CR-189386

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Final Report

A Distributed Analysis and Visualization System for Model and Observational Data

Funded In Response to NRA-89-OSSA-21
Award NASA/USRA 5555-06

July 31, 1991 - July 31, 1994

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Overview

A proposal entitled "A Distributed Analysis and Visualization System for Model and Observational Data" was jointly submitted by the University of Illinois and the NASA-Goddard Severe Storms Branch in response to NASA Headquarters' Research Announcement, NRA-89-OSSA-21. Funding was provided to NCSA (National Center for Supercomputing Applications) and to NASA separately, with NASA funding ending early in the third year of NCSA funding.

The work accomplished during the three year NASA funding was part of a larger effort to develop an analysis and display software system for handling and visualizing the massive amounts of data generated from satellites, observational field programs, and from model simulations during or after their execution. Components of the completed system include GEMPAK analysis, data handling, and display modules for which NASA had primary responsibility, and prototype software modules for three-dimensional interactive and distributed control and display, as well as data handling, for which NCSA was responsible. Overall process control was handled through a scientific and visualization application builder from Silicon Graphics known as the Iris Explorer. In addition, the GEMPAK related work (GEMVIS) was also ported to the Advanced Visualization System (AVS) application builder. Specifically, the NASA related objectives at NCSA included providing animation and three dimensional display, handling and displaying data from different sources and on different grids, and developing new analysis and visualization modules within the IRIS Explorer environment.

This larger project within which these objectives were accomplished is known as PATHFINDER (Probing ATmospHeric Flows in an INteractive and Distributed EnviRonment). The mission of the PATHFINDER Project is to create a flexible, modular, and distributed environment for data handling, model simulations, data analysis, and presentation to be used in studying atmospheric and fluid flows, and which can be tailored for specific scientific research and weather forecasting needs. More specifically, in this environment the user should be able

1) to manage large amounts (gigabytes and beyond) of data generated by satellites, observational field programs, and model simulations,

2) to couple multiple and heterogeneous computers (e.g. SGI VGX, Cray Y-MP, CM-5),

3) to utilize existing diagnostic and analysis software capabilities such as those found in GEMPAK (the GEneral Meteorological PAcKage built at Goddard Space Flight Center),

4) to process multiple data streams(both model and observational) in creating a visualization,

5) to access a variety of analysis and display capabilities including three dimensional rendering, animation, and collaborative tools for interacting with remote users on different workstations across the national network, and

6) to incorporate video recording and playback, high definition monitors, and a virtual reality viewer.

PATHFINDER Modules Developed Under the NASA Award - General:

NASA support enabled the development of many new SGI Explorer modules that are available freely to the NASA and national research community. The modules and documentation were developed in the context of existing commercial and public domain software packages such as SGI's Iris Explorer, GEMPAK, AVS, Inventor, HDF, netCDF, DTM and NCSA Mosaic. The final release of the NASA funded modules occurred on July 18, 1994 and included

1) Support for Explorer 2.2 (including both Inventor 1.1.2 and OpenIventor 2.0)
2) Complete online documentation (via WWW)
    http://redrock.ncsa.uiuc.edu/PATHFINDER/pathrel2/top/top.html
3) Full source code as well as ready to run binaries.

Some highlights of this release are:

HDF file support: Reading multiple SDS's from all existing versions of HDF files and reading and writing palettes and 24bit raster images
NetCDF file support: Reading all data from Unidata or MFHDF3.3 netCDF files
Visualization: Improved contour generation, three-dimensional vector display ectors, arbitrary 2D slicing, and particle advection
Annotation and display: Adding materials, color bar annotation, 2D and 3D title generation
New Grid datatype for Explorer: The Grid datatype is an extension to Lattice that allows metadata such as variable and coordinate names and units to be passed along with the data thru the Explorer map. A type extension file, a library, header files, some sample and utility modules are included.
Other: Simple lattice math and filename generation for numbered sets of files

PATHFINDER Modules Developed Under the NASA Award - Specific:

The Iris Explorer modules developed under the NASA award were designed as part of the NSCA PATHFINDER project to aid in the analysis and visualization of atmospheric and other fluid flow data. Many of the modules were developed to fill in gaps in the capabilities provided by Explorer that were needed to accomplish NASA funded objectives. A more complete description follows.

HDF file support

The following modules provide support for the NCSA Hierarchical Data Format files (HDF). The HDF library (available on the NCSA ftp server, ftp.ncsa.uiuc.edu) provides a uniform method for storing multiple data fields in a single file, along with associated metadata.

ReadDF: is capable of reading from a variety of HDF files (files created with HDF versions 3.1, 3.2, 3.3, MFHDF/3.3) and even Unidata netCDF files. The latter format translation is handled transparently. Up to five unique lattices may be generated from the file (as these files can contain multiple data fields) using a single module. A variety of dimensionalities and data types are supported also. Multiple variables may be combined in a single lattice to generate vector data. All three Explorer coordinate systems are supported. A user friendly interface provides control and information about the contents of arbitrary HDF and netCDF

files. (Note, HDF images and palette are not supported by this module, see the modules below)

Read_HDF_Image: reads 24 bit raster images stored in HDF files (versions 3.1-3.2) and outputs them as a 2D lattice suitable for use with the Explorer image modules provided by SGI

Read_HDF_Palette: reads palettes from HDF files (versions 3.1-3.3) and outputs them in a format compatible with that of GenerateColormap. (1-D, 4 vector float lattice) (NCSA)

Read_Palette: reads palettes from HDF files (versions 3.1-3.3) or raw palettes and outputs them in a format compatible with that of GenerateColormap. (1-D, 4 vector float lattice) A raw palette is a binary file containg 256 bytes of red values, followed by 256 bytes of green values, and 256 bytes of blue values. The module will automatically recognizes the file type. A single color palette can be outputted by selecting a color index from the current palette.

Write_HDF_Image: writes 24 bit raster images to an HDF file (version 3.3) input is a 2D lattice.

Write_HDF_Palette: writes palette from GenerateColormap to an HDF file (version 3.3) as an HDF palette.

Visualization

Contour2: an improved version of the Contour module that comes with Explorer. Allows the specification of either the number of contour levels desired or a specific contour interval. The data value range that is contoured can be either fixed or data dependent. The zero contour line can be hidden and negative contour lines can be displayed differently to distinguish them if desired.

ParticleAdvect: generates points (random, uniform or ring structure) in a user specified subvolume of a given vector lattice field and advects all the points until they are out of the data domain. The user specifies step size and has choice for using adaptive/fixed step size, integration method (Euler, second-order Runge-Kutta and fourth-order Runge-Kutta) and interpolation method (trilinear/nearest neighbor).

Streakline2: a slightly modified version of the Explorer Streakline module. The main change is that the controls to manually specify a release point from the control panel without having to use picking have been enabled. (Only .mres and .help files are provided as it uses the existing Streakline binary)

VectorDisp: a much enhanced version of the Vector module that comes with Explorer. New features include several vector styles, adjustable vector length, arrowhead size and scaling (including an automatic scaling mode), and a variety of methods to map colors to the vectors.

Vslice: takes an arbitrary 2D vertical slice from a 3D lattice. The location of the slice is specified by selecting two end points of the slice in a small window on the control panel. A line is drawn between the two selected points and extended to the boundaries. Contour lines of a horizontal plane are drawn as a reference. Unlike OrthoSlice, the slice does not need to be orthoginal.

Annotation and Display

AddMaterial: adds a material to a geometry stream in an Explorer map. Sliders and a material editor widget allow easy specification of material properties. Unlike materials set from inside Render which must be reset with each use, the values are saved as module parameters between sessions.

ColorKey: takes a color map and generates a horizontal colored bar that displays the gamut of colors and tick marks with labels indicating the correspondence between colors and data values. This is sent to Render to annotate a visualization.

Display: an enhanced version of Render. The main addition is the ability to capture new frames as they are rendered (as in a map that contains a loop) and then play back the captured frames at various speeds. The actual geometried are stored instead of the images.

Text2D: generates a simple 2D title as a geometry to be sent to annotation port on Render. The position, size and font are set from the control panel.

Text3D: like Text2D, except that 3D text is used. This allows it to be included within the visualization as normal geometries. 3D text is always oriented correctly for reading no matter how the object is rotated in Render. The components of the 3D font, front back and sides, may be turned on or off individually. (NASA)

WireFrame2: an enhanced version of WireFrame that allows control over the wireframe's material.

Simple Lattice Math

These very simple modules are written in the Explorer Shape language and can serve as examples for your own lattice math modules. The SubtractLat module is particularly useful for finding the difference between two lattices that are being compared.

AddLat:	Adds two lattices together, point by point
DivideLat:	Divides one lattice by another, point by point
MultiplyLat:	Multiplies one lattice by another, point by point
SubtractLat:	Subtracts one lattice from another, point by point

Miscellaneous

TimeFilename: This module will construct file names from 4 components: path(string), name(string), time(numerical value) and extension (string). A printf() like format string specifies how these components are to be combined and formatted. The resulting filename may be passed as a parameter to modules that read to or write from files. It is useful to allow a loop in a map to access a series of sequentially numbered files.

The Grid Data Type for Iris Explorer

In addition to the predefined data types that come with Explorer such as lattice, parameter, pyramid, etc., SGI also provides a mechanism to create custom data types. This is different from the "Unknown" data type. These new types are dynamically loaded into Explorer at startup time and become as much a part of Explorer as the standard ones. For example, they show up in port names and in the module builder as valid choices for port types.

The Grid data type is essentially an extention of the Explorer lattice. In fact, it contains a lattice within its structure. In addition to the data carried within the lattice definition, it provides an arbitrary name space for additional metadata, such as variable and dimension names, units, etc. Some of these new metadata fields are predefined, but any arbitrary piece of metadata can be included.

The Grid's namespace works very much like the environment of a C shell (csh). It consists of a series of keyword, string value pairs. An example would be: UNITS=g/kg where UNITS is the keyword and the string "g/kg" is the value.

Data file formats such as HDF, netCDF and GEMPAK grid files often contain useful metadata that describes the actual data. A limited amount of this information such as dimension sizes and coordinates may be passed from module to module using the Explorer lattice type. Other information such as variable and dimension names, units, missing value flags, etc. is left behind in the file. The Grid type provides space to carry this information from module to module. User developed modules can make use of this information for things like automatic geometry annotation and missing value handling.

Utilities and Sample Modules for the Grid Data Type

Converters:

LatToGrid: converts a lattice to a Grid. Additional Grid information is supplied via type-in boxes on the control panel.

GridToLat: converts a Grid back into a lattice

Information:

PrintGridInfo: prints out the contents of the Grid namespace.

Sample Visualization modules using Grid type:

Contour2G: same as Contour2 (in General directory) except uses Grids instead of lattices. It handles missing values.

GridTitle: generates 2 and 3D text for annotation. This text can contain references to Grid keywords for which the module automatically substitutes the corresponding values from an input Grid. Is useful for automatically annotating a display based on input data. Multiline text is supported. The module has controls for text font, scaling, placement and other properties.

OrthoSlice2G: same as OrthoSlice but uses Grids

ReadDFG: same as ReadDF (in General directory) except outputs Grids instead of lattices. Some of the additional metadata in the data files is used to fill in the Grid fields.

WireFrame2G: same as PATHFINDER WireFrame2 but accepts a Grid input.

The Grid Library

The Grid Library is provided for developing your own Grid modules. It includes a comprehensive API designed after Explorer's lattice access API so that it will be easy for Explorer programers to use.

GEMVIS

GEMVIS is software for the interactive analysis and three-dimensional visualization of atmospheric data. It is based on GEMPAK (The General Meteorological Package); it reads GEMPAK grid files and includes various GEMPAK analysis and map projection capabilities in the form of modules. This version runs within the Iris Explorer or AVS environments and enhances GEMPAK capabilities with three dimensional visual displays. GEMVIS was developed by NASA / Goddard Space Flight Center and NCSA as part of the NCSA Pathfinder project. GEMVIS is provided in source code format only due to restrictions on distributing pre-compiled versions containing the GEMPAK libraries.

To build GEMVIS it is necessary to link to GEMPAK subroutine libraries. These libraries are created as part of the standard GEMPAK build procedure. GEMPAK can be obtained from the Unidata Program Center, a division of the University Corporation for Atmospheric Research ((303) 497-8678 or support@unidata.ucar.edu) or from COSMIC (the NASA Computer Software Management and Information Center, (706) 542-3265 or service@cossack.cosmic.uga.edu).

The set of capabilities targeted to the GEMPAK user community includes:

GEMPAK grid diagnostics & file access:
      the full range of GEMPAK functions and operators supported
      a new operator implemented for 3D vector data
      all GEMPAK grid data formats supported
      all vertical coordinate systems handled
      relevant modules: GemGetGrid , GemGridFunction

Map projections & topography :
      a wide variety of map projections
      maps registered with data set visualizations
      topography displayed in appropriate projections
      relevant modules: GemDrawMap, GemTopo, GemGetGrid, and
          GemGridMapping

A visualization obtained using GEMVIS is shown in the following figure. The lower left window contains a potential vorticity surface over a topographical map of the eastern part of the U.S. along with a vertical slice of the three-dimensional winds. The slice is taken through a line the user forms by selecting two points over a map of the U.S. as shown in

the upper left window. The upper right window contains the Iris Explorer map used in creating the three dimensional image. It contains some of modules written as part of the PATHFINDER project funded by NASA.
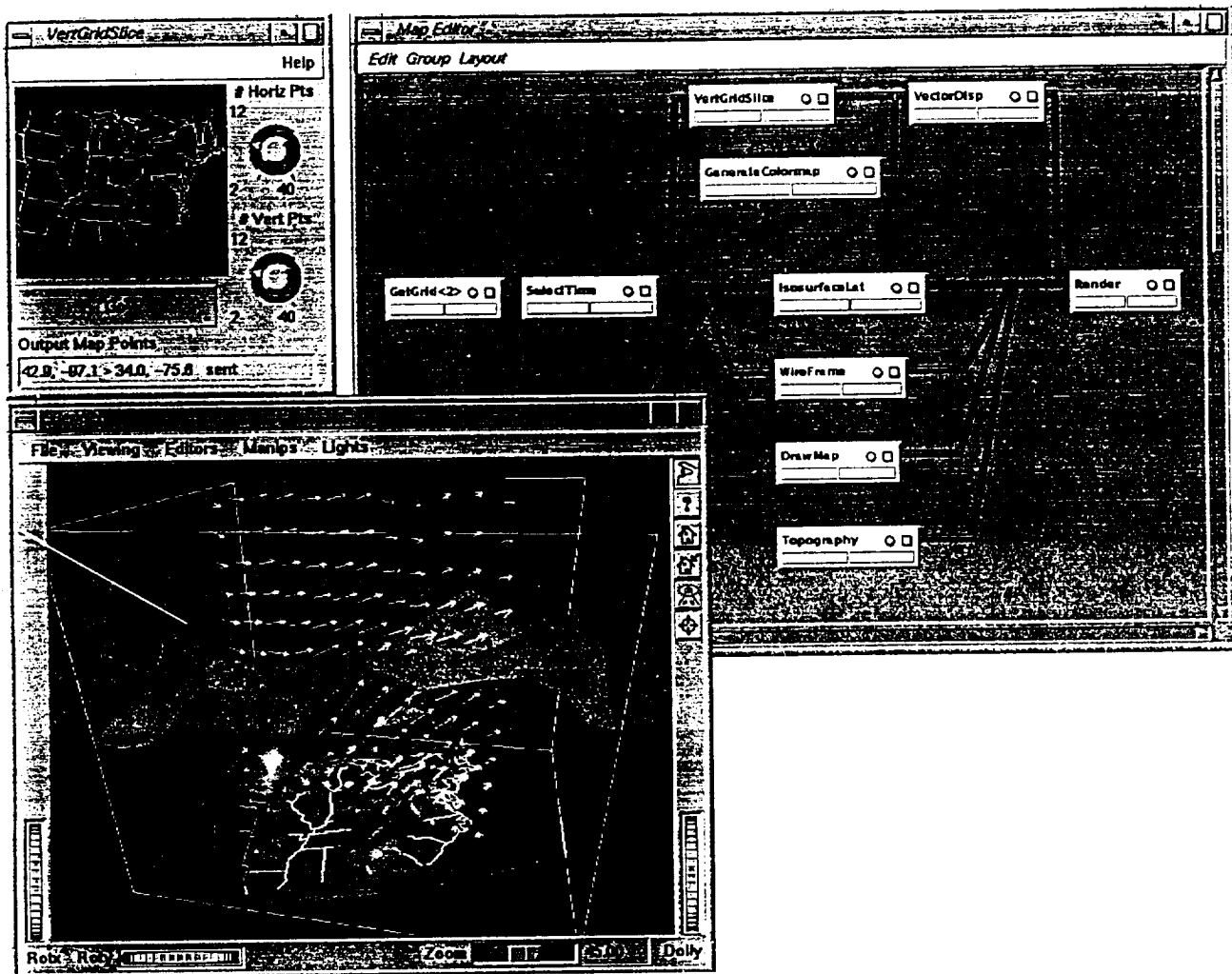

Technology Transfer

The Numerical Algorithms Group of the U.K. provides Explorer support for SGI and is working to port Explorer to other platforms, selected PATHFINDER modules we have developed will be included in their work.

Other Related PATHFINDER Activities

More research oriented accomplishments in the context of PATHFINDER include the prototyping of a distributed computer simulation control system that interfaced a computer model running on a supercomputer with the Explorer environment and the

prototyping of an Inventor based 3-D animation tool as well. In addition, beta testing of new SGI Explorer versions was carried out. An visualization of these other activities is shown on the next page. A growing severe storm is shown together with the associated SGI Explorer dataflow network (including some of the modules developed as part of the PATHFINDER project funded by NASA). An interactive window for controlling the storm simulation on a Cray Y-MP is shown in the lower left. In the lower right the cloud surfaces and horizontal contours are automatically updated as the simulation proceeds.
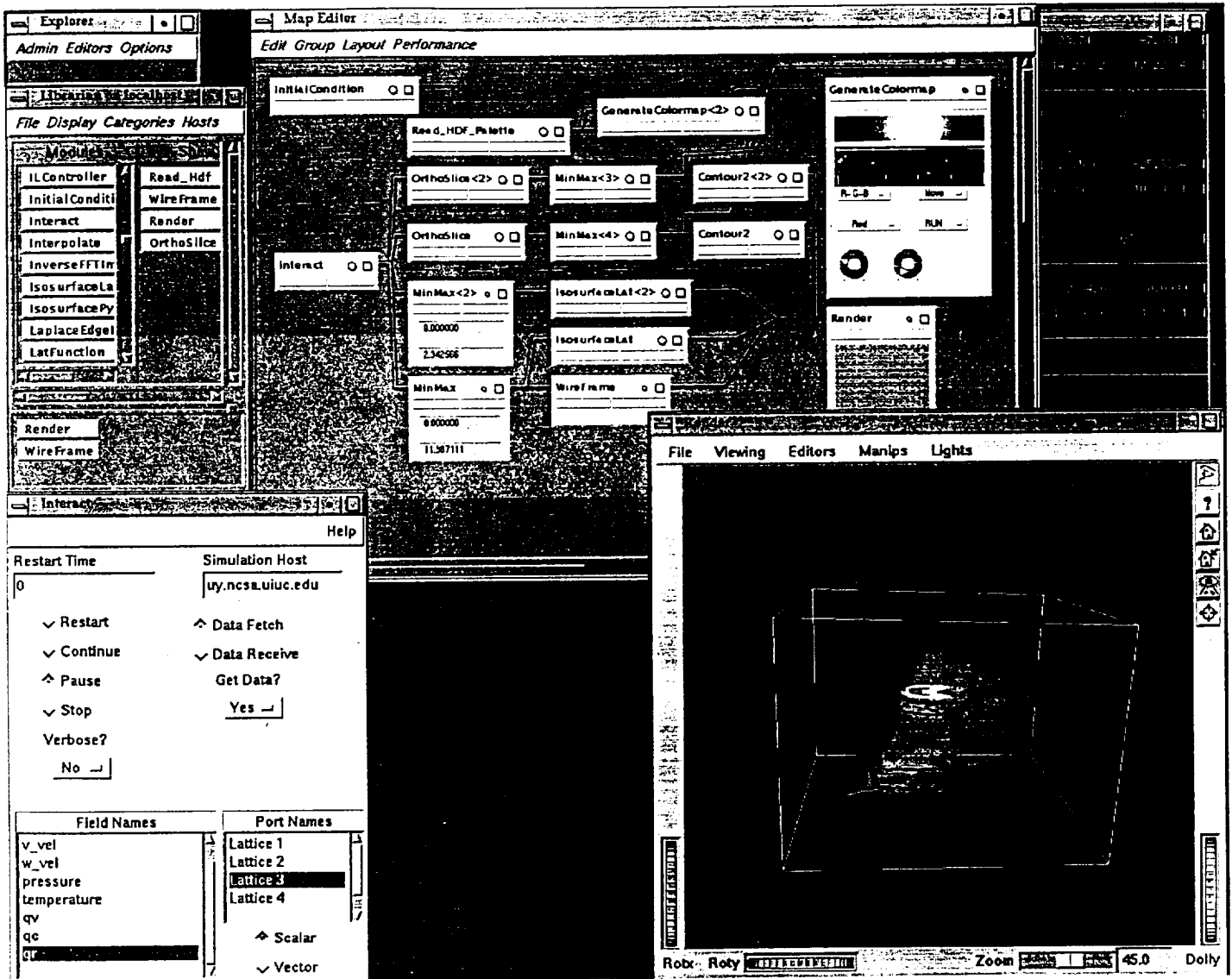
Electronic Communications

WWW/Mosaic:

    PATHFINDER Home Page:
    http://redrock.ncsa.uiuc.edu/PATHFINDER/pathrel2/top/top.html

    AISRP'94 Workshop presentation (Boulder):
    http://redrock.ncsa.uiuc.edu/PATHFINDER/aisrp94/talk.html

FTP:

    redrock.ncsa.uiuc.edu in /pub/PATHFINDER

E-mail:

    General Inquiries: pathfinder@redrock.ncsa.uiuc.edu

Publications

Wilhelmson, R. B., M. K. Ramamurthy, et al, 1992: PATHFINDER: Probing ATmospHeric Flows in an INteractive and Distributed EnviRonment. ACM SIGGRAPH '92 19th Annual International Conference on Computer Graphics and Interactive Techniques, Chicago.

Wilhelmson, R., S. Koch, M. Arrott, J. Hagedorn, G. Mehrotra, C. Shaw, J. Thingvold, B. Jewett, and L. Wicker, 1993: PATHFINDER-Probing ATmospHeric Flows in an INteractive and Distributed EnviRonment. Preprints, Sixth International Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, AMS.

Wilhelmson, R.B., 1994: NCSA PATHFINDER: Probing ATmospHeric Flows in an INtegrated and Distributed EnviRonment. NASA Science Information Systems Newsletter, Feb., Issue 31.

Wilhelmson, R. B., D.P. Wojtowicz, C. Shaw, J. Hagedorn, and S. Koch, 1994: NCSA PATHFINDER: Probing ATmospHeric Flows in an INtegrated and Distributed EnviRonment. AGU Special Publication. (to appear)

REPORT DOCUMENTATION PAGE			

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1, 1994	3. REPORT TYPE AND DATES COVERED Contractor Report

4. TITLE AND SUBTITLE A Distributed Analysis and Visualization System for Model and Observational Data	5. FUNDING NUMBERS 930
6. AUTHOR(S) Robert Wilhelmson	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NCSA/Beckman Institute 405 N. Mathews Urbana, IL 61801	8. PERFORMING ORGANIZATION REPORT NUMBER NAS5-32337 5555-06

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration - HQ/ OSSA Washington, D.C. 20546-0001 Universities Space Research Association 10227 Wincopin Circle, Suite 212 Columbia, MD 21044	10. SPONSORING/MONITORING AGENCY REPORT NUMBER CR-189386

11. SUPPLEMENTARY NOTES

Technical Monitor: J. Hollis, Code 930

12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified–Unlimited Subject Category 82 Report is available from the NASA Center for AeroSpace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090; (301) 621-0390.	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Software was developed with NASA support to aid in the analysis and display of the massive amounts of data generated from satellites, observational field programs, and from model simulations. This software was developed in the context of the PATHFINDER (Probing ATmospHeric Flows in an Interactive and Distributed EnviRonment) Project. The overall aim of this project is to create a flexible, modular, and distributed environment for data handling, modeling simulations, data analysis, and visualization of atmospheric and fluid flows. Software completed with NASA support includes GEMPAK analysis, data handling, and display modules for which collaborators at NASA had primary responsibility, and prototype software modules for three-dimensional interactive and distributed control and display as well as data handling, for whcih NCSA was responsible. Overall process control was handled through a scientific and visualization application builder from Silicon Graphics known as the Iris Explorer. In addition, the GEMPAK related work (GEMVIS) was also ported to the Advanced Visualization System (AVS) application builder. Many modules were developed to enhance those already available in Iris Explorer including HDF file support, improved visualization and display, simple lattice math, and the handling of metadata through development of a new Grid datatype. Complete source and runtime binaries along with on-line documentation is available via the World Wide Web at:

http://redrock.ncsa.uiuc.edu/PATHFINDER/pathre12/top/top.html

14. SUBJECT TERMS Visualization, Dataflow, Distributed Computing, GEMPAK, Atmospheric Sciences	15. NUMBER OF PAGES 9
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited