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Governing Dynamic Laws of Spatiotemporal Predictability and Uncertainty under Synergistic and Coevolutionary Uncertainty Sources

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Predictability and uncertainty assessments of dynamic models are traditionally made on an exploratory basis, often by running the particular model of interest with randomly perturbed initial/boundary conditions and parameters, and producing computationally expensive ensembles relative to which uncertainty metrics are computed. These traditional approaches provide a lumped view of uncertainty evolution, without explicitly eliciting the role of fundamental processes and interactions at play in the uncertainty dynamics.

In order to address these limitations, a systematic dynamical framework is hereby introduced for forecasting spatiotemporal uncertainty evolution and assessing dynamic predictability in general complex systems without a predefined structure.

For that purpose, the present study builds from the author's advances in theoretical physics to analytically derive general governing equations of uncertainty dynamics and predictability in terms of the fundamental nature of dynamical systems and underlying uncertainty sources, independent of any particular problem under consideration.

The analytical formulation hereby obtained relates multiple uncertainty sources, along with their synergistic and coevolutionary interplay, with the intrinsic dynamic principles underlying the system, enabling a comprehensive and explicit analytical treatment of uncertainty dynamics along space and time, without requiring numerical integration of exploratory model ensembles.

In doing so, computational resources are freed and a quick and effective a-priori systematic dynamic evaluation is made of predictability evolution and its challenges, including aspects in the model architecture and intervening terms that may require optimization ahead of initiating any model runs for operational purposes.

Moreover, the framework brings out universal statistical and dynamic features in the error dynamics elusive to any case specific treatment, shedding further light on the challenging issue of predictability.

The formulated approach, framed with broad mathematical physics generality in mind, is then implemented in dynamic models of nonlinear geophysical systems with various degrees of complexity, in order to evaluate their limitations and provide informed assistance on how to optimize their design and improve their predictability in fundamental dynamical terms.