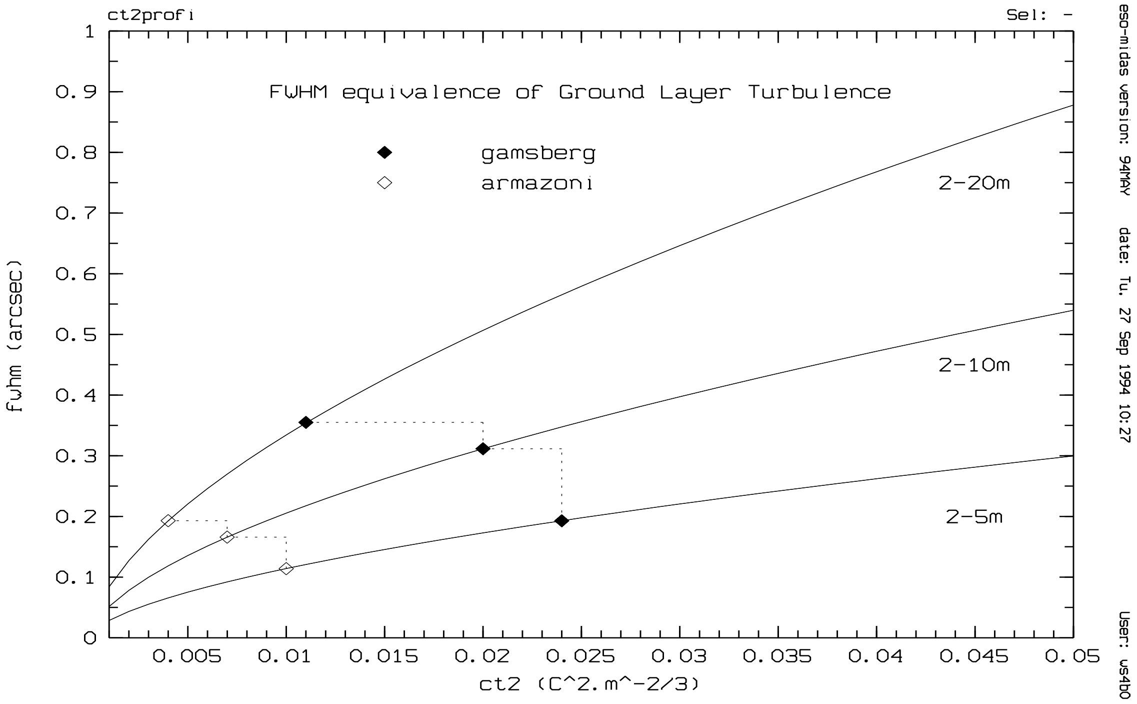

Figure 2: Seeing due to the ground layer only as a function of the thermal turbulence averaged over the path considered. The cases of 2-5 m, 2-10 m and 2-20 m thickness are compared for Gamsberg (filled lozenges) and Armazoni (empty lozenges).

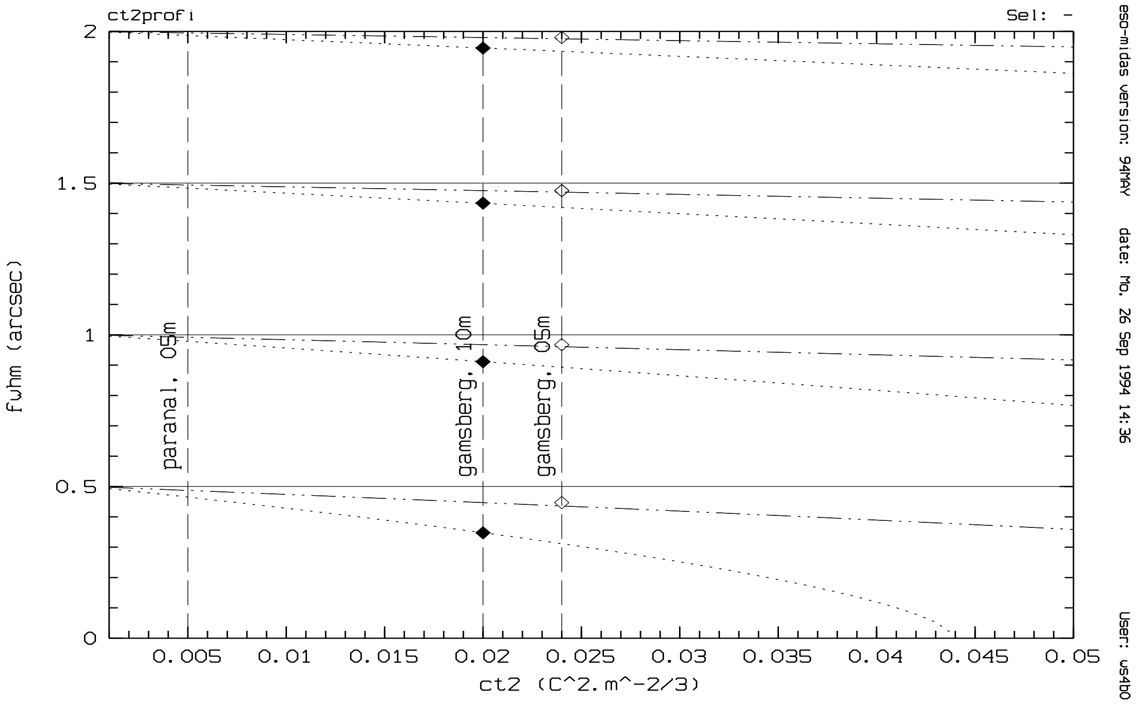

Figure 3: Correction to be applied to seeing measured at 2 m above ground as a function of the thermal turbulence averaged over the path to be removed. The seeing drops from it initial value (full line) to the dash-dotted line at 5 m and further to the dotted line at 10 m. The cases of Gamsberg 2-5 m (empty lozenge) and 2-10 m (filled lozenge) layer removal are compared to Paranal 2-5 m for different seeing conditions. The Paranal profile is assumed to be parallel to the Armazoni profile of Fig. 1

height (m)	FWHM (arcsec)			
	Gamsberg		Armazoni	
2	0.5	1	0.5	1
5	0.43	0.96	0.47	0.98
10	0.35	0.91	0.45	0.97

Table 3: Improvement in seeing when raising the telescope out of ground turbulence at two different sites.

5 Detailed analysis of the Gamsberg data

The variance of the temperature structure coefficient is generally very high and we have been considering up to know only average conditions for seeing correction. Assuming complete independency of the two data sets, a general correction of the Gamsberg seeing statistics could be done at the end only, disregarding time of occurrence.

The reliability of the previous analysis depends on the degree of correlation between total seeing and local conditions, both data sets were binned with a 10 minute temporal window and simultaneous measurements are plotted on Figure 4. It is clear on this plot that low overall seeing also implies low thermal turbulence at ground level, the same is true for high seeing until 2 arcsec. The abscence of correlation above this value shows that the very bad seeing events (2.5 to 5 arcsec) which sometimes occurred at Gamsberg belong to a very specific regime corresponding to a dense turbulent layer flying a few hundred meters (not higher than that because they did not produce an increase in scintillation) above the site without interaction with the mountain itself.

6 Conclusion

A correct processing implies that the 2 m to 10 m layer effects are subtracted from the total seeing on a bin to bin basis. The result, for the first two weeks of September, is shown on Figure 5 with a 10% decrease of the median seeing when the telescope is raised from 2 m to 10 m. This value is in accordance with the previous global analysis (cf. Table 3). On the other hand the correction of very good seeing period is much less than foreseen in the global method with a 5 percentile value of 0.67 arcsec down by only 8% to 0.59 arcsec at 10 m height.

References

[Andreas 88] Edgar L. Andreas; *Estimating C_n^2 over snow and sea ice from meteorological data*;J. Opt. Soc. Am. A **5**, n^o 4, Apr. 1988.

[Moresmau 86] J.M. Moresmau; *Signal Conditioner for a Turbulence Sensing Device*; ESO Intern. Techn. Report TPE/JMM-zi/0001Z/17.07.86.

[de Baas 91] A.F. de Baas, M. Sarazin; *The Temperature Structure Function for Complex Terrain*; Eight Symposium on Turbulent Shear Flows, Munich, September 9-11, 1991.

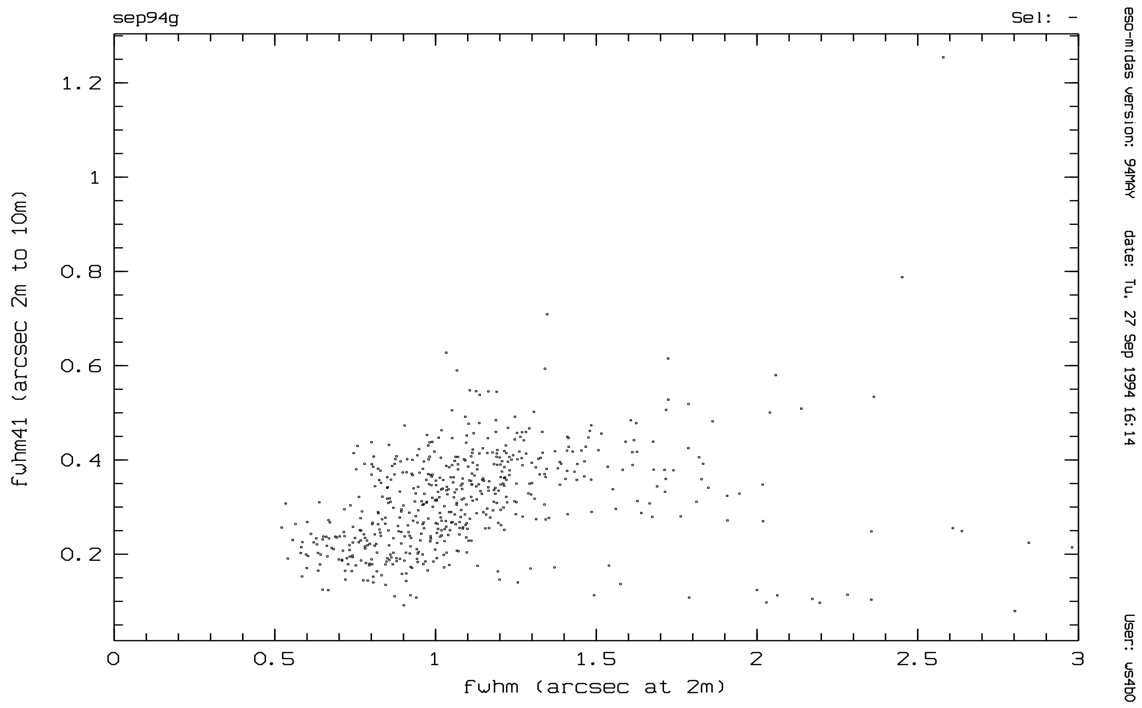

Figure 4: Correlation of seeing with ground turbulence: 10 minutes bins of the Gamsberg seeing measured with a DIMM at 2 m are plotted against FWHM of the 2 m to 10 m layer turbulence computed from microthermal sensors output.

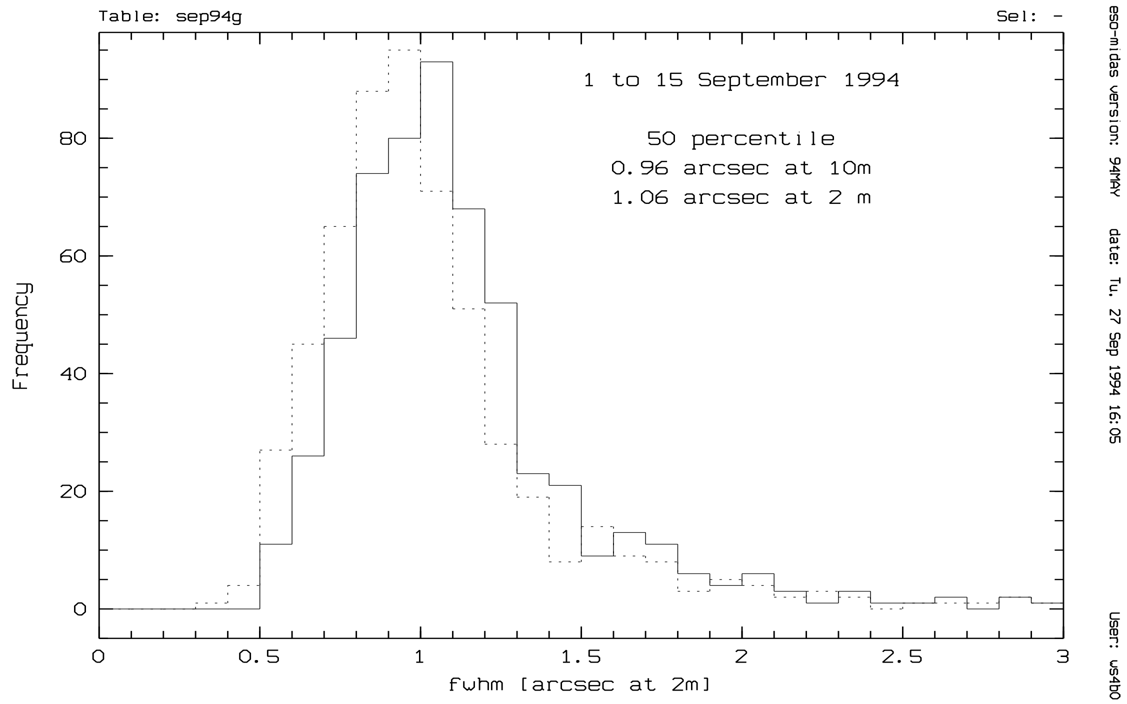

Figure 5: Correction of seeing from ground turbulence: statistics of 10 minutes bins of the Gamsberg seeing measured with a DIMM at 2 m (full line) and after correction from the 2 m to 10 m layer turbulence computed from microthermal sensors output.