A century of numerical weather prediction: The view from Limerick

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Just 100 years ago, the Norwegian scientist Vilhelm Bjerknes mapped out a two-step plan for rational weather forecasting (Bjerknes 1904). The first step was a quantitative analysis of the state of the atmosphere, expressed as a series of charts valid at an initial time. The second step was a systematic method of graphical processing, to deduce how this state would evolve over time. Bjerknes used the medical terms 'diagnostic' and 'prognostic' for these two steps:

Bill Bjerknes defined, with conviction,
The science of weather prediction:
By chart diagnosis,
And graphic prognosis,
The forecast is rendered non-fiction.

In the same year that Bjerknes published his 'manifesto', the Austrian meteorologist Max Margules considered the possibility of predicting pressure changes by direct use of the continuity equation (Margules 1904). He showed that the calculation of divergence is very error-prone, so that, to obtain an accurate estimate of the pressure tendency (where dp/dt represents the change in pressure with time), the winds must be known to an impossible precision (Lynch 2003). Margules (pronounced 'MAHR-goo-lez') concluded that any attempt to forecast synoptic changes by this means was doomed to failure:

Said Margules, with trepidation,
"There's hazards with mass conservation:
Gross errors you'll see
In dee-pee-dee-tee,
Arising from blind computation."

The lines are best spoken in West Country style.

During the First World War, Lewis Fry Richardson carried out a manual calculation of the change in pressure over central Europe (Richardson 1922). His initial data were based on Bjerknes' synoptic charts. From these data he computed the rate of change of pressure at a single point. To do this, he used the continuity equation, employing precisely the method which Margules had shown to be problematical. The resulting prediction of pressure change was 145 hPa (mbar) in six hours, a completely unrealistic result:

Young Richardson wanted to know
How quickly the pressure would grow.
But, what a surprise, 'cos
The six-hourly rise was,
In Pascals: One Four Five Oh Oh!

At some later stage, Richardson did come to a realisation that his method was unfeasible. He went on to speculate that the vertical component of vorticity might be a suitable prognostic variable. This foreshadowed the use of the vorticity equation for the first successful numerical integration. Charney (1948) analysed the primitive equations using the technique of scale analysis, and simplified them in such a way that the gravity-wave solutions were completely eliminated. The resulting equation is the quasi-geostrophic potential vorticity equation:

Jule Charney was quite philosophic:
"The system called Q-geostrophic,
With filtered equations
Sans fast oscillations,
Will obviate trends catastrophic."

In 1950 the non-divergent barotropic vorticity equation was numerically solved on the Electronic Numerical Integrator And Computer, the ENIAC. The result was a realistic forecast (Charney *et al*. 1950). Charney sent an account to Richardson, who congratulated him and his collaborators on the "enormous scientific advance" which had been made. So, we may conclude that:

Old Richardson's fabulous notion
Of forecasting turbulent motion
Seemed totally off-the-track,
But then came the ENIAC,
To model the air and the ocean.

Progress over the past 50 years has been dramatic, but we have also learned much about the limitations of deterministic forecasting. Edward Lorenz elucidated the role of chaos in forecasting when he presented a talk entitled "Predictability: Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" at a conference in Washington (Lorenz 1993). Thus:

Lorenz demonstrated, with skill,
The chaos of heatwave and chill:
Tornadoes in Texas
Are formed by the flexes
Of butterflies' wings in Brazil.

Beyond the short-range, focus has now shifted to predicting the probability of alternative weather events rather than a single outcome. The mechanism is the Ensemble Prediction System (EPS), and the world leader in this area is the European Centre for Medium-Range Weather Forecasts (ECMWF):

If errors still bother you, tough!
Uncertainty is 'the right stuff'.
It's anyone's guess,
So use EPS,
From ECM Double-you-uhf.

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