

# A Practical Guide to Wavelet Analysis



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## ABSTRACT

A practical step-by-step guide to wavelet analysis is given, with examples taken from time series of the El Niño–Southern Oscillation (ENSO). The guide includes a comparison to the windowed Fourier transform, the choice of an appropriate wavelet basis function, edge effects due to finite-length time series, and the relationship between wavelet scale and Fourier frequency. New statistical significance tests for wavelet power spectra are developed by deriving theoretical wavelet spectra for white and red noise processes and using these to establish significance levels and confidence intervals. It is shown that smoothing in time or scale can be used to increase the confidence of the wavelet spectrum. Empirical formulas are given for the effect of smoothing on significance levels and confidence intervals. Extensions to wavelet analysis such as filtering, the power Hovmöller, cross-wavelet spectra, and coherence are described.

The statistical significance tests are used to give a quantitative measure of changes in ENSO variance on interdecadal timescales. Using new datasets that extend back to 1871, the Niño3 sea surface temperature and the Southern Oscillation index show significantly higher power during 1880–1920 and 1960–90, and lower power during 1920–60, as well as a possible 15-yr modulation of variance. The power Hovmöller of sea level pressure shows significant variations in 2–8-yr wavelet power in both longitude and time.

## 1. Introduction

Wavelet analysis is becoming a common tool for analyzing localized variations of power within a time series. By decomposing a time series into time–frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time. The wavelet transform has been used for numerous studies in geophysics, including tropical convection (Weng and Lau 1994), the El Niño–Southern Oscillation (ENSO; Gu and Philander 1995; Wang and Wang 1996), atmospheric cold fronts (Gamage and Blumen 1993), central England temperature (Baliunas et al. 1997), the dispersion of ocean waves (Meyers et al. 1993), wave growth and breaking (Liu 1994), and coherent structures in turbulent flows (Farge 1992). A

complete description of geophysical applications can be found in Fourfoula-Georgiou and Kumar (1995), while a theoretical treatment of wavelet analysis is given in Daubechies (1992).

Unfortunately, many studies using wavelet analysis have suffered from an apparent lack of quantitative results. The wavelet transform has been regarded by many as an interesting diversion that produces colorful pictures, yet purely qualitative results. This misconception is in some sense the fault of wavelet analysis itself, as it involves a transform from a one-dimensional time series (or frequency spectrum) to a diffuse two-dimensional time–frequency image. This diffuseness has been exacerbated by the use of arbitrary normalizations and the lack of statistical significance tests.

In Lau and Weng (1995), an excellent introduction to wavelet analysis is provided. Their paper, however, did not provide all of the essential details necessary for wavelet analysis and avoided the issue of statistical significance.

The purpose of this paper is to provide an easy-to-use wavelet analysis toolkit, including statistical significance testing. The consistent use of examples of

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In final form 20 October 1997.

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**Yi-Tong Ma**



## **A Practical Guide To Wavelet Analysis:**

A Practical Guide to Wavelet Analysis, 1996 Presents information on wavelet analysis compiled by Christopher Torrence and Gilbert P Compo for the University of Colorado at Boulder Program in Atmospheric and Oceanic Sciences PAOS Includes a FAQ section an online article an interactive wavelet plot and links to related Web sites Wavelets in Medicine and Biology Akram Aldroubi, Michael Unser, 1996-04-24 Considerable attention from the international scientific community is currently focused on the wide ranging applications of wavelets For the first time the field's leading experts have come together to produce a complete guide to wavelet transform applications in medicine and biology Wavelets in Medicine and Biology provides accessible detailed and comprehensive guidelines for all those interested in learning about wavelets and their applications to biomedical problems **The Illustrated Wavelet Transform Handbook** Paul S Addison, 2002-07-15 The Illustrated Wavelet Transform Handbook Introductory Theory and Applications in Science Engineering Medicine and Finance provides an overview of the theory and practical applications of wavelet transform methods The author uses several hundred illustrations some in color to convey mathematical concepts and the results of applications The first chapter presents a brief overview of the wavelet transform including a short history The remainder of the book is split into two parts the first part discusses the mathematics of both discrete and continuous wavelet transforms while the second part deals with applications in a variety of subject areas such as geophysics medicine fluid turbulence engineering testing speech and sound analysis image analysis and data compression These application chapters make the reader aware of the similarities that exist in the use of wavelet transform analysis across disciplines A comprehensive list of more than 700 references provides a valuable resource for further study The book is designed specifically for the applied reader in science engineering medicine finance or any other of the growing number of application areas Newcomers to the subject will find an accessible and clear account of the theory of continuous and discrete wavelet transforms providing a large number of examples of their use across a wide range of disciplines Readers already acquainted with wavelets can use the book to broaden their perspective

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