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ECMWF — ten years of European meteorological co-operation

By L. Bengtsson
(Director, ECMWF, Shinfield Park, Reading)

Summary

An account is given of the objectives of the Centre which was formally established in 1975, its organization and control by the various countries that support it (the Member States), the forecasting model and data-assimilation system, the computer system, the schedule of operational forecasts, and the way the forecast products are disseminated. There has been a steady increase in forecast skill over the past six years with a corresponding increase in use of the products by the Member States, and further progress is expected.

Background

The European Centre for Medium Range Weather Forecasts (ECMWF) was formally established on 1 November 1975, a date when its Convention had received sufficient ratification to come into force. However, as described by Knighting (1978), this followed a long period of careful planning and preparation which started as long ago as October 1967, when the council of Ministers of the European Communities adopted a resolution to promote a common program for scientific and technical research. The problem of extending useful weather prediction into the medium range was singled out as one of several projects where a joint European effort was regarded as essential, and where, according to different assessments, the benefit would by far outweigh the cost.

John von Neumann had already outlined an overall strategy in atmospheric modelling and prediction in 1955 (von Neumann 1960). He considered that the prediction problem could conveniently be divided into three categories depending on the time-scale of the forecast. In one category came short-range prediction of motions, determined mainly by the initial state of the atmosphere. The second comprised much longer-term prediction of characteristics of motion that are largely independent of the initial state, and thus include the problem of climate simulation. In between these two extremes there was another category for which it was necessary to consider the details of both the initial state and of external forcing. The logical approach was to attack these problems in that order.

In the early 1970s there was enough experience in both short-range prediction and climate simulation by numerical models to justify a serious attempt to tackle the medium-range forecast problem which falls into the third, and perhaps most difficult, of the categories listed above. In the planning documents leading up to the creation of the ECMWF, medium-range forecasting was considered to imply a period from four to ten days ahead, but a more natural time interval is perhaps two days to two weeks.

Medium-range forecasting was in many ways an ideal candidate for co-operation. The scientific and technical problems are formidable, and only very few countries have enough scientific and technical experts to tackle them. Moreover, the computer and other resources needed exceed those normally practicable at the national level. Medium-range forecasts are less time-critical than short-range ones, and there is little disadvantage from an operational point of view if they are made at a distance from the national forecast offices, on condition that fast and reliable telecommunication links exist.

The Centre's objectives and organization

It is convenient to recall the objectives of the Centre as laid down in its Convention. They are:

(i) To develop dynamic models of the atmosphere with a view to preparing medium-range weather forecasts by means of numerical methods.

(ii) To prepare, on a regular basis, the data necessary for the preparation of medium-range weather forecasts.

(iii) To carry out scientific and technical research directed towards improving the quality of these forecasts.

(iv) To collect and store appropriate meteorological data.

(v) To make available to the meteorological offices of the Member States in the most appropriate form, the results of the studies and research provided for in the first and third objectives above, and the data referred to in the second and fourth objectives.

(vi) To make available to the meteorological offices of the Member States for their research, priority being given to the field of numerical forecasting, a sufficient proportion of its computing capacity, such proportion being determined by the Council.

(vii) To assist in implementing the program of the World Meteorological Organization.

(viii) To assist in advanced training for the scientific staff of the meteorological offices of the Member States in the field of numerical weather forecasting.

The governing body of the ECMWF is a Council composed of not more than two delegates per Member State. The Council has three advisory bodies on financial, scientific and technical matters. The Council and its advisory bodies meet once or twice a year. The Centre is organized in three departments, and its director is appointed by the Council.

There are at present 17 Member States (see Table I) and, in addition, a special co-operation agreement has been signed with Iceland. The Centre is financed by contributions proportional to the Gross National Product of each Member State, a figure which is reviewed every third year. Member States' contributions for the year 1985 total £8 465 000, almost 95% of which goes on staff, computer equipment and associated expenditure.

Table I. *Percentage budgetary contributions to the ECMWF for the period 1985–87*

Member States	Contribution %
Belgium	3.06
Denmark	1.82
Federal Republic of Germany	22.41
Spain	5.96
France	18.43
Greece	1.23
Ireland	0.53
Italy	11.33
Yugoslavia	2.16
Netherlands	4.64
Austria	2.17
Portugal	0.72
Switzerland	3.17
Finland	1.51
Sweden	3.44
Turkey	1.76
United Kingdom	15.66

The Centre's headquarters are in Shinfield Park, near Reading and about 15 kilometres from Bracknell. The building, covering more than 6000 square metres, and the land were provided by the United Kingdom, and occupied from 1979 (Wiin-Nielsen 1979), the same year that the Centre started to do operational forecasts.

The forecasting system

The Centre's forecasting system consists of two components: a general circulation type model and a comprehensive data-assimilation system. From the very start the Centre set out to develop a model which could describe the evolution of weather on all time-scales; in fact the same model (but with different horizontal resolution) has been used to predict intense small-scale weather phenomena (such as typhoons) as well as to simulate climate for periods of up to ten years. In the same way, the data-assimilation system was built in order to use not only conventional observations such as radiosonde data, but also asynoptic information from satellites and aircraft. The ECMWF data-assimilation system was successfully used to produce global analyses four times a day for the Global Weather Experiment. This data set, consisting of more than 70 000 global fields, has been used extensively by scientists all over the world.

The first numerical model used by the ECMWF was a grid-point model with 15 vertical levels and a horizontal resolution of 1.875 degrees of latitude and longitude. This model served for operational forecasting from September 1979 to April 1983. The finite-difference scheme conserved potential enstrophy during vorticity advection, a condition which is important when extending a prediction beyond several days. In April 1983 the grid-point model was replaced by a model using a spectral representation in the horizontal and a so-called triangular truncation at wave-number 63. The spectral technique was found to be more accurate than the grid-point model for the same computational cost. The number of vertical levels was increased to 16. Finally, in May 1985, a very-high-resolution spectral model was put into operation, whereby the spectral truncation was extended to wave-number 106. By and large this is equivalent to a grid-point model having a horizontal resolution of about 100 km.

Very substantial efforts have gone into developing a detailed description of the different physical processes which become more and more important as forecasts extend into the medium range.

The fundamental process driving the earth's atmosphere is heating by incoming short-wave solar radiation and cooling by long-wave radiation to space. The heating is strongest at tropical latitudes, while cooling predominates at polar latitudes, especially in the winter hemisphere. The bulk of the net incoming solar radiation is absorbed by the underlying surface rather than the atmosphere. However, evaporation of moisture and surface heating lead to much of this energy being transferred to the atmosphere as latent and, to a lesser extent, sensible heat. Thus the dominant direct heating of the atmosphere is found to be the latent heat released with deep tropical convection.

Radiative fluxes in the ECMWF model are calculated for five spectral intervals — two for solar and three for terrestrial radiation. The effects of water vapour, ozone, carbon dioxide and selected aerosols are included. The model predicts the cloud cover as a function of humidity, static stability and convective activity. The Centre's cloud scheme has gradually developed, and several Member States are using predicted clouds as a direct model output parameter. The prediction of boundary clouds and the outflow of cirrus from deep convective clusters were introduced in May 1985 with the new very-high-resolution spectral model.

The treatment of physical processes in the boundary layer deserves considerable attention in medium-range forecasting. The calculation of boundary-layer fluxes is based on the Monin–Obukhov similarity theory, which assumes that the gradients of wind and internal energy are universal functions of a stability parameter to be determined from empirical data. The roughness length over land depends on vegetation and sub-grid-scale orography. Over the sea the roughness length is given by the Charnock formula (Charnock 1955).

The model deals separately with deep and shallow convection. A correct handling of convection is essential, not only for tropical forecasting *per se* but also for the overall maintenance of the large-scale tropical circulation systems, which are important for the large-scale circulation at higher latitudes.

Medium-range weather prediction requires global observations of high quality, coverage and resolution. Thus a continued improvement in medium-range forecasts is strongly dependent on the Global Observing System. Good observations through the depth of the atmosphere over remote ocean areas are as important as good observations over land, so that observing systems providing a homogeneous data coverage for large areas are of particular importance.

For this reason the ECMWF has devoted considerable research efforts to develop a four-dimensional data-assimilation system in order to make efficient use of temperature and moisture soundings from the polar-orbiting satellites and to use wind observations from the geostationary satellite platforms.

The computer system

The ECMWF's first generation computer, installed in 1978, had a Cray 1-A mainframe, with a performance of about 100 MFLOPS (million floating-point instructions per second). This was replaced in 1983 by a Cray X-MP dual processor, which in turn was replaced at the end of 1985 by a four-processor version (the Cray X-MP/48). The throughput of the Cray X-MP/48 is about ten times that of the Cray 1-A.

The Cray X-MP is connected via a data link, the Loosely-Coupled Network. It is also directly coupled to two front-end processors, a Cyber 835 and a Cyber 855. A dedicated VAX 11/750 minicomputer takes care of graphical applications, and an IBM 4341, with an attached mass storage, is needed for archiving the Centre's data. In-house connection to the Cyber computers is via a Gandalf system, and external communication via an RC 8000. It is through this machine (to be replaced by a VAX-oriented system later this year) that the Centre acquires its observational data from the Global Telecommunication System (GTS), via links to the Regional Telecommunication Hubs at Bracknell and Offenbach, and transmits its analyses and forecasts to Member States. Details of the ECMWF computer system are shown in Table II.

Table II. *Details of the ECMWF computer system*

Computer	Memory	Disc or tape storage	
Cray X-MP/48	64 Mbytes 256 Mbytes (SSD)*	21 disc units	10.300 Gbytes
Cyber 835	4 Mbytes	26 disc units	10.700 Gbytes
Cyber 855	12 Mbytes	10 tape units	
IBM 4341	8 Mbytes	10 disc units	12.500 Gbytes
		cartridge tapes	105.000 Gbytes
		6 tape units	
4 × VAX 11/750	18 Mbytes each	7 disc units	2.100 Gbytes
		1 tape unit	
2 × RC 8000	576 Kbytes each	1 tape unit	
		2 disc units	0.132 Gbytes

* Solid-state storage device

Production and dissemination of forecasts

On its general operational schedule, the ECMWF makes one forecast each day for ten days ahead, starting from the 1200 GMT analysis. No other operational forecast is currently run. At about 1700 GMT each day an analysis valid for 1800 GMT the previous day is carried out, thus providing the first guess for the 0000 GMT analysis which is carried out at about 1800 GMT each day. Similarly, analyses for 0600 and 1200 GMT are carried out at around 1830 and 2000 GMT, the final analysis having a data cut-off time of about eight hours. It is from this that the ten-day forecast is run.

Forecasts are distributed to the Member States in digital form. The present distribution amounts to over 10 000 products each day from the Centre. A product is defined as one parameter (e.g. geopotential) for one level (e.g. 500 hPa) for one time-step (e.g. forecast time 240 hours) for one area (e.g. a European area). A selection of ECMWF products is distributed daily to users all over the world via the GTS (Table III).

Table III. *A selection of ECMWF products disseminated on the Global Telecommunication System*

Product	Northern hemisphere (from latitude 20°)	Tropics (35° N to 30° S)	Southern hemisphere (from latitude 20°)
Mean-sea-level pressure	Analysis to day 6	—	Analysis to day 5
500 hPa geopotential	Analysis to day 6	—	Analysis to day 5
850 hPa temperature	Analysis to day 6	—	Analysis to day 5
850 hPa wind	—	Analysis to day 3	—
200 hPa wind	—	Analysis to day 3	—

Results of operational forecasts

Since the Centre started operational forecasting in September 1979 there has been a considerable improvement in the quality of the forecasts. This has been confirmed by both objective assessment and by subjective evaluation by users in Member States and elsewhere. The intercomparison study undertaken by the Commission for Atmospheric Science (Lange and Hellsten 1984) clearly demonstrated this, also that the Centre's forecasts were the most accurate among those participating in the intercomparison.

The improvements are due to continual development of the forecasting procedure, including both the model and the data-assimilation system. The greatest change to the model took place in May 1985; the effect of that change has led to a further significant improvement in predictive skill as can be seen from Fig. 1.

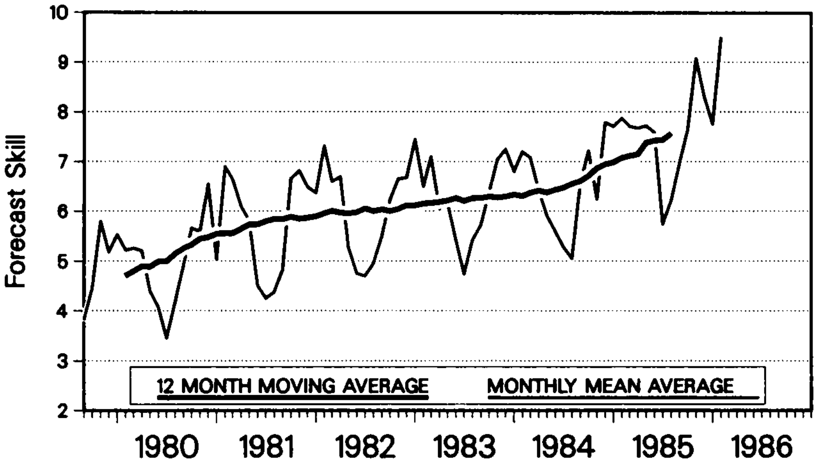

Figure 1. ECMWF forecast skill between September 1979 and February 1986. Forecast skill is based on 'days of predictability' derived locally at ECMWF.

Similar improvements have taken place in respect of forecasts for the southern hemisphere and the tropics, but from a much lower starting point. While the limit for useful forecasts for the northern hemisphere is six to seven days, corresponding values are four to five days for the southern hemisphere and three days for the tropics.

Usage of forecasts in Member States

While the operational forecast is being produced on the Centre's computer system, forecast products in the form of coded fields are being disseminated via dedicated telecommunication lines to the computer systems of the 17 Member States which support the ECMWF. The medium-range products have now become an integral part of the prediction routine in European forecast offices. Member States use the Centre's forecasts not only as an additional reference source, but also often as part of objective (statistical) interpretation schemes, as boundary values for their own limited-area models, or to drive other models (for example, sea and swell models for use in ship routeing). The primary end users of the medium-range forecasts interpreted by Meteorological Services of Member States are in the sectors of agriculture, marine, construction and heavy engineering, energy planning, leisure and tourism, land transport, environment and pollution (see Fig. 2).

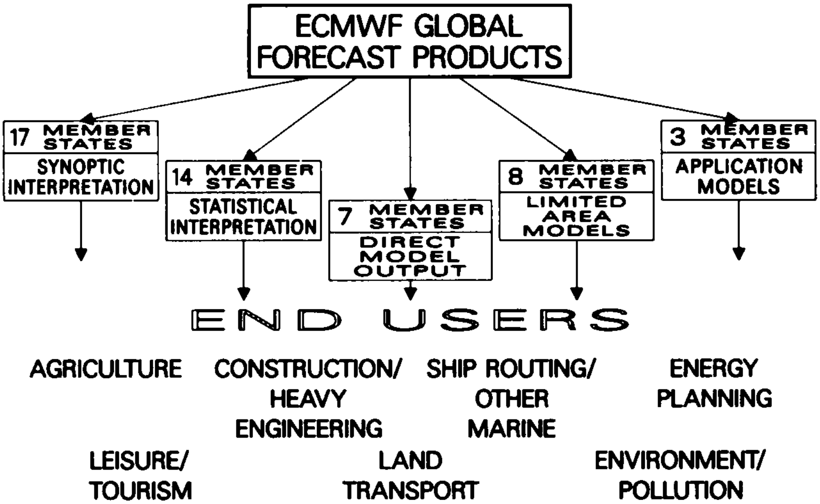

Figure 2. Application and use of ECMWF products in the Member States.

As well as standard operational products, the Centre's forecasting system also produces a range of products which are experimental in nature, such as cloud amounts, winds interpolated to the 10-metre level above the model surface, temperatures interpolated to the 2-metre level, fields smoothed by filtering to remove small-scale features (which cannot be well predicted at the later stages of the forecasts), time-averaged fields, and so forth. These additional products are also made available to Member States, and may be presented directly to forecasters or used in other ways (for example, as input parameters to statistical forecasting schemes). Thus, the Centre is assisting its Member States to improve the 'user interface' between numerically produced fields and the requirements for forecasts of actual weather elements by the end users of the forecasts.

Other services

Twenty-five per cent of the Cray computer resources and ten per cent of the Cyber resources are available for use by Member States. Computer time is distributed among the countries according to a special formula and is only partly proportional to the Gross National Product. Ten per cent of the time allotted to Member States is available for special research projects. Scientists may forward requests for this through any Member State.

The Centre is gradually building up an archive of raw and processed data (global analyses and forecasts). A special data set including selected basic observations and global analyses for seven standard levels has been developed covering a period of five years. The World Meteorological Organization (WMO) has contributed financially to the development of the data set which is currently being sent to a large number of users all over the world. The Centre is also in the process of re-analysing the Global Weather Experiment data using the most recent version of its data-assimilation system. As the Centre's archives are gradually developed, their value for the scientific community will increase more and more.

The Centre provides a two-month training course every year in advanced numerical weather prediction. The course is also open to scientists from non-Member States, 16 of whom participated over the past two years.

The Centre also gives an annual scientific seminar and organizes workshops in different subjects.

Future plans

Predictability studies recently carried out by Lorenz (1982) have indicated that the limit of predictive skill can be extended by between two and four days just by model improvements alone. Further amelioration of approximately two days can be expected due to the positive feedback of the model from the data assimilation. The Centre will maintain its successful 'brute force' strategy by continued enhancements to the complete forecasting system. Major problems are related to the treatment of orography, the parametrization of the boundary layer, and of deep and shallow convection. Continued progress in the performance of supercomputers will probably make it possible to run a global model with a resolution around 50 km before the end of this decade.

The quality of the Global Observing System is crucial for medium-range prediction. In a project supported by WMO, the Centre has recently developed a system for monitoring it. By intercomparisons of very-short-range forecasts (first guess to the analyses) with specific observations over periods of a month or so, systematic errors can be identified in the observations. Several cases of radiosonde observations with large systematic errors have been identified and the operators informed so that corrective action can be taken. It is believed that by instituting systematic quality control of observations with feedback to the producers, we shall achieve better-quality observations and consequently better forecasts.

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