Frequency spectra of optical angle-of-arrival fluctuations in the atmospheric surface layer

Andreas Muschinski[1] and Shiril Tichkule[2]

[1] NorthWest Research Associates, CoRA Office, 3380 Mitchell Lane, Boulder, CO 80301, USA, http://nwra.com

[2] Dept. of Electrical, Computer, and Energy Engineering, University of Colorado at Boulder, 425 UCB, Boulder, CO 80309, USA

Optical waves propagating through the atmosphere undergo spatial and temporal wave-front distortions caused by turbulent refractive-index fluctuations along the propagation path. The statistical characteristics of the associated angle-of-arrival (AOA) fluctuations are relevant for many applications in science and engineering. For example, turbulent AOA fluctuations have often a dominating effect on the performance of optical communication systems, imaging systems, and directed-energy systems.

There is a controversy about the frequency spectrum of the fluctuations of the aperture-averaged AOA in fully developed, Kolmogorov-type turbulence. Clifford (1971: *J. Opt. Soc. Am.*, **61**, 1285-1292) predicts an $f^{-8/3}$ asymptote for sub-aperture scales, while Hogge and Butts (1976: *IEEE Trans. Ant. Prop.*, **24**, 144-154) predict an $f^{-11/3}$ asymptote. However, the empirical material that has been published so far does not allow to settle this controversy conclusively.

Here we present observations of frequency spectra of AOA fluctuations computed from image sequences collected with a digital camera attached to a Schmidt-Cassegrain telescope with an aperture diameter of 36 cm. The observations were taken in a series of field experiments conducted at the Boulder Atmospheric Observatory near Erie, CO (for details see Cheon, Hohreiter, Behn, and Muschinski, 2007: *J. Opt. Soc. Am. A*, **24**, 3478-3492; Tichkule and Muschinski, 2012: *Appl. Opt.*, **51**, 5272-5282). One or two telescopes pointed at several small test lights (krypton flashlight bulbs or LEDs with diameters of a few millimeters) located at a distance of typically 180 m. The propagation path was typically 1.7 m above flat, grassy ground. The digital images consisted of 640 × 480 pixels, and each pixel provided a 16-bit intensity value. The sampling rate was 30 or 60 frames per second. Up to 12 ultrasonic anemometers/thermometers were placed along the propagation path in order to provide independent measurements of mean values and turbulent fluctuations (sampling rate 32 Hz) of the three-dimensional wind vector and the air temperature.

We interpret the observed AOA frequency spectra and the simultaneous and collocated in-situ turbulence and wind measurements in the context of the theoretical predictions.