WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS

EXPERT TEAM ON ENSEMBLE PREDICTION SYSTEMS (ET-EPS)

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FINAL REPORT

Left to right:

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Taken at Met Office UK

Executive Summary

The meeting of the CBS Expert Team on Ensemble Prediction Systems (ET-EPS) was held at the Headquarters of the Met Office UK, 5 – 9 October 2009. Mr Keith Groves, Director of Operations, Met Office UK, emphasized in his opening welcome the great importance that the Met Office places on the use of the EPS products in severe weather forecasting and in general forecasting and recognizes a large potential for use in many applications. Mr Chen, representing WMO Secretary-General, explained the continuing importance that WMO is placing on the development and use of EPS for Members, for example as expressed at the 15th WMO Congress, sessions of Executive Council, and most recently at the 14th session of CBS (2009). While a limited number of GDPFS Centres operationally run EPS, many NMHSs are exploring various applications, and others are seeking to build capacity for their forecasters to access and effectively use EPS products in their forecasting process as well as to deliver services that are based on probabilistic forecasting methods. In particular, EPS application to support early warning of severe weather is of the highest priority, in contributing to disaster risk reduction.

Significant progress has been made since the last meeting (early 2006) in terms of resolution, ensemble size, length of integration and frequency of forecast cycles. The horizontal resolution is increased from about 90-110km to 50-70km for most global system while ECMWF is working towards 30-km. The number of vertical levels is also increasing, and many centers have increased ensemble size, with the length of integration extending to 10 - 15 days at most centres. Higher resolution regional EPS and those that focus on specific high-impact phenomena, post-processing products, and multi-centre ensembles continue to develop.

The Chairperson has been acting as the principal liaison, on behalf of CBS, with the research activities of THORPES/TIGGE, which is exploring the concept of grand global ensemble methods. The meeting was informed about the development and planning of a Global Interactive Forecast System, which could provide new products for operational use, for example via RSMCs and the Severe Weather Forecasting Demonstration Project.

Many NMHSs, especially those of developing countries, do not have the computing facilities or capability to generate products from ensemble fields. EPS outputs need to be calibrated and further post-processed into specific products required by "non-producing" NMHSs, and useful products could only be developed and produced by those centres that have the data processing or data transfer capacity to do so. This could imply that RSMCs might act as the primary producers of national-level EPS products destined for their end-users, shifting from the present practice of EPS centres providing "raw" output datasets as basic construction material for NMHSs' development and production.

The application of EPS to predict severe or high-impact weather events is among the most important topics, e.g., the propagation of the weather forecasts into impact models. The team also discussed the limitations of EPS in predicting severe events, that it is often difficult to provide adequate calibration or validation. The Severe Weather Forecasting Demonstration Project (SWFDP), which emphasizes improving the access and effective use of EPS products, continues in the region of southern Africa, while started a new regional project for the South Pacific Islands. As well, representatives from Japan, China, Morocco, India, and New Zealand, and the MAP D-PHASE project noted direct use of EPS in predicting severe or high-impact weather.

The meeting developed a series of notes upon which guidance on how to use EPS in their routine forecasting process could be further developed for use by trainers and forecasters. It agreed that this guideline could be further developed and improved if examples are provided as part of the guideline. At the same time, it is recognized that further development of additional guidelines on other topics would be very useful to many forecasters, as EPS products are being introduced into forecasting centres.

EPS-related guidelines would be beneficial for general forecasting, severe weather forecasting, development of EPS post-processing, and on how to focus training to better support the use of EPS products. The meeting agreed to develop general guidelines, with the goal of elaborating the

basic considerations relevant to each of these topics, and the initial texts and ideas for each of these topic areas were developed.

Verification of EPS is a function of the designated Lead Centre (JMA). Its implementation continues, with a renewed campaign to request input from all EPS producing centres. The meeting reviewed the current standards in the Manual of the GDPFS and proposed an amendment, to be considered by CBS-Ext.(10).

1 Opening

1.1 The meeting of the Commission for Basic Systems (CBS) Expert Team on Ensemble Prediction Systems (ET-EPS) opened at 9:30 a.m. Monday, 5 October 2009, at the Headquarters of the Met Office UK, in Exeter, UK. The meeting was opened by Mr Ken Mylne, Chairperson of the ET-EPS. Opening welcome and introductory remarks were made by Mr Keith Groves, Director of Operations, Met Office UK, and Mr Peter Chen on behalf of the WMO.

1.2 Mr Groves emphasized the great importance that the Met Office places on EPS and the use of the EPS products in severe weather forecasting and in general forecasting. As well EPS has a large potential for use in many meteorological applications. .He also expressed the importance that the Met Office places on supporting the CBS Severe Weather Forecasting Demonstration Project, whereby WMO benefits in capacity building for many NMHSs of developing countries.

1.3 Mr Chen explained the continuing importance that WMO is placing on the development and use of EPS for Members, for example as expressed at the 15th WMO Congress, sessions of Executive Council, and most recently at the 14th session of CBS (2009). While a limited number of GDPFS Centres operationally run EPS, many NMHSs are exploring various applications, and others are seeking to build capacity for their forecasters to access and effectively use EPS products in their forecasting process as well as to deliver services that are based on probabilistic forecasting methods. In particular, EPS application to support early warning of severe weather is of the highest priority, in contributing to disaster risk reduction.

1.4 Mr Ken Mylne (UK) added his welcome to the members of the Expert Team, recognizing broad representation from many NMHSs around the world.

2 Organization of meeting

2.1 Approval of agenda. The agenda of the meeting was adopted, and is given in Annex 1 of the report. Adjustments to the order that the meeting addressed the items were made to accommodate the limited participation of some participants.

2.2 Agreement of working arrangements. The meeting agreed to the organization of its work including the working hours, and created small work groups to develop EPS-related guidelines (see agenda item 7).

2.3 The list of participants is given in Annex 2 of the report. Mr Gerald Fleming, Chairperson of the CBS OPAG on Public Weather Services participated on two days of the meeting.

3 Terms of Reference

3.1 The meeting reviewed the team’s Terms of Reference as adopted at CBS-XIV (2009), as well as other relevant matters identified at CBS-XIV and CBS-MG 10 (2009), and was satisfied that these terms of reference remain relevant for the team in its work. The terms are annexed to this paragraph.

4 Progress of operational EPS

4.1 The participants who represented centres that run EPS systems made presentations to the meeting regarding recent progress and immediate plans for their respective systems. Much progress has been made by all the centres since the last meeting of the expert team (Feb. 2006). In summary, the following general points were noted:

1. Global Ensemble Prediction Systems (GEPS)

1.1 The Global ensemble systems have improved during the last a few years, in terms of resolution, ensemble size, length of integration and frequency of forecast cycles. The horizontal resolution is increased from about 90-110km to 50-70km for most

GEPS while ECMWF is working towards 30km. The number of vertical levels is also increasing to between 28 and 70 levels. Many centers increased ensemble size and most systems have more than 20 members. The length of integration is 10-15 days at most centres.

1.2 While Singular Vector and Bred Vector methods are still widely used in generating initial perturbations, Ensemble Transform of BV, Ensemble Transform Kalman Filter and Ensemble Data Assimilation are also implemented in various centres.

1.3 Two main approaches are employed to address Model Error. Some systems use a Multi-Model or Multi-parameterization ensemble approach. An increasing number oif centres are now introducing Stochastic Physics Perturbation Schemes. Examples of these include the Tendency Perturbation scheme, Stochastic Kinetic Energy Backscatter and Parameter Perturbations. A different approach recently adopted by one centre is to couple all the ensemble members by stochastically perturbing the total model tendency with tendencies from other ensemble members.

2. Regional Ensemble Prediction Systems (REPS)

2.1 Operational REPS is playing a rapidly increasing important role in NHMSs and Consortia. Currently, the horizontal resolution ranges from 32km to 10km, with up to 70 vertical levels. The ensemble sizes ranges from 15 to 24 and the forecast length ranges from 2 days to 5 days. Many REPSs take multi-model (including multi physics) approach, but single model with stochastic physics is growing in popularity. At some centers, the frequency of output has increased to 1 hour for the first 39 hours to meet the requirement of customers.

2.2 A few centres are also experimenting with convection-allowing ensembles with horizontal resolutions of 1-3km. None of these are operational at the current time, but will provide new opportunities in the next few years for probabilistic prediction of detailed weather such as convective precipitation and low visibility conditions which are not resolved by current EPS systems.

3. High-impact special REPS

3.1 Both GEPS and REPS are operated in the prediction of high-impact weather events. CMA and JMA both have a global Typhoon Ensemble system concentrating on the Western North Pacific Area.

4. Post-processing of products

4.1 To provide better predictions, some centres conduct statistical post processing to their EPS products for bias correction and calibration of the pdf (probability density function). Bias correction is the most widely applied procedure, and an adaptive algorithm with Kalman Filter type weighting functions and the use of reforecast data make it more effective. At some centres, combination of an EPS with the corresponding high resolution deterministic prediction is operationally implemented, and statistical downscaling technique, with high resolution analysis as the reference, is used to provide forecast guidance at local scale. The Bayesain Model Averaging technique developed at the University of Washington is becoming quite widely used and is particularly well-suited to systems incorporating multiple models or parameterizations. Some more sophisticated techniques for calibrating the first and second moments of the pdf are also under development.

5. Multi-Centre ensembles:

5.1 Most GREPS providers are participating in the TIGGE project under the WWRP THORPEX programme for research in multi-centre ensembles. The GIFS plans (see Agenda Item 5) are expected to lead to the development of more multi-system products from the TIGGE project which will be trialled in GIFS-RDPs.

5.2 The North American Ensemble Forecast System (NAEFS), has been in operation since 2006 and has shown significant benefit to its members and the international community. While it continuously increases the number of products for exchange, it will be expanded to include more GEPSs and start REPS data exchange. NAEFS can provide a framework of operational requirements and constraints within which new research must be conceived on one hand, and will offer a receiving end for any new methods developed based on the TIGGE data archive.

4.2 The meeting noted that it would be useful to maintain a Web site providing information and guidelines on EPS systems and their use. The meeting requested the Lead Centre for EPS Verification to consider whether this page could be hosted on the Lead Centre Web site.

4.3 The following paragraphs summarize the major progress achieved by EPS centres and their immediate plans for EPS production, in the order of presentations.

Met Office UK - MOGREPS Ensemble

The MOGREPS ensemble was designed to provide a short-range regional EPS for the UK and Europe. It uses a regional model on a North Atlantic and Europe (NAE) domain running at 24-km resolution with 38 levels and forecasting to 54h (2 days). To provide lateral boundary conditions, there is also a global ensemble running at N144L38 (~90km) to 72h (3d). Both components have 24 ensemble members and run twice a day, the global at 00 and 12 UTC and the regional at 06 and 18 UTC. MOGREPS became fully operational in September 2008. The global ensemble is also run to 15 days ahead as the UK contribution to the THORPEX TIGGE project.

Initial condition perturbations are provided using the ETKF (Ensemble Transform Kalman Filter) method. The ETKF is currently run only in the global ensemble. The global ensemble perturbations are downscaled to provide perturbations for the regional ensemble. In both cases the perturbations are added to the Met Office 4D-Var analysis for the relevant model domain. Localisation is used in the ETKF to provide a realistic scaling of ensemble perturbations at locations around the globe, and reduce spurious correlations between perturbations. Separate ETKFs are calculated at each of ~100 localisation centres, using both radiosonde and ATOVS observations to calibrate the inflation factor which controls the scale of perturbations. Ensemble perturbations are created by interpolating between the ETKFs at adjacent localisation centres. This has provided a good match between the global distribution of forecast errors and ensemble perturbations.

Model physics perturbations are used to account for model error. The strategy is to make all ensemble members equally probable and systematically identical, so all members use the same model configuration with stochastic perturbations to physics. Two main schemes are used. The random parameters scheme perturbs a number of tuneable parameters in the parameterisation schemes. The SKEB (Stochastic Kinetic Energy Backscatter) scheme accounts for excessive dissipation of energy on small scales by reinjecting a proportion of the energy as a spectrum of wind perturbations at length-scales close to the grid-scale, which allows for some energy to propagate upscale and impact the forecast evolution.

A package of upgrades to MOGREPS is planned for implementation early in 2010. This will provide an increase in resolution in the horizontal and vertical. The global ensemble will be increased to N216L70 (~60km) and the regional to 18kmL70. The upgrade will also provide a further enhancement to the ETKF by a vertical “localisation” – the inflation factor will be calculated separately in each of 4 layers in the atmosphere. Currently the perturbations are too small in the boundary layer and slightly too large in the upper air and tropical stratosphere. Vertical localisation will allow this to be rebalanced. A fourth layer will be used to damp perturbations in the upper few model levels to avoid unstable growth of perturbations. The upgrade will also introduce the enhanced version two of the SKEB scheme. The total package is expected to provide a substantial enhancement in MOGREPS performance.

CMC (Canada)

1. Overview of Operational Global Ensemble Prediction System (GEPS)

1.1 Data assimilation

The data assimilation consist of a 6-hour cycle using 4 times 24 configurations of the GEM model providing (96) trial fields over 6-hour time windows. Trial fields at 3, 4.5, 6, 7.5 and 9-h allow interpolation toward time of observations. It is a 4-D data assimilation cycle using Kalman filter (so-called Ensemble Kalman Filter).

The latest update to this assimilation system was the addition of GPS-Radio Occultation observations, and the increase in the number of vertical levels from 28 to 58 in the model configuration.

1.2 Forecast model members

From the 96 Ensemble Kalman filter analysis, 20 are randomly selected to provide initial conditions for 20 members (forecast model). The models are integrated out to 16 days, twice a day (00z and 12z), at 0.9 degrees horizontal resolution and the number of levels remains at 28 levels. Recent tests at 58 model levels did not show significant improvement with the 16 day forecast while improvements were found when using 58 model levels in the data assimilation.

The initial condition uncertainties are represented by the perturbed ensemble Kalman Filter data assimilation, while forecast model uncertainties are reproduced by various model physic's configuration, with a single dynamic core (GEM model). Also stochastic perturbations are added to tendencies ("à la ECMWF") in the parameterized physical processes and back-scattering energy (after Shutts, 2005) parameterisation is used in order to augment the spread of the ensemble.

1.3 Operational products:

The Meteorological Service of Canada made an extension to the public forecast service with the addition of day 6 and day 7 forecasts. While day 1 to 5 are based on the deterministic systems (regional system for day 1-2, and global system for days 3-5) the day 6 and 7 public forecast have been added , thanks to the Ensemble Prediction system. This forecast product generation system is fully automated. The product is delivered to the public, or to clients, on the Web weather portal, on the form of weather icons, and text. An attempt was made to use a clustering method (wet versus dry scenarios) in the making of this product but, at the end, the more simplistic reliable Ensemble mean was implemented in this initial implementation.

Otherwise, a series of typical EPS based Operational products are available for internal use as well on the Official external Web site. Link to public site: http://www.weatheroffice.gc.ca/ensemble/index_e.html

Typical products include the so-called Spaghetti plots, maps with probability of exceeding precipitation thresholds, meteograms, and mean &standard deviation maps for depicting many weather variables such as precipitation, geopotential heights, winds etc.

1.4 Experimental products

Experimental and proof of concept testing activities are ongoing with an interactive user generated meteograms system for preselected sites. Other products will be developed focusing on high impact weather, aiming at offering guidance to operational meteorologists.

2. Overview of Experimental Regional Ensemble Prediction System (REPS)

The REPS is a downscaling of the Global EPS, which should provide more sharpness and skill which could be suitable to address severe weather forecast challenges in the short range. This system is on the process of being implemented in experimental mode, and plans are for an operational implementation by year 2011.

2.1 Data assimilation:

Research plans include the development of an Ensemble Kalman filter for the REPS, but the initial version makes use of the Global Ensemble System analysis.

2.2 Forecast model members

The REPS consists of twenty (20) GEM-LAM members at 33km horizontal resolution and 28 levels. The boundary conditions are provided by the Global EPS 20 members, with a pilot frequency (lateral boundary conditions) of 3 hours. On the contrary to the Global EPS, the REPS uses a single GEM-LAM model configuration, which is equivalent to the 33km Global deterministic forecast model. However, it uses stochastic perturbations of physical tendencies and surface parameters in order to augment the spread of the ensemble. The REPS is now running in experimental mode at 00z and 12z, and will most likely become operational by 2011.

2.3 REPS Experimental Products

Many experimental products are under development while the REPS gradually make its way into Operations.

A series of products in support to the warning program could be developed based on REPS. For instance, severe weather guidance on the likelihood of light, moderate and severe thunderstorms over North-America are in development. A set of guidance products for winter severe weather events, such as freezing rain, blizzards, snowstorms, etc., is also available in experimental mode.

JMA (Japan)

The Japan Meteorological Agency (JMA) launched its operational EPSs for one-month forecasts, one-week forecasts, seasonal forecasts, and tropical cyclone track forecasts over the western North Pacific in 1996 (March), 2001, 2003, and 2008, respectively.

Products derived from the One-Week EPS are routinely used for medium-range forecasting. The products in graphical format are available for access by Asian NMHSs on the JMA medium-range EPS Web site. Verification results of the One-week EPS are published in annual WMO Technical Progress Report on GDPFS. Furthermore, the monthly verification data are available on the Web site of WMO Lead Centre for EPS Verification. In November 2007, JMA enhanced the resolution of its global EPS model to TL319L60 and replaced its initial perturbation (IP) generator with a singular-vector method. It is evident from the verification results that the time evolution of ensemble spread became optimized especially in short range.

The Typhoon EPS is performed four times a day at most with a forecast range of 132 hours. The EPS model and the IP generator are shared with the One-week EPS. The high-frequency products derived from the Typhoon EPS fully support new information of probabilistic type, 5-Day Track Forecast, in Typhoon Bulletins issued by the RSMC Tokyo – Typhoon Center.

RSMC Tokyo maintained its responsibilities as the Lead Centre for EPS Verification, including implemented the required Web site (see agenda item 8).

ECMWF

ECMWF runs an operational ensemble prediction system (EPS) twice daily (from 00 and 12 UTC). The EPS uses the same forecast model as used for the ECMWF operational deterministic forecast, but at lower resolution: T399 (50 km) up to day 10, then T255 (80 km) from day 10 to day 15; 62 levels throughout. Initial SST anomalies are persisted for the first 10 days of the forecast. From day 10 onwards, for forecasts started from 00 UTC analyses, the atmospheric model is coupled to a 29 level ocean model. At present, forecasts started from 12 UTC analyses use persisted SST anomalies throughout. Once a week (from 00 UTC Thursday), the EPS is extended to 32 days to provide a monthly EPS forecast. An ocean wave model is coupled to each EPS member to provide a wave EPS. The ensemble comprises one control forecast (run from the operational analysis) and 50 perturbed members. Initial perturbations are generated by multi-dimensional Gaussian sampling from 50 singular vectors (SV) selected at T42 resolution in the extra-tropics, plus up to 30 SV (5 per Tropical Cyclone) selected in the vicinity of Tropical Cyclones that have been reported on the GTS. Random perturbations of the physical tendencies (stochastic physics) are applied to the perturbed forecasts.

A number of EPS products, including wave forecasts, is available to WMO Members in graphical format via the ECMWF website at:

http://www.ecmwf.int/products/forecasts/d/charts

The resolution of both the deterministic and ensemble forecast systems will be increased in late 2009 or early 2010: the EPS will run at T639 (around 30km) for days 1-10 and T319 (60km) beyond day 10. In 2010, it is planned to replace the evolved singular vectors used in the initial perturbations with perturbations derived from an Ensemble Data Assimilation (EDA) system using an ensemble of 4d-Var analyses. The EDA-based perturbations are less localized geographically, have smaller scales and provide a more extensive coverage of the tropics than the current SV-based perturbations.

The TIGGE (THORPEX Interactive Grand Global Ensemble) archive, giving access to forecasts of ten global ensemble prediction systems, establishes a new benchmark for ECMWF EPS forecasts. Comparing the ECMWF EPS with all other single model systems demonstrates a clear overall superiority of the ECMWF system. A TIGGE multi-model composed of all single models does not provide significantly better forecast than the ECMWF EPS on its own. However, combining only the three best single models (ECMWF, Met Office and NCEP) can improve the forecasts compared to the single ECMWF EPS, in particular for surface variables like 2m-Temperature. This suggests that work is needed in the EPS to perturb land surface variables. However, calibration of the ECMWF EPS using the re-forecast data improves the performance to exceed that of the multi-model system.

In response to requests from Member States and Co-operating States, a range of products to identify and track extra-tropical cyclonic features is under development. A software package originally developed at the Met Office has been upgraded and implemented for the ECMWF forecast systems. This now runs in real-time and provides products on the ECMWF test web site.

ECMWF continues to support the WMO Severe Weather Forecast Demonstration Project (SWFDP) in southern Africa by providing a set of forecast products for participating WMO member states on the ECMWF web site. ECMWF will provide a corresponding set of products for the SWFDP that will begin in the south-west Pacific later this year. A number of participants from these SWFDPs will attend the ECMWF training course on “Use and Interpretation of ECMWF Products for WMO members” in October.

CMA (China)

Global Ensemble Prediction System (GEPS) at NMC/CMA was updated in resolution from T106L19 to T213L31 in 2006. This system has 15 members, 10 days forecasting at 00 and 12 UTC, and the Breeding Growth Mode (BGM) method. On 1 June 2008 the data assimilation system of GEPS was upgraded from OI into 3DVAR system. The products are provided in terms of ensemble mean, ensemble spread and probabilistic forecast, spaghetti, stamp chart. Ensemble Transform initial perturbation method is being experimented. Both ensemble members and forecast range are planed to increase in next 2-3 years.

The TC track ensemble prediction system was developed in 2006 based on T213 GEPS with 15 members and 120 hours forecast at NMC/CMA. The BOGUS vortex initialization scheme was put into real time running in 2007. The Regional TC track ensemble prediction system was also developed in Shanghai Regional Center with 6 members and 72h forecasts based on GRAPES model. The products are TC ensemble tracks and strike probability.

The Regional Ensemble Prediction System (REPS) was implemented for Northern China at NMC/CMA from 2006. It is based on WRF model of 15-kilometre horizontal resolution, 35 vertical levels, 15 members and 36h forecast, running at 00z/12Z each day. The IC perturbation is breeding growth mode (BGM) and the model perturbation is multi-physics with lateral boundary conditions from T213 GEPS. The REPS for South-West China (SW-REPS) was implemented in 2005 at Chengdu Meteorological Centre of CMA with 20km horizontal resolution, 8 members and 48h forecast. The IC perturbation is Different Physical Mode Method (DPMM) developed by local researchers. Products are mean, spread, probability, postage stamp chart and meteogram. A severe convection risk index was implemented in 2009 at NMC/CMA.

NCEP (USA)

1 Global Ensemble Forecast System (SREF)

NCEP's Global Ensemble Forecast System (GEFS) has been in operation since 1993, using the NCEP Global Forecast System (GFS) model for integration and breeding technique to generate initial perturbations. Since 2005, GEFS has been running the perturbed members four times per day (0000, 0600, 1200 and 1800 GMT). In 2006, the control forecast was extended to all cycles and Ensemble Transform with Rescaling (ETR) was added to the Breeding Method. The Number of perturbed members was increased to 14 in 2006 and 20 in 2007. The coming upgrading in late 2009 (http://www.emc.ncep.noaa.gov/gmb/ens/ens_imp_news.html) will increase the resolution from T126L28 to T190L28, and add a Stochastic Perturbation Scheme (SPS) to represent model related uncertainty. Based on the hypothesis that tendencies of the ensemble perturbations provide a representative sample of the random total model errors, SPS stochastically perturbs the total model tendency with tendencies from all ensemble members. These changes will lead to reduction in systematic errors, increased ensemble spread and improved performance of ensemble-based probabilistic forecasts.

2 Short-Range Ensemble Forecast System (SREF)

NCEP's Short Range Ensemble Forecast (SREF) system was operationally implemented in May 2001 as a 10-member Eta (with BMJ convective scheme)/RSM based regional ensemble prediction system. Another version of Eta (with KF convection scheme) and two versions (NMM and ARW) of WRF (Weather Research and Forecasting) Model were included in 2003 and 2005, respectively, leading to a Four-Model and Multi-Physics ensemble of 21 members. With the upgrading in Oct. 2009 (see http://www.emc.ncep.noaa.gov/mmb/SREF/reference.html), the system now has more balanced diversity in model (about 5 members from each model) and physics, and runs at increased horizontal resolution (~32km). The initial perturbations are generated either by regional breeding or using global BV with ETR. All member forecasts are integrated four times daily up to 87 hours with output every hour for the first 39 hours and 3 hours afterwards.

3 Post Processing of Products

A dual-resolution (hybrid) ensemble is generated for the first 180 hours of GEFS forecasts by combining the corresponding deterministic integration (GFS, currently T382L64). Bias correction to GEFS and SREF products has been conducted operationally since 2006 for each variable, each lead time and each forecast cycle on point wise basis. The bias is estimated using an adaptive algorithm and taking the weighted average (with decaying weights) of forecast errors in the most recent forecast cases (about 50 days). The same algorithm is also used to statistically downscale EPS products onto high resolution meshes and provide forecast guidance at local scale, with Real Time Mesoscale Analysis (RTMA, at 5km resolution) used as the reference. New products in the 2009 implementation of SREF include (a) Composite Radar reflectivity and radar echo top/height; (b)Icing and Flight Restriction, etc.; (c) Richardson Number based planetary boundary layer (PBL) height and (d) a Tropical Cyclone tracer.

Météo-France - PEARP

A new version of the Météo-France Ensemble Prediction System (*PEARP*, which stands for "Prévision d'Ensemble ARPège") will be implemented at the end of 2009. The main innovations are:

- The coupling with the 6-members 3D-Var FGAT ensemble assimilation running parallel to the main 4D-Var Arpege assimilation cycle (Berre *et al.*, 2007). One goal of this assimilation ensemble with perturbed observations is to feed the 4D-Var with error statistics of the day. But another equally important goal, will be to provide perturbations for ensemble forecasting in replacing the semi-breeding used currently in PEARP. These perturbations will be combined to the different sets of singular vectors computed over different areas in order to provide the perturbed initial conditions for the ensemble.

- The inclusion of some kind of model error. Each ensemble member will randomly use a particular physical package among the 8 available.
- The increase of the size of the ensemble from 11 to 35 members.
- The implementation of a second run at 06Z with a lead time of 72h in addition to the current one (18Z up to 108h).

The resolution of the ensemble will remind the same at this stage with a spectral truncation of TL358 with a stretching coefficient of 2.4. This corresponds to a resolution of about 23 km over France and 130km over New-Zealand. Nevertheless an update of the resolution is planed at the end of 2010. Using the TIGGE data-base archive, the new PEARP system will be compared with other operational EPS. Particular attention will be paid to the short range probabilistic forecast of precipitation and, finally, the early warning of extreme events will be addressed. As PEARP will have a LAMEPS resolution over Europe, data will be provided for TIGGE-LAM over a 0.25°X0.25° grid.

Post-processing

Post-processing is needed for surface parameters (precipitations, temperature, wind speed) in order to remove biases. Two post-processing is implemented on the first moment of the distribution (Pseudo-Perfect Prog applied to all of the members) and on the second moment of the distribution (calibration by Bayesian Model Averaging is under way by using specific statistical laws).

Applications and products

Products will be developed for forecasters. These products will allow to synthesize information coming from ensembles and single models. Charts of quantiles and maximum values will be made available. An experiment will be conducted next winter to evaluate the usefulness of these new products. Forecasters will be encouraged to give uncertainty qualification for their forecast.

Applications are under development: an hydrological ensemble (Coupling EPS with the hydrological model Safran-Isba-Modcou is experimented at the flood alert office (the “SCHAPI”) and the marine division is testing ensembles for storm surges and marine pollutant tracking.

Reference

Berre, L., O. Pannekoucke, G. Desroziers, S.E. ¸ Stef˘anescu, B. Chapnik and L. Raynaud, 2007: A variational assimilation ensemble and the spatial filtering of its error covariances: increase of sample size by local spatial averaging. Proceedings of the ECMWF workshop on flow-dependent aspects of data assimilation, 11-13 June 2007, 151-168.

KMA (Rep. of Korea)

Korea Meteorological Administration (KMA) has operated a global ensemble prediction system since 2001. An ensemble of 16 members is obtained using a rotated bred vector method, i.e., applying factor rotation after 12 hours of initial growth of perturbation, then fostering perturbation for another 12 hours. Perturbations of physics are not included. Global ensemble runs twice a day up to 10 days with the resolution of T213L40 (0.5625 degrees). There is no regional ensemble system in operation.

There are three major changes in recent years. With the installation of a faster supercomputer, horizontal and vertical resolution was enhanced from T106L30 to T213L40. The forecast length and number of operation have also been extended from 8 days to 10 days, and from once to twice a day (00, 12 UTC) from June 2006. The previous 17 members were added to the current 17 members in generating EPS products.

A post-processing method using a decaying average bias estimation has been introduced to operation since 30 July 2007. This bias correction has resulted in improvement of EPS performance by reducing the strong positive bias in the Northern Hemisphere.

Obtaining initial field for control through interpolation of higher-resolution global analysis could cause loss of high-frequency wave energy. To avoid this, KMA has constructed a 3dVar data assimilation system for global EPS. Control forecast is used as background information and analysis is generated on the same resolution as the ensemble model. This self-cycling ensemble system applied to the operation in September 2008.

With the total replacement of KMA NWP system with UM, the medium range ensemble is also going to be replaced by the UK Met Office MOGREPS. Target is to operate a global ensemble from the end of 2010 with a horizontal resolution of 40km and 70 layers. KMA also plans to launch a regional ensemble based on MOGREPS in 2011.

COSMO - Regional EPSs in Europe

In Europe there are five consortia developing regional models: COSMO, HIRLAM, ALADIN, LACE and UM (UK Met Office). Each consortium runs (or plans to run) a regional ensemble. The activities of COSMO are listed here.

COSMO LEPS is a downscaling of the ECMWF global ensemble. 16 members of this ensemble are chosen by a clustering carried out on days 4 and 5. These members are used as initial and boundary conditions for 16 runs of non-hydrostatic COSMO model with a resolution of 10km. Various products like probabilities and meteograms are generated out of the members of this ensemble. Verification shows that the skill of the ensemble is better than the skill of the driving ECWMF ensemble, especially for higher threshold of precipitation or wind. The resolution of the COSMO LEPS will pass to 7 km during the autumn 2009 and the domain will be extended to cover most of Europe.

A short range ensemble (COSMO SREPS) with a resolution of 10km has also been developed experimentally. Spread in the early time steps is realised by first nesting the COSMO model at 25 km into 4 different global models (GFS, ECMWF, UM, GME). In the second nesting at 10km, various perturbations in the physics are introduced. DWD plans to introduce by 2011 a convection permitting ensemble with a resolution of 2.8km and 20 members

NAEFS (North American Ensemble Forecast System)

1. General description. The Canadian (Meteorological Service of Canada, MSC), the Mexican (National Meteorological Service of Mexico, NMSM), and the US (National Weather Service, NWS) NMS established the North American Ensemble Forecast System (NAEFS). The NAEFS was inaugurated in November 2004, and the first operational implementation of NAEFS products occurred in May 2006. In December 2007, down-scaling products for Continental United States (CONUS) have been implemented in NWS/US operation. Within the NAEFS, ensemble producing centers (currently MSC and NWS) (1) exchange their raw forecast data (operational since September 2004); (2) statistically post-process (include down-scaling) all ensemble members; and (3) jointly with other members (currently NMSM) develop and produce end products based on the combined ensemble of forecasts.

2. Basic products. Statistical post-processing involves (a) the correction of all ensemble members for biases (first and higher moments), (b) the establishment of weights for the combination of all members, and (c) the expression of each bias-corrected forecast member in terms of percentile values within a long-term climatological distribution of the NCEP-NCAR reanalysis. The participating centers collaborate in the development of post-processing algorithms and software and share a common procedure to generate the basic products of bias-corrected forecasts, the corresponding weights and climatological percentile values. The products for probabilistic forecast (10%, 90%, 50%, mean, mode and spread) have been generated after statistical bias correction for

all ensemble members. The free ftp distributions of these basic products were operationally implemented in May 2006 and December 2007.

3. End products. The final goal of the NAEFS is the generation of end products for the use of the participating and other NMS, including those used for severe weather warnings. Down-scaling probabilistic products for CONUS are generated in NDGD grid by using Real Time Meso-scale Analysis (RTMA) as proxy truth. Some of the end products are developed jointly (such as the North American week-2 temperature and precipitation anomaly forecast), while others will be provided by individual participating centers. In all cases, end-products will be based on the common set of basic products described above, ensuring the consistency of all NAEFS end products. NAEFS participants actively seek input from potential users from developing regions (such as the Caribbean, South America and Africa) regarding desired end products for these areas.

4. Expansion of NAEFS. The current NAEFS can be considered as a prototype for a multi-center ensemble forecast system, envisaged by the THORPEX research program. The US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) will be next one to plan to joint NAEFS, while the US Air Force Weather Agency (AFWA) as a user. The UK Met Office also considers its participation, pending the results of a multi-year testing and evaluation phase. These possible expansions will broaden the scope of the NAEFS and may lead to the development of a Global Ensemble Forecast System (GEFS), as the ensemble forecast component of the Global Interactive Forecast System (GIFS), foreseen by the THORPEX program. The NAEFS, and a possible future GEFS will well represent the spirit of the enhanced international collaboration sought by the THORPEX research program. In particular, the NAEFS/GEFS can provide a framework of operational requirements and constraints within which new research initiatives must be conceived on one had, and will offer a receiving end for any new methods developed based on the THORPEX Interactive Grand Global Ensemble (TIGGE) data archive, or related to other THORPEX initiatives.

5 THORPEX/TIGGE/ GIFS developments and plans

5.1 The Chairperson provided a summary of the THORPEX programme. It is a 10-year programme of research under the Commission for Atmospheric Science (CAS) World Weather Research Programme to accelerate the improvements in the accuracy of 1-day to 2-week high-impact weather forecasts for the benefit of humanity. A key component of THORPEX is the creation of the TIGGE (THORPEX Interactive Grand Global Ensemble) database. TIGGE is a database of forecasts from 10 operational or near operational global EPSs which provides a resource for research on the relative skills of different systems and in particular the potential for additional skill from the combination of ensembles in multi-system ensembles. The TIGGE project is guided by the GIFS-TIGGE working group which has been developing plans for the GIFS (Global Interactive Forecasting System). The GIFS plans aim to transfer the benefits from the TIGGE ensemble research into operations. The Chair of ET-EPS attends the GIFS-TIGGE WG as an observer to represent the user needs of CBS. (See: http://tigge.ecmwf.int .)

5.2 The ten production centres that are presently contributing EPS data to the TIGGE archives are: ABoM (Australia), CMA (China), CMC (Canada), CPTEC (Brazil), ECMWF, JMA (Japan), KMA (Rep. of Korea), Météo-France (France), NCEP (USA), and Met Office (UK).

5.3 The TIGGE database has been used to provide some intercomparison verification results between different EPSs. In general the ECMWF EPS is found to perform the best in a variety of scores. For example the meeting was shown RPSS (Rank Probability Skill Scores) for Z500 and Tropical Cyclone track errors. A cluster of other EPSs with similar levels of performance are next best, and then there are a number of less good performers.

5.4 Results from recent TIGGE research show a small potential benefit from multi-system ensembles. Most studies take the best-performing ECMWF EPS as a reference and consider whether the multi-system ensemble can outperform the ECMWF EPS A TIGGE multi-model composed of all single models does not provide significantly better forecast than the ECMWF EPS on its own. However, combining only the three best single models (ECMWF, Met Office and NCEP) can improve the forecasts compared to the single ECMWF EPS, in particular for surface variables like 2-m temperature. However one study by ECMWF has shown that if the ECMWF EPS is calibrated using reforecasts (which they generate operationally for the purpose of training calibration systems) then the calibrated ensemble forecasts are competitive with the multi-system ensembles- both techniques are similarly successful in reducing systematic errors and correcting for spread deficiencies.

TIGGE in Ensemble flood forecasting

5.5 A case study has illustrated how the TIGGE multi-system ensembles can be used to generate flood predictions (Pappenberger et al., 2008). Early and effective flood warning is essential to initiate timely measures to reduce loss of life and economic damage. The availability of several global ensemble weather prediction systems through the TIGGE archive provides an opportunity to explore new dimensions in early flood forecasting and warning. TIGGE data has been used as meteorological input to the European Flood Alert System (EFAS) for a case study of a flood event in Romania in October 2007. Results illustrate that awareness for this case of flooding could have been raised as early as 8 days before the event and how the subsequent forecasts provide increasing insight into the range of possible flood conditions. This first assessment of one flood event illustrates the potential value of the TIGGE archive and the grand-ensembles approach to raise preparedness and thus to reduce the socio-economic impact of floods.

5.6 Operational medium-range flood forecasting systems are increasingly moving towards the adoption of EPS to drive their predictions. A review of the state of the art in this field, with a discussion of the scientific drivers of this shift towards ensemble flood forecasting and discuss several of the questions surrounding best practice in using EPS in flood forecasting systems, has been completed (Cloke and Pappenberger [ECMWF Technical Memorandum 574]). This work also discusses remaining key challenges in using EPS weather forecasts in hydrology in the future.

5.7 Ensemble hydrological prediction is developed under a programme called HEPEX. A recent proposal supported by WWRP has suggested a new THORPEX project on hydrological ensembles in collaboration with HEPEX called THEPS, and can be found at:

http://hydis8.eng.uci.edu/hepex/THEPS/Proposed_HEPEX_THORPEX.pdf

Global Interactive Forecasting System (GIFS)

5.8 The Chairperson invited Mr Richard Swinbank (UK), Co-chairperson of the Global Interactive Forecast System (GIFS - TIGGE) Working Group , to brief the meeting on plans for a GIFS/TIGGE research demonstration project, and activities of TIGGE-LAM, with the view to facilitate CBS to develop feedback on these plans.

5.9 The GIFS strategy developed by the GIFS-TIGGE WG and supported by the Chair ET-EPS is to develop GIFS through a number of small targeted projects to address the needs of society for improved high-impact weather forecasting. The WG has followed the concept of the SWFDP in cascading forecast information from the developed centres to the most vulnerable nations, and developed the concept of GIFS RDP (Research and Development Projects). These projects will aim to develop new tools from TIGGE concepts, such as multi-system ensemble forecasts of tropical cyclone tracks as recently demonstrated in the T-PARC experiment of THORPEX. A second area of priority is the prediction of heavy precipitation. It is important that projects include the communication of warnings to disaster risk managers, and their needs are discussed in the design of products to ensure effective communication.

5.10 While new products would be developed through research and development projects, the meeting suggested that involving WMO’s Regional Specialized Meteorological Centres (RSMC) in the design and planning for eventual production would account for specific regional high-impact weather forecasting needs. This would be particularly true for those RSMCs involved in regional

SWFDP projects (i.e. presently RSMCs Pretoria and La Réunion for Southern Africa, and RSMCs Wellington, Nadi, and Darwin for the South Pacific Islands).

5.11 The Chairperson reported on the activities of the TIGGE-LAM working group, and discussed the limitations of regional EPS for providing an operational service to WMO Members. The meeting reconfirmed the statement made at CBS-XIV (paragraph 6.3.30): "… the Commission felt its interest in multi-model ensembles should focus on global EPS at the present time, while monitoring progress of research results of EPS formulations of Limited Area Models."

5.12 The meeting endorsed the strategy which has been followed by the Chairperson and expressed its appreciation to Mr Mylne for representing the perspective of operational EPS production in the TIGGE research programme.

5.13 Mr Gerald Fleming, Chairperson of the CBS PWS programme, confirmed the difficulty for NMHSs of simply making ensemble fields available in real-time for downloading. Many NMHSs, especially those of developing countries, do not have the computing facilities or capability to generate products from ensemble fields even if they were made available. EPS outputs need to be calibrated and further post-processed into specific products required by "non-producing" NMHSs. Ideally these products should be designed for individual NMHSs, following consultation with their respective users on their needs and decision criteria.

5.14 By nature of the large datasets and computing requirements associated with EPS (as made obvious in TIGGE developments), likely EPS-based products could only be developed and produced by those centres that have the data processing or data transfer capacity to do so (major NWP centres, e.g. many RSMCs). This approach could challenge our present structures in a very fundamental manner as it implies that global or regional NWP centres might act as the primary producers of national-level EPS products destined for their end-users, shifting from the present practice of EPS centres providing "raw" output datasets as basic construction material for NMHSs' development and production.

5.15 The meeting endorsed the idea of the GIFS developing as a cascading structure in which a small number of global centres would run global EPS, and then a number of regional centres or consortia would run regional LAM-EPS for regions of the globe (using the global ensembles for boundary conditions) and provide products to NMHSs in the region. This is the structure proposed for the GIFS-RDP projects which are modeled on the SWFDP and designed to transfer the benefits of TIGGE into operations.

5.16 Research is required into methods for providing high-quality boundary conditions from different global EPSs to different LAM models to support multi-model LAM-EPS approaches.

5.17 The meeting noted that in some parts of the world, notably in Europe, the formation of modelling consortia has supported the provision of high-quality regional NWP and EPS in smaller NMHSs which do not have the resources to develop such systems independently.

5.18 The meeting noted a number of promising results from research based on the TIGGE database, and encouraged the further development of methods and resources to propagate this research into operations for the benefit of society. The team considered that to overcome the difficulties of exchanging very large quantities of ensemble data it would be beneficial for summary products to be generated at the production centres. However, these products should be developed in close cooperation with end users and designed to meet their specific needs for decision-making. Ideally users should be able to generate products interactively on the website to provide the flexibility to meet variable user requirements and thresholds. Much of the user needs could be met from single-system EPS and need not necessarily be from multi—model systems.

5.19 The meeting noted the needs for further research to develop improved tools for severe weather prediction. For example there is a need for the development of diagnostics to aid the identification of the potential for severe convective events from global EPS fields, particularly in the Tropics. Another area is the calibration of EPS forecasts, particularly for variables with non-normal distributions such as precipitation. There is scope for much research in the ability of EPS to provide useful predictability for tropical phenomena such as monsoon circulations, the MJO, Easterly Waves etc. The TIGGE database provides an ideal resource for the development of such tools and for the examination of case studies.

6 EPS in severe weather forecasting, including SWFDP

6.1 Several members of the team showed examples of EPSs being used effectively to support prediction of severe or high-impact weather events. Examples included the propagation of the weather forecast into impact models, for example a recent case where an ensemble was couple to a storm surge model and provided useful probabilistic warnings of a major storm surge event in the North Sea.

6.2 It was noted that extreme events are often predicted towards the extreme end of the forecast pdf, and that it is therefore essential to take account of low probabilities of severe events in order to make effective use of the forecasts and ensure that warnings capture the more extreme events.

6.3 The team also discussed the limitations of EPS in predicting severe events, and noted in particular that some extreme events cannot be adequately represented by the models, especially in global EPS. It noted also that it is often difficult or impossible to provide adequate calibration or verification of capabilities for extreme events due to the small data samples for such rare events.

Severe Weather Forecasting Demonstration Project (SWFDP)

6.4 The Secretariat made a presentation on the status of the Severe Weather Forecasting Demonstration Project (SWFDP), including highlighting the very positive results in introducing EPS products into the forecasting process in the participating NMHSs in southern Africa. The SWFDP in southern Africa commenced in 2006, and is now being implemented for all 16 countries of the region, with RSMC Pretoria playing the role of the main regional centre. RSMC La Réunion is playing its normal role for Tropical Cyclone forecasting in the southwest Indian Ocean. The project is contributing significantly to capacity building in forecasting and improving warning services in many developing and least developed countries.

6.5 Mr Pearson (RSMC, Wellington) informed the meeting of the status of the implementation of the Severe Weather Forecasting and Disaster Risk Reduction Demonstration Project (SWFDDP) for the South Pacific Islands. Much development has taken place since the development of the project's implementation plan (April 2009). RSMC Wellington is playing the role of the main regional centre, with the direct involvement of RSMCs Fiji and Darwin for Tropical Cyclone forecasting. Supply of data from global centres is underway; the new RSMC Wellington Web site is nearly completed; training of the forecasters at participating NMHSs as well as RSMC forecasters is taking place prior to the start-up planned for 1 November 2009.

6.6 The Rapporteur on Applications of NWP to Severe Weather Forecasting (Jean-Marie Carrière, France), provided many examples of EPS-based probabilistic products, both to help forecasters to better understand or develop a sense of confidence in the NWP/EPS predictions of hazardous conditions, as well as guidance for specific users of meteorological forecasts (e.g. hydrology for flooding, coastal protection from surges, heat wave for health).

6.7 The ECMWF's Extreme Forecast Index (EFI) is an example of a useful guidance tool to alert forecasters of possible extreme events, well in advance (medium-range). The meeting agreed that this kind of product that displays possible development of extreme events is very practical for forecasters, and also possibly for some specialized users.

6.8 The team noted the benefits of having a well-defined structure for a warnings system designed in collaboration with users to meet their needs to make effective decisions. As an example, the Met Office uses a 4-tier public warnings structure including: Flash Warnings (immediate, 80% forecaster confidence), Early Warnings (few days, up to 5 days, 60% forecaster confidence), Advisories (days in advance, 60% forecaster confidence), taking account of Risk of Disruption. This structure has been developed in close consultation with end users in the civil protection agencies. The forecaster confidence is only in part supported by objective probabilities from EPS products. For the foreseeable future, it is considered that there will continue to be an important role for forecasters in making decisions on the issue of warnings. However, since the introduction of EPS products into the forecasting process, the lead-times for alerting have much increased.

JMA

6.9 The team member from Japan reported on the use of EPS for severe weather forecasting in Japan, in particular showed JMA's Typhoon EPS applications in its Tropical Cyclone forecasting system, and new information in Typhoon Bulletins issued by the RSMC Tokyo – Typhoon Centre. It is shown that the spread of ensemble TC tracks calibrated by using past ensemble TC tracks leads to the radii of the 4- and 5-day geographical circle, in which the TC centre will reach with 70% probability. The visualized TC information is available at the JMA Web site: http://www.jma.go.jp/en/typh/.

B08RDP - EPS in Severe Weather Forecasting

6.10 The team member from China reported on the experience of the B08RDP which demonstrated the use of EPS systems for the Beijing Olympic Games.

6.11 Beijing 2008 Olympics Mesoscale Ensemble Prediction Project（B08RDP）is designed to contribute to the better understanding and improved forecasting of high impact weather events in summer season in Beijing from 6 to 36 hours with mesoscale ensemble prediction system (MEPS) in support of decision-making in 2008 Olympic meteorological service. The China Meteorological Administration (CMA) acted as sponsor of B08RDP Achievement were arrived as points bellow:

- Six mesoscale ensemble forecasting systems from different weather prediction centers participated in B08RDP (NMC, CAMS, MRI, EC, ZAMG and NCEP). Each participant developed its own MEPS and ran in a common configurations of domain (Beijing and around area) and same resolution, and provided products.

- CMA was responsible for data collecting, decoding, distributing, and establishing the platform for weather forecasts. A number of scientific issues related to the development of MEPS also were explored :
  - different initial perturbation techniques were used in this project, and relative merits of these strategies were investigated;
  - efforts to present the uncertainties in the lateral boundary conditions of MEPSs were made;
  - the different strategies for representation of model errors were tested;
  - the data assimilation systems and numerical models for all participants have been upgrading during B08RDP.
  - the bias correction techniques were used in the ensemble products to provide with reliable products to forecasts.

- B08RDP has been providing with probability products for meteorological office in real time. B08RDP MEPSs caught almost all major precipitation processes in Beijing area in 2008 and successfully demonstrated the importance of MEPS for the prediction of high impact weather.

- The verifications of MEPSs and inter-comparison of different MEPS were carried out, showing the advantages of MEPS over GEPS for the predictions of surface variables, and skill improvement of ensemble forecasts versus control runs. A series of training had been done to make forecasters familiar with the ensemble products.

- During B08RDP, mesoscale ensemble products were applied to daily forecasts. Synoptic verification of MEPSs in the viewpoint of forecaster showed that useful and valuable forecasting information were made by MEPSs during the Olympic Games. The appendices of this report provide more detailed information of each B08RDP MEPS.

Use of ECMWF EPSs products in Moroccan Meteorological Service (DMN)

6.12 The team member from Morocco reported on the experience of Morocco in applying EPS to severe weather forecasting in a country which does not have its own independent EPS

6.13 The role of meteorology in social and economic development today is more and more recognised and appreciated. During the last twenty years and thanks to the high performance computing system, Morocco's National Direction of Meteorology (DMN) has known an important progress at all levels covering the areas of model development, data assimilation, model evaluation, weather forecasting, climate forecasting, and ocean and marine forecasting. By the end of 2006, the DMN has been a co-operating member of the ECMWF.

6.14 This relation with the ECMWF prompted discussion on the merits of introducing a probabilistic element as an alternative approach in formulating forecasts. The DMN also has the responsibility of issuing warnings against severe weather that may affect Morocco, including rainstorms and severe events. Again, a deterministic approach may not be the best option, even in the very short-range, given the highly volatile and unpredictable nature of such severe weather systems. In particular, to tackle the various operational forecasting and warning issues involved, DMN is exploring the use of probability forecast products from ECMWF's EPS. The Weather Risk Management structure is found in the annex to this paragraph.

Use of Ensemble Prediction in India

6.15 Forecasting of high impact weather event is a challenging task in a tropical country like India where weather system such as Monsoon, Tropical Cyclone, local Severe Storm constitute a major convective system affecting a large population. There is a pressing need in operational scenario to provide forecast in a meaningful and quantitative way of these events with greater accuracy.

6.16 Currently India does not have the access to EPS Products. As a major step, India Meteorological Department started issuing district level forecast for parameters such as rainfall, temperature, relative humidity, wind and cloud octa in quantitative terms as required for the Integrated Agro-advisory service of the Country. These forecasts are generated through Multi-model Ensemble (MME) technique (at 25 km resolution) making use of outputs of deterministic global models of NCMRWF, ECMWF, UKMO, JMA and NCEP. Pre-assigned grid point weight for each model at each grid is determined based on past performance of these models. MME technique is also developed for the cyclone track and intensity prediction. The procedure is found promising while used for the operational forecasting. For the forecasting of local severe storm, very high resolution (3 km) non hydrostatic model with assimilation of radar observations is being experimented. Currently under the modernization programme, IMD has been in the process of expanding NWP and computer system. IMD is expected to operate global model T-382 in a few months time. In the near future IMD has the plan to start Global ensemble prediction system and contribute in the TIGGE programmer. IMD also initiated various Forecast Demonstration Projects, having three basic sub-programmes: (a) to improve observational network, (b) to developed data assimilation strategies and to develop improved ensemble prediction system and (c) to improve predictability of high impact weather events.

EPS Guidance Progress at New Zealand MetService

6.17 The use of EPS guidance at New Zealand MetService is in its infancy. To date the guidance used by forecasters has largely been not been calibrated. Recently, an application has been developed which provides fully calibrated probabilistic guidance. This application has shown good promise in calibrating ECMWF and GFS ensemble data for New Zealand locations. It is hoped that this will encourage the uptake of ensemble information by forecasters.

MAP D-PHASE

6.18 MAP D-PHASE is a Forecast Demonstration Project of the World Weather Research Programme (WWRP). Its goal is to demonstrate the ability of reliably and operationally forecasting orographically influenced (determined) precipitation in the Alps and, especially, its consequences on the distribution of run-off characteristics. During the D-PHASE Operations Period (DOP) from June to November 2007, an end-to-end forecasting system was operated. The forecasting system's centre piece was a Visualization Platform, on which equally displayed warnings from some 30 atmospheric and 7 hydrological models (deterministic and probabilistic), corresponding model fields, meteograms, nowcasting information, and end user communication was made available, to forecasters, users, and end users.

6.19 The 'P' in D-PHASE stands for 'probabilistic' and thus an emphasis was put during this project on ensemble prediction systems (D-PHASE as such, with its many different models and sources of information, being a multi-facet ensemble). The feed back from forecasters has been positive, mainly on the visualization platform which gave the possibility to synthesize quickly the warnings produces by all models. On the other hand, the danger of displaying too much information has been pointed at. End users from population protection authorities and water management were also able to get access to the visualization platform. They generally gave back the signal that it useful to look at the background information and not only to receive the final warnings. Finally, running hydrological ensembles based on an atmospheric EPS have proven to be very beneficial to the assessment to protection measures.

6.20 The complete finale report on the MAP D-PHASE project can be found under :

http://www.meteoswiss.admin.ch/web/de/forschung/publikationen/alle_publikationen/veroeff_78.Par.0001.DownloadFile.tmp/veroeff78.pdf

7 Developing guidance for forecasters

7.1 The meeting discussed the use of EPS products by forecasters, and concluded that very little guideline information has been developed, for probabilistic forecasting. It is also generally recognized that while many forecasters have developed their own methods through substantial experience, many other forecasters have little experience and are inadequately prepared to use EPS products. Even in countries with very good access to EPS products forecasters often remain committed to the traditional "deterministic" approach to forecasting – this is commonly driven by the desire from end-users for categorical decision-making despite the presence of uncertainty. Additionally, it was noted that guidelines for forecasters should be based on objective verification results and consistent with EPS concepts and design (e.g. assumptions).

7.2 Many forecasters have not been educated or trained adequately in probability and EPS concepts, production and products. Understanding statistics and probability science should be reinforced. It is important to include EPS training in continuous learning programmes as well as the initial training for new forecasters. At the same time, many forecasters in EPS producing centres have greater experience in the use of EPS products, with particular expertise on how to apply EPS products to severe weather forecasting. Transfer of knowledge and skills have taken place through dedicated training events and through the SWFDP regional projects.

7.3 The meeting noted that CBS had adopted the "Guidelines on using information from EPS in combination with single higher resolution NWP forecasts" which the ET-EPS had developed, which can be found on the WMO Web site at:

http://www.wmo.int/pages/prog/www/DPFS/Documentation/Guidelines_ET-EPS2006.pdf

7.4 It agreed that this guideline could be further developed and improved if examples are provided as part of the guideline. At the same time, it is recognized that further development of additional guidelines on other topics would be very useful to many forecasters, as EPS products are being introduced into forecasting centres.

7.5 The meeting concluded that EPS-related guidelines would be beneficial for general forecasting, severe weather forecasting, development of EPS post-processing, and on how to focus training to better support the use of EPS products. The meeting agreed to develop general guidelines, with the goal of elaborating the basic considerations relevant to each of these topics. The initial texts for each of these topic areas are found in the annex to this paragraph.

7.6 The guidelines prepared include some recommendations on Training of forecasters. The meeting endorsed the view that training has been most effective when conducted in conjunction with an SWFDP. This ensures that after the initial training the forecasters have access to operational EPS data for their region, which allows them to practise what they have learnt and consolidate the training.

7.7 The meeting noted that the PWS programme has already developed the “Guidelines on Communicating Forecast Uncertainty” (2008, WMO/TD No.1422), which is available on the WMO Web site at:

http://www.wmo.int/pages/prog/amp/pwsp/documents/TD-1422.pdf

8 Verification

8.1 At the last meeting the events for probability forecast verification were revised. Previously these were defined in terms of fixed absolute thresholds (e.g. temperature anomalies of 4K). However this is prone to false skill because of differences in the climatological frequency of the event at different gridpoints. Therefore most events were redefined in terms of either standard deviation from climate or percentiles of the climate distribution.

8.2 JMA is the lead centre for EPS verification. At present only JMA and ECMWF supply probability verification results to the lead centre web site. CMC results will be provided soon, however other centres still have difficulty in supplying the required verification data. There were two main reasons for this:

- lack of resources
- inability to calculate required events (now defined in terms of standard deviation from climate mean or percentiles of climate distribution)

8.3 The two are at least partly connected since the routine verification carried out at most centres is not in terms of climate distribution but for fixed absolute thresholds (e.g. temperature anomalies of 4K rather than 1 standard deviation from the climate mean).

8.4 Possible solutions to improve the situation were discussed

- add CRPS score to the list of required verification. This is becoming a more common summary measure at several centres and is therefore already available for at least some parameters from more centres than currently supply results. Also it does not rely on a detailed model climate distribution. It should be noted that the CRPS for a deterministic is equal to the mean absolute error and therefore allows a comparison between performance of probability and deterministic model
- use of the TIGGE database. In principle it is possible for one or more centres to use the TIGGE archive to calculate verification scores for all participating EPSs. This has the following advantages:
    - consistent verification procedure for all systems; even with detailed guidelines it can be difficult to ensure consistent verification. This could be particularly important for verification of surface weather parameters against observations
    - the climate quantiles and standard deviation fields could be provided from one centre that already has these and used for those centres that do not have this information available

- it would resolve the resource issue for the EPS providing centres. However, it would require significant resources to develop the system and perform the initial verification, and then to maintain the system for routine verification updates.

8.5 Role of Lead Centre for Verification should be maintained - this is to collect, archive and display the verification results. However, a coordinated approach may provide a way to address the current difficulties and the feasibility of this option should be investigated.

8.6 Difficulties of precipitation verification - no centre provided results for precipitation. Reason is difficulty of verification against observations, including observation quality control, differences in reporting practice (accumulation period 06-06 UTC, 12-12 UTC etc). An alternative that would allow some comparison of precipitation scores is to use a short-range forecast as a proxy precipitation analysis. This may be more straightforward for centres to implement. An alternative is for one centre to maintain a global set of synoptic precipitation observations and to verify the EPS precipitation fields from all global centres, possibly using the TIGGE archive to retrieve the EPS data.

8.7 The Lead-Centre is requested to update the guidelines on the exchange of verification results to include: (i) information on whether verification is against observations or proxy analyses and (ii) format for the exchange of CRPS.

Amendment to the Manual on the GDPFS

8.8 The meeting recommended that the following texts be added to the appropriate place in the current text of the Manual (Vol. I – Global Aspects, Part II, Appendix II-6, paragraph 4.1 Ensemble Prediction System Products:

- (a new note at end of EPS Verification section: "In the case of CRPS, centres are encouraged to submit this for both EPS and the deterministic (control and high-resolution) forecast as well - CRPS for deterministic forecast is equal to the mean absolute error."
- (last bullet in "List of Parameters", following the sentence referencing the GCOS list of surface stations: "Verification of precipitation may alternatively be against a proxy analysis, i.e. short-range forecast from the control or high-resolution deterministic forecast, e.g. 12-36h forecast to avoid spin-up problems."

Principles for verification of short-range EPS (grid spacing < 10km)

8.9 The development of EPS for very high-resolution EPS is in the early stages of research, and appropriate methods of verification are still very much an area of active research. However a few principles can be suggested:

- Since upper air parameters will hardly be distinguishable from those of the driving EPS, the verification will concentrate on parameters connected to local weather elements: precipitation, cloudiness, 2m temperature, 2m dew point, wind speed, wind direction, wind gusts.
- Point observations of temperatures and winds are verified against the closest representative gridpoint.
- Point observations of rainfall and cloudiness can be verified against an aggregation of gridpoints surrounding the observation point. The aggregation can for instance be the mean value (upscaling) or the probability to exceed some threshold (neighbourhood method).
- Observed fields of precipitation (radar) or cloudiness (satellite) can be verified using fuzzy verification techniques (e.g. upscaling, fraction skill score).

Probabilities can also be derived from deterministic small scale models. A PDF extracted from the statistics over neighbouring gridpoints can be built. This PDF can be verified in a probabilistic way. These scores should be compared with the corresponding scores resulting from the EPS in order to show the eventual added value of the EPS.

9 Review of EPS aspects of the Manual on the GDPFS

9.1 The meeting reviewed the relevant sections of the Manual on EPS (WMO-No. 485, Supplement 11) and proposed only the agreed changes to the verification requirements (see item 8). The proposed amendment to the Manual can be found in the annex to this paragraph, shown in tracked-changes from the current text.

10 Other business

None.

11 Closing

11.1 The Chairperson expressed his thanks for the most valuable input to the meeting and the work of the Expert Team, especially in the development of practical guidelines. He noted that there will be further work needed in polishing the guidelines and in taking the proposals forward and invited members of the team to continue to participate in this work.

11.2 The Chairperson closed the meeting at 5:15 pm, Friday 9 October 2009.

ANNEX I

PROVISIONAL AGENDA

1 Opening
2 Organization of meeting
3 Terms of Reference
4 Progress of EPS implementations
5 THORPEX/TIGGE/ GIFS developments and plans
6 EPS in severe weather forecasting, including SWFDP
7 Developing guidance for forecasters
8 Verification
9 Review of EPS aspects of the Manual on the GDPFS
10 Other business
11 Closing

ANNEX II

LIST OF PARTICIPANTS

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Annex to paragraph 3.1 – ET-EPS Terms of Reference

ET-EPS Terms of Reference (October 2009)
The following terms of reference for the CBS Expert Team on EPS were reviewed and accepted at the meeting, unchanged from those adopted at CBS-XIV (Dubrovnik, 2009):

a) Provide advice on EPS in relation to probabilistic forecasts in the context of short- and medium-range EPS products, focusing on applications concerned with all aspects of the EPS systems which forecast the weather on a daily basis;

b) Review progress on EPS and its application to severe weather forecasting including progress on multi-centre ensembles and on regional model based EPS, and prepare ways to make best operational usage of these developments;

c) Propose guidance for the generation of EPS products (e.g. EPS-grams, presentation of cyclone tracks and strike probabilities, hazard maps, calculation of probability, calibration methodologies, etc.) to ensure compatibility of EPS products supplied to WMO Members by different centres;

d) Develop education and training material for forecasters including rationale of concepts and strategies of EPS, and on the nature, interpretation and application of EPS products;

e) In consultation with the Coordination Group on verification, review verification system for EPS products and provide guidance on the interpretation of verification;

f) Support the further development of the Lead Centre on Verification of EPS by reporting on verification measures and determining the best way of presenting skill of ensemble forecasting systems. Provide relevant software to NMHSs through the Lead Centre Website;

g) To review the Manual on the GDPFS (WMO-No. 485) and propose updates as necessary concerning EPS;

h) Develop specifications for the introduction of probabilistic information into products from RSMCs with geographical specialization;

i) Participate in THORPEX Working Groups:

   (i) To ensure that the proposed GIFS (Global Interactive Forecast System) is suitable for operational implementation and application;
   (ii) To review progress on the use of EPS for targeting of observations.

Annex to paragraph 6.14 – Weather Risk Management in Morocco

Weather Risk management

Disaster reduction activities are at the core of a number of DMN scientific and technical programmes. These programmes are particularly contributing to global capabilities in the detection, forecasting and early warning of hazards, and providing effective means and procedures to minimize their adverse consequences. The DMN, with the relevant authorities, have developed and implemented a weather risk management strategy:

- **Pre-warning:**

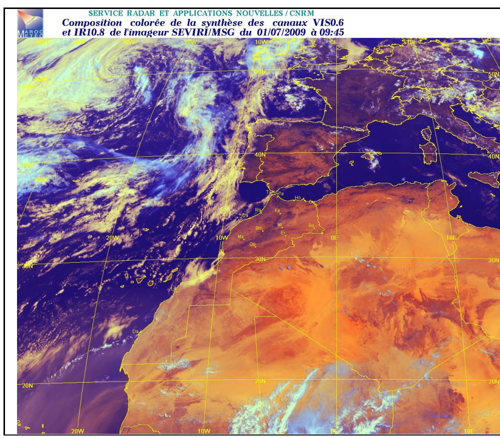
Whenever there is a chance that the weather could affect one or many locations, a meteorologist personally assesses the situation and pre-defined criteria to determine the likelihood of weather related impacts. A pre-warning is disseminated to the relevant authorities.

- **Warning:**

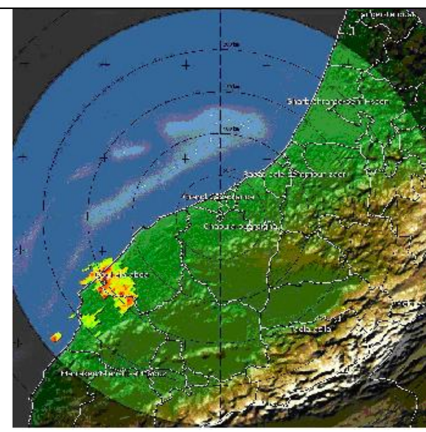
When the forecast team confirms the weather risk, dissemination of warnings to the relevant authorities and to the public is activated.

The procedure of risk management is based on:

- Use of radar, satellite and lightning data for the monitoring of severe weather events over the area

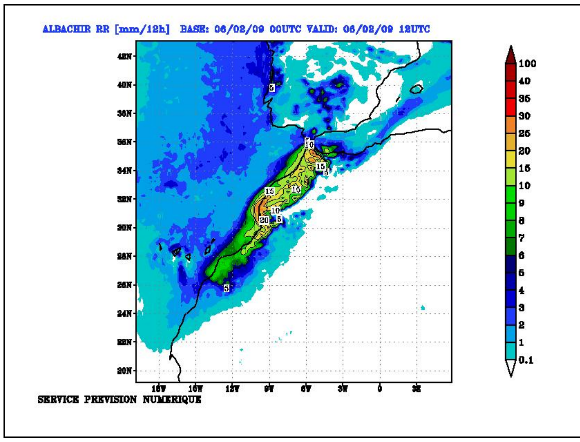


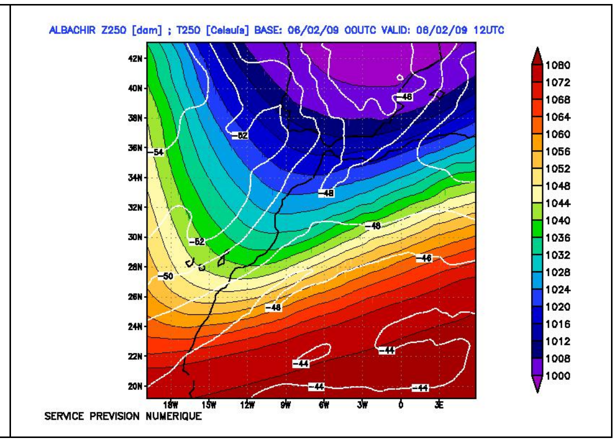
Satellite IR



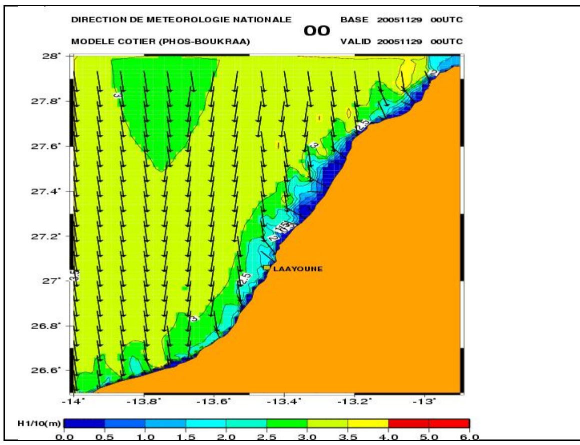
Radar

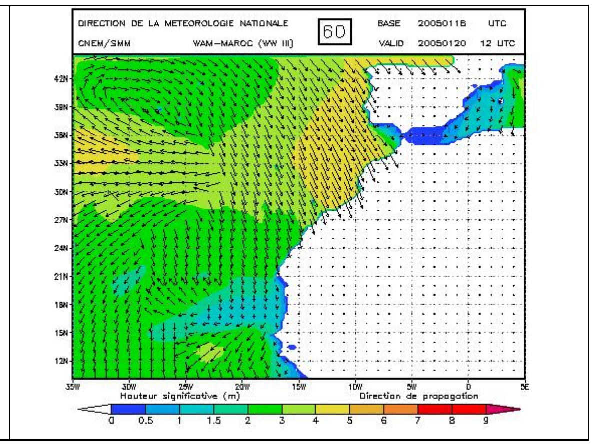
- Operational use of high resolution modelling for the provision of weather forecasts and for all major meteorological parameters (winds, rain, snow, temperature, etc).



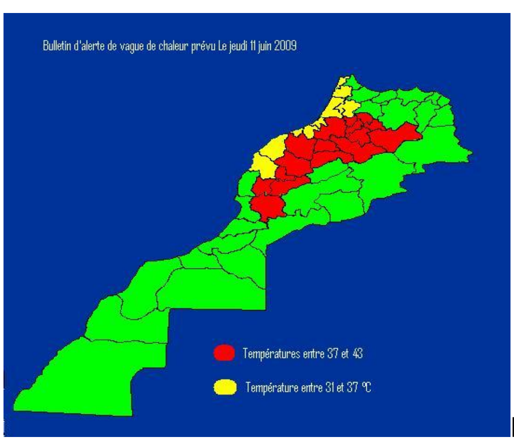


- Use of a wave model in case of strong winds and adverse marine conditions near selected coasts





- Use of ECMWF EPS products
- Presentation of the results in a user-friendly way, in accordance with the requirements from the end-users, and dissemination of the warnings (fax, through a dedicated web page, e-mails, sms and mms to mobile phones etc).



Example of warning map

Annex to paragraph 7.5 – Guidelines on EPS and Forecasting

I. General points

- An EPS is only as good as the model(s) it uses.
    - If a model is unable to represent certain phenomena, the EPS will also be unable to represent it.
    - An EPS will share any systematic biases of the model used.
- Ensemble best represents uncertainty in resolved variables
    - Upper-air usually more skilful than surface
        - Surface parameters affected by sub-grid scale uncertainty
- How to combine deterministic forecast with ensemble/probabilistic?
    - Relative capabilities of ensemble members compared to hi-res/control
- Can a forecaster improve the distribution by re-weighting members (e.g. hi-res) or rejecting some members?
    - Forecasters may think that some members are unrealistic
    - Can we eliminate some members on the basis of recent observations or pick a “best member”?
        - PERHAPS, for certain aspects of the forecast over very short-period forecasts
        - NOT for longer period forecasts
    - Recommend that forecaster should use the whole distribution in a probabilistic approach
- Decision-making with uncertainty – cost-loss
- Presentation methods for effective communication (e.g. PWS Guidance Notes)

To be expanded by: Gerald

- Different predictability range of convective cells, mesoscale structures, synoptic structures (fronts), large scale synoptic features (ridges, troughs,…).
- Predictability can be different from day to day and place to place.
- Strengths and weaknesses of the models/ensembles have to be known (proper verification: stratification by threshold, weather classes,…) → text easily available to the forecaster.
    - Verification of multiple thresholds to be available
    - Summary doc of strengths and weaknesses by season
- Description of each product easily available.
- Be careful with “end of chain” parameters (precipitation, cloudiness,…)
- Show upper air features not only weather elements – environment/precursors for high-impact weather developments

The use of EPS (and other probabilistic tools) opens the possibility of issuing two different types of forecast, fully probabilistic, or deterministic with supplementary uncertainty information. Which type we use affects who makes decisions from the forecast. In general the use of fully probabilistic forecasts allows each user to tailor their decision to their specific needs (eg using cost-loss estimation), and is therefore strongly encouraged.

II. Issue probabilistic forecasts → the end user takes decision

- Calibrated, bias corrected forecast can be directly issued to the end user (low cost).
- This approach allows for the possibility of issuing automated forecasts for many locations and users.
- Use of fully probabilistic forecasts based on ensemble members retains consistent correlations between different weather variables and also different locations (e.g. the correlation in temperature between two locations).

- Direct model output (DMO) from ensembles should be used with care, as it may not provide reliable probabilistic forecasts, but will often nevertheless provide valuable information. In some cases use of DMO may be essential where there is no calibration system in place – calibration is difficult for certain variables such as precipitation, or where adequate observations are not available.
- Production by the forecaster: can rely on calibrated EPS and/or generate probabilistic forecasts using subjective methods, with or without an EPS, (using experience, analogues,…). Forecasters may be able to correct for some known system biases or model weaknesses, but in many cases it is not clear that forecasters can add significant value.
- In general it is recommended that where probabilities are indicated for significant high-impact weather, a forecaster-written comment or warning should be added.

III. Issue deterministic forecasts (incl. warnings) → the forecaster takes decision
If you issue a deterministic forecast, it should be augmented by a statement of the confidence of this forecast. The confidence will not always be the same for all elements of the same forecast – confidence indices, if used, are best provided separately for each variable.

The best approach will depend on the predictability as indicated by the ensemble spread:

- Small spread in the ensemble (good predictability)
  - In this case it may be reasonable to offer more detail in the forecast.
  - Take the control, the high resolution control, the ensemble mean or the median as a guide (with due regard for the need for calibration or bias correction).
  - Spread may often differ between model variables so small spread in one parameter does not guarantee confidence in all aspects of the forecast.
    - Good synoptic scale predictability does not always mean predictability in surface weather variables such as temperature or convective precipitation.
    - Forecaster should still take account of uncertainty in parameters not resolved by the model.
- Large spread in the ensemble (poor predictability)
  - Take most representative member of the ensemble (e.g. most populated cluster or mode of pdf) as a guide to the most probable outcome
    - Note that the most representative ensemble member may not give the most probable value for each weather element (e.g. most probable temperature at a location may not be correlated with the most probable precipitation amount.)
  - Avoid giving too much detail in the forecast
  - Communicate that there is uncertainty.
    - Encourage users to follow forecast updates.
  - Take into account extremes of the EPS and of the high resolution control
    - Communicate clearly the risks and impacts associated with worst-case scenarios alongside the most likely outcome.
      - Encourage users to be prepared for worst-case scenarios, but without over-reaction.
    - Make a careful evaluation of the possible evolutions of the synoptic situation and their potential impacts.
    - Take into account the behaviour of models.
      - The high-resolution control may be better able to represent certain high-impact events.
- In the short range (12 - 18 hours), it may be possible to take into account the latest observations (3-6 hours into the forecast) in order to choose a scenario or a member of the ensemble.
  - For example, a rapidly evolving cyclone may be best predicted by the member with the best position after a few hours.

  - *ONLY* in the very short-range!
  - Be aware that future evolution will be influenced by features coming from upstream. This makes member selection for forecasts beyond ~24h impossible.

Taking decision

- The choice of making a deterministic forecast for a specific event to occur or not has to be taken with some knowledge of the cost / loss ratio of the end user. This ratio can be assessed by a survey or a direct discussion with the end user.

In general, uncertainty has to be communicated in every circumstance, preferably by using the PWS Guidance (WMO TD-1422).

IV Special considerations for the use of EPS for severe weather prediction

- A well structured NMHS warning system should have appropriate thresholds, lead-times and level of service agreed with users.
  - Types of warnings; regions; thresholds (severity/impact and probability)
    - Risk = Impact*Probability
  - A good warning system is one that will be easily understood by users, with standard thresholds adhered to by forecasters.
  - A good warning system will require feedback from users to NMHSs. The NMHSs in turn should give feedback to producers enabling them to design appropriate products.
  - Provides a guide to the EPS and NWP products required to deliver

- Severe or high-impact weather events occur on a wide range of scales in space and time, from Tropical cyclone, extratropical cyclone, monsoon system at the large scale, to smaller scale systems such as local severe storms, orographic rain, thunderstorms and tornados.
  - Must take account of different predictabilities of different types of events (e.g. do not try to predict a thunderstorm 3 days in advance)

- EPS can only predict severe events which the model can resolve
  - Sometimes can identify pre-cursor conditions for severe developments

- EPS are a powerful tool in predicting severe weather events. However, EPS can only predict severe weather which the model(s) can resolve:
  - Numerical Weather Prediction has limitations in explicitly resolving smaller scale phenomena, which leads to under-estimation of extreme events likelihood within EPS.
  - Lower resolution EPS (Global) is less likely to be able to resolve details of an extreme event
  - Regional EPS, which usually has higher resolution, should have less outliers (Observed severe events not forecasted within the spread).
- The majority of *extreme* events will be predicted at the high end of the ensemble distribution.
  - Therefore forecasters and users should not ignore low probability events, especially when those events are very rare.
    - For example, ignoring probabilities below 20% or even 10% could result in missing the most important events signalled by the EPS.
    - Must communicate clearly the risk of “false alarms” with low probability warnings – these are actually a correct feature of low probabilities.
- Expect probability to increase closer to the event – usually but not always

- An extreme event may also be forecast essentially correctly, but with errors in location or timing.

- Synoptic interpretation (e.g. weather feature tracking, use of analogues) or statistical downscaling tools are ways to add skill to the basic (Global) EPS.
  - Note that statistical methods require large data samples for training, and may not be well-suited to rare or extreme events.
  - Cyclone tracking products (for both tropical and extra-tropical cyclones) can provide a useful summary of the development of high-impact storms.
  - There is potential for development of more feature-based diagnostics for poorly resolved severe weather systems.
- The Extreme Forecast Index (EFI) can be a useful tool in alerting forecasters to a potential severe event.
  - EFI does not provide explicit probabilities of specific events, and should be interpreted in conjunction with other tools.
  - Currently only a small number of systems can provide an EFI due to the need for a model climatology.
- Regional EPS may better represent local features such as orographically enhanced precipitation or small scale extreme events by dynamical downscaling of the global EPS.
- Production of verification highlighting the skill and limitations of EPS is important.
  - Users of EPS should be aware of those limitations and strengths.
  - However, due to the rarity of most extreme events it is often impossible to provide reliable (or statistically valid) verification of probabilistic performance. It may be necessary to extrapolate from the verification of less-severe events.

- Given the diminishing of the EPS skill with increasing lead time, latest available products are generally given higher credibility. However, previous runs of an EPS may still provide useful information about a rare event because of the lack of spread (limitation in the sample size).

V. Forecaster Training

Training should include:

- NWP basics, capabilities, strengths and weaknesses e.g.
  - Dynamically resolved and parameterised variables
  - Parameterizations and sub-grid scale processes
  - Observations and data assimilation.
- Motivation for probabilistic forecasts – chaos theory and its impact.
- Statistical background theory and approaches.
- Aims of initial condition and model perturbations.
- Standard ensemble verification tools and their meaning.
- Explanation of basic meaning of products (e.g. lines on chart).
- Methods of post-processing and their impacts.

- Practical training is really only useful when an NMHS has access to operational EPS data, the operational time to use it and the products and tools to make direct use of it.
  - Benefits of training which is not reinforced by operational practice are rapidly lost.
  - Provision of training in conjunction with a demonstration project such as the SWFDP can help to ensure that the training is reinforced and consolidated by the provision of relevant operational EPS data.

- *Learning Through Doing* – The training of forecasters in the use of EPS guidance should be a practical experience using tools which are as close as possible to those used in operations.

  - Web based tools can be ideal in training, as they can be used on any workstation system through a standard browser to ensure continued access afterwards.
- During training case studies should be worked through showing the appropriate use of EPS guidance, both in routine and severe weather scenarios.

- In the relatively new area of EPS, periodic training is expected to generate the best benefit. Forecasters require time to build experience in using this guidance followed by further training to reinforce key concepts. It would also be of benefit if various NMHSs could share their experience with EPS.

VI. EPS Post-processing

The aim of this guidance is to provide explanation and advice for post-processing using statistical and dynamical approaches to improve EPS outputs. There are numerous approaches and the paragraphs below capture some of the most common. Some methods are quite generic and may be best applied by EPS producers at source, while others are quite specific to applications and may be better applied specifically for individual users.

1. Statistical post-processing

Generally speaking statistical post-processing is needed in order to correct systematic errors in models and thereby add value to direct NWP model output. These errors are particularly important for surface parameters (2m temperature, 2m humidity, 10m wind speed, precipitations, total cloudiness, …) and are linked to local conditions.
More precisely, statistical post-processing is used to:

- Remove systematic biases
- Kalman-filter and other adaptive methods are recommended to allow the corrections to be automatically updated to account for model changes (upgrades) and changes in the season.
- Quantify uncertainty not represented directly by the EPS
- Predict what model does not represent explicitly (eg low visibility)
- Produce site-specific forecast
- Assist forecasters : « First guess » for expected local conditions
- Adjust ensemble spread

1.1 Bias correction of the First Moment of the PDF (Probability Density Function)

This post-processing is similar to MOS (Model Output Statistics) methods applied for single models, but with some important differences. For ensembles, it is well known that a traditional MOS which is trained specifically for each forecast lead-time will lead to a significant decrease of the ensemble spread at longer lead times. Instead, it is recommended to use a pseudo-perfect prognosis approach. This method is based on the use of MOS statistical models computed over the first 24h of the forecast and then applied to the corresponding steps during at all forecast lead-times.

- In the case of single-model ensembles (ie the same model is used for all of the members, even where model perturbations are implemented) the same statistical model should be applied to all of the members .
- In the case of multi-models ensemble (ie where different models are used to build the pdf, or systematically different model versions are applied, e.g. different parameterization schemes) specific statistical models should be trained and applied for each model version.

  In either case the development of these statistical models need a training set of model outputs (predictors) and observations (predictands). In the case of adaptive methods such as the Kalman filter this training set is updated continuously from the daily forecasts.

The “observations” can be either site-specific observations or may be high-resolution analyses. In the case of site observations the statistical post-processing will lead to local forecasts (ie at each site specific point where observations are available). When analyses are used the end product is a bias-corrected and downscaled gridded forecast.

It should be noted that when different weather variables are independently bias-corrected, some of the correlation between variables represented by the different ensemble members may be lost. For this reason forecasters may prefer to view direct model outputs.

1.2 Calibration of higher Moments of the PDF

- Bias removal for the second moment of the pdf. is often known as the “calibration” post-processing. It aims to improve the reliability of the probabilistic forecast. Therefore this kind of post-processing is specific to ensemble prediction systems and is particulaly important to give confidence on probability forecast. A method developed at the University of Washington is now considered as one of the best to deal with this issue. This method, called “Bayesian Model Averaging” is based on specific statistical laws (eg normal laws for temperature). As for the first moment bias correction, calibration is based on local conditions and often needs observations or high quality reference.
- A number of other methods are under development which attempt to calibrate both the first and higher moments of the pdf to optimize the complete distribution.

The above methods are commonly applied to variables such as temperature and wind-speed. Variables such as precipitation are more difficult to correct due to the nature of the pdf and the local variability of observations. Some specific approaches are under development, but post-processing methods are at present less successful and may not improvge significantly over raw model outputs.

It has to be said that statistical process present limitations especially in case of severe events. The main reason for this fact is that observations of these kinds of events are rare. Therefore it can not be expected to provide significant improvement for the raw forecast in this case and probabilities given by ensemble can not be considered as reliable. As a consequence, the human expertise is particularly important and it is recommended to give particular attention on the comparison between the usual ensemble behavior and the forecast pdf (see §3).

2. Dynamical downscaling

Dynamical downscaling may be defined as the use of a higher resolution limited-area NWP model to add detail forced by topographic detail and to resolve fine-scale processes such as convection. Ideally all ensemble members will be downscaled, but where cost constraints prevent this a selected set of members may be downscaled. In downscaling the analysis, boundary conditions and perturbations are taken directly from the lower resolution EPS members. Care must be taken to ensure that the downscaling is appropriate to ensure good performance of the high-resolution model, e.g. appropriate ratios of grid sizes, rate of updating of boundary conditions etc. The model performance should be carefully tested over the domain.

A one-dimensional model could also be used for specific forecast (eg 1D fog models for airports).

3. Clustering techniques

Classification process can be used to synthesize the huge amount of information contained in ensembles especially for the most populated ensembles. Different kinds of classifications can be implemented :

- Clustering attempts to identify some significantly different solutions among the ensemble members and to gather the other members closer to these solutions.
- The tubing classification identifies the closest members from the ensemble mean (the so-called "central cluster") and the farthest ones (tube extremes).
- Classification of forecasts by matching ensemble members to a defined set of flow regimes, for example the Grosswetterlagen types defined for central Europe.

It is recommended that such classification methods may be useful in condensing the information in the EPS. .

Use of Reforecasts

Recent research has shown that calibration of ensemble forecasts using historical sets of "reforecasts" – forecasts run from sets of historical cases initiated from reanalyses – can be very effective in improving the quality and reliability of probabilistic forecasts. Such reforecasts provide a better dataset for training of statistical post-processing methods compared to using recent forecasts, as they provide a better sampling of different weather regimes and types. At present very few EPSs have reforecast datasets available, but their use is recommended where possible.

One application of reforecasts is the computation of an Extreme Forecast Index.
NWP models and EPS systems do not represent accurately the climate of the real atmosphere, and identification of extreme events may be best done in relation to model climatology. The Extreme Forecast Index developed by ECMWF allows identification of forecasts which are extreme relative to the model climate, providing an alert to a risk of severe weather. The EFI does not provide explicit probabilities of severe events.

Reforecasts can also be used to assess forecast severity in relation to climatological return periods, which can be a useful way to communicate the severity of an event.

VII. Severe Weather Impact Modelling

The uncertainty in the weather forecast can be propagated through to uncertainty in impact by coupling ensemble members to impact models and generating a distribution of impact predictions. Examples include hydrological models for probabilistic flood forecasting, coastal storm surge models, heat health models etc.

Annex to paragraph 9.1 – Proposed amendment to the Manual on the GDPFS

Manual on the GDPFS, Appendix II-6, parag. 4.1 Ensemble prediction system products
(proposed amended text in tracked-changes and highlighted in yellow)

4.1 Ensemble prediction system products

4.1.1 Products for short range and medium range

(*a*) GLOBAL PRODUCTS FOR ROUTINE DISSEMINATION
(Period for all fields: forecast D+0 to D+10 (12-hour intervals) at highest resolution possible)
Probabilities of:
(i) Precipitation exceeding thresholds 1, 5, 10, 25 and 50 mm/24 hours
(ii) 10 m sustained wind and gusts exceeding thresholds 10, 15 and 25 m s–1
(iii) T850 anomalies with thresholds -4, -8, +4 and +8 K with respect to a reanalysis climatology specified by the producing Centre
Ensemble mean (EM) + spread (standard deviation) of Z500, PMSL, Z1000, vector wind at 850 and 250 hPa Tropical storm tracks (lat/long locations from EPS members)

(b) MODEL FIELDS
Full set or subset of EPS members' variables and levels for requesting WMO Members for specific applications.

(c) OTHER GRAPHICAL PRODUCTS
Location-specific time series of temperature, precipitation, wind speed, depicting the most likely solution and an estimation of uncertainty ("EPSgrams"). The definition, method of calculation and the locations should be documented.

4.1.2 Products for extended range

ENSEMBLE MEANS ANOMALIES/SPREAD
One-week averages and the monthly mean (all anomalies with respect to model climate):
Tropical SST
Standard ENSO/indices
Z500 and Z1000, precipitation, T850 and surface temperature

Probabilities:
Terciles: above, below, normal (with respect to model climate)
Precipitation
Z500
Z1000
T850 and surface temperature
Model fields:
(a) Full set or subset of EPS members' variables and levels for requesting WMO Members for specific applications.
(b) Relevant post-processed fields from sequence of daily output (e.g. indices of monsoon onset, droughts, tropical storm activity, extratropical storm track activity)
(c) Extended-range forecasts (levels and parameters as appropriate with 5-, 10-, 15- or 30-day mean values as applicable)

Manual on the GDPFS, Attachment II.7 Table F - Factors and methods used in standardized verification of NWP products, Section III - Standard verification measures of EPS

III – STANDARD VERIFICATION MEASURES OF EPS

EXCHANGE OF SCORES

Monthly exchanges:

Ensemble mean
For verification of ensemble mean, the specifications in this table of the attachment for variables, levels, areas and verifications should be used.

Spread
Standard deviation of the ensemble averaged over the same regions and variables as used for the ensemble mean.

Probabilities
Probabilistic scores (excluding the CRPS) are exchanged in the form of reliability tables. Details of the format of the exchange of verification data are provided on the website of the Lead Centre for verification of EPS.

List of parameters

PMSL anomaly ± 1, ± 1.5, ± 2 standard deviation with respect to a centre-specified climatology
Verified for areas defined for verification against analysis

Z500 with thresholds as for PMSL. Verified for areas defined for verification against analysis

850 hPa wind speed with thresholds of 10, 15, 25 m s^{-1}. Verified for areas defined for verification against analysis

850 hPa u and v wind components with thresholds of 10th, 25th, 75th and 90th percentile points with respect to a centre-specified climatology. Verified for areas defined for verification against analysis

250 hPa u and v wind components with thresholds of 10th, 25th, 75th and 90th percentile points with respect to a centre-specified climatology. Verified for areas defined for verification against analysis

T850 anomalies with thresholds ± 1, ± 1.5, ± 2 standard deviation with respect to a centre-specified climatology. Verified for areas defined for verification against analysis

Precipitation with thresholds 1, 5, 10, and 25 mm/24 hours every 24 hours verified over areas defined for deterministic forecast verification against observations

Observations for EPS verification should be based on the GCOS list of surface network (GSN). Verification of precipitation may alternatively be against a proxy analysis i.e. short range forecast from the control or high-resolution deterministic forecast, e.g. 12-36h forecast to avoid spin-up problems.

NOTE: Where thresholds are defined with respect to climatology, the daily climate should be estimated.

Scores

Brier Skill Score (with respect to climatology) (see definition below*)
Relative Operating Characteristic (ROC)
Relative economic value (C/L) diagrams
Reliability diagrams with frequency distribution
Continuous Rank Probability Score (CRPS)

NOTES: Annual and seasonal averages of the Brier Skill Score at 24, 72, 120, 168 and 240 hours for Z500 and T850 should be included in the yearly Technical Progress Report on the Global Data-processing and Forecasting System.

In the case of CRPS, centres are encouraged to submit this for both EPS and the deterministic (control and high-resolution) forecast as well - CRPS for deterministic forecast is equal to the mean absolute error.

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* The Brier Score (BS) is most commonly used for assessing the accuracy of binary (two-category) probability forecasts. The Brier Score is defined as:

$$BS = \frac{\sum_{ij}\left(F_{ij} - O_{ij}\right)^2}{N}$$

where the observations *Oij* are binary (0 or 1) and *N* is the verification sample size. The Brier Score has a range from 0 to 1 and is negatively-oriented. Lower scores represent higher accuracy.

The Brier Skill Score (BSS) is in the usual skill score format, and may be defined by:

$$BSS = \frac{BS_C - BS_F}{BS_C} \times 100 = \left[1 - \frac{\sum_{ij}\left(F_{ij} - O_{ij}\right)^2}{\sum_{ij}\left(C_{ij} - O_{ij}\right)^2}\right] \times 100$$

where *C* refers to climatology and *F* refers to the forecast.