AN INTERACTIVE DISPLAY SYSTEM FOR RADAR DATA

by

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1. Introduction

In this paper I discuss the design of the FRONTIERS* interactive display for processing radar observations of rainfall. In the introduction, I review the experience that led to the proposal for such a system. Frontiers has now been specified in detail and delivery of the complete system is expected during 1983.

The UK Meteorological Office has been developing a combined display of data from a network of radars for about a decade (Larke and Collier, 1980; Collier, 1980). Radars are usually associated with the observation of large solid objects such as aircraft, but raindrops will also reflect radar signals and, if the radar echo is averaged appropriately, it is possible to estimate surface rainfall from the strength of the reflected radar beam. The radars used by the Meteorological Office can observe rainfall at ranges up to about 200 km. Data from the network of, at present, four radars is collected at a central point (Malvern), where they are combined in a single display of equivalent surface rainfall values. The data are presented on a regular Cartesian grid that covers most of England and Wales with a resolution of 5 km. The radar observations are made every 5 minutes, but at present, the combined display is only produced every 15 minutes.

This combined display is of considerable value in its present form, and it is available at a number of UK Meteorological Office forecast offices. Apart from satellite cloud imagery, radar is the only data source that provides (virtually) spatially continuous coverage; the observations are available in forecast offices five minutes after they are made; and, unlike satellite imagery, the parameter observed by radar is of direct interest to a wide range of customers. However, the relationship between surface rainfall and radar echo strength is not fixed and universal and, even after appropriate averaging, there are often significant echoes that are not due to rainfall.

* Forecasting Rain Optimised in Near real Time using Interactively Enhanced Radars and Satellite

The difficulty of correcting the calculation of surface rainfall objectively in real time led Browning, 1979, to propose the Frontiers interactive display system, which is the subject of this paper. Some of the causes of this difficulty will be reviewed in Section 2.

Besides the quality control of radar observations, Frontiers will enable its operator to use geostationary satellite data to extend the surface rainfall analysis beyond the area of radar coverage. This will involve subjective judgment as well as algorithms that relate surface rainfall to cloud brightness and temperature, e.g. Lovejoy and Austin, 1979. A Primary Data User Station (PDUS) has been installed at Malvern and passes digital satellite data, observed by Meteosat 2, to a local display computer every thirty minutes. The distortion due to the view from space is removed objectively, but the image is not always positioned accurately and this is corrected subjectively. Based on current experience, satellite images could be available to Frontiers within fifteen minutes of the observation time, and it should take about twenty seconds to correct the positional error by comparing the image with a coastline overlay.

The third major interactive function of Frontiers is making short range (up to six hours) forecasts of rainfall based on simple extrapolation of the perceived motion of the observed areas of rain. This is currently done automatically, but it has been found (Browning et al, 1980) that subjective forecasts based on exactly the same principles are more accurate and reliable. The main cause of this discrepancy is that humans can identify and allow for errors in the rainfall analysis, but another important cause is that the objective algorithms used do not perform completely reliably. The Frontiers computer will take the burden of calculation away from the operator, but allow him to make a variety of logical choices and, if he wishes, modify the forecast that has been calculated.

In Section 2, the main causes of error in the present rainfall analyses are discussed. Section 3 specifies the hardware that is to be used. Section 4 reviews the design of the Frontiers system and its interaction with the operator.

2. Errors in the infra-red rainfall

The primary function of Frontiers is the quality control of the rainfall analysis, although this will not necessarily take most of the operator's time or be the most important in the long run. It is convenient to take the problems in the order that the Frontiers operator is expected to consider them (see Fig. 2). The list is not an exhaustive catalogue of everything that can go wrong, but our experience suggests that nothing important has been omitted.

Spurious Echoes: echoes that are not due to precipitation have to be deleted. The most serious and frequent examples are due to reflections from the ground or sea, reflections from chaff and interference with other radars. There are always reflections from the ground but, by and large, they always occur in the same place and can be removed from the data before they are transmitted to Malvern. Unusual echoes from the ground and echoes from chaff can be recognised subjectively by their context and characteristics. At present they cannot be recognised automatically. Interference produces echoes in distinctive patterns.

Bright Band: the strength of the echo from precipitation particles depends on their size and phase. In this context, melting snow looks like extremely large drops of rain. In frontal situations, snow can melt in a well defined layer. Since the altitude of the radar beam increases with range, it can intersect this melting layer at a well defined range leading, in archetypal cases, to an annulus or band of bright echo. This "bright band" is visually disturbing and leads to quantitative errors in the infra-red surface rainfall.

Calibration Errors: various effects can cause the overall amplitude of the echoes for a given radar to be in error.

Range Dependent Corrections: because of variations in the nature of precipitation particles, the reflectivity of the precipitation corresponding to a fixed surface rainfall varies with height. Thus, for a given radar beam, it also depends on range in a way that varies with the meteorological situation. The range dependent factors for shallow drizzle and deep convective rain are different, and allowing for this effect depends on knowing the nature of the rainfall.

Long Range Errors: at long range, where the beam is very high, it is possible to observe rain that is evaporating before it reaches the ground, or fail to observe rain that is forming below the radar beam.

Orographic Corrections: surface rainfall is enhanced when a precipitating air mass passes over hills or mountains. Typically, this enhancement occurs at low levels and will be only partially observed by the radars. Unfortunately, the enhancement depends on factors that are not normally observed in an automatic radar system (e.g. wind direction, humidity) but which will be known to a forecaster.

Summary: there is some scope for recognising and correcting some of the errors described above automatically but it is not realistic to expect the majority to be correctable in the foreseeable future except through the intervention of a human forecaster. By and large, the errors do not occur together but, even so, an operator correcting a complete radar composite every fifteen minutes will have a substantial workload. The aim has been to design Frontiers so that the operator can consider each of these possible errors in a logical sequence and suffer no delay due to the nature of the computer or the interface.

3. Hardware

At present, satellite images received by the PDUS are pre-processed in a DEC PDP 11/34 and the radar composite pictures are produced by a DEC PDP 11/40, the Network computer. These two computers pass their products to a local display computer, where much of our research is carried on prior to the arrival of Frontiers. Arrangements are being made to pass traditional observations to the Network computer and thus to Frontiers when it is delivered. The PDUS and Network computers will use high speed (56000 bps) DMR11 interfaces to pass data to the Frontiers computer.

The Frontiers computer will be a DEC Vax 11/750 supported by an RM80 disc and a TGU 77 tape drive. This computer will provide images to a RAMTEK 2455 display system, which will support two colour monitors (one 13" and one 19") and two joysticks. The small monitor will be fitted with a TDS touch screen, which is sensitive to touch and passes coordinate information to the computer. The large monitor is for background information rather than working with and will be set further away from the operator. Images can be replayed at ten frames per second on either screen and the response time for calling up an image is effectively instantaneous (i.e. less than one second). The computer will also support two VDUs (Visual 100s) fitted with touch screens, and the operator will control the system by making choices from menus presented on the VDUs. The only essential use of a keyboard will be when the operator enters his name.

4. The Frontiers system

The first step in constructing Frontiers was specifying all the functions that the operator might want to perform and, in scientific terms, how they would be performed. The system was then designed to meet these specifications and the additional requirement that it must be easy to add or remove functions, or vary the way in which any function is carried out. Figures 1 to 4 summarise the structure of Frontiers as the operator will see it. All the main functions are shown in their natural relationship to each other. It is clear that a system supporting this structure can support any similar structure provided that the software design makes only a few general assumptions about the nature of the structure. The Frontiers design is in general terms and it is easy to change the details of Figures 1 to 4.

An important constraint placed on Frontiers was that it should be easy for a complete novice to use with almost no training. The meteorologist must be allowed to concern himself with only meteorology. This implies that keyboards, codes and complicated instruction sets must be banished. This has been achieved by basing the system on menus that are displayed as required, from which the operator chooses the correct action by touching the screen; the numbers in Figures 1 to 4 refer to the menus corresponding to the actions described. Some decisions involve more than logical choice, but only two (typing in name and some data handling in experimental mode, which is discussed below) require anything other than touching a screen or using a joystick. For example, an area of echo that must be deleted is defined by drawing a line round it on the colour monitor, and the displacement needed to position a satellite image accurately is defined using a joystick to push it in the right direction.

An example menu (1.4, range dependent correction factors) is shown in Fig. 5. Using this menu, the operator can marshall his evidence by looking at the latest raingauge data (SREW) or by looking at the latest satellite imagery. When he is ready, he specifies the nature of the rain for each of the radars in the network; this will enable the computer to correct the relationship between radar echo and rainfall at long range (deeper, thundery rain giving more intense echoes for the same surface rainfall as described in Section 2). The depth of the rainfall also affects how far away the radars can see it and the second option, 'boundaries', allows the operator to vary the boundaries beyond which the display shows no radar data.

Not all menus are shown in Figures 1 to 4. There are two screens carrying menus and those discussed so far are system control menus displayed on the 'right hand' screen. It will usually be possible to guess the current activity from the contents of this screen. The 'left hand' screen will allow actions that have a more general meaning, e.g. 'zoom', which provides zooming into a restricted part of the current image, and 'pan', which allows the operator to move the screen display across a larger image held in the system. An example that contains pan and zoom is shown in Figure 6. The image changing menus shown on the 'left hand' screen will vary according to the context, but there will be relatively few of them and they will not have the same ordered relationship to each other as the system control menus.

An example of the sort of operation that will be possible using Frontiers is provided by the Lagrangian replay facility. As part of the forecasting sequence (Fig, 4) the computer will identify areas or 'clusters' of rainfall and calculate their velocity. Menus 3.3.2 and 3.3.3 allow the operator to modify the clusters (by drawing on the image) and the velocities that have been calculated. The operator is allowed to make his own determination of the velocities in several ways, one of which is referred to as 'Lagrangian replay'. When the operator requests Lagrangian replay, he defines a window that contains the features he is studying. This window is assumed to move across the radar network with a velocity that the operator can modify using a joystick. The system calculates a sequence of images at successive times in the Lagrangian frame defined by the window, and displays them in fast replay. The operator then modifies the velocity until he is satisfied that the image is stationary in the Lagrangian frame and, at that point, the velocity of the features in the window is defined. The operator can use the second joystick to vary the replay speed.

Frontiers will operate in four distinct modes:

i. system generation
ii. operational
iii. experimental
iv. automatic

System generation mode allows the operator to modify the menus and other sets of tables that are used by the system in other modes. A degree of computer expertise is assumed for it.

Operational mode is the important mode around which the system has been designed. The operator will work with a fresh radar image every fifteen minutes and fresh satellite images every thirty minutes, in real time, providing, eventually, an operational service. To achieve this, he will take the various aspects of his job in the order that has been found to be most effective. He will never see the system control menus marked with an X in Figures 1 to 4 and, by and large, he will work through the remaining menus in a fixed sequence.

Experimental mode will allow the operator freedom to move through the menus in any way, and is designed for use with old data archived on tape as part of Operational mode. Thus (see Fig. 1) when the operator has entered his name in response to menu 0.0, and selected Experimental mode from menu 0.1, he will have to enter the date of the data that interests him (menu 0.2, which will tell him which tape to mount) and then use menu 0.3 to choose which of the major functions shown in Fig. 1 he wishes to concern himself with. By contrast, if he selects Operational mode from menu 0.1, he proceeds directly to the first action in the current radar analysis, which is the definition of the composite radar picture using menu 1.1.1.

Automatic mode has been defined with two aims in mind. In operational practice, there will be a schedule for data dissemination that the system will have to be able to meet. In general, this schedule will have to be designed to reflect the abilities of most operators, so there should be no serious problem. However, operators will occasionally lose time and then the system will first warn him of the situation and then, if necessary, take over and complete the current sequence using Automatic mode. This is possible because there is a default for every menu supported by the system. (The default choice can be varied using System Generation Mode). In many cases, the default choice will reflect the current circumstances, e.g. "same as last time", so this mode should still produce results superior to those obtainable with a completely automatic system. The second use of Automatic Mode is to maintain the operational processing of data when experimental mode is being used.

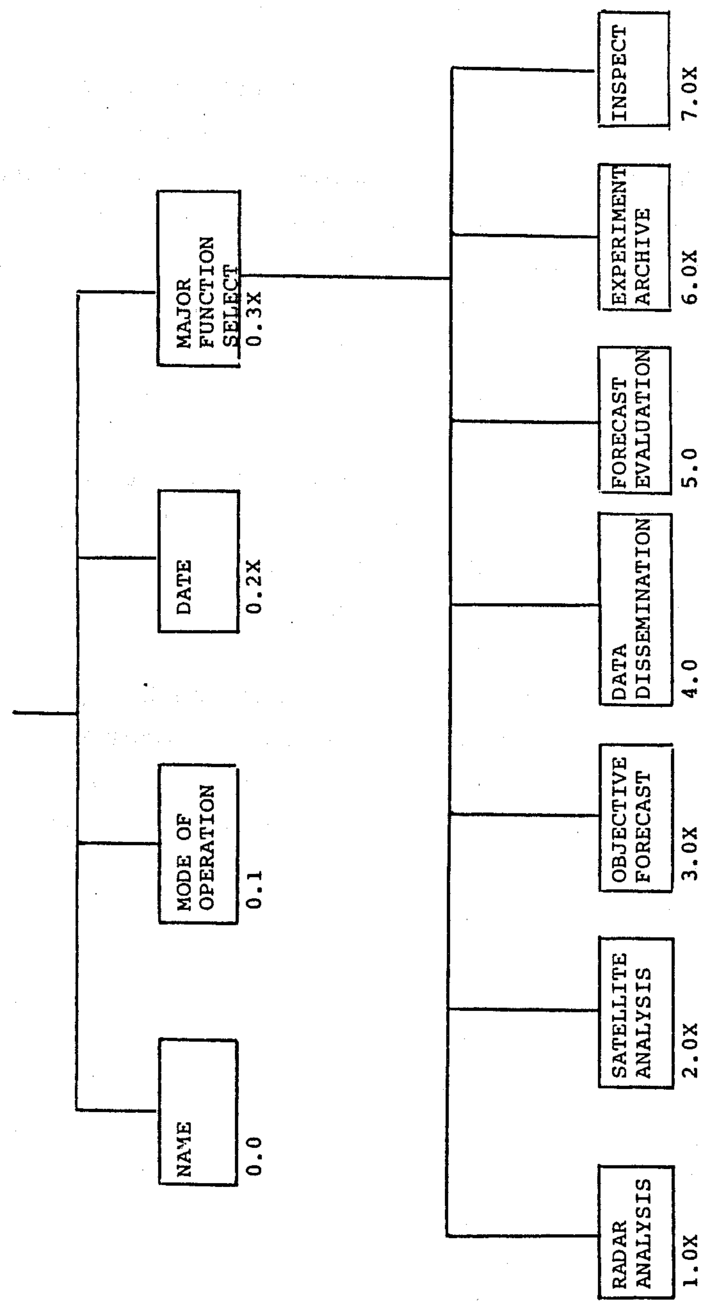

NAME
0.0
MODE OF OPERATION
0.1
DATE
0.2X
MAJOR FUNCTION SELECT
0.3X
RADAR ANALYSIS
1.0X
SATELLITE ANALYSIS
2.0X
OBJECTIVE FORECAST
3.0X
DATA DISSEMINATION
4.0
FORECAST EVALUATION
5.0
EXPERIMENT ARCHIVE
6.0X
INSPECT
7.0X

Fig. 1

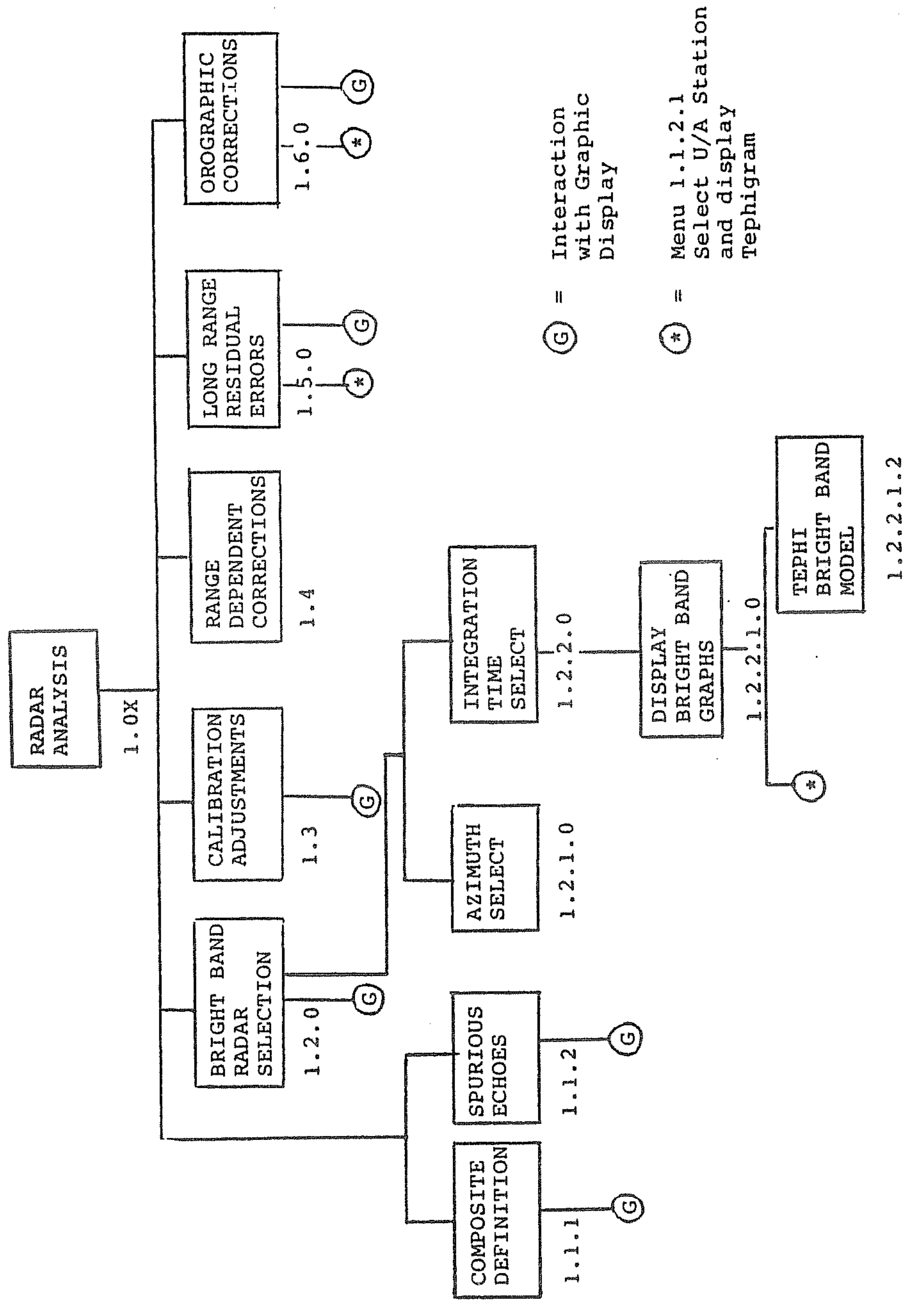
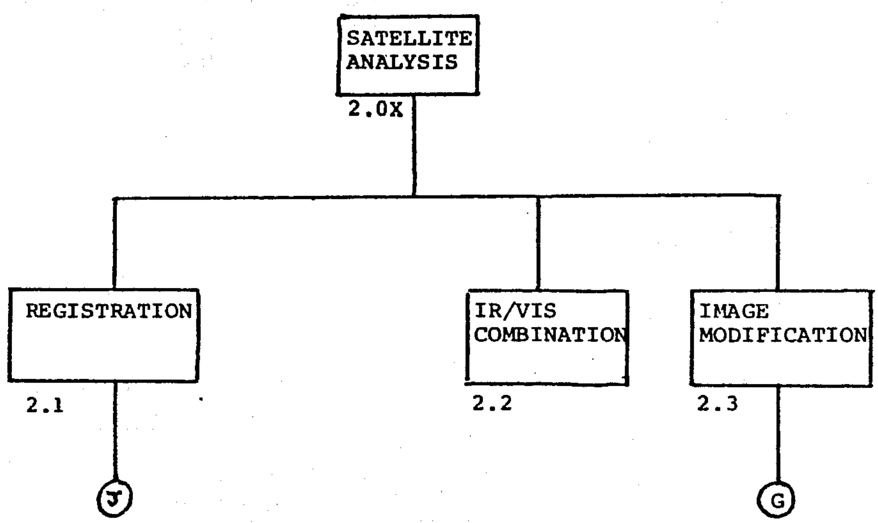

RADAR ANALYSIS
1.0X
BRIGHT BAND RADAR SELECTION
1.2.0
CALIBRATION ADJUSTMENTS
1.3
RANGE DEPENDENT CORRECTIONS
1.4
LONG RANGE RESIDUAL ERRORS
1.5.0
OROGRAPHIC CORRECTIONS
1.6.0
COMPOSITE DEFINITION
1.1.1
SPURIOUS ECHOES
1.1.2
AZIMUTH SELECT
1.2.1.0
INTEGRATION TIME SELECT
1.2.2.0
DISPLAY BRIGHT BAND GRAPHS
1.2.2.1.0
TEPHI BRIGHT BAND MODEL
1.2.2.1.2
G = Interaction with Graphic Display
* = Menu 1.1.2.1 Select U/A Station and display Tephigram

Fig. 2



Ⓙ = Uses Joystick

Ⓖ = Interactive Modifications with Graphic Display

Fig. 3

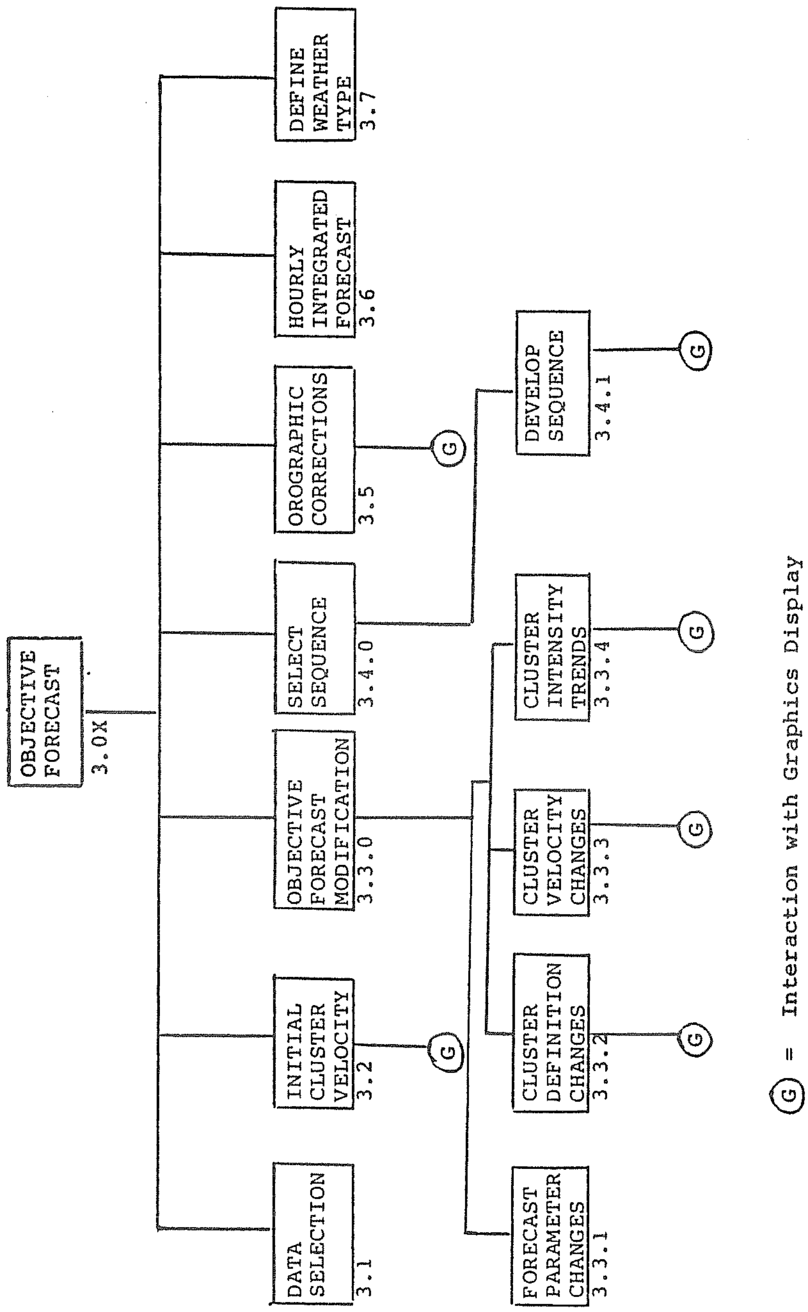

OBJECTIVE FORECAST 3.0X
DATA SELECTION 3.1
INITIAL CLUSTER VELOCITY 3.2
OBJECTIVE FORECAST MODIFICATION 3.3.0
SELECT SEQUENCE 3.4.0
OROGRAPHIC CORRECTIONS 3.5
HOURLY INTEGRATED FORECAST 3.6
DEFINE WEATHER TYPE 3.7
FORECAST PARAMETER CHANGES 3.3.1
CLUSTER DEFINITION CHANGES 3.3.2
CLUSTER VELOCITY CHANGES 3.3.3
CLUSTER INTENSITY TRENDS 3.3.4
DEVELOP SEQUENCE 3.4.1
G
G = Interaction with Graphics Display

Fig. 4

PROMPT LINE

RANGE DEPENDENT CORRECTIONS

*** SELECT SREW OVERLAY OFF ON ***

- SELECT CORRECTION FACTOR FOR EACH RADAR
- SELECT BOUNDARY OF USABLE DATA ALSO IF DIFFERENT

	** CORRECTION FACTOR **			** BOUNDARIES **		
HAMELDON	SHALLOW	MOD	THUNDERY	SHALLOW	MOD	THUNDERY
CLEE HILL	SHALLOW	MOD	THUNDERY	SHALLOW	MOD	THUNDERY
UPAVON	SHALLOW	MOD	THUNDERY	SHALLOW	MOD	THUNDERY
CAMBORNE	SHALLOW	MOD	THUNDERY	SHALLOW	MOD	THUNDERY
LONDON	SHALLOW	MOD	THUNDERY	SHALLOW	MOD	THUNDERY

*** DISPLAY SAT VIS ***
SAT IR

MESSAGE LINE:

DEFAULT CANCEL IMPLEMENT HELP

Main Menu

PROMPT LINE

FOR EACH RADAR SELECT THE RANGE DEPENDENT CORRECTIONS REQUIRED FROM THE LEFT HAND SIDE OF THE SCREEN. IF YOU WANT TO CHANGE THE BOUNDARIES INDEPENDENTLY SELECT AN OPTION FROM THE RIGHT HAND SIDE.

DEFAULT IS MOD FOR ALL RADARS.

RETURN

Associated HELP Menu
Menu 1.4

Fig. 5

PROMPT LINE
∘ COASTLINE ON/OFF ∘ TITLE ON/OFF ∘ CHANGE COLOUR ∘ PAN ∘ ZOOM IN/OUT ∘ ZOOM (SPECIAL) ∘ DELINEATE AREA AND INSERT COLOUR ∘ DELINEATE AREA AND DELETE DATA ∘ CHANGE LEVEL SLICE REPLAY ALTERNATE

Fig. 6

5. Conclusion

Frontiers is a system for analysing surface rainfall using radar and satellite data, and making short range forecasts of rainfall in real time. The operator will have to cover a great deal of ground in a short time, working to a fairly rigid schedule. To enable this, the system has been designed so that the operator will be conscious only of the meteorological judgments that he has to make, and will be led through the necessary actions in a logical order. The interaction between the operator and the computer data base must be as simple as writing on paper and the computer's response will be effectively instantaneous.

6. Acknowledgement

The figures were taken from material prepared by Logica Ltd., UK. For an alternative description of Frontiers, see Saker, 1981.

7. References

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