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PERSPECTIVE

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Usability of climate information: Toward a new scientific framework

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Abstract

Climate science is expected to provide usable information to policy-makers, to support the resolution of climate change. The complex, multiply connected nature of climate change as a social problem is reviewed and contrasted with current modular and discipline-bounded approaches in climate science. We argue that climate science retains much of its initial "physics-first" orientation, and that it adheres to a problematic notion of objectivity as freedom from value judgments. Together, these undermine its ability to provide usable information. We develop the notion of usability using work from the literature on adaptation, but our argument applies to all of climate science. We illustrate the tension between usability and the objective, physics-first orientation of climate science with an example about model development practices in climate science. For solutions, we draw on two frameworks for science which responds to societal challenges: post-normal science and mandated science. We generate five recommendations for adapting the practice of climate science, to produce more usable information and thereby respond more directly to the social challenge of climate change. These are: (1) integrated cross-disciplinarity, (2) wider involvement of stakeholders throughout the lifecycle of a climate study, (3) a new framing of the role of values in climate science, (4) new approaches to uncertainty management, and (5) new approaches to uncertainty communication.

This article is categorized under:
Climate Models and Modeling > Knowledge Generation with Models
The Social Status of Climate Change Knowledge > Sociology/Anthropology of Climate Knowledge
Perceptions, Behavior, and Communication of Climate Change > Communication

KEYWORDS
adaptation, mandated science, post-normal science, scientific objectivity, usability of climate information

1 | INTRODUCTION

All science is expected to deliver usable information to society. While pure research and the resulting advance of knowledge are intrinsically valuable, climate science rightly faces a demand for more direct and immediate return on investment. The risks posed by climate change create a moral imperative to respond, and in our societal distribution of labor, climate scientists are designated to help us navigate this possibly existential threat. Despite this, there is a usability gap between the kinds of outputs climate science typically provides and what users really need, a problem which has been discussed extensively for climate change adaptation (Hewitt et al., 2017; Lemos et al., 2012; Nissan et al., 2019; Porter & Dessai, 2017; Raaphorst et al., 2020). The usability gap is both an epistemic and ethical issue. There is an increased level of uncertainty associated with local projections, the scale on which adaptation efforts typically occur. Furthermore, the predominantly physics-based perspective falls short in providing environmental and ecosystem impact studies with desired data, for example, agricultural factors (e.g., drought indices) or biological and health factors (e.g., wet bulb temperature), as they do not derive directly from the physical laws employed in climate models. There is a wide range of needs and values to satisfy, coming from impact researchers, policy-makers, engineers, or citizens. The usability gap is ethical insofar as, often, the available climate models better represent the geographical regions prioritized by their designers, and therefore the most vulnerable populations are often the least informed by those models, thus increasing climate injustice. Yet climate impacts occur in ways that increase already existing social inequalities and injustices.

We take usability to be crucial for all of today's climate science, understood widely. In this perspective, we argue that the current methodology of climate science and its conception of objectivity are (in part) responsible for the usability gap. We contend that this science requires a methodological shift away from its "physics-first" orientation and toward one of usability-centered science-for-policy. This orientation, defined below, is most prevalent in the science of the "physical climate" or, in the IPCC's phrase, in the "physical science basis" of climate change, but it permeates climate science including contributions to all working groups. Our argument is about climate science as it exists now, in a context where climate change is a pressing global policy issue—a future science of the climate will (hopefully) face different demands.

2 | A "PHYSICS-FIRST" ORIENTATION

Early conceptions of the climate system tended to locate the physical climate at the heart of the modeling process (Heymann & Achermann, 2018), and climate models were first developed using atmospheric physics, fluid mechanics, and non-linear dynamics (Edwards, 2010). Climate science's "physics-first" orientation refers to a set of cultural attitudes and presumptions within the field about the relative priority and centrality of physical science approaches to studying the climate and in particular climate change. These attitudes guide the allocation of research funding (Overland & Sovacool, 2020), and so shape the study of the climate.

We call this an "initial" orientation since climate science has begun to incorporate the life sciences more thoughtfully and there is increasing focus on broader Earth system models rather than global circulation models. That said, climate science still poorly integrates environmental, ecosystemic and socioeconomic dimensions of climate change (Beckage et al., 2020), thus failing to address various concerns related to social justice, public health, environmental safety, biodiversity, and economic growth. The coupling and interactions between the physical climate and the biosphere, including human activities, would be required—in line with the project of Earth System Science—to trace how, for instance, social inequalities evolve with climate change, how biodiversity is affected or, in turn, how the redistribution of ecosystems and animals can impact the physical conditions of the climate.

3 | CHANGING THE ORIENTATION

Confronting the multi-dimensional challenge of climate change requires a change in this orientation. While astrophysics or particle physics could be idealized as independent and autonomous sciences, pursuing their own ends, climate science today is at the service of society—more akin to epidemiology or nuclear physics. We claim that this requires a shift, both in climate science's methodological norms and in how it manages values.

3.1 | Modular, mono-disciplinary science

Mono-disciplinary or modular studies are ill suited to the study of climate change. The climate change problem has multiple dimensions which cross-disciplinary boundaries. The study of the physics of the climate is valuable and necessary but insufficient to support climate change policy-making. To take a mitigation example, understanding and intervening on the emissions-to-greenhouse effect causal pathway requires that we understand not just the physical science of the net warming effect of greenhouse gases, but the sources of emissions, the societal pressures for those emitting activities, the political ramifications of reducing emissions, and the justice considerations of distributing the burdens associated therewith. A modular approach to science-for-policy, in which researchers act relatively independently within disciplinary boundaries, fails to capture the nature of the problem.[1] The human society-global ecology-climate system is interconnected, with multiple feedbacks. Climate scientists acknowledge this and recent Earth system modeling attempts to incorporate more of these interactions, but much remains to be done in terms of societal feedbacks especially.

3.2 | Methodological norms

There is growing acknowledgement of a difference between what climate scientists consider to be “good climate information” and what really makes for “usable climate information.” As an example, consider model development. Currently, this development is based on norms that are standard in physics. Models focus on the physical climate: the atmosphere, oceans, ice sheets, and landmasses. Scientists often work from the global level and seek general explanations. There is a strong emphasis on creating more accurate and more complex models: parameterizations are replaced by explicit theoretical equations; previously omitted processes are represented; resolution increases. The aim is to provide more fine-grained and precise predictions. (For an example which explicitly articulates and reinforces these goals, see Slingo et al., 2022.) Uncertainty is investigated, managed, and communicated with an eye to these goals. In addition, engagement with policy is often linear: the modeling is done first, in isolation, and its results are then passed on to policy-makers. However, these inherited norms of physical science are partly responsible for the usability gap.

One striking illustration is the production of probabilities for policy-makers. Policy decision-makers desire probabilistic projections to support their planning and look to climate model results for the relevant information. But the physics-first orientation, focus on model accuracy, and positive value on increased complexity lead to a plurality of competing models: a “collection of best guesses” (Parker, 2013). In practice, the available probabilities are based on the collection of models which happen to have been built, and their soundness is therefore undermined by the ensemble not being a genuine statistical sample of climate possibilities (Parker, 2018; Tebaldi & Knutti, 2007). The sequence of steps which leads to this situation is perfectly sensible from the perspective of the individual climate modeler, but the result is a mismatch between the information produced and the needs of the user. Similar concerns have been raised about climate science's global and general focus: the effects of climate change are felt locally, and policy-makers have at most regional authority (Shepherd & Sobel, 2020). But, for current modeling practice based on “physics-first” logic, the local is last in line and associated with the greatest uncertainty. As a result, model-based climate information often poorly fits the needs of policy-makers.

At the core of the physics-first orientation of climate science is a set of methodological norms which are not suited to tackling climate change. Model development and probabilities from model ensembles are but two examples where there is a mismatch between output and user needs, arising from the sensible application of these physical science norms.

3.3 | Objectivity and freedom from values

Physical science is traditionally conceived of as an impartial, neutral, and autonomous epistemic enterprise (Lacey, 1999). These are elements of the stereotype of the objectivity of science. It is *impartial* in that scientific practice takes place with reference only to epistemic values (such as improving accuracy, and in contrast with “non-epistemic” values like pursuing justice.) It is *neutral* in that scientific results make no value statements (e.g., about what society ought to do). It is *autonomous* in that science's sole goal is to increase knowledge; values do not determine the research agenda. However, operating impartially, neutrally, and autonomously is in tension with producing knowledge that is usable.

Stakeholder values play a central role in defining the attributes of usable information. Three attributes are often discussed: usable information must be simultaneously (and sufficiently) credible, salient and legitimate (e.g., Cash et al., 2002). It must also be timely (Lemos et al., 2012, pp. 789–790). "*Credible*" has historically referred to information that is authoritative, believable, and trusted. User perceptions of credibility are complex, including multiple and sometimes competing factors such as scientific rigor, independence, and according with or incorporating users' background knowledge and experience (Cash et al., 2003). Information is *salient* when it is relevant to the users and their decisions, and it is *legitimate* if it is perceived to have been produced by a process which was unbiased and which respected stakeholder values. *Timely* information is supplied at a point in time when it can play an important role in decision-making; an example of a failure on this front might include an assessment like the US National Acid Precipitation Assessment Program, whose report took 11 years to produce and came a year after the 1990 Clean Air Act Amendments (Oppenheimer et al., 2019).

The tension between objectivity, in the sense just described, and the production of usable information is clear. Salience requires tailoring studies, and the information they produce, to users' interests and the specific problems they face, which often requires deep engagement and understanding. This conflicts with autonomy, in the sense that it introduces practical problem-solving goals into the scientific process. This need not be a problem, as autonomy is perhaps the least compelling aspect of scientific objectivity—it is widely acknowledged that research agendas are set by goals other than the pursuit of pure knowledge; goals that are set or interpreted by funding agencies, political agendas, and industry interests. However, usability requires engaging with and taking direction from different groups: policy-makers, community interest groups, and climate service users more broadly.

Legitimacy is more challenging to secure. It requires demonstrating that information results from an unbiased process, and yet is sensitive to and perhaps framed by user values. This may conflict with both impartiality and neutrality, as it requires scientists to take into consideration the desires, values, and political realities of the communities whose problems they investigate. Whether this is detrimental to the traditional scientific project of producing knowledge and understanding of the natural world is a separate question (cf. Douglas, 2009, 2021). Philosophers of science have argued that objectivity as it traditionally framed is an inefficient mechanism for the pursuit of such goals and that norms of objectivity in fact obscure bias.[2] In addition, some apparent conflict between legitimacy and objectivity is superficial; for example, calls for more scientists and perspectives from the Global South can be seen as attempts to remove bias (toward a Global North default), rather than to introduce it.

Credibility likewise involves more than the production of "authoritative" information, which is often associated with centralized production by groups of global elites. For example, the local nature of the adaptation challenge implies that the relevant stakeholders and users are diverse local groups, and so credible information results from relations of trust, collaboration, and co-creation with them. This would be better served by a "bottom-up," decentralized approach to climate science (Guldi, 2021; Rodrigues & Shepherd, 2022).

Physical science's "value-free ideal" can hamper the production of usable science-for-policy, as it conflicts with producing science that is salient, legitimate, and timely. While norms targeting objectivity might be presumed to reinforce credibility, science designed with user needs in mind can in fact improve credibility.

4 | MOVING TO SCIENCE-FOR-POLICY

Climate scientists need not reinvent the wheel when it comes to adapting to a more policy-oriented practice. The science studies literature has distilled methodological lessons from different areas of societally-engaged science, which can be applied here. We propose drawing on two frameworks. The first is "post-normal science" (PNS), a framework for adapting science in response to urgent, high-stakes and contested societal problems (Funtowicz & Ravetz, 1993). The second is "mandated science" (MS), a framework for understanding science-for-policy, specifically regulatory science, and the changes it necessitates for scientists (Salter, 1988). We offer five suggestions: 4.1 concerns multi-disciplinarity (related to 3.1), 4.2–4.3 concern value management (related to 3.3), while points 4.4–4.5 concern changes of norms (related to 3.2). Some align with existing suggestions (e.g., Adams et al., 2015) but our view is both more expansive and more integrated. Drawing on MS in particular allows us to offer a clear vision of what a more usable climate science could look like (Boxes 1 and 2).

BOX 1 Post-normal science

Post-normal science is defined with respect to the kind of problem it responds to. Funtowicz and Ravetz (1993) considered situations in which decisions are urgent, stakes are high, values are contested, and uncertainties are deep and systematic. They claim that, for such issues, "straightforward research studies, and even professional consultancy, are incomplete, inadequate or inappropriate" (Funtowicz & Ravetz, 2020). Environmental issues were key examples of situations requiring post-normal science, and climate change is similarly an acknowledged example (Saloranta, 2001). Funtowicz and Ravetz made several suggestions for how science should adapt in such circumstances, centered on an "extended peer community." We discuss several of their suggestions in the text.

BOX 2 Mandated science

Mandated science is a term introduced by Salter (1988) to describe science which is produced, or assessed and interpreted, for the purposes of public policy. It is "mandated" in the sense that a governmental (or indeed intergovernmental) body has mandated scientists to provide input or recommendations for decisions that have a large scientific component (Levy, 2001). The core cases are regulatory science, such as the regulation of chemicals in industrial processes. Such regulatory processes involve corporate and political lobbying, and require the production of highly specific, usable, scientific information. Successfully producing mandated science requires different skills from academic research, related to engaging with the political and legal environments of regulation. This all leads to changes in the science, reflected in both its practice and its outputs. Climate science has not, to our knowledge, been discussed as a mandated science, but we see great value in learning from how mandated science succeeds.

4.1 | Integrated cross-disciplinarity

Both PNS and MS demand integrated, cross-disciplinary scientific work; in stark opposition with physics-first modular climate science. Urgent societal problems do not respect disciplinary boundaries, and the solutions to them require multiple disciplinary expertises. In MS, scientists work closely with policy-makers and with experts from other disciplines, to co-develop answers to entangled questions about safety or efficacy. Climate adaptation in particular requires this close cooperation and co-development between physical science, the life and environmental sciences, water and land management, climate engineering, and social scientific studies of the communities the adaptation targets. Much MS work involves assessing and reviewing existing science, identifying gaps, and commissioning or performing highly specific cross-disciplinary research to answer similarly specific policy questions. Participating in MS can therefore require relinquishing preconceptions about what counts as good or important research, and it often does not result in published products. Usable climate science might similarly fit poorly into present academic credit structures. The literature on MS can provide inspiration for the institutional adjustments required to incentivize and credit such work, for example, housing this work in prestigious government research agencies (Bach & Döhler, 2012). Disciplines with significant engagement in science-for-policy, such as chemical engineering, may serve as models for new norms to be adopted into climate science departments at universities.

4.2 | Wider involvement of stakeholders

The problems of climate change cannot be met by a model of scientific engagement in policy in which the science is held separate and functions as an isolated and objective source of information (Pielke, 2007). Both PNS and MS encourage the inclusion of outsiders to the scientific community, who participate directly in scientific problem-solving. This can take a variety of forms, including setting research priorities, defining problems, and specifying what counts as a solution. This requires more than lip-service stakeholder dialog. Instead, we must recognize that climate science is *for* policy, build-in the needs stakeholders from the beginning, and ensure that science occurs with them as opposed to being handed over to them.

MS offers a model which goes beyond most stakeholder-engagement proposals for climate services. It flips the order of priority: rather than having "stakeholders" participate in creating science, scientists become participants in a policy decision-making process. In Salter's regulatory cases this is a legal process and its norms of evidence, argument, and persuasion are a hybrid of scientific and legal norms. MS centers the needs of this process, and the science is custom-built to answer those needs. Such processes have well-defined and influential roles for certain stakeholders, such as governments, industry bodies, and trade unions. The role of laypeople is less clear, though Salter (1988, pp. 190–194) discusses instances of laypeople participating in studies, initiating regulatory reviews, and offering testimony. While our context is not that of legal regulation, climate science can usefully reframe its work in similar ways.

This need not undermine the scientific *quality* of climate science. Scientists working in regulatory environments have created credible and independent scientific bodies which nevertheless produce specific, actionable, and tailored information (Bijker et al., 2009; Jasanoff, 1990; Salter, 1988). Climate scientists who undertake to conduct our proposed kind of science-for-policy can learn from this experience—both via the cited literature on it and by engaging directly with successful MS participants.

4.3 | New framing of role of values

Disputes in MS cannot be neatly decomposed into a scientific truth-seeking component and a political justice-seeking component. Science-for-policy is characterized by mixed-disputes, where the definitions of key terms such as "harm" and the scope of whose harms will be measured plays a key role in the scientific formulation of, for example, a standard for hazardous chemicals. Climate science's post-normal characteristics similarly call for this: questions of values cannot be "settled" before the scientific work begins because, as PNS, climate science involves issues where values are highly contested and will need to be continuously negotiated among stakeholders. It is therefore not enough to identify sites in the scientific process where values play a role, for the purpose of transparency. There needs to be active and continuing engagement on how choices are made at various stages of a study, from research questions and definitions to model building and results analysis (cf. Parker & Lusk, 2019).

Existing proposals for the co-creation of climate information provide some ways to accomplish this, by building in consultations with users and marginalized communities, though public forums or deliberative groups of citizens. MS tackles this by embedding the scientist into a policy process, where such processes explicitly and legitimately incorporate stakeholder interests. These interests direct the work of mandated science, but it is nevertheless important to restrict their impact on scientific truth-seeking. Salter discusses how this is achieved in regulatory science, highlighting the importance of transparency (within a regulatory process, though not necessarily to those outside of the process) and contestation (in the form of legal disputation).

4.4 | Uncertainty management

PNS is science where uncertainties are severe and fundamental. This calls for broader and more comprehensive uncertainty management, covering not merely internal errors, but the scientists' confidence in their methods and explicit assessment of the quality of their evidential base. The default application of common statistical techniques should not be assumed to be a sufficient treatment of uncertainty. Regarding model ensembles, one alternative would be to construct models with the decision-makers' desire for informative probabilities in mind—and thus instead of aiming for "best guesses," designing models which span a more informative space of possibilities. This is an instance of our broader proposal: managing uncertainty with an eye to which uncertainties are relevant to users, especially policymakers. These considerations of user capabilities and needs should reach back right to the start of the scientific process, in the selection of methods and design of studies. Recently, a host of approaches have emerged which center policymakers in this way, including storylines (Shepherd, 2019; Shepherd et al., 2018) and the identification and use of climate analogues (Copernicus, 2022).

4.5 | Uncertainty communication

Funtowicz and Ravetz (1990) developed a system of communicating uncertainty, which reflects the need for PNS to tackle deep uncertainties. It emphasizes the need for expressing nuances such as qualitative judgments about the information being conveyed, and evaluations of the mode of production of this information and of its potential uses. To prevent this qualitative information being severed from the numerical information, they cast their system as a kind of notation which is packaged together. The IPCC's likelihood and confidence notation is an example of an effort in this direction, though it does not match the clarity or breadth called for by Funtowicz and Ravetz.

MS happens in policy environments where regulators and policy-makers are often untutored in understanding uncertainty and (sometimes deliberately) misinterpret typical scientific caveats as signs that the science itself is unreliable (Salter, 1988, pp. 7–8, 204–207). Scientists working in a regulatory environment learn to adapt their communication styles to its needs and strictures. This does not imply downplaying uncertainty for strategic ends, but rather developing an understanding of what information the decision-maker needs, and why, and communicating what is available effectively. This involves the development of new skills, and familiarization with new environments which operate under different discursive norms. The old world is not left behind, however: scientists who work in MS often need to manage two-sided communication, in which they engage simultaneously with their peer experts and with a critical non-expert audience. Climate scientists can balance these demands through close cooperation with policymakers: understanding the decisions being made allows for targeted investigation of uncertainty, and the tailoring of uncertainty communication.

5 | CONCLUSION

These considerations motivate for some radical changes in how climate science is organized, conducted, and communicated. At a high-level, climate science needs to be more interdisciplinary, in closer contact with local users and stakeholders, and adapted in its methods and focuses to the needs and values of those stakeholders.

How exactly that should happen will depend on the particular set of users and their needs. But in broad strokes, it must surely involve more thoroughgoing integration with biological and social sciences in order to confront the problem of climate change as people experience it. Similarly, considerations from both MS and PNS support the recent argument of Rodrigues and Shepherd (2022, p. 6), that “climate information should be produced by many people, spread around the world, rather than by a small number of experts.” This reflects the extended community that PNS calls for, and is necessary for the kind of embedded interdisciplinarity of scientists doing regulatory work in MS.

Stakeholder engagement and user involvement in science is a complex topic which we cannot hope to give justice to here (Skelton et al., 2017). Our conclusion is simply that scientists must engage with this topic and acknowledge that stakeholder engagement is not an esoteric nice-to-have, it is a core requirement of producing information that is actually usable.

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Julie Jebeile: Conceptualization (equal); methodology (equal); writing – original draft (equal). **Joe Roussos:** Conceptualization (equal); methodology (equal); writing – original draft (equal); writing – review and editing (lead).

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Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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ENDNOTES

[1] Mono-disciplinarity and modularity are of course not unique to physical climate science. Indeed, these tendencies can also hinder the success of environmental social sciences, for the same reasons.

[2] Regarding efficiency: Kitcher (1990) makes an efficiency-based argument for intervening in the scientific community to direct some research attention toward specific hypotheses, in a way which challenges the notion that autonomous, objectivity-directed community of scientists is best-suited to pursue truth. Regarding bias: feminist philosophers of science argue that traditional notions of objectivity hamper the scientific pursuit of knowledge. For example, Longino (1996) argues apparently knowledge-oriented values such as simplicity or breadth of scope in fact import social values into scientific judgment. See Reiss and Sprenger (2017) for a review of the philosophical discussion of scientific objectivity.

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