Comparison of slant-path scintillometry, sonic anemometry and high-speed videography for vertical profiling of turbulence in the atmospheric surface layer

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ABSTRACT

The optical effect of atmospheric turbulence greatly inhibits the achievable range of Detection, Recognition and Identification (DRI) of targets when using imaging sensors within the surface layer. Since turbulence tends to be worst near the ground and decays with height, the question often arises as to how much DRI range could be gained by elevating the sensor. Because this potential DRI gain depends on the rate of decay of turbulence strength with height in any particular environment, there is a need to measure the strength profile of turbulence with respect to height in various environments under different atmospheric and meteorological conditions. Various techniques exist to measure turbulence strength, including scintillometry, sonic anemometry, Sound Detection and Ranging (SODAR) and the analysis of point source imagery. These techniques vary in absolute sensitivity, sensitivity to range profile, temporal and spatial response, making comparison and interpretation challenging.

We describe a field experiment using multiple scintillometers, sonic anemometers and point source videography to collect statistics on atmospheric turbulence strength at different heights above ground. The environment is a relatively flat, temperate to sub-tropical grassland area on the interior plateau of Southern Africa near Pretoria. The site in question, Rietvlei Nature Reserve, offers good spatial homogeneity over a substantial area and low average wind speed. Rietvlei was therefore chosen to simplify comparison of techniques as well as to obtain representative turbulence profile data for temperate grassland. A key element of the experimental layout is to place a sonic anemometer 15 m above ground at the centre of a 1 km slant-path extending from ground level to a height of 30 m. An optical scintillometer is operated along the slant-path. The experiment layout and practical implementation are described in detail and initial results are presented.

Keywords: Atmospheric turbulence, sonic anemometer, scintillometer

1. INTRODUCTION

Atmospheric turbulence is very often the factor limiting the achievable range of surveillance tasks using imaging sensors in the atmospheric boundary layer. The vertical profile of turbulence strength in various environments and under different meteorological conditions is therefore important when performing analysis or design of long-range imaging surveillance systems. In most such instances the surveillance sightline is a slant path or passes over undulating terrain. Methods of reducing the impact of turbulence on image quality have strategic value and vertical turbulence profiling can contribute to the development of such methods.

There have been quite a number of published campaigns, executed in various environments, to measure diurnal turbulence strength on horizontal sightlines at fixed height above the surface.[1,2] Likewise, particularly in the astronomy community, there have been many campaigns to measure the vertical turbulence profile of the entire atmosphere. Fewer campaigns have set out to measure the vertical profile with emphasis on the boundary and surface layers. The VerTurM experiment in northern Germany[3] is one of the most comprehensive, long-term efforts to perform this type of measurement. In the campaign described here, measurements were performed using slant-path and horizontal scintillometry, high speed videography of quasi-point-sources and sonic anemometry, with the specific intention of comparing these three measurement techniques. A further goal was to obtain surface layer turbulence strength data representative of a sub-tropical grassland environment.

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Table 2. Times of Key Events and Periods

Event	Time (UTC)
Sunrise	4:54
Morning Turbulence Minimum	5:30
Wind Swing to WNW	7:00
Local Noon	10:10
Afternoon Turbulence Minimum	14:25
Sunset	15:25
Nautical Twilight End	16:20
Wind Swing to SSW	17:00

Period	Time (UTC)
Day Wind	07:00 - 17:00
Core Daytime	6:40 - 13:10
Twilight	15:15 - 16:00
Evening Transition	16:00 - 17:00
Night Wind	17:00 - 07:00
Core Nighttime	19:15 - 5:00

Values of C_n^2 derived from the SLS20 scintillometer and the sonic anemometers are plotted for two days in Figure 7. The core daytime period (3.5 hours before local noon to 3 hours after local noon), morning and evening turbulence minima as well as the twilight periods are clear.

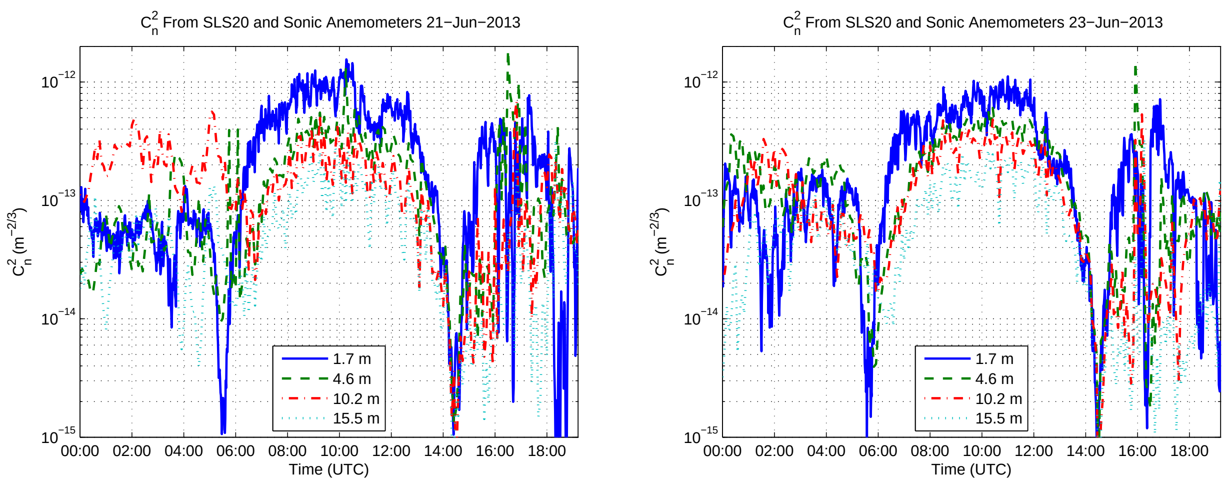

Figure 7. C_n^2 From SLS20 and Sonic Anemometers

Some of the simplest models for variation of C_n^2 with height are of the form

$$C_n^2(z) = C_n^2(z_0) z^{-k}, \tag{1}$$

where z is the height above ground, z_0 is the reference height for the anchor value of C_n^2 and k is a period-dependent parameter.

For C_n^2 derived from the sonic anemometers during the core daytime period at Rietvlei, the mean best fit log-log slope with respect to height was $k = -0.70$ with a standard deviation of 0.24.

If the data from the SLS20 scintillometer at 1.7 m height is included with the sonic anemometer data in the log-log fit, the mean best fit value of k is -0.66 with a standard deviation of 0.26. This suggests good power-law agreement between the SLS scintillometer and the sonic anemometers for the core daytime period.

5.2 Sonic Anemometers and BLS Scintillometers

A few periods were chosen in which to compare the turbulence strength derived from the BLS900 scintillometers to that derived from the sonic anemometers. This was a direct comparison without any effort to compensate the BLS results for slant path bias. Figure 8 shows some typical results.

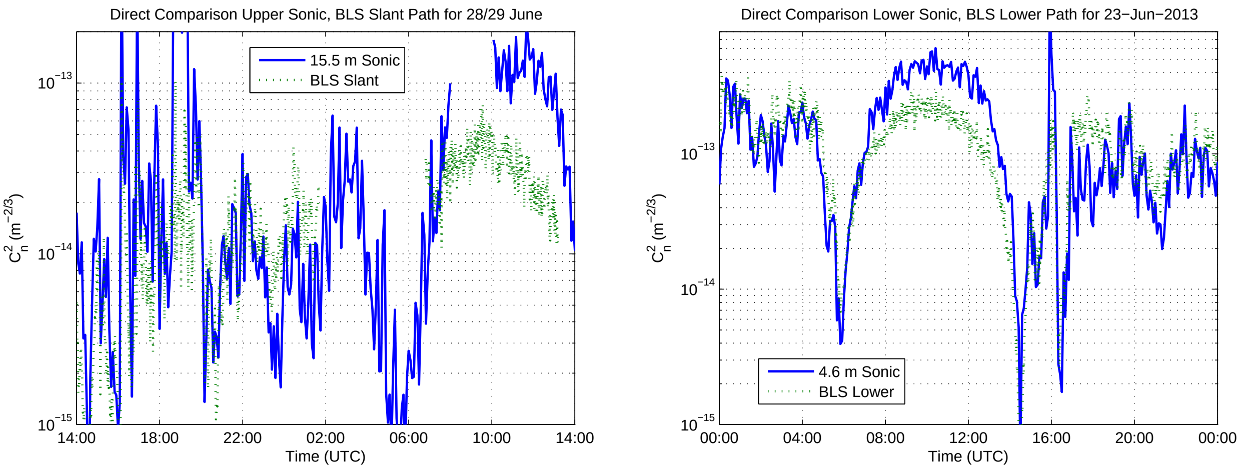

Figure 8. Direct Comparison of C_n^2 from Sonic Anemometers and BLS900 Scintillometers

The expectation was that the slant path BLS900 results would compare well to the results from the uppermost sonic anemometer (15.5 m height) since the slant path BLS900 would peak in sensitivity very near this height. Likewise, the lower sonic results were expected to track the lower BLS900 path. Figure 8 suggests that the two sets of results compare reasonably well during the night, but the absolute consistency breaks down during the core daytime convective period. This pattern for the upper sonic anemometer compared to the slant-path BLS900 and lower sonic compared to the lower BLS900 is consistent across the dataset.

A further observation was that across the whole dataset, the 5 minute averages of C_n^2 derived from the sonic anemometers showed greater variability that those from the BLS900 scintillometers. This is to be expected, since the BLS900 integrates over a much greater volume of air. While the values of C_n^2 derived from the sonic anemometers and the BLS scintillometers did not always agree very well in absolute terms, there was a very obvious and expected tendency of the slant path BLS900 results to co-vary with the upper and (to a lesser degree) mid-level sonic anemometers rather than the low-level sonic anemometer.

6. CONCLUSIONS

The 2013 field campaign at Rietvlei Nature Reserve to measure the vertical profile of atmospheric turbulence strength has been described in relation to operation of optical imaging systems near ground level. A number of measurement techniques including scintillometry, sonic anemometry and high speed videography of point sources were used.

The daytime vertical distribution of turbulence was largely systematic and driven by the convective process as expected. Vertical distribution of turbulence strength at night was more complex and chaotic and perhaps driven in part by intermittent katabatic airflow in the presence of stable layer formation at ground level. Discrete layers and strong spikes in turbulence strength at night are thought to result from wind-driven mixing of air layers of different temperatures.

Most existing models of vertical variation of turbulence strength are large scale models of the electro-optical community disregarding the special features of the atmospheric surface layer such as the strong variability of atmospheric stability driven by the heating and cooling from the ground. There are some meteorological models based on the Monin-Obukhov similarity theory which parametrise the height dependency of turbulence with the atmospheric stability based on the Obukhov-length. This campaign shows that there is small scale but potentially predictable detail in the turbulence strength picture within the lower atmospheric boundary layer. Combining different methods of turbulence measurement can contribute to understanding of the nature and origin of these details.

The dataset recorded at Rietvlei, particularly the video dataset requires further and deeper analysis and is a promising source of further insight.

7. ACKNOWLEDGMENTS

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