ABSTRACT

Quantifying the predictability limits of complex geophysical systems such as the atmosphere is crucial for understanding the possibility of reliably predicting their future states. However, earlier studies dealing with the predictability of atmospheric fields frequently neglect intermittency and anisotropy, which are typical features of such fields, especially in the storm-scale regime. Motivated by this lacuna, the present work uses a correlation spectra-based approach to analytically express the predictability limits of atmospheric fields as a function of their multifractal and anisotropy parameters. Subsequently, the thesis utilizes this expression to theoretically investigate the impact of spatial anisotropy of a field on its predictability. The investigation suggests that for horizontal wind fields, the interplay between spatial-anisotropy and atmospheric predictability could account for the better predictability of rotating thunderstorms and Indian summer monsoon breaks. The thesis then generalizes this analytical expression for theoretical predictability limits via higher-order autocorrelation functions to explore the entire range of multifractal singularities. Further analysis using this generalized expression reveals that reliable storm-scale forecasting with around three to five hours lead time on average is theoretically possible, advocating optimism in the future of strategic aviation weather forecasting required to mitigate airspace delays caused by storm-scale convective weather. Moreover, the thesis empirically estimates spheroscales during convective weather over northeast India using reflectivity data from CloudSat orbiting radar. These estimates are further utilized to make a semi-empirical estimate of the storm-scale atmospheric predictability over northeast India and thereby illustrate that atmospheric fields with larger spheroscales are less predictable, in agreement with the theoretical conclusions. Having demonstrated the pivotal role of spatial anisotropy in the predictability of geophysical fields, this thesis finally aims at cost-effectively simulating such turbulent and turbulent-like fields in an anisotropic scale-invariant continuous-in-scale multifractal framework approaching the theoretical predictability limits, for practical applications. The thesis attempts to do this via a combination of generalized singularity correction methods and nesting techniques to attenuate the deviation of simulation statistics from the theoretically expected multiscaling behavior. Subsequent statistical analyses indicate a significant reduction in computational cost, suggesting that nested singularity-corrected cascades offer an attractive framework for quantitatively modeling geophysical systems and associated fields.

Keywords: Complexity, Chaos, Uncertainty, Storm-scale atmospheric predictability, Multifractals, Emergent laws of turbulence.