Weathering Heights: The Emergence of Aeronautical Meteorology as an Infrastructural Science

Roger Turner

University of Pennsylvania, rogert@sas.upenn.edu

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Weathering Heights: The Emergence of Aeronautical Meteorology as an Infrastructural Science

Abstract
The first half of the 20th century was an era of weathering heights. As the development of powered flight made the free atmosphere militarily and economically relevant, meteorologists encountered new kinds of weather conditions at altitude. Pilots also learned to weather heights, as they struggled to survive in an atmosphere that revealed surprising dangers like squall lines, fog, icing, and turbulence. Aeronautical meteorology evolved out of these encounters, a heterogeneous body of knowledge that included guidelines for routing aircraft, networks for observing the upper air using scientific instruments, and procedures for synthesizing those observations into weather forecasts designed for pilots. As meteorologists worked to make the skies safe for aircraft, they remade their science around the physics of the free atmosphere. The dissertation tracks a small group of Scandinavian meteorologists, the “Bergen School,” who came to be the dominant force in world meteorology by forecasting for Arctic exploration flights, designing airline weather services, and training thousands of military weather officers during World War II. After the war, some of these military meteorologists invented the TV weather report (now the most widely consumed genre of popular science) by combining the narrative of the pre-fight weather briefing with the visual style of comic-illustrated training manuals. The dissertation argues that aeronautical meteorology is representative of what I call the “infrastructural sciences,” a set of organizationally intensive, purposefully invisible, applied sciences. These sciences enable the reliable operation of large technological systems by integrating theory-derived knowledge with routine environmental observation. The dissertation articulates a set of characteristics for identifying and understanding infrastructural science, and then argues that these culturally modest technical practices play a pervasive role in maintaining industrial lifeways. It concludes by noting that while meteorology successfully helped aviation become a reliable, taken-for-granted part of the transportation system, the interests of aviation created a meteorology that centered on the needs of pilots, to the detriment of fields like agricultural climatology.

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WEATHERING HEIGHTS: THE EMERGENCE OF AERONAUTICAL METEOROLOGY AS AN INFRASTRUCTURAL SCIENCE

Roger Turner

A DISSERTATION

in

History and Sociology of Science

Presented to the Faculties of the University of Pennsylvania

in

Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

2010

Supervisor of Dissertation

_____________________

M. Susan Lindee, Professor of History and Sociology of Science

Graduate Group Chairperson

_____________________

Robert Aronowitz, Professor of History and Sociology of Science

Dissertation Committee

M. Susan Lindee, Professor of History and Sociology of Science

Ruth Schwartz Cowan, Professor of History and Sociology of Science

James Fleming, Professor of Science, Technology and Society (Colby College)
Weathering Heights: The Emergence of Aeronautical Meteorology as an Infrastructural Science

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Roger Turner
For Emily
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I have been blessed to receive so much assistance, from so very many sources, that this dissertation should really be seen as a communal production. Greedily, however, I claim the mistakes that remain entirely for myself.

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Finally, my family. To Polly Eddy, the Hahns, and the Spicers, thank you for a loving Thanksgiving retreat. My parents, Mary and Bill Turner, and my sister Kate have supported me through it all with so much laughter and love. And last and most of all, to Emily Pawley, to whom, with love, I dedicate this dissertation.
The first half of the 20th century was an era of weathering heights. As the development of powered flight made the free atmosphere militarily and economically relevant, meteorologists encountered new kinds of weather conditions at altitude. Pilots also learned to weather heights, as they struggled to survive in an atmosphere that revealed surprising dangers like squall lines, fog, icing, and turbulence. Aeronautical meteorology evolved out of these encounters, a heterogeneous body of knowledge that included guidelines for routing aircraft, networks for observing the upper air using scientific instruments, and procedures for synthesizing those observations into weather forecasts designed for pilots. As meteorologists worked to make the skies safe for aircraft, they remade their science around the physics of the free atmosphere. The dissertation tracks a small group of Scandinavian meteorologists, the “Bergen School,” who came to be the dominant force in world meteorology by forecasting for Arctic exploration flights, designing airline weather services, and training thousands of military weather officers during World War II. After the war, some of these military meteorologists invented the TV weather report (now the most widely consumed genre of popular science) by combining the narrative of the pre-fight weather briefing with the visual style of comic-
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Introduction

Uncovering Infrastructural Science

In November 1933, the National Academy’s Science Advisory Board, made up of some of the most distinguished scientists in the United States, reported on the temperature sensitivity of bananas. “Bananas,” they wrote, “require very careful handling and must be kept at a temperature of 58 degrees to 65° F during shipment,” lest they become discolored or ripen too quickly. Bananas were just one of many industrial products that were sensitive to temperature extremes. The Advisory Board’s report was titled “The Work of the Weather Bureau,” and it began by describing how a single temperature forecast rippled through a city. On the prediction of a cold wave,

Greenhouses are closed and boilers fired. Preparations are made at once by heating and lighting plants, whether gas, electric, steam or hot water, to meet the increased demands that will follow. Fire hydrants, exposed mains and general plumbing are protected. Small householders as well as large stockyards drain their mains. Gasoline engines are drained and water-cooling systems are protected by the use of anti-freeze solutions. Work in concrete is stopped. Street-car railway companies arrange for more heat in their cars. … Merchants direct their advertising and attention largely to cold weather articles. Oyster dealers increase their reserve stocks. Coal dealers supply partial orders to all customers needing fuel … Ice factories reduce their output. … Charity organizations prepare to meet increased demands for food and fuel, and thus minimize the suffering of the poor.

Outside the city, railroads rerouted cattle, fruit and vegetable shipments, or moved their cargoes into roundhouses for protection. While only shippers directly saw the impact of a forecast, “its benefits are felt by every one both in the price and quality of our food stuffs.”

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In fact, the Advisory Board argued, the Weather Bureau “probably touches directly the immediate needs of more of the people of the United States than do all other federal services combined,” excepting the postal service. However, there was “little general realization either of the extent of the personal interest of the whole population in this service or of the magnitude of the organization and the labor involved in serving this universal individual need.” People rarely thought much about it, but meteorology required thousands of observers distributed across the hemisphere, who twice a day made routine weather observations. Communicated by telegraph to the Central Office in Washington DC, these observations made possible daily forecasts that affected the operation of the infrastructure on which everyone’s daily life depended. In short, meteorology was pervasive but little noticed, an unobtrusive science crucial to regulating the flows of industrial society.

Little noticed, that was, until it failed. The Advisory Board’s report had been triggered by the worst aviation disaster in American history. Seventy-three men, including Admiral William Moffett, in charge of the Navy Bureau of Aeronautics, had died when the dirigible Akron crashed in a storm off the coast of New Jersey on April 3rd, 1933. How, the Board asked, should the Weather Bureau more effectively understand and predict conditions above the earth’s surface?

Answering this question were three of America’s most distinguished scientists. One was Robert Millikan, the nation’s leading physicist, the chairman of the California Institute of Technology, and the man who had supervised a weather observation network in France as the Army’s Chief scientist during World War I. The second was Isaiah Bowman, president of Johns Hopkins University and geographical advisor to President
Wilson during the Versailles Treaty negotiations. Third was physicist Karl Compton, recently installed as president of the Massachusetts Institute of Technology with a mandate to improve the school’s standing in scientific research. To ensure the Weather Bureau was represented, Charles D. Reed was added, bringing his long experience as a forecaster in the midwest.²

After describing the uses of forecasts, the committee recommended changes that would reorient the Weather Bureau’s attention from predicting conditions at the surface towards charting and understanding the behavior of the upper air, the part of the atmosphere that moved largely free of the inference of obstructions at ground level. “Every one knows that the accuracy of weather forecasting is far from perfect,” wrote the committee, but “in recent years there have been developed and tested new methods of forecasting which increase this accuracy.”³ The bureau needed to adopt “air-mass analysis,” a set of concepts developed by Norwegian theoretical meteorologists that used upper air observations and models of atmospheric dynamics to predict the weather. Air mass analysis would require establishing twenty to twenty-five aerological stations that would launch daily flights to record conditions at ascending heights. To save government money, the committee naively suggested the Army and Navy make these flights as part of their normal operations. Weather Bureau instruments should be moved from city centers to airports, thus eliminating the turbulence and radiation effects produced by large, heated buildings. To take full advantage of air mass analysis, the drawing of synoptic maps

should be increased, from two maps daily to three or even four. A modern weather
service also needed a unified and efficient communications system. The Civil
Aeronautics Authority should give its airways teletype weather reporting system to the
Weather Bureau for regular operation, and the Weather Bureau should adopt the
numerical code agreed upon by the International Meteorological Organization for
transmitting weather observations. The committee also recommended that the Weather
Bureau establish a system of postgraduate training, sending its best young men to
educational institutions “of recognized leadership” in meteorology for formal instruction
in the more modern methods of weather prediction. (Both Caltech and MIT were
developing graduate programs in meteorology in 1933.) Finally, the committee
recommended, a permanent committee “composed of four or five of the outstanding
scientists of the country” should be established to advise the Weather Bureau and present
its claims to the government and general public.

In the bland tones typical of committee work, the committee thus recommended a
transformation in how the government managed the nation’s relationship to weather. For
decades, Congress had poured cold water on the Weather Bureau’s occasional efforts to
support theoretical research in meteorology.⁴ Now, in support of aviation safety, the
government needed to create new data on the free atmosphere and to train meteorologists
in how to use them. The government should import a set of foreign scientific practices
and make them central to American weather forecasting. The seat of weather prediction,
the instruments and local offices of the Weather Bureau, should be moved away from
concentrations of people, off of the tall buildings in the center of cities, to the new

⁴ Edmund P. Willis and William H. Hooke, “Cleveland Abbe and American Meteorology, 1871–1901,”
airfields springing up at the sparsely populated edges. The report thus marks a transformational period in the history of science, when the upper air became the focus of meteorology.

**Weathering Heights**

This dissertation demonstrates a novel approach for thinking about the importance of science in industrialized societies. The history of aeronautical meteorology reveals how powerful material effects can be produced by integrating large technological systems with pervasive but little noticed environmental surveillance systems. This dissertation shows how a small group of obscure experts, coordinating the activities of government bureaus, commercial firms and academic departments, transformed aeronautical meteorology from a scientific curiosity into an influential body of knowledge crucial for operating a set of technologies essential to global military and economic power. During the first half of the 20th century, the period on which this dissertation focuses, the material and environmental consequences of this emergence far outweighed the cultural ones. Meteorology was essential to managing the world long before most people realized it. Only towards the end of the 20th century did atmospheric science, built in part on the knowledge practices of aeronautical meteorology, produce the culturally disruptive theory of anthropogenic climate change that made it an ascendant subject of critical discourse. During the first half of the century, meteorology lay camouflaged under the routine measurement and prediction work that enabled a thousand environmentally sensitive activities upon which industrial lifeways depended.
The first half of the 20th century was an era of weathering heights. As the development of powered flight made the upper atmosphere more readily accessible, meteorologists discovered new kinds of weather conditions at altitude, for example, narrow bands of 200 mile-per-hour winds and clouds that froze as soon as they touched airplane wings. Pilots also learned to weather heights, as they struggled to survive in an atmosphere that revealed surprising dangers: squall lines, fog, icing, turbulence and lightning. Even maneuvers as seemingly simple as flying through an unbroken stretch of cloud turned out to be hazardous; many pilots were killed before the physiological causes of the “death spiral” were unraveled. As flying organizations turned to meteorologists for advice and training, aviation displaced agriculture and shipping as the most influential usage of meteorological knowledge. Proposals like the Science Advisory Board’s, carried out in many places around the world, directed scientific attention towards the upper atmosphere, reordered the social hierarchy of meteorology, and in time, transformed the way that the general public experienced and interacted with the weather. Understanding modern atmospheric science thus requires tracing the history of aeronautical meteorology.

Perhaps unsurprisingly, aerology and aeronautics had been linked from the beginnings of human flight. From the Montgolfier’s first hot air balloon flights in 1783...
and throughout the 19th century, scientists used balloons to access the upper air, collecting gas samples and carrying aloft thermometers and barometers. Balloonists cited their contributions to the progress of aerology (the study of upper air) when they argued for public support. Meteorology justified aviation research. The development of powered, guided flight at the start of the 20th century, both heavier-than-air craft like the Wright Flyer and lighter-than-air ships like Count Zeppelin’s dirigibles, began to change this relationship.

The development of powered flight transformed aerology from a minor research interest within a diffuse science into the heart of meteorology. The application of aviation to military purposes intensified rapidly as the Great War stabilized into trench warfare. Among the many weapons developed to defeat trenches, aviation and long-range (ballistic) artillery stood out as weapons designed to use the third dimension to overcome armies stalemated on the ground. The unpredictable behavior of the free atmosphere, however, could render these weapons ineffective. To overcome this problem, all fighting nations established weather reporting services to cover the front lines, mobilized their meteorologists, and began to train new ones.

This posed particular problems for Americans. The United States entered the war with only a small community of domestic weather forecasters and almost no meteorological researchers. It had to train hundreds of new officers to handle the Army

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6 While poison gas certainly had important meteorological interactions (which are succinctly described in Kristine C. Harper, “Meteorology’s Struggle for Professional Recognition in the USA, 1900-1950,” *Annals of Science* 63, 2 (April 2006): 179-199), my preliminary reading of the evidence suggests it had a rather separate history from meteorological support for aviation. The development of micrometeorology has not been traced in detail, but it seems to have diverged from aerology institutionally as well as intellectually after World War I. The two were re-integrated institutionally in academic meteorology departments after World War II, as meteorologists took advantage of funding for studying the distribution of radioactive fallout.
and Navy’s weather needs. As chief scientist for the Army, physicist Robert Millikan
headed this training program; Harvard’s Alexander McAdie led the Navy’s separate
training program, while a small number of Weather Bureau forecasters like Edward
Bowie were sent to France to guide the operational work.

For European nations, the war meant adapting their domestic weather services.
Forced from his German university position by wartime shortages, Vilhelm Bjerknes and
his colleagues in neutral Norway put their upper air studies in service of the state. As
military-imposed information blockades hampered synoptic weather mapping, Bjerknes
applied theories of atmospheric physics to compensate, moving from the realm of pure
theory into operational forecasting. The Triple Entente mobilized its meteorologists,
including Vilhelm Bjerknes’s German research assistants. By war’s end, it was clear that
meteorological knowledge was needed for aviation operations. Where in the age of
balloons, meteorology had justified flight, flight now justified meteorology.

Flight was a potent justification. “Aviation,” Michael Dennis writes, “was to
interwar America what guided missiles and atomic energy were to post-WWII America:
technologies of immense strategic and commercial value developed through a complex
interplay among a variety of organizations, both public and private, civilian and
military.” Interwar aircraft were not as menacing as guided missiles, however, at least
until the bombing of Guernica during the Spanish Civil War. Despite their use in the
Great War, planes were more often seem as a hopeful symbol of innovation and
modernity. “We fly no airplanes,” admitted Freihofer’s Fine Bread in a 1928 ad, “but in

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7 Michael Aaron Dennis, *A Change of State: Political Culture, Technical Practice, and the Origins of Cold War America* (Johns Hopkins University Press, Forthcoming): 50. I thank Dr. Dennis for sharing a draft of his first chapter with me.
our own way we too are setting the standards of these modern times.” (Figure 1.1) The value of stock in aviation companies ballooned between Lindbergh’s flight in May 1927 and the market crash in October 1929, buoyed by as irrational an exuberance as dotcom stocks were in the late 1990s. Though aircraft projected modernity, they were more powerful as symbols than as objects before they were integrated into systems that made them reliable and useful.

![Freihofers Fine Bread Advertisement](Image)

Figure 1.1: Excitement over the potential of flight made aviation nearly synonymous with innovation during the late 1920s. Even bread advertisements traded on that enthusiasm. (Freihofers Fine Bread advertisement, published in *Laws, Ordinances and Regulations of the Department of Public Health of the City of Philadelphia*, 1928.)
During the 1920s, aeronautical meteorology emerged as a heterogeneous body of knowledge that drew upon the experience of pilots as well as the observations and theories of meteorologists. It combined abstract formulas and theoretical science with practical instructions for doing things in the world. Aeronautical meteorology was knowledge held inside heads, written into texts, or deployed in procedures. Some of its procedures involved guidelines for deciding when to launch aircraft, how to route them, and how to pilot them. Other procedures related to the collection, dissemination and interpretation of atmospheric observations made with scientific instruments. Aeronautical meteorology combined knowledge derived from theories of atmospheric physics with knowledge generated from direct interactions with the upper air, as experienced by pilots and balloonists. Weather forecasting was a central technical practice.\(^8\)

As aircraft became crucial to commerce, military power, exploration, and leisure during the 20\(^{th}\) century, aeronautical meteorology grew rapidly. Governments around the world moved their weather services from scientific or agricultural ministries to military or aviation divisions. The most influential scientific leaders of this transformation were a group of mostly Scandinavian geophysicists who had trained under Vilhelm Bjerknes at

\(^{8}\) A note on the differences between weather forecasting and meteorology: weather forecasting is a technical practice that is largely but only partially built on scientific knowledge, while meteorology describes a science that is substantially broader. Atmospheric science, as meteorology has been renamed since the late 1950s, includes: theoretical studies of atmospheric dynamics; quantitative measurements of the planet’s radiation budget; studies of the chemistry of the atmosphere’s constituent gases; climatological surveys of the distribution of temperature, precipitation, or humidity; radar-based studies of the life cycle of tornadoes, and many other subjects. Some parts of this knowledge are combined to enable weather forecasting, a technical practice that could be separated from theoretical science (there are many folk and vernacular forecasting techniques unconnected to scientific meteorology) but in most places is not. On the tensions between weather prediction and meteorological science, see Katharine Anderson, *Predicting the Weather: Victorians and the Science of Meteorology* (University of Chicago Press, 2005). For insight into the conflicted relationship that current weather forecasters have with meteorological science, see Gary Alan Fine, *Authors of the Storm: Meteorologists and the Culture of Prediction* (University of Chicago Press, 2007): chapter 2.
Bergen, Norway. The “Bergen School” sought to develop quantitative explanations of the behavior of the oceans and atmosphere using hydro- and thermo-dynamics. Though prizing abstract research, they regularly worked with weather forecasters, aviation organizations, and militaries to solve practical problems. Through these connections, members of the Bergen School became leaders of academic and government meteorological institutions, responsible for training the next generation of meteorologists.

Bergen School ideals thus became organizing principles in modern meteorology; mathematically adept, theoretical researchers were the most celebrated scientists, standing above the “operational” meteorologists who predicted the weather from day to day. The emerging social hierarchy of meteorologists came to mirror an ontological hierarchy that permeated their science: the ultimate causes of the atmosphere’s behavior lay in the dynamics of the upper air, while the weather most people experienced at the Earth’s surface was merely a secondary effect of the atmosphere’s general circulation. This principle has guided the construction of the numerical models that are the foundation for both contemporary weather forecasting and for understanding climate change. As meteorologist Horace Byers put it in 1955, computer models simulated the atmosphere at the hemispheric level, but there remained “a second step, such as pinpointing cloud, rain, and temperature areas, [that] is left for the harassed local weatherman.” The privileging of the global over the local has guided the construction

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of the numerical models that are the foundation for both contemporary weather forecasting and for understanding climate change.

The most immediate consequence of advances in aeronautical meteorology was an improvement in the safety and reliability of air travel. As aircraft became capable of completing missions more reliably, even when confronted by adverse weather conditions, they became integral to daily life in industrialized societies. The United States Post Office pioneered the use of regularly scheduled aviation, making airmail an essential part of the communications system. Airmail contracts supported the development of passenger service, eventually transforming leisure and business travel as well as the distribution of population, particularly in isolated regions. During the first half of the 20th century, aviation became infrastructure, a central component of the transportation and communication systems of modern societies. Aeronautical meteorology enabled that infrastructure to operate, becoming what I will call in this dissertation an “infrastructural science.”

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14 William Leary writes, “For the airline industry in the United States to achieve its position as the prime mover of intercity passenger traffic, two things had to happen. First, air travel had to be made safe and reliable; and second, air travel had to be able to compete economically with other forms of intercity transportation. Safety and reliability came in the years before American entry into World War II … the economic revolution in airfares occurred after the Second World War.” “Safety in the Air: The Impact of Instrument Flying and Radio Navigation on U.S. Commercial Air Operations between the Wars,” in *From Airships to Airbus: The History of Civil and Commercial Aviation, Volume 1: Infrastructure and Environment* (Smithsonian Institution Press, 1995): 97-113. Quotation on 97.
Theorizing Infrastructural Science

Infrastructure defines industrial lifeways. From water pipes to power grids, factory farms to forestry, roads to rivers, broadcasting to banking, a carefully constructed infrastructure underlies nearly everything we do. The presence of large technological systems that reliably bring people water, food, heat, power, and information defines the developed world. These systems are so reliable that we only think about them when they break down (or pay the utility bills). Yet they all exist in what Aristotle called the sub-lunar world of change, endangered by floods, storms, surges, earthquakes and fires.

The living world also threatens—tree roots strangle water pipes and jostle sidewalks, animals burrow into levees, bacteria grow nearly everywhere. Operating infrastructure thus requires continuously watching, adjusting, and predicting where the next problem will occur. Industrial society depends upon monitoring, controlling, and manipulating nature on a massive scale. This work in turn relies on the knowledge produced by a diverse group of applied sciences that I call the infrastructural sciences (see Table 1.1).

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15 Ruth Schwartz Cowan argues “industrialization transformed every American Household sometime between 1860 and 1960.” Before the Civil war most families did their housework in ways that would have been familiar in the Middle Ages; a century later, just a few families lived this way. *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave* (Basic Books, 1983): 3-4.


17 The history of development projects in the global south highlights that it is not the presence of these systems that leads to development, but the maintenance and operation of them reliably over long terms. Many roads and power plants were constructed, but without building the crucial matrix of expertise, governance, spare parts, and political economic culture necessary to keep those capital outlays in working order.

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<td>Fisheries management</td>
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<td>Epidemiology</td>
<td>public health</td>
<td>controlling disease, improving health of populations</td>
<td>hospital reports, standardized diagnostic criteria</td>
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<td>Hydrology</td>
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<td>Vulcanology</td>
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<tr>
<td>Forestry</td>
<td>forests</td>
<td>Production of building materials and fuel</td>
<td>Watch towers, measuring tools</td>
<td>Botany, ecology, mathematics</td>
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<tr>
<td>Operations research</td>
<td>flows and stocks</td>
<td>efficient movement and production</td>
<td>surveys, reports, transponders, maps</td>
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</tr>
<tr>
<td>Metrology</td>
<td>weights and measures</td>
<td>reliable, interchangeable commodities and manufactured goods</td>
<td>Inspection agencies, calibration depots</td>
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</tr>
<tr>
<td>Macroeconomics</td>
<td>national/international economy</td>
<td>maintain/create patterns of trade and wealth distribution</td>
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<td>macroeconomics, psychology</td>
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<td>Market Research</td>
<td>Consumers</td>
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<td>Surveys, focus groups, purchase tracking</td>
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<tr>
<td>Astronomy</td>
<td>Heavenly bodies, Time</td>
<td>Navigation</td>
<td>Telescopes, satellites, astrolabes, sextants</td>
<td>Gravitational Dynamics, trigonometry</td>
</tr>
</tbody>
</table>

Table 1.1: Examples of Infrastructural Science. “Material interventions” describes the types of activities that depend on the products of infrastructural sciences.

As the examples in Table 1.1 suggest, an infrastructural science is a body of technical practices that enable material interventions by integrating theory-derived
knowledge with routine observations. Like field science, infrastructural science is a cross-disciplinary category—it highlights common practices and problems across disparate disciplines, showing us similarities between meteorology and macroeconomics, or entomology and epidemiology, for example.\(^{19}\) Take meteorology and epidemiology. While most meteorologists have probably never met an epidemiologist, both sciences integrate theoretical insights derived from numerical modeling and field studies with continuous monitoring through geographically distributed, standardized surveillance systems, in order to provide advance warnings to governments in order to save lives.

While infrastructural science is a category created for contemporary analysis, it does have similarities to past actors’ categories like William Whewell and George Airy’s “permanent sciences” or 19\(^{th}\) century American notions of “science in the service of the state.” The infrastructural sciences share a set of attributes that make them crucial to industrial society but simultaneously render them obscure to outside observers. These attributes describe their work practices, spatial arrangement, temporal orientation, primary function, key products, and connections to theoretical and academic science.

Formulaic and Routine Work

The work practices of infrastructural science emphasize routine observation. Large numbers of individuals with a moderate amount of technical training conduct

\(^{19}\) As Robert Kohler and Henrika Kuklick have shown in examining field science, I argue that infrastructural science pulls together a variety of seemingly disparate disciplines, and reveals that they have common qualities that are not often discussed. The category does not aim to explain entire sciences, but rather aspects of various disciplines. Just as not all of biology is dependent upon the production of knowledge in the field, not all parts of an infrastructural science are involved in supporting infrastructure. Not all meteorological or microbiological work goes towards the operation of infrastructure, but knowledge produced by these sciences is crucial. Henrika Kuklick and Robert Kohler, “Science in the Field: Introduction,” Osiris, 2\(^{nd}\) series 11 (1996): 1-14.
established, repetitive observations. These observations often must be made on an externally arranged schedule, often in coordination with other observation stations. The observations are carried out according to carefully standardized procedures, using instruments or tests that have been calibrated and distributed across a testing network. The work is literally formulaic, as observers reduce their readings according to standardized formulae, and then record their observations on pre-printed forms transmitted up the organization hierarchy for analysis and distribution to users. As individuals, these technicians rarely measure anything particularly notable. As components of an extensive, centrally controlled network, they can create vast data sets to support authoritative statements of average conditions and records of anomalies.

Depending on what is being monitored, routine surveillance work can take many forms. In sciences like meteorology, oceanography, seismology and hydrology, technicians generally report instrument readings. While these instruments sometimes are extremely sophisticated, the most enduring observation networks tend to use relatively inexpensive instruments. Because the value in these observations lies in their comparability, continuity and geographical distribution, these instruments often are well-established and relatively inexpensive. For instance, thermometers and barometers were invented in the 17th century, and while they have undergone substantial changes in form, they remain among the standard instruments used in weather observation. In sciences like microbiology and epidemiology, surveillance begins with standardized laboratory tests. Drinking water quality and food safety, for instance, rely on routine sample testing to ensure that established operational procedures are being followed. Epidemiology also

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uses a third surveillance tool, surveys, which are used by sciences like macroeconomics, market research, and economic entomology as well. Survey work depends upon the cooperation of a network of observers and reporters to submit data. Maintaining a network of appropriate people willing to complete surveys is a considerable challenge, undertaken by organizations as diverse as the Centers for Disease Control, the National Bureau of Economic Research, the Nielsen TV ratings company, and Billboard Magazine, which maintains the Soundscan system for tracking music popularity.\textsuperscript{21}

The creation of surveillance systems generally requires a staff of inexpensive, and thus low status, observers and technicians to take observations or test samples. This leads to hierarchical personnel arrangements ostensibly organized by educational attainment, though more deeply structured by class and gender. For example, the success of the Pap Smear as a cancer surveillance tool depended on the invention of a class of low paid, largely female cytotechnicians to sort through thousands of non-pathological slides and flag the few abnormal results for further examination by largely male pathologists.\textsuperscript{22}

\textsuperscript{21} Soundscan tracks music consumption at the point of sale; it superceded surveys of radio broadcasts, effectively making paying consumers, rather than DJs and station managers the arbiters of popularity. Introduced in the early 1990s, Soundscan uncovered the enormous appeal of Garth Brooks, whose songs previously received little air time. Because it cannot track file sharing, Soundscan makes Bob Dylan and Barbara Streisand appear to be far more relatively popular than they actually are, given that their listeners are among the few who still buy CDs. “The Future of the Music Industry,” \textit{On the Media} (WNYC Radio, October 23rd, 2009).

Observation Networks

The spatial arrangement of the infrastructural sciences is usually a network of observation stations connected to what Bruno Latour has called “centers of calculation.”\(^2\)

In the case of meteorology, by the middle of the 18\(^{th}\) century various natural philosophers had come to believe that coordinated, geographically distributed observation was crucial to understanding the weather.\(^2\)\(^4\) Some natural philosophers participated in these observing projects with considerable devotion; Thomas Jefferson famously kept a detailed weather diary every day for decades (his observations on the weather for the morning of July 4\(^{th}\), 1776 are often quoted). Correspondence networks became the model for the Smithsonian’s research into American weather in the decades before the civil war, first using the mails, then telegraphy.\(^2\)\(^5\) As a model for organizing and coordinating scientific observation, the correspondence network has thus depended upon the development of reliable communications systems, from state postal systems in the 18\(^{th}\) century through telegraphy in 19\(^{th}\) century to cyberinfrastructure today.\(^2\)\(^6\) Meteorological services thus exemplify how modern technocratic societies have managed the tightly coupled infrastructure necessary for industrial life on an increasingly crowded planet.

The contemporary world is layered with environmental surveillance systems like flood gauges, seismographs, bacteriological tests of drinking water supplies, and satellites that warn telecommunications system operators of changes in “space weather.” Tsunami

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\(^6\) On the history of the mails, a sadly neglected topic, see Laurin Zilliacus, *Mail for the world: from the courier to the Universal Postal Union* (New York: J. Day Co., 1953). Perhaps the most fascinating study on the meanings and importance of postal systems is Richard R. John, *Spreading the news: the American postal system from Franklin to Morse* (Cambridge: Harvard University Press, 1995).
warning networks offer a particularly clear example of the strengths and weaknesses of surveillance in protecting populations. Developed as a result of advances in oceanographic knowledge, and the disastrous tsunamis that hit Alaska and Hawaii in 1964, these networks use a combination of seismographs, water pressure sensors, and radio equipment on oceanic buoys to report the passage of massive waves through the ocean. Combined with numerical modeling based on theoretical and empirical studies of wave dynamics and the ocean floor, substantial systems have been developed to monitor the progress of tsunamis and warn areas likely to be endangered. These systems are expensive, however, and only rich countries, particularly vulnerable Pacific nations like the United States and Japan, had built them during the second half of the 20th century. While these systems had only limited coverage of the Indian Ocean, they were able to detect and predict the massive tsunami that affected coastlines along the Indian Ocean on December 26, 2004. But the effectiveness of centralized detection and warning systems depends upon delivering credible warnings to affected areas in advance of the hazard. US and Japanese monitoring could not effectively contact the areas in Indonesia, Myanmar, India and Sri Lanka most at risk. More than 220,000 people died. In response, new surveillance of the Indian and Southern Oceans has been established through the Joint Australian Tsunami Warning Center and the German-Indonesian Tsunami Early Warning System, funded by the German government. This system will use satellite

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communications to connect seabed and surface to shore sensors with a warning center, aiming to provide warnings within five minutes of an undersea earthquake.28

Environmental surveillance systems can also be used to watch human activities. As James Fleming has memorably shown, the Army Signal Corps meteorology program also became a domestic intelligence system, monitoring Native Americans, infiltrating labor rallies and reporting on major strikes.29 Kai-Henrik Barth has described the transformation of Cold War seismology when the US government agreed that seismographs could be useful for detecting nuclear weapons tests. A global seismographic network, combined with “sniffer” aircraft sampling the stratospheric winds, became central to enforcing nuclear testing treaties.30

Scientific planners have repeatedly discovered that operating environmental surveillance networks present unexpected challenges. The environment they seek to monitor has many uses, which often conflict with scientific plans. In his history of the ocean buoy networks that became central to understanding El Niño, for example, Greg Cushman notes: “Buoy tests near Midway Island in 1966 encountered unforeseen difficulties, most related to human use of the sea: fish bite damage, ship collisions, entanglement with long-line fishing gear—perhaps even vandalism by other ocean scientists.” The revised budget had to allocate “the same amount to mooring tests, service, and buoy replacement as to basic construction, installation, and data analysis.” The increased logistical requirements required the network to be scaled down to just a

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fifth of the original size. Meteorologists during the 1920s and 1930s encountered rats that chewed holes in weather balloons, insects that damaged radiosonde batteries, and Gooney birds on Midway Island that disrupted radio communications by perching on the antennae. The environment of infrastructural science can be crowded in a way unimaginable in the lab.

*Engaged in “Future work”*

The infrastructural sciences share a temporal orientation towards the future, what Gary Alan Fine calls an emphasis on “future work.” Their most influential products tend to be predictions, forecasts, and prognoses. These texts, things like weather forecasts, flu season outlooks, and predictions of market demand, allow decision makers to take future conditions into account while making choices about present actions. Models are a particularly influential tool for producing predictions, often allowing decision makers and infrastructural scientists to explore their assumptions and the potential results of decisions by simulating futures using different parameters. While many of these models are numerical and run on computers (like fishery ecology models, and global circulation models used for weather or climate prediction) there are spectacular exceptions. The US Army Corps of Engineers, for instance, has constructed

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32 Fine, *Authors of the Storm*.
a massive physical analog of the Mississippi river basin, allowing it to test the effects of hydrological management choices.\textsuperscript{34}

In an essay on the historical development of prediction in the earth sciences, Naomi Oreskes distinguishes between two kinds of prediction in the sciences: logical prediction and temporal prediction. Logical prediction, like Einstein’s prediction that light would bend in the presence of gravity, is used to test theories by comparing their predictions to observations. Temporal prediction, such as forecasting the path of a hurricane or the timing of an earthquake, is a relatively recent development in the history of the earth sciences (although it was common in physical astronomy, for example). “For the better part of at least two centuries,” she writes, “most earth scientists eschewed temporal prediction, viewing it as beyond the scope of their science. Times have changed, and now earth scientists routinely attempt to predict the future.” Part of this change is attributable to changes in the philosophy of science in the 20\textsuperscript{th} century, particularly the development of the hypothetico-deductive method as a model for science beyond empiricism. Scientists should use hypotheses to guide their observational programs, some scientists and philosophers argued; making temporal predictions and seeing if they came to pass could guide scientists in refining their theories and deciding what should be observed to produce new discoveries. However, a more powerful force elevating the status of temporal prediction are the needs of public policy in the anthropocene age: “As more and more people live along America’s coastlines, as the population of Southern California grows, as humans increasingly become agents affecting the composition of the

\textsuperscript{34} John McPhee, \textit{The Control of Nature} (New York: Farrar, Straus & Giroux, 1989).
earth’s oceans and atmosphere, earth scientists are increasingly being asked to predict hurricanes, earthquakes, and the impact of human activities,” Oreskes writes.35

Aids to Governance and Management

The infrastructural sciences function as tools for managers.36 As a result, the infrastructural sciences are conducted in a wide variety of institutions, including some often overlooked in the history of science. In addition to universities and government research centers, corporations and private organizations often carry out infrastructural science work. For businesses like electrical utilities or airlines, this means assisting managers in running large technical systems efficiently, reliably and safely. For governments, infrastructural science enables state bureaucracies to manage the people, resources, and physical geography of polities. Looking for these sites can help us better map science’s concrete influences on the modern world.

That infrastructural science should be supported largely by governments is no surprise; outside of the Anglo-American tradition, nearly all science and natural philosophy has been state supported and managed, with scientists very often employees of state institutions directly controlled by governments. Infrastructural sciences, however, are also tools of governance, the daily activities of managing a polity. They tend not to produce ornamental knowledge to buttress a regime’s claims to legitimacy and wisdom, in the way that courtly philosophers and artists did in the absolutist courts of the

36 Oreskes, “Why Predict?”
Renaissance or human spacecraft did in the space race. Rather, they produce knowledge useful for the daily and long-term management of the state. They contribute to governance, affecting how a polity is managed, rather than politics, deciding who is in charge. (While the disastrous response to hurricane Katrina offers a very recent example of how competent governance affects political legitimacy, as the history of 19th-century France shows, politically turbulent states can experience surprisingly stable governance.) Because the infrastructural sciences are continual government expenditures for maintaining a functional state, rather than ostentatious cultural displays, cost is much more of a concern than for particle physics or manned space exploration. Infrastructural science contributes to daily governance by creating the knowledge necessary to manage a polity’s resources, tracking changing situations and suggesting appropriate responses, and crafting predictions about the future that leaders can use to guide (and legitimate) their decisions.

**Produce Public Goods**

The key products of the infrastructural sciences tend to be public or quasi-public goods, that is, economically beneficial services that are difficult to produce efficiently for profit because they are hard to sell or it is difficult to exclude non-payers from using them. These goods are generally distributed in the form of texts. Weather forecasts are an obvious example of this sort of public good. Economic historian Erik Craft has examined the effects of weather forecasts on Great Lakes shipping in the 1870s and 1880s, tracking the costs of ship insurance. Using a natural experiment where storm warnings were

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abruptly stopped after Congress discovered major embezzlement within the Army Signal Corps meteorology program, Craft calculates that the national weather service provided a greater than 60% social return on investment just from reduced insurance rates for the Great Lakes, to say nothing of the lives saved or benefits to agriculture.\(^{38}\)

Standards are a second type of public good produced and maintained by various infrastructural sciences. From the certification of scales at the grocery store to the standardization of time, government led metrology has played a crucial role in coordinating economic production and engendering public trust. As Simon Schaffer has argued, metrology was crucial to Britain’s ability to tax, thus enabling the state to support tremendous military operations from the 18th century forward.\(^{39}\) Standards produced through cooperation between government, academia and industry have likewise been crucial, as historians have best documented in the development of electrical systems and telecommunications systems.\(^{40}\)

**Connections to Theoretical Science**

While infrastructural science is primarily utilitarian, applied, and conducted in industrial and government settings, it does have important interactions with theoretical and academic science. First, academic scientists may develop the tests and methods later scaled up for use in full observation networks. As a result, existing theory powerfully


shapes the interpretation of data generated by environmental surveillance. Satellite
observations of extremely low ozone levels over the Antarctic, for instance, were initially
dismissed as instrument error, given that then accepted theory gave no reason to expect
such low levels.\textsuperscript{41} Second, infrastructural science is not intended to produce discovery.
Sometimes, as in the case of George Biddell Airy and Neptune, it actively eschews
discovery.\textsuperscript{42} Nonetheless, academic researchers often make theoretical claims using data
repurposed from industrial use. Third, theoretical research can be inspired by
infrastructural problems, as Peter Galison shows for the work of Henri Poincaré and
Albert Einstein.\textsuperscript{43} Finally, as Sharon Traweek has pointed out, modern scientific
communities are replenished through education.\textsuperscript{44} Industry and governments’ steady need
for qualified technicians has been essential to the emergence of science as a career,
justifying academic research and teaching programs.\textsuperscript{45}

A clear example of the interplay between practical and theoretical science can be
found in the development of knowledge about ocean tides. Michael Reidy has described
the central role played by William Whewell, the man who coined the term “scientist,” in
developing a systematic theory of the tides used by the British navy and merchant marine
to rule the world’s littoral regions during the 19th century. As industrialization enabled the

\textsuperscript{41} Erik Conway, \textit{Atmospheric Science at NASA: A History} (Johns Hopkins, 2008).
\textsuperscript{42} Airy, as head of the Royal Observatory, led the British government’s effort to produce extremely
accurate astronomical observations used to produce the tables of ephemerides crucial to navigation and
time signals. He had the chance and resources to pursue a very promising lead on looking for an
undiscovered planet. He declined, arguing that institutions like his were engaged in “permanent science,”
and that moving into the realms of “progressive science,” the work of discovery, would harm the efficiency
of the essential work being done in government observatories. When French astronomers discovered
Neptune instead, Airy was exposed to considerable public controversy. Iwan Rhys Morus, \textit{When Physics
Became King} (University of Chicago Press, 2005): 197-201 provides a useful description of Airy’s work in
“industrial astronomy.”
\textsuperscript{44} Sharon Traweek, \textit{Beamtimes and Lifetimes: The World of High Energy Physicists} (Cambridge, MA:
Harvard University Press, 1988): Ch. 3.
production of iron ships with deeper drafts, every port on the East coast of Britain was rendered inaccessible except at high tide. Without more precise knowledge of the environment, Britain’s essential sea-borne trade would run aground. Whewell carefully coordinated mass observations, a “tidal crusade,” and combined these observations with mathematically and astronomically rigorous theory to produce tide charts that could be printed cheaply for distribution to ship captains. This work required producing novel self-registering tide gauges and other kinds of scientific instruments, as well as recruiting and maintaining a network of observers to ensure the instruments were functioning properly and to report the measurements. Government funding was crucial to the establishment of these expensive and expansive networks, while military discipline was essential to their continued operation. These were activities that required an aspect of completeness and continuity that could not regularly be produced by amateur science, by the voluntary networks of gentlemen characteristic of enlightenment natural philosophy. As Reidy shows, it is no accident that professional modern science emerged from this increasingly organized and formalized milieu.  

*Culturally Modest*

The infrastructural sciences tend to have modest cultural ambitions. They are quietly pervasive, functional rather than spectacular. They rarely make metaphysical or cosmological claims; they do not speak to what it is to be human or make explicit normative assertions about how we should live in the world. To use the categories of Renaissance knowledge, most infrastructural sciences have contentedly remained forms

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of “mixed mathematics,” avoiding the bold venture from utility to philosophy that made Galileo notorious and got him arrested.\footnote{Biagioli, \textit{Galileo, Courtier}.} They function in the background, rarely becoming subjects of major cultural controversy. As a result, while hydrologists never become as famous as Darwin or even Richard Dawkins, they rarely have to contend with intransigent fundamentalists seeking to teach creationist theories of flood management.\footnote{Creationist meteorology textbooks feature much the same physical theory and formulae as more standard science textbooks, though adding a theological gloss about finding God’s design for man in the weather, and explaining how modern theory can account for biblical events like the Flood.} Because of their utilitarian aims and low public profile, the infrastructural sciences rarely are subjects in long-running controversies propagated by political leaders.

One consequence of this cultural modesty is historians of science and STS scholars have paid them relatively little attention. The history of science has focused on sciences that have cultural prestige, rather than material impacts. Historians of science produce Darwin studies on an industrial scale, but far fewer works on economic entomology, for instance.\footnote{Paolo Palladino, \textit{Entomology, ecology and agriculture: the making of scientific careers in North America, 1885-1985} (Amsterdam: Harwood Academic Publishers, 1996).} Reviewing a rare history of economic entomology in 1998, Nicolas Rasmussen argued that historians of science too often act as if they find only the “great men” of currently ascendant fields of intellectual high culture worthy of their attention. Thus we find much research on the founders of molecular genetics, particle physics, and of course cosmology, and substantially less on economic botany, materials science and chemical engineering. In the life sciences, scholars of science studies mirror this overarching bias with great enthusiasm for studies on nobly theoretical, ’basic’ fields of knowledge … while they show strikingly less favour—given the economic and cultural importance of the products of these sciences—for the fields related to agriculture.\footnote{Nicolas Rasmussen, “Down-to-Earth Science,” \textit{Social Studies of Science}, Vol. 28, No. 1 (Feb., 1998): 183-186.}
In designing courses or giving lectures, few scholars pick studies of fertilizer, grain, breeding, land use or pest management as iconic representations of the role of biology in modern society. Similarly, science studies evolved as a field that sought to challenge claims that science produced disinterested, timeless truths about the world. Scholars sought to demonstrate that that science was a social activity, and the knowledge that it produced was full of contestation, politics, and parochial interests. If politics and social values could be found at the base of those sciences with the strongest claims to objectivity and disinterestedness, the hardest cases, then scholars could reasonably claim that their findings applied to all sciences. As such, science studies often focused on the most culturally prestigious disciplines. These studies emphasized what we might call the “cultural consequences” of these sciences, rather than their material consequences. They explored how claims about nature were made and defended, for instance. But even as science studies scholars scientific knowledge as a cultural construct, their studies helped propagate the hierarchies that privileged these sciences in the second half of the twentieth century. Despite their cultural prominence, particle physics, molecular genetics and cosmology reveal only a small slice of the pervasive presence of science in modern life. While the pronouncements of Stephen Hawking or newspaper stories about fleeting hadrons or magazine articles about “the gay gene” attract commentary, it is the quotidian presence of the TV weatherman, the unseen microbiological assays of the water quality tester, and the tiny certifications attached to grocery scales by a state metrological inspector that define the scientific and technological world in which we live.
Structure of the Dissertation

I describe aeronautical meteorology’s development into an infrastructural science in five episodes, beginning with the polar exploration in the wake of World War I and ending with aeronautical meteorology’s role in the invention of the television weather report in the decade after World War II.

After the end of the Great War, the Arctic was an important place. Geopolitical thinkers saw the possibility of flying across the Arctic as important to future military and economic power. The first chapter documents how efforts to make the Arctic flyable fostered the international spread of the Bergen School. As British, American, Norwegian, Italian, German and Soviet teams launched pioneering polar flights in the 1920s and 1930s they were assisted by Bergen school meteorologists who could manage the Arctic atmosphere. Avid skiers from neutral countries who had long lived in the Arctic, these meteorologists drew on both their experience working in harsh conditions, and theories of the polar front and air mass analysis to provide meteorological advice crucial to polar flights. This work brought them international attention, leading to influential careers in American academic institutions. While Arctic flyways did not become part of the world’s main transportation routes as quickly as boosters expected in the 1920s, by World War II they were essential paths for delivering warplanes from American factories to European battlefields. The Arctic remained a privileged place in meteorological theory, leading the Allies to attack German meteorological missions to Greenland.

As the emigration of Bergen School acolytes reveal, the United States offered perhaps the richest place for developing aeronautical meteorology from the mid 1920s
forward. The later chapters therefore move away from a global focus to explore the development of aeronautical meteorology in the United States.

Underlying the institutional expansion of meteorology was the development of the American airline industry. Chapter two describes the central challenge of commercial flight: keeping to a reliable schedule while flying safely through changing weather conditions. Aviation historians have described many innovations that contributed to the solution of this problem, including: instruments that enabled pilots to fly “blind” inside clouds and fog; radio navigational beacons; lighted airways; and stronger, more powerful airplanes that could fly around storms or divert to clear airports. I show the important role played by meteorological experts. Airline meteorologists helped transform aviation form entertainment into infrastructure; in turn, airline needs shaped the development of academic meteorology, as illustrated by Horace Byers’s *Synoptic and Aeronautical Meteorology*, one of the most important meteorological textbooks of the century.

Within infrastructural science, the interplay between theory and practice often plays out in the operational patterns of institutions. Chapter Three uses institutional history to examine the tensions between meteorological theory and weather forecasting practice. Airline meteorology gave the Bergen School an institutional toehold in the United States in 1928, when Carl-Gustaf Rossby was appointed professor of meteorology at MIT. He developed a remarkable research program, but struggled to get air-mass analysis adopted by the US Weather Bureau, the dominant arbiter in American meteorology through the 1930s. Bureau observations of the upper air provided material for Rossby’s theorizing, while theory influenced when and how the air might be observed. However, practical constraints limited this interplay, as access to an
environment as distant as the upper air was in the 1930s remained expensive and circumscribed. While monitoring the upper air was both dangerous and expensive, it led to Rossby’s discovery of hemispheric waves that could be mathematically calculated to improve forecasts for upper air conditions.

The coming of World War II brought a tremendous expansion of military aviation. As officers realized the constraints weather imposed on force projection, they turned to academic meteorologists. Chapter four focuses on mass meteorological training for the military. I track the development of two training programs, one for pilots and one for meteorologists. Where pilots learned their meteorology from manuals that employed the military’s “thought-picture” method, a style that used comic art, to make technical information engaging and memorable, military meteorologists went through an intensive nine-month academic training program equivalent to a master’s degree in meteorology. This program taught a generation of meteorologists to imagine the atmosphere as a global entity, best understood in the universal language of physics. By retaining their best graduates to work as teachers and researchers, organizers of the program helped create a social hierarchy that privileged theory over operations.

The different training systems experienced by pilots and by meteorologists created a tension manifested at the most important moment of interface between them, the pre-flight briefing, when meteorologists would explain to pilots the conditions they would face in flight. Military fliers complained that academically-trained meteorologists had trouble communicating with pilots, failing to clearly and efficiently convey the essential information pilots needed. Meteorologists responded to these concerns by developing visual aids and a formulaic narrative that more clearly highlighted crucial
information. Some even adopted the visual style that had underlain pilots’ meteorological education, drawing cartoons to make their pre-flight briefings more memorable and engaging.

The final chapter explores the invention of the TV weather report in the decades after World War II, showing how aeronautical meteorology transformed public images of weather expertise and then was concealed by those public images. Ex-military meteorologists were among the first to present the weather report on television; they invented a deeply formulaic genre that combined simplified, hand drawn weather maps with a narrative largely derived from pre-flight briefings they had developed to communicate with cartoon educated pilots. This genre became wildly popular, with unexpected consequences. While meteorologists hoped TV would promote meteorological education and a better understanding of the challenges of weather forecasting, they did not anticipate that weathercasters would become celebrities or primarily entertainers. Although the vast majority of meteorologists do largely invisible work in support of industrial and military operations, the TV weathercaster has become the public face of meteorology today. The trivialization of weather forecasting by television has obscured meteorology’s importance as a support system for industrial life.

The dissertation concludes by reflecting on how infrastructural science can help historians of science become culturally relevant again. Contemporary industrialized lifestyles depend upon massive flows of material around the globe. These flows have released carbon dioxide, methane and other greenhouse gases that are transforming the atmosphere with potentially devastating effects. The discovery of global warming has revealed that human lifestyle choices can have planet-wide consequences. Perhaps
because industrialization has so comprehensively transformed daily life, history offers
one of the few perspectives from which to apprehend our utter dependence on the
infrastructure that supports these material movements, and the energy consumption that
makes them possible. While the infrastructural sciences are not currently prestigious in
the way of, say, evolutionary theory, they have an enormous influence on the ways
billions of people in the industrialized world live their daily lives. By drawing our
attention to the interconnections between knowledge, technological systems and the
environment, infrastructural science offers historians of science a perspective from which
to contribute to contemporary discussions of energy and environmental policy.
Aeronautical meteorology’s emergence as an infrastructural science began about as far from established infrastructure as anyone could get in 1926: high above the North Pole. It began with a machine that now seems slow, awkward and vulnerable, but then appeared fast, graceful and well-suited for long-range flight. Captaining the dirigible *Norge* were Roald Amundsen and Umberto Nobile, seeking to prove the Arctic could be flown safely. Standing behind those celebrated explorers in the control car was a vital expedition member, meteorologist Finn Malmgren. At his fingertips was a radio that connected him to additional Arctic weather experts at Tromsø, Oslo and Bergen, a communications machine that could also receive weather observations from the handful of stations scattered across the Arctic. In his head were physical theories that could organize those isolated observations into useful descriptions of the present and future state of the sky. Malmgren had learned to read the polar atmosphere first as a scientific assistant to Harald Sverdrup on a three year cruise across the Arctic Ocean, and then in an intensive tutorial at the Geophysical Institute at Bergen, Norway. Upon his trained judgment (and luck) depended the fate of the first flight across the top of the world.

The development of aviation gave the Arctic a new geopolitical importance in the 1920s and early 1930s. Boosters of Arctic economic development hoped aviation would make it affordable to extract the rich oil and mineral deposits discovered in Alaska and
Canada’s far north. Aviation was expected to make distant places close, and open inaccessible regions to economic and social development. Explorations that once took months would now take hours, while difficult journeys over rugged terrain would become common aerial jaunts. Geographers and navigators argued that great circle routes between Europe, Asia and North America would be safer and faster than established routes across the Atlantic and Pacific. Explorer Vilhjalmur Stefansson envisioned the Arctic as a “northern Mediterranean,” a place where the transports of all nations might harmoniously share routes and ports as they carried on the world’s commerce. Less idealistically, military strategists like U.S. General William “Billy” Mitchell argued that control over the Arctic air would hold the key to future wars fought between the industrialized powers of the northern hemisphere.

Building infrastructure always requires geographical knowledge. Expanding transportation infrastructure into the far north required answering questions about the Arctic environment, and especially about its atmosphere. Was the Arctic a place where aircraft could fly? What kinds of aircraft were best suited to flying there? When and where did hazards like fog, clouds, or strong winds prevail? Where could bases be constructed? To answer these questions, governments and private organizations in many nations supported Arctic expeditions. To understand if the Arctic was suited for flight, these expeditions flew planes, dirigibles, kites, and balloons. They trekked through the Arctic on surface ships, submarines, Icelandic ponies, skis, and propeller-driven motor

sleds. Wealthy private adventurers like Lincoln Ellsworth supported expeditions, like Nobile’s, sometimes in concert with geographic societies. The Norwegian Geographical Society helped fund Amundsen and Nobile’s dirigible flight in 1926, while Mussolini’s fascist government funded Nobile’s follow-up 1928 expedition in the dirigible Italia. Plans for intercontinental commercial service led the British air ministry to fund a survey of Arctic air routes in 1931, while Pan American Airlines retained Stefansson as a consultant and hired Charles and Anne Morrow Lindbergh to explore similar possibilities.

Public interest in polar flight also generated funds. Newspapers like the Detroit Free Press first sold papers by reporting the drama emerging from the Arctic, and then attempted to drive circulation by sponsoring flights in exchange for exclusive coverage. The largely German Aeroarctic expedition, for which Vilhelm Bjerknes was a scientific advisor, funded their Zeppelin flight by selling stamps, and they were not the only polar expedition to find a lucrative philatelic market for high latitude cancellations. Charitable foundations and government weather bureaus chipped in to support the International Meteorological Organization’s Second International Polar Year.⁵ All these expeditions sought to gather meteorological information. They carried weather instruments and meteorological charts, discussed studies of polar weather, and argued about the influence of the Arctic on weather around the world. Polar aviation depended on knowing the weather.

It was in this context that the Bergen School, a circle of Scandinavian physical scientists, centered on Vilhelm Bjerknes and his son Jacob, emerged as a leading force in meteorology worldwide, for the Bergen School was uniquely placed in the new geopolitical situation that followed the Great War. Where other meteorologists developed empirical rules of thumb for forecasting, the Bergen School sought to model the ocean and atmosphere in thermo- and hydro-dynamic terms. Ideally, they argued, meteorologists should predict the weather exactly and objectively, by solving a set of equations that describe real physical relationships in the atmosphere and oceans. This distant goal would establish meteorology among the physical sciences, “appropriating the weather” for physics in Robert Marc Friedman’s phrase.6

The Bergen School was essential to polar aviation for several reasons. First, these scientists had been closely allied with aviation since Vilhelm Bjerknes turned towards aerology, the study of the upper air, at the start of the 20th century. They studied atmospheric conditions at heights of interest to fliers. Working from a three-dimensional model of the atmosphere, they saw aviation as both an ally and a tool—a source of political and financial support, and a way to get data about the free atmosphere, which they believed was the driving force and basic cause of surface weather. Second, both the theories and the lives of the Bergen School were oriented around the Arctic. At the center of their theory of atmospheric dynamics was the border between polar and mid-latitude air. This “polar front,” the location of the conflict that drove weather, became a signature theoretical construct, simultaneously dramatic and easily explained. They theorized the polar front while forecasting the weather from government institutes covering Norway’s

1,600-mile coastline into the far north. Third, many Bergen scientists grew up under and continued to live with Arctic weather. They combined theoretical knowledge and practical experience of the Arctic. They were athletic, rugged men who could survive and work in frigid conditions, often reveling in the struggles of Arctic life. They loved to ski. Finally, the scientists trained at Bergen offered a unique connection between the scientific communities of the victorious allies and the defeated Germans and Austrians. As citizens of countries that had been neutral during the war, they had maintained ties with both sides, and these connections proved important during the difficult postwar years when the defeated nations were excluded from international scientific and cultural groups.

This chapter analyzes connections between polar aviation and the Bergen School, first placing them in a broader geopolitical and technical context, and then following them more concretely by examining the careers of four Bergen school scientists: Finn Malmgren, Harald Sverdrup, Jørgen Holmboe, and Sverre Petterssen. These men built international scientific reputations through their contributions to polar exploration, helping to bring international attention to the “new Norwegian methods” of meteorology. The three who survived their polar fieldwork [Malmgren died young] parlayed this reputation into influential jobs at American research institutions during the mid 1930s. The early career of another Bergen disciple, Carl-Gustaf Rossby, illuminates the value of Arctic field experience in establishing international credibility. Though Rossby’s time in the Arctic amounted to just a brief cruise off the coast of Greenland, he presented footage of the cruise’s most dramatic events when he first arrived in the United States. To understand why polar exploration could launch distinguished careers in aeronautical
meteorology, we need first to examine Arctic geopolitics and the meanings of polar aviation in the wake of the Great War.

**Geopolitics After the Great War**

The Great War and the Russian Revolution shattered the balance of powers that had defined 19th-century geopolitics, leaving an uncertain situation pulled between fear and hope. Difficult as it is to imagine in the light of World War II, military planners during the early 1920s envisioned a future war between Great Britain and the United States. One trigger, they argued, might be Pacific expansion. Britain and Japan had a long-standing military and economic alliance, which had served each during the War. The Imperial Japanese Navy, trained by British officers and sailing British-built warships, had protected the Canadian Pacific coast from German commerce raiders, thus freeing the Royal Navy to focus on defending the Atlantic. America’s emergence as a first-rate world power, though built upon its enormous internal market and domestic resources, challenged the pre-eminence of the British Empire, especially as the leading arbiter of global trade. Leadership in global trade had long meant naval power, a point emphasized by German U-boat operations during the war. The US had already reached naval parity with Great Britain, a fact ratified by the 1922 Washington Naval Treaty. But wartime advances in aviation suggested that flight might become an equally important factor.

Countries that first mastered potentially valuable air routes could use that mastery to conquer markets and exercise control. To prevent the US from developing a powerful

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8 Perras, “Covert Canucks.”
lead in air transport during the 1930s, the British government sought to stall the
development of transatlantic flight. It forbade the use of Canadian and English landing
fields for regular commercial flights between the US and Great Britain until both nations
had airplanes and airlines equally capable of flying the routes. Efforts to fly the Arctic
thus reflected the powerful influences of nationalism and beliefs in a sequential hierarchy
of nations.

If the suspicious minds of conservative military planners saw the threat of war
looming everywhere, optimistic progressives dreamed of a demilitarized and open future
emerging from the terrible ashes of the Great War. The Washington Treaty struck a
hopeful note for multilateral disarmament, as powerful nations voluntarily agreed to scrap
dozens of warships on the slips while limiting the destructive power of future fleets. The
Washington Treaty also replaced the Anglo-Japanese alliance with a multilateral
agreement not to fortify Pacific islands west of Hawaii, potentially easing tensions
between Japan and the United States. As elaborated in President Woodrow Wilson’s
Fourteen Points, progressives hoped that open agreements openly arrived at, informed by
objective scientific advice, might resolve international disputes without war. In this
view, scientific internationalism offered a model for organizing global affairs, where the
cooperation amongst unprejudiced scientists of all nations represented the noblest pattern
of human organization. A hierarchy of merit and accomplishment, guided by objective

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9 The US airplane manufacturing industry had made such significant strides in reducing the structural
weight of planes that the US was far in advance of the British in being ready to introduce such flights on a
commercial basis. Richard K. Smith, “The Intercontinental Airliner and the Essence of Airplane
10 A key example of this view was Isaiah Bowman, President Wilson geographical advisor at the Versailles
negotiations. A leading proponent of polar exploration after the war, he served as president of the American
Geographical Society and Johns Hopkins University, as well as a member of Franklin Roosevelt’s Science
Advisory Board. Neil Smith, *American Empire: Roosevelt’s geographer and the prelude to globalization*
facts discovered through natural and social science, could guide sound negotiations free from the hysterical nationalisms created by propaganda and the mass press.

Meteorology both displayed and fed on these contradictory tendencies. The International Meteorological Organization (IMO) reconvened in Paris in 1919, five years after its last meeting, and set to work re-establishing the international data sharing that had become crucial to weather forecasting across Europe.\(^1\) It excluded representatives of the Central Powers, however, cutting off many of the best-educated and most accomplished meteorologists in the world. As in other branches of science, German and Austrian researchers were shunned for having supported their governments in the run up to War.\(^2\)

Like meteorology, polar exploration too was buffeted by the contradictory impulses shaping interwar geopolitics. While explorers from many nations cooperated in a wide range of bilateral and international expeditions, support for their expeditions came from backers on both sides of the geopolitical fence. Progressive internationalists presented polar exploration as a display of international cooperation, establishing the Arctic as a crossroads of mankind. But exploring also legitimated national claims to administer Arctic spaces under international law. As ongoing discoveries revealed the mineral wealth of the Arctic, discovering (and controlling) new lands could provide access to crucial resources. The potential economic importance of the Arctic played a key role in the activities of Canada, the United States, Great Britain, Denmark, and Norway. To the defeated populations of Germany and Austria, the Arctic offered a space for


national redemption, a place to prove to themselves and to the world their enduring cultural power. For governments of dubious international standing, such as fascist Italy, polar achievements became a means of asserting ideological legitimacy.

Conquering the Arctic through flight offered a particularly powerful symbol of modern accomplishment. Flying great circle routes would offer the fastest and most efficient way to move between Europe, North America, and Japan. The geographical advantages of great circle routes had long been obvious to anyone with a globe and a piece of string. Taking advantage of these shorter routes, however, was harder than stretching string. Travelers first had to control their own locomotion; sailing ships made faster passages by following routes that conformed to seasonal patterns of reliable winds. Northerly great circle routes also required new kinds of environmental surveillance. Steamships encountered icebergs, incurring losses that culminated in the sinking of the Titanic in 1912, which led to the creation of the international ice patrol, an endeavor that depended on radio.\textsuperscript{13} Arctic great circle routes presented problems with persistent fog, strong winds, ice, and severe cold. With the expectation, voiced loudly by aviators and commentators, that aviation would transform power-relations and the fighting of wars, knowing how to fly and live in the Arctic seemed quite important in the wake of the Great War. Yet meteorologists agreed that navigating the Arctic atmosphere required coordinated observations across the top of the world. The Arctic atmosphere was thus alluring to nationalists and internationalists alike.

Interwar Meteorology and Polar Exploration

Polar exploration was a very different activity after the Great War than before it. Coinciding with the war, the Shackleton Expedition’s disastrous fate had marked the end of the “Heroic Age” of exploration. The 1920s would see the emergence of new patterns for organizing polar expeditions, especially their scientific work. The postwar also saw the emergence of a more practical and utilitarian interest in the Arctic. Expeditions more often sought to prove the viability of operations in the Arctic, rather than the harshness and challenges of its conditions. For expeditions such as the Navy’s Arctic flight, and the flight of the Norge the goal was to show the feasibility of flight, despite the harsh conditions. Expedition publications asserted that flying would transcend distance and environmental conditions. They hoped to show that Arctic flying was a reasonable, not exceptional, activity that should become commonplace.

At the heart of these utilitarian interests in the Arctic was the expectation that aviation would open the Arctic to economic exploitation. Before the Great War, interest in the Arctic was usually related to more symbolic or cultural concerns. After the war, with nearly the entirety of the world’s land now under the political and economic control of the industrialized nations, the Polar Regions offered the last chances for discovering and claiming new land. The Arctic had previously been economically exploited by sea, primarily for sealing and whaling. Sea travel prevailed, at least during the summer, and

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15 One illustration of this increasingly utilitarian focus can be found in the changes between editions of Adolphus Greely’s Handbook of Polar Discoveries. First published in 1896, the fifth edition published in 1928 had an expanded economic emphasis and was retitled The Polar Regions in the Twentieth Century: Their Discovery and Industrial Evolution.
16 Fogelson, Arctic Exploration and International Relations
maritime access organized the pattern of settlement and exploitation. The development of aviation might change these patterns, especially by opening the interior of the Canadian and Soviet Arctic. While overland travel was known to be dangerous and slow, flying offered the promise of being both safe and quick, taking hours to travel distances that took months on foot or with dog sleds. Arctic boosters hoped (a hope that was eventually borne out), that aviation could deliver the tools and personnel necessary to recover mineral deposits in Alaska, Northern Canada, and Siberia.

Meteorology had long been a central activity of polar exploration. The Humboldtian scientific expeditions of the 19th century always included meteorological instruments for recording the weather they encountered as they trudged or sledded across the Arctic. The International Meteorological Organization put together the first International Polar Year in 1882-83, just about a decade after the IMO had been established. Polar exploration also provided career credibility in meteorology: three years after being rescued from Ellesmere Island, where he was leading an ill-fated American Polar Year expedition, Adolphus Greely of the US Army Signal Corps became head of the Corps and the national weather observing network it ran. The so-called “Heroic Age” of polar exploration likewise sought to measure and record weather. In part, these records of extreme conditions served to emphasize the dangers and difficulties of polar exploring, thus strengthening the argument that such expeditions proved the masculinity of the explorers. Weather records buttressed the notion that the hardy

17 Lueddecke, “The First International Polar Year (1882-83): A Big Science Experiment with Small Science Equipment”
endurance of adventurers served as a public antidote to concerns that industrialization had emasculated and enfeebled western men.\textsuperscript{19}

Where meteorology had benefitted from polar exploration, with aviation, polar exploration became more dependent on meteorology. Successful polar exploration had long depended upon at least moderately favorable weather conditions,\textsuperscript{20} but the use of aviation greatly narrowed the range of weather conditions when successful polar exploration could occur. Meteorological observations had previously been something expeditions collected. They now became essential to daily operations as well. Meteorologists accordingly played crucial parts of the leadership and management of polar expeditions. The knowledge and advice of meteorologists determined the routes expeditions took, when they began, and where they chose to stop. Recounting the flight of the \textit{Norge} Finn Malmgren noted, “On the 10\textsuperscript{th} of May, in the evening, it was announced that the airship was now ready. We now merely waited for word from the meteorologists.”\textsuperscript{21} Mechanizing polar exploration made explorers \textit{more} dependent upon environmental conditions.

Not all explorers embraced the dependencies created by mechanizing exploration.\textsuperscript{22} British explorer George Binney bemoaned how flight made the explorer dependent upon the work of distant craftsmen: “Aeroplanes are mechanical, unreasoning, and unreasonable things… Because some craftsman at home carelessly mixes the

\textsuperscript{20} Susan Solomon, \textit{The Coldest March: Scott's Fatal Antarctic Expedition} (Yale University Press, 2002).
\textsuperscript{21} Amundsen and Ellsworth, \textit{First Crossing of the Polar Sea}.
\textsuperscript{22} Dependency on remote suppliers is a definitive aspect of industrialization, as Ruth Schwartz Cowan explains in the introduction to her book \textit{More Work for Mother}. 
components of an alloy in their wrong proportions, we all but lose our lives. … The explorer who relies on his dogs and on his own powers of traveling is not subject to the whims of inaccurate craftsmen. He has the making of his own success or failure.”

Binney preferred to trust his life to his own character and preparation, rather than the work of anonymous mechanics. He was not opposed to using aircraft entirely. The proper place for aviation lay at the expedition’s start; the explorer ought to pack a plane with sledges, dog teams and rations, rather than tanks of petrol. The expedition should fly as far as possible, then abandon the plane on the ice and sledge on from the landing site, never expecting to see the plane again. “Under these circumstances the crew can regard with equanimity the possibility of a forced landing on the pack-ice, either through mechanical defect or through blizzard, because they have the necessary food and equipment for a long polar sledge journey.” For Binney, successful explorers eliminated external dependencies. Rather than rely on flawless machines or suitable weather conditions, the explorer should be prepared to survive regardless of circumstances.

The belief that aviation would make the Arctic a place of practical utility shaped the meteorological interests of postwar expeditions. While expeditions continued to attend to surface conditions, they became increasingly interested in the conditions of the upper air. They typically included someone specifically concerned with aerology and often carried things like kites, pilot balloons, and radiosondes to observe the air well above the surface. In addition to new instruments, expeditions used new forms of transport in their exploring, such as airplanes, autogyros (a sort of airplane/helicopter hybrid) and dirigibles.

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24 Binney, *With Seaplane and Sledge* 147.
As arctic explorers focused their attention on aerology to aid practical flight, meteorologists focused on the arctic upper air for theoretical reasons. An increasing number of meteorologists were coming to believe that the general circulation of the atmosphere was central to understanding local weather prediction.

Meteorology has often been described as a science of interconnections. Rather than isolating variables or attempting to perform mimetic experiments in laboratories, meteorologists in the 1920s and 1930s typically sought to find connections, such as those between ocean and atmosphere or between ice and cyclones. The key to understanding weather lay in a rigorous knowledge of the physics of the atmosphere, a physics that aspired to use global interconnections to explain local conditions. Understanding the weather in Des Moines required observations not just of Iowa, but a global, or at least hemispheric, observing system. As more and more areas of the map were filled in working northward, and into the oceans, the far north remained a key blank region. The Arctic became central to understanding the weather of the northern hemisphere.

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25 While mimetic experiments did exist, sometimes carried out by leading meteorologists (such as Napier Shaw’s cloud chambers and Rossby’s unsuccessful efforts with rotating tanks) these were not the dominant patterns of inquiry—interwar meteorology was an observational science, not an experimental one. Peter Galison and Alexi Assmus, "Artificial Clouds, Real Particles," in The Uses of Experiment, ed. David Gooding, Trevor Pinch, and Simon Schaffer (Cambridge: Cambridge Univ. Press, 1989), 225-274. Richard Staley, “Fog, Dust and Rising Air: Understanding Cloud Formation, Cloud Chambers, and the Role of Meteorology in Cambridge Physics in the Late 19th Century,” in Intimate Universality: Local and Global Themes in the History of Weather and Climate, edited by James Rodger Fleming, Vladimir Jankovic, and Deborah R. Coen (Sagamore Beach, MA: Science History Publications, 2006): 93-113. Carl-Gustaf Rossby, “On the Solution of Problems of Atmospheric Motion by Means of Model Experiments,” Monthly Weather Review 54 (June 1926): 237-241. Rossby noted the importance of experimental methods to naval architecture and aerodynamics, mentioning wind tunnel and Gustav Eiffel’s experiments in air resistance. He sought to use rotating basins of melted paraffin as an alternative approach to understanding turbulence, given that the “classical theoretical lines of work” were rendered inaccessible by “the difficulties which arise when we try to integrate the fundamental equations of hydrodynamics.”
The Arctic was not only a meteorologically blank region, but also one that occupied a theoretically influential place. As one *Popular Science* headline put it in 1933, “Air Leaks in Polar Waste Hold Secrets of Coming Weather.” (Figure 1.2)

![Figure 1.2](image)

**Figure 1.2:** The Arctic represented an important space in meteorological theory, generating the reservoir of cold air that animated temperate weather. Note, however, that air masses form in clear, not cloudy conditions, as depicted above. (From “Air Leaks in Polar Waste Hold Secrets of Coming Weather.” *Popular Science*, 1933, p. 13.)

The region included the source region for cold air masses that affected the temperate latitudes. The new focus on the Poles continued a major development in meteorology, the construction of meteorology as a global science, one dependent upon widely dispersed,

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28 “All the well-known theories of the general circulation of the atmosphere—Maury’s or James Thomson’s or Ferrel’s and even V. Bjerknes’ and, with a dislocation of the northern pole from 90° to somewhere in Greenland, W. H. Hobbs’s also—are zonal and have a certain symmetry about the pole. The question naturally arises, ‘Is there really a meteorological pole around which weather is symmetrical?’” Sir Napier Shaw, “Arctic Weather of April 15-16, 1928: With Some Observations on Polar Weather in Relation to the General Circulation,” *Geographical Review* 18 (October 1928): 556-566.

coordinated observing stations, and thus also dependent upon international cooperation. As meteorologists developed this vision of meteorology as an international science, they emphasized working through international institutions like the IMO. But they also needed people who could bridge the chasms produced by the Great War—the bitter divides between people caused by nationalism. The Bergen School filled this niche admirably.

The Bergen School and Aviation

The Bergen School justifiably stands at the center of the historiography of 20th century meteorology. Robert Marc Friedman’s pioneering study, Appropriating the Weather, introduced historians to the circle of early 20th century Scandinavian scientists around Vilhelm Bjerknes and his son Jacob, who sought to understand the ocean and atmosphere through classical physics. Ideally, the Bergen School argued, meteorologists should predict the weather exactly and objectively, by solving a set of equations that describe real physical relationships in the atmosphere and oceans. This distant goal established meteorology among the physical sciences, providing a research direction that yielded key advances in understanding the atmosphere’s behavior, from the identification of air masses and the polar front, through numerical weather prediction, to the general circulation models central to understanding climate change today. Deborah Day has described how Jacob Bjerknes and Vilhelm’s student Harald Sverdrup moved to the United States to build research programs in meteorology and physical oceanography,

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establishing southern California as “Bergen West.”

Gregory Cushman has extended that story southward, showing how Bergen School training programs helped keep Latin America in the United States’ political and commercial orbit after Franklin Roosevelt renounced military intervention. Kristine Harper documented the crucial role played by another Bjerknes student, Carl-Gustaf Rossby, and his colleagues in developing operational numerical weather prediction in the decade after World War II. Computer historians have used Bergen School-style numerical weather prediction to show how computation and simulation became a novel path to natural knowledge in the 20th century, from Frederik Nebeker’s study of meteorological calculation technologies, to Paul Edwards’s argument that “the global atmosphere” as an object of scientific and political significance emerges from the computing and communications infrastructure that underlies a planetary network of sensors. These studies have revealed the Bergen School’s pivotal role in developing objective, reliable techniques for predicting the behavior of the atmosphere and oceans.

While scholars have emphasized the Bergen School’s contributions as theorists and modelers, they have also attended to the Bergen School’s applied work. Harper and Friedman have documented how the necessity of developing operational forecasting services crucially affected the Bergen School’s theoretical contributions. Harper argues that a “tag team” of Scandinavian meteorologists played a decisive role in making

numerical weather prediction feasible, bringing a combined experience in daily forecasting and theoretical modeling that the younger American dynamicists lacked, and making the first generation of weather simulations behave more realistically. This integrated approach developed in the Swedish and Norwegian national meteorological services, particularly the Bergen forecast office. As Friedman describes, aviation’s military uses during World War I and its expected commercial development after the war had provided key support for Vilhelm Bjerknes’s efforts to create a separate forecasting office, which was established in Bergen and led by his son Jacob. This office had considerable autonomy from the central Norwegian weather service in Christiana (Oslo), enabling it to experiment with new techniques for analyzing weather maps, as well as incorporate upper air observations into daily forecasting. The daily routines of forecasting pushed the Bergen School to simplify their efforts to calculate the weather, encouraging the development of graphical methods, rather than strictly numerical ones. These methods eventually made it easier to teach the new approaches to operational forecasters who were not as deeply trained in physics and mathematics. Most importantly, the daily routines of making and analyzing weather maps, when combined with previous training in dynamic meteorology, led to theoretical insights that produced the two of the most significant developments in synoptic meteorology: the concept of the air mass and Jacob Bjerknes’s theory of cyclogenesis. The Bergen Office became a central node in the network distributing the Bergen School approach to understanding the atmosphere, with several meteorologists working and learning there prior to serving on polar expeditions.

36 Friedman, Appropriating the Weather, 141-236.
The daily work of the forecasting office demonstrated the practical value that the Bergen School’s dynamic meteorological techniques could provide, particularly in understanding the weather at flying altitudes.

The historiography of the Bergen School, however, has paid little attention to the crucial role of fieldwork. Existing studies depict the Bergen School inside offices and classrooms, working with maps, equations and computers. Like the contemporary American weather forecasters Gary Alan Fine has studied, the Bergen School are usually presented as men who “live in a world of clean hands and indoor work.” But the Bergen School contributed more than just weather forecasts to Arctic aviation expeditions during the 1920s and 1930s. Several Bergen School scientists joined the expeditions directly, journeying across the Arctic and Antarctic alongside more famous explorers.

Beyond their theoretical and practical knowledge of the upper air, Bergen School scientists made ideal polar explorers in the post-war world because of their nationalities, Arctic experience and their physical hardiness. As Scandinavian scientists, they participated in the institutions and social networks central to polar exploration, while as citizens of neutral countries, they could negotiate between national animosities in the wake of World War I, enabling them to join the national expeditions of other countries, as well as play a leading role in organizing multinational scientific collaboration. Some grew up north of the Arctic Circle, learning to read the Arctic environment from their parents and grandparents. Life in this rugged climate developed physical strength and personal fortitude, traits reinforced in these fit and athletic young men through strenuous outdoor activities like military training, skiing and hiking. The lives of several Bergen

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School scientists reveal how these traits intertwined to produce successful Arctic expeditions that launched internationally prominent careers.

*Sverre Petterssen: Growing up in the Arctic*

The influence of living and working in the Arctic on the Bergen School is shown by the career of Sverre Petterssen (1898-1974), one of the leading weather forecasters and synoptic meteorologists of the twentieth century. Petterssen grew up in a Norwegian coastal community north of the Arctic Circle. Fishing was central to the economy of his home in the *nordland*, though it required braving the dangerous storms of the Barents Sea. At his grandfather’s knee, Petterssen learned how to read nature, being taught “a great deal about whales, porpoises, cod and herring; the seasons of the Lofoten and the Finnmarken fisheries; the calendar of the migrating birds; and the deeds of famous fishermen.”38 His memoir describes his fondness for the outdoors, recounting rowing voyages with his older brother, long ski trips, and bird watching afternoons. Summers spent in the military reserve kept his body fit while studying at gymnasium and then the University of Oslo, where he first encountered meteorology. An international seminar on meteorology in 1923 brought him into the Bjerknes orbit. After working in the Bergen forecast office and on a mountaintop weather observatory, Petterssen was posted to the Norwegian Geophysical Institute at Tromsø, Norway’s most northerly weather office.

Petterssen’s forecasting work at Tromsø would bring him international recognition, but his memoir emphasizes the opportunities the north presented for adventures. As he put it, “Tromsø was a skier’s paradise; I simply lived on skis. In my

daily work I found the rucksack more convenient than the briefcase.” He joined a skiing expedition that zigzagged through the rugged mountains between Tromsø and the Finnish border, crossed the Swedish wilderness, and ended with “nineteen hours of difficult skiing” to reach “the nearest farmhouses in Norway—at four o’clock Good Friday Morning.” He described how moving back to the Arctic deepened his appreciation, noting, “In my childhood I had taken life in Nordland for granted. … Returning to it, I tried to make a deliberate effort to observe and understand what I saw.” Opportunities for observation came on trips into Lapland and to Spitsbergen, delivering replacement instruments and maintaining the stations that radioed weather observations. After missing a coal ship that should have borne him back to the mainland, Petterssen had eighteen days to bird watch, visit the glacial tongues, and witness icebergs calving from Spitsbergen’s glaciers. Returning to Tromsø, Petterssen combined his knowledge of the Bergen School techniques with the experience of two older forecasters to ensure the fishing fleet was not caught at sea by severe storms. “Once in a while,” he remembered, decades later, “I wished my grandfather had been there to see how things had changed: better boats and a reasonably reliable storm warning service.”

Petterssen integrated this storm warning service into polar aviation in connection with the exploration flights of the late 1920s. Within Petterssen’s forecast area were the far northern islands of Svalbard, including Spitsbergen. Because Spitsbergen was inhabited by Norwegian coal miners and accessible by sea, it became a key launching point for polar flights. These flights tested the new service’s limits. In April 1926,
Petterssen forecast for the *Norge* flight, which was expected to take about 70 hours crossing from Spitsbergen to Nome, Alaska. “Until then, I had never attempted to forecast for such a long period.” Petterssen correctly predicted the fine flying conditions north of the 80th parallel, and the clouds and strong winds in the northern approaches to Alaska that eventually required the ship to land in Teller, AK, somewhat short of its destination at Nome.

In 1927 polar flights ceased for a round of fundraising and planning; they would resume around Spitsbergen in 1928. The first of these was Sir Hubert Wilkins and Carl Ben Eielson’s flight from Alaska to Spitsbergen. Petterssen and the forecasting office at Tromsø knew nothing of this flight until several days after their plane had been forced down, apparently, it was later revealed, by a storm of the “Bjerknes type.” “About twelve hours before takeoff a storm began to develop right on the east coast of Greenland, about 71° N. At the time of takeoff intensification set in.” The storm reached peak intensity near Spitsbergen just as the plane approached the islands, but good fortune and Eielson’s considerable skills enabled the plane to land in deep snow. Five days later, they hiked

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43 Petterssen, *Weathering the Storm*, 47.  
44 Petterssen, *Weathering the Storm*, 55.
into Green Harbor after being given up for lost. To raise funds for future expeditions, Wilkins needed a scientific account of the conditions he had experienced. “What he needed was dignified publicity to assist in raising funds for new enterprises.” Generating the content for this report became Petterssen’s job, but since he was just a junior forecaster in a remote Norwegian weather office, “it was understood that my [Petterssen’s] factual report would be used by Sir Napier Shaw, a prominent and exceptionally eloquent British meteorologist and physicist, to write an article of the type Wilkins had in mind.”  

This article, published in leading British journal *Geographical Review*, would help bring attention to the theories of the Bergen School.

Petterssen parlayed this publicity, and his new connections into a broader career, putting himself in a position that would allow him to influence the next generation of meteorologists. After returning to Bergen in 1928, he was recruited to teach forecasting in Canada, the U.S. Weather Bureau, and then at MIT. While teaching at MIT, Petterssen remembered, “some of my more venturesome students even joined my Sunday skiing school in the hills north of Boston.” He played a pivotal role in the forecast for D-Day, and later became the director of scientific services for the US Air Force weather service. Near the end of his life, he renounced his US citizenship in protest over the corruption of the American political system reflected by the Nixon Administration.

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45 Petterssen, *Weathering the Storm*, 55.
47 Petterssen, *Weathering the Storm*, 82.
Like Petterssen, Jørgen Holmboe (1902-1979) grew up in a small community north of the Arctic Circle, where, also like Petterssen, he developed a love of skiing, hiking and observing nature. With his training in meteorology, these traits would take Holmboe from nearly the top to nearly the bottom of the world, and around its circumference as well. He forecast weather on four continents, and taught meteorology in New Zealand and the United States, where he also instructed a group of leaders of Latin American weather services during World War II. His warm and enthusiastic personality and habit of generous hospitality made Holmboe an effective international ambassador for the Bergen School.

Holmboe’s participation in vigorous winter sports became a key part of his identity, just as they had with Petterssen. His obituary celebrated him as “an avid out-of-door person, hiking, skiing, and gardening throughout his life. (One daring ski run down the mountains outside Bergen shortly after his return from Antarctica had both disastrous results--broken bones and hospitalization--and happy consequences, since it introduced him to his nurse, Kirsten Bendixen, whom he subsequently married.) Colleagues and students well remember hiking with him in the early years [of his time in California, the 1940s] in the canyons of the Santa Monica Mountains. It was all they could do to keep up with his long rapid strides; while he eloquently propounded on his current ideas on science, politics, or the arts, they were too breathless to agree or dissent.” Outdoor sports also shaped his working life and the arc of his career, both by directing him

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49 Neiburger, Edinger, and Wurtele, “Jørgen Holmboe,”
towards the study of mountains, and by preparing his body for the rigors of polar exploration.

Born on an island near the northernmost point of Norway, Holmboe attended secondary school in Tromsø before moving south to the University of Oslo. Here, from 1925 to 1930, he served as a research assistant to Vilhelm Bjerknes who had just retired and handed over leadership of the Geophysical Institute in Bergen to Harald Sverdrup. After receiving his advanced degree in 1930, Holmboe joined the Norwegian Weather Service as a forecaster at Tromsø before being transferred to Bergen in 1932. This put him in a position to work with polar flights, and in doing so to promote the techniques of the Bergen School. From 1933 to 1935, Holmboe acted as the meteorologist for the Lincoln Ellsworth Antarctic expedition, which made pioneering flights around the South Pole. During a delay before the launch of that expedition, he demonstrated Bergen School techniques to the New Zealand Weather Service.

Like Petterssen, Holmboe turned the credibility and connections he had gained through polar exploration into an institutional home at MIT, where he taught from 1936-1940. In 1940 he joined Jacob Bjerknes in founding UCLA’s meteorology program where, during the 1950s, he headed a study of mountain meteorology that used instrument-laden gliders to skim along mountain ridges. Before his retirement from UCLA in 1970, his home was “the unofficial social center of the department,” as he and

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his wife hosted parties and dinners for the faculty, staff, students, and many scientists who visited this leading department.51

*Harald Sverdrup, International Arctic Organizer*

The “quiet mannerly” Harald Sverdrup was one of the most important institution builders of the Bergen school.52 The son of a minister and history professor, Sverdrup was not initially an athlete. But he received serious physical training during his year of compulsory military service at the Norwegian Military Academy. Sverdrup recognized he needed physical training and was proud of finishing “as the top man in athletics,” according to his eulogist and oceanography colleague Walter Nierenberg. “It probably was essential to his survival and positive performance later during his long Arctic ordeals.”53

Sverdrup learned dynamic meteorology and oceanography as an assistant to Vilhelm Bjerknes, funded by the Professor’s long running grant from the Carnegie Institution of Washington. Sverdrup then left for seven years sailing the Arctic with Roald Amundsen from 1918 to 1925, returning to take up the chair at the Bergen Geophysical Institute when Bjerknes retired. In addition to his oceanographic research, Sverdrup researched the boundary layer between the atmosphere and glaciers on Spitsbergen. He organized the scientific group for the failed North Polar Submarine

53 Nierenberg, “Harald Ulrik Sverdrup.”
expedition of 1931 led by Hubert Wilkins and Lincoln Ellsworth.\textsuperscript{54} He became director of the Scripps Institution in 1936, leading the expansion of physical oceanography in the United States. An article celebrating his installation at Scripps noted, “no doubt from Professor Bjerknes, Sverdrup received an excellent theoretical background which greatly facilitated his advance to the enviable position which he now holds among men of science.”\textsuperscript{55}

Sverdrup’s role in exploration and polar fieldwork helped bring him to international attention, positioning him to organize the Second International Polar Year. Sverdrup was one of five people who served on the sub-commission that drew up a formal proposal for IPY2. After this proposal was approved by the International Meteorological Conference of Directors in September 1929, Sverdrup became one of the original seven members of the commission charged with planning the observation schedule. Sverdrup and British meteorologist George Simpson determined what instruments were to be used for meteorological observations, while Sverdrup, Simpson, and the French geophysicist C. Maurain were appointed to arrange for the publication of the results of the IPY observations. World War II disrupted full publication of the observations, but Sverdrup was also appointed to the postwar Liquidating Commission charged with “bringing the manifold activities of the Second International Polar Year to a

\textsuperscript{54} Walter Nierenberg, “Harald Ulrik Sverdrup,” \textit{Biographical Memoirs of the National Academies of Science}, accessible online at: http://www.nap.edu/readingroom/books/biomems/hsvdrup.html

\textsuperscript{55} “Harald Ulrik Sverdrup—New Director of the Scripps Institution of Oceanography,” \textit{BAMS} 17 (October 1936): 306-308: q. on 307.
satisfactory conclusion, thereby endeavoring to derive the maximum benefit for the
science of geophysics from the multitude of data and publications available.”56

The IPY2’s surface weather observations formed the basis for a set of synoptic
charts of the Northern Hemisphere. These were to be prepared by the Deutsche Seewarte
in Hamburg. When the war broke out in 1939, maps covering ten months had been
printed; an additional six weeks of charts were printed after the war, but the material
covering the final two weeks of the IPY was destroyed during the war. As British
meteorologist C.E.P. Brooks noted, “the form of the isobars shows the charts to have
been … analysed on the Norwegian method, but fronts as such are not indicated.”57

Probably Sverdrup’s most enduring contribution to the IPY was administering
grants that paid for the first substantial production of the radiosonde, a new tool for
studying the upper atmosphere in real time. The radiosonde was actually a complex of
instruments for measuring the humidity, barometric pressure and temperature of the air.
Attached to a pilot balloon, these instruments rose through the air at a constant speed,
while the radiosonde broadcast this information to a receiving station on the ground. By
triangulating the signal, upper level winds could also be measured. One early Russian
radiosonde model had been tested on the Aeroarctic’s Graf Zeppelin flight in 1931. With
50,000 francs from the International Meteorological Association and $10,000 from the
Rockefeller Foundation, the IPY2 was the first time radiosonde observations of the upper
atmosphere could be coordinated on a large scale. While “many difficulties arose
because the instrument … [had] only recently been designed and was still in an

211-234. Quotation on p. 221
experimental stage,” the Polar Year clearly “expedited the development of the radiosonde.”58 As C.E.P. Brooks noted, “preparations for the manufacture of some hundreds of instruments speeded up its development very considerably.”59 Within a few years, radiosondes had become standard equipment in weather services across Europe and North America.60

Sverdrup’s Arctic fieldwork was an essential aspect of his emergence as an international leader in geophysics. An article announcing his arrival at Scripps touted, “Dr. Sverdrup has not confined himself to mere study in the library and laboratory, for he has filled out his researches by carrying out with brilliant success what has probably been the most ambitious and versatile field program of any modern investigator.”61 His career made clear that successful polar research built international connections, while demonstrating that a scientist was capable of integrating theory and fieldwork to produce accurate and useful knowledge.

Finn Malmgren, Bergen Teamwork

Unlike Petterssen, Holmboe, and Sverdrup, Malmgren was a Swede. Also unlike them, he began with polar exploration and then moved to meteorology. Yet his career likewise shows the value of Bergen School meteorology to international Arctic flights.

Malmgren learned how to live and work in the Arctic under the watchful eye of Norway’s most famous Arctic Explorer, Roald Amundsen, aboard the Maud from 1922.

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60 On the history of radiosondes, see: John L. Dubois, Robert P. Multhauf, and Charles A. Ziegler, The Invention and Development of the Radiosonde (Smithsonian Institution Press, 2002).
61 “Harald Ulrik Sverdrup—New Director of the Scripps Institution of Oceanography,” BAMS 17 (October 1936): 306-308; q. on 307.
until 1925. As the expedition’s assistant scientist, he worked with Sverdrup, forging a close bond with him. Malmgren was an easy man to like, quick with a joke and happy to laugh at himself. Amundsen described him as a most popular crew member, writing “If it is true that a good laugh lengthens life, then, thanks to Malmgren, I shall live to a ripe old age.”

Living in the Arctic molded men socially as well as physically. Long expeditions tested the character of men, and it was here that Malmgren particularly excelled.

Amundsen’s respect for Malmgren brought him an invitation to serve as meteorologist and chief scientist for the Norge’s flight in 1926. The expedition was absolutely thick with connections to the Bergen School. Malmgren began his preparations by studying at the Bergen Geophysical Institute then under Sverdrup’s leadership, where he became acquainted with “the new weather-report methods which have been in the first place worked out by the meteorologists [Jacob] Bjerknes, [Halvor] Solberg, and [Tor] Bergeron.”

The crew picked up the Norge in Italy where it had been manufactured under the supervision of Umberto Nobile, who would fly on as Captain. The semi-rigid airship flew to Spitsbergen with stops in England, southern Scandinavia, Leningrad, and Vadso. While the ship stopped over at Pulham, England, Malmgren had a chance to consult with Jacob Bjerknes, who was then temporarily lecturing and researching in Britain. After departing England, the ship had special weather reports radioed to it, including many from Petterssen’s office in Tromsø. Malmgren chronicled the essential role played by Theodor Hesselberg, the head of Norway’s national weather service and

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63 Amundsen and Ellsworth, First Crossing of the Polar Sea: 258
64 Amundsen and Ellsworth, First Crossing of the Polar Sea: 261.
another former assistant to Vilhelm Bjerknes. Malmgren credited Hesselberg with “having arranged the whole of the meteorological precautionary service,” noting that Hesselberg’s “international connections” enabled him to procure “help for the expedition from several institutes abroad—from the Italian, French, English, Swedish, Russian and American.” This international assistance helped ensure the Norge flew in reasonably clear skies. Malmgren noted the amount of work this apparent good luck required: “The story of the expedition shows that on the whole the various stages of the journey were favored with the best of weather. That such was the case was not a matter of mere chance. With the help of a well-planned organization and a good deal of labor we succeeded … in making a start at such points of time when the weather was fine.” The Norwegian weather service also loaned the expedition all the meteorological instruments the ship carried, and authorized special in flight updates and warnings to be sent from Tromsø and Oslo.

Malmgren described polar aviation in an essay that appeared in Amundsen and Ellsworth’s book First crossing of the Polar Sea, the kind of serious but accessible exploration narrative whose publication was crucial to funding and maintaining public interest in future expeditions. He described the three main meteorological challenges to the expedition as wind (including eddies around the hanger at launching), ice forming on the ship, and fog and visibility hazards that hampered navigation. “Almost all the difficulties encountered by the airship,” he noted, “were connected with unfortunate conditions of weather.” Malmgren explained his work this way:

65 Amundsen and Ellsworth, First Crossing of the Polar Sea: 257-258
66 Amundsen and Ellsworth, First Crossing of the Polar Sea: 257-258; 251.
67 Ibid.: 251.
[the expedition meteorologist’s] duty was to foresee the weather, and, in conjunction therewith, give the leaders advice in those matters where the weather more or less plays a part. It was thus his work to point out, by the help of synoptic charts, the best flying route, and, by the help of the telegraphed pilot balloon pointers, indicate the best altitude of flight. Besides this he should give the probable value of a number of meteorological values in landing, as, for instance, the barometric position of the place, and its temperature in places where not telegraphed. Finally, he should take the observations of weather that were collected during the Norge’s voyage. These included, amongst others, barometer, thermometer, and humidity readings, and also observations of clouds and such things. During the polar flight itself there were added a number of air-electric measurements.68

These were heavy responsibilities, and Malmgren had no assistant, other than the help he might be able to raise on the radio depending on conditions. As the flight lasted over 70 hours, he was collapsing with exhaustion as they approached Alaska, just at the moment when his expertise was most needed to judge the winds while finding a space to land.

Despite the strain, Malmgren so enjoyed the enterprise that he signed up for the sequel, Nobile’s 1928 flight in the new dirigible Italia. Again he would serve as flight meteorologist, though this time he would be the only non-Italian aboard. Nobile and Amundsen had a falling out in the wake of the Norge flight, and Nobile now sought to prove his own merit independent of the “Great Man.” Unfortunately, Nobile was a much better aeronautical engineer than a leader of men. The mission was poorly planned, ineptly equipped, and chauvinistic. The Italians wanted no international help. Numerous delays pushed the expedition to the edge of its weather envelope, and the flight ended in disaster. On the return leg south from the Pole, a weather-related crash left the surviving crew members stranded on ice floes about 180 miles from Spitsbergen. As one of the hardiest men in the crew, and the only one with extensive Arctic experience, Malmgren

68 Amundsen and Ellsworth, First Crossing of the Polar Sea: 259.
set out across the ice with two others to get help. Though his two companions were eventually rescued, he died of exposure.69

Carl-Gustaf Rossby: Arctic Fieldwork and International Credibility

Rossby’s polar experience was diametrically opposed to Malmgren’s tragic and deep involvement. Rossby’s field experiences consisted of a single observational cruise off the coast of Greenland in the summer. In a clear demonstration of the importance of Arctic field experience for international credibility, however, this short trip became central to Rossby’s self-presentation when he introduced himself to the American meteorological establishment in 1926. Not long after Rossby arrived in the United States on a fellowship provided by the American-Scandinavian Foundation, he presented a motion picture he made on his 1923 Greenland cruise aboard the *Conrad Holmboe* at the April, 1926 meeting of the AMS in Washington. The film made quite an impression. According to a summary of the meeting, the film showed: “The ship had been sent to effect a change of personnel for the meteorological station at Scoresby Sound. Its mission very nearly ended tragically for those on board, and did so for those who were to have been relieved. When the *Holmboe* got within a few miles of the station, ice pressure so opened her seams that continuous pumping until she reached Iceland alone saved her. While the ice pressure was at its worst, the personnel of the station were observed setting out in a boat along leads in the ice, were then lost sight of, and have not since been heard from.”70

As the film makes clear, arctic meteorology and Arctic dangers heroically

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overcome, modeled by scientists like Greely and Sverdrup, had become a valuable component of the meteorologist’s life story.  

Conclusion

The Bergen School was ideally placed to take advantage of a new interest in the Arctic, expressed by military planners as well as progressive internationalists after the Great War. As aviation made the Arctic geopolitically important, the Bergen School had the theoretical and practical knowledge necessary to make the Arctic flyable. Their life experience in Arctic conditions, as well as their Scandinavian nationalities, put them in the middle of Arctic flights that generated international attention. Those Bergen School scientists who survived their Arctic fieldwork parlayed these connections into careers leading American scientific institutions during the 1930s.

The infrastructure to support Arctic flight eventually became every bit as important as boosters like Stefansson said it would. During the Second World War, both the northern Atlantic and Alaska became crucial airways for delivering warplanes from American factories to European battlefields. The importance of the Arctic for weather forecasting made Greenland into a minor battlefield itself. The German military surreptitiously landed weather observing teams on the icecap, leading to Allied missions to hunt down these teams, some led by pilots who had first cut their teeth on the exploring flights of the 1920s. During the Cold War, the threat of nuclear attack by

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71 While this film helped Rossby establish his credibility as an experienced scientist, it also contributed to building relations between the American meteorological community and Norway, as was the goal of Rossby’s fellowship from the American-Scandinavian Foundation. The AMS adopted a resolution of gratitude to Theodor Hesselberg, Director of the Meteorological Institute of Norway and another student of Vilhelm Bjerknes, for loaning the film.
bombers and missiles coming over the pole heavily militarized the Arctic. The US and Canada built a line of warning radars across the top of the world, paralleling a Soviet system of defenses.

Only after the end of the Cold War did the Arctic become a “northern Mediterranean.” True trans-polar flights today take passengers from Chicago (or Newark!) to Beijing non-stop, flying at altitudes far above the fog that bedeviled fliers in the 1920s. Yet the technology that makes these flights safe and reliable has created a surprising new natural hazard. Flying at 35,000 feet in the highest latitudes, where the Earth’s magnetic field least shields the planet, planes can encounter higher levels of radiation, and electromagnetic interference with radio and navigation devices. Flight has turned the aurora borealis from a natural beauty into a natural hazard. Flights across the North Pole today are diverted based on forecasts of solar storm activity, which depend upon observations taken by satellites orbiting the Sun, relayed to Earth and interpreted by employees of the National Weather Service. These observers of solar storms have modeled their “space weather” services on the environmental surveillance systems originally designed to monitor what is now quaintly called “terrestrial weather.”
Chapter Two

Keeping Schedule: Aeronautical Meteorology in United States Airline Operations

Airline flights were a gut-wrenching experience in the 1930s. Relatively light piston-engine airplanes cruising in the lower troposphere exposed their occupants to such noise, vibration and turbulence that simply sitting as a passenger was physically draining. Flying was considered so arduous that Franklin Roosevelt challenged the idea that polio had crippled him by publicly flying to accept the Democratic nomination in 1932. His flight encountered strong headwinds and considerable turbulence between Albany and Chicago, arriving two and a half hours late. Nearly everyone vomited. Though Roosevelt told newspapers he found the trip “delightful,” he did not fly again for nearly ten years.¹

Adverse weather posed even more serious discomfort to airline managers. Weather historian William Meyer has calculated that, largely due to weather conditions, “nearly 20 percent of scheduled air trips were either canceled or not completed,” in the early 1930s. This unreliability of service devalued aviation’s chief marketable asset, speed.² “The greatest hazard and the greatest obstacle to the regular operation of airplanes on schedule is the weather,” wrote National Air Transport’s operations manager Wesley Smith.³ He spoke from painful experience. As a pilot for the United States Government’s airmail service between 1919 and 1927, he barely survived the hazards posed by fog, ice, low clouds and thunderstorms. In one 1920 flight he dodged a fog-

shrouded steeple only to smack into a mountain crest hidden in the murky skies. He crawled from the wreckage as flames erased the day’s Washington to Newark mail shipment. By rendering flights unsafe and schedules unreliable, weather threatened the viability of the entire industry.

Learning to manage the weather was essential to transforming civilian aviation from entertainment to infrastructure during the interwar period. While barnstormers could make do with informal arrangements and landing in a field whenever flying conditions deteriorated, commercially viable aviation required firms to deliver safe, reliable service from terminal to terminal on pre-determined schedules. As David Courtwright has noted, aviation became infrastructure (that is, a taken-for-granted, widely used part of the transportation system) in two stages. The first, increasing safety and reliability, largely took place in the 1930s and 1940s. The second stage, becoming cheap and ubiquitous, occurred after the introduction of jets and economy-class travel in the 1960s and 1970s.

Aviation historians have recognized many of the key advances that contributed to reliable flight, including stronger airframes, navigation systems, new kinds of flight instruments, and strict government regulation. But these accounts pay only fleeting attention to

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4 William M. Leary, *Aerial Pioneers: The U.S. Airmail Service, 1918-1927* (Washington, D.C.: Smithsonian Institution Press, 1976): 111, 230. Smith had a fine baritone voice and dreamed of a career in grand opera, but as his wife and former music teacher observed, “he had trouble keeping on key.” He had a mechanical engineering degree from Berkeley, and learned to fly during World War I. After joining the Air Mail in November 1919 he developed a reputation as a “determined bad weather pilot.” He later worked as the operations manager for National Air Transport, a private airline that took over the eastern part of the transcontinental route on April 15 1927.


meteorology, usually treating weather as a kind of inevitable, unmanageable force.

Implicit in these accounts is a narrative of escape: as people succeeded in building more powerful planes and flying higher, flight gradually escaped the weather’s gravity, in both senses: weather became a less serious threat, and a less powerful restraint. To be sure, weather causes many fewer crashes today than it did in the 1920s. But this is not just because of stronger aircraft. This chapter explores how meteorology helped airlines to re-imagine weather, not as an inevitability that needed to be battled, but as an ever-changing set of conditions that sometimes constrained operations and sometimes made them more efficient.

Meteorological knowledge allowed airlines to become flexible organizations that could take advantage of tailwinds and cloud breaks, while mitigating the dangers of headwinds, fogged in airports, and icing. The airlines hired a new kind of weather expert to provide the advice necessary to make flight safe and reliable. Trained at MIT, Caltech, or a small number of flight schools, airline meteorologists were never numerous, numbering only 94 in the United States by July, 1940, roughly a quarter of all the qualified forecasters in the United States. Yet they played an indispensable role, judging the weather, explaining current and possible future conditions to pilots, and advising dispatchers how to route and manage flights. They also spread advanced meteorological knowledge by training other personnel to understand adverse weather conditions. Limited to roles as technical specialists, airline meteorologists did not become corporate leaders.

Internally, the emerging airlines used meteorology primarily to manage daily operations.

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Externally, airlines advertised their meteorological expertise to present flying as a safe, efficient and modern mode of transport.

The meteorological needs of airlines also shaped the research culture of academic meteorology. Beginning with Carl-Gustaf Rossby’s work with Western Air Express in 1927, airlines helped launch the careers of several leading American researchers. Rossby's students Horace Byers and Jerome Namias also worked for commercial airlines during the 1930s, a time when economic conditions made support for academic research particularly scarce. The porous boundaries between academic and industrial meteorology made the airlines among the earliest American users of the Bergen School, with its emphasis on geophysical models and numerical calculation in weather forecasting. The growth of aviation generally, and airline jobs in particular, supported the establishment of the first academic meteorology departments in the US. Perhaps the most influential meteorological textbook of the early 20th century, Horace Byers’ *Synoptic and Aeronaucal Meteorology*, began as a lecture course for airline personnel, and then developed into a normative guide that structured how meteorologists-in-training learned to imagine the atmosphere and its behavior. The financial support and cultural prestige of the American airline industry thus shaped the 20th century development of American meteorology into an internationally prominent research discipline built around three-dimensional physical models of the atmosphere.

**Flying the Mail: The Challenge of Regular Service**

The first effort to develop regularly scheduled air service in the United States came from the Post Office, which began airmail operations in October 1918. While
several small airmail experiments had been made as early as 1910, the assumption that urgent dispatches would need to be moved quickly during wartime initially justified a much larger effort to develop airmail in 1918. The airmail survived the end of the war thanks to the leadership of second assistant postmaster general Otto Praeger, a progressive reformer who sought to improve the operations of a government department notorious as a den of patronage. (Presidents usually appointed their campaign managers or another influential partisan as postmaster general, because the office controlled the most pervasive collection of government contracts.) Though Praeger was determined that the mails should get through regardless of weather (“neither wind, nor rain, nor sleet …”) his organization struggled with unreliable engines, inadequate maps, an intermittently supportive Congress, pilots who sometimes refused to fly when weather conditions were impossible, and who occasionally died when they consented.\(^8\)

By February 1921, as the Wilson administration came to an end, Praeger planned a spectacular demonstration of the development and accomplishments of the airmail. Flying day and night, pilots would seek to carry mail from one coast to the other in less than 36 hours. Two planes would take off from either end of country, each carrying 350 pounds of mail. However, heavy icing over Pennsylvania required one of the west-bound planes to make a forced landing that damaged the landing gear. The other plane fought through bad weather to get to Cleveland, then picked up a new pilot to struggle through to Chicago, where a combination of rain, snow, and fog to the west ended all hope of getting through. On the east-bound flight, two pilots left San Francisco at 4:30am,

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\(^8\) Leary, *Aerial Pioneers*. Management pressure to fly in potentially dangerous conditions remained an important cause of labor strife throughout the interwar years, contributing to the formation of the Air Line Pilots Association during the 1930s. George E. Hopkins, *Flying the Line: The First Half Century of the Air Line Pilots Association* (Washington, DC: ALPA, 1982).
climbed to 18,000 feet to cross the Sierra Nevadas, and landed at Reno. Pilots Samuel Eaton and William Lewis took over for the flight to Salt Lake City, with a scheduled refueling stop in Elko, Nevada. Departing Elko, Lewis stalled his plane at 500 feet and died in the crash. “His mail pouches were gathered up, the broken ones turned over to the local post office, and the unbroken ones put aboard a standby aircraft.” By 1:10am, the remaining mail from the two planes had reached Omaha, but it looked like the end of the demonstration. The only pilot who knew the route to Chicago refused to fly in the worsening weather. But Jack Knight, sporting a broken nose from an emergency landing on a mountainside near Laramie the week before, volunteered to fly. Nearing Des Moines, a descending layer of white cloud forced him down to 100 feet to stay in sight of the ground. “The air was rough and the valleys were packed with fog. Next I began to get snow flurries,” he said later. Finding railroad tracks headed in the right direction, he finally made it to Iowa City for refueling, though finding the airfield required flying “in and out the town, dodging steeples and looking for that field.” As mechanics refueled his plane, he called Chicago for the weather report: still bad. Trusting to faith he lingered over cigarettes and a sandwich before taking off. Managing to negotiate more fog before catching a fortunate break in the clouds over Illinois, his engine cut out just as he came overhead the field. He glided to a dead stick landing at 8:30am, exhausted. Two more pilots braved low clouds, snow and sleet to arrive in New York at 4:50 pm, 33 hours and 20 minutes after take off in San Francisco.  

All told, the transcontinental attempt had killed one pilot, destroyed a plane and damaged a second, and resulted in two forced landings. Just part of one of the four mail

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9 Leary, *Aerial Pioneers*, 140-143.
shipments got through. Astoundingly, however a New York Times editorial hailed the achievement, writing “the modern world demands efficiency and speed; aviation is international and competitive. The United States has distanced all countries in transportation of mails through the air.” Praeger hailed the event as the “most momentous step in civil aviation,” saying that Knight’s improvised flight at low altitude, through snow and fog, over an unfamiliar airway, was a “demonstration of the entire feasibility of commercial night flying.”

Though some critics argued the airmail was both unsafe and uneconomical, nonetheless, Praeger had managed to secure the airmail: it survived and grew modestly under the Harding and Coolidge administrations.

For the next six years, administrators of the airmail service worked primarily on improving safety, constructing lighted airways along key parts of the routes, mapping emergency landing areas, and developing point-to-point radio. In 1922, for instance, field radios were established at every transcontinental way station except Rawlins, Wyoming, allowing pilots to receive advance weather reports from observers trained to know what weather information was relevant and how to report it. This reduced the kinds of stories that circulated among pilots of exchanges like this, based on the older telephone system:

“Mr. Brown, how’s the weather at your place?”
“Good, for this time of year.”
“No, I mean, is it raining?”
“Well, no, not yet.”
“Then, it looks as if it might rain?”
“We surely could use some.”
“Well, how about this, Mr. Brown—can you see a long way?”
“I can see the barn.”
“Oh, that’s fine. Uh, Mr. Brown, by the way, how far away is the barn?
“It’s across the yard.”

Leary, Aerial Pioneers, 143.
While this particular story is probably apocryphal, that it was told at all, (and found funny) reveals the significance pilots gave to disciplined and standardized weather information. Looking higher and farther than the barn, trained observers produced the kinds of information that could be incorporated into pilot practice.

The postal system that Praeger had built was dismantled by the Air Commerce Act of 1926. The government shifted the airmail to a system of contracts to given to various private airlines to fly the mail on a given intercity route. While these contracts were open to competitive bids, Postmaster General Walter Folger Brown largely ignored the prices submitted, instead awarding routes only to firms that in his judgment would provide reliable service using the most modern equipment. This excluded small and local airlines and benefited the three large aviation holding companies that combined an airframe manufacturer, an engine maker, and an operating airline. Brown argued this policy would most rapidly develop a stable and technologically advanced aviation system in the United States. Certainly, it provided airlines with a vital subsidy, but it also presented them with the same meteorological challenges.

A Model Airline Weather Service

The first important private commercial airline weather service was developed by Carl-Gustaf Rossby in 1927 and 1928.\(^\text{12}\) In 1927 Rossby worked for the Daniel Guggenheim Fund for the Promotion of Aeronautics, which was busily cultivating the Western Air Express, a California airline, in order to demonstrate that private commercial air travel could be safe and profitable without government subsidies. Rossby and the

\(^\text{12}\) This section is based on the Collected Papers of the Daniel Guggenheim Fund for the Promotion of Aeronautics, Library of Congress. Box 8, Files 1 and 2. (Henceforth, DGFPAs).
Guggenheim fund believed that aeronautical meteorology could make the airline both safer and more efficient.\textsuperscript{13} Rossby’s success with the Model weather service soon led to a professorship at MIT for himself, while creating a service emulated by other airlines and adopted by the Weather Bureau. While organizing the meteorological service, Rossby also made key connections that would be essential to his scientific research in the decades to come.

At twenty-seven years old, Rossby was ambitious, confident, and forceful. He had spent his late teens and early twenties studying meteorology and atmospheric physics with Vilhelm Bjerknes at the Bergen Institute. After further study and work as a meteorologist for the Swedish Meteorologic Service, Rossby won a fellowship from the American-Scandinavian Foundation, and settled at the US Weather Bureau where he studied the application of polar front theory to American Weather. Rossby’s foreign theories of atmospheric physics—and more particularly his willingness to issue forecasts without his superiors’ authorization—did not endear him to the Weather Bureau administration. When the leaders of the Daniel Guggenheim Fund for the Promotion of Aeronautics came looking for a bright young meteorologist to assist on various projects, the Weather Bureau was more than happy to pass Rossby along.

The Guggenheim Fund for the Promotion of Aeronautics was the brainchild of Harry F. Guggenheim, and funded by his father Daniel, the millionaire mining magnate. Harry Guggenheim had learned to fly during the earliest stages of aeronautics and served in Naval aviation during the Great War. Believing aviation would be essential to economic and military power in the future, he and his father were particularly disturbed

to see the US falling behind Europe in the development of aviation during the 1920s. Their Fund, established in late 1925, was intended to kick-start American aviation growth. It disbursed its capital to a wide variety of pioneering projects, aiming to catalyze the development of aviation at a crucial period, and then disband. The fund ceased operations in February 1930, after expending 2.6 million dollars on the development of instrument flying techniques, which enabled pilots to fly safely through fog and cloud when landmarks were invisible. It supported of Charles Lindbergh’s triumphant national tour, and promoted a “safe airplane” competition, which aimed to create an airplane as safe and easy to use as an automobile.\textsuperscript{14} The fund also endowed schools of aeronautics at Caltech, MIT, Stanford, Michigan, Georgia Tech, and the University of Washington.

Like many pilots in the 1920s, Harry Guggenheim felt strongly about aviation’s particular need for reliable weather forecasts. To this end, the Fund established a committee on Aeronautical Meteorology in August 1927.\textsuperscript{15} chaired by Rossby, that included Willis Gregg of the Weather Bureau, Maj. William Blair of the War Department, Thomas Chapman of the Commerce Department, Lt. Francis Reichelderfer of the Navy. The committee took its initial task to be the establishment of an “experimental weather reporting service” to assist the model airline that the Guggenheim fund was supporting in California. This weather service was to forecast upper air conditions, cloud cover, head and tailwinds, and landing conditions at airfields between Los Angeles and Oakland. (San Francisco was still building its first airport.) It would also establish means of communicating changes in forecasts to aircraft while they were in

\textsuperscript{15} Hallion, \textit{Legacy of Flight}, p. 92.
flight. Rossby’s efforts to build a network from the ground up reveal the inner anatomy of meteorological observation.

Rossby spent much of June and July 1928 establishing observing stations and getting a feel for the airways between Oakland and Los Angeles by traveling them. (His expense reports from those months include entries for 1000 weather maps, $80.00 for a pilot to fly him up and down California for ten days, and $19.25 for a leather flying helmet and goggles.16) He linked observing stations by telephone to centralized collecting offices in Oakland or Los Angeles. (In 1928, it was expensive to collect weather reports by telephone. Pacific Telegraph and Telephone agreed to donate their services only after a high-level negotiation between the company and Harry Guggenheim himself.)

The “Instructions for Observers” issued by the Fund’s meteorological committee give some indication of the ways that observers were disciplined to interact with the telephone network:

At 9:35 AM., 11:05 AM., and 12:35 PM., the observer should take place at the official telephone of the station, keeping the observation sheet before him. As soon as the collecting station … calls and mentions the key word “Weather report, please”, he should proceed to read his report off the sheet with a clear, steady voice, not too fast and not too slow. The Collecting Station marks the end of the report with the words “Thank you”. … The reading of the weather report should not be interrupted by any remarks or comments. … These three regular daily telephone calls are strictly reserved for weather reporting and all other matters should be taken up with other parties. If the collecting station at the end of report mentions the word “extra”, then the observer has to make another observation—30 minutes later, and in regular order wait for a call from the Collecting Station.17

16 Carl-Gustaf Rossby, Expense report, July 1928. DGFPA.
17 “Instructions for Observers of the Experimental Meteorological Service, Organized by the Daniel Guggenheim Fund for the Promotion of Aeronautics,” undated manuscript. DGFPA.
Each report included several standardized parts: the location of the observing station, the wind direction and velocity (on the Beaufort scale), a one to three word description of the weather at the ground, the amount of clouds, the cloud forms, the ceiling, the visibility, the temperature, and the atmospheric pressure. When read in code by a disciplined observer, this information could be communicated in about 20 seconds. By the end of the summer of 1928, reports from over 35 stations were being gathered and plotted in under an hour. All forecasting and analysis of observations was made by Rossby’s handpicked men at the Oakland and Los Angeles terminals.

While the Weather Bureau had been slow to integrate the polar front theory into its operations—in part because of questions regarding how continental US weather differed from the North Atlantic—Rossby trained his observers in practices grounded in Bergen school methodology. For example the Bergen School had connected atmospheric physics to cloud forms, using that information for predictive purposes—in the experimental weather reporting service, observers were given a cloud atlas. They were expected to include cloud formations in their reports, and were explicitly instructed not to conflate cloud movement with surface winds.

Another challenge facing Rossby was the need to take increased numbers of upper air observations on which to base forecasts. He contacted the air corps, hoping they might be willing to launch regular flights to take upper air data, and obtained a number of pilot balloons and related equipment from the Navy. As a foreigner snooping around airfields,

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19 “Instructions for Observers,” DGFPA.

20 Rossby to Maj. G.C. Brant, 8/18/28. DGFPA.
obtaining expensive navy property, Rossby raised the suspicions of a naval intelligence officer working within the San Diego chamber of commerce. This officer dashed off a worried latter to the Guggenheim fund headquarters:

I have been advised that a Dr. Carl Gustaf Rossby, secured a number of valuable meteorological instruments from the navy department for installation at Vail Field, Los Angeles. An Investigation disclosed that Dr. Rossby has no connection with the Western Air Express, which uses a [sic] Vail Field as an air mail and Passenger base. He is said to have secured the meteorological instruments on the assumption that he is connected in an official capacity with the Guggenheim foundation.\(^{21}\)

The Guggenheim Fund’s secretary immediately wrote back, vouching for Rossby and letting the officer know that “the meteorological instruments mentioned by you were obtained thru Assistant Secretary of the Navy, [Edward P.] Warner, and the Bureau of Aeronautics, Navy Department, is fully conversant with this situation.”\(^{22}\)

No longer a target of suspicion, Rossby managed to build a denser network of upper air readings into the Model weather service.

Although initially challenged by a lack of experienced, available meteorologists in California Rossby soon found a bright, organized young man who would become his life-long colleague and chief lieutenant. While fishing for weather talent in early 1928, Rossby was introduced to Horace Byers, than a junior at Berkeley with an interest in physics and climate. By July, Byers was on the Guggenheim payroll at $175 per month, and was quickly becoming Rossby’s most trusted lieutenant. According to Rossby’s letters to the Fund’s headquarters, Byers was doing “splendid work” while teaching the

\(^{21}\) Howard E. Morin to J.W. Miller, 5/21/28. DGFPa.
\(^{22}\) J.W. Miller to Howard E. Morin, 5/26/28. DGFPa.
Weather Bureau how to run the reporting service, and beginning some empirical studies of California weather.\textsuperscript{23}

The Experimental Weather Reporting Service proved successful during its operations in 1928 and 1929. The Western Air Express suffered no weather-related crashes or mishaps, and the efficiency and reliability of its schedule increased. As Edward Bowie, the Weather Bureau’s Meteorologist in charge at San Francisco noted, the Experimental Service’s forecasts spread beyond the airline, to the members of the Automobile Club of Southern California who used them in making travel predictions and the California State forester who used them to help predict forest fires.\textsuperscript{24}

Despite its successes, the model reporting service nearly collapsed in the spring of 1929 when the Guggenheim fund planned to turn the service over to the Weather Bureau. The Weather Bureau refused to fund the reporting service, which was only saved by a last minute action by departing President Calvin Coolidge.\textsuperscript{25} Coolidge’s action was in accord with the interests of incoming President Hoover, whose son Herbert Jr. was a pioneer in integrating radio, including weather updates, into aviation communication, and worked for the airline (Figure 2.1).

\textsuperscript{23} Carl-Gustaf Rossby to Harry F. Guggenheim, 7/23/28. DGFPA.
Figure 2.1: Herbert Hoover, Jr. in March, 1929. As part of his duties as a Vice-President for Western Air Express, Hoover kept pilots informed about changing weather conditions. This large chalkboard was used at Vail Field in Los Angeles to organize weather observations from various stations, which appear to have been erased from the far left hand column in this staged photo. (Author’s personal collection)

This financial rescue draws attention to the weather service’s political positioning. Like the airlines and airmail contracts, the meteorological service displayed the characteristics of Hoover’s “associative state:” negotiating standards, limiting destructive competition, and using the resources of the state to improve industrial efficiency. This vision of government depended upon close working relationships amongst the military, civilian bureaucrats, stable businesses, and wealthy philanthropists. Rossby’s work managed to add meteorologists to that web of mutually beneficial relationships. The
Guggenheim Fund was organized and supported by one of the richest families in America, and operated for the direct benefit of a privately held airline that offered services well beyond the reach of most citizens. In addition to these lower level officers working directly with the committee, the Guggenheim Fund for Aeronautics also took advantage of connections at the highest levels of government. The Guggenheim family, which continued to make money in mining operations, had an amicable relationship with Herbert Hoover (who had trained as a mining engineer) dating back to at least 1921. Hoover’s position as Secretary of Commerce and then as President certainly played a useful role in the success of the Fund’s activities, perhaps making possible the Fund’s frequent access to assistant secretaries for aeronautics of the War, Navy and Commerce departments. Airlines’ close identification with the governing methods of the associative state made them vulnerable after the economic crisis brought a sea change in American politics.

**The Army Flies the Mail**

Franklin Roosevelt’s sweeping victory in 1932 led to an enormous but short-lived upheaval in the airline industry. Early in 1934 Roosevelt’s Postmaster General, James Farley, announced that the airmail contracts had been awarded corruptly and canceled nearly all of them. He planned to re-open the bidding, but only to firms that had not been tainted by the previous back-room deals, effectively ruling out all the major firms with experience and adequate equipment for scheduled operations. Just in advance of this announcement, Army Air Corps General Benjamin Foulois was asked if the Army could
fly the mail while new bids were arranged. Caught off guard, Foulois said the Army could.26

The Air Corps flew the mail for 78 days, beginning in February 1934, but winter weather, inadequate airplanes and poor navigational skills led to chaos, including 66 crashes and 12 deaths. Air Corps planes were not equipped with the latest navigational aids, and worse, “most pilots had not trained in blind flying, were unfamiliar with the expensive new radio equipment, and had flown only during the daytime and in decent weather.”27 Clearly, airmail demanded new expertise and new technical systems.

Despite its brevity, the air mail fiasco compelled the Air Corps to alter its practices, paying more attention to navigation and instrument flying. Army leaders established rush programs to teach instrument landing, and a year later, in March 1935, new Army regulations prescribed instrument and navigational standards for all Regular Army and Reserve pilots.28 As Randolph Field, the Army’s school for primary flight training, received the latest navigational equipment coming into the Air Corps in 1936, officers experimented with teaching blind flying, using a canopy drawn over the head of a student pilot flying a BT-2. (Completing the training earned the trainee a diploma from the “Institute of the Blind.”) Ground-based Link trainers, a kind of closed cockpit mini-plane attached to analog recorders and the first true flight simulator, became a crucial tool for teaching pilots to trust their instruments while navigating in zero visibility. While the Navy had ordered a Link as early as 1931, it was only “after the disastrous experience of

flying the air mail in 1934 and the concomitant push to improve instrument training, the Army, too, ordered the trainer.” But Army pilots were still taught to fly more by feel, sound and sight than by instruments. While training in instrument flying became more widespread, a continued lack of equipment and funds for additional flights ensured that it remained superficial.29

**Airline Meteorology on Display**

With the restoration of airmail contracts, the airlines had regained the subsidy essential to their commercial survival.30 Profitability, however, would require making operations more efficient, as well as boosting passenger traffic. Meteorologists played important but overlooked roles in these challenges. This section explores the emergence of airline meteorology as an industrial occupation, and examines how airlines used meteorology in public relations.

*The Work and Persona of Airline Meteorologists*

Just who was an airline meteorologist in the interwar years? The US airline meteorologist of the 1930s was white and male, and young, probably in his 20s or early 30s. He might or might not have a pilot’s license, but he was strongly interested in the development of aviation. Airline meteorologists worked eight-hour shifts in the administration building at an airport and earned good money: $200 to $300 per month.31 In 1938, an airline operations office might employ “one chief meteorologist and three or

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30 On these negotiations, see van der Linden, *Airlines and Air Mail*.
four principle assistants, each of whom has several skilled men under him,” for a
maximum of about a dozen meteorologists for a domestic airline. Pan Am employed
more, as it required forecasters as well as observers for every spot its planes regularly put
down along its far-flung international routes.

The Boeing School of Aeronautics, involved in training airline meteorologists,
described meteorology as a field that appealed to people who like “technical” work, while
noting that “the duties of the airline meteorologist entail a great deal of responsibility,
since his decisions carry great weight with the pilots and dispatchers in determining
whether or not a scheduled trip can be made safely in existing weather.” Meteorologists
usually worked a 48 hour work week, consulting with pilots and dispatchers, making trip
forecasts for each out bound flight, preparing eight-hour local forecasts for the terminal
and a twenty-four hour operational forecast covering all routes flown by the airline. The
school estimated that airline meteorology would continue to “provide positions each year
for a certain number of well-trained men.” Unlike academic or military scientists, an
airline meteorologist could work his way through a corporate hierarchy, from
Meteorology Clerk to Junior Meteorologist, Assistant Meteorologist, Meteorologist in
charge of station, Division Meteorologist, culminating in Chief Meteorologist for the
airline. He would experience a variety of working conditions, both indoor and outdoor,
with “considerable responsibility.” His job duties were: “Interprets and amplifies
Government weather reports for aeronautical application, prepares and analyzes weather
maps, and makes forecasts for various sections of the airways and airline terminals.”

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33 “Boeing School of Aeronautics, 1941,” p. 13.
34 “Boeing School of Aeronautics, 1941,” p. 40.
The airline meteorologist’s work centered around two tasks. First, he had to produce a synoptic map showing the current conditions in his area of responsibility. This involved translating a long string of coded weather observations delivered by Weather Bureau teletype circuit and plotting them on a map, four times a day. According to one career guide, this routine work made him look like “probably the most dissatisfied worker in the airline. He does a good job in making a map, and yet within six hours he decides the old one is no good and draws a new one.” The second part of the job involved analyzing the map and predicting the atmospheric conditions each flight would experience. He then briefed the pilots and dispatchers on these conditions. In cases where flying conditions were marginal and potentially dangerous, the dispatcher, pilot and meteorologist would cooperatively decide whether a plane could take off and what altitudes it ought to fly at. Although these decisions were taken cooperatively, ultimate responsibility for flight safety lay with the pilot.

The pre-flight briefing was the key moment of intersection between weather knowledge and the act of flight; the meteorologist translated his technical knowledge into a personal communication with the pilot who would experience the conditions the meteorologist was struggling to understand. This moment produced both an emotional bond between the two men, each an accomplished expert in his field, as well as barriers imposed by their necessarily different encounters with the weather. Pilot Bob Buck, who flew TWA DC-3s in the late 1930s at the start of long career in commercial aviation and weather research, described the relationship:

The bond between pilot and meteorologist is like that between patient and doctor … one looks to the meteorologist to explain the often unexplainable, and to tell

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you honestly about what he doesn’t and can’t know, and why, and what to expect if the unknown appears as you fly toward or through it. This bond started with my earliest flights, and has been the same with the meteorologists I’ve dealt with since.\footnote{Bob Buck, \textit{North Star Over My Shoulder} (Simon and Schuster, 2002): 27. Buck is best known to pilots as the author of \textit{Weather Flying} (New York: Macmillian, 1970), a guide to negotiating difficult flying conditions, which emphasizes developing the ability to judge when \textit{not} to fly. He also wrote \textit{Sparring with the Weather}, a 1940 pamphlet produced by Aviation Underwriters to help private pilots fly more safely.}

A good aeronautical meteorologist needed to be someone who pilots felt they could trust to give them an honest read of the weather. At the same time, they also needed to be strong enough not to simply tell pilots what pilots wanted to hear. Though the weather forged a bond between pilot and meteorologist during the pre-flight briefing, their very different experience of that weather left a divide between the two. Buck described a moment late in his career when he was flying 747 jets, and a meteorologist told him about the rough air likely to be found near a kink in the jet stream:

\begin{quote}
I wonder how he visualizes this, if his mind makes a picture of the turbulence, or if he just thinks in principles and formulae. He isn’t thinking of it the way I do, picturing the airplane jouncing, seeing myself reaching to get the seatbelt sign on, reducing power so as to slow to turbulence penetration speed, being a little apprehensive in the dark night, hoping it doesn’t get real nasty.\footnote{Buck, \textit{North Star}: 27.}
\end{quote}

Because of this complicated relationship, Boeing asserted that airline meteorologists:

\begin{quote}
“Must be sound physically, mentally alert, industrious, cooperative, have teaching skill, and sound judgment and principles.”\footnote{“Boeing School of Aeronautics, 1941,” p. 39-41.}
\end{quote}

\textit{Meteorology in Advertising}

The moment of expert consultation became a very public part of the airline’s strategy to make flying look safe. Pictures of the pre-flight weather briefing between pilot, dispatcher and meteorologist, often with a caption describing the meteorologist’s
advanced training and the pilot’s years of experience, became a favorite trope of airline advertising, appearing also in *Popular Aviation* articles and airline timetables. A 1950 ad for American Airlines explicitly highlighted the connection between meteorological expertise and safety. “Here begins your Flagship’s flight… Here in conference between pilot, dispatcher and meteorologist. Their accurate decisions, reflecting years of specialized study and practical experience, have played no small part in making air transportation such a safe, comfortable way to travel.”  

Ford Motor Company (which made a not very successful foray in commercial airplane manufacturing) promoted air travel by invoking the government’s growing commitment to aeronautical meteorology. “Whose guiding hand kept the flier safe from fog?” asked a Ford advertisement. It was “The Weather Man at Washington who watches the pathways of ships at sea … who warns the traveler on his way … who tells the farmer clearly when danger to his crops is rolling towards his horizon … the weather man is now lifting his eyes to the pathways of the sky!”  

In a related strategy, airlines highlighted the climatological advantages of their routes. Standard Airlines touted the “Fair Weather Route” in its ads, suggesting smoother flights in the warm sun of the US southwest.  

In advertising the role of meteorology in safety Pan Am mingled impressive figures with a streak of nativism. Highlighting the integral role played by weather observations among forms of navigational safety devices making long distance flight reliable, a Pan Am marketing brochure from 1934 described the airway to Nassau, Bahamas, Havana, Cuba, and on to South America this way:

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39 Author’s Personal Collection.  
Today, great aerial highways link the continents… one hundred and forty-seven airports have been developed, often in the face of incredible difficulties… seventy-two ground radio stations maintain constant communication with all airliners en route… as many private weather bureaux at strategic points along the airways advise the pilots continuously of all weather conditions… directional radio stations have been perfected to guide the airliners faithfully over the longest routes… and a staff of American experts has been carefully trained to man these important observational posts. 41

As an airline whose operations extended beyond the network of the US Weather Bureau, Pan Am often had to create its own systems for producing the meteorological information on which its flights depended. Station managers launched weather balloons at Wake Island, while engineers pioneered radio systems for receiving updated forecasts en route. 42 On its tropical routes to Latin America and the South Pacific, Pan Am faced an additional challenge. Most meteorological research examined mid-latitude weather conditions that affected Europe and the United States. The world’s premier meteorologists assumed their theories of atmospheric physics were universally applicable; dispatchers and pilots working in the tropics quickly discovered they were not. 43 Pan Am personnel became experts on the effects of tropical weather upon flight operations. When World War II expanded into the South Pacific early in 1942, the Navy and Army Air Force relied upon Pan Am employees to provide meteorological and operational advice. 44

41 Wright State University special collections, MS-167 International Cyclopedia of Aviation Biography, box 37, file 21 (Pan-American Airways). Ellipses in the original.
Training Airline Meteorologists

After leaving Guggenheim’s Weather Service, Rossby played a crucial role in creating this class of aeronautical meteorologists. Of the handful of institutions that offered training in aeronautical meteorology during the interwar period, Rossby’s program at MIT offered the most rigorous training in theory and research. After 1933, Irving Krick also led a less successful meteorology program at Caltech that focused on commerce and the Army Air Corps and was less oriented towards research and theory. Graduates of this program included Peter Kraght and Mort Rubin. Two private flight schools, Parks Air College and the Boeing School of Aeronautics, also offered courses in airline meteorology.

The Boeing School offers particular insight into commercial airline operations; it was part of United Aircraft and Transport Corporation, a vertically integrated holding company that brought together Pratt and Whitney engines, Boeing airplanes, and the operational activities of Boeing Air Transport, which was soon renamed United Airlines. Beginning operations in September of 1929, and managed by transport pilot Theophilus Lee Jr, the school offered to help its students find jobs in aviation, but fed its best graduates into jobs with United. As the school made clear in a 1941 promotional brochure, its role in the operations of a commercial airline was central to its claims to expertise: “As an integral division of the United Air Lines Transport Corporation, it has

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at its command the vast experience gained from more than 160,000,000 miles of air transport flying and thirteen years of airline operation.”

The School was well positioned to become a model flight school. Located at the Oakland Municipal Airport, one of just a handful of the most advanced airports rated A-1-A by the Department of Commerce, the School adjoined offices of the Civil Aeronautics Authority, the Postal Service, and the Weather Bureau. Because the school shared hangers with United Airlines, students could observe passenger and air mail operations firsthand. In 1941, the school maintained a fleet of fourteen training planes, ranging from open-cockpit Boeing 203-Bs and Stearman biplanes for basic flight training, up through an airline standard twin-engine Boeing 247D, complete with an enclosed hood for instrument training and radio navigation equipment necessary for flight in heavy weather. Other school equipment included a construction and repair shop; an “aviation” laboratory with sextants, drift indicators and dead reckoning computers; a communications shop for building and repairing radio equipment; a 48 seat drafting room; an engine laboratory with viscometers and Orsat Gas Analyzers for testing fuels and components; an engine shop with 16 types of engines used in Boeing aircraft; an instrument laboratory and repair shop, featuring cut-away models of aircraft instruments like artificial horizons and directional gyros; a five hundred volume aeronautical library; specialized shops for propellers, parachutes, dope and fabric, wood, metal, and welding; plus classrooms and a science laboratory equipped for instruction in kinetics and kinematics, as well as general physics.47

46 Promotional Brochure, “Boeing School of Aeronautics, 1941.” Photocopy of original in Author’s personal collection.
47 “Boeing School of Aeronautics, 1941,” pp. 6-7.
Boeing offered two training courses to become an airline meteorologist. Students who had graduated high school could take a twenty-four month course in “Airline Operations and Engineering,” with a major in meteorology. For the first four quarters, meteorology majors joined with flight engineers and maintenance engineering students to study subjects like “airplanes and theory of flight,” “blue print reading and shop sketching,” air law, and shop practices. In the second year, meteorology majors apprenticed part-time in the United meteorology office while taking specialized courses in synoptic and dynamic meteorology, forecasting analysis, avigation, and the practical aeronautical applications of meteorology. Tuition for this course was $1440, payable in 24 equal monthly installments. The second option, for students who had graduated from an accredited four-year engineering college, was a nine-month course in “Airline Meteorology.” Built around 408 hours of lectures and 828 hours of laboratory work, the course included most of the same classes as the second year of the meteorology major, including “Principles of Meteorology,” “Synoptic and Dynamic Meteorology,” and “Meteorology, Forecasting Analysis.” In the classroom, students in Principles of Meteorology covered these topics:

Theory of physical laws governing weather. Relation of weather phenomena in the upper air to surface observations such as winds, fogs, and ice-forming conditions. Analysis of flying routes and prediction of weather interferences.

The more advanced classes integrated physics with some of the key concepts developed by the Bergen School:

The detail of hydrodynamics and thermodynamics, with special application to atmosphere phenomena. The statics and kinematics of the atmosphere. The study of the upper air sounding for use in forecasting fog, clouds, thunderstorms, ice

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49 “Boeing School of Aeronautics, 1941,” p. 36.
forming conditions, etc. Air mass analysis and the study of fronts, frontogenesis and frontolysis. Study of the structure of the extratropical cyclone and the general circulation of the atmosphere. Local effects of topography upon frontal movements and upon air mass properties.50

Laboratory sections focused on the practical work of supporting flight operations, disciplining students in the tasks they would face as workers.

The Boeing School’s laboratory was built to simulate the routine work of airline meteorology, the interpretation of the meteorologist’s central tool: the synoptic map. Each student sat at a drafting table, plotting and analyzing their own copy of the current map, facing previous maps clipped to a board mounted at the edge of the desk. The lab received updated weather information 24 hours a day through a dedicated teletype line, as well as constant access to United’s meteorological office and “one of the most advanced and best equipped Airport Weather Bureau stations.”51 An airy space with both natural light and overhead electric lamps, the meteorology lab overlooked the flying field, and was equipped with an anemometer, an external wind vane with an indicator inside the laboratory, mercury barometer, barograph, and “apparatus for determining relative humidity, temperature, and dew point,” probably a hair hygrometer, a sling psychrometer, and a slide rule.52 A photo showed an instructor teaching air mass and frontal analysis comparing a table top, three dimension model of an occluded front with the two dimensional representation of the same on a synoptic map.

At Boeing, students learned to function in a rapidly bureaucratizing industry. They decoded weather reports and drew weather maps, used meteorological instruments, and made airways forecasts for selected routes as well as preparing flight orders like

50 “Boeing School of Aeronautics, 1941,” p. 36.
51 “Boeing School of Aeronautics, 1941,” p. 7.
52 “Boeing School of Aeronautics, 1941,” p. 35.
clearances, most efficient flying altitude, and best flying course. Through institutions like Boeing, the role of the airline meteorologist was enshrined in standardized routine.

The Effect of Commercial Airlines on Academic Meteorology

Although there were fewer than 100 airline meteorologists at the start of World War II, aviation exerted a strong influence on the development of the discipline, employing meteorologists like including Jerome Namias, Irving Krick, Mort Rubin, and Horace Byers, who would go on to become leaders in academic and government meteorology.

The early career of Horace Byers is a good example of how aviation’s cultural authority affected the disciplinary development of meteorology. Byers was one of the most important 20th century American meteorologists; a member of the National Academy of Science, he founded the graduate program at the University of Chicago in 1940 and helped manage the expansion of meteorological education and research institutions in the wake of Sputnik. Though he’s best known for having lead the Thunderstorm Project after World War II, for his research on cloud physics, as well as for his extensive work as a teacher, organizer and administrator, his few years as an airline meteorologist powerfully shaped his future career path.53

Between his introduction to meteorology in 1928 and his move to the University of Chicago in 1940, Byers was in regular contact with the airlines. Byers was an undergraduate geography major at the University of California at Berkeley when he began taking observations as a volunteer “cooperative observer” for the U.S. Weather

Bureau in 1928. After the summer working with Rossby on the model airway service, Byers returned to Berkeley, completing his A.B. degree in geography in 1929 and gathering data for his first research paper, “Summer Sea Fogs of the Central California Coast,” which addressed a key problem for the airline flights between Los Angeles and Oakland. After receiving his bachelor’s degree, Byers secured a fellowship from the Guggenheim Fund for the Promotion of Aeronautics to become Rossby’s first graduate student, and earned his M.S. from MIT in 1932 for a study of the characteristic weather phenomena of California. Byers then returned to California to work as a research assistant at the Scripps Institution of Oceanography under the direction of Harald Sverdrup. After a semester, however Byers returned to the airline weather service he and Rossby had created. Western Air Express had been purchased and expanded, and was now called Transcontinental and Western Airways and owned by the General Motors Corporation. Byers developed an extensive series of lectures and notes for teaching the Bergen techniques to TWA’s personnel. After a year with as an employee of a GM subsidiary, Byers became eligible for an Alfred Sloan fellowship, which supported his continued studies at MIT. Byers completed his doctorate degree in 1935, writing a dissertation on “The Changes in Air Masses during Lifting.”

The general expansion of aviation during the 1920s and 1930s had pushed the Weather Bureau to expand its upper air observations and incorporate the methods of the Bergen School. Byers’ expertise, developed with Rossby at the Weather Service here came into play. In June of 1935, the bureau appointed Byers to head a new Air Mass Analysis Section. For the next five years, Byers taught small groups of Weather Bureau forecasters about fronts, air mass analysis, and how to incorporate upper air data into
their forecasts. In 1940, Byers was detailed to Chicago to establish a new forecasting center. He left the Weather Bureau soon after, to become the founding faculty member at a new Institute of Meteorology at the University of Chicago; Rossby followed him and became director of the Institute.

Byers’s greatest influence on the disciplinary culture of American meteorology can be seen by analyzing his textbook *Synoptic and Aeronautical Meteorology*. Byers’s book is one of the key textbooks in the history of American meteorology. It went through four editions between 1937 and 1974, and is still widely held in research libraries. Expanded and retitled *General Meteorology* in 1944, it was the primary text used for instructing the roughly 6,000 weather officers trained for military service during WWII, a generation of men who dominated meteorology for the next 30 years. Even today, any roomful of senior or recently retired American meteorologists is likely to find several or many who used the last edition of the book.

*Synoptic and Aeronautical Meteorology* emerged from the work practices of airline meteorology. As Byers noted in the preface, the “preparation of this book was carried out at the suggestion, and under the auspices, of Transcontinental and Western Air, Inc., and is based on a course given to the personnel of that company by the author during the year 1933-1934.” The book began as Byers’s notes for teaching the new methods in meteorology to TWA personnel, and the airline actually owned the copyright to the 1937 edition. Byers prefaced his 1937 edition by noting that it was for “pilots and

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54 Textbooks are one of the most accessible sources for helping us to understand what instructors hoped to teach their students, revealing how they learn what kind of knowledge they should aspire to create, how they should conceptualize their objects of study, what constitutes praiseworthy forms of explanation or of practice. For more on the role of textbooks, see Thomas Kuhn, *The Structure of Scientific Revolutions* (1962); M. Susan Lindee, “The American Career of Jane Marcet's Conversations on Chemistry," *Isis* (1991): 8-23; and David Kaiser, *Drawing Theory Apart* (University of Chicago Press, 2003).

students of meteorology who wish to begin a study based on the newer methods of
synoptic meteorology, called, in general, the air-mass analysis system.” He noted that this
book was intended to build upon a previous introduction to meteorology, “such as that
given in aviation ground school.”

At the heart of the book are the key Bergen themes, using air masses and fronts to
model the three-dimensional physics of the atmosphere. Byers wrote that, “the modern
application of the principles of physical hydrodynamics to the weather has given
conclusive evidence that the vertical components of air motions are the principle factors
in the producing the more important meteorological phenomena.” Air masses “profundly influenc[ed] weather conditions as they migrate.” The book included a careful description
of the conditions pilots would experience in the upper air as they flew through warm and
cold fronts. Physical models of the atmosphere also suggested that it was possible to
predict the weather through calculation, with the same kind of impersonal objectivity
(though much less precision) that astronomers had in predicting the location of planets.
Byers’s chapter on weather forecasting included formulae for calculating the
displacement of fronts, for instance. Other chapters in the book explain atmospheric
phenomena of key interest to aviators, such as fog and the formation of ice, in terms of
air masses and fronts. Since TWA flew the central transcontinental route, taking its
planes over the heart of the Dust Bowl, the text also includes a chapter on the causes and
aerological effects of dust storms.

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58 This chapter is one of the surprisingly few efforts by interwar American meteorologists to address the
Dust Bowl. During his time at TWA, Byers worked with TWA meteorologist Gordon Parkinson to
understand the problems that dust storms posed to airline traffic. In a 1936 article in the *Bulletin of the
The 1944 edition of the textbook shows the extent to which aviation had become the central concern of the American meteorological community. Now titled *General Meteorology*, the book included plenty of new material, including a chapter on hurricanes, as well as several introductory chapters examining the effect of solar radiation in driving the behavior of the Earth’s atmosphere. Yet it was notable for not focusing on topics like frost forecasts for orchards, the relationship between weather and human behavior, or atmospheric acoustics, subjects that were included in earlier American general meteorology texts.\(^6\) It did include a chapter dealing with cold waves, another common and important topic in American general meteorology texts, but it sought to explain these events in terms of the free atmosphere. Chapter XVI, “Highs, Lows and the Upper Air,” framed middle latitude heat waves and cold waves as secondary effects of

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*American Meteorological Society*, Parkinson made a detailed study of dust storms on the Great Plains, analyzing them in terms of air masses and incorporating observations made by pilots as they flew through and around the brown clouds. The paper begins by exploring the sources of the Dust, noting that precipitation records showed drought conditions throughout the Western Plains states for several years prior to May 1935. He noted that the majority of storms occurred in late winter and spring, when strong winds blew over barren soil, following farmers’ plowing, disking, and harrowing the earth to prepare it for spring planting. Parkinson had been stationed in Amarillo, Texas during 1930 and early 1931, and then transferred to Kansas City for the rest of the 1930s. After Byers moved from TWA to the Weather Bureau, he wrote a short article that used soil analysis by the Soil Conservation Service to track the continental movement of the dust storm of February 1936. Byers used Parkinson’s paper as the basis for the final chapter of *Synoptic and Aeronautical Meteorology*. While this textbook went on to play an important role in the history of American meteorology, the dust storm chapter met a very different fate. G.R. Parkinson, “Dust Storms over the Great Plains,” *Bulletin of the American Meteorological Society* 17 (1936): 127-135. Harry Wexler, “A Note on Dust in the Atmosphere,” *Bulletin of the American Meteorological Society* 17 (1936): 303-305. Horace R. Byers, “Meteorological History of the Brown Snowfall of February 1936,” *Monthly Weather Review*, March 1936: 86-87.

\(^{50}\) I explore reasons for this lacuna in “Where is the Dust Bowl in American Meteorology? Explaining a Curious Absence.” Climate Change Science, Environmental Challenges, and Cultural Anxiety: Historical Perspectives, April 3, 2009, Colby College.


the behavior of air masses and fronts. Dust storms almost disappeared from the 1944 edition, receiving only a short mention in the context of a chapter on “atmospheric turbulence and the wind structure near the surface of the Earth.” More revealing is the change that took place in the discussion of air masses. In 1937, one chapter was titled “Air-Mass analysis of the synoptic chart,” while in the 1944 edition, practically the same text had become more general—air mass analysis had become the basics of the whole field, so that the same text was now titled “Technique of synoptic-chart analysis.”

In support of aviation, the Bergen School had changed the epistemic hierarchy of atmosphere. The weather that people experienced at the surface became a secondary phenomenon, while the primary cause of weather (and thus the key object of meteorological explanation) was the general circulation of the atmosphere.

Conclusion

During the interwar period, aviation became an essential part of the American transportation system, carrying urgent mail and a modest number of passengers across the country. Troubled by fog, squall lines, and turbulence, the airlines turned to aeronautical meteorology to help make flight reliable and safe. The operational needs of the airline industry enabled Rossby, initially to plant the Bergen School in the United States. Rossby and his students could then use airline support to show the effectiveness of Bergen School concepts, and to produce textbooks and operational procedures. But while the airlines could afford to hire experts to analyze the weather for their operations, gathering the data on which that analysis depended required a large expenditure and huge organization. Running the environmental surveillance system essential to airline safety
was the job of the US Weather Bureau, and it remained the dominant institution in American meteorology. And it was hesitant to displace the attention to local and surface conditions for a headlong rush into calculating the weather. Only by converting the Weather Bureau could the apostles of the Bergen School make the upper air the center of American meteorology. It is to that institutional struggle that we turn next.
Chapter Three

Institutionalizing Aeronautical Meteorology:

Connecting Research and Operations

Airline meteorologists’ efforts to find the friendly skies during the 1930s relied on two innovations: widespread observations of the upper air, and practices of knowledge making that could translate those observations into meaningful statements about the atmosphere’s behavior, connecting research with operations. The first of these tasks, monitoring the upper air, became a core task of the Weather Bureau, a central part of the Bureau’s burgeoning role in aviation support. The development of this observation network was guided by advances in meteorological theory. At the same time, the expanding observation system provided data useful for further theorizing and forecasting.

Because the Weather Bureau was by far the most significant meteorological institution in America from the 1870s through the 1920s, Carl-Gustaf Rossby and his students desperately wanted the Bureau to utilize their theories and methods in crafting forecasts. However, as theorizing about the upper air became increasingly important to researchers, it exposed significant social, epistemological and educational gaps between the small but growing group of academic researchers and the practical forecasters who populated the Weather Bureau. The result was a campaign by the theorists, to remake the Weather Bureau as a “modern” scientific organization. Theorists pushed the Bureau to hire men with graduate training in meteorological theory, and preferably to give those trained men leading roles in improving the Bureau’s services. Yet once inside the
Bureau, young dynamic meteorologists found few rewards. They were asked to teach the complicated new methods to senior forecasters with decades of experience and no institutional incentive to change their work practices. The Bureau had a well-established institutional culture quite different from the privileging of research and abstract theory that characterized the group of academic meteorologists that grew around Bergen School emigrants.

The group of theoretically-trained American meteorologists who sought to appropriate the Weather Bureau had emerged from a group of new institutions, in particular the meteorology program established in the aeronautical engineering department at MIT in 1928, and the American Meteorology Society. Rossby played a major role in steering both these institutions towards theoretical research. As the MIT program’s first professor, Rossby oversaw its elevation from a program to a stable department engaged in an extensive research program. The American Meteorological Society, founded in 1919 in part to offer a forum for the men who had been trained during the Great War, became an increasingly professional organization beginning in the mid-1920s, and offered an institutional form parallel to but independent of the Weather Bureau, though many of its members and officers were Bureau men. Encouraged by Rossby, AMS meetings provided a forum for discussing advances in meteorological theory, while its *Bulletin* provided a new journal for publishing research, one independent of the primary American meteorological publication, the Weather Bureau’s *Monthly*
Weather Review. At Rossby’s urging, the AMS established an award to recognize promising young researchers.¹

Institutional history is crucial to understanding infrastructural science. To understand the rise of the Bergen school, to see how aeronautical meteorology in particular emerged as an infrastructural science, we need to explore the institutions in which it flourished, and the institutional cultures that made atmospheric physics a fruitful pursuit. To understand the processes central to infrastructural science more generally, we have to study the physiology of the organizations that coordinate observation networks and manage forecast production. Finally, to understand how infrastructural science enables powerful material interventions, we need to reassess the various kinds of work that scientists perform. We need to see institution building itself as a crucial kind of scientific labor. This chapter examines how the development of an influential group of academic theorists reshaped the way that weather was observed, predicted, and conceptualized in the United States during the 1930s.

Seeing the Weather: The US Weather Bureau in the 1920s

In the five decades following the establishment of a national weather service in 1871, the US Weather Bureau grew into the dominant American meteorological institution.² While a few independent observatories collected weather data, University graduate programs in meteorology were basically non-existent, and few other institutions

¹ This was the C. Leroy Meisinger Award, named after a young Weather Bureau researcher killed by lightning in 1924 while making a research balloon ascent.
played a role in meteorology. As late as 1940, the Weather Bureau employed over two-thirds of all the trained or experienced meteorologists in America. As the agency that controlled the observational network and the nation’s climatology records, the Weather Bureau played the key role in organizing and administering American meteorology, linking nearly all Americans paid to theorize about and forecast the weather.

In part this dominance came from money. Within American meteorology, only the Weather Bureau had a significant and reliable source of funds. While congressional appropriations were never adequate to meet the demands placed on the Bureau, and became particularly inadequate as aviators required more extensive upper air observations during the 1930s, the Bureau’s budget towered above all the other sources of funding for meteorology in the interwar period. In 1923, the Bureau’s appropriation was a bit over $1.9 million, while by 1932, it had swelled to just under $4.5 million. In comparison, the new meteorology graduate program at MIT in 1928 depended upon a $34,000 grant from the Guggenheim Fund. On the public stage, the Weather Bureau was nearly synonymous with orthodox meteorology. The Bureau issued the forecasts that appeared in newspapers and it was the first authority journalists consulted when judging the validity of meteorological claims. The title of a 1920 children’s book suggests how

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5 Others included the Blue Hill observatory. Some teaching and research into weather and climate occurred in geography departments, as at Clark University and by Charles Brooks at Harvard (Koelsch, "From Geo-to Physical Science"). On journalists and the validity of meteorological claims, see Clark C. Spence, The Rainmakers: American "Pluviculture" to World War II (Lincoln: University of Nebraska Press, 1980). For more about the Weather Bureau before the transfer to civilian control, see James Rodger Fleming, "Storms,
inseparable weather science was from the organization that controlled it: “Gilbert Weather Bureau (Meteorology) For Boys.”

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

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6 This book was intended to drive sales of the A.C. Gilbert Company’s Weather Bureau set, a collection of meteorological instruments. The advertisement at the back of the book encourages boys to, “Learn to use the Gilbert Weather Bureau to read weather indications from instruments set up by yourself … Your boy friends will listen to you with interest when you explain to them the cause of storms and how important it is to have a knowledge of climatic disturbances.” Alfred C. Gilbert, Gilbert Weather Bureau (Meteorology) for Boys (New Haven: The A. C. Gilbert Company, 1920): 85.

The Bureau’s daily forecasting practice depended upon visual techniques for analyzing synoptic weather maps. These techniques had developed alongside the telegraph-based observing network in the years after the establishment of the Signal Corps weather service in 1871, and had changed little over the decades. According to historian Donald Whitnah, “the general forecasts of 1933 did not vary basically from those of 1871. The movements and relationships among areas of high and low barometric pressure formed the primary source of Weather Bureau prognostications.”

Synoptic weather maps revealed pressure area movements and the daily production and interpretation of synoptic maps formed the base of a Bureau man’s knowledge of weather. The map was constructed twice a day, based on morning and evening observations. As a torrent of weather observations flooded over the telegraph lines from remote observing stations each morning, map plotters or junior meteorologists at the forecasting stations wrote the data on pre-printed blanks. Then the station’s “meteorologist-in-charge” (usually the most senior forecaster) would analyze the chart and dictate a forecast. Observing stations were widely dispersed, however, and a useful weather map depended upon the continuities of barometric pressure areas, of isothermal lines and bands of precipitation. In creating and interpreting weather maps, forecasters routinely used interpolation and educated intuition. This practical knowledge slowly developed from the daily routine of watching the play of weather observations across a map of America.

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

The Weather Bureau’s recruitment and training practices reinforced the development of forecasting through practice. Lead forecasters typically worked their way up from Junior Observer after entering the Weather Bureau with a high school education. New weather forecasters were promoted from the ranks, “by choosing the

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10 Ibid.: 3.
12 Writing in the early 1990s, university-trained, theoretically attuned Jerome Namias felt differently: “*Weather Forecasting in the United States*, written by top forecasters of the U.S. Weather Bureau, contained hundreds of charts and rules for forecasting, empirically derived and completely lacking in interpretation. Many of the rules seemed contradictory. The book was frustrating to read and, though published in 1916, was studied by few. After just a few years, the book was already a relic, only of historical interest.” (Jerome Namias, “Francis W. Reichelderfer,” *Biographical Memoirs of the National Academy of Sciences*, v. 60 [1991]: 272-291, quote on 275.)
13 Bates, “Formative Rossby-Reichelderfer Years.” Charles L. Mitchell, one of the Bureau’s leading forecasters in the 1930s and 1940s described his career track when testifying before Congress at the Akron crash hearings. (Joint Committee to Investigate Dirigible Disasters, *Investigations of Dirigible Disasters: Hearings before a Joint Committee to Investigate Dirigible Disasters*, 1st Session, 1933: 197.) See also the reminiscences of Jack Thompson, an Observer in the Weather Bureau during the late 1920s and 1930s. (Jack C. Thompson, "Weather Prediction at the Local Weather Bureau Office as Concepts from the Bergen School Came to the U.S.,” *Bulletin of the American Meteorological Society* 66, no. 10: 1250-1254.)
winners of contests in making daily practice forecasts.”

With little formal education or opportunities in meteorology available outside the Weather Bureau, seniority—rather than education or research attainments—largely determined status. Keeping one’s intellectual and social distance from unorthodox theories of forecasting demonstrated the sobriety that distinguished a reliable weatherman. Successful careers were made by observing instruments carefully, plotting maps accurately, and forecasting responsibly.

Despite its conservatism, the Bureau hoped to see the expansion of meteorological education in the United States. But the real driving force behind creating new places for meteorological education in the 1920s came from the Navy, particularly Francis Reichelderfer, the Navy’s head aerologist.

**Meteorology at MIT**

Francis Reichelderfer’s knowledge of meteorology came from the Navy’s need to support flight. He had joined the Navy during World War I, after completing a chemistry degree at Northwestern, and learned meteorology through the Navy’s emergency training program under Alexander McAdie at Harvard, before being posted to the Canadian Atlantic coast to support coastal patrol flights. Even as nearly all of his colleagues returned to civilian life as the military demobilized, Reichelderfer chose to stay on in the Navy after the war to expand on the potential he saw in the future of aviation and meteorology. He began by learning to fly himself. Reichelderfer became an important part of the Navy competitive ballooning teams that entered into national and international races. During the early 1920s, he became head of the Navy aerology office, working out

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14 Whitnah, *History of the Weather Bureau*, 159
of the Bureau of Aeronautics in Washington, and supervising a handful of lieutenants and about fifty enlisted men who took weather observations and supported flying observations at Naval Air Stations, as well as the Navy’s expanding lighter-than-air operations.¹⁵

As part of his duties in the aerology office, Reichelderfer was also responsible for meteorological training. He began by establishing some temporary courses through the Navy Postgraduate School. However, feeling the program needed to be more strongly institutionalized, that the Navy’s needs could better served through a proper academic and scientific education in meteorology, and that the US needed a research program in meteorology, Reichelderfer developed a plan and began shopping for a school. He initially approached Harvard, which had traditionally been allied with the Navy, and which hosted the Blue Hill meteorological observatory. Harvard’s Robert DeCourcy Ward only felt himself qualified to teach climatology, however, and the University did not embrace the opportunity. Keeping his focus on Cambridge, Reichelderfer turned to MIT. While MIT had no meteorologists on faculty, Reichelderfer knew one who was available: Rossby, whom he had met while visiting the Weather Bureau to obtain the daily weather map.

Using his connections through the Naval Postgraduate School, the Weather Bureau and the Guggenheim Fund for the Promotion of Aeronautics, Reichelderfer began lobbying for the creation of a meteorology course at MIT with Rossby as its leader.

At the end of May 1926, the head of the US Navy Postgraduate School sent the MIT administration a copy of the proposal for a meteorology program originally sent to Harvard.\textsuperscript{16} During the spring of 1927, leading men in the Weather Bureau prepared letters recommending Rossby to MIT. William Humphreys, one of the few research-oriented senior figures in the Weather Bureau (his title was “professor of meteorological physics”), asked his friend G.K. Burgess, of the Bureau of Standards, to pass along a recommendation to MIT president S.W. Stratton. Rossby was “much better prepared to teach advanced meteorology than any other man now available in this country,” Humphreys said, because of his “knowledge of meteorological phenomena, and exceptional training in mathematical physics.” Rossby also had initiative, “and yet admirably adapts himself to cooperation, or teamwork. Furthermore he is companionable and in every way a gentleman.”\textsuperscript{17} Weather Bureau chief Charles Marvin echoed these sentiments, saying “I know of no young man, whether in this country or abroad, better equipped to teach meteorology as it should be taught, than Mr. Rossby. Furthermore, he is thoroughly gentlemanly in his behaviour, mixes well, and has an excellent command of English. This is a most exceptional opportunity to obtain a teacher of scientific meteorology.” He also emphasized the Bureau’s interest in exploring a different approach to teaching meteorology: “the Weather Bureau has long endeavored to have meteorology taught in American universities as a branch of physics and mathematics rather than as a


\textsuperscript{17} WJ Humphreys to GK Burgess, 3/8/27, AC 13, b. 29, f. 493.
part of the sections devoted to geology and geography, as is the usual custom.”

Marvin even went so far as to sound out Rossby regarding his salary expectations.

Then MIT institutional politics intervened. By July, as Rossby’s fellowship from American-Scandinavian Foundation ran out, he felt confident enough to write to President Stratton with an ultimatum. Rossby said he had received an offer from another institution (“without any solicitation on my part”) and asked if MIT was still interested in hiring him. But Charles Norton, head of the MIT Physics department, did not see meteorology as a departmental priority. While acknowledging that Rossby was a good man and the physics department would be glad to have him, Norton saw meteorology as an unaffordable luxury. Rossby became a full-time employee of the Guggenheim Fund instead, leaving for California to establish the model airway weather service.

Reichelderfer switched tactics. To sidestep financial constraints, he began lobbying for a meteorology program within MIT’s aeronautical engineering program, to be funded by a grant from the Guggenheim Fund. Late in 1927 Edward Warner, formerly Guggenheim professor of aeronautics at MIT, now assistant secretary of the Navy for Aeronautics and an advisor to the Guggenheim Fund, let Harry Guggenheim know that the Navy needed a good training course for its weather forecasters. Fishing for financial support from “some public-spirited citizen or organization like your own,” Warner sought a “fully rounded course to prepare men for meteorological work either in the services or in civil life.” Warner sent a copy of the program description to President Stratton as well. Stratton endorsed the proposal, telegraphing “Will proceed at once, preferably in

18 CF Marvin to SW Stratton, 4/4/27 AC 13, b. 29, f. 493.
19 Charles Norton to SW Stratton, 7/7/27. AC 13, b. 29, f. 493.
20 Edward P. Warner to Harry F. Guggenheim, 12/7/1927. DGFP A.
connection with aeronautics as physics has not shown much interest heretofore when this work was proposed.” The MIT executive committee then approved hiring a meteorology professor, and Stratton asked Warner to recommend someone to fill the job. Warner’s lobbying of the Guggenheim Fund succeeded. On June 18, 1928, the Fund approved a grant to establish a meteorology program. MIT received $34,000 total, to pay for three years worth of: salary for one professor ($4,000/year), three graduate fellowships ($2,000/year), $2,000 per year of research funds, and one time expenses of $10,000 to buy equipment.

Reichelderfer’s efforts had been successful at last. Rossby reported for work on September 7th, bringing with him the vigor and overwhelming enthusiasm that marked his entire career. The classes he taught were small, usually three or four Navy officers and one or two graduate students. Horace Byers became the program’s first graduate student, while Jerome Namias, Harry Wexler, and Athelstan Spilhaus all studied at MIT during the 1930s. Their distinguished careers in geophysics are a testament to Rossby’s considerable skills in mentorship. Rossby’s charm and generosity marked his teaching. Horace Byers recalled that Rossby’s “informal discussions over luncheon or a cup of coffee … were nothing less than an inspiration.”

Rossby’s most important research occurred during the ten years he spent at MIT. This work focused on exploring the influence of upper air conditions upon the movements of air masses. Working from the increasing number of upper air observations

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21 Stratton to Warner, AC 13, b. 21, f.619.
22 Guggenheim Fund to SW Stratton, 6/18/28. AC 13, b. 29, f. 493.
being taken around the northern hemisphere (and some of which he arranged in the
Boston area), Rossby developed techniques for identifying and tracking air masses. By
charting constant potential temperature (isentropy), the boundaries of air masses could be
identified and followed over time. To understand what caused the movement of air
masses, Rossby returned to the rotation of the earth, and its effect on the general
circulation of the atmosphere. From upper air observations, he teased out a pattern of
enormous tongues of low pressure, reaching downward from the pole. These large-scale
atmospheric disturbances, he realized, were waves that had periods of a few days, the
same order as many substantial changes in weather. Following a line of mathematical
reasoning that stretched back to Laplace’s theory of ocean tides and through a theorem of
Hermann Helmholtz, Rossby developed an equation that could be used to calculate the
movement of these waves, later known as “Rossby Waves.” The equation, published in
1939, accounted for shifts in the upper-level westerlies, the steering winds which guided
air masses. The result made Rossby world-famous amongst physicists studying the
atmosphere.25

Rossby’s research program was defined by expansion and continual new plans for
the “modernization of American meteorology.”26 As early as his second semester, Rossby
managed to add an assistant professor in Hurd C. Willet, a former Weather Bureau
observer and one of the few American meteorologists with a Ph.D. (Physics, George
Washington University), as well as secure additional university funds to pay for a

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(New York and Oxford: Oxford University Press, 1996); Carl-Gustaf Rossby et al, "Relation between
Variations in the Intensity of the Zonal Circulation of the Atmosphere and the Displacements of the Semi-
26 Rossby to Stratton, 11/5/28, AC 13, b. 29, f. 493
radioman to receive and plot upper air observations taken by the Weather Bureau. He also hired an assistant to work at MIT’s Round Hill Observatory and spent $2,000 on new equipment.  

The Guggenheim committee’s interests strongly shaped meteorological research at MIT, though given Rossby’s force of character, he tended to be the dominant personality on the Guggenheim committee. For example, Warner encouraged Rossby to address a new issue of considerable commercial and military importance: “Hope you will also give consideration to development of instrument for analyzing atmospheric structure and movements at various altitudes this is a problem of enormous importance for airship development and hardly a beginning has as yet been made.” Addressing another interest of the Guggenheim committee on aeronautical meteorology, the characteristics of fog, Rossby asked President Stratton to assign a professor from electrical engineering and another from chemistry to assist him and Willett. This study sought to understand fog, in the hopes of eventually developing an effective means of artificial fog dissipation. Fog would remain an important subject of research at MIT through the early 1930s.

In his first year, Rossby made clear the elements of his institution building strategy. During his ten years at MIT, he recruited additional faculty attracted private graduate students, established a burgeoning line of research projects, and trained the Navy aerology officers who were the program’s original raison d’être. Rossby’s research program included a dedicated airplane used to make upper air observations over Boston, collaboration with the Woods Hole Oceanographic Institution on the boundary layer

28 Telegram, Warner to Rossby, 2/15/29. AC 13, b. 29, f. 494.  
29 Rossby to Stratton, 3/15/1929. AC 13, b. 29, f. 494.
between the ocean and atmosphere, and investigation into long-range forecasting, ostensibly in response to drought in the Dust Bowl region. 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. Though the Great Depression limited his ambitions, Rossby managed a complex agenda as he built MIT into a world-leading center for meteorological research and education.

Institutional Exchanges

One of Rossby’s key strategies for promoting intellectual change was one that he had inherited from Vilhelm Bjerknes: institutional exchanges. Rossby himself toured Europe in the summer of 1930, spending ten days with his colleagues in Bergen, attending the International Geophysical Union meeting in Stockholm, studying techniques of upper air observation at Lindenberg and Templehof Airport in Berlin, and catching up on developments in dynamic meteorology and turbulence in Vienna, among other stops across central Europe.\(^\text{30}\) As early as March 1929, Rossby suggested that a Navy aerology student should be sent to study European methods. Rossby suggested one of his first students, asserting that

This year’s graduates in aerology from M.I.T. form the first group which has ever been given the thorough course in the theoretical aspects of meteorology. They are therefore capable of conducting independent research work, keeping the fundamental problems of meteorology in mind, whereas the practical aerologists taken direct from the naval service may well be acquainted with instruments and the daily routine work but hardly have an eye open for the fundamental problems of meteorology.\(^\text{31}\)

\(^{30}\) Rossby, Proposed itinerary, 3/10/30. AC 13, b. 29, f. 494.

\(^{31}\) Memo, Rossby to Stratton, 6/18/1929. AC 13, b. 29, f. 494.
The head of the Bureau of Aeronautics, Admiral William Moffett, disagreed. Moffett demanded an officer with “a thorough education in meteorological and aeronautical subjects who has also had considerable practical experience.” Moffett sent Reichelderfer. It was on this tour that Reichelderfer directly encountered the Bergen school.

Reichelderfer spent six months in Bergen in 1931–1932, working with Jacob Bjerknes, Tor Bergeron, and Sverre Petterssen to analyze both American and European weather maps. Promptly, Reichelderfer became a conduit for Bergen methods. His summary, *Report of Norwegian Methods of Weather Analysis*, became an informal bible. Though marked “Restricted,” mimeographed copies circulated among Army and Weather Bureau forecasters in addition to Navy officers.32

Rossby also brought the Bergen School to MIT in person. He asked President Stratton for permission to invite Harald Sverdrup to MIT for a series of lectures in late May, 1930, describing Sverdrup as “Director of the Geophysical Institute, Bergen, Norway, for seven years leader of the scientific work of Amundsen’s Maud Expedition to the Arctic, and one of the outstanding meteorologists and oceanographers of our time.”33 Rossby also arranged for Jacob Bjerknes to lecture at MIT in 1933 and 1939, and secured both Sverre Petterssen and Jörgen Holmboe to join the faculty. Petterssen took over for Rossby as chair when Rossby took a leave of absence to work in the Weather Bureau in 1938. In fact, the presence of so much of the Bergen School at MIT gave Jacob Bjerknes an excuse to avoid a large commitment to the institute during his 1939-40 tour of North

33 Rossby to SW Stratton, 4/28/30. AC 13, b. 29, f. 494. Stratton responded by cautioning Rossby about the perils of the American Academic calendar: “you will find it very difficult indeed to get together students for special lectures during the month of May. The fine weather and the preparations for final examinations seem to have the right of way.” He allowed Rossby to invite Sverdrup for a single lecture on May 23rd, provided Rossby saw to it that Sverdrup had a reasonably good audience. 5/1/30 AC 13, b. 29, f. 494.
America. Rossby noted wryly that Bjerknes preferred not to spend too long at MIT, “since he feels that the Department then would become practically a Norwegian institution, both Petterssen and Holmboe being Norwegian citizens.”

Not all Rossby’s exchanges were so dramatically successful. Indeed one of Rossby’s most interesting attempts at institutional exchanges failed completely, with important consequences for the future of American atmospheric science. C. Warren Thornthwaite (1899-1963) had trained in geography Ph.D. under Carl Sauer at the University of California, Berkeley. During a peripatetic career that took him to the Universities of Oklahoma and Pennsylvania, the Soil Conservation Service in the Department of Agriculture, and finally a major commercial farm in New Jersey, Thornthwaite developed a vision of climatology that connected human behavior, plant physiology and climatic variation across many scales. He consistently took an integrative, interdisciplinary approach as he sought to measure climate from the point of view of individual plants or discuss the role of drought in human migration from the Great Plains. In addition to climatology, Thornthwaite was quite familiar with advances in meteorology (his first scientific paper was “The Polar Front in the Interpretation and Prediction of Oklahoma Weather,” in 1929), and Rossby attempted to recruit him to teach at MIT in 1939. Rossby had been hoping to expand MIT’s meteorology program by adding Oliver Wulf to address atmospheric chemistry, and Thornthwaite for agricultural meteorology. Thornthwaite wanted too high a salary, according to Rossby’s initial

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sounding, so Rossby turned his attention to Thornthwaite’s colleague John Leighly. Rossby proposed a one-year exchange with Berkeley. However, Carl Sauer, the head of the Berkeley Geography department, vetoed this plan saying students needed more time to plan their course of study, and so he could not let Leighly leave without at least a year’s notice.  

MIT never developed analytical climatology, and Thornthwaite’s vision of an integrative applied climatology remained unfulfilled. His decline to move to MIT at this crucial juncture meant that he spent the rest of his career outside of the emerging networks that controlled American atmospheric science.

*Upper Air Observations: By Plane and Balloon*

Directly monitoring the upper air would begin to provide Rossby with the data he needed to understand the physics behind the atmosphere’s hemispheric circulation. To produce the knowledge that would help make possible technological system of flight required a technological system of its own. Beginning in November 1931, he organized a program of upper air observations, and adjusted his program through the 1930s in response to changing technologies for accessing this remote environment.

Rossby began with a light airplane, a Warner Cessna, purchased for $5,000 using the Guggenheim Funds, and based at the East Boston Airport. “The primary object of the daily flights,” he wrote, “is to collect in routine fashion information regarding the vertical temperature and humidity distribution over Boston. These data will be studied from day to day in connection with our daily weather map colloquium.” His plane would also be equipped with a camera to take pictures of the distribution of fog over Boston and the

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36 Some of this conspiring is documented as early as the Spring-fall of 1939, in AC 4, Box 187, Folder 2: Rossby 1939-45. He was also considering recruiting Thornthwaite to MIT.
harbor area. Dr. Karl Otto Lange was immediately in charge of the plane, while it was piloted by MIT professor Daniel C. Sayre. Charles Stark Draper built the initial instruments, early in a long and influential career aerospace instrument design. All were subject to Rossby’s overall supervision. The Boston observations would fill a gap in Weather Bureau upper air observations, the nearest of which were at Royal Center, Indiana and Anacostia in the District of Columbia. The department would combine these observations with about 1300 kite records, in order to study “the structure and in particular the conservative properties of different American air masses.” Like the work in Bergen during the Great War that had led to the discovery of the Polar Front, Rossby sought to connect daily observations with theoretical insights into atmospheric dynamics.

As the plane had a large capacity, it attracted the interest of other researchers at MIT anxious to get instruments into the air. By June of 1932, in addition to an aerometeorograph strapped to the wing, the plane was also carrying: gas samplers to study the chemical composition of upper air; dust collectors for Harlow Shapley’s studies of cosmic radiation at the Harvard Observatory; insect traps for the Bureau of Entomology; and bacteria plates for MIT’s Department of Biology and Public Health. In applying for grants from the Rockefeller Foundation, Rossby and Karl Compton touted the multiple lines of research the plane supported. Like oceanographic vessels or space satellites, the plane thus initiated interdisciplinary interactions by offering access to an

37 My thanks to Michael Aaron Dennis for sharing a draft of the first chapter of his forthcoming book with me.
38 Memo, Rossby to Compton, 11/18/31. AC 4, B. 147, F. 11.
39 Letters between Rossby, Compton and Max Mason, AC 4, b. 147, f. 10.
otherwise inaccessible environment. These interdisciplinary connections, in turn, stabilized and strengthened Rossby’s own institution.

**Collaboration with Woods Hole**

As Rossby organized coalitions of institutions around specific technologies, he was also organizing coalitions around specific questions. In the late 1920s, Rossby became interested in physical oceanography, since the oceans, like the atmosphere, had large-scale waves. By 1931, Rossby had reached out to Woods Hole Oceanographic Institution, initiating contact between the MIT and the research center 75 miles to the south. Rossby was appointed “associate in dynamic oceanography,” and by December 1931 Woods Hole was paying him $1,250 per year (in addition to the $6,000 he was than making from MIT). He began a joint publication program for research papers on dynamic meteorology and oceanography, with the two institutions chipping in cover publishing costs. The collaboration supported the doctoral studies of Raymond Montgomery in dynamic oceanography. One of the key outgrowths was the development of the bathythermograph by Rossby’s student Athelstan Spilhaus. Spilhaus was a bold South African who parachuted behind enemy lines to make weather observations during World War II, drew a widely syndicated science education comic strip from 1957-1973, led Institute of Technology at the University of Minnesota, presided over the Franklin Institute, and Served on a wide variety of government advisory panels. The

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41 Rossby, “Memorandum Concerning Present status of meteorological research at M.I.T. and Concerning Proposed Cooperation the meteorological course of the M.I.T and the Woods Hole Oceanographic Institution,” 12/11/31 AC 4, B. 147, f. 11.
bathythermograph became a crucial tool in anti-submarine operations during the war, detecting the sonar-distorting thermoclines that could obscure U-boats. The second key outgrowth was Rossby’s work on understanding the Gulf Stream. His work trying to understand the physics driving the stream, and to develop methods to calculate it, developed in parallel, and addressed many of the same questions and principles, that underlay his more famous work on Rossby waves (discussed below).\(^{42}\)

**Finding Support**

Supporting this expanding research enterprise presented a challenge. Rossby initially looked to a series of familiar private foundations. However, by the late 1930s, when foundation funding began to dry up in the face of the depression, the climatic catastrophe of the Dustbowl presented him with new opportunities. Rossby turned to the federal government, receiving funding from Congress earmarked to support scientific research relevant to the Dust Bowl.

When the initial Guggenheim grant expired in the midst of the economic crisis, Rossby sought several sources of new funds. His first foray was to his old employers. In March, he dashed off a letter to Chief Marvin asking the Weather Bureau to offer a contract that would pay between $7 and $10 for each weather observation flight that reached 3,000 meters above Boston, noting that MIT’s flight data had always been freely shared with the Bureau. Chief Marvin declined the suggestion that he should create such a contract to subsidize MIT, though he did note that the observations were soon going to be sent by teletype to the Central Office in Washington for use in general forecasting, and

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that “the information has been of considerable value, particularly in connection with determining the likelihood of ice formation.”

Rossby then turned to private industry. On Rossby’s behalf, MIT’s new President Carl Compton wrote to aviation dynamo Jerome Hunsaker, then developing a passenger dirigible partnership between Goodyear and Zeppelin, to pay for Rossby to continue a study of “a meteorological project of interest to aircraft operators.” Hunsaker replied that appreciated the study’s value, but needed to “conserve resources for the lean years ahead.” Referencing a recent accident where the Akron was dramatically spun on her nose (fortunately causing only minor damage) he offered to try to persuade the Navy to pay for a technical “report” from general funds.

Rossby next tried to persuade his old patron Harry Guggenheim, now serving as Ambassador to Cuba, to fund a new airplane for MIT. Guggenheim apologized, saying that he had stopped funding aviation work since he became ambassador, but encouraged Rossby to keep up the good work. Rossby next turned to the Rockefeller and Carnegie foundations. Warren Weaver at Rockefeller eventually granted $8,400 to support upper air flights in 1934, describing the project as an "interesting and valuable demonstration,” but warning that the Foundation would not further support the work.

Desperate for funds, Rossby turned to a new source, the Federal Government, and found that the environmental aspects of the economic crisis would prove of enduring value. As the dust storms swept topsoil from the plains and deposited it as far away as Washington D.C., as images of the drought and walls of blowing dust became national

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44 Jerome Hunsaker to Compton, 3/22/32. AC 4, b. 147, f. 10.
45 Weaver to Karl T Compton, 12/19/33. AC 4, b. 147, f. 11.
icons, the plight of farmers and Dust Bowl refugees rapidly became a subject of considerable political importance.

In response to this devastation in the Dust Bowl region, Congress passed the Bankhead-Jones Act, which appropriated funds specifically for research intended to address the region’s problems. The Bankhead-Jones funds supported Rossby’s long-range forecasting group at MIT, which began work in 1937, and moved into the Weather Bureau in 1941. According to Rossby’s assistant and student Jerome Namias, who would take over the project when it moved from MIT into the Weather Bureau, “the government’s interest in the field of long-range forecasting was stimulated during the dust-bowl days.”

Rossby argued that advances in long-range weather forecasting (i.e., more than 2-3 days in advance) would benefit agriculture. Rossby’s group sought to extend forecasts by developing a better physical understanding of the atmosphere’s general circulation, including:

  anticyclogenesis… particularly as related to the influence of lateral mixing; a study of how systems become dynamically unstable; and the development of a theory of flow patterns in the atmosphere as shown on isentropic charts.

By developing theoretical tools to understand the atmosphere’s general circulation, Rossby also hoped to learn to interpret past climate fluctuations. Although his research was funded as a response to the Dust Bowl, in performing it, Rossby was not concerned

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46 Kristine Harper argues the Bankhead-Jones Act brought credibility and funding to the study of long-range weather forecasting, previously a practice of dubious scientific standing but enormous popular interest. Harper, *Weather by the Numbers*: 64.


48 Harper, *Weather by the Numbers*: 64.

49 Harper, *Weather by the Numbers*: 64.

with the Dust Bowl’s actual conditions. Improvements in five-day weather forecasting would likely have been of little use to farmers suffering drought on seasonal to interannual timescales. Predictions of the climate were not part of the project.

Rather than as a practical response to the Dust Bowl, the project should be viewed as an institutional strategy. Rossby used Dust Bowl money to broaden the reach of the Bergen school, by funding his continuing efforts to theorize and model the general circulation. The project’s primary impact, other than sustaining Rossby’s research group during the last years of the Great Depression, was to help launch Namias’s outstanding career in atmospheric dynamics, long range forecasting, and eventually climate research. According to Rossby, however, during WWII the considerable military interest in longer range forecasts would bring this knowledge to the fore.

While Rossby was building a research program, aviation continued to grow, despite the global economic collapse. Between 1928 and 1940, five American universities established graduate programs in meteorology. Following MIT in 1928, the California Institute of Technology established a program in 1933, and Rossby’s student Athelstan Spilhaus led a department at New York University from 1937. These programs were each connected to Guggenheim-funded schools of aeronautics. In 1940 the University of Chicago and the University of California, Los Angeles introduced

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53 Led by Irving Krick, Cal Tech’s program was quite different from the Bergen programs at the other four universities. Despite being Horace Byers’s brother-in-law, Krick was hated by many meteorologists. By the 1950s, his support for unorthodox methods and bold forecasting claims made him a boundary case for acceptable professional behavior. For more on Cal Tech’s program, see J. M. Lewis, "Cal Tech's Program in Meteorology: 1933-1948," Bulletin of the American Meteorological Society 75, no. 1 (1994): 69-81.
professional meteorological instruction. All five programs focused upon preparing students for careers in aviation, and began to send graduates into the Weather Bureau following reforms in the 1930s.

**Reforming the Weather Bureau**

For the emergence of aeronautical meteorology as an infrastructural science, the most important aspect of Rossby’s institutional agenda was his effort to change the practices of the Weather Bureau. Defining modern meteorology as dynamical studies and the methods of the Bergen School, Rossby sought to “modernize” the Bureau.

Aviation helped him with this goal. While Rossby worked at MIT, flying interests called for improvements in the Weather Bureau’s aviation forecasting services. The resulting reforms embraced the values of the Bergen School. By the time Rossby rejoined the Weather Bureau in 1939 as assistant director for research, directives from outside the Bureau had set it on a course towards full adoption of Norwegian methods. University education of young men was the primarily mechanism for spreading the Bergen School.

Though the Air Commerce Act of 1926 directed the Weather Bureau to provide forecasts and warnings useful for aviation, flying grew far faster than appropriations. In the late 1920s, the Bureau struggled to provide adequate observations and forecasts for the nation’s airways. The economic collapse of 1929 also hindered appropriations, though it was not until the first Roosevelt budget that government spending was drastically curtailed. The Weather Bureau lost nearly $2 million, about 45% of its budget,
between the 1932 and 1933 appropriations. Chief Marvin dismissed nearly 500 employees, about 20% of the Bureau’s workforce.  

Even before these cutbacks took effect, the Bureau faced a new and humiliating catastrophe. On April 4th, 1933, the Navy dirigible USS Akron crashed in an unpredicted squall, killing 73, including the head of the Navy’s Bureau of Aeronautics, Adm. William Moffett. Resulting Congressional hearings explored the inadequacies of the Weather Bureau, while highlighting the credibility problems faced by such a public science. In one hearing, Charles Mitchell, the Bureau’s most respected forecaster, battled a Senator who claimed expertise based upon many years of study of Weather Bureau reports, while the committee chairman spoke of meteorology as “this so-called ‘science’.” Later in the hearings, air power advocate General Billy Mitchell argued that the weather service should be rearranged, removed from the government department responsible for “raising onions, potatoes and such things,” and run by the military.  

President Roosevelt took a moderate response, calling upon a new institution: the Science Advisory Board, an institution linked to Rossby through its chair, MIT president Karl Compton. The Board appointed a subcommittee to recommend improvements to the Weather Bureau: one Weather Bureau meteorologist, Charles D. Reed, and three university presidents: Compton, Johns Hopkins’s Isaiah Bowman, and Cal Tech’s Robert Millikan. In addition to being America’s most distinguished physicist, Millikan had

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55 Investigations of Dirigible Disasters: Hearings before a Joint Committee to Investigate Dirigible Disasters, 203-4, 696.  
headed the Army’s meteorology program during the Great War. Bowman was an avid supporter of polar exploration and president of the American Geographical Society.

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

The Weather Bureau’s adaptation to air mass analysis, however, “proved to be a painfully slow process.” The Akron crash ended Chief Marvin’s tenure in January 1934; he officially retired eight months later after fifty years with the weather service. The new chief was Willis Gregg, head of Bureau’s aerology division. Gregg’s promotion made clear the centrality of aviation interests. But while Gregg had been a member of the Guggenheim committee on meteorology alongside Rossby, he remained an insider who

58 Ibid.: 606.
had spent his career with the Bureau. Between 1935 and 1938 the Bureau appointed roughly “a dozen young university men with air mass training.”60 Among these men were Rossby’s students Horace Byers, Harry Wexler, and Stephen Lichtblau.61 Gregg’s choices about how to pay for the new technique may have caused some of the conversion pains. Money intended for salary increases in 1935 was diverted to the new air mass section instead.

A novel by America’s greatest novelist of infrastructure best captured the tension between young university men and senior, experienced forecasters. Based on ethnographic research, George R. Stewart’s best-seller Storm featured a university-trained meteorologist struggling to understand a major winter storm and its effects on California.62 This passage described the Junior Meteorologist’s difficult adjustment to the culture of the Weather Bureau:

He admitted that he had been unhappy in the Weather Bureau; his mathematical training did not seem to help him, and sometimes he thought that it even was a handicap. Sometimes it seemed as if the Chief were only using the same methods that any shepherd might have used back in the time of the Patriarchs; he just

60 Ibid.: 161.
62 The book was favorably reviewed in the NY Times, and selections of the novel even appeared as part of the booklet Boy Scouts studied from to earn their merit badges in meteorology. Storm was a selection of the Book-of-the-Month club, which probably helped it secure a wide readership, and which certainly increased its visibility. The novel’s story resonates with the larger effects associated with the emergence of “middlebrow culture” associated with the Book of the Month Club. As Janice Radway argues in her study of the history of the club, “middlebrow culture and the particular configuration of taste it cultivated developed as a kind of social pedagogy for a growing class fraction of professionals, managers, and information and culture workers as well as for those who aspired to the status of this class, to its work routines, and to its privileges. … [E]ven as the club taught its subscribers how to desire a world in which technical, specialized knowledge would reign supreme, it also implicitly attempted to counter some of the social costs and individual losses that would obtain in such a universe.” Storm beautifully demonstrated how the technical knowledge of specialized professionals had become essential to managing those industrialized lifeways defined by infrastructure and large technological systems. Janice A. Radway, A Feeling for Books: The Book-of-the-Month Club, Literary Taste, and Middle Class Desire (Chapel Hill, NC: University of North Carolina Press, 1997): 15. Weather, Merit Badge Series (New York: Boy Scouts of America, 1943).
looked at the sky, and decided from the appearance of things what weather would come along after a while. The Shepherd, of course, never saw farther than the actual horizon. By the weather map the Chief extended his view for several thousands of miles. There was a tremendous pyramiding of information, but not much change in method.63

To the young men trained in the methods of the Bergen School, the empirical methods of senior forecasters simply looked obsolete—the methods of stubborn old-timers resisting the progress of modern meteorology. Reminiscing in 1981, Jerome Namias took the resistance to Bergen methods as evidence of the Bureau’s “provincial and narrow view.”64

To the experienced forecasters responsible for issuing reliable forecasts on tight schedules, however, the intuitive processes refined through years of practice represented a skilled judgment that couldn’t be learned in a classroom. Running a weather service was different from talking about one. The Bergen School learned this difference when Chief Gregg died from a heart attack in 1938. At the suggestion of the Science Advisory Board, President Roosevelt appointed Francis Reichelderfer to replace him.

Reichelderfer learned of the offer as he entered port aboard the USS Utah.65 Not only was

63 George R. Stewart, Storm: A Novel (Lincoln, Nebraska: University of Nebraska Press, 1983 [1941]): 232. While Storm is fiction, Stewart was an eyewitness. Almost an ethnographer in his commitment to realism, Stewart described his research for the book this way: “When a bad storm broke, I took to the road—up to the Pass, out with the Highway Patrol… I talked with the men, and saw what they were doing, and I was sometimes cold and wet and hungry with them.” According to one scholar, Stewart “secured introduction to the staff of the Weather Bureau in San Francisco, visited them during storms, and learned to draw his own weather maps.” (John Caldwell, George R. Stewart, vol. 46, Boise State University Western Writers Series (Boise, ID: Boise State University, 1981): 30.) Jack Thompson, a meteorologist in the San Francisco office during the 1930s, remembered Stewart as a “familiar visitor around the office for a while” (Thompson, “Local Weather Bureau Office,” 1252).
64 Namias, "The Early Influence of the Bergen School on Synoptic Meteorology in the United States," 492.
65 Biographers have occasionally noted that Reichelderfer gave up a promising navy career in which he was second in command of a battleship. While he was second in command, his ship, the USS Utah, had been decommissioned as a battleship following the London Naval Treaty of 1925. The big guns were removed, radio steering gear and extra armor were added. The ship became a mobile target. By 1938, when Reichelderfer was serving aboard, Utah had been fitted with various small guns to serve as an anti-aircraft training vessel. Utah retained her target capability, however. In August, 1937 she was pummeled by 40
the 43 year-old Navy Officer not a longtime Bureau employee, as the three previous
chiefs had been, he hired Rossby as Assistant Director for research and education.

Reichelderfer proved a conscientious administrator, and he avoided making
wholesale changes to his new organization. The Civil Aeronautics Act of 1938 gave him
a useful tool for gradual change: education. The act directed the Weather Bureau to send
men each year to universities for “training at Government expense… in advanced
methods of meteorological science.” Such men also retained their seniority as they
learned.66 Reichelderfer further reformed the Bureau by addition. Senior forecasters could
continue to forecast as they had, while new methods and new men were added to the
process.

The Department of Agriculture’s 1941 Yearbook of Agriculture: Climate and Man
illustrates these processes of reform. In an early chapter, Reichelderfer laid out the new
goals that marked modern meteorology. In its current stage, expert forecasting remained
“a combination of training, experience and native ability. However, as progress is made
in three-dimensional analysis of the weather and …knowledge of its physical processes…
the science will become more systematic and exact.” Progress would come through
research. Meteorology’s goal was not only better forecasting, but also to diminish the
importance of “personal factors” in the process.67

Rossby’s contribution reiterated the commitment to research as the engine of
progress. In “The Scientific Basis of Modern Meteorology,” Rossby laid out a “semi-

technical” presentation of the physics of Northern hemisphere atmospheric
circulation. “Genetics, soil science and nutrition have all made great strides based upon
important fundamental discoveries,” he argued. “Latest to join this group is
meteorology.”68 Arguing for the primacy of theory, he wrote, “it is safe to say that until
the proper theoretical tools are available, no adequate progress will be made either with
the problem of long-range forecasting or with the interpretation of past climatic
fluctuations.”69 While much of his article seems far too “semi-technical” for the average
reader, he ended his piece with a short demonstration of “amateur forecasting from cloud
formations.”

Though a product of institutions developed for aviation, this 1248 page book was
a public response to a different challenge: the Dust Bowl. It included relatively accessible
essays on a wide range of topics, including “Climatic Change through the Ages,” Climate
and Settlement in Puerto Rico and the Hawaiian Islands,” “Health in Tropical Climates,”
eleven essays on the relation between climate and different crops, “Flood Hazard and
Flood Control,” and “World Extremes of Weather.” A state-by-state climate summary
occupies nearly 500 pages, thick with data tables compiled by Works Progress
Administration relief workers from Weather Bureau records. The book represents a
provocative effort to provide the public with an accessible survey that integrates
knowledge about atmospheric dynamics, agricultural practices, and government policy.

The boldest essay is Thornthwaite’s primary contribution, “Climate and
Settlement in the Great Plains,” which integrated grain prices, climatic data, and the

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68 Carl-Gustaf Rossby, “The Scientific Basis of Modern Meteorology,” in Climate and Man: Yearbook of
Agriculture 1941, ed. F. W. Reichelderfer (Washington, D.C.: Department of Agriculture, Government
69 Ibid.: 600
history of human settlement to argue that the Great Plains are not suitable for the consistent production of grain for export. Both periods of adequate rainfall and periods of extended drought are to be expected in this region. Thornthwaite concluded by advocating constraining agricultural development to fit this climatic reality. Yet from his minor office at Soil Conservation Service in the USDA, away from the influential flood of students soon to be training at MIT, Thornthwaite remained far from the emerging main stream of meteorology. He pointed towards a path that meteorology did not travel, a path bricked up by the exigencies of World War II.

Conclusion

During the 1930s, Carl Rossby developed institutions and a disciplinary culture that would eventually raise the academic status of meteorology. Working at MIT, Woods Hole and the Weather Bureau, and, through his students and colleagues, at NYU, UCLA, and Chicago, Rossby established meteorology as an academic and research discipline in the United States. Rossby used this system of universities as his primary tool for pursuing theoretical research and training colleagues. At the same time however, he recognized the key role of the military and airlines in creating careers for students, and in providing a justification for theoretical research. His academic program grew because they addressed the needs of aviation organizations for specialized technical experts. As American meteorology developed into a research field focused on the realm of flight, it became a respectable science whose practitioners could achieve the presidencies of the National

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Academies, and even Nobel prizes, albeit only for interdisciplinary work like Ozone chemistry. Through these institutional gains Rossby’s work both guided how the upper air would be observed, and used those observations for further theorizing. His work shows the interplay between theory and observation, and between research and operations, characteristic of infrastructural science.

However, this expansion of aeronautical meteorology also led to the rejection of other meteorological subjects and methods. Before aviation, American meteorology’s central topics of inquiry included the relationships between weather and health, agriculture, or human behavior as readily as studies of the structure of the atmosphere. The ineffectual response of American science to the catastrophe of the Dust Bowl suggests some of the dangers inherent in connecting atmospheric science too tightly to the needs of a single technological interest. Aviation captured the American meteorological researchers, focusing them on a narrow set of problems essential to flight, but kept them from the attending to the human dependencies on climate and weather pressing down on refugees from the Great Plains. The abstracting of weather knowledge from personal experience would only be intensified by the coming of another global war.

Robert M. White, President of the National Academy of Engineering, and Ralph Cicerone, President of the NAS, for instance.
Chapter Four

Mass Meteorology: World War II, the Weather Cadets, and the expansion of the Bergen School

“You and your instructors have helped solve one of the Navy’s most important wartime problems—the training of men to carry out the specialized tasks demanded by modern warfare. The importance of your field—meteorology—cannot be over estimated.”

—Admiral John McCain to UCLA professor Joseph Kaplan, celebrating the graduation of a class of military meteorologists in 1942.¹

Enormous numbers characterize every aspect of World War II. The Soviet Union manufactured 36,200 shturmovik attack planes to defend against the German Army, which invested 7,146 division-months (something like 2.6 billion man-days) in combat on the eastern front alone. Japan imported 6,460,000 tons of coal and 2,110,000 tons of rice in 1941, dwindling to just 548 and 201 tons in 1945, as the Allies sank 2,345 Japanese merchant ships. Many were torpedoed by US submarines, of which 53 were destroyed, a number that pales beside the 785 German U-boats sunk, which does not include the 221 more submarines scuttled after Germany’s surrender. The Allies produced over a billion metric tons of crude oil, more than 15 times as much as the Axis. Much of it was shipped across the Atlantic, where between 62 and 131 merchant ships were sunk every month during 1942, totaling 1,170 ships lost that year. The United States produced 4,123,200 metric tons of aluminum between 1942 and 1945, fashioned into

¹ Navy Bureau of Aeronautics to Joseph Kaplan, 12/7/1942. Dept of Special Collections, UCLA, RS 359, Box 136, folder 2b.
more than 35,000 four-engine strategic bombers. Those bombers helped kill perhaps 600,000 European and 1.2 million Japanese civilians, staggering numbers that nevertheless represent less than 4% of the estimated 50 million people who died as result of the war.²

We know some of these numbers with surprising precision because fighting a global, total war required mobilizing technical expertise. Physicists famously contributed to military hardware like radar, the proximity fuse, rocket motors and the atomic bomb, proclaiming the conflict “the physicists war.”³ Many other kinds of technical experts were needed to manage the massive flows of material, money, and people; they mobilized with less notoriety. Applied mathematicians constructed the field of operations research out of their efforts to calculate efficient ways destroy enemy industrial production and convoy war materials across submarine-infested oceans.⁴ Economists worked to devise policies that would control prices and maximize production.⁵ Nutritionists devised systems for rationing civilian food and feeding soldiers efficiently.⁶ Organic chemists investigated the synthetic rubber and enriched fuels crucial to global mobility.⁷ The military and universities negotiated new kinds of contracts for managing

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the relationship between science and the government. To house the bureaucracy that managed these managers, buildings mushroomed in Washington D.C., while across the Potomac the US military constructed the world’s largest office building, with 3.7 million square feet of office space. President Roosevelt insisted the new building’s façade contain no marble, but the Pentagon’s concrete edifice nevertheless became a monument to military management.

Meteorologists too mobilized to help the military control the atmosphere and oceans. The crucial role of meteorology in the success of the D-Day invasion is, of course, its most famous contribution. Thanks to two skilled and lucky forecasts (that nearly went the other way) Allied troops invaded Europe during a tiny window of favorable conditions, catching the defenders off guard since the German meteorologists had predicted the weather would not clear. The Allies’ forecast team included senior meteorologists like the Norwegian Sverre Petterssen, who had cut his teeth forecasting for polar dirigible flights in the 1920s, and Irving Krick, a former airline meteorologist for TWA, and British forecasters with comparable experiences.

Less dramatic, but perhaps even more essential to the war effort in the aggregate were the routine observations, forecasts and weather briefings carried out by junior weather officers in support of the thousands of American planes around the globe. By

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1944, pilots carried the daily synoptic chart with them, using it to find cover from anti-aircraft fire in predicted clouds, or clear landing fields in case of diversion or emergency.\textsuperscript{11} However it was immediately apparent that the pre-war United States had far too few meteorologists to support military operations. A professional census in July 1940 counted just 377 qualified weather forecasters in the United States: 150 in the Weather Bureau, 94 in the civil airlines, 62 in the Army, 46 in the Navy, and only 25 in educational and other institutions.\textsuperscript{12} (Germany was believed to have mobilized 2,700 forecasters into military service.\textsuperscript{13})

While maintaining its domestic weather service, the US would have to create new observation networks and forecasting stations where the fighting occurred. To meet this need, the nation’s few academic meteorologists led by Carl-Gustaf Rossby worked with the military to produce a large training program based at the five universities with graduate meteorology programs and at Chanute Field. An official history of the Army Air Force’s weather training program wrote that the curriculum “was in essence a modification of the meteorological course developed at MIT over a period of 15 years,” providing military cadets with nine months of intensive training in dynamic meteorology and weather forecasting.\textsuperscript{14} By the end of 1944, this program had turned out approximately 6,200 male weather officers and 100 women.\textsuperscript{15} Some of the women were civilians trained to fill temporary vacancies in the Weather Bureau, while others were military volunteers.

\textsuperscript{11} Thomas Childers, \textit{In the shadows of war: an American pilot’s odyssey through occupied France and the camps of Nazi Germany}. (Henry Holt, 2003).
\textsuperscript{13} Petterssen, \textit{Weathering the Storm}: 82.
deployed in the United States to support airways and pilot training bases. The men forecast weather in every theater of the war, providing knowledge necessary for effective strategic bombing, amphibious invasions, ferrying aircraft and supplies from factory to battlefield, and other vital military operations. Almost none had had any prior technical training in how to monitor and predict weather.

The training program created a large new cadre of meteorological experts trained to understand the weather in the geophysical terms of Bergen School models. A subset of the men of this “weather cadet generation” would dominate American (and thus to a large extent international) meteorology, from the 1950s into the 1980s. The vast group of meteorologists created for the war, would, in the peace, become the basis for both meteorology’s public face, on television, and for its hidden, much larger, networks of industrial, military and government scientific workers. Its scale made possible its later ubiquity, and its place as national infrastructure.

Fighting a global war also demanded many new pilots. Aircraft had become far more complicated since World War I, and the training necessary to fly and fight in an advanced machine had similarly increased. Learning to read the weather was just a fraction of the extensive training pilots required. To meet these imperatives, the flying services, like other branches of the US military, employed a variety of media to teach servicemen about the technical tasks they would have to complete. Visual materials played a particularly important role. In addition to films, models and posters, the military

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extensively used comic art, an aspect of print culture intimately familiar to trainees from pre-war comic strips, advertising, and comic books. Using the “thought-picture method,” weather manuals in particular deployed comic art to make an arcane, complicated subject memorable and comprehensible to trainees. Artists, some drafted from the comic book industry, others discovered in meteorological units, drew comics to teach weather flying. Cartoons exhorted pilots to heed the advice of their weather officers and to learn to read the clouds, often through satirical characters who screwed up with tragicomic results.

Wartime operations, however, revealed that these parallel training systems did not inevitably produce weather officers and pilots who could work together effectively. The training shortcomings were particularly evident at the key moment of interface between meteorologists and pilots, the preflight weather briefing. In their day-to-day operations, most aeronautical meteorologists briefed pilots on the day’s weather, explaining forecasts and helping pilots to understand the conditions they would encounter in flight. This was a moment essential to the safety of flights and the success of operations. Military officers evaluating the university meteorological training programs found that meteorologists came out with too much training in meteorological theory, and not enough knowledge about the tasks they would need to perform in military service, particularly talking to pilots. While academic meteorologists added lessons in communications skills and practical work, it fell to the meteorological officers serving at airbases to invent a communications style that effectively reached pilots. Some of these meteorologists deployed the techniques of comic art deeply familiar to pilots, sketching cartoons to hold pilots’ attention and make forecasts memorable. These airfield interactions created the
rudiments of the visual style and narrative structure of the television weather report that members of the weather cadet generation invented after the War.

Part I: Mass Producing Meteorologists

Even before the United States declared war, the military dramatically increased its training program for meteorologists. In 1940, the few dozen existing military weather officers had largely learned their meteorology at MIT or Cal Tech during the 1930s—as they attempted to expand their ranks they looked to the research universities, and found a group of academic meteorologists eager to work with the military. As of October, 1940, there were 150 new cadets studying meteorology at MIT, Cal Tech, NYU, UCLA, and the University of Chicago. Managing this training program was the University Meteorological Committee (UMC), led by Carl-Gustaf Rossby and academic meteorologists representing each of the schools involved. Describing itself as “a clearing house for the exchange of ideas between the [AAF] Directorate of Weather and the individual universities,” the committee was “at the disposal of the Army Air Forces whenever technical problems arise.” The UMC coordinated the training program, exchanging research, curricula and even instructors. Above the UMC stood the Joint Meteorological Committee composed of representatives of the Army, Navy, Weather Bureau, and the “Big Five” University programs, divided into subcommittees charged with handling specific tasks. In late 1942, for instance, UCLA’s Joseph Kaplan chaired the “Personnel and Recruiting” sub-committee, the Weather Bureau’s William Thickstun

18 Fuller, Thor’s Legions, 30.
19 C. G. Rossby, “Preliminary Report on the Activities of the University Meteorological Committee,” January 24, 1943. Box 3, University Meteorology Committee Papers (MC 511), Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts. (Henceforth, UMC).
led “Weather Observing and Station Management,” and Irving Krick from Cal Tech chaired the group on “World Weather, Climatology and Forecasting.” From his post at the University of Chicago, Rossby chaired two groups, the Curriculum sub-committee and the Civilian Advisory Committee on Meteorology.

Following the attack on Pearl Harbor, the mass production of meteorologists ramped up substantially; the five schools went to year-round programs and began taking in two classes of meteorological cadets per year in 1942. Col. Donald Zimmerman, the head of AAF Weather Service, estimated that the AAF would need 10,000 weather officers by the start of 1945. In December 1943, Americans could read in National Geographic that “Army and Navy Turn out Needed Weather Experts by Mass Production.” According to the caption accompanying a photo of nine tiers of uniformed men, close packed into a classroom and studiously taking notes, “More than 100 students from both services, only a part of one class, compose this picture at the University of California at Los Angeles. So important is weather in planning and fighting the war that thousands of officers and enlisted personnel are being trained as weather forecasters and observers.” These “weather cadets” understood they were being mass-produced and trained in an abstract understanding of weather. “The days of our years took on a more universal aspect and almost unconsciously we came to measure time by new and different standards,” wrote one reflective cadet. “The doldrums moved South despite the fact that

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20 “Conference of Army, Navy, Weather Bureau and Universities,” Department of Special Collections, UCLA, RS 359, Box 136, folder 2b. (no date, ~late 1942).
21 Fuller, Thor’s Legions, 51.
150 neophytes had been strapped to the NYU assembly belt and were being processed into weathermen.”

The “assembly belt” of this industrial process was a university-centered, graduate-level education in atmospheric physics, primarily concerned with conditions that impacted air operations: upper air winds, fog, visibility distances, and cloud ceilings. The weather cadets learned mathematical and graphical techniques that applied physical theory to weather prediction. In doing so, they learned to understand weather in ways that were abstract, objective, and impersonal. Training thousands of men to share this understanding of weather, and using that understanding to operate an integrated, global weather monitoring system, enabled Army Air Force pilots to reach targets, even after a flight of 1500 miles from the Mariana Islands to Japan.

The weather cadets were taught a way of knowing weather that aspired to render place irrelevant. Ideally, given an adequate observation network, accurate knowledge of the immediate future conditions of any place could be produced anywhere—the forecaster need not be in a particular location to know what the weather would be at that place. Global military power depended upon disciplining personal environmental perception.

Questions of supply

Creating a mass of disciplined weather officers began with recruiting intelligent and well-educated young people, mainly men. Initially, the program required recruits to have a bachelor’s degree, one year of college physics, and differential and integral

calculus. This was later reduced to the successful completion of two full years of college, but with no change to the math and physics requirements. The program did not seek out individuals interested in weather or trained in geography, and actually recruited a particularly large number of chemistry majors. The key qualification was the math and physics education. “As a result of some remarkable foresight in setting high standards for admission to these training programs,” wrote members of a commission on meteorological education in 1958, “a large number of young people with excellent backgrounds in mathematics and the physical sciences was brought into the field.”24 The influx of students helped reorient meteorology as geophysical rather than a geographical science.25

Rather than being randomly assigned by the Army, students were recruited to the program and announced their intention to become weather cadets when they enlisted. The program promised pay during training at cadet levels, as well as a commission as a 2nd Lieutenant upon graduation. Given that forecasters were unlikely to fight on the front lines, it is likely that some young men joined the weather program to avoid combat. Enlisting to join a particular technical training program also offered young men more control over what they did and learned in the military, while being drafted offered almost none. The UMC recruited through advertising as well as through informal university networks. The University of Chicago, for example, helped produce a half-hour radio program titled “The Invisible Allies! A Thrilling Chapter from the Notebooks of

Science—and War!” that featured an appeal for meteorology recruits from Nobel laureate physicist Arthur Compton.26

Because of the stiff educational pre-requisites and the need for scientists and engineers throughout the war effort, the UMC established a second and third series of preparation programs.27 The existing 9-month long graduate programs became Advanced Meteorology (the “A” courses), while a second-tier feeder program (a six month Premeteorology course, the “B” courses) was established to teach calculus and physics to students who had only a year of college. A third program, Basic Premeteorology (the “C” courses) prepared high school graduates for the A course in 12 months, with instruction in college mathematics, calculus, physics, cartography, history, and military drill. The B courses were conducted primarily at twelve major universities scattered across the country, while a majority of the C course sites were liberal arts colleges.

As a result of misjudgments in planning requirements, the UMC “A” Courses trained many more weather officers than the Army Air Force (AAF) ultimately needed. At the end of 1942, the AAF expected to field 10,000 weather officers by the start of 1945, and structured training and recruitment programs accordingly. Where AAF administrators initially believed that every squadron would need its own set of weather officers, for instance, experience during the war revealed more efficient forms of labor organization. Ultimately over 1,800 of the 6,200 meteorologists trained were assigned to

26 Compton was not otherwise involved with the meteorological training program, but was well-enough known for his physics research to make a credible celebrity presence. Radio script, UMC, box 3. Hand notation says the program was given 2/4/43, on the Mutual Network, Station WGN. Diane Rabson has discussed this recording in “It Happened Here: The Invisible Ally,” Staff Notes (University Corporation for Atmospheric Research) October, 1998. Available online at http://ucar.edu/communications/staffnotes/9810/here.html
other duties. Sverre Petterssen, who oversaw the beginning of the training program at MIT, noted, “everyone agreed we needed more, but no one tried to decide how many. The program continued to snowball long after a balance between supply and demand had been reached.” This planning mistake caused considerable consternation in the AAF office of Operations, Commitments and Requirements (a tone of exculpation runs through participants’ accounts), but it seems to have caused no great harm. As an Air Force official history notes, “a weather officer … could insist, quite seriously and with some impunity, that wars were lost through shortages, not overages.”

“To bridle the mighty air masses with weird and unholy formulae”: Physics and Placelessness

At the core of the training program’s curriculum were the ideas of the Bergen School. Most of the textbooks were written by Vilhelm Bjerknes’s students, like Sverre Petterssen, Harald Sverdrup and Bernhard Haurwitz, or by students of Bjerknes’s students, like Rossby’s early students Horace Byers, Jerome Namias, and Victor Starr.

(Table 4.1) In contrast to Rossby and Byers’s pre-war efforts to teach dynamic meteorology to experienced Weather Bureau forecasters, the course put dynamics and calculational approaches to understanding the weather at the beginning of a

28 Petterssen, Weathering the Storm, 82.
30 Navy Bureau of Aeronautics to Joseph Kaplan, 12/7/1942. Dept of Special Collections, UCLA, RS 359, Box 136, folder 2b.
31 University of Chicago Archives, Presidents’ Papers, 1940-1946. Box 11, Folder Two: Horace R. Byers to President Robert Hutchins, 8/13/43.
32 University of Chicago Archives, Presidents’ Papers, 1940-1946. Box 11, Folder Two: “Menu suggestions for Luncheon on May 10, 1943.”
33 On the development of the Bergen School prior to about 1925, see Robert Marc Friedman, Appropriating the Weather: Vilhelm Bjerknes and the Construction of a Modern Meteorology (Cornell University Press, 1990).
meteorological education. As one student yearbook put it, “For the information of our
descendants Basic Meteorology is a noble attempt of Messrs. Bjerknes, J. and V. and
others of their ilk to bridle the mighty air masses with weird and unholy formulae.”

Remembering his training many years later, Robert Fleagle noted, “we got a heavy dose
of air mass and frontal analysis and of Petterssen’s forecasting methods.” Sometimes the
emphasis on fronts went overboard, as “We were indoctrinated with the belief that a good
analyst should be able to find a front to account for any area of nonconvective cloud or
precipitation.” Formerly an “advanced subject,” the atmospheric physics of the Bergen
School had become the basis of modern meteorology.

| Table 4.1: Books Issued to Meteorology Cadets, UCLA A-level Class, March 1943 |
|---------------------------------|---------------------------------|---------------------------------|
| Horace R. Byers                 | Synoptic and Aeronautical Meteorology | McGraw-Hill, 1937             |
| Bernhard Haurwitz               | Dynamic Meteorology              | McGraw-Hill, 1941              |
| Bernhard Haurwitz               | The Physical State of the Upper Atmosphere | Royal Astronomical Society of Canada, 1941 |
| Wilfred Kendrew                 | The Climates of the Continents, 3rd edition | Oxford University Press, 1937 |
| W. E. K. Middleton              | Meteorological Instruments       | University of Toronto Press, 1942 |
| Jerome Namias                   | Air Mass and Isentropic Analysis | American Meteorological Society, date? |
| Sverre Petterssen               | Weather Forecasting and Analysis | McGraw-Hill, 1940              |
| Athelstan Spilhaus and James Miller | Workbook in Meteorology        | McGraw-Hill, 1942              |
| Victor Starr                    | Basic Principles of Weather Forecasting | Harper, 1942                 |
| Harald Sverdrup                  | Oceanography for Meteorologists | Prentice-Hall, 1942            |
| G. E. F. Sherwood and Angus Taylor | Calculus                      | Prentice-Hall, 1942            |

34 “Synopsis: Class 2-a-44,” 30th AAF Training Detachment: 8.
36 This list is representative of the books used in other programs. (See Chicago curriculum for another example. Chicago, directly supervised by Rossby and with probably the strongest geophysical orientation, used Helmut Landsberg’s Physical Climatology instead of Kendrew, and used the manuscript of Byers’ General Meteorology instead of his earlier Synoptic and Aeronautical Meteorology.)
37 The development of this hundred-page pamphlet is described in Bernhard Haurwitz, "Meteorology in the 20th Century: A Participant's View (Part III)," Bulletin of the American Meteorological Society 66, no. 5 (1985): 501.
The cadets’ textbooks asserted that ideally meteorologists should understand weather in physical and mathematical terms, and exhorted them to try to quantify and calculate its changes. Victor Starr’s *Basic Principles of Weather Forecasting* described calculating the weather as the ultimate goal, while admitting that it remained distant. “Since we know the fundamental laws” of fluid mechanics and thermodynamics, “it might appear that a forecast of future motions could be made completely by analytical means. Unfortunately, although we do know the elementary principles of atmospheric motions, the problem of integrating them and obtaining a forecast by purely analytical procedures is too complex to be treated by a direct frontal attack.” Starr then footnoted Lewis Fry Richardson’s “effort in this direction.”

Textbooks presented weather as a secondary phenomenon, the local consequences of the general circulation of the atmosphere. “The general problem of forecasting weather conditions may be subdivided conveniently into two parts,” wrote Starr. “In the first place, it is necessary to predict the state of motion of the atmosphere in the future.” As a second step, only after predicting the atmosphere’s general motion, “it is necessary to interpret this expected state of motion in terms of the actual weather which it will produce at various localities. The first of these problems is essentially of a dynamic nature, inasmuch as it concerns itself with the mechanics of the motion of a fluid.” Successful forecasting, textbooks made clear, would result from first understanding the physical principles that governed the atmosphere, then applying them to the local situation.

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39 Ibid.: 1
The texts produced for the wartime training program also made some influential choices in presenting climatology and dust storms. For example, when Horace Byers released a new edition of the textbook he had written for the airlines, he made expanded claims for relevance (instead of *Synoptic and Aeronautical Meteorology*, the title of the 1937 edition, the book had become *General Meteorology*) but dropped the chapter on dust storms, despite the recent memory of the Dust Bowl. Similarly, Bernhard Haurwitz and James Austin’s 1944 textbook *Climatology*, developed from material used in teaching a thirty-hour course to aviation cadets at MIT, chose to ignore not only dust storms but also, “the many applications of climatology in agriculture, industry, merchandising, transportation, medicine and other fields,” instead stressing “the physical causes of the climates and of the variations of the climatic elements in space and time.”

Justified by the needs of wartime aviation, such omissions would have major consequences. By shaping the attitudes of a generation of atmospheric scientists, these books contributed to the reinvention of climatology as a physical science built around radiation and dynamics, replacing earlier visions of climatology that had integrated vegetation, agriculture, and human relations.

Beyond the textbooks, students experienced extensive lectures, demonstrations, forecasting practicums, and instrument laboratories, much like airline students had at the Boeing school before the war. (Table 4.2) According to a report summarizing the

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University of Chicago program, the curriculum mixed a heavy dose of physical theory with hundreds of hours of synoptic map analysis:

The program offered by the Institute for the training of cadets as meteorologists for the Army Air Corps, and of Navy officers as aerologists, has been planned to provide each student with the utmost practical experience in the analysis of weather charts and forecasting, and at the same time to endow him with a broad theoretical background in modern meteorological physics. To accomplish this, the academic week at the Institute comprises approximately 20 to 24 hours of practical weather analysis and forecasting in the synoptic laboratories and 12 hours of formal lectures. From two to four hours of the weekly laboratory time are devoted to discussions, ... A two-hour examination covering all subjects is held weekly, and final examinations are given in each course.42

Examinations and quizzes ensured that students stayed engaged with the material. Along with frequent quizzes, students were rated on all the work they turned in, including worksheets, their efforts at constructing synoptic maps, and upper air observations.43 Students achieving consistently low marks were failed out, and usually reassigned to other training programs in the Army Air Force Technical Training Command. While coursework and laboratories followed the academic mold, cadets also learned to march, shoot, salute, and defend themselves against poison gas attack when they were not calculating radiative cooling.44

| Table 4.2: Curriculum for Wartime Training Classes
| Institute of Meteorology, University of Chicago |
|---------------------------- |-----------------|
| Subject                                | Total # of hours|
| Synoptic laboratory                    | 672             |
| Dynamic meteorology                    | 116             |
| Synoptic and aeronautical meteorology  | 72              |

42 University of Chicago curriculum, 1943. This forty-nine page description of the curriculum of the Chicago A level school gives a detailed, week by week overview of what students were taught. “Syllabus of Courses Comprising the Training Program of Meteorologists for the United States Army Air Corps and Aerologists for the United States Navy,” 82-56, Box 1, Folder 46 “Sverdrup, Misc. --Meteorology Programs 1943-1945.” Scripps Institution of Oceanography Archives, San Diego, California.
43 Fleagle, Eyewitness, 2.
44 The students picked up on the tension between academic and military life right away: “Throughout our life at NYU an indecisive battle royal raged between the academic and the military for our poor GI souls,” wrote students in one yearbook. "Synopsis: Class 2-a-44."; 3
<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory meteorology</td>
<td>43</td>
</tr>
<tr>
<td>Hydrodynamics</td>
<td>42</td>
</tr>
<tr>
<td>Field course</td>
<td>24</td>
</tr>
<tr>
<td>Radiosonde</td>
<td>53</td>
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<tr>
<td>Climatology</td>
<td>32</td>
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<tr>
<td>Geography</td>
<td>22</td>
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<tr>
<td>Physics of the High Atmosphere</td>
<td>32</td>
</tr>
<tr>
<td>Oceanography</td>
<td>20</td>
</tr>
<tr>
<td>Fieldwork with mobile weather unit</td>
<td>18</td>
</tr>
<tr>
<td>Examinations</td>
<td>95</td>
</tr>
</tbody>
</table>

Crucially for the development of meteorology as an academic and research discipline after the War, Rossby and the academic members of the UMC won the right to retain the best students from each class as instructors for future classes. In contrast to pilot training, where top cadets went on to the most challenging types of combat flying, top meteorologists would stay at the universities to become teachers and researchers.

Among the dozens of cadets retained as officer instructors were: Edward Lorenz (MIT), later an atmospheric computer modeling pioneer and leading chaos researcher; Robert M. White (MIT), who became Chief of the Weather Bureau in 1963 after the retirement of Francis Reichelderfer and later served as first head of the Environmental Science and Service Administration, and its successor, the National Oceanic and Atmospheric Administration; Robert Fleagle (NYU), a noted dynamic meteorologist and AMS president in 1981; Loren W. Crow (Caltech), a commercial consulting meteorologist and weather modification expert after the war; and George E. Forsythe (UCLA) later a pioneering computer scientist who founded the Stanford computer science department.

Rather than forecasting and communicating with pilots, America’s top young meteorologists thus spent the war working with theory: earning advanced degrees,
generating new knowledge about atmospheric dynamics, and learning how to teach meteorology in the style of the Bergen School.

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

Earlier methods of training meteorologists, particularly in the United States Weather Bureau, were based entirely on the accumulation of experience. A man trained over a number of years in, say, San Francisco, would in that fashion become a good forecaster for our West Coast but would have to start all over again if he were transferred to another part of the country.

We do not have the time to give our students adequate basic training and also a large amount of experience within the short period of time at our disposal. Hence, we must concentrate on the application of fundamental principles of analysis and forecasting which can be used in any part of the world.45

Rossby argued that physicist forecasters were not only superior, but also the only effective kind that could be produced quickly. His vision of dynamic meteorology promised portable, placeless knowledge. Knowing the weather through physics meant forecasters could become another interchangeable part of the war machine, ready to be shipped wherever they might be needed.

To summarize, the transformation of the social and epistemic hierarchy of American meteorology depended upon military-sponsored education. Before World War II, the iconic weather expert was a figure like the Chief in George Stewart’s 1941 novel *Storm*: an old Weather Bureau hand, deeply experienced in watching and predicting the weather, with an intuitive sense for how conditions would change.46 During the war,

46 George R. Stewart, *Storm: A Novel* (Lincoln, Nebraska: University of Nebraska Press, 1983 [1941]). For an analysis, see Bernard Mergen, *Weather Matters: An American Cultural History since 1900* (University
thousands of students were taught to understand weather as the local manifestation of
the general circulation of the atmosphere. They learned to quantify the atmosphere’s
properties and calculate the equations that governed its motions. Through the disciplining
effects of lectures, examinations, graded assignments and tutorials with instruments,
trainees came to accept the hierarchy that placed dynamical equations as the ultimate,
*fundamental* description of weather. Only by mastering the general mathematical
relationships that described the behavior of particular weather phenomena was the
highest, most valued form of meteorological knowledge produced. Meteorological truth,
the weather cadets learned, was to be sought at the level of abstractions, not particulars;
theoretical laws, not empirical rules. The men who could deduce those rules, who could
mathematize the skies, were the new ideal meteorologists. In 1960, the American
Meteorological Society commemorated this changed focus by renaming its highest
award. It is now called the Carl-Gustaf Rossby Research Medal.47

“A GI life of calculus, physics, and meteorology”: *The Weather Cadet Experience*48

Although the students were military officers in training, the meteorology training
program retained a collegiate atmosphere. College professors led lectures and labs, while
students took exams and lived together in dormitories or apartments. Like many college
classes, the weather cadets often produced commemorative yearbooks to construct and

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47 Beginning in 1951, the AMS awarded an occasional “Award for Extraordinary Scientific Achievement.”
To honor Rossby after his sudden and early death, the award was changed in 1960 to “The Carl-Gustaf
Rossby Award for Extraordinary Scientific Achievement.” The award was renamed “The Carl-Gustaf
Rossby Research Medal” in 1963, and first awarded under that name in 1964.

48 Ibid.: 8
solidify the meanings of their experiences (Figure 4.1). These books suggest how meteorologists-in-training understood their education.

Figure 4.1: A weather cadet’s representation of the meteorological training program. The series of panels circling the page beginning at top left illustrates the daily routine, including falling asleep five minutes after the second morning lesson, and struggling to complete the push-ups at 1750hrs. The four images in the middle narrate the transition from civilian leisure to military discipline, culminating in a pre-flight briefing conducted by the newly commissioned lieutenant. This set of comic images was probably drawn by Robert C. Petterson, one of the cadets in class 1A, 1944, at New York University. (Source: Endpaper from Synopsis 1-A-44, NYU, author’s personal collection).

The yearbooks narrated a stylized story of growth and learning, progressing from naiveté through challenge to triumph and graduation, deploying the genre conventions of
other memorial yearbooks. Full of inside jokes, the student authors drew upon military and weather metaphors to recreate shared experiences. For example, “the big guns—Bjerknes and Kaplan and Holmboe—bombarded us without quarter,” and “the worst maps turned up as test maps, which is what is meant by periodicity in weather.”

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

The world around us changed quickly; a cloudy sky became a nimbostratus overcast, the wind that tugged at our overcoats became a Beaufort 6 and we all looked for 00 Wx [clear skies] on our weekends.

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

Instruments transformed the subjective, personal experience of weather into objective quantitative descriptions of atmospheric conditions. The yearbooks captured the

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50 Colver R. Briggs, Arden Lanham, and Bruce Heater, eds. Class 5: Meteorology Cadets (University of California, 1943). UMC, box 5, “UCLA”.
51 *Synopsis: Class 2-a-44* UMC, box 5, “NYU”.
52 *Synopsis: Class 2-a-44*: 17
triumph students felt as they learned to master various instruments, as well as their ambivalence:

As our final act of subservience to the Demanding Instrument, we followed the Instrument’s faithful disciple, Lt. [Fred] Decker, in a night and day orgy known as radiosonde lab. We calibrated, released and recorded until those little lines on the thermodynamic diagrams symbolized for us hours of blood, sweat and tears.

Despite the urgings of their academic teachers towards theory, abstraction, the rejection of subjective experience and those little lines on the thermodynamic diagrams, the irreducible world of embodied experience remained a fundamental category for fully understanding the meanings of their new role. Now, however, the relevant physical experience was that of flight:

In reward for beavering well done, we were given an opportunity during that last quarter to fulfill our manifest destiny—that of becoming “flying fighting meteorologists.” A convalescent B-18 was assigned to our detachment for weather reconnaissance, and group by group we groundlings took to the air verifying our own forecasts. Frozen limbs and upset stomachs made lapse rates and turbulence less academic, and we returned sadder but wiser weathermen.53

To be a true fighting meteorologist, a man had to both understand the physics of weather, as well as the physical experience of what those map symbols meant to the men flying bombers through limb-freezing, turbulent air against murderous enemies.

Part II: Mass Producing Pilots: Comic Art in Training Manuals

If the emblematic objects of training for meteorologists were the synoptic map and the radiosonde, the emblems of weather training for pilots were pugilistic cartoon clouds and satirical comic characters like Aviation Cadet Knucklehead (Figure 4.2).

Seemingly simplistic, comic art was a sophisticated educational tool used by the military

53 *Synopsis: Class 2-a-44*: 25
across many fields, and one that, like physical theory, enabled technical training to be scaled up rapidly.

Figure 4.2: Clouds were routinely depicted as enormous boxers ready to punch out an unwary pilot, as in this picture from “Thunderstorms,” a pamphlet produced by the Navy Bureau of Aeronautics in 1943. (Author’s personal collection).

World War II could be as accurately called “the technicians’ war” as it could “the physicists’ war.” The ability to operate, supply, maintain and repair complicated machines, often thousands of miles from factories, played a decisive role. This was particularly noticeable in aviation, where small faults could easily result in the destruction of the entire aircraft. Lauding the ground crews who maintained strategic bombers, a US propaganda film reminded the home front that

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55 David Edgerton has recently reminded historians of technology about the importance of maintenance. He notes that many machines last for decades in regular use, and that far more engineers maintain or supervise existing technological artifacts than design or manufacture new ones. David Edgerton, The Shock of the Old: Technology and Global History since 1900 (Oxford University Press, 2007), ch. 4. He also notes that airplanes require intensive surveillance because they fail much more catastrophically than other forms of transport; cars or trains stop, planes crash.
The normal work of keeping an airplane fit for operation is enormous, even in peacetime. When you add to this already great job the element of battle damage, the problem becomes gigantic. Engines, wings, propellers, controls, wiring, fuel system, oxygen system, the thousand and one elements that go to make up the mechanics of a heavy bombardment plane, all must be kept in perfect shape. The failure of any one of them on a mission can easily mean the loss of a plane and its personnel, or at best, such a failure will cause a plane to abort.

Entering the war, the Army Air Force only expected about 37% of its planes to be available for fighting at any particular moment. Thanks to the heroic work of the ground crew, the film announced, the readiness rate for bombers was nearly fifty percent.\(^5\) By the middle of the twentieth century, training masses of technicians who could keep extremely complicated machines functional just half the time had become essential to fighting wars.\(^6\)

Making the challenge harder was that many, probably most, perspective technicians were draftees whose diverse employment experiences had not prepared them to perform the novel technical tasks that supported modern warfare. Some skills translated easily. Civilian and military organizations alike required bureaucratic abilities like typing, filing, tracking and reporting.\(^7\) Skilled metal workers found the same kinds of machine tools in maintenance depots and on the lower decks of battleships that used in domestic factories. But farmers, laborers, assembly line workers and men from hundreds of other occupations had to be trained in gunnery, ordnance, radio operations, oxygen

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\(^6\) Launching weapons while protected by distance and armor fits uncomfortably with traditional military values of valor and courage, as David Mindell explores in *War, Technology and Experience Aboard the USS Monitor* (Johns Hopkins University Press, 2000). Charles Lindbergh expressed his deep discomfort at the distance between the bomb dropper and the destruction he caused; see Yuki Tanaka in the introduction to *Bombing Civilians*. Films like *Target for Today* attempt to restore some element of heroism to these "machine operators" by celebrating their technical skill.

\(^7\) Joann Yates explores the crucial role of low technologies like filing in coordinating the large managerial corporations that emerged during the latter half of the 19th century in *Control through Communication: The Rise of System in American Management* (Johns Hopkins University Press, 1989).
systems and hundreds of other skills, not to mention skills never required before the
war. The war pulled the national economy from more than 20% unemployment to beyond
full employment, as people—particularly women—who had not expected to work
replaced men drafted into the service.

To train technicians quickly, the US military developed curricula that relied
heavily on visual materials. For teaching skills as diverse as defense against chemical
attack, marksmanship, and aircraft identification, the military developed films, maps,
pictures, and three-dimensional models. Since many of the technical tasks that draftees
would have to carry out were “extra-textual,” that is, they involved manipulating objects
and images, not just words and numbers, visual materials allowed the first stages of
training (and of weeding out the non-adept) to be done in classrooms, without giving up
the visual stimulus that would eventually be essential to doing the required tasks
effectively. As aviation historian Donald Nijboer notes, posters and illustrations in
manuals were “designed to be easily deciphered by the thousands of new recruits.”
Technical drawings made for training aircrew were three-dimensional perspective
drawings, in contrast to the two-dimension drawings made for engineers. These materials
dramatically improved the efficiency of technical education. Good graphic design and
clear illustrations could save weeks of training. “In 1944, U.S. designer Will Burtin
produced a series of instruction books to help air gunners in their training. His manuals

59 Major Paul A. Witty, “Some Uses of Visual Aids in the Army,” *Journal of Educational Sociology* 18,4
(Dec. 1944): 241-249.
shortened the gunnery course from six months to six weeks.” Most surprisingly, many training materials used cartoons and other elements of comic art.

Comics made effective training materials for several reasons. First, comics integrated text and image, allowing each aspect to reinforce the other’s message. Avoiding photo-realism, cartoon images could emphasize the most salient parts of a technical image. Second, comic manuals could be cheaply printed in great quantity. Third, readers associated comics with leisure and pleasure. Military manuals often used humor to make their messages both memorable and more likely to be read. Fourth, comics featured a familiar repertoire of satirical techniques for gently correcting readers without offending them. The emotional distance created by caricature meant that cartoon characters could do all the dumb things that other novices did, often with fatal results, but without quite implying that the trainee himself would be so stupid as to make that mistake. Finally and most importantly, comic art was a visual language pervasively familiar to the American men drafted into the military. As George Gallup discovered in 1930, super-majorities in every social class, education level and demographic group eagerly read newspaper comic strips. Young men (and women) voraciously consumed comic books beginning in the mid-1930s, and continued throughout the war to overwhelm military Post-Exchanges with requests for the latest exploits of Superman.61

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61 Ian Gordon has collected evidence on the extensive reading of comics from the 1890s into the 1950s. According to surveys conducted by the Advertising Research Foundation between 1939 and the mid-1950s, “nowhere in the country did the median of comic strip readership fall below 75 percent,” while breaking down the numbers by occupation revealed surprisingly little variety. Professional women were the least avid readers of comics, but still 68 percent of them followed the comics regularly. During 1943 and 1944, the Army distributed over 100,000 copies of Superman comic books every other month. “Between 1941 and 1944 sales of comic books doubled from 10 million to 20 million copies a month despite paper shortages. … In military training camps, 44 percent of men read comic books regularly and 13 percent read
In short, comic art was both the best-loved and the lowest common denominator of American visual culture. While this section focuses on the use of cartoons to teach meteorology to pilots, elements of comic art can be found throughout military training materials developed throughout World War II and beyond.

*The Evolution of Comic Art in American Culture*

Understanding how comics work suggests why they were such a useful training tool. Describing the comics as “a medium in their own right,” cultural historian Roger Sabin notes that the comics “are a language, with their own grammar, syntax, and punctuation.” Comic strip communication does not “‘happen’ in the words, or the pictures, but somewhere in-between, in what is sometimes known as ‘the marriage of text and image’.” The basic building block of a comic is the strip, a “narrative in the form of pictures,” often supplemented with text. Like any communications medium, comics have conventions. Conventions like speech- and thought-balloons allow linguistic input, while artistic conventions like speed-lines bring motion into the still images. Exaggerated sweat beads show anxiety, one of many conventions used to depict emotion. The most basic graphic convention are bordered panels, “which serve to break down the action into 9 [or] 10 readily-understandable segments,” on a typical page of a comic book. “Taken together, these conventions constitute an abbreviated style … that allows the reader to fill in the gaps using his or her imagination.” But reading the comics is not automatic; it requires a complex pattern of eye movements as readers focus on image, then text, then

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dialogue, then image again before moving to the next panel. As Sabin puts it, “reading a comic is an acquired skill.”

Americans had acquired this skill through advertising and nationally syndicated strips printed in local newspapers. Efforts to duplicate the success of British comic weeklies like Punch had introduced comic art into mass circulation in the US during the late 1870s and early 1880s, but it was the adoption of the comic strip in newspapers during the 1890s that made comic art commercially valuable and nationally recognizable in the United States. The comic pages were the most read section of the paper—88% of subscribers complained when it was not included in a delivery. (Only 4.5% complained if they didn’t get the news section.) Laborers and doctors, factory workers and engineers alike enjoyed reading the comics, incorporating them into their leisure patterns. Alerted to the broad-based popularity of the comic pages by a George Gallup survey in 1930, advertisers made extensive use of this combination of familiarity and pleasure during the 1930s. This constant exposure made comic art perhaps the most widely shared aspect of American visual culture.

Although the comics were widely loved, they were not widely respected. Criticism of comic books was especially strong amongst educators and religious authorities. Educators felt comic books distracted students from better reading

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63 Gordon, Comic Strips and Consumer Culture; Roland Marchand, Advertising the American Dream (University of California Press, 1986).
64 Partially in response to this scorn, much of the scholarly literature seeks to legitimate comic art. See M. Thomas Inge, Comics as Culture (University Press of Mississippi, 1990); and Sabin, Adult Comics.
65 In 1930, education researcher Louise Dahlberg studied the newspaper reading habits of 40 girls in grade 7B, ranging from 11 to 15 in age, considered to be “the children of tradesmen and artisans.” Thirty-nine of the forty students read the comics in the Daily News. Fourteen read only the comics, while the rest read the comics as well as a few other features in the paper. Three read the headlines of the main news stories. Dahlberg did not consider the comics to be a suitable educational experience: “In general, then, newspaper
materials, taught them unrealistic behaviors, exposed them to art of inferior quality, and celebrated lewd, lascivious, and rule-breaking behavior.\textsuperscript{66} Comics were low culture, vulgar and cheap, their readers dim and poorly educated; as one 1908 critic put it, the comic supplement appealed to people “who don’t care for fine shades of humor, because they can’t appreciate them.”\textsuperscript{67}

While critics chastised comics for degrading the reading abilities and moral sense of children, some publishers sought to make comics educationally and morally constructive. As one reviewer wrote, “Increasingly, teachers and educators, aware of children’s universal interest in comics, are becoming interested in the possibility of using comics as instructional material.”\textsuperscript{68} One such figure was M. C. Gaines, a former school superintendent, who sold his major entertainment comic books publishing business in 1945 to organize Educational Comics, Incorporated. A 1945 review showed Gaines planned to publish a series “frankly educational materials in comic form,” which would address the Bible, America history, science, natural history, and mythology.\textsuperscript{69}

Before World War II, educational comics were most widely used in aviation. Stimulated by the drama of World War I aces, polar exploration flights during the 1920s,

\textsuperscript{66} See Amy Kiste Nyberg, \textit{Seal of Approval: The History of the Comics Code} (Jackson: University Press of Mississippi, 1998). These concerns came to a head after World War II, particularly in regard to depictions of violence and sex in comic books, eventually reached a powerful and broad enough audience that they compelled some changes in the content of comic books. After congressional hearings into comic books and their connections to juvenile delinquency between 1948 and 1954, the leading producers of comic books volunteered to follow a self-censorship policy, the Comics Code, which was essentially a rewritten form of the Film Production Code of the 1930s.


and then Charles Lindbergh’s transatlantic solo, aviation had become a central subject in mass culture. Aircraft and fliers featured prominently in movies, radio plays, illustrated magazines and newspapers. Hundreds of books were published to explain how planes worked. Among the most successful were a series of richly illustrated books by Assen Jordanoff, a Bulgarian immigrant who became a commercial pilot for American Airlines. (Figure 4.3) Several comic artists illustrated Jordanoff’s many books. Perhaps the most important for this story was Eric Sloane, a complicated personality who invented a style of cartoon instructional guides that found wide use during World War II.

Figure 4.3: Cloudy Joe, a cartoon foil for Assen Jordanoff’s flying advice, prepares to challenge the air masses, here identified by their type and origins. TG meant tropical gulf, PC polar continental, PA polar Atlantic, and TC tropical continental. His plane is worried. (Source: Assen Jordanoff, Through the Overcast (Funk and Wagnall’s, 1938, p. 4). Illustration by Fred Meagher.)

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70 A. Bowdoin van Riper, Imagining flight: aviation and popular culture (Texas A&M Press, 2004).

71 Jordanoff’s books include: Flying and How to do it! (1932) illustrated by Larry Whittington; Your Wings, first published in 1937 with illustrations by Frank Carlson, later expanded with additional illustrations by Fred Meagher in 1940 and Eric Sloane in 1942, and reprinted in French, Russian and Japanese editions; Through the Overcast, (1938) illustrations by Carlson and Meagher; Safety in Flight (1941) illustrations by Carlson and Meagher; Man behind the flight: a ground course for aviation mechanics and airmen (1942); Jordanoff’s Illustrated aviation dictionary (1942); and Power and Flight (1944), illustrations by Elizabeth Paige and others.
One Strategy for Comic Technical Manuals: Eric Sloane's “Thought-Picture” Method

Today Eric Sloane is best known as a nostalgia artist who memorialized the cool stone barns of a New England that never was. However, his less well remembered work celebrated the sleekest modernity, in both comic art and fine oils, from a massive mural at the entrance to the Smithsonian’s National Air and Space Museum to illustrations for science texts like Jordanoff’s and military instructional guides.72

For his pedagogical manuals, Sloane developed an illustration technique he called the “Thought-Picture” method. Sloane began one manual explaining his strategy. (Figure 4.4) “Pictures are easier to remember than words!” he asserted. “Military training has accepted the ‘Thought-Picture’ method: it is just as scientific to present these facts in cartoon as it is to do them by diagram and chart.”73 At the bottom of the page, a mortarboard-topped professor with a long white beard and an arm armful of books chides, “Tsk! Tsk! It’s all very unscientific!” while a smiling fighter plane answers, “This flyer understands what he’s reading!” The fighter plane and its pilot recurred throughout the manual, while the professor was a stock Sloane character.

Sloane first explored his “thought-picture” method in his 1941 book Clouds, Air and Wind, which combined advanced meteorological concepts, elegant pen-and-ink cloudscapes, and comic art to produce a memorable and approachable text on the flyable

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73 Sloane, Your Body in Flight, 3.
The book began with a preface by Sverre Petterssen, one of the leading synoptic weather forecasters of the 20th century, and Sloane’s teacher at MIT.75

Figure 4.4: Eric Sloane articulates his “thought-picture” method. (Your Body in Flight, page 3.)

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Petterssen praised both Sloane’s more formal pictures of clouds (recognizable according to standard methods of classification) and his ability to write “a truly popular presentation of the vagaries of Nature.” Analyzing a typical comic illustration shows what Petterssen meant. In the illustration “Dangers of Clouds, Air and Wind,” Sloane shows why pilots need not fear lightning, but should worry about fog and ice. (Figure 4.5) He explains the different kinds of ice that threatens planes, how they form, and the mechanical devices used to combat ice. He shows where dangerous turbulence can be found and how to avoid it. Finally, he throws in a tip for gaining an advantageous tailwind by dodging bad weather conditions properly. The page uses various conventions of comic art, including dialog balloons, motion lines, a sequence of frames, expressive lettering to suggest sound, personification of inanimate objects, visual cues for depicting emotion, and one character recreated several times in different situations. In an economical single page, Sloane conveys a wealth of flight safety information, much more memorably than the similar information communicated by the column of prose on the facing page.
Figure 5: Some of the dangers of weather to flight. Several illustrations like this were reproduced on small cards and distributed as reminders to experienced aircrew. (Eric Sloane, Clouds, Air and Wind, 1941: 64).
Sloane’s work was widely used in training fliers during World War II. The publisher’s preface to the revised edition of *Clouds, Air and Wind*, published after the bombing of Pearl Harbor, emphasized how the book’s pictorial approach made it useful for training across linguistic lines. The Army Air Force used a Spanish edition of the book to teach Argentine pilots, while Chinese pilots training at American flight schools also were said to find the book helpful. Pages of the book were also reprinted on small cards that could fit in a shirt pocket and given to pilots. The cards reminded pilots of the dangers of thunderstorms, the hazards of winter flying, and so forth. These small cards, with their almost unreadable text and shrunken cartoon images, were not intended to be read. Rather, they were a memory aid, an image and textual arrangement seen previously during an earlier phase of preparation. They played on the ways that early trainees used graphics differently from experienced crewmen. “For new and inexperienced aircrew, these illustrations were tools upon which their very survival depended, to be closely studied; for battle-weary crews, these images were merely glanced at.”

Sloane’s comic style also played a key role in the AAF’s efforts to help aircrew manage their bodies. The Army Air Force’s Aero Medical Laboratory at Wright Field worked with Eric Sloane to produce *Your Body in Flight*. Touted as “an illustrated ‘book of knowledge’ for the flyer,” the 83 page, 8.5” x 11” black-and-white booklet mixed printed text, hand drawn pictures, and hand drawn text. (Figure 4.6) The book taught pilots how to manage their bodies as they flew at different altitudes. Physiologists, psychologists, and flight surgeons had developed extensive knowledge about the effects of high altitude flight; the book sought to translate that knowledge into a form that pilots

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76 The author has eight of these cards in his personal collection.
would use and remember. It was the pilot’s job to put this scientific knowledge to use, because using such knowledge would “help you get more planes over the target, bring more planes back, and increase your own chances for survival.” The manual addressed how pilots were supposed to operate their machines to protect their bodies, including when they should don oxygen masks, how high they should fly, and what sorts of food they should eat to lessen painful gas and avoid nausea. But, it warned, even when aircrews avoided soda, beans and weanies, diminishing air pressures would make them belch and fart as they climbed through 20,000 feet.

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78 Aero Medical Laboratory, United States Army Air Forces (T.O. no. 00-25-13) Your Body in Flight (July 20th, 1943).
Figure 4.6: Comic manuals often mixed images, hand drawn text and type set text. (Eric Sloane, *Your Body in Flight*, p. 4).

**Comic Strategy II: Will Eisner and the Caricature Counter-Example**

A second common strategy in comic-illustrated manuals was pioneered by Will Eisner. A successful comic book artist who had created *The Spirit*, Eisner was drafted into the Army’s Ordnance Command. Early in his service, Eisner encountered a unit largely composed of illiterate soldiers. He later recounted how that experience highlighted the importance of reaching readers at the most basic level. In 1942, he
became the artistic director for a minor publication, *Army Motors*, charged with promoting preventative maintenance. He created a lovable loser, Private Joe Dope, who always did things wrong, showing his readers what not to do. *(Figure 4.7)*

![Figure 4.7: Will Eisner's Joe Dope offered textbook examples of what not to do. Eisner's posters, magazine illustrations, and cartoons appeared throughout the US Army. (Source: http://www.comicartville.com/eisnerdopeposter.jpg, accessed April 21, 2010.)*

To understand why characters like Joe Dope were effective teachers, we need to understand the mechanics and limits of identifying with caricature. In his work on comic strips and consumer culture, historian Ian Gordon argues characters are “re-created in each instance of a strip in a never-ending construction of identity.” Readers were supposed to understand characters through repetition, and through that familiarity they would come to identify with them. But “the caricature techniques of comic art, and the often satirical nature” of the action, “sets readers apart from the strips. In the distance between the eye and the page, readers come to look on comic humor as a satire on the
foibles of a strip’s characters and not on the reader’s own idiosyncrasies.” This tension between identifying with the situation of the cartoon pilot and laughing at his mistakes was to help pilots learn to fly safely.80

As the Army expanded, so did its need for training materials. Eisner became responsible for instructional comic strips in the Army’s Technical Manual series. His strips translated the technical language of the manuals text into more familiar language, while his artwork illuminated the technical discussion from a different perspective. While photographs produced exact reproductions, comic drawings could exaggerate the important elements, showing the action from the point of view of the personal reading the manual and expected to perform the technical task. Because the comics memorably integrated image and text, comics led to easily portable publications that could be printed cheaply. Manuals often used the humorous elements familiar to comic art to reinforce particularly important aspects of equipment operation.

No cartoon character carried out this mission with more devotion than Aviation Cadet Knucklehead. (Figure 4.8) Willfully ignorant of the weather, he died six times before earning his (angel) wings near the end of Technical Manual 1-232, “Basic Weather for Pilot Trainees.” Drawings regularly included an X to mark the spot where Knucklehead came to grief. The manual begins by describing the AAF’s weather service and the role it plays in supporting flying operations, then explains why pilots must maintain close contact with weather officers before each flight. Knucklehead’s first death begins by skipping a stop at the weather office before taking off, else he would have known about the need to plan an alternate field. (Figure 4.9) Later mishaps result from

failing to adjust his altimeter for changes in the pressure field during a long distance flight, getting caught in the most dangerous parts of thunderstorms as a result of three different mistakes, and flying into the occluded portion of a front rather than around it.¹¹

Figure 4.8: Aviation Cadet Knucklehead. Characters who committed common mistakes frequently showed up in cartoon-illustrated manuals. Throughout “Basic Weather for Pilot Trainees,” X marked the spot where Knucklehead perished as a result of not understanding how to navigate dangerous weather. (Source: Technical Manual 1-232. Author’s Personal Collection)

Figure 4.9: A knuckleheaded pilot thinks he doesn’t need expert advice on the weather forecast. (Source: Technical Manual 1-232, p. 4. Author’s Personal Collection)

Despite comics’ ubiquity, not everyone within the military felt comic art an appropriate medium for technical instruction. According to Eisner’s authorized biography, to counter continued skepticism he persuaded the Adjutant General’s department (in charge of producing technical manuals) to put his publications up to a test against more traditional manuals. Administered by the University of Chicago, the test showed that “the readability and retention level” of Eisner’s material “was greater than
that of the precise but dry and pedantic technical manuals.”

Perhaps similar struggles played out differently in other nations; comic art was a distinctly American and British strategy, and was not found in German manuals.

Probably the most avid user of comic illustrated manuals was the Training Division of the Navy Bureau of Aeronautics. It produced a series of 30 to 40 page booklets, 6” x 4”, stapled and double hole punched, covering subjects like “Ice Formation on Aircraft,” “Thunderstorms,” “Fog,” or “Air Masses and Fronts.” The inside cover bade students, “Keep This Booklet. This is the first of a series of booklets on aerological subjects,” which when bound together would produce “a complete text on Aerology. … [This pamphlet] is the starting point of a text that will be of value to you throughout your entire flying career.”

The first twenty-five pages describe the kinds of ice that form on aircraft, where it forms, and ways to prevent it. The takeaway message comes on pages 26 and 27. On the top half of the pages, a cartoon grandfather standing under a calendar labeled 1980, wearing a parachute and flying gear, holding a model plane, balances on a footstool in mid-swoop, regaling his grandchildren with war stories. One of the kids clutches his father’s leg in terror, a sailor hat shooting up from his head. “If you ever expect to tell your grandchildren about your flying career,” the caption says, “remember these 15 rules.” The most important is “Maintain your flying speed!” listed as number one, and then again as number fifteen, in bold and a larger font. The second pamphlet in the series echoed this formula, building to a series of 16 rules for safely navigating thunderstorms, illustrated by eleven cartoons of a pilot and his tuna-like plane. They find

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83 Nijboer, *Graphic War*: 12, 28.
84 Training Division, Bureau of Aeronautics, U.S. Navy. “Ice Formation on Aircraft,” Aerology Series, Number One. No date. [Circa 1943].
a saddleback above a horse-shaped cloud, fly around a thunderstorm while looking down at the island maiden with her grass skirt and ukulele, and he stares at the picture of his girl (signed “to my ace”), pinned-up on the instrument panel, so the bright flashes of lightning don’t blind him temporarily. (Figure 4.10) These pamphlets also mixed in more serious drawings to illustrate different phenomena, sometimes using stylized clouds and airscapes, sometimes using familiar objects like bicycle pumps to explain heating by compression.

![Image](image.jpg)

**Figure 4.10:** The Navy produced a series of small booklets with cartoon-illustrated rules for flying in different kinds of weather. Ordinary American women, as well as movie stars, commonly posed for pin-up style photos to send to their husbands and boyfriends serving away from home. (Source: “Thunderstorms,” US Navy Bureau of Aeronautics, 1943. Author’s Personal Collection.)

*How to Speak to Pilots: The Tone and Style of Pilot Meteorological Manuals*

Manuals used colloquial language and usually addressed readers as “you.” The tone suggested that military service was an extension of democratic life, implying the

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85 Pin-up photos were one of the most ubiquitous images created during the War. In addition to commercial images, wives and girlfriends commonly posed for pin-up style pictures to send to their men at the front. Robert Westbrook has argued that these women, including his own mother, created pin-up photos not just as erotic aides, but also as symbolic reminders of the private obligations to women that American soldiers fought to protect. Robert B. Westbrook, “‘I Want a Girl, Just Like the Girl that Married Harry James’: American Women and the Problem of Political Obligation in World War II,” *American Quarterly*, Vol. 42, No. 4, (Dec., 1990): 587-614.
American military was assembled through education and persuasion, rather than coercion. The texts implied that authors had already “been there,” and might have lost some buddies along the way; trainees were being given the chance to learn from the examples and advice of peers. The tone aimed to evoke the informal “hanger talk” conversation between an experienced pilot and a newbie. Some manuals quoted older pilots explicitly, usually identifying them only with titles like, “a former Randolph Field navigation instructor now on duty in Newfoundland.”

A representative Navy manual that was used widely enough to be printed in several editions was *Aerology For Pilots.* (**Figure 4.11**) It combined a conversational tone with technical education, humorous instructive cartoons, meticulously detailed scenes reminiscent of dramatic comic books, and strong elements of patriotic encouragement and lectures on Navy duty. The manual used meteorology to mobilize the atmosphere for American military service, asserting “Weather fights on the side of the airmen who understand and use it!” It emphasized the global nature of air power; among the things a Navy pilot had to know about aerology was the “general world distribution of types of weather” because “United States naval aviators may fly anywhere!”

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86 On the tension between democracy and a nation mobilized for total war, see Benjamin L. Alpers, “This is the Army: Imagining a Democratic Military in World War II,” *Journal of American History* 85 (1998): 129-163.
87 On the crucial role of hanger talk in developing a pilot’s judgment and widening his experience, see Bob Buck, *North Star Over my Shoulder: A Flying Life* (Simon and Schuster, 2002).
A plane piloted into a violent thunderstorm gets rough treatment. It can be tossed, rolled, carried rapidly upward in a great thermal updraft, dropped in a downcurrent with a rushing downpour of rain, pitched helplessly sideways and snaked upward again, structurally twisted and broken, pelted with hailstones, struck by lightning, thoroughly iced, possibly dropped and tossed a few more times and emitted from the great cumulonimbus cloud at any unpredictable point between earth’s surface and the stratosphere—possibly in pieces. In addition, any pilot who guides his plane into a genuine thunderstorm (if he is still in the cockpit) may be thoroughly frightened by the harmless thunder!

Though a great “show-off,” the thunderstorm is no “bluff.” It embodies five hazards: turbulence, icing, hail, lightning, and poor visibility. It may come in any one of three general types: (1) air-mass thunderstorm, (2) frontal thunderstorm, or (3) mountain thunderstorm. Regardless of type, the cumulonimbus cloud form provides visible evidence; and all types are to be avoided, or, if the mission is urgent, negotiated with understanding of thunderstorm hazards. There is a saying, “Every pilot has been through one thunderstorm.”

* Editor’s Note: I have lost two good friends in them—one shed his wings, the other was forced into a mountain. I’ve been through a couple—that’s why I’m gray and somewhat bald.”
Like the struggle air mail and commercial pilots faced to maintain schedules in the face of threatening weather, military pilots often experienced a tension between completing important missions and avoiding dangerous atmospheric conditions. In expressing this tension, *Aerology for Pilots* lapsed into contradictory advice. A lengthy section first explained why pilots should not fly through thunderstorms. A plane in a violent thunderstorm can be tossed, rolled, carried rapidly upward in a great thermal updraft, dropped in a down current with a rushing downpour of rain, pitched helplessly sideways and sucked upward again, structurally twisted and broken, pelted with hailstones, struck by lightning, thoroughly iced, possibly dropped and tossed a few more times and emitted from the great cumulo-nimbus cloud at any unpredictable point between earth’s surface and the stratosphere—possibly in pieces.

The manual detailed how to recognize and avoid different types of thunderstorms. The distinctive anvil shape atop a towering cumulo-nimbus signified a thunderstorm in full progress. “Don’t fly through it,” a stunt that might provide tall tales for future grandchildren, but also “scare the virility out of a man.” Nor should pilots fly near it, since turbulence within 1,000 feet of a thunderhead might knock a plane out of control. If a pilot faced a line of closely spaced thunderstorms, the Navy advised, “and your mission is not immediately urgent, retreat. You are not fully equipped to fight nature.” Yet in the very next sentence, pilots were told to “Live to whip the Axis. When whipping the Axis means going through a thunderstorm, Navy fliers go through.” While the Navy taught its pilots to understand the threats posed by weather, it ultimately demanded men to put war objectives first while bearing the risk of hazardous storms.

Trainee pilots, like their weather cadet colleagues, returned from flights sadder but wiser to the dangers posed by the churning atmosphere.

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90 *Aerology for Pilots*: pp 86, 88.
Finally, the manuals make clear that instilling a respect for meteorologists was a crucial aspect of pilot meteorological training. *Aerology for Pilots*, like other meteorological manuals, drilled home the importance of talking to meteorologists before every flight, of learning how to ask them questions and confirm understandings, and of treating meteorological advice as essential to a pilot’s life. Developing a shared language for communicating the weather was a crucial part of the training of both pilots and aviation forecasters:

The aerologists’ forecasts may be received in written form or may be obtained in conferences with the aerologists. Most of the forecasts or reports contain special aerological “jargon” (the aerologists contain the same), and this “jargon” must be understood by the pilots. (The aerologists cooperate; when explaining their forecasts, they use much pilot “jargon.”)\(^9\)

A reliable and effective fighting force required these two very different sorts of technicians to work together effectively, although they were trained separately.

**From Training to Operations: The Interface between Pilots and Meteorologists**

One of the few weather briefings recorded (or staged) for posterity comes from the propaganda film *Target for Today*.\(^9\) In the middle of this documentary about the bombing of Germany, a mustachioed weather officer with close cropped hair, a slight southern drawl, and a pointing stick briefs a large room packed with B-17 pilots. Looking mainly at a massive topographical map of Western Europe, rather than the assembled pilots, he begins:

\(^9\) *Aerology for Pilots*: 4.

\(^9\) Because briefings were for given shortly before flights for immediate use, and contained data that rapidly went out of date, they were rarely recorded. For similar reasons, relatively few old TV weather reports are preserved, as the next chapter explores. “Target for Today.” Made available by Public.Resource.org at http://www.youtube.com/watch?v=Rt-B6i90X3w (retrieved 9/7/09). Weather Briefing begins at 34:59.
The synoptic situation today is this: we have a high pressure system centered over northwest Europe, up here near Finland, extending down southwestward across the British Isles, causing an influx of south and southwesterly air going up in this direction, hence causing little or no cloud in the area towards your target.

A fine day for a thousand-plane bombing raid. “There are no fronts to affect your route today except a frontal system off to the west which will cause an increase of medium and high clouds as you come back across the North Sea.” He continues personalizing the situation with “you” and “yours,” an acknowledgement of the pilots’ upcoming direct experience of the weather.

Calling for the lights to be turned off, a stratified route chart is projected via lantern slide. Marked at 5,000 foot intervals from the ground to 30,000 feet, the chart follows a line from base to target, depicting a patch of fog below 5,000 feet near the bases in England, stratus clouds drawn in at 10,000 feet over the North Sea, and a note warning of light rime icing near 10,000 feet. Temperatures range from +11°C at the ground to -41°C at 30,000 feet. A line is drawn at 13,000 feet, the altitude at which the bomb run is to be made. “At take off time there will be nil with three tenths clouds, also there will be a layer of high clouds 23,000 feet, 4 to 6 10ths in amount, also a little layer of clouds in there between 10 and 12 thousand feet, these medium and high clouds decreasing out over the north sea to 3 to 5/10ths each in amount,” and so on, describing cloud cover at different heights and locations, patches of fog, the freezing points and temperatures at various key altitudes, and a visibility of 4 to 6 miles.

The camera occasionally pans to the pilots, shown looking attentive and taking notes, glancing at each other to make sure they have it right. In the film, the weather briefing takes about two minutes and forty seconds, though this was likely edited down.
The whole presentation has a very serious tone, no jokes, not even a smile from the weather officer. The pilots do not ask questions, though they would have received a copy of the latest weather chart before they took off.

When it reached the screen, this act of communication had gone through a double processing. Obviously, it had been cleaned up by the director of the film, and by the men who knew they were being recorded. More obscurely, though certainly more significantly, the pilot briefing was the result of a long struggle to standardize and render functional a form of communication on which human lives depended.

Inspection reports from the field revealed a less cooperative scene. Many university trainees, they admitted, lacked the “qualities necessary for a technical officer,” a failing that particularly showed in weather briefings. Working in an American military culture that intensely valued oral communication skills, particularly brevity and clarity, many officers “lacked the ability to give their forecasts orally—to ‘talk’ weather to a pilot so that he could understand it.” Officers also had trouble fitting into Army bureaucratic culture, failing to correctly fill out weather service forms and aircraft clearance records. Moreover, meteorologists trained at different universities had trouble agreeing on what information should be communicated. “A deputy commander, two years out of MIT, would raise hell when maps were drawn in UCLA style,” remembered one weather cadet.94

Hearing complaints about the lack of operational knowledge, universities responded in several ways. First, they established functioning weather stations at each

94 Charles Bates, quoted in Otha Spencer, Flying the Weather, p. 22.
university. Due to wartime secrecy and the value of weather information to the enemy, all data on current conditions had been kept out of public circulation. As a result, where the Boeing students had had regular access to weather reports, military students did not experience the emotional engagement provided by watching the behavior of the atmosphere in near-real time. The university meteorologists noted how current observations stimulated student interest far better than the “canned data” they were otherwise given in exercises. University weather stations were initially rejected in late 1942 by Lt. Col. Oscar Sentor, the chief of the Operations Division, who argued that staffing five additional weather stations would tax the manpower of the weather service and risk the security of weather information. These objections were overcome by staffing the stations with a rotating pool of cadets, and charging the military officers detailed to the universities as instructors with keeping weather observations secure.

Second, the universities developed ways of communicating with their former graduates, by now officers in the field, giving them access to new methods developed through research. By the middle of 1943, the first graduates of the weather cadet generation, the class of 1941, had been running weather stations and briefing pilots for close to two years, with little exposure to the insights developed through research since then. In June, the commander of the Weather Wing suggested officers who had been in the field for 18 months or more might need refresher courses to familiarize them with the advances in meteorology the war had brought. Rossby, ever eager to create future

95 Since weather generally travels from west to east, access to North American and Atlantic weather observations were of particular value to the Germans. They used U-boats and long range flights from France for Atlantic observations, and repeatedly tried to establish secret meteorological outposts in Greenland. Wilhelm Dege, War north of 80: the last German Arctic weather station of World War II, translated from the German and edited by William Barr (University of Calgary Press, 2004).
colleagues in dynamic meteorology, seized on the idea. In December he proposed a curriculum for an “Advanced Meteorology” course at Chicago. AAF headquarters rejected Rossby’s proposal, saying it was “‘excellent’ for a second-year graduate course in meteorology, but far ‘too academic for the purposes of the Weather Service in Wartime.’”97

Despite these measures, inspectors continued to report that weather officers needed a broader and more practical education than provided by the universities. An AAF captain spent 17 days touring air bases in the Pacific Northwest in the fall of 1943, investigating how the meteorological training schools might improve their training. Some of the feedback reflected local circumstances that challenged the universal applicability of meteorological training. Base weather officers in this mountainous region hoped the schools would spend more time on orographic effects, finding that valleys, plateaus and mountains had more effect on the synoptic situation than was commonly thought by meteorologists who had never been to the area. Nor did operational realities match the training program’s assumptions. Officers felt that the schools should emphasize short range forecasting rather than 24 hour spot forecasts, asserting that “most forecasts are for routes and for time intervals of 2 to 4 hours.”98

The biggest problem remained getting new meteorologists to work well with others. Operational forecasters had more time to analyze the daily map than the schools thought, but they needed better training in how to cooperate with other officers to maintain the continuity of weather maps and observations. (Drawing synoptic maps from

98 Norman R. Kilvans, “Extracts from report concerning training of meteorological officers by Meteorological Training Schools and Centers,” October 20, 1943. SIO Office of the Director (Sverdrup), 82-56, Box 1, Folder 46 “Sverdrup, Misc. Meteorology Programs 1943-44.”
teletype data was a partially subjective process, but storms that jumped illogically at shift changes confused pilots and discredited meteorology as a science.) Students needed to learn more about teamwork and how to maintain cordial, working relationships with officers and enlisted men, the inspector reported. The relationship between meteorologists and flight crews represented a particular problem. Meteorologists were having trouble communicating weather data clearly, leading to “a gap between the weather service (personnel, equipment, and knowledge) and flying personnel, which can be bridged by better and unique presentation of weather data.”

Even in early 1944, the nine-month curriculum for the aviation meteorological cadet courses spent relatively little time on the crucial task of weather briefings. While 511 hours of instruction went to Surface Weather Charts and Forecasting, 132 hours to Air Mass Analysis, and 99 to Dynamic Meteorology, only 24 were spent on Weather Station Operation. This subject was expected to cover a wide range of topics, including the AAF Weather Service’s history and organization, as well as the administration and daily operation of a weather station. Buried in this course was instruction in “display and dissemination of weather information” and “preparation of weather forecasts for the AAF.”

Consequently, continuing education programs run by the AAF’s Air Weather Service emphasized communicating forecasts clearly. For instance, the 1944 Advanced and Refresher Course at Chanute Field spent nearly half of its 396 hours of instruction in “Weather Forecasting and Briefing Laboratory,” where officers developed “station and route forecasts,” giving “simulated briefing presentations” with “special attention to

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99 Norman R. Kilvans, “Training of meteorological officers.”
100 Walters, “Weather Training in the AAF”: 220-221.
upper air data.” A June, 1945 course to develop the skills of higher-ranking Staff
Weather Officers similarly built public presentation skills, with seven of the nineteen
days covering briefing related topics, like “Principles of weather briefing and mission
briefing,” “Weather briefing to commanding officers of air forces and commands,” and
“Special briefing on contrails.”

One of the strategies developed for presenting weather data better involved
constructing the stratified route charts that would feature so centrally in the AAF’s
propaganda film. (Figure 4.12) Drawing on techniques used by Pan Am from the late
1930s, these charts traced the route in length and altitude, showing dimensions of the
pilots’ experience that were left out of synoptic maps. They marked the level and extent
of clouds, winds, fog, icing conditions, temperatures at different altitudes, and potential
convection areas. In mountainous areas, they also marked the height of landforms. These
charts helped pilots find and follow safe and advantageous altitudes to fly along preset
courses. During the war, complicated routes were carefully constructed to avoid giving
away the target too soon, to avoid known concentrations of anti-aircraft guns (flak), and
to provide for alternate targets in case the primary was obscured. These charts were
crucial in helping pilots avoid dangerous weather by going above or below, since they
were very often constrained from going around, as commercial pilots in peacetime could.

102 On route planning, see Eugene Fletcher, The Lucky Bastard Club: A B-17 Pilot in Training and in
Figure 4.12: A sample stratified route chart like those used by Pan Am pilots in ferrying airplanes from US factories to the North Africa and China-Burma-India military theatres of operation. Pan Am had been presenting weather information this way since the late 1930s. (Source: Pan American Ferries, Inc. Report 1941-42, Volume 5. “Meteorological Department Report.” Pam Am Collection, Accession II, Box 17. University of Miami Archives and Special Collections.)

While the universities adjusted their training program to produce better operational meteorologists, the responsibility for finding ways to communicate effectively with pilots ultimately rested on individual weather officers in briefing huts and flight lines. In daily work on the flight line some meteorologists improvised by imitating forms of training culture; they discovered that cartoons worked as well in briefing pilots as they did in training them. Maud Greenwood was one of about 100 WAVES who received advanced training as weather forecasters. After completing the nine-month training program at the University of Chicago, she was posted to the Naval
Air Training Base at Corpus Christi, Texas, where she briefed student pilots on the conditions they would face on training hops. To encourage the rookies to pay attention, she illustrated her forecasts with cartoons. As she remembered it, “The commander of the aerology office saw my drawings, liked them and put me to work painting weather pictures on the walls and special stands around the base. Next thing you know, I’m on my way to Washington, D.C. as a meteorologist/artist to help with aerological publications.” After the war, Greenwood sought to stay in aviation weather forecasting, but was told by prospective employers that women could not deal with pilots. As the next chapter will show, the mode of communication she helped create would powerfully shape the culture of meteorology that rejected her.

Conclusion

World War II solidified and made permanent the connection between air power and the Bergen School’s vision of modern meteorology. Facing a dire scarcity of expert labor, academic meteorologists mass-produced (though imperfectly standardized) a new kind of military technician, scientific officers who imagined weather in abstract, mathematical terms. These men learned to value placeless weather knowledge that could be produced at MIT and shipped to a “weather central” at Guam. From Guam, that knowledge supported bombers as they crossed 1,500 miles of ocean to Japan. While this

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abstract training did not prepare men well for the daily chores of operations, it proved a viable foundation for a system that projected military power globally.

The nuclear age was populated by atmospheric scientists for whom a military background was as typical as it was for pilots. In 1954, 80% of American meteorologists had military ties, while a decade later, military weather research and operations employed three times as many people as similar civilian activities.104

Only about 20 percent of the weather cadet generation stayed in meteorology after the war, yet many who left went on to influential careers in remarkably diverse fields.105 Some weather cadets who became postwar American intellectual leaders include: Kenneth Arrow (NYU), whose first published scientific paper, on using upper level winds to optimize flight times, played no role in his Nobel Prize in Economics; W. Hubbs Rehnquist, a member of Flight D-2 in the 1944 Pre-meteorology program at Denison University who became a non-commissioned weather observer after sufficient numbers of weather officers were already trained, later went to Stanford Law School, briefly dated fellow student Sandra Day O’Connor, and eventually became Chief Justice of the Supreme Court106; George M. Keller (MIT), who as head of the Standard Oil Company of California acquired Gulf Oil, forming the Chevron Corporation in the largest corporate

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106 Rehnquist was co-editor of Tattoo, the yearbook produced to commemorate the 62nd Army Air Forces Technical Training Detachment. The book described him this way: “Lazily stretched out on his bed with his patented eye-ear-nose sleeping bag over his head is Hubbs Rehnquist, that great liberal and crusader for the Wisconsin dairy farmer.” [Author’s personal collection].
merger to that time\textsuperscript{107}; Luna B. Leopold (UCLA), son of the naturalist and writer Aldo Leopold, became chief hydrologist at the US Geological Survey\textsuperscript{108}; Edward B. Lewis (Caltech), nicknamed “Doc” by his fellow weather cadets in 1943 because he already had a Ph.D. in genetics, won the 1995 Nobel Prize for his observations on the role of genes in embryonic development\textsuperscript{109}; Herbert V. Schuster (MIT), whose postwar plan to study chemistry led him to a doctorate in food technology, pioneered the manufacture of private-label goods, those cheaper knockoffs of expensively advertised name brand items\textsuperscript{110}; and Clifton Keith Hillegass, the inventor and publisher of Cliffs Notes, the study aid crucial to passing literature classes for many American students.\textsuperscript{111} Graduate level education in mathematics and physics proved remarkably useful in Postwar American society.

Those weather cadets who remained in meteorology became a cohort that defined American atmospheric science into the 1980s. Because of American diplomatic efforts to use science in constructing the post-war international political order, these men would also play a crucial role in the course of international meteorology.\textsuperscript{112} Though meteorology had traditionally struggled to attract the best science students, the military selection process directed a flood of exceptionally bright students into the field. Some of these men

\begin{thebibliography}{99}
\bibitem{110} “Herbert V. Shuster, 75, Consumer Products Tester,” \textit{New York Times}, September 25, 1999. He is pictured on p. 37 of MIT’s \textit{CAVU: Class Book of the 3515\textsuperscript{th} AAF Base Unit: Meteorology}, June 1944.
\end{thebibliography}
became the leaders of the expanding institutions of American atmospheric science, founding new academic departments, staffing the National Center for Atmospheric Research founded in 1960, and building a strong atmospheric science program at NASA. They played key roles in developing computer simulations of the atmosphere now central to weather forecasting and understanding climate change, pioneered the development of remote sensing and weather satellites, and founded companies that provided industrial consulting services, including unreliable and often contentious weather modification applications. Finally, they transformed the public image of meteorology after the war, constructing the television weather report around the briefing styles and cartoons they had used during wartime, then struggling with the consequences of commercial television as they sought to secure the authority of professional meteorologists over the air.

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Chapter Five

Broadcasting Infrastructural Science:

Publicity and Professionalization after World War II

Frank Forrester, former military meteorologist and Pan Am forecaster, occasional TV weatherman, scientist at the Hayden Planetarium, paused. In the midst of answering 1001 questions about the weather, he reflected on his science’s improving public image. “Not too long ago the weatherman was caricatured as an ineffectual, bearded, finger-wetting and preoccupied sky gazer,” he wrote. “Today’s weatherman is much more impressive. He is part of a complex corps of specialists who are constantly laboring to expand and apply their science. Industries and armies have come to rely upon him for guidance in their planning.”¹ As he wrote in 1957, meteorologists had good reason to be content. Meteorology was ensconced as a science essential to air safety and national defense, valued in an increasing number of industrial settings. Numerical models of the atmosphere, running on the expensive new digital computer, had recently started producing operational forecasts for the US Weather Bureau and the military.² The International Geophysical Year was showcasing meteorology’s advances as a global

¹ Frank H. Forrester, 1001 Questions Answered about the Weather (New York: Dodd, Mead and Co. 1957): 292. According to the dust jacket on his book The Real Book about the Weather, Forrester had been an observer and forecaster for the US Marine Corps, a meteorologist for Pan American Airlines, and now worked as the “weather expert for Florida’s TV station WMBR,” where he was “one of the few ‘forecasters’ who is actually a meteorologist.” Frank H. Forrester, The Real Book About the Weather (Garden City, New York: Garden City Books, 1958).
science, drawing together scientists from more than thirty nations to study the atmosphere’s general circulation, among many other topics.  

However, the mid-1950s also gave American meteorologists some cause for unease. President Eisenhower cut the federal budget in 1953, and Weather Bureau Chief Francis Reichelderfer chose to reduce the number of ships patrolling for hurricanes off the Atlantic coast. Then the weather shifted: hurricanes Carol, Edna, and Hazel swept up the Eastern seaboard in 1954, the first major storms to hit America’s cultural and political core in fifteen years. Whispers circulated that nuclear bomb testing had damaged the weather. Inland, cloud seeders proclaimed their ability to control the skies. Chemist Irving Langmuir, a Nobel Laureate with no meteorological training, boasted about changing rainfall across the entire desert west, while many private companies sold questionable weather modification projects to ranchers, power companies, and municipal governments. Calling for more research, the usual calmative for worries over scientific authority, offered no tonic for meteorologists since top graduate students were eschewing the uncertainties of the winds for the glamour of particle physics. Worst of all, the

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increasing millions who turned on their new televisions often saw entertainers embellishing the weather forecast, rather than technically trained meteorologists explaining the atmosphere’s behavior. Many stations employed comedians, cartoonists or puppets; dozens of other stations hired “weather girls,” aspiring actresses and beauty queens with no experience in meteorology who wrapped the forecast in poetry, songs and double entendres. The public image of the weather expert was becoming a sexy young woman holding not a degree in science, but a ukulele, as one photograph in *Vogue Pattern Book* showed New York weather presenter Jan Crockett.\(^8\) Meteorologists thus found their authority challenged by nature, commercial television, and femininity.

This chapter explores how meteorologists worked to present meteorology as a mature, professional science in the wake of World War II. Meteorology’s ties to aviation played an essential role in changing the science’s public image, as meteorologists touted the reliance of industry and the military on meteorological expertise. Even more influentially, demobilized weather cadets invented the television weather report by adapting the pre-flight briefings and cartoon illustration style they had used to communicate with pilots during the war. These illustrated weather reports became popular with audiences and sponsors alike, rapidly spreading nationwide after the Federal Communications Commission lifted its freeze on new TV stations in 1952. TV weather emerged as the most commonly viewed scientific genre, and meteorologists had great hopes that it would showcase their growing skill and knowledge. But station managers interpreted cartoons as evidence that the weather was a bland subject that needed

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\(^8\) *Vogue Pattern Book*, August-September 1962, p. 57.
presentational spice. Between 1952 and 1955, women became perhaps half of all weather presenters, while a widely watched fraction of the men were cartoonists or comedians with no meteorological training.

Meteorologists sought to control their public reputation through an agenda of professionalization, primarily implemented by the American Meteorological Society. Professionalizing meteorology involved excluding people who did not have training and experience, as well as excluding nearly all women, regardless of their training and experience. Ensuring the professional qualities of TV weather reporters was particularly challenging, however, as meteorologists had no authority in the commercial television industry. Meteorologists attempted to create leverage by inventing a “Seal of Approval” program that certified the professional qualifications of broadcasting meteorologists. This effort particularly excluded women, with implications for gender discrimination in atmospheric science down to the present day.

The chapter thus describes the construction of meteorology’s public face, a façade that hides the government, academic and industrial activities that make up weather science and weather service. While academic meteorologists played some role in constructing this mask, much more influential work was done by a haphazard series of forecasters, station managers, advertisers, consultants and performers. The television weather report developed from modes of aeronautical meteorology and infrastructural science, and then concealed those origins.
Professionalizing Post-War Meteorology

During the 1940s and 1950s, a series of officers and committees sought to transform the AMS into a professional society, a society that could regulate the employment, scientific practices, and public statements of weather experts. During the 1940s, the AMS launched a research journal, created a class of ‘professional’ members with the exclusive right to elect AMS officers, and encouraged industries to hire meteorologists. In the 1950s, AMS committees tried to codify rules for meteorological consulting practices, began to publish consensus statements about the limits of scientific capability, threatened to expel members who made “exaggerated claims” in public, and created certification programs. While AMS efforts to discipline meteorology never gained the statutory recognition that empowered professions like law, medicine or engineering, they did produce considerable benefits for the career prospects of credentialed meteorologists. These gains, however, came at the expense of people systematically excluded from the institutions of meteorology, especially women.

Even before the end of the war, AMS president Carl-Gustaf Rossby and the Society’s governing council reformed the AMS constitution to institutionalize the authority and power of university-trained meteorologists. In a June 1944 letter “to the Members of the American Meteorological Society from the Council,” which accompanied a ballot for members to vote on changes in the bylaws and constitution, the AMS Council proposed splitting the membership into two castes. “It is recognized that the Society contains two broad groups of members,” the Council wrote performatively, “one consisting of those employed as professional meteorologists, and the other consisting of sub-professional and interested amateurs.” Though the two groups have
different needs, “it is clear that the future strength of American meteorology lies in unity rather than in independent action by separate groups.” Instead of separate popular and professional groups, the Council argued, putting the professionals in charge would strengthen American meteorology. “Since it was felt that the administration of the Society should be in the hands of those most vitally interested in the science, it is proposed that the President, Vice President, Secretary, and three of the five Councilors elected each year be Professional Members.” Professional members would also be charged $10.00 per year, nearly tripling the rate of regular membership in 1943.

By giving control over the Society to those experts with either education or employment in meteorology, this constitutional change created an organization dedicated primarily to the interests and concerns of its professional members, while retaining the potential influence that could accompany a broader membership. Its language of professionalization partly reflected long-established Weather Bureau usage, where the ‘professional’ and ‘sub-professional’ grades marked a key difference in rank and responsibility; the professional grades worked as analysts, forecasters, and managers, while the ‘sub-professional’ grades read instruments and recorded observations. Rossby also used the word ‘professional’ to draw sharp lines between people with certified education in meteorology (either in universities or military institutions like the Naval Post-Graduate School) and people who did meteorology-related work but lacked formal training. By creating clear boundaries between meteorological experts and the lay public, the word professional, also helped to solve meteorology’s longstanding credibility

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9 Here the Council was declaring that it had decided against Rossby’s earlier thought that the Society ought to be broken apart into a professional organization and a popular one.
problems. Twenty-five years later, Horace Byers would applaud the stratification of the AMS: “Professional membership now distinguished the trained and experienced meteorologists from the hacks and the dilettantes, and the Society was taking its place among the distinguished learned societies.”

Professionalizing meteorology also meant marginalizing women. During the war, about 200 women had trained alongside the male weather cadets, in the same classrooms by the same faculty. While military rules kept them from being posted overseas, women worked as aviation forecasters, classroom instructors and scientific researchers just like their male counterparts. In post-war employment, by contrast, women were offered only ‘sub-professional’ jobs below their experience and training. Maud Greenwood, for example, had been a Navy forecaster responsible for giving trainee pilots pre-flight weather briefings during the conflict. She hoped to be an airline forecaster after the war, but was told, “a woman could not deal with pilots and dispatchers,” though she “could be hired as a map plotter.” Within the Weather Bureau, women were rarely employed in forecasting and supervisory positions. In education Rossby, like many male professors, refused to accept women for graduate study, even women like Joanne Malkus who had

earned a masters degree for research conducted during the War. While Malkus persevered against this discrimination to become a pioneering role model for later women meteorologists, the discriminatory actions of the 1940s and 1950s reduced the numbers of women in meteorology to a level that did not threaten the social standing of the science. The handful of women working as professional meteorologists became unthreatening curiosities. In all these regards, meteorology was part of the much larger pattern of employment and educational discrimination against women after World War II.

Casting meteorology as a profession also required expanding career options beyond the Weather Bureau and the military. Rossby, with an almost paternal concern for his male weather cadets, worked through the AMS to create job opportunities. He created an employment file at AMS headquarters, intended for use as a placement service in peacetime, and for quickly locating properly trained meteorologists during future wars. Extensive records in the UMC files show Rossby’s attempts to encourage various sectors of private industry to explore how meteorologists might be of value. Rossby emphasized that the men of the weather cadet generation were a new class of weather experts; their university training and wartime forecasting experience made them ‘professional’ meteorologists. From the pulpit of the AMS presidency, he also encouraged the development of meteorology classes as part of the liberal arts curriculum.

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15 Simpson, Joanne. *Oral history collected as part of the AMS Tape Recorded Interview Project, conducted by Margaret LeMone*. Archives of the University Corporation for Atmospheric Research, September 6, 1989.


17 Records of the University Meteorological Committee, MC 511, Institute Archives, Massachusetts Institute of Technology.
while working to integrate meteorology into the work of civil engineers and the training of research geologists, oceanographers, and hydrologists.\textsuperscript{18}

**A New Career: TV Weatherman\textsuperscript{19}**

The most visible new meteorological career was on television. Television stations popping up across the country experimented with broadcasting weather forecasts, either as part of the local news, or as a stand-alone show. In contrast to genres like the variety show or detective drama, the TV weather report was little influenced by precedents in radio. Rather, discharged military meteorologists adapted the wartime pre-flight briefing for a new audience. As Robert Henson notes, “Dozens of these veterans showed up on local weather programs in the late 1940s.”\textsuperscript{20} Influential early TV weathercasters who served as military meteorologists during World War II included Louis Allen, Frank Field, Harold Taft, Clint Youle, Jim Fidler, Frank Forrester, Nash Roberts, and Don Woods. These men worked in major markets like Washington D.C and New York, as well as smaller markets across the country like Tulsa and New Orleans.

Meteorologists had great hopes that television would prove a useful tool in professionalization, by educating the public about the advances their science had made.

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\textsuperscript{18} For examples, see SIO Office of the Director (Sverdrup), 82-56, Box 1, Folder 46 "Sverdrup, Misc. -- Meteorology Programs 1943-1944," Scripps Institute of Oceanography Archives.

\textsuperscript{19} A note on terminology: Historical documents display considerable slippage between various terms for weather experts, both on and off TV. While there is some evidence that stations switched from using “weatherman” to “meteorologist” during the 1970s in the wake of the Weather Underground violence, different sources use “weatherman,” “meteorologist,” and “weathercaster” almost interchangeably. “Weathercaster” came into widespread usage in the 1980s as a gender inclusive term that makes no assertions about the presenter’s scientific training. I use “weathercaster” as the most general term for any weather presenter on TV or radio and “meteorologist” to refer exclusively to academics or government employees with scientific training who are paid to research or forecast weather. I use “weatherman” and “weather girl” in the same way my actors used them in the 1950s and 1960s.

\textsuperscript{20} Henson, *TV Weathercasting*, 7.
\end{flushleft}
during the war, and helping modern meteorologists break from historical associations with charlatans and weather prophets. Meteorologists’ research on atmospheric physics, and the widely believed (and publicized) possibility that the digital computer could lead to weather control, suggested to meteorologists that they might finally escape the stigma they felt they had labored under for so long. Discussing the proper persona for a TV weatherman, pioneering radio meteorologist James Fidler emphasized

There is no place for a ‘character’ insofar as the profession of meteorology is concerned. The weatherman has too long been pictured in the public imagination as a grotesque creature, so care must be taken that this new medium presents him to the public in what (we trust) is his true personality.

By performing a dignified, sober personality, TV meteorologists would persuade the public of the prestige of their young science.

Meteorologists also hoped that TV could enable the public to understand the complexities of forecasting the weather and thus to better tolerate the weatherman’s failures. By demonstrating “to the public at large the how’s and why’s of the weather,” forecasters could describe exactly how a weather forecast was prepared. Seeing the maps and charts would enable the public to appreciate the forecast and its limitations. Watching the forecaster at work, meteorologists hoped, would help the public “sense some of the responsibility the forecaster feels as he struggles over his prognostic charts,” while ultimately resulting in “increased public understanding of the weatherman’s work

and greater tolerance of his inevitable ‘busts.’” While meteorologists’ early writings hint at building public empathy for the struggles of forecasters, they seem not to have thought TV weathermen would become subjects of strong emotional connection. They expected TV weathermen to be teachers, not celebrities.

**TV Weather’s connections to Aviation**

The television weather report as a genre evolved from the pre-flight briefings that had been central to the daily work of aviation meteorologists. The weather cadets who invented TV weather reporting adapted the narrative structure and the visual pedagogical style they first used to communicate with military pilots.

*Narrative Structure*

Pre-flight briefings were the most common presentation for most military meteorologists. As such, it provided a model for how to present the weather on television. In a 1982 interview with a journalism scholar, Harold Taft recalled how he and two other airline meteorologists approached WBAP-TV in 1949 with a plan for a weather show:

We thought it would be a good idea to use the briefing techniques that we used for pilots during the war for television, because it was a natural medium for it. … We would put a map up, we’d show ‘em what the weather was, what it was going to be at the target, and what they’d expect when they returned. We gave ‘em a briefing. Same thing we do today. … Give me a map, a piece of chalk, and a stick and I’ll tell you about the weather.

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According to the interviewer, “Taft said he learned everything he knew about presenting the weather while briefing pilots in World War II.”

Jim Fidler argued that television meteorologists should adopt the same persona they had used to gain the trust of pilots:

> During the war it was found that the personality of the weatherman was important; pilots had to have confidence in their weather officer, both in his personality and in his professional ability. In television, the personality of the weatherman assumes a similar, but even greater importance.

Managing one’s personality, projecting a persona that displayed confidence in the capacities of modern scientific meteorology, inspired the trust pilots needed to have in their forecasters as they went to fight the enemy. Fidler attempted to project that same attitude in his TV presentations.

**Visual Style**

The visual style of TV weather evolved from a mating between wartime educational practices with synoptic maps, the long-established public representation of meteorology, under the constraints of low-resolution TV screens. This produced a simple aesthetic where the weatherman used a thick marker to draw simplified maps and cartoons live on the air, while narrating yesterday’s weather, current conditions, and the forecast.

The synoptic map, a map depicting simultaneous weather conditions across the United States, was the main visual language for public meteorology prior to the development of television, and the main way that Americans saw the nation’s weather.

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Producing such a map was an enormous feat of organizational and technological prowess, that involved coordinating instruments and observers at hundreds of locations, communicating those observations to all the offices in the network, and then drawing and printing charts for public distribution. Produced since the establishment of the federal government’s weather service in 1871, synoptic maps became an iconic representation of the Weather Bureau, symbolizing the Bureau’s scientific authority and capability.  

The Bureau worked hard to ensure the accurate and consistent production of these charts across the United States, distributing these maps through public displays, direct mail, and in newspaper reproductions. The Bureau also mailed tens of millions of synoptic maps directly to subscribers. The central office in Washington produced the largest and highest quality maps, both in terms of printing capability and completeness of data. By the first decade of the 20th century, stations in other major cities used lithography to produce a 1,000 or more copies of each day’s map, usually printed on a 11” x 16” sheet of paper along with the text of the local forecast and tables of meteorological data, while smaller stations might mimeograph a dozen maps a day. For a small subscription fee, interested people could have the day’s weather map mailed to them by the local Weather Bureau office. 

By 1910, static appropriations and the increasing costs of printing encouraged the Bureau to turn towards newspapers as the primary means of distributing synoptic maps. Scattered American newspapers had printed weather maps since 1879; many papers had

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printed maps for months or years, before abandoning them because of space constraints or the relative cost of the printing graphics. An 1894 survey of the four newspapers running daily weather maps (in Boston, Cincinnati, New Orleans, and San Francisco) showed that nearly 50,000,000 weather maps a year were circulating in these cities alone. These maps were visually complicated, and rich with data from many cities, including the state of the sky, temperature, barometric pressure, and wind direction.\textsuperscript{29} By 1912 the “commercial weather map” was carried in 147 newspapers with circulation of 2.9 million.\textsuperscript{30}

The technical limitations of analog broadcasting made this kind of intricate map impossible to broadcast on television. Since American television offered only 525 horizontal scan-lines, legible labels could not be less than 1/10th to 1/25th the height of the screen.\textsuperscript{31} As a result, “broadcasters avoid complex displays likely to antagonize viewers and undermine ratings.”\textsuperscript{32} The national weather maps faxed from the Weather Bureau in the late 1940s were “unsuitable even for close-ups, and had to be redrawn and simplified.”\textsuperscript{33} Consequently, early TV weather maps echoed the clear lines and relatively thin amount of information that had appeared in many of the sketches and educational maps of wartime meteorology textbooks.\textsuperscript{34} Weathercasters drew simplified maps live on screen (\textbf{Figure 5.1}). A story in the \textit{Radio Farm Digest} described how weatherman Louis Allen started with

\textsuperscript{29} One is pictured in Mark Monmonier, \textit{Air Apparent: How Meteorologists learned to Map, Predict, and Dramatize Weather} (University of Chicago Press, 2000), 162-163.
\textsuperscript{30} Monmonier, “Telegraphy,” 20.
\textsuperscript{31} European broadcasters agreed on a slightly different standard, which still did not offer particularly fine resolution.
\textsuperscript{32} Monmonier, \textit{Air Apparent}, 178.
\textsuperscript{33} Monmonier, \textit{Air Apparent}, 181.
\textsuperscript{34} Monmonier, \textit{Air Apparent}, 185.
an outline of the U.S. and a facile pen with a felt nib capable of interesting line effects… and filled with instant drying ink. … With a friendly flourish of rapid-fire pleasantries about fan mail (which he does get) and weather matters, he attacks the map with an easy sweep of pen, sketching in a few of the major current, and incubating, phases of weather: advancing cold front, lines indicating a major temperature zone or so in the Northeast, etc.  

This performance was “an impressive act to a home audience,” remarkable because it suggested a weathercaster had extensive knowledge at easy command. In fact, this “spontaneous” appearance depended upon careful planning. As Doug Wallace, a longtime weathercaster in Columbus, Georgia, put it,

> Many viewers wondered how it was I was able to remember so much information and do the show without use of notes. No problem. The truth is I did use a form of notes to a great degree by simply making a light outline of most of the weather data on the weatherboard, too light for the camera to pick up but heavy enough for me to see. This was done with a soft carbon pencil.

Chalk boards or large sheets of paper were most common in the late 1940s, while clear plexiglass maps began to appear in the mid-1950s.

> Presenting with a felt pen in hand made it easy to add comic embellishments to enliven the presentation. These ranged from stylized pictograms like “hot” dripping with sweat to cartoon depictions of the sun or a rain storm. The most obvious of these cartoons were recurring characters. Don Woods created Gusty, a skittish sprite drawn from a tornado of swirling strokes. The use of hand-drawn maps and cartoons also produced a piece of original artwork every day. Weathercasters often gave away these objects to viewers. Louis Allen received frequent requests for his daily doodles. Don Woods had a

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36 Monmonier, *Air Apparent*, 182.
37 Doug Wallace, *The Weatherman* (Self Published, Author’s Personal Collection): 168.
lottery at the end of each report, where he chose a name out of a bowl to receive the day’s picture of Gusty. He had more than a thousand entries when he retired. Late in Doug Wallace’s career, the host of his morning broadcast arranged a daily drawing to distribute his weather map to a lucky viewer. Winners sometimes sent him pictures of his maps framed and hanging over their mantels. These contests connected the broadcast to the local community, while adding a bit of drama at the end of the report.

Figure 5.1: Louis Allen, the prototype for the modern TV weatherman, developed a visual style built around a hand-drawn simplified synoptic map, and a cartoon to illustrate the forecast at the end of his segment. (Courtesy of the Bulletin of the American Meteorological Society)

Louis Allen: prototype of the modern television weatherman

No ex-military meteorologist had a greater influence on the development of the weather report than Louis Allen, who began broadcasting in Washington D.C. in 1948.

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Allen has been described as the “prototype of the modern television weatherman,” because he combined formal meteorological training with an engaging television persona. Allen earned a bachelor’s and master’s degree in meteorology, and thought education was a crucial part of the weather report. Akin to the military comics that used entertainment to make education memorable, he held his audience’s attention by sketching a ‘doodle’ that symbolized tomorrow’s weather. Viewers requested copies of his maps and doodles, writing, “the maps and the diagrams make a subject, otherwise technical, very easy to follow,” and “All our neighbors gather ‘round our TV set every evening just to see you,” more interested in learning about the weather than ever before.

“At the end of each five-minute show, Allen preceded the official forecast by drawing a quick sketch that symbolized the next day’s expected weather. For example, a picture of two boys on swings denoted warm weather appropriate for outside play. (The doodle concept grew out of drawings sent to Allen by his wife during World War II, when Allen was a military forecaster.)” Allen did his sketch on camera, bringing a compelling bit of action to the weather report. According to Charles C. Bates, a weather cadet who later became a key figure in the development of seismic networks for monitoring atomic tests, oceanographer and scientific advisor to the coast guard. Allen “met [his] competition head-on by drawing on his background gained from visual teaching of the slow learner. As a result, he climaxed his nightly 5-min weather show with a ‘doodle’ cartoon that attracted an extensive following ranging from 5-year-olds to grandparents as well as the

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40 Henson, *TV Weathercasting*, 35
42 Henson, *TV Weathercasting*, 35.
Allen’s weather show became a model for other presentations, as his show-stopping “doodle” connected the leisure and pleasure viewers associated with the comics to the informative and educational aspects of the weather report. Allen’s doodles generated so much enthusiasm that cartoon weather reports spread across the country. By 1952 a *New York Times* headline bemoaned that the “Televiewer is Wilted by Wave of Weather Men, Pointing, Doodling and Spouting Temperatures.”

**An Unintended Consequence of Comic Art: Cartoonists and Weather Girls**

The success of Allen’s cartooning encouraged many other stations to try similar approaches to the weather. According to Robert Henson, “other weathercasters noticed Allen’s doodling or came up with the notion themselves as an onslaught of cartoon characters invaded weathercasts over the next few years.” Before long, meteorological knowledge became secondary to cartooning skill and an engaging manner in becoming a television weathercaster. In some cases cartooning skills even became crucial to getting the job. Don Woods describes how he got his first job in TV meteorology:

> Not only was Don Woods a professional meteorologist; but he could also draw! Actually, Don found this little known talent after a few cartooning lessons and persuasive motivation from the Kansas TV station - a job requirement. They insisted that Don would draw a cartoon character for the weather section.

The *New York Times* echoed this language of requirement, scowling that, “one qualification for a television weather man is that he must be skilled in doodling. While

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45 Henson, TV Weathercasting, 35.
talking about the weather map or chart, he has to draw circles and lines in rapid motions, presumably illustrating what he is talking about.” While the animation lent “movement and variety to the show,” the reporter felt that it conveyed “not a lot of intelligence.” Despite the Times’s scorn, map historian Mark Monmonier argues that in the 1950s “skill as an illustrator was a marketable asset for the weathercaster who could quickly sketch clouds, a lightning bolt, or a radiant ‘Mr. Sun.’”

While Louis Allen used weather comics as an engaging pedagogical device, like they had been during the War, television producers interpreted weather cartoons as “sugar coating” to sweeten “a rather dull subject.” Comic books and cartoons were seen as low culture, entertaining rather than educational. Since viewers liked weather comics, it stood to reason they must not consider the weather to be an important subject. Station managers began to use comic weather reports to leaven their serious news programs. Using the data and official forecast available to anyone at the local Weather Bureau office, men with no meteorological training became some of the most successful weathercasters during the 1950s. Chicago cartoonist P. J. Hoff created beloved characters like the Vice-President-in-Charge-of-Looking-out-the-Window (Figure 5.2), while Tippy Stringer drew Senator Fairweather in Washington D.C.

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48 Monmonier, Air Apparent, 182.
50 On the tensions between education and entertainment in cultural hierarchies, see Lawrence Levine, High Culture, Low Culture.
51 Henson, TV Weathercasting, 36.
Figure 5.2: This play kit distributed in Chicago in 1963 featured cartoon cut-outs so children could re-enact P.J. Hoff’s popular TV weather forecasts. (Author’s personal collection).

A major reason weather cartooning spread quickly could be seen nightly in New York City. Tex Antoine broadcast in New York City from 1949 into the 1970s, armed with no meteorological training, but a fabulously expressive pen and a compelling personality (Figure 5.3). At the centre of his broadcast was “Uncle Wethbee,” a bald-pated character with big eyes and a Texas mustache. Antoine drew and dressed Uncle Wethbee for tomorrow’s weather. His mustache drooped in advance of rain and curled with the return of the sun. In 1951, the Times explained the “saga behind the rise” of the character:
It all started two years ago when Antoine, who had a knack for drawing cartoons, was asked by WNBT in midweek to come up with a five-minute weather show by the following Monday. From an orange crate Antoine cut the head of a character he named “Uncle Wethbee.” He also cut out different sets of interchangeable mustaches and ties so that “Uncle Wethbee” could simulate a visual effect for the various weather predictions.\(^{52}\)

Figure 5.3: Tex Antoine wearing typical costume, a painter’s smock, interprets Uncle Wethbee’s meteorological signs on behalf of his sponsor, the New York Electrical company Consolidated Edison. (Source: *Life Magazine*, March 28\(^{st}\), 1955)

Antoine helped maintain his place in the public eye (and solidify the new visual culture of public meteorology) by producing promotional books and pamphlets. He promoted his weather broadcasts and his sponsor, Consolidated Edison, in a series of yearly almanacs. The 1963 version was a 32 page, 5” x 8” stapled pamphlet. The pamphlet led off with an iconography, explaining how to read the forecast from the cartoon (Figure 5.4). “Uncle Wethbee’s expression and dress tell us what weather to

expect. Since 1949 he and Tex Antoine have been working together. Unk predicts andTex reports via Channel 4, WNBC-TV, Monday through Friday at 11:10pm. For officialinformation on weather conditions, naturally they depend upon the New York WeatherBureau.” Each month featured historical records for Central Park, times for high tides atthe Battery, sunrise and setting times, a lunar calendar, a portrait of Uncle Wethbeeappropriately dressed for the season, and a bit of doggerel beneath Unk’s smiling mug,like “We know that Spring will soon be here/ But Winter’s not quite gone, we fear.”Interspersed with advice on home barometers and how to read a weather map wereexplanations why electric dryers do it better, and the benefits of an automaticdishwasher.53

![Unk’s Weather Symbols](image)

**Figure 5.4:** Tex Antoine developed a complicated iconography to show the weatherthrough his Unk Wethbee cartoons. Free pamphlets helped to spread this visualcode, as well as messages from Antoine’s primary sponsor, the Consolidated EdisonCompany. (Author’s personal collection).

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53 “Uncle Wethbee’s 1963 New York Weather Almanac, with Tex Antoine.” Author’s PersonalCollection.
Inexpensive or free materials like Antoine’s almanacs kept the forecaster and his comic style familiar to a wide audience, even when he was not on the air. Similar sorts of guides have become a common product of TV stations across the United States and around the world, as stations, sponsors and weathercasters trade on television celebrity by producing a variety of almanacs and weather books, sometimes for sale, sometimes distributed free as advertising.\footnote{Robert Henson estimates that perhaps a million copies of such publications were being distributed each year in the late 1980s. Henson, \textit{Television Weathercasting}, 45. Other examples of books trading on the celebrity of weathercasters include: Don Woods, \textit{Woods’ Weather Wisdom: Starring Gusty} (Oklahoma: Leake Industries, 1980); \textit{Dr. Frank Field’s Weather Book} (New York: G.P. Putnam’s Sons, 1981); \textit{Dick Goddard’s Weather Guide and Almanac for Northeast Ohio} (Cleveland: Gray & Company, 1998).}

\textit{Cue the Weather Girls}

Antoine’s success also led to a new kind of public face for meteorology: the “weather girl.” Antoine’s continued high ratings on WNBT pushed the other New York City stations to experiment. In 1952, WCBS and WABC hired attractive women to present the forecast, an idea that quickly caught on nationally. By 1955, “women made up a major fraction of all weather anchors, if not a majority,” according to the leading historian of weathercasting, Robert Henson.\footnote{Henson, \textit{TV Weathercasting}, 82.} \textit{Life} magazine noted, “between girls and gimmicks, men are more and more being left out in the rain.”\footnote{\textit{Life}. \textit{Weather Work for Women: Visual Tricks Brighten Forecasts}. March 28, p. 8-10. 1955: 9.} News directors emphasized beautiful women, aiming to attract male viewers with models, actresses, and beauty-pageant winners.\footnote{Former “Miss San Diego” Raquel Welsh got her start in broadcasting as a weather girl for KFMB in San Diego, before going to a career in the movies. Other TV entertainers who worked as weathercasters include comedian David Letterman, game show host Pat Sejac, and news anchors Tom Brokaw and Jane Pauley.} Maxine Barrat presented the weather to Miami in a bathing suit, while Ginger Stanley presented the weather immersed in a bathtub on CBS’s
“Morning Show.” “Perhaps the greatest indignities of all,” Henson writes, “were experienced by Tedi Thurman of NBC, whose weathercasts on the Jack Paar ‘Tonight’ show of 1957 were just short of burlesque.” Peaking from behind a shower curtain, she might report, "The temperature in New York is 46, and me, I'm 36-26-36." Situation comedy writers invoked the familiar sexual attractiveness of female weathercasters in episodes of *The Dick Van Dyke Show* and *The Beverly Hillbillies*.

Since few early weather reports were recorded, *The Beverly Hillbillies* episode “Granny versus the Weather Bureau” (1964) offers a unique source for exploring how ‘weather girls’ threatened the authority of meteorologists. The episode also suggests how different kinds of viewers were expected to react to ‘weather girls,’ admittedly in caricatured form. As the show opens, a gangly young man leaps out of his jalopy and rushes into the family mansion, announcing “It’s time for the weather on television!” Jed Clampett asks his daughter Elly May, “Since when is Jethro so interested in the weather?” “Since he seen that pretty girl that talks about it,” she answers. The scene cuts to an attractive young brunette whose pearls emphasize a swooping neckline, televised in front of a simplified map of the northern hemisphere (Figure 5.5). With an alluring smile and a provocative sway of her hips, she announces that a high-pressure system will hold back the mass of moist air moving in across the Pacific. (“Hot diggity dog, ain’t she pretty!” comments Jethro.) “By the way, there’ll be a full moon tonight,” she continues,

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58 Henson, Television Weathercasting, 81
“Perfect for a weenie roast on the beach. See you there…” she invites with a wink.

While Jethro says “You sure will!” Granny complains that the girl hadn’t gotten the forecast right all week.\footnote{The Beverly Hillbillies. Granny Versus the Weather Bureau. First aired March 25, 1964. Columbia House Collector’s Edition. 1989. Video.}

Figure 5.5: The flirtatious weather girl featured in The Beverly Hillbillies episode “Granny versus the Weather Bureau, aired March 25, 1964.

Station managers realized that overt sexual appeals to male viewers risked offending women. Fred Thrower, the executive vice president of New York’s WPIX, believed that “women don’t like bosomy dames. Nor do they necessarily like to have their husbands ogle them.”\footnote{Gilbert Millstein, “The Weather Girls Ride Out a Storm,” New York Times Sunday Magazine, October 8, 1961: 62, 64, 66, 69.} His station employed Gloria Okon, a woman “as wholesome
as the bread, rolls and cookies she pushes,” according to the *Times*.\(^6^3\) Other station managers hoped that emphasizing fashion would make sexually attractive weather girls appealing to (heterosexual) female viewers as well as men. According to WABC’s station manager Joseph Stamler, “We feel that women—or ladies—have greater acceptance than men, because, well, with the combination of an attractive-looking personality the men prefer to look at and the women are attracted to because of the fashions they wear, we’ve really got a two-fold program.”\(^6^4\) Fashion magazines embraced New York weathergirls as celebrity models. A 1962 *Vogue Pattern Book* spread featured an image of a smiling Jan Crockett strumming in front of a weather map, wearing “a figure skimming ‘Young Fashionables’ coat dress of clear water-lily green worsted and silk, double-breasted with self-covered buttons.” In an article emphasizing versatile clothing for fall, the magazine noted that her job as a weather reporter gave her an advantage in “deciding whether to bundle up or to dress for Indian Summer,” but that her “what-to-wear problems are compounded by a kaleidoscopic daily routine as wife, mother, and television performer.”\(^6^5\) Another picture showed Crockett taking her script from the suited, rather dumpy-looking male meteorologist who actually produced the forecast. Regardless of fashion or domesticity, the ‘weather girls’ represented hegemonic femininity, put on screen to attract the heterosexual male gaze, not educate the public about meteorology.

The sexualized weather girls threatened the authority of credentialed meteorologists, who felt they obscured male scientific labor while making weather forecasting seem like a trivial activity unfit for scientific status. The huge amounts of

men’s work in collecting, charting and analyzing weather data disappeared behind a pretty female face, which rendered the actual atmosphere almost irrelevant. Choosing a weathercaster based on looks suggested that anyone could be a forecaster, and that research, theorizing and observation were irrelevant. But most importantly, that pretty face connoted a set of associations with subjectivity, sex, and emotional engagement. ‘Weather girls’ implied meteorology could not produce the objective, reliable predictions considered the hallmark of true scientific knowledge.

For meteorologists in the 1950s, historical connections between the feminine and subjectivity particularly threatened their credibility. Dynamic meteorologists asserted that the atmosphere was fundamentally predictable, working to transform weather forecasting from an intuitive, experiential art into objective calculations based on the basic equations of physics. Yet commenting on weather girls in 1955, *Life* wrote that “the only thing as variable as the weather is the ways of women.” Femininity invoked a long-established discourse about the need to maintain emotional distance between the object of scientific study and researcher, which stood in contrast to equally long-established cultural notions of women as emotional and irrational beings. The imagined closeness of women to nature was believed to make it impossible for them to detach themselves emotionally to produce objective knowledge.

Televised feminine weather experts contradicted an emerging set of images depicting the meteorologist as heroic man protecting society from dangerous female

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The panels of a 1958 Chesterfield Cigarette advertisement, “Men of America: Hurricane Alert,” credit the US Weather Bureau for a series of “live action shots” that feature a thick-necked, clean-cut, cigarette-smoking man reading the teletype, plotting a hurricane track, and issuing a “radar warning, storm will hit our shore.”

(Figure 5.6) Frank Capra’s 1957 Bell Science TV program, *The Unchained Goddess*, had personified the weather as the capricious Goddess Meteora, who unleashes a thunderous wrath after a male scientist scorns her flirtatious affections. Beginning about 1953, the Weather Bureau publicly named hurricanes after women, an informal meteorological practice that first came to widespread attention after the 1941 publication of George Stewart’s novel *Storm*, a best seller and “book of the month club” selection that was even excerpted in Boy Scout manuals. But the “weather girls,” like the poorly-predicted 1954 hurricanes Carol, Edna and Hazel, threatened claims that meteorologists produced dependable knowledge essential to keeping society safe. Women weathercasters subconsciously reminded viewers that forecasting remained a subjective and intuitive enterprise, that the weather remained uncontrollable, and that meteorology might not be so rigorous a science as its professional practitioners asserted.

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68 On the different ways in which similar scientific labor is construed when conducted by men in contrast to when it is conducted by women, see Naomi Oreskes, “Objectivity or heroism? On the invisibility of women in science,” *Osiris* 11 (1996): 87-113.


Figure 5.6: This 1958 cigarette ad is representative of images depicting heroically masculine meteorologists protecting America from dangerous female weather during the later 1950s. (Unknown publication, author’s personal collection)

The AMS Responds

The AMS reacted to weather girls and comedian weather presenters by launching a Seal of Approval program. Serious discussions about the Seal began near the peak of
“weather girl” era, when the AMS Council, led by president Horace Byers, voted to establish an ad hoc Committee on Radio and Television at its meeting in New York in January 1954. In May 1955 the Committee became permanent, and the Council agreed to its suggestion that the AMS approve exemplary programs, rather than condemn low-quality broadcasts. Efforts to define a good weather program focused on the personality of the presenter, emphasizing that presenters must maintain a “professional manner,” in the words of Committee member James Fidler. The proper weathercaster should make “an accurate presentation of the facts,” that was “audibly coherent” and “smooth to watch,” while “always appear[ing] sincere and confident.”

Fellow committee member Frances Davis seconded Fidler’s focus on the persona projected by a weather presenter, implying that the authority of meteorology depended upon the representations shown on TV. Under the assertion “Weather is no Laughing Matter,” Davis went public with the AMS’s plan in a July 1955 article in TV Guide, writing

> If TV weathermen are going to pose as experts, we feel they should be experts. We think the weather should be discussed with dignity. Dignity, not dullness. We think many TV ‘weathermen’ make a caricature of what is essentially a serious and scientific occupation, [and] help foster the notion that forecasters merely grab forecasts out of a bowl.

Displaying a professional manner thus required a weathercaster to perform a confident, dignified and technically accurate presentation of weather facts while projecting the authority of natural science. University of Texas meteorologist K. H. Jehn, writing “as a professional,” sought to add a pedagogical component to this burden. Believing that “the

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73 Quoted in Henson, TV Weathercasting, 9.
educational feature is essential,” Jehn hoped, “viewers will learn something about the weather at the same time that they hear […] the forecast for tomorrow.” He argued that the “basic criteria for issuance of the seal” should include “a technically correct presentation, with an educational feature and entertainment value.” At the time, Jehn was a meteorology professor, not a broadcaster, but the AMS apparently appreciated his contributions enough to appoint him chair of the Radio and Television Committee.

While it was easy to tell other scientists that the weatherman should be dignified and accurate, educational and authoritative, the realities of commercial broadcasting gave meteorologists little control over the presentation of the weather. As Frances Davis noted as early as 1949, because broadcasting was a money-driven business,

the professional meteorologist in radio must be reconciled to having the virtues of various products extolled before and after his weather broadcast, and sometimes in the middle. And he will find it to his advantage occasionally to tie the sponsor’s product in with the weather incidents described in the body of his own script, contrary as it may be to his professional principles.75 Photographs show sponsors’ logos displayed prominently on maps and behind weathercasters during the 1950s76 while video clips from 1960s weather reports show weathercasts supported by gasoline companies and local banks. The Savannah Bank and Trust Company sponsored Cap’n Sandy on WSAV-TV in Georgia during the early 1960s. A series of different weathercasters played Sandy over the years, each wearing a

captain’s hat and naval jacket while they narrated their hand-drawn weather maps.

Pausing between describing the national and the regional weather conditions, Sandy would introduce a message from his sponsor, like a one-minute pitch for a vacation loan and a reminder to buy traveler’s checks, which the Cap’n said was “mighty good advice.” Wilber the Weather-Bird, dressed in rain gear, might drop in with a forecast clamped in his beak, and then Sandy would read “the official Department of Commerce Weather Bureau forecast” before thanking “Arthur” for showing 88° and noting with a twinkle that “Arthur-mometer is right up there today.”

In the eyes of the station managers who hired and fired, it was sponsorship that defined a successful weathercast, not the presentation’s educational value or the dignified authority of a professional meteorologist.

The tensions between commercial reality and meteorologists’ conceits delayed the Seal of Approval program for nearly four years. It was not until February 1959 that K. H. Jehn, describing himself as “older and wiser now, and with nearly two years experience in the ways of radio and television production,” was able to announce the criteria for awarding Seals of Approval. First, all Seal applicants had to be Professional Members of the AMS. In 1957, the AMS Council had changed the procedure for becoming a Professional Member, requiring that a candidate be sponsored by two existing Professional Members, “have completed a professional course in meteorology at an institution of recognized standing and have been employed in meteorological or climatological work at a professional level for at least two years, one of which must be

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the year prior to election.” After meeting those standards, a weathercaster would submit an application and fee to the AMS. Members of the Radio and Television board, along with local AMS members in the broadcast region, would then evaluate “the performer and his or her program” on four criteria: informational value, audience interest, educational value, and professional attitude. Each criterion was judged unsatisfactory, marginal, satisfactory, or excellent, and a performer had to score at least satisfactory in all criteria to be accepted. The committee placed special emphasis on professional attitude, defining it by noting: “He [the weathercaster] acts in such a way as to enhance the prestige of meteorology as a science and a profession.” In a footnote, the Committee emphasized that a professional attitude “is an expected attribute of a competent meteorologist,” in contrast to merely a creditable weathercaster. Only professionals were true meteorologists.

The Seal of Approval program’s statistics reveal how the practices of professionalization excluded women. Because AMS Council members and committee members generally retained their own records, evidence of who applied and who was rejected is not readily available. But the names of successful applicants provide telling evidence. Between January 1960 and December 1972, the AMS awarded 95 Seals to men before approving the first woman. Of the first 200 approved weathercasters, from 1960 to 1979, just 3 were women. The rate of women in the next hundred seals more than

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80 Jehn, K.H. “Recognition of Competence in Weathercasting,” original emphasis.
doubled, but was still just 4%. By the end of 1984, twenty-five years after the start of
the program, just 11 out of 352 seal holders (3.1%) were women.81

Today, as the Seal of Approval nears its fiftieth birthday, women weathercasters
continue to work beneath a “chromakey ceiling.”82 While the AMS has taken positive
steps to integrate women into meteorology, such as establishing a Board on Women and
Minorities in 1975 and awarding a significant percentage of its undergraduate and
graduate scholarships to women, women constitute only about 20% of the AMS
membership overall.83 Regarding professional certifications, women hold about 18% of
active television Seals of Approval, a higher percentage than ever before (Table 5.1).

<table>
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<th>Certification</th>
<th>Men</th>
<th>Women</th>
<th>Percentage</th>
</tr>
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<td>149</td>
<td>18.2%</td>
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<td>1</td>
<td>4.3%</td>
</tr>
<tr>
<td>Certified Broadcast Meteorologist (Total)</td>
<td>264</td>
<td>30</td>
<td>10.2%</td>
</tr>
</tbody>
</table>

Table 5.1: Gender of active AMS broadcast meteorologist certification holders,
September 2008.84

Yet two disturbing facts challenge this apparent progress. First, American women
weathercasters are much more likely to broadcast at less prestigious times; nearly three
quarters of women work the weekend, morning or noon shows, while almost 60% of men

81 Historical list of Seal holders published in Henson, TV Weathercasting, Appendix II.
82 Wilson, Kris M. Television Weathercasters as Prominent Science Communicators. Public Understanding
of Science, v. 17, n.1, p. 73-87. 2008: 78. Chromakey refers to a video production process where part of an
image is removed to reveal an image beneath it. Weathercasters stand in front of a large green or blue
screen, while the video production team digitally removes the background color to reveal an underlying
image of a map or radar scan. Weathercasters thus cannot directly see the image that the audience sees
behind them. A separate monitor, just off screen, helps them position their hand to point properly. A
weathercaster must avoid wearing clothes the same color as the background, lest he appear to have radar
stains on his shirt or tie. A recurrent joke, particularly on a wacky weatherman’s last broadcast, is to put a
ridiculous picture in place of the weather map, and see how long it takes him to notice.
83 Murillo, Shirley T. et al. An Overview and Longitudinal Analysis of the Demographics of the AMS.
84 Savoie, Kelly Garvey, AMS Director of Special Programs. Personal communication. October 2, 2008.
work prime time. Second, the AMS’s new, more advanced certification program has an even lower percentage of women than the AMS membership as a whole. Introduced in January 2005, the Certified Broadcast Meteorologist program aims to

raise the professional standard in broadcast meteorology and encourage a broader range of scientific understanding, especially with respect to environmental issues. The goal of the CBM program is to certify that the holder meets specific educational and experience criteria and has passed rigorous testing in their knowledge and communication of meteorology and related sciences needed to be an effective broadcast meteorologist.

While improving public understanding of environmental issues is laudable, certifying the education and professional standards of broadcasters is a problematic way to achieve this end. As the history of the AMS Seal of Approval shows, professional certifications can be exclusionary tools used to establish public authority. Once a profession has established its authority, certifications reinforce existing social hierarchies, requiring new entrants to gain the approval of older leaders. A certification program’s internal effects on the behavior and demographic composition of professional members are much more direct than its external effects on public education. The act of judgment is inextricable from the act of exclusion; it is through such exclusions that gender boundaries are crystallized and maintained.

Conclusion

The TV weather report is the most visible manifestation of a pervasive science whose evolution has been driven by the needs of industry and the military. The influence of aviation runs unacknowledged throughout the three-minute segments shown every

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night on the news, from the theory and methods that underlie the predictions, to the data and radar images shown on the maps, to the visual idioms of comic art like shimmering heat waves and radiant suns. Although the vast majority of meteorologists work invisibly behind the scenes to support the operation of technological systems, TV weathercasters have become the science’s public face.

While most of meteorology’s growth in the 20th century is due to the science’s role in supporting infrastructure, that growth has also revealed a deep popular interest in weather. By the early 1980s, watching the weather on television had become so popular amongst American viewers that TV weathercaster John Coleman launched a dedicated 24-hour cable station. Though often derided as a joke, The Weather Channel was reported to fetch $3.5 billion when it was sold in 2008. Recent surveys show that 96-98% of people use forecasts regularly, while the typical American adult accesses weather forecasts about 115 times per month (or almost 4 times a day). More than 70% of people obtain forecasts from local television news at least once a day, while cable TV, radio, newspapers and the Internet are other common sources. Under normal circumstances, the general public primarily uses this information for deciding how to dress, how to travel to work or school, and simply because they are interested in tomorrow’s weather. But when severe weather threatens, forecasts play a powerful role in shaping public

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responses, including evacuation decisions. 

Television weather forecasts have become central to how Americans interact with the environment.

As a result, television weathercasters have become the most visible symbols of meteorology. Weathercasters report being involved in public outreach activities like giving guest lectures, participating in science and career fairs, and mentoring students, at a higher rate than any other group of American Meteorological Society members. While the AMS’s efforts have been only partially successful in ensuring that weathercasters are actually meteorological experts, many people treat them as such. Because celebrity is one of mass culture’s key modes of credibility, the opinions of TV weathercasters have a disproportionate influence. John Coleman’s status as founder of The Weather Channel justifies reporting his denials of climate change, although his degree is in journalism.

The history of television weather reporting challenges scholars to think more deeply about the public understanding of science. In contrast to the audiences for documentaries and science journalism, the near universal consumption of weather forecasts suggests a much broader population that is interested in scientific information, albeit science in its most attenuated form. The unique status of TV weathercasters as communicators of science requires us to consider the role of celebrity in the production of credibility. The publicity and professionalization of meteorology in the decades since World War II reveals the turbulent confluence of visual culture, technoscientific, and

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91 Charles Homans, “Hot Air: Why don’t TV weathermen believe in climate change?” *Columbia Journalism Review* (January/February 2010), cover story.
environmental perception. Meteorology feels so familiar and trivial from TV that we forget its significance as an industrial governor.
Conclusion

In the mid-1960s, comedian George Carlin created a satirical newscast so he could comment on the world’s absurdities. One of his anchors was Al Capp, “the hippy-dippy weatherman, who brings you all the hippy-dippy weather, man.” Echoing the patter familiar to any TV viewer, he’d announce that the temperature at the airport was such and such, with winds from the west at so and so miles per hour. Then he’d pause, and puzzle in his hippy-dippy way: “Why do they always tell us the weather at the airport? Nobody lives there.”

At its simplest level, this dissertation is a prosaic answer to George Carlin’s question. They tell us the weather at the airport because, since the 1930s, that’s where the government’s official weather observation for each city takes place. The observation is made there because the safety of air travel depends on good weather observations. Meteorology is essential for reliable flight, and thus for economic productivity and military power, so the government has made sure that good weather reports are available. And airports are particularly good places to record the weather, say meteorologists. Because airports have open, exposed areas remote from the distorting influences of the “urban heat island” effect produced by buildings and chimneys and air conditioners, weather observations are not contaminated by the effects of human habitation. The data is more accurate, more true to nature, when it is collected far from where people live.
But there’s a barb buried in Carlin’s joke. Even something as ordinary as the weather report, he implies, has been distorted by the needs of the industrial system. Meteorology serves machines, not men.

At a deeper level, this dissertation explores a hidden relationship between science, industrial society, and the environment. It shows how the reliable operation of “second nature,” those infrastructural systems that deliver food, water, energy and information to us, require the monitoring and prediction of “first nature.” It explains how industrial lifeways depend on certain kinds of scientific practices: routine observation, forecasting, theorizing. A broad collection of obscure, little-celebrated technical practices are essential if we want to live healthy lives of material abundance in densely populated, energy-intensive societies. Aeronautical meteorology is an example of these technical practices, representative of the many infrastructural sciences that define the industrialized world.

However, aeronautical meteorology has also created knowledge that extends beyond the industrial network it was built to support. The challenges of predicting the weather at altitudes outside of ordinary human experience, and the meteorological support necessary for long-range, long-endurance flights, encouraged theoretical research into the atmosphere’s general circulation. As dynamical models grew, voraciously demanding global datasets to feed their calculations, atmospheric scientists came to understand the global atmosphere as a single, coherent entity potentially subject to systematic change. Theoretical research, though initiated to address military and corporate problems connected to flying, developed a culture and sustained institutions
that began to make different inquiries. In connection with other scientific discoveries and broader cultural movements, atmospheric scientists developed a new understanding of the depth of human influence on the atmosphere. Their work has shown that there is nowhere on Earth, not even at the remotest airfield, where we can collect data on weather that has not been affected by human activities.

As the implications of climate change pull meteorology out of cultural obscurity, there is a tentative but growing call for a much broader vision of atmospheric science. Natural scientists, watching immediate disasters like Hurricane Katrina and creeping crises like climate change, are concluding that better numerical models alone will not save lives or produce the political and economic transformations necessary to minimize dangerous human effects on the Earth’s systems. Pioneering social scientists are reaching out, building capacity for integrated studies of weather, climate, and society. Founded by aeronautical meteorologists among others, the American Meteorological Society has begun to support a robust policy program that calls scientists’ attention to the power of government in science and environmental issues. In journals and conferences, atmospheric scientists are encouraging each other to bring their skills to bear in interdisciplinary teams with economists, communications experts, and sociologists, to work with local governments and non-governmental organizations, and to tackle practical challenges like helping farmers respond to changing drought patterns or communicating probabilistic severe weather forecasts in formats that the public can better use. These efforts are a necessary corrective to a disciplinary culture that has produced Ph.D.s with
rigorous training in geostrophic approximations and cloud dynamics, but little knowledge of human interactions with the weather.

Yet it is this disciplinary culture, a disciplinary culture that prizes fundamental explanations of physical and chemical phenomena in the atmosphere, that has also produced astonishing gains for meteorologists over the last ninety years. In the decades since the beginning of the modern disciplinary era, atmospheric science has become far better funded, has supported many more highly-educated practitioners, and been recognized as central to national defense. While these successes reflect the triumphs of science generally in the United States during the 20th century, and though meteorology never became as culturally prestigious as high-energy physics or molecular genetics, meteorology’s re-emergence as a credible and respectable discipline was closely tied to the creation of institutions pursuing theoretical research. During the 1920s, it is important to remember, American meteorology was dismissed as a “guessing” science, its leaders viewed as Weather Bureaucrats who were not invited to membership in the National Academy of Sciences. Over the next four decades, numerous universities established graduate programs in meteorology and created new academic research organizations like NCAR. In the late 1950s, threatened by the cultural (and hence recruiting) appeal of high-energy physics,1 leaders in American meteorology sought to recast “meteorology” as “atmospheric science,” expanding their science beyond weather to encompass atmospheric chemistry, climate dynamics and ionospheric physics.2 These moves have

helped atmospheric scientists to Nobel prizes in chemistry and even to the presidencies of the National Academies. But they also led to the diminution of subjects and methods.

Ninety years ago, American meteorology’s central topics of inquiry included the relationships between weather and health, agriculture, or human behavior as readily as studies of the structure of the atmosphere. Meteorology’s transformation in support of aviation focused scientists’ attention on the upper air, a simpler place where equations could adequately describe the environment. The needs of the commercial airlines sustained a small research community during the 1930s, while the coming of World War II required a crash program that trained thousands of meteorologists in the universal knowledge of dynamics, so they could be deployed and redeployed anywhere the global battle might need them. These thousands of rapidly trained men solidified a disciplinary culture that valued theoretical rigor over practical skill, which emphasized fundamental causes, not local effects. The war established the epistemological values and social hierarchies that would shape atmospheric science for decades, laying the ground work for the challenging task that now faces us, producing an integrated science that recognizes the complexity of human interactions with the atmosphere.

One advantage of historical research is that it records the entrances to paths that might have been taken, but instead receded into the wilderness of contingency in which we always wander. One such example is provided by C. Warren Thornthwaite, the Soil Conservation Service climatologist who declined the opportunity to come to MIT just as it was becoming the center of institutional power in meteorology. Thornthwaite’s calls

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3 Robert M. White, President of the National Academy of Engineering, and Ralph Cicerone, President of the NAS, for instance.
for interdisciplinary experts competent to address problems at the intersection of climate and society sound strikingly contemporary, even more than 60 years later. Thornthwaite recognized the inevitable tensions between human desire and the limits imposed by nature. Describing a strategy for humanely managing the Great Plains, a region defined by climatic variability, Thornthwaite wrote,

> It must be recognized that in the future there will be a recurrence of rainy years that will attract settlers and invite extension of wheat production and land speculation. Past experience has shown conclusively the need for setting up restraints before the onset of a series of years favorable to commercial grain production in order that the population of the future may be less vulnerable to the terrors of inevitable future droughts.\(^4\)

Here was a vision of a quite different atmospheric science, also infrastructural—still engaged in observation and prediction in support of environmental management—but focused on a very different community of users.

As the practices of aeronautical meteorology became dominant, and weather moved to the airport, these users—farmers, poor people, people living in ecologically sensitive landscapes—were built out of the new infrastructural science of meteorology. Only now, under the threat of global catastrophe, are they being built back in. As citizens of the industrialized societies, it is our obligation to understand such dynamics—those changes in knowledge that make possible the operation of our infrastructure, but also make parts of the world that materially affect us either visible or invisible. These shifts in modes of knowledge-making, in the infrastructural sciences, affect every aspect of our material lives. The infrastructural sciences build and maintain the environments where we

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live. Tracing their rise and their shifts should be a central task for historians of technology and science.