Chapter 26

Social Sciences, Weather, and Climate Change

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ABSTRACT

Few currently deny that extreme weather and climate change are among the most pressing problems of our times. There is also general agreement that humans are intrinsically part of the problem and of the solution. For the past hundred years, the American Meteorological Society (AMS) has supported weather and climate science, but only recently has it included the social sciences. In this chapter we review a few trends in the social science of climatic impact currently informing understanding of human interactions with weather, hazards, and climate change, including the science of science use, vulnerability and adaptation, and climatic change, health, and security. We argue that the social sciences have been steadily growing within AMS journals and have made an impact on the field (especially after the launching of a specific journal focusing on impact—*Weather, Climate, and Society*) but still have much room to grow within AMS to represent the many areas of social studies of weather and climate in the literature. One grand challenge that remains is to increase the usability and use of AMS-produced knowledge to inform decision-making in mitigating and responding to climatic change.

1. Introduction

Few currently deny that extreme weather and climate change are among the most pressing problems of our times. For the past hundred years, the American Meteorological Society (AMS) has supported and fostered science focusing on meteorology and climatic change, but only more recently has this effort included the social sciences (Demuth et al. 2007). In this chapter, we review some of the social science currently informing our understanding of human interactions with all forms of climatic change including weather, hazards, and climate change, and/as well as their impacts and potential solutions.

The importance of understanding the impact of weather extremes and climate on society cannot be overstated. Short- and long-term impacts of extreme events, El Niño, and incremental and/or abrupt climate shifts have the potential not only to offset decades-long gains in antipoverty programs worldwide but also to critically compromise the ability of future generations to thrive (World Bank 2010; Denton et al. 2014). While climate change emerged first as an atmospheric rather than a societal problem (Sarewitz and Pielke 2000), it soon became clear that understanding and addressing its global and local scopes would require more than atmospheric and oceanographic sciences alone. Accordingly, the past few decades have seen the steady emergence of a wide range of disciplines and interdisciplinary fields of study focusing on climatic changes. And whereas the social sciences are a

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somewhat late comer to this landscape, they have dramatically grown in influence and in the number of disciplines and areas of research represented. It is precisely because of this rapid growth, diversity, and range of foci that the task of representing *all the social sciences* in this book is daunting and unattainable. Hence, from the start, we recognize any attempt to do so will be incomplete and likely biased toward those areas where we have developed our own work. Given the focus of this volume on the last 100 years of AMS research, we also acknowledge that it is only recently that the social sciences have featured more prominently in AMS journals, especially with the creation in 2009 of *Weather, Climate, and Society* (*WCAS*). In addition, while the other chapters in this monograph focus on different disciplines within the Society, our task is made more complex by the sheer number of social sciences disciplines that have contributed to the human dimensions of climate and weather—itself an unsatisfactory term to define this rich body of work. Hence our goal here has been to contextualize a few trends in the vast social science literature focusing on weather and climate for the book and to identify research gaps within these trends. In this sense, this chapter is neither a summary of all social science for the past 100 years, nor is it an attempt to systematically suggest grand challenges for future research across the social sciences—both tasks that are much beyond our capacity or ambition to carry out.

Having stated that, we have attempted to bound this chapter by adhering to a few criteria to make it manageable. Our overall rationale is to focus on the social sciences of weather and climate impact, that is, on the contributions of the social sciences toward understanding processes and responses at the places where weather and climate impacts affect critical aspects of society (vulnerability and adaptation, hazards, health effects, and security). Second, we focus on social science fields of study that seek to understand drivers and constraints to the use of atmospheric and oceanographic sciences, and we focus on how to overcome these barriers in support of decision-making to solve weather and climate impact problems in an ethical and just manner (e.g., weather and climate knowledge usability, decision and behavioral sciences, communication, and climate justice). Third, while we recognize the vast existing literature and the critical value of other areas of foci such as mitigation and energy, global governance, and the role of public opinion and skepticism, among others, we are not including them in this review given their lower prominence within the scope of AMS journals.

We organize this chapter as follows: First, we focus on the role of the social sciences in climatic research in general and how it has evolved through time, including within AMS. Second, we survey the field of the social sciences of weather and climate, including the social contribution to hazard events, the science of knowledge use, communication, and climate justice. Third, we review the sprawling literature of vulnerability and adaptation, especially focusing on broader trends in understanding and growing complexity. Last, we briefly assess climate health and climate and security as two emerging areas within AMS journals. Wherever possible, we made a concerted effort to provide references from AMS journals, especially the *Bulletin of the American Meteorological Society* (*BAMS*) and *WCAS*.

2. Social science in the American Meteorological Society

Although humans have been increasingly the focus of attention within the scope of climate and weather research, contributions from social sciences as a significant and stand-alone body of work have come late to AMS. In one sense, AMS has had a long-term orientation of its science toward societal needs because its earliest members were professional meteorologists seeking to improve the forecasting of weather and extreme events for the benefit of agriculture, national defense, and other sectors. As early as the 1920s, *BAMS* (https://www.ametsoc.org/ams/index.cfm/publications/bulletin-of-the-american-meteorological-society-bams/) started publishing peer-reviewed contributions of interest across the fields of meteorology, including social science. It was not until the 1970s that *BAMS* started to more consistently publish contributions stemming from interdisciplinary questions of interest to the social sciences, such as the impacts of weather and climate and their extremes on society, the connection between urbanization and weather patterns, professional decisions about and communication of forecasts and warnings, the economic value of weather and climate information, the use of information in decision-making, and the attribution of damages to particular weather or climate causes. However, key topics within *BAMS* remain largely focused on weather and climate (Fig. 26-1). Occasionally other AMS journals such as the *Journal of Applied Meteorology*, *Monthly Weather Review*, and *Weather and Forecasting* have also published a few articles on these topics.

Moreover, in the latter half of the twentieth century, AMS was actively seeking to increase its societal focus and relevance. In 1976, the pages of *BAMS* featured a selection of views solicited from the AMS Committees of the Scientific and Technological Activities Commission as input to the ‘‘debate within the scientific community on the need to contribute effectively to the solution of the problems of our society’’ (Winchester 1976). The issues identified therein are eerily relevant today: energy generation, food supply, environmental pollution, public health, the effects of increased use of

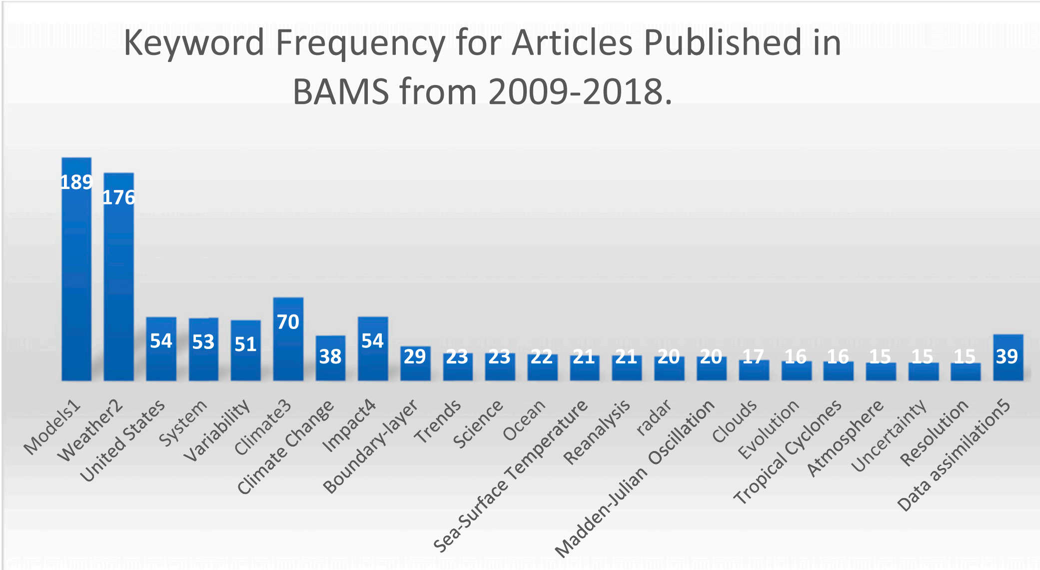

FIG. 26-1. Keyword frequency for articles published in *BAMS*. We used WoS to produce a list of all journal articles published in *BAMS* from 2009 to 2018. This query yielded a total of 935 articles after excluding conference proceedings, letters, meetings, editorials, abstracts, and reviews. We then imported these data into BibExcel, version 2014-3-11 (https://homepage.univie.ac.at/juan.gorraiz/bibexcel/; Persson 2009), which is an open-source software designed for conducting bibliometric analysis, to generate a complete list of keywords derived from WoS's "KeywordsPlus." We truncated responses at nine to remove low-frequency keywords. WoS's KeywordsPlus is a list of keywords that a publication's editors provide for an article. We then performed a frequency count to analyze how often particular keywords appear in articles published in *BAMS*. For readability, we shortened the keywords for some of the bars. They are as follows: Models1 = model, models, prediction, simulation, simulations, and ensemble; Weather2 = weather, precipitation, temperature, rainfall, and forecasts; Climate3 = climate and climatology; Impact4 = impact and impacts; Data assimilation5 = data assimilation and data assimilation system.

space on the environment, deliberate weather modification, the need for better probabilistic understanding, and of course, "inadvertent effects" on the atmosphere and global climate (Winchester 1976). Also, it is important to recognize the role of AMS itself in supporting the growth of social sciences within the community of meteorology and atmospheric sciences. In the 2000s, leaders in AMS such as Bill Hooke and Roger Pulwarty recognized that providing venues for the sharing of scholarship at the interface of social science and meteorology or climate was necessary to advance the field and grow the community of scholars. First, AMS made a significant decision to support a Policy Program within its Headquarters that included a summer Policy Colloquium to encourage interaction among all scholars interested in their work's application to policy. Second, AMS started a new Annual Meeting Conference Track in 2006, first called the Symposium on Policy and Socioeconomic Research and later renamed the Symposium on Societal Applications: Policy, Research and Practice. The Conference has steadily grown and attracts submissions from scholars all over the world. Moreover, projects such as Weather and Society*Integrated Studies (WAS*IS) and Social Science Woven into Meteorology (SSWIM), led by social scientists such as Eve Gruntfest, helped to organize communities of young scholars across disciplines to promote the "incorporation of social science tools and concepts into meteorological research and practice" (Demuth et al. 2007, p. 1729).

In 2009, AMS finally launched a journal dedicated to interdisciplinary research at the intersection of weather, climate, social science, and policy: *Weather, Climate, and Society*, which has become the go-to journal among interdisciplinary scholars working at this interface. The addition of *WCAS* to the roster of AMS journals has helped to expand and to consolidate the focus of social science research within AMS. As Fig. 26-2 illustrates, authors publishing in *WCAS* are largely concerned with questions about the usability of climate information and decision-making; communication; risks and hazards; and vulnerability, adaptation, resilience, and adaptive capacity.

Figures 26-1 and 26-2 illustrate the recent evolution of the social sciences within AMS. They are based on a nonextensive, bibliometric analysis of *BAMS* and *WCAS* that shows the frequency of keywords appearing in peer-reviewed articles published in both journals

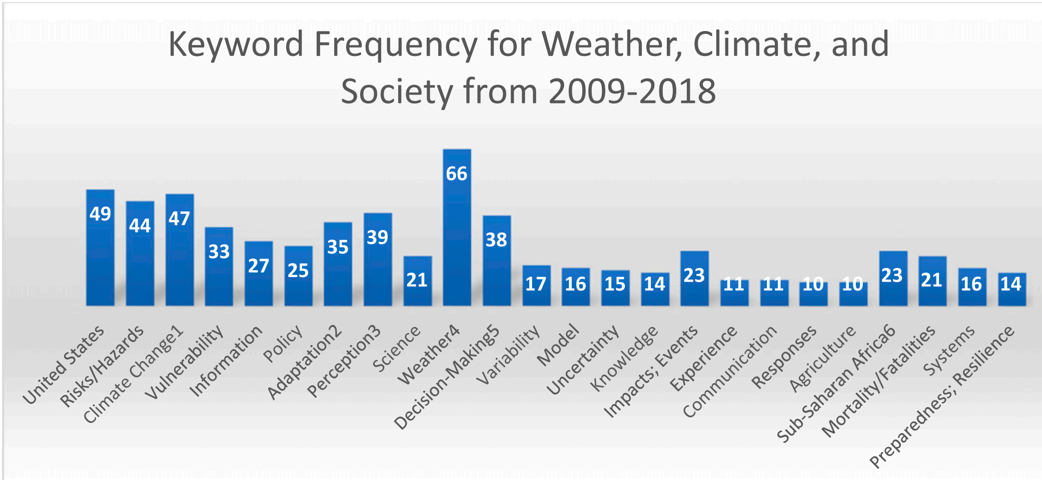

FIG. 26-2. As in Fig. 26-1, but for articles published in *WCAS*. This query yielded a total of 278 articles after excluding conference proceedings, letters, meetings, editorials, abstracts, and reviews. Shortened keywords are as follows: Climate Change1 = climate change, climate, and anthropogenic climate change; Adaptation2 = adaptation, adaptation strategies, adaptation insights, climate change adaptation, change adaptation, and adaptive capacity; Perception3 = perception, farmers' perceptions, and risk perception; Weather4 = weather, rainfall, precipitation, temperature, and forecasts; Decision-Making5 = decision-making, management, and risk management; Sub-Saharan Africa6 = sub-Saharan Africa, Burkina Faso, West Africa, and southern Africa.

from 2009 to February 2018 using the Thomson Reuters/Clarivate Analytics Web of Science (WoS). Although this analysis provides a cursory overview of the literature published in both journals, it does indicate the main topics published in them. Overall, peer-reviewed articles in *WCAS* cover a wider breadth of social science topics (Fig. 26-2), whereas peer-reviewed articles in *BAMS* tend to focus on issues related to climate and weather (Fig. 26-1).

The direct citation network (Fig. 26-3) from *WCAS* shows a predominance of two main interrelated clusters: one around risk perception, knowledge usability, and the political ecology of climate and weather and a second around weather and weather communication. The analysis illustrates the growing diversity across the social sciences within AMS, but it also suggests that there is room for growth and depth of integration with other areas of AMS.

Why the social sciences?

Any hope we have to address the impacts of climatic change better is predicated on our ability to understand the problem and come up with viable solutions. From an impact perspective, individuals, communities, institutions (rules, norms, and practices), and organizations at every scale are an integral part of the climatic change problem either by being vulnerable to its impacts or by being able to avoid (plan and prepare) and respond to them (adapt).

Early on, pioneers in the area of "human dimensions of climate change" were critically arguing that without understanding social processes and how they influence vulnerability and response, we were doomed to fail to plan and prepare for climatic impacts. Numerous reports from governments (e.g., IPCC or national assessments), international organizations (e.g., World Bank or United Nations), nongovernmental organizations, and scientific organizations (e.g., National Academy of Sciences or Future Earth) have urged governments and research communities to better integrate all areas of related knowledge, but especially the social sciences, in an effort to avoid and respond to climatic change. For example, the U.S. National Research Council of the U.S. National Academy of Sciences alone released at least six reports in the last 15 years that critically highlighted the role of the social sciences in understanding and responding to climatic change (NRC 2006b, 2009a,b, 2010, 2013; NAS 2018). They were right, yet more than a decade later we are still grappling with a basic understanding of the "wickedness" of climate impact, not the least of which examples is the role of climate science and its inherent limitations (e.g., uncertainty, scale, and resolution mismatch relative to decision-makers' needs) in informing policy (McNie 2007; Dilling and Lemos 2011). Beyond climate science itself, the intersection between climate impact and humanity's age-old intractable problems such as poverty and underdevelopment (defined as lack of access to basic livelihood capitals such as money, education, health, political voice, safety, and natural resources), injustice, and conflict have attracted a thriving

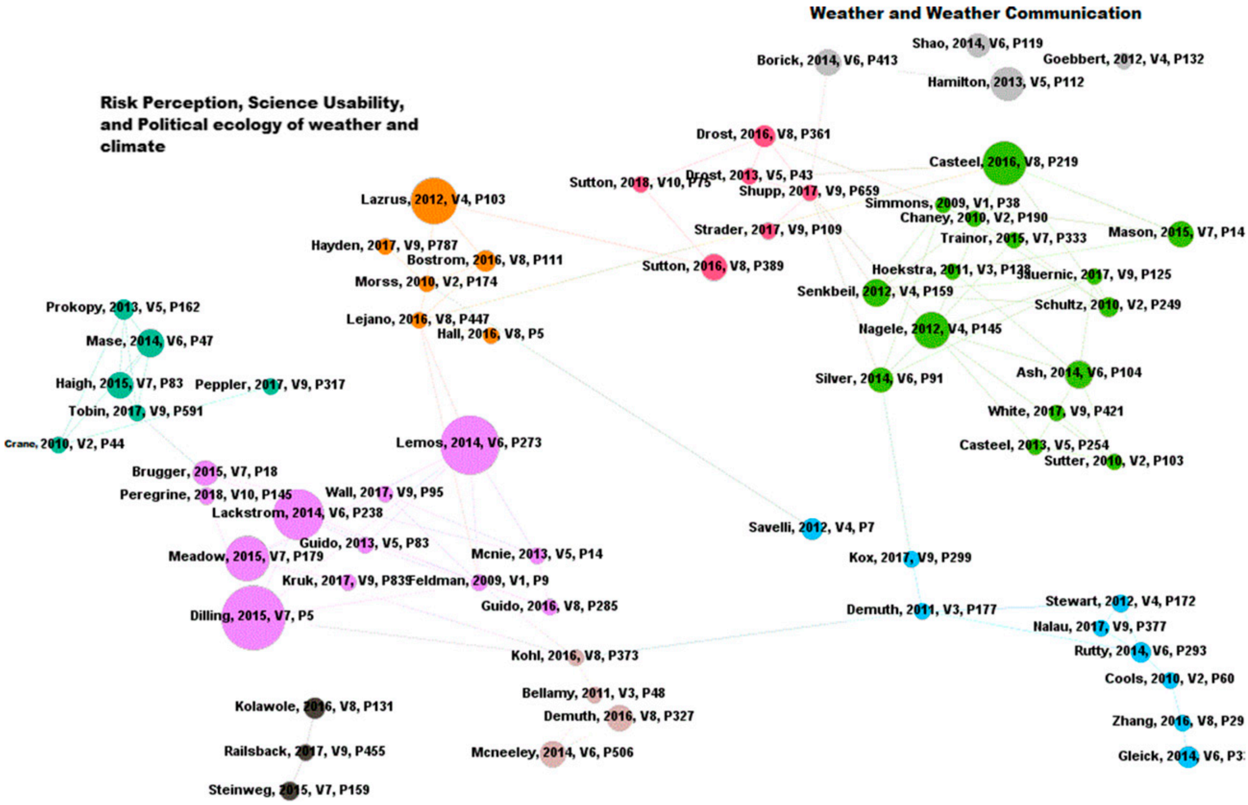

FIG. 26-3. Direct citation networks for *WCAS*. Direct citation networks allow us to examine the flow of information between two articles by looking at who is cited among the articles published in a journal. BibExcel was used to standardize references by omitting the author's second (and any subsequent) initial to reduce the chances of missing a link because of spelling variations in the author's name. We then linked articles on the basis of author's last name and first initial, year of publication, journal, and volume. Direct citation network files were created in BibExcel and imported into Gephi, which is an open-source software that is commonly used to visualize and analyze network data. We used a ''force atlas'' algorithm for its layout, which clusters nodes closer together if they have more links. Scholarly communities were then identified by using a modularity analysis in Gephi, which groups nodes according to how densely connected they are to one another.

community of social scientists from and across disciplines focusing on climate-related problems.

On the one hand, the social sciences have come a long way from the nondescriptive umbrella of so-called human dimensions of climate change. Today almost all disciplines of the social sciences and many in the humanities (e.g., economics, geography, political science, sociology, psychology, education, philosophy, anthropology, and history) and their cross and sectoral fields of study [e.g., science, technology, and society (STS), political and human ecology, urban studies, organizational studies, decision sciences, and complex systems] have turned their attention to weather and climate-related issues. In broad terms, the last 100 years have witnessed a massive growth in research and knowledge production in human–environment interactions, with a strong focus in recent decades on human adaptation and vulnerability to environmental change, particularly to climatic change (Janssen et al. 2006). Much of this knowledge production has drawn from longstanding disciplinary traditions, focusing, for example, on environmental risk perception (e.g., Slovic 1987; Kasperson et al. 1988), planning and policy for effective hazard and disaster risk management (e.g., White 1973; Burton et al. 1978), food security research and policy and research in international development (e.g., Sen 1981; Watts 1983), environmental governance (Ostrom 1990), and understanding societal impacts of climate and weather (Glantz and Katz 1977; Glantz 1982). On the other hand, the social sciences have not gone far enough in integrating and commanding the funding and attention comparable to the physical and natural sciences in either the weather or climate change domain, despite wide recognition of their importance (NRC 2009b; NAS 2018).

In this landscape, there are increasing calls for interdisciplinarity (the integration of different disciplines to understand and solve climate problems) and transdisciplinarity (the deliberate engagement of users of weather and climate information in the process of knowledge making). The rationale is that without the involvement of different disciplines and of those tasked with making the politically and economically costly decisions to prevent and respond to climate impact, action will not happen (NRC 2009a). Moreover, social sciences have much to contribute if we want those preventative actions and responses to be ethical and just and lead to increased societal well-being (O'Brien and Leichenko 2003; Adger et al. 2006; Roberts and Parks 2006; NRC 2010).

Specifically focusing at the intersection of weather, climate, and social systems, research into the impacts of hazards in society and our capacity to mitigate such impacts has shaped theories and concepts associated with human behavior in the face of risk, as well as the relation of behavioral responses to policy incentives and the institutional context of decision-making.

In the 1960s, at the dawn of the environmental movement in the United States, environmental psychologists created analytical tools to help evaluate human risk perception and attitudes about the environment, as well as theories to explain the divergence in the perception of nonexpert (''lay'') versus expert knowledge communities over risk (Slovic et al. 1981). This research coincided with the evolution of hazards research and policy in the United States, led by Gilbert White's research into the inefficiencies and failures of contemporary flood risk management policy (White 1986). White (1986) revealed the inadequacy of hazard risk management policy that only focused on infrastructural interventions and early warning systems without taking into consideration the attitudes, perceptions, and associated behavioral responses of the public to hazard information and risk.

By the latter half of the twentieth century, the social sciences were highlighting the fact that social vulnerability to hazards could not be addressed only through improved information on risk and infrastructural investments. Informed by new insights into decision-making, such as the concept of ''bounded rationality'' (Simon 1955), social scientists questioned the assumption that additional information about hazards—whether climate forecasts, early warnings, or more accurate flood maps—would necessarily result in better decisions. In addition, other aspects of vulnerability such as decision-making heuristics, risk perception, environmental attitudes, and economic and public policy all interacted in shaping behavioral responses (Burton et al. 1978).

Similarly, understanding why climatic knowledge is used or not in decision-making has played a critical role in bridging AMS physical climate science to the social sciences. In the 1980s, advancements in understanding the coupled atmosphere–ocean system led to the tantalizing discovery of some skill in predicting the El Niño–Southern Oscillation (ENSO) climate pattern months ahead of time (Zebiak and Cane 1987) and revealed ENSO's teleconnections to droughts and flooding events in different regions of the world (Ropelewski and Halpert 1987). These advances opened the door to the possibility of using the predictability of the ENSO system as an input to decision-making for farmers, water managers, fisheries, and other resource managers around the world. These early studies also involved understanding how to characterize and measure drought so that metrics could be more useful in decision-making (Glantz and Katz 1977; Katz and Glantz 1986)—including the seminal recognition that drought can be defined in different ways depending on the discipline or the societal perspective (e.g., agricultural, socioeconomic, or hydrological) (Wilhite and Glantz 1985).

Early experiments in understanding the use of seasonal to interannual climate forecasts focused on the Northeast region of Brazil, Peru and Chile, southern Africa, Australia, and some areas of the United States (Hammer 1994; Pulwarty and Melis 2001; Broad et al. 2002; Orlove et al. 2004; Vogel et al. 2007). What many of these experiments showed, however, is that the real-world use of these forecasts was disappointingly less than scientists expected and was fraught with issues of equity and potential unintended outcomes (Lemos and Dilling 2007). Through this evolution of the field in the 1980s and 1990s, social scientists became increasingly drawn into the coupled questions of why decision-makers do or do not use climate information and how climate research could be conducted so that it is more usable for decision-making (Vogel and O'Brien 2006; Patt et al. 2007; Dilling and Lemos 2011; Lemos et al. 2012).

Since then, this literature has spread out and matured, going much beyond seasonal climate forecasting to include all forms of climate information and different analytical frameworks from such diverse areas as health-based translational sciences, business, organizational studies, sociopsychology, and STS. These approaches have critically enhanced not only our understanding of constraints and opportunities for climate information use but have also informed a rich practice on engagement with different communities of practitioners in areas such as water management, agriculture, and urban planning (Lemos and Morehouse 2005; Bolson and Broad 2013; Briley et al. 2015; Kalafatis et al. 2015a; Prokopy et al. 2017; Vogel et al. 2016).

In more than one sense, these broad streams of literature have informed our understanding of both the impact of and responses to climatic change. In the next few sections we review them more specifically, keeping in mind that any attempt to survey all the critical insights advanced to date would be incomplete. Rather, we look at the evolution of these issues in the context of a few specific areas of study: the science of science use, vulnerability and adaptation and the intersection between climate impacts, health, and security.

3. The social sciences of weather and climate

a. The science of usability and communication

1) Understanding perceptions, value, and use of weather and climate information

The generation, use, and understanding of weather forecasts have been a fruitful area of collaboration between social scientists and atmospheric scientists. While skill verification is a common feature of atmospheric sciences, human dimensions of forecasting became the focus of research in the 1980s. Early examples of research in this area compared the skill of "objective" and "subjective" forecasts (the latter being generated by judgment of forecasters rather than numerical–statistical procedures; Murphy and Brown 1984) and understanding how the public actually understood forecasts and whether they had confidence in them (Fischhoff and MacGregor 1982; Murphy et al. 1980).

More recent research in this area includes work on perceptions of hurricane forecasts and decisions to evacuate (Dow and Cutter 2002; Broad et al. 2007; Demuth et al. 2012; Lazo et al. 2015; Bostrom et al. 2016; Demuth et al. 2016), coastal storm evacuation messaging (Cuite et al. 2017), flash flood warnings and risk perception (Benight et al. 2007; Ruin et al. 2007; Lazrus et al. 2016; Feldman et al. 2016), tornado warnings (Barnes et al. 2007; Simmons and Sutter 2009; Hoekstra et al. 2011; Klockow et al. 2014; Ripberger et al. 2015), drought early warning (Pulwarty and Sivakumar 2014), the communication of probability (NRC 2006a; Joslyn and Nichols 2009), challenges in reaching vulnerable populations (Phillips and Morrow 2007; Hayden et al. 2007), and the use of social media for the communication of severe weather and warnings (Sutton et al. 2008; Freberg et al. 2013; Morss et al. 2017; Demuth et al. 2018). Community calls for focused research in the social science of forecasts and warnings have accompanied the growth of the field (Montz and Gruntfest 2002; Morss et al. 2008b; Gladwin et al. 2009; Gruntfest 2018).

In the 1990s, the weather community also began to look more systematically at the societal impact of weather events and at how weather information could make a difference in preventing losses and deaths. Stanley Changnon stands out as a frequent contributor to the AMS journals in this arena, calling attention to the potential role of atmospheric science in informing energy demand and supply (Changnon et al. 1995), mitigating the impact of heat waves (Changnon et al. 1996), economic and human health impacts (Kunkel et al. 1999), examining the use of climate forecasts in agriculture (Changnon 2004), and the emergence of weather derivatives and risk models (Changnon and Changnon 2010). As the role of climate change became a more salient policy question, some of this work turned to the question of attribution of losses. Work at this interface showed that society was facing increasing financial and damage losses because of societal choices in how and where to build assets. This research also suggests that such losses were not likely to decrease even if climate change was mitigated (Changnon et al. 2000; Pielke 2007a).

Another strand of work in interdisciplinary meteorological social science work is the investigation of the economic value of forecasts or weather information in general. Early work in this area focused on agricultural applications such as fallowing/planting decisions and fruit frost responses (Stewart et al. 1984; Brown et al. 1986) but has now extended to many other areas of weather and climate (e.g., value of hurricane forecasts; Letson et al. 2007).

2) Usability of weather and climate information

In trying to understand how useful and usable climate knowledge is in informing decision-making, scholars have uncovered several reasons why people do not use weather and climate information or at least do not use it to its full potential. Some of the reasons have to do with the characteristics of the information itself, which in turn is influenced by how the information is produced in the research process. Other constraining factors lie completely outside of the scientific process and relate to the decision context (Dilling and Lemos 2011).

In a seminal paper addressing the use of information by assessment processes, Cash et al. (2003) lay out three main criteria needed for information to be usable in decision-making: credibility, salience, and legitimacy. Credibility is the degree to which the scientific information is seen as high quality as judged by the standards of the scientific community, including peer review, institutional source, and established methodological procedures. Salience refers to the relevance of the information for the decision at hand: these factors might include relevant spatial scale, timeliness, appropriate selection of variables, and understandable presentation format. Legitimacy comes from the process used to produce the information, which must be seen to be free from bias and perceived by stakeholders to be transparent. In a review of over 30 empirical studies on the use of seasonal to interannual climate forecasts, Dilling and Lemos (2011) found that spatial and temporal scales, skill of forecasts, timing of availability of forecasts, trust in the forecasts and process, and accessibility and understandability of forecast products were all cited as important mediators of use.

TABLE 26-1. Summary of opportunities and barriers that affect usability as derived from the literature. This table is from Lemos et al. (2012) and is reprinted by permission from Springer Nature.

Barriers identified in the literature		Opportunities identified in the literature	
		Fit	
Not accurate and reliable	Not timely	Accurate and reliable	Timely
Not credible	Not useful; not usable	Credible	Useful; usable
Not salient	Excessive uncertainty	Salient	
		Interplay	
Professional background	Insufficient technical capacity (e.g., lack of models)	Previous positive experience	Technocratic insulation
Previous negative experience	Culture of risk aversion	Threat of public outcry; public pressure	Water scarcity
Value routine; established practices; local knowledge	Insufficient human or financial capacity	Perception of climate vulnerability	In-house expertise
Low or no perceived risk	Legal or similar	Sufficient human or technical capacity	Triggering event/crisis (drought, El Niño, etc.)
Difficulty incorporating information	Lack of discretion	More flexible decision framework	Organizational incentives
			Value research; information seeking
		Interaction	
Not legitimate	Infrequent interaction	Legitimate	Trust
One-way communication	End-user relationship	Two-way communication	Long-term relationship
		Iterative	Coproduction

In addition, the very context of use was instrumental in determining whether even relevant information would be taken up by the decision process (Dilling and Lemos 2011).

Contextual issues influencing use include inflexible institutional rules about acceptable sources of information, "fit" to the decision when compared with other priorities at hand, organizational cultures and reward structures, and the availability of alternative courses of action (Lemos et al. 2012). Furthermore, the very notion of "what use is" in a weather and climate context has been more deeply interrogated and shown to have a variety of dimensions, from use from an instrumental perspective, in which information directly impacts a decision, to use for "enlightenment" or confirmational purposes, in which, although the decision itself may not have changed, information may have played a role in informing or confirming an existing decision path (Wall et al. 2017). Table 26-1 illustrates some of these constraints reviewed in the literature [the table is taken from Lemos et al. (2012)].

It is also important to recognize that the use of information is not neutral, but in fact may serve in some cases to reinforce or reenact existing power structures and inequities in society. For example, Broad et al. (2002) found that while the application of seasonal to interannual forecasts in the case of a Peruvian fishery affected by ENSO resulted in little use by fisherman, it was used by fishing companies to scale down their activities, including firing employees. Indeed, producing and disseminating information devoid of the cultural context or understanding of the complex dynamics of a region can be ineffective at helping communities manage their vulnerabilities (Vogel and O'Brien 2006). Moreover, recent scholarship has increasingly focused on the potential for unequitable and unjust outcomes of the coproduction of climate knowledge, whereby scientific knowledge can potentially crowd out or discredit local and indigenous knowledge (Meehan et al. 2017).

Intertwined with these investigations of what usable information looks like and how context enables or prevents use has been an effort to understand how to improve the use of information in practice. In 2005, Lemos and Morehouse identified the importance of coproduction as a process grounded in iterativity, a concept that lies at the intersection of interdisciplinarity, stakeholder participation and usable knowledge (Lemos and Morehouse 2005). Coproduction at its heart relies on the interaction between researchers and stakeholders and places the emphasis on "beginning with users' needs" while taking into account the possibilities and limitations of what science can provide (Meadow et al. 2015). This represents a departure from the 1940s mental model of a linear process in which scientists conducted their research largely in isolation from societal needs and then placed the results in a "loading dock" where others could then take it up for use (Cash et al. 2006). The loading-dock model has been critiqued as one of the factors that contribute to research being at the wrong scale, being available at the wrong time, or focusing on the wrong variable, for example. Instead, in the past decade, coproduction has been taken up as a rallying concept through many different processes and organizations, including those led by practitioners in the field (Beier et al. 2017; VanderMolen and Horangic 2018; Kruk et al. 2017). Similarly, social science research in the severe weather meteorological community has identified the need to reconceptualize research processes as ''end-to-end-to-end,'' embodying multidirectional communication, sustained interactions with multiple partners, and interdisciplinary collaborations (Agrawala et al. 2001; Morss et al. 2005).

As coproduction has matured as a concept, more attention has been focused on understanding empirically the details of how interaction might work to increase the usability of potentially useful information. McNie et al. (2016) have set forth a comprehensive set of attributes that organizations focused on conducting user-centric research might embody across their knowledge production, learning, and engagement activities, including the way expertise is conceptualized, how research goals are envisioned, and how success is evaluated. At the same time, the idea of coproduction as a panacea for lack of information use has been questioned, and examples of how coproduction may fall short have emerged in the literature (Lövbrand 2011; Meehan et al. 2017; Lemos et al. 2018).

Organizations can play a key role in making science more usable to decision-making. ''Boundary organizations'' in this context are those organizations that sit at the interface between the production of scientific information and those that are making decisions (McNie 2008; McNie 2013; Guido et al. 2016; Feldman and Ingram 2009; Lynch et al. 2008). Successful organizations play a role in translating, mediating, and communicating across the boundary. Functionally, it is important that boundary organizations not only serve as knowledge brokers, but also act to maintain ''dual lines of accountability,'' which allows both sides of the boundary to remain credible within their own spheres (Kettle and Trainor 2015). This type of work is labor and time intensive and carries high transaction costs. As a result, to reach the broad range of stakeholders with varying amounts of capacity in a region, organizations have adapted to different strategies such as ''boundary chains'' with smaller, more localized organizations (Lemos et al. 2014). Case studies have shown that boundary chains can be effective in improving the understanding of the usability of climate information as well as increasing its actual use, but questions remain in terms of their long-term sustainability and ability to smooth risks across the different organizations involved (Meyer et al. 2015). More broadly, regional networks and specialized networks and communities of practice within a region have played a critical role in amplifying access to knowledge and ultimately tailoring that knowledge to particular groups and contexts (Dow et al. 2013; Dilling et al. 2015a; Kalafatis et al. 2015b).

Research examining coproduction and the production of usable science or actionable knowledge points to the importance of a deliberate process to facilitate engagement between scientists and decision-makers (Meadow et al. 2015; Wall et al. 2017). Indeed, organizations operating in this space need to ''own'' the process of producing usable science—just assuming it is ''someone else's job'' will often mean that usable science falls off the table as low priority (Dilling and Lemos 2011, Meadow et al. 2015). Scholarship has also increasingly questioned coproduction as a model in terms of both outcomes and costs (Lemos et al. 2018; Meehan et al. 2017).

3) Communicating weather and climate

Another factor affecting climate information usability is how it is communicated and understood by potential users. Communication research surrounding public understanding of warnings, forecasts, and scientific information itself has bloomed in the past several decades. And while weather information itself has been produced for over a century at an institutional level through national meteorological offices, it has only been in the past 25 years that social scientists have become deeply engaged in interdisciplinary research with the meteorological community on questions of why individuals do not heed severe weather warnings or what people actually understand when they hear a weather forecast, for example (Demuth et al. 2011).

Because the Internet and social media are rapidly changing both the way people obtain information and the way they interact with those sources of information, it is important to revise how we conceive of communication and think of it as an ''interactive experience among people who are working within their own evolving, uncertain worlds, embedded in larger socio-technological contexts'' (Morss et al. 2017, p. 2654). Similarly, technological advances allow for much greater targeting and tailoring of messages to specific audiences regarding climate change (Bostrom et al. 2013). Framing is also critical for climate change communication but may be serving to reinforce divides rather than seeking common ground (Nisbet 2009). Research in this area has contributed to questioning the ''information deficit model'' that assumed that lack of climate-related action was caused by lack of information rather than by poor communication or efforts to enable use (Moser and Dilling 2011). While the public does not always understand the technical, meteorological definitions of weather forecasts, lay people do understand that deterministic forecasts are uncertain, and they have a general sense of which types of forecasts are likely to be more accurate (Morss et al. 2008a). The Morss et al. (2008a) research suggests that understanding the preexisting concepts and understanding that laypeople construct from weather information is critical to making future weather research and forecasts more usable.

4) Challenges in knowledge usability

Despite much progress in the science of science use, many challenges remain in our ability to make the science of weather and climate usable in solving societal problems. First, we still know little about decision contexts more specifically and how they affect climate information uptake and use. While we have been good about asking stakeholders what they need, we have paid less attention to how they make decisions and how social science can help in overcoming some of the identified barriers. Indeed, we know considerably more about producing and communicating scientific climate knowledge (Sarewitz and Pielke 2007) than we know about how practitioners make decisions. Second, while the science of science use has been instrumental in generating recommendations on how to coproduce, create, and evaluate usable scientific weather and climate knowledge, it has done less in reflecting how its own knowledge is usable to solve climate problems (e.g., Pielke 2007b; Lemos et al. 2018). Third, there is a need for more empirical and systematic research about the potential for both positive and negative outcomes of coproduction. While most of the focus has been on the process of coproducing itself, much less attention has been paid in documenting the actual outcomes of coproduction in terms of knowledge use, positive or negative (Lemos et al. 2018). Finally, in addition to normative calls for equity and justice we need much better empirical understanding of the winners and losers of climate impacts, including the implications of scientific knowledge use and coproduction in this context.

b. Vulnerability and adaptation

1) Vulnerability and climate

The growing recognition of the threat of climate change has consolidated the diverse contributions of the social sciences to climate research into a knowledge domain often referred to as human dimensions research (Stern et al. 1992). Human dimensions research encompasses a diversity of topics associated with the human experience of and responses to environmental change, including impact and vulnerability analyses, decision analysis, governance, institutional design, risk perception, social–ecological resilience, and adaptation and adaptive capacity. It places human systems, rather than the biophysical stressors, as the entry point for analysis. In doing so, the larger objective of human dimensions research has been to situate environmental change within the social systems that filter, structure, and shape how humanity is affected by climatic stressors and change. Human dimensions research has also enabled a focus on how, in the past, social systems have responded to environmental change, and what this understanding implies for society's ability to respond to current and future changes.

Much of the core knowledge production from the social sciences has been in relation to the constructs of social vulnerability (i.e., the propensity of any entity to suffer harm or loss; Eakin and Luers 2006) to climatic stressors and change, and adaptation (i.e., the actions, processes, and outcomes intended to maintain human capacity to deal with current and future change and avoid loss; Nelson et al. 2007). Early social science work on vulnerability to climatic risk and hazards stems from the tradition of human–environment or human–ecology research in human geography and anthropology of the early twentieth century (Judkins et al. 2008). With a strong environmental deterministic lens and claims that environmental conditions had significant influence over the development of economic, cultural, political, and social life, the primary questions for the social sciences related to human adjustments to distinct and often adverse climatic stress and environmental constraints (Peet 1985). Initially, vulnerability as related to climatic events was evaluated as originating from external environmental stressors—an outcome of the exposure of individuals and communities to extremes and adverse environmental conditions (O'Brien et al. 2007; Adger 2006).

The environmental determinism strain of human environment research began to be challenged with the work of such scholars as Carl Sauer and Julian Steward (Solot 1986; Judkins et al. 2008), who carefully documented the ways in which social practices and social organization had significantly transformed landscapes across the world to meet social needs. Extensive case study research that demonstrated society's capacity to modify the environment became a focal point of study, providing historical evidence of the degree to which local and regional environmental processes could be affected by human action (Turner et al. 1990). In the 1980s and 1990s, scholars began to formally challenge frameworks of analysis that suggested that vulnerability was, in fact, simply a product of biophysical exposure. Instead, social scientists (e.g., Hewitt 1983; Watts 1983; Liverman 1990; Cannon 1994; Blaikie and Brookfield 1987) put forth evidence that social systems play significant roles in creating the social, political, and economic conditions that result in differential exposure to hazards and thus differential—and often inequitable—distribution of vulnerability. This socially informed political–economic perspective on vulnerability has increasingly become central to a global understanding of climate change risk, climate justice, and climate impacts, as reflected in the more recent IPCC assessments (Eakin and Luers 2006; Adger 2006).

The emergence of cultural ecology, human ecology, and, eventually, political–ecology research provided an interdisciplinary domain for research into the social factors influencing environmental change, as well as the documentation of the creativity and innovative responses of social systems to environmental constraints (e.g., Mortimore 1989; Netting 1993). The practices and culture of rural populations living in agroclimatic conditions that would seem inhospitable for human subsistence activities were the focus of much of this work (Denevan 1983; Wilken 1987; Batterbury and Forsyth 1999; Zimmerer and Bassett 2003). In anthropology and geography, for example, such research illustrated how traditional smallholder farm systems had developed sophisticated means of adjusting to variable climatic conditions and microclimatic variations (e.g., Bebbington 1999; Roncoli et al. 2002; Eakin 2005).

While this work long preceded international concern over global climatic change, the knowledge produced has provided an empirical and theoretical foundation for adaptation research, demonstrating not only what adaptations are possible, but also the conditions under which such adaptations emerged, are disseminated, and adopted. Cultural ecology and human–environment research in geography and anthropology also paved the way for a recognition of the critical importance and influence of local knowledge: knowledge acquired through practice, cultural tradition, and local experimentation. Local knowledge and observation have not only informed our understanding of what environmental changes have occurred and are occurring (Berkes et al. 2000) but also human capacities and limitations in response to such change.

2) Climate adaptation

As the inevitable necessity for adaptation to climate change was recognized in the 1990s (Schipper 2006), international organizations, funding agencies, and governmental bodies began to focus on what adaptation would mean in practice. Social scientists in interdisciplinary teams worked to develop guidelines, tools, and approaches for operationalizing adaptation planning and policy (Klein and Maciver 1999; Smit et al. 1999; Schipper 2006). Initially, adaptation planning followed from impact assessment: once robust projections of anticipated climate impacts could be determined from biophysical models, scenarios, or historical assessments of exposure and hazard frequency, then suites of specific forms of technological or policy interventions could be proposed to reduce such impacts. In this context, the U.S. Agency for International Development sponsored adaptation and vulnerability planning in the Countries Studies Program (USCSP 1999). In the United Kingdom, the Climate Impacts Program (UK CIP) was developed to facilitate systematic adaptation planning among public and private entities (McKenzie Hedger et al. 2006) and internationally, the United Nations put forth the Adaptation Policy Framework to support the integration of adaptation into international development programs (Spanger-Siegfried et al. 2004).

These efforts in supporting organized and structured adaptation planning at different levels of governance were instrumental in advancing the consideration of climate change risk in formal decision and policy processes (Tompkins et al. 2010; Ford et al. 2011). Nevertheless, the operationalization of the proposed frameworks was challenged by the real-world decision context of policy makers and development practitioners: climate risk and vulnerability are only one of many stressors faced by public sector actors (O'Brien and Leichenko 2000), planning for adaptation itself also requires specific skills and capacities that are often lacking (Eisenack et al. 2014), and the politics and social relations involved in adaptation decision-making are often more determinant than the technical considerations of risk and impacts (Vogel and O'Brien 2006). The lessons from intentional, planned adaptation now provide significant opportunities for science to advance understanding of the challenges of responding to climate information, scenarios, and projections (Eakin and Patt 2011).

3) Evolution and challenges in vulnerability and adaptation research

Social science perspectives on climatic risk, vulnerability, and adaptation have evolved into a dynamic, diverse, and highly interdisciplinary field, assuming prominence in the IPCC's report and attracting increasing amounts of national and international research (Roder et al. 2017; Hayden et al. 2017; Gaskin et al. 2017; Schipper and Pelling 2006; Ford et al. 2008; Berrang-Ford et al. 2011). In an era of unprecedented environmental change, it is now widely acknowledged that societies across the globe are both vulnerable to uncertain and potentially significant impacts and presented with new opportunities. Some scholars have noted an emergent "adaptation science": a field of both basic biophysical and socioeconomic research, as well as an applied science focused on enhancing decision-making capacity in the face of deep uncertainty (Meinke et al. 2009; Moss et al. 2013). Others have questioned whether our understanding of vulnerability and adaptation is yet sufficiently mature to be called a science in and of itself (e.g., Swart et al. 2014), noting that many challenges remain in the practice of ''science for adaptation.'' Below, we highlight some of these contemporary challenges and opportunities at the heart of transdisciplinary human–environment research.

First, while social science research has put forth many hypotheses on what constitutes an adaptive society, organization, or individual, many if not most of these hypotheses remain relatively untested (Engle and Lemos 2010; Swart et al. 2014). For example, adaptive capacity—or the attributes of any system, organization or household that facilitates effective responses to climatic stressors—is associated with material asset endowments (Yohe and Tol 2002); access to information, knowledge, and finance (e.g., Eakin and Bojorquez-Tapia 2008; Speakman 2018); perception and cognition (Grothmann and Patt 2005; Marshall 2010; Torres et al. 2018; Doll et al. 2017; Ambrosio-Albala and Delgado-Serrano 2018; Mkonda et al. 2018); with identity, cultural processes, and social relations (e.g., Frank et al. 2011; Torres et al. 2018); and the broader and dynamic governance and institutional context in which decisions are made (e.g., Engle and Lemos 2010; Eakin 2005; Peregrine 2018; Gaskin et al. 2017). Nevertheless, methodological challenges have inhibited rigorous testing of these hypothesized capacity attributes (Engle 2011). Researchers are still uncertain, for example, what combination of attributes best enable adaptive actions, or whether there are some conditions in which there may be trade-offs among specific attributes (Engle and Lemos 2010; Eakin et al. 2014; Nelson et al. 2016). There is some emerging evidence that there may be some attributes—such as a population's sense of attachment to place (Halperin and Walton 2018)—that may encourage adaptation initially but serve as an impediment to more significant change if adapting current practices becomes unviable (Marshall et al. 2012).

Second, while it is generally assumed that societies characterized by relatively high human welfare and well-being will be more adaptive, the correlation between economic development and adaptation is complex. Economists have demonstrated that when viewed in relation to a population's economic and material wealth, the harm produced by climatic shocks and stress is often far more damaging to low-income populations than to their wealthy neighbors (e.g., Paolisso et al. 2012; McNeeley 2017). Natural disasters and chronic exposure to environmental shocks reduces the capacity for economic stability and growth and exacerbates poverty and health impacts (Hallegatte et al. 2017; Bedran-Martins et al. 2018; Githinji and Crane 2014). Others have challenged the relatively simple narrative concerning the relationship of poverty and vulnerability, arguing that this relationship is conditioned by historical, institutional, and political–economic contexts (Eakin et al. 2014; Nelson et al. 2016; Paolisso et al. 2012; McNeeley 2017). In some places, investing in ''generic'' capacity attributes such as education, health, and ''good government'' may be more important to managing vulnerability than efforts to create insurance markets, early warning systems, and infrastructure investments to reduce exposure; in other contexts, populations may already have adequate generic capacity attributes and more attention to managing specific climate risks may be more critical. Ultimately a balance is needed, and the public sector has a strong role to play in encouraging appropriate allocation of resources among generic and specific capacities (Nelson et al. 2016).

Third, as governments, corporations and other organizations make decisions to reduce vulnerability in the face of increased climatic risk, it is becoming clear that ''not all adaptations are good ones'' (Eriksen et al. 2011). While the political nature of adaptation is not by any means new to social science [see, e.g., the early work in political ecology and environmental change captured in Blaikie et al. (1994) or Watts (1983)], in the context of climate change, adaptation is often presented as an apolitical, technical, or managerial tool for policy. Nevertheless, adaptation, like any process of decision-making, is embedded in the social and political contexts in which decisions are being made. Maladaptation—adaptations that ultimately result in exacerbating vulnerability at some level or for some populations—may become an increasing issue as populations move forward to address the challenges of climate change (Barnett and O'Neill 2010). Scholars have pointed out that in face of significant uncertainty and unprecedented change, adaptations can fail to reduce vulnerability, or they may serve some segments of a population but augment risk for others (Barnett and O'Neill 2010; Eriksen and Brown 2011; Dilling et al. 2015b). Social scientists have called for increased scrutiny of what we are labeling adaptation in society with the goal of making adaptation reflect the broader ambitions of sustainable development: actions that not only reduce vulnerability but also enhance social equity and justice (Eriksen and Brown 2011; O'Brien 2012). Adaptation decisions are not only technical in nature; they are political as well, often reflecting the agendas, priorities, and trajectories of the more influential actors in any social system (Eriksen et al. 2015; Manuel-Navarrete and Pelling 2015).

Fourth, social scientists have recognized that to account for the complex temporal and spatial implications of adaptation choices, theoretical advances are needed (Nelson et al. 2007). The linear relationship linking climate threats to climate perception that ultimately leads to decision-making and then actions is inadequate to account for how adaptation, as a dynamic process, takes place in society. Drawing from complex systems dynamics and social–ecological resilience, the science of adaptation has expanded to focus on ''adaptation pathways'': trajectories of decision cycles, processes of experimentation and learning, reflection, and adjustment (Haasnoot et al. 2013). A pathways approach retreats from considering adaptation as a definitive outcome and situates adaptation in complex system dynamics in which outcomes are uncertain, surprise is common, and maladaptation is a reality (Wise et al. 2014). In these contexts, capacities for learning, inclusive governance, and a willingness to reflect on trajectories of change are critical adaptive attributes at the societal level (Wise et al. 2014). Methodologically, a complex systems approach to evaluating vulnerability and adaptation leads to the embrace of dynamic systems modeling tools and approaches such that unexpected thresholds, nonlinear system responses, and the potential for maladaptive outcomes can be explored as vehicles for learning (e.g., Fraser et al. 2011). Nevertheless, measuring and integrating the critical social attributes that represent vulnerability into such models is challenging. The temporal and spatial resolution of data that represents salient social indicators—such as institutional flexibility, inclusive governance, or capacity for learning—is often absent, or poses challenges to integration with biophysical data (Preston et al. 2011). Some attributes such as cultural traits, well-being, and safety are hard to quantify in a way that fully reflect their role in explaining vulnerability (Brooks et al. 2005). Social indicators assessed at the system level are often presented as static: uncertainty concerning their evolution confounds efforts to combine these with projections of change in biophysical variables over time (Jurgilevicet al. 2017). The challenge of adequately representing the social dynamics and complexities in exploratory modeling and climate scenario research is compounded by the growing recognition that in many, if not most social–ecological systems, the social dynamics (e.g., human cognition, social and cultural relations, political processes, institutional structures, and economic trajectories) have a dominant role in system change (Davidson 2010; Manuel-Navarrete and Pelling 2015; Eakin et al. 2017).

Fifth, in the face of high uncertainty and considerable risks associated with not only climate change but economic and political change as well, resilience as a desirable goal has been widely adopted by municipalities and communities (Meerow and Newell 2016). The spread of this conceptualization of resilience in the discourse of urban planners and civil society at large represents an embrace of the challenge of managing risk and uncertainty at the local level, as well as a societal shift in recognizing that the status quo is unlikely to produce sustainable futures. Spurred on by initiatives, such as the Rockefeller Foundation's 100 Resilient Cities program (https://www.rockefellerfoundation.org/our-work/initiatives/100-resilient-cities/), cities are undertaking resilience plans and embarking on participatory processes to raise awareness and implement strategies to ensure that communities and cities have the capacity to recover essential functions following significant, unexpected disturbance. Resiliency planning is emphasizing new assets in communities, highlighting ecological processes as the basis for creating green infrastructure solutions and ''ecosystem-based adaptation'' (Pickett et al. 2004; Childers et al. 2015). Following insights from institutional analysis, such planning also is encouraging more decentralized and participatory governance (Bahadur and Tanner 2014; Meerow and Newell 2016). As these plans and strategies have been implemented, social scientists have served as a sounding board, calling attention to the need for such plans to address social equity (Ahern 2011; Meerow and Newell 2016). For many populations—particularly those who are most subjected to the negative effects of shocks and stress—maintaining existing system functions and restoring society to ''what it was before'' is insufficient. They demand more transformative action, such that their social and economic conditions will be improved as cities and communities prepare for and build back from disasters and shocks. In these cases, asking ''What resilience? For whom? Where? And Why?'' is critical (Meerow and Newell 2016).

c. Climate, health, and security

Climate health and security have emerged as strong foci of social science research with critical areas of application for societal well-being. Within the AMS published research, the connections between weather, climate, and health were being made as early as the 1960s, with *BAMS* featuring a few articles at this intersection. It was not until the 1990s—with the growing understanding that to better understand the problem climate and weather variables needed to be integrated with other livelihood and ecosystems stressors—that the inclusion of social variables expanded. This included studies on the impact of heat islands, warning systems, the costs and benefits of different interventions, and the intersection of climate-related and geophysical factors (e.g., rainfall, temperature, altitude, glacier melting, pollutants, and vector and respiratory diseases) and health (e.g., Kalkstein et al. 1996; Ebi et al. 2004; Kunkel et al. 1999; Greene et al. 2011; Abdussalam et al. 2014;

Githinji and Crane 2014). Indeed, it is not surprising that among the areas focusing on the intersection between climate change and humans, health has a high level of cross scholarship with other areas of focus within AMS, especially modeling (e.g., Abdussalam et al. 2014). While climate security studies are less prominent in AMS journals, there are a few notable articles focusing on security (Butke and Sheridan 2010; Gleick 2014; Malone 2013) and many others that have critical implications to human security in general (e.g., Simmons and Sutter 2009; Demuth et al. 2012; Cuite et al. 2017).

1) Climate and health

The key factors at the intersection of climate and health are succinctly described by the World Health Organization (WHO) areas as 1) the indirect effects of climate change on determinants of health (clean air and water, food, and shelter), 2) the devastating number of deaths expected globally in the next few decades (between 2030 and 2050: 250 000 per year from malnutrition, malaria, diarrhea, and heat stress), and 3) the staggering costs (2–4 billion U.S. dollars per year by 2030) and disproportionately high impacts on less-developed regions (WHO: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health). Public health and social sciences scholars have led most of the research focusing on the impact of climate on health, including social drivers of health risks and social determinants of health, especially in less-developed regions.

Overall, scholars are increasingly arguing for the need to understand both the complexity and multiplicity of natural and social factors that mediate the relationship between climate and health to inform policy and response. The IPCC Fifth Assessment Report (AR5) chapter focusing on climate and health highlights three main sets of factors that directly or indirectly shape the relationship between climatic change and health: 1) direct impacts of climate and weather (e.g., heat, cold, and flooding); 2) ecosystem-mediated impacts (e.g., vector-borne and other infectious diseases such as malaria, dengue, and West Nile; food- and water-related diarrheal infections; and health effects of pollutants exposure); and 3) health impacts mediated by human institutions (e.g., nutrition and occupational and mental health) (Smith et al. 2014). Each of these involve diverse and complex mechanisms, which are often not well understood.

Among interdisciplinary publications that pay substantial attention to climate and health, there is a growing contribution of the social sciences, primarily in understanding the role of socioeconomic factors in mediating health effects and building the capacity of different systems (e.g., infrastructure, governance, and risk management) to modulate these effects. Different literatures focused on climate and health have increasingly not only included socioeconomic data in their analyses but also progressively considered issues related to values, human rights, equity, and justice. For example, the IPCC AR5 review of this literature finds that there is high confidence that socioeconomic and demographic factors (e.g., age, education, and gender) affect the intersection of climate and health (Smith et al. 2014). Woodward et al. (2011) argue that one critical limitation for improving projections of future malaria under different climate scenarios is the way that these models represent socioeconomic factors influencing transmission and ability to respond.

Indeed, the literature of climate and health has increasingly focused on understanding the intersection between different social determinants of health (e.g., access to clean water and air, food security, and shelter) and climate and weather events, especially in less-developed regions (e.g., Githinji and Crane 2014). Impacts of projected climate changes are expected to indirectly affect human health through the three pillars of food security—availability, access, and utilization of food (Vermeulen et al. 2012), availability and access to clean freshwater (Vörösmarty et al. 2000; Watkins et al. 2006), and safety (e.g., conflict, migration) (Gleick 2014; McMichael et al. 2012).

Similarly, empirical studies examine the intersection of livelihoods (the resources and assets available to allow people to live their lives), vulnerability, and health. For example, there is growing evidence that climate stressors not only can offset quality-of-life gains (e.g., financial, educational, and health resources) but can also slow down future development (Tol 2008; World Bank 2010). In the drought-ravaged Northeast Region of Brazil, Bedran-Martins et al. (2018) find that a lack of access to health is the primary reason that poor agricultural households perceive that they are ''worse off'' (i.e., they are less satisfied with their lives) despite experiencing a significant spike in their quality-of-life indicators. Few and Tran (2010), focusing on the relationship between livelihoods, climate variability, and change in Vietnam, point to a close relationship between health risks and poverty-driven vulnerability, and they demonstrate that addressing health issues for the poor may be more related to the protection of livelihood and assets than to more conventional preventive health actions. Beyond the more commonly assessed health risks linked to climate changes, Driscoll et al. (2016) find that injuries rise among Alaskan traditional communities during periods of unseasonable environmental conditions (Driscoll et al. 2016). Climate is also found to negatively affect two factors related to health in Africa: the ability of children to learn and their birth weight (Grace et al. 2015).

On the one hand, many of the articles focusing both on air- and waterborne diseases and climate focus on social determinants of health as they examine other factors that influence sensitivity and susceptibility to diseases, especially in less-developed regions. Not surprisingly, many of these scholars point out the close relationship between vulnerability, adaptation, and health (Githinji and Crane 2014; Woodward et al. 2011). On the other hand, some scholars looking at the relationships between climate, adaptation, and development have often included health variables when assessing vulnerability (Brooks et al. 2005; Bedran-Martins et al. 2018), and others have looked for cobenefits between adaptation, mitigation, and health (Balbus et al. 2014). Still others suggest specific frameworks to assess adaptation for health-related issues such as infectious diseases, mortality, and extreme heat (e.g., Declet-Barreto et al. 2016; Berisha et al. 2017; Ebi et al. 2013; Bélanger et al. 2015).

2) Climate and security

The term ''climate security'' encompasses broad notions at the intersection between climate impacts and the safety of both human and ecological systems that depend on them (Adger et al. 2014). Understanding the relationship between environmental change and safety and security is not new (Holdren 1991; Lonergan and Kavanagh 1991; Beck 1992). Socioenvironmental scholars have defined environmental security broadly as the need to minimize anthropogenic threats to the integrity of both social and ecological systems (Barnett 2001). Others have highlighted the security and spatial implications more directly by defining it as the ''relative public safety from environmental dangers caused by natural or human processes due to ignorance, accident, mismanagement or design and originating within or across national borders'' (The Millennium Project: http://107.22.164.43/millennium/es-2def.html).

In both of these conceptualizations, environmental security considers a wide range of socioenvironmental stressors that threaten both natural and human resources. These implications are made more complex because many of these natural resources cross national borders and their scarcity may lead to national security problems (Malone 2013), including conflict and war (Dellmuth et al. 2018). Dispute over resources can exacerbate and act as a threat multiplier for existing negative socioeconomic states such as poverty, stress migration, lack of democracy, food insecurity, gender inequality, and warfare, especially in less-developed communities and regions (Adger et al. 2014; Sanfo et al. 2017; Rowhani et al. 2011; King and Gulledge 2014; Ransan-Cooper et al. 2015). For example, conflict over transboundary water resources including placement of infrastructure, spatial and historical distribution of water, and the potential of climate events to further exacerbate water availability can worsen existing, and create new, conflicts and war (Gleick 2014; Salehyan and Hendrix 2014). In contrast, scarcity and unequal distribution of resources can act as a driver of collaboration and joint governance of resources (Priscoli and Wolf 2009; Böhmelt et al. 2014).

Moreover, the word ''security'' has been deployed both to mean a lack of resources and entitlements (as in ''human security'') and threats to national security (Adger et al. 2014). For example, the IPCC chapter focusing on human security defines at least three additional dimensions of human security—economic and livelihoods, cultural, and migration and mobility—besides armed conflict (Adger et al. 2014). Each of these meanings has generated a growing literature in its own right, although theoretical constructs and empirical analyses often conflate them (Barnett 2003; Smith et al. 2014). For example, on the one hand, analyses of climate security frequently consider livelihood capitals as direct or indirect drivers of security issues; on the other hand, studies of vulnerability factor safety and security as predictive variables (Brooks et al. 2005; Malone 2013). A growing literature is focusing on understanding potential relationships between security and adaptive capacity (Zografos et al. 2014; Lemos et al. 2016; Feitelson and Tubi 2017). Zografos et al. (2014) argue for three main sources of human insecurity: lack of democracy, adaptations with adverse effects, and structural violence often related to economic growth and state development. Lemos et al. (2016) suggest that adaptive capacity and water security are intrinsically linked and thinking of them together in terms of policy can lead both to the creation of opportunities and better risk management.

Specifically referring to climate-related threats, scholars have focused both on 1) how climate impacts may affect resources vital for safety and security (e.g., water, food, shelter) (Linke et al. 2015; Raleigh et al. 2015) and 2) how an increase in temperature, precipitation, and extreme events (e.g., drought, flooding, and heatwaves) may affect people's safety and potential for violence (Hsiang and Burke 2014). For example, Butke and Sheridan (2010) find a positive relationship between weather and violent crime in Ohio. In a review of 50 articles focusing on quantitative analysis of the relationship between violent conflict and social–political stability and climatological variables, Hsiang and Burke (2014) find both a causal association between the two worldwide and that the literature is currently unable to decisively exclude any proposed pathway. However, historical reconstruction of climatic change and conflict have found exactly the opposite, with conflict increasing in colder rather than in warmer climates (Zhang et al. 2006; Tol and Wagner 2010). Yet other reviews systematically question these associations, finding rather that socioeconomic and political factors serve as the primary explanatory variables (Wischnath and Buhaug 2014).

3) Challenges in climate and weather security research

The contested nature of this deep division in the literature is partially explained by what scholars believe to be robust evidence from both sides—that is, whether there is causal correlation between conflict and climatic change—and by what many fear could lead to dangerous outcomes and maladaptation as policy prescriptions run ahead of current available evidence (Barnett 2009; Theisen et al. 2013; Adams et al. 2018). In the same vein, Dewulf (2013) calls attention to how different frames in policy making can lead to questionable outcomes. For example, framing climate adaptation in terms of security may have implications in terms of scale and response when the ''securitization'' of climate by different governments is used to support different political agendas (Dewulf 2013). In Turkey, so-called adaptation policies have been in actuality biopolitical interventions to secure the uninterrupted circulation of commodities and workers rather than to reduce root causes of vulnerability (Turhan et al. 2015). In the academic and political circles of China, the debate around climate and energy has increasingly been linked to security (Nyman and Zeng 2016).

Many other scholars have questioned these associations not only conceptually (e.g., lack of theorization and simplification of complex processes at play) but also methodologically (e.g., sample selection and research design). Methodologically, the past few years have seen a rapid proliferation of articles focusing specifically on research design and methods of climate security studies, in part because of its equity and ethical implications, and in part because of the lack of consistency across findings (Buhaug 2015; Ide 2017; Nordkvelle et al. 2017; Adams et al. 2018). In a thorough review of these methodologies published in 2017, Feitelson and Tubi (2017) identify large-*N* statistical analyses and qualitative case studies as the most used approaches in the field. They also evaluate four emerging approaches: 1) integration of statistical techniques and qualitative case studies, 2) field experiment, 3) risk analysis based on geographical information systems, and 4) qualitative comparative analysis. The authors advocate for pluralism of approaches to gain a deeper understanding of the relationship between climatic change and conflict. Buhaug (2015) lists five main challenges, especially related to the lack of theoretical thinking in the field: 1) specifying relevant climatic conditions, 2) specifying causal mechanisms and context, 3) specifying actors and agency, 4) specifying social outcome, and 5) justifying the spatiotemporal domain.

Perhaps the most prominent problem emerging from this literature is that of sample selection (Oh and Reuveny 2010; Buhaug 2015; Adams et al. 2018). A recent published review (Adams et al. 2018) focusing specifically on the issue of sampling confirms many of the early criticisms by systematically evaluating sampling across many studies. They find that there is indeed a problem of the ''streetlight effect'' in existing research (i.e., sampling biases as a function of convenience in accessing data) and that studies focusing on a small number of cases often select them on the basis of the presence of conflict while failing to sample the independent variable (climate impact or risk). Interestingly, they highlight the inability of this literature to explain peaceful outcomes.

Moreover, scholars warn of a disconnect between the policy analysis of climate security based on climate projections and input from the social sciences and call for integration in a more systemic approach (Lewis and Lenton 2015). Early on, Liverman (2009) cautioned against climate determinism and the lack of complexity in these analyses, and instead advised a more productive focus on sustainable futures. Similarly, Gemenne et al. (2014) argue that many analyses overemphasize deterministic mechanisms, despite the high level of complexity involved. They also recommend more and better input from the social sciences to understand and theorize causes and consequences and the use of established social science theory (e.g., asymmetrical power relations) to inform research.

Hence, not surprisingly, the science of climate security remains a challenge not only in terms of understanding drivers and causal relationships (Buhaug 2015; Adams et al. 2018), understanding feedbacks, and anticipating tipping points but also in terms of creating actionable knowledge that informs governments and other decision-makers. Other challenges include questions related to how to prevent and mitigate climatic stressors and impacts in a systemic and coupled way across social and ecological systems that takes into consideration 1) present lack of capacities and capitals that can be mobilized to manage risk (e.g., income, education, safety, technology, inequality, access to health and clean water, access to knowledge and power, and access to land), 2) present and future threats (e.g., climate change impacts, resource scarcity and pollution, spread of disease, land and water grabbing, political instability, and political and religious conflict), and 3) the potential for climate security research to identify opportunities for socioenvironmental sustainability and perhaps even transformation in the context of socioenvironmental change.

4. Conclusions

The role of the social sciences in explaining and contributing to solutions of weather- and climate-related problems is well established. On the one hand, the rapid evolution of a robust theoretically and empirically rich literature focusing on hazards, weather, and climatic impact and how to avoid, respond, and adapt to them is a testament to the importance of the many social sciences disciplines in tackling the challenge of addressing climatic impact. On the other hand, the emergence of new fields of study and the rapid revolution of interdisciplinary and transdisciplinary approaches to understand and address climatic change speaks to how much further we need to go to accomplish these goals. There are many areas within this vast scope that need more research and empirical evidence, but perhaps the grandest challenge for all sciences of climate and weather—but especially for the social sciences—is to increase their relevance to decision-making and policy making. After 100 years of the physical and social science of weather and climate, the grand challenge is still to make it usable and used.

Within AMS, the social sciences have been a recent addition but have quickly expanded. Yet overall the relatively small contribution of the social sciences to AMS in terms of publications and influence remains a challenge. As AMS enters into its second century, social science has come along with it farther than ever before, but there is still room for social science to be integrated further within AMS to meet the challenges of the twenty-first century.

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