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HUMAN RESPONSE TO WEATHER AND CLIMATE

GEOGRAPHICAL CONTRIBUTIONS

W. R. DERRICK SEWELL, ROBERT W. KATES, AND LEE E. PHILLIPS

DESPITE its charm and wit, the oft-quoted aphorism attributed to Mark Twain, "Everybody talks about the weather but nobody does anything about it,"[1] is hardly accurate. Men do, in fact, do something about the weather. They adapt to it or adjust to it, they move toward certain climatic regimes or away from them, and they have long contemplated weather modification. However, although geographers undoubtedly recognize that weather and climate have pervasive effects on human activity, there appears to have been a general decline in their interest in these relationships and in their ability to answer certain fundamental questions. These questions have become more and more important in recent years as man's ability to predict and modify the weather increases.

THE MODERN ERA OF WEATHER MODIFICATION

Traditionally, human response to weather and climate has consisted in adaptation, adjustment, and movement.[2] Men readily *adapt* physiologically to wide ranges of weather and climate. In a broad spectrum of human activity weather and climate have little perceptible effect on the activity pursued or on the rhythm of its pursuit. Other activities men can try to *adjust* to variations of weather and climate. This response functions on several levels. At a minimum level man changes his clothing to adjust to daily changes in the weather. At a more permanent level he insulates his home and installs a furnace or air conditioning to adjust to seasonal fluctuations; he builds stormproof structures to resist high winds; he develops weather-resistant crop varieties to withstand droughts or floods. A more drastic adjustment is

[1] H. L. Mencken, edit.: A New Dictionary of Quotations on Historical Principles (New York, 1942), p. 1278. "Author unidentified; commonly ascribed to S. L. Clemens (Mark Twain), but not found in his published works."

[2] J. Sonnenfeld (Variable Values in Space and Landscape: An Inquiry into the Nature of Environmental Necessity, *Journ. of Social Issues*, Vol. 22, No. 4, 1966, pp. 71–82) describes two major sets of reactions to the physical environment: adjustment and adaptation. In his definition movement and modification would presumably be a part of adjustment.

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movement to another place or region. Sometimes man finds that he is unable to withstand, physically or psychologically, severe climatic conditions, such as long periods of cold or heat or persistent rain. Technology helps him to adjust to these conditions, but it may be too costly, or it may result in such an artificial environment that he abandons it.

True, there have been attempts almost since the dawn of civilization to increase or reduce rainfall, to suppress lightning, to disperse hailstorms. But lack of scientific proof of the success of these attempts caused weather modification to be regarded by most people as an interesting idea but impossible to achieve consistently. Most skeptical of all were the research scientists who were studying the atmosphere.[3]

In the past few years, however, views about the possibility of modifying the weather have changed radically. Although the conclusion of the President's Advisory Committee on Weather Control in 1957[4] that precipitation could be substantially increased by artificial means was regarded with much skepticism by professional meteorologists, similar findings of the more recent Special Commission on Weather Modification[5] and the National Academy of Sciences–National Research Council Panel on Weather and Climate Modification[6] have aroused little debate. These later reports conclude that it is now possible to increase precipitation from winter orographic storms, to disperse cold fog, and to suppress lightning. They view with some optimism the possibility of successfully modifying hailstorms in the near future. Alteration of the tracks of major storms such as hurricanes and tornadoes is not ruled out, though it is regarded as not yet on the horizon.

The ability to alter the weather raises a number of questions. What would be the probable effects? Would some activities benefit and others suffer? Would some areas gain at the expense of others? Is modification superior to other possible means of accommodating to weather fluctuations? There are no simple answers to these questions, but it is clear that answers are urgently required, particularly since it seems likely that weather-modification activity in the United States will increase considerably in the next few years. Com-

[3] See, for example, Horace R. Byers: What Are We Doing about the Weather? *in* Science and Resources: Prospects and Implications of Technological Advance (edited by Henry Jarrett; Baltimore, 1959), pp. 37–53. See also D. S. Halacy, Jr.: The Weather Changers (New York, 1968).

[4] "Final Report of the United States Advisory Committee on Weather Control" (2 vols.; Washington, D. C., 1958).

[5] "Weather and Climate Modification: Report of the Special Commission on Weather Modification," *NSF 66–3,* National Science Foundation [1966].

[6] "Weather and Climate Modification: Problems and Prospects: Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences," *NAS-NRC Publ. No. 1350,* 2 vols., Washington, D. C., 1966.

mercial weather-modification firms feel that the reports of the two scientific committees substantiate claims which they themselves have been making for years. Consequently, commercial operations are almost certain to increase. In addition, several agencies of the federal government have already announced plans for major modification programs. For example, the Bureau of Reclamation has a multimillion-dollar program under way in several western states the aim of which is to find ways of enlarging snowpacks through cloud seeding. The resulting water would be used to expand irrigation. Other federal agencies are busily competing for the main responsibility for managing atmospheric resources.

The ability to modify the weather holds some intriguing possibilities. Most people would prefer to have it rain at night rather than during the day. A reduction in the almost constant drizzle on the Northwest Coast during the winter would be welcomed by most people in Seattle, Portland, and Vancouver. Farmers on the Great Plains would be happy to see their scanty rainfall augmented. Residents in Florida would doubtless be delighted to hear that a way had been found to reduce the incidence of hurricanes. Those in Bismarck, North Dakota, or Winnipeg, Manitoba, would be glad to have much milder temperatures in winter than those they now experience.

It is not certain, however, that alterations in the weather are uniformly beneficial. A rancher might be able to increase his profits as a result of a heavier rainfall on his range at a particular time, but the heavy rain might also fall on the fields of a neighboring farmer and ruin his crop. An electric-power utility might be able to increase its operating efficiency by raising the level of its reservoirs through cloud seeding, but the precipitation might ruin the holiday of vacationers who happened to be in the reservoir area at the time. The alteration of the track of a hurricane could reduce damage over a large area, but it would also divert precipitation on which city water utilities and electric-power companies depended to maintain the levels of their reservoirs. Weather modification would have differential effects not only within a given area but possibly between areas also. One area might benefit by an increase in precipitation, but this increase might have been achieved only by a reduction somewhere else.[7]

Concomitant with the new possibilities for weather modification have been improvements in the range and quality of forecasts. The use of satellites, the World Weather Watch, and the improved numerical models of the atmosphere linked to larger and faster computers suggest, for example, that

[7] Evidence from studies in connection with the University of Chicago research project Whitetop seems to raise the possibility that such reductions would occur.

eight-day forecasts with positive accuracy on the eighth day are only a decade or so away.

Weather modification and new information systems widen the range within the alternatives from which an accommodation to weather and climate can be chosen. The best choice in any given instance will depend on a careful weighing of the overall gains and losses of the alternatives—adaptation, adjustment, movement, and modification. The following questions give some indication of what it would be desirable to know to enable an objective appraisal. To what extent are various human activities sensitive to changes in the weather? What is the locational impact of weather and climate? How does weather enter into decision making? How do human activities affect the weather? It is pertinent to examine the contributions geographers have made so far that might help to answer these questions, and the further research that they could usefully undertake toward this end.

Contributions to the Geographical Literature[8]

From an early stage in the development of their discipline geographers have been interested in the relationship between the distribution of human activity and variations in climate. Indeed, beginning college students in geography might conclude that this is the fundamental factor accounting for the global distribution of man. One reason for this impression could be the emphasis on climate and its effects on human activity found in introductory textbooks. Of twenty-six textbooks commonly used in beginning geography courses in the United States, fourteen use climatic variations to regionalize the world.[9]

The geographer's view of the relationship between climate and man has

[8] This review is based mainly on North American geographical serials but also includes material in British, New Zealand, and Australian journals. It is incomplete to the extent that geographers may have contributed on the subject to literature outside the field of geography and to the extent that contributions to foreign-language geographical journals were not covered.

[9] George F. Deasy, Phyllis R. Griess, E. Willard Miller, and Earl C. Case: The World's Nations (Philadelphia, 1958); Loyal Durand, Jr.: World Geography (rev. edit.; New York, 1958); Otis W. Freeman and H. F. Raup: Essentials of Geography (2nd edit.; New York, Toronto, London, 1959); Paul F. Griffin and Ronald L. Chatham: Introductory College Geography (San Francisco, 1965); Oliver H. Heintzelman and Richard M. Highsmith, Jr.: World Regional Geography (3rd edit.; Englewood Cliffs, N. J., 1967); Joseph Bixby Hoyt: Man and the Earth (2nd edit.; Englewood Cliffs, N. J., 1967); George Kish, edit.: An Introduction to World Geography (Englewood Cliffs, N. J., 1956); Alfred H. Meyer and John H. Strietelmeier: Geography in World Society (Philadelphia and New York, 1963); E. Willard Miller, George T. Renner, and associates: Global Geography (2nd edit.; New York, 1957); Richard Joel Russell and Fred Bowerman Kniffen: Culture Worlds (New York, 1951); O. D. Von Engeln and Bruce Carlton Netschert: General Geography for Colleges (New York, 1957); Jesse H. Wheeler, Jr., J. Trenton Kostbade, and Richard S. Thoman: Regional Geography of the World (rev. edit.; New York, 1961); C. Langdon White and George T. Renner: College Geography (New York, 1957); C. Langdon White, George T. Renner, and Robert T. Novak: Essentials of College Geography (New York, 1958).

changed over time. Simplistic theories of cause and effect, subsumed under the rubric of environmentalism or environmental determinism,[10] have given way to probabilism and possibilism. The shift in emphasis is well recorded, but its implications for geographical thought are still not well understood.

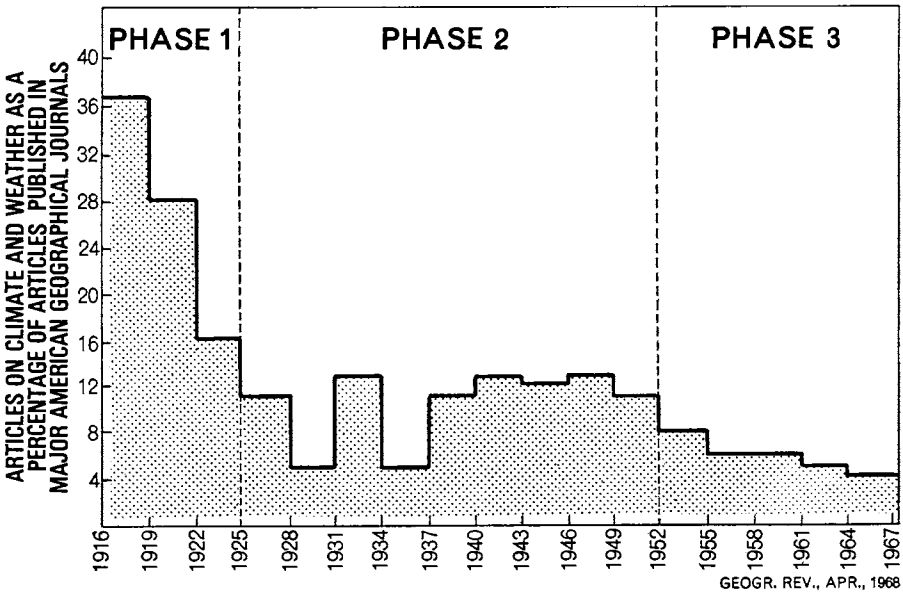

FIG. 1—Articles on weather and climate in American geographical journals.

In retrospect the retreat from environmentalism appears as a retreat from grand theory in geography. As Rostlund has perceptively put it, "environmentalism was not disproved, only disapproved."[11]

Accompanying the changes in geographical thought about the relationship between weather and climate and human activity has been a general decline in geographical interest in the matter. This is well illustrated by the relative number of articles devoted to the subject in the major American geographical journals in the period 1916–1966 (Fig. 1). In the early part of the period more than one-third of the articles in these journals were devoted to weather and climate and to their impact on human affairs. At the end of the period less than 5 percent of the articles dealt with these matters. There

[10] See, for example, Ellsworth Huntington's "Civilization and Climate" (New Haven and London, 1915) and "Mainsprings of Civilization" (New York and London, 1945); and Ellsworth Huntington and Sumner W. Cushing: Principles of Human Geography (2nd edit., rev.; New York and London, 1922). For a recent review see Gordon R. Lewthwaite: Environmentalism and Determinism: A Search for Clarification, *Annals Assn. of Amer. Geogrs.*, Vol. 56, 1966, pp. 1–23.

[11] Erhard Rostlund: Twentieth-Century Magic, *in* Readings in Cultural Geography (edited by Philip L. Wagner and Marvin W. Mikesell; Chicago, 1962), pp. 48–53; reference on p. 49.

are many possible interpretations of this trend, but three distinct phases may be observed, each associated with one or more major shifts in the field of geography. In the first phase, from 1916 to 1925, there was a general shift from environmentalism to other interpretations of the distribution of human settlement and activity. The second phase, from 1925 to about 1952, coincided with the concern of geographers with regional description. The third phase, from about 1952 to 1966, coincided with other changes in geographical interest, such as the shift from physical to human geography, from agrarian to urban concern, and, possibly, from the descriptive to the theoretical.

On the whole, geographers appear to have been more interested in the physical dimensions of the relationship between weather and climate and human affairs than in the human dimensions. Of 172 articles on the subject published in the period 1916–1966, only 71 dealt with the human aspects. The rest were concerned with climatological theory and classification, distribution, and description. However, some important contributions were made, notably by Thornthwaite and his associates in their work on the water balance, which has provided the theory and classification prerequisite to an evaluation of human use of the atmosphere.[12] Articles on the human dimensions have been concerned mainly with description and the generalization of the impact of atmospheric variables on various types of economic activities on the one hand, and physiologically on human beings, animals, and plants on the other.

EFFECTS ON AGRICULTURE

The fortunes of agriculture are closely related to fluctuations in the weather. Although technological advances have enabled the development of weather-resistant crops, and improvements in forecasting have made possible minor adjustments in planting and harvesting schedules, agricultural production in many areas is still much at the mercy of the weather.

Numerous geographical studies have been made of agriculture in different parts of the world. Most of them note that "weather fluctuations have important economic effects," but few discuss the importance in any detail. Several have analyzed the relationship between rainfall and crop yields,[13]

[12] See the following articles by C. Warren Thornthwaite in the *Geographical Review:* "The Climates of North America According to a New Classification" (Vol. 21, 1931, pp. 633–655), "Problems in the Classification of Climates" (Vol. 33, 1943, pp. 233–255), and "An Approach toward a Rational Classification of Climate" (Vol. 38, 1948, pp. 55–94).

[13] For example, Stephen S. Visher: Weather Influences on Crop Yields, *Econ. Geogr.*, Vol. 16, 1940, pp. 437–443; Thomas Frank Barton: Rainfall and Rice in Thailand, *Journ. of Geogr.*, Vol. 62, 1963, pp. 414–418; and P. N. Hore: Rainfall, Rice Yields and Irrigation Needs in West Bengal, *Geography*, Vol. 49, 1964, pp. 114–121.

but these have tended to concentrate on a single crop in a single area. There have been some studies of effects of particular weather events on agriculture, such as Calef's article on the winter of 1948–1949 in the Great Plains,[14] Subrahmanyam and Subramaniam's on drought in peninsular India,[15] and Hewes's on drought as a cause of wheat failure in the central Great Plains.[16] These studies, like those on the relationship between rainfall and crop yields, are mainly descriptive. Little attempt has been made to assess the economic importance of weather fluctuations either to the agricultural industry or to the economy of a region. Important exceptions are Maunder's study of the implications of climatic variations in New Zealand, in which a model is developed for determining the overall impact of variations in different weather parameters on the economy of a region,[17] and Curry's work in connection with the analysis of seasonal programming of agriculture in the United States and in New Zealand.[18]

Apart from these exceptions, the geographical literature contains little that would enable estimates to be made of the economic and social effects of weather variations on agriculture. And these exceptions, it should be noted, deal with Western society, in which agriculture is undertaken principally for commercial purposes and weather fluctuations mainly affect profits. In some societies the impact of weather changes may filter through the economic life into social relationships.[19] A drought in such societies may, therefore, have more profound effects, and the social impacts may be more critical than the economic ones.

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[14] Wesley Calef: The Winter of 1948–49 in the Great Plains, *Annals Assn. of Amer. Geogrs.*, Vol. 40, 1950, pp. 267–292.

[15] V. P. Subrahmanyam and A. R. Subramaniam: A Climatic Study of Droughts in Peninsular India, *Geogr. Journ.*, Vol. 129, 1963, pp. 122–125.

[16] Leslie Hewes: Causes of Wheat Failure in the Dry Farming Region, Central Great Plains, 1939–1957, *Econ. Geogr.*, Vol. 41, 1965, pp. 313–330.

[17] W. J. Maunder: Climatic Variations in Agricultural Production in New Zealand, *New Zealand Geographer*, Vol. 22, 1966, pp. 55–69.

[18] Leslie Curry: Climate and Economic Life: A New Approach: With Examples from the United States, *Geogr. Rev.*, Vol. 42, 1952, pp. 367–383; *idem.:* The Climatic Resources of Intensive Grassland Farming: The Waikato, New Zealand, *ibid.*, Vol. 52, 1962, pp. 174–194.

[19] Vogt has shown that fluctuations in weather have profound importance for the social relationships of certain tribal societies, such as the Navahos and Zuñis of the arid southwestern United States and the Zinacantecos of the humid central highlands of Chiapas, Mexico (Evon Z. Vogt: Some Implications of Weather Modification for the Cultural Patterns of Tribal Societies, *in* Human Dimensions of Weather Modification [edited by W. R. Derrick Sewell], *Univ. of Chicago, Dept. of Geogr., Research Paper No. 105*, 1966, pp. 373–392); and Bennett has investigated social adaptation in arid regions (John W. Bennett: Two Memoranda on Social Organization and Adaptive Selection in a Northern Plains Region, *Plains Anthropologist*, Vol. 8, 1964, pp. 10–12; *idem:* Risk and Rationality: Aspects of Behavioral Adaptation in an Arid Variable Habitat, *ibid.*, Vol. 7, 1963, pp. 8–21; and *idem:* Social Adaptation in a Northern Plains Region: A Saskatchewan Study, *in* Papers Presented at Great Plains Symposium [Institute of Regional Studies, North Dakota State University, Fargo, 1963]).

EFFECTS ON TRANSPORTATION

The operations of road, railroad, airline, and ocean transport systems are highly sensitive to changes in weather, and especially to heavy precipitation, fog, and winds. In the United States these weather phenomena result in losses estimated by the Weather Bureau to exceed four hundred million dollars a year,[20] most of which is attributable to costs of delays in air transportation.[21] Losses are said to be substantial in other countries as well.[22]

Although geographers have made many important contributions to the understanding of transportation development, they have shown comparatively little interest in the relationship of weather to the operation of the various forms of transport. Apart from Van Cleef's pioneering study of streetcar traffic in Duluth, Hay's article on the effects of weather on railroad operation, maintenance, and construction, and Rooney's work on the urban snow hazard,[23] there have been few studies of the effects of various weather phenomena on roads, railroads, airlines, or water transport. Nor have geographers undertaken many investigations of the effects of particular weather events on the transportation of given regions.[24]

EFFECTS ON INDUSTRY

Fluctuations in temperature, and to some extent in precipitation and wind, lead to fluctuations in the demand for fuel and power,[25] and affect the operation of various energy-supply facilities.[26] Here again, geographers have made

[20] Derived from estimates presented in E. Bollay and Associates, Inc.: Economic Impact of Weather Information on Aviation Operations: Final Report to the Federal Aviation Agency (Washington, D. C., 1962); M. A. Senko: Weather Satellite Study (U. S. Weather Bureau, Washington, D. C., 1964); and "Plan for a Marine Weather Service," *Planning Rept. No. 4,* ESSA, U. S. Weather Bureau, Washington, D. C., 1966.

[21] J. C. Thompson: The Potential Economic and Associated Values of World Weather Watch, *World Weather Watch Planning Rept. No. 4,* World Meteorological Organization, Geneva, 1966.

[22] *Ibid.*

[23] Eugene Van Cleef: The Influence of Weather on Street-Car Traffic in Duluth, Minnesota, *Geogr. Rev.,* Vol. 3, 1917, pp. 126–134; W. W. Hay: Effects of Weather on Railroad Operation, Maintenance, and Construction, *in* Industrial Operations under Extremes of Weather (edited by J. A. Russell), *Meteorol. Monographs,* Vol. 2, No. 9, 1957, pp. 10–36; John F. Rooney, Jr.: The Urban Snow Hazard in the United States: An Appraisal of Disruption, *Geogr. Rev.,* Vol. 57, 1967, pp. 538–559. However, several studies of the influence of weather on transportation have been undertaken by applied meteorologists and others; see, for example, J. C. Tanner: Weather and Road Traffic Flow, *Weather,* Vol. 7, 1952, pp. 270–275, which analyzes the effect of various weather phenomena on daily and holiday road traffic.

[24] Here again applied meteorologists have made several interesting contributions. See, for example, Donald L. Champion: Weather and Railway Operation in Britain, *Weather,* Vol. 2, 1947, pp. 373–380.

[25] For a discussion see W. J. Sweeney: Importance and Need of Degree-Day Forecasting for the Petroleum Industry, *Weatherwise,* Vol. 10, 1957, pp. 197–201 and 214.

[26] See, for example, M. Davies: Grid System Operation and the Weather, *Weather,* Vol. 15, 1960, pp. 18–24; and W. R. Derrick Sewell: Weather Modification and Hydro-electric Power, *Water Power,* September, 1966, pp. 353–357.

useful contributions to the understanding of the development of energy industries but have shown comparatively little interest in the economic effects of various weather phenomena on these industries. An exception is Manley's study of climatic fluctuations and fuel requirements,[27] in which he estimates needs for coal where seasonal temperatures fall below certain levels.

A considerable part of geographical research, especially in recent years, has been focused on the location of manufacturing industry. Many valuable studies have been undertaken, including studies of particular industries or of manufacturing activity in particular regions. In addition, geographers have made major contributions to an understanding of the distribution of such activity through the development and application of theoretical models.

In searching for explanations of the location of manufacturing industry, geographers have examined the potential importance of a wide variety of factors, including climate. Most researchers seem to have concluded that climate and weather are seldom major determinants of location, and that they generally do not greatly affect operations. Summarizing the findings of a series of monographs on applied meteorology published in 1957, Russell noted that climate and weather appear to influence only the construction, automotive, and aircraft industries to any large extent.[28] Other industries, he suggested, are either unaffected by variations in precipitation, temperature, pressure, and wind or have been able to protect against them at small cost. Valuable as these studies are for isolating the possible effects of various weather parameters on different industrial processes, no information is given on the economic significance of these effects.

Climate may play an indirect role in industrial location. The migration of population to the American West since World War II is a reflection of the fact that technological advance and increasing affluence have loosened locational ties. The list of footloose industries has grown enormously in the past twenty years. Arizona, California, Texas, and Florida have become magnets for population and for footloose industries.[29] Recognition of these forces led to Ullman's pioneering study of the role of amenities in industrial location.[30]

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[27] Gordon Manley: Climatic Fluctuations and Fuel Requirements, *Scottish Geogr. Mag.*, Vol. 73, 1957, pp. 19–28.

[28] J. A. Russell: The Problem, Method, and Conclusions, *in* Industrial Operations under Extremes of Weather [see footnote 23 above], pp. 1–9.

[29] There have been a few studies of the growth of urban communities in areas of pleasant climate, such as Margaret T. Parker: Tucson: City of Sunshine, *Econ. Geogr.*, Vol. 24, 1948, pp. 79–113; and Andrew Wilson: The Impact of Climate on Industrial Growth: Tucson, Arizona: A Case Study, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 249–260.

[30] Edward L. Ullman: Amenities as a Factor in Regional Growth, *Geogr. Rev.*, Vol. 44, 1954, pp. 119–132.

Unfortunately, the amenities factor seems to have received relatively little attention in subsequent geographical analysis.

EFFECTS ON TERTIARY ACTIVITIES

A principal focus of geographical research in recent years has been urban development, and an important part of this work has been concerned with the growth of tertiary activities, particularly wholesale and retail trade. Here, too, geographers have made major contributions, too numerous to mention, to the understanding of the location of economic activity.

Climate and weather seem to have an influence on various tertiary activities, especially wholesale and retail trade and recreation. Department-store sales, for example, fluctuate with variations in the weather. Sunshine increases recreational enjoyment, rainfall reduces it. Snowfall at the right time in ski areas multiplies recreational opportunities. Geographers have undertaken a few studies of the influence of weather on such activities, but none of these have been penetrating. None answer such questions as what difference a wet Monday in spring makes to department-store sales in a particular city; whether similar variations in the weather have similar effects on the retail trade of cities in different parts of the country; what the effect is on baseball of a rainy Sunday in July in Chicago as compared with a rainy Sunday in New York; or whether a period of continuously warm weather affects boating more in the Midwest than in the Pacific Northwest.

EFFECTS ON ACTIVITIES OTHER THAN ECONOMIC

Studies by natural scientists and others have shown that activity of human beings is affected in a wide variety of ways by changes in the weather. Human beings are able to withstand considerable extremes of temperature, but productivity seems to fall rapidly before these extremes are reached. There also seem to be variations with fluctuations in rainfall, wind, and pressure. And weather changes apparently stimulate psychological reactions also.[31]

Geographers have undertaken a variety of studies concerning physiological and psychological reactions to fluctuations in the weather. Maunder has attempted a classification of climate based on indices of human comfort.[32] More recently, Terjung has devised comfort and wind-effect indices to pro-

[31] For a review of the literature on the effects of climate and weather on human beings see Selco W. Tromp: Medical Biometeorology (Amsterdam, London, New York, 1963); and Marston Bates: The Role of Weather in Human Behavior, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 393–407.

[32] W. J. Maunder: A Human Classification of Climate, *Weather*, Vol. 17, 1962, pp. 3–12.

duce a map of annual physioclimatic extremes in the United States.[33] Lee and Lemons have discussed man's adaptation to climate as revealed by the adoption of different kinds of clothing.[34] Several geographers have studied geographical aspects of public health. Shoshin, for example, has examined the incidence of various types of disease in the Soviet Union,[35] and Murray has investigated causes of death in England and Wales as they relate to the weather.[36] Lee has also investigated the problems that armed forces face in adapting to foreign climates.[37] Studies by geographers of impacts of weather on human physiology, psychology, and activity complement studies by applied climatologists and others.[38]

CLIMATE, WEATHER, AND THE DECISION-MAKING PROCESS

Man's accommodation to his atmospheric environment no doubt reflects his perception of the effects of temperature, precipitation, and wind, and of the opportunities for adapting to them. The fact that he rejects certain climatic regions but accepts others indicates that he is unable to pursue some activities where temperatures are very high or very low, where precipitation is scanty or too heavy, or where winds are especially strong. However, accommodation to a given type of climate varies from region to region, ac-

[33] Werner H. Terjung: Annual Physioclimatic Stresses and Regimes in the United States, *Geogr. Rev.*, Vol. 57, 1967, pp. 225–240. See also his "Physiologic Climates of the Conterminous United States: A Bioclimatic Classification Based on Man," *Annals Assn. of Amer. Geogrs.*, Vol. 56, 1966, pp. 141–179.

[34] Douglas H. K. Lee and Hoyt Lemons: Clothing for Global Man, *Geogr. Rev.*, Vol. 39, 1949, pp. 181–213.

[35] A. A. Shoshin: Geographical Aspects of Public Health, *Soviet Geography*, Vol. 5, No. 7, 1964, pp. 68–72.

[36] Malcolm Murray: The Geography of Death in England and Wales, *Annals Assn. of Amer. Geogrs.*, Vol. 52, 1962, pp. 130–149.

[37] Douglas H. K. Lee: The Role of Bioclimatology in the Armed Forces, *Bull. Amer. Meteorol. Soc.*, Vol. 41, 1960, pp. 235–237.

[38] Clarence A. Mills: Depression Weather and Health, *Human Biology*, Vol. 10, 1938, pp. 388–399; *idem:* Weather and Health, *Bull. Amer. Meteorol. Soc.*, Vol. 19, 1938, pp. 141–152; *idem:* The Influence of Climate and Geography on Health, *Bull. New York Acad. of Medicine*, Ser. 2, Vol. 17, 1941, pp. 922–933; Alan C. Burton and Otto G. Edholm: Man in a Cold Environment: Physiological and Pathological Effect of Exposure to Low Temperatures (London, 1955); W. S. S. Ladell: The Influence of Environment in Arid Regions on the Biology of Man, *in* Human and Animal Ecology: Reviews of Research (Arid Zone Research No. 8; UNESCO, Paris, 1957), pp. 43–99; R. E. O. Williams: Weather and Health, *New Scientist*, Vol. 4, 1958, pp. 1583–1584; Robert L. Hendrick: An Outdoor Weather-Comfort Index for the Summer Season in Hartford, Connecticut, *Bull. Amer. Meteorol. Soc.*, Vol. 40, 1959, pp. 620–623; "Environmental Physiology and Psychology in Arid Conditions: Reviews of Research" (Arid Zone Research No. 22; UNESCO, Paris, 1963); P. M. Stephenson: An Index of Comfort for Singapore, *Meteorol. Magazine*, Vol. 92, 1963, pp. 338–345; "Environmental Physiology and Psychology in Arid Conditions: Proceedings of the Lucknow Symposium" (Arid Zone Research No. 24; UNESCO, Paris, 1964); and P. Fergusson: Summer Weather at the English Seaside, *Weather*, Vol. 19, 1964, pp. 144–146. The major reference for the effects of weather and climate on physiology and psychology is Tromp, *op. cit.* [see footnote 31 above].

cording to cultural background, level of technology, degree of economic development, and so on.

The relationship between perception of effects of atmospheric variations, particularly short-term variations, and action to accommodate to them is only vaguely understood. How much change in temperature, precipitation, or wind does it take to stimulate action? How do people decide whether or not to carry an umbrella? Do factory owners gear operations to changes in the weather, or do they adjust to climate rather than to weather? How do people use weather forecasts? Do they prefer to adapt or adjust to the weather or to try to change it? Answers to questions such as these require an understanding of man's perception of the effects of weather changes and his means of dealing with these changes.

Geographers have undertaken a few investigations that further such understanding. Kates's study of perception of flood hazards[39] and studies by Burton and Kates[40] of other natural hazards have provided a framework for analysis of human adjustment to variable physical phenomena, such as floods and winds. Saarinen's work on adjustment to drought in the Great Plains[41] and Rooney's on adjustment to snow in various parts of the United States[42] furnish further insight into the relationship between perception of weather events and adjustment to them.[43] In another vein, studies by Saarinen[44] and by Sewell and Day[45] of the relationships between perception of the effectiveness of weather modification and attitudes toward its adoption suggest new avenues of inquiry into man's accommodation to weather variations. Gould has introduced a relatively new technique of analysis, the theory of games, as a tool of research and as a conceptual framework for human and economic geography.[46] However, as with natural-resources development in general, the role of perception and attitudes in decision making relating to the use

[39] Robert William Kates: Hazard and Choice Perception in Flood Plain Management, *Univ. of Chicago, Dept. of Geogr., Research Paper No. 78,* 1962.

[40] See, for example, Ian Burton and Robert W. Kates: The Floodplain and the Seashore: A Comparative Analysis of Hazard-Zone Occupance, *Geogr. Rev.,* Vol. 54, 1964, pp. 366–385.

[41] Thomas Frederick Saarinen: Perception of the Drought Hazard on the Great Plains, *Univ. of Chicago, Dept. of Geogr. Research Paper No. 106,* 1966.

[42] Rooney, *op. cit.* [see footnote 23 above].

[43] These four studies have recently been reviewed in Ian Burton, R. W. Kates, and G. F. White: The Human Ecology of Extreme Geophysical Events (forthcoming).

[44] T. F. Saarinen: Attitudes towards Weather Modification: A Study of Great Plains Farmers, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 323–328.

[45] W. R. Derrick Sewell and J. C. Day: Perception of Possibilities of Weather Modification and Attitudes toward Government Involvement, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 329–344.

[46] Peter R. Gould: Man against His Environment: A Game Theoretic Framework, *Annals Assn. of Amer. Geogrs.,* Vol. 53, 1963, pp. 290–297.

of atmospheric resources remains a critically important but still undeveloped field of inquiry.

EFFECTS OF HUMAN ACTIVITIES ON WEATHER AND CLIMATE

The physical environment places various limitations on human settlement and activity. But in his attempts to accommodate to this environment, man himself creates other limitations. In many parts of the world concern is now growing about the effects of human activitity on the land, the water, and the atmosphere. Geographers have tried to trace the impact of certain activities on the physical environment. Some, for example, have studied the effects of deforestation on the hydrologic cycle.[47] A few have shown particular concern about effects on the atmosphere.[48] Others have investigated the influence of urbanization on climate,[49] particularly the effects of urbanization and industrialization on air pollution and the weather.[50] A recent study of effects of human activities on weather and climate is that of Bryson on the formation of the Rajputana (Thar) Desert in northwestern India.[51]

PURPOSEFUL WEATHER MODIFICATION

As was noted earlier, man can adapt to the weather, adjust his activities to weather changes, or move elsewhere. He can also alter the processes that produce these changes. Although geographers have shown considerable interest in other forms of human modification of the physical environment, such as agricultural development, harnessing of water resources, and deforestation, they have undertaken only a few studies of weather modification. Apart from contributions by Ackerman and Löf[52] and by Spilhaus,[53]

[47] For example, J. G. Nelson and A. R. Byrne: Man as an Instrument of Landscape Change: Fires, Floods, and National Parks in the Bow Valley, Alberta, *Geogr. Rev.*, Vol. 56, 1966, pp. 226–238.

[48] The most comprehensive review of this subject is C. W. Thornthwaite: Modification of Rural Microclimates, *in* Man's Role in Changing the Face of the Earth (edited by William L. Thomas, Jr.; Chicago, 1956), pp. 567–583.

[49] For example, H. E. Landsberg: The Climate of Towns, *in* Man's Role in Changing the Face of the Earth, pp. 584–606. Potter has examined the influence of urbanization on snowfall (J. Graham Potter: Changes in Seasonal Snowfall in Cities, *Canadian Geographer*, Vol. 5, No. 1, 1961, pp. 37–42).

[50] For example, P. D. Tyson: Some Climatic Factors Affecting Atmospheric Pollution in South Africa, *South African Geogr. Journ.*, Vol. 45, 1963, pp. 44–54; and Philip A. Leighton: Geographical Aspects of Air Pollution, *Geogr. Rev.*, Vol. 56, 1966, pp. 151–174.

[51] Reid A. Bryson: Is Man Changing the Climate of the Earth? *Saturday Rev.*, Apr. 1, 1967, pp. 52–55. See also Reid A. Bryson and David A. Baerreis: Possibilities of Major Climatic Modification and Their Implications: Northwest India, A Case for Study, *Bull. Amer. Meteorol. Soc.*, Vol. 48, 1967, pp. 136–142.

[52] Edward A. Ackerman and George O. G. Löf: Technology in American Water Development (Baltimore, 1959), especially pp. 356–383 and 630–637; and Edward A. Ackerman: Weather Modification and Public Policy, *in* Science and Resources [see footnote 3 above], pp. 54–62.

[53] Athelstan F. Spilhaus: Sea and Air Resources, *Geogr. Rev.*, Vol. 44, 1954, pp. 346–351; and *idem:* Control of the World Environment, *ibid.*, Vol. 46, 1956, pp. 451–459.

little is to be found in the geographical literature relating specifically to this subject that would enable an appraisal of accommodation to the atmosphere.

Only recently have geographers, like other social scientists, begun to examine the possibilities and implications of man's ability to alter the weather. The Symposium on Economic and Social Aspects of Weather Modification held in Boulder, Colorado, in July, 1965, provided a needed stimulus. Several geographers made contributions to this symposium dealing with such matters as the identification and measurement of effects of weather modification, the role of perception and attitudes in acceptance of modification, and the evaluation of weather-modification research.[54] Some of them have undertaken further studies on these topics and participated in a Task Group on the Human Dimensions of the Atmosphere sponsored by the National Science Foundation.[55] More recently a Conference on the Present and Potential Contribution of the Social Sciences to Research and Policy Formulation in the Quality of the Physical Environment[56] brought together representatives of all the social sciences to discuss the status of research on economic, social, and institutional aspects of the management of atmospheric resources.

Priorities for Future Research

Having identified the questions relating to human adjustment to weather and climate that are of interest to geographers, and having reviewed contributions to the geographical literature on these matters, it is pertinent to outline directions that future geographical research should take. Four main directions of inquiry are recommended, corresponding to the four major questions posed earlier in the paper.

Sensitivities to Weather and Climate

Human activities differ considerably in their sensitivity to temperature, precipitation, and wind. Some activities can be undertaken under a wide range of atmospheric conditions; others are profoundly affected by the slightest change in the weather. Our knowledge of these sensitivities, however, is imprecise. We know that a cold spring can result in large losses to agriculture, but we do not know how far these losses extend into the economy as a whole. We can calculate the impact of a ten-inch increase in rainfall in July on corn

[54] See the contributions by Edward A. Ackerman, Leslie Curry, W. L. Garrison, Robert W. Kates and W. R. Derrick Sewell, T. F. Saarinen, W. R. Derrick Sewell and J. C. Day, Gilbert F. White, and Andrew Wilson in "Human Dimensions of Weather Modification" [see footnote 19 above].

[55] Final Report of the Task Group on the Human Dimensions of the Atmosphere (National Science Foundation; forthcoming).

[56] Boulder, Colorado, January 31 and February 1 and 2, 1967 (Environmental Science Services Administration). The proceedings are soon to be published, under the title "Social Sciences and the Environment," by the University of Colorado Press.

farming in Iowa, but what effect would the same increase in the same month have on farming elsewhere in the United States? And although information on agricultural impacts is far from complete, it is much more comprehensive than that on most other activities.[57] Data on the effects of weather variations on the manufacturing industry are almost nonexistent. Apart from some studies of effects on the transportation industry,[58] the construction industry,[59] and some tertiary industries,[60] impacts on nonagricultural industries have been investigated to only a small extent. Much more work needs to be done before precise estimates can be made of effects of changes in various weather parameters on given industries or activities, and before the impact of such changes on the economy as a whole can be traced.[61]

Geographers could make valuable contributions to the understanding of the impacts of weather variations by studying the sensitivity of different economic activities to various weather parameters. Two broad types of investigation are needed: studies of impacts on particular industries and studies

[57] See, for example, "Weather and Our Food Supply" (Center for Agricultural and Economic Development, Ames, Iowa, 1964); Emery N. Castle and Herbert H. Stoevener: The Economic Evaluation of Weather Modification with Particular Reference to Agriculture, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 141–158; and John W. Kirkbride and Harry C. Trelogan: Weather and Crop Production: Some Implications for Weather Modification Programs, *ibid.*, pp. 159–168.

[58] Most of these studies relate to the influence of weather on airline operations. See, for example, "A Preliminary Analysis of the Effects of Weather on Airport Traffic Flows, Airport Capacity and Acceptance Rates" (U. S. Weather Bureau for the Federal Aviation Agency, Washington, D. C., 1961); Elden J. Weigman: Analysis of Wind and Weather Factors on the New York–London Air Route for Peak Traffic Day of August 22, 1962 (Menlo Park, Calif., 1963); Bollay, *op. cit.* [see footnote 20 above]; and W. B. Beckwith: Impacts of Weather on the Airline Industry: The Value of Fog Dispersal Programs, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 195–207. A few works have dealt with the influence of weather on railroad operations; for example, Champion, *op. cit.* [see footnote 24 above]; and B. J. Wintle: Railways versus the Weather, *Weather*, Vol. 15, 1960, pp. 137–139.

[59] For example, Palmer W. Roberts: Adverse Weather—Its Effect on Engineering Design and Construction, *Civil Engineering*, Vol. 30, 1960, No. 6, pp. 35–39, and No. 7, pp. 44–47, Vol. 32, No. 2, 1962, pp. 46–49, and Vol. 33, 1963, No. 5, pp. 50–54; and J. A. Russo, Jr., K. Thouern-Trend, and others: The Operational and Economic Impact of Weather on the Construction Industry of the United States (Travelers Research Center, Inc., Hartford, Conn., 1965).

[60] Studies of the effects of weather on consumer sales that have been undertaken by economists, applied meteorologists, and others include Mary T. Petty: Weather and Consumer Sales, *Bull. Amer. Meteorol. Soc.*, Vol. 44, 1963, pp. 68–71; A. T. Steele: Weather's Effect on the Sales of a Department Store, *Journ. of Marketing*, Vol. 15, 1950–1951, pp. 436–443; and R. H. Sutherland: Seasonal Variation in the Sydney Meat Market, *Quart. Rev. of Agric. Economics*, Vol. 17, 1964, pp. 113–119.

[61] For discussions of types of analytical tools required see Edward A. Ackerman: Economic Analysis of Weather: An Ideal Weather Pattern Model, *in* Human Dimensions of Weather Modification [see footnote 19 above], pp. 61–75; and James R. Hibbs: Evaluation of Weather and Climate by Socio-Economic Sensitivity Indices, *ibid.*, pp. 91–109. See also two publications by The Rand Corporation, Santa Monica, California: Richard R. Nelson and Sydney G. Winter, Jr.: Weather Information and Economic Decisions: A Preliminary Report (1960); and R. R. Rapp and R. E. Huschke: Weather Information: Its Uses, Actual and Potential (1964).

of impacts on particular regions. Their purpose would be to make it possible to answer such a question as what is the economic (and/or social) impact of an extra inch of rainfall or an extra degree of temperature on a particular activity or what is the economic impact of a hailstorm or a hurricane on a given region.

Models capable of giving preliminary answers to these questions are presently available. Langford[62] has proposed the use of input-output analysis for both intraregional and interregional evaluation of weather-modification and information programs. Such models trace through a regional economic system the alterations in production functions that follow from weather modification or from improvements in informative systems. Potentially, they can take into account the interregional effects as well. The simulation of climatological events has been suggested by McQuigg[63] and by Hufschmidt and Fiering[64] in order to examine the trade-offs between assumed levels of information and modification potential. For example, it should be possible, by use of the methodology developed by the Harvard Water Program,[65] to examine the countervailing effects of hurricane modification that could provide positive benefits in flood prevention and negative benefits to water supply. It should be pointed out, however, that the application of these techniques is not to be taken lightly. The development of the Harvard Water Program Model, and of the Philadelphia Region Input-Output Table developed by Walter Isard and his colleagues at the University of Pennsylvania to illustrate the interconnections between various economic activities, has required many man-years of effort and hundreds of thousands of dollars of expense.

LOCATIONAL IMPACT OF WEATHER AND CLIMATE

Although climate has usually been a minor factor in locational decisions, its importance seems to be growing. Greater affluence has increased labor mobility, and people are moving to sunnier climates to earn a living as well

[62] T. Langford: A Proposed Model for the Evaluation of the Economic Aspects of Weather Modification, *in* Final Report of the Task Group on the Human Dimensions of the Atmosphere [see footnote 55 above], Appendix.

[63] James D. McQuigg: The Use of Simulation Models as a Tool to Study the Relationships of Weather and Human Activity, *in* Final Report of the Task Group on Human Dimensions of the Atmosphere [see footnote 55 above], Appendix.

[64] Maynard M. Hufschmidt and M. B. Fiering: Simulation Techniques for Design of Water-Resource Systems (Cambridge, Mass., 1966).

[65] A. A. Maass, M. M. Hufschmidt, and others: Design of Water-Resource Systems (Cambridge, Mass., 1962).

as for retirement. Some industrialists are competing for skilled labor by offering the fringe benefit of "a pleasant place to live and work." At the same time, industry itself has become more mobile. The most rapidly growing industries tend to be those which have great flexibility in locational preference. The two processes of increasing labor mobility and increasing industrial mobility have contributed substantially to the postwar growth of the Far West, the Southwest, and the Southeast.

Although climate has also played a role in the growth of these regions, its relative importance is uncertain. Nor is it obvious whether increased labor mobility or increased industrial mobility has been the more important. Some industries have moved in to take advantage of the growing pools of labor. Others have conducted nationwide campaigns to attract workers to plants located in regions of pleasant climate. Still other industries have been attracted into such regions to serve the needs of retirement populations.

Studies are needed to determine the influence of climate in the postwar expansion of the West, Southwest, and Southeast. They could be of several types, such as investigations of reasons why people move to Tucson or Santa Barbara or of the requirements of industries that have moved into such places. Much could now be added to Ullman's thoughts expressed in 1954 on the role of amenities in regional growth.

THE ROLE OF WEATHER AND CLIMATE IN DECISION MAKING

How do people decide which of several means of accommodating to different weather parameters is the most appropriate? Much depends on how they perceive these parameters, and on their perception of, and attitude toward, alternative adjustments. Relatively little is known, however, about such perceptions and attitudes.[66]

To illustrate, consider the probabilistic forecasts of precipitation currently issued by the Weather Bureau. Official practice calls for such statements as "There is a 30 percent chance of rain tomorrow." Little is known as to what meanings recipients attach to this forecast—whether, for example, it is perceived as equivalent to "Three chances in ten of rain tomorrow," "There is a small chance of rain tomorrow," or "It is going to rain tomorrow." Research on this question is currently being undertaken by the University of Denver Research Institute.

Even if the meaning attached to the forecast coincides with that perceived

[66] See, for example, Douglas H. K. Lee: The Role of Attitude in Response to Environmental Stress, *Journ. of Social Issues*, Vol. 22, No. 4, 1966, pp. 83–91.

by the forecaster, it is still not clear how the recipient will utilize the forecast. This is true even for those who habitually make use of such information in ordering their activities. First, the nature and magnitude of the response or adjustment are significant. Wearing a raincoat requires less effort than canceling a vacation trip. Second, the outcome to which the response is directed

TABLE I—FORECAST PROBABILITIES REQUIRED FOR ADJUSTMENTS FOR DIFFERENT INFORMATION AND OUTCOMES

OUTCOMES	ALTERNATIVE INFORMATION			
	Supportive		Contradictory	
	ADJUSTMENTS			
	Minor	Major	Minor	Major
Major	30%	60%	60%	80%
Minor	40%	60%	70%	90%

may vary considerably. Getting wet at the beach is viewed differently from having a brand-new suit of clothes drenched. Third, a weather forecast is only one channel of information, and frequently it is a secondary one. Observation or the evidence of one's own senses may either support or contradict the forecast, depending on whether it is clear or cloudy at the time it is received.

The hypothetical interaction of these factors is illustrated in Table I. The alternative channel of information may either support or contradict the weather forecast, and the response or adjustment is classified as major or minor. A 30 percent chance of precipitation on a gray, overcast day (supportive information) might induce a rational individual to wear a raincoat (minor adjustment) over his brand-new suit (major outcome). All other conditions would require higher probability forecasts to lead to similar actions.

Despite our inability to specify the use of such simple information as a forecast of rain, some progress has been made in developing normative models to describe how information or weather modification could be used. A number of examples have been prepared dealing with the demand for natural gas or the scheduling of agricultural activities.[67]

[67] See, for example, two publications by The Rand Corporation, Santa Monica, California: L. L. Kolb and R. R. Rapp: The Utility of Weather Forecasts to the Raisin Industry (1961), and R. R. Nelson and S. G. Winter, Jr.: Weather Information and Economic Decision (1963); also J. D. McQuigg: Foreseeing the Future, *Meteorol. Monographs,* Vol. 6, No. 28, 1965, pp. 181–188 (Chap. 12, Forecasts and Decisions); James D. McQuigg, Oscar H. Calvert, and Wayne L. Decker: Using Weather Information to Cut the Cost of Getting a Good Stand of Cotton in Southeast Missouri, *Univ. of Missouri College of*

THE ROLE OF HUMAN ACTIVITIES

In addition to studies of human response to the atmospheric environment, investigations are needed to increase knowledge of human effects on the atmosphere. There have been, as was noted earlier, a few studies of the influence of urbanization on climate and weather. Cities may provide radically different radiation regimes.[68] The varied man-made topography of the city results in changes in wind patterns and temperature. On a larger scale, man-made lakes may alter regional climates.[69] In a more speculative realm, the earth is seen as heating up from the increased CO_2 content of the air,[70] deserts have been attributed to dust particles,[71] and the contrails of future supersonic jet planes are viewed as a potential source of climatic disturbance.

The foregoing suggestions for geographical studies dealing with human response to weather and climate are intended merely to illustrate the types of problems that merit attention. Many other topics could be proposed. But much more important for geography than a checklist of useful research is a reexamination of its commitment to the study of weather and climate. It seems ironic that today, when tools and instruments of considerable sophistication are available to define with some precision human response to weather and climate, the level of geographical discourse still rests primarily either on Huntingtonian assertion or on introductory textbook generalization.

Agriculture Bull. 835, 1965; James D. McQuigg and Russell G. Thompson: Economic Value of Improved Methods of Translating Weather Information into Operational Terms, *Monthly Weather Rev.*, Vol. 94, 1966, pp. 83–87.

[68] For example, Clarence A. Woollum: Notes from a Study of the Microclimatology of the Washington, D. C. Area for the Winter and Spring Seasons, *Weatherwise*, Vol. 17, 1964, pp. 263–271; A. Garnett and W. Bach: An Estimation of the Ratio of Artificial Heat Generation to Natural Radiation Heat in Sheffield, *Monthly Weather Rev.*, Vol. 93, 1965, pp. 383–385; and Richard J. Hutcheon, Richard H. Johnson, and others: Observations of the Urban Heat Island in a Small City, *Bull. Amer. Meteorol. Soc.*, Vol. 48, 1967, pp. 7–9.

[69] See, for example, S. L. Vendrov and L. K. Malik: An Attempt to Determine the Influence of Large Reservoirs on Local Climate, *Soviet Geography*, Vol. 6, No. 10, 1965, pp. 25–40.

[70] See, for example, by Gilbert N. Plass, "The Carbon Dioxide Theory of Climatic Change," *Tellus*, Vol. 8, 1956, pp. 140–154, and "Carbon Dioxide and Climate," *Scientific American*, Vol. 201, No. 1, 1959, pp. 41–47; and F. Möller: On the Influence of Changes in the CO_2 Concentration in Air on the Radiation Balance of the Earth's Surface and on the Climate, *Journ. of Geophys. Research*, Vol. 68, 1963, pp. 3877–3886.

[71] Reid Bryson, for example, has suggested that the Rajputana Desert of northwestern India was once a fertile, inhabited area. Up to 1500 B.C. it was occupied by the Harappan culture. Successive croppings, however, seem to have led to wind erosion on a vast scale, similar to that in the United States in the dust-bowl years. The soil particles were whipped into huge clouds of dust, which reduced radiation and made the climate progressively drier. Attempts to extend the margin of cultivation by plowing up more land merely accelerated the process, and gradually the whole area became a desert. Bryson believes that if grass could somehow be persuaded to grow, the dust cloud that now covers this part of India could be dispersed and the Rajputana Desert become fertile once more. See Bryson and Baerreis, *op. cit.* [see footnote 51 above].