Complexity in climate science: nonlinear dynamics, emergent properties, and the necessity of systems thinking

Most global systems are inherently complex, consisting of multiple interacting sub-units. Scientific attempts to model these complex systems in isolation, often along distinct disciplinary lines, generally produce internally stable and predictable behavior. However, real-world coupling between sub-systems can cause sets of interacting systems to exhibit new collective behaviors—called ‘‘emergent properties’’—that may not be clearly demonstrable by models that do not include such coupling. Such is the case with the climate system.

Furthermore, changes in climate can have far-reaching implications for human welfare and the health of the biosphere. Human-induced climate change involves interactions between complex global geophysical, biological, social, and economic systems. Systems concepts, principles, and methods are essential to understanding the climate system and the dynamics of human-induced climate change. In this chapter, we propose to review concepts and issues related to complexity in the climate system and its interactions with other natural and human systems, including:

--Nonlinearity and threshold behavior

--Multiple equilibria

--Path-dependence and irreversibility

--Predictability and chaotic dynamics

--Emergent properties of coupled systems

--Detail vs. breadth, which provides more information about complex systems?

We propose to discuss these topics and their relevance to climate science by providing specific illustrative examples while emphasizing the fundamental theoretical issues involved. Our discussion will focus on the importance of systems thinking for modeling the climate system and human-induced climate change, and as requested, will also incorporate examples from medical treatment where appropriate, such as the nature of exponential growth swamping initial conditions and the need to supplement a frequentist approach (clinical trials) with a more decision analytic framing, such as Bayesian updating and process-based modeling.