PROBLEM DEFINITION IN ATMOSPHERIC SCIENCE PUBLIC POLICY

The Example of Observing-System Design for Weather Prediction

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To help atmospheric scientists contribute more effectively to societal decision making, this article describes and illustrates the importance of problem definition in atmospheric science policy, using the example of observing-system design for weather prediction.

Information about weather, climate, and related phenomena contributes to many public policy decisions, on topics ranging from natural hazards to environmental regulation to climate change. In addition, much of the atmospheric science community relies on data, research funding and results, and operational products provided by governments—in other words, on resources allocated through public policy decisions. Consequently, all atmospheric scientists—those seeking to help society address important issues, and those seeking primarily to advance science—have an interest or stake in public policy. Yet the processes of science and public policy are sufficiently different that atmospheric scientists often find it challenging to contribute effectively to atmospheric science policy.

One public policy issue currently of interest to both atmospheric scientists and policy makers is designing a cost-effective, integrated global observing system (e.g., Emanuel et al. 1997; NRC 1998; Shapiro and Thorpe 2003; Lautenbacher 2003). Although observing-system design has been discussed in the atmospheric science community for decades (e.g., WMO 1967; NRC 1969, 1980),[1] atmospheric scientists still struggle with connecting atmospheric science research and development to policy decisions on observing systems. A common approach is to address scientific and engineering aspects of observing systems, then add a societal or policy component as needed to market the scientific "solution." Unfortunately, as scientists who

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DOI:10.1175/BAMS–86–2–181

In final form 20 September 2004

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[1] For a brief review, see Morss et al. (2004).

have been involved in public policy can attest, such an approach often fails to convince policy makers to implement proposed observing-system modifications or fund additional atmospheric science research and development. Because it develops scientific and technical solutions without fully considering the societal context in which they will be used, this approach also limits our ability to design improved observing systems for the benefit of meteorology and society.

Public policy researchers have developed ways of thinking about such issues that can benefit atmospheric scientists. From a policy perspective, problems are human constructions: a situation (such as the observing system) becomes a problem only when people perceive the situation as different from what they would like.[2] Any "problem" can therefore be interpreted in numerous ways, depending on a person's perspective and values. The way a person perceives a problem, referred to as his or her problem definition,[3] has a major influence on how he or she believes the problem should (or should not) be addressed.

Public problems are also social constructions; they are interpreted and addressed in a complex public arena that contains numerous participants with different perspectives and values, in other words, with different problem definitions. Within this arena, potentially problematic situations grow and decline in prominence, policy options are developed and matched with different issues, and problem definitions emerge and evolve.[4] Because problem definition has a major influence on problem solution, convincing others to define a problem in a certain way (or simply to view it as problematic) can be a major step toward gaining support for a policy option.

These lessons from public policy research suggest that problem definition is important in atmospheric science for at least two major reasons: it affects how we address policy-related issues, and it affects how successfully we advocate our preferred public policies. This importance of problem definition is evident in several historical and ongoing examples in the atmospheric and related sciences, including acid rain (e.g., Herrick and Jamieson 1995), U.S. hurricanes (Pielke 1997b), and climate change (e.g., Sarewitz and Pielke 2000a). Problem definition is therefore not just an academic exercise; it affects us and our science. By learning to analyze and synthesize problem definitions, atmospheric scientists can learn to formulate atmospheric science issues in a way that integrates science and public policy perspectives, benefiting science, policy, and society.

To help atmospheric scientists develop such a capacity, this article examines the intersection of atmospheric science, policy research, and policy decisions—the red-shaded area in Fig. 1. It focuses on the importance of how atmospheric science policy problems are defined,[5] illustrated by presenting and examining alternate problem definitions for the example of observing-system design. It closes by discussing three guiding principles on problem definition for atmospheric scientists considering policy issues. In doing so, the article aims to help the atmospheric science community contribute more effectively to societal decision making—not only on observing-system design, but also on other topics.

THE IMPORTANCE OF PROBLEM DEFINITION.

To introduce the importance of problem definition in atmospheric science policy, this section discusses some of the ways that a person's problem definition affects how he or she analyzes and communicates about policy options. It also discusses attributes of problem definitions that help or hinder balanced analysis and effective communication—attributes that will be echoed in the examination of alternate problem definitions that follows.

The discussion is organized by dividing problem-solving into components, using an idealized model of how people analyze information to make decisions. This decision-making model is (like all models) simplified and incomplete, and thus does not describe how

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[2] Problems are sometimes defined not simply as discrepancies, but as discrepancies that something can be done about, or as opportunities for improvement. For further discussion, see, for example, Dery (1984), Kingdon (1984), Pielke (1997a), and references therein.

[3] Other terms include problem formulation and problem frame. See, for example, MacRae and Wilde (1979), Bardach (1981), Dery (1984), Bardwell (1991), Rochefort and Cobb (1993, 1994), and Pielke (1997a).

[4] For further discussion of problem identification, framing, and definition in the public arena, see, for example, Kingdon (1984), Schön and Rein (1994), and Stone (2002).

[5] Note that public policy is a rich field, containing a diverse, interwoven set of concepts applicable to the atmospheric science/public policy interface. By focusing on the analytic lens of problem definition and its role in analysis and communication of policy options, this article addresses other relevant concepts only generally (an unavoidable limitation of a single introductory article). For further introduction to relevant public policy concepts, the reader is referred to the overviews in Birkland (2001), Clark (2002), Pielke (1997a), and references therein, along with the references cited elsewhere in this article.

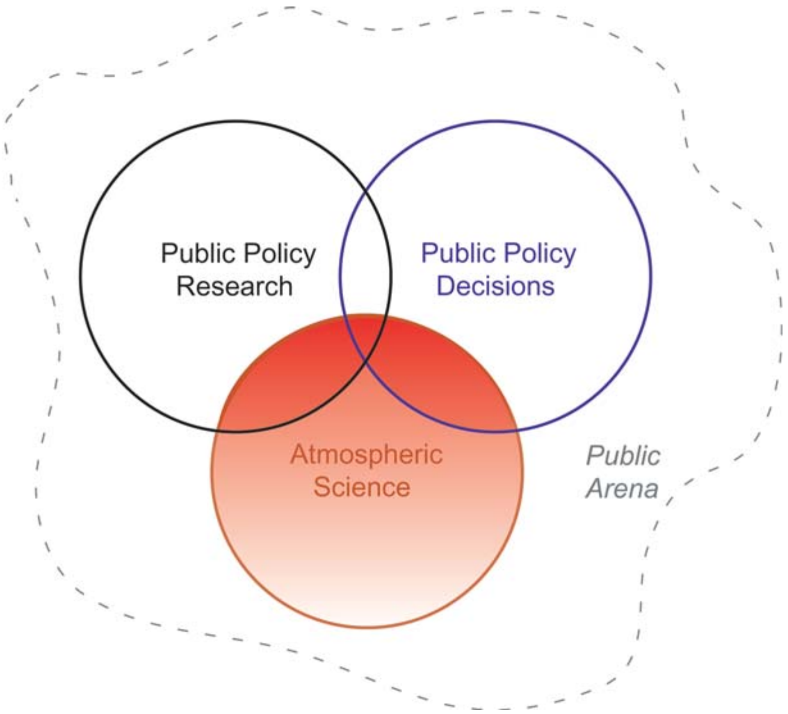

FIG. 1. Schematic illustrating the focus of the article: the intersection among atmospheric science, public policy research, and public policy decisions within a complex, nebulous public arena. The article addresses both the dark red–shaded area, where atmospheric science influences public policy research and decisions, and the lighter red–shaded area, where public policy and the public arena influence atmospheric science.

most policy decisions are actually made. However, it is frequently used in the public policy (e.g., Lasswell 1970; Stokey and Zeckhauser 1978; Patton and Sawicki 1986; Bardach 2000) and decision analysis (e.g., Patton and Sawicki 1986; Clemen 1997; Hammond et al. 1998) arenas to identify major components of decisions. These components include defining the problem, selecting criteria for evaluating alternative solutions, selecting a set of alternatives to consider, connecting the alternatives with the criteria by predicting the alternatives' effects, and selecting among the alternatives. In public policy decision making, the recommended alternatives are then communicated with participants in the policy process.

Defining the problem. Problem definition sets the stage for the other components of the decision process, and thus is a key aspect of policy decision making. When analyzing and communicating policy options, a person can develop a problem definition consciously, by considering relevant information and perspectives, or unconsciously, by accepting his/her preconceived notions or a problem definition proposed by someone else.[6] Insufficient attention to problem definition can lead to many analysis pitfalls, including incomplete consideration of goals, substitution of means for ends as the focus of problem solving, blind spots, and justification of solutions by defining them into the problem instead of using evidence to construct a coherent argument. These can lead to communication pitfalls, particularly when one attempts to discuss or advocate policy options with people who approach the issue from a different perspective.

Although problem definition can appear deceptively simple, these potential pitfalls mean that even subtle details of one's problem definition can be important. As a result, constructing a problem definition is generally considered a key component of formal policy analyses, and is often quite time consuming. To motivate the importance of conscious, careful problem definition, the remainder of the article describes, illustrates, and discusses these pitfalls (and others) in further detail. The process of problem definition is not addressed extensively, although it is illustrated through the sequence of problem definitions provided later. Initial suggestions for defining atmospheric science policy problems are also provided in the final section of the article.

Selecting criteria for evaluating alternatives. In defining problems, people invariably state or imply unmet goals. These goals form the basis for interpreting how well alternative solutions address the problem. In this way, a person's problem definition has a large influence on the criteria he or she uses to evaluate alternatives. For example, defining an education "problem" by citing low student test scores suggests a different

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[6] Note that this individual process of problem definition is different from (but connected to) the societal process of problem definition, in which public problems are defined and redefined through discussion and debate in the public arena. Although this public process of problem definition is not addressed explicitly in this article, it is also a key aspect of policy decision making. See, for example, Kingdon (1984), Rochefort and Cobb (1994), Schön and Rein (1994), Pielke (1997a), and Stone (2002).

criterion than describing the same situation using student drop-out statistics.

If a person's problem definition omits relevant goals, he or she is likely to use incomplete criteria, and thus to overlook important outcomes (MacRae and Whittington 1997; Weimer 1998; Weimer and Vining 1999). A problem definition that focuses on means rather than ends—for example, on teachers rather than educational outcomes—tends to generate criteria that do the same, prematurely limiting the set of alternatives considered (MacRae and Whittington 1997; Weimer and Vining 1999). And although vague problem definitions can help generate consensus, they also allow multiple interpretations of goals, complicating developing clear criteria and obtaining agreement on solutions.

Selecting alternatives to consider. A person's problem definition includes his or her interpretation of the most important aspects of the issue and how they connect. The factors and causal relationships in this conceptual model suggest possible interventions, in other words, alternative solutions (e.g., Stokey and Zeckhauser 1978; MacRae and Whittington 1997; Bardach 2000). For example, a model that connects the student–teacher ratio with educational outcomes suggests alternatives related to the number of teachers and class size, while a model that also includes teacher contact time as a causal factor suggests additional options, such as lengthening the school day. In this way, problem definition plays a key role in determining which alternatives one considers—and which alternatives one does not.

Problem definitions that deemphasize or neglect important dimensions of an issue can "limit understanding and narrow analysts' vision," creating "blind spots" in which people will not see potentially valuable alternatives (Stern 1986, p. 200). The extreme case is when a person "smuggl[es] an implicit solution into the problem definition" (Bardach 2000, p. 7)—for example, by incorporating the statement "we don't have enough teachers." Such problem definitions lead one to neglect other options, including no intervention (which is always an option, since resources are limited). Such problem definitions also encourage justifying recommendations using assumptions rather than evidence (Bardach 1981, 2000). At best, this slants analyses or evaluations toward certain options; at worst, it makes them self-fulfilling exercises. Such problem definitions also fail to convince people with other points of view to support one's recommendations.

Predicting alternatives' effects. To predict alternatives' effects, people use models (e.g., conceptual, mathematical, numerical) of the problem, derived from existing knowledge (e.g., Stokey and Zeckhauser 1978; McRae and Whittington 1997; Weimer and Vining 1999; Bardach 2000).[7] People's problem definitions influence their predictions by indicating where to look for predictive models. For example, problem definitions that focus on economic aspects of education suggest using economic concepts for prediction, whereas definitions that focus on psychological or sociological aspects suggest other approaches (e.g., Stern 1986; Dunn 1994).

If a person's problem definition omits important aspects of the issue, he or she is likely to neglect intervening factors, side effects, or other important considerations when predicting alternatives' effects. More generally, assumptions embedded in problem definitions will be incorporated into predictions. If these assumptions are invalid, inappropriate, or outdated, the predictions are likely to be inaccurate (e.g., Ascher 1978). Such assumptions may also mask sources of uncertainty, leading to overconfidence in predictions and failure to consider alternate outcomes. And when predictions are inaccurate or overconfident, recommendations are likely to fail to achieve the desired results.

Selecting among alternatives. What appears to be the best solution is determined largely by the criteria, the alternatives considered, and the alternatives' predicted effects. By influencing these, people's problem definitions naturally play a key role in which alternative they select.

Often, however, different alternatives best satisfy different criteria, so that no alternative is clearly preferable. When this occurs, selecting among alternatives requires weighting the criteria and making trade-offs among them, which is necessarily a subjective process. One can try to avoid appearing subjective by combining the criteria—for example, by combining costs and benefits of education into a single number. However, doing so simply subsumes trade-offs (in this case, between what society is willing to spend on education and what it achieves) into the choice of criterion. Leaving trade-offs explicit, on the other hand, reduces hidden value judgments and increases transparency, enhancing credibility (MacRae and Whittington 1997; Weimer and Vining 1999). Consequently, problem definitions that neglect or subsume important trade-offs can lead to inadvertently biased evaluations and unpersuasive recommendations.

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[7] As this suggests, aiding prediction is a major (but not the only) role of scientific research in public policy. For further discussion, see, for example, Ascher (1978), Brunner (1999), Byerly (2000), and Sarewitz and Pielke (2000b).

More generally, problem definitions influence selection among alternatives by guiding how choices are framed. As shown by idealized decision-making experiments, "seemingly inconsequential changes" in framing a choice, such as presenting options in terms of losses rather than gains, can cause "significant shifts of preference" (Tversky and Kahneman 1981, p. 457). Although results from idealized contexts are not directly transferable to real-world decision making (e.g., Stewart 1997), the range of framing effects that have been demonstrated (e.g., Nicholls 1999) suggests that even subtle aspects of problem definitions can influence which alternative is preferred. Thus, even seemingly minor details in the language used to define a problem can be important (e.g., Stone 2002).

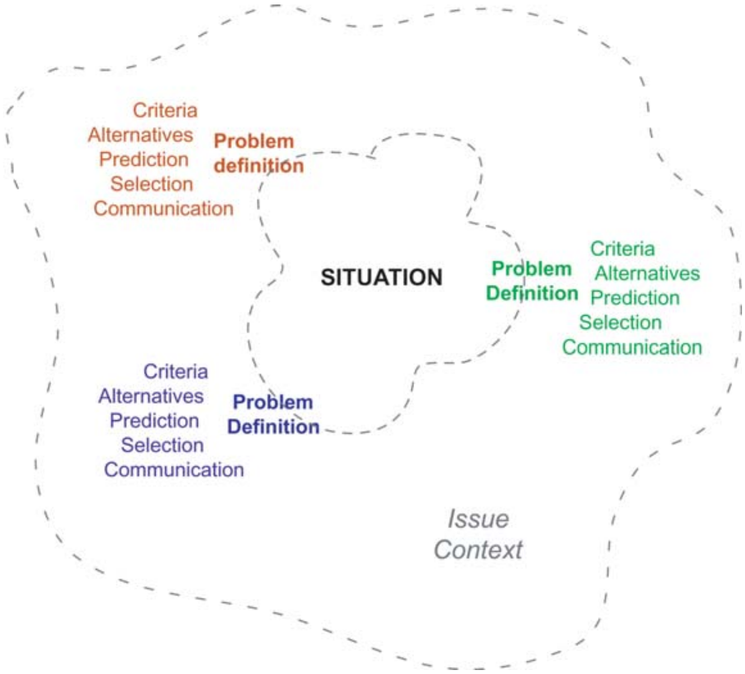

Fig. 2. Schematic illustrating how a situation and its context can be interpreted using different problem definitions, each of which may lead a person down different solution and communication paths.

Communicating recommendations. Public policies are developed and implemented in the public arena, through the collective decisions of multiple actors. Thus, a key aspect of achieving one's policy goals is communicating recommendations to diverse audiences. Important audiences may include other researchers, stakeholders (affected parties), and decision makers in various roles.

Because a person's problem definition represents his or her perspective on an issue, it naturally influences how he or she communicates which policy actions are recommended and why. Audiences who disagree with how a person defines a problem are almost certain to disagree with his or her criteria, alternatives considered, predictions, and/or evaluation, and thus with his or her analysis and recommendations. The extreme case is a problem definition that contains unshared assumptions. For example, the problem definition "new schools are being built too slowly to improve student test scores" (modified from Bardach 2000, p. 5) assumes that 1) the goal is improving test scores, 2) the solution is more schools, and 3) building more schools will improve test scores. Audiences who do not share these assumptions will view the analysis as slanted, irrelevant, or invalid—and may not even perceive the situation as problematic. In such situations, the audience is unlikely to be persuaded to act on the recommendations.

These effects of problem definition may not be noticeable when one communicates with people who share one's perspective—for example, when an atmospheric scientist communicates with other atmospheric scientists. However, to communicate effectively with audiences who have different knowledge, experience, and values, it can be crucial to use a problem definition that incorporates (or at a minimum, acknowledges) their perspective.

ALTERNATE PROBLEM DEFINITIONS FOR OBSERVING-SYSTEM DESIGN.

As depicted in Fig. 2, any policy issue can be approached using different problem definitions, each of which may lead down different paths. To illustrate how this can occur, this section presents and discusses five alternate definitions of the "problem" of observing-system design for weather prediction.

Each of the sample problem definitions is examined according to its effects on analysis and communication of policy options, using the concepts introduced in the previous section. Aspects of the problem definitions that may cause difficulties are identified, then modified in subsequent problem definitions. The sequence therefore generally increases in complexity, scope, and breadth of perspective, building toward a recommended problem statement for observing-system design. Developing such a problem definition would then be the first step in a formal policy analysis of observing-system options.

Note, however, that observing-system design is not only a problem, but also a policy recommendation that addresses broader societal issues related to weather, climate, and the environment. Thus, to some extent, all of the sample problem definitions that are presented here have problems and solutions intertwined. While this is not an uncommon feature of problem definitions (e.g., Bardwell 1991; Rochefort and Cobb 1993), it might be preferable to expand the problem definition to consider observing-system design in its broader context, in order to compare observing-system design with other alternatives that might help achieve the same goals. This broader context is considered when discussing the final sample problem definition.

The five sample problem definitions were constructed by synthesizing statements about the meteorological observing system from the literature, discussions at scientific meetings, and informal conversations. Although specific references are not provided, readers familiar with the issue will recognize many elements. The first few problem definitions are based on the type of statement atmospheric scientists often use or have in mind when advocating observing-system improvements, or when discussing observations within the atmospheric science community. In doing so, atmospheric scientists are (subconsciously) using such statements as their problem definition for observing-system design. As is evident from the discussion, these problem definitions have undesirable attributes for analyses of policy options, and thus would not generally be labeled "problem definitions" in a policy analysis context. Here, however, different problem definitions that would often remain implicit, as people's abstract conceptions of an issue, are stated and examined explicitly, as a mechanism for demonstrating the importance of how issues are framed.

> Problem definition 1 (PD1): The observing system should be improved because doing so will improve weather forecasts, which will benefit society.

PD1 defines the solution "improving the observing system" into the problem, implicitly rejecting the option of no intervention. In doing so, it assumes that the observing system should be improved, without providing a framework for deciding the form of those improvements. People who disagree with this assumption or wish to compare different options are unlikely to be convinced to support the general recommendation. Moreover, the goal suggested by PD1, "societal benefit," can be interpreted in many ways, which means that different people will use different criteria. Thus, although PD1 can be (and often is) used for *advocating* observing-system improvements of any type, it is inadequate for evaluating or designing observing systems, or for communicating about observing-system design with many audiences (particularly those outside the atmospheric science community).

> Problem definition 2 (PD2): Each year, extreme weather–related events, such as tornadoes, floods, and heat waves, cause deaths, injuries, and property damage. By improving weather forecasts, improving the observing system will decrease these losses.

Although PD2 softens PD1's advocacy phrasing, PD2 still assumes that improving the observing system is better than no intervention. By neglecting a comparison with the status quo, PD2 neglects another potentially important criterion: the improvements' costs—and costs are nearly always a consideration, since resources are limited. Like PD1, PD2 also provides no structure for comparing different observing-system improvements.

PD2 refines the goal "societal benefit" from PD1, suggesting that observing-system improvements be evaluated according to deaths, injuries, and property damage caused by extreme weather–related events (hereafter referred to as *extreme events*). Although these represent important societal goals that are related to weather forecasts, the range of goals they represent is limited. Society is harmed by extreme events in other ways, for example, through general misery and economic disruption. Members of society also use weather forecasts in "routine" (nonextreme) weather situations, and to increase gains (e.g., by facilitating more efficient use of resources) as well as decrease losses. PD2 suggests using criteria that neglect these important uses and effects of weather forecasts.

PD2 also implies that improving the observing system *will* improve weather forecasts, which *will* decrease losses due to extreme events. Although these predictions are often valid, they cannot be assumed a priori. Improving the observing system does not always improve weather forecasts because factors such as the data assimilation system, the numerical prediction model, and limits of atmospheric predictability may intervene (e.g., Morss and Emanuel 2002). And improving weather forecasts does not always decrease societal losses because losses may be dominated by other factors, such as population changes, economic factors, and the capacity and willingness of people at risk to take protective action (e.g., Pielke and Landsea 1998; Drabek 2000). A person using PD2 is likely to incorporate these assumptions into his or her predictions, and thus to predict outcomes that are (at best) overoptimistic.

Considering observing-system design using PD2 would therefore likely generate recommendations that focus on forecasting extreme events, with little concern for costs. In the extreme, this suggests a very costly observing system, with observing platforms that are capable of taking data nearly everywhere, but with most observations taken only when an extreme event is expected. PD2 is also likely to lead one to oversell the benefits of the recommended observing-system improvements, and perhaps to recommend improvements that will not reduce losses. Thus, PD2 remains inadequate for evaluating or designing observing systems. Moreover, for people who understand that forecasts have multiple uses and that resources are limited, or who recognize the invalid assumptions in PD2, recommendations communicated using PD2 are unlikely to be persuasive.

> Problem definition 3 (PD3): Weather forecasts help individuals and organizations decrease losses and increase gains due to extreme weather–related events, routinely disruptive weather, and good weather. Improving the observing system can improve weather forecasts, benefiting people more than it costs.

PD3 expands PD2's suggested criteria to include decreased losses and increased gains in three types of weather situations: extreme events, routinely disruptive weather, and good weather (situations adapted from Pielke and Carbone 2002). It also adds to the criteria the improvements' costs. By comparing benefits with costs, PD3 implies comparing observing-system improvement with the status quo. However, this still does not provide a framework for comparing alternative cost–beneficial improvements.

For one to choose to adopt a proposed observing-system improvement, PD3 requires only a lower-bound estimate of benefit to people that exceeds costs. PD3 suggests measuring benefit according to the forecast improvements' effects on individuals and organizations. At first glance, it might appear that this lower bound could be calculated by estimating large benefits to specific entities until together they exceed costs. However, because individuals in society interact, estimating societal benefit also requires accounting for indirect effects. Take, for example, an idealized (short term) example of two companies operating in the same market: Company A is able to use improved weather forecasts to decrease the costs of production and lower its product's price, but company B is not. While company A's sales and profits will increase, company B's sales and profits will decrease—in other words, company A's benefits are partially offset by company B's losses. Thus, one entity's benefit is not necessarily a lower bound of societal benefit (for a more detailed explanation, see, e.g., Freebairn and Zillman 2002). One can imagine similar examples, with winners and losers, based on geographic location, socioeconomic class, and so on. The benefits and costs of modifying the observing and forecast system therefore depend on who one considers. The phrases "routinely disruptive weather" and "good weather" are then also ambiguous, since what is good weather for one person can be routinely disruptive (or extreme) for another.

Moreover, by requiring only a lower-bound estimate of benefit, PD3 encourages estimating only those benefits that are largest and easiest to measure. Although the tendency to focus on benefits that are easily measured is common (e.g., Weimer and Vining 1999), it can lead to several types of difficulties. First, estimating benefits to specific entities without considering the potentially offsetting effects on others is likely to significantly inflate predictions of observing-system improvements' positive effects. Second, focusing on easily measured benefits biases estimates of benefits toward certain types of benefits. If such an estimate of benefit is used to compare observing systems, one may inadvertently direct public resources to benefit specific groups—groups that are selected only because their benefits are easily measured. PD3 can therefore lead to biased evaluations of observing systems, and it is insufficient for selecting among several observing-system improvements.

Finally, the phrases "improving the observing system" and "improve weather forecasts" in PD3 are ambiguous and contain embedded value judgments. Improving the observing system can be interpreted narrowly, to mean adding new or improving existing observing platforms, or, more broadly, to include reallocating resources among existing platforms or making the existing system adaptive. More generally, whether an observing-system modification is an improvement or not depends on one's perspective, and forecast improvement can depend on the verification (evaluation) measure. This phrasing also prematurely limits the alternatives and outcomes considered; for example, when budget cuts are possible, observing-system and forecast degradations may need to be considered (e.g., Doswell and Brooks 1998). Overall, therefore, PD3 still provides an inadequate framework for observing-system evaluation and design.

> Problem definition 4 (PD4): Modifying the observing system affects weather forecasts, which can affect societal losses and gains in a range of activities. Which of the proposed observing-system modifications will

i) maximize the (positive) difference between societal benefits and societal costs?
ii) maximize the ratio of societal benefits to societal costs?
iii) minimize societal costs yet provide societal benefits of at least Y?
iv) maximize societal benefits yet cost society less than X?

PD4 provides a structure for evaluating, comparing, and selecting among a range of observing-system modifications, and it recognizes the trade-offs between aggregated societal costs and benefits in doing so. Unlike PD1–PD3, therefore, PD4 could provide a framework for observing-system design. However, to avoid explicit trade-offs, PD4 reduces the cost and benefit criteria to a single criterion. Four choices for doing so are offered: i) and ii) combine costs and benefits into a single measure, while iii) and iv) use one as a criterion and the other as a constraint. Unfortunately, the different norms can produce different answers,[8] and the most appropriate choice depends on the circumstances.[9] In addition, although PD4 avoids PD3's potentially biasing suggestion to measure effects on individuals, combining effects on multiple activities into a single measure of "societal benefit" is still a conceptual and practical challenge. Combining all costs and benefits into a single criterion may also be unsatisfactory because some costs and benefits may be most appropriately measured in different units. A more general approach would be to formulate the problem using multiple criteria, recognizing the inevitable trade-offs involved in public policy decisions.

The phrasing "observing-system modifications" in PD4 may also focus the alternatives considered on incremental changes, rather than dramatically different configurations (which may or may not be desirable, depending on the context). In addition, PD4 suggests that it is possible to predict which observing-system modification *will* best satisfy the criterion. In reality, the many links between observations and societal outcomes make such predictions fairly uncertain—and neglecting uncertainty in predictions can produce recommendations that are unrealistic and unpersuasive.

> Problem definition 5 (PD5): Weather forecasts help society protect life and property and enhance the national economy. What configuration of the observing system is most likely to produce weather forecasts that will help society realize these goals, accounting for the societal costs of implementing the modified observing system?

PD5 represents U.S. society's goals with respect to weather forecasts in terms of the U.S. National Weather Service (NWS) mission: to provide forecasts and warnings "for the protection of life and property and the enhancement of the national economy" (NWS 2003). By framing societal goals using the stated goals of the NWS, a U.S. agency overseen by a representative government, a person using PD5 to design, evaluate, or advocate observing systems can make a straightforward, convincing argument that his or her results and recommendations support U.S. society's collective goals with respect to weather prediction. Similar statements of goals could be developed for other countries, or for the international community based on World Meteorological Organization goals.

These goals in PD5 suggest at least four criteria: protection of life, protection of property, enhancement of the national economy, and societal costs. Rather than combining these goals into a single criterion, PD5 suggests evaluating observing-system alternatives using a "multigoal" or "multicriteria" analysis. To guide the necessary trade-offs, one can construct and use a matrix like that depicted in Table 1 (e.g., MacRae and Whittington 1997; Weimer 1998; Weimer and Vining 1999).

These goals are sufficiently general, however, that evaluating options still requires translation into clear, implementable criteria. Translating goals into specific measures invariably involves deciding what and whose outcomes will be included in the analysis. For example, defining protection of life to mean immediate deaths would result in neglecting slower-acting health effects of pollution; choosing to measure protection of property using only insured loss data would result in neglecting property losses of people without insurance. When a single measure is inadequate, progress toward one goal can be measured using multiple criteria; effects on different groups (distributional effects) can also be considered. An important aspect of observing-system design is therefore choosing how to measure societal outcomes—in other words, choosing a norm.

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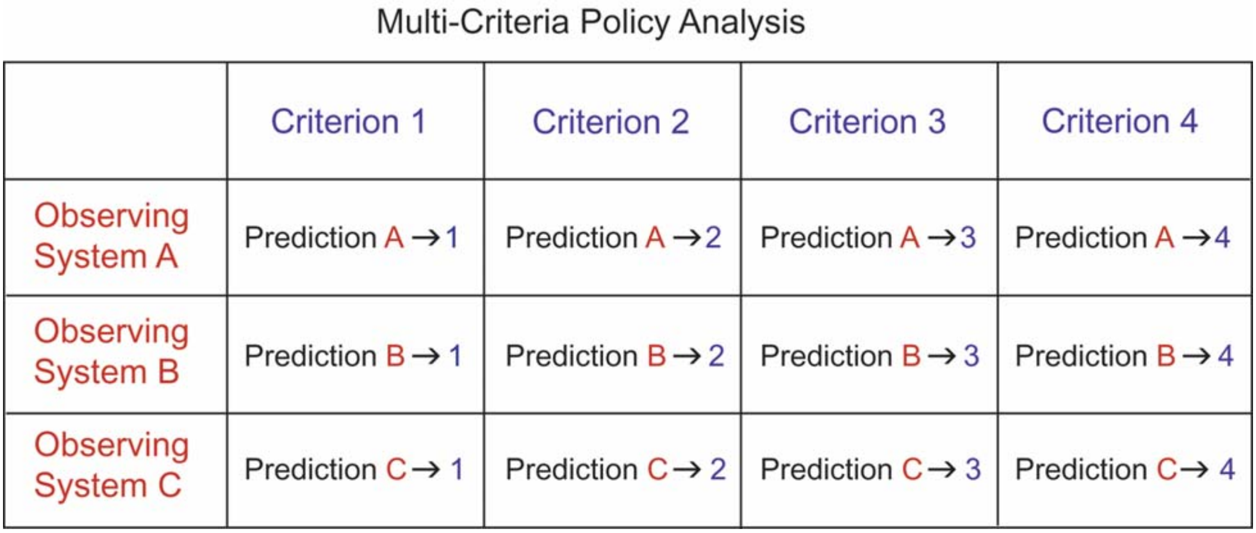
[8] Take, for example, two alternatives: *P,* with benefits = 400 and costs = 100; and *Q,* with benefits = 50 and costs = 5. Using i) would select *P,* while using ii) would select *Q.* If $X = Y = 75$, then iii) would select *P,* while iv) would select *Q.*

[9] Criterion ii) is often avoided, however, because a benefit–cost ratio is sensitive to what is defined as a benefit and what is defined as a cost (e.g., Stokey and Zeckhauser 1978; Weimer and Vining 1999). Maximizing benefits for the minimum costs is not included as a criterion because generally one alternative will not satisfy both parts of the criterion simultaneously; see the example in the previous footnote.

TABLE 1: Example of the type of matrix one can use to help guide the trade-offs necessary in a simple multigoal or multicriteria policy analysis.



Multi-Criteria Policy Analysis

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Observing System A	Prediction A → 1	Prediction A → 2	Prediction A → 3	Prediction A → 4
Observing System B	Prediction B → 1	Prediction B → 2	Prediction B → 3	Prediction B → 4
Observing System C	Prediction C → 1	Prediction C → 2	Prediction C → 3	Prediction C → 4

Although PD5 considers only observations for weather prediction, the problem definition could be expanded to consider the observing system in its broader context. Effects of the observing system depend on other components of the weather prediction system, such as data assimilation systems, numerical prediction models, other forecasting tools, and human forecasters, as well as on numerous societal factors. Incorporating these factors into PD5 would facilitate considering this broader context when evaluating observing systems; PD5 would then also provide a framework for analyzing the configuration of the entire weather prediction system—for example, for comparing the effects of modifying different components. In addition, the global observing system provides data for many purposes in addition to real-time weather prediction, including climate, ocean, hydrological, and environmental monitoring and prediction, as well as research. Incorporating these uses into the problem definition would facilitate a fuller accounting of benefits and costs—and provide a framework for designing a multipurpose, integrated observing system.

Expanding PD5 to frame the evaluation of observing-system alternatives in a larger context would increase the comprehensiveness of the analysis, but also its scope and complexity. The most appropriate problem definition depends on the resources one has for evaluating options, as well as the context in and purpose for which the definition will be used. In other words, there is no single "correct" problem definition for any issue; problems are not discovered, but are constructed.

THREE GUIDING PRINCIPLES ON PROBLEM DEFINITION.

As this article has illustrated, even subtle changes in problem definition can significantly influence how one analyzes and communicates about public policy. Learning to define problems consciously, by evaluating and synthesizing different perspectives, can help atmospheric scientists consider policy options in a more balanced way and communicate policy recommendations more effectively. Doing so will help atmospheric scientists contribute more effectively to societal decision making on topics of importance to our community and to society. It will also help us conduct atmospheric science research and development that better helps society achieve desirable outcomes.

Based on the preceding analysis, three suggestions on problem definition are provided for atmospheric scientists considering policy issues.

1) *Pay attention to goals.* Which options appear most favorable depends on one's goals. An important component of any problem definition is therefore what (and whose) goals are emphasized—and what (and whose) goals are not. This includes goals that are stated explicitly, and goals that are implied or assumed. Paying attention to goals, by identifying and evaluating the goals in different people's problem definitions (including one's own), is therefore a key component of developing beneficial policy options and convincing recommendations.
2) *Identify and evaluate significant assumptions.* Assumptions in problem definitions can take numerous forms, including assumptions about goals, causes, predictions, and solutions. Such assumptions will

be transferred into the analysis and communication of options, and become so embedded that they are difficult to recognize. Although assumptions cannot be avoided entirely, significant assumptions—that is, "those that may significantly affect the conclusions of the analysis" (Morgan and Henrion 1990, p. 38)—can lead to many of the difficulties discussed earlier. Consequently, identifying and evaluating significant assumptions in problem definitions, and then modifying them or tracking their influence, is an important step toward balanced consideration of options and persuasive communication.

3) *Consider different perspectives.* People invariably approach public issues from different perspectives, depending on their knowledge, experience, and values. Atmospheric scientists can therefore not take for granted that others define problems the same way we do, or even that they view our "problems" as problematic. By considering different perspectives and value systems, we can identify current and potential sources of disagreement about problems and solutions. Incorporating this understanding into how we define problems then produces more societally beneficial, more policy-relevant, and more marketable options. Important perspectives to consider include those of major stakeholders, including the intended audience, and those of people with less evident or more diffuse interests, such as under-represented groups and the general public (who might otherwise be neglected).

To conduct policy-relevant research and develop effective policy recommendations, the atmospheric science community must rigorously address both science and policy aspects of atmospheric science policy issues. Starting from the beginning, by thinking through how we define atmospheric science policy problems, is an important first step toward doing so. Consciously defining problems can also help us communicate more effectively about science and policy with people who approach issues from a different perspective, including policy makers and members of the public. This holds for observing-system design—as illustrated by the five sample problem definitions presented above—and for other public issues of interest to the atmospheric science community.

In closing, this article has illustrated how atmospheric scientists can apply concepts from the field of public policy to contribute more effectively to societal decision making. More generally, by considering atmospheric science in its broader societal context, the concepts discussed can help atmospheric scientists understand and navigate the often unfamiliar territory where science and society intersect.

ACKNOWLEDGMENTS. The author acknowledges Roger Pielke Jr. for invaluable assistance with early versions of this work. Thanks are also given to Lisa Dilling, Michael Glantz, Eve Gruntfest, Shannon McNeeley, Chris Snyder, Bill Hooke, and three anonymous reviewers for their helpful comments and suggestions.

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