WORLD METEOROLOGICAL ORGANIZATION

EXPERT MEETING ON THE APPLICATION OF PROBABILISITC FORECASTING

PUBLIC WEATHER SERVICES

Shanghai, China

24-28 September 2007

FINAL REPORT

1. INTRODUCTION

1.1 An expert meeting on the Application of Probabilistic Forecasts was held in Shanghai, China from 24-28 September 2007 and was chaired by Mr Ken Mylne (UKMO). The list of participants is attached in Annex I. The agenda of the meeting is attached as Annex II.

2. OPENING OF THE MEETING

2.1 The meeting was opened at the Shanghai Weather Bureau in Pudong by Dr Tang-Xu, the Director of the Shanghai Weather Bureau. In his welcome address, Dr Tang-Xu explained the importance of not only the preparation of probabilistic forecasts but their communication to end users as well as the specialized users such as the emergency management organizations.

3. BACKGROUND

3.1 The meeting was informed by Ms Kootval (WMO Secretariat that the PWS OPAG Expert Team on Services and Products Improvement (ET/SPI) had at its meeting in 2006 under one of its terms of reference the task of exploring and advising on development of appropriate probabilistic forecast products and services enabled by advances in ensemble prediction systems. As a result of discussions of this term of reference a deliverable had been identified by the Expert Team as the organization of a meeting of experts to address this particular issue and to prepare a set of guidelines on the communication of forecast uncertainties. The PWS OPAG Expert Team on Communication Aspects of PWS developed a guideline on this subject. One of the main tasks of the Expert Meeting in Shanghai was to review and complete these guidelines.

3.2 The result of work of the Expert Meeting is summarized below.

4. PROBABILISTIC FORECAST SYSTEMS OVERVIEW

4.1 Before going into the detail about how to communicate forecast uncertainty, the meeting overviewed probabilistic forecast systems which was presented by Mr M. Yamaguchi (JMA). Although the meeting was not focusing on the science of forecast uncertainty, it agreed that this overview would be a good starting point for the discussion on the communication of forecast uncertainty because it is important that meteorological services are based on good science.

4.2 Mr Yamaguchi explained a probabilistic forecast system as follows. It is a system which produces forecast uncertainty information or forecast probability. Techniques such as ensemble prediction system (EPS) and statistical methods like a multiple regression method are major examples of probabilistic forecast systems. EPS provides forecast uncertainty as a form of PDF, (Probability Density Function). Using the outcomes of EPS, one can estimate forecast probabilities, which change day by day, region by region and variable by variable, by counting the proportion of ensemble members which forecast a specific event to occur. For example, if the number of possible weather scenarios is estimated only as one, it means the scenario is a highly likely scenario. People can act accordingly and in areas where the possibility of the particular event is estimated quite low they can avoid taking unnecessary actions against the event. On the other hand, even if the best likely solution goes wrong, several other scenarios presented help people act accordingly and in some cases they can prepare for the anticipated damage well in advance. When assessing the measure of forecast uncertainty, the PDF of climatology would be a good reference. In addition, climatological PDF gives information on whether issued forecasts are belonging to the forecasts of rare case weather events or climatologically usual events. Nowadays there exist various types of EPS for different purposes. EPS not only deal with the uncertainties of initial conditions of NWP models, but also consider the imperfection of NWP models or boundary conditions are now being operated over the world. Furthermore, Multi Center EPS, collecting a number of deterministic forecasts or ensemble forecasts and comprising an EPS, has been attracting attention, encouraged by TIGGE (THORPEX Interactive Global Grand Ensemble) activity or NAEFS (The North American Ensemble Forecast System). The forecast range is also different from one EPS to another, covering short range to seasonal or longer scale.

4.3 He added that verification and calibration are essential parts of probabilistic forecast systems. For example, verifying the reliability of probabilistic forecasting is important because correct and accurate use of probabilistic forecasting means that, given a large sample, on average an event will occur at the same frequency as the forecast probability. Calibration is another essential part because probabilities derived from EPS, for example should not be assumed to be reliable due to the imperfection of NWP systems.

4.4 Dr Chen (CMA) provided some information on the current EPS in CMA as follows. The Global EPS is run daily at CMA. It is developed mainly on the global model which has been operational since 2002 using the approach of BGM (Breeding of Growing Mode) for generating the initial perturbations. It consists of 15 members for 10 day global forecast. The EPS products include accumulated total precipitation, wind speed at 10m, maximum and minimum temperature at 2m, temporal change of temperature, and 850hPa temperature anomaly for probabilistic forecasts; and accumulated precipitation, temperature at 2m and 850hPa, sea level pressure, temporal change of sea level pressure, wind speech at 850hPa (700hPa, 500hPa, 200hPa), and geopotential height at 700hPa (500hPa, 200hPa for ensemble mean and spread.

4.5 Since 2005, a Meso-scale EPS (M_EPS) has been developed at NMC/CMA in collaboration with CAMS (Chinese Academy of Meteorological Sciences. M_EPS is based on two meso-scale models, WRF (Weather Research and Forecast, NCAR) and GRAPES (Global/Regional Assimilation of PrEdiction System, CMA). The BGM approach is also used for the initial perturbation generation in association with a physical perturbation. The M_EPS participated in B08FDP/RDP project of WMO-WWRP, which was endorsed by WWRP/SSC 7th Session as a five-year (2005-2009) international demonstration project conducted by the CMA to support the meteorological services at the Beijing 2008 Olympic Games. It includes two components: nowcasting (FDP, Forecast Demonstration Project) and Meso-scale Ensemble Prediction (RDP, Research Development Project). 6 participating Meso-scale EP systems have been involved in the experiments: GRAPES_MEPS(CMA), SREF (NCEP), R_EPS (CMS), Global/meso-scale EPS (JMA), WRF_EPS (NCAR), ARPEGE/ALADIN/AROME (Austrian weather service and Météo-France). Two trials of these 6 participating MEPS systems have been successfully carried over Beijing area in 2006 and 2007 for the period of time of B08-Olympic Games.

5 PWS REQUIREMENTS AND OPPORTUNITIES FOR PROBABILISTIC PRODUCTS AND SERVICES

5.1 Mr K. Mylne presented ideas for products suitable for PWS illustrated with examples from the UK Met Office’s new short-range ensemble prediction system, MOGREPS. Colour-shaded contour charts of the probability of defined events such as the probability of strong wind-speeds or large rainfall accumulations can provide a useful indication of severe weather risks. Charts of tropical cyclone track probabilities are generated to provide tropical cyclone strike probabilities; similar tracks can also be generated for extra-tropical cyclones.

5.2 For many PWS applications, however, simple grid-point probabilities are not appropriate. In the UK the National Severe Weather Warnings Service includes probabilistic Early Warnings issued up to 5 days ahead. Issue of these warnings is based on the probability of severe weather occurring somewhere over the UK over a period over 12-24 hours, so the probability is estimated from the ECMWF EPS by scanning all model grid-points over the UK at any verification time over a period of 12h. Probabilities are also calculated for smaller regions of the UK. The probabilities calculated are calibrated empirically by adjusting the severe event thresholds over a period of one year to optimise the probability bias. This way the EPS provides forecasters with reliable first-guess warnings in the format required for PWS services. Today the UK PWS is planning an update to the warning service including warnings based on probabilities even in the short range – 3 different levels of warning (yellow, orange, red) will be issued based on either different probability levels of severe weather or lower probabilities of extreme weather. Work is underway to develop a first-guess of these new warnings based on MOGREPS.

5.3 Another potential PWS service is to provide uncertainty information in forecasts for specific locations. Full ensemble forecasts for several weather variables are stored in a data-base of different sites to allow generation of forecasts with full uncertainty information in a variety of formats including EPS-meteograms, wind-roses and probability graphs.

5.4 In his presentation, Mr J. Guiney (NWS, NOAA) explained that most PWS areas lend themselves to probabilistic products and services and will benefit from the integration of probabilistic information. There are several requirements that will promote the effective incorporation of probabilistic and uncertainty information in NMHS PWS products and services. These include the use of consistent terminology to express uncertainty, the adaptation of the presentation of probabilistic information to specific phenomena and/or target user group (e.g. temperature vs. wind, emergency planners vs. transportation departments), and engaging specific user communities to define needs and presentation preferences.

5.5 In addition, training, education and outreach for the user community is vital to the success of probabilistic and uncertainty products and services. It is also critical that forecasters are provided training and education on probabilistic forecasting and that they know what and how users are applying NMHS probabilistic/ uncertainty forecast information into their decision making process. While some NHMSs are providing probabilistic and uncertainty products and services (e.g. tropical cyclones, hydrology, climate), other opportunities are available for NMHSs to exploit probabilistic and uncertainty information in PWS products and services. Potential focus areas include short fuse warnings (e.g. heavy rainfall, strong winds), fire weather, public health (e.g. air quality), and hazardous material events (e.g. wind information).

6. PROBABILISTIC FORECASTS APPLICATIONS: SERVICE DELIVERY AND USERS

6.1 Examples of the use of probability forecasts in Southern Africa were presented by Mr E. Poolman (SAWS). These included severe weather guidance products and categorical probability forecasts as used in the SARCOF (Southern African Regional Climate Outlook Forum) process. The difficulty for many users, particularly the less sophisticated users, to properly understand and use the seasonal forecasts in the way it is presented, was discussed at length. The presentation also emphasized the place for subjective decision making systems, particularly for lesser developed countries that do not have access to EPS output data, but are using web-based EPS probability products. In the discussions it was proposed that the large weather centres running EPS could consider producing EPS probability products in consultation with other NMHSs that will aid the latter to provide relevant uncertainty information in their forecasts. The need for user involvement in developing suitable products for decision-making using uncertainty was emphasized. User needs differ, and the communication of forecast uncertainty to particularly less sophisticated users in developing countries is quite a challenge, but not less important.

6.2 In his presentation, Dr Tang-Xu explained that the application of probabilistic forecasts and deterministic forecasts are equally important in PWS. However, what people are mostly concerned with is not probabilistic product itself, but information or values from the products. Application process of probabilistic products is very important for users to decide when, what and how certain actions should be taken. Application of variation of probability with different lead times is also very important to start the multi-phase, multi-area, multi-agency and multi-level responses. Additional application products based on probabilistic forecasts could be used in the development of indices for public such as the so called public living indices e.g., clothing index and fire risk index that have been developed in China.

6.3 Dr Tang-Xu explained that the application of probabilistic forecasts products in multi-hazards early warning can identify and link the occurrence possibility of hazards and potential risk to assist multi-agency preparedness and multi-phase response in public emergency response. Partnership mechanism should be developed to form application thresholds of probabilistic products for different users. End-to-End mechanisms (provider-user) should be emphasized in the application of probabilistic forecasts. Probabilistic products are also necessary for loss and risk pre-assessment which is one of important elements in multi-hazards early warning. Dr Tang-Xu concluded that evaluation measurements, including objective evaluation from forecasters and users, should be established for probabilistic products.

6.4 An example was provided by Dr Gu (SWB) of the probabilistic products used in operational forecasting in Shanghai. These include global / regional EPS products, forecasts of tropical cyclones, convective events, and climate. Global / regional EPS products include spaghetti diagrams, probability of exceedance, mean and spread, and cluster diagrams. Tropical cyclone products include tropical cyclone probabilistic forecasts of track, surface wind speed, precipitation and tropical cyclone strike probability. Convective products include convective outlooks such as the probability of severe convection in East China every 6 hours in two days outlook, degree of threat, probability threat area forecasts (Color-coded threat area map). Climate forecast products include probability distribution of high temperature / precipitation such as the probability of precipitation for 30 years at interval of 15 minutes, probabilistic prediction of climate change, probabilistic estimates of climate sensitivity, and probabilistic prediction of climate extreme events.

6.5 In China, Meteorological bureaus closely work with the governments at different levels (from national, provincial, to regional levels) for prevention and reduction of meteorological disasters. MBs also provide meteorological services to the oceanographic, hydrological, transportation, environmental, aviation and public sanitary and healthy sectors and agencies.

6.6 Weather forecasts are delivered to the general public via radio, television, internet, news papers and mobile phones. Since 1997, meteorological services for daily life have been provided at local MB (for example, Beijing MB, Shanghai MB) to the general public. Until now, 10 kinds of meteorological services have been developed for daily life, such as weather & fitness, weather & health, weather & studying, weather & working, weather & tourism, weather & traffic, weather & living, weather & gourmand, weather & clothes and weather & environment. There are 10 kinds of services cover 60 types of indices for daily life. These are as follows; **Spring:** Index for Air Quality, Index for Morning Exercises, Index for Drying Clothes in the sun, Index for Comfort, Index for Sunshine, Index for Clothing, Index for Climbing, Index for Medicine, Index for Fishing, Index for Blooming, Index for Rowing, Index for Washing car, Index for Anion, Index for Drinking Bear; **In Summer:** Index for Air Quality, Index for Mildew, Index for Drying Clothes, Index for Comfort, Index for UV-radiation, Index for Drinking Bear, Index for Climbing, Index for Sunstrokes, Index for Fishing, Index for Swimming, Index for Rowing, Index for Washing car, Index for Anion, Index for Air Conditioning; **In Autumn:** Index for Air Quality, Index for Enjoying the sight of red maple leaves, Index for Clothing, Index for Comfort, Index for UV-radiation, Index for Drinking Bear, Index for Climbing, Index for Sunstrokes, Index for Fishing, Index for Swimming, Index for Rowing, Index for Washing car, Index for Anion, Index for Working at heights (e.g., construction); **In Winter:** Index for Air Quality, Index for Morning Exercises, Index for Skating, Index for Wind Chill, Index for Sunshine, Index for Clothing, Index for Climbing, Index for Medicine, Index for Winter Swimming, Index for Client Numbers who are shopping in a market, Index for Rowing, Index for Washing car, Index for Anion, Index for Cement Freezing.

7. COMMUNICATION OF PROBABILISTIC FORECASTS PRODUCTS

7.1 Mr Mylne reported on work conducted by Mark Roulston at the Met Office on the public understanding of forecasts including uncertainty information. Products for possible publication on the internet were designed taking account of studies on understanding of risk by psychologists. Forecasts are presented graphically including the previous day’s observations to provide users with a reference they can easily relate to. “Probabilities” are described in terms of Natural Frequencies (eg. 90% confidence intervals are described as “On average temperature will fall in outer range 9 times out of 10”) which are much better understood by the public. A web survey of users of the Met Office website showed that for temperature a fan chart showing a spread of uncertainty was popular with users, and preferred to other options. Following this survey, this preferred option was tested for user understanding in the Experimental Economics lab of Exeter University. These tests showed that users receiving information on uncertainty made significantly better decisions than users without the uncertainty information. This was equally true for users with a science background or those from other academic disciplines, indicating that most members of the public can benefit from uncertainty information. Another web survey has since been conducted and identified a preferred presentation for rainfall probabilities. The meeting decided to include these preferred presentations in the guidelines on communication of uncertainty.

7.2 Two Ideas on how to use uncertainties of typhoon track forecasts were presented by Mr. Yamaguchi. One is a cluster analysis method and the other is the optimal use of ensemble spread. In a cluster analysis, the analyzed number of clusters changes according to the uncertainties of typhoon track forecasts, and therefore it is good for measuring or even categorizing the uncertainties of the typhoon track forecasts. The verification of a cluster analysis method developed at JMA showed that typhoon track predictions in cases where the number of cluster was analyzed only one has smaller error than the annual average position error. As for the optimal use of ensemble spread, he explained that uncertainties of typhoon forecast positions are not isotropic and ensemble spread can represent such uncertainties. For example, after recurvature in general, forecast uncertainties are larger in an along-track direction than a cross-track direction due to the jet stream. Therefore using ensemble spread, an area which tries to represent typhoon position uncertainties could be optimized in an oval shape for example, not in a circle.

7.3 Dr Gu explained that communication chain includes products (technical skill), interpretation (mechanism of the synoptic phenomena and introduction of the products), presentation (icons, graphs, words and color), delivery (form), understanding (users), interaction (feedback, discussion and suggestion), decision-making, and promotion of products. Interpretation refers to the use of well-defined terminology and clear language and appropriate likelihood scale to describe the terminology about uncertainty. Uncertainty can be expressed in spatial and temporal forms, so it is suggested to combine the two aspects. For decision-making services, it is better to choose threshold of the extreme situation carefully (e.g. alternative and worst-case scenarios). It is suggested that special users participate in the process of provision of information and decision making.

8. PREPARATION OF GUIDELINES ON COMMUNICATING FORECASTS UNCERTAINTY

8.1 The Expert Meeting reviewed the guidelines on communication of forecast uncertainty at length and spent a substantial portion of the duration of the meeting on this task. The reviewed guidelines will be finalized and published by the Secretariat.

9. WHERE DO WE GO FROM HERE?

9.1 The Expert Meeting agreed on a number of steps as a follow up to the meeting. The first will be to finalize and publish the guidelines which will be distributed to all NMHSs and placed on the PWS Website as well. The guidelines will be well advertised at the forthcoming International Symposium on PWS (Geneva, Dec. 2007) and will be used in the training seminars on PWS. In addition, Mr Mylne will advise the members of his expert team of the availability of the guidelines. The members of Expert Team will be advised of any future meeting as a follow up to the meeting in Shanghai.

10. CLOSURE

10.1 The meeting closed on Friday evening following expressions of thanks to the hosts for the excellent facilities and exceptional hospitality provided by the Shanghai Weather Bureau.

ANNEX I

EXPERT MEETING OF THE APPLICATIONS OF PROBABILISTIC FORECASTING TO PWS

(Shanghai, China, 24-28 September 2007)

Mr Ken Mylne, **Chair** Met Office Exeter EX1 3PB United Kingdom Tel: +44 1392 886070 Fax: +44 1392 885681 E-mail: ken.mylne@metoffice.gov.uk	Dr Chen Dehui National Meteorological Centre Numerical Weather Prediction Division Baishiqiaolou No. 46, Beijing 100081 China Tel: Fax: E-mail: chendh@cma.gov.cn
Mr Gu Jianfeng National Meteorological Centre Numerical Weather Prediction Division Baishiqiaolou No. 46, Beijing 100081 China Tel: Fax: E-mail: jfgu@sohu.com	Dr TANG Xu Shanghai Meteorological Bureau, Shanghai Regional Center, CMA 166 PuXi Road, Shanghai 200030 China Tel: (86-137) 6422 9911 Fax: (86-21) 648 75 023 E-mail: tangxu570512@vip.sina.com
Mr Munehiko Yamaguchi Japan Meteorological Agency 1-3-4, Otemachi Chiyoda-ku, Tokyo 100-8122 Japan Tel: +(81-3) 3211 8408 Fax: +(81-3) 3211 8407 E-mail: m-yamaguchi@naps.kishou.go.jp	Dr Andre Kamga Foamouhoue African Centre for Meteorological Applications to Development (ACMAD) Weather and Climate Forecasting in AMMA Europe Project P.O. Box 13184, Niamey, Niger Tel: (227-20) 734 992 Fax: (227-20) 723 627 E-mail: akamgaf@yahoo.com
Mr Said Abdallah Alharty Directorate General of Civil Aviation and Meteorology Ministry of Transport and Communication P.O. Box 275, P.C. 112, Ruwi Oman Tel: (968) 2451 9649 Fax: (968) 2451 9363 E-mail: s.alharthy@met.gov.om	Mr Eugene Poolman Head, Prediction Research South African Weather Service Private Bag X097 Pretoria 0001 South Africa Tel: (27-12) 367 6001 Fax: (27-12) 367 6189 Email: eugene.poolman@weathersa.co.za
Mr John Guiney National Oceanic and Atmospheric Administration - National Weather Service Eastern Region Headquarters 630 Johnson Avenue Bohemia, NY 11716, USA Tel: (1-631) 244 0121 Fax: (1-631) 244 0167 E-mail: john.guiney@noaa.gov	Ms Haleh Kootval WMO Secretariat Case Postal No. 2300 CH-1211, Geneva 2 Switzerland Tel: (41-22) 730 8333 Fax: (41-22) 730 8021 E-mail: Hkootval@wmo.int

ANNEX II

Expert Meeting on the Application of Probabilistic Forecasting

(Shanghai, China, 24-28 September 2007)

AGENDA[1]

Chair: Ken Mylne

1. Opening of the Meeting

2. Adoption of the agenda

3. Background, objectives and expected outcomes of the Expert Meeting **(Haleh Kootval)**

4. Probabilistic Forecast Systems Overview **(Munehiko Yamaguchi)**

5. PWS Requirements and Opportunities for Probabilistic Products and Services **(John Guiney, Tang-Xu)**

6. Probabilistic Forecasts Applications: Service delivery and users **(Ken Mylne, Andre Foamouhoue, Eugene Poolman, Chen Dehui)**

    - ✓ Forecasters as users
    - ✓ Public as end users

7. Communication of Probabilistic Forecasts Products **(Said Al Harthy, Ken Mylne, Gu Jianfeng)**

8. Preparation of Guidelines on Communicating Uncertainty **(All)**

9. Preparation of the report of the meeting **(All)**

10. Where Do We Go From Here? **(All)**

11. Closure
