Bi-Co Mathematics Colloquium & Young Academic Alumni Lecture Series

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“Challenges in predicting future weather and climate: turbulence, chaos, and (un)predictability”

Monday, November 21, 2022
Talk at 4:00 – Hilles 109
Tea at 3:30 – Foyer outside of H109

Abstract:

Climate change caused by human-emitted greenhouse gases poses an existential challenge for society in the 21st century and beyond. Accurate predictions of the future are necessarily not only to justify climate mitigation efforts (e.g. phasing out fossil fuels in favor of renewable energy), but also for adapting to climate impacts that are already here or are coming down the pipeline (e.g. by relocating low-lying coastal communities or making air conditioning more accessible). Statistical models are not well equipped for extrapolating historical trends into an unknown future. A more reliable approach is to leverage physical conservation laws (e.g. Newton’s F=ma) to build dynamical Earth system models consisting of many coupled partial differential equations that can be integrated forward in time. For complex systems like Earth’s climate, these systems of equations are far too complicated to solve analytically, so we must instead resort to numerical computations of their discrete approximations. The biggest supercomputers on the planet allow Earth’s surface to be chunked up into millions of discrete pixels of about 10km by 10km; starting from the past or present, the state of Earth’s climate can then be integrated forward in time indefinitely, one hour at a time. In practice, this exercise is further complicated by the turbulent nature of the atmospheric and oceanic flows, which couples millimeter-scale vortices to global-scale winds and currents through a cascade of non-linear cross-scale interactions. Much of modern weather and climate modeling consists of developing new and improved ways to convert these complex cross-scale turbulent flow interactions into programmable algorithms; I will give a couple of examples of this from my own work.

In the 1960s, the first efforts to use these kinds of numerical models to predict changes in the weather just a few days in advance were thwarted by an annoyingly sensitive reliance on initial conditions—hence the discovery of *chaos*, a.k.a. “the butterfly effect”. While modern numerical weather forecasts can now reliably predict the weather up to a week in advance, turbulence-induced chaos fundamentally limits deterministic weather forecasts to an upper bound of just two weeks. How, then, can we justify using predictions of climate several decades in the future to inform era-defining transformations to industrial policy? The answer is that climate is not weather, but rather the *statistics* of weather. Predicting the statistics of weather many years in the future may still be an enormous challenge, but at least it not impossible. Indeed, I will show that even the earliest attempts at predicting human-caused climate change (from the 60’ and 70’s) were successful in predicting the rough magnitude and pattern of global warming. I will then fast-forward to the present and summarize our ongoing efforts at NOAA’s Geophysical Fluid Dynamics Laboratory to develop a next-generation computational model for climate prediction. Finally, I will conclude by sharing that climate science is an active and growing field in the academy and both the public and private sector, and is in need of students with both a deep mathematical training and a broad liberal arts perspective.

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