Meteorol. Zeitschrift, N.F. 7, 326–331 (Dezember 1998)

REPRINT 305

Use of wind profiler in severe weather monitoring

K. K. YEUNG, Hong Kong Observatory

Summary. A 1299 MHz wind profiler was acquired to monitor low level winds near the Hong Kong International Airport. It was found that the equipment was also capable of yielding quality data to support the study of severe weather. The presence of abundant amount of moisture in the lower and middle troposphere during heavy rain or tropical cyclone events enabled good and ready measurements up to about 6 km height, a range much greater than the equipment could reach in ordinary days. Preliminary results indicated that the wind profiler could help to improve the understanding of the atmospheric processes involved in severe weather in the subtropical region. In the case of a tropical cyclone, it is apparent that the equipment could be used to provide clues for the forecasting of the maximum strength of the winds and the arrival time of strong winds and gales.

Verwendung eines Windprofilers zum Monitoring von Schlechtwetterbedingungen

Zusammenfassung. Zur Überwachung des Windes in der unteren Troposphäre wurde ein 1299 MHz Windprofiler auf dem Internationalen Flughafen von Hong Kong installiert. Es zeigte sich, daß dieses Gerät auch geeignet ist, Daten zur Untersuchung von Schlechtwetterbedingungen zu liefern. Der hohe Feuchtigkeitsgehalt in der unteren und mittleren Troposphäre während Starkregen-Ereignissen oder tropischen Zyklonen erlaubt Messungen in guter Qualität bis zu einer Höhe von etwa 6 km, diese gute Höhenverfügbarkeit wird an normalen Tagen vom Gerät nicht erreicht. Die vorläufigen Resultate machen deutlich, daß der Windprofiler zu einem besseren Verständnis der atmosphärischen Vorgänge unter Schlechtwetterbedingungen in den Subtropen führen kann. Im Falle tropischer Zyklonen kann das Gerät augenscheinlich Schlüsselinformationen für die Vorhersage des Eintreffens und der maximalen Windstärke bei Starkwind und Sturm liefern.

1. Introduction

A Radian LAP®-3000 lower tropospheric wind profiler was installed in Hong Kong in February 1996 to measure low level winds near the Hong Kong International Airport in an attempt to strengthen windshear monitoring. The profiler operated at 1299 MHz with a beam width of 9 degrees. The oblique beams were tilted about 15.5 degrees from the vertical and directed in the four orthogonal directions. To maximize applications, the equipment was operated on a 400 ns and a 2800 ns pulse length modes simultaneously. While the 400 ns mode provided the necessary low level winds at about 60 m height resolution to meet the needs for aviation meteorological services, the 2800 ns mode probed the atmosphere at a coarser height resolution of 200 m but up to a greater height of about 6 km for severe weather monitoring. For both modes, the data acquisition cycle was one profile every 10 minutes. Consensus averaging and intermittent clutter rejection algorithm supplied with the equipment were applied during data acquisition. The data was quality assessed for consistency using the Weber-Wuertz algorithms after each data acquisition cycle. Probably due to the coastal location of Hong Kong, the valid data availability was reasonably good. For heights below 2000 m, it was found to be consistently above 85 %. The availability fell gradually for greater heights and became 50 % or less above 3000 m.

2. Comparison with radiosonde measurements

A detailed assessment of the performance of wind profilers can be found in SCHLATTER & ZBAR (1994). To evaluate the performance of the wind profiler (WP) in Hong Kong, we have compared its wind profiles with those obtained simultaneously by radiosondes launched from the upper air station of Hong Kong at King's Park (KP). The two sites are about 2 km apart. The comparison covers 18 months from 1 May 1996 to 31 October 1997 and the comparison is made only with 00Z and 12Z data where simultaneous wind and temperature measurements are made by radiosonde so as to minimize height errors in the radiosonde winds. In short, there are only two pairs of profiles each day and for each pair, there are at most 30 levels for comparison. Comparison is made only when valid data are available from both equipment. Due to the large amount of data involved in the comparison, only a typical scattered plot for wind speed is shown in Fig. 1. From this figure, a relatively linear relation up to 17 m/s is observed. The slope and the intercept are around 0.85 and 0.84 respectively. The correlation coefficient is around 0.83 which was probably acceptable in view of the differences in measurement technique, location of sensors and the averaging time of the profiler and the radiosonde system. To provide a complete picture, Fig. 2 and 3 show the frequency distribution (histogram) of wind speed and wind direction deviations between the two

0941-2948/98/0007-0326 $ 02.70

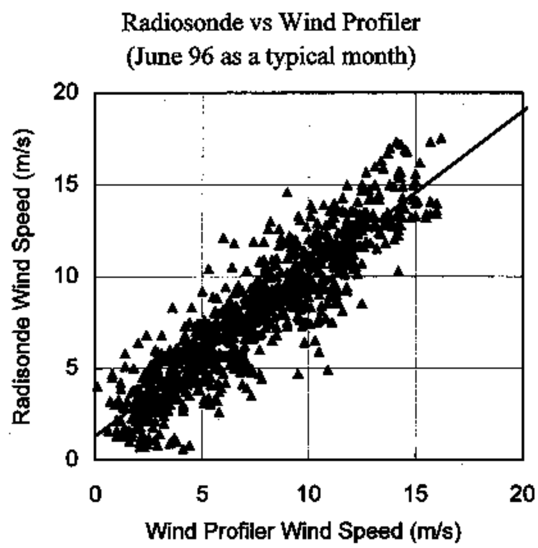

Fig. 1. A typical comparison of wind speed between wind profiler and radiosonde over Hong Kong urban area (data extracted from 00 and 12Z of June 1996 covering heights from 200 m to 6 km).

Abb. 1. Ein typischer Vergleich der Windgeschwindigkeitsmessung zwischen Profiler und Radiosonde über dem Stadtgebiet von Hong Kong (Daten von 00 und 12 UTC für Juni 1996, Höhenbereich 200 m bis 6 km).

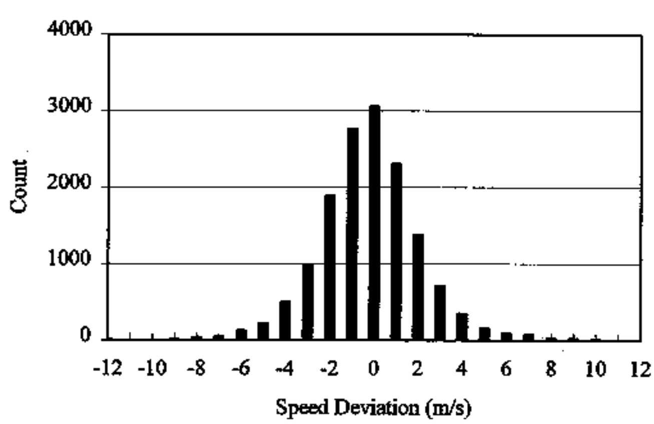

Fig. 2. Histogram of wind speed deviation (WP-RS) between wind profiler (WP) and radiosonde (RS) (data period: 1 May 96 to 31 Oct 97).

Abb. 2. Histogramm der Windgeschwindigkeitsdifferenz (WP-RS) zwischen Windprofiler und Radiosonde (Zeitraum 1. Mai 96 bis 31. Oktober 1997).

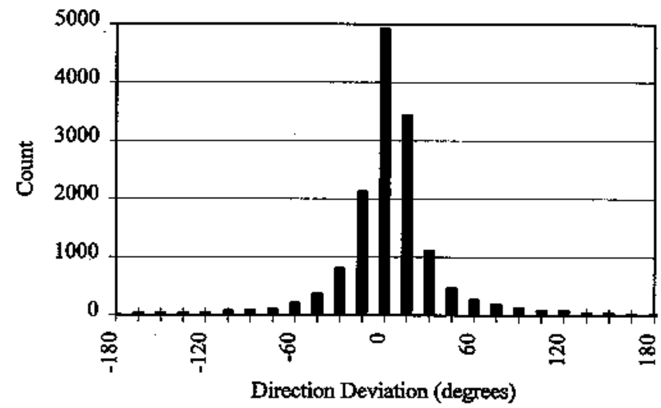

Fig. 3. Histogram of wind direction deviation between wind profiler and radiosonde (data period: 1 May 96 to 31 Oct 97).

Abb. 3. Histogramm der Windrichtungsdifferenz (WP-RS) zwischen Windprofiler und Radiosonde (Zeitraum 1. Mai 96 bis 31. Oktober 1997).

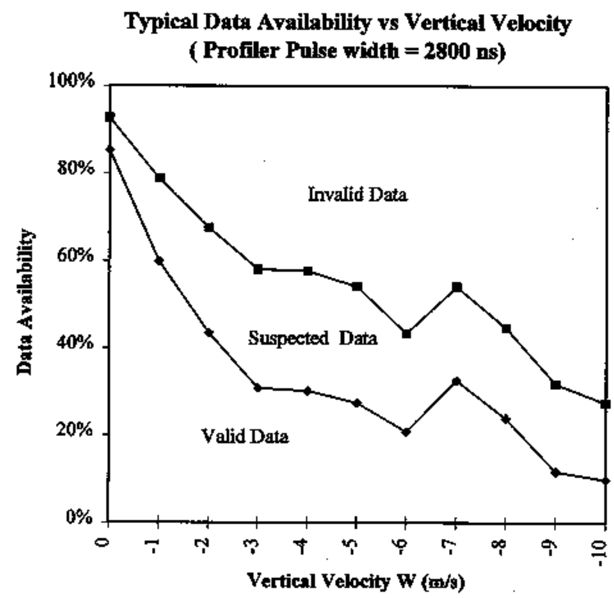

Fig. 4. Availability of valid horizontal winds data with respect to the vertical velocity W measured (Weber-Wuertz algorithms were used in quality control).

Abb. 4. Verfügbarkeit von (durch die Qualitätsprüfung mit dem Weber-Wuertz-Algorithmus) als gültig erkannten Horizontalwinden unter Berücksichtigung der gemessenen Vertikalgeschwindigkeit.

equipments for the entire 18 months period. It is found that about 77 % of the speed deviation falls within ± 2 m/s and about 83 % of the direction deviations falls within ± 30 degrees.

3. Performance in rain

Although the wind profiler performs very well in a humid atmosphere (Rogers et al. 1992), the availability of valid horizontal wind data drops significantly in moderate to heavy rain (Weber-Wuertz algorithm were used to check the validity of the data). Plotted in Fig. 4 is a typical graph showing the data availability in the 2800 ns mode (6 km range) against the measured vertical velocity. We note that in rain, the vertical velocity obtained basically reflects the average falling velocity of rain drops rather than the movement of air along the vertical direction. The graph reveals that the percentage of valid data falls sharply as the vertical velocity change from 0 to –3 m/s. The availability then remains more or less steady from –3 to –7 m/s. When the falling speed is beyond –7 m/s during heavy downpour, the valid data percentage falls again to below 10%. Similar pattern is also observed for the 400 ns mode (2 km range) but the overall availability is much higher.

4. Monitoring significant weather events

In the subtropical western pacific coast, significant weather is almost always associated with heavy rain, tropical cyclones or both. Unlike weather systems in the mid-latitude, these weather systems often show their presence better in the upper air wind field than in the geopotential height field due to the relatively slack height gradient in this region. Therefore, the ability of the wind profiler to provide wind profiles at high frequency, say once every 10 minutes, could offer great help to local forecasters in monitoring, and sometimes extrapolating in real time the movement of atmospheric waves which are usually associated with significant weather systems. From the time of installation of the Hong Kong equipment in February 1996, a number of significant weather events have been successfully captured by the wind profiler. To illustrate the usefulness of the wind profiler, three events namely (a) waves in the mid-troposphere leading to heavy rain, (b) passage of a low level jet leading to heavy rain, and (c) passage of a tropical cyclone nearby Hong Kong, are described in the following paragraphs. The wind profiler excels in capturing moisture-laden mid-tropospheric wave. Whenever there is significant weather system developing in the vicinity, the moisture influx in the mid-troposphere increases. This enhances the data capture rate especially for the layer between 2 and 6 km, allowing mid-tropospheric waves to be seen in great details. Also, for meteorological events where changes in upper air pattern may precede changes in surface pattern, the wind profiler data appears to be able to provide clues to the future development of surface events.

4.1. Waves in mid-troposphere leading to heavy rain

On 5 May 1996, a pressure trough similar to a cold front passed over Hong Kong. With the passage of the trough, winds turned from moderate southwesterlies to strong easterlies around noon. Usually, heavy rain would associate with the arrival of the trough. The present case however found rain beginning to affect Hong Kong about 6 hours before the arrival of the trough. The rain was heavy leading to the hoisting of the Red Rainstorm Warning (a local warning to indicate 50 mm of rain had fallen over most part of Hong Kong in the past one hour).

Fig. 5 is a time-cross section of winds aloft the wind profiler on 5 May 1996. The graph revealed that a mid-tropospheric wave was passing over Hong Kong from 05 to 09 h, the period when heavy rain affected Hong Kong. Since the wave length was short, this wave was not seen by traditional radiosonde time-cross section but readily captured by the wind profiler. Apart from this, the graph also

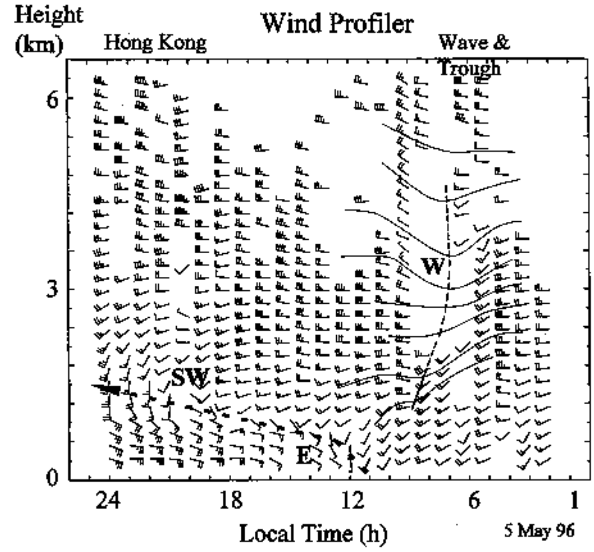

Fig. 5. Time-series of wind profile measured in Hong Kong during the passage of a mid-tropospheric wave and a surface trough on 5 May 1996 (full and half wind barb = 5 and 2.5 m/s; SW and E mark the southwesterly and easterly wind zone; W marks the position of the mid-tropospheric wave).

Abb. 5. Zeitreihe des in Hong Kong gemessenen Windprofils während der Passage einer troposphärischen Welle und eines Bodentrogs am 5. Mai 1996.

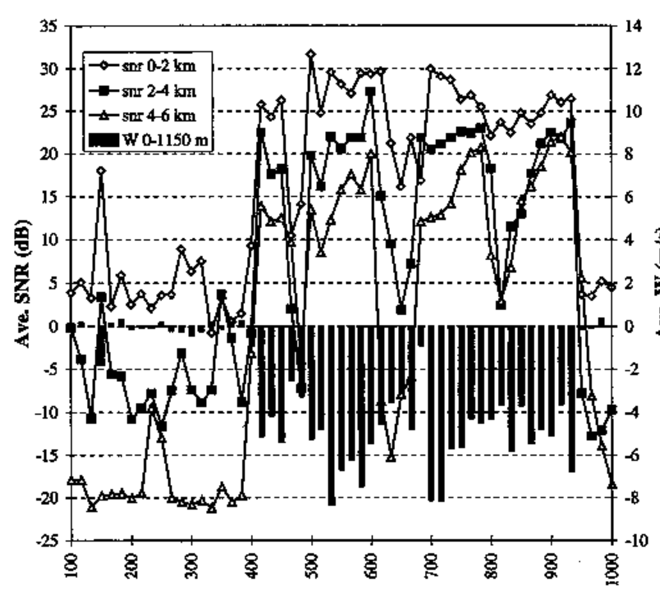

Fig. 6. Variation of 10-minute mean signal-to-noise (SNR) ratio for the 0–2 km, 2–4 km and 4–6 km layers during the passage of a mid-tropospheric wave. The 10-minute mean vertical velocity (W) for the lowest 1 km was plotted to indicate the period of rain.

Abb. 6. Variabilität des über 10 Minuten gemittelten Signal-Rauschverhältnisses für die Höhenschichten 0–2 km, 2–4 km und 4–6 km während der Passage einer troposphärischen Welle. Das 10-Minuten Mittel der Vertikalwindgeschwindigkeit in der untersten Höhe (1 km) wurde zur Identifikation des Zeitraums mit Niederschlag dargestellt.

recorded the turning of surface winds from southwesterlies to easterlies around noon (12 h) and the strengthening and deepening of easterly winds to over 1 km height towards midnight. To study the heavy rain event in greater details, Fig. 6 showed the mean signal-to-noise ratio (SNR) for the three layers (0–2 km, 2–4 km and 4–6 km) together with the mean vertical velocity W for the lowest 1100 m. Since the SNR is a function of the humidity, it may be used to reflect to some extent the moisture amount in the atmosphere. Also, since persistent down draught of high value is rare, a significant negative value of W, say $W < -3$ m/s, would represent rain. Comparing the two parameters may reveal the relationship between atmospheric moisture and the development of heavy rain. In this case, the heavy rain ($W < -6$ m/s) period is found to coincide well with the passage of the mid-tropospheric trough. We also observe that the SNR for the 2–4 km level shoots up rapidly from –10 to over 20 beginning after 03 h, about 1 to 2 hours before the heaviest downpour commences.

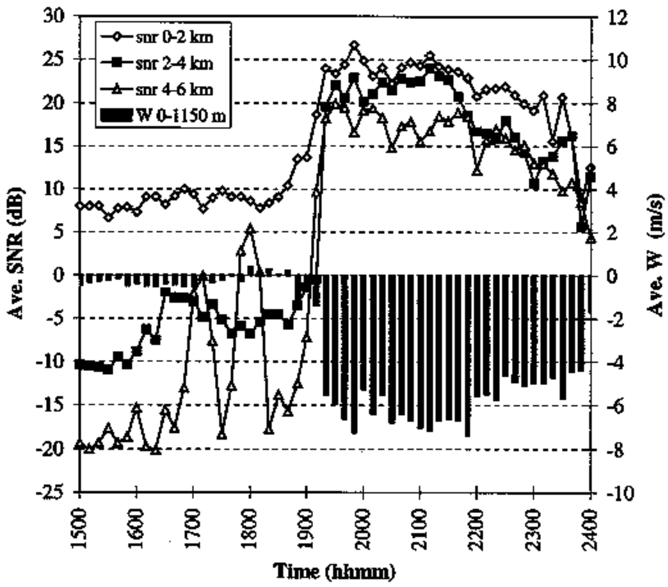

Fig. 8. Variation of the 10-minute mean signal-to-noise (SNR) ratio for the 0–2 km, 2–4 km and 4–6 km layers during the passage of a low level jet. The 10-minute mean vertical velocity (W) for the lowest 1 km was plotted to indicate the period of rain.

Abb. 8. Variabilität des über 10 Minuten gemittelten Signal-Rauschverhältnisses für die Höhenschichten 0–2 km, 2–4 km und 4–6 km während der Passage des Low Level Jets. Das 10-Minuten Mittel der Vertikalwindgeschwindigkeit in der untersten Höhe (1 km) wurde zur Identifikation des Zeitraums mit Niederschlag dargestellt.

4.2. Low level jet leading to heavy rain

On 25 May 1996, a trough of low pressure moved from north to south towards the South China Coast. When it got close to the coastal region, it slowed down and lingered. During this period, a low level jet moved across Hong Kong bringing some squally thunderstorms to the region.

Fig. 7 is a time-cross section of the winds measured by the wind profiler. It is found that the southwesterlies around 6 km begin picking up to over 17.5 m/s at 17 h. The high winds region gradually builds downward until the 17.5 m/s winds boundary gets as low as 1 km. The core of the jet is found to have winds above 25 m/s and the jet core "J" passes over Hong Kong around 19–23 h. Embedded in the high winds, a well organized westerly wave denoted by a heavy dotted line between 3 and 5 km level appears and moves over the wind profiler from 20 to 22 h. It is during these few hours, the ground experiences the heaviest downpour which is verified by the vertical winds time-series as shown and our raingauge records (not plotted). Although not shown in Fig. 7, profiles for the next day indicate that both the rain and the low level jet cease shortly after midnight. Fig. 8 is a graph similar to Fig. 6 but for this event. Again, we could see that the mean SNR, in particular the 0–2 km and the 2–4 km layers both shoot up to about 20 and the rise begins at about 1 to 2 hours before the onset of the heaviest downpour.

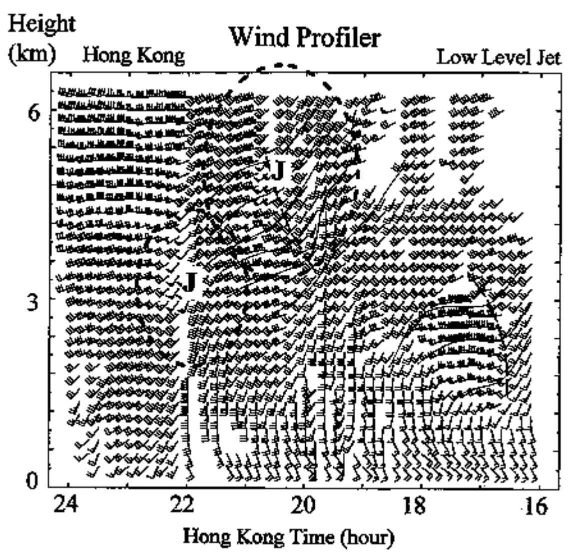

Fig. 7. Time-series of wind profile measured in Hong Kong during the passage of a low level jet on 25 May 1996. "J" marks the position of the jet cores.

Abb. 7. Zeitreihe des in Hong Kong gemessenen Windprofils während der Passage eines niedertroposphärischen Strahlstroms (Low Level Jet) am 25. Mai 1996. „J" bezeichnet die Position des Strahlstromkerns.

4.3. Tropical cyclone

Typhoon Sally traversed the northern part of the South China Sea between 8 and 9 September 1996. At its closest approach, Sally was some 200 km to Hong Kong's south-southwest and brought gale force winds to Hong Kong. Sally's track and the surface pressure pattern at 18Z on 8 September 1996 (2 h on 9 September) when Sally was at the closest approach to Hong Kong is shown in Fig. 9.

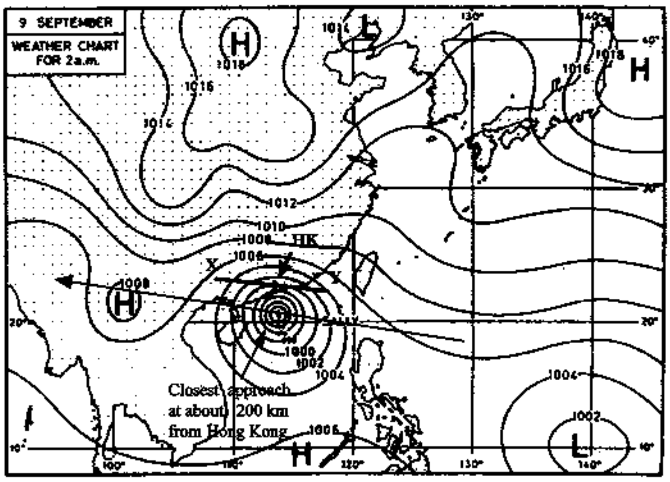

Fig. 9. Surface pressure pattern on 9/9/96 showing the location of Typhoon Sally and its track. At 2 a.m., it was about 200 km from Hong Kong.

Abb. 9. Bodendruckfeld am 9. September 1996, mit Position und Zugbahn des Taifun „Sally". Um 2 Uhr morgens hatte er einen Abstand von etwa 200 km zu Hong Kong.

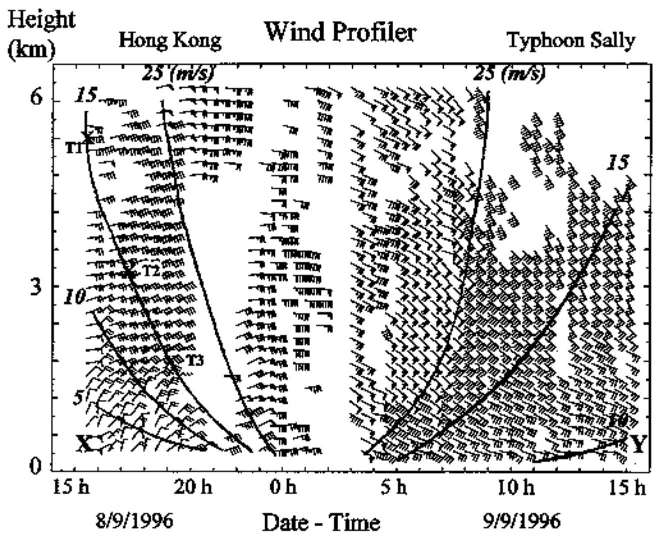

Fig. 10. Time-series of wind profile measured in Hong Kong during the passage of Typhoon Sally across the northern part of the South China Sea (triangular/full/half wind barb represent 25/5/2.5 m/s).

Abb. 10. Zeitreihe des in Hong Kong gemessenen Windprofils während der Verlagerung des Taifuns „Sally" durch den nördlichen Teil des südchinesischen Meeres (Windfähnchen/volle Fieder/halbe Fieder bedeuten 25/5/2,5 m/s).

Fig. 10 shows the evolution of wind profiles over Hong Kong for the 24-hour period beginning at 15 h on 8 September 1996 and ending at 15 h on 9 September 1996. Good observations were generally obtained from the ground to a height of some 6 km albeit some data were lost due to heavy rain. The effective range of the wind profiler is typically 3 km on other days. As Sally's track is a steady west-northwest with little intensity change, in spatial terms these time-cross sections of winds can be considered as the equivalent of those taken along the section marked XY in Fig. 9.

As shown in Fig. 10, the veering of winds from northeast to southeast as Sally approaches and passes Hong Kong is well captured. Also, the isotachs shows that winds strengthen faster on Sally's approach and weaken slower on departure. This asymmetry is in reasonable agreement with the surface pressure pattern of Sally which had slightly tighter gradient in the northwest quadrant than the northeast quadrant. Another interesting observation is that a significant windshear zone appears at height around 1 to 1.5 km from 16 to 20 h. It is likely due to the significant speed reduction of the low level northeasterlies as a result of the sheltering effect of the rugged terrain to the northeast of Hong Kong. We note that there is clearly no corresponding speed reduction for the low level southeasterlies from the South China Sea after Sally passes the closest approach.

The most interesting feature is that the time-cross section displays an organized pattern of different wind speed zones. The forward slanting isotachs observed before the time of the closest approach means that winds of a given speed would appear aloft first, then over the next five or six hours descend to lower and lower altitudes as the typhoon comes closer and closer. For example, winds of 15 m/s are observed at 16 h on 8 September at about 5.4 km, then 3.6 km at 18 h, and 1.8 km at 19:30 h (respectively points T_1, T_2 and T_3 in Fig. 10).

This observation suggests the possibility that, having available several wind profiles in an operational environment and when a tropical cyclone is still distant, one could approximate the shape of the isotach of, say, gales, and then through extrapolation along it estimates the time when gales might be observed at the surface if the tropical cyclone are to maintain its intensity and movement. In the case of Sally, following the points T_1, T_2 and T_3 along the 15 m/s isotach would give surface winds of that strength beginning from about 22 h. This is close to the time of its actual onset.

5. Conclusion

It was found that for Hong Kong, around 80 % of the time the wind speeds and directions of the wind profiler were within ± 2 m/s and ± 30 degrees of those given by radiosondes.

It was also found that the wind profiler, given its sensitivity to irregularities in the moisture field, is a useful tool in monitoring the wind profiles of approaching heavy rain and tropical cyclones. For heavy rain events, the behaviour of the mean signal-to-noise ratio, in particular the layer between 2 and 4 km is of most interest and may have potential to be further developed to help nowcasting of heavy rain. For tropical cyclones, based on the wind profiles obtained for Typhoon Sally, a possible forecasting tool for estimating the time of onset of surface winds due to tropical cyclones is suggested albeit it needs to be further developed and verified.

Acknowledgements

The author wishes to thank Dr. H. K. LAM (Director of the Hong Kong Observatory) for the initiation and support of the study, Mr. K. H. YEUNG, Dr. W. L. CHANG and Dr. B. Y. LEE for the useful comments on the manuscript.

References

Rogers, R.R., C.A. Knight, J.D. Tuttle, W.L. Ecklund, D.A. Carter, S.A. Ethier, 1992: Radar reflectivity of the clear air at wavelengths of 5.5 and 33 cm. — Radio Sci. **27**, 645–659.

Schlatter, T.W., F.S. Zbar, 1994: Wind Profiler Assessment Report and Recommendations for future use. — Obtainable from NOAA Forecast Systems Laboratory R/E/FS3, 325 Broadway, Boulder, CO 80303–3328.

Dr. K. K. YEUNG
134A Nathan Road
Kowloon
Hong Kong
e-mail: kkyeung@hko.gcn.gov.hk

Received 6 August 1997, in revised form: 10 March 1998