The Prehistory of Numerical Weather Prediction: Some Austrian Contributions

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Outline

Max Margules

Felix Exner

Lewis Fry Richardson

Forecast Factory
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1904: A Fateful Year

The year 1904 was pivotal for NWP:

- Max Margules demonstrated that weather prediction was fraught with danger.
- Felix Exner attempted an actual calculation of the atmospheric changes.
- Vilhelm Bjerknes’ announced his program for rational weather forecasting.
Max Margules (1856–1920)

In 1904, Margules published a paper in the *Festschrift* marking the sixtieth birthday of his former teacher, the renowned physicist Ludwig Boltzmann:

Über die Beziehung zwischen Barometerschwankungen und Kontinuitätsgleichung.
Margules’ Approach

- Margules considered the possibility of predicting pressure changes using the continuity equation.
- He showed that, to obtain an accurate estimate of the pressure tendency, the winds would have to be known to an impractically high accuracy.
- So forecasting synoptic changes by this means was doomed to failure.

Margules conclusion:
Weather forecasting is "immoral and damaging to the character of a meteorologist" (Quote: Fortak, 2001).
Tendency from Continuity Equation

- Region around Innsbruck.
- Square of side 15km.
- Like a cell of an atmospheric model.
A Box of Air over Innsbruck

Influx equals Outflow: Pressure unchanged.

Influx exceeds Outflow: Pressure will rise.
Assume a westerly wind over Innsbruck

\[ u > 0 , \quad v = 0 . \]

Assume the surface pressure is initially 1000 hPa.

Using Conservation of Mass, a simple calculation yields the following amazing result:

- If the speed on the western side exceeds that on the east by 1 m/s, then \( \frac{\partial p_S}{\partial t} \approx 7 \text{ Pa/s} \).
- If this influx continues, the pressure will double in about 4 hours.
Pressure Tendency

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We must apply the continuity equation with great care!
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Felix Maria Exner (1876–1930)

First attempt to calculate synoptic changes using physical principles.

Exner’s method radically different from Bjerknes’.

He did not make direct use of the continuity equation.

His method used a system reduced to the essentials.
Exner’s Method

- Exner assumed that the atmospheric flow is **geostrophically balanced** and that the thermal forcing is constant in time.
- He deduced **mean zonal wind** from temperature.
- He then derived a **prediction equation** representing advection of the pressure pattern.
- His method yielded a **realistic forecast**.
Exner’s Forecast

Calculated Pressure Change
between 8pm and 12pm on 3 January, 1895.
Hundreths of an inch. [Steigt=rises; Fällt=falls].
Verification

Observed Pressure Change between 8pm and 12pm on 3 January, 1895. Hundredths of an inch. [Steigt=rises; Fällt=falls].
Richardson’s Reaction

Exner’s work deserves attention as a first attempt at systematic, scientific weather forecasting.

The only reference by Richardson to the method was a single sentence in his book *Weather Prediction by Numerical Process* (p. 43):

“F. M. Exner has published a prognostic method based on the source of air supply.”

It would appear from this that Richardson was not particularly impressed by it!

★ ★ ★ ★
As we shall shortly see:

- Exner’s forecast was unspectacular but reasonable.
As we shall shortly see:

- Exner’s forecast was unspectacular but reasonable.

whereas

- Richardson’s forecast was spectacularly unreasonable.
Pioneers of Scientific Forecasting

Cleveland Abbe, Vilhelm Bjerknes, Lewis Fry Richardson
By 1890, the American meteorologist Cleveland Abbe had recognized that:

*Meteorology is essentially the application of hydrodynamics and thermodynamics to the atmosphere.*

Abbe proposed a mathematical approach to forecasting.
A more explicit analysis of weather prediction was undertaken by the Norwegian scientist Vilhelm Bjerknes.

He identified the two crucial components of a scientific forecasting system:

- Analysis
- Integration
Bjerknes’ 1904 Manifesto

Objective:  
To establish a science of meteorology

Purpose:  
To predict future states of the atmosphere.

Necessary and sufficient conditions for the solution of the forecasting problem:

1. A knowledge of the initial state
2. A knowledge of the physical laws

Step (1) is Diagnostic. Step (2) is Prognostic.
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Forecast Factory
The English Quaker scientist Lewis Fry Richardson attempted a direct solution of the equations of motion.

He dreamed that numerical forecasting would become a practical reality.

Today, forecasts are prepared routinely using his methods . . .

. . . his dream has indeed come true.
Lewis Fry Richardson, 1881–1953.

During WWI, Richardson computed by hand the pressure change at a single point.

It took him two years!
Lewis Fry Richardson, 1881–1953.

During WWI, Richardson computed by hand the pressure change at a single point.

It took him two years!

His ‘forecast’ was a catastrophic failure:

$$\Delta p = 145 \text{ hPa in 6 hrs}$$

But Richardson’s method was scientifically sound.
Initialization of Richardson’s Forecast

Richardson’s Forecast was repeated on a computer.

The atmospheric observations for 20 May, 1910, were recovered from original sources.
Initialization of Richardson’s Forecast

Richardson’s Forecast was repeated on a computer.

The atmospheric observations for 20 May, 1910, were recovered from original sources.

- **ORIGINAL:** \[ \frac{\partial p_s}{\partial t} = +145 \text{ hPa/6 h} \]

- **INITIALIZED:** \[ \frac{\partial p_s}{\partial t} = -0.9 \text{ hPa/6 h} \]

Observations: The barometer was steady!
Richardson’s Forecast and the Emergence of NWP are described in this book.

[Cambridge Univ. Press, 2006]
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Richardson’s Forecast Factory
Zoom: Richardson Directing the Forecast

Lewis Fry Richardson conducting the forecast
Zoom: Historical Figures in Computing

Napier / Babbage / Pascal / Peurbach
Georg von Peuerbach (1423–1461)

Austrian astronomer, mathematician and instrument maker, best known for his *Theoricae Novae Planetarum*. 
Zoom: Communications & Computing

Left: Tube Room.  Right: Computer Laboratory
Zoom: Experimentation & Research

Left: Dish Pan. 

Right: Analytical Engine
Richardson’s Forecast Factory

64,000 Computers: the first Massively Parallel Processor
The Fantastic Forecast Factory

An Artist's Impression of Richardson's Fantastic Forecast Factory

Peter Lynch
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Description to appear in *Weather* magazine.

Preprint available on my website

Image to feature soon on the website of the European Meteorological Society
Thank you