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EXPERIMENTAL EXTENSION OF THE MEASUREMENT RANGE OF A BOUNDARY LAYER WIND PROFILER TO ABOUT 9 KM

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1. INTRODUCTION

A boundary layer wind profiler was installed at Sham Shui Po, Hong Kong in 1996 for severe weather monitoring (Yeung, 1998). Its technical specifications are tabulated below.

Frequency	1299 MHz
Antenna panel	4-panel (antenna size of 1.74 m by 1.74 m)
Beam width	9 degrees
Tilting of oblique beams	About 15.5 degrees from the vertical
Number of oblique beams	4 maximum; 2 in operation
Pulse length	1400 nanoseconds (ns)
Level spacing	200 m
Measurement cycle	10 minutes

Table 1 Specifications of the wind profiler

The wind profiler was configured to measure to a maximum altitude of about 6 km via the configuration files in the equipment. This measurement range is achievable mostly in rainy situations. In the absence of rain, the profiler normally measures to about 3 km.

In Hong Kong, wind data above 6 km are routinely measured by radiosondes three times a day. Availability of these upper-tropospheric wind data at more frequent intervals will greatly assist the monitoring of severe weather, such as rainstorms associated with upper-tropospheric flow divergence and the structure of tropical cyclones at landfall (e.g. Knupp et al., 2000). There are wind profilers in the market that can measure to higher altitudes than boundary layer profilers, e.g. 50-MHz series (about 90-km range) and 400-MHz series (about 20-km range). Apart from high capital cost, the installation of these profilers in Hong Kong have the technical problems of (i) limited space for installation due to hilly terrain in Hong Kong, and (ii) the unavailability of the radio frequency due to widespread use of radios.

Extension of the measurement range of a boundary layer wind profiler is a technically feasible and cost-effective way of getting the required data because:

(a) wind profiler can theoretically measure to higher altitudes in rain (when upper tropospheric wind data are required) as a result of Rayleigh scattering of hydrometeors;
(b) no additional costs are needed to modify the hardware of the profiler as the measurement range extension can be completely achieved through changes in the software configuration.

The present paper summaries the changes made with the boundary layer wind profiler in order to extend the measurement range, the quality and availability of the upper-tropospheric wind data, and their application to severe weather monitoring.

2. TECHNICAL CHANGES WITH THE WIND PROFILER

Since mid-May 2002, two changes were made in the software configuration file of the Sham Shui Po wind profiler in order to extend the measurement range from 6 km to 9.2 km:

(a) Increasing the interpulse period from 48000 ns to 71000 ns to receive the radar signals returned from higher altitudes. With the pulse length (and hence the level spacing) remaining the same, the number of measurement levels of the profiler is increased from 30 to 45 in order to reach 9.2 km.
(b) Transmitting radio pulses of longer duration, which are composed of four complementary, phase-coded pulse cells (i.e. a pulse coding of 4). This is the common technique for boosting the maximum height coverage of radar wind profiler while retaining a fine range resolution.

3. COMPARISON WITH RADIOSONDE

The Sham Shui Po wind profiler is located about 2 km away from the radiosonde station at King's Park. The wind data from the radiosonde are taken as 'sky truth' to assess the quality of the profiler data between 6 and 9.2 km by using the method in Yeung (1998) which studied profiler data up to 6 km only. In summary, for each valid wind measurement of the profiler, the radiosonde data that is closest in space and time is selected for comparison. Following the level spacing and measurement cycle of the wind profiler, the space and time windows for radiosonde data selection are taken to be 200 m and 10 minutes respectively (centred at the wind profiler measurement under study).

In the period of mid-May to September 2002, there were altogether 380 pairs of valid wind profiler measurements and radiosonde data at altitudes of 6 to 9.2 km for comparison. Figure 1 shows the scattered plots of wind speed and direction.

The comparison covers a rather wide range of wind speed, up to 25 m/s (49 knots). On the whole, the radiosonde wind speeds are slightly lower than those of the wind profiler (a slope of about 0.92). Moreover, the data points are quite scattered (correlation coefficient, R^2, of about 0.6 only). About 63% of the wind speed values from the profiler deviate within 2 m/s from the radiosonde data, which is smaller than 77% for profiler data below 6 km in the

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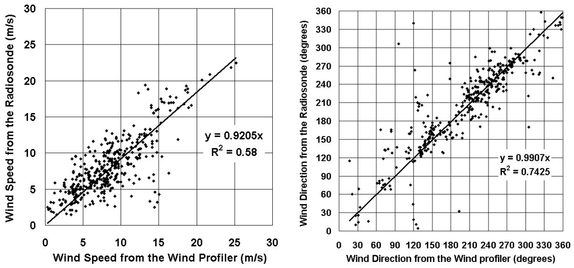

Figure 1 Comparison between Sham Shui Po wind profiler and King's Park radiosonde for wind speed (left) and direction (right).

previous study by Yeung (1998).

The wind direction comparison appears to be better. The proportionality factor (0.99) is closer to unity. The data points are also less scattered, with a correlation coefficient of 0.74. Nearly 80% of the wind direction values from the profiler deviate within 30 degrees from the radiosonde data, which is comparable to 83% in Yeung (1998).

At higher altitudes, the radiosonde balloon may drift further away from the wind profiler and the airflow at the location of the balloon may be different from that overhead of the profiler. This source of wind data discrepancy between radiosonde and wind profiler should be more significant in the present high-altitude study than in the last report in Yeung (1998). Its effect seems to be less profound for wind direction because the upper-tropospheric wind in rain during the study period is normally west to southwesterly (as evident from the clustering of data points in the wind direction range of 210 to 270 degrees in Figure 1). Mesoscale features such as small-amplitude waves may bring about wind direction fluctuations of only a few tens of degrees. On the other hand, mesoscale variations of wind speed may be more significant, e.g. due to jet streaks associated with the rain bands.

Taking into account the above factors and the different technology involved in the measurement, the wind profiler and the radiosonde are considered giving comparable wind data above 6 km.

4. DATA AVAILABILITY

The availability of valid wind data at different levels of Sham Shui Po wind profiler in the period of mid-May to September 2002 is shown in Figure 2. It is classified into "rain" and "no rain" conditions, based on rainfall at King's Park.

In rain, the data availability decreases nearly linearly with height (apart from altitudes of 3 to 5 km) by an average rate of around –6% per 1 km. At the profiler's maximum measurement level (9.2 km), wind availability is about 24%. The deviation from the linear trend between 3 and 5 km is related to radar bright band of convective rain clouds, in which changes in the fall velocities of the hydrometeors are so great that consensus wind data are not available occasionally.

In the absence of rain, the data availability has a maximum at about 1 km and then decreases steadily with height up to 4.6 km. At higher altitudes, it stays at a nearly constant value of around 5%. Valid wind data are still obtained in the upper troposphere because of the scattering from stratiform/cirrus clouds associated with convective clouds. These clouds may have falling constituents, as revealed by a downward velocity of 1-2 m/s from the vertical beam of the wind profiler, which are then evaporated away without forming rain to the ground. They can occur right after rainy episodes (convective rain clouds moving away, with the stratiform/cirrus clouds remaining over the wind profiler) or can be brought in by advection in the upper-tropospheric airflow (no rain being recorded in Hong Kong in the whole process).

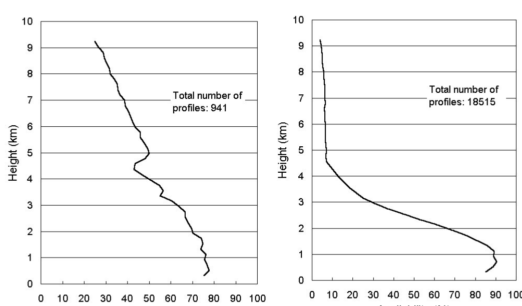

Figure 2 Data availability at different levels of Sham Shui Po wind profiler in rain (left) and no rain (right) conditions.

5. APPLICATIONS TO SEVERE WEATHER MONITORING

The availability of wind data above 6 km from Sham Shui Po wind profiler enables detailed analysis of the meteorological processes, which cannot be achieved by using radiosonde data and weather radar observations only. Two examples are given below.

5.1 17 July 2002

An active southwesterly airstream brought unsettled weather to the south China coast (Figure 3). The rain was the heaviest in the morning with more than 40 mm of rain generally over Hong Kong and even over 140 mm at some places. Figure 4 shows the rainfall time series at King's Park.

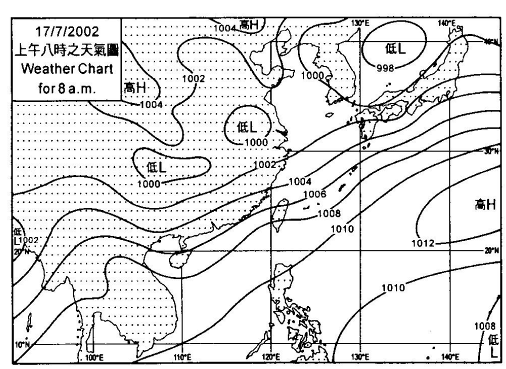

Figure 3 Surface weather chart at 8 a.m., 17 July 2002.

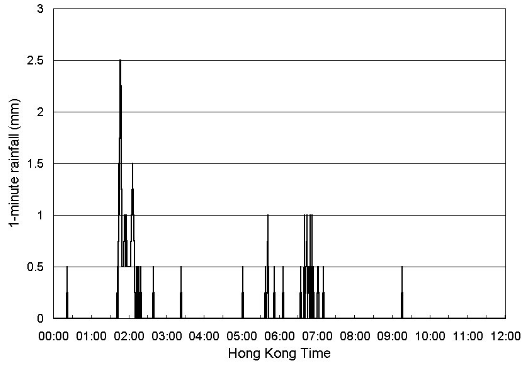

Figure 4 Time-series of 1-minute rainfall at King's Park in the morning of 17 July 2002.

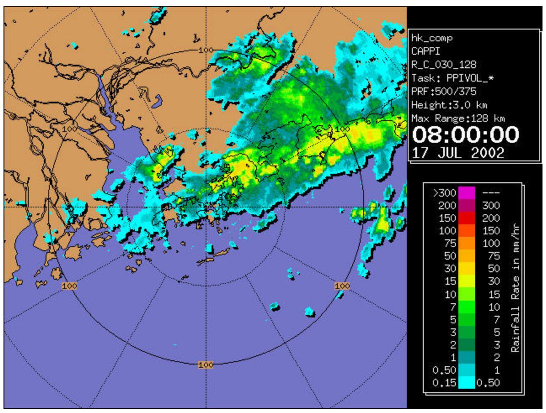

Figure 5 Weather radar imagery at 8 a.m., 17 July 2002.

From the weather radar, a band of rain echoes with ENE-WSW orientation lied across Hong Kong in the early morning (not shown). From around 8 a.m. (in Hong Kong time, which is eight hours ahead of UTC), it moved to the east slowly (Figure 5) and the rain over the territory weakened gradually.

The upper-air ascents at 8 a.m. showed generally southwesterly flow along the south China coast up to 500-hPa level (5.9 km) without significant perturbations (not shown). A mesoscale cyclone could be analyzed in the upper-tropospheric wind field, e.g. at 400 hPa (7.6 km, Figure 6). It moved to the east of Hong Kong during the day and turned into a trough. The proximity of this cyclone triggered intense convection along the south China coast. After its passage, rain subsided in the region.

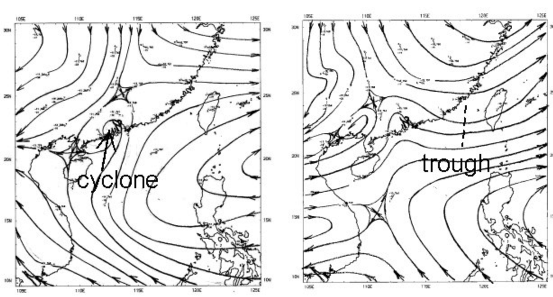

Figure 6 Streamline analyses of 400-hPa winds at 8 a.m. (left) and 8 p.m. (right) of 17 July 2002.

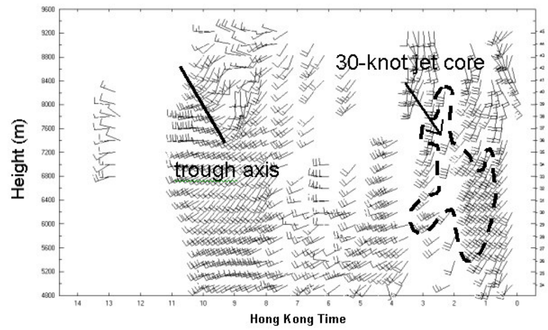

Figure 7 Sham Shui Po wind profiler data between midnight and 2 p.m. of 17 July 2002 (only data above 4.8 km are shown).

The upper-tropospheric flow was depicted in greater details with the more frequent wind data of Sham Shui Po profiler (Figure 7). Three features were observed: (a) the appearance of a southwesterly jet of more than 30 knots between 0:30 and 3:00 a.m. at the altitudes of 5.5 to 8.2 km, which was associated with the first deluge of rain (Figure 4), (b) the manifestation of the upper-tropospheric cyclone as a westward-tilting trough between 7.4 and 8.3 km in the period of 9 to 10:30 a.m., and (c) the appearance of west to northwesterly wind following the passage of the cyclone.

5.2 14 September 2002

Under the influence of an area of low pressure centred at Beibu Wan, the weather was unsettled along the south China coast with thundery and heavy showers from time to time (Figure 8). From the weather radar, an ESE-WNW orientated rain band appeared to the southwest of Hong Kong in the morning and moved northeastwards at about 13 knots. The line of convective rain cells (represented by more intense radar echoes) passed Sham Shui Po wind profiler at about 10 a.m. (Figure 9). The trailing stratiform rain clouds affected the territory until noon.

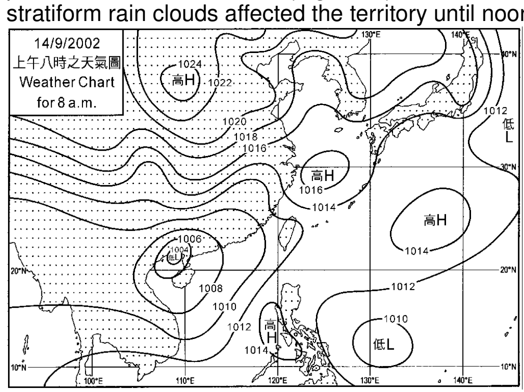

Figure 8 Surface weather chart at 8 a.m., 14 September 2002.

The frequently updated data from Sham Shui Po wind profiler depicted the wind field associated with this mesoscale rain band in detail. The following features were observed (Figure 10):

(a) Convergence between southeasterly and southwesterly winds below about 4.5 km;
(b) Appearance of a jet of more than 20 knots between 1.8 and 6.3 km at the leading part of the

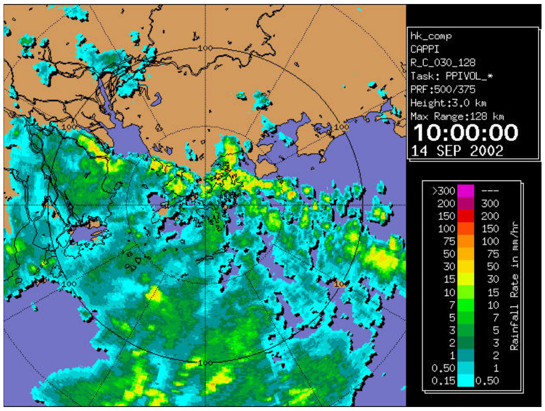

Figure 9 Weather radar imagery at 10 a.m., 14 September 2002.

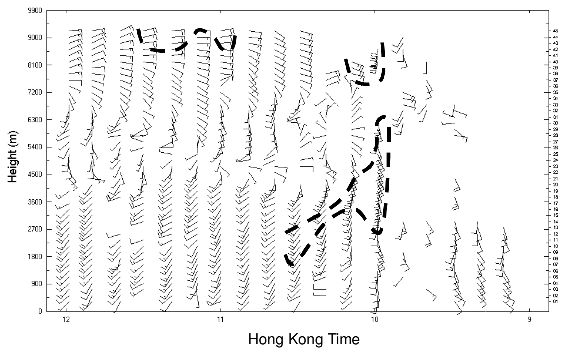

Figure 10 Sham Shui Po wind profiler data between 9 a.m. and noon of 14 September 2002. The major jets of more than 20 knots are indicated by broken lines.

rain band (measured by the wind profiler between 10 and 10:30 a.m.);

(c) Rapid changing of wind direction between 5.4 and 7.2 km from southerly/southeasterly, to northerly and finally to southerly, within about an hour (starting from 9:40 a.m.), which suggested the existence of some tiny cyclones embedded in the leading part of the rain band;

(d) Diffluent airflow at the uppermost levels, namely, changing of south/southwesterly wind to easterly wind above 8 km at around 10 a.m.

Though the vertical velocity of air was not directly available from UHF wind profiler in rain, the above features (low-level convergence, mid-level jet and cyclones, and high-level divergence) were indicative of vertical circulation throughout the troposphere, which favoured the occurrence of severe convection.

6. CONCLUSION

Measurement range of the boundary layer wind profiler at Sham Shui Po, Hong Kong is extended from 6 km to 9.2 km. This is accomplished by increasing the interpulse period and implementing pulse coding.

By using the same radar signal processing and data quality assurance algorithms for lower tropospheric winds, the wind profiler is found to give reasonably accurate data at the altitudes of 6 to 9.2 km when compared with radiosonde measurements in the vicinity. The availability of wind data in the upper troposphere is better in rain, but some data are still available in rain-free situation as a result of the scattering from stratiform/cirrus clouds with constituents having a fall velocity of a couple of m/s.

The more frequent upper-tropospheric wind data from the profiler enable more detailed study of the mesoscale features of rain bands, which evolve so rapidly to be analyzed by using the conventional radiosonde data that are only available three times a day.

References

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