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A Status Report on the Development of SAC2000: A New Seismic Analysis Code

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Lawrence Livermore National Laboratory

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Abstract

We are developing a new Seismic Analysis Code (SAC2000) that will meet the research needs of the seismic research and treaty monitoring communities. Our first step in this development was to rewrite the original Seismic Analysis Code (SAC)—a Fortran code that was approximately 140,000 lines long—in the C programming language. This rewrite has resulted in a much more robust code that is faster, more efficient, and more portable than the original. We have implemented important processing capabilities such as convolution and binary sonograms, and we have significantly enhanced several previously existing capabilities. For example, the spectrogram command now produces a correctly registered plot of the input time series and a color image of the output spectrogram. We have also added an image plotting capability with access to 17 predefined color tables or custom color tables. A rewritten version of the readcss command can now be used to access any of the documented css3.0 database data formats, a capability that is particularly important to the Air Force Technical Applications Center (AFTAC) and the monitoring community. A much less visible, but extremely important contribution is the correction of numerous inconsistencies and errors that have evolved because of piecemeal development and limited maintenance since SAC was first written. We have also incorporated on-line documentation and have made SAC documentation available on the Internet via the world-wide-web at http://www-ep/tvp/sac.html.

Introduction

We are developing a new data-analysis tool, SAC2000, that will help meet the needs of AFTAC and the treaty monitoring community by building upon existing expertise in Lawrence Livermore National Laboratory's (LLNL's) Seismic Analysis Code (SAC, Tapley and Tull, 1992).

SAC is a powerful, widely used tool for data analysis and plotting. It was developed by scientists and computer programmers as a tool for treaty verification and general seismic research. It is currently in use at more than 300 institutions. Its strengths include (1) interactive, macro, and batch processing capabilities; (2) a variety of single- and multi-channel processing capabilities; (3) readily available source code and detailed on-line documentation; and (4) flexible plotting and graphical output capabilities. Table 1 lists some of SAC's processing capabilities.

Table 1. Typical processing capabilities available with SAC.

Capability	**Operation**
Spectral analysis	Filtering, spectral estimation, spectrograms, auto and cross correlation, Wiener filtering, Hilbert transforms
Binary operations	File addition, subtraction, multiplication
Signal correction	Instrument response removal and convolution, glitch removal, interpolation, smoothing
Event analysis	Automated and interactive picking, particle motion analysis
Array analysis	Frequency-wavenumber analysis, record section plotting
Modeling	Trace overlaying, travel time overlaying, source function generation, convolution

Development Plans

To make the new code a robust, easily accessible tool for data analysis, we are developing SAC2000 in the C programming language. We chose C because it will allow us to develop a faster, more flexible code with smaller memory requirements and greater portability between hardware and operating systems. Planned features of SAC2000 include the following:

1. A graphical user interface that will make SAC easier to use and will improve efficiency (a prototype design is indicated in Figure 1.)
2. A new flexible data structure that will allow access to more data types and analysis and manipulation of large, diverse data sets.
3. Enhanced single- and multi-channel processing capabilities.
4. Enhanced graphical output capabilities.
5. More modern visualization tools.

A high degree of backward compatibility is also considered essential. Therefore, we will maintain most of SAC's command line syntax in SAC2000. Although the graphical user interface will not be restricted by existing syntax, we intend to maintain both a graphical and command line interface and will strive for compatibility between them both.

SAC2000 is also being developed with significant user participation and scrutiny. Based on experience with the development of SAC, such interaction provides for the most useful and user-friendly tool from the user's standpoint.

New Features

We have completely rewritten the original SAC code. The original code was a complex Fortran code, approximately 140,000 lines long with more than 200 commands and a number of subprocesses. The new code includes all of the previous capabilities, but it is faster, more efficient, and more portable. For example, SAC2000's initial memory allocation is less than 12% of the memory required by the original SAC code at startup. This improvement is possible because SAC2000 uses dynamic memory management; thus, the program allocates memory as needed instead of allocating a fixed amount at the beginning of execution. In addition, SAC2000 can access and process much larger data sets because it is not limited by predefined memory allocation, and it can process data faster because it demands fewer resources. SAC2000 is also more portable than the original code. For example, we have generated an IBM PC compatible version of SAC2000, which runs under the LINUX operating system.

We have also improved the data processing and graphical output capabilities. For example, the new **`spectrogram`** (time-frequency distribution) command includes options to use the high-resolution Maximum Entropy or Maximum Likelihood spectral estimation methods, a variety of amplitude scaling options, and complete control of the range of frequencies plotted. It also generates a properly registered plot of the input data and a color or grayscale image of the spectrogram along the same time axis (Figure 2). Binary sonograms (e.g., Hedlin, 1989; Wuster, 1993) can also be produced using the **scalloping** command (Figure 3).

The spectrogram and scalloping commands make use of new image processing capabilities. The **image** and **loadctable** commands allows the user to view 3D data as a variety of color or grayscale images (Figures 2 and 3). This capability significantly enhances an analyst's ability to interpret 3D data such as spectrograms because it provides high resolution in both time and frequency and accentuates differences in amplitude.

Inconsistencies in the broadband frequency-wavenumber (**bbfk**) command have been corrected, so it now computes the amplitude and location of the extremum and writes these values to header variables. A new command named **`convolve`** allows the user to convolve two time series.

The development of SAC2000 is focused on doing what is necessary to meet the needs of the monitoring community. With this in mind, we have completely rewritten the **readcss** command so that AFTAC and the monitoring community will have easy access to CSS data. SAC2000 can read any of the binary data formats listed in the css3.0 database schema reference manual and can handle array as well as single-channel data. This capability is particularly important to AFTAC because most AFTAC data are in the css3.0 database format.

In response to numerous user requests, we have implemented on-line help for all the commands listed in the SAC command reference manual. Documentation for the new features discussed in this document are also available via the on-line help package and in appendix A of this manuscript.

Enhanced Capabilities

The following is a brief description of some of the enhancements to previously existing capabilities.

The **readalpha** command was modified to print and ignore lines that are inconsistent with the specified data format. It will also skip over alphanumeric fields in a file and has an option to skip header lines specified by HEADER n, where n is the number of lines in the header. It can also read in more than one set of *y* values from a file.

The width of symbols can now be controlled using the **width** option of the **symbol** command. The symbol width setting is independent of the linewidth setting. The syntax is SYMBOL width n, where n is a number specifying a valid linewidth.

SAC2000's graphics output has been modified to accommodate the new color and grayscale image plotting capabilities. It is also more compatible with external graphics programs such as Adobe Illustrator. Thanks to Chuck Ammon, there is also a new version of the SGF to Adobe Illustrator conversion utility.

Dynamic memory allocation has allowed us to remove previous restrictions on the number of data points processed by numerous commands. For example, the **fft, ifft, transfer, unwrap, convolve,** and **correlate** commands can now be used with any amount of data that will fit within the bounds of physical memory and swap space. Similar restrictions on other commands will be removed as time and priorities allow.

fft and **ifft** are now calculated in double precision to give better accuracy for large numbers of data points.

The **smooth** command now updates the header values depmax, depmin, and depmen.

A More Robust Program

Another advantage of converting from Fortran to C is a more robust code. In the process of converting the code, we uncovered numerous memory problems that sometimes resulted in rather ungraceful exits from the code (e.g., segmentation violations). Most of these problems have been removed.

A number of bugs have also been fixed. For example, it is now possible to use wildcards with a larger variety of filenames including files beginning with numbers such as 999 or 9999.z. The previously nonfunctional `inicm` command (which resets SAC to its startup configuration) now works. Multiple while loops can be executed from the same macro. The `plotpk` markall option now marks the appropriate files in memory. Grid lines plot correctly in both log and linear domains and can be plotted when using the `plotpm` command. We fixed a bug that caused the truncation of value fields in function evaluation. In some cases, the ascii string representing a floating point value was too wide to fit in the space allocated when retrieving certain values from the bulletin board. For example, in cases involving data in exponential format, the exponent was truncated.

Obtaining SAC2000 and SAC2000 Documentation on the World-Wide-Web

We are currently distributing development versions of SAC2000 to selected users as part of a collaborative agreement. Those interested in obtaining a copy of SAC2000 may contact Lee Minner at:

minner1@llnl.gov

Thanks to Carolyn Bailey of LLNL and Craig Scrivner of the Caltech Seismology Laboratory, we are making the SAC manuals available on the internet via the Word-Wide-Web. To access the manuals, open the uniform resource locator (URL) address:

http://www-ep//tvp/sac.html

Appendix B is a reproduction of the SAC2000 WWW home page.

Summary and Conclusions

We are developing a new data-analysis tool, SAC2000, that will help meet the data-analysis needs of AFTAC and the treaty monitoring community by building upon existing expertise in LLNL's Seismic Analysis Code (SAC, Tapley and Tull, 1992). Thus far, we have generated a code that is faster, more robust, efficient, and portable and that has numerous enhancements and additional features needed by the treaty monitoring and seismic research communities. In future work, we will implement a graphical user interface, new data structure, new and enhanced processing, and additional graphical output capabilities. This work will improve our capabilities to do state-of-the-art research and will allow us to increase productivity through more efficient analysis.

Acknowledgments

We are particularly grateful to Jim Hannon, for his encouragement and for making sure that this project continued to be funded, and to Eileen Vergino, who was instrumental in getting this project started. Carolyn Bailey, Farid Dowla, Dave Harris, Steve Jarpe, Keith Nakanishi, Bill Tapley, and Joe Tull have all provided very valuable technical and nontechnical input. In addition to SAC, software developed by Dave Harris (XAP), Keith Nakanishi (Transfer), and many others has been instrumental in the continued development of SAC2000. Perhaps most important are the users who have provided continual input and constructive criticism.

References

Hedlin M., J. B. Minster, and J. A. Orcutt (1989), "The time frequency characteristics of quarry blasts and calibration explosions recorded in Kazakhstan, USSR," *Geophys. J. Int.* **99**, 109–121.

Tapley, W. C., and J. E. Tull (1992), *SAC command reference manual version 10.6e*, Lawrence Livermore National Laboratory, Livermore, CA, M282REV-4

Wuster, J. (1993), "Discrimination of chemical explosions and earthquakes in Central Europe—a case study," *Bull. Seis. Soc. Am.* **83**, 1184–1212.

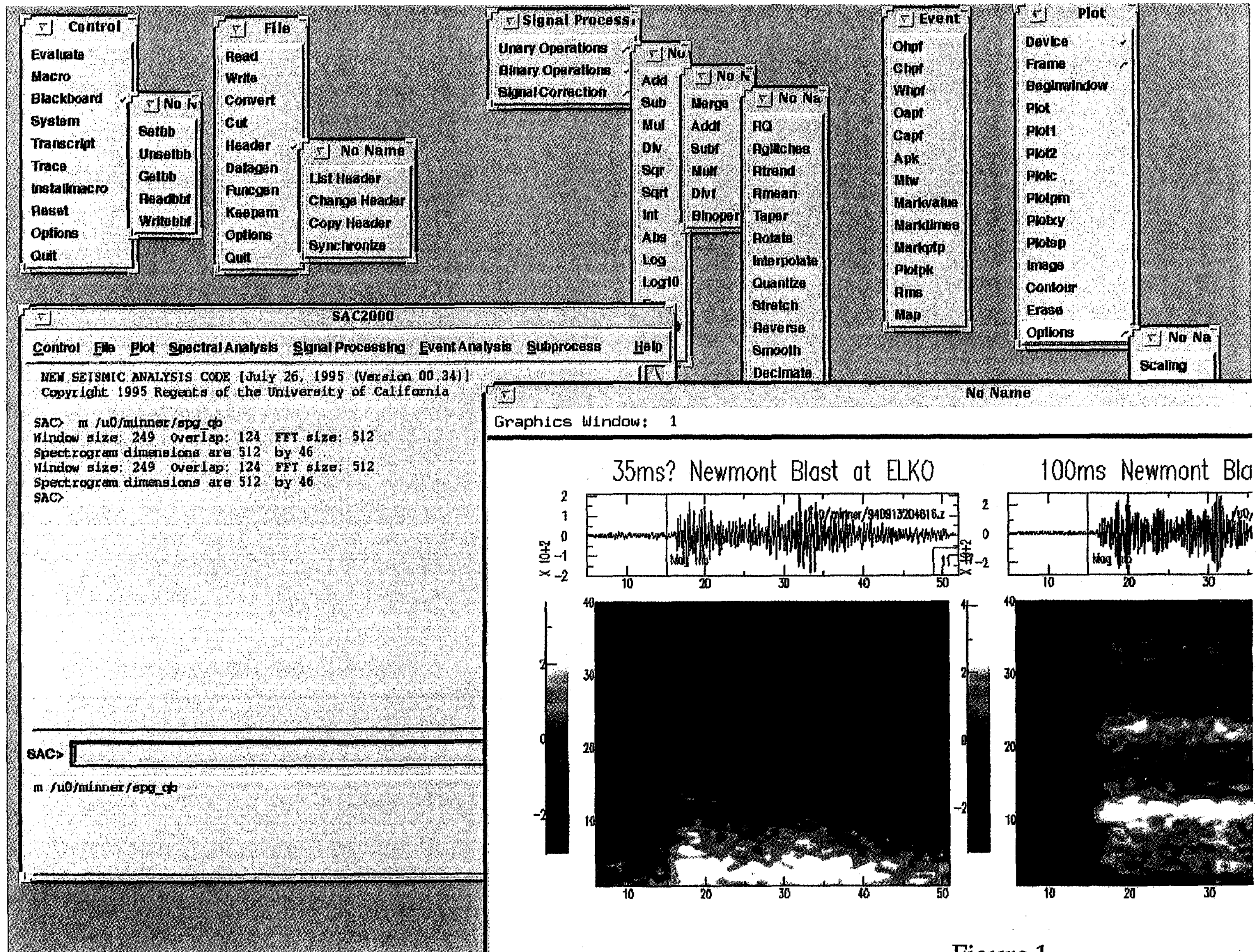

Control
Evaluate
Macro
Blackboard
System
Transcript
Trace
Installmacro
Reset
Options
Quit
Setbb
Unsetbb
Getbb
Readbbf
Writebbf
File
Read
Write
Convert
Cut
Header
Datagen
Funcgen
Keepam
Options
Quit
No Name
List Header
Change Header
Copy Header
Synchronize
Signal Process
Unary Operations
Binary Operations
Signal Correction
Add
Sub
Mul
Div
Sqr
Sqrt
Int
Abs
Log
Log10
Merge
Addf
Subf
Mulf
Divf
Binoper
RQ
Rglitches
Rtrend
Rmean
Taper
Rotate
Interpolate
Quantize
Stretch
Reverse
Smooth
Decimate
Event
Ohpf
Chpf
Whpf
Oapf
Capf
Apk
Mtw
Markvalue
Marktimes
Markptp
Plotpk
Rms
Map
Plot
Device
Frame
Beginwindow
Plot
Plot1
Plot2
Plotc
Plotpm
Plotxy
Plotsp
Image
Contour
Erase
Options
Scaling
SAC2000
Control File Plot Spectral Analysis Signal Processing Event Analysis Subprocess Help
NEW SEISMIC ANALYSIS CODE [July 26, 1995 (Version 00.34)]
Copyright 1995 Regents of the University of California
SAC> m /u0/minner/spg_qb
Window size: 249 Overlap: 124 FFT size: 512
Spectrogram dimensions are 512 by 46
Window size: 249 Overlap: 124 FFT size: 512
Spectrogram dimensions are 512 by 46
SAC>
SAC>
m /u0/minner/spg_qb
No Name
Graphics Window: 1
35ms? Newmont Blast at ELKO
100ms Newmont Bla

Figure 1

Color Spectrograms Can Help Identify Seismic Events

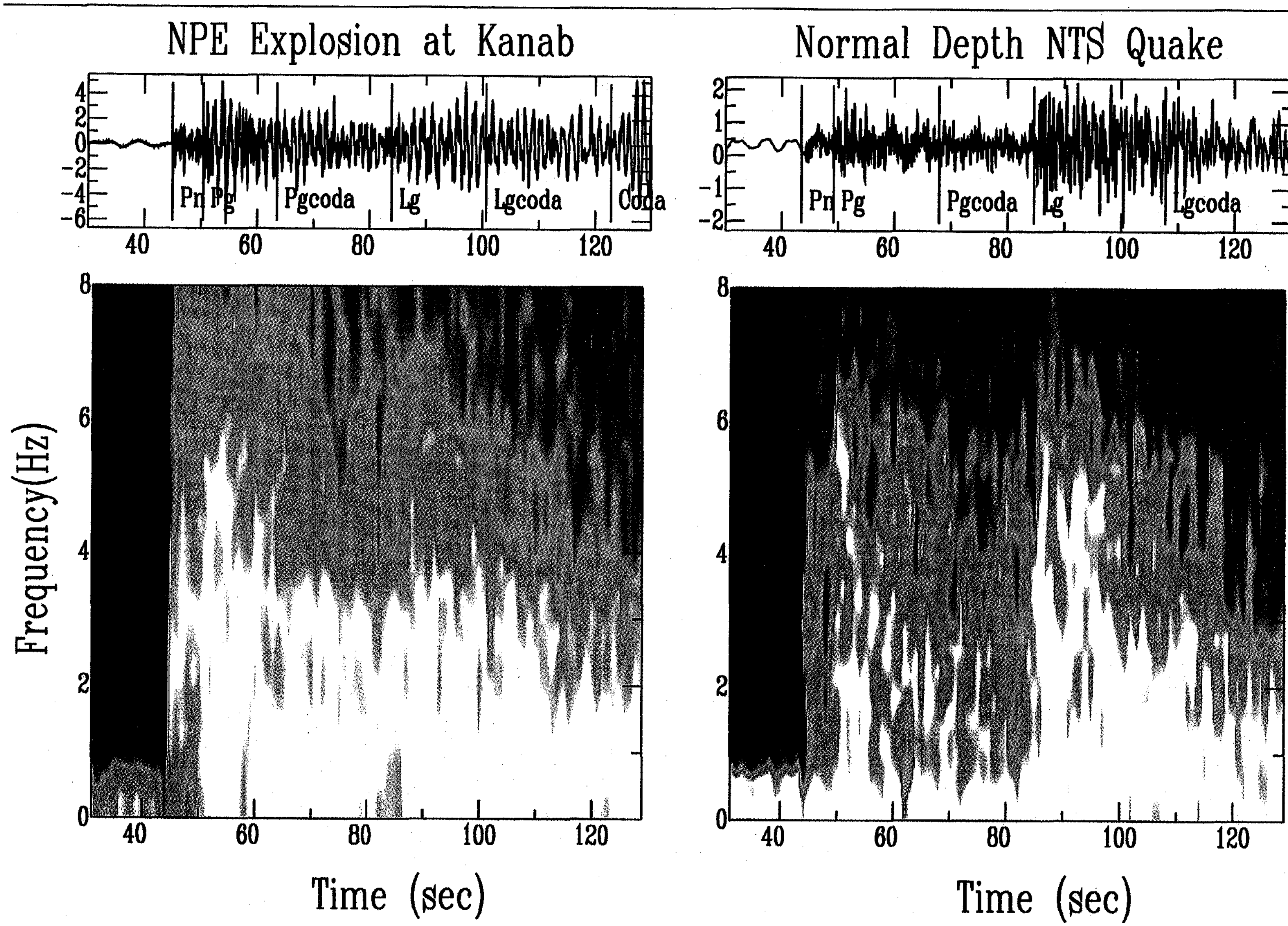


Fig. 2 Waveforms and spectrograms of an NTS explosion and earthquake recorded at KNB.

Binary Sonograms Can Help Identify Some Mine Blasts

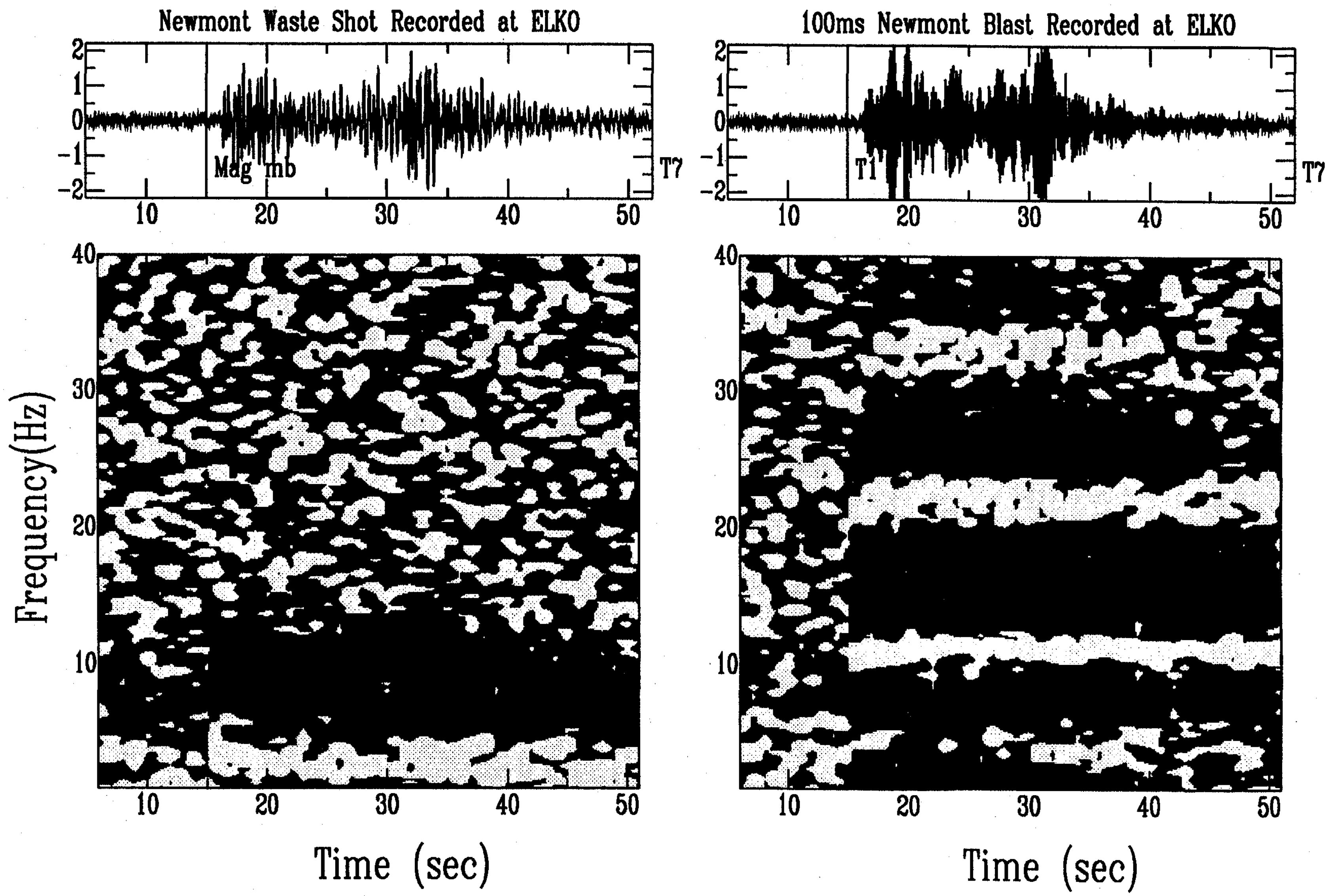


Fig. 3 Waveforms and binary sonograms from quarry blasts at the Newmont mine near Carlin Nevada.

Appendix A

The following are brief descriptions of some of the recent enhancements we have made to SAC2000 and documentation for some of the comands. Documentation for these commands is also available on-line through the help command and via the SAC home page discussed above. In the following descriptions SAC2000 commands and options are in uppercase and user input is in lower case. Curly Brackets indicate optional input.

READCSS: The readcss command allows the user to read data in the CSS2.8 and CSS3.0 formats. Our recent work includes a number of significant improvements to this command including: 1) Access to all binary data formats specified in the CSS3.0 database schema reference manual. 2) The ability to read data whose wfdisc records have been truncated or are inconsistent with the data. 3) The ability read multiple waveforms from within one CSS data file. The following documentation is also available on line via help readcss.

SAC Command Reference Manual READCSS

SUMMARY:
Read data files in CSS external format from disk into memory.

SYNTAX:
READCSS {MORE} {DIR name} wfdisclist {filelist} {css options}
The css options are one or more of the following:

GAIN {LOW | HIGH | *}
BANDWIDTH {SHORT | MEDIUM | LONG | *}
ORIENTATION {NORTH | EAST | Z | *}
VERSION n

which causes this command to further select from files that are qualifying members of filelist based on the content of their corresponding records in the wfdisc file.

INPUT:

MORE : See the READ command.

DIR name : The directory to be searched for wfdisc(s).

wfdisclist : The name(s) of one or more wfdisc files.

filelist : A list of data file names contained in the previously specified wfdisc(s). These files will be searched for first in the directory specified with the DIR option, then using the path specified in the wfdisc. If no filelist is supplied, all the data files defined in the specified wfdisc(s) will be read into memory.

GAIN gain : gain can be one of: low, high or * (for low-gain, high-gain or any gauges) The letter l selects those files whose 'sta' field in the wfdisc record contains a character string ending in L (upper-case). The letter h selects the opposite. The character * selects both.

BANDWIDTH type : type can be one of: short, medium, long or *. Selects those files whose 'chan' field has a leading character which is s, m or l. The character * selects all.

ORIENTATION type : type can be one of: north, east, z or *. Selects those files whose 'chan' field has a second character which is n, e or z. The character * selects all.

VERSION version : Version of CSS format.

DEFAULT VALUES:
READCSS * GAIN * BAND * ORIENT * V 3.0

DESCRIPTION: See the READ command. May 26, 1995 (Version 00.31)

SPECTROGRAM: The spectrogram command allows the user to compute conventional and high resolution spectrograms of time series data. We believe we have corrected most of the serious problems that existed in the original version of this command and have provided some significant enhancements including:

1) A more robust code due to improved memory management and error checking. We've also implemented a ridge regression scheme for dealing with instabilities in the high resolution spectral estimators due to small eigenvalues in the autocorrelation matrix.

2) Easier to use and interpret output because the data are plotted above the spectrogram with a correctly registered time axis. The documentation has also been expanded and improved (see the documentation).

3) Option to compute high resolution spectrograms using the Maximum Entropy or Maximum Likelihood spectral estimators. The user can also control the order of these estimators through an order option. We have also implemented a ridge regression algorithm which should stabalize these estimators when their are very small eigenvalues in the autocorrelation matrix.

4) Improved graphical output including color and grayscale images, consistent axes labeling, and a correctly registered time series above the spectrogram.

5) Options to scale the spectral amplitudes by taking their log to the base 10 (log10) natural log (nlog) or square root (sqrt).

6) Option to control the range of frequencies plotted using ymin and ymax.

The following documentation is also available on-line via help spectrogram.

SUMMARY:
Calculate a spectrogram using all of the data in memory.

SYNTAX:
SPECTROGRAM options
where options are one or more of the following:

WINDOW v
SLICE v
ORDER n
CBAR {ON|OFF}
{SQRT|NLOG|LOG10|NOSCALING}
YMIN v
YMAX v
METHOD {PDS|MEM|MLM}
{COLOR|GRAY}

INPUT:
WINDOW v : Set the sliding data window length in seconds to v. This window length determines the size of the fft.

SLICE v : Set the data slice interval in seconds to v. A single spectrogram line is produced for each slice interval.

ORDER n : Specifies the number of points in the autocorrelation function used to compute the spectral estimate.

CBAR {ON|OFF} : Turn reference color bar on or off.

{SQRT|NLOG|LOG10|NOSCALING} : Specify natural log, log base 10, or square root scaling of amplitudes.

YMIN v : Specifies the minimum frequency to plot.

YMAX v : Specifies the maximum frequency to plot.

METHOD {PDS|MEM|MLM} : Specifies the type of spectral estimator used. MLM stands for maximum likelihood and MEM stands for maximum entropy spectral estimators, respectively. See description and references below.

{COLOR|GRAY} : Specifies a color or grayscale image.

DEFAULT VALUES:
SPECTROGRAM WINDOW 2 SLICE 1 METHOD MEM ORDER 100 NOSCALING YMIN 0 YMAX FNYQUIST COLOR

DESCRIPTION:
A spectrogram is computed by calculating power spectra of consecutive, possibly overlapping time windows of data and plotting the spectra side by side along a time axis. The spectra are calculated from a truncated autocorrelation function using either the maximum likelihood method (MLM), maximum entropy method (MEM), or Power Density Spectral method (PDS). In general, the high resolution, maximum likelihood and maximum entropy methods are preferred because they improve resolution and because they do not produce artifacts (sidelobes) in the spectra due leakage of energy between different

frequencies. Descriptions of these techniques can be found in Kanasewich (1981) and Lacoss (1971) and the references therein. The length of the truncated autocorrelation function is determined by the order parameter. To maintain consistency with the spe subroutines we have set the defaults order to 200 for the power density spectra (pds) and 100 for the maximum entropy and maximum likelihood spectral estimates. In sac the length of each data window is determined by the window parameter. The spacing between spectra along the spectrograms time axis is determined by the slice parameter. The difference between these two parameters determines the amount of overlap between adjacent time window as indicated in the diagram below.

```
Time --->
0  1  2  3  4  5  6  7  8  9  10  11
|..|..|..|..|..|..|..|..|..|..|..|
|____| window 1, First time in spectrogram will be at the center of this window.
   |____| window 2
      |____| window 3

   |..| The slice is the difference between the start times
        of adjacent windows.
                        ...
                                |____|
                                   |____|
                                      |____|
```

The start and end points on the spectrograms time axis depend on the length of the time series being analysed and the window and slice parameters. The spectrogram's start time is one-half a window later than the time series start time because it is defined as the center of time of the first window. SAC doesn't pad the start of the data with zeros.

Kanasewich, E. R., "Time Sequence Analysis in Geophysics", The University of Alberta Press, Edmonton, 1981.

Lacoss, R. T., Data Adaptive Spectral Analysis Methods", Geophysics, Vol. 36, 661-675, 1971.

LIMITATIONS: The size of the image in the frequency direction is 512.

PROBLEMS: There is currently very little error checking of the headers to make sure that they are from the same component and are contiguous in time. This will be corrected in the future.

HEADER VARIABLES:

REQUIRED: : DELTA

CHANGED: : NPTS, DELTA, B, E, IFTYPE, DEPMIN, DEPMAX, DEPMEN

CREATED: : NXSIZE, XMINIMUM, XMAXIMUM, ,BREAK NYSIZE, YMINIMUM, YMAXIMUM

LATEST REVISION:
May 26, 1995 (Version 00.31)

SCALLOP: The scalloping command computes a time-frequency distribution equal to the difference between two smoothed version of the same spectrogram. Depending on the choice of smoothing parameters, fmin and fmax, the resulting time-frequency distribution can enhance small amplitude spectral features that are more difficult to observe in a conventional spectrogram. This is particularly useful when looking for features like high frequency spectral modulations in seismic signals from mine blasts (c.f., Hedlin, 1990, Wuster, 1993).

SUMMARY:
Calculate a time-frequency distribution equal to the difference between two smoothed versions of the same spectrogram.

SYNTAX:
SCALLOP options
where options are one or more of the following:

WINDOW v
SLICE v
ORDER n
CBAR {ON|OFF}
YMIN v
YMAX v
FMIN v
FMAX v
BINARY|FULL
METHOD {PDS|MEM|MLM}
{COLOR|GRAY}

INPUT:

WINDOW v : Set the sliding data window length in seconds to v. This window length determines the size of the fft.

SLICE v : Set the data slice interval in seconds to v. A single spectrogram line is produced for each slice interval.

ORDER n : Specifies the number of points in the autocorrelation function used to compute the spectral estimate.

CBAR {ON|OFF} : Turn reference color bar on or off.

BINARY|FULL : Produce a binary image, or a full color image.

YMIN v : Specifies the minimum frequency to plot.

YMAX v : Specifies the maximum frequency to plot.

FMIN v : Specifies the smallest bandwidth over which each slice in the spectrogram will be smoothed.

FMAX v : Specifies the maximum bandwidth over which each slice in the spectrogram will be smoothed.

METHOD {PDS|MEM|MLM} : Specifies the type of spectral estimator used. MLM stands for maximum likelihood and MEM stands for maximum entropy spectral estimators, respectively. See description and references below.

{COLOR|GRAY} : Specifies a color or grayscale image.

DEFAULT VALUES:
SCALLOP WINDOW 2 SLICE 1 METHOD MEM ORDER 100 YMIN 0 YMAX FNYQUIST FMIN 2.0 fmax 6.0 full color

LIMITATIONS: The size of the image in the frequency direction is 512.

PROBLEMS: There is currently very little error checking of the headers to make sure that they are from the same component and are contiguous in time. This will be corrected in the future.

HEADER VARIABLES:
REQUIRED: : DELTA

CHANGED: : NPTS, DELTA, B, E, IFTYPE, DEPMIN, DEPMAX, DEPMEN

CREATED: : NXSIZE, XMINIMUM, XMAXIMUM, ,BREAK NYSIZE, YMINIMUM, YMAXIMUM

LATEST REVISION:
May 26, 1995 (Version 00.31)

IMAGE: *The image command allows the user to make color or grayscale images from a SAC 3-D data file such as those generated by the spectrogram, scallop, or bbfk commands. It can also be used to plot imported data provided they are in the SAC 3-D data format. Different sections of the image can be viewed using the xlim and ylim commands and amplitudes can be scaled using the usual unary operations provided in SAC.*

SAC Command Reference Manual IMAGE

SUMMARY:
Produces color sampled image plots of data in memory.

SYNTAX:
IMAGE COLOR|GREY BINARY|FULL

INPUT:

COLOR|GREY : Produce a color or greyscale image.

BINARY|FULL : Produce an image where all positive values plot in one color and all negative values plot in a second color, or plot the full range of the data.

DEFAULT VALUES:
IMAGE COLOR FULL

HEADER VARIABLES:

REQUIRED: : IFTYPE (set to "IXYZ"), NXSIZE, NYSIZE

USED: : XMINIMUM, XMAXIMUM, YMINIMUM, YMAXIMUM

LATEST REVISION:
May 26, 1995 (Version 00.31)

LOADCTABLE: The loadcolortable command allows the user to select a new color table or provide their own custom color table by specifying the color table file with a pathname, relative to the current directory.

SAC Command Reference Manual LOADCTABLE

SUMMARY:
Allows the user to select a new color table for use in image plots.

SYNTAX:
LOADCTABLE n | [options] [filelist]
where n is a number (currently between 1 and 17) of a standard SAC color table stored in directory SACAUX, or
where options is the following:

DIR CURRENT|name

options MUST preceed any element in the filelist.

INPUT:

n : The number of a standard SAC color table.

DIR CURRENT : Load color table from the current directory. This is the directory from which you started SAC.

DIR name : Load color table from the directory called name. This may be a relative or absolute directory name.

filelist : file

file : A legal color table filename. This may be a simple filename or a pathname. The pathname can be a relative or absolute one.

DESCRIPTION:
This command allows the user to select a new color table or provide their own custom color table by specifying the color table file with a pathname, relative to the current directory. If the DIR option is not used, SAC looks first in SACAUX for the color table, then in the user's working directory.

LATEST REVISION:
May 26, 1995 (Version 00.31)

HELP: The sac command reference manual is now on line. There may be some inconsistencies between the documentation and sac2000 because many of the commands have not been updated from the form in sac10.6f.

SAC Command Reference Manual HELP

SUMMARY:
Prints information about SAC commands and features.

SYNTAX:
HELP {item ...}

INPUT:
item : The (full or abbreviated) name of a command, module, subprocess, feature, etc.

DEFAULT VALUES:
If no item is requested, an introductory help package is printed.

DESCRIPTION:
Each requested item in the help package is printed in the order they are requested. A short message is printed if no information is available for an item. After a full page of output, the user is prompted to see if he or she wishes to see more information on that item. A response of "NO" or "N" will terminate the printing of that item and will begin the printing of the next item if any. A response of "QUIT" or "Q" will terminate the printing of all items. The help package for each command consists of the entry in the SAC Command Reference Manual. The help package for non-commands may be paragraphs from the SAC Users Manual or other information. There are several special help packages that are always available. HELP COM will list the names of all SAC commands. HELP AUX will list the names of all non-command help packages. Also, the NEWS command prints topical information about the status of SAC.

EXAMPLES:
To get the introductory help package type:

u: HELP

Now lets say you want information on several commands:

u: HELP READ CUT BEGINDEVICE PLOT

SAC begins printing the READ help package. After a full page, it asks if you've seen enough:

s: MORE?

u: YES

SAC prints the rest of the help package on READ, and then begins printing the help package on the CUT command:

s: MORE?

u: NO

SAC stops printing the CUT help package and begins printing the BEGINDEVICE help package:

s: MORE?

u: QUIT

You're getting impatient so you type QUIT. SAC terminates the HELP command so you can try some of the features discussed.

ERROR MESSAGES:
1103: No help package is available.

- SAC can't find the help package. Contact the programmer.
1105: Error reading help information for

- Usually a transient system glitch has occurred. Contact the programmer if this error persists.

CONVOLVE: The convolve command allows the user to compute the convolution of two time series. (The usage is the same as that for the correlate command. See existing documentation.) Analytically, convolution is defined by:

$$h(\tau) = \int_{-\infty}^{\infty} f(t)g(t-\tau)dt,$$

where int means integral from -• to •. This is similar to cross correlation (a previously existing command in SAC), which is defined by:

$$h(\tau) = \int_{-\infty}^{\infty} f(t)g(t+\tau)dt.$$

In fact, it has been possible to do convolutions with SAC for some time by reversing one of the time series with the reverse command and applying the cross-correlation command.
The syntax and output of the convolve command are similar to that of the correlate command, except that the cross-correlation waveform is replaced by the convolution.

SAC Command Reference Manual CONVOLVE

SUMMARY:
Compute the convolution of a master signal with one or more other signals.

SYNTAX:
CORRELATE {MASTER name|n},
{NUMBER n},{LENGTH ON|OFF|v},
{TYPE RECTANGLE|HAMMING|HANNING|COSINE|TRIANGLE}

INPUT:

MASTER name|n : Select master file in data file list by name or number. All files will be correlated against this one.

NUMBER n : Set number of correlation windows to be used.

LENGTH {ON} : Turn fixed window length option on.

LENGTH OFF : Turn fixed window length option off.

LENGTH v : Turn fixed window length option on and change window length in seconds to v.

TYPE RECTANGLE : Apply a rectangle function to each window. This is equivalent to applying no function to each window.

TYPE HAMMING : Apply a hamming function to each window.

TYPE HANNING : Apply a hanning function to each window.

TYPE COSINE : Apply a cosine function to each window.

TYPE TRIANGLE : Apply a triangle function to each window.

DEFAULT VALUES:
CONVOLVE MASTER 1 NUMBER 1 LENGTH OFF TYPE RECTANGLE

HEADER CHANGES: DEPMIN, DEPMAX, DEPMEN

ACKNOWLEDGEMENTS: This command is based on an algorithm developed by Dave Harris.

LATEST REVISION: May 26, 1995 (Version 00.31)

The following is a brief summary of improvements to a few previously existing SAC commands.

BBFK: The bbfk command has bee modified to write the location of the peak amplitude, its wavenumber, and backazimuth to the blackboard variables: bbfk_amp, bbfk_wvnbr, bbfk_bazim. These variables can be access by typing getbb or through the usual blackboard variable access commands.

WRITE: A new option has been added to the write command (KSTCMP) that is particularly useful for writing array data located in a single css waveform file to individual sac files. For example, if a waveform file called array.waveform contained array data pointed to by the wfdisc file array.wfdisc, the sac command "WRITE KSTCMP" would use the station and component fields in the wfdisc to generate individual sac files for each waveform in the array.waveform file.

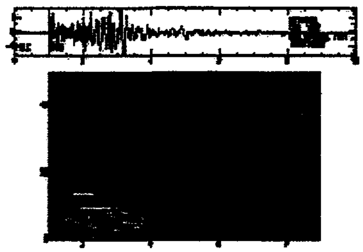
The syntax including options for this command are:

WRITE {options} {namingoptions}
Where KSTCMP is a new namingoption

KSTCMP   Use the kstnm and kcmpnm header variables to define a file name for each data file in memory and write the files to disk.

Appendix B

SAC - Seismic Analysis Code



SAC (Seismic Analysis Code) is a general purpose interactive program designed for the study of sequential signals, especially timeseries data. Emphasis has been placed on analysis tools used by research seismologists in the detailed study of seismic events. Analysis capabilities include general arithmetic operations, Fourier transforms, three spectral estimation techniques, IIR and FIR filtering, signal stacking, decimation, interpolation, correlation, and seismic phase picking. SAC also contains an extensive graphics capability.

■ SAC Manual

- SAC Users Manual
- SAC Tutorial Guide for New Users
- SAC Commands Definitions Alphabetical Listing
- SAC Reference Manual Alphabetic Listing
- SAC Commands Definitions Functional Listing
- SAC Reference Manual Functional Listing
- SAC Graphics File Users Manual
- SAC Spectral Estimation Subprocess Manual
- SAC Signal Stacking Subprocess Manual
- SAC Installation Guide Manual

■ New Features and Releases

■ Bug Reports and Bug Fixes

- **Availability of Source Code**
- **Developers;**
- **Copyright;**

Availability of SAC Source Code

SAC was developed at Lawrence Livermore National Laboratory and is copyrighted by the University of California.

The reader may obtain SAC provided they fill out the collaborative agreement and are elligble according to the Department of Energy's guidelines. When the agreement is received, you will be contacted with instructions on where to ftp the source code.

Copy the collaborative agreement to your workstation, sign it and then mail it or fax it to:

Lee Minner
P.O. Box 808
L-205
Livermore, Ca. 94550
phone: (510) 423-2677
fax: (510) 423-4077

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Many thanks to Craig Scrivner, of the Caltech Seismo Laboratory, who initially converted the Command Reference Manual to HTML format from the LaTex version of the manual.

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