THE CHALLENGE OF VERY SHORT RANGE FORECASTING IN THE TROPICS

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ABSTRACT

The present status of very short range forecasting in the tropics is examined. Indications are that operational results are not as good as those obtained from simple climatological and persistence techniques, but that extra data, enhanced understanding and better methods can produce significant improvements. Available data, technology and communications are underutilized in tropical forecasting offices.

A concept is then provided of an ideal forecasting system based on available people, data and technology. This consists of a network of specialized offices that the forecaster interacts with via a workstation. This workstation also helps manage the forecast routine and provides inbuilt expert training features.

1. INTRODUCTION

The challenge that we face is to determine realistically the best combination of knowledge, data, techniques and technology that can be used to satisfy the requirements of our users. In rising to this challenge, we should neither be constrained by engrained, but archaic, forecast practices, nor be seduced by unrealistic claims that "bigger is better".

This challenge needs to be viewed in the historical perspective of how we arrived at our present status. For example, the second world war brought a surge of interest in tropical weather, and with it a number of forecasters trained in mid-latitude concepts. Historical analyses from this period, with their profusion of fronts drawn through very sparse observations, now look quaint and archaic. But they represented a commendable attempt by those forecasters to apply their limited knowledge to poor data and produce reasonable forecasts.

Today we know much more about the tropical heat engine. We have discovered the 40-50 day cycle and rediscovered the Southern Oscillation. We have dissected tropical squall-lines and hurricanes. We have numerical models, satellite observations, communications and technology on a scale and sophistication that would have seemed incredible to our colleagues in the 1940's.

But have we introduced comparable improvements in the forecasting service to our users? Do we make optimum use of the knowledge and technology at our disposal?

Very short range forecasting in the tropics provides a particular challenge in this regard. In this first 12 hours of the forecast period, tropical forecasters must consider such diverse meteorological phenomena as a tropical cyclone nearing landfall, an afternoon thunderstorm, and the onset of the sea breeze. Similarly diverse is the level of technology, training, and quality of data available to different forecast offices. Such logistical constraints will mean that some forecasts cannot be done, regardless of their desirability.

This paper presents our perspective of the problem and of how it may be tackled. Our aim is to stimulate debate and, most importantly, action towards producing substantial improvements in very short range forecasting in the tropics. Our major argument is that substantial improvements could be made at modest cost by a more effective utilization of currently available microcomputer and communications technology, combined with a development of simple, interactive forecasting techniques.

2. PRESENT STATUS

We define the tropics as the region between the mean subtropical ridge axes at the earth surface (i.e., the region affected by the trade wind easterlies and

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monsoonal circulations). Within this region, between fifty and one hundred centres provide forecast services to about half the world's population. The exact number of centres depends on how we define a "forecast centre". The large majority of these centres are located in developing countries and do not have access to advanced computing technology nor to detailed observing networks.

A variety of customers use this forecasting service and need to be considered in meeting the overall challenge of improving it. Routine forecasts are issued through various media outlets giving the weather status in general terms. More specific forecasts are provided for special users. Examples include: seasonal forecasts for agricultural and mining industries; local waters forecasts for the pleasure boating community; aerodrome forecast for the aviation industry; and very specific forecasts, such as for a concrete pour. Special warnings are provided for severe weather conditions, such as an approaching tropical cyclone, to the general public, to civil defence officials, and to special customers, such as port authorities.

The 1-7 day forecast improvements that have occurred during the past decade in subtropical regions are not likely to be repeated in the tropics (e.g., Shukla, Ref. 1). Here the major cycles, and potential for improvement tend to be at the very short and seasonal ranges. These scales seem also to be of more relevance to our product users: the aviation and construction industries are demanding improvements in the very short range forecasts, whilst economic and social planning people are becoming more aware of the need for seasonal and annual forecasts.

On the timescales relevant to very short range forecasting the weather fluctuations are dominated by local and diurnal influences (e.g., Riehl, Ref. 2). The type of local and diurnal response varies according to the phase of such large-scale and low-frequency oscillations as the 40-50 day cycle, the annual cycle, and ENSO. Severe weather phenomena include tropical cyclones, monsoon depressions and tropical squall-lines. Although such phenomena affect any region only infrequently, their damage potential is so great that they often constitute the most important component of the forecasting duties.

2.1 Techniques used

Recent surveys by Kanimitsu, and Holland and McBride (Refs. 3-5) indicate that less than 10% of tropical forecast centres directly utilise NWP products. Very short range forecasting seems to be mostly subjective and based on hand analyses of conventional observations, together with qualitative interpretaion of satellite and radar data, when available. Climatology, persistence and forecaster experience of previous weather sequences are the major tools, but some objectivity is introduced by use of check sheets and written procedures (e.g., the Dvorak satellite interpretation for cyclones, Ref. 6).

2.2 Data sources

The data sources that are given most prominence in the preparation of forecasts tend to be surface and upper-air observations followed by satellite and radar data. This is illustrated by the survey responses for tropical cyclone structure and position analysis in Table 1.

Table 1. Perceived levels of importance of specified data sources in the analysis and forecasting of tropical cyclone formation and structure change. Numbers in parentheses are for the analysis of tropical cyclone position. (Ref. 4).

	RANKING FREQUENCY				
	1	2	3	>3	NOT USED
UNENHANCED SAT	8(2)	3(3)	0(3)	2(1)	0(0)
SURFACE OBS	8(5)	2(2)	2(0)	1(2)	0(0)
ENHANCED SAT	3(0)	2(3)	0(2)	2(2)	6(2)
AIRCRAFT RECCE	2(3)	2(1)	1(0)	1(0)	6(5)
UPPER AIR OBS	2(0)	2(2)	6(1)	3(6)	0(0)
CLOUD WINDS	0(0)	0(0)	3(1)	5(6)	5(2)
SAT REMOTE SENSING	0(0)	0(0)	0(0)	2(1)	11(8)
RADAR	-(4)	-(1)	-(3)	-(1)	-(0)

Surface observations provided the most used data base for all aspects of tropical cyclone analysis and forecasting. Unenhanced satellite data were the prime source for structure and formation, but these data were not considered to be as useful for position analysis. Upper-air observations had the highest priority for position forecasting (not shown in Table 1, see Ref. 4,5), reflecting the need for an accurate steering current determination. Radar and aircraft reconnaissance data received an overall low rating because they were not always readily available. Most centres give these the highest priority when available, especially for short range forecasting of systems nearing landfall.

2.3 Forecast accuracy

We cannot provide a comprehensive indication of the accuracy of very short range forecasts in the tropics. Although many offices have some form of internal assessment (Refs. 3-5), very few provide a detailed tabulation or publish their results externally. Further, it is not obvious how such assessments should be done, and what weights should be given to different components of the forecast. For example, Darwin Regional Forecasting Centre maintains an internal assessment of various forecast parameters, and also obtains a "reasonable forecast" assessment from a selection of people in the community. One could argue the methodology should be designed to provide a product that the user is happy with.

We therefore use three examples of forecasts from the Darwin centre to illustrate the types of errors involved and the problems encountered. These statistics also form a basis for our discussion in Section 3 on ways to meet the challenge of improving the forecast service.

2.3.1 Tropical cyclone forecasts

Tropical cyclone forecasting consists both of predicting future movement and of predicting intensity and structure changes. At present there are no objective intensity prediction schemes in general use and great reliance is placed on subjective interpretation of environmental features and on climatology. The indications are that there is no intensity forecast skill (Keenan, Ref. 7; Sheets, personal communication 1987), particularly with regard to sudden or rapid intensification. There are a wide variety of motion forecast techniques (e.g. McBride and Holland, Ref. 5; WMO, Ref. 8), but none of these is consistently better than persistence over the first 12 hours. As a result, very short range forecasting of tropical cyclone motion is crucially dependent on accurate and timely position determination. Such position analyses are complicated both by poor, or ambiguous data, and by the need to adequately account for the small-scale oscillations of the eye.

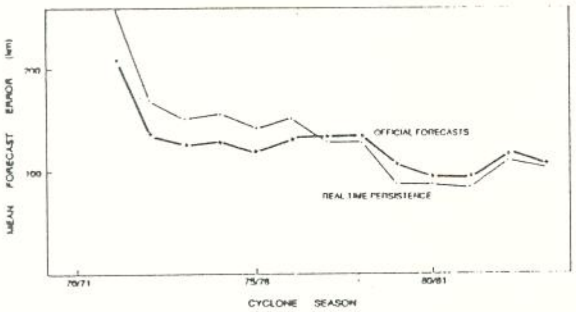


Figure 1. Mean errors for 12 hour official, and real-time persistence forecasts from the Darwin Tropical Cyclone Warning Centre. The curves have been smoothed by a three-season running average.

Unfortunately, improved position analyses do not necessarily lead to comparable forecast improvements. This is illustrated by the long-term statistics for the Darwin Tropical Cyclone Forecasting Centre shown in Figure 1. A distinct improvement is obvious following the commencement of operations of the Japanese Geostationary Meteorological Satellite (GMS) in 1978/79. However, the official forecasts, which were superior to persistence pre-GMS have been distinctly worse than persistence in the post-GMS era; a 35% improvement in persistence forecasts has only produced a 20% improvement in the official forecasts.

The most critical short period forecasts of tropical cyclones are when they are close to land. This includes cyclones approaching landfall and those which are developing just off the coast. At this forecast stage the community should have been warned of the imminent threat and the main responsibility is to maintain a careful watch and update the forecasts at short intervals. The potential disaster following a sudden change of direction or rapid intensification is a major consideration. Such conditions require rapid access to detailed observations, such as by remotely telemetered radar or aircraft reconnaissance, local, interactive resources for processing the data, fast communication lines to the affected community, and rapid community response to forecast changes. Unfortunately, such mechanisms are almost non-existent in many tropical countries (Southern, Ref. 9).

2.3.2 Aerodrome hazardous conditions forecasts

The aviation industry requires very specific forecasts for a range of weather phenomena that are likely to affect aerodrome operations. Such forecasts therefore provide an excellent test of our short range forecasting ability. The Darwin RFC issues Terminal Aerodrome Forecasts (TAF's) for a number of northern Australian airports in 6 hour blocks over 12-24 hour periods. These TAF's are issued every 6 hours and are valid from 3 hours after issue time, or around 4-6 hours after observation time. In addition, local Weather Service Offices (WSO's) issue 3 hourly Terminal Trend Forecasts (TTF's) at major aerodromes. The TTF's are updated every 30 minutes.

We compared predictions of conditions hazardous to aviation at the Darwin and Gove aerodromes for the transition and summer monsoon seasons of 1983 and 1984. Such hazardous conditions included thunderstorms, low cloud, fog, and reduced visibility in heavy rain. The statistics were derived from 00, 06, 12 and 18 GMT forecasts and a correct hazardous conditions forecast was defined as any occurrence in the validity period (6 hours for TAF and 3 hours for TTF). Three simple tests of forecast skill were used:

the Detection Ratio (DR), the False Alarm Ratio (FAR) and the Critical Skill Index (CSI).

		FORECAST	
		YES	NO
OBSERVED	YES	A	B
	NO	C	D

$$DR = A/(A+B)*100$$

$$FAR = C/(A+C)*100$$

$$CSI = A/(A+B+C)*100$$

Darwin and Gove were chosen to provide a comparison of forecasts at a local and a remote site. Darwin is the base of both the RFC and WSO, has radar coverage and upper air observations, and has been well-documented by many operational studies. Gove is a jet and commuter aerodrome some 500km east of Darwin. It is remote from the forecast offices; at the time the study was done, Gove had no radar coverage, no upper-air observations, and barely adequate surface observations; and it has not been well documented. Because of the presence of a major El Nino, anomalous dry conditions were experienced in 1983, so that forecasts from this period can be compared to those from the more typical 1984 season.

The monthly-mean results for the Darwin TAF's and TTF's and the Gove TAF's in Tables 2 and 3 show that forecast skill is higher during the summer monsoon season months of January to March than during the transition months of November, December and April. Forecasts of hazardous conditions in the typical 1984 season also were more skilful than were those in the anomalous dry El Nino year of 1983. These differences in skill were largely due to better detection of hazardous conditions during periods of highest frequency. Although these results are only for a relatively short period at two stations, it seems reasonable to assume that they are indicative of a general trend for less skilful forecasts of rarer events.

Notice the high false alarm ratios in all forecasts in Tables 2 and 3. When conditions are uncertain forecasters tend to increase the economic cost (in terms of the additional fuel carried to avoid forecast, but not observed hazardous conditions) to avoid the catastrophic consequences of a major aircraft accident. This is especially evident from a comparison of Darwin and Gove forecasts in Table 3. In addition to being a remote station, Gove has a history of difficult forecast situations and a couple of near disasters. Thus, forecasters obtain a higher detection ratio there than at Darwin, but at the cost of higher false alarm ratios and substantially lower forecast skill. In terms of actual hours of hazardous conditions, the ratio of number of hours in the forecast to number of hours observed at Darwin is 2:1 compared to 6:1 at Gove.

Table 2. Comparison of the very short range (TAF) forecasts and nowcasts (TTF) at Darwin aerodrome for the summer monsoon and transition seasons in 1983 and 1984. Each row gives the forecast skill by month; the top two columns give the hazardous conditions detection ratio (DR), the next two columns the false alarm ratio (FAR), and the overall forecast skill (CSI) is shown in the right two columns.

		DR		FAR		CSI	
		TAF	TTF	TAF	TTF	TAF	TTF
	JAN	73	69	56	74	38	23
	FEB	84	61	48	62	48	30
	MAR	87	93	70	83	29	17
1983	APR	70	65	71	82	25	16
	...						
	NOV	70	73	67	64	29	32
	DEC	74	66	65	75	31	23
	JAN	85	79	60	74	38	24
1984	FEB	94	90	65	90	35	10
	MAR	78	70	63	73	34	25
	APR	50	100	86	65	13	35

Table 3. Comparison of the very short range (TAF) forecasts at Darwin and Gove aerodromes for the summer monsoon and transition seasons of 1983 and 1984. Details are the same as in Table 2.

		DR		FAR		CSI	
		DARW	GOVE	DARW	GOVE	DARW	GOVE
	JAN	73	75	56	81	38	18
	FEB	84	80	48	86	48	13
	MAR	87	100	70	72	29	27
1983	APR	70	85	71	77	25	25
	...						
	NOV	70	25	67	92	29	06
	DEC	74	83	65	67	31	31
	JAN	85	90	60	80	38	19
1984	FEB	94	100	65	69	35	31
	MAR	78	100	63	78	34	32
	APR	50	33	86	96	13	04

The substantial economic cost of these conservative forecasts was a major factor in the recent installation of an upper-air and radar observing station at Gove.

Of particular concern is the finding (Table 2) that the short period TTF is consistently less skilful that the longer period TAF. During the transition months, the TTF's detect significantly more of the observed hazardous conditions, but also have a higher false alarm ratio than do the TAF's. There is little difference between the detection ratios during the summer monsoon season, but the TTF's have a substantially higher false alarm ratio than the TAF's, indicating a high level of 'panic forecasting' at short time scales. Such skill degradation can be attributed to the lack of mesoscale networks available to the TTF forecasters. However, Schlatter et. al. (Ref. 10) indicate that with very detailed mesoscale networks there is little improvement in skill at forecasting the initial development of such hazardous conditions. The main improvement is in the ability to detect, track and extrapolate observed conditions.

2.3.3 Quantitative rainfall forecasts

Various techniques of forecasting rainfall were compared in a real-time forecast experiment over three months of the 1986/87 summer monsoon season at Darwin. This period coincided with the extensive observing system upgrade for the Australian Monsoon Experiment (Holland et. al., Ref. 11). A complete description of the experiment will be provided in a forthcoming paper by Fraedrich and Leslie and only a few salient details will be used here.

Probabilistic and categorical forecasts were made each day for rainfall during the period 06-18 LST, and for heavy rain (>5mm) in the periods 06-12 and 12-18 LST. The techniques used were:

1. Subjective forecasts with 0 and 12 hours lead time using all data and techniques routinely available at the Darwin centre, and an especially designed climatology (P.A. Riley, personal communication, 1986);

2. Climatology defined by the mean frequency of rainfall in each month;

3. Persistence of the conditions from the previous day;

4. Numerical Weather Prediction (NWP) rainfall from the Australian region FINEST model (Leslie et. al., Ref. 12; lead times 8.5 and 20.5 hours);

5. MOS rainfall using FINEST and equations developed by R. Tapp (personal communication, 1986, see also Mills and Tapp, Ref. 13);

6. Markov Chain Model rainfall (Fraedrich and Leslie, Ref. 14; lead time 0 hours only);

7. Linear Combinations of some of the above techniques.

The relative skill of each method was assessed from the half-Brier score

$$B = 1/m \sum_{i=1}^{m} (\delta_i - POP_i)^2,$$

where m is the number of forecasts, POP_i is the predicted precipitation probability, and δ_i = 0 or 1 respectively for observed dry or wet conditions. For categorical forecasts, POP_i is also 0 or 1 for dry or wet forecasts. The larger the half-Brier score, the worse the forecasts, and B=0 for a perfect forecasts.

The results for rainfall forecasts in the 06-12 LST period are shown in Table 4. If we consider climatology and persistence to be a zero skill forecast, then only the Markov Chain and combined Markov-persistence forecasts displayed any skill at forecasting Darwin rainfall. The FINEST forecasts performed worst, but this may be due in part to the proximity of Darwin to the northern boundary of the model. A separate test is being conducted using a version of the FINEST model on a tropical domain.

Table 4. Half-Brier scores for forecasts of rainfall at Darwin. The predictions are verified against present weather observations of rainfall in the Darwin region. For the NWP and MOS forecasts add 8.5 hours to the lead time.

	LEAD TIME (HOURS) 0	12
PROBABILISTIC		
FORECASTER	.195	.187
MOS	-	.221
CLIMATOLOGY	.153	.153
MARKOV	.147	-
CATEGORICAL		
FORECASTER	.200	.226
NWP	.511	.461
PERSISTENCE	.222	.222
COMBINED		
NWP-CLIMAT	.263	.231
PERS-CLIMAT	.151	.151
MARKOV-PERS	.128	-

The NWP and MOS forecasts were much better at forecasting heavy rainfall in the 06-12 and 12-18 LST periods (Table 5). However, the Markov chain technique provided the only consistently skilful forecasts.

The Darwin forecasters also made forecasts at Gove for comparison with a remote station. They did not do as well at the remote Gove station as they did at their home station of Darwin, even though the persistence forecasts were quite similar. This result is consistent with the above findings on hazardous weather forecasting at aerodromes.

2.4 Forecaster Education and Training

It is our impression that forecasters generally receive a good education in meteorological theory and basic forecast practice before taking up their positions. However, they are provided with little, if any, education on media communications and on the social and psychological response of communities to different levels of perceived threat from weather hazards.

For operational forecasters, "bench experience" is the major educational process. Although the procedures for objectively measuring this bench learning

Table 5. Half-Brier scores for forecasts of heavy rainfall (>5mm) at Darwin airport. For the NWP and MOS forecasts add 8.5 hours to the lead time.

		LEAD TIME (HOURS) 0	12
PROBABILISTIC			
FORECASTER	06-12	.117	.122
	12-18	.191	.129
MOS	06-12	-	.087
	12-18	-	.129
MARKOV	06-12	.069	-
	12-18	.094	-
CLIMATOLOGY	06-12	.102	.102
	12-18	.116	.116
CATEGORICAL			
NWP	06-12	.120	.120
	12-18	.130	.130
COMBINED			
NWP-CLIMAT	06-12	.119	.119
	12-18	.125	.125

process are only in their infancy, the results (e.g. Allen, Ref. 15) indicate that the current forecast practices do not provide an environment for imparting such experience in an optimal manner. The major problem seems to be that forecasters are on the bench at random times, have a hectic, shift-work schedule, and often do not experience the results of their forecasts directly. Thus there is insufficient objective cataloguing of forecast decisions combined with direct, positive feedback on the errors and on their consequences.

Experience with rare, but severe weather phenomena can take many years to obtain, with potentially disastrous consequences in the meantime. Holland et. al. (Ref. 16) advocate the use of simulation techniques aimed at providing forecasters with such experience in controlled conditions with direct feedback on the consequences of their decisions.

The PROFS experience (e.g. Schlatter et. al., Ref. 10), indicates that radical changes to forecaster interactive, computer based systems requires concomitant changes in forecaster-training techniques.

2.5 Summary

We draw the following tentative conclusions from the above survey and discussion on the present status of very short range forecasting in the tropics:

1. Very short range forecasting is normally no better than persistence and climatology, and can be much worse;

2. Improvements in persistence forecasts may not produce similar improvements in actual forecasts;

3. In uncertain situations with high stakes, there is a tendency to increase the number of false alarms to ensure 100% detection, with resultant decrease in forecast skill;

4. Forecast skill varies in proportion to the frequency of occurrence of the phenomena. Overforecasting tends to occur for rare, but significant events;

5. Better data and better understanding, produce better forecasts. As the TAF and TTF comparison showed, using synoptic scale data for mesoscale forecasting can actually lead to a worse forecast than that originally made on the synoptic scale;

6. Simple, locally applicable techniques, such as the Markov chain, can provide good routine forecasts.

To these conclusions we add some perceptions:

1. There is too much emphasis on the 24 hour time-scale in tropical forecasting. More emphasis should be given to the very short, and seasonal scale forecasts;

2. The PROFS experience (Schlatter, Ref. 10) indicates that there is little expertise at forecasting formation, even on short timescales. Considerable potential seems to exist for forecasting development and movement of existing systems;

3. The methods of forecasting are, in general, very similar to those of a generation ago and have not advanced in step with our levels of understanding or the improvements in technology;

4. Communications have been developed to a high level for collecting observations, but the level of communication of products back to tropical forecasting offices is quite poor;

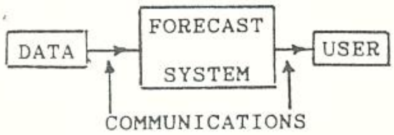
5. The enormous potential of mini- and micro-computer technology has not been realized, especially in those majority of tropical forecast offices in developing countries;

6. Current education practices do not adequately prepare forecasters for severe weather events, nor do these methods provide the needed background on the social and economic side.

3. THE CHALLENGE

The levels of forecast improvement that can be achieved are a basic function of the level of resources that can be made available. This resource level is, in turn, determined by the economic and social return that the improved forecasts can provide. The challenge to us as meteorologists is obtain the maximum level of resources consistent with this economic and social return and to utilise them in the optimum manner. We must consider the entire forecast process and the best answers can be achieved only by informed and widespread debate. The following perceptions are aimed at stimulating such debate.

The total forecast process includes the four components shown below



We shall concentrate on the data and forecast system components in the remainder of the paper.

3.1 Data

There is little doubt that improved mesoscale data networks can lead to better and more confident forecasts (e.g. the skill of persistence forecasts, and the Gove/Darwin comparison discussed in Section 2). In the tropical cyclone survey by McBride and Holland (Refs. 4,5), tropical cyclone forecasters were nearly unanimous in noting that lack of data was a major impediment to improved forecasts. However, it is notable that all survey respondents called for better data, regardless of their current level of sophistication in data retrieval and analysis. It also is notable that simply presenting forecasters with more information does not necessarily improve their product (e.g. Allen, Ref. 15).

Very high resolution mesoscale data are expensive and difficult to obtain. In some cases, such as aircraft reconnaissance of tropical cyclones, the economic and social benefits to the community far outweigh the cost of data collection. In these circumstances we must ensure that adequate resources also are provided for development of analysis and forecast methods to properly utilise the data. In other cases, the mesoscale data costs will simply not be justified. Then the results in Section 2 indicate that significant forecast improvements are still possible from the currently available data base. Where improvements are impossible, we should be informing our users of the circumstances under which we cannot provide adequate forecasts.

3.2 The Forecast System

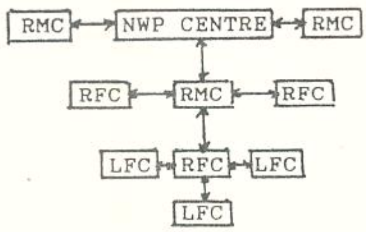
Given that data limitations always will exist, what constitutes the best possible very short range forecast system? Because of the short timescales involved, such a system must be designed around fast communication of suitable information to the forecaster and rapid dissemination of the forecasts to the users. We suggest that the ideal (but achievable with current technology and resources) system would contain the following features:

3.2.1. Rapid access to, and analysis of appropriate data

Obviously for short range forecasting the data must be made available in the shortest possible time. The point here is that emphasis should be given to the data appropriate to the task; a fine balance is required to stop excessive information overload. The available data also will be in different forms, conventional, radar, satellite, etc., and will be received at odd times. A MCIDAS type, four dimensional analysis scheme capable of assimilating all types of data as they arrive is therefore essential.

3.2.2. Rapid, user initiated access to relevant products from other centres.

Very few offices can afford, or need to produce a full range of meteorological products. Indeed we suggest that a better forecasting system will result from a network of specialized centres, each utilizing the products from the others as needed. Our concept is for a nodal network of centres, each providing components of the total forecast system, and each based on graded levels of computing capacity. The network is shown schematically below.

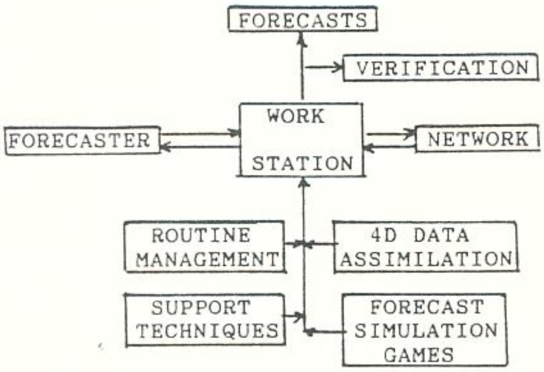


NWP CENTRE = Major, Global Numerical Weather Prediction Centre
RMC = Regional Meteorological Centre
LFC = Local Forecast Centre

The centres described above already exist and have similar functions to those envisaged here. The major difference is that the transmission of products would be on a demand basis for interactive local use at the user centres.

3.2.3. Interactive Workstation

The forecaster, as the hub of the forecasting system, needs to be able to interact with the system. This interaction can be visualized in the following schematic



The need for a network interaction and for a 4D data assimilation scheme has been discussed above. Two other functions are introduced here: routine management and forecast simulation games.

Routine management could be based on an expert system that would monitor all incoming data and messages and immediately cue the forecaster as necessary. For example, an alert might be given for a discrepancy between forecast and observed hazardous conditions at an aerodrome. The system could be designed to provide a range of forecasts from various techniques and indicate the best choice for the present conditions. Most importantly, the routine monitoring system could prepare many of the routine forecasts. As we indicated in Section 2, persistence and climatology often provide the best forecasts. Automating these forecasts would allow the forecaster more time to both monitor the overall output and to respond to alerts and to specialized user requirements.

The performance of this interactive workstation system will be very much dependent on the degree of expertise of the forecasters who operate it. Past forecasting experience may be of little use in this new environment, and may actually be detrimental. The workstation/forecaster interaction can help to provide this expertise in two ways. First, the routine monitoring system can archive and verify the output of each forecaster and provide regular feedback on performance (as discussed in Section 2.4). Second, a series of simulation games could be provided with the aim of providing the forecaster with expertise in specific situations. An analogy is the simulation training of commercial airline pilots. A more extensive discussion on such games may be found in Holland et. al. (Ref. 16).

5. Finally we note that such a system must be flexible and allow local adaptation.

4. CONCLUSION

This forecasting system concept would be difficult to achieve, but no more difficult than other accomplishments that have already occurred. The network communications are no more complex than those already in place to gather data into centralized locations. The workstations could use micro- and mini-computer technology that can be bought off the shelf right know at prices any forecasting office can afford. Prototype systems are already appearing. For example T. Tsui (personal communication, 1987) has an interactive tropical cyclone forecasting station, and a personal computer based MCIDAS is being tested at the Darwin forecasting centre. If users can network into telemail and stockmarket systems, why not meteorologists?

These concepts are introduced here with the aim of stimulating further debate and action towards the design of a forecasting system of the next decade. Whatever shape this forecasting system takes, we believe that it must be: 1) forecaster interactive (with well designed capabilities for individual development), 2) networked, 3) flexible, and 4) affordable by all countries (use available technology where possible). We should, further, be providing realistic assessments to our users of situations in which available data and techniques cannot produce adequate forecasts.

We look forward to receiving other opinions and views.

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