The Meteorological Monitoring System (MMS) for Kennedy Space Center/Cape Canaveral Air Force Station*

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ABSTRACT

ENSCO developed the Meteorological Monitoring System (MMS) as a unique system of computer workstations for monitoring meteorological conditions and warning affected personnel when weather hazards are about to occur. These weather hazards such as lightning and/or high winds adversely affect every day operations and launch activities at Kennedy Space Center and Cape Canaveral Air Force Station (KSC/CCAFS).

Air Force weather forecasters, NASA test directors and NASA duty officers who currently handle the large task of disseminating weather warnings and advisories to the numerous work operations use the MMS to enter operations constraints and to receive warnings when weather violates the constraints. We developed the MMS to take advantage of advances in computer workstation and expert system technology and provide a faster and more reliable system for meteorological monitoring and warning.

The primary functions of the MMS are:

- To monitor local meteorological sensors including wind towers, radar, and lightning location and detection systems and to alarm users both audibly and visibly when constraints have been violated.
- To receive and disseminate weather warnings and advisories from weather forecasters.
- To graphically display real-time data including data trends and interrelationships.

The initial MMS consists of three DEC 5000/120 workstations running software developed in C programming language, using X-Windows under a UNIX environment. The system uses the expert system shell CLIPS to process meteorological data, make decisions and send audible and visible alarms. One of the workstations functions as a preprocessor and receives data from the Meteorological Interactive Data Display System (MIDDS). The other two workstations perform as monitoring display stations and allow users to enter data, make selections, and receive warnings when adverse weather occurs. These two workstations are located at different locations at KSC/CCAFS. The system design allows for future expansion of workstations.

INTRODUCTION

The Meteorological Monitoring System (MMS) is a unique system of computer workstations for monitoring meteorological conditions and warning affected personnel when weather hazards are about to occur. We installed the system at Kennedy Space Center and Cape Canaveral Air Force Station (KSC/CCAFS). The MMS receives data from meteorological sensors such as wind towers and lightning detectors through MIDDS and compares the data with weather constraints established for each operation such as moving the Space Shuttle from the Vehicle Assembly Building to the launch pad. If the weather violates a constraint then each workstation receives an audible and visible alarm. The MMS has other important uses such as graphically displaying meteorological data and disseminating weather forecasts, advisories, and warnings to workstations at KSC/CCAFS.

The purpose of this paper is to describe the MMS which will soon be operational as a prototype system monitoring the meteorological conditions at KSC/CCAFS. This paper describes the hardware, the software, and the system configuration used to build the MMS. The paper describes the Preprocessor and the Monitoring Display Stations including the user interface, the expert system monitoring controller, and the meteorological data displays. The paper also discusses expandability and future enhancements of MMS.

MONITORING SYSTEM NEED

Weather affects most NASA operations at Kennedy Space Center. Severe weather can result in injury to people, loss of equipment and even destruction of a space vehicle. Therefore, NASA has developed a ground operations safety plan which limits certain work operations and procedures to very specific weather conditions[1]. For example, if lightning occurs within 5 miles of the Vehicle Assembly Building, all crane hoisting outdoors must stop.

Prior to the MMS weather forecasters and operations officers used the following procedures for issuing warnings (See Figure 1a): An Air Force weather forecaster at the CCAFS would observe or forecast an adverse weather event such as a lightning strike within five miles of KSC. Forecasters use various sensors to make these observations or forecasts (e. g. the Lightning Location and Protection (LLP) System or the Launch Pad Lightning and Warning System (LPLWS)). Once the forecaster observes or forecasts lightning they would telephone the NASA Duty Officer at Kennedy Space Center. The Duty Officer, who has many other responsibilities, would call the NASA Test Director, who is the manager responsible for overseeing daily work operations. The Test Director would notify the workers and they would take appropriate action due to the lightning advisory.

With the MMS, weather forecasters and operations officers will use the following procedures for issuing warnings (Figure 1b): Lightning sensors detect lightning within five miles of KSC. The MMS monitors the lightning data and sends an alarm to the workstations of the Air Force weather forecaster and of the NASA Test Director. The Test Director acknowledges receiving the alarm, notifies the workers affected by the lightning, and if desired then displays maps of the lightning or other data. The weather forecasters who also receive the alarm use the MMS to augment their observing capabilities. Also, if the forecaster was issuing a forecast, advisory, or warning of adverse weather then they would enter the information into their MMS workstation and the warning would trigger an alarm at the Test Director's workstation.

PREVIOUS SYSTEMS

To support space launch and safety operations, NASA and the Air Force collect meteorological data from many different types of sensors and instruments and then process and display the data on many different computers and displays[2]. The NASA Operations personnel currently can view displays of meteorological data in the KSC/CCAFS area with the Meteorological and Range Safety Support System

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(MARSS). ENSCO developed the MARSS system for NASA and the Air Force[3]. MARSS is a system of minicomputer-based graphical displays used for predicting diffusion of toxic spills and for displaying local weather data. The system is extremely important for safety analysis and produces high quality displays of wind tower data. However, the MARSS system does not provide a warning capability and the graphical displays are relatively slow when compared to displays produced by today's faster and more technologically advanced computer workstations.

Therefore, based on NASA Operations' current weather warning procedures and their current weather graphics displays, they needed an improved system.

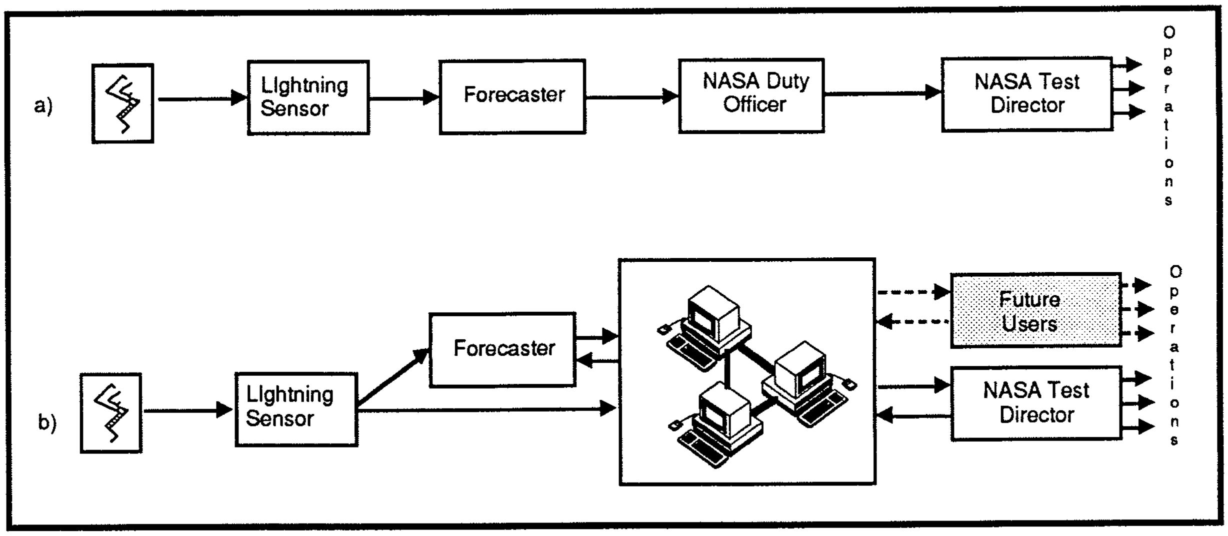

Figure 1. The data flow of lightning strike information from its occurrence to the NASA Test Director a) Before MMS and b) With MMS.

MMS HARDWARE

We established the MMS hardware requirements in an initial Phase 1 MMS requirements analysis[4]. In conjunction with the requirements analysis, we also conducted a trade study to select the hardware configuration for the MMS. The trade study incorporated the following factors: system requirements, hardware reliability, maintenance requirements and costs, development environment, system expandability, component costs, system expansion costs, and our experience with the components and the vendors. During the study, we considered microcomputers and workstations made by Sun Microsystems, Digital Equipment Corporation (DEC), IBM, Hewlett-Packard, and Apple.

The primary components of the system are three identical DECStation 5000/Model 120 workstations and one DECServer 300 terminal server. Table I presents a list of the hardware used to build the MMS. Figure 2 presents a diagram of the system hardware configuration.

Table I. MMS Hardware and Specifications.

Quantity	Equipment	Description
3	Workstation	DECstation 5000 Model 120 with 24MB of 1Mbit Dram, 20Mhz CPU SCSI Controller
3	Keyboard	108 Key
3	Color Board	DS5000 8PL Color, Fct Inst.
3	Monitor	16" Color (120V 60hz refresh rate)
3	Hard Disk	RZ55 665MB Disk,
1	Tape Drive	320MB TZK10 1/4" Tape in a dual drive expansion box
1	Hard Disk	RZ55 665MB Disk Drive in dual drive expansion box
1	CDROM	600 Mbyte CDROM SCSI tabletop 5 1/4" half height w/2 caddys
1	Tape Drive	TZ30 95MB Tape Drive in dual drive expansion box
2	Laser Printer	8 PPM Simplex Laser Printer (w/ DECANSI/Sixel & PostScript Protocol, Toner Cartridge, Serial/Parallel Interface)
1	Terminal Server	DECserver 300 Terminal Server (16 async. EIA-423 lines, DECserver 300 S/W License)
4	Modems	Telebit Trailblazer modems

TERMINAL SERVER

A terminal server is a hardware device which runs software and firmware to provide an efficient way to connect a variety of asynchronous, serial devices such as modems, terminals, printers, and personal computers to an Ethernet local area network. The terminal server can support up to 16 devices. The MMS terminal server is a very important part of the MMS because all data passes through it. Data from the various sources enters the MMS through 9600 baud modem lines which connect to the terminal server. The terminal server connects to the Preprocessor with an Ethernet connection. The Ethernet provides high speed data transfer between the preprocessor and the terminal server. The Preprocessor links with the Monitoring Display Stations (MDS) using the Ethernet connection between the Preprocessor and the terminal server and using the 9600 baud modem lines between the terminal server and the MDSs.

Because of the remote locations of the two MDSs and the data sources, the MMS uses modems to connect to the terminal server to each MDS and each data source. We selected Telebit Trailblazer Plus 19.2 KB error correcting modems for the MMS.

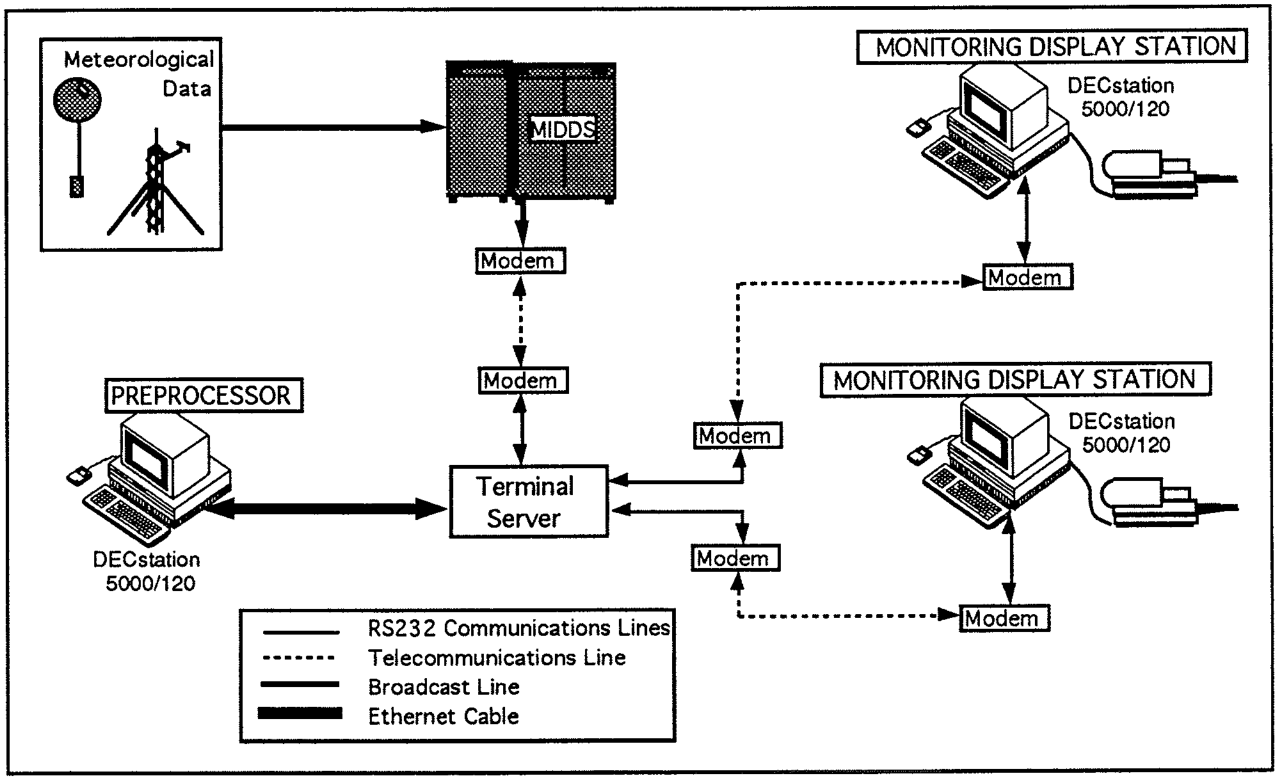

Figure 2. MMS Hardware Configuration

WORKSTATIONS

The design of the MMS calls for one of the workstations to be a Preprocessor and the other two to be the Monitoring Display Stations. The Preprocessor initially processes all meteorological data before it sends the data to the Monitoring Display Stations. The Preprocessor also receives data and messages back from each MDS. The MDSs allow users to enter data, make selections, and receive warnings when adverse weather occurs. The section describing the MMS software provides more detailed descriptions of the functions of the Preprocessor and the MDS.

Serial Line Interface Protocol (SLIP), a public domain package that supports Transmission Control Protocol / Internet Protocol (TCP/IP) over serial communication lines, provides communications between the MMS Preprocessor and MDSs. SLIP allows fast efficient file transfers and two-way communications between the Preprocessor and the MDSs.

DATA SOURCES

The MMS currently ingests data from two different data sources:

- Meteorological Interactive Data Display System (MIDDS)
- McGill Volumetric Scan Radar (VSR).

The MIDDS data source is the most important data source because most of the monitoring that the system performs uses this data. MIDDS collects data from many sources. The data received by the MMS from MIDDS includes:

- WINDS. The WINDS data is the wind speed, wind direction, wind gust, wind standard deviation, temperature, dew point, and pressure data collected from the multi-level tower network located in the KSC/CCAFS area. The current network consists of approximately 54 towers. MIDDS send five-minute averages of the WINDS data to the MMS within about one minute after the end of each five-minute interval.

- Lightning Location Protection (LLP) system. The LLP data is collected by sensors which determine the location of cloud-to-ground lightning strikes. MIDDS sends the LLP data as latitude and longitude locations asynchronously. The range of the LLP extends beyond the KSC/CCAFS area to cover most of the state of Florida.

- Launch Pad Lightning and Warning System (LPLWS). The LPLWS data is collected by a network of field mills located in the KSC/CCAFS area. The field mills measure electrostatic potential near the ground to infer the potential for lightning to occur. The MMS receives the LPLWS data as Volts/meter on a grid of 25 x 25 meters.

- Upper-air data. The MMS receives upper air data from sounding balloons launched periodically from CCAFS. The types of upper air soundings are:
  * Rawindsonde
  * High Resolution Rawindsonde
  * Jimsphere

  The upper-air data consists of measurements of temperature, dew point, wind speed, wind direction, pressure, and altitude.

The Volumetric Scan Radar data which the MMS will receive consists of Constant Altitude Planned Position Indicator (CAPPI) data for the 10,000 ft. level. The VSR measures the reflectivity ratio of rainfall in a vertical column and produces CAPPI data for different altitudes.

With the present terminal server, the MMS has the capability of receiving data from many different other sources. These sources include:

- Interactive Weather Dissemination System (IWDS)
- Lightning Detection and Ranging (LDAR)
- Local Surface Observations
- NEXRAD Doppler Weather Radar
- Wind Profiler

SOFTWARE ENVIRONMENT

We designed and implemented the MMS software so that the system is easy to maintain and expand. The MMS software can be easily transported to other hardware and software platforms. The software runs on a UNIX platform and utilizes the AT&T System V ipc facilities (shared memory, message queues, semaphores). We developed the user interface using C, X Windows, Xt intrinsics and the OSF/Motif toolkit. The programming language is C. To test the systems portability, we have compiled and run parts of the system on an IBM RS6000 workstation and a Sun SPARCStation workstation.

In addition to the software mentioned above we used the software tools SL-GMS and CLIPS to assist in the development of the MMS.

SL-GMS is a tool kit developed by SL Corp. used for developing dynamic graphics screens for real-time or highly interactive applications[5]. Users can design application screens in a standard drawing tool mode, connect them to real time data sources and animate screen objects to visualize changing data values. We used SL-GMS to develop most of the data displays in MMS.

CLIPS (C Language Integrated Production System) is an expert system tool developed by the Software Technology Branch, NASA/Lyndon B. Johnson Space Center[6]. CLIPS is designed to facilitate the development of software to model human knowledge or expertise. We used CLIPS to develop sets of rules for comparing meteorological data with user-specified constraints. In the MMS, CLIPS compares the weather conditions against user established criteria and sends an alarm to the user when the data exceeds the criteria.

MMS PREPROCESSOR

The primary function of the Preprocessor workstation is to receive the data from the various data sources, perform some initial processing of the data and then send the data to the MDSs. We designed the software on the Preprocessor to handle these functions and to also receive messages from the MDS. We developed each major function of the Preprocessor as a separate Computer Software Component (CSC). Figure 3 shows a diagram of the structure and data flow of each CSC. The following is a brief description of each of the Preprocessor functions:

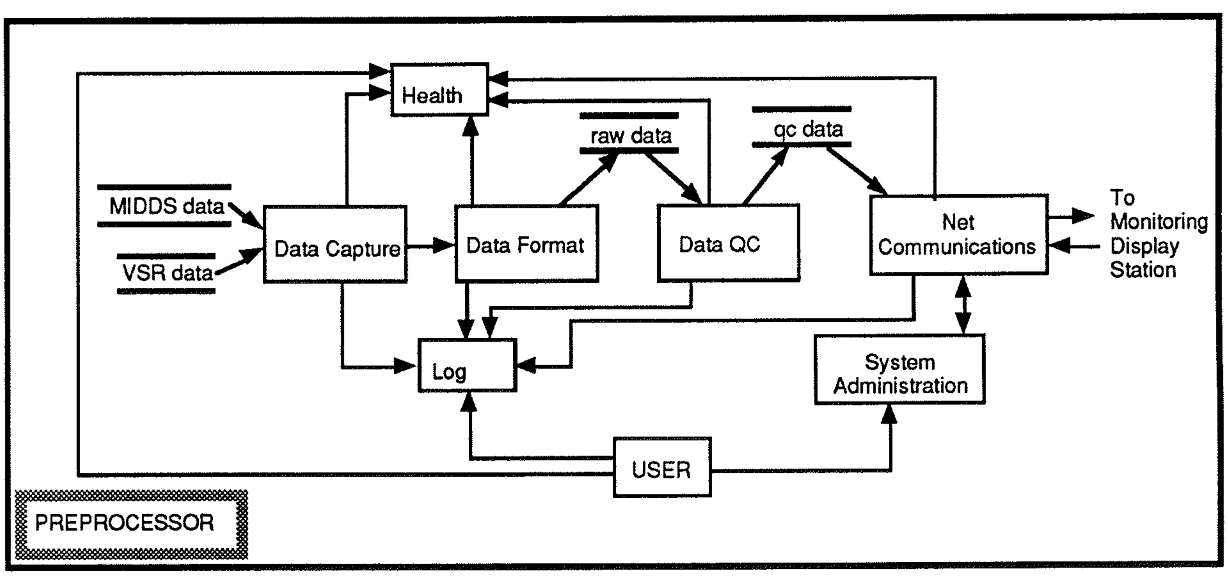

Figure 3. Data flow and organiization of the Preprocessor functions.

Data Capture. Data Capture reads the raw data coming into the Preprocessor from the different data sources and sends it to Data Format.

Data Format. Data Format gets the data from Data Capture, formats it, and puts it into shared memory.

Data QC. Data QC reads the data in shared memory, performs range checking and/or time series analysis and then writes the quality controlled data out to the hard disk. Different QC procedures exist for each data type.

Net Communications. Net Communications sends the meteorological data and the constraint data base out to the Monitoring Display Stations and receives messages and acknowledgments from each MDS.

Health/System Administration. These CSCs keep track of system functions, system health, and other network communications functions.

Log. The Log CSC keeps records of the MMS and Preprocessor events.

MMS MONITORING DISPLAY STATIONS (MDS)

The primary functions of the Monitoring Display Stations (MDS) are to receive and display the meteorological data, monitor the weather, alarm the user of adverse weather, and provide the user an interface for easily viewing and interacting with the MMS. Like the Preprocessor, we developed each major function as a separate CSC. A diagram showing the structure and data flow of each CSC is shown in Figure 4.

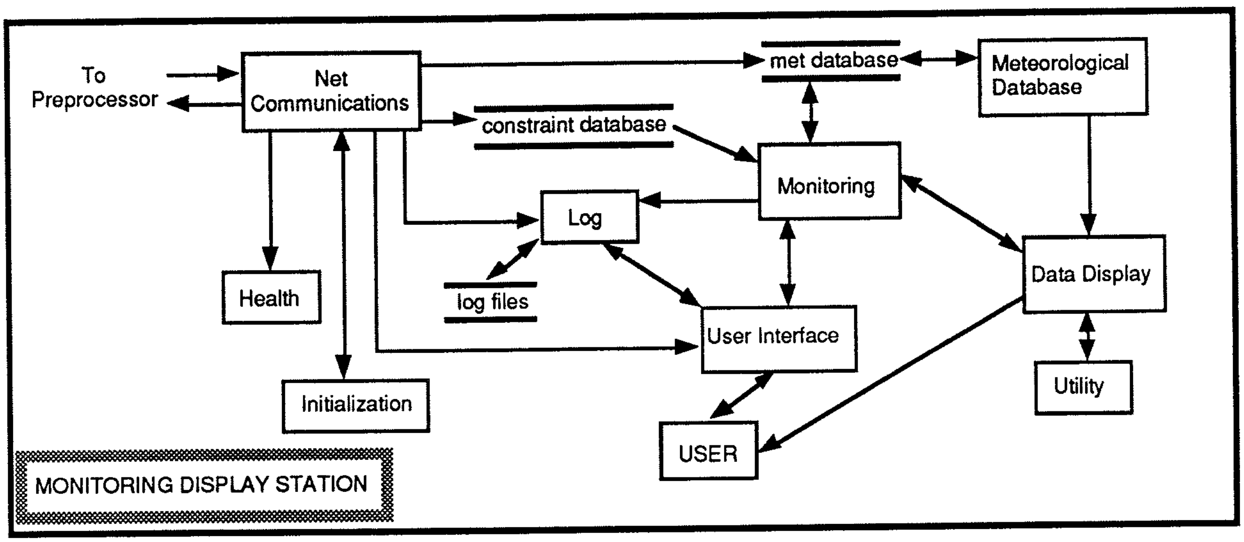

Figure 4. Data flow and organiization of the Monitoring Display Station functions.

The following is a brief description of each of the Monitoring Display Stations functions.

Net Communications. Net Communications receives meteorological data, constraint data, weather forecasts and warnings, and system status information from the Preprocessor. It also sends messages and system health/administration information to the Preprocessor. The MDS of the weather forecasters will send forecasts, advisories, and warnings.

Log. The Log CSC records pertinent information and events on the MDS and generates output for the user interface which displays logs of the System Log File, the Forecast/Advisory/Warning Log File, and Monitoring Log File. The System Log contains system and health information about the individual MDS as well as information about the rest of the MMS. The Forecast/Advisory/Warning Log contains information on the time, issuance, cancellation, and description of a forecast, an advisory or warning issued by one of the weather forecasters. The Monitoring Log contains records of the activation, deactivation, alarming, and de-alarming of monitoring events. For example this log would contain the description of an active operation and the time of activation or the time the constraints associated with that operation were violated.

Met Database. Puts the meteorological data into a data base.

Health. Health keeps track of trapped errors, the MDS system status, and the entire MMS system status.

Utility. Utility contains miscellaneous routines which the MDS needs to support its various functions.

User Interface. We designed the User Interface on each Monitoring Display Station to allow users to perform the following functions:

- Select the current days' work operations from a list of predefined operations. Once a user selects an operation, the MMS monitors the weather and weather constraints associated with that operation (Figure 5).

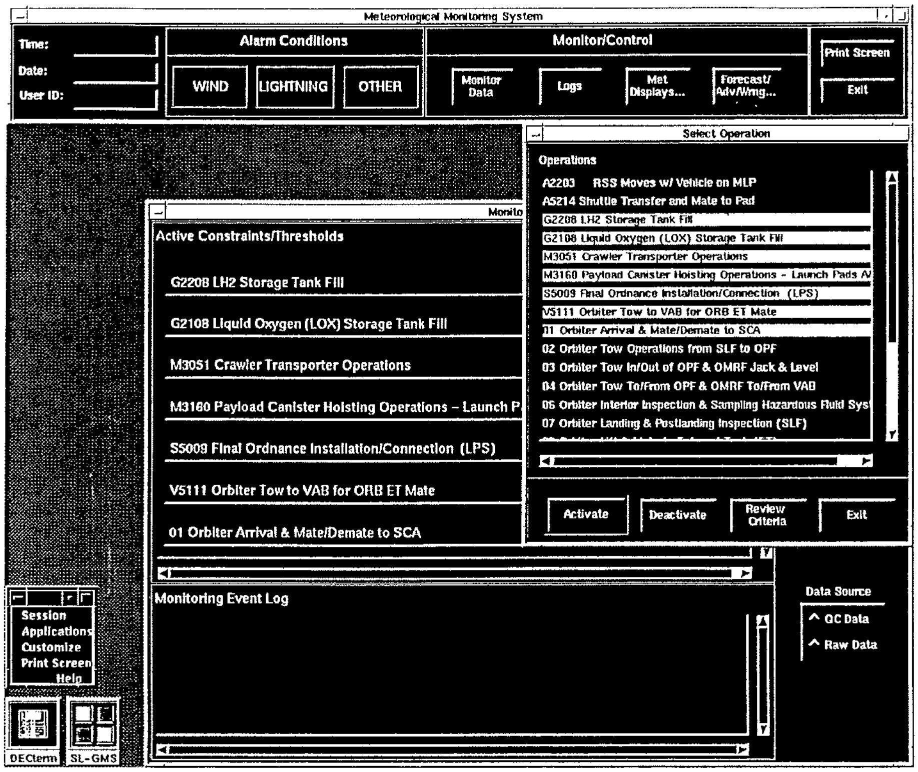

Figure 5. User Interface showing the selection of an operation for monitoring.

- Enter user-specified weather limits. The MMS monitors these weather limits (thresholds) by comparing them with incoming meteorological data.
- Observe the visible and audible alarm. The MMS flashes a red button on the screen labeled as WIND, LIGHTNING, or OTHER while a series of audible beeps alerts the user that the weather has violated a constraint.
- Display maps and graphs of meteorological data. The user selects from the following map displays: local and Florida area maps of wind barbs, wind fields, lightning location (LLP), field mill grid (LPLWS), and Volumetric Scan Radar. The user selects from the following graphs: wind roses, rawindsonde data graphs, and jimsphere data graphs (Figure 6).
- Receive weather Forecasts, Advisories, and Warnings (FAW). Weather forecasters at CCFF frequently issue FAWs to the KSC/CCAFS area when adverse weather occurs or is expected to occur. Examples of adverse weather include lightning within 5 miles of KSC, wind speeds in excess of 18, 35, 45, or 60 knots, or temperatures below 32°F. Users that receive a Forecast, Advisory, or Warning must acknowledge its receipt (Figure 7).
- Enter weather FAWs. The MMS allows only authorized personnel such as Air Force weather forecasters to issue the FAWs.

Monitoring. The Monitoring process applies user-specified weather constraints to forecast and near real-time meteorological data. This process activates alarms when weather -- predicted or actual -- violates an active set of constraints. Monitoring covers both simple and complex meteorological comparisons. An example of a simple comparison is "wind not to exceed 18.5 knots at launch pad." An example of a complex comparison is "divergence of xxx coupled with an electrical potential of yyyy."

We designed the MMS so that monitoring activity occurs within the CLIPS expert system shell. Meteorological data and forecast data enter CLIPS along with the appropriate set of rules developed for each constraint. If meteorological data violates the rules, CLIPS sends an alarm trigger to the user interface. If new data entering CLIPS violates the rules again, CLIPS recognizes that the alarm was already triggered and will not trigger it again unless the conditions causing the original violation fall below violation conditions. For example, if the MMS repeatedly receives meteorological data which violates the rule "wind>18.5 knots", the monitoring function will not repeatedly trigger alarms. The wind must fall below the specified limit, in this case 18.5 knots, and then exceed it to violate the constraint again. An alarm deactivates if none of the rules from a specific constraint trigger an alarm.

Data Display. Data Display controls the display of maps and graphs of the meteorological data. This module uses the graphics development tool SL-GMS to generate many of the displays.

SL-GMS (SL Graphical Modeling System) provides an environment to create and embed dynamic graphical screens into application software. In MMS, we used SL-GMS to manage the display of near real-time data. We used an SL-GMS internal table to link variables to screen elements. This table-driven design allows screens to update elements whose attached data variables have changed.

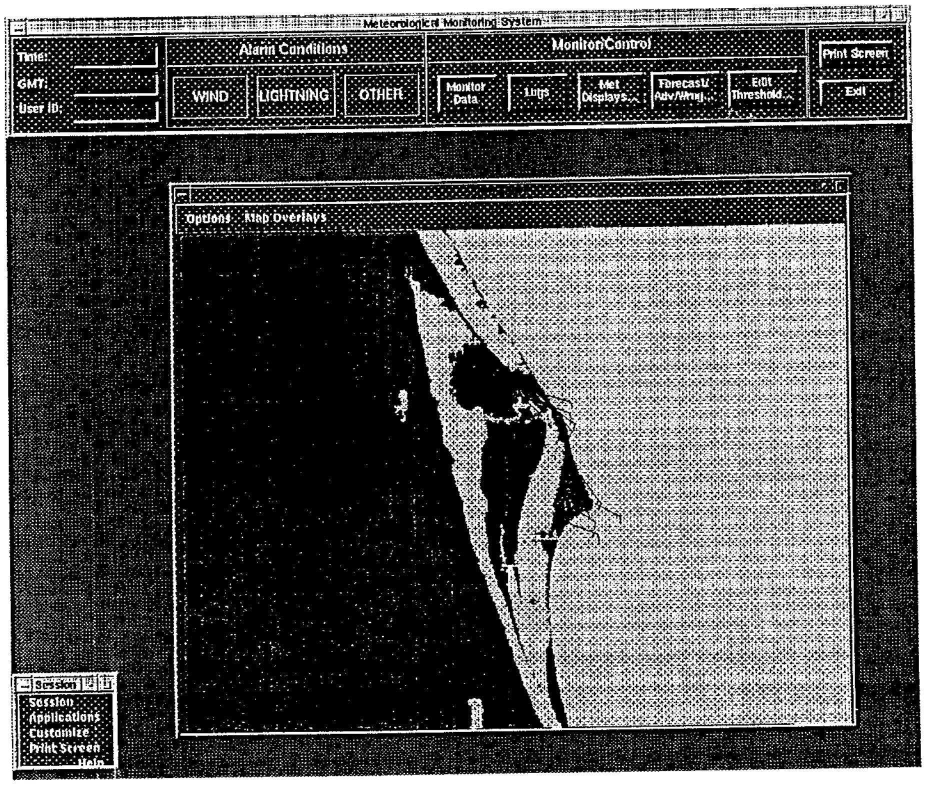

Figure 6. User Interface showing Wind Barb Meteorological Display

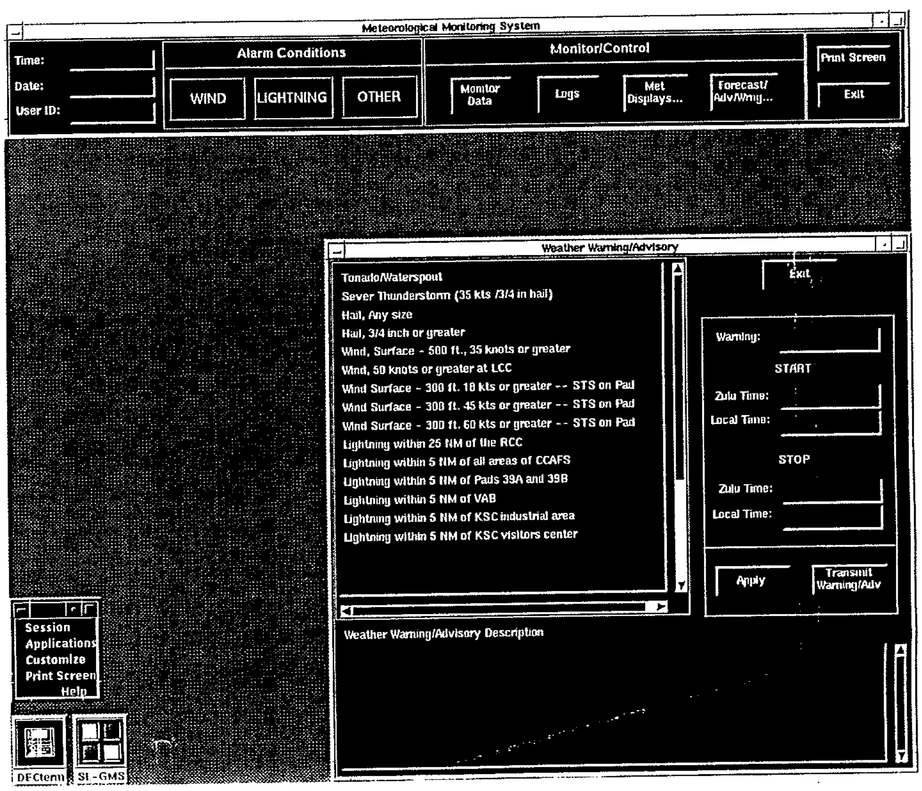

Figure 7. User Interface showing input of Forecastt, Advisories and Warnings.

SL-GMS consists of the SL-DRAW editor and a library of GMS functions. After the programmer defines the static appearance of the graphical model, they can attach dynamic attributes to describe how the model will respond to changes in real-time data. Some of the dynamic attributes include text replacement, scaling, rotation, translation transformation, percent fill, color, width, and style.

We created the Wind Barb display in MMS using the SL-DRAW editor. We first created a background map as a model with no dynamic attributes. Next, we created another model to represent a wind barb with rotation, scaling, color, and visibility dynamic attributes attached. We then duplicated the wind barb model many times to represent a series of wind towers. We used some of the GMS library functions to integrate the graphics model to the application software. As a result, each wind tower icon rotates and scales in response to the arrival of real-time data.

SUMMARY AND FUTURE MMS

The current MMS is an operational prototype which NASA and the Air Force use for monitoring the meteorology, setting work operations priorities, and disseminating weather information to the KSC/CCAFS area. ENSCO developed the current MMS under a Phase 2 SBIR contract. To upgrade the MMS to a fully operational system the following enhancements should be completed:

Add diffusion modeling capabilities. Safety personnel use the current MARSS system in operation at KSC/CCAFS primarily to display meteorological data and to predict toxic corridor locations. These diffusion modeling capabilities in MARSS should be included into the MMS to make it a monitoring system which safety and operations personnel could use. MMS could incorporate any number of diffusion models into the system including: OB/DG, LOMPUFF, AFTOX, or other model developed for emergency response applications.

Include maps and data bases. The MMS could be enhanced by adding automated mapping and data base retrieval functions similar to the MARSS safety map function. One possible solution might be to include a Geographic Information System (GIS). A GIS is a computer software product used to automate, manipulate, analyze and display geographic data in digital form. A GIS features data base management, map overlay, spatial analysis, interactive display and queries, and graphic editing. The GIS could utilize data from KSC/CCAFS on many different applications for emergency or routine operations. These applications include roads, buildings, personnel locations, soils, vegetation, or hazardous material storage sites.

Add data sources. NASA and the Air Force collect meteorological data from many different sensors and systems at KSC/CCAFS. The MMS currently only receives data from MIDSS and Volumetric Scan Radar. In the future the MMS could be modified to receive data from these other sources. MMS could then display the data as well as process the data for monitoring. Other possible data sources are: Interactive Weather Dissemination System (IWDS), local NWS or FAA surface observations, LDAR, NEXRAD Doppler radar, wind profiler, or acoustic sounder.

Expand network. The current configuration of the MMS consists of one preprocessor and two Monitoring Display Stations (MDS). Additional MDSs could be added with very little impact on the performance of the Preprocessor or the rest of the MMS. The MDSs could be added to other sites around KSC/CCAFS or to nearby Patrick Air Force Base. Also, since we developed the MMS software using standardized tools and techniques such as UNIX and C, we could install the MMS on any UNIX based computers. For example, we could install the MMS in the workstations of the Command Control and Monitoring System 2 (CCMS2) which is NASA's launch processing system currently under development.

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