N87-26557

ANIMATED COMPUTER GRAPHICS MODELS OF SPACE AND EARTH SCIENCES DATA GENERATED VIA THE MASSIVELY PARALLEL PROCESSOR

Lloyd A. Treinish, Michael L. Gough and W. David Wildenhain

National Space Science Data Center
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

ABSTRACT

The objective of this research is to develop the capability of rapidly producing visual representations of large, complex, multi-dimensional space and earth sciences data sets via the implementation of computer graphics modelling techniques on the Massively Parallel Processor (MPP) by employing techniques recently developed for typically non-scientific applications. Such capabilities can provide a new and valuable tool for the understanding of complex scientific data, and a new application of parallel computing via the MPP. A prototype system with such capabilities has been developed and integrated into the National Space Science Data Center's (NSSDC) Pilot Climate Data System (PCDS) data-independent environment for computer graphics data display to provide easy access to users. While developing these capabilities, several problems had to be solved independently of the actual use of the MPP, all of which are outlined.

Keywords: Computer Graphics, Parallel Processing, Solid Modelling, Animation, Generic Data Representation

BACKGROUND

General

Over the past several years computer graphics has been used to display multi-dimensional (*i.e.*, greater than three) data in support of computer-aided engineering and design, and the film industry via the techniques of solid modelling and animation. These techniques are, in general, very data or application specific, and highly intensive users of computing resources. For example, typical non-scientific applications require almost dedicated use of computers like a Cray X-MP or Cyber 205. To date, such technology has not been commercially available to perform complex, scientific data representation in a generalized and near-real-time fashion, especially at GSFC.

The MPP, which was developed at GSFC, has the potential to process data many times faster than a conventional supercomputer such as the aforementioned Cray or Cyber. If the enormous processing power of the MPP can be applied to the generation of complex computer graphics models then the MPP may have an important impact on the problem of displaying and understanding of complex, multi-dimensional scientific data sets from a variety of disciplines (*e.g.*, space physics, climatology, earth resources, astrophysics) for GSFC researchers.

Many research programs at GSFC generate multi-dimensional data sets from a variety of space and earth science disciplines (*e.g.*, observations of temperature as a function of latitude, longitude, altitude and time). Because of the complexity of such data, it has been quite difficult to gain a complete understanding of their significance. To date, the comprehension of the physics behind the observations has generally been limited to the interpretation of only two- or three-dimensional slices of the data sets of interest because of the lack of appropriate analysis tools.

A data-independent framework for the display of multi-dimensional data sets via computer graphics has been established at GSFC within the NSSDC, as part of the PCDS (Ref. 1). This framework is well-suited for the analysis and display of complex data sets. However, the techniques for performing such data representations beyond simple three-dimensional slices in a useful manner exceed the current capabilities of any computer graphics facility at GSFC. This data-independent framework is supported by the NSSDC Common Data Format (CDF), which is a data abstraction for the source-independent storage and manipulation of data. It provides generic access to structured data and meta-data for applications such as data display (Ref. 2).

Candidate Applications

As a proof of concept, several candidate applications have been selected, from which data sets of interest can be derived, to illustrate the potential of this type of graphical representation for scientific research. The first application is in Middle Atmosphere Electrodynamics (MAE), in which the temporal, spatial and spectral distribution of *bremsstrahlung* x-rays and precipitating electrons during auroral events are studied. Data sets from such observations can fill up to a 6-space model (*e.g.*, x-ray flux as a function of latitude, longitude, altitude, energy and time). Current graphical analysis techniques are limited to subset slices only, for example, spatial distribution of flux at a specific energy level, flux versus energy, flux versus time, etc. It is hoped that through such improved display techniques, a better understanding of energy deposition in the middle atmosphere can be achieved (Ref. 3-4).

A second candidate application is for the generation of simulated mean sea surface maps from satellite altimetry to support oceanography. Traditional display techniques for satellite altimetry cannot show the very subtle variation in the mean sea surface, which relect the composition of the

PRECEDING PAGE BLANK NOT FILMED

lithosphere, and hence, the ocean oathymetry. Solid modelling techniques with appropriate light shading applied to these data have the potential to highlight the detailed structure of the sea surface, in which the light source simulates the action of the active altimeter. It is hoped that through such improved display techniques, a comparison of sea surfaces with ocean bathymetry and gravity fields can be achieved.

Other candidate applications can be derived from the multitude of large, complex data sets managed by the PCDS, whose conventional display techniques are inadequate for some data. In addition, data derived from the LANDSAT Thematic Mapper, could be displayed using solid modelling techniques, when merged with topographic map data.

Representation Methodologies

The NSSDC provides techniques for the conventional representation of arbitrary data, stored in a CDF, in a data-independent fashion, through the PCDS. For one-dimensional data, the display of a histogram would be an appropriate way of illustrating the data. For two-dimensional data, the conventional x-y plot would be appropriate, or a three-dimensional histogram. For three-dimensional data, contour plots, three-dimensional wire-frame or surface diagram, three-dimensional scatter diagram (*i.e.*, x-y-z plot), or a color or gray-scale image would be appropriate. In any of these representation schemes, the use of different coordinate systems or projections may be applied (*e.g.*, cartesian versus polar coordinates, Mercator versus Cylindrical Equidistant map projections, perspective versus orthographic viewing) (Ref. 7).

However, to represent data of greater than three dimensions, as might be available in any of the aforementioned applications, new representation techniques must be developed, in four potential areas. First, for the animation of histories of three-dimensional displays, one would apply any of the conventional three-dimensional representation schemes on a large sequence of the three-dimensional data with respect to some fourth dimension. This concept can be illustrated for an example of global temperature distributions, in which five dimensions of data are available. The first three dimensions are latitude, longitude and altitude, in which this spatial information can be modelled into a three-dimensional wire-frame display. Next, the wire-frame can be filled by a color spectrum, which is mapped to the variation in temperature (*i.e.*, blue implies low temperatures, red implies high temperatures). Finally, a sequence of these solid models of temperature can be brought together by animation to represent the passage of time. Of course, the display can be enhanced by transforming the spatial portion to a map projection of choice, adding a world coastline overlay, graphics arts fonts for annotation, etc.

A second type of data representation, would be in the area of remote sensing scene simulation, in which a complex geometry of instrument movement is used to collect data of interest. This geometry could be combined with the data itself into a complete display that illustrates the nature of the observation geometry at a particular instant or configuration with the appropriate data. A third type of representation would apply to some remotely sensed data that is acquired through active rather than passive sensors, as with radar mapping. Light shading techniques can be used to simulate the characteristics of the active sensor with the resultant observations illustrated as a solid model illuminated by such a light source. A fourth area of data representation techniques, would be for the realistic rendering of remotely sensed data, in which the data of interest is combined with other information to provide sufficient visual cues to help in the understanding of the data. An example of this would be the warping of a classified LANDSAT scene to a topographic map registered over that scene into a three-dimensional solid model.

CONCEPT

This research is motivated out of several factors, one of which, obviously, is the need to provide to the NSSDC community, the ability to display complex, multi-dimensional data sets. However, the NSSDC lacks any significant computational resources, especially for graphics, so an alternative outside of the NSSDC had to be found. Why was the MPP chosen? - essentially because it is there. As mentioned earlier, the MPP has enormous computational potential, which could be applied to graphics. When this work began, the feasibility of developing appropriate parallel algorithms for the MPP was not known. In addition, the configuration of the MPP hardware and software, in principal, allowed it to be the only large-scale computational resource available that is appropriate for its use as a background geometry engine for interactive graphics applications. As it turned out the MPP's hardware and software configuration is not appropriate for such applications, which is discussed below, but no alternatives have yet to become available.

APPROACH

In order to provide an operational capability at the NSSDC to enable users of the data that it supports to display complex data, a systematic approach was developed. The steps in this approach were as follows, but not necessarily pursued in the enumerated order:

- Augment the NSSDC Computer Facility (NCF) with appropriate commerical hardware and software to enable NSSDC software systems to display graphics models.
- Select and prepare candidate data sets within the PCDS via the CDF.
- Devise multi-dimensional representation methodologies appropriate for the candidate applications.
- Develop custom software to link the PCDS to new commerical hardware and software.
- Study feasibility of using the MPP for generation of graphics models.
- Develop modelling algorithms on the MPP.
- Link MPP model generation with data display and management in the PCDS.
- Study and analyze candidate data sets.

This step-wise approach was adopted, so that a useful capability could still be applied to the NSSDC, even if one or more of the steps failed.

ACCOMPLISHMENTS TO DATE

In the implementation of the approach outlined above, the following achievements have been made:

- A development effort to extend conventional two- and three-dimensional graphics within the PCDS data-independent environment to that of true multi-dimensional representations, including animation, has been completed.

- An analysis of typical geometric rendering algorithms has been done in light of the SIMD architecture of the MPP. Some simple graphics algorithms have been developed for the MPP for ray tracing, calculation of surface normals, etc., and shown to be adequate for basic geometric rendering applications. However, for an operational environment, a surface fitting algorithm has been developed, in which a large sequence of arbitrary triples of data (*i.e.*, [x, y, z]) are sent to the MPP, and an empirical functional relationship (*i.e.*, z[x, y]) is established.

- An extensive survey of the advanced computer graphics workstation market has been conducted, which led to the competitive procurement of a Megatek Merlin 9200, which has been integrated into the NSSDC Computer Facility (NCF) via its local area network and hence, SESNET, for direct communications to the MPP. Figure 1 illustrates the configuration of this hardware, and the communications links that support the the transfer of data to and from the MPP and the Merlin 9200.

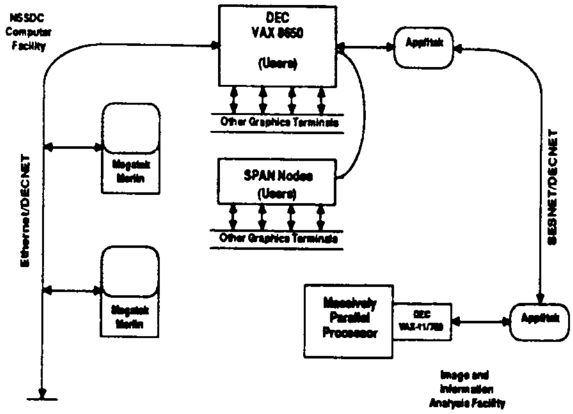
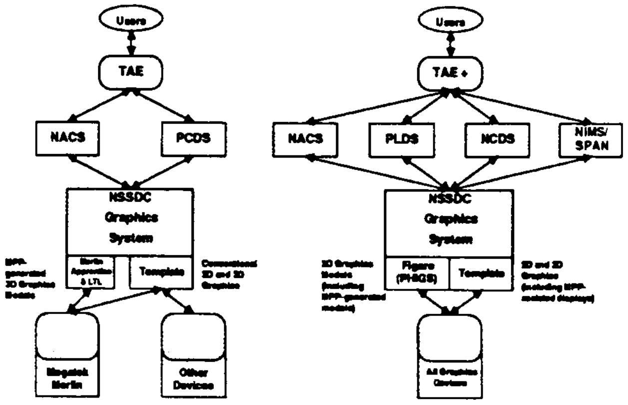


Figure 1. Hardware Configuration for MPP Graphics at the NSSDC

- Several generic data representation methodologies have been developed for the display of complex, geophysical data sets, which have been implemented via the MPP and the NCF.

- The software on the MPP and the NCF have been integrated with the workstation environment to permit a potential user of these advanced graphics techniques to easily get at and work with data of interest. Basically this has involved the tying of these display techniques on the MPP with the PCDS in a transparent fashion, and the establishment of a user-friendly environment for these tools. Figure 2 illustrates the configuration of this software in the NCF environment, in which several NSSDC software systems access a generic graphics system for data representation, and utilize the Merlin 9200 as well as other graphics hardware for actual displays.



FY86 Configuration FY87 Configuration

Figure 2. Software Configuration for MPP Graphics at the NSSDC

- Some candidate data sets have been identified from which complex, graphics models have been generated, in the areas of solar-terrestrial physics, climatology, and oceanography.

MPP ALGORITHMS

Obviously, the MPP has enormous computational power, but its SIMD architecture is really not the optimal one for graphics modelling. In fact, efforts to utilize a parallel architecture for computer graphics have only begun fairly recently (Ref. 8-9). Therefore, an investigation and evaluation of different graphical techniques was begun for the MPP. This effort began with an examination of traditional graphics rendering algorithms (*e.g.*, ray tracing, depth sorting, area subdivision, z-buffering, etc.). Some experiments were done with brute forcing ray tracing, using the array as a z-buffer for hidden line and surface removal to prove the feasibility of using the MPP for graphical rendering. However, given the limitations implied by the current hardware and software environment to support the operational scenario, which is outlined in a subsequent section, it was decided to utilize the MPP for only partial rendering of the data of interest. In this situation the MPP is used to calculate surface meshes from arbitrary data, from which a final rendered display is generated at the NCF.

Within this revised environment, the MPP basically performs two functions. First, it is used to construct a three-dimensional surface on a uniformly spaced grid of specified resolution from a non-uniformly distributed set of arbitrary input data points. Second, it computes vectors, which are normal to the three-dimensional surface at each of the grid locations. The SIMD architecture of the MPP is used to perform these calculations simultaneously for each grid point. Several different gridding techniques have been implemented and tested with a random distribution of data points, which are outlined below. Two of the methods, which compute a local surface function for each grid point (methods 6. and 7. below), were first implemented on the NCF DEC VAX 8650 for testing. They were found to be inadequate because they resulted in excessive surface undulations. The other methods resulted in surfaces with much better behavior. In particular, methods 4. and 5. below seem to provide the best surface representation. An additional method was also investigated, in which bicubic Bezier patches were used to constructed local surfaces for each grid point based upon the closest 16 data points (Ref. 10). However, this method required the solution of two very complicated simultaneous equations, which proved to be beyond the ability of the symbolic mathematics package, MACSYMA, available on the NCF VAX 8650 (Ref. 11). There was insufficient manpower and funding resources to attempt to solve these equations using an interative numerical approach.

Step One

The construction of a gridded three-dimensional surface from a non-uniform distribution of arbitrary data points was attempted via seven different techniques enumerated below:

1. Nearest Point Algorithm

The Euclidean distance between each incoming data point (represented by an arbitrary 3-tuple [x,y,z]) of the non-uniform distribution and each grid point is computed to find the closest data point to each grid point of the uniform grid. Each grid point is then merely assigned this z-value.

2. Average of All Data Points Weighted by Inverse Distance

The Euclidean distance between each incoming data point and each grid point is computed. Each grid point is assigned a z-value based upon a weighted average of all of the incoming data points, with the weights being assigned on the basis of the distance between the data point and the grid point. The closer points are given a higher weight than the farther points since the inverse of the distance is used as the weight.

3. Average of All Data Points Weighted by Inverse Squared Distance

This method is identical to method 2. except the weight is based upon the inverse square of the distance between the data point and the grid point.

4. Weighted Average of the 5 Closest Data Points to each Grid Point

The Euclidean distance between each incoming data point and each grid point is computed to determine the 5 closest data points to each grid point. A z-value is then assigned to each grid point based upon a weighted average of these 5 closest points, with weighting being done with the inverse of the distance.

5. Weighted Average of the 3 Closest Data Points to each Grid Point

This method is identical to method 4. except that 3 points are used rather than 5.

6. Construction of a Hyperbolic Surface for each Grid Point

The Euclidean distance between each incoming data point and each grid point is computed to determine the 6 closest data points to each grid point. A 6 x 6 matrix, **A**, is then constructed for each grid point with the following basis functions:

$$\begin{array}{ccc} 1 & x & y \\ xy & x^2 & y^2 \end{array}$$

Using the z-values of the 6 closest points as the right-hand side, **b**, the following can be established:

$$\mathbf{A}\,\mathbf{x} = \mathbf{b}, \qquad (1)$$

which can be solved for **x**, to yield the coefficients of a local hyperbolic function. Each function is then sampled at the grid location to generate a z-value for that point.

7. Construction of a Simple Surface for each Grid Point

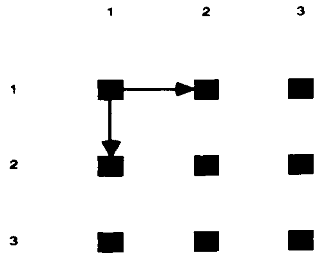
The Euclidean distance between each incoming data point and each grid point is computed to determine the 4 closest data points to each grid point. A 4 x 4 matrix, **A**, is then constructed for each grid point with the following basis functions:

$$\begin{array}{ccc} 1 & x & y \\ x & xy & \end{array}$$

Using the z-values of the 4 closest points as the right-hand side, **b**, then equation (1) for a 4 x 4 system can be utilized, which can be solved for **x**, to yield the coefficients of a local surface function. Each function is then sampled at the grid location to generate a z-value for that point.

Step Two

The construction of a normal vector at each grid point of the uniform, gridded three-dimensional surface calculated in Step One is done in two steps. First, two non-colinear line segments from each grid point on the southward and eastward directions are constructed, which is illustrated in the schematic below, in which the two line segments are constructed from the extreme northwest point in a sample grid:



Let the label, *A*, designate the line segment or equivalent direction vector, extending from the grid point (1,1) to grid point (2,1), in this example, where the notation (row, column) is utilized. This direction vector is formed by merely subtracting the [x,y,z] components of point (1,1) from the [x,y,z] components of point (2,1). Let the label, *B*, designate the line segment or equivalent direction vector extending from grid point (1,1) to grid point (1,2). This second direction vector is formed by subtracting the [x,y,z] components of point (1,1) from the [x,y,z] components of point (1,2).

Second, take the cross-product of the two line segments from each grid point. In the above illustration, this would imply *A* x *B*, with the resultant vector being perpendicular to the plane defined by the two line segments, *A* and *B*. This resultant vector is the normal vector to that particular grid point, and is used by the NCF hardware and software to render a final display. This procedure is carried out simultaneously for each of the grid points of the surface mesh, with the exception of the last column and the bottom row of the grid, which require northward and westward constructions of the line segments.

OPERATIONAL SCENARIO

The aforementioned tools have now been integrated at the NCF in the graphics workstation environment to permit a user to view such complex models of data via the same, simple mechanism that a user can view data of interest in the PCDS environment in a conventional two or three-dimensional form. This system represents the first *operational* use of the MPP, in the context of an extant user-friendly software system. Figure 3 is a schematic of the information and data flow that supports this operational graphics capability, in the context of the hardware and software configuration shown in Figures 1 and 2, respectively. In this system a user creates or generates data of interest in terms of CDF for the PCDS. A user can then create conventional representations of two or three-dimensional slices of the data. However, a user can also generate a solid model representation. When that happens, the data of interest from the CDF, and the model request are shipped over to the MPP via SESNET, where a batch job is submitted under interactive control at the NCF. The MPP software generates the surface rendering, and ships it back to the NCF for final display and rendering on the Merlin 9200. Animation is achieved via the display of sequences of such models.

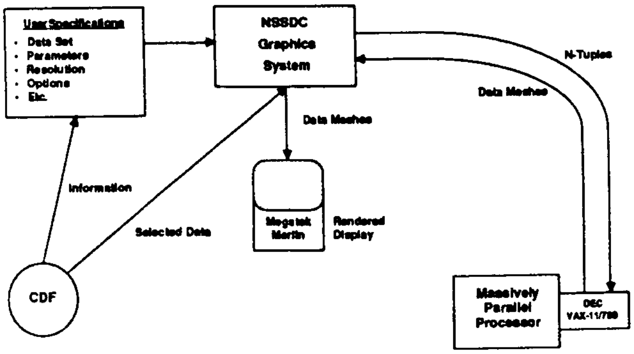


Figure 3. Data Flow for MPP Graphics at the NSSDC

At this point any member of the MPP Working Group is cordially invited to view this capability in action, and to evaluate its utility to supporting their research.

MEGATEK MERLIN 9200

The Megatek Merlin 9200 is an advanced solid-modelling graphics terminal, that is oriented around a hierarchical three-dimensional architecture for graphics, and a distributed processing concept. This terminal supports a 3072 x 2304 display resolution with 12-bit planes of double buffered display memory. It is capable of processing full three-dimensional transformations on 50,000 vectors per second or 3800 shaded polygons per second. Within its three-dimensional graphics capabilities it can support a data base of up to 4 MB with a dedicated processor. Its graphics processor also supports light shading via flat, Phong and Gouraud algorithms. It has a separate local task processor, which can be programmed independently from the host, supported with 1 MB of memory. The Merlin relies on the NCF VAX 8650 as a host computer, which communicate via a DECNET/Ethernet connection for graphics, and conventional asynchronous communications for alphanumerics. The Merlin also supports multiple input devices, including three valuators, a keyboard, joystick, and data tablet. The surfaces calculated on the MPP are downloaded to the Merlin graphics database, and then rendered by the Merlin itself. In this sense, the VAX 8650 acts as a user interface, and communications handler between the user, the MPP VAX-11/780 and the Merlin (Ref. 12).

RESULTS

This research has yielded a new operational capability to display complex data sets in a novel fashion. At this time, the tools are just beginning to be used to analyze space and earth sciences data of interest. Color Plate V is an example of the type of graphical product that the system can generate. It illustrates the spatial and spectral distribution of gridded energy fluxes calculated from remotely sensed x-ray counts observed from a sounding rocket instrument during an auroral event (Ref. 4).

Problems

While doing this work several unforseen problems arose, which has delayed the completion of all of the proposed activities, and has prevented the completion of the actual analysis of the candidate data sets via their geometry, which was originally planned for the current fiscal year. There were two major problem areas that were encountered. The first problem is related to the MPP itself. The MPP software environment lacks sufficient flexibility and ease of use to permit the development of an operational MPP-based graphics system (Ref. 13). The current MPP environment is only suited for the clumsy development of *one-shot* code, and not for the development of real applications systems. Therefore, a conceptual framework for such a proper environment was developed and implemented to permit simpler access to the MPP via a software *toolbox* as a collection of procedural abstractions, which includes a virtual memory manager, and transparent task-to-task communications across SESNET or the Space Physics

Analysis Network (SPAN) (Ref. 14). This MPP task funded and supervised the development of this toolbox. This software can be made available to MPP Working Group for use in any applications software to provide for the first time reasonable access to the MPP's enormous computational power. The details of this software development effort and the resultant package is described in a companion paper to this one, **A Generic Applications Subroutine Library for the MPP** by Michael L. Gough and W. David Wildenhain (Ref. 15). Of course, this toolbox permitted the completion of the graphics applications.

The second major problem area was in procurement. The acquisition process for the advanced computer graphics workstation necessary to support this work required over a year. This delayed the development of system-specific software, and learning how to employ such a state-of-the-art hardware/software system.

PLANNED FUTURE WORK:

It is expected that this work can continue in several different areas if funding is made available. The efforts described herein, were funded primarily by the NASA/GSFC Director's Discretionary Fund for FY85 and FY86. However, there is no currently available funding to continue this work, even though it is still part of an approved MPP Working Group project.

Of course, the actual analysis of the candidate data sets should be supported as part of any continued research effort. However, much interest has been generated in these graphical modelling techniques for a wide variety of space and earth science data sets, especially those that are managed by the NSSDC. Hence, one would like to apply these display techniques to a number of data sets that the NSSDC manages in a variety of disciplines. Therefore, the tools developed to date will be *turned over* to the NSSDC for use in its operational PCDS-supported research, for example.

In addition, further efforts in the exploration of computational power of the MPP, in the context of the MPP Working Group, should be pursued. In particular, the development of other data representation schemes coupled with the development of other rendering algorithms offers a number of challenging ideas. For example, revisiting the idea of implementing surface fitting via bicubic Bezier patches would be of great interest.

Although the implementation of these tools has been established for the Megatek Merlin 9200 hardware, it should be recast in terms of the proposed ANSI standard for PHIGS, the Programmer's Hierarchical Interactive Graphics Standard, to provide computer as well as device portability, with high-level three-dimensional functionality. This will permit the future use of these applications in a wide variety of environments, including other high-end graphics systems for the display and manipulation of such models (Ref. 16).

REFERENCES

1. Treinish, Lloyd A. *A General Scientific Information System for the Study of Climate-Related Data.* NASA Technical Memorandum, September 1984.

2. Treinish, Lloyd A., Michael L. Gough, C. Edwin Wilson. *A Software Package for the Data-Independent Management of Multi-Dimensional Data*, NSSDC, September 1986.

3. Goldberg, R. A., C. H. Jackman, J. R. Barcus and F. Soraas. "Nighttime Auroral Energy Deposition in the Middle Atmosphere." *JGR, 89*, pp. 5581-5598.

4. Goldberg, R. A., J. R. Barcus, L. A. Treinish and R. R. Vondrak. "Mapping of Auroral X-Rays from Rocket Overflights." *JGR, 87*, pp. 2509-2524.

5. Koblinsky, C. J., J. G. Marsh, C. Nethery and V. Zlotnicki. *Development of a Graphical Analysis System for the Study of the Earth and the Oceans.* A Proposal Submitted to the Director of NASA/GSFC, 1984.

6. Marsh, J. G., C. J. Koblinsky, A. Brenner, B. Beckley and T. Martin. "Global Mean Sea Surface Computations Based upon a Combination of SEASAT and GOES-3 Satellite Altimeter Data." *EOS, 65*, 45, p. 857.

7. Reph, Mary G., Lloyd A. Treinish, Carey E. Noll, Thomas D. Hunt and Shue-wen Chen. *Pilot Climate Data System User's Guide.* NASA Technical Memorandum, January 1986.

8. Dippe, Mark and John Swenson. "An Adaptive Subdivision Algorithm and Parallel Architecture for Realistic Image Synthesis." *Computer Graphics, 18*, 3, ACM Siggraph '84 Proceedings, pp. 149-158.

9. Levinthal, Adam and Thomas Porter. "Chap - A SIMD Graphics Processor." *Computer Graphics, 18*, 3, ACM Siggraph '84 Proceedings, pp. 77-82.

10. Foley, J. D. and A. van Dam. *Fundamentals of Interactive Computer Graphics.* Addison-Wesley, 1982, pp. 505-538.

11. Symbolics, Inc. *VAX UNIX MACSYMA Reference Manual.* Version 11, November 1985.

12. Megatek Corporation. *Merlin 9200 User's Guide.* Version 1.0, February 1985.

13. Fischer, Jim. *MPP User's Guide.* NASA/GSFC, January 1986.

14. Green, James L. and David J. Peters. *Introduction to the Space Physics Analysis Network (SPAN).* NASA Technical Memorandum, April 1985.

15. Gough, Michael L. and W. David Wildenhain, "A Generic Applications Subroutine Library for the MPP." *Proceedings of the First Symposium on the Frontiers of Massively Parallel Scientific Computation*, NASA/GSFC, 1986.

16. TEMPLATE. *Understanding PHIGS.* Megatek Corporation, 1985.