

# LinkWinds: An Approach to Visual Data Analysis<sup>1</sup>

Allan S. Jacobson  
Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive  
Pasadena, CA 91109

## ABSTRACT

The Linked Window Interactive Data System (LinkWinds) is a prototype visual data exploration and analysis system resulting from a NASA/JPL program of research into graphical methods for rapidly accessing, displaying and analyzing large multivariate multidisciplinary datasets. It is an integrated multi-application execution environment allowing the dynamic interconnection of multiple windows containing visual displays and/or controls through a data-linking paradigm. This paradigm, which results in a system much like a graphical spreadsheet, is not only a powerful method for organizing large amounts of data for analysis, but provides a highly intuitive, easy to learn user interface on top of the traditional graphical user interface. This linking of data displays and controls for their manipulation provides great flexibility in rapidly interacting with large masses of complex data to detect trends, correlations and anomalies. The system, containing an expanding suite of non-domain specific applications, provides for the ingestion of a variety of database formats, and hardcopy output of all displays. It can also be linked to other networked workstations running LinkWinds, providing a Multi-User Science Environment (MUSE) for collaborative data exploration by scientists geographically separated from one another. The system is being developed in close collaboration with investigators in oceanography, geology and upper atmospheric science, and is currently being used to support the Microwave Limb Sounder in orbit aboard the Upper Atmospheric Research Satellite.

## 1. INTRODUCTION

Modern space, sensor and computer technologies have made it possible to understand the Earth and its environs as never before. Population pressures and modern technology have also tended to make it imperative that we do so. To accomplish this, tremendous masses of data must be gathered, transported, stored and comprehended. To address some of these topics, a program of research is being conducted into the application of computer graphics to the problems of quickly and interactively exploring and analyzing very large amounts of scientific or engineering data. The objectives of the program are (1) to develop a software environment which will support the rapid prototyping of visual data analysis applications, while at the same time maintaining the high level of performance necessary for interactively manipulating graphical displays; (2) to develop a user interface that is truly intuitive and easy to learn and allows quick access to the software for the novice as well as the advanced user; (3) to provide a suite of sample applications which are useful across a variety of scientific disciplines; and (4) to provide tools to support user development of applications for this environment.

<sup>1</sup>This work represents one phase of research carried out at Caltech's Jet Propulsion Laboratory under contract with NASA.

## 2. LINKWINDS

The Linked Windows Interactive Data System, or LinkWinds is a prototype product of this research effort. In compliance with our research objectives, it is a visual data analysis/exploration system designed to rapidly and interactively investigate large multivariate and/or multidisciplinary data sets to detect trends, correlations and anomalies. LinkWinds is an integrated multi-application execution environment with a full graphical user interface (GUI). The system, operating under Unix, is based on an object-oriented programming model and is implemented in the c-language. For its graphical user interface and graphics support software, it draws upon the Silicon Graphics Inc. (SGI) GL-library, and presently runs only on workstations supporting this library. This includes all SGI workstations, and those of other manufacturers who have licensed and support the GL-library.

Individual tools and data sets are coded as objects, each occupying a window on the LinkWinds screen, and communicating with other objects through a message passing protocol. The objects or windows, containing data displays and controls for manipulating these displays, can be linked or unlinked at the discretion of the user. The act of linking the windows together sets up one-way message paths. This data-linking paradigm makes the system perform much like a graphics spreadsheet, and as in a spreadsheet, is a powerful way of organizing the data for analysis while at the same time providing a natural and intuitive interface. Data-linking, and its user interface implications are discussed below.

Messages generated by LinkWinds objects are recorded as program statements in an underlying language called Lynx. The message passing characteristics are the basis for two key LinkWinds functions. The first of these is the maintenance of an internal journal of all user originated commands executed by the environment. This file can be saved at anytime through a menu option. The record can then be replayed at the initiation of subsequent LinkWinds sessions, allowing the user to draw upon a previous layout of LinkWinds applications and links, or repeat a full analysis session.

The second function based upon the Lynx message passing protocol is the multi-user science environment (MUSE) which provides a method for multiple LinkWinds systems to communicate via networks. Using menu options, users remotely separated can connect to one another, and by also establishing a telephone voice connection, can cooperatively view and manipulate their data. A successful connection requires that each user be executing LinkWinds and that each has access to the data sets that are being analyzed. This is normally arranged by transporting the data sets to each user prior to the collaborative sessions. The MUSE capability is also used to give tutorials over the network to new users unfamiliar with LinkWinds, and to allow users to demonstrate recommendations for application changes or to point out bugs.

Hard copy of the LinkWinds displays are provided by function keys on the keyboard. Placing the cursor in a window, and pressing F1 produces an image of a window's contents; pressing F2 saves the complete window; and F3 saves the full screen. The figures show were obtained in this manner.

## 3. DATA-LINKING AND THE USER INTERFACE

In addition to the normal GUI functions provided by the windowing environment, dynamic manipulation of graphs and images is facilitated through the data-linking paradigm. Data-linking can be understood in the context of a spreadsheet, where cells containing numbers are linked to other cells. Formulae are associated with each cell, so that when a number changes, all cells linked to the changed cell recalculate their values and update. LinkWinds does the same thing, but in a graphics environment where

the rigid grid structure gives way to free form, and a cell can translate, for instance, into a slider or large scale number arrays such as images.

The user interface based upon the data-linking paradigm is one of the most distinguishing features of LinkWinds. It evolved from a desire to create a truly easy-to-learn and intuitive user interface. It is based upon the principle that users are impatient and want to get started on productive work as quickly as possible. Therefore, an interface was needed which can be learned by exploration, and which **conforms to user expectations** as they work with it.

Data-linking is affected through two icons. The link icon is a button displaying two interlocking rings, while the unlink icon displays two rings that are separated. Each object on the screen has either a single link button, or the full set of link and unlink buttons. The presence of a single link button indicates a data object, while the presence of the pair indicates applications with control functions. To perform a link, the cursor is placed on the appropriate button, and a "rubber band" is dragged out and dropped into the application to be linked. To break the link, the same thing is done using the unlink button. There are two simple rules to follow in applying the linking paradigm,

1. When as a result of menu selections an empty window appears on the screen, put data in it. This is done by linking a data object into the window.

2. When an object with the pair of link symbols appears, exercise its control function by linking it with any application object.

#### 4. DATABASE INTERFACE

The current version of LinkWinds works with both archived and real-time data. The archived data mode accepts data in the 8-bit raster or scientific Hierarchical Data Format (HDF) created and supported by the National Center for Supercomputing Applications (NCSA) at the University of Illinois, Champagne/Urbana. A 2D data file is a single image, while a 3D data file is a sequence of images. The data ingestion is controlled by two text files which are generated by the user. Sample versions of each of these files are provided and serve as self-explanatory templates. The first is a file which lists all of the databases of interest to the user. Those listed appear in the top level "Databases" menu. The second file is a data description containing the filenames of all data sets to be associated during the analysis, the number of axes and their names, any metadata needed to translate axis values to numbers meaningful to the data, etc. Data sets listed in these files appear in the top-level "Data" menu. A palette may be included in the HDF file if the user desires, or it may be defined in the data description file. Colors can also be assigned during a data analysis session using a color management tool provided. A much greater range of data formats will be acceptable to LinkWinds in future versions.

The real-time mode of LinkWinds is a recent development, and must be exercised through the creation of a server tailored to the format of the data stream. As a test demonstration, it is currently being prepared for use in support of the Plasma Wave Spectrometer aboard the Galileo spacecraft during the Earth 2 encounter in December 1992.

#### 5. APPLICATIONS OVERVIEW

A suite of applications useful across many disciplines has been developed for the LinkWinds environment. Figure 1 shows a typical session to explore a data set collected by the Microwave Limb

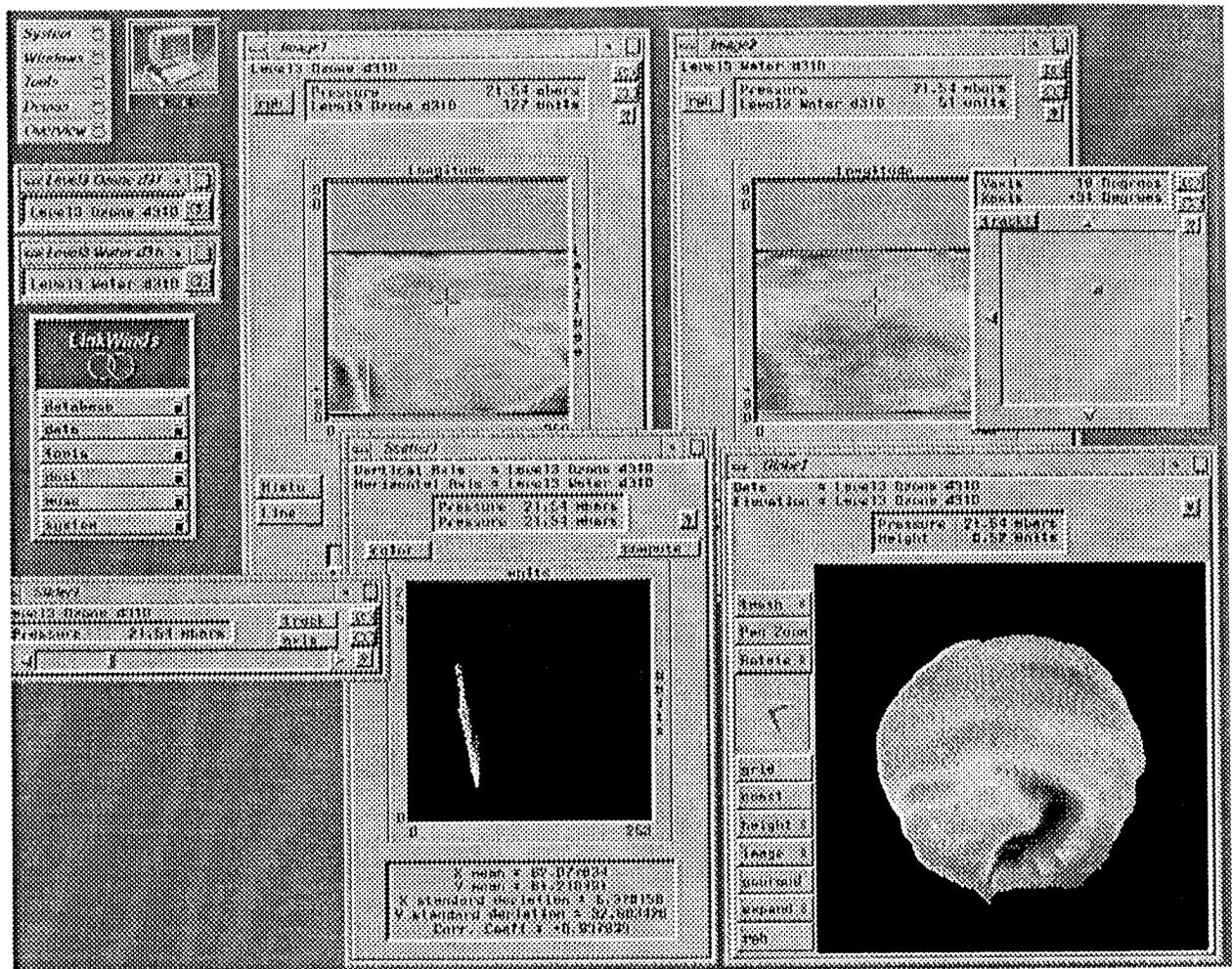


Figure 1- LinkWinds session to explore correlations in upper atmospheric ozone and water vapor measured by the Microwave Limb Sounder experiment aboard the Upper Atmospheric Research Satellite (UARS).

Sounder (MLS) currently in orbit aboard the Upper Atmospheric Research Satellite (UARS). The LinkWinds top-level menu is shown on the left. It is from this menu that databases, tools and system options are selected. Data objects, with their single link buttons, are in the upper left-hand corner. In this case, the data displayed are ozone and water vapor. The window entitled Image1 contains a slice of the data at an altitude of 21.54 mbars, as selected by Slider1 which is linked to it. Image2 is also linked to Slider1 and shows the water vapor at the same altitude. Slider 1 permits the user to scan the full data set from the maximum to minimum altitudes. We can also switch to any of the three orthogonal axes and similarly scan them. The southern hemisphere ozone hole is shown at the lower left of Image1, and a high value of the water vapor is shown in a corresponding location in Image2. The anticorrelation is clearly shown in Scatter1 where the points shown come from the region defined by a bounding box control embedded in Image1 and linked to Scatter1. Also shown in the text box of Scatter1 are various statistical quantities associated with the scattered data. The bounding box in Image1 can be resized or moved as desired. The ozone data are displayed in Globe1 as a height field rendered on a sphere. The ozone hole associated with the south pole, as well as regions of high ozone adjacent to the hole are clearly seen. Slider 1 also controls the depth of this display, and the height scale is controlled by a rotary slider along the right side of the window. A 2-Axis Rotator control is also linked to Globe1 allowing it to be positioned as desired.

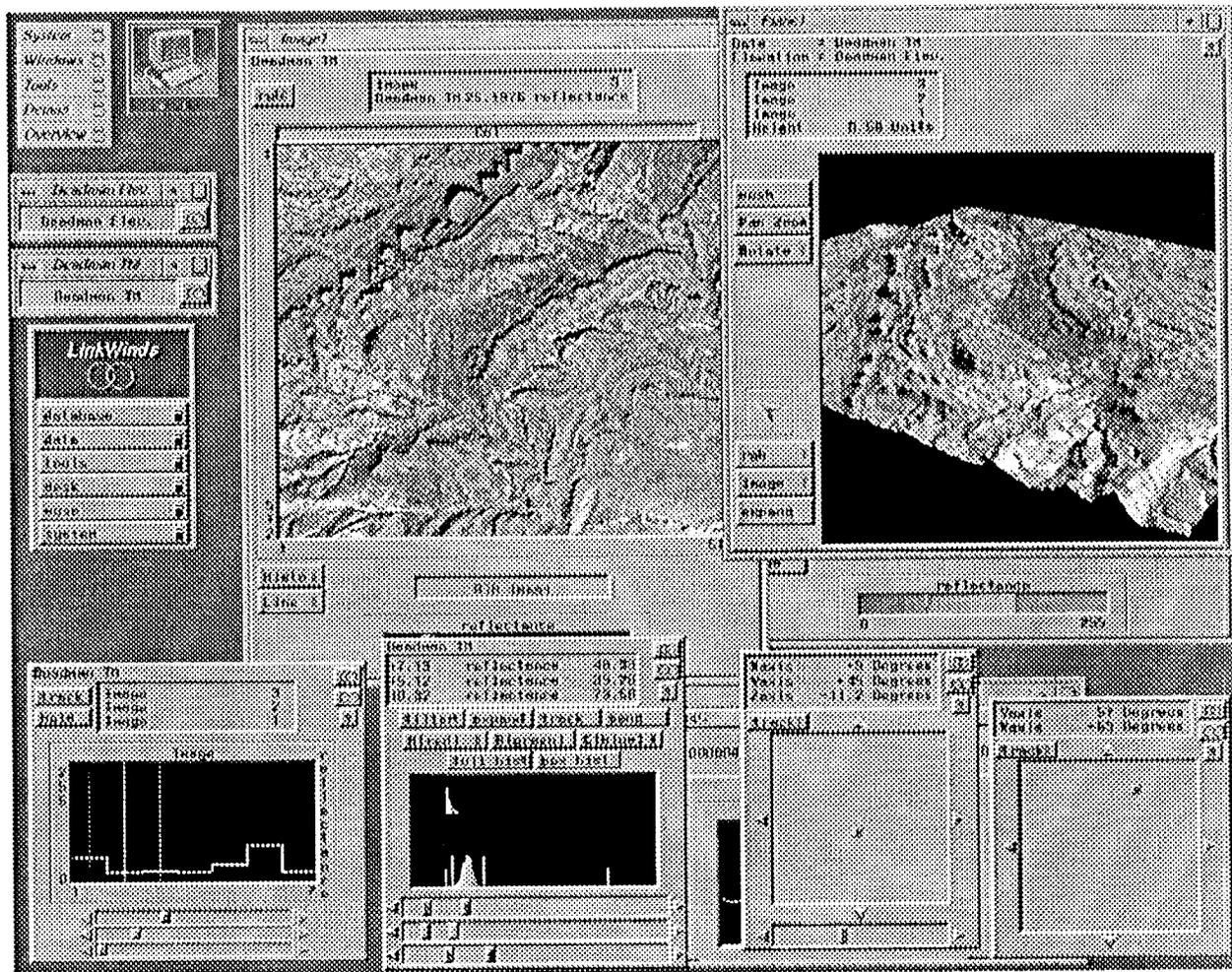


Figure 2 - Analysis of Thematic Mapper Data and elevation data gathered in the region of Deadman's Butte in Wyoming

Figure 2 shows geological data collected in the Deadman Butte area of Wyoming. These are Thematic Mapper spectral image data, and elevation data. Line Plot at the lower left corner shows the 7-channel spectrum at a point designated by a cross-hair control embedded in Image. Any interactive movement of the cross-hair is immediately reflected in the Line Plot spectral display, allowing the user to view the spectrum at any location on the image. Sliders on Line Plot can, in turn, be linked to the Image, allowing the selection of up to three of the channels to be composited in Image and colored red, green or blue. The RGB Filter located next to the Line Plot displays the histogram of up to three of the data channels and permits interactive color stretching of each of these channels. These applications also control the colors used for the perspective rendering of the data in Plane, shown in the upper right corner of the figure. This application allows the superposition of up to two data sets and displays them in perspective. The elevation scale is adjustable using the rotary slider on the left of Plane's frame. In this case, the remotely sensed terrain is overlaid on an elevation data set. The view is interactively positioned using the Pan/Zoom and 2-Axis Rotator controls shown in the lower right corner.

Many other tools are currently available in the system. These include a color tool which allows interactive selection, editing and ramping of colors, and an Animator. The Animator makes it possible to select a starting set of control settings and an ending set. It then automatically interpolates between those settings, recording the number of frames the user designates. This results in an animation of the sequence of settings which can subsequently be replayed with utilities provided.

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## KEYWORDS

**scientific** visualization, data analysis, computer software, image analysis