RECENT DEVELOPMENTS IN SAC2000: ENHANCED PROCESSING, DATABASE INTERACTION, AND COMPATIBILITY WITH OTHER TOOLS

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ABSTRACT

Development of the Department of Energy Comprehensive Nuclear-Test-Ban Treaty Research and Development (DOE CTBT R&D) Knowledge Base is a complex, evolutionary process involving a large number of signal processing and data analysis tasks and tools. Our efforts have been focused on the development of signal processing and data analysis enhancements that help facilitate this process. We have also developed database access and data management capabilities that improve access to data and facilitate the utilization of multiple tools. These developments have been used to address a number of knowledge-base-related tasks including:

- Data selection, inspection, and quality control
- Phase picking and amplitude measurements
- Magnitude estimation
- Discrimination studies
- Depth and mechanism estimation
- Geophysical model development using waveform modeling

Recent developments in SAC2000 include a number of capabilities needed by the DOE CTBT R&D program. These developments include a mixture of relatively new capabilities and enhancements to existing capabilities. All of these capabilities resulted from direct requests from researchers at Lawrence Livermore National Laboratory and in the monitoring community. A sample of some of these capabilities is given below.

- READCSS and WRITECSS, which have been completely rewritten so that they are 100% compatible with CSS3.0; thus, a user can read in CSS3.0 data, process it, and pass it back out in CSS3.0 without losing any of the relevant CSS3.0 parameters. This provides improved access to CSS3.0 parameter data and significantly improved compatibility with other tools.
- COMMIT, ROLLBACK, and RECALLTRACE, which allow the user to combine parameters calculated from processed data with unprocessed waveforms, undo the effects of processing on seismic waveforms, and commit process data to an input/output buffer for future processing.
- READGSE and WRITEGSE, which read and write GSE2.0 format, and a READSUDS command which reads PC SUDS data.
- TRAVELTIME, which has been modified to allow the user to save model travel times in the SAC headers and use general 1-D velocity models to compute travel times.
- TRANSFER, which has been updated to read instrument responses from an Oracle database and to allow the use of FAP files.
- SORT command, which allows users to sort their data based on SAC header fields.
- WHITEN command, which flattens the spectrum of a user's data.
- FILTERDESIGN, which has been updated to allow the user to save the results to files so that they can be used with other processing.
- PRINT options, which have been added to a number of commands.

Key Words: database, knowledge base, data processing, data analysis

INTRODUCTION

SAC2000 or SAC, as many users refer to it, is a fundamental signal processing and analysis tool for a large portion of the international seismological community including academic, government, and business institutions. SAC has attained this popularity for a variety of reasons. Foremost, are its extensive, well-documented, well-tested, and well-maintained mathematical capabilities, its macro programming language which allows users to develop new analysis techniques and customized processing programs, and its ability to do both batch and interactive processing. SAC's Strengths also include its ability to process a diverse range of data types and its extensive usage (> 400 institutions worldwide) which has made it much easier for researchers to develop collaborative research projects. SAC is relatively easy to use and is available on a variety of hardware platforms. Much of its popularity is probably due to its user oriented development philosophy which has led to consistent, backward compatible development guided by users input and needs.

SAC2000's extensive signal processing capabilities include: data inspection, signal correction, and quality control, unary and binary data operations, travel-time analysis, spectral analysis including high-resolution spectral estimation, spectrograms and binary sonograms, and array and three-component analysis (Figure 1). These capabilities have proved useful for solving a number of geophysical problems including, estimation and analysis of strong ground motions, earthquake, explosion, volcanic source studies, seismic discrimination and identification studies, magnitude estimation, travel-time analysis, studies of wave propagation phenomena such as path and site effects, and investigations of Earth structure. It has also proved useful for analysis of other geophysical data such as measurements of electromagnetic or hydro-acoustic phenomena.

OVERVIEW OF RECENT DEVELOPMENTS

Over the last few years, our focus has been on enhancing the ability to combine and utilize data and results from a variety of tools and data sources. A number of processing and analysis tools have been incorporated such as more powerful TRANSFER and TRAVELTIME capabilities and an interface to MATLAB. Table 1 lists new or enhanced processing and analysis tools.

I/O has been overhauled to make SAC2000 completely fluent in the CSS 3.0 schema. SAC2000 can read and write CSS 3.0 flat files, and our new CSS 3.0 binary file; it also reads CSS 3.0 data from an Oracle™ database. Other I/O improvements include the ability to read and write GSE 2.0 data, and to read PC SUDS and IRIS/PASSCAL SEGY data. Table 2 lists the new or enhanced I/O capabilities.

Table 3 lists a number of features that have been added to make SAC2000 more convenient. These features include a SORT command, the ability to delete selected files from memory (DELETECHANNEL), a unix-style history capability (HISTORY), and an in-memory cut command (CUTIM).

Table 4 describes new features that provide for more efficient processing of data, and Table 5 displays features that allow custom software development: integrating the user's software into SAC or integrating SAC's I/O functions into the user's software.

Some of these functions are described below. For more details on any function, get the latest version of SAC2000 from our ftp site, and use the HELP command.

Powerful Tools

The following table lists recent enhancements to SAC2000's processing and analysis capabilities. More details are also available in the HELP facility built into SAC.

Table 1. Recent Additions to SAC's Processing and Analysis Capabilities.

TRANSFER FROM EVALRESP	Utilizes Tom McSweeney's evalresp library to correct for instrument response
TRANSFER FROM FAP	Utilizes a frequency/amplitude/phase (FAP) file to correct for instrument response
TRANSFER FROM DBASE	Finds an evalresp, fap, or polezero file from an Oracle database to correct for instrument response
TRAVELTIME TAUP	Reads traveltime curves produced by TauP (Crotwell et. al. 1998)
TRAVELTIME PICKS	Stores arrival information in T0 - T9 headers
WHITEN	Applies a linear filter to the input signal to "whiten" or "flatten" the signal's spectrum
FILTERDESIGN FILE	Saves the responses from FILTERDESIGN to a set of SAC files for analysis
GMTMAP/MAP	Mapping display using Generic Mapping Tool
3C	MATLAB based three component analysis tool
MAT	A general interface between MATLAB and SAC

TRANSFER
SAC's TRANSFER command has long been used to remove instrument responses from waveform data. Three new options bring it up to date with modern instrument response technology:

The EVALRESP option enables the user to apply transfer functions extracted from SEED data volumes using the evresp code (Version 3.2.11) by Thomas J. McSweeney. The RESP files must be in the current directory or must be specified by full path and name. The EVALRESP option uses the STATION-CHANNEL-NETWORK-DATE-TIME information in the SAC headers to identify the correct RESP file and extract the proper transfer function from that file. However, it is possible to override the header values by specifying additional options to TRANSFER. The possible options are: STATION, CHANNEL, NETWORK, DATE, TIME, TYPE, and FNAME. Each option must be followed by an appropriate value.

The FAP option uses instrument response information from a frequency-amplitude-phase (FAP) file in the standard format used at the Center for Monitoring Research (pIDC). FAP files have five columns: frequency, amplitude, phase, amplitude error, and phase error.

The DBASE option searches an Oracle™ database for the applicable instrument response file which must be of type EVALRESP, POLEZERO, or FAP. The file found is used in the calculations of the TRANSFER command. Note: In order to use the DBASE option, the user must have access to an Oracle™ database with links to the applicable files, the database must be formatted as described in the HELP TRANSFER documentation, and the user must have the Oracle™ version of SAC2000.

TRAVELTIME
The TRAVELTIME command has been a part of SAC's Signal Stacking Subprocess (SSS) for a number of years now. It allows the user to produce traveltime curves from the iasp91 model, or to read curves in from text files. These curves can be overlain on a record section plot using command PRS TTIME ON. Now the PICKS option allows the times where the curves intersect the waveforms to be stored in the header fields T0 - T9.

TauP is a very flexible traveltime estimator developed by Philip Crotwell at the University of South Carolina (Crotwell et. al. 1998). It allows the user to produce traveltime curves from a model of the user's

design. The TRAVELTIME command in SAC2000 now takes a TAUP option which allows it to read the traveltime curves generated with TauP. Used in conjuction with PRS TTIME ON, this allows the display of TauP curves on record section plots in SAC. Used in conjunction with the PICKS option, it puts TauP traveltimes into the T0 - T9 header fields in SAC files.

MATLAB Three-Component Data Analysis Tool
We have developed a new, MATLAB-based tool for interactive and batch mode analysis of 3-component seismic data. This tool will improve a user's ability to detect and identify seismic phases, especially secondary phases. It has also helped us process data and identify problems with data such as incorrect sensor orientation information.

This tool has a number of capabilities including: graphical data selection and filter design, automatic back-azimuth and incidence angle estimation, interactive, graphical, three-component particle motion analysis, and maximum-likelihood probability estimates of selected wavetypes (Christoffersson et al., 1988).

Figure 2 displays a selected example of the interactive version of this three-component data analysis tool. Interactive data/window selection, phase picking, and signal rotation are done in the main window. Popup windows are used to: filter the data (no windows shown), interactively analyze particle motions (Particle motion module), and compute maximum-likelihood probabilities for selected wavetypes (ML-polarization analysis module).

I/O

Table 2 displays new I/O commands which make SAC useful on a wider range of data files and formats.

Table 2. Recent Additions to SAC's I/O Capabilities.

READCSS/WRITECSS	Complete CSS 3.0 compliance; reads and writes both CSS 3.0 flatfiles, and a CSS 3.0 binary formats
READDB	Access CSS 3.0 data from an Oracle database
READGSE/WRITEGSE	GSE 2.0 I/O
READSUDS	Reads PC SUDS with automatic byte conversion
READ SEGY	Reads IRIS/PASSCAL version of SEGY files
READ ALPHA	Reads SAC formatted Alpha files (replaces CONVERT)
READTABLE	This is the old READALPHA command, renamed to avoid confusion with READ ALPHA

With the release of version 0.58, SAC2000 now has two parallel internal data buffers: the original buffer which houses the data in traditional SAC format, and a second buffer which stores the data in CSS 3.0 tables. As needed, SAC2000 can seamlessly move the data between the two buffers, allowing fully compliant CSS 3.0 reading and writing capability. The READDB command allows SAC to read CSS 3.0 data directly from a properly configured Oracle™ database.

This data storage modification has dramatically improved SAC's ability to read other relational formats, enabling the reading and writing of GSE 2.0 files and the reading of PC SUDS files. Also, SEGY files of the type available through IRIS/PASSCAL can now be read with the SEGY option to the READ command.

The READ command now has a new ALPHA option which reads SAC formatted alphanumeric text files (those produced by WRITE ALPHA). READ ALPHA replaces the old CONVERT command which could only handle one file at a time and didn't take the MORE option. To avoid confusion, the one-word command READALPHA – which reads columns of data – has been given an alternative name: READTABLE.

Added Convenience

Most of the recent ease-of-use enhancements to SAC2000 are highlighted in Table 3. Those changes involving process management are listed in Table 4.

Table 3. Recent Enhancements to SAC's Ease-of-use.

SORT	Sort files based on header values
CUTIM	Cut files in memory, can make multiple cuts
PRINTHLP	Prints the specified HELP file
PRINT option	An option to most plotting command, sends plot to printer
PRINT command	Prints the most recent SGF file
SGF OVERWRITE	Allows SGF files to over-write previous SGF files
DELETECHANNEL	Removes specified files from memory
FILENUMBER	Tags most plots with filenumbers, for use with DELETECHANNEL
PICKAUTHOR	Specifies preferred authors when reading picks from CSS data
PICKPHASE	Specifies preferred phases when reading picks from CSS data
MERGE	MERGE can now merge overlapping files
HISTORY	View prior SAC commands. Reissue commands with ! or !! (as in UNIX)
maximum file number	SAC can now hold 1000 files in memory

SORT allows the user to sort files in memory based on header fields. Up to five fields can be selected, and for each field the sort can be in ascending (default) order or descending order.

CUTIM is similar to CUT, except that while CUT simply sets the parameters and lets the cut happen on the following READs, CUTIM cuts the data in memory, and has no effect on subsequent READs. CUTIM also allows files to be cut into multiple pieces, so that if you start with two files, and specify three cut segments, you will end up with six files in memory – three segments from each of the original two files.

DELETECHANNEL allows the user to remove specified files from memory. For example, one can read large sets of data from relational files or large directories of SAC files, sort them on a particular header field, and then delete those files which don't match desired criteria. The command FILENUMBER is helpful for determining the file numbers of files to be deleted.

HISTORY works much like the UNIX history command. It lists previous SAC commands given in the current session. The exclamation point (!) can be used to reissue commands in three ways: !! reissues the previous command, !n (n denotes a number) reissues command n as listed by the HISTORY command, and !s (s denotes a character string) reissues the most recent command which begins with the string s.

Table 4. Process Management Commands

COMMIT	Protect changes from being undone with ROLLBACK or REACALLTRACE
ROLLBACK	Undo changes since last COMMIT
RECALLTRACE	Commit the header, rollback the waveform

The process management capability is made possible by the dual data storage buffers mentioned in the section about I/O. ROLLBACK undoes all the changes since the last COMMIT (or the READ). COMMIT protects changes from being undone. RECALLTRACE (RECALL) rolls back the waveform along with those header fields which are tightly bound to the waveform (such as npts, delta, etc.) and commits the header fields which are not tightly bound to the waveform (such as picks and event information).

Incorporating Your Own Code

The following table lists features which allow the user to incorporate code into SAC, or to read and write SAC data files from his/her own code.

Table 5. Software Interface Enhancements

command interface	Allows users to write commands in C or FORTRAN and add them to SAC
sacio.a	A library with SAC's I/O routines callable from stand-alone FORTRAN or C programs

For more details regarding the external command interface, use HELP EXTERNAL_INTERFACE and HELP LOAD at the SAC> prompt.

For details about the sacio.a library, use HELP INPUT_OUTPUT, HELP BLACKBOARD, and HELP APPENDIX at the SAC> prompt.

CONCLUSIONS

We have implemented a number of new processing capabilities and enhancements in SAC2000 that will improve users' efficiency and their ability to accurately interpret data. We have also developed a new, flexible data structure for SAC2000 that will allow us to access, modify, and output all the information in CSS3.0-based Oracle™ databases or CSS3.0 flat files. Other data schemas can now be read. Among them, GSE can also be written. These new capabilities are essential for efficient processing and analysis of the large amounts of seismic data that are currently being collected. A number of conveniences have been added to SAC2000 including SORT, DELETECHANNEL, and HISTORY which make the process flow more smoothly from the human perspective. Also, facilities are in place which allow SAC to interface with other software.

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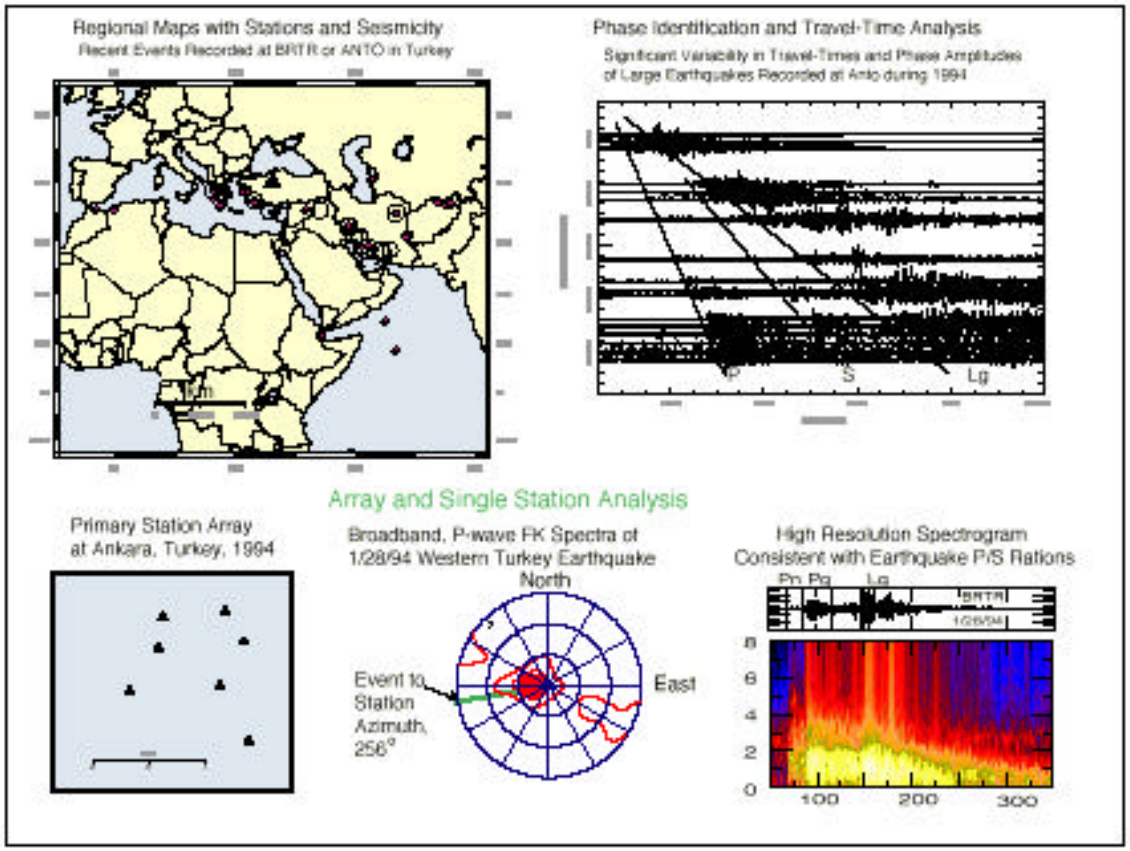

Figure 1. Selected signal processing and analysis capabilities in SAC2000.

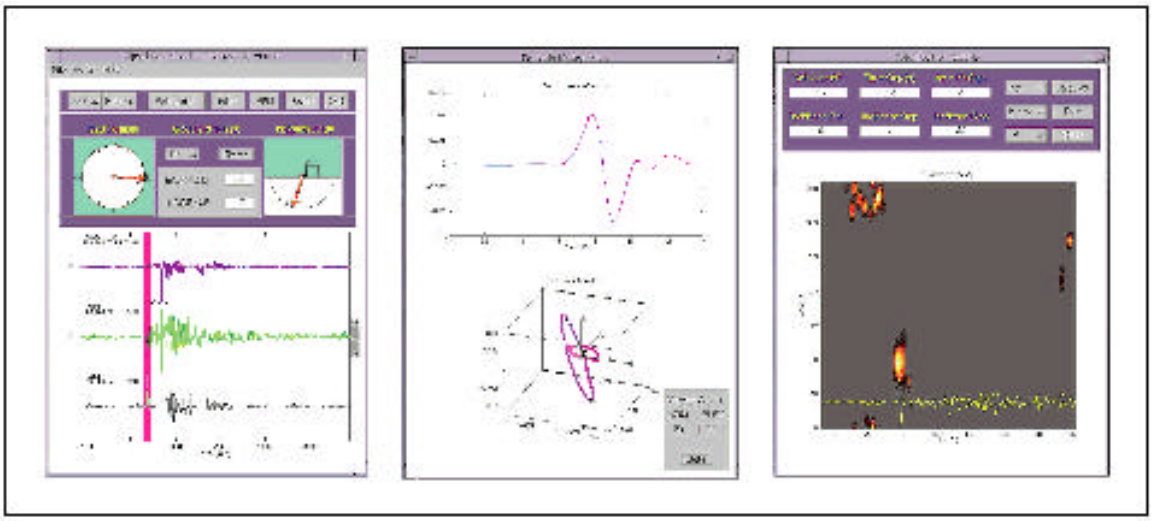

Figure 2. Interactive version of SAC2000's 3-component datainspection and analysistool.