Physical-Statistical Modeling and Prediction

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Two powerful formulas have been available to scientists for more than two centuries: Newton's Second Law, providing a foundation for classical physics, and Bayes's Theorem, prescribing probabilistic learning about unknown quantities based on observations. For the most part use of these formulas has been separated, with Newton being the more dominant in geophysics. In the presence of uncertainty and complexity, this separation appears untenable, though there are a variety of difficulties in implementing Bayesian analysis in complex settings. However, recent advances in both modeling strategies and computational tools have contributed to a significant change in the scope and feasibility of Bayesian analysis. I discuss the Bayesian framework for analyzing physical problems. This paradigm provides opportunities for the combination of physical reasoning and observational data in a coherent analysis framework, but in a fashion which manages the uncertainties in both information sources. A key to the modeling and prediction is the hierarchical viewpoint in which separate statistical models are developed for the process variables studied and the observations conditional on those variables. Modeling process variables in this way enables incorporation of physics across a spectrum of levels of intensity ranging from qualitative use of physical reasoning to strong reliance on numerical models. Selected examples from this spectrum are reviewed. Depending upon time, these include approaches to analysis of near-surface ocean wind fields, forecasting Pacific sea-surface temperatures, and glacial dynamics.