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FRANCIS W. REICHELDERFER

1895—1983

A Biographical Memoir by

JEROME NAMIAS

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August 6, 1895–January 26, 1983

BY JEROME NAMIAS[1]

FRANCIS WILTON REICHELDERFER'S career spanned that exciting era when meteorology was transformed from a qualitative to an exact science, from a discipline dependent on rather simple instruments to one employing sophisticated radar, satellites, and high-speed computers. As chief of the U. S. Weather Bureau (now the National Weather Service) from 1938 to 1963, Reichelderfer, who had a keen sense for meteorology's future, played an important role in initiating and maintaining these developments. He was also a sympathetic administrator who helped his staff and soothed the tantrums of more belligerent colleagues. As a government official with many fires to extinguish, he yet managed to get the most out of his staff, both for official tasks and for making contributions to science.

EDUCATION AND EARLY YEARS

Francis Reichelderfer was born in Harlan, Indiana, on August 6, 1895, and died in Washington, D.C., on January 26, 1983. The son of a Methodist minister, he grew up in the Midwest and enjoyed boating and water sports but showed

[1] The Academy wishes to express its special thanks to Dr. Daniel R. Cayan of the Scripps Institution of Oceanography, University of California, San Diego, for his editorial help with the preparation of this essay.

no great interest in meteorology—although he did build an aneroid barometer. He was more interested in chemistry and chemical engineering, and when he went to Northwestern University, he majored in this field, taking a B.S. degree in 1917.

When he graduated, the United States had just entered World War I, which had much to do with his joining the U.S. Naval Reserve Force with the aim of becoming a pilot. He was sent to the ground school at MIT, where he signed up for aerological (meteorological) training—in part because he thought it meant he would soon be off to the front lines in Europe. When he got his commission, however, his name was apparently not English enough for some Allied bureaucrat, and he was sent instead to Nova Scotia to brief anti-submarine patrols on weather phenomena.

At that time the Naval weather service was minuscule, but Reichelderfer sensed that the science of weather forecasting was to become increasingly important, not only for sea maneuvers but also for aircraft, which he saw as the wave of the future in warfare. In December 1917, Assistant Secretary of the Navy Franklin Delano Roosevelt asked Dr. Alexander McAdie, director of Harvard's Blue Hill Meteorological Observatory, to help the Navy by organizing a training program for weather officers. Reichelderfer was selected to take the intense course, which sharpened his interest in meteorology as a science and possible career.

After the Armistice he decided he must have flight training. His request to the Navy was approved, and he was sent to Miami and Pensacola to earn his wings. Shortly afterward he was sent to Lisbon, Portugal, to be meteorologist for the first transatlantic flight of the Navy's NC-4.

In December 1919 he was assigned to the Naval Air Station at Hampton Roads, Virginia, where he got a first taste of the dangers of flying squall lines when Billy Mitchell, a

pioneer who would later make aviation history, was forced to land his light observer's plane on the beach. This event impressed Reichelderfer with the frightening responsibility of being a forecaster and the need to improve the science (or art) of weather forecasting. He devoted much of his subsequent life to this, not through working directly on scientific problems, but in initiating and encouraging the development of instrumentation, networks, and international collaboration among the many branches of meteorology.

While at Hampton Roads Reichelderfer analyzed weather maps and studied articles relating to weather and meteorology. Although there were a number of texts on meteorology, little had been written in America on how to construct weather maps or on how to forecast weather. One of the better books at that time was Milham's *Meteorology*,[2] but even this was far from practical. *Weather Forecasting in the United States*, written by top forecasters of the U.S. Weather Bureau, contained hundreds of charts and rules for forecasting, empirically derived and completely lacking in interpretation. Many of the rules seemed contradictory. The book was frustrating to read and, though published in 1916, was studied by few. After just a few years, the book was already a relic, only of historical interest. Today only a handful of meteorologists even know it exists.

THE NORWEGIAN SCHOOL AND NAVY AEROLOGY

It was in this atmosphere that Reichelderfer decided to "learn by doing" and turned to the publications of the Bergen School, directed by the famous Norwegian meteorologists, V. and J. Bjerknes. The first eight-page paper he read—"On the structure of moving cyclones," by J. Bjerknes—ex-

[2] Willis I. Milham, *Meteorology: A textbook on the weather, the causes of its changes and weather forecasting for the student and general reader*, New York: Macmillan, 1912. New editions appeared in 1914, 1921, 1925, and several times thereafter.

cited him and many other meteorologists around the world. For the first time weather phenomena—clouds, rainfall, and temperatures—were treated in physical terms and not as exercises in isobaric geometry.

The Bergen school method became known as "air mass and frontal analysis" and viewed fronts as discontinuities separating air masses deployed from polar and tropical source regions. Using the Norwegian method, Reichelderfer analyzed many maps and made forecasts. He also gave reasons for his analyses and later on expanded this work into a more complete report. Now called *The Reichelderfer Papers*, it resides in the headquarters of the American Meteorological Society in Boston. Though never published, this report was studied by many fledgling meteorologists, both in and outside the Navy (1920?,1).

In 1922 Reichelderfer was appointed head of Navy Aerology, where he worked in a corner of the Map and Forecast Room of the U.S. Weather Bureau and was regarded as harmless. Not interfering with the official forecast work of the Weather Bureau, he was content to serve as liaison officer with the Navy and occasionally try out one of his new-fangled ideas. Head of Navy Aerology from 1922 to 1928, Reichelderfer built it into a first-class organization. He developed special training courses for officers and enlisted men who served as observers.

In the mid-1920s, lighter-than-air craft in the form of dirigibles came into vogue, and Reichelderfer quickly saw their importance to meteorology. He convinced his superiors to expand the Navy Aerological Service and to assign him to Lakehurst, New Jersey, where he became chief meteorologist for all lighter-than-air operations. He served as weather officer for the flights of the *Los Angeles*, one of the best-known Navy dirigibles. He also took direct part in free-air ballooning and participated in contests, including the International Bal-

loon Races at Brussels. His flights on the *Los Angeles* were credited as sea duty, important for advancement in the Navy.

During his stint at the Weather Bureau he met Carl-Gustav Rossby, a Swede who worked on many topics, including air mass and frontal analysis and rotating tanks in which fluid motions simulated atmospheric circulations on the rotating earth. They became friends and this friendship was to lead to successful careers for both.

BERGEN, NORWAY (1931)

Reichelderfer, active in air mass and frontal analysis, wanted to go to the source of these ideas in Bergen and finally convinced the Navy to assign him there for several months in 1931. Certain reactionary meteorologists at that time were not encouraging. When he did get to Europe, the meteorologist in charge at Tempelhof Airport in Berlin said, "How could anything important scientifically come out of a tiny, conservative country like Norway?"

In 1928, a few years preceding this trip to Norway, C. G. Rossby—Reichelderfer's old friend from his Weather Bureau days—established the United States' first, full-fledged meteorological department at MIT. Rossby had left Washington upon the completion of his Scandinavian-American fellowship to establish the first airways meteorological network, funded by Harry Guggenheim, on the West Coast. Reichelderfer knew Guggenheim and was able to play an indirect part in the establishment of the MIT department (also funded by Guggenheim) by supporting Rossby (as did many others) as its head. MIT further profited by this friendship in that Reichelderfer arranged for naval officers to be sent there for graduate training in meteorology.

At that time the central problem in meteorological research was air mass and frontal analysis, so it is not surprising that the new curriculum at MIT was heavily slanted in this

direction. As new methods of map analysis were taught at the new department, Reichelderfer compared his own analysis and sometimes found disturbing differences. This was part of the reason given to Navy authorities for his study sojourn in Norway.

Shortly after arriving in Bergen, Reichelderfer began to analyze weather maps, first for Europe and later for North America. He got on well with the Bergen group and became good friends with J. Bjerknes, its leader and principal instructor. In a letter to his Navy superiors, Reichelderfer requested a series of North American maps of abnormal meteorological situations, writing:

"There certainly is something fundamental and of value in the new principles vs. the old. It is a chance of a lifetime to develop those as applying to the U.S. and to use them to improve forecast service."

He reanalyzed these problem cases with the help of Bjerknes and other members of the Bergen team, including Tor Bergeron (later a professor at the University of Uppsala), and Sverre Petterssen (who would replace Rossby at MIT).

While at Bergen, Reichelderfer reviewed many scientific papers and became conversant with the new techniques being developed. This work enabled him to write the *Report of Norwegian Methods of Weather Analysis* used by Navy meteorological officers around the world and, coincidentally, by many other progressive meteorologists.

At Bergen Reichelderfer learned that deck experience was required in order to qualify for lieutenant commander. He was, therefore, assigned to the battleship *Oklahoma* for two years. At the end of this tour of duty he returned to Lakehurst and to his role in the rigid airship service.

In 1936 he was, as meteorologist, taking part in flights of the *Hindenburg*, the famous transatlantic dirigible that used hydrogen and suffered a tragic fire. Reichelderfer was lucky

not to have been aboard on this trip, or on the fatal flights of the *Akron* and *Shenandoah*. These tragic events signalled the end of the airship as a means of transatlantic travel and the end of Reichelderfer's career in this specialized branch of meteorology. He was then assigned to an aircraft carrier and later, in 1938, to the battleship *Utah*.

CHIEF OF THE U.S. WEATHER BUREAU

In 1938 Willis R. Gregg, head of the Weather Bureau, died suddenly and a new chief had to be selected. One of the people selecting the new head was Robert A. Millikan, president of Caltech. He had met Reichelderfer several times when the latter was sent by the Navy to evaluate a new meteorology department being established at Caltech by Irving P. Krick. Millikan's support, plus the fact that Reichelderfer was well known as one of the top experts in the United States on Norwegian methods, had rendered considerable services to aviation, and was politically acceptable resulted in his appointment as chief of the Weather Bureau.

Becoming chief of the Weather Bureau in 1938 was not exactly an envious assignment, but it was certainly one of the most challenging. I have hinted at the sad state of science at the Weather Bureau at that time, in part because the prevailing notion was that meteorology was largely learned by apprenticeship. Problems of weather forecasting, furthermore, were treated as problems of geometric or pattern recognition. Whereas today even high school students know that upward vertical air motions are largely responsible for clouds and precipitation, at that time some people in top jobs—including many forecasters—did not. Many believed that rainfall came from the mixing of bodies of air with differing temperature and moisture content—an idea that elementary physics easily disproves. Many of Reichelderfer's colleagues ignored and even frowned upon the Bergen school's ideas of

air mass and frontal analysis, and if the Norwegian publications were in the excellent Weather Bureau library, it would have taken sleuths to discover them. Their study was not encouraged.

Forced to face this situation, Reichelderfer did so most effectively. First he persuaded C. G. Rossby to take the job as assistant chief (a job Rossby held for two years before returning to academia). Together, Reichelderfer and Rossby instituted many innovations at the Bureau. Perhaps most importantly, they set up a thorough training course with scholarships for Weather Bureau employees, who were then encouraged to take graduate courses and conduct scientific research. In this way they helped create a cadre of young enthusiasts that was to influence the entire course of meteorology in America to a degree never before dreamed of.

World War II brought with it tremendous changes in science and science administration, and the Weather Bureau was no exception. Even before the United States entered the war the military saw the need for meteorological support. Reichelderfer encouraged the universities—at that time mainly MIT and Caltech—to teach forecasting and its applications, and the Army Air Corps and Navy sent more officers to school for advanced training.

Several officers were sent to MIT and Caltech to do research and develop extended forecast techniques. Aided administratively by Reichelderfer and Henry Wallace, Secretary of Commerce and Reichelderfer's superior at the time, Rossby and his colleagues pioneered in this effort. Since Wallace was a famous agriculturalist, he took more than a casual interest in meteorology and was cooperative on many pressing matters. He appreciated scientific work, went out of his way to inquire about new developments in weather forecasting, and suggested new avenues of approach.

Many revolutionary developments were taking place in

atmospheric sensing, including the introduction of radar. Reichelderfer, who saw its meteorological potential early on, asked R. A. Watson-Watt, pioneer in the invention of radar, to help introduce it as a major tool in the Weather Bureau's observational and forecasting program. Radar was most useful in determining winds aloft—information vital to aviation.

At times it appeared that its service to aviation might swallow up the Weather Bureau, but Reichelderfer managed to keep this important branch of meteorology in perspective so that other facets (agriculture, marine meteorology, cloud physics) would not suffer. He served, alongside the heads of the Navy and Air Force, as the civilian member of the Joint Committee on Meteorology, a group that made important decisions on emerging problems.

As an outgrowth of the recommendations of Horace Byers' advisory committee, appointed a few years earlier by Franklin Roosevelt, Reichelderfer established an Air Mass and Frontal Analysis (AMAFA) Center manned by capable Weather Bureau meteorologists, later supplemented by colleagues from the Air Force and Navy. Reichelderfer disbanded Byers' program so as not to interfere with AMAFA's operations and, much to his gratification, the new analysis center soon enjoyed national—and later international—acclaim. After the war the AMAFA Center became a model for weather bureaus all over the world.

Another major accomplishment Reichelderfer helped to bring about during World War II was the preparation of a forty-year series of carefully analyzed weather maps, which extended the Northern Hemisphere surface analyses back to 1899. The project involved scores of specialists and technicians and produced maps of great value to research and forecasting during the war and for decades thereafter.

Passionately interested, Reichelderfer insisted on reviewing all the maps produced, piling them so high on his desk

he could hardly be seen. On one occasion a top staff member asked him what he was doing with them. Replying gruffly, "Damn it, I'll show you!" Reichelderfer pulled out some analyses on which he had altered the indicated frontal positions—an example of the "hands on" approach that characterized all his efforts and led to the criticism that he was overly concerned with detail.

Reichelderfer was also criticized for the penury of his budget requests to Congress. He felt a personal responsibility to see that none of the taxpayers' money was wasted and occasionally went so far as to interview young men recommended for promotion from "subprofessional" to the lowest professional grade. On one occasion the Undersecretary of Commerce for Transportation asked if Reichelderfer were a "magician"—he had accomplished so much on such a very small budget.

Reichelderfer's wartime effort also included encouraging some of his key men to lecture at universities and military schools and to serve in research projects at the Pentagon and in the Navy. Some of his people entered the military to serve in the theaters of war; others worked on the home front. While Rossby and Joseph Kaplan directed the selection of thousands of college men to attend the meteorology courses, Reichelderfer helped shape the public policies to get the training program started and keep it maintained. To this day, the elite corps they assembled and trained comprises the major contributors to the science of meteorology.

Cloud Seeding and Rainmaking

After the war, both the Weather Bureau and the universities attracted hundreds, if not thousands, of capable young meteorologists from the military. The cream of the crop applied for positions, and Reichelderfer took an active part in getting funds to hire them. Those with advanced university

training enabled the Bureau to introduce new techniques and programs, including numerical (objective) forecasting with the help of high-speed electronic computers, advanced radar, remote sensing by satellite, and studies in cloud physics.

Cloud physics, however, proved disappointing to enthusiasts who thought that seeding clouds with dry ice or silver iodide would increase rainfall appreciably. Reichelderfer, ever the skeptic about claims of rainmaking, had insisted on proof, and his conservative view led to much criticism. Many meteorologists and others, sometimes in high places, thought that he was becoming reactionary and averse to new developments—a depressing turn of events for one who had always been known as progressive.

Reichelderfer insisted that his scientists test cloud seeding and rainmaking efforts to evaluate the extravagant claims made by university researchers and commercial cloud seeders. When his chief science advisor, Harry Wexler, joined him in asking for proof, he too was called a reactionary. Yet both Bureau tests and research elsewhere failed to indicate that cloud seeding—and especially rainmaking—was successful to an economically valuable degree. A couple of decades later, a thorough study of thirty-five rainmaking experiments in different countries showed that only one (in Israel) may have led to positive results. Though studies relating to the physics of clouds contributed to basic scientific knowledge, the ultimate goal of causing precipitation at will was never realized.

Computers and Numerical Weather Forecasting

One of the most successful advances in forecasting came with the introduction of electronic computers for numerical weather forecasting. The idea of numerical forecasting was first proposed by the English meteorologist, L. F. Richardson,

in a classic paper of the early 1920s. But without high-speed computers, the necessary data, and correct numerical methods to implement the theory, he was unable to verify his idea.

Reichelderfer had heard of John von Neumann's new use of computers to attack ballistic problems at the Institute for Advanced Study in Princeton, where he had access to ENIAC, the first electronic computer. The two met at a banquet in Washington, and some say Reichelderfer put forward weather forecasting to von Neumann as a likely candidate for machine computation.[3]

It is probable that von Neumann would have proceeded along this path without urging, for in the mid–1940s he and V. K. Zworykin, head of RCA Laboratories and inventor of the electron microscope, came to Washington to brief Weather Bureau officials on new possibilities of numerical forecasting with computers. This was an exciting meeting that fired up all those present, even though the goal sounded remote.

Reichelderfer brought the subject before the Joint Meteorological Committee, which then established a meteorological center at the Institute for Advanced Study with von Neumann as head. Top Weather Bureau, Navy, and Air Force scientists were scheduled to go to Princeton frequently to see how this work was proceeding.

In 1948 Jule G. Charney returned from a year of study

[3] This story, credited by many, cannot be entirely authenticated. In his biography of Jule Charney, to appear in *Biographical Memoirs* vol. 66, Norman A. Phillips records that Charney attended a meeting at Princeton's Institute for Advanced Study in August 1946. Von Neumann had convened the meeting on the subject of the application of electronic computers to weather forecasting. "In his conversations with [G.] Platzman," Phillips writes, "Jule suggests that this idea might have come from von Neumann's acquaintance with V. Zworykin at nearby RCA. F. Nebeker, however, points out in his Princeton University [doctoral] thesis that it was [C.-G.] Rossby who suggested to von Neumann that the Institute for Advanced Study should submit a proposal for meteorological funding to the Naval Office of Research and Invention, and that this was done by May 1946." *Editor's note*

in Norway to join the project, bringing with him fresh ideas, enthusiasm, and an ability to work well with von Neumann. Not long after, the team produced the first computer-generated numerical forecast—for weather patterns at about five kilometers and twenty-four hours in advance. Though the computation took ENIAC about twenty-four hours to complete the calculations, this was a real breakthrough and fully justified the Weather Bureau, Air Force, and Navy's support.

John Mauchly, incidentally, one of the inventors of the ENIAC, was himself a meteorologist who dreamed of realizable numerical forecasting. It is also noteworthy that the method for making the first forecast incorporated ideas developed in the Extended Forecast Project by Rossby and his colleagues at MIT.

Following this first success, progress was rapid. In 1954 a joint Numerical Weather Prediction Unit (Weather Bureau, Air Force, and Navy) was established in Washington and obtained a new computer in 1955. George Cressman (later chief of the National Weather Service) was selected as head, and it numbered Joseph Smagorinsky and Phillip Thompson among its top scientists.

Reichelderfer spent a great deal of time and effort seeing to it that this unit got all it needed, including state-of-the-art computers and manpower. In later years the endeavor was to be repeated at many centers around the world. It led, furthermore, to a new, efficient form of research on topics ranging from the climatic effects of rising CO_2 to more objective forecasts covering several days. Meteorological research without high-speed computers is almost unthinkable today.

Satellites, Radiation Sensing, and International Meteorology

Later in Reichelderfer's tenure, the science of meteorology was greatly advanced by the use of satellite photos

and radiation sensing. Seeing the potential of the rocket-sounding experiments at White Sands, which returned cloud pictures from aloft, Reichelderfer established a Satellite Meteorology Division outside Washington, D.C. He and Keith Glennan, a NASA administrator, ensured efficient collaboration between the two agencies, and the effort soon became international in scope.

Well before the Sputnik-and-satellite era, Reichelderfer was active in international affairs. He did much of the planning for the World Meteorological Organization (WMO) and in 1951 was elected its first president. He greatly helped worldwide observing and forecasting programs, including the early World Weather Watch pioneered and planned by Harry Wexler and the Russian meteorologist, Bugaev.

In addition to all these activities, Reichelderfer managed the multifaceted operations of the Weather Bureau, whose research had by that time expanded to include prediction of tornadoes, hurricanes, air pollution episodes, stratospheric behavior, advanced aircraft environment, and long range (a month to a season) general weather characteristics.

By 1963 Reichelderfer felt that it was time to step down and let a younger man take over. President Kennedy appointed Robert M. White, now president of the National Academy of Engineering, to succeed him. In his congratulatory letter to White, Reichelderfer wrote:

"It has been my great fortune to be in office during a period of rapid development in the technology of meteorology and its data-gathering facilities and in the capabilities and responsibilities of the Weather Bureau. It has been a period of unusually rewarding personal associations and noteworthy achievements. I do not know of a greater expression of best wishes to you in your new capacity than to desire for you all of the gratification, the rewarding associations, and the loyalties that [it has] been my privilege to enjoy during these many years past; and knowing the Weather

Bureau and its fine men and women as I do, I am confident you will receive no less in the years to come.

With Best Wishes for Every Success,
Cordially, Reich"

HONORS AND AWARDS

Reichelderfer received many honors and was a member or fellow of a number of scientific societies. He was elected to the National Academy in 1945 and was a member of the Philosophical Society. He received the International Meteorological Organization (IMO) Prize in 1964 and later received awards from Chile, Cuba, France, Japan, and Peru.

In 1919, he became a charter member of the American Meteorological Society and was later made a fellow and honorary member; he served as its president in 1941 and 1942. He received the Society's 1964 Cleveland Abbe Award for distinguished service and was given a Special Award in 1972. In the fall of 1982, shortly before his death, the American Meteorological Society voted to establish, in his honor, the Francis W. Reichelderfer Award.

Reichelderfer was also a member of the American Geophysical Union and was elected vice president from 1949 to 1953 and 1959 to 1960. He was president of the Meteorological Section of the American Geophysical Union from 1944 to 1947. Mention has already been made of his election as first president of the World Meteorological Organization, in which post he served from 1951 to 1955. He was a member of the Institute of Aeronautical Sciences and belonged to the Cosmos Club and the Federal Club.

IN CONCLUSION

Reichelderfer is survived by his son, Bruce Allen Reichelderfer, of Roanoke, Virginia. His wife, Beatrice,

passed away in 1975. In the two decades following his retirement he kept abreast of meteorological developments both domestic and international and served as a consultant on many issues.

Perhaps the best summing up of his career was that delivered by President John F. Kennedy on the occasion of Reichelderfer's retirement:

"You have held the post of Chief of the Weather Bureau with great distinction under four presidents. . . . As Chief of the Weather Bureau, you presided over the evolution of meteorology and weather forecasting from an art to a science."

A GOOD DEAL OF THE MATERIAL for this memoir comes from personal letters sent to me from time to time by Francis Reichelderfer. These were largely in connection with a report on the history of American meteorology that I presented at a symposium in Philadelphia sponsored by the American Meteorological Society on the occasion of the U.S. bicentennial celebration (*Bulletin of the American Meteorological Society*, vol. 64, no. 7, July 1983). In addition, Patrick Hayes's two papers on Reichelderfer's career (*Weatherwise*, April and August, 1981) were very helpful. Obituaries and articles by George Cressman (*Bulletin of the American Meteorological Society*, 64[4]: April 1983, and 66[11]: November 1985) were also valuable sources.

SELECTED BIBLIOGRAPHY

1920?

Air mass analysis as practiced by the Bergen School. Unpublished monograph.

1921

Forecasting thunderstorms by means of static electricity. *Mon. Weather Rev.* 49(March):152–53.

1928

Aeronautics' challenge to weather science. *Pap. Intl. Civ. Aeronaut. Conf., Washington, D.C., 1928.*

1930

Airship meteorology. In: *Aeronautical meteorology*, ed. W. R. Gregg. New York: Ronald Press Company.

1929

Some aerological principles applying to airship design and operation. *Aeronaut. Eng.* (July-Sept.):171–75.

1932

Norwegian methods of weather analysis. U.S. Bureau of Aeronautics, Navy Department. 45 pp.

1939

Recent progress in meteorological service for aviation. *Nat. Aeronaut.* 17(9):44–45.

1940

The contribution of Wilkes to terrestrial magnetism, gravity, and meteorology. *Proc. Am. Philos. Soc.* 82:583–600.

1941

The how and why of weather knowledge. In: *Department of Agriculture Yearbook, 1941*, pp. 129–53. Washington, D.C.: Government Printing Office.

The Weather Bureau—fifty years of progress. *Sci. Mon.* 53:482–85.

1943

Something is being done about the weather. *Dept. Comm.* 31:3–7.

Weather's role in the fight for freedom. U.S. Weather Bureau, Office of the Coordinator of Inter-American Affairs, Press Division, April.

1945

Meteorology and climatology. In: *The American yearbook, 1944*, pp. 764–66.

1946

Remarks on Weather Bureau policy, plans and program. *Bull. Am. Meteorol. Soc.* 27:169–71.

1947

The science of the atmosphere. In: *The scientists speak*, ed. Warren Weaver, pp. 19–23. New York: Boni & Gaer.

1950

The importance of meteorological observations from ocean station vessels. U.S. Weather Bureau. Mimeo.

1952

Physical basis of water supply for the United States. In: *U.S. Congress, House Committee on Interior and Insular Affairs, Physical and Economic Foundation of Natural Resources*, vol. 2, pp. 11–14.

1954

Meteorological services and bad weather flying. *Interavia* 9:220–23.

1957

Hurricanes, tornadoes, and other storms. *Ann. Am. Acad. Polit. Soc. Sci.* 309:23–35.

1959

United States National Hurricane Research Project. *Marine Obs. (London)* 19(186):188–91.

1960

On the role of the IUGG in advancement of geophysics. *Trans. Am. Geophys. Un.* 41(March):1–3.

1961

Meteorological satellite systems in weather research and services. *Aeros. Eng.* 20:22–23, 91–96.