

EDDY DISSIPATION RATE (EDR) PROFILE DETERMINED FROM A MINISODAR IN TERRAIN-DISRUPTED AIRFLOW

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Abstract: Chan (2004) demonstrated that the wind measurements from the individual beams of a minisodar could be used to determine the EDR profile of the boundary layer. Some examples of the evolution of EDR profile in terrain-disrupted airflow at the Hong Kong International Airport are presented in this paper, namely, a strong southwest monsoon case and a gale-force easterly wind case associated with a typhoon. Applications and limitations of the EDR profiles provided by the minisodar in the monitoring of low-level turbulence at the airport would be discussed.

Keywords: *minisodar, EDR, turbulence*

1. INTRODUCTION

To ensure aviation safety, the Hong Kong Observatory (HKO) provides low-level turbulence alerting services for arriving and departing aircraft at the Hong Kong International Airport (HKIA). In accordance with the practice of International Civil Aviation Organization (ICAO), turbulence intensity is expressed in terms of the cube root of the eddy dissipation rate (EDR). For low-level turbulence, $EDR^{1/3}$ varying between 0.3 and 0.5 $m^{2/3}s^{-1}$ is taken to be moderate turbulence and $EDR^{1/3}$ of 0.5 $m^{2/3}s^{-1}$ or above refers to severe turbulence.

Measurement of EDR is an important component in the provision of turbulence alerting services. The Windshear and Turbulence Warning System (WTWS) of HKO currently determines EDR at the flight paths of HKIA mainly based on anemometer measurements. HKO also explores the possibility of using remote sensing data to calculate EDR, including minisodar (Chan 2004), radar wind profiler (Chan and Chan 2004) and Doppler LIDAR (Chan 2006). This paper will focus on the application of minisodar to EDR determination.

In the previous study (Chan 2004), the accuracy of the wind and turbulence intensity data from the minisodar was established by comparing with the measurements of a co-located meteorological tower. Later on, in the middle of 2005, the minisodar was moved to Siu Ho Wan, a site near HKIA (location in Figure 1) to continue measurement. With the proximity to the airport, the possibility of using EDR profiles provided by the minisodar in the monitoring of turbulence intensity along the flight paths could be studied. At first, the minisodar had the default configuration of measuring up to 200 m above ground, so that the sampling by the vertical beam (the data of which are used in the computation of EDR) was performed at roughly once per every 4 seconds only. Since 21 July 2006, the maximum measurable height of the minisodar has been reduced to 100 m, so that measurement by the vertical beam is carried out once every 2 seconds.

Turbulent airflow occurs at HKIA when strong winds from east through southwest climb over the mountainous Lantau Island to the south of the airport (Figure 1). The EDR profiles computed from minisodar data in two cases of terrain-disrupted airflow will be presented in this paper, namely, strong southwest monsoon in the summer and gale-force southeasterly wind associated with a tropical cyclone. The application of the EDR profiles in the alerting of low-level turbulence will be discussed.

2. A REVIEW OF EDR PROFILE COMPUTATION

The vertical profile of EDR is calculated using basically the same method as described in Chan (2004). A brief review of the computation method is given here. The radial velocity from the vertical beam measurement (sampled at 0.25 or 0.5 Hz, depending on the maximum measurable height configured for the minisodar) is the basic dataset for calculating EDR. For a particular measurement height of the minisodar, the time series of vertical velocity at 1 Hz is constructed using the actual measurements and their interpolated values to fill in the data voids. This time series is then put through Fourier analysis and the range of frequency which satisfies the -5/3 law of inertial subrange is then determined.

Least square linear fit is made to the inertial subrange of the frequency spectrum. Let a and b be the slope and y-intercept of this linear fit respectively. EDR is then given by

$$EDR = \frac{11.2}{V} 10^{3b/2} f^{(5+3a)/2} \quad (1)$$

where V is the mean horizontal velocity and f is frequency. If a exactly equals $-5/3$, EDR will be independent of f . When a is not exactly equal to $-5/3$, f is taken to be the central frequency of the part of the inertial subrange in the measured frequency spectrum. The above process is repeated for every measurement height of the minisodar to give the EDR profile.

3. EXAMPLES OF EDR PROFILES

Two cases of applying EDR profiles from the minisodar in the monitoring of low-level turbulence at HKIA are studied in this paper. The first case is a strong southwest monsoon episode that occurred between 14 and 18 July 2006. Earlier in this period, an area of low pressure over southern China that was the remnant of Severe Tropical Storm Bilis brought strong south to southwesterly winds to south China coast. Later on, the southwesterly winds were enhanced with the western extension of the subtropical ridge.

The time series of $EDR^{1/3}$ at selected measurement heights of the minisodar at Siu Ho Wan (namely, 30, 50, 70 and 90 m above ground) is shown in Figure 2a. Though there are some periods of missing data (in the mornings of 15-18 July 2006), the general trend of turbulence intensity in this episode is still apparent from this graph. The airflow became more turbulent shortly before midnight of 15 July, with $EDR^{1/3}$ doubled at various heights (from about 0.15 to 0.3 $m^{2/3}s^{-1}$). The winds remained rather turbulent in the next couple of days. Apart from a brief ‘‘dip’’ in the early afternoon of 15 July, $EDR^{1/3}$ remained generally above 0.2 $m^{2/3}s^{-1}$. In the afternoon of 17 July, the winds weakened and $EDR^{1/3}$ also decreased gradually, falling to around 0.15 $m^{2/3}s^{-1}$ viz. the level before this episode of turbulent airflow.

The turbulence reports from the aircraft are also plotted in Figure 2a. Those occurring at the runway corridors closer to the minisodar, i.e. 25RA and 25LA (locations in Figure 1) are indicated by purple squares in the lower part of the graph, whilst the reports at the other side of airport (25LD, Figure 1) are marked by brown diamonds higher up in the graph. It can be seen from Figure 2a that the reports mostly occurred when the $EDR^{1/3}$ values at various heights of the minisodar reach 0.2 $m^{2/3}s^{-1}$ or above. In Chan and Chan (2004), the $EDR^{1/3}$ (y) given by the wind profiler at Siu Ho Wan is found to be related to the anemometer-based value along the eastern runway corridors (x) by the following equation:

$$y = 0.1069 + 0.2693*x. \quad (2)$$

With the minisodar’s $EDR^{1/3}$ of 0.2 $m^{2/3}s^{-1}$, the corresponding value at the eastern runway corridors would be about 0.35 $m^{2/3}s^{-1}$, i.e. reaching the level of moderate turbulence. This is consistent with the pilot reports of moderate or severe turbulence at those runways.

The temporal evolution of EDR profile is also shown in Figure 2b. On 14 July 2006 when the winds at Hong Kong had not yet picked up, the EDR profile evolved in the typical way of a day with convective boundary layer similar to the previous study (Chan 2004), namely, a significant rise of $EDR^{1/3}$ near the ground in the daytime due to solar heating, whilst the profile above 30 m or so did not exhibit such a great change. On the following day, the sky became cloudier with rain and the evolution of EDR profile became mostly related to mechanical turbulence generated in the south to southwesterly wind. A significant increase of $EDR^{1/3}$ was observed above 20 – 40 m. For both thermal and mechanical turbulence, it seems that a change of $EDR^{1/3}$ value occurs at about 30 m, which may be taken as the height of the surface layer.

The $EDR^{1/3}$ values determined from the minisodar are also compared with the LIDAR-derived data. The LIDAR’s 1-degree conical scan shows that strong southwesterly winds prevailed in the airport area (Figure 3a). The $EDR^{1/3}$ calculated from LIDAR data at the location of the minisodar is found to be in the region of 0.25 – 0.3 $m^{2/3}s^{-1}$, consistent with the minisodar value.

The second case is the gale-force southeasterly winds associated with Typhoon Prapiroon in early August 2006. From Figure 4a, it can be seen that most of the pilot reports of significant turbulence took place when the $EDR^{1/3}$ from the minisodar reached 0.2 $m^{2/3}s^{-1}$ or above, except for one report around the noon time of 4 August (at which only the $EDR^{1/3}$ at 30 m is below 0.2 $m^{2/3}s^{-1}$). The EDR profiles at different times (Figure 4b) have the typical shape of mechanical turbulence (c.f. Figure 2b).

The minisodar’s EDR value is also consistent with the LIDAR-derived data. For instance, in the morning of 3 August, the LIDAR depicted the prevailing of gale-force southeasterly winds in the airport area

(Figure 5a) and the $EDR^{1/3}$ in the vicinity of the minisodar appeared to be in the order of $0.35 - 0.4 \text{ m}^{2/3}\text{s}^{-1}$, which is about the same as the value computed from the minisodar.

4. CONCLUSIONS

The application of the EDR profile provided by a minisodar in the monitoring of low-level turbulence at the airport is discussed in this paper. As in the previous study (Chan 2004), the EDR value is computed from the analysis of the frequency spectrum of the vertical velocity measurements from the minisodar. The application potential is demonstrated in two different episodes of turbulence airflow at HKIA in the summer, namely, strong southwest monsoon and gale-force southeasterly wind associated with a typhoon. In both cases, it seems that pilot reports of moderate or severe turbulence mostly occur when mechanical turbulence has an $EDR^{1/3}$ value reaching $0.2 \text{ m}^{2/3}\text{s}^{-1}$ or above for all levels higher than the surface layer of about 30 m. The EDR profile from the minisodar is also found to show different shapes in thermal and mechanical turbulence. The minisodar's $EDR^{1/3}$ is generally consistent with the corresponding data from LIDAR.

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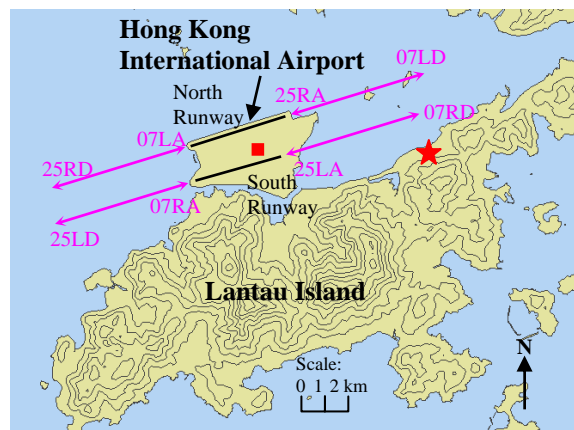


Figure 1: Map of HKIA and Lantau Island (height contours: 100 m), with the location of the minisodar at Siu Ho Wan (red star) and the LIDAR inside HKIA (red square). Runway corridors are shown as pink arrows with the names marked alongside.

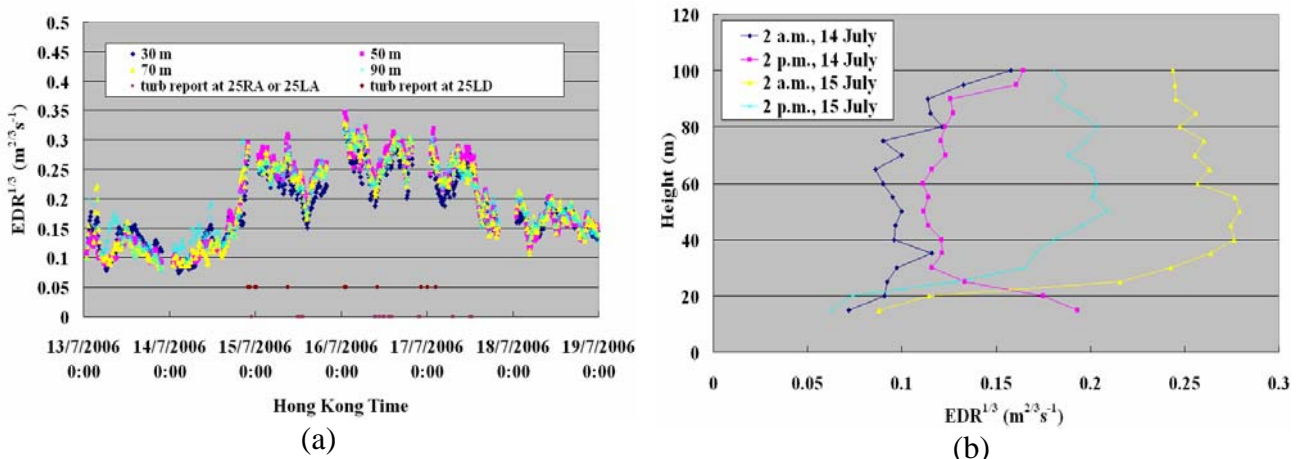
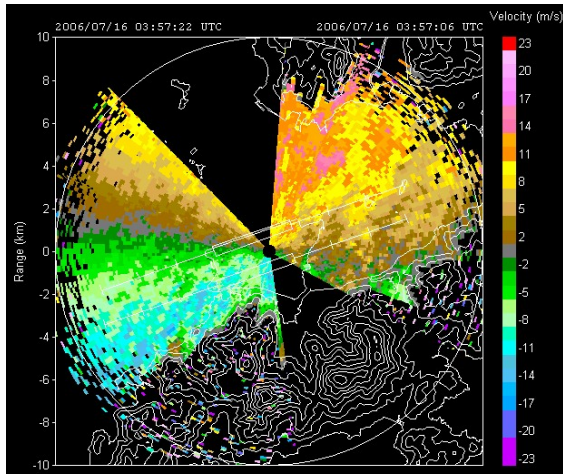
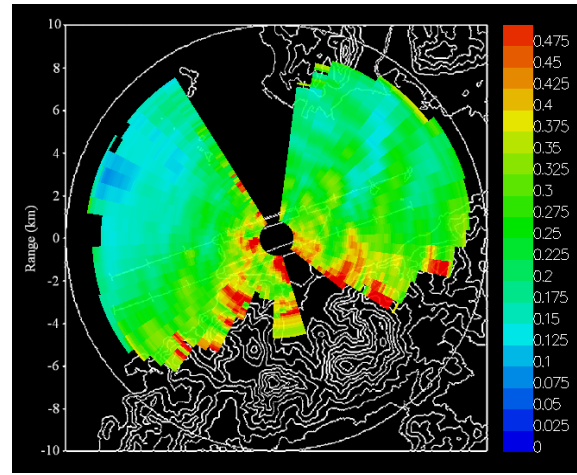


Figure 2: Time series of the $EDR^{1/3}$ value at selected measurement heights of the minisodar in the episode of strong southwest monsoon in July 2006 (a). The EDR profile at four times in this episode is shown in (b).

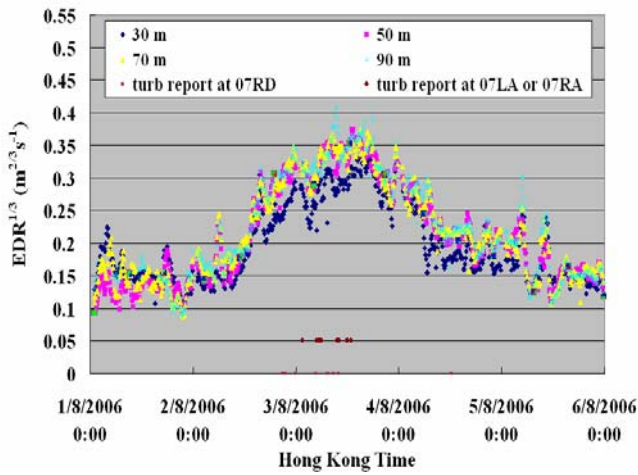


(a)

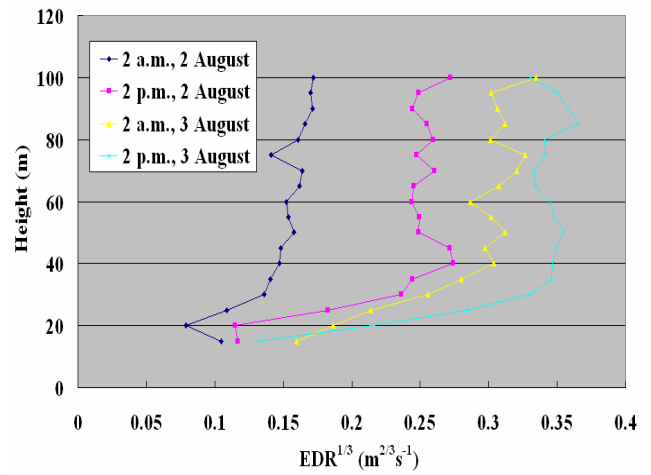


(b)

Figure 3: LIDAR's radial velocity image at 1-degree elevation angle as obtained at noon, 16 July 2006 (a). The EDR map derived from the velocity image is shown in (b). In 1-degree conical scan, the laser beam is about 140 m AMSL at the location of the minisodar, which is placed at about 20 m AMSL.

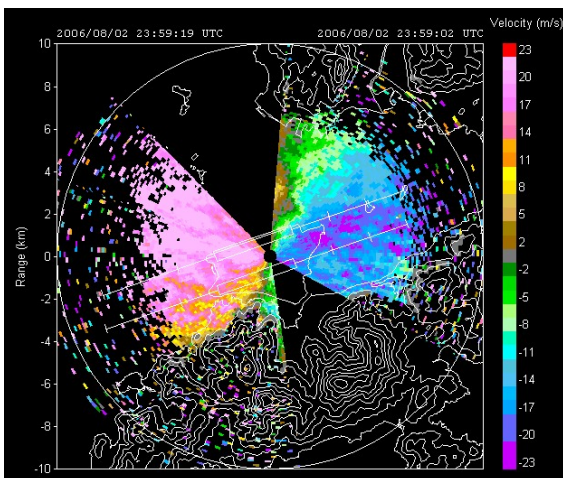


(a)

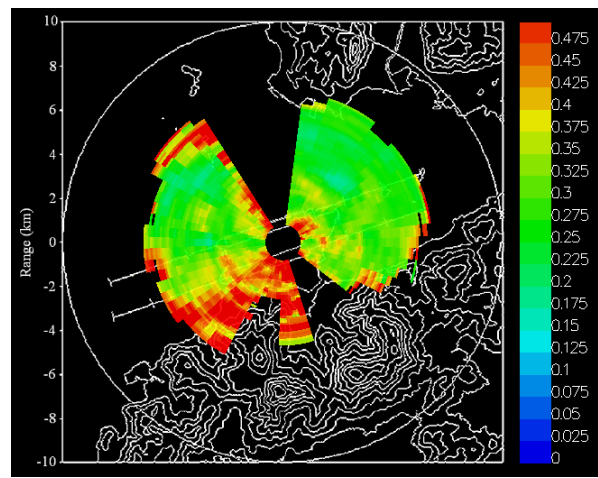


(b)

Figure 4: Same as Figure 2, but for Typhoon Prapiroon case in August 2006.



(a)



(b)

Figure 5: Same as Figure 3, but for Typhoon Prapiroon case at 8 a.m., 3 August 2006.