Communication of Uncertainty

Harold E. Brooks*
National Severe Storms Laboratory (NSSL)/Forecast Research and Development Division
National Weather Center
120 David L. Boren Boulevard
Norman, OK 73072
Harold.Brooks@noaa.gov

Dan O'Hair
University of Oklahoma
Institute for Communication Research
Department of Communication
University of Oklahoma
Norman, OK 73019
hdohair@ou.edu

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*Corresponding author

Theme 1: Communication of Uncertainty

1. Introduction

Weather affects society in a variety of ways, including as threats to life and property. The ability of society to protect itself involves knowing what meteorological events are likely to occur and how to prepare for and respond to them. From the state of the atmosphere to the impacts on society, uncertainty exists; as a result, people have to make decisions with imperfect information. Communicating such information raises challenges throughout the process.

As a starting point for a discussion of the challenges, we created a schematic of the stages where uncertainty arises and those groups or systems that have to deal with it (Fig. 1). At the top, our knowledge of the state of the atmosphere is imperfect. Observational systems and numerical weather prediction (NWP) models can be designed to take uncertainty into account to some extent. In particular, data assimilation schemes and ensemble forecasting approaches, which use multiple runs of prediction models, can integrate estimated error structures of the observations in their initial conditions Researchers are designing adaptive observation systems that can deploy instruments to take observations at locations that are particularly important, but none exists operationally.

Human forecasters have to deal with uncertainty in observations and NWP systems when making forecasts. The availability of observations and NWP output has increased over the last decade, and so too has the challenge of how to communicate that information to the forecaster. Before the availability of ensemble forecasting systems in operational forecasting in the early 1990s, a forecaster might have access to two or three NWP forecasts. A forecaster might be able to look at selected fields from all those models at several different forecast times to get as complete a picture as possible from the operational system. The forecasts might not have been

particularly accurate, but they would represent the complete set of information available from the then state-of-the-art forecast system. Now the world's major operational NWP centers run tens of forecasts from any initialization time. Given that the time of interest for a forecast problem might have forecasts that were initialized at a number of different times, a forecaster could have hundreds of relevant NWP guidance forecasts to consider when making a forecast. To date, some efforts have tried to display the range and uncertainty of the guidance forecasts (e.g., Atger, 1999), but they have been limited, with no particularly satisfactory solution. The spread of the NWP guidance may occasionally give information about the accuracy of the mean of the guidance, but that is not true in all cases. As a result, forecasters frequently know that they cannot have much confidence, but may not know how to use the uncertainty or communicate it to forecast users.

The meteorological research of THORPEX can contribute solutions to the problems in the portion of the schematic with forecasters and above. Although the questions of how to display and communicate uncertainty to forecasters involve social science, most of the issues are more closely identified with the meteorological science. Our primary area of concern in this paper is with those portions of the schematic below the forecasters: communicating science from scientists or output of scientific models to nonscientists and, from there, the effects of that communication on the user community.

2. User community

We identify three components of the user community of interest that receive the forecasts. Members of these components might receive information directly from the observations and forecasts as well as from human forecasters in the process. The first component is risk managers

and, potentially, public resource managers. They must lead public preparation. In some cases, they represent a relatively small group of people that may receive specialized training in understanding the nature of the forecasts they receive and how to interpret them in light of their particular needs. For example, emergency managers in counties on the Gulf and Atlantic coasts of the United States interact with the National Weather Service's Tropical Prediction Center (TPC) when hurricanes threaten. Training those managers to interpret the forecasts is part of the TPC's mission. When forecasts for a specific location are made, the TPC forecasters and the relevant emergency managers communicate directly and frequently.

The second component is the media. Again, some members of the media may have some specialized knowledge that helps them interpret forecasts, but the range of knowledge among media members will be diverse**.** The media play a particularly important role in communicating information to other components of the user community, although other private sector intermediaries (e.g., companies that sell tailored weather forecasts to specific users) also play a major role.

The final component is the end users. They will have, by far, the broadest range of expertise in interpreting the information from forecasters. Some may have specialized knowledge, but many will not. Constituents of this group include the general public, businesses, public agencies, and NGOs. They are considered end users in the sense that they carry no official, weather-related, information dissemination mission.

Depending on the nature of the problem, many forecasts may be available to the user community at different times before an event. Users with sufficient knowledge of their decision problems may be able to take advantage of those forecasts, even if other users get little value from them. For example, consider the problem of water resources managers in California. They

must balance a number of potentially competing factors: They want to maintain sufficient water behind dams for public water use or, potentially, hydroelectric power generation; on the other hand, they have to keep water levels behind the dam low enough that precipitation events will not lead to dam failure or serious flooding. As a result, before heavy rainfall events, they may need to release water from behind dams to lower levels in reservoirs. Forecasts with a great deal of uncertainty with lead times of several days may be of value to the manager in calculating the risk of releasing water compared to not releasing the water. As the event comes closer, it is likely that the forecasts of whether or not the event occurs will become more certain and the manager can take action if necessary.

Often some people use the information because the parameters of their decision problem make the information potentially useful (as in the water resource manager example), whereas the decision for others may have different parameters and constraints that make the information less useful. A broad concern for the user community is the lack of coordination and collaboration among members (Mass, 2006). Fragmentation, territoriality, and institutional silos create a patchwork of efforts that lacks coherent effectiveness.

> **Research Recommendation**: *Systematic research studies should be directed toward the description and evaluation of programs designed to improve interorganizational communication and collaboration among stakeholders (risk managers, media, and end users) in the weather user's community.*

3. Risk managers (risk analysis networks)

An essential component of this forecasting model is the risk analysis network (RAN). These networks are often structured on statutory requirements at the federal, state, and local levels. In many other instances, RANs emerge as semiformal, interrelational configurations owing to common interests in risk awareness and communication issues (Weigold, 2001). For

example, most risk management processes bring together scientists, forecasters, public officials, and practitioners as members of RANs. Risk messages exchanged among these constituents create a communication network essential to communicating uncertainty. Understanding the interdependency of their relationships is important. Scientists depend on forecasters to apply their research findings and then transfer them to the end users. Forecasters and scientists depend on public officials to fund their communication initiatives. All too often the relationships among these network members are dysfunctional or misaligned, resulting in inefficient or even disastrous results (Gupta, 1999; Dickson, 2005). The 2005 tsunami disaster and Hurricane Katrina are noteworthy illustrations of the failure of RANs to operate conjointly. Even under nonevent conditions, the range of collaboration for members of the weather community can be restricted (Mass, 2006; Pielke and Carbone, 2002 **).** The RAN of communities is likely to vary according to a number of factors, including whether the community is rural or urban and the communication priorities of RANs (educating, informing, warning, incident management, etc.). Managing uncertainty among risk analysis network members is realized through network communication, interorganizational collaboration, and sometimes strategic alliances.

> **Research Recommendation**: *Research studies should be directed at identifying effective strategies for effectively communicating uncertainty among the diverse stakeholders in the risk analysis network.*

4. Media

Conventional media (TV, radio, newspapers) use forecast information according to their perception of its relevance to their viewers, listeners, and readers. Media often frame their messages in ways that omit critical information, overemphasize certain circumstantial features, sensationalize the situation, galvanize distrust among those whose job it is to mitigate the threat, and politicize the context of an event (Covello and Sandman, 2001). The media are likely to treat

the forecasting community with “benign neglect” until weather conditions allow them to create a story; for example, recent triple digit temperatures across the Southwest, Midwest, and Northeast spawned news stories that would otherwise be devoted to additional coverage of international conflict Coupled with the meteorological reports were stories about heat exhaustion, harmful effects of exposure to skin, and concerns for special populations. When temperatures hover in only the low to mid-90s, weather is no longer a prime feature of the media and the warnings associated with elevated temperature are less common, *although no less important*. In this context, the media frames a context based on its newsworthy potential rather than its uncertainty management potential.

When considering disaster events, the most recent instantiation of framing came during coverage of Hurricane Katrina, where the media portrayed an America divided along racial lines. Following the coverage, an early September Pew survey (Pew Research Center)**,** for example, demonstrated that two-thirds of African Americans, but fewer than one-in-five whites, said that the government warning and response would have been faster had most victims been White From this perspective, news selections help establish the public’s agenda, news selections “prime” the audience in ways that influence evaluations of political candidates and issues, and journalists’ framing choices can affect the audience’s placement of blame for social issues and their tolerance for civil liberties (Barker-Plummer, 2002).

- Some studies judge the media to be at fault for failing to provide consumers with adequate information to make risk judgments (Ryan et al., 1991). Others criticize journalists for giving disproportionate attention to “minor” hazards or focusing on serious but rare risks (Kitzinger, 1998). The research into “risk reporting” has some recurring findings and insightful suggestions. These are classified into different intersecting themes

on the “nature” of risk, news values, and internal dynamics of media organizations (Kitzinger, 1998):

- The media tend to focus on risks that kill or injure many people at one time rather than those that have a cumulative effect over the year (Hansen, 1994).
- Unusual risks are deemed more newsworthy than common risks (Dunwoody and Peters, 1992).
- Journalists seek out the “human face” of science and risk (Hansen, 1994). Exemplars make the news more vivid, but they can sometimes exert undue influence on people's perceptions of risk probability, even in the presence of base rate information (Zillman and Brosius, 2000**).**
- Personal accounts may allow a risk to gain media attention despite official denials (Kitzinger, 1998**).**
- Reporting tends to be “event” oriented rather than issue oriented (Kristiansen, 1988).
- Long-term and continuous developments have less chance to gain the attention of the media because journalists are concerned with the “news of the day” (Hansen, 1991**).**

Results from these studies lead to an inescapable conclusion that focuses squarely on media behavior. Media treat routine forecast information differently from information that will create human interest. Managing uncertainty in both weather contexts presents challenges that need to be considered from different perspectives and with varying strategies.

Research Recommendation: *Research should be conducted that describes and predicts the messages employed by traditional media for routine and event forecast information.*

a) Access to targets (end users)

Given the media's substantial influence on forecasting messages, it should come as no surprise that forecasters and members of the risk community network have substantial interest in gaining access to the media. Media access depends on the "degree of respect" with which journalists and broadcasters view (weather forecasting) organizations (Blumler and Gurevitch, 1995; Yoon, 2005). According to the media access model, a forecasting organization's public relations expertise, coupled with the media's perceptions of that source's legitimacy, is a significant predictor of gaining access to the media.

A second strategy for accessing targets focuses on direct channels (new media) that forecasters and eventually risk managers employ when sending messages to the community. Land lines, cell phones, pagers, instant messaging, Internet communication, and personal communications are many of the channels risk managers use to reach the public, but strategic decision making for channel selection is far from understood, especially under varying conditions of risk and threat (Gruntfest, 2002). Under what conditions are reverse 9-1-1 systems preferred over sirens? How do advanced systems of geographic information techniques influence channel selection?

> **Research Recommendation:** *Studies should be conducted that explain and predict strategies for most effectively reaching end users through conventional and new media channels.*

b) Target analysis

Constructing appropriate and meaningful messages largely depends on an accurate and complete understanding of the user community (Payne and Shulte, 2003; Granatt, 2004; O'Hair, 2004; O'Hair et al., 2005). Forecasters and emergency managers are likely to possess some knowledge of the demographic and personal factors of their communities, but research on

identifying large-scale projects that construct these profiles in any systematic manner is scant. A research base on the extent to which forecasters and risk managers systematically assess literacy levels and cultural factors in their respective communities is also lacking. Finally, end users' perceptions of risk in their own communities and their anticipated response profiles (compliance levels, peer consultation network, confirmatory behaviors, etc.) are important to understand as well because they constitute part of the community risk communication profile (National Weather Service, 2006).

> **Research Recommendation:** *Community (user) profiling research must become more systematic and sophisticated to better understand comprehension and response behaviors among members of the end-user community.*

5. End users

a. Uncertainty management and information seeking

Forecast information is received and processes in multiple ways, depending on users' frames and needs. Multiple studies have demonstrated that people cope by blocking information from their awareness and strive for a "new normalcy" (Sellnow et al., 2005). This phenomenon is termed the Complacency-Curiosity-Immediacy-Criticality (C-C-I-C) Framework; it integrates individual risk forecasting, information management processes, and media access (O'Hair, 2005). When risk probability is low, messages are unlikely to resonate with individuals who will have little motivation to seek or process information from media sources. This is most likely the case when the chance of inclement weather is low. When risk probability is heightened, individuals become curious, process forecast messages more directly, and may seek additional information. As the threat of severe weather becomes more salient, individuals become more immediate in their desire for information and intensify their information seeking behavior. In the

last stage, when threat seems imminent, the process of information seeking becomes acute and media and other information access becomes vigorous, if not frantic.

This framework is consistent with other models (Griffin et al., 1999, 2004) that examine how people differentially react to risk information; the framework is intended to identify the gap between what people know and what they perceive they need to know (information sufficiency). Affective responses to a risk and beliefs about what others think they should know about the risk predict information sufficiency (Griffin et al., 2004; McComas, 2006).

> **Research Recommendation:** *Laboratory experiments and field investigations should be directed toward understanding how the Complacency-Curiosity-Immediacy-Criticality Framework interacts with routine and event forecast information.*

b. Channel preferences/selection

People depend on multiple sources of information for risk information, including TV, radio, newspapers, friends, and the Internet (Stempel and Hargrove, 2002; Rodriquez, 2004). It is not well known what information sources end users access for weather information in general and forecasts in particular. It is highly probable that people's sources for information about ongoing events might be different than their sources for weather forecasts before an event. Also, information about weather forecasts may also need to diffuse more quickly (see CCIC Model above). Future research should be directed to the types of channels and information sources end users prefer under normal weather conditions (National Research Council, 2006).

Research concerning extreme events is more plentiful and indicates that some people first learn of disasters from others (Greenberg et al., 2002). For example, instant messaging was a prevalent means of warning during the tsunami disaster. The public relies on television viewing to obtain news during a natural disaster, largely because of the public's preferences for visual imagery (Greenberg et al., 2002) and heightened dramatic impact referred to as the "vividness

effect" (Spencer et al., 1992; Piotrowski and Armstrong, 1998). Other research has revealed a "hierarchy of resort." Some people first turn to broadcast media, then to print, Internet, and interpersonal sources. These last three sources confirm, reassure, and provide more in-depth information. Therefore, although mass media may alert the public about health risks and help form societal level judgments, research has shown that people more often rely on interpersonal channels of communication such as social networks to assess their personal health risks (Scherer and Cho, 2003; Petts and Niemeyer, 2004; McComas, 2006).

Other groups of the isolated, impoverished, minority, and rural segments rely primarily on interpersonal and community channels of information first (Glik, 2005). In other research, women were more likely than men to seek information from the media pertaining to family management needs; they appear to assume more responsibility for dealing with adapting to a crisis (Seeger et al., 2002). As media convergence continues to evolve, more individuals are likely to access channels that offer multiple options for forecast information.

The diffusion of information literature, a theoretical offshoot of Rogers' diffusion of innovation theory, has examined how and when people learned of major events from the Kennedy assassination (Greenberg, 1964; Mendelsohn, 1964) to the September 11 attacks (Bracken et al., 2005). In different circumstances, radio, television, and interpersonal communication have all been the main channel of information. From this research we have learned that interpersonal communication plays a larger role (and may become the most important channel) when the event is more significant, having significant implications for forecast information.

Less research has looked at how people receive risk information in the news. Carrocci (1985) found that during the Tylenol poisonings in 1984, 70% of survey respondents learned of

the news through radio or television, but more than 70% reported telling others, a higher percentage than is typically found in other diffusion studies. They mainly told family and close friends. Respondents also reported seeking out additional information from the news media, a process explained by media dependency theory. Media dependency theory (DeFleur and Ball-Rokeach, 1976 **[QA: second author only Rokeach in reference list?])** argues that people in modern societies increasingly rely on mass rather than interpersonal communication for information, that this reliance intensifies in times of crisis or uncertainty, and that those who depend more on the media are more likely to be influenced by it. Hindman and Coyle (1999) found increased dependency on the radio after flooding in Grand Forks, North Dakota, and dependency was linked to volunteer mobilization.

> **Research Recommendation:** *Research programs should investigate channel preferences for forecast information and develop models that predict appropriate and effective message-channel matching for various groups of end users.*

6. Managing uncertainty by understanding risk perceptions

Forecast information is inherently uncertain (National Research Council, 2006), and users' uncertainty management processes are influenced by large number of communicative and perceptual processes. Uncertainty and risk perception processes include the following (Ropeik and Slovic, 2003):

- individuals' perception of *dread* (the significance of the threat),
- their sense of *control* (the extent to which they feel they have some level of management over the threat),
- whether the threat is *man-made or natural*,
- whether it affects *children*,

- whether the risk is *novel or new*,
- what the risk *probability* is (can it happen to me?),
- the *magnitude* of the perceived risk—people tend to overestimate small risks and underestimate large risks (LaFountain, 2004),
- *gender*—white males seem to perceive risks differently than other groups—on average, they perceive risks as much smaller and much more acceptable than do other people,
- *sociopolitical factors* such as power, status, ethnicity, culture, education, and trust, which are known to influence people's perception and acceptance of risk (Flynn et al., 1994).

A different line of research has demonstrated a "negativity bias," where people weigh negative information more strongly than positive information (Flynn et al., 2002), whereas other studies reveal an opposite pattern in which people feel a sense of self-efficacy toward risks, leading to an "optimistic bias." Given the varying perception levels among certain groups, it is concerning that the National Research Council (1999, p. 86) reports that much of the forecast delivery messages are designed for "the educated, the affluent, the cultural majority, and the people in power," with the least effective messages oriented for minorities, the elderly, and the poor.

Models of influence such as protection motivation theory (Rogers and Prentice-Dunn, 1997) posit that people become motivated to protect themselves from a risk when their perception of risk severity and their own vulnerability is high enough to overcome any rewards from not protecting themselves (similar to expected utility theories).

Mass mediated risk communication is often effective at convincing people that *other* people are vulnerable, but people believe themselves relatively invulnerable. Social

psychologists find that people enhance their self-esteem by holding the self-serving bias that bad things are more likely to happen to others, whereas good things are more likely to happen to themselves, a tendency Weinstein (1980) called “unrealistic optimism.” The impersonal impact phenomenon (Tyler and Cook, 1984; Mutz, 1998) suggests that the media influence our beliefs about others but not about ourselves. To influence beliefs about ourselves, we rely more on interpersonal communication (Flay and Burton, 1990; Morton and Duck, 2001).

First- and third-person effects are related phenomena wherein people tend to believe that (harmful) media messages will have greater effects on others than on themselves (Davison, 1983). When messages or potential effects are judged desirable, such as anti-tobacco ads and public service announcements, third-person perceptions are attenuated or reversed into first-person perception, so that people believe they themselves would be more affected by media messages than others would (Meirick, 2005). These perceptions can have behavioral consequences such as censorship: protecting others from harmful messages (Rojas et al., 1996). But the behavioral component bears more investigation in the context of forecasts or warnings. How people respond to an evacuation notice, for instance, may well be influenced in complex ways by how they think *others* will respond as well as by unrealistic optimism about their personal vulnerability to the danger.

> **Research Recommendation:** *Empirical investigations should be directed at understanding and predicting interactional effects among forecast information, risk perceptions, and media effects.*

7. Outcomes

Uncertainty also exists between the users and the outcomes. Users may or may not be aware of the probable effects of adverse weather on them. As a result, effective decision making may

be limited in the face of uncertainty. Sophisticated users may be able to take account of the uncertainty in making optimal decisions, but others may not (Murphy, 1993).

a. Threats to life

Obviously, a most serious situation is when lives are threatened. As seen in the Katrina disaster, different aspects of society may be more or less able to take actions in the face of a threat.

Some sensitive users may require a long lead time to respond and, as a result, have to take action at a time when uncertainty typically is greater. The decisions and actions of the emergency management and media communities may have a great effect on the outcomes experienced by the general public.

b. Economic value

In a similar vein, economic losses can frequently occur in adverse weather situations. Attempts by various components of the user community to mitigate those losses may be more or less successful, depending on the nature of the weather and the options available to the users. Even perfect information and perfect decision making may not lead to loss avoidance. Take the case of a citrus farmer and the threat of a freeze that could potentially kill the crop. If the temperatures are only a few degrees below freezing, it may be possible for the farmer to take preventative action (e.g., using heaters or spraying water on the fruit) to save the crop from damage. There is a temperature below which no action can save the crop, however. The farmer might begin preparing for a potential freeze days in advance on relatively uncertain forecasts. Consider the implication of bad forecasts that miss the freeze. If the forecasts were a little wrong, suggesting temperatures at which protective action would be successful, the farmer might begin action that would be wholly unsuccessful. If, on the other hand, the forecasts were horribly

wrong, leading the farmer to believe that temperatures would be above freezing, so that no action would be necessary, the farmer would not begin those unsuccessful activities. In the end, the slightly bad forecast would produce significantly worse outcomes for the farmer than a very bad forecast. Communicating the uncertainty of the forecasts and understanding the decision problem are both necessary to optimize the choice made by the farmer.

> **Research Recommendation:** *Research programs should be directed toward a better quantification of forecast uncertainty and an understanding of decision making styles, and weather impacts.*

c. Trust

Trust is an all-important goal of risk communication strategies. In 2005 the World Health Organization (2005) issued its long awaited "guidelines for outbreak communication." Trust building is the first communication principle highlighted in their document. Research (Petts, 1998) has demonstrated that different governmental organizations elicit different expectations about "trustworthy" activities, and accordingly require different "trust enhancing" strategies. Different investigations have identified specific variables that influence trust: perceived openness, competence, objectivity, fairness, consistency, independence, and care/altruism (e.g., Renn and Levine, 1991; Petts, 1998; Johnson, 1999). Trust is diminished when experts disagree and when there is a lack of coordination among risk management organizations, a lack of sensitivity to the communication needs of the audience, a lack of information access or disclosure, and a lack of public participation in risk management plans (Covello et al., 2001). This is especially true within the weather community where multiple organizations produce informational and forecast products that seemingly are in competition with one another—private, governmental, media, etc. (Mass, 2006).

The public must gain an uncertainty management perspective through calculated, evolving, and cooperative forecast education activities in such venues as school programs, public education, public participation in planning processes, citizens' group education and training, and small personalized learning environments (Covello et al., 2001; O'Hair et al., 2005; O'Hair and Averso, in press).

> **Research Recommendation:** *Research studies should be designed to understand the impact of educational initiatives on end-user uncertainty levels, their confidence and trust in sources of forecasts, and their propensity for effectively using forecast information.*

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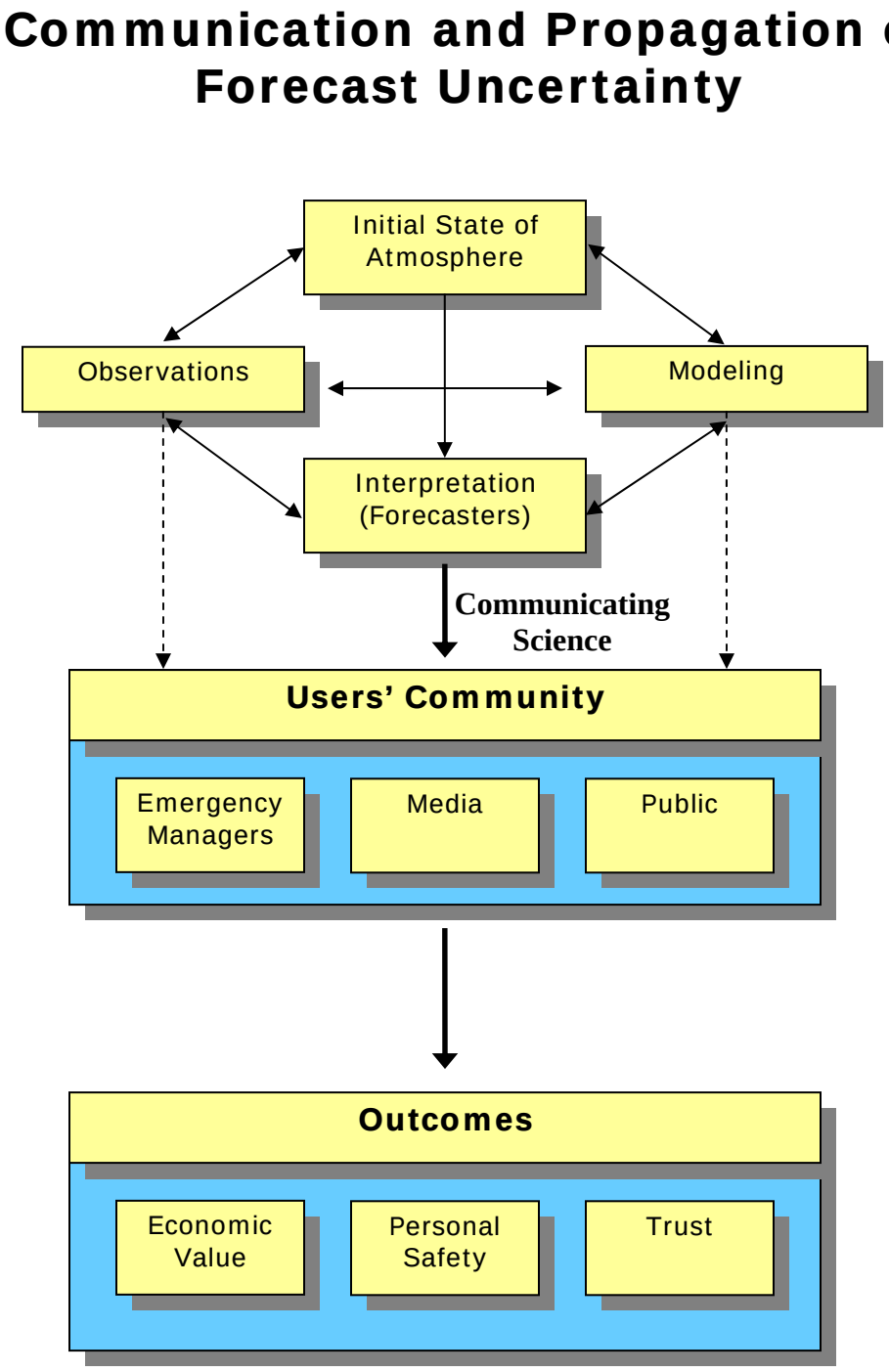

Figure 1: Schematic of process of communication and propagation of forecast uncertainty. Arrows indicate direction of influence of information flow. Dashed arrows indicate that users may or may not have access to raw observational and modeling output.