USING SPECIFIC LANGUAGE TO DESCRIBE RISK AND PROBABILITY

ANTHONY G. PATT [1] and DANIEL P. SCHRAG [2]

[1] *Boston University and Potsdam Institute for Climate Impact Research, Telegrafenberg A31, 14473 Potsdam, Germany*
E-mail: apatt@bu.edu

[2] *Laboratory for Geochemical Oceanography, Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, U.S.A.*

Abstract. Good assessment of environmental issues, such as climate change, requires effective communication of the degree of uncertainty associated with numerous possible outcomes. One strategy that accomplishes this, while responding to people's difficulty understanding numeric probability estimates, is the use of specific language to describe probability ranges. This is the strategy adopted by the Intergovernmental Panel on Climate Change in their Third Assessment Report. There is a problem with this strategy, however, in that it uses words differently from the way lay readers of the assessment typically do. An experiment conducted with undergraduate science students confirms this. The IPCC strategy could result in miscommunication, leading readers to under-estimate the probability of high-magnitude possible outcomes.

1. Introduction

The potential impacts of climate change vary not only according to their timing and magnitude, but also according to the probability with which they will occur. Some of the most consequential potential impacts – such as rapid sea level rise due to the disintegration of the West Antarctic Ice Sheet – thankfully will probably not occur. Effective assessment of climate change allows policy-makers to take into account scientific knowledge about not only the most likely outcomes of environmental change, but also these less likely, but more consequential possibilities. A significant challenge confronting the Intergovernmental Panel on Climate Change (IPCC) and other assessment panels is to communicate the broad range of beliefs, and the uncertainties associated with those beliefs, about the future course of global climate, so that policy-makers can make responsible decisions about societal actions.

The task of communicating uncertainty is made difficult both by the disagreements within the scientific community about what the probabilities are, and by lay people's general difficulty thinking in probabilistic terms. Assessment authors must first resolve among themselves the uncertainty over uncertainty: what the probability of an event's occurring actually is when there is disagreement over that probability. Then, they must figure out how to communicate that uncertainty to a

Climatic Change **61:** 17–30, 2003.

lay audience – policy makers and the public – so that the assessment audience will be able to make effective tradeoffs with society's scarce resources.

The latest report from the IPCC, *Climate Change 2001*, systematically communicates probability using well-defined descriptive language, words such as *very unlikely* (Houghton et al., 2002). Doing so avoids having to arrive at a single point estimate for the probability of an event, or even a precise range of estimates. It also responds to the public's difficulty interpreting quantified probabilities. The IPCC strategy achieves several important objectives, such as promoting internal consensus among chapter authors and conveying a sense of confidence in outcomes of climate. At the same time, the IPCC's strategy does not exactly match people's common use of language, in which the words used to describe the probability of an event also depend on the event's potential magnitude; the IPCC is communicating probability using language commonly used to describe risk, the combination of probability and consequence.

In this paper we examine the potential biases that could result from the possible mismatch between the IPCC's use of words describing probability and people's intuitive understanding of their meaning. After background sections on people's cognitive biases interpreting probability, and the ways that assessments have commonly addressed these biases, we present the results of a simple experiment testing the use and interpretation of descriptive words to describe potential weather events. What we find is a reassuring symmetry in how people use language to describe possible events. Risk communicators exaggerate the likelihood of high consequence events, at the same time that their audience expects such exaggeration, and de-codes accordingly. The IPCC strategy, however, removes the possibility of exaggeration on the part of the communicators, since each descriptive word is assigned a specific probability range that is insensitive to event magnitude. Unless the audience adjusts – ceasing the practice of correcting for expected exaggeration – the result could be a biased under-response to high magnitude events.

2. Probability Interpretation

Both psychologists and behavioral economists have shown that people's descriptions and understanding of probabilities depend on contextual factors such as objective probability, base-rate, and event magnitude (Weber, 1994). In terms of objective probability, Kahneman and Tversky (1979) identify a weighting function people use to interpret evidence of probabilities, shown in Figure 1. People tend to overestimate the probability of relatively infrequent events (such as dying from botulism) and underestimate the probability of relatively frequent events (such as dying from heart disease). The change in people's reactions when an event's assessed probability goes from 0% to 1% is much greater than when it goes from 36% to 37% (Patt and Zeckhauser, 2002). For very small probabilities, people's responses are more binary than continuous (Kammen et al., 1997; Covello, 1990).

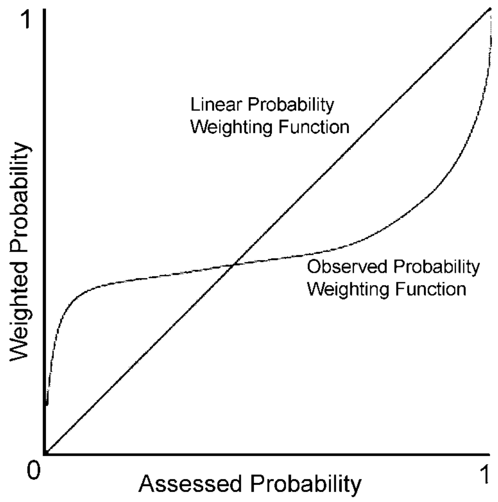

Figure 1. Probability weighting.

Below a certain threshold of concern people view the event as impossible; above the threshold, they take measures to prevent it, measures that may not be justified by the event's small probability. People are relatively insensitive to changes in assessed probability in the middle of the scale, treating all such probabilities as roughly fifty-fifty.

In terms of base rates, Wallsten et al. (1986) observe that people's interpretation of probability descriptors depends on the background frequency of an event. Hence, people interpret a 'slight chance' of rain in London as meaning a higher numeric probability than a 'slight chance' of rain in Madrid. Windschitl and Weber (1999) observe a similar phenomenon even when people are given numeric estimates of event probabilities. In one experiment, subjects are told that a person has a 30% chance of contracting a mild form of malaria during a trip to a tropical destination. Some of the subjects are led to believe that the destination is Calcutta, while others are told Honolulu. Subjects then describe, on a verbal scale, the likelihood of malaria. Those people who are told that the trip is to Calcutta tend to describe the likelihood of malaria with more certain language (choosing terms such as 'somewhat unlikely') than do the people who are told the trip is to Honolulu (choosing terms such as 'quite unlikely'). Later, the same subjects are asked to recall the numeric probability of contracting malaria. Those for whom Calcutta was the destination remember higher numeric probabilities.

In terms of event magnitude, Weber and Hilton (1990) observe people's probability word interpretation responding not only to base rates, but also to the negative utility associated with different events. In one experiment, subjects were asked to decide on the numeric probability they believe their doctor had in mind when describing the likelihood of medical conditions such as warts, stomach ulcers, and skin cancer. For each medical condition the doctor used the same probability words, such as ‘slight chance’. People’s initial estimates of numeric probability are initially lower for the more serious events, such as cancer. The researchers attribute this to the base-rate phenomenon: base rates and severity are usually inversely correlated, and people generally assume higher magnitude negative outcomes are less likely. Later in the experiment, however, people were informed that the base rates were the same for the different conditions. With this new information, people show a non-linear response to event severity. As the severity of events increased, people first showed higher numeric estimates of probability. However, as the events started to become life threatening, subjects’ estimates of probability begin to decrease. Hence for serious events, such as cancer, subjects again ‘de-coded’ the physician’s language to assign a lower numeric probability than for the events of intermediate magnitude.

The sensitivities to changes in assessed probability, base rates, and event magnitude all create challenges for assessors. For example, risk communicators may have to work very hard to convince people that it is more worthwhile reducing one risk from 45% to 30% than another risk from 0.01% to 0.005%. They may have to convince people that even though a given risk has a 0% base rate – it has never happened before – it is still possible that it will happen in the future. And they will need to help people distinguish between event magnitude and probability, so that they can properly compare different risks to make more accurate decisions.

3. Uncertainty Assessment

Fortunately, scientific assessors have increasingly appeared sensitive to audience perceptions, revealed in the variety of ways they have communicated uncertainty. Some assessments fail to report highly uncertain information, or else avoid quantification of uncertainty by giving ranges of expected outcomes without clarifying the probability bounds for that range. This approach offers information that is easy to understand, yet at the same time incomplete. Patt (1999) examines the assessment of a highly unlikely yet highly consequential result of climate change – the rapid collapse of the West Antarctic Ice Sheet – across different types of assessment. He finds that the large, consensus-oriented assessments, such as the IPCC, were less likely to provide information on the event. Smaller assessments, both those conducted by advocacy groups and those responding to specific questions of their intended audience, tended to provide greater detail on the issue. There are several explanations. First, consensus within the assessment team might be difficult to achieve for high-consequence low-probability events. For example, Morgan and Keith (1995) obtained subjective probability judgments from a number of climate change scientists, using a variety of expert elicitation techniques. What they observed was disagreement, often between disciplines, with many experts’ ranges failing to overlap. As events become more and more speculative, it is likely that expert opinion will diverge even more. Patt also concluded that for these extreme events, it is possible that assessment authors would be tempted to view any treatment as counterproductive. Because people's responses to low-probability events are likely to be binary and polarized, discussion of such events may in fact lead to greater conflict within the policy community. If assessment authors see their task as building consensus, not only among themselves but also among decision-makers, then they will limit their discussion to events that are either certain or of middle-probability.

Van der Sluijs (1997), likewise, examines how the IPCC has described the range of future temperature changes associated with climate change. He observes that the range has remained fairly constant, even as new evidence has become available. Assessors were reluctant to depart from a previously stated position, and 'anchored' on the old estimate absent a compelling reason to change it. To maintain intellectual honesty, they failed to quantify the probabilities associated with that temperature range. As long as it remained unclear what a given temperature range actually meant, they could continue to use it. Like the strategy of omitting treatment of extreme events altogether, the anchoring phenomenon is a way of avoiding the rigorous treatment of uncertainty, when being rigorous could make consensus difficult, or could confuse the audience.

Other assessments – assessments of health and technological risks in particular – present quantified probability estimates. This approach offers more information but may be difficult to interpret by an untrained audience. The history of these difficulties is well documented. Leiss (1996), for example, describes three stages in risk communication practice. In the first stage, risk communicators believed that if they simply communicated their best estimates, people would use that information to make consistent tradeoffs. This strategy lasted until the 1980s, by which point it became clear that people were systematically over-reacting to some kinds of risk, and under-reacting to others. In response, risk communicators saw their jobs evolving to include more salesmanship – they would convince people of which risks were worthwhile, and which risks were not – in which the communicator was deliberately trying to bring about a specific behavior pattern that might not have occurred otherwise. Alternatively, many risk assessors and communicators started to suggest that decision-making on such issues be insulated from popular opinion (Breyer, 1993). In many cases, however, such strategies led to increased public resentment of the risk assessors and decision-makers (Freudenberg, 1996; Irwin and Wynne, 1996). The third stage, as Leiss and others (e.g., Fischhoff, 1996) see it, is characterized by a greater attention to public participation, to building partnership between risk assessors and decision-makers in developing appropriate responses to the information. The approach seems to work across issues and cultures to increase the credibility and salience of the information, and to help people respond wisely (Patt and Gwata, 2002).

Many of these considerations entered into the design consideration for the IPCC Third Assessment Report. The challenge was to provide understandable and complete information about uncertainty in a context – the written document – where

Table I
IPCC qualitative descriptors

Probability range	Descriptive term
< 1%	Extremely unlikely
1–10%	Very unlikely
10–33%	Unlikely
33–66%	Medium likelihood
66–90%	Likely
90–99%	Very likely
> 99%	Virtually certain

the audience would be unable to participate. Moss and Schneider (2000) reported to the IPCC lead authors on the communication of uncertainty, recommending a seven-step approach for describing each uncertainty. They suggested, for example, that authors should identify and describe the sources of uncertainty, document the ranges and distribution for each uncertain variable, identify the level of precision possible for describing the variable, and place the expert judgments within a formal decision-analytic framework. The IPCC authors accepted some of Moss and Schneider's recommendations, and not others. Of particular note, however, was the decision by lead authors to use specific qualitative language – words such as *likely*, *very likely*, and *virtually certain*, to describe quantitative probability ranges. Early in the report they define the probability ranges for seven qualitative descriptive terms, and then use those terms rather than numbers (see Table I). This is a more simple strategy than the one that Moss and Schneider (2000) suggest.

There may be good reasons for this approach. First, using language such as *very likely* or *virtually certain* to describe an uncertain outcome avoids the problem of experts having to reach consensus on a particular probability estimate or range. Since it may well be impossible for experts to reach consensus, the alternative to the use of such language may well be complete omission of the uncertain outcome. Obviously, it is better to describe an event than to omit it, even if the probability range is wide and not completely precise. Second, many people understand, or feel they understand, the meanings of such words better than they do accurate numbers or ranges (Wallsten et al., 1986). This is especially true for forecasts of one-time events (e.g., the chances of one meter sea level rise), as opposed to forecasts of frequent outcomes (e.g., the chances of any one person contracting malaria during a visit to Honolulu) (Pinker, 1997). To a lay audience, a numeric probability for the frequent event makes sense; the typical person stands an $X\%$ chance of contracting malaria, since X people in 100 actually do contract the disease. But for the one time event, for which there is no past data, the meaning of the $X\%$ is somewhat different. The probability estimate conveys a degree of confidence in the outcome occurring, rather than a description of past data. The use of probability language to describe degrees of confidence, rather than numeric estimates, makes more sense to most people (Moss and Schneider, 2000). Additional information, the accurate numerical data, may simply upset this simple approach toward communicating uncertainty.

An important component of this approach, in addition to the use of words rather than numbers, is the adoption of a context-*in*dependent scale. Thus, the language the IPCC authors use to describe uncertainty depends only on the probability of the outcome, or the confidence with which they believe it will occur, and not on other characteristics of the event, such as its magnitude. However, the language that people use to discuss uncertainty and the meanings they give to various descriptors depend on the event being described and the context within which it falls: the total risk of an event. When both the communicators and the audience are using uncertainty descriptors to describe risk, and not simply probability, accurate understanding will pass from communicator to audience without bias (Brun and Teigen, 1988). But when the communicators use words to describe probabilities, and the audience still interprets them as describing risk, miscommunication can result. The result of that miscommunication could be for the audience systematically to underweight both the probability and the riskiness of high magnitude events.

4. Experiment

To illustrate how the use of context independent descriptors could be important, we conducted a simple experiment, in which we polled 152 undergraduate science students at Boston University, randomly distributing equal numbers of four different survey questions. The surveys differed across two dimensions, allowing for a controlled experiment. Half of the surveys asked subjects to translate, in the role of risk communicators, numeric probabilities into words – choosing one of the IPCC's seven descriptive terms, from *virtually certain* to *extremely unlikely* – to describe an event of 10% probability. The other half of the surveys asked subjects to assign a probability range – again one the IPCC's seven ranges, from *greater than 99% chance* to *less than 1% chance* – to an event described as 'unlikely, perhaps very unlikely'. This task is equivalent to that of an IPCC audience, making an estimate of the likelihood of an event based on the probability description they hear or read. Within each group, half the surveys asked subjects to describe or interpret the likelihood of a high-impact outcome: a hurricane due to hit land near Boston. The other half involved a low-impact outcome, early season snow flurries. Table II shows the four survey versions.

Subjects were aware that we had distributed several versions of the survey, but were not aware of how the versions differed, or the purpose of the experiment. They were also not generally aware of the IPCC's choice of language to describe uncertainty in Working Group I of the Third Assessment Report. Clearly, undergraduate

Table II
Survey versions

Communicators		Audience	
High magnitude outcome	Low magnitude outcome	High magnitude outcome	Low magnitude outcome
Imagine that you are the weather person for a Boston television station. The date is September 8, 2001.		Imagine that the date is September 8, 2001, and you are watching the weather report on television.	
You are somewhat concerned about a very powerful hurricane currently near Bermuda. Usually these hurricanes hit land in the Carolinas, or else track out to sea, but in this case conditions make it possible that the hurricane could hit land near Boston, devastating the region with sustained winds of over 100 mph and extensive flooding	You are somewhat concerned about a cold front currently over western New York State. Usually at this time of the year these fronts bring isolated thunderstorms and chilly temperatures (40s to 50s) to the region, but in this case conditions make it possible that Boston will see some snow flurries and temperatures dipping into the high 30s.	The weather person is talking about a very powerful hurricane currently near Bermuda. Usually these hurricanes hit land in the Carolinas, or else track out to sea, but in this case conditions make it possible that the hurricane could hit land near Boston, devastating the region with sustained winds of over 100 mph and extensive flooding.	The weather person is talking about a cold front currently over western New York State. Usually at this time of the year these fronts bring isolated thunderstorms and chilly temperatures (40s to 50s) to the region, but in this case conditions make it possible that Boston will see some snow flurries and temperatures dipping into the high 30s.
The National Weather Service is currently predicting the chances of this happening at 10%, and you believe this to be a good estimate. Which of the following language would you use to describe to your viewers the chances of this happening?		The weather person, whom you trust, is saying that it is unlikely, perhaps very unlikely, that this will actually happen. Based on this forecast, what do you think the chances of this event happening actually are?	
a. Extremely unlikely b. Very unlikely c. Unlikely d. Medium likelihood e. Likely f. Very likely g. Virtually certain		a. < 1% b. 1–10% c. 10–33% d. 33–66% e. 66–90% f. 90–99% g. > 99%	

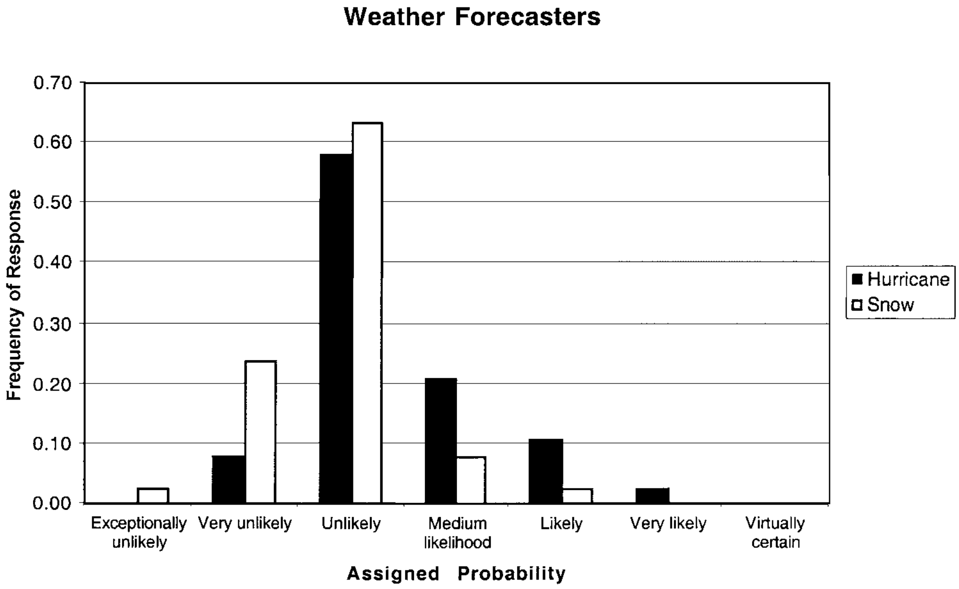

Figure 2. Communicators' probability words.

college students differ in their technical expertise from policy-makers and other readers of the IPCC report. However, what we are testing is whether there exists a basic behavioral tendency for people in general to interpret probability language describing weather events in a way that responds to event magnitude, as others have observed in the literature. It may well be that highly-trained individuals will demonstrate less of a bias. But by using college students as subjects, we can draw conclusions about people's underlying decision-making biases.

The results show significant (χ^2 test, $p < 0.01$) differences between the two outcomes across the two groups of subjects. Among communicators, subjects were more likely to use greater likelihood descriptors to describe the hurricane than to describe the snow flurries, as seen in Figure 2. While the mode descriptor for both events was *unlikely*, more subjects chose the descriptors *medium likelihood*, *likely*, and *very likely* to describe the hurricane than to describe the snow flurries; likewise, more subjects choose the descriptors *very unlikely* and *exceptionally unlikely* to describe the snowfall. Among the audience, subjects estimated lower probabilities of occurrence for the hurricane than for the snow flurries, as seen in Figure 3. The mode estimate for the hurricane was *1–10% chance*, with several subjects estimating *<1% chance*. For the snow flurries, the mode estimate was *10–33% chance*, with more subjects estimating *66–90% chance* for the snow flurries than for the hurricane.

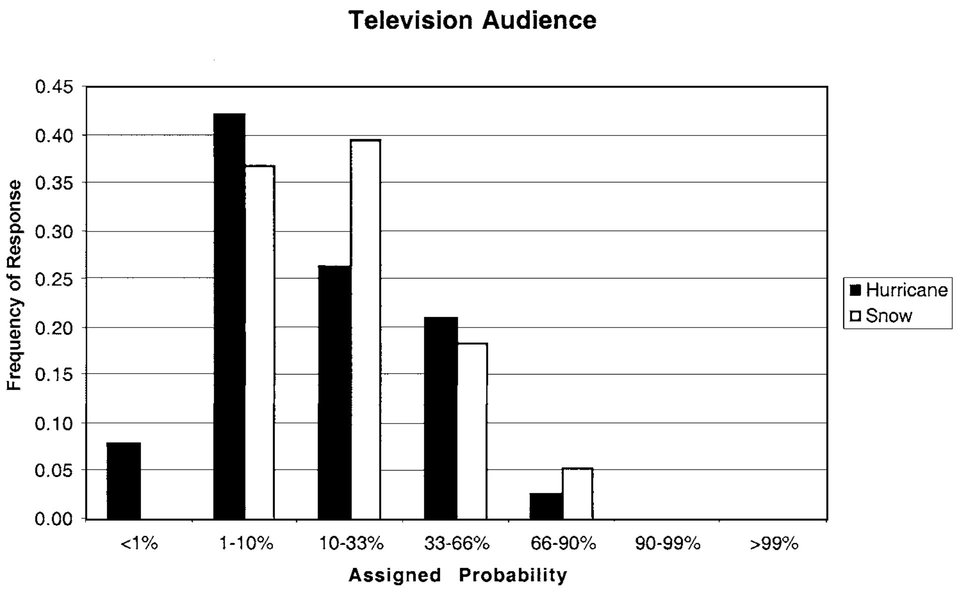

Figure 3. Audience' probability estimates.

5. Discussion

Clearly, the experimental results – surveying only upon undergraduate science students – do not distinguish between different groups of assessment audiences. They are, however, consistent with the existing literature on the use of probabilistic language, and they do suggest an important feature of these probability descriptors: that people both use and interpret them as containing information about event magnitude as well. People are more likely to choose more certain sounding probability descriptors (e.g., *likely* instead of *unlikely*) to discuss more serious consequence events. But people are also sensitive to this practice in others, expecting a certain amount of exaggeration about the likelihood of high magnitude events. A weather forecaster might describe a 10% probable snow flurry as *very unlikely*, which the television viewer would accurately interpret to mean about 10%. Likewise, a weather forecaster might describe a 10% probable hurricane as *medium likelihood*, which the television viewer would again accurately interpret to mean about 10%. The symmetry of the two groups allows for effective communication. Figure 4a illustrates this pattern. Assigning a fixed probability scale to describe uncertain events with significantly different magnitudes of impact could disrupt that symmetry, as seen in Figure 4b. What would happen if forecasters were to use a single phrase, such as *unlikely*, to describe both the hurricane and snowfall? Attempting to correct for the assumed exaggeration, the viewers would understand the single word *unlikely* as implying a smaller chance for the hurricane than for the snow flurries.

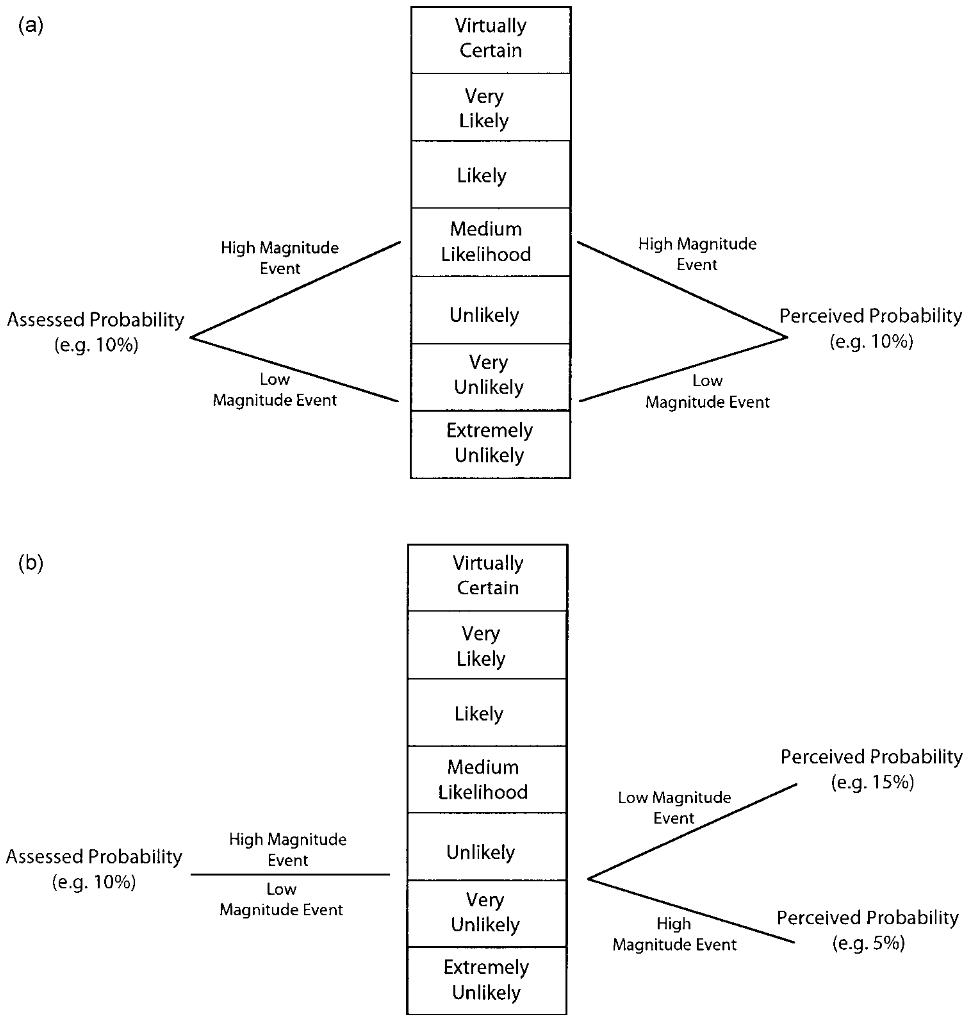

Figure 4. (a) Exaggeration and decoding. (b) Fixed scale and decoding.

5.1. BIASED MITIGATION EFFORTS

In response to the fixed probability scale, people will have a tendency to over-estimate the likelihood of low-magnitude events, and under-estimate the likelihood of high-magnitude events. Importantly, the two errors do not balance each other out, but introduce a bias in people's aggregate responses to the two events. Imagine, for example, that the hurricane, if it hits Boston, will cause damages of \$10 million. The probability of this outcome is 10%, yielding an expected loss of \$1 million, but people underestimate this probability to be 5%, yielding an expected loss of \$0.5 million. The snow-flurries will cause very small damages, perhaps one additional road accidents costing \$10,000. The probability is 10%, yielding an expected loss of \$1000, but people overestimate the probability to be 15%, yielding an expected loss of \$1500. The underestimate of damages for the high-magnitude event completely overshadows the overestimate from the low-magnitude event. People's expectation of damages from the two combined events will be biased downward.

The efficiency of people's efforts to reduce damages, through advance preparation, will also be biased downward, with a net loss in welfare. To see how this is so, consider one possible strategy an individual or local area might pursue: the purchasing of insurance. First, imagine that it is possible to insure against each event at an actuarially fair rate, i.e., 10% of the possible loss from each event. Rational risk-averse actors would gain the greatest expected benefit from fully insuring against each event, purchasing \$1 million of coverage for the hurricane, and \$10,000 of coverage for the snow flurries, reducing to zero the variance of possible outcomes while leaving the expected outcome unchanged. But if people believed the probability of the hurricane were 5%, the insurance at a 10% rate would appear overpriced, and they would underinsure, i.e., purchasing insurance to cover $< \$1$ million. Likewise, estimating the likelihood of snow-flurries at 15%, people would over-insure. In each case, they would have purchased the wrong amount of insurance, resulting in positive variance, and a lowering of expected utility, for each event. Second, imagine that it is possible to purchase a single insurance policy for cover both events. At an actuarially fair rate of 10%, this policy would cost slightly more than \$1 million. With the two errors in probability understanding, people would estimate losses at slightly more than \$0.5 million. The policy would appear too expensive, and people would purchase less than full coverage.

5.2. THE IPCC STRATEGY

Climate change will bring many predictable impacts such as a rise in mean annual temperature, changing precipitation patterns, or mild coastal flooding. It also may bring less probable, more extreme impacts such as major coastal flooding (if polar ice were to deteriorate quickly), prolonged regional droughts, or large increases in storm frequency or intensity. Ideally, policies to mitigate and adapt to climate change will rely on an unbiased appraisal of both the probability and magnitude of each of these different possible outcomes. The communication strategy that the IPCC Third Assessment Report adopts – referring to probabilities through descriptive language matched to precise probability ranges – at first seems to be the best possible approach. Not only does it allow the IPCC more easily to achieve consensus within their own ranks about how to describe levels of confidence, but it also provides a lay audience with information that they can more easily digest.

At closer inspection, however, the strategy could be introducing an unintended bias into the policy process, namely one of under-responding to the aggregate risks associated with climate change. A careful reading of the report, in which the reader takes pains to note the precise probability ranges for each potential outcome, would avoid such a bias. Many readers, however, may lack the time to read the report so carefully. Bias could enter in when readers make intuitive judgements about the likelihood of events, based on less attentive reading in which they fail continuously to match words with probability ranges.

Assessors can take steps to address this bias. If policy-makers read the report with attention to detail, they will both notice and adopt the IPCC's precise, potentially counterintuitive, meaning of probabilistic language. Scientists and assessors hence need to encourage the practice of careful reading, in particular highlighting the meaning of the probabilistic language, and not counting on the audience to do so on their own. But there are also steps that scientists can take to make sure that this happens. Most importantly, scientists should be aware that the potential for bias exists when an audience makes intuitive judgement. When communicating with policy makers or the lay public, scientists should encourage attention to detail. Whenever possible, scientists should refer to uncertainty with greater specificity than the report provides. Scientists should use not only the descriptive language of the report, but also matching those words to their respective probability ranges. As Moss and Schneider (2000) suggest, one approach could be to incorporate the uncertainty into decision-analytic frameworks, such as that carried out above for the simplified choice about purchasing insurance. Putting the numbers to use in this way encourages quantitative rigor, and through this rigor the audience can better understand the relative importance of the different potential outcomes of climate change. From a normative standpoint, the risks associated with low-probability high-magnitude events may be the most important elements of a rational decision-making framework addressing climate change. However, unless scientists encourage quantitative rigor on the part of policy-makers, it is likely the policy-makers will not give enough attention to these risks, and will take inadequate steps either to avoid or to prepare for these risks.

6. Conclusion

The strategy of using specifically defined language to describe the probabilities of climate change risks achieves important objectives, but may also introduce bias into policy-makers responses. Intuitively, people use such language to describe both the probability and magnitude of risks, and they expect communicators to do the same. Assessors need to emphasize that the IPPC's use of this language departs from people's expectations. Unless policy-makers appreciate this fact, their response to the assessment is likely to be biased downward, leading to insufficient efforts to mitigate and adapt to climate change.

References

Breyer, S.: 1993, *Breaking the Vicious Circle: Toward Effective Risk Regulation*, Harvard University Press, Cambridge.

Brun, W. and Teigen, K. H.: 1988, 'Verbal Probabilities: Ambiguous, Context-Dependent, or Both?', *Organizational Behavior and Human Decision Processes* **41**, 390.

Covello, V.: 1990, 'Risk Comparisons and Risk Communication: Issues and Problems in Comparing Health and Environmental Risks', in Kasperson and Stallen (eds.), *Communicating Risks to the Public: International Perspectives*, Kluwer Academic Publishers, Dordrecht, pp. 79–124.

Fischhoff, B.: 1996, 'Public Values in Risk Research', *Annals of the American Academy of Political and Social Science* **545**, 75.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., and Xiaosu, D. (eds.): 2002, *Climate Change 2001: The Scientific Basis*, Cambridge University Press, Cambridge U.K.

Irwin, A. and Wynne, B. (eds.): 1996, *Misunderstanding Science?*, Cambridge University Press, Cambridge U.K.

Kahneman, D. and Tversky, A.: 1979, 'Prospect Theory: An Analysis of Decision under Risk', *Econometrica* **47**, 263.

Kammen, D., Shlyakhter, A., and Wilson, R.: 1994, 'What is the Risk of the Impossible?', *Journal of the Franklin Institute* **331A**, 97.

Leiss, W.: 1996, 'Three Phases in the Evolution of Risk Communication Practice', *Annals of the American Academy of Political and Social Science* **545**, 85.

Morgan, M. G. and Keith, D. W.: 1995, 'Subjective Judgments by Climate Experts', *Environmental Science and Technology* **29**, 468A.

Moss, R. H. and Schneider, S. H.: 2000, 'Uncertainties in the IPCC TAR: Recommendations to Lead Authors for more Consistent Assessment and Reporting', in Pachauri, R., Taniguchi, T., and Tanaka, K. (eds.), *IPCC Supporting Material, Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC*, pp. 33–51.

Patt, A.: 1999, 'Assessing Extreme Outcomes: The Strategic Treatment of Low Probability Impacts in Scientific Assessment', *Risk Decision and Policy* **4**, 1.

Patt, A. and Gwata, C.: 2002, 'Effective Seasonal Climate Forecast Applications: Examining Constraints for Subsistence, Farmers in Zimbabwe', *Global Environ. Change* **12**, 185.

Patt, A. and Zeckhauser, R.: 2002, 'Behavioral Perceptions and Policies toward the Environment', in Gowda, R. and Fox, J. (eds.), *Judgments, Decisions, and Public Policy*, Cambridge University Press, Cambridge U.K., pp. 265–302.

Pinker, S.: 1997, *How the Mind Works*, Norton, New York.

Van der Sluijs, J.: 1997, *Anchoring Amid Uncertainty, on the Management of Uncertainties in Risk Assessment of Anthropogenic Climate Change*, Ludy Feyen, Leiden, The Netherlands.

Wallsten, T. S., Fillenbaum, S., and Cox, J. A.: 1986, 'Base Rate Effects on the Interpretation of Probability and Frequency Expressions', *Journal of Memory and Language* **25**, 571.

Weber, E. U.: 1994, 'From Subjective Probabilities to Decision Weights: The Effect of Asymmetric Loss Functions on the Evaluation of Uncertain Outcomes and Events', *Psychological Bulletin* **115**, 228.

Weber, E. U. and Hilton, D. J.: 1990, 'Contextual Effects in the Interpretations of Probability Words: Perceived Bas Rate and Severity of Events', *Journal of Experimental Psychology: Human Perception and Performance* **16**, 781.

Windschitl, P. D. and Weber, E. U.: 1999, 'The Interpretation of "Likely" Depends on the Context, but "70%" is 70% – right? The Influence of Associative Processes on Perceived Certainty', *Journal of Experimental Psychology: Learning, Memory, and Cognition* **25**, 1514.

(Received 6 July 2001; in revised form 10 February 2003)