A BUYS BALLOT MEDAL FOR EDWARD LORENZ

A Reflection on the History of the Prestigious Award and Evolving Attitudes toward Predictability

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Since 1893, the Royal Netherlands Academy of Arts and Sciences has awarded, once every 10 years, a golden Buys Ballot Medal to a scientist who has made outstanding contributions to the development of meteorology. The award was instituted in 1888 in honor of C. H. D. Buys Ballot (1817–90), upon his retirement as professor of physics at the University of Utrecht. Today, Buys Ballot is remembered best by Buys Ballot's law, which gives the relation between wind and pressure. He derived this law from observations and published it in 1857.[1] Buys Ballot was a pioneer both in weather forecasting and in recognizing the need for international cooperation in meteorology. He founded the Royal Netherlands Meteorological Institute (KNMI) in 1854 and served as its chief director until his death, and was first president (1873–79) of the International Meteorological Committee, a predecessor of the World Meteorological Organization (WMO).

The Buys Ballot Medal is different from most awards in meteorology. First, the medal now reflects more than a century of the history of meteorology. Second, the medal is awarded very infrequently. This is for a simple reason: the available funds are just sufficient to support one medal (six ounces of gold) every 10 years. The list of laureates is therefore short, implying that the medals have only been awarded to the most prominent meteorologists who had a lasting influence on the development of the discipline.

[1] One year earlier, William Ferrel had published his version of the law, derived from theoretical mechanics, but this version remained unnoticed for several decades.

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DOI:10.1175/BAMS-87-12-1662

The 12th Buys Ballot Medal was recently awarded to Edward Lorenz, emeritus professor at the Massachusetts Institute of Technology, for his outstanding contributions to the theory of nonlinear dynamical systems and the predictability of weather and climate, for which the ground was broken by his famous paper on deterministic nonperiodic flow.

In looking back at the illustrious history of this award, we find that most of the laureates were members—and some were the founders—of schools of thought in meteorology. All had their opinion on the predictability of weather, the subject to which Lorenz contributed so much. A review of their contributions sets an apt historical context for Lorenz's work by showing the changing attitudes toward prediction over the 11 decades spanned by the Buys Ballot Medal.

FIG. 1. Buys Ballot [picture provided by James R. Fleming; from Umlauff (1891)].

THE AUSTRIAN SCHOOL. The 1893 medal was awarded to Julius von Hann, founder of the so-called Austrian School. Von Hann was renowned for his comprehensive knowledge of the atmospheric sciences in his time, which he laid down in prestigious handbooks of meteorology and climatology. The meteorologists of the Austrian School considered forecasting to be unscientific, due to the imperfections of the weather forecasts. This was an acceptable opinion for most scientists of those days, in view of the then-current interpretation of Laplacian determinism, which implied the possibility of predictions based on the laws of physics. Evoking the attitude of some members of this school: forecasting is immoral, a danger to the character of a meteorologist, and an affair for romantics.

Buys Ballot had died three years before. It can be doubted whether he would have been in favor of the awarding of the medal to von Hann, because Buys Ballot and his Western European contemporaries, Le Verrier in France and FitzRoy in England, had already established meteorological services in their countries by 1855. They were evidently convinced of a degree of predictability of the weather that would allow for the issuing of weather forecasts. Nevertheless, it should be noted that theories developed by the Austrian School, like Margules's work on the sloping frontal surface, were later used by the Norwegians.

THE UPPER AIR. From observations of the drift and changing aspects of the highest clouds, the meteorologists of the nineteenth century realized that processes in the upper air play an important role in the development of weather systems. They therefore took a keen interest in ballooning. In 1903, the second Buys Ballot Medal was awarded to Richard Assmann and Arthur Berson for their many ascents by balloon, up to an altitude of 10,800 m. Their observational studies contributed to the discovery of the stratosphere. The third medal was awarded in 1913 to Hugo von Hergesell, who extended upper-air research to the Tropics and the polar regions.

THE NORWEGIAN SCHOOL. In the Norwegian School, as far as we know, only Vilhelm Bjerknes and Tor Bergeron discussed the predictability of weather, and in 1933 weather forecasting got a more solid base when the fifth medal was awarded to Bjerknes. Before World War I, Bjerknes had already been a well-known theoretician, applying the theory of hydrodynamics to meteorology. In 1904, he presented in a short note the set of equations that should be solved to calculate the future weather, as an application of Laplacian determinism. He considered weather to be predictable in principle, but he realized that there was still much to be done.

Before World War I, Bjerknes had shared, to a certain extent, the opinion of the Austrian School about the then-current empirical methods for weather forecasting. In 1913, he expressed his preference for weather forecasting by calculation over the empirical method. He characterized the latter "as a highly inexact science." Due to the isolated position of Norway during wartime, Bjerknes took an interest in synoptic meteorology. With a number of young collaborators, he formed the "Norwegian School" in 1917. This group of scientists would soon make major steps forward in the analysis and interpretation of weather maps by introducing the concepts of air masses and fronts and by formulating a conceptual model for the development of frontal depressions. However, by 1933 the methods of the Norwegian School were not yet generally accepted, let alone applied. Fortunately, the selection committee for the fifth Buys Ballot Medal was visionary, and recognized the great contribution of Bjerknes to the development of meteorology.

The sixth medal was awarded in 1948 to Sverre Petterssen for his impressive and versatile career. He started out as a scientist in the Norwegian School, then continued as a teacher and author of excellent textbooks. In the 1930s, he contributed greatly to the training of forecasters in the United States. During

INTERNATIONAL COOPERATION

Scientists known in particular for their contributions to international cooperation in meteorology have been awarded three of the medals. This reflects the activities of Buys Ballot in this field. In 1923, the fourth medal was awarded to Sir William Napier Shaw, director of the British Meteorological Office, for his merits as president of the International Meteorological Organization (IMO) and as the author of comprehensive textbooks in meteorology.

The Czech meteorologist Gustav Swoboda (seventh medal recipient, 1954) was a talented supporter of the Norwegian School. From 1938, he was secretary of the IMO, and after World War II he became the first secretary general of the WMO.

In 1984, the 10th medal was awarded to the Danish meteorologist Axel Wiin Nielsen. He started his career as a student of R. Fjørtoft in Copenhagen, Denmark, and ended as a professor in Fjørtoft's chair. He contributed to the development of numerical forecasting, with Rossby and Bolin in Sweden, while in the Joint Numerical Weather Prediction Unit in Washington and at NCAR. He was the first director (1974–79) of the European Centre for Medium-Range Weather Forecasts (ECMWF) in Reading, United Kingdom. With his skill and dedication, the ECMWF became one of the leading forecast centers in the world in just a few years. After that, he served the WMO for two years as secretary general.

Fig. 2. The recipients of medals 1–11. The second medal was shared by Assmann and Berson.

World War II, he served in the British Meteorological Office as a senior advisor for major military operations, such as the D-Day operation on 6 June 1944.

THE CHICAGO SCHOOL. In 1965, the Finnish aristocrat Erik Palmén was honored with the eighth medal. Before World War II, Palmén cooperated with the Norwegians, and after the war he worked in the United States as a visiting scientist. He had a special skill in the three-dimensional analysis of aerological data, the interpretation of which resulted in many papers of high quality. We should mention in particular his contribution to the identification of the strong winds in the upper troposphere as an undulating jet stream. This meant a major step forward in the understanding of the development of the weather systems in the midlatitudes.

Nevertheless, the Chicago School was too optimistic regarding what ultimately could be achieved with the numerical method. They were still following the interpretation of Laplacian determinism of Vilhelm Bjerknes, which implies that the horizon of predictability of the weather was restricted only by the imperfections of the observations of the initial conditions and the imperfections in the models, or, in other words, that the limit of predictability eventually would be a cost–benefit problem instead of a scientific issue.

Fig. 3. Edward Norton Lorenz received the 12th Buys Ballot Medal. Photo by E. Landré, taken when Lorenz visited Utrecht University, 16 December 2005.

GENERAL CIRCULATION AND CLIMATE CHANGE. Two laureates reflect the growing interest in climate research. Joseph Smagorinsky (ninth medal recipient, 1973), who contributed substantially to the development of numerical forecasting, was also a pioneer in adapting numerical models for the study of the general circulation of the atmosphere. The study of small trends in climate, whether of natural or man-made origins, required refining the models with respect to the interaction of radiation with gases and aerosols in the atmosphere. Outstanding work in this field was done by Veerabhardan Ramanathan, who received the 11th Buys Ballot Medal in 1995.

CHAOS THEORY, PREDICTABILITY, AND THE GENERAL CIRCULATION. The selection committee for the 11th medal found out that in 1903 a condition had been introduced that implied that the medal should pertain to work done in the preceding decade. This condition worked out adversely, because often the deeper value of scientific work is only recognized after more than 10 years. The committee remarked that the application of this condition was probably the reason why the medal had not been awarded in a timely manner to such eminent scientists as Carl-Gustav Rossby, Jule Charney, and Edward Lorenz. The selection committee for the 12th medal, however, looked again at the original documents and found out that the above-mentioned restriction (research during the last decade) was not supported by the initial regulations of 1888. This paved the way for the offer of the medal to Dr. Lorenz (Fig. 3), who was awarded the medal on 12 May 2004. Because he was ill at the time, the medal was presented to his daughter.

During the ceremony, due attention was paid to the work of Lorenz on the theory of nonlinear dynamical systems and the predictability of weather and to his work on the general circulation of the atmosphere. His WMO monograph of 1967 on this subject gives a historical review of the theories on the general circulation from the time of Halley. This demonstrates the great interest that Lorenz has in the historic development of meteorology. The WMO monograph is now compulsory reading for anybody interested in the subject.

Fortunately, in December 2005, Professor Lorenz was able to visit the Netherlands and gave seminars at Utrecht University and the KNMI. These seminars were received with great enthusiasm and respect.

The work of Lorenz has had a major impact on operational meteorology. Deterministic forecasting according to the Chicago School was replaced by probabilistic forecasting based on Lorenz's findings. Today, ensembles of several dozen deterministic calculations are run with small differences in the initial conditions. This brings to light the sensitivity of the results of the calculations to the unavoidable uncertainties in initial conditions. Probabilistic forecasts are then derived from these ensembles.

Schools of thought in meteorology are usually also "schools" in the sense of them having a founder and collaborators. At first sight there is no such "School of Lorenz," but we may say that Lorenz has inspired other researchers around the world to investigate issues raised by his pioneering work in chaotic systems.

THE PREDICTABILITY OF THE WEATHER IN THE SUCCESSIVE SCHOOLS OF THOUGHT. As revealed by the history of the Buys Ballot Medal, the problem of the predictability of the weather has occupied meteorologists and other scientists for a long time. As early as 1819, the German astronomer Johann Elert Bode published an interesting view. He stated that the "invariable laws of nature" hold for the atmosphere, but that atmospheric physics is an "obscure and complex chapter of physics," and that therefore we will never be able to develop a scientific method for weather forecasting. If we replace "obscure and complex" with "deterministic and chaotic" we see a striking resemblance between the intuitive vision of Bode and the work of Lorenz, with Bode being only somewhat too pessimistic in his conclusion.

In 1959, in a splendid review of the history of operational meteorology, Bergeron cited the opinion of the great Helmholtz, who asked himself in 1875 why the atmosphere apparently does not obey the laws of physics that hold so well for celestial bodies. Bergeron also remarked that many leading meteorologists estimated the horizon of predictability of weather at two to three days. Their argument was that the atmosphere shows several forms of instability, which make the weather hard to predict.

Eric Eady was, as early as 1951, of the opinion that even with the aid of the electronic computer, the horizon of predictability of the weather could not be extended considerably. He therefore advised that probabilistic forecasts be derived from ensembles of deterministic calculations (Eady 1951). He was ahead of his time by decades!

In 1957, Philip Thompson came close to the ideas of Lorenz. He estimated the horizon of predictability to be about a week, and he mentioned, as an important factor, the sensitivity of the results of numerical forecasts to small differences in initial conditions.

It was left to the genius of Lorenz to develop an irrefutable theory of the predictability of weather, the result of which is his research on the mathematics of nonlinear dynamical systems. Before Lorenz, weather forecasts were considered by many as, at best, a "highly inexact science," to cite Bjerknes. Lorenz solved the paradox of the "deterministic chaos": the fact being that for some physical systems, calculated forecasts of their future behavior will be imperfect, while at the same time Laplacian determinism holds. Weather forecasting therefore need no longer be designated as "empiricism," because operational meteorology now has a solid—and even sophisticated—scientific background.

The fondest wish of Buys Ballot is thus fulfilled: the recognition of weather forecasting as a serious branch of science.

ACKNOWLEDGMENTS. The authors are indebted to Robert Mureau, Wim Verkley, Theo Opsteegh, and James R. Fleming for their critical comments on drafts of the paper. An inspiring text was the 30-page survey on the history of operational meteorology of Tor Bergeron mentioned above. The interested reader will find there 194 references to the literature on the history of operational meteorology.

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