WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS

MEETING OF THE CBS EXPERT TEAM ON ENSEMBLE PREDICTION SYSTEMS (EPS)

MET OFFICE UK HEADQUARTERS
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FINAL REPORT

Executive Summary

Fourteen GDPFS centres around the world are running ensemble prediction systems (EPS), some are running multiple systems, and their products are of considerable interest to all WMO Members. The interest continues to grow, EPS products being a realization of quantifying uncertainty in the numerical simulations and predictions of the atmosphere. The continuing development of EPS, in terms of model resolution, methods of accounting for uncertainties, forecast ranges, and applications, means it has increasing importance as a vital tool for weather forecasting, and potentially on all time scales (short-range to long-range) of prediction. CBS-XIII (2005) continued to recognize these trends and noted that guidance was needed on how to use EPS products in relation to those from deterministic models, in the preparation of forecasts and warnings. At the same time CBS wished to develop forecasting standards and recommended practices; this could be achieved by developing a guide to the use of EPS in the weather forecasting process. CBS encouraged members to access EPS products of GDPFS centres, and also invited these centres to provide the access information for their respective EPS web-sites. The Expert Team recognized the continuing demand for training for operational forecasters on the use of EPS. It noted the success of recent training workshops and considered various approaches to provide further training in a cost-effective manner with sustainable results.

The Expert Team reviewed progress made by EPS producing centres including their developments and implementations, products for international exchange, application to severe weather forecasting, verification standards and exchange through the Lead Centre, training, and coordination with THOPREX and GIFS/TIGGE.

The Expert Team produced a text entitled: “Guidelines on using information from EPS in combination with single higher resolution NWP forecasts”, which is reproduced below.

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Guidelines on using information from EPS in combination with single higher resolution NWP forecasts

Motivation

Traditionally forecasters have focused their attention on finding the most likely solution for the future weather. This is the first and most important aspect of weather forecasting. As the lead time for forecasts increases, the uncertainty associated with the most likely solution generally also increases. Information about the uncertainty in the forecasts is critical for a large group of users. One way of assessing uncertainty in traditional single (or “control”) forecasts is through collecting verification statistics over a period of time, and using the error statistics as a way of providing a distribution of expected errors in a forecast. This process, however, assumes that errors for a given lead time are stationary. Operational experience shows that this is not a valid assumption. NWP-based ensemble forecast systems were designed, through dynamical methods, to quantify forecast uncertainty as a function of uncertainty in the initial conditions, in the NWP model, and the evolution of the atmosphere under different synoptic situations. The ET-EPS recommends the more widespread use of EPS systems to provide the best estimates of forecast uncertainty.

Properly describing the uncertainty in any forecast requires the use of probability distribution functions (pdfs). An EPS can be used to form such a pdf in a consistent manner. Due to resource limitations, EPS systems involve many forecast integrations and therefore often have to be run at a somewhat reduced resolution. Questions arise as to the compatibility of information from a single higher resolution integration versus an ensemble of lower resolution runs. In particular, higher resolution integrations generally show a lower level of systematic error, and may simulate certain aspects or phenomena of the atmosphere with more fidelity (e.g., diurnal cycle, meso-scale features, frontal structures, etc.). Guidance has been sought by WMO members as to the proper use of high-resolution control and lower resolution ensemble information, in particular regarding when information from one or the other system may be more relevant and how they can be best combined/utilized in the forecast process.

Determining the most likely scenario

The initially symmetric cloud of possible solutions that are centered around the control analysis in a set of ensemble forecasts deforms with time into an irregularly shaped cloud. This is due to nonlinear processes that necessarily displace the control from the center of the cloud. The critical level of nonlinearity is reached sooner for smaller scale and/or more unstable phenomena. For example, in case of convective precipitation, linearity may be lost in a matter of hours, while large scale features may retain linearity for several days.

A forecaster can assess how much weight to place on a single high-resolution forecast (or on the ensemble control) from the spread in the ensemble. Small spread in the ensemble provides confidence in the single forecast, while larger spread indicates that it is essential to include information on forecast uncertainty. If the single model forecast is significantly different from the ensemble mean, in relation to the spread, then very little weight should be given to the high-resolution forecast.

As spread increases, it is less appropriate to rely on a single forecast as the most likely scenario (be it the high resolution or the control forecast of the ensemble). All solutions in the ensemble must then be considered when weighing the likelihood of different forecast scenarios . However, until the lead time where an ensemble indicates large forecast uncertainty, a high resolution control forecast can be utilized in the formation of the most likely scenario. Once nonlinearities become dominant, the high resolution control forecast should be considered only to analyze detailed structure of relevant phenomena indicated, but not necessarily resolved well by the lower resolution ensemble members. However, one should keep in mind that the higher resolution control has its own limitations (e.g. biases in two model resolutions may not be drastically different etc). In less predictable situations the most likely scenario can be derived from the ensemble, e.g., the ensemble mean, median or mode.

Assessing forecast uncertainty

So far we have focused on the estimate of the most likely state of the system (first moment). Regarding the important issue of assessing the uncertainty in the most likely forecast (second and higher moments of the pdf), the lower resolution ensemble can be used. As long as the best estimate of the state is based on the ensemble solutions (including the equivalent resolution control that we consider as a member of the ensemble), the same solutions offer a proper way of quantifying forecast uncertainty. For example one can consider the 10, 50, and 90 percentile values in the ensemble distribution at any point and lead time as a simple measure of predictability. If necessary, additional percentile levels can be added, or a detailed pdf can be provided. If the forecaster’s best estimate of the state is based more on the high resolution control forecast, the range of ensemble solutions, with a good approximation, can still be considered for establishing a range of possible solutions as far as the scales resolved by the lower resolution ensemble are considered. Consider a thought experiment where an ensemble with the higher resolution model is run (that we cannot afford in real practice due to computer limitations). We expect that uncertainty regarding the larger scales resolved by the higher resolution ensemble would be very similar to that captured by the lower resolution ensemble. What will be missing from the uncertainty estimate derived from the lower resolution ensemble is related to the smaller scale details that are represented only by the higher resolution model.

These guidelines were written as a first attempt to reconcile the concepts of using single high resolution forecasts and EPS in the weather forecasting process. Many more tools than those described above are available at advanced centres including probabilistic forecasts, assessment of alternative scenarios (clusters, tubes, and other classification techniques). Based on such a rich array of ensemble-based tools, the ET-EPS recommends more widespread use of EPS in weather forecasting.

Developments on post-processing

The aim of post-processing should be to produce a pdf taking account of information from both single high-resolution model run and EPS members. In general it is expected that in short-range forecasts high weight will be attached to the high-resolution forecasts and lower weights to the perturbed members whereas for the longer range forecasts it is expected that similar weights will be applied to all members. Post-processing methods to achieve this are under development.

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1. OPENING OF THE MEETING

1.1 The meeting of the CBS Expert Team on Ensemble Prediction Systems (EPS) was opened at 10:00 a.m. on Monday 6 February 2006 by Mr Steve Noyes, Director of Production of the Met Office UK, at the Met Office Headquarters in Exeter, UK. Mr Noyes welcomed the meeting and stressed its importance for all producing centres of EPS and for the customers of the EPS products. The work continues to require collaboration, among producers, scientists, forecasters, and the customers, while everyone continues to learn how best to use the products. An important issue is how to best communicate probabilistic forecasts to the citizens so that they are conveyed correctly, and used effectively and confidently.

1.2 On behalf of the Secretary General of WMO, Mr Peter Chen welcomed the participants to the Meeting. He noted that there are fourteen meteorological centres around the world that are running ensemble prediction systems. Their ensemble products are of interest to all countries, and some of these predictions can be received by NMCs either through the WWW-GTS, or through Internet access, or through direct satellite dissemination systems.

1.3 The 14th WMO Congress in 2003 noted that ensemble forecasting was becoming increasingly important and was evolving as a vital tool for weather forecasting, and potentially on all time scales (short-range to long-range) of prediction. The interest was still growing, its products being a realization of quantifying uncertainty in the numerical simulations and predictions of the atmosphere.

1.4 Two WMO regional EPS training events were conducted in 2005 (Brasilia in January, Shanghai in April) following a programme that was developed by this expert team. In addition EPS was also presented at a training event in RA I (Africa), where for some forecasters, the subject was a discovery. EPS training continues to be in high demand (e.g. CBS-XIII, 2005). WMO recognizes the lecturers and their home organizations that have dedicated their time and energy to develop materials and deliver the training.

1.5 CBS-XIII (2005) continued to recognize these trends and noted that guidance was needed on how to use EPS products in relation to those from deterministic models, in the preparation of forecasts and warnings. At the same time CBS wished to develop forecasting standards and recommended practices; this could be achieved by developing a guide to the use of EPS in the weather forecasting process. CBS encouraged members to access EPS products of GDPFS centres, while also invited these centres to provide the access information for their respective EPS web-sites. The CBS severe weather forecasting demonstration project seeks to explore a cascading forecasting process, to make NWP products, including those from EPS, more useful to NMHSs of developing countries for forecasting severe weather.

1.6 Mr Ken Mylne, Chairman of the Expert Team extended his welcome to the members of the Expert Team and provided his opening remarks in the introductory section of the meeting (Agenda item 3, below).

2. ORGANIZATION OF THE MEETING

2.1 Approval of the agenda

The agenda of the Meeting was adopted and is given in Appendix I.

2.2 Agreement of working arrangements

The Meeting agreed on its working arrangements and the list of participants is given in Appendix II.

3. INTRODUCTION BY THE CHAIR

3.1 Mr Ken Mylne, the Chairman of the Expert Team provided an overview of the status of the work and the terms of reference of the team. The team first met in Tokyo in 2001 and then again in Geneva in 2003. Reports from both meetings can be found on the WMO website at http://www.wmo.ch/web/www/CBS-Reports/DPFS-index.html. The 2001 meeting focused particularly on the needs of countries which do not have direct access to EPS data and recommended a list of products which might be exchanged to provide such countries with the benefits of EPS. Recommendations were also made on a set of verification procedures, which might be used to assess and compare the capabilities of EPS systems. These recommendations are now included in the Manual on the Global Data Processing System (WMO No 485) following their adoption by subsequent meetings of CBS. CBS has also approved the establishment of a lead centre for the exchange of EPS verification, and has appointed JMA, Tokyo as that lead centre. The 2003 ET meeting focused primarily on the need for training amongst WMO member states, and made a detailed set of recommendations for what should be covered in training and how this might best be achieved. While limitations on funding mean that these recommendations could not be fully implemented, they have provided a valuable framework for two very successful training workshops, which have subsequently been held in Brasilia and Shanghai during 2005.

Terms of Reference

3.2 The Terms of Reference of the ET are wide-ranging. It will be necessary to focus on the issues related to operational capabilities, or operational capabilities expected in the near future, and how we can improve the supply of the benefits of operational EPS and their products to Members of WMO. New ways in which NMHSs are applying EPS in practical forecasting and in their warnings programmes are of particular relevance and interest. At the same time CBS has expressed the need to develop guidance and advice on how to use and apply EPS products, in the context of providing "forecast standards and recommended practices" to NMHSs. A key theme of CBS activities is the prediction of severe weather, including the plans for severe weather forecasting demonstration projects, and the capabilities of EPS to support severe weather warnings are therefore of particular relevance.

3.3 The meeting discussed its terms of reference and concluded that while it is the CBS Expert Team on EPS, its focus is on operational implementation, use and applications of EPS, and that it is primarily concerned with all aspects of the EPS systems which forecast the weather on a daily basis (as opposed to longer-range forecasting where the average weather over a week or longer is predicted). This effectively means that the team should provide advice on EPS in relation to probabilistic forecasts in the context of short- and medium-range EPS products, i.e., the forecast range up to 15 days. The Expert Team recommended that its Terms of Reference be updated to reflect this scope related to time scale of interest.

3.4 The meeting also noted that coordination is needed with other programme areas, such as with the Public Weather Service programme regarding their requirements for EPS products that support probabilistic forecasting, and also with research and development activities (e.g. THORPEX, development of verification systems) that they should recognize existing operational NWP/EPS production and be advised on operational implementation issues, where relevant.

3.5 The Chairman remarked that the membership of the Expert Team should have more representation by NMHSs that do not run their own EPS, and which could represent active users of EPS products in their forecasting systems. The meeting noted the possibility of invited experts to participate at expert team meetings, as appropriate.

Applications of EPS

3.6 Ensemble Prediction Systems are not the only way to provide probabilistic forecast information. Real EPSs provide far from perfect probability forecasts, especially for the surface weather parameters that are of real interest to end-users. Statistical methods have existed for much longer than EPS and are normally much cheaper to run, so are more accessible to many WMO Members. To provide Members with good advice on EPS, it is not appropriate to promote EPS as the answer to all their needs, but to focus on where EPS has demonstrable advantages over other methods. The main advantages of EPS over statistical methods of estimating forecast uncertainty are:

- a spread-skill relationship allows the estimated uncertainty to vary synoptically;
- better estimation of the probability distribution function in extreme synoptic conditions when statistical information is unrepresentative;
- ability to handle meteorologically consistent multi-variate probability distribution functions (e.g. joint probability of precipitation and low temperature);
- meteorologically consistent probability distribution functions at different points in time and space;
- each ensemble member can be used to drive an application model (e.g. wave, hydrology, dispersion) to provide probabilistic forecasts of the application.

3.7 What evidence is there for real capability in these areas? Potential advantages of meteorological consistency can be lost if we need to calibrate imperfect ensemble probabilities. So, in providing objective advice to WMO Members there is a need to focus on where there are demonstrable real advantages of using EPS in practical forecast applications, and not over-promoting ensembles because of our own personal enthusiasm for the science behind them and the personal efforts we have invested in them! With this consideration, the meeting should focus on practical applications and if at all possible those where skill can be demonstrated. If skill can be compared with that of alternative methods such as statistically generated probabilities, that would be particularly useful.

Verification

3.8 The meeting will review the progress with the Lead Centre for EPS verification and the engagement of the operational EPS producing centres to provide their respective verification data. It should also review whether the verifications that were recommended in 2001 are providing the information that producers and potential users require. The verification methods that were recommended are based on the standard tools that ensemble scientists use, particularly for the ability to estimate probabilities. Do these statistics answer the questions that forecast users and managers of forecast centres want answered? For example, managers may want to know whether they can (potentially) get a better deterministic forecast by using an EPS. The spread-skill relationship is a key EPS capability for many applications – should this be verified?

Training

3.9 Training was covered very comprehensively at the 2003 meeting. However, review of any feedback from the workshops in Brasilia and Shanghai would conclude if any changes should be recommended. One aspect of the feedback is the expressed need to develop regional case studies to demonstrate how EPS products could be used and incorporated into the forecasting process, particularly with respect to severe weather forecasting, its strengths and weaknesses. Regional case studies bear numerous potential benefits for the programme.

THORPEX

3.10 THORPEX and TIGGE (THORPEX Interactive Grand Global Ensemble) is a high profile programme for WMO affecting many aspects of forecasting. For CBS it must be recognized that THORPEX is a research project and is not expected to offer much in the way of operational products for some time. While TIGGE will be set up with some real-time data-handling, it will not be designed to provide operational services. Some operational products will become available from the operational NAEFS project which is linked with THORPEX, and it would be useful to review the status of this project. THORPEX does offer some ideas for the way forward for weather forecasting. As well, it is an opportunity for CBS to feed back to THORPEX the operational requirements of Members and to help steer the objectives of THORPEX to produce solutions which meet these needs in the long-term.

Outlook for ET-EPS

3.11 The meeting needs to discuss potential future tasks, such as continuing some current tasks as well as addressing new requirements.

3.12 The meeting noted that the present WMO Manual on the GDPFS (WMO-No.485) does not make reference to statistical post-processing of EPS outputs, while these aspects are important in the enhancement of the accuracy and reliability of the final EPS-based products.

3.13 The team noted that future tasks could include focus on post-processing and applications of the EPS and how to integrate them into the forecast system.

4. ADVANCES IN THE SCIENCE AND CAPABILITIES OF EPS

4.1 Experts made presentations on the status of operational EPS implementations and related developments in their respective centres. The highlights are presented below:

4.1.1 CMA, Beijing

Major advance in China Meteorological Administration (CMA)

1. The major changes in the operational global ensemble prediction system in 2005 are initial perturbation and model resolution. CMA new version global EPS (based on T213L31, 15 members, with BGM perturbation) has been installed on the new operational computation platform, and run in real-time in parallel test with the operational system (based on T106L19, 33 members, with SV perturbation). The results show that the products of new GEPS have larger spread than operational system. The global EPS will be operational running in the spring of 2006.

2. The meso-scale EPS based on WRF (with NCAR dynamic core) is being developed focusing on: a) 3DVAR data assimilation (observation/background error tuning, development of AWS and Doppler radar wind profile assimilation schemes); b) mesoscale model physics (development of cloud physics scheme and city-scale boundary layer scheme, and land surface); c) physics selection and bias remove; d) EPS framework with SMS. Meso-scale EPS will be parallel running and start to provide products during May 2006. The EPS will add components from CMA new generation unified grid model GRAPES in the end of 2006

3. CMA takes part in B08RDP project from 2004, which focuses on high impact weather in summer of Beijing for Olympics Game. B08RDP will closely connect with B08FDP project, which focuses on 0-6 hour now-casting. The significant advances for B08RDP can be found in documents from WMO WWRP/SSC 8th meeting, which was held in Kunming city at the end of October, 2005. In scheduled B08RDP project will take 2 weeks continue tests. The tests will include most of B08RDP meso-scale EPS systems, and focus on 15km system. The second B08FDP/RDP workshop was planed to be hold in August based on those continue test, the topics of workshop will include the advancement of EPS, the verification, the preliminary results, and the key problem and connect with B08FDP.

4. CMA takes part in TIGGE project from 2004, and confirms to be one of three TIGGE data archive centres. Two major operational centre of CMA, National Meteorological Centre (NMC/CMA) and National Meteorological Informational Centre (NMIC/CMA) were undertaken this task. The develop steps for upgrade archive system and internet speed and for TIGGE data storage and archive were started, and phase-1 TIGGE data collection, archive and distribution will be start in spring-summer 2006. The internet user interface and system safety will start in the middle of 2006.

5. The typhoon relocation techniques were transferred from NCEP to upgrade CMA global typhoon prediction system (based on T213L31, with BOGUS). The Global typhoon ensemble prediction system is being developed based on Breeding vector and relocation techniques, and will be parallel running and start to provide products during June 2006.

6. The upgrade of EPS verification system was started from June 2005. The new system was designed to be more flexible, and the verification methods will be increased. This system is also designed to support B08RDP project.

7. The ETKF initial perturbation method for meso-scale model was developed in CMA research department since 2005. Case study was performed and will be pushed to operational running.

8. Plan for training of centre meteorological office forecaster to use meso-scale EPS products is under presents.

4.1.2 JMA, Tokyo

1. Japan Meteorological Agency (JMA) launched its operational EPSs for one-month forecast, one-week forecast, and seasonal forecasts in March of 1996, 2001, and 2003, respectively. At present, the suite of JMA EPSs covers a wide range of forecast periods from early medium-range forecast to seasonal forecast.

2. Products derived from the One-week EPS are routinely used for medium-range forecasting. The low-resolution version of JMA Global Spectral Model (T106L40) and 25 initial conditions generated by a breeding method are used in the One-week EPS for producing an ensemble of 9-day forecasts. JMA will enhance the ensemble size from 25 up to 51 in March of 2006. It is evident from a case study of tropical cyclone (TC) that a 51-member ensemble potentially can have higher capability to capture the observed TC track. JMA also plans to operate a new EPS for TC track forecasting four times a day up to 84 hours in 2007.

3. JMA operates several sites to provide the information on its operational EPSs and their products to the NMHSs of WMO. The One-week EPS products in graphical format are routinely available for access by NHMSs on the JMA medium-range EPS Web site (http://eps.kishou.go.jp/EPSMRF/). Starting from April 2005, the data subset over the South China Sea is routinely provided in GRIB2 format to Hong Kong Observatory (HKO) via the GTS. HKO also receives via the GTS additional EPS forecast data in BUFR format at four points in the vicinity of Hong Kong. Ensemble TC track information encoded in BUFR format is provided to HKO via another Internet ftp site on a research basis

4. When a TC approaches Japan, JMA issues quantitative forecasts such as the maximum rainfall amount in each regional area. JMA is developing new techniques to promote the application of EPS to the quantitative level, since the configuration (spatial resolution, precipitation physics, etc) of the One-week EPS is not adequate to predict the severity of the resulting weather events. A down scale experiment is conducted with JMA non-hydrostatic meso-scale model whose specifications are identical to the operational settings. Experimental results show that the down scale technique enables us to identify the orographic and band-shaped rainfall area.

4.1.3 KMA, Seoul

1. Review

During the past six years from October 2000 to October 2005 Korea Meteorological Administration(KMA) has operated a global NWP model (T213L30) in the Global Data Assimilation and Prediction System (GDAPS) twice a day to produce 10 days forecasts KMA has also run a global EPS model (T106L30) with 16 members in the Global Bred-vector Ensemble Prediction System (GBEPS) once a day to provide 8 days forecasts. In addition, KMA has run regional models with both high (10 km) and low (30 km) horizontal resolutions in the Regional Data Assimilation and Prediction System (RDAPS) to produce short-range forecasts. The supercomputer NEC/SX5 has been dedicated to the operational works before it stepped down. KMA has been providing verification data once a month to the Lead Centre, JMA.

2. Present status

A new supercomputer Cray X1E was introduced in KMA in November 2005. It is fully dedicated to the operation of all NWP models with the maximum peak speed of 4.4 Tera flops and the main memory of 3.8 Tera bytes. KMA was motivated to upgrade both the GDAPS and RDAPS. In the late 2005, the new GDAPS (T426L40) started to produce 10 days forecasts with the data assimilation (Unified 3dVar). The GBEPS increased its horizontal and vertical resolutions to T213L40 and produced 8 days forecasts with expanded 32 ensemble members. The global model (GDAPS) produces 10 days forecasts twice a day. At the same time KMA is testing a new regional model (WRF) with the horizontal resolution of 10 km and the vertical resolution of 30 levels to produce short-range forecasts.

3. Plan for coming year and near future

The current status and future plan for development of KMA's operational models is described in the table given below. Test of the 4dVar data assimilation for both global and regional models will continue in parallel with operational models. In 2007, KMA will increase the vertical resolution up to 70 levels in the global model. In 2008, the 4dVar data assimilation will be operational for both global and regional models

Table. The current status and future plan for KMA's operational models..

Year	Data assimilation	Global model	Regional model	Ensemble model
2005	Test of Unified 3dVar, and direct satellite assl. of AMSU-A (AQUA)	Test of high resolution versions, (T426L40, YOURS)	Test operation of WRF (10km L33)	Increase members from 16 to 32
2006	Unified 3dVar with COSMIC GPS AIRS, AMSU-B, AMSR-E	Operation and tuning of high resolution global model (T426L40)	Operation of extended domain of WRF (10km)	Increase resolution from T106L30 to T213L40 (32 members)
2007	Test of 4dVar	Increase vertical resolution to L70	Operation of WRF (5km L40)	Increase members from 32 to 50
2008	Operation of 4dVar	Tuning of physics	Test of WRF (1 km L70) for very short range forecast of severe weather	Tuning of physics

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4.1.4 CPTEC, Brazil

<u>CPTEC EPS SYSTEM</u>

1. The Centre for Weather Forecasting and Climate Studies (CPTEC) of the National Institute of Space Research in Brazil is the only operational meteorological institution in South America to process EPS based on perturbations of the initial condition in S. America. The CPTEC operational forecasting suite runs on a computer system based on a NEC-SX6 system with 12 nodes (8 processors each) with almost 1Tf peak performance. Following a method developed at Florida State University, an Empirical Orthogonal Function analysis is performed on the difference

between an unperturbed 36-hour integration and a randomly disturbed forecast (temperature) with amplitude similar to the typical forecast errors. The perturbations are applied over a target area, which is supposed to have stronger impact in the forecast error of the area of interest (in this case, South America). The eigenvectors (spatial structure) associated to the largest eigenvalues are associated with the fastest growing disturbance, which are considered to be the optimal perturbations to be applied to the control initial condition after appropriate rescaling.

2. CPTEC current EPS system is based on 15 perturbed initial conditions, twice a day (00 and 12 UTC), integrated up to 15 days with the CPTEC global model at T126L28 resolution. The control simulation is the unperturbed initial condition forecast at the same resolution of the ensemble members. A high resolution T213L48 forecast up to 7 days is also used in the analysis. The products are: spread diagrams, spaghetti diagrams: probability forecasting, probability plumes and clustering analysis. Clustering is based on the determination of pairs of forecasts, which minimize the sum of the square of the distance between the mean of the group and each member. Products are available at a public homepage (www.cptec.inpe.br/ensemble). The system has been used as a forecast guidance tool for the medium range forecast provided by CPTEC. Some outside users make use of numerical products of the EPS system, primarily precipitation products, in agricultural and water resources applications.

3. The CPTEC EPS system has been shown to provide significant improvement of the forecast over South America. The initial perturbation system focus on the best representation of the perturbations over South America and it does not aim large spread at higher latitudes in the northern hemisphere. Comparison of the precipitation skill of the CPTEC EPS system with the high resolution or control forecasts reveals significant gain in most weather patterns, throughout the year. The experience with the CPTEC EPS indicates that there are periods with considerable extension of the forecast skill, sometimes up to 10-12 days. Some intraseasonal variability of the forecast skill of the extended range EPS has been detected and current research is focused on the diagnosis of the relationship with the Madden Julian Oscillation.

4. Immediate future plans include increased horizontal resolution (T170) and number of vertical levels (42) and the operational introduction of a 30 day forecast, twice a day, based on a coupled atmosphere ocean model (already in an experimental cycle) to explore predictability associated with the intraseasonal oscillation in the tropical region. Experimentation with initial perturbations in the wind and moisture field may lead to changes in the operational system in the near future, depending on the evaluation in the parallel cycle.

4.1.5 MSC, Montréal

Advances in the Science and capabilities of EPS at CMC

1. Review of recent implementations at CMC

The Canadian Meteorological Centre (CMC) runs a 17 member (16 perturbed + control) multi-member global ensemble system that produces 16 day forecasts twice a day (00 and 12 UTC). CMC implemented two major changes in the global Ensemble Prediction System (EPS) in 2005:

1.1. In January, implementation of the Ensemble Kalman Filter (EnKF) method (Houtekamer and Mitchell, 2005) in replacement of the OI method to produce the initial perturbed analyses.

1.2. In December, a new set parameterization schemes were introduced in the multi-model EPS system. Two main changes were introduced: replacement of the Manabe scheme by the Arakawa-Schubert (RAS) convection scheme in four SEF members and introduction of the ISBA surface scheme in half of the members.

2. Post-processing

2.1 Bayesian Model Averaging. The Bayseian Model Averaging (BMA, Wilson et al 2006) has been applied to generate surface temperature probability distribution function (PDF) over Canadian stations using the global EPS from CMC. BMA allows the construction of PDF as a weighted average of PDF's centered on bias-corrected individual forecast from each member of the EPS. The weights are the posterior probabilities of each member to be correct. The forecast error PDF's, standard deviation and weights are calculated over a 40-day training period. The weights reflect the relative contribution of each member to the overall accuracy during the training period. Generally, only a few members contribute significantly to the BMA PDF, but over the course of a year, it is not the same members that contribute all the time. The average weight assigned to the high resolution deterministic model as a member of the ensemble is also possible in BMA. For example, forecast temperatures can be expressed in a range with confidence of 80%, based on the last 40 day verification.

2.2 North American Ensemble Forecast System (NAEFS). The first step of the NAEFS work plan, e.g. exchange of raw EPS data, is almost finalized. The next step will be to formally exchange scripts to unbias first moment of data and to produce climate anomaly products. All of these will be one in Grib2 format. This step should be finalized in May 2006.

3. Verification

3.1 WMO verification. Canada has participated in the exchange of EPS verification as described by the EPS ET document meeting in Tokyo 2001. RMS verifications and contingency tables are being sent to the RSMC Tokyo.

3.2 Real time verifications of individual EPS members were introduced in 2004 to monitor the performance of the EPS.

3.3 Verifications using the Continuous Ranked Probability Score (CRPS) have started to be used to evaluate the value of recent changes implemented in the Canadian EPS. Bootstrap technique was also applied in order to define confidence intervals for the comparisons, with confidence interval from 5% to 95% for verification with respect to observational data.

4. Plan for coming years

4.1 **Increased resolution and members**. We hope to increase the resolution of EPS members from 1.2° to 1° resolution and increase the number of members from 16 to 20 in the next year. In order to increase the number of members, we hope to move away from the physical parameterization combination and implement a stochastic physics technique.

4.2 **Improvements of the EnKF.**

- 4.2.1 Increase the resolution model to 1° within the EnKF dataflow.
- 4.2.2 Change the EnKF set-up so that it can assimilate all data in a 6-h window at the appropriate time as is currently done in 4D-Var algorithms.

4.3 **Wave forecasts**. EPS models will be used to drive global wave models and to eventually produce probabilistic wave outputs.

4.4 **More products**. Work will also be done on products to support forecasters and aid in decision-making. This will be done at CMC but also through increasing collaboration through NAEFS.

- 4.4.1 Public forecasts will increasingly make use of EPS outputs, so that probabilistic products can be included (e.g. temperature ranges);
- 4.4.2 Public forecasts lead time will be increased from 5 to 7 days (eventually to 10 days) and ensemble outputs will be used to improve the quality of medium-range forecasts;
- 4.4.3 Week 2 (7-15 day) temperature and precipitation anomaly charts to be produced through the NAEFS agreement;

4.4.4 Charts with probabilities for a variety of weather elements will be generated (wind over certain values, temperature below/above zero, zones with precipitation of 10, 25, 50 mm/day, etc).

4.5 **Short-range EPS:** In the more distant future, it is planned to create a regional EPS with higher resolution members, 48-hour forecasts and geographical coverage limited to North America.

5. Conclusions.

The EPS has been operational for several years but now its use in preparing official forecasts will be growing. Its outputs, available from http://meteo.ec.gc.ca/ensemble/index_e.html, serve as guidance for meteorologists issuing official forecasts. These products are tailored for North America. To make up for this limitation, a large number of raw global EPS outputs are available at CMC, via FTP anonymous in GRIB format. Two sets of resolutions are available: coarse resolution (2.5° X 2.5°) and native resolution (1.2° X 1.2°). The complete set of variables is available on demand. The volume of the complete data set (all members, all time steps, all variables, all levels) is ~700 Mbytes for the native resolution (~165 Mbytes for the coarse resolution), each 2D field taking about 55 Kbytes (13 Kbytes for the coarse resolution).

4.1.6 MétéoFrance, Toulouse

1. Presentation of the system

An ensemble prediction system (PEACE system) is running operationally at Météo-France once a day (at 18UTC) since June 2004. The perturbations used in the ensemble are generated by the singular vectors technique. Nevertheless, vectors are optimized at 12h over a limited area included the Western Europe and the northern part of the Atlantic Ocean. By this way, perturbations are mainly efficient in area of interest for the short range forecast over France. Because of heavy computational cost, the ensemble is limited to 11 members (10 perturbed + 1 control). Nevertheless, it is based on the operational version of the ARPEGE model with a spectral truncation of TL358 with a stretching coefficient of 2.4 (corresponding to a grid mesh of 23 km over France and 100km over New-Zealand). As the perturbations are regional and even the model is global, this EPS could be considered as a regional EPS.

2. Products

Different standard products are provided to the forecasters: stamps, mean and spread fields, probability charts for different thresholds. These products are available on SYNERGIE, the visualization tool developed at Météo-France. Other specific products such as vertical integrated singular vectors energy or low centers trajectories plumes are also available on an internal web page.

3. Applications

The main application is the short-range probabilistic forecast. The system provides an help to the forecasters in their short-range guidance: it gives complementary information especially when models disagree in perturbed situation. This results to a multi-model (deterministic information from different models) and multi-EPS approach (complementary probabilistic information from different ensembles).

Some automatic applications have been also developed: Mixt EPSgrams (PEACE for the 2 first days then ECMWF EPS for the 7 next days with a link between the 2 systems, the idea being to take advantage from the PEARP high resolution for the short range.

More and more customers are interested in probabilistic products and ensemble distributions (energy supplier, road supervisor, civil engineering...)

Other applications : probabilistic forecast for hydrology, atmospheric and marine pollutant and wind power production, will be carried on.

With the PEACE system, Météo-France is also involved in EURORISK project (windstorm package) and will participate in the TIGGE phase I.

4. Post-processing

Regional EPS are directly useful for local probabilistic forecast (e.g. EPSgrams). For that reason, it is especially important to provide unbiased and reliable forecast. In that way some post-processing methods are applied to ensemble distributions. A statistical adaptation is firstly used for bias correction. Then a calibration is applied to ensure a good reliability to the probabilities. In the operational configuration this calibration is realized by using rank diagrams.

5. Future plans

Different ways of improvement of the system will be studied: increase of the final step from 60 to 108h (in test), use of evolved perturbations and transformation of initial perturbations according to statistical analysis errors. New post-processing methods such as Bayesian Model Averaging, statistical methods to assess uncertainty will be tested.

4.1.7 Met Office, UK

MOGREPS – Met Office Global and Regional Ensemble Prediction System

1. The UK Met Office introduced a new short-range Ensemble Prediction System based on the Unified Model during 2005. MOGREPS (Met Office Global and Regional Ensemble Prediction System) provides a 24-member regional ensemble covering the North Atlantic and Europe with a grid-length of 24km, running twice daily (06 and 18UTC) to 36 hours ahead. A global ensemble with grid-length of 90km runs twice daily (00 and 12UTC) to 72 hours to provide the boundary conditions for this regional ensemble. Initial condition perturbations are provided through the ETKF (Ensemble Transform Kalman Filter) method calculated using the global ensemble, and are added to the global 4D-Var analysis. At present 6-hour old global perturbations are also employed in the regional ensemble, added to the regional 3D-Var analysis, but future plans are to introduce a separate regional ETKF.

2. Two stochastic physics schemes are employed to account for model error in assessing forecast uncertainty. In the Random Parameters scheme, tunable parameters in several of the model parameterization schemes are perturbed randomly within an appropriate range to represent the uncertainty in the grid-box average parameterization. In the Stochastic Convective Vorticity (SCV) scheme randomized potential vorticity anomalies are added to the model where organized mesoscale convection is diagnosed to represent the uncertainty in the feedback of such systems on the larger scale flow. This SCV scheme is only used in the global ensemble as such systems are better resolved in the regional model. A third scheme, SKEB (Stochastic Kinetic Energy Backscatter) has also been developed but is not yet implemented. SKEB aims to replace energy which is dissipated excessively in the model at the grid scale by the semi-lagrangian advection and horizontal diffusion schemes. This energy is reinjected at small scales as PV anomalies on a random field, scaled according to the local kinetic energy. The SKEB scheme is more effective than the other two schemes and will be implemented in both ensembles during 2006.

3. Chart-based and site-specific forecast products are provided to forecasters in real-time on an internal web-based system. As the ensemble is intended for short-range forecasting, particular emphasis is put on products to estimate uncertainty in surface weather parameters. The system is currently running under *operational trial* and is being assessed daily by forecasters, but is not currently available for production. It is hoped to start operational running in late 2006/ early 2007 to provide estimates of uncertainty in short-range forecasts including automated products. Objective verification is also being set up and results will be provided to the Lead Centre for EPS Verification when available. It is planned to extend the global ensemble forecasts to 15 days as a contribution to the THORPEX TIGGE project.

4. In parallel with the development of MOGREPS the Met Office is developing new products to present uncertainty to users and the general public. It is planned to trial products including uncertainty measures on the Met Office website during 2006.

4.1.8 MétéoSuisse, Switzerland

COSMO (reported by MétéoSuisse) - Present state and short range plans in EPSs in the COSMO consortium

1. The COSMO consortium gathers Germany, Switzerland, Italy, Greece, Poland and Romania as member states. Its aim is to develop a non-hydrostatic mesoscale model called the Local Model (LM). The model, in various configurations runs operationally in all member states.

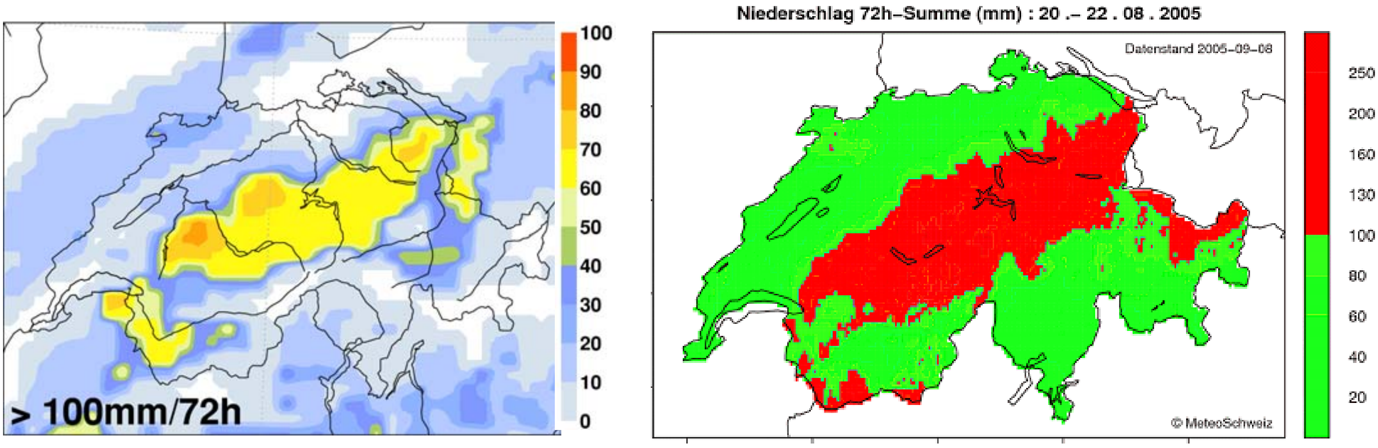
The COSMO LEPS

2. The LM is also used to downscale the ECMWF EPS. The system is called COSMO LEPS (CLEPS). The CLEPS provides a local adaptation targeted on days 3 to 5. A clustering is performed on two consecutive runs of the ECMWF ensemble resulting in 102 members. Sensitivity tests have been carried out in order to optimize the area, the parameters and the algorithm for the clustering. The use of ECMWF moist singular vectors has also been tested in a few case studies (mainly storm lows) and has proven to be beneficial in these cases.

3. The operational setup includes 10 members (16 starting from the 6th February 2006) at a resolution of 10 km. One central member of each ECMWF cluster is chosen to provide the initial state and the boundary conditions for the LM integrations. Half of the integrations use the Tiedke scheme for convection, the other half Kain-Fritsch. No other perturbation in physics is performed.

4. The system has been running is this state since June 2004 and a complete verification report has been produced (www.cosmo-model.org/public/technicalReports.htm, Technical Report No. 8, Evaluation of the Performance of the COSMO-LEPS System). The main findings are the following:

- The CLEPS outperforms the non downscaled EPS for all “strong” events (e.g. precipitation above 10mm/24h). To remain fair, the comparisons have been performed on observations upscaled to the resolution of the global EPS.
- The comparison with statistical downscaling and rescaling (EFI) is somewhat difficult to realize. However all methods produce a quite high rate of false alarms. More precisely, if the threshold in probability (or EFI value) is chosen low enough to provide a high probability of detection, the false alarm rate is also high.
- Local details on extreme events can be cached well. This can be seen in the cases of the Elbe flood (2002) and the flooding of central Switzerland in 2005 (see illustration)



The figure on the left shows the probability that the rainfall amount exceeds 100mm in 3 days, valid for the period 20th to 22nd August 2005. The analysis date is the 19th August at 12z. On the right, a high resolution analysis of over 400 rain gauges for the same period and the same precipitation threshold is displayed. Locally over 300 mm fell and return periods far above 100 years have been calculated. The local details are remarkably well captured. Even the forecast for 250mm in 3 days showed probabilities of about 40% at the correct place.

The SREPS project

5. The SREPS project started in December 2005 and its aim is to produce a short-range mesoscale ensemble to improve the support of the forecasters especially in situations of high impact weather. It should also help to produce a very short-range ensemble for data assimilation purposes (COSMO SIR project).

6. The strategy for generating the ensemble members is to take into account all the possible sources of uncertainty and to model many of the possible causes of forecast errors. The proposed system will benefit of: perturbations in the boundary conditions, perturbations of the model and perturbations of the initial state.

7. The system will use the MUlti-Model MUlti-Boundaries (MUMMUB) ensemble currently developed at INM (Spain). Four different limited-area models (UM, HIRLAM, HRM, MM5) are driven by the four global models (IFS, GME, UM, NCEP) which provides initial and boundary conditions. The LM at a resolution of 25 on a domain covering the North Atlantic and Europe will be added to this set providing four different sets of initial states and integrations. These will each drive a number of LMs at higher resolution (7 or 10 km). Each of the 25 km LM runs provides initial and boundary conditions to a few higher resolution LM runs, in which other perturbations are applied.

8. The SREPS strategy includes the modelling of different sources of forecast error. With regards to the model error, perturbations to the mesoscale model will be added following different techniques: by using different parameterization schemes, by perturbing the parameters of the schemes, by perturbing the physical tendencies.

9. The SREPS ensemble will be designed keeping in mind that it could be used for the new COSMO data assimilation scheme (SIR project). The general idea of this technique is to run an ensemble a time range of 6 to 12 hours and to keep as analysis the member corresponding best to the observations at this time step according to some distance. Much attention will be kept in having a correct amount of spread both in the very short range and throughout all the short-range. The use of a multi-model approach with a limited-area model permits to have a strong link also with the global project TIGGE, where all the available global ensembles will be collected together with the possibility to be used as providers of boundary conditions for limited-area models.

4.1.9 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 will occur in May 2006. Within the NAEFS, ensemble producing centers (currently MSC and NWS) (1) exchange their raw forecast data (operational since September 2004); (2) statistically post-process 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 and the corresponding weights and climatological percentile values. The generation and free ftp distribution of these basic products will be operationally implemented in May 2006.

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. Some of the end products will be 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. Due to the limited bandwidth, end products for these areas will be distributed via the web, beginning in the second half of 2006.

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), and the Japan Meteorological Agency (JMA) expressed an interest in joining the NAEFS as producing centers, 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.

4.1.10 ECMWF Ensemble Prediction System

An Ensemble Prediction System is run at ECMWF twice per day (00 and 12UTC). 50 members (+ one control forecast) are run for 10 days at resolution T399L62 with a 30 minutes time step. Initial perturbations are generated by multidimensional Gaussian sampling from 50 singular vectors (SV) calculated at T42 resolution in the extratropics, plus up to 30 SV (5 per TC) 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.

Variable resolution EPS

1. During 2006 it is planned to extend the forecast range of the EPS to 15 days. To achieve this within available computing resources, the final part of the forecast (Days 11-15) will be run at reduced horizontal resolution (T255). In future it is planned to integrate this Variable Resolution EPS (VAREPS) with the monthly forecast system (currently run once per week using a coupled atmosphere-ocean EPS at T159 resolution). This is part of the ECMWF strategy to work towards a unified ensemble forecast system covering different time ranges. A significant effort will be required to develop products suitable for the developing VAREPS system, to give appropriate guidance for different forecast timescales and to maximise compatibility and consistency of products.

Initial perturbations

2. The impact on the EPS of varying the number of extra-tropical singular vectors (SVs) used to construct the initial perturbations has been examined. Five ensemble configurations using 8, 16, 25, 50 and 100 extra-tropical SVs were considered. The spread is quite similar in all five configurations because the width of the sampled Gaussian distribution decreases with increasing number of SVs. Results based on 27 cases suggest that ensemble scores saturate around 50 extra-tropical SVs.

A revised configuration of the Gaussian sampling was developed. This uses 50 instead of 25 extra-tropical SVs, normalised evolved SVs, and a new algorithm to scale the initial perturbation amplitude. Plus-minus symmetric initial perturbations of pairs of members are produced.

The new configuration leads to a moderate spread reduction (largest in the early ranges) that improves the match between ensemble spread and error of the control forecast. The normalisation of the evolved SVs results in a geographically more homogeneous initial spread which is more consistent with the assimilation scheme's estimate of the standard deviation of analysis errors. The new algorithm to scale the perturbation amplitude is more consistent with the multivariate Gaussian sampling approach and yields a significant speed up of the task that generates the initial perturbations from the singular vectors. The impact on probabilistic scores of extra-tropical height anomalies is positive in both hemispheres and in particular for Europe. The introduction of a plus-minus symmetric sampling approach renders the ensemble mean at initial time identical to the control forecast. Thereby, the RMS error of the ensemble mean is reduced.

Model tendency perturbations

3. The impact of adding a new scheme to perturb model tendencies based on a Cellular Automaton Stochastic Backscattering Scheme (CASBS) has been tested at various resolutions (TL159-TL799) and for a range of parameters controlling the spatial and temporal scales as well as the amplitude of the backscatter forcing. The scheme introduces more variability at the near-gridscale, which seems to have a positive impact on the kinetic energy spectrum. CASBS can increase ensemble spread in the late medium-range more than operational stochastic physics. Further tests to determine the optimal ratio of initial to tendency perturbation amplitudes are required.

Another scheme to perturb tendencies based on Cellular Automata is under development. It attempts a better representation of the Madden-Julian oscillation by adding a non-local stochastic forcing in the tropics. This forcing aims at modelling subgrid-scale fluctuations of convective processes that are not represented by current convective schemes. In order to model eastward propagating convectively organized cloud-clusters as well as individual westward propagating convective cells, a multi-scale cellular automaton has been developed outside the IFS. Tests will be performed as soon as the code is integrated into the IFS.

Calibration and combination

4. A systematic investigation of the impact of various calibration and combination methods on the forecast quality of the EPS has been started.

In order to assess the potential benefits of a simple bias-correction scheme, a limited set of re-forecasts for the period 1980 - 2001 has been produced. Not unexpectedly, the potential to reduce the bias varies with lead-time, variable, and season considered. It seems e.g. that shorter lead times and 2m temperature benefit more from bias correction schemes than longer lead times and mean sea level pressure forecasts. It is planned to extend these investigations to include more advanced methods like logistic-regression. However, to be able to test such methods, additional re-forecasts (including not only the control but also a number of perturbed ensemble members) have to be produced.

The potential benefits of combining information from the high-resolution deterministic forecasts with 00z and 12z ensemble forecasts have been tested with the so-called Bayesian Model Averaging (BMA) scheme. This post-processing scheme does not rely on long re-forecast data sets but uses only information from a limited number of recent forecasts (e.g. the last 40 days of forecasts). Based on this training data set different weights are applied to the high-resolution deterministic, the control and the 00z and 12z perturbed forecasts. First results suggest that it might be difficult to achieve significant improvements of the un-weighted ECMWF EPS with this scheme. However, more detailed investigations and diagnostics are necessary, in particular in view of the expected activities related to the emerging TIGGE project.

4.1.11 The expert member from NMS Morocco was unable to participate at the meeting, however submitted a report on its activities in EPS. The report is annexed to this paragraph.

Additional general observations about the scientific advances in EPS

4.2 The meeting discussed the utility of EPS products in relation to the outputs of the single high resolution NWP run, referred to as the “deterministic” run that is usually of higher model resolution than that of the EPS members. It was agreed that the two kinds of outputs should be examined together, that the EPS could provide an indication regarding the forecast range during which the high resolution “deterministic” run is likely to provide the best forecast, and when the EPS outputs should receive greater consideration. The EPS outputs could be used to provide an estimation of uncertainty of the forecast. This subject was further discussed under agenda item 11.

4.3 The meeting discussed the issue of using the EPS to generate a “confidence index” for forecasts and how to present it to the public. Components of the forecast may have different levels of confidence. There is currently no consensus on how best to achieve this.

5. EPS OUTPUT PRODUCTS REQUIRED FOR INTERNATIONAL EXCHANGE FROM GDPFS CENTRES

5.1 The Meeting reviewed the current paragraphs in the WMO *Manual on the Global Data-Processing and Forecasting System* (GDPFS; WMO-No-485) relevant to EPS. The Expert Team noted that some of the products on the list of products that have been specified for international exchange (Volume I, Part II, Appendix II-6, paragraph 4.1) are available on the Web-sites of some of the EPS producing centres. Producing centres are encouraged to maintain their Web-sites, and provide up-to-date access information to WMO Members, e.g. via the Secretariat. A very limited number of products from some centres is available on the GTS, but the team noted the capacity of the GTS severely limits its use for distributing EPS products.

5.2 In addition to the existing EPS products required for international exchange listed in the Manual, the following additional kinds of graphical products are recommended to be added to the list:

- 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.

This product can be used in severe weather forecasting.

5.3 Centres are encouraged to provide additional products related to severe weather forecasting such as the EFI developed at ECMWF (see agenda item 7, below). The team noted that new products may not always have been fully assessed for all areas of the globe but that producing centres are encouraged to make them available with suitable caveats, and invite feedback.

5.4 The list of EPS products required for international exchange, listed in the Manual on the GDPFS should be revised to incorporate this addition. It is recommended that the Secretariat revise this text for inclusion into the next revision of the Manual.

5.5 The present list of EPS products for international exchange provides sufficient basic data to develop products in applications in the Tropics (e.g. Easterly waves), although the performance of the present EPS outputs are generally unverified for the Tropics.

5.6 The meeting noted that while a number of diagnostic parameters or indices are defined in the literature (e.g. measures of stability for forecasting convective weather, e.g. CAPE, CIN), the method of computation based on NWP/EPS outputs have not been standardized. The meeting recommended that such standards for calculation be developed so that product could be developed with a common method of calculation.

5.7 The ET-EPS noted that the multi-center NAEFS project plans to begin the distribution of user specific end products on its web page in the second half of 2006.

6. SHORT-RANGE AND REGIONAL EPS SYSTEMS

6.1 The meeting noted that increasing number of centres are developing and implementing regional EPS important in short-range forecasting. By their nature, these products are limited in regional coverage, but regional exchange of these products is strongly encouraged.

6.2 Short-range EPS systems are attempting to address forecast uncertainties in the prediction of localized weather parameters (e.g. precipitation) that are quite different in objectives and approach from those in medium-range EPS systems. Different perturbation methods are being developed to account for forecast uncertainties in the parameterization of physical processes that are important to the prediction of surface weather conditions in the 1- to 3-day forecast range.

6.3 There is encouraging evidence that high resolution regional ensembles can provide useful guidance on uncertainty in the forecast of local-scale surface weather parameters of particular interest in the short-range (e.g. wind speed, precipitation intensity, visibility).

6.4 Producing centres are encouraged to provide updating information on their activities in this area.

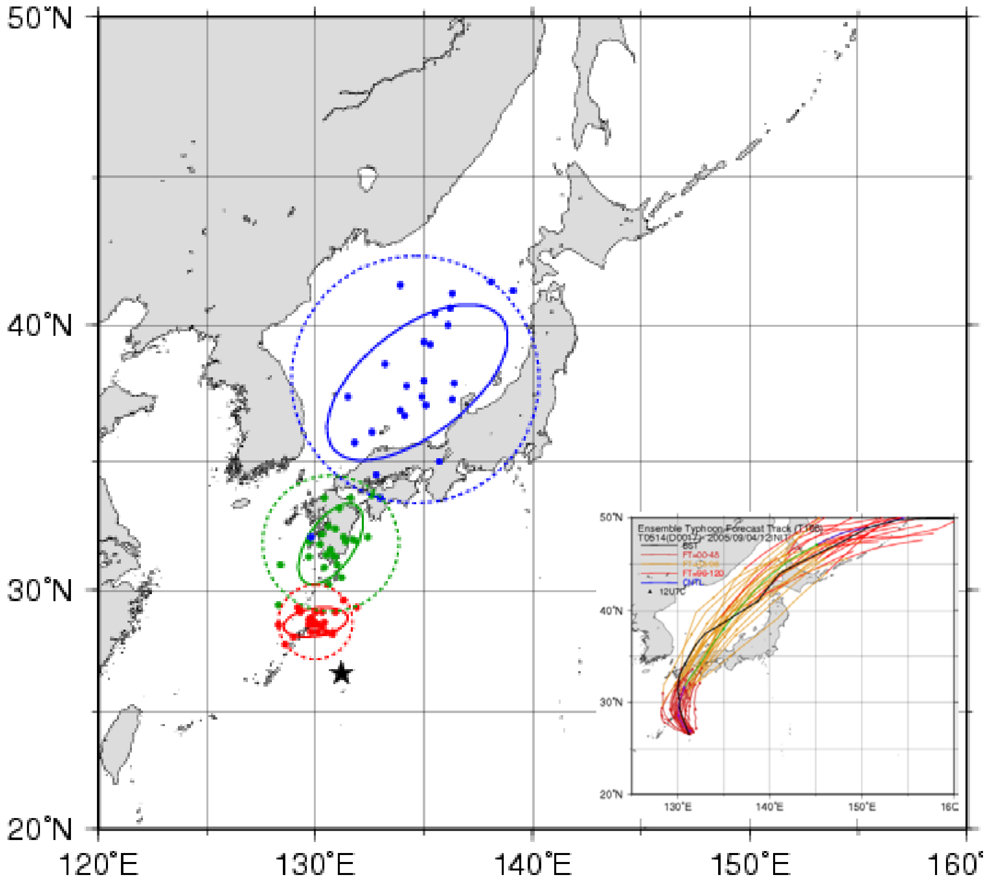
6.5 It was also noted positively that regional groupings of NMHSs are an effective approach to derive benefits from regional EPS systems for the group of countries and centres involved. Example include:

- the COSMO-LEPS which provides regional downscaling of ECMWF global ensemble;
- The EUMETNET SRNWP-PEPS project (a poor-person’s ensemble combining data from different countries’ regional scale models), or
- the South American centres that developed collaboration over the Plata region (MASTER Super Model Ensemble System),

6.6 This concept of collaboration could lead to the development of regional specializing EPS centres that would provide EPS products for NMHSs in a geographical region.

7. APPLICATION OF EPS FOR SEVERE WEATHER FORECASTING

7.1 Experts from JMA, Met Office UK, CPTEC, and NCEP made presentations on how EPS are or could be applied to severe weather forecasting.



Example of geographical type of probabilistic TC warning. Dots are TC positions derived from 25 forecasts in the JMA One-week EPS. Solid and broken circles indicate the type in the development stage and the current stage, respectively. Red, green, and blue represent the lead-time of 24, 48, and 72 hours, respectively. Ensemble TC tracks (colored lines) up to 5 days derived from the JMA One-week EPS and the corresponding observed track (black line) are also shown on the lower right panel.

7.2 JMA showed its EPS applications in its Tropical Cyclone forecasting system, and its Numerical Typhoon Prediction Web-site where it collects and processes track forecasts from 8 contributing NWP centres. Training information is linked to through the JMA medium-range EPS Web-site. An example of a new product "geographic forecast circle" is presented in the figure below. The team particularly liked this product because it displayed the synoptically dependent uncertainty available from the EPS compared to the circles from the climatological error statistics.

7.3 Met Office UK showed its EPS-based system for alerting forecasters in the cases of severe gales, heavy rain and heavy snow in the UK up to 5 days ahead. The system recommends issuing of a warning when the EPS-based probability of exceeding a predefined threshold exceeds 60% (a limit agreed with severe weather warning customers). It was noted that after calibration there is a good relationship between forecast probability and frequency of occurrence. Most severe events can be forecast, but at low probabilities. This means that decision strategies need to make effective use of low probability warnings.

7.4 NCEP showed its application of the "relocation" technique that adjusts the initial central location of tropical storms for each EPS member to the actual location before the EPS run. The introduction of this method has reduced the track error and uncertainty of the EPS-based tropical cyclone track forecasts in the short lead-time range (1-3 days). The ensemble mean of the track forecast is consistently better than the track forecast of the single high resolution NWP run.

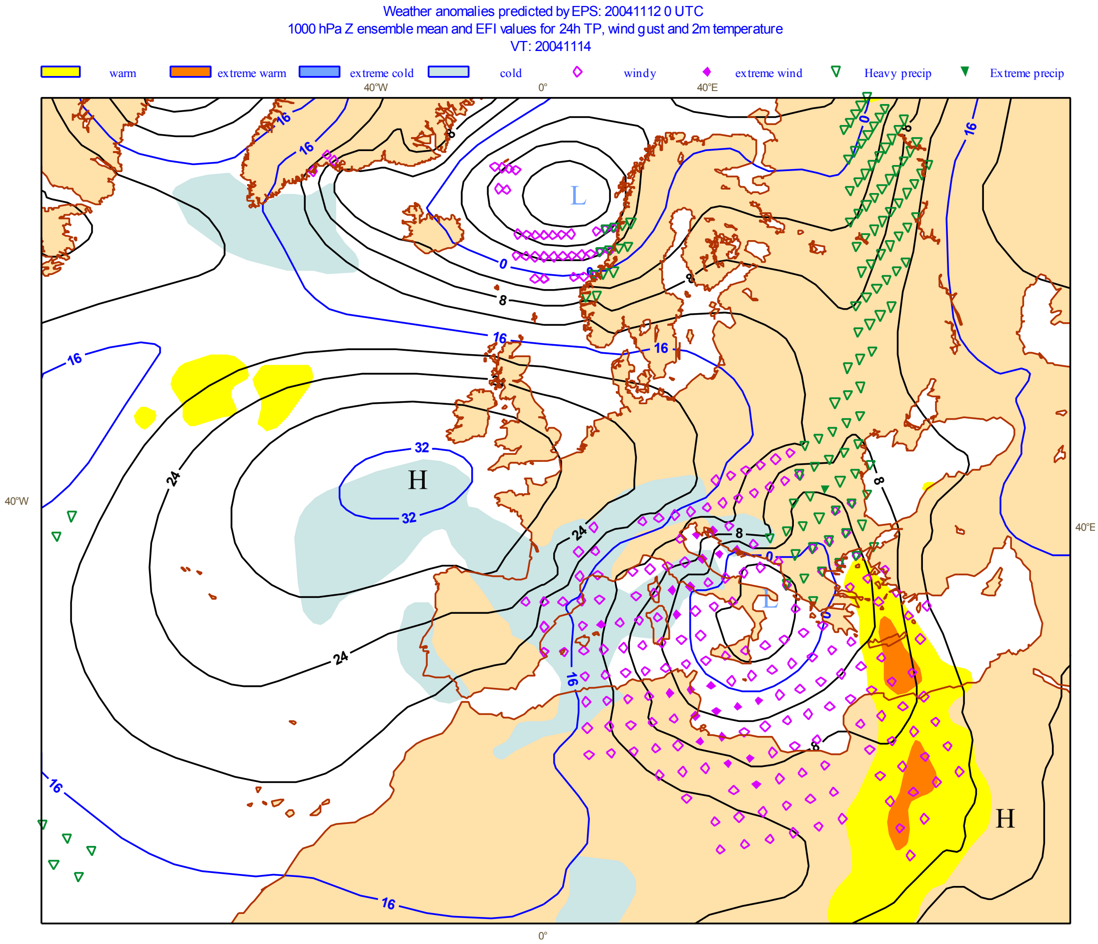
7.5 In order to develop new EPS-based products, it was suggested that the lists of candidate parameters that have been developed for THORPEX and NAEFS be examined. EPS producing centres could explore developing a few products that depict parameters and their associated probabilities that are important to severe weather forecasting.

7.6 The meeting suggested that since EPS producing centres are developing and implementing diagnostic methods and products for severe weather applications for their national requirements, it could be useful to either extend some of these applications to other NMHSs or to provide access to their EPS products or datasets and assist other NMHSs to develop for themselves suitable tools for severe weather forecasting relevant in their own regions of interest. Illustrative examples could be documented and made accessible to NMHSs. The ET-EPS noted with interest the plans of the operational multi-center NAEFS to produce and distribute on its web site weather forecast information, including end products for use in severe weather warning activities. This is occurring in the NAEFS and similarly encouraged elsewhere.

7.7 The forecasting of extreme weather events has become increasingly important in the last few years. The resolution of global EPS models is not sufficient to directly predict the intensity of severe events. Appropriate post-processing and calibration of EPS fields is required. While for specific events relevant diagnostics may be devised, a more general approach may also be useful. Although it may be difficult to predict absolute values, comparing an EPS forecast to a model climate distribution can indicate times when the EPS predicts an increased probability of an extreme event.

Extreme Forecast Index, ECMWF

7.8 The Extreme Forecast Index (EFI) was developed for the ECMWF EPS, to help the forecasters to synthesize the deviation from climatology of the EPS forecasts. This EFI is an integral measure of the departure between the EPS forecasts and the reference climate distributions. The figure below shows an example of an EFI map that shows areas of potential extreme precipitation, 10m winds and 2m temperature on the same plot.



Extreme Forecast Index for 2-m temperature (colour shading), 10-m windspeed (diamonds) and precipitation (triangles), predicted over Europe and the Atlantic valid 14 November 2004.

7.9 The current EFI climatology is generated from a set of EPS control forecasts run from ERA-40 analyses from 1971-2000. For the current day, the EFI climate distribution is composed of the sub climate sample of 31 consecutive days (±15 days), giving a sample of 930 (30*31) each day. The climate runs are updated daily using the operational model so the climatology will always match the current EPS.

7.10 The climate distributions and therefore the EFI values occasionally can show quite large differences depending on the climate sample and model version. First steps to verify the EFI against observations, using additional information from the Meteo-France (EUMETNET/ECSN) station Climate Atlas for Europe, have already been taken. Further evaluation of the EFI is needed.

7.11 Another method applied to severe weather forecasting is dynamical downscaling using regional models to resolve greater detail in weather parameters particularly over topography. A good example of this is the COSMO-LEPS which was developed to focus on forecasting precipitation events over the Alps.

8. EPS VERIFICATION

8.1 JMA presented its report as the WMO Lead Centre for EPS Verification. CBS-XIII (2005) recommended that the general responsibilities for a Lead Centre for Verification of EPS be added to the *Manual on the GDPFS* (WMO-No. 45) and that its President designate RSMC Tokyo as this Lead Centre. Since January 2004, JMA has operated two Internet sites: a FTP-site (ftp://ftpepsv.kishou.go.jp/) for gathering the statistical data of EPS verification, and a Web-site (http://epsv.kishou.go.jp/EPSproducer/) for their publication. The Lead Centre prepared and made available at the Web-site a set of guidelines on the exchange and use of EPS verification for the registered EPS producing centres.

8.2 The Lead Centre is ready to issue, upon request, the log-in information of the sites, such as the user name, to all EPS producers. As of January 2006, the registered centres are CMC (Sep. 2004), CPTEC (Dec. 2005), ECMWF (Jan. 2004), JMA (Jan. 2004), KMA (Jan. 2004), and UKMO (Jan. 2004). In the registration, the Lead Centre requires the EPS producer the IP address of his/her site to log-in the FTP site because of network security of JMA. Currently, the Web- and FTP-sites are password protected and accessible only by the registered centres. The Lead Centre also assigns a change of passwords from time to time in order to maintain security protection of the sites.

8.3 The meeting noted that JMA, ECMWF, CMC, and KMA have been providing their verification data to the Lead Centre and encouraged the other producing centres to commence providing their verification data to the Lead Centre as soon as possible.

8.4 The meeting decided that the details of the required verification for exchange should be posted on the Lead Centre for EPS Verification Web-site. The meeting requested the Lead Centre for EPS Verification to update the Guidelines to include the full details on how to generate the verification data for international exchange, as stated in the Manual on the GDPFS.

8.5 The meeting recommended that access to the Web-site should be available to all WMO Members. The Lead Centre is requested to confirm with contributing centres that they are willing to have their data displayed.

8.6 The meeting recommended that all producing centres of EPS should assess the significance of their own verification system. This is especially important for verifying parameters and thresholds that include small data samples (e.g. extreme events).

8.7 The meeting noted that verification of regional ensembles is a necessary and important activity for the producing centres, however did not feel that this verification is required for international exchange at this time.

Review of, and recommended changes to the Manual on the GDPFS (WMO-No. 485) on EPS Verification

8.8 The Expert Team reviewed the current text in the Manual of EPS Verification and discussed the kinds of verification data and information that the producing centres should provide and exchange internationally. There are two kinds of verification information, one that is for evaluating and comparing the scientific performance of the EPS systems hence more useful for the developers and producers, and a second kind which is more useful to the broader range of users of EPS products, which conveys more the quality of the probability information in relation to the applications. For the second type, verification of surface parameters for end users is more relevant when applied to post-processed products.

8.9 While the team did not prescribe verification data and information for surface parameters (e.g. location specific products) to be exchanged internationally, they would like to promote it to the EPS producing centres to focus efforts in improving these forecasts and probability estimates through effective post-processing. The verification of surface parameters (e.g. 2-m temperature, 2-m dew point, 10-m winds) should be performed against both analysis and observational data.

8.10 The meeting noted that in general the verification scheme does not address NWP/EPS performance in the Tropics well, and recommended that this matter should be examined thoroughly, including the important aspect of moisture in the Tropics. Meanwhile, the meeting recommended that the wind components (u, v) at 250 hPa be added to the list of verification parameters.

8.11 The meeting recognized the importance of verifying precipitation (QPF), but noted the difficulty of obtaining suitable observational data. As well, it is recognized that verification of QPF against observations would be feasible if high density observational data and good quality precipitation analyses become routinely available. The team decided not to revise the current requirements until further study.

8.12 The meeting discussed the added value of exchanging verification in terms of the (Continuous) Ranked Probability Skill Score (CRPSS/RPSS), because it provides a better indication of the skill across the whole probability distribution. The RPSS can not be computed from the verification data that is currently required for international exchange (reliability tables), however should be considered at a future time.

8.13 The Expert Team concluded that several revisions were needed in the Manual and recommended a new revised text for replacement of the existing text; the recommended revised text is found in the annex to this paragraph.

8.14 The meeting noted that the requirements for verification of NWP products need a general review, for example to consider changes to include, as examples, a definition of climatology, which verifying times, and defining the geographical regions (e.g. reference to South America appears missing) for NWP products including EPS.

9. TRAINING ACTIVITIES AND NEEDS

9.1 The meeting reviewed the various reports prepared by instructors and the Secretariat of the two training workshops on EPS, conducted in Brasilia for RA III and RA IV in January 2005 and in Shanghai for RA II and RA V in April 2005. In addition, the topic of EPS was added to a training event in RA I (Africa) on GDPFS products. It was noted that at CBS-XIII (2005), there continued to be demand for training in this area.

9.2 In summary the following key points were made in these reports, based on reactions solicited from the participants:

- The overall impression is that this training was very well and enthusiastically received by the participants. For some this was enhancing their knowledge and skill in the use of the products while for others this was the first time they have been exposed to EPS products;
- There is an important need to develop many more regional case studies to help demonstrate and to explore or practice the use of EPS products within the context of forecasting processes used at NHMSs in different parts of the world and applied to different forecasting problems and in different forecasting ranges;
- Case studies developed in a Computer Aided Learning (CAL) modules can be used in self-directed distance-learning approaches, or be re-used in subsequent training events;
- Some more advanced participants could provide training to their colleagues back at their home offices following their participation at the training workshops. Others would not be able to train others due to insufficient level of understanding, or would not have the necessary facilities at their home offices to train others.
- Participants would like to have scientific support and exchange and follow-up after the training event.
- Participants appreciated both the materials on the subject matter of EPS and probabilistic forecasting, as well as instruction on how to use the Internet tools to access relevant Web-sites where they can obtain EPS products and related information;

- Language of the available training and training materials (e.g. CAL modules) is an issue.

9.3 Despite this positive feedback, the meeting expressed some concern that without positive activities following the course to implement the procedures learned, the benefits of training could be rapidly lost. Students should be encouraged to develop and implement an operational EPS application on their return to their home office to reinforce the learning and show the benefits. The meeting encouraged the Secretariat to develop a post-training questionnaire to seek feedback from the participants that would permit an assessment on how effective the training was in terms of longer lasting benefits related to the use of EPS products in the forecasting process. COMET could possibly assist with an existing evaluation questionnaire for this purpose.

9.4 The meeting noted that one of the strengths of the two training workshops was the mix of scientific experts (including statistics) and experienced operationally-minded lecturers in the lecturing team.

9.5 The meeting noted that training on EPS is still in demand and that while dedicated training courses should still be undertaken in the future to meet the need (requirements), it recommended that other complementary approaches to providing EPS training could be considered. They include:

- Creating additional distance-learning modules, possibly at different levels of difficulty or aimed at different audiences;
- EPS producing centres or centres that have experience in using EPS products host “international training desks” to conduct a programme of on-the-job training for forecasters from other countries or centres (follow the example of NCEP);
- Develop and support trainers at WMO Regional Meteorological Training Centres;
- Develop a series of questions and answers on probabilistic forecasting and EPS products.
- Develop a pool of subject experts who are particularly well suited to provide support to forecasters or to provide lectures when the opportunity arises;
- Emphasize that in the role of RSMCs with geographical specialization, where EPS products that are part of their NWP product suite, these should be supported with suitable documentation and some form of suitable training;
- EPS and probabilistic concepts, as subjects, should be substantially included in any training event on NWP or GDPFS products;
- WMO Regional Associations should play an important role in EPS implementation at the NMHSs;
- Develop and document some examples of how advanced centres have implemented EPS into their operations and how they have benefited.
- Use of video-conferencing.

These approaches could reinforce the initial training acquired at training workshops.

9.6 The concept of including uncertainty in all forecasts needs to be promoted to decision makers and managers who in turn could set new requirements for probabilistic forecasts as part of weather information, forecasts and warnings. The team recommended activities to promote the introduction of requirements of forecast uncertainties in addition to the provision of the most likely scenario at the NMHSs.

10. UPDATE ON THORPEX/TIGGE AND THE POTENTIAL BENEFITS FOR THE GDPFS PROGRAMME OF THE WORLD WEATHER WATCH

Interaction with THORPEX and GIFS-TIGGE

10.1 THORPEX is a research programme operating under WWRP but is of great interest to CBS because it aims to research (and develop) a new global interactive forecast system (GIFS) over the next 10 years, so operational NMHSs represented by CBS are interested in the potential for new products and services.

10.2 Of particular relevance to the ET-EPS is the TIGGE project which aims to create a database and archive of multi-centre ensemble forecasts, as this has the long-term potential to make ensemble forecasts available to WMO members. However it is stressed that the main purpose of Phase 1 of the TIGGE project is to generate an archive for research purposes and it will not provide real-time access to ensemble forecasts. Beyond Phase 1 further developments may include an interface which could access data from a distributed database, and regional centres incorporating regional ensembles. Real-time access may be provided. The Expert Team recognizes the potential benefits and encourages CBS to input to the planning of this work to ensure meeting future operational requirements of WMO Members.

The structure of THORPEX

10.3 THORPEX is headed by an International Core Steering Committee (ICSC) and an Executive Board, which reports to the ICSC. Under the Executive Board are 5 Regional Committees and 6 Working Groups. These WGs cover different aspects of the project and provide the greatest opportunity for interaction with CBS. The WGs are:

- Observation system
- Data Assimilation and Observation Strategy
- Predictability and Dynamical Processes
- Socio-Economic Applications
- GIFS-TIGGE
- Data Policy and Data Management

10.4 Potential areas for interaction identified by the ET were:

- Data Assimilation and Observation Strategy – this WG will look at benefits of the targeting of observations and will need to interact with operational centres for case-selection. EPS data will be required for sensitive-area prediction as well as for case selection;
- Predictability and Dynamical Processes – this WG operates a number of Interest Groups for email discussion of various research topics. One of these is explicitly on Ensemble Forecasting, but others may also be of interest. ET members have the opportunity to influence the discussion to ensure that research is steered to meet the long-term needs of operational centres.
- Socio-Economic Applications – this WG will be researching applications of ensemble forecasts from TIGGE, including post-processing methods, and it will be beneficial for CBS to be aware of the results of this work to aid operational centres in getting the maximum benefit from new systems.
- GIFS-TIGGE – this WG will initially oversee the development of the TIGGE archive, but in the longer term will aim to build the prototype GIFS system. It will be particularly important for the ET-EPS and CBS to develop links with this WG to ensure that the GIFS meets the needs of operational centres and that operational centres are aware of the potential benefits of GIFS so that they can plan to exploit them.

Links with GIFS-TIGGE WG

10.5 Two, possibly three, current members of the ET-EPS are also members of the GIFS-TIGGE WG and will provide a link to ensure the interests of CBS are communicated within the WG.

10.6 The types of requirements which may need to be communicated could include:

- Types of products, parameters etc required
- Speed of availability after data-time
- Data formats for use in forecast production systems
- Guidance on how to make best use of ensemble forecast information and how to communicate this information
- Bias correction systems or guidance on how to apply bias correction and other post-processing;
- Constraints for timeliness and robustness of future operational systems.

Links with other WGs

10.7 The ET does not have direct representation on any other WGs, but members are encouraged to develop links through:

- Participation in Interest Groups;
- Interaction with their national or institutional representatives on WGs;
- Participation in regional committees.

10.8 WMO Member NMHSs should be encouraged through CBS to:

- Participate in research programmes by looking at TIGGE data and participating in evaluation
- Operational centres should consider the need to be prepared for the GIFS developments in their planning and budgeting processes;
- Participate in pre-operational tests.

11. ANY OTHER BUSINESS

GUIDANCE ON THE USE OF EPS FOR WEATHER FORECASTING AND WARNINGS PROGRAMMES

11.1 The Meeting addressed the question of guidance needed by forecasters on how to use EPS products in relation to those from “deterministic” models, in the preparation of forecasts and warnings. It is also recognized that CBS wishes that “forecast standards and recommended practices” be developed as a way to assure quality in the forecasting process and the forecasts and warnings that are produced.

11.2 The Expert Team developed some general guidance for the use of EPS in combination with single high resolution NWP forecasts, expressed as current best practice in relation to EPS products that are presently available. The general guidance is found in the annex to this paragraph.

11.3 In relation to the need to develop “forecast standards and recommended practices” the Expert Team considered the idea of developing a guide for the use of EPS products. Such a document could include a glossary of terminology commonly used in EPS (e.g. “deterministic” forecast versus EPS forecast), various kinds of EPS products including examples, and how best to use these products in a forecasting process. As an initial step, the expert team could develop a Table of Contents, with explanatory text for the major sections of such a guide, possibly extracting useful sections of existing user guides (e.g. ECMWF). Such a guide could be developed by a qualified consultant. It was felt that a guide could be used in training and also as an ongoing reference.

11.4 At the same time, the meeting agreed that it is good practice that for each product that is exchanged internationally, a guide that describes the product is needed.

12. CLOSING

The meeting was closed at 17:30 on Friday, 10 February 2006.

Annex to paragraph 4.1.11

Ensemble forecasts in Morocco

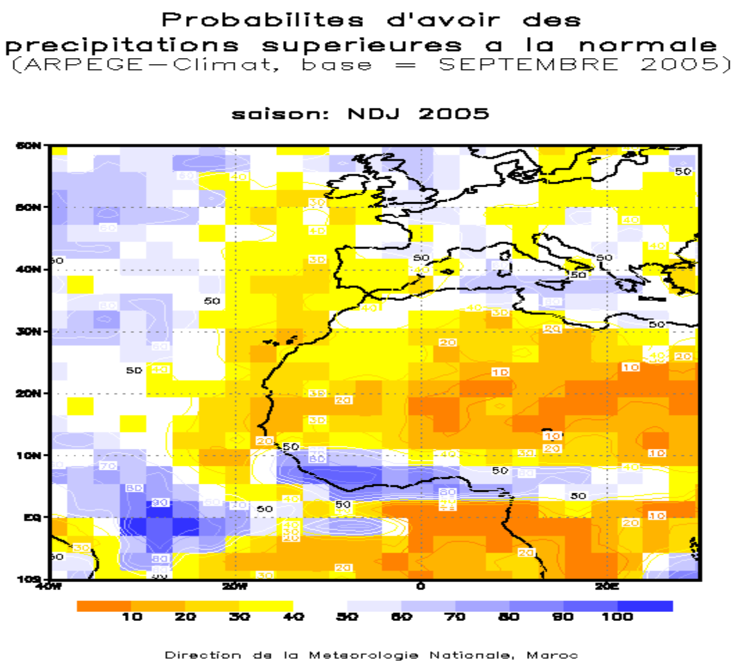
<u>Seasonal predictions:</u>

The French General Atmospheric Circulation Model Arpège-Climat is used, with resolution of 300 Km, to produce forecasts out to 4 months.

Two ensembles of nine members each one are run every month. The first one is constructed using nine different initial states: form j-9 to j-1 where j is the day of forecast start. Members of the second ensemble have the same initial conditions but different boundary conditions: different Sea Surface Temperatures. Predicted SST for the four months of prediction are lightly perturbed to construct nine data fields.

Final predictions are given as ensemble mean forecasts or probabilistic forecasts using the 18 members.

Example of probabilistic forecasts



<u>Medium Range forecasts (Preoperational)</u>

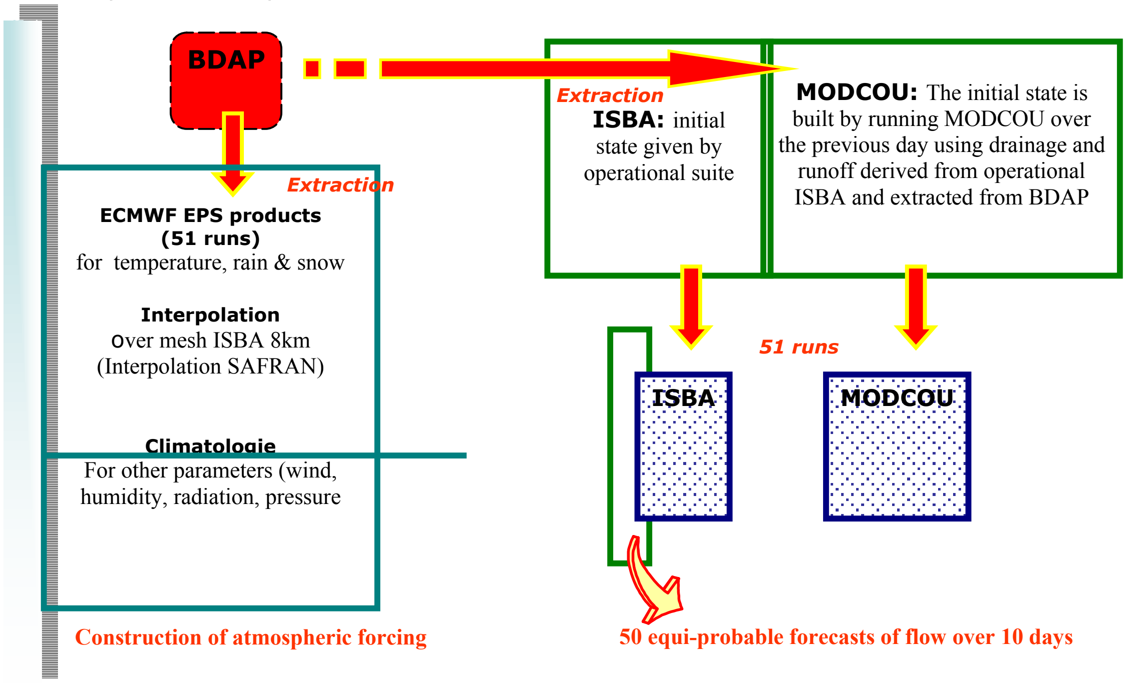
The ensemble prediction system acquires an increasingly important place in the meteorological centres throughout the world. Thus, Maroc-Météo decided to open a field of research on this topic.

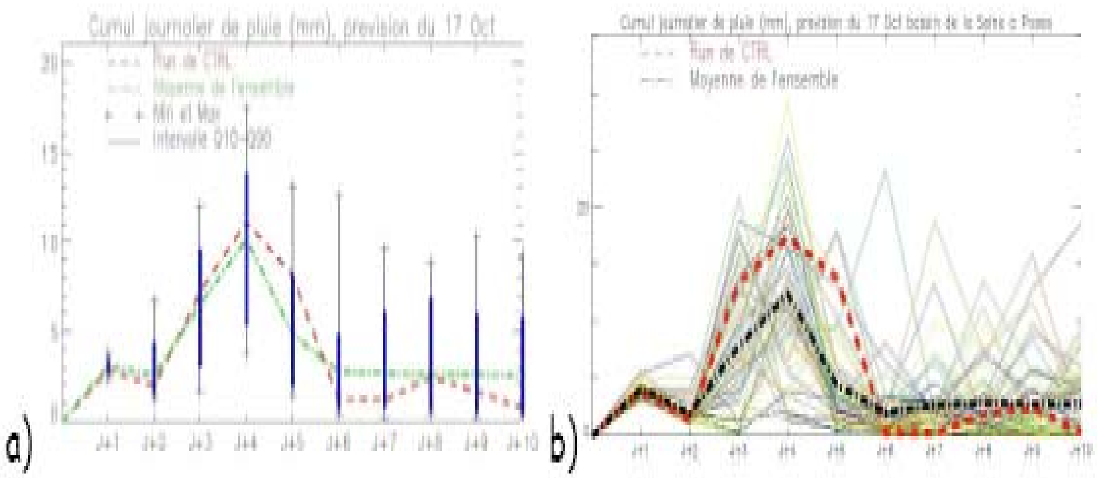
The method used for perturbing the initial condition and so getting 36 members is based on the combination of multi-analysis and multi-guess system. Three different methods of analysis are used: 4D-Var, 3D-Var and Optimal Interpolation. From each method of analysis, we run 12 analyses while using each time a different guess, which makes on the whole 3*12=36 members. This method is in progress of validation.

Ensemble Prediction application for Runoff (under research):

At DMN we started a research field dealing with application of EPS to sectors like water resources management.

Principles of the operational ensemble forecast suite:





Difficulties met:

- ❑ Extraction of ECMWF ensemble forecast fields.
- ❑ Heavy retrieval of data from ECMWF archives.
- ❑ Very long computer time for pre-processing and simulation.

Solutions applied

- ❑ Implementing a system for extraction from the forecast fields.
- ❑ Real time processing (operational suite).
- ❑ Limitation of parameters to T and Precipitation (climatology for the others) and increase of time step of ISBA (from 5 min to 20 min).

Annex to paragraph 8.13

The following is the revised text, recommended by the CBS Expert Team on EPS to replace, in its entirety, the present text of the section of the Manual on the GDPFS (WMO-No. 485, Volume I, Part II, Attachment II-7, Table F.

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 are exchanged in the form of reliability tables. Details of the format of the reliability tables 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 10^{th}, 25^{th}, 75^{th} and 90^{th} 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 10^{th}, 25^{th}, 75^{th} and 90^{th} 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).

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

NOTE: 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 System.

Annex to paragraph paragraph 11.2 of general report text

Guidelines on using information from EPS in combination with single higher resolution NWP forecasts

Motivation

Traditionally forecasters have focused their attention on finding the most likely solution for the future weather. This is the first and most important aspect of weather forecasting. As the lead time for forecasts increases, the uncertainty associated with the most likely solution generally also increases. Information about the uncertainty in the forecasts is critical for a large group of users. One way of assessing uncertainty in traditional single (or "control") forecasts is through collecting verification statistics over a period of time, and using the error statistics as a way of providing a distribution of expected errors in a forecast. This process, however, assumes that errors for a given lead time are stationary. Operational experience shows that this is not a valid assumption. NWP-based ensemble forecast systems were designed, through dynamical methods, to quantify forecast uncertainty as a function of uncertainty in the initial conditions, in the NWP model, and the evolution of the atmosphere under different synoptic situations. The ET-EPS recommends the more widespread use of EPS systems to provide the best estimates of forecast uncertainty.

Properly describing the uncertainty in any forecast requires the use of probability distribution functions (pdfs). An EPS can be used to form such a pdf in a consistent manner. Due to resource limitations, EPS systems involve many forecast integrations and therefore often have to be run at a somewhat reduced resolution. Questions arise as to the compatibility of information from a single higher resolution integration versus an ensemble of lower resolution runs. In particular, higher resolution integrations generally show a lower level of systematic error, and may simulate certain aspects or phenomena of the atmosphere with more fidelity (e.g., diurnal cycle, meso-scale features, frontal structures, etc.). Guidance has been sought by WMO members as to the proper use of high resolution control and lower resolution ensemble information, in particular regarding when information from one or the other system may be more relevant and how they can be best combined/utilized in the forecast process.

Determining the most likely scenario

The initially symmetric cloud of possible solutions that are centered around the control analysis in a set of ensemble forecasts deforms with time into an irregularly shaped cloud. This is due to nonlinear processes that necessarily displace the control from the center of the cloud. The critical level of nonlinearity is reached sooner for smaller scale and/or more unstable phenomena. For example, in case of convective precipitation, linearity may be lost in a matter of hours, while large scale features may retain linearity for several days.

A forecaster can assess how much weight to place on a single high-resolution forecast (or on the ensemble control) from the spread in the ensemble. Small spread in the ensemble provides confidence in the single forecast, while larger spread indicates that it is essential to include information on forecast uncertainty. If the single model forecast is significantly different from the ensemble mean, in relation to the spread, then very little weight should be given to the high-resolution forecast.

As spread increases, it is less appropriate to rely on a single forecast as the most likely scenario (be it the high resolution or the control forecast of the ensemble). All solutions in the ensemble must then be considered when weighing the likelihood of different forecast scenarios . However, until the lead time where an ensemble indicates large forecast uncertainty, a high resolution control forecast can be utilized in the formation of the most likely scenario. Once nonlinearities become dominant, the high resolution control forecast should be considered only to analyze detailed structure of relevant phenomena indicated, but not necessarily resolved well by the lower resolution ensemble members. However, one should keep in mind that the higher resolution control has its own limitations (e.g. biases in two model resolutions may not be drastically different etc). In less predictable situations the most likely scenario can be derived from the ensemble, e.g., the ensemble mean, median or mode.

Assessing forecast uncertainty

So far we have focused on the estimate of the most likely state of the system (first moment). Regarding the important issue of assessing the uncertainty in the most likely forecast (second and higher moments of the pdf), the lower resolution ensemble can be used. As long as the best estimate of the state is based on the ensemble solutions (including the equivalent resolution control that we consider as a member of the ensemble), the same solutions offer a proper way of quantifying forecast uncertainty. For example one can consider the 10, 50, and 90 percentile values in the ensemble distribution at any point and lead time as a simple measure of predictability. If necessary, additional percentile levels can be added, or a detailed pdf can be provided. If the forecaster's best estimate of the state is based more on the high resolution control forecast, the range of ensemble solutions, with a good approximation, can still be considered for establishing a range of possible solutions as far as the scales resolved by the lower resolution ensemble are considered. Consider a thought experiment where an ensemble with the higher resolution model is run (that we cannot afford in real practice due to computer limitations). We expect that uncertainty regarding the larger scales resolved by the higher resolution ensemble would be very similar to that captured by the lower resolution ensemble. What will be missing from the uncertainty estimate derived from the lower resolution ensemble is related to the smaller scale details that are represented only by the higher resolution model.

These guidelines were written as a first attempt to reconcile the concepts of using single high resolution forecasts and EPS in the weather forecasting process. Many more tools than those described above are available at advanced centres including probabilistic forecasts, assessment of alternative scenarios (clusters, tubes, and other classification techniques). Based on such a rich array of ensemble-based tools, the ET-EPS recommends more widespread use of EPS in weather forecasting.

Developments on post-processing

The aim of post-processing should be to produce a pdf taking account of information from both single high-resolution model run and EPS members. In general it is expected that in short-range forecasts high weight will be attached to the high-resolution forecasts and lower weights to the perturbed members whereas for the longer range forecasts it is expected that similar weights will be applied to all members. Post-processing methods to achieve this are under development.

APPENDIX I

AGENDA

1. **Opening of the meeting**

2. **Organization of the meeting**

   2.1 Approval of the agenda
   2.2 Agreement of working arrangements

3. **Introduction by the Chair**

4. **Advances in the science and capabilities of EPS**

5. **EPS output products required for international exchange from GDPFS Centres**

6. **Short-range and regional EPS systems**

7. **Application of EPS for severe weather forecasting**

8. **EPS Verification**

9. **Training activities and needs**

10. **Update on THORPEX/TIGGE and the potential benefits for the GDPFS programme of the World Weather Watch**

11. **Any other business**

12. **Closing**

APPENDIX II

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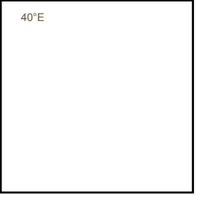

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