THE DESIGN AND IMPLEMENTATION OF METEOROLOGICAL OPERATIONAL SYSTEMS

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Summary: This paper presents some of the basic concepts that govern the design of meteorological operational systems for numerical weather prediction. Three levels of structure are considered: the operational schedules, the major subsystems, and the typical components of each subsystem. The concepts are illustrated by reference to the current operational systems at Bracknell and at ECMWF, and some development trends are noted.

1. INTRODUCTION

The structure of any meteorological operational system will depend on the set of forecasting functions that the system has to support. For any single function, a fairly simple structure would result, with the possibility of tailoring the system specifically for the given purpose. if however the functions are diverse, the structure inevitably becomes more complex and the limitations of computing resources are likely to necessitate compromises in the design to satisfy the several purposes to an acceptable level.

One of the important factors is the range of forecasting that is being attempted. Four ranges have been defined by WMO as follows:

i. Nowcasting and very-short-range forecasting (0-12 hours).
ii. Short-range forecasting (0-72 hours).
iii. Medium-range forecasting (more than 72 hours and up to 10 days)

iv. Long-range forecasting (beyond 10 days).

There is a natural association between the range of forecasting and aspects of the operational NWP schedules such as the frequency of forecast runs, the lead times for the availability of products, and consequently the cut-off times for the arrival of observations.

Another major factor affecting the design of an NWP system is the area of coverage. Once again there are certain natural associations with the range of forecasting. Very-short-range forecasting is inevitably designed for limited regions from which the necessary detailed observations can be collected and processed very quickly. On the other hand NWP for medium and long range forecasting must be global in coverage since on these time scales the forecast in any region of interest might be affected by the initial conditions almost anywhere else. For short-range forecasting the requirements of particular categories of customers also have a bearing on the area of coverage, so that both global and regional NWP systems have roles to play.

The operational schedules for NWP, determined mainly by the range of forecasting involved, represent a first level of structuring of the meteorological operational system. A second level, at which major subsystems are identified, is determined by the areas of coverage and by the requirements of customers for particular types of information. Thirdly, within each subsystem, there is a mainly sequential set of components of the processing that transform the available inputs into the required outputs.

2. SCHEDULES

The impact of the forecasting range on the design of the operational schedules can be illustrated conveniently by comparing the global part of the system at Bracknell with the system at ECMWF.

The global NWP at Bracknell is designed primarily for short range forecasting, as required to fulfil the Met Office's responsibilities in Defence, as a World Area Forecast Centre for civil aviation, and in support of marine and other commercial services. As a consequence the numerical products are required with a short lead time and with a minimum of two issues daily. At present forecasts are run from 0000 Z and 1200 Z starting conditions using cut-off times of 0320 Z and 1520 Z for the arrival of observations. Products out to 72 hours ahead are available for dissemination by 0430 Z and 1630 Z, but these timings depend on a limitation to around 6 minutes elapsed time per forecast day for integrations of the global model on the Cyber 205 computer. The forecasts are then extended to 6 days ahead to provide additional guidance for the early medium range.

Clearly, some important observations from around the world will miss these early cut-off times, and so the relevant parts of the data assimilation are repeated much later, with 1120 Z and 2320 Z cut-off times. These 'update' assimilations for 0000 Z and 1200 Z are followed immediately by assimilations for 0600 Z and 1800 Z which provide the starting points for the next production runs.

As a specialist centre for medium-range forecasting, ECMWF can afford to wait rather longer for the arrival of observations, and a single production run each day is sufficient. A data cut-off of 1930Z has been adopted for observations used to determine the 1200 Z starting conditions for the 10 day forecasts. More time can also be devoted to the integration of the model, and around 15 minutes are used for each forecast day on the Cray X-MP/48. The other data cut-off times in the data assimilation cycle are 1100 Z for the 1800 Z analysis, 1630 Z for the 0000 Z analysis and 1800 Z for the 0600 Z analysis.

Both of the schedules outlined above are liable to be modified in future in the light of requirements. For short-range global forecasting a requirement exists for four issues of numerical products per day (eg for aviation flight planning and documentation), and short runs from 0600 Z and 1800 Z starting conditions have been included in the plans for the use of the new supercomputer at Bracknell. For medium range forecasting the principal unsatisfied requirement is for a priori guidance on the expected skill of each day's forecast. Since variations in skill are associated with uncertainties in the initial state, ECMWF may eventually choose to run an ensemble of integrations from controlled perturbations of the best 1200 Z analysis as a basis for a skill forecasting system.

3. SUBSYSTEMS

The design of the overall meteorological operational system has to take into account a variety of requirements for particular products. In attempting to meet these requirements within available resources a number of subsystems are often implemented. For example, the requirement for detailed short range numerical guidance on fronts, precipitation patterns and surface winds leads to the concept of limited area fine mesh models (LFMs) that employ the same basic formulation as the global models but cover limited regions of interest with higher horizontal resolutions. Again, requirements for sea-state forecasts have resulted in the implementation of numerical wave prediction models in association with NWP models.

The range of subsystems that may be used within a given meteorological operational system includes the following:

i. Global NWP
ii. Regional NWP
iii. Mesoscale NWP
iv. NWP based on imported numerical products
v. Global sea state prediction
vi. Regional sea state prediction
vii. Tidal surge prediction
viii. Air trajectory calculations
ix. Analysis of surface properties (eg SST, soil moisture).

The interconnections between the subsystems must be considered carefully. None of them can be run independently except global NWP, and even that has some dependence on the analysis of surface properties. The other NWP systems require external lateral boundary information. The oceanographic models require forcing fields in the form of surface winds and perhaps sea level pressures.

All of the nine subsystems listed above exist either operationally or on a routine trial basis within the system at Bracknell, and all are expected to be fully operational in an enhanced system that will be set up in association with the supercomputer. However, several of the subsystems require considerable further development before their full potential can be realized. The example of subsystem iv at Bracknell is medium-range NWP based on ECMWF products.

A given subsystem may of course be activated more than once during a full operational cycle.

4. COMPONENTS

Each subsystem of a meteorological operational system can be regarded as made up from a set of interconnected components. It is useful to list these in a general terminology that can then be made specific for any of the subsystems identified in the previous section.

- i. Input from other subsystems or systems
- ii. Preparation of observations
- iii. Quality control
- iv. Human intervention
- v. Observations Processing Database
- vi. Data assimilation
- vii. Prediction
- viii. Derived fields
- ix. Statistical interpretation
- x. Products Database
- xi. Archiving

xii. Verification

xiii. Diagnostics

xiv. Graphical output

xv. Digital output

When implementing a particular subsystem each of the above components can be developed and tested separately provided that the interfaces to other components have been properly defined. The specification of these interfaces in a way that is appropriate to the scientific requirements and allows flexibility for future developments is one of the crucial aspects of the overall design.

5. RELATIONSHIP TO COMPUTING RESOURCES

The meteorological operational system, with subsystems and components as discussed above, has to be mapped onto the available computing resources. These consist typically of a supercomputer, front-end processors and possibly also special facilities for data handling and graphics. (Telecommunications facilities are not considered here.)

At Bracknell one of the difficult aspects to plan has been the division of work between the supercomputer and the front-end processors. This question arises with each subsystem, certain components being run on the supercomputer and the remainder on the front ends. Recent policy has been to carry out the preparation of observations, data assimilation, prediction, derived fields and verification components on the supercomputer. Cases can be made for moving the preparation of observations and verification components to the front-ends, but there are doubts about the necessary front-end resources being available. The optimum division of work is liable to change as either the supercomputer or the front-ends are upgraded, so an important design feature for the future is that the components of each subsystem should be portable among different parts of the computing facilities as far as possible.

6. BACK-UP

Meteorological operational systems require back-up procedures wherever continuity of service is an essential feature. The advent of multiprocessor computers reduces the probability of being unable to carry out an operational run, but reduced processing power may still entail a failure to meet the normal schedules.

Back-up products from a previous run (eg using the previously computed 36 hour forecast when the current 24 hour forecast is late) are normally adequate to protect customers from delays. The NWP and sea state prediction subsystems at Bracknell are backed up in this way when necessary. The regional NWP and sea state models are integrated routinely to 48 hours ahead for this purpose, operational products being restricted to 36 hours ahead.

As a safeguard against prolonged unavailability of the supercomputer, numerical products can be imported from another centre for use in an emergency. GRIB code products from Washington (for the global NWP subsystem) and GRID code products from Paris (for the regional NWP subsystem) are received routinely at Bracknell for this purpose. The incoming products are converted to the form of the Products Database on the front-end so that digital and graphical outputs can be prepared using the normal software.

DATA CUT-OFF	RUN	PRODUCTS AVAILABLE
0200/1400	36 hr REGIONAL NWP 36 hr REGIONAL SEA-STATE 36 hr TIDAL SURGE	0300/1500
0245/1445	18 hr MESOSCALE NWP TRIAL	0315/1515
0320/1520	144 hr GLOBAL NWP 120 hr GLOBAL SEA-STATE	0500/1700
1130	SST ANALYSIS	1200

Figure 1 Schedule of production runs at Bracknell

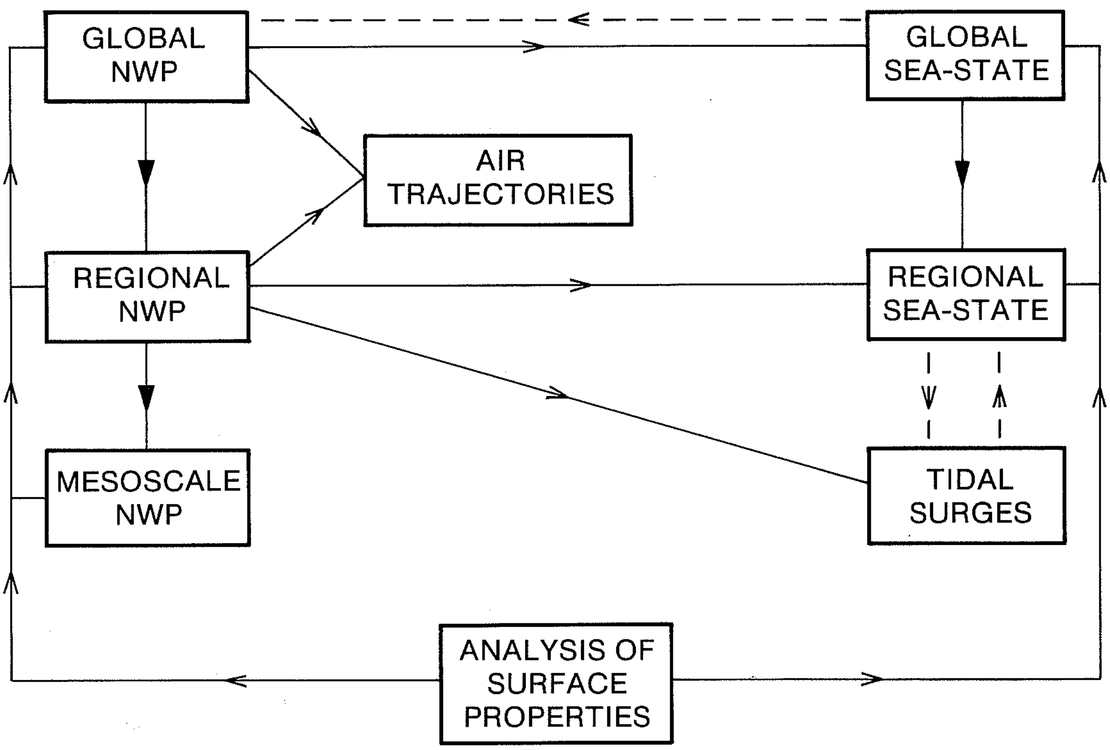

Figure 2. Interdependence of eight operational subsystems

lateral boundary conditions

other existing dependencies

likely future dependencies

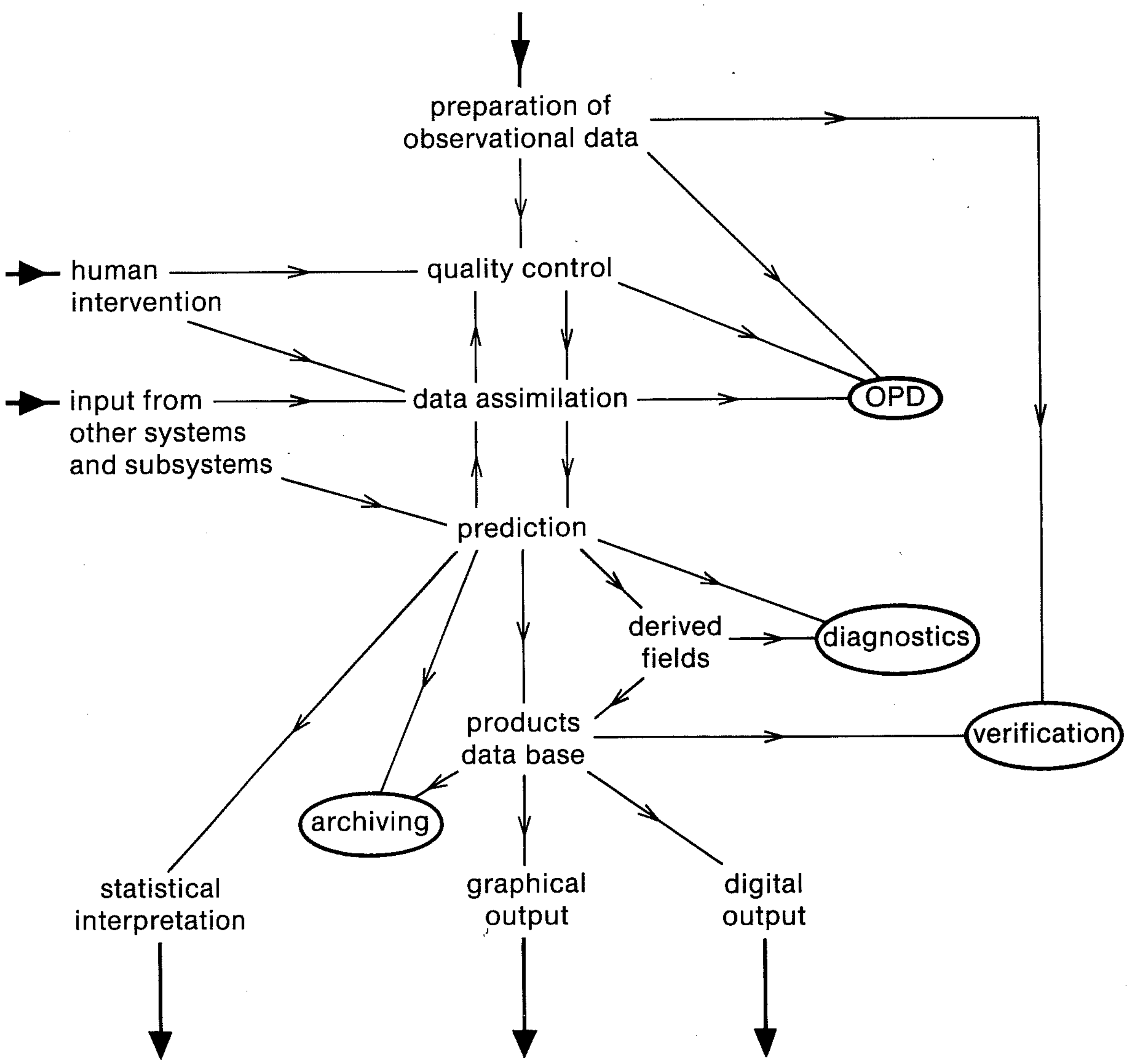

Figure 3 The interconnection of components within a subsystem