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The Problem with Global Climate Change

At present, global climate change is a topic at the center of many discussions and a cause of many debates between both scientists and laypersons. This, therefore, has called for scientific research and experimentation to focus on developing more accurate long-term models of the climate. It was the work of Edward Lorenz that revealed the chaotic behavior of the weather when he endeavored to model weather patterns through his toy version of the weather using a Royal McBee computer. Furthermore, Synoptic and dynamic meteorologists now hold their respective thoughts and approaches to analyzing the complexity of local weather patterns as they relate to global patterns. In weather forecasting, the challenge is making accurate predictions on short time scales predictions that can be sustained as time progresses. However, Lorenz (1995) discovered "in systems like the weather, sensitive dependence on initial conditions was an inescapable consequence of the way small scales intertwined with large." By simulating the complex behavior of the weather on the computer through twelve dynamic variables represented by twelve dynamic equations, he discovered a link between aperiodicity and unpredictability. This has given rise to the concept that weather patterns move along chaotic orbits, which cross a particular set of points in phase space. Yet, the dynamic equations that represent the behavior of the weather as a complex dynamical system do not prohibit *any* atmospheric state, realistic or unrealistic, from being an *initial* state in a solution. Since the various solutions of the equations all converge toward a special set of states, the realistic ones, it is apparent that these states lie on an attractor. Lorenz (1995) further aligns this with the relationship between weather and climate when he states, "As Poincare recognized, dynamics on an attractor is *recurrent*. That is, the state of the system repeatedly comes close to every point of the attractor, and in particular returns close to any previous state."

The ability to identify the recurrent dynamics of the weather during each year indicates that it is on a single attractor, "the one that we recognize by its texture as 'normal weather patterns'" (Stewart, 2002). With this in mind, the term that captures the phrase 'texture of normal weather patterns' is *climate*. This means, then, that the weather is a complex dynamical system that converges toward a special set of states on the climate attractor, which governs the interdependency of local and global weather patterns. If Lorenz's redefinition of a chaotic system (1995) in which the values of at least one virtual constant can be altered, 'one that is sensitively dependent to *interior* changes to initial conditions,' is applied to the pervasiveness of complex weather patterns within a deterministic climate, the complications of global climate change become clear. Though the future recurrence of similar states reveals chaotic behavior of the weather adheres to deterministic laws, it is difficult to determine the state of the system on longer time scales when the combined effect of interior and exterior changes is obscure. It is critical to add that the alteration of the constant within this system will create yet another chaotic system, which is separate from its predecessor. Therefore, investigating this issue is significant because "there is a good case for identifying 'climate' with 'attractor', and if we do, then what we are discussing now is climate change' (Stewart, 2002). The fact is, in normal circumstances it is safe to predict that even after a random disturbance the system will return to its attractor. However, in the real world, the interior conditions of the weather are affected by the massive build-up of human-made greenhouse gases such as carbon dioxide. In understanding that dynamical systems can have more than one attractor and exterior changes larger than the flapping of a butterfly's wings might be capable of switching weather patterns from one attractor to another, the impact humanity can have on the environment becomes apparent. The main difference between the combined effect of butterflies in flight and the combined effect of human beings leading normal lives is that the former might change the timing of events, while the latter has the potential to change the range of possible events that can occur.

The inability to determine the extent of the impact the release of human-made greenhouse gases into the atmosphere is having on global climate stems from speculation that the weather assumes specific sets of states on a *strange* attractor. Research published by Kaustubha Bhattacharya (1993) in the Journal of Earth System Science indicates, "Time series of proxy data representing long-term variation of the terrestrial climate presumably show aperiodic changes, which has given rise to the hypothesis that the dynamics of the earth's climate is governed by a strange attractor." The discovery of aperiodicity implies chaotic orbits in phase space that are physically represented by irregular fluctuations in climate over long periods that are impossible to predict with accuracy. Bhattacharya (1993) explains that in order for experts to begin to make adequate climate predictions a comprehensive search for glaciation cycles of the planet is essential. He expounds on this prospect by stating, "However, that dream has remained elusive due to the aperiodic nature of the climate time-series–a result of non-linear instabilities in the terrestrial climate system." This statement provides further reasoning behind the declining accuracy of weather predictions as a time scale extends further into the future by revealing that 'the future course of every state, regardless of whether it is a state of equilibrium, will differ more and more from the future courses of slightly different states' (Lorenz, 1995). In connecting this to the characterized sensitive dependence to initial conditions of chaotic systems, weather patterns will still adhere to deterministic laws, but exterior changes to the state of the system at any particular point has the ability to shift the climate to another attractor and, in turn, change weather patterns. This climate change is being called global warming, but freelance writer Tom Konrad (2011) who focuses on climate change as investment themes argues, "A better description is 'Global Weirding:' the climate is not becoming a warmer version of what we're used to, it's becoming an entirely new system, with a new set of patterns that will surprise anyone expecting a version of the old climate regime." He also remarks that the past may not necessarily be a reliable guide to the future, which is in line with the climactic irregularities of the past such as the Ice Age and warmer periods. The fact that 'the relatively small changes we are making to the atmosphere have the potential to shift the world's climate into a new regime' (Konrad, 2011) supports the assertion that weather patterns are sensitively dependent to exterior changes in initial conditions. However, the suspected aperiodicity of the climate makes long-term modeling of the weather difficult because without adequate knowledge about sensitive dependence to interior changes in initial conditions it is impossible to predict future states of the system. The impact that humanity is having on the atmosphere through, for instance, rising carbon dioxide emissions makes the global shift to a different climate attractor more likely and more imminent if it were to ever have occurred before.

The issue of global climate change is serious because it has the potential to transform the environment and, in turn, the lives of each and every person who inhabits the planet. It is imperative that measures are taken now on a global scale to avert crisis because humanity already lacks the critical information needed to predict future states of the weather on the climate attractor. Physicist and science writer for Ars Technica Chris Lee (2010) explains that, "The weather is unpredictable because the infinite surface area of the strange attractor requires us to know the starting conditions (i.e. temperature, pressure, humidity, etc) exactly, everywhere on the Earth, which is clearly impossible." This impossibility stems from the almost infinite sets of points that exist all over the globe and assume future states uniquely determined by the initial conditions. However, since there are boundaries to the range of weather conditions that can exist on the attractor, taking a surface of section for many locations and starting positions makes it possible to calculate statistical averages for the planet. Nonetheless, even though particular weather patterns correspond to certain climates, "forecasting the weather is an attempt to get fairly precise information on the state of the atmosphere in the near future" and "forecasting the climate, in contrast, involves an attempt to identify the atmosphere's most probable states on far longer time scales." (Lee, 2010) Further distinction can be made between forecasting the weather and forecasting the climate by comparing short time scales to longer time scales and recognizing the potential for exterior changes at any successive point to uniquely determine the state of the system at some point in the future. Lorenz (1995) confirms that the dynamics of the weather on the climate attractor is chaotic and complex when he states, "Sometimes a distinction is made between 'chaos' and 'complexity,' with the former term referring to irregularity in time, and the latter implying irregularity in space.' This makes sense because there is a greater occurrence of irregular behavior over longer time scales and on global weather models in comparison to short time scales and local weather models. In other words, the predictability of the weather diminishes as time progresses (i.e. longer time scales) and it grows to encompass more space (i.e. a loss of compact surface area) because greater computation is required to calculate the next set of predictions.

Determining a proper approach to slowing climate change will not be a simple task given that the data compiled through scientific research and study reveals nonlinearity in the global climate. According to James Hansen of the NASA Goddard Institute for Space Studies, "Scientists and laypersons have a predilection for deterministic explanations of climate variations. However, climate can vary chaotically, i.e., in the absence of any forcing" (Hansen et. al., 1997). It is the presence of a "forcing," or exterior change, that often corresponds to an anthropogenic impact on the environment and further complicates the accuracy of models as they represent real world conditions. The problem is there are variables that are not represented in long-term models of the climate because they are considered inconsequential or too minute to include. These models can be ran thousands of times each with slightly different initial conditions, called ensembles, to yield specific paths for the weather, but the interaction between deterministic behavior and unpredictable variations diminishes the accuracy as they project further into the future. Hansen (1997) explains, "Interactions connect all parts of the system, giving rise to complex dynamical patterns that never precisely repeat. The slight alteration of initial or boundary conditions changes the developing patterns, and thus next year's weather is inherently unpredictable." This behavior results from the governing, nonlinear dynamic equations that represent the irregular dynamics of the system. Furthermore, with an anthropogenic forcing such as ozone depletion occurring alongside the natural, variability of a volcanic eruption, it can be expected that any states of equilibrium that might have existed without the presence of the former are no longer. Through the investigation of the roles climate forcings and chaos play in climate change by way of climate simulations, public awareness has risen to a point where large regional climate anomalies no longer appear coincidental. It is becoming more apparent that the degree to which the texture of normal weather patterns worldwide will shift is unknown because the combination of anthropogenic and natural factors cannot render accurate predictions of the specific sets of states on the climate attractor upon which the weather may converge. If measures are not taken or policies enacted to reduce the massive amounts of greenhouse gases released into the atmosphere, then humanity will continue on its current course to altering the global climate. This must be avoided at all costs because the continued presence of anthropogenic forcings has a large role in uniquely determining future states of the chaotic weather and accelerating climate change. Therefore, global climate change is a serious issue because if the forcings of humankind are strong enough to push the climate onto another attractor, then the world may experience unusual weather patterns and be impacted in ways that it is not prepared to handle.

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