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Towards the Blending of NWP with Nowcast – Operation Experience in B08FDP

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ABSTRACT

During the Beijing 2008 Forecast Demonstration Project (B08FDP) under the World Weather Research Programme of the World Meteorological Organization, the benefit of incorporating numerical weather prediction (NWP) model outputs to extend the nowcast of precipitation and convective storm development beyond the radar extrapolation technique was demonstrated. In several participating nowcasting systems in B08FDP, storm-scale NWP models with horizontal resolution at several kilometres were operated on a real-time basis to simulate the evolution of severe weather systems. Various types of observations from the automatic weather stations, wind profilers, Global Positioning System integrated precipitable water (GPS-IPW), radar and satellites were assimilated in the models in order to better describe the initial conditions and produce more skilful numerical guidance for blending computation. The blended QPF has demonstrably better performance compared with radar extrapolation. The analyses and short-term forecasts from the NWP models also provided valuable reference to forecasters for their subjective assessment of the potential of convective storm development and related decision making.

In this paper, the phase correction technique adopted in the Hong Kong Observatory nowcasting system to correct the location error of model QPF, the methodology to adjust the model rainfall intensity and the merging of the radar-based QPF with the adjusted model QPF are presented. The impact of NWP models in blending with radar nowcast techniques on aspects like quantitative precipitation forecasts (QPF) and convective storm development are discussed. By applying the time-lagged ensemble approach to the rapidly updated NWP model forecasts and blending computation, probabilistic precipitation nowcast products were also developed. The performance and potential use of this probabilistic rainfall nowcast product are discussed. The Beijing rapid update cycle system (BJ-RUC) based on the Weather Research and Forecasting (WRF) to improve the very short range forecasts for convective storms (3-12h) and to support nowcast operation is presented. The applications of analyses and forecasts from BJ-RUC including the model output soundings, stability indices and wind shear to predict the evolution of near storm environment are illustrated. The experience gained during B08FDP operation are summarized, and suggestions and views on the future development and application of the NWP products and blending techniques in nowcasting are presented.

1. Introduction

Nowcasting of mesoscale convective systems largely relies on radar-based technique by first estimating the motion of echoes, followed by numerical integration of advection equation or simple extrapolation to deduce the precipitation and location of convective storms in the next few hours. As the life cycle of a convective system is typically only a few hours, and their movement and development are usually stochastic, the skill of radar-based nowcasting techniques decreases rapidly within the first few hours of forecast.

On the other hand, recent numerical weather prediction (NWP) models have incorporated more advanced

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features in data assimilation, dynamic and physical processes so that the storm-scale phenomena can be more realistically simulated. By operating a high resolution mesoscale non-hydrostatic model using the rapid-update-cycle (RUC) approach, it is anticipated that the intrinsic "spin-up" problem in NWP model could be reduced, yielding more reliable and skillful forecasts on the evolution of mesoscale convective systems. It becomes feasible to apply the NWP output to optimally merge (Doswell 1986) with the radar nowcast for improved rainstorm predictions in the 1 to 6 hours forecast range.

In the WMO/WWRP B08FDP project, the required nowcasting and very-short-range forecast support included prediction of precipitation, thunderstorm and severe weather phenomena up to 6 hours ahead. In this connection, development and operation of high resolution mesoscale NWP models were implemented by some participating nowcasting teams. Attempts to blend the NWP products with radar nowcasts were experimented and put into operation during the FDP to investigate the usefulness of NWP-nowcast blending techniques.

In this paper, the implementation and operational experience on applying NWP in very-short-range forecast applications and blending with radar nowcasting system are discussed. The two mesoscale NWP modelling systems respectively operated by the Beijing Meteorological Bureau (BMB) and Hong Kong Observatory (HKO) in B08FDP are introduced in Section 2. The products and numerical guidance from the Beijing system for nowcasting of severe weather phenomena are introduced in Section 3. The blending techniques for precipitation forecast implemented in the second generation version of HKO nowcasting system SWIRLS (or SWIRLS-2 in short) are described in Section 4. Selected cases on the application of the NWP guidance and blending techniques are illustrated in Section 5. Discussions are given in Section 6 on the merits and limitations of the NWP products and blending techniques in nowcast applications. Some verification results and suggestions for future research, development and operation considerations are also discussed. Concluding remarks are presented in Section 7.

2. NWP Model Systems in B08FDP

2.1 *Overview of BJ-RUC*

In support of the weather services and providing the short-range numerical weather forecast during Beijing 2008 Olympic Games, BMB operated a rapidly-update NWP system called BJ-RUC (Beijing Rapid Updated Cycling forecast system) (Chen *et al.* 2009) based on the NCAR Advanced Research WRF model (Skamarock *et al.* 2005). BJ-RUC was configured in 3 nested domains (Fig. 2.1) at the horizontal resolution of 27 km, 9 km and 3 km to provide forecasts up to 24-36 hours. Model forecasts and numerical guidance from BJ-RUC were made available to forecasters within 3 hours from the analysis time to facilitate the assessment and prediction of severe weather events and for nowcasting applications. The configuration of BJ-RUC is summarized in Table 1. More details about the system and its performance of model forecasts can be found in Chen *et al.* (2009).

The high resolution BJ-RUC forecasts provide forecasters and users with rapidly (3 hourly) updated information on the storm environment and its development within the next 24-36 hours. From the products and numerical guidance of successive model forecasts products, forecasters could also perform more in-depth assessment of the possible development of severe weather.

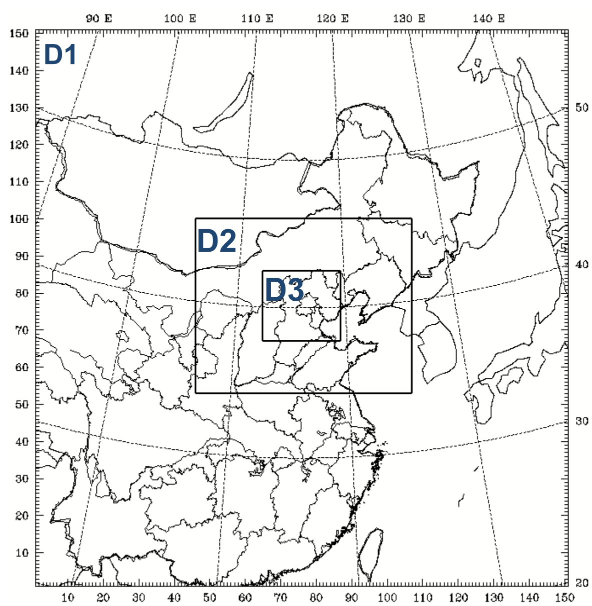


Fig. 2.1. Geographical coverage of BJ-RUC WRF model system.

Model version	WRF ver. 2.2 (with WPS 2.2)
Horizontal resolution and number of grid points	(D1) 27 km : 151 x 151 x 38 (D2) 9 km : 142 x 184 x 38 (D3) 3 km : 172 x 199 x 38
Forecast Range	24 hours (36 hours for 00 and 03 UTC runs)
Update cycle	3 hours
Horizontal grid	Arakawa-C
Vertical coordinates	Terrain following hydrostatic pressure η coordinates

Initial condition	WRF 3DVAR (v2.1)
Observations assimilated	- Conventional observations from GTS (SYNOP, SHIP, BUOY, TEMP/PILOT) - BJ AWS data - Intensive observation upper ascent data - Ground-based GPS precipitable water vapour
Boundary condition	NCEP GFS / CMA T213 global model
Map projection	Lambert conformal
Dynamics	Fully compressible non-hydrostatic Euler equations
Physical processes	- WSM6 cloud microphysics scheme; - Kain-Fritsch cumulus scheme (applied in D1 & D2) - YSU PBL scheme; - RRTM longwave radiation scheme; - Goddard shortwave radiation scheme; - Noah land-surface model;

Table 1. Model configuration of BJ-RUC.

2.2 *HKO Hourly Update Data Assimilation and NWP Model System*

In the Hong Kong Observatory nowcasting system SWIRLS-2, a set of high resolution, hourly updated data analysis system and NWP model was implemented for very-short-range prediction of convective systems and blending with radar-based precipitation forecast. The NWP model is based on the Non-hydrostatic Model (NHM) developed by the Japan Meteorological Agency (JMA) (Saito *et al.* (2007)). NHM is configured with a horizontal resolution of 5 km covering about 750×750 km^2 around Beijing area (Fig. 2.2). The model configuration, dynamic and physical schemes adopted for operation in Beijing are summarized in Table 2.

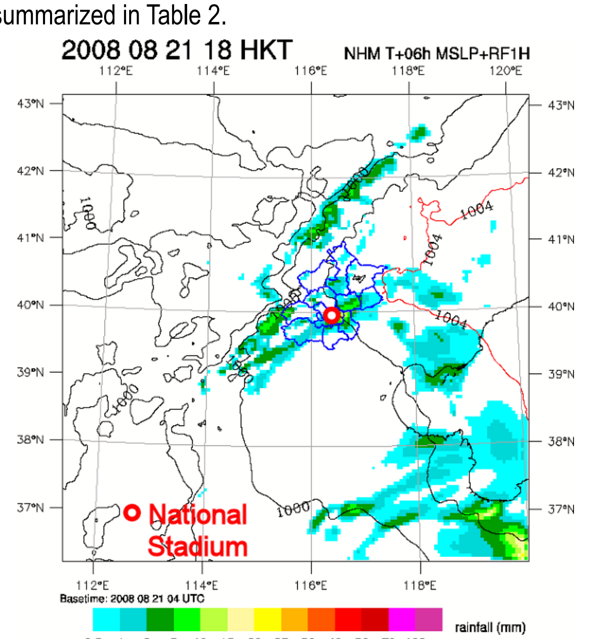


Fig. 2.2. Map showing the forecast domain of NHM in B08FDP operation with blue lines drawing the administrative boundaries of Beijing city and red dot the location of the National Stadium. The 6-hour NHM forecasts for mean-sea-level pressure (MSLP, in contour) and 1-hour accumulated rainfall (RF1H, in colour pixels) initialized at 04 UTC (or 12 noon BJT – Beijing Time), 21 August 2008 are overlaid.

The initial condition of NHM was based on the analysis field computed from following two data assimilation systems:

(i) LAPS (NOAA/GSD Local Analysis and Prediction System) (Albers *et al.*, 1996), and

(ii) JNoVA-3DVAR (JMA Non-hydrostatic model based Variational data Assimilation system) (Honda *et al.*, 2005).

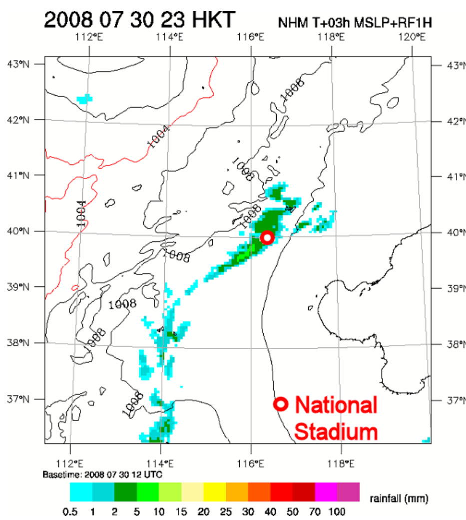
LAPS and JNoVA-3DVAR were operated on an hourly update cycle with a horizontal resolution of 5 km. Local observations, including radar (reflectivity and Doppler velocity volumes), FengYun 2C geostationary satellite (visible albedo, brightness temperature from IR and water vapour channels), AWS and radiosondes were ingested into the LAPS to generate a three dimensional analysis of wind, temperature and moisture. The background fields in LAPS analysis were obtained from the forecasts of NHM.

JNoVA-3DVAR analysis was run to provide the initial conditions for the NHM. One-dimensional vertical profiles of wind, temperature and moisture at the 'rainy' grids were

Model version	JMA-NHM (ver. 0712)
Horizontal resolution	5 km
Number of grid points	151 x 151 x 50
Forecast Range	9 hours
Update cycle	1 hour
Horizontal grid	Arakawa-C
Vertical coordinates	Terrain following height coordinates on Lorenz grid
Initial condition	- JNoVA-3DVAR (ver. 0712) - Specific humidity of water vapour, cloud liquid water, cloud ice, snow and graupel can be initialized by LAPS (ver. 0-29-15) cloud moisture analysis - 4-layer soil temperatures initialized by blending GSM land surface analysis with previous NHM forecast
Observations assimilated	- BJ AWS - intensive upper ascent data - LAPS vertical profiles at radar 'rainy' grids (see text)
Boundary condition	JMA GSM (full horizontal resolution at about 20 km)
Map projection	Lambert conformal
Dynamics	Fully compressible non-hydrostatic governing equations, solved by time-splitting horizontal-explicit-vertical-implicit (HEVI) scheme and 4th order spatial centred finite differencing in flux form
Physical processes	- Kain-Fritsch convective parameterization scheme - Three ice bulk cloud microphysics scheme - Surface flux based on Beljaars and Holtslag (1991) - Mellor-Yamada-Nakanishi-Niino Level 3 (MYNN-3) turbulence closure model with partial condensation scheme (PCS) - Long wave radiation process follows Kitagawa (2000) - Short wave radiation process using Yabu et al. (2005)

Table 2. Model configuration of HKO-NHM.

extracted from the LAPS analysis. Such profiles, together with the AWS and radiosonde observations, were ingested into the JNoVA-3DVAR system to derive an optimal and model consistent initial state. Besides, the cloud moisture analysis from LAPS was also utilized to specify the initial condition of the corresponding hydrometeors contents in NHM. Figure 2.3 shows an example of a 3-hour forecast from NHM, the '3D+1D' approach (JNoVA-3DVAR + 1D LAPS profiles) shows some potential benefits to the storm-scale simulation in the first few hours of NHM forecasts. With an expedited model spin-up, a more realistic precipitation pattern and its development could be simulated.



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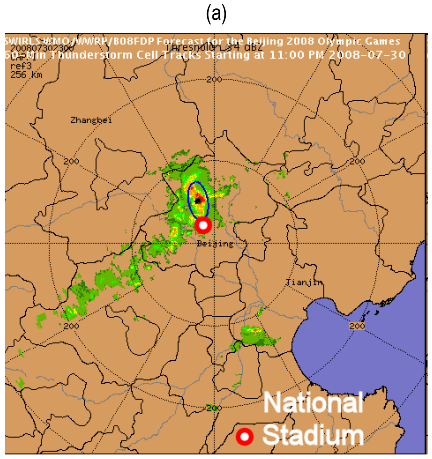


(b)

Fig. 2.3. (a) NHM T+3 hr forecasts of mean sea level pressure (MSLP, in contour) and 1 hr accumulated rainfall (RF1H; in colour pixels) valid at 15 UTC 30 July 2008; (b) 3-km CAPPI reflectivity at the same time with 256 km radius of range centred at Beijing radar site, about 30 km south-southeast of the National Stadium .

Besides the application to the data assimilation and initialization of NHM, the temperature analysis from LAPS was also utilized to derive the isothermal reflectivity field at different temperature thresholds (0, -10 and -20 degree Celsius) which were then input to the module on lightning initiation (see Section 2.3 in Yeung *et al.* (2009)).

2.3 *Other NWP system in B08FDP*

In addition to the above two NWP systems, GRAPES model operated by CMA was used in the GRAPES-SWIFT system to merge with the radar echo tracking vector for rainfall nowcasting applications (Feng, 2009).

3. Nowcasting tools from BJ-RUC

BJ-RUC provided useful reference on the evolution of the mesoscale systems and storm environments for objective and subjective assessments of the impacts on weather.

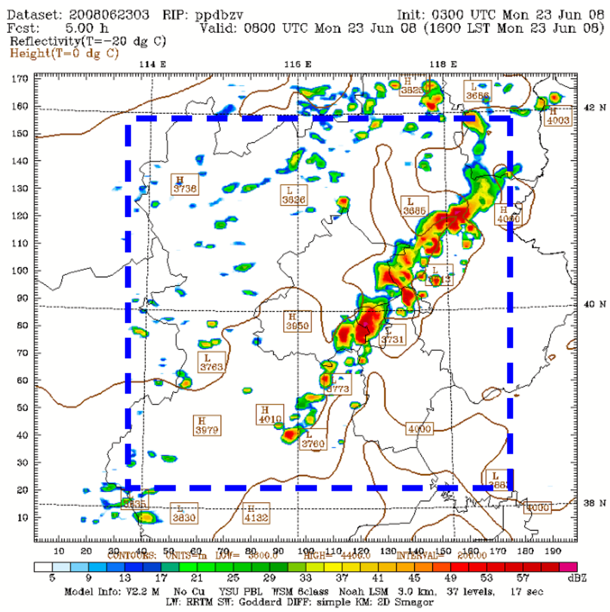
In BJ-RUC, besides the typical weather maps and forecast time series various weather elements (including wind, temperature, pressure, humidity and rainfall), composite prognostic charts and forecast products are also generated to provide objective guidance on severe weather (Table 3).

Heavy rain potential	- surface specific humidity + moisture convergence + wind - moisture flux convergence within 0-2 km
Hailstorm potential	- CAPE (within -10 and -30 degree Celsius layer) + vertical wind shear between surface and 500 hPa level + geopotential height contour at 0 degree Celsius layer - Forecast isothermal reflectivity at -20 degree Celsius + geopotential height contour at 0 degree Celsius layer.
Proximity sounding	- Model derived sounding and instability indices for estimation of convective potential

Table 3. Products of BJ-RUC on heavy rain and hailstorm potentials

An example of hailstorm potential is depicted in Fig. 3.1 for a severe weather event on 23 June 2008. The 5-hour forecast from BJ-RUC initialized at 03 UTC indicates a large vertical wind shear between surface and 500 hPa level as well as a low altitude of 0°C layer (below 4000m) over the Beijing areas in the late afternoon (not shown). The forecast isothermal reflectivity in Fig. 3.1a shows a band of intense echoes extending from northeast to southwest, covering nearly the whole Beijing area which is quite consistent with the radar image (Fig.3.1b), although the forecast reflectivity moved slightly faster than actual by about 1 hour of forecast. The model reflectivity forecasts could provide users with a good indication on the occurrence of intense rainstorms that afternoon.

In Wilson and Roberts (2009), also presented in this Symposium, discussions and reviews are given on using BJ-RUC simulated reflectivity to merge with radar reflectivity to provide storm nowcast in the next 6 hours.



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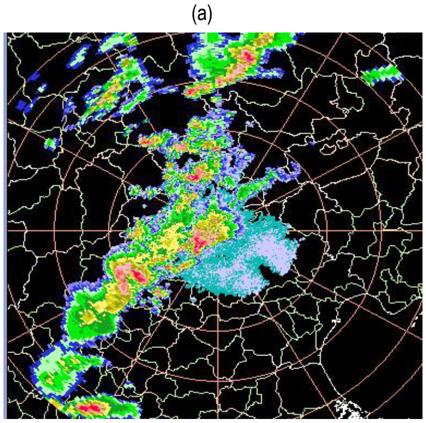
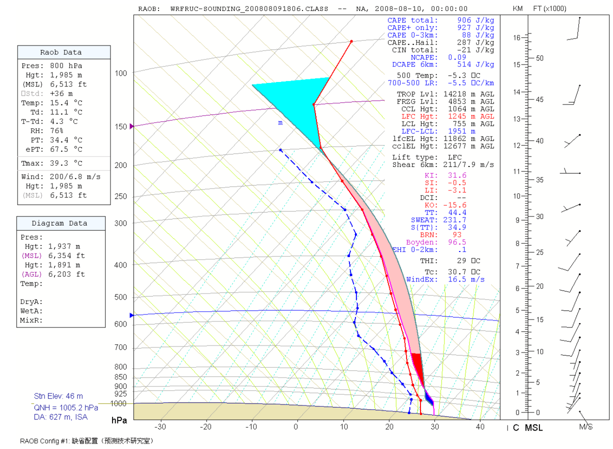


(b)

Fig. 3.1. (a) 5-hour forecast of isothermal reflectivity at -20°C overlaid with geopotential height contour (brown) at 0°C degree Celsius level, valid at 08 UTC 23 June 2008. (b) actual radar reflectivity. Dashed border in (a) corresponds to the coverage of radar image below.

The model forecast sounding (referred as the Proximity Sounding in Table 3) is another application of BJ-RUC to forecast convective potential and pre-storm environmental profile over the Beijing city (Fig. 3.2). The model soundings were available for the analysis time, 3-hour and 6-hour forecasts interpolated to the location of the Beijing radar site (station number 54511). Instability indices or storm parameters including CAPE and vertical wind shear are used as a reference on the likelihood of storm initiation and convective development over Beijing.



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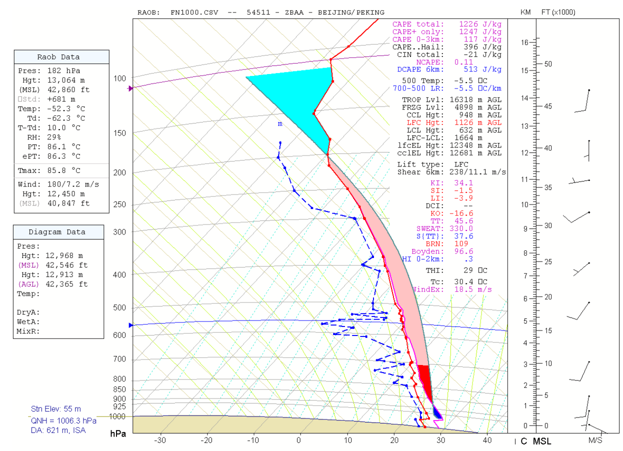


(b)

Fig. 3.2. (a) Tephigram showing 6 hour forecast sounding at the Beijing radar site (station no. 54511) initialized at 18 UTC 9 August. (b) Actual sounding profile at 00 UTC 10 August 2008. Profiles of temperature and dew point are drawn in red solid line and blue dotted line respectively.

4. Blending NWP QPF with Radar Nowcast in SWIRLS-2 and Probabilistic Nowcast Product

4.1 *Blending Algorithm in RAPIDS*

The HKO NWP model and data assimilation system were operated in an hourly update cycle in order to capture the most recent information on storm development. As shown in Fig. 2.3, a two-stage 3D+1D data assimilation system can provide a good initial condition to simulate realistic rain pattern. It contributes towards the development of a seamless integration of the NWP QPF with the radar nowcast. The merging technique is implemented in a system named RAPIDS (Rainstorm Analysis and Prediction Integrated Data-processing System). RAPIDS was first put into trial operation in HKO in April 2005 (Wong and Lai (2006)). In the past few years, research and development were devoted to implement more robust techniques which seamlessly integrate the NWP and nowcast components. In short, the RAPIDS blending algorithm consists of the following procedures:

(i) correction of NWP QPF spatial location error to account for spatio-temporal uncertainty of model QPF (phase correction),

(ii) correction of the intensity of model precipitation based on radar-based quantitative precipitation estimate (QPE), and

(iii) merging of modified model QPF with the radar nowcast, with larger weighting assigned to the latter component at short lead times and increasing weighting to the former component as lead time increases to 6 hours.

Similar algorithms have been experimented in Hong Kong, and potential benefits were demonstrated in rainfall nowcasting applications in both monsoonal rain events as well as tropical cyclone situations (Lai and Wong, 2006). With a view to further improving its performance, several enhancements were made to RAPIDS for B08FDP. For instance, the RAPIDS blending was conducted every 6 minutes in Beijing domain compared to 1 hour update adopted for trial operation in Hong Kong and the use of MOVA (Multiscale Optical flow by Variational Analysis) (Wong and Lai, 2009) to correct for location error (phase error) of precipitation pattern.

A main contributor to model QPF position error is the forecast speed of movement of the mesoscale feature. The computation of phase correction can be expressed in the following form by solving the optical flow equation using variational method (Aubert *et al.* 1999):

$$\min: \; J = \iint \left[\frac{\partial R}{\partial t} + u\frac{\partial R}{\partial x} + v\frac{\partial R}{\partial y} \right]^2_{QPF_{NWP} \to QPE} dxdy \quad (1)$$

where $R(x,y,t)$ denotes the rainfall forecast from the NWP model or radar rainfall estimate. In analogy to apply MOVA to deduce the echo motion vector field ($u(x,y)$ and $v(x,y)$) using successive radar images separated by 6 minutes, as implemented in SWIRLS-2 for storm tracking in B08FDP, the above minimization is carried out for model QPF and radar rainfall estimate at the *same* time to estimate the phase correction vector field (u,v). The phase correction vector field was then applied to model QPF in the subsequent forecast hours.

Discrepancies in the rainfall intensity between the NWP forecasts and the actual are commonly noticed. The problem is probably due to model resolution and, more importantly, the physical processes like convective parameterization and cloud microphysics schemes to control the amount of the model precipitation. The model hourly rainfall forecast and radar QPE are assumed to follow the Weibull cumulative distribution function (CDF). The intensity calibration of model QPF is given in the following relation:

$$\mathrm{QPF}_{\mathrm{modified}} = CDF^{-1}_{QPE}[CDF_{NWP}(\mathrm{QPF}_{\mathrm{NWP}})] \quad (2)$$

where CDF_{QPE} and CDF_{NWP} representing the cumulative distribution function of radar-based QPE at the initial time of 6-hour merging window, and the NWP QPF valid at the same time. In essence, the above relation (2) indicates that the model QPF is mapped to the actual radar-based QPE by assuming identical value of cumulative distribution frequency of the two rainfall fields modelled by the Weibull function.

The last step of the blending process merges the phase corrected and intensity modified NHM QPF with the SWIRLS-2 QPF from 1 hour forecasts up to 6 hours ahead. Taking into account the decrease in nowcast skill with forecast time, especially beyond the first 3 hours, the weighting of NHM QPF varies according to a hyperbolic tangent curve as shown in Fig. 4.1. The weighting at both ends can be specified dynamically using a verification metric incorporating the location and intensity errors (Lai and Wong (2006)). They can also be determined from verification results of past cases. In B08FDP, the latter approach was adopted to reduce the computation time on blending algorithm with the two weightings assigned values of 0.3 and 0.8 based on verification results of past cases.

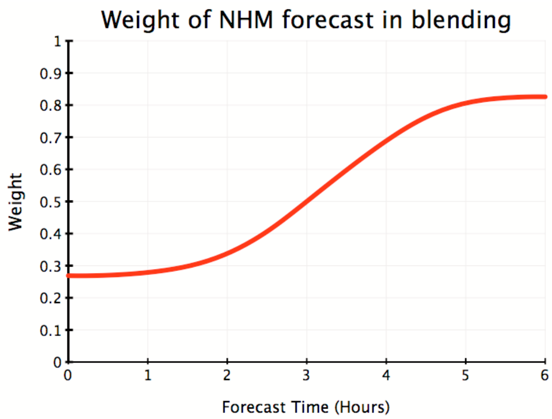


Fig. 4.1. Weighting of NHM QPF within the 6-hour merging window.

4.2 *Probabilistic Rainfall Nowcast in RAPIDS*

The QPF blending algorithm in RAPIDS attempts to combine the best of the radar-based and NWP QPFs and derive a deterministic rainfall nowcast up to 6 hours ahead. However, the location and intensity errors could grow rapidly in the long lead time (3-6 hours) as the uncertainty in the development of convective storm may not be fully represented in the model initial condition. The nowcast operation usually demands a frequent update (~ 6 minutes), a full dynamic ensemble based on NWP models with either perturbed initial conditions or stochastic model physics to capture various realizations of the atmospheric evolution is computationally prohibitive. On the other hand, it may be useful if the uncertainty exhibited in the rapidly-update QPF guidance can be transformed into information indicating the possible scenarios on the location or intensity of rainfall. With such objectives in mind, a simplistic approach was implemented in RAPIDS to incorporate the readily available "perturbations" among rainfall forecasts generated in different update cycles. Probability of precipitation (PoP) can be estimated based on a time-lagged ensemble approach according to the following relation:

$$\mathrm{PoP} = \frac{\sum_{t=-T}^{0} \mu(t) \times \mathrm{QPF}_{\mathrm{RAPIDS}}(t)}{\sum_{t=-T}^{0} \mu(t)} \tag{3}$$

where T is taken as 1 hour and $\mu(t)$ an exponentially decreasing weighting factor which drops from unity at the forecast initial time (i.e. $\mu(0) = 1$) to a prescribed value (about 0.3) with respect to RAPIDS forecasts issued at 1 hour before. The diminishing forecast skill over the lead time of 1 hour is thus incorporated using this time-lagged ensemble technique.

5. Cases in B08FDP Operation

5.1 *10 August 2008*

Widespread precipitation occurred in Beijing and its vicinity during the day upon the arrival of a cold front. Some convective storms caused heavy precipitation in Beijing city. Fig. 5.1 shows the radar imagery and storm cell locations at 1400 Beijing Time (BJT, 8 hours ahead of UTC) depicting large area of rain band over the western part of Beijing area and some small convective cells over the northeastern part. In the following few hours, there were some local developments in the vicinity of urban areas that brought more than 20 mm of rainfall to the city. In the late evening till early hours on 11 August 2008, significant precipitation was also recorded over Beijing.

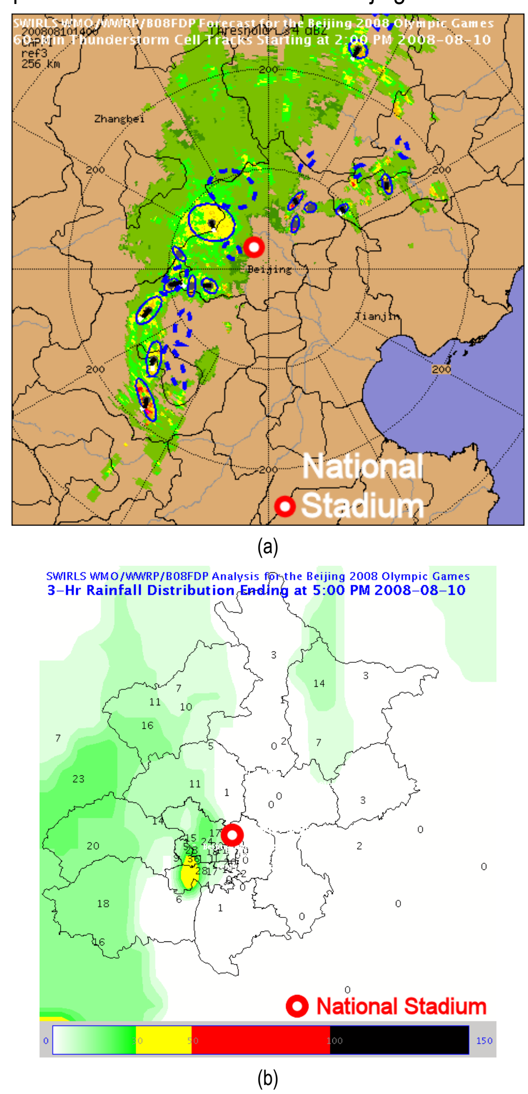


Fig. 5.1 (a) 3 km CAPPI reflectivity at 2 p.m. overlaid with storm cells from SWIRLS-2; (b) actual 3 hour rainfall distribution ending at 1700 BJT.

The time series of CAPE deduced from the forecast proximity sounding of BJ-RUC with initial times from 12 UTC 9 August to 00 UTC 10 August 2008 (a total of 5 model runs) is shown in Fig. 5.2. Although the first few model runs gave an opposite trend of model CAPE compared to the actual situation in the early morning on 10 August (i.e. actual CAPE at 18 UTC), they all suggested that the convective instability would gradually build up towards the late morning. Forecasts initialized at 18 and 21 UTC resulted in CAPE exceeding 1100 J/kg at 01 UTC, which was comparable to the actual value (~ 1300 J/kg) at 00 UTC. Model runs initialized at 15 UTC and thereafter were in good agreement on the release of CAPE over the Beijing area during the day on 10 August, which could be an indicator for the release of environmental convective instability upon the occurrence of significant precipitation.

Forecast reflectivity from the successive model runs of BJ-RUC also depicted development of storms in the vicinity of Beijing areas. For instance, the 12 hour forecast reflectivity from the model run initialized at 21 UTC (Fig. 5.3a) shows a consistent location of radar echoes, though the most intense echoes was forecast to develop mainly to the southwest of the Beijing area (region A), and there were some intense convective cells over the city that could not be predicted by BJ-RUC (region B).

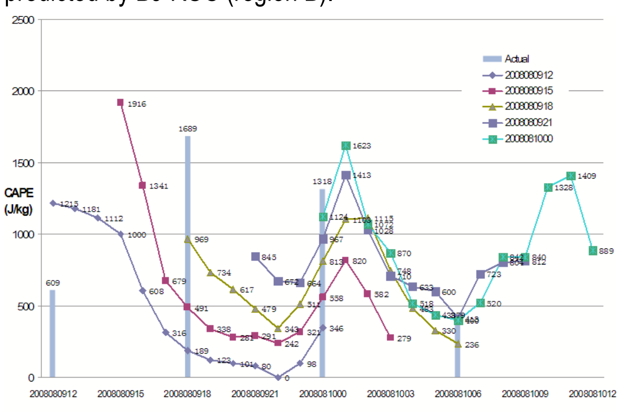
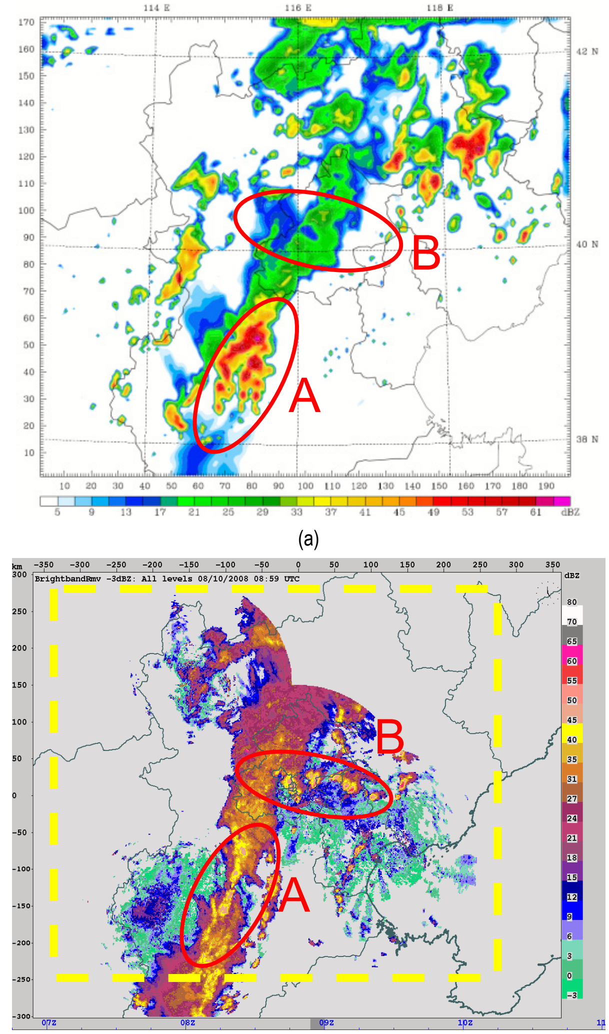


Fig. 5.2. Forecast CAPE time series from 12 UTC 09 August – 00 UTC 10 August 2008. The histograms represent the actual CAPE from the radiosonde available every 6 hours.



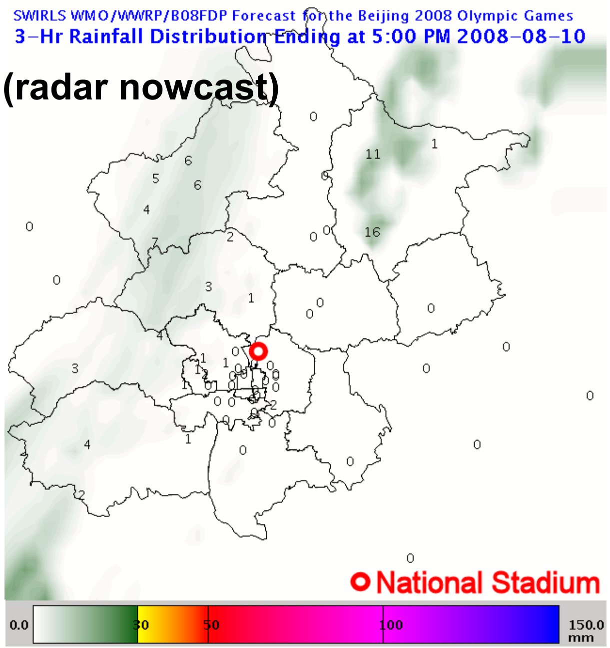
(a)

(b)

Fig. 5.3. (a) 12 hour forecast isothermal reflectivity valid at 09 UTC 10 August 2008. (b) Actual composite radar reflectivity, with the yellow dashed boundary showing the coverage of forecast chart in (a).

The radar-based nowcast QPF in SWIRLS-2 issued at 1400 BJT for the next 3 hours (Fig. 5.4a) indicates widespread rain over the western part of the city with the occurrence of small convective cells over the northeastern part, which is consistent with the 3 hour rainfall analysis based on rain gauge data.

RAPIDS forecast (Fig. 5.4b) issued at 1400 BJT on the accumulated rainfall in the next 3 hours was able to indicate the development of precipitation over the western part of the city, though the spatial coverage was broader than actual. In this case, the localized development was obtained from the NHM forecast initialized at 2 hours before. In preceding NHM as well as the RAPIDS forecasts, precipitation over the western part of Beijing was persistently forecast albeit with slightly weaker intensity and different position errors. The time-lagged ensemble technique took into account the uncertainty in QPF in the recent RAPIDS forecasts to map the region of high likelihood of significant precipitation in PoP product and facilitate the assessment on the potential of heavy rain.



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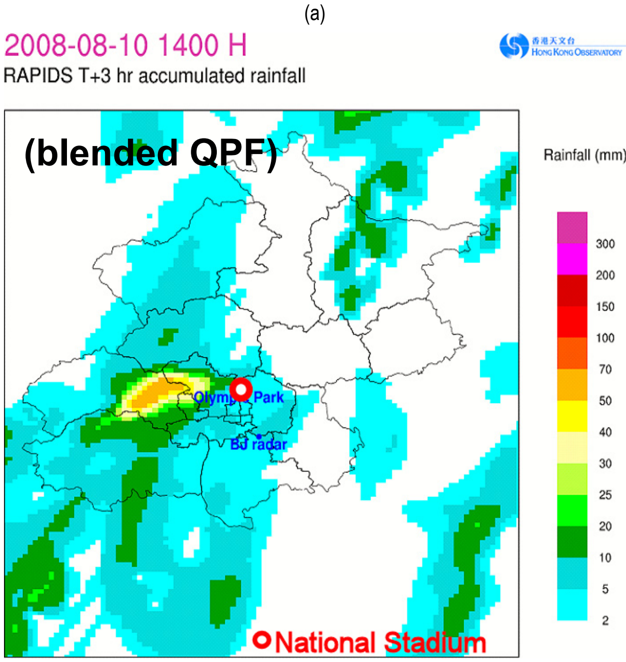

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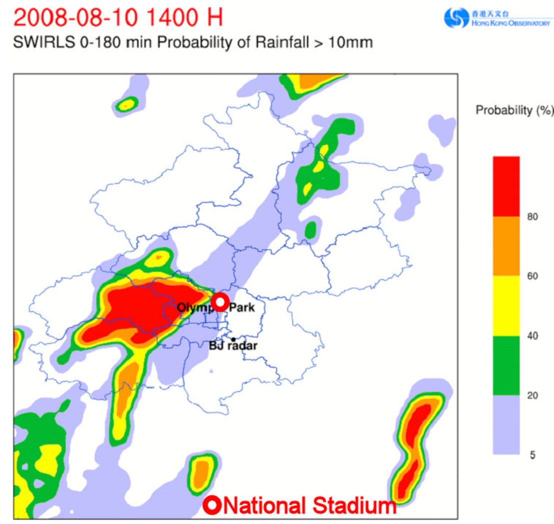

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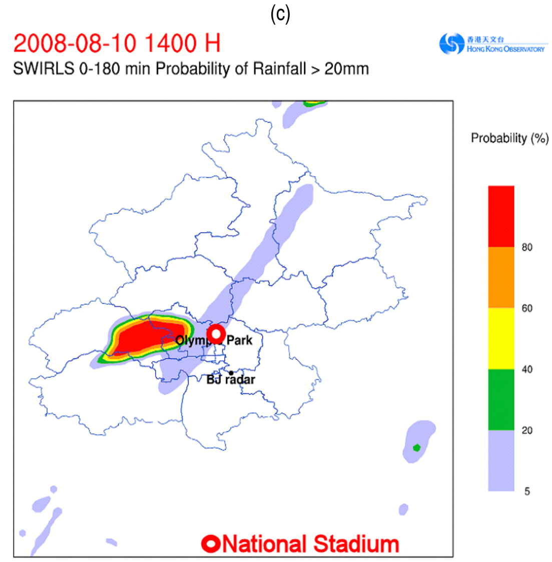


(d)

Fig. 5.4. 3 hour accumulated rainfall issued at 14:00 H 10 August 2008 from (a) SWIRLS-2 radar nowcast, and (b) RAPIDS. (c) PoP for the next 3 hours issued at the same time with the threshold of 10 mm (left) and 20 mm (right).

5.2 *14 August 2008*

The forecast of intense rainstorms in the vicinity of Beijing in the afternoon of 14 August 2008 was rather challenging for the pure radar-based extrapolation nowcasting techniques, as initiation of convective cells around the city was the result of day heating and interaction with the pre-existing cold pools and convergence lines over the city districts.

Fig. 5.5 shows the time series of CAPE from BJ-RUC runs initialized from 18 UTC 13 August to 06 UTC 14 August 2008. The first two runs under-predicted the pre-existing environmental instability in the morning on 14

August. The update cycle approach made a positive impact to adjust the model initial state and the CAPE at 00 UTC. All three model runs (18, 21, and 00 UTC) were in good agreement on the increase of CAPE in the afternoon.

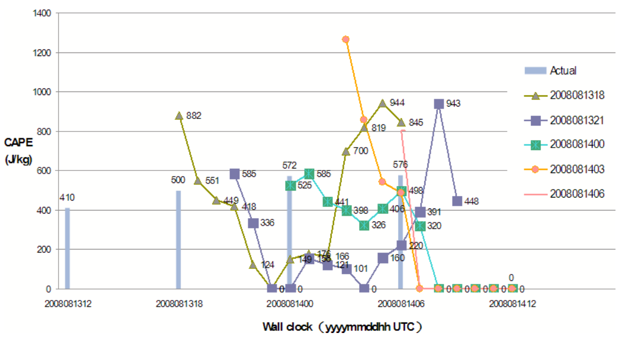
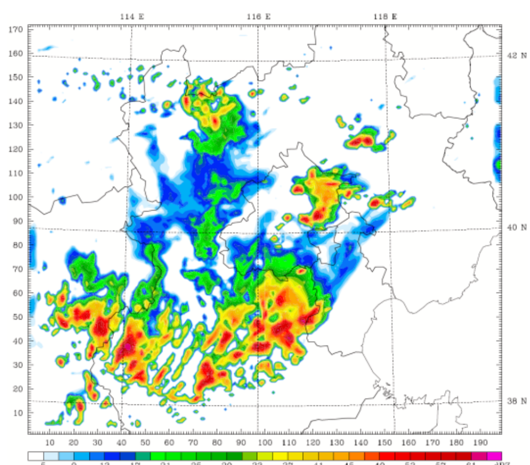
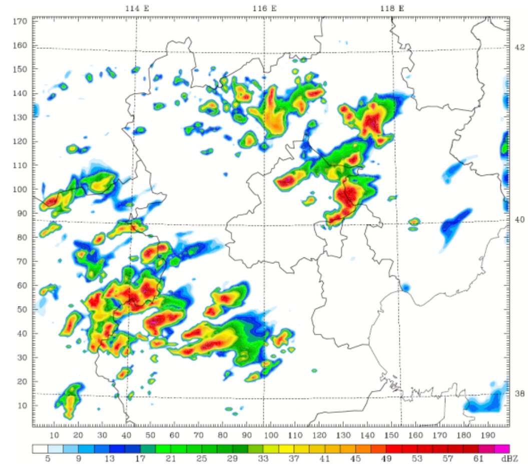


Fig. 5.5. Forecast CAPE time series from 18 UTC 13 August – 06 UTC 14 August 2008. Actual CAPE from the 6 hourly radiosonde data are shown in the blue bars.

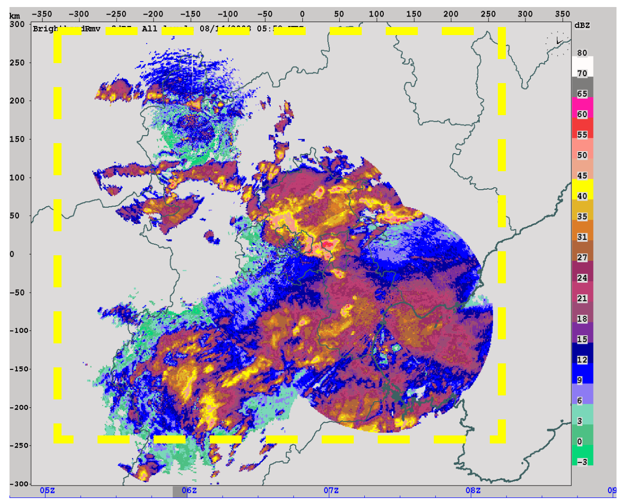
The 12 hour and 6 hour forecast isothermal reflectivity valid at 06 UTC 14 August from two BJ-RUC model runs (initialized at 18 UTC 13 August and 00 UTC 14 August) are shown in Fig. 5.6a and 5.6b respectively. Both forecasts indicated widespread intense echoes to the south and southwest of the Beijing area with small bands of strong convections over the northern part. However, the forecast reflectivity from the two model runs showed discernible differences. Actual radar image at 06 UTC (Fig. 5.6c) showed development of heavy convection near the urban areas of Beijing. More than 50 mm of rainfall was recorded at some locations during the afternoon.



(a)



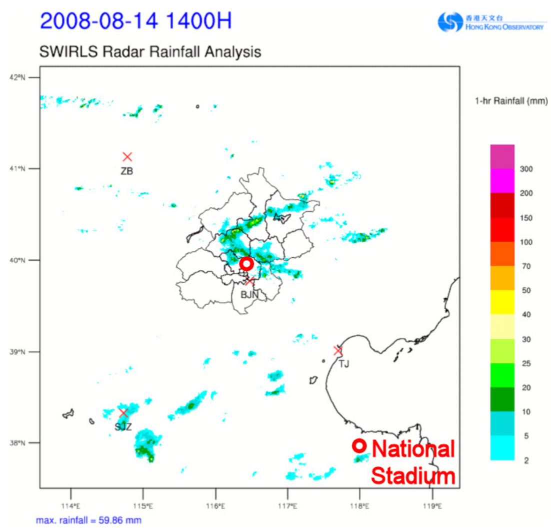
(b)



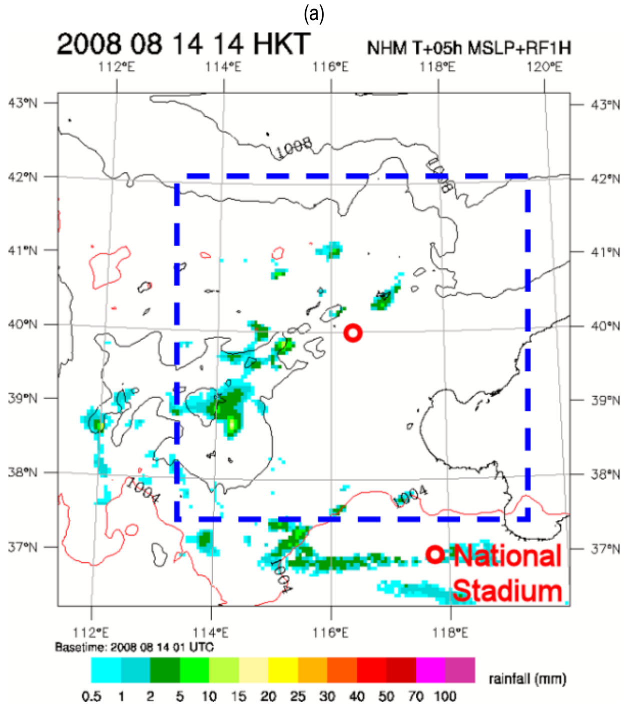
(c)

Fig.5.6. Forecast isothermal reflectivity valid at 06 UTC 14 August 2008 from the BJ-RUC initialized at (a) 18 UTC 13 August and (b) 00 UTC 14 August. Actual composite radar reflectivity is depicted in (c).

The radar QPE in SWIRLS-2 showing the hourly rainfall accumulation at 1400 BJT is given in Fig. 5.7a. The precipitation distribution in the QPE corresponds to the intense echo region in the composite radar reflectivity image. A couple of HKO-NHM forecasts initialized in the morning of 14 August (01-03 UTC) suggested that precipitation would develop mainly over the northern part of the city in the afternoon (Fig. 5.7b), in association with the surface heating and passage of disturbance on 850 hPa level.



(a)



(b)

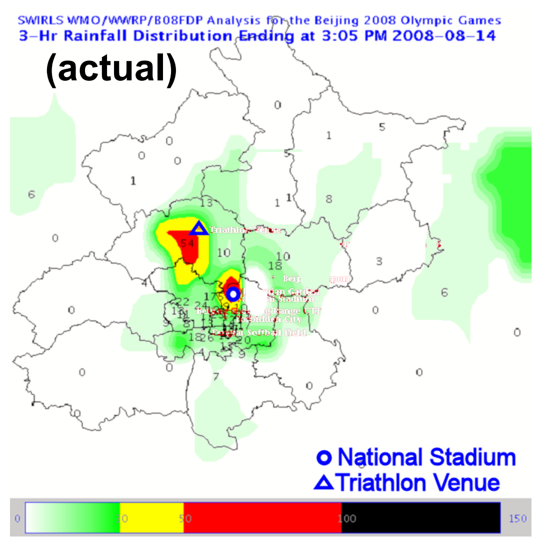
Fig. 5.7. (a) SWIRLS radar-based rainfall analysis showing the 1 hour accumulated rainfall at 1400 BJT. (b) 5 hour forecast of mean-sea-level pressure (MSLP, in contour) and hourly accumulated rainfall (RF1H, in color pixels) from NHM initialized at 01 UTC 14 August 2008. The blue dashed boundary represents the coverage of radar rainfall analysis.

The actual 3 hour accumulated rainfall ending at 1505 BJT is shown in Fig. 5.8a. In general, about 10 mm of rainfall was recorded over Bejing areas. Due to localized convective development, more than 50 mm of rainfall was recorded near the National Stadium (blue circle) and the Triathlon avenue (blue triangle).

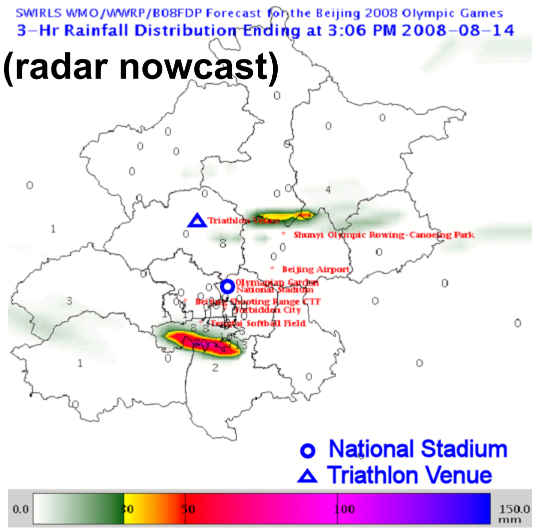
SWIRLS-2 radar nowcast issued at 1206 BJT for the accumulated rainfall in the following 3 hours is shown in Fig. 5.8b. At that time there were only some isolated convective cells over the southern and northern parts of the Beijing urban areas. The resulted nowcast rainfall was different from the actual rainfall distribution.

RAPIDS forecast (Fig. 5.8c) was able to indicate signs of precipitation of about 20-40 mm in the following 3 hours near the National Stadium and in the vicinity of the western boundary of the Beijing area. It provided an useful guidance to the forecasters on the likelihood of localized significant convection near the two locations, though the intensity was not as severe as the actual.

The PoP forecasts issued during 12-13 BJT reflected a medium chance of significant precipitation (over 20 mm in the next 6 hours) as inferred from the subsequent NHM forecasts through the RAPIDS blending algorithm. The blended QPF and PoP in RAPIDS were able to extend the usefulness of the nowcast products before the signal on the convective development was captured by the radar nowcast algorithm (Fig. 5.8d). With the radar nowcast beginning to pick up the new convection developments over the western part of the Beijing area, the chances of significant precipitation gradually increased over the locations (Fig. 5.8e) where heavy rain actually emerged.



(a)



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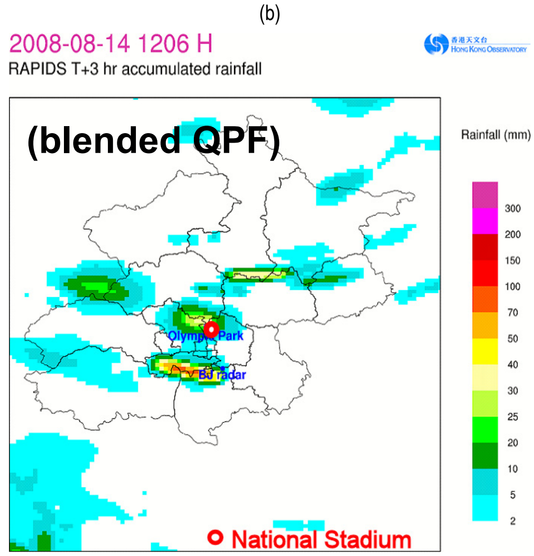
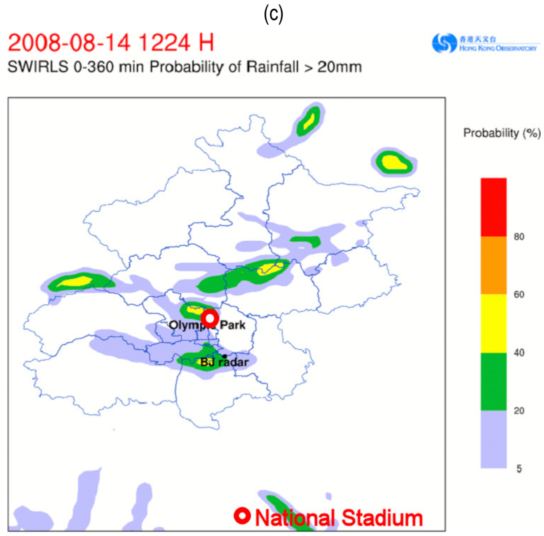
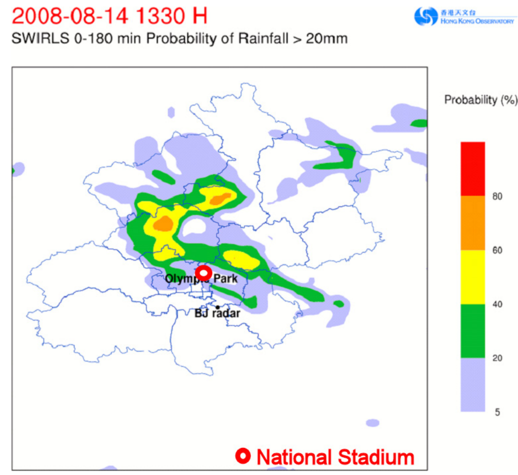


(c)



(d)



(e)

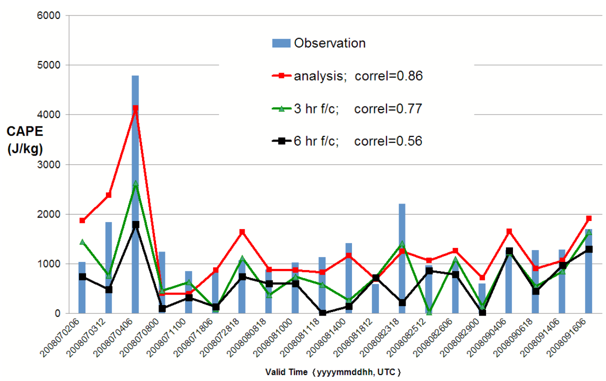
Fig. 5.8. (a) Actual 3-hour rainfall accumulation ending at 1505 BJT 14 August 2008, estimated based on rain gauge data; (b) SWIRLS radar-based 3-hour rainfall nowcast ending at 1506 BJT; (c) the corresponding rainfall forecast from RAPIDS; (d) PoP forecasts issued at 1224 BJT and (e) at 1330 BJT on the probability exceeding 20 mm in the next 6 hours and 3 hours respectively.

6. Discussions

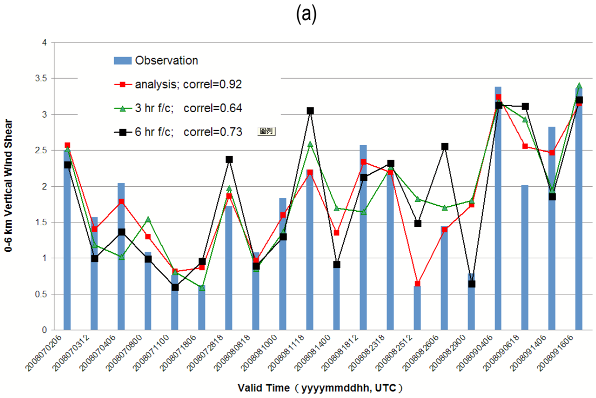
The operation of BJ-RUC and HKO hourly update NWP system in B08FDP demonstrates the usefulness and benefits of high resolution NWP model in nowcast applications. With a computing power of the order of about a few tens of workstations connected with high speed network for parallel computation, real-time storm-scale NWP simulation and data assimilation in RUC mode are made feasible. Intensive observations such as AWS, radar, satellite, and GPS-IPW can be assimilated to better prescribe the model initial state and reduce the model 'spin-up' problem. For instance, the rapid-update data assimilation cycle in BJ-RUC allows a timely adjustment of the model initial state through the ingestion of the most recent observations, leading to improved analysis and forecast of storm parameters.

In BJ-RUC, there are several nowcasting tools made available to provide objective guidance on the chance of convective storm development. The model forecast soundings, instability indices and storm parameter forecasts show their potential use in estimating the atmospheric condition. Based on 20 cases from July to September 2008, a comparison of the storm parameters including CAPE and vertical wind shear are given in Fig. 6.1. The BJ-RUC was able to analyze a consistent atmospheric state (red lines) as shown in Fig. 6.1 where the derived instability indices from the analyses were close to the actual values (histograms) with correlation coefficients at about 0.9 for both CAPE and the vertical wind shear. The 3 hour forecast (green lines) and 6 hour forecast (black lines) in general gave comparable magnitudes, but the correlation coefficients drop to about 0.6 within 3-6 hours of forecasts.

As illustrated in the previous section on the two cases in B08FDP, the forecast isothermal reflectivity demonstrated the potential capability of BJ-RUC in prediction of convective storm development. However, spatial-temporal and intensity errors were found as compared to the actual situations. They are probably attributable to the lack of radar data in the data assimilation system of BJ-RUC during the B08FDP operation. Future research and development will be conducted to improve the performance of model forecast through the assimilation of radar reflectivity and Doppler velocity. Technique development on the estimation of the types of convective storm, location and severity will also be explored.



(a)



(b)

Fig. 6.1. Comparison of (a) CAPE (in J/kg) and (b) 0-6 km vertical wind shear (in m/s) from the BJ-RUC proximity sounding products against actual data for the 20 rainstorm cases. Model derived CAPE (and vertical wind shear) from the analysis, 3 hour forecast and 6 hour forecast are shown in red, green and black lines respectively with actual CAPE shown in the histograms;

As an advance on merging NWP model with radar nowcast, the RAPIDS blending technique has been implemented to merge the best of the two QPFs. RAPIDS has demonstrated successfully its potential to support the nowcasting applications in B08FDP. With the data assimilation system of NHM being able to ingest the intensive observations, development of precipitation could be predicted with more realistic pattern, although phase errors in space and time and model bias in rainfall intensity remained. The phase correction technique based on optical flow method, and the intensity adjustment of NHM QPF using the probability matching technique worked satisfactorily during the real-time operation in B08FDP. From the two cases illustrated above, RAPIDS QPF has shown additional benefits over the radar-based rainfall nowcast. The real time verification results (Ebert *et al.* 2009) for the whole FDP operation period (1 August – 21 September 2008) also indicates that RAPIDS QPF has a higher probability of detection (POD) than the radar-nowcast (Figure 6.2). The performance of RAPIDS QPF has doubled in the forecast lead time over radar nowcast in terms of the same POD level. The critical success index (CSI) is also improved in the blended QPF, although the increase with respect to the radar-based QPF is marginal (not shown) due to a larger false alarm in model QPF.

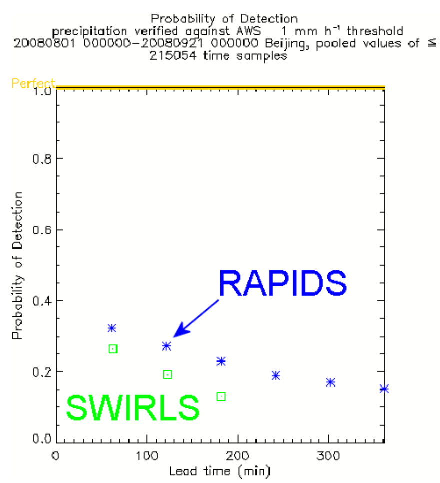


Fig. 6.2. Probability of detection (POD) for nowcasts of hourly precipitation accumulation using a 1 mm/h threshold. Data period: 1 August – 21 September 2008. (adapted from Ebert *et al.* 2009)

The improvement in QPF through NWP-nowcast blending has led to the development of PoP product in RAPIDS based on the time-lagged ensemble approach. The two cases in the previous section indicate that the method worked effectively to give useful reference on the probability of significant precipitation, especially over a long lead time (3-6 hours) when the impact of model QPF becomes prominent.

Future research and development in RAPIDS and NHM will focus on data assimilation and model physical processes in order to improve the skills of model QPF and hence the blended QPF. Other alternatives of robust blending techniques on the phase correction and intensity adjustment will also be explored. The blending algorithm may also be applied to the other forecast quantities like simulated reflectivity and storm parameters.

7. Concluding Remarks

The use of two rapidly update NWP model systems for nowcasting applications in B08FDP, and blending of such NWP products with radar-based nowcast rainfall were discussed in this paper. As illustrated in the two cases during B08FDP, the integration of NWP with nowcast product can double in forecast lead time in terms of the probability of detection. The QPF blending technique implemented in RAPIDS has demonstrated the viability of correcting model phase errors on precipitation location and intensity errors for a more seamless blending with the radar-nowcast.

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