Weathering Risk: Uncertainty, Weather Forecasting, and Expertise

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Abstract

Bridging the sociology of uncertainty and weather, this review paper provides a sociological examination of the weather forecasting enterprise in order to illustrate how expert decision makers negotiate high uncertainty. It begins with an outline of the literature on uncertainty and risk, particularly as it regards the modern experience. It then fleshes out and expands the discussion through an examination of weather forecasting practice. The final section reprises the theme of expert decision making under uncertainty, this time focusing on the communication of risk and uncertainty, and it concludes with a few thoughts on the future of the field.

The beginnings of sociological inquiry coincide with the recognition of the uncertainty of the human condition, a direct corollary of the displacement of god by reason. Yet it is only in the past 20 years or so that a critical mass of sociologists has formed around the explicit study of uncertainty, counting among its ranks cognitive sociologists, environmental sociologists, sociologists of organizations, and sociologists of science and technology. The timing of the emergence of this ''sociology of uncertainty'' and the particular intersection of involved subfields have naturally had a defining effect on what constitutes uncertainty, how it operates, and what is sociologically interesting about it. Against the background of increasingly cheap and easy means to record and accumulate information on the one hand, and the increasing visibility of ecological and technological emergencies on the other, the need to acknowledge – and address – the limits of human understanding appears more acute and inescapable than ever before.

This paper proposes to examine weather forecasting as an instructive case of expert decision making under regimes of high uncertainty. This may perhaps appear a frivolous exercise at first glance. After all, weather may be an iconically chaotic phenomenon, but similarly iconic are the derisive jokes about the profession claiming to be able to predict its future. And yet, weather forecasters are not faring worse at mastering uncertainty than other so-called ''expert decision makers,'' from medical doctors and business strategists to stock traders and professional poker players. As a matter of fact, they are faring considerably better. A sociological examination of the weather forecasting enterprise – a sociology of weather, so to speak – has therefore much to offer to the sociology of uncertainty. I begin with an outline of the literature on uncertainty and risk, particularly as it regards the modern experience. I then flesh out and expand on the concept of uncertainty through an examination of weather forecasting practice. The final section reprises the theme of expert decision making under uncertainty, this time focusing on the challenges facing the communication of risk and uncertainty, and it concludes with a few thoughts on the future of the field.

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Uncertainty and risk in an age of complexity

If one were to pinpoint the beginning of a sociology of uncertainty, it would have to be around the time of the appearance of Ulrich Beck's *Risk Society*. Published in German in 1986 and in English in 1992, *Risk Society* both signaled and fueled a shift away from post-modern critique and toward sociological pragmatism by proposing a new heuristic for unlocking the paradoxes of post-industrialism: the emergence of a new type of risk – a risk extremely unlikely in its occurrence but incalculable in its potential for catastrophe. The distinguishing feature of such risk is the unprecedentedly high level of uncertainty surrounding it. The world is safer than ever before, yet we live haunted by a specter of imminent doom. The infrastructure supporting and supported by the scale of production and the standard of living characteristic of late capitalism has, time and time again, proven too unstable a force to harness. Amid oil spills and nuclear leaks, debates about the rise of allergies and global warming, and calls for greater vigilance against invisible, ever-lurking threats, certitude – as a goal and as a state of being – becomes a naïve and dangerous attitude.

This is not to say of course that risk was not already conceptually wedded to uncertainty. By the late 19th century, the project of ''taming chance'' (Hacking 1990; see also Gigerenzer et al. 1989; Stigler 1986) by devising quantitative techniques and statistical patterns had been well under way. Yet, up to that point, the terms ''risk'' and ''uncertainty'' had a very different valence. As famously defined by economist Frank Knight (1921, 233), ''risk'' implied that the probability distribution of possible outcomes for a given situation was known or calculable, whereas ''uncertainty'' implied that such knowledge was precluded by the uniqueness of the situation. Even so, uncertainty under this view was reducible, even eliminable in principle, given sufficient time and information sharing. In the age of ''reflexive modernity'' (Beck et al. 1994) and the ''collective mania with risk'' (Sapolsky 1990, 83) that follows, however, such trust in the power of rationality becomes deeply eroded, as does the distinction between risk and uncertainty. The multiplied manifestations – actual and rhetorical – of risk now militate for a demarcation between reducible and truly irreducible uncertainty. What emerges is an analytic distinction between epistemic uncertainty, tantamount to the old Knightian uncertainty, and ontological – or aleatory or stochastic – uncertainty. Under the current view, even if all epistemic uncertainty were somehow eliminated and all probabilities calculated, there would still remain an irreducible, ontological uncertainty due to the fundamental randomness of certain natural or social phenomena.

Meanwhile, in practice, the distinction between reducible and irreducible uncertainty is largely moot as it often may well be impossible to reduce measurement or modeling errors beyond a certain level. Paradoxically, the more realistic a model through the introduction of additional parameters, the more uncertain it becomes (Oreskes 2003). But furthermore, it is often easier to quantify and model irreducible ''natural'' uncertainty than ''artificial'' – i.e. measurement- or model-derived – reducible uncertainty. One thus frequently encounters a lumping together of reducible and irreducible uncertainties since only the quantification of this lumped uncertainty may be possible or desirable. Still, such conventional blurring does not warrant an analytic slippage between risk and uncertainty. On the contrary, it draws attention to the need to preserve the analytic distinction between the two terms in order to remain sensitive to, on the one hand, the mechanisms governing cognitive, emotional, and cultural biases of risk perception (see, e.g. Cerulo 2006; Damasio 1994; Douglas and Wildavsky 1983; Kahneman et al. 1982), and the multiplicity of strategies – other than risk assessment – that are employed to cope with uncertainty, on the other (Zinn 2006).

With rising complexity in all aspects of life making the distinction between reducible and irreducible uncertainty unsustainable, scholars have increasingly abandoned the quest for certainty in search of strategies for *mitigating* unpreventable uncertainties and so-called ''second order dangers.'' The buzzword of the day is ''resilience'' (see, e.g. Weick and Sutcliffe 2007), symbolically culminating in the establishment in 2010 of an Office of Resilience within the National Security Council of the White House. This embracing of uncertainty has resulted in an exploration of the positive, productive side of living with uncertainty (Zaloom 2004) and a reformulation of expertise acquisition and decision making more generally. Social actors – individuals and organizations alike – make sense of, and cope with, the equivocality of their environment (Weick 1995) through a process of tinkering, or bricolage (Lévi-Strauss 1966), creatively adapting resources at hand to problems, as they arise. Such ad hoc improvisations include coming up with ''fast and frugal'' cognitive heuristics (for an overview, see Gigerenzer and Selten 2001) as well as material, ''crafted'' solutions. And they pertain to all types of knowledge work, including knowledge work conducted within the hallowed halls of rationality itself: laboratory science (see, e.g. Knorr Cetina 1979, 1981; Latour and Woolgar 1979; Lynch 1985). Not that efforts to mitigate the limits of rational decision making cannot have unanticipated pathological consequences. Ironically, as organizations endeavor to minimize deliberation costs and enhance information exchange, they unwittingly often end up multiplying the uncertainty they are trying to manage (Vaughan 1999). What then of the people who have turned the unknown into a profession? How do they negotiate between the Scylla of uncertainty and the Charybdis of credibility loss? To elaborate on how experts deal with uncertainty, I now turn to the world of weather forecasting.

Uncertainty and weather forecasting practice

The weather is arguably the most famous example of a phenomenon marked by high uncertainty. This uncertainty derives from the chaotic nature of the atmosphere, popularly captured in the notion of the ''butterfly effect.'' But it is further aggravated by the sparseness of weather data, the imperfections of weather measurements, and the dependency of weather prediction models on initialization conditions due exactly to limited scientific understanding of atmospheric complexity (Doswell 2004). Such challenges around the nature of the atmosphere are reflected in the nature of weather forecasts themselves, expressed in probability and range estimates, as in, ''There is a 40% chance of flurries tomorrow morning, mainly between 8:00 and 11:00 a.m.''

This non-determinism of weather forecasts we conventionally like to attribute to a case of forecasters hedging their bets, and this explanation is not untrue, of course (on hedging in weather forecasts see, e.g. Murphy 1978). Yet, a better, more complete explanation must start from the fact that the non-linear hydrodynamic, thermodynamic, radiational, chemical, and physical interactions underlying atmospheric processes prohibit a sufficiently specific, accurate categorical prediction of the weather. In the name of providing more information, forecasters have taken to qualifying their assertions with an estimate of their confidence level based on the meteorological uncertainties associated with a given weather pattern.

Not surprisingly, the high uncertainty of the weather has already brought much scholarly attention to the experts charged with predicting its behavior. Cognitive task analysis in particular – a relatively recent methodological approach to the study of expertise that marries behavioral economics with cognitive science and industrial psychology – has found much appeal in weather forecasting practice as an expert system of uncertainty management. Of particular relevance for the purposes of this discussion are findings that underscore the multiplicity of reasoning styles and forecasting strategies forecasters adopt as a response to the variable weather regimes and information resources they must contend with (Hoffman and Coffey 2004; Pliske et al. 2004). Efforts to elicit and model the cognitive processes underlying the forecasting task in light of the fact that there is no one optimal way to master uncertainty have already found extensive application in visualization and knowledge transfer systems design (see, e.g. Heideman et al. 1993; Hoffman 1991; Hoffman et al. 2005, 2006; Pliske et al. 2004; Trafton et al. 2000). Yet, while such studies – part of a broader recent turn to naturalistic studies of decision making (for an overview, see Lipshitz et al. 2001) – draw attention to the context dependence of weather forecasting practice, still absent is the *social* context of forecast production.

Historical studies of meteorology go a long way toward furnishing the necessary framework for understanding the forces that gave rise to, and continue to shape, weather forecasting as a system of expertise. The weather, of course, has always struck fear and awe in the hearts of men: efforts to reign in its power by making it predictable have existed since before the beginning of history, the earliest recorded endeavor to systematize and theorize atmospheric physics being Aristotle's *Meteorologica*. But it was not until the late 18th century – and the spirit of Enlightenment sweeping Europe and the United States – that weather forecasting as an enterprise came into being (Golinski 2007). The catalyst was a relatively steady supply of weather reports as taking meteorological observations turned into a gentlemanly pastime (Janković 2000). Soon, local initiatives became more or less absorbed into scientific societies, such as the Royal Society of London or the Smithsonian Institution, and, aided by the adoption of the telegraph, there emerged a stable, albeit thin, network of weather observers spanning military hospitals, army posts, school academies, and colleges (Fiebrich 2009). It was the mounting demands for financial and human resources of these expanding weather observation networks around the globe that led to the establishment of dedicated, national weather agencies and the standardization of weather instruments and measurements in the mid-19th century (Fleming 1990; Hughes 1970; Whitnah 1961). Data alone, however, did little to establish weather prediction as a science. If anything, the relative ease with which a wide variety of data on the weather could be collected intensified jurisdictional wars in the form of debates over the scientific merit of local weather versus global atmospheric systems, observation versus speculation, reportage of unusual weather phenomena versus regular weather records (Anderson 2005; Janković 2000). Nor was the development of numerical weather prediction models in the early 20th century enough to legitimize weather forecasting as a science – such efforts were in fact greeted as premature and misguided at the time (Friedman 1989; Lynch 2006; but see Fleming 2001 on the significance of the "D-Day forecast"). It took until the mid-century, when observing networks and numerical weather prediction modeling were harnessed to the computing power of machines – all thanks to the close links between the meteorological community and the military forged during the second world war – for weather forecasting to emerge as a scientific profession in its own right (Fleming 1996; Harper 2003, 2008; Janković 2004; Lynch 2006).

This outline of the history of the professionalization of weather forecasting hardly constitutes a complete explanation of the phenomenon of course. Equally importantly, it glosses over the development of the distinctive national traditions of weather forecasting that, in their interaction, brought forth the current epistemic culture of the discipline. It does, however, help highlight key interrelated regularities structuring the field: a long-standing and extensive weather observing network, buttressed by a project of "infrastructural globalism" (Edwards 2006, 2010); quantitative forecast models, generated by computers powerful enough to absorb the massive amount of available data; wide-ranging and keen stakeholders, given the universal relevance and potential destructiveness of weather. It is this last that provided meteorologists with the collaborative data- and computer-intensive environment necessary for countering uncertainty long before most other fields were able to muster similar resources and support.

Nowhere are these three elements better aligned or more pronounced than in the operations of government weather organizations. Consider the National Weather Service (NWS), the federal agency charged with providing meteorological forecast and warning services for the United States. Contrary to popular perception, NWS forecasting operations are not housed in a centralized meteorological facility but in 122 forecasting offices around the country, assigned to – and located in – a specific geopolitical region. What is commonly understood as the NWS forecast in reality involves over a hundred separately issued and disseminated NWS forecasts, each catering to a particular area of forecasting responsibility but digitally stitched together into an apparently seamless national whole. This decentralized structure of NWS forecasting operations is in fact indicative of a more profound and deep-seated mindset, pervading the entire agency, that sees it as unavoidable, if not necessary, that forecasting offices be allowed to self-determine how operational directives should actually be operationalized in their jurisdiction. So much so, in fact, that, upon comparing the cultures of three forecasting offices, Gary Alan Fine arrives at the conclusion that in ''the local offices of the NWS, it is almost as if 122 organizational experiments are running simultaneously'' (Fine 2007, 71). The rationale given as the basis for this state of affairs is the same one presumably militating for the existence of field offices in the first place: the local particularities of weather and the particular weather requirements of local communities. Crucially, therefore, forecasters are deferred to not simply because they are presumed to be experts on the local indeterminacies of weather but also because they are presumed to be experts on the dynamic complexity of NWS audiences, as well.

To be sure, weather forecasting practice and the management of meteorological uncertainty are predicated on a particular organizational logic and shared, situated practices of looking and reasoning (Daipha 2007, 2010; Fine 2007; Thurk and Fine 2003). An institutional analysis of NWS forecasting is therefore fundamental for appreciating the social structures and cultural context within which it is performed. But the realities of NWS forecasting operations also serve to underscore the tight coupling of material and social considerations at play. The streamlined appearance of their operations room belies the fact that weather forecasters routinely contend with diverse, partial, non-overlapping, and often contradictory weather reports. As preoccupied as they are with the weather pulsating on their screens, they still remain always attuned to a wide variety of meteorological inputs and stimuli in order to compensate for the sparseness of data sites and the limitations of weather instruments and models. But furthermore, while weather forecasters may be ostensibly charged with mastering the uncertainty of the atmosphere, what they are ultimately tasked with doing is arbitrate on its social consequences. What matters, and what is featured in weather forecasts, is the ''weather outside,'' the tangibly real weather, the weather that we get to experience. That is why NWS forecasters strive to move beyond the available variable-based information inside their office toward a more holistic, *experiential* appreciation of meteorological conditions. They have thus carved a space for themselves between the laboratory and the field – between the preprocessed weather on their computer screens and weather in the wild – in order to achieve ''maximum grip'' (Merleau-Ponty, 1962) on the atmosphere. When the data on their screens do not add up, they will look for supplementary information wherever they can find it – even to the point of enlisting their own bodies as yet an additional weather instrument in an effort to translate the complexity of the atmosphere into a coherent, actionable message about the future. Indeed, well aware that their forecast is only as good as it is useful, NWS forecasters will sometimes disregard clear evidence from observation instruments and computer models and omit mentioning a weather event in their forecast if they expect it will not be experienced as such by the public (Daipha 2007). Meteorological risk, after all, is socially defined and context specific. So, too, therefore, is the accuracy of weather predictions. In order to successfully handle atmospheric uncertainty, meteorological decision making must stay firmly grounded in the circumstances of the social phenomenon that ultimately is the weather.

Uncertainty and expert decision making

Up to this point, I have been suggesting that weather forecasting is an excellent site for studying how experts manage uncertainty due to the high uncertainty of its subject matter. I would now like to qualify this position and argue that if weather forecasting presents an excellent site for studying uncertainty management, this is not for the obvious reasons alone. A closer look at the judgment and decision making literature reveals that, unlike most other experts, weather forecasters in fact exhibit a remarkably high degree of reliability in their assessment of uncertainty and risk (Murphy and Winkler 1977; Oreskes 2003; Stewart et al. 1997). All the usual jokes notwithstanding, weather forecasts are continuously getting better, and not simply because computing power and weather prediction models are getting better – weather forecasters themselves are getting better at assessing how good they are. What allows for such an effective calibration of their performance is the fact that they find themselves in the rare, enviable position to be able to evaluate their decisions frequently and in near-real time. Although institutionally and culturally primed to handle uncertainty, however, and despite the relative predictive superiority of their pronouncements about the future, weather forecasters still need to make these pronouncements intelligible and meaningfully relevant to their audience, or else they won't be able to capture its attention. The persistence of jokes about the unreliability of weather forecasts, strong scientific evidence to the contrary notwithstanding, speaks volumes about the central role the *communication* of uncertainty plays in uncertainty management (Hooke and Pielke 2000).

And that is perhaps what is most instructive about the weather forecasting case. Few can aspire to the expansive infrastructure of distributed information and intelligence characteristic of meteorological operations. And fewer still can rely on a long-standing archive of continuous, up-to-the-minute stream of verification data. Yet, considering the tenuous credibility of weather forecasting services, the bigger lesson to be learned is that improvement in calibration and overall decision making skill alone does not lead to effective uncertainty management. Equally, if not more, important is a keen appreciation of the true needs and concerns of one‘s customers and stakeholders. Here, the NWS arguably provides a useful negative example. On the one hand, the complexity of the atmosphere militates for the use of probabilistic statements about its future, conventionally expressed in quantitative language because of its assumed information-rich and unambiguous nature. On the other hand, the general public continues to interpret presumably straightforward forecasts, such as ''There is a 30% chance of rain tomorrow,'' in multiple, mutually contradictory ways (Gigerenzer et al. 2005). This state of affairs is especially pronounced for NWS forecasters due to the great variety of audiences and weather sensitivities they must cater to. Such structural communication obstacles force the NWS to resort to constructing functional substitutes for its audiences, or ''imagined lay persons'' (Maranta et al. 2003), as it deliberates on how to best protect the life and property of the entire nation. It is fair to say in this respect that NWS conceptualizations of its audiences have, by and large, been based on the so-called ''deficit model'' of the public understanding of science (Wynne 1991; Ziman 1991), which conceives of the general public as scientifically ignorant, passive consumers of information, thus naturalizing the epistemic division of labor between experts and laypersons and granting ''scientists broad authority to determine which simplifications are ''appropriate'' '' (Hilgartner 1990, 520). To some extent, of course, it is understandable that weather forecasters would seek to maintain an epistemic asymmetry between themselves and their audience to ensure that their advice comes across as authoritative and competent, hence actionable. A series of studies show, however, that the majority of forecast users do not take a weather forecast at face value but, instead, tend to ''keep their own counsel'' as to its true significance, adapting the forecast message to their daily plans and routines, rather than vice versa. Crucially, this tendency holds true for both ''proactive'' users such as building contractors, farmers, and commercial fishermen, consistently involved in weather-dependent activities, and more ''passive'' users such as housewives and senior home residents, who have a mostly incidental relationship to the weather. In this light, it will not do to try and redress the generalized mistrust over the accuracy, precision, and comprehensiveness of forecasting services by simply ''educating'' the general public about the scientific sophistication of the forecasting process. Nor will it do to continue operating under the assumption that the public is better of being told in categorical, yes/no, formulations what the weather is going to be, or, at any rate, that it should as much as possible be spared the uncertainty underlying meteorological predictions. Rather, efforts would be better spent devising a weather forecast that provides ''consumers with a more scientific basis for second-guessing forecasts (as they now do and will continue to do, in any case)'' (Westergard and Sanders 2000; see also Sanders and Westergard 2002).

The relationship between science and its publics is a topic that has received renewed attention in recent years. It is now generally agreed that science has become more visible and more controversial than ever, a direct outcome of the increasing difficulty to tame complexity-driven uncertainties. The old paradigm of scientific discovery, characterized by the autonomy of formal research institutions, is being superseded by a new paradigm of knowledge production that is socially distributed, application-oriented, trans-disciplinary and subject to multiple accountabilities (Nowotny et al. 2003). Indeed, debates on the dynamics between science and society increasingly move beyond the public understanding of, to the public *engagement with* science. Concurrent with the vision that sees, or would like to see, science in the public sphere, there has recently been an influx of models on ''scientific citizenship'' and ''citizen science'' that seek to reframe the implicit contract between science and the public by challenging and blurring the conventional distinction between expert and lay knowledge and by redirecting and redistributing flows of information toward a true dialog with all concerned parties (see, e.g. Davenport and Leitch 2005; Irwin 2001; Latour 2004; Nowotny 2001).

While such frameworks are consistent with numerous studies indicating that mobilized citizens can, and do, become scientific experts and knowledge producers themselves on matters of significance to them (see, e.g. Brown and Mikkelsen 1990; Corburn 2005; Epstein 1996; Hess 2009; McCormick 2007), it is also the case that the *production* of uncertainty will continue to be concentrated in increasingly complex, hi-tech organizational structures. The preceding analysis of NWS operations outlines a number of parameters to look out for, broadly summarized under the following two headings: data- and computer-intensive collaboration networks, a liminal existence between the laboratory and the field. Yet, in order to capture the multiple subtle dynamics at play, one must take care to situate one's analysis within the real-world settings and contexts where uncertainty management occurs. Sociology of course boasts of a long and rich tradition of studying behavior ''where the action is'' (Goffman 1967). Unfortunately, sociologists have yet to systematically broach the subject of judgment and decision making, let alone to enter into dialog with the behavioral economists and cognitive scientists who dominate the field. While models of bounded rationality (Simon 1957) and prospect theory (Kahneman and Tversky 1979) have been uniquely successful in debunking the myth of the ''rational man,'' paving the way for more socially nuanced and sophisticated approaches to human decision making, the current literature is still fraught with essentializing assumptions and biases about human behavior, relying as it preponderantly does on simulations and (quasi)experimental settings. Meanwhile, the literature on organizational decision making, from garbage-can theory (Cohen et al. 1972) and organizational sensemaking (Weick 1995) to neoinstutionalism (DiMaggio and Powell 1983) and organizational accidents (see, e.g. Clarke 1989; Perrow 1984; Vaughan 1996), tends to analytically privilege the logic of the organization over the individuals and groups embedded in it, thus undertheorizing the fluid spaces for creative, strategic action afforded by the symbolic multivalence of institutional desiderata. Sorely needed are sociological theories of judgment and decision making in the face of uncertainty that simultaneously shed light on the microcontext of action. What is ultimately needed, of course, is interdisciplinary research, research that is not only event-driven but fundamentally informed by a shared commitment to unearthing the forces inexorably drawing together uncertainty and expertise. Only then can we hope to proactively respond to the challenges of an uncertain future.

Short Biography

Phaedra Daipha is Assistant Professor of Sociology at Rutgers, The State University of New Jersey. Her research interests primarily revolve around expertise, prediction, and technology use. She is currently working on a book manuscript that analyzes the process of diagnosis and prognosis under regimes of high uncertainty based on an ethnographic study of forecasting practice at the National Weather Service.

Note

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