# The Application of the Empirical Mode Decomposition and Hilbert Spectral Analysis to Field Data and Future Experimental Designs

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## LONG-TERM GOAL

Our long term goal is to develop a data analysis tool for data from nonstationary and nonlinear processes. The traditional data analysis methods are limited to either stationary or linear processes, or both linear and stationary processes. Unfortunately, natural phenomena are mostly nonstationary and nonlinear. The existing methods can offer little help. Our long term goal is to fill this gap so that we can contribute to our understanding of the dynamics of physical natural phenomena in general and ocean phenomena in particular.

## OBJECTIVES

Our understanding of the natural phenomena comes mostly through direct observations.
For ocean phenomena that are most generated by nonstationary, and nonlinear processes the need is most urgent, for the observation is very costly; therefore, the number is limited. What can we learn from the limited observations through analysis the field data that we can design future field experiments more effectively and satisfactorily is the objective of this study. Here, we cannot use methods developed based on the linear and stationary assumptions. Our objectives here are to extract the characteristic time scales from field data to define the dynamics of the phenomena, so that we can study the coupling of the wind and current fields; calculate the statistics of the data for validation of model results; explore the utilization of the method to other coastal applications; and develop the method as a tool for design future field experiments.

## APPROACH

The tasks of this study are primarily on the data analysis methodology development. We will concentrate on the development of the Hilbert-Huang Transform. The HHT method introduced by Huang et al. (1998, 1999) has proved to be a powerful method in analyzing nonstationary and nonlinear data. Ever since its introduction, many applications have been found (Huang, 2001; Huang et al. 1998a, 1999a, 2000, 2001; Gloersen and Huang, 1999; Loh, et al., 2001; and Wu et al., 1999) that included analyzing acoustic, biological, ocean, earthquake, climate, and mechanical vibration data. Versatile as it is, the method still has a number of vexatious features: The first is the uniqueness, which arises from the free parameters to be selected in the sifting process. The second is the lingering question on the definition of instantaneous frequency and the method in deriving it. Therefore, to make the method more robust and rigorous, we have to remove the uncertainties in the sifting process by

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14. ABSTRACT
**Our long term goal is to develop a data analysis tool for data from nonstationary and nonlinear processes. The traditional data analysis methods are limited to either stationary or linear processes, or both linear and stationary processes. Unfortunately, natural phenomena are mostly nonstationary and nonlinear. The existing methods can offer little help. Our long term goal is to fill this gap so that we can contribute to our understanding of the dynamics of physical natural phenomena in general and ocean phenomena in particular.**

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establishing a statistical measure for the results, and to define the instantaneous frequency more precisely by introducing a fidelity index. These improvements are urgently needed.

Once the methodology is developed, we will use the method to extract the characteristic time scales from field data to define the dynamics of the phenomena. In this step, we will separate the tidal scale from the non-stationary meteorological cycles. In this se-tided data set, we will study the coupling of the wind and current fields to establish the generation and relaxation of the wind induced current field. Then we will calculate the statistics of the data for validation of model results, and to explore the utilization of the method to other coastal applications. Finally, we will use the sum of this knowledge to define a methodology for future field experimental design based on limited data sets.

## WORK COMPLETED

In this study we have developed a method to establish just such a confidence limit as a statistical measure of the fidelity of the result without invoking the Ergodic assumption. We have used the vexing features of uncertainties in the sifting process to our advantage by utilizing the judiciously selected sifting parameters to produce a range of possible results that still retain the most physically meaningful characteristics. We have thus created an artificial ensemble of results from a single set of data. Then, we were able to take the ensemble mean of the results, which is a function of time. The non-stationary characteristics of the data and are preserved in the results. Thus we have turned the vexatious uncertainty of the sifting process mentioned earlier to a constructive end: the establishment of a confidence limit for the Empirical Mode Decomposition result.

Together with Dr. Ronald Lai of MMS, we have extract field data from the Gulf Satations on current vectors and wind. We have also developed methods to extract time scale of tides, wind epsoides, and longer term drifts. Additionally, we have developed the methods to extract the direction and the phase of the current vectors to make comparisons on the depth dependent wind responses. A mauscript is near complete for submission.

## RESULTS

Sifting is a general method of decomposing a given data set. With the variations of selective parameters in the sifting process, we can almost generate infinitely many IMF sets, or at least as many as we want. Those soft conditions are the vexing features of the EMD HSA method. Over the last year, we have utilized those soft conditions in a constructive way to examine data: the introduction of a statistical measure of the confidence limit from a single set of nonstationary and nonlinear data without invoking the ergodicity assumption. With the help of the newly introduced notation for the sifting results, this statistical measure has helped to make the sifting process more definitive. Also by extracting information from the envelope of IMF functions, we have given the IMFs a new significance in data analysis. We have also introduced a fidelity index for the instantaneous frequency determination through Hilbert Transform. Furthermore, we have also devised an LPC method to mitigate the end effects. With these additions and improvements, we have increased the rigor of the Empirical Mode Decomposition and Hilbert Spectral Analysis method, thus also made it more useful.

Meanwhile, we have also test the data analysis methodology on various data sets that including the whether phenomena, ploar ice coverages, earthquakes, and bio-engineering. In every case, we found new insights into the mechanism through the detailed time-frequency-energy presentation of the data.

Results are published in several papers by me and my colleagues. I feel confident that the methodology is ready for coastal oceanography applications.

## IMPACT/APPLICATION

The methodology developed for this study is also applicable to a wide range of other problems. And the method was awarded the NASA Space Act Award 1998 in the *exceptional* category. The NASA Headquarters Inventions and Contributions Board cited that this new method of data analysis has turned out to be “one of the most important discoveries in the field of applied Mathematics in NASA history." This new method is expected to provide a more accurate result for analyzing nonlinear and nonstationary data than the classical Fourier method of spectral analysis. The application is to be far beyond the oceanography applications. HHT has been patented by NASA, and for this invention, the PI was also awarded the 1999 Federal Government Technical Leadership Award; 2001 Federal Laboratory Consortium Technology Development Award, and 2001 R&D 100 Award. Based on his contribution in the field of nonstationary and nonlinear data analysis, he was elected as a member of the National Academy of Engineering, 2000.

## TRANSITIONS

The method has been patented by NASA in four different patents. The first one has just been granted. A licsense is been neigotiated with a private to market the Hilbert Spectral analysis package. A software package is available through Goddard Commericialization Office for lincse and also under Space Act Agreement. Over 70 Universities and Federal Laboratories have tried out the algorithm for various research problems.

## RELATED PROJECTS

1. Speech and sound study. Supported by NASA SRT program and working with colleagues here and NIST, I have developed a method on analysis of sound and speech with an extension for machine health monitoring. These again area problems of scale extraction.

2. Supported by NASA, I have also engaged in earthquake engineering, and financial market data analysis.

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