Sea gulls, butterflies, and grasshoppers: A brief history of the butterfly effect in nonlinear dynamics

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The butterfly effect has become a popular metaphor for sensitive dependence on initial conditions—the hallmark of chaotic behavior. I describe how, where, and when this term was conceived in the 1970s. Surprisingly, the butterfly metaphor was predated by more than 70 years by the grasshopper effect.
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I. INTRODUCTION

The term butterfly effect has captured for the public and much of the scientific community the essence of chaotic behavior in dynamical systems: sensitive dependence on initial conditions. For a chaotic system, even the smallest change in initial conditions, due, for example, to the flapping of a butterfly's wings, may lead to dramatic changes in the behavior of the system. From this simple idea follow the unpredictability of many deterministic systems under certain conditions and the complexity of spatial patterns in turbulence, to mention just two important consequences. What is the origin of this colorful metaphor? The answer turns out to be complex. Part of the story is told in E. N. Lorenz's book,[1] *The Essence of Chaos*. I played a role in tracking down the history of the term butterfly effect, and in this paper I discuss some of the details of this history. I also relate a more recent discovery: the grasshopper effect preceded the butterfly effect by more than 70 years.

The term butterfly effect is usually attributed to E. N. Lorenz. In fact, in his early writing on sensitive dependence on initial conditions and its effect on the predictability of dynamical systems, Lorenz[2] used a sea gull metaphor: ''When the instability of uniform flow with respect to infinitesimal perturbations was first suggested as an explanation for the presence of cyclones and anticyclones in the atmosphere, the idea was not universally accepted. One meteorologist remarked that if the theory were correct, one flap of a sea gull's wings would be enough to alter the course of the weather forever. The controversy has not yet been settled, but the most recent evidence seems to favor the gulls (p. 431).''

The sea gull metaphor, however, was to be short-lived. In the title of a talk given by Lorenz at the 139th meeting of the American Association for the Advancement of Science (AAAS) in December, 1972, the butterfly made its first appearance: ''Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?'' In this talk, Lorenz[1,3] raised the fundamental issue: ''The question which really interests us is whether they [the butterflies] can do even this—whether, for example, two particular weather situations differing by as little as the immediate influence of a single butterfly will generally after sufficient time evolve into two situations differing by as much as the presence of a tornado. In more technical language, is the behavior of the atmosphere *unstable* with respect to perturbations of small amplitude?''

II. WHENCE THE BUTTERFLY?

How and why did the sea gull change to a butterfly? Let us begin with two possible explanations.

First, it has been suggested[4] that the butterfly metaphor arose from the resemblance of the attractor of the Lorenz equations, when the variable Z, in the standard form of the Lorenz system of equations,[5] is plotted against X. (See Fig. 1 for such a plot.) However, in his 1963 paper,[2] Lorenz presented plots of Z against Y and X against Y, and these plots do not much resemble a butterfly.[6] No figures accompanied Lorenz's 1972 talk.[1] Moreover, probably no one plotted Z against X for the Lorenz model until after the mid-seventies.[4]

A second suggestion was made to me in the summer of 1989 by David S. Hall, an Amherst College physics major at the time, who pointed out that a 1952 Ray Bradbury story,[7] ''A sound of thunder,'' tells the tale of time travelers who, in their trip to the past, accidentally kill a butterfly, and return to their present to find history changed. In fact parts of this story read much like segments of current books on nonlinear dynamics: ''Crushing certain plants could add up infinitesimally. A little error here would multiply in sixty million years, all out of proportion. Of course maybe our theory is wrong. Maybe time can't be changed by us. Or maybe it can be changed only in little subtle ways. A dead mouse here makes an insect imbalance there, a population disproportion later, a bad harvest further on, a depression, mass starvations, and, finally a change in social temperament in far-flung countries. Something much more subtle, like that (p. 61).'' However, Lorenz[8] informed me that he had not been aware of the Bradbury story before I brought it to his attention.

What actually happened in the transformation of the sea gull to the butterfly? According to Lorenz,[6] he was out of the country in the fall of 1972, and Philip Merilees, convener of the AAAS session at which Lorenz was to give his talk, concocted the title of the talk in Lorenz's absence. Merilees responded to my inquiry about the butterfly's origins with the following:[9] ''As I recall the circumstances, I was working as Executive Scientist for the UCAR (University Corporation for Atmospheric Research) GARP (Global Atmospheric Research Program) Council under the late Walt Roberts. I was on leave from McGill and was given the job of organizing an AAAS session on GARP. One of the fundamental issues in GARP was the predictability of the weather, in particular the sensitive dependence on initial conditions. Walt told me that it was important to try to come [up] with intriguing titles for the topics in the session because there was much competition for the attention of participants. I had followed Ed Lorenz's work very closely and was aware of the sea gull metaphor, but I thought the butterfly might be more appealing. In addition, I tried for some alliteration; butterfly—Brazil, tornado—Texas. I suppose sea gull in Senegal might have

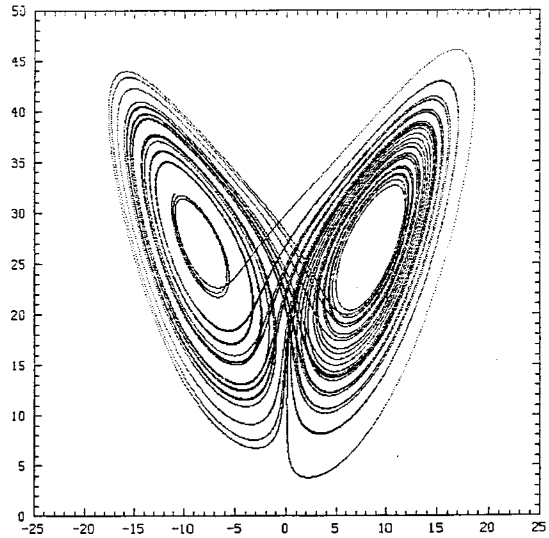

Fig. 1. A phase space projection onto the *XZ* plane of a trajectory of the Lorenz model. (*Z* is the ordinate and *X* the abscissa.) I thank E. N. Lorenz for providing the figure.

worked as well. I can't recall being influenced by someone else's use of the butterfly in this context, but it was nearly 18 years ago!"

A few days before receiving Merilees' letter, I received a telephone call from Douglas Lilly, whose office at the National Center for Atmospheric Research in 1972 was near Merilees. Lilly recalled tossing around ideas for talk titles with Merilees in 1972 and thought that it was he (Lilly) who suggested the use of butterfly in Lorenz's title. But he could not recall a specific influence that led to the adoption of the butterfly. He did suggest that the 1941 novel *Storm* by George R. Stewart[10] might have motivated his thinking. A careful reading of the novel (an intriguing story of meteorologists tracking a Pacific coast storm) revealed no butterflies. But I did find the basic idea of sensitive dependence on initial conditions expressed in the following way: "He [the junior meteorologist] thought of his old professor's saying: A Chinaman (sic) sneezing in Shen-si may set men to shoveling snow in New York City (p. 44)."

With this exchange of letters and telephone calls, my investigations into the origin of the butterfly metaphor reached a dead end. The butterfly entered nonlinear dynamics in the conversations between Merilees and Lilly in 1972 at NCAR. Apparently, it was born as the result of subtle nonlinear interactions among Merilees, Lilly, and Lilly's recollections of Stewart's *Storm* causing, dare we say, a bifurcation from the sea gull metaphor to that of the butterfly. But the precise initial conditions of these diverging trajectories are now beyond our powers of observation.

One minor historical problem remains: How did the butterfly *metaphor* turn into the butterfly *effect*? Lorenz himself never used the phrase butterfly effect. The term appears in Schuster's 1984 text *Deterministic Chaos*[11] and in the now famous *Chaos* by James Gleick.[4] In fact, Gleick[4] wrote that "the Butterfly Effect—the notion that a butterfly stirring the air in Peking can transform storm systems next month in New York (p. 8)." Gleick's statement is an intriguing combination of phrases from Lorenz's title and Stewart's *Storm*.

III. GRASSHOPPERS WERE FIRST

The notion of sensitive dependence on initial conditions has long been a part of the lore of meteorology as Stewart's *Storm* indicates. I recently learned that the butterfly metaphor was, in fact, predated by nearly 70 years by what we should call the grasshopper effect. The late Al McLennan of Lehigh University, knowing of my interest in nonlinear dynamics, had alerted me in 2002 to a review[12] of Pierre Duhem's Traité Élémentaire de Méchanique fondée sur la Thermodynamique (1897). The review was written in 1898 by W. S. Franklin, then a professor of physics at Lehigh. Discussing the sensitivity of the atmosphere to small perturbations, Franklin wrote that "Long range detailed weather prediction is therefore impossible, and the only detailed prediction which is possible is the inference of the ultimate trend and character of a storm from observations of its early stages; and the accuracy of this prediction is subject to the condition that the flight of a grasshopper in Montana may turn a storm aside from Philadelphia to New York!"

It seems as if the notion of sensitive dependence on initial conditions, the hallmark of chaos, has been in the air (so to speak) for some time and that insects have been the creatures of choice for vivid metaphors for these effects.

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Note added in proof. Professor Lorenz recently alerted me to a publication in which a "butterfly" appears, predating his 1972 AAAS paper. The butterfly metaphor occurs in Joseph Smagorinsky, "Problems and promises of deterministic extended range forecasting," Bull. Am. Meteor. Soc. **50**, 286–311 (1969). Professor Lorenz told me that he had read the Smagorinsky paper when it first appeared, but had not remembered the butterfly (on page 289) until recently as he was preparing a talk for an April 2003 symposium honoring Professor Smagorinsky's receipt of the Benjamin Franklin Medal in Earth Science. The relevant sentence reads, "Or, would the flutter of a butterfly's wings ultimately amplify to the point where the numerical simulation departs from reality, so that there will come a time when they must be randomly related to each other?" It is possible that this appearance of the butterfly subconsciously influenced Merilees, who also read the Smagorinsky paper in 1969, when he later created the title for Lorenz's talk.

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[1]Edward N. Lorenz, *The Essence of Chaos* (University of Washington Press, Seattle, 1994).
[2]Edward N. Lorenz, "The predictability of hydrodynamic flow," Trans. N. Y Acad. Sci. **25**, 409–432 (1963).
[3]*The Chaos Avant-Garde, Memories of the Early Days of Chaos Theory*, edited by Ralph Abraham and Yoshisuke Ueda (World Scientific, Singapore, 2000). See pp. 91–92.
[4]James Gleick, *Chaos* (Viking, New York, 1987). Gleick writes: THE LORENZ ATTRACTOR (on facing page). This magical image, resembling an owl's mask or butterfly's wings, became an emblem for the early explorers of chaos. This is historically incorrect because the image was not produced as such until the late 1970's.
[5]Robert C. Hilborn, *Chaos and Nonlinear Dynamics* (Oxford University Press, Oxford, 2000), 2nd ed.

[6]Edward N. Lorenz, letter to Oliver M. Ashford, 27 December, 1989.
[7]Ray Bradbury, ‘‘A sound of thunder,’’ in *R is for Rocket* (Bantam, New York, 1962).
[8]Edward N. Lorenz, letter, 1 May, 1990, to Robert C. Hilborn.
[9]Philip Merilees, letter, 28 August, 1990, to Robert C. Hilborn.
[10]George R. Stewart, *Storm* (Random House, New York, 1941). In a telephone conversation, Lorenz told me that after reading an early draft of this paper, he recalled the Chinaman metaphor from having read the Stewart novel and that this novel was influential in his decision to go into meteorology.
[11]H. G. Schuster, *Deterministic Chaos* (VCH, New York, 1984).
[12]W. S. Franklin, Review of P. Duhem, *Traité Élémentaire de Méchanique fondée sur la Thermodynamique* (Paris, 1897), Vols. 1 and 2, in Phys. Rev. **6**, 170–175 (1898).