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Swirls-2 in Support of the 2008 Beijing Olympic Games

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APPLICATIONS OF THE HONG KONG OBSERVATORY NOWCASTING SYSTEM SWIRLS-2 IN SUPPORT OF THE 2008 BEIJING OLYMPIC GAMES

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ABSTRACT

The Hong Kong Observatory nowcasting system SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) has been in operation since 1999. Its second-generation version (referred to as SWIRLS-2) has been under development and real-time testing in Hong Kong since 2007. To support the 2008 Beijing Olympic Games, a special version of SWIRLS-2 was deployed for the Beijing 2008 Forecast Demonstration Project (B08FDP) under the auspices of the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO).

The original SWIRLS focused primarily on rainstorm and storm track predictions. The much enhanced SWIRLS-2 comprises a family of sub-systems, responsible respectively for ingestion of conventional and remote-sensing observation data, execution of nowcasting algorithms, as well as generation, dissemination and visualization of products via different channels. It embraces new nowcasting techniques, namely: (a) blending and combined use of radar-based nowcast and high-resolution NWP model analysis and forecast; (b) detection and nowcasting of high-impact weather including lightning, severe squalls and hail based on conceptual models; (c) grid-based, multi-scale storm-tracking method; and (d) probabilistic representation of nowcast uncertainties arising from storm tracking, growth and decay.

In this paper, through SWIRLS-2's participation in B08FDP, the system design, functionalities and full product suite of SWIRLS-2 will be presented and the nowcasting techniques behind its various sub-systems highlighted. The performance of SWIRLS-2 will be assessed in a selection of cases. The major limitations of the various nowcasting algorithms, the lesson learnt in B08FDP and the way forward will also be discussed.

1. INTRODUCTION

The nowcasting system of the Hong Kong Observatory (HKO), SWIRLS, has been in operation since 1999 [Li *et al.* 2000, Li & Lai 2004]. The original design objective of SWIRLS focused on quantitative precipitation estimation/forecast (QPE/QPF) and their applications to rainstorms and other related hazards, such as flooding and landslide [Cheung *et al.* 2006], in Hong Kong. Based on radar extrapolation technique, the maximum forecast range was 3 hours. As rainstorm-related warnings affect many social and economic activities, there has been an increasing demand from decision makers for lengthening the lead time of such warnings. Moreover, other high-impact weather phenomena associated with intense thunderstorms, such as hail and severe wind gusts, have also emerged as hazards of significant concerns. These

phenomena are notoriously difficult to predict owing to their transient and localized characteristics.

As such, an enhancement project to develop a second-generation version for SWIRLS (referred to as SWIRLS-2) was initiated. The primary goal was to ingest and analyze new observation types in a rapid-update cycle (RUC) fashion to assist forecasters in identifying and predicting severe weather events with a time frame of about one hour. The secondary goal was to lengthen the QPF range up to 6 hours by merging information from NWP models. SWIRLS-2 has been under active development and real-time testing in Hong Kong since 2007. Under the auspices of the WMO/WWRP, a special version of SWIRLS-2 was deployed for the B08FDP in support of the Beijing Olympic Games. It was the first time SWIRLS was operated in a mid-latitude environment and the B08FDP

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provided a new and challenging testing ground for the enhancement initiatives of SWIRLS-2.

SWIRLS-2 comprises a family of nowcasting sub-systems, responsible for ingestion of conventional and remote-sensing observation data, execution of a rich bundle of nowcasting algorithms, as well as generation, dissemination and visualization of products via different channels. Apart from some differences in end-user requirements (e.g. no landslide and flood warning in Beijing), the two systems implemented in Hong Kong and Beijing were essentially the same.

In this paper, the nowcasting techniques behind the various sub-systems of SWIRLS-2 will be introduced in Section 2. Section 3 will present the products of SWIRLS-2 for B08FDP. The real-time performance of SWIRLS-2 will be illustrated in Section 4 through selected examples. The merits and major limitations of the various nowcasting algorithms will be discussed in Section 5. In Section 6, the benefits and possibilities derived from the B08FDP experience will be assessed, and finally some conclusions drawn in Section 7.

2. SWIRLS-2 ALGORITHMS

2.1 Radar-based QPE/QPF

In SWIRLS-2, there are two major techniques to produce rainfall forecast over a gridded domain, namely radar-based QPF and radar-NWP blended QPF. Inherited from the original SWIRLS, the radar-based QPF of SWIRLS-2 implemented for B08FDP is basically a time integration of a gridded field of rainfall rate R , extrapolated according to a set of tracked echo-motion vectors. Based on radar reflectivity Z at 2-km altitude, R is estimated through a Z - R conversion using the Marshall-Palmer relation $Z = a \cdot R^b$. Treating a and b as adjustable parameters, this conversion formula can be calibrated every 5 minutes using the latest available 5-min rainfall accumulation G registered by a network of surface rain-gauges. In each calibration, a linear regression analysis is performed between the logarithms of G and Z (interpolated values at raingauge locations) to determine the dynamical values of a and b as best fitting parameters. The motion vectors are retrieved by tracking small blocks of reflectivity pixels in two successive radar images according to the traditional TREC (Tracking of Radar Echoes by Correlation) method [Tuttle & Foote 1990]. The extrapolation problem is solved by using a backward semi-Lagrangian advection scheme [Staniforth & Cote 1991]. The forecast distribution of rainfall accumulation is obtained by integrating the

extrapolated rainfall rate field in 6-min time steps out to six hours.

2.2 Blending with NWP

SWIRLS-2 also embraces new nowcasting techniques such as: (a) blending of radar-based nowcast and high-resolution NWP model analysis and forecast; (b) detection and nowcasting of high-impact weather including lightning, severe squalls and hail based on conceptual models; (c) a grid-based, multi-scale and robust storm-tracking method; and (d) probabilistic representation of nowcast uncertainties arising from storm tracking, growth and decay. Old and new techniques were all integrated in SWIRLS-2 as a family of loosely coupled sub-systems.

For NWP input, the Non-Hydrostatic Model (NHM) [Saito *et al.* 2007] of the Japan Meteorological Agency (JMA), configured at 5-km resolution covering about 750×750 km² around the Beijing area, was used to simulate the growth and decay of precipitation in the 6-hour nowcast period. NHM was initialized through a two-stage data assimilation procedure: (1) retrieval of hydrometeor information using LAPS (Local Analysis and Prediction System [Albers *et al.* 1996] developed by the former Forecast Systems Laboratory of the National Oceanic and Atmospheric Administration, USA); and then (2) NHM's 3-dimensional variational data assimilation system, called JNOVA-3DVAR [Honda *et al.* 2005]. All available observation data, including radar, satellite and AWS, etc, were ingested by the data analysis systems to capture the latest atmospheric state in an hourly RUC. JMA's generous offer of its full resolution (20-km) global model data provided the lateral boundary conditions for running NHM.

A new technique called "phase correction" was implemented to rectify the timing or location errors of model predicted rainbands before such information is blended with radar-based rainfall nowcast. The blending technique itself is non-trivial, requiring careful treatment of the uncertainties involved and rationalized weighting between the two pieces of rainfall information at different forecast ranges (increasing weight for model rainfall in the form of a hyperbolic curve). The sub-system to handle this was RAPIDS (Rainstorm Analysis and Prediction Integrated Data Processing System) [Wong & Lai 2006, Wong *et al.* 2009]. For B08FDP, RAPIDS was set up to update at 6-min intervals, in synchronization with the radar-extrapolated QPF.

Despite the above blending effort to combine the best of the two QPFs, large errors could still arise, especially in the

long lead time (3-6 hours) or heavy rain regime. To properly represent the inherent uncertainties, a probabilistic approach was adopted for long lead time QPF. In contrast to a physically or stochastically perturbed ensemble of possible rainfall forecasts, which could be computationally expensive to operate, RAPIDS made use of the readily available “perturbations” from rainfall forecasts generated in previous update cycles and estimated the probability of precipitation (PoP) based on a time-lagged ensemble approach (with exponentially decreasing weighting factors).

2.3 Severe Weather Detection

For the detection of severe weather and their subsequent nowcasts with useful lead times, SWIRLS-2 explored various conceptual models to help select and extract the essential and critical information. To keep the required computation at an affordable level, simple conceptual models were adopted. For example, the sub-system for forecasting cloud-to-ground (CG) lightning initiation DELITE (Detection of cloud Electrification and Lightning based on Isothermal Thunderstorm Echoes) made use of precursors associated with an underlying conceptual model of an electrifying cumulus cloud with its main source of lightning located in isothermal layers above the freezing level, with typical charge carriers in the form of ice or graupel which can be detected as radar echoes when wet. To retrieve echoes at constant temperature levels, the detailed thermal structure of the troposphere must be known in near real-time and such atmosphere analysis, hence isothermal echoes, was made possible by using the LAPS analysis data. In DELITE, the chief precursors were echo top, vertically integrated liquid (VIL) water, 0°C, -10°C, and -20°C isothermal radar reflectivities [Yeung *et al.* 2007]. CG lightning initiation was considered triggered if these five radar parameters exceeded their respective thresholds (7.6 km, 5.9 mm, 47 dBZ, 17 dBZ and 0 dBZ respectively) simultaneously.

For the assessment of lightning threat at a longer lead time, only one sub-zero isothermal reflectivity field (-10°C at a threshold of 20 dBZ in B08FDP) was used as the chief precursor. The field was advected forward in time up to 3 hours. Assuming the exceedance of isothermal reflectivity over the threshold would trigger the occurrence of lightning, the probability of lightning (PoL) was estimated from a time-lagged ensemble of forecast isothermal reflectivity fields in a way similar to the PoP algorithm.

The sub-system BLAAST (Buoyancy contribution and Loading effect of rain water to Air parcel Acceleration in

Squally Thunderstorms) for downburst/squalls nowcasting was developed with reference to the descending forces that created a downburst, namely the combined effect of negative buoyancy as a result of evaporative cooling of falling rain drops and the water loading effect on an air parcel. The latter effect manifested itself under radar surveillance as VIL, a quantity readily available from most radar processing software. If the resultant force acting on an air parcel was pointing downward, a downburst was considered triggered. The maximum gust winds induced on the ground were estimated by converting all the potential energy (due to negative buoyancy and water loading) and kinetic energy (due to horizontal momentum) of the parcel at its descending level into kinetic energy at the ground level [Yeung *et al.* 2008].

The conceptual model behind the hail nowcasting sub-system BRINGO (Buoyancy-supported Rimed Ice Nugget and Graupel Overhang) was also relatively simplistic. Its design was based on the automatic detection of overhanging radar echoes, typically found in hailstorms as a result of strong inflow and buoyancy in the riming process for ice or graupel. Specifically, a hail-prone overhanging echo was identified by BRINGO as intense reflectivity pixels exceeding 60 dBZ at altitudes above 3 km, with VIL in the lowest 1-2 km less than 5 mm.

2.4 Multi-scale Storm Tracking

For the severe weather hazards identified, the next step was to predict their future movement so as to determine the threat areas. In contrast to other cell-oriented approaches, SWIRLS-2 obtained the forecast movement (next 30 or 60 min) of storm cells from the MOVA (Multi-scale Optical flow by Variational Analysis) echo-motion vector field at the cell centroid location. In short, a gridded echo-motion field was retrieved from successive reflectivity fields by solving the optical flow equation using variational minimization technique. A multi-level cascade computation was carried out so that the echo-motion fields at different spatial scales could be obtained subject to prescribed constraint such as smoothness of motion vectors. The motion fields at different scales or cascade levels were then applied to track storm cells or individual reflectivity pixels [Wong & Lai 2009].

Compared to the original storm-cell tracker of SWIRLS, GTrack [Li & Lai 2004], (which determined a cell's future motion by extrapolating the latest 6-min displacement vector of the cell centroid, similar to the TITAN [Dixon & Wiener 1993] approach in two dimensions) MOVA proved to be more

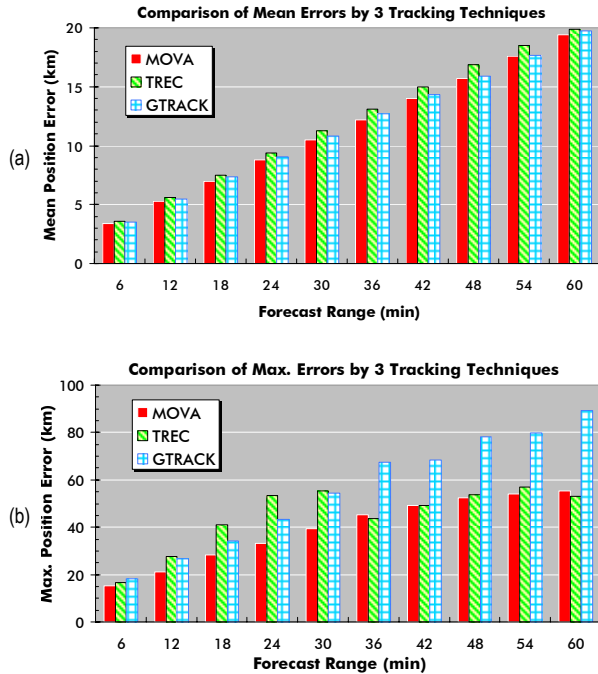


Fig. 1 (a) Mean position errors in storm-track forecasts by the MOVA, TREC and GTrack methods respectively. (b) Maximum position errors by the three methods. Verification based on the 2007 FDP Trial cases.

superior insofar as robustness and location errors were concerned. Fig. 1(a) and (b) summarize and compare the forecast performance of the three tracking techniques available in SWIRLS-2, namely MOVA, TREC and GTrack for the thunderstorm cases of the 2nd FDP Trial (case re-run). The mean errors of forecast position (w.r.t. analyzed position) for all three methods were comparable, with MOVA having a slightly smaller error. Moreover, MOVA generally had much smaller errors in difficult cases in which large errors were often found.

3. NOWCAST PRODUCTS

During the B08FDP intensive operation period (IOP, viz. 1-25 August 2008) the major functions of SWIRLS-2 included: (i) quantitative precipitation estimation (QPE); (ii) quantitative precipitation forecast (QPF); (iii) atmospheric stability analysis; (iv) severe weather detection and nowcasting; (v) rapidly updating atmospheric analysis; (vi) probabilistic representation of nowcast uncertainties; and (vii) visualization and display of nowcast input/output data and severe weather alerts.

Major SWIRLS-2 products are summarized in Table 1, including the output of NWP and observational data, to facilitate forecasters or developers in monitoring the current weather situation and for eyeball verification of the nowcasts

Table 1 — B08FDP Product Suite of SWIRLS-2.

Type	Forecast/Analysis Elements	Output Format	Forecast Range
QPF	radar-based rainfall accumulation forecasts	NetCDF*	0-1 h, 0-2 h & 0-3 h
	radar-NWP blended rainfall accum. forecasts	NetCDF*	0-1h, 0-2h, ..., 0-6 h
	same blended QPF visualized on Google Earth	KML	<i>ibid</i>
	Probability of precipitation (blended QPF)	NetCDF*	0-1 h, 0-3 h & 0-6 h
tracking	storm-cell identification, analysis and forecast	XML*	0-60 min
	TREC echo-motion vector field	image	-
	MOVA echo-motion vector field	image	-
severe weather	4 types of severe weather cells: rainstorm, CG lightning initiation, downburst & hail	XML*	0-30 min
	Severe squalls due to downbursts over the warning area (i.e. all Olympic venues)	XML*	0-30 min
	Probability of lightning threat	NetCDF*	0-1 h, 0-2 h & 0-3 h
combined	interactive GUIs/maps for rainfall, radar-tracking, severe weather, Tephigram & stability indices	image	up to 6 h
	SPIDASS (web interface for integrated display of all severe weather alerts)	HTML, image	up to 6 h and past records
NWP	weather maps from NHM (hourly rainfall accumulations, temp, RH, winds, isobars, etc., at standard levels)	HTML, image	up to 9 h
obs	3D lightning data visualized on Google Earth	KML	-
	FY2C satellite pictures (IR, VIS, WV channels)	image	-

* NetCDF and XML here refer to the B08FDP standards.

from SWIRLS. To meet the B08FDP requirements, a selected set of products were output in B08FDP NetCDF and XML formats, in compliance with the specifications laid down by the forecast verification working group. All nowcast products are updated every 6 minutes, in synchronization with the radar scanning schedule. Typical time latency is about 12 minutes with respect to the start times of radar scans.

With a turn-around time of six minutes, it is almost impossible for users to digest all the available nowcast data and extract the most important messages in support of weather warnings or other related decision makings. To help forecasters or decision makers to absorb and appreciate the vast amount of information processed, SPIDASS (SWIRLS Panel for Integrated Display of Alerts on Severe Storms, the main user interface of SWIRLS-2) extracted and presented the most critical alerting messages according to local warning needs and triggering criteria. To ensure that such alerts could



Fig. 2 Snapshots of SWIRLS-2 KML products: real-time 3D lightning display for Beijing on 14 Aug 2008 (symbols “+”, “=” and “c” represent respectively positive cloud-to-ground (CG), negative CG and cloud-to-cloud lightning at different altitudes).

capture the attention of users, all alerting signals were symbolized, vividly colour-coded and displayed compactly as rolling time series on a dedicated web page.

At the public service front, visual impact and user-friendly delivery were of paramount importance. During the development phase of B08FDP, the Keyhole Markup Language (KML) standard for encoding GIS (Geographic Information System) data and powerful 4D visualization engines such as the Google Earth had emerged. They enabled the successful development of SWIRLS-2 GIS-based nowcast products for forecast rainfall map and 3D lightning location display (a snapshot on 14 August 2008 shown in Fig. 2). Users could easily zoom-in, zoom-out, configure panoramic view and animate the forecast maps of rainfall distribution. Such value-added operations enabled users to concentrate on their own needs (e.g. estimation on the rainfall amount to be expected in any neighbourhood of interest) while at the same time keeping the big picture in mind (e.g. upstream spatial coverage and the movement trends of rain areas).

4. B08FDP APPLICATION EXAMPLES

Fig. 3 shows an example of RAPIDS forecast for 14 August 2008, demonstrating the usefulness of blending NWP rainfall information to supplement the radar-based nowcast. As shown in Fig. 3(a), the 3-hour rainfall nowcast (ending at 3:12 p.m.) based on the radar reflectivity detected at 12:12 p.m. generally underestimated the actual rainfall registered by raingauges in the subsequent 3-hour period (Fig. 3(b) refers).

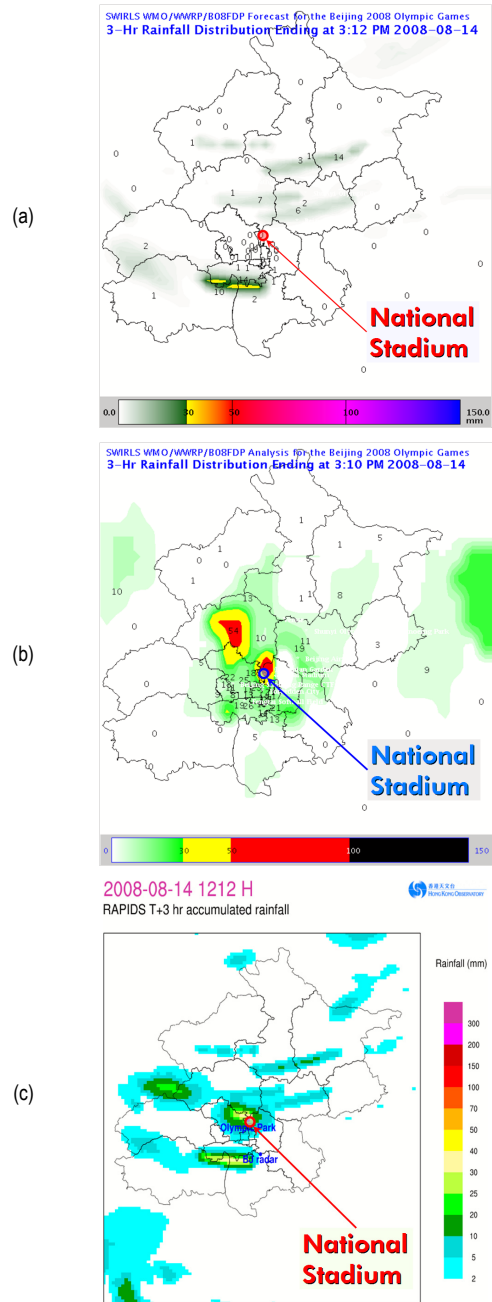


Fig. 3 Example of RAPIDS forecast for 14 August 2008: (a) SWIRLS radar-based 3-hour rainfall nowcast ending at 3:12 p.m.; (b) actual 3-hour rainfall accumulation for nearly the same period (ending at 3:10 p.m.), estimated based on rain gauge data; (c) the corresponding rainfall forecast from RAPIDS.

This was attributed to the explosive convective development triggered shortly afterwards by day heating and interaction between pre-existing cold pools and convergence lines in and around the city area. As shown in Fig. 3(c), the blended rainfall forecast from RAPIDS correctly predicted the rainfall north and northwest of the Olympic Park, indicating that the underlying

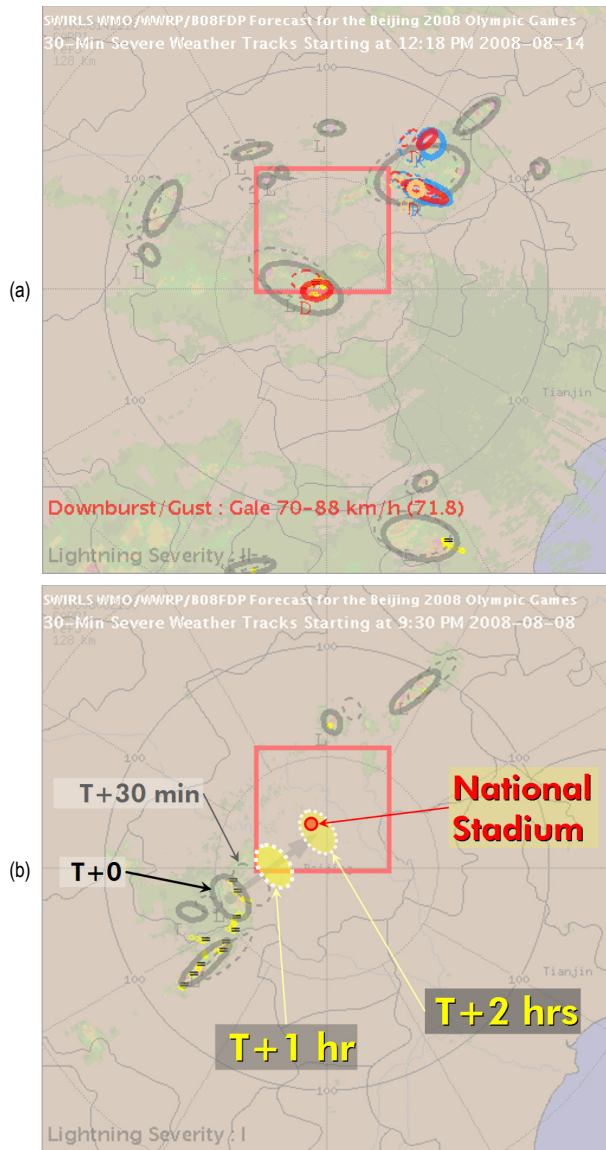


Fig. 4 Real-time examples of SWIRLS-2 severe weather map: (a) Output at 12:18 pm on the stormy day of 14 August 2008; (b) Output at 9:30 pm on 8 August 2008, the day of Olympic Opening Ceremony. Marked by hand on map (b) are the one- and two-hour projected positions (yellow ellipses) of an intruding lightning cell. (See main text for further explanations).

NWP model (NHM) realistically simulated the convective initiation in this case.

Fig. 4 shows two examples of SWIRLS-2 severe weather map generated in real-time. High-impact weather threats were represented as coloured ellipses: rainstorm in blue, CG lightning initiation in gray, downburst/severe squalls in red and hail in orange. Solid and dashed lines represented respectively their analyzed and 30-min predicted locations. The red rectangle near the centre of the map demarcated the warning

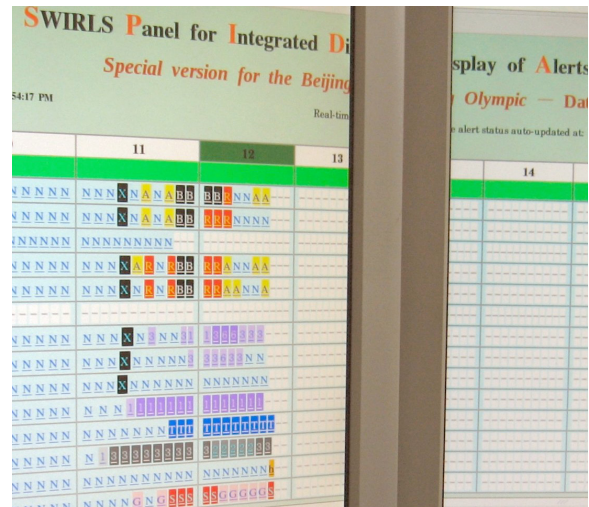


Fig. 5 Snapshot of SPIDASS in action taken at 12:54 p.m. on the stormy day of 14 August 2008.

zone of SPIDASS with all the Olympic venues in Beijing enclosed. If any ellipses cut into the warning zone, corresponding textual alert messages would be displayed near the bottom of the map.

In Fig. 4(a) at 12:18 pm on the stormy day of 14 August 2008, all four types of high-impact weather threats were forecast. According to the records of the Beijing Meteorological Bureau (BMB), all the predicted hazards were actually reported that afternoon. In Fig. 4(b) at 9:30 pm on 8 August 2008, the day of Olympic Opening Ceremony, the T+1 and T+2 hour projected positions (yellow ellipses) for lightning threats approaching from the southwest. This raised the possibility that thunderstorms might affect the National Stadium (the red dot). Fortunately, for hundreds of thousands of spectators still enjoying the ceremony inside the Stadium, the threatening storms eventually fizzled out (claimed to be the result of some mammoth weather modifying effort by the Beijing authority). Nonetheless, SWIRLS-2 provided invaluable nowcast information on the potential threat for reference by the event management.

Fig. 5 is a snapshot taken at 12:54 p.m. on 14 August 2008, showing SPIDASS in action in keeping with the unfolding of convective events. The coloured icons arranged in rows showed the alert status applicable to the warning zone — yellow, red and black colours for three rainstorm categories, light and dark purple colours for medium and high chance of PoP or PoL, pure blue colour for thunderstorm threat, three gray shades for different CG lightning initiation threats, orange colour for hail threat, as well as three red tones for different

downburst/severe squalls threats. The alerts were raised according to the triggering criteria set by the local forecasters. Used together with the QPF and severe weather maps, forecasters could readily appreciate the full picture of impending severe weather threats in and around the warning zone of Beijing.

5. DISCUSSION

The implementation process and algorithm adaptation of the Beijing data turned out to be more difficult than expected. The major challenges in the full operation of SWIRLS-2 during the trials and the Olympic operation were: (i) the asynchronous nature of the radars in and around Beijing; (ii) data quality of the raw radar reflectivity data; (iii) the lack of short duration (5-minute) rainfall data; and (iv) the relative “scarcity” of raingauges over the nowcast domain.

As the first two problems affected all participating nowcasting systems, they were discussed in depth during various FDP meetings and were efficiently solved by colleagues from the China Meteorological Administration (CMA) and BMB before the start of the Olympic Games. Apart from some system malfunctioning and erroneous products during the trials in 2006 and 2007, these two issues did not constitute any obstacles during the IOP in 2008.

Issues in (iii) and (iv) were perhaps unique of SWIRLS because of the dynamic approach taken in calibrating the Marshall-Palmer Z - R conversion formula. As described in Section 2.1, the parameters a and b in $Z = a \cdot R^b$ were treated as adjustable parameters, the calibrated values of which were determined in real-time from the latest radar reflectivity and raingauge data. For this dynamical approach to work effectively, the two pre-requisites were: (1) 5-min rainfall accumulation data G , and (2) sufficiently large number of (G, Z) data pairs to ensure a statistically reliable linear regression analysis. For (1), since only running 60-min rainfall data were provided in the official data server, the required 5-min rainfall data were ultimately settled by modifying the data ingestion routine of SWIRLS to calculate the difference between two consecutive 60-min rainfall values (updated times separated by 5 min). This modification worked quite smoothly during the IOP in 2008.

However, it turned out that pre-requisite (2) was not so easy to resolve. From the 2007 trial cases, it was found that the spatial extent of most rainbands affecting Beijing was not widespread enough to cover a significant number of rain-

gauges in the observation network, especially when the rainbands were still lying beyond the Fifth Ring Road where raingauges were relatively sparse. The consequence was that at each update time, only a handful of (G, Z) data pairs were available. In most cases, even the cumulative number of data points for an entire rain event was well below requirement, nullifying any reliable least-square fit.

The final resolution was to lower the minimum number of data pairs required for linear regression analysis to 100 and, if the situation warranted, to resort to an alternative “climatological” set of (a, b) parameters prepared by pooling all the rainfall information obtained in the 2007 trial. Despite such attempts, real-time experience during the Olympic operation indicated that the dynamic calibration was not activated in most cases and “climatological” values were used instead. Judging from the quantile-quantile plots (not shown) produced by the B08FDP Real-Time Forecast Verification (RTFV) system, the radar-based QPF of SWIRLS was generally under-predicting, and the “climatological” values adopted ($a=864, b=1.13$) could well be sub-optimal.

6. B08FDP BENEFITS & WAYS FORWARD

Participation in B08FDP, in particular with on-site tests and operation in Beijing, brought additional benefits to the SWIRLS enhancement project. In particular, the results served to benchmark the enhanced capability and functionality of SWIRLS against other state-of-the-art nowcasting systems in the world, and the activities facilitated the exchange of nowcasting technology and experiences, especially on the operation of severe weather warnings.

On top of the above “planned” targets, there were also some “surprise” side-benefits: (i) the turn-around time for the original 1-hour update cycle of RAPIDS was enhanced to 6 minutes with improved blending results; (ii) as a result of (i), probabilistic nowcast products using a time-lagged ensemble approach became feasible and operable; (iii) the new multi-scale echo-tracking method of MOVA was found to be a versatile approach and proved not only applicable to storm-cell track forecast but also QPF (MOVA-based QPF algorithm was implemented in Hong Kong under operational trial since May 2009); (iv) implementation of a permanent storm-cell ID assignment scheme to meet the requirement of the RTFV system; and (v) development of GIS-based nowcast products, one of which was already launched as the first public nowcast product in Hong Kong.

In the two FDP training workshops held in April 2007 and July 2008, a special case simulator was set up as an interface for trainees to gain hands-on experience. Such training workshops were also important from a research and development point of view. Through direct interaction among the system developers, product designers and end users, we learnt more about the actual needs and requirements from the major user group, i.e. the local forecasters responsible for the prediction of local severe weather events. By translating the user feedbacks into system/product enhancement priorities and having included this “re-engineering” step in the implementation process, we ensured that nowcast products would be customer-centric and tailor-made, e.g. the design of probability thresholds and alerting criteria in SPIDASS, a popular and proven interface used effectively by forecasters during the actual operation period. Developer-forecaster interaction also fostered deeper understanding on the merits and limitations inherent to different nowcast algorithms.

In the near future, nowcast-NWP merging and probabilistic QPF would be the main thrusts in science and technology development. Several research areas were considered worthy of exploration, including: (a) alternative approaches to address nowcast uncertainties; (b) storm-scale model analysis for the underlying triggers of severe weather events; (c) NWP-based severe weather nowcasting and merging techniques; (d) applications of other remote-sensing data, e.g. dual-polarization radar and GPS/PWV; (e) QPE/QPF applications in tropical cyclone cases; and (f) GIS technology to deliver nowcast products effectively in operational nowcast service.

Based on the experience gained during the project, future international collaborative nowcasting effort on a similar scale should make reference to B08FDP, in particular on aspects such as radar synchronization, standardization of observation data and nowcast products, as well as expert consensus and forecaster interaction on the nowcasting strategy of the day. For decision makers’ risk assessment, probabilistic products will continue to play an indispensable role in conveying forecast uncertainty. Again, B08FDP can provide invaluable reference on practical ways to generate probabilistic nowcasts. With NWP model becoming an integral part in the nowcasting routines, collaboration between nowcasters and modelers is likely to become even more important for future international cooperative effort on nowcasting.

7. CONCLUDING REMARKS

It took about 8 to 9 years for the first-generation SWIRLS to mature into a competent system for rainstorm operations. For SWIRLS-2, the full cycle from basic research to production of a new bundle of nowcasts was greatly shortened to about 4 years only. No doubt, B08FDP provided the trigger needed for the accelerated process. With its enhanced capacity, SWIRLS contributed to the B08FDP in support of the 2008 Beijing Olympic Games.

The enthusiasm of all participants and the synergy of all participating systems ensured that the mission of B08FDP, viz. demonstrating to the world the capabilities and usefulness of the state-of-the-art nowcasting systems in weather-sensitive events such as the Beijing Olympic, was fulfilled. Beijing Olympic’s slogan was “One World, One Dream”. Apart from the exciting events and spectacular successes achieved by the athletes on the tracks and fields, the ambitious vision was fully realized and put into action in one small room with glass walls on the 10th floor of the BMB main building. We all came from different parts of the world, but within that B08FDP operation centre, it felt “one world” and we definitely shared “one dream”!

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