Research Projects

My current research focuses on the analysis of climate data records and the use of climate data in improving and testing low complexity climate models, particularly for paleoclimate – prehistoric climate. Some of the specific projects are listed below.

The climate of the Pleistocene era, 2.5 Myr ago to 12 kyr ago, is characterized by long period oscillations between cold ice ages and warm interglacial states. The time scales and shapes of these glacial cycles are determined by a complex relationship between the variations in the Earth's orbit around the sun (called astronomical forcing) and the internal dynamics of various components of the Earth's climate system (such as atmospheric CO_2, strength of 3D ocean circulation, and large land-based ice sheets.) Roughly 1.2 Myr ago, the oscillations changed from relatively shallow ice ages with interglacials occurring at approximately 41 kyr intervals to deep ice ages with the interglacials only occurring at approximately 100 kyr intervals; this is known as the Mid-Pleistocene Transition (MPT). The physical mechanism for the existence of 100-kyr cycles and the cause of the MPT are poorly understood and there are many proposed hypotheses based on combinations of various physical processes and astronomical forcing. One way to test such hypotheses is to construct low-complexity models (conceptual model) based on a hypothesis, analyze the model (including running simulations exploring the model parameter space) and validate the model against observations. Unfortunately, we have very limited amounts of data, so it is necessary to carefully analyze the data to extract as much information from the sparse data records.

I have two potential projects in this area plus one project focused on improving a time series analysis technique. Most of these are inherently interdisciplinary projects, so a background in all the pertinent components is not expected. Student researchers will be trained as needed.

1. **Analysis of paleoclimate records and validation of conceptual models for the Pleistocene glacial cycles.**
   Use traditional and modern time series analysis techniques to analyze ocean sediment and ice core records to determine key characteristic features of the Pleistocene glacial cycles over the MPT. Use the extracted information to both tune (parameter estimation) and validate one or more conceptual models of the MPT paying careful attention to keeping the information for both tasks independent – thereby avoiding circular reasoning. This project involves a combination of physics, mathematics and statistics with some degree of scientific programming. In particular, many of the conceptual models are based on forced, coupled ODEs, so a background in dynamical systems is useful.
   Most suitable for students in MATH or PHYSICS.
   Required background: introductory differential equations (MATH 242, 244, 344), introductory physics, introductory statistics, familiarity with basic programming - *eg.*, Matlab.
   Useful background: time series analysis (STAT 416), dynamical systems (MATH 416, PHYS 417)

2. **Response of glacial cycle models to various forms of external forcing.**
   Analysis of existing conceptual models for the MPT and their response to various forms of external forcing such as periodic, quasi-periodic and realistic astronomical forcing. This involves analysis of the unforced models plus suites of simulations to explore their forced behavior. This project requires a deeper analysis of the dynamical system models than the previous project, so a stronger math background is expected.
   Most suitable for students in MATH or PHYSICS.
   Required background: introductory differential equations (MATH 242, 244, 344), introductory physics, familiarity with basic programming - *eg.*, Matlab
   Useful background: dynamical systems (MATH 416, PHYS 417)

3. **Improving Empirical Mode Decomposition**
   Ensemble Empirical Mode Decomposition (EEMD) is a modern time series analysis technique which is well suited for analyzing noisy data sets such as climate records. It is a data-adaptive, noise-assisted, nonlinear technique. As such, it avoids many of the artifacts of linear, projective techniques such as Fourier and Wavelet analysis and therefore often provides a more physically interpretable analysis. It is particular well-suited for extracting information from noisy time series which are formed by multiple processes acting on disparate time scales. However, when analyzing smoother time series such as the output from simple models, it does exhibit some mathematic artifacts which impede the interpretation of the decomposition. This project entails exploring modifications to EEMD to remove or ameliorate the effect of these artifacts. For example, EEMD currently uses averaging over a suite of analyses of the data plus additive white noise. What is the effect of using red noise instead?
   Most suitable for students in MATH or STAT.
   Required background: introductory statistics, familiarity with basic programming - *eg.*, Matlab.
   Useful background: time series analysis (STAT 416)