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Wind Data Collected by a Fixed-wing Aircraft in the Vicinity of a Typhoon over the South China Coastal Waters

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Wind data collected by a fixed-wing aircraft in the vicinity of a typhoon over the south China coastal waters

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Abstract:

The fixed-wing aircraft of Government Flying Service of the Hong Kong Government has recently equipped with an upgraded meteorological measuring system. Besides search and rescue (SAR) missions, this aircraft is also used for windshear and turbulence investigation flights at the Hong Kong International Airport. In a SAR operation in July 2009, the aircraft flew close to the eye of Typhoon Molave, when it was located at about 200 km to the east of Hong Kong over the south China coastal waters. The aircraft provided valuable information about the winds in association with Molave.

1. INTRODUCTION

In every summer, a number of tropical cyclones affect the southern coast of China. Monitoring of the movement and development of the tropical cyclones is mostly made through remote sensing methods, such as weather radars installed along the south China coast, and meteorological satellites. Surface observations from islands and ships are available, but not large in quantity. On occasions, there are also weather observations by the aircraft near the centres of the tropical cyclones. Meteorological observations for the tropical cyclones, especially near their centres, would be useful in the weather warning service (e.g. in determining the intensity of the storm), understanding of the structure of the cyclones, and forecasting the evolution of the storms (such as through the data assimilation into numerical weather prediction models).

In mid-2009, a meteorological measuring system was first installed on an aircraft in Hong Kong. The system is the Aircraft Integrated Meteorological Measuring System 20 Hz – AIMMS20. The aircraft is one of the Jetstream 4100 (J41) fixed-wing aircraft of Government Flying Service (GFS) of the Hong Kong Government, which is primarily used for search and rescue (SAR) operation over the South China Sea. This meteorological system is mainly used for collection of windshear and turbulence data at the Hong Kong International Airport by the Hong Kong Observatory (HKO) for the enhancement of windshear and turbulence alerting services. During SAR operation, data collection would still be performed and provide valuable data through in situ meteorological measurements over the data-sparse South China Sea, especially during tropical cyclone situation.

In mid-July 2009, Typhoon Molave developed over the seas to the east of the Philippines and then tracked to the northwest towards the south China coast. In the afternoon of 18 July 2009 when Molave was located at a couple of hundred kilometres to the east of Hong Kong, GFS conducted a SAR operation near the typhoon. The J41 aircraft equipped with AIMMS-20 flied within 100 km from the centre of Molave. At that time, the horizontal wind and pressure measurements from AIMMS20 were checked to be normal. This SAR operation provided valuable observations about the typhoon that could not be achieved with the conventional meteorological measurements (including both in situ and remote sensing measurements) available in the region. In particular, the 20-Hz wind data could be used to calculate the wind spectrum and turbulence intensity such as eddy dissipation rate (EDR) at various locations from the typhoon centre. This paper documents the meteorological data collected by the aircraft in the event.

2. AIRCRAFT INSTRUMENTATION

An overview of AIMMS-20 could be found in Beswick et al. (2008). A summary of the major features of the system, especially the installation on J41 in Hong Kong, is given here.

The meteorological measuring system consists of the following components:

(a) an air data probe mounted externally under the wing of J41 for measuring true airspeed, flow angle, temperature and relative humidity;
(b) a Global Positioning System (GPS) module to determine the position, velocity and true heading of the aircraft using differential carrier-phase technique based on the data collected by two GPS antennae mounted externally on top of the two wings;
(c) an inertial measurement unit to record the rates of rotations and accelerations of the aircraft about all three body axes near the centre of gravity of the aircraft; and
(d) a central processing module within the cabin to collect the data from the above three components, correct for dynamic effects, compute aerodynamic flow corrections, store the meteorological measurements and aircraft data as well as output these data to an external USB drive.

The system outputs the following meteorological elements at 20 Hz at the specified range and accuracy (only those items presented in this paper are given):

Data	Range	Accuracy
Each component of the wind (horizontal wind)	0 to +/- 90 m/s	0.5 m/s for straight level flight; 1 m/s otherwise with bank angle less than 15 degrees
Pressure	500 hPa to 1040 hPa	1 hPa (at a resolution of 0.1 hPa)

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Vibration of the aircraft in flight should not prevent the system from performing to the above requirements. Moreover, the system shall be capable of enduring the environmental conditions expected during flights over land and sea in all weather conditions without deterioration in performance. In particular, the externally mounted modules withstand sea spray and sand and are designed to withstand corrosion, weathering and solar radiation, and to prevent ingression of foreign matters such as bugs in order to protect the sensors and electronic components housed inside the modules.

3. FLIGHT PATH AND WIND SPEED OBSERVATIONS

The flight itself lasted for about 4 hours and the locations of the aircraft at different hours are shown in Figure 1. For each subfigure of Figure 1, the locations of the aircraft and the wind speeds measured by AIMMS-20 on board the aircraft within an hour are shown together with the weather radar picture of Hong Kong at the middle of that hour. For instance, in Figure 1(a), the aircraft data between 07 and 08 UTC of 18 July 2009 are overlaid on the 256-km range radar reflectivity plot of about 07:30 UTC on that day. For simplicity of presentation, only the radar reflectivity at a height of 3 km is shown. Please note that Hong Kong time = UTC + 8 hours. If the aircraft is further away from Hong Kong, e.g. in Figures 1(b) to (d), the 512-km range Plan Position Indicator (PPI) image is used, and this is obtained from horizontal scan of the radar.

It could be seen from Figure 1 that the aircraft departed from Hong Kong at about 07 UTC and flied to a location about 100 km to the north of the centre of Typhoon Molave within the first hour of the flight. It then hovered around the latter location in the next several hours before returning to Hong Kong at about 11 UTC.

From the variation of the measured wind speed along the flight data in the first and the last hours of the flight, the wind speed was higher as the aircraft was located closer to the centre of the typhoon. When the aircraft stayed at about the SAR operation location, the measured wind speed was generally above 20 m/s, and exceeded 40 m/s occasionally.

The time series of 10-minute mean wind speed, 10-minute mean wind direction, pressure and altitude of the aircraft during the flight is shown in Figures 2(a) and 2(b). Since the aircraft was mostly staying in the northwest sector of the typhoon, the measured wind direction was basically northerly to northeasterly. The 10-minute mean wind speed was the largest at the time 10:11 UTC, 18 July 2009, reaching a value of about 92 knots (47.4 m/s). At that time, the aircraft was estimated to be about 91 km north of the typhoon centre. The 1-second mean wind (i.e. the 1-second gust) was the highest at the time 10:10 UTC on that day, reaching a value of about 127.5 knots (65.6 m/s). During the above two times, the aircraft flied at a height of about 220 m above sea level. Assuming a power law of the wind speed variation with height with a power exponent of 0.11 over open sea, the maximum 10-minute mean wind speed and 1-second gust would become 65.5 knots and 90.7 knots respectively at a height of 10 m above sea surface. As such, the aircraft data also confirms that Molave was a typhoon at the time of the measurement. Based on the best track information from HKO, Molave was estimated to have a maximum 10-minute mean wind speed of 70 and 75 knots at 06 and 12 UTC, 18 July 2009 respectively.

4. OBSERVATIONS OF TURBULENCE

The 20-Hz horizontal wind data over each 10-minute period as obtained from the J41 aircraft are analyzed to give the turbulence intensity. Power spectrum $S_u(f)$ is determined by Fast Fourier Transform (FFT), and the mean wind $\overline{U}$ is calculated. The transverse wind component is used in FFT, and it is determined by considering the wind direction in the 10-minute period. Following the method described in Vecenaj et al. (2010), EDR (ε) is calculated using the formula below:

$$\varepsilon = \frac{2\pi}{\overline{U}}\left[\frac{f^{5/3}S_u(f)}{\alpha}\right]^{3/2}$$

where f is the frequency and α is the Kolmogorov constant.

The time series of turbulent kinetic energy (TKE), ε and $\varepsilon^{1/3}$ are given in Figure 2(c). There appear to be two periods of higher values of turbulence intensity, one between 09:30 and 10 UTC, and another between 10 and 10:30 UTC. From Figures 1(c) and (d), the aircraft was located near the centre of Typhoon Molave in these two periods, at a distance within 100 km or so. Severe turbulence was measured at these two periods of time, with $\varepsilon^{1/3}$ reaching 1.2 $m^{2/3}s^{-1}$ occasionally.

A plot of ε versus TKE during the whole flight of the aircraft is made in Figure 3. It could be seen that the data fit quite well the theoretically-expected slope of 1.5 (Vecenaj et al., 2010), the light blue line in Figure 3.

Examples of power spectrum of the wind measured by the aircraft are shown in Figure 4, including the times when the aircraft was flying to the typhoon, hovering near the centre of the typhoon and on the way back to Hong Kong. The spectra could be fitted well using -5/3 Kolmogorov law. As such, the EDR values calculated from the aircraft data are considered to be reasonable.

5. CONCLUSIONS

Aircraft data obtained for Typhoon Molave are documented in this paper. When extended to the surface (10 m above sea level), the 10-minute mean wind and gust were found to reach 65.5 and 90.7 knots respectively, supporting that Molave reached typhoon strength when it was located at the northern part of the South China Sea. Turbulence intensity is calculated from the 20-Hz wind data. $\varepsilon^{1/3}$ reached a maximum value of about 1.8 $m^{2/3}s^{-1}$, and thus severe turbulence was expected near the centre of the typhoon. The wind spectra were found to generally follow Kolmogorov -5/3 law, and the EDR values obtained from the flight data are considered to be reasonable.

The AIMMS-20 system on J41 in Hong Kong would be used to collect wind data in more typhoon cases, when permitted. It would also be used to measure the low level windshear and turbulence at the Hong Kong International Airport, for the development and verification of windshear and turbulence alerts.

References

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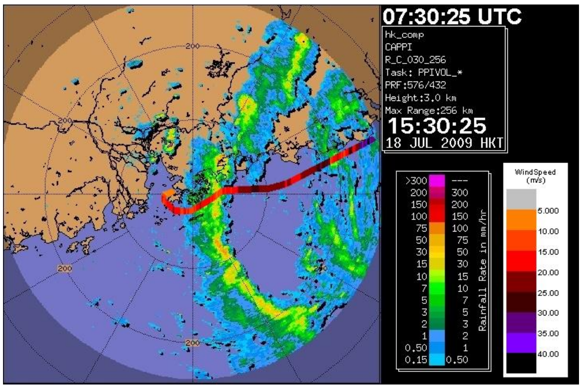
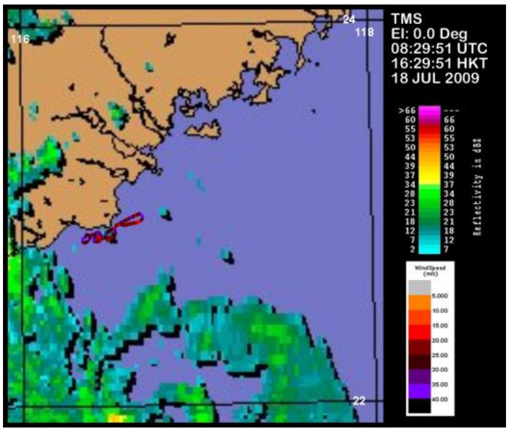
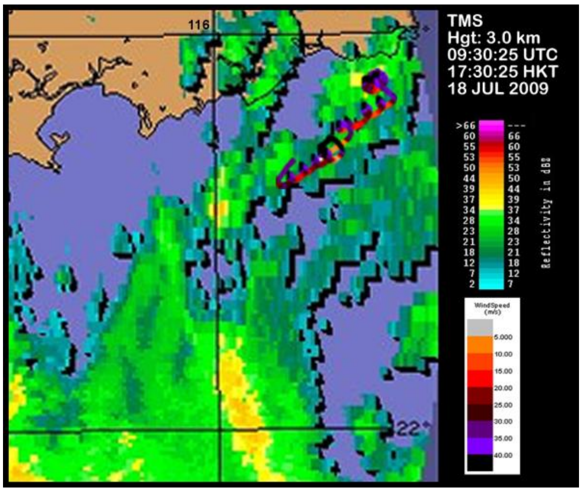


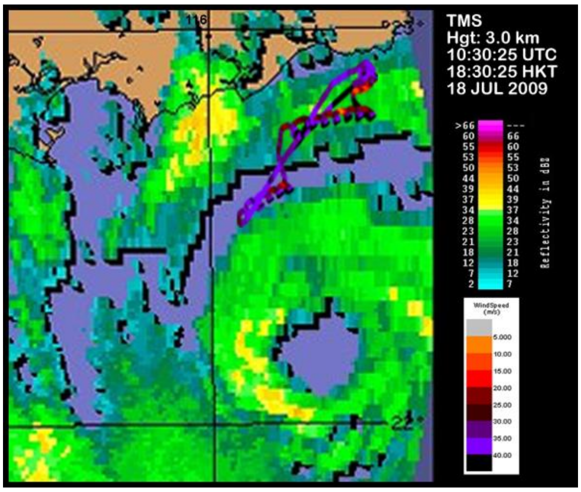
(a) location of the aircraft between 07 and 08 UTC, and radar picture of 07:30 UTC



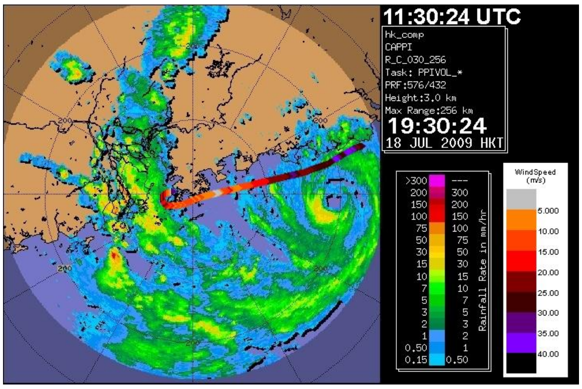
(b) location of the aircraft between 08 and 09 UTC, and radar picture of 08:30 UTC



(c) location of the aircraft between 09 and 10 UTC, and radar picture of 09:30 UTC

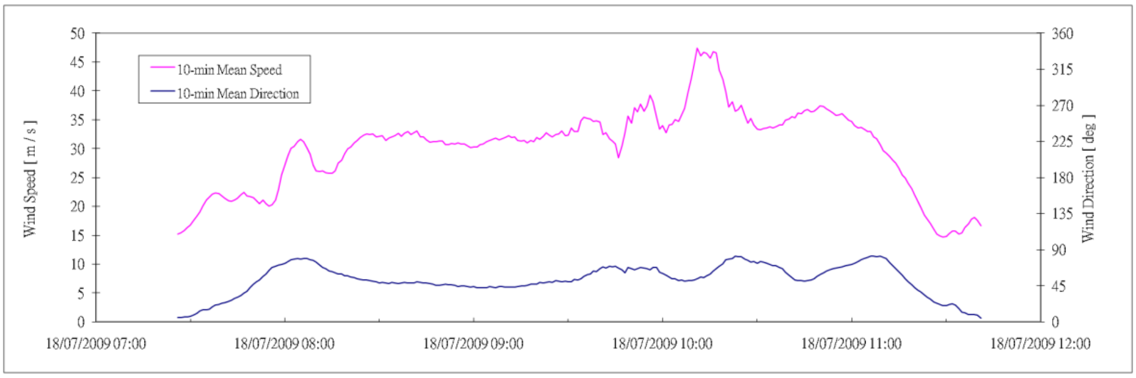


(d) location of the aircraft between 10 and 11 UTC, and radar picture of 10:30 UTC

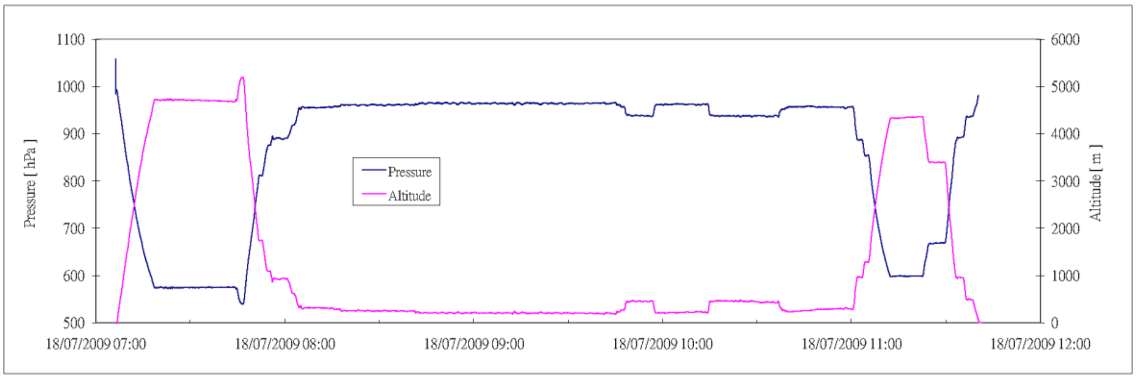


(e) location of the aircraft between 11 and 12 UTC, and radar picture of 11:30 UTC

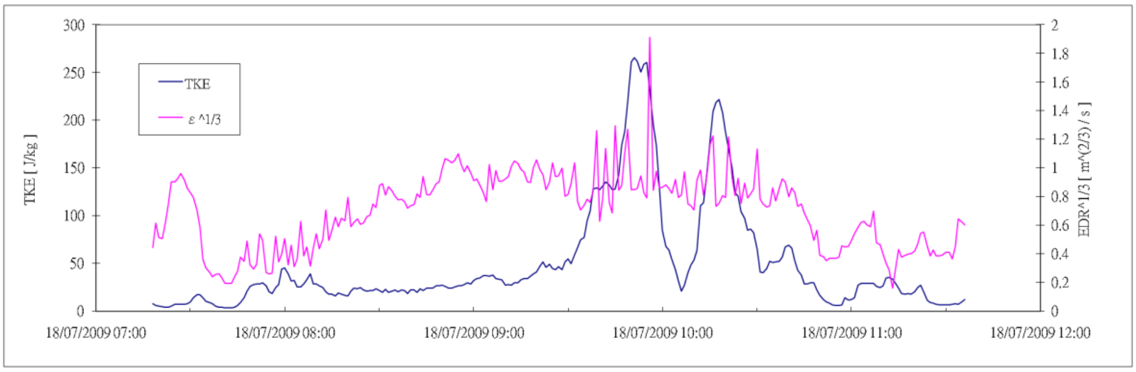
Figure 1 Locations of the aircraft and the wind speeds measured (in m/s) in each hour. They are overlaid on the radar picture in the middle of the hour.



(a)



(b)



(c)

Figure 2 Time series of the parameters measured by the aircraft. Horizontal axes are times in UTC.

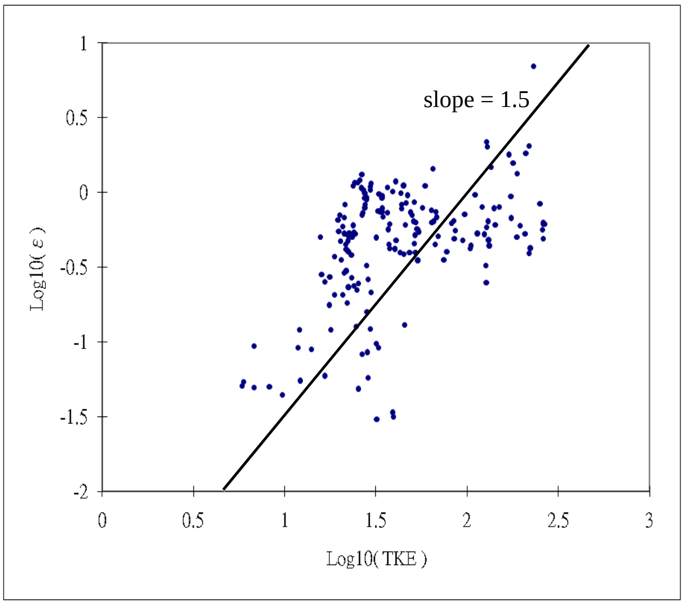
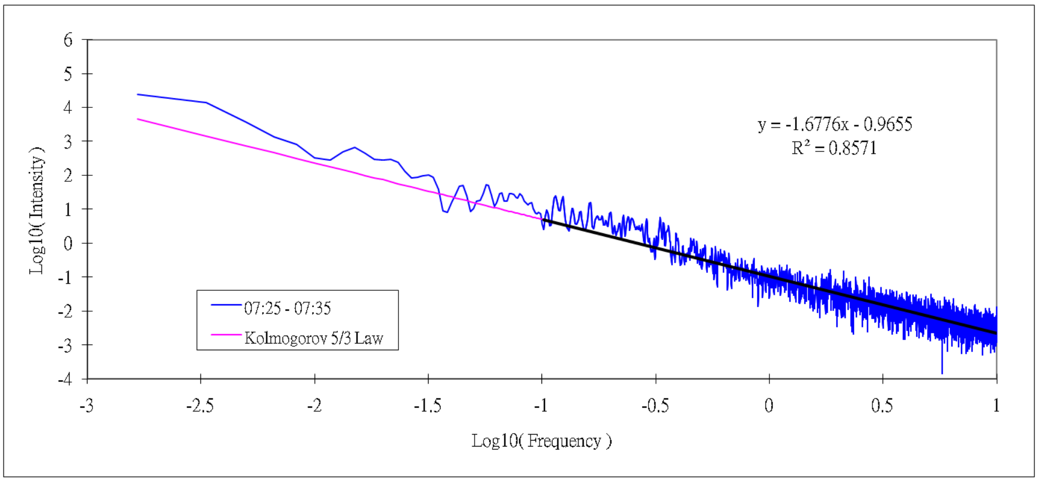
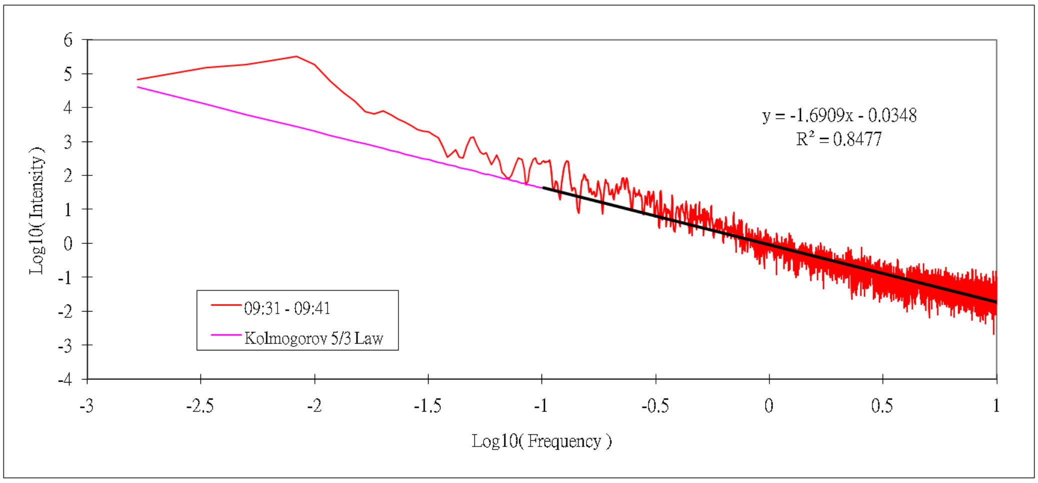


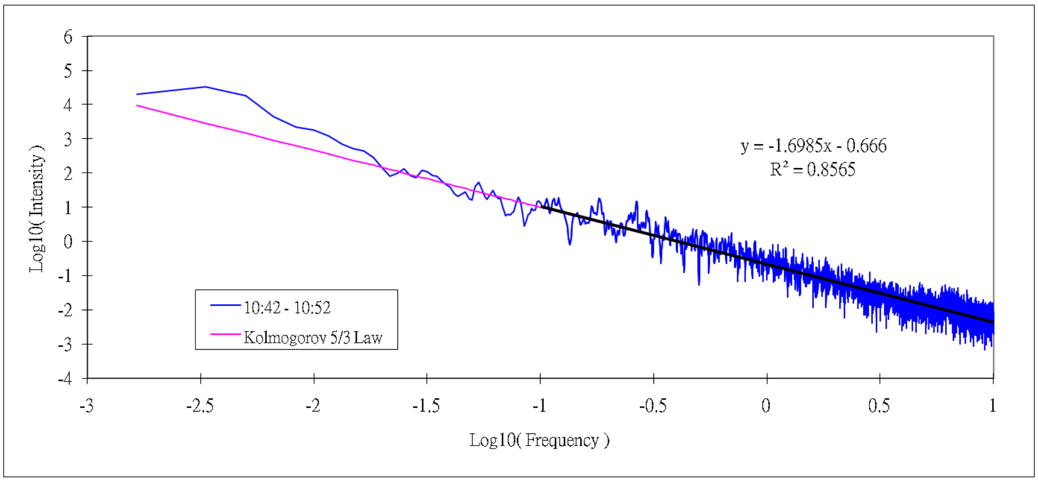
Figure 3 Scatter plot of EDR versus TKE.



(a) between 07:25 and 07:35 UTC



(b) between 09:31 and 09:41 UTC



(c) between 10:42 and 10:52 UTC

Figure 4 Examples of power spectrum of the wind measured by the aircraft.