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The co-production of science and policy in integrated climate assessments

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Abstract

This paper examines the use of interactive models of research in the US regional integrated scientific assessments (RISAS), using as a case study the climate assessment of the Southwest (CLIMAS). It focuses on three components of regional climate assessments: interdisciplinarity, interaction with stakeholders and production of usable knowledge, and on the role of three explanatory variables—the level of 'fit' between state of knowledge production and application, disciplinary and personal flexibility, and availability of resources—which affect the co-production of science and policy in the context of integrated assessments. It finds that although no single model can fulfill the multitude of goals of such assessments, it is in highly interactive models that the possibilities of higher levels of innovation and related social impact are most likely to occur.

Keywords: Integrated assessment; Usable science; Stakeholder interaction; Iterative model

1. Introduction

As policy quandaries, environmental problems are complex and difficult to tackle. They are complex because at the root of their causal chain are intricate interactions between biological, physical and social systems. They are difficult to tackle because their solution depends on the collaboration between scientists, policymakers and the public. Implementing effective environmental policy requires not only the combined efforts of many disciplines to understand environmental problems, but also active interaction with stakeholders. To assist in this effort, interactive models of research are increasingly being adopted to understand complex environmental issues, their impact on human and natural systems, and the opportunities and constraints for policy-making directed towards adaptation and mitigation. Yet, despite efforts to describe and characterize interactive research by many scholars, the existing literature has yet to make explicit, theoretically informed generalizations about the conditions under which interaction achieves greater or less success. This deficiency is understandable to the extent that such generalizations will only be possible after extensive empirical work is carried out to identify different conditions for success. In this context, funding agencies, academic institutions, and policy makers are directing considerable attention to regional climate assessments that are specifically designed to identify meaningful responses to the impacts of climate variability and change.

One such program, the NOAA regional integrated science assessment (RISA), funds research that "seek (s) to improve our understanding of climate systems, climate variability, and the impacts of climate on human and natural systems through synthesizing and evaluating knowledge and projections generated from different

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sources and using an array of different disciplinary approaches. The end goal is to develop decision support tools and climate services application'' (Pulwarty, 2001, p. 40).

We focus on one particular RISA project, the Climate Assessment for the Southwest (CLIMAS) to explore opportunities and constraints associated with implementing innovative research approaches for fostering meaningful interactions between scientists and members of society to produce and implement science and policy collaboratively.[1] CLIMAS defines ''regional assessment'' as involving the development, interpretation, evaluation, and communication of climate-related information useful to decision makers, resource managers, and other interested individuals in specific geographical locations (Bales et al., 1997; http://www.ispe.arizona.edu/climas). As an integrated and interdisciplinary project, CLIMAS incorporates expertise from an array of disciplines including hydrology, anthropology, climatology, geography, and resource economics to address issues that cannot be effectively addressed from the perspective of one discipline alone. Achieving these ends has involved development of a comprehensive understanding of how global and synoptic scale conditions interact with society and the natural environment to produce local and regional-scale impacts. As articulated in CLIMAS, integrated assessment also involves active inclusion of stakeholders in all phases of the research process, as well as integration across scales, in using science to address the multiple stressors that must be taken into account when making decisions. Finally, integrated assessments also involve combining university and governmental research agendas with those of the private and public sectors.

After five years of ongoing research, CLIMAS researchers have learned many lessons about the opportunities and constraints associated with implementing this multifaceted agenda. Some lessons are cautionary, especially concerning the enormous levels of time and material resources involved in developing this kind of project. Others, however, provide a glimpse into the possibilities of interactive research and its potential social, political, and economic contributions.

Using CLIMAS as a case study, this article focuses on one aspect of regional assessment, namely the different kinds of research strategies being employed. In it, we argue for sustaining diversity among the kinds of approaches used. Specifically, we contend that in order to accomplish its goals, regional assessment must incorporate an array of interactive research strategies ranging across the knowledge producer–user divide. The underlying assumption is that, because many factors affect if, when, and how knowledge creation and application interact, no single research model can fulfill the multitude of goals put forward by regional assessment programs. Despite their focus on application, the reality of regional assessments is that they require a combination of knowledge-driven, applied and interactive science which strikes the delicate balance between what we need to know to understand complex problems and what stakeholders perceive to be their immediate needs for making decisions. In addition, there is a time dimension to this issue in that it is often necessary to create new knowledge in order to address stakeholder needs: years may need to pass before stakeholders perceive this new knowledge as ''usable'' for decision making.

Having argued for diversity, it is in a highly interactive model—one that we argue involves high levels of iterativity—that we find possibilities for higher levels of innovation and greater societal impact. We define iterativity specifically as (a) the extent to which the interactions between scientists and stakeholder participants influence how scientists pursue science and how stakeholders understand the possibilities and limits of science, (b) the range of uses to which the scientific knowledge may be put, and (c) the practical value of such knowledge. In turn, the manner and extent to which iterative processes develop may depend on many factors, ranging from the nature of the problem being tackled to the ability and willingness of individuals to participate in interactive research. We suggest that successful employment of iterativity in integrated regional assessments is defined across three dimensions: *interdisciplinarity, interaction with stakeholders*, and *production of usable science*. Although many factors affect these conditions, in this study, we analyze the role of three explanatory variables: (a) the level of *''fit''* between the state of knowledge production and application, (b) disciplinary and personal *flexibility*, and (c) *availability of resources* (time, funds, personnel, infrastructure, etc.). We argue that the higher the level of fit, interdisciplinary and personal flexibility, and availability of resources, the more likely it will be that iterativity in the relation between science and decision-making will occur. This, in turn, can lead to development of more effective policies for addressing regional climate variability and change.

Although climate regional assessments are by nature context-dependent, we believe lessons learned from CLIMAS can inform not only other RISAs but assessment efforts around the world. By focusing our analysis on the processes of knowledge creation and co-production of science and policy within CLIMAS, we hope to share valuable insights that can be useful to the design and implementation of future regional climate assessments.

[1]This research is based on published and unpublished materials about CLIMAS, open-ended interviews with current and former CLIMAS investigators and research assistants, and participant observations of meetings and interactions both between team members as well as between team members and stakeholders.

In this paper, we advance our proposition by elaborating on our concept of iterativity. Section 2 reviews some models of interactive research and highlights some of the characteristics that we believe make them suited to guide regional climate asssessments. We then define a few necessary conditions for our proposed iterative model and use examples from CLIMAS to illustrate the concepts we propose. We conclude by reflecting on some of the lessons learned and proposing areas for further research.

2. Models of interactive research

Many of the influential studies on the use of knowledge-based information in policymaking have focused on the dichotomy between science produced for policy ("applied" or "decision-driven") and science grounded in research alone ("basic" or "knowledge-driven"). More recently, scholars have become increasingly interested in a third approach in which the division between science and policy is blurred and "usable" knowledge is co-produced in the context of everyday interaction between scientists, policy-makers, and the public. Bruno Latour suggests the notion of a "collective experiment," whereby the old culture of certainty associated with pure science has been replaced by a "culture of research" in which science and society come together to ask questions and search for solutions collectively (Latour, 1998). Like Latour, other scholars have proposed models of science–society interaction that aim at depicting the many processes involved in the co-production of scientific knowledge and the political order.[2] Such approaches question the idea of a unified way of doing science, emphasizing the idea of the scientific and technological practice as "quintessentially local, messy, and contingent" (Wolgar, 2000, p. 168).

Whereas many scholars have tackled the difficult task of reconciling knowledge production in the social sciences with policymakers' needs (Weiss, 1978, 1995; Lindblom and Cohen, 1979), questions still remain on how to produce at the same time "usable" knowledge and high quality science. Below, we examine some of the characteristics of interactive research that we believe make it particularly suitable as a model for regional climate assessments.

Scott et al. (1999, p. 4) define interactive research as "a style of activity where researchers, funding agencies and user groups interact throughout the entire research process, including the definition of the research agenda, project selection, project execution and the application of research insights." While the authors emphasize the desirability of such an approach, they also call attention to the many constraints practitioners of interactive research face, not the least of which is the risk of compromising scientific freedom and neutrality in the definition of research agendas (Scott et al., 1999).

Wolgar (2000), in his analysis of the role of interactive research in social science (ISS), suggests that ISS is controversial to the extent that it resurrects questions about the complex interconnection between objectivity, adequacy, relevance, and utility in research. He reviews three "ideals" of how interactive research improves over the kinds of "ordinary" (by which we assume he means non-interactive) research evident in the literature: methodological efficiency, egalitarianism, and accountability. "Methodological efficiency" emphasizes that engagement with recipients of research provides more data, information, and feedback, which, in turn, improve the quality of the research. The "egalitarian ideal" argues that there is an added political–moral imperative in engaging recipients of scientific knowledge, in that the fruits of research need to be shared with those who have assisted in their formation. Finally, the "imperative of accountability" "demands that publicly funded research demonstrate an account of its value in terms of a return on the original investment" (Wolgar, 2000, p. 166).

Another model of interactive research, Mode 2, proposed by Gibbons et al. (1994), differs from the more traditional knowledge-driven, primarily disciplinary and cognitive "Mode 1", to the extent that it is transdisciplinary;[3] it is carried out in non-hierarchical, heterogeneously organized forms, and involves close interactions among many actors throughout the process of knowledge creation.[4] According to the authors, because institutionalization of Mode 2 does not occur primarily within the university structure, and because it stresses involvement with non-academic actors and organizations, the knowledge produced is more socially accountable, and the criteria for what should count as "good science" tend to undergo more careful scrutiny. In this new mode of knowledge production, society speaks back to science, affecting "scientific activity both in its forms of organization, division of labor and day-to-day practices, and deep down in its epistemological core" (Gibbons, 2000, p. 161). Table 1 shows the basic

[2]For a detailed discussion of some of those models, see Jasanoff and Wynne (1998), Gibbons et al. (1994), Scott et al. (1999).

[3]What distinguishes transdisciplinarity from interdisciplinarity is that the inquiry is guided by specifiable consensus with regard to appropriate cognitive and social practices going beyond the mere assembly of teams of specialists from different disciplines (Gibbons et al., 1994, p. 4).

[4]Despite their creation of the term Mode 2 to distinguish new forms of knowledge production from the more traditional Mode 1, Gibbons et al. (1994, p.3) question whether the two modes "are sufficiently different to require a new label or whether they can be regarded simply as developments that can be accommodated within the existing practices. The final answer to this question depends partly on acquiring more data and partly on how Mode 1 adapts to changing conditions in the economic and political environment."

Table 1
Differences between Modes 1 and 2 of research

Mode 1	Mode 2
Problems set and solved in contexts governed by academic interests of a specific community	Carried out in the context of application
Disciplinary	Transdisciplinary
Characterized by homogeneity	Characterized by heterogeneity
Organizationally hierarchical and tending to preserve its form	Organizationally heterarchical and transient
Traditional modes of quality control by academic communities (e.g., institutional communication, peer-review journals, professional conferences, etc.)	Socially accountable and reflexive
Institutionalized primarily within the university structure	Includes a wider set of practitioners collaborating on a problem defined in a specific and localized context

Based on Gibbons et al., 1994.

differences between Modes 1 and 2 of knowledge production.

Within the field of climate research, where there is increasing recognition of the need to involve stakeholders, questions revolve around the extent to which scientists should reach out to potential users, and whether the needs of users should shape research agendas (Agrawala et al., 2001). One widely embraced research approach, the "end-to-end" model, seeks to "link research with social concerns" through conceptualizing a system in which interactions flow "from climate researchers to consumers of climate information, and back again" (Agrawala et al., 2001, p. 459). The components of an end-to-end system are identified as three concentric circles: "(1) a core focusing on fundamental research on climate, human, ecosystem, and decision processes; (2) an applications ring focusing on climate forecasts, decision analysis, and communication; and (3) an outer outreach shell connected with decision makers in various sectors such as farmers, water resources managers, disaster relief agencies, and insurers" (p. 461).

Whereas most studies of interactive research emphasize that there is no single model of engagement (Scott et al., 1999; Wolgar, 2000; Gibbons, 2000), there has been little effort to systematize the different models of interactive research currently available in the context of day-to-day knowledge creation. Further, there is little empirical evidence of how interaction between scientists and stakeholders, whether sustained or not, actually transforms the production of science beyond the advisory level to shape the way scientists formulate research questions and carry out research.

Finally, while new models of "usable" science have focused mostly on transformation within the system of knowledge production, the interaction of these models with policy systems poses its own challenges. Some models reflect the character of the problems knowledge is needed to address; others emanate from the kinds of institutional arrangements within the different systems that produce and use knowledge. Among the challenges to implementation of the end-to-end model, for example, are the limits of scientific understanding of physical systems and the complexity of users' environments (Agrawala et al., 2001). Indeed, the literature provides several examples of how the current level of skill in climate forecasting falls short of users' needs (Rayner et al., 2002; Lemos et al., 2002). Many scholars have also pointed out the importance of context in understanding the opportunities and limitations of knowledge use in decision making. Here, beyond the immediate applicability of knowledge to problem solving, there are also broader issues to be considered, including equity, unintended uses, negative consequences to stakeholders, and opportunity costs (Sarewitz et al., 2000; Brunner, 2000; Pfaff et al., 1999; Morehouse, 2000a; Lemos, 2003). Still other analysts have focused on the difficulties surrounding the implementation of different levels of interactive research models. Likewise, institutional arrangements within the systems producing and using knowledge can pose significant challenges to the implementation of interactive research models. These challenges include distinct cultures between scientists and policymakers, the role of funding opportunities and shifting political agendas, loss of academic freedom and elimination of dissent, organization of research environments, and the pitfalls of interdisciplinary versus disciplinary approaches—not only across the biophysical and social sciences but within their domains as well (Weiss, 1978; Gibbons et al., 1994; Keyfitz, 1995; Baldwin, 2000; Malone and Rayner, 2001).

It is the intention of this article to propose a model for iterative research within the context of regional climate assessments. We demonstrate the model's use through examination of several examples from CLIMAS. Below, we describe the iterative model; this description is followed by assessment of the three critical variables using examples from CLIMAS.

3. A proposed model of science-policy co-production

Our model takes as its starting point our concept of *iterativity*, which emphasizes the need for assessment models to build effective internal and external networks, including the capability to sustain ongoing flows of information and participation between science and decision makers from the public, non-governmental, and private sectors. As illustrated below, iterativity involves three essential components: sustained stakeholder interaction, usable science, and interdisciplinarity. Fig. 1 illustrates the iterative model.

Stakeholder interaction refers to the degree to which representatives of the constituency base are involved in aspects of the research: defining the problem, formulating research questions, selecting methods, conducting research, analyzing findings, developing usable knowledge, testing/evaluating research results, participating in dissemination of results, and participating in identifying next research steps (if any are required). In turn, we expect that users' perceptions and decision processes will be affected by their iterative interaction with knowledge producers, particularly as a relationship of trust develops between both groups. In this model, besides the flow of information between disciplines and "producers" and "users", there is an actual re-shaping of both groups' perceptions, behavior, and agendas that occurs as a function of their interaction. Thus, iterative research, if carried out well, produces sustained, regular interaction among participants and creates relationships between science and decision-making that can shape the ways knowledge is produced as well as how the usefulness and value of knowledge is perceived. In such case, we expect that participants will gain from knowledge production

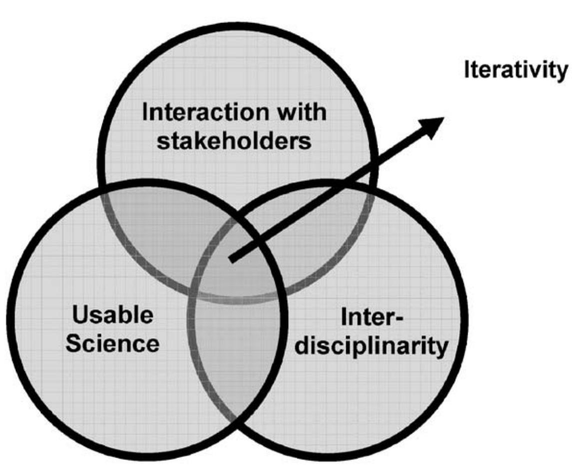

Fig. 1. Model for co-production of science and policy through integrative science.

and, through better decision making, improve the implementation of public policy.

As a principle, in this model, the direction of research is guided and informed by those whose livelihoods, work, and decision-making processes in general depend on, benefit from, or inform the knowledge being created. The relationship with stakeholders must transcend the discussion phase and achieve sustained interaction. From the point of view of knowledge production, such interaction would ideally result both in an exchange of information and in adaptation of research to users' needs. In other words, the model entails the existence of a synergistic relationship between knowledge production and stakeholders' needs; that is, through interaction, each process is adapted and transformed. Thus, as mentioned before, the iterative model goes beyond complementarity to a fusion of the interests of knowledge producers and users whereby their original outlook might be fundamentally changed by the relationship itself.

From the point of view of regional-scale integrated assessments and related assessments of policy implications, the ability to build relationships of trust among participants makes policymaking and implementation more likely to succeed. First, establishing trust and credibility with stakeholders requires sustained interaction as well as demonstrated openness to incorporating stakeholders as full partners in the assessment effort. Second, the types of research carried out under regional assessments require a focus on innovative approaches to real-world problem solving; this in turn entails sustained interaction with users to clarify precisely what kind of knowledge is needed, as well as the timing, scale, and format in which information should be provided. Third, the length of time between identification of user needs and capacity to deliver results may range from a few months to several years. Keeping users involved throughout the process, particularly during the stretches of time when the research is being largely carried out by scientists, reassures the users that work is progressing, and that the work continues to reflect their concerns; if concerns arise, the process provides opportunities for clarification or course correction. Fourth, interactive exchanges between users and scientists allows for the possibility of new insights, ideas, discoveries, or developments arising subsequent to initiation of the research to be identified and considered. Finally, involvement with stakeholders increases the likelihood that policies reflecting the results of such research will be perceived as legitimate, which, in turn, can attract broader constituent support and dampen opposition.

Usable Science refers to the degree that the science produced through the integrated assessment process results in knowledge that meets constituent needs. Thus, the knowledge produced should directly reflect expressed constituent needs, should be understandable to users, should be available at the times and places it is needed, and should be accessible through the media available to the user community. Achievement of usable science must also include consideration of how the knowledge will be operationally delivered to assure regular and consistent access and to assure that maintenance, updates, and improvements occur in a satisfactory fashion. In many cases, operationalization will be carried out by a public agency, non-governmental organization, or private entity.

Cash et al. (2003) argue that in order to connect knowledge to action, information has to be sufficiently salient, credible and legitimate in the eyes of multiple audiences—where salience relates to the relevance of information, credibility concerns the technical adequacy of information, and legitimacy refers to the fairness of the process of creating information. In 1990, the US Congress defined "usable knowledge" for global change research in terms of the need for information that would, in part, "combine and interpret data from various sources to produce information readily usable by policy makers attempting to formulate effective strategies for preventing, mitigating and adapting to the effects of global change" (Pielke Jr., 1995, p. 41). In this context, we define usable knowledge as that which can be incorporated into the decision-making processes of all stakeholders, and which enhances their ability to avoid, mitigate, or adapt to stressors in their environment. We recognize, nevertheless, that defining what is "useful" and what is "usable" is far from straightforward. In order for knowledge to be useful it not only must be tailored to fit stakeholders' needs and uses, but must also be made accessible to those users. Here, the 'fit' between the many means of communication and transfer of knowledge and stakeholders' expectations is critical to their perception of usefulness. The methods to move information to society, far from being ad hoc, should be based on rigorous knowledge-transfer and evaluation methods developed within the social sciences.

Interdisciplinarity is defined as the effort of scientists from different disciplines to work together to tackle problems whose solutions cannot be achieved by any single discipline. This is particularly important relative to complex systems such as global climate change. Schneider (1997, pp. 230–231) distinguishes "inter" from "multi" disciplinary "in the sense that multidisciplinary implies ideas and methods from many disciplines brought to bear to help deal with a systems problem, but in which these ideas and methods remain largely unintegrated, persisting primarily in their discipline of origins." Interdisciplinary in turn implies "an original combination of multidisciplinary ideas or methods that permits explanation or assessment not achievable by an unintegrated application of multidisciplinary ideas or tools." Further, he argues that through interdisciplinarity "greater realism can be attained, and thus increasingly useful insights can be added to the policy process dealing with climate change problems".

While interdisciplinarity does not preclude scientists from different disciplines from applying their highly specialized knowledge separately, it means that knowledge producers must work together in an iterative fashion throughout the process to define research questions and hypotheses, make decisions regarding the conduct of the research, and identify how best to integrate, to "package", and to disseminate the results outside the project structure. Yet, knowledge producers still can (and should) work different parts of the problem separately if solving the problem so requires. This is especially relevant in the context of scientific climate assessments where interdisciplinary projects often cross over social and biophysical sciences. Still, generating the levels of mutual understanding and trust needed to carry out interdisciplinary research effectively, especially when disciplinary and professional perspectives are widely disparate, requires open mindedness, patience, and good will, all of which demand considerable time and effort. Of course, the rewards expected from interdisciplinary research must be perceived to be worth the high levels of commitment required.

4. Fit, flexibility, and resources

We consider interdisciplinarity, stakeholder interaction, and usable science to be the three fundamental components of our iterative model; the degree to which these components are achieved depends on three crucial variables: the level of fit between the state of knowledge production and application, disciplinary and personal flexibility among assessment participants, and availability of financial and human resources.

Over the past five years of its existence, CLIMAS has employed diverse research approaches to linking science with policy and has achieved varying degrees of success in achieving iterativity between science and policy. In this section and the next, we examine a few examples of CLIMAS research to illustrate the ways in which fit, flexibility, and resources have influenced the degree of iterativity achieved in each of the initiatives. We also discuss other cases where iteration was either not appropriate or not achievable, given the nature of the research activity. We use these examples to support our argument that a good fit between knowledge and applications, flexibility, and availability of sufficient resources play a critical role in the ability to co-produce science and policy. For more details about CLIMAS, see the Appendix section.

Level of fit reflects the process through which the knowledge being produced increasingly matches the information stakeholders believe they need to address problems they have defined. Goodness of fit may be evaluated as achieving relevance (i.e., it addresses the problem at hand), usefulness (i.e., it is provided in forms and at temporal and spatial scales that fit with user practices and needs), and usability (i.e., stakeholders can actually access and use the information in the form that it has been delivered), for the intended uses and user communities. In our model, achieving a good fit between researchers and stakeholders requires well-designed iterativity in all phases of an initiative, from problem formulation through delivery/subsequent refinement of the knowledge-based product. Ideally, this process will include post-delivery assessment of the degree to which the knowledge provided influences policies and actions. This is a tall order, and one that has not been completely operationalized by any integrated project we know of. Through its emphasis on ethnographic and related stakeholder-interactive research methods (e.g., interviews, surveys, workshops), CLIMAS has striven to build and sustain a stakeholder network that facilitates articulation of important scientific knowledge needs, provides guidance on the use of knowledge products as they are developed, encourages testing of existing and new products, and affords insights into how these products influence activities and decisions.

Knowledge products tailored to fit specific applications may also have a positive effect when stakeholders, perceiving that the knowledge produced is useful, develop sustained interactions with the knowledge producers. Typically, building these kinds of relationships requires significant commitments of time and effort. In some cases, methodological approaches must be tailored to accommodate different categories of stakeholders. As Baldwin (2000, p. 184) points out, ‘‘It takes a fair amount of time and thought to develop and use methods for fully involving (respondents) in research. Likewise, it takes time and effort to involve busy policy makers in advisory groups, pull the relevant people around the table to discuss emergent findings, and identify champions to take these forward. Moreover, this kind of activity is not directly funded.’’ Hence, one challenge of continuously involving stakeholders is that, besides the usual time spent in producing knowledge, researchers need to devote significant amounts of time and effort building and sustaining such relationships.

Second, personal and disciplinary *flexibility* (including the ability to work with others in developing a mutually acceptable research theme) among the participating scientists affects their ability and willingness to engage in interdisciplinary research and in stakeholder interactions. We define flexibility in terms of individual willingness to engage in interdisciplinary research and availability of institutional incentives to support interdisciplinarity. Within CLIMAS, for example, building interdisciplinarity has been a long and complex effort. For the first three years, the effort included carrying out numerous meetings where much of the discussion revolved around how to overcome barriers presented by different approaches to theorization of problems, issues of terminology and methodology, and ways of analyzing and articulating results. The CLIMAS experience demonstrates that achieving interdisciplinarity requires experimentation with various strategies and iteration among participants to achieve and enhance team integration and collaboration. These strategies have included mandatory participation in all-team meetings, participation by co-investigators in higher-level meetings, organization of researcher retreats, cooperative organization of and cross-disciplinary participation in workshops, and joint authoring of papers and reports. One of the most effective tools for team integration has been a concerted effort to formulate research questions that not only cut across disciplines, but also address problems that cannot be resolved through disciplinary research alone.

Based on our CLIMAS experiences, we find three considerations paramount in achieving the personal and disciplinary flexibility required for interdisciplinary projects. First, fostering participation by graduate students and postdoctoral researchers is important. The high profile and enhanced funding opportunities associated with interactive, integrated assessments provide opportunities for fostering an interdisciplinary ‘‘culture of research’’ during the formative stages of their intellectual and career development, before they face the level of institutional expectations and constraints that confront more senior researchers. Second, providing resources to junior-level faculty, such as graduate student assistantships, summer salary stipends, and sometimes a buy-out of teaching time, can facilitate their continued participation even as they prepare for tenure reviews. Equally essential to sustaining flexibility is explicit support from senior-level researchers that generates disciplinary payoffs (such as peer-reviewed papers) for the junior-level investigators. Third, providing centralized project administration and coordination (such as maintaining communications with the funding agency, dealing with budget matters, organizing team meetings and retreats, and encouraging participation in professional meetings), contributes to sustaining researchers' personal and disciplinary flexibility.

Finally, with regard to *resources,* scientists who conduct research that aims for a good fit with societal needs must not only have sufficient flexibility to operate beyond their customary boundaries, but must also be able to call upon sufficient resources (funds, personnel, infrastructure, and time) to achieve effective co-production of usable science and policy. Funds in particular are essential not only to pay for needed equipment and supplies, salaries, and research activities, but also to support a coordinating structure that oversees the project and provides the "glue" that holds the various components of the project together. Support personnel, often not funded under federal grant monies, must also be made available to provide services ranging from answering telephones to maintaining computer equipment, handling financial matters, assisting with organization of meetings, and any number of other activities. Likewise, infrastructure needs, such as space for desks and computers, Internet access, and equipment must be met. Finally, but certainly not least, time must be available to accomplish the tasks at hand. In CLIMAS, time may be the resource that is most scarce, given the scale of the project and its broad web of links to other scientists and to stakeholders.

In CLIMAS as well as in other integrated assessments, contextual factors may pose hurdles to progress. For example, the amount of flexibility available to investigators working on integrated assessments can be affected by institutional arrangements that are beyond the control of the project. One potentially serious influence on flexibility is that researchers tend to be extremely busy with their own disciplinary careers and often have research interests beyond those defined within the interdisciplinary project framework. To keep investigators sufficiently engaged in complex interdisciplinary projects, sustained inter-personal and inter-team communications are essential. Another area of concern involves issues of career development. Careful attention must be paid to assuring that participation in interdisciplinary projects does not cause career-related problems, especially for junior/untenured faculty, postdoctoral researchers, and graduate students. Job security and the future careers of these individuals can be negatively affected by a research effort that does not easily fit within academically recognized disciplines. Further, interdisciplinary projects may require a long maturation period and may generate mutually dependent research that produces interdisciplinary deliverables (e.g., publications, joint reports).

For individuals concerned about the timelines and milestones of their own careers, this time span and emphasis on interdisciplinary products may seriously inhibit willingness to participate, particularly when such demands lie largely outside the control of the individual participants. In some cases, researchers' efforts to fit already-existing research agendas into integrated assessment activities can pose problems such as reduced interdisciplinary cohesion and weakness in the fit between researcher knowledge and consequent diminished relevancy to stakeholder applications. Finally, researcher involvement with stakeholders presupposes willingness to participate in a myriad of activities not commonly part of the academic endeavor, such as long-term sustained interactions with constituents, efforts to design methods for communication and delivery of knowledge products, as well as to sustain bi-directional flows of information between project members and stakeholders. These kinds of "extracurricular" activities require considerable commitment from team members as well as acceptance that rewards might be delayed, incomplete, or unhelpful to disciplinary advancement. Careful selection of investigators, proactive management of potential issues, and an environment of open and cordial team relations can go a long way toward addressing these kinds of challenges.

Below, we use selected CLIMAS activities to illustrate different degrees of achievement of iterativity. We discuss the examples based on the model's components of interdisciplinarity, stakeholder interactions, and usable science, and in terms of the three variables influencing them: flexibility, goodness of fit, and resources.

5. Iterativity within CLIMAS

As we observed earlier in this paper, the evolution of CLIMAS as an iterative model for co-production of science and policy emerged slowly and evolved to reflect the vicissitudes of the project's experiences. One of the more successful examples of achieving iterativity in the co-production of science and policy was also one of the earliest: development of a forecast evaluation decision support tool (Hartmann et al., 2002a, b). The project was undertaken in direct response to repeated stakeholder comments that lack of such information was a significant barrier to their use of climate information. Through repeated consultations with potential users and iteration in development of the forecast evaluation products, the level of fit between knowledge produced and stakeholders' steadily increased. Researcher flexibility, in terms of willingness to think across the science-policy divide was essential; in particular, the project's success is in no small part attributable to the flexibility of the primary researcher (who began the task as her Ph.D. project and continues to work on it now as a research scientist), and the researcher's disciplinary department to undertake this cross-disciplinary effort. Later, as the high costs of developing a web-based tool became increasingly apparent, assuring availability of sufficient resources became somewhat problematical, although not insurmountable as the project was able to leverage funds from other sources. The resulting web-based forecast evaluation tool, currently in beta test mode, provides rigorous assessments of the accuracy and skill of climate forecasts across the United States and allows users to examine differences in the two variables over time and space. The interactive tool has broad applicability for decision making in a number of areas, including wildland fire management, water resource management, agriculture, ranching, and energy management.

Efforts to provide useful climate information for wildland fire management provides a second example of how the variables in our iterative model for co-production of science and policy affect interdisciplinarity, production of usable science, and interaction with stakeholders (see Morehouse, 2000b; Garfin and Morehouse, 2001; Garfin et al., 2003). The fire–climate initiative has specifically focused on development of usable science that integrates climate and other information into products needed specifically for strategic planning. The ultimate goal is to reduce risks associated with policies and decisions regarding management of fuels in the region's forests and allocation of resources in anticipation of fire fighting needs during the fire season. Stakeholders and scientists representing a wide range of expertise have participated in the workshops and other interactions with CLIMAS researchers. The co-development of usable knowledge for strategic planning has been the primary objective of the initiative from the beginning. Close interactions with the National Interagency Fire Center (NIFC) throughout the multi-year workshop process have resulted in an ongoing effort to operationalize fire forecasting and related fuels assessments at the national and regional levels (Garfin et al., 2003). The success of this effort lies in part to the high level of flexibility possessed by the researchers and stakeholders who have also collaborated to produce the fire–climate forecast products. Their availability to participate in annual workshops and assist in transitioning fire–climate forecasting from the CLIMAS research mode to operational status has been indispensable to the initiative's goals, and has helped to build the best possible fit between scientific knowledge production and stakeholder needs.

A third example reflects a rapid response to emerging drought conditions in the region. In 2001, several years of dry conditions signaled the start of what looked to CLIMAS scientists to be a significant drought episode in the CLIMAS region. When, in early spring 2002, the first inklings of an El Niño forecast for winter 2002–2003 began appearing, the CLIMAS Core Office embarked on an initiative to inform stakeholders in the Southwest about the interactions between El Niño and existing dry conditions, to encourage use of climate information, and to identify climate information needs that could not be addressed with existing products. Of particular concern was communicating to stakeholders that even if there was a wet-winter El Niño event, it would probably not break the drought. The effort, which began in summer 2002, initially focused on two tasks: working with a group of about 30 stakeholders to assess the usefulness and usability of a suite of drought-related climate products and to track news media coverage of drought and El Niño. The initiative required a sustained commitment of resources (time, personnel, and funds) from CLIMAS, considerable flexibility among CLIMAS researchers, and a substantial commitment of time and goodwill on the part of the stakeholders. The success of the initiative has led to production of a monthly Southwest Climate Outlook, currently being supported by the Bureau of Reclamation to support development of a drought plan for the State of Arizona.[5]

In several instances, for a variety of reasons, iterativity has been less pronounced within CLIMAS. For example, an investigation of the role of climate in producing higher or lower incidences of valley fever (*coccioidomycosis*, a disease endemic to parts of desert areas in Arizona, California and northern Mexico) reflected low levels of interdisciplinarity within CLIMAS and relatively low fit. In terms of interdisciplinarity, the initiative did not require involvement of other project investigators, who lacked expertise in this field. Rather, it emerged from an overlap between the interests of a CLIMAS co-investigator, through one of his graduate students, and a separate—and highly interdisciplinary—initiative being run by the UA Valley Fever Center of Excellence to improve knowledge about and treatment of this disease. The range of stakeholder interactions was relatively narrow in that the primary users were physicians and public health specialists; a second user community included the broader scientific community interested in valley fever. The CLIMAS portion of the project, which aimed to determine the links between climatic conditions and spatiotemporal occurrence patterns of the disease, led to development of an experimental model to predict heightened likelihood of an outbreak following specified sequences of climatic conditions (see Kolivras et al., 2001). However, the fit between science and societal needs was incomplete due to the fact that, while sufficient knowledge was available to develop a successful model experiment, insufficient scientific understanding existed of crucial factors, such as the dynamics of the fungus that is the source of the disease. In terms of resources, the climate-Valley Fever work relied on outside leveraging from the University of Arizona's Valley Fever Center of Excellence. Although not as iterative as other CLIMAS initiatives, this project is a good example of how flexibility enables researchers to take advantage of opportunities to generate relevant science despite the fact that the level of fit between stakeholders' needs and the science produced has yet to develop fully.

In some cases, research is essential to providing scientific foundations for implementing iterative models. In the case of CLIMAS, need was identified early in the

[5] This process, which emerged in summer 2003 in response to proclamation issued by Arizona Governor Janet Napolitano, involves participation of all State agencies whose constituents are impacted by drought and includes a Drought Monitor committee, of which the CLIMAS Program Manager is one of two co-chairs.

project for a synthesis of the state of knowledge about the climate of the Southwest (Sheppard et al., 2002). The research produced an invaluable reference document for subsequent CLIMAS research and public outreach activities, but was not specifically designed to address stakeholder needs, nor did it require sustained interactions with stakeholders or with the CLIMAS social scientists in its production. In other cases, basic scientific research may be required to establish the foundations needed for co-production. Within CLIMAS, snowpack modeling is one example of such efforts. While this effort is directly linked to needs for better snowpack information expressed by river forecasters and river managers, basic research aimed at producing inputs to river forecasting models was required before stakeholder needs could be met. Although substantial interaction with these and other stakeholders to co-produce usable science is anticipated, the high level of expertise needed to develop basic model inputs has required starting with a traditional disciplinary research approach.

6. Conclusions

Co-production of science and policy in the context of integrated assessment activities requires substantial commitment to the three components we have identified: interdisciplinarity, stakeholder participation, and production of knowledge that is demonstrably usable. Interaction among these components determines the degree to which iterativity is generated and sustained between knowledge producers and stakeholders. As illustrated in the CLIMAS examples discussed above, the degree of integration and iterativity that is possible or desirable varies depending on the problem being addressed and the context within which the initiative is being conducted. Resource availability, flexibility, and the level of fit between science and stakeholder needs/expectations interact with the three components noted above to either facilitate or limit the scope of co-production in different situations. In the end, whether the knowledge produced through interactive scientific assessments ultimately gets used may depend on factors beyond the scope of the assessment process itself. Among the many potential barriers to use are lack of resources to implement changes, political impediments, professional resistance to change, and cultural resistance. Further, what science can produce at any given time may not be sufficient to fulfill user needs or expectations. The model we present in this paper, with its emphasis on the value of iterativity, offers a preliminary view of what integrative research means, the level of integration possible under different situations, and examples of some of the different paths that may be taken to achieve integration. In addition, it suggests the extent to which, under different conditions, integration is required to achieve co-production of science and policy. Additional research is required to refine this model. For example, a more structured means of assessing and weighting the various factors that contribute to each of the components is necessary to fully evaluate progress toward stated goals. Additional studies are also needed to refine the list of factors contributing to iterativity, integrative science, and ultimately co-production of science and policy.

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Appendix. The Climate Assessment for the Southwest (CLIMAS) Project

CLIMAS was initiated in 1998 under funding from the NOAA's Office of Global Projects. From the beginning, CLIMAS was explicitly structured to emphasize both interdisciplinarity and stakeholder integration. Initially CLIMAS included five principal investigators from anthropology, geography, hydrology/hydroclimatology, and paleoclimatology, and two affiliated researchers from physical geography/applied climatology and human geography. In recognition of the fact that integration across disciplines and with stakeholders would require concentrated and sustained effort, the project structure also included a Core Office, overseen by a Ph.D.-level Project Manager with the assistance of a dedicated graduate student and administrative staff. Over the course of the next four years, with some changes and additions in PI participation, the project grew to include expertise in resource economics and fire ecology; the Core Office grew to include two postdoctoral researchers and additional graduate students. As anticipated, the Core Office became a key focal point for sustained interactions with stakeholders, the media, other RISAs, and experts working in governmental agencies, non-governmental organizations, and other academic institutions. The investment in the Core Office function has provided the project with a considerable degree of flexibility in initiating research and outreach activities that address unanticipated situations, such as the recent development of sustained drought conditions in the Southwest.

Each of the NOAA-funded RISAs operates on a somewhat different model, in keeping with the experimental nature of the RISA program (see http://

www.risa.opg.noaa.gov). CLIMAS places a strong emphasis on integrating social science in the formulation and pursuit of the project's research agenda. Initial inspiration for the CLIMAS agenda arose from stakeholder concerns voiced at a US Global Change workshop held in fall 1997 (Merideth et al., 1998). The project's agenda was further refined based on the results of a beginning-of-project stakeholder survey conducted by team members in spring 1998 (Benequista et al., 1999), and of a workshop involving water supply forecasters. The findings of these activities led, respectively, to initiation of in-depth ethnographic analysis of climate impacts on rural livelihoods (see Finan et al., 2002) and structured assessment of the skill and validity of climate forecasts (see Hartmann et al., 2002b). Other early research inspired by stakeholder input included assessment of the use of ENSO forecasts in decision making (Pagano et al., 2002), and assessment of the sensitivity of urban water resources in four study areas to severe droughts of one, five, and 10 years' duration (Morehouse et al., 2002).

Several major research activities subsequently emerged in response to changing climatic conditions in the region and the high likelihood of related societal and ecological impacts. For example, an interannual shift from wet El Niño winter conditions to dry La Niña winter conditions between 1998 and 2000 posed unusually high wildland fire risk, leading to initiation of an ongoing series of fire-climate workshops and development of seasonal climate prediction capacity designed specifically for wildland fire management (Garfin et al., 2003; Garfin and Morehouse, 2001), as well as a project funded under the Environmental Protection Agency's Science to Achieve Results (STAR) program (STAR Grant #R-83873201) to build an integrated fire-climate-society GIS model for strategic planning in wildland fire management (see http://walter.arizona.edu). CLIMAS participation on the Arizona Governor's Drought Task Force, initiated in 2003, was likewise linked to deepening drought conditions in the region.

In fall 2004, CLIMAS is embarking on the most focused test yet of its interdisciplinarity and iterativity: a fully integrated assessment of the Little Colorado River Basin, located in the northeastern corner of Arizona and a small portion of northwestern New Mexico.

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