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Chaos theory is void

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Abstract

This paper demonstrates that in the real world, Chaos Theory is Void. "Void" is used to mean that the theory is logically coherent and perhaps even true, but it can never contribute to scientific enquiry because it cannot be tested or applied. A Void theory is not necessarily false, it is just scientifically inoperative. Chaos theory does apply in General Circulation Models, but in this context there is no useful relationship between General Circulation Models and the real world. This has positive implications for both climate prediction and weather forecasting: by using a more appropriate model structure than General Circulation Models, it may be possible to improve climate prediction and to extend weather forecasting beyond the generally-accepted two-week prediction horizon.

Keywords: Butterfly Effect; Chaos Theory; Climate; Clouds, GCM; General Circulation Model; Physics-Based Model

1. Introduction

This paper examines Chaos Theory with respect to Earth's climate and with respect to General Circulation Models (GCMs). Here, "GCMs" includes coupled GCMs, and any other climate models with a similar structure and methods. They will all be referred to here as GCMs. They can also be referred to as physics-based models.

The key attribute of GCMs, for the purposes of this paper, is that they apply the physical processes of Earth's atmosphere, surface and oceans, using a three-dimensional grid [1]. Properties such as temperature, pressure, and wind or ocean current velocity, are evaluated at each grid point over a set of time intervals. Particular reference is made to the CESM1(CAM5) model used by Kay et al (2015) ("Kay") [2]. In this model, a typical surface grid cell area is about 6,000 sq km at latitude 60 degrees, and about 12,000 sq km at the equator. Time intervals are typically 30 minutes but radiation as affected by clouds is evaluated only every hour.

Chaos Theory (aka "the Butterfly Effect") is represented as being a sensitive dependence on initial conditions. This was demonstrated by Kay who imposed tiny (order of 10^{-14} K) adjustments to initial conditions for multiple runs of the CESM1(CAM5) model, and the results varied in some regions by several K.

2. Analysis

The CESM1(CAM5) model used by Kay had nearly 2 million air cells (about 55,000 columns with 30 levels). In absolute terms, Kay's initial adjustments are equivalent to a 2 * 10^{-8} K order of difference at one cell. Data in Jiang et al (2022) can be interpolated to show that low cloud could change surface air temperature by 0.2-0.4 K in an hour [3]. In a 10,000 sq km cell, a 0.2 K temperature change over just 0.001 sq km (1,000 sq m) changes the average surface temperature of the cell by 2 * 10^{-8} K. In other words, a single 1,000 sq m cloud at one location for one hour can produce a global

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average total atmosphere temperature change that is the same order of magnitude as the initial differences applied by Kay. That is a very small cloud.

Note that the initial differences applied by Kay were at a single point in time, and their CESM1(CAM5) model applied radiation (as affected by clouds) hourly, so it is legitimate to compare the initial Kay differences with the one-hour effect of a cloud.

With about 55,000 surface air cells in the model and 8,766 hours in a year, there are over 400 million opportunities per year for a single very small cloud in thousands of sq km to perturb Earth's climate by a similar total amount to the global initial differences used by Kay. If we go with the Chaos Theory idea that there are weather/climate events which might or might not happen, and if we assign a reasonable probability to the formation or non-formation of a very small cloud, then the number of times that Earth's climate can be disrupted by such a cloud is massive. Not only that, but there would presumably be many occasions when a cloud might not have formed but did form, and many occasions when a cloud might have formed but did not form. There is no certainty that their effects would not cancel each other out. And Chaos Theory is not restricted to just the formation or non-formation of clouds.

But this is all academic. Chaos Theory can never be tested or applied in the real world. It relates to perturbations that might or might not happen, but the real world only ever gets the perturbations that actually do happen. No-one can ever test what would have happened in the real world with different perturbations. In a real world context, Chaos Theory is Void.

"Void" is used to mean that the theory is logically coherent and perhaps even true, but it can never contribute to scientific enquiry because it cannot be tested or applied. A Void theory is not necessarily false, it is just scientifically inoperative.

By contrast, Kay has demonstrated that Chaos Theory does apply in GCMs.

3. Discussion

Selz and Craig (2023) investigated error growth from small-amplitude initial condition perturbations using the artificial intelligence-based ("AI") weather prediction model Pangu-Weather [4]. They found that the error grew very slowly and almost linearly. They commented that the model "*fails completely when the initial condition uncertainty is small and is not able to simulate any indication of the butterfly effect or any indication of accelerated growth rates and intrinsicly[sic] limited predictability.*". This is actually the expected outcome, not a failure, if Chaos Theory applies only in GCMs and not in the real world. But since Chaos Theory is Void in the real world, this is not possible to determine. Suffice it to say that Pangu-Weather's results cannot reasonably be described as a failure.

Selz and Craig (2026) shows that other AI models consistently show smaller error growth from tiny perturbations than in physics-based models [5]. They say "*However, none of the AI models reproduce this physical behavior correctly. Some models show no rapid initial growth at all, behaving as if the atmosphere were more predictable than it really is*.". Again, given that Chaos Theory is Void in the real world, this is an unsupportable statement. However, they also say "*There is currently no indication that the inability to reproduce the butterfly effect has any negative consequences for global weather forecasting, where these models are now widely used.*" which aligns well with Chaos Theory being Void in the real world. In other words, for all real world purposes, Chaos Theory can safely be ignored.

A General Principle

The following general principle is proposed:

Any predictive system constructing cycles of variable duration and/or varying amplitude will fail after a few cycles if the mechanisms behind the variability are not fully understood and/or cannot be accurately replicated.

The underlying reason for proposing this principle is that by definition the situation at the end of a cycle is close to the situation at the start of the cycle, so that every small prediction inaccuracy during a cycle becomes a large error, proportionately, at the end of the cycle. Without the usage of factors that transcend the cycle, the predictive system must break down after a few cycles. "Few" is not quantified, and would clearly depend on the specifics of each situation.

It can be argued that GCMs primarily use mechanisms that do not transcend the daily cycle, and that this aspect of GCMs leads to the instability which is interpreted as the Butterfly Effect. This raises the possibility that the Butterfly Effect is an artefact of the GCMs, but because Chaos Theory in the real world is Void, this would be difficult or impossible to test.

The implications of ignoring Chaos Theory and applying the above General Principle for weather and climate model forecasting are interesting. To forecast beyond a week or two, the models cannot work only on time periods of less than a day because they will break down after a few days - as has already been discovered. But if a weather model works with factors that operate on periods of more than a day, there is no intrinsic reason why it cannot make meaningful predictions over longer periods. In other words, the generally-accepted perception that weather models have an absolute prediction horizon of about two weeks may well be incorrect - provided, that is, that they can be structured to make use of factors that transcend the daily cycle [7].

Similarly, climate models may be able to make reasonable predictions if they do not depend on iterations of a day or less and are structured to make use of factors that operate over longer periods. Applying the above principle, for a climate model to make reasonable predictions over a few years it must work with factors that operate over a year or more. To make reasonable predictions over a few decades it must work with factors that operate over a decade or more. And so on.

With respect to use of the term "Void": The scientific literature has been searched unsuccessfully for a term that means that a theory is logically coherent and perhaps even true, but is scientifically inoperative. The term "Void" has been adopted for that meaning, based loosely on its meaning in law, ie, without legal force or binding effect [6]. This is not the same as "Null" which means invalid, or effectively no legal existence.

4. Conclusion

In the real world, Chaos Theory is Void. The theory does apply in GCMs, but in this context there is no useful relationship between GCMs and the real world. This has positive implications for both climate prediction and weather forecasting: by using a more appropriate model structure than GCMs, it may be possible to improve climate prediction and to extend weather forecasting beyond the generally-accepted two-week prediction horizon.

Compliance with ethical standards

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