The Prehistory of Numerical Weather Prediction: Some Austrian Contributions

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Outline

Max Margules

Felix Exner

Lewis Fry Richardson

Forecast Factory

Outline

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

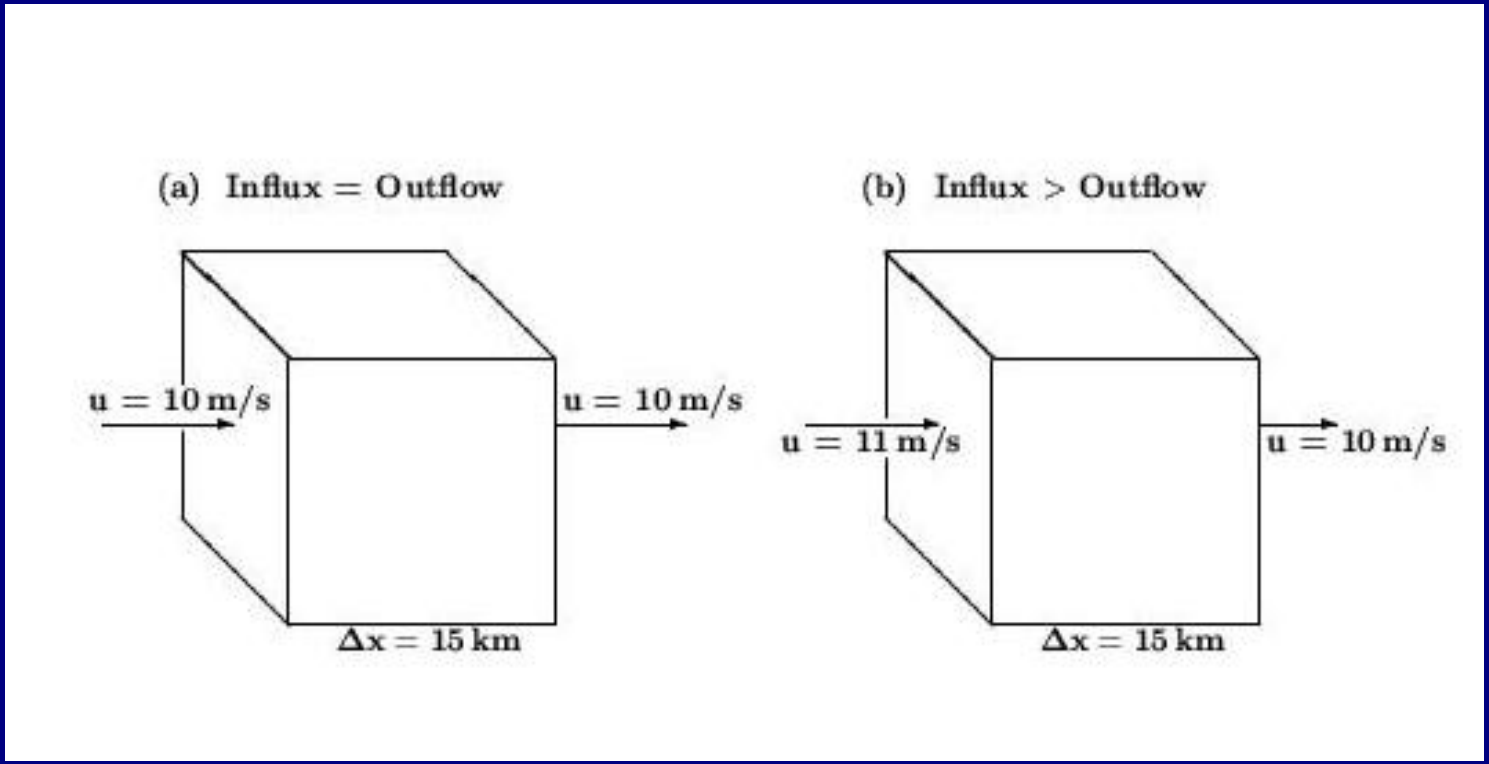
- Margules considered the possibility of predicting pressure changes using the continuity equation.
- He showed that, to obtain an accurate estimate of the pressure tendency, the winds would have to be known to an impractically high accuracy.
- So forecasting synoptic changes by this means was doomed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

Pressure Tendency

Assume a westerly wind over Innsbruck

$$u > 0\,, \qquad v = 0\,.$$

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 $\partial p_S/\partial t \approx 7$ Pa/s.**
- **If this influx continues, the pressure will *double* in about 4 hours.**

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We must apply the continuity equation with great care!

Outline

Felix Maria Exner (1876–1930)

First attempt to calculate synoptic changes using physical principles.

Exner's method radically different from Bjerknes'.

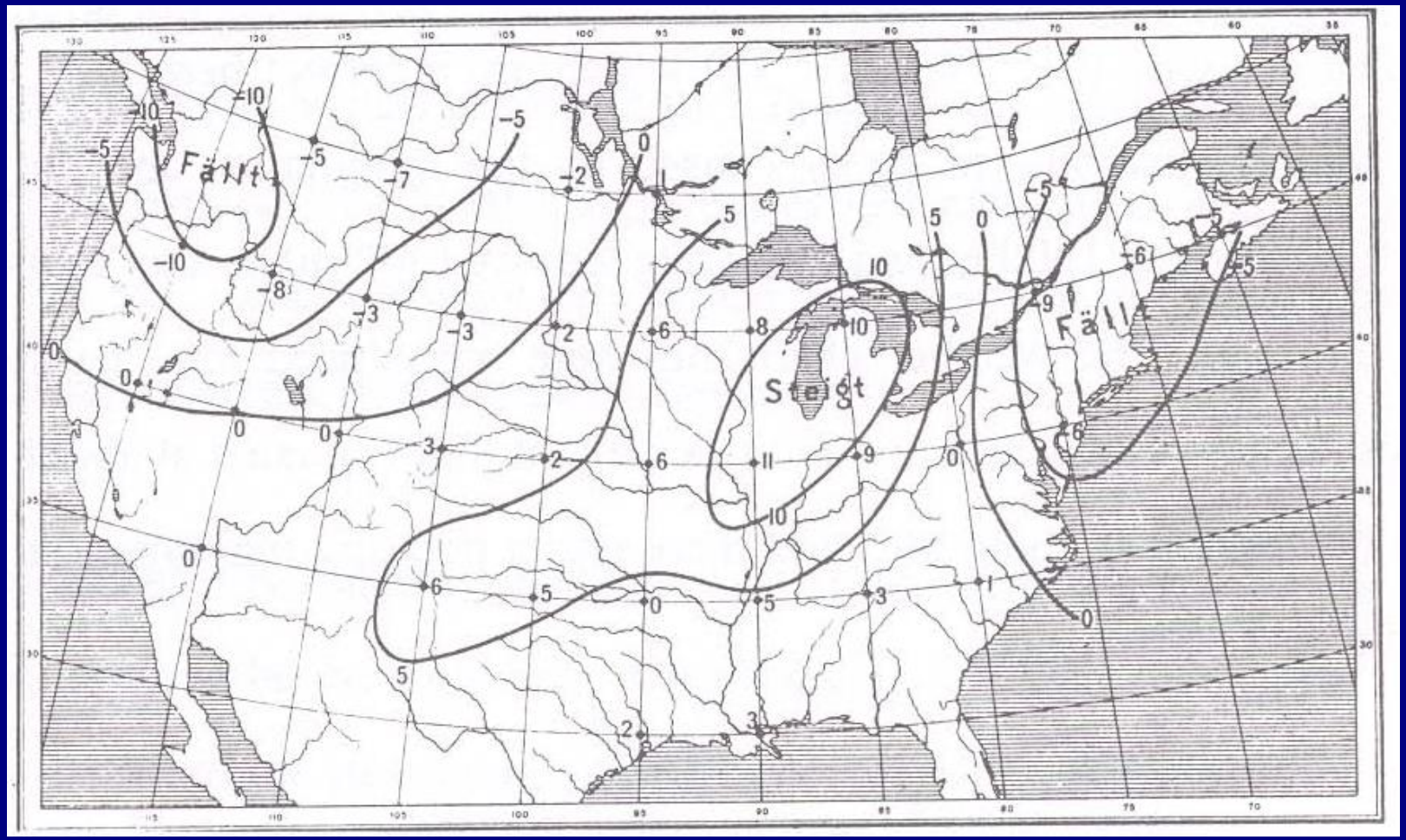
He did *not* make direct use of the continuity equation.

His method used a system reduced to the essentials.

Exner's Method

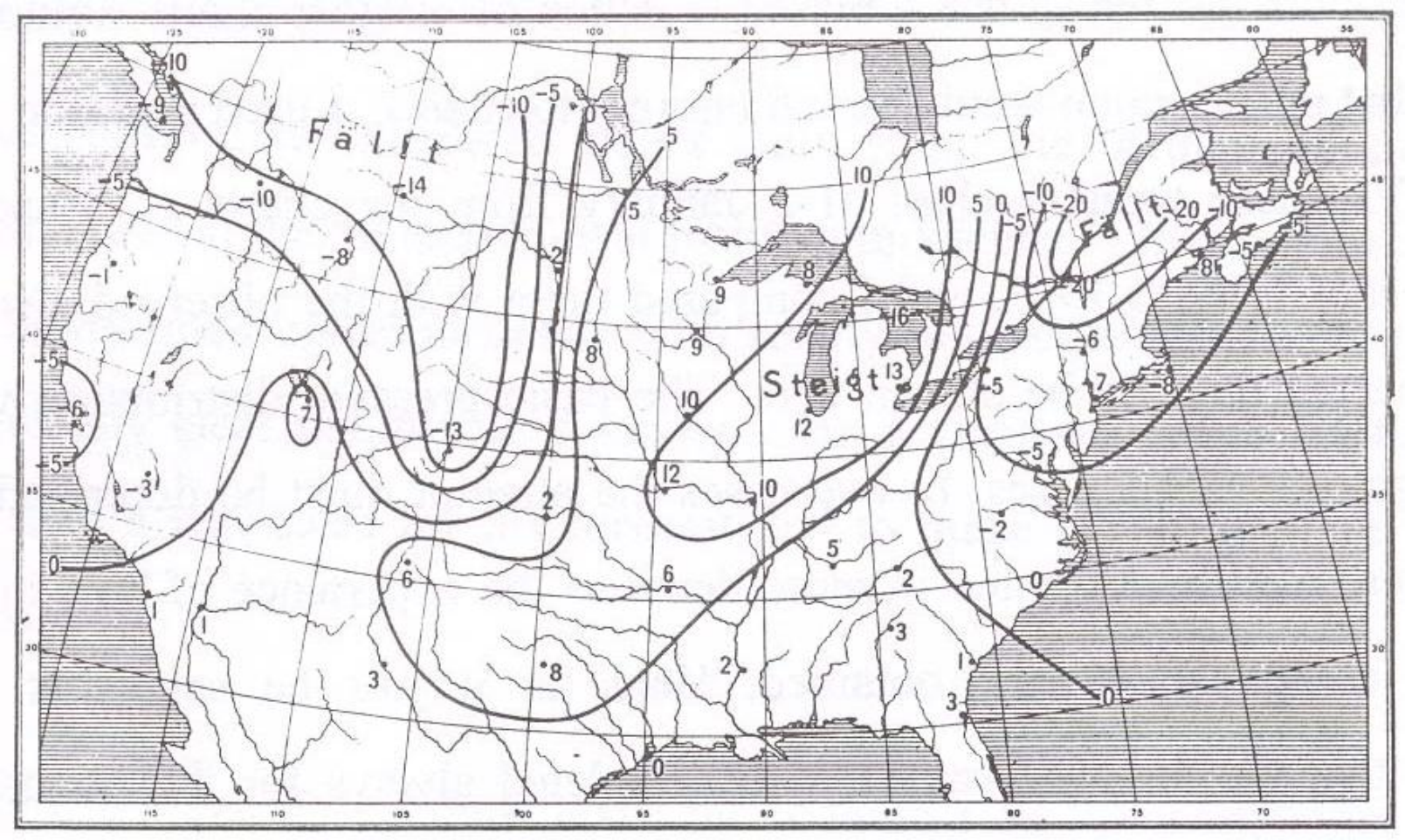
- Exner assumed that the atmospheric flow is geostrophically balanced and that the thermal forcing is constant in time.
- He deduced mean zonal wind from temperature.
- He then derived a prediction equation representing advection of the pressure pattern.
- His method yielded a realistic forecast.

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.
Hundreths 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!

$\star$ $\star$ $\star$

As we shall shortly see:

- **Exner's forecast was unspectacular but reasonable.**

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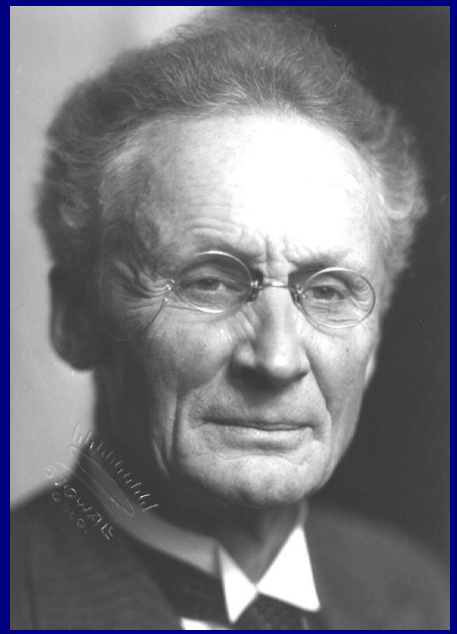
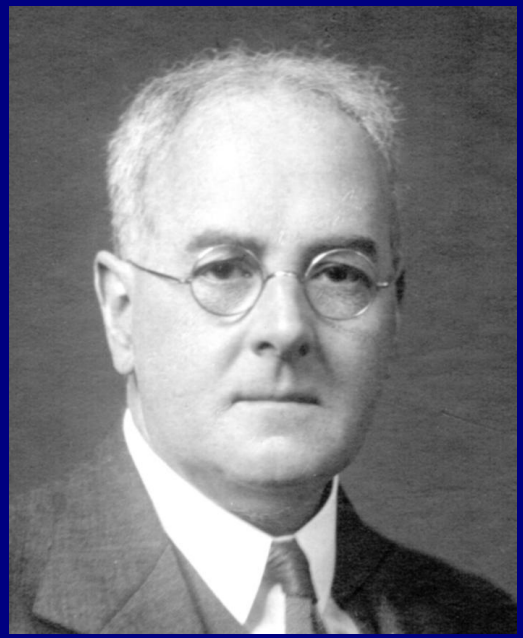
whereas

- Richardson's forecast was spectacularly unreasonable.

Pioneers of Scientific Forecasting

Cleveland Abbe, Vilhelm Bjerknes, Lewis Fry Richardson

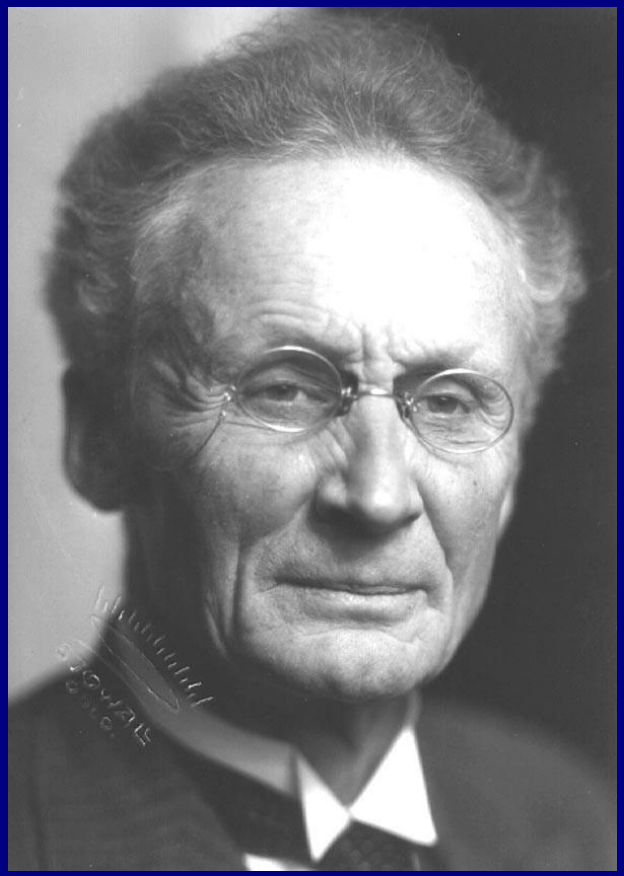
Cleveland Abbe

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.

Vilhelm Bjerknes



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.

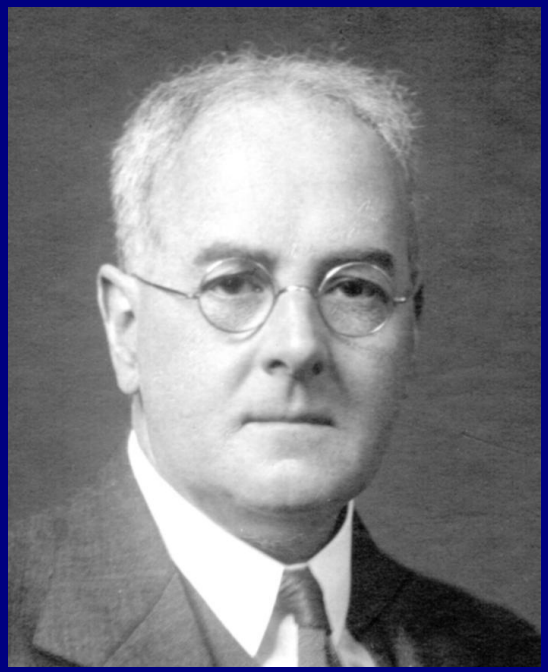
Necessary and sufficient conditions for the solution of the forecasting problem:

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

Step (1) is Diagnostic. Step (2) is Prognostic.

Outline

Lewis Fry Richardson



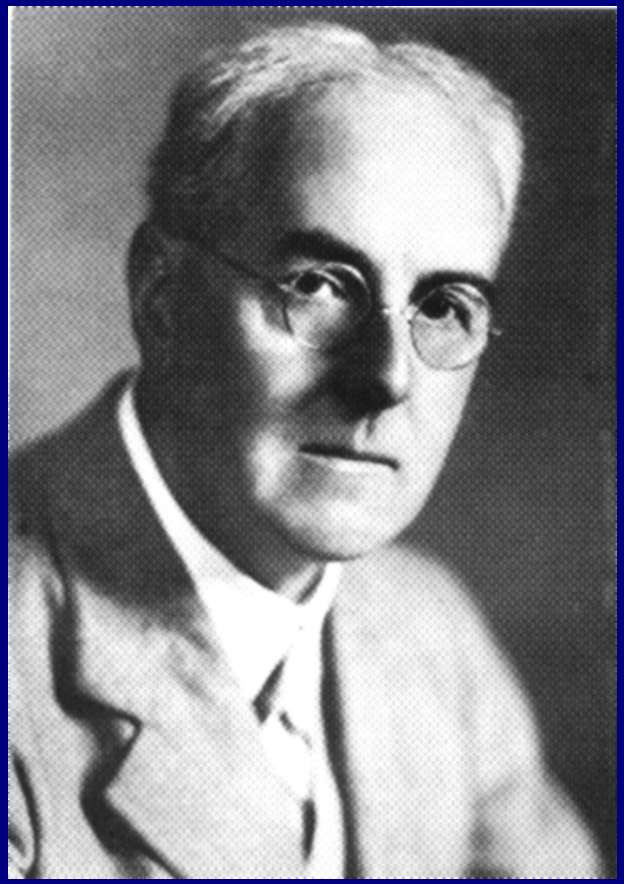
The English Quaker scientist Lewis Fry Richardson attempted a **direct solution of the equations of motion.**

He dreamed that numerical forecasting would become a practical reality.

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

. . . his dream has indeed come true.

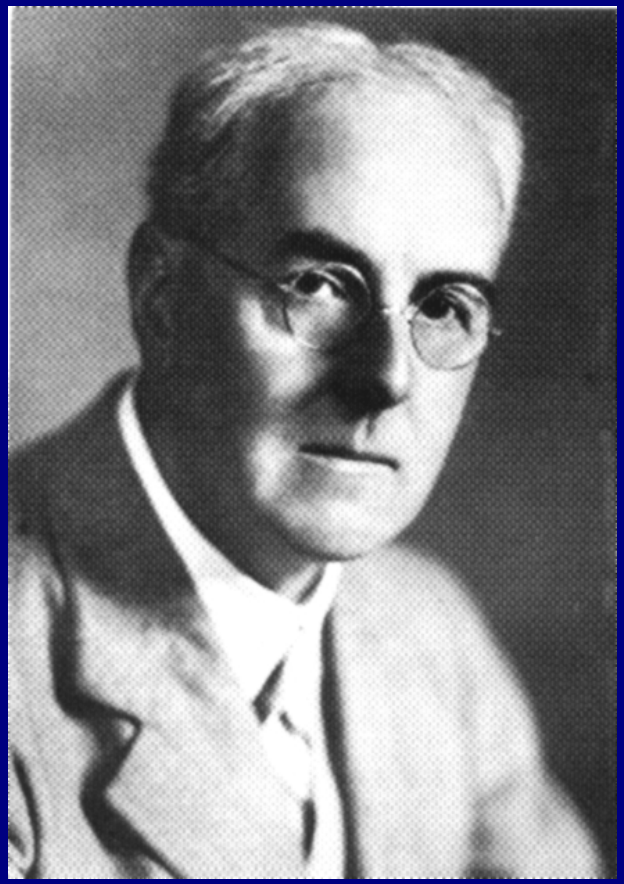
Lewis Fry Richardson, 1881–1953.



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

It took him two years !

Lewis Fry Richardson, 1881–1953.



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It took him two years !

His ‘forecast’ was a catastrophic failure:

$\Delta p =$ 145 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

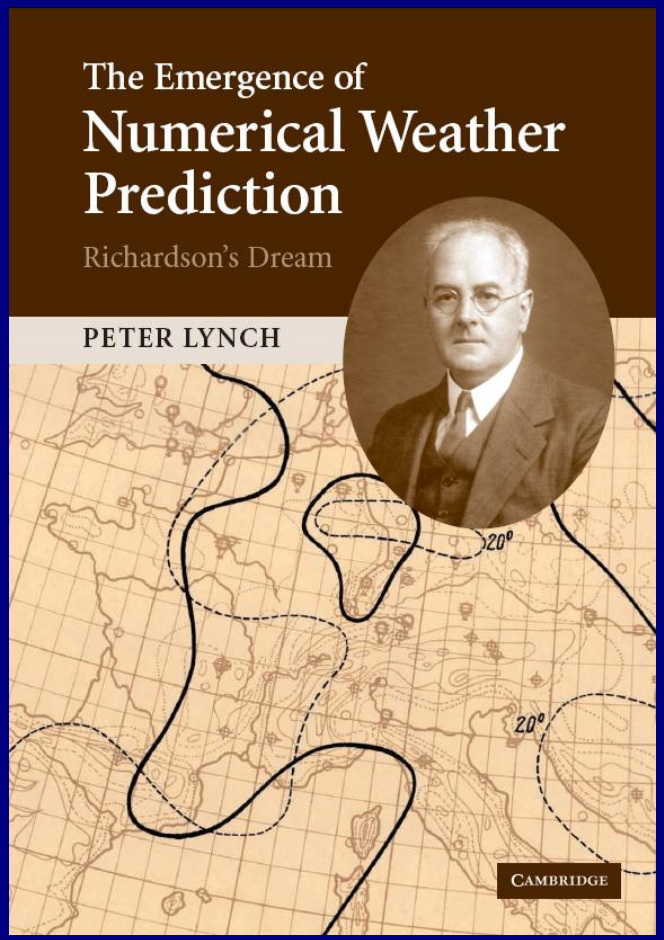
Richardson's Forecast was repeated on a computer.

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

- **ORIGINAL:** $\frac{\partial p_s}{\partial t} = +\mathbf{145}\,\mathrm{hPa}/6\,\mathrm{h}$
- **INITIALIZED:** $\frac{\partial p_s}{\partial t} = -\mathbf{0.9}\,\mathrm{hPa}/6\,\mathrm{h}$

Observations: The barometer was steady!

Full Account of the Forecast

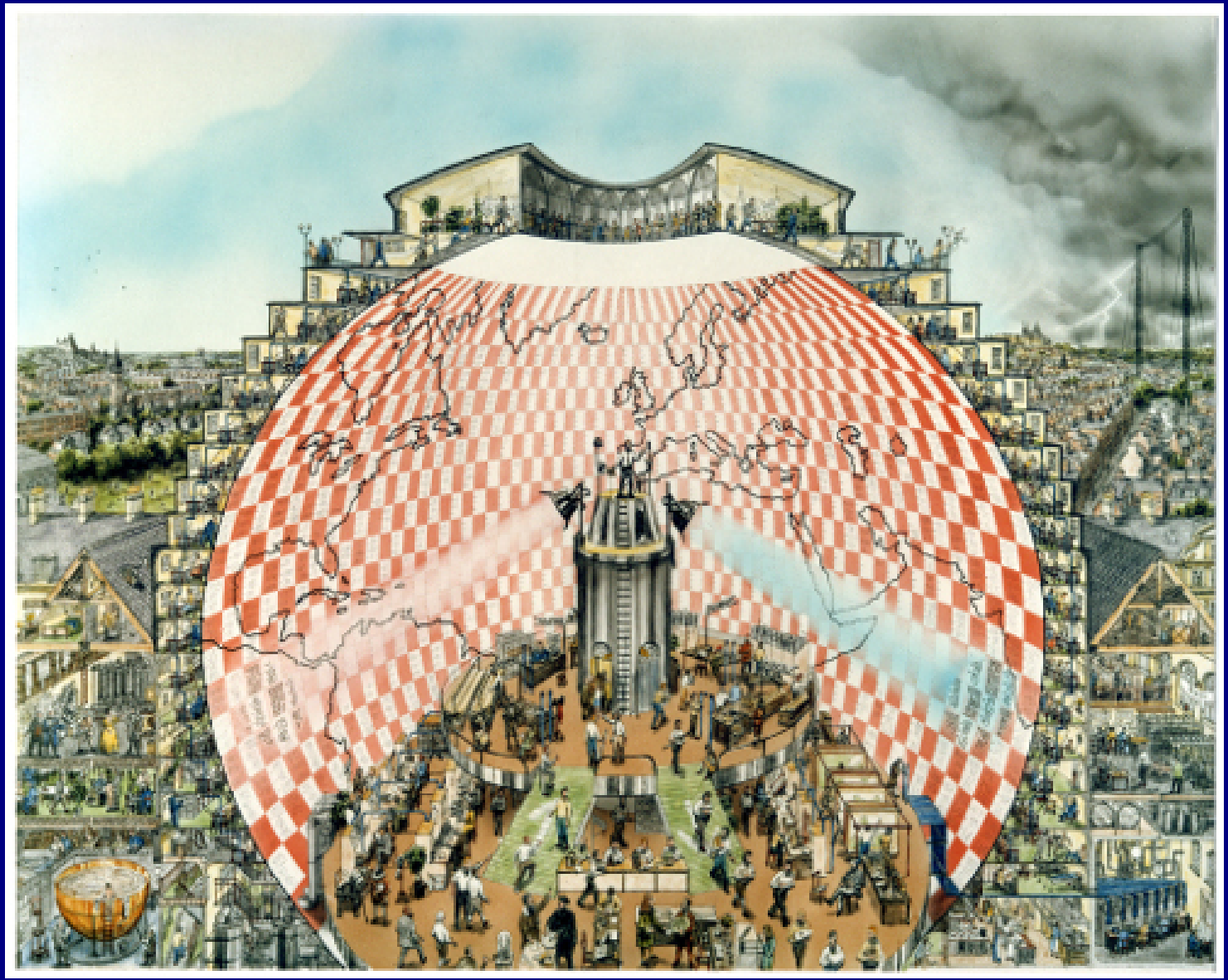


Richardson's Forecast and the Emergence of NWP are described in this book.

[Cambridge Univ. Press, 2006]

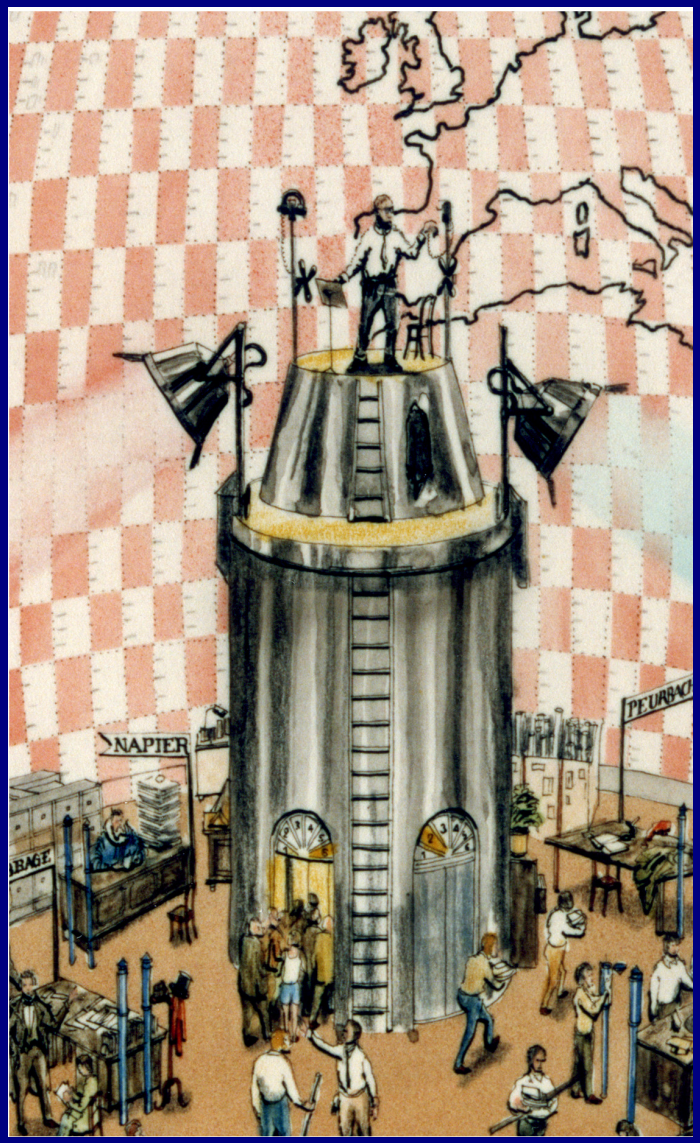
Outline

Richardson's Forecast Factory



©Stephen Conlin, 1986

Zoom: Richardson Directing the Forecast



Lewis Fry Richardson conducting the forecast

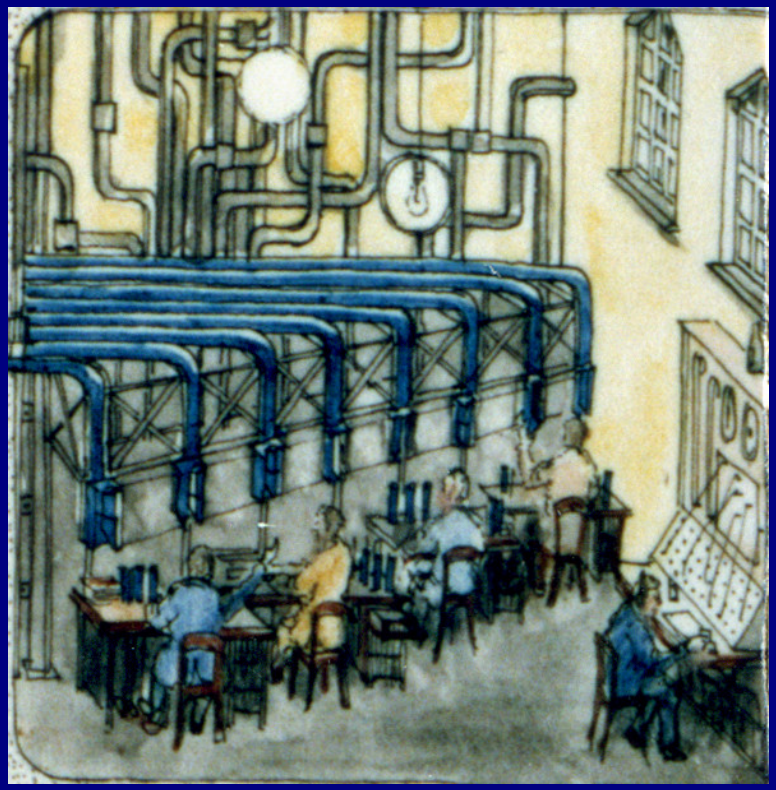
Zoom: Historical Figures in Computing

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

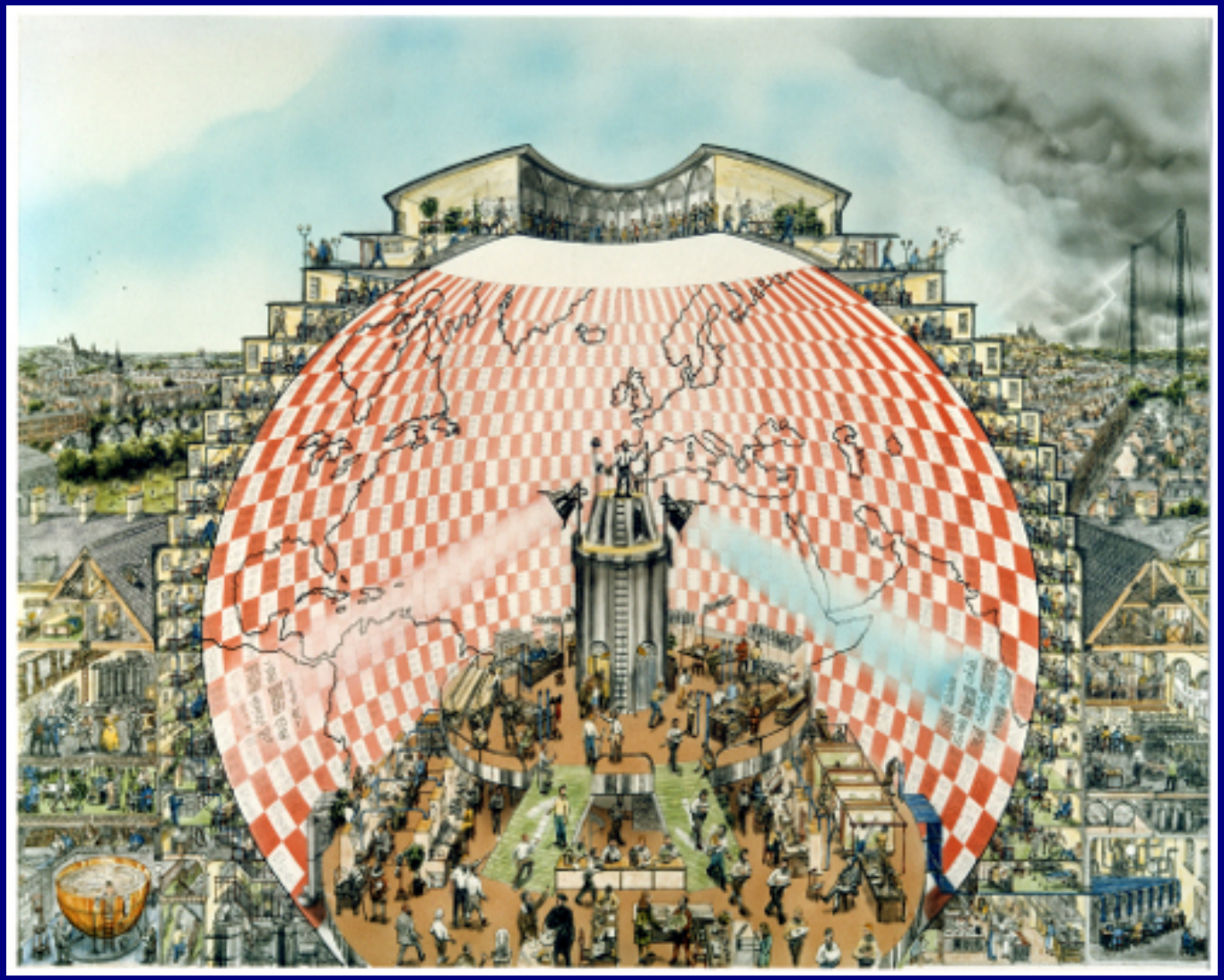


Left: Tube Room. **Right: Computer Laboratory**

Zoom: Experimentation & Research

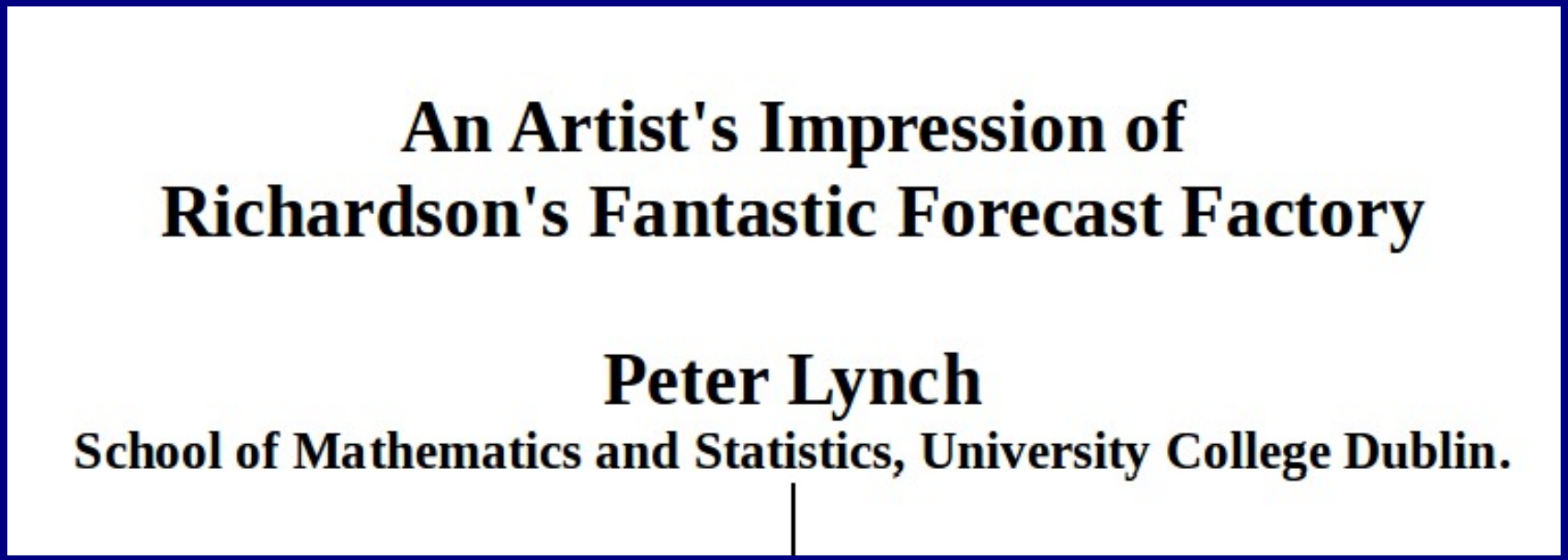
Left: Dish Pan. **Right: Analytical Engine**

Richardson's Forecast Factory



64,000 Computers: the first Massively Parallel Processor

The Fantastic Forecast Factory



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