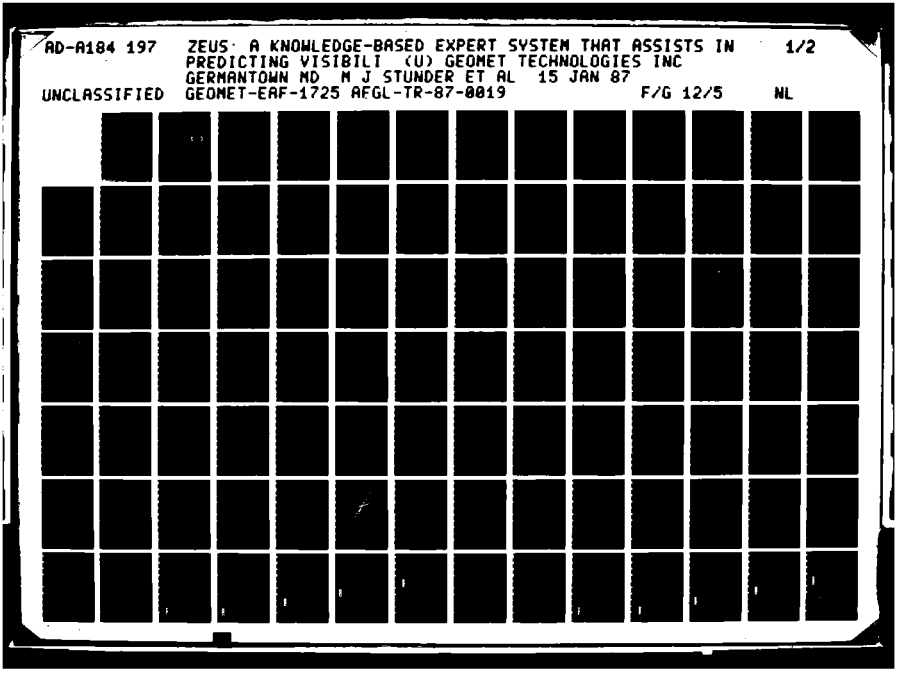
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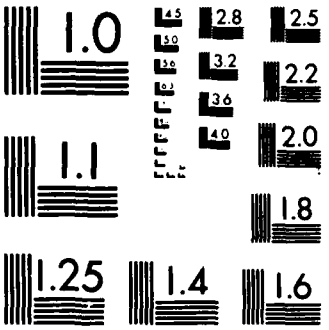

AFGL-TR-87-0019

ZEUS: A Knowledge-Based Expert System That Assists in Predicting Visibility at Airbases

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15 January 1987

Final Report
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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731

This technical report has been reviewed and is approved for publication.

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An Artificial Intelligence (AI) knowledge-based expert system (KBES) was developed to demonstrate the feasibility of using this approach to assist forecasters in predicting local visibility. The study developed a knowledge structure for handling rules and data needed to advise on advective and radiation fog formation processes. A review of alternatives for developing the needed software led to selection of the EXSYS, AI programming shell for developing and running a KBES on PC-compatible computers. The KBES for advising forecasters is called Zeus and was developed in three versions to be used at each of three airbases: Dover, Seymour Johnson, and Fort Bragg. The system was enthusiastically used at the bases for a 2-mo period as reported in a user survey. The Zeus forecast results from user interactions and from a historical data evaluation that produced overall skill scores of 0.35 and 0.38, respectively. The skill scores were significantly better than for forecasters (at one of the bases) during the user test period. A drawback of the system is a tendancy to underpredict the frequency of occurrences of low-visibility categories. The good performance and the high user acceptance demonstrates a successful proof-of-concept. Further development of the approach is recommended.

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PREFACE

The following scientists contributed to the research reported in this document:

D.J. Pelton, knowledge acquisition and structuring

M.B. Charlton, data acquisition and review.

The following previously produced publications resulted from total or partial sponsorship of the contract:

Evaluation of the Feasibility of Applying Artificial Intelligence Techniques to the Prediction of Visibility at Selected DoD Bases and Development of a Knowledge-Based Expert System. First Quarterly Report, December 17-March 31, 1986. Second Quarterly Report, April 1-June 30, 1986. Third Quarterly Report, July 1-September 30, 1986.

Stunder, M. J., R. C. Koch, and R. Dyer. The Use of an Expert System in Assisting Forecasters in Visibility Prediction. Reprints. Third International Conference, Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology. January 12-16, 1987, New Orleans, LA.

ACRONYMS

AF	Atlantic Flow
AFGL	Air Force Geophysics Laboratory
AI	Artificial Intelligence
AIRID	Air Identification
ART	Automated Reasoning Tool
AWS	Air Weather Service
AV	Attribute Value
CASES	Capability Assessment Expert System
FROPA	Cold-Frontal Passage
KBES	Knowledge-Based Expert System
KEE	Knowledge Engineering Environment
KES	Knowledge Engineering System
LCD	Local Climatological Data
MOS	Model Output Statistics
NADL	National Climatic Data Center
NWP	Numerical Weather Prediction
OAV	Object-Attribute-Value
PIREPS	Pilot Reports
TAP	Terminal Aerodrome Forecasts
TFRN	Terminal Forecast Reference Notebook
TIMM	The Intelligent Machine Model
WBAN	Constant Pressure Data

Section 1.0

INTRODUCTION

This final report describes all efforts performed under Air Force Geophysics Laboratory (AFGL) contract number F19628-86-C-0033, entitled "Evaluation of the Feasibility of Applying Artificial Intelligence Techniques to the Predicition of Visibility at Selected DoD Bases and Development of a Knowledge-Based Expert System."

The format of the final report is to first introduce the reader to the project objectives and then proceed with a general discussion on Artificial Intelligence/Knowledge-Based Expert Systems (AI/KBES). Next, we follow the evolution of the KBES through various stages by first introducing the reader to a general discussion of each generic step and then specifically applying the discussion to our KBES development. An expert system was developed for three airbases including Seymour Johnson, North Carolina, Dover, Delaware, and Fort Bragg, North Carolina. The construction of each system is similar in terms of physical principles such that the three expert systems are variations of each other. We call the system "Zeus." The results of evaluating each system using independent data for each airbase are presented and the lessons learned are discussed. Finally, we present our conclusions as well as recommendations for future work.

1.1 AFGL PROJECT OBJECTIVES

The project objectives were twofold:

1. To determine whether forecast techniques can be expressed using AI structures and software

2. To determine whether Air Weather Service (AWS) base personnel would accept the idea of a KBES providing meteorological advice.

This effort is a proof-of-concept and has never been tried within AWS. Thus, many of the technical AI terms and the software were unknown at the start by AWS base personnel.

Longer term objectives are to:

1. Improve short-range (0- to 12-h) Terminal Aerodrome Forecasts (TAF)

2. Improve forecaster performance in relation to use of time and focusing of resources

3. Decrease orientation period (training) time in a new location

4. Increase safety through more accurate predictions.

These longer term objectives are the goal of an integrated AI effort within AWS.

1.2 ARTIFICIAL INTELLIGENCE/EXPERT SYSTEMS--A BRIEF OVERVIEW

Artificial Intelligence is the science of understanding how to make machines of any type create the results that would normally require human intelligence.

Thus, AI is a subfield of computer science that is concerned with various concepts and methods of symbolic inference and symbolic representation of knowledge to make the inferences.

AI generally involves the investigation of two broad topic areas:

1. Intelligent thought and action itself

2. Computer software and hardware to express what is understood about intelligence.

More specifically, the evolution of AI, as shown in Fig. 1, has led to three major areas of emphasis:

- Natural language processing
- Robotics
- Expert systems.

The first area involves computer processing in the English language itself, such as speech interfaces that are used for several DoD aircraft control projects. The user speaks to the computer and the computer responds by initiating an action or by talking with the user.

The second area involves mechanical devices designed to improve either the efficiency of an operation or to perform under hazardous conditions. For example, robotic systems are used for such things as retrieval of engine parts from storage areas to demilitarization of chemical warfare munitions.

The expert system area has been shown to have increasing promise for use in environmental decision making (1) and in meteorology (2, 3).

A KBES (see Fig. 2) is basically a structured collection of knowledge that can interact with users. This interaction is accomplished by a series of questions and answers or by a series of data inputs directly into the system. These questions or data inputs are in a controlled sequence that is designed to access the knowledge data base. The end product results in the user receiving recommendations with a probability of success. Expert systems also include the capability to describe their line of reasoning and to play "what if" games with various data input.

EVOLUTION OF AI

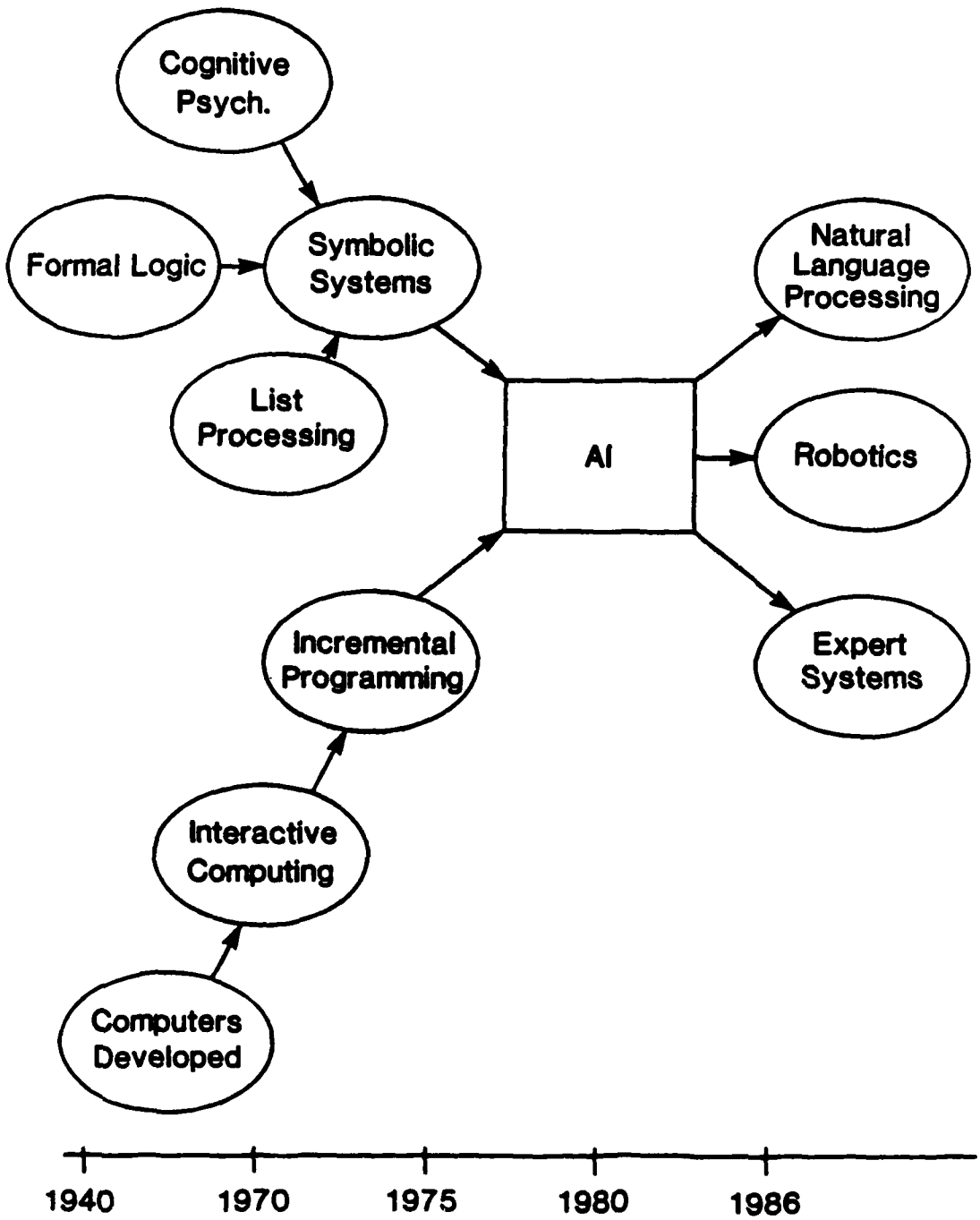


Figure 1. Evolution of AI.

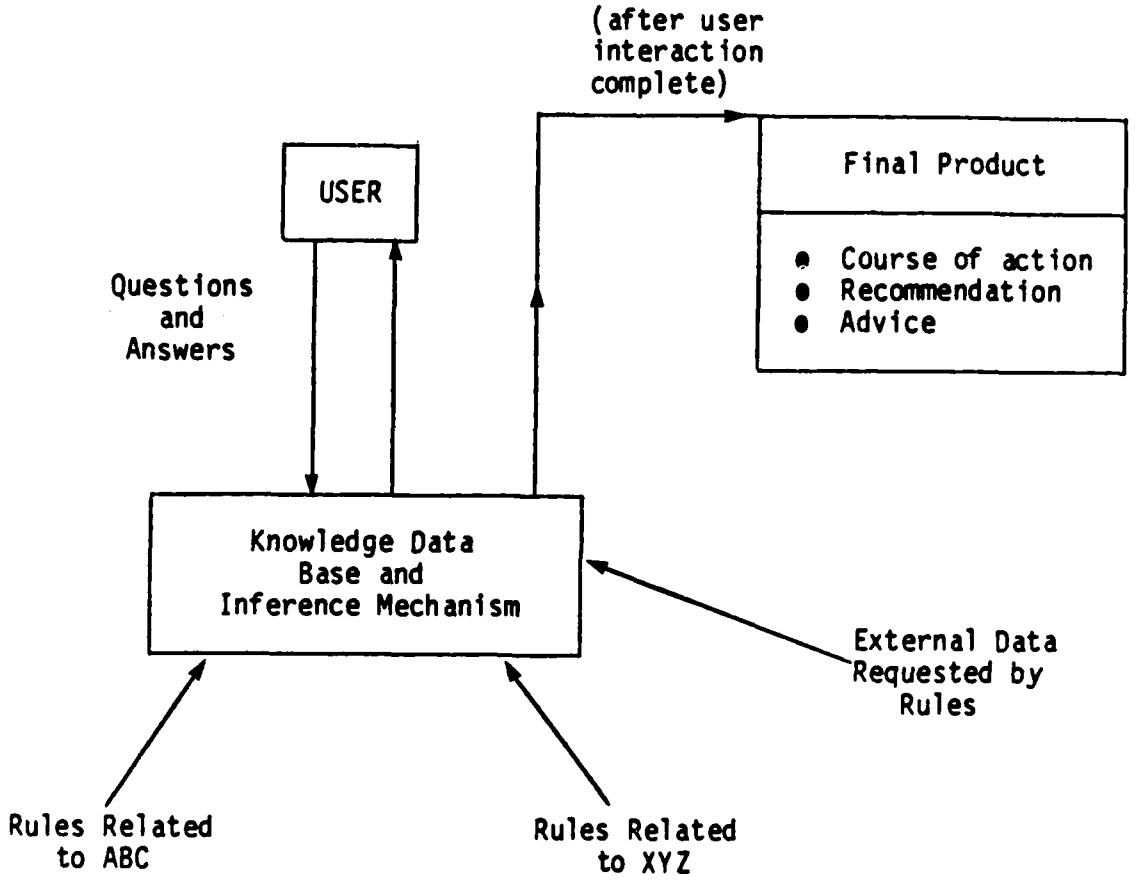


Figure 2. Generalized structure of an expert system.

TABLE 1 illustrates the basic differences between conventional and symbolic programming. The major differences include numerically addressable data versus symbolically structured data and interactive explanation features.

TABLE 1. Basic Difference Between Conventional and Symbolic Programming.

Conventional Programming	Symbolic Programming
Oriented toward numerical processing	Oriented toward symbolic processing
Numerically addresses data base	Symbolically structured knowledge base
Algorithms	Declarative knowledge
Sequential, batch processing	Highly interactive processing
Program specification	Iterative refinement
Mid-run explanation impossible	Mid-run explanation easy

A meteorological expert system would differ from more traditional Model Output Statistics (MOS) or numerical-model-related, output-oriented programs in three key areas:

- Representation of information (data/knowledge)
- Processing
- Explanation.

The algorithmic approach to weather forecasting is basically an approach that if given the correct input data you will get a correct answer. Of course, part of the problem in numerical weather predicition (NWP) is the right initialization of data (a subject that is always discussed on the human-machine mix product). NWP models manipulate data only. The KBES, on the other hand, deals with heuristics and knowledge (along with data needed to

use the knowledge). Expert systems are able to represent the total meteorological picture using rules of thumb or structures and are not encumbered by number crunching.

A second difference involves processing. MOS, for example, relates meteorological categories and key parameters to statistical analysis based on a comprehensive data base. MOS is oriented toward numerical and statistical processing. Expert systems, in contrast, are oriented toward symbolic processing and inferential reasoning. The expert system deals with manipulatory knowledge and not statistical regression equations.

A third area of difference is in the explanation function. MOS cannot explain why, for example, it is changing the temperature in such a manner. Many forecasters are wary of MOS when a front is forecast to come through at 1200 Z. Forecasters are also cautious in using numerical output during seasonal changes. Many numerical model discrepancies have been pointed out in the daily human-machine mix weather discussions. Expert systems, in comparison, have explanatory facilities and the ability to explain both their line of reasoning and individual rules. An expert system knowledge data base also has the capability to be readily changed should new information become available; it is much more difficult to change model code.

It is important to keep in mind, however, that although expert systems differ from traditional programming and MOS techniques, they should be used in concert with these techniques and be viewed as an aid to a forecaster.

The military has been using expert systems since the mid-1970's. These systems have included packages such as the Automatic Target Recognizer (4) that classifies military targets from sensor images and rules, Air Identification (AIRID) that uses various aircraft structural rules to determine aircraft type (5), and the Capability Assessment Expert System (CASES), being developed by the Space and Naval Warfare Command, that provides decision support to the U.S. Pacific fleet.

The above military applications and other military and civilian expert system applications, including environmental applications, have several common starting criteria (6) in terms of:

- Initial requirements for the expert system
- Justification for the expert system
- General characteristics of the proposed expert system.

We have listed these criteria in TABLE 2 to illustrate that the development of a low-visibility expert system is possible.

TABLE 2. General Expert System Development Criteria Versus Low-Visibility Expert System Effort.

Generalized Expert System Development Criteria	Visibility Effort
Does effort require only cognitive skills?	Yes: No physical (e.g., robotic) manipulations were undertaken.
Does a base of genuine expertise exist?	Yes: Sufficient numbers of meteorologists (AWS and others) with visibility experience exist. Significant amounts of meteorological literature also exist.
Is the effort simplistic enough in the temporal sense?	Yes: Meteorologists take only a few hours at most (or usually several minutes), but not days to arrive at a low-visibility decision. However, how to deal with time within the KBES will be difficult.
Does problem area appear to be well structured?	Qualified yes: Certainly basic research is still occurring in the visibility area; however, enough knowledge exists in the literature and within AWS to structure a knowledge base.
Will the expert system have a high payoff?	Yes: An expandable KBES concentrating in low visibility first and then moving to other areas could save considerable amounts of time and effort in the interpretation of visibility-related data and better focus base weather resources to potentially more serious weather problems.
Is human expertise scarce or will it be scarce in the future?	Yes: Meteorological visibility expertise currently exists within AWS; however, many senior civilian AWS meteorologists are approaching retirement and this special expertise may be lost. In addition, as in all service functions, AWS personnel are shifted, thus causing a scarcity of base-specific knowledge that only longevity at a base can provide.
Could the problem area use heuristic solutions?	Yes: A heuristic solution refers to a solution based on rules of thumb. Visibility forecasting and other areas of meteorology are full of rules of thumb from the days of J.J. George and LaRoche in the 1950's to the present Terminal Forecaster's Notebook.
Is the problem of manageable size?	Yes: To include precipitation into the KBES would make the system too large for a proof-of-concept. Thus, we included only low visibility caused by obstructions to vision.

TABLE 2 attempts to answer the question "Will an expert system approach work in a low-visibility (or meteorological) application?" The table indicates that low-visibility (meteorology) as a problem area is ripe for an expert system application; however, certain aspects such as the scope of the initial system and the user interaction with the expert system must be kept in perspective.

Perhaps the most crucial expert system development question centers around the scarcity of human domain (domain in this case referring to visibility -meteorology) expertise. Technology transfer and the codification of knowledge from places such as Air Force Global Weather Central, AFGL, and the AWS-base personnel seems to be a prevalent problem not only in the Air Force, but in some of the other environmental areas.

For example, GEOMET's efforts to develop a command, control, and communication-environmental tactical expert system in modular format for the Army is driven by the need to rapidly transfer laboratory, or on another level, command center environmental knowledge down to the small field combat units. Other GEOMET environmental efforts for the Navy have clearly indicated the need for integrating expert system usage for not only real-time needs, but as a training vehicle to distribute expert knowledge to individual users.

The next section discusses a development concept, which is based on the coupling of the human and machine with an interface that complements each side. The successful development and implementation of the KBES will require a system design approach that is based on graceful growth and gradual enhancements.

1.3 STEPS IN CREATING AN EXPERT SYSTEM

The evolution of an expert system proceeds through a series of steps or phases designed to incrementally improve the use of the system knowledge. The five phases of any KBES development are illustrated in Fig. 3.

It is important to note that the design of an expert system is an ongoing dynamic process. Even though on paper, generic Phase II (for example) may be complete and work is proceeding on other phases, the creation of the expert system requires knowledge. Thus, any additional knowledge sources found later would most certainly be included in the knowledge base.

A discussion of each generic phase follows.

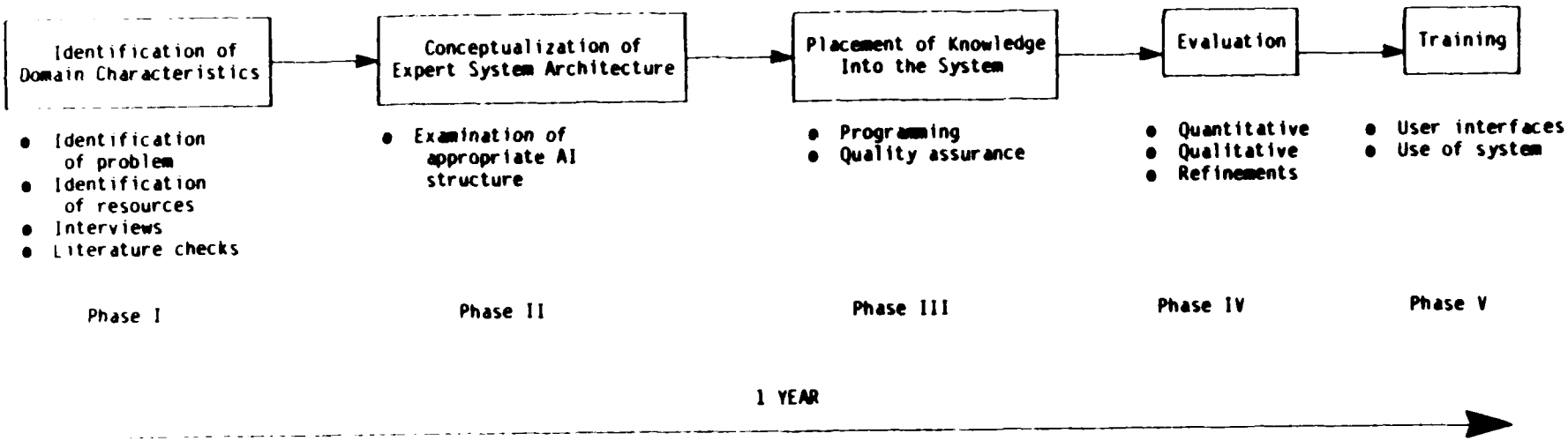


Figure 3. Five phase approach to developing any KBES.

Generic Phase I: Identification of Domain Characteristics

The first generic step in developing an AI/KBES is the characterization of the domain (in this case meteorology) knowledge. The knowledge can either be embedded in the literature or acquired from experts. Various techniques can be used to acquire knowledge from experts including observing the expert at work or interviewing the expert.

Generic Phase II: Conceptualization of the Expert System Architecture

This phase involves selection of an architecture appropriate for system design. Two general approaches include frames and rules. A frame contains knowledge about a topic in the form of slots; rules contain individual if-then or similar structures. This phase also involves selection of either an AI language such as LISP or PROLOG or a shell, which is a software package that aids in expert system development through input of rules and knowledge much like Lotus 1-2-3 aids in graph creation through data input by the user.

Generic Phase III: Placement of Knowledge into the System

In this phase, the various logic structure goals/subgoals, frames, etc., are placed into the expert system. Placement of rules into the system early enough in the project allows for any pitfalls to be uncovered. Generally, early placement of rules into the expert system also allows for limited evaluation of the various rule or logic paths.

Generic Phase IV: Expert System Evaluation

A formalized system evaluation can help both the user and the developer in terms of interaction and refinements. Typically, evaluations are quantitative in nature, although several KBES evaluations are beginning to become more qualitative.

KBES evaluations, however, have shied away from the field evaluation concept that is used by many scientific organizations. Instead, many KBESs remain buried in a laboratory environment and never get a full field evaluation.

Generic Phase V: Training

Typical KBESs involve some level of user interaction that requires some degree of training. This training could involve merely a system or module overview or a hands-on user interaction with the system or module, all under control of a team member.

Low-Visibility KBES Development

Development of the low-visibility KBES (hereafter called "Zeus") follows a similar progression of the phases just described. Fig. 4 shows the various steps in creating Zeus and key issues under each step. To appreciate

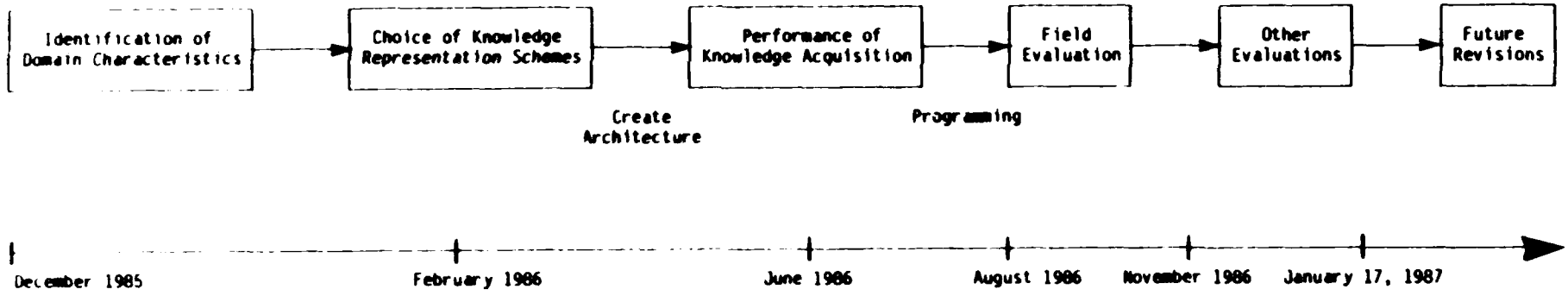
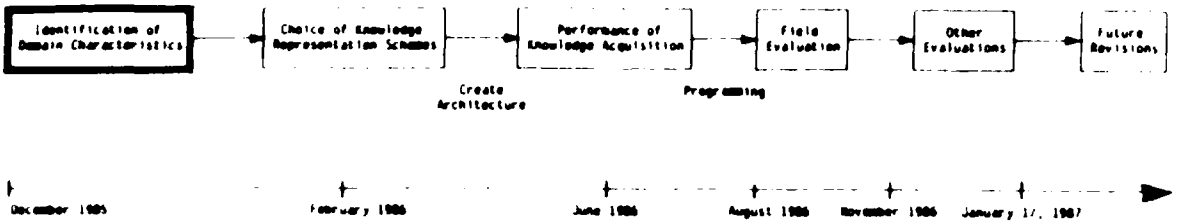


Figure 4. Steps used in the creation of Zeus.

what truly makes up an expert system design, we follow and discuss each step in the following sections. The reader will notice some slight differences in the generic approach that can be applied to any system versus Zeus, but on the whole, the approaches are the same.



Section 2.0

IDENTIFICATION OF DOMAIN CHARACTERISTICS

In this section, we describe the domain that characterizes the parameters used in low-visibility forecasting and the operating environment to which the expert system will be constrained. The discussion includes the following topics:

- The meteorological phenomena of fog
- Base-specific meteorology
- Base weather forecasting time constraints
- Available computer resources.

2.1 IDENTIFICATION OF THE METEOROLOGICAL PROBLEM--FOG

2.1.1 Background

Visibility is of considerable importance to the Air Force and military community in general, mainly because of the transportation-oriented operations that may be hindered or stopped altogether by visibility below certain limits. Visibility throughout history has played a significant role in many areas including battles and transportation disasters. For example, the 1986 aircraft collision at Tampa's airport was directly influenced by low airport visibility at the time of the accident.

Obstructions to vision have been defined as nonprecipitating phenomena that reduce visibility. Examples include haze, smoke, blowing dust and sand, blowing and drifting snow, and fog.

Haze has been considered as a form of atmospheric pollution and is composed principally of very small salt crystals and dust particles. Aqueous haze droplets tend to form on hydroscopic condensation nuclei. Haze droplets develop as the relative humidity increases above a certain critical point, which is 50 percent (7). Smoke is a result of industrial processes, coal and wood burning, and forest fires. Dust is composed of thousands of small soil or sand fragments that are carried to great heights by thermals and to great distances by winds. Blowing sand is regarded as larger soil or sand particles, which are carried or supported by surface winds. Blowing snow is generally characterized by a drier snow, which is carried aloft by gusty surface winds. Both horizontal and vertical visibility are restricted. Drifting snow, to a lesser extent, affects only the horizontal visibility.

During the very early stages of Zeus development, we decided to limit the system to obstructions to vision (specifically, fog and haze). Precipitation-induced low visibility was not considered because this would require a very large knowledge base and possibly the introduction of pattern-matching techniques. We believe that the large knowledge base at this time would defeat the purpose of this effort, which was to establish a proof-of-concept in meteorological AI; thus, we chose the limited fog and haze phenomenon.

Visibility restrictions caused specifically by fog and haze are of major concern to Air Force operations. Numerous studies provide descriptions on how visibility restrictions affect operations such as takeoffs and landings as well as battlefield and aerial refueling.

2.1.2 Advection Fog Formation Conceptual Model

Fogs have been classified into various types by early authors such as Willett (9) and George (10) and by recent papers such as Welch et al. (11). Fifteen categories of fog exist; however, the two broad types of fog are advection and radiation. True advection fogs are sea fog, arctic steam mists, and snow-surface-induced fogs (i.e., fogs caused by air with a dewpoint above freezing traveling over a snow surface). Actually these true types of advection fog do not occur over the United States very often.

Alternatively, the literature has provided a looser definition of advection fog to represent fog caused by sufficient moisture to ensure saturation after a reasonable amount of cooling. Typically, parcels of air are moved over surfaces colder than themselves and therefore, cool, producing a fog. Thus, fogs that depend on wind to alter temperature or moisture content (or both) of the air parcels in such a manner that saturation is achieved are called advection fogs. The simplest definition contained in the literature is the one we have adopted to avoid confusion: The air in which the fog forms must have had at least a short path over water since the preceding day. A search of the literature indicates that many authors refer to this as advection-radiation fog; however, we will call it advection fog for simplicity's sake.

Source regions for advection fog naturally include areas within approximately 200 mi of a large body of water. Occasionally, however, advection fogs have been observed "being fed" by ground moisture coming from an area that has experienced thunderstorms or rainshowers (12).

Advection fog is formed under synoptic conditions that allow for the boundary-layer transport of moist air into an area with relatively cloud-free skies (hence, the "radiation influence"). Therefore, a key parameter in forecasting advection fog focuses on the use of the surface wind and boundary-layer trajectories. If the surface and boundary-layer flow is off a water body, then depending on the synoptic situation, there is an increasing probability of advection fog.

By having an understanding of the influence of surface and boundary-layer windflow, one can then introduce other forecast parameters into the analysis. Even though winds must be sufficient to transport moisture into an area, the winds cannot be so strong that they tend to warm the boundary layer and reduce condensation, thereby reducing the fog threat.

Physical evidence of the dissipation of advection fog due to wind has been presented by Jiusto (13), who links changes in fog density to the Richardson number that is defined as

$$R_i = \frac{g}{\theta} \frac{d\theta/dz}{(du/dz)2} \qquad (1)$$

where

$d\theta/dz$ represents the vertical potential temperature (θ, in K) gradient
du/dz represents the windspeed (u, in m) change with height
g represents gravity.

Typically, low visibilities have tended to occur when $R_i > 0.5$. With $R_i < 0.5$, vertical mixing is dominant; a strong boundary-layer wind will keep the boundary-layer well mixed and $d\theta/dz$ low. Both the cooling and the moisture from the surface are distributed upward and this produces stratus clouds rather than fog. This suggests that critical boundary-layer and surface windspeeds must be established within Zeus to reflect this physical reasoning.

Another parameter of importance involves the amount of cloud cover between a forecast site and the moisture source. Large amounts of intervening cloud cover will tend to limit any cooling of the boundary layer, thereby restricting fog formation. Fig. 5 dramatically illustrates the effect of variable cloudiness during an advection fog case in the New York City area. A cloud bank passed near and overhead of the observing site from around 2200 EST to 2345 EST. Visibility clearly improved with the arrival of the cloud bank and was, in fact, directly correlated with the level and thickness of the cloud bank. The cloud bank effectively reduced outgoing radiation from about 3.5 mW cm^{-2} to 0.5 mW cm^{-2}.

Advection fog is also characterized by well-defined boundaries, which are usually (assuming the absence of thin, higher level clouds) evident in both the visible and IR satellite imagery. A windward edge or side of an advection fog area remains quasi-stationary, but the edges and lee side typically extend various distances outward. A shift of the wind or the introduction of drier air may alter the entire fog pattern.

With the above physical factors in mind, we developed a conceptual model of a forecaster's probable thinking when deciding on an advection fog forecast. This model, shown in Fig. 6, was developed prior to the formal

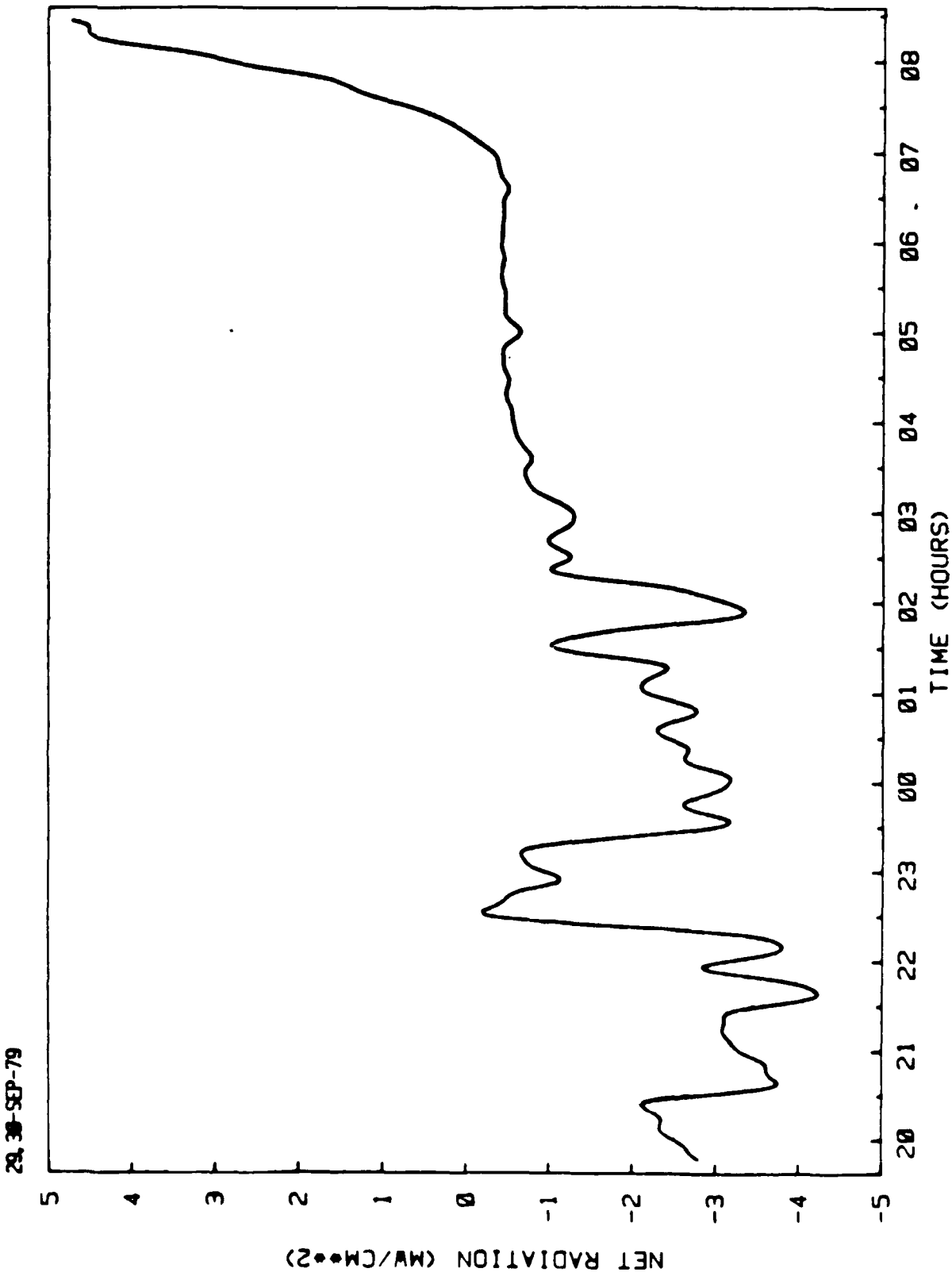


Figure 5. Net radiation (2 m) vs. time (29-30 Sept. 1979) (reference 13).

Problems

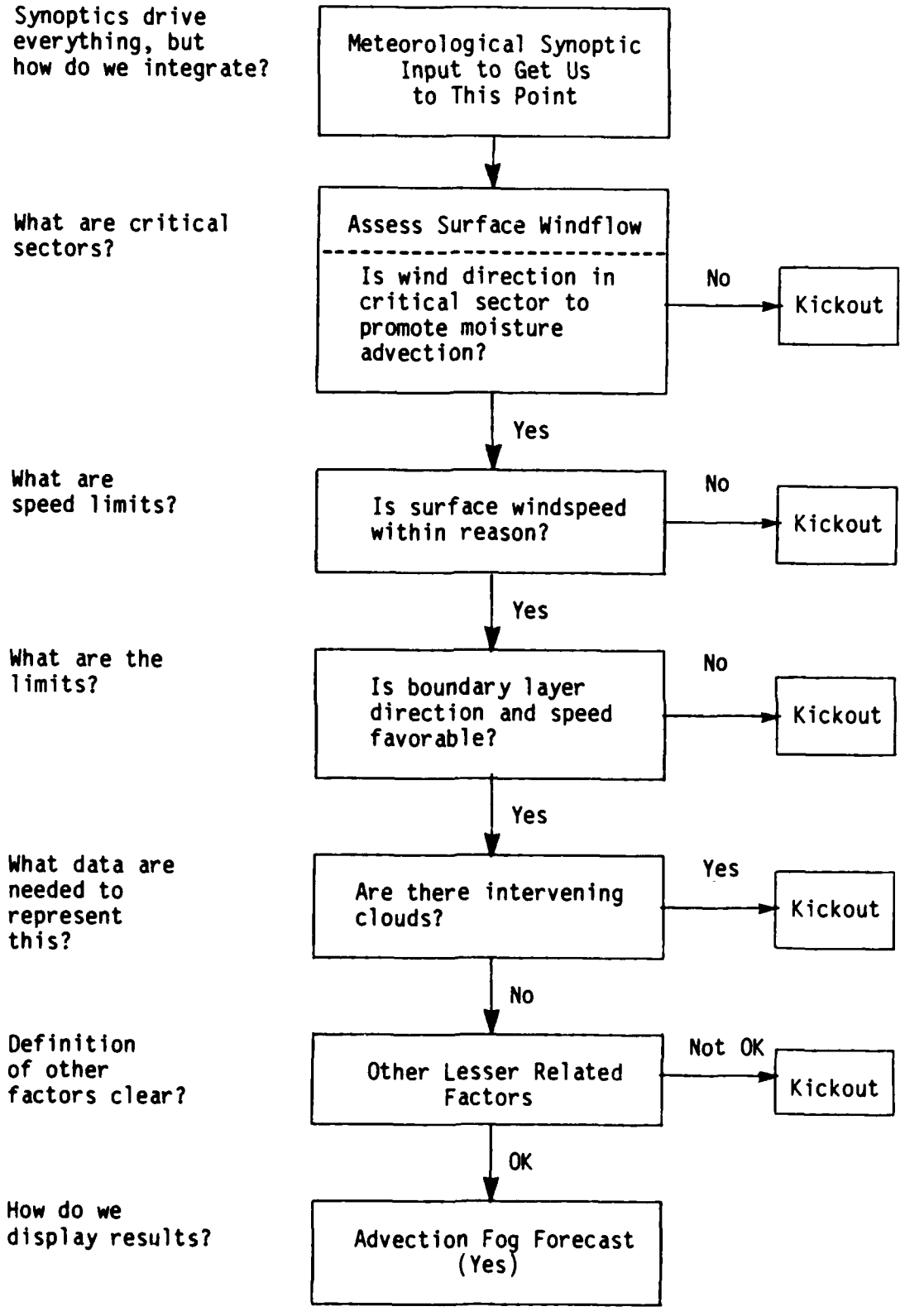


Figure 6. Conceptual model (based on physical reasoning) of an advection fog forecast.

interviews in the knowledge acquisition phase and served as a framework for discussions with AWS personnel. The model indicates a chain-of-thought based on physical reasoning, with the key parameter being the advection of moisture from a moisture source.

Other specific parameters included the windspeed itself, which can be considered in the broad sense a measure of boundary-layer turbulence, and the clouds. Other related factors, which at this stage referred to any peculiar base-specific meteorology, are also considered.

We were immediately faced with several problems, including:

1. How do we identify the synoptic situations favorable for advection fog?

2. How do we "kickout" of the conceptual model if necessary conditions are not present?

These problems were carefully noted for special attention in later phases.

A similar conceptual model was developed for radiation fog and is discussed in the next subsection.

2.1.3 Radiation Fog Formation Conceptual Model

Radiation fog occurs in an air mass when sufficient cooling occurs due to radiative loss of sensible heat. Considerably more literature exists on radiation fog than on advection fog. A search of this literature indicates several key parameters for the formation of radiation fog:

- Clear or mostly clear skies
- Adequate relative humidity in the surface layer (lowest 100 m) [wet ground may be substituted]
- Lack of strong surface and boundary-layer winds.

It appears from the literature that radiation fog formation is the end product of a very complex set of processes within the surface and boundary layer.

Assuming relatively clear skies, the net cooling of the ground surface begins just prior to sunset. The radiational balance at that time appears as follows:

$$R_L^- > R_{Sun}^+ + R_{Sky}^+ + H_o + R_L^+ \qquad (2)$$

where:

R_L^- = heat lost by long-wave radiation to sky
R_{Sun}^+ = short-wave radiation from sun
R_{Sky}^+ = short-wave radiation from sky
H_o = heat conducted from upper ground levels
R_L^+ = long-wave radiation received from atmosphere.

Net cooling includes cooling of the air at and near the ground. When the ground has cooled to the dewpoint temperature, dew deposition begins. Sufficient, but not overwhelming turbulence is needed in the surface layer to bring fresh supplies of air to the ground. Monteith (14), for example, suggests that windspeeds less than 0.5 m sec^{-1} are insufficient to promote dew deposition.

If sufficient turbulence is present, the amount of water vapor decreases (falling dewpoints), so the temperature must continue to fall before fog forms. This is a critical time of delicate balance in the fog formation cycle. Usually, temperatures and dewpoints continue to fall and fog forms, first in very thin layers separated by clear air from the ground. Radiational cooling from the fog layers themselves leads to thickening and vertical extensions. Radiational cooling at the fog top, which could range from 10 to 300 m, may be as much as 2 °C in 30 min (15).

Our literature review also indicated many overnight temperature prediction schemes that incorporate dry-bulb and dewpoint temperatures near sunset and extrapolate these values through to sunrise to determine a critical fog temperature. The technique of Craddock-Pritchard (16) for example, uses the following linear regression equation:

$$T_{Fog} = 0.044T_{12} + 0.844T_{d12} - 0.55 + A \quad (3)$$

$$T_{Fog} = Y + A \quad (4)$$

where:

T_{12} = temperature at 12 Z
T_{d12} = dewpoint temperature at 12 Z
Y = calculated value of expression (3) in nomogram form
A = lookup factor (in degrees) based on sky cover and mean geostrophic forecasted windspeeds for 18Z, 00Z, and 06Z.

The next step involves taking T_{Fog} and using it such that

$$E = T_{Fog} - T_{min} \quad (5)$$

where

T_{min} relates to another Craddock-Pritchard lookup table and
E = final value that is then compared to an E table fog risk (high, moderate, or low).

Other graphical methods exist such as George's method (17), which has been used by several AWS personnel.

George's empirical equation is:

$$T_{Fog} = 6.13 \log_e 0.18 (S + D) + 3.2 \quad (6)$$

where:

T_{Fog} = time of fog formation in hours after sunset when visibility is less than or equal to 1 mi
S = number of sunshine hours
D = dewpoint depression at sunset.

Conditions for use of this formulation include:

- Reasonable amounts of cloudiness during day
- Gradient wind below 25 mi/h
- Decreasing cloudiness at night.

This formulation is based on several years of meteorological data from Atlanta, Georgia, and has been confirmed at other cities such as Nashville, Louisville, and Chicago.

As with any statistical methods, the results (the regression equations) express only mean relationships. Thus, caution should be exercised in using these equations as a predictor alone. However, modifications to these equations in terms of meteorological parameters that may influence dewpoint depression (for example) would be a very powerful use of statistics and knowledge.

Any conceptual model of radiation fog forecasting must consider the predominance of statistical methods of forecasting radiation formation. Fig. 7 shows our conceptual radiation fog model based on the physical reasoning presented above.

This conceptual model was developed to guide our interview process and includes such general physical characteristics as the clear skies and moist ground features discussed earlier.

As with the advection fog conceptual model, we were faced with several problems (as listed in the figure), namely:

1. How do we deal with surface layer moisture?

2. How do we identify the favorable synoptic situations for radiation fog?

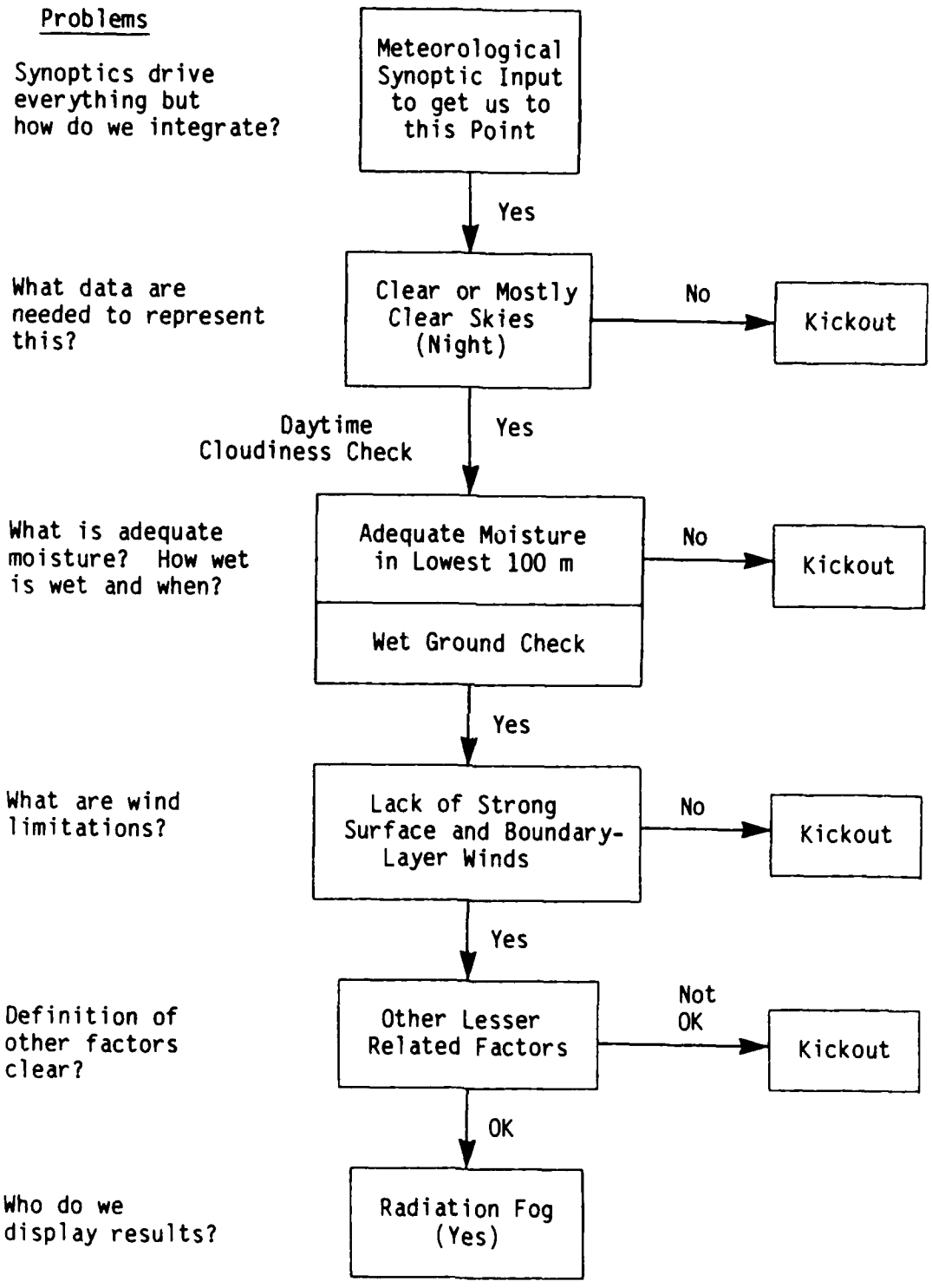


Figure 7. Conceptual model (based on physical reasoning) of a radiation fog forecast.

The first problem was directly addressable by our domain experts. The second problem is common to both advection and radiation fog and is the topic of a separate subsection below.

A third concern that arose at this stage was how to deal with the multiplicity of "kickouts" that the system would require should a condition not be sufficient. Thus, a preliminary decision was reached based on these two conceptual models to analyze the possibility of advection fog first, simply because of the moisture, and boundary layer assessments that could be made early in the program run and the commonality of such assessments in radiation fog. This led to presenting the conceptual models to AWS personnel in the advection and then radiation fog order, with synoptics being intertwined in the discussion.

2.1.4 Synoptic Conceptual Model

During the development of the conceptual models for radiation and advection fog, it was noted that a recurring theme of the synoptic situation driving the local meteorology occurred; thus, special thought was given to developing a general conceptual synoptic model. The danger in developing such a model, however, was to "go overboard" and create the "catch-all" synoptic expert system--which is really beyond the scope of this proof-of-concept effort.

A more detailed description of base-specific meteorology appears in a later section; however, several key synoptic features (identified in the literature) are prerequisites for fog formation:

- High/ridge in a favorable position to permit at least weak oceanic flow (advection)
- High/ridge in a favorable position overhead, or nearby to allow for subsidence, and clear skies (radiation)
- Lows not expected to affect weather next 12 h
- Fronts (except backdoor cold front) not in a position to threaten area
- Backdoor cold front (front moving southward from the north or northeast of a base) in a position to threaten area.

At this early stage, due to proof-of-concept limitations, we introduced the idea of the AWS forecaster (the user) deciding where the synoptic features will go. We were forced to "draw this line" because the number of rules on movement and strength of synoptic systems alone were very complex and could involve an entirely separate expert system.

Fig. 8 shows the synoptic conceptual model. One interesting aspect that the development of this conceptual model indicated is the need for a temporal sense of influencing synoptic features. In other words, the

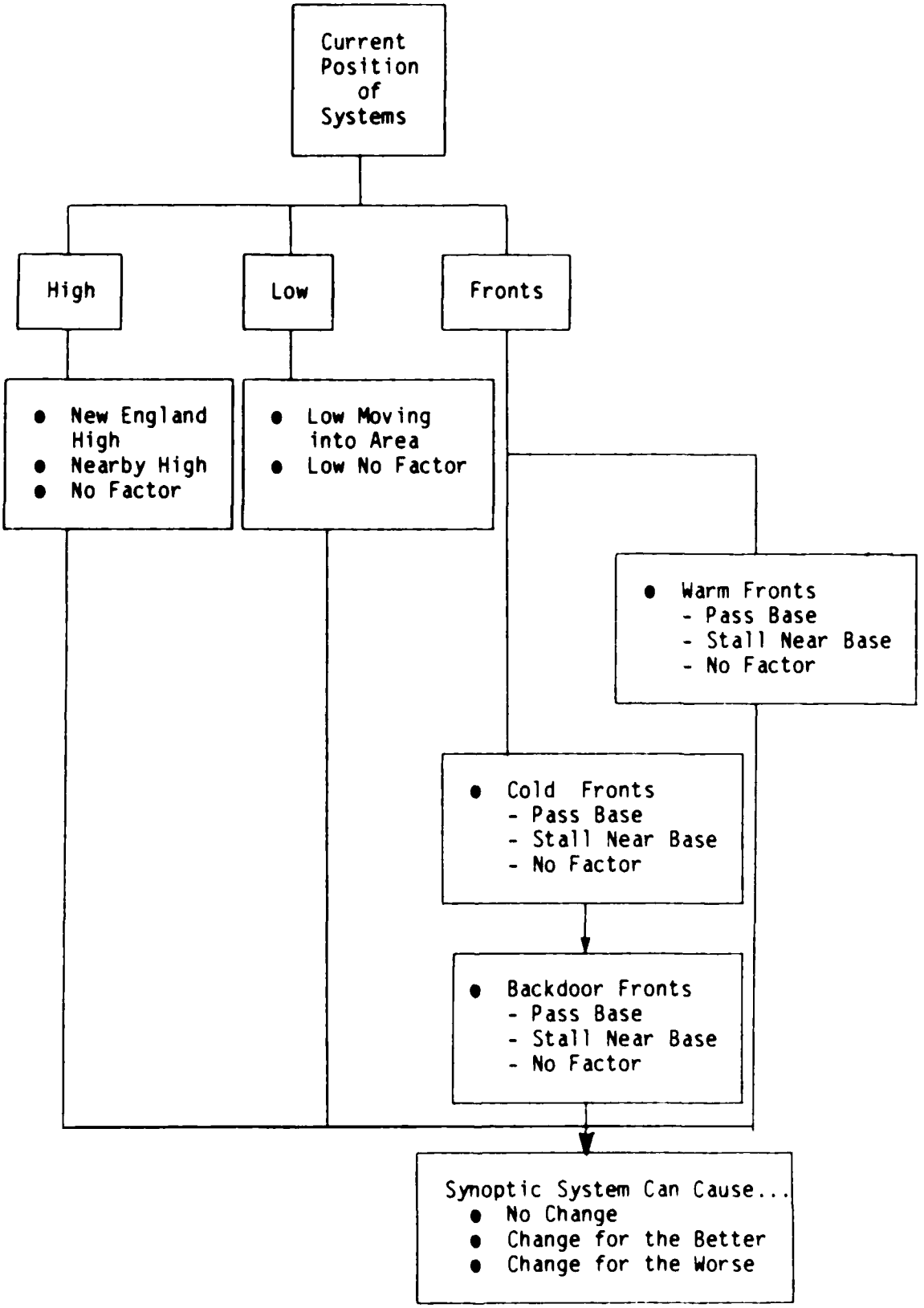


Figure 8. Conceptual model of synoptic features that are favorable for fog formation.

timing of highs moving into New England influences the occurrence of advection fog and should be included in any mid-Atlantic fog expert system.

In addition, this conceptual model forced us to begin to consider how the expert system would actually position the various synoptic systems (thus, the concept of "regions" that is introduced in Section 3.0).

The conceptual model also forced us to realize that synoptic systems can influence base weather in three common sense ways:

- Cause no change
- Cause a change for the better
- Cause a change for the worse.

For example, a cold frontal passage (continuous movement--no stalling) should cause a change for the better because these fronts tend to clear an area of existing weather. On the other hand, backdoor cold fronts (which slide down the East Coast from the north or northeast) usually cause a change for the worse because their passage allows for the advent of a moist northeasterly (oceanic) flow conducive to advection fog formation.

The major problem with the synoptic conceptual model is how to link or use the information in the other conceptual models. This is discussed in the knowledge representation section in terms of a hierarchy of operations.

As an indirect result of developing the conceptual synoptic model, we also began to realize that the fog problem needs to be carried through a full cycle. We began to examine how synoptic meteorology could affect the dissipation of fog and thus, developed the fog dissipation conceptual model.

2.1.5 The Fog Dissipation Conceptual Model

One interesting aspect of the fog forecasting problem that was initially neglected during the identification phase was the forecasting of fog dissipation.

Our literature search found several methods of predicting fog dissipation. All methods were based on daytime fog being dispersed by incoming solar radiation. At night, fog is typically decreased by outgoing radiation being cutoff by intervening clouds. Fog may be cleared anytime by either increasing the wind or advecting in drier air, both of which are characteristics of typical (nonstalling) cold fronts on the East Coast.

It appears from climatology that most radiation fogs in the coastal plain south of New Jersey "break" (visibility increases to greater than 1 mi) within 1 to 4 h after sunrise (18). Typically, the earlier the fog forms (and barring any changes), the denser it will be. East Coast nomograms of fog dissipation times based on density have been developed (18).

The conceptual dissipation model appears in Fig. 9.

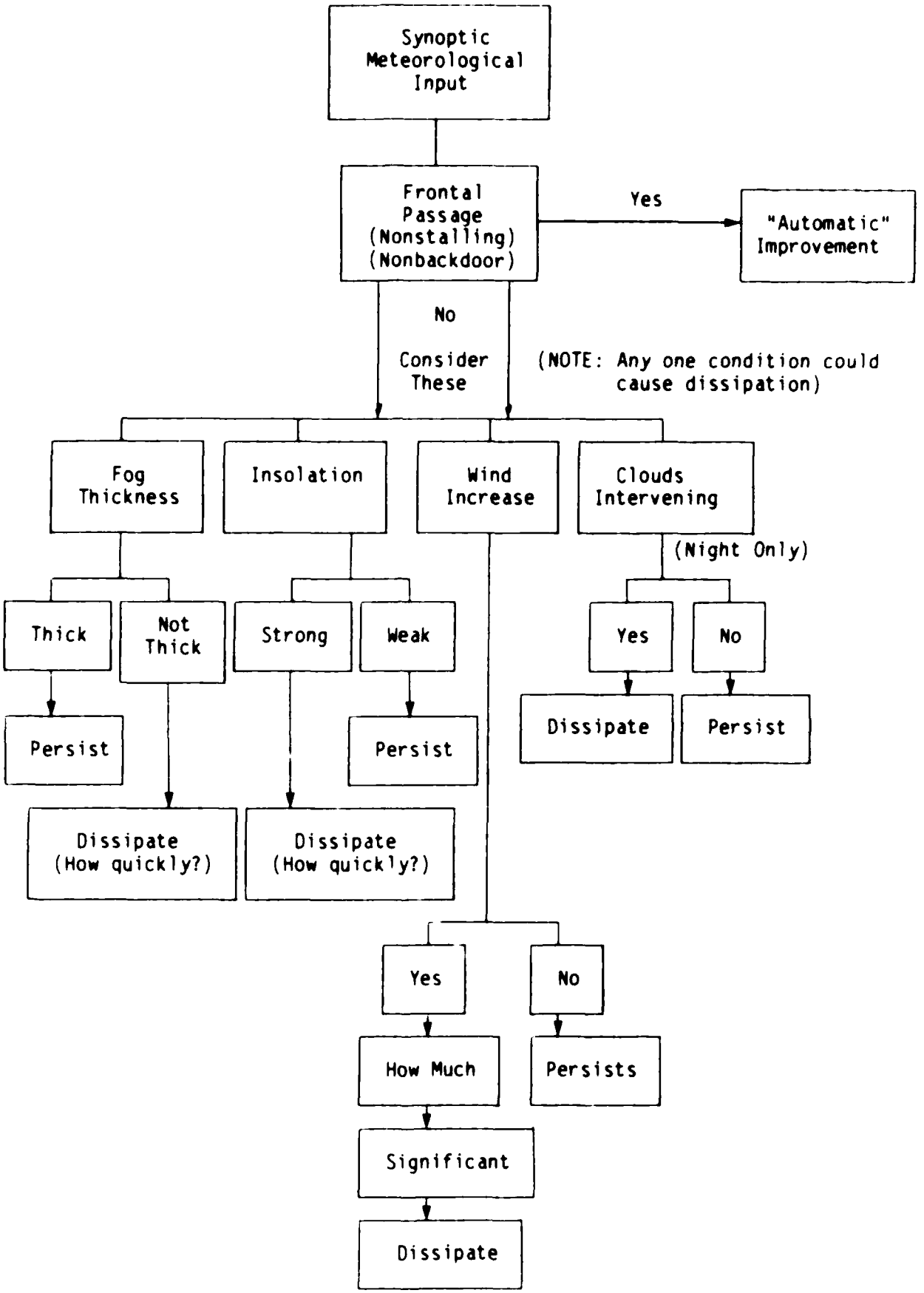


Figure 9. Conceptual model of fog dissipation (assume fog exists now).

The four conditions listed can either independently influence the dissipation of the fog or jointly affect dissipation. Key questions to be answered include how quickly will the fog dissipate and to what degree will the dissipation occur (improve to 1, 2, or 3+ mi)? Also, our conceptual model indicates an "automatic" improvement feature that allows for clearing after the passage of a cold front. This was the result of developing the change, no-change concept in the synoptic model.

We next examined the meteorology for each selected USAF base.

2.2 IDENTIFICATION OF BASE-SPECIFIC METEOROLOGY

Three bases (shown in Fig. 10) were selected for the expert system proof-of-concept evaluation. These bases and their accompanying weather code and USAF flight functions are:

- Dover Air Force Base (AFB), Delaware, DOV, MAC (C-5, C-130)
- Seymour Johnson AFB, North Carolina, GSB, TAC (F-4, KC-135, KC-10)
- Simmons Army Airfield (Fort Bragg), North Carolina, FBG (helicopters).

Various visibility criteria were obtained from the Terminal Forecast Reference Notebook (TFRN) for each base and are listed in TABLE 3. These criteria were subsequently modified slightly to reflect the more general categories that appear in TABLE 4.

A brief description of base-specific meteorology appears below.

2.2.1 Dover AFB (DOV)

Dover AFB is located approximately 4 mi southeast of Dover and is 28.6 ft above sea level. The Delaware Bay is 3 mi to the east and the Chesapeake Bay lies 35 mi to the west (see Fig. 11). The Atlantic Ocean at the mouth of the Delaware Bay is 25 mi southeast. With the proximity of water nearby, there is great concern over advection fog.

Beginning with the microscale, the base sits on the southern end of a slight ridge. Slight cold air drainage is experienced on cloud-free nights with light winds. According to the TFRN, this effect occasionally keeps the marshes around the base covered with radiational fog while the base itself is free of fog.

The TFRN also mentions the following factors pertaining to fog conditions:

- Winds from the southwest through north rarely produce fog

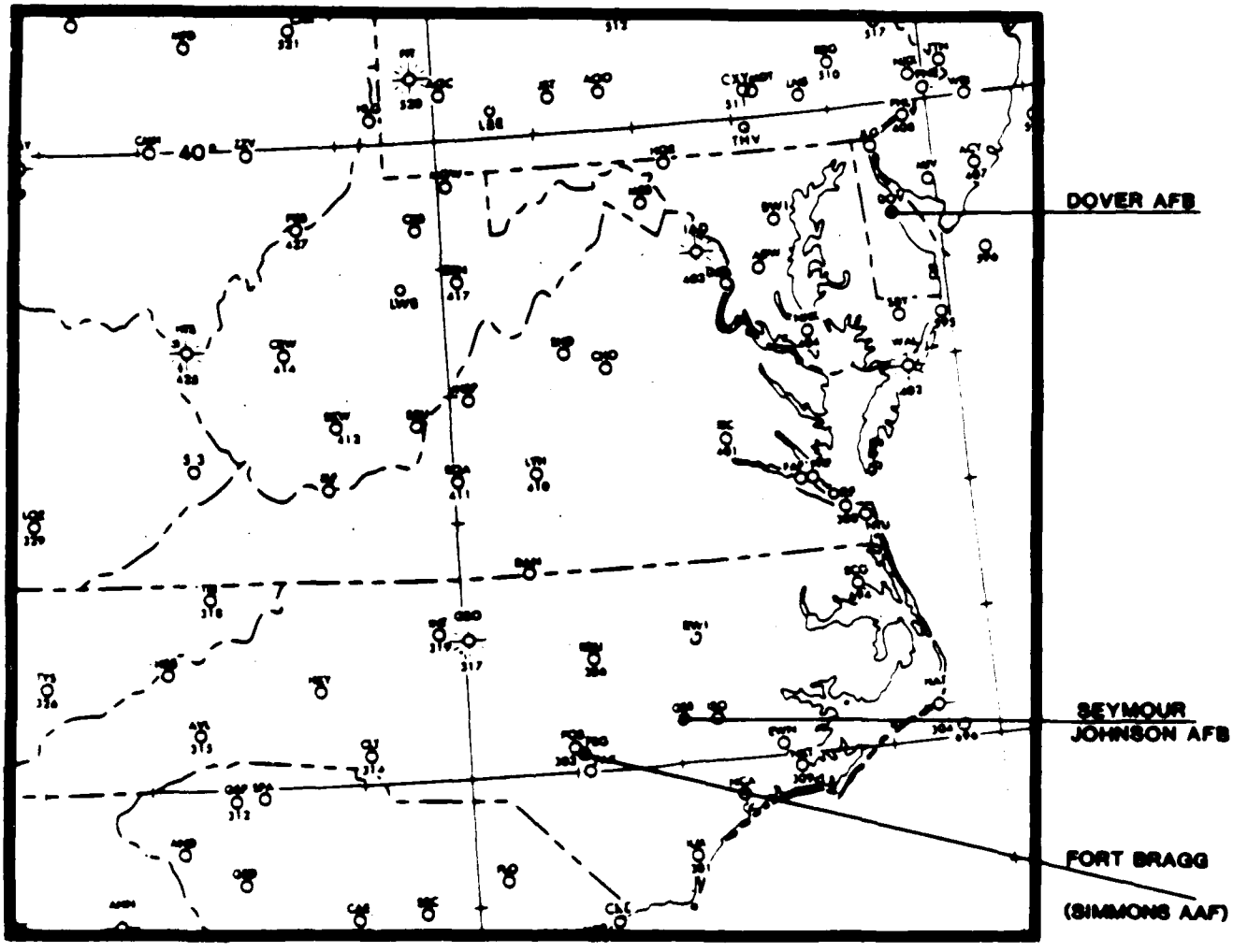


Figure 10. Location of three study airbases.

TABLE 3. Visibility Criteria for the Three Selected Airbases (Source: Base Terminal Forecast Handbooks or Weather Support Plans).

Ceiling/Visibility	Result/Implication
Seymour Johnson Air Force Base (GSB) Criteria	
3000/5	Flight control checks limited
3000/3	VFR limitation
1500/3	Category E pilot mission minimums (defined as a pilot with all initial and sequential training prior to formal instrument evaluations)
700/2	Category D pilot mission minimums (defined as a pilot having completed instrument evaluation)
500/1.5	Category C pilot mission minimums (defined as a pilot having 50 actual flying hours, and 500 total hours)
100/0.25	Absolute airfield minimum
KC-10 tanker minimums are not yet available.	
Fort Bragg (Simmons) Army Air Field (FBG) Criteria	
300/3/4	Base minimums
Dover Air Force Base (DOV) Criteria	
1000/2	Training mission minimums
200/1/2	Landing minimums

TABLE 4. Modified Airbase Visibility Criteria for this Study.

GSB and FBG	
Visibility	Zeus Category
$\geq$ 3	3
$\geq$ 1 and < 3	2
< 1	1

DOV	
Visibility	Zeus Category
$\geq$ 2	3
$\geq$ 1/2 and < 2	2
< 1/2	1

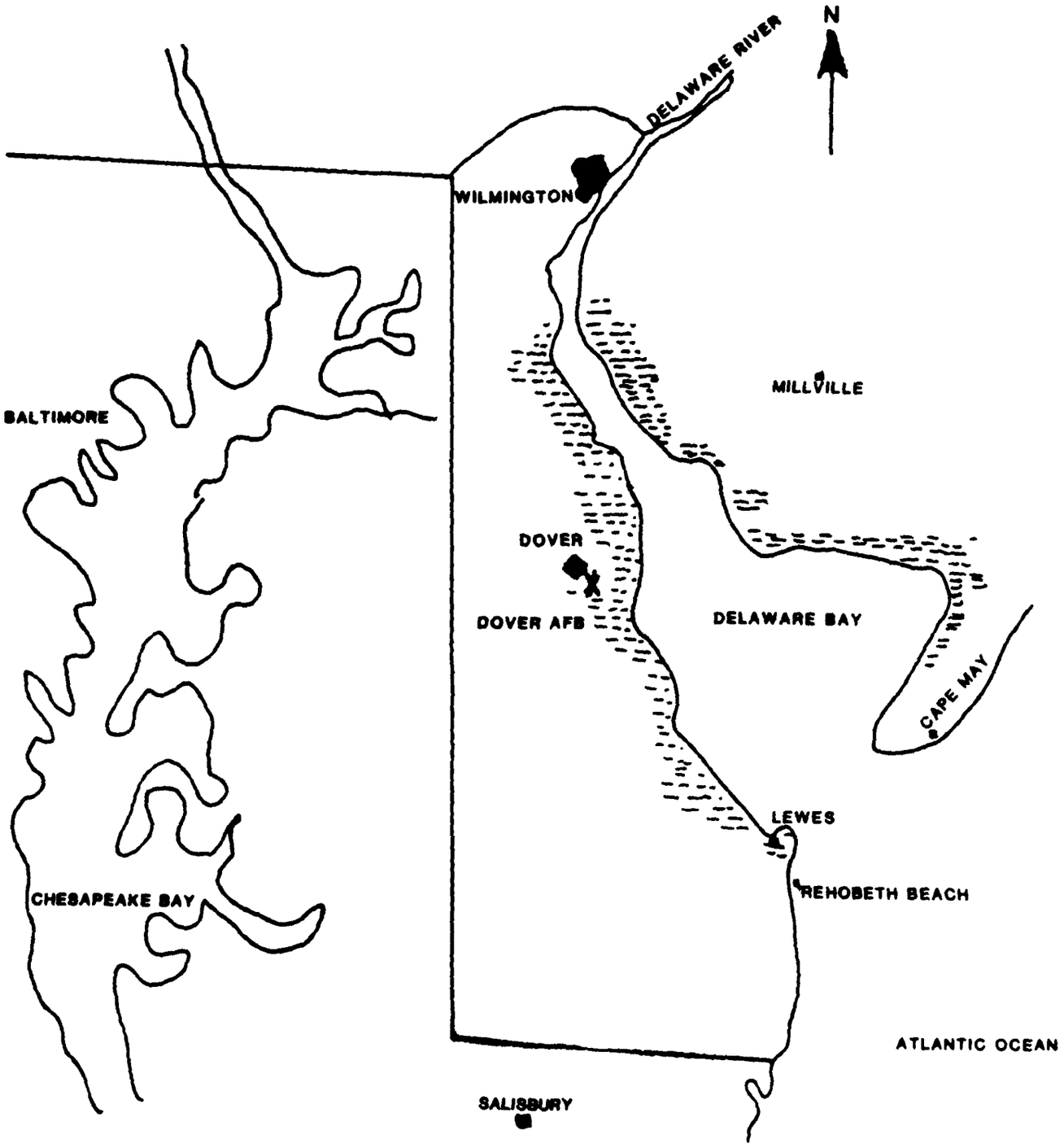


Figure 11. Dover AFB location.

- Summertime sea breezes add to the moisture concerns in the boundary layer and hence, to the possibility of fog.

In general terms, spring is a transition time with several backdoor cold frontal passages resulting in periods of dense fog. During early spring, land-sea temperatures are basically equivalent, but the conflict between the retreating Labrador nearshore oceanic current and the Gulf Stream produces advection fog. Radiation fog, which is moved into the area from offshore waters, is less common.

The Bermuda High causes radiation fog and haze conditions in the summer with average dewpoints in the 60s. Visibilities typically drop to 2 to 3 mi in fog and haze overnight, except in early September where sea surface temperatures become, on an average, warmer than the daily minimum. Therefore, southeasterly winds at Dover would, in late summer and early fall, transport warm moist air over cooler land, thus causing fog.

This fall-type condition persists through winter and into early spring with the daily maximum temperature typically falling well below the sea temperature. This, in turn, causes widespread fog (and stratus) that may be hard to break.

Statistics from the AWS Climatic Station Brief indicate that visibility due to fog alone (fog alone carried on the hourly or special observation) occurs annually at a mean rate of 183 days in an average year. TABLE 5 gives a breakdown by month of the mean number of fog days per month; TABLE 6, also taken from the AWS Climatic Briefs, gives a further breakdown of ceiling and visibility category by percentage and cross referenced by month (and time). From both tables, it appears that the highest incidences of fog (climatologically) appear in summer and early fall, and as common meterological sense would dictate, occur with maximum frequency between 6 a.m. and 8 a.m.

2.2.2 Seymour Johnson AFB (GSB)

Seymour Johnson AFB is located in the western section of the North Carolina coastal plain at an elevation of 109 ft. Terrain varies from 50 to 200 ft around the base. The base is located approximately 125 mi from the ocean. Regionally, the base is influenced by downslope winds from the northwest. Converserly easterly winds tend to "dam" the air up against the Appalachians and cause low ceilings and precipitation. Fig. 12 from the TFRN, depicts the larger regional scale terrain features. The base weather is locally influenced by the Neuse River, which is located near the west end runway 08/26. Fog typically forms over the river and could possibly advect over the field depending on the wind direction.

The TFRN, along with other base-specific guidance documents, indicate several key parameters for determining low visibility. They are:

- Temperature, dewpoint, and dewpoint spread

TABLE 5. Dover AFB Low Visibility Climatology.

Month	Mean number of days of fog
January	13
February	12
March	14
April	13
May	16
June	16
July	18
August	20
September	18
October	16
November	14
December	13
Total	183

Note: Based on 32 years of data.

TABLE 6. Percent Frequency of Low Visibility/Ceiling by Two Hourly Periods (by Month).

NOTE * DATA NOT AVAILABLE		# ABTS < UNITS SHOWN IN HEADING				** INSTANTANEOUS PEAK WINDS		§ % CALM SETS % PLYS OBSTN				# BASES OR < FULL MONTHS		
CAV FREQ(%)	HRS LST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
CEILING LESS THAN 3000 FT AND/OR VISIBILITY LESS THAN 3 mi	00-02	19	17	19	14	21	12	15	11	15	18	20	16	16
	03-05	21	18	20	14	24	20	23	19	20	20	22	18	20
	06-08	22	19	23	16	26	21	26	28	24	23	24	19	23
	09-11	17	19	21	13	23	18	14	15	16	16	21	17	18
	12-14	17	18	20	12	18	10	9	9	12	11	17	16	14
	15-17	19	16	19	11	14	8	7	7	10	11	16	16	13
	18-20	17	16	18	10	17	9	10	7	9	11	16	17	13
	21-23	16	16	17	12	18	10	10	8	10	14	19	17	14
	ALL HRS	19	17	20	13	20	14	14	13	15	16	19	17	16
CEILING LESS THAN 1000 FT AND/OR VISIBILITY LESS THAN 3 mi	00-02	15	15	14	11	18	10	14	9	11	15	15	13	13
	03-05	17	15	17	12	22	17	21	15	16	16	16	14	17
	06-08	18	16	19	14	23	17	24	25	19	20	19	15	19
	09-11	14	15	15	12	16	12	9	10	10	13	15	13	13
	12-14	14	13	14	10	10	7	4	4	5	7	12	12	9
	15-17	14	11	15	7	9	5	4	3	4	7	11	10	8
	18-20	13	12	15	7	12	7	7	6	6	7	10	13	10
	21-23	11	13	13	8	15	8	8	7	8	9	14	13	11
	ALL HRS	15	14	15	10	16	10	11	10	10	12	14	13	13
CEILING LESS THAN 1000 FT AND/OR VISIBILITY LESS THAN 1 mi	00-02	12	13	13	8	14	7	9	4	7	11	12	10	10
	03-05	13	12	15	10	17	11	13	9	11	14	14	10	12
	06-08	12	13	15	11	16	11	14	13	13	15	15	11	13
	09-11	10	12	13	9	10	6	5	4	5	9	11	10	9
	12-14	10	9	11	7	6	3	1	1	2	5	9	9	6
	15-17	10	8	10	6	5	3	1	1	2	6	7	8	5
	18-20	9	9	12	5	8	5	4	3	4	6	8	9	7
	21-23	9	10	11	6	12	6	5	3	5	6	11	10	8
	ALL HRS	11	11	13	8	11	7	7	5	6	9	11	10	9
CEILING LESS THAN 200 FT AND/OR VISIBILITY LESS THAN 1/2 mi	00-02	2	4	3	2	2	1	1	1	1	4	3	2	2
	03-05	3	5	3	3	4	3	2	3	3	5	4	2	3
	06-08	3	4	3	3	2	1	1	2	3	4	5	2	3
	09-11	1	2	1	2	0	0	0	0	0	0	2	1	1
	12-14	1	2	0	0	0	0	0	0	0	0	0	0	0
	15-17	0	1	0	0	0	0	0	0	0	0	1	0	0
	18-20	1	2	2	0	1	0	0	0	0	0	2	1	1
	21-23	2	4	1	1	1	1	1	0	1	1	4	1	2
	ALL HRS	2	3	2	1	1	1	1	1	1	2	3	1	2

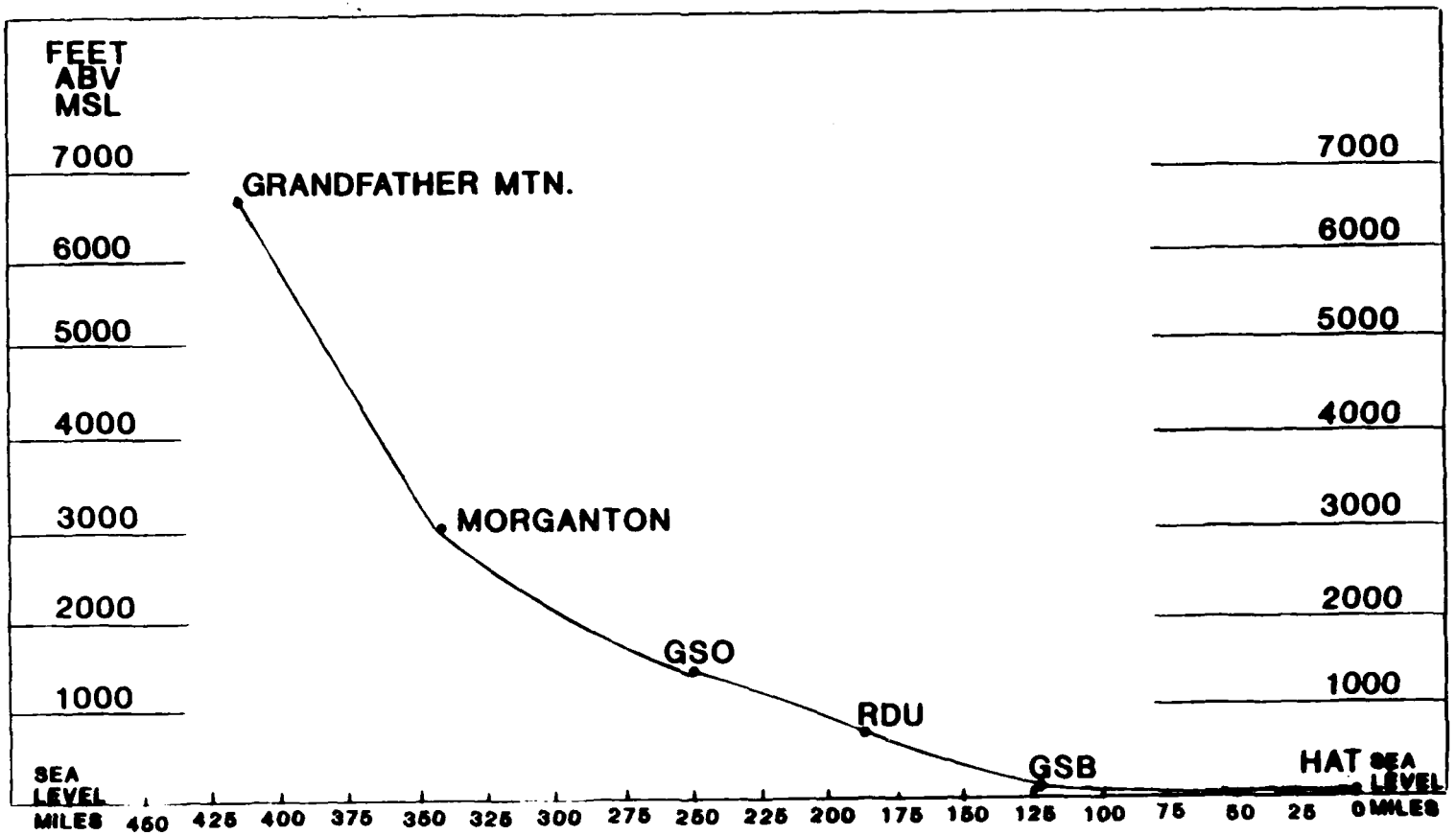


Figure 12. Regional map (profile view) of Seymour Johnson's elevation relationship to the rest of North Carolina.

- Sky cover (overnight)
- Wind direction and speed
- Precipitation.

A search of a more detailed climatological record of fog by month (19) revealed some interesting aspects of Seymour-Johnson fog.

In January (based on 8 year's worth of data), 83 percent of the below 2 mi occurences were associated with precipitation the previous day and it was noted that most fogs were radiational in nature. This trend continued throughout the winter (81 percent occurrence in February, 89 percent in March) with dewpoint spread becoming increasingly important.

In the spring, fog forecasts are influenced by advection of maritime air down the coast due to backdoor cold fronts. Advection fogs appear to dominate during this time of the year.

In the summer, light winds promote radiation fog with numerous cases of persistent radiation fog noted. Radiation fog lifting to haze (2 to 3 mi) by midday is also a common problem. The Neuse River also causes problems in late summer-early fall in terms of acting as a generator of local fog banks.

Light winds continue to be a major factor contributing to fog in the fall with many instances of cold fronts followed by stagnant large areas of high pressure that can persist over the area for days.

Statistics from the AWS Climatic Brief indicate that visibility due to fog alone occurs annually at a mean rate of 202 days. TABLE 7 provides a breakdown, by month, of the mean number of fog days; TABLE 8 gives a further breakdown of ceiling and visibility category by percentage and cross-referenced by time and month. Both tables indicate that the dominate fog occurrences are in late summer-early fall with the time of occurrence between 6 a.m. and 8 a.m. with a secondary maximum between 3 a.m. and 5 a.m.

2.2.3 Simmons AAF (Fort Bragg) (FBG)

Simmons AAF is located approximately 20 mi from Pope AFB in the vicinity of Fayetteville, North Carolina. The elevation is 242 ft. Simmons is located geographically within the transition zone between the coastal plains and Piedmont Plateau of North Carolina.

The Atlantic Ocean ranges from approximately 170 nmi east-northeast of the base to approximately 80 nmi southeast of the base. Several ponds and potential cold air drainage flow areas surround the base.

TABLE 7. Seymour Johnson AFB, Low Visibility Climatology.

Month	Mean number of days of fog
January	13
February	12
March	13
April	12
May	18
June	19
July	22
August	23
September	22
October	14
November	16
December	13
Total	202

Note: Based on 22 yr of data.

TABLE 8. Percent Frequency of Low Visibility/Ceiling by Two Hourly Periods (by Month).

CAT FREQ (%)	HRS LST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
CEILING LESS THAN 200 FT AND/OR VISIBILITY LESS THAN 1/2 MI	00-02	2	2	2	0	0	0	0	1	1	0	1	2	1
	03-05	2	2	3	2	1	2	1	3	4	3	4	4	3
	06-08	1	1	5	1	2	2	2	5	6	5	3	3	3
	09-11	1	1	0	0	0	0	0	0	0	0	0	1	0
	12-14	0	1	0	0	0	0	0	0	0	0	0	0	0
	15-17	0	1	0	0	0	0	0	0	0	0	0	0	0
	18-20	1	1	0	0	0	0	0	0	0	0	0	1	0
	21-23	2	1	0	0	0	0	0	0	0	0	1	1	0
	ALL HRS	1	1	1	0	0	1	0	1	1	1	1	2	1
CEILING LESS THAN 1000 FT AND/OR VISIBILITY LESS THAN 2 MI	00-02	16	11	12	7	8	6	4	5	8	6	10	11	9
	03-05	15	11	16	9	15	16	15	17	19	15	13	13	15
	06-08	17	12	16	12	19	20	18	27	28	21	16	14	19
	09-11	15	12	14	5	6	4	5	5	8	7	10	12	9
	12-14	12	6	10	2	3	1	1	2	3	2	5	9	5
	15-17	10	7	7	2	2	2	1	1	1	2	4	9	4
	18-20	12	8	8	3	2	2	2	1	3	2	5	9	5
	21-23	15	10	10	4	4	2	2	2	3	3	7	10	6
	ALL HRS	14	10	12	6	7	7	6	8	9	7	9	11	9
CEILING LESS THAN 3000 FT AND/OR VISIBILITY LESS THAN 3 MI	00-02	20	14	14	9	11	9	7	9	12	11	12	14	12
	03-05	20	13	19	12	22	23	23	28	29	22	16	17	20
	06-08	22	14	22	16	24	26	27	39	37	28	21	19	25
	09-11	19	14	19	9	11	9	9	9	14	12	12	15	13
	12-14	16	12	14	4	5	4	3	3	6	4	7	13	8
	15-17	14	10	9	4	4	3	2	3	3	3	7	11	6
	18-20	16	11	11	4	5	4	5	3	4	4	9	10	7
	21-23	19	12	12	5	5	4	4	4	4	5	10	12	8
	ALL HRS	18	13	15	8	11	10	10	12	14	11	12	14	12
CEILING LESS THAN 7000 FT AND/OR VISIBILITY LESS THAN 5 MI	00-02	26	18	16	11	15	12	6	11	13	10	15	17	15
	03-05	25	18	23	16	25	26	24	29	31	26	19	21	24
	06-08	27	18	27	21	27	28	29	40	40	32	23	25	28
	09-11	23	17	24	14	19	15	14	16	18	17	16	23	18
	12-14	21	16	21	11	12	9	8	9	11	9	13	20	13
	15-17	20	15	15	7	8	7	5	6	8	8	10	17	11
	18-20	22	14	16	6	8	8	7	6	9	8	11	16	11
	21-23	24	15	15	7	9	8	6	7	9	8	12	17	11
	ALL HRS	23	16	20	12	15	14	13	16	17	15	15	19	16

During the latter part of spring, through summer, and into early fall, radiation fog appears to dominate over advection fog. There appears to be nothing unusual about these radiation fogs other than the TFRN noting that radiation fogs are typically thin. Summertime haze is also present on many days. Summertime fogs also form after rainshowers, particularly with southwest flow.

Later in the fall and throughout the winter, advection fogs begin to dominate. The fogs are caused by a combination of an easterly gradient transporting warm moist air inland from the coast and the associated slight upslope motion (0 to 242 ft). Easterly gradients are typically caused by highs located in the New England area. Thus, care is needed to determine whether a true easterly gradient exists, as occasionally easterly winds in a tight gradient may not have an Atlantic trajectory. Steam fog may also form over many of the nearby drop zones (due to the presence of the ponds) and never affect the base itself.

Statistics from the AWS Climatic Brief indicate that visibility due to fog alone occurs annually at a mean rate of 200 d in an average year. TABLE 9 provides a breakdown, by month, of the mean number of fog days; TABLE 10 gives a further breakdown of ceiling and visibility category by percentage, cross-referencd by time and month. An examination of both tables reveals that the highest incidence of fog (climatologically) appears in midsummer with July and August being the highest months. The most critical time for fog appears to be from 6 a.m. to 8 a.m., although it is interesting to notice in TABLE 10 the flattening of the percent data in February to a broad peak between 6 a.m. and 11 a.m., thus indicating in a general sense the problem of advection fog dissipation.

2.3 IDENTIFICATION OF BASE WORK CONCERNS

Toward the end of the identification stage we began to list various possible problems that the bases could have in forecasting fog. These problems or factors were not directly related to the meteorology itself (i.e., the physics), but instead to some of the human factors that go into creating a forecast. The factors can therefore be called human system design concerns. The factors appear in TABLE 11.

Perhaps the greatest factor that we could get a sense of during this identification phase was the hurry factor. (This subsequently was confirmed over and over during the later knowledge acquisition phase, and thus, had a major impact on system design.)

The hurry factor involves a combination of each base preparing three to four TAFs a day (see TABLE 12) interspliced with a constant need to brief aircrews and ground operations on enroute or base weather. In addition, there are administrative, maintenance, and training requirements for many base AWS personnel. The hurry factor could cause a vital piece of information

TABLE 9. Simmons AAF Low Visibility Climatology.

Month	Mean number of days of fog
January	15
February	12
March	14
April	11
May	18
June	19
July	22
August	23
September	21
October	16
November	14
December	15
Total	200

Note: Based on 17 yr of data.

TABLE 10. Percent Frequency of Low Visibility/Ceiling by Two Hourly Periods (by Month).

CAT FREQ (%)	HRS LST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
CEILING LESS THAN 3000 FT AND/OR VISIBILITY LESS THAN 3 MI	00-02	25	19	18	18	19	11	8	10	14	11	14	19	16
	03-05	26	16	22	16	23	21	19	23	24	18	17	21	21
	06-08	30	19	25	19	29	29	31	38	38	23	20	24	27
	09-11	29	20	23	14	21	19	17	20	21	16	17	21	20
	12-14	25	17	18	8	13	11	10	10	15	11	13	20	14
	15-17	21	14	13	4	8	8	5	5	9	7	11	17	10
	18-20	21	12	15	4	7	7	7	6	9	6	10	15	10
	21-23	22	14	16	6	8	8	6	8	11	7	13	17	11
	ALL HRS	25	16	19	10	15	14	13	13	16	12	14	19	16
CEILING LESS THAN 1000 FT AND/OR VISIBILITY LESS THAN 3 MI	00-02	19	12	15	8	10	8	7	8	10	8	11	16	11
	03-05	22	12	18	12	18	18	17	21	20	14	14	17	17
	06-08	27	16	21	15	23	26	29	37	33	20	18	20	24
	09-11	24	17	20	8	12	10	10	13	14	11	15	18	14
	12-14	19	13	13	3	6	3	3	4	5	4	8	15	8
	15-17	15	10	10	3	5	4	2	2	4	2	7	13	6
	18-20	16	10	12	3	5	4	4	4	5	3	8	11	7
	21-23	18	11	13	5	6	6	6	6	6	3	9	13	8
	ALL HRS	20	13	15	7	11	10	10	12	12	8	11	15	12
CEILING LESS THAN 500 FT AND/OR VISIBILITY LESS THAN 1 MI	00-02	13	10	12	6	8	6	5	5	8	3	10	15	9
	03-05	18	9	16	8	15	13	12	16	15	9	12	15	13
	06-08	23	12	19	11	19	19	20	26	24	14	15	16	18
	09-11	20	13	16	4	8	4	3	7	9	7	11	15	10
	12-14	15	9	10	2	3	1	1	2	3	2	6	12	6
	15-17	12	8	7	2	3	2	1	2	3	1	5	11	5
	18-20	13	8	9	3	3	2	2	3	3	2	6	10	5
	21-23	14	9	11	3	4	3	3	3	5	2	7	12	6
	ALL HRS	16	10	13	5	8	6	6	8	9	5	9	13	9
CEILING LESS THAN 200 FT AND/OR VISIBILITY LESS THAN 1/2 MI	00-02	2	3	1	1	1	0	1	0	0	0	1	3	1
	03-05	3	2	4	1	3	2	2	4	1	2	3	3	3
	06-08	4	2	3	2	2	3	3	7	5	4	3	4	4
	09-11	2	2	1	0	0	0	0	0	0	0	1	2	1
	12-14	0	1	0	0	0	0	0	0	0	0	0	1	0
	15-17	1	1	0	0	0	0	0	0	0	0	0	1	0
	18-20	1	1	0	0	0	0	0	0	0	0	0	1	0
	21-23	2	1	0	1	0	0	0	0	0	0	1	2	1
	ALL HRS	2	2	1	1	1	1	1	1	1	1	1	2	1

TABLE 11. Key Factors That Could Cause Fog Forecast Error.

I. The Hurry Factor

A. Vital parameter not considered

B. Inadequate preparation of the forecast

1. Careless forecaster worksheet preparation
2. Lack of forecast continuity
3. Collection of data incomplete

II. Increased Data Factor

1. Forecaster misled by additional or special observation information after forecast time

III. The Bust Fear Factor

1. Forecaster hedges on forecast ("sits on the fence") for fear of missing or busting

IV. Logical Factor

1. No way the forecast could have logically been made

V. Carelessness Experience Factor

1. Pure carelessness or lack of experience in making a fog forecast.

TABLE 12. Summary of TAF Times for the Selected Airbases.

Base	Times (Zulu)			
Dover (DOV)	0400	1000	1600	2200
Seymour Johnson (GSB)	0400	1000	1600	2200
Fort Bragg (FBG)	1000	1600	2200	

NOTE: TAFS can be amended as needed.

to be missed or a whole train of thought to become discarded. For example, a forecaster may immediately notice a severe weather threat due to dry air intrusion at 700 mbar, but he/she (in turn) may skip over (due to priorities) the fact that conditions later may be favorable for fog.

Therefore, an expert system could solve many of these factors with special emphasis on the lack of time and corresponding quantity of resources that a forecaster needs to prepare the TAF.

2.4 IDENTIFICATION OF AVAILABLE COMPUTER RESOURCES

Our final step in identifying domain characteristics was to categorize and then select AI software that could create the expert system.

The three airbases all have Zenith Z-100 microcomputers with 256 K memory, monochrome displays, dual disk drives and various printer configurations.

The Z-100 is not a directly PC-compatible machine, thus posing some problems in software selection. The following two subsections describe efforts to identify the appropriate AI software to begin KBES development.

2.4.1 AI/KBES Development Software--Overview

The purpose of this subsection is to briefly review the various expert system development tools and to present our strategy in selection of the proper tool. Expert system development tools can be viewed as software packages that aid in the creation of the expert system. Basically, there are two general software methods to create an expert system:

- Computer languages
- Compiled AI/KBES shells.

Purely AI-oriented computer languages center around the use of languages called LISP (LISt Processing) and PROLOG (PROgramming language for LOGic). Both languages compute with symbolic expressions rather than numbers. In fact, PROLOG is more logic-oriented than LISP and includes declarative and procedural styles of programming.

Other languages that are not purely AI oriented but have been used for building expert systems include FORTRAN, PASCAL, and C. GEOMET is currently, for example, examining a PC version of a KBES written in PASCAL that determines enemy course of action. The C language is also now being viewed as a very popular AI-oriented language primarily because of its speed and reverse notational capabilities.

A KBES shell is a "canned" software package that aids in expert system development through input of rules and knowledge much like Lotus aids in graph creation through data input by the user. Many shells now exist on the market; however, certain criteria can be established to screen these shells prior to deciding on the software.

2.4.2 Computer Language Expert System Development Approaches

An AI computer language approach in expert system development has several advantages over using a shell approach:

- Flexibility in program development
- Flexibility in editing/debugging
- Built-in functions (called primitives).

The greatest advantage in using this approach is in the flexibility of the overall system or module development.

LISP, which was invented in 1954 at MIT, represents data as list-linked structures. Almost everything in LISP revolves around developing these list structures, but LISP (unlike FORTRAN) has never been standardized. This is because there are only a few basic LISP functions and the programmers can create any number of higher level functions using the small number of basic functions.

The flexibility of the LISP language has led to programming advancements designed to address a user-specific problem or special computing environment. Thus many variations of LISP exist (for both PC and mainframe use) including:

- IQLISP (PC and mainframe)
- Common LISP (IBM PC-AT, 1M RAM, large memory, and mainframe)
- TLCLISP (PC and mainframe)
- BYSOLISP (mainframe)
- InterLISP (PC and mainframe).

Basically LISP has two data structures, atoms and lists. An atom is an object that cannot be broken down any further, thus, it is typically a name or number. Lists in turn are composed of atoms (or in some cases other lists). Recursive procedures, involving searching through lists until the unknown atom is found or until a question needs to be asked of the user, is also a highly desirable feature of LISP.

PROLOG, which was invented in France in 1972 and is the principal Japanese Fifth Generation and European AI language, has seen a recent (mid-1985 to present) surge in use in the United States. PROLOG is based on the concept of predicate calculus. To invoke predicate calculus reasoning a programmer first specifies facts about objects and relationships. He/she then establishes linkages regarding the objects and relationships. The programmer states the facts and PROLOG structuring determines whether any specific conclusion can be deduced from the facts. PROLOG is therefore the closest language that represents true logical deduction. PROLOG also uses a form of "backward chaining" where it searches for a match of conditions that meet the conclusion. Primatives (inherent functions) and atoms also exist in PROLOG.

Several PC versions of PROLOG exist including:

- Micro-PROLOG
- PROLOG 1/2
- MPROLOG
- Arity PROLOG.

One of the widely used PC-oriented PROLOGs is called Arity PROLOG. Arity features include:

- String support
- Speed
- Primitive resources
- Linkages to external programs.

The string text support provided by the Arity compiler and interpreter goes beyond the atom level. This means that phrases or concatenations can be supported. Arity is the fastest micro-based PROLOG compiler available and has the ability to handle arithmetic, floating point, and computational quantities. Arity also has the inherent capability of over 150 primitives, which in itself is an aid to a programmer. Arity also provides for linkages to other programming languages such as C, Assembly, FORTRAN, PASCAL, or even LISP.

A separate specialized expert system development package that is included with the Arity PROLOG compiler and interpreter allows the creation of modules either using a frames-based architecture or a rules-based architecture. The rules-based architecture is geared, however, not toward the true if-then structure but to deriving rule values from other frames. Frames and rules will be further explained in the knowledge representation sector. The

Arity expert system development package requires the PROLOG compiler and interpreter. Unfortunately, as in most PROLOG-compiled systems, Arity is memory hungry. A minimum of 512 K memory is required on an IBM PC-AT with 640 K memory recommended.

2.4.3 The KBES Shell (Tool) Expert System Development Approach

As part of this and other AI efforts, we have and continue to update market surveys of current software shells. Several larger shells (sometimes called "tools"), which require discussion, exist in the marketplace. These larger shells or "tools" are:

- Knowledge Engineering System (KES)
- Automated Reasoning Tool (ART) and other "large system" shells
- Knowledge Engineering Environment (KEE).

KES

KES contains backward chaining, but no forward chaining, and has hypothetical reasoning and object description. KES cannot be imbedded into other systems. KES is sold in pieces but generally does not include an editor, which is a major user-friendly drawback. KES is really like a batch file expert system where the knowledge base is written using (for example) WORDSTAR and then compiled in KES. This really slows down and complicates the development process. KES is compiled in various forms of LISP.

ART and Other "Large System" Shells

ART is available on LISP computers (Symbolics, Xerox, etc.). ART is more oriented toward a primary expert system tool and can perform backward and forward chaining. ART consists of four components: a knowledge language, a compiler, an applier, and a development environment.

The drawbacks in using ART for this application are twofold: (1) ART cannot be easily transported from its resident LISP machine down to a PC and (2) ART is too knowledge-engineer-oriented for the proof-of-concept task requirement.

The downloading of expert systems created by ART (or other similar creation language shells such as OPS5 or ROSIE) on larger machines to a PC is a difficult and laborious task. The steps involved are:

1. Scale down and recompile rules on the large system
2. Download (modem hookup) to PC
3. Recompile rules with a LISP compiler on PC (and hope for the best).

Each step is filled with challenges such as how to scale down object-attribute values (or ART quantifiers) for transport without losing the larger system hierarchical intent. Each step also takes a considerable amount of time, which can be better used to refine a resident (originally based) PC system.

Also, many larger or specialized machine expert system tools are too purely AI-oriented. Certainly arguments can be made that changes to large meteorological automated system be made on one large machine and then sent to the base PCs; however, each change to the PC version coming down from the larger machine must proceed through the three difficult and time-consuming steps above. This is not to say that this can't be done, just that it goes beyond the purpose of a proof-of-concept. In addition, any minor (three- to five-rule) base-specific changes must be sent through the large machine, and hence through the three steps rather than the easier route, which could allow the base itself (or the knowledge engineering team) to quickly make changes on the spot. Extensive training is necessary to use ART.

KEE

Another tool is Knowledge Engineering Environment (KEE), which is a forward and backward chaining system with hypothetical reasoning. KEE also provides full object description using frames. KEE has PC application problems similar to ART because it must be transported from specialized LISP machines such as the Xerox 1100 or Symbolics 3600 series down to the PC level. KEE is also very complicated and extensive training is necessary.

Many smaller shells specifically for PC application exist and are described below. These shells are:

- The Intelligent Machine Model (TIMM)
- Rulemaster
- Expert Ease
- Personal Consultant/Plus
- Insight 2 Plus
- M1.

TIMM

TIMM has forward chaining, but no backward chaining, which puts it at a great disadvantage for meteorological users. Objects are described in terms of attributes of a single problem. The base language is FORTRAN 77,

which makes TIMM much slower than other systems. TIMM is more examples based, where each set of examples forms a matrix and each matrix is a rule. This approach could cause problems in knowledge representation and acquisition. A similar system called KIBASE can run on a Symbolics (larger machine) or a PC, but has the same problems as TIMM and the same inherent transfer problems as ART.

Rulemaster

Rulemaster is a simplified form of machine intelligence because the only logic is in a decision-tree format. Forward chaining is not supported. Rulemaster was originally imported from England where decision-tree induction was a popular format in the late 1970's. Unfortunately, the decision-tree-examples format is the only problem solver provided and this could pose problems for our application, particularly in the synoptic area, where much time could be wasted in determining proper examples and then finding out that the examples selected are incomplete. A second negative factor involves the use of the radial language, which requires completion each time code is changed. These two factors have been a major drawback in the knowledge acquisition and consequent representation process of Rulemaster ever since its importation into the United States.

Expert Ease

Expert Ease has no backward or forward chaining but operates like Rulemaster in that it is a simplistic, decision-tree-examples problem solver. Expert Ease recently failed a NASA sample expert system development problem and is viewed by the AI community as a simplistic first-time expert system learning tool, which is not appropriate for full-scale expert system development.

Personal Consultant/Plus

This system uses forward and backward chaining in both system versions (regular and plus) and uses the object-attribute-value scheme of (described in Section 3.0) representing rules. Personal Consultant, however, is not very user friendly when producing rules and even though the system has facilities for the "unknown" response to a question, reasoning with "unknown" is somewhat hampered by the internal program structure.

Insight 2 Plus

Insight represents rules in either attribute value or object-attribute-value triplets. Insight 2 has recently been updated to Insight 2 Plus; Insight 3 is the VAX version, which will be available later in 1987. Insight 2 Plus is a goal-driven shell only that has had several problems associated with memory requirements during various recent NASA tests. Insight also does not allow for efficient arithmetic computation within the shell itself.

M1

M1 operates on an IBM PC/XT/AT using a minimum of 384K bytes of memory (512K memory is recommended). M1 is a highly sophisticated KBES development tool that was originally compiled in PROLOG/1 but is now available in compiled C. The M1 shell is based on backward chaining; the shell does not have a true forward-chaining capability.

M1 is particularly sensitive to the order in which rules are placed into the shell. It is also sensitive to the use of metaknowledge (knowledge within knowledge).

Other features of M1 include:

- Reason explanation (an advantage in meteorological applications)
- Arithmetic computational capabilities
- Degrees of certainty or uncertainty
- Multiple window displays (aids user/developer considerably).

Given all the advantages of M1 outlined above, there appears to be three disadvantages: blackboard, price, and training.

M1 has no direct provision for blackboard space. Instead, the programmer is required to write linkage programs in another language and then transfer qualifers among the modules. This is quite cumbersome.

The M1 base price of $5,000 is also competitively high when compared to other shells. The $5,000 price includes five user copies of the M1-created expert system (but not the generator). Each additional user copy costs $500 (up to 10), then the cost drops to $250.

Finally, M1 requires extensive vendor-supported training that can be tedious and very time consuming.

2.4.4 Selection of Our Shell

Several criteria were used to select the shell for this effort. First, the tool or large shell approach was ruled out due to the limitations of the Z-100 computer. Tools usually need dedicated (and expensive) AI machines to run on. We also ruled out the use of a language as a proof-of-concept software development mechanism because of the time involved in programming. It was felt that time could be better used developing the knowledge.

Thus, we were left with the shell approach by virtue of their flexibility in running on PC-compatible machines. AWS detachments are in the process of upgrading their Z-100s to Z-248s or IBM PC-compatible Zenith PCs, thus, we selected a shell that can run on a PC-compatible machine. We also wanted the AWS personnel to evaluate the system now, so IBM PC clones were provided to each base to test Zeus.

The key criteria (or questions) we used for selection of a KBES shell are as follows:

KBES Shell Criteria

1. Does the shell have computational capability? This is especially important when deriving meteorologically important parameters such as potential temperature, lapse rate, etc.

2. Does the shell allow probability calculation? This is especially important for our purposes because the end KBES result is that the base weather officer will examine a listing of the probability of visibility less than certain ranges (i.e., probability of less than a half-mile, 1 mi, 3 mi, etc.)

3. Can the shell link to external programs/monitors? This feature is extremely important because it allows the KBES to pause and obtain necessary information from an external program in BASIC, FORTRAN, dBASE III, LOTUS, etc. This information could be based on an initial KBES user input variable (i.e., humidity, temperature) and an external program result (dew-point), which is then transferred back to the KBES for further use. Linkage to meteorological monitors is also noteworthly (i.e., windspeed could be automatically input from the sensors instead of keyed in by the base meteorologist).

4. Does the shell permit the KBES to run in a reasonable time? KBES FORTRAN- and PASCAL-based shells run much slower than LISP and C language shells. C language shells are faster than LISP shells.

5. Is the shell user-friendly? This is an extremely important consideration and involves display techniques and help facilities.

6. Is the shell price competitive and capable of running on a standard PC? The price of shells run anywhere from $15,000 down to $100.

The shell called "EXSYS" and developed by EXSYS, Inc. of New Mexico, was selected because it met all of the criteria previously outlined. The EXSYS shell (VER 3.0) was developed in 1983, and is now used by over 1600 groups. Polaroid uses EXSYS, for example, in many of its decision-making process applications. The Dupont Corporation has also used EXSYS as part of its extensive expert system development. Other EXSYS application areas include medicine, agriculture, and construction.

EXSYS more than meets all of the criteria outlined above and also provides a "what-if" feature that allows meteorologists to perform sensitivity analyses on key questions asked by the KBES. Thus, GEOMET meteorologists will be able to easily see what effect changing one or more of the user answers will have on the conclusion.

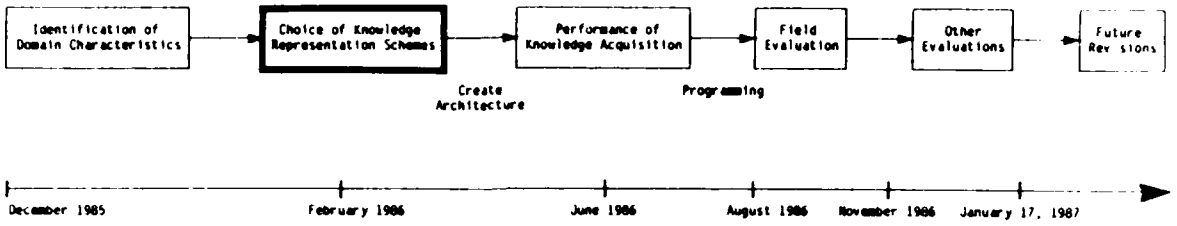
The EXSYS shell attributes (in addition to meeting the criteria mentioned) are as follows:

- Minimum of 256 K required = 700 rules. Every 64 K over 256 K = 700 rules. We can run EXSYS on one of our 640 K PC-AT, which will handle about 5,000 rules. The base IBM clone PCs (640K) can also handle 5,000 rules.
- Arithmetic, trigonometric, log, and square root functions are supported.
- Backward-type chaining is supported allowing large problems to be broken down into smaller ones.
- Forward-type chaining is also supported allowing for more intensive data-driven applications.
- Report generation procedures (i.e., how EXSYS arrived at a visibility forecast of less than 1 mi and a simple end result format).
- English text, menu selection, algebraic expressions, and color supported.
- C language based for speed.
- Unknown accepted as an answer.
- VAX compatability (can upload and run on a VAX if need be).

The EXSYS shell consists of two programs: Rule Editor and Runtime. The Rule Editor can be used, for example, to create, edit, or delete meteorological rules (i.e., modify the knowledge base). The Runtime program runs the rules created. Thus, different module-specific Runtime programs can be created and yet maintenance of a general meteorological expert system architecture is possible.

EXSYS also provides a "what-if" feature that can allow a knowledge engineering team to perform sensitivity analyses on key questions asked by the KBES. Therefore, the team has the capability to easily see what effect changing one or more of the user answers will have on the conclusion.

EXSYS also has a blackboard feature that allows for rapid transfer of knowledge or data between system modules. EXSYS, which is rapidly growing, has an agressive, ongoing corporate R&D program to provide user interface aids such as lookup table linkages and other desktop functions directly into EXSYS, making EXSYS one of the most efficient at linking an external data base with a shell.



Section 3.0

KNOWLEDGE REPRESENTATION

The problem of representing knowledge, and particularly temporal knowledge, arises in a wide range of disciplines, including computer science, philosophy, logistics, and psychology. This section describes our selection of meteorological knowledge representation techniques.

3.1 BRIEF REVIEW OF POSSIBLE KNOWLEDGE REPRESENTATION SCHEMES

Knowledge within an expert system can be represented using a variety of techniques. The two major architectural mechanisms for representing knowledge are:

- Forward Chaining
- Backward Chaining.

Under forward chaining, the entire process is data driven and the various rulepaths within the expert system examine the available data and try to test any data-specific hypothesis to acquire more facts or knowledge about a situation. This architecture could be most useful in the emergency threat environmental area (i.e., dispersion of a toxic gas) or other areas where final goals are not clear.

Under backward chaining, the rulepaths are oriented toward a common main goal. This goal is achievable if the rules satisfy various subgoals. In other words, the conclusions are already in the system and the job of the system is to test to see if those conclusions can be proved with the knowledge the system has within itself.

Either representation architecture will work in the meteorological area; however, it is our experience that backward chaining is much more readily convenient given the natural structure of environmental problem areas, and particularly meteorology, toward goal orientation. An example of meteorological goals include categories of low visibility (in our case) or could include items such as the rain or snow forecast goals, windspeed goals, or temperature goals.

The backward-chaining approach can be a very powerful tool within a specific meteorological area such as mesoscale meteorology where subgoals can be established and the expert system can review required subgoals with the user indicating to the user where and how subgoals were derived.

The representation of knowledge in the expert system under backward chaining still takes the form of rules. These rules can be represented in four different methods:

- Object-Attribute-Value (OAV triplets or Attribute-Value (AV) pairs)
- Frames
- Semantic networks
- Logical expressions.

The OAV method describes objects as either conceptual or physical quantities, attributes as a characteristic of the object, and the value as the specific nature of the attribute as indicated below:

Example of OAV Triplet

Surface Wind	Greater *than* 353° *and* Less *than* 120°	*Trajectory* Sufficient	90 Percent
OBJECT	ATTRIBUTE	RESULT	VALUE

The relationships of OAVs can be recorded within a backward-chained system to reflect a "dynamic" knowledge change (changes every time system is run) or as "state" knowledge (same every time). In this example, the object in question is the surface wind; the attribute refers to the characteristic of that wind. The OAV approach can also have a certainty factor attached to it, such as a measure of confidence that the trajectory is sufficient (i.e., the value). Certainty factors represent the degree to which the OAV standard rule is true.

The AV method is similar to the OAV method except that multiple objects, such as types of wind (i.e., gradient, 850 mbar) cannot be represented properly. GEOMET has used OAV triplets in several of its expert system applications, but has not used very many AV pairs.

Frames provide a different means of structuring knowledge. The idea of a frame has been introduced in the AI literature in 1974 by Minsky (20) as a slot concept. Each object (such as the surface wind) has a series of slots. Slots can represent properties associated with the wind (or default values if information is not available), and various "inheritance" features that can lead to other frames in the path leading up to the goal or subgoal.

Each slot within a frame can have various procedures attached or triggered by the slot as shown in Fig. 13. Typical examples include:

If needed procedures: The slot is empty--rules execute when knowledge is needed for the slot

If added procedures: Rules execute when new knowledge is placed in the slot

If removed procedures: Rules run when knowledge is deleted from the slot.

The frames figure indicates the same basic OAV triplet as before, but now the triplet is imbedded within a wind frame.

The slot and frame procedure is particularly useful in organizing large knowledge data sets.

Semantic networks involve nodes that represent objects and various direct linkages that relate to the nodes by definition or direct action. GEOMET has used one semantic network to represent certain terrain features; however, the difficulty in semantic networks is in their broadness. OAV triplets and other methods are much more specific.

Logical expressions refer to propositions such as AND, NOT, and OR. These expressions are extremely powerful in an OAV or frames format. For example, two wind rules sharing the same values can be combined into one rule using AND or two other rules can be declared as conditional using OR.

3.2 SELECTION OF REPRESENTATION SCHEME

From the conceptual models developed in Section 2.0 during the identification of the problem, it became readily apparent that a backward-chaining, goal-directed, rule-driven, proof-of-concept system was required for several reasons:

1. A goal-directed system put definite bounds on the base meteorological categories.

2. Forecasters tend to think in terms of OAV triplets (with less emphasis on confidence values assigned to the triplet).

3. Four clear requirements were identified for any fog forecast.

AREA: WIND

Characteristic 1	Direction	--	--Critical --Noncritical	If Added and Removed Procedures/Rules
Characteristic 2	Speed	--	--Critical --Noncritical	If Added and Removed Procedures and Rules
Characteristic 3	Temporal History	--	--If Needed Procedures --If Changed	(link to another frame)

Figure 13. Typical organization of meteorological frame.

First, a goal-directed system as a proof-of-concept made a lot of sense given the base TAF requirements of parameter-bound or category forecasts of low visibility (<1, 1 to 3, 3+ mi). Reaching these goals can be easily structured in any backward chaining format, but particularly in EXSYS.

The conceptual models developed during the identification phase also clearly indicated fog breakpoints, such as advection and radiation, along with attendent characteristics of each, thus, promoting the idea of subgoals under each area. Second, we found in the TFRNs, the other literature, and by interview that forecasters inherently think in terms of if-then-else rules, thus, an expert system that can draw on that type of structure can become a powerful tool.

Finally, as a result of close examination of the conceptual models, it was found that in any given (fog) forecast, five basic things could happen:

- Forecast degradation from current visibility > 3 conditions
- Forecast degradation from an existing condition
- Forecast improvement
- Forecast improvement to a better condition (but still below criteria)
- Forecast persistance.

In the first case, visibility may be greater than 7 mi and forecast to degrade to 2 mi. Similarly, visibility could be 2 mi and drop to 1/2 mi (degradation from existing condition). In the third and fourth cases, visibility could improve from 1/2 to 7+ mi or improve from 1/2 to 2 mi and in the fifth case, visibility could persist at a low 1/2 mi for several hours.

From the conceptual models and the five basic ideas regarding overall structure outlined above, a preliminary system design was developed. This design reflects the forecast degradation case and depicts the initial ideas behind representing the knowledge. Subgoals derived from the conceptual model receive information from a synoptic module and then follow rulepaths to a major or minor goal depending on how various rules are executed, or in AI terminology "fired."

It was becoming increasingly obvious at this time that various conditions needed to be met to establish the subgoal (or goal) as being valid. This now meant that all rules would relate to "conditions." This, in turn, impacted on knowledge acquisition because interview discussions were oriented along the lines of obtaining necessary and sufficient conditions to satisfy the goals or subgoals through rulepath formulation.

We also began to realize with the initial structure that clock time would become a critical aspect throughout the expert system. We consequently introduced clock time in a subsequent design review described in the next subsection.

3.3 LINKING KNOWLEDGE REPRESENTATION TO THE METEOROLOGY

3.3.1 Overall Structure

It is important to reiterate that knowledge representation and acquisition go hand-in-hand during expert system development. One cannot acquire domain expertise through interviews with an expert without first at least knowing how that knowledge will be represented. (That is why the identification phase is so critical to the success of the project.)

Our initial representation scheme was consequently modified by the interviews. The new (and final) scheme is given in Fig. 14. Solid lines represent rulepaths throughout the system.

The structure revolves around the user entering the current observation with a natural branch being triggered by this observation (i.e., greater than or less than 3 mi--a common base TAF checkoff point). The system then decides whether one of the four basic items of degradation (from existing), degradation (from nonexisting), improvement (to existing), improvement or persistence will occur. Should the current visibility be greater than 3 mi, then the two possible solutions to the forecast are degradation below 3 mi or persistence (remaining good) on the other side, if visibility is below 3 mi, then any one of the four solutions could occur. This key breakpoint is graphically illustrated in Fig. 15.

After the controller determines the proper path, Zeus then proceeds to assess each module in terms of whether necessary and sufficient conditions are met (i.e., the subgoals). The following subsections describe each module drawing on the knowledge obtained from development of the conceptual models.

3.3.2 The Advection Module

The advection module for each base is very similar in that its major goal is to determine whether "Atlantic Flow" (AF) is sufficient. The need for an oceanic trajectory has been discussed under the advection conceptual model presented earlier.

The advection module, independent of the synoptic module, determines first whether AF exists; then executes rules to determine surface and aloft moisture values, and finally integrates synoptic rules. The basic outline of the module appears in Fig. 16.

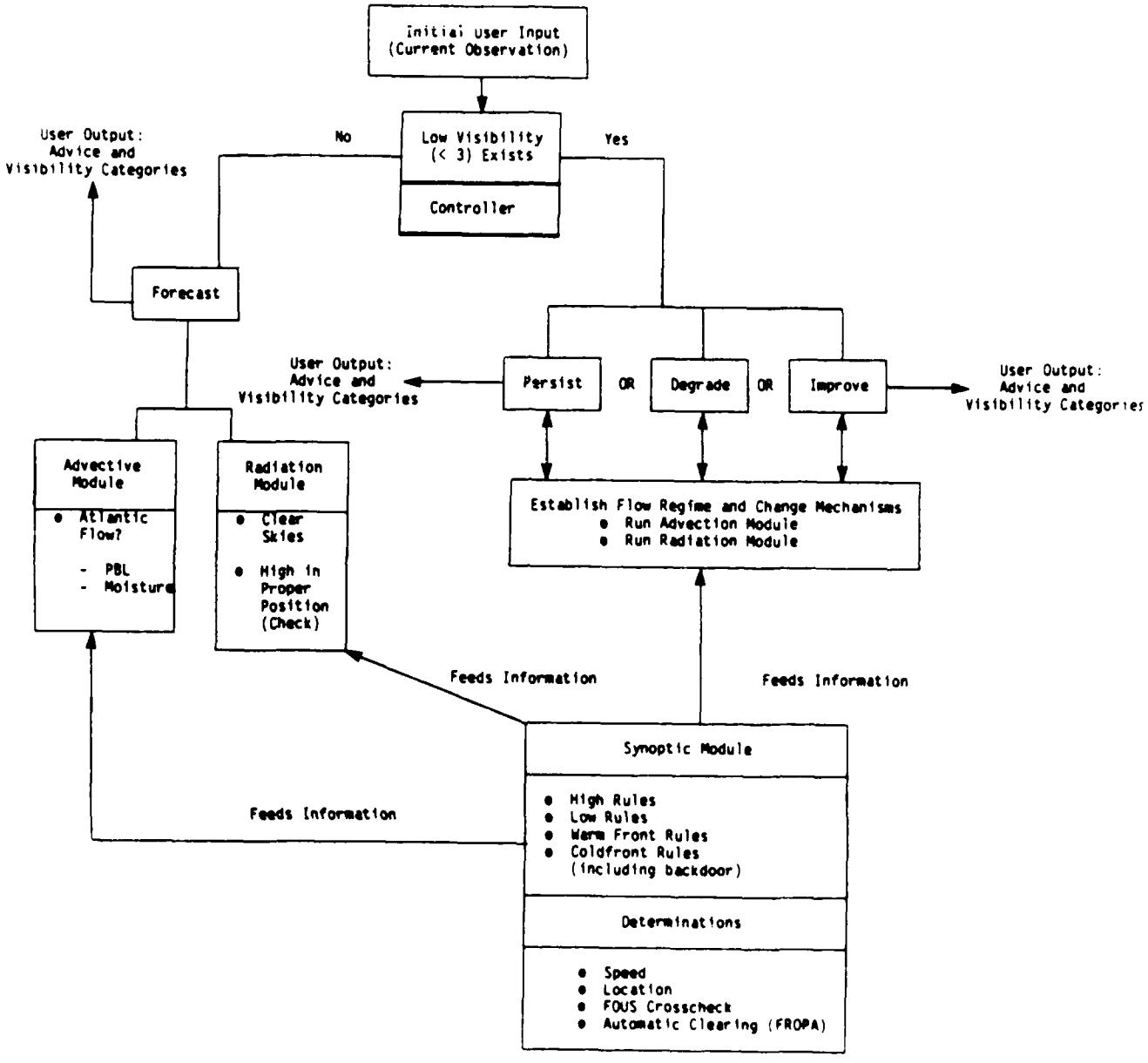


Figure 14. Final Zeus system design.

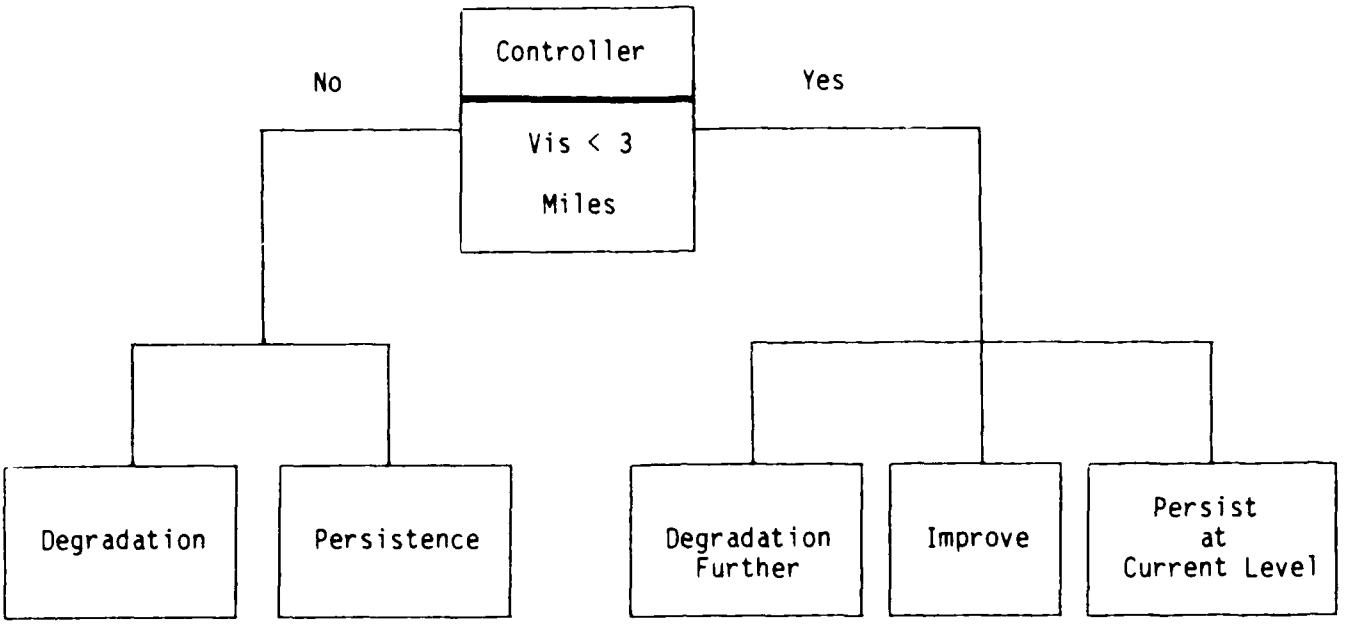
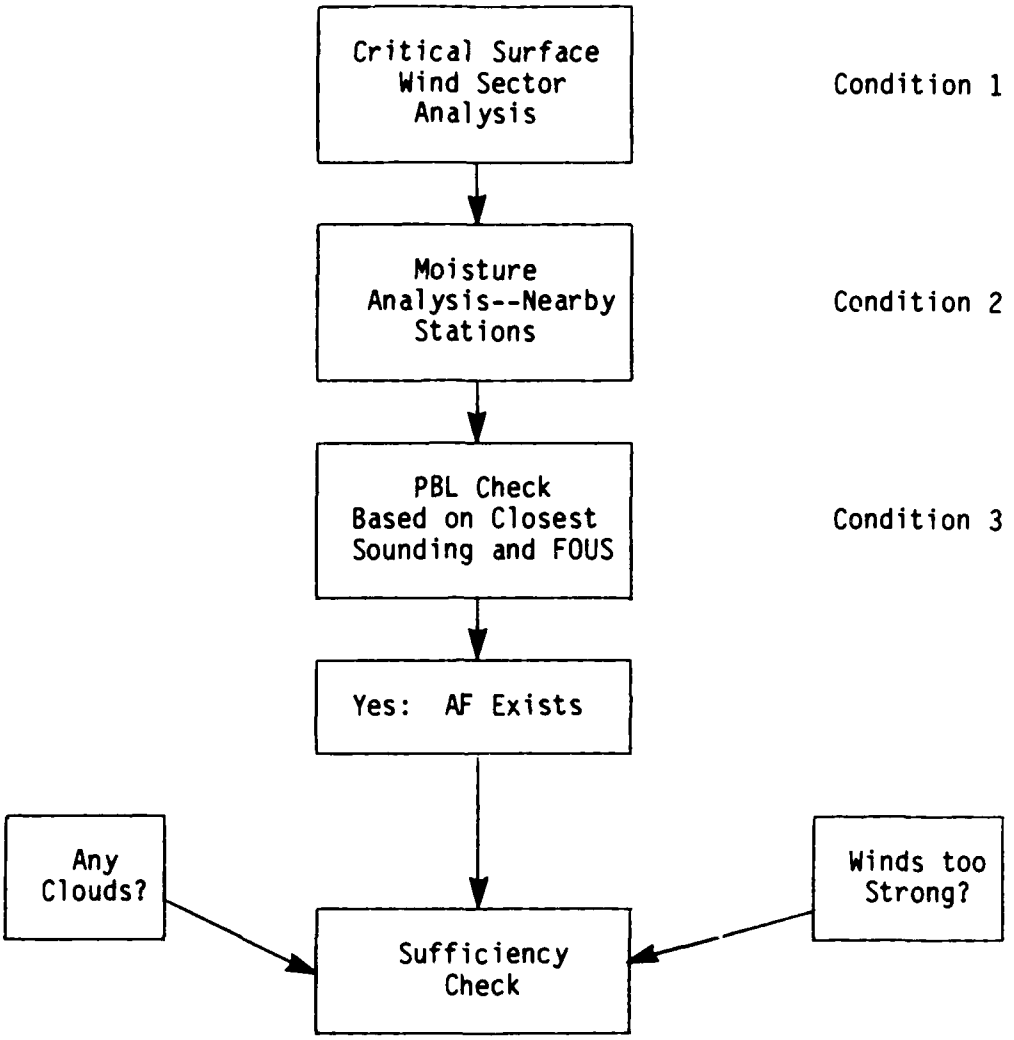


Figure 15. *The Zeus Controller*.

Objective: Sufficient Atlantic Flow, Yes or No?



NOTE: Any negatives associated with any of these three condition boxes indicates no AF at the moment.

Figure 16. Basic outline of advection module.

The rules are divided into three key areas that are organized as conditions 1, 2, and 3 (or subgoals 1, 2, 3). In the first area, critical surface wind sectors were established for each base. These sectors reflected surface flow off the Atlantic and are based on a combination of TERN information and interviews. The second area involved a simplified comparison of dewpoint depression between nearby stations to obtain an idea of how much moisture was being advected into the area. At Dover, the 70 percent RAFS RH line was also used, although this parameter was not used at Simmons or Seymour Johnson.

The third area involved rules designed to use the observed and FOUS predicted against both the vertical profiles of wind direction and speed. This check (called condition 3) is critical because many fog situations as shown in the conceptual model discussion and later borne out by interviews are greatly influenced by the boundary-layer wind structure.

If all three conditions are met, then AF exists. Should any one of the conditions not be met, then AF does not exist and the program does one of two things (See Fig. 17). It searches to see if AF is possible at a future time or it goes to the radiation module. The advection module uses information from the synoptic module to confirm the AF existence and also uses synoptic information to inform users of the possibility of AF at a later time.

The above discussion reflects the controller selecting the route referring to visibility greater than 3. Should visibility currently be less than 3 mi, then the major function of the advection module is to determine whether the present fog is advective in nature. If so, then the module feeds the information to a breakout routine.

The breakout routine follows the conceptual dissipation model introduced in Section 2.0, however, we chose to integrate the rules into the advection and radiation modules because each fog is treated slightly differently in terms of dissipation. One interesting feature of the breakout routine is the use of Pilot Reports (PIREPS), a possible source of information on cloud heights and thickness. A redundancy feature has been built into the PIREP question such that if PIREPs are not available, then the user is prompted for satellite information. Other satellite-based assessments are made using observations based on rate of burnoff from the edges of an advection (or radiation fog area). Fig. 18, in summary form, indicates how the advection module reacts to visibility below the 3-mi threshold.

Some of the problem areas that were listed in the conceptual model discussion were solved by knowledge acquisition and structured as part of representing the knowledge.

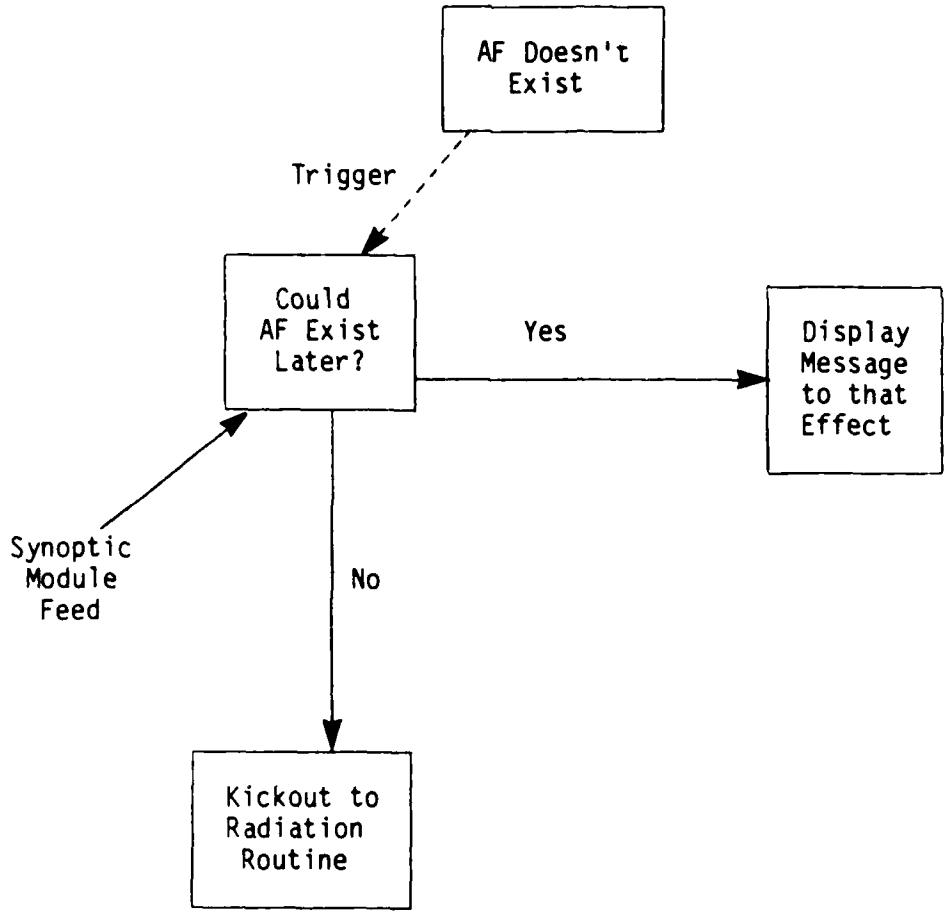


Figure 10. Advection Module

Figure 17. Result of Atlantic flow not existing (one or more conditions not met) (visibility > 3 currently).

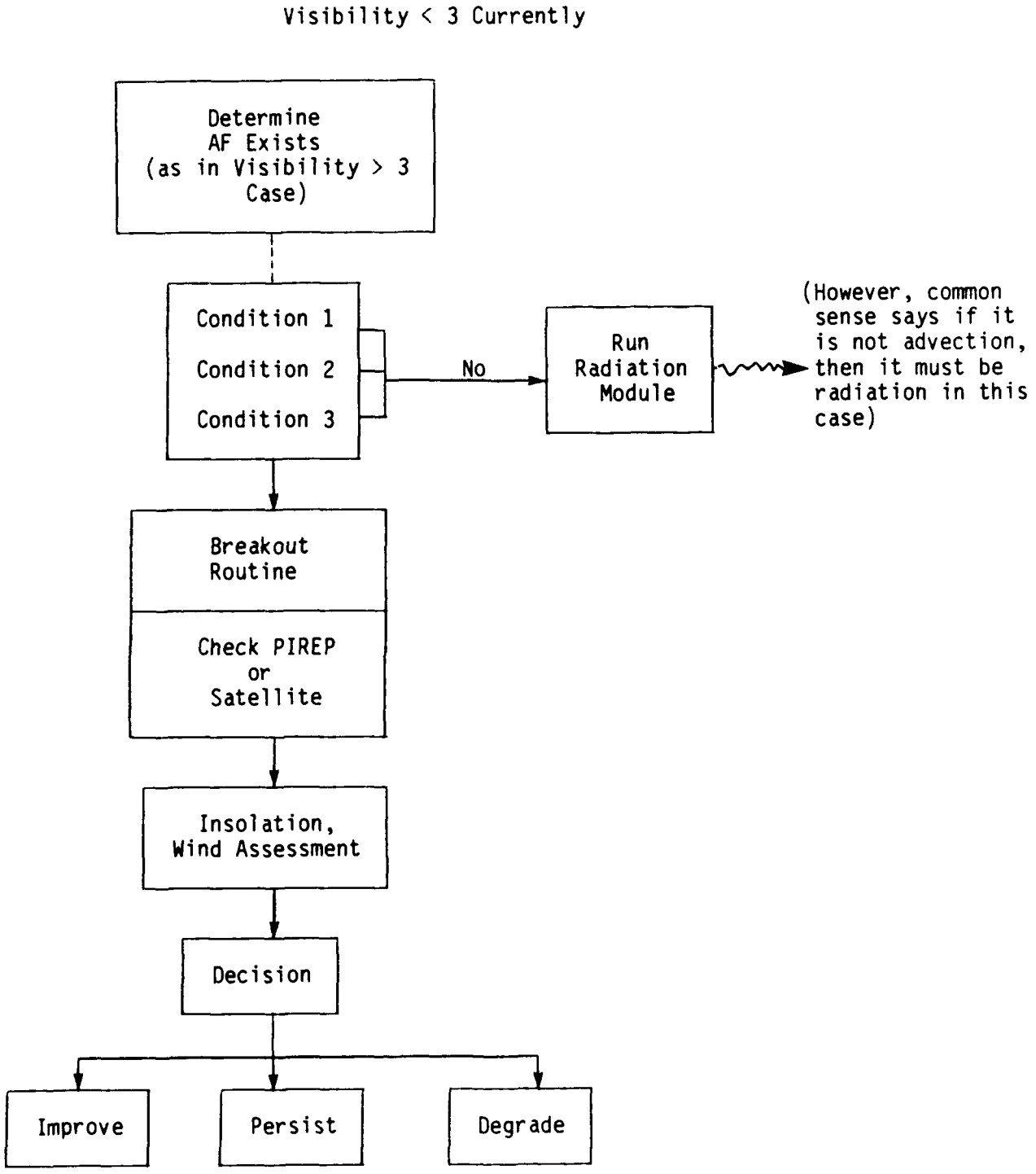


Figure 18. Advection module: illustration of visibility < 3 mi currently.

In summary, the advection module is run after the controller determines the proper pathway to take based on current visibility. The advection module can:

- Determine whether Atlantic flow exists
- Supplement Atlantic flow possibility assessments from the synoptic module
- Determine persistence, improvement, or degradation of visibility based on information from the synoptic module or from the breakout routine.

The early use of the conceptual model greatly aided in the "fleshing out" of the advection module during the knowledge acquisition phase.

3.3.3 The Radiation Module

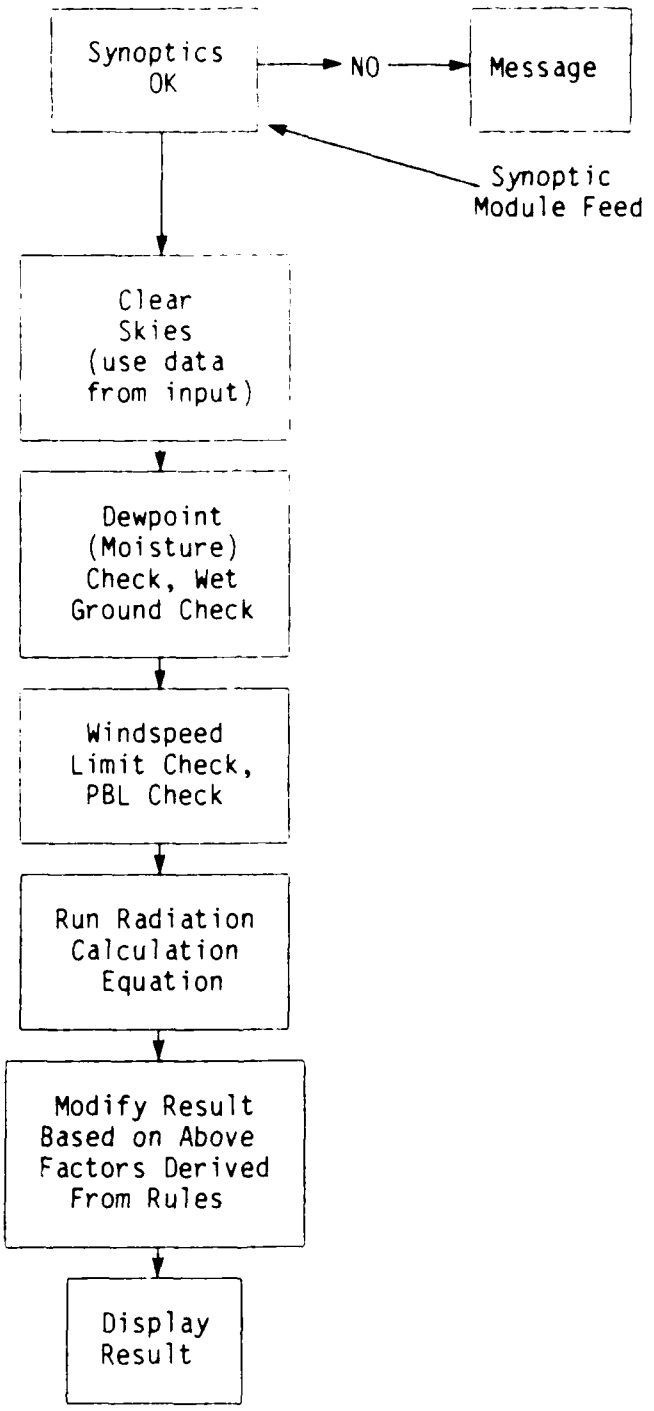
The radiation module has, as its primary function, to determine whether radiation-induced fog will occur. A key factor involved in radiation fog formation is a nearby high-pressure center or ridge. Thus, the module relies on information from the synoptic module to make an initial judgment of radiation fog.

Three conditions were established for radiation fog, one of these conditions is implied. The conditions are:

- Condition 1: radiation fog possible
- Condition 2: special condition for radiation fog behind warmfronts
- Implied Condition 3: no radiation fog.

Under condition 1, the radiation module uses input from the synoptic module such as positioning of the high to reach conclusions on the possible radiation fog conditions. After passing this first screening, the module then basically follows the outline presented in the conceptual model as shown in Fig. 19.

The assessment of clear skies is based on the current and forecasted local sky conditions. The module can take up to scattered cloud conditions; however, should broken conditions occur, messages are displayed indicating that potential cloudiness could eliminate the chance of radiation fog (thus, radiation condition 1 is not met).



NOTE: A negative result from any of these rulepath functions causes an explanatory message on why radiation fog is not possible.

Figure 19. Radiation module (visibility > 7 mi currently).

Similar checks are done using dewpoint depression information, wet ground, and boundary-layer structure. A lot of time has been spent on representing the various windspeeds needed for fog because the knowledge acquisition phase indicated great forecaster concern over windspeed. Therefore, in addition to standard checks on windspeed limits being exceeded, an additional crosscheck is made using FOUS data to ensure proper boundary-layer and surface windspeeds.

The radiation fog equation is then executed. The result of the equation is a duration and intensity of radiation fog. This result is, in turn, modified usually in terms of the duration, by the meteorological rules previously "fired." A result is then displayed based on category and time.

If the controller selects the path of visibility currently less than 3 mi due to fog or haze, then the job of the radiation module is to determine improvement, persistence, or further degradation.

Improvement involves the breakout routine mentioned under the advection module. The routine is basically the same with assessments of breakout being made based on PIREP, satellite, and sounding information along with a surface wind assessment. Persistence is based in part on low surface visibility at surrounding stations indicating the extent of the low visibility problem along with synoptic information.

Finally, further degradation is determined by integrating synoptic information and by assessments such as moisture on windshields (or wet ground checks) indicating sufficient surface layer moisture that when combined with other factors could indicate decreasing visibility. Fig. 20 depicts the radiation module in the visibility less than a 3-mi mode.

Condition 2 radiation fog reflects a relatively common case associated with radiation fogs after warm frontal passages, and is based on our interviews. This condition is satisfied if a warm front has passed north of the station and the cold frontal passage is lagging. The synoptic module, in combination with the radiation module, determines whether the condition exists. After this, the radiation module proceeds with its assessment of the situation and then produces a specialized message if all radiation condition 1 requirements are satisfied.

Finally, a third condition is implied throughout the radiation module. If condition 1 or 2 is not met, then messages are provided to indicate no fog. This follows the Zeus logic of first assessing advection fog, then radiation fog; if neither are true, then no fog is assumed and associated messages are printed.

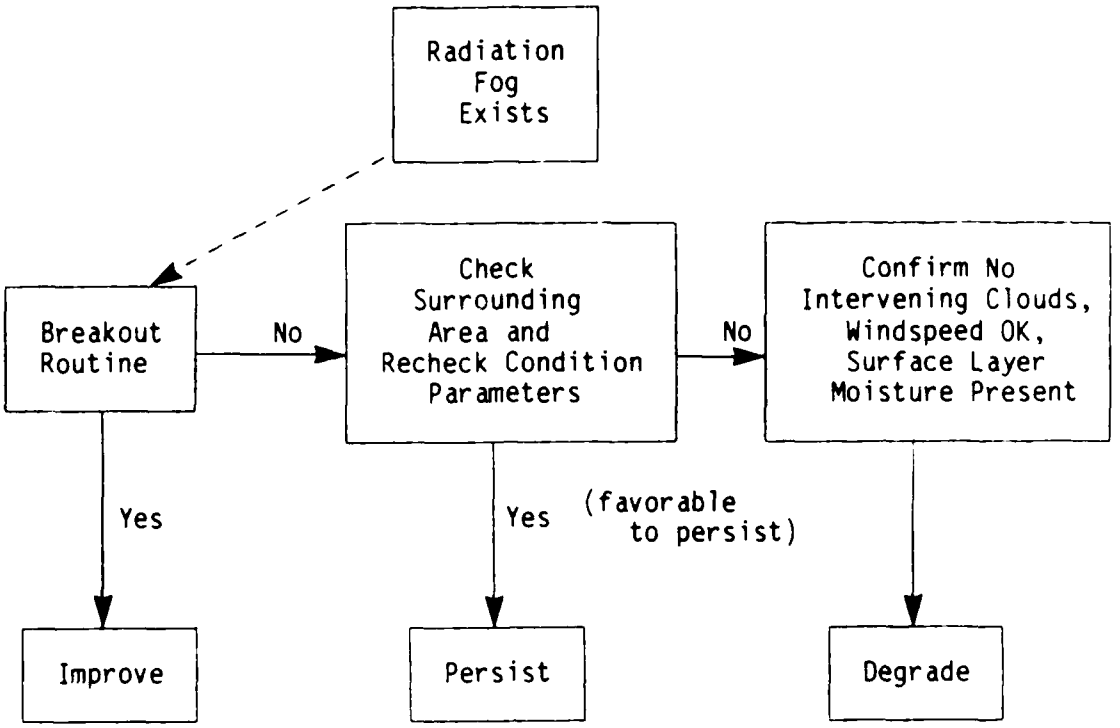


Figure 20. Radiation module (visibility < 3 mi currently).

In summary, the radiation module is run after the advection module fails to identify an advection fog situation. The controller, in turn, determines which pathways the module takes in terms of low or good current visibility. The functions of the module are:

- Determine radiation fog possibilities by independent and synoptic module integration
- Determine persistence, improvement, or degradation based on the breakout routine or on degradation-specific radiation rules.

The early use of the conceptual model also greatly aided development of this module.

3.3.4 The Synoptic Module

The synoptic module is really the heart of the expert system because information gathered from its rules are fed to the other modules.

The objectives of the module are twofold:

- Determine location of synoptic scale systems
- Determine movement and effect of the movement of synoptic systems.

Location of the varying synoptic features are most important. For example, a high near TTN (Trenton, New Jersey) would affect weather differently than a high near CLT (Charlotte) in western North Carolina.

Thus, a scheme was needed to geographically identify the location of the various weather systems. Several methods were examined to depict the location of systems. One obvious method of using real-time information with the system was ruled out in the proof-of-concept stage because it was felt that such an effort now would be beyond this proof-of-concept in AI-meteorology.

A second method of asking the user for latitude and longitude coordinates was deemed to be too rule-intensive at this time. Instead, through our terms of knowledge acquisition work, we found that forecasters tend to think in terms of regions. Thus, we developed a map (Fig. 21) divided into sections for positioning of systems.

The map shows six areas of which areas 2 and 3A are of extreme importance.

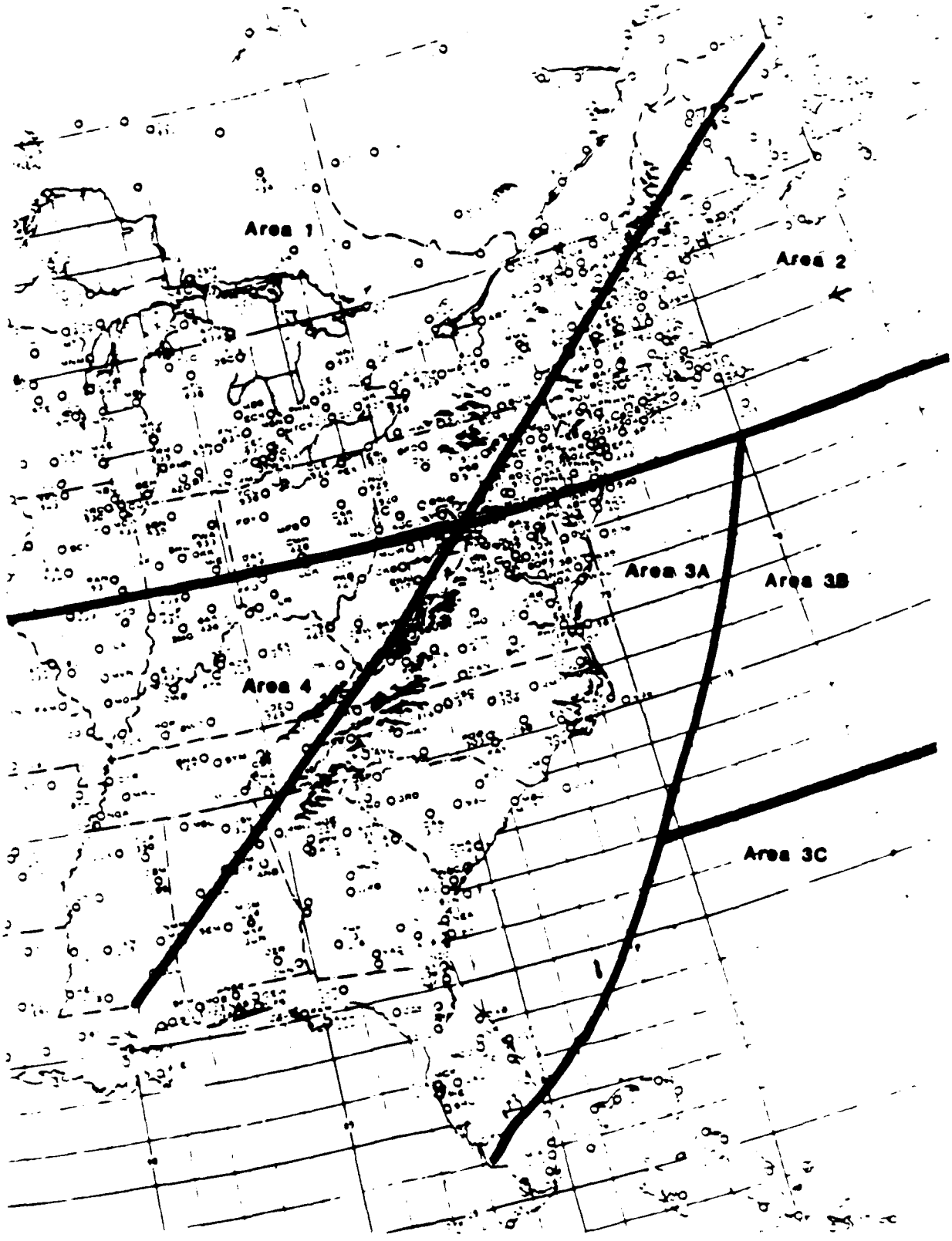


Figure 21. Map showing sectors used by synoptic module to identify weather system locations.

It appears that the positioning of high-pressure systems (and not so much low pressure) is a driving force behind fog formation. For example, highs in area 2 tend to influence the development of Atlantic flow and highs in region 3A with clear skies could lead to the radiational case.

For high pressure systems, three characteristics were established:

- Movement (north, south, east, west, stationary)
- Structure (ridge, center)
- Location.

After a user places the high in the proper position, he/she is asked for movement and, based on the response, various actions are undertaken. These actions are summarized below in TABLE 13.

TABLE 13. Summary of High-Synoptic Module Results.

High Located in Area...	Moving	Action
1	Eastward	Potential for advection-fog-later messages
1	Stationary, north-south, ridging	No fog messages
1	Southeast	Later potential for Radiation fog if moving to 3A
2	Anywhere	Generally potential sign of advection fog; run advection module for further assessment
	Ridging/stationary	Same as above, different messages
3A	Eastward	Possible advection fog, run advection module and radiation module
3A	Stationary, ridging, any other direction	Potential for radiation fog; run radiation module
3B, 3C	Anywhere	Same as 3A, but less emphasis because system is farther from coast
4	Eastward	Potential for radiation fog later
	Anywhere else	No fog

The high functions also execute under the persistent, improvement, and degradation situations.

For example, should Atlantic flow be established, then the job of the synoptic module is to determine whether the flow can maintain itself over the next 6 to 12 h. In this case, movement of the high out of Area 2 (a cold-frontal passage), or any number of events could trigger the improvement forecast.

Similarly, low pressure systems are treated according to the same areas. After lows are placed in the proper area, various actions are undertaken. These are summarized in TABLE 14 below.

TABLE 14. Summary of Low-Synoptic Module Results.

Low Located in Area...	Moving	Action
1	Anywhere	No factor
2	Anywhere	No factor
3A	Anywhere	Precipitation--can't handle messages
3B	Anywhere	Precipitation--can't handle messages
3C	Anywhere	Precipitation--can't handle messages
4	East	Precipitation--can't handle messages
4	Anywhere else	No factor

Lows provide an interesting case resulting in one of two actions: either a no-factor result or precipitation result. The no-factor result means just that; the low is not considered by the advection or radiation module. The precipitation results are a cautionary message to indicate to the users that Zeus cannot currently handle precipitation. This stems from us "drawing the line" in regards to the proof-of-concept and not going into developing rules and structures for precipitation forecasting. It was felt

that the proof-of-concept should be narrow in scope and that an outlet should be provided to later expand the system into other meteorological areas. The "can't handle" messages provide this outlet.

Cold fronts are also treated in terms of their geographic location and movement. Cold fronts are geographically determined as to their position relative to the base and fall into the categories of:

- West or northwest of the base (common)
- South or southwest of the base (rare)
- North or northeast of the base (backdoor)
- East (past base).

Cold fronts are broken down by movement into the categories of:

- Will pass in the next 0 to 12 h
- Will stall within 100 mi
- Will not affect (will not pass).

Should cold fronts pass a base and not stall, then no fog will occur. If current conditions are less than 3 mi in fog or haze, then a cold frontal passage (FROPA) without stalling generates an automatic clearing or improvement message. If the cold front stalls within 100 mi, messages appear alerting the forecaster to the potential of a wave developing on the front--something that the system cannot currently handle. Special advisory messages appear on the handling of a backdoor cold front passage. Finally, if a cold front is east of or will not affect the station, then the cold front is deemed to be of no factor.

A similar structure exists for warm fronts. Position categories are:

- East or southeast of base (coastal front)
- South or southwest of base (common)
- North or will not affect base.

Movement categories are:

- North (or pass base)
- Stall.

Warm fronts can result in prolonged periods of low visibility and precipitation so many messages appear to the user regarding the precipitation possibility--which Zeus cannot handle at this time. Many times, however, the warm front is north or will not affect the station. A special message is transferred to the radiation module, if a warm front has just passed the base, alerting the module to the possibility of post-warm-frontal radiation fog.

Messages and the results of various synoptic rule executions are routinely passed to the appropriate module first as a block of mandatory information such as synoptic information or on a requested basis by each individual module. The passed information, in most cases, relates to the changes for the better, worse, or no change. These changes are represented by setting or not setting one of the three change conditions (introduced earlier) that, although not grammatically correct in our language representation, are called:

- Change good
- Change bad
- No change.

As an example, assuming no other influential factors and current visibility greater than 7 mi, a high moving eastward from area 1 would trigger a change-bad condition. This is because a high moving into area 2 from area 1 could eventually result in Atlantic flow that, in turn, could lead to advection fog. This result in its various forms would be transferred to the advection module for further processing. Depending on the execution of the rules within the advection module, results could vary from providing guidance to the forecast. It could range from key signs to examine over the next 6 to 18 h to actually giving 6-h visibility category advice.

In summary, the early use of the conceptual model provided a framework for the development of the synoptic module that is really the driving force behind execution of any of the advection or radiation module rules.

3.3.5 The Concept of Time

The need to reason with and use time has been a recurring problem not only in AI, but in many other areas of computer science. In meteorology, almost all numerical models (i.e., NGM, LFM, Spectral) have time components and time-related differential equations. Meteorologists deal with time systems such as local and Greenwich time and with time constraints such as the TAF deadline.

The easiest way to create a time subsystem within Zeus is to divide the 24-h day into daytime and nighttime periods based on sunrise and sunset times. Thus, Zeus has built in sunrise and sunset times by month, rounded off to the nearest half-hour period.

The day and night division allow convenient representation of certain rule paths. For example, fog formation times were derived from the executed rules within the modules providing time increments. These meteorological increments were added to sunset or in some cases subtracted from sunrise times to obtain formation time.

In the breakout routine time is critical. Breakout time is derived similar to the formation time. However, the rules change at 12 m. because, based on climatology, fog lasting into afternoon is a special case. Rules are then executed to determine regional extent of the problem and various assessments are made. Late in the afternoon, other special rules are used to determine reformation of the fog (degradation from an already existing situation) near sunset. Thus, sunset time becomes extremely important.

Time is used in other determinations such as the analysis that goes into visibility fog actually degrading at time of Zeus run and occasionally within the synoptic module.

Finally, given the entire nature of the visibility forecasting problem, we have overall Zeus system time constraints. This means that the system is useful in the time range of 0 on, out to 18 h. Most advice refers to the 0- to 12-h period. For forecasts greater than 18 h in advance, more numerical guidance would be needed as Zeus input. We decided not be bring this additional information into Zeus at this time to put clear time constraints on this proof-of-concept effort.

The Zeus system also required current time input. Various methods were tried; however, we decided that the easiest method to use current time within the system was to create a batch file to access the PC system clock. Current time is passed directly to Zeus from the PC clock and used throughout the program.

Calendar dates are also received from the PC clock, thereby providing a convenient method of applying monthly climatological rules. This was especially useful in analyzing the various base wind sectors for Atlantic flow by month.

3.3.6 Expert System Internal Rule Structure

The rules are the representation of the knowledge within Zeus. A rule contains one or more IF statements followed by one or more or THEN or ELSE parts. Notes and references can also be included under each rule.

The rules are in English or algebraic expressions. Rules may also contain choices in the THEN part. Choices are possible major goals of the system. The three choices that Zeus has are the three visibility categories 1 through 3. Choices can include a probability in either the yes/no, 0 to 10, or -100 to +100 decision systems. In our case, we selected the 0 to 10 probability system.

The rules are structured along the lines of conditions. A condition is a statement of fact or potential fact Conditions can be either text or mathematical. Text can be true or false. Each condition has two parts, a qualifier and a value. Qualifiers refer to the part of the condition before the verb. The values are possible completion phrases for the rest of the condition.

Fig. 22 illustrates the rule concept; Fig. 23 illustrates a specific meteorological rule.

IF conditions, then conditions choices, else conditions choices.

Figure 22. Typical Zeus rule internal structure.

If wind is 360 to 040, then condition 1 is met.
Else condition 1 is not met.

Figure 23. Example of rule structure.

The condition is in reality the entire rule. The qualifers are "wind is" and "condition 1 is." Values are "360 to 040," "met," "not met." One can imagine how powerful such a rule structuring system can be in terms of improving system design. We were able to isolate qualifers and match them with existing or newly created values. Thus, many times when faced with a new rule situation, one has to merely search the existing knowledge base to determine whether any qualifers exist.

Upon selection for inclusion into the system, a split screen appears that allows for piecing together of rules. Standard IF, THEN, ELSE prompts appear and the user is guided along in rule development.

The IF part of the rule is a set of conditions. EXSYS, the software driver, tests the conditions against input to see if the IF conditions are true. The THEN grouping also uses conditions, but introduces choices. If the "IF" is satisfactory, then the "THEN" is executed (otherwise, the ELSE is executed).

Each rule has the capability to draw on the logic structures operating within the entire system. This means that logic operators such as NOT, AND, or OR can be used almost anywhere in system development.

Within the structure of Zeus, two major facilities exist that aid in either debugging or backtracking distance. The facilities are:

- Why
- Change and rerun.

The "why" facility allows for first, second, and third (inner) tier reasoning. By indicating the "why" facility, the user can readily receive information on why fog was advised or not advised.

The change and rerun command allows a user to select one or several parameters for "tweaking." Change and reruns usually tap into the various upfront data sheets. A forecaster can, therefore, change a temperature or the position of a synoptic feature to understand how sensitive the forecast is to any uncertainties he/she may have about input data.

3.3.7 User Interfaces and Result Display

The use of user interfaces throughout AI has been a topic of great discussion at many recent computer conferences. User interfaces range from windows with mouse-controlled functions to detailed diagrams with light pen pointer functions.

We decided in this proof-of-concept effort to limit ourselves to simplistic user interfaces and spend most of our effort in the structuring and knowledge acquisition aspects of the study. We adopted this philosophy for one primary reason: the current proof-of-concept nature of AI-meteorology. We believe that once representation structures and acquisition techniques have been established, then sophisticated user interfaces can be developed. This philosophy is analagous to what has transpired in the medical AI field where considerable recent effort has been spent in real-time data acquisition, display, and user interfaces only after representation and acquisition schemes were well developed.

We initially identified, by the conceptual models, that real-time data was required by the system. We decided not to pursue automatic data acquisition and instead concentrated on manual input that can be readily transferred to automatic input at a later date.

A basic program was created to handle the input. This program runs just prior to the main body of Zeus and feeds information directly to the expert system.

The first type of input that is passed is called a variable (V). The variable has a unique identification number assigned to it for tracking purposes. The value of the variable can be either integer or real.

A second type of input transfer involves the use of qualifiers. A qualifer is typically completed by a linking verb such as:

The month is:
January
February
March
.
.
.
etc.

"The month is" is the qualifer ("is" is the linking verb), and January, February, etc., are the conditions of the qualifer. Qualifers such as "The month is September" are routinely passed to Zeus from the input program.

Key weather observing stations contained in the input for Seymour Johnson are: ILM, EWN, HAT, 2DP, ECG, ORF, and Seymour Johnson itself.

Key weather observing stations contained in the input for Dover are: BWI, SBY, WAL, ACY, ILG, and Dover itself.

Key weather observing stations contained in the input for Simmons are: GSB, NKT, EWN, ILM, MYR, and Simmons itself. Should observations not be available, latest or nearest observations are substituted. The required inputs are temperature and dewpoint for the regional stations and basic meteorological input for the base.

Base inputs include FOUS (PBL) data, closest sounding winds, sunset temperature parameters, sky cover, and current visibility. Time and month are automatically filled in by the PC clock batch access program.

Figs. 24 to 45 illustrate the user input requirements for base and regional stations.

Seymour Johnson's input screen is similar to Fort Bragg's screen except for the page two-station page. Dover's input screen contains several different parameters than the other bases such as fraction of cloud cover at sunset, sea surface temperature, and FOUS 6-h relative humidity (boundary layer). These factors are used more often at Dover than at the other bases.

Figs. 24 to 45 also include the four windows and map used to input synoptic information. The windows are cursor controlled for display purposes. The map provides reference to the areas and includes a distance bullseye reference.

```
**  INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (GSB)  **

<PAGE 1 of 3>

CURRENT DATE     (mm-dd-yy): [06-14-86] CURRENT TIME    (0001-2400): [1658]
SUNSET SURFACE TEMP.    (F): [75 ]      SUNSET DEW-POINT TEMP.  (F): [65 ]
WIND DIRECTION        (deg): [060]      WIND SPEED            (mph): [5  ]
HAT 850MB WIND DIR    (deg): [050]      HAT 850MB WIND SPD    (mph): [20 ]
FOUS 06 HRS WIND DIR  (deg): [030]      FOUS 06 HRS WIND SPD  (mph): [12 ]
FOUS 12 HRS WIND DIR  (deg): [040]      FOUS 12 HRS WIND SPD  (mph): [15 ]
FOUS 18 HRS WIND DIR  (deg): [050]      FOUS 18 HRS WIND SPD  (mph): [10 ]
FOUS 24 HRS WIND DIR  (deg): [070]      FOUS 24 HRS WIND SPD  (mph): [10 ]
SKY             (See below): [3  ]      VISIBILITY          (miles): [7  ]


(SKY Codes: 1=CLR, 2=SCT, 3=BKN, 4=OVC, 5=-X, 6=X)


 Use arrow keys to move cursor to where you want it, then just type input.
 When done, hit F1 key to see the next page.  There are three input pages.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit
```

Figure 24. Inputs for Zeus meteorological advisory system (GSB).

** INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (GSB) **

<PAGE 2 of 3>

	GSB	2DP	ORF	EWN	ECG	ILM
SURFACE TEMP. (F):	[75]	[79]	[75]	[80]	[78]	[83]
DEW-POINT TEMP. (F):	[64]	[69]	[63]	[59]	[62]	[66]

Get the latest surface observations for the listed stations and enter them.
Use arrow keys to move cursor. When done, hit F1 key to see the next page.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit

Figure 25. Inputs for Zeus meteorological advisory system (GSB).

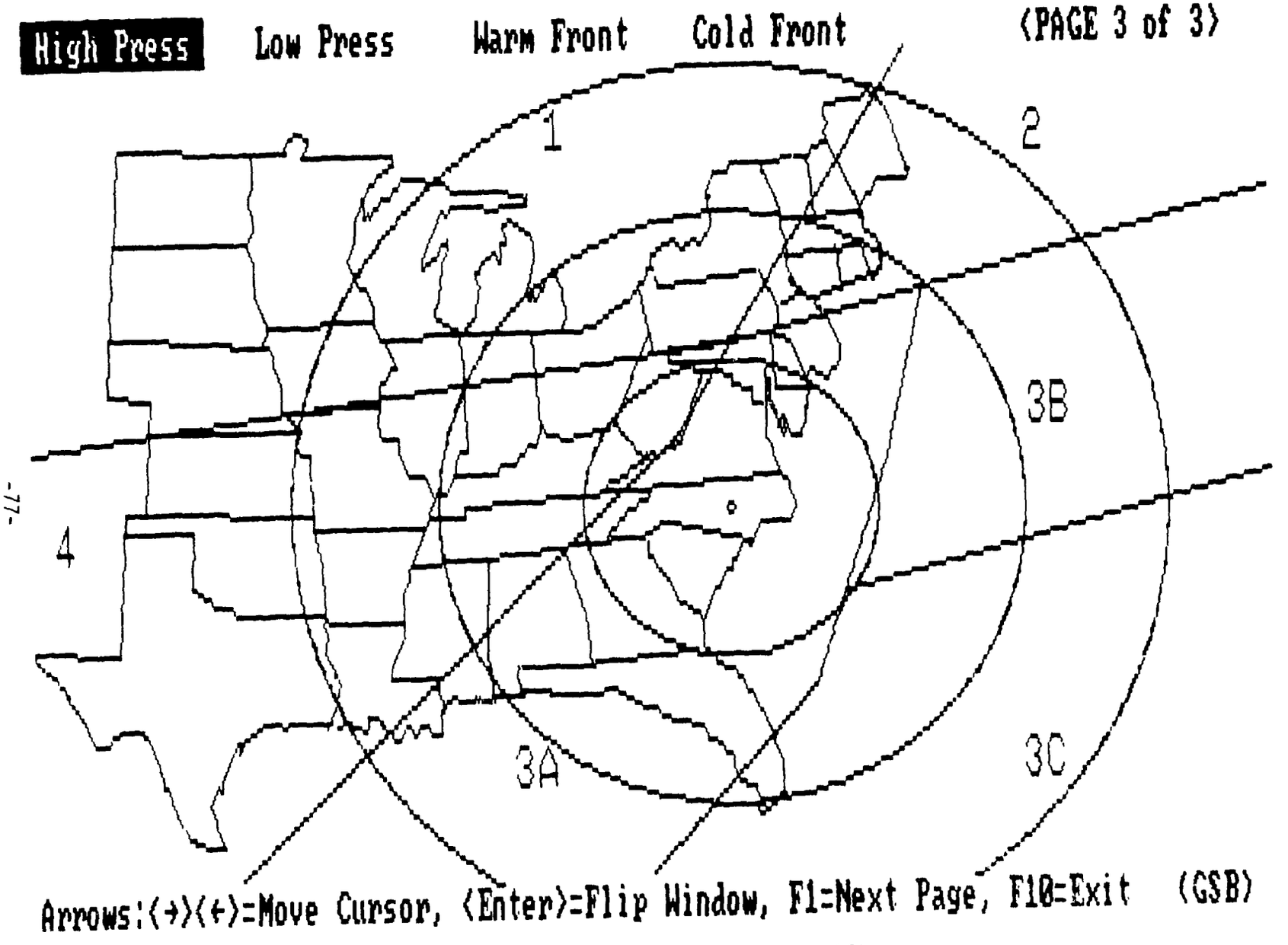


Figure 26. Map-related input, GSB.

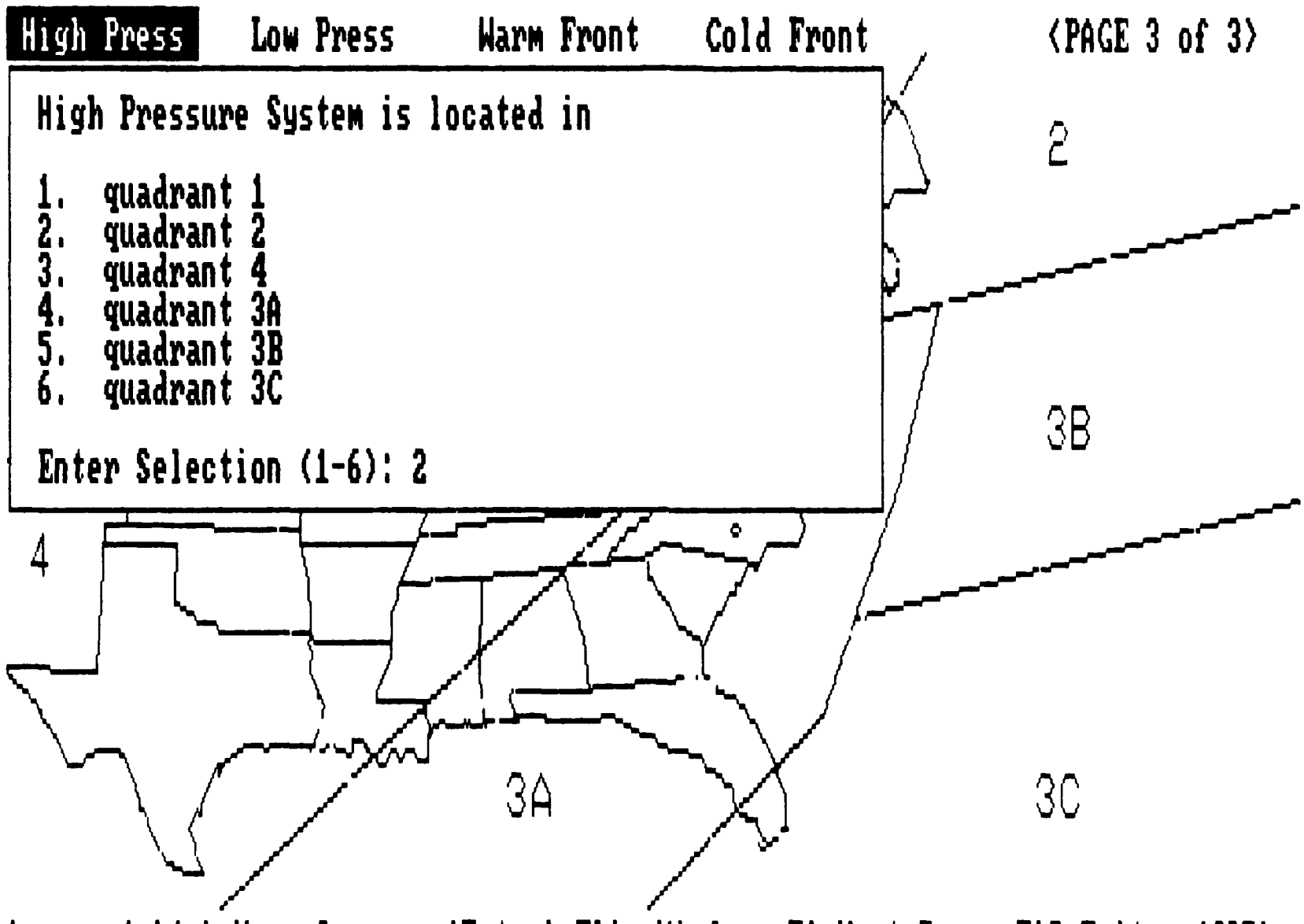


Figure 27. Map-related input, GSB.

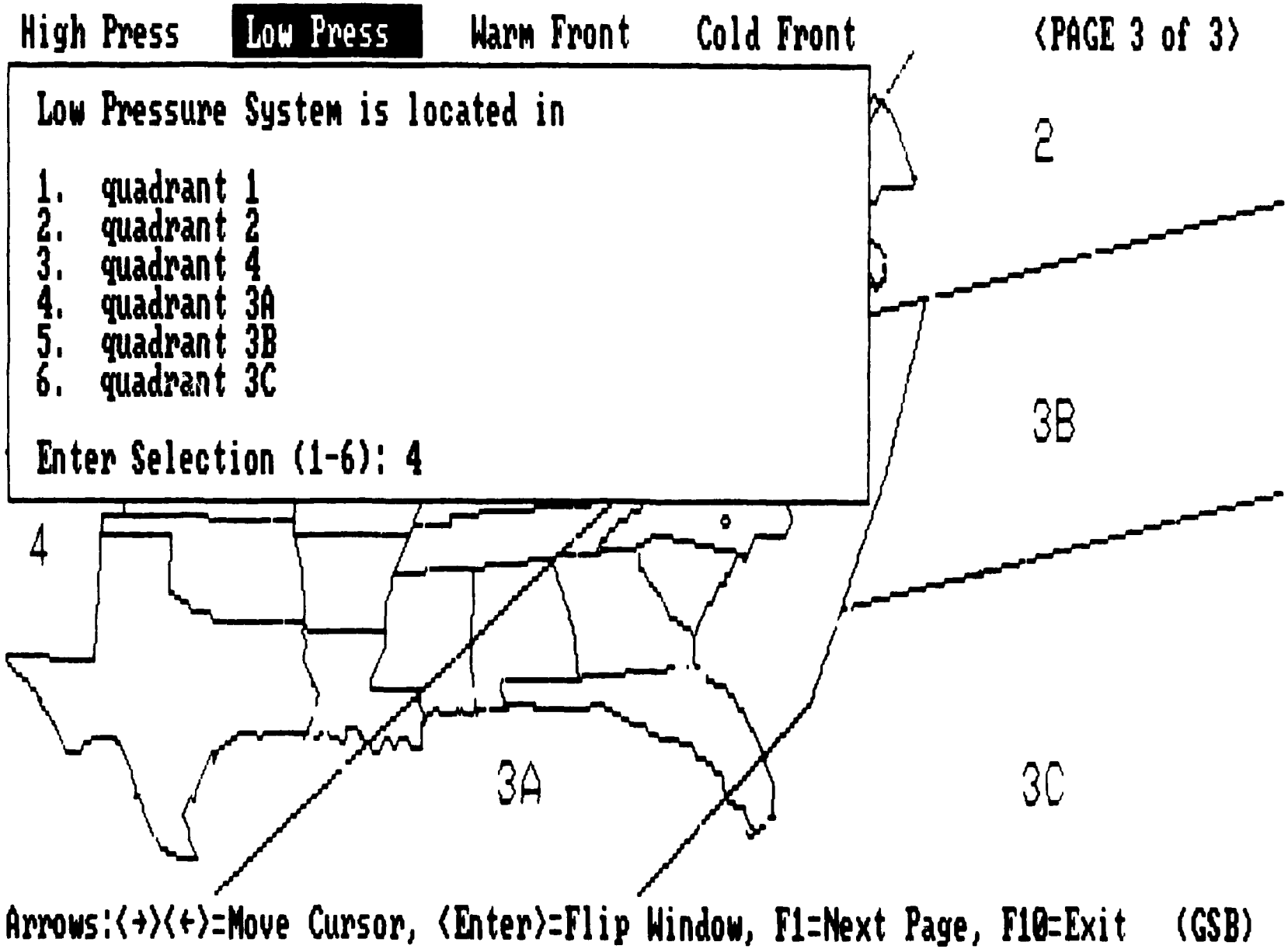


Figure 28. Map-related input, GSB.

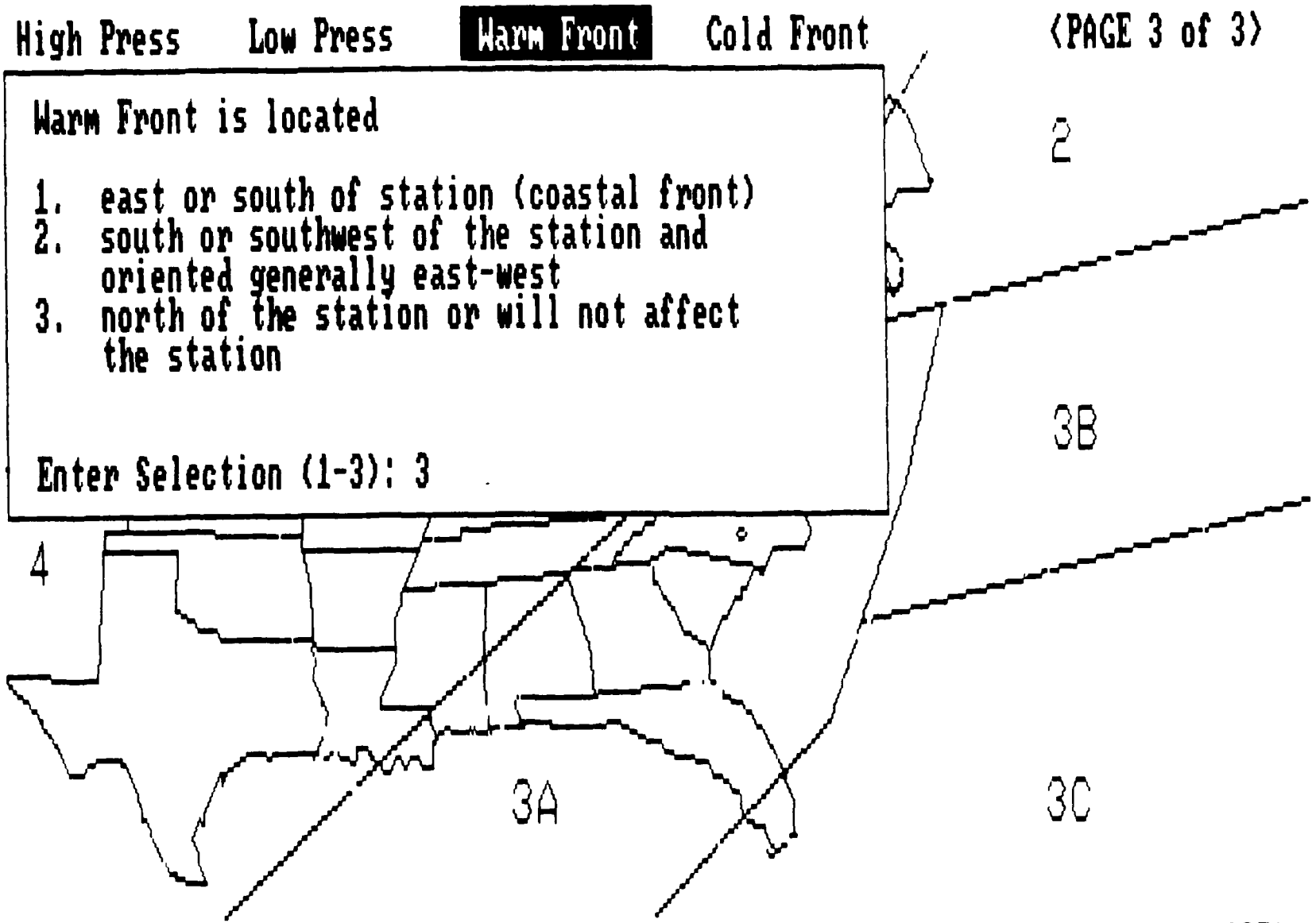


Figure 29. Map-related input, GSB.

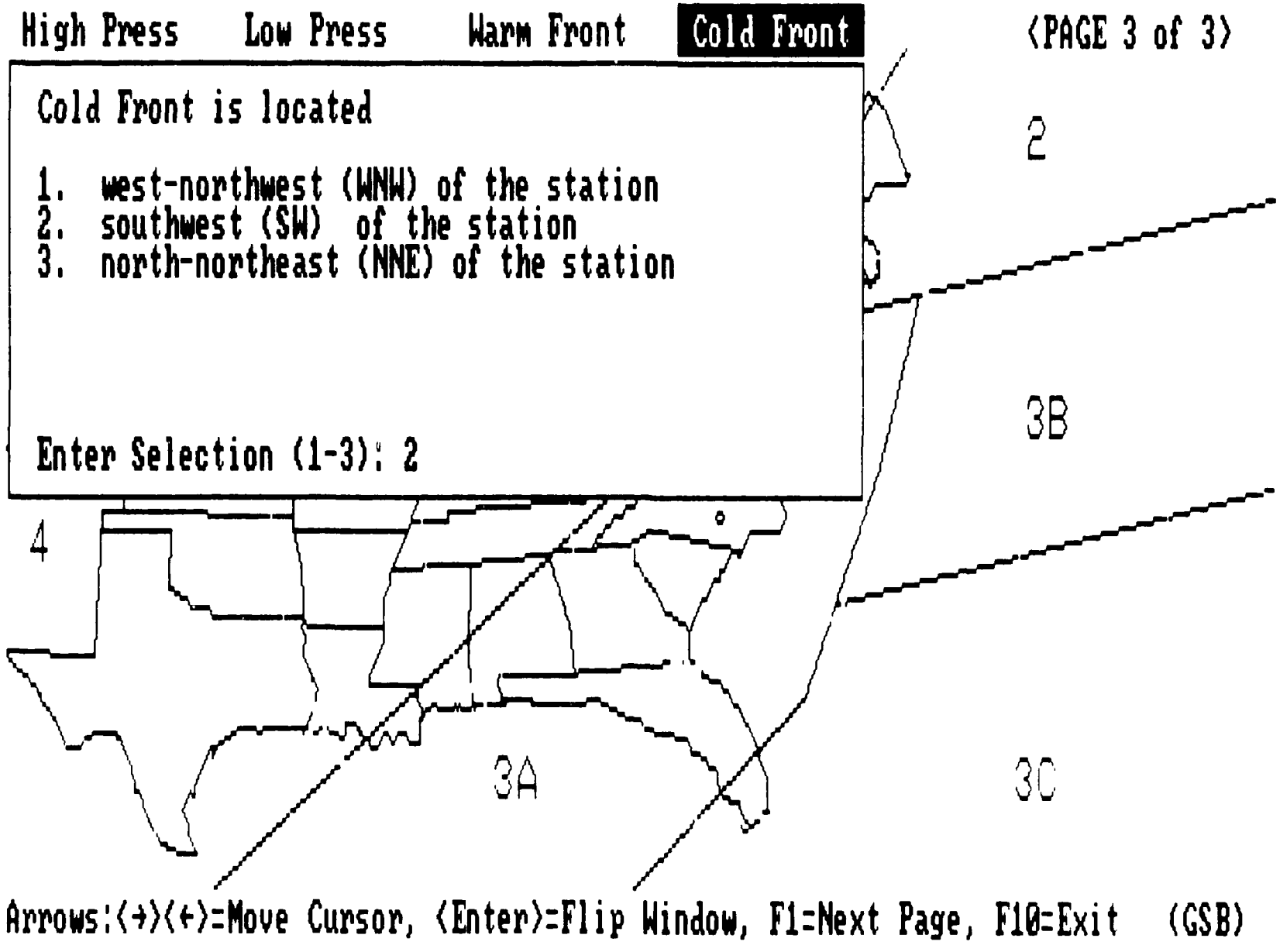


Figure 30. Map-related input, GSB.

```
**  INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (FBG)  **

                        <PAGE 1 of 3>

CURRENT DATE     (mm-dd-yy): [06-24-86] CURRENT TIME    (0001-2400): [1705]
SUNSET SURFACE TEMP.    (F): [75 ]      SUNSET DEW-POINT TEMP.  (F): [68 ]
WIND DIRECTION        (deg): [240]      WIND SPEED            (mph): [4  ]
HAT 850MB WIND DIR    (deg): [324]      HAT 850MB WIND SPD    (mph): [15 ]
FOUS 06 HRS WIND DIR  (deg): [200]      FOUS 06 HRS WIND SPD  (mph): [5  ]
FOUS 12 HRS WIND DIR  (deg): [190]      FOUS 12 HRS WIND SPD  (mph): [8  ]
FOUS 18 HRS WIND DIR  (deg): [200]      FOUS 18 HRS WIND SPD  (mph): [10 ]
FOUS 24 HRS WIND DIR  (deg): [210]      FOUS 24 HRS WIND SPD  (mph): [10 ]
SKY             (See below): [1  ]      VISIBILITY          (miles): [7  ]

(SKY Codes: 1=CLR, 2=SCT, 3=BKN, 4=OVC, 5=-X, 6=X)


 Use arrow keys to move cursor to where you want it, then just type input.
 When done, hit F1 key to see the next page.  There are three input pages.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit
```

Figure 31. Inputs for Zeus meteorological advisory system (FBG).

** INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (FBG) **

<PAGE 2 of 3>

	FBG	GSB	NKT	EWN	ILM	MYR
SURFACE TEMP. (F):	[74]	[73]	[65]	[67]	[66]	[71]
DEW-POINT TEMP. (F):	[68]	[65]	[62]	[65]	[62]	[65]

Get the latest surface observations for the listed stations and enter them.
Use arrow keys to move cursor. When done, hit F1 key to see the next page.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl← >=Move Cursor, F1=Next Page, F10=Exit

Figure 32. Inputs for Zeus meteorological advisory system (FBG).

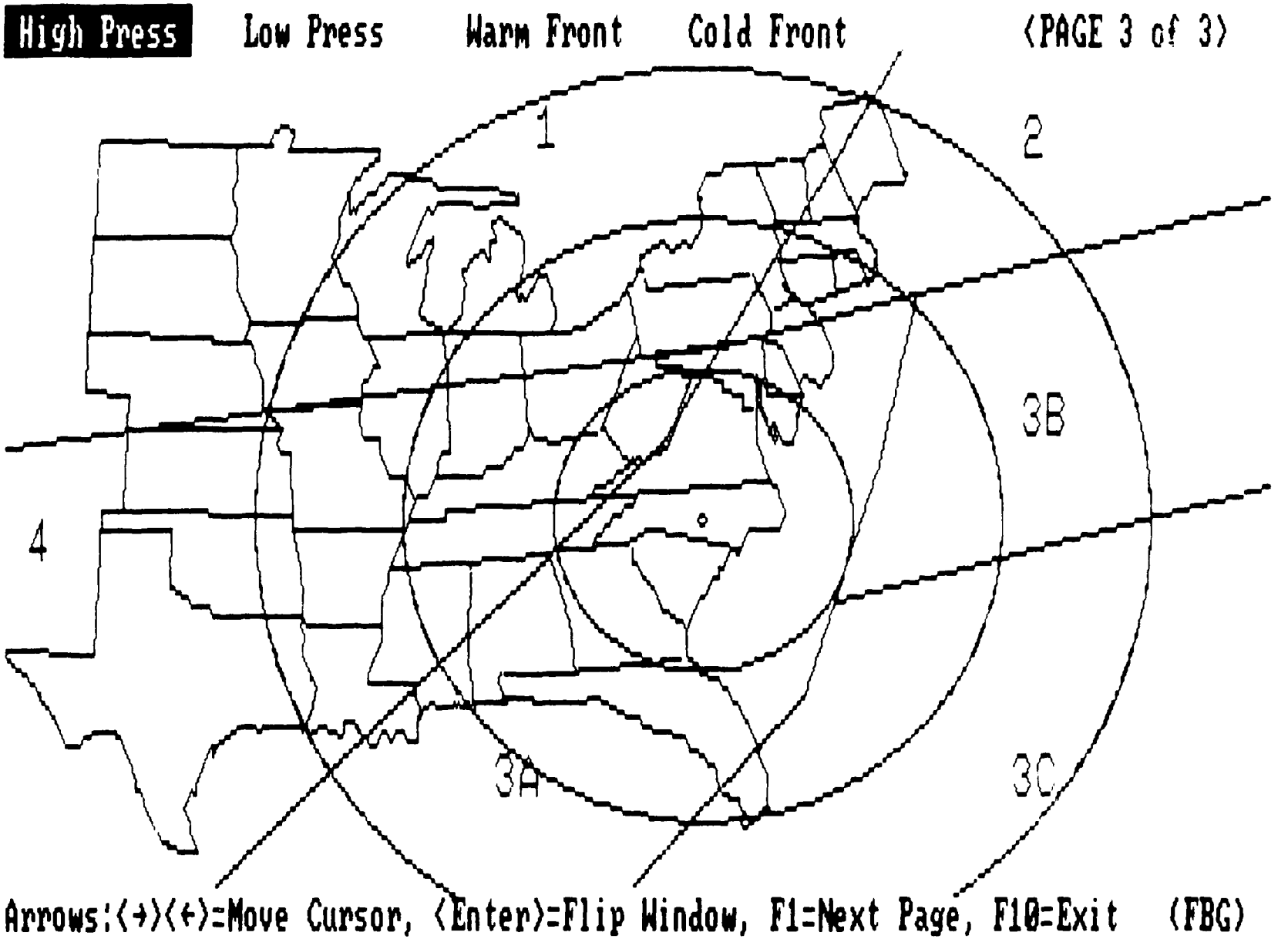


Figure 33. Map-related input, FBG.

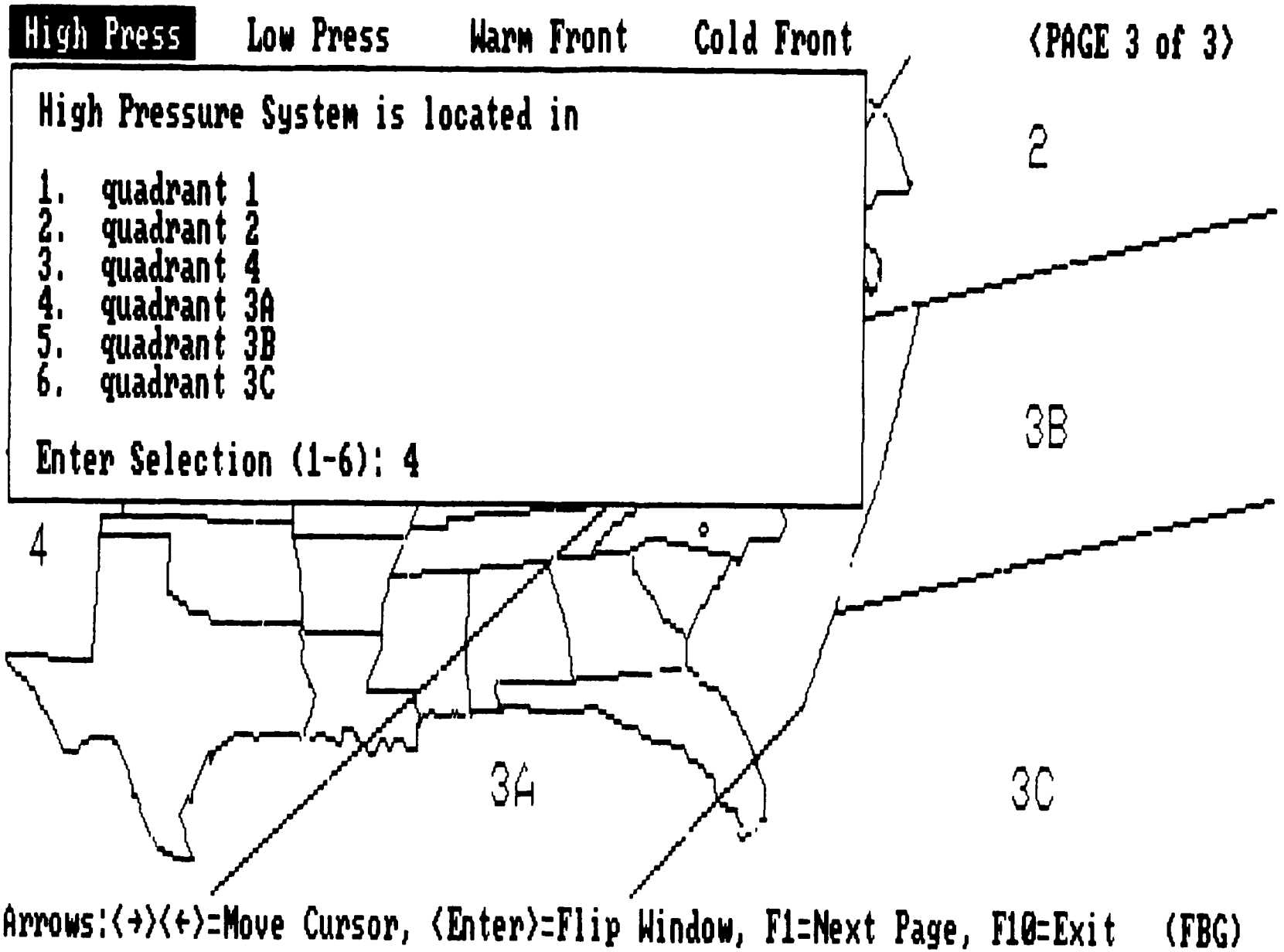


Figure 34. Map-related input, FBG.

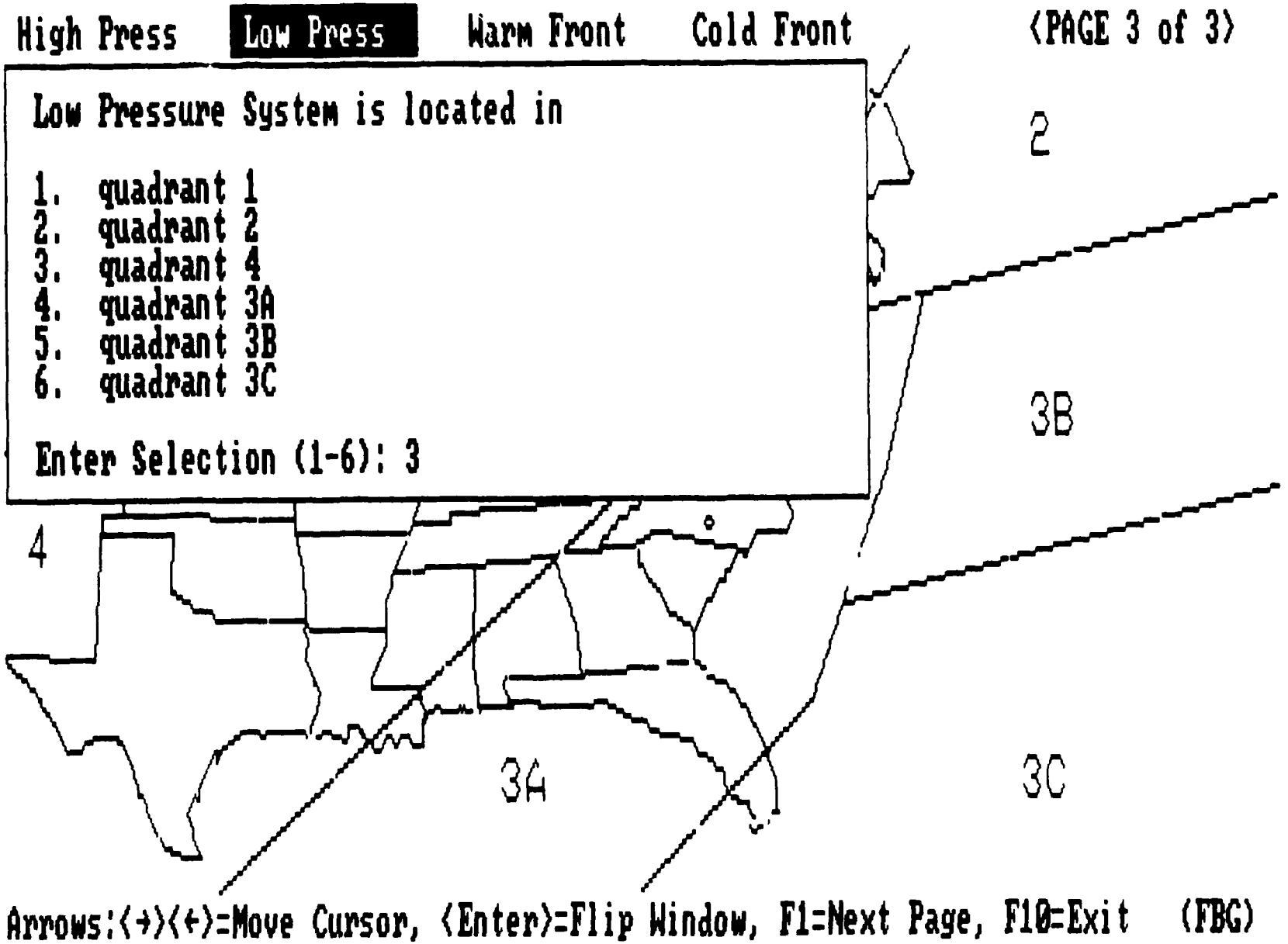


Figure 35. Map-related input, FBG.

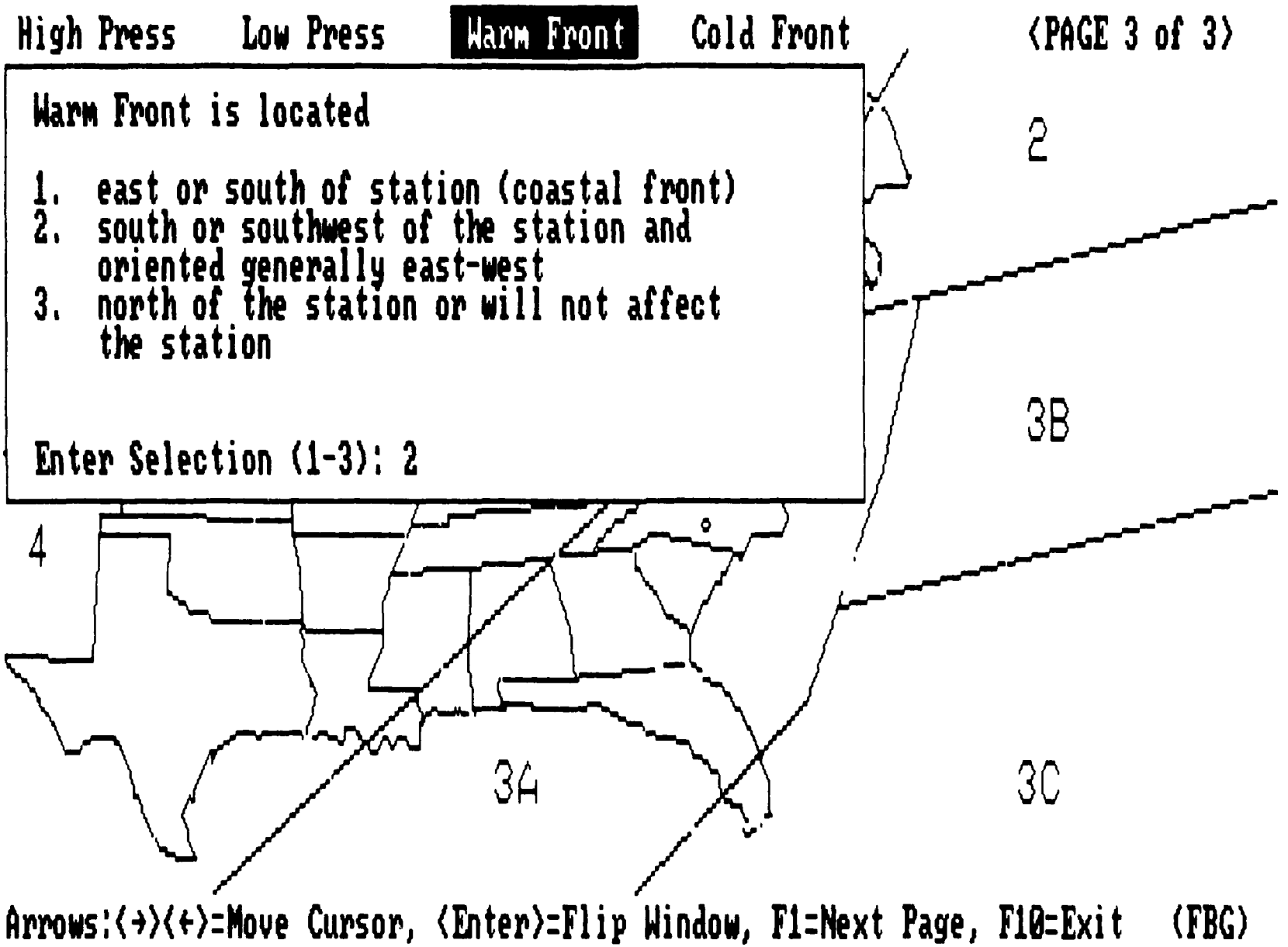


Figure 36. Map-related input, FBG.

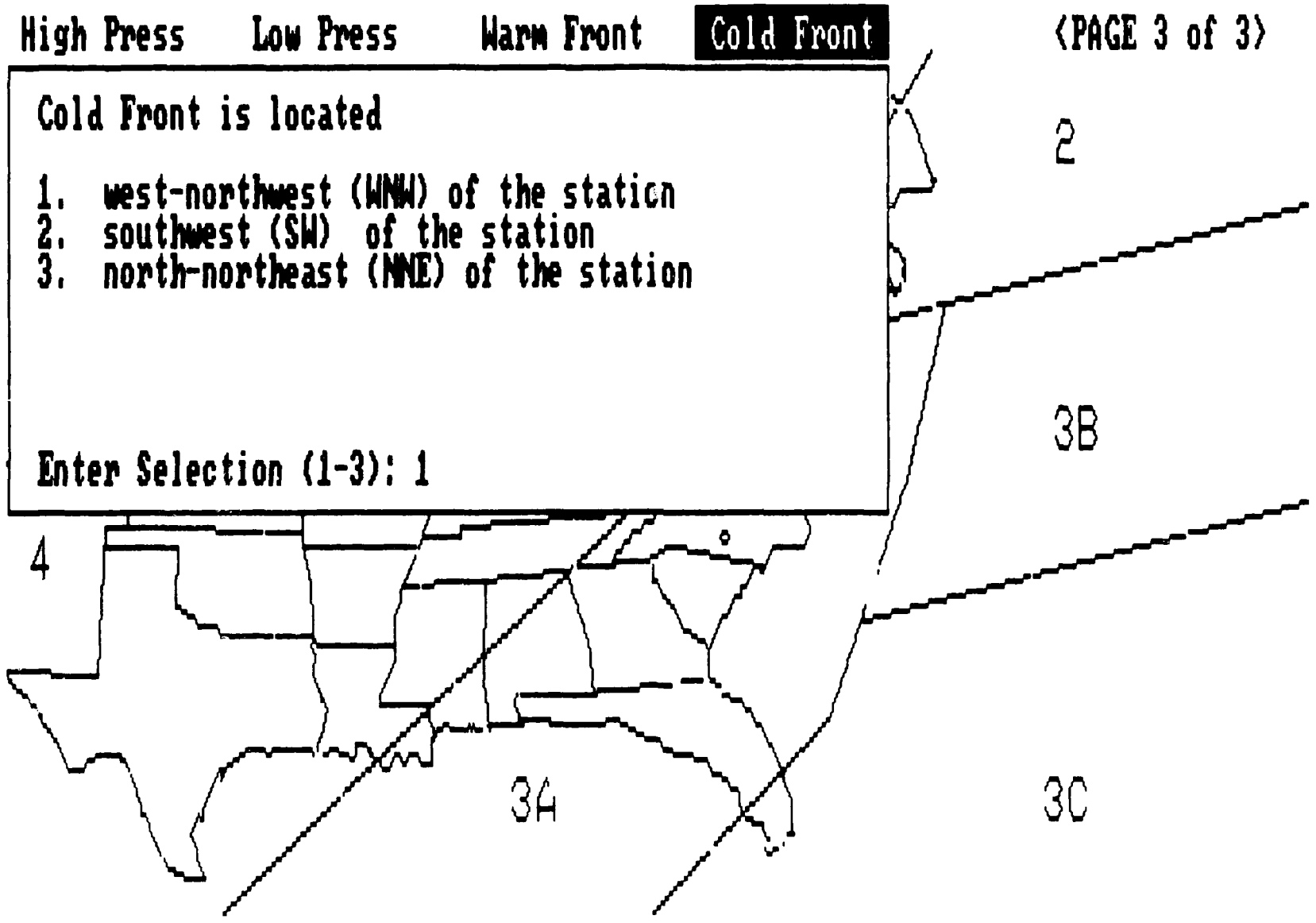
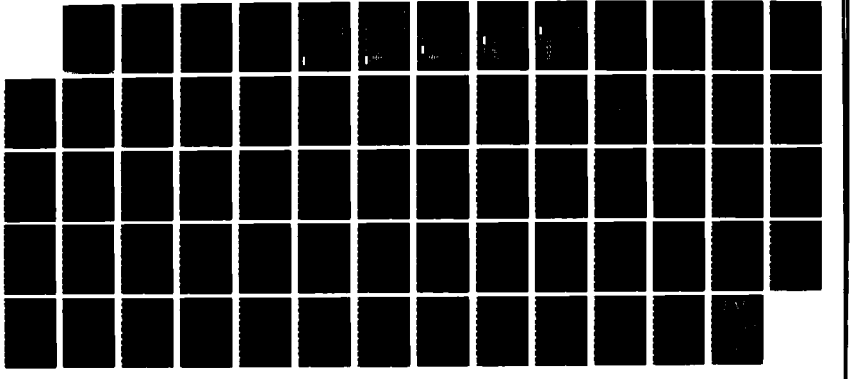
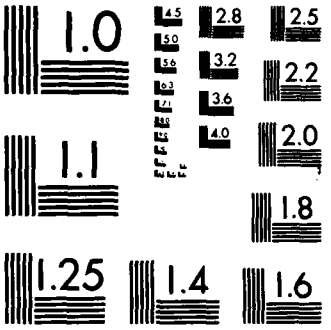


Figure 37. Map-related input, FBG.

AD-A184 197 ZEUS: A KNOWLEDGE-BASED EXPERT SYSTEM THAT ASSISTS IN PREDICTING VISIBILI (U) GEOMET TECHNOLOGIES INC GERMANTOWN MD M J STUNDER ET AL 15 JAN 87 2/2

UNCLASSIFIED GEOMET-EAF-1725 AFGL-TR-87-0019 F/G 12/5 NL





```
**  INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (DOV)  **

                        <PAGE 1 of 4>


CURRENT DATE     (mm-dd-yy): [06-14-86] CURRENT TIME    (0001-2400): [1750]
SUNSET SURFACE TEMP.    (F): [77 ]      SUNSET DEW-POINT TEMP.  (F): [68 ]
WIND DIRECTION        (deg): [260]      WIND SPEED            (mph): [12 ]
ACY 850MB WIND DIR    (deg): [252]      ACY 850MB WIND SPD    (mph): [32 ]
FOUS 06 HRS WIND DIR  (deg): [220]      FOUS 06 HRS WIND SPD  (mph): [10 ]
FOUS 12 HRS WIND DIR  (deg): [205]      FOUS 12 HRS WIND SPD  (mph): [5  ]
FOUS 18 HRS WIND DIR  (deg): [190]      FOUS 18 HRS WIND SPD  (mph): [5  ]
FOUS 24 HRS WIND DIR  (deg): [180]      FOUS 24 HRS WIND SPD  (mph): [5  ]
SKY             (See below): [2  ]      VISIBILITY          (miles): [7  ]


(SKY Codes: 1=CLR, 2=SCT, 3=BKN, 4=OVC, 5=-X, 6=X)


 Use arrow keys to move cursor to where you want it, then just type input.
 When done, hit F1 key to see the next page.   There are four input pages.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit
```

Figure 38. Inputs for Zeus meteorological advisory system (DOV).

```
**  INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (DOV)  **

<PAGE 2 of 4>


LATITUDE  OF SURFACE H.P. CENTER (deg): [40 ]
LONGITUDE OF SURFACE H.P. CENTER (deg): [73 ]
TEMPERATURE OF SEA SURFACE     (deg F): [65 ]
CLOUD COVER FRACTION AT SUNSET   (0-1): [.4 ]
FOUS 06 HRS - RELATIVE HUMIDITY    (%): [75 ]




 Use arrow keys to move cursor to where you want it, then just type input.
 When done, hit F1 key to see the next page.   There are four input pages.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit
```

Figure 39. Inputs for Zeus meteorological advisory system (DOV).

** INPUTS FOR ZEUS METEOROLOGICAL ADVISORY SYSTEM (DOV) **

<PAGE 3 of 4>

	DOV	SBY	ILG	WAL	ACY	BWI
SURFACE TEMP. (F):	[80]	[78]	[82]	[79]	[75]	[80]
DEW-POINT TEMP. (F):	[65]	[64]	[64]	[68]	[69]	[63]

Get the latest surface observations for the listed stations and enter them.
Use arrow keys to move cursor. When done, hit F1 key to see the next page.
<↑><↓><→><←><Home><End><Ctrl→><Ctrl←>=Move Cursor, F1=Next Page, F10=Exit

Figure 40. Inputs for Zeus meteorological advisory system (DOV).

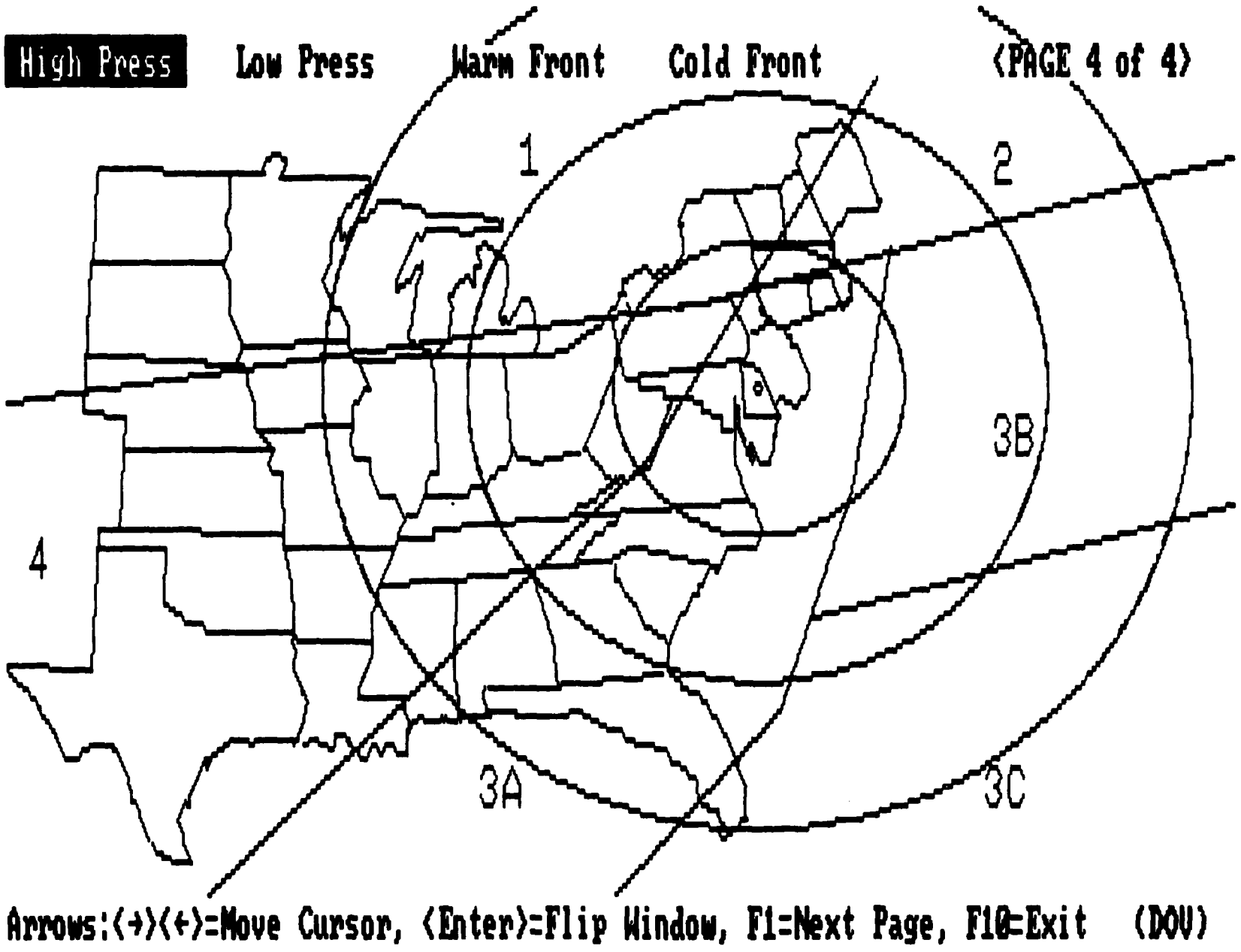


Figure 41. Map-related input, DOV.

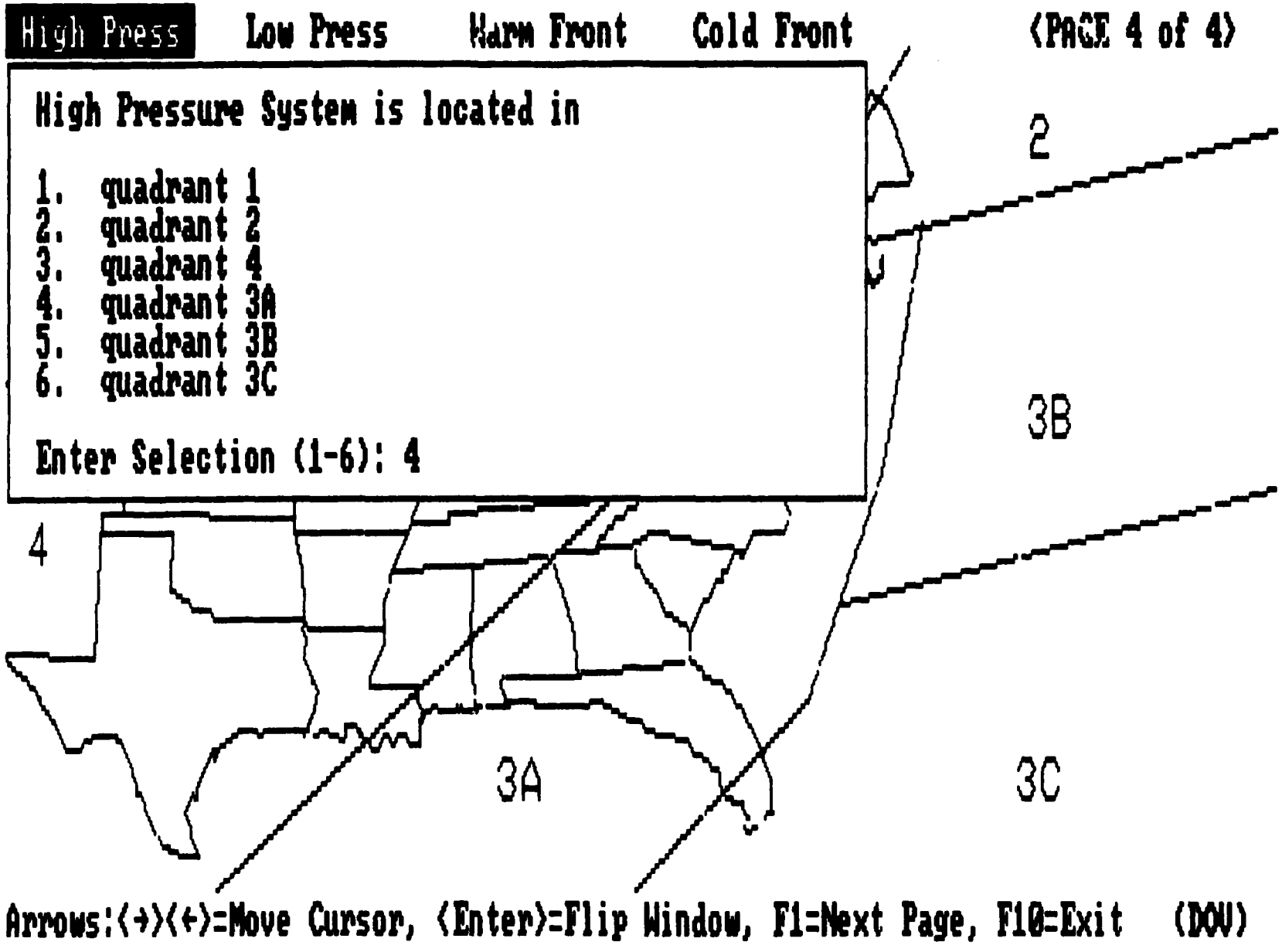


Figure 42. Map-related input, DOV.

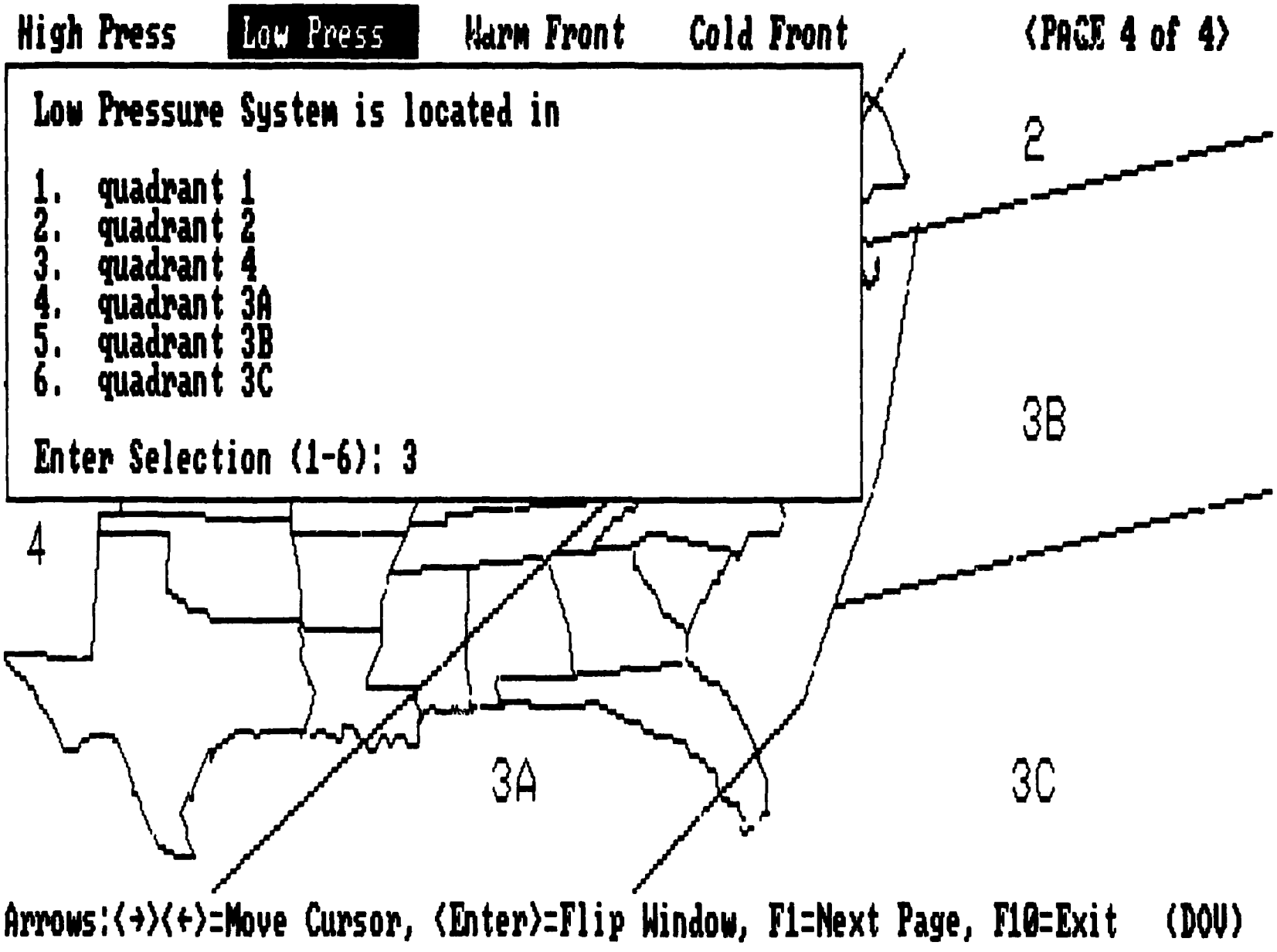


Figure 43. Map-related input, DOV.

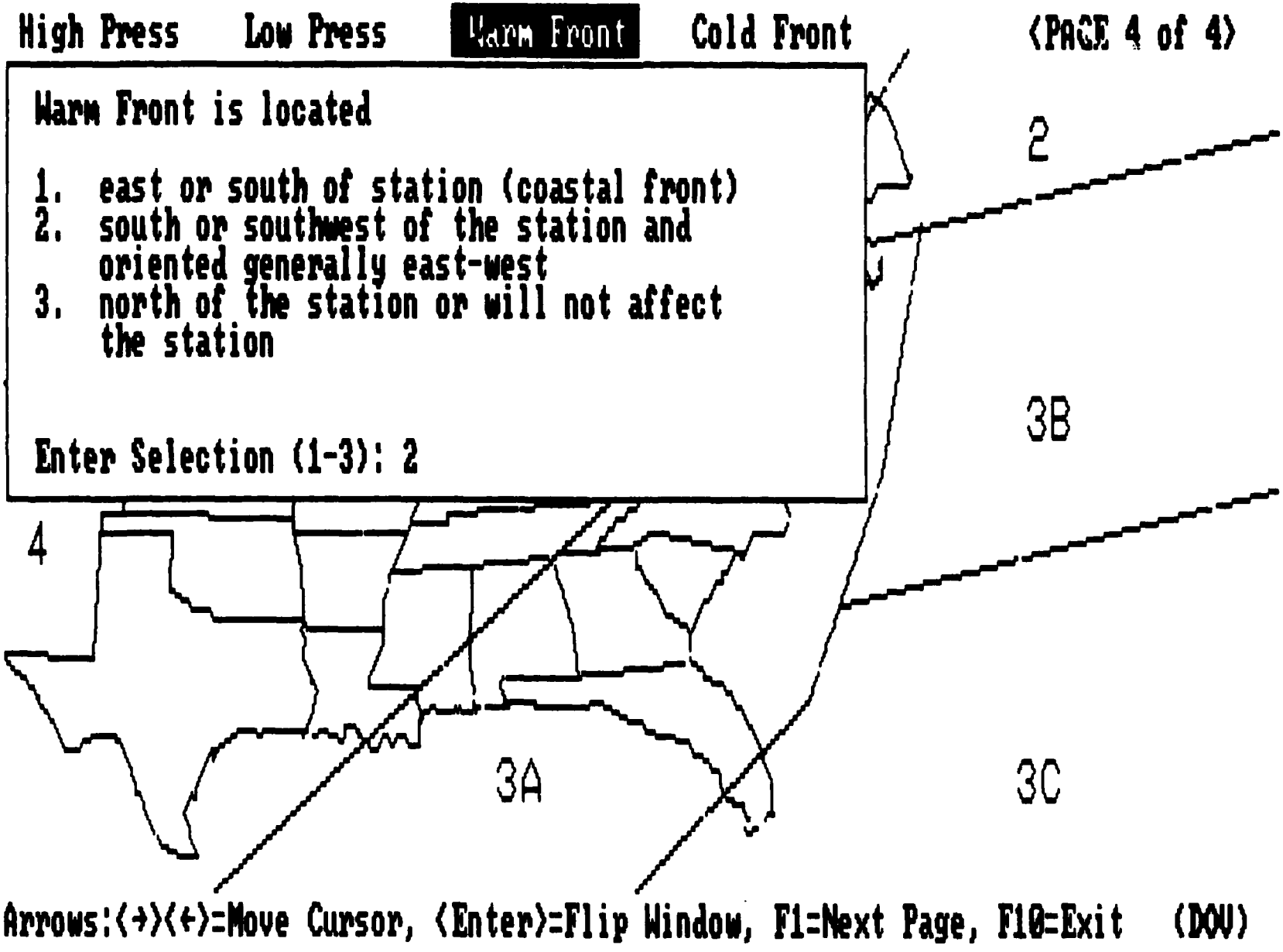


Figure 44. Map-related input, DOV.

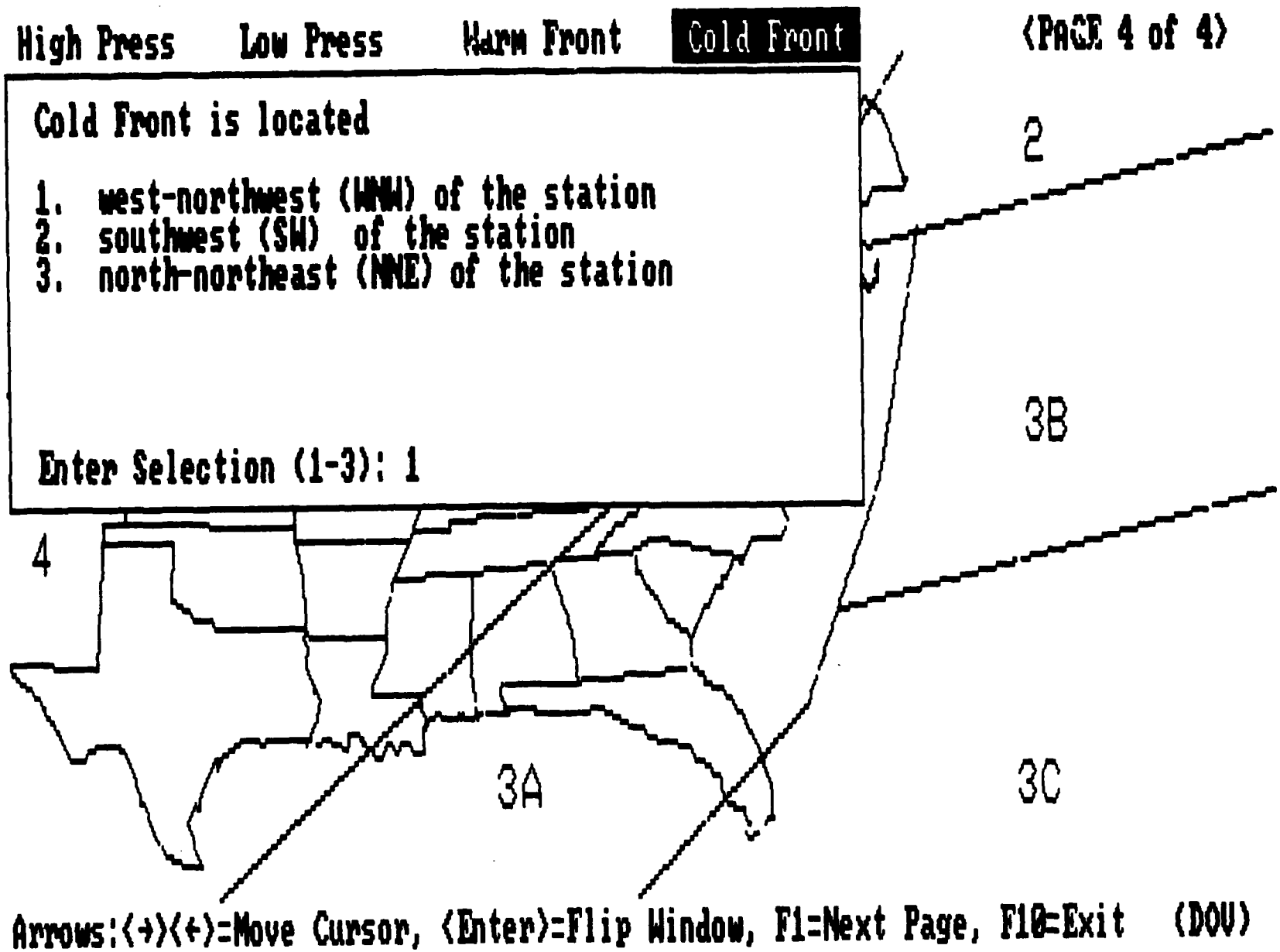


Figure 45. Map-related input, DOV.

TABLE 15 indicates where Zeus input program variables/qualifiers are used within the main Zeus program.

The user interface idea was modeled along the lines of the forecaster worksheet that appears in Fig. 46. Base forecasters are required to fill out the forecaster worksheet in his/her TAF preparation procedure. These sheets provide for a convenient recording of meteorological information for ready base access.

Finally, the output display of Zeus results consisted of advisory text and visibility categories. Sample output appears in Figs. 47 and 48. Unfortunately, it is difficult to graphically depict fog on a computer screen (short of turning the screen white when fog is expected)! We did consider a graph of visibility over time, but we finally decided on explanatory text that fit nicely into the segmented advisory messages being produced by each module used to input synoptic information.

In the next section, we describe the various knowledge acquisition procedures used to "fill out" or "flesh out" the structure presented in this section.

TABLE 15. Zeus Input Program Versus Zeus Main Program Use (Example: Simmons AAF).

Input Variable/ Qualifier	Source	Where Used (in Zeus)
Time	System clock	Many rules.
Month	System clock	Sunrise/sunset rules; wind direction-Atlantic flow rules; any climatology-related rules.
Wind direction and speed	Simmons surface observation	Radiative and advective modules. Speed used in breakup (faster means breakup quicker) and in formation (i.e., high winds indicate no fog).
HAT 850 mbar, wind direction and speed	Hatteras sounding	Atlantic flow determination; speed important for radiative fog.
FOUS	Wilmington (for Simmons)	Combined with other conditions--determines whether Atlantic flow could exist or whether other flow regimes exist.
Sky, visibility	Simmons surface observation	Sky: combined with other conditions determines radiative potential. Visibility: important variable, used in major triggering rules: if low, then system follows path of persistent low visibility or improvement; if greater than 3, system determines whether low visibility will exist in the future.
Surface temperature and dewpoint at surrounding stations	Surrounding station observations	Used in temperature minus dewpoint spread analysis of eastward stations if speed analysis is less than 10°.

DATE:	FORECAST WORKSHEET/VERIFICATION LOG	FCSTR:

I. SYNOPTIC SITUATION _____

_____

_____

RADAR INDICATES _____

SATELLITE INDICATES _____

LAWC/SXUS AT _____Z INDICATES _____

_____

AFGWC MWA _____ CURRENT TEMP-DEWPOINT _____

II. FORECAST CONSIDERATIONS:

A. FOUS 62 KWBC

	BOUNDARY WINDS	R1	R2	R3	SI	PRECIP	PRESS
6HR____Z	_____	___	___	___	___	_____	_____
12HR____Z	_____	___	___	___	___	_____	_____
18HR____Z	_____	___	___	___	___	_____	_____
24HR____Z	_____	___	___	___	___	_____	_____

B. FJUE 53 KGWC

700 MB HT UP/DOWN 500 MB HT UP/DOWN ARE BOTH UP/DOWN YES/NO SI____

C. FOUE 05 KWBC

	TSTM	WINDS	C/V
6HR____Z	_____	_____	_____
12HR____Z	_____	_____	_____
18HR____Z	_____	_____	_____
24HR____Z	_____	_____	_____

D. LFM: IS THE LFM INITIALIZED PROPERLY? YES/NO

VORTICITY ADVECTION (POS/NEG/NEUT) CURR:_____ 12HR:_____ 24HR:_____

THICKNESS ADVECTION (INC/DEC/NEUT) CURR:_____ 12HR:_____ 24HR:_____

GSB IN/OUT 700 MB 70% ISOPLETH CURR:_____ 12HR:_____ 24HR:_____

5400 M LOCATION (FALL/WINTER ONLY) CURR:_____ 12HR:_____ 24HR:_____

850 MB TEMP ADVECTION (W/C/NEUT) CURR:_____ 12HR:_____ 24HR:_____

E. TURBC: FANH 2 INDICATES TURBC YES/NO, LEVELS _____ TO _____

SKEW-T INDICATES TURBC (SPEED/DIRECTION SHEAR PRESENT) YES/NO,LEVELS _____ TO _____ FANA INDICATES TURBC BELOW 10,000FEET YES/NO

F. ICG: FANH 2 INDICATES ICG YES/NO, TYPE _____ LEVELS _____TO _____

FREEZING LEVEL _____FT AT _____. IS SIG MOISTURE AVAILABLE AT THE FREEZING LEVEL? YES/NO FANA INDICATES ICG BELOW 10,000 FEET YES/NO

G. RDU FCST _____

_____

H. ARE AREA OR TERMINAL METWATCH ADVISORIES IN EFFECT FOR ICG, TURBC, TSTMS, ETC?

5WW FORM 65 DEC 84

Page 1 of 2 pages

(Continued)

Figure 46. Seymour Johnson forecaster's worksheet.

INITIAL FORECAST DESSEMINATION: T/A _____Z COMEDS _____Z ATAD _____Z

NOTE: APPEND A HARD COPY OF THE GSB TAF TO THIS FORM, CHECK AND INITIAL FOR ACCURACY.

AMD # _____ BEFORE AFTER REASON?

GSB TAF ____AMD _____

DISSEMINATION T/A _____Z COMEDS _____Z

FORECASTER REMARKS, NOTES, HINDSIGHT, SECOND THOUGHTS, MINI REVIEWS!!!!!!!!!!

TEMP/PA FCST: FROM NWS FAX CHART: _____ MIN _____ MAX

TIME (L)												
TEMP												
PA												

VERIFICATION: PERSISTENCE _____

FCST HR	1	2	3	4	5	6	9	12	18	24
FCST C/V										
OBSVD C/V										

Page 2 of 2 pages

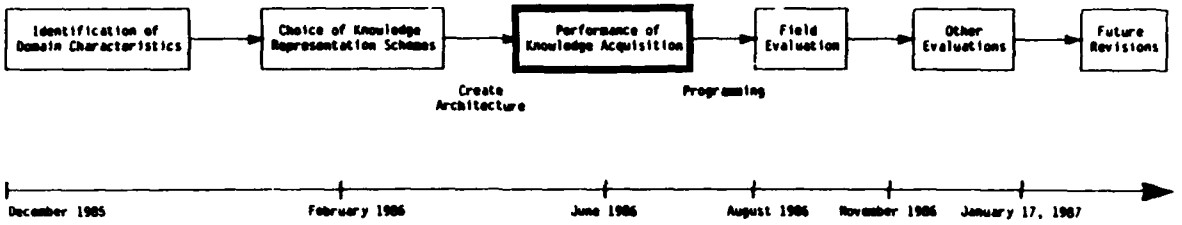
Figure 46. Seymour Johnson forecaster's worksheet (Concluded).

```
1     Advise Visibility Category 3
  70

  Current time (in hhmm) = 1900.000000
  Current visibility (in miles) = 7.000000
  ADVECTIVE FOG FORMATION TIME (APPROXIMATELY) = 0.000000
  High is moving eastward or northeastward or north from New England
  area.  Monitor dew-points and any gradual windshifts over next several
  hours for any change in temperature minus dewpoint differences in
  surrounding area; look for any increase in easterly component to the
  wind at the surface and aloft in boundary layer.
  Even though synoptic features indicate surface Atlantic flow needed fo
  ADVECTIVE FOG is present, necessary boundary layer features are NOT
  NOW present.
  Overall synoptic situation is not favorable for RADIATIVE FOG formatio
  during the next 12 hours.
  RADIATION FOG EXPECTED FORMATION TIME (APPROXIMATELY) = 0.000000
```

Figure 47. Typical Zeus output.

```
1     Advise Visibility Category 1
 85

 Current time (in hhmm) = 1900.000000
 Current visibility (in miles) = 3.700000
 ADVECTIVE FOG FORMATION TIME (APPROXIMATELY) = 0.000000
 High is either becoming stationary or is ridging down coast which
 increases nighttime RADIATIVE FOG and daytime HAZE possibilities if
 summer, or nighttime RADIATIVE FOG possibilities if winter.
 RADIATION FOG EXPECTED FORMATION TIME (APPROXIMATELY) = 300.000000
 Backdoor coldfront is to your north.  As a reminder, make sure front is
 not moving down coast as this could affect forecasts dramatically.
 Check surface obs. for little frontal movement; check 850mb flow for
 signs of weakening;Make sure winds are parallel to front...anything
 else...then be suspicious of movement southward....
 RADIATIVE FOG is expected to form around radiative fog formation time
 and then lower to below 1 mile.  Keep an eye out for any intervening
 clouds, but conditions look favorable at this time.
 Current date = 07-04-80
```

Figure 48. Typical Zeus output.



Section 4.0

KNOWLEDGE ACQUISITION

"Knowledge" itself is the key ingredient to any expert system development. Thus, knowledge acquisition is probably the most important aspect of developing an expert system. It is important, not only because knowledge is necessary to make the expert system run, but it is also important because of the importance of expert system developer-user interaction. The term "knowledge engineer" has been associated with the person who collects the knowledge and formulates the presentation schemes.

The knowledge engineer usually has intensive interactions with the domain experts. This poses some interesting situations in many AI applications where AI-oriented knowledge engineers try to become pseudo-experts in a particular field. Sometimes it is successful as in several medical AI systems, where after a year or two, the knowledge engineers become pseudo-doctors or medical technicians. In other expert system developments, it has not been very successful.

In the meteorology field, there is no reason why meteorologists cannot become knowledge engineers themselves provided they have the proper training. A readily apparent analogy can be drawn between computer scientists and meteorologists. Most meteorologists can program in FORTRAN or other common computer languages. They also know how to logically design a structured program. Consequently, they can do much of the work themselves. Should a more theoretical programming problem be encountered, a computer scientist could be called in to help the meteorologist resolve the difficulty. Similarly, in AI-meteorology, meteorologists can be trained as knowledge engineers and conduct interviews and structure expert system themselves. Should a major difficulty be encountered, the meteorologist could call on a (pure) knowledge engineer or theorist. This is the approach that has been adopted by DuPont where over 300 successful KBES projects have been developed by non-AI-oriented personnel to date.

The use of trained knowledge engineers with meteorological backgrounds provides another great advantage in terms of time, because the meteorological knowledge engineer is already familar with the domain and could save considerable amounts of effort in interacting with fellow (domain) meteorologists.

4.1 GENERAL KNOWLEDGE ACQUISITION MECHANISMS

The process of acquiring knowledge can be divided into four categories:

1. Literature review
2. Structured interview
3. Study of domain experts performance of tasks
4. Performance of experts on tough cases.

The literature review usually occurs first and sets the stage for the later interviews. The review is straightforward with domain and other resources examined.

The structured interview results from a close literature review and combining that knowledge with any similar knowledge engineering experience to form a complete picture of the situation. This "first-pass" or conceptual model is then used as a source of questions to the experts. The interview leads to additions and deletions of information.

The third category involves studying the actions of the experts while they are engaged in typical tasks. The object of the specific study is to look for commonalities in terms of goals, data records produced, imagery viewed, or information the experts like to have available.

The final category involves the way the expert handles a tough case. The expert could be presented a previous problem and be asked to solve it. The knowledge engineer then looks for subtle or refined aspects of the expert's reasoning and uses this information to further enhance the knowledge data base.

4.2 APPROACH TO ZEUS KNOWLEDGE ACQUISITION

4.2.1 Compilation of Rules and Techniques from Literature Review

The literature search consisted of examining the following resources for useful information:

- GEOMET's corporate library
- NOAA library (Rockville, Maryland)

- North Carolina State University library (Raleigh, North Carolina)
- AWS library (Scott Air Force Base, Illinois)
- DTIC/NTIS.

Twenty-two visibility documents were borrowed on interlibrary loan from the AWS library along with numerous copied "bits and pieces" of other key documents such as RUSSWO's. Several key documents were copied from the NOAA library and a cross-check was made to avoid duplication of documents from other sources. A list of reference material appears in Appendix B.

GEOMET requested DTIC meteorological search terms are listed in TABLE 16. The search was requested for the years 1950-present. A quick scan of the search indicates many RUSSWO document citations for other airbases, which will not serve our purpose.

In addition, GEOMET was placed on the DTIC recurring reports list for the created visibility search strategy and received biweekly DTIC updates on new visibility developments. This greatly aided in any modification or additions to the knowledge base due to new research or reports over the course of the project.

A typical visibility document evaluation consists of the following questions asked internally by a GEOMET meteorologist:

- Is the document specific to the mid-Atlantic, Southeast region, or study airbase? If the answer is yes, special attention is given to any rules mentioned within the case review text or special meteorological analysis procedures presented. For example, special note has been made of the satellite "burnoff from the edges technique" used to forecast fog dissipation described in a Seymour Johnson/SE United States document.
- Does the document contain a general review of visibility techniques? If this is the case, particular attention is paid to subsections regarding specific types of fog (advection, radiation, etc.) or phenomena (drizzle, stratus, etc.).
- Is the document more equation/model oriented? Several evaluated documents derive numerical models for predicting fog (see, for example, reference 11).

TABLE 16. GEOMET Requested DTIC Search Terms for Low-Visibility References.

First-Level Search Terms

Slant Range
Visibility
Visual Flight
Visual Range

Second-Level Search Terms

Anticyclones
Atmospheric Condensation
Atmospheric Motion
Atmospheric Precipitation
Atmospheric Refraction
Atmospheric Temperature
Barometric Pressure
Ceiling
Cloud Cover
Clouds
Cold Fog
Cold Fronts
Crosswinds
Cumulonimbus Clouds
Cumulus Clouds
Cyclones
Dew
Dust Storms
Fog
Fronts (Meteorology)
Geostrophic Wind
Gusts
Hail
Haze
Hydrometeors
Ice Fog
Jet Streams
Lapse Rate
Lightning
Meteorological Phenomena
Meteorology
Microbarometric Wave
Monsoons
Nimbostratus Clouds
Rain
Sea Breeze
Snow
Snow Cover
Snowdrifts
Snowfields
Storms
Stratus Clouds
Temperature Inversion
Thunderstorms
Tornadoes
Tropical Cyclones
Wind

Rules were recorded on 4" X 6" cards for easy reference.

Other information such as simplistic equations are also recorded on the 4" x 6" cards. These simplistic equations were thought to be useful in deriving future rule required quantities such as mixing ratios, boundary layer depth, etc.

4.2.2 Compilation of Rules from Airbase-Specific Literature and Airbase Personnel

Interviews with airbase personnel were conducted from February 24 through 28, 1986. These interactions consisted of the following four components:

- GEOMET briefing to AWS personnel on the AI/KBES project.
- General round-table discussion with available AWS personnel on visibility forecasting at the particular airbase.
- Individual interviews with available AWS personnel.
- Identification of important base-specific meteorology and documents.

A listing of AWS and civilian personnel interviewed appears in TABLE 17.

GEOMET personnel briefed all available AWS personnel on the nature of the project. These briefings typically took an hour and included many exchanges of ideas and information. GEOMET meteorologists began the discussion by questioning the audience on whether they had ever heard of AI and then by giving an overview of AI and expert systems.

Careful emphasis was given to the fact that this effort is both exploratory (i.e., feasibility study, proof-of-concept ideas) and not meant to replace humans. A particular effort was made to stress that the KBES is really a knowledge or meteorological advisory system. GEOMET personnel have been sensitive even prior to contract start to the potential public perception that AI is a "2001" technology and that it does away with humans. It is our opinion that the bases reacted favorably to the project description, are not perceiving AI in the wrong manner, and are more than willing to cooperate throughout the project as evidenced by the amount of information obtained and enthusiasm shown during the interviews.

A second component of the visits involved a round-table discussion of conditions that can cause low visibility at the various airbases. This discussion laid the groundwork for the interviews.

TABLE 17. AWS Personnel Interviewed and Assisting in the Artificial Intelligence Effort.

Seymour-Johnson AFB 24-25 February 1986	Simmons AAF 26-27 February 1986	Pope AFB 27 February 1986	Dover AFB 24-25 February 1986	North Carolina State University 28 February 1986	Civilian Meteorologists 28 February 1986
Capt. Edwin Arrance (Det Co)	Lt. Col. Ron Parker (Det Co)	Capt. Clayton (Det Co)	Major Tom Gray	Capt. Frank Estes	Mr. David Martin
2d Lt. Steven Bertone	2d Lt. Chris Brooks	MSgt. Peterson (Supplemental Interviews)	MSgt. Paul Dries	Capt. James Kroll	Mr. Greg Fischell
Sgt. John Blackburn	MSgt. James Norris		TSgt. Ed Zemba		
SSgt. Debra Davis	MSgt. Earl Simons		SSgt. Scott Klaiber		
TSgt. Andrew Farley	Mr. Robert Madison				
SSgt. John Jackson					
SSgt. Donald Jeter					
SSgt. Jerry Sanders					
SMSgt. Thomas Scholl					
2d Lt. Markus Sonells					
MSgt. George Strunk					
TSgt. Carlos Vasquez					
Mr. Gene McKemie					
Major Love* (New Det Co)					

* Interviewed later.

The individual interviews initially consisted of discussing the experience of the AWS person. This included questions such as educational background, forecasting/observer background, general meteorological background, and length of time at the base. This preliminary discussion will aid us in determining the quality of information obtained from the interviewee. Obviously, the AWS person who has been at the station 3 years and in AWS 11 years has more experience than a person who has been at the station 3 months and who has only 8 weeks of formal meteorological training. Yet, the less experienced forecaster may have valuable insights into either a low-visibility case he/she was specifically involved with or in placement and use of the KBES.

The next step in the interview was to quickly establish the generalized meteorological situations under which certain parameters or events were likely to occur. For example (based on the initial discussion), North Carolina low-visibility situations may be divided into wind flow regimes such as:

- Atlantic flow
- Southwesterly flow.

Questions were directed toward key parameters that can be used to predict the onset of one of the flow-associated weather conditions. AWS personnel were given several "what if" conditions and asked how they would respond as a forecaster. We present in Appendix C the conversation held between Mark Stunder (GEOMET meteorologist) and Bob Madison (Fort Bragg civilian meteorologist) as an example of a typical GEOMET-AWS meteorological interview. Most interviews were recorded on cassette tapes.

Simplistic fog routines were obtained from Dover and Pope AFB (located 20 mi from Simmons). These routines are shown in Figs. 50, 51, and 52. The parameters of these routines were included in the various rulepaths as indicated by the various interviews.

Additional interviews were held by conference telephone calls or correspondence. All information was encoded into rule format for use in EXSYS.

FORECAST CHECKLIST

STRATUS/FOG

1. DATA REQUIRED: DATE_____

a. POB maximum temperature_____ °F

b. POB surface wind direction (1500E)_____.

c. POB surface temperature (1500E)_____ °F

d. POB dew-point temperature (1500E)_____ °F

e. POB dew-point depression (1500E)_____ °F

f. Was there stratus/fog this morning? Yes_____No_____.

g. Was, or will there be local showers(1200E-0000E)? Yes____No____.

h. Is POB 1500E dew-point 65°F or higher? Yes_____No_____.

i. Is or will the wind flow come inland from overwater? Yes___No___.

2. STEPS:

a. If 1a is less than 55°F, the method is not applicable, Stop.

b. Enter the forecast diagram with 1b and 1e. Yes____No____Stop.

c. If the point falls in the southwest quadrant "possible" area and at least two of 1f, 1g and 1h are yes, forecast Yes_____, otherwise forecast No_____.

d. If the point falls in the Northwest "possible" area, and 1i is yes, forecast Yes____ _, otherwise forecast No_____.

3. VERIFICATION:

a. Forecast: Yes____ No____; Observed: Yes____ No____

b. Time of occurence_____ Time of Dissipation_____

c. Lowest Condition:_____

d. Remarks:_____

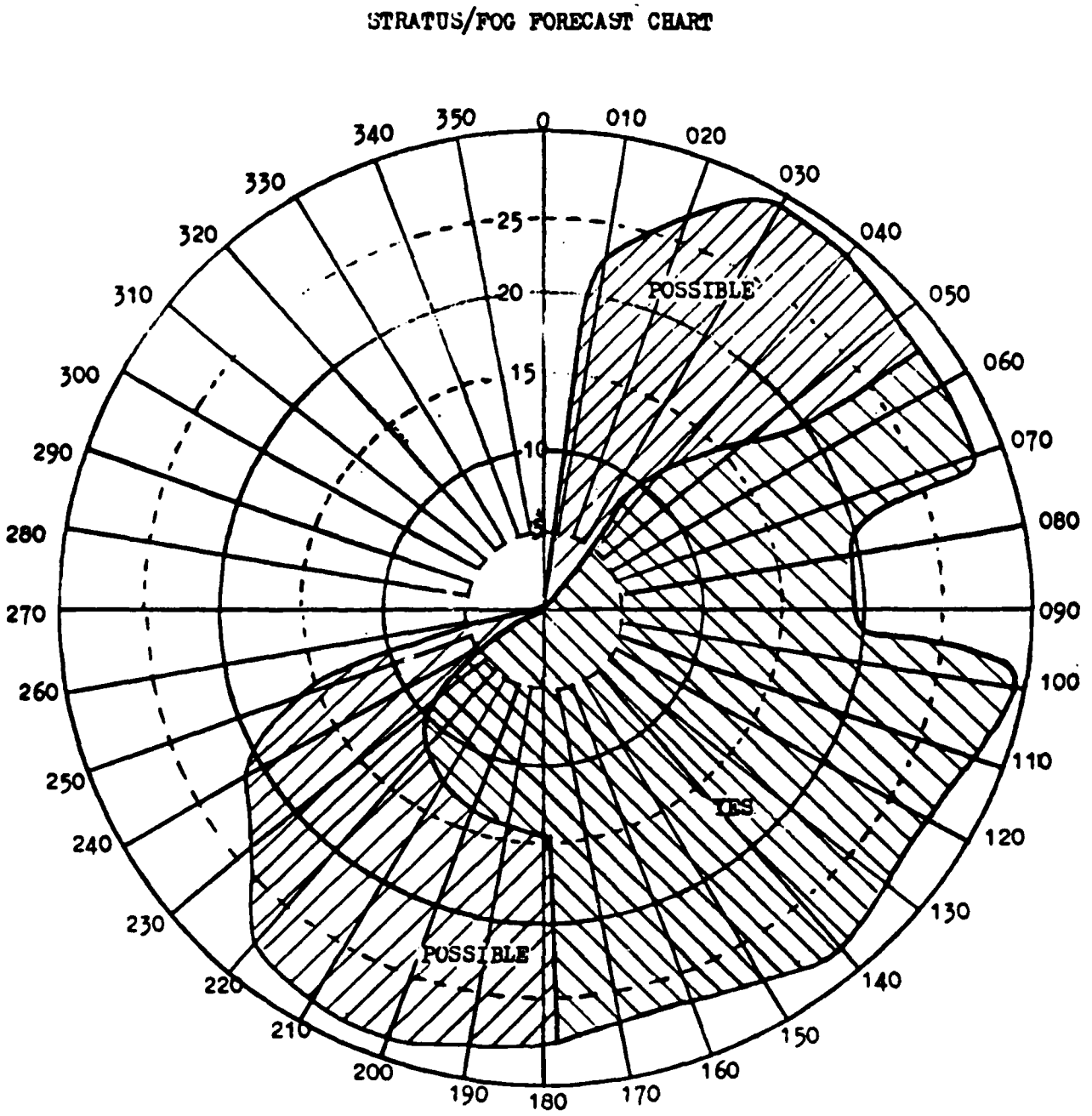
_____

2-6

APPENDIX 2
TFRM
Det 4, 5 Wwg, Pope AFB

Source: Clark (1965)

Figure 50. Forecast checklist--stratus/fog, Pope AFB.



1500E Surface Wind Direction (in degrees) Versus 1500E Dew-Point Depression (in degrees Fahrenheit).

Figure 51. Stratus/fog forecast chart (source: reference 21).

FOG STUDY WORKSHEET

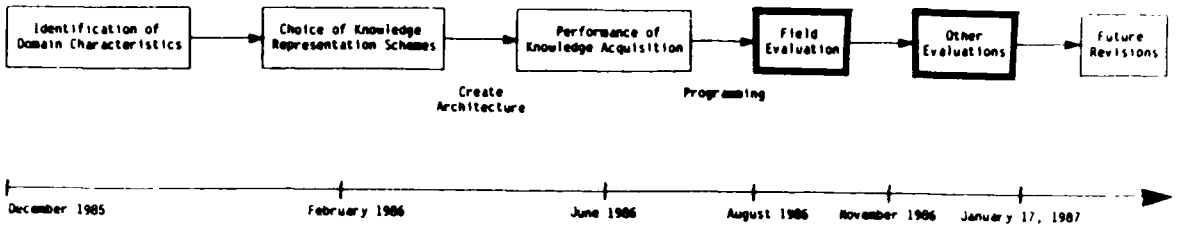
	YES	NO
1. High pressure centered between 38n and 45N east of 70w.		
2. Dewpoint equal to or higher than sea temp(ARQ Sxus 8 KNYC and KORF).		
3. Subsidence and/or nocturnal inversion from 500 ft to 1500 ft.		
4. Surface winds less than 8 kts with a 040 to 180 direction.		
5. Clear or scattered clouds at sunset.		
6. FOUS 61 KWBC data (use PHL) shows high RH (greater than 75%) in boundary layer and wind direction in NE to SE quadrant with speed less than 15 kts.		
7. Area of moisture over new Jersey and Delmarva at 8 50mbs (outline dewpoint depressions of less than 5.		

Important No Fog parameters

a.) radiation fog - 850mb ridge to pass over DOV during night.

b.) advection fog - moderate to strong low to move into Ohio Valley during period.

Figure 52. Dover fog checklist.



Section 5.0

EVALUATION

5.1 EVALUATION OF EXPERT SYSTEMS

Technically speaking, the development of an expert system is always being evaluated because the development under each phase is considering questions such as:

- Is the knowledge representation adequate or should it be modified?
- Can users easily interact with the system?
- Are rules consistent with the expert's opinion?

Evaluation of expert systems can be classified into two broad categories: quantitative and qualitative. Quantitative evaluation includes derivation of statistical results from either real-time or past events. This involves compilation of observed versus expert system predicted results. Qualitative analyses is much more difficult, but centers around the fundamental question: "Did the expert system help the user?" If the expert system is able to meet the needs of the user and provide him with advice on recommendations, then the system has fulfilled its job.

5.2 ZEUS RULE EVALUATION

Our evaluation philosophy involved both the generic quantitative and qualitative options described above. Individual rules or rulepaths were evaluated based on a combination of how they were used by the experts in reaching a decision and on how they were related to the physical reasoning. Individual rules were also examined using several past cases and by comparing the rules used by experts at one base with rules used by experts at another base.

5.3 BASE FORECASTER SURVEY FORMS

5.3.1 Philosophy/Methodology

Standardized forms were developed for each base to reflect the qualitative aspect of expert system evaluation. It was important to have this record of information to see:

- When Zeus was used in TAF preparation
- How Zeus was used in TAF preparation
- What Zeus problems arise.

The forms also served an additional purpose of requiring the users to run Zeus over a several-month period.

The forms follow our philosophy of allowing the user to truly dictate how he or she will use the system. This effort has been one of the first AI efforts that allowed users early hands-on experience with an expert system still in the proof-of-concept phase. The initial format of the form appears in Fig. 53.

This form is structured along general lines and was used early to get initial opinions of the system.

After the first set of evaluation forms were received at GEOMET, and based on discussions with the AFGL Project Officer and base personnel, modifications to the evaluation form were made. The revised form (Fig. 54) was organized to capture forecaster experience in using the system during TAF preparation as well as other times.

5.3.2 Statistical Summary

Survey forms were left with each of the three bases when Zeus was demonstrated. Forecasters were asked to fill out a survey form each time they used the system. A total of 143 survey forms were completed and returned to GEOMET, including 45 using the original format and 98 using the revised format.

A tabulation of the answers received on 45 original forms is shown in TABLE 18. The answers received on 98 revised forms are tabulated in TABLE 19.

It is clear that Zeus was well received by the forecasters that used it. Of the 45 that responded on the first form, 42 liked the system; of the 98 that responded on the second form, 76 liked the system. The first form focused on introductory responses to the system. The system was understood by 41 of 45 users; however, 15 of 45 users indicated they would prefer a less burdensome method of entering data. The explanatory features of systems were found adequate by 40 of 45 users, and 32 of 45 thought they would be helpful on a daily routine basis.

1. Date _____

2. Time _____ (Local)

3. Did you like the way the system interacted with you? (Circle one)

   Yes No

   Why? _____

   _____

4. Did you understand all the questions that it asked you?

   Yes No

   What questions did you not understand? (if any)

   _____

   _____

   _____

5. Would you prefer a different method of entering the information that the system requested?

   Yes No

   Why? _____

   _____

   _____

6. Did you use the system ... (Check one)

   as needed _____

   just prior to TAF time (1 hour) _____

   other times (specify) _____

7. Are the explanation features adequate?

   Yes No

   If no, why not? _____

8. Do you think this system will be helpful in your everyday routine? (Circle one)

   Yes No

   Why? _____

   _____

   _____

Figure 53. Initial user evaluation form.

Date _____

Time _____ (Local)

Name _____

1. Did this system assist you in preparing the new TAF? (Circle one)

   Yes No Not applicable

2. Did you like the way the system interacted with you during this session? (Circle one)

   Yes No

   Comments:

   _____

   _____

   _____

3. Did this particular run of the system cause you to: (circle one or more)

   a. Amend the current TAF?
   b. Think about a weather factor that you might have missed otherwise? Which factor? _____
   c. Confirm the current TAF as still being OK?
   d. Have no reaction?
   e. Other (please explain) _____

   _____

   _____

   Comments:

   _____

   _____

   _____

4. Any other remarks?

   _____

   _____

   _____

Figure 54. Revised user evaluation form.

TABLE 18. Summary of Forecaster Replies on Original Form (see Fig. 53).

Question Number (See Form)	Answer	Dover AFB	Seymour Johnson AFB	Fort Bragg AAF	Total
3	Yes	6	22	14	42
	No	0	2	1	3
4	Yes	6	21	14	41
	No	0	3	1	4
5	Yes	1	9	5	15
	No	5	15	10	30
6	As needed	0	10	5	15
	TAF	5	10	9	24
	Other	1	4	1	6
7	Yes	6	21	13	40
	No	0	3	2	5
8	Yes	2	19	11	32
	No	4	5	4	13
Number of Forms		6	24	15	45

TABLE 19. Summary of Forecaster Replies on Revised Form (see Fig. 54).

Question Number (See Form)	Answer	Dover AFB	Seymour Johnson AFB	Fort Bragg AAF	Total
1	Yes	9	30	0	39
	No	13	32	11	56
	Not Applicable	1	1	1	3
2	Yes	17	50	9	76
	No	6	11	3	20
	No Response		2		2
3	Amend	1	1	0	2
	WX Factor	0	2	0	2
	Confirm	11	38	1	50
	No Reaction	7	17	10	34
	Other	3	3	1	7
	No Response	1	2	0	3
4	Other				
Number of Forms		23 + 6	24 + 63	12 + 15	98 + 45
(Added to Table)		29	87	27	143

The Zeus system was most commonly used when the TAF was being prepared as indicated by 24 of 45 uses on the old form and 39 of 98 uses on the new form. In addition, responses on the new form indicated that 52 of 98 uses led to confirming or amending the TAF. This suggests that even if Zeus was not used in preparing the TAF, it was subsequently used to review the need to amend the TAF. It is interesting that in two cases, forecasters actually decided to amend their forecasts on the basis of assistance from Zeus, and in two other cases, forecasters were alerted to weather factors that they might not otherwise have considered.

Overall, the forecasters were very receptive to the computerized expert system approach to providing them with advice. The user liked the system in 118 out of 143 reported uses, or about 82 percent of the time. The use is not limited to official forecast preparation (TAF), because only 63 out of 143 uses or 44 percent were reported as assisting in TAF preparation.

5.3.3 User Comments

The survey forms provided a method for users to indicate problems with Zeus. This is one of the major benefits that was anticipated from the distribution of Zeus to active forecasters. All three bases reported that the structure and general knowledge content of Zeus seem to be fine; however, the following five problems were commented on:

Problem	Location
1. Sunshine question	All bases
2. HAT 850 mbar wind direction/FOUS	Seymour Johnson
3. Synoptic descriptors	All bases
4. Air trajectory question	Fort Bragg
5. Speed	Dover

Problem 1: Sunshine Question

The sunshine question appearing below has caused the greatest problem among the bases. The question asked by Zeus is:

> Number of hours of sunshine today? (Note: Answer 1 if time now is between sunrise and 1200 noon; take a good guess if current time is between 1200 noon and sunset; and finally, try to really get a good estimte from the day's observations if the current time is after sunset and before sunrise)

This sunshine parameter was determined to be necessary based on conversations with several base personnel. The physical reasoning was that an air mass under cloudy skies all day and advected into the base in question has a greater moisture supply than if skies are clear. Sufficient cooling should cause the temperature-dewpoint depression to narrow and fog to form.

Too much sunshine, for example, during the day may dry out the air and restrict fog formation at night. The rules-oriented programming using results of this question requires an answer (thus, the "1" answer for the morning period). Bases are having difficulty in determining amount of sunshine that has either been forecasted or has occurred.

We can see two solutions to the problem:

1. Change question to read: "Enter number of clear, scattered, broken, or overcast hours" with Zeus, determining sunshine hours from these results. The scattered, broken, or overcast hours can be compiled from the WBAN observation forms at the station.

2. Eliminate the question. One alternative is to use a substitute input variable of cloud cover at sunset (this is in use at Dover only) and incorporate it at Seymour Johnson and Fort Bragg. (In reality, Dover has both the standard sunshine question and clouds at sunset input requirement because personnel tend to look at both.)

Problem 2: HAT 850 mbar Wind Direction/FOUS Restrictive

An interesting result regarding boundary layer winds/FOUS has come out of the evaluation at Seymour Johnson. Initial knowledge-engineering-related discussions (February 1986) with Seymour Johnson personnel indicated the use of boundary layer (< 3000 ft) winds at Raleigh as one potential trajectory-related trigger that could lead to Atlantic flow (and advective fog). Clear limits were placed on the FOUS boundary wind direction and on HAT directions. However, evaluations have indicated that the limits are too restrictive. For example, a change from 040° to 039° (i.e., across a HAT 850-mb-wind-direction limit) will trigger a big change in Zeus output (low visibility to good visibility). In selecting these limits, the initial hope was to usefully classify the boundary layer wind direction, but it appears that the system is too sensitive to this one parameter. One reason may be that the FOUS 6-h boundary layer output is not a good representation of the actual back trajectory.

Another reason, which has been suggested by Seymour Johnson personnel, is the 850-mbar surface is too high to represent the boundary layer flow. They have suggested that the chart F4531-Surface/geostrophic wind and relative vorticity be examined to determine the direction of the boundary layer flow. This may provide a more realistically oriented estimate than just one sounding station. There is a need to incorporate this product into Zeus. Many Seymour Johnson forecasters are now examining this chart to determine whether an easterly flow or "drift" exists.

Problem 3: Synoptic Description

All bases have reported some problems in visualizing where synoptic systems are located. Many personnel have suggested a fixed-map that will clearly indicate the boundary regions of the various quadrants that are used in Zeus.

Seymour Johnson forecasters have indicated difficulty in determining which response to answer when faced with a ridge line down the east coast. In response to comments we have added a ridge line question into the map software used with Zeus.

One potential difficulty that may not be resolved under this effort is to come up with a scheme that will differentiate the dominance of one system over another. For example, given a high over New England and a cold front over the Ohio Valley (and approaching), which one will dominate? Currently, the system asks the user whether the front will pass and makes judgments (using other parameters) if the user answers no.

The system also cannot handle restrictions in visibility caused by precipitation such as is found with overrunning conditions, low-pressure passages, thunderstorms, or unusual weather events (we had to draw the line somewhere). However, messages are flashed on the screen to indicate that the system is not able to handle the current situation. Some general meteorological advice is provided to the user regarding the situation.

Problem 4: Air Trajectory Question

At Fort Bragg, a problem was identified with the question regarding air trajectories under cloudy or clear skies. This question was established to get a better sense of moisture content along the trajectory. Fort Bragg personnel have indicated that this question can be removed without major meteorological consequences. There is a need for more extensive checking of past results with and without the question for the consequences before removing this question from the logic.

Problem 5: Speed

Prompts on the monitor to indicate that Zeus is working have been installed. Dover forecasters found that it takes approximately 0.5 h to run the system; other forecasters have reported taking approximately 10 min.

Discussions with the Detco at Dover revealed the following two problems that have been causing run delays:

1. Physical system location
2. Run again prompt.

Moving the system to the counter area of the station where maps and charts are readily available improved the total runtime to 10-15 min.

Additionally, at the end of a Zeus session, the "Y" key was hit in response to the "Run Again" question, and the system left on. If the "N" key is hit, the system must reread all rules before the next execution. This was a considerable time saver in terms of start-up processing time and alleviated the speed concerns.

5.4 STATISTICAL EVALUATION

Two types of forecast accuracy comparisons were made. One comparison was based on forecast advice from the Zeus system during interactive sessions with Zeus by forecasters while the system was available at the three airbases. The results of this evaluation are discussed in Section 5.4.1. The other type of comparison was based on running Zeus on historical data and comparing the forecasts with observations. This required a mechanical and objective method of interaction with Zeus so that the user could not influence the system forecast. This comparison is discussed in Section 5.4.2.

5.4.1 Zeus User Forecasts

The Zeus system was run during the time the forecaster was preparing the TAF (four times a day) or a revision to the TAF. The forecaster would obtain the input data requested by Zeus from the latest observations from the teletype circuits, local observations, facsimile charts, or other information available at the time.

The forecast and observed visibility category for validation purposes was the lowest visibility category over the next 12 h. No attempt was made to validate the specific timing of low visibility events.

During the period that the Zeus system was available at the three bases, forecasters were requested to print the results of Zeus sessions and to send them to GEOMET along with a survey form. We received printed results of 36 sessions from Dover AFB, 36 sessions from Fort Bragg, and 104 sessions from Seymour Johnson AFB. When cases were eliminated for which a visibility forecast was not applicable or not made by Zeus because of precipitation influences, there were 29 cases for Dover, 29 cases for Fort Bragg and 100 cases for Seymour Johnson. TABLES 20 through 22 show three-by-three contingency tables for these cases, using the three operational visibility categories that are applicable to each base. The tables show the numbers of occurrences of each forecast category in terms of what category was actually observed.

TABLE 20. Contingencies of Zeus Forecasts and Observations of Three Categories of Visibility at Dover AFB.

	Observed Visibility		
	3	2	1
Forecast Visibility	≥ 2 mi	≥ 1/2 and < 2 mi	< 1/2 mi
3	20	2	3
2	1	0	0
1	1	1	1

TABLE 21. Contingencies of Zeus Forecasts and Observations of Three Categories of Visibility at Fort Bragg.

	Observed Visibility		
	3	2	1
Forecast Visibility	≥ 2 mi	≥ 3/4 and < 2 mi	< 3/4 mi
3	25	3	1
2	0	0	0
1	0	0	0

TABLE 22. Contingencies of Zeus Forecasts and Observations of Three Categories of Visibility at Seymour Johnson AFB.

	Observed Visibility		
	3	2	1
Forecast Visibility	≥ 3 mi	≥ 1 and < 3 mi	< 1 mi
3	79	3	6
2	2	4	0
1	2	1	3

TABLE 23 shows a contingency table for results at all three bases combined. We have used these results to compute skill scores (SS) and P-scores (PS) by means of the following relationships:

$$SS = \frac{R - E}{T - E} \tag{1}$$

where

$$E = \frac{1}{T} \sum_{i=1}^{3} F_i O_i \tag{2}$$

E = expected number of correct forecasts
R = number of correct forecasts
T = total number of forecasts
F_i = number of forecasts in category i
O_i = number of observations in category i.

The above relationship was presented by Panofsky and Brier (1968).

In this relationship for the skill score, the expected number of correct forecasts (E) is based on chance. If there is no relationship between the forecast and the observation, this is the number of correct forecasts that can be expected.

The P-score can be represented by:

$$PS = \frac{2}{T} \sum_{i=1}^{3} \sum_{\substack{j=1 \\ j \neq i}}^{3} C_{ij} \tag{3}$$

where

C_{ij} = number of forecasts in category i when category j was observed.

TABLE 23. Contingencies of Zeus Forecasts and Observations of Three Categories of Visibility--Combined Results.

	Observed Visibility		
Forecast Visibility	3	2	1
3	124	8	10
2	3	4	0
1	3	2	4

Equation (3) is derived from the following relationship for P-score (Panofsky and Brier 1968).

$$PS = \frac{1}{N} \sum_{m=1}^{r} \sum_{n=1}^{N} (f_{mn} - E_{mn})^2 \qquad (4)$$

where

N = number of cases
r = number of classes for the event being forecast
f_{jk} = forecast probability that the event occurs
E = 1 or 0 according to whether event occurs or not.

$$\sum_{m=1}^{r} f_{mn} = 1 \qquad (5)$$

In the case being evaluated, we have divided the cases into nine classes as represented by the contingency table. One of these nine classes was forecast to occur. That class is assigned $f_{mn} = 1$; all the other classes are assigned $f_{mn} = 0$. Actually, there are only three forecast categories, but each forecast category can be subdivided into three subcategories, according to which of the three observed visibility classes was subsequently observed. If the classes are numbered from one to nine, starting with upper-left category of the contingency table and proceeding across the first, then the second, and finally the third row, for each case that class 1, 5, or 9 occurs.

$$(f_{mn} - E_{mn})^2 = (1 - 1)^2 = 0.$$

That is, the event will have been forecast and will have occurred. For each case with any other class, there will be

$$(f_{mn} - E_{mn})^2 = (1 - 0)^2 = 1$$

and the other will be

$$(f_{mn} - E_{mn})^2 = (0 - 1)^2 = 0.$$

For all cases with a class other than 1, 5, or 9, a value of two must be summed. Therefore, we can write our summation over all N cases as indicated in Equation (3). That is, two is summed C_{ij} times, where C_{ij} is the class designated by forecast category i and observed category j, except when i = j, we sum the value zero.

The skill score gives the fraction of cases that are correctly forecast from among the number of cases that occur beyond the number that are expected to be correctly forecast by chance. If the number of correct forecasts is equal to or less than the randomly expected number, then a zero or negative score occurs. If 50 percent of the cases above the number of expected correct forecasts are correctly forecast, a score of 0.5 occurs. Obviously, if all forecasts are correct, a perfect score of 1.0 occurs.

The P-score is a method of evaluating forecasts, especially probability forecasts, that gives minimum weight to a high probability estimate for a correct forecast and maximum weight to high probability estimate for an incorrect forecast. Because the forecasts here are all defined to be certain forecasts with an assigned probability of 1, the forecaster gets a score of 0 when correct and 2 when wrong. As a result, the P-score is simply twice the fraction of incorrect forecasts. It is provided primarily as a convenience in comparing the results from this study with results from other studies that provide P-scores. A score of 0.28 indicates that 14 percent of the forecasts are incorrect.

TABLE 24 shows the skill scores and the P-scores calculated for each base and for the results of all bases combined using the data presented in TABLES 20 to 23. The best skill score of 0.46 was obtained for Seymour Johnson. The best P-score of 0.28 was obtained both for Seymour Johnson and Fort Bragg.

TABLE 24. Skill Scores and P-Scores for Zeus Forecasts.

Base	Skill Score	P-Score
Dover AFB	0.16	0.55
Fort Bragg	0.00	0.28
Seymour Johnson AFB	0.46	0.28
Combined Result	0.35	0.33

The combined results for all three bases gave a skill score of 0.35 and a P-score of 0.33. The results for Dover and Fort Bragg are less reliable than the results for Seymour Johnson due to the much smaller number of cases.

To provide more insight into what value can be anticipated from the Zeus advice, forecasts made by forecasters at Seymour Johnson AFB (the published TAF) and for a nearby National Weather Service station (Raleigh, North Carolina) were obtained for the same periods that the Zeus forecasts were made. The three-by-three contingency tables for these forecasts are shown in TABLES 25 and 26. The data shown included the same 100 time periods for the Seymour Johnson forecasters; however, only 83 of the 100 forecasts were obtained for the Raleigh forecasts.

TABLE 25. Contingencies of Seymour Johnson AFB Forecaster Forecasts and Observations of Three Categories of Visibility.

	Observed Visibility		
Forecast Visibility	3	2	1
3	73	4	9
2	7	3	1
1	0	2	1

TABLE 26. Contingencies of Raleigh, North Carolina, Forecaster Forecasts and Observations of Three Categories of Visibility.

	Observed Visibility		
Forecast Visibility	3	2	1
3	43	6	4
2	11	3	1
1	5	4	6

Skill scores and P-scores for the forecasters at Seymour Johnson and at Raleigh are listed in TABLE 27. The skill scores at both locations are about equal, but significantly less than was obtained for Zeus, i.e., 0.46 for Zeus compared to 0.23 for Seymour Johnson forecasters and 0.24 for Raleigh forecasters. The P-scores were 0.46 for Seymour Johnson forecasters and 0.75 for Raleigh forecasters. Both values are significantly higher and thus, poorer than the 0.28 obtained for Zeus.

TABLE 27. Skill Scores and P-Scores for Seymour Johnson and Raleigh, North Carolina, Forecasters.

Base	Skill Score	P-Score
Seymour Johnson AFB	0.23	0.46
Raleigh, North Carolina	0.24	0.75

As a means of comparison, a skill score was computed to compare the improvement in P-scores that is obtained by the Zeus system over the forecasters above without Zeus. This was computed as follows:

$$SS = \frac{P_F - P_Z}{P_F}$$

where

P_F = P-score of forecaster
P_Z = P-score of Zeus.

The skill score for Zeus in comparison to Seymour Johnson forecasters is 0.39. In comparison to Raleigh forecasters the Zeus skill score is 0.63.

5.4.2 Historical Evaluation

To get a more seasonally balanced evaluation of Zeus than was provided by the user session results, we selected a set of historical data to select inputs for Zeus forecasts. The Zeus historical evaluation used surface synoptic observational data obtained from the National Climatic Data Center (NCDC) for Dover AFB, Seymour Johnson AFB, and Fort Bragg. The data were selected by NCDC from the U.S. Air Force DATSAV Station files and recorded on tape in the TD 9685 format. These data include hourly observations of many key variables required by Zeus including temperature, dewpoint, windspeed and direction, sky cover, and visibility at all three bases. Summary of Constant Pressure Data (WBAN) and Local Climatological Data (LCD) monthly summaries

provided by the National Climatic Center, contained the necessary upper air and surface data to complete Zeus input tables. Daily weather maps published in a weekly series by NOAA were used to determine positions and motion of surface weather systems.

Using data provided by the above sources, Zeus runs were made at 12 and 00Z for selected months in 1980. The months chosen (January, April, July, and October) were selected to ensure that each season was represented in the evaluation. Due to time constraints, only the first 2 weeks of each month were evaluated. Additionally, because Zeus does not provide advice on low visibility caused by precipitation, all runs that occurred on days of restricted visibility due to rain or snow were omitted from the tabulations. Official National Weather Service forecasts (FOUS) of wind direction and speed at 6, 12, 18, and 24 h, a required Zeus input, were not available. To overcome this absence, observed surface windspeeds and directions were averaged for the 3 h centered on the 6, 12, 18, and 24 h FOUS times. Temperature and dewpoint from local observing stations were obtained from LCDs for as many stations as were available. Because some stations were not available and frequently the required hour was missing, the average temperature-dewpoint differences from all surrounding available stations was used as the difference for all stations. The stations used for Zeus data for each airbase forecast are listed in TABLE 28. Because synoptic weather charts were available daily at 12Z, it was necessary to interpolate between charts to obtain reasonable positions of weather systems at 00Z. Dover AFB inputs of 850 mbar windspeed and direction were not available from Atlantic City, New Jersey, prior to September 1980. These inputs were substituted with 850 mbar data observed at Fort Totten, New York.

TABLE 28. Local Stations Used to Obtain Temperature and Dewpoint Data from Local Climatological Data Summaries.

Location	Local Temperature-Dewpoint Observations
Dover	Atlantic City, New Jersey Baltimore International Airport, Maryland Wallops Island, Virginia (12Z only) Wilmington, Delaware
Fort Bragg	Cape Hatteras, North Carolina Norfolk, North Carolina Seymour Johnson AFB, North Carolina Wilmington, Delaware
Seymour Johnson	Cape Hatteras, North Carolina Fort Bragg, North Carolina Norfolk, North Carolina Wilmington, North Carolina

Contingency tables of forecasts and observations of three visibility categories at Fort Bragg are presented for the months of January, April, July, and October and for all periods combined in TABLE 29. The same sets of three-by-three contingency tables are presented in TABLES 30 and 31 for Seymour Johnson and Dover, respectively. An overall set of contingency tables for the three bases combined is presented in TABLE 32. Cases of rain or no forecast by Zeus during the periods of evaluation are not included in these tables.

As can be seen in all the contingency tables, the occurrence and forecast of category 3 is the most common contingency, occurring 88 percent of the time or 247 out of 280 cases. The remaining 33 cases include 31 observations of category 1 or 2 visibility and 15 forecasts of category 1 or 2 visibility. This suggests that the frequency of forecast of category 1 and 2 is too low by a factor of 2. For the forecasters at Raleigh (see TABLE 26) the frequency of forecasting category 1 and 2 exceeded the number of occurrences. This showed a tendency to overforecast fog or be more conservative in issuing low visibility forecasts. Out of 83 cases, there were 30 category 1 or 2 forecasts compared to 24 observations. Nine (or 30 percent) of the 30 Raleigh forecasts were correct while 6 (or 40 percent) of the 15 Zeus forecasts in TABLE 32 were correct. The primary lesson here is that the Zeus system may need some further refinement to increase the frequency with which low visibility advice is offered. Although, as subsequent discussion will bring out, the overall accuracy of the system is probably better than the average forecaster, the advice on low visibility forecasts may be the most important advice given.

TABLE 33 presents a summary of skill scores and P-scores for each of the contingency tables in TABLES 29 to 32. Over all locations and periods the skill score was 0.38 and the P-score was 0.18. The scores over all periods for each of the three bases range from 0.23 for Fort Bragg to 0.55 for Dover (skill scores) and from 0.26 for Fort Bragg to 0.12 for Dover (P-score, low is best). The scores over all bases for each of the four periods range from -0.03 for January to 0.51 for October (skill score) and from 0.29 for July to 0.14 for April (P-score). The best skill scores were obtained for the October period at each base, and the worst skill scores were for January. This is true partly because there are fewer observations and fewer correct forecasts for January and April compared to July and October. This is not because poor visibility does not occur in January and April, but because the poor visibility is mostly associated with precipitation accompanying winter storms, for which Zeus is not designed to advise. Cases of poor visibility associated with precipitation were excluded from the evaluation. However, in cases where radiation and advection are the primary causes of fog, the system does show skill as indicated by the skill scores for July and October at all bases and for April at Dover. The skill score is very sensitive to the number of correct forecasts in categories with low observed frequencies. Months for which there were no correct forecasts in categories 1 and 2 all produced low skill scores. A more accurate skill score requires that more cases be validated.

TABLE 29. Contingencies of Forecast and Observed Occurrences of Three Categories of Visibility at Fort Bragg.

a. January

	Observed		
Forecast	3	2	1
3	17	2	0
2	1	0	0
1	0	0	0

b. April

	Observed		
Forecast	3	2	1
3	19	2	0
2	0	0	0
1	0	0	0

c. July

	Observed		
Forecast	3	2	1
3	17	2	0
2	0	0	0
1	0	1	0

d. October

	Observed		
Forecast	3	2	1
3	21	2	0
2	0	0	0
1	0	1	1

e. Combined

	Observed		
Forecast	3	2	1
3	74	8	0
2	1	0	0
1	0	2	1

TABLE 30. Contingencies of Forecast and Observed Occurrences of Three Categories of Visibility at Seymour Johnson.

a. January

	Observed		
Forecast	3	2	1
3	17	2	0
2	0	0	0
1	0	0	0

b. April

	Observed		
Forecast	3	2	1
3	22	1	0
2	0	0	0
1	0	0	0

c. July

	Observed		
Forecast	3	2	1
3	18	1	0
2	0	0	0
1	1	2	1

d. October

	Observed		
Forecast	3	2	1
3	21	2	0
2	0	0	0
1	0	1	1

e. Combined

	Observed		
Forecast	3	2	1
3	78	6	0
2	0	0	0
1	1	3	2

TABLE 31. Contingencies of Forecast and Observed Occurrences of Three Categories of Visibility at Dover.

a. January

	Observed		
Forecast	3	2	1
3	24	0	0
2	0	0	0
1	0	0	0

b. April

	Observed		
Forecast	3	2	1
3	22	1	0
2	0	0	0
1	0	1	1

c. July

	Observed		
Forecast	3	2	1
3	23	1	1
2	0	0	0
1	0	1	1

d. October

	Observed		
Forecast	3	2	1
3	26	1	0
2	0	1	0
1	0	0	0

e. Combined

	Observed		
Forecast	3	2	1
3	95	3	1
2	0	1	0
1	0	2	2

TABLE 32. Contingencies of Forecast and Observed Occurrences of Three Categories of Visibility, Combined for Three Bases.

a. January

	Observed		
Forecast	3	2	1
3	58	4	0
2	1	0	0
1	0	0	0

b. April

	Observed		
Forecast	3	2	1
3	63	4	0
2	0	0	0
1	0	1	1

c. July

	Observed		
Forecast	3	2	1
3	58	4	1
2	0	0	0
1	1	4	2

d. October

	Observed		
Forecast	3	2	1
3	68	5	0
2	0	1	0
1	0	2	2

e. Combined

	Observed		
Forecast	3	2	1
3	247	17	1
2	1	1	0
1	1	7	5

TABLE 33. Skill Scores and P-Scores for Zeus Forecasts on Historical Data by Location, Period, and Combined.

Location	Period	Skill Score	P-Score	Number of Cases
Fort Bragg	January	-0.07	0.30	20
	April	0.00	0.19	21
	July	0.22	0.30	20
	October	0.46	0.24	25
	All	0.23	0.26	86
Seymour Johnson	January	0.00	0.21	19
	April	0.00	0.09	23
	July	0.44	0.34	23
	October	0.46	0.24	25
	All	0.38	0.22	90
Dover	January	--*	0.00	24
	April	0.57	0.16	25
	July	0.46	0.22	27
	October	0.65	0.07	28
	All	0.55	0.12	104
All	January	-0.03	0.16	63
	April	0.36	0.14	69
	July	0.40	0.29	70
	October	0.51	0.18	78
	All	0.38	0.19	280

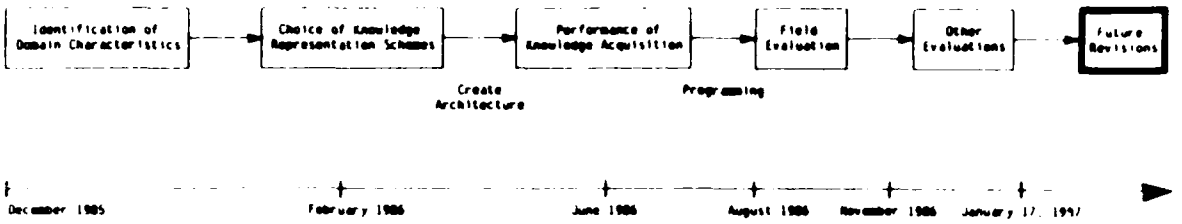
* Undefined because only one category was forecast and observed.

5.4.3 Summary of Statistical Evaluation

In general, the Zeus system shows skill in forecasting visibility as measured by statistical scores. This is evident by the overall skill scores of 0.38 on the historical data and 0.35 on the user run cases. In addition, the Zeus system results on user run cases showed better skill scores than forecasters for the same period and location. The Zeus skill score for Seymour Johnson user runs was 0.46 compared to the Seymour Johnson forecaster score of 0.23 and Raleigh, North Carolina, forecaster score of 0.24. In addition, in comparing P-scores, the Zeus system showed 39 percent improvement over Seymour Johnson forecasters and 63 percent improvement over Raleigh forecasters.

There is another characteristic of the Zeus forecasts worth noting. When the results from the historical data are combined with the user runs with Zeus for category 1 and 2 conditions, we find that Zeus forecast these categories 31 times while they were observed 59 times. However, the Zeus forecast was correct 14 times, or 24 percent of the time. Category 3 was forecast 36 times when 1 or 2 was observed or 61 percent of the time. In the remaining nine cases, category 1 was forecast when category 2 occurred. The data in TABLES 25 and 26 show that forecasters at Seymour-Johnson and Raleigh forecast the lowest two categories of visibility 44 times and it was observed 44 times. They were correct 13 times, or 30 percent of the time. Category 3 was forecast 23 times, or 52 percent of the time when category 1 or 2 was observed. These results suggest that there may be a tendency for Zeus to slightly underforecast the frequency of occurrence of the low visibility cases.

Finally, the number of cases for which the system has been evaluated is relatively small. The results do not allow definitive conclusions to be developed about performance during specific times of the year. In particular, the results for performance during January and the winter period is indefinite because of the small number of low-visibility cases without precipitation influence.



Section 6.0

PROPOSED TASKS FOR IMPROVING AND EXPANDING THE USE OF ZEUS KBES FOR AIRBASE FORECASTERS

As a result of initial efforts to apply artificial intelligence techniques to visibility forecasting, it is clear that the use of a knowledge-based system has merit, is needed and wanted by operational forecasters, and can be a useful guide to inexperienced forecasters.

When the forecaster is busy (often due to changing and marginal weather situations), the automated weather advisor can save the forecaster valuable time. Based on experience gained in developing an initial demonstration system, the following are suggested ways to improve the usefulness of the initial product to forecasters at airbases:

- Modify and extend the initial system based on detailed interviews with system users after they have had several months of experience with it and based on statistical evaluations of the system's performance.
- Develop the capability of the system to accept inputs continuously from online data interfaces; extend the system's capability to aid in a continuous weather-watch mode and to issue warnings to forecasters of possible pending changes
- Add the capability to advise on forecasting cloud ceiling height to the present system capability.
- Develop guidance for implementing KBES at other bases and develop command-level plans for Air-Weather-Service-wide implementation.

An advisory visibility forecasting system has been developed for each of three airbases: Dover AFB, Seymour Johnson AFB, and Fort Bragg AAF. The KBES for each base contains general rules that are applicable to any base, and local rules that are specific to a single base or a group of nearby bases. For each KBES, the user is advised about expected future visibility conditions (up to 12 h in advance) as a result of answering a series of questions about existing and recent weather or about readily available synoptic weather analyses. The specific questions to which the user must reply depend on his/her answers to previous questions. In the end, the user is advised about the occurrence of different levels of visibility for forecast periods. The user may interrogate the system to determine what rules it used to develop its advice. In addition, the user may examine "what if" propositions to determine how the system's advice will change if different input information is available. Differences in input information may be selected to represent uncertainties in the information provided. The tasks described here are modifications and extensions of three visibility KBESs that are currently under development. The proposed work is based on lessons learned in the course of developing these initial systems.

Section 7.0

CONCLUSIONS

This study has analyzed the feasibility of using the techniques of KBESs from the field of AI to develop a system to advise weather forecasters on local airbase visibility conditions. The study included selecting software, structuring the knowledge base, collecting the expertise, developing the advisory system, introducing the system to users, and evaluating the system. Three versions of the system (Zeus) were developed for use at Dover AFB, Fort Bragg, and Seymour-Johnson AFB. The following conclusions were drawn from the study:

1. The user of a KBES shell that runs on and produces a system that runs on a PC-compatible microscale computer was found to be a practical way to develop an advisory system for weather forecasters. In this study, we found that the EXSYS shell allowed us to devote a minimal amount of time to programming and to use most of the effort to collect and structure expertise into a useful knowledge base.

2. After reviewing alternative approaches, we found that a rule-based system that uses backward chaining with defined goals and subgoals was the best approach for a KBES to advise forecasters on visibility conditions.

3. The expertise relevant to visibility forecasting was found to be conveniently divided into rules relating to advection and radiation as the primary physical processes that affect visibility, i.e., except for precipitation effects that were excluded early in the study. Rules relating to synoptic considerations were found to be needed as a related knowledge area. Fog dissipation processes were also found to be a subject area that was convenient for structuring rules.

4. Four sources of expertise found to be useful in developing Zeus were the open literature, Air Weather Service climatic summaries, local airbase technical reference notebooks, and interviews with local forecasters.

5. Operational considerations found to be important to users of Zeus were the time required to interact with the system, inconvenience of manually entering data, accuracy of the advice, friendly prompting, and clear explanations and advice.

6. The Zeus system was found to be an excellent way of advising forecasters, based on the favorable response reported by users in 80 percent of 143 uses.

7. The Zeus system was found to give skillful advice to forecasters based on the responses on user survey forms and the 0.35 skill score computed for the Zeus advice given in 158 uses.

8. The Zeus system was found to give accurate advice when given historical data for input, based on results for the first 2 weeks of January, April, July, and October of 1980 for each of the three bases. The overall skill score was found to be 0.38.

9. The system was found to need further refinement of its rules to increase the frequency with which low-visibility categories are forecast.

10. When the Zeus system advice developed during user interactions was compared to published forecasts from Seymour Johnson and Raleigh, North Carolina, for the same period, the Zeus system was found to give more accurate advice based on better skill scores and p-scores.

11. Overall, we conclude that the Zeus system demonstrated the feasibility of using the KBES approach to assist forecasters. In particular, the system demonstrated user acceptance, accuracy, and suitability for the weather detachment environment.

Section 8.0

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Appendix B

EXAMPLE INTERVIEW

Mark Stunder (S)

"Today is February 26, 1986, and this is Mark Stunder. The time is 1312 and we are here at Simmons Army Airfield and we are going to be discussing Central North Carolina meteorology with Mr. Bob Madison. Mr. Madison is a civilian meteorologist here at Simmons Army Airfield.

"Could you just take a second and go through your background in meteorology and the Air Weather Service?"

Mr. Bob Madison (M)

"In 1963, I completed the basic observer's course and came to Fort Bragg as an observer in the fall of 1963, and stayed in the Fort Bragg area until the fall of 1965. As an observer I went to Korea and returned to Pope Air Force Base, North Carolina, as an observer in 1966 until 1969. I went through the basic forecasting course at Chanute Air Force Base in May 1969 until January 1970. I graduated from the basic forecasting course and was assigned to Shaw Air Force Base in South Carolina in January 1970, ...

"I spent 3 years at McGuire and returned to Fort Bragg as Assistant Station Chief in July 1979. I retired here in March 1983. I just came back on board as civilian forecaster in December 1985."

(S) "If you add up all those years, how long would you have been at Fort Bragg, in terms of forecasting and total air weather service time?"

(M) "About 7 years."

(S) "What I would like to do is just go through a couple of general cases, see what you think of some of these scenarios, and see if you would use any rules of thumb."

"The first instance that comes to mind, not only in this area but throughout most of North Carolina, is the northeasterly wind flow, where you would have a high pressure system up over New England or as far south as Pennsylvania. In that case we may be looking at low visibility with an increase of moisture or some low stratus, or maybe even a little bit of fog or maybe a little bit of drizzle, but mostly a fog situation versus stratus."

(M) "Yes, there seems two offshoots of that case. One is if you drop a back door down to Virginia and the second one is just the good old high pressure system without a front but with sufficient overwater trajectory."

(S) "That's right. So could you comment first on the back door situation?"

(M) "The back door you are talking about is when you get an elongated Eastern seaboard ridge and a front. You get a relatively persistent ridge up and down the Eastern seaboard on the lee side of the Appalachians. Usually along with that you have an overwater trajectory advection. Usually it is a bit of a problem. If you had overwater flow for 18 to 24 hours, then it's a good case to forecast below mins. If the ridge persisted for 48 to 72 hours, you'd have one to three mornings (of below mins). If you have 100 miles of overwater trajectory, the anticyclone curvature and subsidence below 3000 ft to compact all that moisture into the lower 50 to 100 mbar at the atmosphere, it is a difficult forecast situation."

(S) "If faced with that potential backdoor situation right now, what would you?"

(M) "Beginning with the forecast date, forecast it down--but first you have to forecast if the front will pass FBG. Use acetate to determine if you have any kind of persistent southerly movement. If it shows it is moving south at about 10 kn (they don't move directly south very fast on this side of the mountains), then a back door cold front will sneak in. This (FBG) is about as far south as they go. If you can prog it past you, I would tend to drop the visibility way down. If the 850 mbar trough is very broad and a northwest flow across the mountains, the I would tend to drop that front down into the 850 mbar trough right down to the surface until it is just about parallel to the flow and trough.

"If that extrapolation puts the front past you, begin to look if low visibility is persistent on the north side of the front. Are low or below normal conditions already there or is it reasonably dry with the low very far offshore and just the ridge is pushing it (the front) along?"

(S) "Ok, but if the FBG trajectory is veering around to give flow from, say, a Wallops Island direction then what?"

(M) "That is a typical fog situation with winds between 030 to 060. To forecast it down, if it is not down here, you look for appearance of low-level moisture at Rocky Mount (RWI), look at the temperature and dewpoint at Rocky Mount, Wilson area (if they are in business), watch Winston (INT), Raleigh (RDU), Goldsboro (GSB)--see if there is any significant dewpoint deflection. If there are, then try to determine the rate of increase; a good estimate can be made as to when it will reach here."

(S) "So, what would be a typical time lag before the ceiling lowers if the front does go through here and stops about 50 miles south?"

(M) "About 6 to 9 hours. A stratus situation needs about a 5- to 7-kn wind; with a fog situation, it takes much longer. It will take 18 to 24 hours to set up. You need the persistent overwater flow. You have to see it developing and have the increase in low level-moisture, not only on the surface but at least through 50 mbar. It is not an easy forecast to make but is easy after it develops."

(S) "You have just indicated that there are two phenomena that can occur with backdoors, stratus, and fog. Could you further comment on the moisture parameters you would examine for stratus?"

(M) "Stratus will come in with 5 to 7 kn of surface wind. You will look at the sfc pressure gradient. Anything less than 5 to 7 kn will be a fog and stratus combination or just fog. The stronger the high is, the more likely moisture advection you will have, particularly in the 2000- to 3000-ft ranges. Looking at Wallops Island or Hatteras soundings, if 2000- to 3000-ft winds are on the order of 25 to 30 kn northeasterly, you look for advected Atlantic stratus. If it is appearing along the coastal areas, then chances are it will arrive here. If the cold front is already south or if it is very close to you, you will probably still have low ceiling and low visibility situation. The position of the front is very important. Usually when a front back doors then it usually already has the ominipresent moisture. It is usually socked-in on the north side of us then it just gradually creeps along. It is a matter of timing; if the front is through, then it is a question of when it is going to go away..."

(S) "The major back-door case then appears to be a matter of timing and whether the front is going to make it through. But what about a high pressure

system moving slowly, to your north, without a front--strong high, persistent flow?"

(M) "This is a low visibility situation that will occur on more than one morning, usually look for some type of upslope effect in western Carolina. It (air) reaches saturation by moving gradually uphill; dewpoints are relatively high but there is a 6-, 8- or 10-degree spread here, but by the time it (air) gets out to the Charlotte area it is saturated..."

(S) "How would you utilize LFM/FOUS data in fog forecasting?"

(M) "I would begin to look to fog forecasting if I had greater than 50 percent RH in R1 and boundary-layer winds 030 to 060 FOUS--was just civilian stations but now includes military stations so we can use POPE."

"The LFM has become so "reliable" we have become mental cripples without it."

(S) "When do you bring the LFM into the forecast process?"

(M) "It's immediate with most forecasters."

(S) "But how does Mr. Madison go through a typical forecast using the LFM?"

(M) "The first thing I do is get a cup of coffee. I start out by looking at the surface analysis--take an acetate and get 12 to 24 hours of continuity on the pressure centers and ridge lines and positions. We (Fort Bragg) do a local area 0600Z local area work chart, analyze the 0600Z, analyze that workchart, then 00Z upper air emphasizing the 850 mbar analysis, doing frontal analysis, moisture analysis, temperature analysis advection patterns, moisture and stacking the surface frontal systems to the 850. Then the 700 and 500 mb and 300 mb levels."

"The first 3 to 6 hours of forecast preparation I use extrapolation techniques which work very well. I then use the LFM in forecast preparation in the 12- to 24-hour period for downstream for system development. I want to see what the LFM package does with the trajectory of the upper air, if the LFM is bringing it through, from what direction etc. I look at the relative humidity package, that's a good surface indicator of moisture."

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