

met 66.00. I I  
✓

THE SCHWERDTFEGER LIBRARY  
1225 W. Dayton Street  
Madison, WI 53706

Report to  
Section on Atmospheric Sciences  
National Science Foundation  
Grant GP-444

ANNUAL SUMMARY--1965-66  
INTERDISCIPLINARY PROGRAM OF CLIMATIC RESEARCH

Prepared under the supervision of  
Professor R. A. Bryson  
Department of Meteorology  
University of Wisconsin  
Madison, Wisconsin

872

## CONTENTS

	<u>Page No.</u>
Preface	1
I. Historical Climatology	1
A. Wisconsin Cultures	4
B. Southern Plains	6
C. Pollen Profile	6
D. Clamshell	8
E. Frontier Fort	11
F. El Niño	11
G. Snow Line	13
II. Field Climatology	15
A. Tree-Line	18
B. Great Lakes	19
C. Hurricane	19
D. Hudson Bay	20
E. Cold Pole	20
III. General Circulation Climatology and Climatology	21
A. Dust Patrol	23
B. Red Noise	24
C. Circulation Types	26
D. Weather Factor	27
E. I.T.C.	30
F. African Evaporation	33
IV. Bioclimatology	34
A. Tree Ring	34
B. Pollen Factor	37
C. Soil-Plant-Air	38
V. Microclimatology	41
A. Xmas Tree	42
B. Sunblink II	42
C. Thermo-Tide	42
References	43
Staff	45
Publications, Papers and Manuscripts	47

## ANNUAL SUMMARY 1966

### INTERDISCIPLINARY PROGRAM OF CLIMATIC RESEARCH

#### Preface

The Interdisciplinary Program of Climatic Research in the University of Wisconsin Department of Meteorology, now in its fourth year, has been supported principally by the National Science Foundation through Grant GP-444. The work in Historical Climatology has been supplemented by NSF Grant GS-433 and a grant from the University of Wisconsin. Work in Field Climatology has been largely supported by ONR contract Nonr 1202(07) and that in Microclimatology by the Army through contracts with and grants from the Army Electronics Proving Ground, Fort Huachuca, Arizona. One project (Dust Patrol) because of its complex nature was supported by NSF, ONR, ESSA, and the India Meteorological Department.

The original structuring of the program into historical climatology, field climatology, general circulation climatology, microclimatology, and bioclimatology has continued to work well, and the close association and personnel exchange between these groups has now started to produce beneficial feedback. For example, Project Northern-Air has produced distributions of air-mass frequencies and climate-vegetation relations which have been found very useful by those working on Projects Weather Factor, Tree-Ring, and Frontier Fort.

In the following pages, this report will deviate from previous annual reports in that briefer, selected summaries of progress will be presented, omitting some projects except for a

sentence explaining their general orientation. The following table will indicate the status of old projects described in the annual report for 1964-65 and list the new projects as of May, 1966. The following code is used in the table:

----	continuing
----X	completed and published
----W	completed and being written up
----A,W	analysis and writing under way
---->	sequential development to new project
----	new project

1964-65

1965-66

### I. Historical Climatology

A. Project Oneota	----A,W-->	A. Project Wisconsin Cultures
B. Project Southern Plains	----W-->	B. Southern Plains
C. Project Pollen Profile	----	C. Project Pollen Profile
D. Project Clamshell	----	D. Project Clamshell
E. Project Indian Mound	----(merged with Wisconsin Cultures)	
F. Project Frontier Fort	----	E. Project Frontier Fort
G. Project El Niño	----A,W-->	F. Project El Niño
H. Project Milankovitch	----X	
	----	G. Project Snow-Line

### II. Field Climatology

A. Project Northern-Air	----X	
B. Project Tree-Line	----	A. Project Tree-Line
C. Project Barchan	----A,W	
D. Project Great Lakes	----	B. Project Great Lakes
E. Project Sub-Arctic Radiation	----X	
	----	C. Project Hurricane
	----	D. Project Hudson Bay
	----	E. Project Cold Pole

### III. General Circulation Climatology and Climatology

A. Project Dust Patrol	---->	A. Project Dust Patrol A
		Project Dust Patrol B
B. Project Red Noise	----W-->	B. Project Red Noise
		C. Circulation Types
C. Project Coherence	----(dropped)	
D. Project High Primary	----(dropped)	
	----	D. Project Weather Factor
	----	E. Project ITC
	----	F. Project African Evaporation



1964-65

1965-66

#### IV. Bioclimatology

A. Project Climate Design → A.W

B. Project Weatherwood-----X

C. Project Tree Ring-----

### A. Project Tree Ring

— B. Project Pollen Factor

— C. Project Soil-Plant-Air

## V. Microclimatology

A. Project Bird's Eye III—X

B. Project Xmas Tree-----

### A. Project Xmas Tree

Project Sunblink-----

B. Project Sunlink

D. Project Lake Tower-----X

E. Project Profile Sweep ———X

— C. Thermo-Tide

## 1. Historical Climatology

After assessment of the state of knowledge and theory of past climates (Bryson, 1963) and an attempt to reconstruct the climate of two specific recent centuries (Bryson and Jullien, 1964) it became apparent that before much progress could be made there had to be a much firmer factual basis, and new interpretations of the mode of climatic change. Faint estimates of temperature and precipitation anomalies at rather indefinite times and random places hold little hope, especially when derived from such wide-tolerance indicators as human economic activities and plant community genus composition. It would appear that there are several requisite steps:

1. Establishment of the quantitative relation of economic, floral, faunal etc. patterns to climatic patterns.
2. Investigation of how these climatic patterns vary within the instrumental era, and the selection of boundary regions which might react sensitively to change.
3. Selection of specific, sensitive locales for investigation--for acquisition of data on boundary fluctuations which can in turn be related to climatic changes. Time selection is obviously important as well.
4. Initial investigation of more recent climatic history in order to keep the number of unknowns to a minimum.

The research program of the past four years was planned with these desiderata in mind.

We have been able to show that mean frontal zones for the various seasons can be defined on the basis of low-level mean streamlines of air flow, air trajectories, and airmass frequencies, (Project Northern-Air). In turn it has been possible to show that the inter-frontal regions characterized by specific frequencies and sequences of airmasses, are occupied by distinctive plant community structure and economic activities. (Project Tree-Line; and also Larsen, 1964, 1965a, 1965b; Knollenberg, 1964; Bryson and Baerreis, 1964).

These natural climatic boundaries have moved from time to time, and they provide logical locales for specific studies of the time and magnitude of climatic change. Several studies based on this selection of sensitive areas have been undertaken and are now in progress. For example, the western edge of the region dominated by Pacific air during the climatic winter (Nov.-Mar.), tropical air in summer (June-Aug.) and mild southern air in spring and fall, i.e. the "corn belt," is a region that is particularly sensitive to changes in the zonal index (Project Prairie Drought). On this basis we "forecast" that around 1300 A.D., when European evidence suggests that there was increasing zonal index, there should have been a change in economy towards a more "plains" rather than "woodland" basis in Western Iowa. Project Mill Creek was undertaken for verification of this "forecast" and showed that there was indeed such a change indicated in the remains of the Mill Creek people who occupied the area at that time (Bryson and Baerreis, 1964).

At the same time Projects Prairie Drought and Southern Plains provided a basis for explaining why widespread abandonment

of Kansas, Nebraska and South Dakota by the desert farmers of the end of the 19th century, due to drought, should have been associated with movement of these people or their culture traits into Oklahoma and Texas. High index means reduced rainfall in the central plains, but increased rainfall in Oklahoma and Texas. (Baerends and Bryson, 1965a, 1966)

For more recent times the position of the mean mid-summer position of the polar front in the early 1800's is being investigated using instrumental evidence from the 1830-1850 period (Project Frontier Fort). Earlier movements of the summer position of the Arctic front (ca. 1500 B.C. - 1100 A.D.) were established on the basis of stratigraphic and radiocarbon evidence relating to the northern edge of the boreal forest. (Projects Tundra Fire; Pollen Profile; and Bryson, Irving, and Larsen, 1965; Bender, 1964, 1965; Nichols, 1966)

From the results of these studies it appears that relatively small changes from the present day circulation patterns are all that is required to produce significant ecological effects. It appears that the inter-annual variability which can be studied for the instrumental era is similar to the inter-century variability of the past (Project Red Noise).

A particularly promising tool for the study of past hydrological conditions is being investigated as Project Clam-shell. Molluscs are particularly sensitive indicators of ecological conditions in general, but the consensus is also that there is a correlation between shell composition and water composition which in turn is related to rainfall-runoff relations. Results to date are promising.

Further elucidation of the nature of climatic change in the past 5000 years in central Canada, related to the position of the Arctic front, has been obtained by Project Pollen Profile. On the longer time scale, Project Milankovich has considered the variations of sun-earth radiation geometry over the past half-million years directly in terms of the resulting thermal Rossby number. It appears that the thermal Rossby number was different for glacial and interglacial periods, though the magnitude of the differences is still under study.

The historical climatology projects active at the present time are:

A. Wisconsin Cultures

With the aid of a grant from the University of Wisconsin Graduate Research Committee a pilot program (Project Indian Mound) was initiated to test the feasibility of approaching climatic change through the analysis of fossil soils buried beneath pre-historic Indian mounds. The research design involved testing a series of sites in a transect across the tension zone in Wisconsin between the southern prairie-forest and the northern-hardwoods province. It was assumed that past migrations of this tension zone due to climatic factors might be revealed by buried soils in view of the distinctive characteristics of prairie versus forest soil types. The distinctive mounds of the Wisconsin Effigy were selected as a focus of investigation since the radiocarbon dates presently available for this culture (c. A.D. 500-1200) indicated a time range immediately antedating the climatic episode involved in Project Oneota. Thus a further objective was to push the time period of climatic investigation farther into

the past in a logical, orderly fashion from the known to the unknown.

Field investigations in the summer of 1965 carried out by a crew of archaeologists with W. Barley in charge located two strategic sites--one in Portage County and one in Waupaca County--where the buried soils when compared with soil profiles that were not buried suggest vegetational changes that seem to be a consequence of climatic change. Thus at site 47PT29 in Portage County the buried soil beneath the mound was a prairie soil, but modifications subsequent to mound construction indicate a change to a temperate, humid forest environment.

Preliminary analyses of soil samples by W. James from both Waupaca and Portage Counties indicated the presence of pollen in a good state of preservation indicating that palynology can be used to supplement and confirm the postulated vegetational changes. The recovery of faunal remains from the sites tested indicated that this approach to environmental reconstruction can also be utilized, and preliminary studies of this material were undertaken by L. Lippold.

Plans were formulated to continue this research through extensive field work beginning in the summer of 1966, and funds were granted through NSF GS-433 to aid in carrying out the study. Collateral investigations are also planned by the archaeological staff of the State Historical Society of Wisconsin to investigate prehistoric remains in Trempealeau County, Wisconsin (J. Freeman and J. Brandon). Both projects are focussing upon the climatic characteristics of the Sub-Atlantic episode (c. 500-600 B.C. to A.D. 300-400) and the transition to the subsequent Scandic episode.

Analysis of the materials recovered under Project Oneota continues with doctoral dissertations in preparation by R. Peske, A. Henning and D. Henning. A report on one site was completed in an M.S. thesis by G. Gibbon (1966).

Thus, in summary, the new Project Wisconsin Cultures represents the absorption and amplification of Project Indian Mound and the projection of the approach of Project Oneota backward in time to antecedent climatic episodes. Limited support was provided W. Hurley to complete the analysis of a series of sites of relevant time period in Monroe County, Wisconsin (Hurley, 1966).

Prof. D. Baerreis

#### B. Southern Plains

Further progress on the character of late climatic changes in the Southern Plains has recently been reported (Baerreis and Bryson, 1966). A series of 36 radiocarbon dates confirms our postulated age of A.D. 1250 to A.D. 1450 for the occupation of the panhandle region of Texas and Oklahoma by the Panhandle Aspect cultures. Given the agricultural character of their economy and present rainfall patterns, the data are regarded as supporting the hypothesis that the time interval involved was one of higher precipitation.

Prof. D. Baerreis

#### C. Pollen Profile

Basically this project aims at the collection and analysis of a series of pollen profiles at fairly close and



collected intervals from the Arctic Circle to the Gulf of Mexico, thus delineating the movements of the major climatic regions across 50-100° W. longitude.

During the past year the peat cores from the Pas, near The Pas, Manitoba, in 1964 was analysed for fossil pollen grains and plant macro-fossils, and a pollen diagram was constructed. This indicated that when the late-Wisconsinan ice sheet melted and organic deposition began at Lyon Lake (4500 years ago), a forest of spruce and alder was very quickly established on the exposed ground (with no evidence for an initial tundra period), which probably reflects a swift amelioration of climate. The vegetative data were combined with those from Ennadai Lake, near The Pas, (pollen diagram completed in 1964), to form a climatic interpretation based on the movements of the tundra-trees-line boundary.

Subsequent radiocarbon dating of this material indicates that these climatic changes parallel and are synchronous with those recognized in Northern Europe. European pollen diagrams covering the past 5000 years reflect vegetation changes produced by human activity as well as by climate, so that the vegetational history of central Canada (largely undisturbed by man) offers a valuable comparison of climatic history during the past 6000 years. A paper correlating the history of climate and vegetation in central Canada and Northern Europe has been accepted for presentation at the International Conference on Palynology, Utrecht, September 1966.

A pollen diagram from The Pas, Manitoba has been completed, and analysis made of the plant material composing the

8  
deposit. Palynological evidence for wet and dry periods has been supported by the recognition of changes in peat humification similar to those used by European workers to distinguish regional climatic changes.

Pursuing the investigation of sites along approximately 100° West longitude a field excursion was made to the southern U. S. A peat borer for the recovery of intact 50cm cylinders of organic material for palynology and radiocarbon dating was designed, and it was manufactured by engineers of the University of Wisconsin. With the aid of the new borer, samples were recovered from a lake and a swamp in southern Louisiana, and numerous trial borings were made in Arkansas and Missouri. An exposed assemblage of wood and leaves near Baton Rouge which had been reported to contain Boreal species indicative of cooler climate was relocated and sampled. The analysis of these southern materials for evidence of climatic change is now under way.

Dr. H. Nichols

#### D. Clamshell

The objective of this project is to study the feasibility of using the alkaline earth metal composition of fresh water clamshells as an indicator of paleohydrologic conditions. The study was continued in three phases as follows.

##### 1. Midden Shell Composition

In conjunction with the other studies in the overall project, clamshells were analyzed from two archeological sites in northwest Iowa.

The Kimball mound site is located on the lower Big

Little River near Sioux City, Iowa. The clamshells from this site were sorted into species based on shell morphology with the three numerically largest groups being analyzed for Ca, Sr and Mg. Seventy-two clamshells of the genus and species Quadrula quadrula and 43 clamshells of the genus and species Lampsilla siliquosa were analyzed.

The preliminary results from the previous year indicated an apparent minimum in the Sr/Ca atomic ratio in levels 8-10 with a corresponding minimum in levels 9-10 for the Mg/Ca atomic ratios. The minimum remained substantially the same with a decrease in the standard deviations in each level for Quadrula quadrula, the only species previously determined. The number of clamshells of these two species analyzed totaled 115 which is an addition of 61 over last year.

Thirty-six clamshells of the genus and species Leptodea fragilis were also analyzed. This is an extremely thin shelled variety and makes it impossible to separate the laminar, or growth layers, from the mantle and peripheral layers. The results of this analysis showed an essentially random distribution with overlapping standard deviations for both atomic ratios. The differences in morphology and preparation of this species would indicate from the results that it is not possible to utilize all species of fresh water clams in this type of study.

The Phipps site is located on Mill Creek approximately three miles from the junction with the Little Sioux River. Twenty-five clamshells of the genus and species Quadrula quadrula distributed through levels 5-12 were analyzed. The Sr/Ca atomic ratios present a minimum in levels 8-10, while the Mg/Ca atomic

ratios exhibit a minimum at the lowest levels.

Radiocarbon dates for the two sites show that they were occupied at the same time from about A.D. 900 to A.D. 1400. The minimum from both sites, especially the Sr/Ca ratios, occur chronologically when suspected climatic changes should have taken place.

## 2. Stream Discharge Composition

During the year, 79 samples were collected for the determination of Ca, Mg and other elements from Black Earth Creek near Madison. The initial comparison with stream discharge indicates a direct relationship with the Mg/Ca atomic ratios.

This spring a field trip was made to Mill Creek. Water samples and clamshells were collected along the length of the stream and a collecting station was arranged. Weekly water samples and the gage height are being forwarded to this laboratory from the vicinity of the Phipps site for elemental determinations and comparison with stream discharge.

## 3. Lake Clams

In order to ascertain the relationship between clamshell composition and the elemental composition of water, 26 samples from Lake Mendota were analyzed for Ca, Sr, Mg and other elements. The results indicate that increases in the atomic ratios of Sr/Ca and Mg/Ca tend to coincide with increases in algal production.

The results obtained to date can be summarized as follows:

- a. The alkaline earth metal composition of clamshells does appear to be useful in elucidating past hydrological conditions.

- d. The Ca/Mg ratios of Black Earth Creek water appears to be related to stream discharge. The understanding of this relationship is a necessary prerequisite in positing past hydrological conditions.
- e. The previous report showed that there was a high degree of variability among the growth layers of the lake clams. This variability may be related to the differences in algal production causing changes in the elemental ratios.

Prof. G. Fred Lee  
Mr. William Wilson

#### E. Frontier Fort

There are available in archives a considerable number of meteorological records for the mid-west dating from the early 1800's. Preliminary analysis of these shows that the climate was quite different than the recent. Since the Neo-Boreal extended to at least 1850, these give us an indication of what climatic conditions were like during Oneota occupation of the region.

Prof. R. A. Bryson  
L. Jungkans

#### F. El Niño

During the summer of 1965 radial cross sections of trees were collected from the savanna plains of southwestern Ecuador for the purpose of constructing a tree ring chronology for this region which would provide a record of past occurrences

of the El Niño phenomenon.

The Ecuadorian collection comprises forty-six samples representing twenty species of deciduous, drought resistant trees and tree shrubs. They were surfaced, identified as to species (5 species still undergoing herbarium analysis), and studied in the laboratory to determine their suitability for dendrochronological analysis. All of these tropical angiosperms present problems of varying degree in the recognition and delineation of annual rings. Two species, Capparis ovalifolia and Busera graveolens, were found to have growth increments unrelated to an annual cycle. Some, such as Loxopterygium huasango and Tabebuia rufescens, have rings which are too indistinct for definite recognition using present methods. In most other species the gross overall patterns of ring widths are visible to the unaided eye and there is in these patterns the variability which the dendrochronologist seeks. With the use of a 10X microscope the identification of most of the individual rings in each specimen is accomplished with ease. However, in every case, regardless of species, there are rings in some parts of the cross section which, for one reason or another, are extremely difficult to distinguish. In some samples, cross-dating, even of different radii within a tree, is questionable.

Rings have been measured from 29 of the samples, where possible using 2 or more radii, cross-dating them and averaging them. In a preliminary run, data from 10 trees were compared with rainfall records to get correlation coefficients. The coefficients range from  $-.26$  to  $.44$  and indicate not only the possibility of incorrect calendar dates on the rings, but also that

a more complex relationship may exist than that described by the linear model. Regarding the dates, in most cases the different rings to delimit are those nearest the bark. Where rainfall records are sufficiently long, as at Ancon (41 years) and the trees are from a nearby site (stand #1), it may be possible to consider the rainfall records a "master chronology" and the tree ring data a "floating chronology" and statistically fit it in on the master chronology where the match is good in enough places to eliminate doubt.

Further analysis is needed, both in the laboratory and with statistical techniques, in order to determine if there is a consistent and predictable relationship between ring widths and rainfall in the savanna region of southwestern Ecuador. The development of a tool for dating and evaluating the past occurrences of El Niño is contingent upon the existence and demonstration of such a relationship.

M. Nay

#### G. Snow Line

Observations on the modern and the pleistocene snow lines were made during travel through the Peruvian Andes. En route observations were supplemented by an evaluation of air photos in the Servicio Aerofotográfico in Lima and a survey of the present literature.

The modern snow line drops from more than 5,800 m on the arid Pacific coast of southern Peru to about 4,900 m on the Amazonian slopes of the Andes, the pleistocene snow line correspondingly from 4,500 to 4,200 m. Consequently, the pleistocene



snow line depression decreases from more than 1,300 m on the arid Pacific side of the Altiplano to only about 700 m on the Amazonian slopes. In the Western Cordillera, the modern snow line drops from more than 6,000 m in northern Chile to about 5,000 m in the latitude of Lima, and to somewhat lower elevations in northern Peru. The pleistocene snow line drops from about 5,000 m in northern Chile, to 4,500 m in the Arequipa region, 4,200 m in the latitude of Lima, and to less than 4,000 m in northern Peru. Considering a large-scale South-North profile along the Western Cordillera, the pleistocene snow line depression decreases from northern Chile to about the latitude of the Cordillera Blanca, but increases again farther northward, reaching another maximum in the Cordillera de Talamanca of Costa Rica.

The large-scale variation of the pleistocene snow line depression suggests for the Pacific region of southern Peru a somewhat higher precipitation during the pleistocene, and not necessarily a drop in temperature. For the Cordillera de Talamanca of Costa Rica, on the other hand, a decrease of pleistocene temperatures must be assumed, possibly of the order of 7°C, while a change in precipitation need not be postulated. The peculiar latitudinal variation of the pleistocene snow line depression appears to be best explained with a maximum drop of pleistocene temperatures in equatorial latitudes and a maximum increase of precipitation in about the latitude of southern Peru and northern Chile.

Prof. S. Hastenrath

## 18. Field Climatology

"Field climatology" is here meant to refer to those investigations which utilize natural climatic indicators to obtain insight into the climate of areas where normal climatic data is sparse or lacking. During the past three years this part of the program has been directed towards one group of problems in the Canadian sub-arctic (largely supported by the Office of Naval Research), and another group of problems in the Peruvian Desert.

The Canadian research has been centered on the climatic conditions associated with the location and orientation of the taiga-tundra boundary. Briefly, it has been possible to corroborate the idea that the tree-line is the mean summer position of the Arctic front (Project Northern-Air), and that the distribution of plant communities, treated by factor analysis, yields component sub-communities (factors) which are closely related to the air-mass climatology of the regions where they are found (Larsen, 1965c). The freeze and thaw pattern of lakes in the area also shows that the peculiar NW-SE orientation of the tree-line is climatic in origin (McFadden, 1965; Ragotzkie et al., 1964).

Project Barchan, supported entirely with NSF GP-444 funds, investigated the remarkable train of crescentic dunes on the Pampa de la Joya in southern Peru. These dunes lie on an extremely flat but gently sloping surface between the Andes and the sea. The area is almost totally rainless and the general airflow is not strong. One would expect by normal meteorological reasoning that the seabreeze-mountain breeze circulation would

dominate the region, but the dunes show that the most important winds blow parallel to the surface contours. Lettau has developed a new theory of "thermotidal" winds to account for this situation, including thermal-wind and inertial considerations in the theory of flow within the friction layer (Lettau, 1964). This theory has been corroborated very nicely by field evidence from Peru, both in the behavior of the dunes and in the wind structure shown by pilot balloon observations. The theory also has broader applications to the general question of effects of the diurnal cycle of heating in the atmosphere over terrain which shows a systematic and large-scale slope. It relates the nighttime low-level jet of the central U. S. slope, between the Mississippi and Rocky Mountains, to the nocturnal thunderstorm activity of the region, as a counterpart to a daytime low-level jet along the pacific slope of the Peruvian Andes related to the suppression of convection and the desert character of this region. There are significant prospects of new explanations for other previously unexplained features of atmospheric circulations in relation to topographic features.

Project Barchan also provided a field test of the climatonic principles of Lettau (Lettau and Lettau, 1965).

The phase of work which dealt with the evaluation of direct measurements of sand transport, obtained during the 1964 expedition to the Pampa de la Joya, has been completed.

As one of the principal results of this study, it is shown that the barchans of the region, when surveyed from month to month or over the years, can be looked at as relatively reliable wind-vanes and anemometers. In detail it is shown that this

"calibration" includes (1) determination of the wind-tunnel velocity of sand movement, (2) the micrometeorological relationship between wind speed at a given level of the diurnal surface layer and the surface drag, and (3) the proper value of a dimensionless coefficient of sand transport due to surface drag. The results of our own "in situ" measurements of all three parameters have been described and compared with previous work, especially wind tunnel studies, reported in the literature.

These factors for the Pampa de la Joya, together with estimates of barchan volume and dune displacements 1958 to 1964 were applied to a 6 km<sup>2</sup> area, containing 114 individual barchans, or about 10% of the barchans of the entire pampa. Values of bulk transport for five adjacent cross-wind strips indicate that a transport divergence exists which corresponds to a scour-down rate of the desert floor of 0.2 mm/year. Sand transport by rolling-over of dune material is quantitatively separated from movement of sand across the pampa floor by "streamers" released at the horn-tips of one barchan and intercepted by another barchan down-wind of the former. This process amounts to a continuous renewal of material of any individual barchan, with a complete change-over period of about 64 years.

In another application of volume calculations and sand transport parameters the increase in velocity of the dune-moving winds between the periods of 1955-1958 and 1958-1964 was evaluated.

Some previous speculations concerning foreign versus local origin of the barchan sands in the Pampa de la Joya were reviewed. In contrast to most of these, our findings suggest that wind erosion is sufficiently powerful to form the barchans from locally available sand supply.

#### A. Tree-Line

Studies of the bioclimatology of the Canadian arctic and subarctic were continued, with emphasis upon the characteristics of the transition zone and the low arctic tundra in the general region of the central Canadian tree-line. This is a continuation of the research described in part in previous publications (Larsen 1965). Two technical reports, one on the soils of the boreal forest, and another on the climatological relationships of plant community structure over a wide area, were completed and are now in the process of duplication (Larsen 1966a, 1966b). Additionally, new radiocarbon evidence was obtained in the Artillery Lake area substantiating the earlier evidence (from the Ennadai Lake and Dubawnt Lake areas) that the forest zone at one time extended farther northward than it does at the present time, indicating the existence of periods in the past when climates more favorable for tree growth were to be found in regions farther to the north than they are today (Larsen 1965; Bryson, Irving, Larsen 1965).

Analysis of the vegetational data from study sites throughout the area encompassed by the boreal forest (west of Hudson Bay) continued. The analysis indicates that a rather clearly defined relationship exists between the characteristics of the plant communities and variations in the climatic parameters of the study areas throughout the region under consideration (Larsen 1966a). Definitive patterns can be discerned in the floristic and structural composition of communities which appear to correlate well with the air mass characteristics of the region under consideration. This data is being analyzed in the context of the

the wind frequency patterns revealed in the study of Lagergren (1955).

In the 1965 field season, investigations of plant communities were conducted in the area extending roughly from 107°W through the Lockhart Basin to 108°W, 62°30'N. A search throughout this area was made for paleobotanical evidence of former forest and a collection of archeological artifacts for analysis of former human occupation of the area was obtained. This latter collection has been given to the National Museum of Canada, where it will be analyzed by Wm. Irving, a specialist in this area.

Analysis of the plant community data from this and other areas of the study is continuing and work progresses on additional reports.

J. Larsen

### B. Great Lakes

This project is directed towards the establishment of the surface temperature and current patterns of Lakes Michigan and Superior, and the relation of these to climate. Airborne survey is used, with surface ship control. Excellent progress has been made in showing how the gross pattern is related to heat fluxes between lake and air and how the smaller scale patterns are related to current systems.

Prof. R. A. Ragotzke  
N. Smith

### C. Hurricane

In cooperation with the U. S. Navy Hurricane Hunters

the sea surface temperature structure under a hurricane will be mapped with infrared bolometry and droppable bathythermographs. The purpose is to establish a factual basis for testing the theory that sea structure operates as a control on hurricane intensity and thus explains the regions of normal intensification.

Prof. R. Bryson  
W. Wendland  
S. Kahn

#### D. Hudson Bay

This is a study of Hudson Bay similar to Project Great Lakes. One map of surface temperatures on Hudson Bay has been completed for September, 1965.

Prof. R. A. Bryson  
W. Wendland

#### E. Cold Pole

In the summer of 1966 an expedition will go to the region north of Baker Lake, Keewatin, N.W.T., a site on the Keewatin ice divide which is in the center of the region with lowest mean January temperatures in North America. The permanent snow banks in the area will be excavated for evidence of their antiquity, and heat budget studies will be carried out.

Prof. R. A. Ragotzkie  
J. Larsen  
J. Ahrnsbrak  
H. Cole  
Prof. C. R. Stearns



### III. General Synthesis of Climatology and Circulation

This section of the overall program was attached to the original proposal as being one of the two areas for major emphasis. The work over the past three years has been centered around four climatology (Project Carib-Water, Project Hi-di, Project Monsoon Data), climatic implications of atmospheric dust (Project Indian dust, Project Dust Patrol) and studies of the statistical behavior of the atmosphere (Project Red Noise, Project Concordance, Project High Primary).

Project Carib-Water has been concerned with the general circulation and energy budget of the downstream portion of the trade winds. Many studies have been made on the structure of the upstream portions, such as the classical studies of Hergesell, deBart, and V. Ficker, in the eastern portion of the sub-tropical anticyclones, but very few studies are extant on the western ends. Using the 1960 aerological data for 25 stations Hastenrath (1965) has established the seasonal variation of the western tip of the subtropical anticyclone in the Caribbean and Gulf of Mexico, and the associated variation of energy fluxes.

Pronounced lower troposphere subsidence is found over both the Gulf and Caribbean in winter, changing to mean upward motion in summer, which is insufficient, however, to explain the required vertical flux of heat. Convective activity transfers heat to the upper layers where it is exported.

Budgets of mechanical and latent energy were also calculated from the aerological data. The analysis of these calculations provides the most extensive treatment of the downstream portion of the trades yet, and serves to give new insights into

some of the peculiar climatic characteristics of the region. This study is now complete and is being duplicated.

In contrast to this regional study, Project Red Noise has investigated climatic features of hemispheric scale. Aimed at the question of why so many meteorological parameters follow Markov rather than Gaussian statistics, it was first necessary to devise a means of establishing what features of the circulation were persistent and under what conditions. To this end a system of Bessel-Fourier orthogonal functions was devised (Kutzbach, 1965). These functions are unusually efficient at describing the hemispheric contour pattern and open up a new realm of climatic studies at upper levels. A particular investigation currently underway is concerned with persistent patterns, their duration, identification, and frequency.

Large parts of the subtropics (Africa, Near East, India) are characterized by deep, dense dust layers in certain seasons. The radiative effect of this dust sheet has been investigated in the Northwest Indian Area. (Project Indian Haze, Project Dust Patrol; also see Bryson et al., 1964, Bryson and Baerreis, 1965b). With the cooperation of the U. S. Weather Bureau and the India Meteorological Department, radiation sondes were flown in the area in the pre-monsoon season of 1963. It was shown that the radiation divergence in mid-troposphere was increased about 50 percent by the presence of the dust. Reasonable estimates of dust content were made from the effect of the dust on the infrared transfer. Field investigation suggests that the dust is primarily of local origin, and in fact some photographs made by Cooper from the Mercury capsule give evidence

For the dust origin in the Rajasthan Desert. Dr. J. G. W. Wilson, Meteorological Department, has shown that the subsidence over the desert requires about 50 percent more diabatic cooling than that calculated from the moisture and carbon dioxide distribution. Thus it appears that the subsidence which maintains the desert is increased by the dust from the desert--so that if there were no dust there would be less subsidence, more chance for showers and grass, thus less dust, etc., etc. The possibilities are so intriguing for climate modification that the basic research supported by the National Science Foundation under this grant is also being aided by the Indian Government (maintenance of three radiation sonde stations in the desert for weekly soundings, and through further mathematical modelling by P. K. Das), the U. S. Weather Bureau (supply of radiation sondes and counterpart FL-480 Funds), and the U. S. Navy (assignment of Orion aircraft for direct dust sampling over the Rajasthan Desert).

At the local climatic scale, Lettau has continued the development of closed solutions for the calculation of the local heat budget and climate, given the solar forcing function and substrate characteristics (Lettau and Lettau, 1965).

#### A. Dust Patrol

The main portion of this project, designated Dust Patrol A is described above. In April and May, 1966, a Navy Orion aircraft with six Wisconsin scientists flew to India to measure:

- 1) Dust size distribution--cascade impactor
- 2) Dust mass--Phoenix-Sinclair forward-scattering photometer

- 3) Zenith red scattering
- 4) Net radiation vertical distribution--flux plate radiometers and economical radiometers
- 5) Vertical albedo variations--Kipp and Zonen radiometers (collimated)

These measurements will be used to test the hypothesis that the dust changes the infrared radiation flux significantly.

Dust Patrol B is an extension of these ideas and observations to the study of world wide trends in turbidity and its global effect.

Prof. R. Bryson  
 Prof. J. Weinman  
 W. Wendland  
 J. Peterson  
 R. Steventon

## B. Red Noise

### 1. Hemispheric Flow Pattern Studies

Approximately four years of daily 500 mb charts for the northern hemisphere have been represented in terms of functions orthogonal in polar coordinates. This technique, which is similar to a spherical harmonic representation, has been described (Kutzbach and Wahl, 1965). A number of studies have been made with the coefficients of these orthogonal functions. These are summarized below.

a. Time variability. Time plots of the variations of amplitude and phase of the major harmonics have been prepared. The phase angles of some of the major harmonics show fairly regular displacements associated with the traveling planetary waves. Other harmonics, for example the  $C_{11}$  term (which is the

major contributor to asymmetry of the height field, snow cover, etc. The  $C_{11}$  term is well-developed and stationary throughout the winter portion of the year and a weak, traveling wave during most summers. In the years examined, it became stationary sometime in October and remained so until the first part of April. Periods of unusual behavior can be identified. For example, in the summer of 1961, the circulation pole was displaced 15 degrees of latitude from the geographic pole along the 30W meridian. During the summers of 59, 60 and 62 displacements of the circulation pole were much smaller and less systematic. During the winter season, the tendency for the circulation pole to be displaced down the 180th meridian (first noted by LaSeur, 1954) is apparent.

b. Classification. The only form of temporal averaging that has gained wide acceptance in meteorology is the use of such arbitrary intervals as weeks or months. We investigated the possibility of forming ensemble averages, i.e., finding periods when the large-scale features over the entire hemisphere were stationary or quasi-stationary.

A classification technique developed by Lund (1963) was used to identify similar circulation patterns. The technique involves searching the correlation matrix between all maps in a particular season; the elements of the correlation matrix were formed from the inner products of the coefficients of the orthogonal functions (the coefficients were normalized and the annual variations of the zonal terms were removed). During the winter season, 317 of 355 maps were classified into 25 groups containing from 4 to 37 days per group. For the summer season,

192 of 364 maps were classified into 23 groups containing from 4 to 67 days per group (a minimum of 4 days was required). Mean maps and standard deviation maps for these groups or ensembles are being prepared. This part of the project is being expanded and extended to other applications as Project "Circulation Types".

c. Comparisons. Contingency tables showing the frequency distributions for various combinations of hemispheric patterns and Grosswetter types have been prepared. Some Grosswetter types (in particular those related to blocking) are found with only a small number of hemispheric patterns. Others, for example the zonal flow types, occur with a wide variety of hemispheric patterns.

Parameters representing atmospheric energy or energy transformation show no systematic differences from group to group when the parameters are not presented in spectral form.

## 2. Climatic Anomaly Patterns for North America

Little is known about the covariance structure of climatic parameters over large areas. What forms do the departures from the average or normal fields take? Using monthly values of pressure, temperature and precipitation over a network of 23 stations in North America, empirical orthogonal functions (obtained by the principle component technique) showing the simultaneous spatial distribution of pressure, temperature and precipitation anomalies over the continent have been prepared. It is usually possible to relate the time variations of the coefficients of these orthogonal patterns to time variations in features of the large-scale circulation over or adjacent to the North American continent (blocking in the Gulf of Alaska, latitude

of the storm track, etc.). However, in most cases examined, some variations in the coefficients are not closely related to time variations in half-hemisphere zonal indices or indices further removed from North America (such as blocking over W. Europe).

An hypothesis frequently made in studies of climatic change over the past three or four centuries is that only the frequency and not the character of possible circulation patterns has changed. As our knowledge of the spatial distribution of past climate increases, this hypothesis can be tested by comparing these objectively determined anomaly patterns with evidence from the past.

J. Kutzbach  
Prof. E. Wahl

#### D. Weather Factor

This research has been directed toward the analysis of weather element complexes to determine whether independent distinctive combinations exist which can be associated either with synoptic situations, "air masses", or both.

The basic data were surface observations at noon and midnight for January 1955, 1956, 1957 and 1958 as recorded at Madison, Wisconsin. Each day was meteorologically described by 30 variables (15 at noon and 15 at midnight). In order to establish a mathematical model having the property of orthogonality, component analysis was performed on these 30 original variables.

As a result of this analysis, the 30 original variables were reduced to 9 statistically independent components while still



accounting for 80% of the total variance. These 9 components can be expressed in terms of the original meteorological variables and, as such, they identify the most significant elements of the observations as well as giving good indication that some of the components are probably related to "air mass" properties and others to synoptic situation. Of the 80% total variance accounted for by the 9 components, 34% could be attributed to "air mass" properties and 46% to synoptic situation.

Using the 9 components as the causal variables, one can write a complete mathematical model for each day as

$$\hat{\tilde{y}}_i = b_{1i}\tilde{x}_1 + b_{2i}\tilde{x}_2 + \dots + b_{9i}\tilde{x}_9 \quad (1)$$

where

$$i = 1, 2, 3, \dots, 124$$

$\hat{\tilde{y}}_i$  = weather for day i and = (30 x 1) column vector

$\tilde{x}_1, \tilde{x}_2, \dots, \tilde{x}_9$  = the 9 independent components

and  $\tilde{X} = (30 \times 9)$  design matrix

In order to classify the days into different types, one computes the correlation coefficient between day i and day j by

$$r_{ij} = \frac{\sum_{n=1}^9 b_{ni}b_{nj}}{\sqrt{\sum_{n=1}^9 b_{ni}^2 \sum_{n=1}^9 b_{nj}^2}} \quad (2)$$

Then, using  $r = 0.70$  as the boundary for each cluster, 107 of the 124 days were classified into 25 groups which were designated as 25 weather types.

Each day classified in a type was compared to the synoptic situation that was observed at 1200Z of that day to test whether these types represented true synoptic patterns or whether this method produced types regardless of synoptic situation. A

generalized, schematic synoptic chart for January was developed and the position of Madison for each of the 107 days was plotted on the chart. Preliminary results indicate that this method grouped the days into types that represent true synoptic situations. With the use of this schematic chart, the forecaster may relate definitive values for the 30 original variables by merely forecasting the position of his station on the chart. This system is somewhat unique in that it will even provide definitive values for the 30 original variables in all areas of the pressure pattern rather than merely precipitation and cloudiness in the vicinity of cyclones and fronts as emphasized in most other similar schematics. Furthermore, the sequence of types indicated on the schematic may be utilized by the forecaster to assist him in assigning definite values to his extended forecasts.

Finally, the frequency distributions of the 9 components were analyzed. As one may suspect, most of the distributions were multimodal and these modes were converted into "partial collectives" by partitioning the frequency distributions. Preliminary results indicate that the "air mass" properties agree well with each other and that Madison was subjected to 6 basic "air masses" during the period; and the synoptic situation components "partial collectives" can be easily associated with weather types.

In summary, the results found to date in this investigation are very encouraging. Further January data for Madison will be analyzed to test the weather types as well as the same 4 years of January data for Minneapolis-St. Paul to test whether these types are local or may be applied on a larger lateral scale. The methods described herein will also be applied to some 5 years

of Madison July data to test the applicability of the method to summer data. The final results from the entire study should be available by August, 1966.

Prof. R. Bryson  
W. Christensen

#### E. I.T.C.Z.

This investigation is an attempt to provide some background for a climatology of the intertropical convergence zone (or simply ITCZ) in the western Central Pacific Area between  $0^{\circ}$  to  $23 \frac{1}{2}^{\circ}$  North latitude,  $120^{\circ}$  to  $180^{\circ}$  East longitude. The ITCZ as defined in this study is the zone where the northern and southern hemisphere air streams converge in the summer hemisphere.

As a new project the major part in the initial part of the work was mainly devoted to the collection of the data from various sources, classifying and processing them for analysis. After preliminary analysis of the data, it was deemed advisable to divide the investigation into three parts which are described briefly in the subsequent sections.

#### 1. Observed Atmospheric Mean Field of Motion and Mean Rainfall Patterns of Some Selected Stations

Monthly mean resultant winds for 850, 500, 300 and 200 mb levels were already plotted. From the streamline analysis of the 850 mb level for July, difficulty was encountered in locating the mean position of the ITCZ. This was attributed to the apparent sparse data points in the area. As an aid in locating its mean position, the divergence field of the area was computed by graphical methods using the plotted meridional and

mean components of the mean resultant winds.

The collected surface wind data on hand were originally reported as mean wind rose values. These data are currently being entered onto the IBM cards in order to compute the mean resultant winds, meridional and zonal components. To date, the data for six months have been computed. Of these, the values for January and July were plotted and are being analyzed.

Meanwhile, the mean monthly rainfall patterns for some selected stations in the area of study will be investigated in relation to the mean meridional and zonal wind components for the different pressure levels mentioned earlier. Analysis of the rainfall data for Guam showed two peaks: one in May amounting to 28.28 inches and the other in September, 44.45 inches. It is interesting to note that the corresponding graph of the zonal components for the 850, 700, 500 and 300 mb levels showed different patterns for these same months. In May, the zonal components tended to be more easterly at 850 mb level with a value of -11.97 knots and becoming more westerly at 300 mb level amounting to 11.54 knots using the usual convention where the easterly and westerly components are, respectively, negative and positive. In September, the zonal components were all easterly for all levels and tended to cluster together. The values ranged from -9.36 knots for 500 mb level to -6.39 knots for 850 mb level with the values of the other levels lying between the given range. These results showed that the two rainfall maxima were associated with different atmospheric conditions.

## 2. Infrared Radiation Measurements and the Presence of High Level Clouds in the Migratory Area of the Intertropical Convergence Zone

Mean monthly frequency of daytime observations of high clouds over Guam and Kwajalein which are located in the area of study showed seasonal variations of these observed clouds which suggests that these clouds are related to the ITCZ. Because of the inherent limitations of using surface cloud observations, infrared radiation measurements are being used in this study for (1) evidences from direct measurements and theoretical considerations showing that radiation convergence near the tropopause is attributable to the presence of cirrus clouds as has been reported by several investigators and (2) to establish whether the general behavior of the atmosphere could be quantitatively expressed in terms of radiation.

Thirty-six weekly nighttime radiometersonde flights made on Guam and Canton Island were already processed using the Johnson's data reduction technique to recover maximum information by filtering the random error component of the radiometersonde system. The data for 20 flights were machine-plotted and the tropopause levels were determined. In this way, the "filtered" net radiation and cooling rate, and air temperature will be plotted as a linear function of the pressure difference from the tropopause level. This will make the mass between levels equivalent regardless of the daily variations of the tropopause heights.

It is expected that the more pronounced features of the sounding for each season could be described.

13

Satellite Observed Features of the ITCZ and Air Stream  
Structures in the Vicinity of the Inter-tropical  
Convergence Zone

Based on the definition of the ITCZ mentioned earlier in this paper and examination of streamline analyses of some recently published papers, a tentative idealized model of the different types of air stream patterns forming the ITCZ was constructed. A number of daily surface and 700 mb charts are being re-analyzed by kinematic technique to show the streamlines and the position of the ITCZ.

TiROS pictures for the corresponding days have been printed and are being gridded. The surface and 700 mb kinematic analyses for the area included in each picture will be superimposed on that picture using transparent overlays. Then the clouds seen on the pictures will be categorized and related to the air stream patterns.

It is expected that a table could be presented showing a combination of the most frequent cloud forms for the various combinations of surface and 700 mb types of air stream patterns that would be possible.

Prof. R. Bryson  
A. Sandoval

F- African Evaporation

This is a study of the distribution of evaporation over West Africa, comparing the available methods for estimating from standard meteorological data.

T. Lawson

#### IV. Bioclimatology

The results in Bioclimatology are more extensive than would appear at first sight, for several of the projects described so far have bioclimatic implications or involve biological tools in climatology. (Project Tree-Line, Project Tundra Fire, Project Mill Creek, Project Clamshell; Larsen, 1964, 1965a, 1965b, 1965c).

Over the past two years, Weinman and Nay (1965) have developed a partly-automated tree ring interval counting key-punch (PATRICK) for processing the increment cores to be used in Project Tree Ring.

Project Climate Design has been concerned with radiative transfers within a house and losses through walls to the atmosphere with various wall surface treatment (U. S. Forest Products Laboratory support). Quite remarkable results have been attained in the small house built for this research, a single 100 watt light bulb sufficing for radiative heating in a Wisconsin winter!

Project Weatherwood, also with U. S. Forest Products Laboratory support, has been concerned with the microclimate of wood surfaces and weathering (Shinn, 1965).

##### A. Tree Ring

Mean biological growth curves have been constructed for black spruce, white spruce and jack pine by performing a superposed epoch analysis of each species using ring width data from the region around The Pas, Manitoba. This analysis consists of averaging the first year of growth, the second year of growth, etc. for all trees of a given species without regard to the

calendar year in which growth occurred. Since the trees were taken at breast height, the first year of growth on the bole is not the first year of growth for the tree. This analysis shows the general age trend in the growth of black spruce and jack pine. In black spruce, the width of the annual ring increases for about ten years after the tree reaches breast height. This is evidence of mast trees, since the region of maximum ring growth is now just below the active crown and progresses upward as the active crown moves upward. Once the region of maximum growth in black spruce passes breast height, the growth curve decreases with time for about fifty years, after which it begins to level off.

The mean biological growth curve for jack pine is much the same as the curve for black spruce. One difference between the two is that maximum growth at breast height in jack pine is reached in six or seven years as opposed to the ten years for black spruce. In addition to this, the early growth of jack pine is much more rapid than it is in black spruce. In jack pine, once the inverse range, that portion of the growth curve where ring width decreases with time, is reached, ring width decreases rapidly for about thirty years. It then decreases more and more slowly.

The mean biological growth curve for white spruce is very different from that of the two species just discussed. In white spruce, ring width decreases for about eight years and then remains constant for forty or fifty years. What happens beyond this point is not known, since the trees used in the study were only about sixty years old. This lack of an age trend



simplifies the use of white spruce in climatic studies, since the age trend does not have to be removed.

Once the superposed analysis was completed, polynomials were fitted to the inverse range portion of the mean biological growth curves of black spruce and jack pine in an effort to find a method of removing the age trend from these trees. This was done by stepwise multiple regression. It was found that the simple equation

$$\text{Ring Width} = A + B/X$$

where X is the age of the tree (beginning when the tree reached breast height), and A and B are regression coefficients, explains 99% of the variance in both cases. It is assumed that this curve represents the biological aspects of growth for the tree and that deviations from this curve are due to fluctuations in the environment of the tree. This curve, hereafter, will be called the biological growth curve.

A curve of this type was fitted to each individual tree for which data was available. In almost all cases, this equation explained more than 85% of the variance. The use of additional powers of X did not increase the explained variance enough to warrant their use.

The fitted equations for the black spruce from thirteen sites in Ontario, Manitoba, Keewatin and Mackenzie were used to obtain predicted ring widths ten years and 100 years after the tree reached breast height. These parameters were mapped and an attempt was made to analyze their areal distribution by fitting a surface to the data. The surface used is a function of latitude and longitude to the first and second powers, latitude times

latitude, and the size of the latitude. This new type of analysis will be applied to the general distribution of the average tree line for the twenty year period from 1936 to 1958. All of these comparisons parallel the present tree line to some extent but the details of distribution can be more accurately studied when more tree line data become available in the near future.

The biological growth curve for each of the black spruce from Fort Rae was subtracted from the observed growth curve, thus removing the age trend and giving indices that can be compared with environmental factors. At the present time these indices are being compared with climatological data for that area for the period 1934-1958 in an effort to find the meteorological parameters that most influence tree growth. Once these parameters are found, methods for a reconstruction of climate can be tested using known data. After these reconstruction techniques are tested and refined, a reconstruction of the past climates of central Canada can be attempted.

V. Mitchell

#### B. Pollen Factor

The purpose of this project is to determine whether it is possible, by factor analysis or similar techniques, to go directly from observed present day pollen rain distributions to plant distributions (see Project Tree-Line) or even directly to climatic distributions. Most studies of the present pollen rain have gone from genus to genus rather than generic ensemble to plant community, and apparently none have gone directly to climatic ensemble. If this can be done, interpretation of past

climates from pollen assemblages will be much easier.

H. Cole

### C. Soil-Plant-Air

Work on this project has progressed along two lines: (1) the development of a hypothesis which is a new approach to the problem of evaporation from vegetation, (2) the design and testing of a lightweight instrument package for profile measurements of net radiation, temperature, humidity, and windspeed over a wide range of vegetation types.

The hypothesis approaches the problem of evaporation from vegetation by attempting to use the liquid water transport properties of the soil and the plant as a means of constructing a single, predictable system. First the hypothesis proposes characteristic lengths in soils and plants as a means of reducing the variables of water transport. It is suggested that data from all types of vegetation and soils can be compared on a common series of scales. Grasslands as well as forests, mesic agricultural crops, and xeric desert vegetation are suggested to have properties of water export which are similar and which can be expressed as characteristic lengths. Likewise, the mechanics of water movement in substrates beneath these communities appear to have similarities that can be reduced to characteristic lengths.

To obtain a basis for comparison using the characteristic length scales, methods used in fluid dynamics are applied. The proposal outlines how aerodynamics uses a characteristic length in constructing Reynolds numbers to study fluid flow

developed, and discusses the applications of characteristic length to flow through porous media. The special considerations and availability conditions required for application to the soil-plant system as a porous medium are then discussed. Extension of this concept to the plant community is made using data from the literature to illustrate kinematic properties such as the relation between leaf water potential and intracellular water. During these considerations two length scales for each medium are suggested, a macrolength and a microlength, and arguments presented for and against for each choice.

The application of transform variables obtained from the scales is to be examined at some future date. The flow properties of the soil and plants may be analyzed to some extent by data from the literature. Preliminary work has been done on this.

Further tests and analysis of the hypothesis will utilize simultaneous studies of soil and plant water potential with micrometeorological measurements of evaporation by the "energy budget" technique over Wisconsin vegetation.

The instrumentation for this phase of the project has progressed from laboratory bench models to construction of flight models. A lightweight, low cost, sensor system has been adapted from another project in the University of Wisconsin Meteorology Department. A new sensor unit has been added using a ventilated net radiometer, a wet-dry bulb thermistor psychrometer, a Weather Bureau hygrometer, and a wind-tunnel tested resistance anemometer.

The instrument package will be raised and lowered from ground level to a maximum height of eighty feet. A portable, crank-up tower will be used to support the instrument. Analog to digital conversion is provided within the instrument package.

and the data is to be received at a portable ground station with optional wire or radio transmission. The minimum hardware needed on the ground is a transistorized frequency counter, a digital recorder, and a generator. Measurements will be performed during characteristic periods over a number of vegetation types, beginning in summer, 1966.

This project is sponsored by an NSF grant through Prof. O. Loucks, Dept. of Botany.

Joseph H. Shinn

## Microclimatology

Most of the microclimatology program under the direction of Prof. Lettau has been supported by U. S. Army funds. This group has been working on air/water interaction and albedo modification, thermal response experiments, and controlled experiments on wind profile modification.

An important segment of the microclimatology program supported by NSF GP-444 has been Project Bird's Eye I, concerned with the mapping of regional and seasonal variation of albedo over North America (Kung et al., 1964). This project found that the snow cover is the most important modification of the earth's surface, giving a significantly higher mean albedo. The quantitative relationship between snow cover and albedo was examined. Surface albedo values for various regions of the continent were mapped on the basis of 210,000 inflight measurements, for the various seasons.

Another segment supported by GP-444 has been Project Barchan, reported extensively in the Annual Summary for 1964-65, and listed primarily under field climatology. The micrometeorological data from Peru has now been analyzed. A method of analysis of soil temperature and heat flux profiles utilizing harmonic analysis of the time series at several depths was tested. It was found possible to determine the relative depths and calibration of the sensors in situ, if an assumption is made about the volumetric heat capacity of the soil. Improved methods of calculating the displacement height of the wind profiles have also been developed.

A. Xmas Tree

This project was reported in the Annual Summary for 1964-65. It is one of a series of experiments carried out on the ice of Lake Mendota. During the last winter the project was dormant due to poor ice conditions and short ice cover.

Prof. C. Stearns  
J. Zabransky

B. Sunblink II

The basic experiments of this project have been concerned with establishing the surface thermal response to various frequencies of the radiative forcing function. This new phase of the study is concerned with the response of a finite depth surface layer (such as a forest) using cloud shadows to generate variations in the radiative forcing function.

J. Lambert

C. Thermo-Tide

This is an extension and elaboration of the thermo-tidal wind theory of Lettau (previously reported) to other situations, especially to the phase shift of  $180^\circ$  expected across  $30^\circ$  latitude.

K. MacKay

## References

- Bryson, R. A. and R. A. Bryson, 1965. "Historical Climatology and the Southern Plains: A Preliminary Statement," Hull. Calif. Anthro. Soc. 13:69-75.
- Endler, Margaret M., R. A. Bryson, and D. A. Baerreis, 1965. "University of Wisconsin Radiocarbon Dates I," Radiocarbon 7:119-127.
- Bryson, R. A., 1962 (compiled by). "Paleoclimatology and Climatic Change," Trans. AGU 44:21:396-400.
- Bryson, R. A. and P. R. Julian, 1963. "Proceedings of the Conference on the Climate of the Eleventh and Sixteenth Centuries," NCAR Technical Notes 63-1.
- Bryson, R. A. and D. A. Baerreis, 1964. "Paleoclimatology and the Hill Creek Culture of Northwest Iowa," Paper given at Soc. for Amer. Archaeol., Chapel Hill, N. C.
- Bryson, R. A., C. A. Wilson, and P. M. Kuhn, 1964. "Some Preliminary Results from Radiation Sonde Ascents over India," Proc. WMO-IUGG Sympos. on Tropical Meteor., Rotorua, N. Z., Nov. 63.
- Bryson, R. A. and D. A. Baerreis, 1965. "Possibilities of Major Climatic Modification and their Implications: Northwest India, A Case for Study," Part of proceedings of Symposium on Social and Economic Implications of Weather Modification, Boulder, Colo., July 1-3, 1965.
- Bryson, R. A., Wm. N. Irving, and James A. Larsen, 1965. "Radiocarbon and Soils Evidence of Former Forest in the Southern Canadian Tundra," Science 147 (3653):46-48.
- Hastenrath, Stefan, 1965. "Studies of the General Circulation and Energy Budget in the Area of the Central American Seas," (ms), pp. 200.
- Knollenberg, Robert (M.S.), 1964. "The Distribution of String Bogs in Central Canada in Relation to Climate."
- Kung, Ernest C., R. A. Bryson, and D. H. Lenschow, 1964. "Study of Continental Surface Albedo on the Basis of Flight Measurements and Structure of the Earth's Surface Cover over North America," Mon. Wea. Rev. 92:543-564.
- Kutzbach, J. E. and E. Wahl, 1965. "The Representation of Scalar Fields with Functions Orthogonal in Polar Coordinates," Journal of Applied Meteorology 4:542-544.
- Larsen, James A., 1964. "The Role of Physiology and Environment in the Distribution of Arctic Plants". Technical Report 16. ONR NR 387-022 Nonr 1202(07). University of Wisconsin, Department of Meteorology.



- Larsen, James A., 1965a. "The Vegetation of the Ennadai Lake Area, NWT: Studies in Arctic and Subarctic Bioclimatology, I," Ecol. Monogr. 35:37-59.
- Larsen, James A., 1965b. "An Outline of Materials for a Post-Glacial Bioclimatic History of Keewatin, Northwest Territories, Canada," Technical Report 15, ONR NR 387-022 Nonr 1202(07). University of Wisconsin, Department of Meteorology.
- Larsen, James A., 1965c. "Relationships of Central Canadian Boreal Plant Communities: Studies in Subarctic and Arctic Bioclimatology, II," Task NR387-022 ONR CONTRACT 1202(07) Technical Report 26, Department of Meteorology, University of Wisconsin.
- Larsen, James A., 1966. "Soils of the Boreal Forest," Technical Report 25, ONR NR 387-022 Nonr 1202(07). University of Wisconsin, Department of Meteorology.
- Larsen, James A., and R. A. Bryson, 1966. "Relationships of Central Canadian Boreal Plant Communities and Air Mass Characteristics: Studies in Arctic and Subarctic Bioclimatology, III" (in progress)
- Lettau, H. H. and C. R. Stearns, 1964. "Micrometeorology and Aerodynamics of Sand Dune Migration," Paper given at Amer. Met. Soc., Salt Lake City, Utah, Oct. 1964.
- Lettau, H. H. and K. Lettau, 1965. "Climatology of a Rainless Tropical Region," pp. 60, (ms)
- McFadden, James, 1965. "The Interrelationship of Lake Ice and Climate in Central Canada," Task NR387-022 ONR CONTRACT 1202(07) Technical Report 20, Department of Meteorology, University of Wisconsin.
- Ragotzkie, R. A., R. A. Bryson, and J. D. McFadden, 1964. "Climatological Significance of the Freezing and Thawing of Lakes," Paper given at AMS-AAAS, Western Div., Vancouver, Canada, June, 1964.
- Shinn, J. H., 1965. "Low Speed Shear Flow in a Wind Tunnel over Flat Wood Surfaces and the Determination of the Local Drag Coefficients and the Convective Heat Transfer Coefficients." (ms)
- Weinman, J., M. Nay, and V. Mitchell, 1965. "PATRICK--Partially Automatic Tree Ring Increment Counting Keypunch," Tree Ring Bulletin (in press)

# Staff

Prof. R. A. Bryson	Meteorology
Prof. W. A. Ragotzkie	"
Prof. L. H. Lott	"

## Physical Climatology

Prof. R. A. Bryson	Meteorology
Prof. D. A. Baerreis	Anthropology
Prof. E. F. Lee	Civil Engineering
Prof. G. Lee	Soils
Prof. P. Hale	"
Prof. K. Dutzer	Geography
Prof. L. J. Maher	Geology
Prof. R. Dott	"
Prof. W. Schwerdtfeger	Meteorology
Prof. J. Kutzbach	"
Dr. H. Nichols	"
Dr. J. Freeman	Wis. St. Hist. Soc.
Mr. J. Brandon	" " " "
Miss L. K. Lippold	Anthropology
Mr. G. Gibbon	"
Mr. W. Hurley	"
Mr. W. R. James	"
Mr. W. Wilson	Water Chemistry
Mrs. M. Nay	Meteorology
Mr. T. Webb	"

## External Collaborators

Dr. Charles Cleland	Mich. St. Hist. Soc.
Dr. Andreas Paloumpis	Illinois Normal Univ.
Dr. Richard Yarnell	Emory Univ.
Dr. Hugh Cutter	Missouri Botanical Gardens
Dr. Robert E. Bell	Univ. of Oklahoma
Dr. E. Mott Davis	Univ. of Texas
Mr. W. D. Frankforter	Grand Rapids Public Museum
Dr. A. E. M. Nairn	Univ. of Newcastle
Dr. M. Matteson	Univ. of Illinois
Mr. D. Henning	Univ. of Missouri
Mrs. D. Henning	" " "
Mr. R. Peske	Univ. of Wisconsin--Milwaukee

## Field Climatology

Prof. R. A. Bryson	Meteorology
Prof. R. A. Ragotzkie	"
Dr. S. Hastenrath	" U.W., Milwaukee
Prof. C. R. Stearns	"
Prof. J. Thomson	Botany
Mr. J. A. Larsen	"
Mr. N. Smith	Meteorology
Mr. W. Wendland	"
Mr. V. K. Menon	"
Mr. J. Ahrensbrak	"

External Collaborators

Dr. F. Prohaska	Univ. of Wisc.--Milwaukee
Dr. A. Nursall	Univ. of Alberta
Dr. S. Orvig	McGill Univ.

General Circulation Climatology and Climatology

Prof. H. H. Lettau	Meteorology
Prof. R. A. Bryson	"
Prof. E. Wahl	"
Dr. S. Hastenrath	"
Dr. K. Lettau	"
Mr. T. Lawson	"
Mr. J. Peterson	"
Mr. J. Kutzbach	"
Mr. W. Bendel	"
Mr. A. Sandoval	"
Mr. S. Kuhn	"
Maj. W. Christensen	"

Internal Collaborators

Mr. R. Stewart	State Univ., New York
Dr. P. K. Das	India Meteor. Dept.
Miss A. Mani	" " "

Bioclimatology

Prof. R. A. Ragotzke	Meteorology
Prof. J. Weinman	"
Prof. B. Bloomfield	Environmental Studies
Prof. O. Loucks	Botany
Mrs. C. Steinkopff	Meteorology
Mr. V. Mitchell	"
Mr. J. Shinn	"
Mr. H. Cole	"

Internal Collaborators

Various scientists and engineers of USDA Forest Products Laboratory

Microclimatology

Prof. H. H. Lettau	Meteorology
Prof. C. Tanner	Soils and Meteorology
Prof. C. R. Stearns	Meteorology
Mr. K. MacKay	"
Mr. J. Lambert	"
Mr. J. Zabransky	"
Mr. J. Turner	"

General Services

Mrs. Ruth Decker, Secretary  
Mr. R. L. Steventon, Technician  
Dr. M. Bender, Radiocarbon Lab.

UNIVERSITY OF WISCONSIN  
CLIMATE RESEARCH PROGRAM  
CLIMATE RESEARCH PROGRAM IN CLIMATE

UP-408

UNIVERSITY OF WISCONSIN, Department of Meteorology

CLIMATE RESEARCH

Due to the interlocking nature of many of the research  
programs in climatology at the University of Wisconsin, support  
from more than one source is almost more normal than single source  
support. Because this is the case, an attempt is made to identify,  
as well as possible, the degree of support for each paper listed,  
though this is often a very difficult estimate to make. A large  
X at the right hand margin will indicate major or complete NSF  
support; an S, support about equally divided; and an n, minor  
NSF support. Papers reported previously are omitted from this  
listing.

I. Papers Published or in Press

15. Baerreis, D. A. and R. A. Bryson. "Climatic Episodes and the Dating of the Mississippian Cultures"  
Wisconsin Archaeologist Vol. 46, Dec. 1965 M
16. Bender, M. E., R. A. Bryson, and D. A. Baerreis.  
"University of Wisconsin Radiocarbon Dates II"  
Radiocarbon (accepted for 1966 issue) M
17. Montmeyer, Peter L. and J. E. Kutzbach. "A higher order theory for deep water waves"  
Univ. of Wisconsin Math. Research Center, Tech. Rept. #C10, Feb. 1965. n
18. Kutzbach, J. E. and E. W. Wahl. "The representation of scalar fields with functions orthogonal in polar coordinates"  
Jour. Appl. Met. 4:542-544, 1965. M
19. Mahi, A., C. R. Sreedharan, and V. Srinivasan.  
"Measurements of Infrared Radiative Fluxes over India"  
Jour. Geoph. Res. 70:4529-4536, 1965. S
20. Butzer, Karl W. and C. L. Hansen. "Upper Pleistocene Stratigraphy in Southern Egypt"  
Wanner-Gren Fnd. Symp. on Systematic Invest. of African Later Tertiary and Quaternary, 1965. n
21. Kutzbach, J. E., R. A. Bryson, and W. C. Shen.  
"An Evaluation of the Thermal Rossby Number in the Pleistocene"  
Meteor. Monographs (to be published) M
22. Weinman, J., M. Nay, and V. Mitchell. "PATRICK-- A partially automatic tree ring increment counting keypunch"  
Tree Ring Bulletin (to be published) M
23. Bryson, Reid A. "Recent Climatic Episodes in North America"  
Proc. Southeastern Archaeol. Conf. pp. 78-81, 1965 M
24. Nichols, H. "Pollen Diagrams from Sub-Arctic Central Canada"  
Submitted to Science M
25. Kutzbach, J. E., editor. "Proceedings of the Seminar on Possible Responses of Weather Phenomena to Variable Extraterrestrial Influences"  
NCAR Tech. Note TN-8, 1965 n

13. Lettau, H. and H. Lettau. "Glossary of terms frequently used in Cloud Physics"  
Amer. Inst. of Physics, March 1966
14. Lettau, H. "A new method for predicting the blooming date of spring flowers"  
Trans. Acad. of Arts, Sci. Letters,  
Spring 1966
15. Baerreis, D. A. and R. A. Bryson. "Dating the Panhandle Aspect Cultures"  
Bull. Okla. Anthro. Soc. 14:105-116, 1966
16. Shinn, J. H. "Low speed shear flow in a wind tunnel over flat wood surfaces and the determination of the local drag coefficients and convective heat transfer coefficients"  
Final Report on Wind Tunnel Studies under Master Memorandum No:12-11-012(560), Supplement 4, USDA Forest Service, Forest Products Laboratory and the University of Wisconsin, April, 1965.

#### Papers Given at Professional Meetings

15. Kutzbach, J. E., R. A. Bryson, and W. C. Shen. "An Evaluation of the Thermal Rossby Number in the Pleistocene"  
VII INQUA Congress, Boulder, Colo., 1965
16. Bryson, R. A., J. A. Larsen and W. N. Irving. "Climate and Post-Glacial Forest History in SW Keewatin, N.W.T.: I Soils and Radiocarbon Evidence"  
VII INQUA Congress, Boulder, Colo., 1965
17. Nichols, H. "Climate and Post-Glacial Forest History in SW Keewatin, N.W.T.: II Palynological Evidence"  
VII INQUA Congress, Boulder, Colo., 1965
18. Baerreis, D. A. and R. A. Bryson. "Archaeological Site Distribution and Climatic Change in the Southern Plains"  
VII INQUA Congress, Boulder, Colo., 1965
19. Bryson, R. A. "Internal Waves in the Easterlies"  
Indian Meteor. Soc., New Delhi, Jan. 1966
20. Lettau, H. "Dune Migration, and a New Theory of Atmospheric Circulation in the Arid Zone of Peru"  
Peruvian Society of Civil Engineers, Special meeting, Lima, Peru, March 1966

21. Lettau, H. "Effects of Large-Scale Terrain Slope on Air Motion in the Planetary Boundary Layer" American Meteorol. Society, 25th National Meeting, jointly with Annual Meeting of American Geophys. Union, Washington, D. C., April, 1966
22. Lettau, H. "Case Studies of Airmass Modification over Lake Michigan Using Instrumented Aircraft" The Ninth Conference on Great Lakes Research, Chicago, Illinois, March 1966
23. Lettau, H. "On the Meteorological Causes of Coastal Deserts" NASA-Sigma XI Greater Boston Area--Special Lecture at U. S. Army Natick Laboratories, Natick, Mass. (in honor of Dr. E. E. Mackay), July, 1965
24. Bryson, R. A. "Inadvertent Climatic Modification"
  - a) Amar. Inst. of Physics, Seminar for Science Writers, Mar 1966
  - b) Symposium on Social and Economic Implications of Weather Modification, Boulder, Colo., July 1965
25. Ragotzke, R. A. "Infrared and hydrographic studies of Lake Superior" Ninth Conference on Great Lakes Research, IIT Research Institute, Chicago, Ill., March 28-30, 1966
26. Kohn, P. M., E. Meeson, and R. A. Ragotzke. "Double bolometer measurement of the effects of atmospheric radiators" Remote Sensing Symposium, Univ. of Mich., April 1966 (to be published in the Proceedings)

### III. Theses Supported

9. Leuschen, D. (Ph.D.) "Airborne Measurements of Atmospheric Boundary Layer Structure"
10. Super, A. (Ph.D.) "A Study of Small-Scale Air Mass Modification over Lake Mendota"
11. Hamilton, H. (Ph.D.) "Measurements of Infrared Radiation Divergence and Temperature Profiles near an Air-Water Interface"
12. Stearns, C. (Ph.D.) "Micrometeorological Studies on the Coastal Desert of Southern Peru"

13. Kutzbach, J. (Ph.D.) "The Representation and Classification of Fields of Atmospheric Variables" M
14. Lettau, B. (Ph.D.) "The Use of Sub-Arctic Bogs as Natural Climatic Indicators" n
15. Gibbons, G. (M.S.) "The Midway Village Site: An Intra-site Analysis" n
16. Hurley, W. (M.S.) "The Silver Creek Sites (47-Mo-1 TO Mo-5): A Complex of Five Woodland Site Localities in Monroe County, Wisconsin" n