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Gust Measurements by a Monostatic Minisodar

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ABSTRACT

In previous versions of the monostatic minisodar (with an operating frequency of about 4.5 kHz), only the mean wind and turbulence quantities (such as turbulent kinetic energy and eddy dissipation rate) were measured. The signal processor of the minisodar may not be able to filter the noise (e.g. due to clutters) and the spectrum of the backscattered signal has limited number of data points. As a result, the quality of the gust data may be affected at times because the measurement of gust requires that every piece of the instantaneous horizontal wind data should be accurate. Equipped with the latest signal processor, a minisodar is studied in the present paper by examining the quality of its gust data through comparison with the measurements of a meteorological tower. Propeller and sonic anemometer data at 30 and 50 m above the ground level are installed on the tower. The study period covered the summer time in 2009, including the passage of a tropical cyclone over Hong Kong. Based on the limited dataset, it appears that the gust measurements from the minisodar are of reasonable quality. Both the gust speed and the gust direction have good correlation with the tower measurements. It may be concluded that, with the modern signal processors, the minisodars could be used to make gust measurements as well.

1. INTRODUCTION

Measurement of vertical profiles of mean wind, gust and turbulence intensity could be useful for a variety of applications, such as the assurance of aviation safety. At the Hong Kong International Airport (HKIA), a number of remote-sensing meteorological instruments have been operated by the Hong Kong Observatory (HKO) in collecting wind data in the lower troposphere, such as boundary-layer type radar wind profilers and LIght Detection And Ranging (LIDAR) systems. The use of minisodars at the airport is also under exploration. Compared to radar wind profilers, the sodar could provide wind data at lower altitudes (starting height of about 25 m, compared to 120 m of the boundary-layer type wind profiler) and higher vertical resolution (5 – 10 m, vs. 60 m of wind profiler). The sodar gives the three components of the wind, whereas the LIDAR measures the line-of-sight velocity only. As such, the sodar could be useful in providing vertical wind profiles and turbulence profiles at high temporal resolution (every 5 – 10 minutes) in the first couple of hundred metres above ground, which would be useful for aviation forecasting applications.

The performance of a minisodar was studied in [1], with particular emphasis on aviation applications, such as the measurement of the standard deviation of the vertical velocity (sigma-w) and eddy dissipation rate. However, the performance of gust measurement was found not so satisfactory. Occasionally, there could be exceptionally high values of gust as given by the minisodar, particularly at higher altitudes (50 m or higher). The existence of the high gust values was not supported by other measurements, such as the data collected by the co-located anemometer mast in the study of [1], and did not seem to be meteorologically reasonable. As discussed with the manufacturer, the occurrence of the high gust might be related to the quality of the return signal and the number of data points employed in digitization of the Doppler spectrum. Since the gust may occur for a brief period of time, a single piece of erroneous data may result in unreasonable estimation of the gust value. This is different from the measurement of the mean wind in which the data over a certain period of time (5-10 minutes) would be considered and thus the impact of isolated pieces of erroneous data may not be equally significant.

Over the years, the signal processor of the minisodar has been improved and it would be useful to find out the latest performance of the minisodar, particularly the measurement of gust. A study was conducted between April and September 2009 by using co-located wind measurements by the minisodar and an instrumented tower of 50 m at a construction site for the new Stonecutter's bridge in Hong Kong. This paper presents the results of comparison of wind data.

2. INSTRUMENTS

The minisodar considered in the present study uses acoustic waves with a central frequency of 4,500 Hz to probe the lower atmosphere, up to a height of 200 m above ground. It employs a 3-beam configuration, namely, the vertical beam and two oblique beams. The latter beams are directed away from the co-located anemometer mast with a height of 50 m. The minisodar provides the three components of the wind, their standard deviations and the gust every 5 minutes. The wind data are available every 10 m.

The anemometer mast is located at about 20 m to the southeast of the minisodar. Due to the limited space available at the construction site, it is not feasible to arrange larger separation between the two instruments and other orientation of the minisodar with respect to the mast. Wind sensors were set up at two heights of the mast, namely, 30 and 50 m above ground. Two types of sensors were installed at each height, namely, a propeller anemometer (which gives 2D wind) and an ultrasonic anemometer (which gives all the three components of the wind). The wind data are available at 1 Hz and 4 Hz respectively.

A photograph of the setup of the minisodar and the anemometer mast is given in Figure 1.

3. MEAN WIND MEASUREMENTS

The comparison of the 5-minute mean winds from the minisodar and the propeller anemometers at 30 m and 50 m above ground could be found in Figure 2, for both the wind speed and the direction. It could be seen that the comparison result for the wind direction is generally satisfactory. Deviations of the data points from the 1:1 straight line could be expected, for instance, in the more variable wind directions in the lighter wind conditions. Probably because of the exposure of the site, a large portion of wind data collected in the study period was rather light winds with wind speeds of a few m/s only.

On the other hand, for wind speed comparison between the two instruments, the correlation of the two datasets is good, but the slope is far less than unity at both heights. The 5-minute mean winds from the minisodar were about 70% of the corresponding wind speeds from the propeller anemometers. Similar results are obtained for comparison of the winds between the minisodar and the sonic anemometers (not shown). This behaviour was not observed in [1]. A possible cause of the discrepancy of the wind speed may be due to partial blockage of the sampling volume above the minisodar by the anemometer mast located to its southeast. In fact, for periods of higher wind speeds (above 7 m/s from the propeller/sonic anemometer), the majority of the data points were obtained for wind directions of southeasterly. These data points of higher wind speeds have significant impact on the positioning of the straight line of least square fit. Unfortunately, due to the spatial constraints of the site, there was not much freedom to install the minisodar with better exposure in all wind directions.

4. GUST MEASUREMENTS

The comparison results for gust speeds and directions between the minisodar and the propeller anemometers at 30 and 50 m above ground could be found in Figure 3. For the gust directions, the comparisons are once again very satisfactory. The best fit straight lines have slopes close to unity. For gust speed, the comparison results turn out to be better than those for the mean wind speeds. The slopes of the best fit straight lines are only slightly less than unity. It appears that the blockage of the minisodar's sampling volume by the anemometer mast does not affect very much the high winds that briefly occur downstream of the mast.

There are a number of isolated data points at the upper left parts of Figures 3(a) and 3(b), i.e. the gust speed from the minisodar is significantly greater than that from the propeller anemometer. For instance, the gust from the minisodar may reach 18 – 20 m/s, whereas the corresponding value from the propeller anemometer is 3 – 7 m/s only. Though the majority of the gust speed from the minisodar appears to be reasonable, there could still be isolated instances in which the gust of the minisodar is not determined accurately. Such erroneous data points may be filtered by applying continuity check in the height-time distribution of the gust, i.e. they should appear as isolated spikes in the height-time "surface" of the gust. Additional improvements of the hardware and software of the signal processor of the minisodar would be required in order to obtain completely "clean" values of gust. Having said that, the quality of the gust data from the minisodar has already been significantly improved with the current technology and such data could be useful for reference by the weather forecasters.

It is noted from the gust speed plots that the minisodar seems to have a "cut-off" of the gusts in the order of 1.5 – 2 m/s, i.e. the gust speeds did not occur below this cut-off value. Similar cut-offs do not seem to be present in the 5-minute mean winds (Figure 2). The cut-offs may occur due to the signal processing and internal calculation algorithm of the minisodar. The issue would be discussed further with the manufacturer.

Comparisons of gust speeds and directions have also been made between the minisodar and the sonic anemometers. The results are largely similar to those given in Figure 3 (not shown).

5. SIGMA-W MEASUREMENTS

The sigma-w data from the minisodar and the sonic anemometer are compared in Figure 4. The two datasets are found to have good correlation. The sigma-w from the minisodar appears to be smaller in general by 14 – 24%, which may again due to exposure issue with the minisodar.

6. CONCLUSIONS

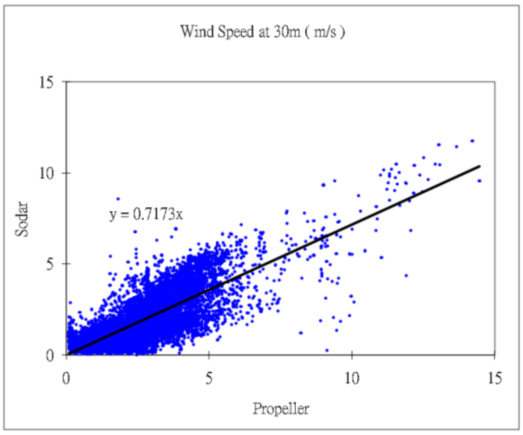
Based on the results of a field comparison study in 2009, the minisodar with the latest technology appears to provide gust data, in addition to mean wind and sigma-w data, of sufficiently good quality for weather applications, in comparison with similar instrument several years ago. The gust speeds and directions from the minisodar are compared well with those from the anemometer mast measurements at two heights. A couple of deficiencies are still identified with the quality of gust data from the minisodar, namely, isolated data points in which the gust speeds are unreasonably high, and a "cut-off" or lower bound of the gust speed values in the order of 1.5 – 2 m/s. The manufacturers of similar minisodars in the market are encouraged to keep up the effort of further improving the processing of the raw acoustic signals and the retrieved wind data in order to obtain "clean" gust values for all non-rainy weather conditions.

Unfortunately, due to the site constraint, the comparison results for horizontal mean winds and sigma-w are not so satisfactory with the present study. It is hoped that another field study could be carried out in the future with fewer site constraints in order to examine the performance of the minisodar with high confidence.

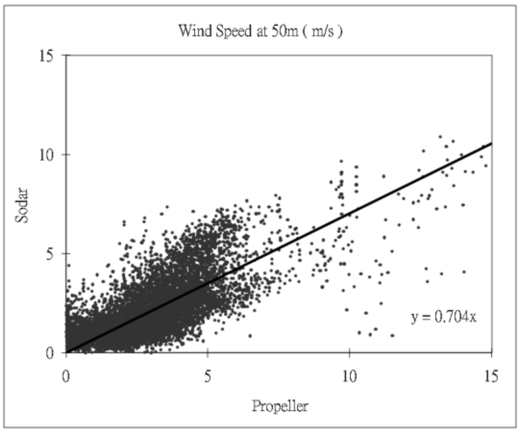
REFERENCES

[1] Chan, P.W., 2008: Measurement of turbulence intensity profile by a mini-sodar, *Meteorological Applications*, **15**, pp. 249-258.

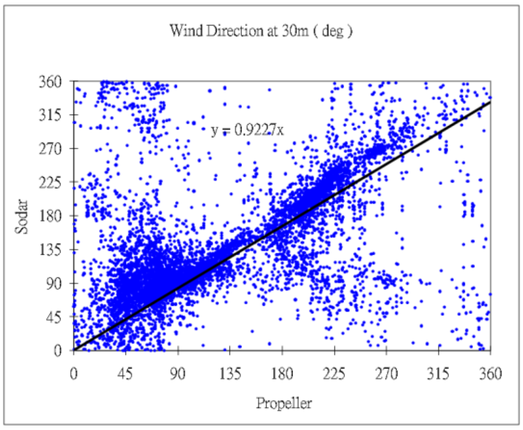
Figure 1 Setup of the minisodar and the 50-m tower.



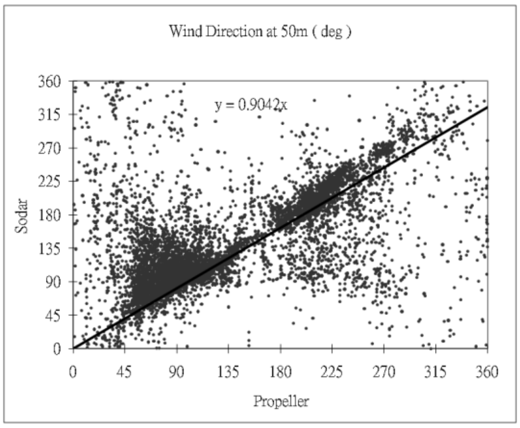
(a) mean wind speed at a height of 30 m
(R^2 = 0.8590)



(b) mean wind speed at a height of 50 m
(R^2 = 0.8326)

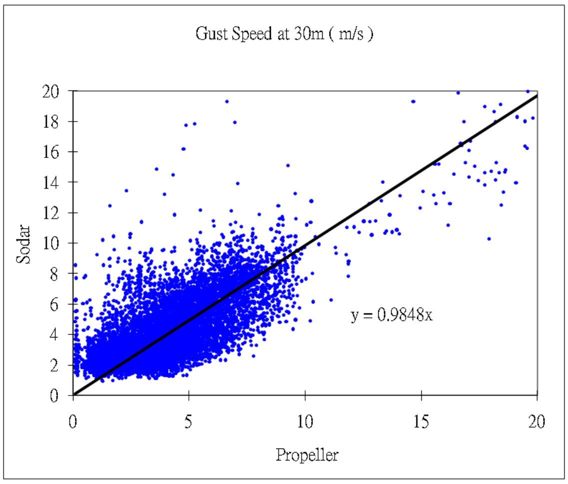


(c) mean wind direction at a height of 30 m



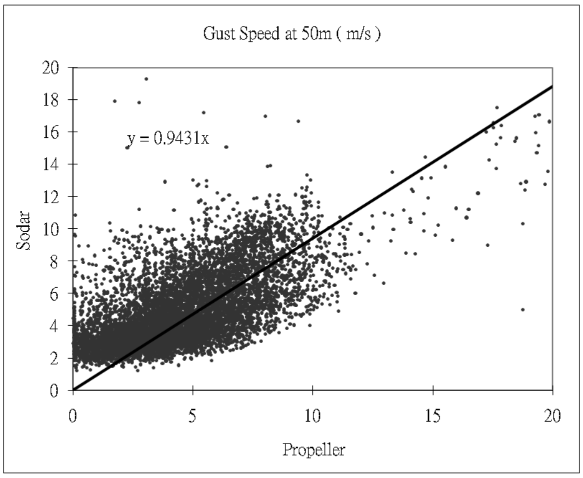
(d) mean wind direction at a height of 50 m

Figure 2 Comparison of the mean wind quantities between the minisodar and the 50-m tower.



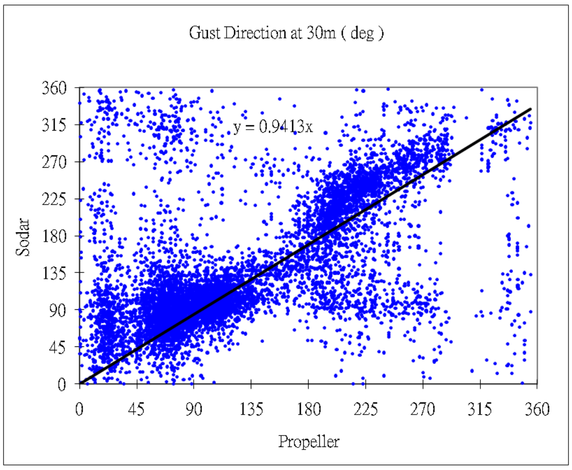
(a) gust speed at a height of 30 m

(R^2 = 0.8648)

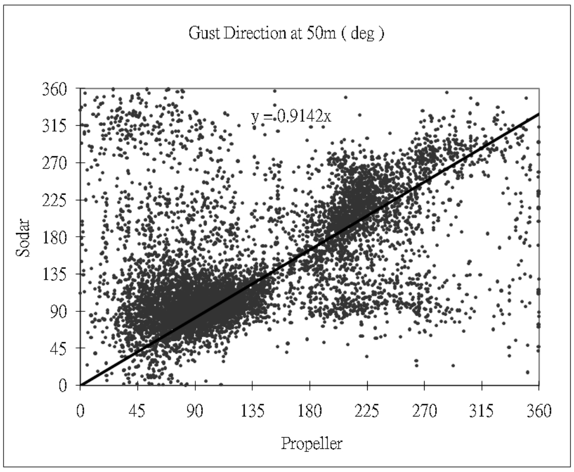


(b) gust speed at a height of 50 m

(R^2 = 0.8382)

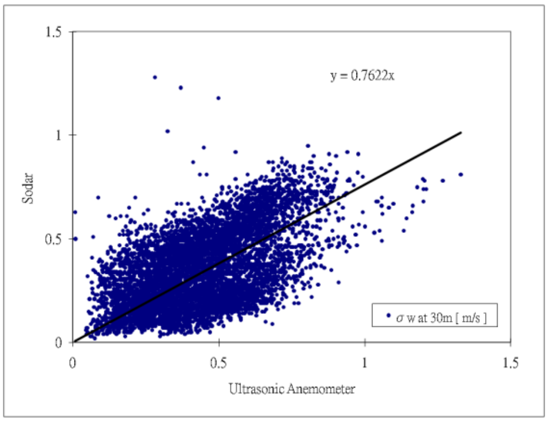


(c) gust direction at a height of 30 m



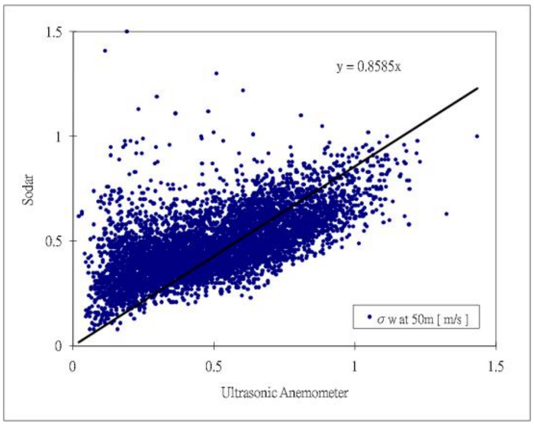
(d) gust direction at a height of 50 m

Figure 3 Comparison of the gust quantities between the minisodar and the 50-m tower.



(a) at a height of 30 m

(R^2 = 0.8682)



(b) at a height of 50 m

(R^2 = 0.8757)

Figure 4 Comparison of the standard deviation of the vertical velocity between the minisodar and the 50-m tower.