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Forecasting the Future: The Early United States Weather Bureau

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Introduction

Many historians write that American meteorology finally emerged as a world leader in scientific development in the 1950s with the establishment of Operational Numerical Weather Prediction. Before this time, historians put forward the notion of an obdurate weather bureau with no interest in modernization or improvement. According to some, the U.S. Weather Bureau focused only on short term practical forecasting rather than the theoretical understanding of atmospheric circulation and composition.[1] These representations magnify the delayed incorporation of emerging techniques such as air-mass analysis, while they deny, or at least minimize, the meteorological improvements and dedication to advanced methods that are apparent in the history of the national weather service and the employees who consistently struggled with bureaucratic infighting and a lack of funding.

Historians such as Edwards,[2] Harper,[3] Turner,[4] and Nebeker[5] focused their attention on the 1950s in order to perpetuate the idea that the Cold War transformed meteorological practices in the United States, which it did. However, this post-World War II focus resulted in sensational claims of rapid development and modernization such as one from Edwards who wrote that numerical weather prediction, "revolutionized weather forecasting,

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1 Harper, *Weather By the Numbers,* 2.
2 Edwards, *A Vast Machine.*
3 Harper, *Weather By the Numbers.*
4 Turner, "Weathering Heights."
5 Nebeker, *Calculating the Weather.*

transforming an intuitive art into the first computational science."[6] Although it is true that computational forecasting transformed the practices of the bureau, Edward's statement ignores the scientific techniques of the past. Such other historians as Weber,[7] Whitnah,[8] and Popkin[9] dedicated their study to the bureaucracy within the bureau, largely ignoring the historical context of the time. This failing is made clear through Whitnah's statement that the incorporation of air-mass analysis "proved to be a painfully slow process"[10] as he ignored the practical reasons for the delay such as urgent daily reporting requirements, a lack of funding, new technological developments and burdens, and some unfortunate scandals. Despite the fact that the agency has not continuously been at the forefront of meteorological sciences since its inception, to cast the bureau and its precursors in an archaic, stagnant light ignores the rich meteorological history within the United States, conflates meteorological science with weather services, and obscures the progression of meteorological advancement.

Willis Ray Gregg echoed this devotion to improvement and the links between innovation and quotidian practices in an article written in 1933. At the time, Gregg headed the Aerological Section and a year later received a promotion to chief of the bureau. He wrote of the agency's acceptance of new

6 Edwards, *A Vast Machine,* 111.
7 Weber, *The Weather Bureau.*
8 Whitnah, *A History of the United States Weather Bureau.*
9 Popkin, *The Environmental Science Services Administration.*
10 Whitnah, *A History of the United States Weather Bureau*, 160.

methods and techniques, however that it erred on the side of caution before adopting change due to their obligation to keep up daily operations:

> There is reason to believe that the basic and essential features are sound and will probably endure, but there are bound to be changes in details as new ideas and methods are proposed. We should, and undoubtedly shall, in the future as in the past, adopt such changes as are shown to be superior to present methods.[11]

Such statements as these are ignored by historians such as Harper, who instead write that the bureau discarded data and treated the work of the service as more of an art than a science.[12] I am arguing against the common historiographical trend and instead offer one that identifies the difficulties, obligations, and burdens of the bureau that influenced the development of the scientific service agency within the United States until its incorporation into ESSA (the Environmental Science Services Administration) in 1965.

Meteorological services are vulnerable to criticism from a number of different perspectives. Every individual citizen is affected by the weather, so any missed forecast can result in the condemnation of the forecasters involved, if not the entire bureau. Despite this skepticism of weather services, many national meteorological agencies emerged in the 19th century, including the United States. Throughout its history, American meteorology has had times of lethargy and times of cutting-edge development. The agencies, when viewed in their entirety however, show a dedication to development that is

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[11] Gregg, "History of the Application of Meteorology to Aeronautics."

[12] Harper, *Weather By the Numbers*, 2

largely ignored in current publications. The focus by many historians on the early Cold War transformation of meteorology or the bureaucratic struggles either ignores or distorts the longer scientific record of the agency. When the history of the national weather service is viewed from the perspective of the scientists of the time, a much more positive picture emerges, which indicates that from the early 19th century, American meteorologists have diligently worked to maintain a cutting edge in scientific practices.

19th Century Meteorology

Throughout the 19th century, a number of private and federal agencies recorded meteorological information. The U.S. Army began weather observations in 1812, with private sector work beginning in New York academies in 1825. In the 1830s the Joint Committee (between the American Philosophical Society and the Franklin Institute) in Philadelphia provides an example of early theoretical work, which continued in the Smithsonian meteorological project from 1849-1874. The Smithsonian project grew into a network of meteorological stations that collected standardized observations of temperature, barometric pressure, humidity, wind/cloud conditions, and precipitation as far away as Mexico and Canada.[13] The Civil War interrupted the practice however, and the Smithsonian meteorological project never recovered its antebellum status.

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[13] Fleming, *Meteorology in America,* 76.

Practical value in crop production and commerce security provided the impetus for sponsored scientific study into the atmosphere and the emergence of weather prediction around the globe. Even Vilhelm Bjerknes, dubbed the father of modern meteorology due to his application of physics to the atmosphere, began his forecasting in Bergen to aid the Norwegian crop production and fishing industry during World War One. Forecasting primarily aimed at avoiding loss of property and life, while maximizing agricultural output, in other words, applied meteorology. Some individuals utilized the data collected for climatic and theoretical study, yet the central focus remained the impact of weather on agriculture. As the nation expanded westward in the 19th and early 20th centuries, with lands previously considered deserts opening to pioneers and agriculture, the bureau's already extensive list of duties grew to include a much larger and less populated area. The need to provide forecasting and crop information to the west strained the limited funding of the agency, which resulted in a prioritization of bureau sections based on utility for the American citizen.

American meteorology has a substantial history of data compilation because intellectuals studied the climate in an attempt to bring rational understanding to the new world. Statesmen-naturalists such as George Washington, Benjamin Franklin, and Thomas Jefferson all kept weather journals and advocated weather data collection in order to understand climate and weather patterns for the benefit of the American citizenry.[14]

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[14] Cohen, *Science and the Founding Fathers.*

American meteorological data expanded through army observations and the emergence of scientists who devoted themselves to the study of meteorology.

Joseph Henry (1798-1878), the first Secretary of the Smithsonian Institution, head of the Smithsonian's meteorological project, and reluctantly President of the National Academy of Sciences, fostered international collaboration through data exchange, a process that is critical to meteorological advancement. James Pollard Espy (1785-1860) provides an example of another pioneer of early American meteorology. Dubbed the "Storm King" for his work in storm formation and precipitation, Espy theorized and experimented on the subject of what we might now call saturated adiabatic expansion. Elias Loomis (1811-1889) created the first synoptic weather map in 1846 and meticulously researched cyclones and anticyclones through collected data. William Redfield (1789-1857) tracked storm damage from Connecticut to Massachusetts before concluding that storm winds blow counterclockwise around a center that follows the path of prevailing winds. Redfield and Espy had a number of lively debates on this hypothesis, as Espy theorized that vertical convection and condensation were the essential components of storms; further developments revealed that both premises are necessary for a complete storm theory. While this list of early American meteorologists is by no means complete, these individuals serve the purpose of illustrating the constant and significant work on meteorological issues before the establishment of a state sponsored agency.[15]

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[15] Fleming, *Meteorology in America*, Pp 35-54.

During the 19th century, especially in the latter half of the century, American contributions to the science of meteorology have to be considered as advanced if not more so when compared with its counterparts in Europe. William J. Humphreys, a senior meteorological physicist for the bureau and editor of the *Monthly Weather Review* from 1931-1935, wrote about Espy in a 1942 paper: "From 1835 to the end of his life he devoted practically his entire time to the study of meteorological problems, to which subject he became one of America's greatest contributors."[16] Loomis also falls into the category of one of America's most influential meteorological contributors through his rigorous work with collected data. In 1840 he advocated the idea of overlapping warm and cold air masses, however he did not use this terminology.[17] Humphreys accredited Loomis with scientific understanding well ahead of his time, "He reaches important conclusions previously not generally accepted or, in some cases, not even suspected, that are entirely sound."[18] Humphreys continues the praise later in his article stating that anyone who read Loomis' paper would believe:

> That he was reading a sound theoretical discussion by one of our most advanced air mass analysts. This paper is a very important contribution to air mass analysis made more than one hundred years ago by one of our greatest contributors to the science of meteorology.[19]

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16 Humphreys, "A Review of Papers."
17 Loomis, "The Storm Which was Experienced."
18 Humphreys, "A Review Of Papers," 32.
19 Ibid.

In the same paper Humphreys wrote about the importance and subsequent neglect of 19th century meteorological work, a mistake that has continued into the present day.[20] Although this discussion of 19th century American meteorological advancements pre-dates the weather bureau, it is crucial for the development of the national weather service. American meteorology held great value to the development of the scientific field in the 19th century and set the stage for the government sponsored service to emerge.

The Signal Service

The establishment of the national weather service through the military came about due to the tireless effort and insistence from Increase Lapham and Cleveland Abbe. Head of the U.S. Army Signal Corps, Colonel Albert J. Myer, also advocated for the service to be added to his department's responsibilities. Myer witnessed a drastic decrease in funding after Appomattox, and as a result, welcomed the new obligations for his agency. These three men convinced Congress of the benefit that a weather service could afford the nation and provided the agency to house it.[21]

While Abbe highly influenced American meteorology generally, Lapham's influence on the national weather service is limited to the inception of the agency. Still, Lapham published over forty papers and circulated Espy's storm theory around the Midwest in order to gain support for a storm

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20 Humphreys, "A Review of Papers," 31.
21 Fleming, "Storms, Strikes, and Surveillance."

warning system through scientific practice.[22] Lapham witnessed devastating effects of storms on the Great Lakes and the toll on the nation's commercial interests. Eric Miller wrote about Lapham's concern, "Shipwrecks on the Great Lakes were a matter of grave concern to Lapham, hence when the reports of Espy, formulating the laws of storms were published, Lapham began agitating for their practical application."[23] Lapham and Abbe were able to gain the support of Wisconsin Congressman General Halbert E. Paine who studied under Elias Loomis at Western Reserve College and saw the benefit of a storm warning system in his immediate region. The process of establishing the service consisted of prolonged effort and continuous insistence by Abbe, Lapham, and Congressman Paine. Lapham, who focused upon the practical utility of the service, wrote multiple letters to Paine who read them to Congress, including one in 1869 that reads:

> I take the liberty of calling your attention to the accompanying list of disasters to the commerce of our Great Lakes during the past year, and to ask whether its appalling magnitude does not make it the duty of the Government to see whether anything can be done to prevent, at least, some portion of this sad loss in the future.[24]

Lapham was not the only one to write Paine and Congress, as Colonel Myer insisted upon the service being assigned to his department. As Paine recalled years later, "a stranger called upon me and introduced himself as Colonel Myer, of the Signal Corps. He exhibited the most intense anxiety for the

22 Miller, "New Light on the Beginnings of the Weather Bureau."
23 Ibid.
24 Miller, "New Light on the Beginnings of the Weather Bureau," 67.

success of the measure. It seemed to me that his zeal and enthusiasm marked him as the fit man to launch the new enterprise."[25] Congress hesitated to endorse the service due to concerns over fiscal responsibility and overall efficacy of the proposed benefits. After significant loss of life and goods on the Great Lakes and repeated insistence from Abbe, Lapham, and Myer, the weather division of the U.S. Army Signal Service was established in 1870 with Myer as Chief.[26]

Both Abbe and Lapham questioned the military's involvement in the scientific endeavor; however, as Roy Popkin wrote, Myer "pointed out that military discipline might help achieve uniformity of reporting and that utilization of military personnel would save considerable money."[27] This interaction between the military and the national weather service is found consistently throughout American history. Meteorology provides information for each armed conflict, while military technology is utilized for updating and improving meteorological data collection and research. Despite their reluctance to enact the service, Congress quickly recognized the contributions of the Signal Service as valuable to American commerce and agriculture as is reflected through a dramatic 800% funding increase between 1869 and 1874.[28] This budgetary growth needs to be justified by the fact that the amount

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25 Ibid, 68.

26 Weber, *The Weather Bureau; Its History, Activities, and Organization*.

27 Popkin, *The Environmental Science Services Administration*, 56.

28 Fleming, "Storms, Strikes, and Surveillance."

consistently displeased Myer. Miller wrote that the funds were "quickly swallowed by rapidly increasing demands for service to the public."[29]

The Signal Service effectively utilized telegraphy to transmit information across the continental U.S. for the benefit of the American citizen. The reports focused on agricultural effects as well as storm warnings, as James Fleming writes, "Signal service observers reported on the hatching and migration of locust swarms, on frost and drought in the cotton, corn and tobacco-growing regions, on hazards to shipping along the coast. Mercantile interests were advised of weather conditions affecting the packing and shipment of perishable goods such as oysters, pork and ice."[30] The service not only engaged in practical storm warning and predictions, but it also included a theoretical branch. Patrick Hughes wrote about this research section's place within the bureau, "Although its emphasis was always on the practical application of the weather service, the Signal Service did foster a modest meteorological research program."[31] At Cleveland Abbe's insistence the Service established a "study room" at the main office for research purposes and in 1881 established a school for specialized training in meteorology at Fort Myer, Virginia. William A. Koelsch wrote about this in-service training and how it perpetuated through time,

> The Signal Corps school was America's first postgraduate program in meteorology, and the military continued to use this in-service model through the 1919-1945 period. Out of the Signal Service venture also

29 Miller, "New Light on Beginnings," 69.
30 Fleming, "Storms, Strikes, and Surveillance."
31 Hughes. *A Century of Weather Service*.

> came cooperative research and study arrangements with physical scientists at several universities.[32]

Although the school shut down due to fiscal concerns, the weather bureau chiefs insisted that meteorologists under their employ give lectures to universities and high schools in order to foster a youthful interest in atmospheric studies. As Frank Hartwell (a senior meteorologist within the bureau) remembered, “The greatest encouragement was given to officials in charge to speak before schools and academies.”[33]

After General Myer passed away in 1880 the Service underwent a decade of turmoil and strife. General William Hazen replaced Myer and quickly added four senior and three junior professors to increase the scientific standing of the agency. Unfortunately for Hazen, the agency was forced to reduce its budget significantly after it surfaced in 1881 that Captain Henry W. Howgate embezzled up to $237,000.[34] Howgate, a disbursing officer, made use of fraudulent vouchers for his crime that caused the entire agency to come under suspicion of fraud. This scandal was the first, but by no means the last to tarnish the reputation and foster a distrust of the weather service. Hazen’s administration also came under criticism in regards to its autonomy within the army. The War Department believed that the Signal Service’s weather obligations would render them useless for combat in an armed conflict. The growing distrust resulted in the congressional appointment of the Allison

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32 Koelsch, “From Geo- to Physical Science,” 512.

33 Hartwell, *Forty Years of the Weather Bureau,* 32.

34 NOAA, "A National Weather Service Publication."

Commission in 1884, which reviewed the Coast and Geodetic Survey, the Hydrographic Office of the Navy Department, the Geological Survey, and the Signal Service in order to assess the work of government sponsored science.

Each of the agencies under review experienced conflict within the government due to jurisdiction, scandal, or purpose and the Commission was tasked with finding a solution. As David Guston wrote, "Given the uncomfortable jurisdictional problems and the scientific character of each of the disputed agencies, prominent voices from the scientific community called for at least the consolidation of the surveys or even for the creation of a new Department of Science."[35] The scientists of the agencies under question viewed the Allison Commission as congressional meddling, an inappropriate judgment by laymen. The Commission focused on the practical value of the agencies, putting little to no value on theoretical research. The Commission decided to close the school at Fort Myer and recommended a slow transition of the bureau out of the military in order to avoid a disruption of function due to turnover.[36]

When General Hazen died in 1887, General A. W. Greely stepped in as his successor. Greely's administration faced many of the same problems as Hazen and as a result, Congress moved the weather service out of the military and into the Department of Agriculture. In 1890 the weather responsibilities of the Signal Service transferred to the newly established U.S. Weather Bureau with Professor Mark Harrington from the University of Michigan as

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35 Guston, *Between Politics and Science,* 33.
36 Ibid.

chief. Harrington welcomed the appointment and the continued employment of Cleveland Abbe who fostered a dedication to research and improved methods within the bureau.

Cleveland Abbe

The national weather service developed in the United States largely due to the contributions of Cleveland Abbe (1838-1916). America's first weather forecaster, born in New York City, pursued an academic career as an astronomer. In 1867 he switched academic departments and entered the field of meteorology in order to overcome humanity's ignorance of destructive winds and rains and other weather phenomena. In 1869 he established the first system of daily weather reports and maps in Cincinnati with the support and assistance of the Chamber of Commerce and the Western Union Telegraph Company. Lapham utilized the established infrastructure and obvious utility of Abbe's forecasts as examples of how the service could run under government control. Abbe's experience and success prompted Colonel Myer to offer him the position of civilian assistant in the office of the Chief Signal Officer where he could prepare his daily reports for circulation.

Abbe joined the U.S. government's weather service as its first chief meteorologist in 1871 with two goals in mind: the optimization of the weather service and the study of theoretical meteorology.[37] His background in astronomy and interest in the outer reaches of the atmosphere led Abbe to

[37] Willis and Hooke, "Cleveland Abbe and American Meteorology."

utilize kite soundings in order to access data from the free-air at increasing altitudes (kites affixed with a meteograph recorded information on temperature and barometric pressure). He worked alongside Professor Charles Marvin, who went on to become chief of the bureau, but during Abbe's time held the title "professor of meteorology;" Marvin and Abbe collaborated in order to devise instrumentation for precise data collection, which afforded them domestic and international recognition.

Abbe studied in Russia during his youth, exposing him to European languages and academics. This experience made him a conduit for European scientific ideas to be expressed in American practice. He advocated for scientific forecasting based on equations of thermodynamics and fluid dynamics; he even developed equations of atmospheric motion in 1901 that are similar to those of Vilhelm Bjerknes' of 1904. According to Willis and Hooke, "Both cataloged the necessary equations of state, continuity, thermodynamics, and motion. Both recognized the need for upper-atmospheric observations."[38]

While the kite soundings did not provide the upper-air information of later technologies such as radiosondes and airplanes, Abbe and Marvin were able to collect accurate data from higher altitudes than was common practice at the time by flying the kites in tandem using piano wires. This innovation and development of instrumentation highlights the fact that American meteorology operated at the cutting edge of the science at the inception of the

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[38] Ibid.

bureau. While the agency may not have had the budget for extensive theoretical study, it is clear that individuals such as Cleveland Abbe were still able to explore research problems, simply on a reduced scale. Abbe insisted on establishing data collection stations on mountaintops, in order to monitor atmospheric data from the highest altitude possible. While this information proved useful for specific studies, Chief Willis Ray Gregg wrote in 1933 about why the data collected at mountaintop stations proved difficult to utilize in air-mass analysis:

> It was soon recognized, however… that they were not truly representative of conditions in the free air. They were too much influenced by the mountain itself and by the neighboring terrain. In short, they represented neither true surface nor true free-air conditions.[39]

These problems highlight the necessity of developing accurate tools to measure the free air removed from obstructions. As air masses are forced into the upper atmosphere by mountaintops the air condenses and cools. This problem was not limited to mountaintops though, as the neighboring terrain also often affected data collected from rooftops. While Abbe did not know of this problem, he recognized the importance of collecting the information in order to further study atmospheric circulation.

Although some of the early members of the weather service were civilians or enlisted men without meteorological training, Abbe stressed the importance of high scientific standards and "required the weather service to

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[39] Gregg. "History of the Application of Meteorology to Aeronautics."

stay at the forefront of technology."[40] Each Signal Officer was required to pass an exam of scientific merit that would undoubtedly stump many graduate students today. Abbe was a contemporary and a colleague of Vilhelm Bjerknes. Independently, they developed similar work and maintained a cordial and beneficial relationship. As Robert Marc Friedman wrote in *Appropriating the Weather*, "Bjerknes began a correspondence with Abbe that proved valuable during the next several years."[41] In 1905 Abbe helped Bjerknes secure funding from the Carnegie Institution for a full-time assistant and provided him with upper-air data from cyclones and anticyclones in the United States as collected from kites.

Abbe prepared three weather probabilities a day for the Signal Service, earning him the nickname "Old Probabilities," a moniker bestowed upon him by Mark Twain.[42] He also founded the *Monthly Weather Review*; from humble beginnings in 1873 the journal transformed into one of the leading meteorological journals of the world in only twenty years under Abbe's editorship. The foundation of the national weather service and its devotion to cutting edge meteorological practices of the time highlights the problem with the commonly held opinion that the weather bureau was archaic and anti-reform. Abbe worked in collaboration with the bureau until his death in 1916, the beginning of a forgettable time in American meteorology according to many historians; however, I disagree. Although the loss of Abbe diminished

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40 Willis and Hooke, "Cleveland Abbe and American Meteorology."
41 Friedman, *Appropriating the Weather,* 38.
42 Abbe, *Professor Abbe… and the Isobars.*

the scientific practices of the agency, the subsequent two decades resulted in great advancement in meteorological practices around the world, the United States included.

Cleveland Abbe serves as a contradiction to common historical representations of the bureau as he constantly refined the scientific practice of meteorology in the United States. His accomplishments and recognition abroad highlights the necessity for historians to include greater detail on his career in their histories of the weather service, as his work and influence are clear examples of excellence within the field.

The United States Weather Bureau

In 1890 Secretary of Agriculture Jeremiah Rusk invited Mark Harrington, a professor of astronomy and meteorology at the University of Michigan to be the first civilian chief of the weather bureau. While the agency under his guidance is not known for its development of theoretical research, Harrington emphasized climate studies before developing an interest in Abbe's work in numerical forecasting.[43] Unfortunately, the economic depression of 1893 brought government agents of fiscal responsibility into office who viewed the bureau as a wasteful department. Tensions between the chief and his superiors over practices and funding plagued the bureau for much of the first three decades of its civilian existence.

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[43] Willis and Hooke, "Cleveland Abbe and American Meteorology."

The fact that the agency transferred to the Department of Agriculture highlights its focus on practical tasks. Westward expansion opened up immense tracks of land for crops and farmers were in constant need of weather forecasts. Accompanying the transfer of weather services from the military into the civilian government was the definitive establishment of the bureau's duties. Section three of the act reads:

> That the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, on and after July 1, 1891, shall have charge of the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rainfall conditions for the cotton interests, the display of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.[44]

As the nation's infrastructure developed in the early 20th century, the weather bureau assumed responsibility for highway weather forecasting, aerological studies to support aviation, and a fire-weather service in association with the forestry department. With such an extensive list of obligations, the agency

[44] Popkin, *The Environmental Science Services Administration*.

struggled to keep up with its duties and required the assistance of cooperative observers (volunteers) from across the country.

Many of the individuals who worked for the bureau were not meteorologists, but citizens trained for a specific duty. Fleming writes that these employees had specific tasks, their "duties included reading the instruments, launching balloons and wiring data to Washington."[45] Although these observers were not ideal in terms of their qualifications, it was imperative that information be collected from all around the country and transmitted to the meteorologists at the bureau's headquarters. Without the assistance of volunteers, the bureau could not have collected nearly enough information in order to compile climate data for the country.

While Chief Harrington aimed to improve the scientific practices of the bureau, his tenure (1891-1895) was marred by controversy within the hierarchy of the Department of Agriculture. Research under Harrington was not ignored as has been purported in the past, but rather focused on the practical utility and benefit of meteorology to the American citizenry. As Popkin wrote:

> In the research area, climatology and the relationship between weather and crops was given major emphasis… In addition, a systematic aerology research program was planned, focusing on the use of balloons for high-altitude studies and observations.[46]

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[45] Fleming, "National Weather Service Modernization."
[46] Popkin, *The Environmental Science Services Administration*, 71.

Unfortunately, Harrington's quarrels with Julius Morton, Secretary of the Department of Agriculture in the late 1890s, resulted in Harrington's ultimate dismissal. Morton also had issues with other members of the weather bureau including Cleveland Abbe. Willis and Hooke wrote about Morton's disapproval with the weather service: "Morton had taken office with the Cleveland administration just before the Panic of 1893 and the ensuing depression. Budget cutting extended across all agencies. He let it be known that over 20 years Abbe had received $90,000 in compensation 'for which the government had received back no adequate return.'"[47] Morton used his authority to demote and reduce Abbe's salary, illustrating the strained relationship between the agency and the policy makers in Washington, who consistently attempted to cut the agency's funding. As Popkin wrote about the struggle, "Morton feuded with Cleveland Abbe in an effort to reduce research funds. Abbe resisted eloquently, and his salary was reduced only over Chief Harrington's objections; there was constant friction between Morton and Harrington over budget cuts."[48]

Professor Willis Moore replaced Harrington as chief in 1895, but encountered similar problems as his predecessor. A native Pennsylvanian who worked his way up the ranks of the bureau, Moore proved to be a capable chief until he undermined his tenure through his own political aspirations and personal confrontations. The agency's reputation suffered further disgrace due to a missed forecast of the Galveston Hurricane in 1900 in which

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47 Willis and Hooke, "Cleveland Abbe and American Meteorology."
48 Popkin, *The Environmental Science Services Administration,* 72.

8000 individuals perished in the deadliest hurricane in American history.[49] Despite these issues, there were individuals who sympathized with Moore such as Frank Hartwell who wrote that he was a victim of, "A hostile campaign launched against him by politicians without and petty enemies within the Bureau, men with fancied grudges who aided and abetted the politicians."[50] The first scandal of Moore's career resulted from a careless mistake, which accentuated the perception of the bureau as mismanaged and set the tone for the rest of his tenure. Moore did not adequately inform Congress of the application of the bureau's appropriations, specifically with respect to Mount Weather in Virginia. Moore failed to outline the planned construction and was accused of building his own vacation home to escape the Washington summers, neglecting the needs of the nation.[51]

Mount Weather, in the Appalachian Mountains some 60 miles west of Washington, was established in the 1890s, before Moore's time as chief. Construction continued on Mount Weather each year, adding facilities as they were needed. Accompanying this accusation was the fact that Moore held high standards for the members of the bureau, and some came to resent it, resulting in further complications from bureau employees. Popkin wrote about the time,

> The controversy resulted in an era of hypercritical examination of the Bureau's fiscal practices. At the same time, employees of the Bureau

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49 Kasprak, "Hurricanes as Social Probes: Galveston 1900, New England 1938, New Orleans 2005."

50 Hartwell, *Forty Years of the Weather Bureau*, 31.

51 Popkin, *The Environmental Science Services Administration*, 76.

> were becoming increasingly bitter about Moore's harsh enforcement of discipline. Their complaints led to additional investigations and more relationship problems.[52]

These allegations were exacerbated by a missed forecast for President Taft's inauguration and a bitter, retired division chief, James Berry, who provided congress with a great deal of derogatory information about Moore and the bureau. *The New York Times* reported in 1913 that Berry provided Representative Robert Fowler of Illinois with documents that called weather bureau affairs into question. The article describes Berry's personal relationship with Moore as strained, "[Berry] has been after Prof. Moore's scalp for years."[53] Moore's career as chief of the bureau came to an end largely due to these documents and the accusation that he utilized bureau funds and employees to promote his campaign for Secretary of Agriculture. Moore disputed these claims in the media to no avail, "I brand as infamously false the intimation that any man in the Weather Bureau has been coerced into supporting me for the Secretaryship, any man promoted for serving me, or a dollar of public money expended in my candidacy. I worked for the place and spent my own money, and so did many of my friends."[54] Moore's bid for the secretary position not only ended his government work, but it also further tarnished the perception of the bureau.

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52 Ibid, 76.
53 "Moore Dismissed As Weather Chief."
54 Ibid.

With all of the negative attention received by the bureau throughout the tenure of the first two civilian chiefs the negative light in which the bureau has been cast and the difficulties in procuring funds becomes clear. The scandal that ended Moore's career in 1913 resulted in further sanctions toward the bureau that persisted into the tenures of subsequent chiefs. Popkin wrote about its effect, "Many other Weather Bureau employees were dismissed or otherwise punished, but the worst effect of the scandal was that for several years afterward, the weather bureau had difficulty obtaining increased appropriations and most research activity was dropped or severely limited."[55]

Donald Whitnah, who wrote a history of the agency in 1961, credits Moore with advancing the bureau despite the scandals and difficulties of securing funding, including a sixty-one data collection station expansion, "Moore was energetic and continually operating on the premise that all public services and research must be broadened; he expanded operations noticeably while head of the Bureau."[56] During the subsequent leadership of chief's Charles Marvin (1913-1934), Willis Ray Gregg (1934-1938), and Francis Reichelderfer (1938-1963) the U.S. Weather Bureau left a majority of the controversy that plagued the first few decades behind. Inheriting a controversial agency with influential enemies limited the effectiveness of these chiefs, however they were still able to improve the bureau markedly. According to Popkin:

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[55] Popkin, *The Environmental Science Services Administration,* 78.
[56] Whitnah, *A History of the United States Weather Bureau*, 83.

> Marvin and Gregg were frequently called conservative, but internal employee relationships and working conditions improved markedly under their administrations. Both of these chiefs moved as best they could to bring about improvements within existing techniques and methodology.[57]

Marvin set the stage for the bureau's rapid modernization through his influential technical work on meteorological instruments. Hartwell remembered Marvin's important contributions to the field, "He spent much time in the field, was head of the instrument division for a number of years, where he improved and devised self-recording apparatuses and instruments which received recognition from meteorological services at home and abroad."[58] World War I provided Marvin the opportunity to institute upper-air sounding balloons and to develop marine and aviation weather services. This daily data collection supported reconnaissance, mail flights, troop movement, camp health, use of poison gas (hourly collection), and long-range artillery shelling throughout America's brief, but intense military campaign.[59,60]

These soundings continued after the war due to the growing aviation industry as well as the knowledge that upper air influences surface weather. The growing necessity of attaining upper-air data to benefit aerology required intensive labor and research. Coupled with the benefit for aviation, upper-air

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57 Popkin, *The Environmental Science Services Administration,* 79.
58 Hartwell, *Forty Years of the Weather Bureau: The Transition Years*, 62.
59 Fleming, "National Weather Service Modernization."
60 Popkin, *The Environmental Science Services*, 79.

information proved vital to the emerging meteorological practice of air-mass analysis and the polar front theory. Vilhelm Bjerknes founded the Bergen School in Norway in 1917 and worked with his son and other scientists to develop these theories into effective methods of forecasting and atmospheric understanding.

The Bergen School, Vilhelm Bjerknes and Associates

Vilhelm Bjerknes set up the Bergen School of Meteorology in Norway and began extensive study into the atmosphere and climate. In the late 1920s and early 1930s the Bergen school techniques of air-mass analysis and the polar front garnered increased attention from the international meteorological community, the United States included. Their incorporation into meteorological practices around the globe however, required time for further study. Tor Bergeron, one of the Bergen school pioneers, wrote about a great many failures during 1918-1925 in both theoretical and practical work in Norway due to "the purely practical circumstance that the meteorologist could not distinguish the representative observations from the irrepresentative ones."[61] Bergeron, one of the primary contributors to Bergen theories, is credited with discovering the occlusion process, which is the final stage of an extratropical cyclone.[62]

While it is true that the methods developed at the Bergen school eventually revolutionized meteorological practices, it is important to keep in

61 Bergeron, "A New Era in Teaching Synoptic Meteorology," 258.
62 Schultz and Friedman, "Tor Harold Percival Bergeron."

mind that these ideas developed slowly over time through the collaboration of many individuals. The first detailed publication about the Bergen methods did not arrive until 1924 in a paper titled "Waves and Vortices at a Quasistationary Frontal Surface over Europe."[63] Only after Bergeron's 1928 dissertation, "Three-Dimensionally Combining Synoptic Analysis," were the methods widely understood and largely accepted across the globe, however incorporation necessitated further study. Chief Gregg compared upper-air meteorological advancements between Europe and the United States in the 1920s in an article he wrote for the *Monthly Weather Review.* He admitted that some countries progressed more rapidly, but that "there as here this whole period was one of transition and experiment."[64]

Vilhelm and Jakob Bjerknes traveled throughout Europe and the United States, meeting with Gregg and other national weather service chiefs, in order to promote their ideas. Universal acceptance that these methods would benefit the practical work of the agencies did not emerge, as Friedman wrote, "part of the problem was that they were trying to market an incomplete product. Theoretical underpinnings for the new models had yet to be worked out: heavy work loads left little time for writing and publishing."[65]

Carl-Gustaf Rossby and Sverre Petterssen aided in the United States Weather Bureau's implementation of air-mass analysis, as they were previously trained at Bergen. Rossby, who went on to teach at MIT and the

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63 Ibid.
64 Gregg, "History of the Application of Meteorology."
65 Friedman, *Appropriating the Weather,* 198.

University of Chicago, made major contributions to most meteorological developments in the 20th century, as Turner wrote, "He also developed a theory of atmospheric motion that enabled hemispheric scale changes to be calculated, a discovery that made him one of the most celebrated atmospheric physicists since Vilhelm Bjerknes."[66] The process of incorporating these new methods necessitated the training and hiring of new meteorologists; Harry Wexler, Jerome Namias, and Horace Byers are three who fulfilled this need. Byers wrote in 1934 about the benefit of the air-mass work to the weather forecaster in relation to the time spent preparing a prediction:

> Recent advances in the graphical representation of air-mass properties and new knowledge concerning the behavior of the upper air have been helpful. In the course of nearly a year's work in practical forecasting… the writer has found a highly satisfactory degree of success possible without the expenditure of a great deal of time.[67]

Byers' optimism with the new methods was not uniformly shared around the world. David Brunt, professor of meteorology at Imperial College, strongly objected to the Norwegian emphasis on upper-air data in 1935, due to the lack of practical application:

> There has unquestionably been a considerable increase in the amount of upper-air data available every day, but it is doubtful whether they have proved as useful as was anticipated some 16 years ago. In practical forecasting the use which can be made of upper-air data is relatively small. At times an observation of temperature in the upper

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66 Turner, "Weathering Heights," 105.
67 Byers, "The Use of Free-Air Soundings in General Forecasting."

> air may facilitate the forecasting of thunderstorms or of rainfall, but there are many days when the practical use made of the upper-air data is only slight.[68]

Skepticism, funding, and a focus on practical utility delayed the incorporation of Bergen techniques into weather bureau practices. Byers, Wexler and Namias, all of whom studied under Rossby, advocated for and incorporated the Bergen methods in the 1930s. Despite their enthusiasm for the techniques, a taxing and arduous transition lay ahead as they encountered numerous difficulties in the implementation of the Norwegian methods to the North American climate.

Air Mass Analysis in the United States

The expansive territories of North America necessitated the establishment of multiple new observation stations and trained observers to monitor them. Chief Gregg discussed in 1937 that the International Meteorological Committee recommended fifty upper air-monitoring stations for Europe and upwards of one hundred and twenty five for North America.[69] Without the appropriate amount of data, the air-mass analysis section of the weather bureau was doomed to inadequate and faulty forecasting. Even with the necessary aerological stations the techniques were difficult to utilize, as Tor Bergeron wrote in reflection in 1941, “In fact, part of the new methods

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68 Brunt, “Some Problems of Modern Meteorology.”
69 Gregg, “Advances in International Meteorology in 1936 and 1937.”

seemed impossible to learn from books and could only be taught by prolonged personal contact with the adepts of these methods."[70]

The Gulf of Mexico, the Rocky Mountains, and the Gulf Stream all distort air mass movement or tracking and highlight the importance of further collection and study of upper-air data. Air-mass movement is distorted by lee side lows after moving across the Rocky Mountains while the temperature and humidity of air moving over the Gulf of Mexico and Gulf Stream are not as clearly defined as they are over the North Sea or Siberia. The Gulf Stream is affected by planetary waves (discovered and defined by Rossby in the 1930s, named Rossby Waves), which can intensify the currents as well as push them off their usual course. These currents transport immense quantities of heat; a minor shift in their position can dramatically affect weather in the United States and around the globe. In 1927, Rossby wrote about the geographical differences between Scandinavia and the United States as they pertained to air masses, "In Europe there is a large land area in the south with a comparatively warm ocean to the north and west, while in the Gulf region the distribution is just the opposite."[71] The paper that he co-authored with Richard Hanson Weightman discussed the differences in greater detail, highlighting the necessity of establishing a greater number of observation centers:

> As regards the distribution of stations, it is obvious that over the West they are entirely too scattered to make possible a reliable analysis of

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[70] Bergeron, "A New Era In Teaching Synoptic Meteorology," 255.

[71] Rossby and Weightman, "Application of the Polar-Front Theory," 429.

> the fronts. The topography, which is extremely irregular, not only affects but in many cases actually determines the movements of the fronts, and a network of stations at least as dense as that over the East is necessary for even a rather crude analysis.[72]

Although the need for upper air data collection had been known since Chief Moore's time in office, researchers encountered significant difficulties in gathering it.[73] Abbe and others engaged in kite measurements since the turn of the century; however, they did not reach an appropriate altitude and as Rossby made clear, there were hardly an adequate number of observation stations around the United States. Accompanying the lack of stations were obvious shortcomings within all the established upper-air data collection methods in the first few decades of the 20th century. In the 1930s the bureau had to develop ways of collecting accurate data from across the country despite a revitalized skepticism and distrust of the agency.

In 1933 the USS Akron dirigible crashed due to severe weather off the coast of New Jersey killing seventy-three, the greatest lighter-than-air disaster in history at the time. Although blame rested with the pilot, the bureau's severe weather advisory was considered lacking. The Akron incident provided the impetus for President Roosevelt to sign into existence the Science Advisory Board, which acted as a review panel for government scientific agencies, including the weather bureau. *The New York Times*

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72 Ibid.
73 Hartwell, *Forty Years of the Weather Bureau,* 32.

reported the board as an extension of the New Deal with a goal to further science in the United States, not curb it:

> This collective and cooperative organizing does not call for any regimenting of science into a goose-step discipline: indeed, it cannot if science is to live; but it does require a national awareness of what is being done in the laboratories, and a national plan to foster research all along the front and to make prompt use of its discoveries and inventions. The setting up of the Science Advisory Board is interpreted as a first step in such a policy.[74]

The special committee on the weather bureau included Isaiah Bowman (chairman of National Research Council and director of the American Geographical Society), Karl T. Compton (chairman of the Science Advisory Board, president of MIT), Charles D. Reed (a weather bureau forecaster), and Robert A. Millikan (director of Norman Bridge Laboratory of Physics and chairman of the executive council of CIT). They made a number of suggestions, most notably to incorporate the Bergen methods as soon as feasible. The board is often viewed as further insult to the bureau, that bringing in experts from other scientific fields to evaluate the agency signifies how poorly the bureau performed. The board's main goal however, was to prevent harmful and foolish changes in the structure and activities of government science and they insisted on the bureau having access to more funds in order to enact the necessary changes. As Chief Gregg wrote about the report, "the special committee itself has, in its report, sounded a note of

[74] Gray, "Science Shares in National Planning."

caution against too precipitate a change from the old well-established and quite efficient methods of forecasting to the newer, so-called 'Air Mass Analysis' method."[75] The board's report also included positive conclusions about the agency, specifically about the cooperation with volunteer data collectors.[76]

Nevertheless, the bureau could only establish twenty upper-air data collection stations through the collaboration of military and civilian agencies. As Chief Gregg wrote in October of 1934, the concepts were understood and appreciated, but funding held back their incorporation into everyday use. He wrote, "At the outset it should be emphasized that there is nothing particularly new in the 'Air Mass Analysis' concept of forecasting. It has been quite fully understood for many years, but its effective application has not been possible, because it requires a greater wealth of observational material than has heretofore been available."[77] Although the funding limited the rapid establishment of new stations, the bureau's historical dedication to data collection aided in the eventual transition by allowing for further study into North American air-mass movement. As Jerome Namias wrote in reflection about the time period in 1976:

> The Norwegians had developed an air mass classification system that was supposed to give an idea of the structure of the upper air. As it turned out, in America we were fortunate to be able to capitalize on a rapidly developing aerological network, first by kites, then by

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75 Gregg, "Progress In Development of the U.S. Weather Service."
76 NOAA, "Cooperative Weather Observers."
77 Gregg, "Progress In Development Of the U.S. Weather Service."

> airplanes, and then radiosondes. We were routinely analyzing the real structure of the atmosphere when some of the invited Norwegians to the U.S. were still talking 'indirect aerology.'[78]

By indirect aerology, Namias meant the qualitative indications of the stability of an air mass, not the quantitative data that allows for a more accurate understanding and prediction.

A skeptic may claim the lack of funding a result of a mismanaged and poorly performing bureau. However, the crushing economic impact of the Great Depression in the early 1930s reveals the true source of financial difficulties. The bureau had not been adequately funded for theoretical research and practical work before the depression, however as a government agency with mixed reports as to its efficiency, the bureau received heavy cutbacks in the years 1933, '34, and '35. Reorganization, budget reduction, and the cutting of personnel all drastically minimized the agencies effectiveness. Turner wrote that the bureau lost nearly 45% of its funding between 1932 and 1933.[79] Gregg wrote about this funding problem in an article for *Science* in 1934,

> It will not be possible, however, to do all that should be done along this line until more funds are provided. It should not be forgotten that the bureau's appropriation has suffered a reduction of some $800,000 during the past two years, and that much of the service then given up

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[78] Namias, "The History of Polar Front and Air Mass Concepts in the United States."

[79] Turner, "Weathering Heights," 129.

> should be restored. Adding new features now, therefore, while still working on a greatly reduced budget is not a particularly easy task.[80]

Due to funding cuts, the bureau had to reevaluate its priorities. The agency made use of the funds available for the practical utility of the country, sacrificing research questions and forcing a delay in the incorporation of air mass analysis.

A number of individuals in and around the weather bureau were opposed to change. Future head of research Harry Wexler pointed out that there were criticisms "made in the 1920s and early 30s by people who were loath to accept the Norwegian methods, and who seized upon any discrepancy between analyses made by different men to discredit the newer methods."[81] Gregg, Reichelderfer, and Wexler among others however, were devoted to improved scientific methods and technologies throughout their time in the agency. While the bureau attempted modernization, the American economy and agriculture stalled, forcing a weather bureau focus on the Midwest. In the 1930s the bureau dealt with growing outcry and concern over the Dust Bowl (which would continue until 1936). The agency still existed in the Department of Agriculture, hence the weather bureau needed to explain why the Dust Bowl occurred and find a solution. Chief Marvin wrote in 1930 about the growing problem and how little was known about its origins:

> Directing our answer particularly to the extensive drought of 1930, all we can say is that these unusual conditions are best explained as a

[80] Gregg, "Progress In Development Of the U.S. Weather Service."
[81] Wexler, "Memorandum," July 25, 1939.

> prolonged stagnation of the air over nearly the whole continental extent of the United States… but the experts are unable to assign a specific cause for the prolonged stagnation.[82]

The bureau's focus on the immediate problem of the dust bowl further complicated the incorporation of air-mass analysis. Even though Marvin discussed the cause as stagnant air, it was not believed that further research in the upper-air would ameliorate the situation of the American farmer in a timely manner.

Even after the Norwegian techniques were incorporated into the bureau they did not replace the forecasting methods that were already in use. This is not only because some established forecasters were resistant to change, but also because surface data remained of vital importance to the nation and the industries that relied on accurate information. As Whitnah wrote, "In the final analysis, the new technique of analyzing the upper air did not replace but rather supplemented the previous methods of forecasting based on surface conditions. Surface data remained of much importance to the meteorologist."[83] Although the upper air influences weather forecasting and surface weather phenomena, practical information about frost warnings for agricultural purposes still relied heavily on surface data.

The Bergen School techniques entered into practice around the globe after years of study and research. Weather services often required personal instruction from an individual who trained in Norway for accurate

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82 Marvin, "Excerpts From the Annual Report of the Chief."
83 Whitnah, *A History of the United States Weather Bureau,* 160.

implementation. As Tor Bergeron explained, "this method, this system of rules and recommendations, is easy to understand theoretically – the rules being based on clear physical principles and practical observations – experience has shown that the rules are difficult to apply in practice."[84] As a result of the necessary time for implementation, historians such as Frederik Nebeker have made claims about the bureau's resistance that have been accepted as fact: "The stodginess of many national weather services delayed by a decade or so their [Bergen techniques] general adoption."[85]

In order to improve on forecasting accuracy the weather bureau eventually adopted the Norwegian methods. As Gregg wrote in the 1934/35 report of the bureau, "Work in this line [air mass analysis] is progressing. A reasonably successful system of forecasting must not be altered unless and until it is doubly certain that the proposed alteration is really an improvement."[86] Kristine Harper discussed in *Weather By the Numbers* how Reichelderfer had circulated these ideas within the Navy Aerological Service throughout the late 1920s making him the obvious choice to implement them after Gregg's sudden death in 1938. During this time of incorporation, the bureau is accused of excessive obduracy. The weather bureau quickly recovered from this brief delay in large part due to meteorology's renewed importance to the nation during and after the Second World War.

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84 Bergeron, "A New Era in Teaching Synoptic Meteorology," 258.

85 Nebeker, *Calculating the Weather: Meteorology in the 20th Century*, 85.

86 Gregg, "Report of the Chief of the Weather Bureau 1934-35."

William Jackson Humphreys

The meteorological physicist William J. Humphreys provides another example of an individual within the U.S. Weather Bureau who improved the practices and methods of the agency's service. He worked in the bureau from July 1, 1905 until December 31, 1935, thus encompassing a majority of the time period portrayed as a scientific backwater. Humphreys has been disregarded or overlooked in many historical representations of the bureau, but he is a direct contradiction to the notion of a backward, poorly educated pool of employees. While it is true that many of the individuals who gathered supplemental climate data from around the country were volunteers who trained on the job, Humphreys, much like Cleveland Abbe before him, made use of the collected data for theoretical and practical purposes.

Humphreys was born into humble circumstances in a one-room log cabin in West Virginia, but managed to study physics at Washington and Lee University, the University of Virginia (where he also taught), and at Johns Hopkins University where he received his Ph.D. in 1897. Humphreys entered the weather bureau already established in physics through notable contributions to the field of spectroscopy, involving the pressure shifts of spectrum lines, which, according to his colleague Edward Woolard, "ranks among the most fundamental contributions to physics ever made."[87] Not to be overshadowed by his earlier work, however, Humphreys furthered meteorological knowledge through his finding in 1909 of a physical

[87] Woolard, "Dr. William Jackson Humphreys."

explanation for the existence and the principal characteristics of the stratosphere.[88] Humphreys has a long list of published papers and books, most notably his book, *Physics of the Air*, which remained a standard work into the 1950s.

Humphreys' 1933 essay "On the Research Work of the U.S. Weather Bureau," discussed obstacles standing in the way of improved forecasting, as well as the importance of further research projects.[89] His essay also refuted popular misconceptions of the inefficiency of the bureau. In his characteristically subtle yet efficient manner, Humphreys reprimanded those who, without experience of their own, criticize the practice of weather forecasting. He pointed out the layman's mistake through a closer examination of the process of measuring rainfall:

> Of course those without experience in such matters might think that this would be the easiest sort of thing to do. For instance, one who has not tried naturally is cocksure that an accurate measurement of the amount of precipitation is the simplest thing in the world to effect, but investigation soon revealed the disturbing fact that the amount of water captured by any and every rain gage varied with the nature and proximity of neighboring objects, height of the catching vessel above ground, strength of the wind, and other factors.[90]

Even if a rain gauge is perfectly calibrated, Humphreys pointed out, it could not successfully collect and measure snowfall, which requires additional

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88 Ibid.
89 Humphreys, "On the Research Work of the U.S. Weather Bureau."
90 Ibid.

investigation. Precise and representative rain and snowfall measurements over an entire watershed help determine stream flow, which is important in flood forecasts and climatology statistics as well as seasonal irrigation for routine agricultural purposes. By linking measurements, instrumentation, forecasting, and utility together, Humphreys clearly illustrated the difficulties of making what is generally considered to be one of the most basic weather observations.

Humphreys continued his article by discussing the problems with apparatuses that measure humidity, evaporation, and wind data. Although there were methods in 1933 that could record all three variables with some level of accuracy, all required calculations and had innate shortcomings in attaining actual, accurate data**.** The most acute problem was gathering data from the upper atmosphere. It is important to remember that the weather bureau provided an extensive list of services to the entire country, free of charge, highlighting the obligations that required the time of employees. Specific agricultural reports, flooding and river reports, upper air information for the burgeoning aviation industry, as well as forecasting put an incredible burden on the bureau that was exacerbated by public perception and criticisms of their practices. There are numerous examples of articles and letters from within the bureau and in journals (such as Humphreys' article of 1933) that actively seek to make the agency's responsibilities known and appreciated.

Aviation and Upper Air Data Collection

Like all sciences, meteorological advancement is constrained by the instruments and tools that allow accurate measurements. After World War I, it became abundantly clear that weather phenomena arose from or were directly caused by free air circulations far above the surface. Humphreys acknowledged this understanding, writing that, "the necessity was upon us [the weather bureau] to devise some means of sounding the air miles deep for its temperature, humidity, direction and velocity of movement, and any other state or condition that indicates the nature of the coming weather."[91] Meteorologists devised different means of retrieving data, kite soundings were effective, but could not reach the necessary altitude. In the early 20th century, pilot balloons (colored black or white to maximize the contrast with the sky and sometimes affixed with a light for nighttime launches) were released into the atmosphere and tracked visually using a theodolite in order to estimate the direction and velocity of the wind at various heights. Since an observer on the ground made the measurements, the possibility for human error remained quite large, especially when the winds were strong and the balloon travelled away from the observer at an acute angle. Moreover, the balloons disappeared from sight as soon as they rose into the clouds.

Sounding balloons, outfitted with a meteorograph to record temperature, pressure, and humidity, provided important upper-air data, but only after (and if) the instrument package safely parachuted back to earth,

[91] Humphreys, "On the Research of the U.S. Weather Bureau," 421.

then recovered by a passerby, and returned to the weather bureau, a process that could take months.[92] Although aviation proved itself useful during World War I, peacetime aviation still needed to find its place in the American economy. As air travel was not considered safe, meteorological study of the upper air proved critical to aviation. Once the postal service began to utilize air travel the impetus for aerology revitalized the bureau's interest in upper air data. The United States aviation industry gained significant support for research into practical use with the passage of the "landmark" Air Commerce Act on May 20, 1926, which allowed for the subsequent fantastic growth of the industry.[93] This act added another duty to the weather bureau's already extensive list of obligations, but it also resulted in a substantial increase in funding solely for the study of aerology to benefit the aviation industry; "Appropriations for aerology totaled $175,000 in 1927 and surpassed $1.7 million for fiscal 1932."[94] The increase in funding allowed for the establishment of new methods of gathering data from the upper atmosphere. The bureau utilized balloons, kites, and airplanes all with varying levels of success due to various unforeseen problems.

The danger and expense of airplane soundings removed its feasibility for data collection in the 1920s. Funding played a major role in the delay of incorporating airplane soundings as kites and balloons were less expensive

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92 Jeon, "Flying weather men and robot observers," 121.
93 Hughes, *A Century of Weather Service,* 49.
94 Popkin, *The Environmental Science Services*, 87.

and still delivered much of the same information.[95] Airplane soundings began on a regular basis alongside these two previous methods in 1931 because of its ability to take measurements at a higher altitude, fly without the necessity of wind (a kite shortcoming), and bring a human observer into the atmosphere.[96] It is important to note that this inclusion of airplane soundings came before the Scientific Advisory Board's report in 1933, highlighting the fact that the bureau was devoted to improving its science and well aware of the importance of upper-air data.

Of course, the airplane had its own shortcomings when it came to collecting meteorological information. Airplanes are designed to fly horizontally while the interaction of air masses and weather phenomena also occur in the vertical dimension. Air masses tend to spread out horizontally, so unless the pilot consistently changed his altitude, much of his data would be uniform. Further difficulties were found in affixing a meteograph to an airplane in order to be unaffected by the vibrations, exhaust, and heat of the engine, a problem not satisfactorily solved until the mid 1930s.[97] Moreover, as Jeon wrote about the meteograph, "the instrument on a moving airplane was unable to record the actual wind speed, which was one of the important weather factors for aviators."[98] Although this problem can be solved by simple arithmetic, the external variables (vibration, exhaust) rendered the actual data difficult to decipher.

95 Jeon, "Flying weather men and robot observers."
96 NOAA, "Evolution of the National Weather Service."
97 Jeon, "Flying weather men and robot observers," 123.
98 Ibid, 121.

In order to encourage pilots to ascend into the higher levels of the atmosphere the weather bureau provided rewards. Jeon wrote about the program to entice pilots into the risky venture, "There was a 10% bonus policy for each additional 1500 feet (beyond 13,500 feet), which was an 'incentive' for reaching the greatest possible height."[99] Despite the incentives and regular flights, the airplane was not entirely consistent in its collection of meteorological data. For safety's sake, they were unable to fly through severe storm systems, which contain data critical to understanding its movement and composition. While airplanes provided the most accurate and reliable source of information, they were by no means the perfect vessel for acquiring meteorological data and were dangerous to the pilot.

Twelve pilots died during weather missions; a common problem resulted from the icing of the wings at elevated altitudes.[100] Weather data collection proved to be an intricate and dangerous process for all individuals involved. Any minute mistake could ruin the purpose of the flight, Jeon wrote about this danger,

> [Airplane soundings] demanded ceaseless attention, because small disturbances in various segments of each cycle – failure to reach high altitude, instability of the instrument as a result of strong wind and vibration, or even crash of a sounding airplane – could render any inscription impossible or useless.[101]

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99 Ibid, 130.
100 NOAA, "Evolution of the National Weather Service."
101 Jeon, "Flying weather men and robot observers," 120.

As a result, airplane soundings were disciplined with a regulated rate of ascent and an immediate descent once attaining the desired altitude. In order to deal with the instrumentation problems numerous theories as to the proficient manner to affix the instruments emerged, including the suggestion of a passenger holding the meteograph above his head for the duration of the flight.

In 1937 the first radiosonde flew in Massachusetts, spelling a transition from airplanes to balloons as the primary method of sounding the atmosphere as these balloons could reach heights of 50,000 feet and constantly transmit data back to the surface (since its inception in 1937, the radiosonde has been improved to reach heights of 125 miles).[102] By 1940 the radiosonde completely replaced the airplane at weather bureau stations because of their perceived benefits such as vertical travel, speed of data collection, fewer required observers, safety, and extraordinary cost effectiveness. Much like the airplane when it replaced previous balloons and kites though, heavy reliance on radiosondes had problems of its own. Despite calibration in pressure chambers before launch, there were individuals who were skeptical of relying solely on the transmitted data.[103] As a result a series of tests and checks were studied through running simultaneous airplane and meteograph soundings. Since the balloons follow different paths through the air than airplanes, these studies resulted in further discrepancies. Although not clearly evident whether the radiosonde produced a more accurate

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102 NOAA, "NWS Radiosonde Observations – Fact sheet."
103 Dubois et all, "The Invention and Development of the Radiosonde."

recording device than the airplane, the cost and temporal aspects of the radiosonde resulted in its adoption as the primary sounding agent.[104]

Pushback, Misrepresentations, and Weather Control

It is vital to keep in mind just how little was known definitively about the atmosphere in the 1930s. While theoretical work slowly developed into practical use, the weather bureau's chief task of predicting the coming weather, but not necessarily understanding it forced a business as usual attitude until new techniques were adequately proven.[105] While the meteorological community knew that upper air data held the key to understanding the atmosphere, there was simply too much atmosphere to measure. As Harry Wexler stated at the opening ceremony of the International Geophysical Year on June 27, 1957, "Oceanographers like to put us landlubbers in our proper places by pointing out that the oceans cover three-fourths of the earth's surface. In meteorology we have no need for such defense mechanisms – everyone knows that the atmosphere covers *all* of the earth's surface."[106] Not only is it all around us, but miles deep and without recognition of international borders. The necessity of attaining information from around the globe, including over open water, further complicated the bureau's objectives. With all of the obstacles and difficulties in attaining accurate and timely data from the upper atmosphere in the 1920s and 30s, it

104 Jeon, "Flying Weather Men and Robot Observers," 134.
105 Humphreys, "On the Research of the US Weather Bureau," 424.
106 Wexler, "Remarks at International Geophysical Year opening ceremony."

is no surprise that air-mass analysis did not take root in the weather bureau's practices until these matters were addressed. In addition to negative societal perception, instrumentation, and funding problems, the bureau had to deal with swindlers claiming weather control "powers" on a regular basis.

Throughout the first few decades of the 20th century, the weather bureau came under consistent fire from academics, politicians, and laymen alike. *The New York Times* regularly blasted the agency for failed forecasting, such as one headline from 1921 which reads, "Failure of the United States Weather Bureau to forecast conditions that brought about the frost was responsible in large measure for the loss of more than $50,000 by farmers in this section."[107] The weather affects every single individual in the country and when any forecast proved incorrect, the agency was criticized. This fact is evident through letters to the editor of the *Times*,

> Can anybody tell me anything about the Weather Bureau? Has it gone completely cock-eyed? Some of us amateur yachtsmen depend upon the Weather Bureau, but we are getting discouraged with it. We are beginning to believe it is bunk.[108]

While there is no denying that some of the missed forecasts were the fault of the bureau, the developing meteorological practices that allowed for forecasting were in the early stages of unraveling the unknown principles of the Earth's climate. Throughout its existence, the weather bureau

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107 "Weather Bureau Blamed. Crop Damage Ascribed to Failure to Forecast."

108 Brownell, "Amateur Yachtsman Discouraged With Bureau's Reports."

consistently came under criticism due to their wide range of responsibilities, the weather's ever-present threat to turn severe, and the unjustified belief that weather phenomena can be controlled.

It seems that humans have always been fascinated with the weather and the potential for its management. Individuals have sought weather control for personal economic gain, peaceful purposes, and militarization. Weather bureau employees spent ample amount of time disproving control claims, as Humphreys wrote about a conference he attended in Europe:

> Only one man of the considerable number in attendance was cock sure of the weather of the coming one, two, or several seasons in advance. I knew him – pleasant enough personally – and understood that he made his living by selling his season forecasts to gullible dealers in grain futures. When pressed, as I was, for my forecast of the coming season, I replied that I only could make a worthless guess, nor, I added, can anyone else do better, whatever his claims.[109]

There have been ideas for avoiding hurricanes, warming the country, and specifically for cloud seeding that have plagued the bureau and forced critical funds and time to be spent on disproving these charlatan claims. As Humphreys wrote in 1933, "All known schemes for inducing rainfall, or preventing it, have been critically examined, and the cause or causes of the failure of each fully explained."[110] Humphreys also wrote a book, *Rain Making and Other Weather Vagaries* (1926), in which he attempted to inform the public of the problems with weather control and its rich history. Fleming

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109 Humphreys, *Of Me*, 240.

110 Humphreys, "On the Research of the U.S. Weather Bureau."

writes that Humphreys separated rainmaking into three categories: magical, religious, and (supposedly) scientific.[111]

This however, did not discourage individuals such as Dr. George Ambrosius Sykes from claiming rainmaking capabilities. In 1930 he guaranteed horse-racing companies rain-free weeks that he simply could not produce, “In two queer-looking huts, far from the grand stand, Dr. Sykes was believed to have been working manfully with his secret paraphernalia. But opinion as to his success in controlling the weather was divided… drops of water came down.”[112] Another weather charlatan, Charles Hatfield, distracted the bureau as they were forced to disprove his claims as a “moisture accelerator.” He operated throughout the early 1900s in the West as well as Mexico and Canada, capitalizing on agriculturalists in desperate need of precipitation.[113]

The bureau’s dedication to providing the American people with the free service of accurate weather information and ridding the consumer of the faulty claims to weather control are generally overlooked by historians of the agency allowing them to claim a backwards bureau. The rainmaking claims frustrated weather bureau officials, as Humphreys said, “By far the most important feature of the rainmaker’s work consists in playing on the credulity of mankind. Credulity disappointed is likely to be cruel.”[114] In reality, obligations, burdens, technical and logistic challenges, need for study, and an

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111 Fleming, *Fixing the Sky*, 46.
112 “Rainmaker Loses $2000 By Sprinkle.”
113 Fleming, *Fixing the Sky,* 90.
114 “Political Rainmakers,” 28.

insufficient budget all resulted in difficulties that the bureau sought to overcome in its quest for atmospheric understanding.

Military Involvement

The national weather service's history is intimately linked with the military. From data collection to prediction, military applications of meteorological study resulted in times of rapid modernization for the science. The founding of the weather service was located within a Civil War branch of the War Department and military branches consistently utilized meteorological information for preparation and planning. Both world wars resulted in the necessity to train massive numbers of meteorological cadets in order to provide information for aviation, troop movement, and artillery shelling as well as coastal weather-patrol programs. The weather bureau worked in collaboration with the military, affording the war effort with most of its trained meteorologists as well as providing professors for the training programs. Harry Wexler served as one of these professors, stationed in Grand Rapids, Michigan. One of his exams highlights the specific training desired by the military deemed critical for wartime meteorologists. The exam is titled, "Meteorology For Chemical Warfare," it establishes a scenario of poison fallout and questions safe troop movement.[115]

Military support for modernization and improved techniques in meteorological practices resulted in the steady rise in the American science.

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[115] Wexler, "Meteorology For Chemical Warfare."

American scientists influenced World War II by providing intelligence and information for the aerial battles. Accurate predictions and forecasting provided the allied forces the edge they needed against the German and Japanese forces. The invasion of Normandy also benefitted from American meteorologists, although the issue is contentious. Irving Krick and Colonel Benjamin Holzman led the American based meteorological team titled "Widewing." Through their insistence, the allied forces decided to land on the sixth of June, despite bleak forecasts from the other allied meteorological teams.[116] When word reached the United States that American meteorologists were supposedly able to locate a break in the storm that the European's could not, Krick capitalized on the notoriety to increase his own social standing. The story is incomplete however, as Widewing was not entirely responsible for the forecast. Sverre Petterssen, who worked with the British meteorological team, pointed out years later that Widewing adamantly suggested storming the beach on the fifth, which would have resulted in a complete and utter failure.[117] Only through his team's insistence was the offensive delayed, highlighting the importance of collaboration and utilizing multiple methods of weather analysis (despite Petterssen's disapproval).

World War II also allowed the bureau the opportunity to engage in a period of rapid modernization that utilized such technologies as radar, improved aircraft, and an expanding network of radiosonde activities.

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116 Anonymous, "Notes on Weather as it Affected Operations."
117 Fleming, "Sverre Petterssen, the Bergen School, and the Forecasts for D-Day."

Military applications of meteorological services continued their interaction in the post war period as the Cold War initiated an era of fear over meteorological warfare.

Post World War II: Operational Numerical Weather Prediction, Satellites

Historians generally view the post-World War II time period as an unheralded occasion of advancement for American meteorology. The new technologies available for meteorological study immeasurably improved the bureau's practices and techniques. Although there is no denying the assertion of a period of great improvement and modernization, it has its roots in the meteorological past. Popkin wrote in 1967 about how the budget for the bureau after the war steadily increased with only slight reductions in the Eisenhower administration. Despite this increased funding, Popkin wrote, the service of the bureau to the American public hardly changed at all.[118]

In late December of 1945 John Mauchly, a pioneer in computer development, visited Major Harry Wexler at the Air Weather Service in the Pentagon to ask his opinion about the possible uses of computational devices within meteorology. Since the bureau had previously informed Mauchly that interest lay solely in automated data handling and statistical computation, it was a welcome surprise when the future head of research enthusiastically

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[118] Popkin, *The Environmental Science Services,* 90.

supported a more significant role.[119] Mauchly recalled, "[Wexler] suggested immediately that such a machine be employed in integrating hydrodynamic equations occurring in meteorological work. He attaches a great deal of importance to this application."[120] From that moment on, Wexler and the weather bureau were inextricably involved in digital computing.

In 1946 Wexler moved back to the weather bureau where he and his supervisor, Reichelderfer, sponsored a number of meetings with computer specialists. That year, Wexler began working as a liaison to the Institute of Advanced Study Meteorology Project in Princeton, helping to secure funding and offering advice and aid to its director, John von Neumann. Von Neumann, the esteemed mathematician, set himself to work in Princeton developing equations for computational devices to be utilized for meteorological benefit. The weather bureau's influence was paramount to the project's eventual operational success in 1954. Although there were many logistical and academic problems, Reichelderfer and Wexler refused to abandon the project; instead they facilitated an interdisciplinary, international project that utilized the support of the military and teamed up with such influential meteorologists as Rossby and Jule Charney.

By 1954, the weather bureau advanced the program initiated by Abbe (1901) and Bjerknes (1904) of weather prediction as a problem in mechanics and physics. Utilizing newly available electronic computers, Wexler and

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119 Fleming, "Beyond prediction to climate modeling and climate control."

120 Mauchly, "Note on the Possible Meteorological Use of High Speed Sorting."

company helped bridge the gap between the graphical and digital methods. Operational Numerical Weather Prediction came to fruition after years of challenging work by many individuals such as John von Neumann, Phillip Thompson, Jule Charney, and Harry Wexler among others. Wexler acted as liaison to the Institute and dealt with the issues that arose in regards to personnel, logistics, and of course meteorological information.

Wexler also played a critical role in satellite meteorology, through his advocacy of new technologies such as rockets and radar in order to study the outer realm of the Earth's atmosphere. German V2 rockets provided the technological capacity to reach the edge of space and were utilized to collect meteorological data. *Explorer 6* captured the first photograph from space in 1959 and in 1960 *Tiros 1* (Television Infra-Red Observation Satellite) became the world's first weather satellite.[121] Working in collaboration with NASA, the weather bureau became a leader in space meteorology due to satellite technology. Wexler, like Humphreys and Abbe before him, is a prime example of the continuous efforts at modernization and scientific improvement found in many of the employees of the United States Weather Bureau.

Conclusion

The United States Weather Bureau arose as a practical service for business and agriculture, to serve specific purposes for the American people. These demands included specific warnings for agriculture and commerce as

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[121] Fleming, "Beyond prediction to climate modeling and climate control."

well as individual requests made of the bureau.[122] Over the decades, the bureau took on new responsibilities such as forest fire precautions and upper air reports for the aviation industry. After 1908, individuals who purchased Ford Model T vehicles often called into their local weather bureau office looking for predictions about their drive. Insurance agencies that began issuing policies against weather phenomena, and organizers of sporting events also inquired about weather information. The constant needs of the American citizenry are encapsulated in a *New York Times* article from March 12, 1929: "Not infrequently, it was said, 1,500 'busy line' reports have been recorded in a single day at the bureau switchboard and the average number of busy lines is about 1,000 daily. About 2,000 calls receive attention each working day."[123] These obligations limited the amount of resources that could be dedicated to emerging techniques such as air mass analysis. The delay, however, was only of a few years and for specific, justified reasons.

Vilhelm Bjerknes founded the Bergen School in 1917, with general acceptance of their air mass analysis techniques and international diffusion coming by 1928. The geographical features of North America differ greatly from Europe, so adoption of air mass techniques was not straightforward and weather forecasting necessitated a significant amount of further study. The weather bureau carried out this work throughout the late 1920s and 30s through the collaboration of established and emerging meteorologists

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[122] Whitnah, *A History of the United States Weather Bureau*, 150.
[123] "Aviation is Taxing Weather Bureau," 56.

dedicated to improving the accuracy of forecasting and understanding the physical makeup and dynamics of the atmosphere.

The weather bureau has been marred in public perception because of disgruntled individuals and personal vendettas that have maligned the agency for malpractice and misuse of funds. This disparaging view of the agency has persisted through time, perpetuated by historians eager to put forward the notion of American meteorology solely as a post WWII venture. Mainstream media outlets that blasted the agency for any missed forecast ignored the fact that the bureau under Harrington (1891-1895) averaged between 80-85% correct forecasting.[124] It is only through a careful study of the time and agents involved that the bureau's goals and actual practices become clear and separate from the false accusations. The United States Weather Bureau is one of the most misrepresented government agencies in history, with an inordinate amount of duties compared to their meager budget and subject to criticism from all sides.

The agency steadily improved their techniques and habits through increased study and practice. The Norwegian methods of Bjerknes and his colleagues were slightly delayed in their incorporation, however this setback should not overshadow the bureau's historical dedication to advancing meteorology and the service to the American people. With the incorporation of meteorological equipment on the *Tiros* satellites of the 1960s, the United States Weather Bureau firmly established itself, as a premiere meteorological

[124] Popkin, *The Environmental Science Services,* 60.

agency, advanced in both practical and theoretical meteorology through its continuous efforts in modernization. Current historiographical accounts of the national weather service are filled with misrepresentations and incomplete depictions due to the breadth of contributing factors and sources. The agency experienced scandals and shortcomings, but also made great strides in developing meteorological techniques and providing weather services to the growing nation.

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