The Seismic Analysis Code

A Primer and User's Guide

The Seismic Analysis Code (SAC) is one of the most widely used analysis packages for regional and teleseismic seismic data. Now, for the first time, this book provides users at both introductory and advanced levels with a complete guide to SAC, enabling all users to make best use of this powerful tool.

The book leads new users of SAC through the steps of learning basic commands, describes the SAC processing philosophy and presents its macro language in full. The text is supported throughout with example inputs and outputs from SAC. For the more experienced and ambitious practitioners of the code, it also describes SAC's many hidden features, including advanced aspects of its graphics, its file structure, how to write independent programs to access and create files, and use of the methods SAC provides to integrate external processing steps into production-type data analysis schemes. Tutorial exercises in the book engage users with their newly acquired skills, providing data and code to implement the standard methods of teleseismic shear-wave splitting and receiver function analysis.

Methodical and authoritative, this combined introduction and advanced tutorial guide is a key resource for researchers and graduate students in global seismology, earthquake seismology and geophysics.

GEORGE HELFFRICH is a professor of seismology in the School of Earth Sciences at the University of Bristol. His research interests include using observational seismology to study features of the crust, mantle and core. Recently, he has based his analysis techniques on large-scale seismic array data, using SAC as the primary seismological data analysis tool. Before embarking on his research career, Professor Helffrich was a programmer who developed and supported mainframe operating systems. Bringing this experience to the seismological realm, he has contributed to the development of SAC for over 20 years.

JAMES WOOKEY is a research fellow and lecturer in the School of Earth Sciences at the University of Bristol. His research focuses on observational seismology, particularly seismic anisotropy, applied to problems from the inner core to oil reservoirs, with a recent focus on Earth's core–mantle boundary region. Dr. Wookey has spent much of his research career developing and applying novel methods for analyzing seismic data, and comparing them with predictions from mineral physics and geodynamics to better understand Earth processes. His experience with SAC spans 15 years, including as contributor to its development.

IAN BASTOW is a lecturer in seismology in the Department of Earth Science and Engineering at Imperial College, London. His research focuses primarily on the analysis of broadband seismological data from networks of temporary seismograph stations to better understand the Earth's crust and mantle. Dr. Bastow has worked extensively on tectonic problems concerning the seismically and volcanically active East African rift system, as well as on the development of Laurentia, the Precambrian core of North America. He has been a user of SAC for over a decade.

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Preface

One of the most widely used analysis packages for regional and teleseismic seismic data is SAC (the Seismic Analysis Code). It was developed in the 1980s by nuclear test monitoring agencies in the United States, who freely made the source code and paper documentation available to academic users. From this initial distribution, the analysis package became popular in academic circles due to its ease of use and suitability for research data analysis in seismology and geophysics.

SAC's documentation was on ring-bound paper shipped along with the nine-track half-inch source code tapes that you received in the post. The academics in receipt of them generally made copies from the master document and distributed them to colleagues and students. They also tutored new users on the use of SAC, guiding them through their first session and then left them to the documentation. Consequently, much of the knowledge of SAC was passed tutorially from an experienced user, not unlike trade apprenticeship. Those intrepid enough to find and read the documentation usually exceeded their tutors' ability. The far fewer who delved into the source code learned of undocumented features of great utility. The usual reasons for this puzzling knowledge gap apply: in software development, documentation always lags feature development and, for SAC, new releases were sporadic and focused on new capability.

The original SAC documentation consisted of: (1) tutorial guide; (2) command table; (3) detailed command descriptions; (4) SAC file structure internals; (5) auxiliary program guide for programs to turn graphics to hard-copy form. Only the first of these was of any help to the new SAC user. Moreover, it is only in the tutorial guide that SAC's very powerful macro capabilities were described, but then only superficially. Consequently, the typical new user response after reading it, trying a few things out with SAC and getting confused, was to lean over to the nearest grad student and ask for help. SAC's most powerful capabilities could only be learned that way, if at all.

This book aims to remedy this continuing state of affairs when learning to use SAC. Despite the emergence of the web and web-based documentation for SAC, those available reproduce the paper ones as of about 1990. Despite some SAC development since then, no new documentation at the novice level, and little at the command description level, has been written. The main documentation effort today by the IRIS Consortium focuses on enhancing

detail in the individual command descriptions. This book is for new SAC users to lead them through the steps of learning basic commands, to describe the SAC processing philosophy and to describe the SAC macro language in full. All ideas are introduced with example input and output from SAC. For the more experienced user, the book describes the advanced features of SAC graphics: graphical interaction with traces and annotation of displays of traces with auxiliary data. We also describe the powerful, but under-appreciated feature of SAC's array data handling facilities and spectral analysis methods. Also for the experienced user, we show how to write independent programs to access and create files, and how to use the methods that SAC provides to integrate external processing steps into production-type data analysis schemes. We show this with descriptions of code and SAC macros that implement the standard methods of teleseismic shear-wave splitting and receiver function analysis. Example commands and macros for tryout and text for programs is flagged using the following scheme:

Ex-0.1

```
example text here
```

This material is linked from the publisher's web site (www.cambridge.org/helffrich) for download, keyed to the identifier in the box.

We originally developed this material to teach a three-day course in SAC data processing to new PhD students in geology and geophysics. Following the successful reception of the course, we decided to turn the lecture notes and exercises into a more permanent version that redresses the shortcomings of existing SAC documentation. We hope that this book will be of use for incoming and existing PhD students, or in undergraduate courses on seismic data processing. If it is to hand at every seismologist's desk, it will have achieved its aim.

I salute the original authors of SAC, Bill Tapley and Joe Tull, for its design simplicity and implementation clarity. There can be no better testimony to the quality of a piece of software than its being in continuous use for over 30 years.

Acknowledgements

All of us came to use SAC through some variant of my own introduction to it. My thesis advisor, Seth Stein, came by me in the computer room one day, dropped the SAC manual into my lap and said, "You might be interested in using this." At least I think it was him, but some of my fellow PhD students might have different recollections that involve their agency. I apologize for any faulty memory. In the case of IB and JW, Graham Stuart and Mike Kendall were the responsible supervisory parties.

More recently, Frank Scherbaum helped to fill in some blanks in the history of SAC's distribution. I thank him for fingering back through some dusty filing cabinets finding documents he thought he'd never need to look at again – and frankly, didn't want to.

It was Mike Kendall's suggestion that led to us teaching a course on SAC's use. His administrative duties prevented him from contributing to the book, but he deserves the blame for our increased workload and the credit for the book's inspiration when we try to trace its inception. The course went on the road, and Dave Eaton bravely funded its import and field-testing at the University of Calgary.

Finally, I thank Cheril Cheverton, the better grammarian, for reading through the first draft of the book and making countless useful suggestions despite not knowing the subject at all. That kind of criticism is the best.

George Helffrich, for the authors

Citations for development of SAC should include one or more of these articles:

Goldstein, P., and Snoke, A. (2005). SAC availability for the IRIS community. *Electronic Newsletter*, Incorporated Institutions for Seismology, Data Management Center.

Goldstein, P., Dodge, D., Firpo, M., and Minner, L. (2003). SAC2000: signal processing and analysis tools for seismologists and engineers. Invited contribution to *The IASPEI International Handbook of Earthquake and Engineering Seismology*, ed. W.H.K. Lee, H. Kanamori, P.C. Jennings, and C. Kisslinger. London: Academic Press.