P4.1 **An update of the LIDAR Windshear Alerting System (LIWAS) in Hong Kong**

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1. INTRODUCTION

An automatic windshear alerting algorithm based on the wind data of a LIght Detection And Ranging (LIDAR) system, namely, LIWAS, has been developed by the Hong Kong Observatory (HKO) and put into operation for the arrival runway corridors of the Hong Kong International Airport (HKIA) since December 2005. The transient and sporadic nature of the low-level windshear at HKIA and the technical details of LIWAS for arrival runways were described in Chan et al. (2006). In the last couple of years, HKO continued the development of LIWAS in two major aspects, viz. a windshear algorithm for the departure runway corridors and the exploration of the concept of deploying a dedicated LIDAR for a particular runway for enhancing windshear detection. These two development areas will be described in detail in Sections 2 and 3 respectively in this paper.

In examining the performance of LIWAS, it is noted that the algorithm in general captures about 70-80% of the pilot windshear reports, i.e. there are misses of the reports in the order of 20-30%. Moreover, the false alarm rate could at times reach 40% in the commonly used arrival runway corridor at HKIA, namely, 07LA – arriving at the north runway from the west (Figure 1). The misses and the false alarms are studied from several perspectives: Do the pilots have a uniform practice in reporting windshear, or are similar windshear events perceived differently by different pilots? Do the pilots respond to "abrupt" wind changes only, and can this "abruptness" be quantified? How well does the headwind profile measured by the LIDAR approximate the actual headwinds encountered by the aircraft? These issues will be discussed in more detail in Section 4. Conclusions of the paper are given in Section 5.

2. LIWAS FOR DEPARTURE CORRIDOR

A natural choice of the LIWAS algorithm for the departure runway corridors is to adopt the algorithm for arrival runway corridors. While arriving aircraft follows more or less the same glide path, departing aircraft could climb through differing paths, with large variability in the rotation points and climb angles. As a start, the LIWAS algorithm is applied to pre-defined glide-path scans of the LIDAR, which assumes rotation at the middle of the runway and an elevation angle of 6 degrees above ground.

At HKIA, aircraft normally takes off from the south runway. As such the commonly used departure runway corridors are 07RD and 25LD (Figure 1). Since the prevailing wind direction in Hong Kong is from the east, 07RD is used more for departure among these two corridors. However, at their present locations, the two LIDARs (locations in Figure 1) have the laser beams subtending large angles with respect to the eastern part of the south runway, far exceeding the angle threshold of 30 degrees as currently adopted in LIWAS (Chan et al. 2006). As a result, they could not provide wind data that are representative of the headwind to be encountered by the aircraft over the south runway itself for 07RD corridor, which limits the capability of windshear detection. It is planned to tackle the issue by relocating the first LIDAR near the middle of the airfield to a location closer to the south runway so that the laser beam could have a better alignment with respect to the runway. Before the relocation, windshear detection over 07RD corridor would be limited and thus in the following discussion only the 25LD corridor would be considered.

Details of the LIWAS algorithm for arrival corridors are described in Chan et al. (2006). Only a summary of the major features of the algorithm is given here. The headwind profile along the glide path is approximated by the LIDAR wind measurements and it is used to construct the velocity increment profile. The peaks and troughs of the velocity increment profile are in fact the wind changes, or windshear ramps. Prioritization of the ramps for the issuance of a single alert for a runway corridor is based on the argument of Woodfield and Woods (1983) and Woodfield (1994), which suggest a severity factor *S* of windshear:

$$S = (\frac{dV}{dt})(\frac{\Delta V}{V_{app}})^2 = (\frac{\Delta V}{H^{1/3}})^3 / V_{app} \qquad (1)$$

where *dV/dt* is the rate of change of wind speed, *ΔV* the total change of wind, V_{app} the normal approach speed of the aircraft and *H* the ramp length. Thus, the primary parameter turns out to be the normalized windshear value, or windshear intensity *I* given by:

$$I = \frac{\Delta V}{(HV_{app})^{1/3}} \qquad (2)$$

The approach speed is not known for every aircraft, and it is taken to be a constant value of 75 m/s *a priori*.

The performance of the LIWAS algorithm over 25LD is studied for those months in 2004 to 2007 when there is a significant number of windshear reports, viz. about 10 (including both significant windshear encounters and null reports). The results are summarized in Table 1. The hit rate is good, namely, about 78%, and the false alarm rate is at a low level of 17%. However, the alert duration per hit is rather long, viz. about 430 minutes. The long duration may be related to the pilots' practice of windshear reporting during departure. From discussions with the pilots, it has been indicated that the workload is heavy during departure and there may not be sufficient time for reporting of windshear.

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Moreover, a gradual headwind increase fulfilling the scientific definition of significant windshear (15 knots or more over a distance of 400 to 4000 m) may be regarded as "natural" because in general the wind is expected to gain in strength with altitude and thus the pilot may decide not to report the windshear at all.

In order to reduce the alert duration for windshear alerts over the departure corridors, one possibility is to focus on the low-level windshear ramps only, i.e. those ramps occurring below 1600 feet. The performance statistics of this revised algorithm are also given in Table 1. Compared to the original algorithm, there is a drop of hit rate (to 66%) and a slight rise of false alarm rate (19%), but the alert duration per hit is significantly reduced to about 256 minutes at the same time (viz. a decrease of 41%). It looks like the use of 1600-feet cutoff could strike a reasonable balance between the hit rate and the alert duration. This could be the algorithm suitable for operational use.

Two examples of windshear alerting over 25RD by the 1600-feet cutoff algorithm are given in Figure 2. The first case was Tropical Storm Pabuk in August 2007, which was situated over the south China coast and brought strong southwesterly winds to Hong Kong. The second case occurred in July 2006 in which southern China was under the influence of a strong southwesterly airstream associated with an area of low pressure. In both cases, the LIWAS algorithm is able to capture the abrupt wind changes within the first couple of nautical miles away from the runway threshold and the windshear alerts so generated are generally consistent with the pilot reports.

3. DEDICATED LIDAR

The first LIDAR was introduced to HKIA in mid-2002. The second one was installed in October 2006 closer to the north runway (location in Figure 1). It serves as a backup of the first LIDAR. When not required to perform the backup function, it is configured to scan more frequently over the north runway, over which most of the approaches are made. The time interval between consecutive scans over the same arrival runway corridor is reduced from two minutes for the first LIDAR to one minute for the second LIDAR. Moreover, being closer to the north runway, the laser beam from the second LIDAR has better geometry with respect to the runway orientation and resolves the headwind to be encountered by the aircraft more accurately.

To see whether the second LIDAR as a dedicated LIDAR for the north runway could improve windshear detection for this runway, the performance statistics of the two LIDARs for the arrival corridor 07LA are compared in Table 2 on those days in February to July 2007 when data were available from both systems. It could be seen that the second LIDAR achieved a higher hit rate (by nearly 7%), a lower false alarm (by 5%) and a slight drop of alert duration per hit (about one minute). Figure 3 shows two examples of windshear events over 07LA which have been successfully captured by the second LIDAR but not the first one. The headwind profiles from the two systems depict similar wind trends in general, but the relatively abrupt windshear ramps (over a distance less than 1 nautical mile, as highlighted in blue in Figure 3) only appear from the measurements of the second LIDAR. The faster data update and better alignment with the runway orientation are believed to contribute positively to the detection of windshear by this system.

As discussed in Section 2, it is planned to move the first LIDAR closer to the south runway to improve the geometry with respect to this runway. With that setup in plan, one LIDAR would be dedicated to serve a particular runway of HKIA.

4. MISSES AND FALSE ALARMS

From the performance of the LIWAS algorithm evaluated based on pilot reports as described in the above two Sections, it could be seen that the algorithm is not yet "perfect", i.e. a hit rate of 100%, a false alarm rate of 0% and an extremely short alert duration per hit. Though pilot reports constitute an independent dataset for the development and verification of LIWAS, it looks like there are some issues about the subjective perception of windshear by the pilots that have to be taken into account. The LIDAR also has limitations in measuring the winds to be encountered by the aircraft. These topics are discussed below.

4.1 Pilots' practice of windshear reporting

In dialogues with pilots, we understand that they do not yet have direct display of headwind information at the cockpit. As such, different pilots might have different practices in reporting the windshear and estimating the shear magnitude. For example, they might refer to the change of airspeed shown on the airspeed indicator, or the trend arrow (an extrapolation of the wind change in the next 10 seconds or so based on the short-term wind change) shown on the airspeed indicator, or the wind vector display, to report and estimate the shear.

There are numerous examples that, with a very similar windshear ramp detected by the LIDAR, the pilots could have very different response in the provision of windshear reports. Two examples are given in Figure 4 for illustration. In the first case (Figure 4(a)), the LIDAR's headwind profiles depict relatively short ramp length (~1 km) with a headwind gain of 15 knots over the 07LA corridor. For the earlier ramp, there was a pilot report (A333) of 20 knots headwind gain below 1000 feet, consistent with the LIDAR observations. However, for the latter ramp, an aircraft using runway 07LA (B744) gave a windshear report of 10-knot headwind gain only. Since the magnitude of the reported windshear is less than 15 knots, this is taken to be a null report. The second case (Figure 4(b)) refers to relatively gentle windshear ramps (3-4 km) with headwind gain of 16-18 knots that were separated by only 3 minutes. At the time of the earlier ramp, a pilot (B744) reported encountering windshear with headwind gain of only 10 knots at 800 feet. At the latter time, an aircraft (A333) had to conduct missed approach due to encountering of windshear at 400 feet, consistent with LIDAR observations.

4.2 Long and gentle windshear ramps

Besides the windshear intensity *I*, the ramp length is another factor to be considered in studying the effect of the windshear ramp on the aircraft, In Woodfield (1994), the ramp length is normalized by the typical approach speed of the aircraft:

$$\tilde{H} = \frac{H}{V_{app}} \quad (3)$$

The windshear intensities and the normalized ramp lengths of the windshear ramps are plotted in a "Woodfield diagram" (Woodfield 1994) to find out the characteristics of the significant windshear events and the false alarms.

The pilot reports of 2006 and 2007 over 07LA are considered. The windshear ramps are taken from the LIDAR headwind profiles at the times of the pilot windshear reports. The resulting diagram is shown in Figure 5. It turns out that there are two "clusters" of pilot reports in the Woodfield diagram. One cluster (Cluster A) is mainly composed of significant windshear events as reported by the pilots. They have shorter ramp length (less than 3 km) and stronger severity, and thus concentrated in the left hand side of the diagram, with the windshear category considered as "moderate" or "strong" following the classification of Woodfield (1994). The other cluster (Cluster B) is largely made up of the false alarm cases. The data points have longer ramp length (all larger than 3 km) concentrated in the right hand side of the diagram with the windshear category considered as "light" following Woodfield's classification.

It appears that a ramp length of 3 km may be adopted as the threshold delineating significant and non-significant windshear events. However, since the present study is based on limited data from the spring season of one year only, more data would need to be collected in order to confirm the threshold. When this is achieved, the internationally recognized length scale of 400 m – 4 km for windshear would need to be revised.

4.3 Using the LIDAR to measure headwind

Accurate measurement of the headwind (with reference to the runway orientation) that the aircraft would experience is fundamental in the successful detection of windshear. To determine the capability of the LIDAR in measuring the headwind profile along the glide path, the LIDAR headwind estimates obtained in the glide path scans over 07LA are compared with the headwind measurements recorded in the Flight Data Recorder (FDR) onboard commercial transport category aircraft using the same runway corridor. The aircraft data have been processed with a sophisticated FDR wind retrieval algorithm to obtain the wind data at 4 Hz (Haverdings, 2000). Data from 85 flights are used, and the comparison result is shown in Figure 6 based on the headwind estimates obtained from the second LIDAR with better alignment of the laser beam with the runway. The two datasets are found to be well correlated. The bias is 0.77 m/s and the RMS difference is 2.1 m/s. Taking into account the accuracy of LIDAR data (1 m/s), the typical accuracy of aircraft wind data (~0.5–1 m/s) as well as the spatial and temporal differences in the LIDAR and the flight measurements, the comparison results are considered to be very satisfactory.

Two "false alarm" cases (based on pilot reports) are shown in Figure 7(a) and (b). In the first case (Figure 7(a)), both the headwind profiles from the FDR data and the second LIDAR data are generally consistent and show a significant headwind gain of 15 knots from about 3 nautical miles to 2 nautical miles from the runway end. However, the pilot using the runway at that time reported windshear of headwind gain of 10 knots only at 300 feet, which is thus taken as a null report. For the second case (Figure 7(b)), headwind gain in excess of 15 knots between around 1 nautical mile from the runway end and the touchdown zone was depicted in both headwind profiles from the FDR data and the second LIDAR. The pilot reported headwind loss of 10 knots at 100 feet, which does not seem to be consistent with the headwind profiles. In both cases, the headwind profiles estimated from the radial velocity data of the second LIDAR and those analyzed from the FDR data are very similar. It looks like the pilot's perception of the effects of the shear could lead to the reporting of these significant windshear cases as false alarms. The verification results of the LIDAR windshear algorithm above, especially the false alarm rates, should be viewed with this perspective.

The comparison between LIDAR and FDR data also highlights some limitations of the LIDAR in measuring the headwind to be encountered by the aircraft. Two examples are given in Figures 7(c) and (d). In the first case (Figure 7(c)), the headwind change as shown in the FDR data exceeds 20 knots between 1 nautical mile from the runway end and the touchdown zone. The LIDAR-estimated headwind profile shows a similar wind trend, but the magnitude of the wind change is less than the alerting threshold to trigger a windshear alert. Since the wind changes rapidly in terrain-disrupted airflow at HKIA, the finite revisit time of the LIDAR beam over a particular runway corridor (~1 minute for the second LIDAR) may not capture the transient yet significant wind fluctuation encountered by the aircraft in between the LIDAR scans. In the second case (Figure 7(d)), the windshear reported by the pilot appears to be consistent with the headwind gain between 3.5 and 3 nautical miles from the runway end as revealed by the FDR data. However, due to high humidity of the air, the measurement range of the LIDAR extended only to about 3 nautical miles away from the runway end and thus cannot capture this windshear.

5. CONCLUSIONS

This paper summarizes the latest developments of the automatic LIDAR-based windshear alerting algorithm of HKO. The LIWAS algorithm is extended to the departure runway corridors. The inclusion of cutoff of windshear ramps at 1600 feet appears to strike a good balance between the capturing of significant windshear and minimization of alert duration. A dedicated LIDAR has also been deployed to serve the north runway of HKIA, over which most of the approaches are made. Better alignment of the laser beam with respect to the runway and more frequent update of the wind data are found to improve the alerting of windshear. Another LIDAR would be dedicated in the near future to serve the south runway, where most of the aircraft depart from HKIA.

In the development and verification of LIWAS, the pilot reports of windshear are taken as “sky truth”. By comparing with these reports, the LIWAS algorithm is not yet “perfect”, with a hit rate in the region of 70-80% only and a false alarm rate as high as 40% at times. This paper discusses the possible factors that may contribute to the less-than-perfect behaviour of the algorithm, including the lack of a uniform practice of windshear reporting by the pilots, the different responses of the pilots to gentle vs. abrupt windshear ramps, the finite revisit time of the LIDAR scanning over a particular runway corridor, and the limited measurement range of the LIDAR in certain weather conditions. A more objective way of verifying the algorithm would be the collection of a large set of FDR data in different seasons/weather types and detection of significant windshear from the FDR-derived headwind profiles. Future research would be carried out in this direction.

Acknowledgement

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References

Chan, P.W., C.M. Shun and K.C. Wu, 2006: Operational LIDAR-based system for automatic windshear alerting at the Hong Kong International Airport. *12th Conference on Aviation, Range, and Aerospace Meteorology*, American Meteorological Society, Georgia (on-line proceedings).

Haverdings, H., 2000: Updated specification of the WINDGRAD algorithm. NLR TR-2000-63, National Aerospace Laboratory.

Woodfield, A.A., 1994: Windshear and its effects on aircraft. *AGARD Lecture Series on ‘Flight in an Adverse Environment’, AGARD LS-197.*

Woodfield, A.A. and J.F. Woods, 1983: Worldwide experience of windshear during 1981-1982. *AGARD Flight Mechanics Panel Conf. on ‘Flight Mechanics and system design lessons from Operational Experience’, AGARD CP No. 347.*

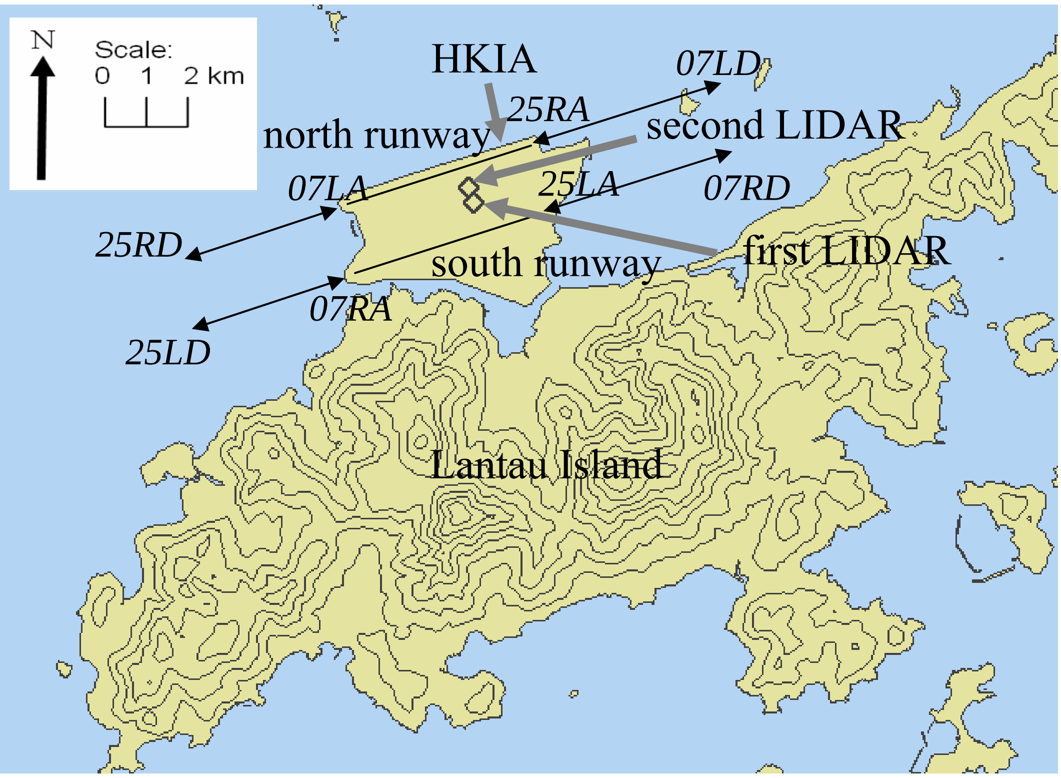


Figure 1 Locations of the LIDARs at HKIA and the nomenclature of the runway corridors. The geographical environment in the vicinity of HKIA is also shown (height contours in 100 m).

Period of study: August 2004; April, May and August 2005; April and July 2006
(excluding those dates when data from the first LIDAR were not available)

	Operational	**1600 feet cut-off**
No. of windshear reports	76	
No. of hits	59	50
No. of null reports	22	
No. of null reports matched with alerts	12	12
Alert duration (minutes)	25376	12781
Hit rate	77.6%	65.8%
Alert duration per hit (minutes)	430.1	255.6
False alarm rate	16.9%	19.4%

Table 1 Performance statistics of LIWAS algorithm of the first LIDAR over 25LD runway corridor.

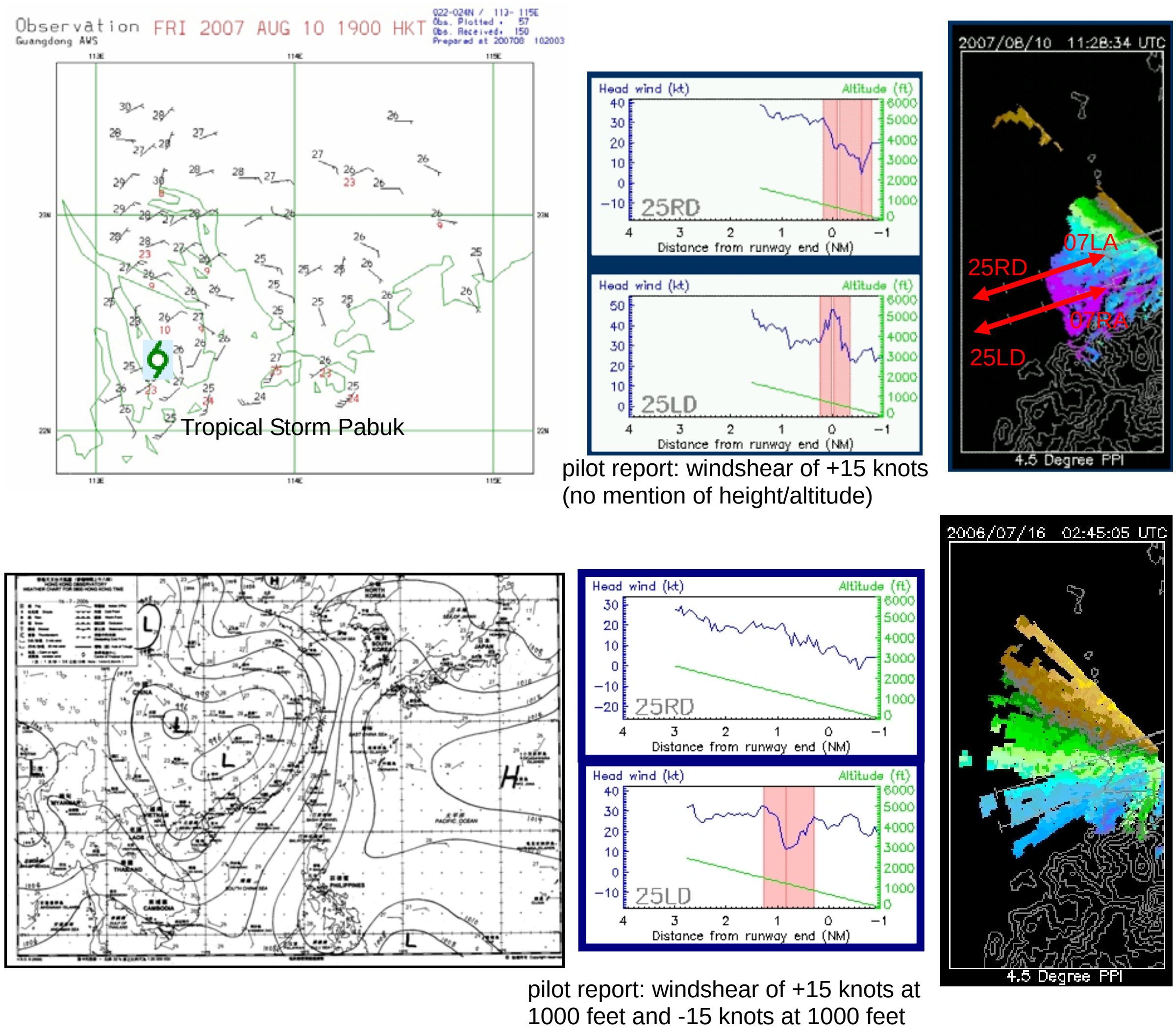


Figure 2 Two cases of windshear alerts over the departing runway corridor 25LD of HKIA. The upper panel is the Tropical Storm Pabuk case in August 2007, and the lower panel is the strong southwest monsoon case in 2006. In each panel, the mesoscale weather situation is shown on the left hand side by the weather map with wind observations (in wind barbs) at the surface weather stations. The middle diagrams show the headwind profiles obtained by the first LIDAR at the two departing runway corridors 25RD and 25LD. The detected windshear ramps are highlighted in red. The right hand side shows the radial velocity distribution measured by the first LIDAR in 4.5-degree PPI scan.

Period of study: 14 February to 31 July 2007
(excluding those dates when data from any one of the LIDARs were not available)

	First LIDAR	Second LIDAR
No. of windshear reports	135	
No. of hits	96	105
No. of null reports	123	
No. of null reports matched with alerts	81	72
Alert duration (minutes)	7332	7929
Hit rate	71.1%	77.8%
Alert duration per hit (minutes)	76.4	75.5
False alarm rate	45.8%	40.7%

Table 2 Performance statistics of LIWAS algorithms of the two LIDARs over the most commonly used arrival runway corridor in the spring of 2007, viz. 07LA runway corridor.

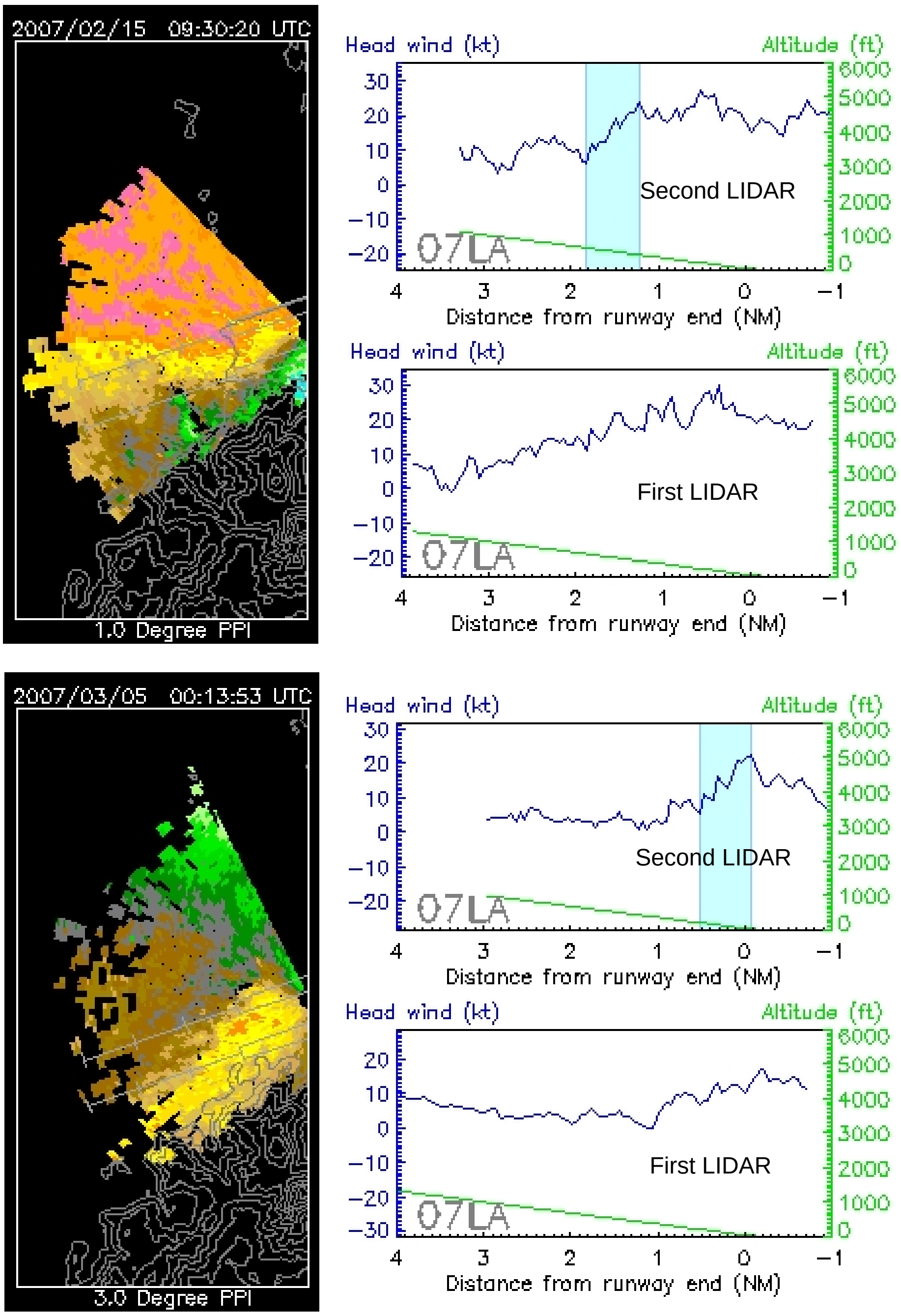
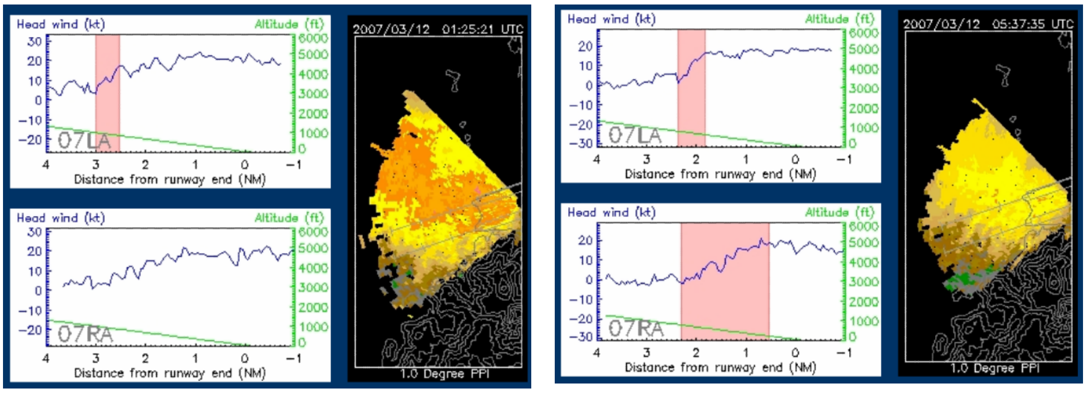


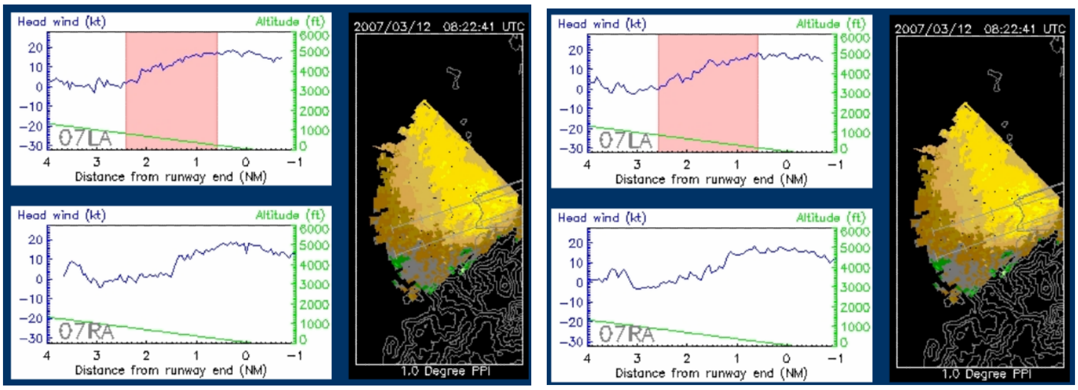
Figure 3 Comparison of the headwind profiles measured by the two LIDARs at HKIA in two cases of easterly winds at HKIA. The detected windshear ramps are highlighted in blue. The left hand side shows the PPI scans at the indicated elevation angles.



01:31 UTC, 12 March 2007
LIWAS alert: +15 knots, 3 nm
Pilot report: below +20 knots, 1000 feet, A333

05:39 UTC, 12 March 2007
LIWAS alert: +15 knots, 3 nm
Pilot report: +10 knots, 300 feet, B744

(a)



08:25 UTC, 12 March 2007
LIWAS alert: +16 knots, 3 nm
Pilot report: +10 knots, 800 feet, B744

08:28 UTC, 12 March 2007
LIWAS alert:+18 knots, 3 nm
Pilot report: missed approach due to windshear
400 feet, A333

(b)

Figure 4 Similar windshear ramps but with very different pilot reports of windshear encounter over the 07LA corridor: (a) sharp wind changes at 01:31 and 05:39 UTC, 12 March 2007, and (b) gentle wind changes at 08:25 and 08:28 UTC, 12 March 2007.

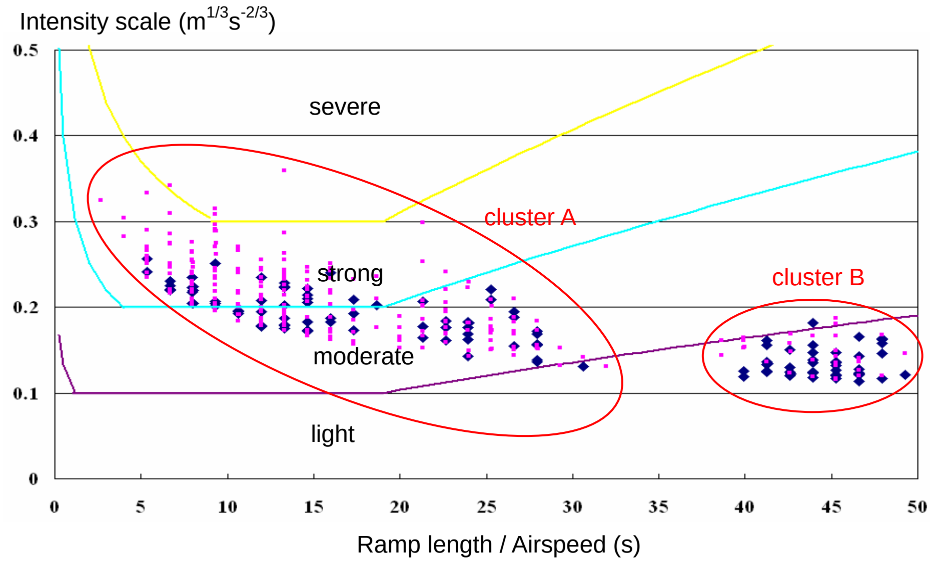


Figure 5 "Woodfield diagram" of windshear reports in 2006 and 2007 over 07LA runway corridor. The significant windshear reports are shown as pink dots and the null reports as blue spades.

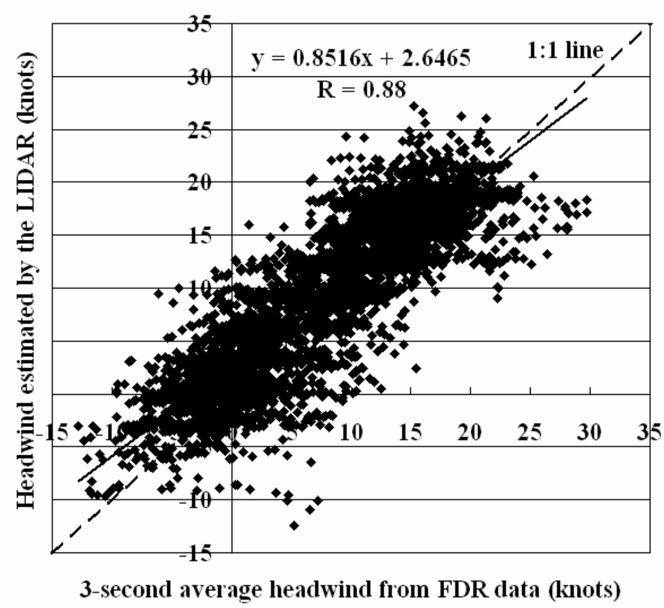
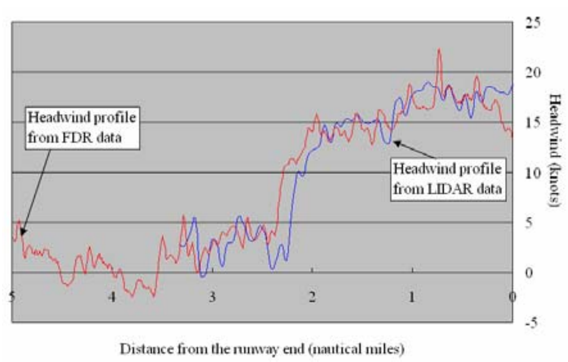
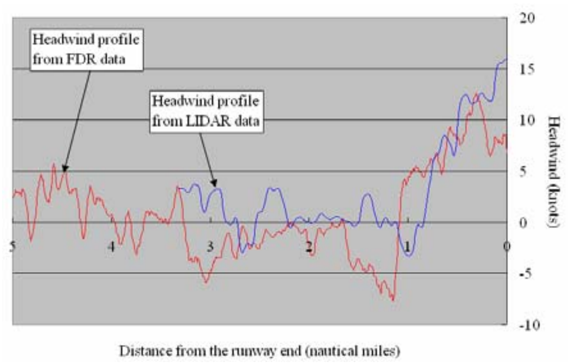


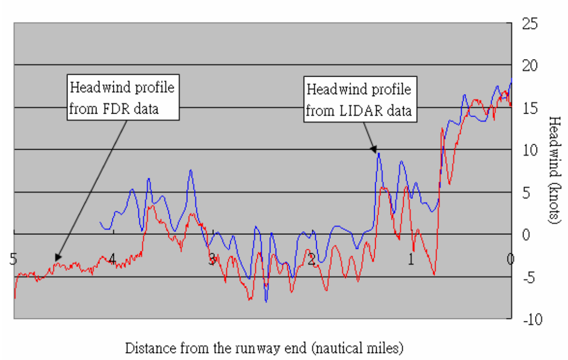
Figure 6 Comparison between the headwinds estimated from the LIDAR and given in the FDR data.



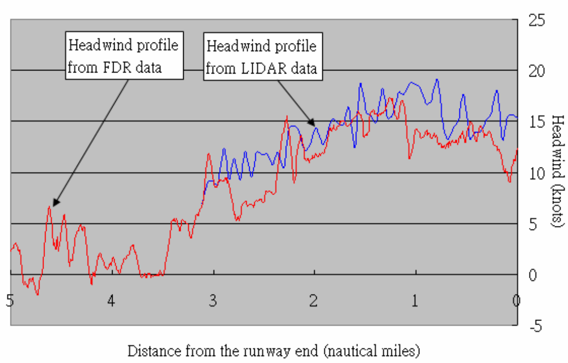
(a) 05:39 UTC, 12 March 2007 (B744)



(b) 07:13 UTC, 13 March 2007 (A330)



(c) 05:03 UTC, 12 February 2007 (B773)



(d) 02:57 UTC, 23 March 2007 (A333)

Figure 7 Headwind profiles from the LIDAR and FDR data in two false alarm cases (upper) and two miss cases (lower).