Forecasts by PHONIAC

Weather – November 2008, Vol. 63, No. 11

Peter Lynch[1] and Owen Lynch[2]

[1]*University College Dublin, Meteorology and Climate Centre, Dublin*
[2]*Dublin Software Laboratory, IBM Ireland*

The first computer weather forecasts were made in 1950, using the ENIAC (Electronic Numerical Integrator and Computer). The ENIAC forecasts led to operational numerical weather prediction within five years, and paved the way for the remarkable advances in weather prediction and climate modelling that have been made over the past half century. The basis for the forecasts was the barotropic vorticity equation (BVE). In the present study, we describe the solution of the BVE on a mobile phone (cell-phone), and repeat one of the ENIAC forecasts. We speculate on the possible applications of mobile phones for micro-scale numerical weather prediction.

The ENIAC Integrations

The ENIAC forecasts were described in a seminal paper by Jule Charney, Ragnar Fjørtoft and John von Neumann (1950; cited below as CFvN). The story of this work was recounted by George Platzman in his Victor P. Starr Memorial Lecture (Platzman, 1979). The atmosphere was treated as a single layer, represented by conditions at the 500 hPa level, modelled by the BVE. This equation, expressing the conservation of absolute vorticity following the flow, gives the rate of change of the Laplacian of height in terms of the advection. The tendency of the height field is obtained by solving a Poisson equation with homogeneous boundary conditions. The height field may then be advanced to the next time level. With a one hour time-step, this cycle is repeated 24 times for a one-day forecast.

The initial data for the forecasts were prepared manually from standard operational 500 hPa analysis charts of the U.S. Weather Bureau, discretised to a grid of 19 by 16 points, with grid interval of 736 km. Centred spatial finite differences and a leapfrog time-scheme were used. The boundary conditions for height were held constant throughout each 24-hour integration. The forecast starting at 0300 UTC, January 5, 1949 is shown in Fig. 1 (from CFvN). The left panel is the analysis of 500 hPa geopotential and absolute vorticity. The forecast height and vorticity are shown in the right panel. The feature of primary interest was an intense depression over the United States. This deepened, moving NE to the 90 ºW meridian in 24 hours. A discussion of this forecast, which underestimated the development of the depression, may be found in CFvN and in Lynch (2008).

Dramatic growth in computing power

The oft-cited paper in *Tellus* (CFvN) gives a complete account of the computational algorithm and discusses four forecast cases. The ENIAC, which had been completed in 1945, was the first programmable electronic digital computer ever built. It was a gigantic machine, with 18,000 thermionic valves, filling a large room and consuming 140 kW of power. Input and output was by means of punch-cards. McCartney (1999) provides an absorbing account of the origins, design, development and destiny of ENIAC.

Advances in computer technology over the past half-century have been spectacular. The increase in computing power is encapsulated in an empirical rule called Moore's Law, which implies that computing speed

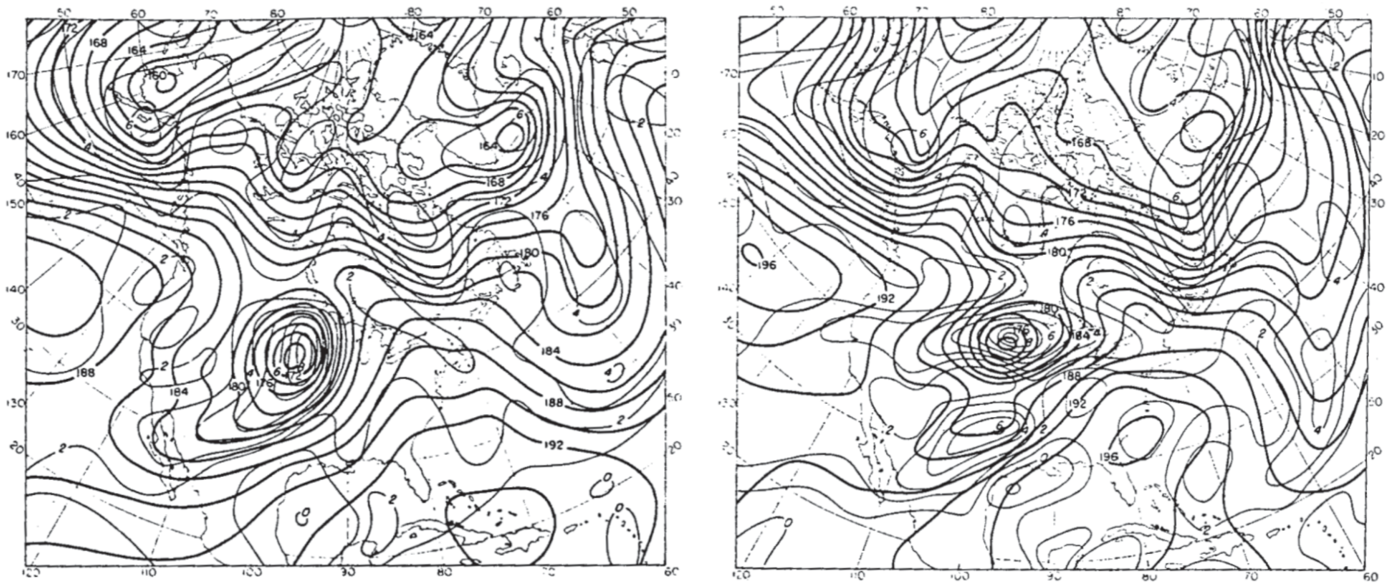

Figure 1. The ENIAC forecast starting at 0300 UTC, 5 January, 1949. Left panel: Analysis of 500 hPa geopotential (thick lines) and absolute vorticity (thin lines). Right panel: Forecast height and vorticity (from Charney, et al., *1950). Height units are hundreds of feet, contour interval is 200 ft. Vorticity units and contour interval are 10–5 s–1. One line is omitted from the southern edge and two lines from the remaining edges.*

RMetS
Royal Meteorological Society

doubles about every 18 months. Thus, a modern microprocessor has far greater power than the ENIAC had. We therefore decided to repeat the ENIAC integrations using a programmable mobile phone. This technology has great potential for generation and display of operational weather forecast products.

The principal designers of ENIAC were John Mauchly and Presper Eckert. It is noteworthy that Mauchly's interest in computers arose from his desire to forecast the weather by calculation. The computer was originally called the Electronic Numerical Integrator. A US Army Colonel suggested adding the words 'and Computer' to give the catchy acronym ENIAC (McCartney, 1999). This set a trend for naming computers: later machines designed by Mauchly and Eckert were called EDVAC, BINAC and UNIVAC. Computers based on John von Neumann's design were called JOHNNIAC and ILLIAC. Nicholas Metropolis of Los Alamos National Laboratory named his version of this line MANIAC (Mathematical Analyzer, Numerator, Integrator and Computer) in the hope of stemming the tide of silly acronyms. But his was a vain hope: the first Australian computer was called SILLIAC (Sydney version of ILLIAC). In the tradition of constructing names of ever-increasing daftness, we unashamedly call our cell-phone weather forecasting device the Portable Hand-Operated Numerical Integrator and Computer, or PHONIAC.

Recreating the forecasts

Lynch (2008) presented the results of repeating the ENIAC forecasts using a Matlab program `eniac.m`, run on a laptop computer (a Sony Vaio, model VGN-TX2XP). The main loop of the 24-hour forecast ran in about 30 ms. Given that the original ENIAC integrations each took about one day, this time ratio – about three million to one – indicates the dramatic increase in computing power over the past half century. The program `eniac.m` was converted from MatLab to a Java application, `phoniac.jar`, for implementation on a mobile phone. Java Platform, Micro Edition (Java ME) is a system for the development of software for small, resource-limited devices such as cell phones. The program `phoniac.jar` was tested on a PC using emulators for three different mobile phones. A basic graphics routine was also written in Java. When working correctly, the program was downloaded onto a Nokia 6300 for execution.

Charney *et al.* (1950) provided a full description of the solution algorithm for the BVE. The programs `eniac.m` and `phoniac.jar` were constructed following the original algorithm precisely, including the specification of the boundary conditions and the Fourier transform solution method for the Poisson equation. Hence, given initial data identical to that used in CFvN, the recreated forecasts should be identical to those made in 1950. Of course, the reanalysed fields are not identical to those originally used, and the verification analyses are also different. Nevertheless, the original and new results are very similar.

The initial fields for the four ENIAC forecasts were valid for dates in January and February, 1949. A retrospective global analysis of the atmosphere, covering more than 50 years, has been undertaken by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (Kistler *et al.,* 2001). This reanalysis extends back to 1948, including the period chosen for the ENIAC integrations. The reanalyzed data are available on a 2.5° by 2.5° grid. The GRIB fields of the 500 hPa analyses were downloaded from the NCEP/NCAR reanalysis website, converted from GRIB to ASCII and interpolated to the ENIAC grid.

Figure 2 shows the recreated forecast for 0300 UTC on January 6. The main features of the analysis (left panel) and forecast (right panel) are in broad agreement with the originals in Figure 1. This forecast, run on the laptop computer with the program `eniac.m`, is discussed in Lynch (2008). In Figure 3 we show PHONIAC and the forecast for 0300 UTC, 6 January, 1949 made with the program `phoniac.jar`. It is identical to the forecast in Figure 2 (maximum difference 0.01 m).

In CFvN it is noted that the computation time for a 24-hour forecast was about 24 hours, that is, the team could just keep pace with the weather provided the ENIAC did not fail. This time included off-line operations: reading, punching and interfiling of punch cards. PHONIAC executed the main loop of the 24-hour forecast in less than one second. The main steps in the solution algorithm are presented in Lynch (2008, Appendix B). For the benefit of students, the MatLab and Java codes are available on a website (http://maths.ucd.ie/~plynch/eniac/). Maps of the four original and recreated forecasts are also available there, along with miscellaneous supplementary material relating to the ENIAC integrations.

Micro-scale forecasting

The computing power of cell-phones is significant, and is growing rapidly. The Nokia 6300 runs at a frequency of about 237 MHz, with one million instructions per second (MIPS) per MHz. The phone supports 'jazelle', a technology to execute Java byte-code in hardware, so that one instruction translates into one floating point operation. Thus, we may estimate the peak speed

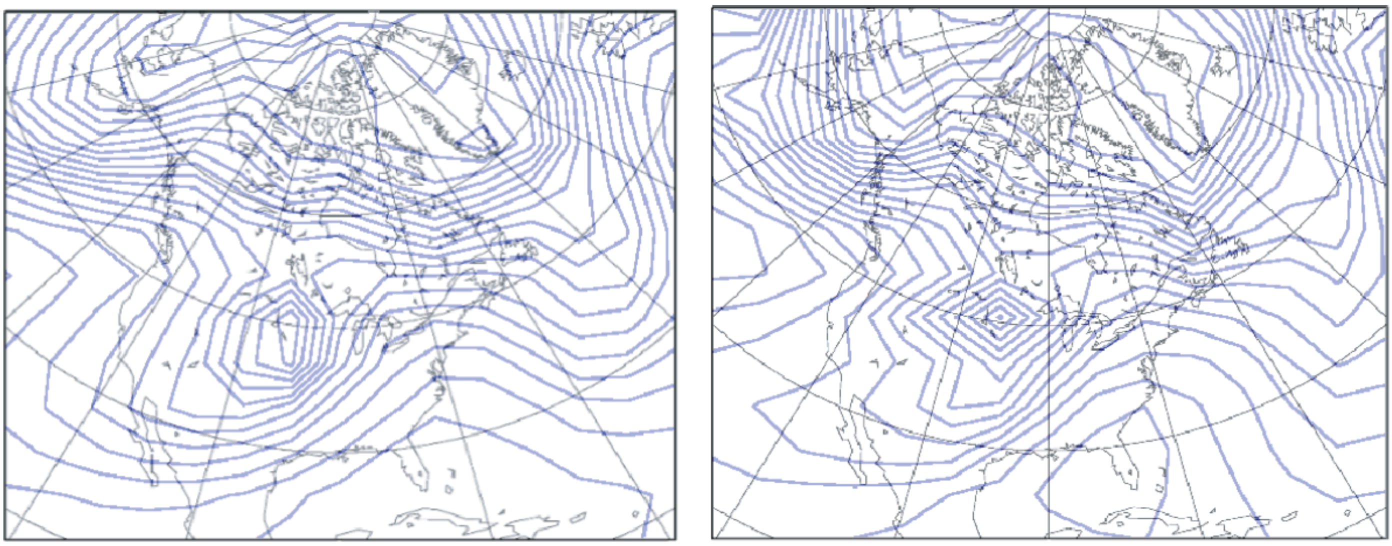

Figure 2. Reconstruction of the ENIAC 24-hour forecast starting at 0300 UTC, 5 January, 1949. Left panel: Analysis of 500 hPa geopotential. Right panel: 24-hour forecast geopotential made with the program `eniac.m`. No contour smoothing has been applied and boundary rows have been clipped, as in CFvN. The contour interval is 50 m.

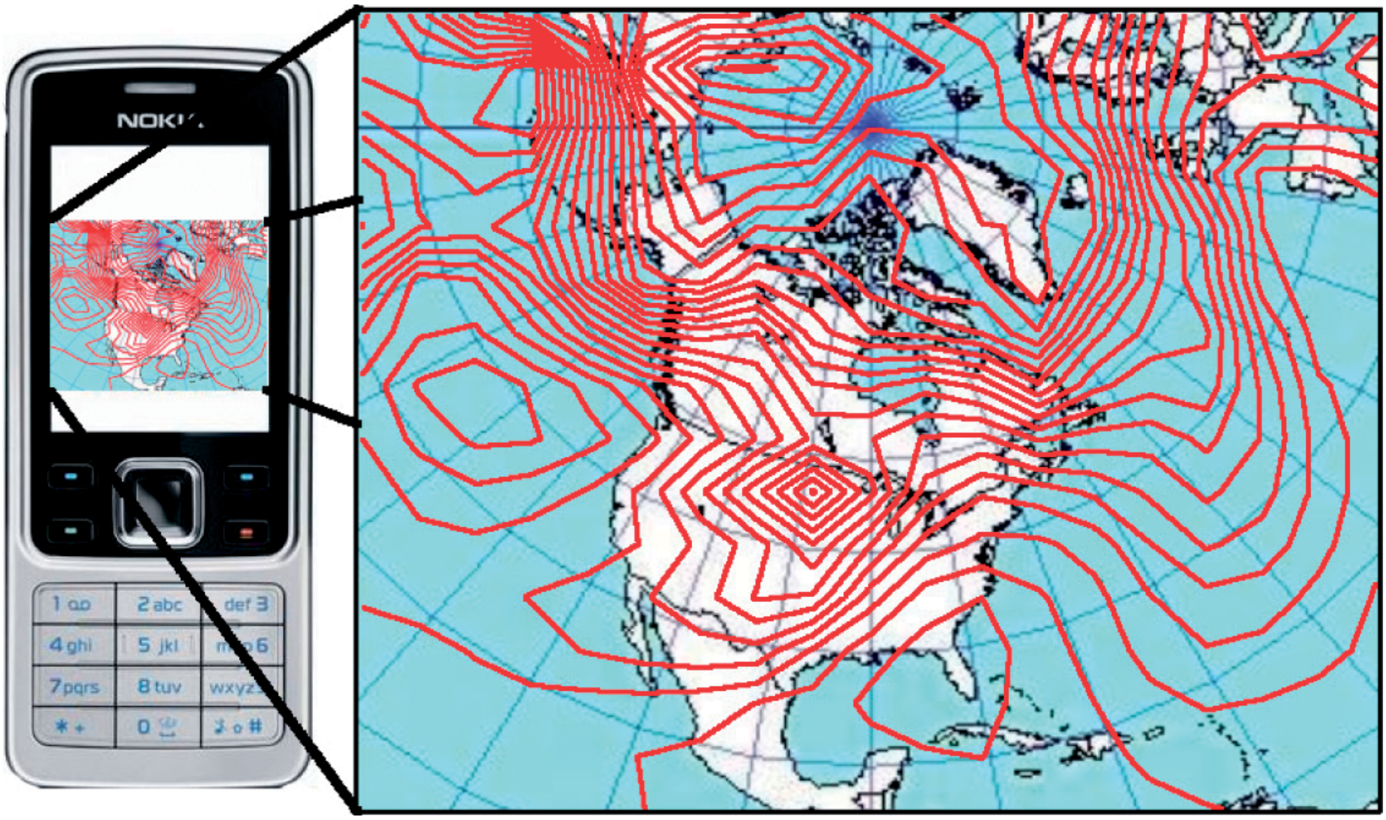

Figure 3. The Nokia 6300, dubbed PHONIAC (left) and the forecast for 0300 UTC, 6 January, 1949 (right) made with the program `phoniac.jar`*. The contour interval is 50 m, as in Figure 2. The complete forecast area, including boundary points, is shown.*

of PHONIAC to be 237 MFLOPS (million floating-point operations per second). The CRAY-1, the first super-computer acquired by the European Centre for Medium-Range Weather Forecasts (ECMWF) reached 160 MIPS. Making full use of the vector features (which is feasible for meteorological applications) the CRAY-1 peaked at about 250 MFLOPS. Thus, in terms of raw computational power the CRAY-1 and the Nokia 6300 are in the same league. The CRAY-1 used some 115 kW, comparable to ENIAC; the Nokia 6300 uses about 1.5W under a full load.

The graphics capabilities of modern mobile phones are also impressive. They provide a basis for local processing of meteorological data. For example, selected output from the Met Office 4 km UK model (http://www.metoffice.gov.uk/research/nwp/numerical/operational/) could be acquired with a high time-frequency and statistically or dynamically downscaled to sub-kilometre resolution. Combining this with GPS data and high-resolution topographical data, local adaptation of the flow could be simulated. One could imagine a yachtsman modelling local eddies during a race in the Solent, or an engineer extrapolating a sequence of radar images to anticipate a downpour on a construction site in difficult terrain. There are many possibilities for adding value to general forecasts for specific applications. Perhaps PHONIAC will be the forerunner of such micro-scale forecasting systems, just as ENIAC foreshadowed global and regional numerical weather prediction.

Acknowledgements

The assistance of Chi-Fan Shih in acquiring the NCEP/NCAR reanalysis data is gratefully acknowledged. The java function atan2 uses code written by Paulo Costa. We thank Hendrik Hoffman, UCD, for advice on the comparative power of PHONIAC and Cray-1.

References

Charney J. G, Fjørtoft R. and von Neumann J., 1950. Numerical Integration of the Barotropic Vorticity Equation. *Tellus,* **2**: 237–254.

Kistler R, Kalnay E, Collins W, Saha S, White G, Woollen J, Chelliah M, Ebisuzaki W, Kanamitsu M, Kousky V, van den Dool H, Jenne R, Fiorino M. 2001. The NCEP-NCAR 50-Year Reanalysis: monthly means, CD-ROM and documentation. *Bull. Amer. Met. Soc.*, **82**: 247–268.

Lynch P. 2008. The ENIAC forecasts: a recreation. *Bull. Amer. Met. Soc.,* **89**: 45–55.

McCartney S. 1999. ENIAC: *The triumphs and tragedies of the world's first computer.* Berkley Books, New York, 262pp.

Platzman G W. 1979. The ENIAC computations of 1950 - gateway to numerical weather prediction. *Bull. Amer. Met. Soc.,* **60**: 302–312.

Correspondence to: Peter Lynch,
UCD Meteorology and Climate Centre,
School of Mathematical Sciences,
University College Dublin,
Belfield,
Dublin 4,
Ireland

Email: Peter.Lynch@ucd.ie

DOI: 10.1002/wea.241

RMetS
Royal Meteorological Society