Society for Industrial and Applied Mathematics

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Extreme Learning

Big Idea. Extreme weather events are the visible effects of a changing climate. We propose to develop and apply novel mathematical and statistical techniques to capture, characterize and predict extreme events. We need: (1) more data on extreme meteorological events; (2) input from meteorological subject matter experts to identify particular types of extremes; and (3) new mathematical algorithms that can quantify the likelihood of particular extremes given a non-stationary background.

Reasoning and Justification. Adapting our infrastructure to extreme weather events of ever-increasing severity and frequency requires a much better understanding of the statistics and dynamics surrounding them. We have limited data on past and current extremes and an incomplete representation of the climate system within which extremes form. We lack mathematical approaches that can incorporate and account for a non-stationary (or unstable) climate from which extremes can develop, as well as ways to describe and measure extremes that would occur after a climate has reached a tipping point. Advances in these areas require investigations along multiple pathways: (1) loss functions that better match predictions with observed extreme behavior; (2) improved stochastic optimization techniques; (3) new approaches to bypass the 1/p number of samples required by brute-force numerical simulations; (4) new statistical models that account for a lack of stationarity in space and time as well as the fat-tail behavior of the marginal distributions; and (5) new research in copula approaches informed by machine learning.

Requirements. There are three main requirements: (1) more data for extreme weather events; (2) stakeholder input to identify particular types of extreme events; and (3) new mathematical algorithms that can quantify the likelihood of particular extremes (or tail events) given a non-stationary background. This research thrust will determine data sources and needs for future data collection efforts and assess the quality of existing data. This program requires stakeholder meetings, including with infrastructure planners and operators, to identify initial types of extremes for focus. The program requires fundamental advances in mathematics and statistics that accurately predict extremes - averages as well as variances - under a non-stationary background. Computing and data storage needs will be significant for the project. Transdisciplinary collaborations between climate scientists, meteorologists, mathematicians, statisticians, and computer scientists and with users of extreme weather forecasts - industry, state and local decision makers, engineers, and social scientists.

Value and Impact.

- Tools and approaches will be developed to map out climate scenarios in greater detail, focusing on rare but powerful events that have the largest impact on human wellbeing and on ecosystems.
- Interdisciplinary training in mathematics, various domain sciences, computer science, computational science and engineering, data science, and statistics, including aspects of business, economics, social science, political science, architecture, information science, etc.
- Climate extremes are global, fostering cooperation with researchers outside the U.S. is essential. Partnerships with industry should be encouraged.
- With accurate predictions of alternative scenarios and anticipated catastrophic events and possible cascading effects, decision making and intervention at multiple scales can be prioritized.

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