SafeWind

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Abstract: Besides global ECMWF Ensemble Prediction System (EPS) data available to SafeWind participants, an extensive investigation has been focused on the opportunities to use Limited Area Model (LAM) EPS forecasts for improved wind predictions on local to regional scales. A link between different Limited-Area EPS (LEPS) Groups and the wind power community has been sought during different activities. Contact has been made with all major European LEPS Groups (as the UK Met Office MOGREPS – Meteo France PEACE/PEARP – Spanish Meteorological Service AEMET-SREPS – Hungarian Meteorological Service GLAMEPS-LAMEPS – Austrian Meteorological Service GLAMEPS-ALADIN-LAEF – Norwegian Meteorological Institute GLAMEPS-NORLAMEPS – DWD SRNWP-PEPS – Italian Hydro-Meteo-Climate Service of the Environmental Agency of Emilia-Romagna's (ARPA-SIMC) COSMO-SREPS and COSMO-LEPS). Most of European LEPS Groups showed a vivid interest and willing to cooperate in the context of SafeWind project. In addition, arrangements were made concerning specialised data sets reflecting to different case studies. A considerable amount of various LEPS data sets are available to SafeWind for further use & exploitation. So far, activities concerning collection of test cases and assessment of selected LEPS runs in terms of surface winds suitable as input to wind power prediction platforms have been focused on COSMO-LEPS in S-Range & early M-Range forecast horizons and ALADIN-LAEF in S-Range, verified over various strategically selected subareas of Europe. Meteo-France PEACE/PEARP platform has been also utilized for the assessment of the Xynthia windstorm over Central Europe. Potential weaknesses and strengths of various LEPS platforms have been investigated by inter-comparison to ECMWF EPS, which has been considered as the backbone ensemble prediction system utilized by the SafeWind Project.

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Appendix A: UK Met Office MOGREPS-NAE

Appendix B: Meteo France PEACE-PEARP

Appendix C: Spanish Met Agency AEMET-SREPS

Appendix D: Hungarian Met Service GLAMEPS-LAMEPS

Appendix E: Austrian Met Service GLAMEPS ALADIN-LAEF

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Appendix H: ARPA-SIMC (Emilia Romagna, Italy) COSMO-SREPS

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NOMENCLATURE

NWP:	Numerical Weather Prediction
ECMWF:	European Centre for Medium-Range Forecasts
IFS:	ECMWF Integrated Forecast System (Deterministic Platform)
EPS:	ECMWF Ensemble Prediction System (Probabilistic Platform)
VarEPS:	ECMWF Variable Resolution EPS (extension of EPS)
SV:	Singular Vector (method)
BV:	Bred Vector (method)
NCEP:	National Centres for Environmental Prediction
NAEFS:	North American Ensemble Forecast System
MSC:	Meteorological Service of Canada
NWS:	National Meteorological Service of USA
NMSM:	National Meteorological Service of Mexico
CMC:	Canadian Meteorological Centre
JMA:	Japan Meteorological Service
CMA:	China Meteorological Agency
KMA:	Korea Meteorological Administration
RSMC:	Regional Specialized Meteorological Centre of Tokyo
WPF/P:	Wind Power Forecasting/Prediction
GEPS:	Global Ensemble Prediction Systems
LEPS / REPS:	Limited-Area / Regional Ensemble Prediction System
PDF:	Probability Density Function
ICs:	Initial Conditions
PSU:	Pennsylvania State University
NCAR:	National Centre for Atmospheric Research
MM5:	Fifth-Generation Mesoscale Model
MARS:	Meteorological Archiving System (ECMWF)
ECFS:	ECMWF File Storage System
ERA-40:	ECMWF 40-year Re-analysis Project
ERA-Interim:	ECMWF Reanalysis Project for 1989 to 2013
DWD:	German National Meteorological Service
M-Range:	Forecast horizon of Medium-Range (120 to 168 hours) also denoted as *M-R*
Early M-Range:	Forecast horizon of early M-R (60 to 120 hours) also denoted as *early M-R*
Late M-Range:	Forecast horizon of late M-R (168 to 240 hours) also denoted as *late M-R*
S-Range:	Forecast horizon of Short-Range (12 to 60 hours) also denoted as *S-R*
Very S-Range:	Forecast horizon of very S-R (0 to 12 hours) also denoted as *very S-R*
Nowcasting:	Forecast horizon of 0 to 6 hours (being included in the very S-R)

TSOs:	Transmission System Operators
ROC:	Relative Operational Characteristic
ROCA:	Area Under ROC Curve (skill score)
NSWWS:	National Severe Weather Warning System (U.K.)
NAO:	North Atlantic Oscillation
NMSs:	National Meteorological Services
WMO:	World Meteorological Organisation
WWRP:	World Weather Research Programme
THORPEX:	The Observing System Research and Predictability Experiment
TIGGE:	THORPEX Interactive Grand Global Ensemble
GIFS:	Global Interactive Forecast system
GIFS-RDPs:	GIFS – Research & Development Programs
CONUS:	Continental United States
EKF:	Ensemble Kalman Filter
ETKF:	Ensemble Transform Kalman Filter
EDA:	Ensemble Data Assimilation
ETBU:	Ensemble Transform of BV
SKEB:	Stochastic Kinetic Energy Backscatter
PP:	Parameter Perturbations
SWFDP:	Severe Weather Forecasting Demonstration Project
MAP:	Mesoscale Alpine Program
GEM:	Global Environmental Multi-scale (model) of CMC
OI:	Optimum Interpolation
BGM:	Breeding Growth Mode (methodology)
GRAPES:	Global and Research Analysis and Prediction System of CMA
TC:	Tropical Cyclone
WRF:	Weather Research & Forecasting (mesoscale model)
DPMM:	Different Physical Mode Method
GFS:	Global Forecast System of NCEP (USA)
ETR:	Ensemble Transform with Rescaling (methodology)
SPS:	Stochastic Perturbation Scheme
B-M-J scheme:	Betts-Miller-Janjic convective scheme
RTMA:	Real Time Mesoscale Analysis
SREF:	Short-Range Ensemble Forecast System of NCEP (USA)
BMRC:	Bureau of Meteorology Research Centre of Australia
ZAMG:	Austrian Met Service

CPTEC:	Centre for Weather Forecasts & Climate Studies of Brazil
NDGD:	National Digital Guidance Database of USA
RTMA:	Real Time Meso-scale Analysis
FNMOC:	Fleet Numerical Meteorology and Oceanography Centre of US Navy
AFWA:	Air Force Weather Agency of USA
GEFS:	Global Ensemble Forecast System of NAEFS
SRNWP:	Short Range Numerical Weather Prediction
UK Met Office:	Meteorological Service of U.K.
Meteo France:	Meteorological Service of France
AEMET:	Meteorological Agency of Spain
GLAMEPS:	Grand Limited Area Model Ensemble Prediction System
HMS:	Hungarian Meteorological Service
NMI:	Norwegian Met Institute
ARPA-SIMC:	Regional Met Service of Bologna (Emilia Romagna, Italy)
UFI:	Useful Forecast (time) Interval
MOI:	Minimum Overtaking Interval
PREVIEW:	Prevention, Information and Early Warning European FP6 Project
MOGREPS:	UK Met Office Global and Regional Ensemble Prediction System
LBCs:	Lateral Boundary Conditions
ATOVS:	Advanced TIROS Operational Vertical sounder
SKEB:	Stochastic Kinetic Energy Backscatter
3D-VAR:	Three-Dimensional Variational Data Assimilation System
4D-VAR:	Four-Dimensional Variational Data Assimilation System
FGAT:	First Guess at Appropriate Time
IP:	Initial Perturbation (Generator)
VSREF:	Very Short Range Ensemble Forecast System
UM:	Unified Model (UK Met Office)
SREPS:	Short Range Ensemble Prediction System
DEMETER:	European multi-model ensemble system for seasonal to inter-annual prediction
SAMEX:	Storm and Mesoscale Ensemble Experiment
ALADIN:	Aire Limitée Adaption Dynamique Development International (model)
NCSB:	Non-Cycling Surface Breeding
DFI:	Digital Filter Initialisation
TEPS:	Targeted Ensemble Prediction Systems

1. Introduction

1.1 Numerical Weather Prediction: potential & capabilities

The atmosphere is a complex dynamical system with many degrees of freedom. In Numerical Weather Prediction (NWP), the state of the atmosphere is described by the spatial distribution of wind, temperature, specific humidity, liquid water content and surface pressure. The mathematical differential equations used to predict the system time evolution include Newton's laws of motion and the laws of thermodynamics. NWP models predict the time evolution of the atmospheric state by solving numerically the system equations. NWP models can be *global* models having global extent, *regional* models covering a sizeable fraction of the globe, say a continental land mass and surrounding oceans, while *mesoscale* models can have extents of the order of hundreds of kilometres. The resolution of a given model is constrained by the computational and memory limitations of the computers used to run it, hence, global models have the coarsest resolution, regional models have intermediate resolution and mesoscale models have the finest resolution.

A deterministic forecast is a single integration of the system equations. The practical usefulness of a single deterministic weather forecast is limited by the day-to-day variability in its accuracy [1]. This variability is partly associated with fluctuations in the predictability of the atmospheric flow, with predictable states (i.e. flows characterized by a slow amplification of initial errors) alternated by unpredictable states (i.e. flows characterized by a fast amplification of initial errors). For different resolutions, different models of the physical processes taking place in the atmosphere, such as cloud generation (convection-allowing schemes), are required. Nevertheless, forecast accuracy has improved as increasing computational power has allowed the use of progressively finer resolution, more sophisticated model physics, and better data assimilation methodologies.

1.2 Limits of predictability: ensemble forecasting

Inherent limits in atmospheric predictability ([2] & [3]) may restrict the value of further decreasing grid spacing in numerical weather prediction models. For example, real-time forecasts at the University of Washington using the Pennsylvania State University-National Centre for Atmospheric Research fifth-generation Mesoscale Model (PSU-NCAR MM5, [4]) suggest diminishing returns as grid spacing drops below 12 km, when evaluated using standard measures of forecast skill [5]. Furthermore, numerical model forecasts can be very sensitive to slight changes in the larger-scale initial conditions [6]. Recognition of such predictability issues has led to increased interest in developing an alternative strategy for further improving numerical weather forecasts ([7] – [8] – [9] & [10]), namely, ***ensemble forecasting.***

Furthermore, ensemble systems are practical tools designed to assess the predictability of the daily atmospheric flow. More generally, they can be used to predict the time evolution of the Probability Density Function (PDF) of forecast states. Ensemble forecasting provides a practical way of addressing variability in the initial conditions (ICs), uncertainties in model physics, and the inherent uncertainty in atmospheric prediction. For example, using forecasts started from varying ICs, each being equally likely to match the actual atmospheric state, a collection of weather scenarios and their relative likelihood may be constructed. An approximation to the forecast PDF of model variables can be defined by the calibrated frequency distribution of the resulting ensemble forecasts [11] – [12] & [13]. Thus, ensemble forecasting lends itself to prediction of forecast probability, an advantage over deterministic forecasting [14]. Meantime, computer power resources have greatly increased in the last years, thus allowing the generation of more and more sophisticated NWP model with accurate parametrisation of physical processes supported by high horizontal and vertical resolution.

Ensemble systems have been operational since 1992 at the European Centre for Medium-Range Weather Forecasts (ECMWF, UK) and at the National Centers for Environmental Prediction (NCEP, US), and since 1995 at the Canadian Meteorological Center (CMC, Canada). These three ensemble systems have been designed to estimate the forecast PDF in the short- and medium-forecast range, i.e. for up to 15 days. Beside this operational activity, many international centers, universities, national and regional meteorological centers have been involved in research and experimental activities in this field. It should also be mentioned that experimental ensemble systems are currently under development and are tested for seasonal time scales.

1.3 Global Ensemble Prediction Systems

Global Ensemble Prediction Systems (GEPSs) have improved during the last a few years, in terms of resolution, ensemble size, length of integration and frequency of forecast cycles. The horizontal resolution is increased from about 90-110km to 50-70km for most GEPSs while ECMWF currently has a resolution of 32 km (from 26 January 2010 onwards). The number of vertical levels is also increasing to between 28 and 70 levels. Many centres increased ensemble size and most systems have more than 20 members. The length of integration is 10-15 days at most centres.

While Singular Vector (SV) and Bred Vector (BV) methods are still widely used in generating initial perturbations, Ensemble Transform of BV (ETBV), Ensemble Transform Kalman Filter (ETKF) and Ensemble Data Assimilation (EDA) are also implemented in various centres. Two main approaches are employed to address Model Error. Some systems use a multi-model or multi-parameterization ensemble approach. An increasing number of centres are now introducing Stochastic Physics Perturbation Schemes. Examples of these include the Tendency Perturbation scheme, Stochastic Kinetic Energy Backscatter (SKEB) and Parameter Perturbations (PP). A different approach recently adopted is to couple all the ensemble members by stochastically perturbing the total model tendency with tendencies from other ensemble members [15].

1.4 Regional or Limited-Area Ensemble Prediction Systems

The successful application of ensemble prediction systems on the global scale at the National Centres for Environmental Prediction (NCEP) [9] and the European Centre for Medium-Range Weather Forecasts (ECMWF) [8] & [10] has motivated exploration of ensemble forecasting for shorter lead times on the mesoscale scale. Most of the times short-range forecasts do not use probabilistic information. Although such forecasts are more and more skilful, some events remain unpredictable. Based on this, many European Weather Centres express the intention of using probabilistic forecasts at short range in order to get an assessment on extreme events risks. At the time being, ensemble forecasting seems to be the more simple and efficient tool to achieve these goals. However, methods used in such ensembles cannot be directly applied for the short range forecasting [16].

New methodologies and techniques though, have allowed to the development of various Limited-Area EPS (LEPS) platforms. These systems are playing a rapidly increasing important role in National Met Services (NMSs) and Consortia. Currently, the horizontal resolution ranges from 32 km to 10 km, with up to 70 vertical levels. The ensemble sizes ranges from 15 to 24 and the forecast length ranges from 2 days to 5 days. Many LEPSs take multi-model (including multi-physics) approach, but single model with stochastic physics is growing in popularity. At some centers, the frequency of output has increased to 1 hour for the first 39 hours to meet the requirement of customers (which is especially suitable for WPF/P applications). A few weather centres (NMSs) are also experimenting with convection-allowing ensembles with horizontal resolutions of 1-3 km. None of these are operational at the current time, but will provide new opportunities in the next few years for probabilistic prediction of detailed weather such as convective precipitation and low visibility conditions which are not resolved by current EPS systems [15].

Many NMSs, especially those of developing countries, do not have the computing facilities or capability to generate products from ensemble fields. EPS outputs need to be calibrated and further post-processed into specific products required by “non-producing” NMSs, and useful products could only be developed and produced by those centres that have the data processing or data transfer capacity to do so. This could imply that Regional Specialised Meteorological Centres (RSMCs) might act as the primary producers of national-level EPS products destined for their end-users, shifting from the present practice of EPS centres providing “raw” output datasets as basic construction material for NMSs’ development and production. The application of EPS to predict severe or high-impact weather events is among the most important topics, e.g., the propagation of the weather forecasts into impact models. The Severe Weather Forecasting Demonstration Project (SWFDP) [17], which emphasizes improving the access and effective use of EPS products, continues in the region of southern Africa, while started a new regional project for the South Pacific Islands. As well, representatives from Japan, China, Morocco, India, and New Zealand, and the WMO World Weather Research Program: MAP D-PHASE (Demonstrating forecast capabilities for flood events in the Alpine region) project noted

direct use of EPS in predicting severe or high-impact weather [18].

2. Major Global Ensemble Prediction Systems

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, but as the forecast horizon 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 (deterministic) 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 forecast horizon are stationary. Operational experience shows that this is not a valid assumption. Global Ensemble Prediction Systems (GEPSs) have been 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 [19]. In the Sections following, the major GEPS platforms are (briefly) described.

2.1 ECMWF GEPS

The old ECMWF Ensemble Prediction System (EPS) [20] comprised *50 perturbed members* initialized at 0000 UTC and 1200 UTC every day, at TL399 (~50 km) resolution out to Day 10 (and at TL255 resolution from Day 10 to Day 15). All integrations have 62 levels. Model errors due to physical processes and subgrid-scale effects are represented in the ensemble by stochastic perturbations of tendencies of physical processes. Initial condition perturbations are constructed using Singular Vectors (SVs), which represent the fastest linear growing error structures over a 48-hour period. In addition to the 50 routine hemispheric SVs that use a dry total energy norm [21], 5 extra SVs with a diabatic version of the tangent-linear model and moist total energy norm are computed in up to 6 subspaces enclosing tropical cyclones, at T42 resolution and with 42 vertical levels [22] & [23].

Furthermore, on 26 January 2010 ECMWF upgraded the horizontal resolution of the deterministic forecasting system and Ensemble Prediction System (EPS) that form components of the Integrated Forecasting System (IFS) [24]. For the deterministic forecast and analysis the horizontal resolution increased to TL1279 (~16 km grid spacing) from TL799 (~25 km) and the EPS resolution increased to T639 (~32 km) from TL399 (~50 km) for leg1 (the first 10 days of the forecast) and to TL319 (~65 km) from TL255 (~80 km) for leg2 (day 9 to day 15 and day 32 for the monthly forecast). The vertical resolution remained unchanged at 91 levels for the deterministic system and at 62 levels for the EPS (as shown in Figure 2.1.1 for the lower part of PBL). The various resolution increases have been implemented as IFS Cycle 36r1. In addition, a correction to the interaction of short-wave radiation with clouds is also included in this cycle.

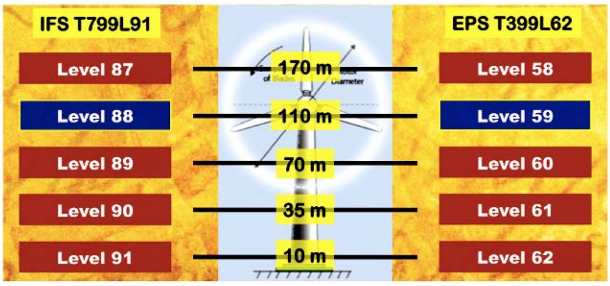

Figure 2.1.1: *ECMWF model level configuration for IFS & EPS platforms.*

The use of the ECMWF IFS & EPS platforms in numerical weather prediction is well established. They provide useful deterministic forecast guidance and information on the uncertainty of the weather prediction for many different end-users and the public. ECMWF IFS & EPS have been applied to wind power forecasting to extend the range of skilful wind power predictions from the short-term to the medium-term. At the same time, information about the uncertainty has been linked to decision-making based on probabilities of a specific event to happen. It is critical that ensemble forecasts represent the “true” distribution of probabilities that can develop from an initializing analysis. It is also important that these probabilities can provide early warnings in cases of extreme wind events.

The ECMWF EPS combines one control run (CF: Control Forecast), started from the same analysis as the IFS HR, and 50 perturbed members. The EPS was implemented operationally almost 18 years ago [8] & [10] and has undergone many changes since then [14]. In practical terms, the value of an ensemble prediction system is that it gives forecasters the means to assess quantitatively their risk to weather sensitive events in the days ahead. It is important to note that ensemble forecasts provide probabilistic predictions for the future state of the atmosphere. The probability of a given event can be determined from the fraction of ensemble members predicting the event. The ultimate value of a weather forecast system lies in its ability to improve weather related decision-making processes. Thus, it is of importance to consider the end users of EPS forecasts and the way the EPS is integrated into their decision-making processes. This is one of the principal guidelines of the SafeWind project.

2.2 UK Met Office MOGREPS-G GEPS

The UK Met Office Global and Regional Ensemble Prediction System (MOGREPS) is an ensemble system that produces uncertainty information for short-range forecasts, up to two days ahead. It focuses on aiding the forecasting of rapid storm development, wind, rain, snow and fog. MOGREPS platform comprises two components:

• the global ensemble – produces forecasts for the whole of the globe

• the regional ensemble – produces forecasts for an area covering the North Atlantic and Europe (NAE) as shown by the coloured area in Figure 2.2.1.

The UKMET MOGREPS-G ensemble (known as the global version of MOGREPS) comprises *24 members* integrated at 00 UTC and 12 UTC each day, at ~90 km resolution with 38 levels. The ensemble is integrated out 15 days. The Ensemble Transform Kalman Filter (ETKF) is used to initialize the ensemble, with model uncertainty perturbations prescribed via a stochastic kinetic energy backscatter scheme [25] & [26].

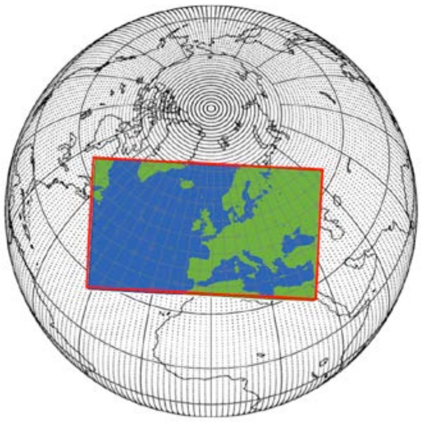

Figure 2.2.1: *MOGREPS-GEPS and MOGREPS-NAE (red rectangular) integration domains.*

The MOGREPS Ensemble Prediction System has been designed to provide a short-range regional EPS for the UK and Europe. It uses a regional model (control run) on a North Atlantic and Europe (NAE) domain running at 24-km resolution with 38 levels and forecasting to 54 hours. To provide lateral boundary conditions, the global ensemble is running at N144L38 (~90km) to 72 hours. Both components have 24 ensemble members and run twice a day, the global at 00 and 12 UTC and the regional at 06 and 18 UTC. MOGREPS became fully operational in September 2008. The global ensemble (MOGREPS-GEPS) is also run to 15 days ahead as the UK contribution to the THORPEX TIGGE project. In the new (mid-January 2010 onwards) regional ensemble the model parameters (temperature, pressure, wind, humidity, etc.) are forecast at grid points separated by about 18 km and at 70 vertical levels. Both the global and regional ensembles have 24 ensemble members – each model is run using 24 different starting conditions and produces 24 different forecasts. Details of both the MOGREPS-GEPS and MOGREPS-NAE platforms can be found in Appendix A.

2.3 Canadian Meteorological Centre GEPS

Canadian Meteorological Centre (CMC) GEPS data assimilation consists of a 6-hour cycle using 4 times 24 configurations of the GEM (Global Environmental Multi-scale) model providing (96) trial fields over 6-hour time windows. Trial fields at 3, 4.5, 6, 7.5 and 9 hours allow interpolation toward time of observations. It is a 4-D data assimilation cycle using Kalman filter (so-called EKF: Ensemble Kalman Filter). The latest update to this assimilation system was the addition of GPS-Radio Occultation observations and the increase in the number of vertical levels from 28 to 58 levels in the model configuration.

From the 96 Ensemble Kalman filter analysis (as shown in Figure 2.3.1), 20 are randomly selected to provide initial conditions for *20 members* (at final forecast mode). Models are integrated out to 16 days, twice a day (00z and 12z), at 0.9 degrees horizontal resolution and the number of levels remains at 28 levels. Recent tests at 58 model levels did not show significant improvement with the 16-day forecast while improvements were found when using 58 model levels in the data assimilation. Initial condition uncertainties are represented by the perturbed ensemble Kalman Filter data assimilation, while forecast model uncertainties are reproduced by various model physics' configuration, with a single dynamic core (GEM model). Also stochastic perturbations are added to tendencies (as in ECMWF case) in the parameterized physical processes and back-scattering energy parameterisation is used in order to augment the spread of the ensemble [27].

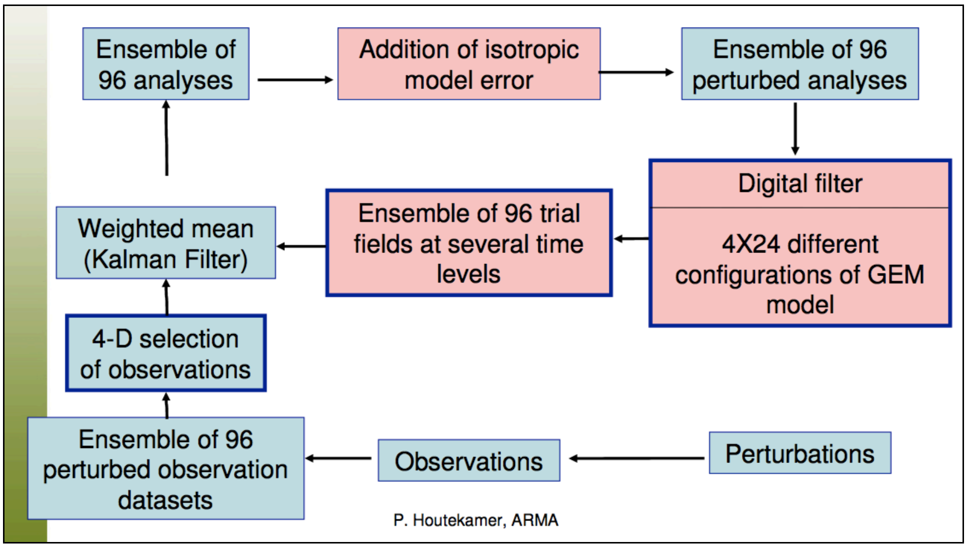

Figure 2.3.1: *CMC data assimilation component configuration (from P. Houtekamer).*

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

Typical products include the so-called Spaghetti plots, maps with probability of exceeding precipitation thresholds, meteograms, and mean & standard deviation maps for depicting many weather variables such as precipitation, geopotential heights, winds etc. It should be pointed that CMC GEPS platform is one of the basic components of the North American Ensemble Forecast System (NAEFS). NAEFS is a joint project involving the Meteorological Service of Canada (MSC), the United States National Weather Service (NWS) and the National Meteorological Service of Mexico (NMSM). NAEFS was officially launched in November 2004 in presence of representatives of the three countries. NAEFS combines state of the art ensemble forecasts, developed at the MSC and the NWS [28].

2.4 Japan Meteorological Agency GEPS

The Japan Meteorological Agency (JMA) launched its operational GEPS – comprising *51 members* – for one-month forecasts in March 1996. In 2001 JMA launched one-week forecasts, while in 2003 JAM provided the users with seasonal forecasts. Finally in 2008, JMA launched tropical cyclone track forecasts over the western North Pacific. Products derived from the one-week EPS are routinely used for M-Range forecasting. The products in graphical format are available for access by Asian National Met Services & Agencies on the JMA M-Range EPS Web site. Verification results of the one-week EPS are published in annual WMO Technical Progress Report on GDPFS. The topography used and the domain of integration of different models running in JMA is shown in Figure 2.4.1. Furthermore, the monthly verification data are available on the Web site of WMO Lead Centre for EPS Verification [29].

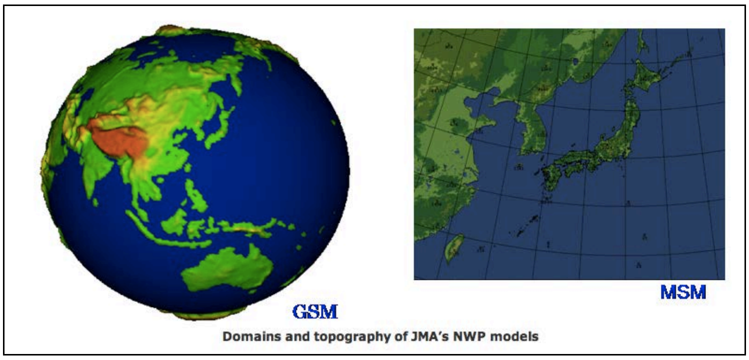

Figure 2.4.1: *Topography and domain of integration of different models running in JMA.*

In November 2007, JMA enhanced the resolution of its global EPS model to TL319L60 and replaced its initial perturbation (IP) generator with a SV method. It became evident from the verification results that the time evolution of ensemble spread became optimized especially in short range. The current configuration of various JMA models is shown in Table 2.4.1. The Typhoon EPS is integrated four times a day at most with a forecast range of 132 hours. The EPS model and the IP generator are shared with the one-week EPS. The high-frequency products derived from the Typhoon EPS fully support new information of probabilistic type, 5-Day Track Forecast, in Typhoon Bulletins issued by the RSMC (Regional Specialized Met Centre of Tokyo). RSMC Tokyo Typhoon Centre maintained its responsibilities as the Lead Centre for EPS Verification, including implemented the required Web site.

Table 2.4.1: *Main features of various JMA model configurations.*

2.5 China Meteorological Administration GEPS

The CMA-GEPS at National Meteorological Centre (NMC) of CMA was updated in resolution from T106L19 to T213L31 in 2006. This system has *15 members*, 10 days forecasting at 00 and 12 UTC, and the Breeding Growth Mode (BGM) method. On 1 June 2008 the data assimilation system of CMA-GEPS was upgraded from OI into 3DVAR system. The products are provided in terms of ensemble mean, ensemble spread and probabilistic forecast, spaghetti, stamp chart. Ensemble Transform initial perturbation method is being experimented. Both ensemble members and forecast range are planed to increase in next 2-3 years, based on the next generation Unified Model named GRAPES (Global and Research Analysis and Prediction System) as shown in Figures 2.5.1. & 2.5.2.

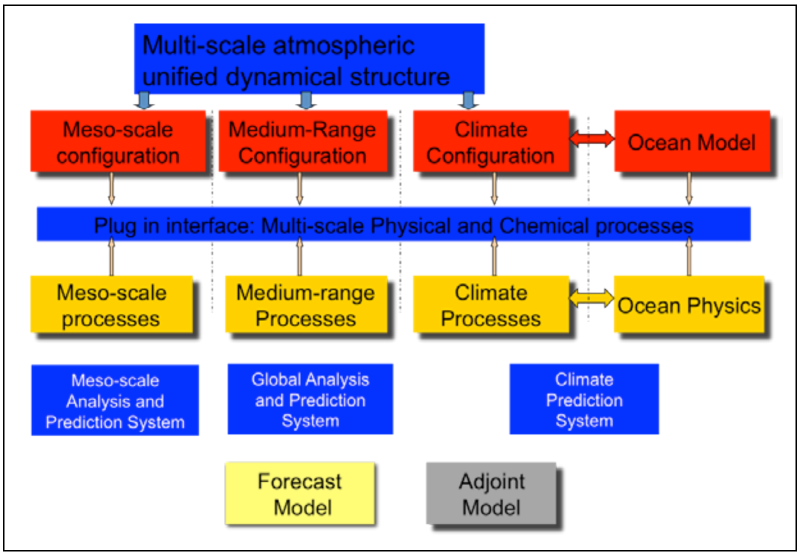

Figure 2.5.1: *CMA's next generation unified model (GRAPES) configuration.*

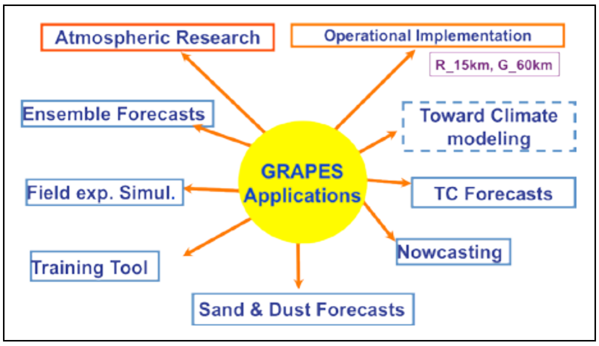

Figure 2.5.2: *CMA's next generation unified model (GRAPES) application framework.*

The TC (Tropical Cyclone) track ensemble prediction system was developed in 2006 based on TL213 GEPS with 15 members and 120 hours forecast at NMC/CMA. The BOGUS vortex initialization scheme was put into real time running in 2007. The Regional TC track ensemble prediction system was also developed in Shanghai Regional Centre with 6 members and 72h forecasts based on GRAPES model. The products are TC ensemble tracks and strike probability. The Regional Ensemble Prediction System (REPS) was implemented for Northern China at NMC/CMA from 2006. It is based on WRF (Weather Research & Forecasting) model of 15-kilometre horizontal resolution, 35 vertical levels, 15 members and 36h forecast, running at 00z/12Z each day. The IC perturbation is breeding growth mode (BGM) and the model perturbation is multi-physics with lateral boundary conditions from T213 GEPS. The REPS for Southwest China (SW-REPS) was implemented in 2005 at Chengdu Meteorological Centre of CMA with 20km horizontal resolution, 8 members and 48h forecast. The IC perturbation is Different Physical Mode Method (DPMM) developed by local researchers. Products are mean, spread, probability, postage stamp charts and meteograms. A severe convection risk index was implemented in 2009 at NMC/CMA [30].

2.6 National Centres for Environmental Prediction GEPS (USA)

The NCEP GEPS platform has been in operation since 1993, using the NCEP Global Forecast System (GFS) model for integration and breeding technique to generate initial perturbations. Since 2005, GEPS has been running the perturbed members four times per day (0000, 0600, 1200 and 1800 GMT). In 2006, the control forecast was extended to all cycles and Ensemble Transform with Rescaling (ETR) was added to the Breeding (Vector) Method. *The number of perturbed members was increased to 14 in 2006 and to 20 in 2007.* The last upgrading in late 2009 has increased the resolution from T126L28 to T190L28, and introduced a Stochastic Perturbation Scheme (SPS) to represent model related uncertainty. Based on the hypothesis that tendencies of the ensemble perturbations provide a representative sample of the random total model errors, SPS stochastically perturbs the total model tendency with tendencies from all ensemble members. These changes have contributed to the reduction in systematic errors, increased ensemble spread and improved performance of ensemble-based probabilistic forecasts.

The NCEP Short-Range (S-Range) Ensemble Forecast System (SREF) platform was operationally implemented in May 2001 as a 10-member Eta (with BMJ convective scheme)/RSM based regional ensemble prediction system. Another version of Eta (with KF convection scheme) and two versions (NMM and ARW) of WRF (Weather Research and Forecasting) Model were included in 2003 and 2005, respectively, leading to a Four-Model and Multi-Physics ensemble of 21 members. After last update the system now has more balanced diversity in model (about 5 members from each model) and physics, and runs at increased horizontal resolution (~32km). The initial perturbations are generated either by regional breeding or using global BV with ETR. All member forecasts are integrated four times daily up to 87 hours with output every hour for the first 39 hours and 3 hours afterwards. A dual-resolution (hybrid) ensemble is generated for the first 180 hours of GEFS forecasts by combining the corresponding deterministic integration (GFS, currently T382L64). Bias correction to GEFS and SREF products has been conducted operationally since 2006 for each variable, each lead-time and each forecast cycle on point wise basis. The bias is estimated using an adaptive algorithm and taking the weighted average (with decaying weights) of forecast errors in the most recent forecast cases (about 50 days). The same algorithm is also used to statistically downscale EPS products onto high-resolution meshes and provide forecast guidance at local scale, with Real Time Mesoscale Analysis (RTMA, at 5km resolution) used as the reference. New products linked to the implementation of SREF include (a) Composite Radar reflectivity and radar echo top/height; (b) Icing and Flight Restriction, etc.; (c) Richardson Number based planetary boundary layer (PBL) height and (d) a Tropical Cyclone (TC) tracer.

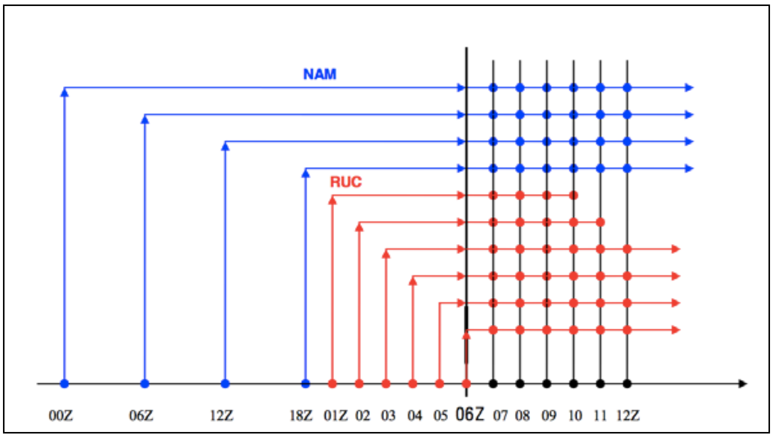

Figure 2.6.1: *VSREF membership configuration for today's 06Z cycle, which is composed of 10 finished cycles, including 00Z, 06Z, 12Z and 18Z NAM cycles (blue dots) of yesterday, and today's 01Z, 02Z, 03Z, 04Z, 05Z and just finished 06Z RUC cycles (red dots), with hourly output at 07Z, 08Z, 09Z, 10Z, 11Z and 12Z (black dots), totally 6 forecast hours.*

In recent years, NCEP has been making efforts to apply its Short Range Ensemble Forecast System to aviation weather forecast [31], including system configuration, post-processing and preliminary aviation-related ensemble products.

However, the current system configuration for the NCEP SREF still dose not meet "very short-range" requirement of NextGen (the new wide ranging transformation of the entire national US air transportation system), the Federal Aviation Administration's new Air Traffic Management System (ATM). Currently, NCEP has a Rapid Update Cycle model (RUC: http://ruc.noaa.gov) that is hourly run and specially serves deterministic aviation weather prediction. However, due to uncertainties of model prediction and its critic impacts on aviation traffic decision making procedure, NextGen *will heavily rely on ensemble-based probabilistic forecast data* as input [32] & [33].

As a promise to support and comply with the NextGen requirements, NCEP and Global Systems Division (GSD) of Earth System Research Laboratory (ESRL) of NOAA will cooperate to develop NCAR ARW-WRF based Rapid Refresh (RR) and High-Resolution RR (HRRR) systems. The RR or HRRR based ensemble forecast system (NARRE – North American Rapid Refresh Ensemble and HRRRE – High-Resolution Rapid Refresh Ensemble) would be established in 2014 as planed. As a prelude of the RR/HRRR ensemble development stages, a RUC-NAM based Very Short Range Ensemble Forecast System (VSREF) has been first suggested and developed at NCEP recently.

The basic idea of the VSREF (explained graphically in Figure 2.6.1) is time-lagging the forecasts from existing RUC and NAM cycles. An obvious advantage of the time-lagged technique is its low computational cost since it uses existing model output data without large amount of computational resources including CPU and memory space as requested mainly by, for instance, integrating a model and generating initial condition perturbations such as Ensemble Transform used by GEFS and breeding technique used by the SREF [34]. The only cost for the time-lagged ensemble forecast system is on the procedures to collect the existing model data and then apply a post processor to generate required ensemble products. For the VSREF, a rapid refreshed ensemble forecast system, employing the time-lagged ensembling technique is an appropriate choice for current computational condition at NCEP. The current VSREF system consists of three procedures, including the ensemble member creation, the aviation ensemble product generation and the ensemble product visualization.

2.7 Meteo France ARPEGE-PEARP GEPS

The Meteo-France Ensemble Forecasting System (PEARP) is entirely based on ARPEGE, with nearly the same model configuration as the ARPEGE-France deterministic data assimilation and forecast suite. The main difference is the ARPEGE model resolution (PEARP uses T358C2.4L55, i.e. slightly coarser resolution than the deterministic run). One unperturbed plus ten perturbed ARPEGE forecasts run every day at 108h range, which make up an 11-member ensemble with the unperturbed, deterministic ARPEGE 18UTC run. The ensemble perturbations are created as follows:

• the initial perturbations of the ensemble are a combination of singular vectors and evolved perturbations of the previous PEARP run (10 perturbations from 24h earlier)

• a flow-dependent background error estimate is used in the computation of singular vectors

• the singular vectors [10] are a combination of targeted singular vectors over Europe-North Atlantic (16 vectors at resolution T95L55), the Northern, Southern Hemispheres and the Tropics (10, 20 and 10 vectors, respectively, at T44L55 resolution).

Table 2.7.1: *Main features of various REARP global ensemble prediction platforms.*

Version	Initial state perturbations	Model perturbation	Size	Runs	Final step	date
PEARP1	SV over Atlantic Ocean and Western Europe	No	11	1 (18UTC)	60h	June 2004
PEARP1.5	SV all over the globe + breeding	No	11	1 (18UTC)	108h	January 2008

PEARP2	SV all over the globe + Data Assimilation Ensemble	Different packages	35	2 (18 and 06 UTC)	108h / 72h	End of 2009

The singular vectors are computed using a Lanczos algorithm on a dry linearized version of ARPEGE, in the vicinity of a 36-h ARPEGE forecast. PEARP can be regarded as both a global ensemble system, and a regional one optimised for Western Europe, with a resolution similar to foreign limited-area ensembles. Furthermore, an assimilation ensemble system (not yet coupled with the PEARP system) runs in real time since early 2008. It contains 6 instances of the ARPEGE assimilation perturbed by adding random noise to observations, with a few differences from the main, unperturbed ARPEGE system: cheaper algorithm (3DVar-FGAT instead of 4DVar), lower, uniform horizontal resolution (T359c1 instead of T538c2.4). As of mid-2008, only the background vorticity variances predicted by this ensemble are used. They are fed into the 4DVar background error model, which gives flow-dependent weight to observations, and into the initial perturbation generation for the PEARP ensemble forecasting system.

Nevertheless, the current configuration of ARPEGE-PEARP global ensemble forecast system contained in the Table 2.7.1 is:

- horizontal grid: global Schmidt T358c2.4 (i.e. 23km to 134km), 720x360 grid (T538 after December 2010 with resolution 15km over West Europe),

- vertical grid & timestep: Arp L65, same timestep as ARPEGE-France,

- forecasts: *35 members,* twice per day: 72h range from 06UTC analysis, 108h range from 18UTC analysis

ARPEGE-PEARP has been transformed into a more state-of-the-art ensemble prediction system that is both global and mesoscale over North-Atlantic and Europe area. One important innovation that has been introduced in Meteo-France's operational system in 2008 is a 6-members 3D-Var FGAT ensemble assimilation running in parallel to the main 4D-Var ARPEGE assimilation cycle [35]. One goal of this assimilation ensemble with perturbed observations is to feed the 4D-Var with error statistics of the day. But another, equally important goal, is to provide better initial conditions for ensemble forecasting. Replacing the semi-breeding with perturbations from the assimilation ensemble is one primary feature of the 2009 changes. Another one is to include some kind of model error. One source will be to use several sets of physical parameterizations. According to one month test period taken place during March 2008, these two aspects are able to bring very significant improvements, in particular with the probabilistic forecast of "actual weather" parameters (rainfall, near-surface state). Playing with the horizontal resolution (by changing the geometric factor *C*) had also been considered: the specific geometrical grid transformation of ARPEGE was finally utilized. The new PEARP system has the same characteristics as most of the existing global EPS but with a grid resolution over Europe close to most of the existing LAMEPSs (Limited-Area Ensemble Prediction Systems). Finally, the ensemble size has been significantly enlarged up to 35 members.

Furthermore, a second run has been implemented at 06h, in order to update short-range probabilistic forecasts. Using the TIGGE database archive, the new PEARP system is to be compared with other operational EPS. Particular attention is to be paid to the short-range probabilistic forecast of precipitation and, finally, the early warning of extreme events should be appropriate addressed. As PEARP will have a LAMEPS resolution over Europe, data will be provided for TIGGE-LAM. Overall, Meteo-France intends to implement a complete production suite of probabilistic forecasts. In this respect, efforts are to be made in:

- generalizing probabilistic forecast different applications (hydrology, marine, environment, etc)
- developing well-adapted products of visualization
- fixing a methodology for analyzing and choosing the right probabilistic scenario among all available scenarios
- achieving statistical post-treatments in order to improve the reliability of surface parameters forecast distributions according to local conditions
- giving to the forecasters the possibility to tune these distributions

- defining end-users products matching their needs
- evaluating the quality of such probabilistic forecasts organizing regular training both for forecasters and end-users

2.8 Korea Meteorological Administration GEPS

Korea Meteorological Administration (KMA) has operated a GEPS platform since 2001. An ensemble of *16 members* is obtained using a rotated bred vector (BV) method, i.e., applying factor rotation after 12 hours of initial growth of perturbation, then fostering perturbation for another 12 hours. Perturbations of physics are not included. Global ensemble runs twice a day up to 10 days with the resolution of T213L40 (0.5625 degrees). There is no regional ensemble system in operation, although there are three major changes in recent years. With the installation of a faster supercomputer, horizontal and vertical resolution was enhanced from T106L30 to T213L40. The forecast length and number of operation have also been extended from 8 days to 10 days, and from once to twice a day (00, 12 UTC) from June 2006. The new 16-member set is being added (combined with) to the existing 16-member set in generating EPS products [15].

A post-processing method using a decaying average bias estimation has been introduced to operation since 30 July 2007. This bias correction has resulted in improvement of EPS performance by reducing the strong positive bias in the Northern Hemisphere. Obtaining initial field for control through interpolation of higher-resolution global analysis could cause loss of high-frequency wave energy. To avoid this, KMA has constructed a 3dVar data assimilation system for global EPS. Control forecast is used as background information and analysis is generated on the same resolution as the ensemble model. This self-cycling ensemble system applied to the operation in September 2008.

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

2.9 Bureau of Meteorology GEPS (Australia)

The Bureau of Meteorology Research Centre (BMRC) Medium-Range Ensemble Prediction System (BoM-EPS) has been running in research trial mode since May 2000, and as a BoM operational trial system since 5 July 2001. The rationale for the ensemble approach is based on sampling the uncertainties in numerical weather predictions, coming from sources such as specification of the initial state of the atmosphere (analysis) and numerical forecast model uncertainties. The individual forecasts within the ensemble progressively diverge from one another during the forecast period, in the same sort of way as forecasts from different centres, which make up another type of multi- model ensemble, the so-called “poor-man’s ensemble” [36].

The BoM-EPS consists of a *33-member ensemble* of 10-day forecasts, based on the BoM Global Assimilation and Prediction System (GASP). The ensemble forecasts are run at TL119L19 resolution, with approximately 150 km grid spacing, compared to the TL239L29, 75 km resolution of the deterministic operational BoM GASP system. The ensemble perturbation strategy follows the singular vector approach pioneered in the ECMWF EPS (EC-EPS). Perturbations are scaled linear combinations of the 16 fastest growing 48hr T42L19 adiabatic singular vectors, localized to the Southern Hemisphere region 20S-90S. In April 2001, the BoM-EPS was upgraded from T79L19 resolution with Eulerian advection to TL119L19 semi-Lagrangian.

In December 2001, Northern Hemisphere perturbations were added and the EPS suite was extended to run twice daily, at 00Z and 12Z; the 12Z run is timed to be available for BoM forecasters use before 9am local time, in time for when the medium-range forecast policy is prepared in each Region [37].

2.10 Centre for Weather Forecasts & Climate Studies GEPS (Brazil)

The CPTEC (Centro de Previsão de Tempo e Estudos Climáticos – Centre for Weather Forecasts & Climate Studies) GEPS, i.e., the global ensemble prediction system also of the Brazil National Institute of Meteorology started operationally in October 2001. Two runs are performed daily starting from 00 and 12 UTC analysis. Each run represents a set of *15 forecasts* (1 control plus 14 perturbed members)

up to 15 days with resolution of T126L28 [38]. Its perturbation methodology is based on the method developed by Zhang and Krishnamurti [39] and modified by Coutinho [40]. The model is considered as a perfect model, while the perturbed region is defined over the area: 45S-30N / 0-360E.

3. Multi-Centre GEPS

3.1 THORPEX Interactive Grand Global Ensemble (Project)

TIGGE, the THORPEX (The Observing System Research and Predictability Experiment) Interactive Grand Global Ensemble project, is a key component of WWRP (World Weather Research Programme) of WMO (World Meteorological Organisation) to accelerate the improvements in the accuracy of 1-day to 2 week high-impact weather forecasts for the benefit of humanity. All GEPS providers described in Section 2, are participating in the TIGGE project. The GIFS (Global Interactive Forecast system) plans are expected to lead to the development of more multi-system products from the TIGGE project that will be trialled in GIFS-RDPs (GIFS – Research & Development Programs).

Table 3.1.1 contains the basic features of the ten (10) GEPS comprising TIGGE platform. The models are BOM: Bureau of Meteorology (Australia), CMA: China Meteorological Administration (China), CMC: Canadian Meteorological Centre (Canada), CPTEC: Centro de Previsão de Tempo e Estudos Climáticos (Brazil), ECMWF: European Centre for Medium-Range Weather Forecasts (International), JMA: Japan Meteorological Agency (Japan), KMA: Korea Meteorological Administration (Korea), MeteoFrance: French National Meteorological Service, NCEP: National Centres for Environmental Prediction (USA), MetOffice: The UK Met Office (United Kingdom).

Table 3.1.1: *Main features of GEPS platforms participating in TIGEE project.*

GEPS	Horizon (days)	No. Members	Resolution (deg)	Vertical Levels
BOM	10	32	1.5 x 1.5	19
CMA	16	14	0.56 x 0.56	31
CMC	16	20	1.0 x 1.0	28
CPTEC	15	14	~1.0 x 1.0	28
ECMWF	15	50	~0.5 x 0.5 (up to 10d) ~0.7 x 0.7 (10 to 15d)	62
JMA	9	50	1.25 x 1.25	40
KMA	10	16	1.25 x 1.25	40
Meteo-France	4.5	35	1.5 x 1.5	65
NCEP	16	20	1.0 x 1.0	28
Met Office	15	23	1.25 x 1.25	38

The TIGGE archive consists of ensemble forecast data from the ten global NWP centres mentioned above [41], starting from October 2006, which has been made available for scientific research (http://tigge.ecmwf.int/). TIGGE has become a focal point for a range of research projects, including research on ensemble forecasting, predictability and the development of products to improve the prediction of severe weather. The TIGGE project is overseen by the GIFS-TIGGE working group, which includes representative of the TIGGE data providers and the TIGGE archive centres.

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

3.2 North American Ensemble Forecast System

The North American Ensemble Forecast System (NAEFS) has been in operation since 2006 and has shown significant benefit to its members and the international community. While it continuously increases the number of products for exchange, it will be expanded to include more GEPSs and start REPS (Regional EPS) data exchange. NAEFS can provide a framework of operational requirements and constraints within which new research must be conceived on one hand, and will offer a receiving end for any new methods developed based on the TIGGE data archive. NAEFS is comprised the Canadian (Meteorological Service of Canada, MSC), the Mexican (National Meteorological Service of Mexico, NMSM), and the US (National Weather Service, NWS) NMS. The NAEFS was inaugurated in November 2004, and the first operational implementation of NAEFS products occurred in May 2006. In December 2007, down-scaling products for Contiguous United States (CONUS) have been implemented in NWS/US operation. Within the NAEFS, ensemble producing centres (currently MSC and NWS) exchange their raw forecast data (operational since September 2004), statistically post-process (include down-scaling) all ensemble members and jointly with other members (currently NMSM) develop and produce end products based on the combined ensemble of forecasts.

NAEFS in simple words combines global ensemble forecasts from Canada & USA, resulting to *40+ members per cycle*, 2 cycles per day from MSC (Canada) & NWS (USA) with a 6-hourly output frequency (instead of current 12-hourly), replacing the current 26 members once a day setup. Its basic scope is to generate basic products using same algorithms/codes in order to [42]:

- reduce systematic error (bias estimation),
- combine two ensembles (determine weights) and
- express forecast in terms of climatological anomalies (compare forecast with reanalysis climate distribution)

Statistical post-processing involves the correction of all ensemble members for biases (first and higher moments), the establishment of weights for the combination of all members, and 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 centres collaborate in the development of post-processing algorithms and software and share a common procedure to generate the basic products of bias-corrected forecasts, the corresponding weights and climatological percentile values. The products for probabilistic forecast (10%, 90%, 50%, mean, mode and spread) have been generated after statistical bias correction for ensemble members. The free ftp distributions of these basic products were operationally implemented in May 2006 and December 2007.

The final goal of the NAEFS is the generation of end products for the use of the participating and other NMS, including those used for severe weather warnings. Down-scaling probabilistic products for Contiguous United States are generated in NDGD (U.S. National Digital Guidance Database) grid by using Real Time Meso-scale Analysis (RTMA) as proxy truth. Some of the end products are developed jointly (such as the North American week-2 temperature and precipitation anomaly forecast), while additional products will be provided by individual participating centres. 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. 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 Centre (FNMOC) will be next one to plan to joint NAEFS, while the US Air Force Weather Agency (AFWA) as a user. The UK Met Office also considers its participation, pending the results of a multi-year testing and evaluation phase. These possible expansions will broaden the scope of the NAEFS and may lead to the development of a Global Ensemble Forecast System (GEFS), as the ensemble forecast component of the Global Interactive Forecast System (GIFS), foreseen by the THORPEX program. The NAEFS, and a possible future GEFS will well represent the spirit of the enhanced international collaboration sought by the THORPEX research program. In particular, the NAEFS/GEFS can provide a framework of operational requirements and constraints within which new research initiatives must be conceived on one had, and will offer a receiving end for any new methods developed based on the TIGGE) data archive.

4. Major LEPS & REPS (Regional EPS) platforms

Our investigation focused on major LEPS platforms (both operational & semi-operational) in Europe since this has been the main area of interest for the SafeWind Project. The SRNWP (Short Range Numerical Weather Prediction) Working Group was established during the autumn of 1993 in Toulouse (Meeting on Organisation of Short Range Numerical Weather Prediction Developments in Europe. Since that time the SRNWP project is the main vehicle for the cooperation between the European limited area modelling consortia. These numerical weather prediction consortia are the ALADIN (http://www.cnrm.meteo.fr/aladin), COSMO (http://www.cosmo-model.org), HIRLAM (http://www.hirlam.org), LACE (http://www.rclace.eu) projects and the UK Met Office (http://www.metoffice.com/research/nwp/index.html). The C-SRNWP ("C" stands for the coordination) Programme has been working under the EUMETNET project since 2000. These five consortia (shown in Table 4.1) are developing regional models as: the COSMO, HIRLAM, ALADIN, LACE and UM (UK Met Office). Each consortium runs (or plans to run) a regional ensemble (i.e. LEPS).

Table 4.1: *Main consortia and models of European Limited Area Modelling.*

Consortia	Model(s)
ALADIN	ALADIN (ALARO – AROME – HARMONIE)
COSMO	COSMO
HIRLAM	HIRLAM – HARMONIE (ALADIN – ALARO – AROME)
LACE	ALADIN (ALARO – AROME – HARMONIE)
UK Met Office	Unified Model

The inter-consortia cooperation is stimulated by a part-time coordinator (Programme Manager) and realised in the activities of the Expert Teams (ET). Figure 4.1 contains in detail the various European countries participating in the five SRNWP consortia.

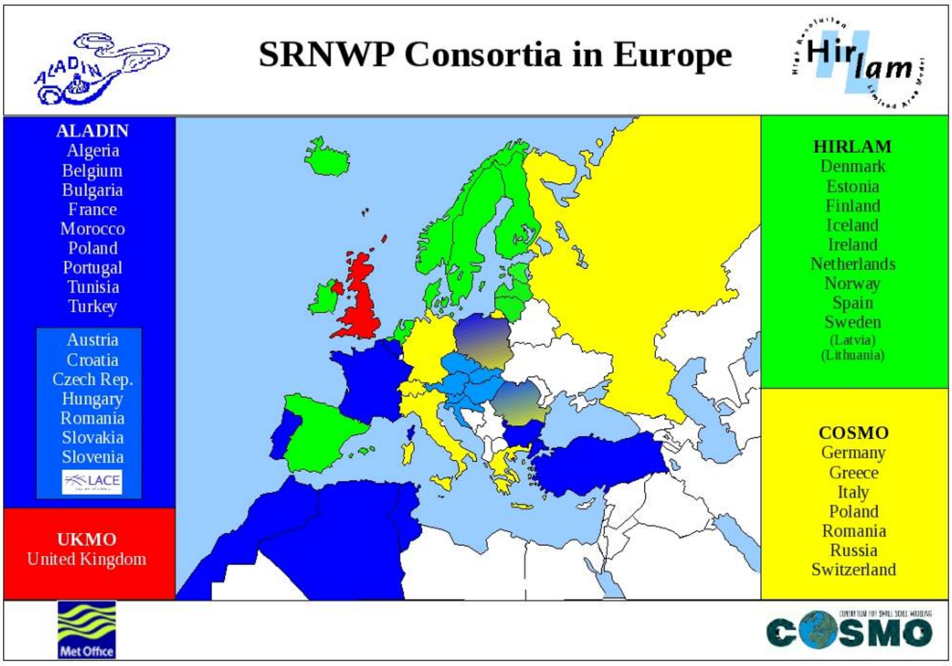

Figure 4.1: *Short Range NWP consortia in Europe.*

Nevertheless, it should be pointed out, that in Europe, it is the ECMWF that has pioneered the Ensemble Prediction System (EPS). The global ECMWF EPS has been greatly refined these last years and is today a standard tool for medium-range weather forecasting. Most of the development work in EPS today is done for the *Single-Model EPS* technique. When just one model is used, the different forecasts are created by defining different initial conditions or by changing physical parameterizations in the model. In the case of Limited Area Models (LAMs), a *Single-Model EPS* scheme can also be created, by using different boundary conditions. A list of major European Limited-Area Ensemble Prediction Systems (LEPS) is following [15]:

4.1 UK Met Office – MOGREPS-NAE (Appendix A)

The MOGREPS Ensemble Prediction System has been designed to provide a short-range regional EPS for the UK and Europe. It uses a regional model on a North Atlantic and Europe (NAE) domain running at 18-km resolution with 70 levels and forecasting to 54 hours. To provide lateral boundary conditions, there is also a global ensemble running at N144L38 (~90km – after mid-January 2010: ~60km) up to 72 hours. Both components have 24 ensemble members and run twice a day, the global at 00 and 12 UTC and the regional at 06 and 18 UTC. MOGREPS became fully operational in September 2008. The global ensemble (MOGREPS-GEPS) is also run to 15 days ahead as the UK contribution to the THORPEX TIGGE project. Brief description of MOGREPS-NAE is contained in Table 4.1.1, while details and references can be found in Appendix A.

Table 4.1.1: *Main features of UK Met Office MOGREPS-NAE.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
MOGREPS-NAE	54	24	18	70

Person(s) contacted (UK Met Office):	Ken Mylne Caroline Woolcock Rob Darvell	ken.mylne@metoffice.gov.uk caroline.woolcock@metoffice.gov.uk rob.darvell@metoffice.gov.uk

4.2 Meteo France – PEACE-PEARP (Appendix B)

A new version of the Meteo France Ensemble Prediction System PEARP (Prévision d'Ensemble ARPège) has been implemented at the end of 2009. The resolution of the ensemble has remained the same with a spectral truncation of TL358 with a stretching coefficient of 2.4. This corresponds to a resolution of about 23 km over France and 130km over New Zealand. The latest update also includes some kind of model error. Each ensemble member randomly utilises a particular physical package among eight schemes available. Furthermore, the size of the ensemble has increased from 11 to 35 members, while an implementation of a second run at 06Z with a lead time of 72h in addition to the current one (18 UTC) up to 108h has added to the operational cycle. As PEARP has now a LAMEPS resolution over Europe, data will be provided for TIGGE-LAM over a 0.25°x0.25° grid. Brief description of the PEARP is contained in Table 4.2.1, while details and references can be found in Appendix B.

Table 4.2.1: *Main features of Meteo-France PEACE-PEARP.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
PEACE-PEARP	72 / 108	35	23	60

Person(s) contacted (Meteo-France):	Philippe Frayssinet Thierry Jimonet	philippe.frayssinet@meteo.fr thierry.jimonet@meteo.fr

4.3 Spanish Met Agency – AEMET-SREPS (Appendix C)

AEMET (Spanish Met Agency) SREPS runs twice a day (at 00 and 12 UTC) at AEMET Central Headquarters. Boundary conditions are received daily from five operational Global Models and then five Limited Area Models are integrated locally at a CrayX1e vectorial supercomputer. Horizontal resolution of members is 0.25 degrees of longitude and latitude and they have 40 vertical levels, while the maximum forecast horizon has been set up to 3 days (H+072). As a result, of crossing models and initial conditions, the EPS is composed of 25 members. The underlying idea is that the ensemble performance has to improve as far as each member has itself the better possible performance, i.e. the better operational configuration limited area models are combined with the better global deterministic model configurations initialized with the best analysis. Due to this special construction of SREPS platform there is no need for a global EPS to provide initial conditions or the application of different model settings as multi-parameterizations or multi-parameters for the generation of AEMET-SREPS. Brief description of SREPS is contained in Table 4.3.1, while details and references can be found in Appendix C.

Table 4.3.1: *Main features of Spanish Met Agency AEMET-SREPS.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
AEMET-SREPS	72	25	~25	40

Person(s) contacted (AEMET):	Carlos Santos Burguete Jose Antonio Garcia-Moya	csantosb@aemet.es jgarciamoyaz@aemet.es

4.4 Hungarian Met Service GLAMEPS – LAMEPS (Appendix D)

The short-range limited area ensemble prediction system – LAMEPS (Limited Area Model Ensemble Prediction System) of the GLAMEPS (Grand Limited Area Model Ensemble Prediction System) – of the Hungarian Meteorological Service (HMS) is running every day in quasi-operational status. It is run with cycle 30 of the ALADIN limited area model driven by the members of the global Meteo France PEARP system. Following closely the old PEARP setup the LAMEPS has currently 11 members. At present no local data assimilation or generation of local perturbations are applied. Forecasts are made once a day starting from the 18 UTC data. The system is made up of Fortran programs and UNIX shell scripts that are responsible for the different sub-tasks, and it is running on a Unix cluster machine. When the initial and lateral boundary conditions are in the proper format (resolution, domain, etc.) the integration of the model can start. The ALADIN ensemble system is running on a domain covering large part of Continental Europe with a horizontal resolution of approximately 12 km. In the vertical 46 levels are used. Forecast length is 60 hours and the time step used for the integration is 450 seconds (7.5 minutes). As a last step of post-processing, files are converted from the so-called FA format of ARPEGE/ALADIN to the most common GRIB and NetCDF formats to be used for visualization and verification. Brief description of GLAMEPS-LAMEPS is contained in Table 4.4.1, while details and references can be found in Appendix D.

Table 4.4.1: *Main features of Hungarian Met Service GLAMEPS-LAMEPS.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
GLAMEPS-LAMEPS	60	11	12	46

Person(s) contacted (Hungarian Met Service):	Szepszo Gabriella Horanyi Andras	szepszo.g@met.hu horanyi.a@met.hu

4.5 Austrian Met Service GLAMEPS – ALADIN-LAEF (Appendix E)

Demand for bigger ALADIN-LAEF domain with better topography representation arose mostly out of two reasons. One of them is inclusion of the whole Black Sea (requested by Romania) and coverage of Turkey (as a new ALADIN partner) in the computational ALADIN-LAEF domain. The second reason is the request for the cooperation with GLAMEPS (Grand Limited Area Model Ensemble Prediction System). Hence the key factors for setting up new ALADIN-LAEF domain were to cover up whole Turkey and the Black sea (unconditionally); to enlarge the domain as much as possible towards the north and west taking into consideration the pre-operational GLAMEPS domain; to increase horizontal resolution to approximately 10-12 km (as much as it can be afforded); to cover the whole Mediterranean Sea, while at the same time not exceeding serviceable CPU time limit at ECMWF's HPC which is available for Austria. Additional research has been planned to investigate in more depth, whether more profit would be gained from such high-resolution ensemble or rather from increased number of ensemble members at the new domain but necessarily with coarser horizontal resolution (currently there exist 16 members at a resolution of 18 km). New blending ratio must be re-computed (and corresponding low spectral resolution CLIM files prepared) regarding new ALADIN-LAEF domain. Brief description of GLAMEPS ALADIN-LAEF is contained in Table 4.5.1, while details and references can be found in Appendix E.

Table 4.5.1: *Main features of Austrian Met Service GLAMEPS – ALADIN-LAEF.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
ALADIN-LAEF	60	16	18	37

Person(s) contacted (Austrian Met Service):	Yong Wang Florian Weidle	yong.wang@zamg.ac.at f.weidle@zamg.ac.at

4.6 Norwegian Met Institute GLAMEPS – NORLAMEPS (Appendix F)

The main approach behind NORLAMEPS has been the carefully selected ensemble members that account for uncertainties in initial data used to quantify the predictability of actual situations. SVs that maximise the total perturbation energy over finite time intervals and the extra-tropical northern hemisphere are used for computing initial perturbations in the ECMWF EPS. By maximizing the total energy norm of perturbations in a smaller target area, a system can be designed for a specific region of interest. Thus, it is possible to generate Targeted Ensemble Prediction Systems (TEPS) for parts of Europe. In the target area TEPS account for a larger portion of the entire probability distribution than the operational EPS at ECMWF, with the same number of ensemble members. The TEPS focus on a limited area, but the resolution of the model is the same as for the ECMWF operational EPS. A mesoscale ensemble prediction system requires that much smaller scales are resolved, rendering global calculations too expensive. In a LAM (model) initial errors and boundary-field errors combined with atmospheric instability eventually lead to loss of predictability in the target area. Furthermore, atmospheric models are still not perfect, which also contributes to forecast errors. Brief description of NORLAMEPS is contained in Table 4.6.1, while details and references can be found in Appendix F.

Table 4.6.1: *Main features of Norwegian Met Institute GLAMEPS – NORLAMEPS.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
GLAMEPS-NORLAMEPS	48 / 60	20	12	60

Person(s) contacted (Norwegian Met Institute):	Trond Iversen	trond.iversen@met.no

4.7 German Weather Service (DWD) SRNWP-PEPS (Appendix F)

In 2002, DWD (German Weather Service) had the idea of bringing together all available high-resolution numerical forecasts in a Poor Man's Ensemble Prediction System (PEPS). It was suggested at a EUMETNET Council meeting that a SRNWP (Short Range Numerical Weather Prediction) project should be started under the umbrella of EUMETNET. One of the main goals of the project has been the evaluation of PEPS to decide whether it provides a significant support and improvement of the warning process. The single model forecasts are interpolated onto a reference grid, the PEPS grid. It has a grid spacing of 0.0625° (~7 km) like the DWD Lokal Modell, covering Europe from 30°W to 30°E and 35°N to 70°N. Exceedance probabilities are calculated at each PEPS grid point from the ensemble members using a nearest neighbour approach. Because the individual members have different resolutions and integration areas, the ensemble size depends on location.

In June 2003 the director of the SRNWP EUMETNET Program, Jean Quiby, started the project by asking the European National Meteorological Services to participate. At that time, 20 Weather Services had joined the project, providing 23 forecast models. As a result, 40 deterministic and probabilistic forecast products are distributed to the contributing members on an operational basis. At the end of 2004 an operational suite was established at DWD. The ensemble products are calculated four times a day. Ensemble means and medians (precipitation and total snow) as well as probabilistic products are calculated. Brief description of SRNWP-PEPS is contained in Table 4.7.1, while details and references can be found in Appendix G.

Table 4.7.1: *Main features of EUMETNET SRNWP Poor Man's Ensemble Prediction System (PEPS).*

Model	Horizon (hours)	No. Members	Resolution (km)	Main Run (UTC)
SRNWP-PEPS	24 / 78	10 / 23	7 / 22	00 / 06 / 12 & 18

Person(s) contacted (DWD / ECMWF):	Michael Denhard	michael.denhard@ecmwf.int michael.denhard@dwd.de

4.8 ARPA-SIMC (Emilia Romagna, Italy) COSMO-SREPS (Appendix H)

A short-range ensemble COSMO-SREPS (Short Range Ensemble Prediction System) with a resolution of 10km has been developed experimentally. Spread in the early time steps is realised by first nesting the COSMO model at 25 km into 4 different global models. In the second nesting at 10km, various perturbations in the physics are introduced. DWD plans to introduce by 2011 a convection-permitting ensemble with a resolution of 2.8km and 20 members. The SREPS Project focused on the building up of a high-resolution ensemble system for the short-range. The project main tasks have been to develop and implement such an ensemble, then to run it over extensive testing periods and to evaluate the system features and performances. The ensemble is based on 16 integrations of the limited-area non-hydrostatic ARPA-SIMC (Regional Met Service of Bologna, Italy) COSMO model at about 10 km of horizontal resolution, with 40 vertical levels. Brief description of COSMO-SREPS is contained in Table 4.8.1, while details and references can be found in Appendix H.

Table 4.8.1: *Main features of Italian ARPA-SIMC COSMO-SREPS.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
COSMO-SREPS	21	16	10	40

Person(s) contacted (ARPA-SIMC):	Andrea Montani	amontani@arpa.emr.it

4.9 ARPA-SIMC (Emilia Romagna, Italy) COSMO-LEPS (Appendix I)

Many Limited-Area Ensemble Prediction Systems (LEPS) have been recently developed, either in research or in operational mode, so as to address the need of detailing high-impact weather forecasts at higher and higher resolution and to support the reliability of the deterministic forecast beyond the very short range. As far as operational implementations are concerned, the Consortium for Small–Scale Modelling Limited-Area Ensemble Prediction System (COSMO–LEPS) was the first mesoscale ensemble application running on a daily basis in Europe. This system (http://www.cosmo-model.org), initially developed and implemented by the Hydro-Meteo-Climate Regional Service of Emilia-Romagna, in Bologna, Italy (ARPA–SIMC), has been running at ECMWF since November 2002.

Nowadays, COSMO-LEPS is based on 16 integrations of the non-hydrostatic mesoscale model COSMO, formerly known as the Lokal Modell. This methodology aims at combining the advantages of the probabilistic approach by global ensemble systems (as the ECMWF EPS) with the high-resolution details gained in the mesoscale integrations. In the construction of COSMO-LEPS, an algorithm selects a number of members – referred to as Representative Members (RMs) – by a global ensemble system. This intermediate step, referred to as “ensemble-size reduction”, is required to keep the computational load operationally affordable, since it is not presently feasible to nest the limited-area model on each individual member of a highly populated global ensemble. After the “ensemble-size reduction”, the selected RMs are used to provide both initial and boundary conditions to the integrations with the non-hydrostatic COSMO model, which is run once for each RM. Therefore, COSMO-LEPS performs a sort of dynamical downscaling of a global-model probabilistic system, limiting to a certain extent the computation investment.

The present status of COSMO-LEPS, based on 16 integrations of the COSMO-model (7 km of horizontal resolution, 40 vertical levels, 132 hours of maximum forecast range) is running operationally as a 'time-critical application' at ECMWF. COSMO-LEPS application starts at about 20.50 UTC, once the ECMWF EPS starting at 12UTC has passed T+144 hours forecast range. Products are disseminated to Met-Ops rooms of COSMO weather offices starting from 23.00UTC. Concerning the skill assessment of COSMO-LEPS so far (outside the SafeWind context) an analysis has been performed mainly in terms of probabilistic prediction of 12-hourly accumulated precipitation for a number of thresholds. The evolution of the skill of the system has been assessed over a 7-year period, namely from December 2002 up to November 2009. Observations of 12-hour accumulated precipitation were taken from the SYNOP reports over the Alpine area and compared to the nearest grid-point forecasts of the COSMO-LEPS members. A number of probabilistic indices has been used so as to evaluate both reliability and resolution of the system and to assess the extent to which the quality of COSMO-LEPS forecasts improved in recent times.

Work is in progress at both ARPA-SIMC and MeteoSwiss to provide calibrated COSMO-LEPS forecasts, thanks to the results obtained by various re-forecast exercises. This would improve the skill of COSMO-LEPS forecasts, making the system more reliable than it is now. As for the future, it is being tested the increase of the horizontal resolution of COSMO-LEPS runs so as to provide more detailed forecasts for the interaction of the flow with orography and to describe with a higher degree of accuracy mesoscale-related processes and local effects. This would have a positive impact on the prediction of a number of those surface fields still nowadays strongly influenced by local effects and not always properly represented in terms of their uncertainty by mesoscale ensemble systems. Brief description of LEPS is contained in Table 4.9.1, while details & references can be found in Appendix I.

Table 4.9.1: *Main features of Italian ARPA-SIMC COSMO-LEPS.*

Model	Horizon (hours)	No. Members	Resolution (km)	Vertical Levels
COSMO-LEPS	132	16	7	40

Person(s) contacted (ARPA-SIMC):	Andrea Montani	amontani@arpa.emr.it

5. Skill assessment of ECMWF EPS (Appendix J)

In this Section the results concerning the skill assessment of ECMWF IFS (Integrated Forecasting System) and EPS (Ensemble Prediction System) winds at surface (at 10-meter height) and at various model levels (of the surface layer) for different areas over the globe (due to SafeWind's international partners) and selected European subareas for a period of two years (2008-09) are given. Due to the rather extensive investigation required in this task, details can be found in Appendix J.

Besides the typical verification scores (as the ACC – RMSE – BS – BSS – IS – ISS – ROC – Area Under ROC Curve – RPS – RPSS – CRPS – CRPSS – Talagrand Rank Histograms), the Useful Forecast Interval (UFI), i.e. the maximum forecast horizon that ACC stays above the 60% level, and the Minimum Overturning Interval (MOI), i.e. the minimum forecast horizon that beyond this, the EPS Ensemble Mean scores better than the high-resolution IFS operational forecast are being utilised also. The verification covering eight full seasons (i.e., DJF-2008, MAM-2008, JJA-2008, SON-2008, DJF-2009, MAM-2009, JJA-2009 & SON-2009) has been performed mainly on the basis of defining a Reference Skill Platform (RSP) for any potential improvements (of skill) coming from the development of Combined Prediction Systems (CPSs) involved in Task 5.5. Furthermore, such a RSP could provide the means of evaluating the skill of various LEPS (Limited-Area Ensemble Prediction System) components being investigating in this current Task (5.3). The various forecast time ranges used in such verification are defined in Figure 5.1. Based on these forecast range reference values improvements are sought for various LEPS schemes

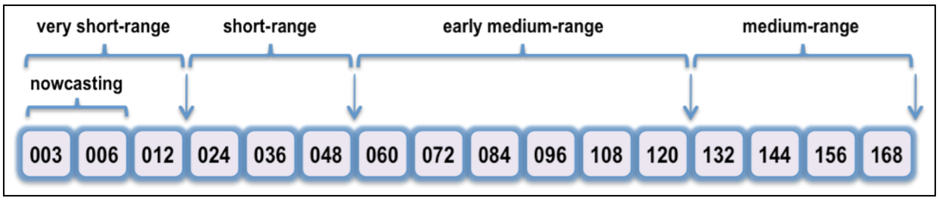

Figure 5.1: *Definition of forecast horizon intervals used in the skill assessment of EPS & various Limited-Area Ensemble Prediction Systems.*

Furthermore, appropriate databases (for surface and IFS & EPS model level parameters) have been constructed and saved in ECFS (i.e. the archiving system of ECMWF). Verification of IFS & EPS components was also made against FINO1 (North Sea) & FINO2 (Baltic Sea) observational platforms. Results have shown that both the IFS and EPS are capable of providing useful forecast guidance concerning wind speed prediction at different model levels. More specifically:

In probabilistic mode, probabilities and uncertainty estimation based on EPS are more reliable over "synthetic" probabilities produced by Ensemble Mean (EM), Control Forecast (CF) or IFS High-Resolution (HR) for both the Short-Range (S-R) and Early Medium-Range (EM-R) horizons. The superiority of IFS HR probabilities over CF's was also established. Furthermore, IFS HR probabilistic forecasts found superior to EM's during S-R, but EM proved to provide more reliable (probabilistic) guidance than HR during EM-R interval. The mean MOI (Minimum Overtaking Interval) was estimated to ~2.5 days. RPSS & CRPSS values for EPS found better than corresponding values for CF, EM & HR. During S-R interval, HR represents a better option over CF and EM, while EM probabilities proved to be superior to both the CF's and HR's during EM-R. EPS spread from EM found comparable to corresponding EM's skill (error) at the late EM-R reflecting to a well-tuned EPS, although a clear underestimation takes place during S-R.

In deterministic mode, IFS HR forecasts show considerable skill during S-R, whereas EPS EM, although better than CF, represents a less skilful option. During EM-R, EM becomes more skilful than HR, resulting to higher Useful Forecast Interval (UFI). Furthermore, it was shown that IFS and EPS deterministic components forecast slightly better at the lowest (10-meter) model level. Resolution increase does not reflect to any significant impact for relatively large areas, but it favours IFS HR over smaller areas. Over European subareas (high-res mode), MOI values vary considerably, with a mean value for Europe of 2.65 days. Results for EM-HR difference formulation expressed in RMSE reveals that EM becomes better than HR between 24 and 36 hours over most of European subareas.

Overall, in deterministic mode, high-resolution IFS guidance has found superior to EPS Ensemble Means's during S-Range (12 to 60 hours). Although IFS UFI reaches 4.5 days, Ensemble Mean found superior to HR during early M-Range (60 - 120h). Furthermore, in probabilistic mode, probabilities based on EPS found superior to "synthetic" IFS, Control Forecast and Ensemble Mean during S- and EM-Range. IFS probabilistic forecasts have proved to be more reliable than probabilities based on Ensemble Mean during S-Range. Ensemble Mean's probabilities have been more reliable than probabilities based on Control Forecast and IFS during early M-Range.

6. Skill assessment of COSMO-LEPS (Appendix K)

In this Section the results concerning the skill assessment of COSMO Limited-Area Ensemble Prediction System (LEPS) winds at surface (at 10-meter height) and at 100 meters for different areas over Europe and various European subareas for two periods (DJF 2009 & DJFM 2010) are given. The COSMO-LEPS system has been based on the dynamically downscaling of the global VarEPS forecasts provided by ECMWF. Results in brief are mentioned below, while details can be found in Appendix K.

The *first Section* of Appendix K discusses results obtained by COSMO-LEPS system for the period *DJF 2009* (December 2008 – January & February 2009). The population of the COSMO mesoscale system had been 16 members with a horizontal resolution of 10 km. For DJF 2009 period, COSMO-LEPS forecasts have been compared to ECMWF Ensemble Prediction System (EPS) forecasts to assess whether they can add valuable information to the one produced by the EPS. COSMO-LEPS and EPS platforms differ both in membership (16 for LEPS compared to 50+1 of EPS) and resolution (10 km for LEPS compared to 50 km of EPS). To assess the impact of ensemble size, COSMO-LEPS is compared to both the full-size EPS, and to the first 16-member EPS. To alleviate the fact that COSMO-LEPS has a higher resolution, both systems are verified on the same 0.5 x 0.5 degree grid.

Based on ACC scores, results have shown that both COSMO-LEPS Control (also COSMO Operational) Forecast and COSMO Ensemble Mean perform less skilfully than ECMWF EPS's components over Europe for DJF 2009. Furthermore, ECMWF IFS high-resolution forecast keeps its superiority over COSMO not only for large (as Europe) but also for smaller subareas (of Europe). In probabilistic mode, both EPS and LEPS provide better probabilistic guidance that their corresponding "deterministic" components based on Continuous Ranked Probability Skill Score (CRPSS) values. Once more, EPS in both of its formulations (16- and 50-member EPS), scores better than COSMO-LEPS (based on CRPSS values).

In the *second Section (DJFM 2010 period)* COMSO-LEPS scheme with its new (currently) horizontal resolution of 7 km is compared to both the old ECMWF EPS of 50 km resolution (period DJ 2010) and to the new (currently) EPS of 32 km (FM 2010 period). It is worth to point out that in the first Section common ECMWF analysis fields were used for the skill assessment (which has been somehow unfair to COSMO-LEPS), while in the second Section, each platform has been verified against its own analysis.

Results concerning the DJ 2010 period *(new COSMO-LEPS Vs old EPS)* have documented the superiority of IFS over EPS Control and COSMO Operational for all forecast horizons based on ACC scores. IFS found to possess the highest Useful Forecast Interval value of all. In probabilistic mode, CRPS values for both EPS (the limited 16- and the full 50-member EPS) formulations found to provide better probabilistic guidance over corresponding COSMO-LEPS not only for Europe but for smaller European subareas also.

Results concerning the FM 2010 period *(new COSMO-LEPS Vs new EPS)* have revealed that LEPS Ensemble Mean (EM) found less skilful compared to both 16- & 50-member EPS EM formulations. At the same time, IFS found to be superior over COSMO Operational (considered also as COSMO Control) forecast for all forecast horizons.

In probabilistic mode (based on CRPSS values), differences in probabilistic skill between IFS and EPS Control were documented but they are not considered significant (critical), while probabilities based on COSMO Operational forecast seemed unable to provide better forecast guidance than climatology for horizons longer than 24 hours. Furthermore, CRPSS values for the 16-member EPS show large similarities to the full 50-member one, while both ECMWF EPS formulations found to provide better probabilistic guidance over corresponding COSMO-LEPS for Europe and European subareas.

Based on the fact that in a perfect EPS, the time-mean ensemble spread about the ensemble-mean equals the time-mean RMS error of the ensemble-mean, the relationship of spread / skill of both EPS and LEPS platforms were investigated. ECMWF EPS spread in general has remained smaller than EPS EM skill (e.g., EM's RMSE), reflecting to the known deficiency of EPS concerning its under-dispersion. COSMO-LEPS Spread (from the ensemble mean) on the other hand, exhibits higher values than both EPS 16- & 50-member formulations for all forecast horizons. This characteristic of COSMO-LEPS can be of great value when atmosphere enters into its chaotic non-linear regime and most ensemble members are likely to be drawn towards model's climatology. In such cases, a larger spread may reflect to the capability of EPS to include the "extreme" solution as one of its ensemble members. It should be pointed out though, that the larger spread of COSMO-LEPS corresponds to a larger error of its ensemble mean that makes also LEPS under-dispersive for most of forecast horizons. LEPS becomes over-dispersive after the 72-hour forecast horizon.

Nevertheless, COSMO-LEPS appears not only to have larger spread (compared to EPS's) but most importantly a more "harmonized" relationship between Spread & Skill values. Furthermore, a closer investigation focusing on the full 50-member formulation of ECMWF EPS compared to the 16-member COSMO-LEPS has revealed that COSMO-LEPS scheme manages to stay closer to its optimal "Talagrande" distribution concerning the total number (sum of left and right outer bins) of outliers. This means that COSMO-LEPS appears to have a better chance in capturing possible extreme values such as those falling in the outer left & right bin categories.

7. Skill assessment of ALADIN-LAEF (Appendix L)

In this Section the results concerning the skill assessment of GLAMEPS ALADIN-LAEF winds at surface (at 10-meter height) for different areas over Europe and various European subareas for the period of February & March 2010 (FM 2010) are given. Various subareas of verification as defined in Figure J.13 (of Appendix J) have been utilised. The ALADIN-LAEF platform currently comprises 16 members at a resolution of 18 km focusing mainly over Central Europe. Results in brief are mentioned below, while details can be found in Appendix L.

ACC values for ECMWF IFS High-Resolution Operational Forecast (IFS-OPER), EPS Control Forecast (EPS-CF) and ALADIN-LAEF (ALAN-OPER) Operational Forecast (also considered as the LAEF Control Forecast) have been estimated for Europe and selected European subareas. Although IFS found superior over ALAN-OPER for Europe (the largest area of verification), there exist many areas belonging to the greater North European verification area that ALAN-OPER seems to provide better forecast guidance. Germany is one of them, especially its central and south parts, which have distinct orographic characteristics (as Alps).

In probabilistic mode, ECMWF EPS is capable to provide better probabilistic than ALADIN-LAEF. Both EPS and LAEF platforms found capable to provide the user with probabilities that are better (more reliable) than climatology (the climatological threshed is denoted by the zero dashed line) for all forecast horizons. The superiority of EPS over LAEF (valid for Europe) was not documented over smaller European areas (as in the case of IFS and ALAN-OPER inter-comparison). LAEF found to perform better over North Europe and Germany especially for T+012 – T+036 & T+060 forecast horizons. These probabilistic forecasts have been verified against 00 UTC analysis, so, it seems as the new ECMWF EPS platform has certain difficulties to simulate correctly the atmospheric flow in early morning hours. Nevertheless, stability issues especially over high terrain (orographic) areas (as Central & South Germany) seem to limit the predictability of both ECMWF IFS and EPS platforms.

Concerning the spread (from the ensemble mean) of ALADIN-LAEF, results suggested that similarly to the EPS, ALADIN-LAEF is not capable to harmonize its spread to the skill (in terms of RMSE) of its ensemble mean over Europe. Although LAEF appears to have a larger spread, the error of its ensemble mean is also large. Nevertheless, LAEF seems to perform better than EPS in harmonising its spread / skill relationship for forecast horizons longer than 48 hours. Furthermore, although ALADIN-LAEF found to exhibit larger spread values for most of forecast horizons true for Europe and most of European subareas) there still exist a considerable “gap” between the LAEF spread and the skill of the its Ensemble Mean. A closer investigation focusing on Talagrand Rank (Bin) Histograms was necessary to examine the true capability of ALADIN-LAEF to “capture” extremes as those falling in the outer Talagrand bins. Results concerning the left outer bin suggest that ECMWF EPS (in its full 50-member formulation) does a better job in capturing extremes belonging to the left outer bin(s), i.e., it scores less misses. Nevertheless, both EPS and LAEF found to be far from their optimal “Talagrande” frequency (i.e., 1.96% & 5.88% respectively). On the other hand, one very promising signal has been the reduction of outliers for both LAEF and EPS platforms as the forecast horizon was increased (from 12 to 60 hours). Results concerning the right outer bin suggest that ALADIN-LAEF seems to do significantly better than EPS in capturing “real” extremes, i.e., extremes belonging in the right outer bin(s).

Overall, LAEF manages to stay close or even below its optimal “Talagrande” distribution during all forecast horizons. EPS has found unable to capture all extremes (of the right bin category), although the reduction of “misses” as the forecast horizon is increased is obvious. Finally, it looks like that the ALADIN-LAEF is biased to stronger wind speeds (i.e., it shows a tendency to over-forecast wind speeds), which may be one of the reasons behind its ability to capture higher percentage of “real” extremes for all forecast horizons.

8. Study case: Xynthia windstorm (Appendix M)

So far, activities concerning collection of test cases and assessment of selected LEPS runs in terms of surface winds suitable as input to wind power prediction platforms have been focused on COSMO-LEPS in S-R & early M-R forecast horizons and ALADIN-LAEF in S-R, verified over various strategically selected subareas of Europe. Meteo-France PEACE/PEARP platform has been also utilized for the assessment of the Xynthia windstorm over Central Europe. Potential weaknesses and strengths of various LEPS platforms concerning their ability to provide useful (and early warning) forecast guidance in the case of Xynthia windstorm have been investigated by inter-comparison to ECMWF EPS, which has been considered as the backbone ensemble prediction system utilized by the SafeWind Project. Due to the different initialisation times (06 & 18 UTC) of PEARP forecasts, different forecast horizons have been utilised. For instance, for day 1 forecasts, the corresponding T+018 PEARP forecast initialised on 18 UTC of the previous day has been utilised for inter-comparison with EPS and LEPS T+024 components. Every block of forecasts (belonging to a specific verification day interval) is considered as a block of information concerning the absolute maximum, (i.e. the maximum of all different maximum coming from EPS – LEPS & PEARP). Investigation has shown that all absolute maximum values are coming out from the ECMWF EPS platform, suggesting that there is no real advantage of using LEPS or PEARP platform in capturing the “extremicity” of Xynthia windstorm for T+024 – T+048 & T+072. Furthermore, the same holds for the T+096 forecast horizon (already investigated for EPS and LEPS platform). It should be noted that the new EPS has a resolution of 32 km, but it comprises 50+1 members. LEPS on the other hand has a (higher) resolution of 7 km, but it only comprises 16 members, while PEARP seems to have some how intermediate characteristics, since it has a resolution of 23 km (over Central Europe) and comprises 35 members.

Lastly, although ALADIN-LAEF (comprising 16 members with a resolution of 18 km) maximum forecast horizon is limited in S-R, its potential capability to complement EPS in the case of Xynthia has also been investigated for T+024 and T+048 forecast horizons, both verifying on 28 February 12 UTC. Based on Table M.2, ALADIN-LAEF does not seem capable of providing a more useful (max) value for the coming (Xynthia) windstorm. For both the T+024 and T+048 forecast horizons, EPS managed to provide a more representative envelope (of wind speed values) that contained the IFS T+000 analysis value over the area of maximum impact.

9. Conclusions

Besides ECMWF EPS data available to SafeWind participants, an extensive investigation focuses on the opportunities to use Limited Area Model (LAM) EPS forecasts for improved wind predictions on local to regional scales. A link between different Limited-Area EPS (LEPS) groups and the wind power community has been sought during different activities. All major LEPS groups currently in Europe were contacted and a collaboration concerning test cases, verification of various model runs and provision of special data sets was established. Table 9.1 contains briefly the status of this on-going effort.

Table 9.1: *Status of collaboration between SafeWind and major European LEPS providers.*

LEPS Group *& Person(s) contacted*	**Status (in brief)**
MOGREPS-NAE **UK Met Office** *Ken Mylne* *Caroline Woolcock*	UK Met Office is not participating in the SafeWind Project. At the same time UK Met Office has being putting emphasis on its new Meteorology Energy (solar & wind power) Section. Collaboration of SafeWind with PREVIEW Project (led by UK Met Office) has been not possible. No PREVIEW data available to SW either, although issue remains open.
PEACE-PEARP **Meteo France** *Philippe Frayssinet* *Thierry Jimonet*	Meteo-France is participating in the SafeWind Project. A special set of PEARP data is stored at ECMWF ECFS. Data contain winds at different heights in the lower atmosphere with PEARP's new ensemble scheme comprising 35 members. A subset of these data was used for the study of Xynthia windstorm (selected case study).
AEMET-SREPS **Spanish Met Agency** *Carlos Santos Burguete* *Jose Antonio Garcia-Moya*	Data sets for DJFM 2010 winds at surface and various model levels of AEMET-SREPS have been prepared at the Spanish Met Agency for SW needs. Some (last) details to be finalised concerning issue(s) of retrieving data and saving at ECMWF ECFS.
GLAMEPS-LAMEPS **Hungarian Met Service** *Szepszo Gabriella* *Horanyi Andras*	Requested data for extended winter season (DJFM 2010) were not available due to a failure of GLAMEPS-LAMEPS archiving system. Nevertheless, there always exist the ability for SafeWind to acquire LAMEPS data for other period(s). Really excellent cooperation and willing to support and contribute to the full spectrum of SW work.
GLAMEPS ALADIN-LAEF **Austrian Met Service** *Yong Wang* *Florian Weidle*	Requested data for extended winter season (DJFM 2010) are now available from ECMWF ECFS. Additional surface wind data are also available from ECMWF MARS. A subset of ALADIN-LAEF data was used for inter-comparisons with ECMWF EPS and COSMO-LEPS. Details are contained in Appendix K.
GLAMEPS-NORLAMEPS **Norwegian Met Institute** *Trond Iversen*	Luck of data due to the fact that NORLAMEPS platform has not been operational yet. Ability for SafeWind to acquire future data sets. Prof. Trond Iversen (head of NORLAMEPS Group) showed vivid personal interest and has already agreed to provide NORLAMEPS data during possible future collaboration(s) of NMI & SafeWind.
SRNWP PEPS **German Met Service** *Michael Denhard*	Due to the non-uniform coverage (domain of integration) and different resolution of models involved direct inter-comparison of PEPS and EPS not straightforward. Availability of PEPS data to SW possible (currently & in the future) through DWD channels (Dr. Michael Denhard).
COSMO-SREPS **ARPA-SIMC (Italy)** *Andrea Montani*	COSMO-SREPS has remained in experimental mode. Despite some promising results in the methodology as a whole, it was recognised a general lack of spread in the COSMO-SREPS ensemble in terms of the variables of concern for the data assimilation. No data available to SW.
COSMO-LEPS **ARPA-SIMC (Italy)** *Andrea Montani*	Excellent cooperation with COSMO-LEPS core Group. Extensive data sets are being stored at ECMWF ECFS. LEPS data of surface winds available from MARS also. Additional LEPS model level data available to SW are stored at ECMWF ECFS.

From Table 9.1, it becomes clear that in Europe there exist five consortia developing regional models (e.g., COSMO, HIRLAM, ALADIN, LACE and UM of UK Met Office). It should be pointed out that most of the LEPS groups showed a vivid interest and willing to cooperate in the context of SafeWind. Arrangements were made concerning specialised data sets reflecting to different case studies. Results of the skill assessment of various LEPS (by inter-comparison to EPS) are given briefly in Table 9.2. Joint work of COSMO-LEPS Group and SafeWind is contained in Table 9.3.

Table 9.2: *Results of skill assessment of various LEPS by inter-comparison to ECMWF EPS.*

	Period(s)	**Results in brief**
ECMWF EPS	DJF 2008 MAM 2008 JJA 2008 SON 2008 DJF 2009 MAM 2009 JJA 2009 SON 2009 & DJFM 2010	• IFS guidance superior over EPS EM's during S-Range. • Although IFS UFI reaches 4.5 days, EM found superior to HR during EM-Range (60 - 120h). • Probabilities based on EPS found superior to "synthetic" IFS, CF and EM during S- and EM-Range. • IFS probabilistic forecasts have proved to be more reliable than probabilities based on EM during S-Range. • EM's probabilities more reliable than probabilities based on CF and IFS during EM-Range.
COSMO-LEPS	DJF 2009 & DJFM 2010	• COSMO-LEPS appears not only to have larger spread (compared to EPS's) but most importantly a more "harmonized" relationship between Spread & Skill values. • Closer investigation focusing on the full 50-member formulation of ECMWF EPS compared to the 16-member COSMO-LEPS has revealed that COSMO-LEPS scheme manages to stay closer to its optimal "Talagrande" distribution concerning the total number (sum of left and right outer bins) of outliers. • COSMO-LEPS appears to have a better chance in capturing possible extreme values such as those falling in the outer left & right bin categories.
ALADIN-LAEF	February & March 2010	• Overall, ALADIN-LAEF manages to stay close or even below its optimal "Talagrande" distribution during all forecast horizons. ECMWF EPS has found unable to capture all extremes (of the right bin category), although the reduction of "misses" as the forecast horizon is increased becomes obvious. • It seems as ALADIN-LAEF is biased to stronger wind speeds (i.e., it shows a tendency to over-forecast wind speeds), which may be one of the reasons behind its ability to capture higher percentage of "real" extremes for all forecast horizons, besides its larger spread.
PEARP/PEACE Xynthia Storm	26 to 28 February 2010	• All absolute maximum values found coming out from the EPS platform, suggesting that there is no real advantage of using LEPS or PEARP platform in capturing the "extremicity" of Xynthia windstorm for T+024 – T+048 & T+072 horizons. • The same holds for the ALADIN-LAEF platform as well, i.e., it does not provide any stronger speed values than EPS.

Table 9.3: *Presentation of joint work of COSMO-LEPS Group and SafeWind*

ECMWF Users Meeting 9-11 June 2010	• Petroliagis T.I.: Wind power forecasting utilizing global & limited-area ensemble prediction systems (COSMO-LEPS Vs EPS)
European Meteorological Society Annual Meeting, 13-17 September 2010	• Petroliagis T.I. et al.: Global & limited-area ensemble prediction systems deployed for wind power forecasting (LEPS Vs EPS)

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Appendix A: UK Met Office MOGREPS-NAE

In 2003 UK Met Office set out plans for the development of a short-range (regional) ensemble prediction system based on the North Atlantic and European (NAE – previously EuroLAM) model, with initial condition perturbations provided using an Ensemble Transform Kalman Filter (ETKF) [A1] & [A2] and stochastic physics perturbations to account for model error. Supplementary work to investigate alternative perturbation methods, particularly the use of moist singular vectors (SVs) was also included [A3]. Following these plans, MOGREPS (Met Office Global and Regional Ensemble Prediction System) was successfully implemented in the operational suite in the summer of 2005 and it became fully operational in September 2008 after three years of trials. Figure A.1 shows the domain of integration of MOGREPS-NAE.

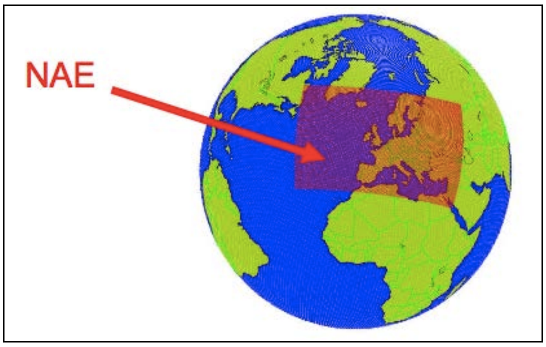

Figure A.1: *MOGREPS-NAE domain of integration.*

MOGREPS has consisted of two components, a 24-member global ensemble at N144L38 resolution (~90km) running to T+72 (MOGREPS-G) and a 24-member NAE regional ensemble at 24 km resolution running to T+54 (MOGREPS-R). Currently (after latest update taken place mid-January 2010) the “global” resolution has become 60 km, while the vertical resolution has been 70 levels (compared to the old 38-level resolution). Same wise, the new resolution of regional MOGREPS-NAE has become 18 km (horizontal) and 70 vertical levels [A4]. Initial condition perturbations calculated using ETKF in the global ensemble, are taking account of all observations processed in 4D-Var. MOGREPS-G runs from start-times of 00 and 12 UTC with perturbations added to the 4D-Var global analysis. MOGREPS-R runs from 06 and 18 UTC NAE analyses, taking its Lateral Boundary Conditions (LBCs) and initial perturbations from the 6-hour-old MOGREPS-G forecast. Both ensembles include stochastic physics systems. Products from both ensembles are available for assessment by forecasters around 8 hours after data-time.

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

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

The latest model upgrade has been targeting for a further enhancement to the ETKF by a vertical "localisation" – the inflation factor will be calculated separately in each of 4 layers in the atmosphere. In the past, perturbations were too small in the boundary layer and slightly too large in the upper air and tropical stratosphere. Vertical localisation has allowed this to be rebalanced. A fourth layer is used to damp perturbations in the upper few model levels to avoid unstable growth of perturbations. The upgrade has also introduced the enhanced version two of the SKEB scheme. The total package is expected to provide a substantial enhancement in MOGREPS performance.

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Appendix B: Meteo France PEACE-PEARP

Meteo France runs operationally since 2004 an ensemble forecast based on its global model ARPEGE, developed within its forecast department. It is called *PEARP* [B1], French acronym for *ARPEGE ensemble forecast (Prévision d'Ensemble ARPège).* The ensemble has 11 members, it runs once per day following the 18UTC production assimilation. It is initialized with singular vector perturbations computed over the Northern Atlantic and Europe with an optimization time of 12 UTC. The model was unperturbed and exactly identical to its deterministic version. This ensemble was primarily meant to provide possible alternative scenarios in situations favourable to rapid storm development. As the interest for producing actual probabilistic forecasts raises, it has been decided to hand the future evolution of the ensemble forecasting tool to the research department, while the forecast department would concentrate on developing methodologies and probabilistic products from both PEARP at short range and the ECMWF EPS at longer range.

On 28 January 2008, a first step of evolution within the new organization has been completed. A new version, termed *PEARP 1.5* has been declared operational. It includes the following changes.

• although ensemble size is still 11, the horizontal resolution of the base PEARP model has been uncoupled from that of the deterministic version and fixed at T358 with the geometric factor C of the Schmidt-Courtier-Geleyn transform at $C = 2.4$. However, the vertical resolution continues to follow that of the other ARPEGE-ALADIN models (changing from 41 to 60 levels), except that the mesosphere is removed,

• further singular vectors are computed in all parts of the globe, although at low resolution (T44). The most significant change to the initialization, however, is the inclusion of some form of breeding. Indeed, initialization now includes the 24 h evolved perturbations from the previous run, combined to the singular vectors,

• furthermore, the final anomalies added to the analysis are scaled to an amplitude sized using error variances derived from the 4D-Var assimilation cycle,

• the complete TIGGE requirements for output have been implemented, coupling files for the Hungarian Met Service limited area ALADIN ensemble forecast are produced.

A new version of the Meteo France PEARP has been implemented at the end of 2009, with the following main characteristics:

• the coupling with the 6-members 3D-Var FGAT ensemble assimilation running parallel to the main 4D-Var Arpege assimilation cycle [B2]. One goal of this assimilation ensemble with perturbed observations is to feed the 4D-Var with error statistics of the day. But another equally important goal will be to provide perturbations for ensemble forecasting in replacing the semi-breeding used currently in PEARP. These perturbations will be combined to the different sets of singular vectors computed over different areas in order to provide the perturbed initial conditions for the ensemble.

• the inclusion of some kind of model error. Each ensemble member will randomly use a particular physical package among the 8 available.

• the increase of the *size of the ensemble from 11 to 35 members*.

• the implementation of a second run at 06Z with a lead time of 72h in addition to the current one (18Z up to 108h).

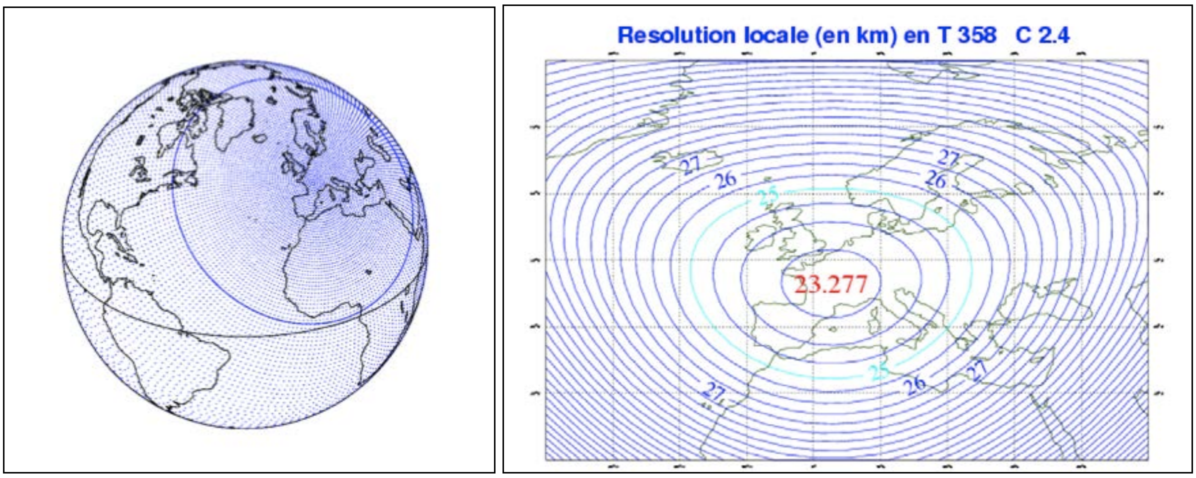

Figure B.1: *The variable resolution grid of the ARPEGE model. Higher horizontal resolution in the area of interest (Europe) and lower resolution on the other side of the globe (left). The variable resolution of the ARPEGE model as used in the PEARP system in km (right).*

The resolution of the ensemble remained the same at this stage with a spectral truncation of TL358 with a stretching coefficient of 2.4. This corresponds to a resolution of about 23 km over France and 130km over New Zealand (an example is shown in Figure B.1). Nevertheless an update of the resolution has been planed at the end of 2010. Using the TIGGE data-base archive, the new PEARP system will be compared with other operational EPS. Particular attention will be paid to the short-range probabilistic forecast of precipitation and, finally, the early warning of extreme events will be addressed. As PEARP will have a LAMEPS resolution over Europe, data will be provided for TIGGE-LAM over a 0.25° x 0.25° grid. Post-processing seems necessary for surface parameters (precipitation, temperature, wind speed) in order to remove biases. Post-processing has been implemented for both the first moment of the distribution (Pseudo-Perfect Prog methodology applied to all of the members) and for the second moment of the distribution (calibration by Bayesian Model Averaging is under way by using specific statistical laws).

Operational products are to be developed for forecasters. These products will allow synthesizing information coming from ensembles and single models. Charts of quantiles and maximum values will be made available. An experiment will be conducted next winter to evaluate the usefulness of these new products. Forecasters will be encouraged to give uncertainty qualification for their forecast. Furthermore, applications are under development, as a hydrological ensemble (Coupling EPS with the hydrological model Safran-Isba-Modcou) being tested at the flood alert office (the “SCHAPI”) and the marine division has been testing ensembles for storm surges and marine pollutant tracking.

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Appendix C: Spanish Met Agency AEMET-SREPS

The AEMET (Spanish Meteorological Agency) SREPS platform puts emphasis on the Mediterranean region, which has a distinct meteorological behaviour dominated by the interaction of synoptic flow with orographic small-scale features and Mediterranean Sea. Such interaction involves mesoscale structures that are difficult to model using Global Models (GMs) or even Limited Area Models. In order to improve the forecast of these structures AEMET set out plans some years ago to create a SREPS (Short Range Ensemble Prediction System). The main goal of an ensemble prediction in respect to a deterministic one is that it takes into account the forecast uncertainty by the means of a probabilistic prediction. Furthermore, in an ensemble system the Probability Density Functions are constructed dynamically, not statistically.

There are several ways of making a SREPS. AEMET-SREPS is based on the multi-model multi-analysis and multi-boundary conditions technique [C1] & [C2]. Uncertainties of model, analysis and boundary conditions are sampled by construction. To take into account implicitly the model errors, five purely independent different limited area models are used (shown in the first column of Table C.1). These models are the COSMO (of COSMO Consortium), the HIRLAM (of HIRLAM Consortium), HRM of DWD (German Weather Service), MM5 (of NOAA) and UM-NAE (of UKMO). The ensemble has 25 members that are generated combining these five LAMs with five GMs (shown in the second column of Table C.1). Each one of these global numerical models are daily integrated and verified at different National Weather Services all over the world representing currently the *state-of-the-art* Numerical Weather Prediction (NWP) models. On the other hand, as all numerical models being have systematic errors, it would be beneficial to calibrate the ensemble.

Table C.1: *Details of LAMs and GMs involved in the construction of AEMET-SREPS*

LAM Models	Boundaries (Global Models)
HIRLAM (http://hirlam.org)	ECMWF
HRM of DWD (German Weather Service)	UM (UKMO)
MM5 (http://box.mmm.ucar.edu/mm5/)	GFS (NCEP)
UM of UKMO (UK Met Office)	GME (DWD)
LM - COSMO Model (http://www.cosmo-model.org)	CMC (SMC)

SAMEX [C3] and DEMETER [C4] experiments demonstrated that such a multi-model / multi-boundary ensemble technique gives more skill in probabilistic forecasting than any other one. This fact was supported by one of the conclusions of the last workshop on SREPS hold at Exeter on June 2009 [C5]. AEMET-SREPS runs twice a day (at 00:00 and 12:00 UTC) at AEMET Central Headquarters. GM boundary conditions are received operationally and then five LAMs are integrated locally at our CrayX1e vectorial supercomputer. Horizontal resolution of members is 0.25 degrees of longitude and latitude and they have 40 vertical levels. Figure C.1 shows the integration domains of each LAM, and in blue the common (SREPS) one. The maximum forecast horizon has been set up to 3 days (H+72).

As a result, of crossing models and initial conditions, the EPS is composed of 25 members. The underlying idea is that the ensemble performance has to improve as far as each member has itself the better possible performance, i.e. the better operational configuration limited area models are combined with the better global deterministic model configurations initialized with the best analysis. Due to this special construction of SREPS platform there is no need for a global EPS to provide initial conditions or the application of different model settings as multi-parameterizations or multi-parameters for the generation of AEMET-SREPS.

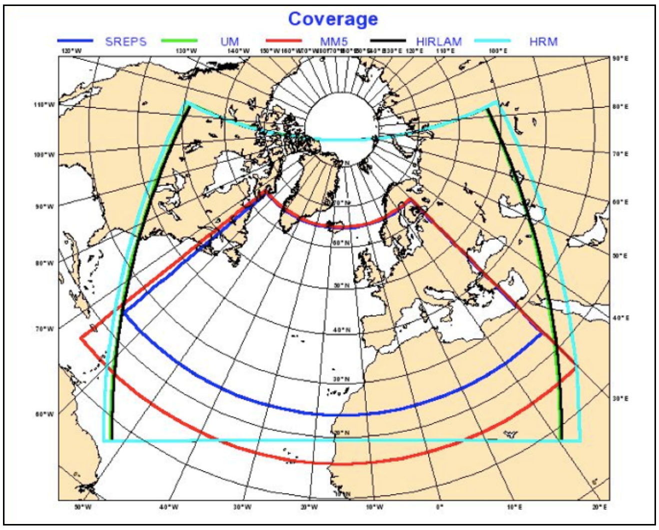

Figure C.1: *AEMET-SREPS domain of integration of various LAMs.*

Concerning performance over different regions, the SREPS probabilistic precipitation forecasts over various Mediterranean areas have a little less reliability and resolution than areas over North Europe especially for higher thresholds of 10 and 20 mm/day. These results suggest that in SREPS the representation (simulation) of the mesoscale meteorological events around the Mediterranean basin has to be improved, and most probably the orographic-related processes as well like the orographic enhancement of the precipitation. Overall, the skill of SREPS over the Mediterranean could be improved if the horizontal and vertical resolution of each limited area model of the system could be increased as well in order to take into account the meso-beta scale.

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Appendix D: Hungarian Met Service GLAMEPS-LAMEPS

The short-range limited area ensemble prediction system – LAMEPS (Limited Area Model Ensemble Prediction System) of the GLAMEPS (Grand Limited Area Model Ensemble Prediction System) – of the Hungarian Meteorological Service (HMS) is running every day in quasi-operational status. It is run with cycle 30 of the ALADIN limited area model driven by the members of the global PEARP system [D1]. Following closely the old PEARP setup the LAMEPS has currently 11 members. At present no local data assimilation or generation of local perturbations are applied. The main characteristics of GLAMEPS-LAMEPS platform are shown in Table D.1.

Table D.1: *Basic characteristics of HMS GLAMEPS-LAMEPS platform.*

Multi analysis ensemble	The analysis fields made at different centres (or at the same centre but using different assimilation methods) are collected. From each of them forecast is made. These forecasts will be the members of the ensemble system.
Multi model ensemble	In this case the forecasts made at different centres (or at the same centre but with different models) are collected. These forecasts will be the members of the ensemble system. The method is often referred to as "poor man's ensemble system", because each participating centre has to create only one member (which is generally the operational forecast of that centre) of the ensemble.
Perturbation of observations	Observations used for data assimilation are perturbed (perturbations are of the order of observation error). This results in different initial conditions and finally in a set of forecasts. These forecasts will be the members of the ensemble system.
Generation of initial perturbations	Perturbations used in this method are again of the order of analysis error. The two most frequently used techniques are singular vector method and breeding method. *Breeding method:* As a first step initial conditions are randomly perturbed, then forecast is made from all these perturbed initial conditions. At the end of the forecast perturbations are re-scaled, the actual analysis is modified with these perturbations and the process continues. After 4-5 days this method leads to the selection (breeding) of fastest growing perturbations. *Singular vector method:* This method requires the solving of an eigen-value problem and has a strong mathematical basis. Using this method is very expensive in terms of CPU time.
Perturbation of physics	In this case parameters of physical parameterization packages or the packages themselves are changed resulting in a set of different forecasts.
Downscaling of global ensemble forecasts	This is the easiest method of all, because all we have to do is to use the global ensemble members as initial and boundary conditions for our limited area ensemble system. The problem is that the perturbations generated for the global ensemble system are usually effective only on medium range and large scales therefore it is not sure that they are optimal for short-range ensemble forecasts. Another method is when only few members of the global ensemble system are used as initial and boundary conditions. For example: members of the global ensemble prediction system are grouped in different clusters. Within each cluster one representative member is selected according to the criterion that the representative member is closest to the members of its own cluster and most distant from the members of the other clusters. Finally all representative members are used as initial and boundary conditions for the limited area ensemble system.

Forecasts are made once a day starting from the 18 UTC data [D2] & [D3]. The system is made up of Fortran programs and UNIX shell scripts that are responsible for the different sub-tasks, and it is running on a Unix cluster machine. The whole forecast process takes about 3-3.5 hours using 32 processors of the computer. The schematic view of the system is presented in Figure D.1.

Appendix E: Austrian Met Service GLAMEPS ALADIN-LAEF

The Central European Limited Area Ensemble Forecasting system ALADIN-LAEF has been developed the in frame of the international cooperation ALADIN/LACE. LACE has been a group of ALADIN members, using ALADIN software. The first operational ALADIN-LACE model was run in Toulouse where the LACE management group was hosted (1994). In 1998, the LACE operations were transferred to Prague Regional Centre (RC). From 2003, each RC LACE Member is responsible for its own operational NWP system, but scientific research and development is co-ordinated within the LACE project.

ALADIN-LAEF platform has put into pre-operational since March 2007. The main feature of the pre-operational ALADIN-LAEF is dynamical downscaling of the ECMWF EPS. In February of 2009, ALADIN-LAEF has been upgraded. In the new ALADIN-LAEF, several methods for dealing with the forecast uncertainties are developed, and implemented on ALADIN-LAEF for improving the forecast quality. Those are:

• perturbations to initial conditions are calculated by blending the large scale perturbation generated by ECMWF Singular Vector and the small scale perturbation generated by ALADIN-Breeding,

• multi-physics scheme are applied for model perturbation and

• NCSB (Non-Cycling Surface Breeding) technique is for perturbations applied to initial surface conditions.

The key element of a LAMEPS system is its limited area model. LAEF uses high resolution LAM ALADIN-Austria as the model system. ALADIN-Austria is the ALADIN configuration running at ZAMG operationally [E1]. ALADIN is a hydrostatic, spectral LAM model. It includes a hybrid vertical co-ordinates; spectral method with bi-periodic extension of the domain using elliptical truncation of double-Fourier series; two-time level semi- Lagrangian advection scheme; semi-implicit time-stepping; fourth order horizontal diffusion; Davies-Kalberg type relaxation and digital filter initialisation (DFI).

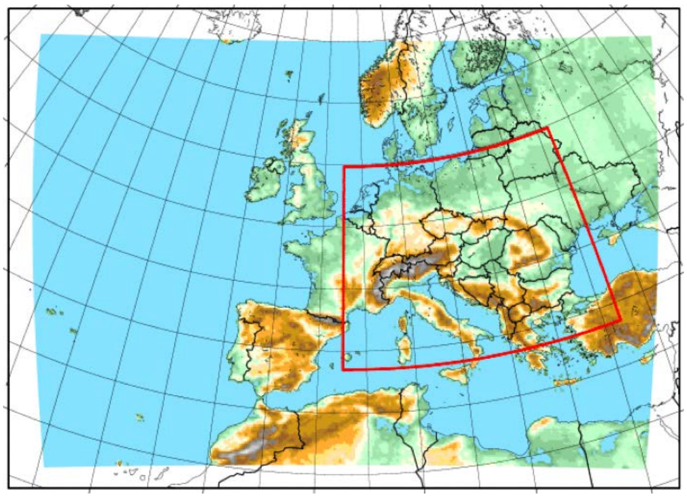

Figure E.1: *ALADIN-LAEF domain and model topography. The inner limited-area domain in red is the verification domain, which covers Central Europe of 0.15 x 0.15 degree resolution.*

The ALADIN-LAEF integration domain covers whole Europe and large part of Atlantic, shown in Figure E.1. This is based on the fact that the development of many weather systems in the Atlantic is very important for the forecast over Central Europe on one side, on the other side the domain is chosen big enough, so that the impact of the LBC is not strong and direct on the Central European region. ALADIN-LAEF is run at a resolution of 18 km in horizontal and 37 levels in vertical. The LAEF forecast is to 60 h ahead and twice per day at 00UTC and 12UTC.

LAEF is constructed with 18 members, of whom 16 members are perturbed, while LBC perturbations are provided by the first 16 ECWMF EPS members. The other 2 LAEF members take LBC from ECMWF EPS control member and ECMWF deterministic forecast respectively.

The main methods for generating the initial perturbation i.e., breeding, blending, NCSB (Non-Cycling Surface Breeding) and the multi-physics approach, to account for the uncertainties of the model formulation, are all introduced in ALADIN-LAEF. For the LBC perturbation, a 12h time lagged coupling with ECMWF EPS forecast is applied in ALADIN-LAEF. It is considered for operational purposes. LAMEPS should be available as earlier as possible. The technical implementation of the new ALADIN-LAEF is schematically described in Figure E.2.

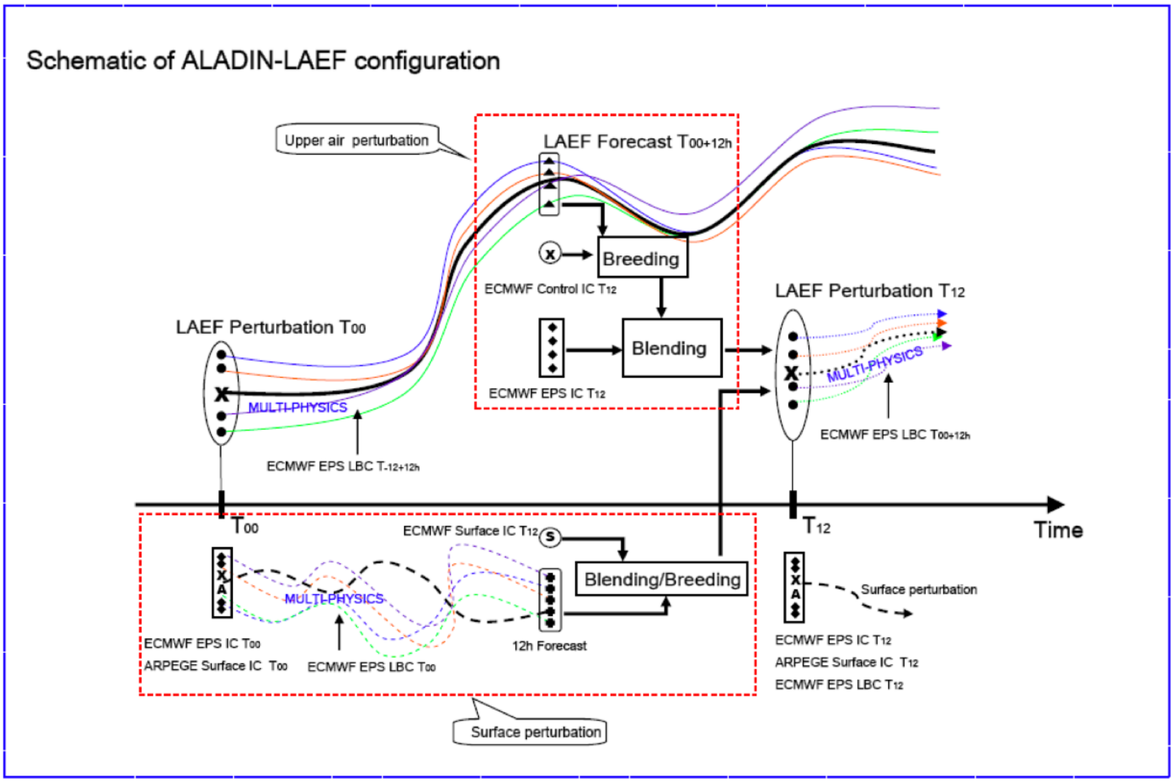

Figure E.2: *Technical configuration and operational cycle of ALADIN-LAEF.*

Each day two ALADIN-LAEF runs are performed, with initial time at 00 UTC and 12 UTC. As for the 12UTC run, the 12h forecasts of ALADIN-LAEF started at 00UTC LAEF Forecast T00+12h, which is computed with LAEF Perturbation T00, multi-physics, and time lagged ECMWF LBC ECMWF-EPS-LBC T-12+12h, together with the ECMWF control analysis valid at 12UTC ECMWF Control IC T12, ALADIN breeding is performed for the generation of the mesoscale part of the perturbation. The ALADIN breeding perturbation is then mixed with the ECMWF initial perturbations generated by SV. This is the Blending resulting to the new upper air perturbation for the ALADIN-LAEF at 12 UTC.

The generation of initial surface perturbation for 12UTC run is ALADIN integration started with the 00 UTC ECMWF upper air perturbation from ECMWF EPS members and the ARPEGE surface. The corresponding LBC from ECMWF 00 UTC run and multi-physics are used for the integration. 12h ALADIN surface forecasts of this additional ensemble run provide the new surface conditions at 12 UTC, which is used for breeding with the ECMWF surface analysis valid at 12UTC. Again the breeding results are used as the new initial surface perturbation at 12UTC. With the new upper air perturbation by blending and initial surface perturbation from NCSB, the new LAEF perturbation at T12 are built. ALAADIN model starts for the 12UTC run with multi-physics and the time lagged ECMWF LBCs. After the LAEF main forecast, the preparation for the next cycle begins, the 12h ALADIN-LAEF forecast is prepared for the 00UTC breeding cycle. Another cycle independent 12h ALADIN forecast with ECMWF EPS member is prepared for the initial surface perturbation.

Demand for bigger ALADIN-LAEF domain with better topography representation arose mostly out of two reasons. One of them is inclusion of the whole Black sea (requested by Romania) and coverage of Turkey (as a new ALADIN partner) in the computational ALADIN-LAEF domain. The second reason is the request for the cooperation with GLAMEPS (Grand Limited Area Model Ensemble Prediction System). Hence the key factors for setting up new ALADIN-LAEF domain were as follows:

• to cover up whole Turkey and the Black sea (unconditionally),

• to enlarge the domain as much as possible towards the north and west taking into consideration the pre-operational GLAMEPS domain,

• to increase horizontal resolution to approximately 10-12km (as much as it can be afforded)

• to cover the whole Mediterranean Sea, while at the same time

• not exceeding serviceable CPU time limit at ECMWF's HPC, which is available for Austria (upper limit would be something like 16x106 CPUs instead of current 2x106 CPUs spent by operational ALADIN-LAEF suite with actual smaller domain and 18km horizontal resolution).

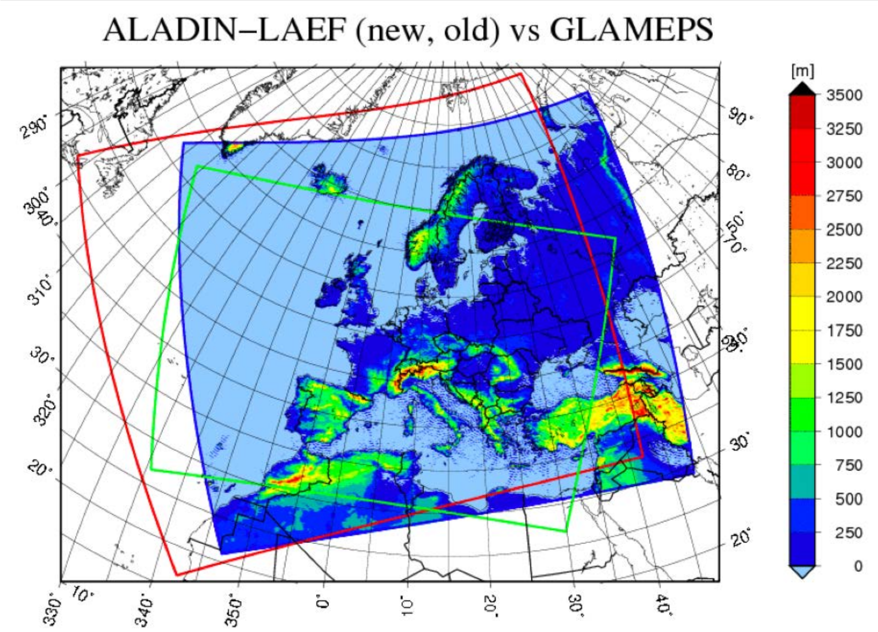

Figure E.3: *Comparison of the old ALADIN-LAEF domain with the new one and its corresponding GLAMEPS/ALADIN domain.*

In Figure E.3 the comparison of the old operational ALADIN- LAEF domain (green rectangle) with the new one (blue rectangle, topography map) and also with the GLAMEPS/ALADIN domain (red rectangle) can be seen. Additional research is planned to investigate in more depth, whether more profit would be gained from such high-resolution ensemble or rather from increased number of ensemble members at the new domain but necessarily with coarser horizontal resolution (currently there exist 16 members at Δx = 18km). New blending ratio must be re-computed (and corresponding low spectral resolution CLIM files prepared) regarding new ALADIN-LAEF domain. Eventually, all this effort should come into operations just by the end of 2010, mostly because of only limited number of CPUs which are now available for Austria and also because some precise parallel testing of the whole LAEF suite must be done at first.

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Appendix F: Norwegian Met Institute GLAMEPS-NORLAMEPS

The GLAMEPS (Grand Limited Area Modelling Ensemble Prediction System) is a platform under development in the HIRLAM-ALADIN co-operation for probabilistic NWP on the short range. At present stage most preparatory experiments for constructing an operational system within the next 2 years are made with computers at ECMWF through a special project (named: SPNOGEPS). The major amount of resources to this project is, however, dedicated from national member quota. The test-system is entirely set up at ECMWF, and is based on major elements in the existing systems running in Norway (NORLAMEPS) and Spain (SREPS). It is intended that the system will be partly set up in a distributed fashion, so that computer capacity in partner countries are utilized. Some elements will nevertheless be run at ECMWF on national quota dedicated for the task, and the operational solution will be a trade-off between the need for computer power to produce ensemble members and the need for swift data transfer between the partner countries.

There are also many important activities presently not directly included in the pre-operational GLAMEPS, since they require more research and development before they are ready for pre-operational experiments. These activities include generation of LAM-specific initial perturbations (singular vectors, ETKF, SLAF), and model perturbations (stochastic forcing, parameter perturbations, forcing sensitivities). These are indeed important activities, which are expected to gradually improve the GLAMEPS operational production as soon as they reach a sufficiently ripe stage.

Concerning the main approach behind NORLAMEPS [F1], it should be noted that carefully selected ensemble members that account for uncertainties in initial data are used to quantify the predictability of actual situations. At the ECMWF singular vectors (SVs) that maximise the total perturbation energy over finite time intervals and the extra-tropical northern hemisphere, are used for computing initial perturbations [F2]. By maximizing the total energy norm of perturbations in a smaller target area, [F3] the system can be designed for a specific region of interest. Thus, it is possible to generate Targeted Ensemble Prediction Systems (TEPS) for parts of Europe [F4] & [F5]. In the target area TEPS account for a larger portion of the entire probability distribution than the operational EPS at ECMWF, with the same number of ensemble members [F4].

The TEPS focus on a limited area, but the resolution of the model is the same as for the ECMWF operational EPS. A mesoscale ensemble prediction system requires that much smaller scales are resolved, rendering global calculations too expensive. As is regularly carried out for deterministic mesoscale forecasts, one option could be to use a limited-area model with finer resolution, and with the global TEPS providing boundary fields at the open lateral boundaries, constituting a LAMEPS system. In a limited-area model initial errors and boundary-field errors combined with atmospheric instability eventually lead to loss of predictability in the target area. Furthermore, atmospheric models are still not perfect, which also contributes to forecast errors. This has been taken into account at ECMWF by stochastically perturbing the tendencies calculated by the model physics [F6]. Further development of LAMEPS was encouraged by a preliminary feasibility study by Frogner and Iversen [F7].

A reason for increasing the resolution of the forecast model in the target area is, as for deterministic forecasts, to obtain better descriptions of ground-surface properties and dynamical features responsible for significant weather. Moreover, extreme weather events are frequently confined to areas that are too small to be properly resolved by e.g. the TL159 resolution used in TEPS, and even large-scale precipitation involves strong mesoscale variability and is strongly influenced by orography. The simplified analysis of Lorenz [F8] gave quite pessimistic prospects for mesoscale predictability. Later tests with full numerical weather prediction (NWP) model systems have revitalized the optimism. A significant part of the mesoscale variability is controlled by ground-surface properties ([F9] & [F10]). Thus, slower error-growth rates than predicted by the turbulence model of Lorenz [F8] may occur for some significant mesoscale weather systems. Scandinavia is dominated by topography, complex coastlines and seasonally varying sea-ice and snow cover. It is our hope that a mesoscale LAMEPS utilizing global perturbations targeted on northern Europe would enable better forecasts of possible extreme events compared to TEPS or pure deterministic forecasts. So far only ten cases have been studied due to limited computer capacity.

Overall, it seems clear that there is a need for probabilistic forecast systems with resolution and coverage between those presently used in GEPS platforms for the medium range ([F11] – [F12] & [F13]), and those required in systems for "nowcasting" deep convective storms, hydraulic shocks, etc. GLAMEPS sets forth to establish a system for operational numerical ensemble prediction for probabilistic forecasting up to 60 hours ahead on the intermediate "grey- zone" scales. The idea is to utilize the distributed computer resources in countries participating in the HIRLAM and ALADIN consortia. A number of partners will then produce a minor subset of the ensemble members and submit the result to a common data centre. Probabilistic forecast products can then be synthesized from the entire ensemble of results, and be downloaded by the partners. The intention is that the system should transform all quantifiable sources of uncertainties in the LAM formulation and in the input data into forecasts of probability density functions for weather elements. The integration domain for each ensemble member is as common as the numerics in the LAM versions permit (Fig. 1). The shape of the PDFs will vary in space and time in intentional coherence with actual weather predictability. Several practical obstacles as well as scientific issues need to be solved before an operational GLAMEPS becomes a reality.

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Appendix G: German Weather Service SRNWP-PEPS

One of the most important challenges the operational forecaster is faced with is the effective usage of the existing variety of operational numerical weather forecasts. There is the feeling that joining these operational forecasts in a multi-model ensemble could lead to better results within the forecast and warning process [G1]. Regional Modelling in Europe is organised in 5 consortia: HIRLAM, ALADIN, LACE, COSMO and the UK Met Office, each of them having their own regional model. A reasonable variety of operational forecasts exist, which are produced on different domains with different grid resolutions and use different model parametrizations and data assimilation techniques.

In 2002, DWD had the idea of bringing together all available high-resolution numerical forecasts in a Poor Man's Ensemble Prediction System (PEPS). It was suggested at a EUMETNET Council meeting that a project should be started under the umbrella of EUMETNET.

Table G.1: *Details of European Weather Services participating in SRNWP-PEPS project.*

Meteorological Service	Regional Model	Coupling Model	Resolution (km)	Forecast Period (h)	Time Interval (h)	Main Run (UTC)
Belgium	ALADIN	ARPEGE	15	+60	1	0, 12
France	ALADIN	ARPEGE	11	+48	3	0, 12
Austria	ALADIN-AUSTRIA	ARPEGE	9.6	+48	1	0, 12
Croatia	ALADIN	ARPEGE	9	+48	3	0, 12
Czech. Repub.	ALADIN-LACE	ARPEGE	9	+48	3	0, 6, 12, 18
Hungary	ALADIN-LACE	ARPEGE	11	+48	1	0, 12
Slovakia	ALADIN-LACE	ARPEGE	11	+48	3	0, 12
Slovenia	ALADIN-LACE	ARPEGE	9.5	+48	3	0, 12
Denmark	HIRLAM	ECMWF	16	+60	1	0, 6, 12, 18
Finland	HIRLAM	ECMWF	22	+54	1	0, 6, 12, 18
Spain	HIRLAM	ECMWF	22	+24	1	0, 6, 12, 18
Netherlands	HIRLAM	ECMWF	22	+48	1	0, 6, 12, 18
Ireland	HIRLAM	ECMWF	16	+48	3	0, 6, 12, 18
Norway I	HIRLAM	ECMWF	11	+30	1	0, 12
Norway II	HIRLAM	ECMWF	22	+30	1	0, 12
Sweden I	HIRLAM	ECMWF	11	+48	3	0, 6, 12, 18
Sweden II	HIRLAM	ECMWF	22	+48	3	0, 6, 12, 18
Germany	LME	GME	7	+78	1	0, 12, 18
Switzerland	aLMo	ECMWF	7	+72	1	0, 12
Italy	EuroLM	EuroHRM	7	+60	3	0
Poland	LM	GME	14	+72	3	0, 12
United Kingdom I	UKMO-Meso	UM NAE	12	+48	3	0, 6, 12, 18
United Kingdom II	UKMO-NAE	UM global	12	+48	3	0, 6, 12, 18

One of the main goals of the project has been the evaluation of PEPS to decide whether it provides a significant support and improvement of the warning process. The single model forecasts are interpolated onto a reference grid, the PEPS grid. It has a grid spacing of 0.0625° (~7 km) like the DWD Lokal Modell, covering Europe from 30°W to 30°E and 35°N to 70°N. Exceedance probabilities are calculated at each PEPS grid point from the ensemble members using a nearest neighbour approach. Because the individual members have different resolutions and integration areas, the ensemble size depends on location (as shown in Figure G.1).

In June 2003 the director of the SRNWP EUMETNET Program, Jean Quiby, started the project by asking the European National Meteorological Services to participate. At that time, 20 Weather Services had joined the project, providing 23 forecast models (as shown in Table G.1). As a result, 40 deterministic and probabilistic forecast products are distributed to the contributing members on an operational basis. At the end of 2004 an operational suite was established at DWD. The ensemble products are calculated four times a day. Ensemble forecasts are calculated for the following meteorological parameters:

- Accumulated total precipitation
- Maximum 10 m wind speed
- Maximum and minimum 2 m temperature
- Accumulated total snow fall
- Maximum 10 m gust speed

Ensemble means and medians (precipitation and total snow) as well as probabilistic products are calculated. According to the requirements of operational forecasting, a 24h accumulation period was defined lasting from +06h to +30h relative to the 00 and 12 UTC runs. Additionally, 12h forecast products from +06h to +18h and from +18h to +30h are derived from the 0, 6, 12, and 18 UTC runs with slightly different thresholds for the probabilities.

As shown in Table G.1, only the 00 UTC run incorporates the maximum number of model forecasts. Moreover, the ensemble size varies with parameter (Table G.2) because not every model provides every forecast parameter, e.g., only some of the ALADIN and COSMO countries operate empirical parametrizations of wind gusts within their modelling environment. An ensemble size per grid point of at least 3 has to be reached to activate the calculation of the probabilistic products.

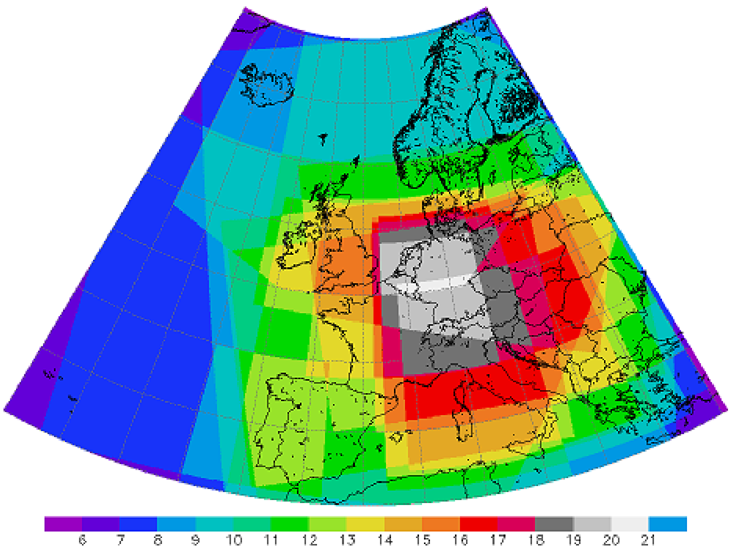

Figure G.1: *Domain and maximum ensemble size of the SRNWP-PEPS.*

Table G.2: *Maximum ensemble size dependent on model lead time and on meteorological parameter.*

Model Lead Time	Total Precipitation	Total Snow	Wind Speed	Gust Speed	Temperature
00 UTC	23	22	23	9	23
06 UTC	10	9	10	1	10
12 UTC	22	21	22	9	22
18 UTC	11	10	11	2	11

The forecasts are provided in a password-protected area of the official SRNWP-PEPS web site for evaluation purposes. This site is updated every 6 hours. In addition to the European size standard products, plots of a smaller domain focused on Germany are made. These are available to the forecasters at DWD only and allow them to analyse the products in more detail. Using DWD & DMI “NinJo” workstations it is be possible to combine the PEPS products with any other meteorological information available such as synoptic observations, radar products, satellite images or numerical models. The NinJo system was introduced in WGCEF Newsletter No 10 [G2].

At the Central Forecast Office of DWD the pre-operational SRNWP-PEPS products were evaluated on a daily basis. First evaluation results were presented at the 11th Meeting of the WGCEF in De Bilt, September 2005. The results were promising and suggested that operational usage of the PEPS products will be useful, especially for short range forecasting and in the warning decision process. The issue of severe weather warnings is often a very difficult matter due to the uncertainty in predicting the location, timing and intensity of extreme events. To quantify the forecast uncertainty in a reliable way a variety of different numerical models with slightly different analyses or physical parametrizations should be available. These are provided by the SRNWP-PEPS, incorporating the most sophisticated high-resolution numerical weather prediction models of Europe.

The first evaluation of the SRNWP-PEPS has been promising, though many questions still remain open. These concern for example, the simple assumption of giving equal weights to the individual ensemble members and using the total number of forecasts as a proxy of the actual probability of an event. Furthermore, the SRNWP-PEPS platform is biased and it has not been calibrated yet, so the potential for future improvements clearly exists.

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Appendix H: ARPA-SIMC (Emilia Romagna, Italy) COSMO-SREPS

A short-range ensemble COSMO-SREPS (Short Range Ensemble Prediction System) with a resolution of 10km has been developed experimentally. Spread in the early time steps is realised by first nesting the COSMO model at 25 km into 4 different global models. In the second nesting at 10km, various perturbations in the physics are introduced. DWD plans to introduce by 2011 a convection-permitting ensemble with a resolution of 2.8km and 20 members. The SREPS Project focused on the building up of a high-resolution ensemble system for the short-range [H1]. The project main tasks were to develop and implement such an ensemble, then to run it over extensive testing periods and to evaluate the system features and performances. The ensemble is based on 16 integrations of the limited-area non-hydrostatic COSMO model at about 10 km of horizontal resolution, with 40 vertical levels. SREPS platform has been built to fulfil some needs that have recently arisen in the COSMO community:

- to have a short-range mesoscale ensemble to improve the support especially in situations of high impact weather,
- to have a very short-range ensemble for data assimilation purposes,
- to provide boundary conditions for the COSMO-DE-EPS convection-resolving ensemble currently under development at DWD.

Therefore, the ensemble had to be designed to describe the uncertainty affecting the short- range

predictions of surface weather parameters at a high spatial resolution. Aiming at this purpose, the strategy to generate the mesoscale ensemble members proposed by this project tried to take into account as many as possible sources of uncertainties which affect the scales of interest in the weather forecast at the short time range, in order to model many of the possible causes of the relevant forecast errors. Hence, perturbations have been applied both in the driving model and in the mesoscale model. The driving model error is described by means of a multi-analysis multi-boundary approach. Initial and boundary condition perturbations are applied by driving the 10-km COSMO runs with the four 25-km COSMO members of the Multi-Analysis Multi-Boundary SREPS system of INM. These four lower resolution COSMO runs, nested on four different global models (IFS, GME, GFS, UM), which use independent analyses, are provided by Spanish Meteorological Agency (AEMET) for this purpose. A representation of the smaller scale uncertainty is accomplished by applying limited-area model perturbations as well: the values of a number of parameters included in the sub-grid process parametrization schemes are randomly changed (within their range of variability) in the different ensemble members. The main issues that have been addressed in the system evaluation are:

• if the system shows a good spread/skill relationship, representative of the capability of the ensemble in describing the forecast error,

• how the different perturbations contribute to the spread and to the skill of the system and

• which is the ensemble skill in the forecast of surface weather parameters.

COSMO-SREPS takes both initial and boundary conditions from 4 integrations of the COSMO-model, performed over the Euro-Atlantic area at 25 km of horizontal resolution, and differentiated from each other according to the global model used to drive the runs. The 4 integrations at 25 km are nested on the following global forecasting systems: ECMWF (IFS), DWD (GME), NCEP (NCEP) and UKMO (UM). Since these global systems are 4 different and independent state-of-the-art forecasting chains, a good deal of differentiation in the global models driving the limited-area runs is ensured. These integrations are performed by the INM, which provides directly the fields generated by the 4 runs of the COSMO-model at 25 km. For each of the 4 sets of initial and boundary conditions, the COSMO-model integrations at 10 km of horizontal resolution are then performed over a domain covering Central and Southern Europe (as shown in Figure H.1). Each 25-km run drives four 10-km integrations, which differentiates from one another for different choices of the parameters representative of sub-grid physical processes.

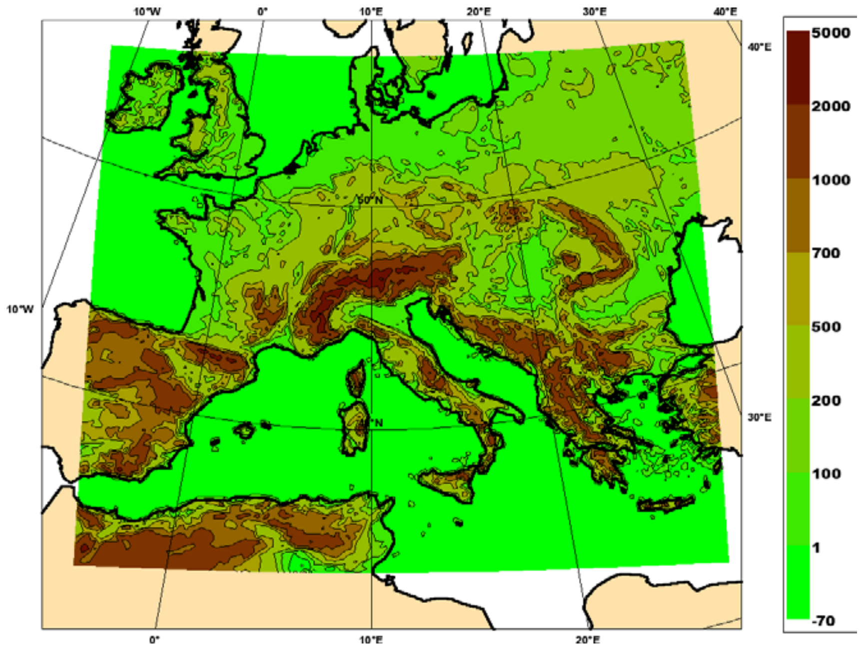

Figure H.1: *COSMO-SREPS integration domain with orography (in meters).*

During the first phases of the project, the ensemble was designed and implemented, and then it was

tested over long periods, in order to derive a robust statistical assessment of its features [H1]. In particular the system was running during the whole DOP of the MAP D-PHASE project (June to November 2007). The analysis of its performances was carried out over two COSMO regions: an alpine area and Greece. The main findings were:

• a good correlation between spread and error is observed, but the system tends to be under-dispersive. The gap between the spread and the error has been observed for a number of meteorological variables, both surface and upper-air, while the gap decreases moving from surface towards upper-air variables. This evaluation is influenced by the presence of a model bias, especially evident for 2-meter temperature,

• it has been recognized the need of applying more model perturbations. An extensive testing of new and more diverse parameter perturbations has been carried out within the project, but it is needed to continue this testing in the following of the project, due to the great amount of time and resources required. Furthermore, it has been decided to add also perturbations in the lower boundary of the COSMO model, to represent better the model uncertainties,

• the different types of perturbation contribute differently to the spread and to the skill of the system. In particular, driving model perturbation is the main source of spread in the ensemble as well as the main source of ensemble skill. COSMO model perturbation (parameter perturbation) plays a minor role, but contributes to the ensemble spread as well, with an amount variable according to the considered meteorological variable,

• the quality of the different driving models and of the different parameter choices are generally equivalent, since none of the different components of the system is always over-performing the others. The only exceptions are: the use of GME-driven initial and boundary conditions improve the system performances in terms of 2m temperature in summer, probably due to the coherence between soil and atmospheric fields; the use of the Kain-Fritsch scheme for the parametrization of the deep convection improves the precipitation detection at the expense of a larger number of false alarms.

• the ensemble skill in the forecast of surface weather parameters is reasonable. An objective assessment of the system quality will be carried on in the framework of the D-PHASE project, where the system performances will be compared with those of other state-of-the-art ensemble systems.

Furthermore, a special project so-called FEAR (Flow dependent Error statistic for satellite data Assimilation in Regional model) was to be developed to improve a short-range limited-area ensemble (COSMO-SREPS) utilising ECMWF computer resources [H2]. The final aim has been to determine flow dependent model error statistics to be employed in the assimilation system of the high-resolution non-hydrostatic limited-area model COSMO. For this purpose, it is desirable that the ensemble spread in the first 12 hours is representative of the forecast uncertainty at the correct spatial and temporal scales. To meet this necessity, a set of perturbations of the COSMO model have been tested and implemented in the COSMO-SREPS system. The final aim of this task is to end up with a system where the ensemble spread is representative of the model error during the first 12 hours of model integration, especially in terms of T (Temperature) and other surface variables.

For this purpose, a suite where the new COSMO model perturbations are implemented and tested, permitting to have a robust statistical assessment of the perturbation impact was utilised. Despite some promising results in the methodology as a whole, it was recognised a general lack of spread in the COSMO-SREPS ensemble in terms of the variables of concern for the data assimilation. This has lead to the necessity of tackling more directly the issue of the ensemble perturbation strategy, before concentrating on the data assimilation itself. Hence, the investigation and the computing resources are mainly focussed to develop and test more adapted perturbations of the parameters included in the physics of the COSMO model, particularly in turbulence, soil scheme and microphysics.

A strategy for the perturbation of the soil moisture field, which serves as initial condition at the lower boundary of the model has also being developed and later tested in this system, but this task has been delayed of few months due to problems encountered in the implementation of the methodology.
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Appendix I: ARPA-SIMC (Emilia Romagna, Italy) COSMO-LEPS

Many Limited-Area Ensemble Prediction Systems (LEPS) have been recently developed, either in research or in operational mode, so as to address the need of detailing high-impact weather forecasts at higher and higher resolution and to support the reliability of the deterministic forecast beyond the very short range. As far as operational implementations are concerned, the Consortium for Small–Scale Modelling Limited-Area Ensemble Prediction System (COSMO–LEPS) was the first mesoscale ensemble application running on a daily basis in Europe [I1] & [I2]. This system (http://www.cosmo-model.org), initially developed and implemented by the Hydro-Meteo-Climate Regional Service of Emilia-Romagna, in Bologna, Italy (ARPA–SIMC), has been running at ECMWF since November 2002 [I3] thanks to the ECMWF computer resources provided by the COSMO country-members that are ECMWF Member states. Nowadays, COSMO-LEPS is based on 16 integrations of the non-hydrostatic mesoscale model COSMO, formerly known as the Lokal Modell [I4]. This methodology aims at combining the advantages of the probabilistic approach by global ensemble systems (as the ECMWF EPS [I7]) with the high-resolution details gained in the mesoscale integrations. In the construction of COSMO-LEPS, an algorithm selects a number of members – referred to as Representative Members (RMs) – by a global ensemble system [I1] & [I5].

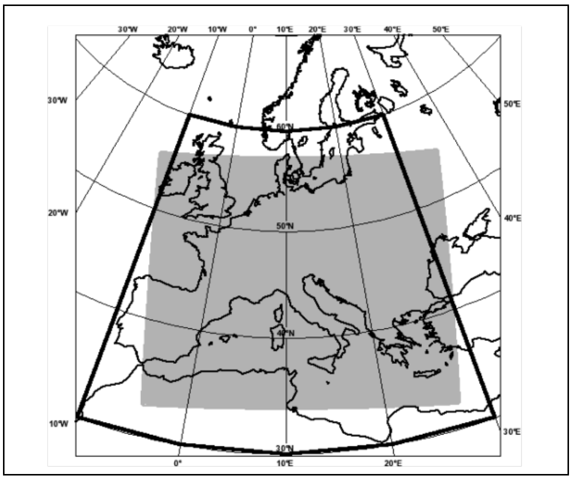

Figure I.1: *COSMO-LEPS integration domain (gray shaded area) and clustering area (rectangular).*

This intermediate step, referred to as “ensemble-size reduction”, is required to keep the computational load operationally affordable, since it is not presently feasible to nest the limited-area model on each individual member of a highly populated global ensemble. After the “ensemble-size reduction”, the selected RMs are used to provide both initial and boundary conditions to the integrations with the non-hydrostatic COSMO model, which is run once for each RM. Therefore, COSMO-LEPS performs a sort of dynamical downscaling of a global–model probabilistic system, limiting to a certain extent the computation investment [I6]. The COSMO-LEPS (Limited-Area Ensemble Prediction System) started to run on an experimental semi-operational basis on November 2002 and in November 2005 became an ECMWF member-state time-critical application, managed by ARPA-SIM. COSMO-LEPS runs on a daily basis using currently 7 km grid spacing and 40 vertical layers, starting at 12UTC and with a forecast range of 132 hours.
The computer time to run the system at ECMWF is provided by a joint account, with the contributions

of the COSMO countries that are also ECMWF member state (namely, Germany, Greece, Italy and Switzerland). As designed and developed, COSMO-LEPS platform aims at improving upon the early and medium-range predictability of extreme and localized weather events, especially when orographic and mesoscale related processes play a crucial role. The rotated lat-lon coordinates of the lower left and upper right corner of the integration domain are lon=-12.5°, lat=-16.0° and lon=14.95°, lat=7.13°, respectively. Figure I.1 shows the integration domain and clustering area of the COSMO-LEPS.

The present status of COSMO-LEPS, based on 16 integrations of the COSMO-model (7 km of horizontal resolution, 40 vertical levels, 132 hours of maximum forecast range) is running operationally as a 'time-critical application' at ECMWF. COSMO-LEPS application starts at about 20.50 UTC, once the ECMWF EPS starting at 12UTC has passed T+144 hours forecast range. Products are disseminated to Met-Ops rooms of COSMO weather offices starting from 23.00UTC. Concerning the skill assessment of COSMO-LEPS so far (outside the SafeWind context) an analysis has been performed mainly in terms of probabilistic prediction of 12-hourly accumulated precipitation for a number of thresholds [I8].

The evolution of the skill of the system has been assessed over a 7-year period, namely from December 2002 up to November 2009. Observations of 12-hour accumulated precipitation were taken from the SYNOP reports over the Alpine area and compared to the nearest grid-point forecasts of the COSMO-LEPS members. A number of probabilistic indices has been used so as to evaluate both reliability and resolution of the system and to assess the extent to which the quality of COSMO-LEPS forecasts improved in recent times. The main findings can be summarised as follows:

• time-series scores of the ROC (Relative Operating Characteristic) area values for different thresholds indicate a clear improvement of COSMO-LEPS skill throughout the years, with an increase of this score up to 2006, then slower growth in the 2 following years and a resumption of growth in the last part of 2009. This holds in the short as well as in the early-medium range,

• as for the Brier Skill Score (BSS) and the Ranked Probability Skill Score (RPSS), the month-to-month variability of the time-series scores is higher than for the ROC area and the positive impacts of system upgrades are more difficult to detect. If 12-month filters are applied to the scores, more in-sight is gained and forecast improvements with time become more detectable. As for an estimate of the improvement, RPSS values enables to quantify it as “2 days of predictability gained in the last 5 years”,

• time-series of the OUTL (i.e., the percentage of outliers) indicate a decrease of Outliers up to early 2007 for various forecast ranges and a steady behaviour since then on. A new decrease is evident in 2009, with the OUTL below 10% from day 2,

• seasonal scores confirm to a large extent the previous results, so, they enable to highlight the progresses in the skill of the system over the same season but in different years. The improvements in skill are well noticeable in terms of RPSS during summer, where the gain in forecast skill can be estimated as about 2 days of predictability in the last 4 years of activity.

The reasons for the different results between the BSS and the ROC area were shown to be due to the different type of information conveyed by the two indices. On the one hand, the BSS (and the RPSS) gives information about both the reliability and the resolution of the forecast system [I9]. The former one indicates how well the forecast probabilities by the ensemble system match the observed frequencies. The latter one indicates the extent to which the system can discriminate among events in different categories. Reliability can be increased after a good calibration, which manages to match probabilities and frequencies; resolution cannot be improved by any statistical post-processing. On the other hand, the ROC area provides information only about the discrimination capability of the forecast system. As such, the ROC area scores show the COSMO-LEPS ability to detect between events and non-events, despite the reliability, and represent the hypothetical skill of the system once it were properly calibrated. It was shown that the reliability component of COSMO-LEPS forecasts did not increase in the last years at the same pace as the resolution one, this explaining the better results obtained in terms of ROC area.
Work is in progress at both ARPA-SIMC and MeteoSwiss to provide calibrated COSMO-LEPS

forecasts, thanks to the results obtained by the re-forecast exercise described in [I10]. This would improve the skill of COSMO-LEPS forecasts, making the system more reliable than it is now. As for the future, it is being tested the increase of the horizontal resolution of COSMO-LEPS runs so as to provide more detailed forecasts for the interaction of the flow with orography and to describe with a higher degree of accuracy mesoscale-related processes and local effects. This would have a positive impact on the prediction of a number of those surface fields still nowadays strongly influenced by local effects and not always properly represented in terms of their uncertainty by mesoscale ensemble systems. Skill assessment of COSMO-LEPS (inside the SafeWind context) is contained in Appendix K. Results for the winter period of DJF are presented referring to the inter-comparison of the old ECMWF EPS formulation (with horizontal resolution of 50 km) against the old COSMO-LEPS (having resolution of 10 km). Furthermore, since the latest verification results for ECMWF EPS (Appendix J) are valid for two periods, before and after 26 January 2010 (date that the latest upgrade of EPS and IFS took place), same wise verification results for COSMO-LEPS are also referred to these two periods (also contained in Appendix K). Emphasis is given on the performance of ECMWF EPS & COSMO-LEPS investigating cases of particular interest over Europe, such as extreme events (Appendix M). The additional information coming from COSMO-LEPS, complementing the coarser resolution ECMWF EPS has been validated.

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