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INTRODUCTION

Introduction: Critical and historical perspectives on usable climate science

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The quest for "usable science" is shaping a new era of research into climate impacts and strategies of adaptation. Since roughly 2012, major international scientific research and assessment programs like the IPCC and Future Earth have begun to insist on the necessity of incorporating the knowledge, experience, and values of "users," "stakeholders," and indigenous communities into the process of producing knowledge about the impacts of anthropogenic climate change. On smaller scales as well, for instance in the provision of regional "climate services," efforts are multiplying to bridge the "usability gap" by making science more responsive to the needs of citizens. The descriptor "usable" has been applied to climate research conducted under the banners of "postnormal science," "citizen science," "sustainability science," and "community-based participatory research." It is often associated with research programs tailored to users' needs, such as climate services, or attribution studies designed for legal applications. These initiatives tend to be self-consciously interdisciplinary between the natural and social sciences, but they have been less engaged with the humanities and with activists outside the academy. While there is much to admire about these initiatives, they raise pressing questions about epistemic standards, scientific ethics, and social justice that have not been adequately examined and that would benefit from sustained, transdisciplinary analysis.

Scholars in the social sciences have observed that "usable science" does not yet have well-defined criteria for success, nor clear mechanisms of assessment (Gerlak et al. 2018; Vaughan and Dessai 2014). It seems self-evident that common modes of scientific assessment, based on consensus among experts, are insufficient for evaluating "usable" knowledge. Moreover, usable knowledge, virtually by definition, quickly becomes defunct, so assessment must be conducted at a new pace (Clark et al. 2016). How then should the "usability" of scientific knowledge be judged? By producers or users? According to product or process? How might process-based criteria like "diversity" and "iterativity" be judged in

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practice (Lemos and Morehouse 2005)? More generally, what kinds of critiques are appropriate for non-scientists to make of the practice of science (Douglas 2017)? Should users' values be allowed to influence choices between frameworks of analysis (Parker and Lusk 2019)? Should "usability" be the exclusive goal of these programs, or might they embrace other epistemic goals, such as reflexivity or understanding? Some of these scholars have also noted that these initiatives raise ethical questions. Have the circumstances of anthropogenic climate change and the political resistance to mitigation generated new responsibilities for scientists? Do scientists have a moral responsibility to produce usable knowledge? What are the consequences of taking up such work for a scientist's career path (Brugger et al. 2016)?

In recent years, many climate scientists have felt increasingly motivated to increase the relevance of their work to societal aims. The motivation can be internal or external (or both), and there are multiple ways of responding to it, including but not limited to the following: public communication and outreach of research; spending time outside science per se, such as working in government or the private sector, in order to learn how science is used (or not used) in those contexts; changing the balance of applied to basic research in one's portfolio; and integrating stakeholder engagement into the research process. Some of these activities are, to varying degrees, outside the definition of a traditional scientific career, at least as practiced in the USA in the years since World War II. Integrating them into one's career can be challenging, and the resulting need to prioritize raises broader questions about what the purpose of science is, why it is done the way it is currently done, and how it might be different. As scientists become more self-aware about these and similar questions, it is natural to turn to humanist colleagues within the academy who are already using their own disciplinary tools to study them.

This special issue reflects critically on the ideals and practices of use-oriented modes of climate change research, past and present. Together, its eleven articles stage a vital conversation across disciplines and sectors about the implications of global warming for the way science is conducted. The essays emerged from a pair of workshops convened at Yale University in February and November 2018 on "Usable Climate Science and the Uses of History." The workshops brought together scholars and activists from an unusual range of fields, including the earth and environmental sciences, history, philosophy, law, policy, and community organization. Participants brought to these workshops quite different points of view and motivations. Among the academics, many of us had been asking ourselves some form of the question: what is the moral responsibility of the researcher in the face of climate change? Can scientists take up advocacy without jeopardizing their professional authority? Does new research have any chance of helping to forestall disaster? Some of us brought concerns about the utilitarianism implied by the goal of usability: where does it leave questions of justice? Some of us came with more pragmatic concerns about navigating the political impasse on mitigation or informing adaptation measures.

To be sure, no one took the position that socially engaged research is the *only* research worth pursuing. Among scientists, humanists, and practitioners, there was agreement that sheer curiosity is still a valid motivation for research — for its own sake, and perhaps also because it cannot be entirely disentangled from more worldly motivations. The linear model, which presumes that basic research informs applied research which in turn informs policy, is a flawed description of reality; it has also been a vector for a hierarchical view that devalues engagement with users. But science that is oriented towards specific ends still bears multiple close connections, in practice, to that which is not, even if the linear model fails to capture all those connections well.

Given both the high stakes for the planet and the deep investment of our participants in the subject matter, it's not surprising that there were moments of misunderstanding and disagreement. Some of those disagreements are captured in the essays that follow. Indeed, one conclusion of the workshop was that the quest for consensus may be a red herring. As the historian Andrew Stuhl put it: just as it takes fire to forge iron, the heat of disagreement may be a necessary precursor to social change.

Participants in these workshops pressed hard on the question of what constitutes *useful* information about climate change. Are short-term predictions more useful than long-term? Local studies more useful than regional ones? Can interpretive knowledge be as useful as predictions? Or does utility depend less on the type of information than on the means by which it circulates? Our participants articulated a range of different ideas about the mechanisms by which science can influence the world. While a narrow interpretation of usability implies working closely with specific users, more diffuse, indirect paths are possible, such as by influencing public opinion through the media, or developing tools or data sets that benefit broad classes of users. Again and again, we came up against the gaps in existing data sets, agreeing on the need to build capacity for data that serves the needs of disadvantaged communities. To do so requires a mode of collaborative research for which today's scientists are not trained. Teona Williams, an environmental organizer and scholar of African-American history, described how her work with community members in Flint, Michigan, had taught her "to listen." Echoing others who suggested that climate studies might learn from religious studies, Teona proposed that we think of such communication as a form of "ritual," conveying meaning beyond its verbal content. In this respect, she reminded us that the history of colonialist and racist science weighs heavily on efforts at outreach today. This history was also at the center of the keynote speech delivered by the Indigenous STS scholar Candis Callison (subsequently published as Callison 2020).

We also struggled with questions about how to evaluate usable science. Should the usability of information be judged by the frequency with which it is cited? By the range of communities it is designed to serve? By its potential to further the goals of its intended users? Wendy Parker, a philosopher of science, proposed that "fitness for purpose" would be a more appropriate goal than usability, since it aims not simply at use but *successful* use. Yet she joined others in worrying that this too could mean blindly subordinating the scientist's values and goals to those of the intended users. In the pursuit of usable science, how should the potential ethical consequences of its applications be weighed?

Repeatedly, conversation returned to the obstacles to building a career around usable science. Graduate students in the sciences asked for career advice. What choices should a young scientist make if they wish their work to contribute to the public good? How can their mentors and institutions support them in this goal? These questions deserve much more time and attention than we could give them. What is clear is that most scientific institutions presently disincentivize engagement with users more than they incentivize it, and that it will take more than changes in stated intent to change this reality. Some called for new criteria for promotion at universities, while others emphasized the need to build new communities of practice and to train more people in the skills of facilitating participatory research. These proposals are arguably radical, to the extent that we imagine them changing the fundamental incentives embedded in current practices by which scientists are trained, hired, and rewarded. If implemented seriously, they involve bringing the voices of users — almost by definition, people and groups outside universities — into processes that universities have historically struggled to keep internal and confidential.

One of the most powerful voices in these workshops belonged to Lisa Goddard. Tragically, Lisa died in January 2022, at the age of 55. We dedicate this issue to her memory.

As the director of the International Research Institute for Climate & Society from 2012 to 2020, Lisa partnered with a wide range of scientists and policy-makers in the Global South to improve seasonal climate forecasting for agriculture, hydrology, and public health. In this capacity, Lisa thought deeply about goals of justice. Throughout our discussions, she stressed the need to equip poorer countries to produce their own climate data. "Until those populations have control over their own information," she argued during one of our panels, "they are not going to have any control over their agency in international decisions." In her position paper for the conference, she called on universities to support climate researchers who address the needs of the public sector and corporations. "As universities figure out how to embrace the multi-disciplinary world of real problems, I predict that in 5–10 years the universities and other research institutions will actively seek to hire these 'professors of practice.'" Lisa's career exemplifies the value of engaged, accountable research.

Overall, our discussions emphasized the gap between data and narrative, between information and understanding, and between intention and outcome. If a single phrase can encapsulate the lessons of the workshop, it would be the refrain, "usable for whom"? Participants urged everyone to make this question explicit in discussions of usable science. If researchers aren't asking *who* will use the research and *how*, their work is all too likely to reinforce existing social hierarchies.

The title of this issue is "Critical and Historical Perspectives on Usable Climate Science," but the "and" may be superfluous: we foreground critiques rooted in history. To paraphrase Candis Callison's keynote, the histories of colonialism and slavery "determine what and who is in crisis" today. When we talk about usable science, we are invoking a tradition of utilitarian thinking that dates back to the era of the slave trade. It's a tradition that has often been used to legitimate the brutal exploitation of those who are poor, disabled, or non-white. Sheila Jasanoff went so far as to question whether "usable" was a positive attribute at all. Not from the perspective of justice, she argued, since knowledge alone is incapable of producing social change. Beyond seeking new solutions, we need to consider how the problems have been defined. Thinking with history, we can see how scientific problems have been framed in ways that privilege the interests of dominant groups, and we can begin to imagine different framings, different questions.

The disciplinary affiliations of the authors of these essays are diverse, and approximately representative of those more broadly present in the workshops, including natural sciences, social sciences, humanities, journalism, and activism. The collection embodies sustained communication across disciplinary lines, reflecting the discussions at the workshops and going beyond them. Two of the essays (Lloyd and Shepherd, Shepherd and Lloyd) are collaborations between a philosopher and a climate scientist; one (Drake and Henderson 2022) is a collaboration between a climate scientist and a political scientist; and the entire project is a collaboration between us, a historian (Coen) and a climate scientist (Sobel). One of the essays (by Drake and Henderson, authors not present at the workshops) was written in response to another (by Sobel) after publication of the latter. All the essays were informed by each other, most directly because early drafts were circulated among the authors, but also because they grew out of the workshops. These exchanges have informed the essays beyond what can be indicated by explicit cross-citations. We encourage readers to read not only those essays that relate most directly to their own interests, but to continue on to others, so as to join the broader conversation we have tried to open here.

Productive discussions of usable climate science should start with a definition of what the phrase means. In "A brief history of usable climate science" (Coen 2021), Deborah Coen provides such a definition by analyzing the term's provenance and genealogy. She shows how "applied," "useful," and other similar qualifiers have, over several centuries of

use (primarily in Europe and North America), been prepended to the noun "science" in the context of a dichotomy between constraint and freedom. Constraint makes scientific knowledge useful by directing the scientist's effort towards problems of interest to users, while freedom — seen as a privilege to be bestowed on the best — allows scientists to follow their curiosity, leading to breakthroughs that could not have been visualized ahead of time. Coen argues that usable climate science, as practiced in the last half-century at the institutions where it has seen the most development, is best viewed not as lying on the constrained end of the applied-basic spectrum, but on an axis orthogonal to it. Considering the experiences of researchers at the International Research Institute for Climate and Society (IRI) at Columbia University in New York, and the International Institute for Applied Systems Analysis (IIASA) in Vienna, she argues that the ideal of usable climate science signals "an ethos of care and an acceptance of interdependence", conditions that "have nothing to do with either freedom or constraint." The challenges of doing such work can be substantial and include hostile national politics (e.g., in the USA) as well as institutional metrics of career success that favor individualism. Yet many individual scientists as well as scientific institutions now recognize that the climate crisis demands it; the question is to what extent they have the skills, relationships, or institutional structures in place to do it at scale.

Sheila Jasanoff, one of the founders of Science & Technology Studies, argues in "Knowledge for a just climate" (Jasanoff 2021) that the quest for "usable" science often fails to ask the key question: usable for whom and to what end? For instance, research on solar geoengineering might prove usable, but who gets to decide whether those uses are desirable? Jasanoff proposes a shift towards "climate research for social justice." What this entails, she argues, is coming to terms with what scholars in STS call "co-production," a usage that differs from the way the term is more commonly used in climate science today (to designate collaboration between scientific experts and other groups). In precirculated materials for the workshop, Jasanoff defined co-production as "the proposition that knowledge and norms, or science and social order, are jointly produced through simultaneous acts of knowing the world and legitimating actions within it." Only by redirecting attention to this fundamental relationship between knowledge and power can climate research genuinely pursue the goal of justice, she argues. This entails, for instance, studying how dominant science has been perceived by non-dominant populations and the dynamics that build or corrode trust in science. It means introducing "critical, interpretive" methods into a field of inquiry that has long privileged prediction, quantification, and consensus.

While social scientists like Jasanoff have developed such complex theories of the science-policy relationship, the atmospheric physicist Adam Sobel argues (Sobel 2021, "Usable climate science is adaptation science") that most physical climate scientists cling, at least implicitly, to the belief that good science inevitably leads to good policy. This is evident, he shows, in the claims they make for the "usefulness" of their research. Given the political obstacles to cutting greenhouse gas emissions, he sees little chance that reducing the uncertainty of predictions of global-scale trends will have any significant influence on policy-making. Sobel accuses his fellow physical scientists of willful naivete on this count. He urges scientists to be more honest with themselves about how exactly they intend their research to be socially relevant, to make explicit their "theory of change." He considers the options they have if they genuinely want to make a difference, ranging from research on the local scale, oriented towards climate adaptation, to a pivot to activism.

In "A defense of usable climate mitigation science: how science can contribute to social movements," Henri Drake and Geoffrey Henderson (Drake and Henderson 2022) take up Sobel's challenge to physical scientists. Drawing on Drake's expertise in physical

oceanography and Henderson's in political science, they argue that there remains a sense in which global-scale research can indeed be usable: not via direct translation of science into policy, but rather by galvanizing popular movements, which in turn can drive policy change. Like Shepherd and Lloyd (2021), they see global-scale research as limited by a lack of meaningfulness, namely its failure to address the question of responsibility for warming. By pinning blame for climate change squarely on the largest emitters, global-scale research has the potential to become usable. Their examples include the calculation of the amount of carbon that the world can consume without overshooting the 1.5-degree temperature rise, as well as extreme event attribution studies, which could potentially hold emitters liable for damages. They show how these innovations have inspired activism, and they offer suggestions to climate scientists for producing more usable science in the future.

Candis Callison approaches questions about useful knowledge and justice from the perspective of an Indigenous scholar and former journalist in "Refusing more empire: utility, colonialism, and Indigenous knowing" (2021). She critiques the utilitarian orientation characteristic of much scientific engagement with Indigenous climate knowledge, as well as the assumptions about what constitutes "useful" knowledge among journalists. These use-oriented enterprises, often framed as responses to the climate "crisis," fail to recognize, first, that that Indigenous populations have lived in a prolonged state of crisis since the onset of settler colonialism and, second, that climate change is a continuation of the same historical dynamics that robbed Indigenous peoples of their ancestral lands. Moreover, the modalities of "useful" knowledge, such as a drive towards centralization and standardization, have often been used to bolster colonialism and silence its critics. Utilitarian frameworks are inadequate to address Indigenous knowledge as a way of life and a spiritual orientation.

Jo Guldi (2021, "What kind of information does the era of climate change require?") also addresses anti-colonial modalities of knowledge production, drawing on her research as a historian of infrastructure. Guldi thinks the problem lies not in the translation of science into policy, but rather in the data on which science relies. Climate justice, she argues, depends on empowering the disadvantaged to produce their own data. To inform that goal, she reflects on the history of efforts to facilitate the participation of local communities in data-driven decision-making, which have taken forms such as popular epidemiology and participatory mapping. She concludes by calling for an international network to coordinate local participatory research on climate change. Crucial to that enterprise, she argues, would be an ethical code, including guidelines for crediting the embodied knowledge of the most vulnerable and compensating participants for their labor. Equally essential would be the creation of an international institution with the power to regulate industry on the basis of the data collected.

Liz Barry's "Community science and the design of climate governance" (2022) is about a recent incarnation of this tradition of participatory research, namely "community science." Barry, a co-founder of the non-profit organization Public Lab, defines community science in terms of its twin principles of procedural justice and epistemic justice. She traces its origin to the failures of regulatory science, which have motivated non-experts to take the production of data into their own hands. Her essay reflects on her experience as a "facilitator" of participatory research, specifically on a case of mobilization around a polluted waterway in New York City, and she discerns lessons for those who aspire to produce "usable climate science." What would it mean, she asks, to democratize climate science? As she says, "participation is expensive" and hard to "scale up." Success in these respects will depend on the contributions of facilitators, who can "lower the cost" for participants and build networks "across scales."

Instead of co-production of knowledge with specific users identified ahead of time, "Meaningful Climate Science" by Ted Shepherd and Lisa Lloyd (2021) focuses "on how climate information can be *packaged for travel*" to potential users who are unknown at the time the information is generated. Specifically, they argue that the "storyline" approach gives climate science meaning, and that meaning confers usability. They define a "physical climate storyline" as "a physically self-consistent unfolding of a past event, described in terms of causal elements," as opposed to the probability-based approaches common in climate science overall, and extreme event attribution specifically. In the storyline approach, one does not ask whether human influence made an event more or less probable (and the approach is often applied to events for which that question cannot be clearly answered) but rather, given that it did occur, how the human influence may have changed its properties or consequences. A storyline embraces what makes an event unique, rather than its membership in a class to which probabilistic methods can be applied. Shepherd and Lloyd's examples illustrate how a storyline can create meaning — and, one hopes, provide a basis for action — even when uncertainties are large and (as is almost inevitably the case in real events) climate change is but one of many relevant causal factors. They consider the relationships between storylines and related concepts: "narratives," "scenarios" (a term at the core of reports by the Intergovernmental Panel on Climate Change), "boundary objects," and "data journeys." The latter two terms describe, in different contexts, things that allow information and meaning to cross disciplinary boundaries. They explain why "climate storylines are not simply *stories*," but are truly scientific, because they consider "alternative explanations and plausible counterfactuals". Here the goal of usability, and the choice of narrative as its vector, influences not just the choice of research questions, but the construction of the methodology itself. The influence of humanistic thought on scientific practice is perhaps more evident here than anywhere else in climate science, and the potential for further cross-disciplinary collaboration to make climate science meaningful is large.

In "Climate change attribution and legal contexts: evidence and the role of storylines," Lisa Lloyd and Ted Shepherd (2021) make the case for the usability of storylines more concrete in a specific context, namely the courtroom. While tort cases seeking to establish liability for climate-related harm due to greenhouse gas emissions have not been widely successful yet, we can expect more of them in future, and what kinds of scientific arguments are permitted in such cases is a question of potentially enormous consequence. Using the recent case of *Juliana vs. the United States* for illustration, Lloyd and Shepherd refute the argument that storylines are unscientific or illogical in this context, instead showing that their underlying logic is the same as that used in other kinds of tort cases, as well as having a solid basis in climate science. It seems clear that any science that influences a legal outcome should be considered usable; this raises an interesting question, however, about whether usability need arise out of direct collaboration with users. While a storyline attribution study could be done in support of a specific case (and might be more effective if so), an attribution study done for other reasons could presumably still serve as evidence if it addressed the event at legal issue.

In "Making the climate crisis personal through a focus on human health," Vijay Limaye (2021) makes the case for science that makes concrete the impacts of climate change on human health. He emphasizes the enhancement of advocacy — by influencing public opinion — as a mechanism of usability. Given this mechanism, science is usable to the extent that it increases understanding of and concern about the various health ramifications, direct and indirect, of global warming. Here again the question of scale is paramount, as many health impacts manifest most clearly at regional and local spatial scales; thus Limaye advocates interactive mapping that allows individuals to explore exposure to climate-related

health risks at these scales. The time scale, too, is a factor; Limaye argues that the most prominent scientific assessment reports, namely IPCC reports and US National Climate Assessments, are too infrequent, and too focused on century-scale trends as well as too global in spatial scale, to be as effective as they might be, and that more frequent and more local syntheses could be more compelling. He also argues that framing health impacts in economic terms "makes clear the financial benefits of climate response policies that reduce adverse (and sometimes irreversible) health impacts and costly medical care in hospitals and emergency rooms," and helps justify investment in such policies.

In "Land-grant lessons for Anthropocene universities," Robert Kopp (2021) argues that land-grant universities in the USA offer a historical model for usable science in the current era of climate change and biodiversity loss. While acknowledging that the history of these universities is problematic, as "the land-grant system has supported settler colonialism and racist hierarchies" in a variety of ways, their agricultural experiment stations and cooperative extension services have brought academics and stakeholders together in the kind of sustained, democratizing engagement that the most usable science requires, to genuine public benefit. Kopp emphasizes the multiple spatial and time scales accessible to these organizations, and particularly the ability of universities to take the long view — due to tenure, academic freedom, and their educational mission — that is disincentivized in both the private sector and government, but that is essential in the Anthropocene. Yet he points out that even so, short-term pressures within universities themselves can make it difficult to build the kind of sustained relationships, particularly with marginalized communities, that usable science in the public interest requires. Cooperative extension services situate those relationships in the institution as a whole, rather than solely in individual sponsored projects or principal investigators, allowing trust and understanding to build over longer times.

Collectively, these essays address the questions of who benefits from science and how science influences action. For scientists and their partners — users, stakeholders, colleagues, communities — there are multiple paths, multiple processes by which to pursue the goals that, despite our disagreements, our group of authors shares: effective, just, democratic, and equitable mitigation of and adaptation to climate change. The essential ingredients are research defined by clear intention-setting to support these goals; a dose of realism, informed by history and evidence, regarding the mechanisms by which it will do so; and engagement with those to whom the outcomes matter. Good intentions notwithstanding, these ingredients are by no means universally present in the climate science of today, let alone the larger world in which climate change is debated. We hope this collection contributes usefully (usably?) to moving them to the center of the conversation.

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