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**Agenda Item 2: Improving the safety and efficiency of international air navigation through enhanced meteorological service provision**

**2.1: Enhancement of existing meteorological service provision to support current strategic, pre-tactical and tactical operational decision-making (including ASBU Module B0-AMET)**

# DEVELOPMENT OF FINE-SCALE AVIATION MODEL IN SUPPORT OF SHORT-TERM WEATHER FORECASTS IN HONG KONG, CHINA

(Presented by China)

**SUMMARY**

This paper presents the development of a fine-scale numerical weather prediction model in Hong Kong, China in support of aviation operations. The result highlights the importance and benefits to aviation of high-resolution regional prediction systems assimilating local meteorological observations.

## 1. INTRODUCTION

1.1 Unique geographical location of the Hong Kong International Airport (HKIA) leaves it susceptible to a wide range of weather phenomena which are capable of bringing significant impact to aviation operations as well as passenger safety. On the grandest scale, passage of tropical cyclones and cold fronts may be accompanied by extensive significant convection, occupying flight routes and holding points. At the other end of the spectrum, complex topography surrounding HKIA is known to bring about such local effects as sea breeze and terrain-induced windshear/turbulence, influencing runway usage and pilot decisions.

1.2 As discussed in MET/14-WP/38|CAeM-15/Doc. 38 on Future Aeronautical Meteorological Service Provision, accurate forecasting of meteorological conditions at the terminal area and beyond would then rely not only on weather information from a global perspective but also knowledge of local processes, which are often of spatial scales unresolvable by global prediction systems and challenging even to conventional regional forecast models. Coupling of high resolution regional NWP and nowcasting systems, with the benefit of local observations, will play a key role in enhancing the aeronautical meteorological service, especially in the larger terminal area.

1.3 To meet emerging user needs for more detailed and specific weather information in support of air traffic management (ATM) while taking advantage of advances in high-performance computational technology, the Hong Kong Observatory (HKO) has begun trial operation of a fine-scale aviation model (AVM) since late 2013, with the aim of aiding assessment of regional weather evolution around HKIA, particularly those associated with local or geographical effects, in the nowcast (0–1 hour) to short term forecast (1–6 hour) time frames.

1.4 The AVM is a high-resolution regional prediction system based on the weather research and forecast (WRF) model, providing hourly-updated forecast of winds, temperature and precipitation up to 6–9 hours ahead for the Pearl River Estuary region ("PRD Domain", about 350 km x 350 km) at horizontal resolution of 600 m and the immediate vicinity of HKIA ("HKA Domain", about 50 km x 50 km) down to 200 m. Areal coverage of the two model domains are shown in Figure 1. Initial conditions are generated by 3-dimensional variational (3D-VAR) analysis of surface and upper-air measurements from the dense regional observation networks based on "first guess" from RAPIDS-NHM, the 2-km operational mesoscale NWP model of HKO adapted from the Japan Meteorological Agency, which also serves as a source of boundary conditions in alternation with the global model of the European Centre for medium-range weather forecasts (ECMWF).

1.5 Preliminary performance of the AVM forecasts in a number of typical high-impact weather scenarios at HKIA will be illustrated in the following cases.

## 2. RUNWAY WINDS

2.1 Wind direction and speed over the aerodrome directly affects runway usage and is therefore of operational concern. At HKIA, entrance and retreat of sea breeze fronts, usually occurring under fine weather with weak background winds, is a major cause of significant runway wind changes requiring inclusion in aerodrome forecasts.

2.2 Information on sea breeze occurrence is also currently provided to ATC in the form of probabilistic assessment ("low", "medium", "high") but accurate forecasting of onset timing and duration continues to pose considerable challenge to forecasters given resolution constrains of existing global and regional models in representing the complex land-sea distribution.

2.3 Forecast surface wind distribution by the AVM in a recent sea breeze case is shown in Figure 2. On this day, a sea breeze front developed west of HKIA under bright sunshine and propagated eastward across the parallel runways between 05 and 06 UTC against background easterly winds of 10 to 15 knots. It could be seen that, at 4 hours ahead, the timing of westerly winds covering HKIA, as well as location of the sea breeze front near the eastern end of the runways, were reasonably reproduced by the AVM forecast, which were not otherwise revealed by the operational global/regional models.

## 3. LOW-LEVEL WINDSHEAR

3.1 Low-level windshear is one of the potential aviation safety hazards encountered by landing/departing flights at HKIA. Major causes include terrain-disrupted airflow due to nearby mountains and passage of sea breeze fronts. Automatic windshear alerts at HKIA are provided by the windshear and turbulence warning system (WTWS) of HKO incorporating light detection and ranging (LIDAR) system, terminal doppler weather radar (TDWR) and anemometer observations. In particular, two LIDARs perform specialised scans to detect sudden headwind changes along all arrival and departure aircraft glide-paths as part of the LIDAR windshear alerting system (LIWAS) as presented in the accompanying paper on Development of Windshear Alerting Service at the Hong Kong International Airport (MET/14-IP/16|CAeM-15/INF. 16).

3.2 Here the sea breeze case in paragraph 2 is revisited. Using high-resolution output of the AVM, headwind values predicted along different runway corridors could be extracted. Figure 3 shows the forecast headwind profile over the departure glide-path for corridor 07RD (i.e. departing eastwards from the South Runway of HKIA) between 06 and 07 UTC, condensed into a single box-and-whisker plot, at 4 hours ahead. A potential region for low-level windshear could be identified between the 0 and 1 nautical mile points, corresponding to an expected headwind change from about -10 to +10 knots associated with passage of the sea breeze front. Within this hour, 4 departing flights reported encountering significant windshear over 07RD, with magnitude between +15 to +20 knots.

3.3 Comparison with the Observatory's LIWAS (which successfully alerted all 4 events) would suggest a general resemblance of forecast headwind features with LIDAR observations in this case. The 1-nautical mile difference between location of forecast and detected headwind change could be traced to positional errors in the sea breeze front (about 1 nautical mile too far towards the east – see Figure 2).

## 4. LOW-LEVEL TURBULENCE

4.1 Disruption of cross-mountain flow e.g. during tropical cyclone passage by mountains to the south of HKIA is a major cause of low-level windshear/turbulence at the airport. Automatic turbulence alerts of the WTWS are based on a combination of TDWR and anemometer data. Real-time algorithms using LIDAR measurements are also under development at HKO.

4.2 Figure 4 shows the forecast distribution of low-level turbulence intensity (in terms of the cube root of the eddy dissipation rate (EDR)) around HKIA during passage of severe typhoon Utor in 2013. Jet streaks exhibiting moderate-to-severe turbulence intensity could be observed to emanate from the southern terrain and propagate towards the runway areas in the 5-hour forecast. During the hour of this forecast 4 reports of significant windshear were received from departing aircraft.

## 5. SIGNIFICANT CONVECTION

5.1 Significant convection over the terminal area or holding points is capable bringing major air traffic disruptions. In support of ATM operations and capacity management, HKO has developed advanced significant convection products based on extrapolation of weather radar return and blending with outputs from global and regional forecast models, incorporating forecasters' judgment.

5.2 Spatial resolution of the AVM allows more detailed representation of physical processes involved in convection phenomena. A resulting forecast weather radar return by the AVM during a significant convection event is shown in Figure 5. This case involves the development of an intense squall line which traversed the Pearl River Estuary (and Hong Kong) during passage of a cold front. Comparing with the concurrent actual weather radar image, aspects of the convective system (e.g. maximum intensity, shape and location of the leading edge) could be reasonably approximated at about 10 hours ahead, although deficiencies are also apparent especially regarding spatial coverage of the thunderstorms over the inland areas. The development of this intense squall line however was not captured by the global models.

5.3 The major holding points and way points have been incorporated in the experimental product shown in Figure 5. Based on thresholds for weather radar return in existing nowcasting products (see paper on Nowcasting Services to support Air Traffic Flow Management and Airport Operation at HKIA, MET/14-IP/11|CAeM-15/INF. 11), expected severity of convection at major holding points based on AVM output can be provided in the form of colour-coded alerts (e.g. amber or red) for forecasters' reference.

5.4 It must be stressed that forecasting of significant convection remains a challenge to high-resolution prediction systems, which may exhibit high degrees of uncertainty due to the intrinsic limit of predictability of the mesoscale meteorological phenomena. Model performance would be closely assessed in the convective season of 2014.

## 6. CHALLENGES AHEAD

6.1 While the improved spatial resolution of forecast products offers the capacity for more realistic depiction of possible future weather scenarios, challenges, both scientific and operational, must also be noted.

6.2 With increasingly detailed forecasts generated by fine-scale models, error in predicted timing and/or location of weather systems tend to be heavily penalised by existing verification metrics such as POD and FAR. Development of appropriate verification methodology would be required to provide balanced assessment of model capabilities.

6.3 Plans for future development of the AVM will focus on on-going model improvements by enhancing representation of various physical processes and utilization of regional observational data; establishment of verification metrics for different weather events; as well as development of automation techniques in identification of weather objects which would facilitate eventually translation into operational impacts to aviation users.

6.4 It is hoped that the capability of the AVM in anticipating mesoscale/local weather phenomena of impact to aviation operations could serve as demonstration that, despite the increasing sophistication of global meteorological forecast models, high-resolution regional prediction systems leveraging local observations and geographical details will continue to be of value to the aviation community in the future.

## 7. ACTION BY THE MEETING

7.1 The meeting is invited to note the information contained in this paper.

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**APPENDIX**

**FIGURES**

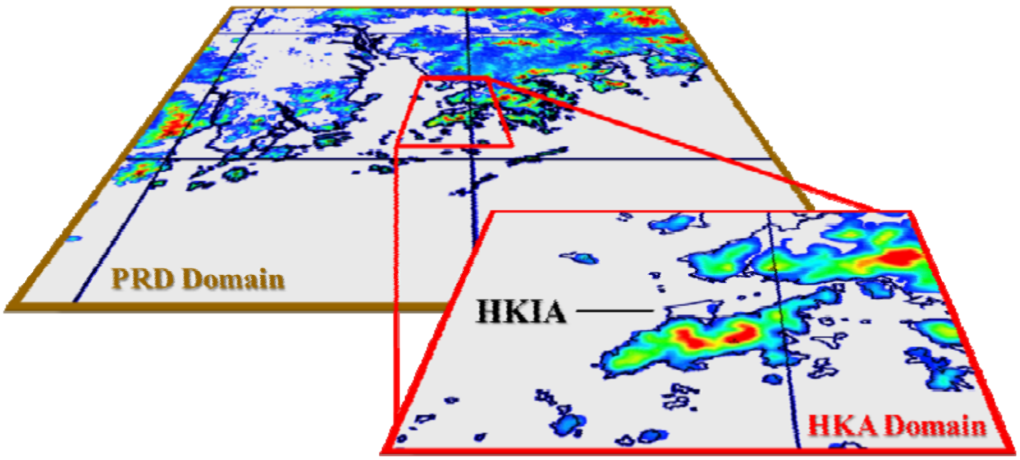


**Figure 1.** Schematic diagram of the nested domains of the HKO Aviation Model, covering the Pearl River Delta region at horizontal of 600 m ("PRD Domain") and the immediate vicinity of the Hong Kong International Airport (HKIA) at 200 m ("HKA Domain").

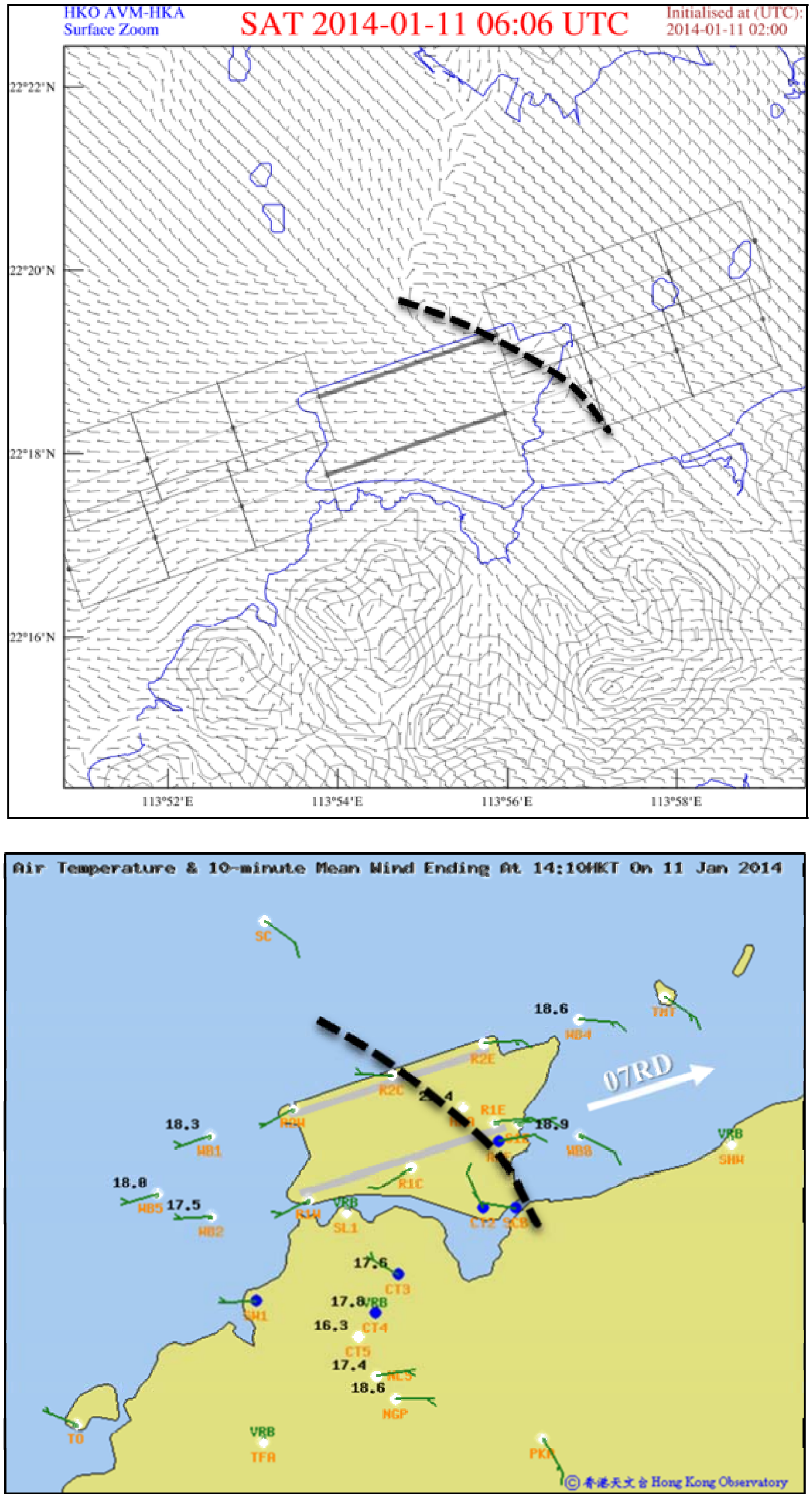


**Figure 2.** High-resolution surface wind forecasts (top) by the aviation model suggesting occurrence of sea breeze against prevailing easterly winds of 10 to 15 knots at 4 hours ahead. Location of the observed sea breeze front (to nearest 10 minutes) shown below for comparison.

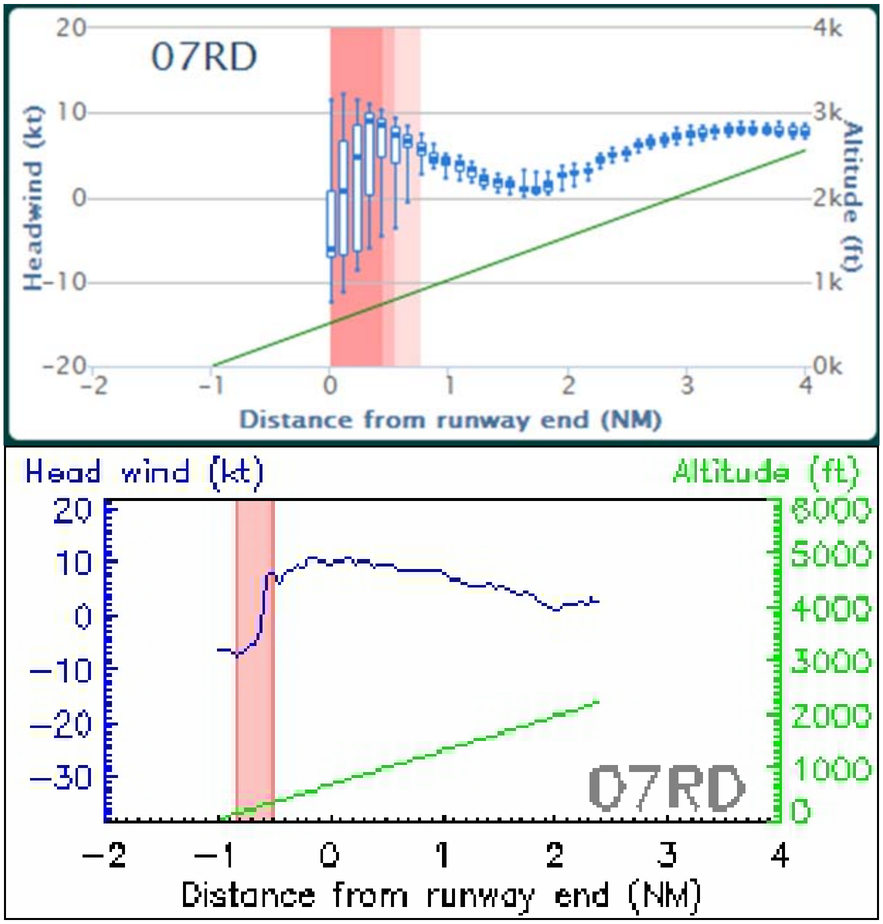


**Figure 3.** Forecast headwind profile (top) by the aviation model indicating potential for occurrence of low-level windshear (highlighted) over corridor 07RD at 4 hours ahead. Within the 1-hour validity period of this forecast, reports of significant windshear were received from 4 departing flights using 07RD. Headwind profile as detected by the Observatory's LIDAR Windshear Alerting System (alert highlighted) during one of the events shown below for comparison.

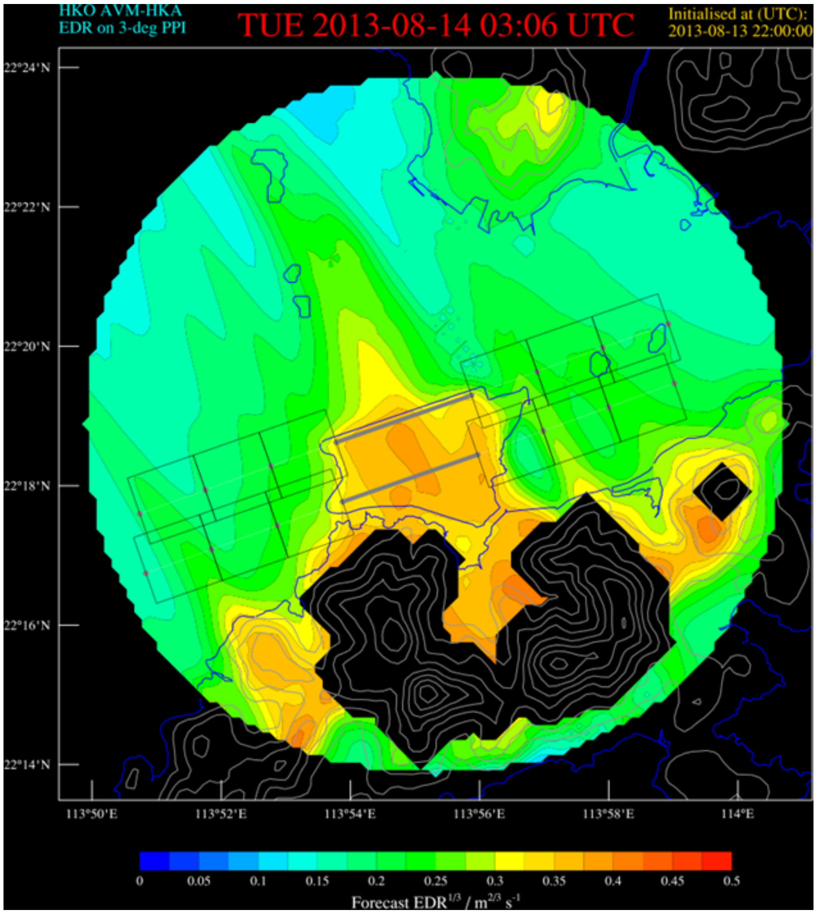


**Figure 4.** Forecast distribution of low-level turbulence intensity in the vicinity of the Hong Kong International Airport during passage of severe typhoon Utor in 2013 suggesting potential for moderate-to-severe low-level turbulence over the runways at 5 hours ahead. During this hour, 4 departure flights reported encountering significant windshear.

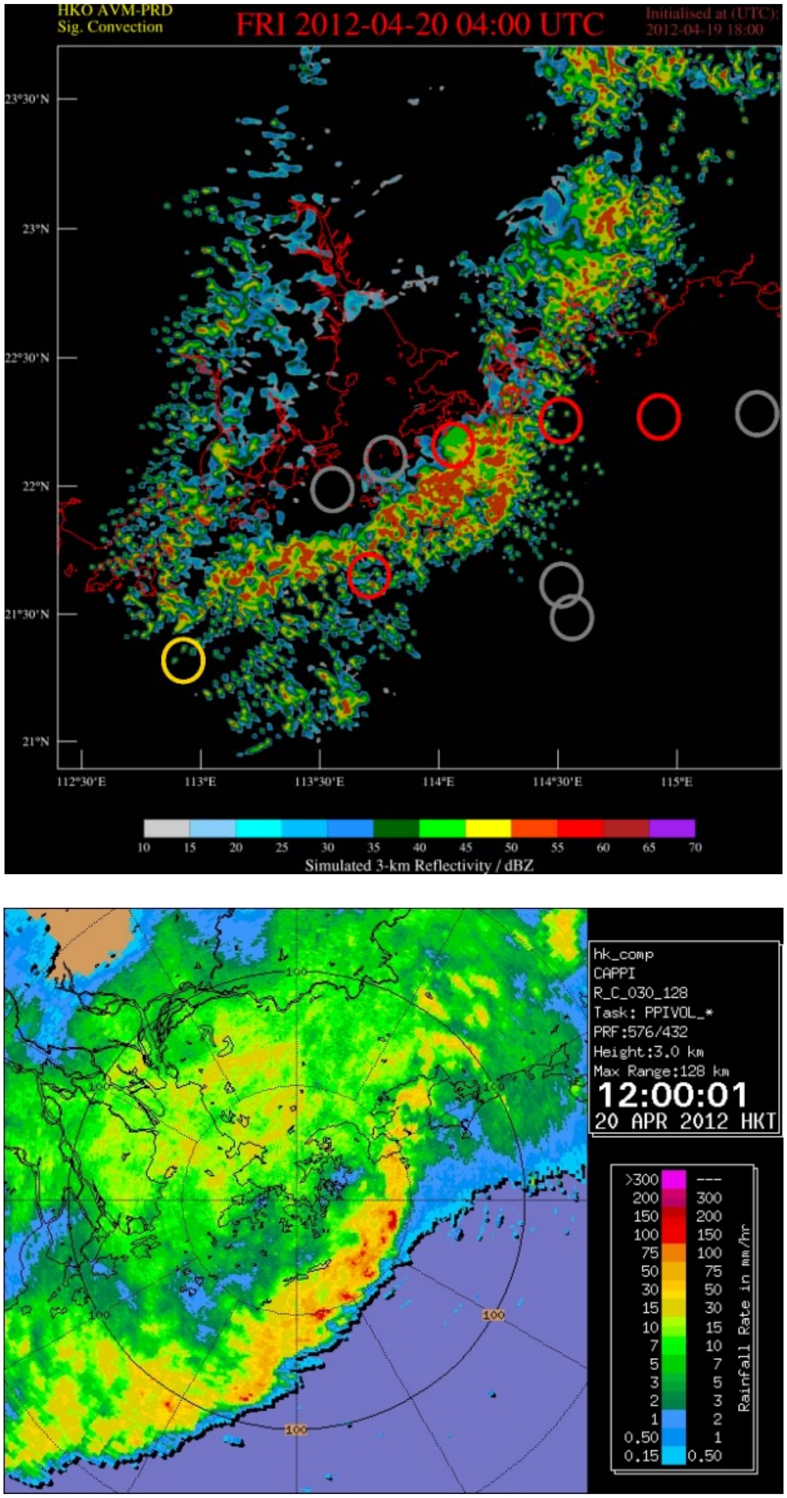


**Figure 5.** Forecast weather radar return (top) over the Pearl River Delta region in a case of spring-time squall line at 10 hours ahead. Potential impact at major holding points (circles) are indicated by colour codes (grey for "no major impact", amber for "medium" and red for "severe"). Actual radar picture valid at the time of the above forecast shown for comparison (below).

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