Intimate Universality

Local and Global Themes in the History of Weather and Climate

JAMES RODGER FLEMING,
VLADIMIR JANKOVIC,
AND
DEBORAH R. COEN
EDITORS

Science History Publications/USA
Sagamore Beach
2006

64. David Brunt, *Physical and Dynamical Meteorology* (Cambridge: Cambridge University Press, 1939), 231.
65. Johannes Grunow, *Wetter und Klima: Ihr Wirken und ihre Beziehungen zur lebenden Welt* (Berlin: Wegweiser, 1937), 216.
66. A contemporaneous work of popularization was the multi-authored *Klima, Wetter, Mensch*, ed. H. Woltereck (Leipzig: Quelle & Meyer, 1938), to which the Austrian Brezina contributed.
67. Albrecht was the son of Karl Haushofer, the founder of the German school of geopolitics, who was a mentor to Rudolf Hess, one of Hitler's early close associates in the Nazi Party.
68. A. Haushofer, *Allgemeine Politische Geographie und Geopolitik*, vol. 1 (Heidelberg: K. Vowinckel, 1951), 85–87. The treatise was published a decade after Haushofer's execution.
69. Rudolf Geiger, *Das Klima der bodennahen Luftschicht: ein Lehrbuch der Mikroklimatologie*, second edition (Braunschweig: Vieweg & Sohn, 1942), 4.
70. See note 1.
71. Karen Barkey, "Thinking About Consequences of Empire," in Mark van Hagen and Karen Barkey, eds., *After Empire: Multiethnic Societies and Nation-Building* (Boudler, Colo.: Westview Press, 1997), 99–114, on 106–7.
72. Musil, "The 'Nation' as Ideal and as Reality" (1921), in *Precision and Soul*, 101–116, on 103 and 111.
73. Brunngraber, *Karl und das 20. Jahrhundert* (Göttingen: Steidl, 1999), 162.
74. Karlheinz Rossbacher, *Literatur und Bürgertum: Fünf Wiener jüdische Familien von der liberalen Ära zum Fin de Siecle* (Wien: Böhlau, 2003), 467; Hofmannsthal, "Festspiele in Salzburg," and "Das Schriftum als geistiger Raum der Nation," in *Gesammelte Werke* 9, 227–245, esp. 235–36.
75. Albrecht Haushofer, "Zur Problematik des Raumbegriffs," *Zeitschrift für Geopolitik* 9 (1932): 723–734, on 723.
76. Mechtild Rössler, *Wissenschaft und Lebensraum: Geographische Ostforschung im Nationalsozialismus* (Berlin: D. Reimer, 1990), 2.
77. Martha Muchow, *Lebensraum des Großstadtkindes* (Hamburg: M. Riegel, 1935).
78. David Livingstone, *The Geographical Tradition* (Cambridge, Mass.: Blackwell Publishers, 1993), 177ff; Woodruff D. Smith, *Ideological Origins of Nazi Imperialism* (New York: Oxford University Press, 1986), 91 and Chapter 7. For examples of geographers grappling with this problem in this period see Hugo Hassinger, *Geographische Grundlagen der Geschichte* (Freisburg: Herder, 1953), esp. 6; Willy Hellpach, *Geopsyche* (Leipzig: W. Engelmann, 1939), esp. 213, 246; Giselher Wirsing, *Zwischeneuropa und die deutsche Zukunft* (Jena: E. Diederichs, 1932), 9–10.

CHAPTER 6

Teaching the Weather Cadet Generation

Aviation, Pedagogy and Aspirations to a Universal Meteorology in America, 1920–1950

ROGER TURNER*

Clouds of carbon dioxide ice crystals scudded across the sky. At another time, the cyclone blowing at 55° N 10° E might have been a weak nor'easter. But for the readers of "Some Aspects of the Meteorology of Mars," in the February, 1950 issue of the *Journal of Meteorology*, storm fronts sweeping across Mars were a logical, if surprising, product of three decades of pedagogical and institutional development.[1] Beginning in the 1920s, American meteorology students learned that a universal ideal lay at the heart of their emerging profession. Meteorology was the science of atmospheres. By 1950, this community could recognize that weather events on Mars, like weather on Earth, should be understood as particular cases of the general laws that governed all atmospheres.

The discoverer of that Martian nor'easter was Seymour Hess. While his studies of Mars were "generally considered 'far out' figuratively as well as literally" by his colleagues, he was representative of the new American meteorological community. He was one of roughly 6,000 "weather cadets," young men trained to forecast weather for the United States Army Air Force and Navy during World War II. Picked out by the training program's leader, Carl-Gustaf Rossby, as one of the brightest in his class, Lt. Hess spent the war at the University of Chicago. He taught subsequent classes of cadets how to calculate the movement of air masses, locate frontal systems, and predict conditions in the upper atmosphere. Like hundreds of his peers, he completed an advanced degree after the war, then spent a successful career developing the "young science" of meteorology. Hess helped establish a department of meteorology at Florida State University and later worked extensively with NASA.[2] His peers founded dozens of other academic departments, forecast weather for the military around the globe, managed weather conditions for airlines, integrated radar, satellites and computer modeling into the daily work of the Weather Bureau, and generally made secure, middle-class lives from the science they had first learned during the war. As Figure 1 shows, the weather cadet generation dominated the demography of American meteorology for decades.

To understand this post-war community of scientists, we need to recognize that it was actively constructed by an earlier generation of meteorologists. The leaders of this earlier generation, Carl-Gustaf Rossby and Francis Reichelderfer, are now celebrated as the founders of modern American meteorology.[3] Between the 1920s and the 1940s, Rossby, Reichelderfer and their allies designed the institutions, established the curriculum, and cultivated the values that guided the weather cadets trained during World War II. Understanding their agenda within the social and political context of the interwar years reveals why the weather cadet generation was taught to aspire to produce a universal science of the atmosphere.

Most accounts of this period focus on the introduction and acceptance of the "Bergen School" into American meteorology.[4] They explore how the Norwegian concepts of air masses, fronts, and the genesis of cyclones were slowly incorporated into American meteorology. The central puzzle in several accounts is why these concepts, now so familiar to meteorologists and the television-watching public, were resisted by the US Weather Bureau well into the 1930s—despite the charm and boyish enthusiasm of Bergenite Carl-Gustaf Rossby, on his way to becoming the foremost theoretical meteorologist of his era. Memoirs written by meteorologists who were young during the 1930s and 1940s solve this puzzle by blaming the senior forecasters who ran the Weather Bureau. Poorly educated bureaucrats who stubbornly clung to obsolete methods, these old men did not understand the math and physics behind the Bergen School, and were blind to the path-breaking research that would transform weather forecasting from an art to a science.[5]

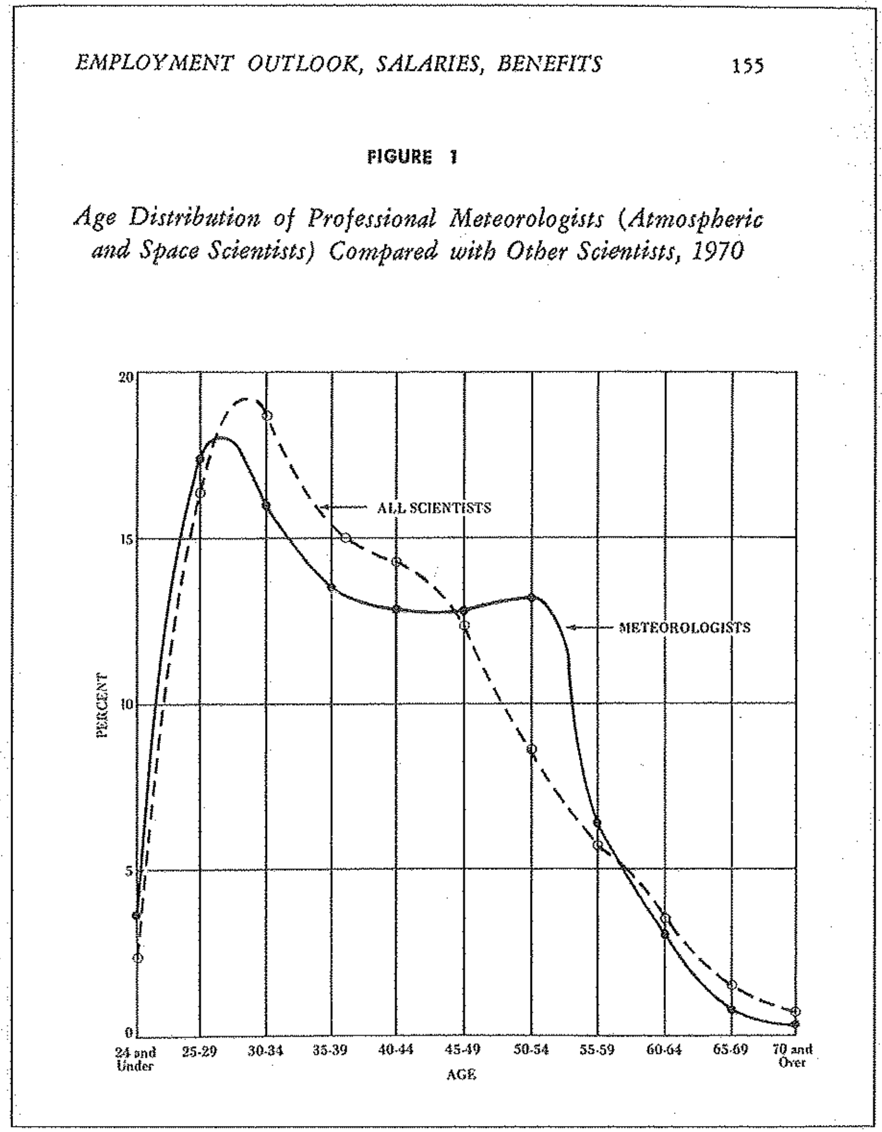

FIGURE 1 Age Distribution of Professional Meteorologists. Source: Miles F. Harris, *Opportunities in Meteorology* (New York: Vocational Guidance Materials, in Association with the American Meteorological Society, 1972): 155.

My account reinterprets this era in two ways. First, inspired by studies of scientific practice, I explore the daily work practices of the Weather Bureau: collecting observations, making maps, and issuing regularly scheduled forecasts.[6] In light of their successful experience and the daily demands placed upon them, the hesitancy of Bureau forecasters to embrace alternative theoretical models of meteorology seems quite sensible. Second, I frame the adoption of the Bergen School concepts as part of an ideological transformation driven by aviation interests. Carl-Gustaf Rossby successfully persuaded a series of audiences that dynamic meteorology, the branch of meteorology that dealt with the theory and physics of weather, was the best solution for explaining and predicting the weather phenomena crucial to aviation. Sometimes wrestling with the synoptic meteorologists who ran the Weather Bureau, Rossby and Reichelderfer positioned dynamics at the core of meteorology. As Robert Marc Friedman has shown, dynamic meteorology grew out of 19th-century German physics, brilliantly applied to the atmosphere by Vilhelm Bjerknes and the Bergen School. By positioning dynamical explanations at the heart of meteorology, Rossby encouraged meteorologists to aspire to create a universal science of the atmosphere.

Yet even universal sciences grow from particular contexts. In the wake of World War I, as Deborah Coen shows in this volume, the political and geographical situation of a defeated Austria made specific, local studies the most reasonable path to a successful future for the Central Institute for Meteorology in Vienna. The world looked different to the War's victors. The United States emerged from World War I as a recognized world power, undamaged by the fighting, with the strongest economy of any nation. With a unified, continental-scale weather reporting network and control over its vast ocean approaches, global meteorology looked possible from the U.S. Rossby saw a career opening and secured an American-Scandinavian Foundation fellowship to escape the depressed economy of his native Sweden in 1925. As Gregory Cushman points out, Jacob Bjerknes came to the U.S. in 1940 in part because the American context offered him the chance to do large-scale science that could not be carried out in Europe. But it was the American enthusiasm for aviation, another result of World War I, which offered the strongest support for a universal science of the atmosphere. Air power advocates like Gen. Billy Mitchell and Hap Arnold used American geography—especially the wide seas that separated the U.S. from its potential enemies—to argue for the development of aviation generally, and for building airships and long-range, heavy bombers in particular. Lt. Reichelderfer led the Navy Aerology section during the 1920s and 1930s,

working closely with the Navy's dirigible program. Reichelderfer and Mitchell realized early in the 1920s that long-range bombers and airships needed meteorological support of a different kind than had evolved in the Weather Bureau over the previous fifty years. High-level winds, the structure of squall lines, and icing conditions in the upper air were irrelevant to a farmer or produce shipper, but of life or death importance to a flyer.

If aviation was the primary source of political and economic support for a universal meteorology, institution building and pedagogy were the mechanisms by which it was created. As Sharon Traweek has pointed out, modern scientific communities are replenished through education.[7] While existing Weather Bureau meteorologists tended to be allergic to the math and physics of Scandinavian dynamic meteorology, a new generation of meteorologists *learned* to aspire to a universal science of the atmosphere from teachers like Rossby and Jacob Bjerknes. These men and their allies then created places where their students could work. The intimate experience of education instilled the universal ideal. David Kaiser's broad interpretation of pedagogy, which expands beyond classroom techniques to encompass the various institutions of training, illuminates how disciplinary cultures are created. Likewise Kenji Ito's work on the movement of the *Kopenhagener Geist* to Japan highlights how educational role-models shape the transmission of values and ideals across national contexts.[8]

This paper begins by describing the culture of the Weather Bureau in the 1920s, exploring how an intensely visual approach to forecasting emerged from daily work practices. The paper next follows the early career of Carl-Gustaf Rossby. Rossby's brief tenure in the Weather Bureau introduced Bergen School concepts into American meteorology, before the ambitious young foreigner issued a forecast for Charles Lindbergh and was fired for transgressing the Bureau's hierarchy. Hired by Harry Guggenheim, the richest aviation booster of the 1920s, Rossby established a model weather service that used Bergen methods to demonstrate that airlines could fly safely and regularly. At the urging of the Navy, Guggenheim then paid for Rossby to become a professor at MIT, where Rossby taught Navy flyers and began to theorize about the general circulation of the atmosphere. The paper returns to the Weather Bureau, focusing on efforts to reform the Bureau after the crash of the Navy dirigible *Akron* in a 1933 squall. After the leadership of the Weather Bureau is firmly in control of the universal meteorologists in 1938, the paper shifts to the training programs established for Army Air Force officers in the lead-up to World War II. The paper explores the education of these "flying fighting weathermen" using the yearbooks they produced to memorialize their experience. Managed by Rossby, the training programs taught a comparatively huge group of meteorologists to see weather forecasting as a problem in applied dynamics. The narrative concludes with a study of Rossby's reforms of the American Meteorological Society in 1944–45, which emphasized the privileged place that theoretical research and academic credentials played in the identity of a new scientific discipline now institutionally and intellectually secure, thanks to the success of the Army Air Force in World War II.

SEEING THE WEATHER: THE US WEATHER BUREAU IN THE 1920S

In the five decades since the establishment of a national weather service in 1871, the US Weather Bureau grew into the dominant American meteorological institution.[9] While a few independent observatories collected weather data, the Weather Bureau played the key role in organizing and administering American meteorology. Nearly all people paid to theorize about or forecast the weather were in some way connected to the Weather Bureau. Even as late as 1940, the Weather Bureau employed over two-thirds of all the trained or experienced meteorologists in America. The Bureau controlled the observational network and the nation's climatology records. University graduate programs in meteorology were basically non-existent, and few other institutions played a role in meteorology.[10]

Within American meteorology, only the Weather Bureau had a significant and reliable source of funds. While congressional appropriations were never adequate to meet the Bureau's perceived needs, and became particularly inadequate as aviators required more extensive upper air observations during the 1930s, the Bureau's budget towered above all the other sources of funding for meteorology in the interwar period. In 1923, the Bureau's appropriation was a bit over $1.9 million, while by 1932, it had swelled to just under $4.5 million. In comparison, the creation of a new meteorology graduate program at MIT in 1928 depended upon a $34,000 grant from the Guggenheim Fund.[11] On the public stage, the Weather Bureau was nearly synonymous with orthodox meteorology. The title of a 1920 children's book suggests how inseparable weather science was from the organization that controlled it: "Gilbert Weather Bureau (Meteorology) For Boys."[12] The Bureau issued the forecasts that appeared in newspapers. It was the first authority journalists consulted when judging the validity of meteorological claims.[13]

The Bureau upheld orthodox meteorology through a culture of conservatism. A domain as important—and public—as the weather attracted many people who claimed revolutionary techniques for improving forecasts or controlling the weather. In terms of social standing, these claimants ranged from fast-talking, itinerant rain-makers like Charles M. Hatfield to Dr. Charles Greely Abbott, a student of astrophysical connections to weather—and the assistant secretary of the Smithsonian Institution. These techniques almost never proved effective or repeatable, but neither did they die. By attracting the attention of a powerful official or two, nearly any idea about the weather might gain celebrity. In 1934, the Secretary of Agriculture appointed a statistician to investigate astrometeorological connections for long-range forecasting, an idea long rejected by the Bureau.[14] The Bureau maintained its intellectual and political authority by generally refusing to support meteorological claims made by people outside of the organization. Bureau officials expected that new techniques would gain only brief, though bright and annoying, prominence, and then fade into the regular background of extravagant stories invented by kooks.

The Bureau's daily forecasting practice depended upon tried and true techniques that had developed alongside the synoptic observing network. According to historian Donald Whitnah, "the general forecasts of 1933 did not vary basically from those of 1871. The movements and relationships among areas of high and low barometric pressure formed the primary source of Weather Bureau prognostications."[15] Synoptic weather maps revealed those pressure area movements. The daily production and interpretation of the synoptic map formed the base of a Bureau man's knowledge of weather. As a torrent of weather observations flooded over the telegraph lines from remote observing stations each morning, meteorologists at the forecasting stations plotted the synoptic weather map. After plotting work by junior figures, the station's "meteorologist-in-charge," usually the most senior forecaster, would analyze the chart and dictate a forecast. Observing stations were widely dispersed, however, and a useful weather map depended upon the continuities of barometric pressure areas, of isothermal lines and bands of precipitation. In creating and interpreting weather maps, forecasters routinely used interpolation and educated intuition. This practical knowledge was born out of experience and the feedback of a daily routine of watching the play of weather observations across a map of America.[16]

The Bureau's leading forecasters attempted to codify their practical knowledge in 1916. Initiated at the request of the new chief Charles F. Marvin, *Weather Forecasting in the United States* attempted to "explain, more or less fully and in detail, the processes by which forecasts can be made," intended for the "guidance and instruction of beginners."[17] But forecasting was an activity that was learned by doing and watching, not reading. "The consensus of opinion seems to be that the only road to successful forecasting lies in the patient and consistent study of daily weather maps."[18] Emphasizing that point, more than one hundred weather maps illustrated 370 pages. The book was a supplement to apprenticeship, and made sense primarily in that context.[19]

The Weather Bureau's recruitment and training practices reinforced the development of forecasting through practice. Lead forecasters typically worked their way up from Junior Observer after entering the Weather Bureau with a high school education.[20] New weather forecasters were promoted from the ranks, "by choosing the winners of contests in making daily practice forecasts."[21] With little formal education or opportunities in meteorology available outside the Weather Bureau, seniority—rather than education or research attainments—largely determined status. Keeping one's intellectual and social distance from unorthodox theories of forecasting (whose advantages were usually illusory) demonstrated the sobriety that distinguished a reliable weatherman. Successful careers were made by observing instruments carefully, plotting maps accurately, and forecasting responsibly. In 1925, an effervescent Swedish visitor stepped into this culture.[22]

BERGEN COMES TO AMERICA

Carl-Gustaf Rossby was 26 when he arrived in America. Rossby was initially appointed by Chief Marvin as a research associate to confer with the Bureau's forecasters and "demonstrate the application of the Bjerknes method of weather forecasting" in the United States.[23] The "Bjerknes method" is better known today as the concepts of the Bergen School. Emerging from the work of the meteorologists assembled by Vilhelm Bjerknes in Bergen, Norway, this approach to meteorology introduced new concepts for analyzing weather maps. The most distinctive of these concepts were the polar front and air mass analysis. Conceived during the waning years of World War I, the polar front represented the boundary between cold air coming down from the north and warm, tropical air moving toward the pole. Where these armies of air collided, storms emerged. Vilhelm Bjerknes's son, Jacob, proposed a novel model of cyclogenesis (storm-creation) in 1919–1920, which emphasized the three-dimensional physical nature of storms. Later in the early

1920s, these concepts were extended through air mass analysis. While just one polar front could exist, air masses could explain the formation of storms at multiple locations. Sometimes thousands of miles across, large pockets of air took on the characteristics of their surroundings if left undisturbed for a few days. Maritime tropical air became warm and moist, while a continental polar air mass was cold and dry. When these air masses bumped against each other, the thinking of the Bergen school went, the physical laws of hydro- and thermodynamics could be used to explain how they would interact. Connecting dynamic and synoptic meteorology, using physical explanations to improve weather forecasting, was a characteristic desire of the Bergen School.[24]

The desire to connect dynamic and synoptic meteorology grew out of Vilhelm Bjerknes's attempt to build a career in classical physics on the periphery of the European scientific community at the end of the 19th century. By connecting storms and weather to theory, Bjerknes aimed to "appropriate the weather" for physics, in Robert Marc Friedman's phrase. The desire to reformulate meteorology as a branch of physics and convert existing meteorologists to this vision marked many Bergenites. Desirable allies were, first and foremost intelligent, rather than kind, experienced or senior. Understanding the physical reasoning behind the techniques mattered most. By the early 1920s, Bergenites were thinking of themselves as "apostles" of the polar front.[25]

Just a year after arriving in Bergen, Carl-Gustaf Rossby became one of these apostles. At Bergen, Rossby had developed twin reputations for charm and brilliance. One of Rossby's co-workers, Tor Bergeron, remembered Rossby's "budding eloquence and power to persuade people to do the things they least of all had intended to do." The young man's "far-reaching ideas and high-flying plans often took our breath away."[26] Rossby returned to his native Sweden to preach to the Swedish meteorological service in 1922.[27] In the following years, Rossby also earned an advanced degree in mathematical physics from the University of Stockholm. By 1925, Rossby set his sights on broader horizons. He won a fellowship from the American-Scandinavian Foundation, promising to study dynamic meteorology problems and the application of the polar front to American weather forecasting.[28] Rossby's experience at the Weather Bureau seems to have begun well. Though institutional culture and Congressional disapproval had made research a low priority at the Bureau, Chief Marvin lauded Rossby's character and intellect in a letter to the American-Scandinavian Foundation in October, 1926.[29]

More importantly, Rossby made an enduring friendship with Lt. Francis Reichelderfer, an officer who headed the U.S. Navy's Aerology section. Young men with a strong scientific education (Reichelderfer had worked as a chemist before World War I), they both worked outside the stable hierarchy of the Weather Bureau. Reichelderfer had become interested in the Bergen methods following a near-disaster in 1921. Flying as an observer during an air power demonstration, Reichelderfer's plane was badly shaken by an unpredicted squall line. This storm front forced the demonstration's leader, General Billy Mitchell, to land his plane on the beach to avoid a crash. Mitchell presented this demonstration, a simulated attack on the captured German battleship *Ostfriesland*, as evidence of the superiority of aircraft to battleships. For Reichelderfer, it was a spur to explore the Bergen methods.[30]

As the head of the weather services for Navy aviation, Reichelderfer had extensive contacts in the aviation community. The most valuable was Harry F. Guggenheim, an heir to the famous mining fortune. Guggenheim had learned to fly in the Navy during World War I. He met Reichelderfer through balloon racing, a sport "as stylish as polo or yacht racing" in the early 1920s; the Navy often fielded entries.[31] Guggenheim believed aviation would be essential to economic and military power in the future, and believed the U.S. was falling behind Europe. As a remedy, he convinced his father to endow The Guggenheim Fund for the Promotion of Aeronautics in 1925.[32] Like most early aviators, Guggenheim appreciated the importance of weather forecasting. Reichelderfer persuaded him to support Rossby's research after the American-Scandinavian fellowship ran out.[33] In August 1927, Guggenheim appointed Rossby chair of the Fund's Committee on Aeronautical Meteorology.[34]

Rossby's connections to the Guggenheim Fund soon brought him into trouble with the Weather Bureau, however. Playing the apostle, he worked to persuade Weather Bureau forecasters to adopt Bergen techniques. "Unfortunately," notes meteorologist-turned-historian Charles Bates, "Rossby was lecturing staid bureaucrats 40 yr his senior."[35] Rossby's strained status with the Bureau leadership took a fatal turn when he made an unauthorized forecast for Charles Lindbergh. Following his famous crossing of the Atlantic, Lindbergh had toured the country sponsored by the Guggenheim Fund. When Lindbergh decided to make a 27-hour winter flight from Washington D.C. to Mexico City, he ignored the Weather Bureau and went straight to Rossby. Public forecasts were strictly the dominion of Weather Bureau regulars. An incensed Chief Marvin allegedly declared Rossby *persona non grata*.[36]

THE GUGGENHEIM MODEL AIRLINE (1927–1928)

Expelled from the Weather Bureau, Rossby began the organizing activities that would eventually make him the leader of the American meteorological community. But at the time, he was a simply an ambitious young foreigner with charm and connections. Harry Guggenheim put Rossby to work developing meteorological services in support of the Western Air Express, a model airline the fund was supporting in California. Rossby's "experimental weather reporting service" would forecast upper air conditions, cloud cover, head- and tail-winds, and landing conditions at airfields between Los Angeles and the San Francisco Bay area.

Rossby spent June and July 1928 establishing observing stations and learning the airways between San Francisco and Los Angeles. His expense reports include bills for 1000 weather maps, $80.00 for a pilot to fly him up and down California for ten days, and $19.25 for a leather flying helmet and goggles.[37] Each observing station was connected by telephone to centralized collecting offices in Oakland or Los Angeles. In addition to air mass analysis and fronts, Rossby's operation drew upon the Bergen school's use of cloud forms to inform prediction.[38] Observers were given a cloud atlas and were expected to include cloud formations in their reports.[39] They were explicitly instructed not to conflate cloud movement with surface winds.[40] To obtain adequate upper air measurements, Rossby contacted the Army Air Corps, hoping they might be willing to launch regular flights to take upper air data, and obtained a number of pilot balloons and related equipment from the Navy.[41]

Rossby also had to recruit and train forecasters. While fishing for weather talent in early 1928, Rossby was introduced to Horace Byers, a junior at Berkeley with an interest in physics and climate. By July, Byers was Rossby's trusted lieutenant, on the Guggenheim payroll at $175 per month. According to Rossby's letters to the Fund's headquarters, Byers was doing "splendid work" teaching the Weather Bureau how to run the reporting service, and beginning empirical studies of California weather.[42]

The Experimental Weather Reporting Service proved successful during 1928 and 1929. Western Air Express suffered no weather-related crashes or mishaps, while the efficiency and reliability of its schedule increased. As the Weather Bureau's San Francisco meteorologist-in-charge noted, the Experimental service's forecasts were also utilized by members of the Automobile Club of Southern California and the California State forester.[43] Despite its successes, the model reporting service nearly collapsed in the spring of 1929 when the Guggenheim fund planned to turn the service over to the Weather Bureau. Weather Bureau headquarters refused to fund the service, and only a last-minute action by departing President Calvin Coolidge (thought to be instigated by incoming President Hoover) explicitly funded it.[44]

TEACHING UNIVERSAL METEOROLOGY, PART I: GRADUATE PROGRAMS

Late in 1927, Edward Warner, formerly Guggenheim professor of aeronautics at the Massachusetts Institute of Technology, now assistant secretary of the Navy for Aeronautics, let Harry Guggenheim know that the Navy needed a good training course for its weather forecasters. Fishing for financial support from "some public-spirited citizen or organization like your own," Warner sought a "fully rounded course to prepare men for meteorological work either in the services or in civil life."[45] A year layer, Guggenheim's public spirit brought Rossby to MIT as assistant professor of meteorology.

Rossby began training a group of colleagues in addition to teaching his military students.[46] Horace Byers became the department's first graduate student. Jerome Namias, Harry Wexler, and Athelstan Spilhaus studied at MIT during the 1930s, and all went on to distinguished careers in geophysical research. In the spring of 1929, Hurd C. Willet, a former Weather Bureau observer and one of the handful of Americans with a Ph.D. in meteorology, joined the department as assistant professor.[47] Rossby's charm and generosity marked his teaching. Horace Byers recalled that Rossby's "informal discussions over luncheon or a cup of coffee . . . were nothing less than an inspiration."[48]

Rossby's most important research occurred during the ten years he spent at MIT. This work focused on exploring the influence of upper air conditions upon the movements of air masses. Working from the increasing number of upper air observations being taken around the northern hemisphere (and some of which he arranged in the Boston area), Rossby developed techniques for identifying and tracking air masses. By charting constant potential temperature (isentropy), the boundaries of air masses could be identified and followed over time. To understand what caused the movement of air masses, Rossby returned to the rotation of the earth, and its effect on the general circulation of the atmosphere. From upper air observations, he teased out a pattern of enormous tongues of low pressure, reaching downward from the pole. These large-scale atmospheric disturbances, he realized,

were waves that had periods of a few days, the same order as many substantial changes in weather. Following a line of mathematical reasoning that stretched back to Laplace's theory of ocean tides and through a theorem of Hermann von Helmholtz, Rossby developed an equation that could be used to calculate the movement of these waves. This equation, published in 1939, accounted for shifts in the upper-level westerlies, the steering winds which guided air masses. The result made Rossby world-famous amongst physicists studying the atmosphere.[49]

While Rossby was making an international reputation, aviation continued to grow, despite the global economic collapse. Between 1928 and 1940, five American universities established graduate programs in meteorology. Following MIT in 1928, the California Institute of Technology established a program in 1933,[50] and Rossby's student Athelstan Spilhaus led a department at New York University from 1937. These programs were each connected to Guggenheim-funded schools of aeronautics. In 1940, the University of Chicago and the University of California, Los Angeles introduced professional meteorological instruction. All five programs focused upon preparing students for careers in aviation, and began to send graduates into the Weather Bureau following reforms in the 1930s.

REFORMING THE WEATHER BUREAU

While Rossby worked at MIT, flying interests called for improvements in the Weather Bureau's aviation forecasting services. The resulting reforms embraced the values of the Bergen School. By the time Rossby rejoined the Weather Bureau in 1938 as assistant director for research, directives from outside the Bureau had set it on a course towards full adoption of Norwegian methods. University education of young men was the primary mechanism for spreading the Bergen School.

The Air Commerce Act of 1926 directed the Weather Bureau to provide forecasts and warnings useful for aviation. Flying grew far faster than appropriations, however, and the Bureau struggled to provide adequate observations and forecasts for the nation's airways. Nor did the economic collapse of 1929 help appropriations, though it was not until the first Roosevelt budget that government spending was drastically curtailed. The Weather Bureau lost nearly $2 million, about 45% of its budget, between the 1932 and 1933 appropriations. Chief Marvin dismissed nearly 500 employees, about 20% of the Bureau's workforce.[51]

On April 4th, 1933, the Navy dirigible USS *Akron* crashed in an unpredicted squall, killing 73, including the head of the Navy's Bureau of Aeronautics, Adm. William Moffett. Resulting Congressional hearings explored the inadequacies of the Weather Bureau, while highlighting the credibility problems faced by such a public science. In one hearing, Charles Mitchell, the Bureau's most respected forecaster, battled a Senator who claimed expertise based upon many years of studying Weather Bureau reports, while the committee chairman spoke of meteorology as "this so-called 'science.' " Later in the hearings, air power advocate Billy Mitchell argued that the weather service should be rearranged, removed from the Department of Agriculture (which was responsible for "raising onions, potatoes and such things,") and run by the military.[52]

President Roosevelt took a moderate response, calling upon a new institution: the Science Advisory Board.[53] Chaired by MIT president Karl Compton, the Board appointed a subcommittee to recommend improvements to the Weather Bureau: one Weather Bureau meteorologist, Charles D. Reed, and three university presidents: Compton, Johns Hopkins's Isaiah Bowman, and Cal Tech's Robert Millikan. In addition to being America's most distinguished physicist, Millikan had headed the Army's meteorology program during the Great War.

The subcommittee's report called for the immediate adoption of "air-mass analysis methods." With air-mass analysis, the committee wrote, "there is the practical certainty that our whole forecasting service can be improved both as to accuracy and reliability."[54] Since air mass analysis required upper air data, the report suggested that the Army and Navy provide daily aerological measurements during their regular training flights. The report called for the Bureau to keep up with new developments in air-mass analysis. In addition, the Committee recommended that a system of post-graduate training for Weather Bureau meteorologists be initiated. All forecasters should receive "thorough instruction in the more modern methods," while those "who already have a good basic training in meteorology, physics and mathematics and have shown some proficiency in the actual art of forecasting" should be detailed "to an institution of recognized leadership in this field" for six months or a year of advanced instruction.[55] Superior meteorological knowledge now came from universities, this group of college presidents implied.

The Weather Bureau's adaptation to air-mass analysis, however, "proved to be a painfully slow process."[56] The *Akron* crash ended Chief Marvin's tenure in January 1934; he officially retired eight months later after fifty

years with the weather service. The new chief was Willis Gregg, head of the Bureau's aerology division. Gregg's promotion made clear the centrality of aviation interests. But while Gregg had been a member of the Guggenheim committee on meteorology alongside Rossby, he remained an insider who had spent his career with the Bureau. Between 1935 and 1938, the Bureau appointed roughly "a dozen young university men with air mass training."[57] Among these men were Rossby's students Horace Byers and Harry Wexler. Gregg's choices about how to pay for the new technique may have caused some of the conversion pains. Money intended for salary increases in 1935 was diverted to the new air mass section instead.

George R. Stewart's best-selling 1941 novel, *Storm*, suggests the tension within the Bureau between young university men and senior, experienced forecasters:

> [The Junior Meteorologist] admitted that he had been unhappy in the Weather Bureau; his mathematical training did not seem to help him, and sometimes he thought that it even was a handicap. Sometimes it seemed as if the Chief were only using the same methods that any shepherd might have used back in the time of the Patriarchs; he just looked at the sky, and decided from the appearance of things what weather would come along after a while. The Shepherd, of course, never saw farther than the actual horizon. By the weather map the Chief extended his view for several thousands of miles. There was a tremendous pyramiding of information, but not much change in method.[58]

To the young men trained in the methods of the Bergen School, the empirical methods of senior forecasters simply looked obsolete. These men seemed to be stubborn old-timers resisting the progress of modern meteorology. Reminiscing in 1981, Jerome Namias took the resistance to Bergen methods as evidence of the Bureau's "provincial and narrow view."[59]

To the experienced forecasters responsible for issuing reliable forecasts on tight schedules, however, the intuitive processes refined through years of practice represented a skilled judgment that couldn't be learned in a classroom. Running a weather service was different from talking about one.

The Bergen School learned this difference when Chief Gregg died from an unexpected heart attack in 1938. At the suggestion of the Science Advisory Board, President Roosevelt appointed Francis Reichelderfer. Commander Reichelderfer learned of the offer as he entered port aboard the *USS*

Utah.[60] Not only was the 43-year-old Navy Officer the first outsider to head the Bureau, he hired Rossby as Assistant Director for research and education.

Reichelderfer proved a conscientious administrator, and he avoided making wholesale changes to his new organization. The Civil Aeronautics Act of 1938 gave him a useful tool for gradual change: education. The act directed the Weather Bureau to send men each year to universities for "training at Government expense . . . in advanced methods of meteorological science." Such men also retained their seniority as they learned.[61] Reichelderfer further reformed the Bureau by addition. Senior forecasters could continue to forecast as they had, while new methods and new men were added to the process.

The Department of Agriculture's *1941 Yearbook of Agriculture: Climate and Man* illustrates these processes of reform. In an early chapter, Reichelderfer laid out the new goals that marked modern meteorology. In its current stage, expert forecasting remained "a combination of training, experience and native ability. However, as progress is made in three-dimensional analysis of the weather and . . . knowledge of its physical processes . . . the science will become more systematic and exact." Progress would come through research. Meteorology's goal was not only better forecasting, but also to diminish the importance of "personal factors" in the process.[62]

Rossby's contribution reiterated the commitment to research as the engine of progress. In "The Scientific Basis of Modern Meteorology," Rossby laid out a "semi-technical" presentation of the physics of Northern hemisphere atmospheric circulation. "Genetics, soil science and nutrition have all made great strides based upon important fundamental discoveries," he argued. "Latest to join this group is meteorology."[63] Arguing for the primacy of theory, he wrote, "it is safe to say that until the proper theoretical tools are available, no adequate progress will be made either with the problem of long-range forecasting or with the interpretation of past climatic fluctuations."[64] While much of his article seems far too "semi-technical" for the average reader, he ended his piece with a short demonstration of "amateur forecasting from cloud formations."

Rossby's heart didn't seem to be in popularization or administration, however. In 1941, he followed his protégé Horace Byers to the University of Chicago, where Rossby took over a new Institute for Meteorology. From the Institute, Rossby organized academic meteorology through the University Meteorological Committee, which eventually supplied thousands of weather forecasters to support an air force capable of winning a global war.

TEACHING UNIVERSAL METEOROLOGY, PART II: FLYING FIGHTING WEATHERMEN

Franklin Roosevelt's 1940 call for a 50,000-plane air force set Army and Navy officers to thinking about training. New squadrons would need pilots and bombardiers—and weather officers. War would also require establishing weather-observing stations around the globe.[65]

In 1940, the few dozen existing military weather officers had largely learned their meteorology from MIT or Cal Tech during the 1930s. They looked to the research universities for expanded training programs. As of October 1940, there were 150 new cadets studying meteorology at MIT, Cal Tech, NYU, UCLA, and the University of Chicago.[66] Following the attack on Pearl Harbor, the immediate need for new meteorologists loomed large. As the five schools went to year-round programs and began taking in two classes of meteorological cadets per year in 1942, Col. Donald Zimmerman, the head of AAF Weather Service, estimated that the AAF would need 10,000 weather officers by the start of 1945.[67]

The University Meteorological Committee (UMC) saw itself as "a clearing house for the exchange of ideas between the [AAF] Directorate of Weather and the individual universities," while the committee was "at the disposal of the Army Air Forces whenever technical problems arise."[68] The UMC coordinated the training program, exchanging research, curricula and even instructors.

The UMC had to secure an adequate number of suitable young men to train.[69] Advertising and recruiting efforts were extensive, even including a half-hour radio program titled "The Invisible Allies! A Thrilling Chapter from the Notebooks of Science—and War!" that featured an appeal from Nobel laureate physicist Arthur Compton.[70] The graduate program's stiff educational prerequisites (one year of college physics, differential and integral calculus, and the successful completion of two full years of college) made necessary a second and third series of preparation programs.[71]

The curriculum mixed a heavy dose of physical theory with hundreds of hours of synoptic map analysis:

> "The program offered by the Institute for the training of cadets as meteorologists for the Army Air Corps, and of Navy officers as aerologists, has been planned to provide each student with the utmost practical experience in the analysis of weather charts and forecasting,

and at the same time to endow him with a broad theoretical background in modern meteorological physics. To accomplish this, the academic week at the Institute comprises approximately 20 to 24 hours of practical weather analysis and forecasting in the synoptic laboratories and 12 hours of formal lectures. From two to four hours of the weekly laboratory time are devoted to discussions, . . . A two-hour examination covering all subjects is held weekly, and final examinations are given in each course."[72]

While this pattern adhered to the academic mold, cadets also learned to march, shoot, salute, and defend themselves against poison gas attack when they were not calculating radiative cooling.[73] The students called it a "GI life of calculus, physics, and meteorology."[74]

The Bergen School's abstract way of knowing weather formed the core of the curriculum. The textbooks taught that the basic goal of meteorology was to understand weather in physical and mathematical terms, so it could

Curriculum for Wartime Training Classes
Institute of Meteorology, University of Chicago

Subject	*Total # of hours*
Synoptic laboratory	672
Dynamic meteorology	116
Synoptic and aeronautical meteorology	72
Introductory meteorology	43
Hydrodynamics	42
Field course	24
Radiosonde	53
Climatology	32
Geography	22
Physics of the High Atmosphere	32
Oceanography	20
Fieldwork with mobile weather unit	18
Examinations	95

Books Issued to Meteorology Cadets, UCLA A-level Class, March 1943[75]

Horace R. Byers	*Synoptic and Aeronautical Meteorology*	McGraw-Hill, 1937
Bernhard Haurwitz	*Dynamic Meteorology*	McGraw-Hill, 1941
Bernhard Haurwitz	*The Physical State of the Upper Atmosphere*[76]	Royal Astronomical Society of Canada, 1941
Wilfred Kendrew	*The Climates of the Continents,* 3rd edition	Oxford University Press, 1937
W. E. K. Middleton	*Meteorological Instruments*	University of Toronto Press, 1942
Jerome Namias	*Air Mass and Isentropic Analysis*	American Meteorological Society
Sverre Petterssen	*Weather Forecasting and Analysis*	McGraw-Hill, 1940
Athelstan Spilhaus and James Miller	*Workbook in Meteorology*	McGraw-Hill, 1942
Victor Starr	*Basic Principles of Weather Forecasting*	Harper, 1942
Harald Sverdrup	*Oceanography for Meteorologists*	Prentice-Hall, 1942
G. E. F. Sherwood and Angus Taylor	*Calculus*	Prentice-Hall, 1942
Weather Bureau	Circular N	

be quantified and calculated.[77] Victor Starr's *Basic Principles of Weather Forecasting* described numerical calculation as the ultimate goal, while admitting that it remained distant. "Since we know the fundamental laws" of fluid mechanics and thermodynamics, "it might appear that a forecast of future motions could be made completely by analytical means. Unfortunately, although we do know the elementary principles of atmospheric motions, the problem of integrating them and obtaining a forecast by purely analytical procedures is too complex to be treated by a direct frontal attack." Starr then footnoted Lewis Fry Richardson's 1922 "effort in this direction."[78]

Weather was generally presented as a secondary phenomenon, the local consequences of the general circulation of the atmosphere. "The general problem of forecasting weather conditions may be subdivided conveniently into two parts. In the first place, it is necessary to predict the state of motion of the atmosphere in the future," wrote Starr. As a second step, only after predicting the atmosphere's motion, "it is necessary to interpret this expected state of motion in terms of the actual weather which it will produce at various localities. The first of these problems is essentially of a dynamic nature, inasmuch as it concerns itself with the mechanics of the motion of a fluid." Successful forecasting resulted from first understanding the physical principles that governed the atmosphere.[79]

While reforming meteorology around a quantitative and physical understanding of the atmosphere was central to Rossby and the Bergen School's long-term agenda, the military needed to be convinced why it should pay for (and wait for) its cadets to learn so much theory. Rossby drew upon the claims of physics to universality:

> Earlier methods of training meteorologists, particularly in the United States Weather Bureau, were based entirely on the accumulation of experience. A man trained over a number of years in, say, San Francisco, would in that fashion become a good forecaster for our West Coast but would have to start all over again if he were transferred to another part of the country.
>
> We do not have the time to give our students adequate basic training and also a large amount of experience within the short period of time at our disposal. Hence, we *must* concentrate on the application of fundamental principles of analysis and forecasting which can be used in any part of the world.[80]

Rossby argued that meteorologists grounded in such principles were not only superior, but also the only effective kind that could be produced quickly. Dynamic meteorology promised portable, placeless knowledge. Knowing the weather through physics, Rossby argued, meant forecasters could work effectively anywhere the global war might require them.

Wartime experience in the tropics suggested otherwise, however. New forecasters found that techniques developed in Norway did not always describe tropical weather patterns. In the South Pacific and Latin America, experienced dispatchers and forecasters from Pan American Airlines provided the local knowledge necessary to safely route planes.[81] The UMC established an Institute of Tropical Meteorology at the University of Puerto Rico to train advanced students—and conduct research to expand dynamic meteorology into tropical skies.

While the UMC curriculum taught students to understand the weather in terms of physics, other aspects of the wartime experience shaped the emerging culture of modern meteorology. First and foremost, the weather cadets were military men, under the orders and authority of the Army Air Force.[82] When the cadets graduated, they earned officer's bars, and they were expected to be leaders and soldiers. The UMC classes were powerful selectors on the basis of race, sex and class. Very few black men became weather officers, and those who did were segregated to support all-black fighter units.[83] About two hundred women studied meteorology in the universities during the war.[84] The high educational prerequisites almost certainly excluded people from poorer and immigrant backgrounds. These excluded groups missed the emerging social and educational networks so central to postwar professional meteorology.

THE CADET EXPERIENCE

Although the students were military officers in training, the meteorology training program retained a collegiate atmosphere. College professors led lectures and labs, while students took exams and lived together in dormitories or apartments. Like many college classes, the weather cadets often produced commemorative yearbooks to construct and solidify the meanings of their experiences. These books followed the genre conventions of other memorial yearbooks.[85] Full of inside jokes, the student authors drew upon military and weather metaphors to recreate shared experiences. For example, "the big guns—Bjerknes and Kaplan and Holmboe—bombarded us without quarter," and "the worst maps turned up as test maps, which is what is meant by periodicity in weather."[86] These books offer a way inside the classroom to see how meteorologists-in-training understood their education.

Reflective writers in the meteorology classes felt their training instilled a new way to know and understand weather. Entering the military, the cadets understood weather as something experienced bodily and discussed in commonplace terms. Learning to see their surrounding environment in more abstract ways de-centered their individual experiences. Personal feelings, bodies, and the particulars of place became increasingly extraneous to the description of events:

> The world around us changed quickly; a cloudy sky became a nimbostratus overcast, the wind that tugged at our overcoats became a

> Beaufort 6 and we all looked for 00 Wx [clear weather] on our weekends. The days of our years took on a more universal aspect and almost unconsciously we came to measure time by new and different standards. . . . The doldrums moved South despite the fact that 150 neophytes had been strapped to the NYU assembly belt and were being processed into weathermen.[87]

The students felt the tension between the vernacular weather culture they entered with and the scientific way of seeing they were being taught. While they felt a chilly wind tugging at an overcoat, they learned to abstract that gust into a number on the Beaufort scale that could be compared to other wind measurements anywhere in the world.

Yet for the bomber crews the weather cadets were training to serve, weather remained a phenomena experienced in the gut and the fingers. Some weather cadets flew training missions to learn how to forecast and surveil weather from the air.

> In reward for beavering well done, we were given an opportunity during that last quarter to fulfill our manifest destiny—that of becoming "flying fighting meteorologists." A convalescent B-18 was assigned to our detachment for weather reconnaissance, and group by group we groundlings took to the air verifying our own forecasts. Frozen limbs and upset stomachs made lapse rates and turbulence less academic, and we returned sadder but wiser weathermen.[88]

Despite the urgings of their academic teachers towards theory, abstraction, and the rejection of subjective experience, the irreducible world of embodied experience remained a fundamental category for fully understanding the meanings of their new role. To be a true fighting meteorologist, a man had to both understand the physics of weather, as well as the physical experience of what those map symbols meant to the men flying bombers through limb-freezing, turbulent air against murderous enemies.

PREPARING A POST-WAR DISCIPLINE

By 1944, it was clear that the UMC had produced more than enough new weather forecasters for the AAF. As the training programs wound down, Rossby turned his attention towards shaping the structure of post-war

meteorology. As president of the American Meteorological Society, Rossby spent 1944–1945 overseeing a major transformation of the AMS (while also trotting the globe as an Air Force consultant). He reformed the constitution, creating a two-tiered membership structure, and introduced a new technical journal, the *Journal of Meteorology*. He worked to create a placement service for meteorologists, promoting the development of "industrial meteorology." He also encouraged the development of meteorology classes as part of the liberal arts curriculum, while working to integrate meteorology into the work of civil engineers and the training of research geologists, oceanographers, and hydrologists.[89]

Rossby's constitutional reforms at the AMS institutionalized the authority and power of university-trained meteorologists. A June 1944 letter "to the Members of the American Meteorological Society from the Council" reveals this institutionalization. The letter accompanied a ballot for members to vote on significant changes in the bylaws and constitution. Splitting the membership into two castes most clearly stated the Society's new priorities. "It is recognized that the Society contains two broad groups of members," the Council wrote performatively, "one consisting of those employed as professional meteorologists, and the other consisting of sub-professional and interested amateurs." Though the two groups have different needs, "it is clear that the future strength of American meteorology lies in unity rather than in independent action by separate groups."[90] Instead of schism, putting the professionals in charge would strengthen American meteorology. "Since it was felt that the administration of the Society should be in the hands of those most vitally interested in the science, it is proposed that the President, Vice President, Secretary, and three of the five Councilors elected each year be Professional Members." Professional members would also be charged $10.00 per year, a hefty increase over the rate of regular membership, $3.50 in 1943.

By giving control over the Society to those experts with either education or employment in meteorology, the constitutional change created an organization dedicated primarily to the interests and concerns of its professional members, while retaining the potential political influence that comes with a large membership. It also helped to move meteorology further away from the public, a useful move for a science long plagued by credibility problems.[91] Twenty-five years later, Horace Byers applauded the stratification of the AMS: "Professional membership now distinguished the trained and experienced meteorologists from the hacks and the dilettantes, and the Society was taking its place among the distinguished learned societies."[92]

In addition to changing the membership structure, Rossby oversaw the introduction of the *Journal of Meteorology*, a new journal dedicated to publishing high-quality theoretical research, including research that had been conducted during the war as it was released from security restrictions. The journal became an important organ for research into the atmosphere's general circulation, and featured Seymour Hess's study of Mars in 1950. Finally, Rossby initiated a system of personnel cards, intended for use as a placement service in peacetime, and for quickly locating properly trained meteorologists during future wars. Extensive records in the UMC files show Rossby's attempts to encourage various sectors of private industry to explore how meteorologists might be of value. From the pulpit of the AMS presidency, he also encouraged the integration of meteorology into the general liberal arts curriculum, thereby hoping to create a need for meteorology teachers at the high school and college level.

CONCLUSION: A THRIVING COLD WAR DISCIPLINE

American meteorology emerged from World War II as a thriving scientific discipline. The aspiration towards a universal science of the atmosphere generated journals, departments, graduate students, national research centers, military support, and research dollars.[93] Global meteorology was also becoming a key element in U.S. foreign policy. In the next essay, Gregory Cushman shows how Rossby and Jacob Bjerknes worked to spread their meteorological approach into Canada and Latin America during the war, and how the U.S. government used the weather cadet training program as a way to orient Latin American meteorology towards the United States. After the war, the State Department promoted "scientific internationalism," to challenge the international appeal of communism. The World Meteorological Organization, created in 1951 with Francis Reichelderfer as its first president, worked to integrate the weather observing systems of member nations into a global network for freely exchanging data.[94]

These efforts coincided with the aspirations to create a universal science of the atmosphere that the weather cadets had learned during the war. The mathematics and physics training at the heart of their education helped them to integrate new technologies for remote sensing and computation into meteorological practice. Radar networks and weather satellites enabled meteorologists to construct synthetic views of the globe, while atmospheric modelers

constructed virtual global atmospheres from equations and electrons. Large-scale atmospheric models became the central basis for weather forecasting practice in the later third of the 20th century. Built into these models was the new social order of meteorology: dynamicists created, synopticians applied. Horace Byers pointed this out to the National Academy of Sciences in 1955 when he celebrated Jule Charney's advances in the numerical simulation of atmospheric flows while noting that "a second step, such as pinpointing cloud, rain, and temperature areas, is left for the harassed local weatherman."[95]

While increasingly detailed weather simulations elevated the dynamic meteorologist, they also revealed the limits of the universal ideal for meteorology. By the 1970s, computer simulations had led to the discovery of chaos, one of the ways in which mathematical knowledge of complex systems like weather is fundamentally limited. Ironically, a pioneer in this exploration was Edward Lorenz, who first learned meteorology as a weather cadet in the academic department Carl-Gustaf Rossby had founded.[96]

NOTES

*A National Science Foundation Graduate Research Fellowship supported the research and writing of this essay. The opinions expressed here are mine alone, and do not reflect the official position of the NSF.

1. Seymour L. Hess, "Some Aspects of the Meteorology of Mars," *Journal of Meteorology* 7, 1 (February 1950): 1–13.
2. Werner A. Baum, "Seymour L. Hess, 1920–1982," *Bulletin of the American Meteorological Society* 63 (1982): 215.
3. The American Meteorological Society's highest medal is named for Rossby, and the Society bestows an annual award in Reichelderfer's name to honor a provider of meteorological services to the public.
4. Kristine C. Harper's thoroughly-researched, engaging dissertation is the most recent and comprehensive study: "Boundaries of Research: Civilian Leadership, Military Funding, and the International Network Surrounding the Development of Numerical Weather Prediction in the United States" (Ph.D. dissertation, Oregon State University, 2003). John Lewis's fascinating topical studies draw upon a range of little-seen archival sources: "Carl-Gustaf Rossby: A Study in Mentorship," *Bulletin of the American Meteorological Society* 73 (1992): 1425–1438; "Cal Tech's Program in Meteorology: 1933–1948," *Bulletin of the American Meteorological Society* 75 (1994): 69–81; "C.-G. Rossby: Geostrophic Adjustment as an Outgrowth of Modeling the Gulf Stream," *Bulletin of the American Meteorological Society* 77 (1996): 2711–2728; "LeRoy Meisinger,

Part I: Biographical Tribute with an Assessment of His Contributions to Meteorology," *Bulletin of the American Meteorological Society* 76 (1995): 33–45. Frederik Nebeker *Calculating the Weather: Meteorology in the 20th Century* (San Diego: Academic Press, 1995).

5. Charles C. Bates, "The Formative Rossby-Reichelderfer Years in American Meteorology: 1926–1940," *Weather and Forecasting* 4 (1989): 593–603; Horace R. Byers, "Carl-Gustaf Arvid Rossby," *Biographical Memoirs of the National Academy of Sciences* 34 (1960): 248–270; Horace R. Byers, "Carl-Gustaf Rossby, the Organizer," in *The Atmosphere and the Sea in Motion: Scientific Contributions to the Rossby Memorial Volume*, ed. Bert Bolin (New York: The Rockefeller Institute Press, 1959), 56–64; Jerome Namias, "The Early Influence of the Bergen School on Synoptic Meteorology in the United States," *PAGEOPH* 119 (1981): 491–500; Jerome Namias, "Francis W. Reichelderfer, 1895–1983," *Biographical Memoirs of the National Academy of Sciences* 60 (1991): 272–291.
6. For example, Robert E. Kohler, *Lords of the Fly* (Chicago: University of Chicago Press, 1992); Pierre Bourdieu, *Outline of a Theory of Practice* (Cambridge: Cambridge University Press, 1977); Andrew Pickering, *The Mangle of Practice: Time, Agency and Science* (Chicago: University of Chicago Press, 1995).
7. Sharon Traweek, *Beamtimes and Lifetimes: The World of High Energy Physicists* (Cambridge, MA: Harvard University Press, 1988), Ch. 3.
8. David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005). Kenji Ito, "The *Geist* in the Institute: The Production of Quantum Physicists in 1930s Japan," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge: MIT Press, 2005): 151–183.
9. Harper, "Boundaries of Research," 7
10. Ibid., Ch. 3. Harper describes the limited educational opportunities of the interwar years. See also William A. Koelsch, "From Geo- to Physical Science: Meteorology and the American University, 1919–1945," in *Historical Essays on Meteorology, 1919–1995*, ed. James R. Fleming (Boston: American Meteorological Society, 1996): 511–540.
11. Weather Bureau budget information: Donald Whitnah, *A History of the United States Weather Bureau* (Urbana: University of Illinois Press, 1961): 181. For more on the Guggenheim Fund, see Milton Lomask, *Seed Money: The Guggenheim Story* (New York: Farrar, Straus and Company, 1964): 125.
12. This book was intended to drive sales of the A.C. Gilbert Company's Weather Bureau set, a collection of meteorological instruments. The advertisement at the back of the book encourages boys to "Learn to use the Gilbert Weather Bureau to read weather indications from instruments set up by yourself . . . Your boy friends will listen to you with interest when you explain to them the cause of

storms and how important it is to have a knowledge of climatic disturbances." Alfred C. Gilbert, *Gilbert Weather Bureau (Meteorology) for Boys* (New Haven: The A. C. Gilbert Company, 1920), 85.

13. Others included the Blue Hill observatory. Some teaching and research into weather and climate occurred in geography departments, as at Clark University and by Charles Brooks at Harvard (Koelsch, "From Geo- to Physical Science"). On journalists and the validity of meteorological claims, see Clark C. Spence, *The Rainmakers: American "Pluviculture" to World War II* (Lincoln: University of Nebraska Press, 1980). For more about the Weather Bureau before the transfer to civilian control, see James Rodger Fleming, "Storms, Strikes and Surveillance: The US Army Signal Office, 1861–1891," *Historical Studies in the Physical and Biological Sciences* 30, no. 2 (2000): 315–32.
14. For more on Hatfield and commercial "pluviculture," see: Spence, *The Rainmakers*. Harper describes the 1920s battles over insolation and a 1934 astrometeorology affair: Harper, "Boundaries of Research," 47–50.
15. Whitnah, *History of the Weather Bureau*, 159.
16. Alfred J. Henry et al., *Weather Forecasting in the United States* (Washington: U.S. Department of Agriculture, Weather Bureau, Government Printing Office, 1916).
17. Ibid., 3.
18. Cited in Bates, "Formative Rossby-Reichelderfer Years," 594.
19. Writing in the early 1990s, university-trained, theoretically attuned Jerome Namias felt differently: "*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." (Namias, "Francis W. Reichelderfer," 275).
20. Bates, "Formative Rossby-Reichelderfer Years." Charles L. Mitchell, one of the Bureau's leading forecasters in the 1930s and 1940s, described his career track when testifying before Congress at the *Akron* crash hearings (Joint Committee to Investigate Dirigible Disasters, *Investigations of Dirigible Disasters: Hearings before a Joint Committee to Investigate Dirigible Disasters*, 1st Session, 1933: 197.) See also the reminiscences of Jack Thompson, an Observer in the Weather Bureau during the late 1920s and 1930s (Jack C. Thompson, "Weather Prediction at the Local Weather Bureau Office as Concepts from the Bergen School Came to the U.S.," *Bulletin of the American Meteorological Society* 66, (1985): 1250–1254.)
21. Whitnah, *History of the Weather Bureau*, 159
22. "Effervescent" comes from Bates, "Formative Rossby-Reichelderfer Years."

23. Charles F. Marvin to James Creese, October 12, 1926. Published in Norman Phillips and Anders Persson, "C.-G. Rossby's Experience and Interest in Weather Forecasting," *Bulletin of the American Meteorological Society* 82, (2001): 2025.
24. Robert Marc Friedman, *Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology* (Ithaca: Cornell University Press, 1989).
25. Ibid., 195–199.
26. Tor Bergeron, "The Young Carl-Gustaf Rossby," in *The Atmosphere and the Sea in Motion: Scientific Contributions to the Rossby Memorial Volume*, ed. Bert Bolin (New York: The Rockefeller Institute Press, 1959), 52.
27. Friedman, *Appropriating the Weather*, 195. More on Rossby's work with the Swedish meteorological service can be found in Phillips and Persson, "C.-G. Rossby's Experience and Interest in Weather Forecasting."
28. Several useful articles explore Rossby's life, though he has not received the full-length biography his ebullient personality and accomplishments deserve. For biographical information, see Bergeron, "The Young Carl-Gustaf Rossby"; Byers, "Carl-Gustaf Arvid Rossby"; Norman Phillips, "Carl-Gustaf Rossby: His Times, Personality, and Actions," *Bulletin of the American Meteorological Society* 79, (1998): 1097–1112.
29. Charles F. Marvin to James Creese, October 12, 1926, published in Phillips and Persson, "C.-G. Rossby's Experience and Interest in Weather Forecasting."
30. Bates, "Formative Rossby-Reichelderfer Years," 595.
31. Ibid.
32. The Guggenheim Fund aimed to kick-start American aviation growth. It disbursed its capital to various pioneering projects, catalyzing the development of aviation at a crucial period. The fund ceased operations in February 1930, after expending $2.6 million. The best-known projects supported by the fund included the development of instrument flying techniques, enabling pilots to fly safely through fog and cloud; Charles Lindbergh's triumphant national tour; and a "safe airplane" competition, which aimed to create an airplane as safe and easy to use as an automobile. The fund also endowed schools of aeronautics at Cal Tech, MIT, Stanford, Michigan, Georgia Tech, and the University of Washington (Richard P. Hallion, *Legacy of Flight: The Guggenheim Contribution to Aviation* (Seattle: University of Washington Press, 1977), pp 92, 169–172.)
33. Bates, "Formative Rossby-Reichelderfer Years," 596.
34. Hallion, *Legacy of Flight*, 92.
35. Bates, "Formative Rossby-Reichelderfer Years," 594–5.
36. Ibid., 594–5; Byers, "Carl-Gustaf Rossby, the Organizer," 56. While Byers was eager to dramatize Rossby's banishment to other meteorologists in a 1959 memorial, he chose not to mention it in Rossby's biographical memoir for the National Academy of Sciences (Byers, "Carl-Gustaf Arvid Rossby."). I have not seen contemporary documentary evidence regarding Rossby's exile.

37. Carl-Gustaf Rossby, Expense report, July 1928. Collected Papers of the Daniel Guggenheim Fund for the Promotion of Aeronautics, Library of Congress. Box 8, Files 1 and 2 (Henceforth, DGFPA).
38. For more on the Bergen School, see Friedman, *Appropriating the Weather*.
39. "Cloud Forms, According to the International System of Classification," Published by the United States Department of Agriculture and the US Weather Bureau; Prepared by the Weather Bureau's Cloud Committee. Undated.
40. "Instructions for Observers," DGFPA.
41. Rossby to Maj. G.C. Brant, 18 Aug. 1928. DGFPA.
42. CGR to HFG, 7/23/28. DGFPA.
43. Edward H. Bowie, *Weather and the Airplane: A Study of the Model Weather Reporting Service Over the California Airway* (New York: The Daniel Guggenheim Fund for the Promotion of Aeronautics, 1929), 25–27.
44. Bowie, *Weather and the Airplane*, 24.
45. Edward P. Warner to Harry F. Guggenheim, 3 Feb. 1928. Also see Edward P. Warner to Harry F. Guggenheim, 7 Dec. 1927. DGFPA.
46. John M. Lewis, "Carl-Gustaf Rossby: A Study in Mentorship."
47. Harper, "Boundaries of Research," 112.
48. Byers, "Carl-Gustaf Arvid Rossby," 255.
49. Lionel Pandolfo, "Rossby Waves," in *Encyclopedia of Climate and Weather*, ed. Stephen H. Schneider (New York and Oxford: Oxford University Press, 1996); Carl-Gustaf Rossby et al., "Relation between Variations in the Intensity of the Zonal Circulation of the Atmosphere and the Displacements of the Semi-Permanent Pressure Systems," *Journal of Marine Research* 2 (1939): 38–55.
50. Led by Irving Krick, Cal Tech's program was quite different from the Bergen programs at the other four universities. Despite being Horace Byers's brother-in-law, Krick was hated by many meteorologists. By the 1950s, his support for unorthodox methods and bold forecasting claims made him a boundary case for acceptable professional behavior. For more on Cal Tech's program, see J. M. Lewis, "Cal Tech's Program in Meteorology: 1933–1948," *Bulletin of the American Meteorological Society* 75 (1994): 69–81.
51. Bates, "Formative Rossby-Reichelderfer Years," 597; Whitnah, *History of the Weather Bureau*, 21, 183.
52. *Investigations of Dirigible Disasters: Hearings before a Joint Committee to Investigate Dirigible Disasters*, 73rd cong. 1st sess. (Washington, DC: USGPO, 1933), 203–4, 696.
53. For a more detailed discussion of the work of the Science Advisory Board in this matter, see Harper, "Boundaries of Research," 57–64; David Hart, *Forged Consensus: Science Technology and Economic Policy in the United States, 1921–1953* (Princeton: Princeton University Press, 1998): 72–75; Robert Kargon and Elizabeth Hodes, "Karl Compton, Isaiah Bowman, and the Politics of Science in the

Great Depression," *Isis* 76 (1985): 300–318; Carroll W. Pursell, "The Anatomy of a Failure: The Science Advisory Board 1933–35," *Proceedings of the American Philosophical Society* 109 (1965): 342–351.

54. Isaiah Bowman et al., "The Work of the Weather Bureau," *Science* 78 (22 Dec. 1933): 582–585, 604–607, quote on 584.
55. Ibid., 606.
56. Whitnah, *History of the Weather Bureau*, 160.
57. Ibid., 161.
58. George R. Stewart, *Storm: A Novel* (Lincoln, Nebraska: University of Nebraska Press, 1983 [1941]), 232. While *Storm* is fiction, Stewart was an eyewitness. According to one scholar, Stewart "secured introduction to the staff of the Weather Bureau in San Francisco, visited them during storms, and learned to draw his own weather maps" (John Caldwell, *George R. Stewart*, vol. 46, *Boise State University Western Writers Series* (Boise, ID: Boise State University, 1981), 30.) Jack Thompson, a meteorologist in the San Francisco office during the 1930s, remembered Stewart as a "familiar visitor around the office for a while" (Thompson, "Local Weather Bureau Office," 1252).
59. Namias, "The Early Influence of the Bergen School on Synoptic Meteorology in the United States," 492.
60. Biographers have occasionally noted that Reichelderfer gave up a promising navy career in which he was second in command of a battleship. While he was second in command, his ship, the USS *Utah*, had been decommissioned as a battleship following the London Naval Treaty of 1925. The big guns were removed, radio steering gear and extra armor were added. The ship became a mobile target. By 1938, when Reichelderfer was serving aboard, *Utah* had been fitted with various small guns to serve as an anti-aircraft training vessel. *Utah* retained her target capability, however. In August 1937, she was pummeled by 40 practice bombs dropped by Army Air Corps B-17s, and in September 1938 she was attacked by an early air-to-surface guided missile. Japanese pilots also mistook *Utah* for a battleship, and sank her at Pearl Harbor (Myron J. Jr. Smith, *Battleships and Battle-Cruisers, 1884–1984* (New York: Garland Publishing, Inc., 1985), 594, 596, 618.)
61. *Statutes at Large* 1014 (1938), cited in Whitnah, *History of the Weather Bureau*: 161.
62. Reichelderfer, "The How and Why of Weather Knowledge," 138–139.
63. Carl-Gustaf Rossby, "The Scientific Basis of Modern Meteorology," in *Climate and Man: Yearbook of Agriculture 1941*, ed. F. W. Reichelderfer (Washington, D.C.: Department of Agriculture, Government Printing Office, 1941), 599.
64. Ibid., 600.
65. The primary synthesis on 20th century American military meteorology is John F. Fuller, *Thor's Legions: Weather Support to the U.S. Air Force and Army, 1937–1987* (Boston: American Meteorological Society, 1990).

66. Fuller, *Thor's Legions*, 30.
67. Ibid., 51.
68. C. G. Rossby, "Preliminary Report on the Activities of the University Meteorological Committee," January 24, 1943. Box 3, University Meteorology Committee Papers (MC 511), Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts (Henceforth, UMC).
69. The lengthiest secondary source for the history of the wartime weather training is Raymond Walters, *Weather Training in the AAF: 1937–1945, US Air Force Historical Study No. 56* (USAF Historical Division, Air University, 1952). A livelier account is Diane Rabson, "It Happened Here: The Invisible Ally," *Staff Notes Monthly (University Corporation for Atmospheric Research)* October 1998. Available online at http://ucar.edu/communications/staffnotes/9810/here.html
70. Radio script, UMC, box 3. Hand notation says the program was given 4 Feb. 1943, on the Mutual Network, Station WGN. Diane Rabson discusses this in "The Invisible Ally."
71. "Announcement of Special Army-Sponsored Meteorology Training Programs," Undated, probably 1943. UMC box 3. For more on the preparation programs, see: R. E. Rowland, *The Premeteorology Program of the Army Air Force, 1942–1945* (http://www.rerowland.com/premet.html, retrieved 28 April 2004).
72. University of Chicago curriculum, 1943. This forty-nine page description of the curriculum of the Chicago A level school gives a detailed, week by week overview of what students were taught. "Syllabus of Courses Comprising the Training Program of Meteorologists for the United States Army Air Corps and Aerologists for the United States Navy," 82–56, Box 1, Folder 46 "Sverdrup, Misc.—Meteorology Programs 1943–1945." Scripps Institution of Oceanography Archives, San Diego, California.
73. The students picked up on this tension as well. "Throughout our life at NYU an indecisive battle royal raged between the academic and the military for our poor GI souls," wrote students in one yearbook (*Synopsis: Class 2-A-44, 30th AAF Training Detachment* [New York University, June 1944.], 3.)
74. Ibid., 8
75. This list is representative of the books used in other programs. See Chicago curriculum (n. 72) for another example. Chicago used Helmut Landsberg's *Physical Climatology* instead of Kendrew, and used the manuscript of Byers' *General Meteorology* instead of his earlier *Synoptic and Aeronautical Meteorology*.
76. The development of this one hundred-page pamphlet is described in Bernhard Haurwitz, "Meteorology in the 20th Century: A Participant's View (Part III)," *Bulletin of the American Meteorological Society* 66 (1985): 501.
77. These include Jörgen Holmboe, George E. Forsythe, and William Gustin, *Dynamic Meteorology* (New York: John Wiley and Sons, Inc., 1945); Sverre Petterssen, *Weather Analysis and Forecasting: A Textbook on Synoptic Meteorology* (New York: McGraw-Hill, 1940); Victor P. Starr, *Basic Principles of Weather*

Forecasting, ed. Carey Croneis, *Harper's Geoscience Series* (New York: Harper & Brothers, 1942); and Hurd C. Willett, *Descriptive Meteorology* (New York: Academic Press, Inc., 1944).

78. Starr, *Basic Principles of Weather Forecasting*, 2.
79. Ibid., 1.
80. Carl-Gustaf Rossby to Col. H.H. Bassett, March 13, 1943. UMC box 1. Original emphasis.
81. Fuller, *Thor's Legions*, 64, 191–192.
82. *Synopsis: Class 2-A-44, 30th AAF Training Detachment.*
83. The fullest source on African-American weathermen is Gerald A. White, Jr., "Tuskegee Meteorologists in World War II," article in preparation, February 2006. My thanks to him for sending it to me prior to publication. See also Fuller, *Thor's Legions*, 229–230. Charles Anderson went on to earn a Ph.D. after the war, the first African American meteorologist to do so.
84. The best studies of women in wartime meteorology are J. M. Lewis, "Waves Forecasters in World War II (with a Brief Survey of Other Women Meteorologists in World War II)," *Bulletin of the American Meteorological Society* 76 (1995): 2187–2202 and Kathleen Broome Williams, *Improbable Warriors: Women Scientists and the US Navy During World War II* (Annapolis, Maryland: Naval Institute Press, 2001). Three women had notable careers in post-war meteorological research. Joanne Simpson became the first American woman to earn a Ph.D. and has had a lengthy career in hurricane and tropical weather research. Florence Van Straten headed the Navy Weather Service's technical requirements section from 1948 to 1962. Dorothy Bradbury obtained a master's degree from Chicago in 1951, where she worked as a research scientist until retiring in 1974. Joanne Simpson's Oral History, part of the American Meteorological Society's Tape Recorded Interview Project, is available online at: http://www.ucar.edu/archives/publications/simpson-joanne%20interview.pdf. Some further context can be found in Fuller, *Thor's Legions*, 227–228; and Kaye O'Brien and Gary K. Grice, eds., *Women in the Weather Bureau During World War II* (Washington, D.C.: National Weather Service, 1991).
85. A useful source for thinking about the uses of yearbooks is Mariaelena Bartesaghi, "Reconstructing the High School Experience: The Role of Yearbooks in the Social Construction of Memory" (Master's Thesis, University of Pennsylvania, 1992). I thank her for an interesting conversation as well.
86. Colver R. Briggs, Arden Lanham, and Bruce Heater, eds. *Class 5: Meteorology Cadets* (University of California, 1943). UMC, box 5, "UCLA".
87. *Synopsis*: 17.
88. *Synopsis*: 25.
89. For examples, see SIO Office of the Director (Sverdrup), 82–56, Box 1, Folder 46 "Sverdrup, Misc.—Meteorology Programs 1943–1944," Scripps Institute of Oceanography Archives.

90. Here the Council was declaring that it had decided against Rossby's earlier thought that the Society ought to be broken apart.
91. For instance, see Spence, *The Rainmakers* or Katharine Anderson, *Predicting the Weather: Victorians and the Science of Meteorology* (Chicago: University of Chicago Press, 2005).
92. Horace R. Byers, "Recollections of the War Years," *Bulletin of the American Meteorological Society* 51 (1970): 216.
93. David D. Houghton, "Meteorology Education in the United States after 1945," in *Historical Essays on Meteorology, 1919–1995*, ed. James R. Fleming (Boston: American Meteorological Society, 1996), 541–553.
94. Clark A. Miller, "Scientific Internationalism in American Foreign Policy: The Case of Meteorology, 1947–1958," in *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, ed. Clark A. Miller and Paul N. Edwards (Cambridge: MIT Press, 2001), 167–218.
95. Horace R. Byers, "Chairman's Prefatory Remarks," prior to the Symposium on Modern Concepts in Meteorology, April 27th, 1955. Proceedings of the National Academy of Sciences, v. 41, n. 11 (November 15th, 1955): 797.
96. Edward N. Lorenz, "The Evolution of Dynamic Meteorology," in *Historical Essays on Meteorology, 1919–1995*, ed. James R. Fleming (Boston: American Meteorological Society, 1996), 3–19.