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Knowing the Great Plains Weather: Field Life and Lay Participation on the American Frontier during the Railroad Era

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Abstract On the US Great Plains frontier in the late nineteenth century, perhaps no area of scientific knowledge was more contested than the weather, which connected with debates around the long-term climate of this semiarid region. Observation of the weather was shared across the divide between scientists and lay people, illustrating an early historical predecessor of enlisting citizen scientists to help in the production of knowledge. Situating this example of lay participation in the larger context of diverse modes of field practice during the railroad era, this article examines the production of weather knowledge on the Great Plains frontier, especially in Kansas, to explore some important stages in the process of coordinating lay observers, including the ground-level practices of organizing lay people into networks for producing knowledge, and marginalizing and discrediting folk knowledge about the weather that was autonomous from the authorized scientific community. The author argues for greater attention to the historical emergence of crucial hierarchical, structured aspects of lay participation in science, inflected by the Chinese concept of *shi*, in contrast to the recently common focus on flattened, collaborative networks.

Keywords meteorology · weather knowledge · lay participation · observing networks · forecasting

Weather knowledge has long been a powerful arena for encounters of scientific experts with amateurs and lay people—what we might now call citizen science. This article examines a place where weather knowledge might be thought even more crucial than usual: frontier Kansas, in the western US grain belt, as well as other nearby states of the Great Plains. Conditions in Kansas and the Great Plains more generally are influenced not only by weather systems coming over the Rocky Mountains from west to east but also by frigid Arctic air sweeping down from the north and moisture-laden air coming up from the Gulf of Mexico to the southeast, resulting in dynamic, rapidly changing

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patterns of temperature and precipitation, along with relatively frequent tornadoes and thunderstorms. This article considers how lay people and amateurs on the US Great Plains during the frontier era from the 1870s to the early 1900s were organized into weather observing networks, how alternative ways of knowing the weather were marginalized or suppressed, some geographical and temporal issues that contributed to top-down control of weather knowledge production, and the subordination of local observation projects to national research agendas. To be sure, attempts to structure weather knowledge production from the top down have always encountered both environmental and human challenges, sometimes including outright resistance, but the predominant historical trajectory established and reinforced a hierarchical system of knowledge production. With the recent explosion of interest in citizen science (Irwin 1995; Leach, Scoones, and Wynne 2005; Chen and Deng 2007; Fan 2012; Cooper 2016), these relations have become especially important to examine historically.

Like other productive activities in the modern world, then, scientific work is organized through patterned, hierarchical structures. Authority over knowledge making has been distributed unevenly. While such generalizations might seem obvious, it is useful to reassert them in an era when many scholars in science and technology studies (STS) have focused much more on "flattening the social," in Bruno Latour's (2005) terms. Sophisticated scholarship in STS in the past few decades has been increasingly attentive to the messy world of particularities, contingencies, complexities, uncertainties, heterogeneities, performativities, relationalities, fluidities, multiplicities, translations, and coconstructions. Such work triumphantly breaks down dichotomies between global and local, natural and social, human and nonhuman, knowledge and context, science and technology, lab and field, inside and outside, scientific and indigenous knowledge, epistemology and ontology, and modern and traditional (e.g., Latour 1986; Pickering 1995; Law and Mol 2002; Mol 2002; Carolan 2004; Law 2004; Gramaglia and Sampaio da Silva 2012; Law and Lien 2012). It is an impressive body of work, even persuasive, up to a point.

Yet despite its seemingly historicist emphasis on the particular and contingent, such work often resists asking questions about large-scale change over time or historical explanation (Shapin 1988), which would reveal structures and hierarchies that constrain action. We could build productively on the work of scholars like Daniel Lee Kleinman (1998: 286), who has long critiqued much of STS's obsession with agency and enabling situations—its tendency "to ignore, underplay, or dismiss the possibility that historically established, structurally stable attributes of the world may systematically shape" the objects of our study. Embedded in commercial relations that go far beyond the headline-grabbing active entanglement of scientists in the business world, the present-day university laboratory, Kleinman (2003) contends, is shaped by existing structures of the capitalist political economy. In agreement with Kleinman's analysis, this case study in meteorology in the field emphasizes the historical construction of relatively stable structures and power relations fundamentally operating not just in the larger shaping context of science but also undergirding the ground-level work organization of knowledge production.

Such an approach need not deny that these hierarchical structures are relational and situated. Here, the Chinese concept of *shi* may be helpful in reminding us how propensities not only are dynamic, flexible, and heterogeneous, as some STS scholars have emphasized (Law and Lin 2017; Lin 2017), but also indicate configurations of position or power that structure those relations (Jullien 1995). Thus, rather than seeing the subjects of our analysis as independent agents reconstructing their worlds by building their own networks, we might see them as embedded in positions that are already in relations of power with one another. Moreover, by inflecting a structural approach with the Chinese concept of *shi*, its relational and situated aspects can be acknowledged more explicitly. However, if previous attempts to apply the Chinese concept of *shi* to Euro-American material (Law and Lin 2016, 2017) have articulated close conceptual linkages to the poststructural approaches that this article critiques—not to mention the dissolution of the very distinction between theory and case study itself—the analysis below aims to show that a framework emphasizing historically produced power relations and hierarchy over flattened networks can also be productively enriched by the concept of *shi*, and in direct application to an American case study. This blending of STS approaches from diverse origins also contributes modestly to the frequently expressed aim to "apply a non-Euro-American theory to Euro-American cases" (Chen 2017: 253).

Notable work on the field sciences has followed larger trends in STS. Thus, rather than focusing on hierarchical structures or power relations, it instead often stresses, as one now canonical article puts it, how diverse social groups such as professional researchers and hired field hands "collaborate" around shared "boundary objects" (Star and Griesemer 1989). Such work asks if science might be "better thought of as a complex, possibly nonhierarchical, network in which a multiplicity of collaborations result in a heterogeneity of joint productions and products," rather than as "some kind of social hierarchy" (Griesemer and Gerson 1993: 202). To be sure, leading STS work on the field sciences reveals the valuable role of infrastructure networks and standardization in facilitating information flow, but with an emphasis on the agency of smaller-scale independent actors rather than larger structural forces (Bowker 1994). Even in valuable work on aggregating scientific data for larger regions or global science, which has admirably stressed the complications involved in overlapping levels of authority (Bowker 2000; Waterton 2002), a studied agnosticism with regard to structural world-systemic patterning has prevailed. At the same time, other scholarly work, especially in the history of climatology and meteorology, has also emphasized the historical emergence of global infrastructures for the production of knowledge, as well as the ways that such infrastructures have enabled linkages between different scales (Edwards 2003, 2010). Building on other scholars' recent work in the history of meteorology (discussed more fully in the conclusion to this article) and following the viewpoints of historical actors who were successful in centralizing meteorology by the end of the nineteenth century, I aim to argue for greater attention to hierarchy over flattened networks.

To apply an alternative perspective, some historical depth is essential. "Generally speaking," as Fa-Ti Fan (2007: 246) writes, "STS is still rather weak in dealing with macro and long-term social processes. It tends to produce case studies in snapshots." In at least partial agreement with Daiwie Fu (2007), whose caution about abandoning hierarchically structured conceptual frameworks is even closer to my own viewpoint, Fan advocates for examining the "broad historical and political forces that have helped shape science and technology in East Asia," and I see no reason not to extend such a perspective to the rest of the world, including weather observing practices in Kansas. In other words, STS scholars around the world might examine the development of more-or-less stable, *shi*-inflected—and thus situated and relational—structures of work practice over time. Admittedly, any social structural model of science can be built at least in part on the Latourian sociology of the 1980s, deploying concepts such as centers of calculation (Latour 1987). STS scholars have long rightly stressed the importance of control over interpretation—the construction of more prestigious and general facts out of lower-level and more particular ones—and the accumulation of credit for doing so (Latour and Woolgar 1986). It is my task here not to look for the emergence or nonemergence of class consciousness among subordinate participants in scientific work, or to narrate the history of science from the bottom up—such tasks demand case studies with better sources of evidence on such matters—but instead to trace the relations of knowledge production as they manifested themselves in specific forms of scientific work organization. While such relationships could alternately be described as either asymmetrical hierarchies or flattened networks, the preponderance of evidence from the historical actors themselves suggests that the hierarchical power relations were especially salient in how they thought about the citizen science of the late nineteenth century, even if lay and amateur collaborators may not have always fully complied with or accepted those structured power relations.

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In the modern world, the laboratory has cast a shadow over other modes of knowledge production, but underneath its universalizing pall other practices also sprouted in the late nineteenth and early twentieth century: the modes of scientific practice in the field (Kuklick and Kohler 1996; Vetter 2016). Unlike the laboratory, which has aimed to be situated nowhere in particular, field networks have been extended across space, thereby allowing researchers to harness the characteristics and resources of multiple places. In many cases, these lay networks, as we might call them, collected physical specimens, which were then sent to career scientists in distant metropolitan centers. In other cases, however, field scientists sought knowledge that could not be obtained from transportable material specimens. Such standardized evidence was crucial to the production of knowledge through hierarchical networks that relied on trusting local observers who were often lacking scientific training, credentials, or disinterestedness.

Previous historical research on field and observatory sciences has already revealed long-term changes in the social patterning of scientific work, identifying the emergence of the categories of amateur versus professional—and the related but sometimes different categories of lay versus expert—or in many cases problematizing them (Lucier 2010). In early nineteenth-century British geology and natural history, for example, the prevailing hierarchy in scientific credibility and control cut across any putative amateur-professional distinction, dividing practitioners according to social class more than professional status (Rudwick 1985; Secord 1994). Later, during the height of scientific professionalization in the late nineteenth and early twentieth centuries, the role of amateur participation became especially contested, though amateurs continued to play a key role in many sciences, ranging from observatory sciences such as astronomy to field sciences such as botany, ornithology, and natural history (Lankford 1981; Rothenberg 1981; Keeney 1992; Barrow 1998; Alberti 2001). In examining weather observing networks in frontier Kansas, we are not in the bounded and socially exclusive laboratory or observatory but instead at the unbounded and socially permeable field site, where relations between scientists and lay people, and the propensities of each of these roles, were often evident from the earliest stages of the knowledge production process, even if resistance to those roles was also part of those same conditions and circumstances.

Moreover, while the collection of high-value physical objects such as minerals, meteorites, and fossils did involve the creation and maintenance of social relationships with local nonscientists in the field—drawing, in the case of paleontology, on social norms from profit-making economic sectors (Rieppel 2015) and intertwining debates over the authenticity of such material objects with discussions of credibility and identity (Rieppel 2017)—it often allowed the researcher to focus on designated sites of interest, however unevenly distributed they were across the landscape. Producing knowledge about the weather, on the other hand, normally required a network of observers stationed across an entire region. It necessitated a high level of organization and coordination to assemble enough observations to generalize about usual weather patterns and their common characteristics, or to generate useful forecasts in the short run. As James Fleming (1990) has pointed out, a national meteorological project was one of the first major research efforts of the Smithsonian Institution in the mid-nineteenth century. The centralization was made possible by the use of the rapidly expanding telegraph network, just as it was in other parts of the world (e.g., Zaiki and Tsukahara 2007: 6).

It would not be precisely true to say that weather observation networks on the US western frontier came only with the telegraph. On the contrary, the midcentury Smithsonian network, while mostly covering the eastern United States, did have a few outposts in the West. These tended to rely on existing government sites—in particular, US Army posts and Indian agencies—and a few areas of initial white settlement along the eastern edge of the Great Plains. In 1860, for example, the observing sites included fifteen in the Kansas Territory, along with eleven and two in neighboring Nebraska and Dakota Territories, respectively (Bishop 1861: xliii–l). Without a telegraph, however, weather observations might be recorded for long-term data analysis for weather research but could not be communicated quickly for immediate forecast usage. Moreover, weather observations tended to be limited to a few years at each place, impeded by such factors as military post closure or the frequent movement of local observers inhabiting frontier towns. In the early 1870s, when Charles A. Schott (1876), an assistant with the US Coast Survey, brought together weather records from across the continent for the Smithsonian, different places had continuous observations for widely varying time intervals, from only part of 1866 for the small village of Avon, Kansas, to four full decades, 1830–70, in the case of long-lasting Fort Leavenworth on the Missouri River.

When the US Army system—which became known as the Signal Office, Signal Corps, or Signal Service—began operations in November 1870, its outposts stretched across the eastern half of the country, as well as along the few telegraph corridors that had just been completed into the West, most notably Cheyenne in Wyoming Territory along the transcontinental telegraph route (Hume 1940; Hawes 1966; Raines 1996: 49; Tate 1999; Fleming 2000). While most of the activities of the Signal Service centered on collecting routine weather observation data, extraordinary events did receive some extra research scrutiny, such as J. D. Finley's (1881) report on some especially severe

Kansas tornadoes in May 1879, whose paths he tracked all the way across the ninety-eighth parallel. In addition to telegraph-based networks of observers, the Signal Office also organized networks around post offices, such as in the summer of 1884, when they brought together observations regarding thunderstorms from "post-offices and other centres . . . over a limited extent of country, at distances of about 30 miles" (*American Meteorological Journal* 1884: 44–45). By sending a very specific set of instructions through the postmaster general's office about what data to record (e.g., direction, time of beginning and ending, rainfall amount), the Signal Office used an existing network that was already hierarchically organized in order to collect data not required for immediate forecasting and tracking purposes.

By the early 1890s, noted one meteorologist, the army-based Signal Service had embraced a telegraph network of 150 geographically dispersed sites within the United States—along with 26 in Canada and 1 in Cuba—telegraphing their 8 a.m. and 8 p.m. observations of "air pressure, temperature, dew point, relative humidity, precipitation, direction and force of wind and the amount, kind and direction of clouds" (Smith 1891: 50). This was transmitted with code words—"not for secrecy, but to save expense and time"—so that a typical telegram conveying a mixture of numerical readings, directions, and standardized sky terms such as *cloudy* or *stratus clouds* would read something like this: "Boston Fanfoot Regnest Beget Holdfast Moral Perfidy Null." This enterprise conjured up vivid images of synchronization and choreography in line with hierarchy and top-down control. "If you could have taken a bird's-eye view of the United States this morning at about two minutes of eight o'clock," wrote J. Warren Smith, "you would have seen observers all over the country climbing the stairs to their instrument shelters" (50). Thus, the adoption of hierarchical organization from the military may have been even stronger than it was in the apparently similar nineteenth-century large business corporations such as railroad companies, which despite some "indirect impact" due to the military training of many civil engineers, offered "little evidence that railroad managers copied military procedures" (Chandler 1977: 95).

During the same period when federal weather information gathering and research were housed in the US Army Signal Corps, local and regional efforts to collect weather observations also emerged, for example, in Kansas on the central Great Plains. These microcosms of national-scale meteorology reflected many of the same patterned relations and propensities that linked people in different positions within hierarchies, but at a smaller scale. One such example on the frontier was the Topeka Scientific Club, organized in the Kansas capital city in the late 1870s. "There are always to be found in every community willing observers of the weather," declared J. T. Lovewell (1879–80: 83) of Washburn College in Topeka, Kansas, an early leader of the club. In his view, the club should find "a way of utilizing the universal interest in the subject so as to obtain a multitude of willing observers of weather phenomena, each of whom will help in establishing the basis of fact out of which all valuable theories grow and on which they rest."

Yet, as Lovewell pointed out, many local observers subverted the tight discipline that was required for aggregating weather knowledge. Except at a few sites that were either military posts or university towns, observations at most places were only taken irregularly, "their value . . . lost from lack of continuity and system": "Most observers grow tired of the monotonous record of daily weather changes, and do not perceive the value and interest of such records when long continued and systematically arranged.

Even then it requires the comparison and compilation of many such records, taken at points suitably distributed throughout the State, to be able to understand their real significance and importance" (1879–80: 83–84). In response to this lack of coordination, the club resolved "to try to systematize and utilize volunteer weather observations" in the state and to extend their reach to "every county of the State" by organizing a "Kansas Weather Service." Enlisting "at least the sympathy, if not the active cooperation of the US Signal Service," the Kansans secured some meteorological instruments from Washington for use at the Topeka station at Washburn College (84). By the early 1880s, the Signal Corps was actively encouraging states to establish weather services, and official status was conferred on efforts in Kansas and several other states—led by Iowa in 1878—most of them in the midwestern grain belt (Hubbard 2001: 27). Topeka operated as an intermediate knowledge-production node, simultaneously an outpost of the federal field network and the incipient center of a state-based field network.

The Topeka-centered Kansas Weather Service became a regional precursor to the more tightly coordinated field network that would later be funded by the federal government. In Topeka, Washburn College provided not just leadership but also a "commodious observatory" along with use of "the college laboratory and cabinets" to supplement the government-supplied instruments (Lovewell 1879–80: 84). Lovewell himself directed the service, with the help of two Topeka Scientific Club colleagues. They found observers "in different parts of the State," providing them with "instructions and blanks," as well as "thermometers and rain-gauges" (84). In addition to Topeka itself, approximately twenty-five other places had stations within the first several months. While some of the reports came "with considerable regularity and accuracy," others did not. As Lovewell put it: "There is evidence that much patience and labor are requisite to secure observations at desirable points that will be satisfactory. . . . It must be remembered that all the labor is done without remuneration, and in time snatched from the intervals of other occupations" (84).

Despite these challenges, Lovewell was still confident that the data obtained would prove helpful in answering questions that were both economically and scientifically important. Moreover, he proudly stated that, in combination with similar data from neighboring Missouri and Iowa, the weather observations would constitute "a larger consecutive area of the earth's surface under minute and systematic observation than exists elsewhere to my knowledge." Together they could track storms across the plains and prairies, "from western Kansas to the Mississippi river, many hundred miles in any direction" (85).

Other states also engaged in collective weather observing in the 1880s. Just to the west, in Colorado, for example, an association was chartered in 1885 to collect weather data and issue monthly aggregate reports, with subscriptions running fifty cents a year by 1888. Under the US Army's Signal Service, however, only a few places had regular observations being taken, so the group was envisioned as a voluntary state organization to supplement this meager network with additional sites, taking advantage of instruments supplied by the US government (*American Meteorological Journal* 1885). With the motto "Exactness, Continuity, Thoroughness," the Colorado Meteorological Association collected data for only a few years before its work was taken over by the US Weather Bureau in the 1890s (Doesken, McKee, and Hersh 1991; Wilson 1997: 120).

As the demise of the Colorado Meteorological Association as the main vehicle of organizing local weather observations suggests, in the 1890s a major development was the formation of a US Weather Bureau within the Department of Agriculture. Thus, after several decades under the US Army, the Signal Corps was transformed into a civilian agency by congressional action in 1890, to take effect in July 1891. Over the next three decades, the Weather Bureau would grow quite large, reaching six thousand meteorological stations nationwide by the 1920s, the majority of them staffed by volunteers. The number of "regular" stations staffed by paid staff members expanded modestly, from 161 in 1893 to 197 in 1915. At the same time, the number of personnel exploded from 465 in 1890 to 922 in 1920, and the annual appropriation rose from $889,753 in 1892 to $1,912,930 in 1919 (Weber 1922: 1; Whitnah 1961: 21). The geographical reach of this network of observing sites was primarily achieved through collaboration with lay people and amateurs. By 1921, there were 213 stations operated by paid employees and another 4,500 where observations were made by volunteers (Weber 1922: 38). Thus, those paid employees who were designated as "local forecasters" themselves supervised teams of geographically distributed, and even more local, observers in (typically) smaller towns scattered throughout the country—just as the Topeka station staff in the 1880s reported data to the federal government while supervising its own periphery of volunteer observers.

Short-term prediction of the weather—"forecasting"—was then, as it is now, one important goal motivating weather observations. Practitioners of organized, scientific weather data collection sought to wrest public authority from other claimants, who often themselves adopted the rhetoric of science, even if the meteorological experts initially disclaimed an interest in making long-term predictions. As Katharine Anderson (2005: 73) shows for the case of mid-nineteenth-century Britain, many popular "weather prophets" published almanacs whose existence and broad appeal "intensified the difficulty of establishing the authority of a scientific theory or scientific individual." The authority conveyed by well-known names in weather prophecy, she points out, "stood in stark opposition to the quiet, relatively anonymous labor of observation." Likewise, in the United States, as Jamie L. Pietruska (2011: 79) observes, the national Weather Bureau under the leadership of Willis Moore "sought to build its institutional reputation based on authoritative short-term 24-hour forecasts by discrediting the popular and ubiquitous 'weather prophets' who made long-range predictions"—even as the Bureau itself cautiously expanded into longer-range forecasting by the early twentieth century (Pietruska 2017).

On the Kansas frontier, as in Britain and in US national meteorology, an important task for organized, observational meteorology was to displace such popular sources of authority. In Kansas, one weather prophet whose work was especially targeted by meteorological experts was C. C. Blake of Richland, who authored "a little folio called *The Future*, which proposed to predict the weather on certain principles" that Blake labeled as "astronomical" (*American Meteorological Journal* 1886b: 161); such long-term weather predictions were tested by comparing with actual weather results and found wanting. At the Kansas Academy of Science in 1889, a former professor of mathematics at Washburn College in Topeka named George E. Curtis argued the case against the same popular almanac author. In his attack on "Blake's Table of Weather Predictions for 1889," Curtis examined the almanac's predictions and ruthlessly critiqued them using actual weather data from the same year. He further attacked the author's methods and ridiculed his pretensions to scientific authority, musing that "for some reason Mr. Blake has not seen fit to publish the detailed methods that he has employed in calculating his 'Tables,' and he has given only vague references to 'four large account books filled with formulas and figures,' and to the discovery of a mysterious 'universal law of axial rotation,' which has been the 'stepping-stone' to his success" (1889: 37). After appealing to the practical consequences of weather forecasting for the state's largely farming public in the paper's title by asking the rhetorical question, "Who Sold His Wheat for $1.40?" Curtis concluded that "a weather prophet could scarcely have failed more signally in determining the marked characteristics of the seasons than has Mr. Blake" (42).

But Curtis was not content merely to point out the deficiencies of a weather prophet's almanac. He also used the occasion to argue on behalf of systematic, observational meteorology as the true science of the weather. "Scientific men obtain their laurels by the fullest publication of their work," he declared (42), "and one who refuses to make such publication deserves no following, for this of itself is prima facie evidence of presumption or fraud." Instead of relying on almanacs with secret methods, therefore, people should rely on systematic observational science:

> A true knowledge of the climate of Kansas is being accumulated by the Kansas Weather Service, and everyone by taking simple observations may aid in its work. The relation of crops to climate is being studied by the agricultural colleges and experiment stations, and every farmer should read the publications of the State Board of Agriculture and of the Agricultural Department of the Government, in which the results of their valuable experiments are made accessible. It is in these directions that agriculturists may reasonably look to obtain a conquest over climate, rather than to the presumptuous predictions of professional prophets. (42)

One can scarcely imagine a more direct statement of the vision of the frontier partisans for organized science. Under such a view, research and publications funded through state-supported scientific institutions, aligned with the propensities for the distinct social roles of experts and their data gatherers, would provide a more secure base of knowledge for people to make a living in the central plains and prairie environment of Kansas.

Yet, as the phrase "everyone by taking simple observations may aid in its work" reminds us, knowledge-producing researchers still needed the collaboration of geographically distributed local observers. It takes a high level of organization and coordination to put together enough observations to generalize about usual weather patterns and their common characteristics or to generate useful forecasts in the short run. In other words, weather phenomena have been increasingly viewed as large in scale rather than localized. Even the most prominent exceptions, such as Henry Helm Clayton at the Blue Hill Meteorological Observatory near Boston, who advocated not only for civilian control but also for local weather forecasting, clearly succeeded in achieving the former goal but ultimately saw his and other locally based projects overshadowed. "With the realization of Clayton's goal," concludes James Bergman (2016: 340), "came the end of some of the local serves and research that was motivated by the need for an 'alternative' to the national weather service's centralized infrastructure." The dependence of the science of weather on integrating geographically dispersed observations was nicely expressed by Lovewell (1879–80: 83), who stated: "Meteorology has been raised to the dignity of a science by virtue of combined systems of observation over vast areas, corresponding in some degree with the magnitude of the phenomena they undertake to interpret." Such a perspective neatly expressed the combination of reliance on local observers with a centralized system of control by experts whose purview over larger geographical regions their work made possible.

By the mid-1890s, when the national forecasting network had come under the control of the US Weather Bureau—despite some evidence that some local forecasters were defying the bureau's authority and continuing to issue their own forecasts (Pietruska 2017: 143–44)—top-down authority over local weather observers was becoming more firmly entrenched. As the chief of the US Weather Bureau, Willis L. Moore (1895: 214) wrote:

> Forecasts were made only at the Central Office at Washington, and the local observers were allowed to disseminate no other, nor to give public expression to any opinion to of their own which might be construed into a forecast. Considering the very limited training of the observers and the lack of all charted meteorological conditions for their study and enlightenment, the wisdom of that regulation could hardly be questioned.

Thus, it was not just independent weather prophets and almanac writers whose forecasts were displaced by the centralized Weather Bureau but also its own local observers and collaborators. On the basis of both geographical scope and skill level, such a hierarchy was deemed essential as a firmly expressed and strongly enforced rule.

Achieving a wider geographical spread for weather observations was a significant issue for the early state-based networks, such as the lack of observers living in the far northern and western parts of Nebraska (*American Meteorological Journal* 1886a: 531), and it required both increasing settlement density and the top-down organizational efforts of the US Weather Bureau to remedy this a decade later. One consequence of this regional or national focus of interpretation was the possibility that local knowledge bearing on the particular conditions in one place or another could be lost as knowledge was aggregated. This possibility was explicitly discussed by H. A. Hazen at the US Signal Office. In considering the "errors which arise in making forecasts at the central office in Washington," Hazen (1892: 220–21) rejected the view that "serious failures have occurred from neglecting local signs." Instead, he argued, the vast majority of such mistakes were explicable at a higher level of top-down analysis, rather than by knowledge accumulated over time at a purely local level—in his words, as being "due to rapid changes in the greater or more general movements of the atmosphere, and not to the neglect of local causes." Hazen explicitly linked the greater geographical purview of centralized experts with their special knowledge and training, contending that such "greater movements may be more carefully studied at a central office by experts than by local forecasters at their stations."

Another anonymous meteorological expert took Hazen's critique of local knowledge claims even further, questioning the indefiniteness of how weather observers referred to their own "local" phenomena. Giving a few examples from observation reports, including one from the southern Great Plains state of Oklahoma, the writer drew attention to their widely varying distances encompassed by the "local," calling for more "precision" in observations, by asking observers "when practicable, [to] specify approximately the area in square miles over which any phenomenon is visible rather than content themselves with an indefinite word or usage" (*Monthly Weather Review* 1897). By obtaining location-specific data—including the extent over which observations were made—centralized experts could use this information for drawing their own conclusions rather than relying on the interpretations of local observers over indefinite geographical areas.

Contrasting with the superior spatial scope of centralized experts, which gave authority to their own interpretations as part of their situation or circumstances, was the inferior temporal scope often attributed to local observers, whose work had to be carefully scrutinized in order to remedy the deficiencies—in the duration or quality over time—of their observations. To be sure, there were efforts to locate and bring together weather observations that had already been collected by local people on their own terms. The existence and potential utility of such data did complicate the top-down hierarchy of weather knowledge production, given that these observers were not necessarily guided or directed, and since they were only aggregated for more long-distance purposes after the fact. However, even in cases where such data were sought, their usefulness was limited, not only by the lack of standardized reports in many cases or the difficulty of assessing the validity of records but also by their short duration and inconsistency over time. The director of the Nebraska Weather Service in the mid-1880s, S. R. Thompson (1884: 56, 58), searched out what he regarded as "all the authentic records of rainfall in the state," but he was able to find only a few records that were of sufficiently long duration for long-term conclusions, such as those of the unnamed army surgeon at Fort McPherson in the western part of the state. Despite his view that volunteer weather observers were thriving in the state at the time, he was skeptical that he had enough long-term records to provide solid evidence of an increase in rainfall since the onset of Euro-American settlement.

Besides the difficulties in the duration of observing, many local observers were also sometimes judged to be lacking in the skills and training required. In 1886, a change in the leadership of the Nebraska Weather Service led to "the entire overhauling and revision of the reports of observers from the year 1878 down to date with a view to selecting out what was reliable and discarding what was not" (*American Meteorological Journal* 1886a: 530–31). This assessment of reliability of lay observers revolved around the actual practices they used to record and analyze their data. "Many of the observers were untrained in the careful methods of meteorology to-day" (530), which could point to something as simple as deficiency in basic mathematical skills. "Some did not know how to make averages correctly," especially when considering temperatures that were below zero degrees. Some of these errors could be corrected, but others could not, and the remaining "doubtful data" had to be eliminated.

Was there any pushback from local observers, either disputing the conclusions that were reached with the data they collected or against their subordination to routine fact gathering? Other studies of weather networks in the same region, such as the early twentieth-century Corn and Wheat Observers and River Observers of the Kansas City regional office of the US Weather Bureau in the same region (Vetter 2011), suggest that hierarchical organizations could cope with recurring failures to comply with top-down bureaucratic procedures. Such transgressions could be contained and managed, both in their historical operations and in the documentary record, which is typically found in the archives rather than in publications of these networks. Few if any of the published reports in meteorological journals present the responses of local observers directly.

Occasional comments by metropolitan experts do provide some evidence, at least if we cast our net nationally rather than just within the Great Plains region itself. One meteorological society, in New England, did report "occasionally receiving letters from the observers commenting on some mistake that the Forecasting Office has made and giving the forecasts as they would have made them" (Smith 1891: 52). And W. M. Davis (1893: 69) wondered whether observers for the state weather services—more than two thousand of them, by his estimation—might include "many persons well fitted for co-operative investigations, and many who would be interested in such undertakings." Davis thought it "unfortunate that such a body of observers should not attempt from time to time, something more than the routine observations to which their attention" had been "so largely restricted." He proposed that these observers be encouraged to take part in more advanced cooperative studies, besides simple data collection, although this work would still be coordinated across the country. He anticipated there would be "numerous teachers, scholars, doctors, tradesmen, mechanics, farmers, and intelligent citizens generally, women as well as men," eager to take part in such "national work," which he thought "might arouse a wide-spread interest" (71). Thus, even when a more capacious role was envisioned for local observers, this was still imagined as occurring under the hierarchical umbrella of national coordination, not as something spontaneously generated from the bottom up.

One rare exception to the lack of interpretations by local observers extending beyond their appointed roles in hierarchical systems of knowledge production is an article by Colorado's J. B. Willsea (1904), which appeared in the *Monthly Weather Review*. He was a voluntary observer in Fruita, in western Colorado, which is outside of the Great Plains region itself but nonetheless offers a nearby example. For over a decade, Willsea made a dedicated hobby of closely observing the clouds where he lived, "but without the aid of teachers, books, or instruments." He presented some generalizations about the shapes and directions of clouds, which departed quite dramatically from the typical numerical data collected with standardized instruments, or even the standardized descriptive terms favored in state and national reports. Notably, the editor of the journal felt it necessary to add a comment encouraging Willsea's observations while putting them in their proper place as merely confirmatory of what was already well known to expert meteorologists. Moreover, Willsea positioned himself as subordinate in scientific authority, calling upon better-trained meteorologists or their assistants to perhaps "find a kernel of grain in the chaff I present." We cannot be sure of the feelings of all local observers, most of whom have left far less of a paper trail to follow, but the writings of centralized and metropolitan experts leave no doubt as to the prevailing social structures of scientific practices articulated in national scientific journals and in other widely circulated publications.

* * *

As Euro-American settlers moved into an unfamiliar natural environment in the late nineteenth century, questions about climate and its possible changes were front and center: Was Kansas and the rest of the Great Plains destined to remain semiarid? Or might its rainfall be increasing over time due to human actions such as plowing (Smith 1947) and tree planting (Emmons 1971)? Data for assessing claims about the changeability of Kansas's climate came from daily weather observations extended over decades. The early Kansas Academy of Science debated the issue and included meteorology as part of its official committee structure. Kansas University science professor F. H. Snow (1884: 101–2) examined the weather records of Fort Leavenworth and Fort Riley, two army posts within the state, as well as those from the State Agricultural College in Manhattan and the university in Lawrence. In his view, the data from these four locations—significantly, all in the eastern part of the state—established "the fact of an increase in rainfall" in Kansas. He further suggested that the massive expansion of agricultural settlement had increased rainfall "beyond a doubt." Ultimately, such an interpretation would not prevail, but its prevalence in frontier Kansas offers a suggestive indication of the early and close relationship between weather observations and more general knowledge of the climate. The discussion of climatic data extended into other parts of the Great Plains, such as the Dakotas, by the early 1890s (Finley 1893). Around the same time, there arose debates and controversies over "rain making" on the plains, which have been amply chronicled in the secondary literature (Spence 1980; Fleming 2010; Sweeney 2011; Whitaker 2013; Courtwright 2015). A worthwhile follow-up to this article might consider how the social organization of scientific practice emphasized here intersected with the interpretive disputes over issues such as changes in climate and rain making.

In focusing on the practice of weather science, however, I have aimed in this article to go beyond the content of scientific debates in order to understand how relations between emerging experts and lay people were structured. I have emphasized the importance of top-down, hierarchical power relations rather than the mutual, socially flattened viewpoint that has sometimes prevailed in STS studies of the past few decades (if somewhat less so in histories of meteorology and climatology). Moreover, as I have argued, the Chinese concept of *shi*, with its broadly compatible emphasis on power, patterns, conditions, circumstances, and propensities, offers relational and situated inflections, which soften some of the rigidities often associated with structural frameworks. Although my subject here has been a North American settler colonial society, my conceptual concerns for STS are closely related to debates about postcolonial approaches in other parts of the world, where a shift away from structured, hierarchical power relations has brought similar losses in analytical clarity. As Daiwie Fu (2007: 6) argued in the inaugural issue of this journal, "There is much more in the various sophisticated center-periphery, world system, and dependent development models, including various theses of dominance, dependency, and resistance," asking if "a postcolonial STS enterprise" might risk "abandon[ing] them as well, in favor of less loaded terms, like traffic, networks, and reciprocity."

To be sure, there is ample historical evidence that collaborators in the field, whether in weather observing networks or other case studies, did possess and could exercise some leverage, as Fa-ti Fan has emphasized in his study of British naturalists conducting field work in Qing China. "It is important to remember," writes Fan (2004: 138), "that the distribution of power in fieldwork relations did not necessarily favor the naturalists. Even in the colonies, European naturalists in the field often found their authority undermined by the natives' subtle tactics of resistance." Not only were the visitors "highly dependent and vulnerable in unfamiliar places," but local collaborators such as guides or porters could engage in theft or “stalling or ‘soldiering,’” or they could “run away, willfully give misinformation or sabotage the equipment or specimens.” Although we do not have much evidence of such tactics used in the weather observing networks, in principle the cooperative observers had a great deal of autonomy and were usually physically distant from their organizers. Any account of their work must therefore take into account the possibility of resistance, which is fully compatible with the structured power relations emphasized here, especially when inflected by the concept of *shi*. Moreover, STS work on meteorology and other sciences involving citizen participation also rightly acknowledges historical examples that disrupt our conventional assumptions about scale, recognizing the many case studies where the local and the global were intertwined (Fleming, Jankovic, and Coen 2006).

At the same time, however, these potential resistance tactics and scalar disruptions were circumscribed by the structured, hierarchical patterning of the lay networks for observing weather. This was achieved through a variety of means, including government authority, inclusion or exclusion from the observer network (whether paid or volunteer), personal exhortation by mail or during site visits, and perhaps most important of all, the deployment of standardized instruments, forms, procedures, and technologies. Admittedly, this article views such relations largely through the eyes of meteorological experts, which could rightly be considered a limitation, to be remedied only through further study of the archival records of such agencies as the US Weather Bureau. Such archival investigations undoubtedly would reveal more about the challenges posed by resistant or uncooperative observers for the experts’ centralizing projects, just as a more detailed examination of such sources in the same region has already indicated for the Bureau’s Kansas City–centered weather observing networks (Vetter 2011). Further historical work in those archives would be valuable and may qualify some of my conclusions here, but I suspect that the ascendancy of the experts who were building power through hierarchies will remain a central pattern. Indeed, the very asymmetry between the meteorological journals and the suppressed examples of resistance and failed attempts to cooperate behind the scenes that may be revealed only in archives (or local newspapers)—and especially the increasing success over time in how fully the expert centralizers asserted their authority—might even reinforce, rather than limit, the interpretation I have provided here.

Even those who only partially succeeded in their centralizing ambitions, during the early part of the era I describe here, were already articulating the pull of hierarchical relations over flattened networks. Indeed, meteorological experts in the nineteenth century, even in regions with well-known local expert observers, often focused on the assertion of centralized authority through instruments, communication networks, and standardized instructions, which extended to voluntary networks run by scientific societies and associations. For example, the New England Meteorological Society, founded in 1884, aimed to assemble local weather observation data and promote “greater accuracy and uniformity of observations,” as well as a larger number of locations and a better distribution of sites around the region (Koelsch 1981: 90). While those who sought to professionalize the society may not have succeeded, they nevertheless aimed to follow increasing standards of rigor that were becoming prevalent during this period.

This was even more true of government meteorology, as Jamie Pietruska (2016: 419–21) shows in the case of the West Indian weather service of the US Weather Bureau. She describes this as “a project of imperial meteorology that sought to impose a rational scientific and bureaucratic order on a region that American officials considered racially and culturally inferior,” insisting on retaining the “center-periphery model” of imperial science, “suggesting that imperial meteorological infrastructures are characterized by imperial hierarchies of power as well as local networks of knowledge production.” At the same time, she also contends that “a singular center-periphery framework does not adequately capture the region’s various meteorological infrastructures,” supporting a model that is also based on contingency, contestation, and renegotiation. Ultimately, Pietruska concludes, American imperial meteorology “would depend on hierarchies of imperial power and scientific authority as well as collaborative relationships with scientists, observers, and the press in the West Indies.” Likewise, in Britain, as Simon Naylor (2006: 432–33) has contended, “the history of British meteorology was assuredly one of increasing centralization, institutionalization and marginalization of provincial contributions,” but it was also complicated by local environmental and social conditions, so that the “geography of power was negotiated and relational and certainly not predetermined or fixed.”

In my own interpretation, I have built on the work of Pietruska, Naylor, and others, but I have attempted to push more forcefully for an emphasis on structured hierarchy over flattened networks. Rather than simply acknowledging the centrality of power relations structured from the top-down on the way toward a greater emphasis on complications and countercurrents, I have reasserted the primacy of these hierarchical aspects of the networks as they emerged historically. Coordination of weather observations through communications technologies, the use of standardized reporting procedures and instruments, and the attempt to produce knowledge at a larger scale beyond the local have all played a role in facilitating this suite of practices. Some of these things were new in the nineteenth century and enabled forms of top-down control that would not have otherwise been possible—most notably the telegraph. Indeed, the telegraph became a vehicle not just for aggregating weather observations in order to make forecasts but also to disseminate those forecasts quickly enough to make them useful to the public. The uses of forecasts within the context of an expanding capitalist economy go beyond the scope of this article but are a vital area for further research. As we consider the interactions between lay people, or citizen scientists, as they are often now called, and experts in the practice of science, it is helpful to consider how these structures have been produced historically, whether in the recent past, or a full century ago.

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