Preface

Spectral analysis is one of the most widely used methods for interpreting time series and has been used in diverse areas including – but not limited to – the engineering, physical and environmental sciences. This book aims to help data analysts in applying spectral analysis to actual time series. Successful application of spectral analysis requires both an understanding of its underlying statistical theory and the ability to transition this theory into practice. To this end, we discuss the statistical theory behind all major nonparametric and parametric spectral analysis techniques, with particular emphasis on the multitaper method, both in its original formulation in Thomson (1982) involving Slepian tapers and in a popular alternative involving the sinusoidal tapers advocated in Riedel and Sidorenko (1995). We then use actual time series from oceanography, metrology, atmospheric science and other areas to provide analysts with examples of how to move from theory to practice.

This book builds upon our 1993 book *Spectral Analysis for Physical Applications: Multitaper and Conventional Univariate Techniques* (also published by Cambridge University Press). The motivations for considerably expanding upon this earlier work include the following.

[1] A quarter century of teaching classes based on the 1993 book has given us new insights into how best to introduce spectral analysis to analysts. In particular we have greatly expanded our treatment of the multitaper method. While this method was a main focus in 1993, we now describe it in a context that more readily allows comparison with one of its main competitors (Welch's overlapped segment averaging).

[2] The core material on nonparametric spectral estimation is in Chapters 6 ("Periodogram and Other Direct Spectral Estimators"), 7 ("Lag Window Spectral Estimators") and 8 ("Combining Direct Spectral Estimators"). These chapters now present these estimators in a manner that allows easier comparison of common underlying concepts such as smoothing, bandwidth and windowing.

[3] There have been significant theoretical advances in spectral analysis since 1993, some of which are of particular importance for data analysts to know about. One that we have already mentioned is a new family of multitapers (the sinusoidal tapers) that was introduced in the mid-1990s and that has much to recommend its use. Another is a new bandwidth measure that allows nonparametric spectral analysis methods to be meaningfully compared. A third is bandwidth selection for smoothing periodograms.

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[4] An important topic that was not discussed in the 1993 book is computer-based simulation of time series. We devote Chapter 11 to this topic, with particular emphasis on simulating series whose statistical properties agree with those dictated by nonparametric and parametric spectral analyses of actual time series.
[5] We used software written in Common Lisp to carry out spectral analysis for all the time series used in our 1993 book. Here we have used the popular and freely available R software package to do all the data analysis and to create the content for almost all the figures and tables in the book. We do *not* discuss this software explicitly in the book, but we make it available as a supplement so that data analysts can replicate and build upon our use of spectral analysis. The website for the book gives access to the R software and to information about software in other languages – see “Data, Software and Ancillary Material” on page xx for details.

Finally, a key motivation for us to undertake an expansion has been the gratifying response to the 1993 book from its intended audience.

The following features of this book are worth noting.

[1] We provide a large number of exercises (over 300 in all), some of which are embedded within the chapters, and others, at the ends of the chapters. The embedded exercises challenge readers to verify certain theoretical results in the main text, with solutions in an Appendix that is available on the website for the book (see page xx). The exercises at the end of the chapters are suitable for use in a classroom setting (solutions are available only for instructors). These exercises both expand upon the theory presented and delve into the practical considerations behind spectral analysis.
[2] We use actual time series to illustrate various spectral analysis methods. We do so to encourage data analysts to carefully consider the link between spectral analysis and what questions this technique can address about particular series. In some instances we use the same series with different techniques to allow analysts to compare how well various methods address questions of interest.
[3] We provide a large number of “Comments and Extensions” (C&Es) to the main material. These C&Es appear at the ends of sections when appropriate and provide interesting supplements to the main material; however, readers can skip the C&Es without compromising their ability to follow the main material later on (we have set the C&Es in a slightly smaller font to help differentiate them from the main material). The C&Es cover a variety of ancillary – but valuable – topics such as the Lomb–Scargle periodogram, jackknifing of multitaper spectral estimates, the method of surrogate time series, a periodogram based upon the discrete cosine transform (and its connection to Albert Einstein!) and the degree to which windows designed for one purpose can be used for another.
[4] At the end of most chapters, we provide a comprehensive summary of that chapter. The summaries allow readers to check their understanding of the main points in a chapter and to review the content of a previous chapter when tackling a later chapter. The comprehensive subject index at the end of the book will aid in finding details of interest.

We also note that “univariate” is part of the title of the book because a volume on multivariate spectral analysis is in progress.

Books do not arise in isolation, and ours is no exception. With a book that is twenty-five years in the making, the list of editors, colleagues, students, readers of our 1993 book, friends and relatives who have influenced this book in some manner is so long that thanking a select few individuals here will only be at the price of feeling guilty both now and later on about not thanking many others. Those who are on this list know who you are. We propose to thank you with a free libation of your choice upon our first post-publication meeting

(wherever this might happen – near Seattle or London or both or elsewhere!). We do, however, want to explicitly acknowledge financial support through EPSRC Mathematics Platform grant EP/I019111/1. We also thank Stan Murphy (posthumously), Bob Spindel and Jeff Simmen (three generations of directors of the Applied Physics Laboratory, University of Washington) for supplying ongoing discretionary funding without which this and the 1993 book would not exist.

Finally, despite our desire for a book needing no errata list, past experience says this will not happen. Readers are encouraged to contact us about blemishes in the book so that we can make others aware of them (our email addresses are listed with our signatures).

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