SUMMARY REVIEW OF THE SHANGHAI 2010 WORLD EXPO NOWCASTING SERVICES (WENS) DEMONSTRATION PROJECT

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1. INTRODUCTION

1.1 Weather service requirements of Expo

The Shanghai World Expo 2010 was held from May to October in 2010 (184 days). Under the theme of "Better City, Better Life", the Expo put on display the splendid achievements of contemporary civilizations, pooled human wisdom in exploring the path of urban development, set many Expo-related records, and added a glorious chapter to the Expo history. This successful international event attracted 246 official participants, including 190 countries and 56 international organizations, and 73 million visitors. All these figures are new records in World Expo history, the first of which was held in London in 1851.

Fig1 Closing Ceremony of the Shanghai World Expo 2010 on Oct. 31, 2010

With a pleasant northern subtropical maritime monsoon climate, Shanghai enjoys four distinct seasons, with generous sunshine and abundant rainfall. The city is bordered by the Yangtze River to the north and Hangzhou Bay to the south. Shanghai receives an average annual rainfall of 1,200 mm; nearly 60% of the precipitation occurs from April to September. July and August are Shanghai's hottest months with average highs of 32.4°C, and daytime average of humidity is 75%. On average there were 15 rainy days, and 8 thunderstorm days per month during the Expo period of operations. Abnormal rainfall events can occur during this period, e.g. on the 25th of August, 2008, the precipitation exceeded 100 mm in a one hour period.

Expo brought a lot of requirements of meteorological services. Planning an event during the warm season of a year in Shanghai, a time of frequent precipitation and thunderstorms, together with some high impact weather (HIW), such as heavy rainfall, squalls, hail, lightning, and tropical cyclones could bring weather-related disasters. In addition, Expo 2010 Shanghai was the first Expo to be held in the downtown area of a mega-city, the Expo site was located on the banks of the Huangpu River in the downtown area, covering an area of about 5.3 km^2, which is a relatively small area or a point in terms of operational weather forecasting. The topography, surface features, and the urban “heat island” effect could play important roles in the initiation and evolution of weather systems, which increases the difficulty of forecasting meso-scale weather.

Weather services were also required to support planning and coordination of EXPO operations and activities. Important issues concerning the weather’s effect on individual exhibition pavilions and potential impacts associated with the outdoor exposure of a large number of people, and a large extent of property.

There were about 250 pavilions in the Expo site, some important activities (including the Opening Ceremony, the Closing Ceremony, parades, etc.) and more than 20,000 smaller scale activities, over 70 million visitors during the Expo period, which demanded detailed, targeted, and tailored meteorological services.

The Shanghai Meteorological Service (SMS) of China Meteorological Administration (CMA) was responsible for providing weather services for the whole Expo activity. Challenges of the meteorological services included the difficulty of forecasting these frequent high impact weather during the Expo period.

Nowcasting is defined as Very Short-Range (0-6 hour) forecasts, and nowcasts of HIW are particularly important components of the World EXPO 2010 weather service requirement. In case of thunderstorms and other severe weather forecast, severe weather outlooks (0-12 hour) need to be normally issued at 6 hour intervals for the EXPO site, and special early warning information need to be issued through the Dissemination Platform of the Shanghai Multi-Hazards Early Warning System (MHEWS) in a timely manner.

In November 2008, the World Expo Nowcasting Services (WENS) project was officially established as one of the World Meteorological Organization's (WMO) demonstration projects. The WENS Implementation Plan was drafted through the joint efforts of the experts from WMO, China Meteorological Administration (CMA), Australia Bureau of Meteorology (BOM), Hong Kong Observatory (HKO), and CMA's SMS and Beijing Meteorological Service (BMS).

At the recommendation of the WMO Implementation and Coordination Team on Public Weather Services, WENS focused on the "services" rather than the "systems", in particular, the translation of nowcasting system outputs to timely, relevant and user-friendly products for decision makers and stakeholders. WENS products were made available to local weather forecasters on duty. A post-project review was conducted to assess the impact of WENS. This was to be followed by the publication of guidelines on the provision of nowcasting services reflecting the experience gained from WENS, and the conduct of capacity building workshops for WMO Members. This project was conducted in the framework of the "Learning through Doing" concept as developed by PWS Programme Experts.

The WENS has been conducted over four years (2008-2011) by CMA and international participating groups with active support from WMO. The formal WENS was conducted over the period 1 March to 31 October 2010. This project was also in the framework of the "Learning through Doing" concept as developed by PWS Programme Experts.

1.2 Goals and objectives of WENS

The World EXPO presents a unique and exciting opportunity to reach out to the general public on a global level. The WENS aimed to be an excellent example of how Meteorological and Hydrological Services can participate in international events in more than just a service capacity. The improvements in DRR (Disaster Risk Reduction) for natural disasters as well climate change adaptation strategies are highlighted and public awareness of meteorological sciences and services are gradually increasing.

Therefore, the goals of WENS are as follows:

- In the context of multi-hazard early warning services (MHEWS), to demonstrate how Nowcasting applications can enhance short-range forecasts of severe weather using the opportunity afforded by the Shanghai World EXPO 2010; and

- Promote the understanding and enhance the capability, as appropriate, of WMO Members in nowcasting services.

The objectives of WENS are as follows:

- Provide advanced high impact weather and precipitation nowcasting products and services in the context of the World EXPO 2010;

- Enhance the capacity of the SMS in MHEWS to: Address the problem of urban inundation; Provide improved heavy precipitation warnings; Evaluate the contribution of Quantitative Precipitation Estimates (QPE) and Quantitative Precipitation Forecasts (QPF) to the overall effectiveness in the risk assessment process; Effectively present the information to the decision makers and the public.

- Demonstrate the introduction, optimal implementation, and training in use (technology transfer) of advanced nowcasting systems in operational forecasting and in the generation of enhanced products and services;

- Evaluate the impact of the implementation of operationally focused nowcasting on the quality of high impact weather and precipitation forecasts, on forecasters and on end-users of a local meteorological service;

- Promote the implementation of nowcasting services in the Shanghai region initially and ultimately for the benefit of WMO Members, especially those in East Asia.

The nowcasting service product providers for WENS project are China Meteorological Administration (CMA), Australian Bureau of Meteorology (BOM), and Hong Kong Observatory (HKO). The participating nowcasting systems are:

The Terms of Reference for NSPPs are as follows:

a) To provide nowcasting services products or systems in support of the World EXPO 2010 on a functional real-time basis;

b) To assist in the customisation, support, maintenance and interfacing of their systems to operational data feeds and information / dissemination systems as agreed for implementation in Shanghai;

c) Offer consultancy and advisory support and undertake agreed interface and capacity-building activities.

1.3 Organization of WENS

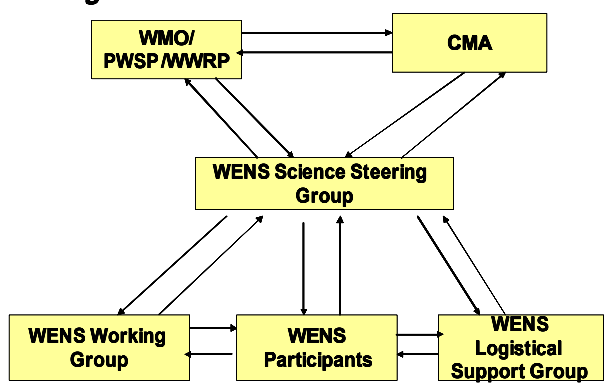

Fig 2 Organization of WENS

A WENS Scientific Steering Group (SSG) was established to plan and steer implementation of the project recognizing a requirement for a focus on service delivery aspects. The SSG is in charge of developing an agreed business/project plan based on the MHEWS project plan. The WENS project plan defines project participant roles and responsibilities, agreed timetable and financial arrangements. A WENS Working Group (WENSWG) oversees the development of an implementation plan, its execution and reports to the SSG.

The responsibilities of the WENS/SSG are: to formulate strategies of the WENS implementation (scientific and technical aspects), to monitor progress of WENS implementation including review of the implementation plans of the participants, to oversee training programme, and prepare reports on scientific aspects of WENS.

The SSG comprises SMS/CMA, PWS Secretariat, ICT Chair, JONAS SC Co-chairs and PSOs, capacity building lead, a socio-economic lead with the WENSWG Chair serving as secretary. The WENSWG comprises of SMS/CMA experts, PSO representatives, PWS expert(s) and other experts deemed necessary serving as resource agents.

A comprehensive user evaluation process was also developed and applied to all WENS products and services by the WENS Working Group.

1.4 Milestones of WENS

From the beginning of 2009, WENS related work was pushed forward smoothly in accordance with the Implementation Plan thanks to the great efforts and contributions of the participant systems. There are milestones of the whole WENS project:

1) Sep. 2008: Establishment of WENS Scientific Steering Group (SSG) and WENSWG by interim SSG, draft TORs and draft business plan for WENS. (Interim SSG).

2) Nov. 2008: SSG Planning Meeting finalized TORs and WENS Business Plan on project scope, duration, milestones and deliverables as well as funding arrangements (SSG).

3) NEED Date: Pre-Training in Hongkong and Australia: HKO (Linus Yeung and his colleagues) and BOM (Alan Seed and his colleagues) provided trainings to the SMS staff on application of the nowcast products of SWIRLS and STEPS.

4) Jul.-Aug. 2009: First trial run (WENSWG): the participant systems were installed and fine-tuned under the guidance and support of the experts and operational training courses for WENS forecasters were taken.

5) Oct. 2009: Interim Review Meeting: Review objectives, undertake validation and performance assessment of systems taking part in trial run; engage key stakeholders/users to provide feedback on products.

6) Apr. 26 – Oct. 31, 2010: WENS in Full Operation.

7) Sep. 20-24, 2010: WENS Review presentation, in the WMO Public Weather Services Core Implementation and Co-Ordination Team meeting, Shanghai, China.

8) 8-10 Feb., 2011: WENS Review presentation on internet, in the WMO WWRP Working Group on Nowcasting Research, Geneva.

9) Nov. 14-18, 2011: WENS Final Review meeting of WENS was held in Shanghai, China.

2. DATA AND WEB SITES

2.1 Data

There are 200 automated weather stations (AWSs) or rain gauges in the Shanghai area. The spatial resolutions of the AWS network and the rain gauge network are about 8 km and 5 km, respectively. The temporal resolution of these two observation systems is 1 min. All the data are communicated in real-time using the GPRS/CDMA.

There are two Doppler weather radars in Shanghai, a WSR-88D Doppler weather radar in the east coastal area of Shanghai, and a CINRAD in the western area of Shanghai. They run a volume scan each 6 min and provide three types of base data: reflectivity, radial velocity, and spectrum width, and more than 70 derived radar products. With the CINRADs at Zhoushan, Ningbo, Changzhou, Nantong, and Hangzhou, a Doppler weather radar network over the Yangtze River Delta provides weather information in real time.

A total lightning detection network detects total lightning that includes Intra-Cloud (IC) lightning and Cloud to Ground (CG) lightning. The lightning data are transported with the CDMA technique to the central station in real time.

Doppler radar volume scan level-2 data, geostationary satellite data, conventional climate station and radiosonde data, all real-time AWS and lightning location data in Shanghai, Jiangsu, and Zhejiang.

2.2 Web site

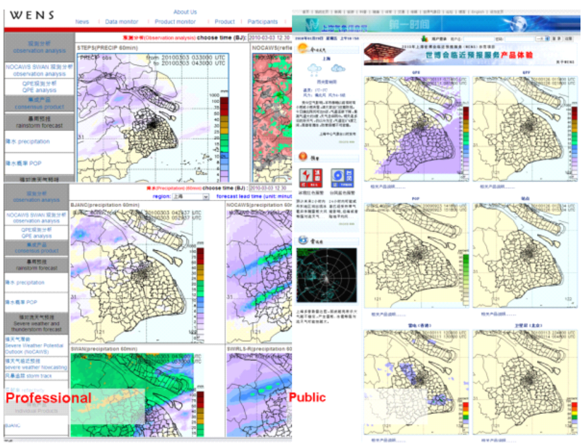

Fig 3 Professional WENS web site (left) in SMS and the public WENS web page (right)

An official WENS web site was set up in the SMS's intranet for professional users at Expo. These professionals included forecasters in the SMS weather office and in the Expo Operation Center, and service officers and coordinators of the SMS. On the page, observations and nowcasting products such as QPE, QPF, Severe Storm Nowcasts, and a host of other participating systems could be displayed.

A temporary web page on the public web site of the SMS displaying real time WENS products was available for the public during the WENS period. Some key users and specialized users had their own accounts to visit their own pages and products.

3. PARTICIPATING NOWCASTING SYSTESMS

Four CMA nowcasting systems participated the WENS project: SWAN (Severe Weather Automatic Nowcast system), BJANC (Beijing Auto-Nowcastor), NoCAWS (NowCAsting and Warning System), and SMS-WARR (WRF ADAS-3DVar Rapid Refresh system). The Australia BOM provided the STEPS (Short Term Ensemble Prediction System), and HKO SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems).

3.1 BJANC (CMA-BMS)

BJANC is a fruit of an international collaborative project between China (BMS) and USA (NCAR). BJANC was focused on severe convective storm analysis and nowcast in support of the 2008 Olympics, and convective weather warning in Beijing area. BJANC produces 0-1 hr forecasts of convective storm location and intensity with optional human enhancement to forecasts by entering boundary layer convergence line or modifying focused forecast areas. Severe storm extrapolation from the system can be extended to 2 hrs. BJANC combines meteorological observations, high-resolution low-level thermodynamic structure analysis based on a 4D-Var technique, rapid-updating Meso-NWP outputs and several storm feature detection and tracking algorithms, as well as local data analysis algorithms, to provide routine nowcasts of position, intensification and evolution of convective storm. The resultant nowcasts of storm initiation, growth, and decay can be used as guidance by the forecasters or nowcasters.

3.2 NoCAWS (CMA-SMS)

NoCAWS is an operational system for severe weather very-short range forecasting and nowcasting, with the following functions: data process and management, GIS-based integrated display, severe weather automatic alert, nowcasting products of precipitation and lightning stroke, analysis tools (sounding and 3-D lightning), and interactive nowcasting and warning generation. NoCAWS uses some relevant techniques in the system, such as severe weather outlook, regional severe weather watch radar echo extrapolation, QPE, QPF, storm life-cycle analysis & estimate, and lightning threat prediction. Using NoCAWS, the local forecasters can monitor weather, make mesoscale weather analyses, analyze storm environments, diagnose storm structures and life cycles, and interactively make nowcasting and warning products. Some service products can be generated automatically or interactively by the forecasters. The service products are the severe weather outlook (0-12h) for the Yangtze River Delta (YRD) region and Shanghai city, severe weather watch (0-6h) for the YRD region, severe weather warning (0-2h) for Shanghai city and end users.

3.3 STEPS (BOM)

STEPS generates ensembles of rainfall forecasts in the 0-6 hour lead time by blending the radar based extrapolation nowcast with the Numerical Weather Prediction (NWP) rainfall forecasts and then perturbing the blend with a statistical model of the forecast error. The life time of a storm generally increases with the size of the storm, therefore large rain areas in the radar image can be predicted with greater accuracy than smaller rain areas. STEPS models this behavior by decomposing an observed rainfall field into a range of scales and then estimating the error in the advection forecast as a function of scale and lead time. Errors in the NWP also decrease as the size of the storms increases, so STEPS calculates the skill of the NWP as a function of scale and then blends the advection nowcast with the NWP forecasts at each scale according to their relative skills. The ensemble of forecasts is generated by perturbing the blended forecast by means of a model for the forecast error in a manner that preserves the observed statistical characteristics of the rain fields.

STEPS is used to generate nowcast 30 member ensembles over the UK radar network, a domain of approximately 1500 km x 1000 km, at 2 km, 15 minute resolution out to 6 hours and updated hourly. The same system is used in Australia to generate ensembles of nowcasts over a 200 km domain out to 90 minutes, updated every 10 minutes but with no NWP blending and nowcasts over a 400 km domain out to 6 hours at 2 km, 10 minute resolution. These ensembles are used to calculate the probability that rainfall will exceed a range of thresholds and are being tested as drivers of hydrological models so as to calculate the probability that river levels will exceed certain critical thresholds.

3.4 SMS-WARR (CMA-SMS)

SMS-WARR is comprised primarily of 1) a numerical forecast model (WRF3) and 2) an analysis/assimilation system to generate refreshed analysis fields and to initialize the model.

The data analysis system of SMS-WARR is based the ADAS (ARPS Data Analysis System) 3-dvar package which assimilates almost all available data such as radar wind and reflectivity, in addition the complex cloud analysis scheme from the LAPS was adapted into the system, which utilizes radar and satellite observations to make or adjust moisture field and related hydrometers. Together with a digital filter initialization, initial conditions or analyses essentially make the 1-hourly cycle be a warm-start setup. The results indicate that overall spin-up time is less than 30 minutes.

The NCAR WRF ARW 3.0.1 is used as prediction model. The modeling region covers an area about 1600 km X 1900 km with center around Shanghai, and the resolution is 3 km by 3 km with 51 levels. In terms of model physics, the cumulus parameterization was turn off and the WSM 6-class micro-physics package is selected. 12-h and 3-h forecasts are made every 6-hour and 1-hour, respectively, and analysis fields are provided at each hour.

3.5 SWAN (CMA)

SWAN aims at being an integrated operational severe weather nowcast platform of CMA. SWAN ingests data from China's new generation Doppler weather radars, automatic weather station, satellite, and mesoscale numerical weather prediction model. It offers a platform for severe weather monitoring, analysis, warning and prediction. The current version of SWAN system provides a software package that integrates a series of nowcast algorithms and functions.

3.6 SWIRLS (HKO)

The HKO nowcasting system SWIRLS has been in operation since 1999. The second-generation version (referred to as SWIRLS-2) has been under development and real-time testing in Hong Kong since 2007. A special version of SWIRLS-2 was implemented for Beijing and run during the WMO/WWRP B08FDP operation period (July to September 2008) to support the Beijing Olympics.

SWIRLS-2 comprises a set of nowcasting sub-systems, responsible for the ingestion of observation data, execution of nowcasting algorithms, as well as product generation and visualization.

4. USERS

4.1 Forecasters:

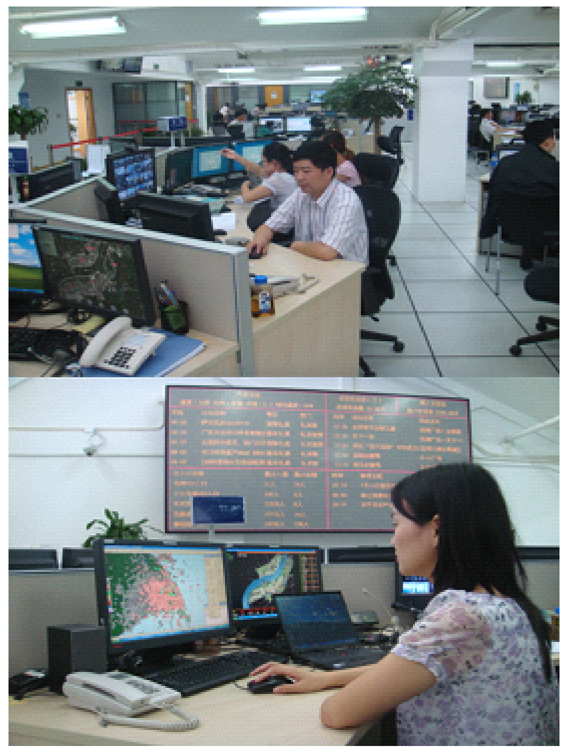

Fig 4 SMS's forecasters in the Expo operation center

The major primary users of the WENS Systems Products were the weather forecasters of the host city's Meteorological Bureau – SMS. SMS has a 24-hour shift for very short range forecasting / nowcasting. The SMS forecasters are responsible for monitoring weather, analyzing mesoscale weather conditions, and the issue of severe weather nowcasts and warnings. WENS systems provided a range of operational products to the SMS forecasters. These operational nowcast products for professional forecasters include some primary products, e.g. radar reflectivity nowcast and convective index forecast, and some warning-related products, e.g., quantitative precipitation forecast, probability forecast of the threat of severe weather, etc. The primary users also include the forecasters of the neighboring weather forecast offices, and the forecasters in Shanghai's two international airports and the Yangshan Deep-sea harbor.

4.2 World EXPO 2010 organization committee and its departments and participants:

Final nowcasts and warnings for severe weather were directly disseminated to the World EXPO 2010 organizers by the SMS forecasters on duty. They organized and adjust the EXPO activities according to SMS's nowcasts and warnings as necessary.

4.3 Relevant government departments:

Some relevant government departments, including the Shanghai Water Bureau (SWB), the Shanghai Emergency Response Centre (SERC), and some key service units, are also key users of WENS. These second category end-users need to have some meteorological background or to be trained in the use of WENS products. The operational nowcasting products for category two indirect end users provided by WENS are generally regular operational nowcast products, such as those for rainfall or severe weather, and some primary products, according to the users' needs. On receiving a warning of heavy rain and flooding, the Water Bureau would instigate urban flood risk management. If severe weather warnings were issued, the Emergency Response Centre would start relevant preparedness activities.

4.4 Specialised users:

Some specialized users, such as media, transport and energy sectors, some private companies, e.g. the Shanghai Yatong Co. Ltd which provides river transportation services in Shanghai, also used the weather forecasts as guidance for their operations.

4.5 The public:

Some public or private agencies or companies, and those organizations or agencies that just want to use the final nowcasting products. The products would inform the users of the immanent occurrence of severe or hazardous weather, and what its impact might be. Category Four end users typically don't have a meteorological background. They receive severe weather warnings via a range of means, such as cell phone message, TV, radio, internet, and the public electronic screens in streets, buildings, buses, metros, schools, and social communities.

4.6 Users and their WENS products

The WENS systems and products are directly used by forecasters in SMS, the Expo weather station, and the Expo operation center. Products are directly used by SMS's service officers and assistants. SMS nowcasting products are indirectly used by most of the users (government departments, Expo operation center, specialized users, and the public), while some key users can visit the WENS page on the SMS soweather.com and directly use the nowcasting products.

5. FORMAL WENS OPERATION

The operational phase of WENS commenced on 26 April 2010 and ran for 184 consecutive days, with nowcasting information generated by the participating systems providing advice and warnings to the Expo organizers and other users. During the period of the Expo, 30 warnings of severe weather were issued, encompassing thunderstorms, strong winds and heavy rain.

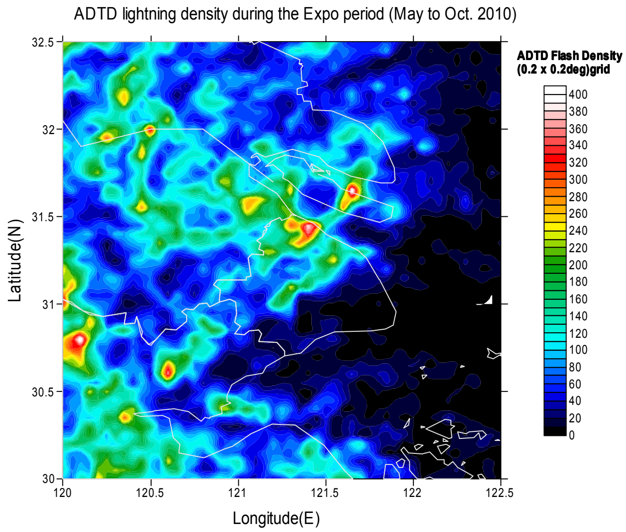

Fig 5 Lightning density during the Expo period (May- Oct. 2010)

During the Expo, there were 1,709 special weather forecasts prepared, as well as 73 special weather warnings, of which 30 related to severe thunderstorm with some high impact weather, e.g., lightning, heavy rain, and strong winds.

After 4-month preparation on fine-tuning of systems and development of services and products, on Apr. 26, 2010, WENS stepped into full operation. During the 184 days, the WENS systems were running operationally and generated routine products for the Expo weather services. The WENS systems and products supported the SMS forecasters and service officials as well as the end users, including the Expo organizers and participants, relevant government departments (especially the emergency response agencies), some special users (particularly those in the transport and energy sectors), and the general public (including visitors to the World EXPO). In some important Expo activities, i.e. the Expo opening ceremony, the Expo site opening ceremony, the WMO Mete-Pavilion Day, etc. WENS systems performed well in monitoring, analyzing, and nowcasting. Using the WENS products, totally 12 lightning, 6 strong wind, and 11 heavy rain warning signals were issued for the Expo site.

Fig 6 WENS team in Expo

The Expo brought together 246 countries, regions and international exhibitors, and was visited by a total of more than 70 million people over the six months. The day of highest attendance saw just over 1 million people visit the site. The emphasis of the Project was to help produce 0-6 hr forecasts and warnings of high-impact weather.

The lead time of early warnings of severe weather issued was 85 minutes on average. The overall Probability of Detection (POD) was 83% with a False Alarm Ratio (FAR) of 17%. The WENS proved to be good at forecasting Mesoscale Convective Systems (MCS), but had more difficulty with local severe thunderstorms and with tropical cyclones (although there was only one cyclone during the operational phase, and this passed by at some distance from Shanghai).

Reviewing the six participating systems, and noting that Quantified Precipitation Forecast (QPF) is a product common to all the six systems. Evaluation of the systems was not straight-forward and was done subjectively by forecasters. Real-time verification system may be introduced to nowcasting operations in order to support choosing the best QPF product and generating a performance-weighted QPF product based on the performance of each system. There was a clear need for more impact evaluation, and improved dissemination of products and communication with users.

An important aspect was that forecasters would be trained to identify the strengths and weaknesses of each system so that they would be in a position to select the best product for issuing a warning in an operational context, given that the lead time in nowcasting is very short. Another outcome was the need for a reliable automatic verification system. The verification scheme developed in CMA was a 3-year project, but it was clear that verification was very "patchy"; it was very difficult to predict the accuracy of nowcasting techniques in the short term, given that they were dealing with low-probability high-impact events.

Three severe thunderstorm cases, one Mesoscale Convective System (MCS) on July 4, one local severe thunderstorm with heavy rain and medium hail on August 25, and one heavy rainstorm associated with tropical cyclone on September 1, during the Shanghai 2010 Expo period are compared using the total lightning data, the WSR-88D Doppler radar data, rain gauge data, and sounding data. Time series of storm structural parameters (e.g. vertical reflectivity core, vertical integrated liquid products above several key levels at 0℃, -10℃, and -20℃, and echo top) derived from radar data, total lightning flash rate, cloud lightning flash rate, and cloud to ground lightning flash rate from the lightning detection data, and rain fall rate over some specific sites are compared. The results show that some structural information of storm (e.g. VILs above different level, echo top, and vertical reflectivity core) and total lightning can be used to describe the development, intensification, and decay phases of a storm life cycle. Very heavy rain rate is often found in tropical cyclone-related storms with a warm rain process. An algorithm for identifying precipitation type and rain rate is being developed based on these comparisons.

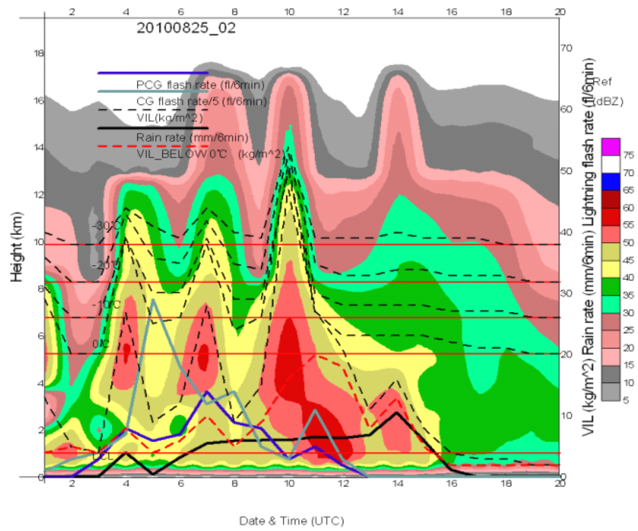

Fig 7 Time series of reflectivity (filled contours, in dBZ), height of VILs (vertically integrated liquid) at different levels, and total Cloud-Ground lightning (CG) and positive CG (PCG) flash rates on Aug. 25, 2010. The bottom axis represents interval of 6 minutes of time

Case study : On July 4, 2010, a Mesoscale Convective System (MCS) brought heavy rain, lightning strikes, and strong winds in the Expo site. In the morning of that day, severe weather early warning was sent to some key users, e.g., local government, emergency response agency, flood prevention department, and the Expo operation center at 00:30 UTC, and this early warning was updated at 05:35 UTC. When some WENS products indicating high probability of severe weather in the Expo site, three types of severe weather warning signals, lightning, wind gust, heavy rain warning, were issued for the Expo site at 05:50, 08:00, 08:40 UTC, respectively. Joint action and cooperation among different government departments were triggered by SMS severe weather warning. Warning information with guidance was also sent to the public via TV, radio, web site (www.soweather.com), cell phone text message.

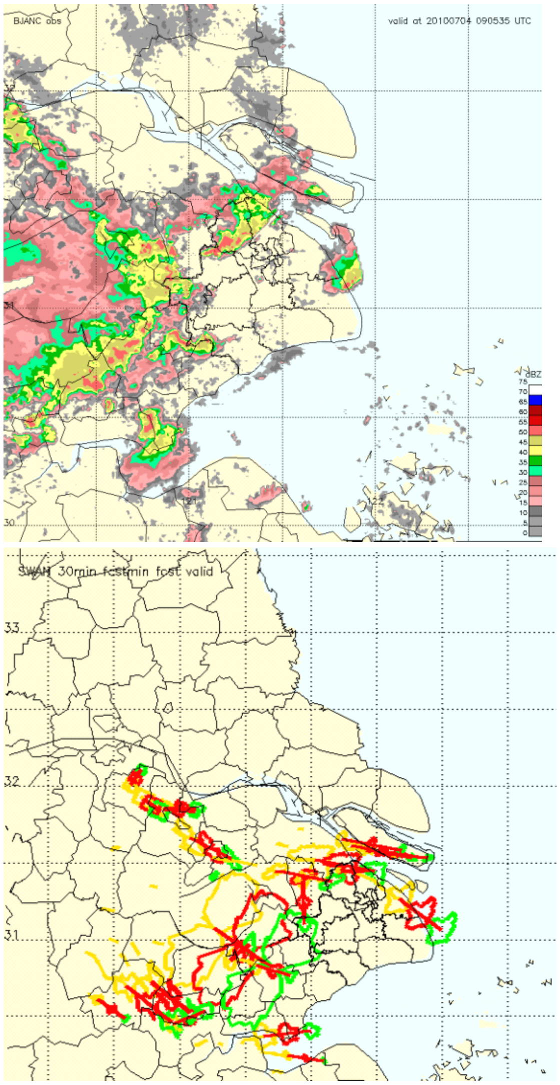

Fig 8 Reflectivity (upper) and storm cell identification and nowcasting (lower) on July 4, 2010

6. WENS EXPERIENCES

6.1 Experiences from the systems

About the technical assessment of the participating systems and experiences learned, the WENS participating systems shared their experiences in Expo:

BJANC (CMA-BMS): Boundary layer convergence is very important for storm development. Proper training of forecasters in nowcasting techniques is crucial. Localized storms posed the most difficult forecasting problems.

NoCAWS (CMA-SMS): It proved difficult to get an accurate estimation of location – this was much more difficult than purely spatial resolution. There were five (5) different types of Z/R relationship automatically used in system, and it was important to have a choice to best fit the actual situation.

STEPS (BOM): STEPS provides a 60 minute accumulation – this is really an ensemble mean rather than a deterministic forecast and gives the lowest RMS error but does not capture the extremes. There is a need to teach forecasters how to use this as it is not obvious of how to interpret it correctly. Future changes include moving from a server to product protocol. There is a whole system connected with STEPS for archiving interesting data for case studies and training – this is a non-trivial task.

SMS-WARR (CMA-SMS): This was the only NWP model employed in the WENS Project. It ran on a 3 km horizontal grid with 51 vertical levels; and, good results were recorded from the model for an extreme temperature case (> 40 deg C) on 13 August 2010. It also produced a good 9 hr forecast for dense fog. However, it was poor in predicting a convective storm on 8 August 2010. The model was run from a warm start every hour, with a cold start at 2 p.m. (local time) each day. This cold start time was later changed to 2 a.m. to avoid starting from cold when convection was already well-underway. During the WENS project there were changes to the data assimilation. The model produced a short-range ensemble. However, very extreme rain was not well-forecasted by using the Ensemble Mean, although use of the Mean proved to be better for “normal” rain.

SWAN (CMA): SWAN under-estimated rainfall in the Tropical Cyclone case. Using real-time rain gauge data for calibration would be an improvement. There are also needs to improve blending between extrapolation and meso-scale NWP. SWAN uses different Z/R relationships in different installations throughout China. SWAN does not have the capability to archive interesting situations for case studies and training.

SWIRLS (HKO): SWIRLS used a suite of radar products generated from the SWAN radar mosaic data by SMS – a successful collaboration experience among the developers involved. SWIRLS produced a rich assortment of products including echo-motion vectors, QPE, QPF, Probability of Precipitation (PoP), forecast reflectivity, storm-cell and severe weather nowcasts. A good appraisal was received from SMS forecasters. Some products, in particular severe weather nowcasts, are highly sensitive to radar data quality. The issues noted initially were much improved after face-to-face interactions with the SWAN developers at the start of the WENS operation. SWIRLS provided QPF products based on radar extrapolation only.

Among the points which emerged from the experience of delivering the Expo Weather Services were: traditional forecast techniques did not meet the unique requirements of user groups; automation as standardization needs to be enhanced; capacity-building is needed, both in technology and human resources; the management of Met Services needs to be strengthened.

6.2 Scientific issues

- Initiation and evolution of severe thunderstorms
- Relationships between a weather phenomena and its synoptic, meso-scale, and storm-scale conditions
- Understanding of physical and dynamical processes on the micro- and mesoscales
  - heavy rain in warm cloud precipitation
  - thunderstorm electrification mechanisms

6.3 Service and Evaluation

- What nowcasting operation needs from nowcasting systems and products: direct conclusion, or support to user for decision making;
- How to improve nowcasting service: to provide what we can provide, or what users need; to do more research on different requirements from users;
- How to improve the service products: nowcast text automated generation, graphic products, or new dissemination methods.

6.4 Lessons learned from WENS

- Information delay: nowcasting based on observation, but severe weather changes rapidly;
- How to use some new nowcasting products: PoP (STEPS/SWIRLS), station PoP (STEPS), severe weather nowcasting (BJ-ANC, SWIRLS, and NoCAWS), and storm evolution (BJ-ANC);
- Which one is the best: six nowcasting systems with at least 5 products each at the same time, which are not always good or bad, e.g., QPF;
- Lack of ‘direct’ nowcasting products for wind gusts, hail, lightning, etc;
- How to improve nowcasting technology: data quality control, weather type-based nowcasting methods.

7. IMPACT ASSESSMENT

7.1 Benefits from WENS

The WENS project has

- improved the Expo weather nowcasting services, especially for the severe convection-related high impact weather;
- improved SMS's nowcasting operations, including upgrading the observation network, and providing new nowcasting techniques, systems, and products;
- provided very successful capacity building: forecasters got well-trained and gained experiences in using new systems and providing nowcasting services;
- established a platform to exchange techniques and experiences among the WENS participant systems;
- obtained new understanding and knowledge of the nowcasting weather service by the active interaction between the participating systems and the local forecasters;
- brought a lot of new operational procedures based on the idea of 'focus on services':
    - severe weather early warning information to some key end users was practiced in Expo;
    - the feedback of these end users is positive and praiseful;
    - new communication and cooperation relationships between SMS and end users have been established.
- obtained new experiences and understanding of the relationship between nowcasting operation and service;
- developed some techniques for weather impact and service evaluation assessment;
- shared nowcasting technology and service for the public education.

7.2 Social and Economic Assessment

This was a very important aspect of the WENS Project; perhaps the first time that a full and proper social and economic assessment had been carried out in conjunction with the scientific aspects of such a project.

The assessments were carried out through expert workshops, on-line surveys and face-to-face interviews. In the Government Agencies and weather sensitive sectors of assessments, the results showed that:

- The total evaluation from each user group scored higher than 80 points for all categories. The highest scores are for satisfaction. Lead time scored higher than accuracy;
- Type of weather is one of the factors affecting the user evaluation; and,
- Expectation is one of the factors affecting the user evaluation: the higher the level of user expectation, the lower the level of satisfaction.

As for the public satisfaction of assessments, it emerged that forecast accuracy and lead-time were deemed to be satisfactory, but that the understanding of forecasts was a problem. Analysis of response by level of education revealed that those with lower levels of education tended to receive their weather information through television, while those with higher levels made more use of SMS and web. In terms of satisfaction ratings, there was no evident relationship between levels of satisfaction and age, gender or level of education.

As regards to lead-time, short lead-times were desirable, with lead-times as low as 12 minutes fully acceptable.

Statistical analysis of the questionnaires indicated that the validity of the assessment exercise was high. The variables that bore on "satisfaction" were: usefulness, accuracy, lead-time and content. The forecast "content" had the greatest influence. Understanding of the forecast was clearly very important, indicating that the education of the public with some meteorological knowledge was always beneficial.

In a case-study on a power-utility, lead-time was judged to be more important than accuracy (though both scored highly).

Among the most important conclusions of the social and economic assessment were:

1) The design of questionnaires was an issue;

2) Content is a critical aspect, and is closely related to comprehension;

3) Proper training for the investigators was crucial;

4) The timing of survey with respect to high-impact weather events had a large bearing on the potential result.

8. FUTURE PLANS

A challenge and opportunity after WENS is how to translate the experiences of WENS from Expo into research and operational focus areas for the future. Nowcasting is still far from mature as a science and the perceived usefulness to the operational forecaster still needs to be addressed.

The results of the WENS Demonstration Project will be published in a WMO Technical Document as an in-depth report on WENS covering all the technical aspects and issues of the Project.

An outcome of the WENS Demonstration Project would be helping to build the capacities of less-developed countries in nowcasting and sharing the experiences of WENS where these were relevant. As a first step, the WENS Final Review Meeting was followed by a capacity-building workshop for Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam. Material flowing from the project could be used in the preparation of WMO training activities which might be undertaken for other developing countries in the future.

According to the Final Review Meeting of WENS, it is suggested that a Task Team (TT) may be established to build on the results of the WENS Demonstration Project. This TT might focus on different aspects of the delivery of nowcasting services, with a special focus on impact-based forecasting and in the context of Mega-cities.

9. REFERENCES

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