Enhancing the Usability of Climate Information and Models Through Stakeholder Engagement

Elizabeth Allen and Jennie C. Stephens

Abstract As the impacts of climate change intensify, environmental scientists and earth system modelers are rapidly advancing our understanding of the complex dynamics of climate change. Although large quantities of high-quality climate data and climate science information are now publicly available, the usability of this information to policy-makers and other nonacademic decision-makers is limited. It is widely recognized that novel approaches to increasing the usability of climate science information and enhancing its influence in decision-making are needed. This chapter reports on a regional climate change impacts modeling project called BioEarth funded by the United States Department of Agriculture (USDA) and based at Washington State University, which is attempting to bridge the gap climate science usability gap. We consider the lessons learned in the course of BioEarth's stakeholder engagement efforts and reflect on how those insights may contribute to other initiatives seeking to develop and communicate useable climate science information. Lessons from BioEarth may be applicable to USDA's recently established Regional Climate Hubs, which are envisioned as internet-based centers that will deliver climate change data and analyses to farmers, ranchers, and forest landowners. This research contributes to the emerging field of policy informatics by exploring mechanisms by which climate science data and models can become more usable to decision-makers.

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Introduction

As climate change is recognized as an inevitable and growing threat to food systems, water supply, infrastructure, and public health, governments around the world are faced with the challenge of how to harness information and models to prepare for impacts and reduce the multiple risks of climate change (IPCC 2014). The past two decades has seen a rapid rise in production of climate change science, yet it is well recognized that climate science information is underutilized in decision-making (Weaver et al. 2013). Acknowledgement of the need to overcome the so-called *climate science usability gap* (Lemos et al. 2012) has resulted in the development of an array of novel government-supported strategies for enhancing the relevance of climate science information and models (McNie 2007; Weaver et al. 2013).

The research presented here contributes to initiatives designed to support societal engagement with climate science by reviewing insights from academic researchers and nonacademic decision-making stakeholders participating in a climate modeling research project, BioEarth, based at Washington State University. BioEarth is a 5-year integrated earth system modeling project focusing on the Columbia River Basin in the Pacific Northwest with an explicit emphasis on engaging directly throughout the modeling process with regional policy-makers and other stakeholders who may be able to use model results to inform their decision-making (Adam et al. 2014). BioEarth can be viewed as a project that takes a bottom-up approach to producing useable climate science information relevant to the forestry and agriculture sectors in the Pacific Northwest. This project involves 18 principal investigators at multiple institutions who are working to integrate process-based models that provide detailed information on specific subsystems including land, air, water, and economics. BioEarth is one of multiple regional-scale earth system models (EaSMs) funded by the United States Department of Agriculture (USDA) to generate usable information for natural resource decision-makers. As such, the project is representative of the value that federal funding agencies increasingly place on integrated modeling approaches and explicit stakeholder engagement processes to ensure buy-in to enhance the salience, credibility, and legitimacy of model results.

In this chapter, we consider lessons learned from the BioEarth project as they relate to other initiatives seeking to provide useable climate science information to policy-makers and resource management decision-makers at the regional level. Specifically, the recently established Regional Climate Hubs are discussed as an example of a program that could benefit from incorporating findings from the BioEarth project related to communication and stakeholder engagement. USDA's Regional Climate Hubs are envisioned as entities that will collaboratively provide data, research findings, tools, and forecasts, i.e., integrated information for the agricultural and forestry sectors, with particular attention to meeting the needs of underserved populations, including rural communities and tribes (USDA 2014).

We juxtapose analysis of the BioEarth regional integrated modeling project with consideration of the newly established Regional Climate Hubs because both

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initiatives seek to operate within the emerging paradigm of enhanced communication and closer collaboration between climate scientists and professionals who make decisions on the basis of technical/scientific information and "useable" science. These two initiatives are dissimilar in their scope, breadth of the intended audience, and decision-making process through which they were envisioned, designed, and implemented, but they share the core objective of enhancing usability of climate science. The major distinction between these initiatives is that the BioEarth project was developed in response to a USDA National Institute for Food and Agriculture (NIFA) and National Science Foundation call for proposals (grant number 2011-67003-30346) for interdisciplinary integrated environmental modeling research, and the Regional Climate Hubs are an initiative explicitly seeking to improve information dissemination, which was called for by the executive branch of the US government as a component of President Obama's Global Climate Change Initiative. The stated goal of the Regional Climate Change Hubs is to "deliver tailored, science-based knowledge to farmers, ranchers, and forest landowners to help them understand and prepare for the impacts of climate change" (Whitehouse.gov 2014). In the case of BioEarth, the stakeholder engagement approach is one feature of the proposal that made it unique and attractive to the funding agency (the USDA), but the research project was primarily selected for funding based on the scientific strength of its goal to link hydrologic, atmospheric, and terrestrial models and assess system changes and feedbacks under future climatic and socioeconomic change.

Based on findings from communication and stakeholder engagement research conducted within the BioEarth project, this chapter presents lessons about effective practices and potential challenges for initiatives seeking to develop and provide useable climate science information to decision-makers. Given the daunting scale and complexity of climate science information, this exploration of initiatives designed to enhance the usability of climate science data and modeling is a novel contribution to the emerging field of policy informatics which includes research and practice focused on supporting policy decision-making based on data, scientific evidence and modeling, and creating, managing, and evaluating systems for policy development, analysis, and implementation (LaValle et al. 2013). Enhancing the usability of climate data is becoming a critical societal challenge, where policy informatics offers valuable insights.

The chapter begins with a review of the literature about interdisciplinary science as it relates to the goal of useable information for decision-makers, focusing on (1) characteristics of information and (2) characteristics of stakeholder engagement approaches that contribute to the production and use of decision-relevant scientific knowledge. The methods section details the process of collecting and analyzing information about the perceptions and information needs of the non-scientist stakeholders involved in the BioEarth project. Specific recommendations and insights from stakeholders are presented in the results section. The concluding discussion considers lessons learned during BioEarth's stakeholder engagement efforts as they may inform and contribute to the implementation of Regional Climate Hubs and other initiatives that seek to engage decision-makers in the production of climate science knowledge and promote the use of earth systems model outputs and scientific information in decision-making.

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Literature Review: Interdisciplinary Science, Big Data, and the Need for Stakeholder Engagement

Complex environmental change questions and resource management decisions, which initiatives such as the BioEarth Project and the Regional Climate Hubs seek to inform, require input from diverse interdisciplinary teams (Adam et al. 2014; USDA 2014). Climate change impacts research connects biological sciences, atmospheric sciences, hydrology, engineering, economics, social sciences, and communication studies. BioEarth and Regional Climate Hubs are representative of a growing body of large interdisciplinary climate change projects working at the confluence of multiple disciplines. The developing interdisciplinary approach stands in contrast to traditional reductionist science (Lélé and Norgaard 2005; Pennington et al. 2013) In interdisciplinary research, the focus is shifted away from analyzing strictly defined inputs and toward synthesizing bodies of knowledge to produce socially relevant outputs (Meinke 2006; Pennington et al. 2013).

Traditional reductionist approaches to problem definition are one central reason why potential end-users of climate science often fail to incorporate state-of-the- science information in their decision-making or deem climate information unusable or irrelevant for their specific needs (Cash and Buizer 2005; Lemos et al. 2012; Weaver et al. 2013). Cash and Buizer (2005) suggest that the effective translation of climate science information into on-the-ground action requires three essential com- ponents: salience (perceived relevance of the information), credibility (perceived technical quality of the information), and legitimacy (perceived objectivity of the information-sharing process). Within the climate science research community, awareness of the need to ensure and highlight the salience, credibility, and legiti- macy of climate science information is expanding (McNie 2007; Allen et al. 2013a, b). BioEarth's stakeholder engagement strategy and the Regional Climate Hubs ini- tiative are both illustrative of this expansion of understanding in the research community.

The complexity, uncertainty, and large quantities of climate science data pose perpetual challenges for usability. As climate science researchers and communicators attempt to improve the usability of the data, they face many challenges including: (1) sources of the climate change problem are diverse and disparate in time and space; (2) the scientific data is complex and uncertain, with linkages and feedbacks that are often not fully understood; and (3) powerful political and economic interests may interfere with the production and dissemination to the policy-making sphere of climate science knowledge (Moser 2010; Weaver et al. 2013). To address these challenges, modeling efforts designed to generate useable climate science information must be able to assess where vulnerably exists in a range of projected conditions, and then explore decisions that perform well across a range of possible futures (Lemos et al. 2012; Convertino et al. 2013). This is in contrast to the conventional assumption that scientists can supply data and models for decision-makers to "predict, then act." The traditional reductionist approach attempts to determine the most likely future conditions to inform the design of appropriate management plans,

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investments, and policies (Lemos et al. 2012; Weaver et al. 2013). A fundamental challenge with this “predict, then act” system is that it places unrealistic demands on climate impacts modeling. The newer more robust modeling framework that assesses vulnerabilities and provides insights on a range of different futures seeks to better understand and better represent how socio-ecological systems work. Models focus on identifying where management plans, investments, or policies may fail—accounting for complexity and uncertainty in both earth systems and human decision-making (Weaver et al. 2013). The new vulnerability assessment approach depends on intensive engagement and collaboration with decision-makers from an early stage in problem definition and research program design (Hegger et al. 2012; Weaver et al. 2013; Pennington et al. 2013). Establishing close working relationships with the stakeholders who may be able to apply current climate science information is essential to overcome shortcomings of the traditional approach (Weaver et al. 2013).

Literature about stakeholder identification and stakeholder engagement in environmental science draws from many fields including business and organizational theory, political science, sociology, and anthropology. In organizational theory, stakeholders are defined as individuals or groups who can affect, or are affected by, the actions and results of a specific organization, initiatives, policies, or projects (Harrison and Freeman 1999). In climate information initiatives reported on in this chapter, stakeholders are considered any individuals or organizations that might have interest or an ability to use climate data and models in their decision-making. In management literature, stakeholder theory is centered on the idea that institutions should focus on meeting a broader set of interests than simply amassing profits for shareholders. Benefits and impacts on other constituents (stakeholders) should also be considered in decision-making. In the context of considering stakeholder theory in research, this translates to focusing on transmitting relevant knowledge and information to a broader set of interests than the traditional academic audience. The key principle of stakeholder engagement is that organizations seek to understand, respect, and meet the needs of parties who have a stake in the actions and outcomes of the organization (Plaza-Úbeda et al. 2010). Involving stakeholders in the production of knowledge can be seen as an ethical requirement of businesses or institutions (Harrison and Freeman 1999). Importantly, in the field of environmental science, and specifically climate change science, working closely with stakeholders outside the academic community can be understood as a strategic necessity to ensure that consideration of up-to-date scientific information about climate change impacts and risks is taken into account in decisions about land and resource management and social policy (Plaza-Úbeda et al. 2010; Hegger et al. 2012).

Stakeholders have been classified in three broad categories: internal, external, and distal (Sirgy 2002). In the case of an environmental science research initiative, internal stakeholders include program administrators, principal investigators, graduate students, collaborating researchers, and science advisors. External stakeholders include all individuals and groups who may be able to use the climate science data. Distal stakeholders are traditionally defined as groups with competing or conflicting interests to the internal stakeholder groups (Sirgy 2002). In the case of research and

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science communication initiatives, groups with directly competing interests may not be readily identifiable. Members of the general public or interest groups without a direct relationship to the research initiative may be considered, or may self-identify, as "non-stakeholders" although it is important to understand that even parties who do not see themselves as having a direct stake in the outcome of a research or science communication initiative may still have an economic, health, or social well-being interest in the larger environmental change issue (Harrison and Freeman 1999; Plaza-Úbeda et al. 2010). An alternate definition and typology of stakeholders is based on the concept that in order to be a stakeholder, the group or individual must possess one or more of the following relationship attributes: power, legitimacy, and urgency (Mitchell et al. 1997). Given the all-encompassing impacts of climate change, it could be argued that everyone and every organization have some legitimacy and power relationship with climate science information.

In addition to grappling with the question of how to define stakeholders, institutions seeking to develop and communicate useable climate science data, information, and decision-making tools must invest time and resources in establishing a plan for how stakeholders will be engaged (McNie 2012). Potential roles of stakeholder in research are varied and can include any of the following:

- Identifying research questions
- Sharing values, preferences, expectations, and perceptions of risk
- Providing quantitative data or local expertise
- Commenting on research concepts, drafts, and results
- Learning from the research process
- Integrating research findings into a decision-making processes (Bucchi and Neresini 2008)

Policy informatics is a field of research and a community of practice focused on: (1) supporting policy decision-making that is based on data, scientific evidence, and modeling; and (2) creating, managing, and evaluating systems for policy development, analysis, and implementation (LaValle et al. 2013). Research focused on the relationship between scientific data, modeling tools, and policy analysis and implementation is emerging contributing to the field of policy informatics (Niemeijer 2002; Pielke 2007; Convertino et al. 2013). Policy informatics includes tools, models, and simulations to help individuals and groups deliberate and evaluate policy decisions that can be informed by large amounts of data (LaValle et al. 2013). There is a practical challenge of reconciling the supply of scientific information with users' demands (McNie 2007; Sarewitz and Pielke 2007). Oftentimes, decision-makers have specific information needs that are unmet, or they may not be aware of the existence of potentially useful information. In the climate science arena, there is a great need for continuing development of climate data and models that represent large amounts of complex and uncertain information in a way that might be salient and relevant to policy-making and other decision-making. Arguably, the greatest needs surrounding climate data do not concern the quantity or quality of information, but rather the organization, representation, communication, and accessibility of that information.

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Research Methods

The BioEarth research team includes a working group focused on communication that facilitates engagement between the academic scientists and nonacademic stakeholders and also conducts research on these interactions. This section describes how nonacademic stakeholders were recruited to participate in the BioEarth project and how the stakeholder engagement workshops were structured. The methods for gathering information from BioEarth researchers and stakeholders about their perceptions relating to characteristics of useable climate science information and characteristics of effective engagement and outreach approaches are detailed.

The stakeholder engagement approach utilized in BioEarth was designed based on a history of cooperative agricultural and forestry extension programs that communicate university research to land managers and decision-makers (Bull et al. 2004). Building on work done by the Washington State University Center for Sustaining Agriculture and Natural Resources (CSANR), BioEarth's communication approach was designed to be bidirectional, allowing the environmental modeling team to learn from stakeholders about concerns and information needs while developing decision-relevant model outputs. BioEarth researchers developed a plan for a series of six issue-based workshops to learn from regional natural resource managers. The project's communication working group has conducted five of those workshops to date; two workshops in 2013 focused on carbon and nitrogen management and water supply, and three workshops in 2014 focused on rangeland management, forestry, and atmospheric pollution. Using existing contacts, internet research, and fellow stakeholders' recommendations, the communication working group identified and invited 384 stakeholders from state, federal, tribal, and local government agencies, private industry, non-governmental organizations, and research institutions. Ultimately, 87 stakeholders participated in a series of five workshops. The workshop format consists of a brief presentation about BioEarth's modeling approach followed by facilitated round-table discussion. Digital response "clickers" are used to allow real-time visualization of perceptions in the room and establish a starting point for conversation about concerns and information needs.

With facilitation from experienced extension faculty on the communication team, BioEarth environmental modelers engage directly with stakeholders with a goal of mutual learning; the modelers learn from the stakeholders and the stakeholders learn from the modelers. Feedback and recommendations provided by stakeholders have been published in a series of Workshop Summary Reports available on the BioEarth website.[1] Specific recommendations from the stakeholders have been tabulated in spreadsheets that research team members use to formulate and prioritize model development plans. Before and after each of the workshops, participating stakeholders completed surveys consisting of multiple choice and open-ended questions. Survey responses (84 pre-workshop surveys and 41 post-workshop surveys) and comments recorded during workshops are the basis of

[1] BioEarth workshop summary report, available at: http://www.cereo.wsu.edu/bioearth/publications.html

reflections and recommendations analyzed in this report. Responses were recorded in Excel spreadsheets and coded based on emergent themes. NVivo qualitative analysis software is being used for further analysis of stakeholders' written responses and the detailed notes recorded by BioEarth communication working group researchers at workshops.

Results: BioEarth Stakeholders' Reflections and Recommendations

Stakeholder advisory workshop discussions in the BioEarth project generated a wealth of information about the types of data that might be useful to decision-makers who are concerned with Pacific Northwest water the Pacific Northwest water supply, carbon and nitrogen cycling, atmospheric issues, and rangeland and forest management. Gaps in understanding related to the feedbacks between these systems in the context of climate change also surfaced. A total of 87 stakeholders from outside the BioEarth research team participated in advisory workshops. A majority of the individuals who participated in these workshops expressed enthusiasm and eagerness to continue to be involved in the BioEarth model development process. Recognition of the BioEarth project's complexity and ambitious scope was frequent among participating stakeholders. At the same time that positive overall reactions to the research initiative were frequently expressed, approximately 75 % of the 41 stakeholders who completed a post-workshop evaluation survey expressed the opinion that the project entailed significant challenges, which they were concerned may not be surmountable within the scope of BioEarth. Stakeholders cited project complexity, funding limits, and time limits as the primary factors that may present challenges for the research team and limit the project outputs' usability and relevance to decision-makers. Participants demonstrated near-unanimous appreciation for the opportunity to contribute to the BioEarth project. One representative from a non-governmental organization expressed, "stakeholder involvement from the early stages of research question formulation generates buy-in and confidence in results," and stakeholders noted frequently that having even more early involvement in research question formulation would be favorable.

Our results suggest that future communication with stakeholders as part of the BioEarth project should include multiple opportunities for reflection, refinement, and revisiting of linked process-based models, for example, providing sample outputs that people can respond to. Seven of the stakeholders who completed a post-workshop survey specifically stated that demonstrating sample model outputs in a tangible way could help decision-makers understand the scope and scale of what is possible, and comments during workshops reinforce this understanding that having results to respond to and ask questions of is essential. Stakeholders urged environmental modelers who are presenting their work to continue to develop their ability to present technical concepts visually, using minimal jargon and acronyms. Along with this feedback, four participants expressed that within interdisciplinary teams, including experienced science communicators is essential for overall project

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success. One stakeholder noted, "researchers should continue to make good use of University Extension programs in the region—this is often where capacity lies in getting information out to people who can use it."

Survey responses and comments during discussion also demonstrate that presentations to stakeholders are most effective when there are explicit linkages between research questions and land or resource management decisions. Two participants perceived a disconnection between the integrated modeling approach and separating workshops based on topic (i.e., cross-specialty dialogue is also important). When prompted to describe which factors enhanced their learning and enjoyment of workshops, stakeholders frequently cited experienced workshop facilitation, thoughtful discussion questions, and having had the opportunity to see other stakeholders' responses to multiple-choice questions.

Reflecting on the project's communication and outreach approaches, different stakeholder groups have diverse levels of experience with environmental models and climate science; their information needs vary accordingly. Responses to a discussion question posed at workshops suggest that fact sheets and research summaries that clearly outline conclusions are more likely to be read and talked about than long articles. The majority of participating stakeholders expressed that visual data, including graphs, maps, and conceptual models are often easier to interpret than dense text or equations and numbers. Among BioEarth stakeholders who completed post-workshop surveys, approximately 70 % expressed strong interest in seeing regional climate science information available via an easily navigable website with the capacity for stakeholders to interact directly with researchers. There is demonstrated interest in tools that would enable decision-makers to ask questions and request clarification directly from scientists. Webinars are also recognized as valuable forums for learning and collaboration, but a majority of participants stated that in-person workshops with environmental modelers are not interchangeable with online presentations; an in-person workshop format enables a level of dialogue and mutual understanding that cannot be replicated via a website or video conference.

BioEarth stakeholders also shared feedback about specific characteristics of climate science data and models that enhance the relevance, accessibility, and utility of that information. One stakeholder summarized the general attitude of many when they stated that "in order for models to be trusted in decision-making contexts, on-the-ground monitoring is essential to track model accuracy." However, it was also stated that for government agencies, using model projections to make management decisions opens up challenging ethical questions of how accurately models represent different areas and processes. A finding from discussions as well as written survey responses is that synthesis and clear interpretation of experimental data and models are frequently of greater value to users than full access to data that contributed to a given analysis.

Within environmental model-based research, which has a goal of understanding complex environmental change and human-earth systems feedback processes, a paradox exists. To adequately represent the diversity and complexity of the dynamics of earth systems, the research must involve people with diverse expertise. Yet as the complexity of model outputs increases, the pool of individuals who can interpret those findings decreases. A high level of technical expertise is necessary to understand

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complex models and to promote the application or usability of that research to decision-making. Many decision-makers who participated expressed that they would welcome more opportunities to learn about the science of environmental modeling and to further interact with BioEarth researchers to deepen their understanding of model structure, limitations and capacity, or possible outputs.

Discussion: Implications for Initiatives Seeking to Produce and Communicate Useable Climate Science

Stakeholders' recommendations and reflections shared during BioEarth project workshops suggest important considerations for other research programs. The discussion section is divided into three sections; we begin with a consideration of the need for research teams to define shared goals and develop communication competencies (section "The Need to Define Goals and Develop Communication Competencies"); next, we present a value chain describing stages in the production of useable climate science information (section "Defining a Useable Climate Science Value Chain"), finally lessons from the BioEarth project are discussed in terms of how they could inform the national Regional Climate Hubs program (section "Applying Lessons from a Regional Project to a National Program").

The Need to Define Goals and Develop Communication Competencies

Stakeholders in industry, government agencies, and advocacy organizations often state that increased access to climate science data would be of benefit to their decision-making. However, we find that there is a disconnect between the kind of information that academic research institutions seek to produce and the kind of information that will be of practical use for land-owners' and resource managers' decision-making (Allen et al. 2013a, b). Synthesis and clear interpretation of experimental data and models may be of considerably greater value to users than would be full access to data that contributed to a given analysis. It is essential for institutions seeking to provide useable information to be closely attuned to their audience's information needs.

A key lesson from BioEarth is that researchers and science communicators must clearly conceptualize joint goals at the outset of a useable climate science project. Often, involvement in interdisciplinary stakeholder-focused research requires that team members to develop new vocabularies and new skills. For example, communication researchers will need to learn about process-based modeling or modelers may need to devote time and energy to developing skills and experience related to stakeholder engagement. Research scientists who are less familiar with policy-making processes and decision-makers' needs may need training and opportunities for learning that will

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enhance their understanding of how scientific information is digested and applied. Based on feedback received in the course of the BioEarth project, we find that if potential benefits to stakeholders can be made explicit from the outset of a project, stakeholders have more clarity of purpose in their engagement. Potential benefits may be different for different stakeholders, but sending a clear signal to stakeholders that their interests and questions are being responded to improve the likelihood the results of scientific inquiry will be applied in decision-making contexts. Certain information needs or useable model outputs are highly specific to different kinds of stakeholders, and those kinds of outputs and analyses cannot be produced in the absence of close working relationships with the stakeholders who may use that information and the model developers. What constitutes meaningful climate science information will certainly vary depending on the defined end-user, and there may be regional variability as to the most pressing information gaps and information needs of policy decision-makers.

Defining a Useable Climate Science Value Chain

The value chain concept, which has origins in business and management literature, describes a series of activities that create and enhance value. Eventually, these activities culminate in an output, which the organization delivers (Porter 1998). The value chain concept has been applied to many specific contexts, including knowledge management (Lee and Yang 2000) and big data development and management (Miller and Mork 2013). Here, we adapt the value chain concept to describe a framework for developing and synthesizing complex, data-intensive climate science information where usability for decision-makers is the end goal (Fig. 1). Processes that add value, as indicated by BioEarth project stakeholders, are summarized and displayed in a value chain diagram that other research institutions and initiatives can refer to and adapt to suit specific project attributes. Steps of knowledge production, information integration, and application of environmental change

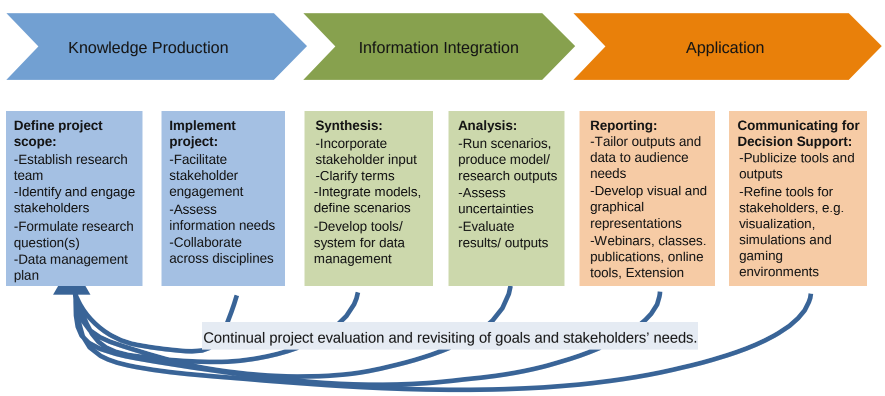

Fig. 1 The useable climate science value chain (adapted from Miller and Mork 2013)

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research products are defined. This value chain is not simply a linear process that produces a defined output. Rather, it is more accurately understood as an iterative cycle because there is a need for continual evaluation and engagement with stakeholders to adapt the research approach and generate relevant outputs.

Applying Lessons from a Regional Project to a National Program

An example of a larger initiative that may be able to incorporate lessons and best practices suggested by the BioEarth regional modeling project is USDA's Regional Climate Hubs program. This recently established initiative has the ambitious vision of accessible, credible, salient, and legitimate climate science, primarily internet-based information, targeted for agriculture, rangeland, and forestry decision-makers. In February 2014, United States Secretary of Agriculture Tom Vilsack announced the seven regional information centers and three sub-hub locations charged with delivering information to support adaptation to climate change and weather variability (USDA 2014). Climate hubs will be located at existing Agricultural Research Service (ARS) or Forest Service locations, and leadership in each regional hub will be provided by the ARS, the Forest Service and the Natural Resource Conservation Service (NRCS) will jointly provide leadership in each Regional Climate Hub (USDA 2014). According to a USDA fact sheet outlining the initiative, partners will include: universities, including extension departments; USDA researchers, programs, and field offices; private sector farm groups; state, local, and regional governments; tribes; National Oceanic and Atmospheric Administration and Department of the Interior regional climate change experts; and non-profits (USDA 2014).

As of December 2014, the structural elements needed to support the Regional Climate Hubs are still under development. This will necessitate allocation of funds, human resources, and development of transdisciplinary science communication expertise. Salience of climate science requires that modelers and researchers look beyond disciplinary boundaries and explore interactions between science and policy decision-making, and between the environment and socioeconomic forces (Meinke et al. 2005; Sarewitz and Pielke 2007). Close communication and engagement with diverse stakeholders can improve the incorporation of socioeconomic variables into future change scenario development. Credibility emerges from social relationships between climate scientists and those affected by climate risk. Science derives credibility not just from its technical precision, but also from engagement processes (Meinke et al. 2005). Establishing legitimacy depends on making processes of knowledge development and sharing transparent and equitable (Meinke et al. 2005).

There are potential tensions and challenges associated with the design of the Regional Climate Hubs. This program was established by the highest level of leadership within USDA as a component of the Obama administration's National Strategy on Climate Change. The decision came without a commitment of new funding, and hub leaders were selected with minimal engagement in the planning and decision-making process. Programmatic decisions made by a high level of lead-

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ership in a federal agency may be perceived by those on the ground as lacking clarity in terms of specific responsibilities and defined, measurable objectives (Sabatier 1986). Observing the general history of top-down program design, there is some risk that the burden of program implementation will fall on agency staff, who are already constrained by limits on available funding and other job demands. While USDA staff and partners will be responsive to the directives from the leadership in the agency, there is also concern that work developing Climate Hubs in the mandated manner will take place at the expense of bottom-up, locally specific approaches to providing decision-makers with relevant and useable climate science information. BioEarth stakeholders' feedback indicates that bottom-up approaches that engage decision-makers directly from an early stage in program design and provide ample opportunities for viewing sample model outputs and data are the surest pathway toward useable climate science information for decision-makers.

It is important to note that analyses and tools that have already been developed in collaboration with stakeholder groups may provide some of the initial content for the Regional Climate Hubs. Established working relationships with stakeholders in diverse sectors may lay the groundwork for an audience or user community that will continue to interact with the regional hub for useable tools. The BioEarth project, for example, may directly integrate and overlap with the emerging Pacific Northwest Climate Hub.

Conclusion

Climate change will dramatically affect our food, water, energy, and infrastructure systems, so building understanding of feedbacks, trade-offs, and drivers of change is of paramount importance (Miller et al. 2013). Moreover, ensuring that information is accessible and readily utilizable by policy decision-makers and land and resource managers is essential (Weaver et al. 2013). Regionally focused research on climate change impacts on natural resource management needs to be a top priority (Convertino et al. 2013; Hegger et al. 2012). Washington State University's BioEarth project and the newly established USDA Regional Climate Hubs are well positioned to carry out and communicate much of this vital work.

In order to maximize usability and effectiveness of knowledge and information, stakeholders' perspectives and information needs must be incorporated into knowledge production and knowledge dissemination initiatives. While BioEarth's focus is specifically on supporting development of a regional integrated earth systems model that is relevant to farmers, foresters and natural resource managers in Oregon, Washington, and Idaho, the lessons learned from round-table discussions at stakeholder workshops and from in depth pre- and post-workshop surveys are applicable beyond the temporal and geographic scope of the research project. Detailed feedback from a diverse group of the term natural resource managers encompasses this group and natural resource decision-makers in BioEarth may contribute to envisioning approaches for other initiatives seeking to create and promote the use of science data and models for decision-makers.

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The potential for transdisciplinary sustainability science research projects to improve the understanding of regional human–environment interactions and inform decisions is large. We find that overcoming multiple challenges related to communication across disciplinary divides and between researchers in academia and stakeholders in government, industry, and non-profit organizations requires learning new approaches to research and communication. These new approaches may include all of the following: working in the early phase of research question development to identify stakeholders' information needs; developing shared vocabularies and new forums for translating and communicating knowledge; and working closely with stakeholder groups to increase organizational capacity to apply research findings.

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References

Adam J, Stephens J, Chung S, Brady M, Evans R, Kruger C, Lamb B, Liu M, Stöckle C, Vaughan J, Chen Y, Guenther A, Harrison J, Kalyanaraman A, Leung F, Leung L, Perleberg A, Tague C, Yoder J, Hamlet A, Nijssen B, Chinnayakanahalli K, Choate M, Jiang X, Nelson R, Yoon J, Yorgey G, Zhu J, Allen E, Anderson S, Malek K, Nergui T, Poinsatte J, Rajagopalan K, Reyes J (2014) BioEarth: a regional biosphere-relevant earth system model to inform agricultural and natural resource management decisions. In: ASA, CSSA and SSSA Annual Meetings on Climatic Change, Cincinnati, OH, pp. 1–17.

Allen E, Kruger C, Leung FY, Stephens JC (2013a) Diverse perceptions of stakeholder engagement within an environmental modeling research team. J Environ Stud Sci 3(3):343–356

Allen E, Kruger C, Leung FY, Stephens JC, Yorgey G (2013) BioEarth stakeholder advisory workshops synthesis report. Washington State University. http://www.cereo.wsu.edu/bioearth/publications.html. Accessed 17 May 2014

Bucchi M, Neresini F (2008) Science and public participation. The handbook of science and technology studies. MIT, Cambridge, pp 449–472

Bull NH, Cote LS, Warner PD, McKinnie MR (2004) Is extension relevant for the 21st century. J Ext 42(6):1–6

Cash D, Buizer J (2005) Knowledge-action systems for seasonal to interannual climate forecasting: summary of a workshop, report to the roundtable on science and technology for sustainability, policy and global affairs. The National Academies Press, Washington, DC, http://books.nap.edu/catalog/11204.html

Convertino M, Foran CM, Keisler JM, Scarlett L, LoSchiavo A, Kiker GA, Linkov I (2013) Enhanced adaptive management: integrating decision analysis, scenario analysis and environmental modeling for the everglades. Sci Rep 3, 2922

Harrison JS, Freeman RE (1999) Stakeholders, social responsibility, and performance: empirical evidence and theoretical perspectives. Acad Manage J 42(5):479–485

Hegger D, Lamers M, Van Zeijl-Rozema A, Dieperink C (2012) Conceptualising joint knowledge production in regional climate change adaptation projects: success conditions and levers for action. Environ Sci Pol 18:52–65

IPCC (2014) Climate change 2014 mitigation of climate change, intergovernmental panel on climate change. https://www.ipcc.ch/report/ar5/wg3/. Accessed 17 May 2014

LaValle S, Lesser E, Shockley R, Hopkins MS, Kruschwitz N (2013) Big data, analytics and the path from insights to value. MIT Sloan Manag Rev 62:4

Lee CC, Yang J (2000) Knowledge value chain. J Manag Dev 19(9):783–794

Lélé S, Norgaard RB (2005) Practicing interdisciplinarity. BioScience 55(11):967–975

Lemos MC, Kirchhoff CJ, Ramprasad V (2012) Narrowing the climate information usability gap. Nat Clim Chang 2:789–794

Meinke, H., & Stone, R. C. (2005). Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. *Climatic change*, 70(1-2), 221–253.

Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R., & Baethgen, W. (2006). Actionable climate knowledge: from analysis to synthesis. *Climate Research*, 33(1), 101.

McNie EC (2007) Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ Sci Pol 10(1):17–38

McNie EC (2012) Delivering climate services: organizational strategies and approaches for producing useful climate-science information. Weather Clim Soc 5(1):14–26

Miller HG, Mork P (2013) From data to decisions: a value chain for big data. IT Prof 15(1):57–59

Miller M, Anderson M, Francis CA, Kruger C, Barford C, Park J, McCowng BH (2013) Critical research needs for successful food systems adaptation to climate change. J Agric Food Syst Community Dev 3(4):161–175

Mitchell RK, Agle BR, Wood DJ (1997) Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts. Acad Manage Rev 22(4):853–886

Moser SC (2010) Communicating climate change: history, challenges, process and future directions. Wiley Interdiscip Rev Clim Chang 1(1):31–53

Niemeijer D (2002) Developing indicators for environmental policy: data-driven and theory-driven approaches examined by example. Environ Sci Pol 5(2):91–103

Pennington DD, Simpson GL, McConnell MS, Fair JM, Baker RJ (2013) Transdisciplinary research, transformative learning, and transformative science. BioScience 63(7):564–573

Pielke RA (2007) The honest broker: making sense of science in policy and politics. Cambridge University Press, Cambridge, p 188

Plaza-Úbeda JA, de Burgos-Jiménez J, Carmona-Moreno E (2010) Measuring stakeholder integration: knowledge, interaction and adaptational behavior dimensions. J Bus Ethics 93(3):419–442

Porter ME (1998) Clusters and the new economics of competition. Harv Bus Rev 76(6):77–90

Sabatier PA (1986) Top-down and bottom-up approaches to implementation research: a critical analysis and suggested synthesis. J Public Policy 6(1):21–48

Sarewitz D, Pielke RA Jr (2007) The neglected heart of science policy: reconciling supply of and demand for science. Environ Sci Policy 10(1):5–16

Sirgy MJ (2002) Measuring corporate performance by building on the stakeholders model of business ethics. J Bus Ethics 35(3):143–162

United States Department of Agriculture (USDA) (2014) USDA regional climate hubs. http://www.usda.gov/oce/climate_change/regional_hubs.htm. Accessed 17 May 2014

Weaver CP, Lempert RJ, Brown C, Hall JA, Revell D, Sarewitz D (2013) Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. Wiley Interdiscip Rev Clim Chang 4(1):39–60

Whitehouse.gov (2014) Climate change and President Obama's action plan. http://www.whitehouse.gov/climate-change. Accessed 17 May 2014

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