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COMMISSION FOR AERONAUTICAL METEOROLOGY

WORKING GROUP ON TRAINING, THE ENVIRONMENT
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NEW DEVELOPMENTS IN AERONAUTICAL METEOROLOGY

Windshear and Turbulence Detection and Warning At Hong Kong International Airport

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Summary and purpose of document

This document presents three cases of wind shear arising from thunderstorms, low-level jets, frontal systems and mountain waves showing how data from the various observing systems contribute to Hong Kong Observatory's wind shear and turbulence warning service

ACTION PROPOSED

The Working Group is invited to note the information provided in this document.

Appendix: Figures 1 to 14

1. INTRODUCTION

1.1 Windshear is the variation of wind speed or wind direction in space. When windshear occurs at low altitude near arrival and departure zones of an airport, it may cause difficulties in the control of the aircraft leading to possible premature landing, overshooting of the runway or failed take-off if the pilot does not intervene appropriately.

1.2 Turbulence also manifests itself as variation of wind speed and direction in space, but compared with windshear is of a smaller length scale and smaller time scale. It exerts forces on the aircraft causing rapid bumps and jolts but its effect on the flight path is relatively small. When turbulence is severe, abrupt changes in the altitude and attitude of the aircraft may occur leading to momentary difficulty in the control of the aircraft.

1.3 Windshear and turbulence can be caused by a wide variety of phenomena including thunderstorms, low-level jets, land/sea breezes, frontal systems and mountain waves. The most severe low-level windshear is microburst. Since the late 80's and early 90's, with the development of Low-Level Windshear Alerting System (LLWAS) and Terminal Doppler Weather Radar (TDWR) among others, timely alerts on the occurrence of microbursts and gust fronts can now be provided to pilots. With the development of the Integrated Terminal Weather System (ITWS) in the States in the 90's, short term predictions (up to 30 minutes) of hazardous weather in the terminal area is now possible.

1.4 Windshear associated with low-level jets were mostly covered by forecasts in the past. As it is non-transitory, there have been some degrees of success in a number of States in the forecasting of its occurrence. With the deployment of Doppler SODAR and wind profilers, it is now possible to detect the actual occurrence of these low-level jets.

1.5 Traditionally windshear induced by terrain is considered non-transitory as the meteorological conditions favourable for its formation could exist for a long time. As a result, it has attracted lesser attention and information on its occurrence has traditionally been covered by forecasting rules. Pilot reports and observations using sophisticated equipment in recent years however reveal that it could also vary dramatically in intensity.

1.6 As the designated authority to provide meteorological services for international air navigation, the Hong Kong Observatory (HKO) has equipped the Hong King International Airport (HKIA) with advanced meteorological systems, including inter alia the TDWR, anemometers and the wind profiler. Data from the various equipment are then ingested into the windshear and turbulence warning system to provide an integrated windshear and turbulence alert for the airport. A more detailed description of the facilities at the HKIA is given in Section 2. In Section 3 to 5 of this paper, three windshear cases observed at the HKIA with the suite of equipment, viz. due to convective storms, low-level jets and terrain, are presented. Training issues in connection with windshear and turbulence at HKIA are briefly discussed in Section 6 followed by conclusions Section 7.

2. WARNING OF WINDSHEAR AND TURBULENCE AT HKIA

2.1 The HKIA came into operation on 6 July 1998. The airport has two parallel northeast-southwest oriented runways designated as RWY 07L/25R and RWY 07R/25L. As part of a comprehensive set of meteorological systems implemented to support the HKIA, the HKO installed a TDWR for detecting microbursts and windshear associated with convective storms, anemometers at strategic locations for windshear and turbulence detection as well as two wind profilers for detecting vertical windshear. Location of various meteorological sensors is given in Figure 1. An automatic system, the windshear and turbulence warning system was specially developed to integrate the data from the various equipment to provide integrated real-time windshear and turbulence alerts to pilots.

2.2 The TDWR is strategically located at Tai Lam Chung about 12 km northeast of HKIA for detecting microbursts and windshear associated with convective. The TDWR has a clear view of the runways, airport approach and departure areas. To avoid beam blockage by nearby ships, the antenna of the TDWR was installed at about 60 m amsl. The TDWR has a half-power beamwidth of 0.55° and operates a highly stable klystron based amplifier which allows clutter suppression of up to 55 dB.

2.3 Apart from the TDWR, the difference in wind measured at adjacent anemometers over the airport is used to determine the location and magnitude of the horizontal windshear in the approach and departure corridors. This algorithm is essentially that of LLWAS-III.

2.4 Other than the 6 anemometers along the 2 runways, another 8 anemometers were installed on hill tops and offshore locations for windshear and turbulence detection. The hill-top anemometers measure the ambient wind speed and direction and their fluctuations, from which the magnitude and location of the terrain-induced windshear and turbulence is determined by correlation method.

2.5 Two wind profilers were installed at Sha Lo Wan and Siu Ho Wan to monitor the vertical windshear at the western and eastern approach respectively. The profilers monitor the lower troposphere continuously allowing a new vertical profile to be generated every 10 minutes.

2.6 Data from these equipment are fed into the windshear and turbulence warning system where the data are integrated to give a coherent alert based on all data sources. Other than integrating windshear alerts from TDWR, the system also re-analyses the base data collected by TDWR for detection of windshear and turbulence. The functional block diagram of the system is given in Figure 2.

2.7 To supplement the various equipment, the aviation forecasters issue windshear alerts based on pilot reports in accordance with ICAO Annex 3. Other than deriving evidence of windshear from the pilot reports, as suggested in the ICAO Circular 186-AN/122 on Wind Shear, knowledge-base on the occurrence of windshear was developed using pilot reports for the aviation forecasters to issue complementary windshear alerts. The HKO is also in the process of acquiring a coherent pulsed Doppler LIDAR to further enhance the detection of terrain-induced windshear in clear air conditions.

3. WINDSHEAR INDUCED BY CONVECTIVE STORM

3.1 It is generally accepted that low-level windshear associated with convective storms, named “microbursts” by Fujita, is the most severe. On 3 September 1999, the TDWR at Tai Lam Chung detected a microburst associated with evening thunderstorms caused by tropical storm Wendy.

3.2 Wendy developed into a tropical depression about 660 km east-southeast of Manila on 1 September 1999. Tracking north-northwestwards, Wendy intensified into a tropical storm on the night of 2 September 1999. At 1945Z 2 September 1999, Wendy was centered about 720 km to the east-southeast of Hong Kong. It adopted a northwestward course and headed toward the coast of Guangdong. Figure 3 shows the surface weather map at 00Z on 3 March 1999.

3.3 As a result of subsidence ahead of Wendy's approach, the weather over Hong Kong was sunny and hot on 3 September 1999. Afternoon temperature rose to 33 degrees, highest of the month. Isolated thunderstorms developed inland and moved southwest at around 07Z. Figure 4 shows the TDWR reflectivity and radial velocity data at 0.6-degree elevation (the lowest elevation scan) at 0737Z when –30 kt (~15 m/s) speed loss was detected close to the TDWR. In the figure, the detected windshear locations are indicated in the form of white "bandaid" shapes with speed losses given in knots near the centre of these shapes.

3.4 Analysis of Figure 4 reveals that apart from the area of divergence close to the TDWR, an area of convergence could be identified over the eastern approach / departure area. The maximum positive (outbound) radial winds was 10.5 m/s while the maximum negative (inbound) radial winds was around 3 m/s. This gives a wind speed gain of around 13 m/s. While the TDWR detected the microbursts, it was not equally successful in detecting this gust front. TDWR algorithm imposed a minimum length of 10 km for gust fronts to be warned to minimize false alarms. The relatively narrow width of the near-sea level gap between the high terrain to the north and south of the airport means that TDWR at Tai Lam Chung will not always be able to detect gust fronts in the vicinity of the airport. In this case, as the length of the convergence line was only 8 km, the TDWR did not generate any gust front.

3.5 Although the TDWR did not generate any gust front in this case, the windshear and turbulence warning system, which does not have a similar requirement, was able to generate a gain windshear shape with a maximum gain of 25 kt (~13 m/s) within the shape (indicated in the form of white polygon). At the same time, the system generated a 20 kt (10 m/s) gain alert for the RWY 07LD. This compares fairly well with the shear, 9.2 m/s, calculated from the 1-minute winds measured at TMT and R2E (see Figure 1 for location of TMT and R2E).

4. WINDSHEAR CAUSED BY LOW-LEVEL JETS

4.1 A number of forcing mechanisms have been proposed to explain the various aspects of low-level jets in a wide variety of environments, notably inertial oscillation, shallow baroclinicity and terrain effects, etc. Since the airport opened, two occasions of windshear due to low-level jets resulting from shallow baroclinicity have been observed. As the cold air moves south from Siberia, it becomes more shallow. Along the coastal region, the upper boundary of the cold air is sometimes near the 850 hPa level resulting in the formation of an inversion around that level. As a result of the strong temperature gradient, a low-level jet forms near the inversion.

4.2 A recent example of significant windshear caused by low-level jet is 31 January 2000. A replenishment of the winter monsoon reached southern China on 30 January 2000. The weather became cloudy with light rain the next day. Figures 5 and 6 respectively show the surface map on 31 January and the 00Z (08H local time) radiosonde ascent on 31 January 2000 at King's Park, around 25 km east of HKIA. Under the dominance of the monsoon, fresh northerlies prevailed at surface locally. This layer of cold air near surface was capped by a warm and moist southeasterly airflow at 850 hPa resulting in an inversion between 1 and 1.5 km. The presence of a low-level jet, with a maximum speed of 12.5 m/s, is also evident from the radiosonde ascent.

4.3 After take-off from RWY 07R at 0232Z on 31 January 2000, an aircraft experienced a gain in airspeed when flying from 2200 ft (670 m) to 3700 ft (1130 m) for a period of about half a minute (Figure 7). This was followed by a speed loss from 3700 ft (1130 m) to 4500 ft (1370 m) in the next 20 seconds or so. The gain in head wind component was about 35 kt (18 m/s) and the loss that followed was about 30 kt (15 m/s). According to the pilot, the airspeed reduced to within 2 kt (1 m/s) of stall speed before stabilizing despite a manual takeover and an aggressive pitch down. It was noted that departing flights preceding and succeeding the aircraft also experienced similar sequence of speed variations.

4.4 Based on the on-board data of the flight departed at 0232Z, during the airspeed gain phase, the average head wind gain was 2.3 kt per 100 ft (or 0.039 s^{-1}). When the aircraft experienced the most rapid loss in head wind, the shear was 4.1 kt per 100 ft (or 0.069 s^{-1}).

4.5 Data from the Sha Lo Wan wind profiler showed that the northerlies prevailed from surface up to about 600 m amsl (Figure 8). Winds then gradually veered to east-northeasterly and the speed increased to a maximum of about 35 kt (18 m/s) between 1000 m and 1100 m amsl. From 1100 m up to 1400 m amsl, winds moderated to 10-15 kt (5-8 m/s). The change in winds as captured by the profiler confirmed the existence of a low-level jet with a core located at about 1000 m to 1100 m amsl. The derived head wind sequence based on the wind profile at 0159Z (Figure 7) looked very similar to that actually observed by the aircraft departing at 0232Z. Nevertheless, the profiler had again measured a lower strength for the jet and the resultant estimated extent of loss was only 20-25 kt (10-13 m/s), comparing with a loss of 30 kt (15 m/s) as recorded by the aircraft.

4.6 This low-level jet was also evident on the TDWR 6-degree elevation scan (Figure 9). Winds were basically northerly near the surface as indicated by the zero isodop. Winds then veered gradually and a low-level east-northeasterly jet became discernible as a narrow region of positive velocity of around 15 m/s appeared around 10 km to the west of TDWR and a region of negative velocity of again around 15 m/s to the east. The core of this jet was determined to be near 3650 ft (1110 m) above ground, in good agreement with the altitude at which the aircraft experienced the greatest head wind.

4.7 It is interesting to note that to an aircraft climbing across a jet that flows towards the aircraft, the head wind change sequence (a wind gain followed by a sudden wind loss) that would be experienced is actually similar to what can be expected when a microburst is encountered. In fact, as there were some light rain around the airport, the pilot in this case had speculated the cause of the windshear to be a mild microburst.

5. TERRAIN-INDUCED WINDSHEAR AND TURBULENCE AT HKIA

5.1 As the HKIA is located to the immediate north of Lantau which is quite mountainous (see Figure 1 for topography of Lantau), when winds blow from the east through southwest, the new airport may also be affected on occasions by windshear and turbulence generated by hills. Since the airport opened, significant terrain-induced windshear at HKIA have been observed in both stably stratified conditions and deep uniform flow.

5.2 The windshear occurred on 8 March 1999 is a typical case of terrain-induced windshear under stably stratified conditions. A cold front crossed the south China coast early on 8 March 1999. On the surface, a ridge of high pressure extended from east China to the south China coastal areas behind the front (Figure 10). As a result, fresh to strong surface easterlies and apart from some rain recorded in the early hours cloudy weather affected HKIA the whole day.

5.3 The surface easterlies gradually veered with height to become southeasterlies at 925 hPa and southwesterlies at 850 hPa. The 12Z (20H local time) radiosonde ascent on 8 March 1999 at King's Park revealed shallow low-level inversions at around 750 m (0.2°C) and 1,940 m (1.0°C) (Figure 11) which corresponded to the respective local maxima of N^2, N being the Brunt-Väisälä frequency.

5.4 Although it was not raining at the time, as TDWR is highly sensitive, it was able to provide high-resolution data even under clear air conditions in this case. At 1137Z, the Doppler radial winds from the TDWR 0.6-degree elevation scan over the HKIA and its western approach were generally away from the radar (positive radial velocity), consistent with the low-level east-southeasterly flow. However, at about 3 nm (nautical miles) from the RWY 07R threshold, the radial winds away from the radar were apparently weaker.

5.5 This area of weaker positive radial winds became more prominent gradually and streaks of radial winds *towards* the radar (negative radial velocity) were seen downwind of NLS and Cheung Shan (CS) from time to time (see Figure 12 for the TDWR 0.6-degree elevation scan Doppler radial winds valid at 1243Z 8 March 1999 and Figure 1 for locations of NLS and CS). These streaks were rather narrow with typical width of about 1 km (equivalent to 13 seconds of flight time assuming an approach speed of 150 kt or 77 m/s), but at times, they joined together to form a larger area of radial winds *towards* the radar. Similar features were detected by the TDWR 1.0-degree elevation scan (the second lowest elevation scan, not shown).

5.6 The 2.4-degree elevation scans of the TDWR during the same period revealed a general veering of winds with height, similar to the radiosonde profile at King's Park. However, a streak with negative radial velocity could be seen downwind of NLS and Lantau Peak in the background of radial winds away from the radar (Figure 13). This streak of negative radial velocity displayed unsteady wave-like behaviour in animation sequence of the 2.4-degree elevation scans at 5-minute update rate.

5.7 At the same time, a number of pilots of aircraft landing at HKIA reported encountering windshear after 12Z on this day. In particular, at around 1230Z, a pilot reported +20 kt (+10 m/s) and then –20 kt (-10 m/s) windshear on approach to RWY 07R (i.e. approach from the west-southwest) and had to undertake a go-around. The plane finally landed at around 1243Z. The following aircraft, first attempted to land at 1232Z, finally diverted to Macau after encountering up to 20 kt (10 m/s) windshear on final approach.

5.8 On-board aircraft data from a later flight arriving at 1252Z shows that the aircraft observed winds were basically southeasterlies as the flight descended from 2,300 ft to 1,350 ft amsl (7 to 4 nm from touchdown) (Figure 14). The wind direction then varied significantly, veering to southwest and then northwest as the wind speed dropped markedly to below 5 kt (3 m/s). As the plane continued its descent, the wind direction again changed significantly to northeast at about 800 ft amsl (2.5 nm from touchdown) before veering to southeast as the wind speed increased to 10 to 15 kt (5-8 m/s). The aircraft data thus confirmed the existence of mountain wake with reverse flow (albeit weak) downwind of the northeast- southwest oriented ridge southwest of NLS.

5.9 At about 650 ft amsl (2 nm from touchdown), there was a sudden increase of the aircraft observed winds from the east and southeast. This increase of the winds from the east and southeast brought a gain in head wind to the aircraft. As the aircraft was downwind of the valley at Sham Wat between NLS and CS at this location, it is reasonable to conclude that it was related to the complex flows around NLS and CS.

5.10 From the above analysis, the terrain-induced windshear downwind of complex terrain such as Lantau can be of many spatial scales. While the individual streaks could be very narrow, of the order of 1 km, these streaks could interact and join together to form larger spatial streaks.

5.11 The above discussion focused on terrain-induced windshear under stably-stratified condition. While this is by far the most significant type of windshear at HKIA, terrain-induced windshear in deep uniform flow were also observed at HKIA, especially in the year 1999 when Hong Kong was hard hit by tropical cyclones.

6. TRAINING ISSUES

6.1 With the introduction of a suite of new meteorological equipment for windshear detection, a major effort was put on the training of the related personnel. The training was not only limited to the forecasters, air traffic controllers and maintenance personnel, a significant part of the effort was on informing the pilots how the systems work and the meaning of the alerts.

6.2 Before the airport opened, a working group with representative from pilots and air traffic controllers was established to lay down the terminology to be used to relay the alerts to the pilots. Information on the system and alerts to be issued are then promulgated in the Aeronautical Information Publication (AIP).

6.3 A large-scale briefing was held in April 1997 to inform the users of the characteristics of terrain-induced windshear and turbulence at HKIA. The briefing was reasonably well received with over 70 participants from various airlines.

6.4 As many pilots flying to Hong Kong had not had the opportunity to attend the briefing, in order to reach a larger audience the HKO had published a brochure on "Windshear and Turbulence Detection for the new airport at Chek Lap Kok" for distribution to all airlines before the airport opened. This was subsequently adapted for publication in the Journal of the British Air Line Pilots Association – "The Log". The HKO also worked with the Hong Kong Airline Pilots Association to publish a special supplement on "Windshear & Turbulence Alert! - Windshear Alert and Turbulence Systems at Chek Lap Kok".

6.5 Apart from the above publications, latest information on windshear and turbulence detection is promulgated in the Aeronautical Information Circular and as amendments to the AIP. Latest findings in respect of windshear and turbulence at HKIA are also published by the HKO in the half-yearly newsletter – "Weather on Wings". A web site, containing latest information on windshear and turbulence warning service at HKIA, has also been developed to provide a centralised location to facilitate access by users.

7. CONCLUSION

7.1 In this paper, three cases of windshear arising from different phenomena are presented. In all these cases, the TDWR which contributes to HKO's windshear and turbulence warning service has proved to be very useful in observing these phenomena.

7.2 Windshear can be caused by many other phenomena such as land/sea breeze, frontal systems etc. The HKO is studying the windshear reported since the HKIA opened to better understand their cause and assess the performance of the various windshear detection systems.

Pilots and air traffic controllers nowadays are fairly knowledgeable about windshear in general. However it is still important for the nature of windshear and the performance of the equipment of the airport concerned to be communicated to the users to facilitate their decision making. In the past two years since the airport opened, much has been learned in these areas. The HKO has plans to produce a new information package for the users.

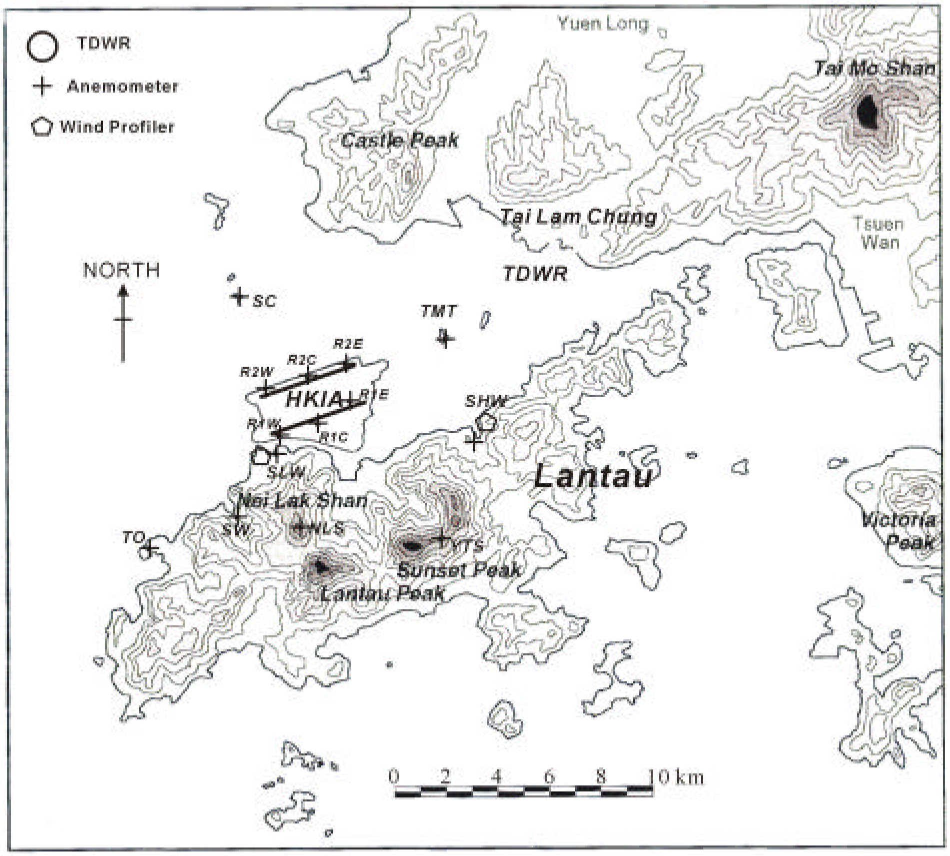


Figure 1 Map of HKIA and its surrounding areas. Terrain contours are given in 100 m intervals.

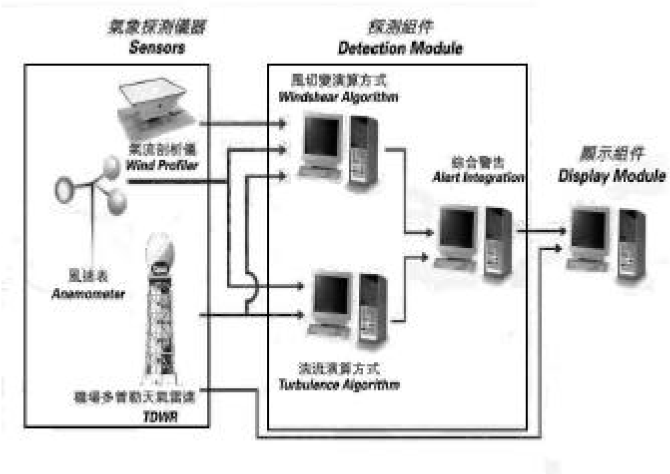


Figure 2 Functional block diagram of windshear and turbulence warning system

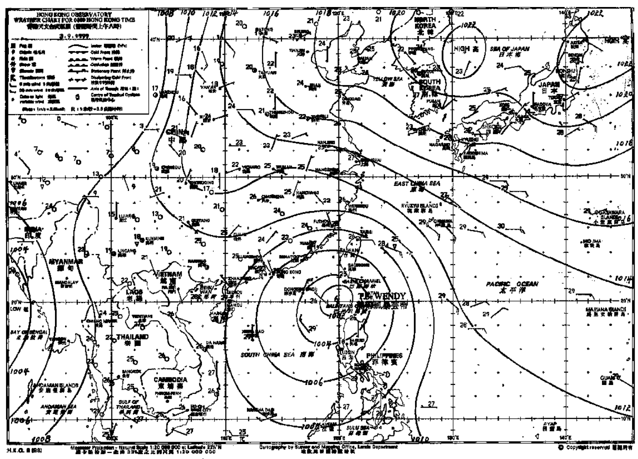
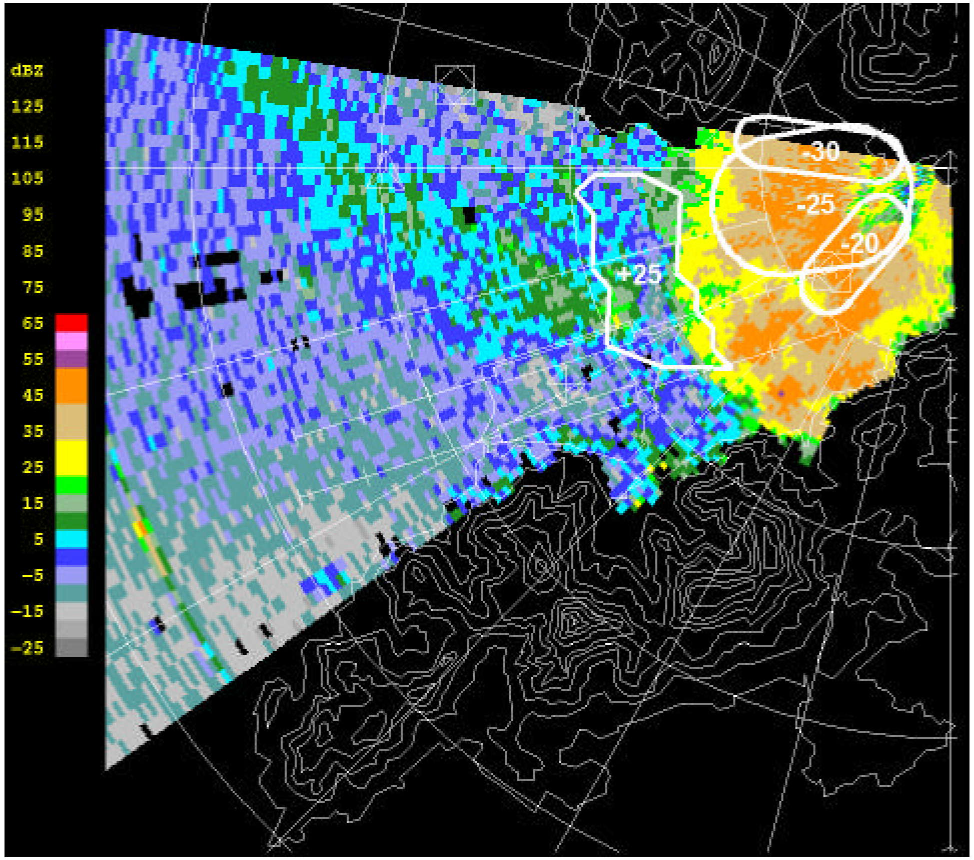
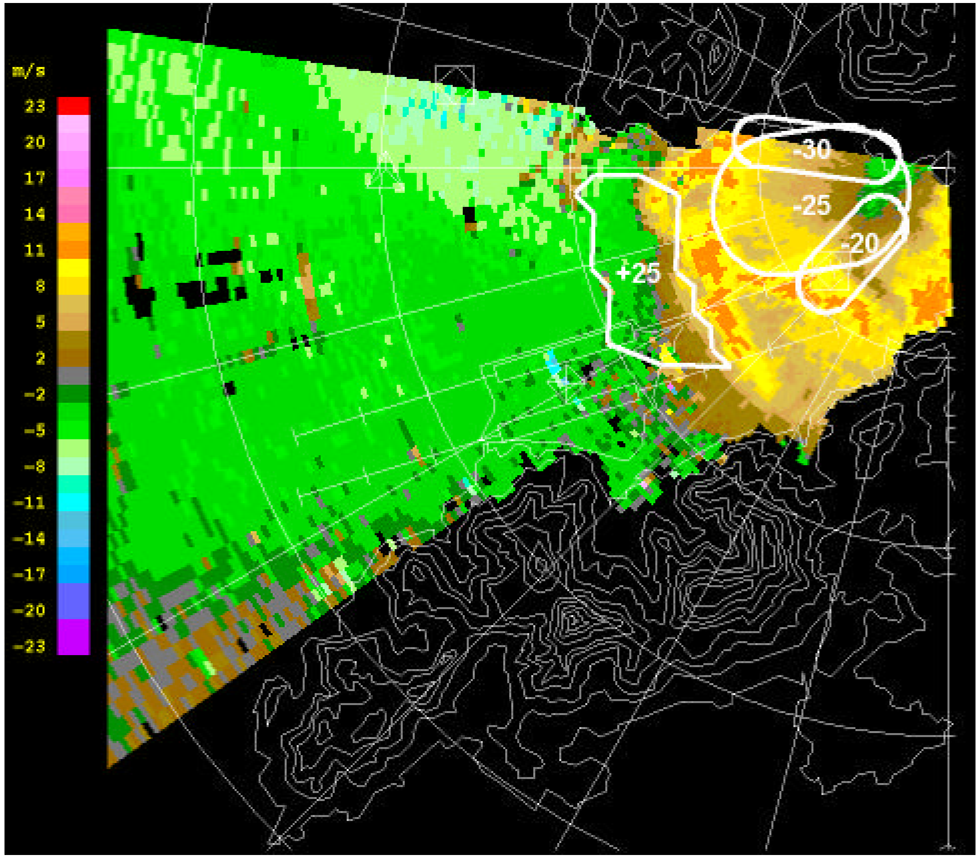


Figure 3 Surface weather chart as at 00Z on 3 September 1999



(a)



(b)

Figure 4 TDWR (a) reflectivity and (b) Doppler radial velocity at 0.6-degree elevation scan at 0737Z 3 September 1999

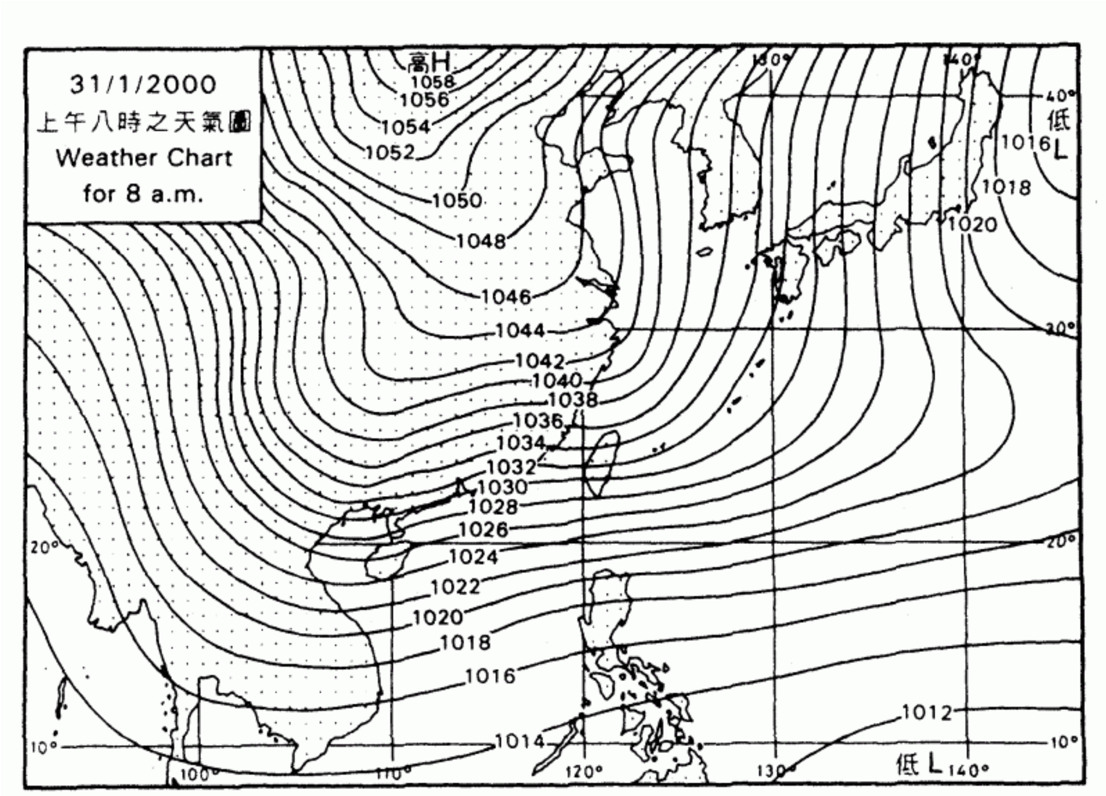


Figure 5 Surface weather chart valid at 00Z 31 January 2000

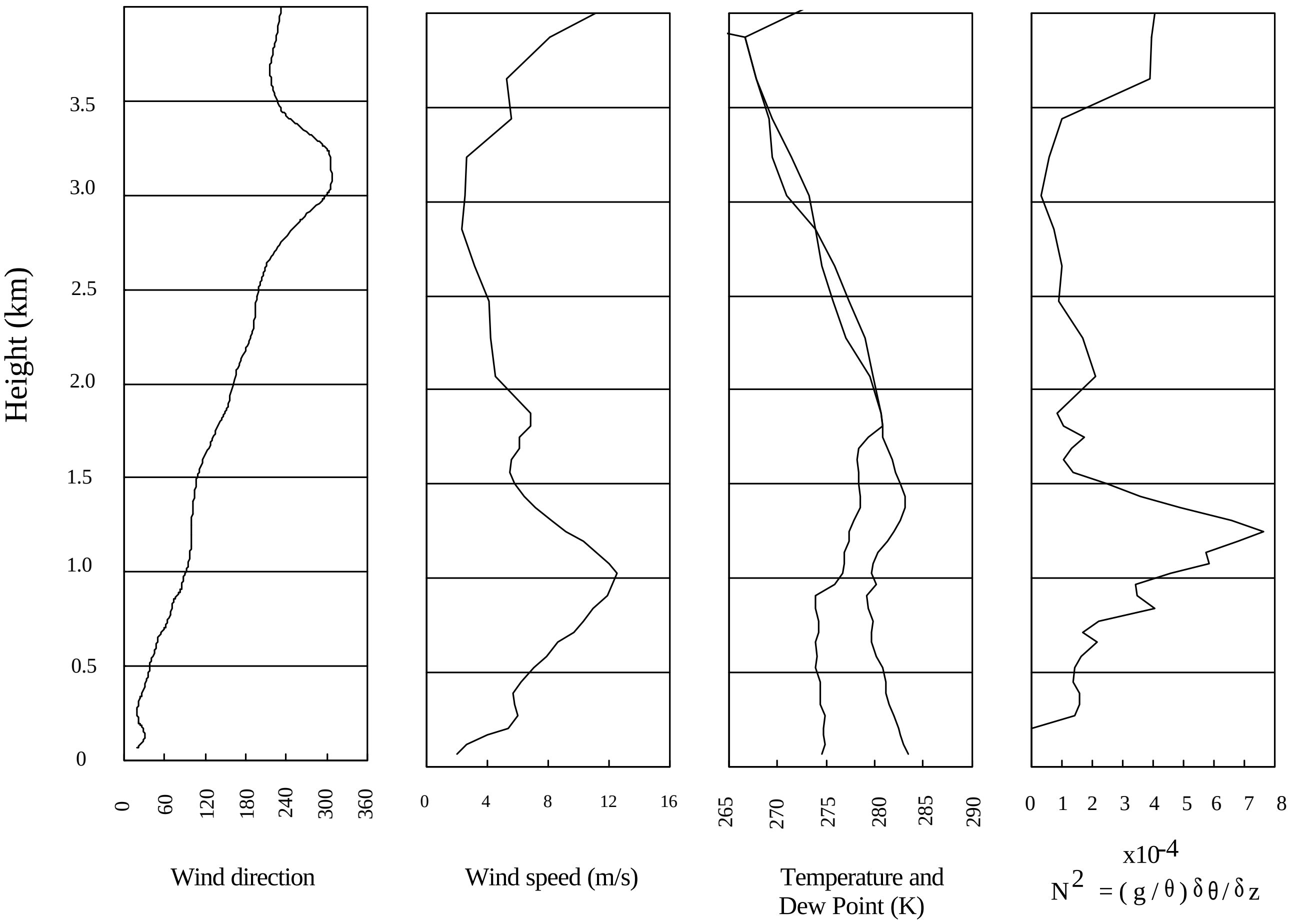


Figure 6 Variation of wind direction, speed, temperature, dew point and N^2 based on the King's Park radiosonde ascent valid at 00Z 31 January 2000

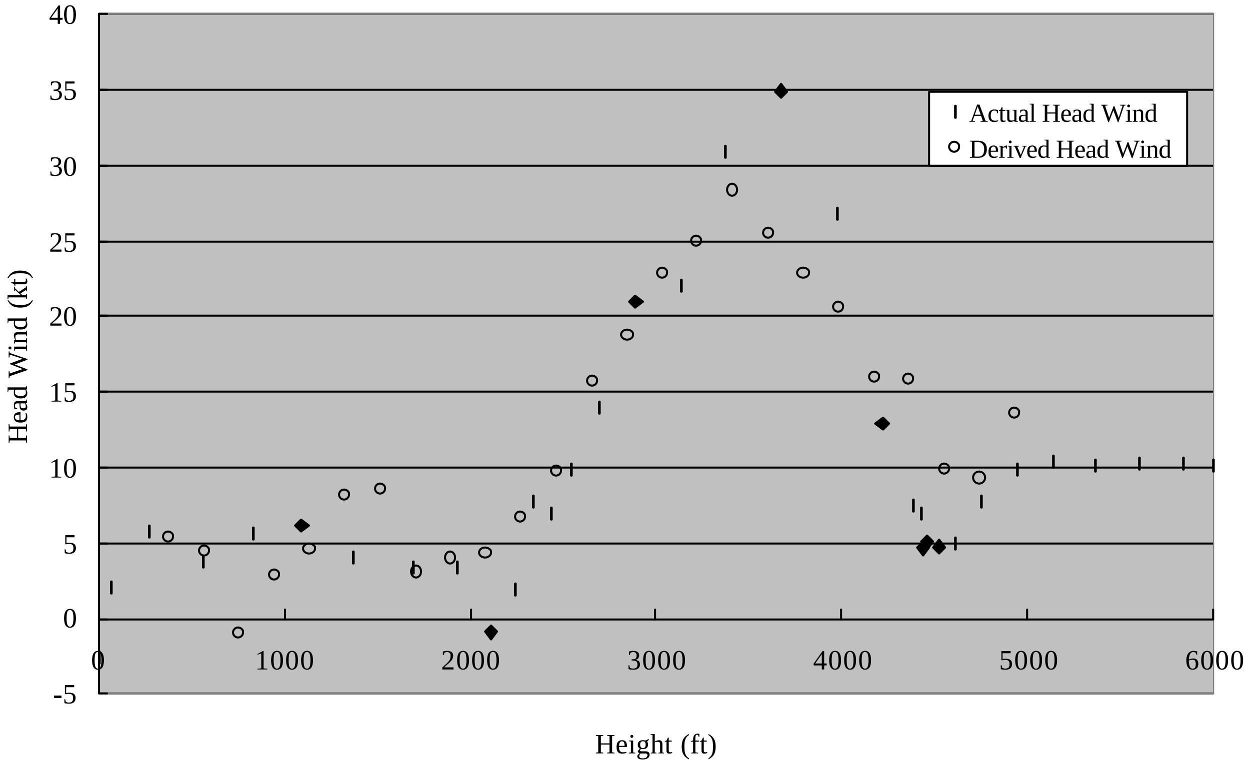


Figure 7 Actual head wind sequence experienced by aircraft. Derived head wind was computed based on vertical profile at 0159Z by Sha Lo Wan wind profiler

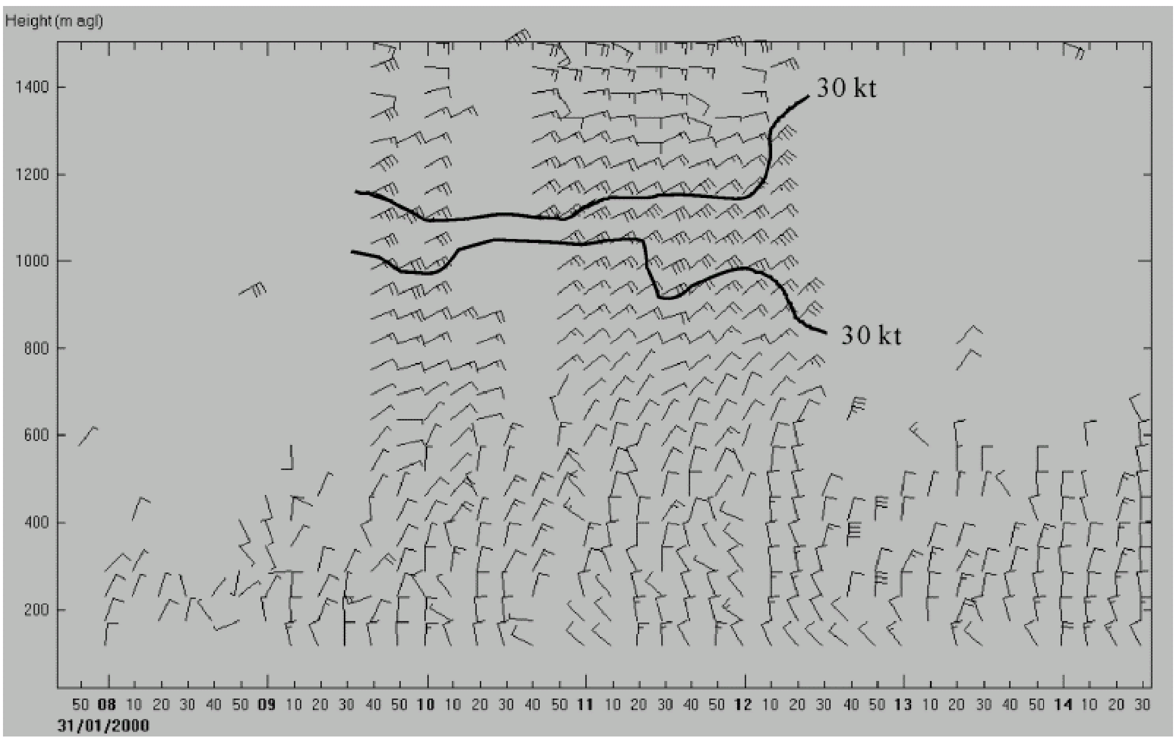


Figure 8 Vertical profiles of winds recorded at Sha Lo Wan on 31 January 2000

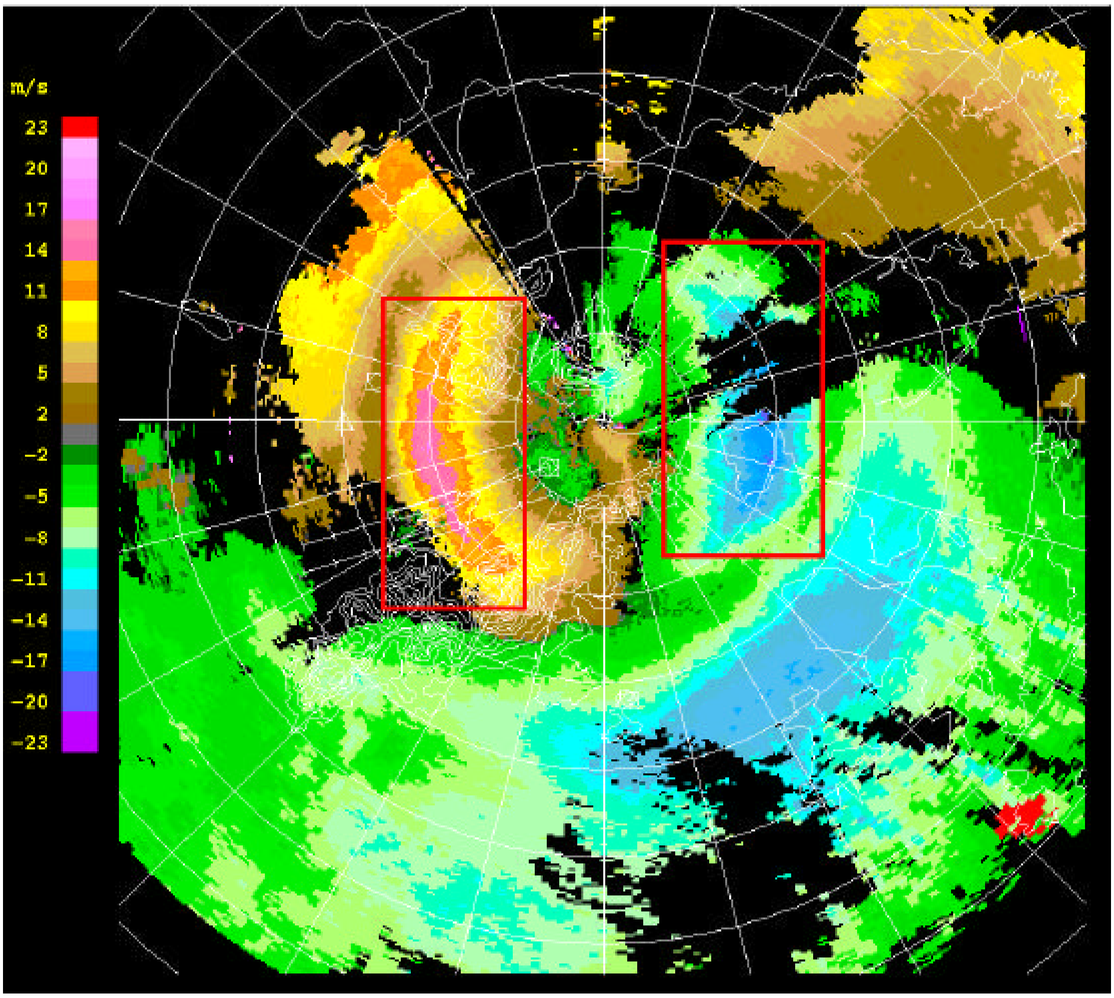


Figure 9 TDWR Doppler radial velocity at 0.6-degree elevation valid at 0217Z 31 January 2000

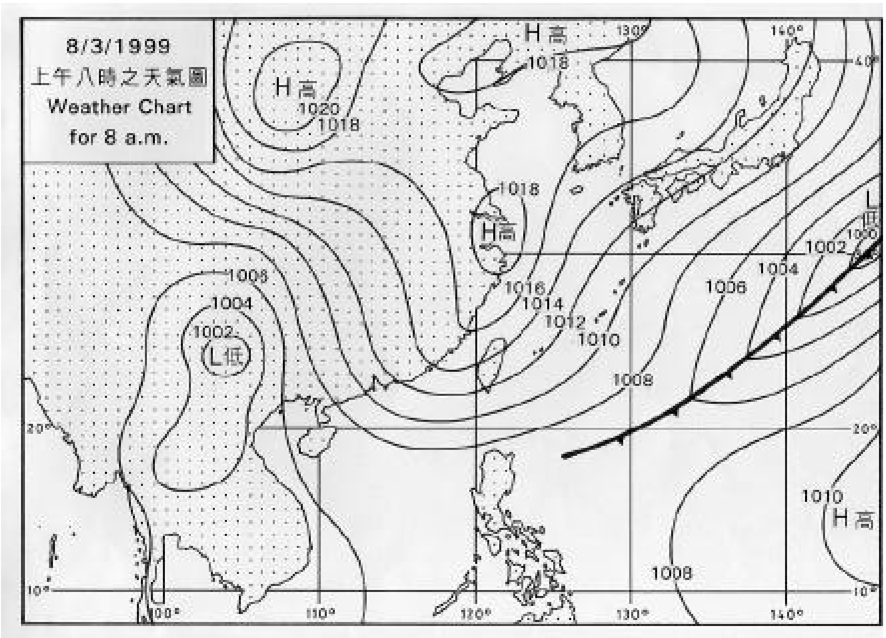


Figure 10 Surface weather chart valid at 00Z 8 March 1999

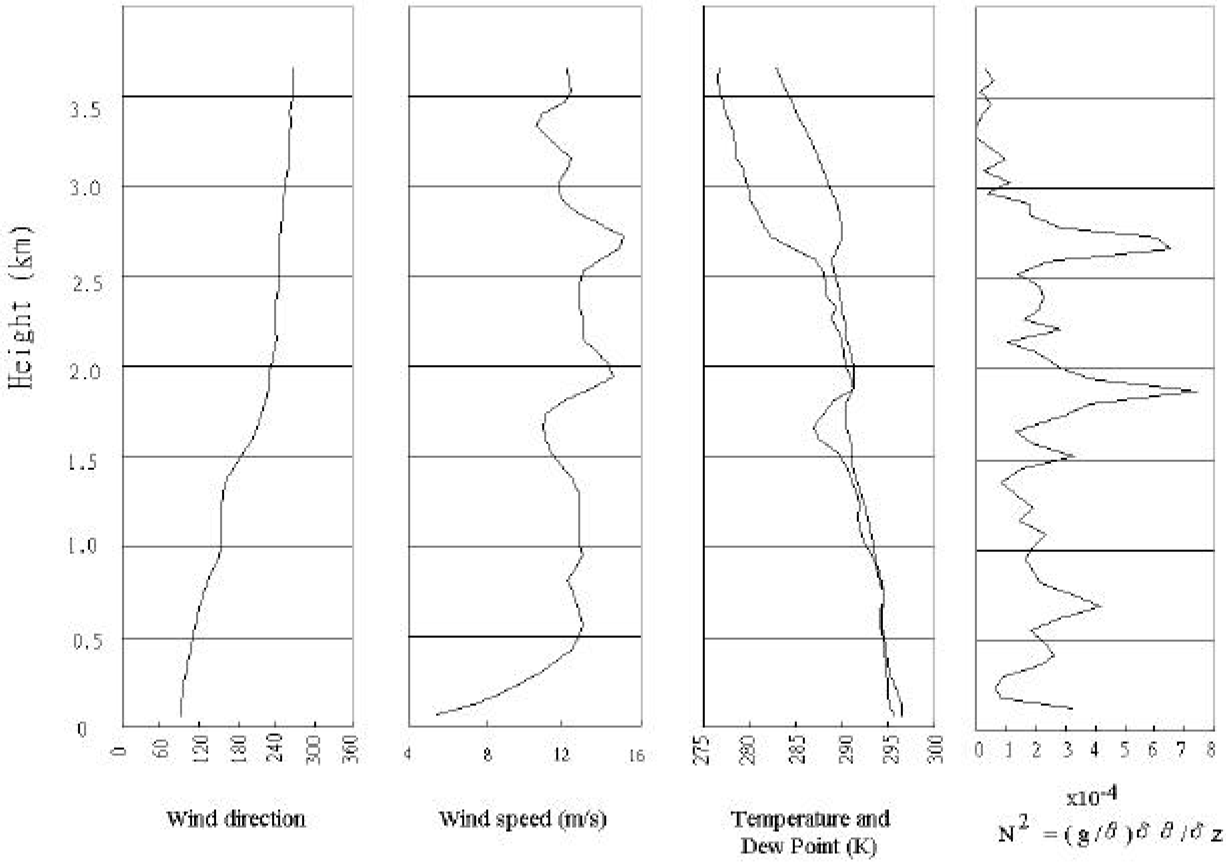


Figure 11 Variation of wind direction, speed, temperature, dew point and N^2 based on the King' s Park radiosonde ascent valid at 12Z 8 March 1999

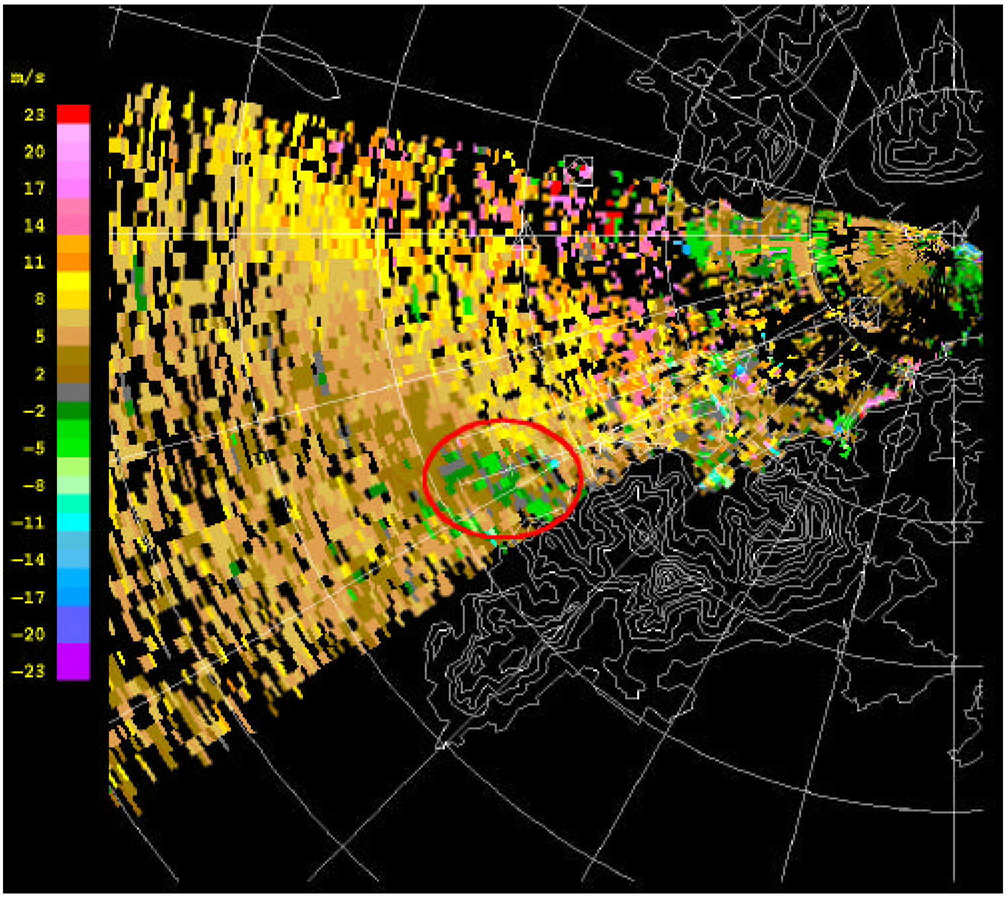


Figure 12 TDWR Doppler radial winds at 0.6-degree elevation valid at 1243Z 8 March 1999

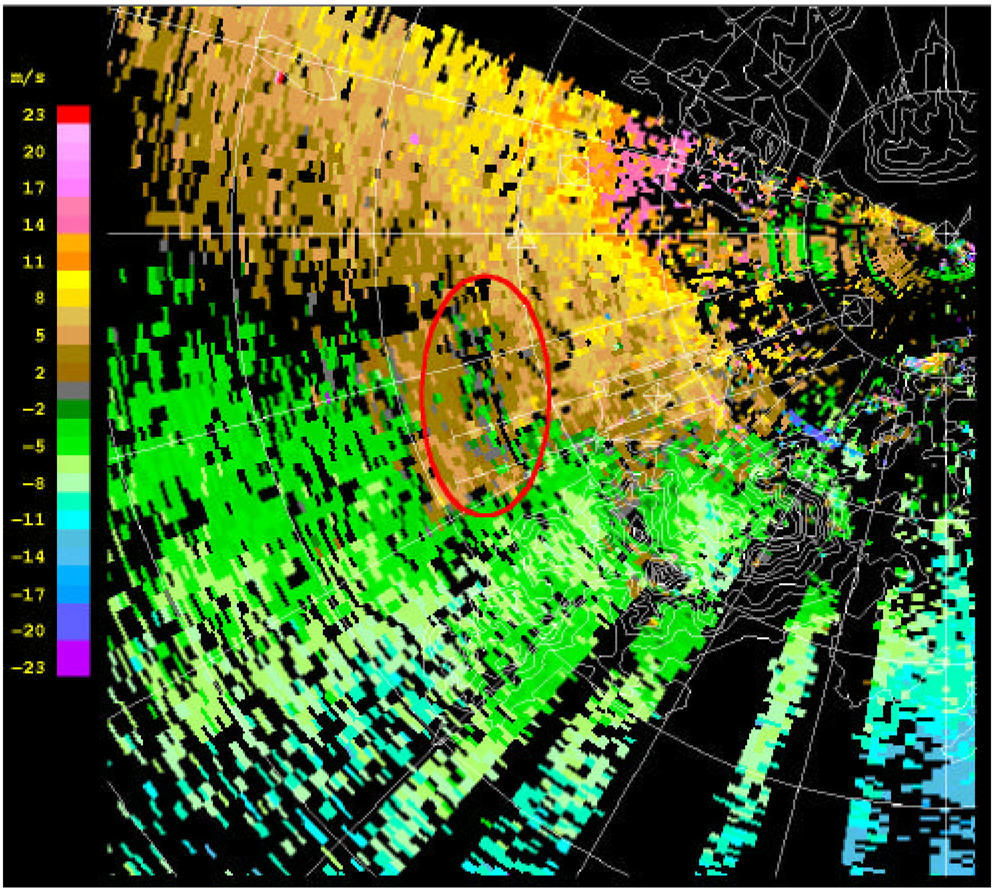


Figure 13 TDWR Doppler radial winds at 2.4-degree elevation valid at 1244Z 8 March 1999

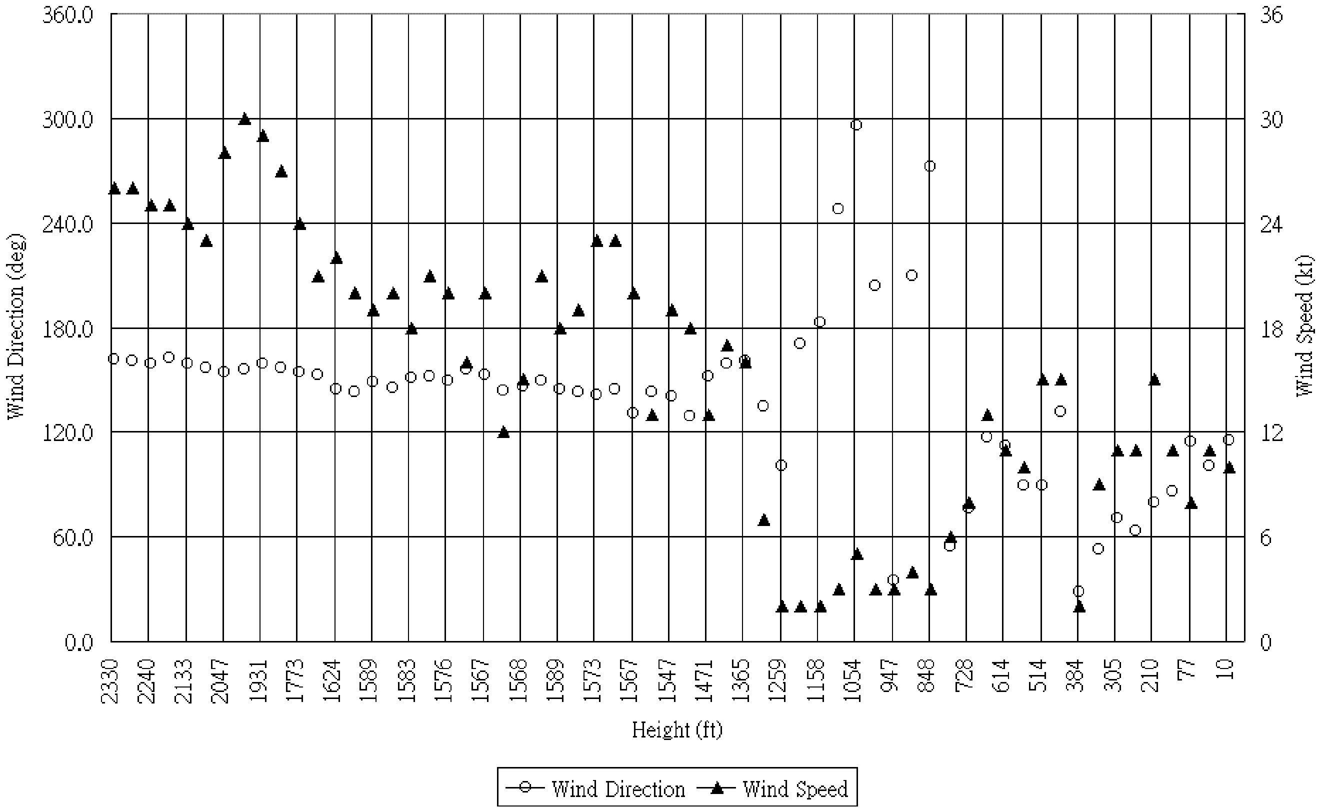


Figure 14 On-board aircraft observed wind direction and speed against the radio height. Data were available every 4 seconds.