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A Generalized Solar Seeing Monitor : M.I.Sol.F.A (Moniteur d'Images Solaires Franco - Algérien)

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Abstract. The statistical analysis of angle-of-arrival (AA) fluctuations appears to be well adapted to monitor the optical effects induced by the atmospheric turbulence on the images observed using ground-based telescopes. In daytime, these fluctuations may be easily observed on solar limb images. In the context of the comparison planned between solar diameter measurements performed from ground (Solar astrolabe and DORaySol experiments) and space (PICARD experiment), a Generalized Solar Seeing Monitor (M.I.Sol.F.A) is proposed. It is based on simultaneous observations in the image and the pupil planes of the AA fluctuations leading, in the framework of the Von Kàrmàn model, to the estimation of the coherence parameters characterizing the wave-fronts (r_0 (or ε_0), $\mathcal{L}_0$, θ_0, τ_0). The optical turbulence profiles $C_n^2(h)$ are also deduced. Preliminary results obtained from the data recorded using the solar experiments based at Calern Observatory are given.

1. Introduction

Observations of the Sun at High Angular Resolution using ground-based telescopes need an accurate modelling of the optical effects induced by atmospheric turbulence. To illustrate the problem, we will take as an example solar diameter measurements. Since more than 25 years, these measurements are performed at Calern Observatory (Observatoire de la Côte d'Azur) with the solar astrolabe (Laclare et al. 1996). More recently, an automatic experiment (DORaySol) (Delmas 2000) has also been implemented on the same site. Soon (2003-2004) will be launched a spatial experiment (PICARD (CNES)) for solar diameter and solar irradiance measurements (http://must.aerov.jussieu.fr/picard.htm). A replica of this experiment, based also on the Calern site, will allow simultaneous measurements. The main objectives are the comparison of the results deduced from spatial and ground data as well as the evaluation of the atmospheric turbulence optical effects on the measurements performed from the ground. The ground observations will be by this way qualified before the development of inverse techniques. A seeing monitor must allow the modelling of these effects. It must give, in the framework of a turbulent model (based here on the Von Kàrmàn model), the values of the integrated optical parameters (Fried's parameter r_0, spatial coherence outer scale $\mathcal{L}_0$, size of isoplanatic patch θ_0, correlation time τ_0 for the fluctuations), but also the vertical profile of the optical turbulence energy given by the structure constant of the air refractive index fluctuations $C_n^2(h)$. Such a generalized monitor could be used for evaluation of sites dedicated to solar observations. Each solar observatory could also be equipped with it. The monitor presented here (under construction) is founded on the observation of angle-of-arrival (AA) fluctuations (solar limb image motion) and on their statistical analysis.

2. Observation of the AA fluctuations from M.I.Sol.F.A

Experimental concept : The AA fluctuations which are fluctuations of the normal to the perturbed wave-fronts, can directly be observed in the image plane (case of Shack - Hartmann's sensors currently used in the adaptive optics system). But, they can also be shown in the pupil plane, for example, when the astronomical sources observed (Sun or Moon) present an intensity distribution with a strong discontinuity (Irbah et al. 1993). In this case, an analysis of the perturbed wave-fronts analog to a Foucault's test can be performed. The monitor device consists in 2 ways. One way, for which a CCD camera is placed on the solar limb image, allows to record directly the AA fluctuations. A beam-splitter allows to create a second way in which the telescope pupil is observed through a narrow slit placed on the solar limb image. One observes in this pupil image intensity fluctuations which at the first order are proportional to the AA fluctuations (Borgnino & Martin 1977, Borgnino 1978). Figure 1 (a) shows a pupil image obtained using such a device. Several photodiodes allow the recording of the intensity fluctuations positioned on this image behind diaphragms of different sizes; so a spatiotemporal analysis may be performed.

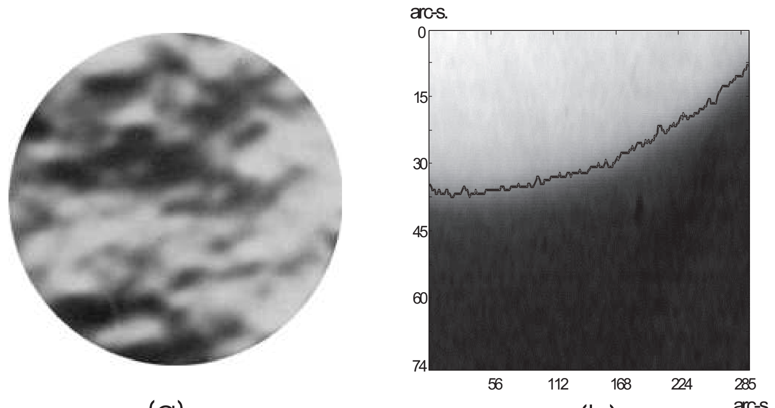

Figure 1. AA fluctuations observed in the telescope pupil image (a) and on the solar limb (b) (see text)

Parameter estimation : The theoretical covariance used here to deduce the parameters has been obtained in the same manner that the one currently used, for nighttime observations, to interpret the experimental data given by the Generalized Seeing Monitor (G.S.M) (Martin et al. 1994, Ziad et al. 2000). Indeed, from the transverse spatial covariance of the AA fluctuations established in the case of the Von Kàrmàn model (Avila et al. 1997) it is easy to obtain the transverse angular covariance (Bouzid et al. 2000, Seghouani et al. 2000). The observations are performed with a telescope (pupil of diameter D) in directions in the sky separated by θ. The altitude h is the one of the equivalent impulse layer giving at ground level same optical effects than the whole turbulent terrestrial atmosphere. This leads to :

$$\mathcal{C}_\alpha(\theta) = K \int_0^{+\infty} df f^3 (f^2 + \frac{1}{\mathcal{L}_0^2})^{-\frac{11}{6}} [J_0(2\pi f(\theta h)) + J_2(2\pi f(\theta h))][\frac{2J_1(\pi D f)}{\pi D f}]^2 \quad (1)$$

where $K = 0.0716\lambda^2 r_0^{-\frac{5}{3}}$. For the temporal analysis (pupil plane), the needed transverse temporal covariance (and/or variance) is obtained doing $\theta h = v\tau$ in the previous formula, v denoting an equivalent speed (weighted average of the different layer speeds) and τ a temporal shift (Conan et al. 2000).
Equation (1) allows to estimate by inversion technique r_0, $\mathcal{L}_0$ and θ_0 from the ratio r_0/h (Seghouani et al. 2000). In the case of a multilayer turbulent atmosphere, the optical turbulence profile $C_n^2(h)$ can be obtained by application of the inversion technique described by Bouzid et al. (2000).

3. First results and conclusion

First results: Some preliminary results concerning the spatio-angular analysis (observation in the image plane) are presented in this section. Images recorded using the solar astrolabe of Calern Observatory are previously processed (cleaning by filtering in the wavelet planes, filtering of the residual noise in the Fourier plane); then a parabolic fit allows to observe the AA fluctuations (see Seghouani et al. in the same issue). Figure 1 (b) shows a solar limb image as well as the limb fluctuations which have been extracted. The transverse angular covariance has been computed and then adjusted using the Von Kàrmàn model. The result is presented on Figure 2 (a). In this case, the values deduced for the parameters are $r_0 = 5.3cm$, $\mathcal{L}_0 = 5.4m$ and $\theta_0 = 1.2$ arcseconds. The transverse angular structure function has also been computed and the turbulence profile $C_n^2(h)$ obtained from inversion techniques (Fig. 2(b)) (Bouzid et al. 2000).

Conclusion: In this paper has been presented a Generalized Solar Seeing Monitor (M.I.Sol.F.A), which is under construction, in the context of the next launch of the spatial experiment PICARD and the planned comparison between the solar diameter measurements performed from space and from ground level. The main objective is the precise modelling of the optical effects induced by atmospheric turbulence on the ground measurements. The experimental concept adopted, based on the AA statistics, will allow to estimate all parameters associated to the perturbed wave-fronts (r_0, $\mathcal{L}_0$, θ_0, τ_0 and turbulence profiles $C_n^2(h)$)in the framework of a turbulent model. Indeed, the observation of AA fluctuations,

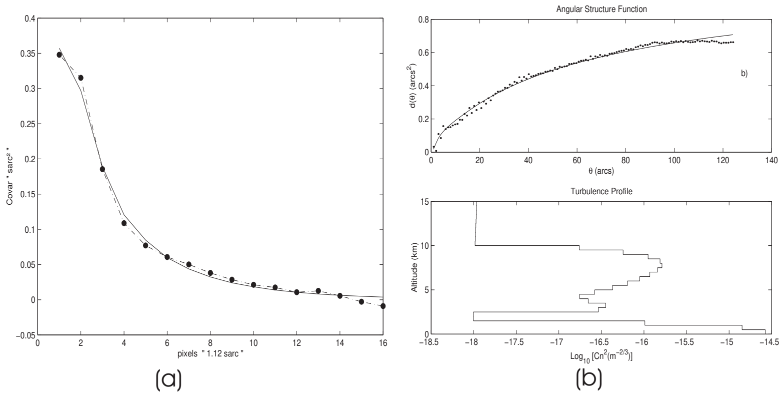

Figure 2. (a) *AA* fluctuations covariance: experimental (.) and Von Kàrmàn model fit(-) - (b) Experimental transverse structure function (top) and the turbulence profile obtained by data inversion (bottom)

simultaneously in the image and the pupil planes, leads to a complete information on the coherence status of the wave-fronts as well as on the localization of the atmospheric turbulence via their variance or covariance (structure function). It could also allow to propose eventually a more realistic modelling.

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