THE MEMBER STATES EXPERIENCES WITH THE ECMWF ENSEMBLE PREDICTION SYSTEM

Horst Böttger

European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX, United Kingdom

1. Predictability

Much progress has been made over the last 10 to 15 years with the development of medium-range forecasting systems. This is reflected not only in the significantly improved skill of numerical models - 7-day forecasts nowadays have the skill of a 5 1/2-day forecast ten years ago (as measured by the anomaly correlation and the RMS errors) - but also in the much improved information content given by the higher resolution models (Burridge, 1993). Developments in numerical techniques, advances in the science, better use of data, in particular additional satellite data, and major increases of computer power contributed towards these achievements.

However, forecasters are still faced with the problem how to make best use of the model guidance when the predictive skill of the models exhibits a certain, from day to day changing, variability. The predictability of the atmosphere varies with the seasons. Verification results also reveal that with the changes in the flow regimes numerical models will show variations in the medium-range forecast skill. The forecaster, therefore, requires guidance with the exploitation of model results at the limit of predictability, when he needs to extract the useful information from the numerical products, which have an unknown degree of uncertainty attached to them.

Inadequacies in the model formulations themselves will contribute towards the forecast errors. It can also be demonstrated that in particular the uncertainties in the initial state of the forecast caused by the lack of the data, poor or erroneous use of the data or by the analysis itself, will lead to model errors which will tend to grow during the forecast depending the flow pattern, the atmospheric structure, etc.

The ensemble forecast technique was developed as a tool to estimate the degree of confidence a forecaster may have in the forecast and to evaluate the possibility of alternative flow scenarios which may evolve in the forecast assuming that there are uncertainties in the initial conditions. ECMWF currently runs an experimental ensemble prediction system (EPS) based on 32 low resolution model runs starting from slightly perturbed initial conditions plus an unperturbed control run. The resulting 10-day forecasts may confirm the high resolution deterministic run, therefore giving the forecaster more confidence in the solution, or the EPS may indicate distinctly different solutions in the predicted flow pattern which can be interpreted in a probabilistic sense and used by the meteorologist in his weather predictions.

2. The ECMWF ensemble prediction system

In December 1992, ECMWF started to operate the experimental ensemble prediction system using a T63L19 model (equivalent horizontal grid of approximately 2 degrees in latitude and longitude and 19 levels in the vertical). Currently the perturbations to the initial conditions are only applied in the Northern Hemisphere.

The techniques to determine the most suitable perturbations are the subject of ongoing research. The procedures have been modified since the beginning of the EPS and are described by Buizza (1994).

Since May 1994, EPS forecasts have been produced daily at ECMWF. All Member States have access to the basic results from the EPS on the Centre's computer for further processing. The Centre provides the Member States through the operational dissemination channels with EPS products, which offer the EPS results in a compressed form and should facilitate a user orientated exploitation. These products were developed at the Centre in close co-operation and liaison with the users in the Member States. The definition and the range of the products are constantly changing and extended according to the requirements of the users and in the light of their experience. In broad terms the products are split into two groups. There are the cluster products (mean and standard deviation) of geopotential height and temperature at some selected levels (1000, 850 and 500 hPa) for the forecast range 72 to 168 hours. The clustering is based on RMS differences between the fields over the trajectory from days 5 to 7 and is applied to the larger European area and more recently also to sub-areas. Forecasters agree that the sub-area clustering provides them with more relevant information which is in agreement with their synoptic perception of the evolution of the flow pattern. The second group of products provides predicted probabilities of the occurrence of weather events such as warm and cold events, i.e. pre-defined deviations from the climate norm, or the occurrence of precipitation and wind in pre-defined categories. Such probabilities may be required as point events at specific forecast times or they can be inferred from spatial and time averages. Each Member State has its own requirement and will eventually introduce its own EPS post-processing orientated towards its user requirements and based on the results from the individual ensemble members. ECMWF therefore also provides a set of basic EPS products from the 33 integrations through the dissemination system.

The forecast of 18 August 1995 will be used to demonstrate some of the products from the EPS and their possible use in an operational forecasting environment. Fig. 1 shows the dramatic change in the weather pattern over Europe between 18 and 25 August when an extended period of prevailing high pressure and blocked upper flow came to an end. Fig. 2 shows the seven-day forecast of 18 August 1995 for the first four clusters from the EPS. The first two clusters have a population of 8 and 7 members of the ensemble while clusters 3 and 4 contain 5 members each. The message from the EPS is clear, i.e. the block at 500 hPa height is likely to be replaced by a mobile westerly flow extending from the Atlantic across western Europe into Scandinavia, while the cut-off low in the Mediterranean will be replaced by a deep trough from the north-west. There is, however, also the signal in the EPS forecasts that the block may persist (cluster 3) or at least a large scale, slow moving ridge may again influence central Europe and Scandinavia seven days into the forecast. The forecast guidance is clearly ambiguous and the cautious forecaster will be aware of the uncertainty and express himself accordingly. Fig. 3 presents a diagnostic tool applied to all 33 members of the ensemble. The three panels show the 576 gpdam contour line for each 500 hPa height forecast for the three ranges 24, 72 and 120 hours, together with the same contour line from the verifying analysis. The different forecast solutions developing over Europe even during this first half of the forecast range are immediately obvious from this type of presentation which was first introduced at NCEP Washington.

To encourage forecasters to use the cluster products in a probabilistic approach to predicting the weather pattern in the second half of the medium-range (beyond day 5) the verification of the cluster forecasts is assessed in reliability diagrams. An example for the period September 1994 to March 1995 combining the results for all clusters and the forecast days 5, 6 and 7 is shown in Fig. 4. The high degree of reliability found for clusters with a lower population is very promising and should encourage forecasters to review their approach to medium-range forecasting and provide the public and specialised customers with tailored forecasts including probabilities of alternative weather scenarii.

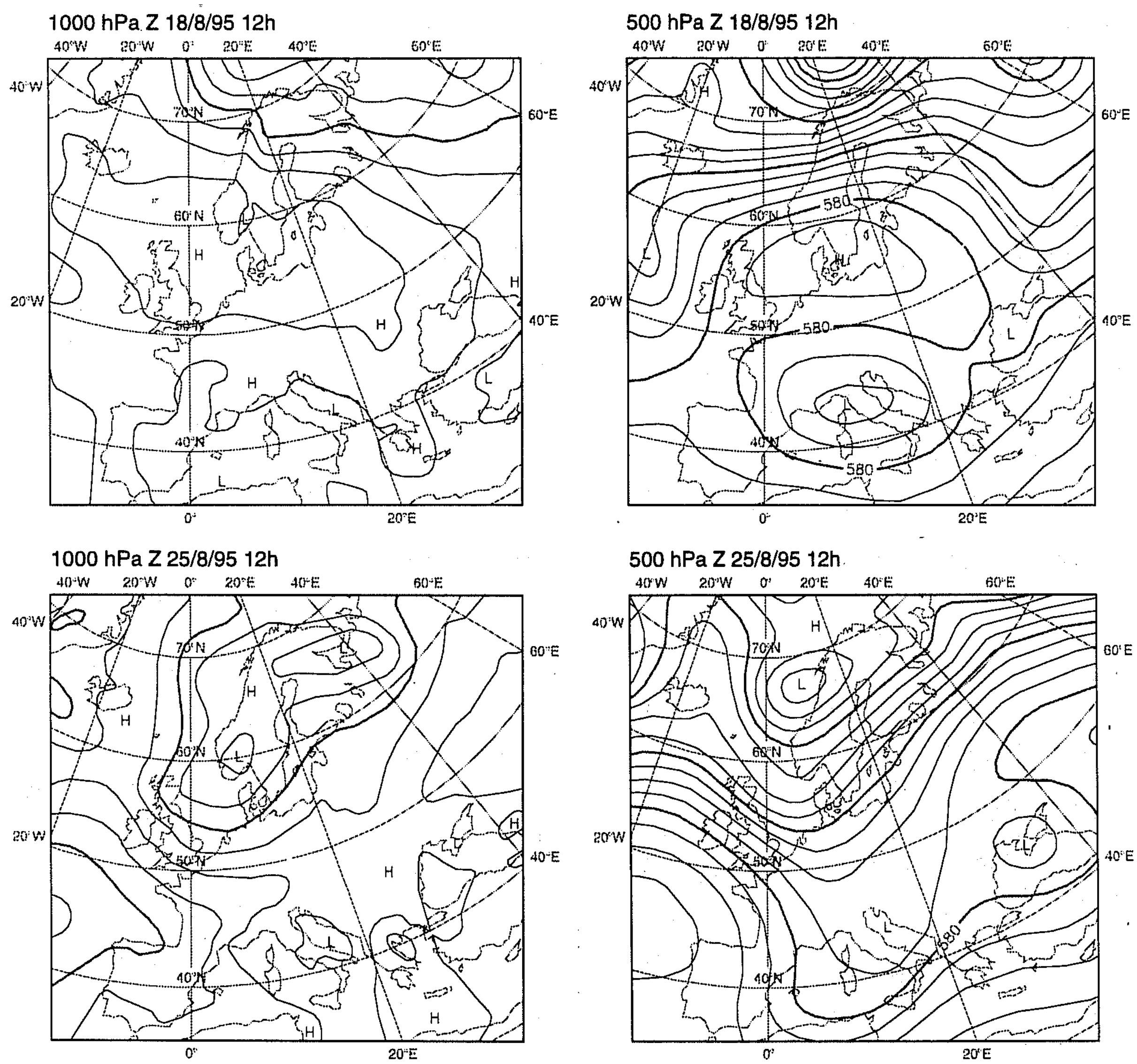

Fig. 1: 1000 hPa (left) and 500 hPa (right) height fields at 12 UTC on 18 August 1995 (top) and 25 August 1995 (bottom), contour interval is 4 gpdam.

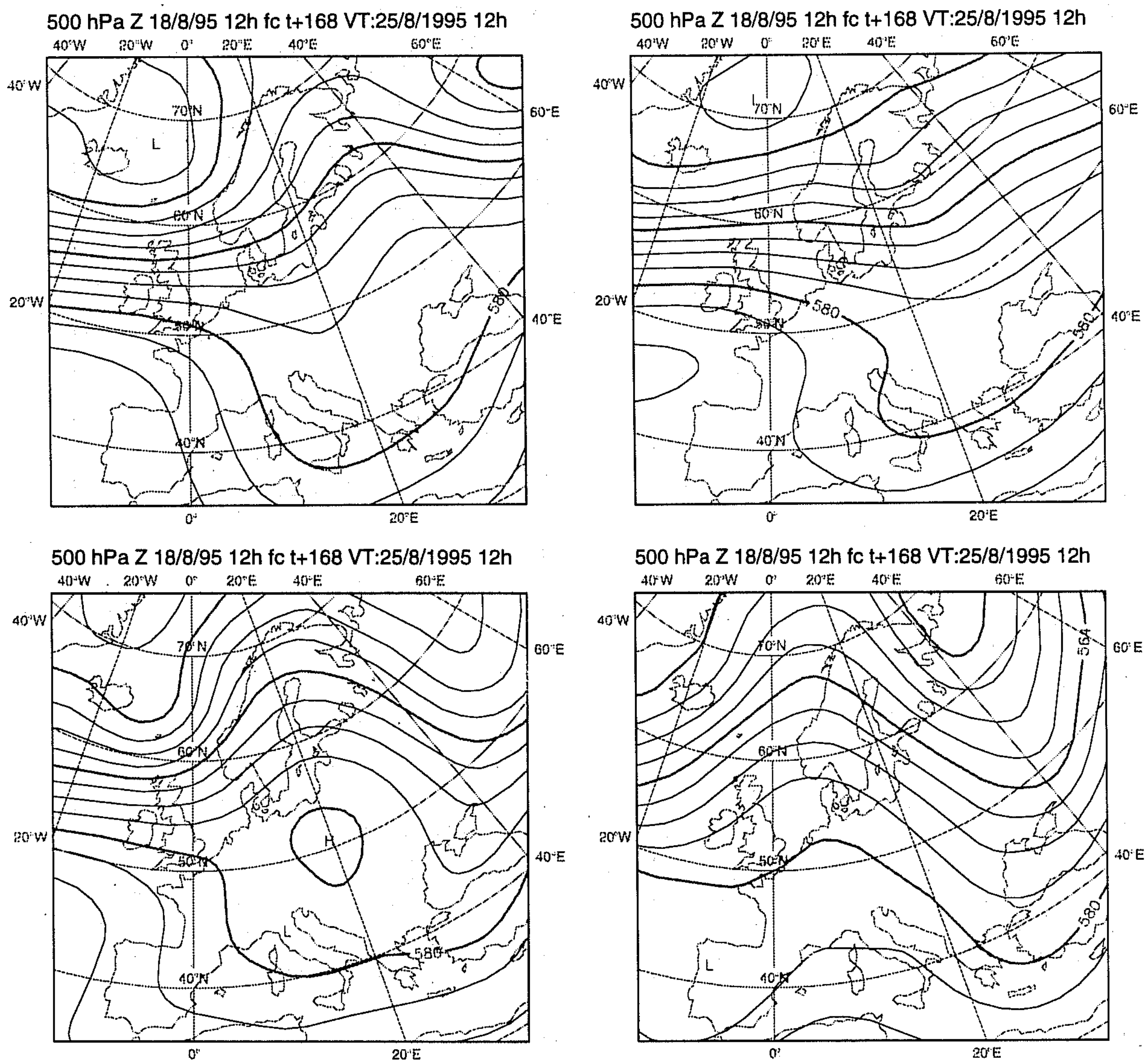

Fig. 2: 500 hPa height fields of 168 hours ensemble cluster mean forecasts valid 25 August 1995, cluster 1 (top left) has 8 members, cluster 2 (top right) 7 members, cluster 3 (bottom left) and cluster 4 each have 5 members, contour interval is 4 gpdam.

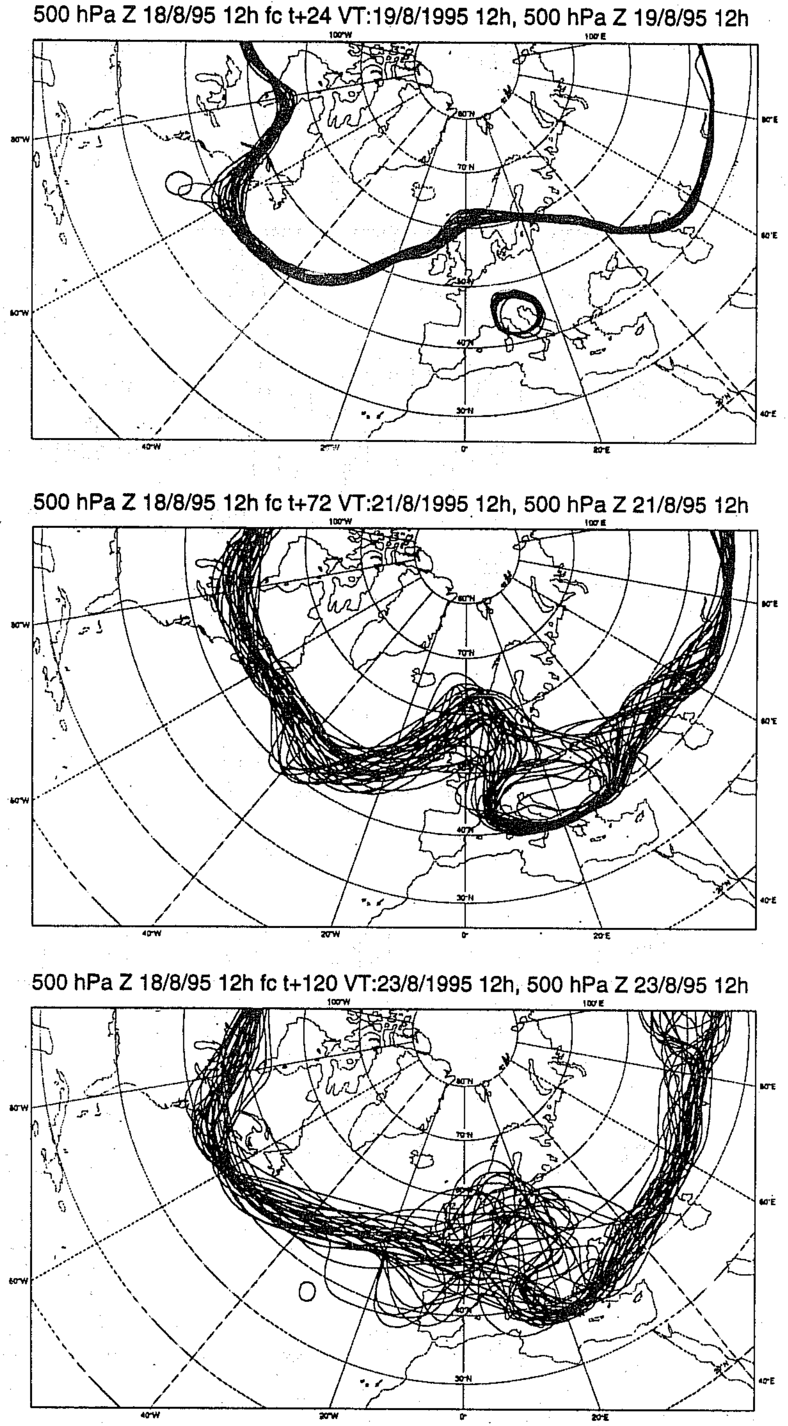

Fig. 3: Diagrams of 576 gpdam contour lines from all 33 members of the ensemble forecast of 18 August 1995 forecast ranges are 24 hours (top), 72 hours (centre) and 120 hours (bottom).

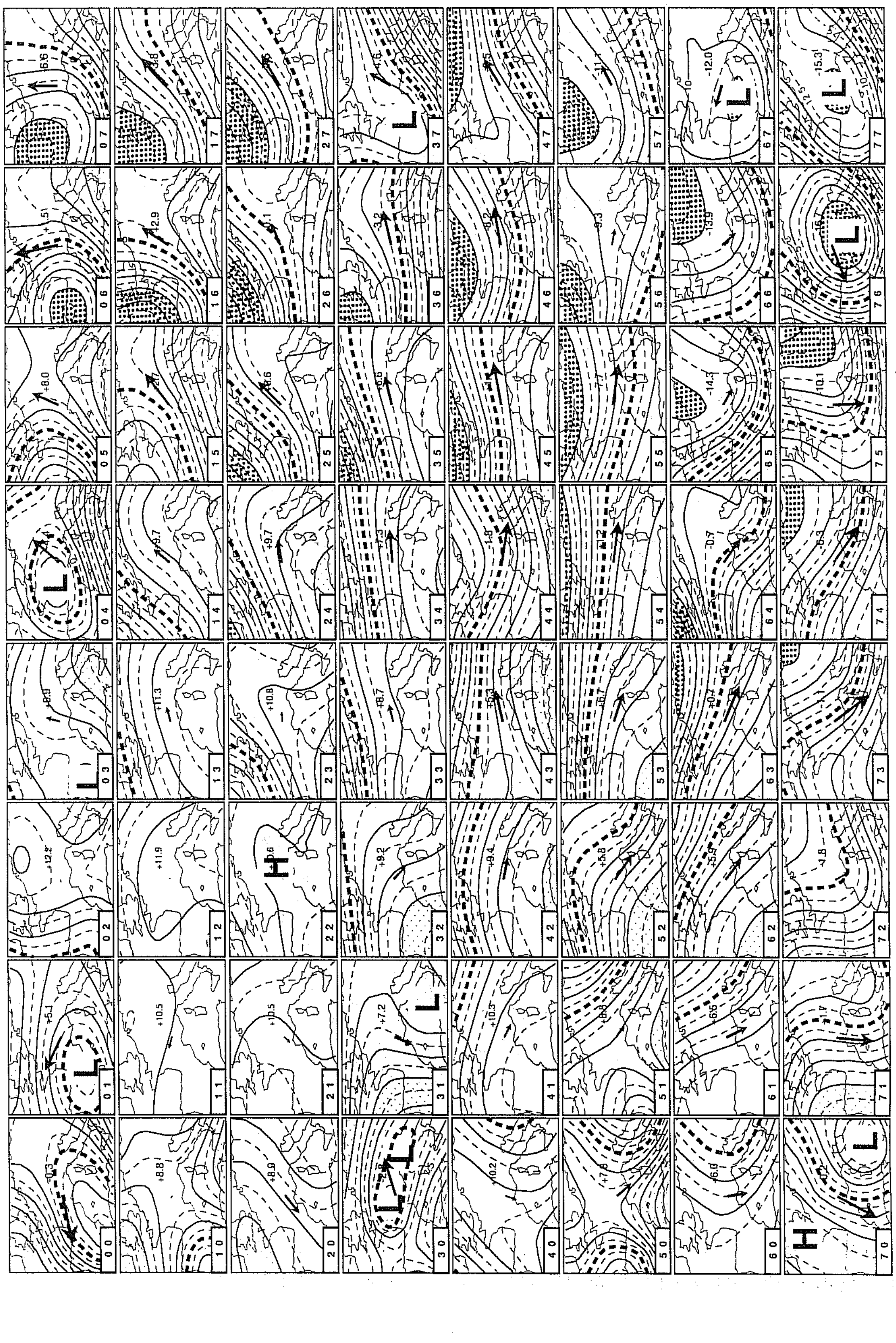

Fig. 4: 8 by 8 matrix of synoptic flow pattern at 500 hPa over central-southern Europe defined by a neural network system at the Swiss Meteorological Service based on a two year learning sample.

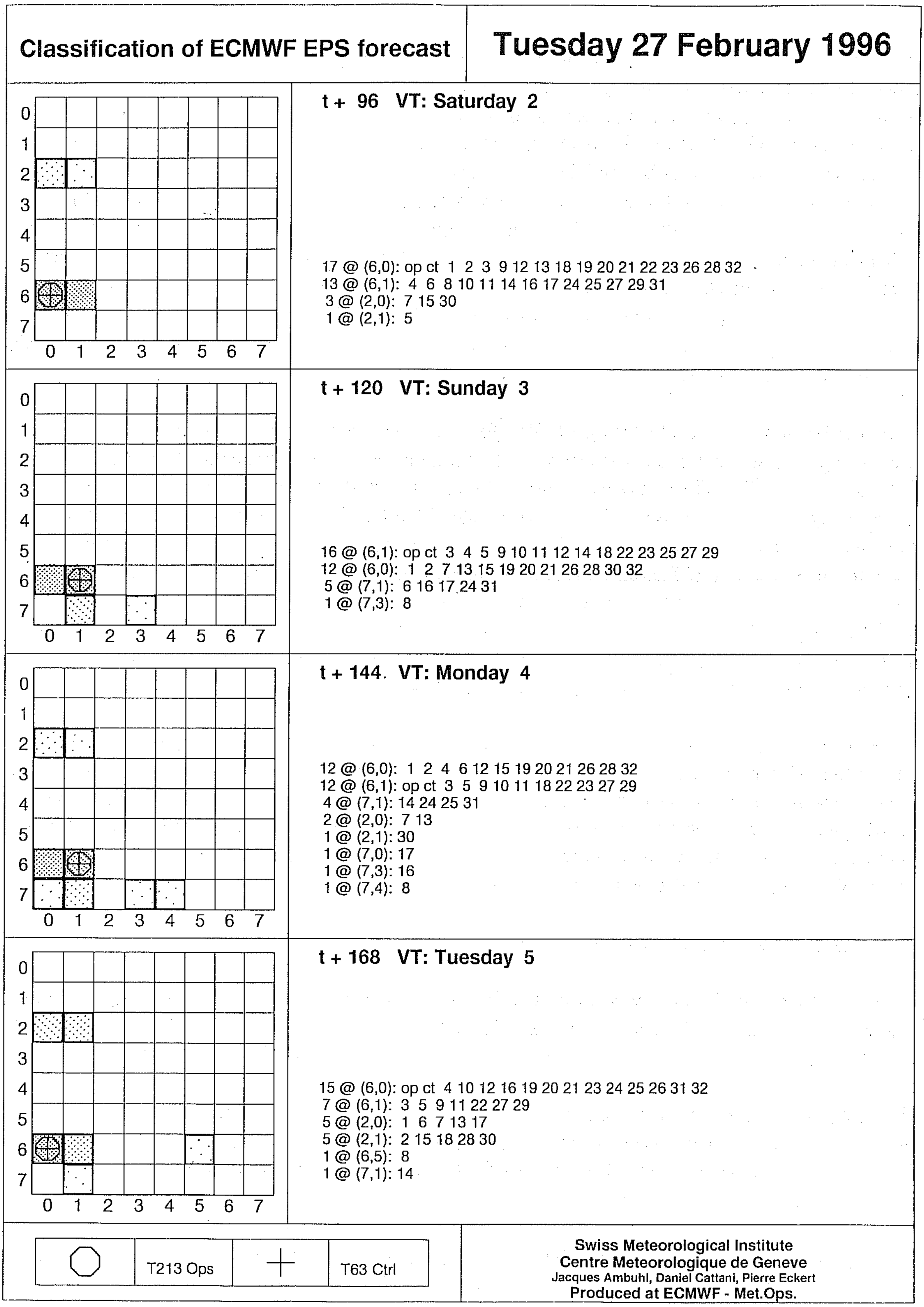

Fig. 5: Example of the output from the Swiss neural network based classification of the ECMWF ensemble forecasts of 27 February 1996 for the forecast ranges 96 (top) to 168 hours (bottom).

3. Use of medium-range forecast guidance

All ECMWF Member States have developed their own procedures and concepts for the use of medium-range forecast products. The primary forecast guidance is the output from the deterministic T213L31 high resolution model. To an increasing extent forecasters are beginning to combine the results from the deterministic model and the EPS in an appropriate way. Small spread in the EPS is seen as a signal of the support for the solution offer by the T213 model and it will give the forecaster more confidence in the overall performance of the forecast system. Forecasters have a cautious approach towards the use of guidance from a diverging EPS system. They tend to rely on the cluster means (or even the total EPS mean) rather than on individual and possibly extreme solutions offered by only a few members of the ensemble. After all, the EPS indicates that such forecasts have a low probability to verify and are therefore used by the forecasters accordingly. The expectation is that a well balanced EPS forecasting system will detect at an early stage possible alternative flow scenarios late in the forecast, which will be confirmed with increasing probabilities in consecutive forecast runs.

A particular approach to clustering of EPS forecasts was chosen and implemented at the Swiss Meteorological Institute. It is a classification of flow pattern based on a neural network approach (Ambühl, Cattani, Eckert, 1995). The neurones (shown in Fig. 5) are based on a learning period of two years. The matrix is organised in a way that adjacent neurons should reflect the affinity in the displayed flow pattern over central southern Europe. The classification is then applied to the individual ensemble members, see Fig. 6 for the forecast of 27 February 1996. Most forecasts in the ensemble including the T213 and control forecasts out to day 7 map onto the north-westerly cyclonic flow pattern associated with the neurons 6.0 and 6.1. The north-easterly anticyclonic pattern features as a minority solution. Forecasters in Switzerland see the neural network classification as a more realistic approach to clustering which is also more in agreement with their synoptic perception of the EPS forecast guidance.

While the cluster products provide the type of classic synoptic forecast guidance which requires further interpretation by the forecasters, it is possible to exploit the predicted probabilities of the occurrence of weather events directly and provide the end-user with tailor-made products. Member States can foresee a growing market for this type of products aiming at the special needs of certain end-users. Some Member States are considering further post-processing of the probabilities combining them with the output from deterministic models in statistical interpretation schemes.

4. Verification and validation of the forecast system

A comprehensive verification system for the EPS is under development to complement the T213 model verification of upper-air and surface parameters. The EPS verification will help the developers to validate the system and provide the users with information on the quality and the reliability of the forecast guidance.

The Centre monitors the spread of the ensemble, the error and anomaly correlation statistics of the individual ensemble members and the cluster means. In a balanced system the spread should be similar to the error of the control, but also the high resolution forecast should lie within the spread of the ensemble. The current system shown some deficiencies with respect to the latter condition, possibly reflecting model error problems. Forecast probabilities of flow scenarios (obtained from the cluster population) and of the occurrence of weather events are verified by means of reliability diagrams and the Brier score. Using climate as a reference skill scores are also computed. The system is still very much under development. First results for the Winter 1994/95 indicate that cluster means provide information on the predicted flow scenario with a certain degree of reliability. Probabilistic forecasts of weather events in the range of days 5 and 6 are skilful but suffer to a large extent from model deficiencies which become more evident in the later stages of the forecast.

5. Outlook

The current experimental EPS is to a large extent bound by the available computer resources. The T63L19 model differs in its characteristics from the T213L31 model and has known deficiencies. Also, it remains part of the development work to determine the appropriate size of the ensemble to capture the required spread in the EPS. A higher resolution model and/or a larger ensemble size will be introduced in the EPS in 1996 when substantially more computer resources will become available at ECMWF with the CRAY C90 replacement.

6. Literature

Ambühl, J., D. Cattani and P. Eckert, 1995, *Classification of ECMWF ensemble forecast members with the help of a neural network,* Report from expert meeting on ensemble prediction system, 22-23 May 1995, ECMWF, Reading (available from ECMWF)

Burridge, D.M., 1993, *Medium-range weather forecasting,* Proceedings First European Conference on Applications of Meteorology, Oxford

Buizza, R., 1994, *Localization of optimal perturbations using a project operator,* O.J.R. Meteorol. Soc., 120, 1647-1681.