IMPLEMENTATION OF A TERMINAL DOPPLER WEATHER RADAR FOR THE CHEK LAP KOK AIRPORT

C.M. Shun
Royal Observatory Hong Kong
134A Nathan Road, Kowloon, Hong Kong

ABSTRACT

In order to enhance the safety of aircraft landing and taking off from the new Chek Lap Kok (CLK) Airport, a Terminal Doppler Weather Radar (TDWR) will be installed at Tai Lam Chung, about 12 kilometres northeast of the airport, for detecting microburst and windshear associated with convective storms.

This paper will present a technical summary of the system design, windshear detection and product generation algorithms, and presentation characteristics. Factors which might affect the radar's performance in the local environment, including effects of ground and sea clutters, terrain blockage, and moving targets, will also be discussed.

1. INTRODUCTION

A new international airport is being built at CLK. In order to enhance the safety of aircraft landing at and taking off from the new airport, a study was carried out as part of the Master Plan Consultancy during 1990-91 to identify the best approach to warn pilots of potentially hazardous windshear and turbulence conditions in the vicinity of CLK. The study concluded that installation of a TDWR was the best viable option for detecting microburst and other low-level windshear events associated with convective storms.

Microburst is a rather short-lived, small and concentrated downdraft of air affecting an area less than 4 kilometres across. When the downdraft reaches the surface, the descending air is forced to spread out in the horizontal direction, producing an area of airflow divergence. An aircraft penetrating this divergence region will experience a sudden loss in the head wind and hence the aerodynamic lifting force. Depending on the intensity of the airflow divergence, the microburst is a hazardous phenomenon for aircraft during landing or taking off.

The Royal Observatory is the designated meteorological authority in Hong Kong responsible for the setting up of meteorological facilities for the CLK airport. The Ambidji Group Pty Ltd in association with Greiner International Ltd and Weather Information Technologies Incorporated have been engaged by the Royal Observatory to provide consultancy support for the siting, acquisition and setting up of the TDWR.

Following a detailed site engineering analysis performed by the consultants, a site for the TDWR installation was identified at the Tai Lam Chung Marine Police Base, roughly 12 km northeast of CLK (Figure 1). From this site, the radar will have a clear view of the airport approach and departure zones, but will have to scan directly over the main shipping channel which is immediately offshore from the radar site. To avoid beam blockage by nearby ships, the base of the antenna will be installed at about 55 m above mean sea level (approximately 30 m above the local terrain).

Figure 2 shows a plot of the anticipated radar horizon from the TDWR site. While the view of CLK will be unimpeded, the radar beam will be blocked to an elevation of roughly 3 degrees by the peaks of Lantau Island immediately behind the airport. Castle Peak and the mountains to the north of the radar site will also give local blockages extending as high as 6 to 8 degrees. Only a small sector to the west is completely unblocked by the local terrain.

A contract for the supply, installation and commissioning of the TDWR was awarded in October 1994 to Raytheon Company. Raytheon is also the supplier of 47 TDWR systems to the United States Federal Aviation Administration (US FAA).

2. SYSTEM FEATURES

In general, the Hong Kong TDWR system follows closely the design of the US FAA TDWR systems currently being installed at airports around the country, with limited local customization of communications, displays and data presentation formats. Appendix I summarizes the major system parameters of the Hong Kong TDWR system. Detailed technical descriptions of the US FAA TDWR system can be found in Michelson et al (1990).

Weather Radar

The weather radar is designed to operate in a high clutter environment normally present in the vicinity of airports. It makes use of a highly stable klystron-based transmitter giving 55 dB of suppression for stationary targets, augmented by clutter residue editing maps using indexed beams, and point target removal algorithms. To minimize clutter, including return from the sea surface, the C-band radar system has a beamwidth of 0.5 degree at the half power points, with excellent side lobe performance (Appendix I). To attain a high system availability level, redundant transmitters, receiver/exciters and signal processing channels are implemented on the radar system.

Since the TDWR site is surrounded by several nearby residential blocks, apart from positioning the antenna above these buildings, the transmitter will also be sector blanked in the direction of the apartments to minimize any potential hazards to nearby residents.

Data Processing

The mission of the system is the detection and warning in real time of microbursts, low-level windshear activity and gust fronts in and near the approach and departure zones, and provision of precipitation maps and storm cell motion information within the total area of coverage. Since the microburst and windshear warnings have to be presented as quickly as possible to air traffic controllers for alerting pilots of aircraft landing at or taking off from the airport, the data processing, weather detection and warning algorithms are fully automated, without the necessity for interpretation by meteorologically trained personnel. These algorithms were developed for the US FAA TDWR program and their performance was validated using data collected in various field experiments (Section 4).

After collection of the clutter filtered zeroth and first moment data from the pulse pair signal processor, the radar product generation processor converts these data into radar base data upon which a number of data conditioning functions are performed. These processing functions include the identification of clutter residue, point targets and range obscured sample volumes, signal-to-noise thresholding and velocity de-aliasing.

After the base data have been conditioned to remove data contamination and radar ambiguities, they are processed by several weather detection and warning algorithms to generate alphanumeric, alarm and graphical products for the end users. Based on pattern recognition approach, these algorithms perform microburst detection, gust front detection and wind shift prediction, and provide concise information on precipitation distribution and storm motion.

Operation Modes

During times when prevailing weather conditions are conducive to an increased likelihood of windshear activity which may affect airport operations, system operations will be automatically switched from the normal monitor mode to the hazardous weather mode. In the hazardous weather mode, the radar spends more time to concentrate on scanning the approach and departure zones, and as a result features a reduced detection time for hazardous windshear near the airport. Microburst and windshear warnings are updated once every minute in this operation mode.

Communications and Display

As soon as the processing of radar base data and application of weather detection and warning algorithms are completed, products, system status and alarms are automatically generated and distributed through redundant high speed communication links from the TDWR station to the airport. In contrast to the use of 9600 bps land lines in the US FAA systems, an E1 data line together with a non-duplicated microwave radio link will be implemented for the Hong Kong system to provide the desired availability level and data volume throughput.

After de-multiplexing the data stream, the information is distributed to various displays for attention of air traffic controllers and aviation weather forecasters. These displays, including the Alphanumeric Alarm Displays (AADs), Graphical Situation Displays (GSDs) and Base Data Displays (BDDs), will be available at the air traffic control centre, air traffic control tower, and forecasting office. In addition, an ethernet capability will be available on the Hong Kong system to allow transfer of the base data stream to the Operational Windshear Warning System (OWWS) (Poon and Wagoner, 1995) for generation of terrain-induced windshear and turbulence warning products.

Alphanumeric Alarm Display

Alphanumeric messages that provide warnings of microburst and windshear activity over the approach and departure zones in a standardized format are presented on the AADs. Figure 3 shows a typical AAD screen. The simple and concise message format allows direct relay of the warnings by air traffic controllers to pilots.

Graphical Situation Display

Apart from displaying the alphanumeric messages, the GSD provides a graphical summary of the various TDWR products, including the locations and strength of microburst and windshear events, gust front locations and forecast movement, wind shift predictions, precipitation map, and storm motion information. Figure 4 shows a typical GSD screen. Through the forecast of gust front induced wind shifts at the airport and depiction of storm motion and precipitation intensity, the GSD helps air traffic control supervisors to improve the management of air traffic in the terminal area. In addition, the weather and warning products will be routinely archived on cartridge tapes for use in accident investigations and for meteorological research.

Base Data Display

The BDD serves as a useful tool for TDWR maintenance and calibration purposes, including generation of clutter residue polygons (Section 4). Furthermore, it provides the capability of displaying radar base data, including reflectivity, velocity and spectrum width, for use by aviation forecasters in real time.

Remote Control and Monitoring

The TDWR station at the Tai Lam Chung Marine Police Base is designed to be an unmanned installation. Provisions have therefore been made for remote control and monitoring of the system through a maintenance data terminal at the airport. On this terminal, system status and performance parameters can be monitored and various commands including changing scan mode, reconfiguring equipment and changing site adaptation data may be executed. In addition, a number of station building services signals including intrusion alarm, fire alarm, air-conditioner status and engine generator status can be remotely monitored.

3. SYSTEM PERFORMANCE

The TDWR is designed to achieve a high probability of detection (POD) and low false alarm rate (FAR) for microburst related windshear. The performance goal set by the US FAA was a POD of 90% and an FAR of 10%. A series of field experiments was carried out in the late-1980's in the US over regions with different climatological characteristics (including Memphis, Huntsville, and Denver) to assess the performance of a prototype TDWR system (Turnbull et al, 1989). Results analyzed by meteorologists from the National Center for Atmospheric Research, National Severe Storms Laboratory and MIT Lincoln Laboratory indicated that detection was very reliable for the strongest windshear events, with overall microburst detection performance meeting the US FAA requirement. The false alarm rate was also well within the requirement.

To optimize TDWR performance in the CLK environment, operational tests and optimization activities will be performed after system installation in mid-1996. Apart from the high ground clutter environment, the waters immediately surrounding CLK have an unusually high density of ship traffic. Special attention will therefore be given to minimize interference from marine vessels, moving or quasi-stationary.

There are several mechanisms built into the TDWR design which can be used for clutter mitigation and minimizing the impact of marine vessels on radar performance. These measures include scan strategy design, clutter filtering, clutter residue editing and polygon definition, point target filter adaptation data changes and adaptation of parameters in the microburst detection algorithms.

The first defense against returned energy from ground targets is to raise the elevation angle of the lowest scan angles. The lowest scan angle for the Hong Kong system is planned to be 0.6 degree, which is slightly higher than values adopted by US FAA TDWR systems. This proposed angle ensures that the lower edge of the -12 dB point* of the beam will be more than 60 m off the surface at ranges beyond 2 km from the radar while the 0.5 degree main beam will be scanning the critical volume for microburst detection from 100 to 300 m above the surface in the vicinity of the airport. The proposed angle also helps to minimize sea clutter within the range covering the approach and departure zones.

Marine traffic and other clutter sources with near zero velocity will be removed with the clutter filters. These filters have a pass band of ± 2 m/s. Therefore all clutters with a radial velocity component within that range will be reduced by 55 dB by the filters. The system also supports the definition of clutter residue polygons. These polygons are defined as areas where the reflectivity return must be higher than some threshold before any data is declared as valid. These polygons are particularly useful in small areas, such as highways and shipping channels, that frequently have "breakthrough" clutter.

To eliminate moving clutters (such as birds, aircraft and automobiles) and targets that are not completely removed by the clutter filtering and residue maps, a moving window type point target filter will be utilized. This filter has both range and amplitude parameters that can be tuned to optimize its effectiveness.

There are also a number of parameters in the microburst detection algorithms that are candidates for optimization so as to reduce the effects of marine vessels and their associated multipath signatures.

4. IMPLEMENTATION PLAN

The CLK airport is scheduled to open in 1998. Under the contract with Raytheon, hardware fabrication and software customization are in progress. Construction of the TDWR station has commenced in August 1995 and the station is expected to be ready for equipment installation by early 1996. A series of post-installation optimization activities and site acceptance tests is scheduled to take place in the second half of 1996.

On-site training of air traffic controllers, aviation forecasters and radar maintenance personnel will also be conducted after system installation. Following the site acceptance tests, it is planned that the system will become ready for service in early 1997 so that users can have ample time to familiarize themselves with system operation prior to airport opening.

5. REFERENCES

Michelson, M., W.W. Shrader and J.G. Wieler, 1990: "Terminal Doppler Weather Radar". Microwave Journal, February 1990 issue.

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* The -12 dB points delineate a region that contains over 95% of the transmitted energy

Poon, H.T. and R. Wagoner, 1995: "Development of an Operational Windshear Warning System for the New Hong Kong International Airport at Chek Lap Kok". *Preprints*, Sixth Conference on Aviation Weather Systems (Dallas, Texas), American Meteorological Society, Boston.

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 Conference on Aviation Weather Systems (Dallas, Texas), American Meteorological Society, Boston.

Turnbull, D., J. McCarthy, J. Evans and D. Zrnic, 1989: "The FAA Terminal Doppler Weather Radar (TDWR) Program". Preprints, Third International Conference on the Aviation Weather System (Anaheim, California), American Meteorological Society, Boston.

APPENDIX I

Description	*System Parameter*
Antenna / pedestal type	Parabolic / elevation over azimuth
Antenna polarization	Linear horizontal
Antenna diameter	7.6 m
Antenna beamwidth	0.5° horizontal and vertical
Antenna gain	50 dB
Maximum side lobe level (near-in)	First side lobe < -30 dB at 1.0°
Maximum side lobe level (beyond 5 degrees)	< -40 dB
Antenna pointing accuracy	0.05°
Antenna pointing repeatability	0.024°
Transmitter frequency	5.625 GHz
Average power output	550 W
Peak pulse power	250 kW
Pulse duration	1.1 μs (-6 dB)
Pulse repetition frequency	2000 Hz maximum
Receiver noise figure	1.8 dB
Receiver bandwidth (-3 dB)	1 MHz
System sensitivity	-10 dBZ @ 16 nmi with SNR > 6 dB
Maximum unambiguous range	89 km Doppler; 460 km reflectivity
Minimum range	450 m
Range resolution	150 m
Azimuth sampling interval	1°
Elevation sampling interval	Scan strategy dependent, typically 1° at low elevation angles
Data dynamic range	-30..80 dBZ reflectivity -80..80 m/s velocity 0..10 m/s spectrum width
Maximum unambiguous velocity	-80..80 m/s (with unfolding)
Fixed clutter rejection capability	55 dB, 4-pole elliptic filters

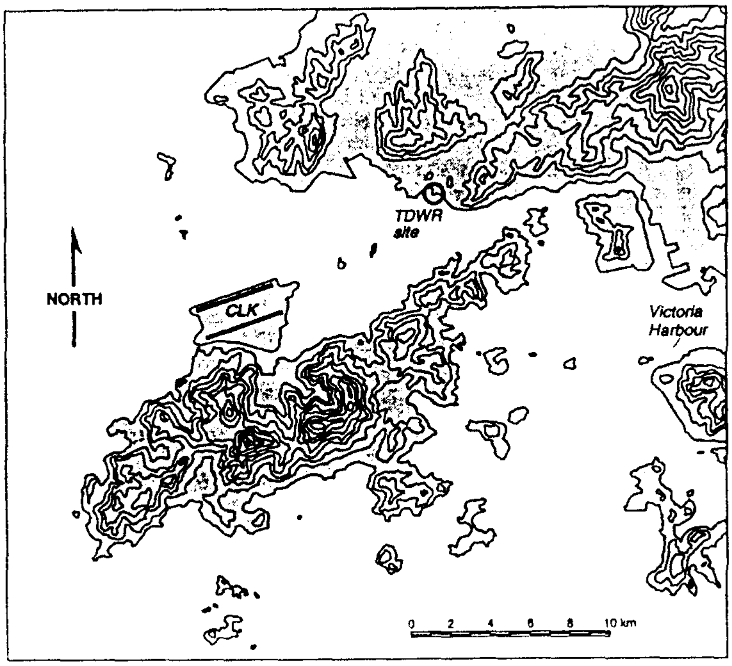

Figure 1. Topographic map of the area surrounding the CLK airport. Elevation contours have been drawn at 100 m intervals. The position and orientation of the airport runways are shown, as is the TDWR site at Tai Lam Chung (Shun and Johnson, 1995).

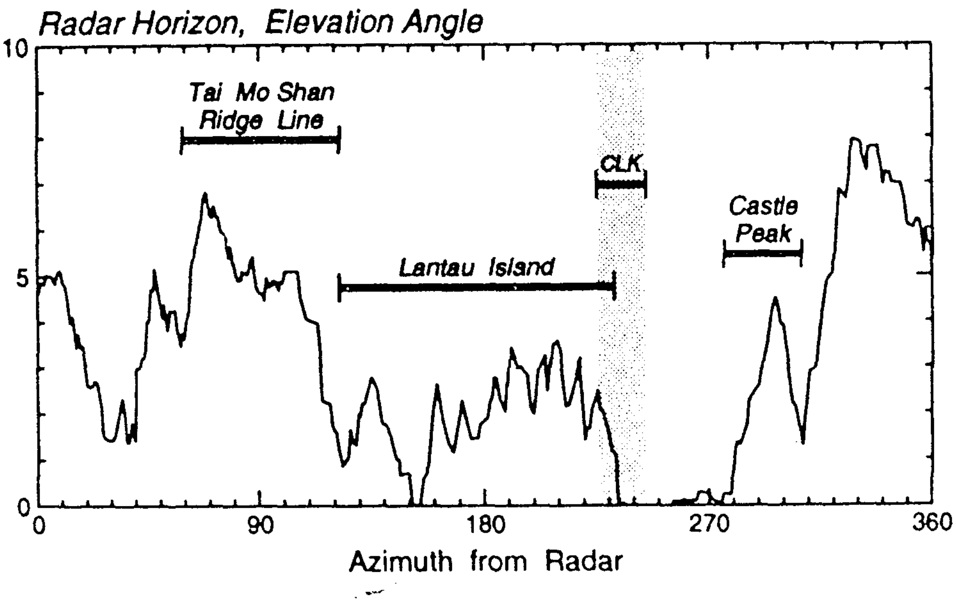

Figure 2. Anticipated radar horizon for a radar installed at the Tai Lam Chung Marine Police Base (Shun and Johnson, 1995).

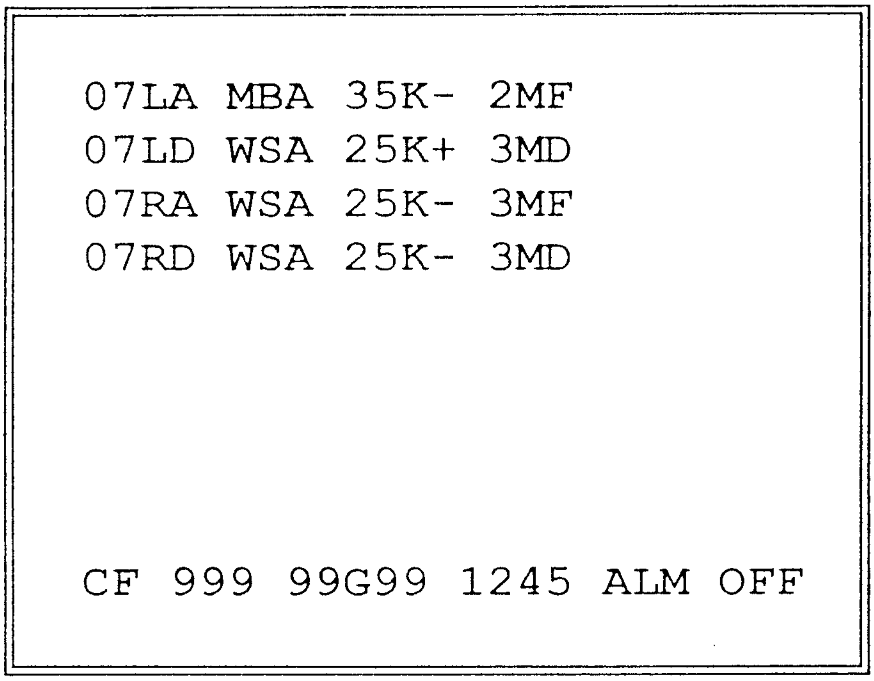

Figure 3. A typical Alphanumeric Alarm Display screen.

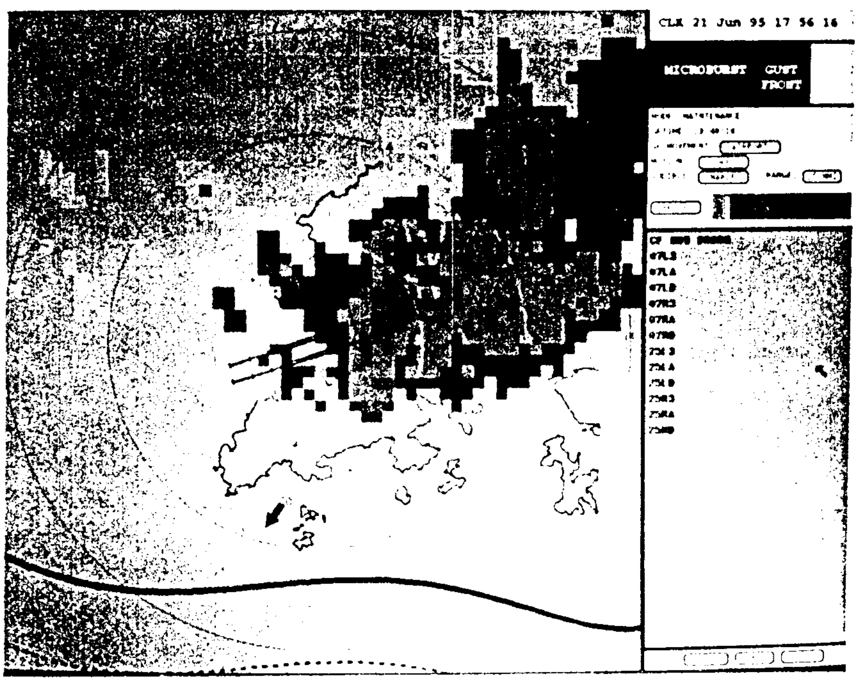

Figure 4. A typical Graphical Situation Display screen, showing the gust front product (bottom), wind shift prediction (arrow) and precipitation map.