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Investigation of the inhomogeneity of atmospheric turbulence at day and night times

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A B S T R A C T

In this work, we introduce for the first time the use of a pair of telescopes facing each other in conjunction with the use of a pair of moiré deflectometers for the investigation of the inhomogeneity of atmospheric turbulence. In the experiment, a laser beam enters a telescope from its back focal point by virtue of a focusing lens and is expanded and re-collimated by it before passing through the turbulent ground level atmosphere. It then enters the aperture of a second telescope, where it is again re-collimated behind the focal point, finally entering a pair of moiré deflectometers. We use the instrument for measuring the fluctuations of two components of the angle of arrival (AA) across the second telescope's aperture. Calculation of the structure functions of the vertical and horizontal components of the AA fluctuations on the second telescope's aperture (over typical vertical and horizontal moiré fringes) at different altitudes and at different latitudes allows a quantitative measure of the inhomogeneity at the day and night times in the atmospheric surface layer. Experimental results show that on sunny days the difference between the structure functions of the horizontal component of the AA fluctuations calculated at two different altitudes over two horizontal moiré fringes is changed as a function of the time and its value meaningfully correlated to the mean value of the temperature of the Earth's surface. We did not find any interpretative correlation for the difference between the structure functions of the vertical component of the AA fluctuations calculated at two different latitudes. In addition, for the data recorded on windy days the observed correlation between the inhomogeneity of the atmospheric turbulence and the Earth's temperature almost disappeared.

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1. Introduction

In recent years, a considerable number of theoretical and experimental studies have challenged the isotropy and homogeneity of atmospheric turbulence. Theoretical studies predict and experimental results show that the statistics of a light beam propagating through the atmosphere does not always guarantee the homogeneity and isotropy of the atmospheric turbulence [1–4]. In addition, significant inhomogeneity and anisotropy in indoor convective air turbulence in the presence of a 2D temperature gradient are reported [5]. Determining and introducing the sources of the observed inhomogeneity and anisotropy of atmospheric turbulence is an important issue and results can help us to look into new concepts in establishing a comprehensive theory for atmospheric turbulence. In this connection, it seems that precise attention to the boundary conditions of atmospheric turbulence and their changes during the day and night times are very important. The Earth's surface is the atmosphere's primary heat source. The value of the solar energy absorbed by the Earth's surface changes during the day time. Also, the absorbed energy at day time is emitted to the atmosphere with a non-constant rate during the night time. Thus, it is reasonable to have changes in the vertical temperature gradient near the Earth's surface as a function of day and night times. On the other hand, it is worth mentioning that as different parts of the Earth's surface absorb different values of the solar energy, it is reasonable to have changes in the temperature with distance in the horizontal direction near the Earth's surface, too. This kind of temperature change is usually observed in very large areas. Therefore, it is expected that near surfaces where the texture of land is the same, the daily changes (both at the day and night times) of the vertical temperature gradient affect the observed inhomogeneity and anisotropy of the turbulence. To the best of our knowledge, until now there have been no comprehensive studies on the inhomogeneity of atmospheric

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turbulence and its behavior at the day and night times. In this work we are reporting the investigation of the effect of daily changes of the Earth's surface temperature on the homogeneity of atmospheric turbulence. It is worth mentioning that in the literature, the temperature and wind velocity changes are stated to be the main sources of the homogeneous and isotropic turbulence in which there is no dominant and stable temperature gradient such as the case occurring on the windy situations near the Earth's surface. In fact, in the atmospheric boundary layer where atmospheric dynamics are dominated by the interaction and heat exchange with the Earth's surface, there is a convective instability and it gives rise to a strong optical turbulence [6]. In the presence of wind, the existence temperature gradient near the Earth's surface is removed by the wind and as a result the turbulence passes to the homogeneous state.

Recently, we have suggested a high-sensitivity and high-resolution method for studying turbulent media based on moiré deflectometry in conjunction with a telescope [7,8]. In the mentioned references, a slightly divergent laser beam passes through turbulent ground level atmosphere and enters a telescope's aperture. These methods suffer a limitation for the investigation of inhomogeneity of the atmospheric turbulence. To study the inhomogeneity of the atmospheric turbulence, we need to compare the statistics of pairs of rays, from a light beam, separated by a constant distance over the propagation path. To this end, in this work, we use a pair of telescopes face to face in conjunction with the use of a pair of moiré deflectometers. This improvement on the set-up allows us to have a collimated and expanded laser beam with a constant beam diameter over the propagation path and as a result, the above-mentioned limitation of the pervious methods is removed.

In this paper, we report the use of a pair of telescopes standing face to face together with the use of a pair of moiré deflectometers for observing the inhomogeneity in the statistical properties of the turbulent ground level atmosphere. In addition, the behavior of the observed inhomogeneity in the day and night times is investigated. It should be mentioned that we have used the above-mentioned set-up for the investigation of the anisotropy and scaling of the phase structure function in indoor convective air turbulence in which the results will be reported elsewhere [9].

2. Experimental set-up and method of data acquisition

A schematic diagram of the experimental set-up is shown in Fig. 1. A laser beam enters a telescope by virtue of a focusing lens and is expanded and recollimated by it before passing horizontally through the turbulent ground level atmosphere and enters another telescope's aperture. The laser beam is collimated behind the second telescope's focal point by means of a collimator. The collimated beam passes through a beam splitter, and the resulting beams pass through a pair of moiré deflectometers which are installed parallel and close together.

The moiré deflectometers are installed close to each other. Directions of the gratings' rulings are almost parallel in each moiré deflectometer but are perpendicular in the two beams. Moiré patterns are formed on a plane where the second gratings of the moiré deflectometers and a diffuser are installed. The moiré patterns from both beams are projected on a CCD camera. Successive moiré patterns are recorded by the CCD camera and transferred to a computer, to allow temporal fluctuations of the AA components to be measured accurately. Displacements of the moiré fringes in the recorded patterns correspond to the fluctuations of two orthogonal components of the AA across the second telescope's aperture.

In this work we will calculate the structure function of the AA components fluctuations. For clarification of the data acquisition procedure in the calculation of the structure functions, here we present in detail the geometry of the measurements of the AA components' fluctuations from the moiré fringes displacements. In Fig. 2(a) a typical recorded frame that consists of two sets of the horizontal and vertical moiré fringes is shown. In Fig. 2(b) the corresponding low-frequency illumination distributions are shown. On the horizontal moiré fringes pattern (left side), two typical moiré fringe maxima are traced by the blue lines. Similarly, on the vertical moiré fringes pattern (right side), two typical moiré fringe maxima are traced by the red lines. For detail of the trace finding see [8,10,11]. In this report, we use the displacement data of these traces for the calculation of the structure functions of the two components of the AA fluctuations. From the displacement data of the blue traces having typical mean altitudes of y_1 and $y_2 = y_1 + \Delta y$, the structure functions of the x component of the AA fluctuations for the corresponding altitudes are to be determined. Similarly, from the displacement data of the red traces having typical mean latitudes of x_1 and $x_2 = x_1 + \Delta x$ the structure functions of the y component of the AA fluctuations at the corresponding latitudes are to be determined. All position coordinates are defined on the second telescope's aperture plane from which the real space for the position coordinates is calculated.

Due to the AA fluctuations, the moiré fringe traces are displaced. We need to calculate the mean positions of the moiré fringe traces in the determination of the AA fluctuations. In order to show the displacements of the moiré fringes, in the plots of Fig. 2(c), two pairs of the horizontal and vertical traced moiré fringes of Fig. 2(b) and their mean position traces are shown by the continuous lines and dashed lines, respectively. From the displacement of the horizontal moiré fringes in the vertical direction (the vertical separation of the adjacent continuous and dashed blue lines in Fig. 2(c)), Δy_m, the horizontal component of the AA fluctuation can be determined, α_x [10]. For given values of the blue lines' altitudes, y_1 and $y_2 = y_1 + \Delta y$, the horizontal component of the AA fluctuation α_x at all of points on the blue lines having different latitudes, x, can be determined. Similarly, from the displacement of the vertical moiré fringes in the horizontal direction

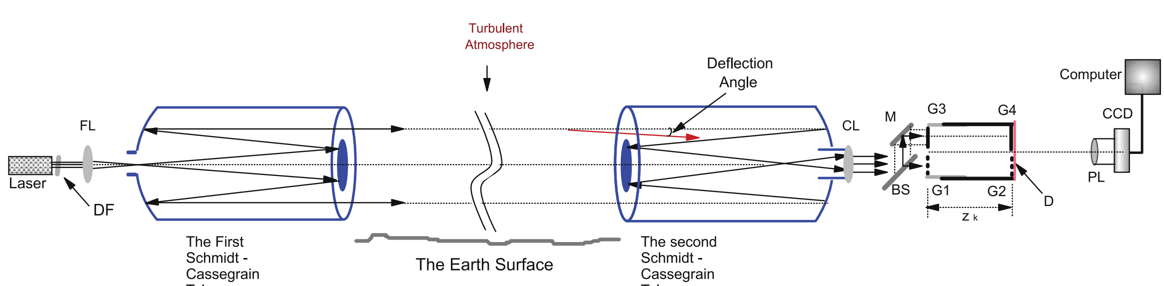

Fig. 1. Schematic diagram of the experimental set-up. *DF*, *FL*, *CL*, *BS*, *M*, D, and *PL* stand for the neutral density filter, focusing lens, collimating lens, beam splitter, mirror, diffuser, and projecting lens, respectively. G1, G2, G3 and G4 stand for the gratings.

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