MR3244181 65-03 01A60 86-03
Lynch, Peter (IRL-DBLN-MCL)

★**The emergence of numerical weather prediction.**
Richardson's dream.
Paperback edition of the 2006 original.
Cambridge University Press, Cambridge, 2014. *xii*+279 *pp. ISBN* 978-1-107-41483-9

Lewis Richardson was a failure. He had to partially subsidize the publication of his book [*Weather prediction by numerical process*, Cambridge Univ. Press, Cambridge, 1922; second edition, Cambridge Math. Lib., Cambridge Univ. Press, Cambridge, 2007; MR2358797]. It predicted a planetary wave circling the atmosphere nine times too fast; his heroic three-dimensional weather forecast, a twelve hours prophecy, predicted the pressure drop of a monster hurricane on a day and time when the sky was sunny. Despite this, Richardson was elected a Fellow of the Royal Society and also of the Royal Meteorological Society and awarded, for his published work, a D.Sc. by the University of London, but his only academic positions were at Westminster Training College and Paisley Technical College. He had three adopted children. His nephew Ralph was a distinguished actor, knighted; his grandniece Virginia was variously Tory Minister of the Environment and of Health and now has the grand title of Baroness Bottomley of Nettlestone.

Uncle and great-uncle Lewis was not even an OBE. He slipped out of life as quietly as he had lived, asleep, in 1953. Yet he did have his titles even so.

He was Richardson of Richardson Extrapolation, Richardson of the Richardson/Jacobi iteration in numerical analysis. In fluid mechanics, he was Richardson of the Richardson Law of Turbulent Diffusion, and also author of a version of a poem by Jonathan Swift that is, in Richardson's rewording, a brief but entirely accurate description of a turbulent cascade:

"Big whirls have little whirls that feed on their vorticity, and little whirls have lesser whirls and so on to viscosity."

And then there is Richardson the Quaker, a forty-year old civilian ambulance driver dodging shells near the front for much of World War I and pioneering the academic study of conflict during and after World War II. Long after his death, Lancaster University established an Institute for Peace Studies, and named it after him.

In papers found after his death, he showed that the length of a coastline varies with the length of the yardstick used to measure it, and calculated the fractional dimension. Benoit Mandelbrot may have coined the word "fractal", but Richardson was thinking of fractals in 1947.

Most Nobel Laureates and Fields Medalists have had one Great Idea; Richardson had half a dozen.

Peter Lynch's book is a fine work of popular science/mathematics, a book that Ian Stewart or Mario Livio would have been proud of. Lynch is a well-respected scientist who worked for many years for the Irish Met Service before sliding over to his present position at Trinity College, Dublin.

Lynch's book devotes two chapters and a final coda, "The Dream Realized", to Richardson, but he tells also of the triumph of Jule Charney and his team, who generated the first successful computer weather forecasts in 1950, and takes the broad outlines of the weather divination story down to the present day. Lynch's book is much more mathematical than the usual pop history, but it delivers a good story even with all the equations covered up.

Lynch gives a good analysis of Richardson's successes and failure. Richardson's 1922 book centered around one very ambitious three-dimensional forecast ("baroclinic" forecast) and the knowledge and computing forms to execute it, initialized with real observational data. Quite sensibly, Richardson also included a two-dimensional forecast ("barotropic") solving what geophysicists call the "shallow water equations", a forecast begun with analytic, geostrophically balanced initial conditions (see [P. Lynch, Bull. Am. Meteorol. Soc. **73** (1992), 35–47, doi:10.1175/1520-0477(1992)073¡0035:RBFAR¿2.0.CO;2], freely downloadable from the American Meteorological Society website). Lynch uses modern technology to show that Richardson was both more wrong and more right than he suspected.

In the history of science, "Whig history" denotes a historiography which ignores dead ends and failed theories to focus only on the winners. Richardson, rusticated in Paisley, would have fared badly indeed in the eyes of the Whiggish except for the fact that he was, incontestably, the Father of Numerical Weather Prediction. His book was a 236-page bet on the future, and, in the end, he won. But an unusual circumstance made Richardson seem even more of a loser.

That unusual circumstance was that the earliest computer forecasts were pure fluid mechanics. Judging from this narrow perspective, Richardson used a timestep which vastly exceeded the as-yet-unheard-of Courant-Friedrichs-Lewy limit and was therefore exponentially unstable. His initial data excited lots of spurious gravity waves, which would have wrecked the forecast even with a very short timestep, and he was ignorant of the quasi-geostrophic approximation, which filters gravity waves and guarantees a stable forecast with a timestep of an hour, albeit a prognostication only moderately accurate in the midlatitudes, and as useless as the hot entrails of temple-slaughtered lambs for forecasting tropical weather and hurricanes.

Jule Charney, who invented the quasi-geostrophic approximation in 1947, and led the team that performed the first twelve-hour computer forecasts over a six-week period in 1950, was well aware of the shortcomings of Richardson's book. Nevertheless, though Richardson was a dozen years retired from Paisley, and had not written a meteorological paper in over a quarter of a century, Charney tracked down Richardson's address and sent him, like a bashful teen to a rock star, reprints of the first, triumphant publication in Tellus. (See [I. Roulstone and J. Norbury, *Invisible in the storm*, Princeton Univ. Press, Princeton, NJ, 2013; MR3024839] for a good discussion of this episode, as well as the fact that the original Charney code was converted to an app that can run on a modern smart phone.) Richardson wrote a courteous thank you, but he was not perhaps as gushing as Charney had hoped. Richardson had been beavering away at his peace-and-conflict studies for over a dozen years since taking early retirement to pursue them, and the world was not rendered noticeably more peaceful. He was old and tired, and only a year from death. But that was not the real problem.

The real problem was that Richardson's vision was far too large to be contained within mere fluid mechanics. He didn't write his book as a manual for a future piece of software. His goal was not to replace one computing protocol with another. Rather, he looked forward long beyond Charney to our time when General Circulation Models are million-statement codes incorporating the vast range of physics and chemistry of which fluid mechanics is but one small part.

Richardson was not merely writing a blueprint for his own time or for Charney 30-odd years in the future; he was also creating an ink-and-paper time capsule for us in the twenty-first century and beyond. Richardson wrote:

"The atmosphere is like London, for in both there are far too many things happening for any one person to attend to."

Although his book is about the fluid mechanics side, mostly, Lynch would agree. Richardson's barotropic forecast was subtly flawed. His geostrophically balanced initial condition was insufficiently balanced, and excites a fairly significant medium frequency Kelvin wave which superimposes its spurious wiggles on the slow and stately evolution of the mode that absorbed most of the energy of the initial condition, the mode that meteorologists now call the lowest symmetric Rossby wave of zonal wave number one. This races around the globe, completing a longitudinal orbit in just five days. This ninety meters per second hustle is far faster than the vortices observed in the early twentieth century, much to Richardson's dismay. Weather is dominated in the middle latitudes by so-called synoptic scale vortices, low-pressure systems that spin counter-clockwise in the northern hemisphere and high-pressure "anticyclones" rotating clockwise, both systems with diameters of one or two thousand kilometers, carried eastward, always eastward, at perhaps ten meters per second. But the "five day wave" is real, and travels at roughly the speed predicted by Richardson. However, computers and modern time series analysis were necessary to extract this mode from the busy and confused dynamics of the atmosphere. The signal is much stronger and easier to see in the stratosphere, but there was no data from such heights in 1919.

Richardson was blessed, and also cursed, with a vision spanning all the geophysical ingredients. Metaphorically, he had a mind that could see over the entire spectrum from deep infra-red to ozone-breaking far ultraviolet.

In his 1989 book [*Does God play dice?*, Blackwell, Oxford, 1989; MR0997093], Ian Stewart described Lewis Fry Richardson as "an unorthodox deviser of half-baked ideas whose name floats in and out of the history of applied dynamical systems".

Not exactly.

Richardson's book ends with a soaring vision of 64,000 human computers crunching the numbers for a real-time forecast in a stadium. A conductor controls it all from an elevated central podium, wielding red and green flashlights to signal "Hurry up" to some regional teams and "Rest a bit" to others. Richardson was to the ordinary run of scientist as Beethoven or Mozart were to a composer of advertising jingles for the local car wash.

He was also definitely a crackpot. One of the strengths of Lynch's book is that he is open about Richardson's deficiencies. Lynch writes on p. 183: "Richardson was reserved and withdrawn, most comfortable when alone and even somewhat stand-offish". On p. 181: "It was without question that Richardson's attempt to predict the weather by numerical means, ... while visionary and courageous, was premature. In fact, there were several obstacles preventing the fulfillment of Richardson's dream, and progress was required on four separate fronts before it could be realized."

"Firstly, in order to develop a simplified system suitable for numerical prediction, a better understanding of atmospheric dynamics ... was required. Secondly ... the development of the radiosonde made observations of the free atmosphere possible in real time. Thus, it became possible to construct a comprehensive synoptic description of the state of the atmosphere. Thirdly, an understanding of the stability properties of finite difference scheme flowed from the work of Courant, Friedrichs and Lewy (1928). And fourthly, the development of automatic electronic computing machinery provided a practical means of carrying out the monumental computational task of calculating changes in the weather."

Today, visions of the future have narrowed to the three-year duration of government contracts. Academics walk the Narrow Way. A Fellow of the American Meteorological Society is one who writes a proposal a month—most rejected, their plans and preliminary calculations as ephemeral as April snow—while churning out Ph.D.'s like sausages. The postdocs write the journal articles while the students supply the catchy graphics and almost never see the bosses, who are perpetually networking and keeping up with the field, kind of, in brief moments of reading on airplanes and at international departure gates. In a funding process where one lukewarm review out of six can scuttle a proposal, the facade of novelty is, below the surface, as rigidly conformist as a Victorian vicar.

To any self-respecting Associate Dean for Research, Richardson was worse than a crackpot. He was unfunded.

Lynch's book is an excellent introduction to the mathematics of weather prediction and climate, more advanced than the usual book for the layman, but an interesting read even for someone who cannot follow the mathematics. To turn from the Narrow Way of model development and algorithm invention, to write instead of history and philosophy of science, Lynch needed a little vision, a little Richardsonian courage. His book is blessed with both.

There is nothing technical or mathematical in Richardson's book that cannot be found, better, in modern books. Yet it is still worth reading, too, in the twenty-first century. Few books in any field, and certainly no other in geophysical fluid dynamics, offer so much courage and so much vision.

John P. Boyd