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Remote Sensing of Windshear under Tropical Cyclone Conditions in Hong Kong

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1. Introduction

Since the opening of the new Hong Kong International Airport (HKIA) in mid-1998, Hong Kong experienced the passage of a number of tropical cyclones which brought strong winds to the airport. When winds came from a general southerly direction, they were disturbed by the terrain of Lantau Island to the south of the airport. Under such strong wind conditions, the disturbed airflow downwind of Lantau was found to bring significant windshear to aircraft landing at or taking off from the airport. This paper presents the terrain-induced windshear conditions during the recent passage of tropical cyclone Hagupit as observed by the Terminal Doppler Weather Radar (TDWR), and discusses the implementation of a Doppler LIght Detection And Ranging (LIDAR) system being undertaken to further enhance the windshear alerting service.

2. Background

The Hong Kong Observatory (HKO) provides windshear alerting service for the HKIA which was built on reclaimed land to the north of the mountainous Lantau Island. Figure 1 illustrates the complex terrain of Lantau Island, the location of the HKIA, and its approach/departure corridors relative to this terrain. The ENE-WSW oriented island has a width of about 5 km and length of about 20 km. In the middle of Lantau, a U-shape ridge with peaks rising to between 750 and 950 m above mean sea level (amsl) and mountain passes as low as 350 to 450 m amsl separating these peaks. The presence of water bodies and mountainous terrain makes the air flow rather complex over the airport and its vicinity.

Experience over the past few years indicates that windshear at the HKIA can be caused by a wide variety of phenomena, including wind blowing across hilly terrain, thunderstorm, gust front, tropical cyclone, sea breeze, low-level jet, strong monsoon wind, and cold and warm fronts. To facilitate the provision of the windshear alerting service for the HKIA, a TDWR located at about 12 km northeast of the airport scans the atmosphere continuously to detect microburst and windshear associated with convective storms [1]. The TDWR is essentially the same system installed by the US Federal Aviation Administration at 45 US airports and is the first such system installed in Asia. This, together with a network of ground-based anemometers over and in the vicinity of the HKIA and two wind profilers over Lantau, form the low-level windshear detection facilities at the airport. To enhance the windshear detection capability in rain-free conditions, the HKO installed in mid-2002, on an experimental basis, a Doppler LIDAR system at the HKIA [2]. See Figure 1 for location of the airport and the weather sensors.

To provide automatic windshear alerts to end users, a Windshear and Turbulence Warning System (WTWS) processes data from the TDWR and ground-based anemometers and integrates them into alphanumeric windshear alert messages to air traffic control personnel for onward transmission to arriving and departing aircraft in real time. To supplement the automatic alerts, the observational data from the suite of weather sensors is also used by the aviation forecaster for issuing windshear alerts to pilots via the Automatic Terminal Information Service (ATIS) broadcasts from the airport.

3. Terrain-induced Windshear Brought by Tropical Cyclone Hagupit

Hagupit (0218) first developed as a tropical depression at about 140 km southeast of Dongsha Dao on 10 September 2002 and moved steadily west-northwest over the northern part of the South China Sea. It intensified rapidly into a tropical storm the same night and became a severe tropical storm on 11 September as it edged closer to Hong Kong. The maximum wind speed near its center was about 110 km/h. Figure 2 shows the track of Hagupit near Hong Kong.

Locally, winds in Hong Kong strengthened from the east on 11 September and in the afternoon, winds offshore and on high ground reached storm force as they veered to southeast. Hagupit was closest to Hong Kong in the afternoon when it was about 150 km to the south-southwest. At around the same time, strong east-southeasterly winds prevailed over the airport with gale to storm force winds blowing over the hilltops of Lantau Island.

Between 1430 and 2230 HKT (HKT = UTC + 8 hours) on 11 September, twenty-three flights on approach to the HKIA had to go around due to windshear. Figure 3 shows the surface winds measured by ground-based anemometers in the vicinity of the airport at 1430 HKT. While there was a gradual veering of the airport winds in the subsequent hours from easterly to southeasterly, a common wind pattern could be identified from Figure 3 which persisted throughout the afternoon and in the evening, viz. the coupling of strong east to southeasterly winds over the airport with gale to storm force southeasterly winds over the hilltops (NLS (Nei Lak Shan) and YTS (Yi Tung Shan)) and valleys (PKA (Pak Kung Au) and TFA (Tai Fung Au)) of Lantau Island. This wind pattern represents one of the typical conditions bringing terrain-induced windshear to the HKIA. In simple terms, aircraft approaching the airport from the west would first experience significant crosswinds before encountering strong low-level headwind from the east, resulting in windshear.

Figure 4 shows the Doppler radial velocity observed by the TDWR at 0.6 degree elevation angle at 1503 HKT, with the ‘warm’ colours (brown, yellow and pink) representing radial velocities away from the radar and the ‘cool’ colours (green, blue and purple) representing radial velocities towards the radar. On the lee side of the Lantau terrain, there were several WNW-ESE oriented streaks of high wind, with maximum velocities exceeding 20 ms^{-1}. In between these high-speed streaks were low-speed streaks, with velocities of just several metres per second. The large difference in winds across these adjacent high-speed and low-speed streaks meant that an aircraft flying through this region would experience appreciable fluctuations in the headwind. The automatic algorithms of the TDWR successfully detected significant windshear (a change of headwind of 15 knots or above), as shown in Figure 5 which presents the TDWR product display at the same time. The display contains windshear information in both graphical and alphanumeric formats for the air traffic controller to relay to landing or departing aircraft. An aircraft which attempted to land from the west at about the same time had to conduct a go-around on account of the windshear.

During similar occasions when Hong Kong was affected by tropical cyclones, the TDWR was capable of observing such terrain-induced wind patterns and provided alerts of windshear. Figure 6 shows the Doppler radial velocity observed by the TDWR at 0.6 degree elevation angle at 2144 HKT on 6 July 2001 during the passage of tropical cyclone Utor (0104). On this occasion, after Utor made landfall and moved inland some 200 kilometres to the northwest of Hong Kong, strong southerly winds blew over the Lantau terrain towards the airport. Similar to Figure 4, high-speed and low-speed streaks oriented in the NNE-SSW direction were again evident in Figure 6, bringing significant windshear over the airport approaches. Indeed, an aircraft which attempted to land in such conditions also experienced significant windshear and had to go around. An analysis of this case based on TDWR data and on-board wind data collected by the aircraft concerned was presented in [3].

The above two cases (the passage of Hagupit and of Utor) exhibited striking similarities in the TDWR Doppler radial velocity patterns, namely the presence of alternating high-speed and low-speed streaks oriented roughly in the prevailing wind direction. Close examination of the TDWR data revealed that the high-speed streaks originated from the valleys of Lantau whereas the low-speed streaks tied in well with the mountain peaks of Lantau. See Figure 7 for a schematic diagram illustrating the observed phenomena in relation to the terrain.

While the broad existence of these terrain-induced streaks could be forecast based on the winds expected at the airport and on the hilltops of Lantau, it is observed however that these streaks exhibited on the TDWR large temporal variations in their strength and structure. As a result of this transient and sporadic nature of the windshear, even though the weather conditions may remain generally similar, some aircraft did experience significant windshear while other preceding or succeeding ones did not. For this, the HKO embarked on a programme this year to better inform pilots using the airport and familiarize them with the windshear and turbulence situation in Hong Kong (see Section 5 below).

4. Terrain-induced Windshear Observed by LIDAR

The Doppler LIDAR system installed in late June 2002 operates by emitting pulses of infrared light into the atmosphere. The infrared light, at 2 μm wavelength, is reflected back by dust particles or aerosols in the air. By comparing the shift in the frequency of the reflected light with that of the original emitted light, i.e. the Doppler shift, the radial component of the winds in the atmosphere can be measured. It should be noted that infrared light is easily absorbed by water droplets in precipitation, thereby limiting the performance of the LIDAR in rainy weather.

The LIDAR system is strategically placed near the centre of the airport between the two parallel runways. See Figure 1 for location of the LIDAR. At this location, the LIDAR is able to scan the flight departure and approach corridors of both runways (Figure 8). It is currently configured to perform sector scans at three different elevation angles between 1.0 degree and 4.5 degrees, to enable the monitoring of wind conditions out to about three nautical miles (5.6 kilometres) beyond the respective runway thresholds. LIDAR data are collected automatically and are updated about once every two minutes.

Since its installation, the LIDAR has already captured some interesting windshear events under fine weather conditions, such as those associated with the onset of sea breeze. Although the LIDAR works best under fine weather conditions, it did capture the terrain-induced windshear brought about by Hagupit at a time when the rain had subsided. Figure 9 shows the Doppler radial velocity observed by the LIDAR at 1.0 degree elevation angle at 1900 HKT on 11 September 2002. Over the approaches to the west of the airport, streaks of high wind speed and low wind speed similar to those revealed by the TDWR in Figure 4 could be observed (at this time the TDWR no longer detected such pattern with the passage of rain). Indeed, around this time another aircraft had to go around due to windshear. This demonstrates the complementary role the LIDAR could play in detecting windshear even under tropical cyclone conditions. This case illustrates how the combination of the TDWR and the LIDAR can assist in covering all weather conditions that can exist during the passage of severe weather systems.

5. Future Work

To summarize, the high-resolution observations collected by the TDWR during the passage of tropical cyclones in the past few years have assisted the HKO in better understanding the characteristics of terrain-induced windshear. To promulgate the knowledge and experience so obtained, the HKO conducts regular briefings and prepares educational material for pilots, air traffic controllers and the international aviation community. An example is a booklet prepared jointly by the HKO and the International Federation of Air Line Pilots' Associations (IFALPA) on "Windshear and Turbulence in Hong Kong – information for pilots" (Figure 10) which is available in hardcopy as well as on the Internet website of the HKO (http://www.weather.gov.hk/aviat/articles/WS-turb-booklet-web-ver.PDF). The booklet gives information on the characteristics of windshear and turbulence, typical scenarios that cause them, their alerting principles and terminology. The importance of effective communication between service providers and end users in the provision of aviation meteorological services has been stressed by international bodies including the World Meteorological Organization (WMO) and International Civil Aviation Organization (ICAO). The HKO is committed to undertake further work in this direction.

As regards the LIDAR implementation, the HKO will continue the ongoing data collection and analysis work over a period of time with a view to developing additional application software and optimizing the functionality of the system. As presented in this paper, LIDAR observations so far are encouraging and the aviation forecaster is already making use of its data in preparation of aerodrome forecasts and issuance of windshear alerts. A plan is in place to post-process the LIDAR data so that it may be better integrated with the existing weather facilities. The LIDAR is expected to become fully operational in 2005.

References

1. Shun, C.M. and D.B. Johnson, 1995: 'Implementation of a Terminal Doppler Weather Radar for the new Hong Kong International Airport at Chek Lap Kok'. *Preprints, Sixth Conf. on Aviation Weather Systems (Dallas, Texas),* American Meteorological Society, Boston, 530-534.

2. Shun, C.M. and S.Y. Lau, 2002: 'Implementation of a Doppler Light Detection And Ranging (LIDAR) System for the Hong Kong International Airport', *Preprints, Tenth Conf. on Aviation, Range and Aerospace Meteorology (Portland, Oregon),* American Meteorological Society, Boston, 255-256 *(Note: two pages of the paper is missing in the conference preprints. The complete paper can be downloaded from the AMS website at http://ams.confex.com/ams/pdfview.cgi?username=39018 or from the HKO website at http://www.weather.gov.hk/publica/reprint/r454.pdf).*

3. S.Y. Lau and C.M. Shun, 2002: 'Terrain-induced Wind Shear during the Passage of Typhoon Utor near Hong Kong in July 2001', *Preprints, Tenth Conf. on Mountain Meteorology and MAP meeting (Park City, Utah),* American Meteorological Society, Boston, 433-436.

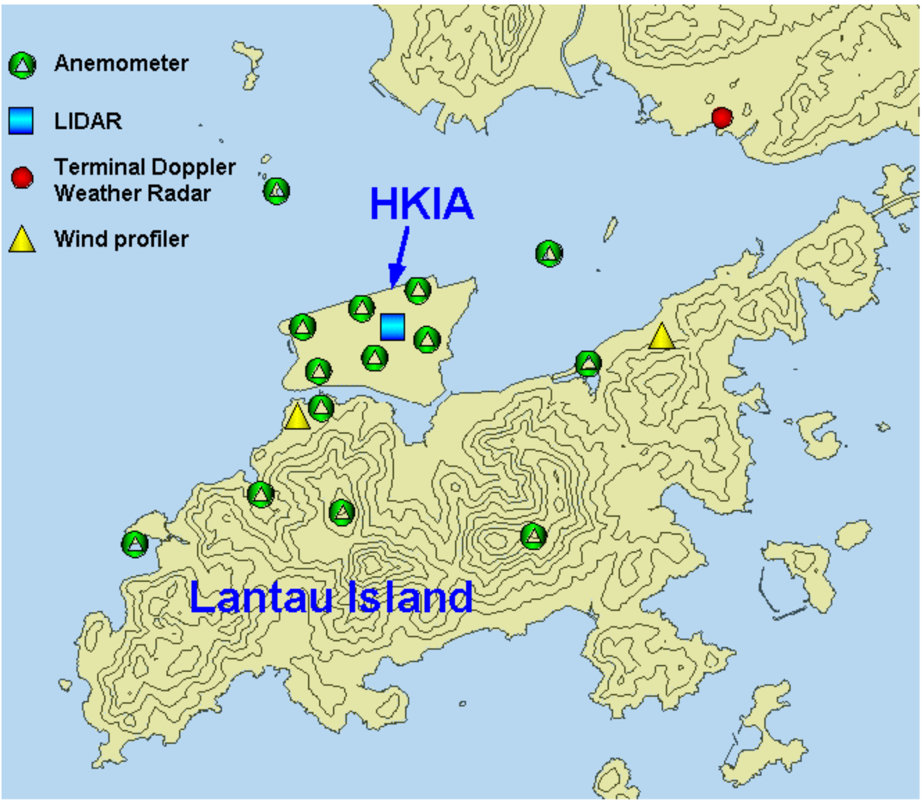

Figure 1. Location of the Hong Kong International Airport (HKIA) and weather sensors. Terrain contours are given in 100 m intervals.

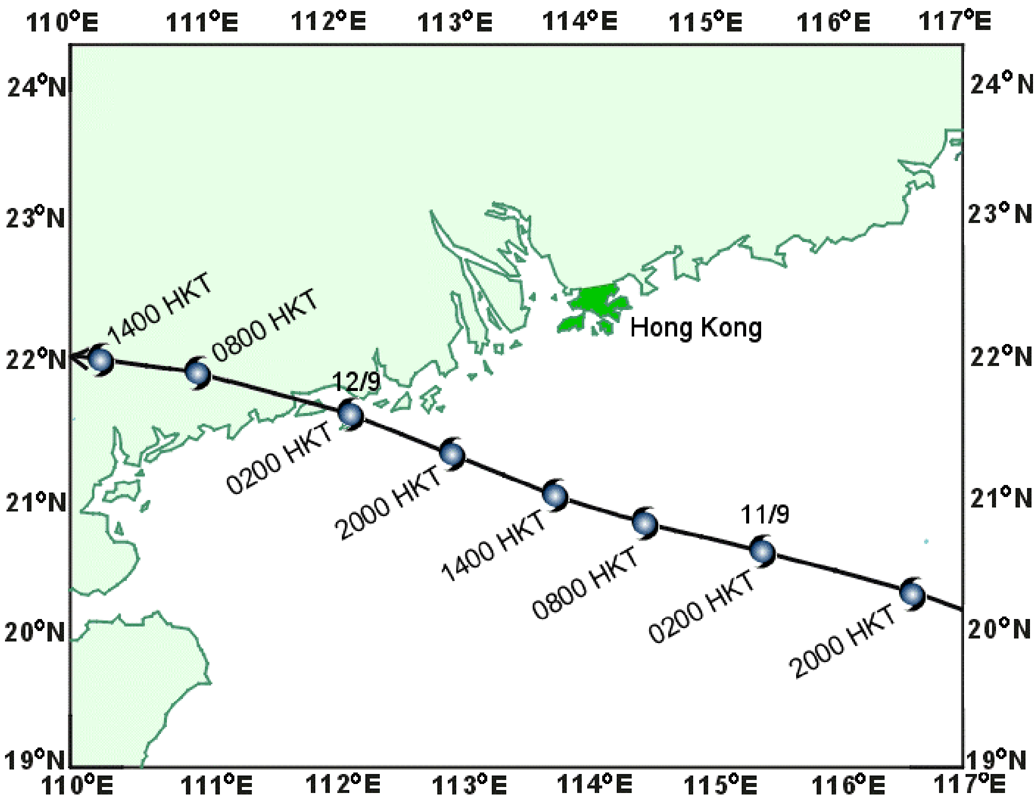

Figure 2. Track of Hagupit near Hong Kong.

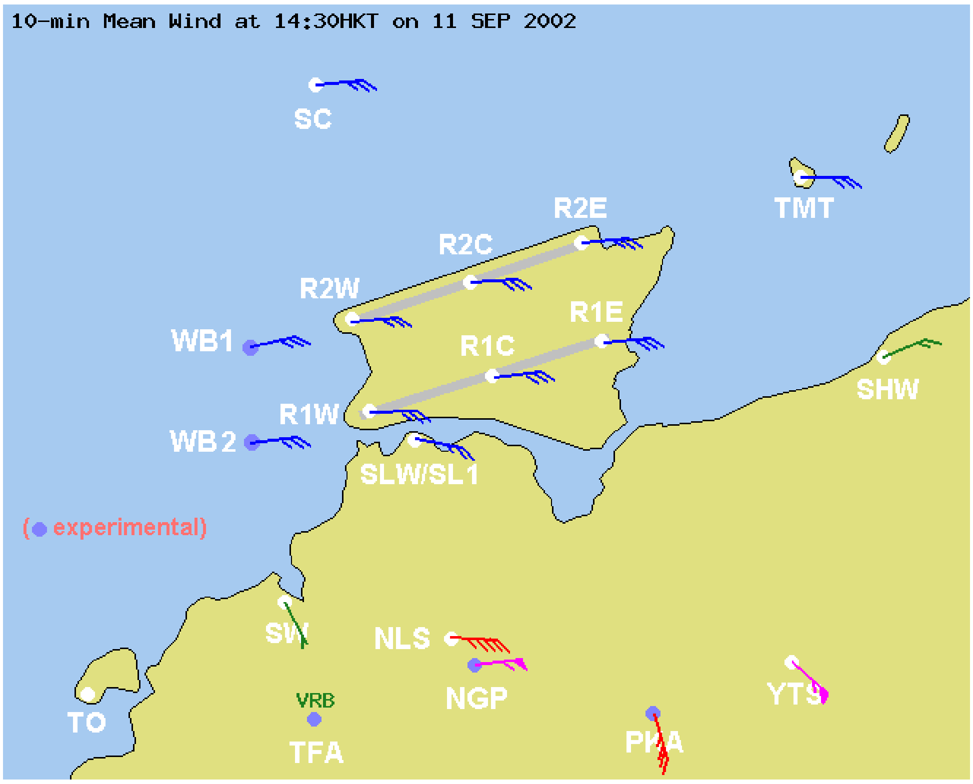

Figure 3. Surface winds in the vicinity of the airport at 1430 HKT on 11 September 2002.

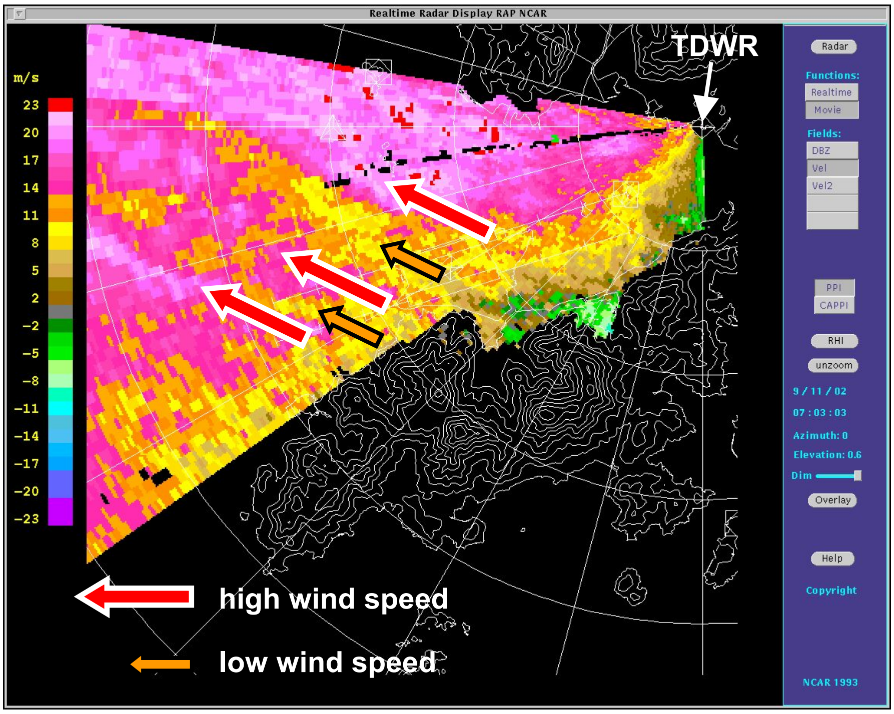

Figure 4. TDWR Doppler radial velocity at 0.6 degree elevation angle at 1503 HKT on 11 September 2002 revealing the presence of streaks of high wind speed and streaks of low wind speed.

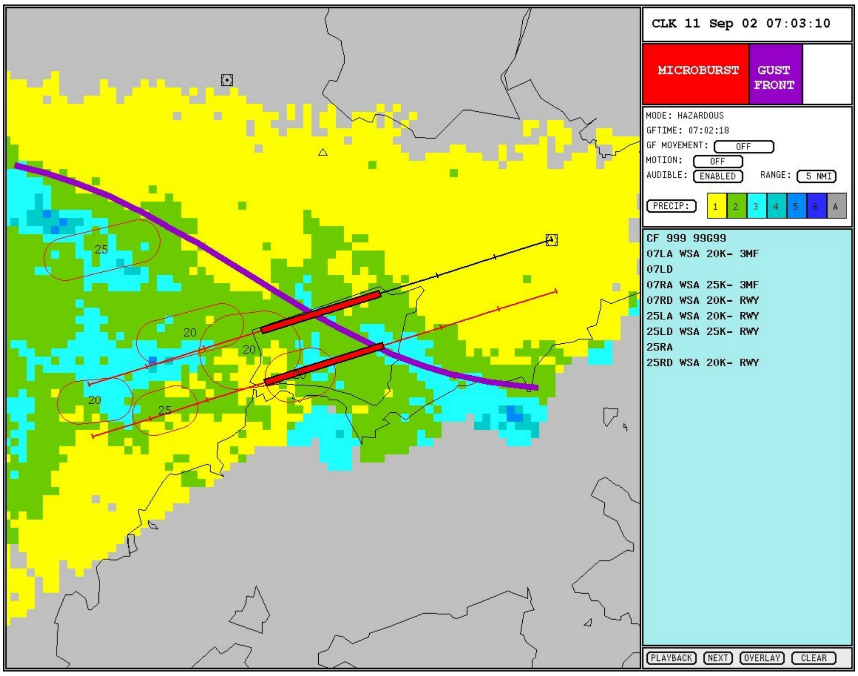

Figure 5. TDWR product display at 1503 HKT on 11 September 2002 presenting windshear information in graphical and alphanumeric formats. In the left hand panel, the 'bandaid' shapes in red represent areas bringing windshear with headwind loss whereas the purple line represents a convergence zone bringing windshear with headwind gain.

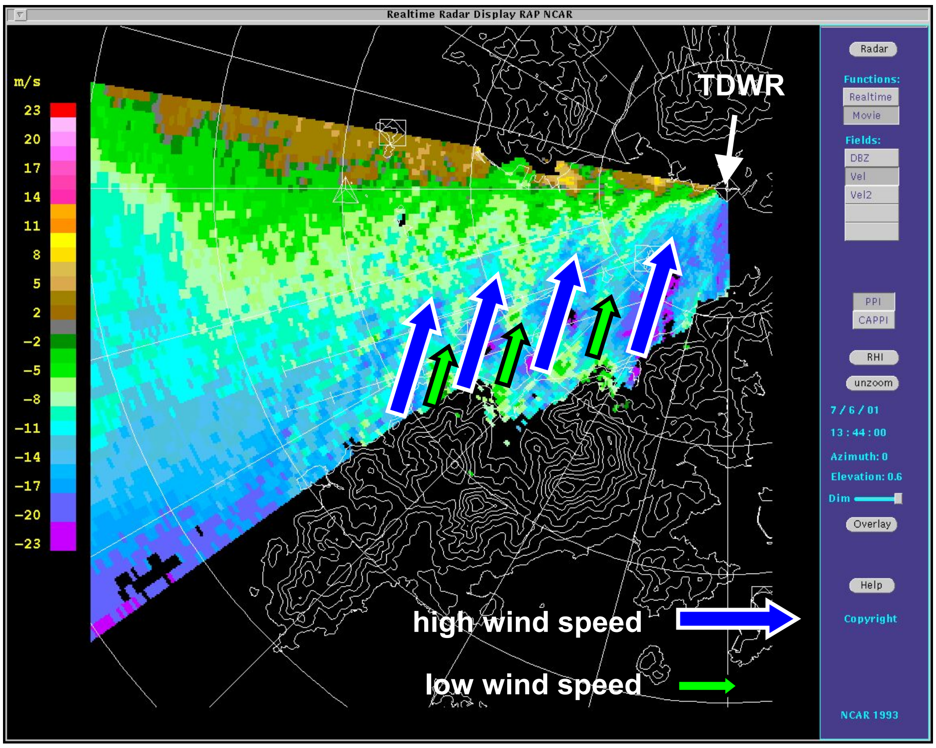

Figure 6. TDWR Doppler radial velocity at 0.6 degree elevation angle at 2144 HKT on 6 July 2001 revealing the presence of streaks of high wind speed and streaks of low wind speed.

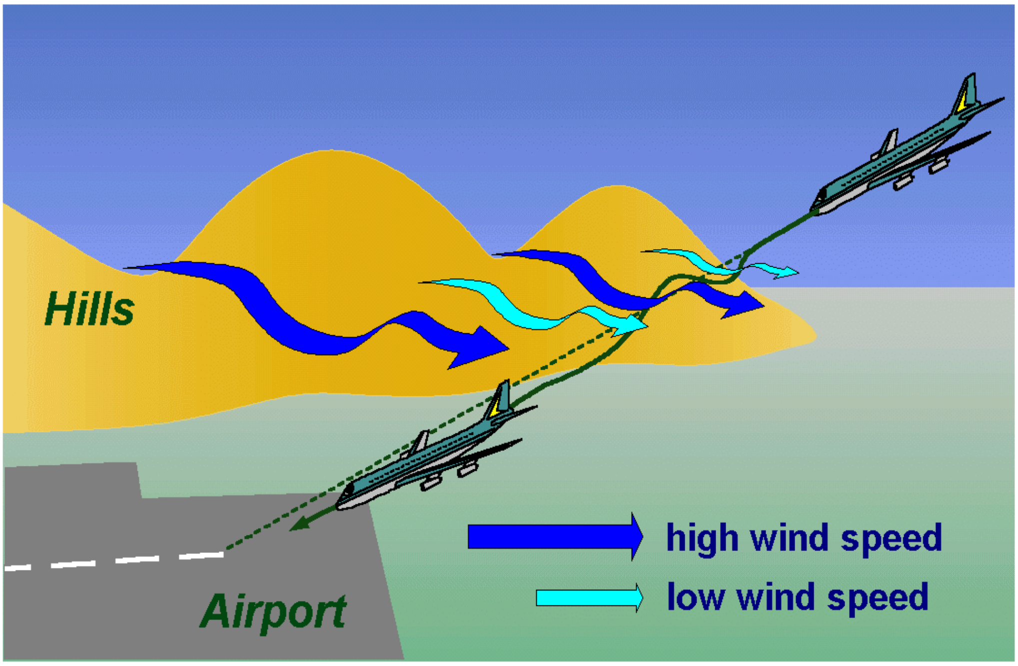

Figure 7. Schematic drawing illustrating streaks of high wind speed and streaks of low wind speed resulting in windshear when strong winds blow across hilly terrain.

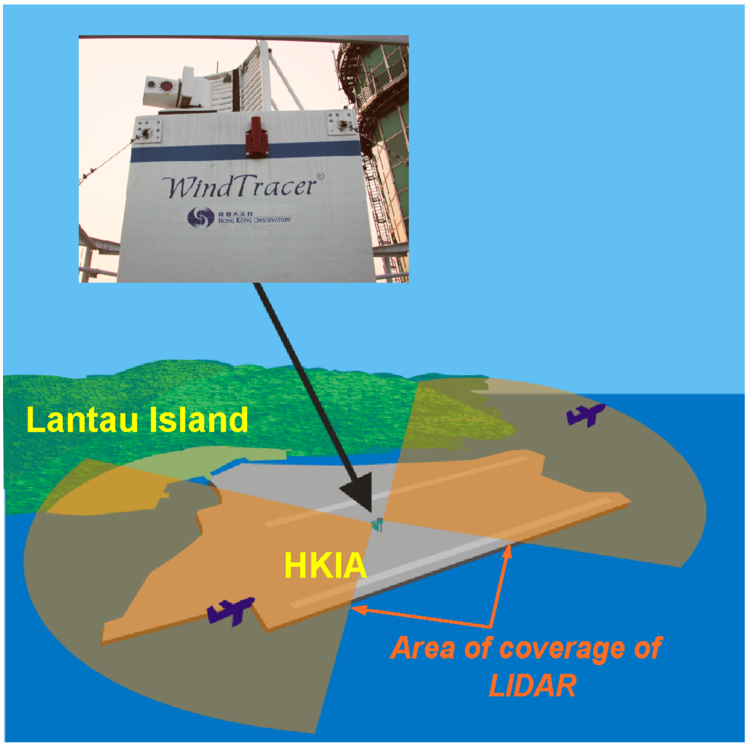

Figure 8. Schematic drawing showing the area of coverage of the LIDAR.

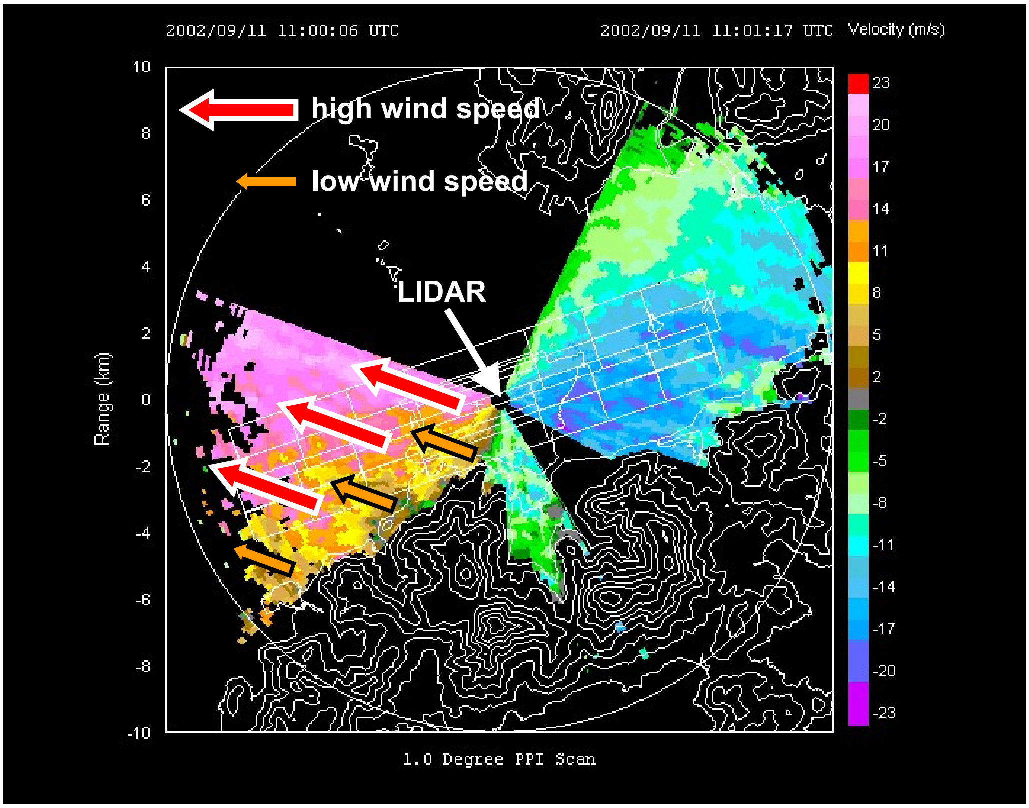

Figure 9. LIDAR Doppler radial velocity at 1.0 degree elevation angle at 1900 HKT on 11 September 2002 revealing the presence of streaks of high wind speed and streaks of low wind speed.

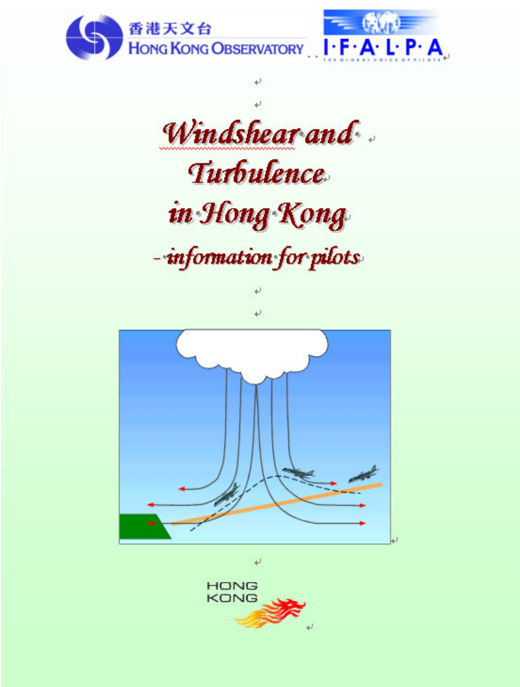

Figure 10. Booklet on 'Windshear and Turbulence in Hong Kong – information for pilots'.