ROOTS OF ENSEMBLE FORECASTING

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In the early 1960s, the hope and promise of long-range prediction (beyond several days) loomed large. Norman Phillips's numerical experiment had clarified the dynamics of the general circulation, and in the wake of this successful experiment several extended-range prediction groups were formed around the world (Phillips 1956; Smagorinsky 1983; Lewis 1998). At this same time, there arose a desire and interest among world leaders to promote scientific collaboration — a collaboration that would build on the success of the IGY (International Geophysical Year) of the late 1950s. Observations from space via artificial satellites were at the center of these plans. As recalled by Joseph Smagorinsky, then director of the General Circulation Research Section of the U. S. Weather Bureau (later re-named the Geophysical Fluid Dynamics Laboratory):

So in the early sixties — well right after the IGY as a result of the remarkable cooperation among the nations of the world, particularly between the Soviet Union and the Western World, it was realized that the IGY coming to an end, that something had to replace it to maintain an open door between the East and West...And there was a mad search for "What is it that can keep this door open?" And I think the first important thing that was [1]done, was in a couple of addresses made by [President][2] Kennedy to the United Nations in the early 1960s, where he made a plea for the peaceful use of space [and] space technology. And as a result, [the] notion of using satellites for meteorological purposes developed...And this was the beginning of te World Weatherr Watch. And as a result of United Nations resolutions [,] the World Meteorological Organization was asked to do something about it. And [Harry] Wexler [U.S.A.] and [Victor] Bugaev [U.S.S.R.] were the ones who wrote a plan for it.

Smagorinsky 1971

In response to this plan for the World Weather Watch, a Panel on International Meteorological Cooperation was established in 1963, headed by Jule Charney. This panel would eventually make recommendations to the National Academy of Sciences (NAS) – National Research Council (NRC) regarding a global experiment (FGGE — First GARP Global Experiment where GARP is the acronym for Global Atmospheric Research Program). In the key report to NAS-NRC in 1965 (Reproduced in *Bulletin of the Amer. Meteor. Soc.* (BAMS) 1966), the word *feasibility* was used in the title, viz., "The Feasibility of a Global Observation and Analysis Experiment". The use of this word had special significance according to Edward Lorenz, a colleague of Charney's

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[2] [...] indicates additions made by the author.

at MIT. With the wave of optimism that surrounded long-range forecasting, Charney felt some pressure to include statements in the report that reflected this optimism. Yet, he had become convinced that results from Lorenz's recent work (Lorenz 1962, 1963) among others (Thompson 1957, e. g.), placing limits on predictability for nonlinear dynamical systems, was cause for concern. As remembered by Lorenz:

When GARP was first brought up, some people were promising that when we get this going we'll have two week forecasts. Charney got a little worried about this... and his recommendation was that we investigate the feasibility of the two week forecast rather than promising to make them.

Lorenz 2002, personal comm.

In this period of heightened interest in long-range prediction, yet with some reservation linked to the growth of errors in numerical models, several lines of research related to predictability became prominent. These lines of research would eventually have bearing on the theory and practice of "ensemble weather prediction". In this historical paper we follow the work of three scientists: Edward Epstein, C. E. (Chuck) Leith, and Edward Lorenz, who studied predictability along paths that were not mutually exclusive, yet they stemmed from distinct traditions in science. We trace backward from the late -1960s, early-1970s with the intention to identify the factors that led these scientists into research related to predictability and ensemble forecasting.

A schematic diagram is shown that categorically identifies the lines of research followed by Epstein, Leith, and Lorenz. In this paper, we elaborate on the various components in this diagram that have led us to our current practice of ensemble weather prediction.

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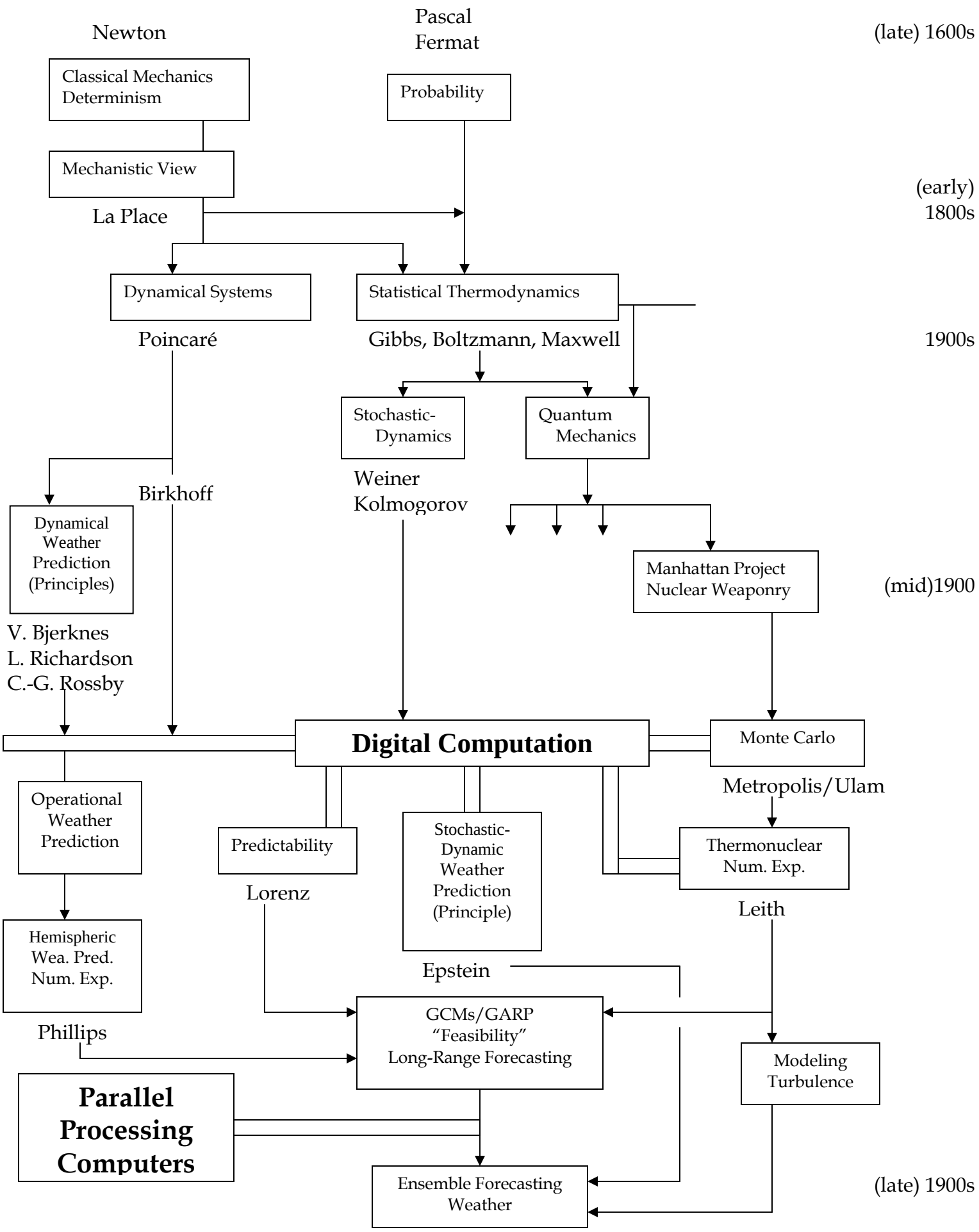
Newton
Pascal
Fermat
(late) 1600s
Classical Mechanics
Determinism
Probability
Mechanistic View
(early)
1800s
La Place
Dynamical Systems
Statistical Thermodynamics
Poincaré
Gibbs, Boltzmann, Maxwell
1900s
Stochastic-
Dynamics
Quantum
Mechanics
Weiner
Kolmogorov
Birkhoff
Dynamical
Weather
Prediction
(Principles)
Manhattan Project
Nuclear Weaponry
(mid)1900
V. Bjerknes
L. Richardson
C.-G. Rossby
Digital Computation
Monte Carlo
Metropolis/Ulam
Operational
Weather
Prediction
Predictability
Stochastic-
Dynamic
Weather
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(Principle)
Thermonuclear
Num. Exp.
Lorenz
Leith
Hemispheric
Wea. Pred.
Num. Exp.
Epstein
GCMs/GARP
"Feasibility"
Long-Range Forecasting
Phillips
Modeling
Turbulence
Parallel
Processing
Computers
Ensemble Forecasting
Weather
(late) 1900s