Final Report

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INTERDISCIPLINARY RESEARCH PROGRAM IN CLIMATOLOGY

GP-5572X

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OUTLINE OF CONTENTS

Section I

SCIENTIFIC RESULTS

The broadly based interdisciplinary team organized to carry out the purposes of the grant was structured to work on several subfields of climatology: historical climatology, field climatology, general circulation climatology and climatonomy, bioclimatology, and microclimatology. Because the field climatology, climatonomy, microclimatology, and bioclimatology research efforts were supported in part by other agencies during the period of the grant, the bulk of the research effort under NSF support was devoted to historical climatology and general circulation climatology. As might be expected in any research program of this breadth, many supplementary studies result which are not neatly classifiable. These will be mentioned below under the supplementary category. Also, several studies of climatic modification evolved from the research, and they will be listed separately. (Numbers at the head of each sub-area below refer to abstracts given in Section 2).

Abstracts of theses supported in whole or in part by this contract are given in Section 3. A list of graduate students supported by this contract is given in Section 4. A list of capital equipment purchased under this grant is given in Section 5.

A. Historical Climatology

(Abstracts 4,7,12,14,15,17,21,23,24,25,29,35,36,37,41,46)

Techniques for identification of past climates were developed primarily along biological lines, but with effort devoted to the development of quantitative measures.

Studies of sub-arctic pollen profiles (7,17) were made which indicated the character of the flora over the past 6000 years. Comparison with present day floristic and climatic gradients, plus fossil soil evidence gathered earlier, then made it possible to reconstruct a sequence of mean summer temperatures near 62° N and 101° W plus positions of the tree line for most of six millenia (24). This technique could not be applied to more complex climatic regions, where multivariate analysis seemed to be a possible approach.

Using an array of sites over the upper midwest and southern Canada for which both modern pollen rain and climatic data were available, the eigenvectors of the pollen array were calculated, then the eigenvectors of the pollen plus climate array. The first three eigenvectors contained most of the pollen variance in both cases, and nearly all of the climatic information was contained in the first three eigenvectors of pollen-cum-climate. This covariance of spatial pollen distribution and macroclimate would be useful if applicable in the past. Several time sequences of pollen (pollen profiles) from Minnesota were then subjected to eigenvector analysis and it was found that the temporal pollen arrays yielded eigenvectors very similar to the spatial pollen arrays. With this indication that space and time might be

interchanged, it was assumed that the coefficients of the eigenvectors of pollen as a function of depth were proportional to the coefficients of the pollen-cum-climate eigenvectors at the same depth. It was then possible, by vector multiple regression, to reconstruct the climate as a function of depth (i.e. time). The reconstructed quantitative estimates of climate were consistent with previous qualitative assessments, and consistent in spatial variation with pollen profiles in other locations (36). This line has now been extended using canonical correlation, with seemingly excellent results.

Using relationships between airstream climate and biota previously developed and scattered pieces of biological data from the past plus a knowledge of the patterns that meteorologically generated climatic boundaries must have, it was possible to reconstruct tentative climatic patterns for several past climatic episodes. For example, in late glacial time the fauna in central Pennsylvania was most like that now found at the northern edge of the tropical airstream in summer. Putting that boundary through Pennsylvania, and knowing that tropical air is limited on the west by the Cordillera, only a rather smooth sweeping curve connecting these points makes meteorological sense as the late Pleistocene position of that boundary. Similarly, the late glacial fauna of southwestern Kansas is now found just south of the winter Arctic-cP boundary, suggesting that that boundary lay along the east face of the Canadian Rockies, through Kansas, then about through Virginia as indicated by plant evidence in the Appalachians. In this way a handful of careful biotic studies make

it possible to rough-out a general climatic pattern (12). Added evidence found later has fitted these climatic reconstructions quite well.

One factor in climatic reconstructions for these early periods is the boundary of the Laurentide Ice Sheet. Since the literature was found to be inconsistent in locating this boundary, which must have represented a significant baroclinic zone, the totality of published radiocarbon dates on the retreat of the ice was scanned and a map of isochrones of ice retreat constructed (23,41). Dates published later, when added to the map have made no appreciable change in the pattern. However, there are several studies in the literature which do not agree with the map and either one or the other must be incorrect. For example, the widely accepted chronology of Glacial Lake Agassiz is totally inconsistent with the map - a critical test is thus possible.

One of the most significant pieces of work done during the grant period was concerned with the nature of climatic change itself, i.e. is it a slow, steady phenomenon or in the nature of a step-function? Making an objective consensus of all published radiocarbon dates identified by the author as indicating a significant environmental change, we found by least-squares fitting of a series of normal distributions that these dates were concentrated at specific times in the past. Using pollen profiles and allowing for the half-life of biotic change it appears that very significant climatic changes occur very fast, the end of "glacial" climate occurring in less than two centuries, for example (35). This has considerable bearing on long-range

prediction, for until our theoretical basis for climatic forecasting is considerably more advanced, we can only look to the past for an indication of what can occur.

Looking at the present day climatic change, it appears that the climate has returned to something like the early 1800's. For comparison, maps of difference in temperature and precipitation between the early 1800's and the present normals were prepared (25).

Reasons for the present climatic change are as varied as the authors writing about it. An attempt was made to reconcile these theories (29). It appears that the rising CO_2 content of the atmosphere was responsible for the warming of the earth up to 1940, but since that time rapidly rising albedo of the earth has counteracted the CO_2 (greenhouse) effect and has depressed the temperature. The rise of albedo appears to be possibly due to increased turbidity of the atmosphere, maybe accentuated by jet contrail formation. More will be said about this possibility in a later paragraph.

B. Field Climatology

(Abstracts 5,6,8,18,39,45)

Field climatology is based on the idea that there is considerable information about present and past climates stored in nature, which is available if suitable tools are employed for its extraction in quantitative form in terms of understandable climatic parameters.

An example of the stored data on past climates is the layered deposit of past pollen rain, if techniques such as those mentioned

in the previous section are used to interpret the record. However, one must be sure that the record is not disturbed. It was found that there are a number of processes which disturb the record in lake sediments, such as stirring by the spring floating of bottom ice and the action of bottom organisms (5,18). Thus at high latitudes where ice disturbance is profound, bogs are far superior locations for finding undisturbed sediments, but are often permanently frozen. We found, however, that chain saws and dynamite are useful for recovering sections for study (6).

Another "natural" source of data is found in tree growth. This has been used extensively in Arizona and the Arctic but has usually been regarded as too complex in other climates. A large collection of tree cores collected over the past decade from the boreal forest was examined and found to yield a pattern of growth that depended on the "arcticness" of the climate and the microclimate of the particular site. Surprisingly, an eigenvector analysis of the climatic factors responsible for growth variation was found to indicate a strong dependence on water availability, though in a complex way (8).

Past studies done by the project group indicated that lakes integrate the air temperature and record the data in their epilimnic temperature. Larger bodies also have a feedback on controlling the air temperature. Some data gathering pertinent to the study of this relation was done in an airborne bolometer survey of the surface temperature of Hudson's Bay (39).

C. General Circulation and Climatonomy

(Abstracts 2,9,10,11,22,32,33,34,42,43,47,49)

A group of studies started under grant GP-444 were completed and published with the support of GP-5572X. These were based on calculations of the fluxes of moisture and energy into and out of the Gulf of Mexico and Caribbean, using radiosonde data at the periphery (10,11,22,32).

Attempting to find quantitative measures which could be used to characterize the complex of variables and patterns which make up the climatic anomaly fields, the idea of the "empirical orthogonal function" of Lorenz, or eigenvector, was applied to monthly anomaly patterns of sealevel pressure, temperature and precipitation as an ensemble. Synoptically meaningful patterns were found to be represented by the eigenvectors, suggesting that they might represent the normal modes of atmospheric behavior that in various combinations characterize each climatic epoch (9,47).

One of the most fruitful avenues toward the construction of a physical basis for the explanation of climate appears to be the "climatonomic" approach of Lettau. In turn an important aspect of this approach is the careful budgeting of the energy fluxes. To this end, several studies were made of radiative (and other energy) fluxes for various situations and climates. After establishing the general requirements of the model, it was applied to a desert location (LaJoya, Peru), a prairie (O'Neill, Nebr.), an urban location (Kew, England) and a monsoon region (New Delhi, India) (42,49).

Field data for energy budgeting at the surface in tundra locations was gathered in Keewatin (34) and for the attenuation

of the radiative fluxes in a dusty atmosphere such as northwestern India (33). The Indian field work showed poor agreement between scattering theory and observation for the infra-red flux, and research in this problem is continuing (43).

D. Climatic Modification

(Abstracts 3,30,31,38,50)

Research on climatic change and on radiation in dusty places leads one to consider whether particulate air pollution might not produce inadvertent climatic modification. Certainly if one regards air quality as part of the climate, pollution is by definition climatic modification.

It appears that the turbidity of the atmosphere is presently increasing at a rather rapid rate (31). There is still a question of how much of the increase is man-made and how much is due to increasing volcanic activity, but if a significant fraction is due to man, then it appears that man is inadvertently modifying the world climate. According to Angstrom, an increase of about 7% in the turbidity factor would decrease world temperatures by about $1^{\circ}C$. The change has been perhaps a quarter of that since 1940, but does not appear to be insignificant (3,30,38,50).

E. Miscellaneous and Supplementary Studies

(Abstracts 1,13,16,19,20,26,27,28,40,44)

Inevitably, in a broad program of research, "targets of opportunity" will appear that are not directly part of the main program, or materials gathered for one purpose will afford opportunities in another direction. A number of publications

under GP-5572X fall in this category.

The radiocarbon dates determined for paleoclimatic purposes were made available for general use through publication in Radiocarbon (13,26,27,40) as well as a study of C^{13}-C^{14} fractionation necessary to obtain greater precision in our dates (28).

An obvious and simple extension of the construction of a map of Laurentide ice retreat (23,41) was to use it, plus estimated ice thickness, to calculate the rate of sealevel rise over the past 10,000 years due to the wasting of the ice sheet (44).

Perhaps an indication of the success of grants GP-444 and 5572X in generating a graduate research and training program is to be found in the fact that a paper on training for climatologists could be prepared for WMO, based on actual experience with a significant number of graduate students (16).

Section II

ABSTRACTS OF PAPERS

SUPPORTED IN WHOLE OR IN PART BY THIS CONTRACT

1. Bryson, R. A., "Climate of Iowa County," Proceedings, Nat'l Conf. of Instructors in Landscape Architecture, Univ. of Wisconsin, Madison, Wis., June 29-July 2, 1966, pp. 23-28.

   In addition to the mean values of meteorological parameters, and the deviations from those means, the atmospheric environment of Iowa County is portrayed in terms of where the air overhead originates and its characteristics. The changing climate of the last century is briefly given.

2. White, F. D. and R. A. Bryson, "The Radiative Factor in the Mean Circulation of the Antarctic Atmosphere during the Polar Night," Proceedings, Intenational Symposium on Polar Meteorology, Geneva, Switzerland, Sept. 1966, WMO Technical Note #87, pp. 199-224, 1967.

   Vertical motions play a major role in the distribution of atmospheric energy. It is necessary to compute it from observed parameters. In the Antarctic, during the polar night, the radiative downward flux is approximately constant so that a close examination of the related meridional circulation is possible. Periodic upper-air radiometer and rawinsonde observations have recently become available for three Antarctic locations during a four-year period, 1959-1962. Vertical velocities are inferred from these radiation observations and standard meteorological measurements, and an estimate is obtained for the resulting Antarctic meridional circulation during the polar night. The net radiation is used as a measure of the diabatic heating. A simplified model is developed, which shows two meridional cells--one in the troposphere and a much weaker one in the stratosphere. Vertical velocities, based on the model developed, provide an upper limit to the mean ageostrophic meridional circulation which may be found in the Antarctic during the polar night.

3. Bryson, R. A., "Inadvertent Climatic Modification," UIR Research Newsletter, Univ. of Wis., pp. 11 & 14, Feb. 1967. Also as "Is Man Changing the Climate of Earth," Saturday Review, 13:52-55, April 1967 and as "Will Climate Take a Turn for the Better," Contemporary Design, Third Quarter, 1967, pp. 20-22.

A discussion of how man is able to modify the climate in various degrees, e.g. clothing, cloud seeding, etc., is followed by a review of man's inadvertent climatic modification. The city environment and the effect of a metropolis on various meteorological parameters is reviewed.

The Rajasthan Desert of northwest India is a case where an ancient culture (the Harappans) may have turned the semi-arid climate of the area to a yet drier regime through poor soil use. The disturbed desert pavement presumably supplies the dust to the atmosphere, so prevalent during the pre-monsoon months of the year. The dust, in turn, modifies the albedo and the radiation regime of the area. It is suggested that the persistent subsidence over the Rajasthan is the result of the dust laden air.

4. Nichols, Harvey, "Vegetational Change, Shoreline Displacement and the Human Factor in the Late Quaternary History of South-West Scotland," Transactions of the Royal Society of Edinburgh, Vol. 67, 145-187, 1967.

Palynological investigations were made at two sites in south-west Scotland where peat bogs overlying late Quaternary marine clays and sands were dated by reference to the established British pollen zonation. The "25 foot" shoreline was formed during late Zone VI and early VIIa near Dumfries (c. 8100 to 6600 years B.P.), while the "50 foot" beach near Campbeltown has been referred to Zone III (ending c. 10,000 years B.P.). Close-interval analysis of the upper sections of the pollen diagrams has allowed the recognition of human interference with the vegetation. Minor short-term changes in Zone VI have been tentatively referred to Mesolithic activities, while from Neolithic times (Zone VIIb) onwards there is evidence for an increasingly effective modification of the natural environment. The pollen diagrams allow some conclusions to be drawn about the types of farming (including cereal cultivation) which were characteristic of the settlements near Dumfries and in south Kintyre.

5. Nichols, Harvey, "Disturbance of Arctic Lake Sediments by 'Bottom Ice': a Hazard for Palynology," Arctic 20(3): 213-214, 1967.

The author observed a small, shallow arctic lake during the spring "break-up" period. After the surface ice had melted, "bottom ice" containing sand and mud in substantial quantity, broke loose and floated to the surface. As this ice melted, the sediments were released and redeposited. The author warns against stratigraphic disturbance due to such possible redistribution.

6. Nichols, Harvey, "Permafrozen Peat Sampling--Dynamite and Chain-Saw," Arctic 20(1):54, March 1967.

Two techniques for removing frozen peat samples are discussed. Dynamite and/or a conventional chain-saw greatly facilitate the removal of frozen peat monolith for later examination.

7. Nichols, Harvey, "Pollen Diagrams from Sub-Arctic Central Canada," Science 155(3770):1665-1668, March 31, 1967.

Peat from Keewatin and Manitoba contained macrofossil and palynological evidence of former latitudinal movements of the forest-tundra boundary in response to the changing location of the mean summer position of the Arctic front. Radiocarbon dating demonstrates the synchroneity of these climatic changes with those registered in northwest Europe during the past 6000 years.

8. Mitchell, Val L., "An Investigation of Certain Aspects of Tree Growth Rates in Relation to Climate in the Central Canadian Boreal Forest," ONR Tech. Rept. #33, Nonr. 1202(07), Dept. of Meteorology, Univ. of Wisconsin, Madison, July 1967.

The Department of Meteorology of the University of Wisconsin has collected several thousand tree cores from central Canada. These cores provide the basis of this study. The core samples were surfaced by sanding, and ring widths were measured using a partially automatic measuring device.

An equation describing the growth trend of a tree-ring series is derived and used to eliminate the growth trend from the ring series. After the growth trend is removed, the data is standardized to form a tree-ring index series which can be compared with appropriate climatological data.

An index of average growth of black spruce is mapped and isolines of growth are found to parallel the tree line. A theoretical tree line is defined and located.

Factor analysis is applied to tree-ring data from Canada and the western United States. The resulting set of eigenvectors show that there is more than one way in which a narrow or a wide ring is formed. The eigenvectors also show the combinations of climatic parameters that result in a narrow or a wide ring.

9. Kutzbach, J. E., "Empirical Eigenvectors of Sea-Level Pressure, Surface Temperature and Precipitation Complexes over North America," Journal of Applied Meteorology 6(5): 791-802, October 1967.

The combined representation of fields of three climatic variables with empirical orthogonal functions, herein referred to as eigenvectors, is discussed. The eigenvectors are derived from measurements of monthly mean sea-level pressure, surface temperature and precipitation at 23 points in North America for 25 Januarys.

Selected eigenvectors of the individual climatic variables are presented; however, the major part of the paper is devoted to the presentation of eigenvectors consisting of combinations of three climatic variables. Empirical eigenvectors derived from fields of two or more meteorological variables have been used in statistical prediction models, but none of the studies to date displayed examples of these eigenvectors or discussed the internal consistency of the combined representations. In this paper it is shown that the structure of the covariances between the three climatic variables, as portrayed by the combined representations, is consistent with synoptic experience. This result illustrates that eigenvector representations derived from fields of several variables can be of considerable descriptive or diagnostic value.

10. Hastenrath, S. L., "Diurnal Fluctuations of the Atmospheric Moisture Flux in the Caribbean and Gulf of Mexico Area," Journal of Geophysical Research 72(16):4119-4130, Aug. 1967.

The moisture flux at 0000 and 1200 hours GCT shows systematic differences, the departure being smallest in winter. The amount of the flux tends to be larger for the morning sounding. The flux is directed into a somewhat more southerly direction in the evening, particularly in the Caribbean area. A relation to the diurnal double wave of atmospheric pressure and diurnal interactions between land and sea is discussed as a possible cause. Implications for the calculation of fluxes of atmospheric properties are pointed out.

11. Hastenrath, Stefan L., "Rainfall Distribution and Regime in Central America," Arch. Met. Geoph. Biokl. B., Bd. 15, H. 3, 201-241, 1967.

Seasonal variations of the atmospheric circulation on the western flanks of the North Atlantic Anticyclone imply upward motion over the Caribbean Sea during the summer half-year, with a secondary minimum in July and August, while ascending motion decreases from November

onward, and a strong subsidence develops towards the end of the winter half-year. This is associated with variations in the persistence of the trade inversion and the development of the Easterly Waves.

The precipitation regime over the Caribbean Sea follows closely the seasonal variations in the field of large-scale vertical motion. A large variety in rainfall distribution and regime is found, on the other hand, on the Central American Isthmus. In qualitative terms, this is controlled by the orientation of mountain ranges and the configuration of coast lines relative to the seasonal flow patterns, that is orographic and stress-differential induced divergence and convergence effects. Due to the latitudinal variation of the Coriolis parameter, stress-differential induced divergence effects should be particularly pronounced in the tropics. The causes for the regional variations in the beginning of the rainy season and the secondary rainfall minimum in midsummer are discussed particularly.

An altitudinal belt of maximum rainfall below the 1,000 m level is found in large parts of the Central American mountains. Recent climatic fluctuations display regional differences which appear to be greatly due to orographic and stress-differential induced divergence effects.

12. Bryson, R. A. and W. M. Wendland, "Tentative Climatic Patterns for some Late-Glacial and Post-Glacial Episodes in Central North America," ONR Tech. Rept. #34, Nonr. 1202 (07), Dept. of Meteorology, Univ. of Wisconsin, Madison, Nov. 1967 and Proceedings, 1966 Conf. on Environmental Studies of the Glacial Lake Agassiz Region, "Life, Land and Water," pp. 271-298, Univ. of Manitoba Press, Winnipeg, 1967.

It has been found that the annual migration limit of some airmass boundaries is very similar to the location of biotic ecotones. The superposition of meteorological and biotic boundaries suggests a technique to investigate climatic regimes of the past. If the present inter-relationships existed in the past, using the principle of uniformitarianism, i.e. the present is the key to the past, one can infer past climatic structures based on biotic information of the time in question.

Information of the late- and post-glacial time is beginning to emerge from pollen diagrams, macrofossil deposits and faunal remains. Such evidence has been studied at tens of sites in North America. While each data site may be rather far removed from its closest neighboring site, meaningful synoptic meteorological patterns can be deduced from these data since airmass

boundaries tend to be rather smooth, flowing lines, and certain features of these patterns are essentially "anchored" by geographical features.

The modal climatic patterns for three periods were constructed. The first was the late-glacial period about 13,000-10,000 years B.P. (before present). The second was a time of minor glacial advance, from 9,000-8,000 years B.P., and the third was early sub-Boreal time, about 5,000-3,500 years B.P. These particular times were chosen because ample evidence suggests that these times were significantly different from each other and different from the time both before and after the period in question.

The floral and faunal information enables one to locate seasonal limits of various frontal movements. Basic meteorological principles enable one to add areal continuity to the surface charts and construct the broad features of an upper air pattern.

The evidence available for the last 3,500 years suggests rather minor fluctuations. These are discussed in the text. This approach of paleoclimatic study requires the aid of many allied fields, and additions and corrections will undoubtedly be made to this series of tentative climatic synoptic patterns.

13. Bender, Margaret M., R. A. Bryson and D. A. Baerreis, "University of Wisconsin Radiocarbon Dates III," Radiocarbon 9:530-544, 1967.

Presents a listing of recent radiocarbon assays.

14. Baerreis, D. A. and R. A. Bryson, "Climatic Change and the Mill Creek Culture of Iowa," Archives of Archaeology 29:1-674, 1967. Also Micp. Cards 1-10, Univ. of Wis. Press, Madison, Wis.

This report brings together the contributions of many concerning the evidence of the Mill Creek culture in Iowa. The 1963 excavations, the artifacts, the ceramics, the Mill Creek skeleton, the fauna, pollen, gastropods and pedological investigations are described.

15. James, W. R. and Harvey Nichols, "Pollen Analysis of Materials from the Phipps, Kimball and Witrock Sites in Iowa," In: "Climatic Change and the Mill Creek Culture of Iowa," D. A. Baerreis and R. A. Bryson, editors, Archives of Archaeology 29:547-573, 1967.

The sampling and sample preparation prior to pollen counting are described. Of the three sites sampled, the Phipps site yielded the most reliable results, and showed significant discontinuities in the record.

16. Bryson, R. A., "A Curriculum for Class I Meteorological Personnel Specializing in Climatology," Bull. AMS 48(10):752-757, Oct. 1967.

A curriculum for research climatologists is presented. The author emphasizes a broad introduction to biological and earth sciences prior to specialization. The bases of the suggested curriculum are discussed.

17. Nichols, Harvey, "The Post-glacial history of vegetation and climate at Ennadai Lake, Keewatin, and Lynn Lake, Manitoba (Canada)," Eiszeitalter und Gegenwart 18:176-197, Dec. 1967.

Peat from Keewatin and Manitoba contained macrofossil and palynological evidence of former latitudinal movements of the forest--tundra boundary probably in response to the changing location of the mean summer position of the Arctic front. There was very rapid melting of the large late-Wisconsin icesheet between 8000 and 6000 years B.P., and swift immigration of Picea, with no evidence of tundra vegetation after deglaciation. From 6000 to 3500 years B.P. the Boreal forest extended far north of its present limit, with a short-lived cooler phase about 5000 years ago. This generally warm period was followed by cooler and variable climatic episodes after 3500 B.P. and by a climatic deterioration about 2600 years ago. There was an amelioration between 1500 and 600 B.P., followed by a prolonged cold episode with terminated peat growth in the tundra. The approximate mean summer temperatures at Ennadai Lake have been estimated from the changing location of the northern limit of forest. The radiocarbon dates for these climatic events coincide with a number of changes recorded in the climatic history of northwest Europe.

18. Nichols, Harvey, "The suitability of certain categories of lake sediments for pollen analysis," Pollen et Spores IX(3):615-620, Dec. 1967.

It is suggested that certain types of lakes are potentially subject to sediment contamination and disturbance of the fossil pollen record; these are: lakes with rich bottom faunas; lakes with sub-lacustrine gullies; lakes subject to earthquakes; shallow lakes at high latitudes or high altitudes whose sediments are or have been liable to freezing; lakes used by cattle; lakes subject to changes of level; and lakes with a history of floating islands of organic matter.

19. Lettau, Katharina, "Regional and Secular Variations of Phenological Events in Milwaukee County," 1967. Distributed by the Wisconsin Phenological Society.

The dependency of lilac flowering dates on air temperature averaged for the months April and May are investigated for two sets of homogeneous observations in Milwaukee county; the records of Father Bruhin from 1870 to 1875 at New Coeln, and those of Philip Whitford from 1962 to 1967 at Wauwatosa. The regression line derived from these observations implies that a decrease of one degree in temperature of the bi-monthly average corresponds to a two-day delay in flowering date in either period within error of tolerance. Consequently, a regression line derived from observations in recent years may permit to make quantitative statements about spring season temperatures from lilac blooming dates in former years in the absence of direct temperature measurements.

The dependency on air temperature of leaf bud development and leaf growth of the American elm are compared at two sites in Milwaukee, at Lake Park and at Mount Mary College (8 miles inland from Lake Michigan) according to observations by Barbara March in 1966. It can be shown that the normalized growth rate (in % of maturity) is the same in both places, which means that each phase of leaf growth requires the same accumulation of degree days independent of location.

20. Peterson, James T. and L. D. Drury, "Reduced Values of Solar Radiation with Occurrence of Dense Smoke over the Canadian Tundra," Geographical Bulletin 9(3):269-271, 1967.

On a reconnaissance flight made on 10 July 1964, dense smoke originating from forest fires in the boreal forest was seen to be transported northward over a wide area of the central Canadian tundra by prevailing southerly winds. Because of the smoke, the average downward solar radiation flux was reduced by as much as 25 per cent.

21. Lee, G. Fred and William Wilson, "The Use of the Chemical Composition of Freshwater Clamshells as Indicators of Paleohydrologic Conditions," Final Report, Water Chemistry Program, Univ. of Wisconsin, Madison, 1967.

Freshwater clams incorporate Ca, Mg and Sr in their shell in proportion to the elemental concentrations in the water environment. The concentration ratios in some streams are correlated to the discharge rate. In some circumstances, then, clam shells could

yield information on hydrology. Shells found in stratified middens may contain a hydrology record of the local area.

The aim of this project is to study the above hypothesis.

While the relationships are poorly understood, it was found that in some cases, the elemental ratios abruptly changed at the time of known environmental change.

22. Hastenrath, Stefan L., "A contribution to the wind conditions over the Caribbean Sea and Gulf of Mexico," Tellus XX (1968),1:163-178.

The wind conditions over the Central American Seas are discussed on the basis of 9-year mean charts for selected pressure levels and meridional cross-sections along 80° W. The field of large-scale vertical motion is computed for all months of one year. Over the Caribbean Sea, a vigorous downward motion is found during the second part of the winter half-year, which is fed by convergence in the upper-tropospheric southwesterly current. During the greater part of the year, however, upward motion prevails, with a weak tendency to subsidence in midsummer. Over the Gulf of Mexico, subsidence is indicated during great part of the year, changing to ascending motion in midsummer. Implications of the vertical circulation for certain climatic characteristics in the region of the Central American Seas are discussed.

23. Bryson, R. A. and W. M. Wendland, "Radiocarbon Isochrones of the Retreat of the Laurentide Ice Sheet," ONR Tech. Rept. #35, Nonr. 1202(07), Dept. of Meteorology, Univ. of Wis., Madison, Dec. 1967; Alberta Anthropologist 2(1):9-15, Feb. 1968.

A map of northern North America is presented which shows isochrones of the outer limit of the Laurentide ice sheet from about 13,000 years ago until the present. The data points are radiocarbon dates of moraines, basal peat, and lacustrine deposits which represent the dates of deglaciation. The chronology of the ice sheet shows that the ice front retreated northward from the Great Lakes to south of James Bay by about 8,000 years ago. By about 7,500 yrs. B.P., the continental ice sheet was split by an open Hudson Bay, with one center of ice over northern Keewatin and Baffin Island, and another about 400 km south of Ungava. By 7,000 yrs. B.P., the ice over Baffin Island had separated from the mass of ice to the west. The Baffin Island ice remained after that

time, and apparently is found today as the Barnes Ice Cap and the Penny Glacier.

The ice retreated faster over the Prairie Provinces than over the Labrador-Quebec area, suggesting that snowfall and/or cloud cover inhibited the retreat in the more maritime area. A glacial energy balance is presented which compares a glacial net radiation regime to that of a non-glacial time. The effect of variations in mean cloud cover and snowfall upon the ablation rate are investigated. It is suggested that cloud cover is the important determining factor for glacial net budget at lower latitudes, and that snowfall is more important at higher latitudes.

24. Nichols, Harvey, "Pollen analysis, paleotemperatures, and the summer position of the arctic front in the Post-Glacial history of Keewatin, Canada," Bull. Am. Met. Soc. 49(4):387-388, April 1968.

Pollen analyses from Keewatin, Canada made by the author, are interpreted in terms of a north-south migration of the tree line, and an inferred temperature departure from the modern mean with time. The basis for climatological inferences from paleo-botanical information is the coincidence of certain biotic ecotones and mean frontal positions.

25. Wahl, E. W., "A Comparison of the Climate of the Eastern United States during the 1830's with the Current Normals," Monthly Weather Review 96(2):73-82, Feb. 1968.

A comparison of climatic data for the eastern United States from the 1830's and 1840's with the currently valid climatic normals indicates a distinctly cooler and, in some areas, wetter climate in the first half of the last century. The recently appearing trend to cooler conditions noticed here and elsewhere could be indicative of a return to the climatic character of those earlier years.

26. Bender, M. M., R. A. Bryson and D. A. Baerreis, "University of Wisconsin Radiocarbon Dates IV," Radiocarbon 10(1): 161-168, 1968.

Presents a listing of recent radiocarbon assays.

27. Bender, M. M., R. A. Bryson and D. A. Baerreis, "University of Wisconsin Radiocarbon Dates V," Radiocarbon 10(2): 473-478, 1968.

Presents a listing of recent radiocarbon assays.

28. Bender, Margaret M., "Mass Spectrometric Studies of Carbon 13 Variations in Corn and Other Grasses," Radiocarbon 10(2):468-472, 1968.

Measurements of the C^{13}/C^{12} ratios of grasses show a division into 2 groups which correspond to the groups which follow two different photosynthetic pathways. Grasses of the Panicoideae sub-group which follow a photosynthetic pathway similar to sugarcane have C^{13}/C^{12} ratios of -11 to -14.5‰, grasses of the Festucoideae sub-group which follow the Calvin cycle in photosynthesis have C^{13}/C^{12} ratios of -26 to -28‰ relative to the PDB standard. Grasses of the Panicoideae sub-group therefore differ in radiocarbon age from the average contemporary wood.

29. Bryson, R. A., "'All other factors being constant'..... A reconciliation of several theories of climatic change," Weatherwise 21(2):56-61,92, April 1968.

Assuming that the net solar energy received by the earth is balanced by the net long wave energy loss, the earth's mean annual temperature is a function of (1) the solar "constant," (2) earth-atmosphere albedo and (3) effective emissivity. The change in mean temperature due to change in the above three factors are discussed. Observations of atmospheric dust concentration, both volcanic and man-made in origin, indicate a substantial increase since the 1930's. It is suggested that this increase in atmospheric turbidity is probably sufficient to explain the recent cooling in the world mean temperature.

30. Bryson, R. A. and J. E. Kutzbach, "Air Pollution," Resource Paper #2, Commission on College Geography, Published by Association of American Geographers, Washington, D. C., 42 pages, 1968.

The particulate constituents of air are reviewed, from small scale point sources to city atmospheres to world-wide pollution. The constituent concentrations are compared and their influence on the climate reviewed. Various studies and reports of pollution and resulting climatic modification, health and economics impact are summarized.

31. Peterson, J. T. and R. A. Bryson, "Atmospheric Aerosols: Increased Concentrations during the Last Decade," Science 162(3849):120-121, 1968.

Atmospheric turbidity values calculated each month from solar radiation observations at Mauna Loa Observatory, Hawaii, show an increase of aerosols from 1958

through the present. These data indicate that either the effects of the Mount Agung eruption are still being observed or a longer-term trend of increasing turbidity is in evidence.

32. Hastenrath, S. L., "Estimates of the latent and sensible heat flux for the Caribbean Sea and the Gulf of Mexico," Limnology and Oceanography 13(2):322-331, April 1968.

Monthly mean values of the latent and sensible heat flux at the sea-air interface ($Q_e + Q_s$) are derived for the areas of the Caribbean Sea and the Gulf of Mexico, separately: 1) from the multiannual mean of the oceanic heat budget; 2) from the atmospheric energy budget, on the basis of the available radiosonde data for the entire year 1960; and 3) by the bulk-aerodynamic method, using 1960 ship observations.

The annual average of the latent and sensible heat transfer in the area of the Central American Seas is of the order of 270 ly/day. Making allowance for the propagation of errors and the different time periods used, the results of the three independent approaches are in fair agreement. The shortcomings inherent in all the procedures make various independent approaches desirable wherever possible.

33. Peterson, J. T. and R. A. Bryson, "The Influence of Atmospheric Particulates on the Infrared Radiation Balance of Northwest India," Proceedings, First Nat'l Conf. on Weather Modification, Albany, N. Y., April-May, 1968, pp. 153-162.

In April and May, 1966 a University of Wisconsin team went to the Rajasthan Desert, India to investigate the pre-monsoon, resident atmospheric dust. Although the history and pre-history of this phenomenon were investigated also, the results of the airborne survey will be reported in this paper. Long- and short-wave, up- and down-ward radiation components; and aerosol concentrations were sensed by instruments aboard an aircraft.

The measured dust concentration distribution over the desert was similar to other studies over continental areas. The observed cooling rate of the atmosphere was significantly greater than water vapor and carbon dioxide alone would warrant. Apparently the dust substantially rearranges the radiation regime with the resulting large cooling rates and net subsidence over the area.

34. Ahrnsbrak, William F., "Summertime Radiation Balance and Energy Budget of the Canadian Tundra," ONR Tech. Rept. #37, Nonr. 1202(07), Dept. of Meteorology, Univ. of Wisconsin, Madison, 1968.

As a step toward understanding the interrelationships between landform, vegetation, and climate of the Canadian tundra, summertime radiation balance and energy budget data obtained during July and August, 1966, at three locations in the district of Keewatin, N.W.T., are presented. Comparisons are made between these findings and estimates from other authors' global and hemispheric radiation balance studies and also with energy budget studies of other investigators at Resolute Bay, N.W.T., and Point Barrow, Alaska. The climate is shown to be one in which latitudinal and seasonal differences account for most of the variation. While during July the storage of heat in the soil accounts for fifteen percent of the energy budget, during the rest of the snow-free season net radiation is nearly balanced by transfer of sensible heat to the atmosphere.

35. Bryson, R. A., D. A. Baerreis and W. M. Wendland, "The Character of Late- and Post-Glacial Climatic Changes," Prepared for Symposium on Pleistocene and Recent Environments of the Central Plains, Lawrence, Kansas, Oct. 25-26, 1968.

Computer analysis of world-wide radiocarbon dates for significant climatically-related events of the last 10,000 years yields an objective consensus that these events occurred at preferred times. These dates match recent datings of the breaks in the Blytt-Sernander sequence, and are also applicable to North America.

Estimates of the time duration of the transition between the Blytt-Sernander episodes, which can be equated to climatic episodes, suggest that significant ecological effects can occur in just a few decades. This is perhaps related to the non-linear behavior of the atmosphere, and non-linear response of biota to climate.

These results confirm the suggestion that the concept of a gradual anathermal-hypsithermal-medithermal trend is oversimplified and should be replaced.

The response of biota to climatic change is much faster than the response of glaciers. Care must be exercised in comparing evidence of such diverse character. It is suggested that some ecological changes might be directly caused by atmospheric changes of global scope.

but that others of a regional nature may be due to "feedback" mechanism or delayed effects of earlier causes. An example is the change of climate on the Great Plains associated with the opening of a low corridor to the Arctic as the Laurentide ice sheet retreated in response to the change from glacial to post-glacial climate. This probably occurred on the order of 2000 years after the basic global climatic change.

The evidence points to a step-like climatic variation and ecological response. There are modern analogues to many of the post-glacial climatic patterns. It is suggested:

1. that the Blytt-Sernander terminology be adopted for North America, since the sequence in time is comparable, and

2. that interdisciplinary research efforts might be fruitfully concentrated on the characterization of the climatic episodes, using more sophisticated descriptions than "warm," "dry," "cool," etc.

36. Cole, Henry S. and R. A. Bryson, "The Application of Eigenvector Techniques to the Climatic Interpretation of Pollen Diagrams: an Initial Study; Part I: Bog D Pond, Itasca," Prepared for Symposium on Pleistocene and Recent Environments of the Central Plains, Lawrence, Kansas, Oct. 25-26, 1968.

A statistical technique is presented for the climatic interpretation of pollen diagrams. Empirical orthogonal functions or eigenvectors are used to determine relationships between present day pollen spectra and airmass frequencies. These vectors are used in conjunction with fossil pollen diagrams to generate theoretical records of airmass frequencies.

In Part I, the technique is applied to the pollen diagram from Bog D Pond, Itasca (McAndrews, 1966) located in the prairie-forest ecotone in northwestern Minnesota. The results of the analysis while tentative are in general accord with previous interpretations of the climatic history of the Itasca region. A considerable portion of the stratigraphic variance can be explained by applying climatically related eigenvectors of modern pollen spectra. The paper emphasizes the development of technique and contains discussion of the problems, questions and possibilities raised by this study.

37. Bryson, R. A. and D. A. Baerreis, "Climate and Prehistory in the Southern Plains," To be published in Proceedings, AAAS Annual Meeting, Dallas, Texas, Dec. 26-31, 1968.

The purpose of this paper is: (1) to attempt to extend available radiocarbon dates to undated complexes; (2) to establish the crucial sites and cultures requiring dates; and, (3) to evaluate the contributions of the cultural sequences to our understanding of the paleoecology and through this to the paleoclimates.

38. Bryson, R. A. and W. M. Wendland, "Climatic Effects of Atmospheric Pollution," To be published in Proceedings, AAAS Annual Meeting, Dallas, Texas, Dec. 26-31, 1968.

The trend of world temperature in this century appears to be directly related to the trends of atmospheric carbon dioxide content and atmospheric turbidity (dustiness). Both are believed by various scholars to be related to human activities. Since 1940, the effect of the rapid rise of atmospheric turbidity appears to have exceeded the effect of rising carbon dioxide, resulting in a rapid downward trend of temperature. There is no indication that these trends will be reversed, and there is some reason to believe that man-made pollution will have an increased effect in the future.

39. Wendland, W. M. and R. A. Bryson, "Surface Temperature Patterns of Hudson Bay from Aerial Infrared Surveys," Proceedings, Remote Sensing Symposium, Madison, Wis., June 1968, pp. 185-193.

Surface temperature patterns of Hudson Bay are presented from four near-synoptic surveys during the ice-free seasons of 1965 and 1967. An airborne infrared radiation thermometer provided essentially continuous data over a known track. Certain large scale surface thermal features persisted throughout most of the ice-free season, from soon after ice-loss until early October, when feature definition gave way to a weak south-north temperature gradient. The melt water of the last significant pack-ice remained a surface thermal feature throughout the summer and into early fall.

40. Bender, M. M., R. A. Bryson and D. A. Baerreis, "University of Wisconsin Radiocarbon Dates VI," Radiocarbon 11(1): 228-235, 1969.

Presents a listing of recent radiocarbon assays.

41. Bryson, R. A., W. M. Wendland, J. D. Ives and J. T. Andrews, "Radiocarbon Isochrones on the Disintegration of the Laurentide Ice Sheet," Arctic and Alpine Research 1(1): 1-14, 1969.

The last great event of the Wisconsin Glacial Stage in North America was the disintegration of the Laurentide Ice Sheet. This occurred between 13,000 and about 5,000 years ago and had a profound effect upon the paleogeography of the continent. Analysis of present-day distribution of fauna and flora, the archaeological record, and climatic and sea-level fluctuations are intimately bound up with ice sheet disappearance, yet there has been no systematic attempt to utilize existing radiocarbon and geological data to attempt a plot of the ice sheet perimeter at specific intervals through time. The present paper makes this attempt in the form of two maps (Figures 1 and 2), the first being an objective portrayal of isolines drawn on the radiocarbon data, the only assumption being that the ice sheet perimeter tended to parallel the coastline or, more particularly, the trend of the outer edge of the continental shelves and the southern limit of Wisconsin till on land; the second map is a subjective interpretation of the first based upon geologic field evidence and the climatic and geomorphic intuition of the writers. Some of the immediate implications raised by the maps are discussed and a series of significant conclusions are derived: (1) The northern limit of the Laurentide Ice Sheet proper was close to the arctic mainland coast of Canada. (2) There was a dramatic change from an east-west ice barrier near latitude 60°N in late-glacial time, to a broad low corridor from the Arctic Ocean to the Great Plains in Boreal time. (3) The Laurentide Ice Sheet retained its identity as a distinct unit until about 8,400 years BP (Cockburn Stade) and had catastrophically disintegrated during Atlantic time, within a few centuries of 8,000 years BP. (4) The three remaining ice remnants centered over Keewatin, Labrador-Ungava and Foxe Basin-Baffin Island persisted through the Atlantic climatic episode (altithermal), that on Baffin Island surviving to the present day in the form of the Barnes Ice Cap.

42. Lettau, H. and K. Lettau, "Shortwave radiation climatonomy," Tellus XXI(1969)2:208-222.

Functional relations are discussed which express absorbing and scattering processes of shortwave radiation in the atmosphere. A simplified model is derived in which only overall intensities (integrated over the spectral band of insolation) are considered. Balance

requirements are established which relate "top albedo" to effective absorption in the air and by the ground, both as fractions of extra-atmospheric irradiance. Measurements of diffuse radiation from the sky, in addition to global radiation, are used to specify scattering versus absorption components of aerosol attenuation for clear-sky conditions with known liquid water content and Rayleigh scattering. Data from three continental locations are selected which are representative of clear-sky attenuation over a desert (La Joya, Peru), an open prairie (O'Neill, Nebraska), and an industrialized urban area (Kew, England). The ratio of absorption to scattering shows significant systematic variation, city aerosol being more efficient as absorber, desert aerosol more as a scatterer. Effects are calculated which result from a systematic variation of (1) surface albedo, (2) liquid water content, (3) aerosol, and (4) cloud cover. Among other results it is demonstrated how top albedo (measurable nowadays from orbiting or synchronous satellites) will react to changes in surface albedo and aerosol scattering. It is also shown numerically, how cloud effects on global radiation are modified by the existing turbidity conditions in the cloudless air.

43. Peterson, James T. and James A. Weinman, "Optical Properties of Quartz Dust Particles at Infrared Wavelengths," Journal of Geophysical Research (in press), 1969. Abstract also published in Trans. AGU 50(4):176, 1969.

The complex index of refraction of quartz is presented for wavelength $1.6\mu \leq \lambda \leq 36$. An ensemble of silica dust represented by the size distribution

$$\frac{dn}{dr}(r) = \frac{13r^{-3.5}}{4.1 \times 10^{4}} \ cm^{-3} - \mu^{-1} \qquad \begin{matrix} .1\mu \leq r \leq 15\mu \\ .03\mu \leq r \leq .1\mu \end{matrix}$$

is utilized in conjunction with Mie theory to determine the extinction coefficient, β ext, the albedo of single scattering, a, and the asymmetry function, $\langle \cos \theta \rangle$ of the phase functions, for wavelengths in this interval. Phase functions are also presented for several selected wavelengths. The radiative effects of silica dust clouds are compared with the spectral radiance measured .7 km over a desert. The effect of a thick dust cloud on equivalent black body surface temperatures measured in the atmospheric window by satellite borne MRIR sensors is also considered.

44. Moran, J. M. and R. A. Bryson, "The contribution of Laurentide Ice Wastage to the Eustatic Rise of Sea Level: 10,000 to 6,000 BP," Arctic and Alpine Research 1(2): 97-104, 1969.

The contribution of the wasting Laurentide Ice Sheet to eustatic sea-level rise between 10,000 and 6,000 BP was estimated. Volumetric models were constructed on the basis of the present Greenland profile and past areal distributions of ice as delineated by the radiocarbon isochrone map of Bryson and Wendland. It was found that even with the assumption of negligible ice in the Arctic Archipelago, the Laurentide sheet was by far the major contributor to sea-level rise. A double-dome model resulted in a eustatic sea-level curve which conforms quite well with those derived in other independent studies.

45. Hayden, Bruce P., "Green Plants as Sensors," Research/Development, July 1969, pp. 26-29.

Measurement of the forcing functions that tie the plant to its environment allows the use of plants as sensors of that environment. The use of one such measurement system is discussed.

46. Nichols, Harvey, "Chronology of Peat Growth in Canada," Palaeogeography, Palaeoclimatol., Palaeoecol., 6(1969): 61-65.

Published and unpublished radiocarbon dates from immediately above the unconformable mineral bases of ombrogenous peat bogs are compared with the climatic history of Canada during the last 4,000 years. Most of the determinations group around a few periods of established climatic deterioration (such as 3,500 and 2,400 B.P.) which suggests that large tracts of Canadian peat originated almost simultaneously under the stimulus of climatic change.

47. Hirose, Mototaka and John E. Kutzbach, "An Alternate Method for Eigenvector Computations," J. Applied Meteor. 8, 701, 1969.

Given an M by N matrix of observations, it is possible to find the eigenvectors and eigenvalues of the smallest cross-product matrix (M by M if $M < N$, N by N if $N < M$) and to obtain the eigenvectors of the largest cross-product matrix by a linear transformation. This can lead to significant savings in computer time and permits calculation of eigenvectors of large cross-product matrices.

48. Nichols, Harvey, "The late Quaternary history of vegetation and climate at Porcupine Mountain and Clearwater Bog, Manitoba," Arctic and Alpine Research 1(3):155-167, 1969.

Radiocarbon-dated pollen diagrams from two sites in the southern Boreal forest of Canada have reflected aspects of the local and regional environments since 6,700 and 1,000 BP, respectively. Spruce forest near Porcupine Mountain was replaced by grassland ca. 6,700 BP, with a maximum of prairie taxa occurring just before 5,140 BP and a short-lived reduction of grass and herb pollen shortly after that date. The grassland episode ended at 4,200 BP when spruce forest dominated Porcupine Mountain. The site experienced very rapid Sphagnum peat growth and increased sporogenesis after 2,450 BP.

A tentative climatic interpretation is supplied which suggests that 6,700 to 4,200 BP experienced generally dry, warm summers, with a maximum of this effect just prior to 5,140 BP and a cooler spell following; after 4,200 BP the summer climate was cooler and moister, especially from 2,450 to 2,000 BP. The possibility of a regional increase in soil erosion and sheet flooding prior to 6,700 BP is examined.

Clearwater Bog is underlain by a spruce forest horizon dated 1,200 BP which was established at a time of reduced water level in Clearwater Lake; the Picea timbers were overlain by very humified peat dated 900 BP. Unhumified Sphagnum peat later formed and continued to the modern bog surface. The climatic interpretation is that the summer climate was warm and dry at 1,200 and 900 BP, and that cooler, wetter summers characterized the period since then to the present day.

The suggested climatic sequences are synchronous at many points with the scheme previously developed for southern Keewatin and northern Manitoba, and some of the vegetational changes are provisionally interpreted as the movement of the southern limit of the Boreal forest in phase with the shifts of the Keewatin forest-tundra boundary described earlier. This correlation encourages comparison with other sites in the Northern Hemisphere.

49. Lettau, Katharina, "Radiation Climate of New Delhi, Part I: Shortwave Radiation," Submitted to Indian Journal of Meteorology and Geophysics.

A budgetary method to appraise the various shortwave attenuation processes in the atmosphere is described. The method is based on observed global and diffuse radiation from sun and sky, given separately for clear days

and all days with average cloud cover. New Delhi was selected as a case study because cloudiness, precipitable water, and aerosol content of the air show pronounced annual variations. It is shown that the monsoon period does not produce radical changes in aerosol absorption. More significant is a decrease in the intensity of aerosol scattering. This may be interpreted as a change in particle composition and size distribution. While the monsoon rains remove most of the mineral dust, enough hygroscopic nuclei remain in the air over New Delhi so that attenuation by absorption decreases only slowly after the rains have stopped.

The total heating by all absorbers in the atmosphere varies from 0.54°C/day in January-March to 1.23°C/day in July-September. Aerosol contributes about 30% to the total heating.

50. Wendland, W. M. and R. A. Bryson, "Atmospheric dustiness, man and climatic change," Biological Conservation (in press).

During the past century the world's mean temperature generally rose at least until the early 1940's, since when it has decreased. Three primary reasons for these trends have been hypothesized by various authors, namely, rising concentrations of atmospheric carbon dioxide brought about by the burning of fossil fuels, sunspot number variations, and dust injected into the atmosphere by volcanic eruptions. Although each of the above can explain short-term temperature trends, they cannot, alone or in concert, explain the entire record. The few observations of atmospheric dust concentrations that exist suggest that a catastrophic rise in concentration since the 1930's, due to human activities, may have overcome the warming trend prior to 1940 and caused the subsequent decrease in world mean temperature. The conservational implications of climatic change may be enormous--especially in terms of biogeography and biological productivity.

51. (Received after this report was written. There may be a few more in the near future)
Duffield, Lathel F., "The vertebrate faunal remains from the School Land I and School Land II sites," Okla. Anthro. Soc. Bull. 18:47-65, 1969.

Animal bone refuse from two excavation units at the School Land site in Delaware County, Oklahoma dating between A.D. 1050 and A.D. 1200 were identified as to species. At School Land II only three species of mammals (deer, elk and bison) were present. At School Land I, mammals included additionally opossum, raccoon, dog, bobcat, beaver and rabbit. In addition, turkey, great horned owl, snapping turtle, soft shell turtle, gar, drum and cat fish were also present. The difference in species between the two site areas suggests an ecological change between the two components though the available radiocarbon dates do not permit a clear temporal ranking of the two components.

Section III

ABSTRACTS OF THESES

SUPPORTED IN WHOLE OR IN PART BY THIS CONTRACT

1. Ahrnsbrak, W. F. (M.S.), 1968, "Summertime Radiation Balance and Energy Budget of the Canadian Tundra"

As a step toward understanding the interrelationships between landform, vegetation, and climate of the Canadian tundra, summertime radiation balance and energy budget data obtained during July and August, 1966, at three locations in the district of Keewatin, N.W.T., are presented. Comparisons are made between these findings and estimates from other authors' global and hemispheric radiation balance studies and also with energy budget studies of other investigators at Resolute Bay, N.W.T., and at Point Barrow, Alaska. The climate is shown to be one in which latitudinal and seasonal differences account for most of the variation. While during July the storage of heat in the soil accounts for 15 percent of the energy budget, during the rest of the snow free season net radiation is nearly balanced by transfer of sensible heat to the atmosphere.

2. Bendel, W. B. (M.S.), 1967, "The Representation of the Prediction Equation in Fourier-Bessel Functions and its Solution by the Relaxation Method"

The use of orthogonal Fourier-Bessel functions in a spectral representation of the prediction equation is discussed. Polar coordinates are used for the grid region from 90N to 20N. A simplified form of the vorticity equation is assumed. The advantages and disadvantages of this mathematical method are discussed.

In this study, the terms on the right side of the prediction equation will be represented in spectral form, but the offered solution of the equation will be obtained by relaxation methods.

3. Blasing, T. J. (M.S.), 1968, "Patterns of Climatic Anomaly over the Upper Midwest in Summer"

There is an increasing amount of evidence that climatic conditions are returning to those of more than a century ago. This study is concerned with the upper midwestern part of the United States where the summer climate has recently been turning cooler. Multivariate

statistical techniques are used to identify recent patterns of climatic anomaly, and it is found that a linear combination of these patterns adds up to a climatic map similar to one for the 1830's. The synoptic situations associated with these patterns in recent years involve cold anticyclones moving far into the Eastern United States from Canada. These situations, while common in winter, occurred seldom during summers between about 1880 and 1950, but in recent summers they have been occurring more often.

4. Christensen, W. I., Jr. (Ph.D.), 1966, "An Investigation of the Potential of Component Analysis for Weather Classification"

Using selected hourly surface observations from Madison, Wisconsin and Minneapolis-St. Paul, Minnesota, as basic data, a series of analyses are performed to determine the feasibility of establishing weather classifications. Component analysis (factor analysis) is applied to a sample of January data for Madison to reduce the number of variables needed to suitably describe each day meteorologically and to create orthogonality among these new variables. Using these results as the design matrix in regression analysis, a mathematical model for each day is constructed and each day is compared to all of the other days in order to classify similar days into distinctive weather types. Every day within each class is compared with the synoptic situation for that day to establish whether these types form a reasonable synoptic pattern. The temporal and spatial validity of these newly found weather types are tested by applying the foregoing results to an independent January sample for Madison and an independent January sample for Minneapolis-St. Paul respectively. The basic analytic techniques are then applied to a Madison July sample.

Some of the newly created hypothetical components are basically related to "air mass" and others to the symoptic situation. The analyses of the frequency distribution of some of the "air mass" components are compared with some results that used daily maximum temperature to determine the occurrence frequency and statistical properties of "air masses" that affect Madison. The results indicate that the new independent temperature component gives a very realistic assessment of the "air mass" properties and occurrence frequencies.

Specifically, the results indicate that the elements of a meteorological observation may be expressed by a smaller number of independent components that agree with our knowledge of dynamics; and, these newly created

components may be applied in a multivariate analysis to establish distinctive weather types. These weather types are synoptically reasonable and their distribution about the usual pattern of "Highs" and "Lows" strongly resemble cloud models and photographs from satellites.

5. Cohen, E. H. (M.S.), 1969, "Eigenvector Analysis of Precipitation Patterns in Wisconsin"

Eigenvector analysis was performed on two regions. The first region was the state of Wisconsin. The second region was the parts of Arkansas and Oklahoma between 92 West and 97 West. Precipitation patterns for Colorado Lows which traveled through southeastern Wisconsin were obtained. An apparent topographic effect was detected in northwestern Wisconsin.

6. Cole, H. S. (Ph.D.), 1969, "Objective Reconstruction of the Paleoclimatic Record through the Application of Eigenvectors of Present-Day Pollen Spectra and Climate to the Late-Quaternary Pollen Stratigraphy"

Empirical orthogonal relationships or eigenvectors were determined from arrays consisting of surface pollen spectra and present-day airmass data for central North America. Vegetation regions encompassed by the survey included mixed conifer-hardwood forest, deciduous forest, boreal forest, aspen parkland and prairie. Eigenvectors characterized by strong covariance between pollen and climate were found to explain most of the total spatial variance of the two fields. The same vectors, referred to as "regional," collectively define a transfer function between pollen and climate which can be used for the statistical, climatic interpretation of pollen diagrams.

Quantitative estimates of paleoclimate were obtained by applying the regional eigenvectors to fossil pollen assemblages using least squares vector multiple regression analysis. Estimates obtained from the Kirchner Marsh, Bog D Pond and Weber Lake pollen diagrams (Minnesota) appear to give reasonable interpretations of the late-Quaternary climatic record. The reconstructions were found to be consistent with previous qualitative interpretation and to be compatible with one another from a climatic standpoint. Further evaluation of the method was made by applying the technique to surface pollen spectra. Fields of airmass frequency reconstructed from surface pollen spectra within the survey region show considerable similarity to the observed present-day distribution of the airmasses.

Stratigraphic variations of pollen spectra were investigated by applying eigenvector analysis directly

to pollen profiles. The dominant stratigraphic vectors were found to resemble the regional eigenvectors. This result indicates that a considerable portion of the stratigraphic variation of pollen spectra is related to macroclimatic change and secondly that spatial and stratigraphic modes of pollen-climate covariance are similar.

There are several problems associated with the reconstruction technique and several sources of potential error in the climatic estimates. Since the vegetation integrates the climate, i.e., responds to the climate more slowly than the climate changes, an adjustment was applied to the climatic reconstructions to lessen the "lag error."

In summary, the study verifies that there is a significant regional covariance (correlation) between modern pollen spectra and macroclimate. Similarity between the dominant stratigraphic and regional eigenvectors indicates that for the purpose of climatic reconstruction space and time appear to be nearly interchangeable. Furthermore, the statistical reconstructions of the paleoclimatic record made in this study appear to be reasonable. Thus, within certain limits, it appears possible to reconstruct climatic history directly from pollen diagrams in an objective manner.

7. Kutzbach, J. E. (Ph.D.), 1966, "Representation and Classification of Fields of Atmospheric Variables"

The results of studies in weather regime classification on both the hemispheric and continental scales are presented.

For the hemispheric scales, an efficient orthonormal expansion, referred to as a Fourier-Bessel expansion, is developed. Its main advantage over a spherical harmonic representation is that the data field need not be specified to the equator. Approximately four years of hemispheric 500mb charts are represented in terms of these functions. The coefficients associated with these functions are used in an objective classification of hemispheric flow patterns. The use of this technique as a diagnostic tool for identification of persistent and recurrent flow patterns is demonstrated. In particular, two patterns in the four years of winter data persisted for much longer periods of time than the rest of the patterns in the sample. One pattern persisted and recurred in four of the twelve winter months in the sample.

On the continental scale, the covariance structure of several climatic variables is investigated using the

principal component technique. A covariance matrix is formed from a 15-year time series of monthly mean values of pressure, temperature, and precipitation at a network of 23 stations on the North American continent. The five eigenvectors (which are by definition orthogonal) associated with the five largest eigenvalues of this covariance matrix are shown to resemble the major features of actual anomaly patterns over the North American continent. The structure of these empirically determined departure fields suggests the large-scale features of the atmospheric circulation over or adjacent to the North American continent.

For use in classification studies, the representation of fields of atmospheric variables in terms of eigenvector patterns (elsewhere referred to as empirical orthogonal functions) rather than a set of rigidly defined orthogonal functions (such as the Fourier-Bessel expansion employed in the hemispheric classification studies) has two distinct advantages. Firstly, the eigenvector patterns represent realistic distributions of departure fields of the climatic variables rather than arbitrary components of the overall pattern. Secondly, the entire patterns, rather than components of the patterns, are orthogonal.

For the reasons outlined above, a technique is described in which the Fourier-Bessel representation of the 500mb height field represents the first step towards an improved method of hemispheric flow pattern classification. In this technique, the time series of the coefficients of the Fourier-Bessel expansion of a sequence of 500mb charts play exactly the same role as the time series of climatic variables in the principal component technique outlined above. The basis for the improved classification is a clustering of points in the space generated by the eigenvectors associated with the largest eigenvalues of the covariance matrix formed from the time variations of the Fourier-Bessel coefficients. The Fourier-Bessel representation of the 500mb height field remains an essential first step needed to reduce the number of observed variables. This would allow opportunities for including details from more than one level (as well as the use of several variables) in the hemispheric classification studies.

Several additional results are reported that are not central to the main theme. These include: a description of the annual variation of the major components of the Fourier-Bessel expansion of the 500mb height field, a study of persistence as a function of the scale size of the terms in the Fourier-Bessel expansion of the 500mb height field, the calculation of

two-dimensional spectra of the kinetic energy at the 500mb level, and the determination of the annual variation in the position of the 500mb circulation pole from asymmetries in the 500mb height field.

8. Lawson, T. L. (M.S.), 1967, "Mean Monthly and Annual Potential Evapotranspiration in West Africa"

Mean monthly and annual values of potential evapotranspiration (PE) are computed, based primarily on the vapor stress of the atmosphere--measured by the vapor pressure deficit--and the available energy in the form of radiation received and/or temperature.

Using the results, corresponding maps of potential evapotranspiration are drawn. An attempt is then made to relate the potential evapotranspiration to the climatology of the region.

It appears that this variable (PE) is controlled largely by the prevailing air-masses: it shows characteristic "wet" and "dry" season distribution respectively as well as two transitional patterns. The annual trend of PE reveals a "double maxima--double minima regime" to the north; a "single maximum-single minimum regime" farther south, and a "coastal regime" which lacks the clear patterns of the preceding two.

9. Mitchell, V. L. (M.S.), 1967, "An Investigation of Certain Aspects of Tree Growth Rates in Relation to Climate in the Central Canadian Boreal Forest"

The Department of Meteorology of the University of Wisconsin has collected several thousand tree cores from central Canada. These cores provide the basis of this study. The core samples were surfaced by sanding and ring widths were measured using a partially automatic measuring device.

An equation describing the growth trend of a tree-ring series is derived and used to eliminate the growth trend from the ring series. After the growth trend is removed, the data is standardized to form a tree-ring index series which can be compared with appropriate climatological data.

An index of average growth of black spruce is mapped and isolines of growth are found to parallel the tree line. A theoretical tree line is defined and located.

Factor analysis is applied to tree-ring data

from Canada and the western United States. The resulting set of eigenvectors show that there is more than one way in which a narrow or a wide ring is formed. The eigenvectors also show the combinations of climatic parameters that result in a narrow or a wide ring.

10. Mitchell, V. L. (Ph.D.), 1969, "The Regionalization of Climate in Montane Areas"

Mountainous regions present special problems in meteorology and climatology. Not only do mountains obstruct airflow, but the differences in elevation from one location to another, in conjunction with the strong vertical gradients of most meteorological parameters, superimpose such a strong pattern of topographically related variance on the spatial field of surface meteorological variables that the horizontal variance is obscured, thereby creating difficulties in synoptic meteorology and climatology.

A case study using equivalent potential temperature to reduce the vertical variance and streamlines of the surface wind field for the period September 13-29, 1968, shows that large mountain masses retard frontal movement, and that modification rates in an air mass moving across the western United States differ from basin to basin.

The mean boundaries between different air masses may be located with the use of equivalent potential temperature patterns and the resultant surface wind field. These boundaries are stable during winter (November-March) and during summer (July-September). The winter and summer boundaries differ in location and causes.

Precipitation values for stations in the western United States may be adjusted to a common elevation, thereby removing the effect of elevation on precipitation observations. The adjusted precipitation field contains significant precipitation boundaries in winter and summer, as well as on an annual basis.

The equivalent potential temperature, resultant wind, and adjusted precipitation boundaries may then be used to define climatic regions in the western United States. Botanical evidence is consistent with the locations of these climatic boundaries.

11. Nagatani, R. M. (M.S.), 1968, "The Dynamic Influences of Diabatic Heat Sinks and the Himalayan Mountain Range on the Vertical Motion Field over India"

Using the linear "omega equation," the effect of heat sinks and the influence of the Himalayan mountain range on the vertical motion field over India was investigated. An "influence function" approach was first used; then using two different heating distributions over northwest India and two different static stabilities, it was found that the more concentrated heat sink created larger vertical motions, and their influence over northeast India was small. For vertical motions caused by forced ascent over mountains, particles approaching the mountain barrier anticipate the mountain, going through cycles of increasing and decreasing vorticities as they approach the mountain and as they go over the mountain.

12. Peterson, J. T. (Ph.D.), 1968, "Measurements of Atmospheric Aerosols and Infrared Radiation over Northwest India and their Interrelationship"

During April and May, 1966, airborne measurements were made of atmospheric aerosols and infrared radiation over northwest India up to 30,000 feet. Simultaneous observations of infrared radiation were also made by balloon-borne net economical radiometers. The instrumentation, which detected both the particle size distribution and vertical variation of the dust concentration as well as the directed infrared radiative flux, is described.

The vertical distribution of the aerosol density was measured on five separate occasions. High concentrations of approximately 700 μgm m^{-3} were observed throughout the lowest several thousand feet of the atmosphere with decreasing amounts above. Three low-level size distributions were measured, all of which were similar, and in general these can be expressed by the relation $dn/dr \sim r^{-3.5}$, for sizes greater than 0.3 micron. A mineralogical analysis of the collected aerosols indicated that quartz was their major constituent.

The nocturnal radiation measurements showed several features which suggested that the infrared radiation was being influenced by the atmospheric dust. In particular, the observed upward flux was consistently greater than similar calculated values, based on dust-free conditions, and these observed--calculated differences diverged throughout the low

levels of high dust density. Observed values of radiative diabatic cooling were significantly larger than the corresponding calculated values, and the observed values were greater when the total amount of dust observed in the troposphere was greater.

Radiative transfer equations were formulated in an attempt to compare the difference between the observed and calculated upward infrared flux data to the simultaneously measured aerosol values. Based on the assumption that all the particles were composed of quartz, the Mie theory was used in conjunction with the observed aerosol size distributions and mass concentrations to calculate the wavelength dependent optical parameters of the particulates (i.e., efficiency factors, scattering albedoes and phase functions). The radiative transfer equations were developed in terms of a model in which the pertinent parameters could be varied so that their effect on the infrared radiative flux could be investigated. When the emissivity of the ground was assumed to be less than 1 and the temperature of the ground to be colder than the shelter temperature, the theoretical results of the model agreed with the observations in the low levels but were of the wrong sign at higher altitudes.

Regression analysis was then used to re-examine the relation between the observed-calculated flux differences and the atmospheric aerosols by using the radiation observations as input into a slightly modified form of the transfer equations. This study indicated that these differences were largely explained by a positive contribution from aerosol scattering. The technique of regression analysis greatly reduced the variation of the aerosol-flux difference relation. Predicted values of observed--calculated differences were near zero for low dust densities but became progressively larger at higher concentrations. Finally, an expression was presented which relates the amount of atmospheric dust to the additional radiative diabatic cooling resulting from this dust.

13. Sandoval, A. R. (Ph.D.), 1967, "Background Studies for a Climatology of the Intertropical Convergence Zone in the Western Central Pacific Area"

The intertropical convergence zone <u>as defined in this study</u> is the zone where the Northern and Southern Hemisphere air streams converge in either hemisphere. Using streamline and isotach analyses, the mean monthly motion and position of the ITCZ in the Western Central Pacific area was determined.

It remains quasi-stationary during the Northern Hemisphere winter, then moves rather slowly in spring and fall, and in summer "jumps" abruptly to a new location.

By kinematic techniques the mean divergence and vertical component of the relative vorticity fields were computed. The convergence area is asymmetric with respect to the position of the ITCZ. On the side of the ITCZ where the air streams are more convergent, and hence more unstable, there are more convective clouds and widespread rainfall. On the side where the air streams are convectively stable, fair weather prevails. The air streams at their source regions have negative (anticyclonic) vorticity. On approaching the ITCZ, the relative vorticity increases and reaches cyclonic values.

If the flow approaching the ITCZ from one hemisphere consists of two air streams of different origin, a convergence between these air streams often develops in the downstream portion near the ITCZ. The intersection of this convergence with the ITCZ forms a "triple point." The fact that the narrow zone of convergence between these two air streams lies nearly parallel to the isolines of the vorticity field suggests that the triple point is a downstream reflection of the vorticity differences of the air streams at their source regions.

The curves of the frequency of observed high clouds for Guam and Kwajalein showed marked differences between months. Diurnal variations have been noted which show apparent dawn and dusk peaks of high cloud.

From the mean radiometer soundings over Guam and Canton Island, a persistent radiative warming in the 100-mb layer below the tropopause was observed throughout the year. A higher value of warming was observed over Guam than over Canton Island. The findings do not seem to show that the radiative warming is related to the ITCZ.

It was found from satellite measurements of radiation that the "ridge" of high albedo coinciding with the "trough" of low long-wave radiation tend to be related to the mean position of the ITCZ in the area of study.

From synoptic analyses by the kinematic method, some typical air stream patterns forming the ITCZ were constructed. Examples of cloud formation related to some air stream patterns were presented.

Section IV

GRADUATE STUDENTS SUPPORTED BY GP-5572X

Ahrnsbrak, W. F.

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Crane, R. V.

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Gary, D. L.

Kahn, S. L.

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Kutzbach, J. E.

Lawson, T. L.

McDonald, N. S.

Menon, V. K.

Mitchell, V. L.

Moran, J. M.

Nagatani, R. N.

Pericht, G. T.

Petersen, J. T.

Reitan, C. H.

Ronberg, P. B.

Sandoval, A. R.

Webb, T., III

Wendland, W. M.

Wilson, W. H.

Section V

CAPITAL EQUIPMENT PURCHASED ON GP-5572X

1 - Tube Tester

1 - Transistor Curve Tracer

4 - Sun Photometers

1 - Trap Bottom for Sample Converter

1 - Infrared Thermometer

2 - Kytoon 9060 with Inflation Assembly

2 - Power Supply (Counter Circuits--Carbon Dating Lab)

3 - Parts Cabinets