January, 1994

A Computer-Based Atlas of Global Instrumental Climate Data

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Abstract

Color-shaded and contoured images of global gridded instrumental data have been produced as a computer-based atlas, available to the climate community through Internet. Each image simultaneously depicts anomaly maps of surface temperature, sea level pressure, 500-mb geopotential heights, and percentages of reference period precipitation. Monthly, seasonal, and annual composites are available, in either cylindrical equidistant or Northern and Southern Hemisphere polar projections. Temperature maps are available from 1854 to 1991, precipitation maps from 1851 to 1989, sea level pressure maps from 1899 to 1991, and 500-mb height maps from 1946 to 1991. All images exist as GIF[1] (Graphics Interchange Format) files (1024 x 822 pixels, 256 color) and can be displayed on many different computer platforms. A Compact Disc Read-Only Memory version of the atlas is also available.

1. Introduction

Access to global gridded datasets has become relatively easy in recent years, but organizing and displaying, or visualizing, such data in a meaningful way requires a considerable amount of effort, even if appropriate software is available. To facilitate a better understanding of climatic conditions over the last 140 years, we have prepared a computer-based atlas that can be readily accessed by any user who has a personal computer (PC), Macintosh, or workstation with an 8-bit red–green–blue (RGB) color monitor (or better) and File Transfer Protocol (FTP) client communication with Internet, without the need for programming experience or sophisticated software. Visual representation of the data helps in understanding the interrelationships between various parameters, both spatially and temporally, and complements statistical analysis of climatic parameters. To this end, several gridded datasets (surface temperature, precipitation, sea level pressure, and 500-mb heights) have been converted into continuous-tone color anomaly maps. The data have been expressed as anomalies from reference period means (or as percentages, in the case of precipitation). By color coding the anomalies and displaying all four maps for a given time period simultaneously, the links between the general circulation and anomalies of temperature and precipitation are more easily recognized. The atlas therefore has applications in both research and teaching.

All data have been processed to produce monthly, seasonal, and annual maps as GIF (Graphics Interchange Format) images using 1024 x 822 pixels and 256 colors. GIF was selected because it uses a highly compressed format (thereby minimizing storage and image retrieval time requirements), enables high resolution and good quality color to be used, and is portable across many types of computer systems (Carlson 1991). Each GIF image represents the data with color contours and shading on world and hemispheric maps (Fig. 1). Three types of images have been produced, one using a cylindrical equidistant projection, the second a polar orthographic projection (displaying both North and South Polar projections), and the third a location map of the actual data points. The polar projection allows data in high latitudes to be examined without the distortion of a cylindrical projection. All composites display maps of temperature, precipitation, and pressure for an individual month, season, or year (where data exist).

2. Data

Various global gridded datasets have been used in creating this atlas, as summarized in Table 1. Monthly, seasonal, and annual maps were produced from the original monthly data (winter = December, January, February; spring = March, April, May; summer = June, July, August; fall = September, October, November; and annual = January–December). For precipitation

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In final form 10 August 1993.
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there were no monthly gridded data, and thus, only seasonal and annual maps were produced.

a. Temperature data

The temperature data are distributed on a 5° latitude by 5° longitude grid, as described in Table 1. There are 2592 (36 by 72) points in the grid. The data are in the form of monthly, seasonal, and annual anomalies to 0.01°C, expressed as departures from a 1950–1979 reference period mean. The original sources of data for the temperature grids are the following.

1) Land-based monthly station surface air temperatures with data from January 1854 through December 1991 and with gross errors and inhomogeneities corrected. This is a version of the data described in Jones et al. (1991b), regridded onto a 5° x 5° grid.

2) The Comprehensive Ocean–Atmosphere Data Set gridded (2° lat by 2° long) monthly sea surface temperatures with data from January 1854 through December 1986 (Woodruff et al. 1987).

3) The United Kingdom Meteorological Office gridded (1° lat by 1° long) monthly sea surface temperature dataset with data from January 1987 through December 1991 (Bottomley et al. 1990).

In both 2 and 3, the data are surface water temperatures from bucket and/or ship intake valve water samples, as discussed by Jones et al. (1991a). In each data compilation, corrections and adjustments were made for assumed problems in measurement techniques (as described in the sources referenced above); no further adjustments to the gridded data were made in producing this atlas. Data from all three datasets were expressed as anomalies, merged and interpolated onto the 5° lat by 5° long grid (Table 1).

b. Precipitation data

The global precipitation data are distributed on a 4° lat by 5° long grid, as described in Table 1. There are 2736 (38 by 72) points in the grid. The data are in the form of seasonal and annual percentages of the reference period (1951–1970) mean precipitation interpolated onto the grid. The original source of data for the precipitation grids is monthly station precipitation records (Eischeid et al. 1991). In this compilation, stations were included only if they had at least 15 years of data in the period 1951–1970, and outliers were flagged and checked against other stations in the same area in order to eliminate clearly erroneous values. In addition, for stations with apparent data inhomogeneities, all or part of their records were eliminated. Nevertheless, it is very likely that precipitation data from regions where snowfall is important are underestimates of actual amounts and may have

TABLE 1. Global gridded datasets used to construct the images.

Source*	Latitude resolution	Longitude resolution	Latitude range	Longitude range	Date range	Data type
1. Jones et al. (1991b)	5°	5°	87.5°N–87.5°S	2.5°E–2.5°W	1854–1991	Monthly surface temperature anomalies (°C)
2. Eischeid et al. (1991)	4°	5°	86°N–62°S	0°E–5°W	1851–1989	Seasonal and annual percents of mean precipitation
3. NCAR	5°	5°	85°N–15°N	0°E–5°W	1899–1991	Monthly sea level pressure (mb)
4. NCAR	5°	5°	10°S–85°S	0°E–5°W	1973–1989	Monthly sea level pressure (mb)
5. NCAR	5°	5°	85°N–15°N	0°E–5°W	1989–1991	Monthly 500-mb heights (m)
6. NCAR	5°	5°	10°S–85°S	0°E–5°W	1973–1989	Monthly 500-mb heights (m)
7. U. of Wash./ NCAR (1990)	NMC Northern Hemisphere equidistant grid				1946–1989	Monthly 500-mb heights (m)

*Dataset 1 is an unpublished version of the gridded set described in Jones et al. (1991b). This version is available from the National Center for Atmospheric Research, Boulder, Colorado.
Dataset 2 is available from the Carbon Dioxide Information Analysis Center, Oak Ridge, Tennessee.
Datasets 3–6 are available from the National Center for Atmospheric Research, Boulder, Colorado.
Dataset 7 is available on CD-ROM from the Department of Atmospheric Sciences, University of Washington, Seattle, Washington.

significant inhomogeneities due to changes in gauge type and recoding protocols (Groisman 1991). We note that considerable research is currently in progress on this matter (e.g., Groisman 1993) and may enable adjustments to be made in a later version of the atlas.

c. Sea level pressure data

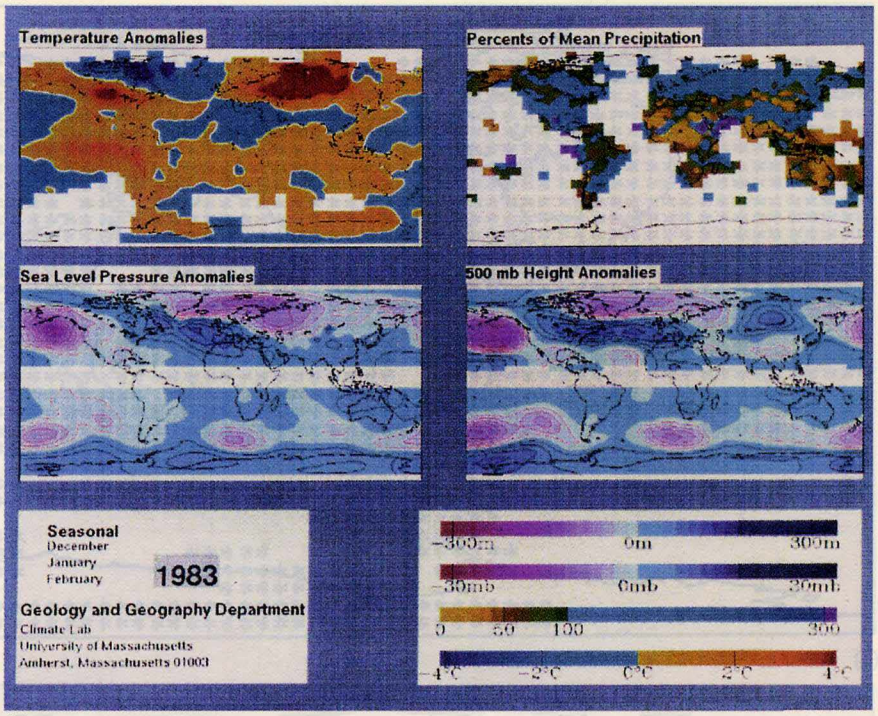
The sea level pressure data are distributed on a 5° lat by 5° long grid, as described in Table 1. There are 2520 (35 by 72) points in the grid. The data are in the form of monthly, seasonal, and annual anomalies to 0.1 mb. The anomalies are calculated as departures from a 1951–1980 reference period mean for the Northern Hemisphere and a 1974–1989 reference period mean for the Southern Hemisphere. The shorter reference period for the Southern Hemisphere is due to the shorter period of record of Southern Hemisphere data. There are no sea level pressure data between 15°N and 10°S. The original source of the sea level pressure grids is the Data Support Section, National Center for Atmospheric Research (NCAR) (Jenne 1975).

d. The 500-mb geopotential height data

The 500-mb height data are distributed on a 5° lat by 5° long grid, as described in Table 2. There are 2520 (35 by 72) points in the grid. The data are in the form of monthly, seasonal, and annual anomalies to 1 m. The anomalies are calculated as departures from a 1951–1980 reference period mean for the Northern Hemisphere and a 1974–1989 reference period mean for the Southern Hemisphere. The shorter reference period for the Southern Hemisphere is due to the shorter period of record of Southern Hemisphere data. There are no height data between 15°N and 10°S. The original sources of data for the 500-mb height grids are the following.

1) National Meteorological Center (NMC) Northern

(a)



(b)

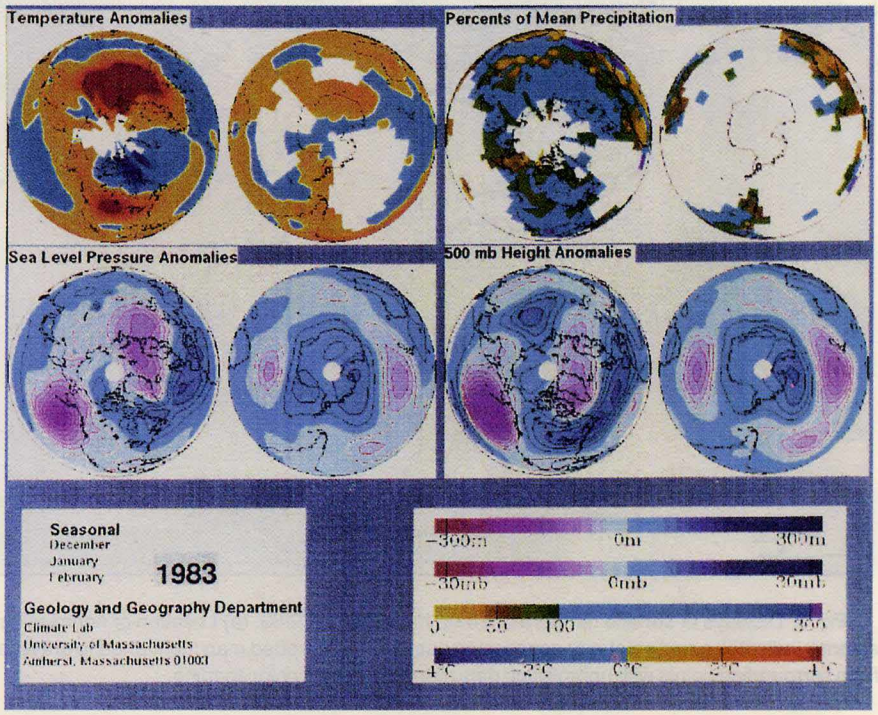
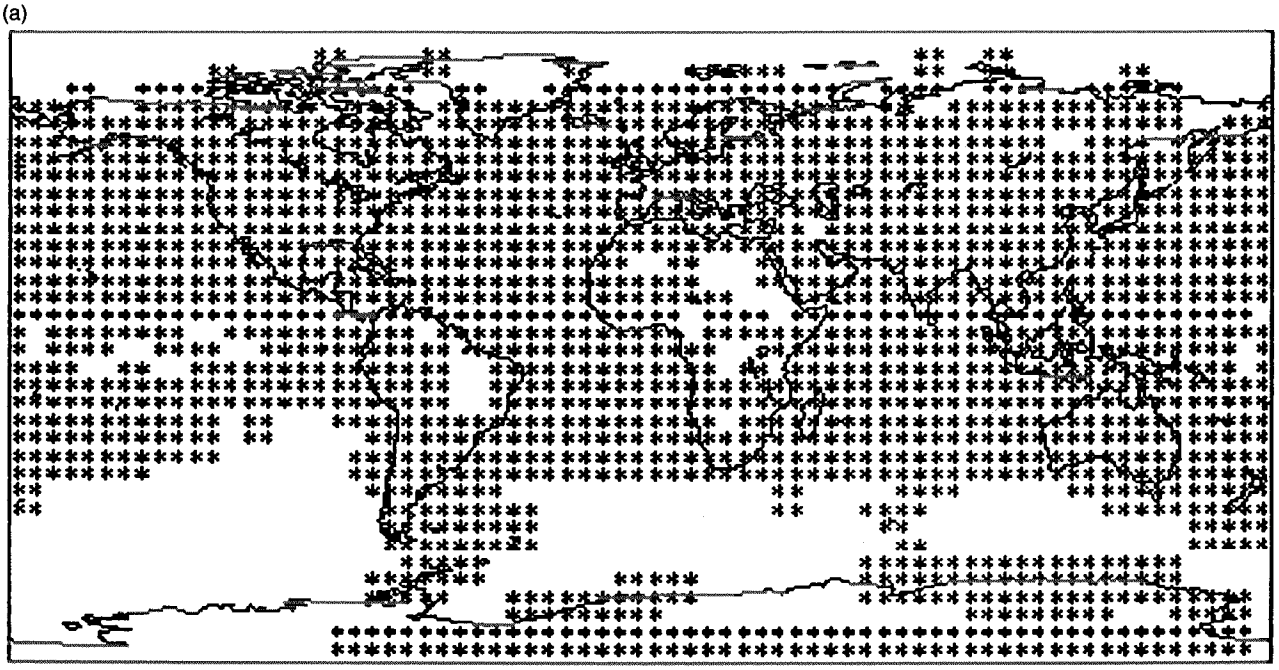


FIG. 1. Composite images of surface temperature anomalies, percentages of reference period precipitation, and anomalies of sea level pressure and 500-mb heights for winter 1982/83: (a) cylindrical equidistant map projection and (b) polar orthographic projection.

(a)



(b)

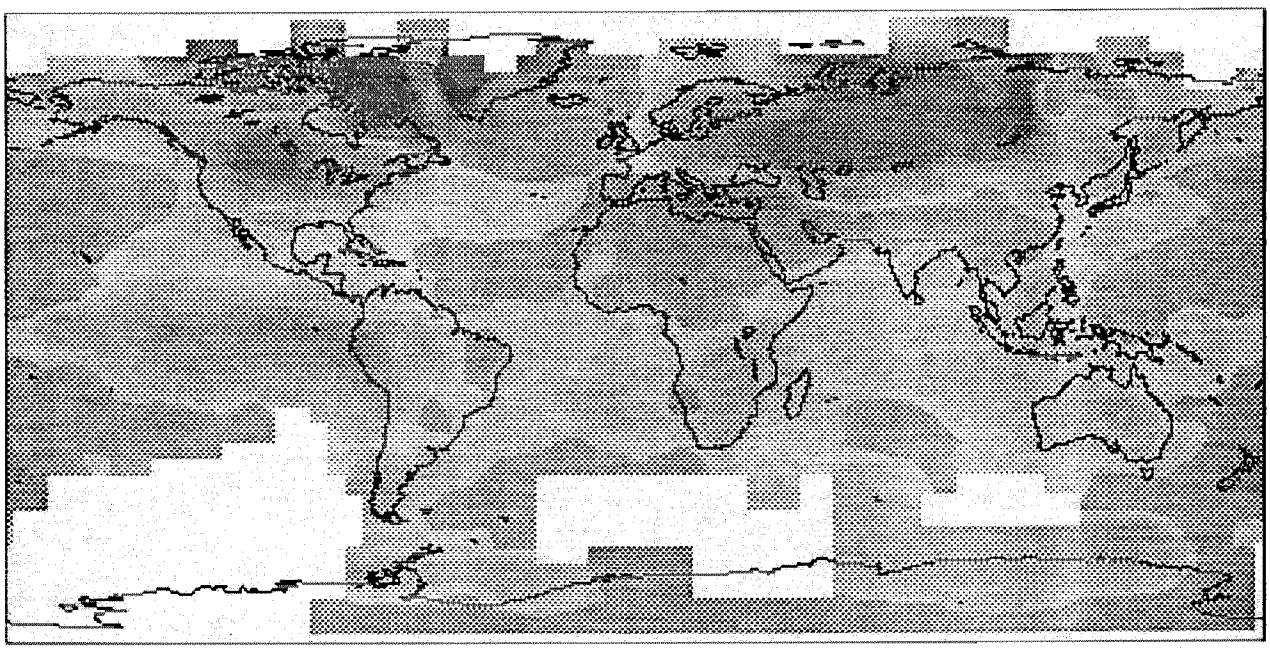


FIG. 2. Displays of surface temperature data for winter 1982/83. (a) Location of nonmissing gridded temperature anomaly data. Each asterisk indicates a grid point with nonmissing data. (b) Color-coded map (converted to grayscale) resulting from the filling of missing data from surrounding points with nonmissing data, contouring, and color shading.

Hemisphere octagonal grid data (Jenne 1975) retrieved from a compact disc produced jointly by the Department of Atmospheric Sciences, University of Washington, and the Data Support Section, NCAR (University of Washington and National Center for Atmospheric Research 1990). The NMC grid is a 1977 point grid whose points are equally spaced when viewed on a polar stereographic projection. The compact disc contains data from January 1946 through June 1989.

2) Files of Northern Hemisphere and Southern Hemisphere gridded 500-mb heights (5° lat by 5° long) from the Data Support Section, NCAR. The files contained data from April 1973 through December 1991.

The NMC data were transposed onto a 5° lat by 5° long grid and combined with the NCAR data to form the data grid described above.

3. Procedures

The data described in section 2 have been processed to produce monthly, seasonal, and annual maps as GIF images. Three types of images have been produced for each time period, one using a cylindrical equidistant projection, and the second a polar orthographic projection (displaying both North and South Polar projections), and the third a location map of the actual data points. Each image is composed of up to four maps showing temperature, precipitation, sea level pressure, and 500-mb height anomalies for a particular time. Table 2 indicates the contour range and contour interval used in each case. All of the maps were produced by importing the data into Fortran programs that used NCAR Graphics Version 3.00 (Clare et al. 1989). NCAR graphics routines were used for contouring, map projections, and color filling.

During initial work on data visualization, it was noticed that some data were being omitted by the contouring procedure. This was due to the fact that, using the NCAR graphics contouring routines, no contours were drawn in any box of the grid with a missing value at one or more of its four corners. Because of the spotty nature of some of the data and the desire to visualize all the data, an algorithm was written to fill missing data values with an averaged sum of all immediately surrounding data values (a maximum of eight values). The net result of this procedure is to both infill the area of missing data and to expand (by one grid point) the outer boundary of an area with data, enabling the visualization of every data point. An example is shown in Fig. 2; Fig. 2a shows actual data coverage, and Fig. 2b shows the resultant color-coded map converted to gray scale. The procedure provides a more visually coherent picture of anomalies, in effect carrying out explicitly the procedure that a viewer would undertake implicitly by mentally interpolating over areas with intermittent data coverage. We feel that the net result provides an objective means of dealing with the recurrent missing data problem for the purpose of obtaining an overview of large-scale patterns. However, users must be cognizant of the fact that some individual data points may not be supported directly by recorded data. For those users who are concerned with the actual gridded data coverage, location maps have been prepared, showing the location of the actual data for all images in the datasets. Figure 2a gives an example of a location map.

TABLE 2. Contour range and contour interval for each map type.

Map type	Contour range	Contour interval
Temperature	±4°C	0.1°C
Precipitation	0%–300%	10%
Sea level pressure (annual)	±28 mb	1 mb
Sea level pressure (seasonal)	±30 mb	2 mb
Sea level pressure (monthly)	±28 mb	4 mb
500-mb heights (annual)	±280 m	10 m
500-mb heights (seasonal)	±300 m	20 m
500-mb heights (monthly)	±280 m	40 m

4. Access to map images

The images are stored at the Carbon Dioxide Information Analysis Center at the Oak Ridge National Laboratory, and they are available on the Internet node cdiac.esd.ornl.gov (or 128.219.24.36). The images may be accessed by means of FTP Transmission Control Protocol/Internet Protocol. The following is the information necessary for a typical user to access the images. The user should consult communication documentation at his/her installation for exact commands. Expressions in italics are to be entered exactly as they appear.

Enter *ftp cdiac.esd.ornl.gov.*
Enter *anonymous* when user name (or ID) is requested.
Enter your email address when password is requested.
Enter the FTP command to allow retrieval of non-ASCII files (usually *binary* or *image*; may be different for your installation).
Enter *cd pub* to change to the public directory.

The user must then change to the appropriate directory and subdirectory, as described herein.

The image management structure is a hierarchical database, implemented using the directory structure of the Unix operating system. The root directory for all the images is "images," with subdirectories "ce" (cylindrical equidistant projection), "loci" (data location maps), and "polar" (polar orthographic projection). The user must also select the time period subdirectory. The following are the names of the directories that contain images:

Directory name	*Description of contents*
images/ce/annual	Cylindrical equidistant projected annual images
images/ce/monthly	Cylindrical equidistant projected monthly images
images/ce/seasonal	Cylindrical equidistant projected seasonal images
images/loci/annual	Data location annual images
images/loci/monthly	Data location monthly images
images/loci/seasonal	Data location seasonal images
images/polar/annual	Polar orthographic projected annual images
images/polar/monthly	Polar orthographic projected monthly images
images/polar/seasonal	Polar orthographic projected seasonal images.

Each annual subdirectory contains 141 images, each seasonal subdirectory contains 563 images, and each monthly subdirectory contains 1656 images.

To retrieve a GIF image, the user must change to the directory that contains the image (by entering *cd* "directory name"—e.g., *cd images/ce/monthly*) and then access the particular images of interest. The file containing an image has been named to reflect the time period of the image. The GIF images have been named using the following convention: xxyyyy.gif, where

xx is
- 05 in the annual directory
- 01–04 in the seasonal directory (winter, spring, summer, fall, respectively)
- 01–12 in the monthly directory (January, February, ...December)

yyyy
- is 1851–1991

Retrieval of an image is accomplished by entering *get* "image name" (e.g., *get 031979.gif*). Multiple images can be retrieved with a single command, as in the following examples.

To retrieve all images in the directory, enter *mget *.gif.*

To retrieve all February images in the monthly directory, enter *mget 02????.gif.*

To retrieve all 1953 images in the directory, enter *mget ??1953.gif.*

The system will prompt you to determine which of the multiple images you wish to retrieve. To inhibit the system from prompting during multiple-image retrieval, enter *prompt* prior to entering the *mget...* command.

When you have completed retrieval of the images you want, enter *quit.*

A Compact Disc Read-Only Memory (CD-ROM) version of the atlas is also available for $30.00. This contains the image and documentation files; it also contains shareware for viewing GIF files (described in the following section). If you would like a copy of the CD-ROM version, send your name and address to Frank Keimig (Department of Geology and Geography, University of Massachusetts, Amherst, MA 01375, or email address frank@climate1.geo.umass.edu).

5. Displaying map images

Users should have a monitor with the capability of displaying 256 colors (SVGA, 8-bit RGB color) and software for viewing GIF files. The monitor is necessary to take advantage of the high-resolution color images available and to display them correctly. There are a number of GIF file viewers available as shareware, and many users are currently using one of those viewers. For users needing a GIF viewer, we have made three shareware viewers available in the directory images/shareware. These viewers are described below.

Computer	*Viewer file*
PC	cshowa.exe
Macintosh	QuickGIF.SIT
Workstation with the X Window System	xv-3.00a.tar.Z

To retrieve any one of the files by means of FTP, change to the *shareware* subdirectory, enter the FTP command to allow retrieval of non-ASCII files (see above), and enter *get* "viewer file name" (e.g., *get QuickGIF.SIT*—note that Unix is case sensitive).

All three files are in a compressed format, and when uncompressed each expands into several files, including documentation files and all files necessary for viewing. The "xv" files must be configured for your workstation and then compiled. In addition, the Sun workstation is distributed with "xloadimage," an executable file; enter *xloadimage* "image name" (e.g. *xloadimage 011977.gif*) to view an image.

Acknowledgments. This work was supported by a grant from the Environmental Sciences Research Division, U.S. Department of Energy. We thank P. Groisman, J. Eischeid, and W. McCoy for serving as test users of the system. We also thank the reviewers for helpful comments on the manuscript.

References

Bottomley, M., C. K. Folland, J. Hsiung, R. E. Newell, and D. E. Parker, 1990: *Global Ocean Surface Temperature Atlas.* MIT Press, 20 pp., plus 313 plates.

Carlson, W. E., 1991: A survey of computer graphics image encoding and storage formats. *Comput. Graphics,* **25,** 67–75.

Clare, F., and D. Kennison, 1989: *NCAR Graphics Guide To New Utilities, Version 3.00.* National Center for Atmospheric Research, 574 pp.

Eischeid, J. K., H. F. Diaz, R. S. Bradley, and P. D. Jones, 1991: A comprehensive precipitation data set for global land areas, DOE Tech. Rep. No. TR051. U.S. Department of Energy, Carbon Dioxide Research Program, 82 pp.

Groisman, P. Ya., 1991: Unbiased estimates of precipitation change in the Northern Hemisphere extratropics. *Proc. of the Fifth Conf. on Climate Variations,* Denver, CO, 42–45.

——, 1993: Towards unbiased estimates of North American precipitation. *Proc. of the Eighth Symp. on Meteorological Observations and Instrumentation,* Anaheim, CA, Amer. Meteor. Soc., j43–j47.

Jenne, R. L., 1975: Data sets for meteorological research. NCAR Tech. Note NCAR-TN/IA-111, National Center for Atmospheric Research, 194 pp.

Jones, P. D., T. M. L. Wigley, and G. Farmer, 1991a: Marine and land temperature data sets: A comparison and a look at recent trends. *Greenhouse-Gas-Induced Climatic Change: A Critical Appraisal of Simultations and Observations,* M. E. Schlesinger, Ed., Elsevier, 153–172.

——, S. C. B. Raper, B. S. G. Cherry, C. M. Goodness, T. M. L. Wigley, B. Santer, P. M. Kelly, R. S. Bradley, and H. F. Diaz, 1991b: An updated global grid point surface air temperature anomaly data set: 1851–1990, NDP020/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, 413 pp.

University of Washington and National Center for Atmospheric Research, 1990: *Grid Point Data Set Version II: Gridded NMC Analyses for the Northern Hemisphere* (CD-ROM). Department of Atmospheric Sciences, University of Washington and Data Support Section, National Center for Atmospheric Research.

Woodruff, S. D., R. J. Slutz, R. L. Jenne, and P. M. Steurer, 1987: A comprehensive ocean–atmosphere data set. *Bull. Amer. Meteor. Soc.,* **68,** 1239–1250.

[Reprinted from BULLETIN OF THE AMERICAN METEOROLOGICAL SOCIETY, Vol. 75, No. 1, January 1994]
Printed in U. S. A.