Time-Series Analysis and Cyclostratigraphy

Examining stratigraphic records of environmental cycles

Increasingly environmental scientists, palaeoceanographers and geologists are collecting quantitative records of environmental changes from sediments, ice cores, cave calcite, corals and trees. These records reveal climatic cycles lasting between one year and hundreds-of-thousands of years, and tidal cycles lasting from half a day to one and a half thousand years. The study of such records is known as cyclostratigraphy and the records themselves, time series. This book uses straightforward explanations of time-series analysis based on numerous original diagrams rather than formal mathematical derivations and equations.

All the main methods used in cyclostratigraphy are covered, including spectral analysis, cross-spectral analysis, filtering, complex demodulation, wavelet analysis and singular spectrum analysis. The problems of distortions of environmental signals during stratigraphic encoding are considered in detail, as are the practical problems of time-series analysis. Finally, there is a summary of the state of research into various types of tidal and climatic cycles and their cyclostratigraphic records. Extensive referencing allows ready access to the literature and the appendix provides a list of sources of computer algorithms.

This book provides the ideal reference for all those using time-series analysis to study the nature and history of sedimentary, climatic and tidal cycles. It is suitable for senior undergraduate and graduate courses in environmental science, palaeoceanography and geology.

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He received a D.Phil from Oxford University in 1987, and has participated in Ocean Drilling Program cruises, off Oman (1987), Brazil (1994) and New Zealand (1998). In 1999 he co-convened a Royal Society Meeting entitled 'Astronomical (Milankovitch) Calibration of the Geological Time Scale'.

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For Alexis and ‘Felix-man’.

Contents

Preface

This book is designed to introduce the main methods used in the examination of quantitative records of ancient environmental changes. Such records are obtained from sources as diverse as the composition of sedimentary rocks, the varying percentages of microfossils and the thicknesses of growth bands in corals. These data sets, or time series, describe environmental changes lasting from half a day to millions of years. The emphasis of the book is on explaining concepts, procedures and problems *not* the details of the mathematics. I have avoided equations and derivations and have instead tried to employ simple diagrams in the explanations. This is because palaeoceanographers, environmental scientists, palaeoclimatologists, sedimentologists and palaeontologists sometimes find it easier to grasp new ideas graphically, rather than through formal mathematical treatments. There are, of course, many texts devoted to mathematical explanations, but this book attempts to explain time-series analysis to non-mathematicians in an accessible form.

Examination of ancient examples of varves and sedimentary cycles linked to orbital-climatic forcing (Milankovitch cycles, explained in Chapter 6) using time-series analysis began in the early 1960s. My own work spans Silurian to Recent cyclic sediments and includes the study of cores from three oceans with an emphasis on orbital-climatic (Milankovitch) forcing (Ocean Drilling Program Legs 117, 154 and 181). However, over the last few years the fastest growth in the use of time-series analysis has been amongst environmental scientists studying short period cyclicity related to phenomena such as El Niño and the Southern Oscillation and millennial-scale cycles and sedimentologists interested in stratigraphic records of tidal cycles. So despite my own perspectives, which have undoubtedly influenced the makeup of the book, I have tried to provide a treatment that is useful to all those interested in time series obtained from a stratigraphic context.

Throughout the book, in addition to demonstrations using artificial time series, I have used an example of a real cyclostratigraphic data set, obtained from British Lower Jurassic strata, to illustrate the major principles. Although this example is not ideal for every situation it does help to understand the procedures described as applied to real data. In several places I have made reference to issues concerned with the processing of sound and electronic digital signals in order to exemplify time series issues from everyday life. I have assumed that the reader is familiar with the concepts of standard deviation, correlation coefficients, moving averages, the normal and chi-squared distributions and covariance (e.g. Williams, 1984; Davis, 1986).

The subject of time-series analysis is full of jargon, so the first use of an important term is placed in **bold** along with the most common synonyms to allow easier reference to other publications. All the computations for the book illustrations used a modest PC running programs based on modifications of the published FORTRAN algorithms listed in the Appendix. Due to their central role, and at the risk of repeating the text, the figures have captions that allow them to almost 'stand alone'. To produce a consistent format all the figures are original and virtually all were created using the package *Microcal* Origin 6.

The intention has been to provide a text that will appeal to many disciplines while recognizing that some material may not appear directly relevant. This book is necessarily only an introduction, but if it helps to encourage new researchers into the field it will have served its purpose.

Graham P. Weedon
February 2002

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