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VISUALIZATION OF MULTISPECTRAL AND MULTISOURCE DATA USING AN INTERACTIVE IMAGE SPREADSHEET (IISS)

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1. INTRODUCTION

The next generation of remote sensing observing systems will routinely provide multispectral data from a very large number of sensors. For example, the Landsat-type instrument of the planned Earth observing system (Eos) satellite will be the HIgh-Resolution Imaging Spectrometer (HIRIS). The HIRIS will have 192 channels, compared to seven on the current Landsat Thematic Mapper (TM). Similarly, the next generation of satellite based weather observing instruments like the MODerate-resolution Imaging Spectrometer (MODIS), also on the Eos platform, will have up to 100 channels, compared to the five Advanced Very High Resolution Radiometer (AVHRR) channels currently available on the NOAA satellites. New methods for visualizing, interpreting, comparing, and analyzing multispectral time sequential satellite data need to be investigated to fully exploit these data sets efficiently. Papathomas, et al. (1988) provide a review of visualization methods applied to meteorological data sets. Satellite image data must be combined with model derived data, digital terrain data, and geographical maps, for any comprehensive scientific investigation (e.g., climatological and classification studies). Such multisource data sets need to be integrated and geocoded for effective interpretation.

The approach of the effort described this paper is to extend the traditional numerical spreadsheet paradigm to organize, manipulate and process multisensor image data sets interactively. The effectiveness of using numerical spreadsheets for solving scientific problems, such as solutions to nonlinear equations, ordinary differential equations or even partial differential equations, has been discussed in detail by Orvis (1991). The possibility of extending such a powerful tool to multiple sets of images is intriguing. An Interactive Image SpreadSheet (IISS) is under development at the Goddard Space Flight Center. In the IISS each cell contains an image which may be one of the following: 1) a complete original or derived image, 2) a partial original or derived subimage, 3) a projection of a multidimensional data set such as a 3-D surface, or 4) a glyph (graphic symbol) representing an image. The term "image" is used in a general sense to include multisource data sets such as digitized geographical and geological maps, digital terrain models (DTM), contour plots, graphs, vector drawings, etc. This kind of variety is becoming common in remote sensing applications (Nguyen and Ho, 1988). The IISS typically contains an array of image cells of arbitrary size. A 3-D or multidimensional spreadsheet can also be defined that can be scrolled or paged through along various dimensions. In certain cases it may also be convenient to nest spreadsheets so that the contents of a cell are not an image but another image spreadsheet. In addition to using row and column based access to cells, some newer spreadsheet designs allow cells to be referenced by combinations of variable names, and contain a separate window showing all of the formulas entered in the spreadsheet (Howard, 1987). One of the advantages of this approach is that complicated relationships among cells (variables) are accessible immediately rather than through a long chain of sequential searches through individual cells. Providing such a feature in an image spreadsheet would be important when cells display the results of a complex interrelated flow of processing, e.g., when the formula in a cell is actually a call to an image analysis algorithm. A cascade of such calls with feedback would be an example of a situation wherein the ability to graphically view all of the formulas simultaneously would be a distinct advantage.

Processing, visualization and analysis of multispectral satellite data using an interactive image spreadsheet has several primary objectives. The image spreadsheet would facilitate the understanding of complex multispectral data time series via interactive techniques. This is achieved by using the spreadsheet to trace the raw data through the correction, enhancement and product derivation stages. This enables the comparison of different algorithms, and enhances the identification of deficiencies in the data processing and analysis steps. The spreadsheet thus provides feedback for improving the algorithms. The spreadsheet would also allow an investigator to easily and interactively experiment with various combinations of channels using a library of standard algorithms, and allow the user to enter custom algorithms. Certain essential primitive image cell operations such as fast zoom, roam, animation and function-execution for a single cell or in synchrony for a set of cells, would be available through the user interface. These computationally challenging objectives become feasible with the availability of multiprocessor workstations that have a large amount of memory, high speed bus, parallelizing compilers, pipelined graphics and image operations. This new hardware enables the prototype development and evaluation of a unique environment for manipulating large complex image arrays. Figure 1 shows our current Silicon Graphics 4D/340 VGX workstation configuration with four MIPS 3000 processors and 256 MB of RAM. Further discussion of the hardware specifications can be found in Section 2.3.

Sample data sets from NOAA/AVHRR, GOES (Geostationary Operational Environmental Satellite), Landsat TM, Special Sensor Microwave/Imager (SSM/I), and Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) with 224 registered spectral channels have been used to develop and evaluate the functionality of an image spreadsheet. Products that have been derived from Landsat TM data include color composites, vegetation indices, perspective and stereo views. The products can be combined and visualized interactively though the complete spreadsheet environment is still under development. Animated time series and image alternation to interactively detect spatial, temporal and spectral differences between images is currently available and effective.

2. IISS SYSTEM DESIGN

2.1 Visual Layouts

A typical spreadsheet may consist of an 8 X 8 matrix of cells each containing an image of size 160 X 128 pixels which is displayed on a standard 1280 X 1024 pixel monitor (Hasler *et al.* 1991b). A cell usually contains only a small subset of a larger data set. Each row of the spreadsheet can be dedicated to an

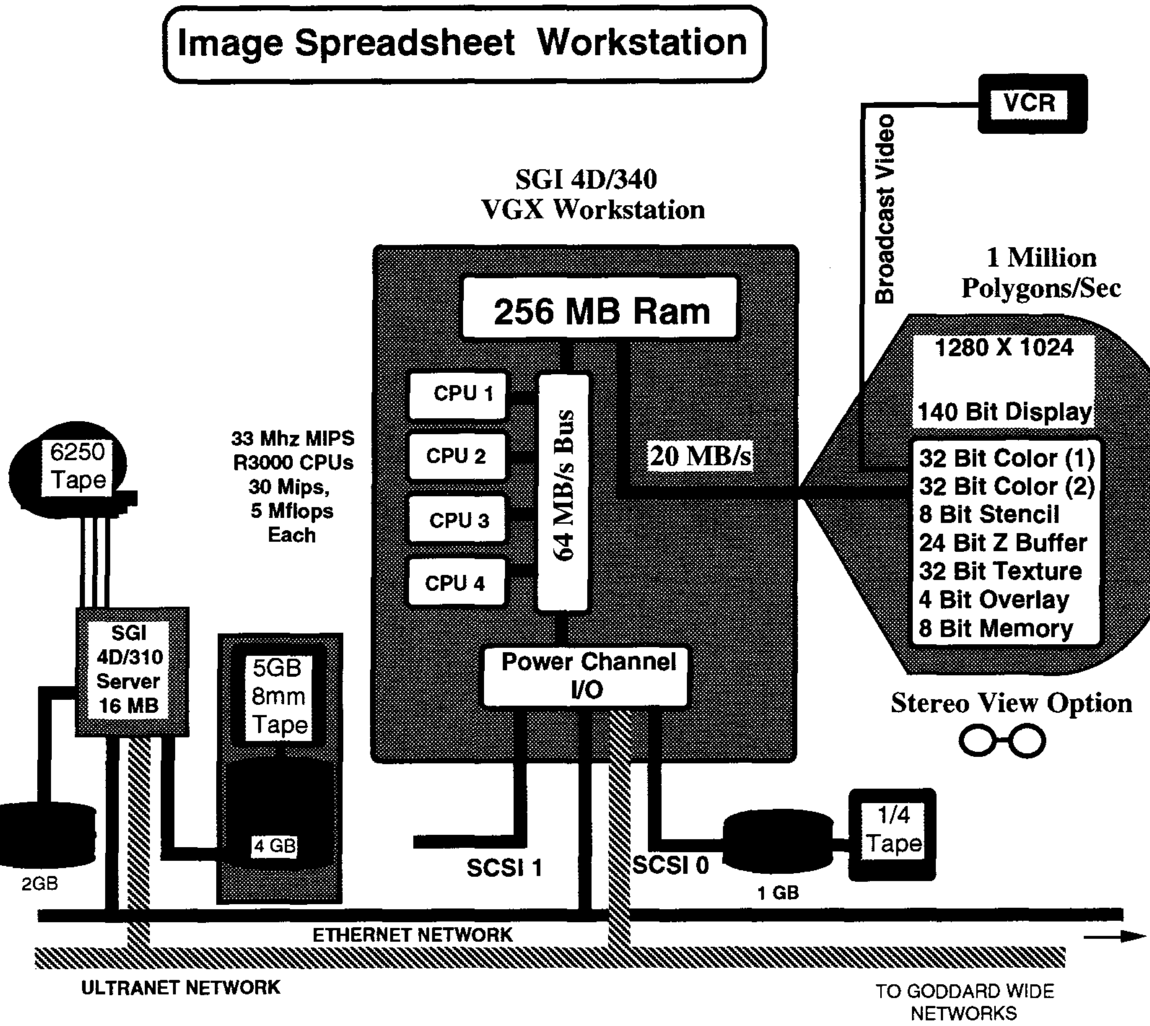

Figure 1. IISS super workstation hardware configuration.

	Raw Data	Destriped (noiseless)	Radiometrically corrected	Geometric Correction	Map Projection
Water Vapor					
Outgoing Longwave					
Vertical Wind Speed					
False Color	//////////////	//////////////	////////////////	//////////////	
	//////////////	//////////////	////////////////	//////////////	
Perspective	//////////////	//////////////	////////////////	//////////////	
	//////////////	//////////////	////////////////	//////////////	
Detect	//////////////	//////////////	////////////////	//////////////	
Clouds	//////////////	//////////////	////////////////	//////////////	

	Water Vapor	Outgoing Longwave	Vertical Wind Speed
Apr			
May			
June			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			
Jan			
Feb			
Mar			

Figures 2a and 2b. Examples of possible IISS configurations (////// indicates empty cells). Figure 2a on the left is a 2D spreadsheet illustration indicating how multichannel data can be displayed and analyzed. Note that the original data as well as the results of various processing steps are readily available. This enables, for example, artifacts in the final product may be related either to the original data or processing steps. Figure 2b on the right is a 3D spreadsheet where both the second (rows) and third (hidden) dimensions represent time. The data in Figure 3 (below) is schematically represented as it would be organized in a spreadsheet with the third dimension being the years 1979-1989 for Water Vapor and Outgoing Longwave columns, and the years 1984-1987 for the Vertical Wind Speed.

instrument channel or combination thereof while the columns show the raw data and the images resulting from different processing operations. A larger virtual spreadsheet could be defined and scrolled through in an analogous manner to that used in traditional data spreadsheets. An instrument with a large number of channels or a long time series could be represented more compactly as a 3D spreadsheet by selecting channels or time steps for the third dimension of cells in the spreadsheet (Hasler et al. 1991b). In this case the primary channel is shown on the uppermost spreadsheet and the other channels are represented as layers below that can be selected as separate pages. The matrix configuration would vary depending on the data set and could be for example, 2 X 1, 3 X 1, 4 X 1, or 4 X 2. For smaller sized arrays it may be practical to view the time sequence images as a synchronized animation.

Examples of some possible IISS configurations are given in Figures 2a and 2b. Figure 2a shows a multichannel data set with the original data as well as the results of various processing steps. Since raw and processed data sets are available side-by-side, this enables artifacts in the final product to be related either to the original data or any of the processing steps. Figure 2b is a 3D spreadsheet where the third dimension contains images in a time sequence. The data in Figure 3 is schematically represented in Figure 2b as it would be organized in a spreadsheet with the third dimension being the years 1979-1989 for Water Vapor and Outgoing Longwave columns, and the years 1984-1987 for the Vertical Wind Speed.

2.2 User Interaction Specification

The appropriate interface for controlling the IISS interactive functions needs to be carefully designed with respect to ease of use, consistency, portability, extensibility and maintainability. Some current options include using the Transportable Applications Environment (TAE+), developed at NASA/Goddard Space Flight Center, which provides a consistent and flexible graphical (Motif X-Windows based) interactive user interface to a system of application programs (Perkins, et al. 1988). TAE+ includes a WorkBench that enables different user interfaces to be defined and tested quickly. TAE+ also provides a portable environment without the necessity for programming directly using the X-Windows libraries. The advantage of using Motif X-Windows or TAE+ is that these libraries are more easily portable to other hardware platforms than the SGI graphics library (`gl`). However, the `gl` graphics library is now available on a number of different architectures. All three of the windowing systems support remote display of windows either directly through library calls, or implemented via UNIX socket calls. The remote display capability would easily allow parameter specification windows and widgets (dialog boxes, slider controls etc.) to be contained in an X-window that the user can place in a screen location on another workstation or inexpensive X-terminal. This would save all of the screen space on the high-performance monitor for displaying the image array. Note that in this approach two input devices (such as a keyboard or mouse) needs to be active for each display unit. A low cost Silicon Graphics Personal IRIS, IRIS Indigo, or X-terminal can be used for the Graphical User Interface (GUI) with a high performance Silicon Graphics Power Series workstation used for the display of the IISS.

A visual programming approach has been implemented in several systems such as the `cantata` tool in Khoros (Rasure and William, 1991), or the IRIS Explorer™ application environment (Gorey, 1991), or the Application Visualization System (AVS) model of the Stardent Corporation. these systems are intuitive and flexible interfaces for providing data management, image processing and derived product calculation capabilities. Such visual language models can be used to help the user keep track of the complex processing steps needed to analyze large multi-channel data sets.

2.3 IISS Hardware Specifications

A set of hardware requirements are given based on ideal spreadsheet performance requirements, for comparison with current and future potential system configurations. The specifications and performance of the current hardware implementation is first presented and then followed by a brief description of hardware capabilities expected to be available in the next few years.

Hardware Performance Requirements

Dual 24 bit color monitors must be available. The image spreadsheet would be displayed on one monitor with the second monitor used for the Graphical User Interface (GUI) and other information such as an overview image with a box showing the region of current interest. Standard image operations, like zoom, reduce, animate, etc., must be executed instantaneously. It must be possible to roam quickly and smoothly around a number of subimage cells simultaneously. The subimage cells are derived from up to five 4096 X 4096 pixel 24 bit images. While a short animation loop of high resolution images (ten 4096 X 4096 pixel 24 bit images) running at thirty frames per second is in progress the user should have the ability to smoothly roam and zoom using the full screen. At least 100 GB of on-line storage must be available with access to remote storage devices including a high performance network interconnect to super computers and other databases.

The workstation must have exceptional input/output (I/O) bandwidth in order to be able to move large amounts of image data from local and remote storage to the screen (via memory). The bandwidth of the system bus connecting main memory (RAM), CPU, display memory, and I/O bus must be very high (at least 150 MB/s) in order to support full screen 24 bit animation at thirty frames per second. The RAM must be very large so that reasonable sized image spreadsheet arrays and animations may be accessed at the 150 MB/s rate. For example, full sized multispectral Landsat scenes, full GOES images and moderate quality thirty second animations can be processed interactively with 256 MB memory. High performance access to the local mass storage system on a hard disk at a rate of at least 10 MB/sec is necessary. This would allow 200 MB of data to be loaded in twenty seconds, and would permit 512 X 512 pixel X 8 bit animation at 30 frames per second directly from mass storage. The same performance across a local or wide area network would allow these operations to be performed directly using the Goddard National Space Science Data Center (NSSDC) databases and eventually the Earth Observing System Data and Information System (EosDIS). On-the-fly data compression and decompression techniques with efficiencies of 100:1 would be necessary for achieving long (for example twenty minute) animations of observed and model data sets.

CPU resources must be high in order to perform simultaneous manipulations on numerous image cells and the calculation of several products based on multiple cells interactively. An ideal workstation would dedicate an individual, fast RISC CPU to each cell in a multiprocessor environment.

Hardware Capabilities

A Silicon Graphics Computer Systems (SGI) super computing workstation SGI 4D/340 VGX with the following major specifications, as illustrated in Figure 1, has been chosen as the platform to demonstrate the IISS. The system has four fast CPUs for a total of 120 MIPS and 36 MFlops, a large, main CPU memory of 256 MB, a high performance (20 MB/s) data transfer rate between RAM and image frame buffer, fast graphics (one million triangles per second), a large amount of mass storage (5 GB with 2 MB/s disk drive system), and parallelizing Fortran and C compilers to take advantage of multiprocessing.

The IISS is displayed on a high resolution color monitor (1280 X 1024) with double buffered 32 bit color, 8 bit stencil, 24 bit Z buffer, 32 bit texture, 4 bit overlay and 8 bit window plane layers for a total of 140 bits. Standard image operations, like zoom and reduce, are nearly instantaneous for reasonable sized images. Smooth and fast zoom and roam operations have been demonstrated on images as large as 5965 X 6967 pixels X 24 bits (120 Mbytes). Animations of 512 X 512 pixels X 8 bits at 70 frames per second and color frames of 512 X 512 pixels X 24 bits at 37 frames per second with full interactive control have been demonstrated. The workstation has good input/output (I/O) and system bandwidth. The data transfer bandwidths for the workstation are as follows:

- System bus from memory (RAM) to CPU at 64 MB/s
- RAM to I/O bus at 34 MB/s
- RAM to Image frame buffer at 20 MB/s for 8 bit images and 30 MB/s for 24 bit images

The RAM is very large (0.25 GB) so that very large IISS arrays may be displayed interactively and long animations (900 frame 8 bit and 300 frame 24 bit color 512 X 512 pixel) may be accessed at 30 frames/sec. Moderate performance access to the local mass storage system on hard disk at a rate of 2 MB/s has been demonstrated on the current SCSI disk drives. Striping of multiple disks should allow us to increase the rate to at least 4 MB/s. It is also expected that the high performance SCSI II disks will allow us to double disk drive I/O in the next few months. On-the-fly data compression and decompression techniques have not yet been implemented. To access remote storage, the super high performance (125 MB/sec) UltraNet network interconnect to Goddard databases and super computers has been installed.

With the four processor SGI 4D/340 VGX workstation an individual high-performance RISC CPU can be assigned to four cells simultaneously.

Next Generation Hardware Performance Specifications

The next generation of workstations will use data paths 64 bits wide instead of 32 bits wide. It is expected that transfer rate requirements of 150 MB/s will be met. The 64 bit architecture will also enable larger memory configurations of at least four GB. Full screen 24 bit animations of 30 seconds and about 5 minutes of broadcast quality digital video will then be possible. Low cost SCSI II hard disk drives should reach 20 MB/s data transfer rate level. Increased data densities will make accessing 100 GB mass store systems more practical. MultiGB RAM disks may also become cost effective allowing an intermediate mass storage system which is of higher performance than hard disk based systems. Data compression and storage systems using magnetic tape or optical media will allow complete remote sensing data sets to be kept on line. The display unit resolution should be increased to 2048 X 2048 and a separate hardware lookup table should be provided for each of the three colors instead of the single lookup table used in current systems.

CPU speeds will increase 2 to 4 times over the current system providing greater capability to do interactive processing of all spreadsheet cells. Using coarse grain parallelism, one processor can be assigned to each cell even for large spreadsheets. To achieve image processing operations at video rates will require a special Image Engine analogous to the Geometry Engine available on the SGI 4D/340 VGX.

2.4 Image Processing Tools

Many standard image processing techniques will be available in a tool box including: destriping, interactive and automatic bad-line removal, spike removal, interactive contrast stretch using level slice, histogram equalization, local enhance, high and low band pass filters, Laplacian illumination, edge enhancement, and perspective rendering of surfaces. Some of the standard image enhancement operations have been implemented in a variety of software packages such as AOIPS (Hasler and desJardins, 1987), VICAR (Video Image Communication and Retrieval/ JPL), ELAS (Earth Resources Laboratory Applications Software/ Stenis Space Center), LAS (Land Analysis System formerly known as Landsat-D Assessment System/ NASA Goddard Space Flight Center), View (Lawrence Livermore National Laboratory), Khoros (University of New Mexico), NCSA XImage (University of Illinois), and Image Vision Library (Silicon Graphics Inc.) and can be used as a guide in the design of the IISS functions. The system will support insertion of the user's own special enhancement algorithm.

The problem of correcting raw satellite data from multiple sensors and hundreds of spectral bands will be a crucial step in obtaining images that can be compared across channels and over long time periods required for climatological studies such as the data sets shown in Figure 3. In this section we provide a brief description of distortion correction and how an image spreadsheet environment would facilitate the analysis and evaluation of different correction algorithms. An illustrative spreadsheet showing the organization of channels, processing steps, and derived products is shown in Figure 2. Radiometric distortion is primarily due to atmospheric propagation and scattering effects and detector response; the former may be corrected for using mathematical models and deconvolution methods and the latter using calibration procedures. There are a number of sources of geometric distortion including spacecraft or platform ephemeris, spacecraft attitude and motion during image acquisition, sensor non-idealities such as band to band or detector to detector offsets and scanner motion, wide field of view of some sensors, curvature of the earth, panoramic effects due to imaging geometry, and the rotation of the earth during image acquisition (Richards, 1986). Geometric distortion can be corrected by a combination of mathematical modelling to explicitly remap each type of distortion, or by using image registration to find the parameters of a transformation relating the distorted image to ground control points. The registration approach in conjunction with nominal models is usually used to account for geometric distortions because navigation parameters and sensor related distortions are not always precisely known. When ground control points are not available but there are several scenes of the same area available (from different times) then the images can be registered to a selected reference image. The image to image registrations are often done manually or with human assistance and many automatic registration methods have been investigated in the past. A typical approach is to use a correlation measure to find corresponding feature points; correlation measures are also often used in automatic stereo (Hasler, et al. 1991a). An alternative approach is to use the method of moments. Region-based moment invariants have been successfully used in image classification, scene matching and object recognition since such features are invariant to translation, scaling, and rotation of the region or to translation and a general linear transformation of the region. Consequently, moment invariants are less susceptible to these types of image distortions and should result in better correspondences. Given the image $f(x,y)$ the moment of order $(p+q)$ is defined by the relation

$$m_{pq} = \sum_x \sum_y x^p y^q f(x,y)$$

The central moments

$$\mu_{pq} = \sum_x \sum_y (x - \bar{x})^p (y - \bar{y})^q f(x,y)$$

can be expressed as a function of m_{pq} and the normalized central moments are defined as $\eta_{pq} = \mu_{pq} / \mu_{00}^{\alpha}$ where $\alpha = (p + q)/2$. The first four of seven invariant moments are given below (Gonzalez and Wintz, 1987)

$$\phi_1 = \eta_{20} + \eta_{02}$$

$$\phi_2 = (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2$$

$$\phi_3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2$$

$$\phi_4 = (\eta_{30} + 3\eta_{12})^2 + (\eta_{21} + \eta_{03})^2$$

The invariant moments under changes in illumination and general linear transformations are given by Reiss (1991). An extremely fast method of computing these moment invariants is presented by Li and Shen (1991) that reduces the complexity of computing these moments from $O(N^2)$ to $O(N)$. Comparing the results of applying different geometric correction algorithms to a set of images would be facilitated in an image spreadsheet environment. Different steps of the correction could also be readily previewed and the alignment accuracy over a sequence of images could be verified at the full resolution for very large images (such as Landsat TM) by roaming and zooming through the image to locate the key feature points, then alternating several of the images in a sequence or viewing them side-by-side.

Standard mathematical functions, such as addition, subtraction, multiplication, division, mean, standard deviation etc., may be performed easily on individual image cells or on groups of two or more images. In designing a formula interpreter the IAX algebraic image processing language implementation could be used as a guide (Jackson, 1988). IAX for example was designed to meet such requirements as providing a simple, concise and powerful language for programming new image processing tasks and prototyping algorithms, allowing specific application oriented routines to be easily specified using IAX primitives, facilitating efficient internal evaluation of operations, and enabling users to write their own extensions as compiled code. A number of specialized algorithms such as those producing rainfall estimates (e.g., Adler and Negri, 1988), cloud type classification, vegetation indices, crop identification, correlation functions (e.g., Hasler et al. 1991a), or cloud free composites will also be integrated into the spreadsheet functions.

3. RESULTS

Several prototype semi-interactive image spreadsheets have been developed on the the SGI 4D/340 VGX IISS workstation using real data sets, to investigate the performance requirements and interactive control features necessary for displaying data in various data formats, and to prototype zoom, reduce, roam, animation, and surface rendering functions. The results from these prototype implementations will be integrated into the design of the functionally complete interactive spreadsheet.

3.1 Interactive Analysis of Long Time Series of Multispectral Climate Data

One objective of the spreadsheet project is to combine data sets from two or more platforms or sources in a manner that similarities and differences in the data can be detected. Another objective is to work with long regular time series of multispectral data. A climatological data set (Chesters and Neuendorffer, 1991 and 1992) was chosen to illustrate this type of analysis. Climatological averages of TOVS 6.5 µm water vapor observations, Outgoing Longwave Radiation (OLR) derived from NOAA/AVHRR 11 µm observations and Vertical Wind Speeds at 500 mbar analyzed at ECMWF (Schubert, et al., 1990) provide three channels for comparison. Figure 3 shows the side-by-side image spreadsheet configuration of the three channels, which can be better interpreted using synchronized animation with interactive rate control. The juxtaposition of these three parameters provides an opportunity to discover when and where regions of subsidence (warm colors in the right-hand column) correspond to cloud-free regions (warm colors in the middle column) and to upper air drying (warm colors in the left-hand column). Both spatially separated and superimposed configurations with instantaneous channel switching are being used to analyze the data, each of which have different characteristics (e.g., the satellite-observed subsidence southwest of Hawaii in January is not supported by the conventional ECMWF analysis, and all three observing systems look different over the Middle East in July). EOS-level animation might require animation of daily frames of a dozen satellite-derived parameters over many years, challenging both the visualization engine and the human mind.

3.2 Interactive Analysis of Very Large Multispectral Images

A full GOES satellite visible image from the Visible Infrared Spin Scanning Radiometer (VISSR) instrument is 16,000 X 16,000 pixels with six bits per pixel for an image storage size of 192 MB. The associated 11µm infrared and 6.7 µm water vapor channels are at the substantially lower resolution of 2,000 X 4,000 pixels with eight bits per pixel. The three channel total data set of 208 MB, once every half hour since 1974, is available from a NOAA maintained archive. A standard Landsat scene Thematic Mapper (TM) has six channels at 5965 X 6967 pixels and the thermal channel TM 6 is one-fourth the resolution at 1491 X 1742 pixels with radiance values (for all channels) digitized to eight bits for a total of 252 MB for all channels. Actual memory storage space required varies somewhat with system architectures since some may require an even number of bytes or four-byte word alignment per scan line. The SGI 340VGX, for example, requires four-byte word alignment. Image data sets of such large sizes for a single scene can be manipulated interactively without segmentation for the first time using the high performance large random access memory (256 MB) available on the IISS workstation. Figure 4 is a subimage of a Landsat TM scene (that has been histogram equalized and four times subsampled) showing three channels (TM7, TM4, TM2) in false color of the oil fires in Kuwait shortly after the Gulf war in May 1991 (Cahalan, 1991). The three channel image of the entire scene occupies 166 MB of memory (due to word-alignment requirements). An interactive program, after reading in the entire multichannel image into memory, can then manipulate an image viewing window up to display size (1280 X 1024 pixels) to roam smoothly over the entire scene in double buffered mode. An instantaneous zoom can be made of the area shown in an interactively located box and once the zoom factor is in effect the entire image can be roamed at the new resolution. The zoom factor and zoom area are variable and can be specified by the size and shape of the box that is drawn by the user.

3.3 Interactive Analysis of Images with a Very Large Number of Channels

Spectrometers with nearly continuous coverage of broad regions of the electromagnetic spectrum present new challenges to data display and analysis systems. For example, the Landsat type instrument on the planned Eos satellite will be the HIRIS spectrometer. The HIRIS instrument will have 192 channels with an instantaneous field of view (IFOV) of 30 m and a swath width of 30 km. The aircraft instrument designed to simulate HIRIS is the AVRIS with 224 channels covering wave lengths of 0.4 to 2.4 µm at 9.6 nm intervals with an IFOV of 20 m and swath width of 11 km. The ImageVision Library™ from Silicon Graphics has been used within SGI to prototype some useful techniques for visualizing multispectral data sets such as that obtained from the AVRIS instrument. The `viewSpectra` tool allows channel selection using interactive slide bars for both monochrome and three color display. Channel number and wave length are both presented with the resulting false color image to aid in qualitatively assessing different false color combination selections. Figure 5 also shows the `cubecut` display prototype which presents the multispectral data set as a cube that can be sliced vertically by channel or spatially in the x and y directions. Interactive control of smoothing by subsampling (to improve the performance while manipulating the entire cube of data) is also an option. Another visualization prototype, (not shown), allows three-dimensional manipulation of a single classification region based on three channel features to be defined and applied to the image data set.

4. CONCLUSIONS AND FUTURE WORK

The design and analysis of a prototype Interactive Image SpreadSheet (IISS) environment has been developed using a very high performance graphics/image processing workstation. Currently, several dynamic spreadsheet configurations with limited interactive capability using real Landsat TM, NOAA/AVHRR, and AVIRIS data sets have been developed using the Goddard Silicon Graphics 4D/340 VGX IISS workstation system. Implementation of the more complete IISS is now in progress.

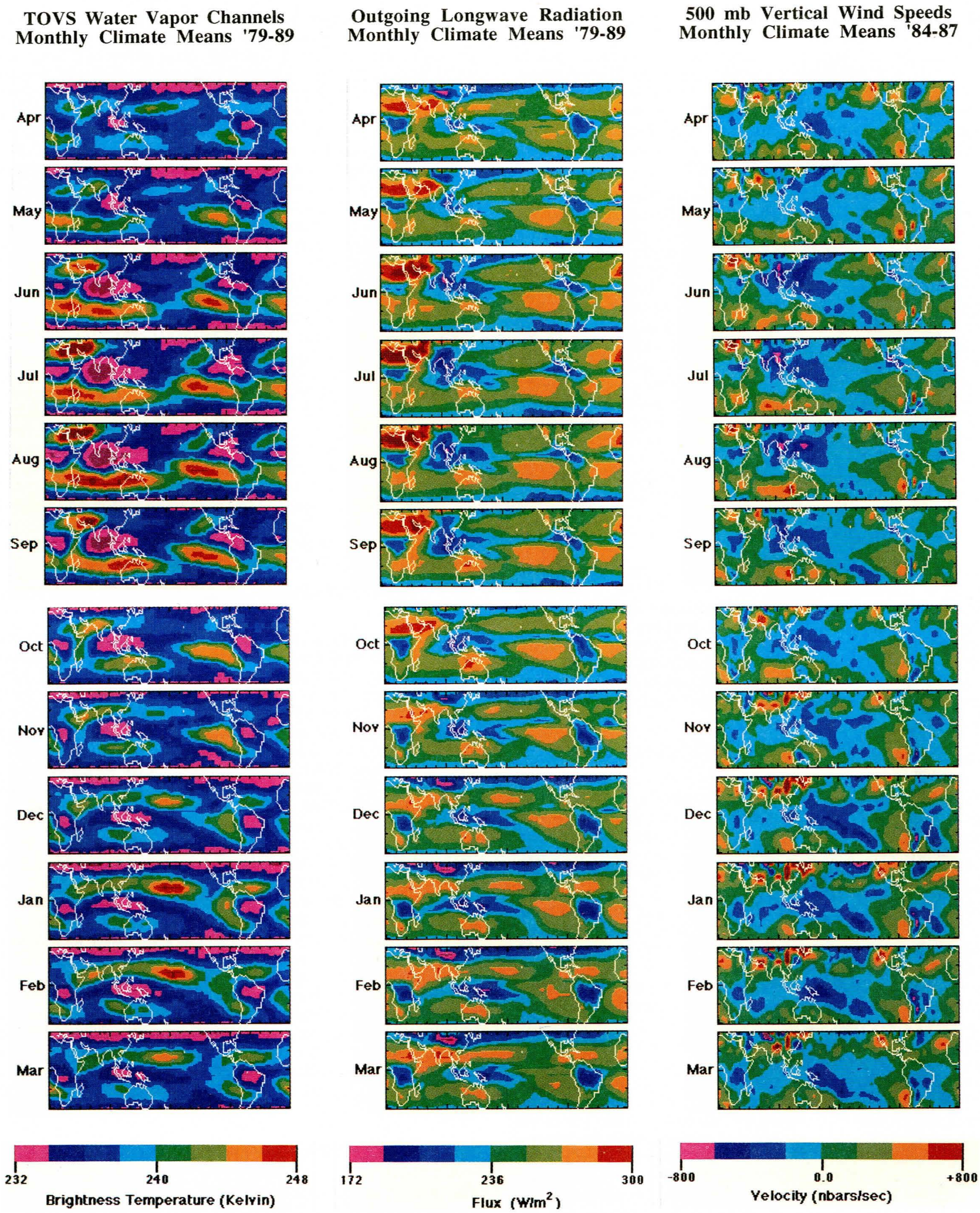

Figure 3. Climatological averages of TOVS 6.5 μm water vapor observations, Outgoing Longwave Radiation (OLR) derived from NOAA AVHRR 11 μm observations and Vertical Wind Speeds at 500 mbar analyzed at ECMWF. This is an example of an image spreadsheet application using time series of multi-channel data. In this typical static display the channels are displayed as columns with time variation by row. In the dynamic version on the workstation this is displayed as a three cell animation or a single cell with rapid switching between animations of the different channels.

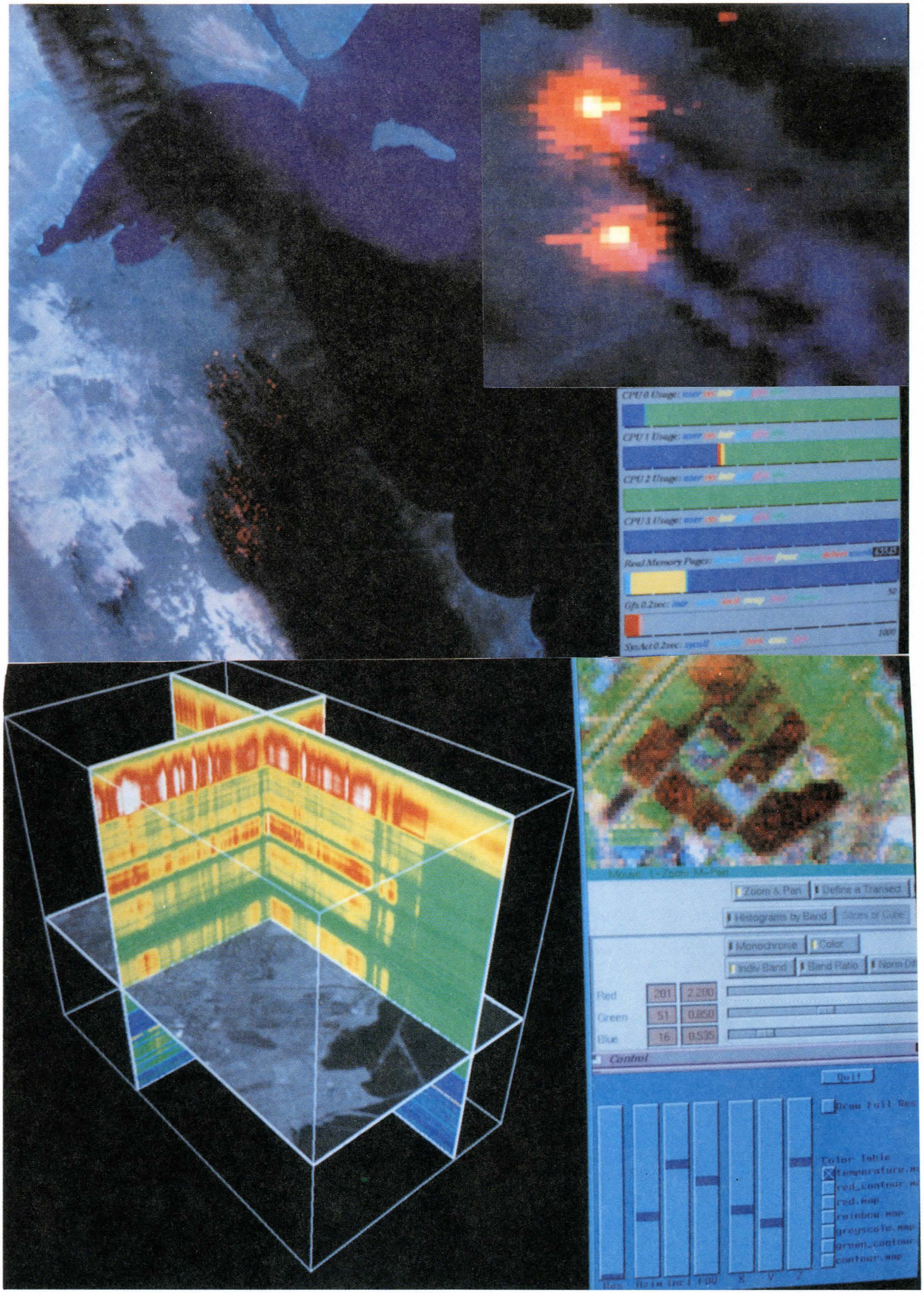
CPU 0 Usage:
CPU 1 Usage:
CPU 2 Usage:
CPU 3 Usage:
Real Memory Pages:
Zoom & Pan
Define a Transect
Histograms by Band
Slices of Cube
Monochrome
Color
Indiv Band
Band Ratio
Red
Green
Blue
201
2.200
51
0.850
16
0.535
Control
Quit
Color Table
red.map

Figure 4. (Upper image on previous page) This figure is a Landsat Thematic Mapper (TM) scene which shows a TM7/TM4/TM2 channel false color composite of the oil fires in the Greater Burgan Oil Field in Kuwait shortly after the Gulf war in May 1991. The entire three channel scene which is 5965 X 6967 pixels X 24 bits (125 Mbytes) has been read directly into memory and manipulated on the IISS workstation. An interactive program that allows a 1280 X 1024 pixel sized window to roam over the entire scene at full, reduced, or zoomed resolution was used to create the insert in the far upper right hand corner showing two of the fires with the heated surroundings, black smoke from burning oil, and white smoke from burning salt.The lower insert is a system performance monitor which reports on usage of different resources on the SGI 4D/340 VGX including the activity of the four CPUs (CPU 3 was fully occupied running a numerical weather model) and memory usage (90% percent of the available memory was used and shared between the large Kuwait Landsat image, the numerical model program and other system processes)

Figure 5. (Lower image on previous page) Visualization software using the ImageVision Library™ from Silicon Graphics provide some useful techniques for viewing three-dimensional data sets such as those provided by the AVRIS hyperspectral instrument. The above figure shows a sample AVIRIS data set of the Ames, California area displayed as a cube with the *z* axis representing frequency. Interactive control of smoothing and two orthogonal cutting planes is available in the `cubecut` program and selection of channels, ratios, or differences for displaying false color images and performing interactive pixel classification is available in the `viewSpectra` program.

A high performance (120 MIPS, 20 MB/s) IISS workstation, with a very large fully configured memory (256 MB) and a large (5 GB) medium performance (2 MB/s) mass data storage system was used for this demonstration. This system has made possible the effective manipulation and analysis of very large data sets. For example full sized multispectral Landsat TM scenes, full GOES images and 900 frame (grayscale) animations as large as 236 MB have been loaded into the workstation for visualization. Work with these very large data sets has emphasized the need for even higher performance systems with massive data storage capabilities. Fortunately, the electronics industry continues to develop higher performance systems at lower cost. At the high-end, workstations are being designed to take over many of the functions of supercomputers, and at the low-end, the first high performance Reduced Instruction Set Computer (RISC) personal computer (< $10,000) has just come onto the market. The RISC PC is being developed for interactive Computer Aided Design (CAD), color publishing, and audio and video production among other applications. These advances are driving down prices to the point where effective manipulation and analysis of very large remote sensing data sets has become practical for most researchers.

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