Wind Observations of Tropical Cyclones Crossing Hong Kong

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ABSTRACT: Hong Kong is situated on the southern coast of China facing the South China Sea. Each year, some of tropical cyclones developed over the western north Pacific move into the South China Sea. On the average each year, there are about 10 to 15 tropical cyclones appear over the South China Sea and about 5 to 6 of them move close or across Hong Kong. Thus, Hong Kong is a suitable place for the study of tropical cyclone winds. Many wind observation stations are set-up all over Hong Kong. Besides anemometers, some stations are equipped with the more advanced SODAR and the wind profiler. This paper reports the wind measurements taken during the passage of three tropical cyclones over Hong Kong. Wind speed profiles at the lower altitudes as well as higher altitudes are presented. These profiles were taken as the tropical cyclones approached, moved across and away from Hong Kong. That means winds were measured with the tropical cyclones at different locations and directions relative to the measurement station. For one occasion the measured wind speed was more than the 50-yr return value.

KEYWORDS: Typhoon, tropical cyclone, wind profile, SODAR, wind profiler, wind speed.

1 INTRODUCTION

Hong Kong is situated on the south east coast of the Asian continent facing the South China Sea. Tropical cyclones frequently develop over the western north Pacific and some of them intensify to become typhoons and move into the South China Sea. On the average each year, there are about 10 to 15 tropical cyclones appear over the South China Sea and about 5 to 6 of them move close or across Hong Kong. Tropical cyclones in Hong Kong occur normally in the summer months from May to September; however some storms can occur as late as November or even December. With such frequencies of typhoon, Hong Kong is a convenient location for the study of tropical cyclone wind. Previous studies of typhoon wind profile in Hong Kong were carried out by Choi [1].

2 TYPHOON CLASSIFICATIONS AND MEASURING STATIONS

2.1 *Tropical Cyclone Classification and Warning Signals in Hong Kong*

In Hong Kong, tropical cyclones are classified into six categories as given in Table 1

Table 1. Tropical Cyclone Classifications

Classification	Max. 10-min mean speed
Tropical Depression	up to 62 km/h
Tropical storm	63 to 87 km/h
Severe Tropical Storm	88 to 117 km/h
Typhoon	118 to 149 km/h
Severe Typhoon	150 to 184 km/h
Super Typhoon	185 km/h and above

These classifications are in line with the recommendations of the World Meteorological Organization. The wind speed is the maximum sustained 10-minute mean wind speed near the centre of the cyclone.

As a tropical cyclone moves near Hong Kong, tropical cyclone warning signals are hoisted. The wind strength referred to in the warning signals is tabulated below.

Table 2. Tropical Cyclone Warning Signal in Hong Kong

Signal	Indication
No. 1	Tropical cyclone centres within 800km of Hong Kong
No. 3	Sustained speed of 41-62km/h and gust may exceed 110km/h
No. 8*	Sustained speed of 63-117km/h and gust may exceed 180km/h
No. 9	Gale force wind, typhoon is imminent
No. 10	Hurricane force wind with sustained speed of over 118km/h and gust may exceed 220km/h

* There are the No. 8NW, 8SW, 8NE and 8SE for winds from the respective sectors

Data presented in the present study are all from periods where the warning signals No. 8 or above were hoisted.

2.2 *Measuring stations and instrumentation*

In Hong Kong, the Hong Kong Observatory has over forty stations monitoring wind speed and wind direction. These stations spread out all over Hong Kong; some of these stations are automatic while the others are manned. The most common wind measuring instrument used is the Munro Mk 4 cup-generator anemometer. There are several stations equipped with the SODAR and the wind profiler which are used to measure wind speed over various height ranges. These are very useful for the study of the variation of wind speed with height. Studies of wind profile using Doppler SODARs were carried out, for example by Tamura et. al.[2, 3].

. For the present study, the station selected is the Siu Ho Wan (SHW) station. This station is selected as it is equipped with both the SODAR and the wind profiler. The geographic location of SHW is shown in Figure 1. SHW is situated on the northern coast of Lantau Island. It is fairly exposed towards its NNE-N-NW directions with 8 to 10km of open water in these sectors. Towards the northwest is the large stretch of open water where the Pearl River exits to the South China Sea. Towards the west it is similar except the piece of flat land of the Hong Kong International Airport sticking out to the sea at about 6 to 10 km from the station. For other directions, E-SE-S-SW, there is the Lantau Island with some tall mountains, e.g. the Lantau Peak (918m) to the southwest and Tai Tung Shan (869m) to the south. Thus it is expected that wind with reasonable fetch over open water from the NNE-N-NW-W sectors can be captured at this station.

Both the SODAR and the wind profiler are mounted at the same location about 250m from the shore at a ground elevation of 22m above mean sea level. The SODAR uses acoustic waves of 4500 kHz to probe the atmosphere. From the backscattered signal, the three-dimensional wind components of the lower atmosphere are obtained. The detection height of the SODAR is 100 m and the height resolution is 5 m. Wind data are available every 5 minutes. The wind profiler is of the boundary layer type. It sends out radar beams of 1299MHz frequency and uses the Doppler effect to measure the wind velocity. It can operate at the low-mode measuring at the height range of 116m to 1500m at 60m intervals, and at the high-mode at the height range of 260m to 6000m at 200m intervals. Data are available every 10 minutes.

Figure 1. Geographic location of SHW station.

3 OBSERVATIONS OF TROPICAL CYLONE WIND

3.1 *Typhoon Nuri*

Typhoon Nuri in 2008 was one that necessitated the issuance of Tropical Cyclone Signal No. 9 since 2003 in Hong Kong. Nuri formed as a tropical depression over the western North Pacific about 2500 km east-southeast of Hong Kong on the 17 August and moved westwards. It intensified into a severe tropical storm and further into a typhoon on 19 August and moved west-northwest. Nuri reached the eastern part of Hong Kong at around 4.50 p.m. on 22 August. It weakened but re-organized itself. A new centre formed over another location at the eastern part of Hong Kong and turned to move westwards. It passed over the Victoria Harbour from the east to the west then reaching Lantau Island and across Deep Bay to the China coast to the north west of Hong Kong. Figure 2 shows the track of Typhoon Nuri.

As can be seen from Figure 2, the eyes of Typhoon Nuri passed over Hong Kong and over SHW station. To have an overview of the wind pattern, the variation of wind speed with height for the twelve hours, starting 11.00 (all time referred to local time) 22/08/2008 and ending 23.00 are shown in Figures 3 and 4. This covers the period when the eye passed over Hong Kong. The hourly averages of the 10-minute wind data of the wind profiler are shown in Figures 3-1 to 3-12 (heights of 116m to 1600m). The hourly average of the 5-minute wind data of the SODAR for the corresponding twelve hours are shown in Figures 4-1 to 4-12 (heights of 20m to 100m). In the Figures, a fitted Power Law profile is also plotted and the Power Exponent is written on the figure. On the top left-hand corner, an arrow showing the wind direction is also presented. It can be seen that initially the wind was from the north. At around 18.00 to 20.00 the wind changed to SSW direction as the eye passed over the measuring station. Strong winds at the eye wall were recorded at around 13.00-16.00 ahead of the closest approach of the eye and 20.00 to 23.00 after the eye.

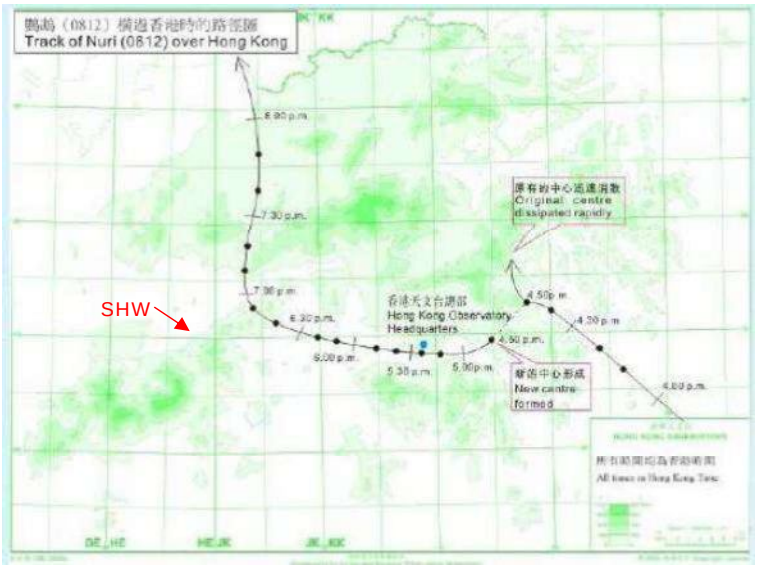

Figure 2. Track of Typhoon Nuri over Hong Kong. (source HKO;)

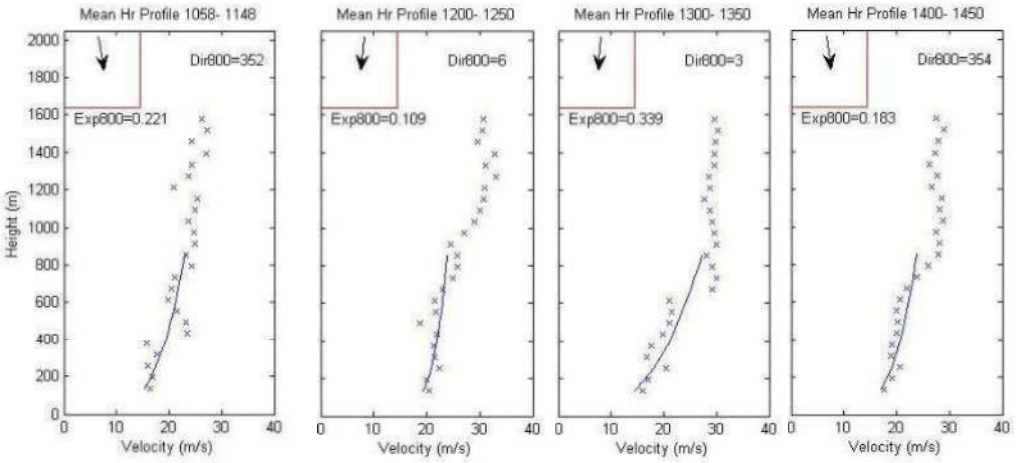

Figure 3-1 to 3-4. Hourly mean wind profile from Wind Profiler data (11.00-14.00)

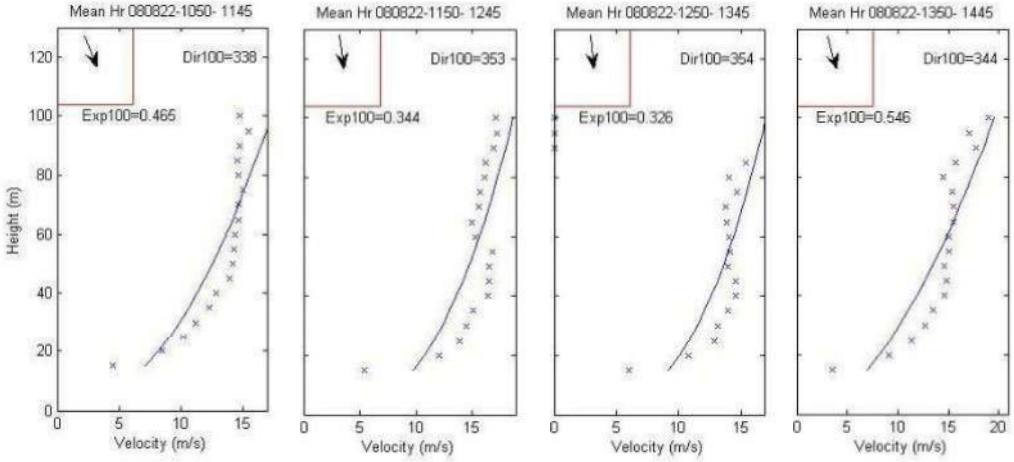

Figure 4-1 to 4-4. Hourly mean wind profile from SODAR data (11.00-14.00)

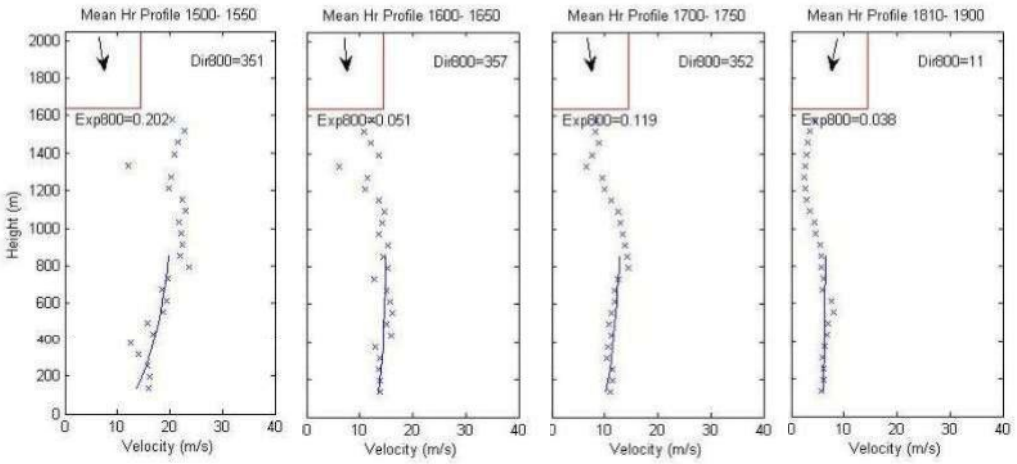

Figure 3-5 to 3-8. Hourly mean wind profile from Wind Profiler data (15.00-18.00)

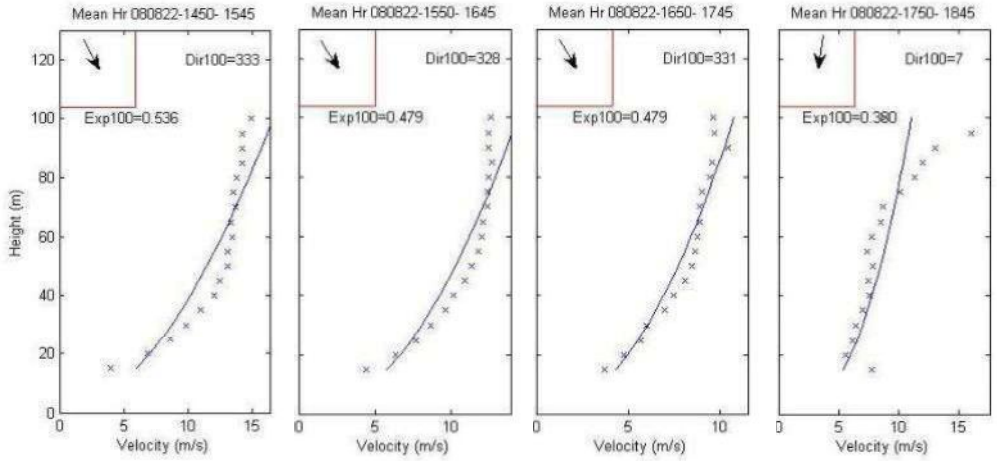

Figure 4-5 to 4-8. Hourly mean wind profile from SODAR data (15.00-18.00)

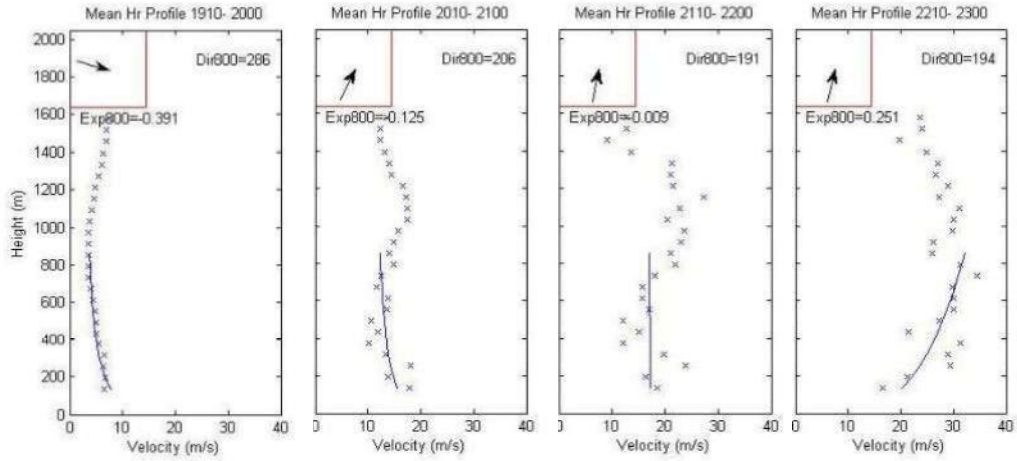

Figure 3-9 to 3-12. Hourly mean wind profile from Wind Profiler data (19.00-22.00)

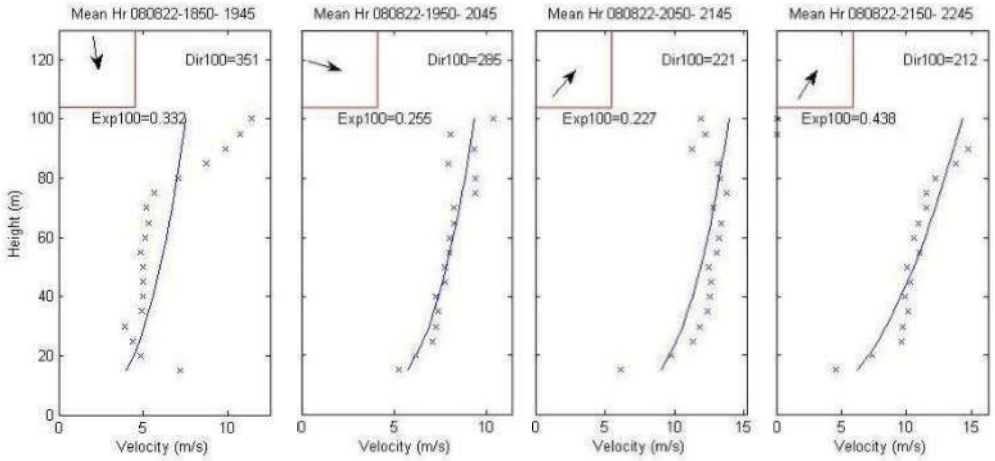

Figure 4-9 to 4-12. Hourly mean wind profile from SODAR data (19.00-22.00)

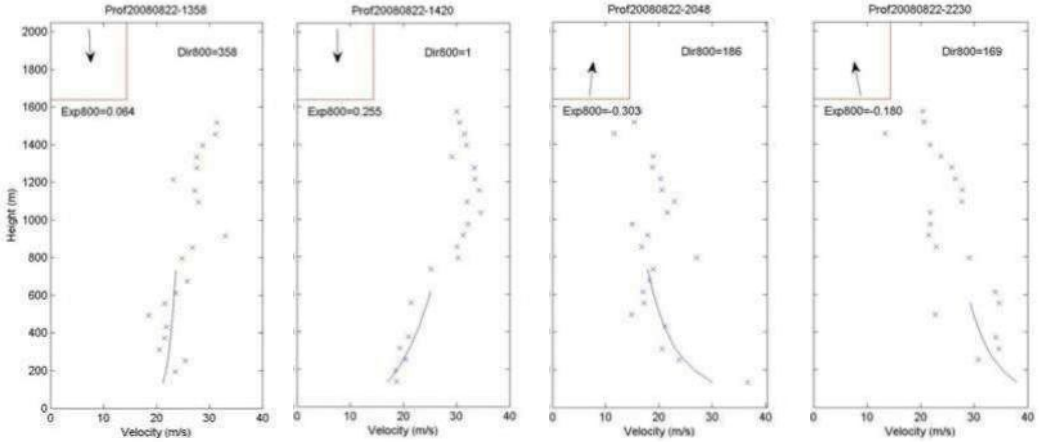

Figure 5-1 to 5-4. 10-minute profile from Wind Profiler data @ 13.58, 14.20, 20.48 and 22.30

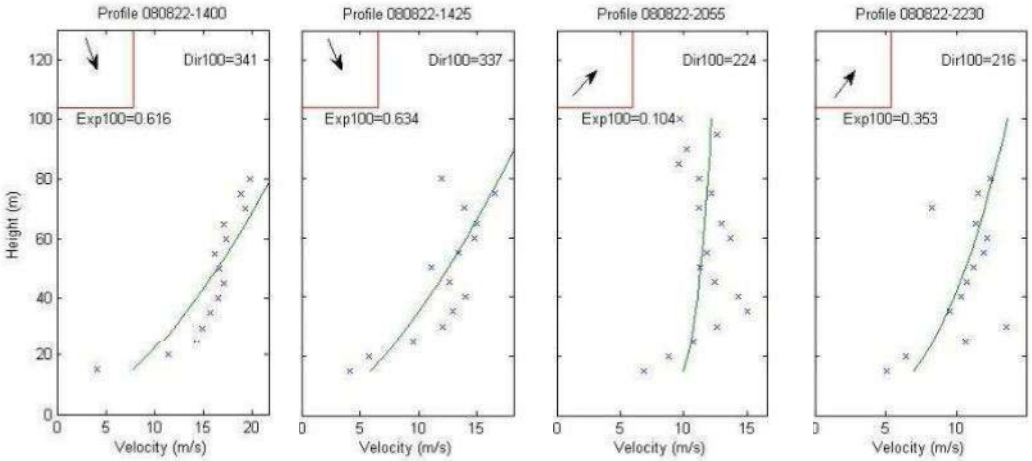

Figure 6-1 to 6-4. 5-minute profile from SODAR data @ 14.00, 14.25, 20.55 and 22.30

During the hours of strong wind say at 14:00, it can be seen that over the lower height range, there was a rapid increase of wind speed with height from ground to about 40m. At 40m to 100m the wind speed remain relative constant. Over the upper height range, there was gradual increase of wind speed with height from 20m/s at 200m to 30m/s at 1000m. After the approach of the eye, during the hour of strong wing at 22:00, the shape of the wind profile at the lower height range was similar to that of the 14:00. However the upper height range profile was different, with the wind speed steady at about 30m/s and perhaps slight decrease of wind speed with height. There was also a greater fluctuation in wind speed.

Besides the hourly mean profiles, short duration profiles are also studied. The wind profile at periods of stronger wind of the Wind Profiler (10-minute) and the SODAR (5-minute) at 14:00 and 14:25 are shown in Figures 5.1, 5.2 and 6.1 and 6.2 before the eye. Figures 5.3 and 5.4 and 6.3 and 6.4 are profiles for period 20:50 and 22:30 after the eye. The profiles are similar to the hourly mean profile, perhaps with a greater fluctuation in value.

3.2 *Typhoon Hagupit*

Hagupit formed as a tropical depression over the western North Pacific about 2 540 km east-southeast of Hong Kong on 19 September 2008 and moved west-southwestwards. It moved northwestwards and intensified into a typhoon on 21 September. Hagupit moved at a speed close to 30 km/h across the northern part of the South China Sea on 23 September and passed about 180 km south-southwest of Hong Kong from about 10 to 11 p.m. on 23 September. The track of Hagupit is shown in Figure 7. Tropical Cyclone Signal No. 8 was issued from 18:00, 23 September to 6:30, 24 September in Hong Kong. Wind profiles during the stronger wind period of Hagupit are shown in Figures 8.1-8.4 for the upper height range wind profiler data and Figures 9.1-9.4 for the lower height range SODAR data.

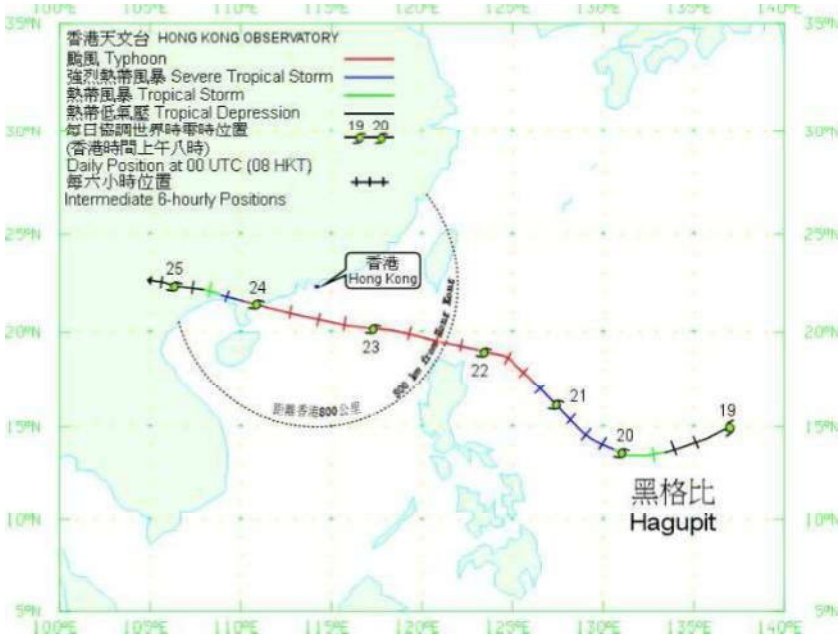

Figure 7. Track of Typhoon Hagupit over Hong Kong. (source HKO)

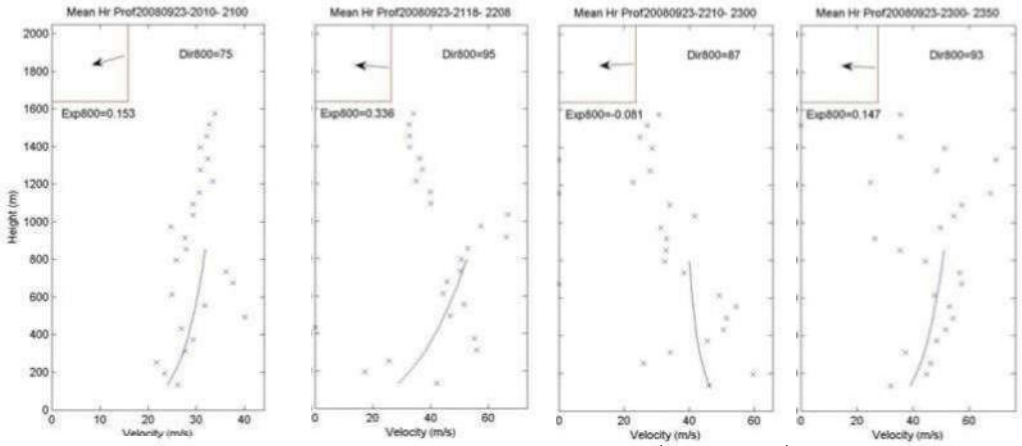

Figure 8-1 to 8-4. Hourly mean wind profile from Wind Profiler data (20.00-23.00)

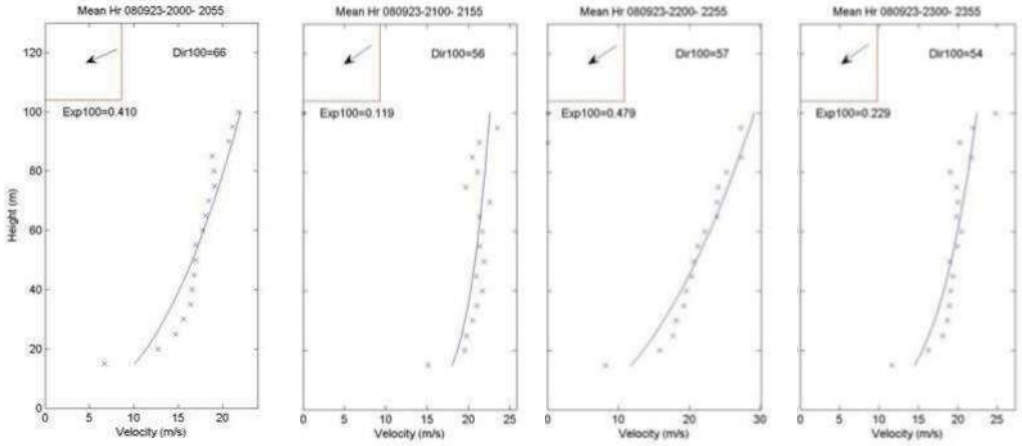

Figure 9-1 to 9-4. Hourly mean wind profile from SODAR data (20.00-23.00)

Although the eye of Typhoon Hagupit did not directly pass over Hong Kong, Hong Kong was still subjected to the strong wind belt around the eye-wall. Looking at Figure 8, mean wind speeds were observed to reach over 60m/s at the height of a few hundred meters (this is greater than the Design Hourly-mean wind speed stipulated in the Hong Kong Wind Code 2004 which is 59.5m/s for >500m). There was significant variation in wind speed. However with the exception of the hour 22.10-23.00, a general trend of increase in wind speed with height can still be observed. The hourly mean wind speed profiles of the lower height range as shown in figures 9 were less erratic. They all showed steady increase in wind speed with height. The rates of the increase were however varied significantly. With the power law fitting, exponents ranging from 0.479 to 0.119 were obtained. Matching the profiles of the upper and the lower height ranges, wind speed increased from about 20m/s at around 40m to more than 50m/s at around 400m to 600m elevation.

Short duration wind profile at periods of stronger wind of the wind profiler (10-minute) and the SODAR (5-minute) at 21:40, 22:20 and 23:20 are shown respectively in Figures 10.1-10.3 and 11.1-11.3. The three profiles are quite different. The 21:40 profile showed wind speeds constant at about 25m/s for heights from 20m to 60m. After which it increased suddenly to about 40m/s at 200m and gradually increased to more than 60m/s at heights of 800m – 1000m. Profile at 22:20 showed steady increase in wind speed with height from 10m/s to around 40m/s at about 300m-400m. After which it steadied at about 30m/s. The

third profile at 23:20 showed speeds constant at about 30m/s at 20m-60m. Then, at higher levels it increased to more than 60m/s.

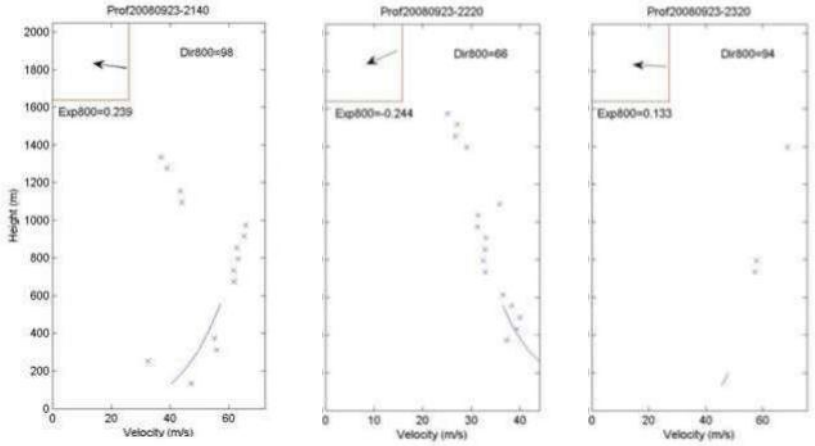

Figure 10-1 to 10-3. 10-minute profile from Wind Profiler data @ 21.40, 22.20 and 23.20

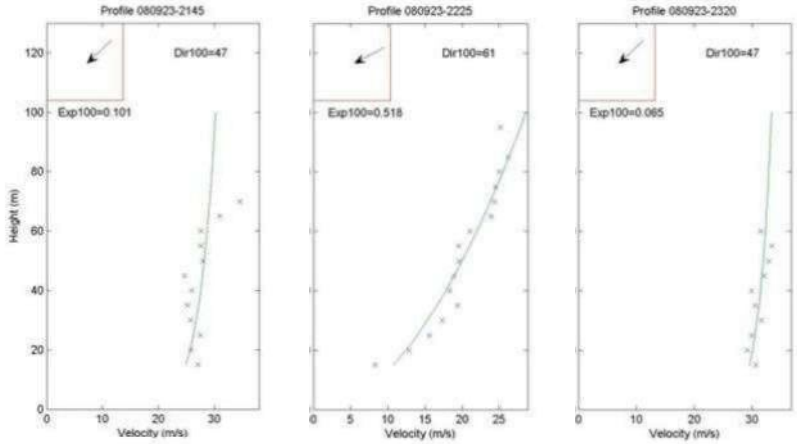

Figure 11-1 to 11-3. 5-minute profile from SODAR data @ 21.45, 22.25 and 23.20

3.3 *Severe Tropical Storm Kammuri*

Kammuri formed as a tropical depression over the northeastern part of the South China Sea. It then intensitfied into a severe tropical storm and moved in the west-northwest direction. It moved close to Hong Kong passing at about 130 km south southwest of Hong Kong on the 6 August 2008, necessitating the issuance of tropical cyclone signal No. 8 in Hong Kong. The track of Kammuri is shown in Figure 12. Winds were strongest during the period 5:00 to 10:00. The hourly averaged wind speed profiles for the Wind Profiler and the SODAR are shown in Figures 13.1-13.6 and 14.1-14.6 respectively.

The upper air profiles did not show clearly increasing wind speed with height. At the stronger wind period, higher wind speeds of more than 40m/s occurred at the lower heights of 400m-600m for 9:00 and 10:00. Whereas for 8:00, wind speeds of over 50m/s occurred at heights of 1200m. Profiles at the lower height range all showed steady increase of wind speed with height; except for 7:00 where wind speed was more or less constant from 20m upwards. The 10-minute Wind Profiler upper height and the 5-minute SODAR lower height range profiles at 7:05 and 7:40 are shown in Figures 15 and 16. While at 7:05 wind speeds were more or less constant at around 30m/s from lower level of 20m right up to 800m; profile

for 7:40 showed steady increase of wind speed from around 15m/s at 20m to over 40m/s at 400m-600m heights.

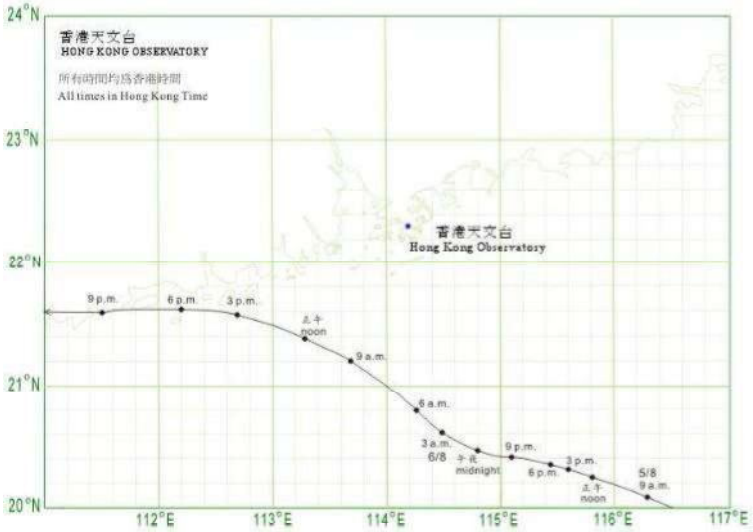

Figure 12. Track of Severe Tropical Storm Kammuri over Hong Kong. (source HKO)

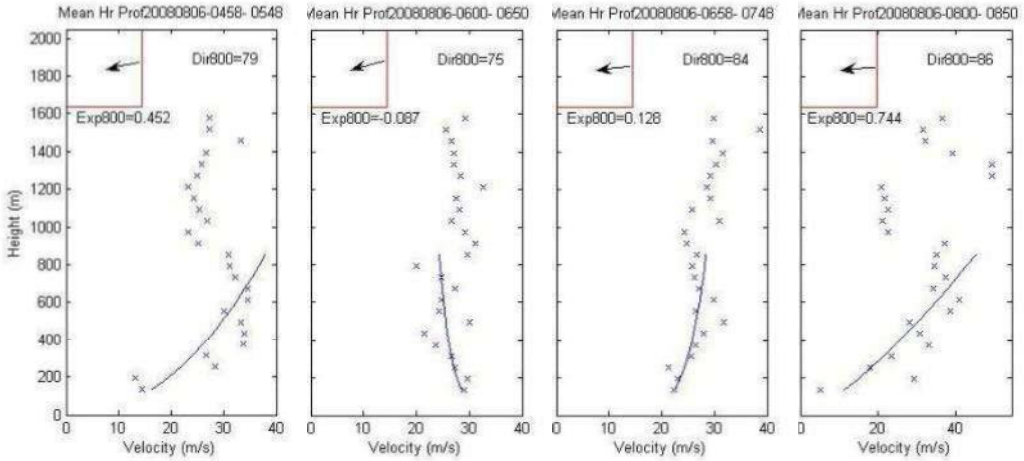

Figure 13-1 to 13-4. Hourly mean wind profile from Wind Profiler data (5.00-8.00)

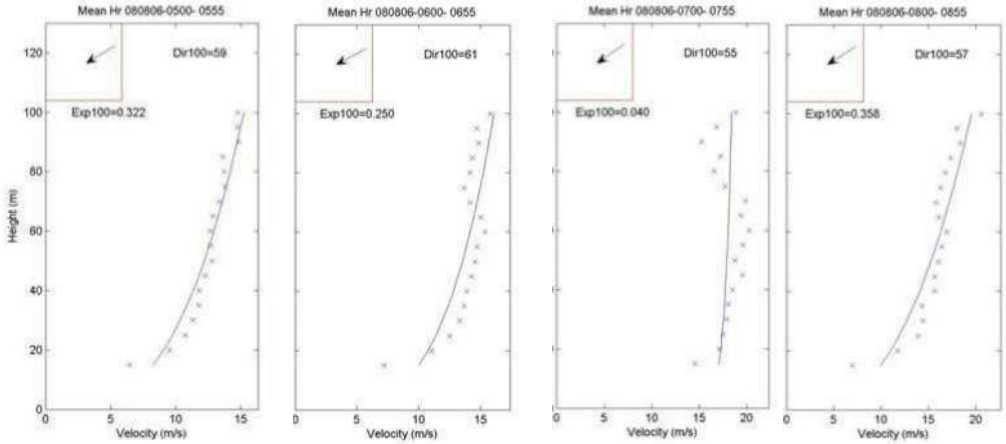

Figure 14-1 to 14-4. Hourly mean wind profile from SODAR data (5.00-8.00)

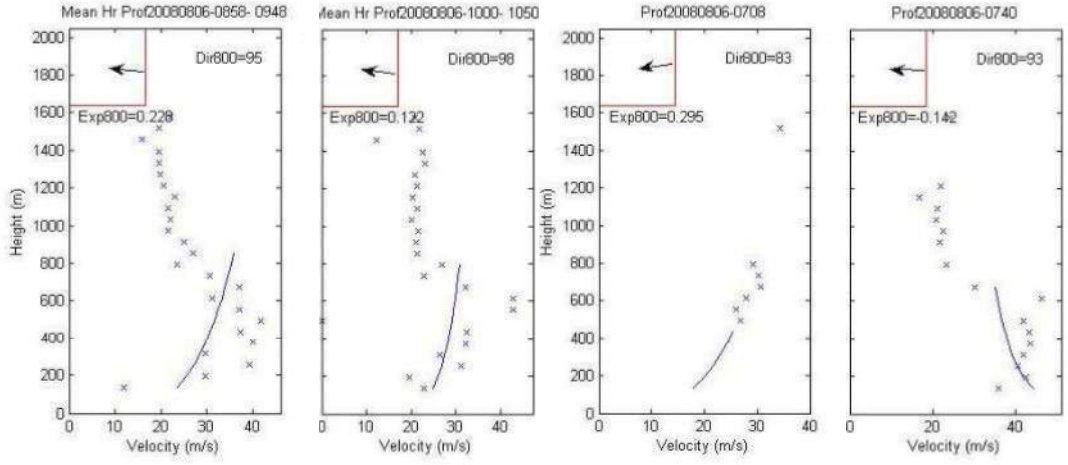

Figure 13-5 to 13-6. Hourly mean wind profile from Wind Profiler data (9.00-10.00)

Figure 15-1, 15-2 10-minute profile from Wind Profiler data (7:08, 7.40)

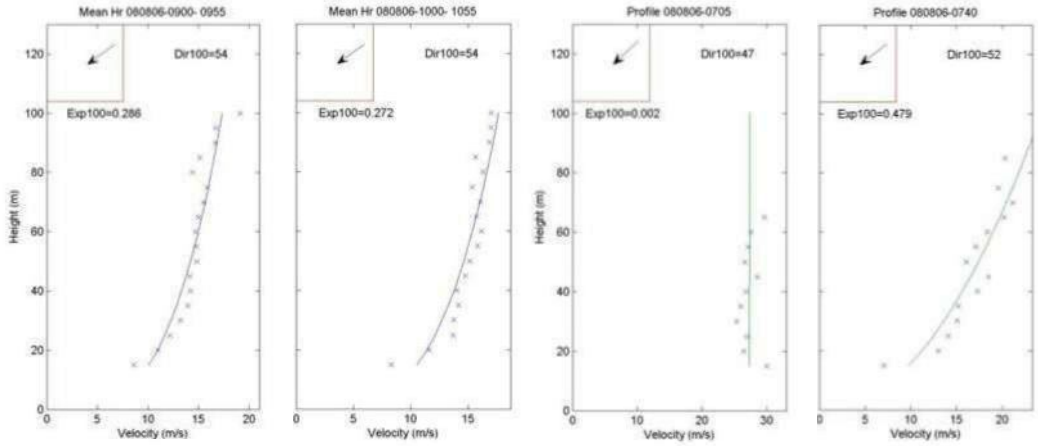

Figure 14-5 to 14-6. Hourly mean wind profile from SODAR data (9.00-10.00)

Figure 16-1, 16-2 5-minute profile from SODAR data (7:05, 7.40)

4 DISCUSSION

This paper presented wind speed measurements during the passage of tropical cyclones over Hong Kong. These were occasions of high winds where the tropical cyclone signal no. 8 was issued. For one occasion, the recorded wind speed exceeded the design wind speed stipulated in the Hong Kong Wind Code. Wind data from the SODAR and the wind profiler were used to investigate the variation of wind speed with height over height ranges of 20m-100m and 100m-1200m respectively. In general over the lowest 20m-100m height range, wind speed was observed to increase steadily with height. The rate of increase differed greatly from hour to hour. When fitted with the power law profile, exponent values from 0.6 to 0.0 were obtained with the more common value between 0.2-0.4. For the 100m-1200m height range, wind speed sometimes increase with height, but sometimes decrease with height. The highest wind speed sometimes occurred at around 200m-600m; but occurred at 1000m-1200m at other times. Overall looking at the whole profile of the very

strong wind occasions, wind speeds at 400m-600m were the highest. It dropped to significantly lower (50%-60%) values at elevations around 100m. At lower elevations, the wind speed could remain relatively constant or dropped steadily from 100m to 20m. Looking at the trend, wind speed would drop rapidly from 20m downwards. It seems the 0.11 exponent used in the Hong Kong wind code would grossly under estimate wind speeds at the 200m - 600m heights for this case.

It is understood that there would be certain amount of topographic effect due to the site environment of the SHW station. This effect would be strong for wind coming from the southerly directions and less for the northerly directions. Wind tunnel study on the topography of the site is being carried out to obtain parameters to normalize the topographic effect on the site wind data.

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6 ACKNOWLEDGEMENT

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