number of direct observations of reversals during that time[4].

Such a stable early geomagnetic field has important implications for our understanding of the geodynamo, which generates the magnetic field and controls its variations. Numerical simulations suggest that the geometry of the liquid core, the amount and type of energy available for driving the dynamo, and the heterogeneous boundary conditions imposed by the mantle on the core can all influence the behaviour of the magnetic field. Mantle convection, for example, produces changes in the boundary conditions, typically on timescales of 100 million years and this could be the cause for the observed variability in the behaviour of the geomagnetic field over the past 200 million years, in particular the transition to the Cretaceous Normal Superchron[5]. However, this sudden transition could alternatively result from a spontaneous transition from a reversing to a non-reversing state of the dynamo[6].

Could similar mantle control also be responsible for the changes observed by Biggin and colleagues on the much longer timescales they investigate? Perhaps, but this is not the interpretation the authors favour. Rather, they note that on the billion-year timescale, the growth of the inner core may have played a more important role than mantle convection. They point out that the size of the inner core is an important parameter for dynamo action, both from a magnetic[7] and dynamic[8] point of view, and that recent simulations[4] show that a smaller inner core can stabilize the field behaviour.

Biggin and colleagues argue that what they have found could be the magnetic signature of a smaller inner core some two billion years ago. But, perhaps even more important than the size of the inner core is the power available to drive the dynamo. This must have been quite different before and during the initial stages of inner core growth from what it is at present[9]. Recent extensive investigations of numerical geodynamo simulations show that energetic considerations are more important in defining the nature of the field produced than previously thought[10]. Changes in available energy to drive the dynamo therefore may well turn out to be the main explanation for Biggin and colleagues' findings. Only future investigations will tell.

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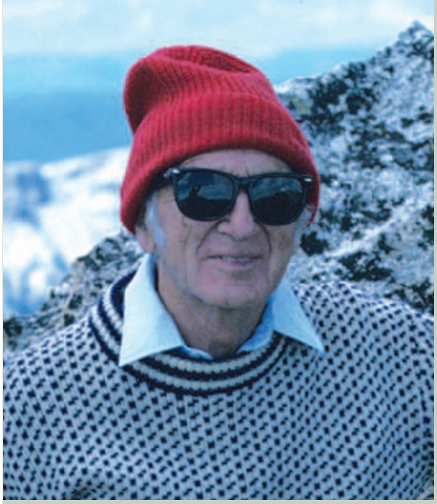
EDWARD LORENZ (1917–2008)

Chaotic beginnings



HOWIE BLUESTEN

Serendipity is a term often misused, but if anyone in modern science could lay claim to it, it was Edward Lorenz. A meteorologist by training, he founded the entire discipline of chaos theory by accident — while attempting to improve a weather forecast.

Lorenz was born on 17 May 1917 in West Hartford, Connecticut, and recalled childhood interests in both mathematics and meteorology that seemed to predestine him for his later career. He first studied mathematics, but became a weather forecaster for the US Army Air Corps during the Second World War. In 1943, he took a masters degree in meteorology at the Massachusetts Institute of Technology, the beginning of a lifelong association with the institution. There, he set about using mathematical tools to break down complex climate phenomena, establishing a series of elegantly simple mathematical models to describe various aspects of atmospheric energetics and transport.

Lorenz was tinkering with one such model in 1961 when, wishing to repeat a simulation over a slightly longer timescale but disinclined to start over again, he began in the middle using values generated from the first run. The print-out with the input parameters rounded the six decimal places of the actual output to just three. Such a small discrepancy would not have been expected to materially affect the end result; but the second simulation produced an entirely different evolution from the first.

At first, Lorenz suspected a computer malfunction, but the irreproducibility of the result proved eminently reproducible. He was quick to grasp the implication that, as far as the atmosphere is concerned, "the prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly" (Lorenz, E. *J. Atmos. Sci.* **20,** 130–141; 1963). In the absence of such knowledge, the question of what the weather will be in a month's time is one we are fated never to answer.

Lorenz first illustrated this with the metaphor that a flap of a seagull's wings was enough to alter the course of the weather forever. It was not until a decade later, in December 1972, at an invited talk at a meeting of the American Association for the Advancement of Science, that he used the description that was to lodge chaos in the public imagination: "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" That vividly framed question had a perfect visual accompaniment in tracings of the 'Lorenz attractor', a three-dimensional representation of chaotic flow established by Lorenz when considering atmospheric convection, whose paths resemble nothing more than a pair of butterfly wings.

For establishing the theoretical basis of climate predictability, Lorenz was awarded the Crafoord prize by the Royal Swedish Academy of Sciences in 1983, and the Kyoto prize of the Inamori foundation in 1991. The citation for the latter prize attested Lorenz as having "brought about one of the most dramatic changes in mankind's view of nature since Sir Isaac Newton". Edward Lorenz died on 16 April at his home in Cambridge, Massachusetts, at the age of 90.

Richard Webb