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Monterey, California



THESIS

SATELLITE IMAGE DISPLAY AND PROCESSING
WITH MICROCOMPUTERS:
A Proof-of-concept for the Navy
Oceanographic Data Distribution System
(NODDS)

by

LT Don T. Conlee, USN

June, 1991

Thesis Advisor:

Professor Carlyle H. Wash

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**SATELLITE IMAGE DISPLAY AND PROCESSING WITH MICROCOMPUTERS:
A Proof-of-concept for the Navy Oceanographic Data Distribution System (NODDS)**

by

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Lieutenant, United States Navy
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of the requirements for the degree of

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ABSTRACT

The capabilities of small, primarily single-user computers have increased to the point where serious attention to the use of these systems as image display and processing stations is warranted. The addition of satellite display and processing to the existing Navy Oceanographic Data Distribution System (NODDS) can represent significant enhancement to the forecasting mission of Naval Oceanography Command Detachments and Facilities. This thesis outlines and demonstrates an approach to adding image functions to NODDS. Software has been written to display Defense Meteorological Satellite Program (DMSP) visual and infrared images within the NODDS software environment. Routines have also been developed to provide enhancement of the imagery. The requirements for communicating the imagery are addressed and supported by the testing of image transfer times. Finally, plans for system improvement and operational implementation are discussed.

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TABLE OF CONTENTS

I. INTRODUCTION	1
II. EXISTING NODDS SYSTEM OVERVIEW	3
A. OPERATIONAL CAPABILITIES	3
B. SYSTEM DESIGN AND ARCHITECTURE	4
C. SATELLITE UPGRADE CONSIDERATIONS	8
III. SATELLITE IMAGE DISPLAY AND ENHANCEMENT	10
A. IMAGE DISPLAY AND PROCESSING FUNDAMENTALS	10
B. SUITABILITY OF MICROCOMPUTERS FOR IMAGE DISPLAY AND PROCESSING	13
C. EXISTING SYSTEMS	17
D. IMAGE DISPLAY TECHNIQUES FOR UPGRADING NODDS	19
1. Introduction	19
2. Software Language Considerations	19
3. Image Format Considerations	21
E. NODDS INTEGRATION DESIGN	23
F. IMAGE ENHANCEMENT DESIGN	27

G. IMAGE PRINTING CONSIDERATIONS	30
IV. COMMUNICATIONS	34
A. INTRODUCTION	34
B. EXISTING FNOC BINARY TRANSFER PROTOCOLS	34
C. A COMMUNICATIONS ALTERNATIVE	36
V. CONCLUSIONS AND RECOMMENDATIONS	40
A. SUMMARY	40
B. OPERATIONAL IMPLEMENTATION	41
C. FURTHER RESEARCH AND DEVELOPMENT	42
1. Existing Algorithm/Code Improvement	42
2. New Algorithms/Features	42
3. Hardware Improvements	43
4. Outlook	44
REFERENCES	45
INITIAL DISTRIBUTION LIST	46

LIST OF TABLES

TABLE 1. AVAILABLE PRODUCTS FOR NODDS VERSION 2.1	1
.....	5
TABLE 2. NODDS FIRST LEVEL MENU STRUCTURE	
.....	7
TABLE 3. IMAGE FILE TRANSFER TIMES FOR PROCOMM INTERNAL PROTOCOLS	
.....	39

LIST OF FIGURES

Figure 1. NODDS 2.1 Display of Surface Pressure Field	8
Figure 2. Components of a generic image display and processing system.	10
Figure 3. Comparison of floating-point processing speed.	15
Figure 4. Functional Design Chart for image display within a NODDS framework.	24
Figure 5. Display of a DMSP visual image mosaic.	25
Figure 6. Display of image with corresponding FNOC surface pressure analysis overlaid.	26
Figure 7. Image Enhancement functional design chart.	28
Figure 8. Display of DMSP IR image with straight gray scale.	29
Figure 9. Display of DMSP IR image with high-cloud enhancements.	30
Figure 10. Laser hardcopy printing of image and overlay from Figure 6.	32
Figure 11. Principal components of test and proposed communications system.	37

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I. INTRODUCTION

The capabilities of small, primarily single-user computers have increased to the point where serious attention to the use of these systems as image display and processing stations is warranted. The cost of such systems is relatively low compared to traditional image processing workstations. Many microcomputers are already in place in environmental support activities, yet most of these facilities have little or no ability to display and process satellite imagery. The typical Naval Oceanography Command Detachment is already using the microcomputer to retrieve and display conventional meteorological data with the Navy Oceanographic Data Distribution System (NODDS) Version 2 (Thormeyer et al. 1990). The addition of satellite display and processing into this system would be a significant enhancement to the aviation forecasting mission. Larger facilities could also benefit from a modified NODDS as a backup and predecessor to larger and more powerful workstations. The existing personal computer (PC) hardware and software system also reduces the investment required to bring image display and processing capability to many activities.

The focus for this thesis is to prepare and demonstrate an approach to add satellite display and processing capability to the NODDS hardware/software system. Specifically, the objectives include: (1) development of PC display routines for Defense Meteorological Satellite Program (DMSP) visual and infrared (IR) images; (2) the

integration of image display into a NODDS environment to allow the overlay of conventional NODDS data over images; (3) the development of a "user-friendly" color remapping enhancement scheme; (4) the proposal of a communications system to deliver the images with benchmark transfer time tests; and (5) development of a plan for system improvement and operational implementation from insight gained during thesis research and development.

Chapter II describes the current NODDS Version 2 system without satellite capability. Chapter III presents a discussion of image display and processing fundamentals and of microcomputer capability and suitability followed by a description of display techniques used in this thesis. Specific examples of already existing systems will be given. Chapter IV will address image communications, to be followed by a conclusions chapter (V) that will address recommended development options for a fully operational NODDS system with satellite image display enhancements.

II. EXISTING NODDS SYSTEM OVERVIEW

The goal of this chapter is to introduce the current NODDS Version 2.1 system without any modifications for satellite image display and processing. This background should be helpful in understanding the issues involved in upgrading the system to perform image-related functions.

A. OPERATIONAL CAPABILITIES

NODDS Version 2.1 is designed "to upgrade and improve support for Naval Oceanography Command Facilities and Detachments by providing a method for obtaining tailored environmental products for their areas of responsibility" (Fleet Numerical Oceanography Center {FNOC} 1990). It provides the capability to define an area of interest and display many different types of conventional data for that area. Virtually all of the standard meteorological fields available from FNOC can be displayed (eg. surface and upper-air analyses and forecasts). Wind fields can be represented as wind barbs, isotachs or streamlines. Synoptic data can be represented with station model plots and skew-T diagrams are also supported.

In addition to the standard meteorological products a wide variety of oceanographic products are available. Derived acoustic propagation products can be displayed as well as more conventional oceanographic data such as wave heights and ice edges. Standard Naval Oceanography Command wind, high seas and tropical cyclone warnings are

depicted graphically and unclassified depictions of oceanic fronts and eddies are available for many areas. Table 1 is a listing of products supported in the current release of NODDS.

NODDS gives the ability to overlay up to three different fields (in different colors) for the same area. The graphic screen can be zoomed for more detail and printed to a graphics-capable printer. Loops can also be created to animate standard fields. An example of a loop is the surface analysis and forecasts every 12 hours extending to 72 hours, providing the user with animation of the evolution of the atmospheric model forecast.

B. SYSTEM DESIGN AND ARCHITECTURE

The NODDS design is highly constrained by the capabilities of the hardware on which it is implemented. The Navy standard hardware available to many users during the program development was the Zenith Z-248 microcomputer. This system represents a relatively slow (8 MHz) IBM AT class Intel 80286 based computer. The typical installed system within the Navy Oceanography Command includes color Enhanced Graphics Adapter (EGA) graphics and a small, slow hard disk drive (typically 20 MB, 65 millisecond access time). NODDS 2.1 squeezes a great deal of productivity from this very dated hardware set. The addition of a mouse greatly enhances the operation of NODDS, and a math-coprocessor is highly recommended. Because of the extreme portability of MS-DOS applications, NODDS 2.1 will run well (and proportionally faster) on more advanced machines such as those based on the Intel 386 or 486 processors.

TABLE 1. AVAILABLE PRODUCTS FOR NODDS VERSION 2.1

Upper Air Sounding	250MB Height
Synoptic Reports	250MB Temperature
Surface Pressure	250MB Wind
Surface Air Temperature	200MB Height
Surface Wind	200MB Temperature
Significant Wave Height	200MB Wind
Sea Direction	
Ditch Headings	Tropopause Height
	Thickness 1000-500MB
1000MB Height	Tropopause Temperature
1000MB Temperature	Tropopause Wind
1000MB Wind	Freezing Level
925MB Height	Wind Warnings
925MB Temperature	High Seas Warning
925MB Wind	Fronts and Eddies
850MB Height	Ice Edge
850MB Temperature	Tropical Cyclone
850MB Wind	Warnings
700MB Height	200MB Jetstream
700MB Temperature	
700MB Wind	Shallow Sound Channel
500MB Height	Strength
500MB Vorticity	Deep Sound Channel Depth
500MB Long Wave	Half Channel
500MB Temperature	Bottom Bounce Range
500MB Wind	Convergence Zone Usage
400MB Height	Convergence Zone Range
400MB Temperature	Sonic Layer Depth
400MB Wind	Sea Surface Temperature
300MB Height	
300MB Temperature	
300MB Wind	

The NODDS system is most unique in its approach to environmental data communications. Once a user has defined an area and the products desired for that area, an automatic process of acquiring the data is initiated when new data is desired. Using

a commercial "off-the-shelf" licensed communication package, the system calls FNOC and requests fields (or other data type) from a security shell in a host mainframe computer. The required fields or data are extracted from the FNOC global databases and a compacted ASCII transmission is generated for each field/product. By transmitting field data and limiting the area extraction to only that required by the user, the transmissions are very small and communications efficient. Once the raw data is received by the user's NODDS system the required contouring, streamlining, etc. is performed automatically until all products are in a ready-to-display format. A typical surface pressure field can be downloaded in less than 2 minutes (including security logon and housekeeping), and contoured for display in about 15 seconds. This process is naturally computationally intensive and demands a math coprocessor for most operational response time constraints. Older generation machines without a coprocessor can take from a few to several minutes to contour and display a typical field.

NODDS employs a user interface of windows and drop-down style menus grouped logically by similarity of function. This proven user-friendly approach enables most operators to completely master the system with little or no training. Within applications which require user responses, case-specific options are presented in borders which do not interfere with the graphic display. Table 2 is a representation of the first level menu structure within NODDS, and Figure 1 is a typical NODDS display of conventional data. Both within applications and in navigating the drop-down menus a pointing device such as a mouse is well supported and enhances ease of use.

The NODDS design of contouring and processing of raw fields within the

TABLE 2. NODDS FIRST LEVEL MENU STRUCTURE

<p>NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM</p> <p>Version 2.1 November 1990</p> <p>Fleet Numerical Oceanography Center</p> <p>Monterey, California 93943-5005</p>			
DATA MANAGER	DISPLAY	FIELDS/AREAS	CONFIGURE
INSTRUCTIONS	MAP	SELECT FIELDS	CONTOUR VAR.
RETRIEVE DATA	LOOP	DEFINE AREA	CHANGE COLORS
ARCHIVE DATA	SKEW T	DELETE AREA	COMMUNICATIONS
RESTORE DATA		RENAME AREA	TIME ZONE
UPPERAIR DATA		DUPLICATE AREA	PRODUCT OPTIONS
OTHER DATA			PRINTER OPTIONS
QUIT			

microcomputer gives the user flexibility in the presentation of products. The user may choose the contour interval and the contour line style. Options are available to tailor the NODDS color scheme to individual tastes.

The majority of code for NODDS 2.1 is written in QuickBasic Version 4.5 from Microsoft. This language is much more capable than the interpreted Basic bundled with most DOS/MS-DOS releases. QuickBasic has both interpreted and compiled modes of

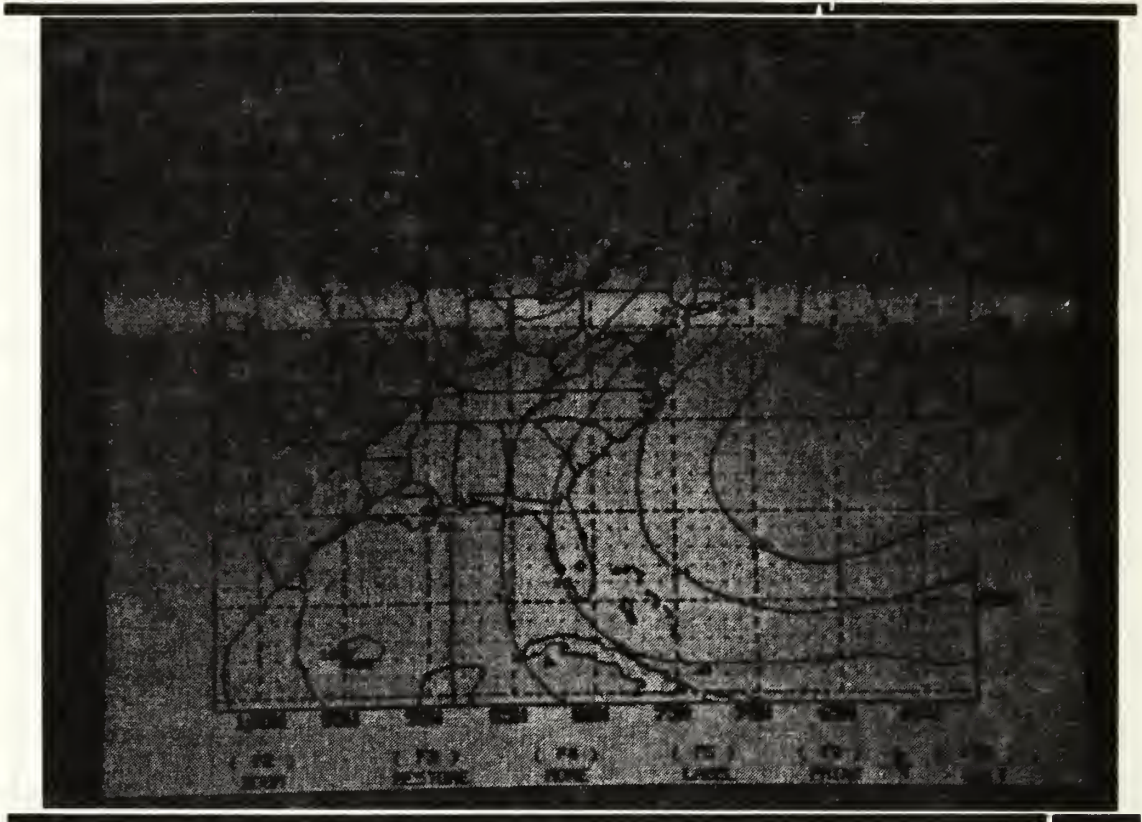


Figure 1. NODDS 2.1 Display of Surface Pressure Field

operation, and provides a conducive environment for modular programming with ample support for code libraries and modules. NODDS has been designed and written to take advantage of this structured approach to programming.

C. SATELLITE UPGRADE CONSIDERATIONS

In many respects, NODDS is an ideal environment to introduce image display and processing functions to the microcomputer. A complete geographic database is resident for adding backgrounds. The applications for display and processing of conventional data to overlay satellite images are already developed. The modular nature of the code allows the reuse of existing library routines, and for the placement of image display and

processing routines within the overall structure.

Two problem areas remain. First, the typical hardware on which NODDS runs (the Zenith 248) is insufficient to meet the needs of image processing in several respects. This will be considered Chapter III. Secondly, the communication of satellite imagery is much more demanding than that of conventional data. This will be addressed in Chapter IV.

III. SATELLITE IMAGE DISPLAY AND ENHANCEMENT

A. IMAGE DISPLAY AND PROCESSING FUNDAMENTALS

There are a number of basic tasks which must be accomplished in order to display and process imagery (of any kind). Figure 2 is a schematic of a generic image display and processing system for environmental satellite data. It is in agreement with the general-purpose image processing system described by Green (1983).

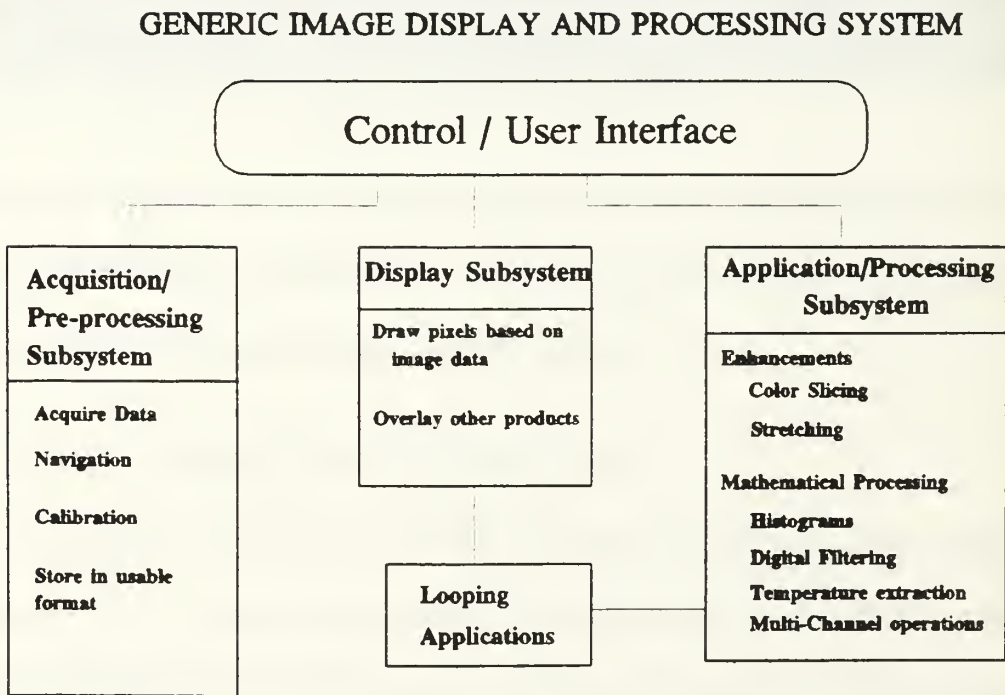


Figure 2. Components of a generic image display and processing system.

All systems must have control software which provides the user-interface to the main functions of image display and processing, as well as other systems level processes. The operating system of the computer may perform most of the control function, supplemented by a consistent user-interface (e.g. menu program) (Green 1983).

The image data must be ingested into the system, and this is the function of the Acquisition/Preprocessing subsystem. A complex and computationally intensive example of this function might consist of the ingest of the real-time digital bitstream from an environmental satellite. At the simple extreme is pre-processed data from a larger system arriving in digital format over a communications link (e.g. RS-232 serial communications port). Once the data arrives in the computer it may need to be navigated, or earth-located, to facilitate any further mix of the image data with conventional data. If the imagery is earth-located prior to ingest, the display and registration function is simplified. If calibration data arrives with the imagery, it should be used so that pixel brightness may correspond to temperature or reflectance. Finally, the imagery must be written to a storage medium in a format ready to be used by the other software and hardware subsystems.

The Applications subsystem consists of processing the imagery to enhance user understanding or interpretation of the data which may not be apparent from basic pixel brightness display. The simplest category is image enhancement, where the pixel brightness is mapped to display intensity in a fashion other than straight gray-scale. This may take the form of displaying data on either side of a brightness/temperature threshold and/or slicing a range to be highlighted in some way (e.g. color). Stretching allows the

display of a range of interest with greater intensity resolution than normally available by mapping the range into a large portion of the available colors/gray-scales. Histograms of pixel values can aid in the selection of stretch ranges and give valuable information about image content. The look-up table (LUT) enables much of this type of processing as each pixel is referred to it for a new display value (Robinson 1985). Processing may also take more complex forms, such as digital filtering, edge detection and enhancement, multi-image mathematics and a host of other more specialized information extraction applications.

The Display subsystem must be able to take the image data, adjust it according to LUT references and write final pixel values to the memory serving as refresh for the video display. In addition, this module would include routines to overlay conventional (non-satellite) data such as contours and surface data plots. A system for hand-annotating the imagery with standard weather symbols is also useful. This necessitates the use of some graphics pointing device, such as a mouse, joystick or trackball, which is also useful for many of the other processing applications.

An important capability of many systems is the ability to loop (animate) geostationary imagery in a fashion similar to the analog movie loops of older systems. Looping has seen widespread use in operational weather forecasting activities and in commercial television broadcasting.

B. SUITABILITY OF MICROCOMPUTERS FOR IMAGE DISPLAY AND PROCESSING

Image processing hardware must meet some minimum requirements to be suitable to perform all or some subset of the tasks listed in the previous section. CPU and disk access speed must be adequate to support the overall system control, as well as perform any of the desired complex single and multi-image processing applications. Response time to perform these tasks must be fast enough to support operational usage. Video hardware must exist to provide display of imagery with adequate spatial resolution. There must also be sufficient bit planes to display the required levels of gray or discrete colors (also known as bits per pixel or thermal/brightness resolution). In 1983 the McIDAS III (Man-computer interactive data access system) was introduced at the University of Wisconsin and represented the near state-of-the-art in operational image display and processing capability. The graphics terminals provided video resolution of 640 x 480 pixels with 6 bits per pixel (Suomi et al., 1983). Though the state-of-the-art has advanced considerably since then, one could conclude that a microcomputer based system that could approach these display specifications would be suitable for many applications. My own experience in viewing imagery with this resolution supports such a conclusion. Finally, if looping is desired, sufficient solid state memory must be present to support the number of images (or frames) to be looped. Thus, three factors become apparent in implementing image processing on microcomputers: sufficient CPU and disk access speed to support operational response time, adequate display capability and sufficient random access memory (RAM) to support any desired looping capability.

The CPU speed of typical microcomputers has dramatically increased over the last 4 to 5 years. The current generation of top IBM PC compatible computers are approaching the computational speed of comparatively young scientific minicomputer systems. A test was conducted to compare the computational speed of PC microcomputers, image processing workstations in the Naval Postgraduate School's IDEA Lab and the NPS IBM mainframe computer (configurations as of September 1990). The test consisted of standard Fortran whetstones designed to measure the floating point computational speed of the processors. The results were given in terms of millions of whetstones completed per second. The results of the test are given in Figure 3. The 486 based microcomputer exceeded the floating point computational speed of the fastest image processing workstation at the Naval Postgraduate School's Interactive Digital Environmental Analysis (IDEA) lab. Since a basic 386/20 MHz machine is comparable in speed to the lower IDEA lab machines, a preliminary conclusion is that such a machine could support the computational requirements of image display and processing functions. Disk access of current generation systems falls in the 10 to 30 millisecond range with data transfer rates around 500,000 bytes per second. Since $512 \times 512 \times 8$ images are less than 300,000 bytes this would suggest that they could be retrieved from disk into memory on the order of 1 second which should be acceptable for most applications.

The graphic display capability of microcomputers has also experienced rapid growth in recent years. In the IBM PC compatible realm, successive hardware and software industry standards have emerged, each with more resolution than the preceding standard. One of the more recent transitions was from the Enhanced Graphics Adaptor

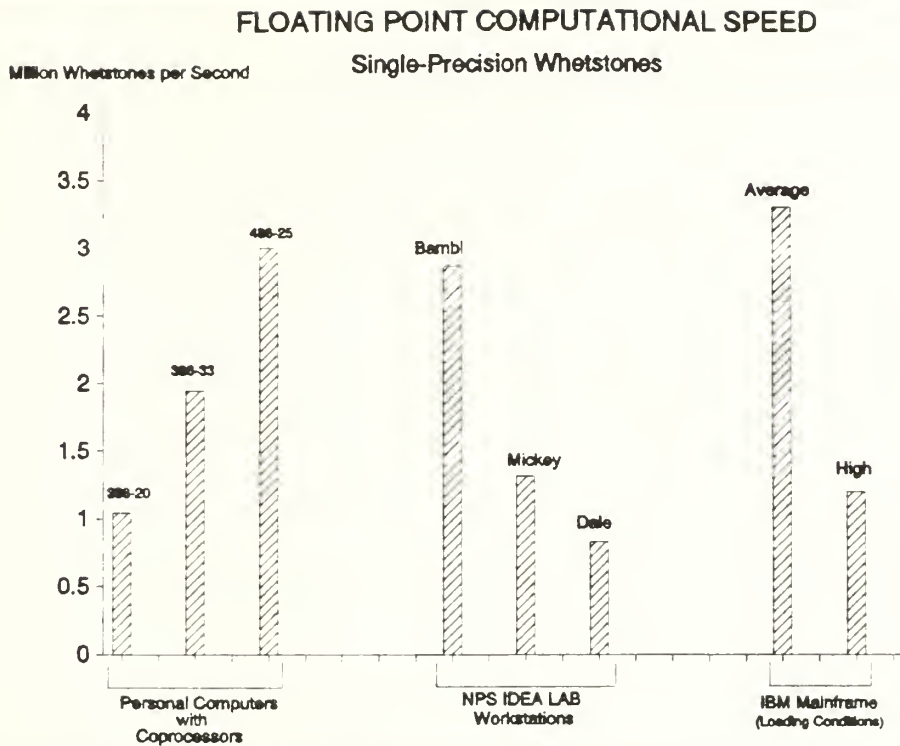


Figure 3. Comparison of floating-point processing speed.

(EGA) to the Video Graphics Array (VGA) standard. Though high-resolution hardware had already been available for custom software applications, the EGA to VGA transition marked the point where industry standard hardware and software would function well in an image display environment. The standard VGA card is capable of 640 x 480 pixel resolution. At this resolution, each pixel can have one of 16 levels of intensity (unique colors) which are a pre-defined subset of 262,144 colors (Microsoft Corp. 1989). The subset is the "palette" of available colors. The possible colors are obtained by mixing the red, green and blue "guns", each of which can have intensities ranging from 0 (no contribution) to 63 (full contribution). Thus the number of possible colors is 64 cubed,

or 262,144 or 256K. By decreasing the pixel resolution to 320 x 200 the standard VGA system can increase its palette to 256 of the 256K colors. Thus, the VGA standard hardware/software presents a trade off between pixel resolution and pixel "depth". Higher resolutions are available on many current systems (so-called Super VGA), but these modes are not standard and are proprietary. Thus, they are not supported directly by most software development tools and languages. Through custom drivers, however, systems can reach resolution of 1024 x 768 with up to 256 colors.

The EGA standard, in contrast, is only marginally suited for any image display. Only four levels of intensity are possible for each primary color, and thus only 64 colors are possible. For gray shading, only black, two levels of gray and pure white are available. The palette is a pre-defined 16 of the 64 possible colors. In the absence of any other imagery or display capability, some strategies may be possible to make the EGA standard microcomputer display marginally acceptable imagery. On some monitors it is possible to switch to all green or amber shading, thus allowing 16 shades of one of these colors. Also, some experimentation with using the possible gray shades with blue shades has been tried and shown to be useful (LCDR D. McCarren, Personal communication).

The amount of memory resident on microcomputers has grown rapidly in recent years as the memory prices have dropped and the capability to effectively manage large amounts of memory has grown. The typical VGA hardware has from 256K to 512K graphics memory "on-board" which can support multiple "pages" or images. On newer systems as much as 16 megabytes of memory beyond the normal system memory can be

installed on the "motherboard". Even more may be added with the addition of memory hardware "cards". This memory can be used to hold imagery for quick transfer to one of the video pages on the VGA hardware. Thus, the microcomputer is capable of significant looping capability at ever-reducing costs. A 512 X 512 image with 16 levels (4 bits) takes approximately 140,000 bytes of memory. Using extended or expanded RAM to refresh the video memory, a machine with 2 megabytes of this type of memory should be capable of looping about 14 images. Thus, a microcomputer with 4 MB total memory should be sufficient to perform basic looping operations.

C. EXISTING SYSTEMS

Evidence of the microcomputer's capability to serve as an image display and processing workstation is found in several new systems which perform at least some image processing functions. The PC-McIDAS is a micro-based version of the very successful University of Wisconsin meteorological analysis system. Implemented on a Intel 386 and VGA-based system, the software is capable of numerous display and processing functions on both conventional data and satellite imagery. Imagery can be navigated and geographic background overlaid. The conventional data, such as surface pressure analyses and data plots, can also be overlaid. Temperature can be extracted from the imagery, and looping is also possible. The system is capable of 12 gray shades, with a background and three colors reserved for overlays (Unidata 1990).

Commercial vendors are now using 386-based microcomputers for image display stations, primarily targeted for the user who needs loops of geostationary imagery.

Northern Video Graphics (NVG) has developed software which allows the microcomputer to perform looping and other image display functions. Histogram calculation and temperature extraction is also possible. Loops can be constructed and placed in memory accessed by any of the common high memory management standards. A meteorological "paint" program is provided to annotate imagery with color meteorological symbols. The system is dependent upon separate NVG image ingest equipment (NVG, Personal communication, 1990). Information Processing Systems (IPS), developer of the DWIPS looper and Naval Satellite Display System (NSDS) is marketing a stand-alone GOESTAP system based on a 386 micro with super-VGA. This system is also capable of ingesting DIFAX products, in addition to the capabilities of the NVG system previously mentioned. The image resolution is 560 x 480 pixels, with a palette of 256 colors (IPS, Personal communication, 1990).

The Naval Oceanographic Office has developed a system to send compacted imagery to fleet units in ASCII message format for display on an HP-9020. The imagery is prepared and displayed on an EGA-equipped 80286 system. Due to the limited gray shade capability of the hardware, the imagery is displayed in subdued colors which give a marginally acceptable display. This system is designed primarily for sea surface temperature depiction from infrared imagery (Naval Oceanographic Office, 1990).

The PC-McIDAS, NVG and IPS systems all support the hypothesis of the preceding section: A 386 system running at 20 MHz, a VGA graphics system and a 10-30 millisecond hard disk system with 500 KB/sec transfer rate should be able to function as an image display and processing system. If looping is required, then 4 mb of memory

must also be installed. It is possible that a very basic image display could be supported on a 80286 machine (such as the older Navy standard Z-248) if it is upgraded to support the VGA video standard. Routines developed for this thesis will be tested on this class of hardware to determine this possibility in order make use of some existing equipment at facilities and detachments.

D. IMAGE DISPLAY TECHNIQUES FOR UPGRADING NODDS

1. Introduction

One of the primary goals of this thesis was to develop software to display DMSP satellite mosaics on a microcomputer within the framework of a NODDS environment. An additional constraint was that the imagery should be in a standard FNOC format. The ability to overlay the FNOC imagery with conventional NODDS products was also a stated goal, and with a great deal of assistance from the NODDS staff at FNOC this has been accomplished. During the development process, several of the problems and trade-offs associated with microcomputer image display were encountered, and this section will discuss these issues.

2. Software Language Considerations

Because all code written in support of this thesis is intended to be eventually integrated into an enhanced version of NODDS, an initial attempt was made to develop the display routines in Microsoft QuickBasic version 4.5, the primary language of NODDS 2. This would enable easier integration and avoid mixed-language problems. A program was written which did display the DMSP mosaics, but two problems were

revealed. First, the binary file-handling intrinsic to the QuickBasic language is quite limited. The only way found to read a single byte from a binary file was to read it as a character variable and then convert the character into a hexadecimal value. The necessity of this stems from a lack of an INTEGER*1 variable type. Thus, a conversion operation must take place for each pixel value read, further slowing the process of image display. The second problem was one of image display speed. The compiled Basic took far longer than similar Fortran code to set each pixel in a scan line (raster) to the appropriate color and eventually "paint" the entire image. Experiments were run to make sure this was not a disk access problem by first reading the image into a large memory array and then displaying. The conclusion is that QuickBasic is just very slow at pixel-by-pixel graphics.

Due to these problems, a Fortran routine was written to improve display speed. Microsoft Fortran version 5.0 does provide INTEGER*1 types and allows the convenient reading of large file blocks into arrays with single statements. The final code displayed an image roughly 5 times faster than the Basic code. The display time even for the Fortran routine is on the order of 90 seconds depending on the speed of the machine. This relatively slow speed is due to the process of converting a brightness or temperature value into a color value for display. However, it was found that this process would only have to be performed for the initial image acquisition. Using other features of the Fortran compiler, the video attributes of the resulting screen can be saved to disk and redisplayed on the order of one second.

Having determined that Fortran was best suited to display imagery, attention was turned to the problem of integrating Fortran code into the NODDS QuickBasic environment. After researching the issues of mixed-language interfacing between the languages a program strategy was developed. Following acquisition of the imagery the initial display is handled by a Fortran routine. This routine also saves the video attributes into a file for fast redisplay from within the NODDS environment as often as required. Once within a NODDS environment, a second Fortran routine quickly re-displays the image in the window provided by QuickBasic. This two-step process is consistent with the nature of the current NODDS Version 2.1: the user orders a product and the raw information must first be processed (contoured, etc.) in order to be displayed.

3. Image Format Considerations

One of the early decisions made in this development process was one of choosing 8 or 4 bit images as the baseline for development. Because the standard VGA can display only 16 gray shades (or colors) in the desired high-resolution modes, there is no advantage to using the full 8-bit image for a display spanning the entire range of values. However, for applications such as sea surface temperature (SST) depiction, having the complete image resolution available and using the available colors to display the portion of the temperature range of interest in its full resolution is desirable. Since for most operational meteorological applications 4-bit images are sufficient and have the advantage of being half as large to communicate, the baseline for development was defined to be 4-bit images. Code was developed to display 8 bit imagery, however, and

the modular nature of this effort and NODDS in general will make adding the capability straightforward.

Though the 4-bit imagery can be mapped directly into 16 levels of gray or colors, some unique colors need to be reserved to display NODDS backgrounds, overlays, instructions, and borders. This problem was handled by mapping the 16 levels into 13 levels, thus reserving 3 of the 16 available colors. This is similar to the image display approach and capability of the PC-McIDAS system. All images appearing in this thesis are displayed with the 13 shade/color mapping.

The constraint that the imagery be of a standard FNOC format was settled with a conference with Jim Cornelius of FNOC. The Data Exchange Format (DEF) is the primary image format at FNOC, and is also relatively straightforward and very well documented. This format is specified in the Standard Formats for Weather Data Exchange published by the Federal Coordinator for Meteorological Services and Supporting Research (1990). The data is formatted in blocks having a mode and submode code which detail the type of information in the block. In the case of FNOC DMSP mosaic images, there are four blocks in a header, followed by blocks of raster image data. The header contains a great deal of information about the image, including product identification, image size, latitude and longitude and imaging sensor. This information could be usable in a scheme to automatically catalog arriving images, and provide parameters to display routines without operator intervention. While DEF may not be the eventual format for transmitting images to microcomputer workstations due to compaction reasons, it is the current standard and requires no unusual effort on the part

of FNOC to prepare. Therefore, it is a logical starting point for this thesis and for subsequent work.

FNOC provides DEF standard images only in a 512 x 512 format, either 4 or 8 bits per pixel. As previously mentioned, the maximum standard VGA resolution is 640 x 480 pixels in 16 colors/gray shades (4 bits). The code was developed to display 512 x 455 pixels (allowing for borders above and below the image), essentially omitting the bottom 52 scan lines.

E. NODDS INTEGRATION DESIGN

The overall functional design for the integrated NODDS satellite-capable system is shown in Figure 4. The user is first asked to choose an area of interest. The images available for this area are given and the user chooses one for display. The appropriate Fortran display routine is then called, and the NODDS QuickBasic code provides the borders, geographic background and presents the user with further options. Figure 5 is an example of the display capability developed, and is a DMSP visual mosaic image displayed with 13 gray shades with geography overlaid in color. By using the NODDS code to overlay the geographic background instead of having FNOC place it in the image, two important advantages are realized. First, the absence of the geographic backgrounds in the original image improves the efficiency of compaction schemes by preserving the rather uniform image pixel values without adding starkly contrasting background values. Second, by performing the background overlay within the NODDS system, the user gains control of the color of the background overlay. Any color change given to the FNOC-

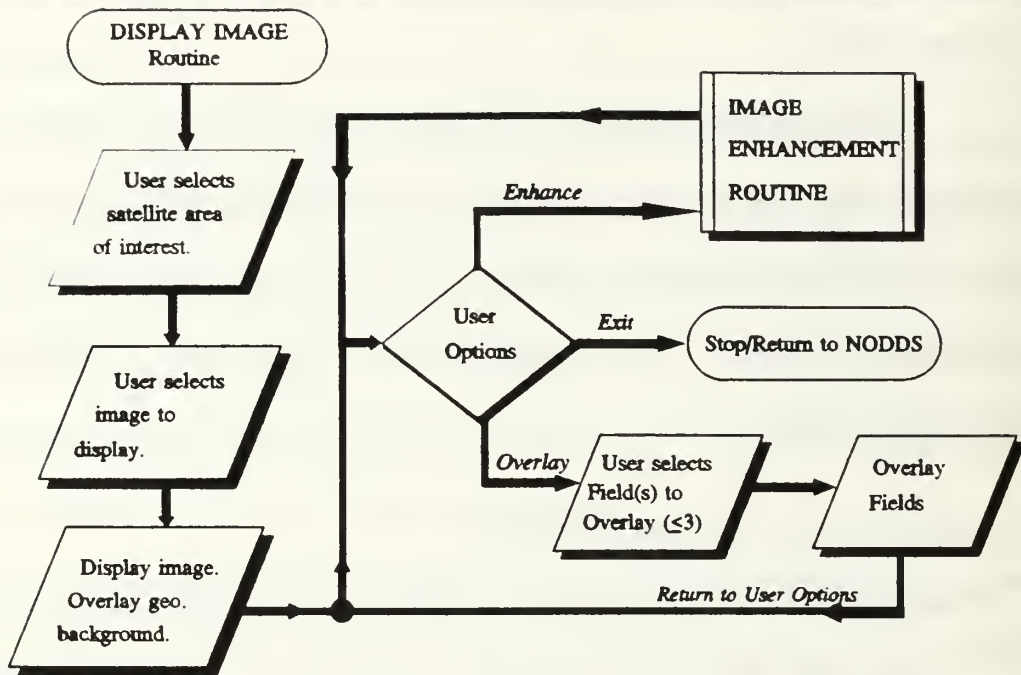


Figure 4. Functional Design Chart for image display within a NODDS framework.

provided background would result in a color change to the image pixels having the same value as the background.

The first option presented to the user is that of overlaying a previously-obtained conventional data field. This operation is identical to that of the conventional NODDS. The user may also choose to overlay additional fields (up to 3), to enhance the image with the procedure described in the next section or to quit the image display procedure entirely. Figure 6 is an example of the same satellite image as Figure 5 with a corresponding conventional product (surface analysis) overlaid.

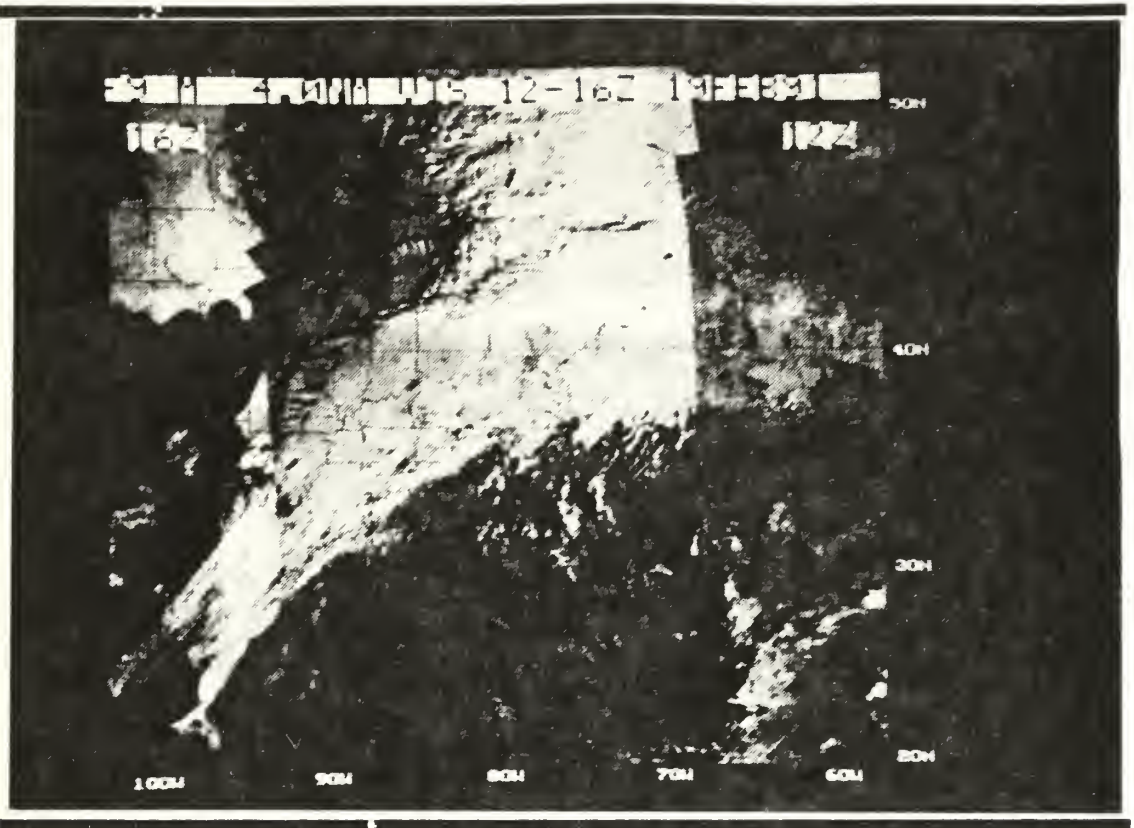


Figure 5. Display of a DMSP visual image mosaic.

One of the primary issues of integrating the display routines into the NODDS environment is one of registration of the imagery with the NODDS geographic background routines and overlays of conventional data. This process is greatly simplified if the imagery is initially provided in a standard projection, such as Mercator or Polar Stereographic. FNOC does provide DMSP imagery already transformed. For the purposes of this thesis, Mercator images were used to demonstrate this registration capability.

FNOC modified the existing NODDS background generating and conventional data overlay programs for use with a VGA system and in conjunction with this project. Since

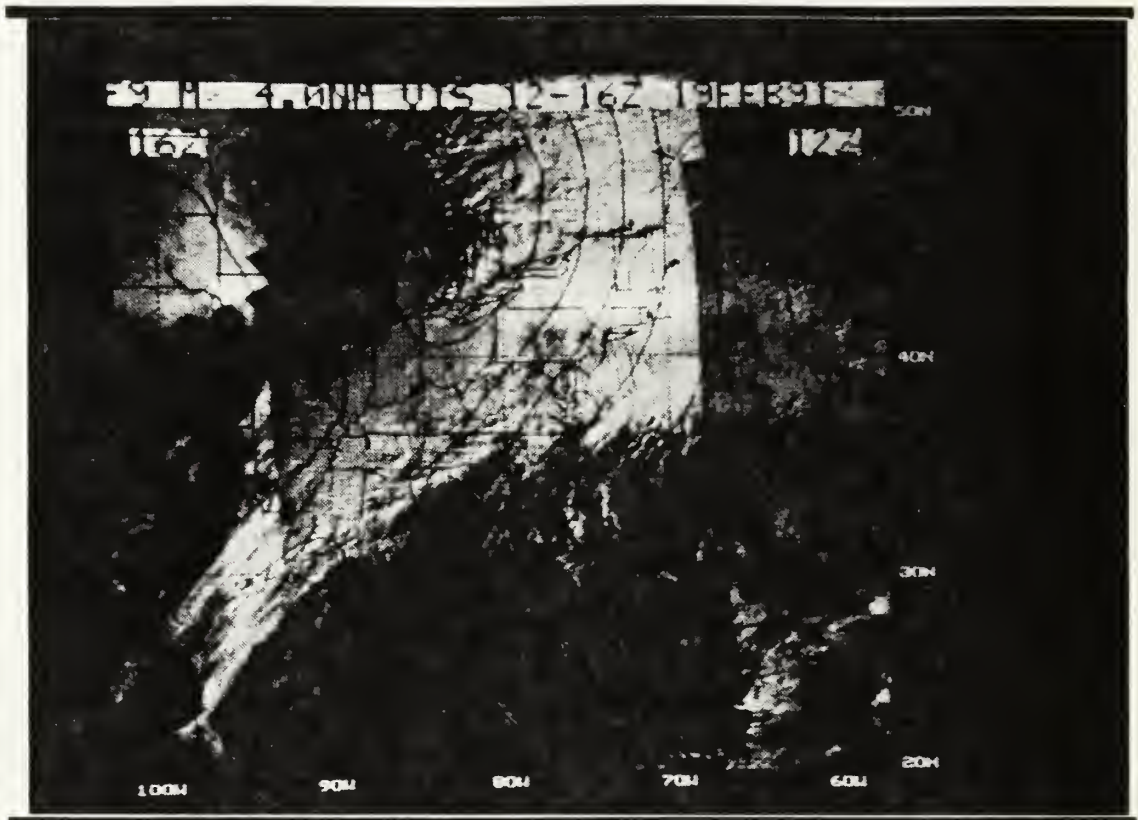


Figure 6. Display of image with corresponding FNOC surface pressure analysis overlaid.

this code already supports Mercator transformation and projection, the problem of registration is reduced to determining the latitude and longitude of the boundaries of the image to be displayed. FNOC provides Mercator images in the DEF format with the parameters of image center location and resolution. An attempt to use these parameters to obtain the image boundaries was unsuccessful. It was revealed that the resolution given with the image is an approximate figure, and not suitable for use in the inverse Mercator equations to obtain the boundaries. However, during the process of processing the imagery for transmission, the boundary latitudes and longitudes are known and can

be used to define the appropriate NODDS area for background and conventional data overlay.

F. IMAGE ENHANCEMENT DESIGN

Another of the goals of this thesis to demonstrate the ability of the microcomputer to process imagery by developing a simple enhancement program. This program is designed to allow the user to adjust any of the gray shades or colors on the display interactively, primarily allowing the highlighting of meteorological features. This same routine may also be used to highlight or mask other features, such as temperatures or brightness values corresponding to sea or land, or to change the color of any of the three overlay planes.

The functional design for the enhancement routine is given in Figure 7. After selecting the "ENHANCE" option, the user is presented with a representation of the gray scale/color palette. Using a pointing device (such as a mouse) the user selects the color to be changed. The new color is defined by interactively adjusting the red, green and blue contributions until the desired color is achieved. During this process the user may also see the changes affecting the actual image. Options are also available to completely restore the palette to the default 13 shades of gray plus 3 color overlays, or to exit the enhancement routine.

The enhancement routine is written entirely in QuickBasic 4.5 for consistency with NODDS. The treatment of the VGA palette is functionally equivalent between QuickBasic and Fortran allowing this routine to operate on the image previously displayed

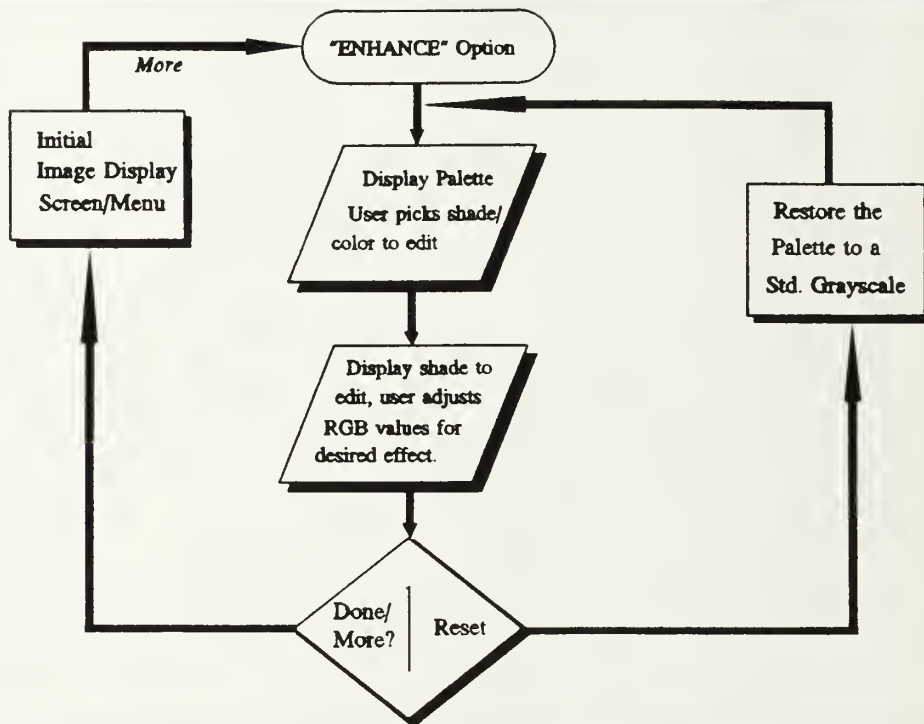


Figure 7. Image Enhancement functional design chart.

by a Fortran routine. QuickBasic has no significant disadvantages to Fortran in this type of program.

Figure 8 shows an IR DMSP image corresponding with the earlier visual image. The image is displayed with a default straight grayscale representing temperatures from 36.8 °C (black) to -83.2 °C (white). The nominal range of temperatures represented by each shade is 7 °C. In order to allow the display of the 16 level imagery with 13 shades, 3 of the shades have a temperature range of approximately 14 °C.

Figure 9 is the same image enhanced to emphasize the location of the middle and higher (colder) cloud tops. Temperatures from -23 to -38 °C are represented in a red color and temperatures from -38 to -46 °C in yellow. These colors accentuate the

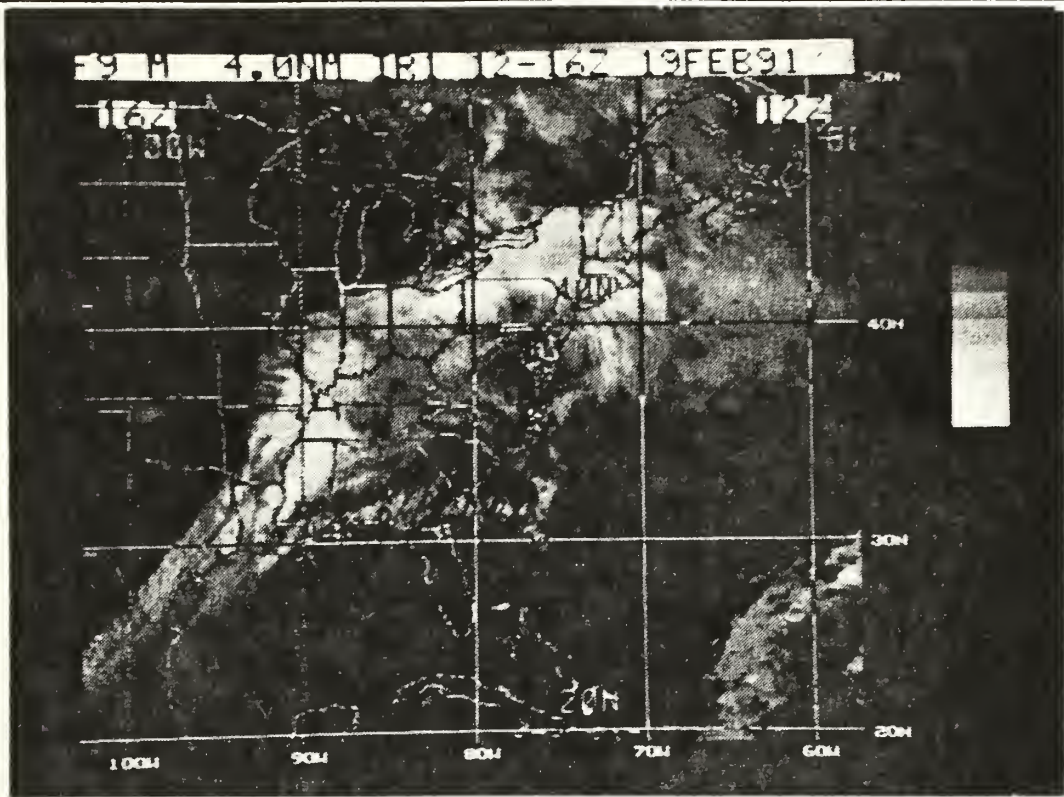


Figure 8. Display of DMSP IR image with straight gray scale.

middle-level clouds defining the shape of the synoptic scale system, particularly the developing frontal wave in the Missouri/Illinois region. Orange represents a temperature range from -46 to -53 °C. In particular, this shade highlights an area of more intense convection occurring in the northern portion of the system in upstate New York and northern New England. The light blue represents the coldest temperatures in the image from -53 to -60 °C. This color reveals the cold overshooting tops of the strongest thunderstorms, concentrated in the southern portion of the system in the vicinity of the developing wave and ahead of the trailing cold front. A smaller area of intense convection is also indicated in upstate New York.

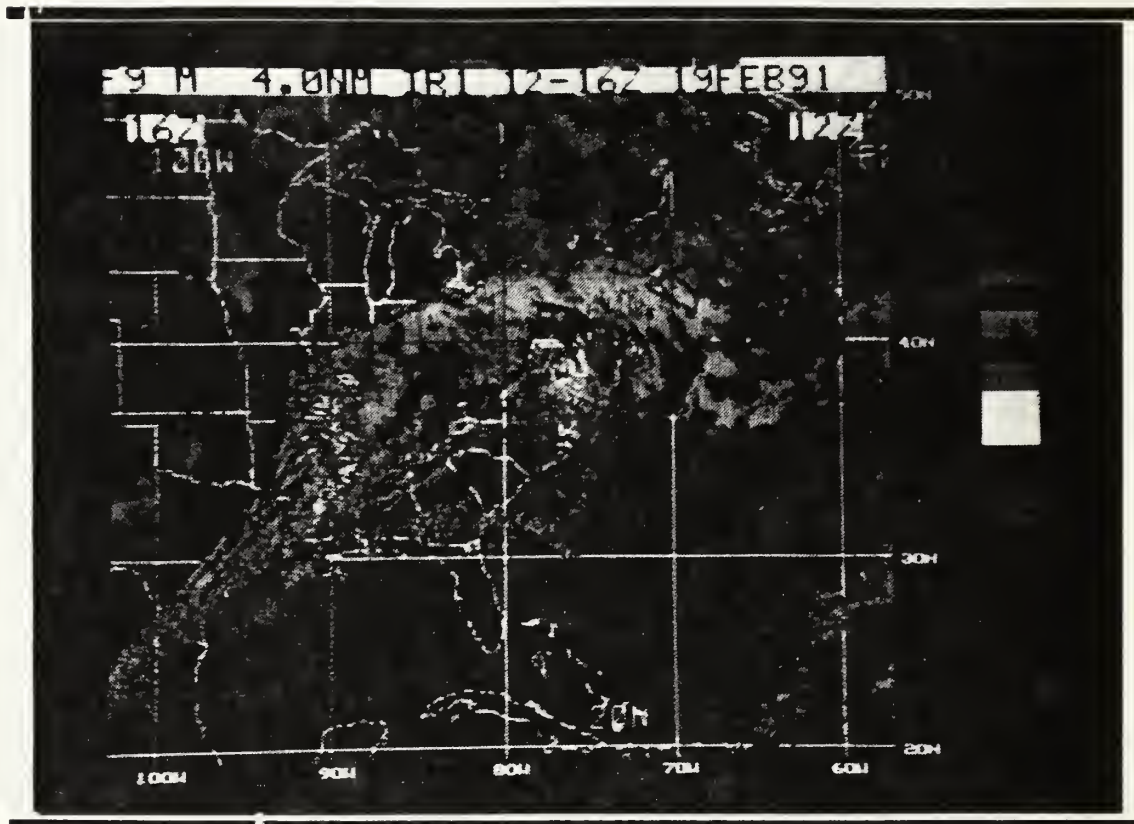


Figure 9. Display of DMSP IR image with high-cloud enhancements.

G. IMAGE PRINTING CONSIDERATIONS

In many operational scenarios, the most convenient form of display for meteorological and oceanographic products is printed hardcopy. The complex color and gray shades of satellite imagery and imagery with conventional overlays significantly complicates the process of printing. In general, the printer must represent shades of gray by adjusting the dot density, a process known as dithering. Small areas may not be correctly represented since the printer must sacrifice resolution to create the gray shades. The greater the number of dots-per-inch (DPI) the printer is capable of printing the better the resulting printed image resolution and shading representation.

The simplest approach to printing images is to display the image and then use a memory-resident program to "grab" the image from the screen by storing the pixel values in a standard file format printable by a graphics software package. The memory resident image capture routines are included with most major presentation graphics, drawing and painting programs. A more involved technique is to write a custom software printer driver program to print the screen image. Such a technique requires a different driver for each type of printer to be used.

Using a memory-resident image capture program and a commercial graphics program a typical satellite image with overlays was printed on a variety of printers. The result of this test showed that dot-matrix printers produced nearly unusable hardcopy. Laser and laser-quality inkjet printers produced hardcopy that preserved much of the meteorological information of the screen image. Figure 10 is a hardcopy laser printing of the visual image and overlay found in Figure 6. Regardless of the printer chosen the printing process was lengthy, typically 10 to 15 minutes. The majority of this time is in preparing the complex dithered print codes by the PC, not in the physical printing of the image. This time constraint may eliminate the routine printing of images, but facilities which have laser or laser-quality printers may benefit from the ability to make occasional hardcopies for off-site briefing or other purposes.

This chapter has demonstrated the ability to display meteorologically useful satellite images within a NODDS environment. Issues involved with the display and the enhancement of imagery have been presented, along with functional designs of the algorithms coded. Examples of the display capability have been given, and the issue of

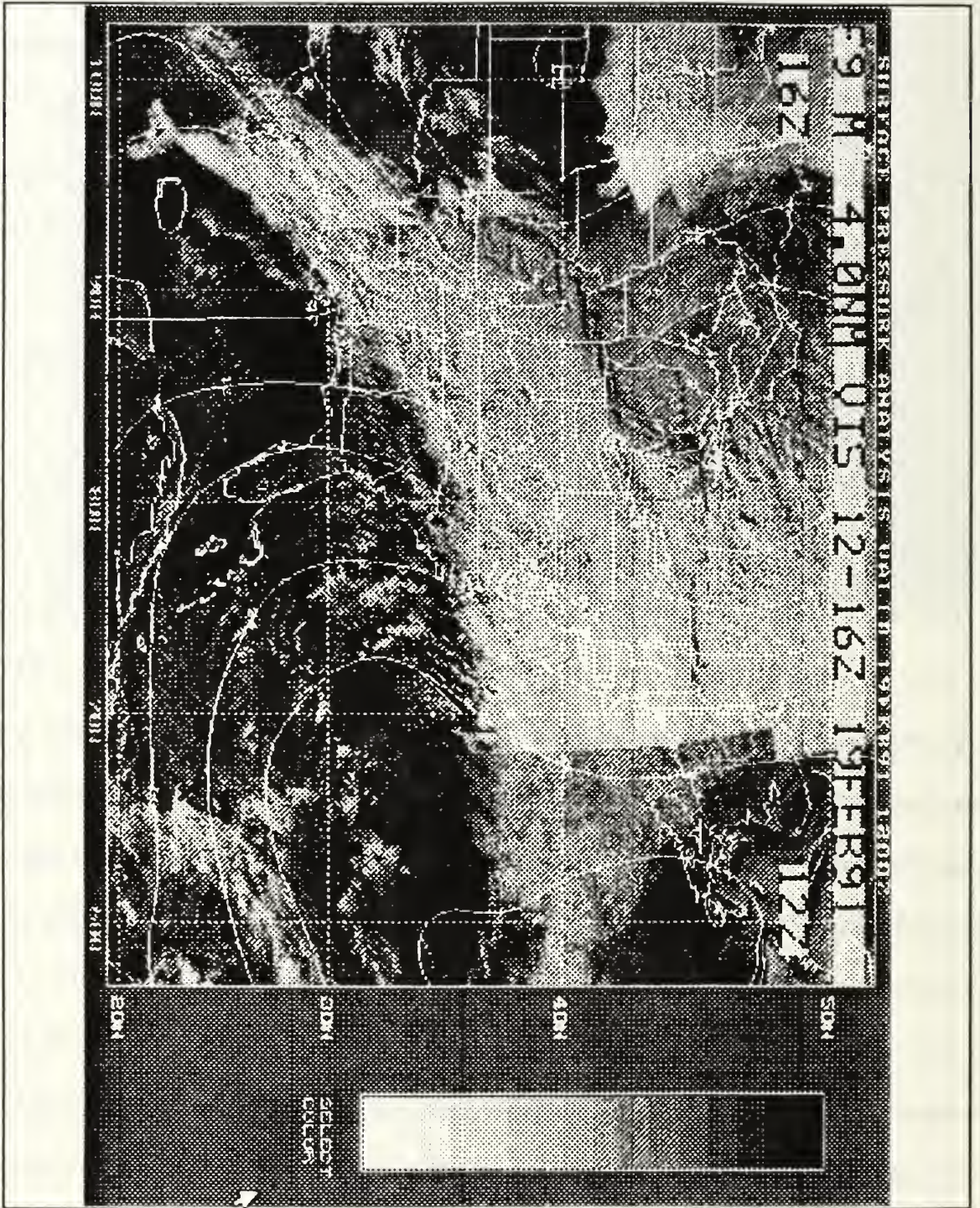


Figure 10. Laser hardcopy printing of image and overlay from Figure 6.

hardcopy printing has been addressed. As evidenced by current generation microcomputer capability and by existing systems, the PC is a suitable platform for image display. The current NODDS system, in particular, is a near-ideal system for mixing DMSP satellite imagery with FNOC conventional data.

IV. COMMUNICATIONS

A. INTRODUCTION

Though a microcomputer is capable of performing many of the traditional image display and processing tasks, the imagery must first be communicated to the system. For the purposes of this thesis, only imagery available from Fleet Numerical Oceanography Center is considered for implementation into the NODDS system. A suitable communications link is required to communicate binary image files from FNOC mainframes to the NODDS system. As implemented in earlier NODDS releases, telephone communication from the microcomputer to the mainframe computers at FNOC is the primary communications path. The conventional data is transmitted in the form of ASCII messages. However, binary satellite images are much larger than conventional NODDS data, and require error-free transmission. In order to transmit these images over a telephone line at a nominal 2400 baud rate within a reasonable operational time span, an efficient error-correcting binary protocol is required.

B. EXISTING FNOC BINARY TRANSFER PROTOCOLS

The Control Data Corporation mainframes at FNOC do support two binary transfer protocols. Kermit, a near-universally accepted and implemented protocol, is available. The flexibility of Kermit to work on many different systems makes it an inherently slow protocol. Attempts to use this protocol to download DEF standard 512 x 512 4-bit

satellite images (140,000 8-bit bytes) directly from FNOC mainframes revealed that the transfer time would be totally unacceptable for any operational use. The effective transfer rate was only about 30 bytes per second or 240 bits per second, thus using only about 10% of the theoretical 2400 baud transmission speed. Image transmission at 2400 baud would typically take over one hour without any compression. This transfer rate did not improve appreciably with tests at 9600 baud indicating the communication was limited by the ability of the mainframe to service the communication process.

Control Data Corporation (CDC) markets a proprietary mainframe to microcomputer communications package called VistaHost/VistaCom. Tests using this protocol showed much better transfer rates than Kermit, up to 150 bytes per second or about 1200 bits per second at 2400 baud. This speed was highly variable depending on mainframe loading. With the best observed throughput uncompressed images could be transmitted in about 15 minutes (2400 baud), which is close to being operationally useful. However, serious problems in Vista emerged during tests: the binary data was corrupted to the point of the arriving file being twice as large as the original and was completely unusable. Multiple hardware sets were used to ensure that the problem was not due to the microcomputer. The problem appears to be with some portion of the Vista software and FNOC personnel were notified. However, it was stated that the Control Data software technical support for the version of VistaHost in operation at FNOC was very limited (Frank Carillo, personal communication). The future of using this protocol to operationally transfer images to NODDS systems appears very unlikely.

Current NODDS transmissions of conventional data are first encoded in ASCII, and then compressed using Run-Length Encoding (RLE) for transmission. RLE consists of scanning the file for repetitive values and reducing the size by sending the value only once along with the number of times it is repeated. While it is possible to use such a system to send satellite images, an initial penalty must be paid in using an ASCII byte (8 bits) to represent a four-bit pixel. This two-to-one expansion may be offset with RLE techniques to obtain a transmission file roughly the same size as a 4-bit image file. Drawbacks with this scheme are the likelihood of communications errors over such a long file and the inherent problems of the mainframe supporting the file transmission during heavy operational usage. Image compression techniques could be used to reduce the file size dramatically but require a tradeoff in the loss of original image content.

C. A COMMUNICATIONS ALTERNATIVE

Because the CDC mainframes do not adequately support binary image transfer and ASCII-conversion techniques are at best an interim solution, a logical alternative is to have a communications "front-end" processor. Such a system could either be a UNIX workstation or a high-end MS-DOS microcomputer. Either system would be able to support the many binary protocols and no-data-loss compression techniques which are already available. This approach expands the range of protocols beyond those available when communicating directly with FNOC mainframes. For the purposes of this thesis a demonstration system was assembled to receive the image data from the FNOC mainframes with hard-wired high speed links and then transfer the imagery to a

microcomputer via telephone line. Figure 11 depicts the principal elements of the system.

The link from the FNOC mainframe to the communications front-end microprocessor runs at a speed of 9600 baud under the HASP protocol. This processor

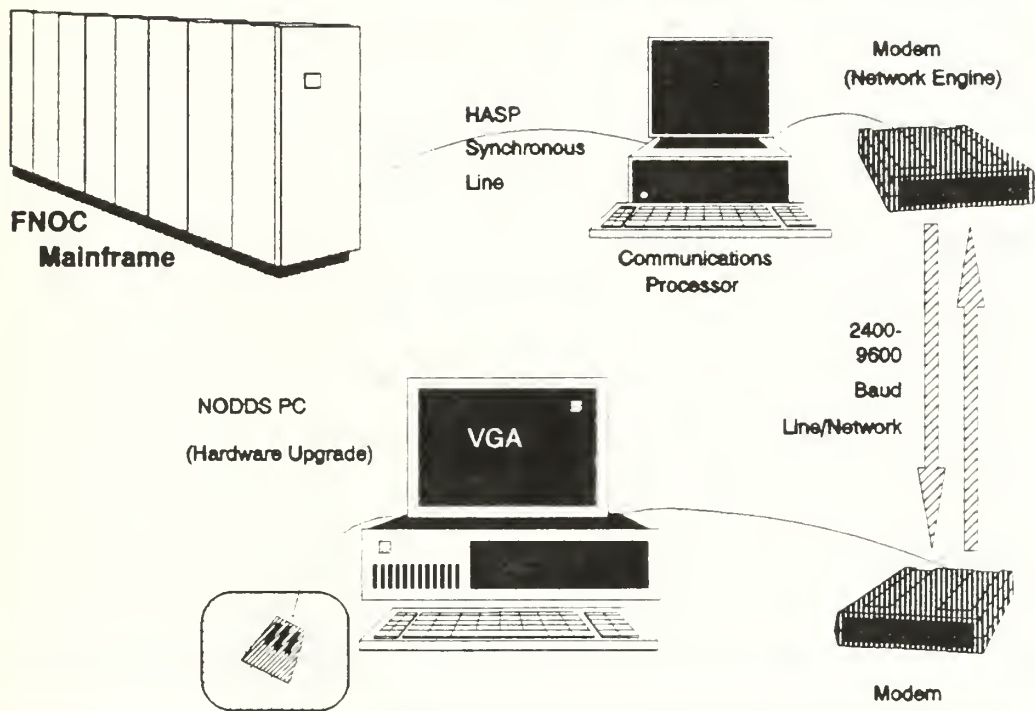


Figure 11. Principal components of test and proposed communications system.

is equipped with a HASP hardware board and a synchronous modem. The transfer of a 512 x 512 4-bit DEF image averaged 2 minutes, which represents a transfer rate of approximately 95% of the baud rate. This high efficiency is achieved in spite of the error-checking overhead through the no-loss compression implicit in the HASP protocol.

error-checking overhead through the no-loss compression implicit in the HASP protocol.

The arriving images were compressed using a public-domain loss-less technique (LHARC). The compression for the test file was from 140,000 to 88,192 bytes but operational compressions using this software will vary with image type and content. Since the variability is generally higher in visual images with large amounts of cloud cover, the test image represents a near worst-case file size. LHARC compressions of relatively quiescent infrared images demonstrated reduction from 140,000 to approximately 67,000 bytes.

The compressed file was transferred to the NODDS system over a 2400 baud telephone link using Procomm Plus, the commercial communications package licensed to all NODDS sites. During multiple image downloads seven of the internal protocols in Procomm Plus were tested. Table 3 shows the various throughput speeds obtained. Using the best protocol, the transmission time of the compressed test image was about 6 minutes. Considering that a GOESTAP analog facsimile transmission takes 15 minutes, this should be an operationally acceptable download time.

File decompression with LHARC is virtually instantaneous on the arrival PC. More sophisticated compression techniques resulting in higher compression ratios at the expense of loss of image information are also available. Such techniques could be implemented readily within the framework of this communications "front-end" design, since the systems are similar at the compression and decompression ends.

TABLE 3. IMAGE FILE TRANSFER TIMES FOR PROCOMM INTERNAL PROTOCOLS

PROTOCOL	TRANSFER TIME (Minutes)
IMODEM	6:10
YMODEM-G	6:20
YMODEM	6:20
SEALINK	6:20
XMODEM	7:05
TELINK	7:12
WXMODEM	---Unable to transfer.

dropping significantly. These new-generation modems include hardware compression schemes which can increase their efficiency to beyond the rated baud rate. It is likely that transfer times of the images described in this thesis would be in the 1.5 to 2 minute range, similar to that of the asynchronous HASP link. These developments offer further encouragement that this image display capability will be operationally useful.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis demonstrated the addition of image display capability to the NODDS system. The overlaying of NODDS backgrounds and conventional data fields onto the imagery also has been shown. A simple enhancement scheme with significant operational usefulness was developed and tested.

Several communications options were evaluated and tested. Binary communication directly with FNOC mainframes was shown to have serious shortcomings. A test communications system with a front-end processor to an FNOC mainframe was assembled, tested and used to obtain imagery for research. This system demonstrated capability to move full resolution (non-degraded four-bit) imagery from FNOC to the NODDS user in an operationally satisfactory time period.

A satellite-capable NODDS system could be used in several operational scenarios. The Naval Oceanography Command Detachment (NOCD) stands to benefit most since many such facilities are not scheduled to receive the Tactical Environmental Support System (TESS) and have no other system capable of displaying DMSP imagery and combining the imagery with conventional data. Because this system could be implemented relatively rapidly, it could also serve the detachments and facilities scheduled to receive TESS prior to delivery and afterward as a backup system. It is even

conceivable that ships at sea could use a satellite NODDS system prior to and in backup of a TESS system using satellite communications.

B. OPERATIONAL IMPLEMENTATION

This system can be implemented into the present operational NODDS framework, but will require effort in several areas. The NODDS users must have a minimum hardware setup including a VGA color monitor and card and a mouse. Though existing Z-248 computers modified with the above equipment would be sufficient, newer generation systems such as the Desktop III contract equipment based on the i386 processor would be desirable.

The images must be prepared in pre-defined areas by FNOC automatically. In order to initially prepare a satellite image area the latitude and longitude of the corner points (edges) must be known. The images must have a suitable naming convention to distinguish their area and data type (eg. visual or IR).

A communications system must be implemented to transfer images from FNOC to the NODDS user. It is recommended that a communications processor be used vice communicating directly with FNOC mainframes. A system similar to the test system for this thesis could be implemented exclusively for image transfer. This would serve as an interim system until the entire NODDS communications functions can be transferred to a communications multi-processor such as a UNIX workstation.

Finally, the large number of keystrokes and manual interventions involved with downloading imagery and placing it in proper NODDS directories on the PC need to be

automated. This automation is not feasible until a suitable communications system is chosen and implemented.

C. FURTHER RESEARCH AND DEVELOPMENT

Suggestions for improving a NODDS satellite-capable system following initial operational implementation are now presented.

1. Existing Algorithm/Code Improvement

The current method of display using FORTRAN requires an initial slow display of the images in order to prepare them in a format for much faster display. This two step process could probably be combined into one with the use of assembly language programming. The enhancement scheme could be improved with the ability save a user-developed enhancement for later recall with the same or other images.

2. New Algorithms/Features

Many significant features could be added incrementally to improve the operational usefulness of a satellite-capable NODDS system. The use of full 8-bit imagery could allow the addition of oceanographic analysis functions to the system. Such functions might include display of full-resolution imagery in the sea-surface temperature range to aid identification of thermal features such as fronts and eddies. The extraction of sea surface temperatures by the user using a pointing device would also be desirable. The development of automatic cloud masking according to temperature could be implemented.

The display of oceanographic imagery might be significantly improved by using the proprietary modes of most VGA cards which allow 256 color (64 gray shade) display at resolutions of 640 x 480 and higher. At present, this would probably require the use of multiple assembly language display routines to support the most widely available VGA cards in the field.

The addition of capability to display images and prepare overlays in polar-stereographic projections would enhance use of the system in high-latitudes and polar regions. This is particularly desirable since DMSP provides coverage of these areas that geostationary satellites do not.

The development of an interface to geostationary imagery (such as GOES) would allow operational users the ability to mix this high-quality and timely image data with conventional FNOC products for the first time. Specifically, the new looping systems scheduled to arrive at detachments need to be reviewed thoroughly for possible interfacing to a NODDS system. For users who lack looping capability, the addition of an interface to GOESTAP or WEFAX would allow the development of satellite looping applications.

3. Hardware Improvements

The desire to obtain quality printing of imagery or imagery/conventional data mixes will probably require the addition of ink-jet or laser printers to the system. This will also require some software printer driver development or purchase.

The procurement and use of 9600 baud modems with advanced data compression schemes would allow image transmission in the range of 1 to 2 minutes.

This would not only benefit the operational meteorology user but would also significantly ease the communications burden of sending full-resolution 8-bit imagery for oceanographic purposes.

4. Outlook

The NODDS system represents a nearly ideal platform to mix DMSP satellite imagery with conventional FNOG data. The existing experienced user base, the existing equipment and the continued favorable trend in price/performance of microcomputers combine to make a satellite-capable NODDS system achievable and cost-effective. Armed with this system, even the smallest detachment can have meteorological and oceanographic analysis and visualization capabilities formerly only available at large installations and research/education laboratories.

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