Richardson's Forecast-factory: the $64,000 Question

by

Peter Lynch, Meteorological Service, Dublin

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Lewis Fry Richardson served as a driver for the Friends' Ambulance Unit in the Champagne district of France from September 1916 until the Unit was dissolved in January 1919 following the cessation of hostilities. For much of this time he worked near the front line, and during the Battle of Champagne in April 1917 he came under heavy shelling (Ashford, 1985). It is a source of wonder that in such appallingly inhuman conditions he had the buoyancy of spirit to carry out one of the most remarkable and prodigious calculational feats ever accomplished. During the intervals between transporting wounded soldiers back from the front he worked out by manual computation the changes in the pressure and wind at two points, starting from an analysis of the condition of the atmosphere at 0700 UTC on 20 May 1910. Richardson described his method of solving the equations of atmospheric motion and his sample forecast in what has become the most famous book in meteorology, his *Weather Prediction by Numerical Process* (Richardson, 1922). The unrealistic values which he obtained are a result of inadequacies and imbalances in the initial data, and do not reflect any flaw in his method, which is essentially the way numerical forecasts are produced today.

How long did it take Richardson to make his forecast? And how many people would be required to put the method to practical use? The answers to these two questions are contained in §11/2 of his book, but are expressed in a manner which has led to some confusion. On p. 219 under the heading 'The Speed and Organization of Computing' Richardson wrote

> It took me the best part of six weeks to draw up the computing forms and to work out the new distribution in two vertical columns for the first time. My office was a heap of hay in a cold rest billet. With practice the work of an average computer might go perhaps ten times faster. If the time-step were 3 hours, then 32 individuals could just compute two points so as to keep pace with the weather . . . .

Could Richardson really have completed his task in six weeks? Given that 32 computers working at ten times his speed would require 3 hours for the job, he himself must have taken some 960 hours — that is 40 days or 'the best part of six weeks' working flat-out at 24 hours a day! At a civilized 40-hour week the forecast would have extended over six months. It is more likely that Richardson spent perhaps ten hours per week at his chore and that it occupied him for about two years, the greater part of his stay in France.

Now to the question of the resources required to realize Richardson's dream of practical forecasting. Quoting again from p. 219 of the book:

> If the co-ordinate chequer were 200 km square in plan, there would be 3200 columns on the complete map of the globe. In the tropics the weather is often foreknown, so that we may say 2000 active columns. So that $32 \times 2000 = 64{,}000$ computers would be needed to race the weather for the whole globe. That is a staggering figure.

It is indeed staggering, when we recall that these 'computers' were living, feeling beings, not senseless silicon chips. Richardson proposed taking 128 chequers or grid-boxes around each parallel and 100 between the poles. This gives a grid cell which is roughly a square of side 200 km at 50° North and South. He outlined a scheme for reducing

the number of chequers towards the poles but made no allowance for that in the above reckoning. His claim that 3200 columns or chequers would cover the globe has been questioned by Sydney Chapman in his Introduction to the Dover Edition of *Weather Prediction by Numerical Process*:

> As to Richardson's estimates of the time and cost of full application of his methods, he made an uncharacteristic error in giving 3200 as the number of squares ... to cover the globe. His number is only a quarter of the true value, so that his required staff and his cost estimate must be quadrupled.

So, Chapman's estimate of the staff required is $4\times64{,}000=256{,}000$. However, this is not entirely correct. The envisaged computational grid would indeed have required $128\times100=12{,}800$ chequers for global coverage — four times the value stated by Richardson. But Richardson considered the grid-boxes in pairs, one for mass and one for momentum, and it was such a pair for which he made his sample forecast and upon which he based his estimates. Thus, 6400 pairs of chequers would cover the globe and, with 32 people working on each pair, a total horde of 204,800 would be involved in a bid to race the weather for the whole globe. That is a stupendous figure!

So where did Richardson come by the figure of 3200 chequers to cover the globe? The error is inescapable but is not, I believe, a numerical slip. Richardson intimated that the weather in the tropics was sufficiently steady for variations to be neglected. But in such a case the global forecasting problem falls neatly into two parts and it is natural to consider each hemisphere separately. The Northern hemisphere can be covered by 3200 *pairs* of columns. Assuming with Richardson that the values at 1200 pairs may be prescribed and assigning 32 individuals to each of the remaining pairs, one finds that $32\times2000=64{,}000$ souls are needed to race the weather *for the extra-tropical Northern hemisphere.*

If this is what Richardson intended, his 'uncharacteristic error' was not an arithmetical howler but a lapse of expositional precision. For his staggering figure of 64,000 is clearly stated to refer to *the whole globe.* Later in the paragraph he speaks of a forecast-factory for the whole globe (in fact, the word 'globe' occurs five times on p. 219). In his wonderful fantasy of a theatre full of computers, the tropics 'in the upper circle' are treated on an equal footing with the temperate and frigid zones. Given that Richardson's assumption of constancy of tropical weather was over-optimistic, a full complement of 32 computers for each pair of columns in his *forecast-factory for the whole globe* would have provided work for 204,800 people.

Even this vast multitude could compute the weather only as fast as it was evolving. To obtain useful and timely predictions, the calculations would need to go several times faster than the atmosphere. Allowing for a speed-up factor of five, the establishment of a 'practical' forecast-factory would have reduced the ranks of the unemployed by over a million.

References

Ashford, Oliver M., 1985: *Prophet—or Professor? The Life and Work of Lewis Fry Richardson.* Adam Hilger, Bristol and Boston, xiv+304 pp.

Richardson, Lewis F., 1922: *Weather Prediction by Numerical Process.* Cambridge University Press, xii+236 pp. Reprinted by Dover Publications, New York, 1965, with a New Introduction by Sydney Chapman, xvi+236 pp.