NASA-CR-192929

Final Report to

John F. Kennedy Space Center
National Aeronautics and
Space Administration
December 1985

Weather Forecasting Expert System Study

ART BELLER
DC-DSD-22
KSC, FL 32899
305/867-3224
407-861-4174

OK

Arthur D. Little, Inc. *Reference 36105*

Acknowledgements

We would like to thank all of the people from NASA, the Air Force and elsewhere who assisted us during this project.

First of all, welcome management support was provided by T. Davis and R. Miller of KSC. W. Jaffries of KSC provided valuable insights into the nature of STS operations and the peculiarities of lightning measurement.

We also with to thank Col. E. Kolsinski, Col. T. Myers, Capt. R. Parks and the staff from the 3rd Weather Squadron at Patrick AFB, who contributed freely of their time and resources. We especially wish to thank all of the duty forecasters at Cape Canaveral Forecasting Facility, whose encouragement and overall competence impressed us greatly.

Very much appreciated was the time graciously given to us by D. Cote of ERL/Boulder and J.T. Young of UW/Madison.

Finally, special thanks go to J. Nicholson of Lockheed and J. Smedley of Low Latitude Dynamics, for the time and energy they gave us while we tried to understand their forecasting expertise.

Preface

This report refers extensively to visual aids presented during two separate briefings to NASA project management, and comprise the Appendices to this report. These two sets of materials have been combined for the reader's convenience so that they form one continuous document.

The organization of the report is such that there is a separate appendix for each chapter. Each appendix contains those visual aids which pertain directly to that chapter, and is used as a set of supporting tables for the text.

Weather Forecasting Expert System Study

Final Report

to

National Aeronautics and Space Administration

Kennedy Space Center

December 1985

Table of Contents

Table of Contents

Executive Summary

Weather forecasting is critical to both the Space Transportation System (STS) ground operations and the launch/landing activities at NASA Kennedy Space Center (KSC). The current launch frequency places significant demands on the USAF weather forecasters at the Cape Canaveral Forecasting Facility (CCFF), who currently provide the weather forecasting for all STS operations. As launch frequency increases, KSC's weather forecasting problems will be greatly magnified.

The single most important problem is the shortage of highly skilled forecasting personnel. The development of forecasting expertise is difficult and requires several years of experience for a number of reasons:

- Climatological conditions at KSC are unique because of its geographic location.
- Validated numerical models are not available for mesoscale (within 30 miles) nowcasting (next 6 hours) at KSC, therefore accumulated experience is the major basis for forecasting expertise.
- Unique data systems are being installed at CCFF which take time to master and integrate with traditional forecasting methods.

Frequent personnel changes within the forecasting staff jeopardize the accumulation and retention of experience-based weather forecasting expertise.

The primary purpose of this project was to assess the feasibility of using Artificial Intelligence (AI) techniques to ameliorate this shortage of experts by capturing and incorporating the forecasting knowledge of current expert forecasters into a Weather Forecasting Expert System (WFES) which would then be made available to less experienced duty forecasters. The determination of feasibility hinged on answering the following questions:

- Are there people in the Cape area who are recognized as being significantly better weather forecasters than others?
- What is the nature of their expertise?
- Are currently available AI techniques adequate to capture and automate this expertise?
- What is the best way to evaluate the technical and economic feasibility of building a WFES?

After numerous interviews with duty forecasters, staff meteorologists, NASA personnel and outside experts, a handful of people were identified as being more expert than others at forecasting the weather at KSC. A distinguishing characteristic of these experts emerged: the high degree to which each has formulated his day-to-day forecasting experiences into usable "scenarios" or, to use a meteorological term, "analogs". These scenarios are technical stories abstracted from past weather patterns that the forecaster has encountered. The are subsequently used as hypotheses to guide and direct the development of a current forecast. An experienced forecaster often entertains several scenarios concurrently.

No single AI technique is adequate to represent these scenarios in an expert system. However, a compound knowledge representation scheme was developed that combines a significant number of the most frequently used representation techniques in applied AI: rules, objects, predicates, and causal models. Based on preliminary knowledge engineering, a control logic ("inference engine") also was proposed that mirrors how experienced forecasters appear to utilize scenarios in predicting the weather.

An evaluation was done of the degree to which AI-based pattern recognition should play a role in the WFES. It was concluded that automatic recognition of complex patterns in CCFF's data streams represents a very large R&D effort unrelated to the question of whether forecasting expertise can be captured and automated. The proposed WFES design relies upon the forecasters to identify abstract patterns, but does so in a way that will allow it to be interfaced to pattern recognition programs when such become available.

To evaluate the proposed system design, a two-year development plan was presented to build a proof-of-concept WFES that focuses on capturing and encoding scenarios related to the formation of thunderstorms within 5 miles of KSC. Thunderstorms were chosen because of the skill required to predict them accurately, and because they contain all of the weather events that have a major impact on STS operations. Two expert weather forecasters were identified for use as domain experts. Two versions of the plan were presented representing different levels-of-effort; a stand-alone WFES (medium effort); a WFEs tightly coupled to the MIDDS system (large effort).

Introduction

Background

The geographical location of Kennedy Space Center and the nature of the Space Transport System (STS) mission make weather forecasting a difficult and important problem. Weather regimes range from temperate to tropical during the course of a year, often resulting in unique weather systems. Due to the complexity of STS operations, forecasts must be both spatially and temporally more precise than is typical. Extensive data systems have been installed to aid the forecasters at the Cape Canaveral Forecasting Facility (CCFF), but mastering the use of those systems requires additional training. Much of the forecasting expertise developed at KSC is regularly lost due to the frequent turnover of Air Force personnel at CCFF, who are responsible for all KSC-specific weather forecasting in support of STS operations.

Objectives

The primary objective was to determine the feasibility of using AI techniques to capture and encode the expertise that presently exists within expert weather forecasters at KSC. Once feasibility had been established, a plan was to be developed for the development of a prototype Weather Forecasting Expert System (WFES).

Scope

The primary sources of information about the STS requirements and the weather forecasting processes were two domain experts identified by NASA. Additional interviews were conducted with Air Force staff, and documents were collected for analysis whenever available.

Approach

The evaluation and feasibility study was to cover STS processing functions, key weather scenarios, forecasting methods, pattern recognition and data systems and tools. A plan was to be developed for the construction of a prototype WFES.

1. WEATHER DEPENDENT STS PROCESSING FUNCTIONS

1.1 Forecasting Support

The Cape Canaveral Forecasting Facility (CCFF) of the USAF provides meteorological support for a large number of programs and agencies in the coastal areas of Florida, in addition to its support role for the STS program. CCFF's responsibilities include range safety, recovery forces (air and sea), ESMC operations, Aerostat, Navy, Patrick AFB 3rd shift, and the bombing range. Each of CCFF's customers has a different set of forecasting requirements.

There are two general classes of weather sensitive operations associated with the STS program. One group centers around major Shuttle events such as launch and land operations. The second group relates to the day-to-day tasks that are part of the processing activities between major events.

1.2 Major Events

The weather constraints related to the major STS events, briefly summarized in the Appendix 1, are well-specified and are generally familiar to even the newest duty forecaster. CCFFs best meteorological support is provided for these events. The most senior forecasters are present to support these operations, and extra personnel are added to the normal contingent of duty forecasters. However, the current launch frequency taxes the present capacity of the staff. The basic problem is a shortage of experienced staff, and this problem will become more serious as launch frequency increases over the coming years. Furthermore, the assignment of expert staff to m major events results in the day-to-day operations being staffed by less experienced forecasters.

1.3 Day-to-day Activities

The weather constraints associated with the day-to-day processing activities are less well specified and almost unknown to the CCFF duty forecasters. We were unable to find a complete list of these activities within NASA, and compiling such a list was outside the scope of this project.

An examination of the Safety Operating Procedures manual gave some inkling of the number of these tasks. Of 65 topics, 52 require warnings of storms with lightning; 18 have additional meteorological constraints. Only four of these topics have formally-specified procedures for CCFF to follow in issuing specific forecasts.

Interviews with the NASA STS processing expert generated a number of examples of ground processing tasks, such as spray painting and electrical work, which are very weather sensitive but not explicitly covered by policy. From the launch director's point of view, the most serious scheduling problems result from the cummulative effects of day-to-day interruptions of such tasks. Yet, the meteorological support for these activities is the least-developed within the CCFF.

2. KEY WEATHER SCENARIOS AT NASA KSC

2.1 Critical Weather Phenomena

To the extent possible, STS operations at KSC have been designed and engineered so that they are minimally affected by local weather conditions. Even so, a wide variety of STS-related activities are quite sensitive to the weather, often in ways which are unique to the requirements of KSC's STS responsibilities. Overall, the biggest operational problems are posed by lightning, wind and precipitation, in that order. Fog, although traditionally a major aviation concern, only occasionally affects KSC operations.

Lightning protection across KSC is elaborate and effective to the extent possible. One indication of the importance of lightning is that a NASA lightning expert is present at CCFF during all launch and landing operations. The development and installation of better sensing devices (e.g., field mills) for both the detection and prediction of lightning are important parts of current NASA development projects. However, the expertise required for proper use and interpretation of existing data has not been fully developed or tranferred to CCFF forecasters.

Wind is a critical factor in landings because there is only one STS runway at KSC. It is also a very important factor during launch because of the shearing forces it can generate on the shuttle. Wind also poses a particular safety problem for individuals on towers and for handlers of propellants. It presents a problem for sensitive STS payloads because of dust.

Again, the installation and expansion of the mesonet system is an important part of the meteorological improvement plan at KSC. The duty forecasters at CCFF appear to have made considerable progress in integrating the mesonet data into their forecast development process. However, much more work is needed to understand how the data are best used.

2.2 Important Weather Scenarios

For STS operations, the most important weather scenarios vary by season: convective activity in summer; fog and low visibility in the transition seasons; and the approach and stagnation of frontal systems in winter.

Thunderstorms are often imbedded in frontal systems. Summer thunderstorm formation is particularly difficult to forecast because of its small-scale irregularity as well as its sensitivity to mesoscale effects which vary on a daily cycle. National forecasting products (such as the LFM) are of little use during the summer, although they are important in forecasting winter thunderstorms

2.3 Potential WFES Subjects

A wide variety of potential weather topics were considered in deciding on the target subject matter for the WFES. Some of these topics are comparatively simple in that they are concerned with a specific phenomenon, such as precipitation. Other topics are more complex because they focus on compound conditions, such as frontal activity, which are less easy to characterize. A complete list of candidate WFES subjects is contained in Appendix 2.

A number of questions were posed as a way of evaluating which specific weather topic should be the basis of the WFES initial project:

- How serious an operational problem does it pose?
- Does significant expertise exist at KSC or CCFF?
- How frequently does the phenomenon occur?
- Are CCFF-specific data sources required?
- Is KSC forecasting experience essential to forecast it accurately?
- How well is the forecasting problem bounded?

A discussion of the pros and cons concerning each WFES topic is provided in Appendix 2. The following is a summary of the rationale for selecting summer thunderstorms.

Thunderstorms contain all three of the phenomena that have the greatest impact on both major and day-to-day STS operations: lightning, wind and rain. Forecasting summer thunderstorm formation minimally requires several seasons of experience at KSC and depends heavily upon CCFF's unique data sources, many of which require considerable experience before proficiency is developed. The process of forecasting thunderstorms is complex and requires the forecaster to assimilate information from almost all of the CCFF's data sources. On the other hand, it is a highly structured problem due to the diurnal cycle of storm formation. Finally, there are several forecasters who possess valuable expertise in this area.

3. FORECASTING METHODS

3.1 Seasonal Dependency

Forecasting methods used at CCFF differ drastically from season to season (Appendix 3). In general, the primary difference is the degree to which mid-latitude techniques are appropriate:

- Winter forecasting presents problems for which Air Force personnel are well-prepared, mainly because synoptic effects dominate and standard guidance products are useful.

- Summer forecasting is much more difficult, not only because mesoscale effects dominate and few guidance products are reliable, but also because few of the Air Force personnel have had previous forecasting experience in a tropical regime.

Because the focus of the initial WFES will be on thunderstorms, this report focuses on the methods used in forecasting during the summertime

3.2 Summer Forecasting

Broadly speaking, forecasting during the summertime is characterized by four primary methods:

- climatology;
- product evaluation;
- detection and monitoring of mesoscale features; and
- analogical reasoning.

Climatology should be thought of as providing a starting point for the day rather than as an alternate prediction method. That is, climatology provides constraints which serve as a background against which a forecaster makes a set of predictions. For example, there is a regression model at CCFF which predicts the likelihood of lightning each day based upon the morning sounding; if the model indicates a high likelihood of lightning that day, the forecaster is liable to be more alert to thunderstorm development, but will almost surely not base a forecast on the prediction from the regression equations.

The national products available at CCFF consist largely of output from synoptic-scale computer models; a lone exception is the TROPAN chart from the National Hurricane Center showing inferred wind fields in the tropics.

Aside from TROPAN, the evaluation of national products is rarely of direct help during the summer months. Nevertheless, forecasters almost always begin their shifts by examining those products to obtain a broad overview of the current situation at the synoptic scale.

Detection and monitoring of specific mesoscale features occupies most of the forecaster's available time and energy. This is normally a quiet task which becomes hectic only when there is significant convection in the area. Unfortunately, the presence of thunderstorms usually triggers a large number of telephone calls and clerical activities precisely at a time when all of the forecaster's efforts should be devoted to a minute-by-minute monitoring of the current situation.

3.3 Analogical Reasoning

Analogical reasoning involves the comparison of current events with specific forecaster experiences. It is a highly abstract activity, and is the hallmark of the very best forecasters. As we have observed it, analogical reasoning includes three main stages:

- classifying today's conditions and identifying them with one or more specific scenarios;
- anticipating future events implied by those scenarios;
- verifying that the behavior of each scenario corresponds roughly with how today's conditions are evolving.

Furthermore, the forecaster's concept of these scenarios is dynamic rather than static. That is, the description of each scenario is continuously updated and modified as time goes by; current scenarios are rejected, and new scenarios created, according to how the day is evolving. In other words, analogical reasoning is iterative, and a forecaster may go through the three stages mentioned above a dozen or more times during a single shift.

Summer forecasting is based upon analogical reasoning because discrete scenarios provide the forecaster with a conceptual framework. That is, consideration of individual scenarios focuses the forecaster's attention on that data which is most critical to recognizing and interpreting today's significant weather patterns. To some degree, it may be considered an abstract filtering process which allows the forecaster to ignore the vast majority of data which is available, and concentrate on those subsets which are most likely to help discern the direction of development of current conditions.

The most expert forecasters often maintain competing scenarios which describe the general range of possible outcomes during the next several hours. There appears to be some communication of these scenarios between duty forecasters, both in formal documents as well as during shift-change briefings, but it is rather cursory and incomplete. The incompleteness of communication is not because of a lack of interest, but appears to be due to the difficulty of verbally transcribing the contents of a scenario.

4. PATTERN RECOGNITION TECHNIQUES

4.1 Overview

The timely recognition of specific patterns is one of the most fundamental tasks of nowcasting, especially summertime nowcasting in the Cape Canaveral area. Sea-breeze onset and severe-weather signatures in vertical soundings are examples of patterns which most concern CCFF forecasters. Well-trained forecasters were found to be very adept at recognizing such patterns and interpreting their implications for short-range developments.

The data sources available to CCFF provide a rich source of information for detecting patterns which are of interest to the forecaster. Expert forecasters are good at selecting the appropriate data sources to monitor. Depending on the precise type of pattern to be detected, different data sources are most appropriate. Satellite data, for example, are most useful for tracking cloud movement, while mesonet wind data can be used to signal imminent convection.

4.2 Algorithms

Processing algorithms for automatic pattern recognition typically are split into the following stages:

- LOCAL

  First raw data are analyzed (e.g., the pixel level) to identify features or calculate additional variables; for example, IR brightness can be used to calculate cloud-top temperature and height.

- REGION

  Next, pixel-level results are used to group pixels into identifiable regions; to continue the IR example, contiguous pixels indicating a temperature below a certain threshold might be lumped together into a single region.

- OBJECT

  Finally, region-level results are analyzed structurally to associate particular regions with particular objects of interest to the human; to complete the IR example, the region of low temperature might be identified as the center of a small thunderstorm cell.

There are a variety of techniques which may be applied to each of the various processing levels. These techniques are too detailed to discuss here, but are summarized in Appendix 4. Also included are several observations concerning what we believe are the most important types of pattern recognition for summertime nowcasting in the Cape area.

Objective techniques for automatic pattern recognition, however, are not well-developed. The algorithms which do exist are difficult to calibrate and are very computation-intensive. Their development typically requires access to long meteorological records. These and other difficulties quickly convinced us that automatic pattern recognition was not feasible for the first version of the WFES. On the other hand, it was absolutely clear that the WFES design must allow for the inclusion of such algorithms in the future, should they become available.

4.3 Forecaster Expertise

The most valuable expertise of weather forecasters lies principally at the object level. To continue the example above, a minimal amount of knowledge is required to recognize existing thunderstorms from IR imagery. It is much more difficult, however, to forecast the evolution of individual cells once they have been identified, and to extrapolate from the behavior of existing cells to that of cells which have not yet formed.

We believe that the ability to interpret and extrapolate, which lies at a higher level of abstraction, is a key aspect of forecasting expertise and should be the focus of the initial WFES development. We believe this to be true for a number of reasons:

- Automatic pattern recognition algorithms are time-consuming and costly to develop;
- Object-level reasoning is more difficult to learn and is therefore most easily lost through forecaster attrition;
- The evolving logic of the WFES prototype can be used to pinpoint where pattern recognition algorithms should be developed in the future.

5. DATA SYSTEMS AND TOOLS

5.1 CCFF Systems

The CCFF is as well-equipped for nowcasting as any facility in the world. It is especially well-equipped for short-range thunderstorm forecasting. There is an extensive set of data available to CCFF forecasters, ranging from conventional radar to sophisticated local networks which measure atmospheric electricity, wind and temperature.

The most pressing problem at CCFF is that forecasters do not yet have the required expertise for accessing and interpreting all of the data which is available to them. It would be a grave mistake to underestimate the difficulty of developing this expertise:

- Many of CCFF's data sources are still experimental;
- There are very few people anywhere who are expert at interpreting much of the data which exists at CCFF, particularly in an operational setting;
- There are even fewer people who are expert in the operational use of all of CCFF data sources.

New forecasters at CCFF have an enormous amount to learn concerning the effective use of CCFF's data systems and tools, and there is little operational experience to guide them other than the experience which has been gained at CCFF itself.

The recent installation of McIdas workstations at CCFF will alleviate the situation somewhat by bringing all data sources into a single location, but serious difficulties will remain:

- McIdas does not allow the forecaster to maintain a simultaneous view of synoptic-scale, mesoscale and microscale conditions;
- The ability to overlay multiple data types onto a single map, one of the more powerful aspects of the McIdas system, does not solve the problem of there being little operational experience in interpreting such overlays;
- Exotic, unfamiliar data sources (such as Doppler and water vapor imagery) still will be exotic and unfamiliar. We believe that an AI-based system can serve as a powerful tool which will allow forecasters to capture their experience in using CCFF's data sources, and make that experience available to the entire forecasting staff.

5.2 WFES Workstation Technology

The existence of the McIdas system will be a great help in constructing an AI-based system for use at CCFF, as it provides a central repository for all incoming meteorological data. It was not clear, however, that McIdas was the most appropriate workstation technology for use by the WFES. Therefore, a brief analysis was made of alternatives.

For all practical purposes, the only alternative to McIdas is the PROFS software being developed by the Environmental Research Laboratory (ERL) in Boulder, Colorado. In particular, ERL is currently developing the PROFS Operational Workstation (POWS), designed for stand-alone use, which will ultimately be a direct competitor to the McIdas system.

From a technical standpoint, POWS is far more attractive than McIdas, especially for purposes of integrating with the WFES. POWS' use of standard hardware and software, as well as its impressive level of documentation and support, are the main reasons for preferring it over McIdas. From a practical standpoint, however, POWS is not a viable option as a replacement for the existing McIdas system:

- POWS will not be available for general use until 1987 at the earliest;
- The extra cost of installing a POWS at CCFF would be at least $500K.

Thus McIdas is the preferred option for the WFES in the near term, although not necessarily in the long-term.

In any event, the proposed design of the WFES would make it easy to integrate with a POWS at a later date, should that be desired by NASA.

5.3 WFES Hardware and Software

A number of hardware and software options were examined for development of the initial WFES prototype. Hardware options included:

- IBM mainframe (i.e., MIDDS host);
- personal computer;
- Lisp-based workstation.

Due to the lack of appropriate software for large-scale AI development, the first two alternatives were quickly rejected. The choice of a Lisp-based workstation was simplified by the fact that both KSC and Arthur D. Little, Inc. use Symbolics 3600's almost exclusively for their AI-related work.

The choice of software was considerably more difficult. Any AI-based system of the complexity envisioned for the WFES will require a sizeable software environment for its development, and many commercial packages are available. On the other hand, the required software architecture for implementing the WFES does not closely correspond to any of tnose offered as a part of commercially-available packages.

The lack of similarity between the WFES architecture and those available commercially suggested that it might be best to develop a special-purpose environment strictly for building the WFES. We have developed such special-purpose environments in the past, and have found that doing so is sometimes an attractive option. A WFES-specific environment would have a number of advantages, particularly flexibility and speed of execution. However, building such a special-purpose tool would be time-consuming and expensive.

After examining the alternatives, it was decided to use the ART software from Inference Corporation. This decision was based principally on the availability of a robust "viewpoint" mechanism in ART, useful because of the extrapolative and speculative nature of short-range weather forecasting. Furthermore, NASA already possesses several ART licenses, thereby reducing development costs somewhat.

More details concerning hardware and software options are included in Appendix 5.

A number of different schemes were analyzed for interfacing the WFES to the McIdas system. For the initial version of the WFES prototype, it was decided that data transfer between the WFES and McIdas should be performed by offline transfer of data (via magnetic tape). Ultimately, the WFES must have a link to the McIdas system which allows real-time transfer of large volumes of data, including satellite and radar images. The range of available interfacing options is illustrated in Appendix 5.

6. PROTOTYPE WEATHER FORECASTING EXPERT SYSTEM

6.1 Option Evaluation

During the course of the project, various options were identified as potential candidates for the WFES' functionality. These options addressed a wide range of perceived needs at CCFF, and largely corresponded to particular tasks regularly performed at CCFF. They are summarized below:

- automated forecaster worksneet;
- assistance with issuing met watches and advisories;
- equipment-specific advice:
  - pattern identification;
  - pattern interpretation;
- alarm monitoring for key weather parameters;
- advice concerning KSC-specific STS operational requirements;
- a scenario-based system for monitoring weather developments:
  - predefined, rigid scenarios;
  - self-modifying, flexible scenarios;
- interpretation of output from numerical models.

A detailed discussion of these options may be found in Appendix 6.

Each option was evaluated against the following criteria:

1) direct operational benefits to NASA;
2) general level of expertise involved;
3) amount of Cape-specific experience required;
4) degree to which AI technology is necessary;
5) level of effort required for implementation.

Criterion 1 is obvious. Criteria 2 and 3 address KSC's most critical forecasting-related problem, namely the continual loss of hard-earned expertise at CCFF through forecaster turnover. The fourth criterion reflects our general experience that if a particular problem can be solved using conventional techniques, it is probably wiser and cheaper to do so rather than to use AI. Moreover, the stated goal of this project was to find a good application for AI technology. Finally, an application was required which did not require an unrealistic amount of effort for its implementation.

Appendix 6 contains an extensive treatment of the evaluation of each option.

The option chosen was to build a scenario-based system using predefined scenarios. The architecture corresponding to this choice is briefly described in the following section.

6.2 System Design

The primary function of the WFES will be to assist forecasters in anticipating significant weather events relating to summertime thunderstorm formation. As a part of this assistance, the WFES will allow forecasters to store their knowledge concerning particular weather scenarios, and re-examine that knowledge at a later date. In addition, the WFES should improve communication between forecasters by providing a common facility which allows them to describe the evolution of weather events while they are on duty. Finally, the WFES should assist the forecasters in maintaining a continuous train of thought, despite the numerous interruptions which are a part of every forecaster's job.

It is important to note that the WFES architecture corresponds as closely as possible to our understanding of the best experts' actual forecasting process. That is, each WFES module has its parallel in what we observed being done by expert forecasters. This architecture provides an extraordinary degree of flexibility in the WFES implementation, because it allows a large number of options for dividing the effort between human and machine. It also means that not all modules have to be completed to the same level of detail, because the function performed by any specific module could just as naturally be performed by the human.

The system design required is rather complex, but is made up of simple building blocks. Before examining the flow of data within the WFES architecture, it is most important to discuss the principle data structures:

- VARIABLE: a scalar or vector quantity associated with a single meteorological parameter;
- FEATURE: an individual weather entity, usually associated with a relatively small set of VARIABLES;
- EVENT: a qualitative change in a FEATURE, or by extension, a set of FEATURES;
- SCENARIO: a sequence of EVENTS which corresponds to an identifiable type of weather behavior.

A simple example is offered to demonstrate the concept of how these data structures would be used. Assume that a scenario associated with morning showers being blown onshore from the Gulf Stream is being entertained. An event associated with such a scenario might be that light prevailing easterlies should develop during the late evening. The feature to be examined, then, would be the local steering-level wind as measured at 00Z. Finally, the variable associated with the 00Z steering-level wind would be the 700 mb wind at Tampa or West Palm Beach.

A complex scenario is illustrated in Appendix 6. It shows how the scenario mechanism can be used to represent an interconnected set of events throughout a single day, events which ultimately lead to severe weather in the Cape area. The diagram showing this scenario is only a schematic, but it does indicate how small scenarios can be combined to form a coherent story for the entire day. (Note: this "scenario" actually corresponds roughly to what is referred to in the architectural diagrams as Today; see below.)

The flow of data within the WFES architecture will be described briefly. A top-level view is provided in Appendix 6 which shows the primary functions of DETECT, MONITOR and ANTICIPATE. Each of these functions accesses data which is either external to the program (for example, "World" and "Knowledge") or internal (for example, "Expectations" and "Today"). Summary descriptions of the three primary functions are given below:

- DETECT: using expectations of future conditions, selectively process incoming data to confirm or deny those expectations, and update the system's most current description of how today has evolved so far;

- MONITOR: compare current expectations with how conditions are actually evolving, and update the status of actively-monitored scenarios;

- ANTICIPATE: using the current status of actively-monitored scenarios, look ahead to see what the future development of those scenarios implies about upcoming conditions, and modify future expectations accordingly.

Summary descriptions of the major data blocks include:

- World: all meteorological data, taken from whatever source;

- Today: the system's current symbolic description of how today has evolved up to the present;

- Knowledge: the definitions of all predefined scenarios, with their associated events and heuristics;

- Alternate Scenarios: the list of scenarios that are currently being monitored actively;

- Expectations: the next set of future events implied by the Alternate Scenarios.

Even without more detail, we hope the reader can now understand the architectural diagrams in Appendix 6. In addition to the top-level view of the WFES structure, there also are detailed diagrams showing the next level of detail of DETECT and MONITOR. Appendix 6 also contains diagrams which illustrate how data from one set of measurements, the local skew-T, would be processed within the WFES architecture. These diagrams are particularly informative because they give a concrete example for each of the functions and the data associated with the detailed WFES architecture.

6.3 Development Approach

The proposed approach to developing the WFES prototype is a simple one, and has two main features:

- early creation of a usable interface;
- careful attention to the order of module development.

It has been our experience that the development of an AI system proceeds much more smoothly when there is a robust user interface suitable for use by the experts. In the case of the WFES, an editing facility for defining and modifying scenarios, and a crude mechanism for examining how those scenarios will operate, will be built first. By providing tools for the experts to use as early as possible, we anticipate getting valuable feedback concerning how the WFES should interact with the forecaster, as well as suggestions as to how the WFES logic should operate. In addition, by working closely with us as the prototype evolves, the experts will become an integral part of the project team.

The order of module development is critical. Those modules which are necessary for the WFES to be a useful tool will be developed first. The modules which are part of the overall system design, but whose functions could be performed by the human, will be developed next.

The specifics of how each module fits into the overall development approach are presented in Appendix 6. At the same time, the various sources of information for the WFES prototype have been indicated, and the basic roles specified for each group that will provide that information. The primary source of weather-related expertise will be the two experts in thunderstorm forecasting, J. Nicholson of Lockheed and J. Smedley of Low Latitude Dynamics.

6.4 Prototype Options

Two basic options for the WFES prototype were presented to NASA management for evaluation, differing in scope and level of effort, though both involve a two-year program. Option 1 describes a WFES directly linked to the MIDDS system early in the project, which concentrates on providing advice concerning all thunderstorm formation activities which could affect the Cape area. Option 2 is considerably reduced in its goals. It relies upon off-line transfer of data from the MIDDS system to the WFES, and concentrates only on those thunderstorms which form in the immediate Cape area.

The difference in scope between these two options is reflected in the difference in price: the first option has an estimated development cost of around $1.2 million, while the second is estimated to cost around $550 thousand. Because of budgetary limitations, KSC management chose the second option.

To avoid unnecessary repitition, Option 1 will be described first, then the required modifications will be discussed that led to Option 2.

6.4.1 Option 1: High Effort

Under this plan, during the first year the focus of efforts was to be on building a structure for the weather scenarios, and the logic (or "inference engine") required to process those scenarios. Considerable time was to be spent on-site at CCFF working closely with both the domain experts and CCFF staff. The main goal of the first year was to gain sufficient information to assess the requirements for implementing a fully-operational WFES at CCFF. Obtaining this information would require:

- a detailed knowledge of thunderstorm formation in the Cape area as well as a clear awareness of how forecasters respond to those storms;
- a set of software which closely matches that knowledge, including:
  - a robust facility for defining and e editing weather scenarios;
  - a set of logic for identifying and monitoring "interesting" weather features;
  - a graphical, interactive interface to the MIDDS system.

During the second year, the plan called for a three-month operational testing of the WFES prototype at CCFF during the thunderstorm season. This required implementing the details of what had been learned during the first year, and included:

- an advanced user interface suitable for unsupervised use;
- an environment for browsing through, and modifying, the knowledge base of scenarios;
- sophisticated logic for automatic generation and monitoring of significant thunderstorm scenarios;
- automatic, high bandwidth linkage of the WFES to previously-stored MIDDS case histories.

A task diagram in Appendix 6 summarizes the proposed schedule for this first option, and includes approximate costs for completion of each task. As mentioned, the total cost for this option was estimated to be $1.2 million.

6.4.2 Option 2: Medium Effort

Under the second option, major tradeoffs were made between the WFES' functionality and the benefits to be gained by KSC from developing the prototype. The basic aim was to reduce the cost as much as possible without sacrificing the original goal of the WFES prototype: to capture valuable forecasting expertise, specifically relating to Cape-specific nowcasting, in a set of AI-based software.

We firmly believe that, even given the reduced level of effort, Option 2 will provide NASA management with the information they require concerning the cost and overall advisability of implementing an operational WFES during the next several years.

To that end, Option 1 was modified in a number of ways. The major modifications were as follows:

- the knowledge base of weather scenarios will be limited to those thunderstorms which form *in situ* over the Cape;
- data transfer from MIDDS to the WFES will be considerably simplified by using magnetic tape and a low-speed serial link;
- no operational testing will be performed at CCFF, and the role of CCFF staff will be advisory rather than one of direct involvement.

Due to the preliminary nature of the WFES prototype and the lack of operational testing, it was also decided that user documentation would be limited to that required by the developers and a few trained users. Similarly, it was decided that the WFES user interface, though usable, will not be sufficiently robust to support unsupervised use.

Appendix 6 includes a summary chart showing the proposed task breakdown and timing for Option 2, as well as the estimated cost. It represents a two-year effort at a cost of approximately $550 thousand.

APPENDIX O

EXECUTIVE SUMMARY AND INTRODUCTION

CONCLUSIONS

- GROUND OPERATIONS ALL AFFECTED MORE BY INACCURATE FORECASTS THAN STS LAUNCH AND LAND OPERATIONS

- THUNDERSTORMS ARE THE MAJOR FORECASTING PROBLEM

- FORECASTER EXPERIENCE ON-STATION AT CCFF IS A MAJOR DETERMINANT OF FORECASTING SKILL

- STAFF TURNOVER RATE IS HIGH AT CCFF

- THE PROTOTYPE WFES SHOULD FOCUS ON CAPTURING FORECASTER EXPERTISE IN PREDICTING SUMMERTIME THUNDERSTORMS

- THE MAJOR BENEFIT WOULD BE IMPROVED FORECASTING SUPPORT OF DAY-TO-DAY OPERATIONAL ACTIVITIES

KEY FINDINGS

- FORECASTER EXPERTISE LIES LARGELY IN KNOWLEDGE OF WEATHER SCENARIOS
- SUMMERTIME THUNDERSTORM FORECASTING REPRESENTS THE PREFERRED INITIAL TOPIC FOR WFES
- THE AI-ARCHITECTURE REQUIRED TO CAPTURE AND USE WEATHER SCENARIOS IS COMPLEX
- THOUGH COMPLEX, THE REQUIRED AI TECHNOLOGY IS FEASIBLE AND IN CURRENT USE
- THE PROPOSED DEVELOPMENT EFFORT IS MODULAR, FLEXIBLE AND PRESENTS A CLEAR MIGRATION PATH TO A FULLY-OPERATIONAL WFES

PURPOSE OF MEETING ON OCTOBER 21, 1985

TO RESPOND TO COMMENTS FROM ATTENDEES OF SEPTEMBER 9, 1985 MEETING AND TO FILL IN DETAILS BEHIND RECOMMENDATIONS.

1. CIRCUMSTANCES AT KSC

2. KEY FINDINGS

3. RATIONALE FOR PROPOSED WFES PROTOTYPE
   - POTENTIAL WFES FUNCTION
   - POTENTIAL WEATHER SUBJECTS

4. EXPAND ON AI-SPECIFIC TECHNOLOGY
   - PATTERN RECOGNITION
   - KNOWLEDGE REPRESENTATION SCHEME
   - ARCHITECTURE AND MODULES

5. REDUCED SCOPE OF DEVELOPMENT PLAN

CIRCUMSTANCES AT NASA KSC

- WEATHER FORECASTING IS CRITICAL TO STS OPERATIONS
- KSC HAS A UNIQUE CLIMATOLOGY
- FORECASTING EXPERTISE IS BUILT-UP WITH EXPERIENCE AT KSC
- PERSONNEL CHANGES OCCUR FREQUENTLY
- PROBLEM 1: ACCUMULATION OF FORECASTING EXPERTISE IS JEOPARDIZED
- PROBLEM 2: FORECASTERS MUST HANDLE INCREASINGLY GREATER AMOUNTS OF INFORMATION
- THESE PROBLEMS WILL BECOME SIGNIFICANTLY WORSE AS STS LAUNCH FREQUENCY INCREASES

NASA KSC IS AN IDEAL ENVIRONMENT FOR DEVELOPING A WEATHER FORECASTING EXPERT SYSTEM:

- WEATHER HAS A MAJOR IMPACT ON STS OPERATIONS
- UNIQUE DATA SYSTEMS ARE AVAILABLE
- A DEDICATED STAFF IS RESIDENT
- FORECASTING EXPERTS ARE AVAILABLE
- SHORT-RANGE FORECASTING IS AN ART, NOT A SCIENCE

APPENDIX 1

TASK 1

WEATHER DEPENDENT STS PROCESSING FUNCTIONS

THE CCFF PROVIDES METEOROLOGICAL SUPPORT FOR:

STS OPERATIONS: ROLLOUT, LAUNCH & LAND
KSC/CCAF GROUND OPERATIONS
RANGE SAFETY: SPILL FOOTPRINTS, SOUND PROPAGATION
RECOVERY FORCES: AIRCRAFT AND SHIPS
ESMC OPERATIONS
AEROSTAT
NAVY: REDSTONE, CRANE
PATRICK AFB 3RD SHIFT
BOMBING RANGE

STS WEATHER REQUIREMENTS

LAUNCH SITE:

33 F $\leq$ TEMP. $\leq$ 99 F

NO PRECIPITATION: EXTERNAL TANK LOADING THROUGH LAUNCH

ICE $\leq$ 1/16 INCH ON EXTERNAL TANK

SURFACE WINDS PRE-LAUNCH: $<$ 49 KNOTS STEADY

SURFACE WINDS AT LAUNCH: $<$ 34.4 KNOTS PEAK

$<$ 22.6 KNOTS STEADY

UPPER AIR: WIND SHEARS WITHIN VLL

ELECTRIC FIELD CONTOURS: $<$ 1000 V/M

LANDING SITE:

NO PRECIPITATION (RTLS) WITHIN 50 NM (EOM)

SURFACE WIND COMPONENTS: $\leq$ 25 KNOT HEADWIND

$\leq$ 10 KNOT CROSSWIND

$\leq$ 10 KNOT TAILWIND

TURBULANCE: MODERATE OR LESS

VISIBILITY: $\geq$ 7 NM

FLIGHT PATH:

$>$ 5 NM EDGE OF THUNDERSTORM RADAR CELL OR EDGE OF ASSOCIATED ANVIL

$>$ 5 NM FROM CELL WITH TOP REACHING TO -20 C OR CUMULUS CLOUDS MUST HAVE RADAR ECHOES & TOPS BELOW -10 C

LC-39 AREA WIND RESTRICTIONS

$\geq$ 10 KNOTS:	NO SPIDER WORK ALLOWED BETWEEN ET AND ORBITER
$\geq$ 15 KNOTS:	CEASE HAMMERHEAD AND MOBILE CRANE LIFTING OPERATIONS
$\geq$ 20 KNOTS:	NO PERSONNEL WORKING ON FLOATS, SPIDERS OR SCAFFOLDING
$\geq$ 30 KNOTS:	EVACUATE THOSE SECTIONS OF VEHICLE INTERIOR WHERE SAFE EGRESS DEPENDS ON ORBITER ACCESS ENVIRONMENTAL CHAMBER
$\geq$ 49 KNOTS:	SWITCH LH_2 LO_2 LOAD TO DRAIN AND RETRACT GOX VENT ARM

LC-39 AREA LIGHTNING RESTRICTIONS

NO LIGHTNING WITHIN 5 MILES
WEATHER ADVISORIES 30 MIN BEFORE IF POSSIBLE
UPON CONFIRMED STRIKE, ANNOUNCE LIGHTNING PROTECTION POLICY IN EFFECT
WHEN STORM HAS PASSED AT LEAST 5 MILES FROM AREA, ANNOUNCE THREAT NO LONGER EXISTS

SAFETY OPERATING PROCEDURES

- OF 65 TOPICS IN TABLE OF CONTENTS:
  - 52 REQUIRE WARNINGS OF STORMS WITH LIGHTNING
  - 18 HAVE ADDITIONAL METEOROLOGICAL CONSTRAINTS
  - ONLY 4 REQUIRE BY POLICY SPECIFIC FORECAST OR WEATHER SUPPORT

- A HOST OF OTHER GROUND OPERATIONS ARE WEATHER SENSITIVE
  - SPRAY PAINTING: WINDS 17 KNOTS
  - ELECTRICAL WORK: STORM WARNING HALTED WORK AT 2:00 P.M. BECAUSE THEY DIDN'T KNOW WHAT WAS COMING, KNOCKED OFF SHIFT EARLY AND LOST WHOLE DAY.

"IT'S THE DAY-TO-DAY DELAYS THAT CAUSE THE MOST PROBLEMS...LITTLE THINGS..."

BOB SIECK, POINTING AT
JFKSC INTEGRATED CONTROL SCHEDULE

"OUR MAJOR FORECAST PROBLEM IS THE SUMMER THUNDERSTORM SITUATION."

MET MODERNIZATION PLAN, 1984

APPENDIX 2

TASK 2

KEY WEATHER SCENARIOS AT NASA KSC

CRITICAL WEATHER PHENOMENA

- LIGHTNING, WIND AND PRECIPITATION ARE THE BIGGEST PROBLEMS
- FOG ONLY OCCASIONALLY AFFECTS NASA OPERATIONS
- LIGHTNING PROTECTION IS ELABORATE AND EFFECTIVE TO THE EXTENT POSSIBLE
- THE IMPORTANCE OF LIGHTNING IS SHOWN BY THE PRESENCE OF A NASA EXPERT AT CCFF DURING LL
- WIND IS PARTICULARLY A SAFETY PROBLEM FOR INDIVIDUALS ON TOWERS AND HANDLING PROPELLANTS
- WIND ALSO PRESENTS PROBLEMS FOR SENSITIVE STS PAYLOADS BECAUSE OF DUST
- PRECIPITATION CAUSES PROBLEMS FOR THE TILES, CARGO MOVEMENT, PAINTING, ETC.

IMPORTANT WEATHER SCENARIOS

- THE MOST IMPORTANT SCENARIOS BY SEASON:
  - CONVECTIVE ACTIVITY IN SUMMER
  - FOG & LOW VISIBILITY IN TRANSITIONS
  - FRONTAL APPROACH & STAGNATION IN WINTER

- FOG AND LOW VISIBILITY NOT MOST IMPORTANT OPERATIONALLY

- FRONTAL SYSTEMS OFTEN HAVE IMBEDDED THUNDERSTORMS

- SUMMER THUNDERSTORM FORMATION:
  - PRIMARILY FORCED BY MESOSCALE EFFECTS
  - VARIES ON A DAILY CYCLE

- MAJOR PATTERNS OF THUNDERSTORM FORMATION CAN FEASIBLY BE PUT INTO A TAXONOMY OF SCENARIOS

POTENTIAL WFES WEATHER SUBJECTS

SIMPLE

- PRECIPITATION
  - SUMMER SHOWERS
  - FRONTAL
- LIGHTNING
- WINDS
  - GENERAL (DAILY CONSTRAINTS)
  - LAUNCH AND LANDING
- FOG AND STRATUS

COMPLEX

- FRONTAL ACTIVITY
  - MOVEMENT AND DISSIPATION
  - IMBEDDED SQUALL LINES
- THUNDERSTORMS
  - FORMATION OVER CAPE
  - ADVECTION OF EXISTING CELLS
  - END-OF-STORM

POTENTIAL WFES SUBJECTS: QUESTIONS

- IS IT A SERIOUS OPERATIONAL PROBLEM?
- DOES SIGNIFICANT EXPERTISE EXIST?
- DOES IT OCCUR FREQUENTLY?
- ARE CUFF-SPECIFIC DATA SOURCES REQUIRED?
- IS LOCAL EXPERIENCE NECESSARY TO FORECAST ACCURATELY?
- IS THE PROBLEM WELL-BOUNDED?

PRECIPITATION

FOR:

- OCCURS FREQUENTLY

AGAINST:

- EASY TO DETECT AND MONITOR
- DIFFICULT TO SEPARATE FROM OTHER SCENARIOS
- LOCAL EXPERTISE NOT IN PRECIPITATION PER SE
- UNIQUE CCFF DATA SOURCES NOT DIRECTLY REQUIRED

LIGHTNING

FOR:

- AN EXTREMELY SERIOUS OPERATIONAL CONCERN
- OCCURS FREQUENTLY
- LOCAL EXPERTISE IS EXTENSIVE
- LIGHTNING-SPECIFIC EQUIPMENT IS UNFAMILIAR TO NEW FORECASTERS

AGAINST:

- EAST TO DETECT AND MONITOR
- DIFFICULT TO SEPARATE FROM OTHER SCENARIOS
- NOT WELL-UNDERSTOOD PHYSICALLY

WINDS

FOR:

- A SERIOUS OPERATIONAL CONCERN
- SPECIAL KNOWLEDGE REQUIRED TO INFER WINDS INDIRECTLY
- WIND-SPECIFIC EQUIPMENT AT CCFF UNFAMILIAR TO NEW FORECASTERS

AGAINST:

- RELATIVELY INFREQUENT
- DIFFICULT TO SEPARATE FROM OTHER SCENARIOS
- VERY DIFFICULT TO FORECAST: EXPERTISE IS SPOTTY

FOG AND STRATUS

FOR:

- A WELL-BOUNDED PROBLEM
- OBJECTIVE TECHNIQUES EXIST
- LOCAL GEOGRAPHY HAS A LARGE INFLUENCE

AGAINST:

- NOT A SERIOUS OPERATIONAL CONCERN (TO NASA)
- A VERY SUBTLE FORECASTING PROBLEM
- RELATIVELY INFREQUENT
- EXPERTISE IS NOT STRONG IN THIS AREA

FRONTAL ACTIVITY: MOVEMENT, DISSIPATION

FOR:

- FRONTAL BEHAVIOR IN FLORIDA IS UNIQUE
- LOCAL EXPERIENCE IS NEEDED FOR ACCURATE FORECASTING
- ASSOCIATED WITH OPERATIONAL CONCERNS

AGAINST:

- LARGELY A SYNOPTIC-SCALE PROBLEM
- REQUIRES INTERPRETATION OF MODEL RESULTS
- NOT YEAR-ROUND
- COMPLEX

FRONTAL ACTIVITY: SQUALL LINES

OTHER THAN A GENERAL LACK OF A DIURNAL CYCLE, COMMENTS ON "THUNDERSTORMS: ADVECTION" APPLY HERE.

THUNDERSTORMS: FORMATION OVER CAPE

FOR:

- A WELL-BOUNDED PROBLEM
- CCFF'S UNIQUE DATA SOURCES ARE ESSENTIAL
- LOCAL EXPERIENCE REQUIRED FOR ACCURATE FORECASTING
- EXPERTISE IS AVAILABLE

AGAINST:

- RELATIVELY INFREQUENT

THUNDERSTORMS: ADVECTION

FOR:

- CCFF'S UNIQUE DATA SOURCES ARE ESSENTIAL
- OCCUR FREQUENTLY
- A VERY SERIOUS OPERATIONAL PROBLEM
- EXPERTISE IS AVAILABLE
- LOCAL EXPERIENCE REQUIRED FOR ACCURATE FORECASTING
- DIURNAL CYCLE GIVEN A STRUCTURE TO PROBLEM-SOLVING (SUMMER)

AGAINST:

- DIFFICULT TO DEFINE BOUNDARIES OF PROBLEM
- COMPLEX

THUNDERSTORMS: END-OF-STORM

FOR:

- THE MOST SERIOUS OPERATIONAL PROBLEM
- LCFF'S UNIQUE DATA SOURCES ARE ESSENTIAL
- OCCUR FREQUENTLY
- LOCAL EXPERIENCE REQUIRED FOR ACCURATE FORECASTING

AGAINST:

- DIFFICULT TO DEFINE BOUNDARIES OF PROBLEM
- EXTREMELY COMPLEX
- VERY DIFFICULT FORECASTING PROBLEM
- EXPERTISE NOT WELL-DEVELOPED

RATIONALE FOR SELECTING THUNDERSTORM PROBLEM

- LIGHTNING, WIND AND RAIN HAVE GREATEST IMPACT ON OPERATIONS.
- THUNDERSTORMS CONTAIN ALL THREE.
- THUNDERSTORMS FORM RAPIDLY AND REQUIRE CONSTANT ALERTNESS.
- FORECAST TRAINING AND EXPERIENCE STRESSES MID-LATITUDE FORECASTING TECHNIQUES.
- THUNDERSTORM FORECASTING IS LARGELY BASED ON PERSONAL EXPERIENCE.
- TWO OR THREE SEASONS OF EXPERIENCE ARE REQUIRED TO ENCOUNTER A SUFFICIENT NUMBER OF THUNDERSTORM SCENARIOS.
- THUNDERSTORM FORECASTING IS COMPLEX AND REQUIRES FORECASTERS TO ASSIMILATE ALMOST ALL OF CCFF'S DATA SOURCES.
- MANY OF CCFF'S DATA SOURCES ARE UNFAMILIAR TO INCOMING FORECASTERS.
- CONSIDERABLE EXPERIENCE IS REQUIRED BEFORE PROFICIENCY IS REACHED IN USING CCFF'S DATA SOURCES.

APPENDIX 3

TASK 3

FORECASTING METHODS

TASK 3: FORECASTING METHODS
OVERVIEW

FORECASTING METHODS AT CCFF DIFFER DRASTICALLY FROM SEASON TO SEASON. FOR THE PURPOSES OF BUILDING A WFES, THE PRIMARY DIFFERENCE IS THE DEGREE TO WHICH MID-LATITUDE FORECASTING TECHNIQUES ARE EFFECTIVE. IN GENERAL:

- WINTER FORECASTING PRESENTS PROBLEMS FOR WHICH AIR FORCE TRAINING AND EXPERIENCE ARE WELL-SUITED. SYNOPTIC-SCALE EFFECTS PREDOMINATE, AND GUIDANCE PRODUCTS ARE QUITE USEFUL.

- SUMMER CONDITIONS ARE TROPICAL. MESOSCALE EFFECTS DOMINATE, AND SYNOPTIC CONDITIONS BECOME A SLOWLY-VARYING BACKGROUND AGAINST WHICH MESOSCALE EVENTS OCCUR. FEW GUIDANCE PRODUCTS ARE USEFUL, AND FORECASTER EXPERIENCE WITH LOCAL WEATHER PATTERNS IS NECESSARY.

TASK 3: FORECASTING METHODS
OVERVIEW (CONTINUED)

FORECASTING TECHNIQUES CHANGE AS THE INFORMATION AVAILABLE TO THE FORECASTER CHANGES. THIS AFFECTS THE WFES IN TWO WAYS:

- NEW PERSONNEL ARE FACED WITH A WIDE VARIETY OF TOOLS AND DATA SOURCES AT CCFF WHICH ARE ALMOST TOTALLY UNFAMILIAR.

- EXISTING PERSONNEL MUST ADAPT TO CCFF'S RAPIDLY-CHANGING ENVIRONMENT AS NEW TOOLS AND DATA SOURCES BECOME AVAILABLE.

SINCE NEW FORECASTERS MUST BE PRODUCTIVE ALMOST IMMEDIATELY, THE WFES SHOULD PROVIDE OPERATIONAL ASSISTANCE RATHER THAN OFF-LINE TRAINING.

SINCE THE CCFF ENVIRONMENT IS DYNAMIC, THE WFES MUST BE SUFFICIENTLY FLEXIBLE TO ALLOW FOR CHANGES IN FORECASTING LOGIC AND PROCEDURE.

FORECASTING ENVIRONMENT

- THE DUTY FORECASTERS PROVIDE DAY-TO-DAY CONTINUITY.
- THE MOST SKILLED FORECASTERS ARE PRESENT DURING LAUNCH AND LAND.
- PERSONNEL MOST KNOWLEDGEABLE ABOUT NASA OPERATIONS ARE GUARANTEED PRESENT DURING LAUNCH & LAND.
- DUTY FORECASTERS PRIMARY CONTACT WITH NASA IS VIA KSC DUTY OFFICER.
- NUMEROUS SPECIAL REQUIREMENTS MUST BE SATISFIED ON A DAILY BASIS.
- CONSTANT INTERRUPTIONS OFTEN PREVENT COMPLETE ANALYSIS OF WEATHER DATA.
- FREQUENTLY DATA ARE MISSING OR UNAVAILABLE.

BIGGEST PROBLEM

NASA: "AF STAFF TURNOVER BIGGEST PROBLEM."

STAFF MET: "EXPERIENCE ON STATION IS 50% OF ABILITY TO FORECAST."

DUTY FORECASTER: "HARDEST PART OF JOB? TOO MANY DISTRACTIONS."

OTHER PROBLEMS

EACH CUSTOMER HAS DIFFERENT REQUIREMENTS.

DF: "HARD TO REMEMBER WHO NEEDS WHAT..."

FORECASTER VOCABULARY DIFFERENT FROM CUSTOMERS.

DF: "HAVE TO TRANSLATE INTO EVERYDAY LANGUAGE."

REPORTING FORMATS VARY BY CUSTOMER.

TASK 3: FORECASTING METHODS
SUMMER FORECASTING

IN THE SUMMER, SHORT-RANGE FORECASTING IS CHARACTERIZED BY THE FOLLOWING METHODS:

- CLIMATOLOGY
- PRODUCT EVALUATION
- DETECTION AND MONITORING OF MESOSCALE FEATURES
- ANALOGICAL REASONING

TASK 3: FORECASTING METHODS
CLIMATOLOGY

IN GENERAL, CLIMATOLOGY DOES NOT PROVIDE AN ALTERNATE PREDICTION, BUT RATHER SERVES AS BOTH A STARTING POINT FOR THE DAY AND A SET OF FORECASTING CONSTRAINTS.

THE USE OF LOCAL CLIMATOLOGY MAY BE DIVIDED INTO TWO BROAD AREAS:

- PERSISTENCE

  OBJECTIVELY, THE BEST OVERALL "TECHNIQUE" IS SIMPLY TO PREDICT THAT TODAY WILL BE LIKE YESTERDAY

- STATISTICAL

  STATISTICAL ANALYSES AVAILABLE TO CCFF FORECASTERS INCLUDE:

  - CONDITIONAL PROBABILITIES FOR SIMPLE PHENOMENA SUCH AS FOG

  - REGRESSION EQUATIONS WHICH PREDICT SUCH THINGS AS SEA BREEZE ONSET AND LIKELIHOOD OF THUNDER

TASK 3: FORECASTING METHODS
PRODUCT EVALUATION

ALMOST ALL SYNOPTIC-SCALE GUIDANCE PRODUCTS ARE VIRTUALLY USELESS DURING THE SUMMERTIME.

IN FACT, THEY MAY BE WORSE THAN USELESS BECAUSE THEY CAN MISLEAD AN INEXPERIENCED FORECASTER.

MESOSCALE EFFECTS DOMINATE, BUT ACCURATE MESOSCALE MODELS ARE NOT YET AVAILABLE.

EVEN IF A MESOSCALE MODEL WAS INSTALLED TODAY, IT WOULD TAKE YEARS OF EXPERIENCE BEFORE IT COULD BE USED EFFECTIVELY

TASK 3: FORECASTING METHODS
DETECTION AND MONITORING

MOST OF A FORECASTER'S AVAILABLE TIME AND ENERGY IS DEVOTED TO DETECTING AND MONITORING INDIVIDUAL STORM COMPLEXES, WHEN THEY EXIST.

THIS TASK IS BASICALLY A REACTIVE ONE, AND FEW FORECASTERS HAVE SUFFICIENT EXPERTISE TO REASON ABOUT THE PHYSICS OF MESOSCALE EVOLUTION.

IRONICALLY, WHEN THERE IS SIGNIFICANT STORM ACTIVITY NEAR THE CAPE:

- FORECASTERS SHOULD DEVOTE ALL THEIR ENERGIES TO TRACKING CURRENT DEVELOPMENTS, ON A MINUTE-BY-MINUTE BASIS, USING ALL OF THE DATA WHICH IS AVAILABLE;
- IT IS AT THIS TIME THAT THEY ARE MOST CONSUMED WITH ANSWERING INCOMING TELEPHONE CALLS AND PERFORMING PAPERWORK (ASSOCIATED WITH ISSUING WATCHES AND WARNINGS).

TASK 3: FORECASTING METHODS
ANALOGICAL REASONING

ANALOGICAL REASONING INVOLVES THE COMPARISON OF CURRENT EVENTS WITH SPECIFIC FORECASTER EXPERIENCES. IT INCLUDES THREE BASIC ACTIVITIES:

- CLASSIFYING TODAY'S CONDITIONS BY IDENTIFYING THEM WITH ONE OR MORE DISCRETE SCENARIOS;
- ANTICIPATING FUTURE EVENTS IMPLIED BY THOSE SCENARIOS;
- VERIFYING THAT THE BEHAVIOR OF EACH SCENARIO CORRESPONDS, AT LEAST ROUGHLY, TO HOW TODAY'S WEATHER BEHAVES.

IN THE SUMMER, SHORT-RANGE FORECASTING IS DOMINATED BY ANALOGICAL REASONING. THERE ARE SEVERAL REASONS FOR THIS:

- EXPLICIT MODELING OF MESOSCALE FEATURES IS NOT YET RELIABLE.
- ANALOGS PROVIDE A CONCEPTUAL FRAMEWORK FOR RECOGNIZING AND INTERPRETING MESOSCALE PATTERNS.
- CLIMATOLOGICAL ANALYSES ARE UNABLE TO TAKE INTO ACCOUNT THE PRESENCE OR ABSENCE OF THOSE MESOSCALE FEATURES WHICH DRIVE SUMMERTIME WEATHER PATTERNS OVER FLORIDA.

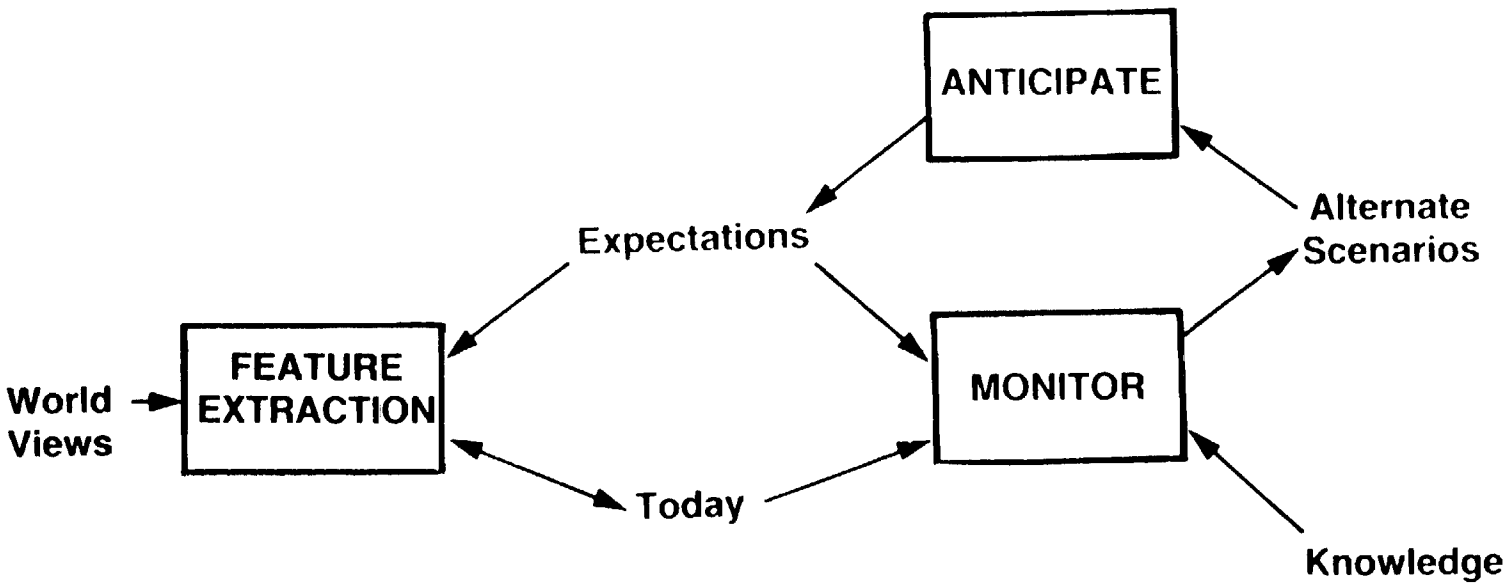
TASK 3 FORECASTING METHODS
ANALOGICAL REASONING (CONTINUED)

WHATEVER THE PRECISE FORM OF A SPECIFIC FORECAST (MET WATCH, 12-HOUR TERMINAL FORECAST, ETC.), IT IS ALMOST ALWAYS BASED UPON A RATHER DETAILED SCENARIO WHICH EXISTS ONLY IN THE MIND OF THE FORECASTER.

THERE IS SOME COMMUNICATION OF THESE SCENARIOS BETWEEN FORECASTERS DURING A SHIFT CHANGE AND IN FORMAL DOCUMENTS, BUT IT IS RELATIVELY CURSORY AND INCOMPLETE.

BETTER FORECASTERS MAINTAIN COMPETING SCENARIOS WHICH DESCRIBE THE GENERAL RANGE OF POSSIBLE OUTCOMES DURING THE NEXT SEVERAL HOURS.

The Forecasting Process



APPENDIX 4

TASK 4

PATTERN RECOGNITION TECHNIQUES

TASK 4: PATTERN RECOGNITION
OVERVIEW

IN ITS MOST GENERAL SENSE, THE RECOGNITION OF PARTICULAR PATTERNS IS THE FUNDAMENTAL TASK OF SUMMERTIME NOWCASTING AT CCFF.

THE FOLLOWING SORTS OF FEATURES, AMONG OTHERS, ARE OF INTEREST:

- SEA BREEZE ONSET;
- CONVECTION ASSOCIATED WITH THE SEA BREEZE FRONT;
- ARC CLOUDS SHOWING OUTFLOWS FROM EXISTING CELLS
- CONFLUENT ZONES WHICH INDICATE POTENTIAL FOR FUTURE CONVECTION AND
- SEVERE-WEATHER SIGNATURES IN VERTICAL SOUNDINGS.

USING THE DATA SOURCES AVAILABLE AT CCFF, A WELL-TRAINED FORECASTER IS EXTREMELY ADAPT AT RECOGNIZING SUCH PATTERNS.

TASK 4: PATTERN RECOGNITION
DATA SOURCES FOR OBJECTIVE TECHNIQUES

THERE ARE NUMEROUS POSSIBILITIES FOR THE USE OF OBJECTIVE, ANALYTICAL TECHNIQUES IN RECOGNIZING CERTAIN TYPES OF PATTERNS. THE USE OF SUCH TECHNIQUES DEPENDS ON THE DATA SOURCE INVOLVED:

- SATELLITE: CLOUD MOVEMENT
- DOPPLER: CELL STRENGTH, STORM SEVERITY
- VOLUMETRIC RADAR: STORM TRACKING, SEVERITY
- MESONET: IMMINENT CONVECTORS, SEA BREEZE ONSET
- FIELD MILLS: LIGHTNING WARNING (BEGINNING AND END)

TASK 4: PATTERN RECOGNITION
OBJECTIVE PATTERN-RECONGITION TECHNIQUES AND THE WFES

- OBJECTIVE TECHNIQUES FOR PATTERN RECOGNITION ARE NOT WELL-DEVELOPED, AND HAVE THE FOLLOWING CHARACTERISTICS:
  - THEY ARE DIFFICULT TO CALIBRATE AND REQUIRE A LARGE AMOUNT OF COMPUTATIONAL HORSEPOWER
  - FEW EXISTING TECHNIQUES ARE SUFFICIENTLY ACCURATE TO BE BLINDLY ACCEPTED BY FORECASTERS
  - THEIR FOCUS IS ON FEATURES WHICH HAVE A TIME SCALE OF THIRTY MINUTES OR LESS
  - THEIR DEVELOPMENT REQUIRES DETAILED METEOROLOGICAL EXPERTISE AND ACCESS TO LONG HISTORICAL RECORDS
- THE INFORMATION REQUIRED FOR QUALITATIVE SCENARIO TRACKING CAN BE OBTAINED WITHOUT OBJECTIVE PATTERN RECOGNITION TECHNIQUES.
- THE INITIAL WFES <u>WILL NOT</u> INCLUDE OBJECTIVE PATTERN-RECOGNITION TECHNIQUES.
- THE WFES <u>WILL</u> BE EXPANDABLE TO INCLUDE OBJECTIVE PATTERN-RECOGNITION TECHNIQUES.

PATTERN RECOGNITION: OVERVIEW

PROCESSING ALGORITHMS ARE SPLIT INTO THREE LEVELS:

- LOCAL (GRID POINT OR PIXEL)
- REGION (CONNECTED GROUPS OF GRID POINTS OR PIXELS)
- OBJECT (SPECIFIC, CLASSIFIED REGIONS OR GROUPS OF REGIONS)

TYPICALLY, PROCESSING IS DONE IN STAGES:

- RAW DATA IS ANALYZED LOCALLY TO IDENTIFY FEATURES OR CALCULATE ADDITIONAL VARIABLES
- PIXEL-LEVEL RESULTS ARE USED TO GROUP NEARBY PIXELS INTO IDENTIFIABLE REGIONS
- REGION-LEVEL RESULTS ARE THEN ANALYZED STRUCTURALLY TO ASSOCIATE REGIONS WITH SPECIFIC TYPES OF OBJECTS AND ASSOCIATED LABELS

IN THE WFES, FORECASTER EXPERTISE IS MAINLY AT THE OBJECT LEVEL.

LOCAL ANALYSIS: OVERVIEW

LOCAL ANALYSIS DIVIDES INTO TWO BASIC TYPES:

- PHYSICALLY BASED
- SIGNAL CLASSIFICATION

PHYSICALLY BASED ANALYSIS OCCURS WHEN NEW VARIABLES ARE DERIVED LOCALLY USING "EXACT" EQUATIONS. FOR EXAMPLE, IR BRIGHTNESS RELATES DIRECTLY TO TEMPERATURE, WHICH RELATES DIRECTLY TO HEIGHT.

SIGNAL CLASSIFICATION IS STATISTICAL AND DERIVES QUALITATIVE PROPERTIES FROM RAW DATA. FOR EXAMPLE, A COMBINATION OF VISIBLE AND IR IMAGERY MAY BE USED TO CLASSIFY CLOUD TYPES.

REGION ANALYSIS: OVERVIEW

REGION ANALYSIS MAY BE PERFORMED IN THREE WAYS:

- SIMPLE CONNECTIVITY TO GROUP LIKE PIXELS INTO INDIVIDUAL REGIONS
- EDGE DETECTION TO IDENTIFY BOUNDARIES
- SPLIT-MERGE TECHNIQUES TO ELIMINATE SPURIOUS, ISOLATED PIXELS

CONNECTIVITY IS STRAIGHTFORWARD THOUGH TEDIOUS.

EDGE DETECTION IS USEFUL WHEN THE SHAPE OF A REGION IS MORE IMPORTANT THAN THE CONTENTS.

SPLIT-MERGE IS OFTEN USED AS A POST-PROCESSOR TO "SMOOTH" A FIELD PRIOR TO USING CONNECTIVITY OR EDGE DETECTION.

OBJECT ANALYSIS: OVERVIEW

OBJECT ANALYSIS INVOLVES CLASSIFYING REGIONS INTO SPECIFIC CLASSES WITH WHICH THE USER IS FAMILIAR.

EXAMPLES: CLASSIFICATION OF CLOUD TYPES
IDENTIFICATION OF GUST FRONTS

OBJECT ANALYSIS IS:

- RELATIVELY EASY WHEN THE OBJECTS CORRESPOND TO SINGLE REGIONS (ISOLATED CELL, GUST FRONT)
- MUCH MORE DIFFICULT WHEN THE "OBJECTS" ARE CLUSTERS OF DISCONNECTED REGIONS (FRONTAL ZONE, THUNDERSTORM COMPLEXES)

PATTERN RECOGNITION ISSUES

- DEPENDING ON ALGORITHM COMPLEXITY AND IMAGE SIZE, EXTREMELY LARGE AMOUNTS OF PROCESSING CAN BE REQUIRED FOR INTERACTIVE USE.
- CLASSIFICATION CAN BE DIFFICULT BECAUSE OF THE LARGE NUMBER OF POTENTIAL FEATURES FROM WHICH TO CHOOSE; ALSO, STATISTICAL DATA MUST BE AVAILABLE AND VERIFIED.
- MEASUREMENT NOISE MAY MAKE CLASSIFICATION DIFFICULT, ESPECIALLY WHEN USING RADAR IMAGERY.
- FOR TRACKING PURPOSES, THE AMOUNT OF TIME BETWEEN SATELLITE IMAGES MAY BE TOO LONG.

PATTERN RECOGNITION TECHNIQUES

PIXEL CLASSIFICATION

- THRESHOLD TESTING
- STATISTICAL CLASSIFICATION
  - BAYESIAN
  - PIECEWISE LINEAR
  - ARBITRARY NON-LINEAR

NOTE: UNCOVERING THE MOST RELEVANT FEATURES IS USUALLY MORE DIFFICULT THAN BUILDING THE CLASSIFICATION SCHEME.

EDGE DETECTION

- TEXTURE ANALYSIS
- MODEL FITTING

CONNECTIVITY ANALYSIS

- SPLIT-MERGE
- DESCRIPTOR MATCHING (CLUSTERING)
- LOW-LEVEL CORRELATION (E.G., EXTRAPOLATION OF ECHOES)
- SHAPE ANALYSIS

WFES PATTERN RECOGNITION PROBLEMS

WE HAVE IDENTIFIED FOUR TYPES OF DESIRED PATTERN RECOGNITION:

- VARIABLE-SPECIFIC
  (EXAMPLES: PRESENCE OF HAIL, CLOUD-TOP TEMPERATURE THRESHOLD)

- BOUNDARY LOCATION
  (EXAMPLES: SQUALL LINES, SEA BREEZE FRONT)

- CELL LOCATION AND TRACKING

- CELL CLUSTER IDENTIFICATION AND MONITORING

OBSERVATIONS OF VARIABLE-SPECIFIC PATTERN RECOGNITION

- SIMPLE LOGIC IS OFTEN SUFFICIENT
- COMBINE IR AND VISIBLE WHEN SATELLITE IMAGERY
- DOPPLER RADAR OFFERS A RICH SOURCE OF DATA FOR PATTERN RECOGNITION
- CLOUD MOTIONS DO NOT FIT ATMOSPHERIC WINDS VERY WELL

OBSERVATIONS ON BOUNDARY LOCATION

- SEARCHING FOR CONVERGENCE ZONES IS FEASIBLE, BUT IT WOULD REQUIRE COMBINING WITH CLOUD POSITIONS: SQUALL LINES ARE EASIER.

- DOPPLER ALGORITHMS EXIST FOR IDENTIFYING GUST FRONTS, BUR SATELLITE DATA LACKS SUFFICIENT RESOLUTION.

- FIXED-LOCATION BOUNDARIES (E.G., SEA BREEZE FRONT) ARE THE EASIEST OF ALL.

OBSERVATIONS ON CELL AND CLUSTER TRACKING

- IF IDENTIFICATION TECHNIQUES ARE GOOD, IMAGES CAN BE CROSS-CORRELATED.
- ALTERNATIVELY, ONE CAN USE POSITION AND VELOCITY TO PREDICT WHERE TO LOOK NEXT, THEN CROSS-CORRELATE AT THE PIXEL LEVEL.
- BECAUSE THE TIME SCALE OF CELLS IS ABOUT THE SAME AS THE TIME BETWEEN SATELLITE IMAGES, IT MAY BE EASIER TO TRACK CLUSTERS THAN CELLS.
- MEASUREMENT NOISE IN STANDARD RADAR IMAGERY MAKES IT VERY DIFFICULT TO USE RADAR FOR AUTOMATIC CELL TRACKING.

PATTERN RECOGNITION: REQUIRED RESOURCES

- IT IS VERY DIFFICULT TO STATE IN ADVANCE WITHOUT DOING SOME EXPERIMENTATION.
- FEASIBILITY CAN BE ASSESSED IN A FEW MONTHS, ALTHOUGH A FULLY OPERATIONAL SYSTEM MAY REQUIRE MANY MAN-YEARS OF EFFORT.
- THE QUALITY (AND REQUIRED EFFORT) OF REGION ANALYSIS IS VERY DEPENDENT ON DATA QUALITY.
- ONCE REGIONS HAVE BEEN IDENTIFIED, OBJECT-LEVEL ANALYSIS REQUIRES MUCH LESS COMPUTATIONAL HORSEPOWER, BUT IS A MORE DIFFICULT PROBLEM.

FOUR MODELS OF MAN-MACHINE COMBINATIONS FOR PATTERN RECOGNITION

1. USER INDICATES AND CLASSIFIES REGIONS OF INTEREST FROM RAW DATA. (OK FOR EXPERIMENTAL PURPOSES)

2. USER INDICATES AND CLASSIFIES REGIONS USING HEAVILY PROCESSING DATA. (MIDDS, PROFS DO SOME OF THIS ALREADY)

3. MACHINE INDICATES REGIONS DIRECTLY, WITH ASSOCIATED PARAMETERS, AND USER VERIFIES AND/OR ADJUSTS. (THIS IS WHAT IS CURRENTLY MOST DESIRED BY MESOSCALE FORECASTING COMMUNITY.)

4. FULLY AUTOMATIC.

PATTERN RECOGNITION AND WFES PROTOTYPE

WE RECOMMEND MAN-MACHINE MODEL #2 BE USED IN THE WFES PROTOTYPE FOR THE FOLLOWING REASONS:

- THE HIGH-LEVEL LOGIC OF THE WFES PROTOTYPE CAN BE USED TO PINPOINT WHERE PATTERN RECOGNITION ALGORITHMS SHOULD BE DEVELOPED.
- FORECASTER EXPERTISE LIES IN THE CLASSIFICATION AND INTERACTION OF REGIONS, NOT THEIR DETECTION.
- REGION-LEVEL PROCESSING ULTIMATELY CAN BE PERFORMED BY THE OBSERVER, THUS FREEING THE FORECASTER FROM WHAT COULD OTHERWISE BE ROUTINE DRUDGERY.

APPENDIX 5

TASK 5

DATA SYSTEMS AND TOOLS

TASK 5: DATA SYSTEMS AND TOOLS
WFES DATA SOURCES

IT WAS RECOGNIZED FROM THE OUTSET OF THIS PROJECT THAT EFFICIENT ACCESS TO CLFF'S DATA SOURCES WAS A CRITICAL NEED FOR THE SUCCESSFUL CONSTRUCTION OF AN EXPERT SYSTEM.

AN ANALYSIS WAS THEREFORE PERFORMED TO DETERMINE WHICH WORKSTATION TECHNOLOGY WAS PREFERABLE FOR USE IN THE WFES.

IT WAS FOUND THAT IN THE NEAR TERM, THERE ARE ONLY TWO REALISTIC ALTERNATIVES:

- THE McIDAS SYSTEM FROM THE UNIVERSITY OF WISCONISN, WHICH FORMS THE BASIS OF THE CURRENT MIDDS SYSTEM;
- THE PROFS SOFTWARE DEVELOPED AT THE ENVIRONMENTAL RESEARCH LABORATORY (ERL) IN BOULDER, ESPECIALLY THE PROFS OPERATIONAL WORKSTATION (POWS).

BOTH SYSTEMS HAVE THEIR OWN ADVANTAGES AND DISADVANTAGES.

Task 5: Data Systems and Tools
Comparison of POWS and MIDDS

	POWS	MIDDS
Data Base	✓	
Display	✓	
Ease of Use	✓	
Standardization	✓	
Extensibility	✓	
Hardware	✓	
Networking	✓	
Operational Experience	✓	
Software Support	✓	
Programmability		✓
Data Analysis		✓
Availability		✓
Cost (from scratch)	✓	
Cost to NASA/KSC		✓

✓ = preferred

TASK 5: DATA SYSTEMS AND TOOLS
POWS VS. MIDDS: CONCLUSIONS

IF MIDDS WAS NOT INSTALLED AT CCFF AND POWS WAS ALREADY AVAILABLE, THEN POWS WOULD BE THE PREFERABLE OPTION.

THE POWS SYSTEM WILL NOT BE AVAILABLE UNTIL AFTER 1987; THIS ALONE MAKES IT UNSUITABLE FOR THE WFES.

THE EXTRA COST OF INSTALLING A POWS AT CCFF IS LARGE, PROBABLY OVER $500K.

MIDDS IS DEFINITELY THE PREFERRED OPTION IN THE NEAR TERM, THOUGH NOT NECESSARILY IN THE LONG TERM.

IT IS POSSIBLE TO DESIGN THE WFES SO THAT IT CAN BE TRANSFERRED TO A POWS AT A LATER DATE, IF THAT IS DESIRABLE.

TASK 5: DATA SYSTEMS AND TOOLS
OVERVIEW

THE CCFF IS AS WELL-EQUIPPED FOR NOWCASTING AS ANY OTHER FORECASTING FACILITY IN THE WORLD. IT IS PARTICULARLY WELL-EQUIPPED FOR SHORT-RANGE THUNDERSTORM FORECASTING:

- REGIONAL SATELLITE IMAGERY AT FREQUENT INTERVALS
- LOCAL VERTICAL SOUNDINGS
- MESOSCALE WIND NETWORK
- LAUNCH TOWER WINDS AND TEMPERATURES
- LIGHTNING MONITORS: LLP, A.D. LITTLES
- FIELD MILL NETWORK
- MIDDS
- RADAR
- VOLUMETRIC RADAR (PLANNED)
- DOPPLER RADAR (PLANNED?)
- LFM
- FAX

TASK 5: DATA SYSTEMS AND TOOLS STATUS

- THE BASIC PROBLEM AT CCFF IS THAT FORECASTERS HAVE NOT YET LEARNED HOW TO USE AND INTERPRET THE DATA SOURCES WHICH ARE AVAILABLE TO THEM.

- THE NEED FOR SIMULTANEOUS USE AND INTERPRETATION OF THOSE DATA SOURCES MAKES THE PROBLEM MORE ACUTE.

- THE CURRENT SITUATION IS THROUGH NO PARTICULAR FAULT OF THE AIR FORCE

  - MANY OF CCFF'S DATA SOURCES ARE STILL EXPERIMENTAL

  - VERY FEW PEOPLE ARE EXPERIENCED IN USING AND INTERPRETING CCFF'S DATA SOURCES

  - EVEN FEWER PEOPLE ARE EXPERIENCED IN THE OPERATIONAL USE OF <u>ALL</u> OF CCFF'S DATA SOURCES

TASK 5: DATA SYSTEMS AND TOOLS ASSESSMENT

A SERIOUS NEED EXISTS FOR A FACILITY WHICH ALLOWS THE FORECASTER TO MAKE OPERATIONAL USE OF THE AVAILABLE DATA IN AN INTEGRATED WAY.

THE COMPLETION OF MIDDS WILL SOLVE PART OF THE PROBLEM BY BRINGING TOGETHER ALL DATA SOURCES INTO A SINGLE LOCATION, BUT DIFFICULTIES WILL REMAIN:

- IT WILL BE IMPOSSIBLE TO HAVE A SIMULTANEOUS VIEW OF SYNOPTIC-SCALE, MESOSCALE AND MICROSCALE CONDITIONS;
- SIMPLY OVERLAYING MULTIPLE DATA ONTO A SINGLE MAP WILL NOT HELP MUCH, SINCE THERE HAS BEEN LITTLE OPERATIONAL EXPERIENCE WITH SUCH OVERLAYS;
- EXOTIC, UNFAMILIAR DATA SOURCES (SUCH AS DOPPLER RADAR AND WATER VAPOR IMAGERY) WILL STILL BE EXOTIC AND UNFAMILIAR.

AN AI-BASED SYSTEM CAN HELP IN CAPTURING EXPERIENCE GAINED THROUGH THE USE OF UNFAMILIAR DATA SOURCES, AND MAKING THAT EXPERTISE AVAILABLE TO THE ENTIRE FORECASTING STAFF.

WFES DEVELOPMENT OPTIONS
HARDWARE

CONSIDERING HARDWARE COSTS ALONE, THE FOLLOWING ALTERNATIVES GO FROM THE LEAST TO THE MOST EXPENSIVE:

- IBM MAINFRAME (MIDDS HOST)
- PERSONAL COMPUTER
- XEROX 1186 LISP MACHINE
  - PC GRAPHICS MONITOR
  - XEROX GRAPHICS MONITOR
- SYMBOLICS 3600 LISP MACHINE
  - PC GRAPHICS MONITOR
  - SYMBOLICS COLOR MONITOR

WFES DEVELOPMENT OPTIONS
SOFTWARE ENVIRONMENT

THE WFES ENVIRONMENT IS THAT SET OF AI-BASED PROGRAMMING TOOLS WHICH DEFINE THE ALLOWABLE DATA STRUCTURES AND INFERENCING SCHEMES TO BE USED IN THE WFES.

THE GENERAL FUNCTION OF AN AI-BASED ENVIRONMENT IS TO ALLOW THE PROGRAMMER (AND ULTIMATELY THE USER) TO COMMUNICATE WITH THE COMPUTER AT A HIGH LEVEL OF ABSTRACTION.

FOUR CHOICES FOR THE WFES ENVIRONMENT WERE SERIOUSLY CONSIDERED:

- ART FROM INFERENCE CORPORATION;
- KEE FROM INTELLICORP;
- KNOWLEDGE CRAFT FROM CARNEGIE GROUP;
- A SPECIALIZED, WFES-SPECIFIC ENVIRONMENT USING A COMBINATION OF LISP AND PROLOG.

WFES DEVELOPMENT OPTIONS
SOFTWARE ENVIRONMENT

THE DESIGN OF THE WFES DOES NOT CORRESPOND EXACTLY TO ANY OF THE KNOWLEDGE REPRESENTATION SCHEMES USED IN THE COMMERICALLY-AVAILABLE SOFTWARE PACKAGES.

ALL OF THE COMMERCIAL PACKAGES WOULD HAVE TO BE CONSIDERABLY EXTENDED WITH CUSTOMIZED "WRAPPERS," BUT ALSO HAVE A NUMBER OF USEFUL FEATURES. THEY SHARE THE FOLLOWING ADVANTAGES:

- FASTER PROGRAMMING, ESPECIALLY IN THE BEGINNING;
- EXTENSIVE DOCUMENTATION;
- SOFTWARE SUPPORT;
- FUTURE PRODUCT EXTENSION;
- FUTURE CAPABILITY TO TRANSFER TO A CONVENTIONAL COMPUTER (ART , KEE).

A SPECIALIZED ENVIRONMENT WOULD BE LARGELY DEFINED BEFORE SIGNIFICANT PROGRAMMING BEGAN, AND WOULD BE CAREFULLY TAILORED TO THE WFES' NEEDS. IT HAS THE FOLLOWING ADVANTAGES:

- FASTER EXECUTION SPEED, PERHAPS MUCH FASTER;
- GREATER FLEXIBILITY; AND
- SIMPLER DESIGN.

WFES Development Options
Hardware vs. Software

	Hardware Cost	Available Software				
		Lisp	Prolog	ART	KEE	Knowledge Craft
Computer: Xerox 1186 Symbolics 3600	 $25K $80K	 ✓ ✓	 ✓	 ✓	 ✓ ✓	 ✓
Software Cost		0	$10K	$25K	$25K	$25K

Assuming a NASA-wide license (approx.)

AI HARDWARE AND SOFTWARE ISSUES: DEVELOPMENT

- THE MAJOR COST OF ANY KBS IS FOR PERSONNEL
- DIFFERENT CRITERIA APPLY TO SELECTING A DEVELOPMENT ENVIRONMENT VERSUS A DELIVERY ENVIRONMENT
- SPECIALIZED LISP MACHINES WERE DESIGNED TO OPTIMALLY SUPPORT AI DEVELOPMENT WORK
- NASA AND ADL ALREADY OWN SYMBOLICS 3600S
- NASA ALREADY OWNS ART LICENSES

AI HARDWARE AND SOFTWARE ISSUES: DELIVERY

- SELECTION OF A DELIVERY ENVIRONMENT SHOULD BE POSTPONED UNTIL KBS REQUIREMENTS ARE UNDERSTOOD
- CURRENT TRENDS IN COMPUTER SCIENCE SUPPORT POSTPONING CHOICE OF DELIVERY ENVIRONMENT:
  - SIGNIFICANTLY REDUCED COSTS OF AI DELIVERY ENVIRONMENTS
  - INCREASING NUMBERS OF ARCHITECTURES FOR INTEGRATING AI AND CONVENTIONAL HARDWARE
  - GREATER EASE IN PORTING AI SOFTWARE

WFES DEVELOPMENT OPTION
USER INTERFACE

IT IS IMPERATIVE THAT THE WFES PROVIDE THE USER WITH A HIGHLY INTERACTIVE ENVIRONMENT FOR ASSESSING TODAY'S WEATHER CONDITIONS.

WE HAVE ASSUMED THAT MIDDS IS THE ONLY SOURCE OF DATA FOR THE WFES.

THE FOLLOWING INTERFACE OPTIONS, THEREFORE, CONCENTRATE ON THE POSSIBLE MIDDS-WFES CONNECTIONS AND THEIR RESULTANT IMPLICATIONS FOR THE USER INTERFACE.

MIDDS ROLE

MULTIPLE COPROCESSING:

ALL FUTURE OPERATIONAL FORECASTING SYSTEMS WILL HAVE MULTIPLE COPROCESSOR ARCHITECTURES.

DIFFERENT PROCESSING ALGORITHMS:

THIS STEMS FROM FUNDAMENTAL DIFFERENCES IN INFORMATION PROCESSING REQUIREMENTS AT DIFFERENT NODES IN THE SYSTEM.

DATA DISPLAY SYSTEM ESSENTIAL:

MIDDS IS THE ONLY CURRENTLY OPERATIONAL DATA DISPLAY AND ANALYSIS SYSTEM.

WFES REQUIRES MIDDS:

THE WFES WILL REQUIRE A SYSTEM LIKE MIDDS, BUT ITS ARCHITECTURE IS NOT DEPENDENT UPON MIDDS PER SE.

MIDDS ARCHITECTURE:

THE MIDDS IBM AI ARCHITECTURE IS OPEN ENOUGH TO PERMIT A WIDE RANGE OF COUPLING OPTIONS.

WFES COUPLING TO MIDDS

NO DIRECT COUPLING:

KEYBOARD ENTRY FOR DATA INTO WFES.

DIGIPAD ENTRY OF IMAGES INTO WFES.

SERIAL LINK FOR COMMANDS:

AI-BASED USER INTERFACE ON WFES.

BACKEND MIDDS COMMAND GENERATOR WITHIN WFES.

MIDDS IBM AI I/O DRIVER.

ETHERNET LINK FOR NONIMAGE DATA:

ETHERNET CARD AND SOFTWARE FOR MIDDS IBM AI WORKSTATION.

NETWORK DRIVER SOFTWARE ON WFES.

ETHERNET LINK FOR IMAGE DATA:

ETHERNET CARD AND SOFTWARE FOR MIDDS IBM AI WORKSTATION.

WFES NETWORK DRIVER SOFTWARE PATCH.

COLOR GRAPHICS DISPLAY PACKAGE FOR WFES (HARDWARE & SOFTWARE).

DIRECT USE INTERACTION WITH MIDDS IMAGE DATA DISPLAY:

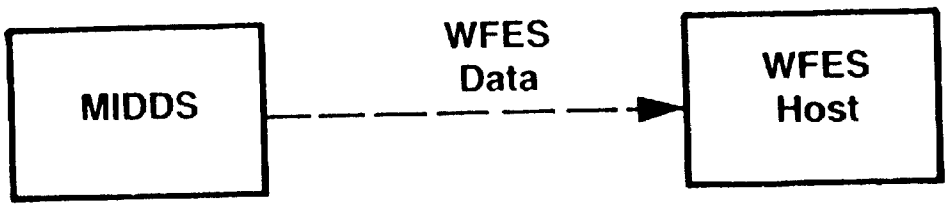
MAJOR EXPANSION OF MIDDS IBM AI I/O DRIVERS.

INCORPORATE MOUSE TO DATA MAPPING PROCESSES ON AI.

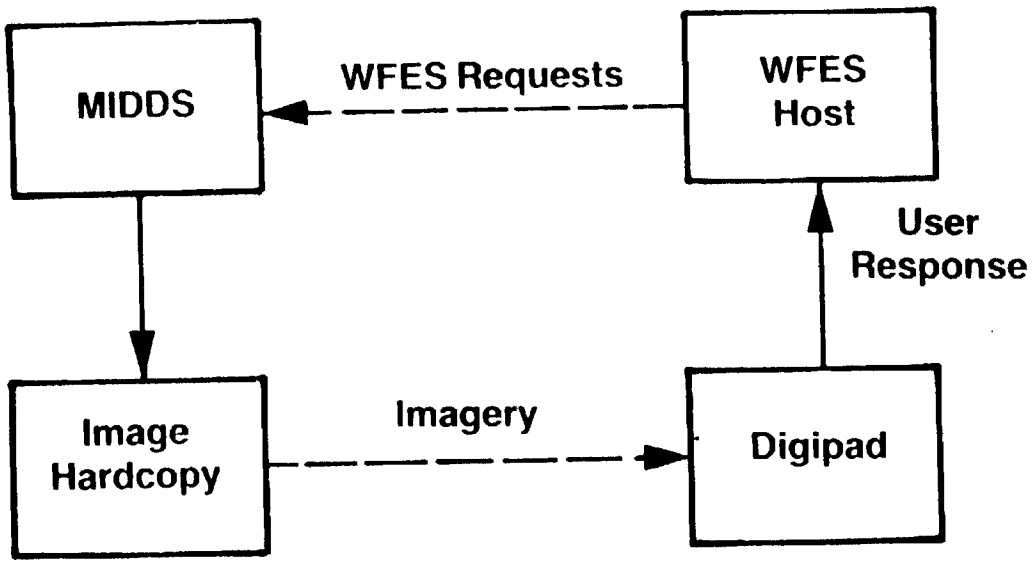
DIRECT USER INTERACTION WITH WFES IMAGE DATA DISPLAY:

PART OF COLOR GRAPHICS DISPLAY PACKAGE FOR WFES.

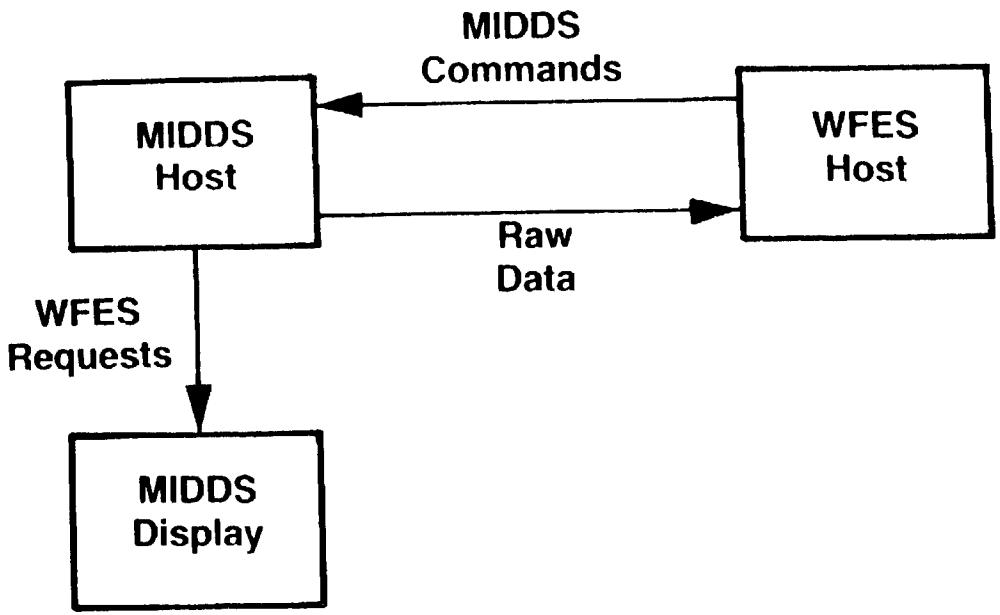
WFES Development Options
User Interface (Continued)



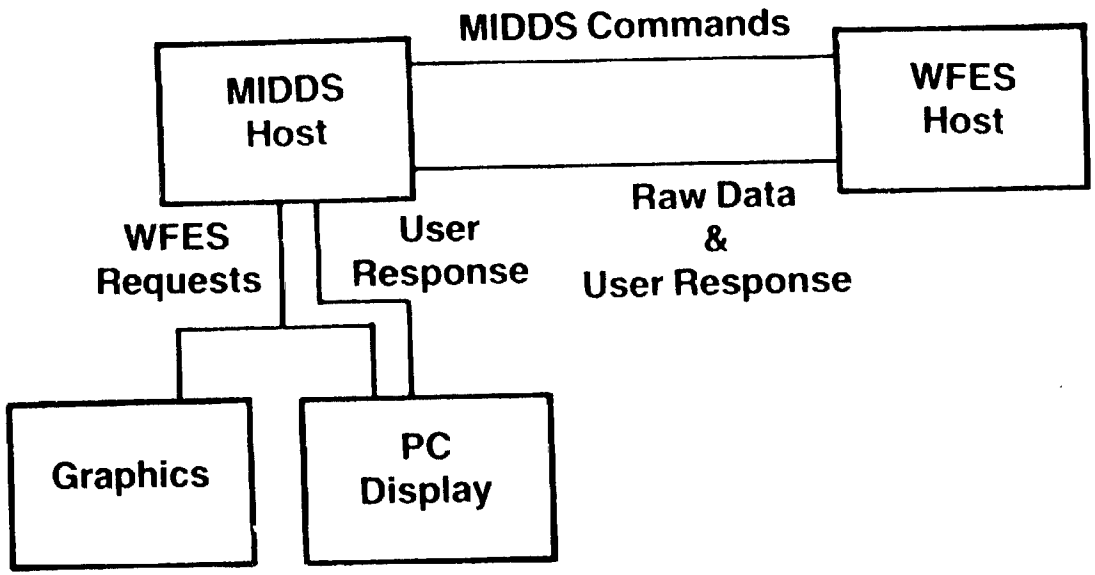
WFES Development Options
User Interface (Continued)



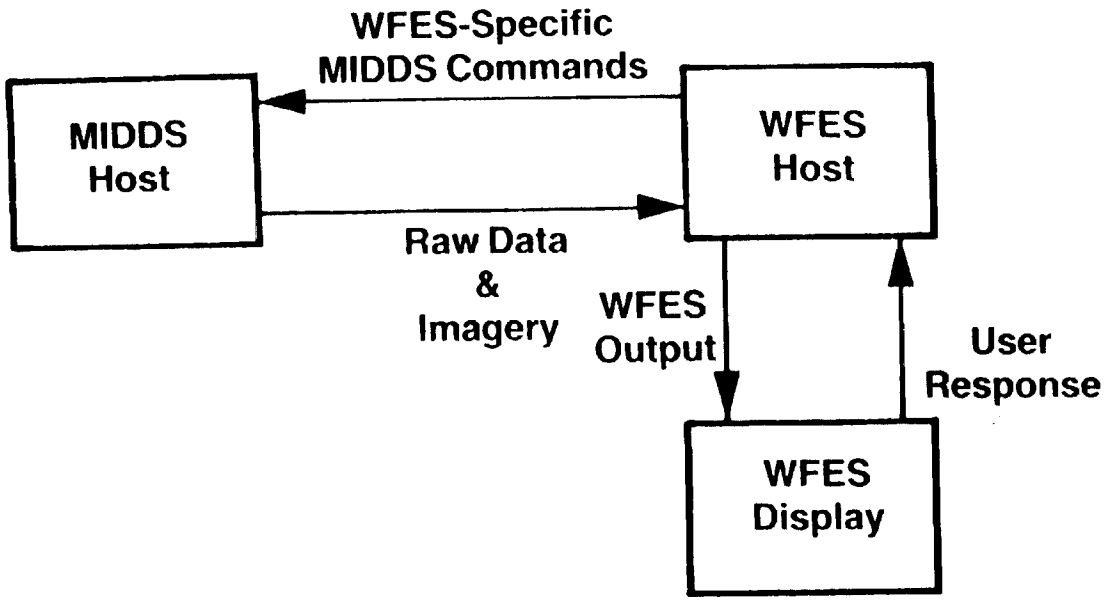
WFES Development Options
User Interface (Continued)



WFES Development Options
User Interface



WFES Development Options
User Interface (Continued)



CHOICE OF DEGREE OF COUPLING

STAGE OF DEVELOPMENT CYCLE:

FIRST STAGE WILL NOT REQUIRE A DIRECT COUPLING.

THE SERIAL LINK SHOULD BE BUILT AS SOON AS POSSIBLE, BUT REQUIRES MIDDS TO BE ADJACENT WFES.

THE ADDITION OF THE COLOR GRAPHICS SYSTEM:

GREATLY ENHANCES THE LIKELY SUCCESS OF WFES

WILL BE ESSENTIAL FOR AN OPERATION TEST OF THE WFES

ENHANCES INDEPENDENCE FROM MIDDS

LEVEL OF FUNDING:

THE SERIAL LINK SHOULD BE IMPLEMENTED INDEPENDENT OF FUNDING LEVEL.

THE ETHERNET LINK IS PROBABLY NOT WORTH IMPLEMENTING WITHOUT THE COLOR GRAPHICS SYSTEM.

THE COLOR GRAPHICS SYSTEM IS THE MOST EXPENSIVE LEVEL OF COUPLING, BUT WOULD ADD ENTIRELY NEW DIMENSIONS TO THE WFES CAPABILITIES.

WFES DEVELOPMENT OPTIONS
OVERVIEW

A WIDE RANGE OF DEVELOPMENT OPTIONS EXISTS FOR THE WFES PROTOTYPE.

THESE OPTIONS MAY BE DIVIDED INTO THREE MAIN CATEGORIES.

- FUNCTIONALITY
- HARDWARE
- USER INTERFACE

WFES DEVELOPMENT OPTIONS
FUNCTIONALITY

GOING FROM THE SIMPLE TO THE COMPLEX, THE FOLLOWING WFES FUNCTIONS WERE EXPLORED:

- AUTOMATED FORECASTING WORKSHEET
- ALARM MONITORS FOR SPECIFIC PHENOMENA SUCH AS:
  - MET WATCH
  - FOG
  - THUNDERSTORM ACTIVITY
  - FRONTAL MOVEMENT
- A GOAL-DRIVEN FACILITY FOR ANSWERING SPECIFIC QUERIES ABOUT TODAY'S WEATHER CONDITIONS, BACKED BY A RATHER DETAILED, PHYSICALLY-BASED MODEL.
- SCENARIO-BASED DETECTION, MONITORING AND ANTICIPATION OF "INTERESTING" WEATHER EVENTS.

APPENDIX 6

TASK 6

PROTOTYPE WEATHER FORECASTING EXPERT SYSTEM

WFES OPERATION

THE WFES WILL BE A HIGHLY INTERACTIVE SYSTEM THAT STRESSES THE SYMBOLIC REPRESENTATION OF TODAY'S WEATHER EVENTS. WFES OPERATION WILL HAVE THE FOLLOWING CHARACTERISTICS:

- IT WILL OPERATE ON A 24-HOUR CYCLE, AND WILL BE INITIALIZED EARLY IN THE MORNING OF EACH DAY.
- AS THE DAY PROGRESSES, THE SYSTEM'S ATTENTION WILL FOCUS ON PHENOMENA WITH PROGRESSIVELY FINER TEMPORAL AND SPATIAL SCALES.
- SYNOPTIC, MESOSCALE AND MICROSCALE SCENARIOS WILL BE LINKED TOGETHER TO FORM COHERENT STORIES.
- MULTIPLE SCENARIOS WILL BE CONSIDERED SIMULTANEOUSLY
- THE FOCUS WILL BE ON HELPING THE FORECASTER ANTICIPATE SIGNIFICANT PHENOMENA UP TO SEVERAL HOURS AHEAD.
- IT WILL <u>NOT</u> AUTOMATICALLY GENERATE FORECASTS.

DEFINITIONS OF EVALUATION TERMS

"LOW" - FORECASTING: THE POINT-OF-REFERENCE IS A NEW DUTY FORECASTER.

AI TECHNOLOGY: OTHER COMPUTER SCIENCE TECHNOLOGIES PROBABLY COULD BE USED AS WELL.

NASA: PROJECT DOES NOT DIRECTLY ADDRESS KEY PROBLEMS, BUT MAY HAVE VALUE.

LEVEL OF EFFORT: ONE-PERSON YEAR.

"HIGH" - FORECASTING: EQUIVALENT TO MOST EXPERT FORECASTER.

AI TECHNOLOGY: MOST ADVANCED COMMERCIALLY VIABLE AI TECHNOLOGY.

NASA: DIRECTLY ADDRESSES KEY PROBLEM.

LEVEL OF EFFORT: SIX-PERSON YEARS.

POTENTIAL WFES FUNCTIONS

	LEVEL OF EXPERTISE	COFF EXPERIENCE	AI REQUIRED	NASA BENEFITS	IMPLEMENTATION EFFORT
METWATCH/ADVISORIES	L	L/M	L	L	L
AUTOMATED WORKSHEET	L	L	L	L	L
EQUIPMENT-SPECIFIC:					
PATTERN ID	M	M/H	VH	L/H	VH
PATTERN INTERPRETATION	M	M/H	MH	M	M
ALARM MONITORING	L	L	L/M	L/M	L/M
NASA STS REQUIREMENTS	M	M	L/M	L/M	M
SCENARIO-BASED SYSTEM:					
PREDEFINED	M	H	H	M/H	M
SELF-MODIFYING	H	H	H	H	H
INTERPRETING MODELS	H	H	H	H	VH

L = LOW
M = MEDIUM
H = HIGH
V = VERY HIGH

METWATCH ADVISORIES

LEVEL OF EXPERTISE: LOW: ROUTINE PART OF GENERAL METEOROLOGICAL TRAINING FOR AF FORECASTERS.

CCFF EXPERIENCE: LOW TO MODERATE: CCFF UNIQUE FEATURES LEARNED VERY QUICKLY AS PART OF ON-THE-JOB TRAINING.

AI REQUIRED: LOW: DEPENDING UPON IMPLEMENTATION AUTOMATION COULD BE ACCOMPLISHED WITH TRADITIONAL DATABASE/FORMS GENERATOR METHODS.

NASA BENEFITS: LOW: WOULD AID IN DISSEMINATION OF INFORMATION, BUT WOULD NOT DIRECTLY ADDRESS KEY PROBLEMS.

LEVEL OF EFFORT: LOW.

AUTOMATED FORECAST WORKSHEET

LEVEL OF EXPERTISE: LOW: ONE OF FIRST POINT OF TRAINING FOR NEW FORECASTERS.

CCFF EXPERIENCE: LOW: IBID.

AI REQUIRED: LOW: PRIMARY TECHNIQUE WOULD BE DATABASE/ FORMS GENERATION: AI COULD BE USED TO PROVIDE ERROR DETECTION AND TO DYNAMICALLY CHANGE INPUT FORMS DEPENDING UPON VALUES INPUT TO SHEET.

NASA BENEFITS: LOW: MARGINAL IMPROVEMENT ABOVE PAPER AND PENCIL VERSION, UNLESS EXTENDED TO COMPLEX PATTERN CHECKING.

LEVEL OF EFFORT: LOW: LEVEL OF EFFORT WOULD INCREASE IN PROPORTION TO AI CONTENT.

EQUIPMENT SPECIFIC: PATTERN IDENTIFICATION

LEVEL OF EXPERTISE: MEDIUM; DEPENDS UPON DATA SYSTEM AND WHETHER SYSTEM IS WIDELY USED IN AF OR IS NASA SPECIFIC; ALSO DEPENDS UPON SUBTLENESS OF PATTERN.

CCFF EXPERIENCE: MEDIUM TO HIGH; IBID.

AI REQUIRED: SEE DISCUSSION OF "PATTERN RECOGNITION."

NASA BENEFITS: LOW OR HIGH; AUTOMATIC RECOGNITION OF COMPLEX PATTERNS WOULD DIRECTLY RELATE TO PROBLEM OF INFORMATION OVERLOAD; GIVEN ENOUGH STAFF, HUMANS PRESENTLY ARE VERY FACILE AT PATTERN RECOGNITION.

LEVEL OF EFFORT: VERY HIGH; LOW TO ASSESS FEASIBILITY; VERY HIGH TO MAKE OPERATIONAL.

GENERAL COMMENTS: FOR THE NEWER DATA SYSTEMS AT KSC, SIGNIFICANT PATTERNS ARE JUST BEING IDENTIFIED (E.G., LIGHTNING SYSTEMS AND WINDS); MOST DUTY FORECASTERS ARE EXPERT ON ONE SYSTEM; NO ONE IS EXPERT ON ALL SYSTEMS; IDENTIFICATION OF MANY METEOROLOGICAL "FEATURES" (E.G., A "CELL") REQUIRES INPUT FROM SEVERAL DATA SYSTEM.

EQUIPMENT SPECIFIC: PATTERN INTERPRETATION

LEVEL OF EXPERTISE: MEDIUM; VARIES WITH DATA SYSTEM AND THE IMPORTANCE OF PATTERN TO CURRENT WEATHER SCENARIO.

LCFF EXPERIENCE: MEDIUM TO HIGH; IBID; LIMITED EXPERTISE EXISTS FOR NEWER SYSTEMS.

AI REQUIRED: MEDIUM TO HIGH; VARIES WITH COMPLEXITY OF PATTERN (E.G., TOWER DATA VERSUS SATELLITE IMAGES); SEE DISCUSSION OF "PATTERN RECOGNITION."

NASA BENEFITS: MEDIUM; IMPROVING INTERPRETATION OF PATTERNS ON SINGLE DATA SYSTEMS NOT AS IMPORTANT TO KEY PROBLEMS AS INTERPRETATION OF PATTERNS ACROSS DATA SYSTEMS.

LEVEL OF EFFORT: MEDIUM FOR EACH COMPLEX PATTERN; LOW FOR SOME (E.G., TOWER SENSOR ARRAY).

GENERAL COMMENTS: THERE ARE MANY DIFFERENT LEVELS OF MEANING ATTACHED TO "INTERPRETATION" OF PATTERNS; INFORMATION OVERLOAD OFTEN STEMS FROM NOT KNOWING WHICH PATTERNS TO LOOK FOR, WITH THE ALTERNATIVE THEN BEING TO LOOK FOR ANY POSSIBLE PATTERN.

ALARM MONITORING

LEVEL OF EXPERTISE: LOW: ASSUMES PERSON MONITORING ONLY FOR PRESENCE OF PATTERN OR CHANGE IN PATTERN.

CCFF EXPERIENCE: LOW: ASSUMES PATTERN HAS BEEN IDENTIFIED BY EXPERT AS BEING IMPORTANT.

AI REQUIRED: LOW TO MEDIUM: ASSUMES A PATTERN FOR MONITORING HAS BEEN CHOSEN HAS CHARACTERISTICS WHICH CAN BE AUTOMATICALLY IDENTIFIED: REPRESENTATION AND REASONING ABOUT TIME WILL MAKE THIS A DIFFICULT PROBLEM ON SOME DATA SYSTEMS.

NASA BENEFITS: LOW TO MEDIUM: AUTOMATING A SINGLE ALARM SYSTEM PROBABLY HAS ONLY LIMITED IMPACT ON KEY PROBLEMS.

LEVEL OF EFFORT: LOW TO MEDIUM: DEPENDS ON PARTICULAR SET OF DATA SYSTEMS AND COMPLEXITY OF PATTERN.

GENERAL COMMENTS: MONITORING SYSTEM FOR COMPLEX PATTERNS CONVERGES TO SCENARIO SYSTEM.

NASA STS REQUIREMENTS

LEVEL OF EXPERTISE: MEDIUM; REQUIRES FORECASTER TO HAVE INTEREST BEYOND METEOROLOGY.

CCFF EXPERIENCE: MEDIUM; STAFF METS TAKE MONTHS TO LEARN ALL OF THE PARTICULARS; A YEAR TO BE EXPERT.

AI REQUIRED: LOW TO MEDIUM; DEPENDS UPON COMPLEXITY OF IMPLEMENTATION DETAILS SUCH AS KNOWLEDGE REPRESENTATION SCHEME AND THE NUMBER OF OPERATIONAL CONSTRAINTS INCLUDED.

NASA BENEFITS: LOW TO MEDIUM; AUTOMATING STS LAUNCH AND LAND REQUIREMENTS HAS LOW BENEFIT UNDER PRESENT CONDITIONS; COULD BE MEDIUM WITH INCREASING FREQUENCY OF LAUNCH, OR INCLUSION OF MOST OPERATIONAL CONSTRAINTS.

LEVEL OF EFFORT: MEDIUM; AUTOMATING JUST LAUNCH AND LANDING REQUIREMENTS IS A SUBSTANTIAL PROJECT.

GENERAL COMMENTS: INFORMATION ABOUT WEATHER-SENSITIVE GROUND OPERATIONS IS WIDELY DISPERSED ACROSS NASA PERSONNEL; GATHERING THAT INFORMATION WOULD BE A MAJOR PIECE OF WORK AND BENEFICIAL IN AND OF ITSELF; WOULD GREATLY IMPROVE COMMUNICATION BETWEEN NASA AND CCFF.

SCENARIO-BASED SYSTEM: PREDEFINED SCENARIOS

LEVEL OF EXPERTISE: MEDIUM; ONCE DELINEATED, DUTY FORECASTERS SHOULD BE ABLE TO UTILIZE THEM.

CCFF EXPERIENCE: HIGH; THE IDENTIFICATION OF SCENARIOS IS HEAVILY DEPENDENT UPON LENGTH OF EXPERIENCE AT CCFF.

AI REQUIRED: HIGH; PROBABLY THE ONLY APPROPRIATE TECHNOLOGY FOR CAPTURING AND PROGRAMMING SCENARIOS.

NASA BENEFITS: MEDIUM TO HIGH; DEPENDS UPON THE SUCCESS OF ELICITING AND REPRESENTING IMPORTANT SCENARIOS FROM IDENTIFIED EXPERTS; PROJECT DIRECTLY ADDRESSES BOTH ACCUMULATION OF EXPERTISE AND INFORMATION OVERLOAD PROBLEMS.

LEVEL OF EFFORT: MEDIUM; THE PRIMARY PURPOSE SHOULD BE TO EVALUATE THE VALIDITY OF USING SCENARIOS TO CAPTURE THE NATURE OF FORECASTING EXPERTISE AT CCFF.

GENERAL COMMENTS: THIS PROJECT DEFINES ONE END OF A CONTINUUM OF PROJECTS THAT COULD BE DONE; IT REPRESENTS THE MINIMUM PROJECT TO EVALUATE TECHNICAL FEASIBILITY OF USING SCENARIOS TO CAPTURE FORECASTING EXPERTISE AT NASA.

SCENARIO-BASED SYSTEM: SELF-MODIFYING SCENARIOS

LEVEL OF EXPERTISE:	HIGH; ASSUMES CONSIDERABLE FLEXIBILITY IN THINKING ABOUT FORECASTING WEATHER EVENTS.
CCFF EXPERIENCE:	HIGH; THE GENERATION AND MODIFICATION OF SCENARIOS IN REAL-TIME IS ONE OF THE IDENTIFYING SKILLS OF AN EXPERT FORECASTER AT CCFF.
AI REQUIRED:	HIGH; ELEMENTS OF EVERY KNOWLEDGE REPRESENTATION SCHEME PRESENTLY IN GENERAL USE WOULD BE REQUIRED FOR THIS SYSTEM, PLUS THE JUDICIOUS USE OF EMERGING TECHNIQUES.
NASA BENEFITS:	HIGH; PROJECT WOULD DIRECTLY HELP SOLVE NASA KSC'S TWO KEY PROBLEMS.
LEVEL OF EFFORT:	HIGH; THIS PROJECT WAS THE ONE PROPOSED AT OUR FIRST ORAL PRESENTATION.
GENERAL COMMENTS:	THE PROJECT DEPENDS ONLY UPON PROVEN AI TECHNIQUES; ITS COMPLEXITY STEMS FROM THE NUMBER OF TECHNIQUES WHICH WOULD BE COMBINED; THE INCORPORATION OF QUALITATIVE PHYSICS INTO THE SYSTEM AS THE BASIS FOR SELF-MODIFICATION WOULD BE THE MOST ADVANCED TECHNIQUE USED, WHICH HAS BEEN USED TO DATE ONLY IN A FEW R&D PROJECTS.

INTERPRETING MESOSCALE MODELS

LEVEL OF EXPERTISE:	HIGH; REQUIRES BOTH ADVANCED EDUCATION AND SIGNIFICANT EXPERIENCE.
CCFF EXPERIENCE:	HIGH; MODELS WOULD HAVE TO BE SPECIFIC TO CCFF CLIMATOLOGY TO BE USEFUL.
AI REQUIRED:	HIGH; MIXTURE OF MATHEMATICAL AND SYMBOLIC REASONING PLACES PROJECT IN R&D CATEGORY.
NASA BENEFITS:	HIGH; IF SUCCESSFUL, PROJECT COULD PROVIDE SPECIFIC, DETAILED FORECASTS.
LEVEL OF EFFORT:	VERY HIGH; PROBABLY PROHIBITIVE, GIVEN R&D NATURE OF BOTH THE DEVELOPMENT OF MESOSCALE MODEL AND APPROPRIATE AI TECHNIQUES.
GENERAL COMMENTS:	PROJECT INCLUDED BECAUSE IT REPRESENTS THE MOS IDEAL APPROACH CONCEIVABLE AT THIS POINT IN TIME, IF IT WERE FEASIBLE.

WFES PROTOTYPE
SYSTEM DESIGN

FUNCTIONS

- ASSIST THE FORECASTER IN ANTICIPATING SIGNIFICANT WEATHER EVENTS WHICH RELATE TO THUNDERSTORM FORMATION.
- CAPTURE FORECASTER KNOWLEDGE OF PARTICULAR WEATHER SCENARIOS FOR LATER USE.
- PROVIDE A COMMON FACILITY FOR FORECASTER-TO-FORECASTER COMMUNICATION.
- ALLOW A FORECASTER TO MAINTAIN A CONTINUOUS TRAIN OF THOUGHT, DESPITE FREQUENT INTERRUPTIONS.

WFES PROTOTYPE
SYSTEM DESIGN

BENEFITS

- PROVIDE MORE CONSISTENT SHORT-RANGE THUNDERSTORM FORECASTING.
- BRING INEXPERIENCED FORECASTERS "UP TO SPEED" MUCH MORE QUICKLY.
- REDUCE THE CONSTANT LOSS OF FORECASTING EXPERTISE THROUGH FORECASTER ROTATION.
- CAPTURE AND USE FORECASTER EXPERTISE IN A WAY WHICH DIRECTLY PARALLELS THE FORECASTING PROCESS.

WFES PROTOTYPE
SYSTEM DESIGN

DATA STRUCTURES

THE DATA STRUCTURES USED IN THE WFES WILL DRIVE THE LOGIC WHICH IS NEEDED TO MANIPULATE THOSE STRUCTURES. THE PRIMARY DATA STRUCTURES ARE:

- FEATURE - AN INDIVIDUAL WEATHER ENTITY, USUALLY ASSOCIATED WITH A SMALL SET OF METEOROLOGICAL OBSERVATIONS.
- EVENT - A QUALITATIVE CHANGE IN A FEATURE OR SET OF FEATURES.
- SCENARIO - A SEQUENCE OF EVENTS WHICH CORRESPONDS TO AN IDENTIFIABLE TYPE OF WEATHER BEHAVIOR.

WFES KNOWLEDGE: SCENARIOS

SCENARIOS WILL BE:

- THE FUNDAMENTAL SOURCE OF THE WFES' FORECASTING EXPERTISE
- THE DRIVING FORCE BEHIND THE REST OF THE WFES ARCHITECTURE
- BASED UPON GENERIC, RATHER THAN HISTORIC, DAYS
- SYMBOLIC "SKETCHES" WHICH CORRESPOND AS CLOSELY AS POSSIBLE TO STORIES TOLD BY ONE FORECASTER TO ANOTHER FORECASTER
- SPLIT INTO THREE DISTANCE SCALES:
  - SYNOPTIC;
  - MESOSCALE;
  - MICROSCALE.

  COMBINATIONS AT MULTIPLE SCALES WILL BE ALLOWED.
- ORDERS OF MAGNITUDE SMALLER THAN A DUMP OF ONE DAY'S RAW DATA

WFES DATA STRUCTURES
ATTRIBUTES

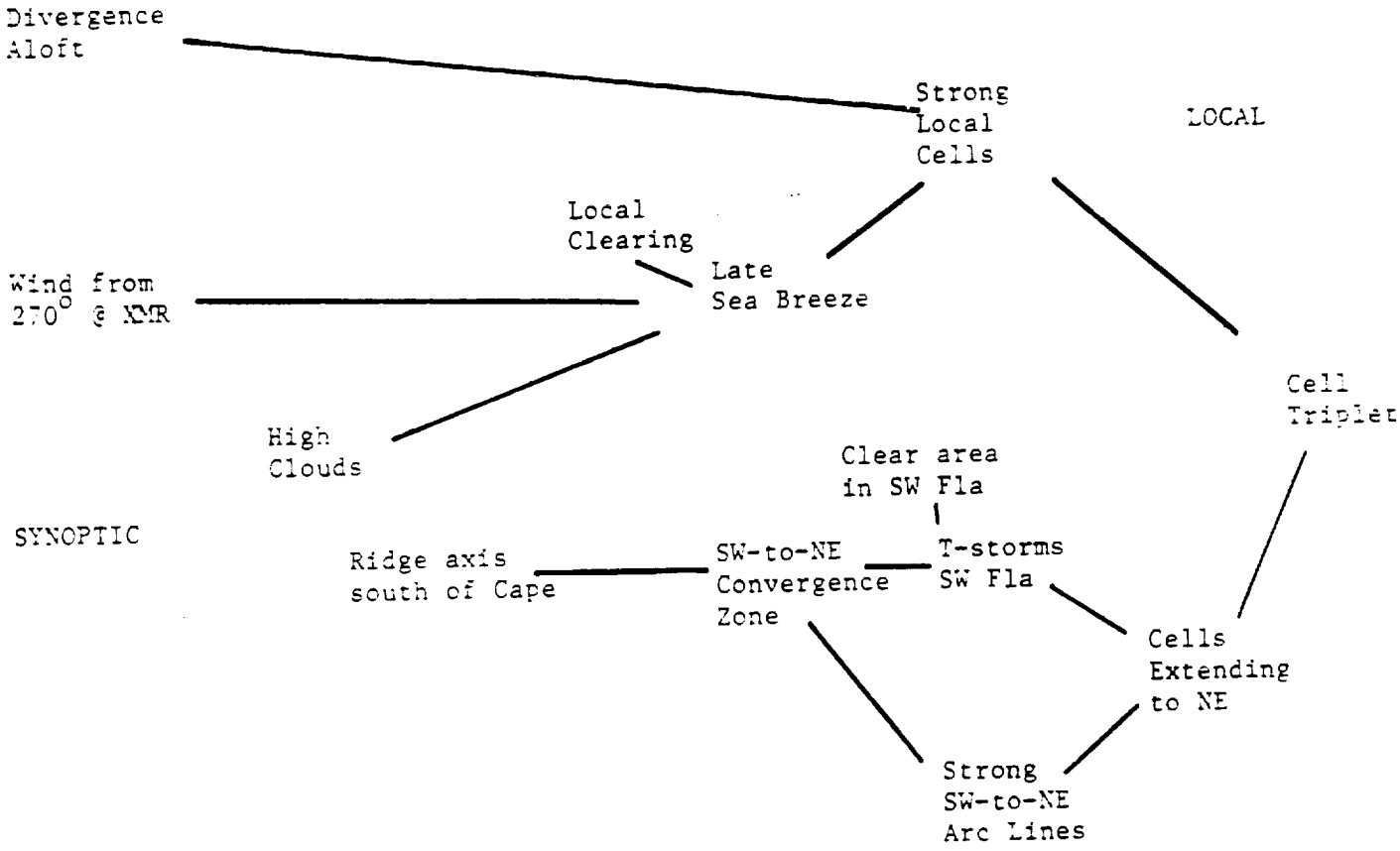
SCENARIO

- EVENTS (TREE)
- SPATIAL SCALE
- RULES OF THUMB
- ASSUMPTIONS
  - NECESSARY
  - SUFFICIENT
- "NOW"

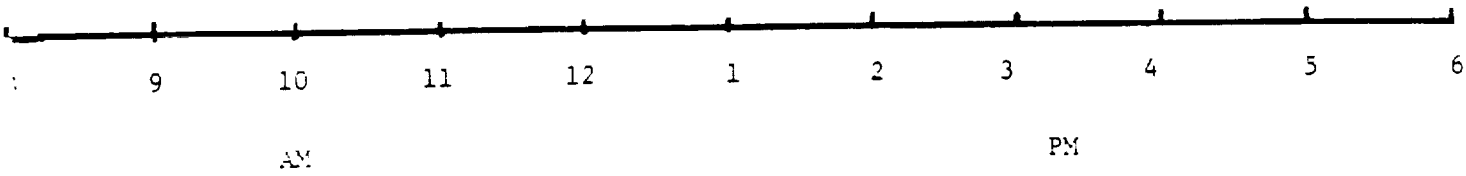
EXAMPLE SCENARIO: CONVERGENCE-DRIVEN CONVECTION IN SW FLORIDA

EVENTS	SW-NE CONVERGENCE ZONE
	ARC LINES
	T-STORMS BETWEEN OKECHOBEE AND TAMPA
	NEW CELLS FORMING TO THE NE
SCALE	MESOSCALE
"RULES OF THUMB"	OKECHOBEE LAKE BREEZE CAN STRENGTHEN CONVECTION SEVERITY GOES UP WITH INCREASING WINDS ALOFT LATE SEA BREEZE ACCENTUATES EFFECT (LOCALLY) LONG ARC LINES (EXTENDING TOWARD CUBA) INDICATE WELL-ENTRENCHED PATTERN
ASSUMPTIONS	RIDGE AXIS TO SOUTH CLOUD COVER ALLOWS SUFFICIENT CONVECTION

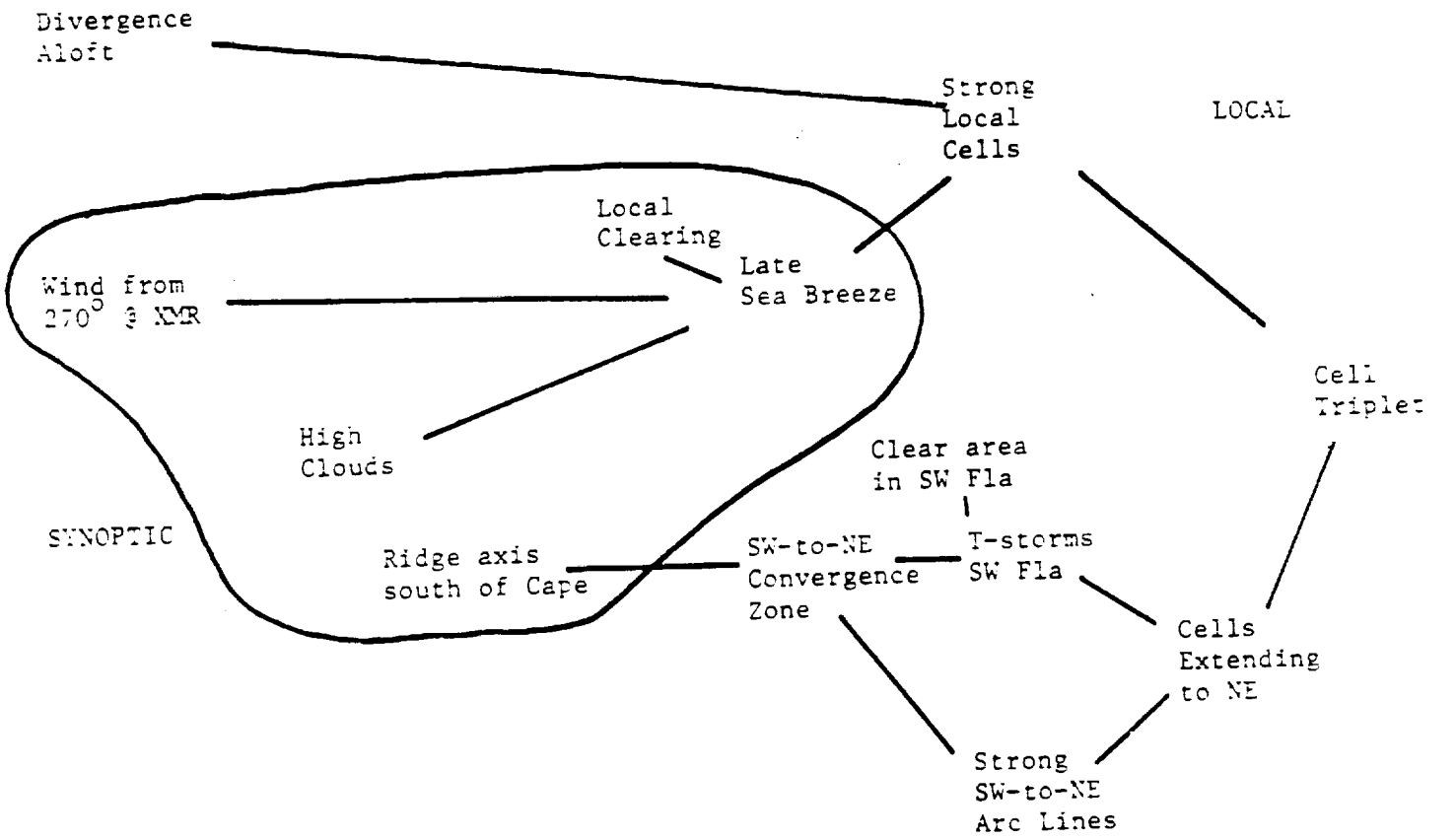
EXAMPLE: COMPLEX SCENARIO



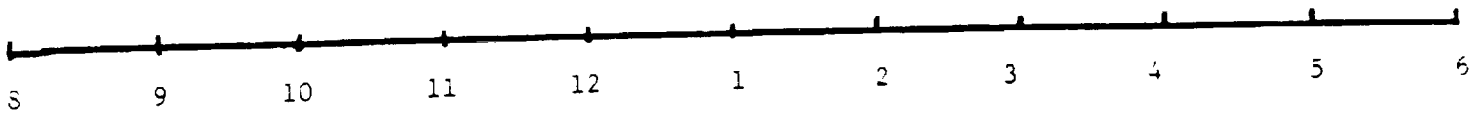
MESOCALE



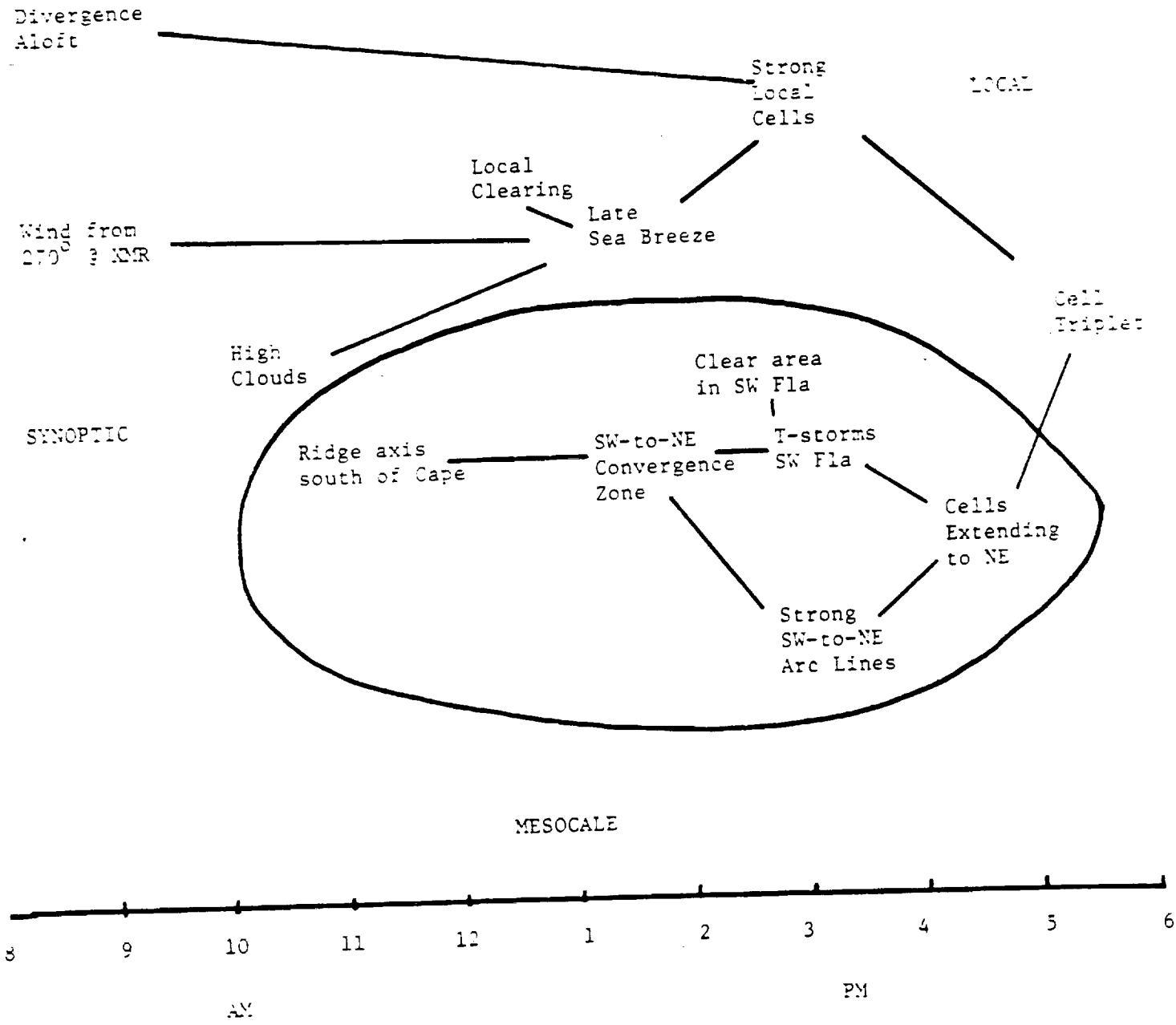
EXAMPLE: COMPLEX SCENARIO



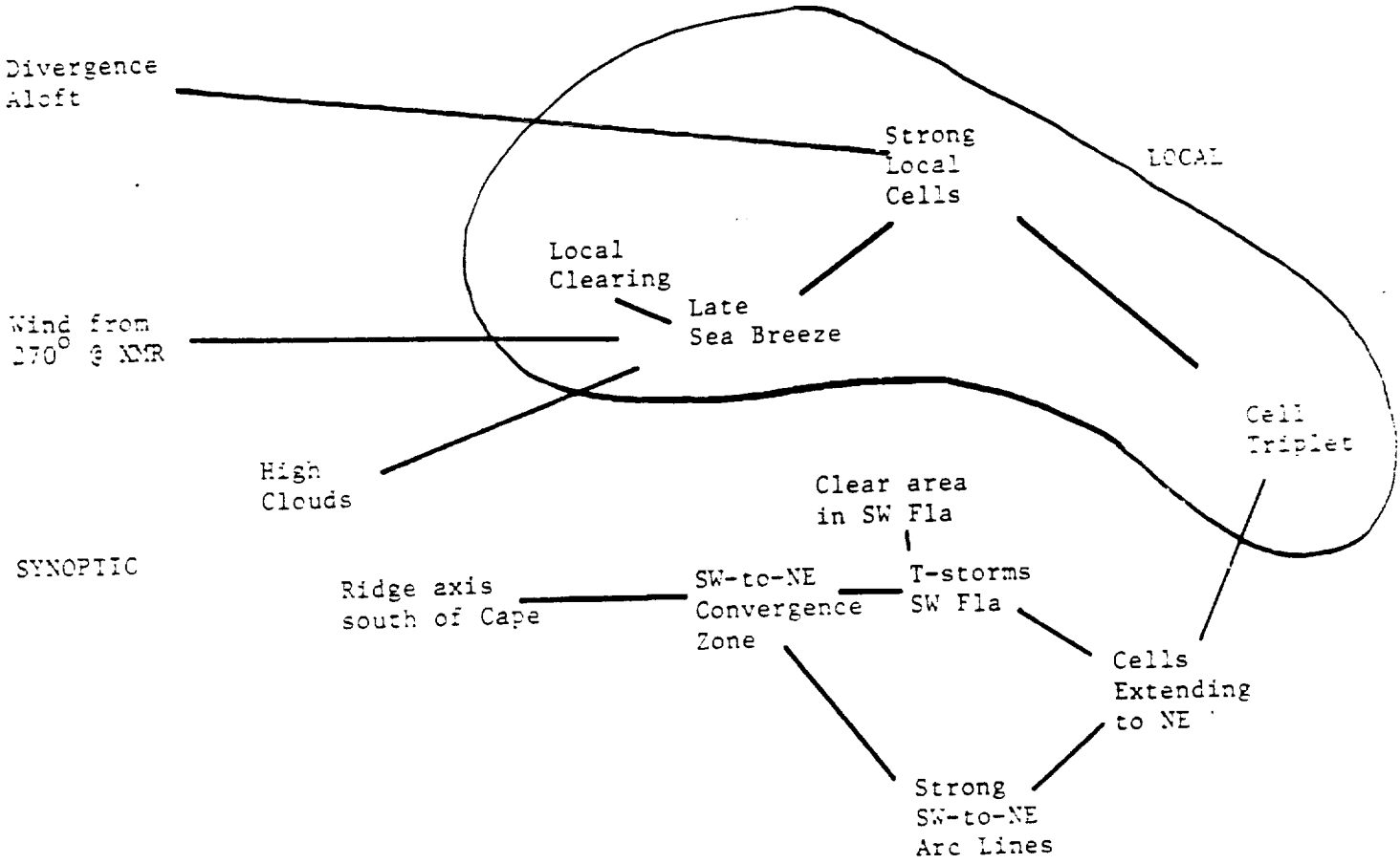
MESOCALE



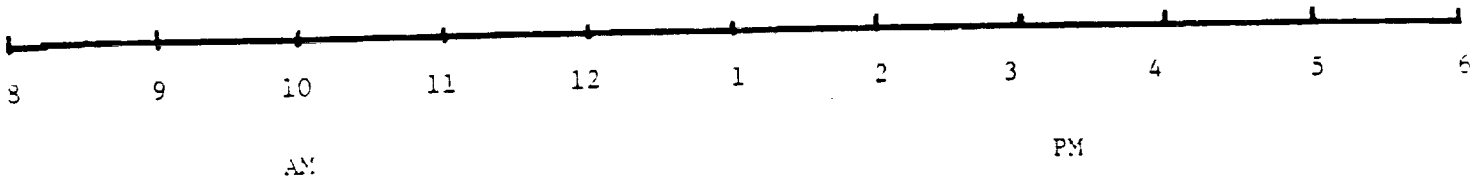
EXAMPLE: COMPLEX SCENARIO



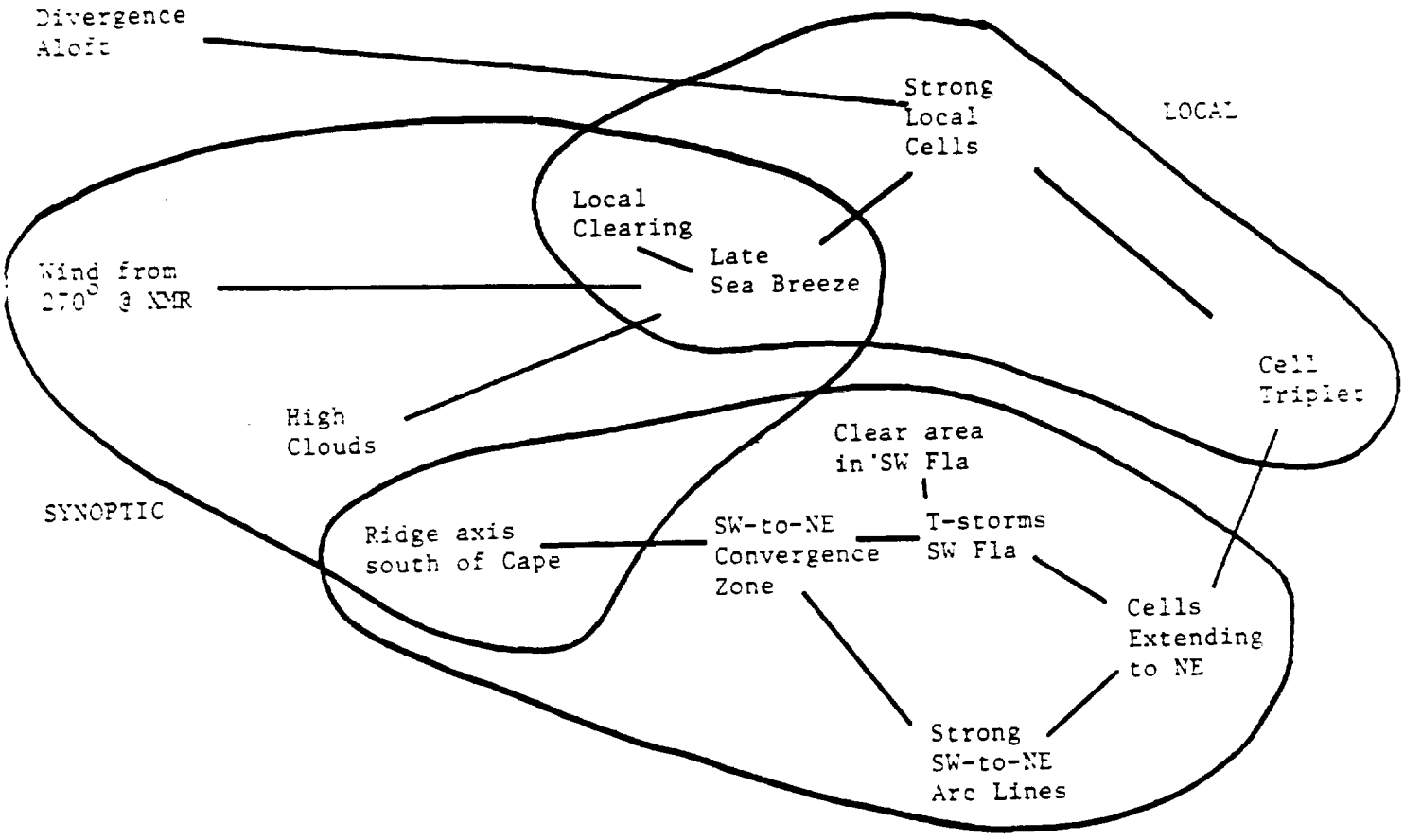
EXAMPLE: COMPLEX SCENARIO



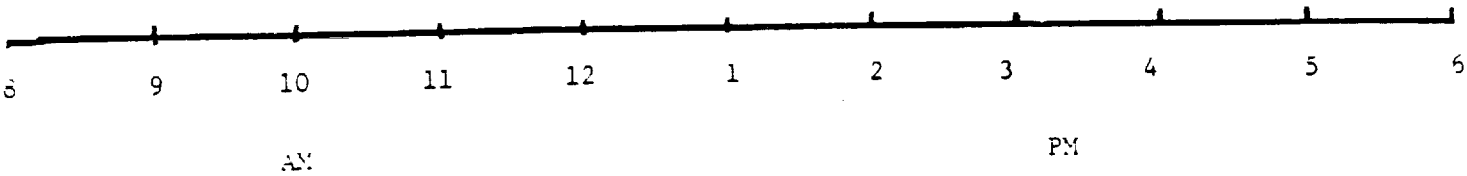
MESOCALE



EXAMPLE: COMPLEX SCENARIO



MESOCALE



WFES DATA STRUCTURES
ATTRIBUTES

EVENT

- FEATURES
- PREDICATE
- TIME STAMP
  - RELATIVE IF IN KNOWLEDGE BASE
  - SPECIFIC IF INSTANTIATED
- EXPLANATION OF CAUSALITY
- SPATIAL SCALE
- OBSERVATION INTERVAL
  - DETECTION
  - MONITORING
- MEASUREMENT METHODS

EXAMPLE EVENT: SW-TO-NE CONVERGENCE ZONE DEVELOPS

FEATURES	ARC LINES
PREDICATE	LOW-LEVEL CONVERGENCE FORMS N OF RIDGE AXIS
TIME STAMP	1800Z
CAUSALITY	"FORCED BY DYNAMICS ON NW SIDE OF RIDGE"
SPATIAL SCALE	MESOSCALE
OBSERVATION INTERVAL	1 HOUR (DETECTION) 1/2 HOUR (MONITORING)
MEASUREMENT METHOD	VISUAL EXAMINATION OF SATELLITE IMAGERY [ALGORITHM WITH DETECTS LONG, PARALLEL CLOUD STREETS?]

WFES DATA STRUCTURES
ATTRIBUTES

FEATURE

- VALUES
- LOCATION
- LIFETIME
- HISTORY
- CLIMATOLOGY (IF IT EXISTS)
- SIZE (IF APPLICABLE)

EXAMPLE FEATURE: ARC LINES

VALUES	1500-1900Z VISIBLE SATELLITE IMAGES
LOCATION	NW OF OKECHOBEE
LIFETIME	2-8 HOURS
HISTORY	(SEQUENCE OF IMAGES)
CLIMATOLOGY	N/A
SIZE	N/A

EXAMPLE: VARIABLE, FEATURE, EVENT, SCENARIO

VARIABLE	WIND AT 700 MB, XMR
FEATURE	STEERING-LEVEL WINDS AT 00Z
EVENT	LIGHT PREVAILING ESTERLIES IN LATE EVENING
SCENARIO	MORNING SHOWERS BLOWN ONSHORE

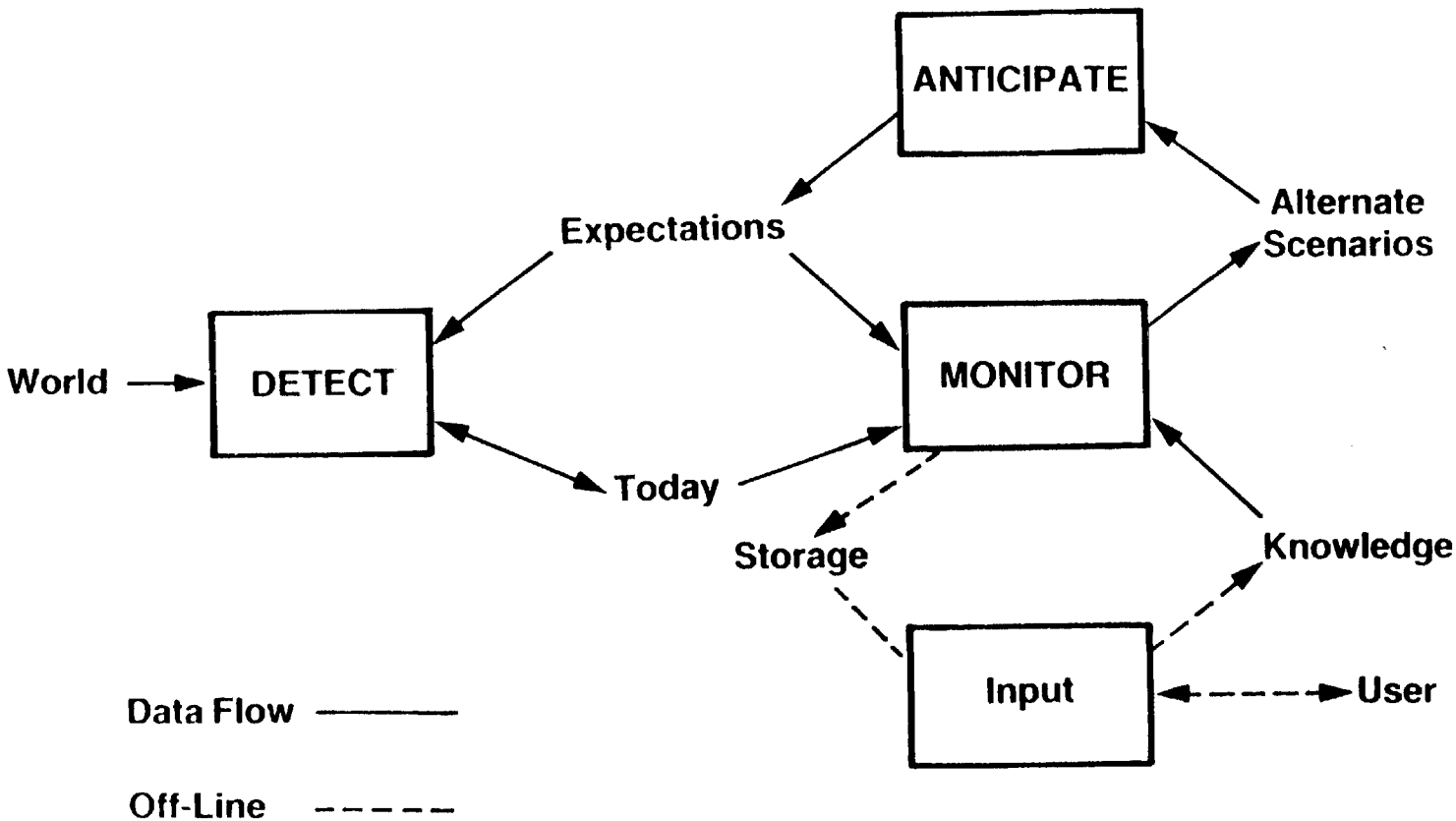
EXAMPLE: VARIABLE, FEATURE, EVENT, SCENARIO

VARIABLE	STEERING-LEVEL WINDS
FEATURE	CONVERGENCE ZONE
EVENT	CONVERGENCE ZONE FORMS, SW-NE WITH WINDS AT 240, NW OF OKECHOBEE
SCENARIO	CONVERGENCE-FORCED CONVECTION ON NW SIDE OF RIDGE AXIS

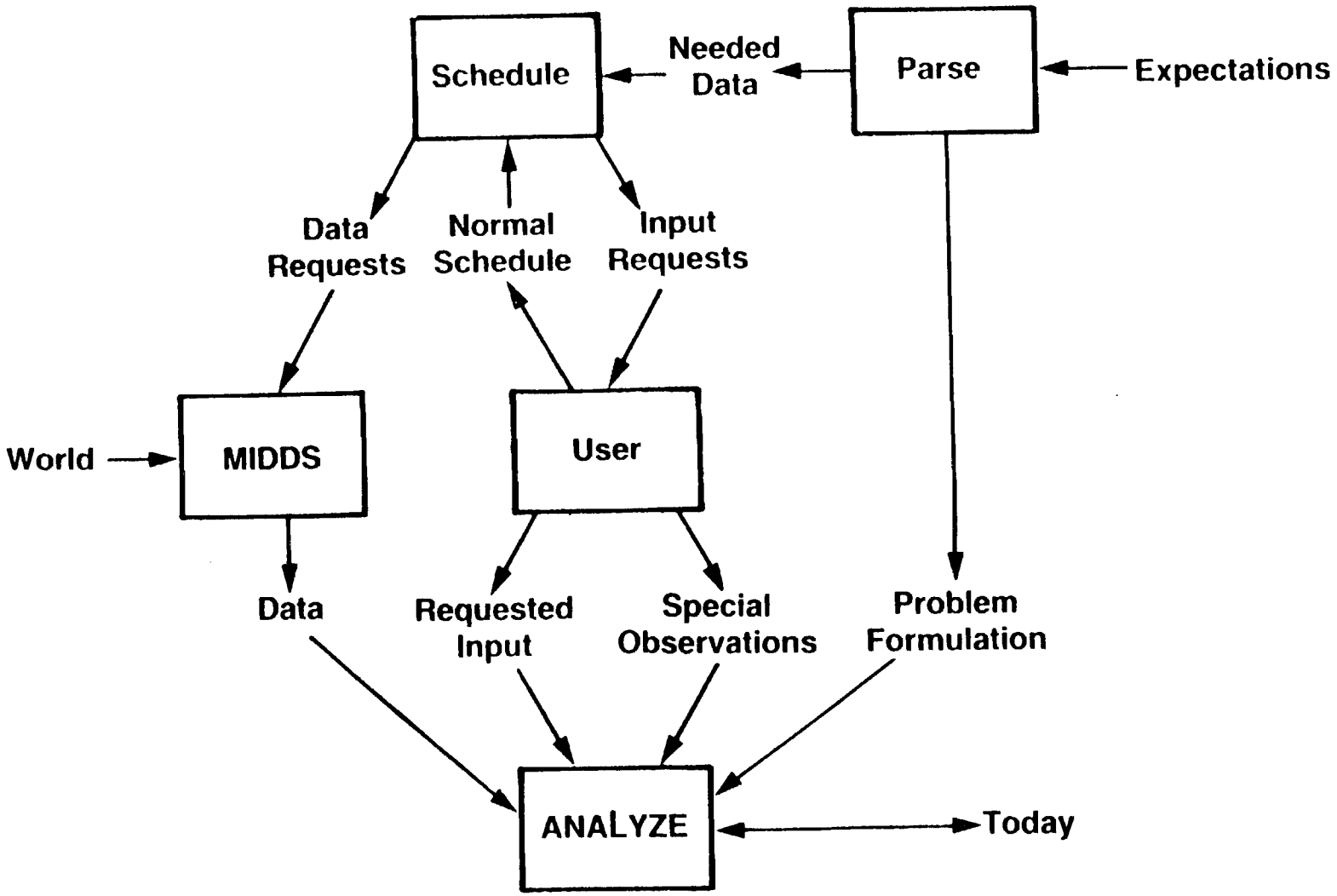
EXAMPLE: VARIABLE, FEATURE, EVENT, SCENARIO

VARIABLE	ELECTRIC POTENTIAL
FEATURE	AREAS OF MAXIMUM/MINIMUM POTENTIAL
EVENT	1) MAXIMUM OR MINIMUM CROSSES THRESHOLD
	2) IMMEDIATE FLATTENING OF FIELD
SCENARIO	ISOLATED CELL FORMS OVER KSC

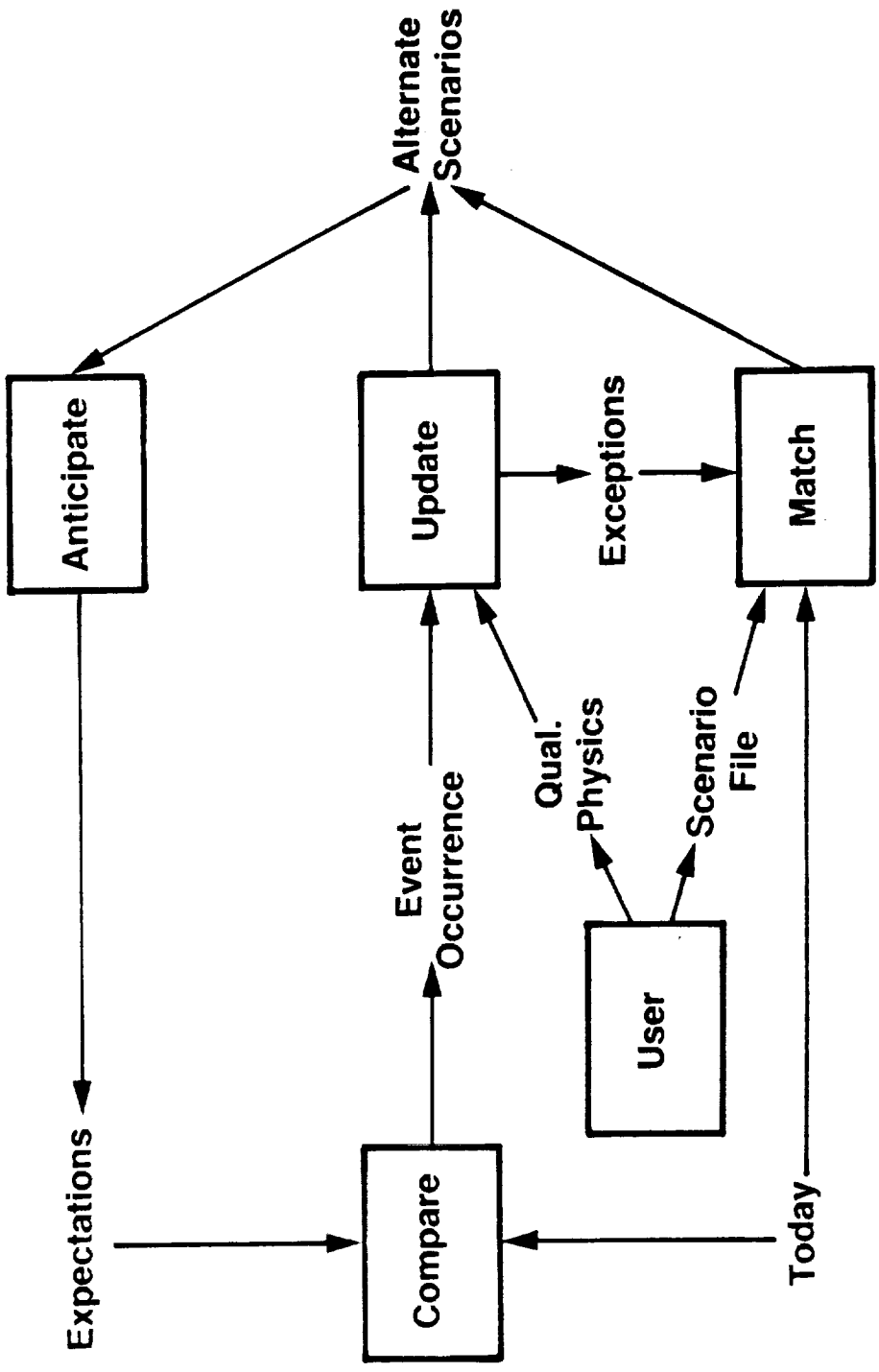
WFES Architecture: Top-Level View

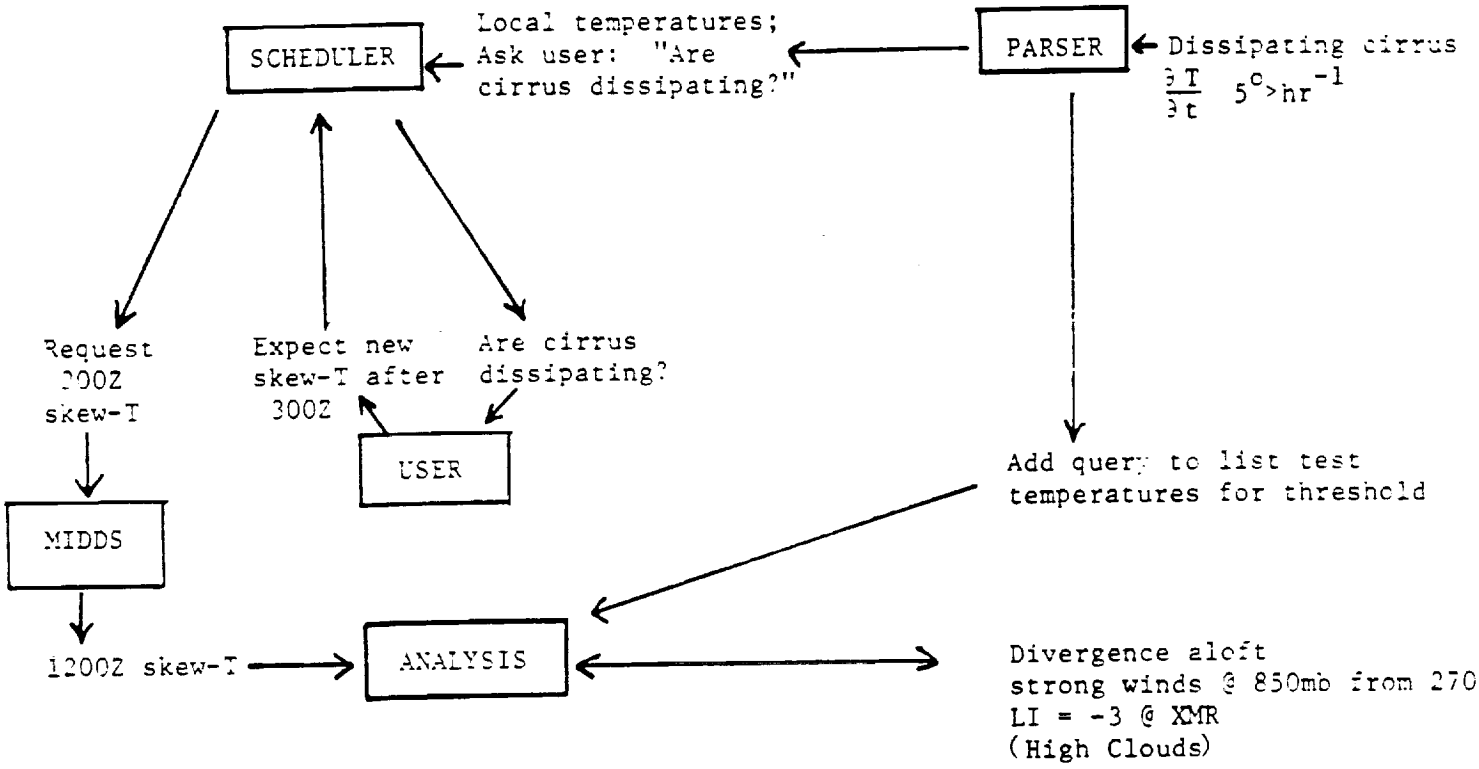


WFES Architecture: Detailed View of DETECT

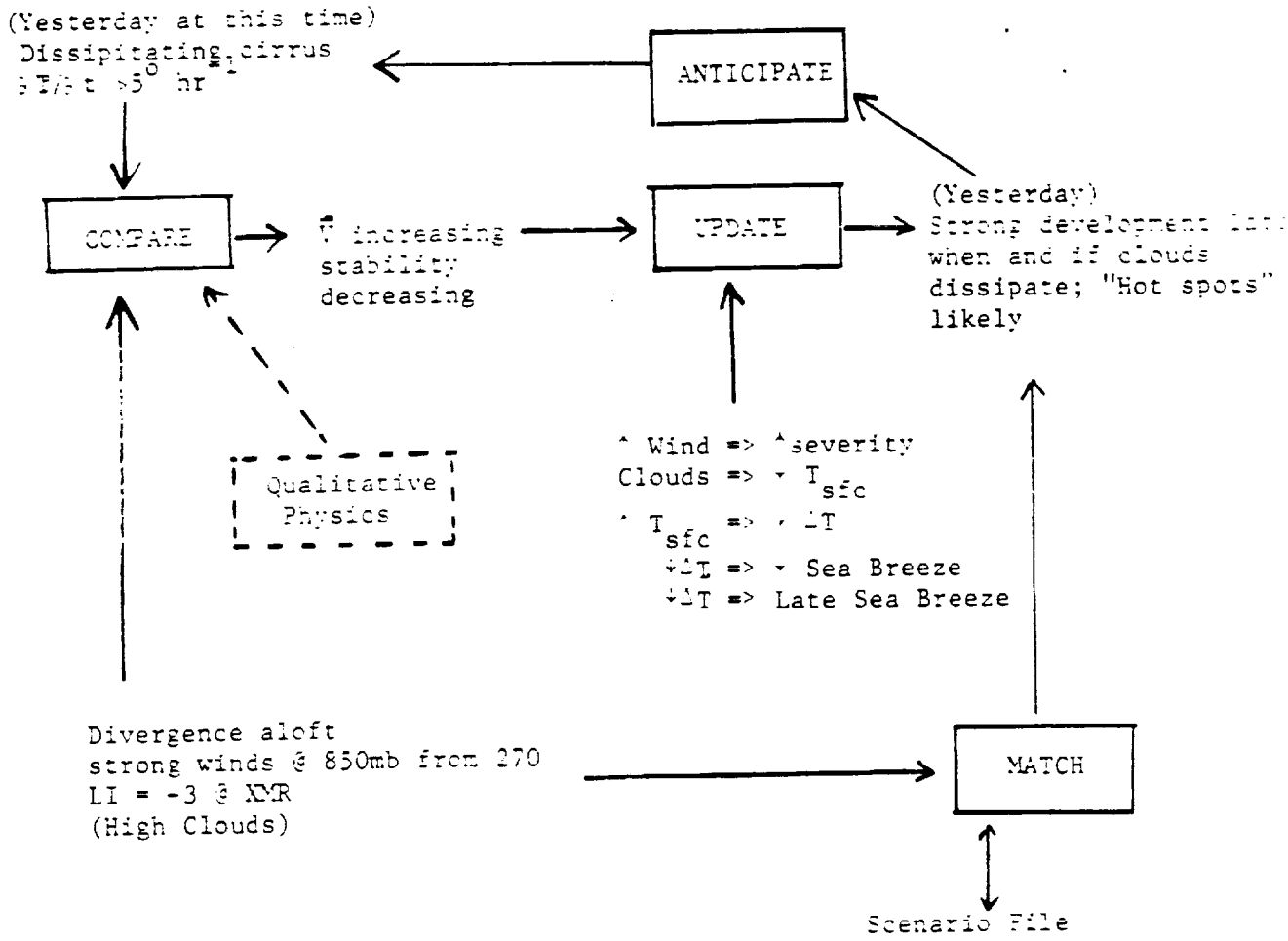


WFES Architecture: Detailed View of MONITOR, ANTICIPATE





Example: Processing of skew-T



Example: Processing of skew-T

THE WFES PROTOTYPE DEVELOPMENT APPROACH HIGH EFFORT

AN OVERRIDING CONCERN WILL BE THE EARLY DEVELOPMENT OF A USER INTERFACE SUITABLE FOR KNOWLEDGE ELICITATION AND EVALUATION.

THE ORDER OF MODULE DEVELOPMENT IS CRUCIAL:

- THOSE MODULES WHICH ARE ESSENTIAL TO MAKING THE WFES A USEFUL TOOL WILL BE DEVELOPED FIRST.
- MODULES WHICH ARE PART OF THE OVERALL DESIGN BUT WHOSE FUNCTIONS COULD BE PERFORMED BY HUMANS WILL BE DEVELOPED SECOND, TIME PERMITTING.

THIS INSURES THAT AT EACH STAGE IN THE WFES DEVELOPMENT, A USEFUL SUBSET OF ALL FORECASTING TASKS IS BEING SUPPORTED.

THE WFES PROTOTYPE
MODULE DEVELOPMENT
HIGH EFFORT

MODULE	STATUS	ORDER
"DETECT		
ANALYZE	U	2
PARSER	U	1
SCHEDULER	U	1
"MONITOR"		
MATCH	U	3
COMPARE	Y	2
UPDATE	Y	2
"ANTICIPATE"	U	
"KNOWLEDGE"		
ANALOGS	Y	1
EVENTS	Y	1
RULES OF THUMB	Y	1
CLIMATOLOGY	N	3
QUALITATIVE PHYSICS	N	3

"Y" = MUST BE PERFORMED BY MACHINE
"N" = NOT ESSENTIAL
"U" = COULD BE PERFORMED BY USER

INVOLVEMENT OF FORECASTING EXPERTS AND FUTURE USERS IN WFES DEVELOPMENT

FORECASTING EXPERTS AND FUTURE USERS WILL BE INVOLVED IN FOUR STAGES OF THE DEVELOPMENT PROCESS:

- KNOWLEDGE ELICITATION
- KNOWLEDGE SYNTHESIS
- IMPLEMENTATION
- TEST AND EVALUATION

- KNOWLEDGE ELICITATION

PURPOSE: ELICITATION OF THE KNOWLEDGE WHICH WILL DRIVE THE WFES

SOURCES:
- DUTY FORECASTERS
- STAFF METEOROLOGIST
- PROJECT EXPERTS
- NASA EXPERTS

ACTIVITIES:
- INTENSIVE DEBRIEFING
- ACTIVE OBSERVATION
- ASSIGNMENTS
- REVIEW AND CRITIQUE OF THE EVOLVING SYSTEM

- KNOWLEDGE SYNTHESIS

PURPOSE: STRUCTURING AND PRESENTING FORECASTER EXPERTISE

SOURCES:
DUTY FORECASTERS
STAFF METEOROLOGISTS
PROJECT EXPERTS
FUTURE USERS

ACTIVITIES: REVIEW OF FORECASTING KNOWLEDGE AS IT IS EMBEDDED IN THE WFES ARCHITECTURE

REVIEW OF PROPOSED USER INTERFACE

- IMPLEMENTATION

PURPOSE: TO IMPLEMENT A SYSTEM WHICH REFLECTS FORECASTER EXPERTISE AND FULFILLS THE NEEDS OF FUTURE USERS

SOURCES:
DUTY FORECASTERS
STAFF METEOROLOGISTS
PROJECT EXPERTS
FUTURE USERS

ACTIVITIES: REVIEW AND CRITIQUE OF THE WFES AS IT DEVELOPS

- TEST AND EVALUATION

PURPOSE: EVALUATION OF THE IMPLEMENTED WFES TO DETERMINE PATHS FOR FUTURE DEVELOPMENT

SOURCES: DUTY FORECASTERS
NASA EXPERTS
PROJECT EXPERTS

ACTIVITIES: EXTENDED TEST OF THE PROTOTYPE WFES AT CCFF

KNOWLEDGE ELICITATION CONCERNING THE OPERATION OF WFES IN REAL-TIME FORECASTING SITUATIONS

THE RELATION BETWEEN THE PROPOSED ARCHITECTURE AND KNOWLEDGE ELICITATION ACTIVITIES

THE PROPOSED ARCHITECTURE REQUIRES EXPERTISE ON THESE TOPICS:

- CASE HISTORIES
- RULES OF THUMB
- QUALITATIVE PHYSICS
- CLIMATOLOGY

	Case Histories	Rules of Thumb	Qualitative Phsyics	Climatology
J. Smedley	✓	✓	✓	
D. Helms	✓	✓		
M. Kazmarak	✓	✓		
W. Jafferis	✓			
T. Myers		✓		✓
W. Boyd		✓		
J. Weems	✓	✓		
J. Nicholson			✓	✓
R. Pielke			✓	✓

HIGH EFFORT
THE WFES PROTOTYPE
YEAR 1

AFTER A ONE-YEAR EFFORT, THE WFES PROJECT WILL PROVIDE SUFFICIENT INFORMATION TO ASSESS THE MAGNITUDE OF EFFORT REQUIRED TO BUILD AN OPERATIONAL SYSTEM. THIS REQUIRES:

- A DETAILED KNOWLEDGE OF:
  - THUNDERSTORM FORMATION IN THE CAPE AREA;
  - HOW FORECASTERS RESPOND TO THOSE THUNDERSTORMS.
- A SET OF SOFTWARE TOOLS WHICH MATCH THAT KNOWLEDGE, INCLUDING:
  - A SIMPLE FACILITY FOR CLASSIFYING AND MONITORING "INTERESTING" WEATHER FEATURES;
  - AN ENVIRONMENT FOR THE DEFINITION, STORAGE AND RETRIEVAL OF PROTOTYPICAL WEATHER SCENARIOS;
  - A GRAPHICAL, INTERACTIVE INTERFACE TO MIDDS.

HIGH EFFORT
WFES PROJECT PLAN
MILESTONES

AT PROJECT MILESTONES, PROGRESS SHOULD BE REPORTED AND ASSESSED BY PROJECT MANAGEMENT.

THE FOLLOWING MILESTONES SEEM ESPECIALLY IMPORTANT:

- MACHINE INSTALLATION AT LCFF FOR DEVELOPMENT, TESTING AND EVALUATION.
- COMPLETION OF THE CAPABILITY TO TRANSFER AND DISPLAY MIDDS DATA IN THE WFES ENVIRONMENT.
- IMPLEMENTATION OF A BASIC USER INTERFACE.
- ROBUST DEFINITION OF A SCENARIO, INCLUDING:
  - DATA STRUCTURES
  - GRAMMAR
- COMPLETION OF THE LOGIC FOR ANTICIPATING FUTURE EVENTS AND COMPARING THEIR STATUS WITH CURRENT CONDITIONS.

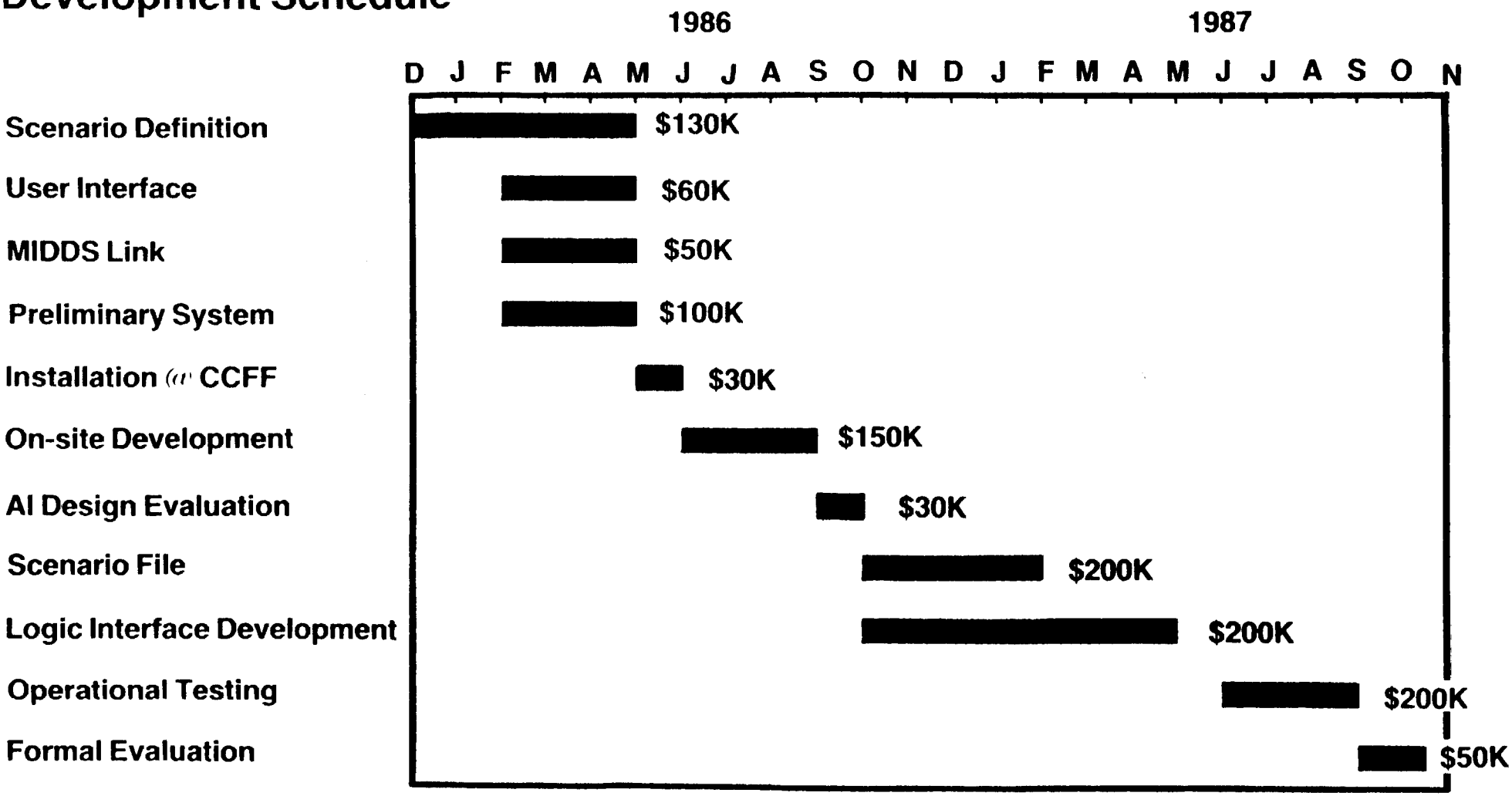
HIGH EFFORT
THE WFES PROTOTYPE
YEAR 2

DURING THE SECOND YEAR, THE WFES PROJECT WILL PROVIDE A 3-MONTH OPERATIONAL TESTING OF A REFINED WFES PROTOTYPE DURING THE SUMMER OF 1987.

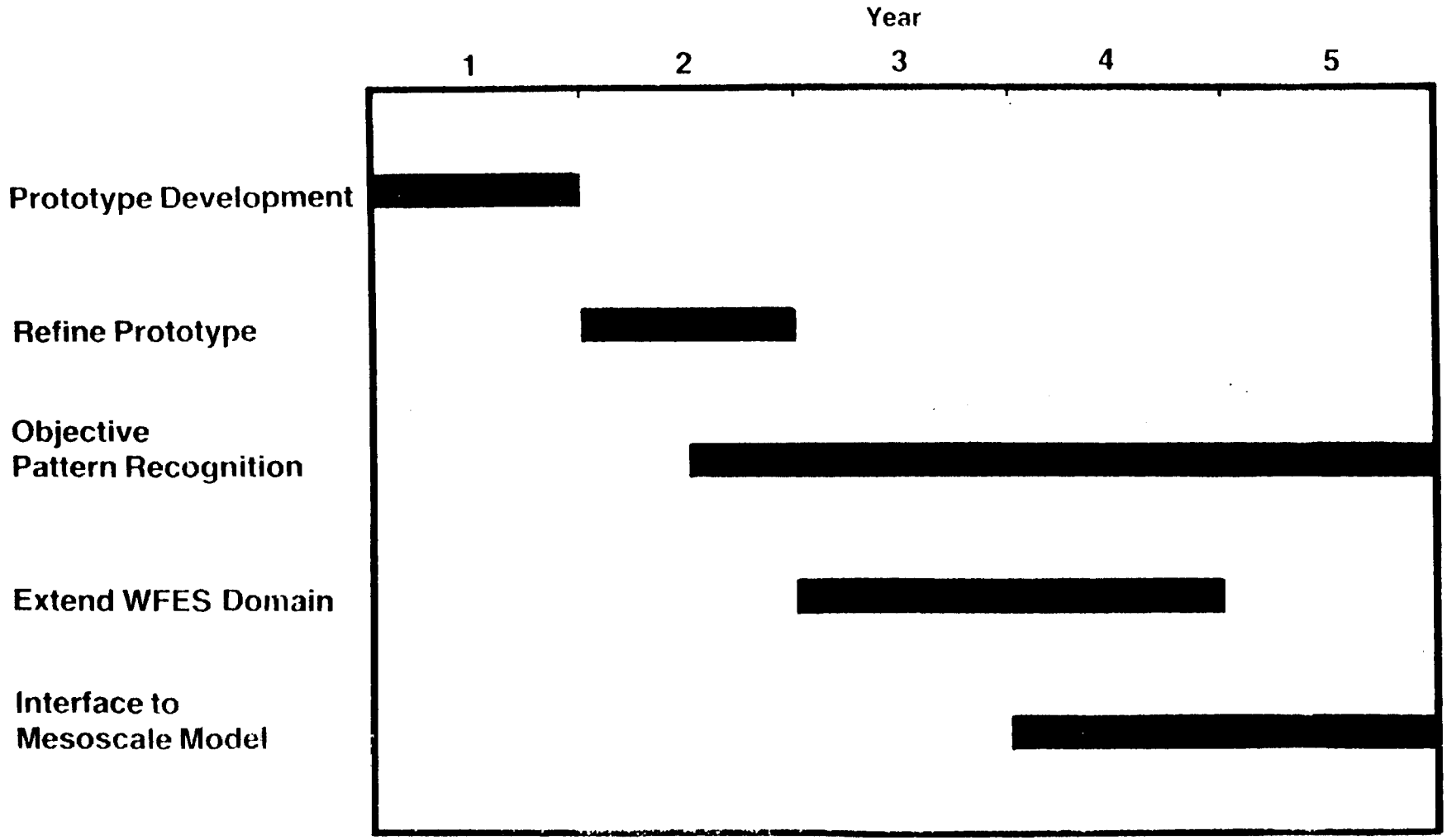
THIS REQUIRES IMPLEMENTATION OF WHAT WAS LEARNED DURING THE PREVIOUS YEAR AND INCLUDES:

- A ROBUST USER INTERFACE WHICH IS SUITABLE FOR UNSUPERVISED USE;
- AN EFFICIENT ENVIRONMENT FOR EXAMINING AND UPDATING THE SCENARIO FILE;
- SOPHISTICATED LOGIC FOR AUTOMATICALLY GENERATING AND MONITORING "INTERESTING" WEATHER SCENARIOS;
- AUTOMATIC LINKAGE TO MIDDS CASE HISTORIES.

High Effort
WFES Prototype
Development Schedule



WFES Prototype Long-Term Schedule



MEDIUM EFFORT

THE WFES PROTOTYPE
YEAR 1

AFTER A ONE-YEAR EFFORT, THE WFES PROJECT WILL PROVIDE SUFFICIENT INFORMATION TO ASSESS THE MAGNITUDE OF EFFORT REQUIRED TO BUILD AN OPERATIONAL SYSTEM. THIS REQUIRES:

- A KNOWLEDGE OF:
  - THUNDERSTORM FORMATION IN THE CAPE AREA;
  - HOW FORECASTERS RESPOND TO THOSE THUNDERSTORMS.
- A SET OF SOFTWARE TOOLS WHICH MATCH THAT KNOWLEDGE, INCLUDING:
  - A SIMPLE FACILITY FOR CLASSIFYING AND MONITORING "INTERESTING" WEATHER FEATURES;
  - AN ENVIRONMENT FOR THE DEFINITION, STORAGE AND RETRIEVAL OF PROTOTYPICAL WEATHER SCENARIOS;
  - A GRAPHICAL, INTERACTIVE INTERFACE TO MIDDS.

MEDIUM EFFORT

WFES PROJECT PLAN
MILESTONES

AT PROJECT MILESTONES, PROGRESS SHOULD BE REPORTED AND ASSESSED BY PROJECT MANAGEMENT.

THE FOLLOWING MILESTONES SEEM ESPECIALLY IMPORTANT:

- MACHINE INSTALLATION AT CCFF FOR DEVELOPMENT, TESTING AND EVALUATION.
- COMPLETION OF THE CAPABILITY TO TRANSFER AND DISPLAY MIDDS DATA IN THE WFES ENVIRONMENT.
- IMPLEMENTATION OF A BASIC USER INTERFACE.
- DEFINITION OF A SCENARIO, INCLUDING:
  - DATA STRUCTURES
  - GRAMMAR
- OF THE LOGIC FOR ANTICIPATING FUTURE EVENTS AND COMPARING THEIR STATUS WITH CURRENT CONDITIONS.

MEDIUM EFFORT

THE WFES PROTOTYPE
YEAR 2

DURING THE SECOND YEAR, THE WFES PROJECT WILL PROVIDE A 3-MONTH OPERATIONAL TESTING OF A REFINED WFES PROTOTYPE DURING THE SUMMER OF 1987.

THIS REQUIRES IMPLEMENTATION OF WHAT WAS LEARNED DURING THE PREVIOUS YEAR AND INCLUDES:

- A USER INTERFACE WHICH IS SUITABLE FOR SUPERVISED USE;
- AN ENVIRONMENT FOR EXAMINING AND UPDATING THE SCENARIO FILE;
- SOPHISTICATED LOGIC FOR SELECTING AND MONITORING "INTERESTING" WEATHER SCENARIOS;
- AUTOMATIC LINKAGE TO MIDDS CASE HISTORIES.

MEDIUM EFFORT

WFES PROTOTYPE COSTS

YEAR ONE

SCENARIO DEFINITION	$100K
USER INTERFACE	25K
MIDDS SERIAL LINK	5K
PRELIMINARY SYSTEM LOGIC	60K
ON-SITE DEVELOPMENT (KE)	50K
AI DESIGN EVALUATION	10K
	$250K

YEAR TWO

SCENARIO KNOWLEDGE-BASE	$150K
SYSTEM LOGIC	60K
KSC TESTING	70K
EVALUATION	20K
	$300K

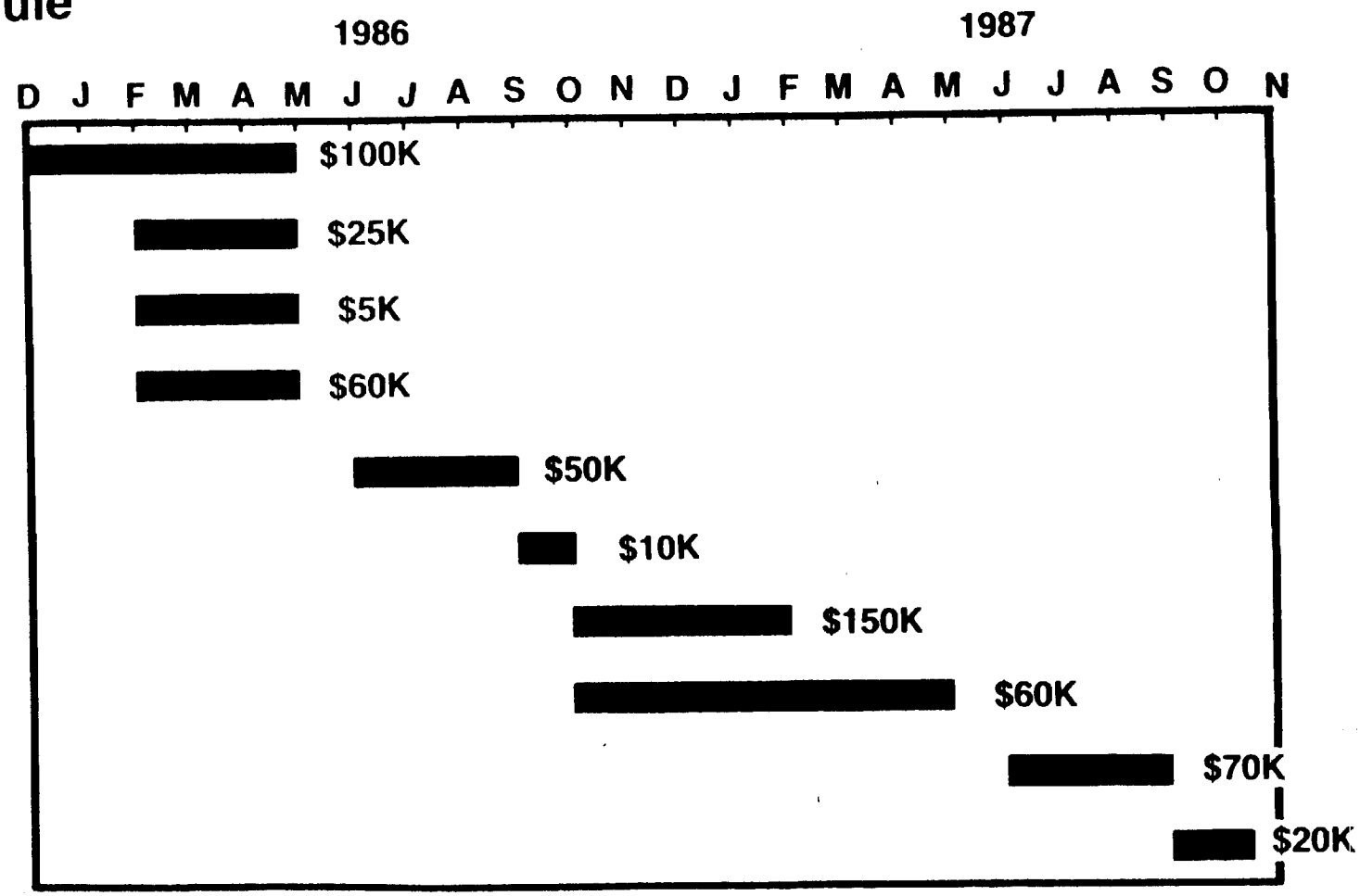
$550K

MEDIUM EFFORT

SUMMARY WFES PROTOTYPE COSTS

SCENARIO DEVELOPMENT (KNOWLEDGE-BASE)	$250K	45%
SYSTEMS CONTROL LOGIC (INFERENCE ENGINE)	100K	19%
USER INTERFACE AND MIDDS LINK	100K	18%
EVALUATION AND TESTING	100K	18%
	$550K	

Medium Effort
WFES Prototype
Development Schedule



MEDIUM EFFORT

WFES PROTOTYPE SCOPE

- KNOWLEDGE-BASE WILL BE RESTRICTED TO SCENARIOS RELATED TO SUMMERTIME THUNDERSTORMS WHICH FORM OVER KSC.
- SYSTEM LOGIC WILL BE FULLY FUNCTIONAL WITH RESPECT TO DEFINING, EDITING, STORING, RETRIEVING AND EXECUTING SCENARIOS.
- SYSTEM LOGIC WILL NOT PROVIDE FOR EITHER DYNAMIC OR AUTOMATIC MODIFICATION OF SCENARIOS.
- WFES LINK TO MIDDS WILL BE A SERIAL LINK FOR PASSING OF DATA AND COMMANDS.
- WFES WILL NOT PROVIDE AN INTERACTIVE INTERFACE TO EITHER MIDDS COMMAND STREAM OR DATA.
- USER INTERFACE WILL BE USABLE BY DEVELOPERS AND SEVERAL TRAINED OTHERS.
- NO USER DOCUMENTATION WILL BE PROVIDED.
- NO OPERATIONAL TESTING WILL BE CONDUCTED.