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Estimating Probabilities of Research Success in the Atmospheric Sciences: Results of a Pilot Investigation

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Abstract. In this paper we have two main objectives. The first of these is to outline a research and payoff (R & P) model that suggests a procedure for evaluating competing or concurrent research projects. The atmospheric sciences provide a good example for an initial application of the model. Weather modification, particularly artificial stimulation of precipitation, has been touted as an answer to many water resource problems. Alternatives to this technology have received little attention. We suggest that the R & P model could profitably be applied in this instance. The second objective of the paper is incorporated in a pilot study of the first step in such an application: namely, the determination of the estimated probabilities of success of various technologies in the atmospheric sciences. For this step, responses to a questionnaire sent to professional atmospheric scientists were examined to determine whether (a) scientists are willing to provide probability estimates of success of various technologies and whether these estimates are consistent with other estimates of success; (b) personal involvement in a field influences such estimates; (c) the probability estimates are consistent with the respondents' assignment of shares of a research budget; and (d) the estimates are generally in agreement with the reports of 'blue-ribbon' panels of experts. We conclude that it is possible to obtain reasonably consistent estimates of research success from those who know most about them. The degree of optimism among those sampled is high, and it is highest for those workers involved in and having a high degree of knowledge of a particular field. Continued efforts in the determination of research success probabilities specifically tailored to the R & P model are recommended.

INTRODUCTION

The U. S. federal government spends over $200 million a year on research and development programs in the atmospheric sciences [*Interdepartmental Committee on Atmospheric Sciences,* 1968]. Although these expenditures increased substantially before the 1960s, there is mounting pressure for much greater support of such programs. As emphasis on environmental quality, air travel, and water resources grows, and as losses from weather-caused disasters continue to mount, the need for more knowledge of the atmosphere and human responses to it will become more and more urgent. But it is not immediately clear how much more support is required or what types of research should receive priority in the allocation of funds. There is also debate over what criteria should be used and as to which bodies are the most appropriate for making decisions about the magnitude and distribution of research funds. This debate has been intensified in recent years by the emergence of the foundling technology of weather modification (see *Waterman,* 1966, *Carey,* 1967, *Kahan,* 1968, for examples of discussions in connection with this debate.)

Much of the interest in weather modification efforts, to date, has come from scientists and engineers interested in water resources. This is natural, since the greatest promise of success has been in the field of artificially stimulating the precipitation process. In the debate over the support of weather modification research, emphasis has been centered on scientific-technological questions: will it work? The sociopolitical and economic justification for large-scale funding of weather modification research, although linked to water resource economics, has never been very clear. In particular, there appears to have been little or no consideration of alternatives to increasing the supply of water by artificial stimulation.

In this paper we have tried to examine the problem of the place of weather modification activity in the atmospheric sciences research program in a larger context. This context is one which the science of weather modification is considered, not unrealistically, to compete with other applied meteorological techniques for the research dollar. A method is proposed whereby various alternative or concurrent technologies may be compared as to their potential for eventual socioeconomic payoff.

A RESEARCH AND PAYOFF MODEL

Although it is recognized that evaluation of investment in research and development is made difficult by the diversity of goals in research and development and by the intangible nature of the findings of basic research, there is increasing agreement that evaluation is not only essential, but also that it is possible. Various criteria have been suggested for weighing the merits of proposals for research [*Weinberg,* 1964]. In the field of economics, several techniques have been developed for identifying and measuring the costs and returns from research and development programs [*Nelson,* 1959; *Nelson and Winter,* 1964; *Sherer,* 1965].

There have been a number of attempts to determine the economic merits of programs of research and development in the physical sciences. Some of these, however, have had substantial weaknesses. In particular, most of them assume that there is a direct link between research and economic payoff. It has been pointed out elsewhere that this assumption is invalid [*Kates and Sewell,* 1965]. Not all research results in an economic payoff, and in any event the link between investment in research and economic and social consequences is seldom direct. Some discoveries are never adopted, and even those that are may be adopted only several years after the discovery was made. Typically, there is a lag between innovation and adoption. A further weakness of previous attempts to identify the merits of atmospheric research programs is that they generally consider only the potential benefits of such programs. Seldom are the possible disbenefits considered.

For example, increased ability to modify the weather would make possible some improvement in human welfare, such as reduced losses from weather-caused disasters or increased productivity on farms resulting from provision of moisture at the right time. But it might result in social losses, too. A hydroelectric power company might be able to increase its operating efficiency by raising the level of its reservoirs through augmenting natural precipitation by cloud seeding. The additional precipitation, however, may ruin the vacation of the tourist in the reservoir area or produce undesirable ecological changes.

Kates and Sewell [1965] have proposed a multistep Research and Payoff model (R & P) that attempts to overcome some of the weaknesses of previous methods of evaluation of research and development in the geophysical sciences. Briefly, the R & P model specifies five steps in the research and payoff chain: basic research, applied research, development, adoption, and economic and social impacts. Basic research refers here to studies of scientific problems of the atmosphere leading to new theory, methods, and instruments. Applied research relates to the application and refinement of theory that have been developed in basic research to create a technology to serve some specified social purpose. The development phase involves engineers, planners, and others who design and implement systems on the basis of the findings of basic and applied research. The period between discovery and adoption varies considerably, reflecting differences in perception of possible applications or of potential payoff, or the existence of social and political guides that either encourage or retard adoption of new techniques. Finally, there is a payoff phase in which economic and social impacts include both the positive and the negative effects, and the direct effects and the external effects. The steps are set out diagrammatically in Figure 1.

A novel element in this R & P model is the estimate of success potential of competing or concurrent research projects. The motivation in attempting to obtain such estimates and to obtain them in terms of probabilities stems from our view that statistical decision theory and so-called subjective probabilities offer a potentially valuable technique for effective utilization of the R & P model. The iterative nature of the model is intended to make use of changing estimates of the likelihood of research success as new discoveries and applications are perfected. The probability measures can thus be looked upon as measures of our state of ignorance that change whenever new knowledge is acquired.

The model would use these estimated probabilities to determine a preference ranking of the competing or concurrent projects. The product of the success probability matrix and the payoff matrix, derived by study of the social and economic benefits accruing from each operational system and adjusted for adoption lag, determines the relative preference ranking of the projects.

It is not our intention here to discuss the operation of the R & P model; the pilot study we are reporting on was intended to discover whether research scientists are willing to make estimates of research success, some of the characteristics of these estimates, and some of the factors that condition the estimates.

The traditional method of assessing the merits of research proposals has been to submit them to panels of scientists of established repute for comment. For small projects reliance is placed primarily on researchers in the field in which the research is to be undertaken. This has been called 'Little Science' by *Weinberg* [1964]. Gen-

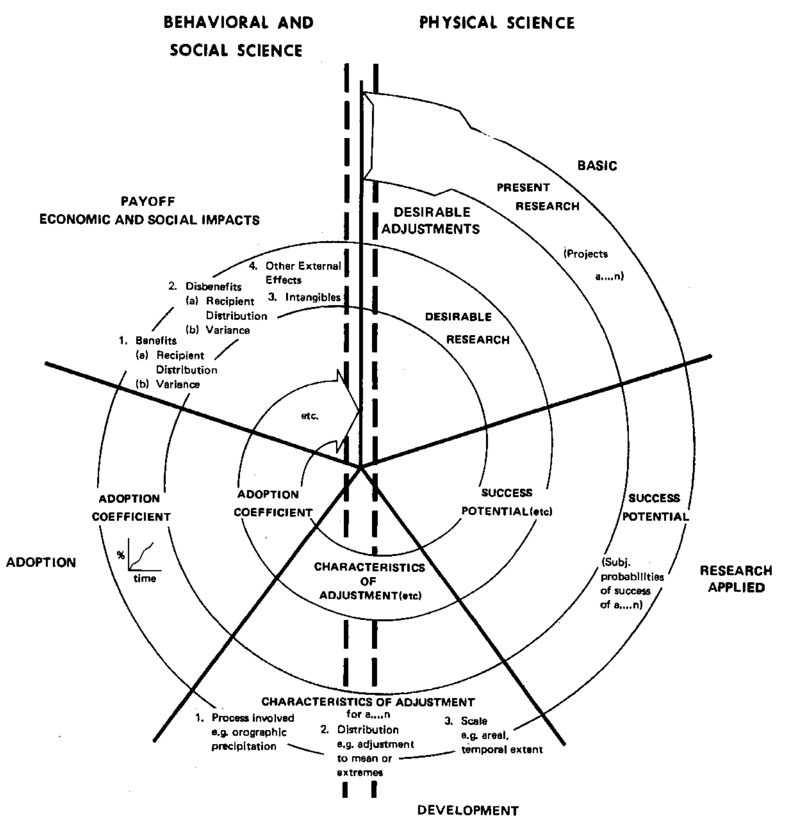

Fig. 1. The relationship between research and payoff: a multistep model.

erally, the criteria that are applied in this instance are those of the ripeness of the field and the competence of the investigator. In the case of 'Big Science' other criteria may be used, such as technological merit, scientific merit, or social merit. The major question posed is why pursue this particular science? Dependence is usually placed on a panel of highly reputed scientists from various related fields for answers to this question.

As noted, thus far there has been little systematic study of the manner in which teams of experts appraise the merits of 'Big Science' projects. We do not know, for example, what factors condition their optimism that a particular research project will advance the frontiers of knowledge. To what extent does their commitment to a particular type of research condition their optimism? Do those who are working in the field of cloud physics feel more optimistic about a project in that field than a researcher in the field of dynamic meteorology appraising the same project? What role does occupational allegiance play in opinions? Are there significant differences in the opinions of civil servants, university professors, and private businessmen about the success of potential of the same research project?

A SURVEY OF SCIENTIFIC OPINIONS ABOUT RESEARCH SUCCESS POTENTIAL

This paper reports the results of a pilot research study of opinions of research scientists as to the success potential of research relating to possible developments in the fields of weather forecasting and weather modification. It is based on the analysis of replies to a questionnaire circulated to about 225 research scientists in the atmospheric sciences in the principal federal government agency dealing with atmospheric problems (the Environmental Sciences Services Administration), a large portion of the academic community, and a private research corporation. Some 125 questionnaires were returned, and of these 113 were sufficiently complete to be usable in the analysis.

It is believed that the sample obtained was reasonably representative of the groups surveyed. We do not claim to have sampled the opinions of the entire atmospheric science community. The major source of bias, if any, results from the omission of commercial organizations involved in weather forecasting and/or weather modification. However, for most of the purposes for which the questionnaire was designed, it was not necessary to attempt to sample discipline-wide opinion. Although the expression of the opinions of the blue-ribbon panels represents the considered views of a few leaders in the profession, the questionnaire hopefully will reflect the views of a large segment of the meteorological research profession.

THE QUESTIONNAIRE

A major objective of the questionnaire was to determine factors that appear to be associated with optimism as to research success potential. A number of working hypotheses were erected about these factors, and information was sought in the questionnaire to test them.

A first hypothesis was that research scientists are willing to estimate research success potential in probabilistic terms, and that such probabilities are reasonably consistent with other non-probabilistic measures of that potential.

To test this hypothesis, a certain amount of redundancy was built into the questionnaire. Respondents were asked how long they thought it would take to develop operational systems for improved weather forecasts and various types of weather modification activity (a choice of five time intervals); in what time scale and with what probability these activities would be attained (five classes of decimal probability range); and to rank 13 various forecast and modification activities according to the order in which they might become operational. In addition, the respondents were constrained to choose from three short statements designed by us to represent an optimistic, a neutral, and a pessimistic summary of the present state of development of one forecast improvement and four weather modification activities selected from the larger group of 13 such activities. (The 13 activities chosen were those listed in Table 6, with hurricane and tornado modification listed separately (making 10), plus two additional forecast improvement techniques (long-range seasonal forecasts and severe storm forecasts) and the prediction of inadvertent climate modification. The five selected fields were: the development of eight-day forecasts with demonstrable skill on the eighth day, a system for nonorographic precipitation increase, a warm fog dispersal system, hail suppression technique, and a hurricane modification system.)

A second hypothesis was that optimism as to research success potential is influenced to some degree by personal involvement in the field of research in question. In the Western World as a whole there is great faith in what can be achieved by science and technology. Recent articles have suggested that this faith is especially strong among those involved in certain physical sciences and among those who are involved in developing and applying technology [*Weinberg,* 1966]. One might expect, therefore, that those who are directly involved in a particular field of research would be relatively more optimistic about potential discoveries in that field than those who are not directly involved. On the other hand, one might perhaps expect that the more familiar a research scientist is with a field, the more aware he is of its complexity and therefore the less optimistic he is likely to be of its research success potential than others who are less involved in the field. To test this hypothesis and to try to determine whether professional involvement leads to optimism or skepticism, information was collected in the questionnaire on the professional background and occupational involvement of each of the respondents. (The respondents were not asked to sign their questionnaires.) These data were then correlated with their opinions as to what was likely to be achieved in the next 5, 10, 25, and 50 years and beyond in connection with the improvement of short-range weather forecasts and weather modification.

The third hypothesis was that optimism as to research success potential would be reflected in views about the relative amounts of money that should be devoted to different fields of research. If this hypothesis is correct, those fields that offer the greatest chance of success, which probably also means early success, would presumably be voted a greater share of available research funds than other fields competing for such funds. To this end, respondents were asked to allocate a hypothetical research budget of $10 million among the five selected competing fields of research.

Another hypothesis was that the opinions of blue-ribbon panels of experts, such as those called together by the National Science Foundation or the National Academy of Sciences, as to research success potential do not necessarily coincide with the opinions of other knowledgeable members of the professions they represent. To test this hypothesis, the rankings given by the respondents to the 13 potential developments in weather forecasting and weather modification were compared with rankings suggested in the report of the *National Academy of Sciences-National Research Council Committee on Weather and Climate Modification* [1965].

ARE RESEARCH SCIENTISTS INTERNALLY CONSISTENT IN THEIR RESPONSES?

A comparison of the responses from the redundant parts of the questionnaire revealed a high degree of internal consistency. The relative ranking, statement choice, and time-scale for system realization for the five selected activities all possessed a high positive association. Space limitations prevent us from documenting all the various combinations, but the reader can judge the nature of this consistency from data given in Table 1 and Table 2.

In Table 1 the respondents' rankings of the five selected fields are stratified as a function of their estimates of the time-scale to realization of each; all five fields are combined. The ranks have been grouped into three classes, anticipating their use as indicators of optimism, as explained in the next paragraph. It is obvious that a significant relationship exists in the Table; high rank is associated with early realization of an operational system and low ranks with the later developments.

For purposes of relating information on subdisciplines, familiarity with research fields, and professional background with the respondents' estimates of research success, two simple scales of optimism as to potential developments were

TABLE 1. Comparison of Respondents' Ranking of Five Selected Research Areas with Their Estimates of the Time-Scale for the Realization of an Operational System for Each. Percentages of Total Replies.

Rank	Time-Scale + 50 yrs.	50 yrs.	25 yrs.	10 yrs.	5 yrs.
1–4	0	0	1.7	10.5	16.5
5–8	0.4	0.9	8.1	21.0	8.5
9–13	5.0	3.5	14.5	8.5	0.9

TABLE 2. Contingency Table Comparing Respondents' Ranking of Five Selected Research Areas with Their Choice of an Optimistic-Pessimistic-Neutral Statement Pertaining to Each Area

Raw frequencies with expected frequencies in brackets.

Statement Choice	Rank 1–4	Rank 5–8	Rank 9–13	
Optimistic	40 [32.4]	44 [43.6]	29 [37.0]	113
Neutral	107 [86.2]	117 [116.1]	77 [98.7]	301
Pessimistic	12 [40.4]	53 [54.4]	76 [46.2]	141
	159	214	182	555

χ^2 for this table = 52.6. χ^2(4 d.o.f.) exceeded by 5% of such tables with cell frequencies randomly determined = 9.3.

constructed. These scales were a tripartite division into optimism, neutrality, and pessimism, and were devised from an analysis of, first, the rankings of all 13 potential developments; and, second, an analysis of the choices of the respondents as to the most appropriate statement of the present status of knowledge and potentialities for development in the five selected fields. The three statement choices included for each of the five fields were intended to represent an optimistic, a neutral, and a pessimistic position. The rankings were divided into three groups, (1–4), (5–8), and (9–13), to give a scale interpretable as optimism, neutrality, and pessimism, respectively.

The table of association, Table 2, using these two measures of optimism exhibits a very strong degree of association. The chi-square computed from the observed and the expected cell frequency (in brackets) is approximately 6 times the value of chi-square necessary for rejection of the null hypothesis of no association at the 5% significance level. We thus conclude that the respondents were internally consistent in expressing their degree of optimism or pessimism as to potential developments.

The degree of consistency in expressing *probabilities* of potential developments is difficult to assess. However, one instructive comparison was made in which the respondents were asked first to state how long it would take for each of five selected potential developments to reach an operational state. Next they were asked to assign their estimate of the probability of each operational system's being realized for each time scale. The probabilities assigned to the particular portion of the time scale selected first were surprisingly low. For example, whereas 86% indicated that an operational system for eight-day forecasts would be realized within 10 years, only 29% of that group indicated that they believed that the probability of such a system's being attained was greater than 0.8, whereas of the one-third of the respondents who felt that hurricane modification would be in operation in 10 years, only 15% of the latter group believed that the probability of the event exceeds 0.4.

Examination of the data giving the probabilities of success in each of the five fields separately for each of the two scales of optimism reveals an obvious association. Optimistic assessments (high ranks or optimistic statement choice) are accorded higher probabilities and, conversely, pessimistic assessments are accorded the lower probabilities. In a gross sense, then, the respondents exhibited a fairly high degree of internal consistency in their assessments. The larger and more important question as to the degree of internal consistency of their estimates of probabilities is still open. Some additional remarks on this problem are given in the final section.

HOW DO RESEARCH SCIENTISTS ASSESS POTENTIAL DEVELOPMENTS?

Within a decade 86% of the respondents foresee weather forecasts for eight days in advance reaching an operational stage of development, and 77% of them feel that precipitation augmentation in nonorographic situations will also become feasible within the period. Two-thirds of the respondents think that warm fog dispersal and hail suppression are likely to become operational within the next 10 years. Even hurricane suppression, the present possibilities of which have been regarded with much skepticism by researchers in the atmospheric sciences, is viewed by more than one-third of those sampled as likely to reach an operational stage within the next decade.

When appraised in terms of the progress that has been made in the atmospheric sciences during the past 10 years, the replies seem to us highly optimistic. This optimism is tempered somewhat by the probabilities assigned by the respondents to the time scale chosen initially, as noted in the previous section.

As one might expect, as the time span increases the level of confidence in the development being attained also increases. Within 50 years some 80% of the total respondents foresee an eight-day forecast system with a probability exceeding 0.8, and 66% specify cumulus and nonorographic precipitation stimulation with that same level of probability. About 60% predict an operational system for hail suppression and warm fog dispersion, whereas 30% foresee hurricane modification, again with a probability exceeding 0.8.

It should be noted that the relative degree of optimism associated with each field on the shorter time scales carries through to the longer time scales. Thus hurricane modification retains the highest proportion of low probabilities on all time scales. We interpret this as an indication of the view that the more difficult technologies now are likely to remain the most difficult and that the general increase in the probabilities of success with increasing time is not *simply* a reflection of the view that 'science wins all in the end.'

Our conclusion from the analysis of the replies as to likely developments resulting from research in the atmospheric sciences is that there is a high degree of optimism as to what is likely to be attained, even taking into account the tempering effect of the probabilities assigned to the various estimates. Significant, major advances are expected to be made in man's ability to understand, forecast, and modify the weather in the next five decades. This would mean that even greater progress has to be made in the atmospheric sciences than has been accomplished in several hundred years of research and experiment to date. We also conclude that in some subject areas, for example, in an operational 8-day forecast system, there is a relatively high degree of agreement among the respondents in the subjective probabilities assigned. Figure 2 shows the percentage of total replies for the indicated probabilities that in 25 years an operational system for 8-day forecasts (left) and an operational system for hurricane modification (right) will be realized. It is rather obvious that there is little agreement with respect to the likelihood of hurricane modification, but that the likelihood of useful 8-day forecasts fosters much greater unanimity.

IS OPTIMISM INFLUENCED BY PERSONAL INVOLVEMENT?

Several sets of data were analyzed to test the second hypothesis that optimism as to research success potential is influenced by personal involvement. It was assumed for purposes of this study that an indication of personal involvement was the nature of the respondent's subdiscipline within the field of atmospheric sciences, and that another was his familiarity with research and potential developments in that field. A third indication was assumed to be that of educational background and professional experience.

To simplify the analysis a tripartite classification of subdisciplines was devised from data on

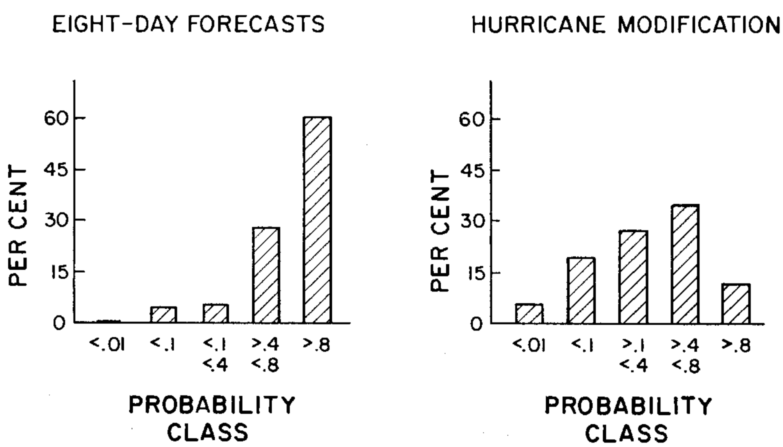

Fig. 2. The distribution of probabilities for an operational system for eight-day forecasts (left) and hurricane modification (right) in 25 years. Per cent of total respondents.

areas of specialization of the sample surveyed. The classification was as follows: physicists-chemists, synopticians, and dynamicists. (Physicists and chemists who consider themselves atmospheric scientists are concerned with the microphysical processes in the atmosphere leading to the formation of hydrometeors and with the physical processes involving trace gases and aerosols. Dynamic meteorologists are interested primarily in the fluid mechanical aspects of the circulations of the atmosphere. Synopticians are those whose interests can be considered as descriptive and/or applied, although it is frequently difficult to distinguish between a synoptic and dynamic meteorologist.) All physicists were grouped together, regardless of whether they indicated that they were cloud physicists or not, and climatologists were lumped with the synoptic meteorologists. A few respondents could not be included in any of the three subgroups.

Respondents were asked to note the extent to which they were familiar with a number of reports of experts on the present status of knowledge and potential developments relating to weather forecasting and weather modification. In another part of the questionnaire they were asked to indicate the highest academic degree they had received and the number of years of professional experience they had had.

THE INFLUENCE OF DISCIPLINARY ATTACHMENT

The table relating to subdisciplines (Table 3) shows some notable results. In particular, the degree of optimism of the dynamicists as to the possibilities of 8-day forecasts is noticeably greater than that of the synopticians. There are probably a number of reasons for this difference, but we believe the major reason is to be found in the differing attitudes towards the future ability of numerical forecasting techniques to give useful applied forecast information. Synopticians are possibly more oriented towards user demands and think of forecasts in terms of specific weather information, whereas the dynamicists are probably sanguine about the development of numerical dynamical forecast techniques for modeling atmospheric flow patterns.

Another interesting observation from Table 3 is that although the physicists-chemists are evenly divided between optimistic and pessimistic statements regarding nonorographic precipitation stimulation, the majority placed this development in the top four of the rankings. It may also be noted that the dynamicists are the most pessimistic of the three groups towards hurricane modification, and that the physicists-chemists are the most optimistic. This may well reflect the fact that some of the latter group are directly involved in research in this connection, but it may also reflect major differences in the outlook of those interested in the microscales as contrasted with those who think in terms of the macroscale.

THE INFLUENCE OF EXPERTISE

Optimism as to research success potential appears to be associated to some extent with the respondent's degree of expertise in the field in question. Expertise was measured in two ways: first, in terms of the respondent's familiarity with research that has been or is being undertaken in the field in question; and second, in terms of the respondent's familiarity with certain reports of blue-ribbon panels of experts. Table 4 compares the degree of optimism with the degree of familiarity with research in question for all five of the selected fields together. To obtain a sufficiently large number of occurrences in each cell of the table of association, the responses for all five of the selected fields were combined. It would, of course, be instructive to learn whether the degree of association varies from one field to another. With the sample size available and acceding to the demands of statistical rigor, however, this could not be done. The examination of the individual tables, however, suggested that the skewed cell frequency pattern was strongest for the hail suppression and warm fog dispersal fields and weakest for the other three. The chi-square values in both sections of the table are significant at the 5% level; thus we reject the null hypothesis of no association. The bias indicates a relationship that may be broadly expressed as 'experts are optimists and novices are pessimists.' Those who had been directly involved in research in the field in question tended to be optimistic, whereas those who were unaware of research in the field tended to be pessimistic.

When expertise is measured in terms of familiarity with reports of blue-ribbon panels, however, the association between optimism and expertise is less clear. In Table 5, the section

TABLE 3. Respondents' Subdiscipline versus Degree of Optimism-Pessimism
All values in per cent of relevant replies. See text for definition of subdisciplines.

Optimistic-pessimistic-neutral Statement Choice Subject Area	Physicists-chemists			Synopticians			Dynamicists		
	O	N	P	O	N	P	O	N	P
8-day forecasts	4	85	11	9	68	23	26	65	9
Nonorographic precipitation	23	50	27	17	57	26	15	56	29
Warm-fog dispersal	44	48	8	21	43	36	20	58	22
Hail suppression	20	48	32	22	44	34	23	43	34
Hurricane modification	16	56	28	24	45	31	7	57	36
Ranking Subject Area	Physicists-chemists			Synopticians			Dynamicists		
	1–4	5–8	9–13	1–4	5–8	9–13	1–4	5–8	9–13
8-day forecasts	41	41	18	42	33	25	63	20	17
Nonorographic precipitation	56	41	3	46	42	12	30	50	20
Warm-fog dispersal	33	48	19	33	46	21	24	48	28
Hail suppression	33	48	19	23	54	23	6	56	38
Hurricane modification	0	78	12	5	25	70	2	20	78

comparing statement choices with the degree of familiarity with the blue-ribbon panel reports appears to indicate that 'experts are optimists and novices are pessimists,' but the section comparing rankings and familiarity with the reports does not permit this conclusion, although it does not show bias in the opposite direction either.

THE INFLUENCE OF QUALIFICATIONS AND EXPERIENCE

Academic qualifications and the extent of professional experience do not appear to influence the degree of optimism as to research success potential. No significant differences in the ranking or in the statement choices were evident when those respondents with Ph.D.'s were com-

TABLE 4. Contingency Tables for Respondents' Statement Choice and Ranking versus Familiarity with Research Areas: Five Selected Subject Areas Pooled
Raw frequencies with expected frequencies in brackets.

Statement Choice	Done Research in Field	Degree of Familiarity Familiar with Research & Literature	Generally or Not Aware of Field	
Optimistic	17 [11.5]	43 [44.0]	53 [56.5]	113
Neutral	39 [33.8]	116 [116.8]	146 [150.5]	301
Pessimistic	6 [15.7]	56 [54.5]	78 [70.0]	140
	62	215	277	554
$\chi^2 = 10.7$				

Rank	Done Research in Field	Degree of Familiarity Familiar with Research & Literature	Generally or Not Aware of Field	
1–4	31 [17.8]	55 [65.6]	75 [77.5]	161
5–8	20 [25.7]	105 [95.1]	108 [112.0]	233
9–13	13 [20.5]	77 [76.0]	96 [89.5]	186
	64	237	279	580
$\chi^2 = 17.2$				

$\chi^2(p = .05) = 9.3$, as in Table 2.

TABLE 5. Contingency Tables for Respondents' Statement Choice and Ranking versus Familiarity with Panel Reports
Raw frequencies with expected frequencies in brackets.

	Degree of Familiarity with Report			
Statement Choice	Participated or Done Research Referred to	Studied Carefully	Generally Aware or Unaware	
Optimistic	37 [29.3]	64 [70.6]	125 [126.0]	226
Neutral	88 [78.1]	195 [188.2]	319 [335.7]	602
Pessimistic	19 [36.6]	88 [88.2]	175 [157.2]	282
	144	347	619	1110
$\chi^2 = 15.4$				

	Degree of Familiarity with Report			
Rank	Participated or Done Research Referred to	Studied Carefully	Generally Aware or Unaware	
1–4	39 [43.5]	102 [100.9]	181 [177.6]	322
5–8	65 [59.3]	133 [137.5]	241 [242.2]	439
9–13	49 [50.2]	120 [116.6]	203 [205.2]	372
	153	355	625	1133
$\chi^2 = 1.3$				

$\chi^2(p = .05) = 9.3$, as in Table 2.

pared with all others. Similarly, no differences were detected when those with 20 years or more experience were compared with those with less than 10 years experience.

IS OPTIMISM REFLECTED IN PROPOSED BUDGET ALLOCATIONS?

The third hypothesis to be tested was that optimism as to research success potential would be reflected in the manner in which the respondents allocated a hypothetical budget among several competing alternative fields of research. The analysis of the replies to this question indicates a high degree of consistency between views expressed elsewhere in the questionnaire and the proposed allocation of research funds. Those types of research that were viewed as having the greatest chance of resulting in the operational system were voted the larger proportion of the available budget. For research leading to 8-day forecasts those choosing the optimistic statement indicated a median of 40% of a budget dollar, whereas those choosing the pessimistic statement would spend only 10% of the budget on this research. The results comparing rankings of potential developments with proposed budget allocations were identical with those comparing statement choices and proposed budget allocations.

For cumulus and nonorographic precipitation stimulation, the optimists indicated a median of 20% of the research budget and the pessimists about 15%. In this instance, those checking the neutral statement provided a median expenditure of 25% of the research budget. Those ranking this field in the top four indicated a median of 25%, and in the last five a median of 12% of the budget.

For warm fog dispersal and hail suppression there was no obvious correlation between the statement choice, ranking, and distribution of the budget.

For hurricane modification the optimists would spend about 20% for research and the pessimists slightly more than 10%.

One of the most important observations is that whereas 20% of the respondents would be willing to spend half or more of the budget on research to develop 8-day weather forecasts, no one would spend more than half of the funds for any other of the four fields, that is, the modification activities. Perhaps this is indicative of a feeling among some of the respondents that an understanding of the physical processes underlying atmospheric behavior, something which is essential for successful forecasting, must precede any large expenditure on weather modification research.

DO THE OPINIONS OF THE BLUE-RIBBON PANELS COINCIDE WITH THOSE OF THE RANK AND FILE?

It is sometimes suggested that the opinions of blue-ribbon panels as to research success potential do not necessarily coincide with views of other top-ranking members of the professions involved. It is evident from the literature in most professions that individuals frequently disagree with views of panels of experts. The analysis of the results of the present survey, however, indicates a broad similarity between the views of the majority of the respondents and opinions expressed in reports of blue-ribbon panels. This can be illustrated by comparing the rankings of potential developments with conclusions of the NAS-NRC Panel of Weather and Climate Modification as to the knowledge and potential advances in this connection (Table 6). It is evident that there is a close similarity between the rankings of the respondents and those of the Panel. Because of the possible bias of our sample discussed earlier (the omission of the commercial sector) we emphasize that this similarity holds only for the group sampled. Indeed, the historical controversy between the proponents of weather modification experimentation (largely those in the commercial sector) and the academic-agency scientists sampled here would suggest that our results represent a fairly conservative position.

There is one comparison in Table 6 worthy of comment. The disparity between the NAS-NRC Panel statement on lightning suppression and the ranking accorded that possibility by the respondents seems notably large. The reason for this disparity is not immediately apparent, but it is interesting to note that it is only in this instance that the NAS-NRC Panel statements and rankings accorded by the respondents differ to any appreciable extent.

CONCLUSIONS

The present survey was intended as a pilot study to determine whether it is possible to obtain probability estimates of research success

TABLE 6. Comparison of Respondents' Rankings with Those Implied in the NAS-NRC Report

NAS Statement	Median Rank Assigned in Respondents' Replies
1. Supercooled fog dispersal "The dissipation of supercooled ('cold') fogs and low stratus over limited areas is operationally practicable."	<1.0
2. Orographic precipitation increase "Evaluations (by this panel) of 41 project-seasons of winter orographic cloud seeding by commercial operators in the western United States support the earlier conclusion (by the Advisory Committee on Weather Control in 1957) that precipitation increases on the order of 10% apparently can result from ground-based silver iodide seeding of winter orographic storms."	1.5
3. Cumulus and nonorographic precipitation increase "Experimental and operational evidence relating to the stimulation of cumulus precipitation remains highly confusing."	4.3
4. Warm fog dispersal "In recent years, no significant progress has been reported in efforts to dissipate 'warm' (non-supercooled) fogs and low status."	5.8
5. Hail suppression "There is a wide range of opinion on whether or not hail can be effectively suppressed or its damage mitigated."	6.1
6. Lightning suppression "Experiments in lightning suppression are beginning to show some promising results."	8.8
7. Hurricane and tornado modification. "With respect to both hurricane and tornado modification, no practical success can be expected before the development of adequate theories of the genesis and behavior of these storms."	11.0 (hurr) 11.7 (torn)
It is of interest to compare with these modification activities the ranking of the subject areas having to do with improvement of forecasting.	
8. Eight-day forecasts (positive skill on final day)	4.5
9. Thirty-day forecasts (positive skill in final week)	9.8

potentials and to isolate factors that appear to influence opinions as to the success potential of research projects in atmospheric sciences.

It is evident from the study that it is possible to get probability statements about the success or failure of various research and development alternatives from those who know most about them. Such statements are of critical importance to the R & P model described above and possibly to the developments of other models for evaluating the merits of competing proposals for research funds.

A second major conclusion is that there is a high degree of optimism among the scientists about the potential success of research in their field. This optimism appears to increase with identification with, and knowledge of, the particular developments in that field. This conclusion is in keeping with findings of studies relating to engineering and certain other professions that there is little man cannot achieve given the time and the money, and that the pace of advancement in the development of new knowledge and technology is bound to be much more rapid in the future than it has been in the past. For those who might have thought that scientists, and especially research scientists, would be highly skeptical about possibilities of advancing the frontiers of knowledge in difficult fields in relatively short periods of time, the finding of high optimism is indeed instructive. For those who are disturbed by the potential impact of burgeoning technology the finding may no doubt be depressing [*Frank,* 1966].

To obtain usable estimates of the probabilities of research success for the R & P model, additional studies must be made. A promising beginning in the art of obtaining quantified judgments of this kind has been made by meteorologists interested in forecasts expressed in probabilistic terms [*Murphy and Epstein,* 1967] and by statisticians [*Winkler,* 1967]. These studies and the present one suggest that the major problems for future study will be: first, to provide a framework by which the interviewee can estimate probabilities that conform in a mathematical sense to probability measures. In this 'normative' framework we must 'force' the estimator to reveal his true judgment, and he in turn must understand enough of probability theory to ensure that he does not make capricious assessments, and that his assessments conform to the rules of mathematical probability. (For example, the sum of his estimates of a set of mutually exclusive and exhaustive events must equal unity.) Second, because the hypothetical sets of competing or concurrent research projects are to some extent interrelated, the success of one may influence success of the others. Therefore, we should attempt to obtain the conditional probabilities of the success of the selected projects.

The results of this pilot project should be useful in designing and administering a future questionnaire tailored to cope with the problems just mentioned. Most likely, following the experience of *Winkler* [1967], this procedure would involve personal interview techniques utilizing a selected subset of 'experts.'

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