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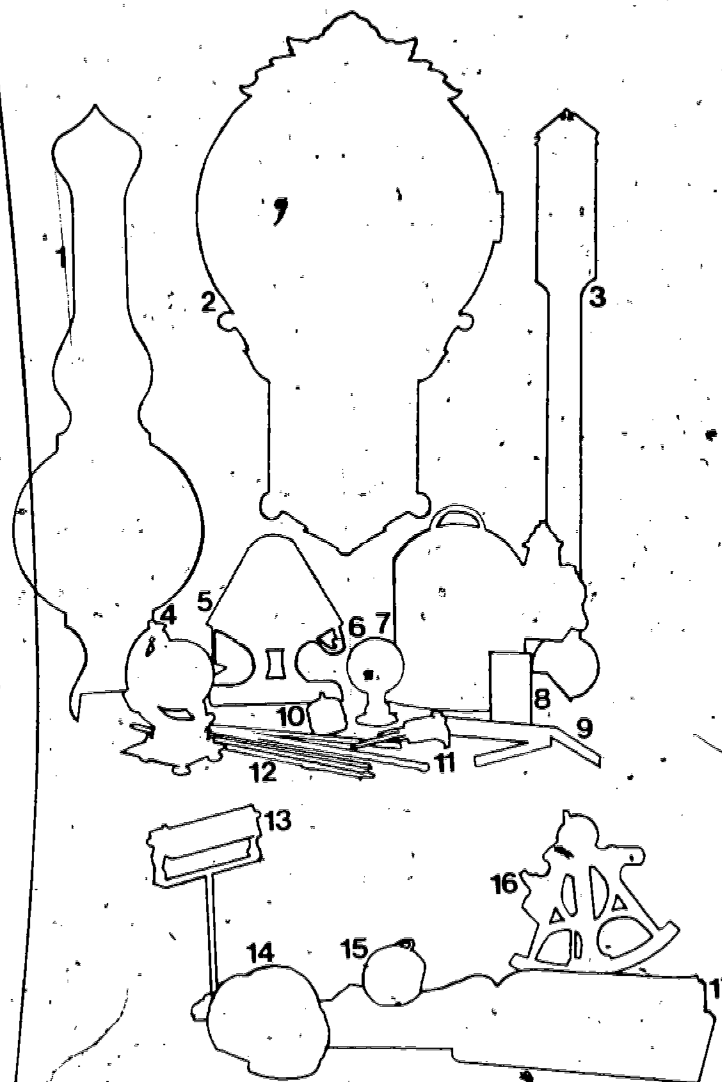
ABSTRACT

This survey of expert opinion was conducted by the National Defense University, Washington, D.C. to quantify the likelihood of significant changes in climate and their practical consequences. The major objectives of the study are embodied in four tasks. This publication presents the results of the first task only: the definition and estimation of the likelihood of climate changes during the next 25 years, and the construction of climate scenarios of the year 2000. It includes an abstract, foreword, summary, three chapters and four appendices. Chapter one describes the methodology used in analyzing the information collected. Chapter two contains narrative and statistical descriptions of five climate scenarios, ranging from large global cooling to large global warming. Chapter three summarizes the aggregated probabilistic data of the climate panelists and compares these data from scenario to scenario, across latitudinal zones, and across three time periods between now and the year 2000. (Author/BM)

CLIMATE CHANGE TO THE YEAR 2000

ON THE COVER:

1. Mercury Column Barometer, circa 1850, developed to expand scale and facilitate reading.
2. Early American Calendar Wall Clock, mid-19th century, by Gilbert.
3. Mercury Barometer, early 19th century, used for measuring station barometric pressure.
4. Campbell-Stokes Sunshine Recorder, early 20th century, used to record duration of sunshine.
5. Hygrodeik, late 19th century, hand calculator for determining relative humidity and water content of ambient air.
6. Pyranometer used for measuring total global radiation.
7. Ship's Binnacle and Gimbaled Compass, 18th century, used for nautical navigation.
8. Field Compass, contemporary.
9. Jointed ruler, early 20th century.
10. Aneroid Barometric Element.
11. Gold Bourdon Instrument.
12. Miscellaneous meteorological thermometers.
13. Prismatic cell, used to demonstrate dispersion of white light.
14. A Student's Volt-ammeter, early 20th century.
15. Aneroid Field Barometer, contemporary.
16. Nautical Sextant, early 18th century, used for finding geographical position by means of celestial bodies.
17. International Cloud Atlas, contemporary.



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CLIMATE CHANGE
TO THE YEAR 2000

A SURVEY OF EXPERT OPINION

CONDUCTED BY THE
RESEARCH DIRECTORATE
OF THE
NATIONAL DEFENSE UNIVERSITY

JOINTLY WITH THE

U. S. DEPARTMENT OF AGRICULTURE
DEFENSE ADVANCED RESEARCH
PROJECTS AGENCY
NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
INSTITUTE FOR THE FUTURE

FORT LESLEY J. McNAIR
WASHINGTON, D.C. 20319
FEBRUARY 1978

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DEPARTMENT OF DEFENSE
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The National Defense University (NDU), a Joint Chiefs of Staff (JCS) organization, was established formally by the Department of Defense on 16 January 1976. The Industrial College of the Armed Forces (ICAF) and The National War College (NWC), collocated at Fort Lesley J. McNair, Washington, DC, are the principal constituent elements of the University, along with the Office of the President and four University directorates.

The mission of the University is to prepare selected military and civilian professionals for high level assignments in the formulation and execution of national security policy. At NWC, the emphasis is on national security policy formulation and strategy, while at ICAF the focus is on the management of resources in the interest of national security. Both programs look to the future to try to anticipate the requirements of national security based on US interests, US objectives, and the employment and management of resources for advancing those interests and objectives.

A corollary of the University's mission is research and the preparation of studies related to national strategy, national security policy formulation, military strategy, and allocation and management of resources for national security.

The Research Directorate coordinates University research efforts. Researchers include students and faculty as well as senior and associate fellows from all of the uniformed services and from other government agencies. The National Security Affairs Institute, an element of this directorate, provides a forum for representatives of the Executive and Legislative branches of government, distinguished scholars, and other citizens from the private sector, who are concerned with national security matters, to exchange views on security issues. An annual National Security Affairs Conference, jointly sponsored with the Office of the Assistant Secretary of Defense (International Security Affairs), brings together senior government officials with prominent representatives of the academic and civilian communities. Research Directorate publications include the *Proceedings* of the National Security Affairs Conference, an extensive monograph series, and books.

Climate Change to the Year 2000, a study sponsored jointly by the National Defense University, the Department of Agriculture, and the National Oceanic and Atmospheric Administration, was conducted under the aegis of the University Research Directorate. We at the National Defense University are deeply grateful for the professional contributions made by all who participated in this study. Without the generous commitment of time and the conscientious cooperation of the many individuals involved, such a complex study would not have been possible.

R. G. GARD, JR.
Lieutenant General, USA
President

ABSTRACT

An attempt to quantify perceptions of global climate change to the year 2000 has been the initial focus of an interdepartmental study at The National Defense University. Subjective probabilities for the occurrence of specified climatic events were elicited by a survey of 24 climatologists from seven countries. Individual quantitative responses to ten major questions were weighted according to expertise and then averaged, a method of aggregation which preserved the climatologists' collective uncertainty about future climate trends. The aggregated subjective probabilities were used to construct five possible climate scenarios for the year 2000, each having a "probability" of occurrence. The aggregated probabilities of contingent events are compared from scenario to scenario, across zones of latitude, and by time periods.

The derived climate scenarios manifest a broad range of perceptions about possible temperature trends to the end of this century, but suggest as most likely a climate resembling the average for the past 30 years. Collectively, the respondents tended to anticipate a slight global warming rather than a cooling. More specifically, their assessments pointed toward only one chance in five that changes in average global temperatures will fall outside the range of -0.3°C to +0.6°C, although any temperature change was generally perceived as being amplified in the higher latitudes of both hemispheres. The respondents also gave fairly strong credence to a 20- to 22-year cycle of drought in the High Plains of the United States but did not agree on its causes.

Consequences of the possible climatic changes delineated in the scenarios are being considered in subsequent phases of this research. A generalized climate response methodology will be demonstrated by its application to crop yield data gathered from a survey of agricultural scientists. The policy implications of the resultant climate/crop scenarios will be examined using a world food economic model.

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FOREWORD

FOREWORD

Within the last few years there has been an increasing public awareness of the impacts of weather and climate on mankind. This concern was highlighted by the severe 1976-77 winter in the eastern half of the United States and subsequent drought conditions in portions of the country. Controversy has arisen about whether the climate is merely fluctuating or is in a long-term trend of change. Any significant change in climate would have profound impacts upon U.S. policies and programs with regard to world food production and reserves as well as a wide range of energy-related and other policy matters.

In view of the potentially serious implications of climatic change, The National Defense University in the fall of 1976 initiated an interdepartmental research project to quantify the likelihood of significant changes in climate and their practical consequences. The major objectives of the study are embodied in the four tasks described in the Summary. This report presents the results of the first task only—the definition and estimation of the likelihood of climatic changes during the next 25 years, and the construction of climate scenarios for the year 2000. Findings of the remaining research tasks will be reported later.

The causes of global climate change remain in dispute. Existing theories of climate, atmospheric models, and actuarial experience are inadequate to meet the needs of policymakers for information about future climate. In the long run, research may lead to reliable forecasts of climate. For the present, however, policymakers have no recourse but to heed expert judgments—subjective and contradictory though they may be—about future world climate and its effects on agriculture and other sectors of the economy. Informed, expert judgments on the likelihood of change, or the odds for a repetition of some event, are useful to the decisionmaker weighing the costs, benefits, and risks of alternative policies. To marshal the full spectrum of expert perceptions, we submitted a structured climate questionnaire to a carefully selected panel of climatologists. We hope the analyses of the probabilistic responses to the questionnaire will lead to a better quantitative understanding of those weather-climate issues that are most relevant to important public concerns about the future of agriculture and the world food situation.

FOREWORD

The *modus operandi* for this project was the establishment of a small, interdisciplinary staff at The National Defense University to act as a focal point for several major sources of substantive research contributions. The first and seminal source is a standing Advisory Group of eminent scientists and administrators who provide guidance and represent many potential users of the research results. Another invaluable source is the Institute for the Future, Menlo Park, California, which furnishes ongoing advice on futuristics methodologies and technical assistance through the auspices of the Defense Advanced Research Projects Agency. A third source is the *ad hoc* Climate Panel of prominent individuals whose subjective assessments of future climate formed the basis of this report. In addition, there are two other *ad hoc* groups of experts concerned with subsequent phases of this research effort. One group is furnishing data on the response of crops to climate changes; the other is preparing to analyze the policy implications of climate/crop scenarios for the year 2000.

Chapter I of this report describes the methodology used in analyzing the information contributed by the panel of climate experts from the United States and abroad. Chapter II contains narrative and statistical descriptions of five climate scenarios, ranging from large global cooling to large global warming. Chapter III summarizes the aggregated probabilistic data of the climate panelists and compares these data—from scenario to scenario, across latitudinal zones, and across three time periods between now and the year 2000. Appendix A is the climate questionnaire sent to the Climate Panel. Because of a limited response, only part of Question VII, "Outlook for 1977 Crop Year," was analyzed. This information is contained in Appendix B, along with an analysis of subjective probabilities concerning the persistence of droughts in the United States. Appendix C provides information on the number of respondents and the average level of expertise for each of the questions in the questionnaire. Appendix D contains references cited by the panelists in their answers to the questionnaire.

ACKNOWLEDGMENTS

ACKNOWLEDGMENTS

Although the Research Directorate of The National Defense University served as the focal point and "broker" for this climate project, many outside individuals generously volunteered their time and knowledge to make it work.

Mr. Joseph W. Willett, Director of the Foreign Demand and Competition Division in the U.S. Department of Agriculture, conceived the climate project. In 1975-1976, while he was a Senior Research Fellow at the Strategic Research Group of The National War College (the predecessor of the Research Directorate of The National Defense University), Joe persuaded us of the need to pursue this undertaking. Now back at the USDA, Joe has remained in close touch with the project and his continuing counsel has been invaluable.

Vice Admiral M. G. Bayne, U.S. Navy (Retired), and Lieutenant General R. G. Gard, Jr., U.S. Army—the former and current presidents of the university—not only approved this novel research, but supported it with enthusiasm.

The study could not have proceeded without funding and encouragement from the Cybernetics Technology Office of the Defense Advanced Research Projects Agency. Dr. Robert A. Young is Director of the Cybernetics Technology Office, and Lieutenant Colonel Roy M. Gulick, Jr., U.S. Marine Corps, is our immediate point of contact in DARPA. Among other things, DARPA funds secured the services of the Institute for the Future. Dr. Roy Amara, president of the Institute, and Dr. Hubert Lipinski were always available to suggest appropriate methodologies and to provide technical assistance in the analytical phases of the study.

From its inception, the project has employed a small team of resident investigators to seek the judgments and perceptions of experts, to collate data and prepare reports, and—no mean task—generally to orchestrate the contributions of the many far-flung participants in the study. Working with this team, the most competent and dedicated group with which I have ever been associated, has been a great personal pleasure. The resident team has consistently received exceptional support from numerous administrative elements of The National Defense University. The advice and skills of many individuals—secretaries, stenographers, editors, research assistants, artists, illustrators, type composers, and printers—have gone into the publication of this report.

ACKNOWLEDGMENTS

At the outset of its entry into the alien field of climate, it was evident that The National Defense University would require expert guidance and direction. To meet this need, we formed a standing Advisory Group of scientists and potential users of the research. The Advisory Group met at Fort McNair in December 1976 and in June and December of 1977. At the first meeting we made it clear that we wanted the advisors, collectively and individually, to be activists and to insure that our efforts were leading to valid and useful results. At each phase we presented our results and future plans to the advisors. Their lively and constructive criticisms were painful at times, as when we had to rework portions of the research. But we are grateful that this group saved us from committing some major blunders and from straying down some dead ends. Any remaining blunders are our responsibility. Many advisors gave liberally of their time and knowledge for at most token compensation.

Last, but far from least, there is the *ad hoc* Climate Panel which provided the grist for this report. This panel was carefully selected with the assistance of the Advisory Group. Pains were taken to include authorities in global, regional and topical climatology, and paleoclimatology, as well as spokesmen for differing viewpoints about future climate trends. The climate panelists' response to our questionnaire provided the judgments, knowledge, and above all, the quantitative perceptions on which this report is based. The panelists labored with much admitted soul-searching for only a nominal honorarium. We are truly in their debt.

The caliber and representativeness of the Climate Panel—the "balance" among specialties and divergent points of view—were obviously crucial to the validity of this study. In November 1977, drafts of Chapters I and II and Appendix B were circulated to the Climate Panel and the Advisory Group for comment. The same drafts were discussed the following month at a meeting of the Advisory Group. The written and oral comments on the drafts, as well as the findings taken *in toto,* lead us to believe we achieved our goals of high caliber and adequate balance in the panel of climatologists. (I note in passing that Chapter III, which contains comparisons of the data in the individual climate scenarios of Chapter II and a selection of the panelists' comments, is the responsibility solely of the resident research staff.)

To those mentioned above, and to all listed below, my most sincere thanks.

Andrew J Dougherty

ANDREW J. DOUGHERTY
Colonel, USAF
Director, Research Directorate

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In order of their appointment as Senior Research Fellows, the principal investigators resident at The National Defense University were:

Mr. William R. Gasser, U.S. Department of Agriculture
Colonel Vernon M. Malahy, Jr., U.S. Air Force
Dr. Paul C. Dalrymple, U.S. Army Engineer Topographic Laboratory
Colonel Theodore H. McCrampton, U.S. Army

The resident staff received valuable assistance on a continuing basis from:

Dr. Richard E. Felch, USDA (formerly with the National Oceanic and Atmospheric Administration)
Mr. Douglas M. Le Comte, NOAA
Major Russell A. Ambroziak, U.S. Air Force Reserve

In addition, Captain Bernard C. Diesen, III, Lieutenant Colonel David S. Lydon, both USAF, and Mr. Richard C. McArdle, USDA, made specialized contributions at various phases of the project.

ADVISORY GROUP

The composition of the Advisory Group has changed over time. Listed below are the advisors who participated in at least one of the meetings of the group. Dr. J. Murray Mitchell, Jr., was the Senior Scientific Advisor to the phase of the research covered by this report. He and Doctors Gilman and Landsberg reviewed early drafts of the climate questionnaire. Among other especial contributors to the project were those who pretested the questionnaire: Doctors Bierly, Namias, Newman, Thompson, and Walther. Dr. David M. Hershfield of the U.S. Department of Agriculture also pretested the questionnaire.

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CLIMATE PANEL

Listed below are the scientists who responded to the climate questionnaire (Appendix A).

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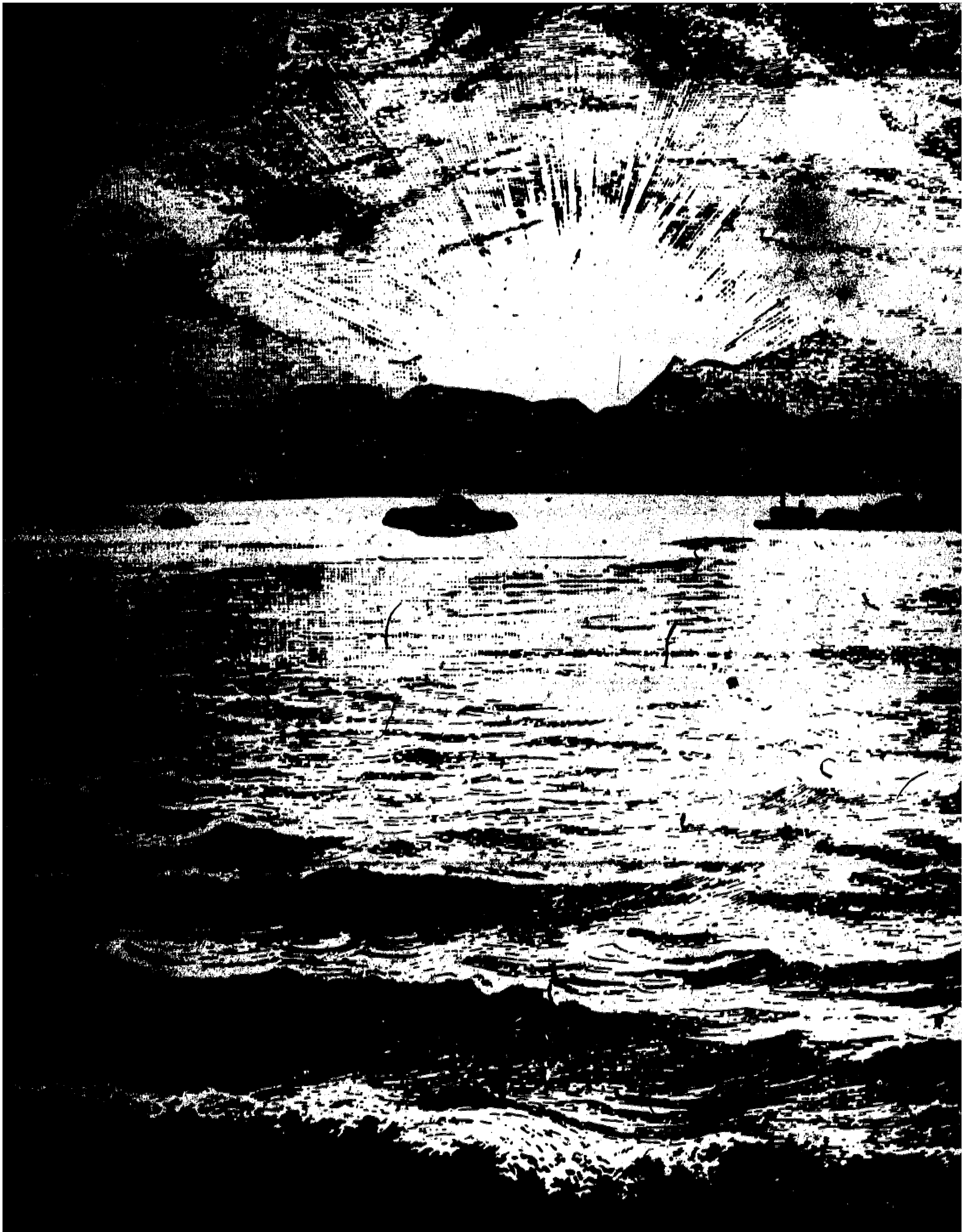
SUMMARY



SUMMARY

Will world climate at the end of this century be substantially different from that of the past two or three decades? Some climatologists postulate a continuation of the cooling trend that began in the 1940's, others contend that the world is entering a period of rapid warming, and many foresee a period of greater climatic variability.

Such conflicting opinions and their implications inspired a study now under way in the Research Directorate of The National Defense University, Fort McNair, Washington, D.C. This project, the first comprehensive attempt to quantify perceptions of climatic changes, is a joint effort of the Department of Agriculture, Department of Defense, and the National Oceanic and Atmospheric Administration. Technical assistance is being provided by the Institute for the Future, Menlo Park, California, through the Defense Advanced Research Projects Agency.

The major objectives of the study are embodied in four tasks:

- Task I: To define and estimate the likelihood of changes in climate during the next 25 years, and to construct climate scenarios for the year 2000.
- Task II: To estimate the likely effects of possible climatic changes on selected crops in specific countries, and to develop a methodology for combining crop responses and climate probabilities into climate/crop scenarios for the year 2000.
- Task III: To evaluate the domestic and international policy implications of the climate/crop scenarios, and to identify the climatic variables that are of key importance in the choice of policy options.
- Task IV: To transfer the climate/crop research results and a generalized climate response methodology to individuals and organizations concerned with the consequences of climatic changes in fields other than agriculture, and to identify areas of research which might refine or extend the findings of the first three tasks.

This report is a summary of Task I, which was carried out by surveying a panel of climatologists. The salient finding is that the likelihood of catastrophic climatic change by the year 2000 is assessed as being small. More specifically, the responses to the survey suggest only 1 chance in 10 that average global temperature in the next 25 years will increase by more than 0.6° C relative to the early 1970's. Likewise, there is only 1 chance in 10 that it will decrease by more than 0.3° C. The most likely event will be a climate which resembles the average of the past 30 years, arising primarily from a balancing of the warming effect of carbon dioxide with the cooling effect of a natural climate cycle. However, the respondents tended to anticipate a slight global warming rather than a cooling.

Most of the climate panelists perceived that any global temperature changes will be amplified at higher latitudes, particularly in the Northern Hemisphere. This magnification will be less pronounced in the Southern Hemisphere because the larger surface area of southern oceans provides more thermal inertia against change.

The panelists' responses reflect fairly strong support for the continuation of a 20- to 22-year drought cycle in the High Plains of the United States. This perception was tempered by the absence of an agreed-upon causal mechanism for the apparent periodicity. For mid-latitude regions outside the United States, there was more uncertainty and less support for cyclic droughts than was evident for the United States. Similarly, no periodicity was identified relative to frequency of drought in the Sahel region of Africa or the failure of the Asian monsoons.

Collectively, the climatologists expressed considerable uncertainty about possible changes in the amount and variability of precipitation—uncertainty not only with respect to the magnitude of changes but in many cases even with respect to the direction of change. This uncertainty was particularly pronounced about possible changes in year-to-year variability. There was, however, some tendency to associate more precipitation and decreased variability of precipitation with global warming, and less precipitation and increased variability with global cooling.

The foregoing conclusions are derived from the quantitative responses of the Climate Panel to a set of questions about significant climatic factors, including variability. The questionnaire (Appendix A) covered the period from the present to the end of the century. The panelists were asked to assign probabilities to specified climatic changes and to give the rationale for their answers. For each question they were also asked to assign a numerical value to their own expertise and that of other panelists.

Of the 24 climatologists replying to the questionnaire, 21 provided a quantitative response to at least one question. The answers of the latter to a question on global temperature were weighted on a well-defined scale of expertise and then averaged to yield a probability density function for changes in global temperature. The range of perceived global temperature changes was partitioned into five subintervals upon which are based five global climate scenarios with corresponding "probabilities" of occurrence. Next, each respondent was associated with a subinterval of global temperature, or scenario, according to his perception of global temperature trends. Finally, details of each scenario were developed as conditional "probabilities" aggregated in a similar manner from the appropriate panelists' answers to other questions. These questions were concerned with the relative influence of selected atmospheric components, the latitudinal distribution of temperature changes, the length and variability of growing season, the amount of precipitation and its year-to-year variability, and the frequency of droughts and monsoon failures. Chapter II contains the five climate scenarios. In Chapter III the aggregated subjective probabilities of contingent events are compared from scenario to scenario, across zones of latitude, and by time periods. (The responses to a question dealing with the outlook for crops in 1977 and with the persistence of drought in the United States are discussed in Appendix B.)

The basic method of weighted averages, described more fully in Chapter I, is considered appropriate when respondents base their replies on a common data base. This method has a tendency to preserve and possibly to overstate uncertainty.

The five climate scenarios and the panelists' comments manifest a broad range of perceptions about future climate. The experts' aggregated subjective probabilities do not reflect a consensus on any narrowly defined climatic issue, but a large majority of the climate panelists were in broad agreement, for example, that the average global temperature is not likely to change more than half a degree Celsius by the year 2000. Constructed by a standard futuristics methodology, the scenario narratives portray reasonable, coherent, and consistent possibilities for world climate around the year 2000. However, as is evident from the probabilistic data that accompany the text of each scenario, it is unlikely that any scenario will materialize in all its stated specifics. Although the scenarios cannot be viewed as alternate and mutually exclusive climate forecasts, they do put plausible quantitative bounds on climatic change over the next 25 years. The "probability" of a scenario provides policymakers with some measure—perhaps the best available—of the confidence to be placed in each of a range of possible climatic changes, none of which can be predicted by the current state of the climatologists' art.

The next objective of this climate research project is to demonstrate for agriculture how climate information can be combined with climate response data to analyze practical implications of possible climatic change. The two primary questions behind this effort are: What are the likely impacts of possible climate changes on global food production? What are the policy implications of these impacts? Among the policy questions of particular interest are those concerning food prices, food reserve requirements, food trade, and related issues. A generalized climate response prediction methodology has been developed, and estimates of the response of selected crops to parametric climate changes have been obtained from a survey of agricultural scientists. The response methodology will be applied to these crop yield data and the climate data reported herein to calculate the expected crop yields

associated with each climate scenario. A world food economic model will be used to examine policy implications of the resultant climate/crop scenarios and their "probabilities" of occurrence.

CHAPTER ONE
METHODOLOGY

Research Approach For Task I
General Features
Panelists' Concerns

Analysis of Data
Self and Peer Ratings
Processing of Responses

Climate Scenarios
Use of Scenarios
Constructing Scenarios
Review of Scenarios
Nature of Scenarios

CHAPTER ONE
METHODOLOGY

RESEARCH APPROACH FOR TASK I

General Features

The purpose of Task I was to define and estimate the likelihood of changes in climate during the next 25 years, and to construct climate scenarios for the year 2000. Information was collected from a carefully selected group of experts through the use of a structured questionnaire. Ten separate questions dealt with particular climatic variables and/or specific geographic regions of interest. These topics of inquiry were as follows:

- average global temperature
- average latitudinal temperature
- carbon dioxide and turbidity
- precipitation change
- precipitation variability
- mid-latitude drought
- outlook for 1977 crop year
- Asian monsoons
- Sahel drought
- length of the growing season

Each question elicited information about three elements: probabilistic (or equivalent) forecasts on a particular climatic variable, reasons for quantitative estimates, and self and peer expertise rating. The complete questionnaire is contained in Appendix A.

A panel of climatological experts from the United States and abroad was selected by the research team, with assistance from the project Advisory Group. The panelists were selected both for their competence in the field of climatology and for the diversity of views which they represented. The list of panelists responding to the questionnaire appears in the acknowledgments.

The questionnaires were sent to 28 panelists and 24 were returned. Of these, 21 contained quantitative information. Appendix C lists for each climate question the number of panelists who submitted quantitative estimates and the average of their expertise.

Panelists' Concerns

Most respondents, as well as some of the invited panelists who declined to participate, voiced some degree of apprehension or concern about the questionnaire and the use (and possible abuse) of the information derived from their responses. These concerns centered on the following issues:

- the lack of sufficient actuarial experience, comprehensive theories, or adequate models to support the quantitative estimates given in the questions,
- the possible suppression of the full range of uncertainty accompanying responses,
- the risk of being an unwitting party to "science by consensus."

The following comments by panelists reflect these concerns:

> To the best of my knowledge, there exist, in general, no techniques for making climate forecasts that have demonstrated skill in the sense that the forecasts are better than a forecast of the long-term average statistics. Knowledge of even the long-term average statistics (means, variances, extremes, conditional probabilities, etc.) would be most useful for some purposes, but even this data is not readily available.

> I think that the strongest message to come from your questionnaire will be that we lack the basis for predicting even the grossest aspects of climate.

> We possess no skill for forecasting beyond a short period, other than that which probabilities based on a frequency distribution can provide. Only a deterioration of climate will fire the imagination of the experts. Prophets become known for their prophecies of doom. A prophecy of status quo or improvement would not be interesting.

> There is a good deal of guesswork involved, due to uncertainties about feedback mechanisms, the importance of aerosols, the general circulation in the atmosphere and oceans, and many other factors.

> I feel that one of the most important outcomes of your study could be a clear statement of our present ignorance. That in itself should clearly indicate the need for contingen... plans.

In the preparation of this report, the project team has given considerable attention to the foregoing concerns in analyzing the data and aggregating the range of views—and the expressed qualifications—provided by the respondents. Realizing that confident predictions of climate are beyond the state of the art, the project team has proceeded on the assumption that expert probabilistic judgments, properly qualified, constitute the best available guidance for those who must make policy in matters affected by climate. The climate data in the report bespeak uncertainty and a wide range of perceptions. In the description of the methodology and the presentation of the analysis and results, appropriate caveats have been introduced to avoid misunderstanding.

ANALYSIS OF DATA

Self and Peer Ratings

An interesting and useful feature of the questionnaire was the concept of self and peer ratings. Figure I-1 is an excerpt of the instructions provided at the end of each question and designed to assess the respondents' expertise.

Figure I-1

SELF AND PEER RATING

Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5 - 4 - 3 - 2 - 1

Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

The categories from 5 to 1 (expert, quite familiar, familiar, casually acquainted, and unfamiliar) were carefully defined in the questionnaire. Table I-1 shows a sample of the degree of correlation between self and peer ratings for five respondents on Question I. The general agreement between self and peer ratings is fairly evident by a scan of the two right-hand columns in the table. A detailed analysis of the correlation between self ratings and the mean of peer ratings shows it to have a value of 0.52 at a significance level of 0.007. This is considered a fairly high correlation.

A simple averaging of self and peer ratings for each respondent on each question, rounded to the nearest integer value, provided a weighting that was subsequently used in aggregating responses. The particular weighting scale that was used is shown in Table I-2. Levels of expertise falling below "familiar" ("casually acquainted" and "unfamiliar") were not used in the processing. Of the three levels shown in Table I-2, the "expert" category was

Table I-1

CORRELATION BETWEEN SELF AND PEER RATINGS
(Examples from Question I)

Respondent	Self Rating	Frequency of Peer Ratings: Expert	Frequency of Peer Ratings: Quite Familiar
A	Expert	10	34
B	Expert	4	3
C	Quite familiar	-	3
D	Quite familiar	1	2
E	Familiar	-	-

weighted twice as heavily as the "quite familiar" category and the "quite familiar" was weighted twice as heavily as "familiar." In effect, this reflects the largely empirical and intuitive notion that an expert's opinion is worth about twice as much as one who is "quite familiar," which in turn is worth twice as much as an individual who is ranked as "familiar" with a topic.

Table I-2

CONVERSION OF EXPERTISE RANKING TO WEIGHTED SCALE

Expertise	Weight
Expert	4
Quite familiar	2
Familiar	1

Processing of Responses

The general schema for processing the information from the questionnaires was as follows:

- tabulate each respondent's probability density function with respect to change about a particular variable at a given time, or derive the probability density function from graphical information provided by the respondent.
- multiply each probability density function by the appropriate expertise weight (as described earlier).
- add the weighted density functions of respondents.
- divide the weighted and aggregated density functions by the sum of expertise weights to normalize the group response.
- combine the panel's responses on each climatic variable into a set of scenarios spanning the range of uncertainty or range of conditions described by the respondents.

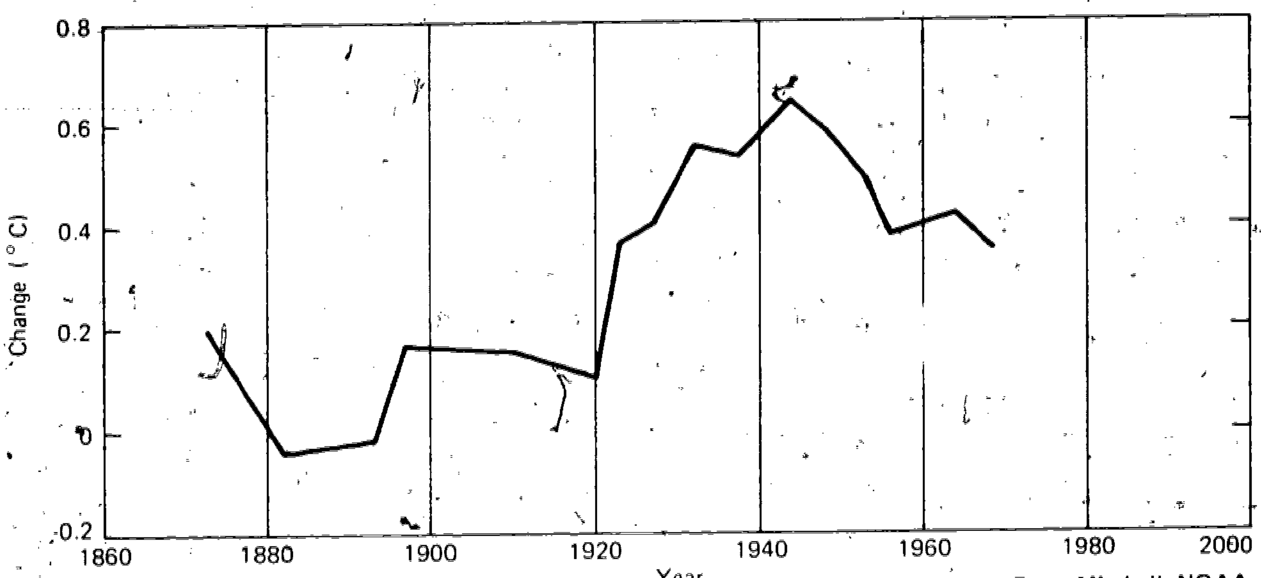
Question I, dealing with possible changes in global mean temperature*, was a pivotal question because perceptions of global mean temperature greatly influence perceptions with respect to the climate variables treated in subsequent questions.

Question I is based on Figure I-2, a plot of historical changes in annual mean temperature during the past century. Each respondent was asked to provide three estimates of the future course of possible changes in global temperature to the year 2000. The first estimate was to be a temperature path to the year 2000 such that there was only 1 chance in 10 that the actual path could be even lower. The second estimate was to be a path with an even chance that temperature could be either lower or higher; and the third was a path based on 1 chance in 10 that it could be even higher.

Figure I-2

GLOBAL TEMPERATURES

Historical record of changes in annual mean temperature during the past century for the latitude band, 0-80°N.



The period 1880-1884 is the zero reference base. —From Mitchell, NOAA

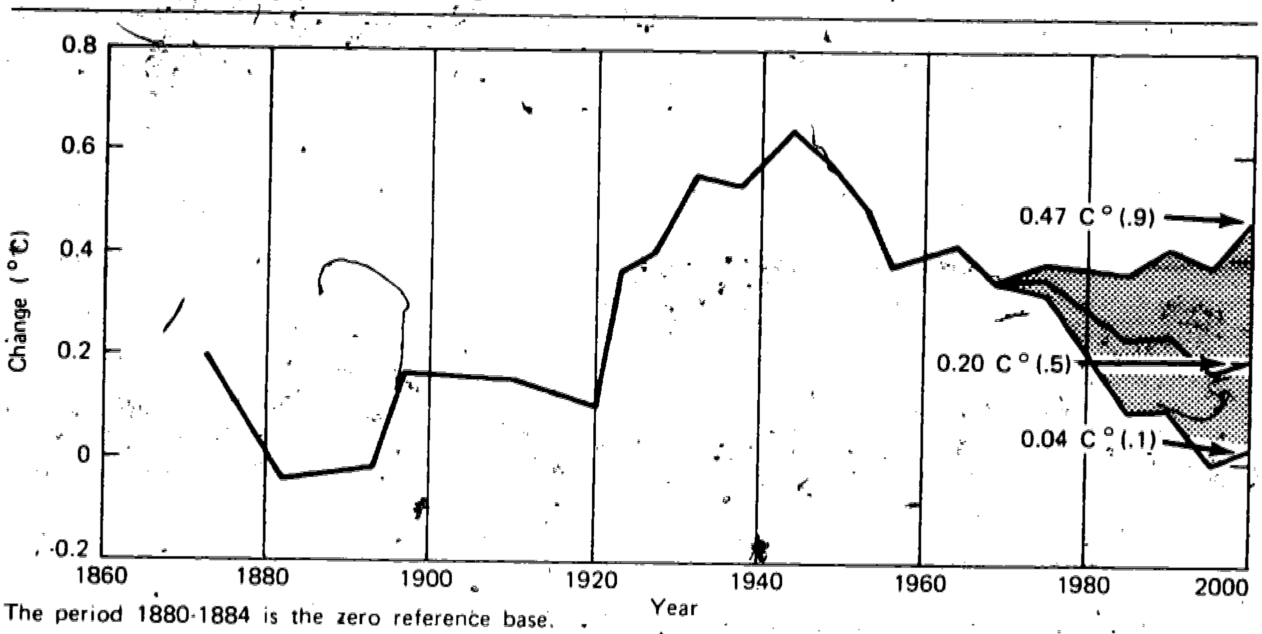
*For the purpose of this study, "global temperature" is used as equivalent to annual mean temperature between 0° and 80° north latitude.

Figure I-3 shows a sample response to Question I by a single respondent. Each of the three estimates could be drawn in any functional form desired. Percentiles of 10, 50, or 90 can be read off for any year between the "present" (the end of the plot in Figure I-2) and the year 2000.

Figure I-3

SAMPLE RESPONSE TO QUESTION I

Actual example of a single response to the instructions



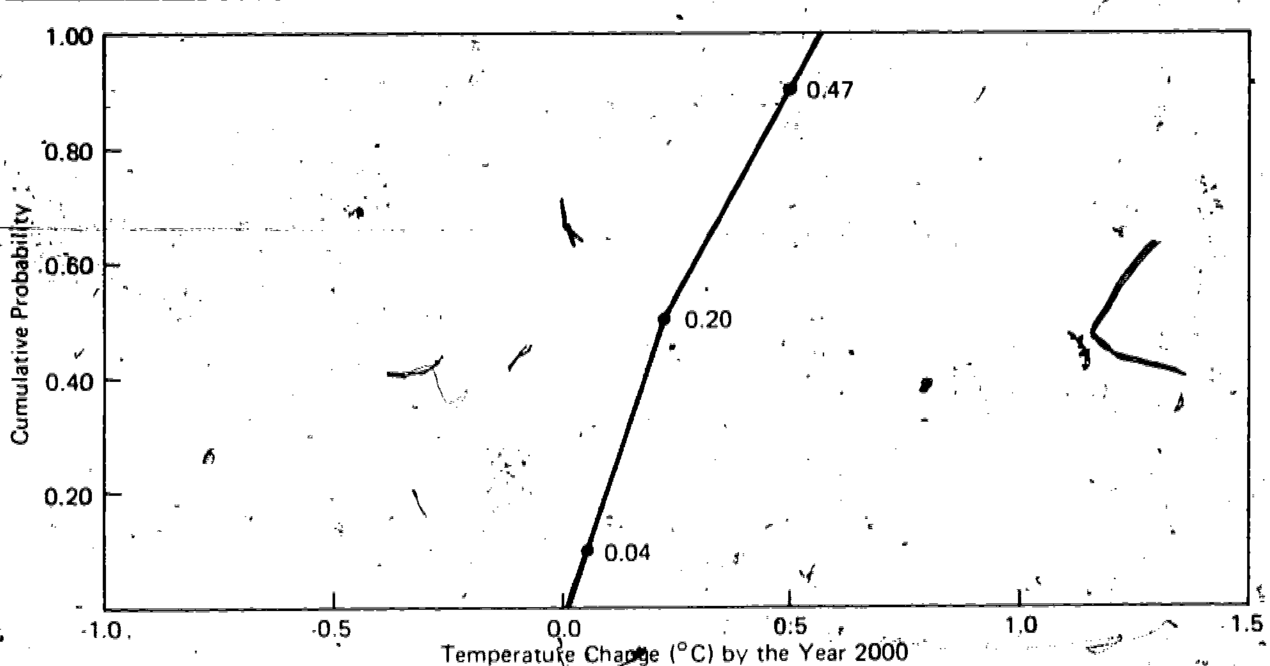
The period 1880-1884 is the zero reference base.

The processing of responses will now be illustrated using the answers to this question by a single respondent. Figure I-4 is a plot of the information shown in Figure I-3 for the year 2000, converted to a cumulative probability function in which the ends of the function have been extended beyond the 90th percentile and below the 10th percentile in a linear approximation. For example, the respondent has indicated a 10 percent chance that the temperature will change by 0.04°C or less, a 50 percent chance that it will change by 0.2°C or less, and a 90 percent chance that it will change by 0.47°C or less.** Similar values can, of course, be obtained for any other year from Figure I-3.

**These temperature changes are in relation to the zero reference base period, 1880-1884, as shown in Figure I-2.

Figure I-4

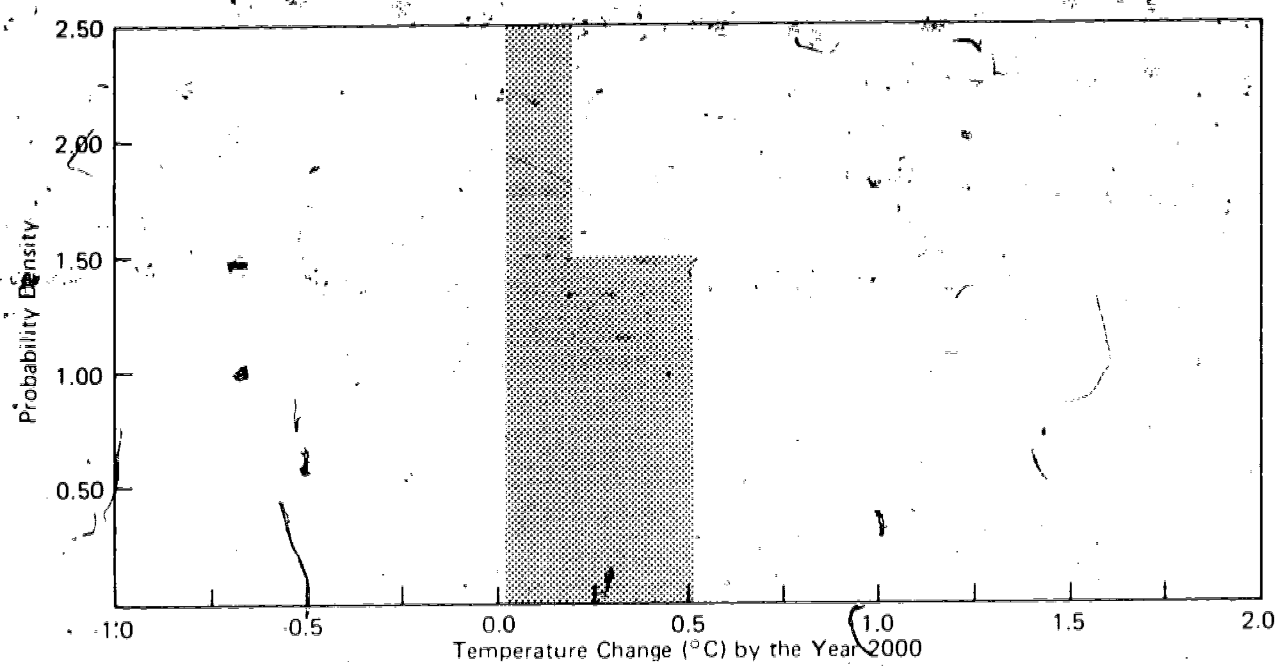
CUMULATIVE PROBABILITY FUNCTION FOR QUESTION I



The period 1880-1884 is the zero reference base.

Figure I-5

EQUIVALENT DENSITY FUNCTION FOR QUESTION I



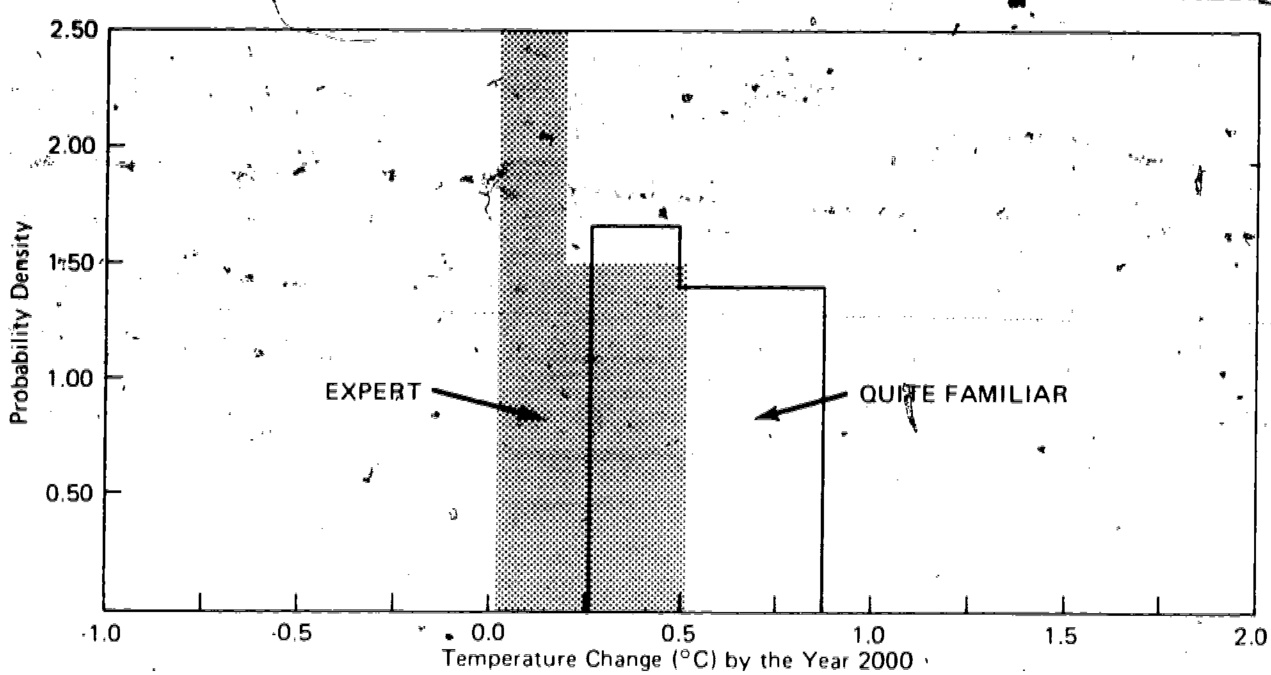
The period 1880-1884 is the zero reference base.

The next step is to convert the cumulative probability function into an equivalent density function by taking the first derivative of the plot in Figure I-4. Since the plot consists of two straightline segments, we have basically two degrees of freedom, or two levels in the density function, which is shown in Figure I-5. The area under the curve intercepted by any particular temperature range is equal to the probability of occurrence of that particular temperature range, and the total area under the curve in Figure I-5 is unity.

Figure I-6 shows unweighted density functions from each of two respondents. The two functions are next weighted by the appropriate expertise weights, added and then divided by the sum of the weights to obtain the combined and normalized density function for the two respondents. Again the area under the curve of this combined and normalized density function, shown in Figure I-7, is equal to unity.

Figure I-6

ADDING TWO DENSITY FUNCTIONS FOR QUESTION I

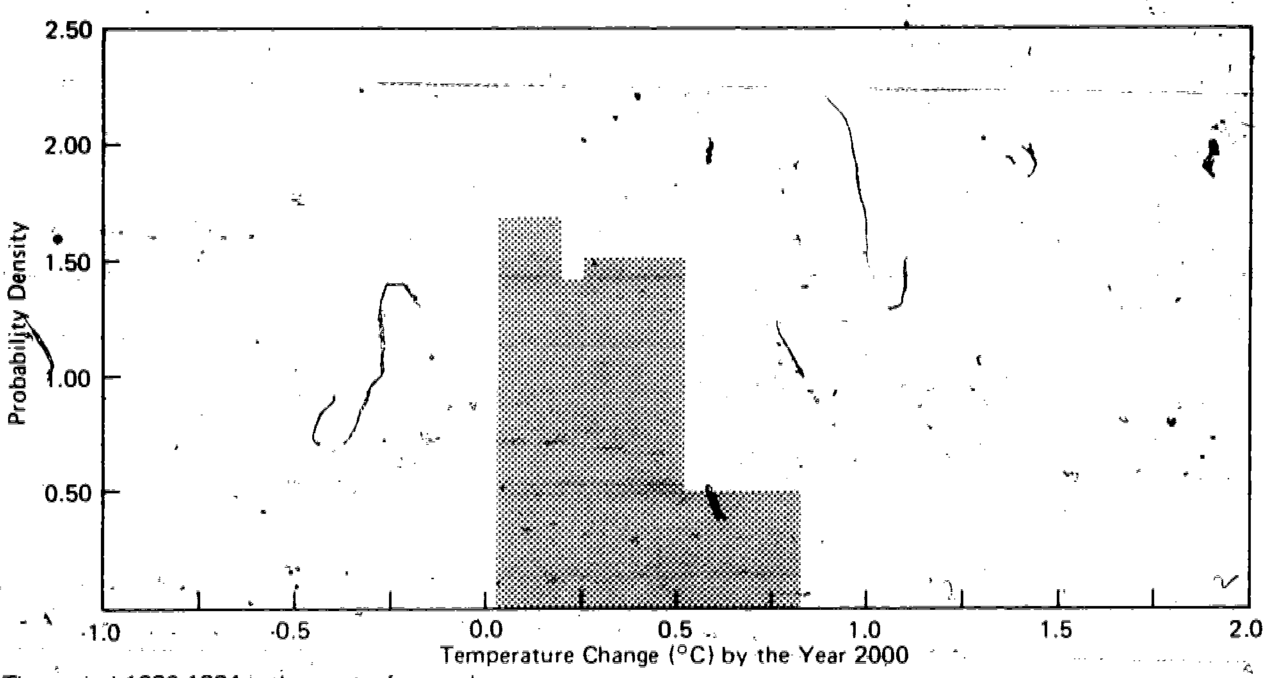


The period 1880-1884 is the zero reference base.

The procedure outlined above is repeated for the responses of each of the other panelists. Figure I-8 is a plot of the aggregated normalized responses of the full panel for the year 2000. An analogous procedure yields probability density functions of mean global temperature change for the years 1975, 1980, and 1990. The information contained in the probability density functions is shown in Figure I-9 as extensions to Mitchell's original curve. The extensions on the curve show the 10th, 50th and 90th percentiles for each year from the "present" to the year 2000. Intermediate percentiles are also plotted. Thus, Figure I-9 is a summary of the aggregated responses of the panelists with respect to global temperature.

Figure I-7

NORMALIZED DENSITY FUNCTION FOR TWO RESPONDENTS TO QUESTION I

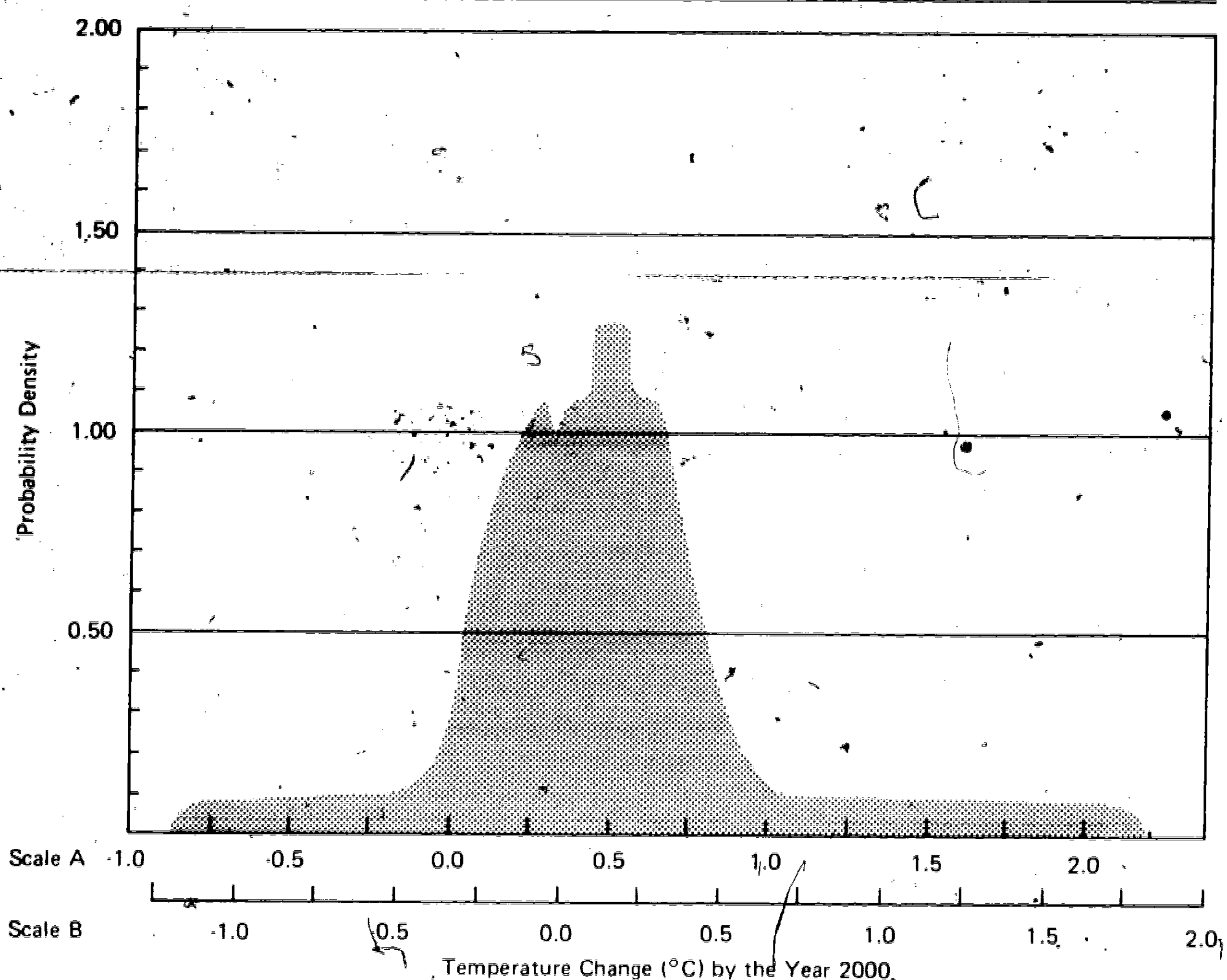


The period 1880-1884 is the zero reference base.

In aggregating the responses by the method of weighted averages, it has been assumed that the respondents are drawing from the same general information base and, therefore, that their information is highly dependent. In such cases of information dependence among respondents, it is customary to use the method of weighted averages to aggregate responses. All responses are used and weighted by the respondents' expertise as perceived by themselves and their peers. The shape and range of the aggregated curves are not acutely sensitive to the weighting system used. The method is "conservative" in the sense that the derived probability curves tend to be broad and to overstate uncertainty as a result of the additive treatment of the individual subjective probabilities. Had the responses been based on independent information, a multiplicative treatment of the individual probabilities would have been more appropriate, and the derived probability curves would have shown less dispersion.

Figure I-8

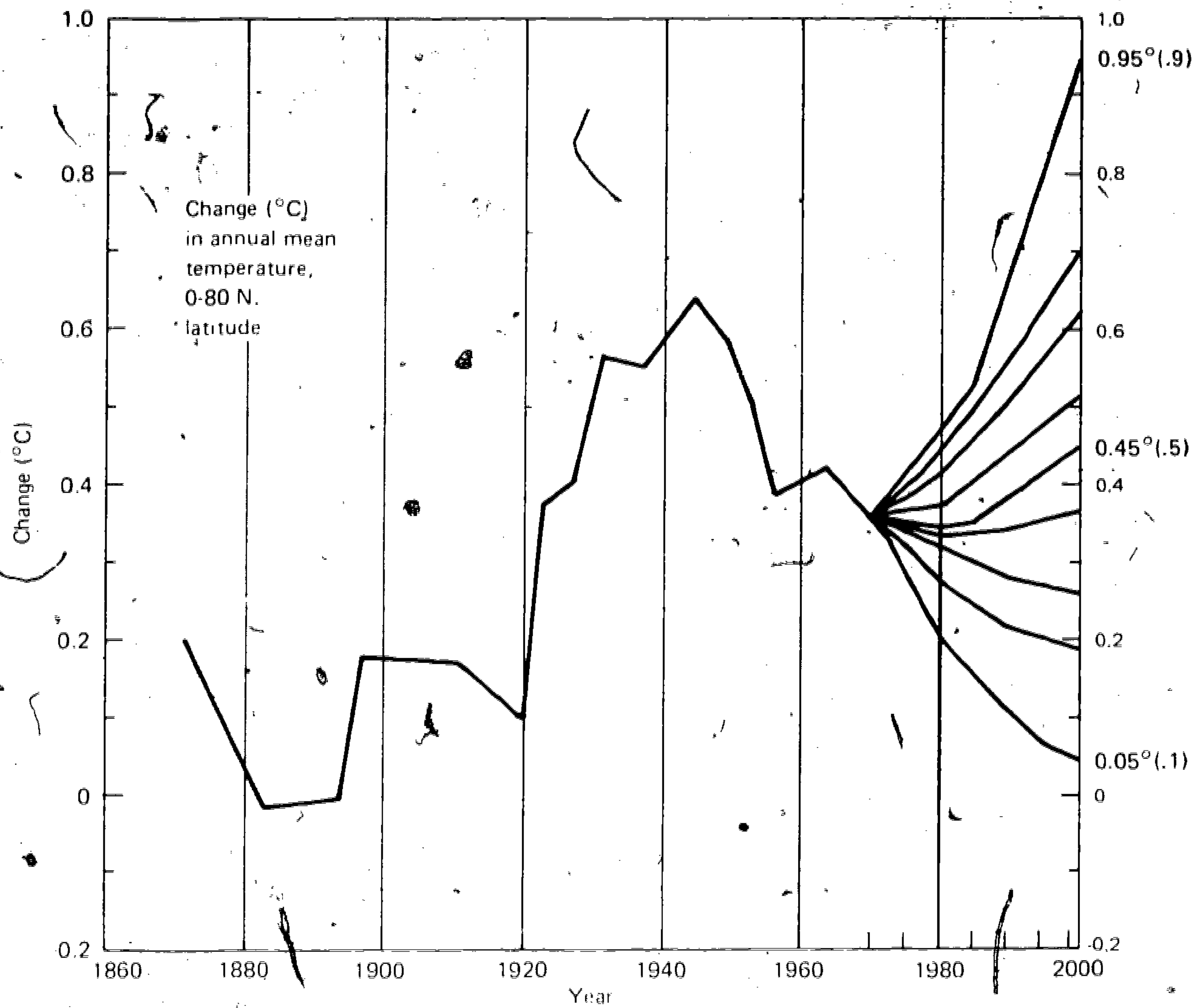
PROBABILITY OF MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE BY THE YEAR 2000 AS DETERMINED BY THE PANEL OF CLIMATIC EXPERTS



Scale A is based on the period 1880-1884 as the zero reference base (see Figure I-2).
Scale B is based on the period 1965-1969 as the zero reference base (see the end point on Figure I-2).

Figure I-9

PROBABILITY OF MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE TO THE YEAR 2000 AS DETERMINED BY THE PANEL OF CLIMATIC EXPERTS



The period 1880-1884 is the zero reference base.

3

CLIMATE SCENARIOS

Use of Scenarios

A convenient procedure for dealing with a range of uncertainty when it is not possible to construct quantitative models is through the use of scenarios, which may be considered plausible sequences of events or trends. Scenarios describe interconnections—perhaps even causal processes—and highlight, where possible, decision points. In a sense, a scenario is a possible "slice of future history."

Constructing Scenarios

In the present instance, since responses on global temperature are pivotal in setting the stage for other climate variables, the plot in Figure I-8 can be used as a basis for dividing the perceived temperature range into a number of categories. These categories then become the bases for constructing scenarios. The number of categories (and scenarios) is, in a sense, arbitrary and can be three or five or even a larger number, if desirable. Table I-3 shows the perceived temperature range divided into five categories. They range from large global cooling to large global warming. Associated with each temperature range is a probability of occurrence where, in fact, the temperature ranges were selected to make these probability ranges symmetrical.

Table I-3

DEFINITION OF TEMPERATURE CATEGORIES

Temperature Category	Change in Mean Northern Hemisphere Temperature from Present* by the Year 2000	Probability
Large cooling	0.3°C to 1.2°C colder	0.10
Moderate cooling	0.05°C to 0.3°C colder	0.25
Same as last 30 years	0.05°C colder to 0.25°C warmer	0.30
Moderate warming	0.25°C to 0.6°C warmer	0.25
Large warming	0.6°C to 1.8°C warmer	0.10

*"Present" temperature is defined as the end point on Mitchell's graph (Figure I-2) -- i.e., the average temperature for the five year period ending in 1969.

In order to process information with respect to other climate variables, it is useful to group respondents with respect to these five temperature ranges, according to where the bulk of each respondent's probability density function lies. Table I-4 is a matrix showing each of the five temperature categories arrayed as rows and the 19 respondents in 5 groups arrayed as columns of the matrix. As will be noted in Table I-4, the bulk of each group's probability density functions lies along the diagonal element of the 5x5 matrix (one respondent at each end, three and four at the intermediate ranges, and ten in the middle range).

The results of the information collected under Task I have been embodied in a set of five scenarios described in Chapter II, with more detailed discussion and comparisons in Chapter III.*

The scenarios are labeled in accordance with the global temperature categories in Table I-3. One purpose is to provide an integrated summary of perceptions of climatologists on climate change and variability to the year 2000. An equally important purpose is to provide a point of departure for structuring questions in Task II and to trace the impact of such possible climatic changes on food production and on the choice of policy options.

Table I-4

PERCENTAGE OF GROUPED PROBABILITY DENSITIES LYING IN EACH TEMPERATURE CATEGORY

Temperature Categories	Number of Respondents 1	3	10	4	1
Large cooling	99	12	2	--	--
Moderate cooling	1	68	24	10	--
Same as last 30 years	--	20	52	31	--
Moderate warming	--	--	22	44	20
Large warming	--	--	--	15	80

The procedure for creating scenarios corresponding to the five global temperature categories is as follows:

- Each respondent is first assigned to a global temperature category, as described in Table I-4.
- Responses within each temperature category are combined for all other climatic variables (except for precipitation and precipitation variability, where all responses were available**).
- Responses are integrated into a narrative, supported by summary tables.

*The responses to Question VII, "Outlook for 1977 Crop Year," are not included in the scenarios. That portion of the information for which expertise levels were considered adequate has been processed and is shown in Appendix B. Included is an analysis of subjective probabilities concerning the persistence of droughts in the U.S.

**For questions on precipitation and precipitation variability only, information was elicited from each respondent based on conditional assumptions with respect to global temperature.

The processing steps for Questions II through X are identical to those for Question I except that, of course, in these other instances, density functions or equivalents are provided directly by the respondents and need not be derived through the use of cumulative probability.

Figure I-10

QUESTION VI – MID-LATITUDE DROUGHT Frequency of Drought

Time period	"Frequent"-i.e., similar to early to mid-1930's and early to mid-1950's		"Average"-i.e., similar to the frequency over the longest period of record available		"Infrequent"-i.e., similar to 1940's and 1960's		Total Probability	
	US	Other mid-latitudes	US	Other mid-latitudes	US	Other mid-latitudes	US	Other mid-latitudes
1977 to 1980							1.0	1.0
1981 to 1990							1.0	1.0
1991 to 2000							1.0	1.0

The sequence of steps is illustrated by using Question VI, which concerns mid-latitude drought. Figure I-10 is an excerpt from Question VI. Table I-5 illustrates how responses for one of the time periods (i.e., 1991 to the year 2000) were weighted and aggregated in the Moderate Warming scenario. The process outlined for Question VI is repeated for each of the other questions.

Table I-5

FREQUENCY OF DROUGHT IN U.S. IN 1991-2000

Respondents Assigned to Moderate Warming	Expertise	Frequent	Average	Infrequent
A	3	0.25	0.50	0.25
B	3	0.60	0.20	0.20
C	5	0.60	0.20	0.20
Weighted average		0.54	0.25	0.21

Review of Scenarios

In June 1977, the project Advisory Group recommended that an *ad hoc* panel review early drafts of the five scenarios for internal and mutual consistency. Accordingly, project staff met in July with six climatologists at the National Center for Atmospheric Research at Boulder, Colorado. The reviewers paid particular attention to the large and moderate warming and cooling scenarios, i.e., those constructed from the smaller data bases. The details and the conditional probabilities of these end scenarios, therefore, reflect the judgments of more people than the limited number of panelists who responded to the questionnaires along the lines of these scenarios. The review process, which essentially strengthened the data bases of the end scenarios, resulted in significant changes to only one of them, the large global cooling scenario.

Nature of Scenarios

Each scenario seeks to describe average climatic conditions as they might exist in a period of years around A.D. 2000. The conditions do not refer specifically to the year A.D. 2000; the climate of that year is likely to differ from the scenario projection to an extent consistent with normal year-to-year climate variability. Some indication of the course of climate changes between the present time and the end of the century is also given in the narrative, and in the tables appended to each scenario.

Each scenario is assigned a "probability of scenario." This "probability" is a derived value based on the panelists' probabilistic temperature forecasts and a weighting scheme to take into account each respondent's expertise as rated by himself and his peers. Therefore, it reflects the range of judgments expressed by the climate panel and the strengths of their beliefs, as well as their level of expertise.*

This probability should not be construed as the likelihood that the *total* scenario will actually materialize in the future. The correct interpretation of the "probability of scenario" involves the following considerations:

*A "probabil[illegible] of 0.25, for example, does not mean that there was universal agreement that the scen[illegible] in question would occur with probability 0.25. Nor does it mean that 25% of the panelists "voted" for that particular temperature change to the exclusion of other changes. Roughly speaking, the "probability" 0.25 is an amalgam of the proportion of panelists who gave some credence to that particular temperature change, the strength of their individual "beliefs" in the change (their individual probabilities of occurrence) and their individual expertise.

(1) The "probability" is essentially a measure of the confidence, expressed collectively by the climate panel, that *the global temperature change between circa 1970 and circa A.D. 2000 will lie in the range indicated by the scenario.* This measure of confidence bears an unknown relationship to the probability that the scenario will actually occur.

(2) It was assumed that the global temperature change indicated by the scenarios has a negligible probability of being greater than +1.8°C (the upper limit of Large Warming) or less than −1.2°C (the lower limit of Large Cooling). In this respect, the five scenarios, taken together, are considered to bracket all realistic outcomes—i.e., the probabilities of the five scenarios sum to unity.

(3) Details are given in each scenario which elaborate on the scenario in respects other than stipulated global temperature change. These are considered by the climate panel to be reasonable inferences about future climatic developments that are consistent with the global temperature change. These details by no means exclude other possible developments. Hence, they are not necessarily to be construed, individually or in combination, as having a probability as high as that indicated for the scenario as a whole. Conditional probability information, given in the tables included with each scenario, can be combined with the overall probability of the scenario to assess the absolute level of confidence to be placed in future events specified in the scenarios. For example, one can find the overall "probability" of a specified event (e.g., "frequent" drought in the U.S. for the period 1991-2000) by first calculating for each scenario the product of the "probability" of the scenario and the conditional probability of the event for that scenario, and then summing the products for all five scenarios.

CHAPTER TWO
CLIMATE SCENARIOS

Large Global Cooling
Moderate Global Cooling
Same as the Last 30 Years
Moderate Global Warming
Large Global Warming

CHAPTER TWO
CLIMATE SCENARIOS

This chapter contains descriptions of five climate scenarios, ranging from large global cooling to large global warming. The last subsection of Chapter I describes the nature of these scenarios, including the correct interpretation of the "probability of scenario" and of the other probabilities associated with the scenarios.

In the text and tables of this chapter, the latitudinal zones are as defined in the climate questionnaire, Appendix A: "polar latitudes," 65° to 90°; "higher mid-latitudes," 45° to 65°; "lower mid-latitudes," 30° to 45°; and "subtropical latitudes," 10° to 30°.

LARGE GLOBAL COOLING*

The global cooling trend that began in the 1940's accelerated rapidly in the last quarter of the 20th century. The average global temperature reached its lowest value of the past century a few years before the century ended. By the year 2000, the mean northern hemisphere temperature was about 0.6°C colder than in the early 1970's and climatic conditions showed a striking similarity to the period around 1820. Climatologists explained this large global cooling in terms of natural climatic cycles, partly solar induced and partly attributable to several major volcanic eruptions that occurred between 1980 and 2000. Although most climatologists had expected a continued increase in carbon dioxide to be reflected in global warming, this warming influence was overwhelmed by the natural cooling in the period.

While temperature decreased over the entire globe, the largest decreases occurred in the higher latitudes of the northern hemisphere. The north polar latitudes, marked by an expansion of arctic sea ice and snow cover

*Statements concerning some details of this scenario reflect a higher degree of certainty than was expressed by the climatologists who participated in this study. See the attached tables for the range of uncertainty. See also the discussion in subparagraph (3) at the end of Chapter I.

Table II-1A

LARGE GLOBAL COOLING

PROBABILITY OF SCENARIO: 0.10
MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE SINCE 1969: between 0.3° and 1.2°C colder

PROBABILITY OF TEMPERATURE CHANGE BY LATITUDE

(Compared with 1970-75)

		2.0-3.0°C colder	1.5-2.0°C colder	1.0-1.5°C colder	0.5-1.0°C colder	0.0-0.5°C colder	0.0-0.5°C warmer	0.5-1.0°C warmer	1.0-1.5°C warmer	1.5-2.0°C warmer
Northern hemisphere	Polar	0.2	0.6	0.1	0.1					
	Higher mid-latitude*		0.1	0.5	0.3	0.1				
	Lower mid-latitude			0.4	0.4	0.2				
	Subtropical				0.5	0.5				
Southern hemisphere	Subtropical				0.5	0.5				
	Lower mid-latitude			0.5	0.4	0.1				
	Higher mid-latitude*			0.6	0.3	0.1				
	Polar			0.6	0.3	0.1				

*Growing season in higher middle latitudes. Probability of an increase (decrease) in the *length* of the growing season exceeding 10 days is 0.0 (0.9); probability of an increase (decrease) in the *variability* of the length of the growing season in excess of 25% is 0.8 (0.0).

PROBABILITY OF PRECIPITATION CHANGE BY LATITUDE

(Compared with 1941-70)

	ANNUAL				GROWING SEASON		
	Increase > 10%	Change < 10%	Decrease > 10%		Increase > 10%	Change < 10%	Decrease > 10%
Higher mid-latitude	0.2	0.5	0.3		0.2	0.5	0.3
Lower mid-latitude	0.3	0.5	0.2		0.3	0.5	0.2
Subtropical	0.2	0.5	0.3		[illegible]	0.4	0.4

PROBABILITY OF PRECIPITATION VARIABILITY CHANGE BY LATITUDE

(Compared with average for the previous 25-year period)

	ANNUAL				GROWING SEASON		
	Increase > 25%	Change < 25%	Decrease > 25%		Increase > 25%	Change < 25%	Decrease > 25%
Higher mid-latitude	0.3	0.5	0.2		0.3	0.6	0.1
Lower mid-latitude	0.3	0.5	0.2		0.3	0.5	0.2
Subtropical	0.4	0.4	0.2		0.4	0.4	0.2

Table II-1B

LARGE GLOBAL COOLING

	Carbon dioxide	Fluorocarbons	Smoke	Volcanic dust	Other particles
RELATIVE IMPORTANCE OF CARBON DIOXIDE AND TURBIDITY (PERCENT) DURING THE PERIOD 1975-2000	15	05	20	50	10

	1977-80			1981-90			1991-2000		
	Frequent	Average	Infrequent	Frequent	Average	Infrequent	Frequent	Average	Infrequent
PROBABILITY OF MID LATITUDE DROUGHT*									
United States	0.6	0.3	0.1	0.4	0.5	0.1	0.7	0.2	0.1
Other Mid-Latitude	0.6	0.3	0.1	0.4	0.5	0.1	0.7	0.2	0.1
PROBABILITY OF SAHEL DROUGHT**	0.5	0.5		0.5	0.4	0.1	0.6	0.3	0.1
PROBABILITY OF MONSOON FAILURE***									
Northwest India	0.4	0.5	0.1	0.4	0.5	0.1	0.5	0.5	
Other India	0.5	0.4	0.1	0.4	0.5	0.1	0.6	0.3	0.1
Other Monsoon Asia	0.5	0.4	0.1	0.4	0.5	0.1	0.5	0.4	0.1

**Frequent* similar to early to mid-1930s and early to mid 1950s, *average* similar to the frequency over the longest period of record available, *infrequent* similar to 1940s and 1960s.

***Frequent* similar to 1940-50 and 1965-73 periods, *average* similar to the frequency over the longest period of record available, *infrequent* similar to 1950-65 period.

****Frequent* similar to 1900-25 period, *average* similar to the frequency over the longest period of record available, *infrequent* similar to 1930-60 period.

(especially in the north Atlantic sector), had cooled by about 2°C since the early 1970's.** The northern higher and lower middle latitudes cooled by slightly more than 1°C. The subtropical latitudes in both hemispheres showed a 0.5°C decrease in average temperature, while the remainder of the southern latitudes showed a 1°C decrease. The large global cooling trend was also reflected in a significant decrease in the length of the growing season in the higher middle latitudes and a substantial increase in the variability in the length of the growing season from year to year.

By the year 2000, it was also raining less in the higher middle and subtropical latitudes, although precipitation amounts in the lower middle latitudes changed little or possibly increased slightly.

Precipitation also became more variable. The westerlies showed a pronounced shift from the higher middle to lower middle latitudes. This shift brought brief, yet severe, "hit-and-run" droughts as well as severe cold spells (including early and late killing frosts) in the lower middle latitudes. The higher middle latitudes, particularly Canada, from which the westerlies and their associated storm tracks were displaced, suffered an increased incidence of long-term drought and winter cold. In the subtropical latitudes, the subtropical highs tended to displace the tropical easterly rainbelt and, hence, increased the incidence of long periods of hot, dry weather. The center and intensity of the Asiatic monsoon changed dramatically between the late 1970's and the turn of the century. The frequency of monsoon failure in northwest India increased to such an extent that the last decade of the 20th century bore a resemblance to the period from 1900 to 1925. Droughts were also more frequent in the Sahel region.

**One climatologist who inclined to this scenario reasoned that the north polar regions would cool only about 0.5°C, considerably less than the cooling in the middle northern latitudes.

MODERATE GLOBAL COOLING*

The global cooling trend that began in the 1940's continued through the last quarter of the 20th century. By the year 2000, mean northern hemisphere temperature had decreased by approximately 0.15°C compared to the early 1970's. Climatologists explained this trend principally in terms of a natural cooling cycle, moderated by the warming effects of increasing amounts of carbon dioxide in the atmosphere. The cooling cycle was partly solar in origin and partly associated with an increase in volcanic activity.

While temperature decreased over the entire globe, the largest temperature decreases occurred in the higher latitudes of the northern hemisphere. Specifically, the polar latitudes of the northern hemisphere cooled by 1°C; the higher middle latitudes by 0.4°C; the lower middle latitudes by 0.3°C; and the subtropical latitudes by 0.2°C. The southern hemisphere, with its more zonal circulation and larger ocean area, cooled more uniformly and slowly; the average cooling in that hemisphere was about 0.15°C. The extent of the cooling in the higher middle latitudes was not sufficiently large to cause a significant change in the mean length or interannual variability of the growing season.

The growing-season precipitation as well as annual precipitation levels remained unchanged in the lower middle latitudes but decreased slightly in the higher middle and subtropical latitudes. Annual and growing-season precipitation variability increased slightly compared to the 1950-75 period, with the strongest tendency toward increased variability in the subtropical latitudes.

Drought conditions again plagued the mid-latitude areas of the United States, corroborating the 20-to-22-year drought cycle hypothesis. In the other mid-latitude areas of the world, there were intermittent drought conditions comparable to those of the 1970's. Droughts were also more frequent in the Sahel region, as was monsoon failure in Asia.

*Statements concerning some details of this scenario reflect a higher degree of certainty than was expressed by the climatologists who participated in this study. See the attached tables for the range of uncertainty. See also the discussion in subparagraph (3) at the end of Chapter I.

Table II-2A

MODERATE GLOBAL COOLING

PROBABILITY OF SCENARIO: 0.25
MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE SINCE 1969: between 0.05° and 0.3°C colder

PROBABILITY OF TEMPERATURE CHANGE BY LATITUDE

(Compared with 1970-75)

		2.0-3.0°C colder	1.5-2.0°C colder	1.0-1.5°C colder	0.5-1.0°C colder	0.0-0.5°C colder	0.0-0.5°C warmer	0.5-1.0°C warmer	1.0-1.5°C warmer	1.5-2.0°C warmer
Northern hemisphere	Polar		0.1	0.6	0.1	0.1	0.1			
	Higher mid-latitude*			0.1	0.4	0.4	0.1			
	Lower mid-latitude			0.1	0.1	0.7	0.1			
	Subtropical				0.2	0.7	0.1			
Southern hemisphere	Subtropical				0.2	0.6	0.1	0.1		
	Lower mid-latitude			0.1	0.2	0.3	0.3	0.1		
	Higher mid-latitude*			0.1	0.2	0.3	0.3	0.1		
	Polar			0.2	0.2	0.2	0.3	0.1		

*Growing season in higher middle latitudes: Probability of an increase (decrease) in the *length* of the growing season exceeding 10 days is 0.1 (0.2); probability of an increase (decrease) in the *variability* of the length of the growing season in excess of 25% is 0.2 (0.1).

PROBABILITY OF PRECIPITATION CHANGE BY LATITUDE

(Compared with 1941-70)

	ANNUAL			GROWING SEASON		
	Increase > 10%	Change < 10%	Decrease > 10%	Increase > 10%	Change < 10%	Decrease > 10%
Higher mid-latitude	0.2	0.5	0.3	0.2	0.5	0.3
Lower mid-latitude	0.2	0.6	0.2	0.2	0.6	0.2
Subtropical	0.2	0.5	0.3	0.2	0.5	0.3

PROBABILITY OF PRECIPITATION VARIABILITY CHANGE BY LATITUDE

(Compared with average for the previous 25-year period)

	ANNUAL			GROWING SEASON		
	Increase > 25%	Change < 25%	Decrease > 25%	Increase > 25%	Change < 25%	Decrease > 25%
Higher mid-latitude	0.2	0.6	0.2	0.3	0.6	0.1
Lower mid-latitude	0.2	0.6	0.2	0.3	0.6	0.1
Subtropical	0.3	0.5	0.2	0.4	0.5	0.1

Table II-2B

MODERATE GLOBAL COOLING

	Carbon dioxide	Fluoro-carbons	Smoke	Volcanic dust	Other particles
RELATIVE IMPORTANCE OF CARBON DIOXIDE AND TURBIDITY (PERCENT) DURING THE PERIOD 1975-2000	20	10	25	30	15

	1977-80			1981-90			1991-2000		
	Frequent	Average	Infrequent	Frequent	Average	Infrequent	Frequent	Average	Infrequent
PROBABILITY OF MID-LATITUDE DROUGHT*									
United States	0.6	0.3	0.1	0.3	0.6	0.1	0.6	0.3	0.1
Other Mid-Latitude	0.6	0.4		0.5	0.4	0.1	0.5	0.4	0.1
PROBABILITY OF SAHEL DROUGHT**	0.4	0.5	0.1	0.4	0.4	0.2	0.5	0.4	0.1
PROBABILITY OF MONSOON FAILURE***									
Northwest India	0.4	0.5	0.1	0.3	0.5	0.2	0.4	0.6	
Other India	0.5	0.4	0.1	0.3	0.5	0.2	0.5	0.4	0.1
Other Monsoon Asia	0.5	0.4	0.1	0.3	0.5	0.2	0.4	0.5	0.1

**Frequent* - similar to early to mid-1930s and early to mid-1950s; *average* - similar to the frequency over the longest period of record available; *infrequent* - similar to 1940s and 1960s

***Frequent* - similar to 1940-50 and 1965-73 periods; *average* - similar to the frequency over the longest period of record available; *infrequent* - similar to 1950-65 period.

****Frequent* - similar to 1900-25 period; *average* - similar to the frequency over the longest period of record available; *infrequent* - similar to 1930-60 period

SAME AS THE LAST 30 YEARS*

The global cooling trend that began in the 1940's leveled out in the 1970's. Average global temperature in the last quarter of the 20th century increased slightly; thus, temperatures were more consistent with those in the period from 1940 to 1970. By the year 2000, mean northern hemisphere temperature had risen approximately 0.1°C compared to the early 1970's. Climatologists explained that the warming effects of the increasing amounts of carbon dioxide in the atmosphere had balanced a natural cooling cycle. Temperature increases were nearly uniform throughout the northern and southern hemispheres, with slightly more warming in the northern hemisphere than in the southern. No significant changes in the mean length or interannual variability of the growing season were noted.

The annual precipitation levels as well as the growing-season precipitation remained unchanged from the 1941-70 period. Also unchanged was the variability of annual precipitation. However, a small shift toward increased variability in the growing season was detected.

Drought conditions again plagued the mid-latitude areas of the United States, corroborating the 20-to-22-year drought cycle hypothesis. In other mid-latitude areas of the world, drought conditions recurred also, but not to the same extent as in the United States. On the other hand, favorable climatic conditions returned to India and other parts of Asia. Monsoon failures became more infrequent. Also, the Sahel region, which had suffered severe drought from 1965 to 1973, returned to average weather conditions.

*Statements concerning some details of this scenario reflect a higher degree of certainty than was expressed by the climatologists who participated in this study. See the attached tables for the range of uncertainty. See also the discussion in subparagraph (3) at the end of Chapter I.

Table II-3A

SAME AS THE LAST 30 YEARS

PROBABILITY OF SCENARIO: 0.30

MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE SINCE 1969: between 0.05° colder and 0.25°C warmer

PROBABILITY OF TEMPERATURE CHANGE BY LATITUDE

(Compared with 1970-75)

		1.0-1.5 C colder	0.5-1.0 C colder	0.0-0.5 C colder	0.0-0.5 C warmer	0.5-1.0 C warmer	1.0-1.5 C warmer	1.5-2.0 C warmer	2.0-3.0 C warmer	3.0-5.0 C warmer
Northern hemisphere	Polar	0.1	0.1	0.1	0.3	0.2	0.2			
	Higher mid-latitude*		0.1	0.2	0.4	0.2	0.1			
	Lower mid-latitude		0.1	0.2	0.4	0.2	0.1			
	Subtropical		0.1	0.2	0.5	0.1	0.1			
Southern hemisphere	Subtropical		0.1	0.3	0.4	0.1	0.1			
	Lower mid-latitude		0.1	0.3	0.4	0.1	0.1			
	Higher mid-latitude*		0.1	0.3	0.4	0.1	0.1			
	Polar*	0.1	0.1	0.3	0.3	0.1	0.1			

*Growing season in higher middle latitudes: Probability of an increase (decrease) in the *length* of the growing season exceeding 10 days is 0.2 (0.1); probability of an increase (decrease) in the *variability* of the length of the growing season in excess of 25% is 0.1 (0.1).

PROBABILITY OF PRECIPITATION CHANGE BY LATITUDE

(Compared with 1941-70)

	ANNUAL			GROWING SEASON		
	Increase > 10%	Change < 10%	Decrease > 10%	Increase > 10%	Change < 10%	Decrease > 10%
Higher mid-latitude	0.2	0.6	0.2	0.2	0.6	0.2
Lower mid-latitude	0.2	0.6	0.2	0.2	0.6	0.2
Subtropical	0.2	0.6	0.2	0.2	0.6	0.2

PROBABILITY OF PRECIPITATION VARIABILITY CHANGE BY LATITUDE

(Compared with average for the previous 25 year period)

	ANNUAL			GROWING SEASON		
	Increase > 25%	Change < 25%	Decrease > 25%	Increase > 25%	Change < 25%	Decrease > 25%
Higher mid-latitude	0.2	0.6	0.2	0.2	0.7	0.1
Lower mid-latitude	0.2	0.6	0.2	0.2	0.7	0.1
Subtropical	0.2	0.6	0.2	0.3	0.6	0.1

Table II-3B

SAME AS THE LAST 30 YEARS

	Carbon dioxide	Fluoro-carbons	Smoke	Volcanic dust	Other particles
RELATIVE IMPORTANCE OF CARBON DIOXIDE AND TURBIDITY (PERCENT) DURING THE PERIOD 1975-2000	50	10	10	15	15

	1977-80			1981-90			1991-2000		
	Frequent	Average	Infrequent	Frequent	Average	Infrequent	Frequent	Average	Infrequent
PROBABILITY OF MID-LATITUDE DROUGHT*									
United States	0.5	0.4	0.1	0.2	0.6	0.2	0.5	0.4	0.1
Other Mid-Latitude	0.4	0.5	0.1	0.3	0.6	0.1	0.4	0.5	0.1
PROBABILITY OF SAHEL DROUGHT**	0.2	0.6	0.2	0.2	0.7	0.1	0.2	0.7	0.1
PROBABILITY OF MONSOON FAILURE***									
Northwest India	0.3	0.6	0.1	0.2	0.6	0.2	0.2	0.5	0.3
Other India	0.3	0.6	0.1	0.2	0.6	0.2	0.2	0.5	0.3
Other Monsoon Asia	0.3	0.6	0.1	0.2	0.6	0.2	0.2	0.6	0.2

*Frequent—similar to early to mid-1930s and early to mid-1950s; *average*—similar to the frequency over the longest period of record available; *infrequent* similar to 1940s and 1960s.

***Frequent*—similar to 1940-50 and 1965-73 periods; *average*—similar to the frequency over the longest period of record available; *infrequent* similar to 1950-65 period.

****Frequent*—similar to 1900-25 period; *average*- similar to the frequency over the longest period of record available; *infrequent*- similar to 1930 60 period

MODERATE GLOBAL WARMING*

The global cooling trend that began in the 1940's was reversed in the last quarter of the 20th century. By the year 2000, mean northern hemisphere temperature had risen by approximately 0.4°C, compared to the early 1970's. Climatologists explained that this increase in temperatures was due principally to the warming effects of increasing amounts of carbon dioxide in the atmosphere, which predominated over a slow, natural cooling effect.

While average global temperature increased moderately, the largest temperature increases came in the higher latitudes. The northern hemisphere warmed slightly more than the southern hemisphere due to its greater land area and the larger thermal inertia of the southern oceans. In the northern hemisphere, the polar latitudes warmed by 1.2°C; the higher middle latitudes by 0.5°C, the lower middle latitudes by 0.3°C; and the subtropical latitudes by 0.25°C. In the southern hemisphere, average temperatures over the polar latitudes increased by 0.65°C; the higher middle latitudes by 0.4°C; the lower middle latitudes by 0.3°C; and the subtropical latitudes by 0.2°C. The increase in global temperature was reflected in a moderate increase in the length of the growing season in higher middle latitudes, but no significant change in the interannual variability of the growing-season was noted.

Annual precipitation levels increased slightly in the higher middle latitudes but showed little change for lower latitudinal bands. Growing–season precipitation also increased slightly in the higher middle latitudes and subtropical regions but remained unchanged in the lower middle latitudes. Both annual and growing-season precipitation variability remained essentially unchanged except for a slight increase in the variability of growing-season precipitation in subtropical latitudes.

Drought conditions again plagued the mid-latitude areas of the United States, corroborating the 20-to-22-year drought cycle hypothesis. Climatic conditions were somewhat more favorable in the Asiatic region and in subtropical North Africa. The frequency of monsoon failure, especially in northwest India, resembled more closely the long-term average; so did the frequency of drought in the Sahel region.

*Statements concerning some details of this scenario reflect a higher degree of certainty than was expressed by the climatologists who participated in this study. See the attached tables for the range of uncertainty. See also the discussion in subparagraph (3) at the end of Chapter I.

Table II-4A

MODERATE GLOBAL WARMING

PROBABILITY OF SCENARIO: 0.25
MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE SINCE 1969: between 0.25° and 0.6°C warmer

PROBABILITY OF TEMPERATURE CHANGE BY LATITUDE

(Compared with 1970-75)

		1.0-1.5°C colder	0.5-1.0°C colder	0.0-0.5°C colder	0.0-0.5°C warmer	0.5-1.0°C warmer	1.0-1.5°C warmer	1.5-2.0°C warmer	2.0-3.0°C warmer	3.0-5.0°C warmer
Northern hemisphere	Polar			0.1	0.1	0.2	0.2	0.2	0.2	
	Higher mid-latitude*			0.1	0.3	0.4	0.1	0.1		
	Lower mid-latitude			0.1	0.5	0.3	0.1			
	Subtropical			0.1	0.6	0.2	0.1			
Southern hemisphere	Subtropical			0.1	0.6	0.2	0.1			
	Lower mid-latitude			0.1	0.5	0.3	0.1			
	Higher mid-latitude*			0.1	0.3	0.5	0.1			
	Polar			0.1	0.2	0.5	0.1	0.1		

*Growing season in higher middle latitudes: Probability of an increase (decrease) in the *length* of the growing season exceeding 10 days is 0.4 (0.2); probability of an increase (decrease) in the *variability* of the length of the growing season in excess of 25% is 0.1 (0.2).

PROBABILITY OF PRECIPITATION CHANGE BY LATITUDE

(Compared with 1941-70)

	ANNUAL				GROWING SEASON		
	Increase ≥ 10%	Change < 10%	Decrease ≥ 10%		Increase ≥ 10%	Change < 10%	Decrease ≥ 10%
Higher mid-latitude	0.3	0.5	0.2		0.3	0.5	0.2
Lower mid-latitude	0.2	0.6	0.2		0.2	0.6	0.2
Subtropical	0.2	0.6	0.2		0.3	0.5	0.2

PROBABILITY OF PRECIPITATION VARIABILITY CHANGE BY LATITUDE

(Compared with average for the previous 25-year period)

	ANNUAL				GROWING SEASON		
	Increase ≥ 25%	Change < 25%	Decrease ≥ 25%		Increase ≥ 25%	Change < 25%	Decrease ≥ 25%
Higher mid-latitude	0.2	0.6	0.2		0.2	0.6	0.2
Lower mid-latitude	0.2	0.6	0.2		0.2	0.6	0.2
Subtropical	0.2	0.6	0.2		0.3	0.5	0.2

Table II-4B

MODERATE GLOBAL WARMING

	Carbon dioxide	Fluoro-carbons	Smoke	Volcanic dust	Other particles
RELATIVE IMPORTANCE OF CARBON DIOXIDE AND TURBIDITY (PERCENT) DURING THE PERIOD 1975-2000	60	15	5	10	10

	1977-80			1981-90			1991-2000		
	Frequent	Average	Infrequent	Frequent	Average	Infrequent	Frequent	Average	Infrequent
PROBABILITY OF MID-LATITUDE DROUGHT*									
United States	0.6	0.3	0.1	0.2	0.2	0.6	0.5	0.3	0.2
Other Mid-Latitude									
PROBABILITY OF SAHEL DROUGHT**	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.3
PROBABILITY OF MONSOON FAILURE***									
Northwest India	0.3	0.4	0.3	0.3	0.4	0.3	0.2	0.5	0.3
Other India									
Other Monsoon Asia									

**Frequent*–similar to early to mid-1930s and early to mid-1950s, *average*–similar to the frequency over the longest period of record available, *infrequent*–similar to 1940s and 1960s.

***Frequent*–similar to 1940-50 and 1965-73 periods; *average*–similar to the frequency over the longest period of record available; *infrequent*–similar to 1950-65 period.

****Frequent*–similar to 1900-25 period; *average*–similar to the frequency over the longest period of record available; *infrequent*–similar to 1930-60 period.

LARGE GLOBAL WARMING*

The global cooling trend that began in the 1940's was dramatically reversed in the last quarter of the 20th century. By the year 2000, the mean northern hemisphere temperature had increased by about 1°C compared to the early 1970's. Climatologists explained that this trend was due principally to the warming effects of the increasing amounts of carbon dioxide in the atmosphere.

While temperature increased over the entire globe, temperature increases were more pronounced at higher latitudes. The subtropical latitudes warmed, on the average, by 0.8°C; the lower middle latitudes by 1.0°C; the higher middle latitudes by 1.4°C; and the polar latitudes by a remarkable 3.0°C, compared to the early 1970's. Symmetry prevailed as similar temperature changes were observed in both the northern and southern hemispheres. The increase in temperature was accompanied by a significant increase in the length of the growing season in the higher middle latitudes, as well as by a substantial decrease in the variability from year to year in the length of the growing season.

Precipitation levels generally increased, especially in the subtropical and higher middle latitudes. In the lower middle latitudes there was little net change of precipitation. Annual precipitation variability decreased slightly compared to the 1950-75 period; precipitation variability during the growing season similarly decreased in the higher middle latitudes, but increased slightly in the lower middle and subtropical latitudes.

The warming trend also ushered in more favorable climatic conditions in India and other parts of Asia. These conditions were similar to those of the 1930-60 period. Monsoon failure was infrequent, especially in northwest India. But in the mid-latitude areas of the United States, extending from the Rockies to the Appalachians, drought conditions similar to the mid-1930's and the early-to-mid-1950's prevailed. In other mid-latitude areas of the world, notably Europe, the probability of drought declined. The increased levels of precipitation also returned the Sahel region to wetter weather conditions.

*Statements concerning some details of this scenario reflect a higher degree of certainty than was expressed by the climatologists who participated in this study. See the attached tables for the range of uncertainty. See also the discussion in subparagraph (3) at the end of Chapter I.

Table II-5A

LARGE GLOBAL WARMING

PROBABILITY OF SCENARIO: 0.10
MEAN NORTHERN HEMISPHERE TEMPERATURE CHANGE SINCE 1969: between 0.6° and 1.8°C warmer

PROBABILITY OF TEMPERATURE CHANGE BY LATITUDE

(Compared with 1970-75)		1.0-1.5°C colder	0.5-1.0°C colder	0.0-0.5°C colder	0.0-0.5°C warmer	0.5-1.0°C warmer	1.0-1.5°C warmer	1.5-2.0°C warmer	2.0-3.0°C warmer	3.0-5.0°C warmer
Northern hemisphere	Polar						0.1	0.1	0.2	0.6
	Higher mid-latitude*					0.1	0.5	0.4		
	Lower mid-latitude				0.1	0.5	0.2	0.2		
	Subtropical				0.1	0.8	0.1			
Southern hemisphere	Subtropical				0.1	0.8	0.1			
	Lower mid-latitude				0.1	0.5	0.2	0.2		
	Higher mid-latitude*					0.1	0.5	0.4		
	Polar					0.1	0.1	0.1	0.2	0.5

*Growing season in higher middle latitudes: Probability of an increase (decrease) in the *length* of growing season exceeding 10 days is 0.8 (0.0); probability of an increase (decrease) in the *variability* of the length of the growing season in excess of 25% is 0.0 (0.7).

PROBABILITY OF PRECIPITATION CHANGE BY LATITUDE

(Compared with 1941-70)	ANNUAL				GROWING SEASON		
	Increase > 10%	Change < 10%	Decrease > 10%		Increase > 10%	Change < 10%	Decrease > 10%
Higher mid-latitude	0.4	0.5	0.1		0.3	0.5	0.2
Lower mid-latitude	0.3	0.5	0.2		0.3	0.4	0.3
Subtropical	0.3	0.5	0.2		0.4	0.5	0.1

PROBABILITY OF PRECIPITATION VARIABILITY CHANGE BY LATITUDE

(Compared with average for the previous 25-year period)	ANNUAL				GROWING SEASON		
	Increase > 25%	Change < 25%	Decrease > 25%		Increase > 25%	Change < 25%	Decrease > 25%
Higher mid-latitude	0.2	0.5	0.3		0.2	0.5	0.3
Lower mid-latitude	0.2	0.5	0.3		0.3	0.5	0.2
Subtropical	0.2	0.5	0.3		0.3	0.5	0.2

Table II-5B

LARGE GLOBAL WARMING

	Carbon dioxide	Fluoro-carbons	Smoke	Volcanic dust	Other particles
RELATIVE IMPORTANCE OF CARBON DIOXIDE AND TURBIDITY (PERCENT) DURING THE PERIOD 1975-2000	90	10	0	0	0

	1977-80			1981-90			1991-2000		
	Frequent	Average	Infrequent	Frequent	Average	Infrequent	Frequent	Average	Infrequent
PROBABILITY OF MID-LATITUDE DROUGHT*									
United States	0.6	0.3	0.1	0.6	0.3	0.1	0.7	0.2	0.1
Other Mid-Latitude	0.5	0.3	0.2	0.5	0.3	0.2	0.3	0.3	0.4
PROBABILITY OF SAHEL DROUGHT**	0.1	0.8	0.1	0.1	0.7	0.2	0.1	0.6	0.3
PROBABILITY OF MONSOON FAILURE***									
Northwest India	0.1	0.8	0.1	0.1	0.6	0.3		0.2	0.8
Other India	0.1	0.8	0.1	0.1	0.6	0.3	0.1	0.2	0.7
Other Monsoon Asia	0.1	0.8	0.1	0.1	0.6	0.3	0.1	0.2	0.7

**Frequent*—similar to early to mid-1930s and early to mid-1950s; *average*—similar to the frequency over the longest period of record available; *infrequent*—similar to 1940s and 1960s.

***Frequent*—similar to 1940-50 and 1965-73 periods; *average*—similar to the frequency over the longest period of record available; *infrequent*—similar to 1950-65 period.

****Frequent*—similar to 1900-25 period, *average*—similar to the frequency over the longest period of record available; *infrequent*—similar to 1930-60 period.

[illegible]

Global Temperature Changes

Latitudinal Temperature Changes

Growing Season

Precipitation

Changes in Precipitation Volume

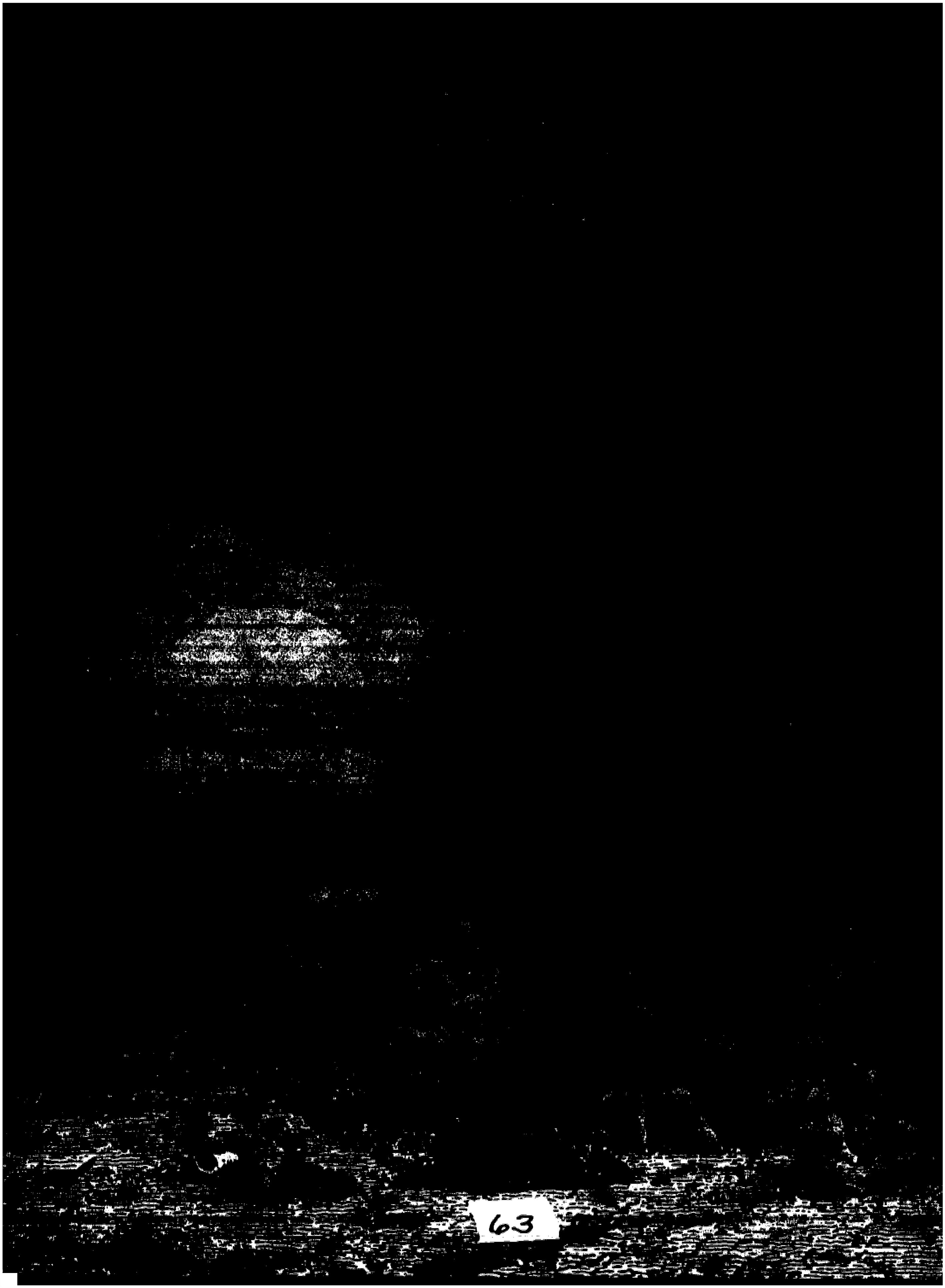
Changes in Precipitation Variability

Drought and Monsoon Failure

U.S. and Other Mid-Latitude Drought

Sahelian Drought and Failure of Asian Monsoons

Conclusions on Climatic Variability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CHAPTER THREE

DISCUSSION OF SCENARIOS AND CLIMATIC PROBABILITIES

GENERAL

This chapter summarizes the aggregated probabilistic data of the climate panelists and makes comparisons of these data—from scenario to scenario, across latitudinal zones, and across three time periods between now and the year 2000. The data received in response to the climate questionnaire (Appendix A) are related primarily to trends in gross climatic parameters rather than the interannual variability of the parameters. In the ensuing discussion, particular attention is paid to the limited data that bear on the panelists' perceptions about the important question of future climatic variability. Also included are some of the climatologists' numerous comments giving rationale for their answers and expressing caveats and reservations regarding their responses.

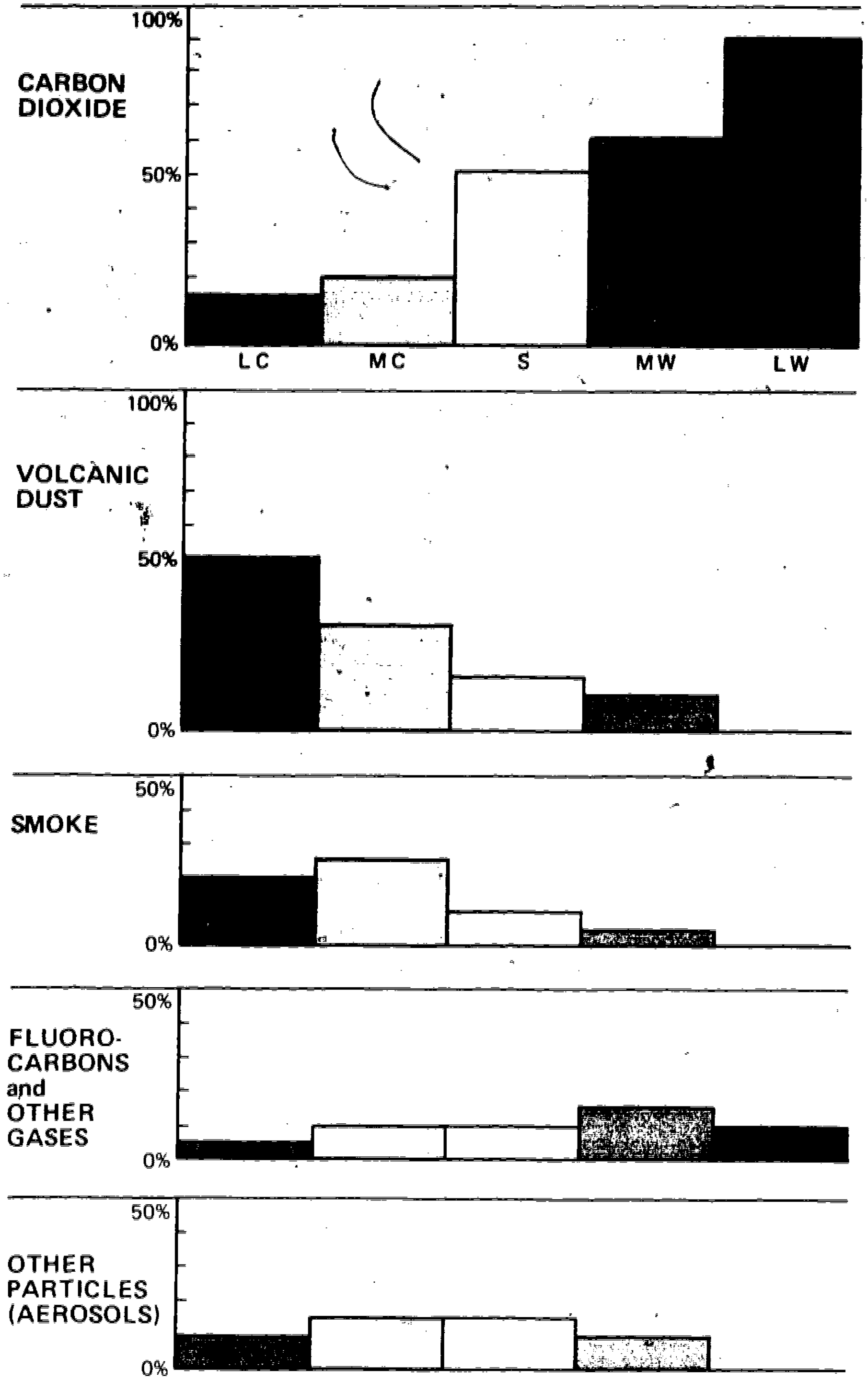
GLOBAL TEMPERATURE CHANGES

The climate scenarios of the preceding chapter are structured around the responses to the first question—Global Temperature— of the climate questionnaire (Appendix A). Table I-3 and Figure I-8 of Chapter I show the "global" temperature range (expressed as the change in mean Northern Hemisphere temperature from present by the year 2000) for each of the five scenarios and the "probability" associated with each scenario. The total span of temperature changes in all the scenarios is 3°C, ranging from 1.2° cooler to 1.8° warmer. The three middle scenarios encompass a range of less than 1°C (from 0.3° cooler to 0.6° warmer), and have an aggregate "probability" of 0.8. This general consensus—that there will be no radical change in global temperature by 2000 A.D.—and the slight group bias toward global warming are considered to be major findings of this study.

Respondents whose probability estimates tended toward the two warming scenarios explained their reasoning primarily in terms of the likely long-term dominance of the CO_2 warming effect. This explanation is reflected quantitatively in Figure III-1, which summarizes the responses to Question III (Carbon Dioxide, Turbidity, and Climate) of the questionnaire. In general, panelists who inclined toward global cooling hypothesized that the

Figure III-1

RELATIVE CLIMATIC INFLUENCE



These five graphs summarize the aggregrated responses to Question III (Carbon Dioxide, Turbidity, and Climate) of the climate questionnaire. The climatologists were asked to indicate the relative influence (in percent) of the indicated atmospheric components on global climate over the next 25 years. The vertical bars reading from left (Large Cooling) to right (Large Warming) correspond to the five climate scenarios.

warming effects of CO_2 might not materialize to the extent suggested by those supporting a strong warming trend, or that the CO_2 warming effects would be overshadowed by a long-term, solar-induced cooling trend. Several respondents also commented on the possible cooling effects of volcanic activity, noting, however, the difficulty of predicting the level or timing of such activity. The middle scenario—that of little change in the mean annual global temperature—is predicated primarily on the warming effects of CO_2 balancing the effects of natural cooling. Some panelists commented on the possible effects on climatic change of dust and other natural and anthropogenic particles, but there does not appear to be a consensus whether such particles have a net warming or cooling effect; also, their effect probably tends to be more regional than global.

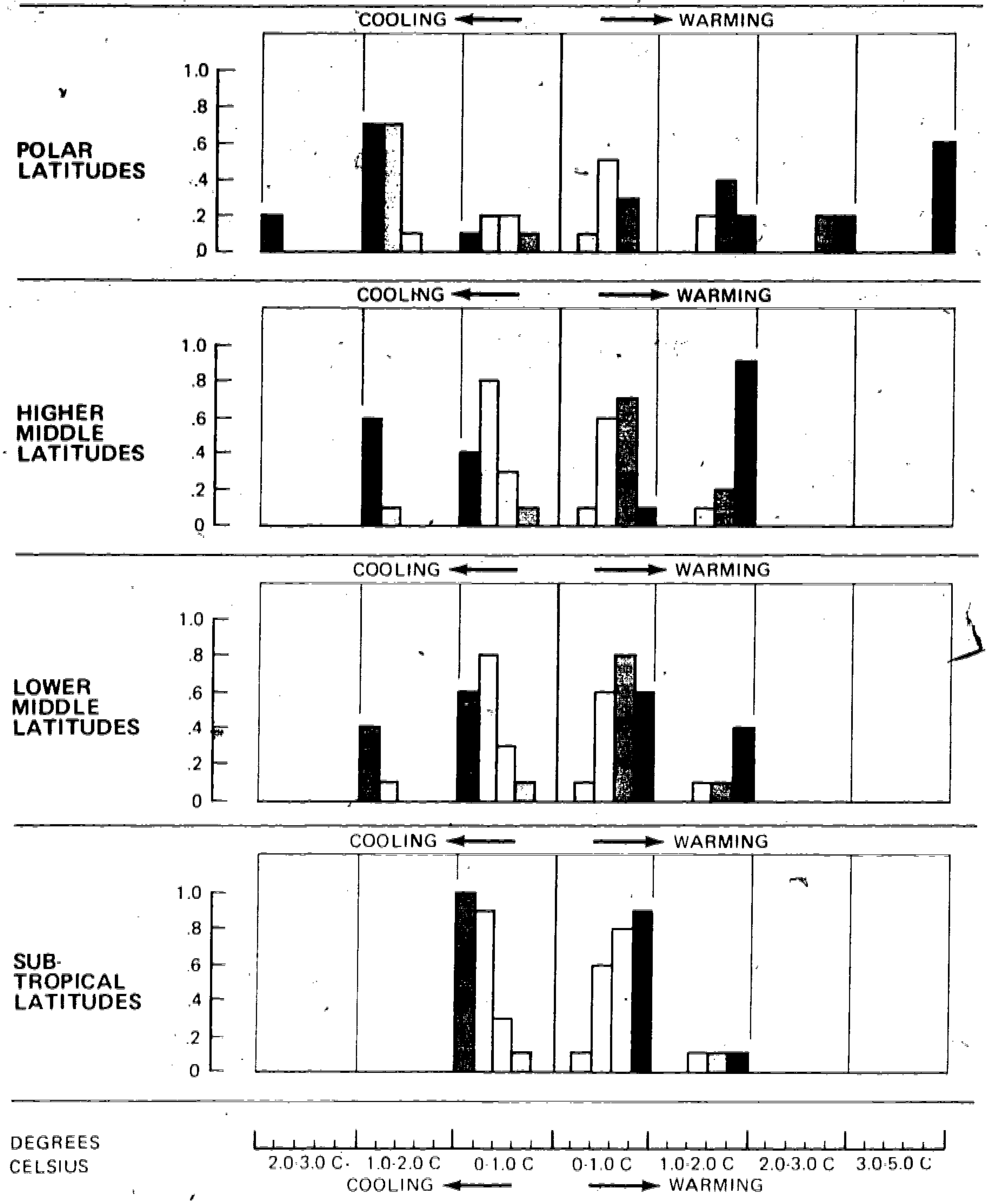
LATITUDINAL TEMPERATURE CHANGES

Perhaps more pertinent than a given change in average global temperature is the nonuniformity of the associated temperature changes at different latitudes. An analysis of the respondents' estimates of likely temperature changes by latitudinal zones (Question II of Appendix A) indicates that global temperature fluctuations are expected to be far more pronounced in the polar regions than in low latitudes. In other words, the poles are perceived as more sensitive to climate change. A number of the respondents judged that the poles may experience a change at least several fold larger than the global average (see Figure III-2). For instance, in the Large Global Cooling Scenario (0.3° to 1.2°C cooler), the probability for a 1.0° to 3.0°C cooling in the northern polar latitudes is 0.9, and 0.6 for a 1.0° to 2.0°C cooling in the northern higher middle latitudes. By contrast, northern subtropical temperatures are perceived to drop by only 0.0° to 1.0°C with probability 1. Similar observations about differential cooling in the higher latitudes hold for the Moderate Cooling Scenario (0.05° to 0.3°C cooler). The question arises as to what extent such an increase in latitudinal temperature gradients could be a mechanism for greater year-to-year climatic variability. The views of several of the panelists are exemplified by one comment to the effect that while "a temperature change *per se* does not imply increased climatic variability, there is some physical basis for saying that a general cooling would imply increased baroclinic instability and therefore increased temperature variability and vice versa."

The picture of increases in latitudinal temperature gradients that can be identified in the two cooling scenarios does not hold in the two warming scenarios. In the Moderate Global Warming Scenario (0.25° to 0.6°C warmer), the probability is 0.6 for a 1.0° to 3.0°C warming in the northern polar latitudes as compared to a probability of 0.6 for a 0.0° to 0.5°C increase in the subtropical latitudes. In this scenario, as well as in the less likely Large Global Warming Scenario, the perceived differential warming

Figure III-2

PROBABILITY OF TEMPERATURE CHANGE IN NORTHERN HEMISPHERE



These four graphs summarize the aggregrated responses to Question II of the climate questionnaire. Depicted for the indicated zones of latitude are the climatologists' probabilities of change in annual temperature by the year 2000, compared to 1970-75. For a given zone of latitude and band of temperature, the vertical bars correspond to the five climate scenarios as in Figure III-1. If the probability of a temperature change in a scenario is zero, the bar for that scenario is absent.

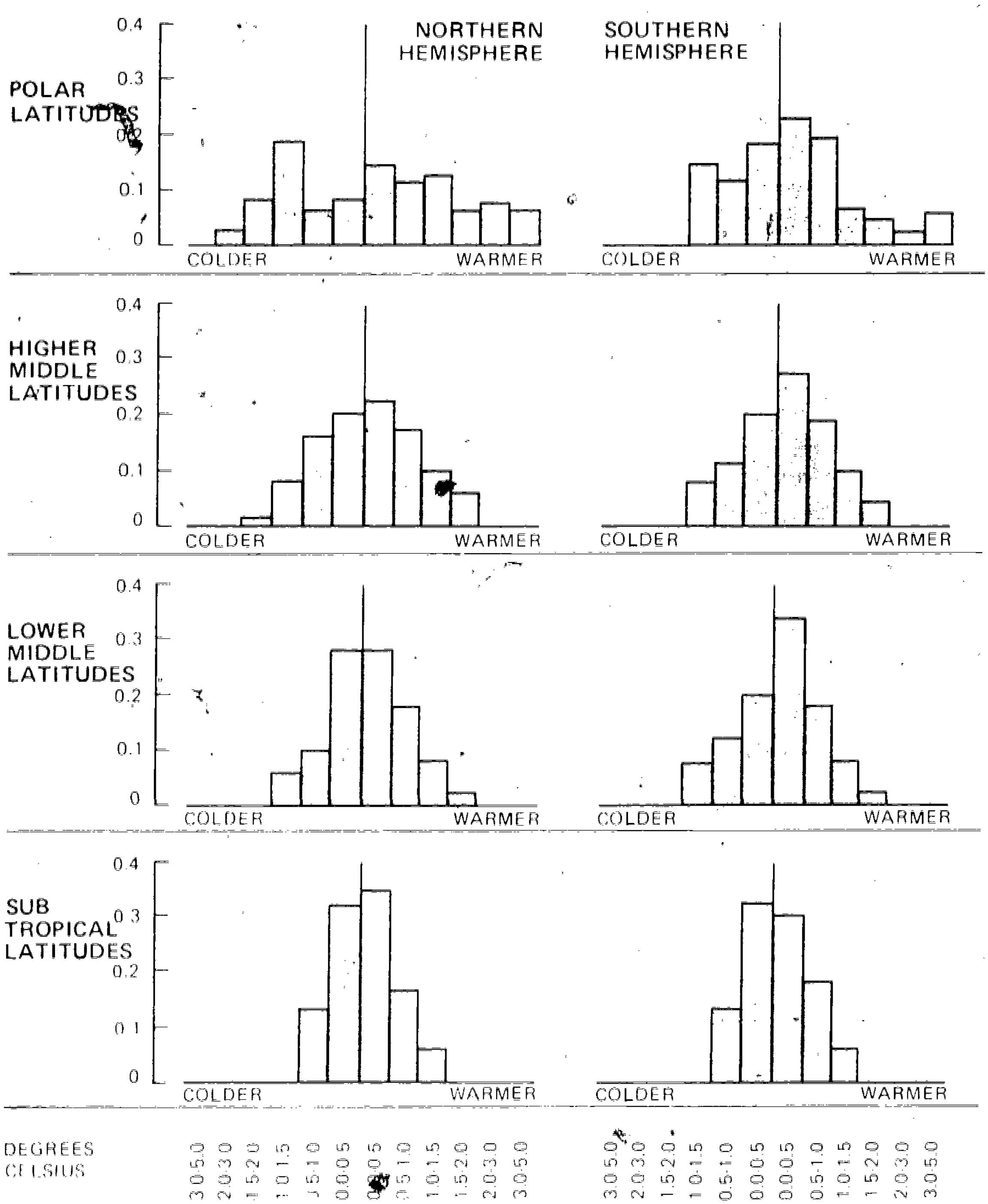
reduces latitudinal temperature gradients. Some panelists associated a reduction of these gradients with a decrease in climatic variability. One respondent, quoted later at great length, commented that "it seems intuitively reasonable" that reduced latitudinal temperature gradients could cause "less variability due to baroclinic instabilities and blocking pressure patterns." As will be seen later, the inferences about climatic variability—less variability in a warming regime and more variability in cooling—are supported by the climatologists' responses to other questions.

Figure III-3 provides a more aggregated view of temperature changes by latitude. Here, the partitioning of the climatologists into the five scenarios has been eliminated. In each latitudinal zone, the frequency distribution of temperature changes is attributable to the Climate Panel as a whole since the probability of a given temperature change was calculated by multiplying the probability of that temperature change in each scenario by the overall probability of the scenario and summing the resulting products over the five scenarios. The flat and wide frequency distributions for the polar regions, especially the Northern Hemisphere, reflect the wide range of opinion and the high degree of uncertainty relative to the warming or cooling issue. As one moves from polar to subtropical latitudes, the probability density plots show a progressive decrease in temperature range and a corresponding peaking in the temperature intervals of little or no change. In the subtropics, the respondents' estimates in aggregate indicate a 0.6 to 0.7 probability that the temperature change will be less than 0.5°C warmer or cooler than at present; in the lower middle latitudes that probability is only slightly less—0.5 to 0.6. In the higher middle latitudes, estimates of temperature change fell within ± 2.0°C, with a probability of about 0.45 for a change of less than 0.5°C warmer or cooler and about 0.75 that the change will be less than ± 1.0°C.

Several respondents commented that temperature changes are likely to be somewhat less in the Southern Hemisphere than in the Northern Hemisphere because of the thermal inertia provided by the proportionally greater ocean surface. Note that in Figure III-3 the temperature range in the polar latitudes is somewhat less for the Southern Hemisphere than for the Northern. Also note that, as in Figure I-8 of Chapter I, the graphs for all the latitudinal bands in both hemispheres show a slight skewness toward warming.

Figure III-3

PROBABILITY OF TEMPERATURE CHANGE (Aggregated across Scenarios)



These graphs aggregate the data of Figure III-2 across the climate scenarios. That is, each bar represents the probability of a temperature change in a zone of latitude as perceived by the panel of climatologists as a whole, without regard to an individual's association with one of the five global temperature scenarios.

GROWING SEASON

Question X of Appendix A dealt with temperature-related parameters: changes in the mean length and variability of growing seasons in the higher middle latitudes during the next 25 years as compared to the present. It was one of the two questions that dealt directly with the subject of climate variability, in this case interannual variability in the length of the growing season. Numerical data from 15 panelists were processed for Question X.

As can be seen from Figure III-4, only in the Large Cooling and Large Warming Scenarios were there high probabilities (0.9 and 0.8, respectively) for a "significant" change—10 days or more—in the length of the present growing season. Moreover, it was only in these two scenarios that the panelists perceived a large probability for a "significant" change (25 percent or more) in the standard deviation of the length of the growing season: 0.8 for an increase in variability under the Large Cooling Scenario and 0.7 for a decrease under the Large Warming Scenario. The aforementioned probabilities are ascribable to two climatologists who inclined to the extreme global temperature scenarios.

With regard to the middle three scenarios, a majority of the panelists tended toward high probabilities (0.7 to 0.8) for no significant changes in the mean length of the growing season and its interannual variability.

The following comments on the length and variability of growing seasons were made by two panelists disposed toward global cooling:

> The changes in the variability or standard deviations of temperature are a very clear function of both the double and the secular solar-climatic cycles. The peak of temperature variability was reached in 1816 (the famous year without a summer, that blew both hot and very cold), the 180-year counterpart of 1996, the low point on my curve in Question I.

> I think it is more likely that the present meridional trend in atmospheric circulation (with longer growing seasons) will prevail for a few years, to be replaced later on by a return to zonal circulation, with shorter growing seasons. Over the 25 years the change might well even out.

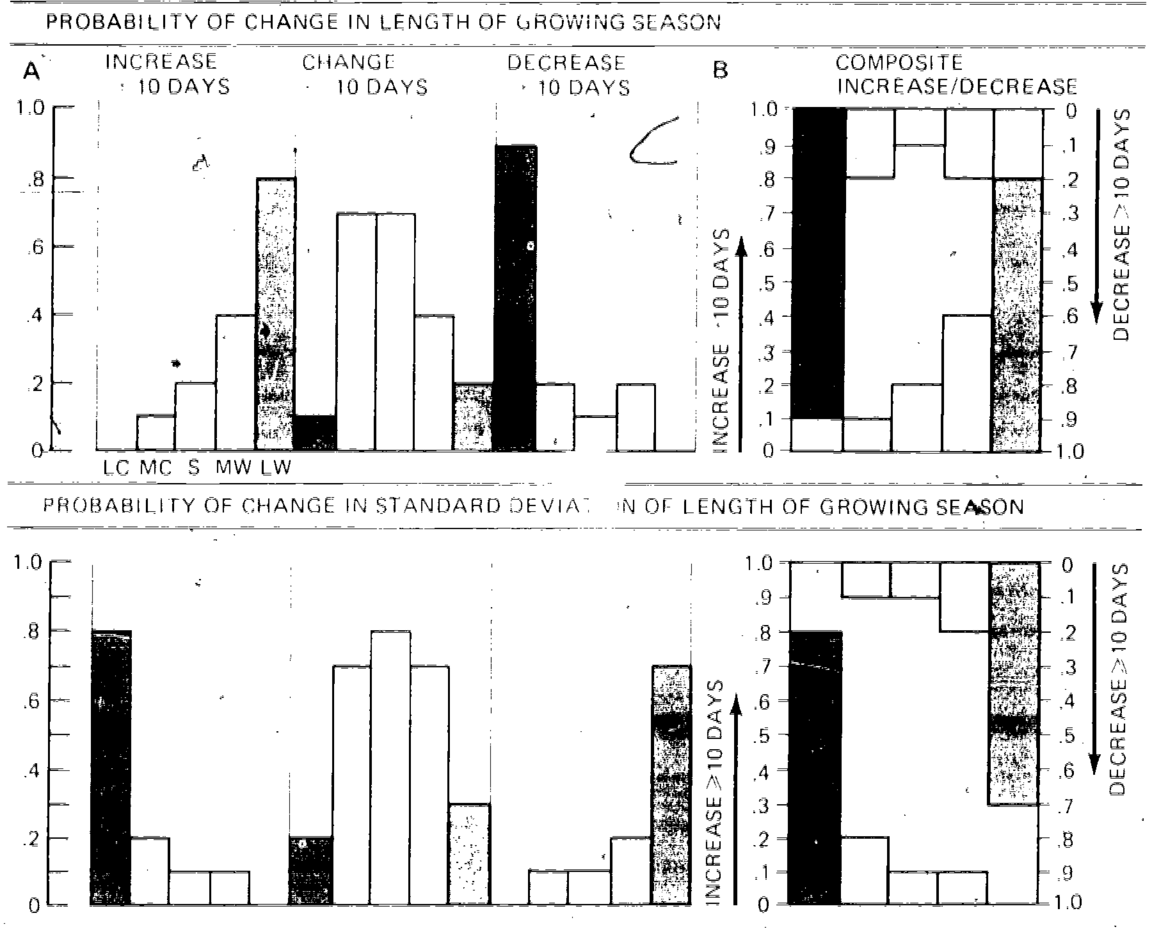
Another adherent of global cooling based his response on his curve for Question I and the "corresponding expectations of change of frequency of blocking and the high variability from year to year which goes with it."

Two panelists who tended toward the "Same" global temperature scenario commented that:

> . . . the growing season could increase north of 40° or 45 N, probably

Figure III-4

CHANGES IN HIGHER MID-LATITUDE GROWING SEASONS BY THE YEAR 2000



These graphs summarize the aggregated responses to Question X (Length of Growing Season). The top row of graphs pertains to perceptions of changes by the year 2000 in the length of the growing season, the bottom row to changes by 2000 A.D. in the standard deviation of the length of the growing season (both changes being relative to the present). The thresholds of "significant" changes are 10 days for lengths of growing seasons and 25 percent for the standard deviations. In each graph the vertical bars, reading from left (Large Cooling) to right (Large Warming) correspond to the five climate scenarios. Figure III-4A presents the climatologists' aggregated data in the form of conventional bar graphs. In Figure III-4B the same data are condensed into single graphs, the format of which is used in subsequent figures. For a given scenario in Figure III-4B, the probability of a significant increase in a parameter is represented by the height of the lower bar measured by reading up on the left-hand scale. The probability of a significant decrease is measured by the height of the upper bar reading down on the right-hand scale. The height of the blank space between the upper and lower bars represents the probability of no significant change in the parameter.

> little in 30°-40°N. Anomalies of spring and fall season are little known, but can be significant.
>
> Not knowing what is meant by "present," the question is vague. Referring to Question I, it would appear that 25 years will encompass variations in both directions.

Quoted below are two adherents of global warming:

> If one plots growing season vs. mean summertime temperature at mid-continental stations (both of which vary with latitude), one can deduce a rule of thumb that a change of ± 1°C corresponds to about ± 10 days in growing season. In 25 years the mean hemispheric temperature should rise about 1°C, and at middle and higher latitudes the corresponding change should be several times larger. Thus, I would foresee a greater than 10-day increase in growing season at middle and high latitudes.
>
> Consistent with a general warming to be anticipated with the CO_2 increase, which would be largest in the high latitudes, I anticipate a higher probability of a lengthened growing season than that inferred from climatological averages. I doubt that the interannual variability of the growing season length would change by more than 25 percent but such changes as there may be are slightly more favored to be in the direction of a decrease than otherwise because the CO_2 increase itself might be expected to discourage very low temperatures a bit more than now.

Two other panelists stressed the difficulty of making any predictions about growing seasons:

> Climate does not necessarily change in the same sense all along a parallel of latitude. This, added to the fact that we have no way of telling how it will change locally, makes it impossible to answer this question.
>
> In my view there is no statistically significant evidence to support a systematic change of the growing season. There will be fluctuations, particularly on the short side associated with volcanoes, but they cannot be forecast.

Notwithstanding the panelists' collective uncertainty in Question X about the growing-season manifestation of temperature variability, one can infer a tendency to associate greater variability of temperature with extreme global cooling and less variability with extreme warming. A similar inclination to associate more variability with cooling and less with warming emerges in the following discussion on precipitation.

PRECIPITATION

Questions IV and V of Appendix A dealt respectively with changes in the volume and variability of precipitation for three bands of latitude. (Question V and Question X, on growing seasons, were the only ones that directly addressed climatic variability.) The two questions on precipitation were unique in that they were couched in terms of conditional probabilities: panelists were asked for probabilities of change under the assumption of three given ranges of temperature changes over the next 25 years.

The answers to both questions on precipitation have been summarized in Figure III-5 to facilitate comparisons of the responses on precipitation volume and precipitation variability. The respondents' estimates of the probabilities of change in precipitation volume and variability indicate a high level of uncertainty not only about the amount of the change but in many cases even about the direction of the change; this is particularly true with respect to possible changes in interannual variability. Keeping this uncertainty in mind, the following cross-scenario and cross-latitude highlights can be identified.

Changes in Precipitation Volume

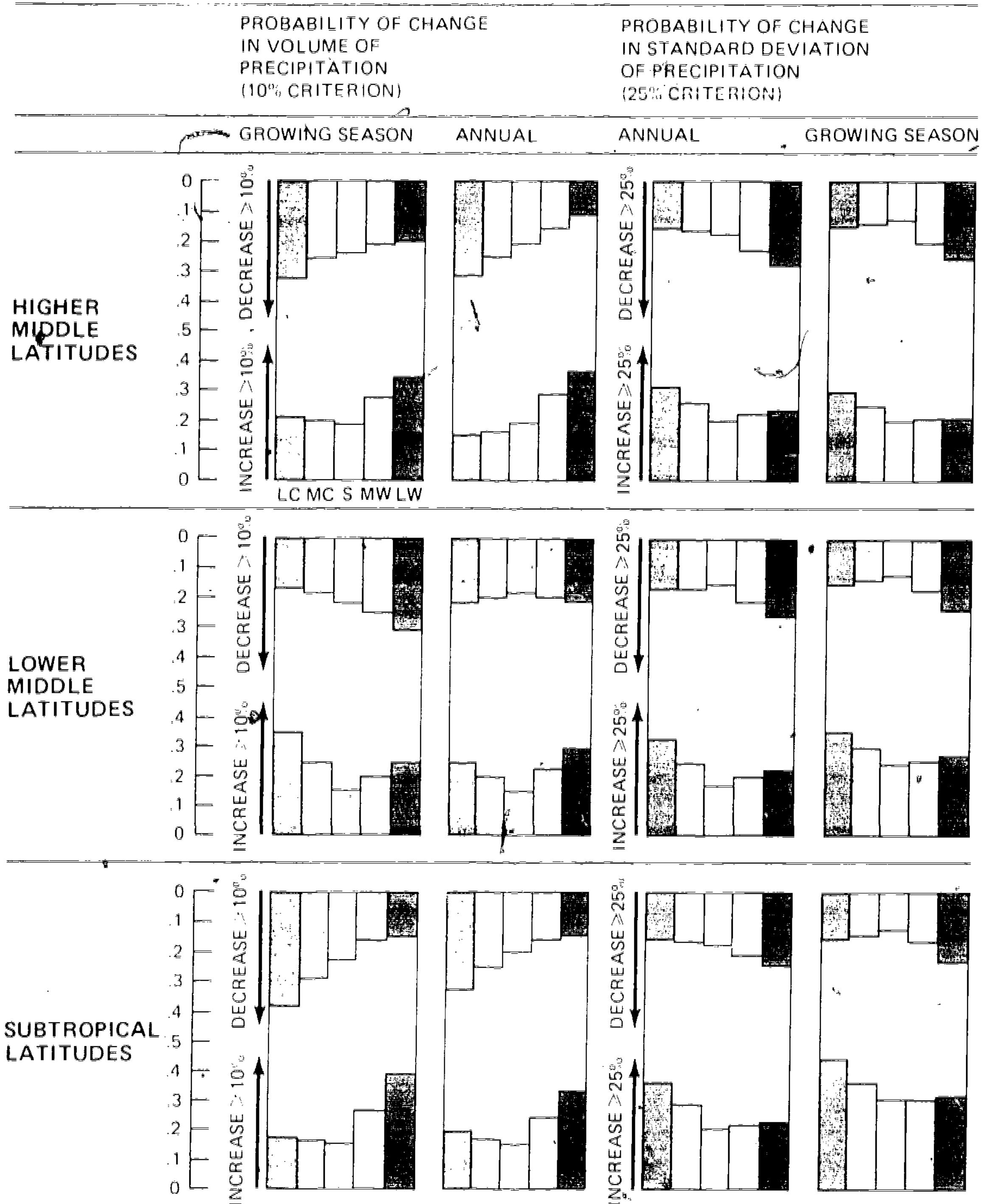
In Question IV the panelists were asked to provide probabilities of changes by the year 2000 in mean annual and growing-season precipitation relative to the "normal" period of 1941-70. The thresholds for "significant" increases and decreases in precipitation volume were defined as ± 10 percent.

For each combination of global temperature scenario and zone of latitude, the highest probability was for no major change in *annual* precipitation (i.e., less than 10 percent change). The highest "no change" probabilities (0.6 to 0.7) were found in the "Same" Scenario; in other words, those who opted for no major temperature changes were, expectedly, the most confident that no major precipitation changes would occur. But even in the extreme warming and cooling scenarios, the aggregated responses indicated a probability of about 0.5 that the precipitation change would be less than 10 percent.

The aggregate responses of the panelists suggest that the highest probability (0.3 to 0.4) for an increase in *annual* precipitation would occur under a warming scenario, especially in the higher middle latitude and subtropical zones. Conversely, a decrease in precipitation was associated with the cooling scenarios. A number of respondents commented that this pattern seems reasonable, based on analogs of previous warm periods, as well as precipitation results from limited numerical experimentation with general atmospheric circulation models. But many panelists also noted the limited scientific basis for assessing the probabilities of precipitation changes under

Figure III-5

CHANGES IN PRECIPITATION AND PRECIPITATION VARIABILITY



The group of graphs on the left pertains to perceptions of changes by the year 2000 in mean annual and mean growing-season precipitation, for three zones of latitude, relative to the 1941-70 "normal" pattern (Question IV). The group on the right pertains to perceptions of changes over the next 25 years in the standard deviations of the volume of annual and growing-season precipitation, relative to the previous 25-year period (Question V). The probabilities of "significant" increases or decreases of the two parameters (at least 10% for volume of precipitation and 25% for the standard deviation) and probabilities of no significant change (less than 10% and 25%, respectively) are displayed in the format described for Figure III-4B.

alternative temperature scenarios. One panelist stated: "A careful answer to this question would require a detailed statistical study. Such a study could and should be done. To my knowledge it has not been done."

To summarize, amid the indications of collective uncertainty about the volume of *annual* precipitation, there was some tendency to associate significantly increased precipitation with the two warming scenarios and significantly decreased precipitation with the two cooling scenarios, except in the lower mid-latitudes, which exhibit a different pattern. In the latter zone, the probabilities of significant decreases were about 0.2 in each scenario. (In the other two bands of latitude, these probabilities show a regular diminution as one goes from large cooling to large warming.) Also, in the lower mid-latitudes there were somewhat higher probabilities of significant increases for the two cooling scenarios than in the other two zones of latitude.

The results on *growing-season* precipitation changes were similar to those for annual precipitation except in the lower mid-latitudes again. For these latitudes, the probabilities of significantly decreased precipitation are low but increase monotonically in going from large cooling to large warming, reaching 0.3 in the latter scenario. This unexplained behavior is the reverse of that for annual and growing-season precipitation in the other two zones of latitude.

For all five scenarios, the pattern of annual and growing-season precipitation probabilities is markedly similar in the subtropical and higher middle latitudes. If the departure of the lower mid-latitudes from this pattern is real, that is, if it reflects a tendency of nature to maldistribute changes in precipitation, then it may have some bearing on the question of precipitation variability.

Changes in Precipitation Variability

A number of prominent climatologists have stated that world weather patterns in the near future are very likely to be more unstable, more variable from year to year, or from one short period of years to the next. In an attempt to get some probabilistic estimate of likely changes in precipitation variability, the panelists were asked in Question V to provide, under alternative assumptions of temperature change, conditional probabilities of changes by the year 2000 in the standard deviation of annual and growing-season precipitation in three bands of latitude. The threshold for a significant change in variability was 25 percent of the standard deviations associated with the past 25 years.

It should be noted that many of the panelists again commented on the lack of sufficient actuarial experience, comprehensive theories, or adequate models to support their estimates. Given this caveat, the aggregate responses of the panelists indicated a relatively high probability (mostly on the order of 0.5 to 0.6 with a range from 0.4 to 0.7) that the change in the standard deviation of the mean annual precipitation would be less than 25 percent, irrespective of temperature trends. The second highest set of probabilities (on the order of 0.3 to 0.4) was assigned to a significant increase in precipitation variability under conditions of large cooling. The probabilities of significant decreases in variability do not exceed 0.2 except in most of the warming cases, for which they rise slightly but still remain less than 0.3. In the two warming scenarios, significant increases and significant decreases of precipitation variability are nearly equiprobable in the range of 0.2 to 0.3. In the two cooling scenarios, by contrast, the probabilities for significant increases of variability are higher than those for significant decreases by a factor of 1.5 to 2.0, but these probabilities are all less than 0.4 except for one case (growing-season precipitation in the subtropical latitudes).

Within each scenario, latitudinal differences in the probabilities of *annual* precipitation variability are negligible. In the case of *growing-season* precipitation, the probabilities for significantly increased variability grow slightly larger with descending latitude in each scenario, while the smaller probabilities for significantly decreased variability are about equal across the zones of latitude in each scenario.

Comparing the variabilities of annual and growing-season precipitation, one notes slightly higher probabilities for significantly increased variability of growing-season precipitation in the lower mid-latitudes from scenario to scenario. The same tendency is more marked in the subtropical latitudes.

The only obvious correlation between precipitation variability and trends in the volume of precipitation is a tendency to associate greater variability with the perception of decreased precipitation in the two cooling scenarios. There is a weaker tendency to associate decreased variability with increased precipitation in the two warming scenarios. These tendencies are manifested visually by the fact that the plots of the probabilities for changes in *annual* precipitation volume and variability are approximate reflections (mirror images) of each other in the three zones of latitude. This mirror-image relationship exists to a lesser degree between the plots for changes in *growing-season* precipitation volume and variability.

The collective uncertainties about precipitation variability that are apparent in the panelists' data are also evident in the verbal comments on Question V. Below are some paraphrases of these comments, which run the gamut of what could be said about variability:

- Less variability with warming
- More variability with cooling
- More variability, regardless of temperature change

- No radical changes expected
- No cause to believe anything about change in the variability of any meteorological element

Following are a few extracts from the actual comments about climatic variability in general and precipitation variability in particular. The first comment is by a panelist who said he had no basis for predicting even global temperature trends.

> A temperature change *per se* does not imply increased climatic variability. There is some physical basis for saying that a general cooling would imply increased baroclinic instability and therefore increased temperature variability and vice-versa. On the other hand, one might also expect general cooling to be associated with less atmospheric water vapor, a weaker hydrologic cycle, and reduced precipitation.

> The proposed associations between changes of temperature and of precipitation variability are difficult areas, on which the necessary knowledge is further from adequate than with the preceding questions. This produces the wide spread of probability assessments which I give for the higher middle latitudes. It may well be that the phasing of precipitation variability is more closely correlated with the periods of changing temperature than with the periods after a temperature anomaly has been established; if so, the precipitation variability is probably generally greatest during cooling periods and least during warming periods.

> The argument concerning variability over time derives primarily from the suggestion that variability seems to have been larger during periods of climatic deterioration, i.e., colder . . . Since my inference is for temperatures as warm, or warmer, than now by 2000, the precipitation variability should not tend to increase. Precipitation variability is likely to increase overall in association with decreasing amounts, especially for convective regimes.

> There seems to have been less variability during the 1945-60 period when it was warmer than average, but I do not know whether this can be attributed to the temperature regime or not. It seems intuitively reasonable that a decrease in the equator-pole temperature gradient could cause a more "summertime" condition and less variability due to baroclinic instabilities and blocking pressure patterns.

> . . . decreasing temperature trend will bring more variability, so the next 25 years in mid-latitudes should be noticeably more variable than the last 25. In the subtropics probably not as much.

The 1940-1970 period was unusually uniform in the perspective of the last century. There is thus a high probability of more variability regardless of temperature change . . . .

. . . I do not expect any radical changes. The variability is induced by extreme events. A single tropical storm rainfall influences standard deviations for a considerable interval.

. . . The standard deviation may not be a very good estimate of the sort of variability that might have practical implications. For example, probability of certain extreme events might be more important.

DROUGHT AND MONSOON FAILURE

The last comment in the preceding section suggests the examination of certain extreme events—drought and monsoon failure—in the context of climatic variability. Questions VI, VIII, and IX of Appendix A were concerned with mid-latitude drought, Asian monsoons, and Sahelian droug[illegible] respectively. In addition, Question VII (Outlook for 1977 Crop Yea[illegible] quantitative perceptions of the persistence of drought in the Unit[illegible] (see Appendix B).

Mul[illegible] a severe droughts do not lend themselves to discussion in strict term[illegible] of interannual climatic variability. Nevertheless, in a broader sense, dro[illegible] and monsoon failure are indicators of climatic variability insofar as they are manifestations of spatial and temporal fluctuations in precipitation.

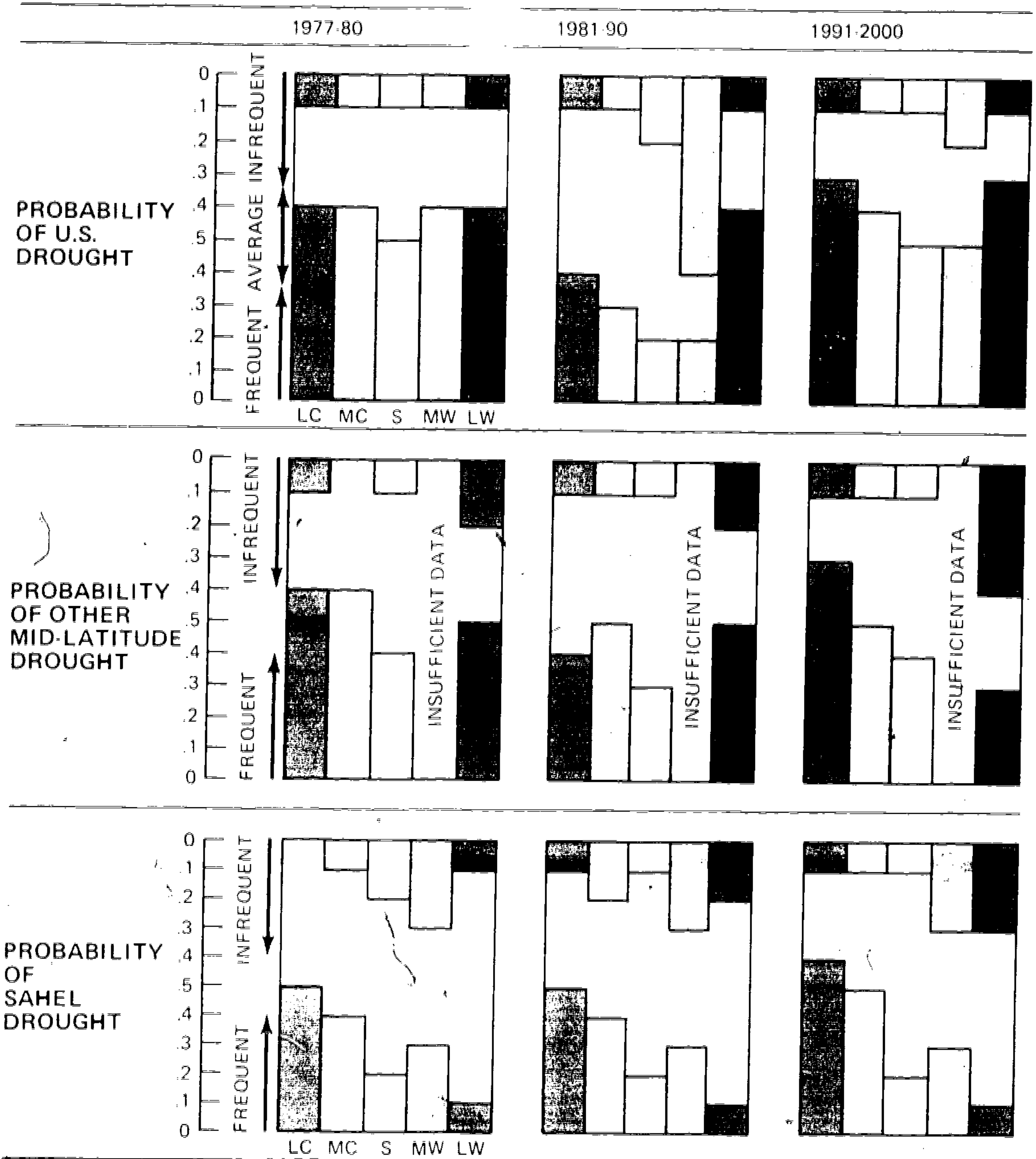
U. [illegible]nd Other Mid-Latitude Drought

The approach in Question VI was to ask the panelists for probabilities of the frequency of drought in the United States and other mid-latitudes. "Dro[illegible]nt" was defined on a one-year basis in terms of crop yields: "A combination of temperature and precipitation over a period of several months leading to a reduction in yield of the major crops to a level less than 90 percent of the yield expected with temperature/precipitation near the long-term average values."* "Frequent" drought was defined as "similar to early to mid-1930's and early to mid-1950's," "infrequent" drought as "similar to 1940's and 1960's," and "average" drought as "similar to the frequency over the longest period of record available." Judgments on the occurrence of drought were asked for each of the time periods 1977-80, 1981-90, and 1991-2000.

*As noted in the footnote to Question VI, there is almost an infinite number of definitions of drought, none of which are completely satisfactory.

Figure III-6

PROBABILITY OF DROUGHT



The top two rows summarize the aggregated responses to Question VI (Mid-Latitude Drought). The bottom row does the same for Question IX (Sahel Drought). For each time period, the vertical bars reading from left (Large Cooling) to right (Large Warming) correspond to the five climate scenarios. For each scenario and time period, the probabilities of "frequent" and "infrequent" drought are given, respectively, by the heights of the lower bar and the upper bar. The height of the blank space between these two bars measures the probability of "average" drought.

Analysis of the panelists' probability estimates (Figure III-6) of the frequency of drought occurrences in the United States during the next 25 years suggests fairly strong support—although by no means unanimous—for a quasi-20-year periodicity, but the cause of this periodicity was clearly in dispute among the panelists. Thus, in all the scenarios the probabilities of "frequent" U.S. droughts are fairly high (0.5 to 0.7) for the first and third periods—1977-80 and 1991-2000. By contrast, the combined probabilities of "average" and "infrequent" U.S. droughts are high (0.6 to 0.8) in the intervening 1981-90 period, except in the Large Warming Scenario. One panelist who strongly supported this scenario gave for each of the three time periods probabilities of 0.6 to 0.7 for "frequent" U.S. droughts, reasoning that 4,000 to 8,000 years ago "when the earth was generally a few degrees warmer than now . . . it was markedly more rainy in the subtropics and also rainier at mid-latitudes in some regions but drier in others. It is notable that in the central United States, in the lee of the Great Divide, it was generally drier and the prairie extended nearly to the Appalachians."

For mid-latitude regions other than the United States, data on the expected frequency of drought are incomplete, and the responses suggest more uncertainty and somewhat less support for the quasi-20-year periodicity than was evident for the United States. The explanatory comments by some of the panelists specifically noted that the pattern of repetition is not the same for all mid-latitude regions. Looking at the probabilities for the terminal 1991-2000 period (Figure III-6) one sees an association of more frequent droughts with the two cooling scenarios and a slight tendency toward more infrequent droughts in the Large Warming Scenario. These associations are consistent with and somewhat stronger than the previously discussed perceptions that global cooling will tend to be accompanied by drier conditions and greater precipitation variability, while global warming will tend to be accompanied by the opposite precipitation conditions.

Below are some of the panelists' comments on the estimation of drought frequency in the United States and other mid-latitude regions. These comments reflect considerable credence in cyclic droughts, but not necessarily in a connection of the cycles with solar activity.

> . . . I am not convinced that a solar-drought effect has been demonstrated.

> . . . I think that the evidence is mounting that there is a 22-year cycle in droughts and that it is related to sunspot activity. However, predictions of the relative intensity and regional distribution patterns lie beyond our scientific knowledge.

> While I do not believe that sunspots are related to drought, there is a statistical behavior of drought that suggests a pattern of repetition . . .

Droughts seem to be related to solar influences . . . Power spectrum analysis shows a very notable 22-year rhythm and a weak one near 11 years.

. . . I feel confident in saying that the risk of drought in the mid-latitude tends to wax and wane quite appreciably in a 20-year cycle. This judgment on my part is the basis for the rather wide swings of probability shown in the table . . .

The 20-year periodicity seems to be a well-documented climatic feature, not only as to Midwestern U.S. droughts, but also in North American winter temperatures, English summer temperatures, and polar mean temperatures. The expected warming towards the end of the century would seem to increase the probability of drought.

. . . The evidence seems to suggest that there is some rough 20- to 22-year periodicity in droughts in various parts of the High Plains, but that both the length and location of these droughts varies considerably . . . There is less known about the periodicity in other locations than the High Plains, and in fact, the whole issue of 22-year drought may be nothing more than a statistical coincidence at one location on earth. I do not believe that the sunspot hypothesis is demonstrated, because there is insufficient physical and statistical evidence to lead to that certainty. Yet, I think it is intriguing and one that requires considerable persistent study to look for possible causal links.

There appear to be quasi-periodic recurrences of drought in many mid-latitude areas—U.S. High Plains, 20 years and South Africa, 20 years—although physical explanations are not yet forthcoming.

I am extrapolating the 20 to 25-year cycle in spite of the fact that we do not understand it (and I do not subscribe to the sunspot theory) . . .

Other panelists alluded to specific mechanisms and other factors as the bases for their probabilities of mid-latitude droughts:

. . . I would assume that a strongly meridional circulation would continue into part of the 1980's, bringing few droughts to the United States and mo[illegible] other mid-latitudes. By the 1990's, the circulation may well revert to [illegible] zonality, with more frequent droughts in the United States and fewer droughts in the more zonally patterned regions, e.g., Europe, USSR, and China.

I cannot put meaningful figures here without making latitude, meridian, and recurrence distinctions, i.e., your term "frequent" applies rather to recurrent persistence in certain regions (e.g., our Midwest) but at the same time persistent absence in other regions (e.g., our East Coast). In North

America, drought prevalence correlates highly negatively between East Coast and Central Plains by decades.

The quasi-20-year periodicity (which I do not think attributable to the solar cycle) is treated as best established and most important in the United States. In the United States, as elsewhere in middle latitudes, the drought frequency seems to me likely to remain higher than in the early part of the century owing to a longer-term increase of "blocking" frequency, which I associate with the present tendency of the natural climate towards Northern Hemisphere (and low latitudes) cooling.

Two panelists who did not furnish numerical estimates for Question VI made the following comments:

I have no way of estimating the frequency of droughts except from a frequency distribution, which varies from one region to another.

I know of no basis for answering the question. Certain statistical facts could be determined from past records, but to my knowledge this has not been done. It could most easily be done for the USA and Europe; data elsewhere may be hard to assemble. The statistics . . . would give an "average" drought frequency (and range) but would provide no basis for different estimates in the three [time] periods.

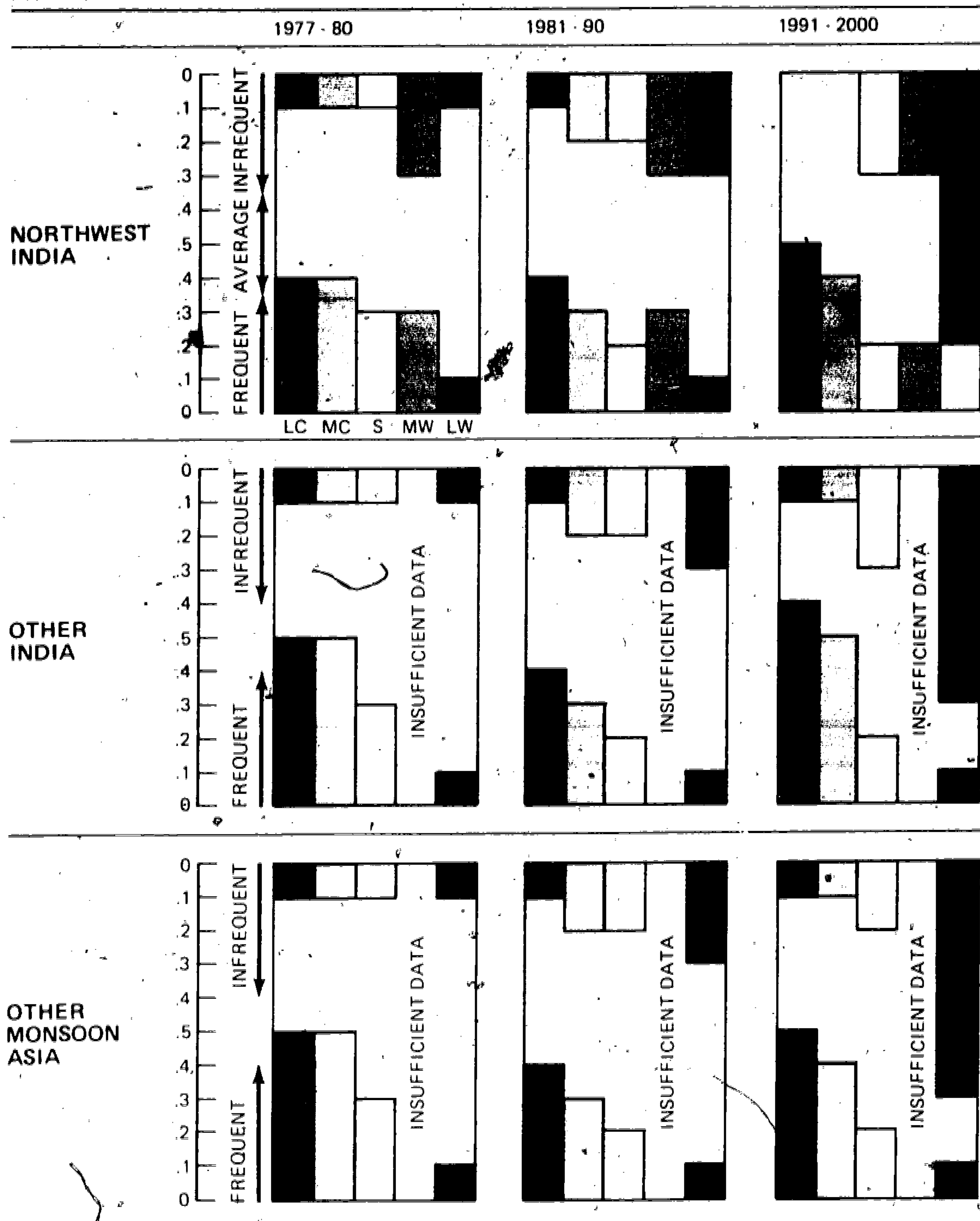
Sahelian Drought and Failure of Asian Monsoons

Questions VIII and IX, on Asian monsoons and drought in the Sahel, used the same approach as Question VI (Mid-Latitude Drought), with appropriate changes in the definitions of "frequent," "average," and "infrequent." Monsoon failure and Sahelian drought were implicitly defined in terms of the reference periods used to specify the three levels of frequency. About as many panelists provided numerical estimates on the Sahel as did on mid-latitude drought, but fewer responded on monsoon failure. One panelist who did venture an estimate on monsoons commented that "for other than monsoon scholars, this is a real guessing game."

In Figures III-6 and III-7, the panelists' probability estimates of the frequency of drought in the Sahel or failure of the Asian monsoons do not show the periodic pattern that was indicated for the United States. In general, the panelists' comments on Questions VIII and IX reflected a consistency with their rationales for responses on other climatic elements. Thus, one sees, especially for the 1991-2000 period, the previously noted general tendency to associate dry and more variable ("frequent" Sahelian droughts and monsoon failures) with global *cooling*, and a weaker tendency to associate wet and less variable ("infrequent" Sahelian droughts and monsoon failures) with global *warming*. These generalizations about Figures

Figure III-7

PROBABILITY OF MONSOON FAILURE



These graphs summarize the aggregrated responses to Question VIII (Asian Monsoons). For each time period, the vertical bars reading from left (Large Cooling) to right (Large Warming) correspond to the five climate scenarios. For each scenario and time period, the probabilities of "frequent", "infrequent", and "average" monsoon failures are displayed in the format of Figure III-6.

III-6 and III-7 are subject to obvious exceptions and to almost complete uncertainty in the Moderate Warming Scenario. In this scenario, there were either insufficient data to warrant processing or virtually equal probabilities for "frequent," "average," and "infrequent" occurrences of Sahelian drought and monsoon failures.

CONCLUSIONS ON CLIMATIC VARIABILITY

The five climate scenarios and associated data in Chapter II bear out and partially quantify climatologists' conflicting perceptions of global temperature and precipitation *trends.* Less evident is the degree to which the climate scenarios and data support the more commonly accepted view that the earth may be in for a period of increased climatic *variability*, whatever the temperature trend.

Given the climate panelists' diverse comments about variability and some tendency to associate greater variability of precipitation and length of growing season with global cooling, but less variability with warming, it cannot be said that the responses to the climate questionnaire corroborate the existence of general agreement about the onset of increased climatic variability. As partial reflections of the panelists' perceptions of future climate, these data could not provide direct, quantitative evidence of increasing climatic variability. The direction and magnitude of trends are obviously in dispute. The nature and extent of future climatic variability are more obscure and hence less amenable to quantification. It may be that the panelists were unaccustomed to thinking about variability in terms of the standard deviation (for which, in any case, historical data are not generally available). On the other hand, the cutoffs for a "significant" change in variability (±25 percent of the standard deviation) may have been too high. That is, a lower cutoff might have elicited higher probabilities of still significant variability.

One climatologist who reviewed the climate scenarios has an interesting conjecture about the tendency of the panelists not to predict significant changes in climatic variability. The conjecture is that some respondents may perceive that the world has already entered a period of increased variability, and, for that reason, do not expect any further major increase in the next 25 years. This conjecture may be tenable for Question X on growing seasons, where the panelists were to compare future variability with that of the "present." It is less tenable for Question V on precipitation variability, where the climatologists were asked to reference their estimates to the previous 25-year period.

One panelist pointed out the importance of distinguishing climate variability and fluctuations with respect to different time scales:

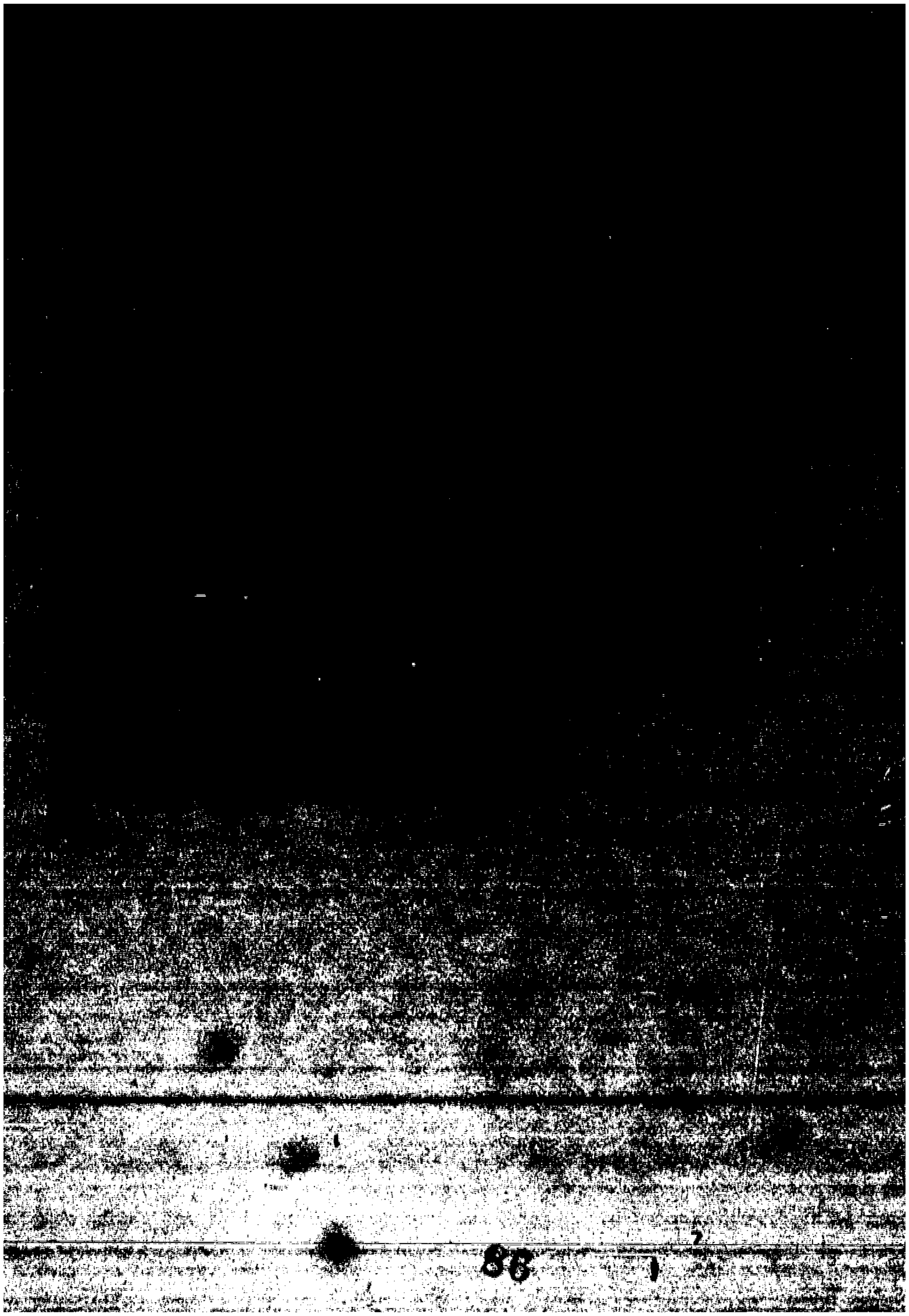
> There are two pertinent time ranges of variability, between weeks, months, and seasons within the year (like the temperature and rainfall extreme variations of the past year—severe droughts of a season or two, reversing the next year, what I call hit-and-run droughts, which pertain to shifting of the wave pattern in strong zonal circulation), and long-term droughts over periods of years (like our Midwest droughts of the 1930's and 1950's which go with weak zonal circulation or strong blocking patterns—strong nonseasonal systems—persisting from year to year). I feel that at the present time the westerlies are shifting from the higher middle towards lower middle latitudes, bringing with them more of the temporary but severe hit-and-run type of drought and severe cold (probably early and late killing frosts), whereas the higher middle latitudes (particularly Canada) from which the westerlies are being displaced, and the subtropical latitudes (from which the subtropical high tends to displace the tropical easterly rainbelt) are likely to suffer increased incidence of the long-term type of drought and cold (Canada) and heat (subtropics). Thus, I find Question V hard to answer, but I have done so specifically with respect to the short-term month-to-month type of variability, the hit-and-run variety which is reflected in the length of the growing season.

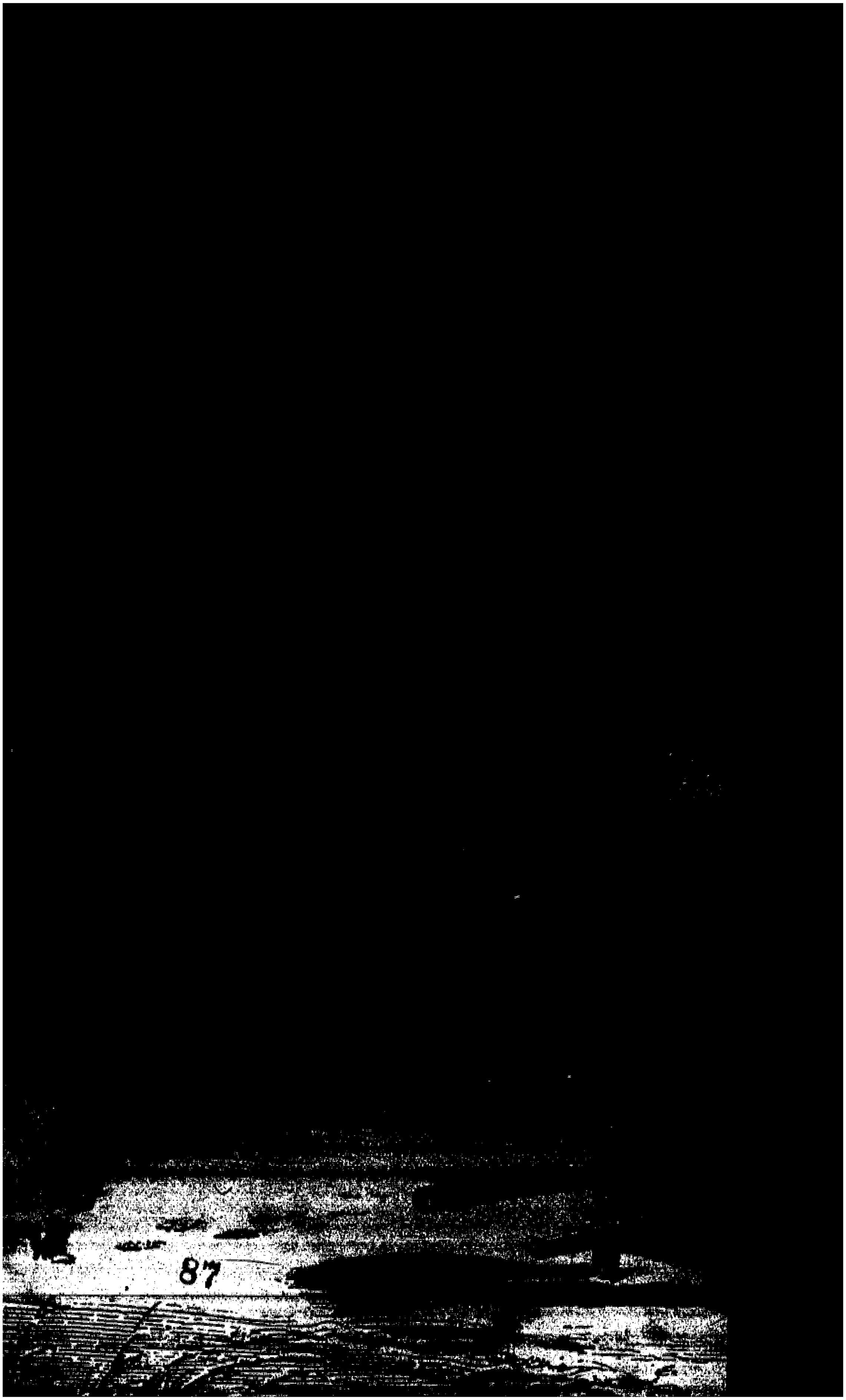
Another respondent questioned use of the standard deviation in certain areas:

> The standard deviation is not an adequate measure of variability where there is zero or near-zero precipitation. In semi-arid climates (and much of the world's grain fields have a semi-arid climate) the frequency distribution of the precipitation is very skewed . . . and other measures, e.g., Maunder's index of variability should be used.

Along this line of using other measures to get more directly at the impact of climate fluctuations, one recalls the panelist who commented (page 51) that the probability of certain extreme events might be more important than the standard deviation in estimating the sort of variability which has practical implications. The latter panelist also pointed out a serious difficulty in dealing with any aspect of future climate by observing that "future climatic changes, especially if related to human activities, need not follow the same probabilities as in the past."

Given the generally accepted economic, social, and political importance of climatic fluctuations and variability, additional efforts should be made to develop methodologies that can quantify climatologists' perceptions of past, current, and future climatic variability. Such efforts could shed light on the research needed to clarify what nature will do, as contrasted to what certain experts believe it will do.

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APPENDIX A
CLIMATE QUESTIONNAIRE

INSTRUCTIONS FOR QUESTIONS

A. Attached is a set of 10 major questions, some of which have several parts. The timespan for the questions varies from the relatively near term (the outlook for the 1977 crop season) to the climate by the end of this century. All individual answers will be held in strict confidence. The aggregation and quantitative analysis of the responses will be made available to all participants and will be included in the final report.

We would appreciate your answering all of the questions in their present form. Your subjective responses may be used to generate another set of questions and to build a set of future climate scenarios. If, in reviewing and answering these questions, you feel strongly that a particular question should be rephrased or additional questions included, you are invited to add your comments or additional questions on extra pages.

B. In questions referring to latitudinal belts, the following definitions apply:

POLAR latitudes	65° to 90°
MIDDLE latitudes	30° to 65°
—Higher middle	45° to 65°
—Lower middle	30° to 45°
SUBTROPICAL latitudes	10° to 30°

C. For each of the 10 major questions, using the self-rating definitions provided below, please indicate your level of substantive expertise.

D. Please identify those other respondents whom you would rank as EXPERT (5) or QUITE FAMILIAR (4) in responding to each of the questions.

E. Guidance for self-ranking expertise:

(5) EXPERT—You should consider yourself an *expert* if you belong to that small community of people who currently study, work on, and dedicate themselves to the subject matter. Typically, you know who else works in this area; you know the US and probably the foreign literature; you attend conferences and seminars on the subject, sometimes reading a paper and sometimes chairing the sessions; you are most likely to have written up and/or published the results of your work. If the National Science Foundation, National Academy of Sciences, or a similar organization were to convene a seminar on this subject, you would expect to be invited, or, in your opinion, you should be invited. Other experts in this field may disagree with your views but invariably respect your judgment; comments such as "this is an excellent person on this subject" would be typical when inquiring about you.

INSTRUCTIONS FOR QUESTIONS (Continued)

(4) QUITE FAMILIAR—You are *quite familiar* with the subject matter either if you were an expert some time ago but feel somewhat rusty now because other assignments have intervened (even though, because of the previous interest, you have kept reasonably abreast of current developments in the field); or if you are in the process of becoming an expert but still have some way to go to achieve mastery of the subject; or if your concern is with integrating detailed developments in the area, thus trading breadth of understanding for depth of specialization.

(3) FAMILIAR—You are *familiar* with the subject matter if you know most of the arguments advanced for and against some of the controversial issues surrounding this subject, have read a substantial amount about it, and have formed some opinion about it. However, if someone tried to pin you down and have you explain the subject in more depth, you would soon have to admit that your knowledge is inadequate to do so.

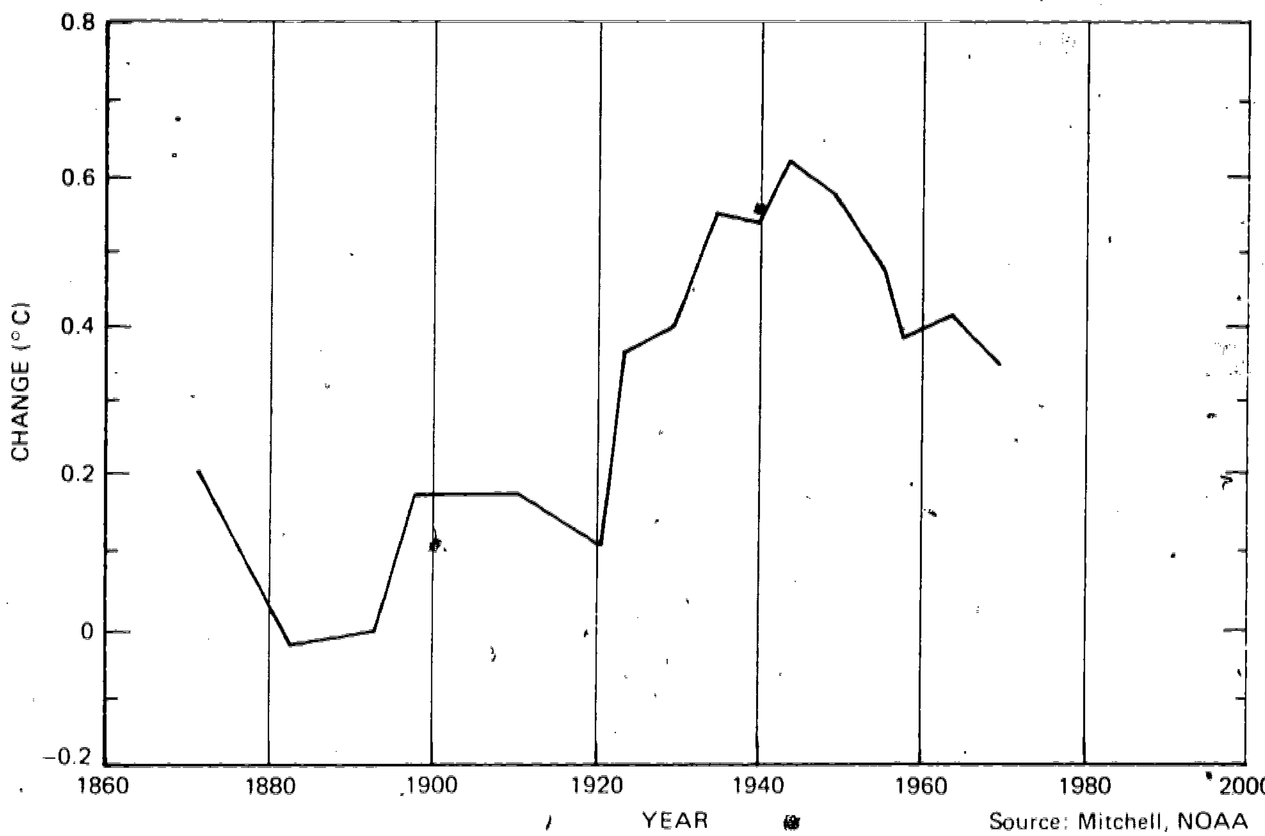
(2) CASUALLY ACQUAINTED—You are *casually acquainted* with the subject matter if you at least know what the issue is about, have read something on the subject, and/or have heard a debate about it on either a major TV or radio network or an educational channel.

(1) UNFAMILIAR—You are *unfamiliar* with the subject matter if the mention of it encounters a veritable blank in your memory or if you have heard of the subject, yet are unable to say anything meaningful about it.

I. GLOBAL TEMPERATURES

Shown below is a historical record of changes in the annual mean temperature during the past century for the latitude band, 0-80° N.

CHANGE (°C) IN ANNUAL MEAN TEMPERATURE, 0-80 ° N. LATITUDE



Source: Mitchell, NOAA

On the graph shown above, indicate your estimate of the general future course of the change in mean annual temperature (for 0-80° N. Lat.) to the year 2000 by:

- drawing a temperature change path to the year 2000 so that you estimate only 1 chance in 10 that the path could be even lower
- drawing a change path to the year 2000 so that you estimate an even chance that the path could be either lower or higher
- drawing a change path to the year 2000 so that you estimate 1 chance in 10 that the path could be higher

CLIMATE QUESTIONNAIRE

I. GLOBAL TEMPERATURES

In the space below, state your line of reasoning for the family of lines you have drawn, referencing if you wish, articles you or other scientists have written that clearly state your position on this subject.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5—4—3—2—1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

II. TEMPERATURE

Please fill in each block of the matrix below with your estimate of the probability of the change (°C) in the annual temperature by the year 2000, as compared with 1970-75, for the regions shown.

PROBABILITY OF TEMPERATURE CHANGE (°C)

	Cooling		"No Change"		Warming		Total Probability
	More than 1.0° Cooler*	0.5° to 1.0° Cooler	0° to 0.5° Cooler	0° to 0.5° Warmer	0.5° to 1.0° Warmer	More than 1.0° Warmer*	
No. Hem. polar latitudes							1.0
No. Hem. higher mid latitudes							1.0
No. Hem. lower mid latitudes							1.0
No. Hem. subtropical latitudes							1.0
So. Hem. subtropical latitudes							1.0
So. Hem. lower mid latitudes							1.0
So. Hem. higher mid latitudes							1.0
So. Hem. polar latitudes							1.0

*If you judge that there is a significant probability that the temperature change in some latitudinal belt may exceed 1.0° (either cooler or warmer), please indicate the level of change expected along with the probability estimate.

II. TEMPERATURE

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

III. CARBON DIOXIDE, TURBIDITY, AND CLIMATE

Carbon dioxide, atmospheric particles, etc., have different effects on the atmosphere and do not have the same relative importance in their influence. Indicate the relative weight (using percentages) of each of the factors identified below in influencing global climate over the next 25 years.

		Relative Weight (Percentage)
A.	Carbon Dioxide	________
B.	Fluorocarbons and other gases	________
C.	Smoke	________
D.	Volcanic dust	________
E.	Other Particles (aerosols)	________
		Sum: 100%

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III. CARBON DIOXIDE, TURBIDITY, AND CLIMATE

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

  5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

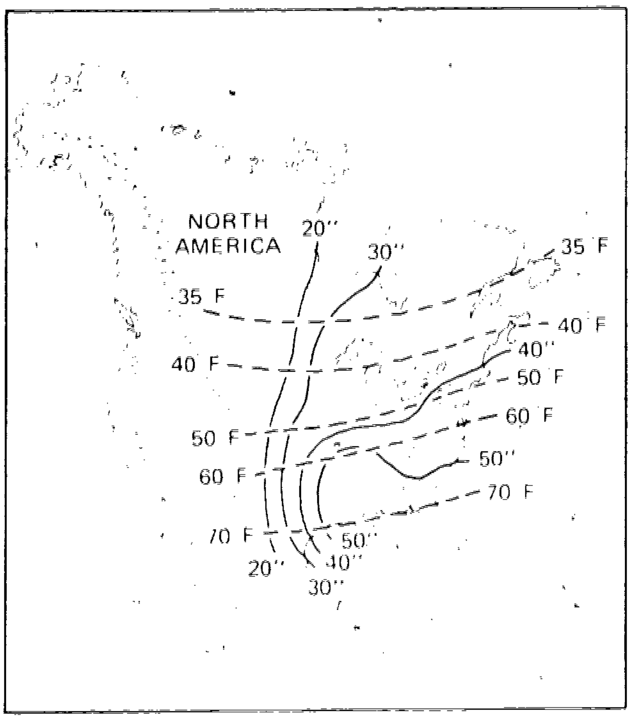
  EXPERT (5) QUITE FAMILIAR (4)

IV. PRECIPITATION

1. Under the alternative assumptions of a temperature change as shown, please fill in each block of the following matrix with your estimate of the probability of change in the mean annual precipitation by the year 2000, as compared with the 1941-70 "normal" pattern, for the regions shown.

2. In your judgment, would these probability estimates be equally as valid for growing season precipitation as for annual totals? (yes ☐; no ☐) If not, please indicate the appropriate probability estimates for changes in growing season precipitation.

3. In many parts of the earth the annual isotherms and annual isohyets tend to run parallel to each other. In North America, however, as Newman and Pickett describe in a 6 December 1974 *Science* article, the effect of the Rocky Mountains range causes the annual isotherms and isohyets to run at approximately 90° to each other, particularly in the midcontinental grasslands region. (See their map, below.) South America is similar to North America in this respect due to the Andes. Newman and Pickett note that:



In terms of agricultural production, these climatic features give an advantage to the New World continents. The mean annual isotherms and isohyets, because they are not parallel in the vast grassland climatic areas of the Americas, allow a favorable water balance to be extended over very broad areas in the north-south direction. Also, they allow for agricultural production areas to be less stratified in a north-south direction than they are in the Eurasian continent, and ensure against a slight mean seasonal shift in the prevailing westerly flow; thus, they reduce climatic risk.

Would these characteristics of the Western Hemisphere region significantly alter your estimates of probability of precipitation change as given in parts 1 and 2 above? If your estimates for North and South America are significantly different from those of the broad latitudinal bands, please indicate the magnitude of these differences in the comments at the end of this question.

PROBABILITY OF PRECIPITATION CHANGE

	Increase by 10% or more*		"No Change" (Less than ± 10%)		Decrease by 10% or more*		Total Probability	
	Annual	Growing Season	Annual	Growing Season	Annual	Growing Season	Annual	Growing Season
Assuming temp. increase of 0.5°C or more								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0
Assuming temp. change of less than ±0.5°C								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0
Assuming temp. decrease of 0.5°C or more								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0

*If you judge that there is a significant probability that the precipitation change in some latitudinal belt may exceed 10% (increase or decrease), please indicate the level of precipitation change expected along with the probability estimate; also, if the temperature change assumed exceeds 1.0°C, please so indicate.

IV. PRECIPITATION

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

V. PRECIPITATION VARIABILITY

The report of a climate/food conference in Bellagio, Italy, in June 1975 includes this statement:

> *....Temperature change* per se *is not the most serious potential climatic threat to food production. There is a possiblity that, associated with the temperature changes, there will be increased climatic variability. Particularly as such variability increases the fluctuations of precipitation, it poses threats to agricultural production.*
>
> *The climatologists participating in the conference agreed that:*
>
> *1. Climatic variability—region by region and from year to year in particular regions—is and will continue to be great, resulting in substantial variability in crop yields in the face of increasing global food needs and short supplies;*
>
> *2. There is some cause to believe—although it is far from certain—that climatic variability in the remaining years of this century will be even greater than during the 1940-1970 period.*

1. Under the alternative assumptions of temperature change as shown, please fill in each block of the matrix below with your probability estimate that the standard deviation of the mean annual precipitation will change by the indicated amount over the next 25 years, as compared with the average for the previous 25-year period.

2. In your judgment, would these probability estimates be equally as valid for variability in growing season precipitation as for annual totals? (yes ☐; no ☐) If not, please indicate the appropriate probability estimates for changes in variability of growing season precipitation.

3. As noted in part 3 of Question IV above, mountain ranges in North and South America cause the annual isotherms and isohyets to run at approximately 90° to each other in major regions of these continents. If, because of these characteristics, your estimates of the probability of change in precipitation variability in North and South America are significantly different from those of the broad latitudinal bands, please indicate the magnitude of these differences in the comments at the end of this question.

PROBABILITY OF CHANGE IN PRECIPITATION VARIABILITY

	Increase in s.d. by 25% or more*		Less than ± 25% change in s.d.		Decrease in s.d. by 25% or more*		Total Probability	
	Annual	Growing Season	Annual	Growing Season	Annual	Growing Season	Annual	Growing Season
Assuming temp. increase of 0.5° or more								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0
Assuming temp. change of less than ± 0.5° C								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0
Assuming temp. decrease of 0.5° C or more								
higher mid-latitudes							1.0	1.0
lower mid-latitudes							1.0	1.0
subtropical latitudes							1.0	1.0

*If you judge that there is a significant probability that the change in standard deviation may exceed 25% (increase or decrease), please indicate the level of the change expected along with the probability estimate; also, if the temperature change assumed exceeds 1.0°C, please so indicate.

V. PRECIPITATION VARIABILITY

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

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VI. MID-LATITUDE DROUGHT

At a 1975 climatic change symposium at the University of North Carolina, Hurd Willett briefly described the drought pattern of the 1930-1970 period as follows:

> *The warm decade of the thirties witnessed the most severe droughts of the century, in the early to mid-thirities, in many regions of the 35°-50° latitude belt, notably the dust bowl in our western plains, the Russian droughts that triggered liquidation of the Kulaks, severe drought in southern Australia, and in other parts of the world. Note that these droughts occurred in marginal midcontinental as opposed to east coastal regions.*
>
> *The forties were in general a decade of generous rains in the drought regions of the thirties, but with a tendency to substantial deficiency in east coastal regions.*
>
> *The early to mid-fifties, like the thirties, were a markedly dry period in the marginal interior continental regions, notably the American southwestern plains. Severe drought was restricted to latitudes equatorward of 40°. Again, there was a notable tendency to east coastal wetness.*
>
> *The sixties were, like the forties, a decade of generous rainfall in the marginal interior continental regions of middle latitudes, but with some record dry years in extensive east coastal regions. During the sixties and early seventies, the development of severe drought occurred in the middle and lower subtropics, notably in southern Asia and Africa (Sahelian area).*

Willett relates the drought occurrences to a solar-climatic hypothesis of climatic fluctuation, based on an observed relationship between solar and climatic cycles, but recognizing that quantitative physical explanations are as yet nonexistent.

1. With this statement as background, plus your own knowledge and interpretation of past events, please fill in each block of the matrix below with your estimate of the probability of frequency of drought occurrence, for global mid-latitude continental areas.

2. Would your estimates for the United States be significantly different from other mid-latitude continental areas? (yes ☐; no ☐) If so, please indicate probabilities separately for US and other mid-latitudes.

VI. MID-LATITUDE DROUGHT

FREQUENCY OF DROUGHT*

Time period	"Frequent"-i.e., similar to early to mid-1930's and early to mid-1950's		"Average"-i.e., similar to the frequency over the longest period of record available		"Infrequent"-i.e., similar to 1940's and 1960's		Total Probability	
	US	Other mid-latitudes	US	Other mid-latitudes	US	Other mid-latitudes	US	Other mid-latitudes
1977 to 1980							1.0	1.0
1981 to 1990							1.0	1.0
1991 to 2000							1.0	1.0

*There are almost an infinite number of definitions of drought, none of which are completely satisfactory. Drought is defined here as in the December 1973 report to the Administrator of NOAA, *The Influence of Weather and Climate on United States Grain Yields: Bumper Crops or Droughts*: "A combination of temperature and precipitation over a period of several months leading to a reduction in yield of the major crops to a level less than 90% of the yield expected with temperature/precipitation near the long-term average values." It should be recognized, however, that yields usually are quoted on a harvested acre basis. In drought years there tends to be a much larger abandonment of crops as well as some deviation in expected yield.

VI. MID-LATITUDE DROUGHT

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5—4—3—2—1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

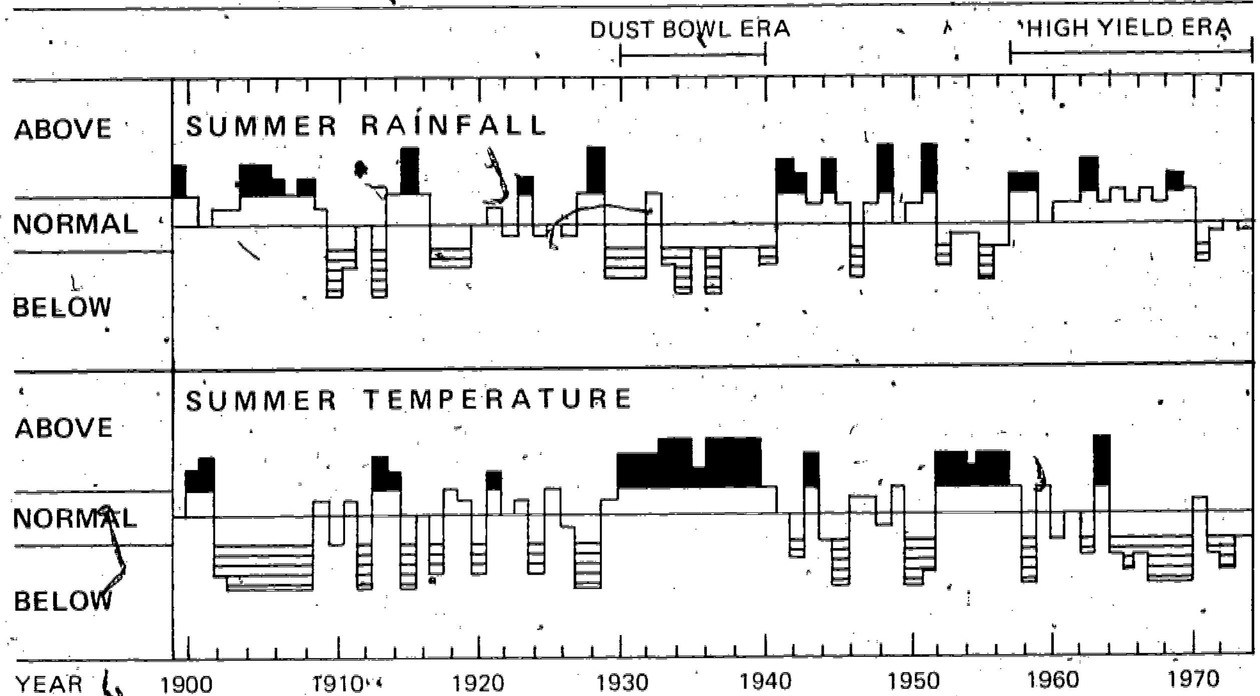
EXPERT (5) QUITE FAMILIAR (4)

VII. OUTLOOK FOR 1977 CROP YEAR

The high plains of the United States (that area approximately 400 miles wide, centered on 101° west longitude from Mexico to Canada) has experienced lower than normal precipitation and attendant drought conditions approximately every 20 to 22 years, i.e., the 1930's, mid-1950's.

The chart below shows the 75-year record of summer average temperature and rainfall in the five major wheat producing states of the United States. The drought period of the 1930's dust bowl and the generally favorable conditions after the late 1950's show clearly.

FIVE "WHEAT BELT" STATES (Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota)



Source: D. Gilman, NOAA

Low soil moisture levels in a number of states in the US wheat and corn belts this past fall and winter have raised considerable concern over prospects for the 1977 harvest.

1. With the above information as background plus any supportive evidence or hypotheses you may have developed as aids in forecasting, please fill in each block of the following matrix with your probability estimate of weather conditions to be expected in 1977 that would result in the yield changes indicated.

VII. OUTLOOK FOR 1977 CROP YEAR

Probability of Yield Change Due to Weather (Relative to Recent Trend Levels)

	Decrease[1] more than 15%	*Decrease 10% to 15%*	*Decrease or increase less than 10%*	*Increase more than 10%*	*Total Probability*
US winter wheat belt[2]	______	______	______	______	1.0
US spring wheat belt[3]	______	______	______	______	1.0
US corn belt[4]	______	______	______	______	1.0

[1] Implies drought conditions similar to the 1930's.

[2] Six states — Missouri, Nebraska, Kansas, Oklahoma, Texas, and Colorado—account for about 50 percent of winter wheat production and have the most variable yields. The 1976 total US winter wheat yield was almost 32 bushels per acre, or about 8% below an estimated trend (1950-1976) value. In the 1970-76 period, the maximum deviations from that 1950-1976 trend line were +11% in 1971 and -12% in 1974.

[3] Five states —Minnesota, North Dakota, South Dakota, Montana, and Idaho—account for about 90 percent of spring wheat production. The 1976 total US spring wheat yield was 27 bushels per acre, or about 7% below an estimated trend (1950-1976) value. In the 1970-76 period, the maximum deviations from that 1950-1976 trend line were +17% in 1971 and -20% in 1974.

[4] Nine states —Ohio, Indiana, Illinois, Minnesota, Iowa, Missouri, Nebraska, South Dakota, and Wisconsin—account for about 80 percent of corn production. The 1976 total US corn yield was 87 bushels per acre, or about 5% below an estimated trend (1950-1976) value. In the 1970-76 period, the maximum deviations from that 1950-76 trend line were +15% in 1972 and -20% in 1974.

2. Should a severe drought occur in 1977, similar to the early to mid-1930's, what is the probability that it will persist for:

		Probability
(a)	less than 2 years	______
(b)	2 but less than 4 years	______
(c)	4 years or more	______
		1.0

VII. OUTLOOK FOR 1977 CROP YEAR

3. There appears to be a correlation with high plains drought conditions and solar activity, i.e., the double or 22-year sunspot cycle, although as Walter Orr Roberts noted in congressional testimony in May 1976, "There is no plausible explanation of how this [sunspot activity] could affect the weather of the high plains." Roberts also commented that "Most of the world's droughts, however, show no recognizable recurrence pattern. They appear to occur at random in time and location, though they often persist for five years or more in a given region." Would you expect to find a correlation between drought conditions and solar activity on a global basis similar to that which appears to have been identified for the US high plains? (yes ☐; no ☐) Please amplify your answer if you desire.

4. In view of the dry conditions noted above in parts of the United States and the resultant concern over prospects for US crops this year, plus the generally less than optimum level of world grain reserves, the prospects for harvests in other major grain producing areas of the world are also of concern.

Based on any evidence available to you on current conditions, or hypotheses you may have developed as aids in forecasting, please fill in the following tables with your probability estimates of weather conditions to be expected in 1977 that would result in the total grain yield changes indicated for the given countries.

A. **USSR**: Probability of total grain yield change due to weather (relative to recent trend levels)

		Probability
(a)	Decrease more than 20%[1]	______
(b)	Decrease 10% to 20%	______
(c)	Decrease or increase less than 10%	______
(d)	Increase more than 10%	______
		1.0

[1] Implies severe drought conditions similar to those in 1963, 1965, and 1975. For total Soviet grain yields in the 1970-76 period, the maximum deviations from a 1950-1976 trend line were +22% in 1973 and -28% in 1975.

VII. OUTLOOK FOR 1977 CROP YEAR

B. INDIA: Probability of total grain yield change due to weather (relative to recent trend levels)

		Probability
(a)	Decrease more than 10%[1]	____
(b)	Decrease 5% to 10%	____
(c)	Decrease or increase less than 5%	____
(d)	Increase more than 5%	____
		1.0

[1] Implies drought conditions similar to or even more severe than in 1957, 1965, and 1966. For total Indian grain yields in the 1970-76 period, the maximum deviations from a 1950 - 1976 trend line were +8% in 1972 and about -7% in 1974 and 1976.

C. CANADA: Probability of total grain yield change due to weather (relative to recent trend levels)

		Probability
(a)	Decrease more than 25%[1]	____
(b)	Decrease 10% to 25%	____
(c)	Decrease or increase less than 10%	____
(d)	Increase more than 10%	____
		1.0

[1] Implies drought conditions similar to or even more severe than in 1961. For total Canadian grain yields in the 1970-76 period, the maximum deviations from a 1950 - 1976 trend line were +14% in 1970 and -16% in 1974.

D. AUSTRALIA: Probability of total grain yield change due to weather (relative to recent trend levels)

		Probability
(a)	Decrease more than 25%[1]	____
(b)	Decrease 10% to 25%	____
(c)	Decrease or increase less than 10%	____
(d)	Increase more than 10%	____
		1.0

[1] Implies drought conditions similar to or even more severe than 1957 and 1972. For total Australian grain yields in the 1970-76 period, the maximum deviations from a 1950--1976 trend line were +10% in 1974 and -27% in 1972.

VII. OUTLOOK FOR 1977 CROP YEAR

E. **ARGENTINA:** Probability of total grain yield change due to weather (relative to recent trend levels)

		Probability
(a)	Decrease more than 15%[1]	____
(b)	Decrease 10% to 15%	____
(c)	Decrease or increase less than 10%	____
(d)	Increase more than 10%	____
		1.0

[1] Implies drought conditions similar to or even more severe than in 1968. For total Argentine grain yields in the 1970-76 period, the maximum deviations from a 1950-1976 trend line were +14% in 1974 and -14% in 1972.

VII. OUTLOOK FOR 1977 CROP YEAR

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

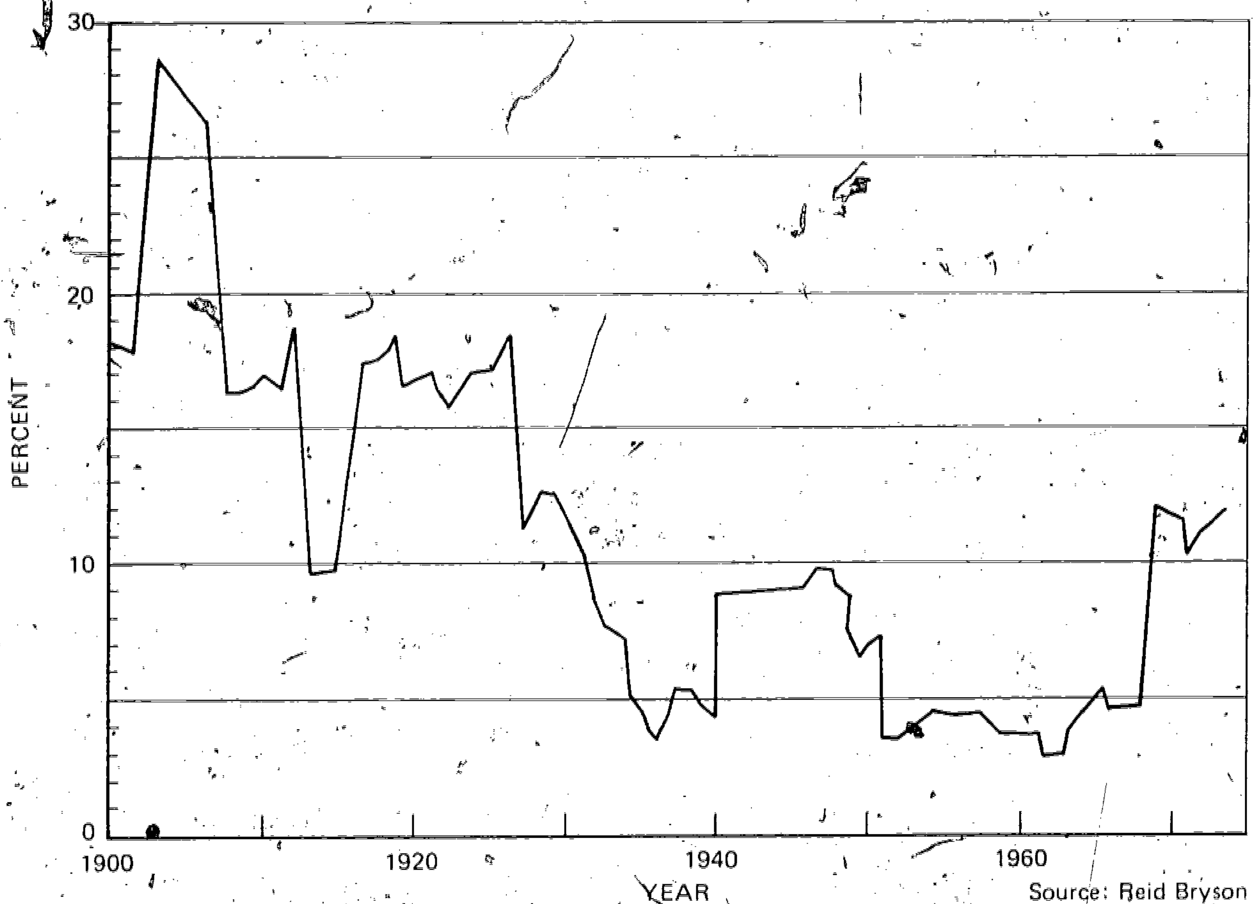
- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

1

VIII. ASIAN MONSOONS

PERCENTAGE OF WEATHER STATIONS HAVING LESS THAN HALF NORMAL RAINFALL



Source: Reid Bryson

Shown above is a chart by Reid Bryson showing the trends in the percentage of weather stations in northwest India reporting less than half the normal annual rainfall in a given year (overlapping 10-year averages).

1. With this information as background, plus your own knowledge and interpretation of past patterns in India, please fill in each block of the following matrix with your estimate of the probability of frequency of monsoon failures in northwest India.

2. In your judgment, would charts for (a) other parts of India and (b) other summer monsoon regions in Asia show a similar pattern to that of northwest India (not necessarily using "less than half of normal annual rainfall" as a cutoff point)? (yes ☐; no ☐) If you judge that other regions of India or monsoon Asia would have a different pattern, please indicate the appropriate probabilities in the following matrix.

VIII. ASIAN MONSOONS

FREQUENCY OF MONSOON FAILURE

Time Period	"Frequent" -i.e., similar to 1900-1925 period			"Average" -i.e., similar to the frequency over the longest period of record available			"Infrequent" -i.e., similar to 1930-1960 period			Total Probability		
	NW India	Other India	Other Monsoon Asia	NW India	Other India	Other Monsoon Asia	NW India	Other India	Other Monsoon Asia	NW India	Other India	Other Monsoon Asia
1977 to 1980										1.0	1.0	1.0
1981 to 1990										1.0	1.0	1.0
1991 to 2000										1.0	1.0	1.0

VIII. ASIAN MONSOONS

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

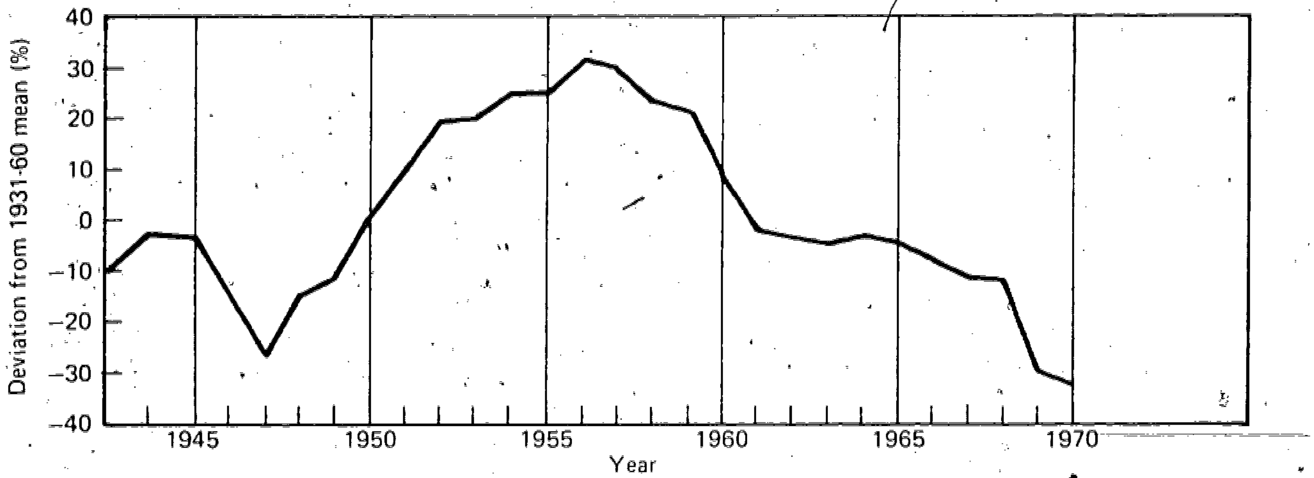
- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

  5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

  EXPERT (5) QUITE FAMILIAR (4)

IX. SAHEL DROUGHT



The above chart shows percentage deviations of the 5-year running means of annual rainfall from the 1931-60 mean for five stations in the Sahel—Gao and Tessalit in Mali; Atar and Nouakchott in Mauritania; and Agadez in Niger. (From Bunting, et. al, in *Nature,* February 20, 1975, based on Winstanley's data in *Nature* September 28, 1973.)

The above chart is consistent with National Academy of Science data shown below for five other stations in the Sahel. (From Michael Glantz in his *Value of a Reliable Long-Range Climate Forecast for the Sahel,* May 15, 1976.)

Previous Extremes of Rainfall *

Runs of years of particularly high rainfall in ZONE 2 (Sahel)

Individual Years	*Rainfall as % of 1931-1960 Mean*					
1929-1931	109	106	121			
1952-1955	117	116	114	108		
1957-1962	112	106	105	107	102	106

Runs of years of particularly low rainfall in ZONE 2 (Sahel)

Individual Years	*Rainfall as % of 1931-1960 Mean*					
1912-1915	85	55	78	94		
1940-1944	80	82	76	101	73	
1947-1949	83	93	64			
1968-1973	72	98	97	74	69	65

*National Academy of Sciences, *Arid Lands of Sub-Saharan Africa: Appendices* (Washington, DC, 1975), p. 155. Zone 2 rainfall stations were as follows: Niamey and Zinder (Niger), Sokoto, Kano, and Maidurguri (Nigeria).

CLIMATE QUESTIONNAIRE

IX. SAHEL DROUGHT

With this information as background, plus your knowledge and interpretation of the Sahelian drought patterns, please fill in each block of the matrix below with your estimate of the probability of frequency of droughts in the Sahel.

FREQUENCY OF DROUGHT

Time Period	"Frequent" -i.e., similar to 1940-1950 and 1965-1973 periods	"Average" -i.e., similar to the frequency over the longest period of record available	"Infrequent" -i.e., similar to 1950-1965 period	Total Probability
1977 to 1980				1.0
1981 to 1990				1.0
1991 to 2000				1.0

IX. SAHEL DROUGHT

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5)	QUITE FAMILIAR (4)

X. LENGTH OF GROWING SEASON

Professor Hubert Lamb has stated: "The average growing season in England for the coldest decade of the last 300 years seems to have been almost a month shorter than in 1930-60 . . . . The differences of prevailing temperature in the English lowland districts have meant changes of 10 to 20 days in the average length of the growing season in different decades since 1870. The shortening by 9 to 10 days since the warmest decades (1930's-40's) continues into the 1970's owing to the cold springs and, in the last year or two, colder autumns also." (Appendix A of report of Rockefeller Foundation-sponsored conference in Bellagio, Italy, June 1975.)

Walter Orr Roberts has stated that "In the USSR growing seasons are now perhaps 10 days to 2 weeks shorter than in 1940-50." (House hearings on National Climate Program, May 20, 1976.)

In Wisconsin, however, the abstract of a paper to be presented at an AMS meeting in April 1977 reports that:

> *Analysis of growing season records from stations representative of each of Wisconsin's nine climatic divisions indicates that the growing season became cooler and shorter from 1958 to the mid-1960's. Subsequently, the same records exhibit a general trend toward warmer and longer growing seasons through 1973 in spite of a continued fall in mean annual hemispheric temperature and deteriorating growing weather elsewhere.*

Reduction in the length of the growing season, particularly in the higher middle latitudes, might require certain crops to be grown farther south than some areas where they are now grown and might require substitution of earlier maturing varieties in some areas which could reduce crop yields.

1. In your judgment, what is the probability of the following changes in the mean length of the growing season in the higher middle latitudes during the next 25 years as compared with the present:

		Probability
a.	Significant increase (say by 10 days or more)	______
b.	Change of less than ±10 days	______
c.	Significant decrease (say by 10 days or more)	______
		1.0

X. LENGTH OF GROWING SEASON

2. An analysis of the length of the frost-free season (32°F.) in Iowa done a number of years ago indicated a standard deviation of about 16 to 17 days. In your judgment, what is the probability of a significant change in the inter-annual variability in the length of the growing seasons in the higher middle latitudes during the next 25 years as compared with the present:

		Probability
a.	Significant increase (say a 25% increase in the standard deviation)	______
b.	Change of less than ±25% in the standard deviation	______
c.	Significant decrease (say a 25% decrease in the standard deviation)	______
		1.0

X. LENGTH OF GROWING SEASON

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

X. LENGTH OF GROWING SEASON

- For the preceding major question, please state the line of reasoning for your response, adding any amplifying remarks as you desire, or referencing articles you or other scientists have written that state your position on this subject. Please use the space provided below or a separate sheet.

- Using the self-ranking definitions provided in the instructions, please indicate your level of substantive expertise on this major question.

5–4–3–2–1

- Again using the self-ranking guide, please identify those other respondents whom you would rate as "expert (5)" or "quite familiar (4)" in their answer to this particular question.

EXPERT (5) QUITE FAMILIAR (4)

APPENDIX B

OUTLOOK FOR 1977 CROP YEAR & THE PERSISTENCE OF DROUGHT

During the month of April 1977, the climatology panelists provided estimates for the expected crop yield change due to weather in 1977 for the following U.S. crops: winter wheat, spring wheat, and corn. The summary of their responses to Question VII follows:

Table B-1

PROBABILITY OF YIELD CHANGE DUE TO WEATHER

(Relative to recent trend levels)*

	Decrease More than 15%	Decrease 10% to 15%	Decrease or Increase Less than 10%	Increase More than 10%
U.S. winter wheat belt	0.1	0.4	0.4	0.1
U.S. spring wheat belt	0.2	0.2	0.5	0.1
U.S. corn belt	0.1	0.2	0.5	0.2

The 12 October 1977 U.S. Department of Agriculture yield estimates for these crops were as follows (figures in parentheses are the percentage deviations from an estimated 1950-76 trend value extrapolated to 1977).

Table B-2

USDA YIELD ESTIMATES

U.S. winter wheat	31.5 bu/acre	(-9%)
U.S. spring wheat	27.6 bu/acre	(-6%)
U.S. corn	90.8 bu/acre	(-3%)

The panelists' relative pessimism in the estimates for wheat, particularly the winter wheat crop, probably reflected the concern over the dry conditions that existed in many areas in late March and early April. Above normal precipitation during the last half of April in much of the Great Plains region improved the growing conditions markedly.

*See questionnaire for details on recent trend levels.

In addition, the panelists provided estimates for drought persistence. Specifically, they were asked, "If a severe drought similar to the early or mid-1930's should occur in 1977, how long would it last?" The summary of responses follows:

Table B-3

LENGTH OF DROUGHT IN THE UNITED STATES

	Probability
Persist less than 2 years	0.6
Persist for 2 but less than 4 years	0.3
Persist for 4 or more years	0.1

An alternate method for presenting the summary responses for drought persistence is by a probability tree. This type of presentation is useful for determining the probability of drought in the next year, given that the drought has already lasted a number of years. In the diagram on page 99, a drought is shown to occur in 1977. According to the panelists, the probability that the drought ends in 1978 is 0.6. The probability that the drought continues, then, is 1 minus the probability of no drought, or 0.4. The "drought ends" branch of the tree terminates at the point A.

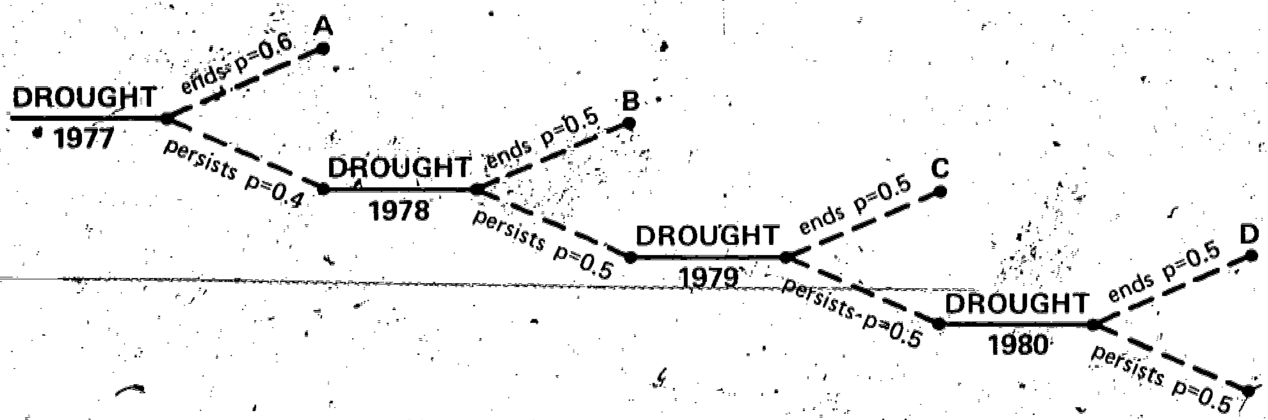
We now continue with the branch in which drought persists through 1978. The panelists estimated a probability of 0.3 that a drought would last for 2 or 3 years. In order to extend the tree, we make a reasonable interpolation: the probability of a drought lasting only 2 years is assumed to be 0.2 and the probability of a 3-year drought is taken to be 0.1. In order to make the product of probabilities equal 0.2 along the path leading to an end of the drought in 1979 (point B), we must ascribe a conditional probability of 0.5 to the case in which the drought persists through 1978 but ends in 1979. This, of course, implies a conditional probability of 0.5 that a drought persisting through 1978 also persists through 1979.

By using the same conditional probabilities—0.5 for termination and 0.5 for persistence of a drought that has lasted for at least a year—we continue the tree into 1980. The product of the probabilities along the branches leading to the termination of drought in 1980 (point C) is 0.1, in agreement with the interpolation assumption about the probability of a drought lasting exactly 3 years.

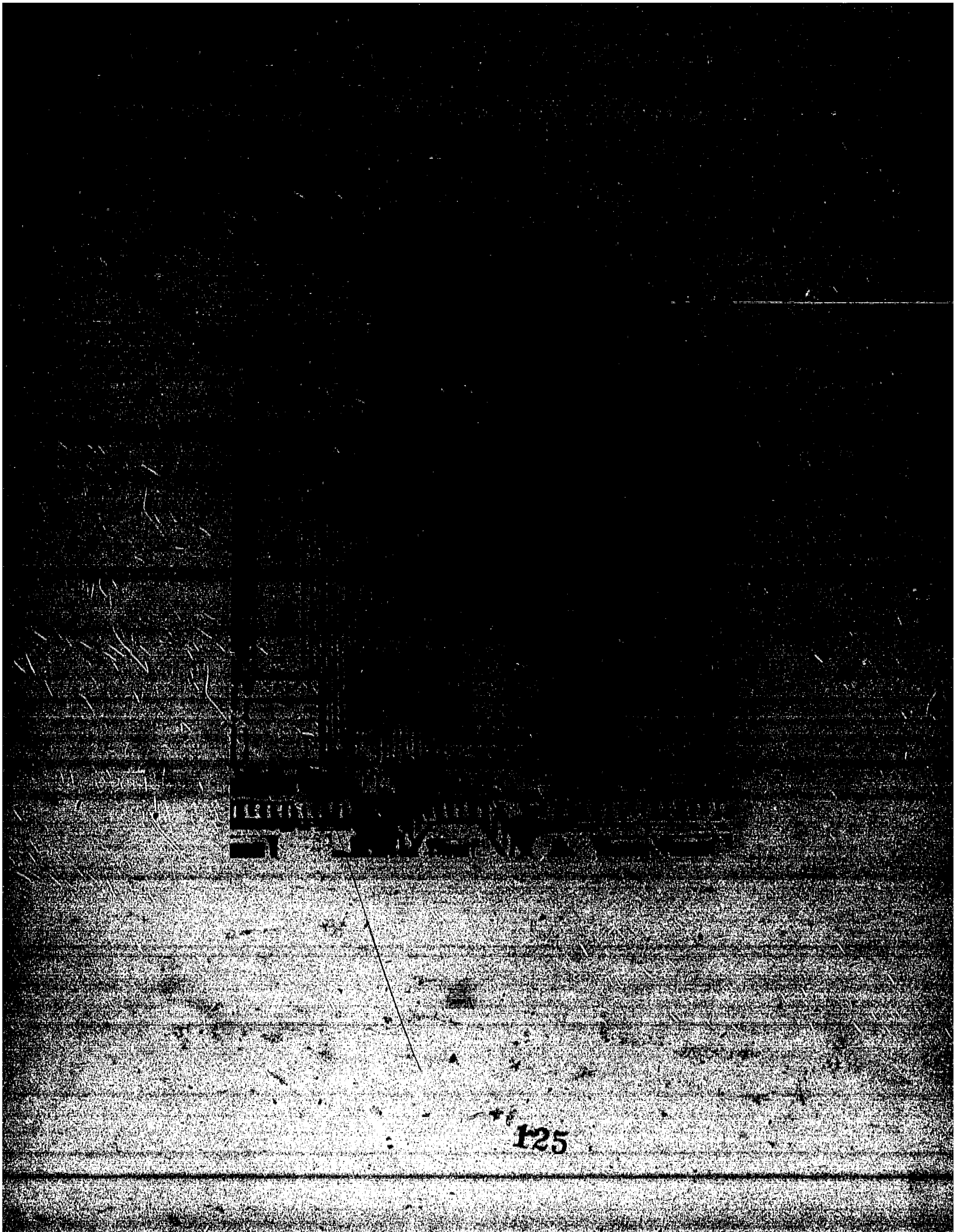
Extending the tree one step further into 1981 with the same conditional probabilities, we get a probability of 0.05 for a 4-year drought (point D) and a probability of 0.05 for 5 or more years of drought. These probabilities are consistent with the panelists' probability of 0.1 for a drought which persists for 4 or more years. At each drought-ending branch, the product of the probabilities from the beginning of the path to the end is equal to the panelists' estimate for a drought of that duration starting in 1977.

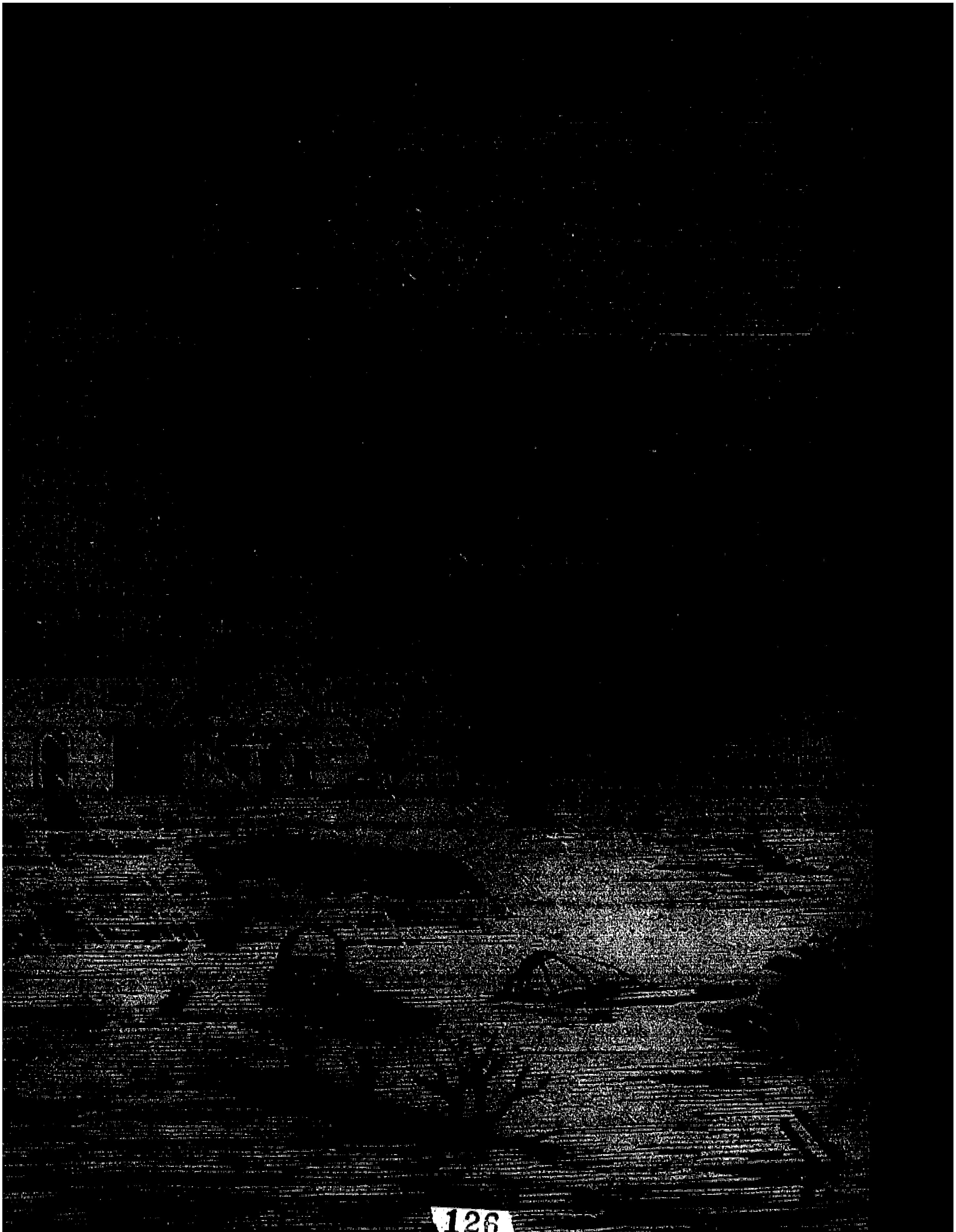
Figure B-1

DROUGHT PERSISTENCE IN THE UNITED STATES



One may note that once a drought has started, there is a relatively high probability that it will continue into the next year. However, the reasoning above should not be extrapolated beyond the panelists' data. Even as drawn, with the interpolated probabilities for 2- and 3-year droughts and with the inferred conditional probabilities used for later years, the probability tree is subject to uncertainty and ambiguity. For instance, the panelists may have assumed different definitions of drought termination, e.g., the return to normal precipitation or the return to normal water supplies. Moreover, it is possible that the reference year 1977, taken in the context of double or 22-year sunspot cycles, affected the panelists' perceptions of drought persistence. Although 1977 was a year of serious localized drought conditions in the United States, it fell short of the widespread drought experienced in the early to mid-1930's.





APPENDIX C

NUMBER OF RESPONSES & AVERAGE EXPERTISE RATINGS

Approximately 50 international authorities on climatic change were considered as potential recipients of the climate questionnaire, but because of time and resource constraints the number had to be reduced. Questionnaires were sent to 28 scientists, including 10 from 8 foreign countries. Replies were received from 24; their names and affiliations are listed in the acknowledgments. The 24 respondents participated in varying degrees. Three, for example, restricted their replies to qualitative comments. The other 21 submitted the requested quantitative data for at least 1 question; of these, 3 answered only a few questions. Fifteen provided quantitative responses to at least 7 of the 10 questions.

The table below shows for each of the 10 questions the number of climatologists who submitted quantitative data and the average of their expertise on the scale of 1 to 5 described in the questionnaire (Appendix A). The number responding quantitatively to a given question ranged from 12 (for Question VIII, Asian monsoons) to 19 (for Question I, global temperature, and Question III, atmospheric constituents).

Table C-1

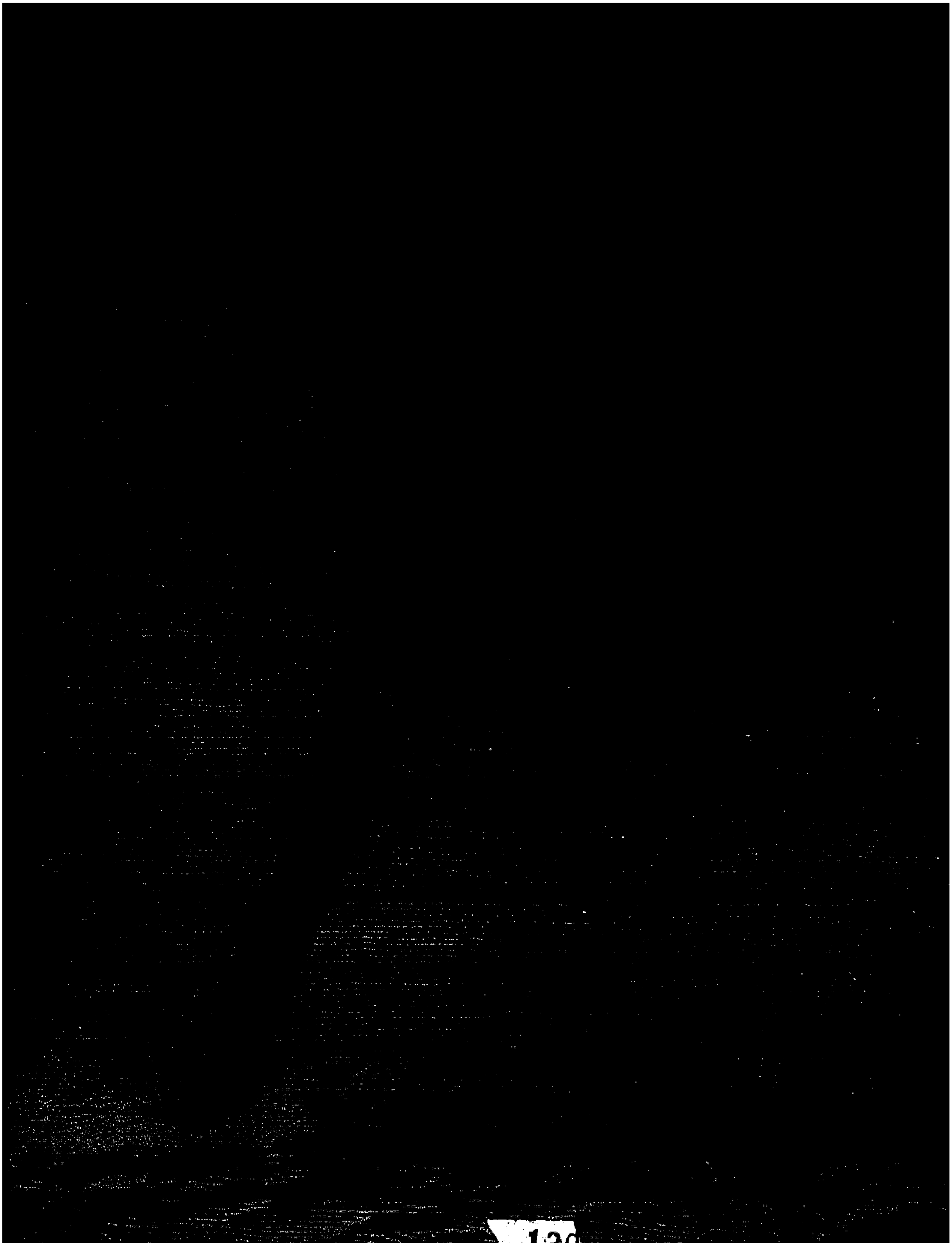
NUMBER OF RESPONSES AND EXPERTISE RATINGS

Question	Subject	Number of Respondents	Average Expertise
I	Global temperature	19	4.2
II	Latitudinal temperature	17	4.2
III	Atmospheric constituents	19	4.1
IV	Precipitation	14	3.9
V	Precipitation variability	14	4.0
VI	Mid-latitude drought	17	4.0
VII	Crop outlook for 1977	14	3.7
VIII	Asian monsoons	12	3.4
IX	Sahel drought	17	3.8
X	Length of growing season	15	3.9

RESPONSES & RATINGS

No one answered all the parts of every question. The 10 questions crossed a broad spectrum of global, hemispheric, zonal, and regional problems pertaining not only to climatic change but also to growing seasons and the outlook for 1977 crops, and no individual could have been expected to be competent in all categories.

The average expertise ratings for each of the questions were in the range of 3.4 to 4.2 (3-familiar, 4-quite familiar, 5-expert). The first two questions about temperatures had the highest expertise ratings. Question VIII on Asian monsoons had the lowest rating, 3.4.



APPENDIX D
REFERENCES

In the climate questionnaire (Appendix A), the panelists were given the opportunity to include references which explain or elaborate their response to each question. These references, arranged alphabetically by questions, are included here as additional background material which may be of value to the reader. No specific references were given for Questions VIII and X, on Asian Monsoons and Length of Growing Season, respectively. References of a general nature are included at the end of the list.

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__________. "The Connection Between Trends of Mean Temperature and Circulation at the Surface: Part III. Spring and Autumn." *Monthly Weather Review* 104 (December 1976): 1591-1596.

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