Weather

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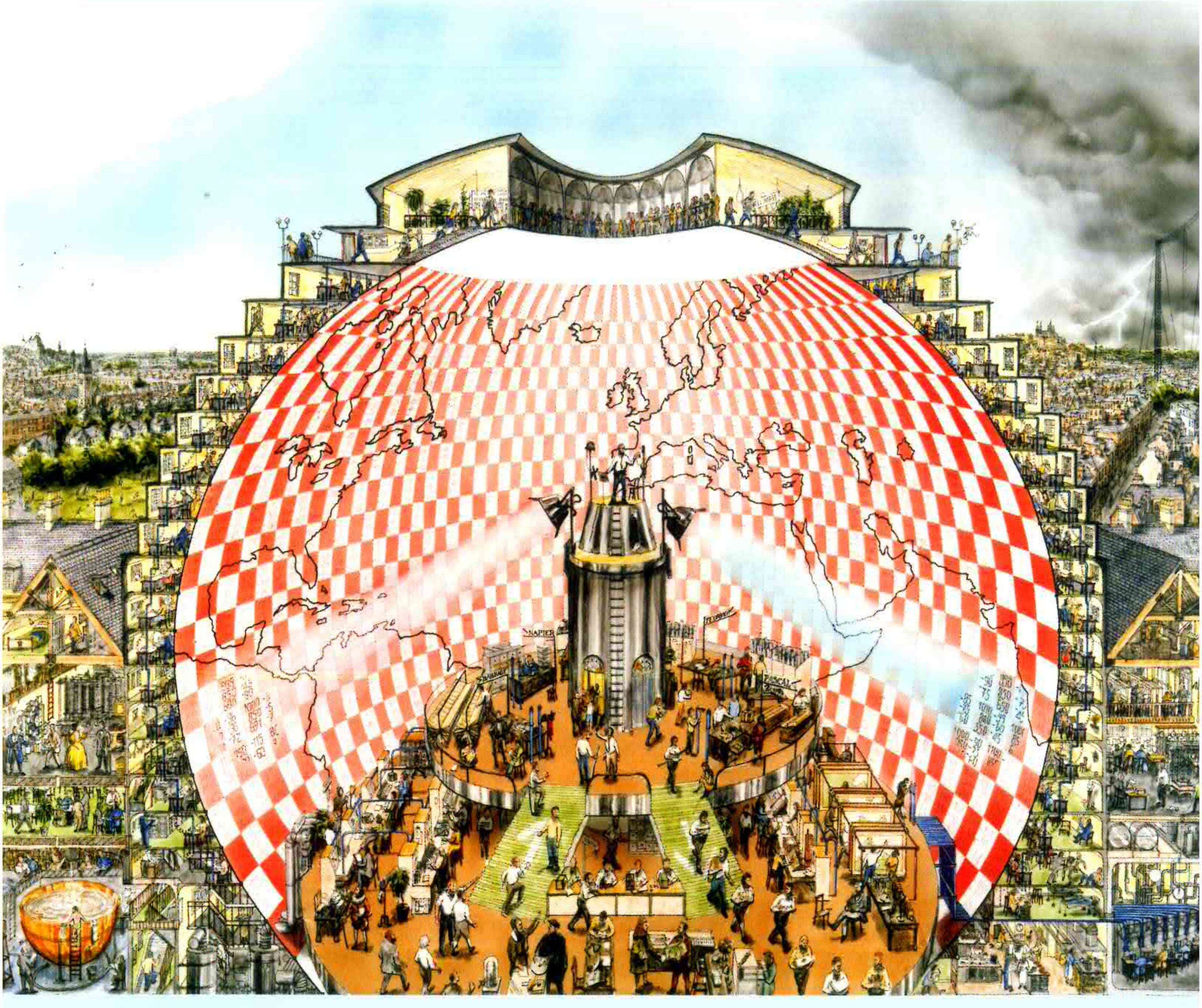

The North Atlantic Ocean and climate change

Pen portrait of P. A. Sheppard

Richardson's fantastic forecast factory

Missing the expected in the Cairngorms

An artist's impression of Richardson's fantastic forecast factory[1]

Peter Lynch

School of Mathematics and Statistics, University College Dublin

Introduction

In 1922 Lewis Fry Richardson published a remarkable book, *Weather Prediction by Numerical Process*, describing his attempt to forecast changes in the weather by numerical means. In his preface, Richardson wrote: *This investigation grew out of a study of finite differences and first took shape in 1911 as the fantasy which is now relegated to Ch. 11/2.*

Weather Prediction by Numerical Process

Richardson devised a method of solving the mathematical equations that describe atmospheric flow by dividing the globe into cells and specifying the dynamical variables at the centre of each cell. Figure 2 shows the frontispiece of his book. His caption began: *An arrangement of meteorological stations designed to fit with the chief mechanical properties of the atmosphere*. Pressure was to be observed at the centre of each shaded chequer and wind velocity at the centre of each white one. This staggered grid was designed to harmonise with the structure of the dynamical equations.

Chapter 11 of Richardson's book is entitled *Some Remaining Problems*. The running header on page 219 is *A Forecast Factory* and §2 on that page is headed *The Speed and Organization of Computing*. Here Richardson presents what he calls his 'fantasy', describing in detail his remarkable vision of an enormous building, similar in some respects to the Royal Albert Hall in London. Richardson did not state the source of his inspiration, but he must have been familiar with the large assembly of (human) computers at University College London which was organised by the renowned statistician Karl Pearson. Richardson was a mathematical assistant to Pearson in 1907 (Ashford, 1985).

Several artists have created images of the forecast factory. One particular image, which has recently come to light, is described in this note. The painting in Figure 1, in ink and watercolours, was made by Stephen Conlin in 1986, on the commission of John Byrne, then Head of the Department of Computer Science in Trinity College, Dublin, who provided both Richardson's text and suggestions regarding the inclusion of important figures from the history of mathematics and computation (for a range of work by Stephen Conlin, see http://www.pictu.co.uk).

During the annual IFIP Congress (International Federation for Information Processing) in September 1986, the painting was part of an exhibition in the Long Room in Trinity College, *Computing through the Ages*. The painting, which has been displayed in an obscure location within the department and has gone unnoticed for many years, is a remarkable work, rich in detail and replete with hidden gems.

Richardson's fantasy

Richardson showed remarkable foresight when he penned his famous fantasy. Let

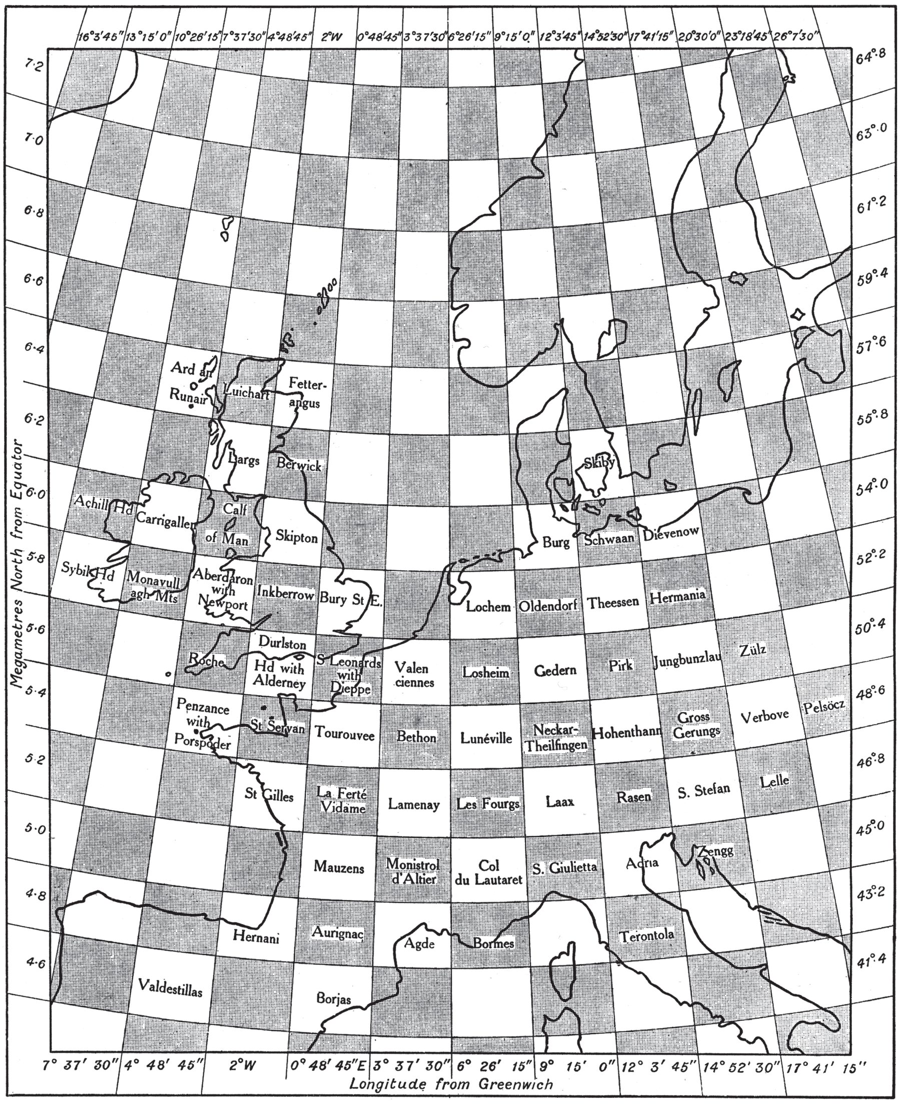

Figure 2. Frontispiece of Richardson's Weather Prediction by Numerical Process.

[1]Dedicated to Oliver M. Ashford, Hon FRMetS, on the occasion of his 100th birthday.

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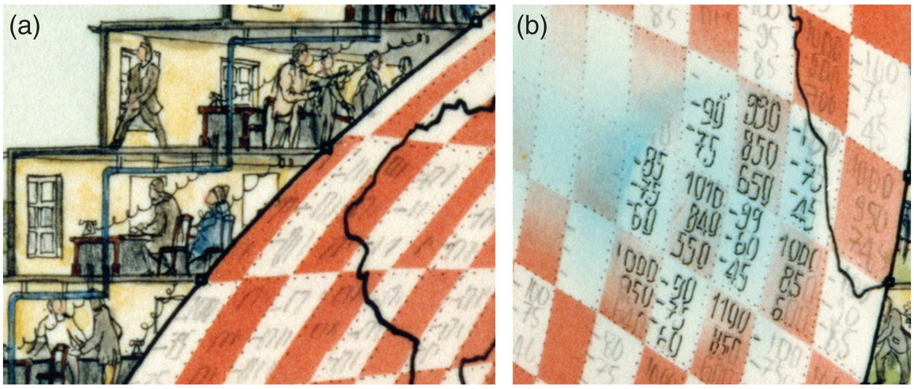

Figure 3. (a) Computers working on the region around Hudson Bay. (b) A section of the computational grid.

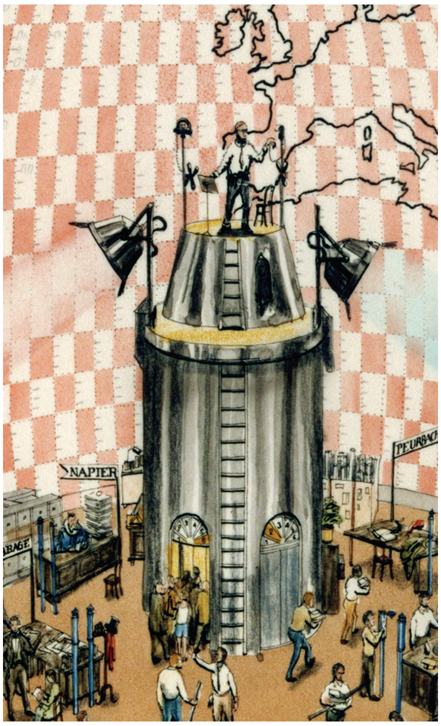

Figure 4. Director of operations standing on central tower. The figure of the director represents Lewis F. Richardson.

us take the words he wrote on page 219 of *Weather Prediction by Numerical Process*, and relate them to Conlin's illustration:

> *After so much hard reasoning, may one play with a fantasy? Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The walls of this chamber are painted to form a map of the globe. The ceiling represents the north polar regions, England is in the gallery, the tropics in the upper circle, Australia on the dress circle and the antarctic in the pit.*

Conlin's image (Figure 1 – front cover) depicts a huge building, some 20 storeys high, with a vast central chamber, spherical in form. On the wall of this chamber is a map with roughly half the globe visible, divided into red and white chequers, like Richardson's grid (Figure 2). The numbers in the red cells represent pressure at the model levels (Richardson's model had five layers) and those in the white cells are momenta or winds.

Richardson's description continues:

> *A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation. The work of each region is coordinated by an official of higher rank. Numerous little 'night signs' display the instantaneous values so that neighbouring computers can read them. Each number is thus displayed in three adjacent zones so as to maintain communication to the North and South on the map.*

Note that Richardson's 'computers' are human. The image divides the globe into about 20 zones, corresponding to an average grid-step of 9° latitude. Figure 3 shows the computers working on a region around Hudson Bay in Canada (left) and a section of the computational grid near India (right); the blue hue indicates that the computations here are falling behind.

> *From the floor of the pit a tall pillar rises to half the height of the hall. It carries a large pulpit on its top. In this sits the man in charge of the whole theatre; he is surrounded by several assistants and messengers. One of his duties is to maintain a uniform speed of progress in all parts of the globe. In this respect he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines. But instead of waving a baton he turns a beam of rosy light upon any region that is running ahead of the rest, and a beam of blue light upon those who are behindhand.*

The Director of Operations stands on a dais atop the tower. He coordinates the computations, signalling by spotlight to those who are racing ahead or lagging behind. There are striking similarities between Richardson's forecast factory and a modern massively parallel processor (MPP). Richardson envisaged a large number of processors – his estimate was 64 000 – working in synchronous fashion on different sub-tasks. In fact, 64 000 was a substantial underestimate (see Lynch (2006), Appendix 4).

The forecasting job was subdivided, or parallelised, using domain decomposition, a technique often used in MPPs today. Richardson's 'night signs' provided nearest-neighbour communication, analogous to message-passing techniques in MPPs. The director in the pulpit (Lewis F. Richardson in Figure 4) with his blue and rosy beams, acted as a synchronisation and control unit.

> *Four senior clerks in the central pulpit are collecting the future weather as fast as it is being computed, and despatching it by pneumatic carrier to a quiet room. There it will be coded and telephoned to the radio transmitting station. Messengers carry piles of used computing forms down to a storehouse in the cellar.*

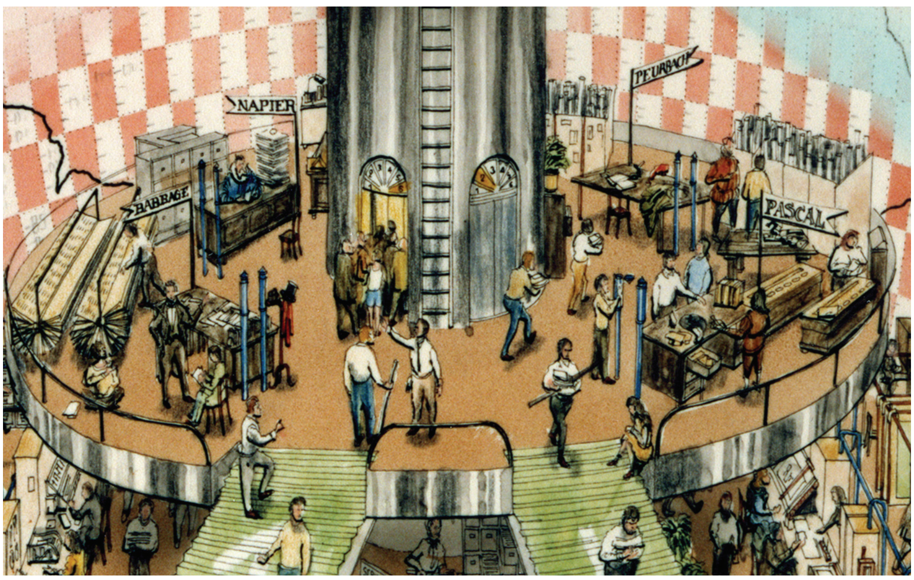

Figure 5. The upper floor. Banners identify the main characters (see also Table 1).

The upper floor, with the desks of the four senior clerks, is shown in Figure 5. A banner on each desk identifies a major figure in the history of computing: Babbage, Napier, Peurbach and Pascal. Beside each desk stands a pair of pneumatic tubes for dispatching results.

Historical characters in the image

Several scholars and savants are depicted in the painting of the forecast factory. The artist, Stephen Conlin, provided a numerical key to the most important of these. It is reproduced in Figure 6.

A list of the individuals corresponding to each letter in the key was prepared by John Byrne at the time the painting was completed. Table 1 is an expanded version of this list.

Pneumatic carriers were systems that propelled cylindrical containers through a pipe network using compressed air. Pneumatic tube networks were popular in the late nineteenth and early twentieth centuries for transport of mail, documents or money within a building, or even across a city. Their use in Richardson's forecast factory is similar to their use in large retail stores, to transport documents to and from a centralised 'Tube Room', where operators could process or redistribute them.

Figure 7 shows the Tube Room. Blue pneumatic tubes can be seen throughout the building. An electrical switchboard on the right controls distribution of forecasts by radio transmission. The antenna is near the top right side of the main picture.

In a neighbouring building there is a research department, where they invent improvements. But there is much experimenting on a small scale before any change is made in the complex routine of the computing theatre.

Figure 8. Computer Laboratory. The apparatus on the lower level is Scheutz's Difference Engine. On the upper level, Hollerith Machines are shown.

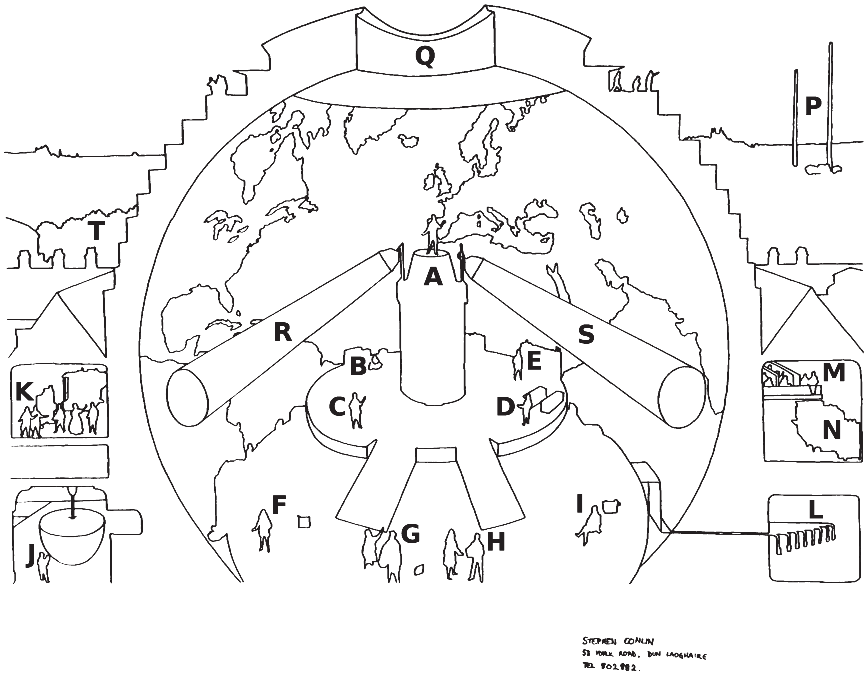

Figure 6. Labelled sketch by the artist, Stephen Conlin, identifying historical characters in the image (see Table 1).

Figure 9. A large hemispheric bowl spinning on a turntable, for geophysical experiments. The figure standing below the tank is Sir G. I. Taylor. More water tanks are seen to the left.

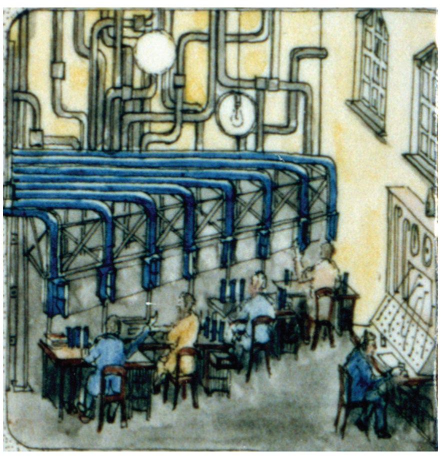

Figure 7. Tube Room for pneumatic carriers. The network extends throughout the forecast factory.

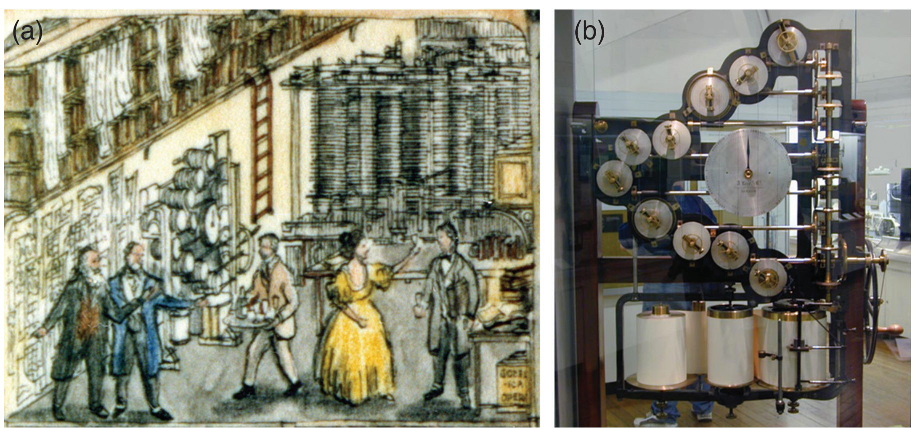

Figure 10. (a) The machine with dials is the tide-predicting machine of Kelvin. The machinery behind Ada Lovelace is Babbage's Analytical Engine. (For identities of the characters, see Table 1, entry K.) (b) Tide-predicting machine at the Science Museum, London. (Source: William M. Connolley, Wikipedia.)

Table 1

Historical characters in the image (see Figure 6)

A	Lewis F. Richardson (1881–1953) in the pulpit, directing operations.
B	John Napier (1550–1617), inventor of logarithms, which had a profound influence on the course of astronomy and of science in general.
C	Charles Babbage (1791–1871), mathematician, inventor and mechanical engineer, originated the concept of a programmable computer and designed highly advanced mechanical calculating machinery.
D	Blaise Pascal (1623–1662), French mathematician, inventor, writer and philosopher. When only 18 years old, he constructed a mechanical calculator capable of addition and subtraction, called the *Pascaline*.
E	Georg von Peurbach (1423–1461), Austrian astronomer and instrument maker who arranged for the first printed set of sines to be computed. He also computed a set of eclipse tables, the *Tabulae Eclipsium,* which remained highly influential for many years.
F	Edmund Gunter (1581–1626), English clergyman and mathematician, inventor of the logarithmic ruler.
G	William Oughtred (1574–1660), English mathematician and Anglican minister, inventor of the slide rule. Walter Lilly (c. 1900), Lecturer in Mechanical Engineering, Trinity College Dublin, with his circular rule.
H	Gottfried Wilhelm von Leibniz (1646–1716), mathematician and philosopher who invented the first mass-produced mechanical calculator. His 'Stepped Reckoner', which performed addition, subtraction, multiplication and division, is illustrated on the table behind him, between Leibniz and George Fuller (one-time Professor of Engineering at Queen's College, Belfast) with his spiral rule.
I	Per Georg Scheutz (1785–1873), Swedish lawyer, translator, inventor and builder of the first practical difference engine. Scheutz's calculator was used for generating tables of logarithms.
J	Sir G. I. Taylor (1886–1975), distinguished hydrodynamicist, grandson of George Boole.
K	The Arithmetic Research Room. Left to right: Lord Kelvin (1824–1907) and his brother James Thomson (with a ball and disk integrator); Percy Ludgate (1883–1922), Irish inventor of an Analytical Engine; Ada Lovelace (1815–1852), daughter of Lord Byron and friend of Babbage; George Boole (1815–1864), inventor of Boolean algebra.
L	Tube Room, or 'quiet room', in which weather information is communicated within the forecast factory by pneumatic tube and to and from the outside world by wireless telegraphy.
M	Hollerith Machines in the research department.
N	Scheutz Difference Engine in the research department.
P	Radio masts for reception of observations and transmission of forecasts.
Q	Public viewing gallery.
R	A rosy light – shone on computers who are forward in their computations.
S	A blue light – shone on computers who are behind in their computations.
T	Recreation area, since *those who compute the weather should breathe of it freely.*

Figure 11. Fun and games in the park behind the forecast factory.

In the building on the right of Figure 1 there is a large room containing computing equipment (Figure 8). Presumably, this is where senior operatives are developing strategies for improving the forecasting operations. The banner reads 'Scheutz Difference Engine'. Figure 9 shows the rotating hemispheric bowl.

> *In a basement an enthusiast is observing eddies in the liquid lining of a huge spinning bowl, but so far the arithmetic proves the better way. In another building are all the usual financial, correspondence and administrative offices.*

In Figure 10 we see Kelvin's tide-predicting machine. This machine was designed by William Thomson (Lord Kelvin) in 1876 and combined ten tidal components. It could trace the heights of the tides for 1 year in about 4 hours.

> *Outside are playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely.*

Richardson, with his Quaker background, was no slave-driver. He anticipated the need for what we now call a good work–life balance. The above quotation is indicative of his humanitarian spirit (Figure 11). He spent the last few decades of his life studying the statistics of warfare in the hope of identifying the causes of human conflict.

Summary

The above extracts are just a small sample of what the original image contains. Examination of the high-resolution image with a computer visualisation program is a rewarding experience and will reveal a wealth of other interesting details. A high-resolution version of Conlin's image is available on the website of the European Meteorological Society, at http://www.emetsoc.org/resources/rff.

Acknowledgements

My thanks first to John Byrne for allowing a copy of his painting to be made and used, and for consultation regarding the background to it, and to Dan McCarthy, Trinity College Dublin, who brought the painting to my attention and arranged the high-resolution scan of it. Special thanks to the artist, Stephen Conlin, for generously permitting reproduction of the image and for information about it.

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Correspondence to: Peter Lynch

Peter.Lynch@ucd.ie

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Missing the expected in the Cairngorms, 1 July 2015

John Turnpenny

University of East Anglia, Norwich

I knew as soon as we left the house that the day was one to remember. The whole country had been talking about it for a week. *There's a heat wave on the way, and it's peaking next Wednesday*. Yes, we were determined not to forget it.

This isn't the Lake District; you don't walk up a big peak and back to your car in a day with a box of sandwiches. But there's an obvious exception. The plan was simple, the easiest way up any of the serious summits without cheating on the funicular railway: park in the Cairn Gorm Ski Centre car park and just climb up via the Tooth of Choire Chais. Then come back down again. A dry, sunny, warm day, 35°C in distant London should translate to 'perfect' four thousand feet higher and four hundred miles north. Occasional thunderstorms were predicted for late afternoon, with the main downpours coming in the night. Leave at nine, start walking at eleven, tea and shortbread at the bottom by three.

In the morning, 4 miles upstream from Braemar, it was 21°C at 9am. A sign of a special day in southern England, never mind up here. Different from a regular summer day – the air felt different, laden, at once heavy with heat and light with expectation. By Tomintoul, one of the highest villages in Scotland, it was 24°C, and still only 10am. Down to Grantown and Aviemore late morning, 28°C now and rising.

This wasn't just a nice day, or even a hot day. It was exceptional. And we were ready. Extra water, extra sunscreen, extra food, extra head gear, sunglasses, map, compass. And a spare bottle to take home a piece of one of the remaining snow patches. The going was unexpectedly hard on our English thighs, and the air, with barely an ounce of moisture, scorching in our lungs. This felt like the Pyrenees or the Canadian Rockies, not Scotland. Feeling ourselves overheating, we needed regular drink and cooling stops. A long lunch, stretched out in a little gully, higher than anyone in England, the heather crisp and the granite radiating heat back at us. A welcome stop at the edge of a snow patch, enjoying the ice while bathed in sunshine.

Looking up from the ice, nearing the top of the Tooth, our sky of blue with white flecks had thickened a little. And a little more. The next breeze brought something more than a stirring of the hot air, it brought a new air with it.

Nearing the top, the sky opened out with each step, revealing a new view south of Cairn Gorm. New valleys, new ridges, new snow patches, new lochs and new weather. Hannah heard it first – thunder? Or just the wind? Only feet to go now, scrambling to reach the secondary 'summit': 1141m (3742 feet), the highest I've ever been in Britain. And finally a full view south from the mountain, into the face of a mass of black cloud, its base well below us, pouring rain into the slopes a mile or two away. We both heard thunder then. No lightning,

Figure 1. Clouds developing over Cairn Gorm on 1 July 2015. The 'Tooth' can be seen in the centre with snow patches on it, with the main summit of Cairn Gorm on the left. (© Hannah Garrard.)

but a prickling primordial danger. The main summit still more than 1km away and even higher up. The ski centre distant below us. No nearby caves, no huts, no shelter, and us two of the highest points in the country. My mind jumbled with pieces of advice, knowledge, scraps of common sense, memories of mountains. The August Saturday on Helvellyn twenty years since, stung and blinded by a sudden hailstorm onto a scree slope with a 300m drop. The section in *What To Do In An Emergency* on *Thunderstorms – Seeking Shelter*. The meteorology lectures on cloud physics so long ago. (Did I get a 2:1 for that exam?) The opening bars of Mussorgsky's *Night on a Bare Mountain*. Johnny Autery's famous photo of lightning striking a tree, showing all the 'streamers' questing upwards to be the one that made the connection