GEOL525-CLIM759 – MODELING EARTH SIGNALS AND SYSTEMS
FALL 2019

Description: This graduate course provides instruction on time series analysis customized for modeling Earth signals and systems. Concepts will be described and applied to time series data sampled from natural processes to address a variety of scientific problems. Prerequisites: calculus, probability and statistics, and matrix algebra; or permission of instructor [3 credits].

Suggested textbooks: *Climate Time Series Analysis: Classical Statistical and Bootstrap Methods. Second Edition (2014),* by Manfred Mudelsee, Springer, Cham, 454 pp.; *Spectral Analysis for Physical Applications (1993)*, by Donald B. Percival and Andrew T. Walden, Cambridge, 583 p.; *Digital Signal Processing: an Interactive Approach (2008)*, by Andreas Spanias, Arizona State University, 326 p.; *Spectral Analysis and Time Series, Volumes I and II (1983),* Maurice B. Priestley, Academic Press, San Diego, 890 p.; *The Fourier Transform and Its Applications, 3rd Edition (2000),* Ronald N. Bracewell, Mc Graw-Hill, Boston, 616 p.; *Time Series Analysis and Its Applications: With R Examples*, *2nd Edition (2006)*, by Robert H. Shumway and David S. Stoffer, Springer-Verlag New York, 575 p.; *The Scientist and Engineer's Guide to Digital Signal Processing (2011),* by Steven Smith, http://www.dspguide.com/pdfbook.htm.

Requirements: 10 assignments (50%); independent project (50%).

Class time and place: Wednesdays, 1:30 pm to 4:10 pm, 1005 Exploratory Hall

SYLLABUS:

WEEK 1—INTRODUCTION TO SIGNALS AND SYSTEMS IN EARTH PROCESSES

Weds, Aug. 28

Objective: Discuss time-variable natural processes in the human experience, e.g., climate change, Earth-space orientation, earthquakes, geodynamo, solar irradiance, river flow, ocean tides, circadian rhythms, acoustics, etc.; and by what means we can interpret, understand and anticipate the time-dependent behavior of these processes.

Assignment: BASIC SIGNALS I (convolution; linear systems; real and complex signals)

WEEK 2—MODELING TIME SERIES AND SYSTEMS

Weds, Sep. 4

Objective: Time series data representing natural processes are normally presented in a discretized format. The creation and treatment of these series requires understanding theoretical and practical constraints in the processing and analysis of discrete-time signals.

Assignment: BASIC SIGNALS II (autoregressive models, Yule equations, the Fourier transform)

WEEK 3—THE Z-TRANSFORM

Weds, Sep. 11

Objective: The Z-transform is a powerful tool for representation of time-dependent signals and for filter design. This class will be spent introducing the Z-transform and basic applications.

Assignment: Z-TRANSFORMS (Z-transforms of discrete time sequences; DTFT; poles and zeros)

WEEK 4—FIR FILTERS

Weds, Sep. 18

Objective: Filters are important tools for isolating specific frequency components in signals for detailed examination. Finite impulse response filters are stable with linear phase responses and no poles. Their design is straightforward and will be explored first.

Assignment: FIR FILTER DESIGN (Bode plots; linear phase filters and frequency sampling)

WEEK 5—IIR FILTERS

Weds, Sep. 25

Objective: Infinite impulse response filters are adaptations of analog filters with digital approximations; while they offer high efficiency implementation, they can be unstable if their poles cross the unit circle.

Assignment: IIR FILTER DESIGN (Application of the Butterworth filter)

WEEK 6—SAMPLING

Weds, Oct. 2

Objective: Sample rate is a basic issue with natural data, especially deep-time Earth data with uncertain time scales (independent variables), or data that cannot be collected at strict uniform time spacings. This class discusses issues related to resampling data, and pitfalls that can arise.

Assignment: SIGNAL SAMPLING (Discrete sampling, aliasing and gaps)

WEEK 7—POWER SPECTRAL ANALYSIS

Weds, Oct. 9

Objective: The keystone of time series analysis is the power spectrum, i.e., the distribution of time signal variance as a function of frequency. This class introduces the power spectrum and its estimation.

Assignment: POWER SPECTRUM ESTIMATION (Harmonic analysis; the power spectrum)

WEEK 8—STATISTICS OF THE POWER SPECTRUM

Weds, Oct. 16

Objective: Estimated power spectra suffer from a variety of problems, including accuracy and frequency resolution. Understanding spectrum statistics and the effects of sample rate and windowing is important for optimizing spectral analysis.

Assignment: OPTIMIZING POWER SPECTRA (Windowing statistics; multi-tapers)

WEEK 9—HYPOTHESIS TESTING AND NULL MODELS

Weds, Oct. 23

Objective: The question of what is signal and what is noise is often asked of natural data. The frequency domain is commonly used to assess bands of concentrated power with non-random variance (signal) and the “background continuum” of random variation (noise). Common approaches to evaluating this problem will be introduced by way of hypothesis testing.

Assignment: SIGNAL-TO-NOISE ESTIMATION (spectral noise models; harmonic F-testing)

WEEK 10—PERSISTENCE MODELS

Weds, Oct. 30

Objective: Recognition of the importance of system “memory” has motivated development of parametric models to quantify time persistence in process noise. These include autoregressive, long-term “Hurst” and non-linear models that can be interpreted directly or leveraged further, e.g., for estimating uncertainty.

Assignment: PERSISTENCE TIME ESTIMATION (autoregressive modeling)

WEEK 11—COHERENCY ANALYSIS

Weds, Nov. 6

Objective: Multivariate time series analysis involves comparing two or more signals that are hypothesized to have a relationship. This class addresses cross-correlation analysis in the time and frequency domains, and explains the statistics and hypothesis testing used to measure how signals are related to each other.

Assignment: EXCITATION/RESPONSE MODELING (coherency and cross phase, and transfer functions)

WEEK 12—POLYSPECTRA

Weds, Nov. 13

Objective: Nonlinear signals can be diagnosed using higher order spectra to identify correlated frequencies, suppress noise and characterize phase and magnitude responses. The third order spectrum and its applications will be featured.

Assignment: NONLINEAR SIGNALS (bispectral analysis)

WEEK 13—TIME-FREQUENCY METHODS

Weds, Nov. 20

Objective: Time series of natural systems may "drift", and their frequencies and magnitudes can change, slowly or suddenly, e.g., seismograms, paleo-climatic series. Other systems may have quasi-periodic or other non-stationary attributes. This requires application of methods that track time-frequency changes along time series; three approaches will be discussed.

Assignment: NONSTATIONARY SIGNALS (spectrograms, wavelets, quadrature signals)

WEEK 14—ADVANCED SPECTRUM MODELING

Weds, Nov. 27

Objective: Natural data do not necessarily conform to analytic statistics (e.g., the Normal distribution) assumed by many spectral estimators and modeling parameters. Therefore, empirical methods must be developed to test the significance of estimated spectra; we will explore three well-known approaches.

Assignment: BOOTSTRAPPING, JACKKNIFING AND MONTE CARLO MODELING