

Air-quality management and weather prediction during the 2008 Beijing Olympics

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Introduction

The 29th Olympiad took place from 8 to 24 August 2008 in Beijing: more than 10 000 athletes from 204 countries, territories or regions participated. It was historically exceptional in terms of its size, variety of sport events and related activities, operations of municipal infrastructure and daily activities of the general public. Over 1.7 million volunteers provided a full range of services. Analysis of the historical meteorological data shows that the olympic sites in late summer are exposed to significant risks from thunderstorms with heavy rain, lightning, high winds and hail. Fair weather also poses challenges such as fog, haze, heat and stable conditions, which are less conducive to the dispersion of air pollutants and can result in poor air quality.

The meteorological services therefore faced significant challenges in minimizing the negative impacts of detrimental events. Multiple weather-related challenges and air quality had to be addressed for the Games to be successful. An unprecedented variety of air-quality management, monitoring and weather prediction solutions were undertaken by China and international partners.

A more detailed report is available online at http://www.wmo.int/pages/publications/bulletin_en/index_en.html

Air-quality management and measurements

Temporary emission reduction regulations were taken by Beijing Municipal Government to ensure good air quality during the Olympic and Paralympic Games, and to fulfil the commitment to host the Games. Some 300 000 “yellow-tag” vehicles were banned from the roads in Beijing from 1 July to 20 September 2008 (two days after the conclusion of the 2008 Paralympics) and all construction activities were stopped. In addition, traffic was reduced by requiring that all the vehicles in Beijing with license plates ending in odd/even numbers would be allowed on the road on odd/even-numbered calendar days from 20 July to 20 September. Additional emission reduction measures that focused mainly on coal-combustion were taken.

From June to September 2008, the China Meteorological Administration (CMA) conducted a non-stop and

extensive online monitoring and analysis campaign that supported the logistics of the Games, but also allowed for a unique assessment of the effects of the efforts to improve air quality (Zhang et al., 2008). The monitoring exercise tracked concentrations of airborne particulate matter PM_{10} and $PM_{2.5}$, including aerosol fractions of organics, sulphate, nitrate and ammonium in PM_{10} , black carbon, aerosol optical depth, ozone and other reactive gases, including nitric oxide, nitrogen dioxide, nitrogen oxide, carbon and sulphur dioxide. Ground-based monitoring was reinforced with measurements of aerosol optical depth and column nitrogen dioxide by satellite retrieval and the analysis of weather processes and characteristics. The monitoring was conducted at three urban stations at different heights and at four rural stations.

During the period of the Games, various atmospheric pollutants decreased dramatically in Beijing. Analysis showed that this decrease was related not only to the implementation of control measures but was also strongly linked to the weather. Specifically, the subtropical high was located to the south so that Beijing’s weather was dominated by the interaction of a frequently eastward-shifting trough in the westerlies and a cold continental high with clear-to-cloudy days or showery weather. After removing estimates of the change

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in concentrations from weather conditions, analysis estimated that the removal of the yellow-tagged vehicles after 1 July 2008 resulted in reductions of: ~40 per cent in various reactive gas concentrations linked with motor vehicles; 15-25 per cent of PM₁₀ particle concentrations; ~25-30 per cent traffic-related black carbon concentration; and 25-40 per cent of particle organics and nitrate concentration.

Various reactive gas concentrations linked to motor vehicle activities decreased by an additional ~15-20 per cent with the introduction of odd/even motor vehicle restriction guidelines after 20 July 2008. While the overall PM₁₀ particle concentrations increased a little, black carbon, particle organics and nitrate were reduced by between 6-20 per cent. Ammonium product and sulphate, however, rose by ~10 per cent and ozone concentration increased by 30 per cent.

Before and during the Games, CMA provided two-day forecasts of PM₁₀, visibility and ozone to Beijing Municipal Government and subsequently to the Beijing Meteorological Bureau and the Beijing Municipal Environmental Protection Bureau. The forecasters used the CMA Unified Atmospheric Chemistry Environment (CUACE) model for haze and ozone forecasting system. This is a unified atmospheric chemistry and environment modelling system that can be easily coupled with different types of weather and climate models at various temporal and spatial scales. For this application, CUACE was fully coupled with the MM5 prediction model with a horizontal resolution of 54 km over Asia and the eastern part of Europe. The initial and boundary conditions were from the CMA operational global medium-range prediction model. CUACE comprised a chemistry module for gases, gas-to-particle conversions, secondary organic aerosols and aerosols.

On the basis of a CMA regional emission inventory from Cao (2006),

CUACE was run in real-time from 1 July to 30 September. Two-day products in 12-h mean and 2-h intervals of PM₁₀, ozone and visibility for Beijing were provided everyday as forecast guidance (Figure 1) with three- to seven-day forecasts of stabilized weather condition forecasts based on a parameter linking air quality and meteorology (Plam) index. This index is derived from the relationship of PM₁₀ and key meteorological data derived on the basis of summer data from Beijing and its surrounding areas from 2000 to 2007. The meteorological data include air temperature, relative humidity, wind, air pressure, visibility, clouds, evaporation, air stability and some history of weather phenomena of the preceding days. Higher Plam indices and poor air quality (>150 µg/m³ PM₁₀) were associated with high temperature, high humidity, lower wind speed and stable weather. An example of the use of the Plam index is shown in Figure 1. Each site outside Beijing was given a Plam weight according to the wind and speed direction relative to the arrival of the airmass in Beijing. The higher Plam value at a site in Beijing's surrounding areas shows

that weather conditions in these areas would be more favourable for pollutant transport to Beijing.

WMO World Weather Research Programme demonstration projects

Under the guidance of CMA, the Beijing Olympic Meteorological Service Centre (BOMSC) successfully provided "characteristic and high-level" meteorological services, based on operational weather forecasting and warning systems and man-machine interactive platforms. In a preliminary assessment, the meteorological services that were provided in this complex and meteorologically challenging environment attained a public satisfaction of 93.1 per cent. These capabilities were developed and tested well in advance by mobilizing national meteorological expertise and resources and through effective international cooperation. The WMO World Weather Research Programme (WWRP) demonstration projects are two examples of this international collaboration.

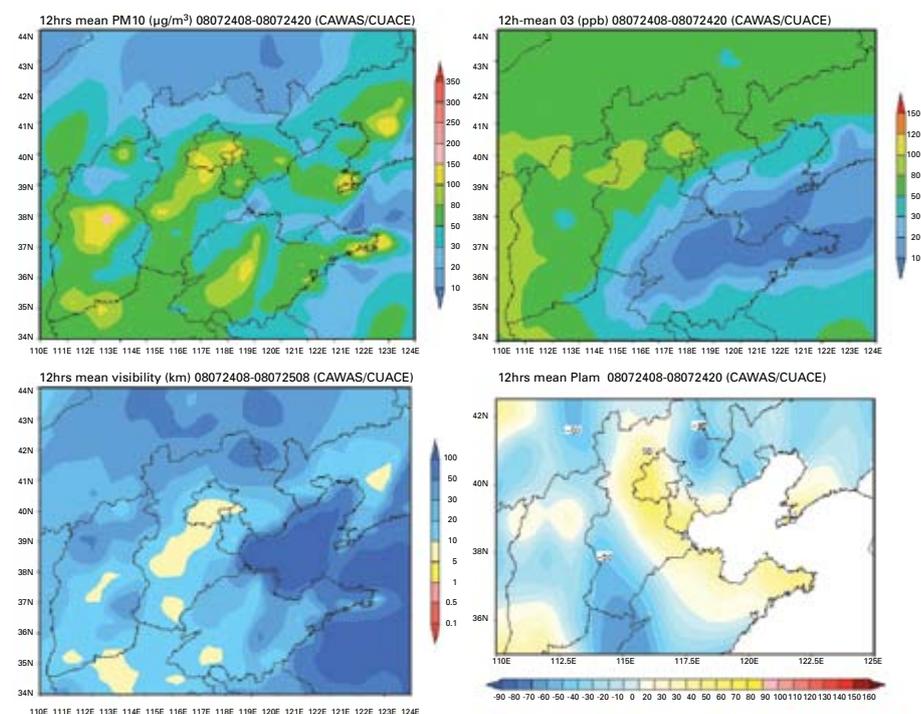


Figure 1 — 12- or 24-h forecast guidance of surface PM₁₀, visibility and ozone as well as Plam index for Beijing and its surrounding areas by CUACE of the Centre for Atmosphere Watch and Services, CMA, starting at 08 BTC, 24 July 2008

Based on the WMO/WWRP project for the 2000 Sydney Olympic Games, CMA formulated plans in 2003 for a WWRP Forecast Demonstration Project (B08FDP) and a Research and Development Project (B08RDP) to assist in the technical support for the weather forecasting and services for the Beijing 2008 Olympic and Paralympic Games.

The overall mission of B08FDP was to demonstrate and quantify the benefits of an end-to-end nowcast (0-6 h range, especially in the 0-2 h time-frame), focusing on the prediction of high-impact weather, using the latest science and technology. It was targeted on the development, application and field demonstration of nowcasting systems for local convective storms, the use of products from these systems in operational forecasting and assessments of socio-

Table 1 — Data provided to B08FDP in the summer of 2008 by the Beijing Meteorological Bureau

<i>Data type</i>	<i>No. of stations and location</i>	<i>Frequency of update</i>
Doppler Radar	4; with time synchronization	6 minutes
AWS	106; in and around Beijing	5 minutes
Radiosonde	5; in and around Beijing	6 hour
Wind profiler	1; in Beijing	6 minutes
NWP-RUC	Horizontal resolution at 3 km, covering Beijing and surrounding areas	3 hours
Satellite-FY2C	1	30 minutes
Lightning	1 in Beijing and 2 in Hebei province	Real-time

economic benefits to end-users. See box below for the eight nowcasting systems which participated.

B08FDP was a 3.5 year effort with two trials in the summers of 2006 and 2007 to improve systems and optimize individual algorithms on storm extrapolation, quantitative precipitation estimation, product generation and other tasks. The field trials also enabled the systems to adapt to local data, computation and network environment. A real-time forecasting verification system was developed by the Australian Bureau of Meteorology and transferred to the Beijing Meteorological Bureau. By mid-July 2008, all these systems met the demonstration requirements. They were finalized and frozen to ingest and process, on a real-time basis, the multivariate and frequent local observational data (see Table 1) and to generate products for prediction (see Table 2) and real-time verification.

Three international workshops and a number of meetings and telephone conferences were held to diagnose the technical difficulties encountered during the different implementation stages, explore solutions, identify responsible working groups and discuss roadmaps and timelines for major activities. Key technical issues included radar data-quality control, radar synchronization, 3-D mosaic of radar raw data and the transfer of research into operations. Two training workshops were held in Beijing in April 2007 and July 2008 to train local experts and weather

forecasters to enhance local support to the B08FDP systems, especially the local application of products. Some end-users participated as trainees.

The B08RDP focused on short-term (6-36 h) predictions through the development and utilization of high resolution (15 km) limited-area short-range ensemble prediction systems by six different participants (the US National Center for Environment Prediction and NCAR; Environment Canada, Japan Meteorological Agency; Zentralanstalt für Meteorologie und Geodynamik of Austria, MeteoFrance and CMA). A common framework was set up in which the six participants ran their computer models remotely in their own institutions with the same computation configuration covering Beijing and surrounding area. The observational data and ensemble member data were transmitted through ftp server in real-time, with unified resolution and area location, unified data format and filename and GRIB2 encoding/decoding standard. Table 3 shows the characteristics of the six systems.

From 2006 to 2008, all participating systems were run in real- or near-real-time in the summer seasons and the predictions were compared and analysed. At the CMA National Meteorological Centre (NMC) and National Meteorological Information Centre, a system was set up to fulfil the tasks of observation and ensemble prediction data transmission, data encoding/decoding, verification, bias correction and product

Participating nowcasting systems

BJ-ANC (Beijing Meteorological Bureau and the US National Center for Atmospheric Research (NCAR))

CARDS (Meteorological Service of Canada)

GRAPES-SWIFT (Chinese Academy of Meteorological Sciences)

STEPS and **TIFS** (Australian Bureau of Meteorology)

SWIRLS (Hong Kong (China) Observatory)

NIWOT (NCAR)

MAPEL (McGill University, Canada, and Weather Decision Technologies, USA)

Table 2 — The B08FDP products on www.b08fdp.org

System		Output products	Forecast range (minutes)
B J A N C	Auto-Nowcaster	Reflectivity \geq 35dBZ	30, 60
		Quantitative Precipitation Forecast (QPF)	0-30, 0-60
		Storm evolution	30, 60
		Boundaries	30, 60
	VDARS	Wind (u and v)	Analysis
		Vertical velocity	
		Perturbation temperature	
Relative humidity			
CARDS	QPF	0-60	
	Point forecast	Every 6 min to 102 min	
	Storm occurrence and properties	6, 12, 18, 24, 30, 42, 60	
GRAPES-SWIFT	QPF	0-30, 0-60, 0-120, 0-180	
	Reflectivity	30, 60	
	Storm track (35, 40, 45, 50, 55 dBZ)	6, 12, 18, 24, 30, 42, 60	
	Convective wx potential	0-60	
MAPLE	QPF	30, 60	
	Reflectivity	30, 60	
NIWOT	Reflectivity \geq 35dBZ	60, 120, 180, 240, 300, 360	
S T E P S	STEPS	QPF (Mosaic domain)	0-30, 0-60, 0-90
		POP (1, 10, 20, 50 mm, Mosaic domain)	0-60
	Rain fields	Quantitative Precipitation Estimation (QPE) (6 min., Mosaic)	Analysis
		QPE (60 min, Mosaic)	Analysis
		QPE (120 min, Mosaic)	Analysis
		QPE (180 min, Mosaic)	Analysis
		QPE (60 min, gauge blended, Mosaic)	Analysis
Gauge (60 min, interpolated, Mosaic)	Analysis		
SWIRLS	QPF (radar)	0-60, 0-120, 0-180	
	Probability of lightning threat	0-60, 0-120, 0-180	
	Storm occurrence and properties (reflectivity \geq 34 dBZ)	6, 12, 18, 24, 30, 42, 60	
	Severe weather: lightning initiation (type & severity), downburst (severity type), hail (type), rainstorm (intensity type)	0-30	
	Severe wind gust (maximum possible)	0-30	
	POP (1, 10, 20 mm for 60 min; 1, 10, 20, 50 mm for 180 min; 1,10, 20, 50 mm for 360 min)	0-60, 0-180,0-360	
	QPF (blended)	0-60, 0-120, 0-180, 0-240, 0-300, 0-360	
T I F S	TIFS	Storm probability ensemble (VIPS lightning warning guidance, automatic mode)	0-60
		Storm probability ensemble (VIPS lightning warning guidance, manual mode)	0-60
		Rain probability ensemble (VIPS rainstorm warning guidance)	0-60
		Probability of wetting rain (2 mm/h)	0-60
TITAN*	Storm occurrence and properties (\geq 35 dBZ)	6, 12, 18, 24, 30, 42, 60	
WDSS*	Storm occurrence and properties	6, 12, 18, 24, 30, 42, 60	

* TITAN is a part of Auto-Nowcaster developed by NCAR, USA. WDSS is a nowcasting system developed by the US National Severe Storm Laboratory. The two systems were participant systems of the S2KFDP for the 2000 Sydney Olympic Games and left to the Bureau of Meteorology of Australia (BOM) after the Games. BOM integrated these two systems into TIFS and as one participant system of the B08FDP.

Table 3 — The B08RDP limited area ensemble prediction system in the summer of 2008

Participants	Model	IC	Initial perturbation	LBC	Lateral perturbation	Physical perturbation
NCEP	WRF-ARW (5) WRF-NMM (5) GEFS-Downscaled (T284L60, 5) (L60M15)	NCEP 3DVAR	Breeding	NCEP Global EPS	NCEP Global EPS	Multi-model
MRI/JMA	NHM (L40M11)	Meso 4DVAR (20kmL40)	Targeted Global SV (T63L40)	JMA Global Forecast (TL959L60)	Global forecast (T63L40) initiated by targeted SV	None
MSC	GEM (L28M20)	MSC Global EnKF	MSC Global EnKF	MSC Global EPS	MSC Global EPS	Physical tendency perturbation with Markov chain, surface perturbation
ZAMG & METEO-FRANCE	ALADIN (L37M17)	ECMWF Global 4DVAR	Blending ECMWF SV with ALADIN Bred Mode	ECMWF Global Forecast	ECMWF EPS Forecast	Multi-physics
NMC/CMA	WRF-ARW (L31M15)	WRF-3DVAR	Breeding	CMA Global EPS	CMA Global EPS	Multi-physics
CAMS/CMA	GRAPES (L31M9)	GRAPES-3DVAR	Breeding	CMA Global EPS	CMA Global EPS	Multi-physics

generation, based on multi-source ensemble prediction data and product display, etc. Most ensemble products were distributed to NMC and the Beijing Meteorological Bureau as guidance for forecasters. The B08RDP also emphasized the real-time demonstration, evaluation and intercomparison of modelling activities that typically lie in the research community (e.g. multi-centre probabilistic products for the high-impact weather, high-resolution cloud-resolving model (about 2-4 km) for severe weather events).

To ensure effective application of ensemble products, NMC had focused on training national- and province-level forecasters in their daily weather forecast duty over the previous few years. Liaison between the mesoscale and nowcasting projects was set up and product requirements were investigated from experts and user groups to meet the needs of the Olympic weather service. The products included the mean/spread/

probability of surface elements, the uncertainties of circulations and the special products associated with high-impact weather. Moreover, probability products for Olympic venues were developed.

The demonstration period for the aforementioned eight nowcasting and the real-time forecasting verification system took place from 20 July to 20 September 2008. Thirteen experts from Australia, Canada, Hong Kong (China) and the USA worked an intensive demonstration period (1-24 August). All B08FDP systems provided a subset of the nowcasting guidance products referred to in Table 2 every six minutes.

For support to operations to be more efficient, a project expert and two local experts were responsible for:

- Organizing analyses and discussions on the weather and nowcasting products within the B08FDP group;

- Preparing the concise texts describing the dominant circulation patterns and weather systems, as well as potential impacts on the Beijing area in general, and on sport venues in particular;

- Interpreting B08FDP products for local forecasters; and

- Participating on behalf of the group in the twice daily weather discussions.

In the case of an important service or a complex weather event, the B08FDP experts and local experts participated in exchanges with forecasters and weather discussions in the enhanced monitoring period more frequently. For the opening and closing ceremonies, B08FDP experts worked together with Beijing Meteorological Bureau (BMB) forecasters to track the variations of weather systems continuously until the end of these events.

Three approaches were implemented to enable weather forecasters and on-site weather service teams to directly access demonstration project products and verification outcomes in a user-friendly manner:

- A Webpage (<http://www.b08fdp.org>) in Chinese and English was developed on the BMB internal Website, dedicated to forecasters and on-site service teams for the products (see Table 2);
- A subset of the B08 products was put into the man-machine interactive platform in the BMB operational nowcasting procedures for direct use as nowcasting guidance by forecasters;
- Local experts provided forecasters with printouts and oral interpretations of products and expert interpretation. In addition, for other end-users (e.g. Beijing Organizing Committee for the Olympic Games (BOCOG)), civil aviation meteorological departments, the boating service unit of the Summer Palace and the general public), the Beijing Olympic Meteorological Service Website (<http://www.Weather2008.cn>) in Chinese and English was opened to access and browse products.

To ensure the practical application of B08RDP ensemble products in the Olympic meteorological services, especially during high-impact weather events, NMC designed several approaches to ensure the direct access of weather forecasters and project participants to ensemble products, observations and analysis fields. First, ensemble products were categorized and translated into different data formats for different end-users or display purposes. Second, the B08RDP Webpage (www.b08rdp.org) was developed in the NMC internal Website to ensure access by all forecasters from BMB/NMC and

project participants in real-time. Third, ensemble products developed for the 17 Olympic venues were transmitted to BMB by a high-speed dedicated cable network. This allowed close collaboration between the B08RDP forecasting and B08FDP nowcasting applications.

CMA B08RDP experts also worked closely with forecasters by transmitting and interpreting ensemble predictions and providing weather forecasting suggestions from the prospective of research. Ensemble forecasts were used to characterize uncertainties in the predictions. Uncertainties are needed to better understand and improve forecasting of high-impact weather events through comparison with single, deterministic forecasts.

Weather forecasting services

The Beijing 2008 Olympic Games involved the host city and six co-host cities (Qingdao for sailing;

Hong Kong for equestrian events; Tianjin, Qinhuangdao, Shenyang and Shanghai for football). With the approval of CMA and Beijing Municipal Government, BOMSC was established as the sole official meteorological service provider in August 2006 (TOK, 2008). Its organizational structure is given in Figure 2.

BOMSC comprised three components: meteorological services of the host city, co-host cities and venue weather offices. Some national operational meteorological centres and research institutions within the CMA framework and six temporary meteorological service bodies were created in Beijing, Qingdao and Hong Kong to support outdoor sporting events and major public gatherings. The meteorological services of the host and co-host cities were to provide weather forecasts and services to the local sport organizing committees and local organizers for major public activities, whereas the national operational centres and research institutions were tasked with providing technical guidance and support to the meteorological

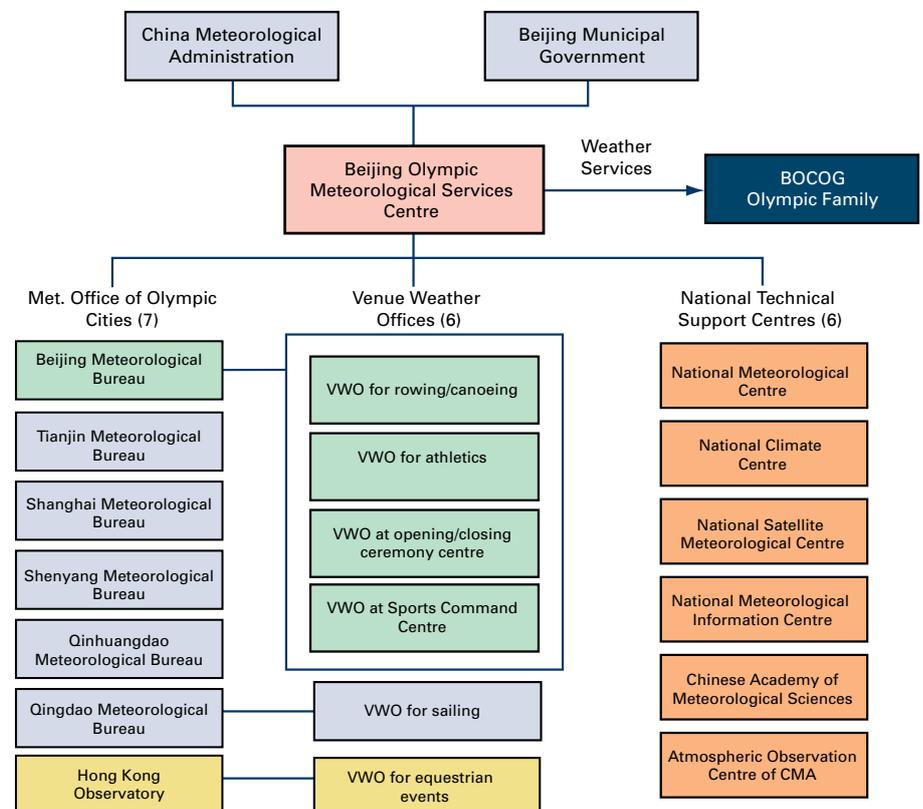


Figure 2 — Organizational structure of the Beijing Olympic Meteorological Service Centre

offices in the host and co-host cities, apart from Hong Kong Observatory, which had full responsibility to provide weather forecasts and services for equestrian events. All relevant observations, forecasts and warnings received by the dedicated Beijing Olympic Information system were collected and converted into a unified format by BMB and then disseminated to BOCOG.

The special demands for highly refined meteorological services sports events and related large social events exceeded the range of routine weather forecasts and operational services in many aspects. To address this issue, BMB, in association with other meteorological services focused on research and the development of new techniques, methodologies and tools to make the refined forecasts of weather elements at specific venues, nowcasts and early warnings of local severe convective weather (Wang, 2007). The following “four systems and two interactive tools” were established:

- The Hi-MAPS system pre-processed a wide range of frequent observations in a rapid update manner (e.g. six-minute radar volume scanning raw data, six-minute wind profiles, five-minute automatic weather station observations, six-hour enhanced radiosonde observations, etc.). Hi-MAPS provided observation data for the BMB operating systems and provided standard data for the eight B08FDP demonstration systems on a real-time basis;
- The BJ-ANC system was developed jointly with NCAR. It produced severe convective nowcasts based mainly on multiple Doppler radar observations with more complex extrapolation techniques. It also incorporated other algorithms, such as the variational Doppler radar analysis system and radar quantitative precipitation estimation and prediction algorithms. The system

generated much nowcasting guidance (see Table 2);

- The BJ-RUC system was developed jointly with NCAR. It is the local version of the Weather Research and Forecasting system with a number of improvements. With a rapid cycle every three hours, it provided high-resolution (3 km) mesoscale numerical output covering Beijing and the surrounding area for the following 24 or 36 hours as forecast guidance;
- The OFIS system was a man-computer interactive tool to facilitate the analysis of weather conditions and the production of three-hourly forecasts of refined weather elements over the following three days (0-63 h) based on a variety of observations, numerical weather prediction (NWP) products and venue forecast guidance, as well as real-time verification of guidance. The venue forecast guidance derived mainly from:
 - Multi-element, venue-specific forecasts by the support vector machine regression method, a statistic interpretation of NWP products;
 - Multi-element, venue-specific forecasts by half-periodic function fit methods, based on the chief forecaster’s conclusions for 12-hourly forecasts for the following three days;
- The VIPS system, a man-machine interactive tool, assisted forecasters in monitoring severe convective weather and producing early warnings in the Beijing area. A variety of high-frequency mesoscale meteorological observations and NWP products, as well as nowcasting guidance and geographical information, could be superimposed on one screen. It also supported early warning mapping and screen-revision functions and

automatically generated warning texts in both Chinese and English with an editing function.

- The OMIS system had multiple functions. It collected real-time observations and venue-specific weather forecasts in Beijing and co-host cities and automatically decoded, converting data format and unit of measurements, translating into the target languages, classifying and packaging for different users in the form of different products and distributing to BOCOG, Beijing Olympics INFO2008 system, Beijing Olympic Broadcasting and Olympic Meteorological Service Website in real-time.

There was more rainfall than normal in Beijing during the Olympic Games. The accumulated precipitation (8-24 August) was 151.7 mm in the plain, 90 per cent higher than the same period of the 30-year average (80 mm). There were four widespread precipitation events across Beijing and another four local precipitation events, of which five individual days had 10 mm of daily precipitation. On 10 and 11 August, the city witnessed heavy storms and rainfall. High-impact weather other than precipitation was less than normal.

In the face of complex and changeable weather, BOMSC paid special attention to some key components in its service delivery:

- **Enhancing weather “consultation”**
Special discussions were organized for important events, such as the opening and closing ceremonies and weather-sensitive outdoor events. Senior forecasters and experts, as well as foreign nowcasting experts, participated;
- **Making good use of advanced technologies**
The “four systems and two interactive tools” were incorporated into early warning

and refined forecast processes to tap the human potential for improving efficiency and quality based on high technologies;

- **Enhancing interactions with venues**

The simplified VIPS version was installed at on-site weather offices so that service teams could access updated observations, forecasts and early warnings and enable them to interact in a timely manner with end-users. At the same time, information communication channels allowed staff on-site and at head office to accommodate the changes in users' demands, and to provide relevant and tailored services at any time.

With the benefit of these initiatives, BOMSC provided BOCOG with "characteristic and high-level" refined forecasts and early warning services,

which helped the organizers arrange the timing of a number of outdoor events. The Olympic Schedule Committee called six telephone conferences and made schedule changes for eight sports events according to the weather forecasts delivered by BOMSC. Despite more rainfall than normal, accurate and timely short-term forecasts and nowcasts, as well as continuous follow-up services, ensured the smooth running of the majority of outdoor events. Only a few were interrupted because of unexpected rainfall.

These weather services contributed significantly to all events. For example, BOMSC forecast that there would be more rainfall before 09:00 on 21 August, but would lessen thereafter. The International Association of Athletics Federations decided that the women's 20-km walk and decathlon would be held on time,

but that the high jump and javelin would be postponed for one hour.

From the check-in of the athletes at the Olympic Village to the end of the Paralympic Games, BOMSC issued and distributed more than 10 000 copies of weather forecasts, reports, briefings and warnings in 18 categories in Chinese, English and French (Table 4). At the same time, more meteorological information than ever before was issued to the general public by television, radio, Internet, telephone, newspapers, messaging and other means and weather information in English was also made available. The Olympic Meteorological Service Website (www.weather2008.cn), established by BOMSC, had a link to the official BOCOG Website, which received more than 15 million visits.

Preliminary verification on the three-hourly weather forecasts for the next

Table 4 — Weather forecast and severe weather warning issued by BOMSC from 25 July to 17 September 2008

No.	Names of products	Sum of products		
		Chinese	English	French
1	3-hourly weather forecast for venues of host and co-host cities	13 160	13 160	272
2	Weather briefing specially for Olympics	110	110	48
3	Severe weather warning for host and co-host cities	390	390	
4	7-day weather forecast of host and co-host cities for Beijing Olympics	55	55	24
5	Hourly wind forecast for Beijing Olympic shooting range (CTF) venue	62	62	--
6	Weather forecast for Beijing Olympic rowing-canoeing venue	60	60	--
7	Weather forecast along roads for 2008 Beijing Olympic marathon	30	30	--
8	Weather forecast for Beijing Olympic urban cycling road course	56	56	--
9	Weather forecast for the opening (closing) ceremony of Beijing Olympics	301	301	--
10	Meteorological risk warning for the opening (closing) ceremony of Beijing Olympics	11	--	--
11	Beijing weather forecast specially for traffic	110	--	--
12	Thunderstorm report for Beijing Olympics	22	--	--
13	Weather outlook of next 10 days for Beijing Olympics	12	--	--
14	Weather outlook of next 30 days for Beijing Olympics	2	--	--
15	Weather forecast specially for Beijing Olympic logistics	55	--	--
16	Weather forecast for the opening (closing) ceremony of Qingdao Olympic sailing	50	--	--
17	Hourly wind forecast for Qingdao Olympic sailing venues	165	--	--
18	Weather report for Hong Kong Olympic equestrian events	138	138	--

63 h targeted at venues in Beijing showed that:

- Forecasters largely depended on the guidance provided; they could make merit-based judgments and amendments;
- The quantitative precipitation forecast is the most difficult one in forecast elements, especially when it relates to specific location and time;
- Forecasters' skills in temperature, relative humidity and wind speed were slightly better than forecast guidance, but their skills for precipitation and wind direction were more or less equivalent to the guidance on average;
- The accuracy rate of three-hourly relative humidity forecasts issued by forecasters, with bias less than 10 per cent against observation, was about 70 per cent within 24 h, 65 per cent in 24-48 h, and 55 per cent beyond 48 h. The mean absolute error of three-hourly temperature forecasts was about 1.7°C within 24 h, 2.0°C in 24-48 h, and 2.2°C beyond 48 h (see Figures 3 and 4);
- Comparing the performance of venue three-hourly precipitation forecasts using the threat score (TS), forecasters had higher skill than support vector machine guidance, but the skill decreased with valid time (TS around 0.1-0.2 within 24 h, and 0.07-0.13 in 24 h-63 h against TS of support vector machine guidance less than 0.1 in 0-63 h). It is noticeable that TS of three-hourly venue rainfall guidance within a 24-h valid time from BJ-RUC had the highest TS among the three. However, its unstable performance on different runs during the daily cycle did not give forecasters the confidence to rely on it more.

Responses to a satisfaction survey showed that users such as BOCOG

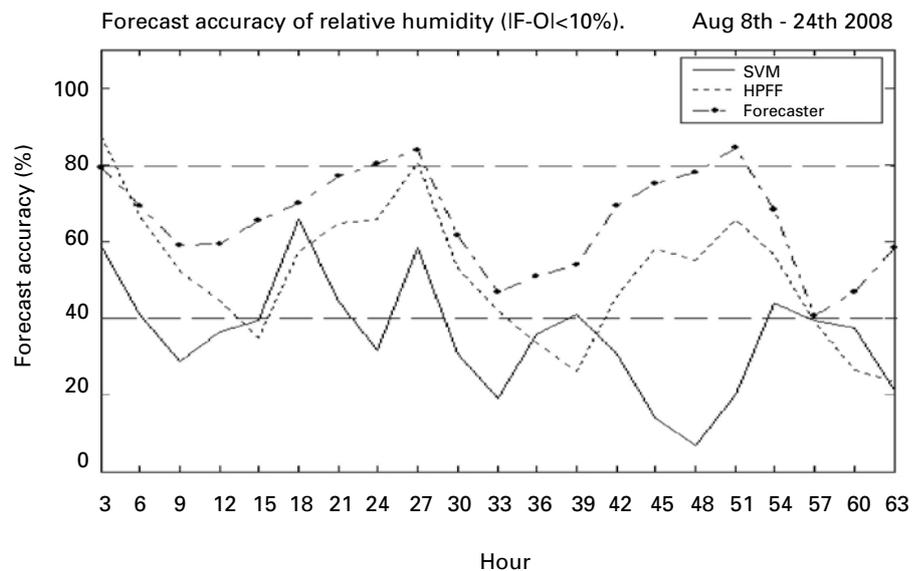


Figure 3 — Forecast accuracy rate of relative humidity (bias < 10 per cent) (statistics based on the data of 8-24 August 2008)

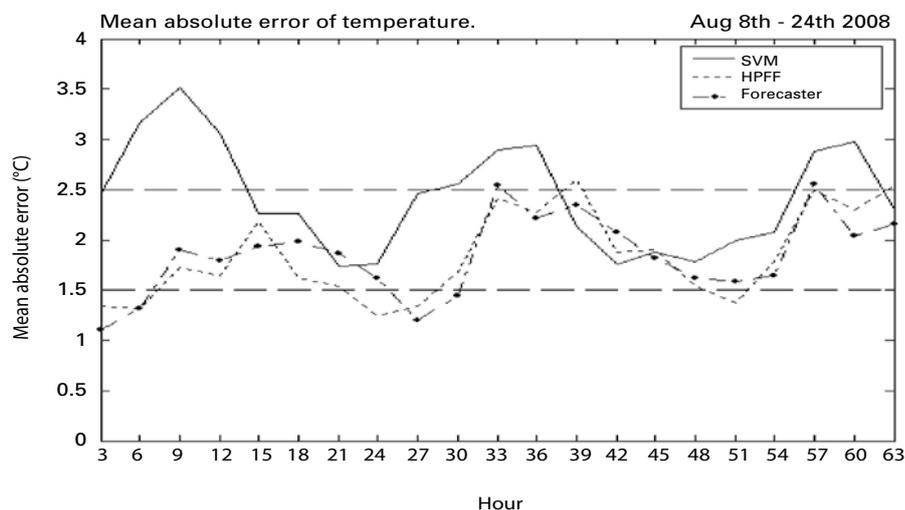


Figure 4 — Mean absolute error of temperature (°C, statistics based on data of 8-24 August 2008)

affiliates, the opening and closing ceremony operators, Shunyi water sports teams, the National Stadium, city operation teams, city officials, sport event organizers, referees, athletes, volunteers and the general public, believed that the forecasts delivered by BOMSC were accurate, timely and effective with a public satisfaction rate of 93.1 per cent.

Conclusions

The successful, extensive and complex set of activities to support air quality and weather during the Olympic and Paralympic Games will

have a lasting effect on both China and the international community.

Large decreases in concentrations of many traffic-related gases and aerosols from traffic restrictions were observed. The yellow-tag vehicle ban had a larger effect on the reduction of atmospheric pollutants than the alternating registration plate restrictions. Several recommendations were made to Beijing Municipal Government for understanding and improving air quality on the basis of these findings, and other urban areas throughout the world could benefit from this knowledge.

BOMSC provided effective and quality weather services in a period having more rainfall than normal. This was recognized by all sectors. The success was due to the use of advanced technologies and techniques, the "human" role, close interactions with end-users, implantation of demonstration projects and unique working and management measures.

The WMO/WWRP B08FDP proved to be very effective in support of the Beijing Olympic nowcasting services not only by providing guidance, but also a complementary highly interactive approach between experts, forecasters and knowledge deliver personnel. B08FDP was a successful example of combining research findings with operational applications. This practice should be followed in developing enhanced nowcasting support elsewhere.

The WMO/WWRP B08RDP furthered knowledge on the use of multi-centre ensembles and characterizing uncertainty. The bias-corrected and combination products of the multimodel ensemble were superior

to any single ensemble so that benefit can be obtained from the real-time utilization of probabilistic products for severe weather. Nevertheless, the paradigm shift of a forecast office from deterministic to ensemble prediction is challenging, even after careful training.

The Olympic Meteorological Service provided a practical opportunity for forecasters to produce refined weather forecasts. However, refined forecasting is a new and challenging task for forecasters whose previous experience in conventional forecasts is not necessarily applicable. At present, skills of forecasters for making refined forecasts slightly outperform the objective prediction methods, but there will be much room for forecasters to play a value-added role in refined forecasts by continuous and cumulative learning from experience.

The activities for the Olympic and Paralympic Games were extensive and much of their success lies in the long-term multi-year planning for all aspects of the effort and commitment of the international partners and local hosts.

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