Letters

Seeding Hurricanes

Howard, Matheson, and North, in their article "The decision to seed hurricanes" (16 June, p. 1191), provide a good framework for an initial consideration of this important subject. They do not, however, include the effect of seeding on the hurricane rainfall rate—only the effects on the maximum sustained wind and on the wind-related storm tide.

While these latter effects may be paramount for coastal areas, in the light of the floods that accompanied hurricane Agnes, the storm rainfall should also be considered a decision factor when further studies are made of the seeding of hurricanes that threaten coastal areas. As seeding could conceivably increase the storm rainfall, both at the coastline and inland, the increased damage from flooding would then have to be balanced against the hoped-for reduction in damage from wind and storm tide.

Research on the control of hurricane direction, as well as on the reduction of wind intensity, appears indicated. If directional control were feasible—and, for example, some control of the rate of release of latent heat in different storm sectors is technically available now—this would be an attractive option in the case of storms approaching coastal areas.

The question of loss of life in seeded hurricanes, not covered in the article, must eventually be faced. The parallel question of seeding in war (News and Comment, 16 June, p. 1216), could also benefit from the same kind of rational and orderly analysis as that begun by Howard *et al.* To be fully useful, a study should attempt to separate the military from the civil effects, and the value judgments should be founded on an analysis of war as a moral problem.

BERNARD A. POWER
255 Touzin Avenue,
Dorval, Quebec, Canada

The article by Howard, Matheson, and North is an elegant decision-making analysis (within a Bayesian framework) that considers the consequences of both property damage and government responsibility of seeding versus nonseeding of hurricanes in terms of change in maximum sustained surface wind. Within this somewhat constrained analysis (surface wind as a surrogate for a complex physical phenomenon, property damage, and government responsibility are the only effects considered), a thorough range of possible outcomes is examined, including the three key hypotheses that seeding is beneficial, ineffective, or detrimental to the goal of reducing the social cost of hurricanes. The central conclusion is that "On the basis of present information, the probability of severe damage is less if a hurricane is seeded" and that seeding should be permitted on an emergency basis and encouraged on an experimental basis. But beyond this recommendation, the analysis itself is suggested as a model for "any complex decision that may affect the lives of millions, a decision analysis showing explicitly the uncertainties and decision criteria [that] can and should be carried out."

Among social scientists working at the boundaries of atmospheric science, the Howard *et al.* analysis has been received with critical enthusiasm. Some 6 years ago, along with Sewell, I suggested a process of analyzing social impacts akin to this analysis (*1*) and undertook with Julian and Sewell (*2*) a modest field survey to determine the expectations of leading atmospheric scientists about the viability of a range of weather modification technologies.

In the spirit of decision analysis, I question the use of the Howard *et al.* analysis and offer three alternative hypotheses to be used in the context of the current social, political, and scientific milieu when such questions as the decision to seed hurricanes are being dealt with.

1) Hypothesis H_1. Decision analysis is a rational method of analysis that systematically precludes in nonrandom fashion significant aspects of the problem, because these aspects are either not known, poorly understood, have low a priori estimates of probability, or seem inappropriate to the terms of reference.

2) Hypothesis H_2. Decision analysis is a rational method of analysis which will be used in an "arational" way.

3) Hypothesis H_3. Decision analysis is a rational method of analysis employed rationally for amoral purposes.

The first hypothesis emphasizes the problem of where to make the cut in systems analysis. Howard *et al.* have so constrained their analysis as to ignore the beneficial and detrimental effects of hurricanes on the water balance of the areas affected (*3*). They also seem unaware of the counterintuitive effects, well documented from other forms of hazard control (*4*), in which the knowledge of seeding may increase the damage toll by influencing negatively other human responses, such as evacuation, preventive measures, and so forth. And there is no mention of the low-probability outcomes, for example, the potentially negative environmental impacts of large-scale injection of silver iodide particles into the atmosphere. Such analyses are always constrained by time, effort, and imagination and must systematically exclude many considerations. And indeed many are missing from the article.

Under the second hypothesis, the use of the analysis serves as justification for decisions made on other more transscientific grounds. Thus if a decision is taken on the basis of considerations extraneous to the analysis (for example, the bureaucratic ambition of an organization for its own growth), will "arational" analysis be used to buttress the decision and give an unwarranted gloss of respectability? How often are even negative results ignored in such cases, with the comforting statement, "Oh, we had Stanford Research Institute carefully study the question." The precedents for this misuse are ample. The most extensive use of rational analysis to date, benefit-cost analysis in water resource development (less elegant than decision analysis, but relevant nonetheless) has served for 35 years to justify a program of water resource development that many feel has served the public less well than it could have if such analysis had been absent (*5*). In another instance of rational analysis, the results of cloud-seeding experiments in Texas, Arizona, and Florida were quickly used to justify operational cloud-seeding programs before adequate control experiments were made in dry periods.

As for the final hypothesis, one need only follow the recent reports in *Science* (News and Comment, 16 June,

p. 1216; 21 July, p. 239; 1 Sept., p. 776; 13 Oct., p. 145) concerning the massive use of environmental modification, including weather control, in Southeast Asia to consider that the experience gained in peaceful geophysical modification can be quickly turned to other purposes less helpful to mankind.

To the extent that any one of these hypotheses is valid, the social scientist committed both to rational analysis and to responsibility for his or her actions is in a dilemma. If the limits of the analysis or its possible misuse are great, would society be better off without it? I think in some cases the answer must be yes, as much in social science as in new technology. Indeed to the extent that social science becomes important (that is, people really take it seriously) social scientists must be as self-critical and responsible about their methods and their possible abuse and misuse as technologists should be about their inventions. In some cases where uncertainty is very great, it may be as irresponsible to advocate a decision-making methodology that does nothing to really reduce the uncertainty or to control its use as it is to build an SST. At the very least, until we can take into account both the limits and unintended use of decision analysis, we should be cautious in its advocacy. And in areas of great scientific unknowns, such as weather modification, where heavy pressure exists for its "arational" use and some pressure for its amoral use, extreme caution is indicated.

ROBERT W. KATES

Graduate School of Geography,
Clark University,
Worcester, Massachusetts 01610

References

1. R. W. Kates and W. R. D. Sewell, *Human Dimensions of Weather Modification* (Department of Geography Research Paper No. 105, University of Chicago, Chicago, 1966), pp. 347–362.
2. P. R. Julian, R. W. Kates, W. R. D. Sewell, *Water Resour. Res.* 5, 215 (1969).
3. L. M. Hartman, D. Hilland, M. Giddings, *ibid.*, p. 555.
4. Taskforce on Federal Flood Control Policy, *A Unified National Program for Managing Flood Losses*, House Document 465, 89th Congr., 2nd sess. (Government Printing Office, Washington, D.C., 1966).
5. G. F. White, in *Water Research*, A. V. Kneese and S. C. Smith, Eds. (Johns Hopkins Press, Baltimore, Md., 1966), pp. 251–273.

Power is correct in suggesting that rainfall and steering effects are important issues in hurricane seeding. Another important factor is storm tide, which can be affected significantly by coastal geography. These effects might be of critical importance in the tactical decision to seed a particular hurricane. As the full report referenced in our article shows, present knowledge concerning these factors is consistent with our strategic recommendation to permit, as an emergency measure, the seeding of some hurricanes threatening a coastal area.

It is possible to conduct a decision analysis to determine the value of research on hurricane steering. However, our discussions with meteorologists have indicated that while the ability to steer hurricanes would be valuable, this ability is unlikely to result from a research program. Consequently, it is not clear that the decision analysis of steering research would demonstrate that the research has a high value.

On the question of loss of life, we found that, given the effective hurricane warnings provided by the U.S. Weather Service, the expected number of lives lost in a present-day hurricane is relatively small. If these lives are valued for decision-making purposes in a range from $100,000 to $300,000 each, they constitute an expected loss of only about one-tenth the expected property damage for the hurricane. Furthermore, since storms that damage less property also tend to kill fewer people, the case for removing the prohibition against seeding is only strengthened by including human loss.

We direct our commentary on Kates's letter to the three hypotheses he suggests for the nature of decision analysis.

Hypothesis H_1 is that decision analysis systematically excludes significant aspects of the problem because they are uncertain or improbable. Anyone familiar with decision analysis knows that its procedures involve not excluding, but discovering and emphasizing, significant aspects of the problem. In fact, decision analysis is uniquely concerned with assessing probabilities and their implications. Kates presents no evidence that our recommendations would be changed by additional analysis of any of the factors he mentions.

Hypothesis H_2 is that decision analysis might be misused. We agree that anything from hammers to medicine may be misused, but we find no logical argument that they should be unused. Moreover, Kates presents no evidence that our hurricane analysis has been or will be misused.

Hypothesis H_3 is that decision analysis might be used for amoral purposes. Presuming that amoral means immoral, we can only reiterate that the fact that hammers and medicine can be instruments of crime is no argument for

discontinuing their production. Kates presents no evidence that our analysis has been or will be used for immoral purposes.

But Kates's hypotheses do not form a collectively exhaustive set. We would like to include a fourth hypothesis, H_4: Decision analysis is a rational method for displaying and balancing the important uncertain, complex, and dynamic factors that surround a decision. We leave it to others to judge whether this hypothesis is supported by our work.

RONALD A. HOWARD
Department of Engineering–Economic Systems, Stanford University, Stanford, California 94301
JAMES E. MATHESON
D. WARNER NORTH
Decision Analysis Group, Stanford Research Institute, Menlo Park, California 94025

Thermodynamics and Information

Witold Brostow, in his discussion of information theory and thermodynamics (13 Oct., p. 123), says that "It took some years after Jaynes's paper . . . until books of statistical mechanics based on information theory began to appear." He thus overlooks the pioneering textbook by Myron Tribus entitled *Thermostatics and Thermodynamics* (*1*), which was published in 1961.

ROBERT LEMLICH
Department of Chemical and Nuclear Engineering, University of Cincinnati, Cincinnati, Ohio 45221

References

1. M. Tribus, *Thermostatics and Thermodynamics* (Van Nostrand, New York, 1961).

I gladly accept Robert Lemlich's correction. I have also learned from Rolf A. Haugan of Pergamon Press that *An Introduction to Equilibrium Thermodynamics* by Bernard Morrill has just been published—with a chapter on Jaynes formalism. Apart from this, Joel H. Hildebrand writes me that, after spending the academic year 1906–07 with Nernst in Berlin, he independently derived the Gibbs-Duhem equation (not mentioned in Nernst's book). He concludes now that, "There is great reward from getting answers out of one's head instead of from a book."

WITOLD BROSTOW
Département de Chimie, Université de Montréal, Montréal 101, Québec, Canada