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SHADOW BANDS AND RELATED ATMOSPHERIC PHENOMENA REGISTERED DURING TOTAL SOLAR ECLIPSES

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Abstract. This study is dedicated to the atmospheric phenomena accompanying total solar eclipses. Observations of shadow bands are shown. We look for a connection between their distribution and the variations of the temperature, speed and directions of the wind before, during and after the totality of two total solar eclipses. A new experiment for registering the shadow bands realized during the last total solar eclipse (2019 July 2) is presented.

1. INTRODUCTION

Total solar eclipses (TSEs) have impressed observers since the beginning of recorded history. Despite the existence of evidence for solar eclipse observations from more than 4 millennia ago, some accompanying phenomenon remained unnoticed for thousands of ages. It wasn't until 1820 that Hermann Goldschmidt noted shadow bands visible just before and after totality at some eclipses (Guillermier and Koutchmy, 1999). Later, in 1842, when George Airy saw his first TSE, he also highlighted the shadow bands (Littmann et al., 1999), but the first hypotheses that successfully explain their formation date back from the late XX century. Previously, XIXth-century observers assumed that shadow bands were some sort of diffraction phenomenon because their linear patterns roughly resemble optical interference fringes. More exotic explanations have been proposed in 1924 (Hastings, 1924). They suggest that the bands were overlapping pinhole images of the Sun formed by vents in the upper atmosphere. More recently A. L. Stanford has proposed a Lloyd's mirror effect, where direct rays from the uneclipsed solar crescent interfere with those reflected from clouds (Stanford, 1973).

But by far the simplest and most satisfactory explanation was the one published in the late 1980’s by Codona (1986). It states that the shadow bands are diffraction effects caused by turbulence in the Earth’s atmosphere when the light from narrow slit-like source passes through (Fig. 1). The roughly linear patterns moving across the ground with typical speeds of a few meters per second usually appear just before and just after the total phase of solar eclipses. Typically, they align parallel to the tangent to the center of the solar crescent (Marschall et al., 1984). They are easily observable by naked eye, but their low contrast makes their quantitatively measurements harder. Still, it is considered that the shadow band spacing decreases and their contrast increases as the totality approaches (Codona, 1986). Probably the first attempt for capturing shadow bands was made during a TSE in 1912 although it was rather unsuccessful. Even nowadays despite the development of technology, registration of the bands by photo or video detectors remains an uneasy task.

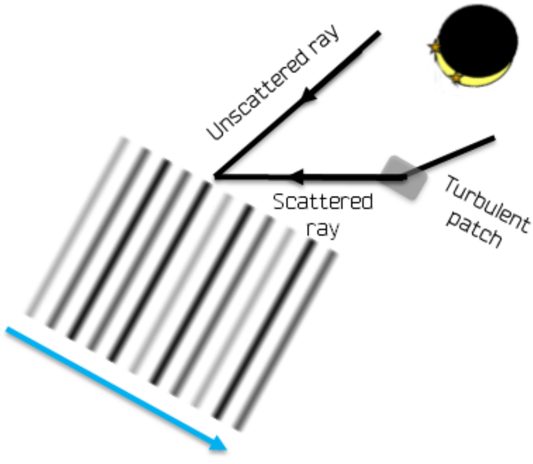

Figure 1: Formation and propagation of shadow bands.

Our team is experienced in shadow bands observations with 4 successful experiments conducted at 4 TSE expeditions – in 1999, 2006, 2017 and 2019. As the techniques and instruments used to register the bands have changed over the years, our latest results are incomparable with the earliest ones. Therefore, the current study summarizes only the data obtained during the last two TSEs (2017 August 21 and 2019 July 2).

2. EXPERIMENTAL SETUP

Our team observed the 2017 August 21 TSE from the northwestern part of the USA – the state of Oregon. We chose an observational spot (44°42'11.6"N 120°47'52.2"W) at distant, uninhabited place at altitude about 1200 m. The setup for the shadow bands experiment included white screen for better visualization and Sony DCR-SR55 digital video camera that takes 25 frames/second. Next to it at altitude 1.5 m above the ground was situated a Gill Windsonic anemometer that records the wind speed and direction 4 times/second.

We repeated the experimental setup two years later, when observing the TSE on 2019 July 2 from Atacama Desert, Chile. The location of our team (29°47'37.0"S 70°53'12.4"W) was similar as the place was far from any settlements and other observers at more than 1400 m above the sea level. The installation for registering the shadow bands and eclipse meteorology was almost the same except for the video camera that was replaced by Sony Alpha 7III that offers better quality and resolution and makes capturing the bands easier taking 50 framse/second.

3. RESULTS

During the two latest expeditions for TSE observations our team performed an experiment dedicated to registration of shadow bands and wind properties. Its aim was to look for a possible relationship between the direction of propagation and the speed of near ground wind and the observed pattern of the shadow bands. The results are summarized in Table 1. Monitoring and recording the wind characteristics and shadow bands was performed both before and after the totality of every eclipse. Unfortunately, the insufficient quality of the videotaping after the totality in 2017 does not allow data processing, thus such information is not included. The average wind speed is given only for the moments of visibility of the shadow bands – periods of about 30 seconds before and after the totality. The frequency is measured after video processing that aims to find and remove all static regions of each frame, so that small changes in the intensity became visible. This has been achieved by clearing small random noises, applying adaptive background learning and subtraction over the sequence of the frames, and amplifying the signal by increasing the contrast and brightness. A mean intensity in a fixed square region is calculated for each frame in the video and the obtained values are saved and subjected to Fast Fourier Transform.

Table 1: Properties of the wind and shadow bands registered at two TSEs – in 2017 and 2019.

	2017	2019	
	before totality	before totality	after totality
Average wind speed [m s^{-1}]	1.01	2.27	1.59
Shadow bands frequency [Hz]	1.35	1.75	1.37

It is obvious that the near ground winds during 2019 TSE were stronger than these two years earlier, but it is also noticeable that the wind speed rapidly changes before and after the totality in 2019. The observed decrement of the wind speed coincides with the decrement of the frequency of the shadow bands. The relationship between the average near ground wind speed and shadow bands frequency is shown on Fig. 2.

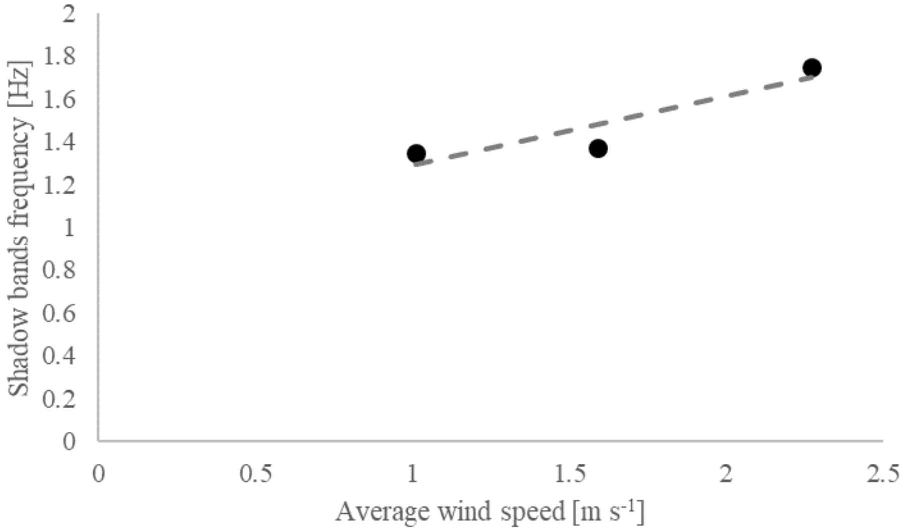

Figure 2: The relation between the average speed of the wind at the moment of shadow bands observations and their frequency.

More detailed information about the wind speed and direction during the observations of shadow bands (not only the average value) gives the wind rose diagram (Fig. 3). It shows the near ground wind properties detected only during the experiment held in Chile in 2019 and shows that the main direction of propagation is the same before and after the totality (eastern-northeastern) as the eastern component becomes weaker after it.

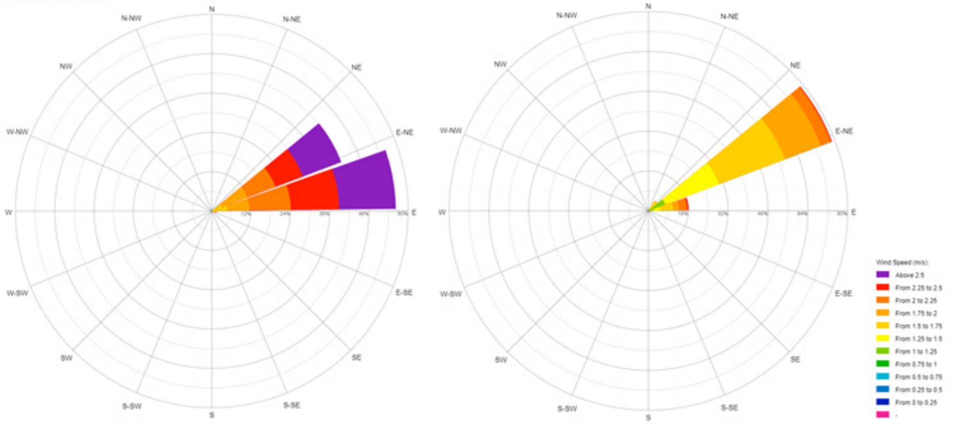

Figure 3: Wind rose diagram showing the direction of propagation and the speed of the wind detected in the periods of visibility of the shadow bands during 2019 TSE before (left panel) and after (right panel) the totality.

Two still frames from the performed videotaping of the shadow bands during the 2019 TSE (before and after the totality) are shown on Fig. 4. The background content is removed and the contrast and brightness of the pixels, which represents moving bands, are increased for better visualization. A comparison between Fig. 3 and Fig. 4 shows that the slight changes in the primary direction of propagation of the wind coincides with similar behavior of the direction of the bands.

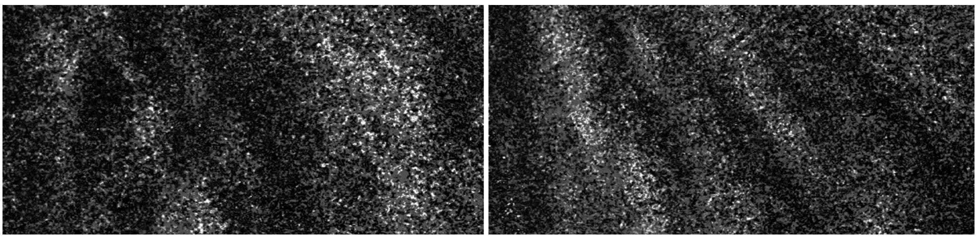

Figure 4: Two frames from the video of the shadow bands during the 2019 TSE before (left panel) and after (right panel) the totality.

4. CONCLUSIONS

We present our results from experiments held during last two total solar eclipses, observed by our team (2017 August 21 and 2019 July 2) on the connection between near ground wind properties and shadow bands pattern. We find a link between the average near ground wind speed and the frequency of the bands. This relation is also confirmed by the matching directions of propagation of the bands and the wind before and after the totality of the eclipse from 2019.

These primary results support the hypothesis that the ground level wind's atmospheric scintillation may influence the pattern of the shadow bands.

Acknowledgements

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