INTRODUCTION

The ECMWF has, over the years, organised and benefited from a series of workshops covering a variety of aspects of its operational and research activities. This workshop on experimental extended range forecasting discussed the predictability of the atmosphere in the medium and extended range. A major part of the workshop centred around the problems of variability of forecast skill and the requirements for a priori estimates of forecast skill.

The workshop was split into two sessions: a session of formal lectures by invited speakers and a plenary session which dealt with:

- the scientific problems associated with the a priori prediction of forecast skill in the short, medium and extended range;

- presentations of the ECMWF Member States' plans for predictability research and areas for collaboration;

- ECMWF plans and collaboration with Member States.

A summary of these discussions is given in these proceedings along with the papers presented at the workshop.

We are indebted to all our visitors for contributing so generously of their time and energy to the workshop and hope that they too have profited from a lively and stimulating meeting.

1. DISCUSSION OF THE SCIENTIFIC PROBLEMS

Two major topics were discussed: predicting the skill of short and medium range forecasts , and extended-range forecasting. These are treated separately in the two sub-sections below.

1.1 Forecasting the forecast skill

(i) Outline of the problem and available tools

The pressing need for the provision of estimates of forecast reliability was stressed in many of the formal presentations. There are examples where a 5-day period of consistently bad forecasts for Europe is succeeded by a 5-day period of remarkably good forecasts for Europe. Similarly, there are longer periods (14 days or so) when the forecast skill of the whole hemisphere is consistently high, followed by equally long periods of consistently poor forecasts over the hemisphere. Each of the periods of good or poor forecasts can be interrupted by a single sporadic forecast of exceptionally bad or good quality. It was agreed that investigations aimed at finding reasons for such behaviour, and developing predictors for changes in forecast skill were an important priority.

Clearly the problem is ripe for attack as a number of datasets are now available for studying the predictability of forecast skill. These include complete ECMWF archives of analyses and forecasts since 1980 (with data available 5 days a week from August 1979 to July 1980). Compressed versions of these archives, the so-called ECMWF Lorenz tapes, are also available from 1980 to 1986. Furthermore, NMC forecast archives exist since 1981, and the CAS intercomparison datasets are available since 1979.

(ii) Strategy

The provision of estimates of forecast skill will require the solution to a wide range of problems and much of the emphasis for initial studies was put on the use of these datasets.

For example, there is some evidence that consistency between successive forecasts may be a reliable indicator of forecast skill, and further investigation of this is a particularly important avenue of research. On the other hand there have been situations where a series of forecasts have been consistent and wrong about a major change in circulation type. In these circumstances, differences between the latest forecast and earlier consistent forecasts may be viewed as positive indicators of quality. The implication being that consistency between successive forecasts is more useful in indicating reliability in some flow types than others.

In the discussion, it was also recognised that analyses and forecasts should be classified in terms of the prevailing flow regime, and estimates of forecast skill for each flow regime made. It has been suggested that there appears to be some relationship between hemispheric forecast skill and the amplitude of the long wave pattern over the northern hemisphere, but this has not been quantified yet. Predictable changes in the long wave circulation might provide a basis for predictable changes in forecast reliability.

For such predictability studies a comparison of consistency between different forecast models would be most relevant. However, in cases where there are consistent forecast differences, attention should be paid to whether this is due to model differences or to differences in initial data; there are a number of documented example where the latter was more important. Hence it may not be true that some situations are more forecastable with one model than another.

Some discussion was given to the theoretical problem of variation of predictability. In particular it was suggested that some large-scale flow regimes are inherently less predictable than others because they are more unstable to some large-scale quasi-stationary instability of barotropic or mixed barotropic/baroclinic type. Theoretical studies of the three dimensional instability of the climatological flow have already been undertaken and these could be extended to apply to flow regimes found to be particularly predictable or unpredictable.

Throughout the discussion, it was emphasised that research in this area should be conducted in collaboration with the member states.

1.2 Extended-range forecasting

(i) Outline of the problem and available tools

The importance of providing information to users for long term weather guidance up to a month ahead was recognised during the discussion. However, in order for such information to be of value, it is necessary to extract useful information from a single integration or ensemble of integrations beyond the forecast model's limit of (instantaneous) deterministic predictability. In view of recent advances in numerical weather prediction models together with enhancements in computer power, it was recognised that further research into extended-range forecasting is now appropriate. Indeed, experimental extended-range forecast programmes are already underway in many major meteorological centres. Since the models at these centres are quite different to one another, together they provide a powerful set of tools with which to study the problem of developing a methodology for extracting useful information from the extended-range forecast.

(ii) Strategy

In the discussion, it was remarked that that the limit of deterministic predictability is longer for time-mean fields than for instantaneous fields, because of the slower error growth of time-mean fields, and also because the spatial variance of time-mean fields is smaller. Spatial filtering was also discussed, and an example of the strong dependence of error growth on spatial scale was shown. It was agreed that temporal and spatial filtering were necessary to produce useful output from extended-range forecasts. This therefore restricts the user of such information to one who does not require weather information for a specific geographical area, or for a specific period of time. It was commented that there is still a wide class of users to whom this sort of information would be particularly valuable

However, it was recognised that temporal and spatial filtering were not sufficient to produce reliably useful information from extended-range forecasts. It was suggested that the most fundamental requirement for a model to be useful in the extended range is an ability to capture regime transitions, or changes in weather type. It requires analysis of a number of sufficiently long integrations to determine whether a model can represent accurately such transitions.

The use of ensembles of integrations, rather than single deterministic forecasts, was also discussed. The inherently probabilistic interpretation of an ensemble forecast was felt by some to be appropriate to the notion of forecasting beyond the limit of deterministic predictability. The divergence of individual members of the ensemble might also give useful information about the reliability of the forecast. Given finite computer resources, the practical strategy of producing forecasts was discussed. It was generally felt that running a small number of time-lagged ensembles was preferable to running a larger number of forecasts from independent single initial conditions. Furthermore, since a number of centres have now started research into ensemble forecasting, it was agreed to try and run forecasts from the same initial dates.

A major benefit of running extended-range forecasts is to provide information about systematic climate-drift errors in the model. These will tend to be accentuated in the extended range. Correction of such systematic errors will clearly be of direct benefit to the medium-range forecast. For this reason it was thought necessary to use the operational model for the extended-range forecast programme, and not to freeze one version of the model for extended-range research.

2. MEMBER STATES' PLANS: AREAS OF COLLABORATION

The second discussion session was devoted to a number of informal presentations by some participants outlining the research plans of their institutions (National Weather Services/Research Institutions from Member States) and the areas of relevant cooperation with ECMWF.

Denmark

The opening presentation was given by A.C. Wiin-Nielsen, Director of the Danish Meteorological Institute (DMI). After briefly outlining the recently enhanced computing facilities, he pointed out that research in extended range weather forecasting at the DMI is an effort coordinated between the Weather Service and the National Climate Committee of the Danish Royal Society. A global version of the ECMWF spectral model is currently being implemented in Copenhagen with the view of employing it in both climate and weather forecast research. Given the constraints of the overall availability of computer resources and the existence of many other important research projects (e.g. HIRLAM), it was envisaged that a version of the model (hopefully T42) would be used for some extended integrations. The opportunity for both coordination on initial dates for such experiments and cooperation in the evaluation of the integrations (including those performed by ECMWF) was pointed out. In particular, the DMI expressed interest in providing assistance in evaluating synoptically (by forecasters experienced in the extended range) some of the monthly integrations performed by ECMWF. They will contact the Centre when manpower and resources to do so become available.

France

M. Jarraud and M. Deque gave an account of the ongoing research at the Direction de la Météorologie (DM) in Paris and Toulouse. While the Toulouse group will concentrate on assessing the effects of boundary conditions on 15 to 45 day numerical forecasts, the Paris group is more interested in improving the tools to measure numerical forecast skill, comparing it with climatology and persistence, and comparing the performance of ECMWF and French model integrations. Improvements in model performance will also be sought by means of ensemble/time/space averaging procedures (including averaging forecasts from different centres) and by developing special indices (e.g. EOFs, spectral modes...). Jarraud stressed the need for close contacts and collaboration between DM and ECMWF both in analysis of experimental forecast results and

planning of progress of common interest. Regular meetings between interested parties should take place to make such contacts easier and more effective. The Centre should favour those lines of extended-range forecasting research that are likely to have the largest impact on medium range prediction, the first priority of the Centre's research. In particular, therefore, the study of model's systematic error in monthly integrations should be emphasized. Jarraud also pointed out that the quasi real-time availability of some of the Centre's experimental extended-range forecasts would make it easier for operational forecasters in the Member States to participate in their synoptic evaluation. The need to make past cases easily available to Member States was also pointed out. This will be made easier by archiving the results of such past and future integrations under the new Centre's archives, MARS.

It was suggested that the creation of an informal Working Group on Predictability Studies, along the lines of existing LAM European Working Group, would meet the expressed need for coordination/cooperation between the Centre and the Member States' Weather Services and between the Weather Service themselves. There appeared to be a consensus that this was indeed the case and that such a group should be formed and that it should meet in different countries in rotation. Wiin-Nielsen emphasized that the procedures of the working group should be kept as informal as possible, avoiding extremely crowded meetings. M. Capaldo pointed out that the Centre was also a good meeting point for such a Working Group.

Netherlands

A.P.M. Baede described the research plans of KNMI. Three main areas will be examined:

1) theory of predictability (local stability and dispersion properties of planetary atmospheric flow, role of steady states in simple model dynamics and analysis of local coherent structures);

2) statistical forecasting of forecast skill (relationships between circulation and error fields and MOS-prediction of forecast skill);

3) Dynamical Extended Range Forecasting (DERF) and the diagnosis of GCM integrations with linear models.

Collaboration with ECMWF, apart from simple provision of archived data, was envisaged mostly on points 2) and 3). Regarding statistical forecasting of forecast skill, KNMI would like to have access to ECMWF forecast data in compact form (Lorenz tapes) and foresees the opportunity, by the time some preliminary practical results will be available, for ECMWF to provide an operational testbed for such results. In view of the Centre's (and other institutions') own research plans in this area, close international coordination was considered to be highly desirable. A working group on predictability was cited again as the vehicle to ensure such coordination and a profitable exchange of ideas. Regarding DERF, access to extended integration datasets was obviously crucial and the necessary contacts with the Centre had already been taken. During the discussion, J. Shukla emphasized the importance of performing some long integrations where all dynamically and thermodynamically important model-generated quantities are archived with high temporal and spatial resolution to allow detailed model diagnostics and to provide input to simpler (e.g. linear) models for the above mentioned comparisons.

United Kingdom

D.E. Jones outlined the United Kingdom Meteorological Office (UKMO) quasi-operational and research activities in Extended Long Range Forecasts. Experimental long range forecasts for the following 30 days are produced every two weeks by blending medium range dynamical-numerical products into the results of statistical methods. The basic forecasts are of surface pressure which are then interpreted to produce forecasts of mean temperature and rainfall for two 15-day periods for 10 districts of the UK. Every 3 months ensembles of 7 dynamical-numerical forecasts, using a Lagged Average Forecast (LAF) technique, are available in time to contribute to these "operational" forecasts. Of particular interest is the possibility of estimating the reliability of the dynamical forecasts a priori, and the ways individual forecasts cluster within an ensemble. The importance of estimating the climatic drift of the dynamical model was emphasized.

A major outstanding problem (also previously mentioned by other participants) was how to interpret practically time-mean maps in terms of parameters useful to the user. Concerning international collaboration (in particular with ECMWF) the coordination of initial dates for extended integrations taking

place with ECMWF and other extra-European institutions (e.g. NMC and CAC in the USA) was mentioned (see J. Shukla's and S. Tracton's contributions in this volume). The opportunity of creating 'grand ensembles' of model integrations from different centres starting from the same initial conditions was considered to be of particular interest. The current lack of systematic knowledge on numerical-dynamical 'forecastability' of the onset of blocking beyond 5 to 10 days was mentioned during the ensuing discussion, as needing particular attention. In replying to a question from H. Tennekes about lack of literature on bench-forecasters' experience with forecast intercomparison (from different models) it was pointed out how difficult it is to persuade forecasters to write about such matters.

Federal Republic of Germany

V. Renner described DWD's activities and plans to investigate the use of dynamical numerical models in monthly forecasting. The research programme develops within the framework of the National Climate Research Programme and in collaboration with the Max-Planck Institute, Hamburg University. The version of the Centre's T21 model running on their computing facility (CYBER 205) will be used to produce a comparatively large number of 60 day integrations starting from initial conditions from four successive winters, with both time-evolving climatological SSTs plus fixed observed anomalies. The evaluation of the integrations will partly follow the lines described in the contribution of H. Von Storch in this volume and will comprise time-dependent energetics, systematic error studies and statistical tests of forecast quality and impact of SST anomalies. The current analogue-based, operational method for producing long range forecasts was envisaged to be maintained until results from such (and other, e.g. ECMWF) research would become available. ECMWF effort in this area is, therefore, considered to be very valuable in planning the next long range forecasting system.

The DWD is interested in having access to the experimental integrations being carried out at ECMWF and, on the basis of exchanges of ideas that took place during the workshop, is investigating the possibility of complementing the research plan described above with some further model integrations (possibly at model resolution T21 and T42) to be coordinated with the Centre's experimentation programme.

H. Von Storch presented the research plans of the Hamburg Max Plank Institute/Hamburg University Meteorological Institute joint effort on coupled ocean-atmosphere modelling. The four main areas of interest are:

1) Verification of Atmospheric GCM Climate simulations against observations;
2) AGCM sensitivity experiments with respect to boundary conditions (SSTs, snow, albedo);
3) AGCM sensitivity experiments with respect to physical processes;
4) Coupled atmosphere/ocean GCMs.

The atmospheric simulations will be performed with the Hamburg version of the Centre's T21 spectral model running on the CYBER 205 in Hamburg. El-Nino type studies featured prominently in the detailed programme and collaboration with ECMWF was sought in order to obtain surface atmospheric forcing fields from T106 extended integrations (possibly up to 60 days) so as to assess the impact of a much higher resolution AGCM on the experimentation. The area of model sensitivity to physical processes was also considered to be a good source of cooperation with ECMWF. The statistical tools to be employed in analysing the results are essentially those described in Von Storch's contribution to this volume.

Finland

J. Kilpinen outlined the current plans of the Finnish Meteorological Institute. There are no plans to build a DERF model. Some experiments in statistical extended range forecasting are currently being carried out to develop experience in this field. The Finnish Meteorological Institute is keen to cooperate with the Centre in synoptic evaluation studies of extended integration products and, in line with previous participants, considered the proposed Predictability Working Group a suitable structure to promote and coordinate such collaborative efforts.

Greece

A. Kakouros outlined the view of the Greek Meteorological Service on extended range forecasting. He explained that little experience in this field is available and no systematic work is planned for the foreseeable future. Short and medium range forecasting absorbs all available resources, since they are

considered areas of priority. Dr. Kakouros was hesitant to widen the interests to Extended Range Forecasting (ERF) and doubted the usefulness of such products. However, the opinion was expressed that some effort should be made by the community to explore the potential usefulness of ERF. Greece supported ECMWF's effort in this area with the understanding that Medium Range should clearly remain the highest priority. Possible cooperative efforts with ECMWF will be considered for the future.

Italy

A. Speranza described the efforts of the Italian Scientific Community in the field of Extended and Long-Range Forecasting. Such efforts are coordinated within the National Programme for Climate Research and takes place mostly in Bologna (University/National Research Council) and in Rome (University/IBM International Research Centre). The effort in Rome is focussed on prototype models of the interactions between baroclinic eddies and mean flow and of their statistical properties. Geostrophic turbulence prototype models are also being developed. The effort in Bologna is more oriented towards phenomenological meteorology with studies of localised effects of orography on baroclinic instability (cf. the ALPEX programme) and observational studies of the statistical properties of the atmospheric general circulation. The areas where collaboration with ECMWF is sought are connected to the current need for theoretical explanations of the of the causes of atmospheric low-frequency variability and to the possible connection between model systematic errors both in mean fields and in energetic conversions and their inability to represent properly observed low-frequency variability. Results from monthly (and perhaps longer) integrations with the Centre's models would be analysed in terms of their statistical properties (e.g. search for the existence of cycles and their dependency upon resolution). Currently available datasets (e.g. Lorenz Tapes) could also be used to study similar problems in the medium-range model performance.

3. ECMWF PLANS AND COLLABORATION WITH MEMBER STATES

In the final session of the Workshop, D.M. Burridge of ECMWF presented an outline plan for the Centre's activity in predictability research and for collaboration with the Member States. The planned activity was divided in two parts, Medium Range Forecasting and Extended Range Forecasting.

3.1 Medium range

The main effort in medium range forecasting will continue to be the development of the Centre's forecasting system comprising the data assimilation system and the forecast model. This central part of the Centre's activity needed little discussion.

The development of procedures to produce a priori estimates of skill is a difficult area where little experience is available. The first ECMWF studies will therefore be of an exploratory nature, to be followed by deeper studies in due course. The following approaches were discussed and will be explored more or less in the order indicated.

(i) Documentation of current levels of reliability

The Centre has a complete archive of forecast scores for all variables for all regions of the globe. Documentation of the statistical distribution of forecast scores was requested by a number of Centres and can be readily provided.

(ii) Measures of consistency

S. Grønaas (1983) has made a start on quantifying forecast consistency and using it as a predictor of forecast reliability. This work will be continued and extended at the Centre. E. Kalnay's pilot demonstration (see this volume) that consistency of forecasts from different assimilations could be used to predict forecast skill will be followed up at the Centre.

(iii) Lagged average forecasting

Beginning in summer 1986, and continuing for some months, the Centre will make 10-day forecasts at both 00Z and 12Z. The experimental 00Z runs will provide an opportunity of evaluating the regional behaviour of the lagged average technique of tempering a forecast.

(iv) Statistical analysis of flow-dependence of forecast error

The Centre is developing a set of statistical tools to investigate connections between patterns of forecast error and the initial data from which the forecast starts, or the verifying data. This will be done for the whole hemisphere initially. If successful the statistical methods would lend themselves to MOS forecasts of flow patterns, analogous to the MOS forecasts of point values.

(v) Regime dependence of forecast error

If the exploratory data analysis of (iv) above is successful, it may provide suggestions for a useful objective categorisation of weather regimes using indicators such as the one developed by Sutera (1986) for example. This in turn might enable a more refined analysis of the relation between flow type and forecast error.

(vi) Forecast system intercomparisons

Intercomparison of forecast results from different forecasting systems has provided much insight into the reasons for variations in predictive skill. The current intercomparisons with the UKMO are proving valuable, and it will be worthwhile to extend the collaboration with other Member States in a multiple intercomparison.

(vii) Longer term statistical investigations

The direct statistical investigations alluded to above involve extensions of regression techniques. The alternative approach of teleconnection analysis has proved useful in the analysis of atmospheric data, and may prove useful also in the analysis of forecast error. Preferred tracks for forecast error growth may be identifiable. Large scale structure in the forecast error in the early stages of the forecast may also be detectable. The area is new and will be explored after the more direct methods have been tested.

3.2 Extended range prediction

In recent years, extended range integrations for periods of 30 or more days have provided a vital research vehicle for work on the physical parameterisations and numerics of the Centre's model. The reduction of the model's climate drift has been a primary objective of the Centre's work from the outset. Extended range integrations provide one of the main test-beds for new development.

It has become necessary to extend the range of initial conditions of the extended range runs to give a better sampling of the climate drift. Since the runs are being made in any event it makes sense to verify them, and to make them available to interested parties in the Member States. As a result of the availability of the CRAY X-MP/22, the Centre has already completed 24 forecasts from the 15/16 of each month from April 1985-March 1986. It is planed to prepare a similar set for 1986/87, with the operational model and this series will be stored in the Centre's new MARS archive.

A number of planned changes in the model formulation offer the hope of a marked reduction in the model's climate drift. They include the introduction of extra stratospheric levels, the use of finite elements in the vertical, and the introduction of a gravity wave drag formulation. In runs from current operational data the impact of the model changes is felt after about 10-15 days. There is some evidence that the benefits are seen within 10 days if the model changes are included in the data assimilation. Some of the regular extended runs may be with pre-operational versions of these modifications.

The evaluation of these runs will be made in a number of ways. They will be studied first of all for the information they provide on the climate drift of the model. Secondly they will be used to evaluate the hypothesis that time averages of the atmospheric flow are more predictable than instantaneous states. There have been only two other extensive studies of this question, at GFDL and UKMO. NMC Washington plans to begin work in this area in 1987.

It is likely that if skill is demonstrable beyond 10 days, it will occur in some situations only. After the initial survey of the problem with a 2-year dataset the Centre will begin investigations of those situations which have proved to be unusually predictable. This will make a direct connection then

between the work on medium range and extended range predictability. The ultimate goal is to be able to identify a priori those cases where skill is possible.

In parallel with the work using the operational or pre-operational model, there will be parallel experimentation with lower resolution models (T63) to explore the value of ensembles of extended range forecasts. These experiments will be coordinated with the other Centres who have similar plans. This work may lead to quantitative estimates of reliability using statistical interpretation techniques.

The Centre also plans to develop its theoretical work in order to analyse the results of the extended range experiments. Initially the work will seek to establish the connection, if any, between linearised stability analyses of the flow and predictability.

3.3 Collaboration

The French proposal to have annual informal meetings on predictability research met with general approval. The areas of collaboration between the Centre and the Member States are reasonably well defined. The Centre will make available operational data-sets and derived sub-sets as well as research integrations to the Member States. Coordination of experimentation between the Member States and the Centre will be valuable in testing the effects of models and initial data on forecast skill. Forecasting experimentation using ensembles will also be coordinated.

There is substantial theoretical activity both in Europe and North America and coordination of theoretical work was not thought to be necessary. The main request from the theoretical groups is the provision of the results of extended integrations. Regular contact between the experimenters and theoreticians is probably the best form of coordination.

References

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