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THE CLIMATE IMPACT, PERCEPTION, AND ADJUSTMENT EXPERIMENT (CLIMPAX): A PROPOSAL FOR COLLABORATIVE RESEARCH

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In recent years, natural experimental designs have been used to examine, in a retrospective mode, the results of combinations of extreme events. Examples include studies of community disasters (Friesma, 1979; Rossi and Wright, 1982), droughts (Bowden et al., 1981), studies of drought, flood, snow, tropical cyclones, and wind in 12 countries at 20 sites (White, ed., 1974), and inadvertent climate modification (Changnon, et al, 1981). CLIMPAX would extend the principle of using the retrospective natural experiment for studying the impacts of climate variation (e.g., a decade of summers with mean temperatures 1° warmer than means for summers of the previous decade), the response to it by ecosystems and social systems, and its perception by individuals and groups. The project will focus on persistent regional deviations from climatic normals in the recent (1931-1982) record for the United States. Such deviations may provide analogs to long-term climatic change.

1.3 Proposed Experiment

The CLIMPAX will address the following questions:

- Can persistent (i.e., interannual or interseasonal) climate fluctuations be identified in various sectors of the United States?
- What are the effects of such persistent changes on society?
- Were the climate anomalies perceived during their period of occurrence?
- What forms of adjustment, if any, can be identified as related to climate fluctuations?
- What lessons can be learned that are relevant to issues posed by slow, cumulative climate change, such as that induced by rising levels of CO_2?
- What are the economic costs (or savings) that accrue to a particular climate fluctuation?
- What lessons can be learned about the feasibility and desirability of public or private contingency planning against a recurrence of the fluctuation?

The proposed experiment can be organized sequentially by the following tasks:

1. Identification of localized climatic fluctuations of such magnitude and persistence as to provide a partial analog to longer-term climate change;
2. Selection of those fluctuations that are most likely to have elicited a detectable response from water supply, agriculture, and energy demand sectors;

TABLE OF CONTENTS

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*Much of the content of this document has been drawn from a proposal for funding that is currently under review at the National Science Foundation.

**Support for the development of the proposal and this working paper was provided by the National Academy of Sciences and the National Climatic Data Center.

3. Examination of primary impacts on water supply, agriculture, and energy demand;

4. Assessment of secondary impacts on population distribution, economic activity, and social life;

5. Documentation of perception of climate variability or change;

6. Enumeration of adjustments (purposeful and incidental) made in response to perceived variability or change;

7. Evaluation of long-term adaptation and potential for contingency planning.

The project is planned in two phases over a 5-year period. During the first two years (described in this paper) the project will:

- Identify geographic areas in the United States where persistent climate fluctuations can be defined based on (a) standard climatologies of temperature and precipitation; (b) analogs to projected future climate induced by rising CO_2 levels, and (c) climate sensitivity indices developed from extensive analysis of the unique characteristics of the agricultural, water, and energy subsectors (Task 1);

- Develop the data base, methodology, design, and protocol for the field study of impacts, perception, and adjustments across the United States utilizing the experimental opportunities afforded by the identified fluctuations (methodology for Tasks 2-6).

An independent assessment of the results of Phase 1 and the proposed design for Phase 2 should follow. If favorable, then a second three-year phase would be initiated centered on a broad field program. Field studies of impact, perception, and adjustment would be carried out in regions which have experienced climate fluctuations and in nearby control areas. A quasi-experimental design of cases and controls (longitudinal and spatial) will explore specific hypotheses developed in the first phase and addressed to the six basic questions of the project. The results of the experiment will be analyzed in terms of these hypotheses, but also in terms of the policy implications and planning activities identified through the experiment. An extensive dissemination of findings will be included.

Phase 1 of CLIMPAX is intended to be self-sufficient in the sense of providing a useful and scientifically significant set of products that will further our understanding of climate and its impact regardless of whether the phase is followed by the expanded field program. These include:

- Data sets and atlases of (1) temperature and precipitation fluctuations and derived indices persisting 10 or more years (means, variance, frequency of extremes), and (2) geographic occurrence and extent of observed climate changes comparable to hypothesized CO_2 changes (e.g., 1° increase in temperature and 10% decrease in precipitation);

- Atlas of fluctuations for climate sensitive indices identified for water, energy, and agricultural sectors of the United States (e.g., stream flow, length of growing season, soil moisture);
- Monograph on regional variations in climate-impact sensitivity and catalogue of ancillary impact-related data (e.g., population and economic indices);
- Field guide and related methodology for retrospective regional study of climate change impacts, perception, and adjustment;
- Pilot case studies that test methodologies;
- Design for Phase II experiment.

These products are elaborated upon in the research plan that follows under the two major tasks of data analysis and methodology development.

2.0 RESEARCH PLAN

2.1 Data Analysis

2.1.1 Climate Fluctuations

Identification of climatic fluctuations of varying magnitudes and durations, and in appropriate locations is an important first step for CLIMPAX. The National Climatic Data Center (NCDC) maintains a digital file of monthly averages (1931-1982) of temperature and precipitation for state climatic divisions, and this data set is used here to identify climate fluctuations. In each state there are from 1-10 climate divisions that are, as nearly as possible, climatically homogeneous (Figure 1). In area, they average about 10,000 square kilometers, with divisions in the west being generally larger than divisions in the east (see Appendix 1 for a more detailed description of the climate data base and fluctuation estimation procedure).

Using this data set, an initial study was made to determine if the climatic record shows fluctuations large enough for use in the CLIMPAX program.* The climatological record was searched for the largest differences between consecutive, nonoverlapping time intervals ranging from one to two decades, with at least the second decade falling within the post-World War II period. In this "consecutive epoch" analysis the means and variances for each pair of nonoverlapping adjacent time segments of length 10 through 20 years were calculated using seasonal (Dec. through Feb., Mar. through May, etc.) and annual data for each climatic division.

The student's t-statistic was used in the initial study to identify objectively major climate fluctuations. Three types of climate fluctuations were identified. The first type (I) relates to the largest changes of temperature or precipitation, with each of these elements considered independently. The second type (II) pertains to the greatest simultaneous changes of temperature and precipitation, and the third (III) is associated with sharp spatial gradients of climate fluctuations of temperature and precipitation.

Examples of each type are shown in Table 1, which lists the type, location of the division exhibiting the change, the length of consecutive epochs, the seasonal or annual nature of the fluctuation, and the character of the change in terms of temperature and precipitation. The four Type-I fluctuations are examples of absolute change in temperatures or precipitation. The eight Type-II fluctuations are combinations of temperature and precipitation fluctuations, whereas the four Type-III fluctuations exhibit contrasting change

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*Karl, T. R., and W. E. Riebsame, "The Identification of 10-20 Year Temperature and Precipitation Fluctuations in the Contiguous United States," forthcoming in the Journal of Climate and Applied Meteorology.

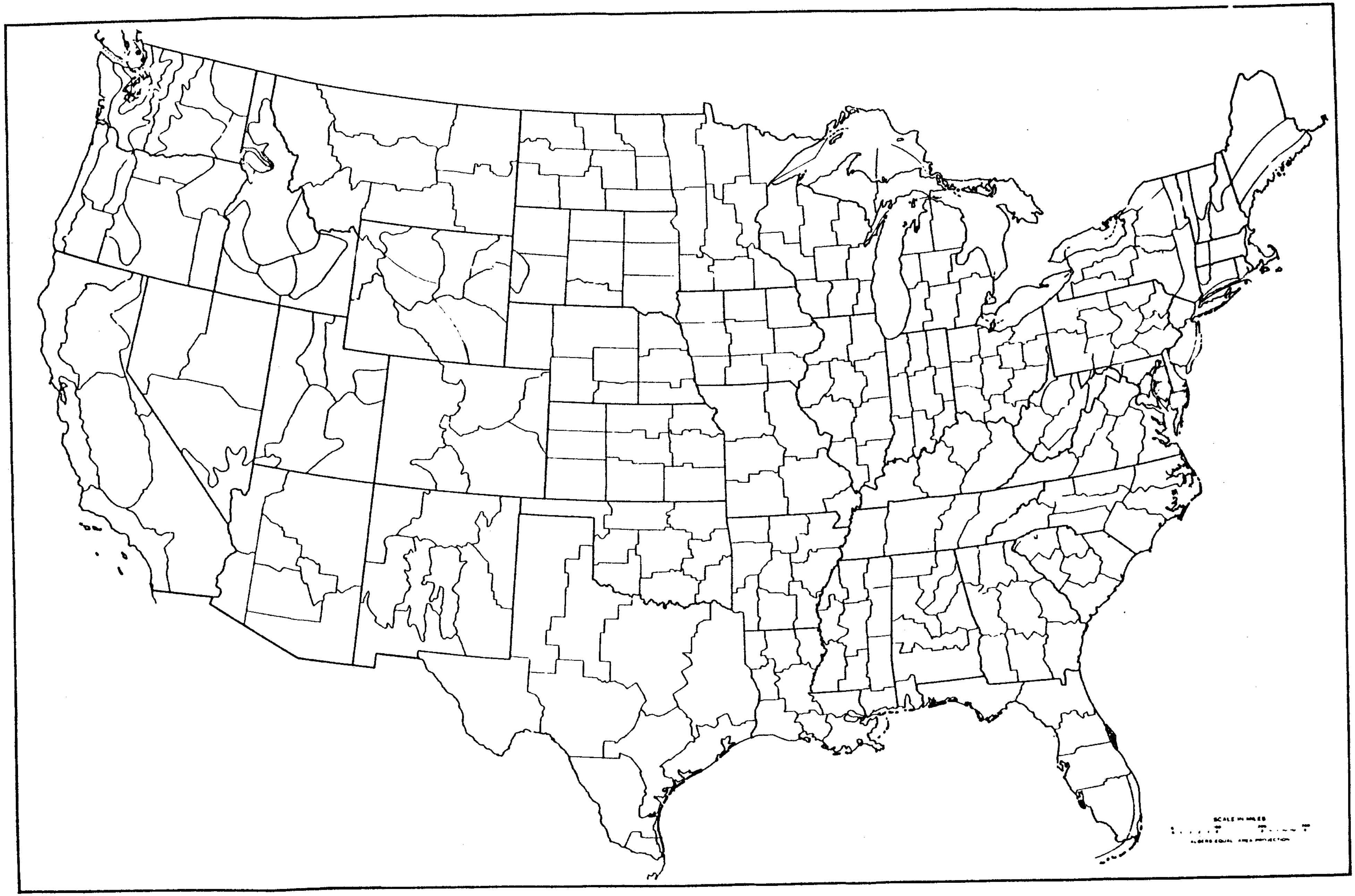

Fig. 1. Climate Divisions in the United States

TABLE 1. Examples of climatic fluctuations in specific climate divisions for each type of fluctuation (± T implies a change in temperature (T), ± P implies a change in precipitation (P), a zero (0) implies little or no change).

TYPE	LOCATION	YEARS	SEASON	SIGN OF CHANGE		T-STATISTIC	ΔT OR ΔP	PERCENT OF YEARS ABOVE (A) OR BELOW (B) PREVIOUS EPOCH'S MEAN
				T	P			
I-1	SAN JOAQUIN DRAINAGE CALIFORNIA	1941-57 VS 1958-74	SUMMER	+		3.9	1.0°C	88A
I-2	CENTRAL INDIANA	1940-59 VS 1960-79	WINTER	-		-4.3	-2.4°C	95B
I-3	EAST ILLINOIS	1951-66 VS 1967-82	ANNUAL		+	2.5	114m	75A
I-4	WEST CENTRAL PLAINS MISSOURI	1940-51 VS 1952-63	ANNUAL		-	-3.4	-234mm	91B
II-1	HUDSON VALLEY NEW YORK	1938-47 VS 1948-57	WINTER	+		3.8	1.9°C	100A
					+	2.3	55mm	70A
II-2	EAST CENTRAL GEORGIA	1943-59 VS 1960-76	SUMMER	-		-5.4	-1.9°C	100B
					+	4.1	79mm	100A
II-3	SOUTH CENTRAL KANSAS	1951-61 VS 1962-72	SPRING	+		2.0	1.0°C	90A
					-	-2.2	-67mm	90B
II-4	MIDDLE TENNESSEE	1943-61 VS 1962-80	WINTER	-		-3.6	-2.0°C	84B
					-	-3.1	-110mm	89B

TABLE 1 (Contd.)

TYPE	LOCATION	YEARS	SEASON	SIGN OF CHANGE T	SIGN OF CHANGE P	T-STATISTIC	ΔT OR ΔP	PERCENT OF YEARS ABOVE (A) OR BELOW (B) PREVIOUS EPOCH'S MEAN
II-5	SOUTH COAST DRAINAGE CALIFORNIA	1943-57 VS 1958-72	SUMMER	+		3.0	0.7°C	80A
					0	-0.1	0mm	46A
II-6	CENTRAL INDIANA	1938-57 VS 1958-77	WINTER	-		-4.1	-2.2°C	95B
					0	-0.2	-6mm	40B
II-7	CENTRAL OKLAHOMA	1963-72 VS 1973-82	SPRING	0		-0.2	-0.1°C	30A
					+	3.4	92mm	90A
II-8	GREEN AND BEAR DRAINAGE WYOMING	1935-51 VS 1952 68	ANNUAL	0		-0.2	0.0°C	52B
					-	-4.2	-71mm	88B
III-1	NORTHEAST LOWER MICHIGAN NORTHEAST WISCONSIN	1932-47 VS 1948-63	FALL	+		2.4	0.8°C	87A
				0		-0.2	-0.1°C	38A
III-2	NORTH CENTRAL KANSAS KANSAS DRAINAGE BASIN COLORADO	1941-55 VS 1956-70	WINTER	-		-2.3	-1.0°C	87B
				0		0.2	0.1°C	53B
III-3	SOUTH CENTRAL NEBRASKA NORTH CENTRAL	1944-56 VS 1957-69	SUMMER		+	2.5	52mm	77A
					0	-0.8	-8mm	46A
III-4	SOUTHWEST WISCONSIN EAST CENTRAL IOWA	1950-60 VS 1961-70	SUMMER		-	-2.7	-76mm	91B
					0	1.3	33mm	27B

among nearby divisions as candidates for a highly differentiated case-control analysis.

For each case the magnitude of the climate change between consecutive epochs is given in terms of the t-statistic, the absolute difference in degrees of temperature, or in millimeters of precipitation between epoch means and the number of individual years within the second epoch displaying this type of difference.

The program used to detect fluctuations of this sort also generates maps of the contiguous United States. In Figure 2, the t-statistic for summer precipitation changes between 1959-69 and 1970-80 is shown for all 344 divisions. By circling those with t-values greater than ±2 (arbitrarily chosen to identify areas of largest fluctuation), concurrent fluctuations are identified for further examination. In this epoch two major precipitation changes took place simultaneously--a very wet fluctuation, which peaks in western Pennsylvania, and a very dry fluctuation, which peaks in eastern Nebraska.

These fluctuations are shown in greater detail in Figures 3 and 4 with the magnitude of the fluctuation given for each of the divisions. Note the area of the fluctuation, extending over at least 20 divisions in four states in the Pennsylvania case and 17 divisions in four states in the Nebraska case. Such areal extent is characteristic of the fluctuations examined to date. Finally, the individual records for each division can be examined. These are shown in Figures 5 and 6 for the peak Pennsylvania and Nebraska divisions.

Table 1 lists only a small fraction of the total number of climate divisions with climate fluctuations of comparable, or even larger, magnitudes. There is no question that a large number of climate fluctuations are available for use within the proposed experiment.*

During the first phase of the experiment, climate fluctuations will be identified not only in terms of epoch means (through use of the t-statistic) but, in addition, the years associated with changes in variability will be identified. Nonparametric statistics can be used to identify the epochs associated with the largest fluctuations of interannual and interseasonal variability using procedures similar to those applied to the t-statistic (see page 6).

If it is concluded that the climate record provides sufficient fluctuations amenable to regional impact assessment, this pilot methodology will be further explored and revised during Phase I using different epoch periods, other indices derived from temperature and precipitation data (e.g., degree days,

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*During preparation of this research, A. B. Pittock published a comparable study for Australia (Climatic Change 5:321-340, 1983) in which he analyzed climatic data in Australia and found significant change in mean precipitation between 1913-45 and 1946-78. Consequently, this climate change was identified as a good analogue for the effects of a CO_2-induced global warming. Pittock did not extend his study to evaluate societal impacts.

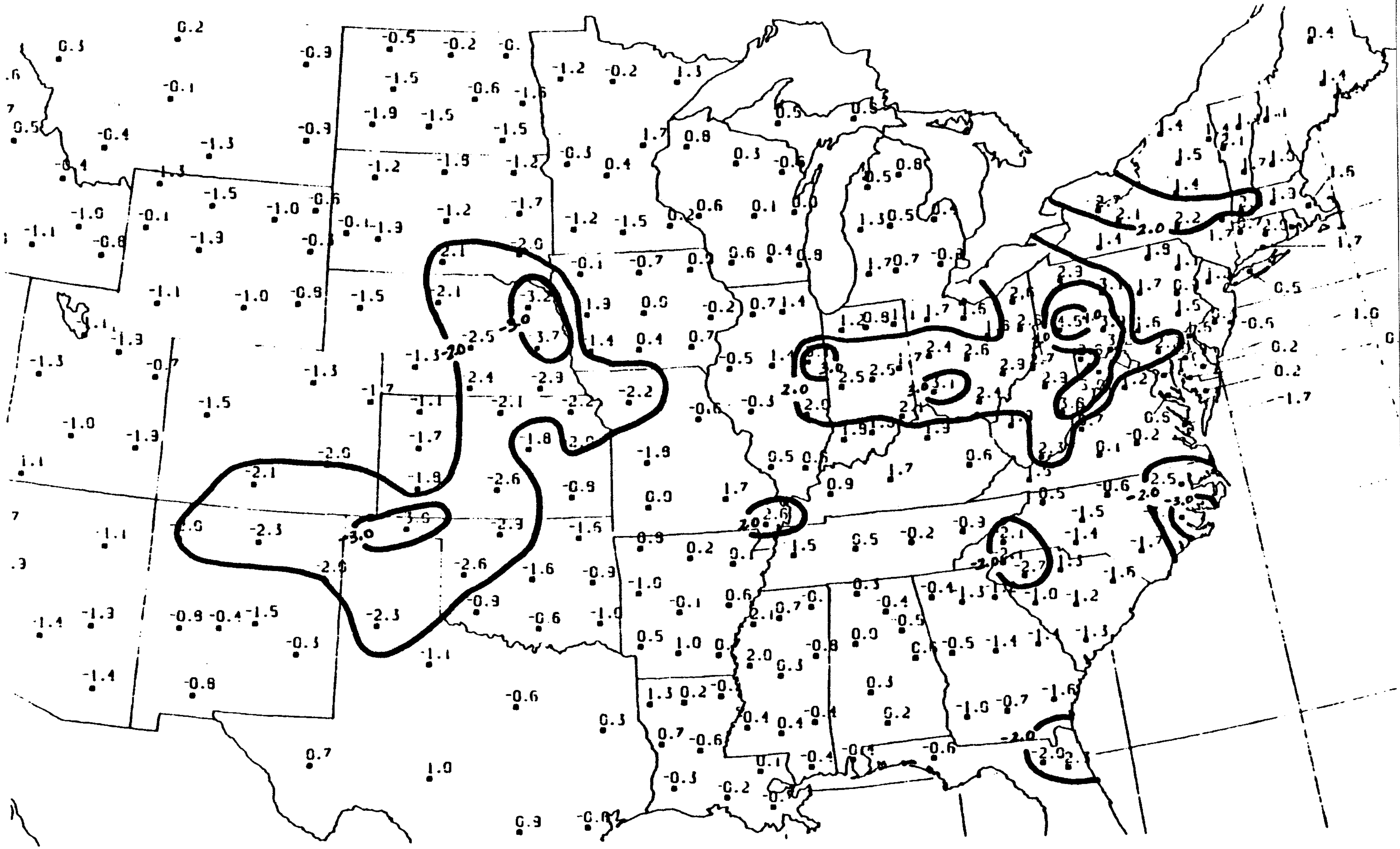


Figure 2. t-statistic for summer precipitation differences, 1959-1969 vs. 1970-1980.

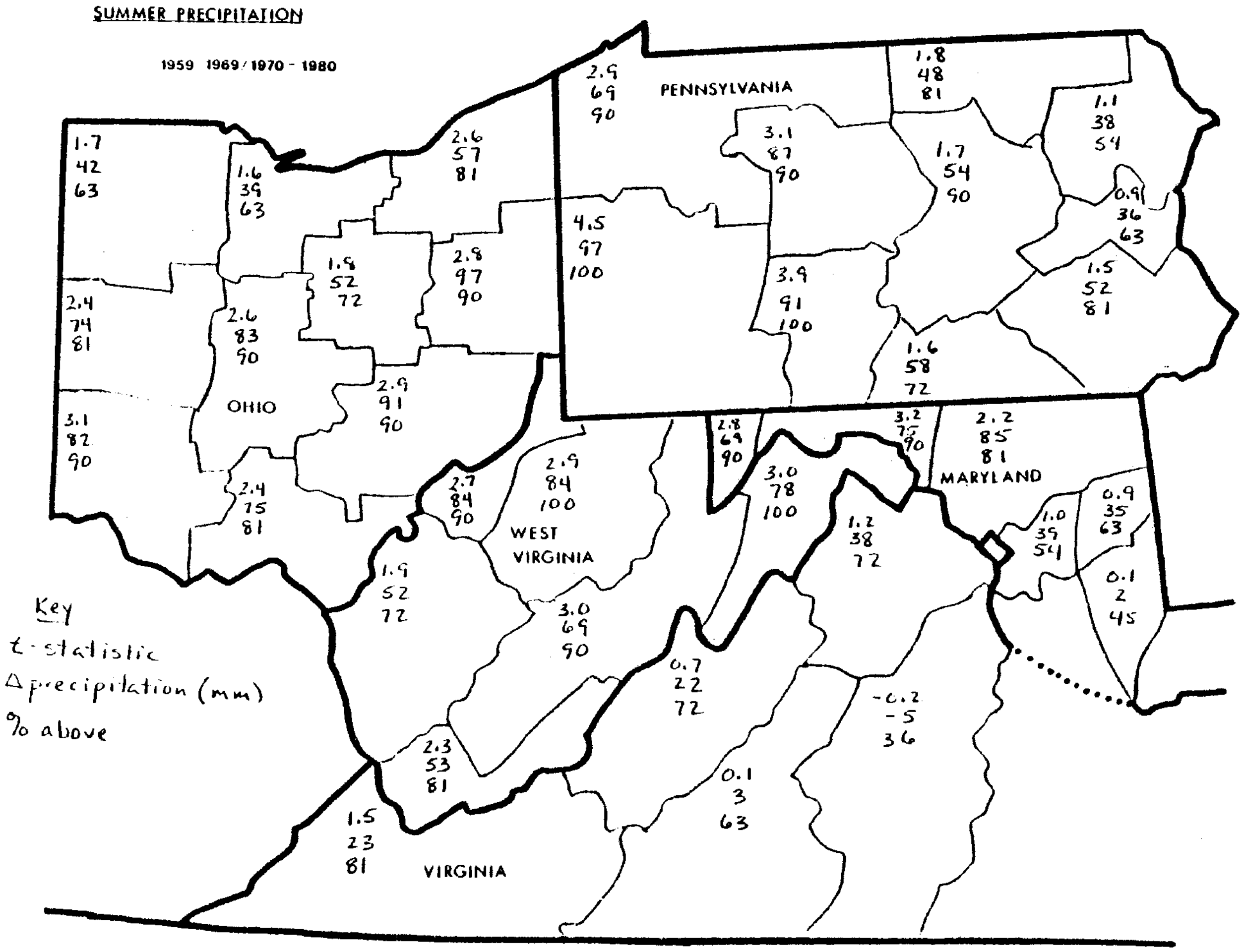


Figure 3. Precipitation t-statistics, absolute differences, and percentage of second epoch years above or below first epoch years for the Pennsylvania fluctuation.

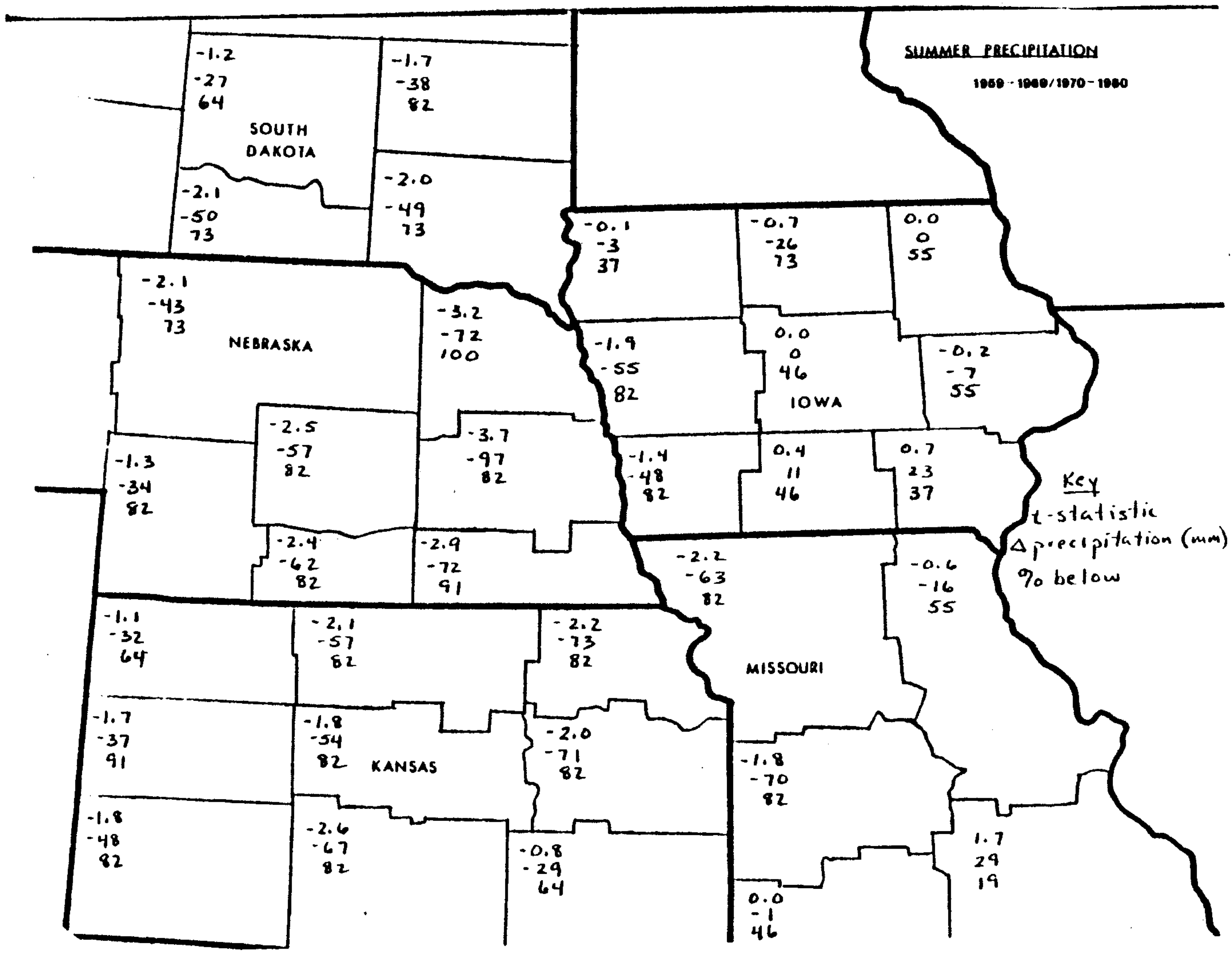


Figure 4. Precipitation t-statistics, absolute differences, and percentage of second epoch years above or below first epoch years for the Nebraska anomaly.

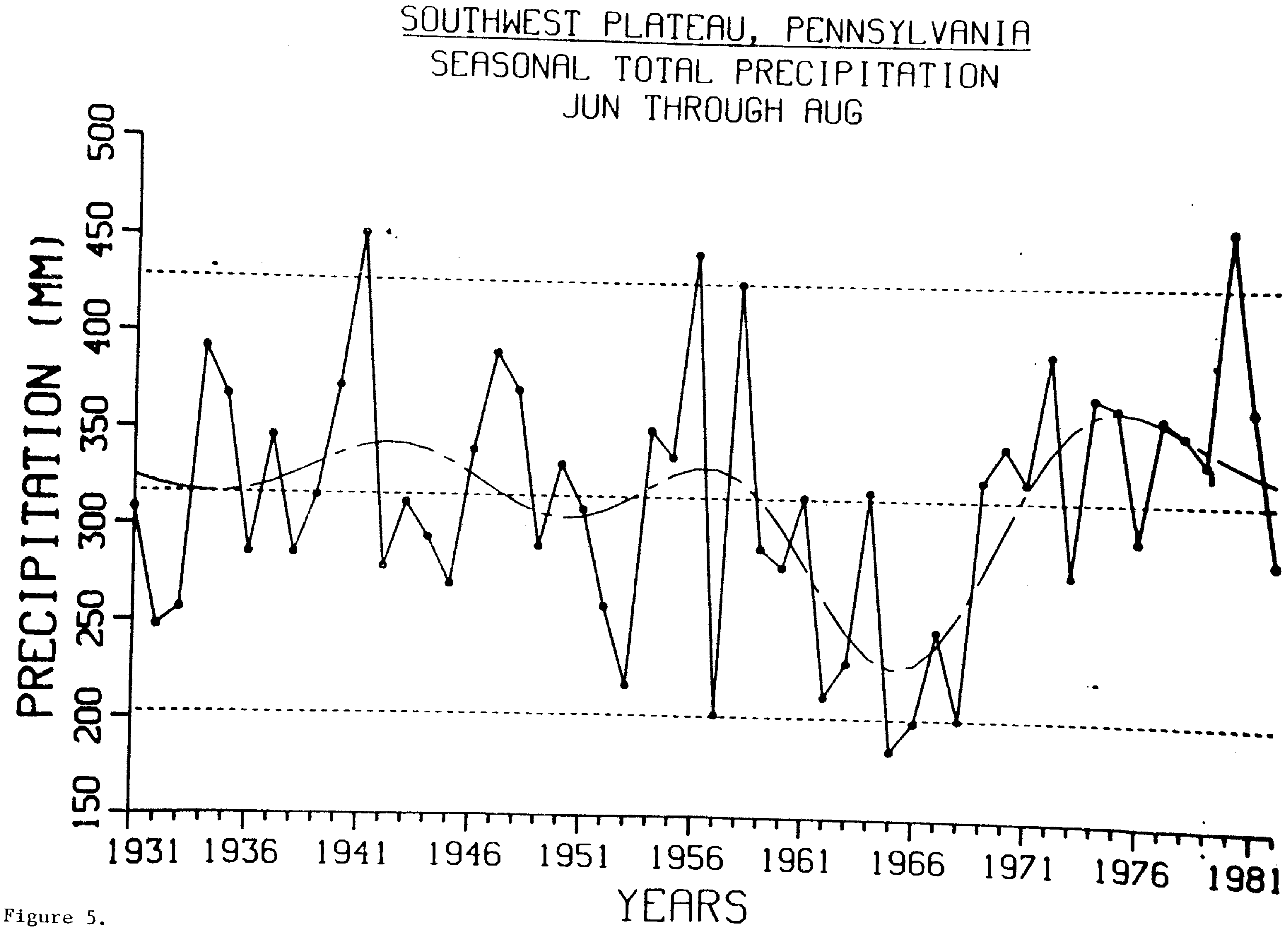

SOUTHWEST PLATEAU, PENNSYLVANIA
SEASONAL TOTAL PRECIPITATION
JUN THROUGH AUG
PRECIPITATION (MM)
500
450
400
350
300
250
200
150
1931
1936
1941
1946
1951
1956
1961
1966
1971
1976
1981
YEARS

Figure 5.

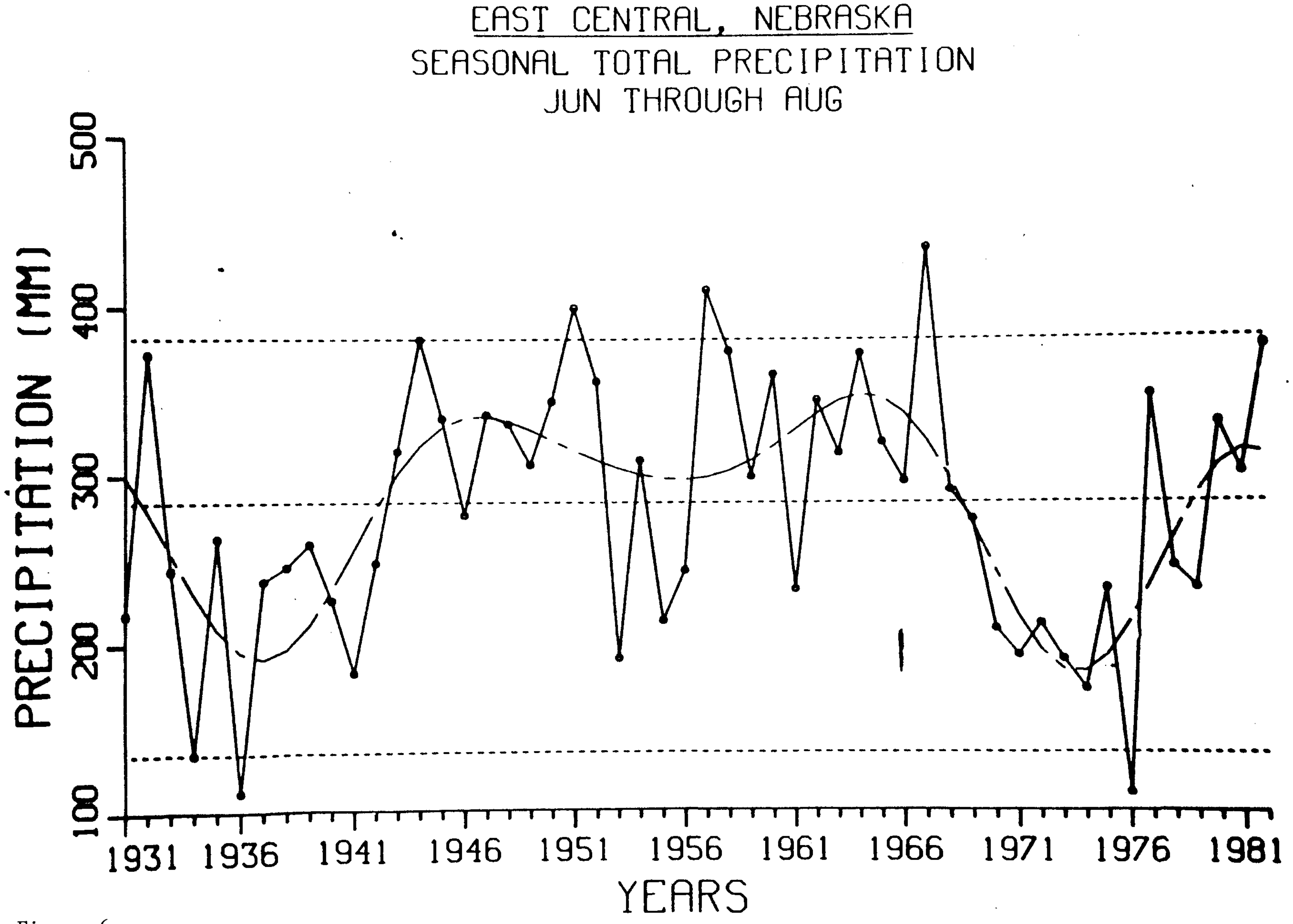

EAST CENTRAL, NEBRASKA
SEASONAL TOTAL PRECIPITATION
JUN THROUGH AUG
PRECIPITATION (MM)
100
200
300
400
500
1931
1936
1941
1946
1951
1956
1961
1966
1971
1976
1981
YEARS

Figure 6.

drought indices), other statistical parameters of epochs (e.g., variances, frequency of extremes), and alternate statistical search routines, and modes of storage and display. Responsibility for this phase of the activity will rest with Thomas Karl of the National Climatic Data Center. Final products will include a summary paper on the methodology employed in selection of the fluctuations, a complete data base of climate-based fluctuations of varying epoch lengths and descriptive parameters, and an atlas of major examples, including frequency statistics of the magnitude of fluctuations across the United States.

A major goal of the CLIMPAX program will be to examine the temperature and precipitation record in terms of extremes and changes in variance. One of the major concerns about CO_2-induced climate change is whether change in the mean would be accompanied by changes in variance. Will, for example, the frequency of extreme events increase? By comparing statistics of different climatic regimes, we intend to investigate changes in variance and determine the extent by which the frequency of extremes changes.

2.1.2 CO_2 Analog Fluctuations

There is a growing body of research on possible future climate changes at varying levels of atmospheric CO_2 increase, for different future dates. The possible regional distribution of such climate changes is not well understood. Nonetheless, it is possible to suggest from paleohistorical analogs and from general circulation models some crude characteristics of future U.S. climates under the influence of increased CO_2 levels.

Assessments of the impacts of such changes often involve selecting some credible value of change and attempting to simulate its impact on some social activity. For example, the recent National Research Council (1983) report Changing Climate provides projections of the effect of a 1° temperature increase and a 10% precipitation decrease on major commercial crops (Table 2). These data are simulated, derived from regional crop-weather multiple regression analyses based on assumptions of constant technology and stable land-use patterns.

The CLIMPAX offers a complementary approach to such projections by identifying regions where changes similar to those projected actually took place over a sustained period. For example, Figure 7a&b shows an area centered on southern Kansas where a 1°C increase in temperature and a 75 mm decrease in precipitation actually occurred. Many other regions could be identified for this and other scenarios. A goal of the CLIMPAX study is to determine if these changes had any impact on the region, if these changes were recognized, and how adjustments were made in response to such changes.

It should be noted that these empirical analogs differ from projected CO_2-induced climate change in very significant ways. The changes are almost instantaneous, are not sustained and cumulative as predicted in the CO_2 case, and are smaller than changes projected by some models at high levels of CO_2--doubling or quadrupling. However, there is no compelling reason to assume that CO_2-induced changes will display a different form of temporal

Table 2. **Climate Change and Agricultural Productivity**[a]

Crop and Region/State	Present Yield (quintals/hectare)	Estimated Change for 1°C Temperature Increase and 10% Precipitation Decrease	
		Amount (quintals/hectare)	Percentage Change (%)
Spring Wheat			
Red River Valley	18.2	-1.32	-7
North Dakota	14.9	-1.77	-12
South Dakota	12.0	-1.36	-11
Winter Wheat			
Nebraska	21.3	-1.04	-5
Kansas	21.3	-1.04	-5
Oklahoma	19.7	-0.37	-2
Soybeans			
Iowa	23.6	-1.55	-7
Illinois	21.9	-0.82	-4
Indiana	22.0	-1.25	-6
Corn			
Iowa	72.7	-2.36	-3
Illinois	68.8	-1.72	-3
Indiana	65.3	-2.80	-4

[a] Examples of the effect of a hypothetical climate change on crop yields, if we assume no significant adaptation of inputs and limited geographic mobility. Results shown are based on statistical multiple regression analysis of observed crop and weather data and are calculated for a nominal 1°C increase in temperature and 10% decrease in precipitation for each season or monthly period used as input to the analysis (National Research Council, 1983).

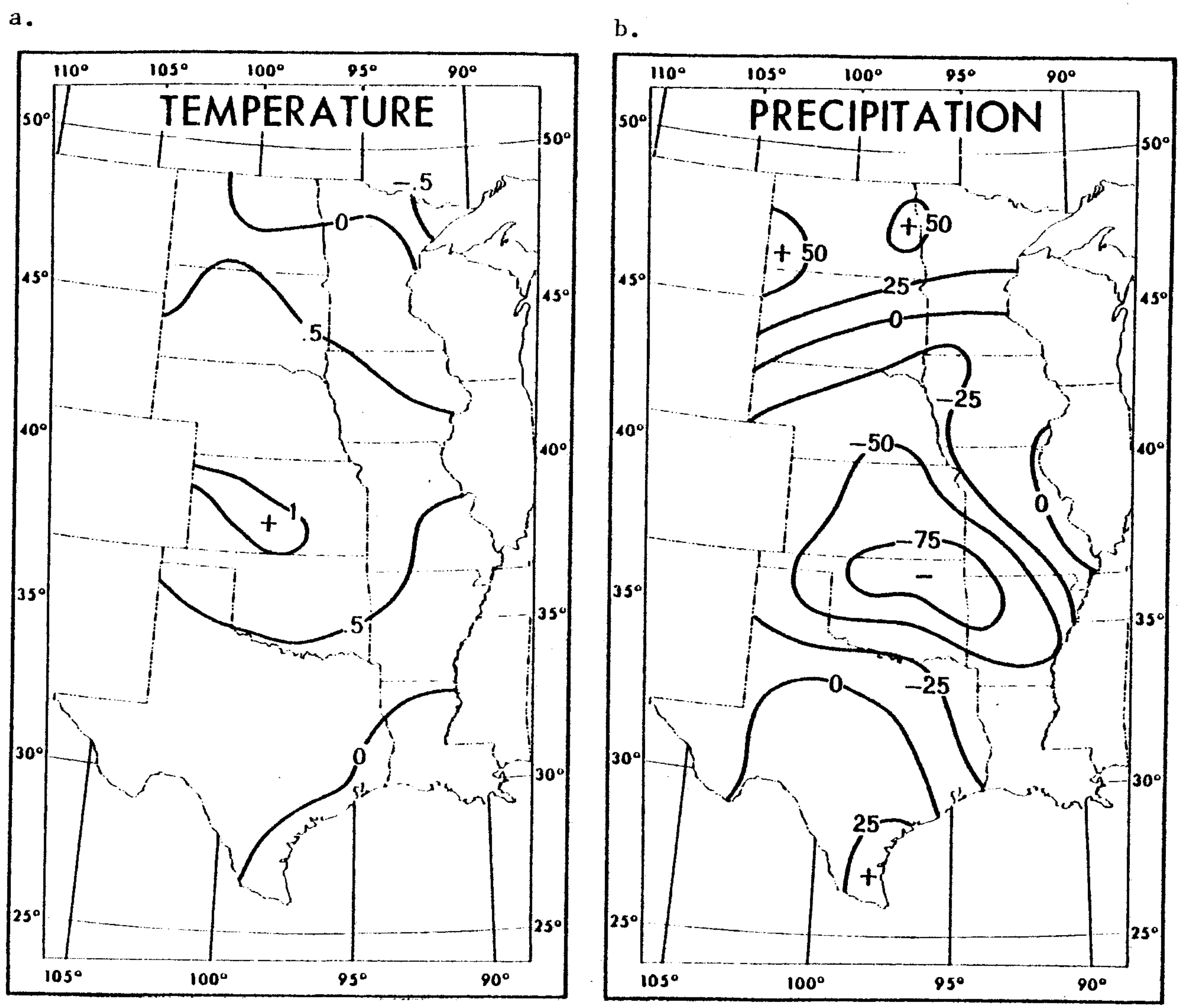


Figure 7. Change in springtime average temperature (^{0}C) and total precipitation (mm) from 1951-61 to 1962-72.

distribution than those experienced in past fluctuations. Even if with the hindsight of many years hence we discover that climate change occurs in sequences very different from the CLIMPAX fluctuations, the more rapid, extreme changes still offer opportunities to explore related issues of impact, perception, and adjustment.

CLIMPAX investigators will prepare a temperature-precipitation atlas for the United States of CO_2 analogue fluctuations.

2.1.3 Impact Sensitive Fluctuations

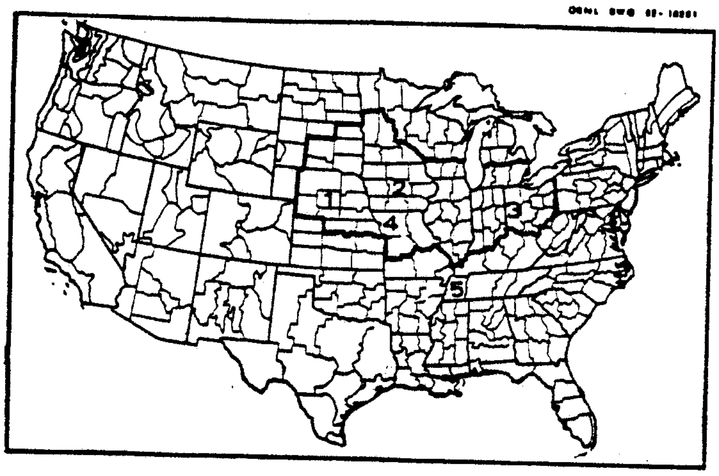
A third type of fluctuation identification begins not with the climate but with affected activities. This component of Phase 1 of the CLIMPAX will allow development of climate fluctuation sets appropriate to the study of climate impacts on the water resources, agriculture, and energy sectors of the economy. This part of the research effort will have two objectives. First, a catalog of climate impact sensitivity indices will be developed for each subsector. Second, to work closely with climate experts to develop climate fluctuation cases from impact sensitivities. Implicit in these objectives is subsequent participation in development of the field guide necessary for measuring impacts, perceptions, and adjustments to climate fluctuations (as described in section 2.2.3).

The Illinois State Water Survey, under its director, Stanley Changnon, will be responsible for the development of criteria for agriculture, water, and energy with the cooperation of the appropriate federal agencies (e.g., Department of Agriculture, Geological Survey, Army Corps of Engineers, Bureau of Reclamation, Bonneville Power Administration).

There is extensive literature on defining climate sensitive indices although it has not been compiled and summarized in one place. The recent study by Blasing and Solomon (1983) illustrates this approach. Figure 8 shows heat and moisture characteristics of 5 sectors of the North American Corn Belt and contrasting characteristics for wheat and dairy regions. The thermal requirements for corn growth are usually expressed as growing-degree days, i.e., the mean daily temperature minus 10^oC accumulated over all days when the mean daily temperature exceeds 10^oC (Newman, 1982). Both temperature and length of growing season are combined in this parameter. Newman (1980, 1982) used this concept to arrive at a first approximation to a geographic shift of the corn belt corresponding to a 1^oC change in temperature.

This is only one of several possible indices of climate impact. Corn is also sensitive, for example, to the distribution of precipitation during the summer months. In eastern and central North America, west of the Appalachian Mountains, the annual amount of precipitation decreases toward the north and west, with peak precipitation usually occurring about May or June (Blasing and Solomon, 1983). Where precipitation is abundant (e.g., in southwestern Illinois) the peak precipitation usually occurs in May, a bit earlier than in the drier regions to the north and west. Other combinations of temperature and precipitation affect corn production in other regions.

a.



State climatic divisions used for characterization of corn-belt climate. Numbers 1-5 correspond to points on the graph in Fig. 8b

b.

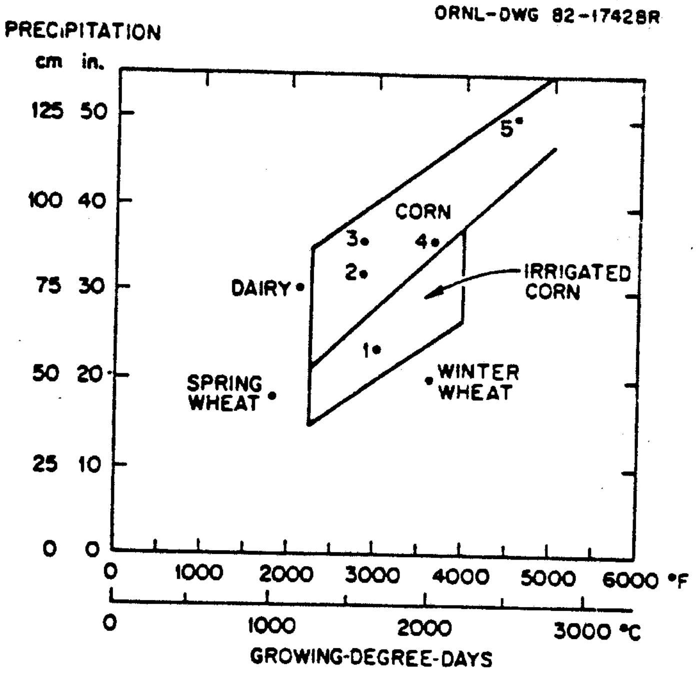


Figure 8. Heat and moisture characteristics of the North American corn belt. Numbers 1-5 correspond to geographical locations in Fig. 8a. Dots outside the lines correspond to central Wisconsin (dairy), central North Dakota (spring wheat), and west-central Kansas (winter wheat).

Using analyses such as this, it will be possible to search the data archive for regionalized "corn-growing fluctuations" based on combinations of growing-degree days (derived from temperature statistics) and growing season precipitation that might increase or decrease corn yields during particularly sensitive growth periods.

It is important that the climate sensitive indices formulated in this effort be sufficiently detailed and sophisticated so as to allow the successful completion of the subsequent phases of CLIMPAX. For example, again consider the relatively simple example of the effect of summer rainfall and temperature on corn production in the Midwest. Although corn is clearly susceptible to these weather conditions, it is not clear that today's corn production system responds in the same manner to a specific climate fluctuation as did the production system of 20 or 30 years ago. Improved crop varieties as well as changing production practices (such as earlier planting dates or heavier fertilization rates) may have altered the weather/yield relationship. Therefore, it is important that indices chosen for the CLIMPAX be sensitive to the influence of changing technology as well as weather on crop yields.

Important to our research is the recognition that the principal investigators have conducted sufficient research concerning the relationships between climate, water, and agriculture to be aware of many of the general climate factors that cause impacts; that is, that July rainfall and mean temperature are major factors influencing corn yields. However, we must have more sophisticated input from highly experienced experts. For example, in the corn illustration, the number of consecutive days during the last 20 days of July (tassel period) that have temperatures above 86°F, coupled with less than 0.6 inch of rain, may be the key climate variables for current agricultural practices.

Following a literature assessment, the activities of the first year will focus on extensive agronomic, hydrologic, and energy expertise on these issues. A number of experts will be commissioned to prepare in-depth assessment papers for each sector. Essentially, these commissioned papers will each focus on the question, "For which facets of the subsector being studied is climate an influential factor and, once identified, what is their degree of sensitivity to climate variability?" For example, if acreage abandonment rates (nonharvest of planted acreage) are indeed influenced by climatic variability, then how much departure from expected climate must be experienced before abandonment rates are affected? To obtain meaningful in-depth assessments, detailed guidelines and work plans for each of these assessment papers will be developed to assure extensive and incisive analyses.

A small number of papers will be commissioned for this effort. Because of the region-specific nature of crop production, more than one of these papers will be devoted to the agricultural sector. Papers will be commissioned which describe the agricultural impacts for regional delineations such as California-Arizona, the range and the forests of the Mountain states, the Great Plains, the Midwest, the Southern and Southeastern states, and the East Coast. Each expert will address the above question in depth for that specific area and prepare an assessment paper.

In the water resources area, experts familiar with western, midwestern, and eastern water issues (design and operations) will prepare in-depth papers assessing and explaining the interrelationships of climate shifts and water resources. Similarly, three experts in the energy field will examine potential regional impacts (western hydropower, midwestern power usage, and eastern power management and operations), and prepare impact-oriented papers.

As a result of this effort, we shall obtain commissioned papers, each focused on identifying indices of sensitivity. Each of these papers will then be reviewed by a group of 3 or 4 additional experts. Discussions will be held involving the authors, the reviewers, and the Survey project staff in a workshop context and the primary findings of each commissioned paper will then be studied and distilled into a digest of impact sensitivities. Important to this effort will be an analysis of similarities and differences in and across sectors. The primary goal will be to discern those findings that affect the development and planning of the future field studies of CLIMPAX.

2.1.4 Ancillary Impact-Related Data

The comprehensive search for contrasting climatic experiences becomes possible only because of the existence of a carefully screened data base of monthly records organized by climatic division. No such equivalent data base exists for impact-related data. These data sets include primary productivity data: time series of streamflow, ecosystem growth, crop yields, etc.; and secondary impact data: time series of economic and social well-being as measured by regional economic indices, enterprise failures, migration, and climate adjustments, such as time series of energy expenditures or water supply storage development. The data exist in scattered holdings with little or no cross-referencing.

In addition, it is desirable to have basic regional descriptive data that can be used to control for socioeconomic differences between climate divisions with and without significant climate fluctuations. Although these data are not organized by climatic division, many are available by counties, which can be aggregated into divisions (e.g., census-type statistics) or by geographical coordinates, which can be cross-referenced with divisions (e.g., streamflow measurements). Other data sets need to be traced through the federal bureaucracy (e.g., water supply data bases--from the Public Health Service to the Environmental Protection Agency) or in the private sector (energy use from private energy supply systems). Based on the analysis of sectoral impact sensitivity and in conjunction with the pilot field studies (described below), a catalog giving source and location of ancillary impact and adjustment-related data will be produced. William Riebsame, a geographer at the University of Wyoming, will be responsible for its assemblage with the collaboration of H. Cochrane (economist), D. Mileti (sociologist) of Colorado State University, and appropriate federal agencies.

2.2 Impact Assessment Methodology Development

The problems associated with gauging climate change impact, perception, and adjustment are addressed in the following subsections with examples included from agriculture and water supply systems. A protocol for a research design and the development of a field guide are proposed. The field guide will be tested in a small number of case studies, revised, and used as an input to the experimental design for Phase II. This section concludes with a description of a potential Phase II experimental technique.

2.2.1 Impact, Perception, and Adjustment

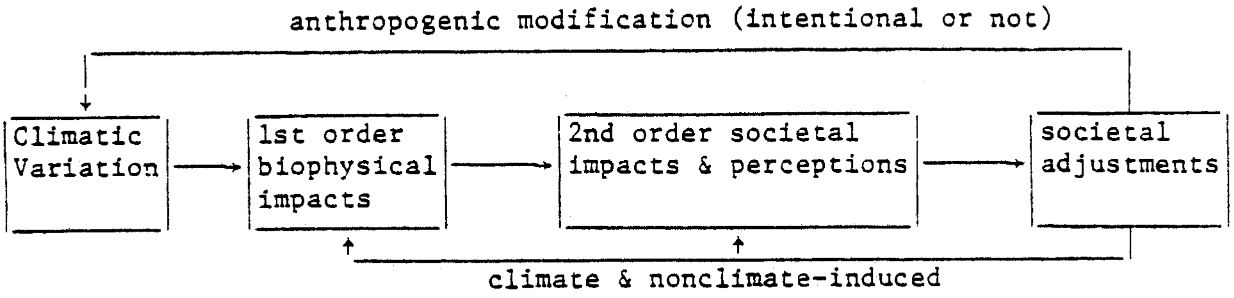
Consider a small region of the United States consisting of several climatic divisions which, over a 10-to-20-year period, has experienced a change in its climate compared to the previous period and vis-a-vis nearby climatic divisions. What are the impacts of such a change? Have individuals and institutions noticed the change? What changes in human activity have taken place in order to cope with or take advantage of the change? Have these changes in turn stimulated further changes? The second major task of Phase I of the CLIMPAX is to design a field effort to answer such questions and to develop and test the methodology to be used in the field. It can draw on a rich tradition of study in natural hazards research, and a growing body of work in climate impact assessment, social impact assessment, and economic analysis, as reviewed in Appendix III.

The relationship between climate change and impact, perception, and adjustment is a close one and should be studied in combination. To simplify the relationship it is now common to present it as a linear relationship with feedback in the form of adjustments, although in reality the relationship is much more complex. A typical generalized climate impact relationship is shown in Figure 9. In this scheme climate is seen as impacting human behavior through a causal chain that begins with first-order biophysical impacts linked to second-order socioeconomic impacts and perceptions. Impacts are affected by the level of adjustment previously adopted, through feedbacks of varying complexities, as well as by the level of adjustment adopted in direct response to the impacts.

Within a region the impact chain can be quite complex. Changnon *et al.* (1977) studied the impact of inadvertent modification of the summer climate through urbanization of the St. Louis metropolitan area. Figure 10 traces the complex components of such a climate change in its primary impacts on soil, streamflow, agriculture, and buildings, as well as secondary impacts on the economy, institutions, and public health and welfare. These causal chains serve as a template for identifying impacts. The investigator follows the chain link by link creating a checklist of possible impacts with the value of each to be determined in the field.

Impacts in the broader sense also include adjustments. Efforts to modify the effects of a climate change are a direct impact of that change and must enter

Figure 9. Generalized climate impact model.



(after Ingram, Farmer, and Wigley, 1981)

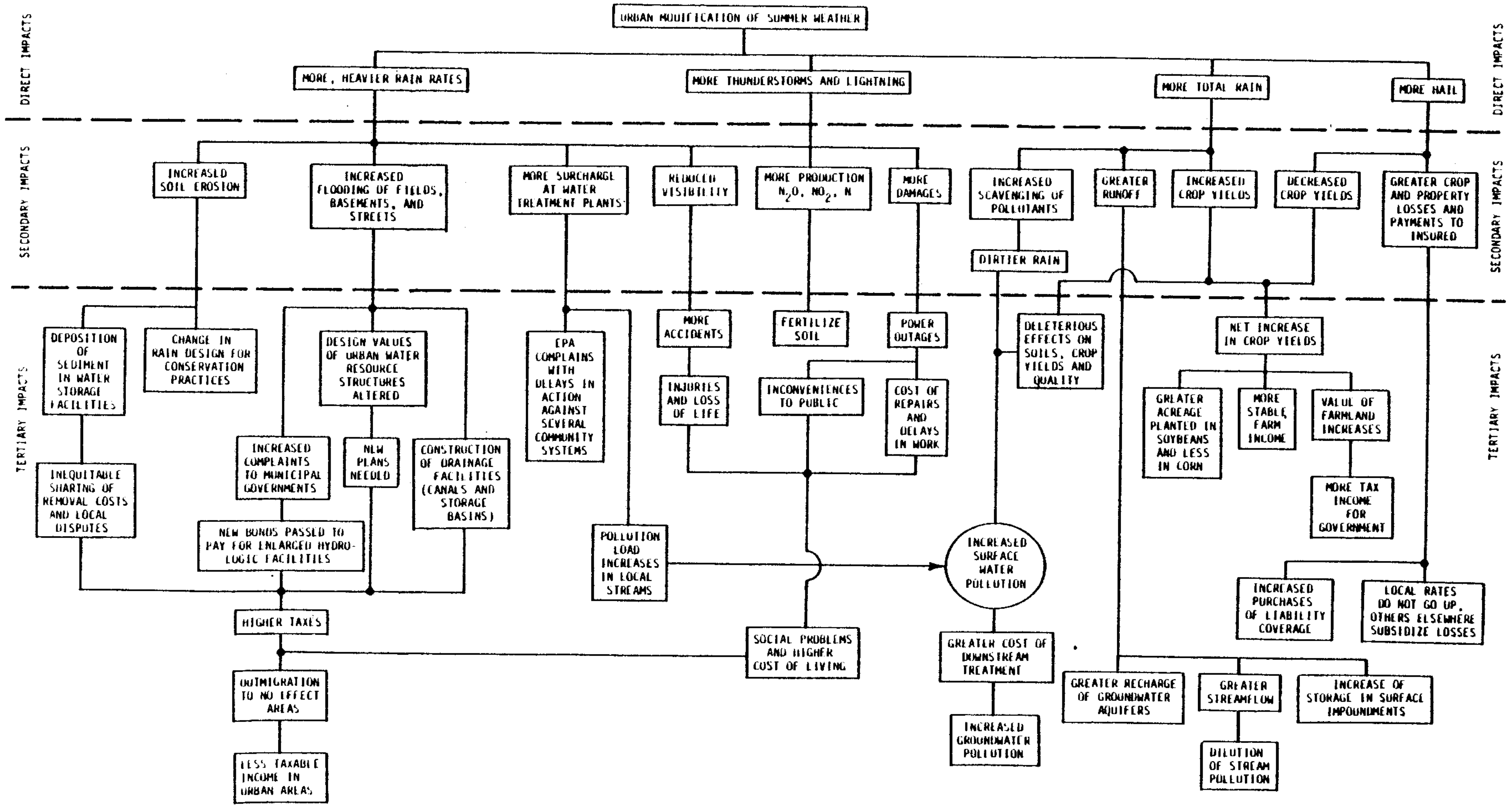


Figure 10. **Interrelated impacts of certain precipitation anomalies** (Changnon, *et al*, 1977).

the calculus of cost, loss or opportunity on an equal level with more familiar estimates of loss or gain in yield, income, and the like. One example of adjustment that has been previously studied (Russell, Arey and Kates, 1970) is the effect of prolonged drought on urban water supplies. Between 1961 and 1966, a prolonged drought affected the Northeastern United States, a drought estimated by researchers in Massachusetts (Russell, Arey and Kates, 1970) to be the most severe in 100 years. Careful studies of the economic impacts of the drought were carried out in three cities. Estimates of the social loss and the cost of adjustment differed by the scale of analysis--the individual, the firm, the city or region, and various accounting assumptions. Nonetheless, they were surprisingly low, averaging $5-15 per capita for the most costly assumption. Similar results were found in a study in Pennsylvania as well.

It would be easy, but perhaps misleading, to conclude that climate has little secondary impact on urban places through their water supply. Urban water supplies have had an enormous historic investment designed to reduce their vulnerability to climatic variation in the form of drought. These investments are usually in the form of dedicated catchment areas, dams and storage structures, and deep wells. Ideally, a well-adjusted system should have little or no impact in the form of drought losses, only heavy expenditures to prevent drought vulnerability.

In reality it is difficult and very expensive to avoid any system failure and an engineering convention uses a "95% safe yield" as a design goal for an urban water system. In theory, such a goal would countenance failure to meet water withdrawals one in twenty years (on the average). In reality there are several failure buffers in the system. Nonetheless, for a specific system the safe yield (SY) of the system in per capita water availability is a measure of adjustment and can be roughly compared between different towns and cities. The ratio of current water use (WU) per capita to safe yield is a measure of system vulnerability. Those with ratios (WU/SY) much exceeding 1.0 are vulnerable to even small droughts, those with ratios much below 1.0 can suffer droughts of great magnitude with little disruption.

The WU/SY ratio of a particular place depends partly on the rate of investment in new water supply and the growth or decline in population and partly on the temporal cycle of providing new water supply. For example, dams are "lumpy" investments and usually provide an oversupply or cushion early in their lives as a city takes advantage of economies of scale. This cushion generally trails off slowly after initial construction, causing a slow, cumulative increase in system vulnerability.

For a region as a whole, the cumulative distribution of WU/SY among all systems is a general measure of the adjustment and vulnerability of the region and takes the form of a sigmoid curve, as shown in Figure 11. An interesting point posed by those data are the regional differences in adjustment. Systems in the arid Southwest are much more cushioned against drought than those in the humid Northeast.

The safe yield of a system reflects the adjustments in place. Consequential adjustments during and after a drought can also limit the losses. Most urban

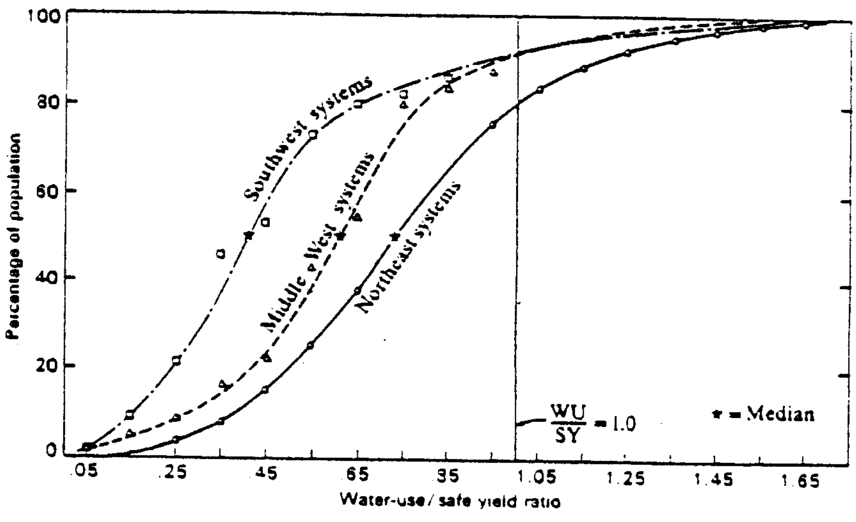


Figure 11. Interregional comparison of the distribution of population over the water-use/safe-yield scale (Russell, Arey, and Kates, 1970).

places can reduce demand by 10-20% for short periods with little loss of wealth and slight loss of convenience. In sum, the impacts of drought on urban water supply vary widely with the level of adjustment, and the cycle of investment in urban water supply, and the perceived importance of continuity in supply and flexibility in demand.

In this urban water supply case there is a convenient summary index of adjustment, the WU/SY ratio which can be tracked over time. In other sectors or places the task may be more difficult.

Identifying the range of adjustments is an integral part of natural hazard case research as illustrated by the collection of studies edited by White (1974). The practice has been to establish an inventory of theoretically possible adjustments and then to compare the potential to actuality. The methods used to identify adjustments range from background research and personal observation to questionnaire surveys. In a recent study of adjustments to drought among North Dakota wheat farmers, Riebsame (1981 and 1983) used manuscript records and official files kept by county agents and other governmental offices, newspaper accounts, oral histories, county tax and vital statistics, land-use data, and farmer interviews to build an extensive inventory of adjustments through time. Analysis of crop yields, experiment station records, and farm income data were then used to ascertain which adjustments were most efficacious in mitigating drought impacts.

In contrast to adjustments, very little work has been done on people's perception of climate fluctuation. Anne Whyte, of the University of Toronto, has studied perception of Toronto's climate and is compiling methodologies that would be useful to the study of climate impact and perception (Whyte, forthcoming). She has also produced a sourcebook on environmental perception study methods (Whyte, 1977), which gives details on over 15 methods for eliciting environmental perceptions in three categories: observation, interviewing, and listening.

Most perception studies rely on personal interviews or some other direct surveying of respondents. This approach ranges from simple, direct questionnaires asking if people noticed, and what they think about, certain environmental attributes or changes, to projective tests using scenes and "story telling" responses to get at underlying perceptions. Saarinen (1966) used scenes to elicit farmer's perceptions of the drought hazard on the U.S. Great Plains and direct questionnaires have been used to elicit people's perceptions of floods, snow, hurricanes, droughts, and other weather phenomena. But, besides Whyte's work, rarely have these studies been designed to get at perceptions of climate fluctuations.

Farhar-Pilgrim's work on the St. Louis fluctuation is a good model for a perception study. She interviewed key decision-makers (e.g., water and energy managers, local officials) with the goals of first assessing their awareness of the fluctuation and then documenting their responses, if any. A simple questionnaire format can be used to assess an individual's awareness of the CLIMPAX fluctuations, any purposeful adjustments <u>if</u> they did indeed perceive the anomalous conditions, and any possible changes in their operations if they did not perceive the fluctuation. "Community" perceptions may be accessible via a review of local newspaper articles, government documents, manuscript records on activities and events in agriculture (for example, county agent records), corporate records, local histories, farm and ranch diaries, etc.

2.2.2 Field Guide

As is evident from the previous two sections, several approaches are available for the study of impacts, perception, and adjustments and some specific case studies have employed these methods within a productive sector or a specific place (see Appendix III). For the CLIMPAX we must draw together these methods, adjust them to the problem at hand, and apply them in case studies.

In the second phase of the CLIMPAX, a broad field program is envisaged, consisting of many studies of specific fluctuations arranged in a design suitable to test hypotheses of climate impacts. The major task of the second year of Phase I is to develop that design and the methods to be used in the field studies. The "field guide" will be a document that will serve both as text and protocol for the field studies. The user of the guide will be a professional researcher in one of the many related disciplines but likely to have had no previous experience in climate impact analysis. Thus, the preparation of the guide includes providing the user with a broad understanding of major concepts and methods in climate impact analysis relevant to regions the size of several climate divisions and a detailed protocol for standardized collection and documentation of impact, perception, and adjustment.

Responsibility for preparation of the guide will rest with Riebsame (U. of Wyoming) and Cochrane and Mileti (Colorado State), with major assistance from the impact-sensitivity group relative to assessment methods for agriculture, water, and energy. The final product will be the guide itself, with an intermediate product a draft guide to be applied to pilot studies.

2.2.3 Pilot Studies

Prior to undertaking a large-scale field enterprise, at least three pilot studies of climate fluctuations will be conducted to test the basic methods of the proposed experiment. These pilot studies will not be simple replicas of the experiment itself, rather they will use alternative methods and design elements to test the draft field guide and to inform the proposed experimental design for Phase 2. The field trials will be under the leadership of Riebsame, Cochrane, and Mileti with substantial input from the impact-sensitivity group, and final products will include case study reports for each trial.

2.2.4 Experimental Design

The central tasks of the Phase II experiment are to test the magnitude of impact following a sustained decadal climate fluctuation, including primary and secondary impacts including adjustments, and to examine the perception, if any, of such fluctuations. For any given fluctuation, three related

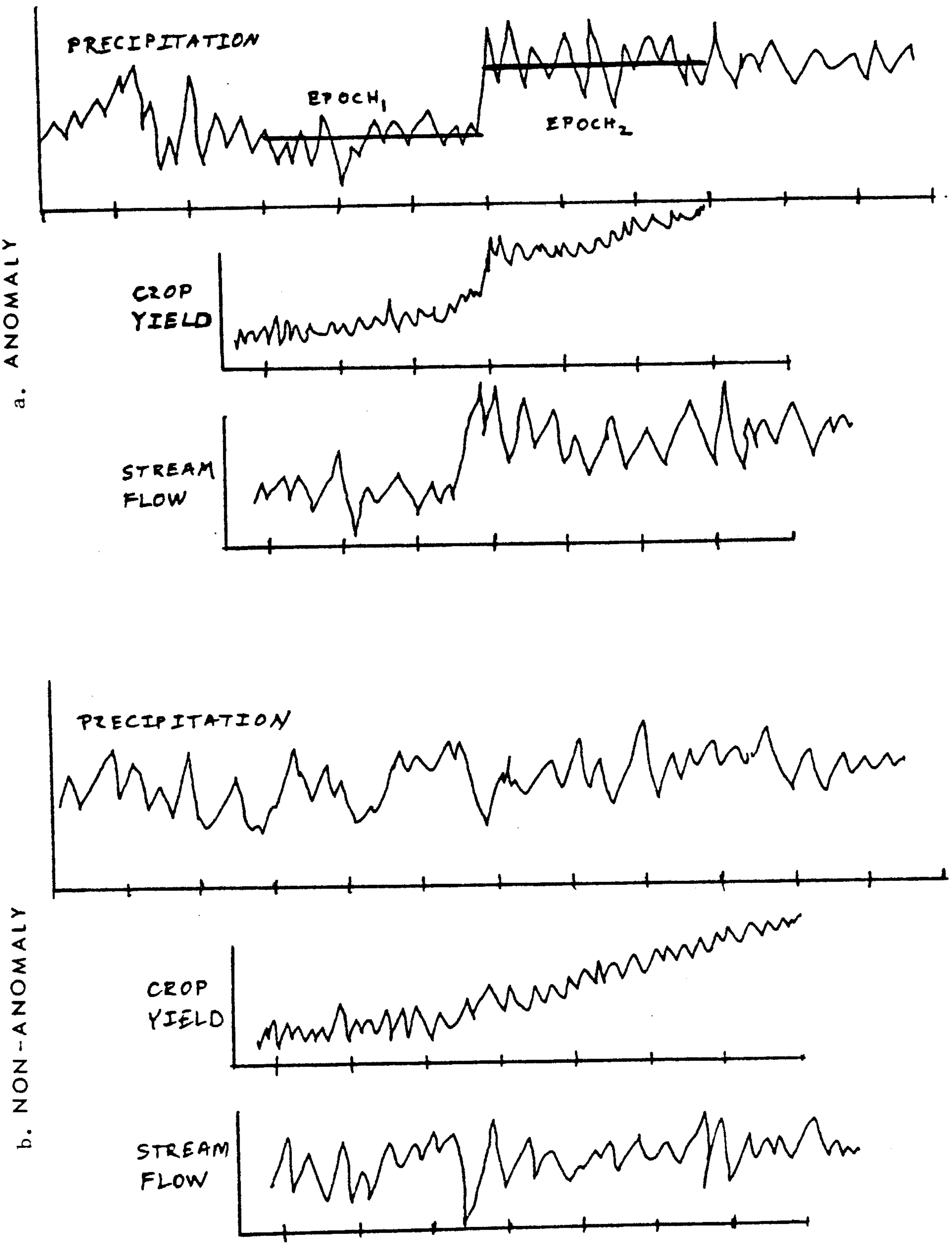


Figure 12. Hypothetical Paired Cases.

approaches are available. An idealized case example is shown in Figure 12. In Case A, a change in precipitation, indices of wheat yield and streamflow are compared with the precipitation record. In the wheat yield case, improvements in technology mask considerably the change between epochs whereas in the unmanaged watershed, streamflow actually amplifies the change. Although such a longitudinal analysis may be illustrative of impacts if their signal is strong, it may suffer from many problems, the most serious of which is the identification of impact in the face of broad secular changes in society or productivity.

The case-control approach is thus critical to establishing climate effects beyond reasonable doubt. Cases should be selected so that nonfluctuation areas nearby are similar enough to be used as nonaffected controls. There are no generally recognized methods for choosing control cases in real-world settings. In CLIMPAX similiarity criteria for control selection (e.g., crop proportions, urban-rural population profiles, production technologies, natural resource similarities, etc.) must be developed. Within the CLIMPAX design it is possible to examine several sets of paired fluctuation/nonfluctuation areas, and thus not rely on a single case-control situation to support the results; the multiple cases should provide the preponderance of evidence that makes empirical findings so compelling.

Part b of Figure 12 illustrates a hypothetical "control" or nonfluctuation series. Comparison of the case (fluctuation) and control (nonfluctuation) variables should yield the measurable climate impact. The difference, if any, between case/control either at individual time steps over the course of the fluctuation or before, during, and after the fluctuation should be in a direction and of a magnitude theoretically consistent with the fluctuation.

METROMEX researchers (cf. Changnon, et al., 1977) used a case-control approach in their search for agricultural, water, and socioeconomic impacts of the St. Louis urban-induced precipitation fluctuation. They termed the analysis "double target-control" wherein effects in the target area were compared to those in a control area for the epochs before and after the change. It is possible to impose a double or triple case-control approach in CLIMPAX wherein effects in the case and control areas are compared before, during, and sometimes after the fluctuation (there is no "after" period for St. Louis' ongoing effect on local and regional climate). Many of the analytical steps described by Changnon and his colleagues are directly transferable to CLIMPAX.

Special case-control conditions are possible in "see-saw" cases defined as situations where a climate fluctuation, by virtue of an opposite fluctuation nearby, results in an intense "fluctuation gradient" over a short space (see Class III anomalies in Table 1). Detection of impacts may be strengthened by comparing impact variables for places at opposite ends of the see-saw. This is the "reasoning from extremes" approach, a common element of climate impacts research, as discussed in Appendix III. In combination the longitudinal, case-control, and see-saw approaches represent straightforward but powerful tools for assessing climate impacts in the CLIMPAX fluctuations.

The responsibility for developing the experimental project design rests with the project executive committee chaired by R. Kates (Clark University) with government liaison from A. Hecht (National Climate Program Office). Final product for this phase of the work will be a design plan for Phase II and an independent evaluation of it (and the supporting documents of Phase I) undertaken by an ad hoc panel of the Board on Atmospheric Sciences and Climate of the National Research Council.

3.0 ORGANIZATION AND WORK PLAN

3.1 Investigation Team

An interdisciplinary team of government and university scientists has been organized to implement the CLIMPAX program. The CLIMPAX organization is shown in Figure 13. Major responsibilities of task groups are as follows:

Executive Committee: R. W. Kates, A. D. Hecht (federal government liaison), M. Berberian, Secy., S. Changnon, T. Karl, and W. Riebsame

The chief functions of this committee are to decide on the scientific strategy of the program; fix milestones; select principal investigators; serve as liaison with government agencies; assure dissemination of scientific results; complete all administrative responsibilities on time, and develop the experimental design for Phase II. Close coordination of government and university scientists will be required to assure access to data and application of data results.

Advisory Committee: G. F. White (U. of Colorado) (Chairman)

This committee of 4-6 members advises on scientific strategies for methodologies, the selection of case studies and geographic areas for field analyses, and the experimental design for Phase II.

Task Group 1: Climatology

This task group has prime responsibility for development of the climate data base and atlases. It will develop the methodology, the criteria for climate and CO_2 analog fluctuations and apply the criteria developed by Task Group 2's study of agriculture, water and energy.

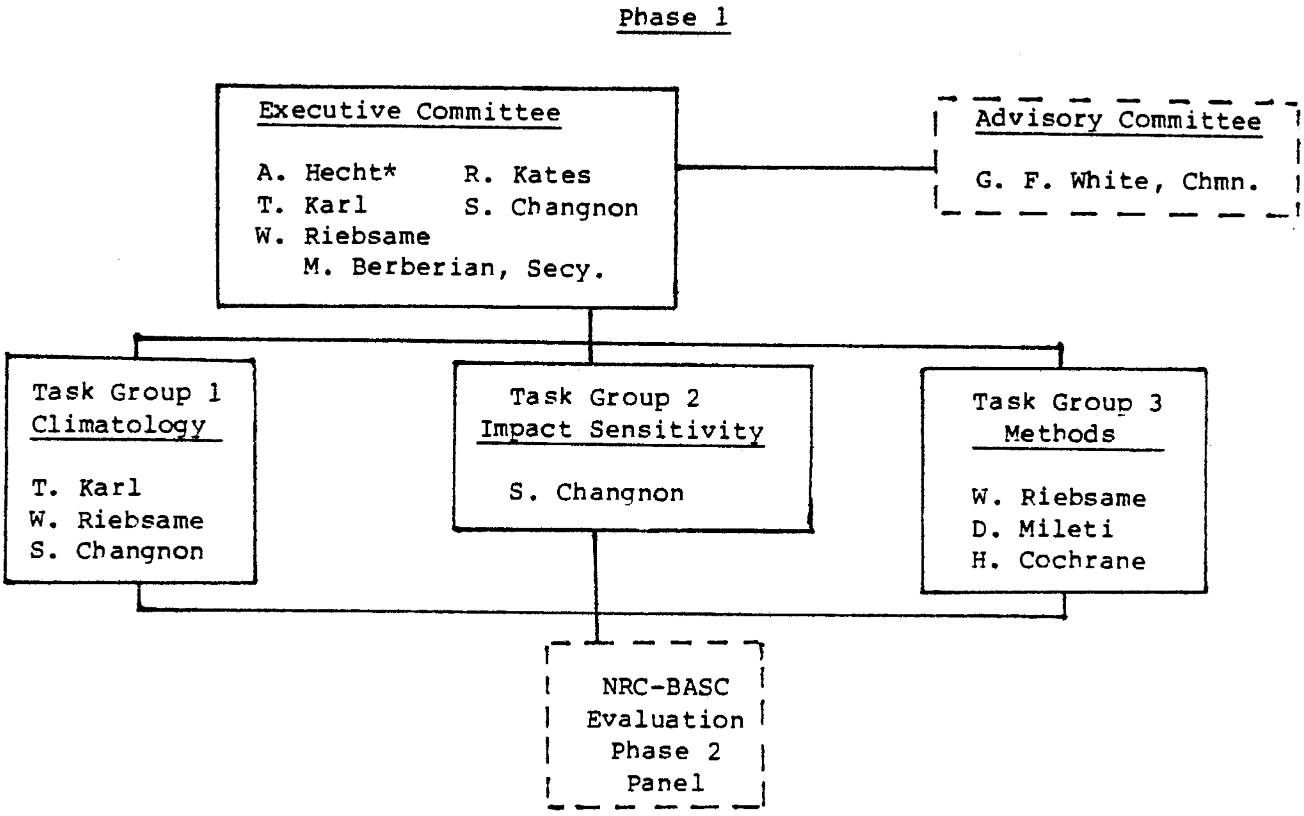
Task Group 2: Impact Sensitivity

This task group will summarize what is known about regional variation in major climate impacts in agriculture, water and energy, review these in specialty workshops, and develop criteria papers for fluctuation selection in major subsectors. They will also develop methods appropriate for agriculture, water and energy impact and adjustment analysis and participate with Group 3 in the development of the field guide and in pilot tests of it.

Task Group 3: Methods

This group will assemble the ancillary data catalog, develop the methods for studying the anomalies, assemble the draft field guide, test it in at least three sites, and prepare a revised final edition.

FIGURE 13. CLIMPAX Organization



*federal government liaison

3.2 Workplan and Schedule

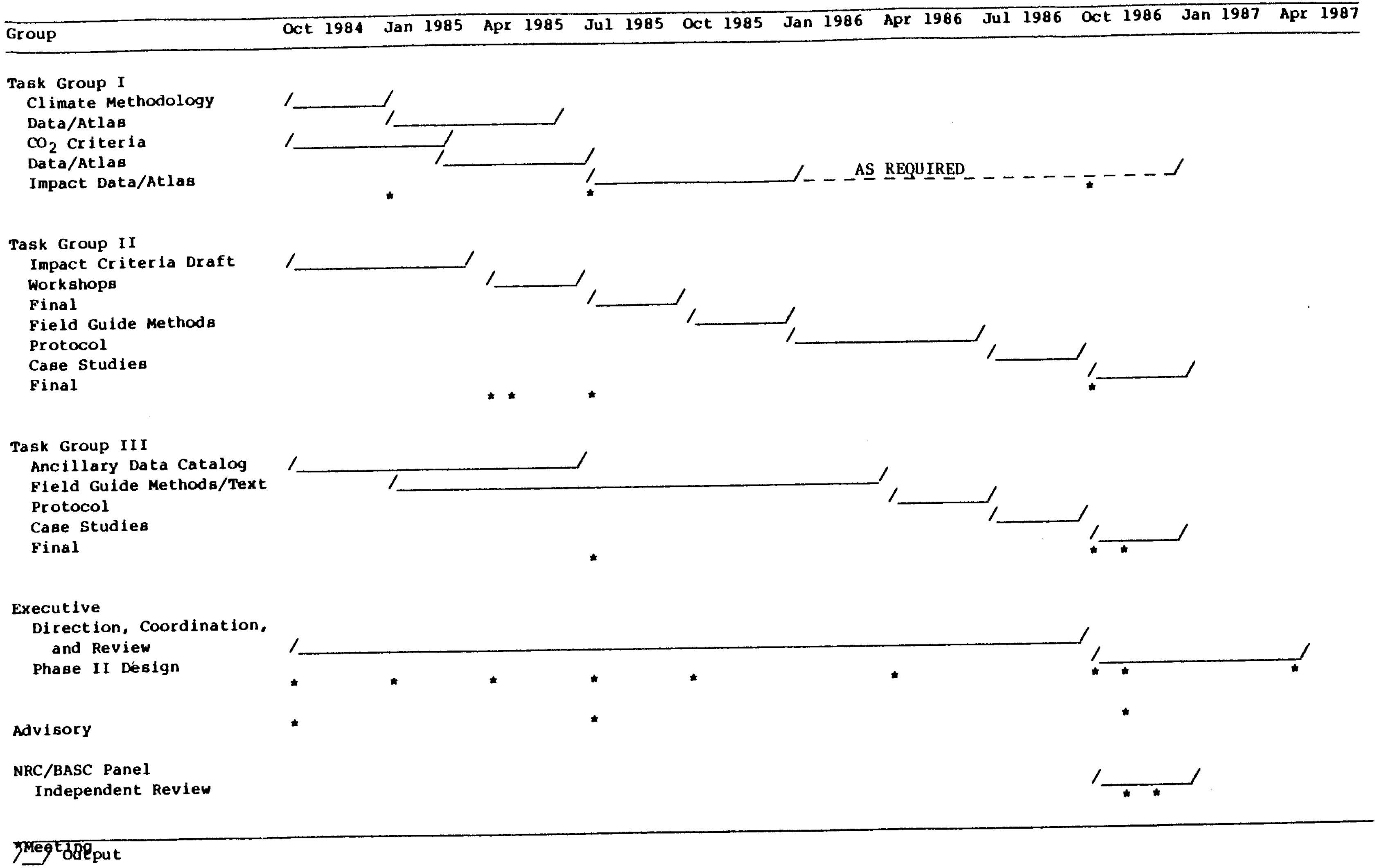
The research for Phase I is actually for 28 months, which include 24 months for research and a four-month period for the independent evaluation of Phase I output and the experimental design of Phase II. Product outputs are given in Table 3 and a calendar by work group is shown in Figure 14.

The executive committee will meet nine times over the 28-month period, including three meetings with the advisory committee. Two of the executive-advisory committee meetings will also include the full task groups. The first such meeting will be at a mid-project workshop to be held in Woods Hole in August 1985, and the second will be at an end-of-project symposium scheduled for Washington in November 1986 and will serve the twin purposes of briefing the independent review panel of the findings in Phase I and disseminating them to the Washington community of interested groups and agencies.

TABLE 3. Project Schedule.

Outputs	Lead Responsibility				Due Dates				Related Meetings		
	Exec./ Advisory	Task Group I	II	III	Draft	Review Resp.	By	Final	Place	Group	Date
Climate Anomalies											
Methodology Paper		X			11/84	Exec./Advisory	11/84	1/85	Washington, DC	Exec./Advisory	11/84
Data Base/Atlas		X						5/85			
CO_2 Analog Anomalies											
Criteria Paper		X			12/84	Exec./Advisory	1/85	2/85	Asheville, NC	Executive	1/85
Data Base/Atlas		X						6/85			
Impact-Sensitive Anomalies											
Specialist Workshop			X					4-5/85			
Criteria Papers			X		4-5/85	Specialist Wkshps	4-5/85	6-7/85	Urbana, IL	Executive	4/85
Data Base/Atlas		X						10-11/85			
Ancillary Data Catalog				X	4/85	Exec./Advisory Federal Agencies	6/85	8/85	Woods Hole, MA	Exec./Advisory Task Groups	8/85
Regional Studies Field Guide											
Methodology/Text			X	X	8/85	Exec./Advisory	10/85	1/86	Washington, DC	Executive	11/85
Protocol				X	4/86	Exec./Advisory	5/86	10/86	Worcester, MA	Executive	4/86
Pilot Case Studies				X	6-8/86	Exec./Advisory	9/86	9/86	Laramie, WY	Executive	9/86
Phase II Experimental Design	X				10/86	NRC/BASC Panel	2/87				
Independent Evaluation	X				11/86	NRC Review Process	1/87	2/87	Washington, DC	Exec./Advisory NRC/BASC Panel Task Groups	11/86
Dissemination	X				Continuous, as needed				Worcester, MA	Executive	3/87

FIGURE 14. Activity by Group.



APPENDIX I

The Climate Data Base and Fluctuation Estimation Procedure

The divisional monthly temperature and precipitation record for 1931-1982 will be used to search for CLIMPAX cases. Since 1931 each monthly average temperature within a division has been calculated by giving equal weight to each station reporting temperature within the division. The number of stations within a division varies over time as stations open and close. By using many stations within a division to calculate averages this potential source of bias is minimized. Divisional averages of precipitation are calculated in the same manner as divisional averages of temperature with one exception. Beginning in the 1950s (the exact date varies from state to state), only those stations which report both temperature and precipitation are used to calculate the divisional average precipitation. Since there are few stations which monitor temperature only, but an increasing number of stations which record precipitation only, this process virtually assures that divisional averages of temperature and precipitation are calculated from the same set of stations. In 1982 approximately 5,000 stations were used to calculate the divisional averages in the contiguous United States.

The divisional data set has some special attributes that make it quite suitable for use in the CLIMPAX. In order to represent accurately the spatial variability of precipitation, particularly during the warm season, a dense network of stations is required, such as those contained in the climate divisions. The divisional data span a sufficient number of years to detect decadal climate fluctuations across the contiguous United States, and yet the spatial resolution of much of the data is fine enough to detect fluctuations over several hundreds of kilometers. And many of the climate divisions have common borders with county lines. This is desirable since a substantial quantity of biophysical and socioeconomic information is categorized by county.

The student's t-statistic was used in the initial study as the primary means of identifying the major climate fluctuations. The advantage of using the t-statistic is that all areas and times are standardized with respect to each other. There is one t-statistic associated with each pair of epochs. The sign of the t-statistic denotes whether the mean is increasing in time (positive t) or decreasing (negative t). It should be noted that the significance levels associated with the t-statistics are not valid for the purpose of accepting or rejecting a hypothesis regarding whether a climate change is statistically significant. That is, the two epochs are samples taken from different distributions of climatic parameters. Indeed, they are not statistically significant since only the highest t-statistics are selected from nearly one million calculations of the statistic used in the pilot study. The significance levels are used merely as a means to detect the epochs with large climatic differences. In terms of human experience, however, the epochs with large t-statistics may be quite significant. They represent a switch from one 10-20 year period of a prevailing climate followed by a similar period with a markedly different climate. The social and biophysical significance of such fluctuations is the focus of CLIMPAX.

APPENDIX II

Analysis of Impact Assessment Studies in Agriculture, Water and Energy Fields

Agriculture. The agricultural sector is a hybrid natural resource area incorporating purely biophysical impacts (e.g., climate impacts on plant evapotranspiration) and human control and inputs (e.g., fertilizer, irrigation, management). A major problem in assessing the impact of a climate fluctuation on crop production is that typical crop-climate models do not distinguish climate influence from management decision. Most models (cf. Baier, 1977) are statistical "black-boxes" from which it is difficult to extract the climate effect. Haigh (1977), working with James McQuigg, made some progress in solving this problem with small grains, and some scientists (see Baier, 1983) are developing deterministic physical models that explicate the roles of climate, other environmental factors, and technological input and management on crop yield. But these approaches are currently too poorly developed for use in the CLIMPAX.

Good crop-climate models do, however, offer the possibility of statistically holding some variables constant while looking for the effect of changes in others. This would be especially useful in assessing multiple climatic impacts as in, for example, fluctuations characterized by changes in both precipitation and temperature. The same effect may be empirically available in fluctuation cases which occur in areas having experimental plots or "constant technology" plots operated by state agricultural experiment stations. Experiment station records may also include information on perceptions of and adjustments to the fluctuation.

Despite the ascendency of crop-climate modeling, agricultural data for the CLIMPAX case studies should first be scrutinized in simple longitudinal and case-control designs. Yield series for crops which agronomists (who are familiar with the region) suggest are sensitive to climate should be plotted and examined for inflections in trends concurrent with the alternation of fluctuation epochs. Next, we would compare yield series for the fluctuation and nearby, agriculturally similar, non-fluctuation areas. This comparison might be reduced to before, during, and after studies similar to the "double target-control" analysis employed in METROMEX.

It is also possible to hypothesize (as was done in METROMEX) differences in yield for stratified wet (cold), normal, or dry (hot) growing seasons, and then look for the changes as the frequency of such seasons is altered by the fluctuation. We should also examine interannual variations in crop yields across the fluctuation. Agricultural economists argue that large increases in yield variations, even if average yield is stable, threaten the financial health of farm firms. The relationships between shifts in mean climate values and yield variability are unclear, and certainly worth investigating. Fortunately, good crop yield data are available back to the 1930s for most county and divisional units across the U.S from joint USDA and state statistical services.

The first steps in a more sophisticated analysis based on crop-climate relationships are to obtain or build a localized crop-climate model and use the model to assess the climate sensitivity of crops (e.g., critical seasons and parameters). We might attempt to "hold technology constant" and compute yields with and without the fluctuation, then compare the results to the actual yield record.

Problems that will complicate the linking of a climate fluctuation with agricultural impacts, besides the role of technology discussed above, include the effects of preexisting (i.e., outside our averaging seasons) soil moisture conditions, the impacts of nonclimatic hazards like pests and disease (which may be indirectly affected by climate), changes in crop yield caused by singular events subsumed in our averaging periods (e.g., short rains or intense heat at a critical time), differential responses of hybrids of the same crop or of different crops, and interactions between temperature and precipitation.

Water. The most important variable to the CLIMPAX water sector assessment is stream discharge. Also of interest might be groundwater depth and recharge, water quality, storage in reservoirs, and changes in the storage-yield-risk relationships of drainages as described by Schaake and Kaczmarek (1979).

Stream discharge is the key link between the climate fluctuation and an element of direct human concern: water supply. Discharge is, of course, affected not only by temperature and precipitation but by drainage basin characteristics like infiltration capacity. Except in basins seriously altered over time (basins which should be avoided in our assessments) we can assume, as do most hydrologists when analyzing stream records, that these hydrological characteristics are constant over the fluctuation period (however, see the discussion below by Matalas and Fiering, 1977).

As with crop yields, the most effective approach to detecting the fluctuation's signal in stream discharge is simply to plot the flow series for gauging stations which are chosen so that the contributing drainage basin is encompassed by the fluctuation area. The signal will be a disruption of discharge rates consistent with the switch in climate epochs and not attributable to a set of reasonable alternative explanations (e.g., initiation of new stream diversion projects). A subsequent check is to compare series from within and without the fluctuation (case-control). Fortunately, reliable stream-flow data are available for most parts of the United States back to the early 1900s.

Matalas and Fiering (1977), in an excellent review of the problems associated with incorporating observed or predicted climatic change in hydrologic systems design, are pessimistic about detecting climate change in stream discharge records; they note:

> Even if there were to be a verifiable change in precipitation, say, a small increase in the mean annual value, it is not clear that the increment would be reflected in flow measurements over the short run coincident with the economic planning horizon. Typically, there would

> be a change in vegetative cover so that only some of the incremental precipitation would appear as incremental runoff, the rest being diverted to modified interception and evapotranspiration. Changes in temperature, whether due to changes in precipitation or to independent causes, might occur; these might produce further shifts in the vegetative cover or in land-use patterns (which might result from changes in cropping patterns induced by small changes in the thermal regime). In any case, however induced, changes in cropping patterns and land use imply new runoff coefficients for the region, so that with limited hydrometeorologic data the incremental precipitation cannot reliably be mapped directly into incremental flow. The same unreliability governs for decreases in mean precipitation.
>
> It is interesting to consider the rate at which regions adapt to new climatologic characteristics. The evolution of new vegetative patterns, the development of residential or commercial properties, and other long-term adjustments such as geomorphologic changes do not occur instantaneously. Adaptation to new precipitation patterns can be presumed to occur at about the same rate manifest by the precipitation, so it might be quite difficult to detect significant changes in runoff moments due to changes in precipitation and temperature. (p. 103)

The authors are discussing long-term climate change and not the 10-20 year fluctuations we will survey in CLIMPAX, but their concerns remain relevant. Models that link temperature and precipitation to stream discharge might be used in CLIMPAX to explore the interactions of climate and changes in basin characteristics.

Examples of case studies of water shortage impacts were reviewed by Meier (1977). Assessment methods in these studies ranged from interviews with local water officials to reviews of news accounts. Mail surveys conducted with the cooperation of local water supply systems were the most productive tools for eliciting adjustments.

Energy. The role of climate (especially temperature) in determining energy demand for space heating is well documented. Warren and LeDuc (1981) noted that energy "consumption for space heating and cooling is strongly related to temperature and can be quantified reliably..." They developed a detailed model that relates climate and price to gas consumption, arguing that price is the key nonclimatic variable affecting demand. The work by Warren, LeDuc and others should pose only a small immediate problem with the CLIMPAX design vis-a-vis energy. Most climate-energy modelers have found that heating or cooling degree-days are better related to energy consumption than raw temperatures. If we want the best fit between a fluctuation and energy demand, we are faced with the prospect of converting the climate data to degree-days. Wendland (1983) has demonstrated that monthly temperatures can be reliably used to model degree-days (the calculation is based on daily maxima and minima), eliminating the need to use a separate degree-day data set.

Our initial search for appropriate energy use statistics shows that they are somewhat limited. The work of energy-climate modelers has focused on data from the 1960s to the present. We have, however, discovered some longer-term records: The American Petroleum Institute has state-level fuel oil consumption statistics back to 1947; The American Gas Association has various gas consumption statistics back to the 1930s; and the Edison Electric Institute also has various statistical data bases. In addition, several long-term (i.e., 1930s to present) federal data sets on U.S. energy consumption are referenced in Schuer's (1972) report to the 1971 Resources for the Future Forum on Energy, Economic Growth, and the Environment. Identification and cataloging of such data sets is an important task of Phase I.

Henry Warren, of NOAA's Assessment and Information Services, has suggested that individual distribution systems and/or companies can be tapped for longer-term records. Much of the empirical work relating energy use to climate relies on relatively long data bases from individual distribution areas or companies (for example, the many studies abstracted in McQuigg, 1975; Woteki and Fels's (1978) study of climate-gas demand in New Jersey; and Greis's (1982) study of water demand for steam-electric generation). It might be possible to analyze consumption data for individual utility systems within and outside the selected climate fluctuation areas. Feasibility of this approach depends on data availability on a case-by-case basis.

Human adjustments (e.g., conservation) and changing space-heating trends will complicate our analysis of the fluctuation-energy connection. Adjustment data are of poorer quality and less easily available for energy than for agriculture and water.

Other Resource Areas. Despite the use of past floral and fauna ranges as indicators of paleoclimates, there remains little work that links contemporary climate fluctuations to changes in systems like forests and grasslands. Baumgartner (1979) belittled the role of climate fluctuations in forestry and cited little research in that field. Grassland ecologies, especially those used for livestock production, have received somewhat more attention (cf. LeHouerou, forthcoming) and some quantitative models linking climate to rangeland productivity have been developed. These might be useful for fluctuation cases in the western United States.

Fisheries, assumed to be affected by ocean temperatures and other characteristics, and shown to be especially sensitive in certain areas (e.g.,/the El Nino region off the west coast of South America) have received some attention from climate-impact assessors (e.g., Cushing, 1982). But poor data, difficulty in observing fish stocks, and complex atmosphere-ocean interactions have hindered the development of climate-fishery linkages, so much so that we might best bypass this resource area in CLIMPAX.

The firmest foundations for climate linkages with resource systems remain in agriculture, water, and energy. We feel that there is insufficient background for the inclusion of these other resource areas without some redefinition of the scope and purpose of CLIMPAX.

APPENDIX III
Related Research

Natural Hazard Research. The many studies of climatic impacts conducted under the rubric of natural hazards (including work on droughts, floods, frost, snow, etc.) have relevance to CLIMPAX. The natural hazards methodological focus is not as much on assessing impacts *per se*, as it is on identifying human perceptions and adjustments (cf. White and Haas, 1975). Major summaries of this research tradition are found in White (1974), Burton, Kates, and White (1978) and are critically assayed in Hewitt (1983).

Perhaps the most valuable legacy of natural hazards research in the United States has been its collaborative and multidisciplinary approach wherein a common framework was applied to a broad range of hazards. The collaboration of sociologists, psychologists, geographers, agronomists, planners, engineers and other scientists was a critical feature of the research which, at the least, serves to illustrate the potential range of expertise that might be brought to bear in CLIMPAX.

Two recent hazard studies have direct application to the CLIMPAX design. Both studies were empirical assessments of the long-term impacts of disasters on individual communities. The first, by Friesema *et al.* (1979), employed a longitudinal approach to systemic impact analysis. The researchers chose four cases of disasters during the 1950s and 1960s. Friesema and his colleagues attempted to apply several types of "interrupted time-series" (ITS) analysis to the data collected for each impacted community. Data quality ultimately restricted them to two practical methods: (1) visual inspection of the series for inflection concurrent with the disaster, and (2) tests of differences in least-squares regression coefficients before and after the disaster. They also used a least-squares regression trend line beyond the disaster to estimate effects attributable to the event (e.g., the difference between predicted and observed employment one year after the disaster).

The second natural hazard study with direct applicability to CLIMPAX is the Wright *et al.* (1979) study of counties experiencing disasters (i.e., tornadoes, earthquakes, floods, etc.). The investigators used a classical case-control design in which counties experiencing disasters between the 1960 and 1970 censuses were paired with unaffected counties. Differences in census data were compared to a set of hypothetical impacts (e.g., a disaster increases employment in the construction industry) and the difference in the ratio of variable values between the case and control counties. This approach encounters less data problems than the time-series approach (which is intolerant of data gaps) used by Friesema *et al.* but allows only a much coarser analysis with the additional problem that the time slices are fixed while the hazard events occur throughout the decade. Wright and his colleagues scale their chief research question to fit the decadal time step by asking if the disasters caused effects enduring enough to show up at the subsequent census. In most cases the answer was no.

Climate Impact Studies. A major work on methodology of climate-impact studies (Kates, forthcoming) is in development under the auspices of the Scientific Committee on Problems of the Environment (SCOPE) and will be available as a review and guide to CLIMPAX assessment methods. It contains a state-of-the-art review of basic concepts and models, current methodology to assess impacts in agriculture, water, fisheries, and pastoralism, disciplinary methods of historical, social, and economic analysis, and methods for simulation, constructing scenarios, and for the study of perception and adjustment.

In the published literature, methodology designed specifically to assess the impacts of climate fluctuations is rare; the field so far consists mostly of idiographic case studies. The wide range of analytical approach is well illustrated by two examples. First, Garcia (1981) employed a broad mixture of mostly informal methods to demonstrate the global impacts of bad crop weather in 1972. Garcia's case study groups were responsible for putting together information on the 1972 droughts and subsequent food supply changes with the goal of determining the relative role of climate and international market and political forces in the ensuing "famine." The study relies on comparison of crop, food stock, price and trade statistics vis-a-vis reports of drought and subsequent malnutrition in selected countries; it was an ambitious data collection and informal (i.e., nonstatistical) correlation effort. Other than this, there was no clearly followed, coordinated methodology.

In contrast, a more formal correlation approach was used recently by Palutikof (1983) in her study of climate impacts on industrial production in Great Britain. Palutikof noted that she was dealing with a linkage (climate-industry) that is not so intuitively obvious as, say, the climate-crop linkage. To overcome this, she took two steps common to climate impact assessments: (1) she selected extreme seasonal fluctuations for study, the assumption being that impacts will be most obvious in extreme cases (i.e., "reasoning from extremes"); and (2) she focused on industries that *a priori* knowledge, logic, and intuition dictate must be climate-sensitive (i.e., manufacturing firms that use hydroelectricity as a major input). She then regressed climate and industrial output statistics, concluding that "seasonal extremes of weather, in the form of severe winters and drought summers, affect industrial output (Palutikof, 1983, p. 78)." Palutikof paid close attention to nonclimate variables (such as labor disputes or inventory backlogs) that might influence output and controlled for their effects in the analysis.

The U.S. Great Plains portion of a climate impact study conducted by a Clark University research group (see Bowden et al., 1981; Warrick, 1980) utilized a case-study approach wherein agricultural counties characterized by a mix of activities and drought histories were compared over time. One goal of the approach was to normalize historical drought intensities in order to compare changes in impacts and adjustments over time. During the long period of study, about 100 years, sociotechnical change probably obscured indications of changes in impacts over time, but the comparison of counties across space (and, thus, across climate settings) was found to be useful in identifying drought impacts and adjustments.

A similar approach, and one related to "reasoning from extremes," is the search for impacts in "marginal areas" where populations and their resource activities are near some climatological barrier (e.g., dry margin, altitude margin, cold margin, etc.). Parry (1981) used this approach in studying historical farm abandonment patterns in Britain and is currently developing it into a focus for case studies to be organized by the International Institute for Applied Systems Analysis (IIASA) as part of the World Climate Impacts Program (WCIP).

Finally, Changnon (1979) used a very straightforward approach to assess the impacts of a severe winter (1977-1978) on residents of Illinois: he performed a mail survey of selected urban and rural households focusing on impacts ranging from extra heating costs to absences from work. From this it was possible to derive rough estimates of losses and to build an inventory of adjustments.

Social Impact Assessment (SIA). Social Impact Assessment is a varied collection of old and a few new approaches applied, especially in the last few years, to measuring the socioeconomic impacts of major projects like hydroelectric reservoirs and strip mines. At first glance this experience would seem applicable to climate impact assessment, especially in projects such as the filling of major reservoirs, fundamental changes in land use, or changes in regional economies. Unfortunately, few assessors have studied such analogs, focusing rather on studies of power plants, highway projects, military base closures, etc. Even in studies that do look at elements akin to climate change, the SIA goal is typically to predict impacts prior to development rather than to assess and monitor actual impacts. The lack of a theoretical and empirical base severely limits SIA's direct applicability to CLIMPAX. Nevertheless, SIA research is improving in scientific content and provides some guidance to CLIMPAX in two areas: (1) what socioeconomic variables are worth looking at, and (2) how to attribute changes to a particular cause (directly or indirectly climate-induced).

Finsterbusch and Wolf (1977) identify these basic categories of critical variables to be assessed in social impact assessment:

- population and migration
- employment
- housing
- health
- crime
- taxes, services
- costs of living
- community structure, cohesion
- leisure and recreation

He provided exhaustive citations to studies of highway projects, energy boom and bust towns, military base closings, etc., but while suggesting items on which to focus (e.g., changes in employment across categories like agriculture and manufacturing), he failed to discuss measurement techniques or the critical issue of causality.

Farhar-Pilgrim's (forthcoming) review of SIA's applicability to climate impacts lists four classes of social data to be included in an assessment: statistical social data (e.g., censal counts, farm size, crop prices, etc.), written social data (e.g., newspaper articles, historical documents, manuscript records), observational social data (e.g., researcher observations of relevant events such as weather modification efforts, land-use changes, etc.) and respondent contact social data (e.g., surveys and interviews). She also provides an informative background to SIA, but within the constraints of paper length, fails to describe applicable methods in detail, enhancing our sense that the SIA field does not offer any immediate assessment tools for the CLIMPAX.

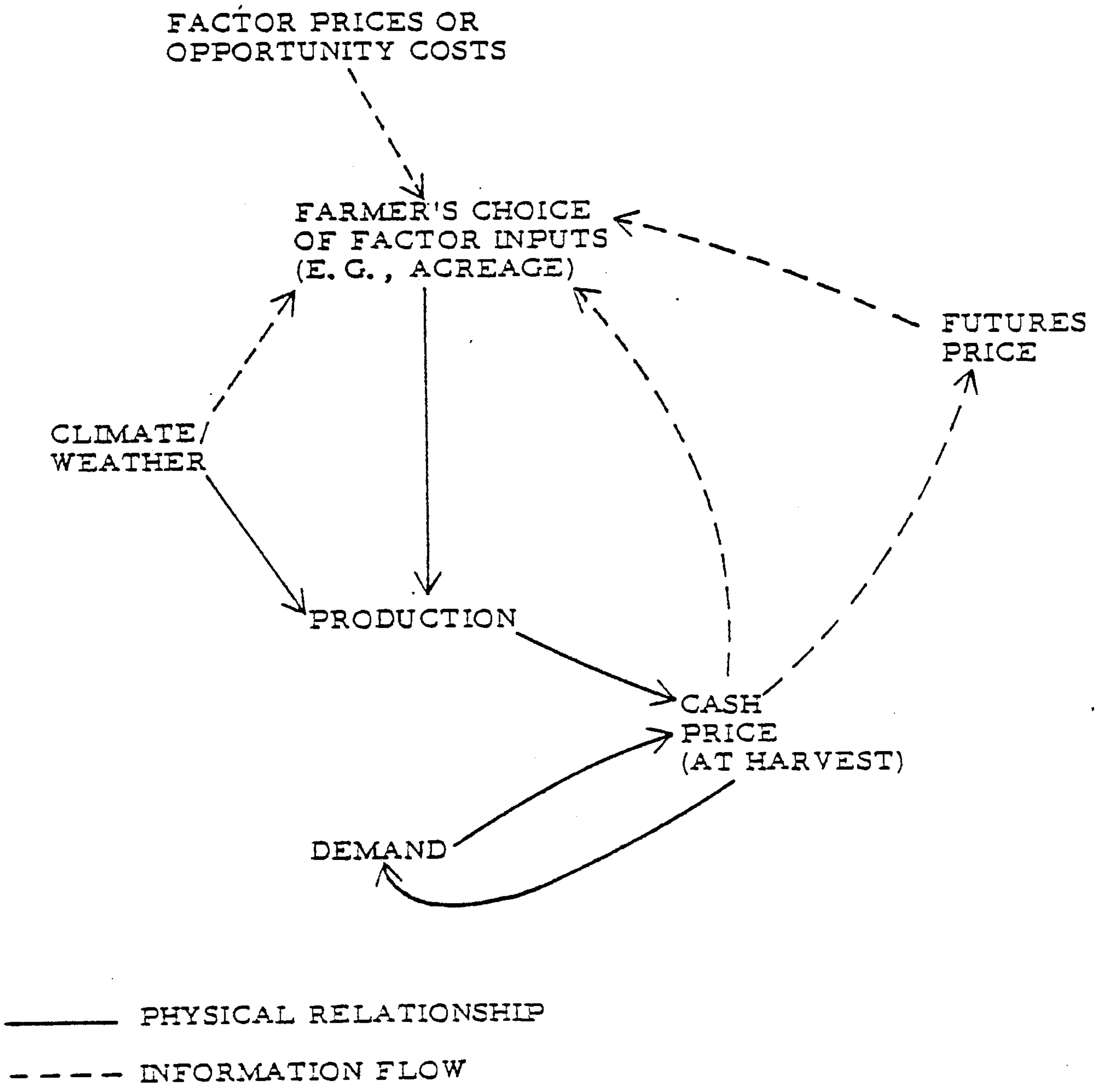
Besides data selection, a critical issue in CLIMPAX, as in climate impact research, will be causality. SIA, with its poor theoretical base, generally assumes (see Wisniewski and Thompson, 1981 for an exception) that changes in an impact variable that logically should be linked to the impacting factor, especially changes that correlate well with the timing of the development project concerned, can be attributed to the project. The search for climate impacts, however, requires a more rigorously established linkage of cause and effect.

Economic Analysis. Economics is rich in theory and methods capable of being employed in impact analysis (see Lovell and Smith, forthcoming) but the applications themselves are limited. In agriculture much of the impacts research has focused on the influence of climate on crop productivity (e.g., Thompson, 1969; McQuigg et al., 1973; Haigh, 1977). Relatively few studies have addressed the subsequent question of to what extent climate variation affects production costs and market prices, and, of those that do, few are empirical evaluations. Anderson (1978) has reasoned that in agriculture economic behavior in response to climate variation can basically be described with two statements: (1) the basic satisfaction of a group of farmers with farming depends on their aversion to risk and anticipated financial performance, and (2) anticipated financial performance of a group of farmers depends on allocative decisions, expected yields, expected prices, and institutional interventions. Allocative decisions subsume all decisions made by farmers such as operational intensities, improvements, acreage abandonment (nonharvest of planted acreage), etc. Climate fluctuations can greatly influence any of these facets. For example, Michaels (1983) has shown that acreage abandonment rates are primarily affected by climate variation and only minimally by expected prices. Furthermore, Agnew and Anderson (1977) have formulated explicit a priori models of the interaction of climate variation with yield, price, and institutional intervention at a regional level (see Figure 15). Thus, we have some systemic economic analyses of climate impacts on agriculture.

There are numerous examples of the economic importance of climate variability to water resources (e.g., Schaake and Kaczmarek, 1979; Development Resources Corporation, 1975; Meier, 1977; Changnon, et al. 1977) including municipal water supply, agriculture, hydroelectric generation, and navigation. Meier has proposed that economic loss from a chronic municipal water supply shortage

Figure 15.

Factors Affecting Producers of Wheat



can be disaggregated to:

1. Residential: increased costs of water (e.g., expanded storage costs passed to consumers)

2. Water-Intensive Industrial: reduced value added by manufacture plus reduction in payroll due to production cutbacks

3. Commercial: tourism (motels, hotels) is decreased and water-oriented firms (car washes, laundries, nurseries, etc.) experience losses

4. Other: water utilities lose revenue and experience increased costs due to implementation of water supplement strategies.

Many of the economic impacts of climate variability on water resources are inseparable from agriculture and energy. The Development and Resources Corporation (1975) has proposed that decreased precipitation, resulting in less and more costly irrigation water might create a net crop production decrease since some marginal lands, arable only with irrigation, might be taken out of production while in rainfed areas (still within the decreased precipitation region) additional marginal lands may be brought into production to offset the loss partially.

The main interaction of water resource systems with energy systems is focused on the effect of changing precipitation amounts, and corresponding streamflows, on hydroelectric generation. This is important because the amount of hydropower produced is proportional to the amount of streamflow passing the generator.

Finally, a good deal of the research on the economic impacts of climate change on energy resources has focused on fluctuations of energy demand, particularly space heating and cooling requirements (Jager, forthcoming; McQuigg, 1975). As noted above, climate and price, or more specifically degree-days and price, are directly related to space heating and cooling consumption. What is not clearly understood is to what extent the relationship between climate fluctuations and energy demand subsequently affects energy production costs and market prices.

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