Asking the Right Questions: Atmospheric Sciences Research and Societal Needs

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ABSTRACT

In recent years, those who conduct federally funded research in the United States have been asked by their patrons, the public and their elected representatives, to demonstrate more efficacy with respect to societal needs. Although there is a long record of efforts to improve connections of research with societal needs, a problem exists in that in recent decades the production of scientific knowledge seems to have outrun its effective use by society. Current debate asks questions such as the following: In what different ways has society understood the connections of research with societal needs? What are the implications of such understandings for the structure and conduct of atmospheric sciences research? How can society (and especially sponsors of science) accurately and meaningfully assess the contributions of the atmospheric sciences to societal needs? This paper seeks to shed light on dimensions of these questions through discussion of the relationship of atmospheric sciences research with societal problems. Because the atmospheric sciences have an extended record of experience in connecting research with practical problems, the lessons of that experience have significance for current efforts to improve the relation of the atmospheric sciences with society's needs. In addition, these lessons have broader relevance for more general understandings of the evolving relationship of science and society.

1. Introduction

In recent years, the public and their elected representatives have asked those who conduct federally funded research in the United States to show a more direct connection between their research and societal needs. This trend was reflected in the themes of the 1996 American Meteorological Society Annual Meeting, one of which was the "application of meteorology to environmental and other needs of society." Although there is a long record of efforts to improve connections of research with societal needs (the topic was even discussed at the Constitutional Convention in 1787), a problem exists: in recent decades the production of scientific knowledge seems to have outrun its effective use by society (Brown 1992).

Ongoing discussion and debate about U.S. science policy has focused on a number of questions, including the following: In what different ways has society understood the connections of research to societal needs? What are the implications of such understandings for the structure and conduct of atmospheric sciences research? How can society (and especially sponsors of science) accurately and meaningfully assess and improve the contributions of the atmospheric sciences to societal needs?

This paper seeks, in two parts, to shed light on dimensions of these questions through discussion of the connections of research to societal needs and in the process to stimulate constructive and open dialogue within the atmospheric sciences community about its relation to the broader society. Part one discusses the significance of change in U.S. science policy, which is in a period of transition from a post–World War II paradigm to a new paradigm in which attention to the connections of science and society will be more im-

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In final form 8 August 1996.

portant.[1] The second part continues with a discussion of how "problems" as defined by various societal actors are central to understanding how the atmospheric sciences can establish a better connection with the broader society of which they are a part.

2. Improving the connection of societal needs and atmospheric sciences research

a. The linear model of science and society

Since the end of the Second World War, a linear model of science and society has implicitly and explicitly shaped thinking about the connection of science and the rest of society (Byerly and Pielke 1995). The components of this linear model are so familiar that they are almost second nature: The model begins with basic research leading to applied research, development, and ultimately applications that provide societal benefits (Price and Bass 1969). The model has its origins in Bush's classic 1945 report *Science: The Endless Frontier,* which laid the foundation for postwar U.S. science policy. The linear model is used as a metaphor or model to explain the relationship of science and technology to societal needs. It is used descriptively to explain how the relation actually works and normatively to argue how the relation ought to work. It appears in discussions of both technology policy, where it is used to describe the relation of research and innovation (e.g., Branscomb 1992), and science policy, where it is used to describe the relation of research and societal needs (e.g., Brown 1992). Figure 1 illustrates the linear model.

[1] This paper does not discuss why the change is occurring. See Byerly and Pielke (1995).

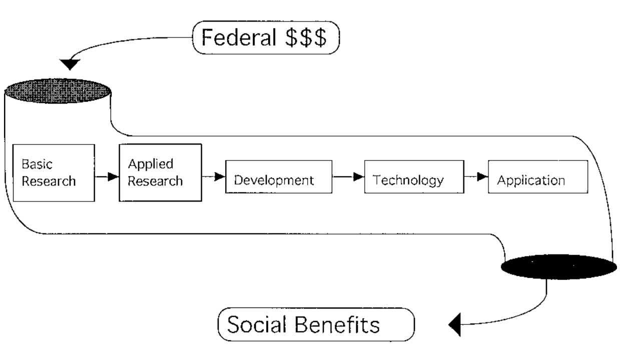

FIG. 1. The linear model of the relation of federal funding for research and resulting societal benefits.

Not only is the model linear, but it is also one way. It links science to society, but conspicuously absent in the metaphor is a return linkage from society to science. The absence of a feedback linkage is explicit in the logic of the linear model; as Bush argued, basic research creates a fund or a reservoir of knowledge from which "the practical applications of knowledge must be drawn" (Bush 1960). The traditional nature of basic research, investigator oriented and curiosity driven, serves to reinforce the isolation of research from societal concerns. A problem arises in that the linear model serves to dissociate the institutions of science from the applications of science. Under the linear model, societal benefits would result no matter where the investigators' curiosity was to lead.

It has been recognized for many years that the linear model serves to isolate science from practical concerns (e.g., Greenberg 1967; Daniels 1967). In recent years the isolation of science from the rest of society has begun to be seen by some as problematic in the sense that "it is not at all clear that advances in science and technology have translated into sustainable advances in quality of life for the majority of the human race" (Brown 1992). Such questioning of the value and usefulness of science has prompted much emotional debate and discussion between scientists and a growing body of vocal critics (e.g., Guston and Kenniston 1994; Kleppner 1993; Lederman 1991). It now seems apparent that the linear model fails to prescribe a healthy normative argument for how the relation of science and society ought to work.

In addition, historians of science have long argued that the linear model is an *inaccurate* description of how science and society are actually connected (Wise 1985). For instance, they have reversed the flow of the linear model and argued that applications often lead to advances in fundamental understanding, as is captured in the frequently repeated assertion that Galileo's discovery of the moons of Jupiter owes more to the technology of the telescope than to the physics of optics. Students of the institution of science have argued that the linear model fails to capture the feedbacks, complexities, and interconnections that have been observed and documented in studies of science and technology (e.g., Kline 1985; Bode 1965). Thus, the linear model fails to accurately serve as a descriptive framework of the relation of science and society.

In short, the linear model fails to describe or prescribe how science and society are or ought to be connected. Perhaps the linear model was appropriate within a context of rapidly rising science budgets; however, its weaknesses have become apparent as science has entered an era of fiscal austerity and demands for a closer connection between the actions of government and the needs of society.

b. An alternative to the linear model: Pasteur's quadrant (Stokes 1995)

As a consequence of change in the environment of science policy, a number of scholars, policy makers, and institutions have considered how U.S. science policy might evolve (e.g., Brunner and Ascher 1992; Brown 1993; National Academy of Sciences, 1993; Carnegie Commission 1993; Mikulski 1994; Tatum 1995; Guston and Kenniston 1994; Byerly 1995; Boehlert 1994; Sigma Xi 1995; National Academy of Sciences 1995). Out of this debate, historian D. Stokes (1995) presents a thoughtful discussion of an alternative to the linear model that helps us move beyond the "grip" that the basic–applied distinction has on how we think about science. Stokes (1995) observes that "the antithesis between basic and applied research still has a remarkable hold on perceptions on both sides. Hence, the policy community easily hears requests for research funding as claims to entitlement to support for pure research by a scientific community that can sound like most other interest groups. Equally, the scientific community easily hears requests by the policy community for the conduct of 'strategic research' as calls for a purely applied research that is narrowly targeted on short-term goals."

Stokes suggests a different way to think about research and its relation to the rest of society. He begins with the one-dimensional linear model, with basic at one end of the spectrum and applied at the other. In his historical study of Louis Pasteur, he found it impossible to describe the man's research by one single point along this spectrum: Pasteur was driven by both a "quest of fundamental understanding and consideration of use" (Stokes 1995). Thus, Stokes simply rotated half of the linear model at its midpoint to create a two-dimensional conceptual plane, with basic and applied forming the two dimensions. Thus, Pasteur's dual objectives could once again be described by a single point in the upper right of the new conceptual plane.

Stokes's alternative to the linear model is shown as a two-by-two matrix in Fig. 2. In the matrix we find the familiar categories of pure basic research and pure applied research. However, a third category has been added, one that is motivated both through consideration of use and a quest for fundamental understanding. Stokes calls this "Pasteur's quadrant" and labels it "use-inspired basic research."[2] In practice, use-inspired basic research ought to be that conducted in any program with stated societal benefit goals.

In the debate over science policy, the concept of use-inspired or problem-oriented basic research has surfaced at times over the years (e.g., Changnon 1976; McElroy 1977) but has never really supplanted the basic–applied dichotomy. The concept ought to be a comfortable one to many in the atmospheric sciences, where consideration of the use and users of meteorological information has a long history (e.g., McKay 1979). One need only peruse the list of speakers at the Symposium on Environmental Applications at the 1996 annual meeting of the American Meteorological Society to see that consideration of the use of this particular field of research receives significant attention. Yet in spite of the advances made in this field, both the perception and reality remain that the atmospheric sciences must do a better job of connecting its basic research with societal needs (e.g., National Science Foundation 1968; Lamb 1981; American Meteorological Society 1988; American Meteorological Society 1992; American Meteorological Society Executive Committee 1995). The concept of "problem-oriented basic research" provides a point of departure to discuss the relation of research and societal needs.

[2] Stokes names the pure basic research quadrant "Bohr's quadrant" in honor of Neils Bohr's quest to understand atomic structure and the pure applied research quadrant "Edison's quadrant" in honor of Thomas Edison's focus on practical applications. Stokes's research is to be published as a book with the title *Pasteur's Quadrant.*

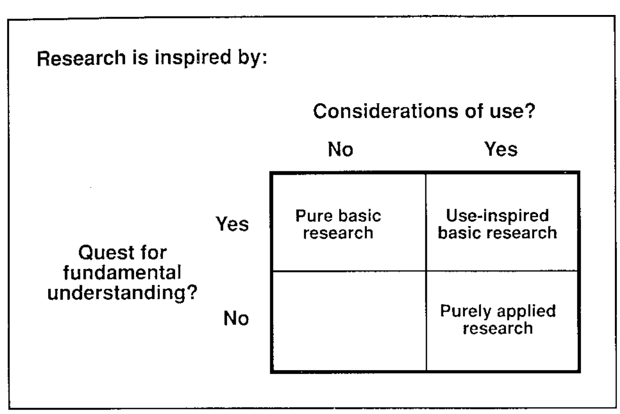

FIG. 2. Pasteur's quadrant, an alternative to the linear model. From Stokes (1995). Figure reprinted with permission of Sigma Xi.

3. Issues, problems, and policies

The characterization of a particular set of circumstances as a "problem" requires attention to who is claiming that a problem exists, their perspectives, and their ability to act (cf. Lasswell 1971). From the standpoint of effective practical action, it is important that a problem be appropriately framed and presented to those with authority and ability to act. There are many examples of modern-day Cassandras who identify important problems that fail to either reach or be understood by decision makers. Hence, the existence of information related to a problem is not a sufficient condition for addressing the problem; attention to a healthy process that actively links that information with a decision maker's needs is also necessary. The following sections discuss how issues become societal problems that create demands for policy action.

a. From issues to problems: Getting on the agenda

Societal problems originate from the universe of "issues," which have been defined as "patterns of events with significance for human values" (Rein and White 1977). For instance, global climate change went from an esoteric scientific issue to an international problem when temperature trend data was associated with societal impacts of climate. Global climate change did not emerge as a policy problem overnight; observers will point out that climate change has been an issue of discussion in scientific circles for more than a century. Why did global climate change, or any other problem for that matter, emerge from the "policy primeval soup" to occupy a place on the public agenda (Kingdon 1984)? Why do problems emerge when they do? What role should the social and physical science communities play in shaping and responding to policy problems? Answers to questions like these lie in a deeper understanding of the role of problems and problem definitions in the policy process.

The first step on the path from issue to problem is a sense of dissonance. J. Dewey, the American philosopher, observed early this century that conscious human action is motivated by a "felt difficulty," that is, "a situation that is ambiguous, that presents a dilemma, that proposes alternatives. As long as our activity glides smoothly along from one thing to another . . . there is no need for reflection" (Dewey 1933). The step from issue to difficulty is an interpretive one. It is the perceptions of people that define which issues are considered important and which are not (Kingdon 1984). A perceived difficulty is not necessarily a problem; "a difficulty is only a problem if something can be done about it" (Wildavsky 1979). To understand or assess whether a particular difficulty is amenable to solution requires reflection, otherwise known as thinking, research, or inquiry. Through conscious thought, a person or a group is able choose a course of action that they expect will improve their condition (this is called "rational" behavior).[3] But before an action can be chosen, alternatives must be available. In most cases the development of alternative courses of action depends on how a problem is framed or defined.

b. What is a problem definition?

People view the world through simplified "maps" or "models" that we create in our minds. Lippmann (1916) referred to this as "the world outside and the pictures in our heads," and cognitive psychologists have explored the phenomena in great detail. Definitions of problems are examples of such maps of the world. Such problem definitions allow for conscious reflection on ends to be sought (e.g., goals) and the means to achieve the desired ends. A problem is a difference between the way things are or seem to be and the way that we would like them to be (cf. Lasswell 1971). Thus, a problem definition contains (explicitly or implicitly) some sense of goals or objectives and some measure of (non-)attainment with respect to those goals. A problem definition is a frame of reference that shapes how people gather, process, and disseminate information about the world outside.

The act of problem definition is integrative and interpretive. Problem definition integrates science with values in the sense that it relates goals (i.e., valued outcomes) to scientific data on trends, conditions, and projections with respect to those goals. It is interpretive in the sense that value differences between individuals or groups often result in different conceptions of the existence, severity, or type of problem.

c. What role do problem definitions play in a policy process?[4]

We use problem definitions to illuminate our social conditions. A consequence of this is that policy

[3] Forester (1984) contains a useful review of the literature on rationality.

[4] The following two sections focus on policy decisions; however the discussion is also appropriate for any situation that requires a decision.

actions are directly tied to how social conditions are framed. For example, if the problem of crime is defined as a consequence of the number of firearms available to criminals, then policy responses would likely focus on limiting or restricting firearm availability. Similarly, if the crime problem is defined as a consequence of a lack of education, then policy responses would likely emphasize a need for education. Because policy actions are so closely tied to problem definitions, it is important to pay close attention to how we define problems and not to allow problems to remained undefined or assumed.

Problem definitions can also blind us to aspects of the world that may be important to the invention, selection, and evaluation of alternative courses of action. Bardwell (1991) presents an example of a water resource controversy in Colorado. Some defined the problem as "we do not have enough water," leading to consideration of a range of alternative actions focused on "getting more water." However, others defined the problem as "we are using too much water," leading to consideration of a range of alternative actions centered on conservation and efficiency. The first definition of the problem blinded participants to a number of alternative response strategies to meet their water needs. How we define our problems often guides actions taken in response. A poorly or misdefined problem can lead to analytical "blind spots" (Stern 1986). Recall the story of the drunk who looked for his keys not where he dropped them, but under the lamp, because that's where the light was.

Because policy actions are highly dependent on how problems are framed, great battles are fought in the public arena over problem definitions. One need only to look at a policy debate to see controversy and debate about how a public issue is framed as a problem; for instance, is logging in the U.S. northwest about jobs for people or habitat for owls? Was the civil rights movement about equality or "states' rights"? Is the space station program about the vision of human spaceflight or high-tech jobs in congressional districts?

d. Problems and the "policy primeval soup"

A number of scholars have explained the dynamics of the transformation of issues on the public agenda to problems by drawing on an evolutionary metaphor (e.g., Carmines and Stimson 1989). Issues emerge from a policy primeval soup to occupy a place on the public agenda (Kingdon 1984). Like their biological counterparts, issues "compete" in a complex environment. In addition, social environments also have a "carrying capacity" that limits the number of issues that can be considered at one time (Hilgartner and Bosk 1988). For example, news stories compete for the finite amount of space on the front page of a newspaper, a congressional committee is limited by available time and staff to conduct hearings, and budgetary considerations often constrain the scientific community.

Issues "evolve" according to a number environmental factors, such as a prominent champion (e.g., the president) or a disaster (e.g., an earthquake) (see Carmines and Stimson 1989 for discussion). For instance, when President Clinton focused on health care shortly after his inauguration, it became an issue of national prominence because of his highly visible and influential position (cf. Theodore Roosevelt's "bully pulpit"). Similarly, most policies to deal with disasters are put in place in the immediate aftermath of an extreme event, like modification to the enforcement of south Florida's building code following Hurricane Andrew. According to Hilgartner and Bosk (1988), drama, novelty and saturation, and culture and politics also influence what becomes defined as a social problem and what does not.

Of course, different people and groups define problems in different ways. The existence of different, often conflicting, problem definitions has political consequences. Even with the same information, value differences between individuals or groups often result in different conceptions of the existence, severity, or type of problem (Rein and White 1977). With regard to the public arena in the United States, such differences are worked out through a process of bargaining, negotiation, and compromise under the provisions of the U.S. Constitution. Often issues evolve through compromise as competing problem definitions move closer together through politics (Schattschneider 1975). Problem definition is further complicated with the existence of uncertain, imperfect, or partial information (Etzioni 1985). Hence, various participants in a decision making process will appeal to (and often selectively ignore) different scientific data for a host of reasons, for example, to justify the primacy of their problem definition over others. Great battles are fought over the meaning and validity of pieces of information central to a problem's definition (e.g., global temperature trends and global warming). Therefore, agreement on a problem definition by a broad range of participating individuals and groups facilitates efforts to act. Any analysis that recommends alternative actions to ameliorate a problem will benefit from explicit definition of the problem to be addressed, including objectives to be achieved and how one might measure progress or lack thereof.

Once an issue becomes defined as a problem or in terms of competing problems, it generally has a finite lifetime. Downs (1972) identified an "issue-attention cycle" in which a particular policy problem "suddenly leaps into prominence, remains there for a short time, and then—though still largely unresolved—gradually fades from the center of public attention." An implication of the issue-attention cycle is that many more societal problems exist than can simultaneously coexist at the focus of public or political attention. The nature of issue dynamics has implications for the design and implementation of science programs that are justified in terms of their contributions to societal goals. For instance, a program ought to demonstrate some use or benefits while a problem is still "hot" or else risk falling off the agenda and suffering a loss of support. An additional factor is that, for many programs, it may not be wise for its supporters to seek undue significant public or political attention to their particular issue, recognizing that after any boom in attention, a bust will likely follow.

To summarize, conditions in society become important from the standpoint of demands for action because people decide that those conditions have an impact on what they value. Politics becomes necessary because people and groups define problems differently and constraints on resources mean that decisions must be made about which problems to address with what level of resources. Consequently, human action is often shaped by how problems are defined and what issues are on the agenda. Issues generally have a finite lifetime of public or political attention.

e. Linking research with societal needs through problems

Defined or undefined societal problems can provide the science community with a natural connection between research and societal needs. For example, a defined problem is the need for aviation safety; it links fundamental research into the nature of freezing rain with a need to make air travel safer. A largely undefined (or unknown to most) problem is ENSO-related impacts of flooding in the Mekong River basin and the opportunity to better mitigate such impacts with information related to ENSO events (Glantz 1995). When defining a problem, clearly some activities will have a closer connection to a societal need than others. However, through consideration of societal problems, in many cases some connection can be made where in the past there was none.

Scientific research often provides insight into new opportunities and alternatives for actions to address problems and sometimes changes the very way that we think about those problems (Mesthene 1967). For instance, with the development of the weather satellite, identification and location of hurricanes allowed for more effective warning and evacuation, thus changing the nature of the hurricane problem. Research into problems associated with supersonic transport led to the discovery of another problem, that of chloroflourocarbon-induced ozone depletion.

4. Practical examples

The concept of problem-oriented basic research poses the following question to the atmospheric sciences community: Of what use to society is atmospheric sciences research? To answer this question under Bush's linear model of the relation of science and society, it would be sufficient to state that research is always useful and leave it at that. However, with the end of the cold war and increasing pressures on the federal budgets, it has become necessary to demonstrate a closer connection between research and societal needs in order to secure and sustain public and political support. One way to do this is to show how societal needs influence the research agenda and, conversely, to show how the research agenda contributes to the identification or resolution of societal problems. The atmospheric sciences community has a head start on many of the other physical sciences because of its long record of connecting its research with the needs of society. Yet the current environment of science means that we must do better. The following five cases illustrate some of the sorts of opportunities that exist in the atmospheric sciences to develop and share with the broader scientific community the idea of problem-oriented research. By taking such opportunities, the atmospheric sciences can become better linked to the needs of society.

a. An untold success story: Wind shear and aviation safety

On 24 June 1975, 122 people died as Eastern Airlines flight number 66 crashed on landing at New York's John F. Kennedy Airport. The accident stimulated a process of interaction between the meteorological research and aviation communities that has led to improvements in airline safety technology and decision making (Fujita 1992). The story of the microburst phenomenon is relatively well known in certain parts of the mesoscale research and aviation communities (e.g., McCarthy and Serafin 1984); however, it is much less well known outside these communities, particularly those aspects of the story related to the close relation of the scientific research and user communities. The case of societal response to wind shear is a success story. Scientists and users of science worked together to identify and address a societal problem. It is likely that the experiences of those involved with this particular successful connection of science and society have much to offer in the way of lessons to the broader meteorological and scientific communities. Yet to be more broadly useful, the lessons of the microburst story must be distilled and related to those outside the group of immediate participants in the meteorological community.

b. A potential success story: Use of ENSO information

Scientists have discovered that increases in sea surface temperature in the eastern and central equatorial Pacific, called El Niño (EN), and differences in atmospheric pressure between the western and eastern Pacific (usually measured between Darwin, Australia, and Tahiti), called the Southern Oscillation (SO), are related to various climate phenomena around the world, especially the Tropics. The production and use of ENSO information provides an opportunity for scientists and users of science to work together on climate-related societal problems. In recent years, there has been increasing attention on the use and value of ENSO information for disaster and famine early warning and agriculture, among other uses (e.g., Glantz 1996). For example, ENSO forecasts and associated teleconnections have been used by decision makers in Australia, Brazil, Canada, Cuba, Peru, North America, Southeast Asia, and southern Africa, with different levels of sophistication and success.[5] The Environmental and Societal Impacts Group at NCAR has held four workshops on El Niño information as "usable science," seeking to bring producers of research and actual/potential users in closer contact (Glantz 1993, 1994, 1995). Based on these workshops, it is clear that the use of ENSO information to help address identified societal problems is an area ripe for additional inquiry that can lead to a better understanding of the connections of atmospheric science and societal needs.

c. What kind of success story?: Stratospheric ozone depletion

Undoubtedly, the case of international policy responses to stratospheric ozone depletion is the most frequently cited example of a successful linking of the atmospheric sciences with a societal problem. Yet there is continuing scholarly debate on the lessons of that success. For instance, scholars variously attribute the primary reason for that success to be the role of diplomacy (Benedick 1991), importance of science (Haas 1991), political skills of agency managers (Lambright 1995), uniqueness of the issue (Doninger 1988), and the existence of a healthy policy process (R. Pielke Jr. and M. Betsill 1996, manuscript submitted to *Res. Policy*). The interpretation by decision makers of the relative importance of these factors is significant because it shapes how they act with respect to current problems that are associated with the ozone issue, with climate change a prime example. The ozone case illustrates the importance of problem definition for purposes of lesson drawing; that is, we do not know the lessons we have learned until we know the problem that we have solved. It seems that in many aspects the scholarly community has yet to converge on an understanding of the lessons of the ozone case; hence its use as a model for understanding and shaping policy responses to climate change must be viewed with some caution.

d. A misdefined problem?: Hurricanes

In recent decades, damages from hurricanes have been rising rapidly in the United States, in spite of the dedicated efforts of many scientists and professionals. For instance, by 1995 the 1990s had already seen more damages than were experienced in the 1970s and 1980s combined (even after accounting for inflation). The rapid rise in hurricane-related damages has led many to mistakenly conclude that severe hurricanes have become more frequent in recent decades. For instance, a 1995 Congressional report on federal disaster assistance incorrectly asserted that hurricanes "have become increasingly frequent and severe over the last four decades as climatic conditions have changed in the tropics." (Bipartisan Task Force on Funding Disaster Relief 1995). In fact, the past several decades have seen a decrease in the frequency of

[5] See, for example, Battisti and Sarachik (1995), Lagos and Buizer (1992), and Glantz (1993, 1994, 1995).

severe storms, and the period of 1991–94 was the quietest in at least 50 years (Landsea et al. 1996). Others believe that hurricanes are no longer a serious threat. Consider the following lead to a Reuters news article: "Great killer hurricanes, like those seen in decades past, appear to be gone forever from the shores of the United States because of early warning systems" (Reuters News Service 1996). In contrast, in 1995 the director of the U.S. National Hurricane Center wrote that a "large loss of life is possible unless significant mitigation activities are undertaken" (Sheets 1995). Taken together, the decrease in intense hurricanes coupled with the rapid rise in damages and apparent complacency lead to a troubling conclusion: The United States is today more vulnerable to hurricane impacts than it has ever been. The increased damages seen in recent years is largely a function of increased societal exposure to hurricanes rather than increased storm incidence. National hurricane policy is one area where decision making can clearly be improved through a closer connection of the atmospheric sciences with decision making (cf. National Mitigation Strategy 1995).

e. An incomplete problem?: Global warming

What problem does climate change pose to societies? There have been many answers presented to this question. For some, it is the risk of a catastrophic change in climate; others expect few changes and minimize the issue as a problem. For many in between, global warming is a matter of regional climate perturbations. For instance, the cover of the 22 January 1996 *Newsweek* magazine carried the following title: "THE HOT ZONE: Blizzards, Floods, and Hurricanes: Blame Global Warming." In spite of their disagreement about the possible impacts of climate change, for each of these groups the problem has been defined as "global warming: yes or no"? One of the largest scientific assessment processes of all time, the Intergovernmental Panel on Climate Change, has been established to address this question. But will a conclusive answer to global warming: yes or no? provide societies with the information that they need to respond to a changing climate? The answer is clearly no. The problem of global warming is much more complex than the simple yes or no debate implies. Yet it seems that much more scientific, political, and public attention is focused on addressing the yes or no question than in developing problem definitions that can lead to effective actions. Thus, the possibility exists that global warming is an incompletely defined problem.

5. Recommendations: On asking the right questions

As the environment of science policy continues to change, one feature of that change stands out: both the scientific community and the society of which it is a part will benefit from a closer connection between research and societal needs. This paper has sought to discuss a number of issues in forging that closer connection and from that discussion I offer the following three recommendations, focusing on what needs to be done and how it might be achieved.

- There is a need to include a process of problem definition as a formal or informal part of any atmospheric science program with stated societal benefit goals. Programs that are justified on the basis of their contributions to society ought to explicitly include or link problem-oriented research to the topic of the actual/potential usefulness of the program's scientific results. This can best be accomplished by creating processes such as workshops, advisory committees, and collaborative research that bring together researchers and the users of research (cf. Pielke et al. 1996).
- In the process of problem definition, there is a need for collaboration across disciplinary and professional lines. Problems exist across disciplines and professions. Thus there is a continuing need for closer collaboration between physical and social scientists and practitioners. This could be achieved by including social scientists and users of research in the scientific planning process from the outset. Social scientists and users must be accepted as full partners in the process of focusing science on societal problems, not simply token participants. Similarly, user groups must reach out to the scientific community. Professional societies, of both scientists and practitioners, ought to encourage this cross-fertilization.
- There is a need to document and disseminate case studies—and the lessons therein—of successful connections between atmospheric sciences research and societal needs. There is also a need to understand why research programs sometime fall short of their societal benefit goals. More effort and resources need to be placed on looking back and seeking to answer the question "How did we do?" All programs with stated societal benefit goals should periodically be evaluated with respect to those goals. The national academies and federal

science agencies should sponsor such reviews, in a manner similar to how they currently evaluate scientific progress.

Ultimately, it is the atmospheric sciences community that must be responsible to ensure that the problems it seeks to address are well defined, that social scientists and users are included in the problem definition process, and that the lessons of experience are distilled and disseminated. Current change in the environment of U.S. science policy means that if the science community does not take on these responsibilities to better link research with the needs of society, they will fall to those with little understanding of or concern about science, or worse, simply be ignored. In either case it will likely be the atmospheric sciences that suffer directly as a result (e.g., possible loss of funding and public and political support). Because the atmospheric sciences have a long track record of connecting their research with the needs of society, they are well positioned to make a transition from the postwar paradigm of a linear relation of science and society to a paradigm of use-inspired research. A focus on societal problems can facilitate that transition.

Problems are at best an approximation of a societal need. Yet by considering societal problems from the outset, research efforts with societal benefit goals can establish a connection with a societal need, which might make a difference in their ability to demonstrate its use and value to society. Furthermore, research programs that explicitly consider societal problems in their implementation may improve their contributions to the resolution of those problems. To paraphrase Stokes, they can inspire use through the asking of the right questions.

Because society undergoes constant change, our problems evolve. Consequently, there is a constant need to remain vigilant as to the nature of the relationship between scientific research and society. In many cases, securing the use of science to aid in addressing societal problems is a difficult and challenging task. However, it is a surmountable challenge that will in the long run prove to be beneficial to both the institution of science and the broader society of which it is a part.

Acknowledgments. This is a paper prepared for a panel on Atmosphere, Environment, and Society, organized by R. S. Pulwarty at the 1996 Annual Meeting of the American Meteorological Society, held in Atlanta, Georgia. I would like to thank Radford Byerly, Stanley Changnon, Theodore Fujita, Michael Glantz, Christopher Landsea, Robert Serafin, and two anonymous reviewers for valuable discussions and suggestions during the preparation of this manuscript. I would also like to acknowledge the assistance of the NCAR director's office. Any errors of fact or interpretation are the author's responsibility.

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