Application of Nowcast Products to Real-time Warning of Hazardous Weather in Hong Kong

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1. INTRODUCTION

Severe weather events may bring about mishaps and disasters to the people or businesses in Hong Kong. Rainstorms may create havoc in traffic and other public services. Severe thunderstorm may also bring lightning to an airport, threatening the safety of the operational staff on the ground and adversely affecting its operation.

The Hong Kong Observatory (HKO) maintains a close watch on the weather. HKO currently operates three rain-related warning systems, namely Rainstorm Warning, Landslip Warning and Thunderstorm Warning. Quantitative precipitation estimates and forecasts generated by SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) are particularly useful for operating Rainstorm Warning and Landslip Warning which are based on exceedance of prescribed rainfall thresholds. The Rainstorm Warning system is primarily designed to warn territory-wide short-duration intense rainfall and the warning criteria for the three categories of warnings, namely Amber, Red and Black, are rainfall intensities of at least 30, 50 and 70 mm/hr respectively. For low-lying areas with poor drainage in the northern part of Hong Kong, a special announcement of flooding (SAF) risks is broadcast based on criterion similar to that for the Red Rainstorm Warning, i.e. 1-hour rainfall reaching 50 mm (revised to 70 mm since April 2006) or more at selected gauges over the northern part of Hong Kong. Landslides are typically associated with prolonged rain events. Currently, the Landslip Warning criteria devised by the Geotechnical Engineering Office (GEO) are based on the correlation between 24-hour accumulated rainfall and landslide frequency. Cheung *et al.* [1] describes in more details how SWIRLS nowcast products are applied to Landslip Warning.

Given the volatile and often localized nature of severe weather such as rainstorms, making accurate and reliable prediction of them, even for a very short forecast time horizon, is a challenge that forecasters have to face up. The Observatory's automated nowcasting system, SWIRLS, was purposely built to meet the local warning needs. Wong et al. [1] discusses in more details on SWIRLS and its development. This paper will discuss the characteristics of typical rainstorms associated with different weather systems and their likely impact on Hong Kong, the applications and performance of SWIRLS in support of rain-related warning operations, and further development of SWIRLS and other nowcasting applications in Hong Kong.

2. RAINSTORM CHARACTERISTICS AND IMPACT ON HONG KONG

In southern China, synoptic weather systems that could bring heavy rain include monsoon troughs, active southwesterly monsoon flow, converging southerly flow on the western flank of the Pacific ridge, tropical cyclones and land-sea breezes. According to a recent study by Li and Lai [1], rainstorms in Hong Kong can be subjectively stratified into seven representative types according to the prevailing synoptic conditions and their radar signatures. In order of decreasing occurrence frequency, they are quasi-stationary southwesterly rainbands (QU), cross-type rainbands (X), land-sea breeze storms (LS), squall-lines or bow echoes (SQ), tropical cyclone rainbands (TC), southeasterly rainbands (SE) and supercells (SU). Fig. 1 shows examples of these rainstorm types as seen on radar.

Rainstorms vary in intensity, translational speed, spatial coverage and shapes, and hence the amount of rainfall produced over Hong Kong. Different rainstorm scenarios can lead to different impact and hazards. The idea that heavy rain occurs where it rains for the longest duration seems too simplistic and naïve to begin with; but it does tell us the basic yet important truth that if the advective term dominates, then the rain is not going to last unless there are mechanisms for sustained rain generation upstream. As such, translational speed of individual cells, orientation of rainbands, group velocity of systems, direction of propagation tendency, merging and slowing-down of rainbands all have a role to play in deciding whether rainstorms occur or not at a certain location.

Analyses based on data in 2001-2005 indicate that while all seven types could lead to Amber rainstorms, only the QU, SE, SQ and X types could produce Red rainstorms, and only QU and X could trigger Black rainstorms. It is interesting to note that the TC type hardly triggers any Red or Black rainstorms despite the destructive power of tropical cyclones, and this obviously has something to do with the dominant effect of advection. For flooding in the northern part of Hong Kong, all but the SE type could be a trigger. Except for the fast-moving SU and SQ cases, all other types could potentially lead to landslides.

3. SWIRLS IN SUPPORT OF WARNING OPERATION AND SERVICES

Table 1 summarizes the reference warning criteria for the above severe weather phenomena in Hong Kong that are heavily linked with rainfall amount. As noted from Table 1, the warnings have different spatial, temporal and intensity requirements on the rainfall distributions and patterns. Nowcasting tools and products provide crucial inputs for operating these warning services. The 1-hour and 3-hour rainfall products of SWIRLS are tailor-made for Rainstorm Warning and Landslip Warning respectively. To offer timely decision support to the forecasters, audio and visual alerts are generated based on SWIRLS' forecast rainfall data and via SWIRLS' graphical interface (Fig. 2).

In addition, a Rainstorm Warning Panel running in real time on a web interface offers a compact view of potential rainstorm risks generated by both nowcasting systems and NWP models (Fig. 3). Forecasters can validate in real time the 6-minute updated QPF guidance against the 5-minute updated rainfall data as reported by over 100 raingauges in Hong Kong. At the same time, objective guidance in terms of advanced alerts of probable occurrence of rainstorms as extracted from the numerical models are synchronously displayed, including results from earlier runs in a time-lagged ensemble fashion.

To draw forecasters' attention to the threat of severe weather associated with rainstorms, SWIRLS also analyzes, tracks and forecasts the motion of convective cells/systems based on radar data. Storm tracks and properties were displayed via the SWIRLS graphical interface (Fig. 4). Presented in the form of highlighted ellipses according to some pre-defined or user-defined reflectivity thresholds, forecasters can evaluate and assess the likelihood of merging of major convective systems, a scenario which could lead to enhanced or prolonged rainfall.

SWIRLS has been in operation since 1999. Fig. 5 shows its overall performance in Red and Amber Rainstorm Warning cases in 2004-2005, and flooding (for northern part of Hong Kong) and Landslip Warning cases in 2001-2005 (more detailed results could be found in [1]). Because of its infrequent occurrences, the Black Rainstorm Warning is yet to be meaningfully verified. In the histogram, the solid colour bars in blue, orange and green indicate the probability of detection (POD), false alarm rate (FAR) and critical success index (CSI) respectively. Assuming that the ideal warning lead times for Rainstorm Warning, Landslip Warning and Special Flooding Announcement are 1 hour, 3 hours and 1 hour respectively, the striated bar in purple shows the percentage of ideal lead (PIL) time achieved by the SWIRLS alerts.

As seen from Fig. 5, alerts on Red and Amber Rainstorm Warning achieve the highest POD and PIL at the expenses of FAR. Because of the significant social impact of Red Rainstorm Warning, the spatial criterion for triggering the alert is purposely tuned towards higher detection rate and longer lead time. In operation, the same criterion is also applied to Amber Rainstorm Warning. In general, the Red Rainstorm Warning alerts have a higher FAR and a lower CSI than Amber. Although also validating QPF for the next hour, performance for the Special Flooding Announcement is relatively inferior, probably owing to the more demanding warning criteria (intense rainfall over a small and specific region in Hong Kong; see Table 1). As far as forecast skill (in terms of CSI) is concerned, Landslip Warning alerts score the highest due to the way the 24-hour running rainfall total is defined (actual rainfall over the past 21 hours plus forecast rainfall for the coming 3 hours). Anchored by the actual 21-hour rainfall amount, the errors of 3-hour rainfall forecasts of SWIRLS are thereby "diluted" to some extent. While POD and CSI are generally highest for Landslip Warning alerts, the PIL is relatively low at just over 50%. This is a reflection of the fact that SWIRLS is not quite able to predict rainstorm development with any reliable skills beyond, say, two hours due to its implicit assumption of rain intensity persistence. Also, the validation is purely aimed at QPF for the next three hours as provided to the Landslip Warning system; how useful is such QPF guidance in relation to the actual landslip incidents reported is discussed in a companion study by Cheung *et al.* [1].

Fig. and Fig. show two rainstorm cases, resulting in a Red Rainstorm Warning/special flooding announcement and a Black Rainstorm Warning on 5 May 2003 and 8 May 2004 respectively. In both cases, QPF guidance from SWIRLS computed about an hour ahead of the events was sufficiently informative to help forecasters evaluate the needs for warning issuance. In day-to-day operation, forecasters on the bench would apply the nowcast products in the context of an evolving situation supported by the latest information gathered from a multitude of sources. For example, they will not rely on one single piece of forecast guidance but instead look for a consistent signal from the rapidly updated forecasts and alerts of SWIRLS. Forecasters will usually check the corresponding forecast rainfall maps and the images on the radar screen to judge if intensity persistence is a valid assumption and whether allowance should be made in terms of location errors in the forecast rainfall distribution.

4. FURTHER DEVELOPMENT

Two major enhancements recently implemented in connection with SWIRLS are respectively the introduction of the Semi-Lagrangian advection technique and a new QPF system in the form of RAPIDS (Rainstorm Analysis and Prediction Integrated Data-processing System), which blends SWIRLS nowcasts with NWP model forecasts to extend the effective QPF range from 3 to 6 hours. RAPIDS is described in more details by Wong [4].

Apart from QPF, HKO has also started research on forecast of high-impact weathers related to severe thunderstorms, including lightning and severe squalls. This calls for the development of new radar analysis techniques and severe weather detection and tracking algorithms. HKO has set up in 2005 a lightning location network covering Hong Kong, China and its vicinity, in collaboration with the meteorological services of Mainland China and Macao, China. The network provides lightning information, including time, location, direction (i.e. cloud-to-cloud or cloud-to-ground) and strike polarity (i.e. positive or negative) within 180 km of Hong Kong. SWIRLS' radar echo motion fields and storm tracks analyzed based on the TREC (Tracking Radar Echoes by Correlation) technique, together with lightning and electric field mill data, are being explored to provide lightning nowcasts to the Airport Meteorological

Office as well as the Airport Authority of the Hong Kong International Airport (HKIA) in support of aerodrome operations. Development of lightning nowcasting products is being carried out in two approaches [5]:

(i) the lightning data within contiguous regions are grouped together to identify active thunderstorms in the vicinity of HKIA. Forecast movement of these lightning regions is estimated by projecting their respective positions in the future along the TREC vectors. When a lightning region is forecast to hit HKIA, an alert would be generated. Initial verification shows that this approach could successfully predict about 74% and 60% of the lightning events occurred over the HKIA respectively 12 mins and 30 mins ahead. Sample display of the forecast is shown in Fig.8a; and

(ii) by employing the TREC technique, the correlation between lightning data and weather radar echo parameters (e.g. echo top, reflectivity at 3 km CAPPI, vertically integrated liquid (VIL)) can be made to estimate the probability of lightning in relation to the radar parameters in the following hour. A sample display of the forecast is shown in Fig.8b.

When accomplished, the enhanced severe weather capability of SWIRLS is expected to contribute to the Thunderstorm Warning, an area where nowcast support is relatively weak at the moment. Such enhancements will be of significant contribution to the safe operation in the HKIA, especially in protecting operational staff on the ground from lightning. The newly developed modules will also be tested during the WMO/WWRP Beijing 2008 Olympic Forecast Demonstration Project (B08FDP).

On the service front, HKO's severe weather warning systems have been evolving over the years to meet the increasing demand of the public. A good warning system should be: (a) easy to understand; and (b) ready to facilitate collective and effective response by the public [4] & [7]. Warning systems are more than just a set of definitions of different "warning status" or warning criteria. As such, consideration has to be given to optimize the use and applications of nowcast products, not just by the forecasters, but also by the general as well as special users in the public domain. One way to go is to incorporate more customer-centric information. Presentation of nowcasting information over a GIS (geographical information system) platform or in more user-relevant formats will be one of the development themes in the coming years (e.g. a sample product developed for the B08FDP is shown in Fig. 9), allowing users to make more intelligent assessment or conscious decisions of the risks of severe weather with respect to their specific locations or their activities of interest.

References

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Table 1 – Reference warning criteria for rain-related severe weather phenomena in Hong Kong (as of 2005).

Warning	Spatial Criteria	Temporal Criteria	Rainfall Criteria
Amber Rainstorm Warning	widespread	Persistent	30 mm/hr or more
Red Rainstorm Warning	widespread	Persistent	50 mm/hr or more
Black Rainstorm Warning	widespread	Persistent	70 mm/hr or more
Landslip Warning	weighted by vulnerable areas	Prolonged	24-hour rainfall → 15 landslides or more
Special Flooding Announcement	northern New Territories	Nil	~50* mm/hr or more

* Special Flooding Announcement rainfall criteria revised to "70 mm/hr or more" since April 2006.

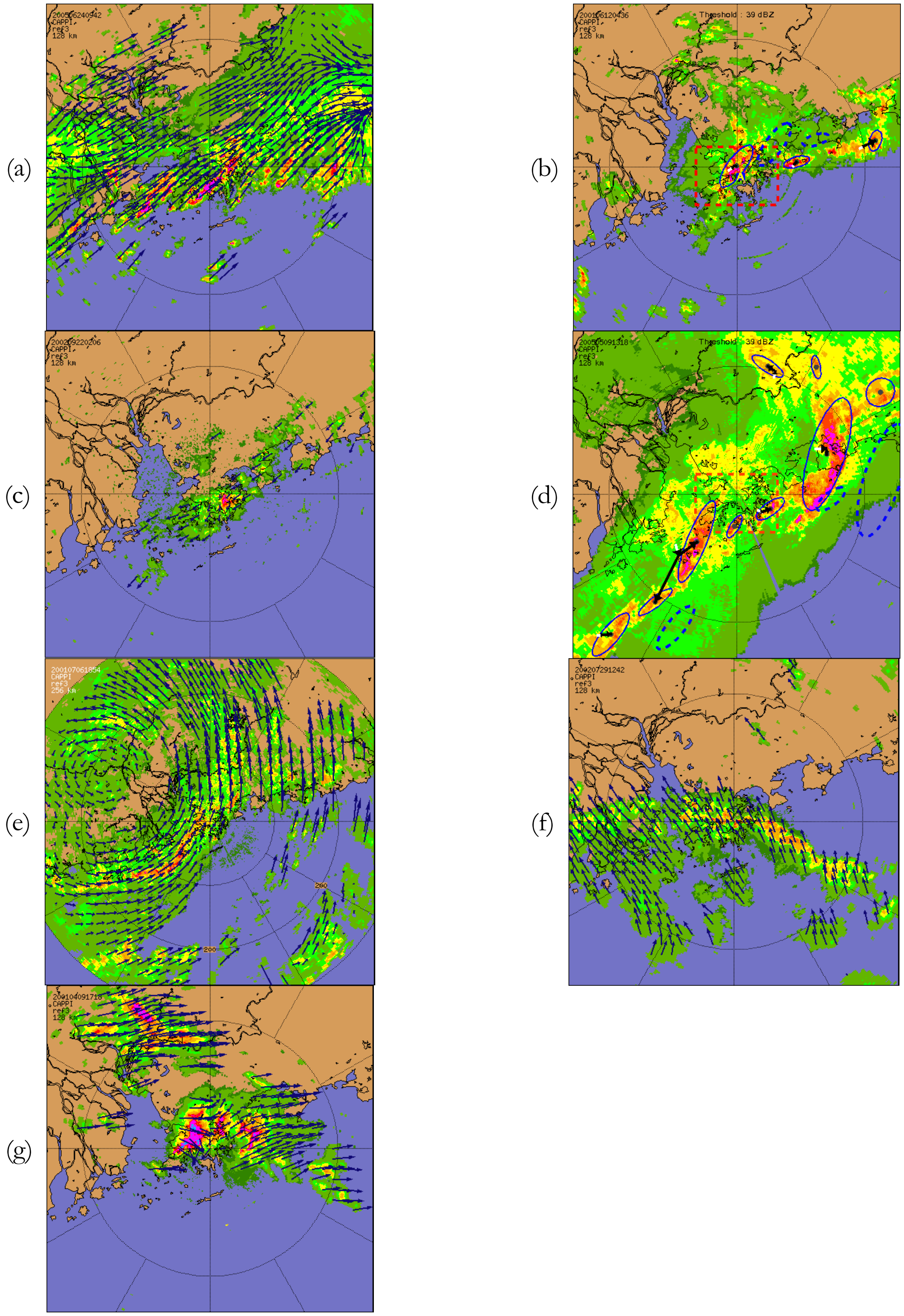

Fig. 1 Typical radar signatures of the seven types of high-impact rainstorms in Hong Kong: (a) QU, (b) X, (c) LS, (d) SQ, (e) TC, (f) SE and (g) SU (see text for details). Arrows and ellipses in blue indicate radar echo motion and storm threat areas respectively.

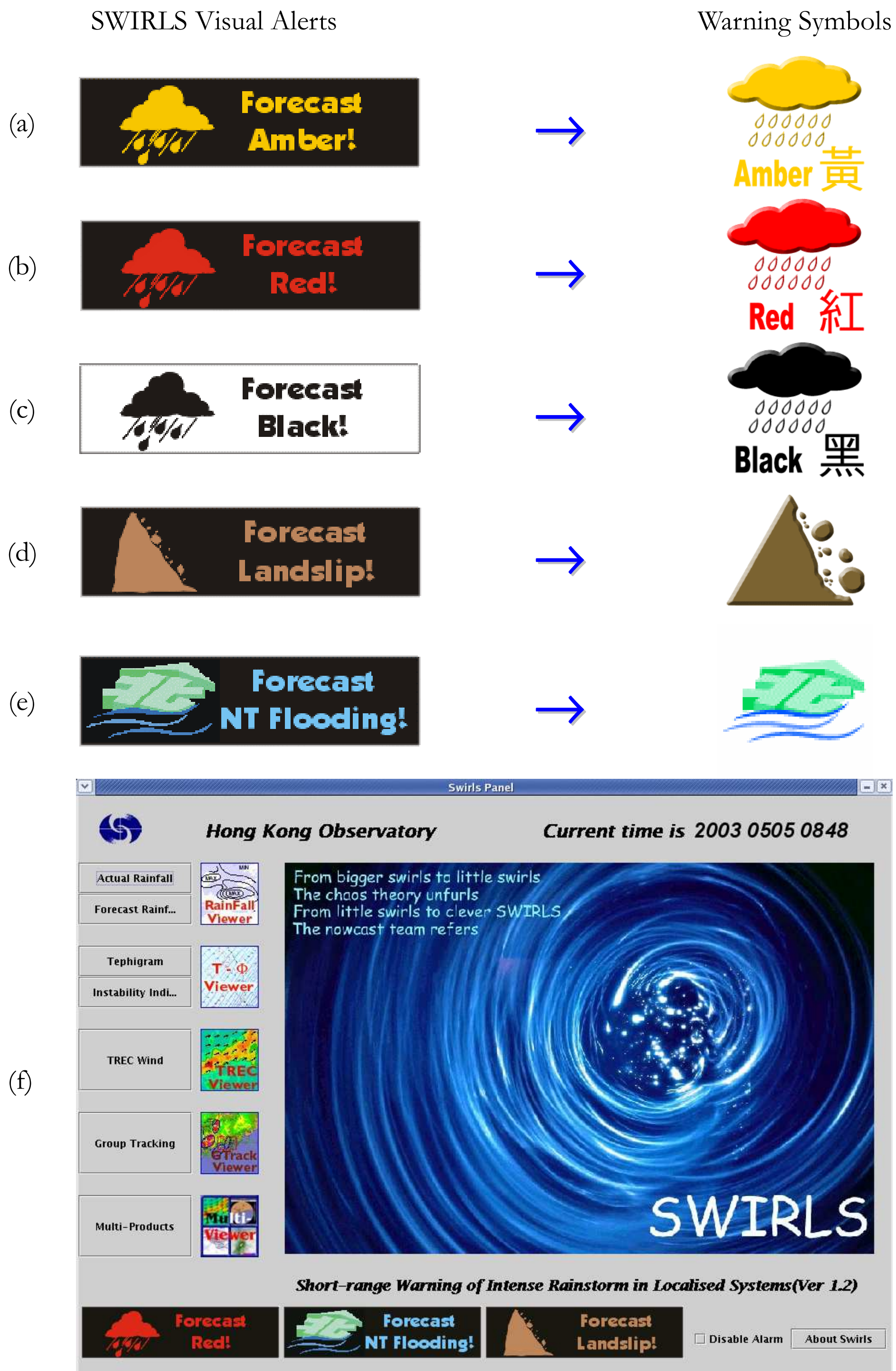

Fig. 2 SWIRLS warning guidance products - visual alerts from top to bottom corresponding respectively to (a) Amber RAINSTORM WARNING, (b) Red RAINSTORM WARNING, (c) Black RAINSTORM WARNING, (d) LANDSLIP WARNING and (e) SPECIAL FLOODING ANNOUNCEMENT. SWIRLS alerts as displayed on the front panel of the SWIRLS graphical user interface are shown in (f).

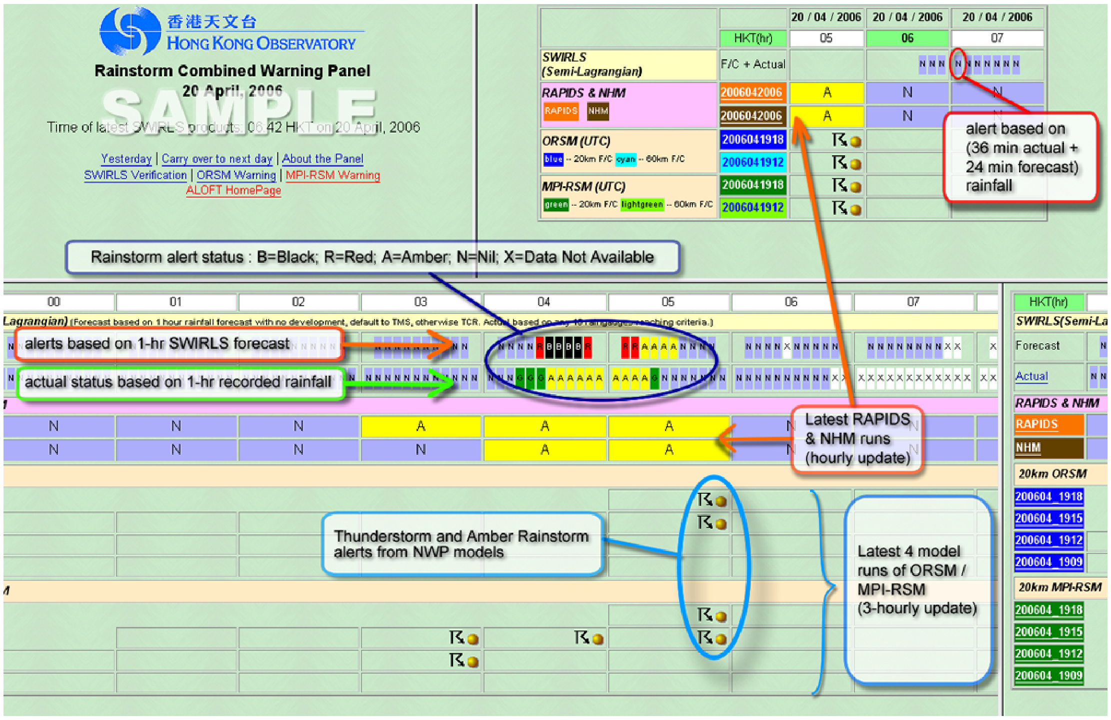

Fig. 3 SWIRLS Short-range Combined Warning Panel. The lower-left frame is the main display sub-panel and rows from top to bottom show the alert status of SWIRLS, actual, RAPIDS, and NWP models respectively. Status in the current hour is displayed in the top-right frame.

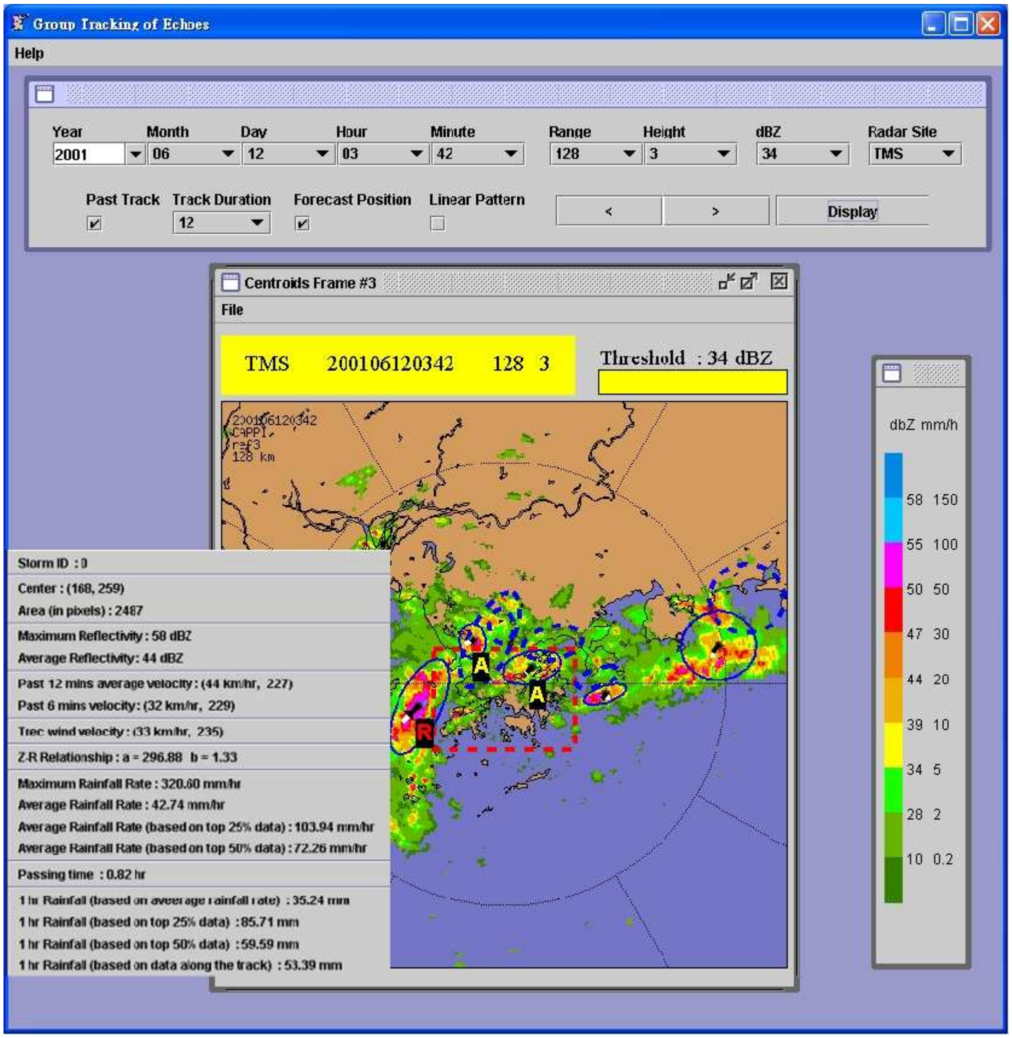

Fig. 4 Storm analysis and tracking in SWIRLS. Complete and dashed ellipses represent analyzed and forecast storm threat areas. Rectangular icons with dark background colour are flags indicating the severity of the storms in terms of rainstorm potential (A and R for Amber and Red Rainstorms respectively). The pop-up window on the lower-left shows storm properties in details.

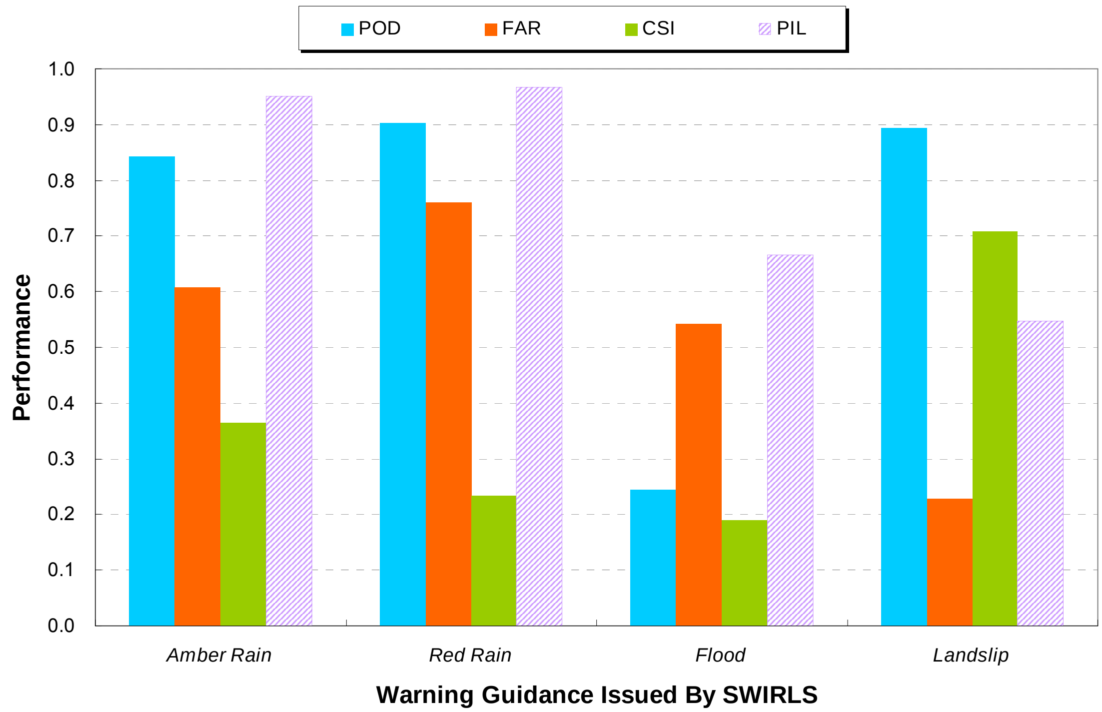

Fig. 5 Performance of SWIRLS forecasts in terms of warning guidance. The acronyms POD, FAR, CSI and PIL stand respectively for the probability of detection, false alarm rate, critical success index and percentage of ideal lead time respectively (see Section 3 in main text). Statistics of rainstorm guidance are based on data in 2004-2005, whereas flood and landslip encompass a larger data set from 2001 to 2005 in order to obtain larger sample sizes.

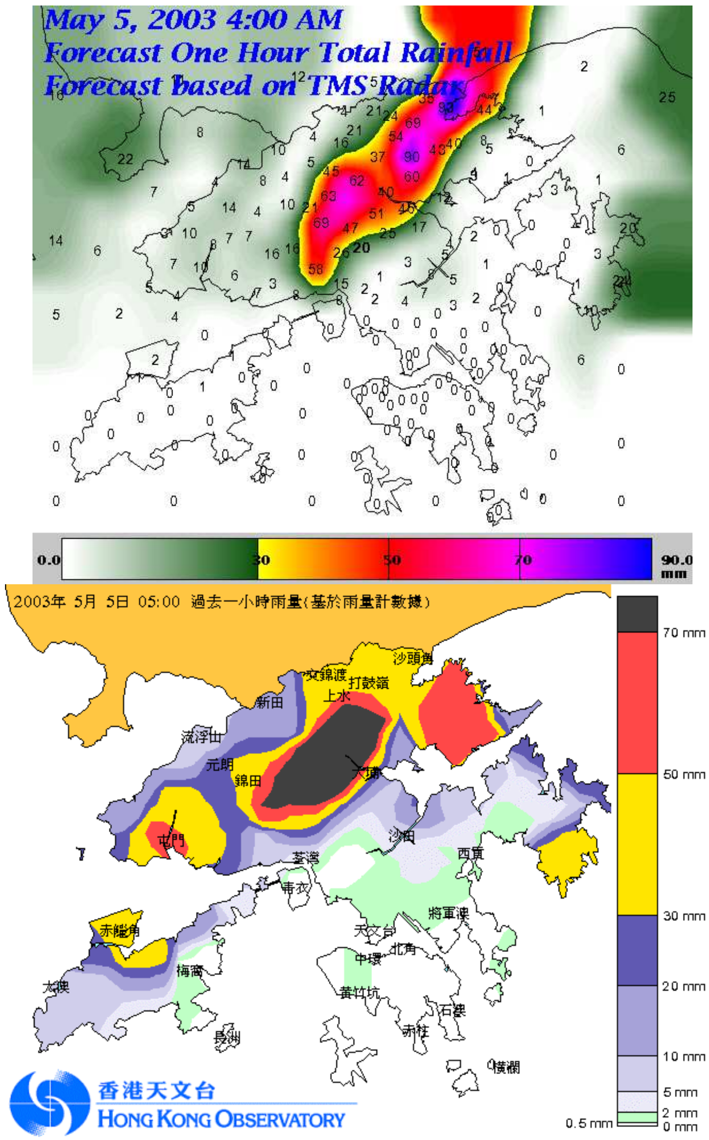

Fig. 6 Rainstorm on 5 May 2003 leading to Red RAINSTORM WARNING and special flooding announcement. SWIRLS one-hour forecast rainfall map (top) issued at 4 am compares favourably with the actual one-hour rainfall distribution (bottom) ending at 5 am.

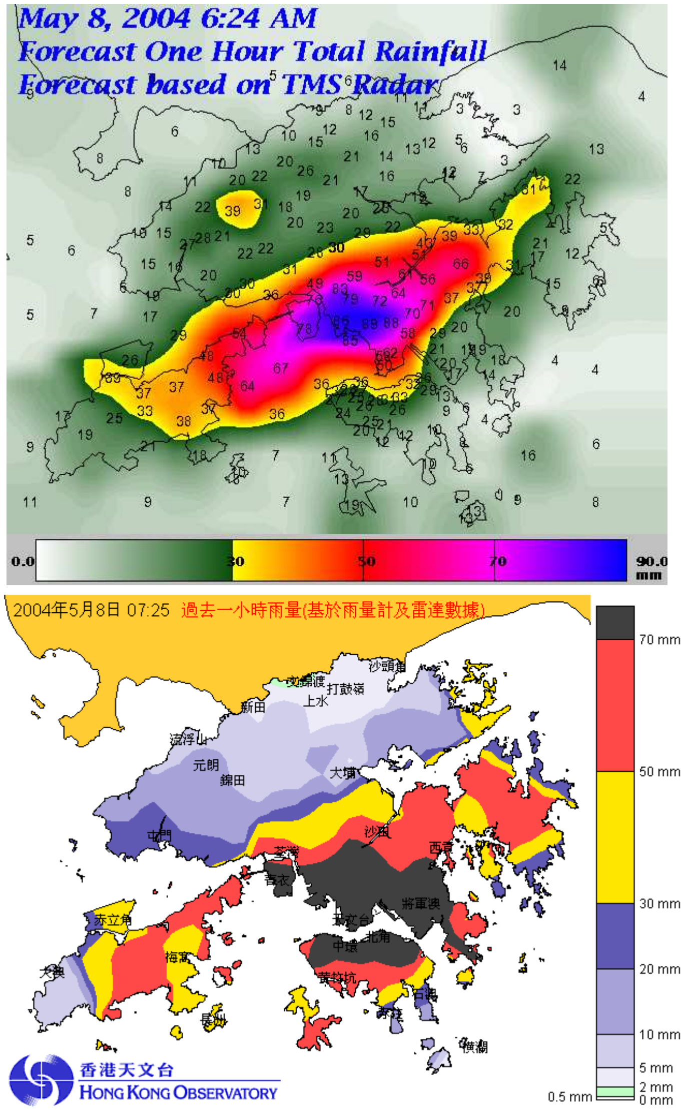

Fig. 7 Rainstorm on 8 May 2004 leading to a Black RAINSTORM WARNING. SWIRLS one-hour forecast rainfall map (top) issued at 6:24 am compares favourably with the actual one-hour rainfall distribution (bottom) ending at 7:25 am.

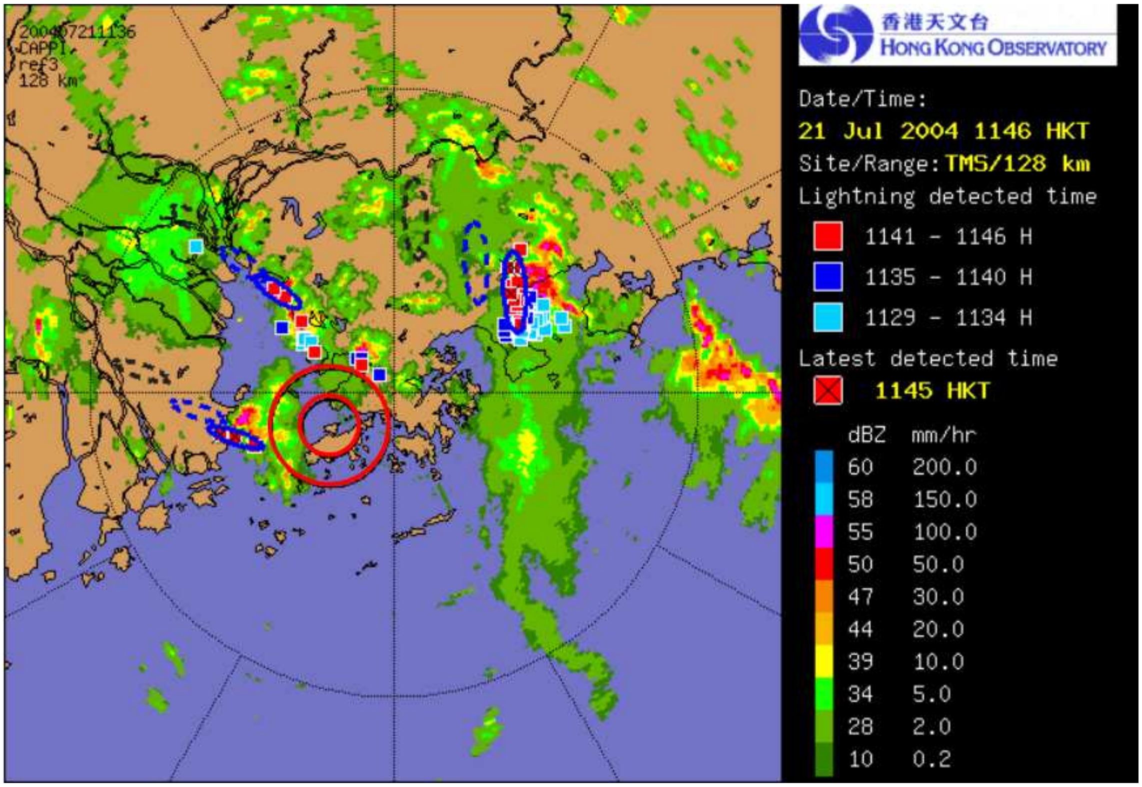

Fig. 8a Aerodrome lightning nowcast based on SWIRLS TREC winds. Full and dashed ellipses represent analyzed and forecast (12 and 30 min) lightning threat areas. Square dots in red, blue and cyan colour indicate lightning strike locations in the latest 5, last 5-10 and last 10-15 minutes. In the centre of the two concentric distance rings in red is the Hong Kong International Airport.

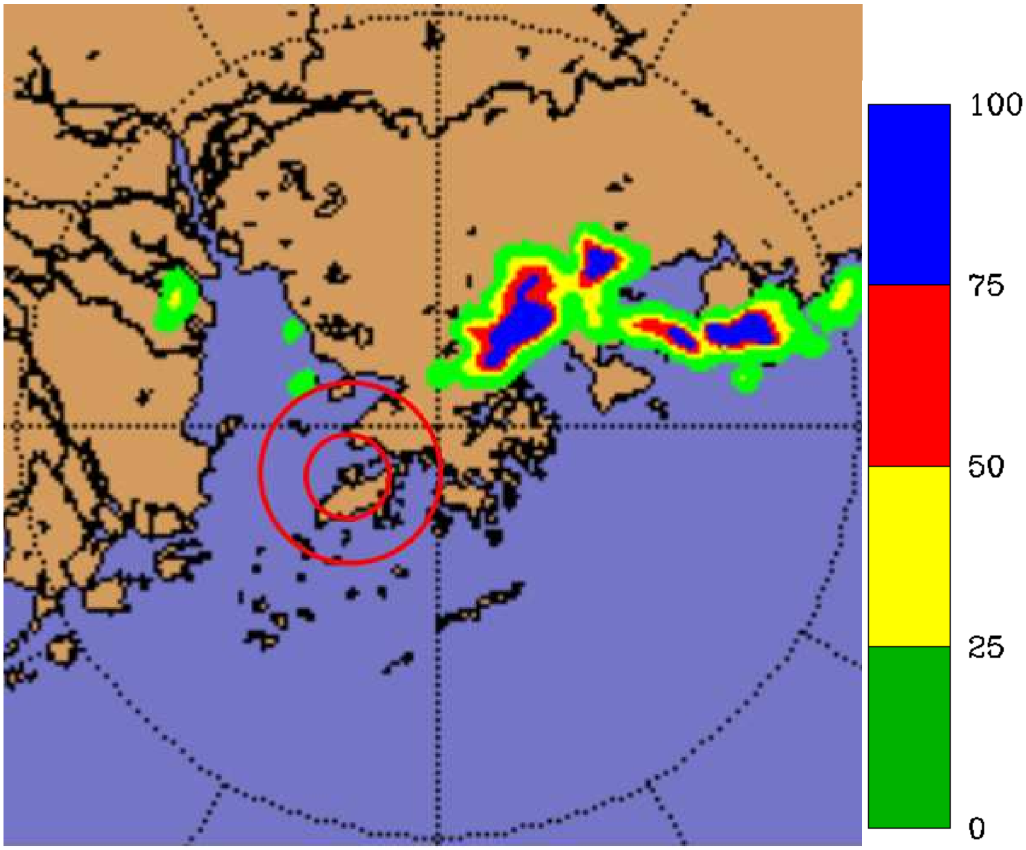

Fig. 8b 1-hour forecast probability of lightning (indicated by colours). In the centre of the two concentric distance rings in red is the Hong Kong International Airport.

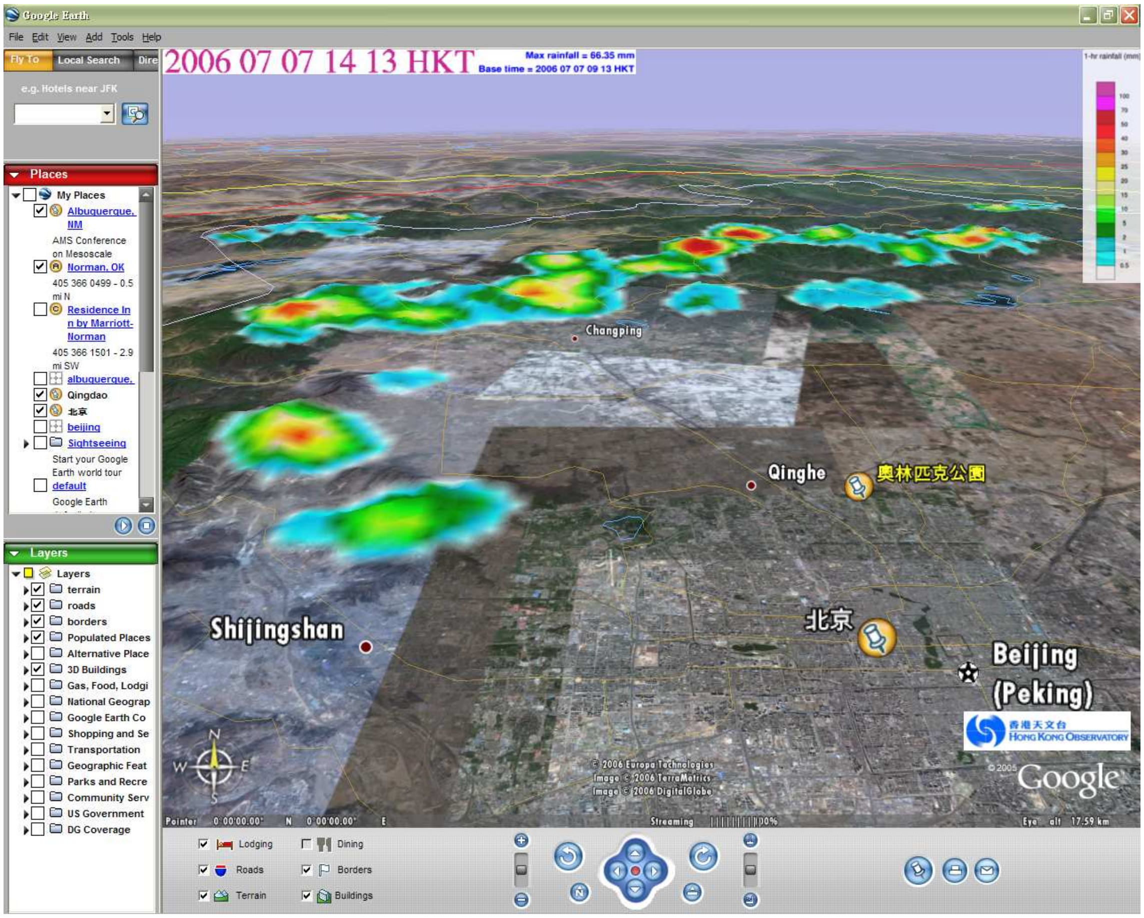

Fig. 9 RAPIDS precipitation forecast for B08FDP 1st trial as presented on a public domain GIS platform, Google Earth.