Optimization of Terminal Doppler Weather Radar of Hong Kong International Airport for Microburst Detection

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Introduction

Hong Kong is situated in a subtropical region at the southeastern coast of mainland China. In winter, northeast monsoon prevails with cold fronts moving across the coast from north occasionally. In spring, humid and warm maritime airstreams from the south set in and bring fog and drizzle to Hong Kong. Besides, in spring, as a transition season between winter and summer, weather becomes convective. In summer, southwest monsoon and tropical cyclones are two typical types of convective weather conditions. The convective weather conditions not only bring showers and thunderstorms to Hong Kong, but also microbursts and significant windshear to the region which affects aviation safety for aircraft landing at and departing from the Hong Kong International Airport.

The Hong Kong International Airport (HKIA) is one of the busiest airports in the world. In 2015, it handled more than 400,000 flight movements (Hong Kong International Airport, 2016), which were more than 1000 flight movements a day on average. The HKIA situates to the north of Lantau Island with hilly topography. Its altitude is less than +10 meters above Principal Datum (mPD) while some areas in the Lantau Island are as high as +900 mPD. Terrain-induced windshear becomes one of the major weather events in HKIA. It sometimes results in head wind loss of more than 15 m/s, i.e. equivalent to the strength of a microburst. With the heavy air traffic, about 1 in 500 arriving and departing flights have reported significant windshear or microburst from July 1998 to December 2009 (Hong Kong Observatory, 2010). Therefore, real-time microburst and significant windshear detection is vital to safeguard aviation safety.

Hong Kong Observatory uses Terminal Doppler Weather Radar (TDWR) to monitor and detect significant windshear and microburst automatically. The first TDWR was installed in 1997. It has been used for nearly 20 years and is aged. To ensure continuous microburst and significant windshear detection and alerting service, a new TDWR was installed in 2014. Immediately after installation, optimization of radar was carried out. The new TDWR was put into operation in 2015. Optimization and performance of severe windshear detection were discussed in this paper.

Optimization

The HKIA is in a highly-cluttered environment with noise from vehicles, ships,
derricks, barges and cable cars, which is within the detection range of the new TDWR. Functions equipped by the new TDWR to suppress clutters and noise while preserving useful data are essential. The new TDWR equips with traditional algorithms to remove point clutters in spatial domain. At the same time, stationary, near stationary and moving clutters are suppressed in spectrum domain which will be discussed below, together with methods for reducing out-of-trip echoes and dealiasing velocity field.

One of the methods to remove stationary and near stationary clutters is interpolation in spectrum domain. Signal levels in spectrum domain at 0 m/s and its vicinity, which depends on the filter size, are replaced by interpolated signal levels. Figures 1(a) and (b) show radar reflectivity with different sizes of clutter filter. A cleaner image with much less clutters was obtained with the use of a wider filter size. Clutters were also removed by using clutter to signal ratio. Figure 1(c) shows that clutters possibly related to civil works were further removed.

LOG threshold is used to remove system noise. Received power of a bin is checked against level of system noise to determine if value of a data point is valid. Figures 2(a) and (b) show results using different LOG threshold.

Moving clutters are removed using Moving Target Adaptive Rejection Map (MTARM). This method has the following three assumptions: 1) signals from moving targets are larger than those from weather; 2) velocity of the moving targets is nearly constant during the scan; and 3) spectrum width of the moving target is narrow. To remove the moving clutter, first, location with moving targets was marked. All points in the marked area (Figure 3) would be checked in the spectrum domain by comparing if any point in the spectrum domain with its value larger than a predefined threshold, which is an average signal level calculated using values of adjacent points multiplied by a coefficient, exists. If yes, the point would be considered as one containing signal from the moving target and is removed.

To reduce out-of-trip echoes, Normalized Coherent Power (NCP) is used (Yamauchi & Suzuki, 2012). In a system using random phase method, power spectrum of out-of-trip echoes spreads out quasi-uniformly between $-v_n$ and $+v_n$ ($v_n$ is the Nyquist velocity) while signal to noise ratio of primary echoes will be degraded. Two parameters, Adaptive Signal to Noise Ratio (SNR), and NCP defined in equations (1) and (2) below are used to determine whether a data point contains out-of-trip echoes by comparing the parameter values against thresholds. Figure 4 shows data
points with high spectrum width (left) which probably includes out-of-trip echoes were removed (right) using the NCP method.

Equation 1:  
$$\text{AdaptiveSNR} = \frac{|R(1)|^{4/3}}{R(0)|R(2)|^{1/3} - |R(1)|^{4/3}}$$

Equation 2:  
$$\text{NCP} = \frac{|R(1)|}{R(0)} = \frac{\text{SNR}}{\text{SNR} + 1} \exp\left( - \frac{\pi \sigma_v^2}{2 v_N^2} \right) = \frac{\text{SNR}}{\text{SNR} + 1} \exp\left( - 2 \pi \frac{\sigma_v^2}{v_N^2} \right)$$

In order to correctly represent velocity field with large velocity gradients and random noise, ‘hybrid multi-PRI method’ (HMP, Yamauchi et al., 2006) is used to dealias radar data. This method can be used in sparsely distributed velocity field without removing data excessively by unfolding radar data by a set of reference data. The reference dataset is created by dealiasing data in two processes, which are areal multi-PRI processing and subareal continuity processing, assuming velocity field can be spatially represented by linear polynomials in areas with different sizes and shapes. By adjusting raw data which is carried out by adding or subtracting multiplies of Nyquist velocity to the closest value of its reference data, the velocity field is unfolded. An example of folded and dealiased radial velocity field is provided in Figure 5. A small region of blue pixels to the south of the south runway in Figure 5 (a) disappeared when a new set of HMP parameters were used in Figure 5(b).

**Characteristics of terrain-induced windshear**

The new TDWR identifies areas with significant windshear which has the following properties: emerging from valleys of the Lantau Island, appearing as streak or wedge (Figure 6), more frequent over the southern runway as closer to the Lantau Island and transient.

In Figure 7(a), areas of significant windshear marked by red ellipses were detected by the new TDWR. To its east, area of convergence (purple line) was also detected. From Figure 7(a), one could expected that a flight approaching the HKIA using runway 07LA would first experienced significant headwind loss. When it moved to the location of the purple line, headwind gain was encountered. It matched with the flight data in Figure 7(b). Figure 7(c) shows another case with
headwind loss near touchdown, which matched with the flight data in Figure 7(d). However, the windshear near the runway threshold was not detected by the new TDWR one minute earlier, indicating that terrain-induced windshear was transient in nature.

**Performance in detecting severe windshear**

In order to quantify performance of the new TDWR in detecting severe windshear which has the reaches the strength of a microburst, i.e. head wind loss of at least 15 m/s, ‘human truth’ was used. Human truth is a method which identifies areas of interest by analysts. The identified areas are considered as “truth” data which are highly reliable (Veillette et al., 2013). In this study, data on 4 October 2016 from 00:00 to 23:59 local time (LT; LT = UTC + 8 hours) were used. During the study period, the HKIA was under influence of Tropical Cyclone Mujigae. Fresh to strong east to southeasterlies prevailed at ground level while winds over high ground in Lantau Island (600 meters) reached storm force occasionally.

Around 1,480 PPI radial velocity images at 0.6 degree were examined. Locations of severe windshear, headwind loss of at least 15.4 m/s, within 14.6 kilometers west of the TDWR on radar images were identified. The results were compared against areas identified by the new TDWR. In total, 128 areas were identified by analysts. 117 areas matched with those from the new TDWR; in other words, 11 areas were missed. On the other hand, one area identified by the new TDWR could not be matched with human truth result.

**Summary and Conclusion**

A new TDWR was used to detect microburst and significant windshear and provided alerting service to the HKIA. System optimization was carried out to remove noise, stationary, near stationary and moving clutters. Besides, out-of-trip echoes were reduced. Velocity field was corrected using HMP method. With a corrected velocity field, the new TDWR identified areas with microburst and significant windshear.

Based on a study using human truth, 128 severe windshear areas were identified. 11 of those matched with areas identified by the new TDWR.
Acknowledgment

The methods discussed in this paper were used in radars of Japan Meteorological Agency (JMA) and being shared with HKO.

Reference


Hong Kong Observatory, 2010. Windshear and turbulence in Hong Kong – information for pilots. Hong Kong Observatory: Hong Kong.


Figure 1 Reflectivity images when (a) clutter filter of 2.0 m/s; (b) clutter filter of 2.3 m/s; and (c) clutter filter of 2.3 m/s and clutter to signal ratio of 25 dB. Most white spots indicating stationary clutters in (a) were removed in (b). Yet, a few spots were still appear in (b) (green circle). They were moved in (c) by using clutter to signal ratio.
Figure 2 Unfiltered reflectivity images with LOG threshold of (a) 1 dB and (b) 3 dB. Noise appeared in white points in (a) was mainly removed in (b).

Figure 3 Region with moving target expected is marked in cyan in a map for MTARM.
Figure 4 Spectrum width images (a) without and (b) with using NCP. Orange regions indicated potential area with out-of-trip signals in (a) disappeared in (b).

Figure 5 Radial velocity images based on (a) old and (b) new HMP. A small region of blue pixels were found to the south of the south runway in (a) with the use of an old set of HMP parameters. (b) The blue pixels disappeared.
Figure 6 Radar velocity image at 0.6 deg showing terrain-induced windshear appears as (a) streaks (black dotted line) and (b) a wedge (area enclosed by black lines).
Figure 7  (a) and (c) Radial velocity images overlaid with windshear regions in red ellipses, and shear line (convergence) in purple line. Number in the red ellipses indicate windshear magnitudes in knots.  (b) and (d) Flight data showing headwind loss encountered by aircraft in red lines and aircraft altitude in blue lines.

Case 1  – (a) showed that an aircraft approaching the HKIA from runway 07LA (west to east) would first encountered windshear (headwind loss), and then a sudden headwind gain when it reached location marked by the purple line.  It matched with flight data in (b).

Case 2  – (c) showed that an aircraft would experience windshear near touchdown (end point of black arrow).  It matched with flight data in (d).