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RADAR AS PART OF AN INTEGRATED SYSTEM FOR MEASURING AND FORECASTING RAIN IN THE UK: PROGRESS AND PLANS

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Radar can observe precipitation in considerable detail and almost instantaneously over large areas. Given a network of radars, the distribution of precipitation could be kept under constant surveillance over the whole of the UK. Depending on the sophistication of the radar system it would be possible to measure the full 3-D distribution of precipitation or merely its horizontal distribution. Information on storm height is of interest, to air traffic for example; however, a knowledge of the distribution of surface precipitation is regarded as being of more general use and this is what we shall be concentrating on in this article. Even in those applications where storm heights are required these can often be inferred from a knowledge of the atmospheric stability and the distribution of surface precipitation intensity. Satellite infra-red imaging is, of course, useful for pinpointing the higher storms.

A detailed description of the current pattern of surface rainfall* intensity is valuable information in its own right, especially if it is disseminated promptly. Such a description is also important as input to detailed short-period weather forecasting procedures and as input to hydrological models for river flow prediction. Unfortunately, because of the rather special attributes of radar information - such as its embarrassingly high data rate and its sometimes qualitative nature - there has been a tendency for

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*Footnote: We shall use the term rain for compactness of style throughout the rest of this article in place of the more general term precipitation.

radar information to be regarded as 'other data' and for it to be excluded from the mainstream of operational procedures. Thus, despite the proven success of radar as a research tool, the failure to weave radar information into the fabric of the overall operational data set has caused it to have rather little operational impact except in countries subject to very severe storms. However, the Meteorologcal Office and RSRE, along with the Water Industry, are now in the midst of a series of programmes to rectify this situation. This article briefly outlines these programmes and points a way forward to harness radar for more effective operational use in the UK.

A TOTAL RAINFALL FORECAST SYSTEM

An idealised forecasting scheme showing the place of radar data in relation to other meteorological products is sketched in Fig.1. We are concerned in this article with the radar-related aspects within the dashed frame. The traditional view, as expressed by V. Suomi, is that the synoptic scale is the choreographer of the smaller or so-called mesoscale weather phenomena. There is, however, a limit to the detail and precision that can be achieved in forecasts by coming down from larger scales. Fig. 1 recognises this limitation: the figure shows ground-based radars, together with satellites, as tools for observing the detailed structure of rainfall systems and associated cloud patterns, thereby enabling deterministic forecasts for periods 0 - 6 h ahead to be made from an extrapolation of current trends.

Synoptic-scale dynamical forcing and topographical effects become increasingly important for forecast time scales longer than 6 h. The traditional forecasting approach of coming down from large scales is then more appropriate. A mesoscale numerical weather prediction (NWP) model parasitic on the output of a conventional synoptic-scale NWP model is being developed by the Forecasting Research Branch of the Met. Office. It is planned that this model will be capable of continuously assimilating observational data on the mesoscale. Fields of humidity, vertical velocity and latent heat release implied by the radar and satellite data will be among the inputs to this model. According to Kreitzberg and Rasmussen (1977) these inputs can be expected to influence the forecasts significantly for periods up to 12 h ahead in some heavy rain situations.

SOME IMPORTANT DEVELOPMENTS IN THE UK

Prospects for implementing the part of the scheme within the dashed frame in Fig. 1 have been enhanced by a number of technical developments:

1. A project carried out in the Dee River area of North Wales (Table 1a), in which the late T W Harrold played a major role, established that a radar calibrated against a small number of raingauges can indeed measure surface rain with sufficient accuracy for most meteorological and hydrological purposes (Central Water Planning Unit, Reading, 1977). This not only confirmed results of studies abroad but also extended their findings by showing that good accuracy is achievable in hilly areas where measurements are more difficult to obtain. It also showed that the radar method is more cost-effective than using telemetering raingauges for obtaining real-time rainfall information over large areas.

2. A research programme at RSRE (Table 1a) has led to the development of means of processing and transmitting real-time rainfall information from a network of radars for display as a merged whole at locations remote from the radars (Taylor 1975). Radars collect data at a high rate and it is only in

the last decade with the rapid development of digital techniques that it has become economic to convert the complex radar signals into quantitative rainfall information for transmission to remote users via ordinary telephone lines.

3. New satellites in the form of the geostationary METEOSAT and the pair of TIROS-N polar-orbiters are now providing sufficiently frequent cloud pictures over the UK for very-short-range forecasting purposes. Satellite cloud images (infra-red + visible), although inferior to radar data as a means of inferring rainfall patterns, are valuable for extending coverage beyond the range of a radar network, thereby giving advance warning of rain systems as they approach the mainland.

4. Short period forecasts are a perishable commodity necessitating frequent updating and the prompt dissemination of a large amount of information. The means are now available, through teletext and viewdata, for achieving this in pictorial format. The information content of pictures is far greater than that of the human voice. The Post Office viewdata system, known as Prestel, will employ a network of regional data banks and so it will be well-suited to disseminating local forecast products.

Spurred on by these developments, two new projects (Table 1b) have been set up which it is hoped will complete the foundations for an eventual National weather radar network. One of these is the North West Radar Project. This is intended to assess the benefits of integrating radar-derived rainfall data into the operational system of a regional water authority. It is also intended to demonstrate the viability of an unmanned radar site as a means of keeping down running costs without compromising the optimum siting of the radars. The other new project addresses the issue of forecasting and is considered now in a little more detail.

THE SHORT PERIOD WEATHER FORECASTING PILOT PROJECT

The broad aim of this project is to develop ways of exploiting radar together with satellite and more conventional data so as to improve short period forecasts of rain (and also snow, hail, thunderstorms and strong surface winds) in the UK. The Pilot Project, based at Malvern, is a balanced programme of research and development with effort in the following areas:

1. Establishment of semi-operational facilities to provide integrated fields of rain and cloud from a network of radars and satellites. This entails the setting up of radars and communications facilities as shown in Fig. 2. Coverage of the initial radar network is shown in Fig. 3 by the hatched shading. The data are displayed on colour television in the manner first described by Taylor and Browning (1974). Satellite cloud imagery for the area depicted in Fig. 3 is remapped and converted into a digital format similar to that of the radar (Ball et al 1979). This permits easy comparison of satellite cloud imagery with the radar rainfall data and enables both to be viewed separately, or merged together, in action replay. The basic cell size used for depicting both sets of data is 5 x 5 km. This corresponds to a degradation of the radar data but is rather finer than the resolution of METEOSAT IR imagery.

2. Fundamental research using these data to improve our understanding of the structure, physical mechanisms and predictability of rain. Given these new facilities (supplemented by serial rawinsondes) we can for the first time build up a systematic body of experience of local weather in the UK. We shall be able to capture in a computer archive the kind of mesoclimatological wisdom implicit in the countryman's local weather lore. At the same time we shall be in a position to construct physical models representing the behaviour of weather systems on these local scales.

3. <u>Development of simple procedures to optimize the use of the radar-cum-satellite data by local forecasters for the provision of more accurate and detailed forecasts</u>. An operationally oriented Forecasting Techniques Group has been established at our Malvern Laboratory. Initially this group is concentrating on developing forecast procedures for periods of only 2 to 3 h ahead - the Americans have made an early start in this area and coined the term 'nowcasts' for such products. With an expanding network of radars, it is hoped to extend the period of improved forecasts up to 6 h. The forecasting procedures involve both subjective and objective methods. It is not simply a matter of linearly extrapolating the motion of rain and cloud patterns, although computer pattern-matching methods are indeed used to do this. In general it will be necessary for the rainfall data to be interpreted within the context of the total set of meteorological information to allow for large-scale developments and for local topographical effects.

4. <u>Assessment from practical experience of the quality and utility of both actual and forecast rainfall information and the determination of the most cost-effective way of extending the observational network and forecasting techniques</u>. Improvements in forecast capability will come only slowly. The Pilot Project is expected to continue for 5 to 8 years, the initial 2 years (1978 and 1979) of which have been dominated by the setting up of radar equipment plus the display and archiving facilities. The first noticeable improvements in forecast capability can be expected in the early 80 ies. It will then be a matter of gradual improvements as we gain understanding and experience in using the data.

THE FRONTIERS PLAN

An important aspect of the Short Period Weather Forecasting Pilot Project is to achieve the maximum possible degree of automation, with all-digital data handling from the observational input through to final dissemination of the forecast product. At the same time it is recognised that a crucial ingredient for local forecasting is the ability to carry out a large amount of manual interaction with the computer-derived products. In the context of rainfall forecasting manual inputs are required for the following purposes:

1. To exercise quality control and apply corrections to overcome limitations of the radar rainfall data not dealt with fully in the automated radar-site processing (tasks include: eliminating spurious echoes due to interference, anomalous propagation, sea echoes etc; readjusting calibrations of individual radars in the light of ground truth and/or space-time continuity considerations; applying corrections to reduce any 'bright-band' effects due to melting snow; determining boundaries of usable data and applying supplementary range corrections as a function of precipitation type; applying corrections in situations of probable orographic enhancement to allow for low-level growth below the radar beam).

2. To analyse satellite data in terms of rain using a combination of objective and subjective techniques and then to combine the resulting patterns with the radar data so as to produce optimum rainfall analyses over an area larger than that covered by the radar network alone.

3. To derive very-short-range forecasts using a combination of objective extrapolation procedures with various subjective methods, including the use of mesocale climatological statistics, conceptual

models and an interpretation of the numerical forecast guidance.

4. To tailor the forecast product for dissemination to different customers (in TV-type picture, worded, or computer-compatible formats).

In order to carry out these tasks rapidly and with adequate scope for the forecaster to exercise his judgement, a man-computer interactive video display facility is being developed. The special display facility will be implemented within the Short Period Weather Forecasting Pilot Project as part of the FRONTIERS plan (Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite). The details of this plan have been discussed by Browning (1979). During the Pilot Project all of the above activities (ie quality control, analysis, forecasting, and tailoring) will be developed on the prototype display system being put together at Malvern. In a subsequent fully operational system, however, it would seem more appropriate for the quality control and analysis tasks to be centralised but for the tailoring and some of the more detailed forecasting to be pursued using separate man-computer interactive video displays at regional forecast offices where the personnel are more familiar with the local weather phenomena and the needs of local customers.

A POSSIBLE FRAMEWORK FOR A NATIONAL WEATHER RADAR NETWORK

An eventual network of 12 or more weather radars will be required to cover the entire UK. Twelve well-sited radars of appropriate design would provide adequate overall qualitative cover, with quantitative cover in some areas(Taylor and Browning 1974). The precise number of radars needed will depend on the detailed operational requirements for quantitative coverage of specific areas and also on the ability to find sites with good horizons and acceptable ground clutter.

One way in which the data from such a network could be handled is illustrated in Fig. 4, which depicts the relationship of regional observing and processing facilities to the centralized processing facilities. There are four principal components - A, B, C and D - depicted in Fig. 4 and their functions are explained in Table 2. We are assuming a roughly one-to-one correspondence between each of the 12 or so radars and a Met. Office outstation (D) somewhere within the radar umbrella. The location D could thus serve both as a Regional Forecast Office and a Communications Node for sending observational data to the Radar-cum-satellete Mesoscale Analysis Centre (B) and the Central Forecast Office (C). Local forecasters at each Regional Forecast Office (D) would, according to this scheme, have the benefit of single-radar data (product P_1) from their local radar available within 1 min of real-time, plus composited, analysed and quality-controlled radar network and radar-cum-satellite data (product P_3) sent a little later from the Mesoscale Analysis Centre (B). Water Authorities could be similarly served and, in addition, could receive subcatchment totals (P_2) direct from the radars and tailored forecast products (P_6) from the appropriate Regional Forecast Office.

Other more conventional meteorological data (P_5) may become available in digital form at Regional Forecast Offices during the 1980ies as a result of the Met. Office programme of Outstation Automation. It is, therefore, appropriate that the man-computer interactive video display techniques developed as part of the FRONTIERS plan should eventually be extended to enable the more conventional data to be superimposed and combined in a flexible manner with the radar-cum-satellite data. Much perseverence will be called for to ensure that the marriage between these different data sources is fully consummated but, in the writer's opinion, the effort will be justified.

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Table 1. Projects relevant to the establishment of an operational weather radar network in the UK.

(a) Projects completed recently

Projects	Principal Participating Agencies	Main Achievements	Dates
Dee Weather Radar Project	Central Water Planning Unit; Meteorological Office; Plessey Radar Ltd., Water Data Unit; Water Research Centre; Welsh National Water Development Authority	Demonstration that radar is capable of measuring rainfall sufficiently accurately for most operational purposes even in hilly areas	1966 to 1977
Weather Radar Network R & D Programme	Royal Signals and Radar Establishment; Meteorological Office	Development of a prototype system for the real-time processing, transmission and display of data from a mini-network of weather radars	1970 to 1978

(b) Current projects

Projects	Principal Participating Agencies	Main Achievements	Dates
North West Radar Project	Central Water Planning Unit; Ministry of Agriculture Fisheries and Food; Meteorological Office; North West Water Authority; Water Research Centre	To establish an unmanned operational weather radar fully integrated with the operational system of a water authority and to assess its benefits	1977 to 1982
Short Period Weather Forecasting Pilot Project	Meteorological Office; Royal Signals and Radar Establishment	To implement a pilot network of 4 semi-operational weather radars, to develop facilities for integrating these data and merging them with satellite cloud data; and to use these facilities to improve understanding of local rainfall systems and develop very-short-range forecasting techniques	1978 until the mid-80ies

Table 2. The principal components of an integrated forecast system incorporating a weather radar network

Principal Components	Functions	Products available in near-real-time	How derived
A. Unmanned radars sited at locations with good horizons (each with its own set of telemetering raingauges for real-time calibration)	Rain surveillance with on-site computers for pre-processing the radar data	P_1 (Surface rainfall distribution from individual radars without quality control P_2 (Areal integrations in river subcatchments	Entirely automatic (as described by Taylor and Browning, 1974)
B. Radar compositing and mesoscale analysis centre	(1) Quality control (to eliminate spurious echoes and apply corrections as described in text) (2) Derivation of a composite rainfall map using data from all radars (3) Analysis of satellite data in terms of surface rainfall to extend the coverage beyond the range of the radars (4) Derivation of a rainfall archive	P_3 (Quality-controlled large-area composite maps of surface rainfall P_4 (Simplified rainfall data in a format suitable for input to a mesoscale NWP model	A combination of objective and subjective procedures implemented using interactive computer driven video display techniques
C. Central Forecast Office	As at present, plus preparation of 3-24 h forecasts using a mesoscale NWP model	P_5 (As at present, plus 3-24 h mesoscale forecasts	Mainly automatic
D. Regional meteorological offices	(1) Preparation of forecasts (2) Tailoring and dissemination of the actual and forecast rainfall information to local users	P_6 (Tailored forecast and actual rainfall information disseminated in picture, worded, or computer-compatible formats	A combination of objective and subjective procedures implemented using interactive computer-driven video display techniques

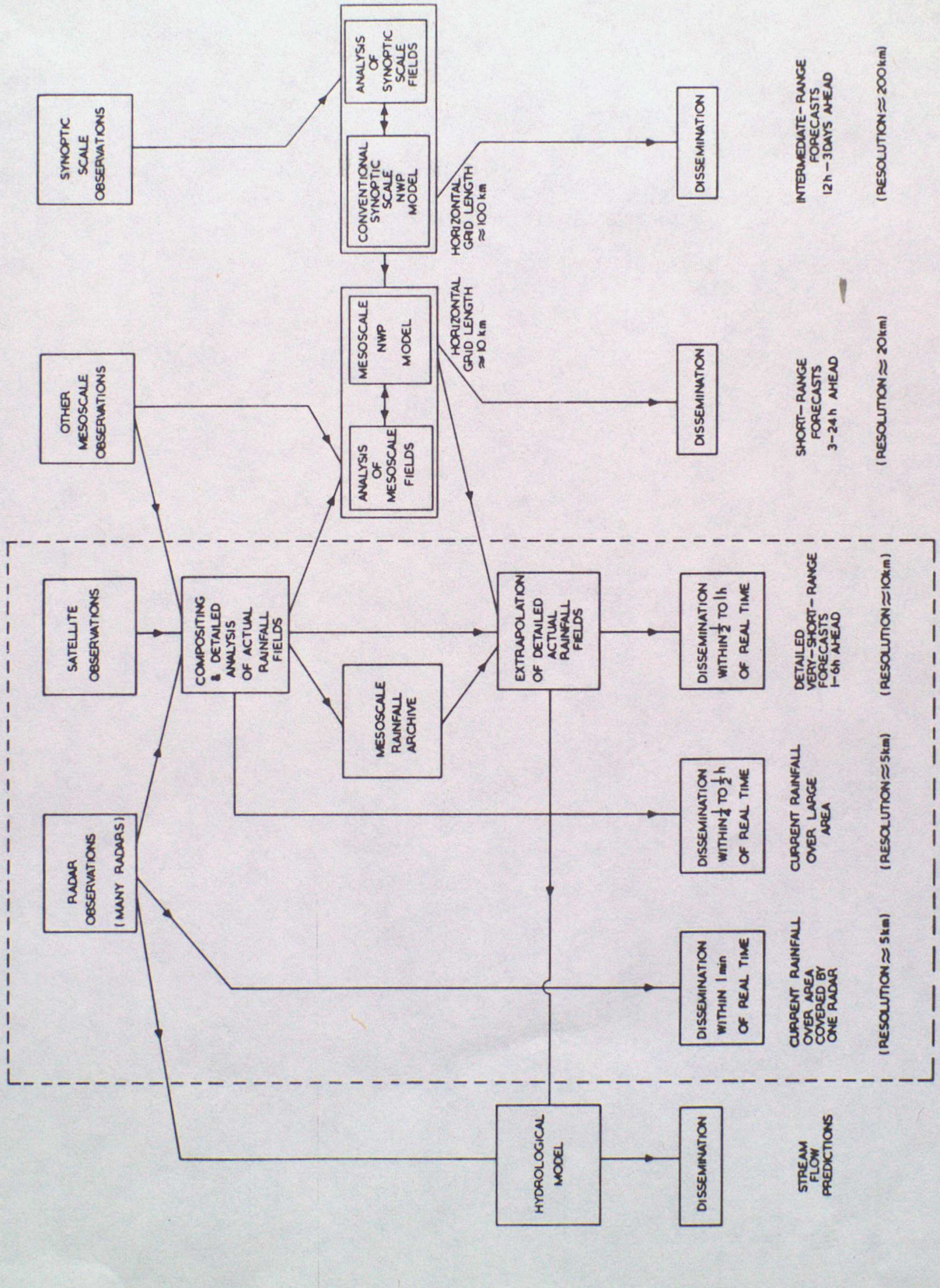
Figure Legends

Fig. 1 Integrated forecast system (From Browning 1979, incorporating suggestions by Dr K M Carpenter)

Fig. 2 Data flow in the Short Period Weather Forecasting Pilot Project as of January 1980.

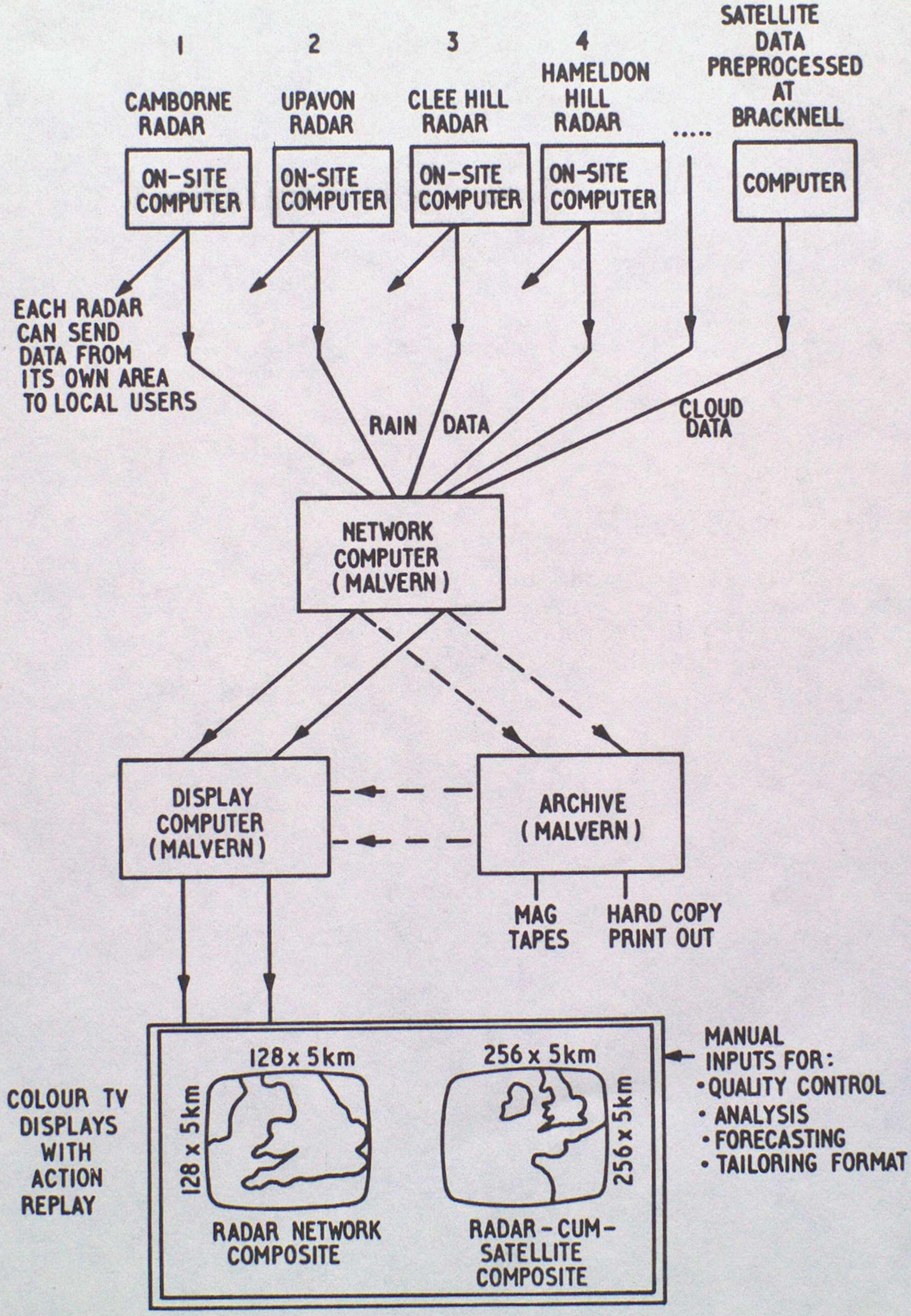
Fig. 3 Coverage of the radar network and radar-compatible satellite data. The shading indicates the approximate area within which rain can be observed qualitatively using radars located at (1) Camborne (Cornwall), (2) Upavon (Wiltshire), (3) Clee Hill (Shropshire), (4) Hameldon Hill (Lancashire). The cross-hatched shading illustrates the typical year-round coverage; the single-hatched shading depicts the typical coverage in summer-time conditions. The square frame RRRR denotes the boundary of the television display on which colour-coded rainfall data from these radars are combined. Satellite cloud data are converted to a radar-compatible format, and the square frame SSSS denotes the boundary of the television display on which colour-coded satellite cloud data are displayed, the radar network data being superimposable in the appropriate area.

Fig. 4 The kind of communications network required to accommodate a National Weather Radar Network.



SYNOPTIC SCALE OBSERVATIONS
OTHER MESOSCALE OBSERVATIONS
SATELLITE OBSERVATIONS
RADAR OBSERVATIONS (MANY RADARS)
COMPOSITING & DETAILED ANALYSIS OF ACTUAL RAINFALL FIELDS
MESOSCALE RAINFALL ARCHIVE
ANALYSIS OF MESOSCALE FIELDS
MESOSCALE NWP MODEL
CONVENTIONAL SYNOPTIC SCALE NWP MODEL
ANALYSIS OF SYNOPTIC SCALE FIELDS
HORIZONTAL GRID LENGTH ≈ 10 km
HORIZONTAL GRID LENGTH ≈ 100 km
EXTRAPOLATION OF DETAILED ACTUAL RAINFALL FIELDS
HYDROLOGICAL MODEL
DISSEMINATION
DISSEMINATION
DISSEMINATION WITHIN ½ TO 1 h OF REAL TIME
DISSEMINATION WITHIN ¼ TO ½ h OF REAL TIME
DISSEMINATION WITHIN 1 min OF REAL TIME
DISSEMINATION
INTERMEDIATE-RANGE FORECASTS 12h-3DAYS AHEAD
(RESOLUTION ≈ 200km)
SHORT-RANGE FORECASTS 3-24 h AHEAD
(RESOLUTION ≈ 20km)
DETAILED VERY-SHORT-RANGE FORECASTS 1-6h AHEAD
(RESOLUTION ≈ 10km)
CURRENT RAINFALL OVER LARGE AREA
(RESOLUTION ≈ 5km)
CURRENT RAINFALL OVER AREA COVERED BY ONE RADAR
(RESOLUTION ≈ 5km)
STREAM FLOW PREDICTIONS

Fig 1



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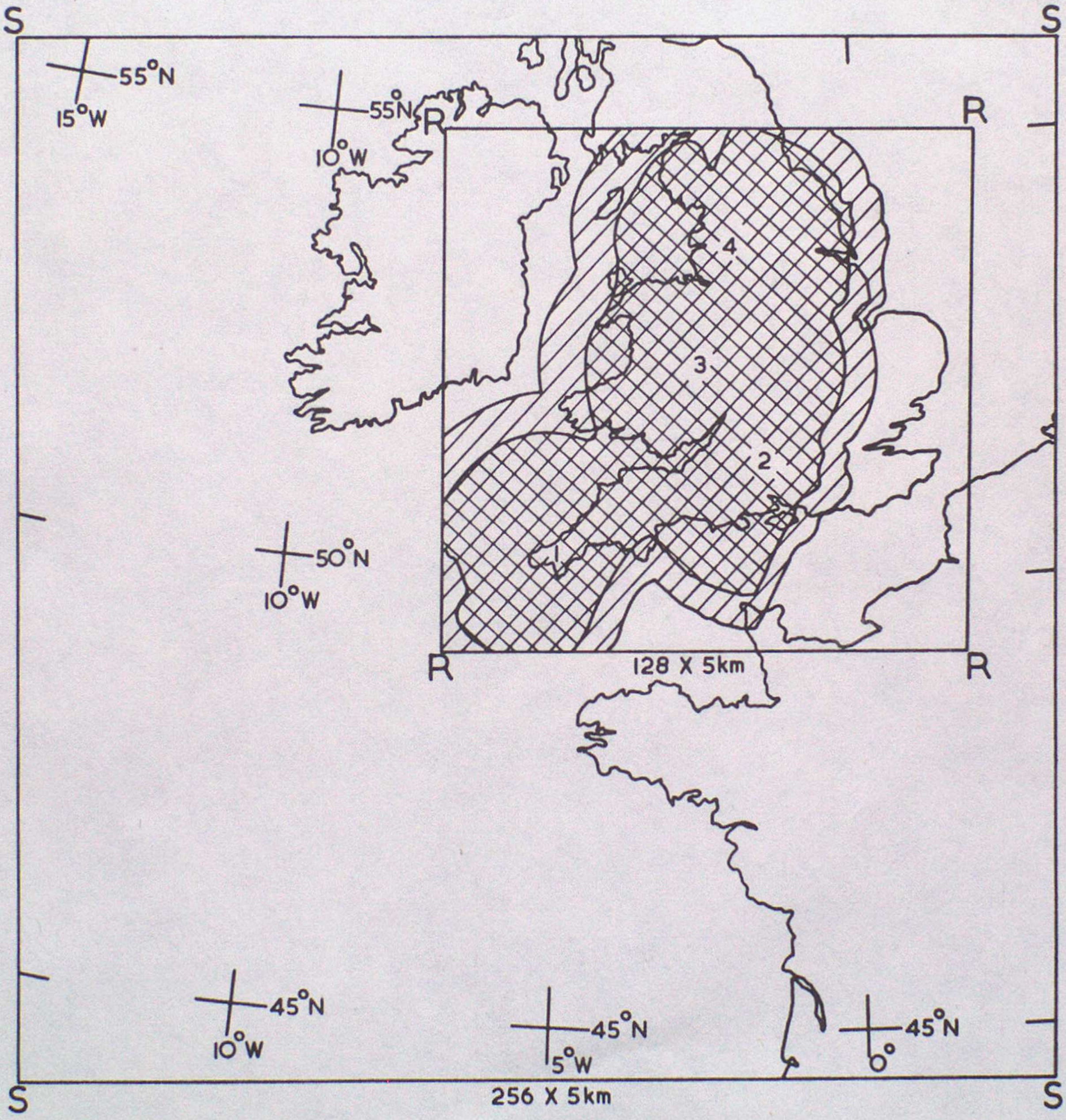
2
3
4
SATELLITE DATA PREPROCESSED AT BRACKNELL
CAMBORNE RADAR
UPAVON RADAR
CLEE HILL RADAR
HAMELDON HILL RADAR
.....
ON-SITE COMPUTER
ON-SITE COMPUTER
ON-SITE COMPUTER
ON-SITE COMPUTER
COMPUTER
EACH RADAR CAN SEND DATA FROM ITS OWN AREA TO LOCAL USERS
RAIN DATA
CLOUD DATA
NETWORK COMPUTER (MALVERN)
DISPLAY COMPUTER (MALVERN)
ARCHIVE (MALVERN)
MAG TAPES
HARD COPY PRINT OUT
COLOUR TV DISPLAYS WITH ACTION REPLAY
128 x 5km
128 x 5km
256 x 5km
256 x 5km
RADAR NETWORK COMPOSITE
RADAR-CUM-SATELLITE COMPOSITE
MANUAL INPUTS FOR:
• QUALITY CONTROL
• ANALYSIS
• FORECASTING
• TAILORING FORMAT

Fig 2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256 X 5km

Fig 3

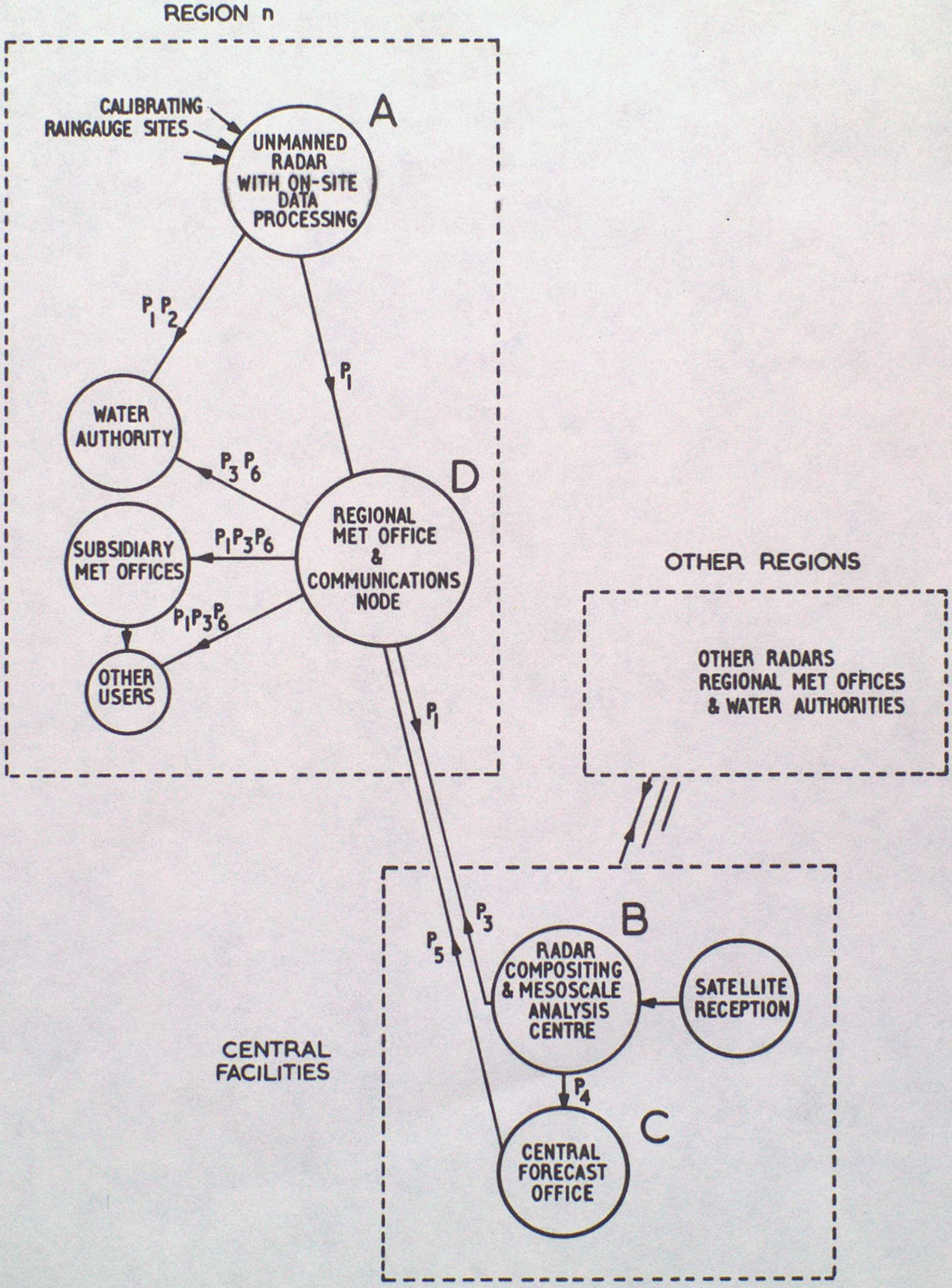
REGION n
CALIBRATING
RAINGAUGE SITES
A
UNMANNED RADAR WITH ON-SITE DATA PROCESSING
P1 P2
P1
WATER AUTHORITY
P3 P6
D
REGIONAL MET OFFICE & COMMUNICATIONS NODE
SUBSIDIARY MET OFFICES
P1P3P6
P1P3P6
OTHER USERS
P1
OTHER REGIONS
OTHER RADARS
REGIONAL MET OFFICES
& WATER AUTHORITIES
P3
P5
B
RADAR COMPOSITING & MESOSCALE ANALYSIS CENTRE
SATELLITE RECEPTION
P4
C
CENTRAL FORECAST OFFICE
CENTRAL FACILITIES

Fig 4

METEOROLOGICAL OFFICE RADAR RESEARCH LABORATORY - MET O RRL

Research Reports

No 1 The Short Period Weather Forecasting Pilot Project
K A Browning

No 2 Observation of Strong Wind Shear using Pulse Compression Radar.
K A Browning, P K James (Met O RRL). D M Parkes, C Rowley A J Whyman (RSRE)

No 3 Assessment of a Real-Time Method for Reducing the Errors in Radar Rainfall Measurements due to Bright-Band
J L Clarke, RSRE, C G Collier, Met O RRL

No 4 Meteorological Applications of Radar
K A Browning

No 5 Structure of the Lower Atmosphere Associated with Heavy Falls of Orographic Rain in South Wales.
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No 6 On the Benefits of Improved Short Period Forecasts of Precipitation to the United Kingdom - Non Military Applications Only
C G Collier

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No 10 Structure, Mechanism and Prediction of Orographically Enhanced Rain in Britain: A Review
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No 11 A Strategy for Using Radar & Satellite Imagery for Very-Short-Range Precipitation Forecasting.
K A Browning, C G Collier, P Menmuir.