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During the past two years, an expert system for forecasting the occurrence of fog has been installed at Seymour-Johnson AFB, North Carolina. Aside from validation of the rule base, this field test has provided valuable insights into some of the problems thatmust be addressed before such systems are deployed operationally worldwide. First is the necessity for a satisfactory trade-off between user involvement and real-time data input. In addition, varying degrees of sophistication on the part of the users must be taken into account. Systems which, like those used in meteorology, are geographically dependent, should be written into a form that makes them readily adaptable from one location to another. Adaptability includes the ability to use alternate data sources for those occasions or locations where standard observations and measurements are not available. This introduces the concept of maintainability, whereby an existing system can be updated to include new data sources and changes in the knowledge base. Each of these concepts is discussed in turn, with particular examples taken from the fog forecast system.

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BETWEEN PROTOTYPE AND DEPLOYMENT: LESSONS LEARNED FIELD-TESTING AN EXPERT SYSTEM

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ABSTRACT

During the past two years, an expert system for forecasting the occurrence of fog has been installed at Seymour-Johnson AFB, North Carolina. Aside from validation of the rule base, this field test has provided valuable insights into some of the problems that must be addressed before such systems are deployed operationally world-wide. First is the necessity for a satisfactory trade-off between user involvement and real-time data input. In addition, varying degrees of sophistication on the part of the users must be taken into account. Systems which, like those used in meteorology, are geographically dependent, should be written in a form that makes them readily adaptable from one location to another. Adaptability includes the ability to use alternate data sources for those occasions or locations where standard observations and measurements are not available. This introduces the concept of maintainability, whereby an existing system can be updated to include new data sources and changes in the knowledge base. Each of these concepts is discussed in turn, with particular examples taken from the fog forecast system.

1. INTRODUCTION

In December 1985, the Air Force Geophysics Laboratory signed a one-year contract with GEOMET Technologies, Inc. for the development of a knowledge-based expert system designed to assist weather forecasters in predicting local visibility conditions. The object of the effort was to demonstrate the feasibility of using this approach, and the system that resulted was meant to be only a proof-of-concept prototype. Nevertheless, it was felt that evaluation of the success of the prototype required testing under near-operational conditions, with comments and suggestions from users who would be representative of weather forecasters within the Air Weather Service. Consequently, the initial prototype was deployed at three test locations (Dover AFB, Delaware and Seymour-Johnson AFB and Fort Bragg, North Carolina) shown in Figure 1. The results of these field tests, which concentrated on verifying that the knowledge bases produced accurate forecasts at each location, have been reported elsewhere (Stunder et al., 1987a and Stunder et al., 1987b).

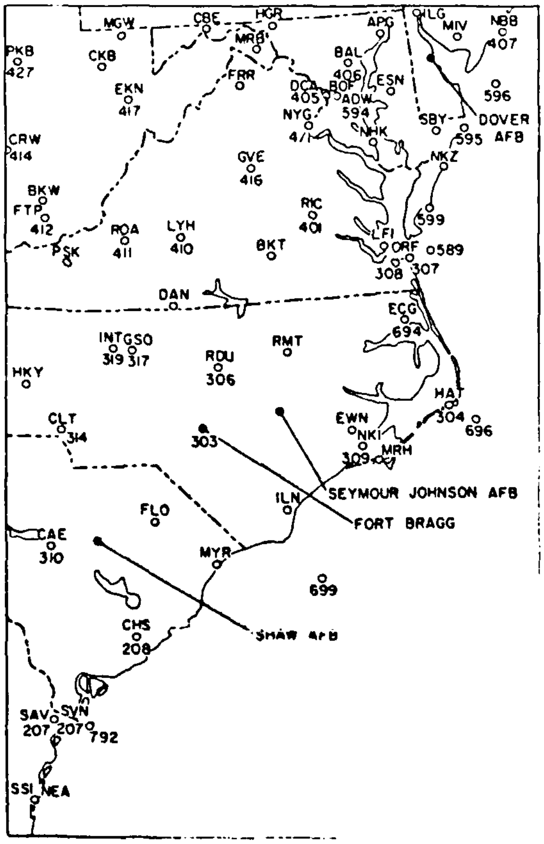

Figure 1. Locations for which fog forecast expert systems were developed. Zeus was developed for Dover, Seymour-Johnson, and Fort Bragg. The system designed for Seymour-Johnson was adapted to Shaw.

During the course of the contract, it became apparent that factors other than simple verification were equally important in evaluating the feasibility of deploying weather forecast expert systems at operational forecast offices throughout the Air Force. Additional evaluations were performed by Geophysics Laboratory personnel, in cooperation with Air Weather Service forecasters at Seymour-Johnson AFB. The lessons learned thus far during this project, which is still continuing, have ramifications for other expert systems destined for widespread deployment.

2. THE ROLE OF THE USER IN EXPERT SYSTEMS

Developers of expert systems, even more than standard computer programmers, must pay particular attention to the user-computer interface. The umbrella title, "user acceptance," includes numerous factors that contribute to the user's perception that the expert system provides a useful adjunct to available computer products and displays. Foremost of these, of course, is that the system produces advice that the user finds reasonable and acceptable. The field program demonstrated that there are many factors entering into this user acceptance/system accuracy equation. In hindsight, it might be argued that these results should have been foreseen: in actuality, it is not possible to predict user reaction to an expert system without having the users evaluate the system under conditions closely resembling those in the field. Problems relating to usercomputer interaction fall into three categories: an incorrect conceptual model of the user; the method of user input; and inappropriate explanation facilities.

2.1 CONCEPTUAL MODEL OF THE USER

The system was designed to be used by apprentice weather forecasters, some of whom may be on their first assignment following forecaster training school. However, it was hoped that more experienced forecasters would also find the fog forecast expert system of some help. The developers of the system were research meteorologists; those interviewed were the more experienced operational forecasters at each location. Consequently, those who were the most likely beneficiaries of the system did not see it before being asked to exercise it in the field.

The first surprise to the researchers was the time it took to train the forecasters in the use of the system. The developers had apparently assumed a level of computer literacy only slightly lower than their own; they encountered more than one user who was completely unfamiliar with personal computers. The second surprise was the realization that queries asking for user input were not crystal clear, and the users asked for clarification. Finally, some of the user input required a level of sophistication in weather forecasting almost equal to that of making the fog forecast itself.

2.2 METHOD OF USER INPUT

In the initial prototype, all data were entered manually, and queries were phrased in a multiple-choice format. This caused immediate rebellion by the users. All the user comments the first week of testing included objections to the length of time it took to enter the observational data required to initialize the expert system, and the multiple-choice format of the non-data entries. This causes a bit of a dilemma. On the one hand, it is certainly not desirable to remove the user completely from the loop, for various reasons cited in the literature (Gordon, 1988). However, weather forecasting is a time-critical activity, and it is simply not feasible to have the forecaster chained to a system that constantly demands input. An appropriate compromise would be to have all numerical data (temperatures, pressures, wind speeds and directions, etc.) entered automatically, and other information, such as the present and future location of synoptic weather features, through a mouse or tablet. Further modifications, such as those suggested by Kemp et al., (1988) will also be tested.

2.3 EXPLANATION FACILITIES

All expert system shells advertise that they have an explanation facility. What this often consists of, as it did in this instance, is a listing of the rules used by the system in reaching the given conclusion, or the rule for which the system is asking information. This often proved to be more exasperating than informative to users of the fog forecast system. Future plans call for a multi-layered explanation capability in the expert system, ranging from presentation of the rule being investigated, through a plain language statement of the line of reasoning being pursued, to a tutorial in the basic physics and meteorology underlying the system. Depending on the time available, and the user's inclination, these successive levels of explanation could be obtained by successive "Why?" queries. an explanation capability of this sort lies in the future, but it will probably be an essential part of the installation program we envision accompanying generic forecast expert systems to be deployed at Air Force weather stations around the world. In that case, once the system is installed, the installation program could serve as the tutorial program.

3. SYSTEM ADAPTABILITY

Even while the performances of the fog forecast prototypes were being evaluated, doubts were raised as to the feasibility of meteorological expert systems in a world-wide network. Obviously, some tailoring must be required to install the system at each location; however, if such tailoring requires extensive additional knowledge engineering, the whole concept of distributed expert systems becomes impractical. Over what geographic area is the prototype knowledge base valid, requiring only minor modification from site to site? How many such systems would have to be developed to cover all locations of potential interest to the Air Force? To evaluate this aspect of expert systems, we introduced the concept of adaptability, defined as the ease with which a system designed for a specific location can be modified for satisfactory performance at other locations.

3.1 MOVING FROM SEYMOUR-JOHNSON TO SHAW

As an initial test of its adaptability, the system designed for Seymour-Johnson Air Force Base was modified and evaluated as a predictor of fog at Shaw Air Force Base, South Carolina (see Figure 1). The modification was done without interviewing any of the forecasters stationed at Shaw, and the resulting system showed no significant difference in performance when compared with the Seymour-Johnson system. These results have been reported elsewhere (Dyer, 1988), and will not be discussed in detail here. The procedure used may be of some interest to those seeking to extend the geographic area over which their system is valid.

The first step was a thorough examination of the knowledge base. The version of the system at our disposal consisted of 207 IF-THEN rules, which can be grouped into the classifications shown in Table 1.

TABLE 1. ANALYSIS OF KNOWLEDGE BASE FOR FOG FORECAST SYSTEM

No Modification Needed:		
10 common sense	(5%)	
21 programming flags	(10%)	
32 basic meteorology	(15%)	(radiation fog)
Modification of Data Interface Sufficient:		
74 weather descriptors	(35%)	(synoptic map)
Modification Needed - Cast into Template Form:		
70 local rules of thumb	(35%)	(advection fog)

In all liklihood, most expert systems dealing with a geographically variable knowledge base will have rules falling into each of the categories listed here: the exact proportions will vary according to programming techniques and the subject of the expert system. In the present instance, only the 70 rules comprising the advective fog module of the system were expressed as local rules of thumb. These were transferred successfully to Shaw by first casting the rules of thumb into template form, then particularizing them to Shaw.

An example should serve to illustrate the template method. Fourteen rules dealt with surface wind directions favorable (or unfavorable) to the formation of advective fog. They were all of the form:

```
            IF     the month is BLANK,
            AND    the surface wind direction is
                   greater than XXX degrees,
            AND    the surface wind direction is
(RULE A)           less than YYY degrees,
            THEN   the surface wind direction is (is not)
                   favorable to the formation of
                   advective fog.
```

The critical wind directions were determined by consulting topographic maps, climatological data, and maps showing the location of meteorological stations. Rules that call for data from specific stations (for example, those upwind of Seymour-Johnson) were readily modified by changing the station designations to those more appropriate to Shaw (for example, those stations upwind of Shaw). There was no deterioration in the performance of expert system when it was used to forcast the occurrence of fog at Shaw AFB, rather than at Seymour-Johnson AFB. No attempt has been made to adapt the prototype as a regional system, but the experience of adapting it from Seymour-Johnson to Shaw indicates that there is nothing inherent in either the knowledge base or the architecture to prevent its adaptation to many locations along the eastern seaboard. However, it is also apparent that the template method of designing regional expert systems cannot feasibly be expanded to a global system. It was decided that future weather forecast expert systems developed at the Air Force Geophysics Laboratory will be generic systems, capable of being installed by personnel at each site.

3.2 THE STRUCTURE OF GENERIC FORECAST SYSTEMS

The proposed generic systems will have the structure shown in Figure 2. Knowledge acquisition will delve more deeply into the knowledge base to determine what physical and meteorological principles underlie the rules of thumb. These will be common to all systems dealing with the same forecast problem, regardless of the location for which the forecast is to be made. For example, the advective fog module might consist of the following two rules:

	IF	a warm moist air mass is advecting towards the station,
(RULE B)	AND	this air mass will cool to its dewpoint when it reaches the station,
	AND	there are no countervening factors present,
	THEN	advective fog will form over the station.
and		
	IF	advective fog has formed over the station,
(RULE C)	AND	there are no fog dissipating factors present or predicted
	THEN	low visibilities will persist.

Rules of this type would constitute the lowest level of the structure shown in Figure 2, and could be obtained directly from the scientific literature. This level would also include common-sense notions such as the fact that strong winds tend to dissipate fog, and that if it is night, the sun is not a factor in warming the air to a temperature above its dewpoint.

The second block in Figure 2 represents that portion of the knowledge base considering the effects of topography and of climatology. For example, this portion of a fog forecast system would contain the information that downslope winds are countervening factors in fog formation, and that during certain months, nearby large bodies of water are potential sources of warm moist air masses. This block would also contain regional climatology: statements to the effect that strong flow from the Atlantic Ocean is often a precursor of fog along the east coast of the United States and that inversion fogs occur along subtropical west coasts of Africa and North and South America.

These two lower blocks would comprise the expert system delivered to the individual forecast offices. The information contained in them can be obtained from textbooks and data bases. The next two blocks, containing local effects and individual rules of thumb, would have to be tailored for each location. Present plans call for the development of an installation program, with the local forecaster entering in the latitude and longitude of the station, and the pertinent topographical information entered from a GIS data base. This could be supplemented by whatever climatological records are available for the site. Like the two lower blocks, this portion of the program (labeled "Local Climatology and Topography" in Figure 2) will remain relatively unchanged.

The top block of Figure 2 represents the local rules of thumb and standard procedures in effect at a particular site. The rules in this segment would be installed during interactive sessions with the local expert forecaster. Ideally, this can be done by having the expert answer computer queries similar to those that would be asked by a knowledge engineer. These questions would be framed in the general form "How do you determine whether or not the statement [an IF clause in a given rule] is correct?." Admittedly, this merely transfers the knowledge acquisition effort from a single team of knowledge engineers to the individual weather forecasters. This may not be a reasonable approach, in view of the lack of computer sophistication exhibited by the users testing the prototype. However, a properly designed installation program should allow the forecaster to tailor the expert system for a particular location. This would make feasible the deployment of versions of the system to multiple locations.

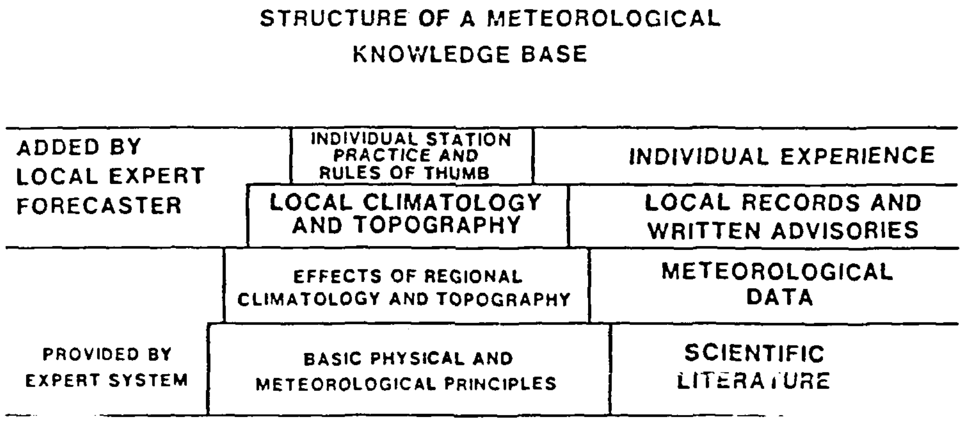

Figure 2. The structure of a knowledge base for generic expert systems in meteorology. The lowest layer contains general physical and meteorological principles taught in the classroom. Progressing upward, each level of knowledge becomes more particularized, culminating in the rules of thumb used by an individual expert at a given location. Typical sources of the knowledge contained in each level are shown at the right. The knowledge contained in the two lower blocks will constitute the generic system. The knowledge of the two upper blocks will be added by a local forecaster at each site.

An additional benefit of the architecture shown in Figure 2 is ease of maintainance. As new data collection and analysis facilities come on-line, they can be incorporated into the system through modifications to the top block, without affecting the rules contained in the rest of the program. Similarly, as new discoveries are made in meteorology, the rules of thumb contained in the upper block will change, also without affecting the remainder of the system. Thus, adaptability will be achieved over time, as well as location.

4. CONCLUSIONS

Field tests of the fog forecast expert system has lead to two main conclusions. First, much more attention must be paid to the user interface. Graphics, mousing capability, menus, light pens, and explanation facilities should all be utilized to make future expert systems as user-friendly as possible. This is not, properly speaking, in the realm of artificial intelligence. Nevertheless, the success of any expert system under battlefield conditions may well depend on how quickly someone unfamilar with the system and with only minimum computer literacy can be taught to use it.

The second lesson learned from these tests is that expert systems written for geographically varying domains such as weather forecasting must be adaptable to multiple locations. Expert system use has progressed beyond the proof-of-concept stage, where an expert system that does a task well is considered a success. Now we are entering a second stage, where hard looks are taken at the time and effort invested in knowledge acquisition and computer program development. If the resultant systems are applicable to only a single location, or a single narrow task, they may not be worth the development effort.

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