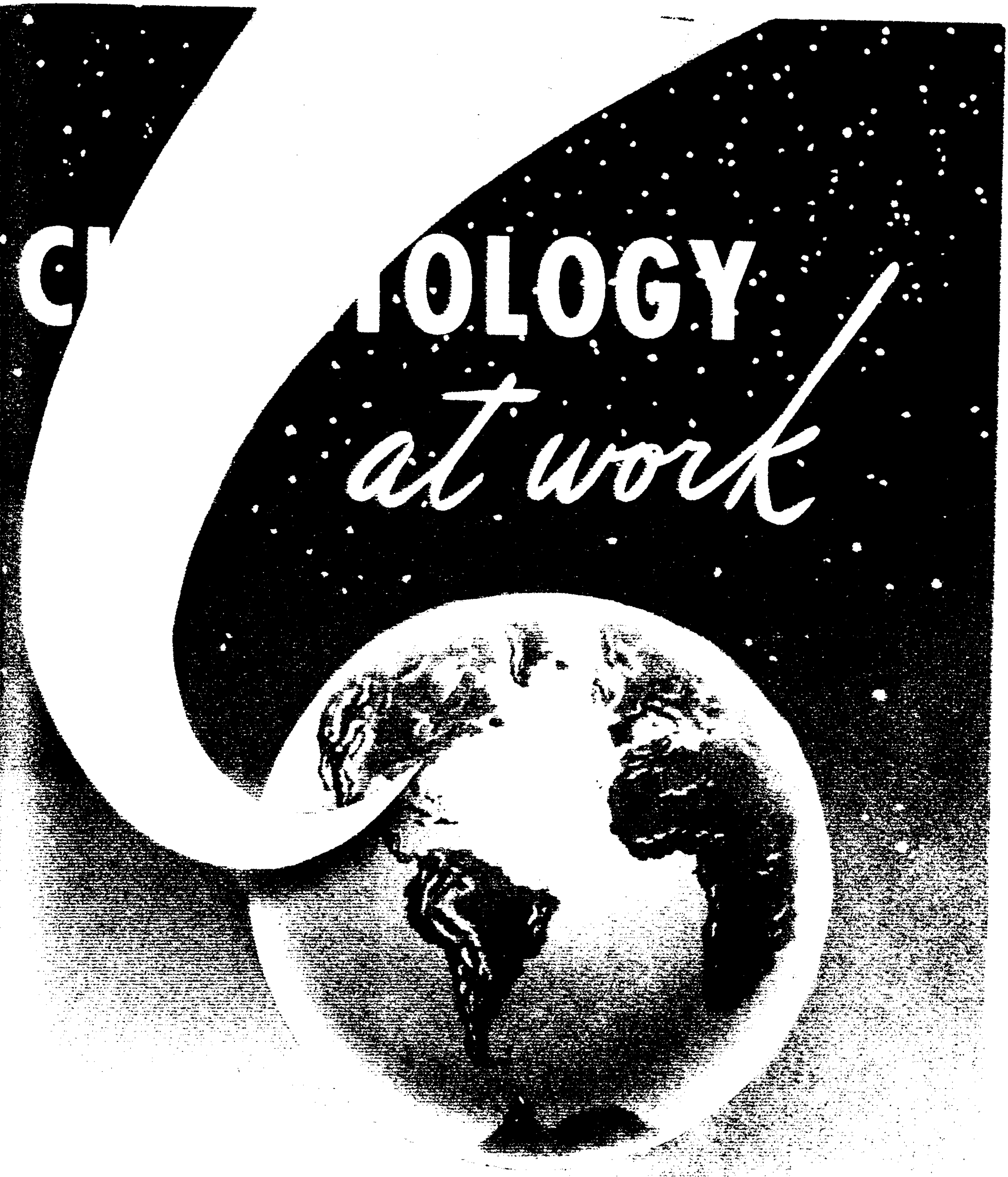


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

January 31, 1974

CLIMATOLOGY AT WORK

Climatology at Work was published fourteen years ago. It has not been updated or modified since.

Climatology at Work had its genesis in New Orleans at the New Orleans Port of Embarkation in June 1948. The New Orleans Port of Embarkation was the home of the Air Force Data Control Unit of the Air Weather Service, the Navy Group and the Office of Climatology, Weather Bureau New Orleans Tabulation Unit. Its genesis was in the publication Machine Methods of Weather Statistics. This was reissued in 1949 in its Fourth Edition.

In 1951, the New Orleans groups moved to Asheville, N. C. where the National Weatner Records Center was to be established. The Machine Methods in Weather Statistics was updated primarily through the efforts of the U. S. Navy group in a contract with the U. S. Weather Bureau. The title was changed to "Climatology by Machine Methods for Naval Operations, Plans and Research." This was prepared for the Office of Naval Operations, Aerology Branch, Washington, D. C., March 1953.

Again the publication was modified and reissued in 1960. Again it was sponsored by the U. S. Navy in cooperation with the U. S. Weather Bureau, Office of Climatology and the Air Weather Service. It was more extensive. As the second issue discussed the newer and better calculating equipment, the third issue saw the introduction and use of electronic data computers.

Since that time computers have increased in potential and capability, in speed and decreased costs because of more and efficient data processing. Archival techniques have progressed. Research capabilities have increased.

The three forms initiated here bring together the state of the art through 1960 and no more than that.

Harold L. Crutcher

CLIMATOLOGY AT WORK

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. - Price 65 cents

U. S. DEPARTMENT OF COMMERCE
FREDERICK H. MUELLER, Secretary
WEATHER BUREAU
F. W. REICHELDERFER, Chief

CLIMATOLOGY AT WORK

MEASUREMENTS, METHODS AND MACHINES

Edited by Gerald L. Barger

Assisted by John C. Nyhan

Produced at National Weather Records Center, U. S. Weather Bureau, Asheville, N. C., with Support of U. S. Navy and U. S. A. F. Air Weather Service

WASHINGTON, D. C.
October 1960

ACKNOWLEDGMENTS

The editor assumes responsibility for the accuracy and organization of the following pages, of course, but the contents are the result of group effort. Recognition is due the following members of Weather Bureau and Air Weather Service staffs for individual contributions in selected subject matter areas:

Norman L. Canfield
Harold L. Crutcher
James R. DeCoster
Oskar M. Essenwanger
Charles M. Horton
Raymond L. Joiner
Thomas L. Long
J. Murray Mitchell, Jr.
John C. Nyhan
Herbert C. S. Thom

The Methods, or statistics, chapter is taken essentially verbatim from material prepared by H. C. S. Thom with the assistance of the Working Group on Statistical Requirements and Methods in Climatology for the Commission for Climatology, World Meteorological Organization.

The Office of Navy Representative, through Lt. Cmdrs. J. M. Frosio and R. C. Parker particularly, has lent continuing support and encouragement to this effort from its initial request to final review of the manuscript.

The assistance of the following is also acknowledged: Raymond D. Crane, Sesto B. Martin, Mrs. Nacy Barnhardt, Miss Ruth Wendel.

The project was under the supervision of Roy L. Fox, Director of the National Weather Records Center.

PREFACE

This publication describes the functions, scope, and capabilities of the centralized climatological facility located at Asheville, North Carolina. This facility consists of the National Weather Records Center operated by the U. S. Weather Bureau, with major support from the U. S. Navy, and the Data Processing Division of the Climatic Center, U. S. Air Force, operated by the Air Weather Service.

We address these remarks to those who want to know how thoughtful weather analysis can benefit them. We attempt to give the reader an insight into the role a centralized climatological facility can play in the operation of his home, his profession, his business, or the community in which he works and lives. Terminology in the following text tries to make practical sense of "climatology at work". A chapter on "Climatology" familiarizes the reader with the type of scientific work conducted at Asheville and succeeding chapters deal with these ingredients of climatological analysis:

(observational) measurements
(analytical) methods, and
(processing and computing) machines

To these must be added the highly trained men and women who integrate the measurements, methods, and machines into a useful product.

Some prior knowledge of meteorology will be helpful but we trust the technician and business or professional man will find assistance in solving his problems -- or at least in seeking solutions. In the Methods chapter some previous familiarity with mathematics and statistics is almost essential. For a quick look, the Product chapter shows a few examples of client requests and the information furnished, as well as the procedure for making requests to the individual weather services occupying the Grove Arcade Building in Asheville. The hurried reader may want to look through the last chapter first. It gives a brief picture of the type of service available and how to "place an order".

TABLE OF CONTENTS

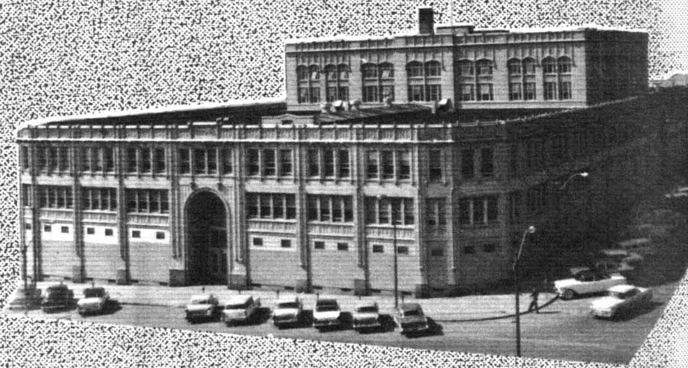
FIGURES

TABLES

Records Received

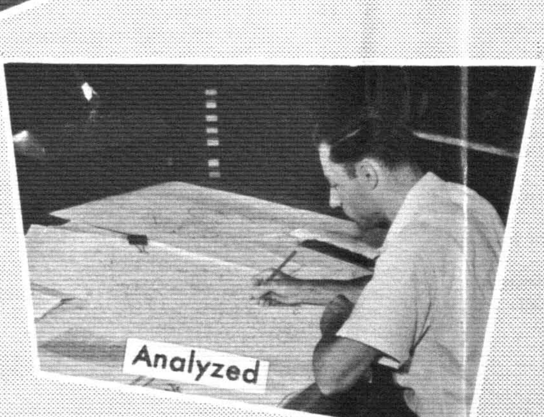
Catalogued

Punched



Quality Control

Processed



Analyzed

Chapter 1

INTRODUCTION

History and Development

1.0 INTRODUCTION

Centralized activity is the basis of operations carried on by the Weather Bureau, Air Force, and Navy in the Grove Arcade Building in Asheville. These cooperating weather services conduct climatological programs which display many similar facets and a variety of differences. All three benefit from the great volume of available observational data maintained by the Weather Bureau as a part of the National Archives. The Weather Bureau and the Air Force maintain separate data processing and computing units, each tailored to its specific purposes.

1.1 HISTORY

It seems pertinent to include here the birth and growth of the nation's weather analysis facility, and the background era of invention and ingenuity which led to its inception. J. Moser (1701-1787), a professor of international law in Germany, designed a card index system in which original information was handwritten on cards which were sorted manually according to different categories [2]. The cards in each group then could be counted and summarized rapidly. In order to facilitate sorting, the cards were notched or colored tags were affixed in various positions. A new era began at the end of World War II when accounting machines were adapted to statistical processing of weather data. These machines used a sorting and counting principle evolved by a French silk weaver, J. M. Jacquard (1752-1832). The pattern of woven material was first punched on cards that controlled the warp thread. The cards were joined together by threads so as to form a continuous belt, foreshadowing the use of continuous paper tapes in modern machines. In 1890, H. Hollerith of the U. S. Bureau of the Census utilized a punched card in essentially its present form after inventing equipment necessary for its successful use. The efficiency of the first semi-automatic machines was demonstrated by the fact that it took seven years to compile the data from the census of 1880, whereas results of the 1890 census were available after only one year.

Meanwhile, Matthew F. Maury pioneered the advancement of meteorological programs when he became Superintendent of the U. S. Navy Hydrographic Office in 1842 [1]. He organized an extensive system for the collection of weather data from logs of warships and domestic and foreign merchant vessels. Expansion of the ranks of oceanic weather observers continued steadily until 1893; however, these new masses of data presented a processing problem to the limited staff at the Hydrographic office.

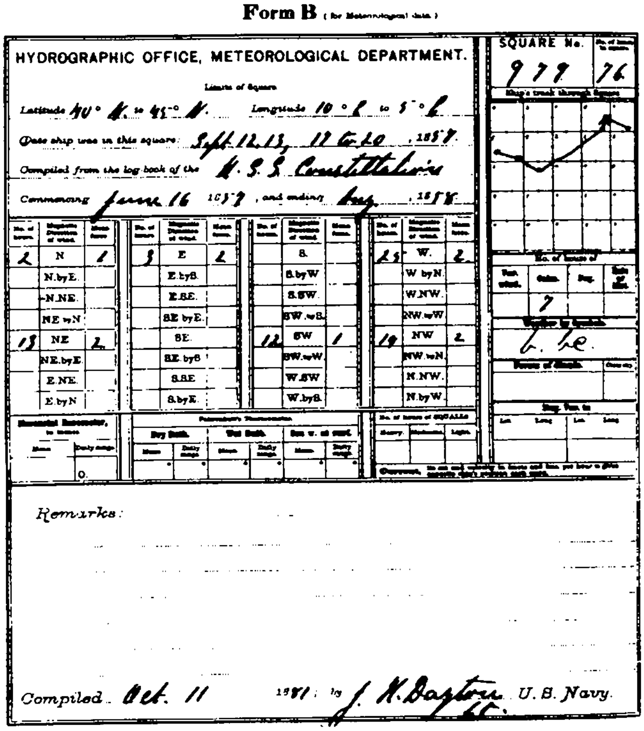


Figure 2. Early Marine Summary

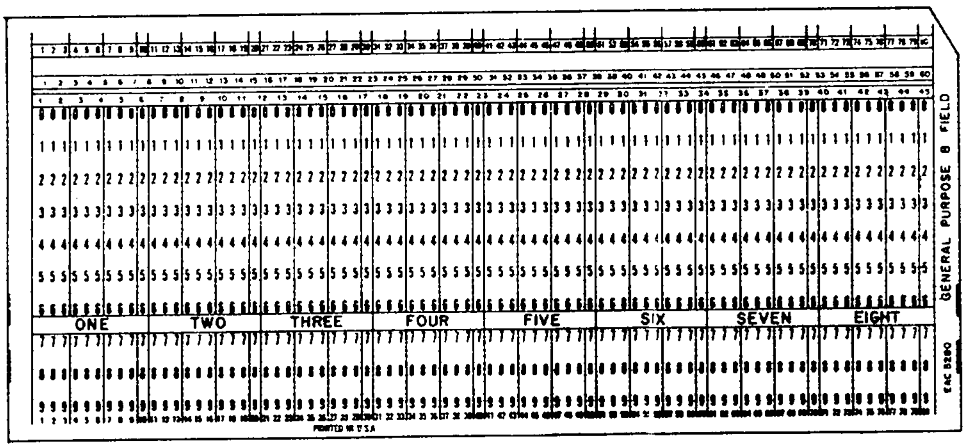


Figure 1. General Purpose Punch Card

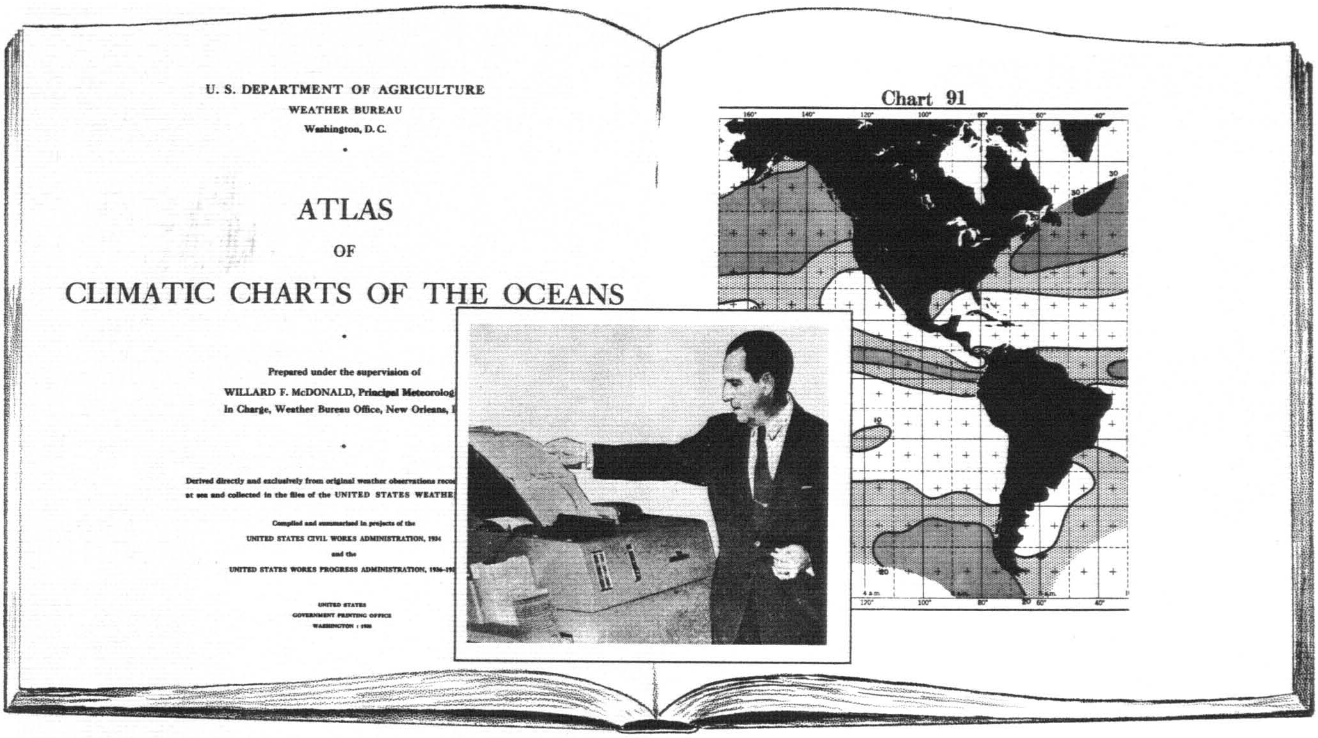


Figure 3. First Marine Atlas by U.S., and (Inset) First Director (NOTU)

In 1895, Commander C. D. Sigsbee, the dynamic new Hydrographer, recognized the value of the electrical tabulating system devised by Hollerith for handling climatic data. This was a meteorological "first". About 1920, the British, Dutch, and Czechoslovakian meteorological services used punched cards to extract meteorological data from ships' logs, processing the cards through machines to obtain climatic summaries.

In the period prior to World War II there was effectively no centralized weather data processing facility in existence; however, a few attempts had been made in extensive data processing and some worthwhile projects were completed. Notably, a WPA project established in 1934 in New Orleans ultimately grew into an important asset. Ocean vessel observations which had accumulated during the years since 1880 were converted into a much needed marine atlas. Still, only about 10% of this work with some five and a half million observations was accomplished by machines. By 1936, punched card compilation and the editing and careful analysis of millions of surface and upper air observations from about four hundred airways weather stations had begun to produce useful weather summaries. In this pre-war era, climatology was generally characterized by individual efforts in many small centers of interest. Each was hampered by non-uniformity in observing and data collection programs and the lack of automation in processing.

By the time the United States entered World War II, twenty million airways observations, taken from 1928 to 1941, had been placed on punched cards. Observational records and/or punched cards from Weather Bureau, Navy, and Army Air Force Weather Units were forwarded to the New Orleans Tabulating Unit (NOTU). Demands for climatological studies to meet military requirements grew by leaps and bounds. The applications of climatology as a factor in strategic and tactical planning, and the keen interest in little known foreign areas, encouraged the initiation of many large scale projects. Among the significant results of the war period were: (a) the recognition of climatology as a significant factor in civil and military planning, (b) the unifying of records and observing techniques of the U. S. services, (c) the establishment of the punched card as a data processing medium with provision for a joint card library (in 1944), (d) the beginning of centralized records collection in the military services to supplement the regular Weather Bureau sources and, (e) the initiation of global weather data procurement.

In the years immediately following World War II, the processing of weather data for climatological purposes became centralized in New Orleans. The USAAF established a Data Control Unit at NOTU in 1946, while the Navy continued its support of maritime studies. Quality control was added to the U. S. records collection program being carried out centrally by the Air Force and Navy and in regional processing units by the Weather Bureau. A variety of machines for producing copies of records became available and all data processing equipment turned slowly toward automation. Card processing equipment was still designed primarily for accounting operations and the more difficult data reduction jobs were accomplished by the addition of auxiliary devices and the use of complex procedures. The first of the machines to depart from purely electro-mechanical operation and to

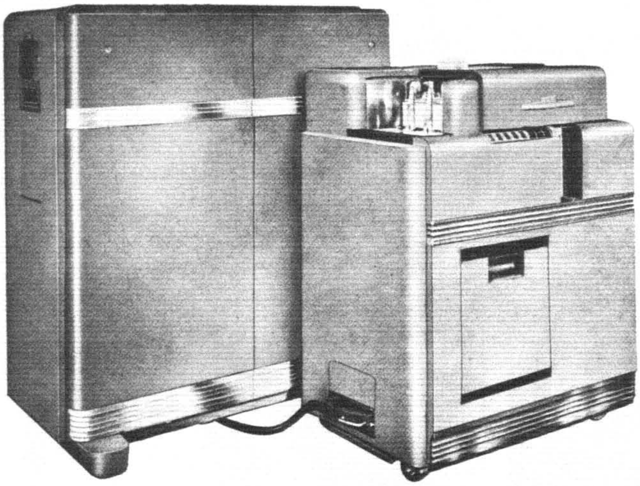


Figure 4. Early Computer

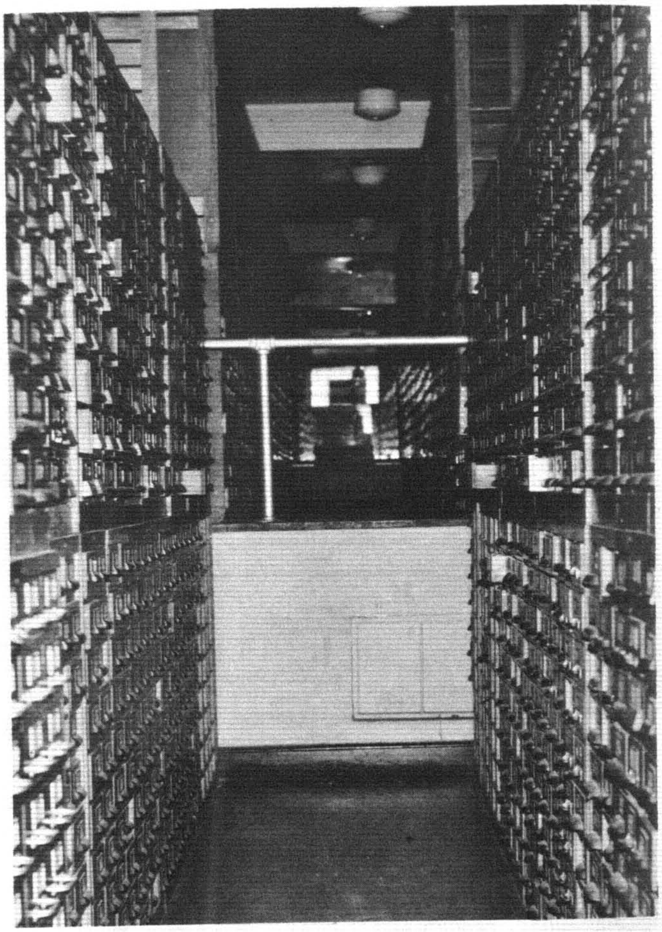


Figure 5. Section of Punched Card Library

begin the use of electronic principles appeared in 1950.

The New Orleans Unit gained much needed space by moving to Asheville, North Carolina, starting in September 1951. With completion of the transfer in January 1952, the Weather Bureau facilities were designated as the National Weather Records Center, the Air Force continued the Data Control Division, and the Chief of Naval Operations established a Navy Liaison Office at Asheville to coordinate the increasing requirements of the Navy.

1.2 CURRENT STATUS

Now, the National Weather Records Center contains approximately 400,000,000 punched cards bearing data which have been compressed by the use of several hundred numerical coding systems. Every effort has been made to insure that some form of copy of each meteorological record collected in the United States and its possessions is stored in the NWRC depository. These files are growing at the rate of about 40,000,000 cards per year, plus the original observing forms and recorder charts which become a part of the archives. The remainder of the 250,000 sq. ft. of floor space in the Arcade Building is utilized by the three services to house a full array of electric accounting machines, five digital computers, and 550 to 600 skilled employees.

The Weather Bureau unit checks and prepares observations for publication, and provides at cost copies of original records, hand and machine tabulations, chart and map analyses, relationship studies, etc. to the general public, industry, agriculture, and to other government agencies. The records are held officially as a designated extension of the National Archives.

Navy climatological data checking, tabulating, and application studies are carried out by the Weather Bureau with transferred funds through liaison with the local Office of the Navy Representative.

The Air Force Unit checks and verifies data collected from its observing stations at home and abroad and carries out studies requested by and through the Air Weather Service for all parts of the Air Force and its contractors. Also, certain Army requirements in climatology are met by the Air Weather Service.

The present large scale electronic data-processing system employed at Asheville immeasurably widens the scope of climatological applications and research. Geophysical research and the solutions to extensive operational problems are now practical. Weather is being interpreted regularly in relation to the many problems of defense and everyday life.

Figure 6. Microfilming Records (to 35mm size)

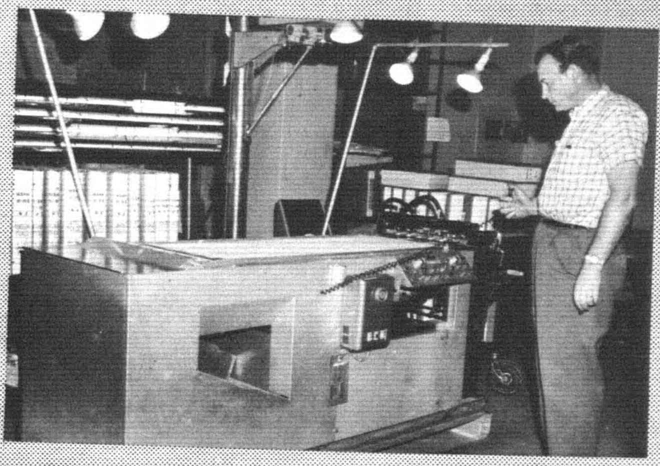
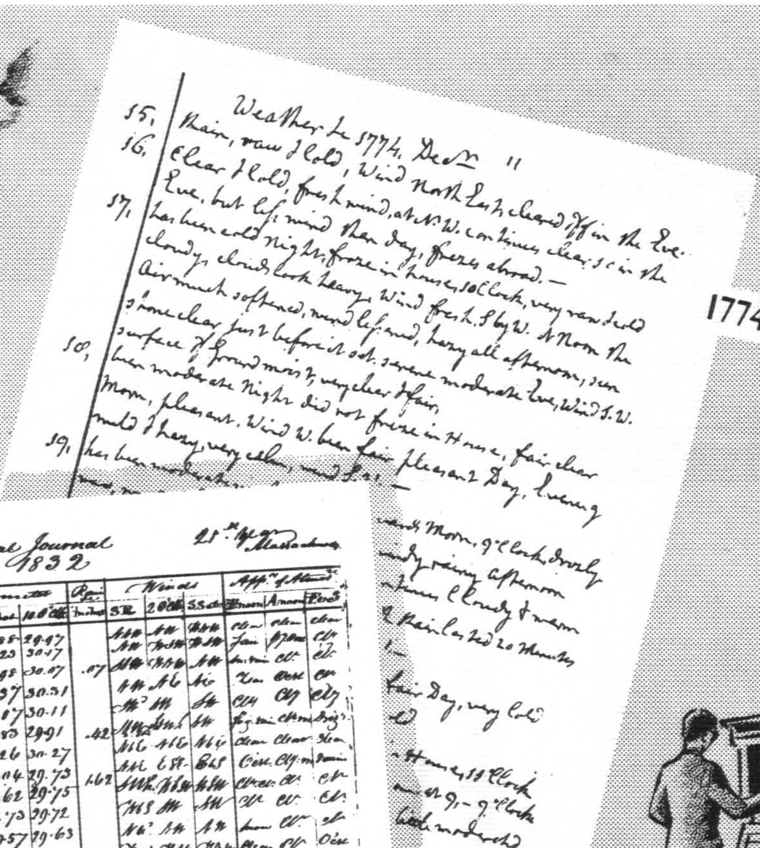


Figure 7. Microfilming with "Mimic" (to 70mm size)

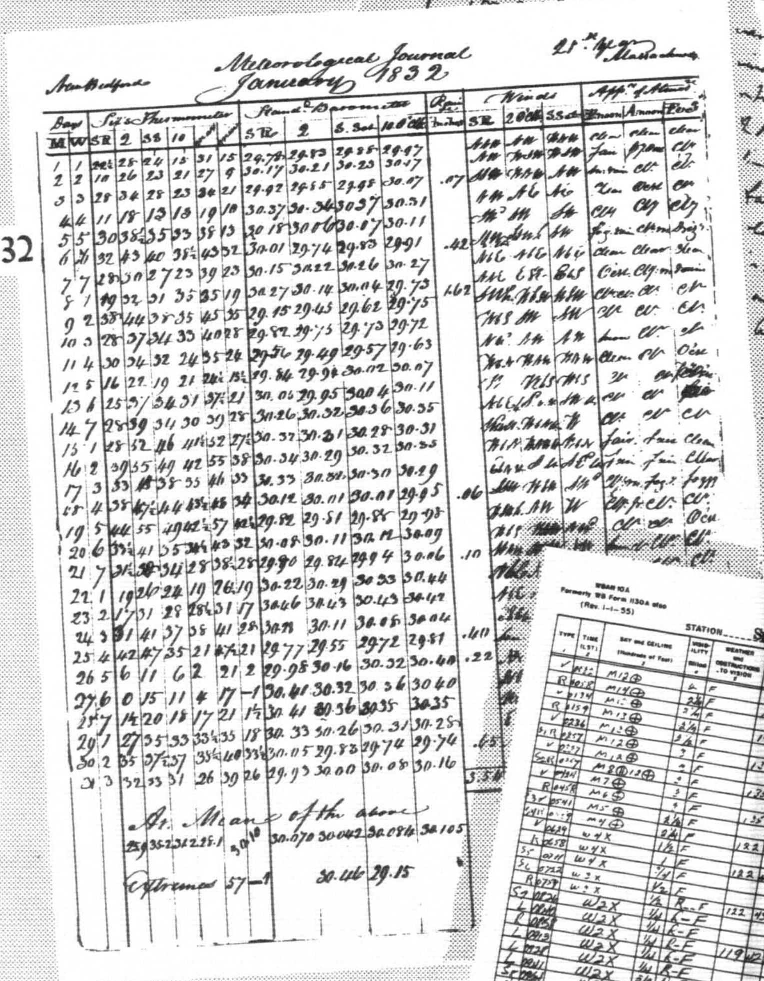
Figure 8. Combined Management (1960)



Weather &c 1774. Decr 11

15. Rain, raw & cold,
16. Clear & cold, fresh wind, Wind North East, cleared off in the Eve.
Clear & cold, fresh wind, at N.W. continues clear &c in the
Eve. but less wind than day, freezes abroad.—
17. has been cold Night, froze in house, 10 Clock, very raw cold
cloudy, cloud look heavy, Wind fresh S. S by W. At Noon the
Air much softened, wind lessened, hazy all afternoon, sun
shone clear just before it set. severe moderate Eve, Wind S.W.
18. surface of ground moist, very clear & fair,
been moderate Night did not freeze in House, fair clear
Morn, pleasant. Wind W. been fair pleasant Day, Evening
19. mild & hazy, very calm,
has been moderate

1774



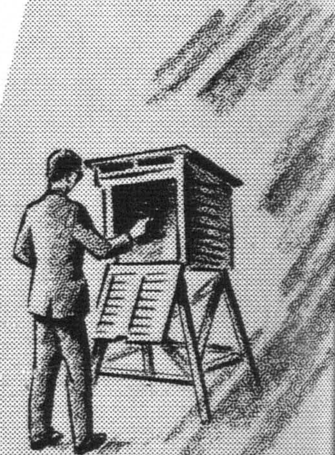
New Bedford — Meteorological Journal — January 1832 — 25th Year, Massachusetts

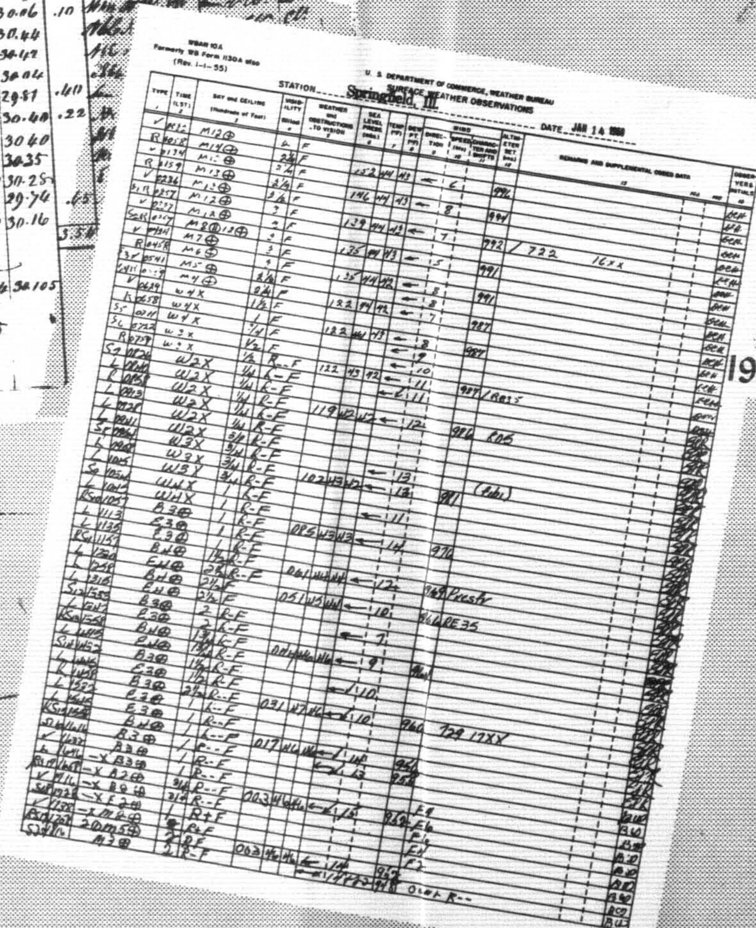
1832

Day M	Day W	Six's Thermometer SR	2	SS	10			Stand. Barometer SR	2	S. Set	10 O'Clk	Rain Inches	Winds SR	2 O'Clk	SS	App. of Atmos. Morn	Aftern	Eve
1	1	32½	28	24	15	31	15	29.74	29.83	29.88	29.97		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Clear
2	2	10	26	23	21	27	9	30.17	30.21	30.23	30.17		[illegible]	[illegible]	[illegible]	fair	[illegible]	Cl.
3	3	28	34	28	23	34	21	29.92	29.55	29.48	30.07	.07	[illegible]	[illegible]	[illegible]	[illegible]	Cl.	Cl.
4	4	11	18	13	13	19	10	30.37	30.34	30.37	30.31		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cl.
5	5	30	38½	35	33	38	13	30.18	30.06	30.07	30.11		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	6	32	43	40	38½	43	32	30.01	29.74	29.83	29.91	.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	7	28	30	27	23	39	23	30.15	30.22	30.26	30.27		[illegible]	[illegible]	[illegible]	Clear	Clear	[illegible]
8	1	19	32	31	35	35	19	30.27	30.14	30.04	29.73	1.62	[illegible]	[illegible]	[illegible]	[illegible]	Cl.	Cl.
9	2	38	44	38	35	45	35	29.15	29.45	29.62	29.75		[illegible]	[illegible]	[illegible]	Cl.	Cl.	Cl.
10	3	28	37	34	33	40	28	29.82	29.75	29.73	29.72		[illegible]	[illegible]	[illegible]	[illegible]	Cl.	[illegible]
11	4	30	34	32	24	35	24	29.56	29.49	29.57	29.63		[illegible]	[illegible]	[illegible]	Clear	Cl.	[illegible]
12	5	16	27	19	21	24½	15½	29.84	29.94	30.02	30.07		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	6	25	37	34	31	37½	21	30.06	29.95	30.04	30.11		[illegible]	[illegible]	[illegible]	Cl.	Cl.	[illegible]
14	7	28	39	34	30	39	28	30.26	30.32	30.36	30.35		[illegible]	[illegible]	[illegible]	Cl.	Cl.	Cl.
15	1	28	52	46	41½	52	27½	30.37	30.31	30.28	30.31		[illegible]	[illegible]	[illegible]	Cl.	Cl.	Cl.
16	2	39	55	49	42	55	38	30.34	30.29	30.32	30.35		[illegible]	[illegible]	[illegible]	fair	fair	Clear
17	3	33	[illegible]	38	35	46	33	30.33	30.34	30.30	30.29		[illegible]	[illegible]	[illegible]	fair	fair	Clear
18	4	38	47½	44	43½	48	34	30.12	30.01	30.01	29.95	.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Foggy
19	5	44	55	49	42½	57	42½	29.82	29.51	29.88	29.98		[illegible]	[illegible]	W	[illegible]	Cl.	Cl.
20	6	33½	41	35	34½	43	32	30.08	30.11	30.12	30.09		[illegible]	[illegible]	[illegible]	Cl.	[illegible]	Ocu
21	7	31½	38	34	28	38½	28	29.90	29.84	29.94	30.06	.10	[illegible]	[illegible]	[illegible]	[illegible]	Cl.	Cl.
22	1	19	26	24	19	26½	19	30.22	30.29	30.33	30.44		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Cl.
23	2	17	31	28	28½	31	17	30.46	30.43	30.43	30.42		[illegible]					
24	3	31	41	37	38	41	28	30.18	30.11	30.08	30.04		[illegible]					
25	4	42	47	35	21	47½	21	29.77	29.55	29.72	29.81	.40	[illegible]					
26	5	6	11	6	2	21	2	29.98	30.16	30.32	30.40	.22	[illegible]					
27	6	0	15	11	4	17	-1	30.41	30.32	30.36	30.40		[illegible]					
28	7	14	20	18	17	21	1½	30.41	30.36	30.35	30.35		[illegible]					
29	1	27	35	33	33½	35	18	30.33	30.26	30.31	30.28		[illegible]					
30	2	35	37½	37	38½	40	33½	30.05	29.83	29.74	29.74	.65						
31	3	32	33	31	26	39	26	29.93	30.00	30.08	30.16	3.5[illegible]						

Av. Mean of the above
25.9 35.2 31.2 28.1 30[10] 30.070 30.042 30.084 30.105

Extremes 57 —1 30.46 29.15





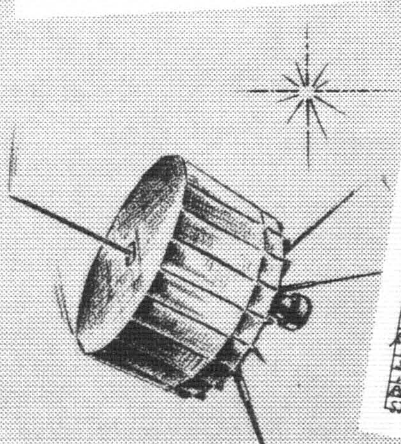
WBAN 10A
Formerly WB Form 1130A also
(Rev. 1-1-55)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
SURFACE WEATHER OBSERVATIONS

STATION Springfield, Ill DATE JAN 14 1960

TYPE	TIME (LST)	SKY and CEILING (Hundreds of Feet)	VISIBILITY (Miles)	WEATHER and OBSTRUCTIONS TO VISION
✓	[illegible]	M12⊕	4	F
R	0058	M14⊕	2½	F
✓	0134	M1[illegible]⊕	2½	F
R	0159	M13⊕	2¼	F
✓	0236	M12⊕	2½	F
S,R	0257	M12⊕	2½	F
✓	0357	M12⊕	3	F
S,R	0357	M8⊕12⊕	2	F
✓	0434	M7⊕	2	F
R	0458	M6⊕	3	F
S	0541	M5⊕	4	F
[illegible]	[illegible]	M4⊕	2½	F
✓	0629	W4X	2¼	F
R	0658	W4X	1½	F
S	0711	W4X	1	F
S	0722	W3X	¼	F
R	0759	W3X	½	F
S	0824	W2X	½	R-F
L	[illegible]	W2X	¼	R-F
R	0858	W2X	¼	R-F
L	0913	W2X	¼	R-F
L	[illegible]	W2X	¼	R-F
L	[illegible]	W2X	¼	R-F
S	[illegible]	W2X	¼	R-F
L	[illegible]	W3X	¾	R-F
L	[illegible]	W3X	¾	R-F
S	[illegible]	W3X	¾	R-F
L	[illegible]	W4X	¾	R-F
R	[illegible]	W4X	1	R-F
L	1113	B3⊕	1	R-F

1960



Chapter 2

CLIMATOLOGY

Selected Elements
of the Science

2.0 CLIMATOLOGY

Simply stated, climatology is the study of climate - the synthesis of weather [7]. Climatology is a branch of meteorology, the study of the atmosphere. This branch deals with similarities and variations of weather from time to time and place to place. The word climate comes from the Greek word "Klima" meaning incline. The ancient Greeks also used this word to signify prevailing weather and its seasonal changes. They correctly associated this with variation in the angle at which the sun's rays strike a location on an earth rotating on an axis inclined from the vertical.

2.1 HISTORICAL DEVELOPMENT

Early man collected sensory knowledge of the winter to summer ranges of climate with all of the attendant stages of vegetation, the daily rise and fall of temperature, the panorama of changing clouds and coming of rainstorms. The march of the seasons dictated man's tribal migrations, controlled his food supply, governed the beginnings of his agriculture. Folklore is rich in references to medicine men, seers, and chieftains elevated to positions of importance because communities of men believed these personages could foretell the hardships and blessings of coming seasons.

Scientific literature, beginning with that of early Greece, including the work of Hippocrates (about 460 B. C.), and continuing today, abundantly attests to the importance of an understanding of the nature of climate, through its variations - its ranges, extremes, and patterns of recurrence - in the processes of civilized life.

Climate became a subject amenable to quantitative treatment only after the invention of basic instruments such as the thermometer (Galileo, about 1590) and barometer (Torricelli, 1643). The study of climatology began in earnest in 1781 with the founding of a German meteorological organization known as the "Mannheimer Akadamie". Observations for two American locations were included in its publications <u>Ephemerides Societatis Meteorologicae Palatinai</u> [6]. Thomas Jefferson was an important pioneer in this field in the United States. He published (1787) one of the first printed climatic summaries in North America. John Ruskin (in 1839) expressed the need for coordination of observations over the world in the meetings of the Meteorological Society of London [13]. It was not until 1853 at the International Conference on Maritime Meteorology held in Brussels, that by international agreement the maritime nations decided to obtain systematic information about weather at sea. The American naval officer, Matthew F. Maury was the prime instigator of systematic observation, collection, and summarization of weather data from the vast ocean areas of the world [4]. The International Meteorological Committee was formed in 1873 and directors of participating meteorological services agreed to exchange and distribute many types of weather information throughout the world.

Further progress in climatology was made possible by general acceptance of specific codes such as those for wind force and "weather" devised by Admiral Sir Francis Beaufort in the early 19th century. Complete standardization and universal acceptance of meteorological codes remains an ideal yet to be fully realized. Advances in climatology as a physical science are directly related to the degree this goal is attained.

Statistical analysis is now the primary method of qualifying climatology. It is employed in each of the three principal approaches to the study of climate - descriptive, physical, and dynamic. Descriptive climatology typically orients itself in terms of geographic regions, and thus is often named regional climatology; physical climatology is approached in the light of the physical processes influencing climate; dynamic climatology attempts to relate characteristics of the general circulation of the atmosphere to climate.

	Fall of rain, &c. in inches	Least and greatest daily heat by Farenheit's thermometer.		WINDS								
				N.	N. E.	E.	S. E.	S.	SW.	W.	NW.	Total.
January.	3.192	38 1/2 to 44		73	47	32	10	11	78	40	46	337
Feb.	2.049	41	47 1/2	61	52	24	11	4	63	30	31	276
March.	3.95	48	54 1/2	49	44	38	28	14	83	29	33	318
April.	3.68	56	62 1/2	35	44	54	19	9	58	18	20	257
May.	2.871	63	70 1/2	27	36	62	23	7	74	32	20	281
June.	3.751	71 1/2	78 1/4	22	34	43	24	13	81	25	25	267
July.	4.497	77	82 1/2	41	44	75	15	7	95	32	19	328
August.	9.153	76 1/4	81	43	52	40	30	9	103	27	30	334
Sept.	4.761	69 1/2	74 1/4	70	60	51	18	10	81	18	37	345
Oct.	3.633	61 1/4	66 1/2	52	77	64	15	6	56	23	34	327
Nov.	2.617	47 3/4	53 1/2	74	21	20	14	9	63	35	58	294
Dec.	2.877	43	48 3/4	64	37	18	16	10	91	42	56	334
Total.	47.038	8 A.M.	4 P.M.	611	548	521	223	109	926	351	409	3698

Figure 9. Climatological Data for Williamsburg, Va., 1772-77, from Jefferson's "Notes on the State of Virginia"

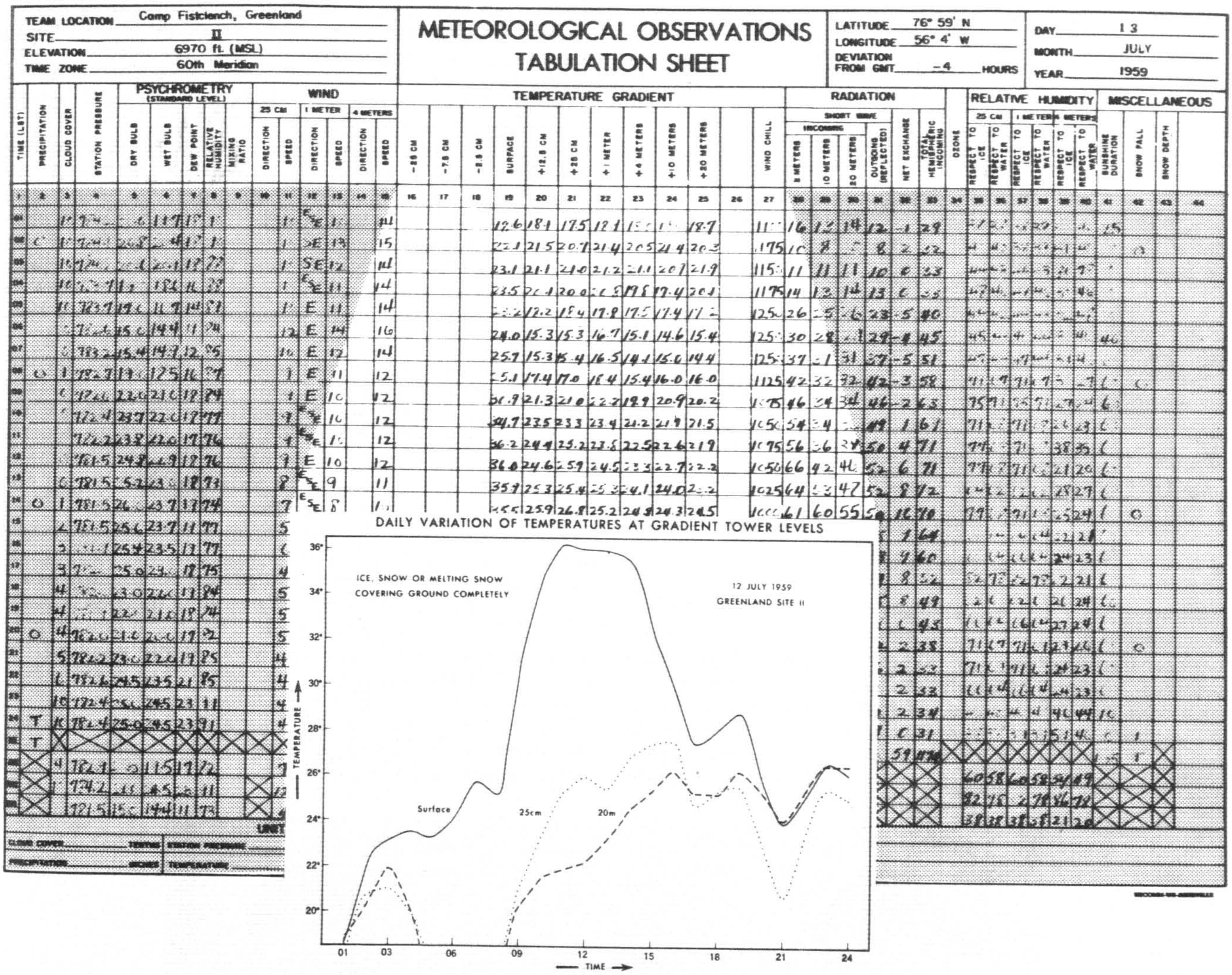


Figure 10. Micro-Meteorological Observations Taken by the U. S. Army in Greenland

2.2 CLIMATOLOGY AS RELATED TO OTHER SCIENCES

One of three prefixes is often added to the word "meteorology" to denote a scale of magnitude: micro, meso, and macro indicate small, medium, and large scales, respectively.

The "micro" scale has found common use in climatology for decades. Microclimatological studies, most actively pursued in Europe [8], often measure contrasts between hilltop and valley, city and surrounding country, etc. Distances may be of still smaller scale - one side of a hedge contrasted with the other, a plowed furrow versus level soil, or opposite leaf surfaces. Climate in the microscale may be effectively modified by relatively simple human efforts. Manipulation of microclimates may be necessary in land utilization, agricultural management, architectural planning, and urban development. Each of these areas has been given attention, and in so doing a number of biological sciences are drawn into the picture. Crop ecology and plant pathology are but two examples of such biological areas of application.

Climate in the "macro" scale also bears on biological sciences, and, as discussed in a following chapter, the first weather observers were often physicians. Bioclimatology [12] lagged somewhat until recent years but "the interactions between physical changes in the atmosphere and living organisms are too great a challenge to scientific curiosity to remain in a relatively unexplored state" [9].

Mesoclimatology embraces a rather indistinct middle ground between micro and macroclimatology.

Climate has become increasingly important in other scientific fields. Geographers, hydrologists, and oceanographers use quantitative measures of climate to describe or analyze the influence of our atmospheric environment. Climate classification has developed primarily in the field of geography. The basic role of the atmosphere in the "hydrologic cycle" is an essential part of the study of hydrology. Parallel to this, both air and water measurements are required to understand the exchange of energy between air and ocean.

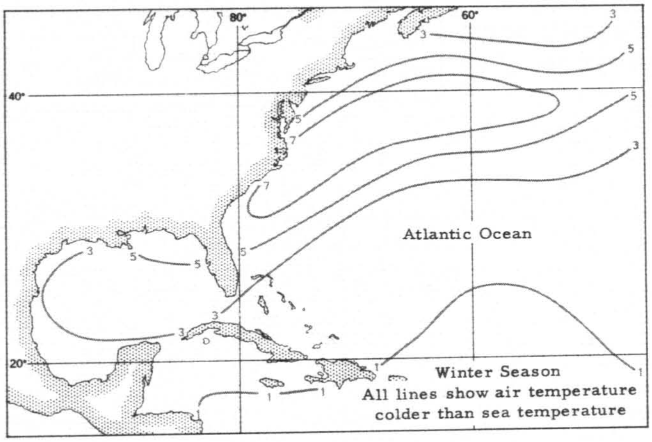


Figure 11. Air-Sea Temperature Difference °F, from the U. S. Navy Marine Climatic Atlas of the World, North Atlantic, Volume I

2.3 APPLIED CLIMATOLOGY

Existing scientific knowledge is the basic ingredient in any applied science. There is a fundamental difference between basic meteorological research and applied climatological science. Though both are often dependent upon past weather observations, meteorological research utilizes weather data in studying weather. Applied climatology is work toward the solution of non-meteorological problems in which climate and/or weather is a factor. Hence, final answers, to be directly usable, are in terms of non-meteorological units. Climatology is introduced where design and operational planning are required for a length of time beyond the range covered by weather forecasting techniques, and, indeed, the latter operate within climatological limits.

Weather is the primary factor in some areas of human activity; for example, aerial navigation. Efficient air route and schedule planning depend to a large extent upon historical upper air observations. Climatological specialization is well developed in industrial and engineering fields where weather and climate are vitally important. The marine, agricultural, and personal comfort aspects of climatology demand the attention of appropriate specialists.

Marine climatology appears first in history as the ancient Greeks, through maritime exploration, partially confirmed their theories of climatic zones. Highly competitive maritime commerce in the 18th and 19th centuries led to the comprehensive and systematic study of climate. Soon quantitative studies of the relationship between climate and crops became important. Jefferson considered a climatic census of basic importance to the development of America's infant agriculture. Still small in comparison with aviation, agricultural applications of climatology today nevertheless save crops - and save their producers money. Perhaps the most striking field of climatological endeavor opened with the invention of the airplane. It became evident that historical upper air observations must be evaluated in planning air routes.

Each of the three "major" specialties continues today. Emphasis on each of them changes as adequate answers to old questions are found and new problems arise.

Figure 12. Former Navy Representative (1957-59) and Staff Member of NWRC Discuss the Marine Atlas Presentation

We have mentioned bioclimatology and its application to health problems. For example, air pollution [10] is a major study today. The analysis of climate is also required in industrial operations [11], microwave propagation [5], and large scale weather modification [3]. Probably the most familiar of all applications is to urban power and fuel consumption as it relates to heating and air conditioning (cooling) in the home, office, and factory.

The term "frozen assets" as applied to weather records is now somewhat outdated when climatic data processing and utilization at Asheville and elsewhere, are considered. Fast and efficient machinery by itself, however, will not advance climatology. Mountains of data are of limited utility unless meaning can be "mined" from them. Existing methods are often inadequate. The science of climatology needs inspired and intelligent minds to develop methods of effectively using the tools offered by fast growing electronic measurement and computer technology.

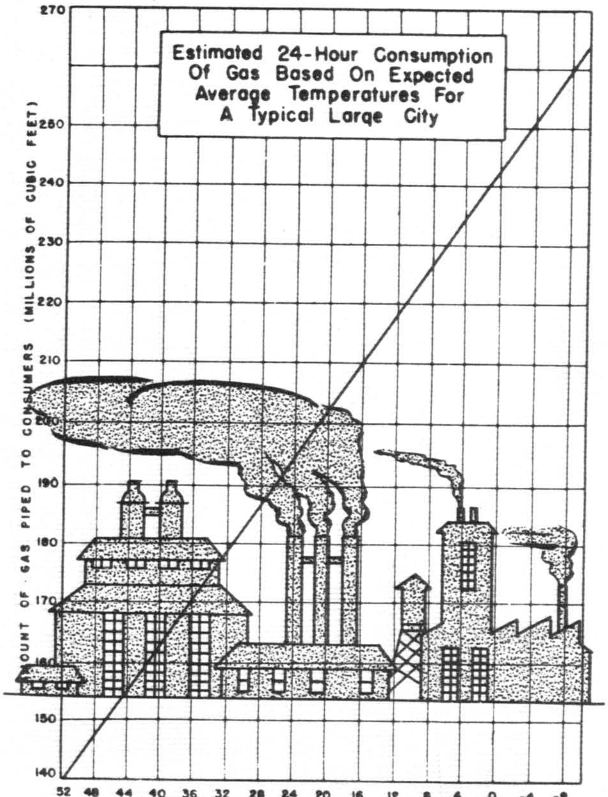


Figure 13. Gas Consumption Probability Graph

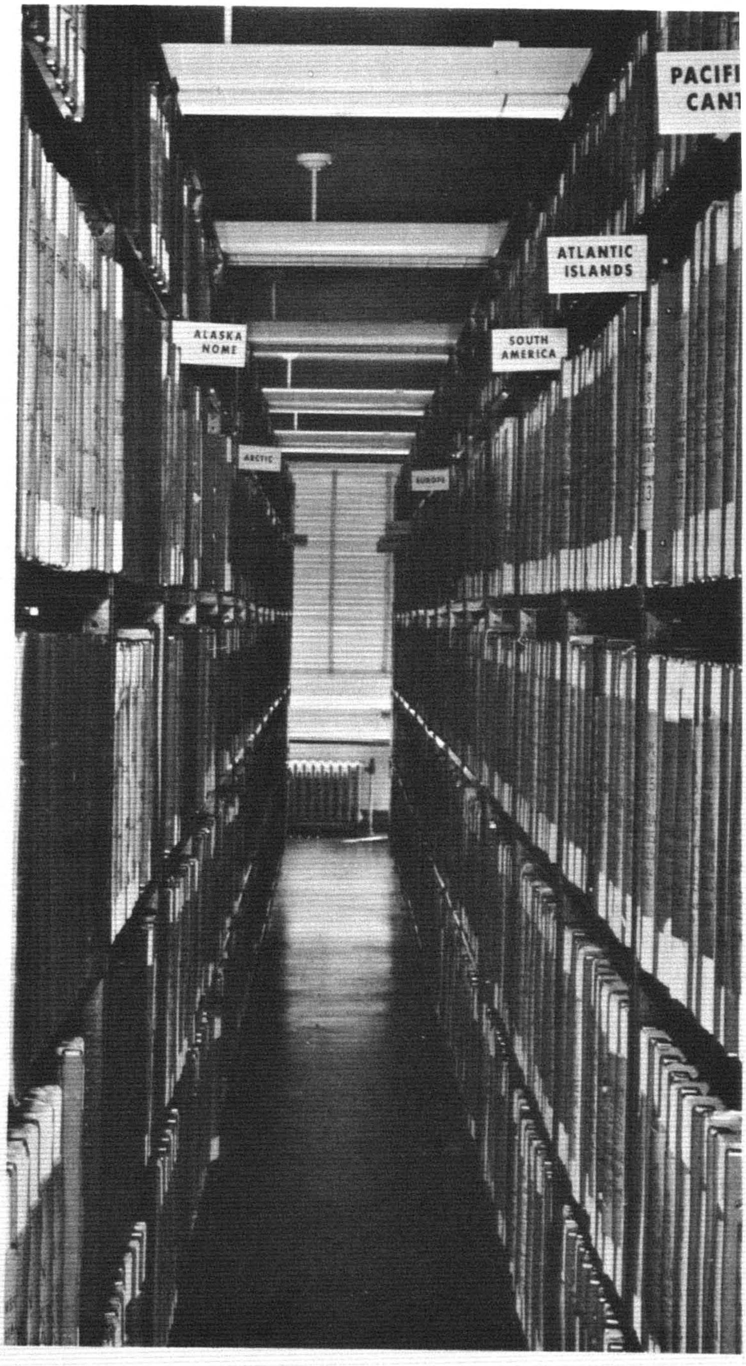


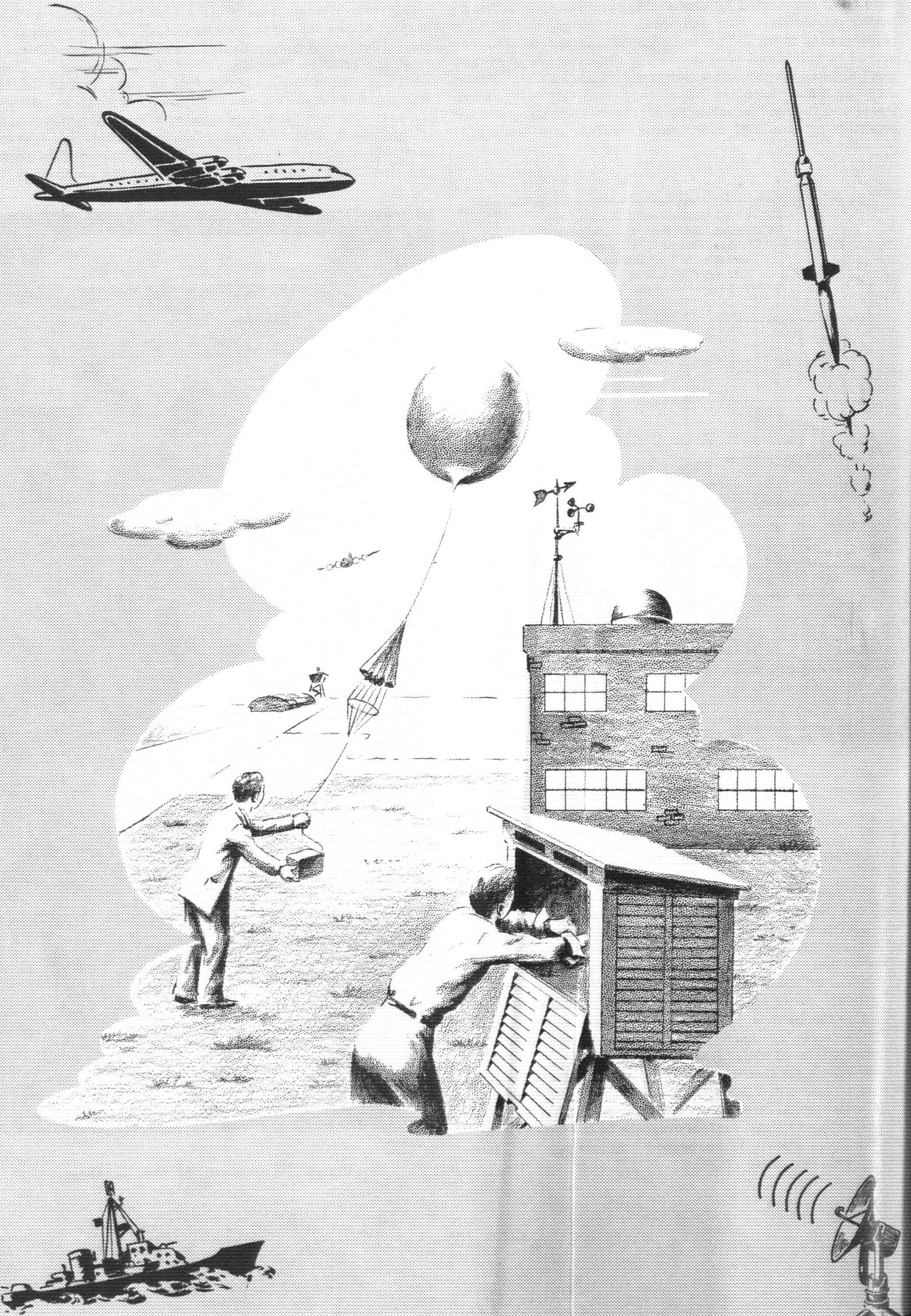
Figure 14. Section of the Archives

2.4 SOLVING APPLIED CLIMATOLOGICAL PROBLEMS

Climatology contributes to the solution of problems ranging from those influenced by obvious and directly measurable climatic effects to those in which quantitative relationships are unknown or only vaguely apparent.

A situation in which the effect of climate is only vaguely apparent, or unknown, requires prior research and development. Joint efforts of the climatologist and the specialist in the primary subject matter may be quite useful if the objective is clear. Developing a method of solving the problem is of uppermost importance.

Suggestions applicable to solving applied climatological problems are given in Chapter 6. Much of the work done by climatological branches of the three weather services as well as by private meteorologists in the United States results from known or suspected applications of historical weather data.



Chapter 3

OBSERVATIONS

Measurement, Enumeration, and Perception

3.0 OBSERVATIONS

The world's greatest centralized climatological archive is the core of the Asheville operation. To understand the scope of this facility, it is important to touch on the history of various types of observations, including European contributions, especially in the upper air. Available records do not always extend back to the historical dates cited but observational forms on file, their availability and distribution are discussed.

3.1 HISTORICAL DEVELOPMENT

Surface weather records date back to 4000 B. C. when ancient Babylonians inscribed weather proverbs on the first clay tablets. From that time until about 1600 A. D. crude observations were taken over the known world, nearly all without the aid of instruments. The results for the most part were inaccurate, but since the thermometer and barometer came into use in the early 17th century, meteorology has been progressing as an accurate science. The first meteorological stations were soon established in northern Italy [23] and the history of modern climatology in Europe had begun.

The earliest known surface weather observations in America were kept by the Rev. John Campanius Holm at Swedes Fort, Delaware (1644-1645). Dr. John Lining of Charleston, South Carolina used the first Fahrenheit thermometer in the United States and took systematic weather observations with instruments under the sponsorship of the local medical society (1738-1750) [22]. The contributions of such men, and others, e. g., Thomas Jefferson, prompted the first systematic United States program of climatological observations, actually undertaken by the medical department of the United States Army in 1814. Weather diaries were originally kept by Army hospitals but the program crystallized in 1820 when regular observations were initiated at Army posts throughout the country. The first summarization of medical department observations was included in an 1842 publication entitled "The Climate of the United States and its Endemic Influences" by Dr. Samuel Forry. The Army continued observations until 1890 when the United States Weather Bureau was established. Concurrently with the Army program, the Smithsonian Institution began collecting meteorological data in 1849. In 1874, however, its work was transferred to the United States Army Signal Corps and merged with the Army records which were turned over to the Federal Weather Service in 1890 [14]. With the establishment of one agency primarily responsible for observation and description of climate, homogeneous climatological records began to emerge.

The history of upper air observations, while more recent than surface records, really began in the time of Aristotle (350 B. C.) when men became interested in "seeing from high places". Many early scientists and explorers climbed mountain peaks to take weather observations with instruments of their day. Their arduous efforts were recognized in the United States when mountain-top observatories were built on Mount Washington, New Hampshire, and Pikes Peak, Colorado, beginning in 1870. The mountain-top observations, however, were still essentially surface observations.

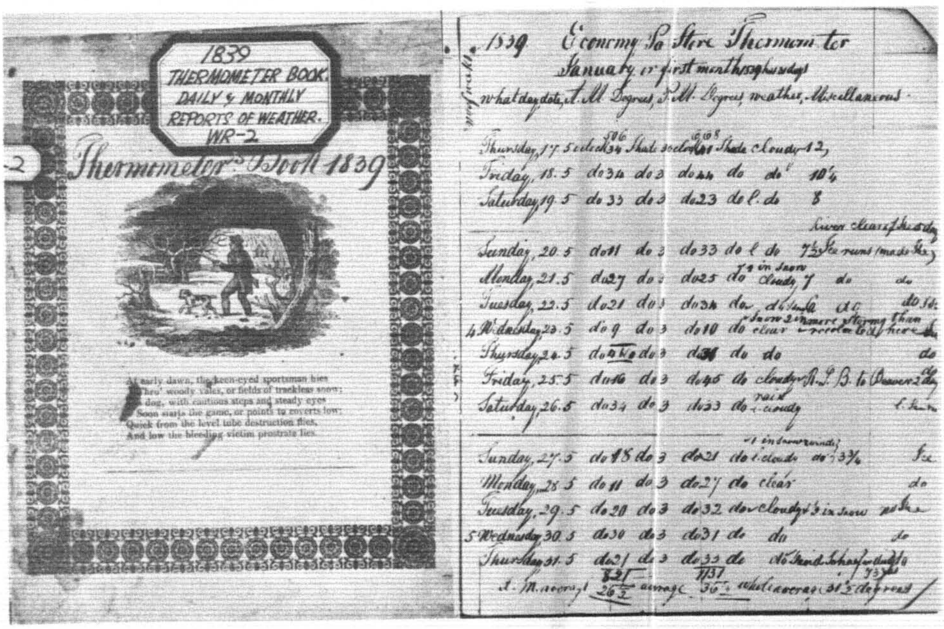


Figure 15. Early Weather Diary at Economy, Pennsylvania

Scientists in the 18th Century used the old Chinese kite idea (a wartime development about 206 B. C.) to probe the atmosphere above ground. Dr. Alexander Wilson and Thomas Melville of Glasgow, Scotland, sent aloft a thermometer suspended from a crude parachute which was attached to a kite string (1749) [23]. Benjamin Franklin also used kites for upper air experiments in the United States. Hargreave of Sydney, Australia developed the boxkite in 1893 and used a number of them in series to obtain heights up to 25,000 to 30,000 feet [20]. That same year the first Chief of the U. S. Weather Bureau, M. W. Harrington, persuaded Congress to appropriate money for upper air experiments with kites and the official kite observation program in the United States was thereby introduced.

The ascension balloon was invented in 1783 by the Montgolfier brothers of France. Manned balloons soon developed and European scientists took meteorological observations in the upper air. Throughout the 19th century these observations, recorded at many places, formed a historical background for climatological upper air research. A new and important balloon developed in the late 19th century as a small paper "pilot" which was sent aloft to show probable direction of the manned balloon flight [17]. A French scientist, P. Schreiber, became the founder of "pilot balloon" observations when he measured the flight course of a free balloon using instruments (1873-1874) [15]. Systematic pilot balloon observations were first taken over western Europe and in the United States as Army and aerial navigation support in World War I.

The United States Weather Bureau began developing its winds aloft program in 1917. Improvement in methods of observation and types of instruments has been continuous. The early meteorograph (1898) gave indications of wind direction and speed; concurrently, the improved theodolite designed by W. R. Blair was used to follow "pilot balloons". The development of the first radio-direction finder in 1943 gave more precise information concerning atmospheric data, particularly wind direction and speed. Later electronic improvements in radio-direction finders have provided more accurate climatological data. These changes are reflected in figure 18, Winds Aloft Network, 1918-1959.

The growth of the observational program in the United States closely paralleled developing airplane traffic. Weather information was required for air safety and economy. The United States Navy initiated airplane observations (APOB) in 1917, and the Weather Bureau, in cooperation with the United States Army, made test soundings in 1918 [19]. Daily airplane soundings were scheduled by the late 1920's and an improved meteorograph was carried aloft to about 16,000 feet. There were 31 APOB stations in operation by 1937.

On March 3, 1927, P. Idrac and R. Bureau, at the Teisserenc de Bort Aerological Observatory at Trappes, France, successfully achieved a radio link with the stratosphere by attaching a low-powered short wave radio transmitter to a free balloon [18]. This marked the introduction of radio soundings into meteorology.

Simply, the radiosonde is a lightweight meteorograph and radio transmitter attached to a small balloon. Pressure, temperature, and humidity are indicated by radio signals which are picked up by a receiver at a ground observatory. The first successful radiosonde ascent was made in 1928 by a Russian meteorologist, Moltchanoff, at Sloutsk near Leningrad [19]. The first in the United States was made by Lange, in 1935, at Blue Hill Observatory. Radiosonde observations were less expensive than APOBS and records were obtained to greater heights and in more "bad weather" situations. Six airplane stations were converted to radiosonde stations in 1938. The growth of the radiosonde program is illustrated in figure 19, Development of Upper Air Sounding Network, 1898 through 1959.

Electronic radio-direction finders came into operational use in 1945. In combination with the radiosonde, one balloon ascent reported all currently available measurements in the upper air.

Cooperation among the Weather Bureau, Air Weather Service, and Navy has expanded the program considerably. The network of stations maintained by the combined weather services is shown in figure 20, Upper Air Network, as of January 1, 1960.

World Meteorological Conferences and comparative tests held in the United States and Switzerland at intervals during the period 1950-1958 have profoundly influenced upper air programs throughout the world.

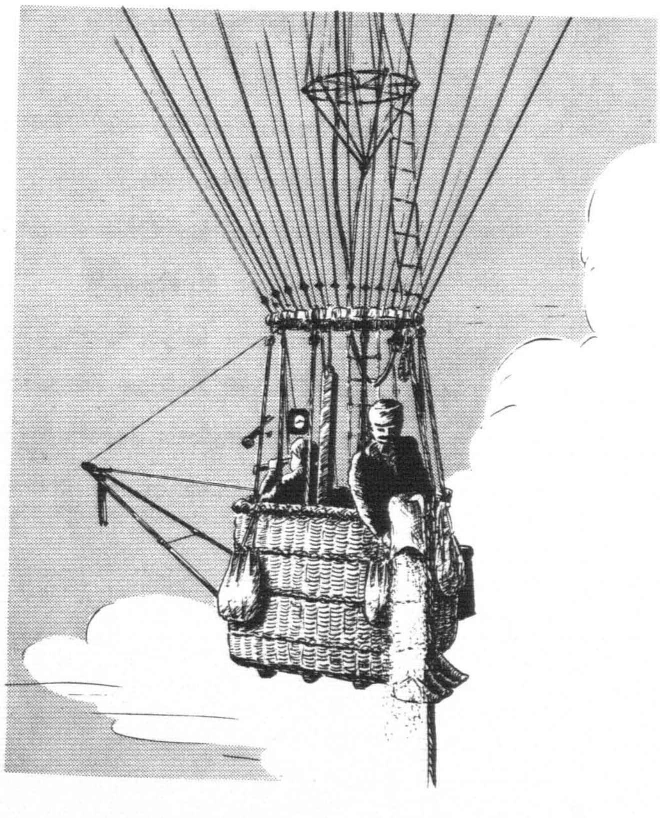


Figure 16. Early Manned Balloon

INSTRUMENTATION

Figure 17. a. Ascension Balloon

b. Early Meteorograph

c. Box Kite

d. Radiosonde Release (RAOB)

e. Radio-theodolite

f. Pilot Balloon Observation (PIBAL)

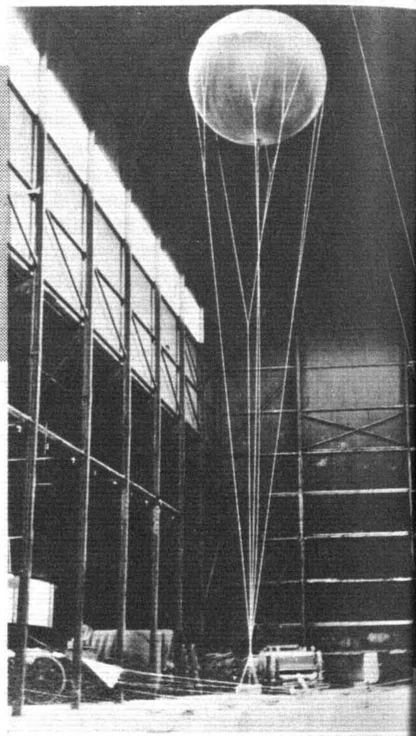
g. 1680mc Radiosonde

h. Airplane Observation (APOB)

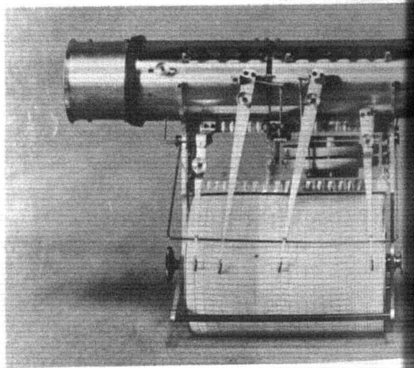
i. SCR-658 Balloon Tracking Device

j. GMD Balloon Tracking Device

k. Nose Cone of the Rocketsonde

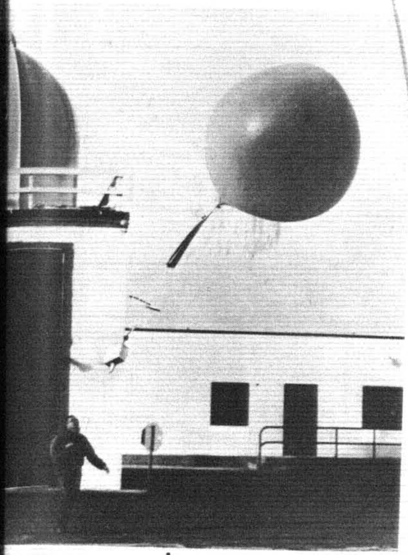


a.



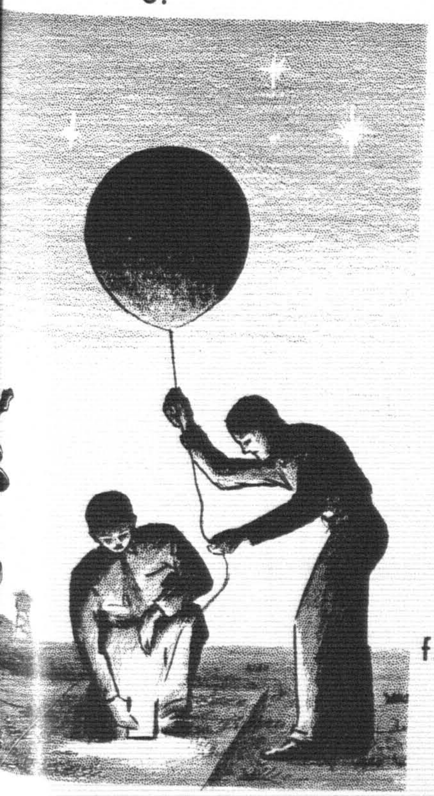
b.

c.

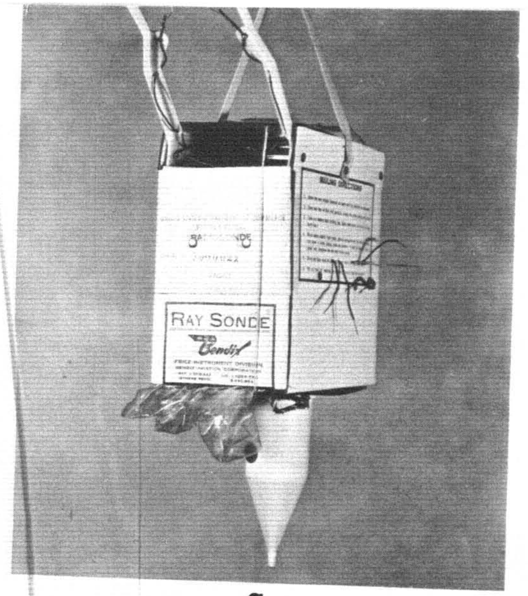


d.

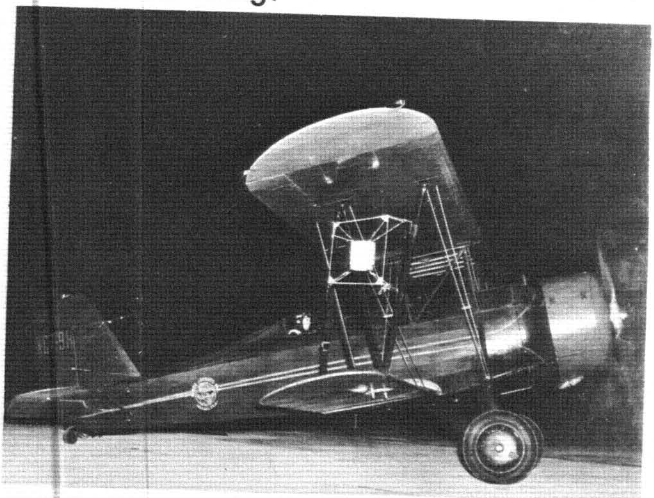
e.



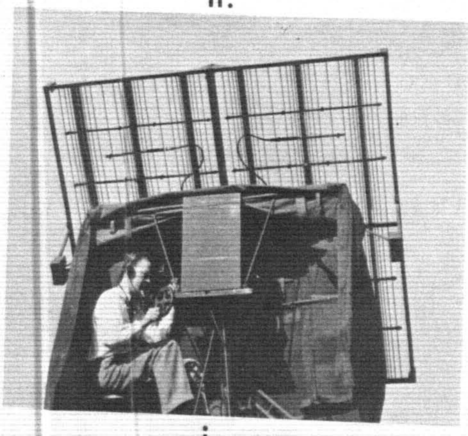
f.



g.

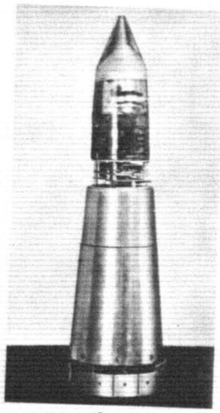


h.

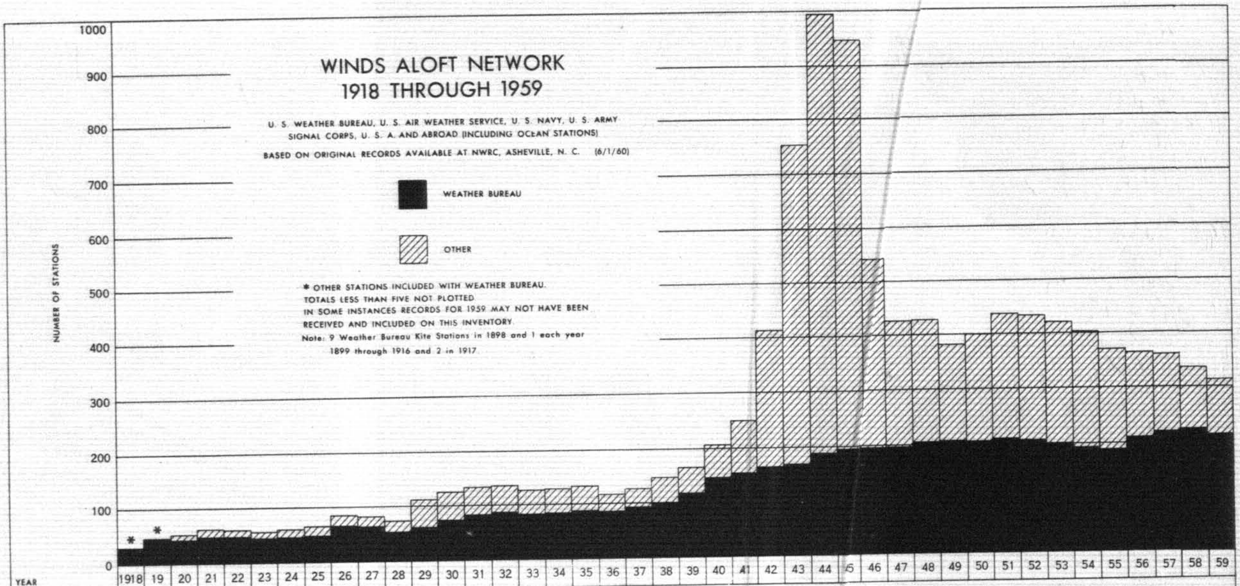


i.

j.



k.

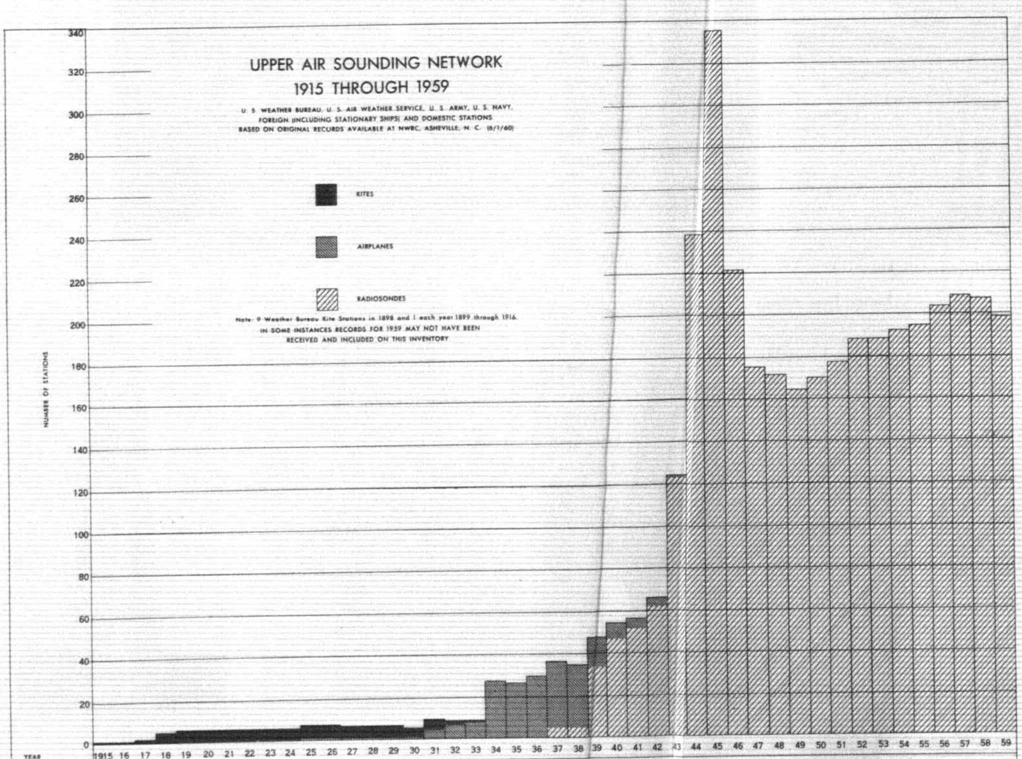


NUMBER OF STATIONS

YEAR	1918	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
WEATHER BUREAU	28	41	43	48	48	44	45	48	67	64	52	60	72	83	88	81	83	89	87	91	100
AIR WEATHER SERVICE	1	1	1	1	1	1	2	2	2	3	7	34	35	33	30	30	28	26	11	19	27
NAVAL WEATHER SERVICE	1	1	8	12	11	12	12	15	16	16	15	16	17	16	17	18	19	18	18	17	19
ARMY SIGNAL CORPS																					
TOTAL STATIONS	30	43	52	61	60	57	59	65	85	83	74	110	124	132	135	129	130	133	116	127	146

YEAR	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
WEATHER BUREAU	115	145	151	162	167	189	195	196	198	204	207	204	209	207	202	191	188	209	222	225	216
AIR WEATHER SERVICE	26	33	61	179	415	612	573	243	154	167	121	139	168	173	160	147	117	100	84	64	57
NAVAL WEATHER SERVICE	22	27	38	71	170	194	78	104	75	58	53	57	61	56	60	63	63	55	53	43	37
ARMY SIGNAL CORPS																1	2	2	2	2	2
TOTAL STATIONS	163	205	250	412	752	995	946	543	427	429	381	400	438	436	422	402	370	366	361	334	312

Figure 18.



NUMBER OF STATIONS

YEAR	1915	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
RADIOSONDE																						
AIRPLANES											1	1	1	1	1	1	5	7	8	28	27	30
KITES	1	1	2	5	6	6	6	6	6	6	7	7	6	6	6	5	5	2	1			
TOTAL STATIONS	1	1	2	5	6	6	6	6	6	6	8	8	7	7	7	6	10	9	9	28	27	30

YEAR	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
RADIOSONDE	6	6	34	47	51	62	123	238	335	221	175	171	164	169	177	188	188	192	194	203	208	207	199
AIRPLANES	31	29	14	7	5	4	1																
KITES																							
TOTAL STATIONS	37	35	48	54	56	66	124	238	335	221	175	171	164	169	177	188	188	192	194	203	208	207	199

Figure 19.

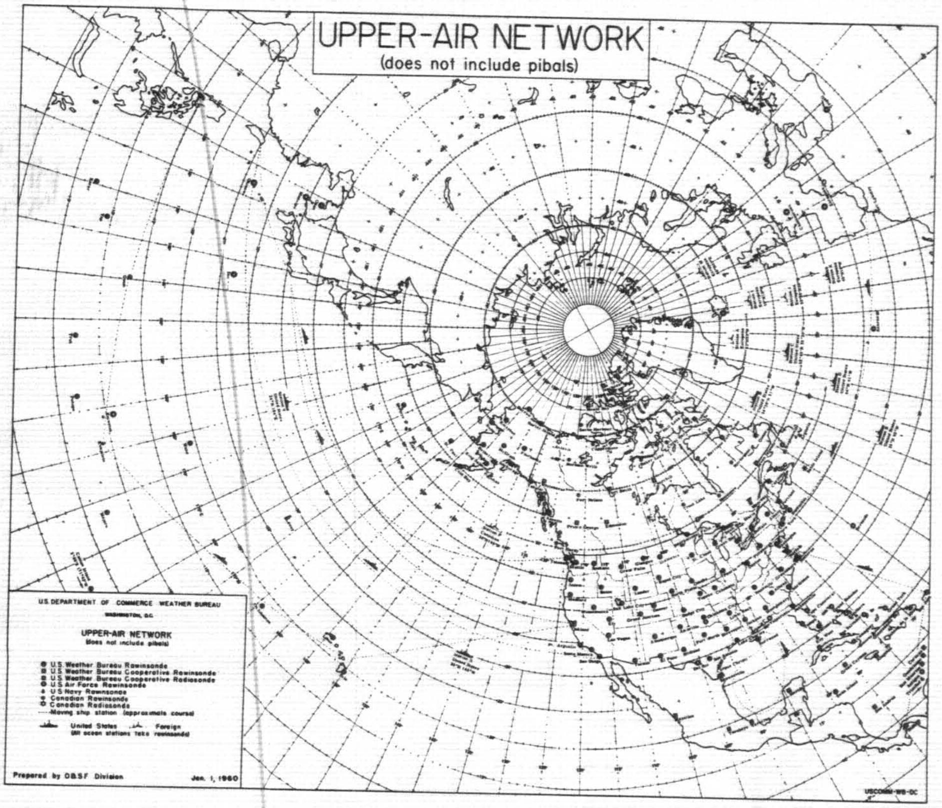


Figure 20.

3.2 OBSERVATIONAL FORMS IN THE ARCHIVES

In the vast depository of records at Asheville is an accumulation of original manuscript observational forms, autographic records of various meteorological elements, and foreign and domestic records reduced to microfilm and punched card form. Since the systematic collection of these data began, numerous changes in the forms have taken place. A complete list of Weather Bureau forms in current use is contained in the U. S. Weather Bureau Forms Catalog (1959) available from the Administrative Operations Division of the U. S. Weather Bureau, Washington 25, D. C. Records on WBAN (Weather Bureau, Air Force, Navy) forms are available from various locations around the world, on both land and sea, as provided by the military and civilian weather forces of the United States, primarily during and since World War II. The examples shown in figures 23 through 28 are typical of the bulk of current observational records filed in the Arcade Building. A fragmentary collection of original weather records for some foreign stations is also on file; however, foreign publications are for the most part filed in the Weather Bureau library in Washington, D. C.

A comprehensive index of available observations is maintained. It consists of a cumulative card file system which sets forth the period of record (year, month) for each type of document, the weather service sponsoring the observations, and other pertinent information concerning availability and location. Using the Washington, D. C. Weather Bureau station as an example, figure 21 pictures the accumulation of knowledge available at Asheville. The shelf space required to accommodate the total volume of records and the annual growth, as shown in figure 22, dramatizes the potential of the climatic archives.

Observations taken at some localities for earlier periods may, in some instances, have been destroyed or lost. While some of these are still being recovered, generally they are not available. Selected elements may not have been recorded continuously; therefore, for any given study or use the entire period needed should be surveyed. Also, some early observations prior to the establishment of the Weather Bureau may be available only at the National Archives, Washington, D. C. Archival specialists at Asheville, however, are equipped to assist in a variety of data procurement problems.

In addition to the original observations, weather data are available in Climatological Record books as well as in the original observations. These are maintained by "First Order" Weather Bureau stations for comparison and public service, except that if these stations are closed the books are sent to Asheville. As soon as any twenty-year period is completed, the books are sent to Asheville anyway where they are microfilmed and returned to the station.

The retirement of original records is a slow process. Some of the records have already been microfilmed and destroyed, but most of the observational forms have not been retired. Ultimately many older records will be available only in microfilm form. This condensation process has another invaluable advantage - the practicability of duplication and separate storage for safety. Equipment and personnel are on hand - only the lack of funds prevents adequate progress in protecting the archives.

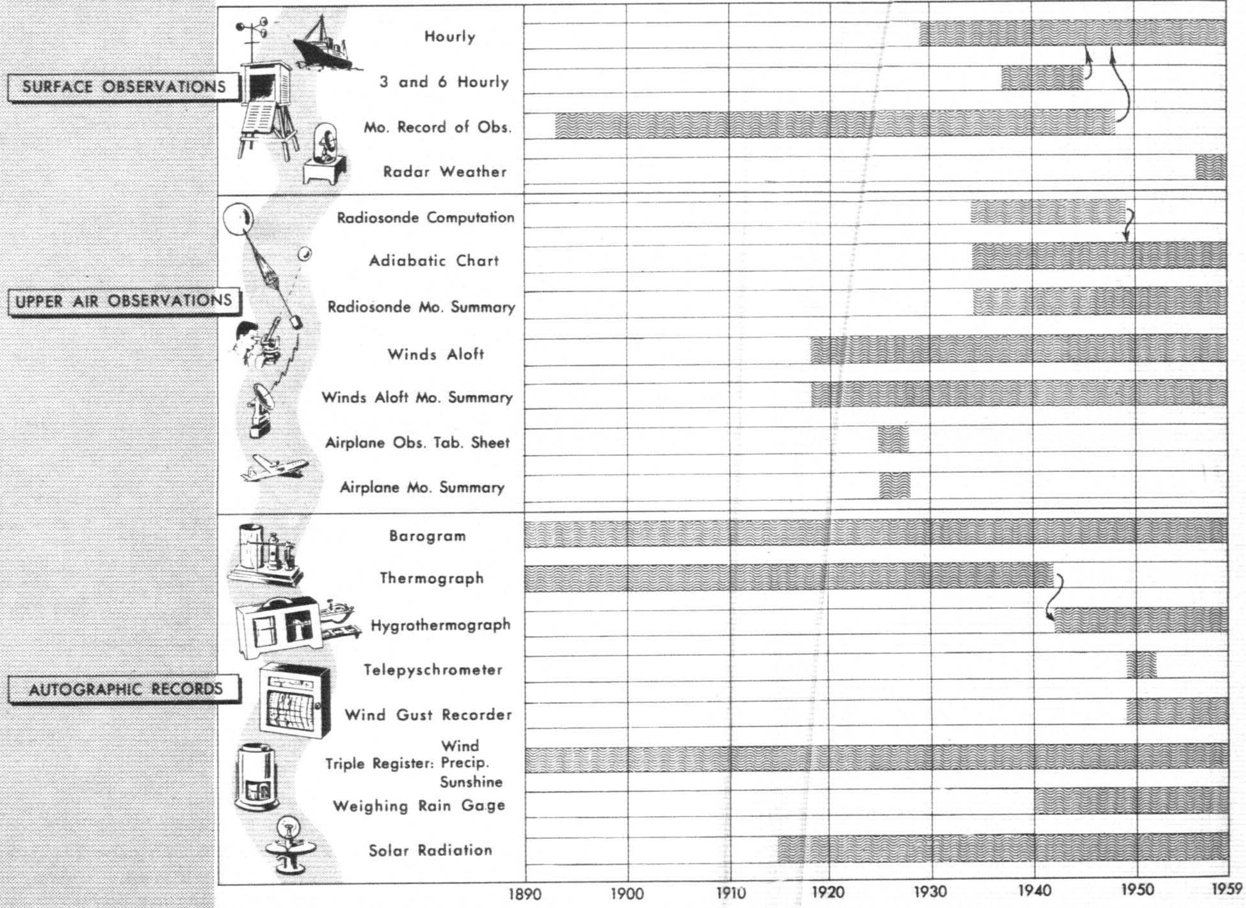


Figure 21. Periods of Record for Weather Bureau Forms Filed at NWRC for Washington, D. C.

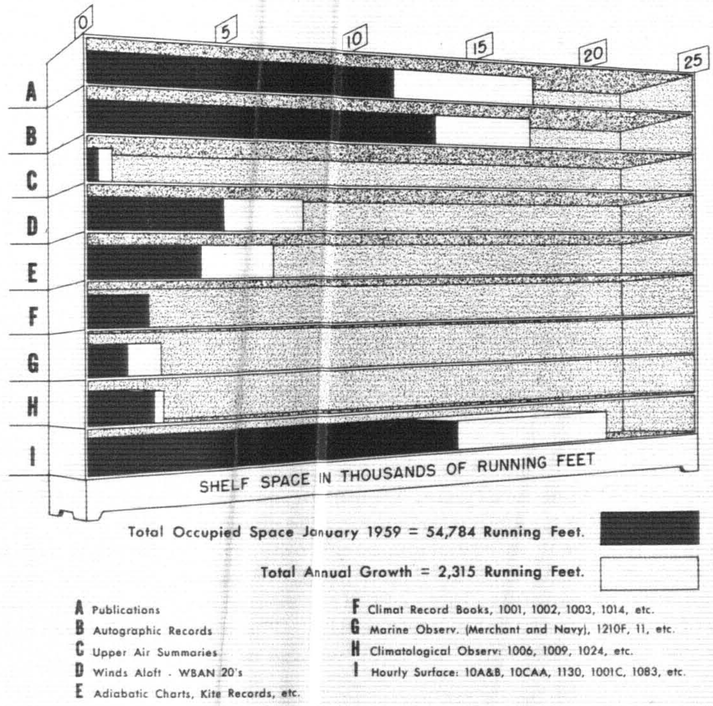
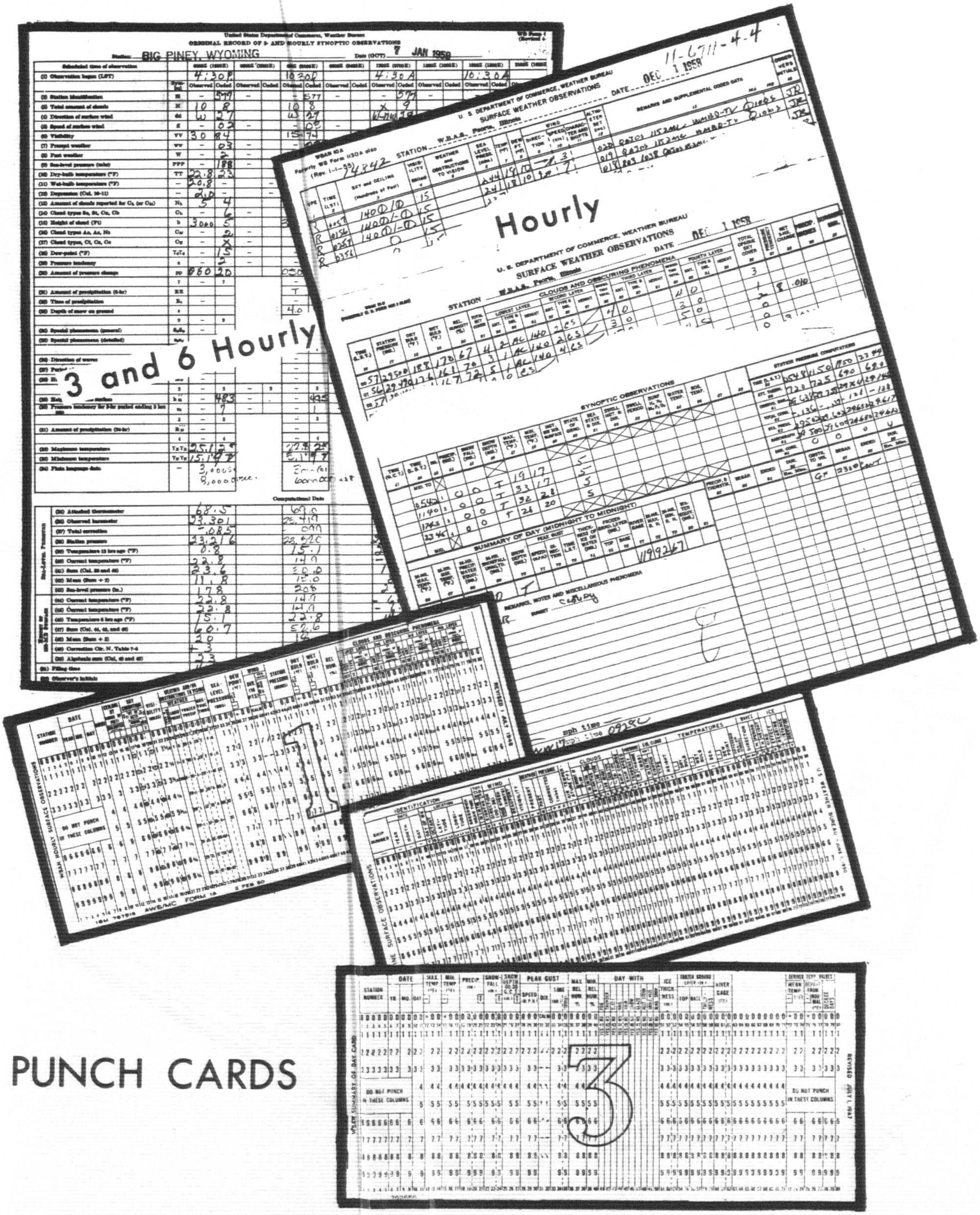


Figure 22. Shelf Space in Use for Original Records and Publications at NWRC

SURFACE OBSERVATIONAL FORMS



PUNCH CARDS

Figure 23.

UPPER AIR OBSERVATIONAL FORMS

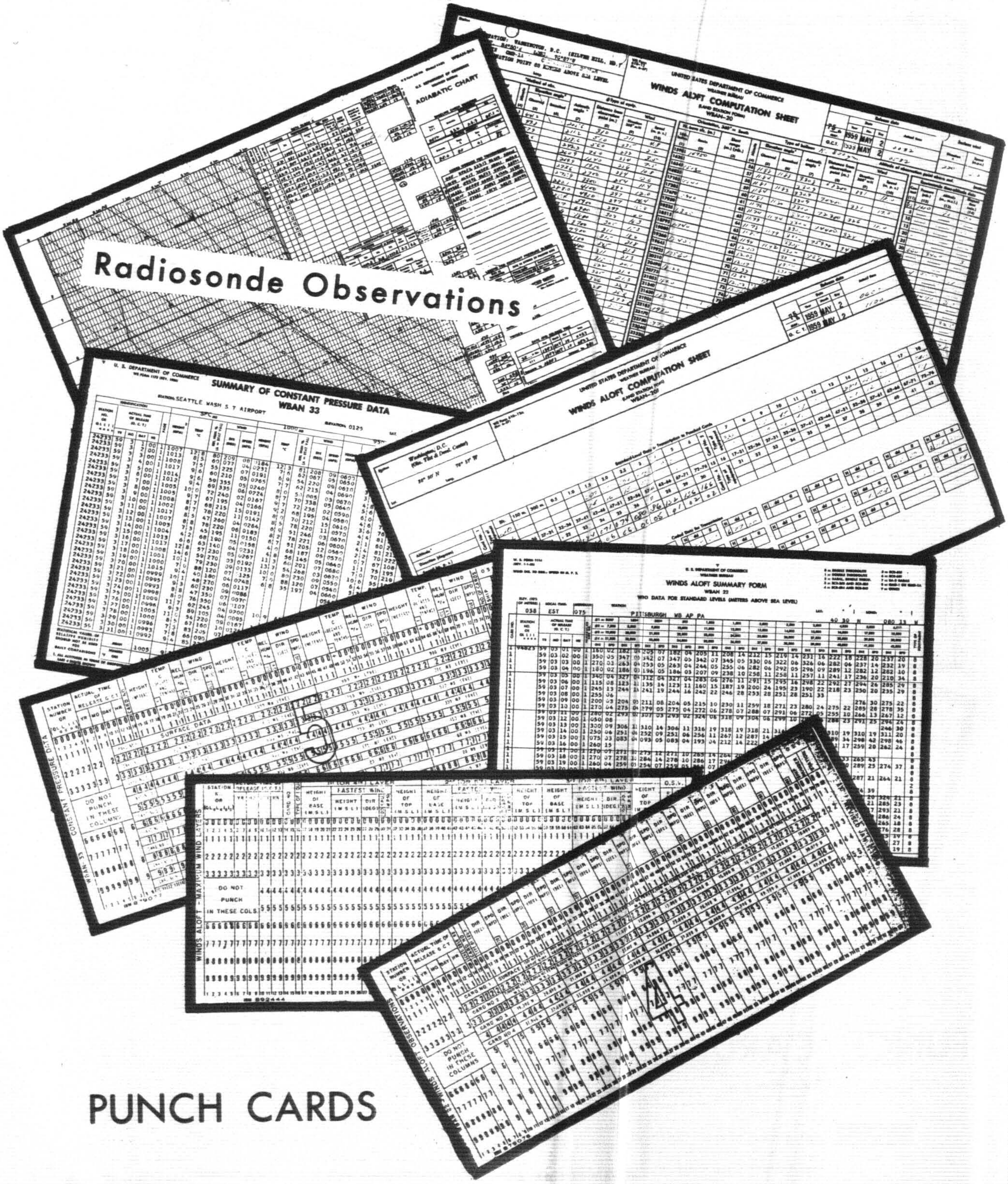


Figure 24.

COOPERATIVE CLIMATOLOGICAL FORMS

PUNCH CARD

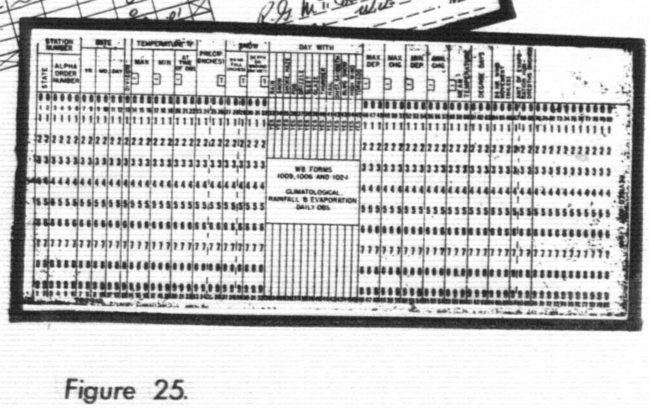
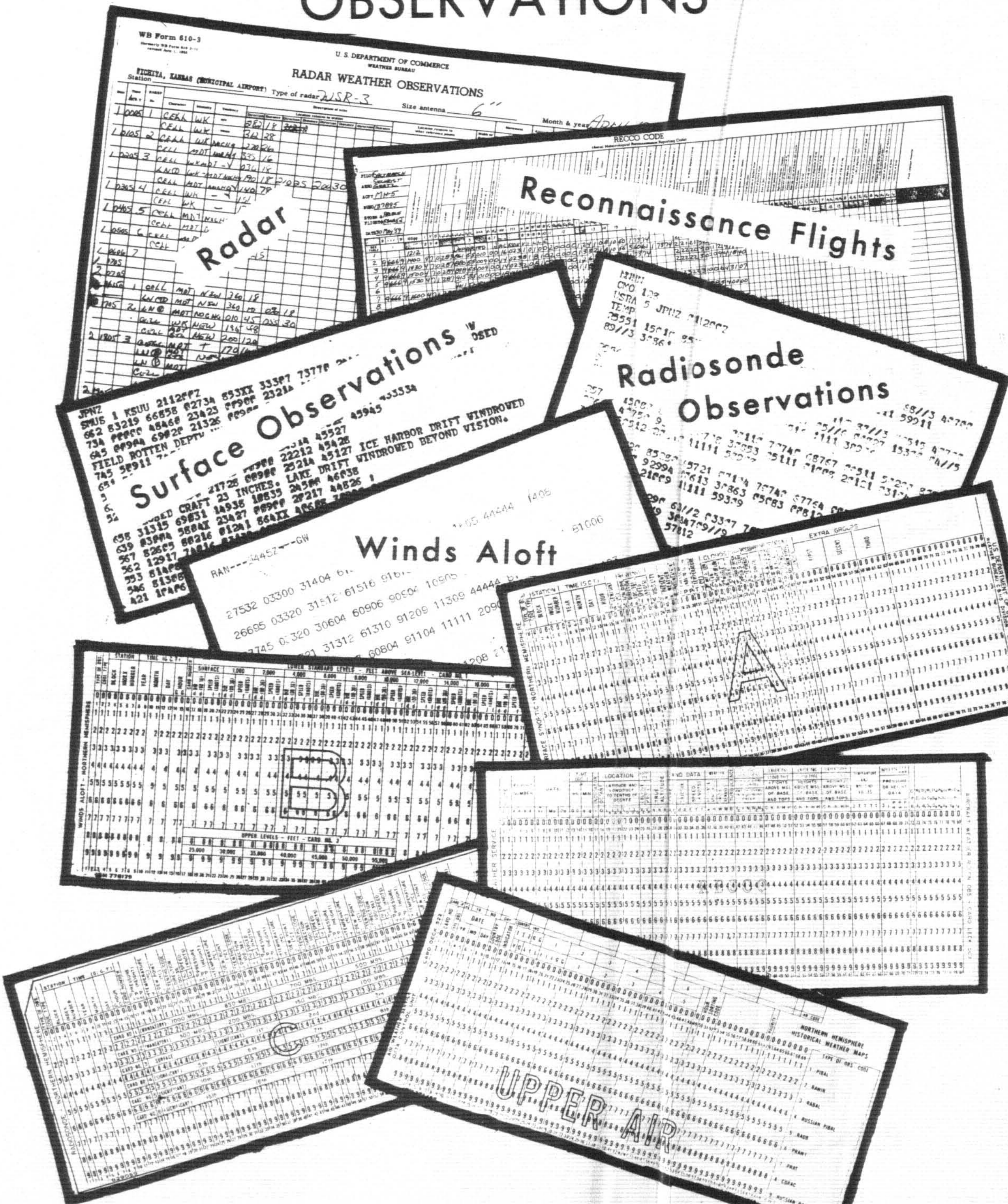


Figure 25.

WORLD WIDE SURFACE AND UPPER AIR OBSERVATIONS



PUNCH CARDS

Figure 26.

MARINE OBSERVATIONS

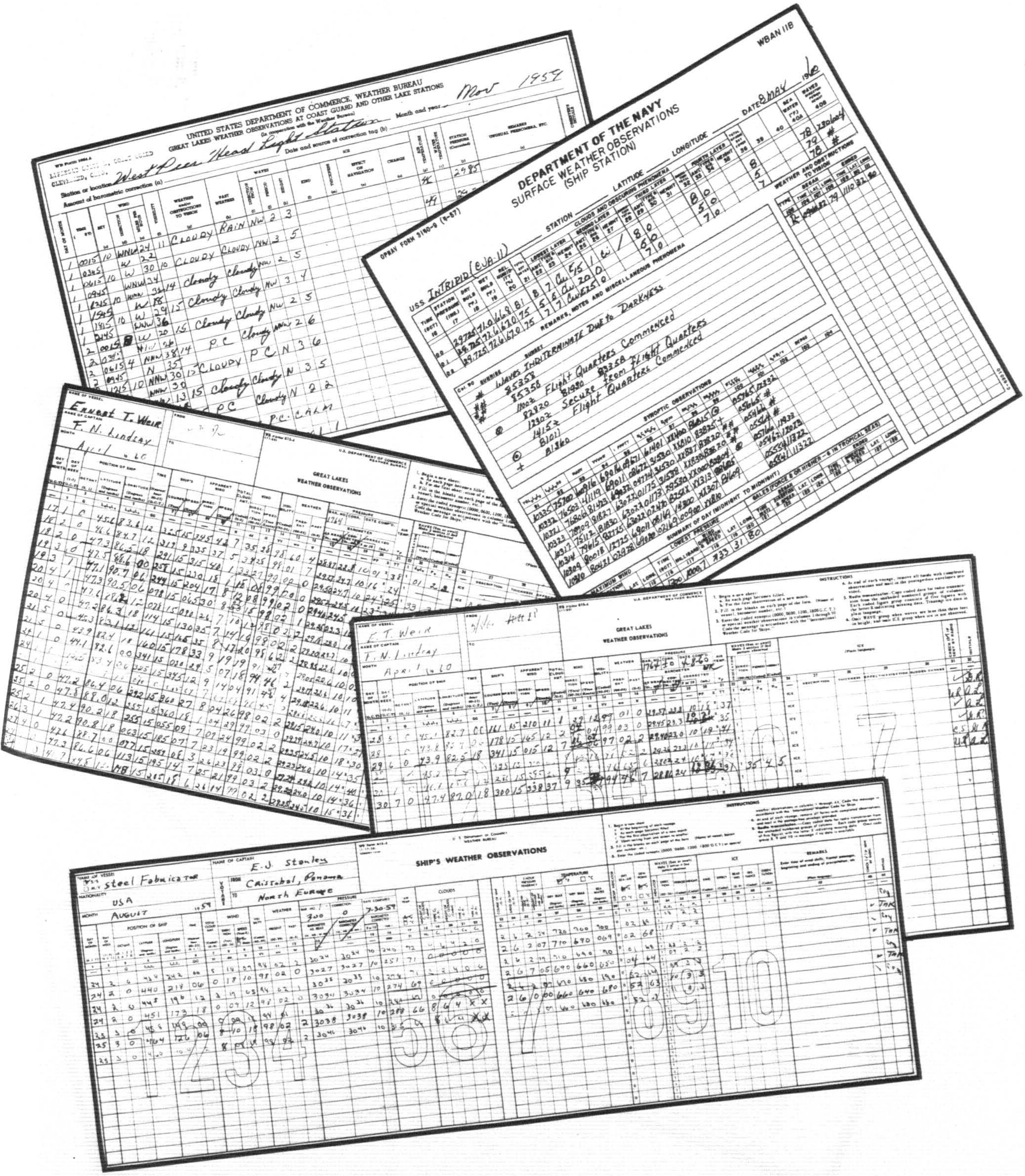


Figure 27.

572 71 O - 60 - 3

AUTOGRAPHIC RECORDS

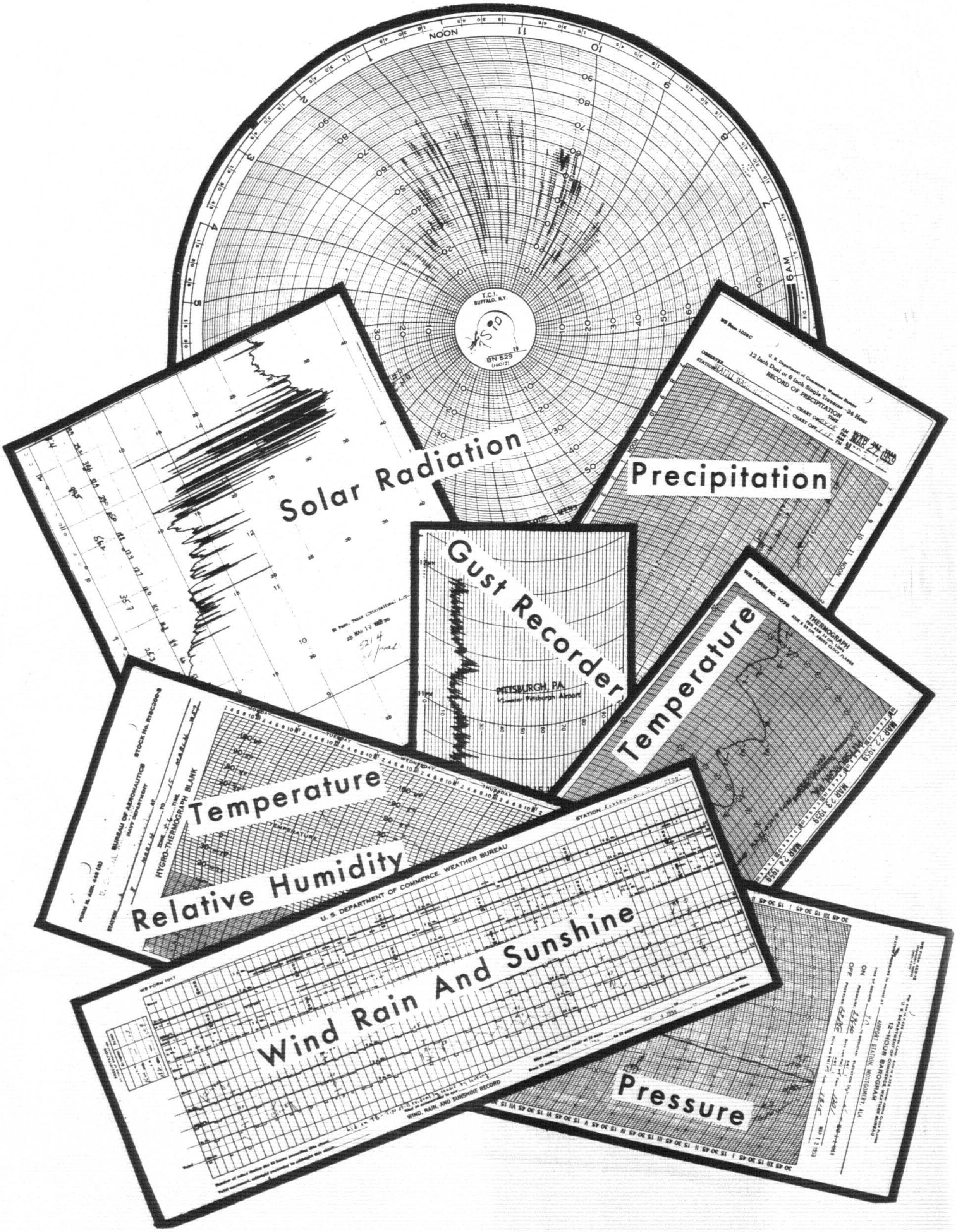


Figure 28.

3.3 CLIMATOLOGICAL NETWORKS

Some 12,000-15,000 surface weather stations comprise the observing networks reporting to Asheville for climatological purposes at present. These stations are located in all fifty of the United States and in the Caribbean. A few hundred stations are maintained as Fruit-Frost, Corn and Wheat, and Fire-Weather stations. About 5,000 of them are the basic climatic network. They take one observation each day of precipitation and maximum and minimum temperature, in addition to notes on the occurrence of frosts, thunderstorms, etc. These are designated as permanent climatological stations manned by the faithful cooperative volunteer observers. Other substation observations are used for river and flood forecast work. Also, there are a number of stations participating in severe storm reporting networks using storm detection radar facilities for public information and similar general purposes. A list of U. S. operated stations reporting to Asheville from locations throughout the world (as of Jan. 1960) is given in table 1. These stations are manned by the Weather Bureau, Air Force, Navy, and other agencies which cooperate in obtaining either 24 hourly (complete surface observations) or in some instances synoptic (only at designated times and for selected elements) observations. Those stations from which forms or radarscope pictures and records are received, and who are concerned with the scanning of storm laden horizons using the latest radar equipment available, are shown in table 2.

The upper air program continues to be a progressive part of the development of climatology. Its quantitative and qualitative growth is shown by figures 18 and 19. Like the surface observational forms, upper air records are regularly received and processed at Asheville, North Carolina. (See Upper Air Observation Forms, figure 24.)

The U. S. upper air station network as of January 1960 is shown in figure 20. Records are available in summarized form for both winds aloft measurements and radiosonde observations only from about 1915. Unlike surface observations, upper air observations are mostly a 20th century product and, in fact, radiosonde observations date back only to about 1940. Prior to machine processing (1950) available summaries were handwritten and hand computed. In addition, as we would expect of a growing technology, many changes in forms and units of measurement have taken place. The potential user, in determining his needs, must evaluate the data by reference to some documentation, such as the "Key to Meteorological Records Documentation" series which is available through the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., or by consultation with records specialists [21].

A number of foreign nations courteously mail monthly transcripts of observations and some published data to Asheville; our Canadian neighbors, France, and Great Britain are among those who regularly exchange information with the United States. In addition, punched cards are exchanged with Canada, France, Great Britain, and other countries supporting such programs. The many library facilities available in Washington and elsewhere are used to fill any gaps in information wherever possible.

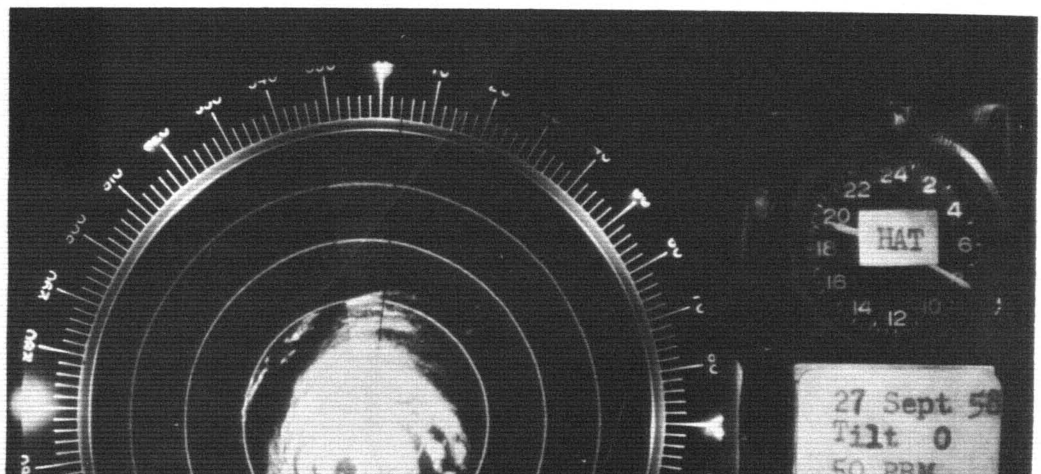


Figure 29. Radar Scope Photo of Hurricane "Helene" from Cape Hatteras, N. C.

Table 1. U. S. Operated Worldwide Hourly* Observation Stations (Based on Records Available at Asheville, N. C., January 1, 1960)

Station	Type of Station**	
ALABAMA		
Anniston	FAA	
Bankhead Tunnel	SAWRS	x
Birmingham	WBAS	
Dothan	FAA	
Evergreen	FAA	
Fort Rucker, Cairns AAF	AWS	
Gadsden	SAWRS	x
Huntsville	WBAS	
Mobile	WBAS	
Mobile, Brookley AFB	AWS	
Montgomery	WBAS	
Montgomery, Maxwell AFB	AWS	
Muscle Shoals	FAA	
Selma	SAWRS	x
Selma, Craig AFB	AWS	
Tuscaloosa	FAA	
ALASKA		
Adak NS	Navy	
Anchorage, Merrill Fld.	WBAS	
Anchorage, Elmendorf AFB	AWS	
Angoon	SNDO	x
Aniak	FAA	
Annette Island	WBAS	
Barrow	WBAS	
Barter Island	WBAS	
Bethel	WBAS	
Bettles	FAA	
Big Delta	FAA	
Cape Decision L/S	USCG	x
Cape Hinchinbrook L/S	USCG	x
Cape Lisburne AFS	AWS	x
Cape Newenham AFS	AWS	
Cape Romanzof AFS	AWS	
Cape St. Elias L/S	USCG	x
Cape Sarichef L/S	USCG	x
Cape Spencer L/S	USCG	x
Cold Bay	WBAS	
Cordova	WBAS	
Craig	SNDO	x
Dillingham	SAWRS	x
Driftwood Bay	AWS	x
Eagle	SNDO	x
Eldred Rock L/S	USCG	x
Fairbanks	WBAS	
Fairbanks, Eielson AFB	AWS	
Fairbanks, Ladd AFB	AWS	
Farewell	FAA	
Five Finger L/S	USCG	x
Flat	SNDO	x
Fort Yukon	FAA	x
Galena APT.	AWS	
Guard Island L/S	USCG	x
Gulkana	FAA	
Gustavus	FAA	
Homer	FAA	
Hughes	SNDO	x
Iliamna	FAA	
Juneau	WBAS	
Kenai	FAA	
Ketchikan	SAWRS	x
King Salmon/Naknek	WBAS	
Kodiak FWC	Navy	
Kotzebue	WBAS	
Lake Minchumina	FAA	
Lincoln Rock L/S	USCG	x
Manley Hot Springs	SNDO	x
McCarthy	SAWRS	x
McGrath	WBAS	
Middleton Island AFS	AWS	
Moses Point	FAA	
Mountain Village	SNDO	x
Nenana	FAA	
Nikolski	AWS	
Nome	WBAS	
Northeast Cape AFS	AWS	
Northway	FAA	
Nunivak	SNDO	x
Nyac	SAWRS	x
Palmer	SNDO	x
Petersburg	SNDO	x
Platinum	WBAS	x
Point Barrow	AWS	x
Point Retreat L/S	USCG	x
Port Alexander	SNDO	x
Port Heiden	SAWRS	x
Port Moller	AWS	x
Puntilla	SNDO	x
St. Paul Island	WBAS	x
Sentinel Island L/S	USCG	x
Seward	SNDO	x
Sheep Mountain	SAWRS	x
Shemya Island	WBAS	
Sister Island	SNDO	x
Sitka Japonski	FAA	
Skagway	SNDO	x
Skwentna	SNDO	x
ALASKA (Cont'd.)		
Sleetmute	SAWRS	x
Sparrevohn AFS	AWS	x
Summit	FAA	
Talkeetna	FAA	
Tanana	FAA	
Tatalina AFB	AWS	x
Teller	SNDO	x
Tin City AFS	AWS	x
Tree Point L/S	USCG	x
Umiat	SAWRS	x
Umnak Island	SAWRS	x
Unalakleet	FAA	
Upper Russian Lake	SAWRS	x
Utopia Creek AFS	AWS	x
Valdez	SNDO	x
Wainwright	SNDO	x
Wales	SNDO	x
Wrangell	SNDO	x
Yakataga	FAA	
Yakutat	WBAS	
ARIZONA		
Chandler, Williams AFB	AWS	
Clifton	SAWRS	x
Douglas	FAA	
Flagstaff	WBAS	x
Fort Huachuca Sig C	Army	
Gila Bend	FAA	
Grand Canyon	SNDO	x
Kingman	SAWRS	x
Page	SAWRS	x
Payson	SAWRS	x
Phoenix	WBAS	
Phoenix, Litchfield Park NAF	Navy	x
Phoenix, Luke AFB	AWS	
Prescott	WBAS	
Safford	SAWRS	x
Show Low	SNDO	x
Tucson	WBAS	
Tucson, Davis-Monthan AFB	AWS	
Winslow	WBAS	
Yuma	WBAS	
Yuma Sig C	Army	
ARKANSAS		
Camden	SAWRS	x
El Dorado	FAA	
Fayetteville	FAA	
Flippin	FAA	
Fort Smith	WBAS	
Harrison	SAWRS	x
Hot Springs	SAWRS	x
Jacksonville, Little Rock AFB	AWS	
Little Rock	WBAS	
Magnolia	SAWRS	x
Pine Bluff	FAA	
Texarkana	FAA	
Walnut Ridge	FAA	
CALIFORNIA		
Alameda FWC	Navy	
Anacapa Island L/S	USCG	x
Apple Valley	SAWRS	x
Arcata	FAA	
Bakersfield	WBAS	
Beale, AFB	AWS	
Beaumont	SNDO	x
Bishop	WBAS	x
Blue Canyon	WBAS	x
Blunts Reef L/S	USCG	x
Blythe	FAA	
Burbank	WBAS	
Burney	SNDO	x
Campo	SAWRS	x
Carlsbad	SAWRS	x
Chico	SAWRS	x
Chula Vista, Brown Fld NAAS	Navy	
Concord	SAWRS	x
Crescent City	FAA	
El Centro NAAS	Navy	x
El Toro MCAS	Navy	
Eureka	WBO	
Fairfield, Travis AFB	AWS	
Fort Bragg	SNDO	x
Fresno	WBAS	
Hayward	SAWRS	x
Imperial	FAA	
Inyokern NAF	Navy	
Lancaster	SAWRS	x
Los Alamitos NAS	Navy	
Los Angeles (Autographic Records)	WBO	
Los Angeles	WBAS	
Marysville	SAWRS	x
Merced	SAWRS	x
CALIFORNIA (Cont'd.)		
Merced, Castle AFB	AWS	
Miramar NAS	Navy	
Modesto	SAWRS	x
Montague	FAA	
Monterey NAF	Navy	
Mt. Hamilton	SNDO	x
Mt. Shasta	WBAS	x
Mt. Wilson	SNDO	x
Muroc, Edwards AFB	AWS	
Needles	FAA	
Oakland	WBAS	
Ontario (Automatic)	SAWRS	
Oxnard	SAWRS	x
Oxnard AFB	AWS	
Palmdale	FAA	
Palm Springs	SAWRS	x
Paso Robles	FAA	
Point Arena L/S	USCG	x
Point Arguello	WBAS	x
Point Piedras Blancas L/S	USCG	x
Point Mugu NAS	Navy	
Red Bluff	WBAS	
Redding	SAWRS	x
Riverside	SAWRS	x
Riverside, March AFB	AWS	
Sacramento	WBAS	
Sacramento (Autographic Records)	WBO	
Sacramento, Mather AFB	AWS	
Sacramento, McClellan AFB	AWS	
Salinas	FAA	
San Bernardino, Norton AFB	AWS	
San Clemente Island NAS	Navy	
Sandberg (Automatic)	WBO	
San Diego	WBAS	
San Diego	SAWRS	x
San Diego	SNDO	x
San Diego FWC	Navy	
San Francisco (Autographic)	WBO	
San Francisco	WBAS	
San Francisco L/S	USCG	x
San Jose	SAWRS	x
San Nicolas Island NF	Navy	x
San Rafael, Hamilton AFB	AWS	
San Ysidro NAS	Navy	
Santa Ana	SAWRS	x
Santa Ana MCAF	Navy	x
Santa Barbara	FAA	
Santa Maria	WBAS	
Santa Rosa	SAWRS	x
South East Farallon Is. L/S	USCG	x
Stockton	FAA	
Sunnyvale, Moffett Fld NAS	Navy	
Surf, Vandenberg AFB	AWS	
Susanville	SNDO	x
Thermal	FAA	
Torrance	SAWRS	x
Ukiah	FAA	
Victorville, George AFB	AWS	
Visalia	SAWRS	x
COLORADO		
Akron	FAA	
Alamosa	WBAS	x
Colorado Springs	WBAS	
Cortez	SAWRS	x
Craig	SNDO	x
Denver	WBAS	
Denver, Lowry AFB	AWS	
Durango	SAWRS	x
Eagle	FAA	
Fort Collins	SAWRS	x
Fraser	SAWRS	x
Grand Junction	WBAS	
Gunnison	SAWRS	x
La Junta	FAA	
Lamar	SNDO	x
Lamar	SAWRS	x
Leadville	SNDO	x
Limon	SAWRS	x
Monte Vista	SAWRS	x
Montrose	SAWRS	x
Pueblo	WBAS	
Rifle	SAWRS	x
Salida	SAWRS	x
Sterling	SAWRS	x
Trinidad	FAA	
CONNECTICUT		
Bridgeport	WBAS	x
East Hartford	SAWRS	x
Middletown	WBO	
New Haven	WBAS	x
New London	SAWRS	x
Hartford (Windsor Locks)	WBAS	
DELAWARE		
Dover AFB	AWS	
Overfalls L/S	USCG	x
Wilmington	WBAS	
DIST. of COLUMBIA		
Washington, Anacostia NAS	Navy	x
Washington, Andrews AFB	AWS	
Washington, Bolling AFB	AWS	
Washington Nat'l. APT.	WBAS	
FLORIDA		
Alligator Reef L/S	USCG	x
Apalachicola (Autographic Records)	WBO	
Bartow AAF	AWS	x
Cape Canaveral MTA	AWS	
Carysfort Reef L/S	USCG	x
Clewiston	SNDO	x
Cocoa Beach, Patrick AFB	AWS	
Crestview	FAA	
Cross City	FAA	
Daytona Beach	WBAS	
Dry Tortugas L/S	USCG	x
Fort Lauderdale	SAWRS	
Fort Myers	WBAS	
Gainesville	SAWRS	x
Homestead AFB	AWS	
Jacksonville	WBAS	
Jacksonville NAS	Navy	
Jacksonville, Cecil Fld NAS	Navy	
Key West	WBAS	x
Key West NAS	Navy	
Lakeland	SAWRS	x
Marianna	SAWRS	x
Mayport NAAS	Navy	
Melbourne	FAA	
Miami	WBAS	
Miami (Autographic Records)	WBO	
Milton, Whiting Fld NAAS	Navy	
Ocala	SNDO	x
Orlando	WBAS	
Orlando, McCoy AFB	AWS	
Panama City	SAWRS	x
Panama City, Tyndall AFB	AWS	
Pensacola	WBO	
Pensacola	FAA	
Pensacola, Ellyson Fld HTU	Navy	x
Pensacola, Forest Sherman NAS	Navy	
Pensacola, Saufley Fld NAAS	Navy	x
Saint Petersburg	SAWRS	
Sanford NAS	Navy	
Sarasota	SAWRS	x
Tallahassee	WBAS	
Tampa	WBAS	
Tampa, MacDill AFB	AWS	
Valparaiso, Eglin AFB	AWS	
Valparaiso, Eglin #3, Duke Fld	AWS	x
Valparaiso, Eglin #9, Hurlburt Fld	AWS	
Vero Beach	FAA	
West Palm Beach	WBAS	
GEORGIA		
Albany	FAA	
Albany, Turner AFB	AWS	
Alma	FAA	
Athens	WBAS	
Atlanta	WBAS	
Augusta	WBAS	
Brunswick	FAA	
Brunswick, Glynco NAS	Navy	
Columbus	WBAS	x
Dawsonville, (Autographic Records)	WBO	
Fort Benning, Lawson AAF	AWS	
La Grange	FAA	
Macon	WBAS	
Marietta, Dobbins AFB	AWS	
Moultrie	SAWRS	x
Moultrie, Spence Fld	AWS	x
Rome	WBAS	x
Savannah L/S	USCG	x
Savannah	WBAS	
Savannah, Hunter AFB	AWS	
Valdosta	FAA	
Valdosta, Moody AFB	AWS	
Warner Robins, Robins AFB	AWS	
Waycross	SAWRS	x
HAWAII		
Barbers Point NAS	Navy	
Cape Kumukahi	SNDO	x
French Frigate Shoals	USCG	x
Hana APT	SAWRS	x

* Includes Synoptic Observations (i.e., those made at n-hour periods, usually 3-hourly and 6-hourly). The "x" in the Type of Station indicates less than 24 observations per day.

** See last column of Table 2 for key to abbreviations.

Table I. U. S. Operated Worldwide Hourly* Observation Stations (Cont'd.)
(Based on Records Available at Asheville, N. C., January 1, 1960)

HAWAII (Cont'd.)	Type of Station**
Hilo	FAA
Honolulu	WBAS
Kahului	FAA
Kamuela	SAWRS x
Kaneohe Bay MCAS	Navy
Kilauea Point L/S	USCG x
Kona APT	FAA x
Kona	SNDO x
Lanai APT	SAWRS x
Lihue	WBAS
Makahuena Pt. L/S	USCG x
Makapuu Point L/S	USCG x
Mauna Loa	WBO x
Molokai, Homestead Fld	SAWRS x
Upolu Point	SAWRS x
Upolu Point	USCG x

IDAHO	
Boise	WBAS
Burley	FAA
Coeur d' Alene	SAWRS x
Dubois	FAA
Gooding	FAA
Grangeville	SNDO x
Idaho Falls	FAA
Lewiston	WBAS x
Malad City	FAA
McCall	SAWRS x
Mountain Home AFB	AWS
Mullan	FAA
Pocatello	WBAS
Salmon	SNDO x
Strevell	SAWRS x
Twin Falls	SAWRS x

ILLINOIS	
Belleville, Scott AFB	AWS
Bloomington	SAWRS x
Bradford	FAA
Cairo (Autographic Records)	WBO
Cairo	SAWRS x
Carbondale	SAWRS x
Champaign	SAWRS x
Chicago, Meigs	SAWRS x
Chicago, Midway	WBAS
Chicago, O'Hare Fld	WBAS
Danville	SAWRS x
Decatur	SAWRS x
Glenview NAS	Navy
Joliet	FAA
Marion	SAWRS x
Mattoon	SAWRS x
Moline	WBAS
Peoria	WBAS
Quincy	FAA
Rantoul, Chanute AFB	AWS
Rockford	WBAS
Springfield	WBAS
Vandalia	FAA

INDIANA	
Bloomington	SAWRS x
Bunker Hill AFB	AWS
Columbus, Bakalar AFB	AWS x
Evansville	WBAS
Fort Wayne	WBAS
Gary	SAWRS x
Goshen	FAA
Indianapolis	WBAS
Kokomo	SAWRS x
Lafayette	FAA
Marion	SAWRS x
Muncie	SAWRS x
Richmond	SAWRS x
South Bend	WBAS
Terre Haute	FAA

IOWA	
Burlington	WBAS
Cedar Rapids	FAA
Clinton	SAWRS x
Des Moines	WBAS
Dubuque	WBAS x
Fort Dodge	SAWRS x
Iowa City	SAWRS x
Lamoni	FAA
Mason City	FAA
Ottumwa	FAA
Sioux City	WBAS
Spencer	SNDO x
Waterloo	WBAS

KANSAS	Type of Station**
Chanute	FAA
Concordia	
(Autographic Records)	WBO
Dodge City	WBAS
Emporia	FAA
Fort Riley, Marshall AAF	AWS
Garden City	FAA
Goodland	WBAS
Great Bend	SAWRS x
Hill City	FAA
Hutchinson	FAA
Liberal	SAWRS x
Manhattan	SAWRS x
Olathe NAS	Navy
Pittsburg	SAWRS x
Russell	FAA
Salina	FAA
Salina, Schilling AFB	AWS
Topeka	WBAS
Topeka, Forbes AFB	AWS
Wichita	WBAS
Wichita, McConnell AFB	AWS

KENTUCKY	
Bowling Green	FAA
Fort Campbell, Campbell AAF	AWS
Fort Knox, Godman AAF	AWS
Lexington	WBAS
London	FAA
Louisville	WBAS
Owensboro	SAWRS x
Paducah	FAA
Pikeville	SNDO x

LOUISIANA	
Alexandria, England AFB	AWS
Baton Rouge	WBAS
Bogalusa	SAWRS x
Burrwood	WBAS
DeRidder	SAWRS x
Lafayette	FAA
Lake Charles	WBAS
Monroe	FAA
New Orleans	
(Autographic Records)	WBO
New Orleans	WBAS
New Orleans NAS	Navy
Patterson	SAWRS x
Shreveport	WBAS
Shreveport, Barksdale AFB	AWS

MAINE	
Auburn	SAWRS x
Augusta	FAA
Bangor, Dow AFB	AWS
Bar Harbor	SAWRS x
Brunswick NAS	Navy
Caribou	WBAS
Eastport	SNDO x
Greenville	WBAS x
Houlton	FAA
Limestone, Loring AFB	AWS
Millinocket	FAA
Old Town	FAA
Portland	WBAS
Portland L/S	USCG x
Presque Isle	SAWRS x
Rockland	SAWRS x
Rumford	SNDO x
Waterville	SAWRS x

MARYLAND	
Annapolis NAF	Navy
Baltimore	WBAS
Fort Geo. G. Meade AAF	AWS
Frederick	WBAS x
Hagerstown	SAWRS x
Ocean City	SNDO x
Patuxent River NAS	Navy
Salisbury	FAA

MASSACHUSETTS	
Bedford, L.G.Hanscom Fld	AWS
Boston L/S	USCG x
Buzzards Bay L/S	USCG x
Chicopee Falls, Westover AFB	AWS
East Boston	WBAS
Falmouth, Otis AFB	AWS
Fitchburg	SAWRS x
Georges Shoals TT-2 AFS	AWS
Hyannis	SAWRS x
Lawrence	SAWRS x

MASSACHUSETTS (Cont'd.)	Type of Station**
Martha's Vineyard	SAWRS x
Nantucket	WBAS
Nantucket L/S	USCG x
Nantucket Shoals TT-3 AFS	AWS
Natick Sig C	Army
New Bedford	SAWRS x
Pittsfield	WBAS x
Pollock Rip L/S	USCG x
South Weymouth NAS	Navy x
Worcester	WBAS

MICHIGAN	
Alpena	WBAS
Battle Creek	FAA
Benton Harbor	SAWRS x
Detroit, City APT	WBAS
Detroit, Metropolitan APT	WBAS
Escanaba	SAWRS x
Escanaba	
(Autographic Records)	WBO
Flint	WBAS
Gladwin	FAA
Grand Rapids	WBAS
Grosse Ile NAS	Navy x
Gwinn, K. I. Sawyer AFB	AWS
Houghton	FAA
Iron Mountain	SAWRS x
Ironwood	SAWRS x
Jackson	FAA
Kalamazoo	SAWRS x
Kinross, Kincheloe AFB	AWS
Lansing	WBAS
Marquette	
(Autographic Records)	WBO
Marquette	FAA
Menominee	SAWRS x
Mount Clemens, Selfridge AFB	AWS
Muskegon	WBAS
Muskegon L/S	USCG x
Oscoda, Wurtsmith AFB	AWS
Pellston	FAA
Saginaw	FAA
Sault Sainte Marie	WBAS
Traverse City	FAA
Ypsilanti	WBAS

MINNESOTA	
Alexandria	FAA
Bemidji	SAWRS x
Bemidji	SNDO x
Brainerd	SAWRS x
Duluth	WBAS
Fairmont	SAWRS x
Grand Rapids	SAWRS x
Hibbing	SAWRS x
International Falls	WBAS
Mankato	SAWRS x
Minneapolis	WBAS
Minneapolis NAS	Navy x
Redwood Falls	FAA
Rochester	WBAS
St. Cloud	WBAS x
Thief River	SAWRS x
Winona	SAWRS x
Worthington	SAWRS x

MISSISSIPPI	
Biloxi, Keesler AFB	AWS
Columbus	SAWRS x
Columbus AFB	AWS
Greenville	SAWRS x
Greenville AFB	AWS
Greenwood	FAA
Gulfport	SAWRS x
Hattiesburg	SAWRS x
Jackson	WBAS
Laurel	SAWRS x
McComb	FAA
Meridian	WBAS
Natchez	SAWRS x
Oxford	SAWRS x
Tupelo	SNDO x
Vicksburg	WBO
Vicksburg	SAWRS x

MISSOURI	
Butler	FAA
Cape Girardeau	SAWRS x
Columbia	WBAS
Farmington	FAA
Grandview, Richards-	
Gebaur AFB	AWS
Jefferson City	SAWRS x

MISSOURI (Cont'd.)	Type of Station**
Joplin	FAA
Kansas City	WBAS
Kansas City	SAWRS x
Kirksville	FAA
Knobnoster, Whiteman AFB	AWS
Malden	FAA
Saint Joseph	WBAS
Saint Louis	WBAS
Springfield	WBAS
Vichy	FAA
West Plains	SNDO x

MONTANA	
Belgrade (Bozeman)	FAA
Billings	WBAS
Broadus	SNDO x
Butte	FAA
Cutbank	FAA
Dillon	FAA
Drummond	FAA
Elliston	SAWRS x
Glasgow	WBAS x
Glasgow	SAWRS x
Glasgow AFB	AWS
Glendive	SAWRS x
Great Falls	WBAS
Great Falls, Malmstrom AFB	AWS
Harlowtown	SAWRS
Havre (Automatic)	WBAS x
Helena	WBAS
Kalispell	SNDO x
Kalispell	WBAS x
Kalispell	SAWRS x
Lewistown	FAA
Livingston	FAA
Miles City	FAA
Missoula	WBAS
Sidney	SAWRS x
Thompson Falls	SAWRS x
West Yellowstone	SNDO x
Wolf Point	SAWRS x

NEBRASKA	
Ainsworth	SAWRS x
Alliance	SAWRS x
Beatrice	SAWRS x
Burwell	SNDO x
Chadron	FAA
Grand Island	WBAS
Hastings	SAWRS x
Imperial	FAA
Kearney	SAWRS x
Lincoln(Autographic Records)	WBO
Lincoln AFB	AWS
McCook	SAWRS x
Norfolk	WBAS x
North Omaha	SNDO x
North Platte	WBAS
Omaha	WBAS
Omaha, Offutt AFB	AWS
Scottsbluff	WBAS
Sidney	FAA
Valentine	
(Autographic Records)	WBO
Valentine	WBAS x
Valentine	SAWRS x

NEVADA	
Austin	SNDO x
Battle Mountain	FAA
Elko	WBAS
Ely	WBAS x
Fallon NAAS	Navy
Las Vegas	WBAS
Las Vegas, Nellis AFB	AWS
Lovelock	FAA
Owyhee	SNDO x
Reno	WBAS
Reno, Stead AFB	AWS
Tonopah	FAA
Winnemucca	WBAS x

NEW HAMPSHIRE	
Berlin	SAWRS x
Concord	WBAS
Keene	SAWRS x
Laconia	SAWRS x
Lebanon	FAA
Manchester, Grenier AFB	AWS x
Mt. Washington	WBO
Portsmouth, Pease AFB	AWS

* Includes Synoptic Observations (i.e., those made at n-hour periods, usually 3-hourly and 6-hourly).
The "x" in the Type of Station indicates less than 24 observations per day.
** See last column of Table 2 for key to abbreviations.

Table I. U. S. Operated Worldwide Hourly* Observation Stations (Cont'd.)
(Based on Records Available at Asheville, N. C., January 1, 1960)

NEW JERSEY	Type of Station**
Atlantic City	WBAS
Barnegat L/S	USCG x
Belmar Sig C	Army
Cape May	SAWRS x
Five Fathoms L/S	USCG x
Fort Dix, McGuire AFB	AWS
Lakehurst NAS	Navy
Millville	WBAS x
Teterboro	SAWRS
Trenton	SAWRS x
Trenton(Autographic Records)	WBO
Wildwood	SAWRS x

NEW MEXICO	Type of Station**
Alamogordo	SAWRS x
Alamogordo, Holloman AFB	AWS
Albuquerque	WBAS
Carlsbad	FAA
Clayton	WBAS x
Clovis	SAWRS x
Clovis, Cannon AFB	AWS
Columbus	FAA
Farmington	FAA
Gallup	SAWRS x
Glenwood	SNDO x
Grants	FAA
Hobbs	FAA
Las Cruces, White Sands MSL Range	AWS
Las Vegas	FAA
Otto	FAA
Raton	WBAS x
Roswell	WBAS x
Roswell, Walker AFB	AWS
Santa Fe	FAA
Santa Fe	SNDO x
Silver City	SAWRS x
Socorro	SNDO x
Truth or Consequences	FAA
Tucumcari	FAA
Zuni	FAA

NEW YORK	Type of Station**
Albany	WBAS
Ambrose L/S	USCG x
Amityville	SAWRS x
Bethpage	SAWRS x
Binghamton	WBAS
Buffalo	WBAS
Calverton	SAWRS x
Elmira	FAA
Farmingdale	SAWRS x
Glens Falls	FAA
Hempstead, Mitchel AFB	AWS
Islip	SAWRS x
Ithaca	SAWRS x
Jamestown	SAWRS x
Massena	FAA
Montauk	SNDO x
Newburgh, Stewart AFB	AWS
New York, Floyd Bennett Fld NAS	Navy x
New York City (Autographic Records)	WBO
New York, Central Park (Autographic Records)	WBO
New York International	WBAS
New York La Guardia	WBAS
New York Shoals TT-4 AFS	AWS
Niagara Falls Municipal APT	AWS
Ogdensburg	SAWRS x
Olean	SNDO x
Oneonta	SNDO x
Plattsburg	SAWRS x
Plattsburg AFB	AWS
Poughkeepsie	FAA
Rochester	WBAS
Rome, Griffiss AFB	AWS
Saranac Lake	SAWRS x
Schenectady	SAWRS x
Syracuse	WBAS
Utica	FAA
Watertown	FAA
Westhampton Beach, Suffolk County AFB	AWS
White Plains	SAWRS

NORTH CAROLINA	Type of Station**
Asheville, (Autographic Records)	WBO
Asheville	FAA
Beaufort	SAWRS x
Cape Hatteras	WBAS
Charlotte	WBAS

NORTH CAROLINA (Cont'd.)	Type of Station**
Cherry Point MCAS	Navy
Diamond Shoals L/S	USCG x
Elizabeth City	FAA
Fayetteville	SAWRS
Fort Bragg, Pope AFB	AWS
Frying Pan Shoals L/S	USCG
Greensboro	WBAS
Goldsboro, Seymour Johnson AFB	AWS
Hickory	FAA
Hot Springs	SAWRS x
Jacksonville, New River MCAF	Navy x
Kinston	SAWRS x
New Bern	FAA
Raleigh	WBAS
Rocky Mount	FAA
Southern Pines	SAWRS x
Wilmington	WBAS
Winston-Salem	WBAS

NORTH DAKOTA	Type of Station**
Bismarck	WBAS
Devils Lake (Autographic Records)	WBO
Devils Lake	SAWRS x
Dickinson	FAA
Fargo	WBAS
Grand Forks	FAA
Grand Forks AFB	AWS
Jamestown	FAA
Minot	FAA
Minot AFB	AWS
Williston	WBAS x
Williston	SAWRS x

OHIO	Type of Station**
Akron	WBAS
Cincinnati Abbe (Autographic Records)	WBO
Cincinnati	WBAS
Cleveland	WBAS
Columbus	WBAS
Columbus, Lockbourne AFB	AWS
Dayton	WBAS
Dayton, Patterson Fld AFB	AWS
Dayton, Wright Fld AFB	AWS
Findlay	FAA
Lima	SAWRS x
Mansfield	SAWRS x
Marion	SAWRS x
New Philadelphia	SAWRS x
Portsmouth	SAWRS x
Sandusky (Autographic Records)	WBO
Toledo	WBAS
Wilmington, Clinton County AFB	AWS
Youngstown	WBAS
Zanesville	FAA

OKLAHOMA	Type of Station**
Ada	SAWRS x
Altus AFB	AWS
Ardmore	FAA
Ardmore	SAWRS x
Bartlesville	SAWRS x
Clinton-Sherman AFB	AWS
Duncan	SAWRS x
Enid	SAWRS x
Enid, Vance AFB	AWS
Fort Sill, Post Field	AWS
Gage	FAA
Guymon	SNDO x
Hobart	FAA
Lawton	SAWRS x
McAlester	FAA
Miami	SAWRS x
Muskogee	SAWRS x
Oklahoma City	WBAS
Oklahoma City, Tinker AFB	AWS
Ponca City	FAA
Stillwater	SAWRS x
Tulsa	WBAS

OREGON	Type of Station**
Astoria	WBAS
Baker	FAA
Brookings	SNDO x
Burns (Autographic Records)	WBO x
Burns	SAWRS x
Cape Blanco L/S	USCG x
Cascade Locks	SAWRS x
Corvallis	SAWRS x

OREGON (Cont'd.)	Type of Station**
Eugene	WBAS
Klamath Falls, Kingsley Fld	AWS
La Grande	SAWRS x
Lakeview	SAWRS x
Lakeview	SNDO x
Meacham	WBAS x
Medford	WBAS
Newport	SNDO x
Newport	SAWRS x
North Bend	FAA
Ontario	SAWRS x
Pendleton	WBAS
Portland	WBAS
Redmond	FAA
Roseburg	WBAS x
Roseburg	SAWRS x
Salem	WBAS
Sexton Summit	WBAS x
The Dalles	FAA
Troutdale	SAWRS x

PENNSYLVANIA	Type of Station**
Allentown	WBAS
Altoona	FAA
Blairsville	SNDO x
Bradford	FAA
Brookville	FAA
Erie	FAA
Franklin	SAWRS x
Harrisburg	WBAS
Hazleton	SAWRS x
Johnstown	SAWRS x
Lancaster	SAWRS x
Middletown Olmsted AFB	AWS
Mt. Pocono	SNDO x
North Philadelphia	SAWRS
Park Place (Automatic)	WBAS
Philadelphia	WBAS
Philadelphia NAAS	Navy x
Phillipsburg	FAA
Pittsburgh	WBAS
Pittsburgh (Allegheny)	FAA
Reading(Autographic Records)	WBO
Wilkes-Barre, Scranton	WBAS
Williamsport	WBAS
Willow Grove NAS	Navy x

RHODE ISLAND	Type of Station**
Block Island	WBAS x
Providence	WBAS
Quonset Point NAS	Navy
Smithfield	SAWRS x

SOUTH CAROLINA	Type of Station**
Anderson	FAA
Beaufort MCAAS	Navy
Charleston	WBAS
Charleston (Autographic Records)	WBO
Columbia	WBAS
Florence	WBAS
Greenville	WBAS
Greenville, Donaldson AFB	AWS
Greenwood	SAWRS x
Myrtle Beach AFB	AWS
Spartanburg	FAA
Sumter, Shaw AFB	AWS

SOUTH DAKOTA	Type of Station**
Aberdeen	FAA
Brookings	SAWRS x
Hot Springs	SAWRS x
Huron	WBAS
Lemmon	SNDO x
Lemmon	SAWRS x
Mitchell	SAWRS x
Mobridge	SNDO x
Philip	FAA
Pickstown	SNDO x
Pierre	FAA
Rapid City	WBAS
Rapid City, Ellsworth AFB	AWS
Sioux Falls	WBAS
Spearfish	SAWRS x
Watertown	FAA
Yankton	SAWRS x

TENNESSEE	Type of Station**
Bristol	WBAS
Chattanooga	WBAS
Clarksville	SAWRS x
Crossville	FAA

TENNESSEE (Cont'd.)	Type of Station**
Dyersburg	FAA
Jackson	FAA
Knoxville	WBAS
Memphis	WBAS
Memphis NAS	Navy
Monteagle	SAWRS x
Nashville	WBAS
Smyrna, Sewart AFB	AWS
Tullahoma	SAWRS x

TEXAS	Type of Station**
Abilene	WBAS
Abilene, Dyess AFB	AWS
Alice	FAA
Alpine	SNDO x
Amarillo	WBAS
Austin	WBAS
Austin,Bergstrom AFB	AWS
Beeville NAAS	Navy
Big Spring, Webb AFB	AWS
Borger	SAWRS x
Brownsville	WBAS
Brownwood	SAWRS x
Childress	FAA
College Station	FAA
Corpus Christi	WBAS
Corpus Christi NAS	Navy
Cotulla	FAA
Dalhart	FAA
Dallas	WBAS
Dallas NAS	Navy
Del Rio, Laughlin AFB	AWS
El Paso	WBAS
El Paso (Cristo Rhey)	SAWRS x
El Paso, Biggs AFB	AWS
Fort Stockton	SAWRS x
Fort Worth	WBAS
Fort Worth, Meacham Fld	FAA
Fort Worth, Carswell AFB	AWS
Galveston	WBAS
Galveston (Autographic Records)	WBO
Harlingen AFB	AWS
Houston	WBAS
Houston(Autographic Records)	WBO
Houston, Ellington AFB	AWS
Junction	FAA
Kerrville	SAWRS x
Killeen, Gray AFB	AWS
Kingsville NAAS	Navy
Laredo	WBAS
Longview	FAA
Lubbock	WBAS
Lubbock, Reese AFB	AWS
Lufkin	FAA
Marfa	SAWRS x
Marshall	SAWRS x
Matagorda Island	AWS x
McAllen	SAWRS x
Midland	WBAS
Mineral Wells	FAA
Palacios	FAA
Paris	SAWRS x
Pecos	SAWRS x
Plainview	SAWRS x
Port Arthur	WBAS
Port Isabel NAAS	Navy x
Presidio	SNDO x
San Angelo	WBAS
San Antonio	WBAS
San Antonio, Brooks AFB	AWS
San Antonio, Kelly AFB	AWS
San Antonio, Randolph AFB	AWS
Sherman	SAWRS x
Sherman, Perrin AFB	AWS
Temple	SAWRS x
Tyler	FAA
Van Horn	SAWRS x
Victoria	WBAS x
Waco	WBAS
Waco, James Connally AFB	AWS
Wichita Falls	WBAS
Wink	FAA

UTAH	Type of Station**
Blanding	SNDO x
Bryce Canyon	FAA
Cedar City	FAA
Coalville	SAWRS x
Delta	FAA
Green River	SNDO x
Hanksville	FAA
Kanab	SAWRS x
Logan	SAWRS x
Milford	WBAS x

* Includes Synoptic Observations (i.e., those made at n-hour periods, usually 3-hourly and 6-hourly).
The "x" in the Type of Station indicates less than 24 observations per day.

** See last column of Table 2 for key to abbreviations.

Table 1. U. S. Operated Worldwide Hourly* Observation Stations (Cont'd.)
(Based on Records Available at Asheville, N. C., January 1, 1960)

Station	Type of Station**
UTAH (Cont'd.)	
Moab	SAWRS x
Myton	SAWRS x
Ogden	FAA
Ogden, Hill AFB	AWS
Provo	SAWRS x
Roosevelt	SNDO x
Saint George	SAWRS x
Salt Lake City	WBAS
Tooele, Dugway Proving Ground	AWS
Vernal	SAWRS x
Wendover	WBAS
VERMONT	
Burlington	WBAS
Montpelier	FAA
Newport	SAWRS x
Newport	SNDO x
Rutland	SAWRS x
VIRGINIA	
Blackstone	FAA
Charlottesville	SAWRS x
Chesapeake L/S	USCG x
Danville	FAA
Fort Belvoir, Davison AAF	AWS
Gordonsville	FAA
Hampton, Langley AFB	AWS
Lynchburg	WBAS
Newport News	SAWRS x
Norfolk	WBAS
Norfolk NAS	Navy
Norfolk FWF NAS	Navy
Oceana NAS	Navy
Quantico MCAS	Navy
Richmond	WBAS
Roanoke	WBAS
WASHINGTON	
Bellingham	FAA
Colville	SNDO x
Columbia River L/S	USCG x
Destruction Island L/S	USCG x
Ephrata	FAA
Everett, Paine AFB	AWS
Hoquiam	FAA
Moses Lake, Larson AFB	AWS
Olympia	WBAS
Omak	SNDO x
Omak	SAWRS x
Pasco	SAWRS x
Port Angeles	SAWRS x
Port Angeles, USCG AS	USCG x
Pullman	SAWRS x
Seattle (Boeing)	WBAS
Seattle (Tacoma APT)	WBAS
Seattle FWC	Navy
Shelton	SNDO x
Spokane (Felts)	WBAS
Spokane, Fairchild AFB	AWS
Spokane (Geiger Fld)	WBAS
Stampede Pass	WBAS x
Swiftsure Bank L/S	USCG
Tacoma, McChord AFB	AWS
Tatoosh Island	WBAS
Toledo	FAA
Walla Walla	FAA
Walla Walla (Autographic Records)	WBO
Wenatchee	WBAS
Whidbey Island NAS	Navy
Yakima	FAA
WEST VIRGINIA	
Beckley	SAWRS x
Bluefield	FAA
Charleston	WBAS
Clarksburg	SAWRS x
Elkins	FAA
Flat Top	SNDO x
Huntington	FAA
Huntington	SAWRS x
Martinsburg	FAA
Morgantown	FAA
Parkersburg (Autographic Records)	WBO
Parkersburg	FAA
Wheeling	SAWRS
WISCONSIN	
Appleton	SAWRS x
Ashland	SAWRS x
WISCONSIN (Cont'd.)	
Clintonville	SAWRS x
Eau Claire	FAA
Grantsburg	FAA
Green Bay	WBAS
Janesville	SAWRS x
La Crosse	WBAS
Land o'Lakes (Seasonal)	SAWRS x
Lone Rock	FAA
Madison	WBAS
Manitowoc	SAWRS x
Milwaukee	WBAS
Oshkosh	SAWRS x
Park Falls	SNDO x
Rhinelander	SAWRS x
Stevens Point	SAWRS x
Wausau	FAA
WYOMING	
Big Piney	SNDO x
Casper	WBAS
Cheyenne	WBAS
Cody	SNDO x
Cody	SAWRS x
Douglas	FAA
Evanston	SAWRS
Greybull	SAWRS x
Jackson	SAWRS x
Lander	WBAS x
Laramie	FAA
Lusk	SAWRS x
Moorecroft	SNDO x
Newcastle	SAWRS x
Powell	SAWRS x
Rawlins	FAA
Riverton	SAWRS x
Rock Springs	FAA
Sheridan	WBAS
Worland	SAWRS x
AFRICA	
Libya, Tripoli, Wheelus AB	AWS
Morocco, Ben Guerir AB	AWS
Morocco, Nouasseur AB	AWS
Morocco, Port Lyautey FWC	Navy
Morocco, Sidi Slimane AB	AWS
ANTARCTICA	
Beardmore Camp	Navy x
Byrd Station	WBO x
Ellsworth	Navy x
Hallett/Adare	Navy
Little America V	WBO
Little Rockford NAAF	Navy x
McMurdo Sound NAF	Navy
South Pole Station (Amundsen-Scott)	WBO
Wilkes Station	WBO x
ARCTIC	
Ice Island B (T-3)	WBO x
Ice Island C	WBO x
ATLANTIC ISLANDS	
Ascension Island AAFB	AWS
Azores, Terceira, Lajes Fld	AWS
Bermuda B.W.I. NS	Navy
Bermuda, St. George, Kindley AFB	AWS
CANAL ZONE	
Balboa, Albrook AFB	AWS
Cocoli, Howard Fld	AWS x
CARIBBEAN ISLANDS	
Bahamas, Eleuthera, Coffin Hills AAFB	AWS x
Bahamas, Grand Bahama, Gold Rock Creek AAFB	AWS x
Bahamas, San Salvador, Bonefish Bay AAFB	AWS x
B.W.I., Antigua, St. Johns AAFB	AWS x
B.W.I., Dominica, Roseau	SNDO x
B.W.I., Grand Turk AAFB	AWS x
B.W.I., St. Kitts, Basseterre	SNDO x
B.W.I., St. Lucia, Castries	SNDO x
P. R., Aguadilla, Ramey AFB	AWS
P. R., Mayaguez	SAWRS x
P. R., Mercedita Central	SAWRS x
CARIBBEAN ISLANDS (Cont'd.)	
P.R., Ponce	SNDO x
P.R., Roosevelt Roads NAS	Navy
P.R., San Juan NS	Navy
P.R., San Juan	WBAS
V.I., Saint Croix, Benedict Fld	FAA
V.I., Saint Thomas	FAA
W.I., Swan Island	WBO
CHILE	
Puerto Montt, Chamiza AFB	AWS x
CUBA	
Guantanamo Bay NAS	Navy
ENGLAND	
Alconbury RAFS	AWS
Brandon, Lakenheath RAFS	AWS x
Bruntingthorpe RAFS	AWS
Chelveston RAFS	AWS
Fairford RAFS	AWS
Fakenham, Sculthorpe RAFS	AWS
Mildenhall RAFS	AWS
Newbury, Greenham Common RAFS	AWS
Oxford, Brize Norton RAFS	AWS
Oxford, Upper Heyford RAFS	AWS
Wethersfield RAFS	AWS
Woodbridge RAFS	AWS
Woodbridge, Bentwaters RAFS	AWS
FRANCE	
Chateauroux, Deols AS	AWS
Chaumont AB	AWS
Dreux AB	AWS
Evreux-Fauville AB	AWS
Laon AB	AWS
Orleans, Saran AAF	AWS x
Phalsbourg AB	AWS
Toul-Rosieres AB	AWS
Verdun AAF	AWS x
GERMANY	
Augsburg AAF	AWS x
Bad Kreuznach AB	AWS x
Bitburg AB	AWS
Geibelstadt AB	AWS x
Grafenwohr AAF	AWS x
Hanau AAF	AWS x
Heidelberg AAF	AWS
Hunsruck, Hahn AB	AWS
Illesheim AAF	AWS x
Karlsruhe AAF	AWS x
Kitzingen AAF	AWS x
Mannheim, Colman AAF	AWS x
Ramstein-Landstuhl AB	AWS
Sembach AB	AWS
Spangdahlem AB	AWS
Straubing AAF	AWS x
Wiesbaden AB	AWS
GREENLAND	
Camp Fistclench Site 2 Sig. C.	Army
Camp Tuto Sta. 1, Sig. C.	Army
Camp Tuto Sta. 3, Sig. C.	Army
Sondrestrom AB	AWS
Thule AB	AWS
ICELAND	
Keflavik Int. APT.	AWS
ITALY	
Aviano AB	AWS
JAPAN	
Ashiya AB	AWS
Camp Zama, Rankin Fld.	AWS x
Fukuoka, Itazuke AB	AWS
Furusaki, Misawa AB	AWS
Iwakuni NAS	Navy
Oppama NAF	Navy x
Tokyo, Atsugi NAS	Navy
Tokyo, Johnson AB	AWS
Yokosuka FWC	Navy
KOREA	
Kunsan AB	AWS
Osan-Ni, Osan AB K-55	AWS
Seoul, Kimpo AB K-14	AWS
Uijongbu, Army Fcstg Team 810	AWS
Tonggo-Ri Team 811/A-9	AWS x
Tongduchon-Ni Team 812	AWS x
NEWFOUNDLAND	
Argentia FWC	Navy
Saglek Bay	AWS x
Stephenville, E. Harmon AFB	AWS
NICARAGUA	
Bluefields	SNDO x
Puerto Cabezas	SNDO x
PACIFIC ISLANDS	
Mariana, Guam, Andersen AFB	AWS
Mariana, Guam, Agana Fld FWC	Navy
Mariana, Saipan NAU	Navy x
Marshall, Eniwetok	AWS x
Marshall, Kwajalein, Roi NAS	Navy
Midway NS	Navy
P.I., Angeles, Clark AB	AWS
P.I., Cubi Point	Navy
P.I., Sangley Point	Navy
Ryukyu, Okinawa, Kadena AB	AWS
Ryukyu, Okinawa, Naha AB	AWS
Volcano, Iwo Jima AB	AWS
SAUDI ARABIA	
Dhahran AB	AWS
SPAIN	
Madrid, Torrejon AB	AWS
Moron de la Frontera AB	AWS
Rota NAS	Navy
Zaragoza AB	AWS
TURKEY	
Adana, Incirlik AB	AWS

* Includes Synoptic Observations (i.e., those made at n-hour periods, usually 3-hourly and 6-hourly).
The "x" in the Type of Station indicates less than 24 observations per day.
** See last column of Table 2 for key to abbreviations.

Table 2. U. S. Operated Radar Stations
(Based on Records Available January 1, 1960)

Station	Type of Station	
ALABAMA		
Birmingham	WB	*
Fort Rucker, Ozark AAF	AWS	#
Huntsville	WB	*
Mobile	WB	*
Mobile, Brookley AFB	AWS	#
Montgomery	WB	*
Montgomery, Maxwell AFB	AWS	#
Selma, Craig AFB	AWS	#
ARIZONA		
Chandler, Williams AFB	AWS	#
Phoenix, Luke AFB	AWS	#
ARKANSAS		
Fort Smith	WB	*
Little Rock	WB	*※
CALIFORNIA		
Eureka	WB	*
San Rafael, Hamilton AFB	AWS	#
COLORADO		
Denver, Lowry AFB	AWS	#
Pueblo	WB	*
CONNECTICUT		
Hartford	WB	*
DIST. OF COLUMBIA		
Washington	WB	*
Washington, Andrews AFB	AWS	#
FLORIDA		
Apalachicola	WB	*
Cocoa Beach, Patrick AFB	AWS	#
Homestead AFB	AWS	#
Miami	WB	*※
Orlando, McCoy AFB	AWS	#
Tampa	WB	*
Tampa, MacDill AFB	AWS	#
Valparaiso, Eglin AFB	AWS	#
GEORGIA		
Albany, Turner AFB	AWS	#
Atlanta	WB	*
Fort Benning, Lawson AAF	AWS	#
Macon	WB	*
Savannah, Hunter AFB	AWS	#
Valdosta, Moody AFB	AWS	#
Warner Robins, Robins AFB	AWS	#
ILLINOIS		
Belleville, Scott AFB	AWS	#
Champaign	COOP	*
Chicago	WB	*
Rantoul, Chanute AFB	AWS	#
INDIANA		
Fort Wayne	WB	*
Indianapolis	WB	*
IOWA		
Burlington	WB	*
Des Moines	WB	*※
Spencer	WB	*
KANSAS		
Dodge City	WB	*※
Goodland	WB	*※
Salina, Schilling AFB	AWS	#
Topeka	WB	*※
Topeka, Forbes AFB	AWS	#
Wichita	WB	*※
Wichita, McConnell AFB	AWS	#
KENTUCKY		
Fort Knox, Godman AAF	AWS	#
LOUISIANA		
Alexandria, England AFB	AWS	#
Baton Rouge	WB	*※
Burrwood	WB	*
Lake Charles	WB	*※
LOUISIANA		
New Orleans	WB	*
Shreveport	WB	*※
Shreveport, Barksdale AFB	AWS	#
MAINE		
Limestone, Loring AFB	AWS	#
MASSACHUSETTS		
Bedford, L.G.Hanscom Fld.	AWS	#
Chicopee Falls, Westover AFB	AWS	#
East Boston	WB	*
Falmouth, Otis AFB	AWS	#
Nantucket	WB	*※
Worcester	WB	*
MICHIGAN		
Detroit, Metro. APT	WB	*
Flint	WB	*
Mount Clemens, Selfridge AFB	AWS	#
Muskegon	WB	*
Ypsilanti	WBAS	*
MISSISSIPPI		
Biloxi, Keesler AFB	AWS	#
Columbus AFB	AWS	#
Greenville AFB	AWS	#
Jackson	WB	*
Meridian	WB	*
MISSOURI		
Columbia	WB	*※
Kansas City	WB	*※
Knobnoster, Whiteman AFB	AWS	#
St. Louis	WB	*※
Springfield	WB	*※
MONTANA		
Great Falls, Malmstrom AFB	AWS	#
NEBRASKA		
Norfolk	WB	*
North Omaha	COOP	*
North Platte	WB	*
Omaha	WB	※
Omaha, Offutt AFB	AWS	#
Scottsbluff	WB	*
NEW JERSEY		
Trenton, McGuire AFB	AWS	#
NEW MEXICO		
Albuquerque	COOP	*
Clovis, Cannon AFB	AWS	#
Roswell, Walker AFB	AWS	#
NEW YORK		
Albany	WB	*
Binghamton	WB	*
Hempstead, Mitchel AFB	AWS	#
Rochester	WB	*
Syracuse	COOP	*
NORTH CAROLINA		
Cape Hatteras	WB	*※
Ft. Bragg, Pope AFB	AWS	#
Goldsboro, Seymour Johnson AFB	AWS	#
Raleigh	WB	*
OHIO		
Akron	WB	*
Cleveland	WB	*
Columbus	WB	*
Columbus, Lockbourn AFB	AWS	#
Dayton, Patterson Fld.AFB	AWS	#
Wilmington, Clinton County AFB	AWS	#
OKLAHOMA		
Altus AFB	AWS	#
Clinton, Sherman AFB	AWS	#
Enid, Vance AFB	AWS	#
Fort Sill, Post Fld. AFB	AWS	#
Oklahoma City	WB	*※
Oklahoma City, Tinker AFB	AWS	#
Tulsa	WB	*※
OREGON		
Astoria	WB	*
PENNSYLVANIA		
Middletown, Olmsted AFB	AWS	#
Philadelphia	WB	*
Pittsburgh	WB	*
SOUTH CAROLINA		
Charleston	WB	*※
Greenville, Donaldson AFB	AWS	#
Sumter, Shaw AFB	AWS	#
SOUTH DAKOTA		
Rapid City, Ellsworth AFB	AWS	#
Sioux Falls	WB	*
TENNESSEE		
Memphis	WB	*
Nashville	WB	*
Smyrna, Sewart AFB	AWS	#
TEXAS		
Abilene	WB	*※
Abilene, Dyess AFB	AWS	#
Amarillo	WB	*※
Austin	WB	*※
Austin, Bergstrom AFB	AWS	#
Brownsville	WB	*※
Corpus Christi	WB	*※
Del Rio, Laughlin AFB	AWS	#
Fort Worth	WB	*※
Fort Worth, Carswell AFB	AWS	#
Galveston	WB	*※
Houston	WB	*※
Houston, Ellington AFB	AWS	#
Lubbock	WB	*※
Lubbock, Reese AFB	AWS	#
Midland	WB	*
Port Arthur	WB	*※
San Angelo	WB	*※
San Antonio	WB	*※
San Antonio, Kelly AFB	AWS	#
San Antonio, Randolph AFB	AWS	#
Sherman, Perrin AFB	AWS	#
Victoria	COOP	*
Waco	WB	*※
Waco, James Connally AFB	AWS	#
Wichita Falls	WB	*※
UTAH		
Ogden, Hill AFB	AWS	#
VIRGINIA		
Hampton, Langley AFB	AWS	#
Lynchburg, Bedford AFB	COOP	*
Richmond	WB	*
WASHINGTON		
Spokane	COOP	*
Spokane, Fairchild AFB	AWS	#
Tacoma, McChord AFB	AWS	#
WISCONSIN		
Green Bay	COOP	*
Madison	WB	*
AFRICA		
Libya, Tripoli Wheelus AB	AWS	#
ATLANTIC ISLAND		
St. Georges, Bermuda Kindley AFB	AWS	#
CANAL ZONE		
Balboa, Albrook AFB	AWS	#
CARIBBEAN ISLANDS		
Aguadilla, P.R. Ramey AFB	AWS	#
San Juan, P.R.	WB	※
Swan Island	WB	*
ENGLAND		
Fakenham, Sculthorpe RAFS	AWS	#
Oxford, Brize Norton RAFS	AWS	#
GERMANY		
Hunsruck, Hahn AB	AWS	#
ICELAND		
Keflavik APT.	AWS	#
JAPAN		
Fukuoka, Itazuke AB	AWS	#
Furumaki, Misawa AB	AWS	#
Tokyo, Johnson AB	AWS	#
KOREA		
Osan-Ni, Osan AB	AWS	#
PACIFIC ISLANDS		
Eniwetok Atoll, Marshall Is.	AWS	#
Iwo Jima AB	AWS	#
Okinawa, Kadena AB	AWS	#
Okinawa, Naha AB	AWS	#

Key to Abbreviations

AAB	Army Air Base
AAF	Army Air Field
AB	Air Base (Air Force)
AF	Air Force
AFB/AAFB	AF Base (U.S.)/Aux. Base
AFS	Air Force Station
APT	Airport
AS	Air Station
AWS	Air Weather Service
COOP	Cooperative
FAA	Federal Aviation Agency
FWC	Fleet Weather Central
FWF	Fleet Weather Facility
HTU	Helicopter Train'g Unit, Navy
L/S	Lighthouse Station (Ship)
MCAF	Marine Corps Air Facility
MCAS	Marine Corps Air Station
MSL	Missile Range Station
MTA	Missile Testing Area
NAB	Naval Air Base
NAF	Naval Air Facility
NAS/NAAS	Naval Air Station/Aux. Sta.
NAU	Navy Administration Unit
NF	Naval Facility
NS	Naval Station
RAFS	Royal Air Force Station
SAWRS	Suppl. Airways Wea. Rptg. Sta.
Sig C	Army Signal Corps
SNDO	WB Second Order Sta. Type S.
T.T.	Texas Tower Station
USCG	United States Coast Guard
USCGAS	U.S. Coast Guard Air Sta.
WB/WBO	Weather Bureau/City Office
WBAS	WB Airport Station
*	WB Form 610-3, Radar Wea. Observations (Land)
※	Radarscope Picture
#	AWS Form 54, Radar Weather Observations

3.4 REGULAR DATA PUBLICATIONS

The work of conserving records for future reference is ever present but the dissemination of information is a more immediately fruitful responsibility of the climatic center at Asheville. The regular publication of basic data proceeds in accordance with public needs and the capacity for processing and printing. Various activities are served in the design of a particular publication; for example, the Local Climatological Data is meant to serve large cities, whereas the State Climatological Data might best serve non-urban and agricultural interests.

Continuing the geographical breakdowns, national and world-wide bulletins contain some specialized observations and of course wider coverage (figures 31 through 38). More specific information may be obtained by reference to the Key to Meteorological Records Documentation Series 4.1. This series has been established to provide guidance information to research personnel making use of climatological data.

3.5 IGY METEOROLOGICAL DATA

The International Geophysical Year (and succeeding programs) was a world-wide cooperative effort in many branches of science. Asheville became well known as the United States participated in the collection and processing of meteorological data during the IGY [16]. Over ten million (10,000,000) cards were punched in the checking and preparation of observations from land and sea and from the surface of the earth to 25 miles up into the atmosphere. Electronic data processing machines eventually reduced these data to some 200,000 specially designed forms to be made available to scientists all over the world.

In addition to this role as an active participant, the NWRC, because of the staff and facilities available, was designated by the U. S. National Commission for the IGY as World Data Center-A for meteorology, and also nuclear radiation. With counterparts in Moscow, Geneva, Stockholm, and Tokyo, this "Center within a Center" was charged with the collection, safekeeping, and dissemination to requesting scientists of all available data within the two disciplines. Over 1/3 million data forms are now on file in these categories. While this rather specialized data collection is small compared with the overall archival function of the NWRC, it does represent another channel through which the public may be served, especially in polar and some other remote areas.

As a result of this cooperative venture by scientists of many nations, a pole-to-pole atmospheric cross section is being prepared. In the Northern Hemisphere the study will follow the 80° west meridian; however, due to the paucity of data in the Southern Hemisphere, the cross section will be generally along the 75° west meridian, and will actually be more of a station by station analysis than a continuous cross section.

Figure 30. Publication Preparation

LOCAL SUMMARIES

LCD Monthly and Annual, Climatic Guides, Summary Hrly. Observations, Substation Clim. Summary, and Substation History

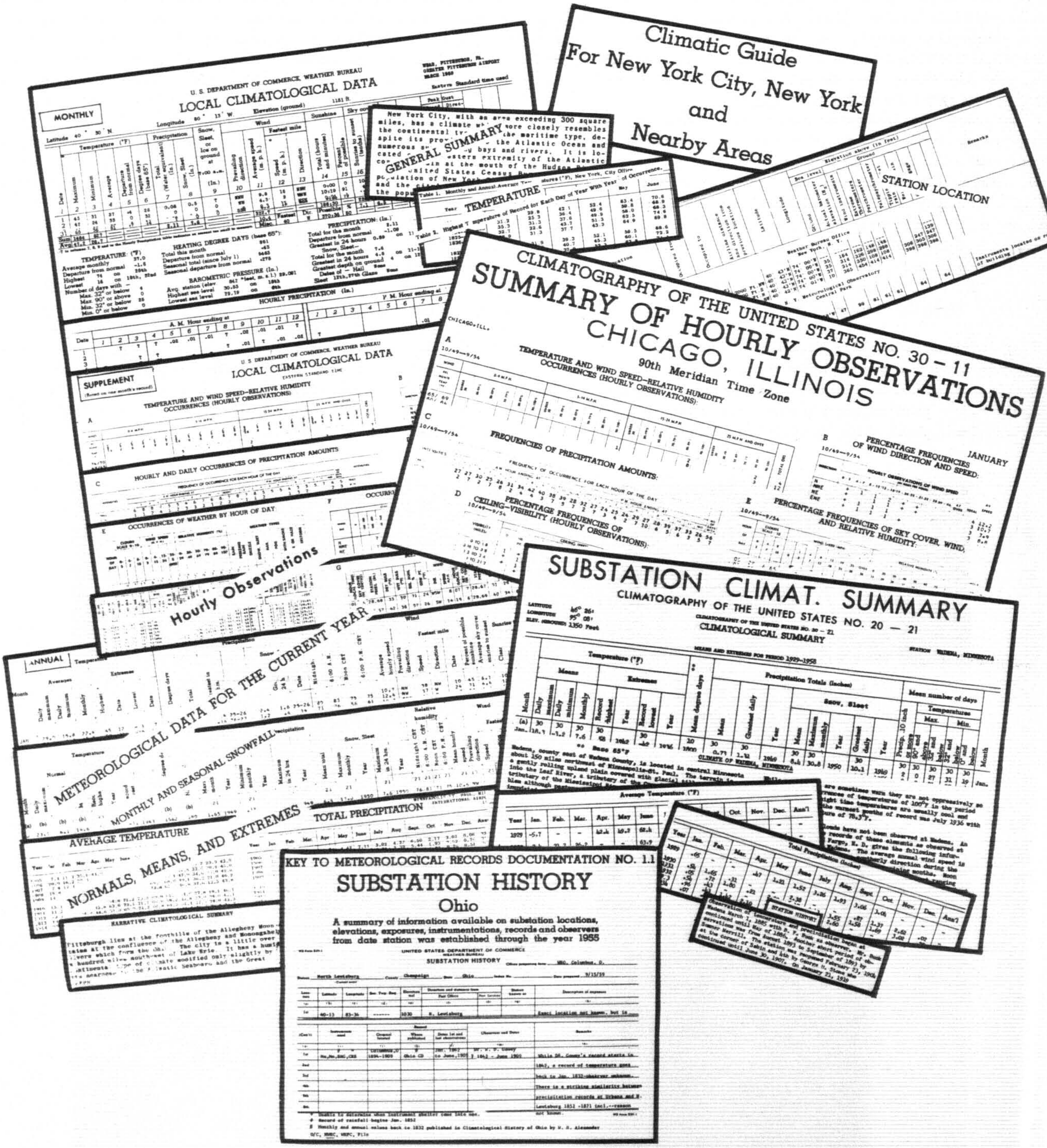


Figure 31.

STATE SUMMARIES

CD Monthly and Annual Bulletin W, Hourly Precipitation

Figure 32.

NATIONAL SUMMARIES

CD Monthly and Annual

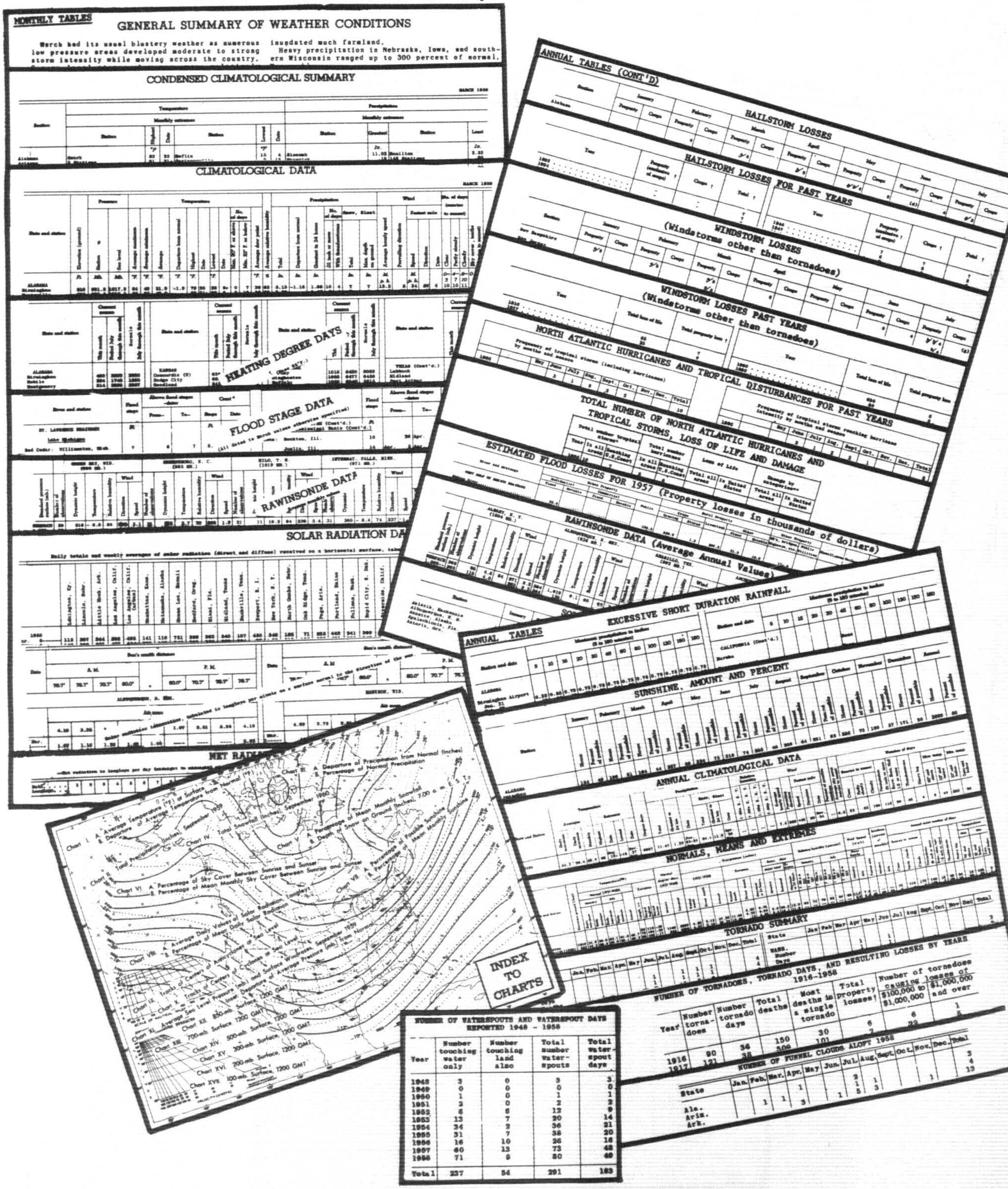


Figure 33.

NATIONAL SUMMARIES

Storm Data, Hurricane Packages

Figure 34.

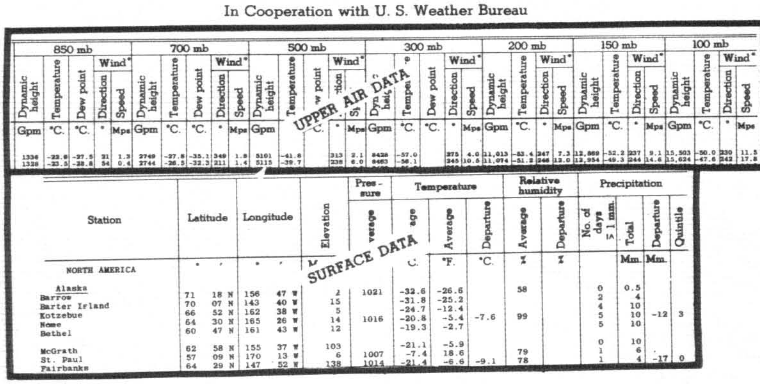
CLIMATIC DATA FOR THE WORLD

MONTHLY CLIMATIC DATA

Sponsored by

World Meteorological Organization

In Cooperation with U. S. Weather Bureau



Station	Latitude		Longitude		Elevation	Pressure Average	Temperature Average	Temperature Average	Temperature Departure	Relative humidity Average	Relative humidity Departure	Precipitation No. of days ≥ 1 mm.	Precipitation Total	Precipitation Departure	Precipitation Quintile
	°	′	°	′	M		°C.	°F.	°C.	%	%		Mm.	Mm.	
NORTH AMERICA															
Alaska															
Barrow	71	18 N	156	47 W	2	1021	-32.6	-26.6		58		0	0.5		
Barter Irland	70	07 N	143	40 W	15		-31.8	-25.2				2	4		
Kotzebue	66	52 N	162	38 W	5		-24.7	-12.4				4	10		
Nome	64	30 N	165	26 W	14	1016	-20.8	-5.4	-7.6	99		5	10	-12	3
Bethel	60	47 N	161	43 W	12		-19.3	-2.7				5	10		
McGrath	62	58 N	155	37 W	103		-21.1	-5.9				0	10		
St. Paul	57	09 N	170	13 W	6	1007	-7.4	18.6		79		1	6		
Fairbanks	64	29 N	147	52 W	138	1014	-21.4	-6.6	-9.1	78		1	4	-17	0

Daily Series, SYNOPTIC WEATHER MAPS, Part II

Northern Hemisphere Data Tabulations

DAILY BULLETIN

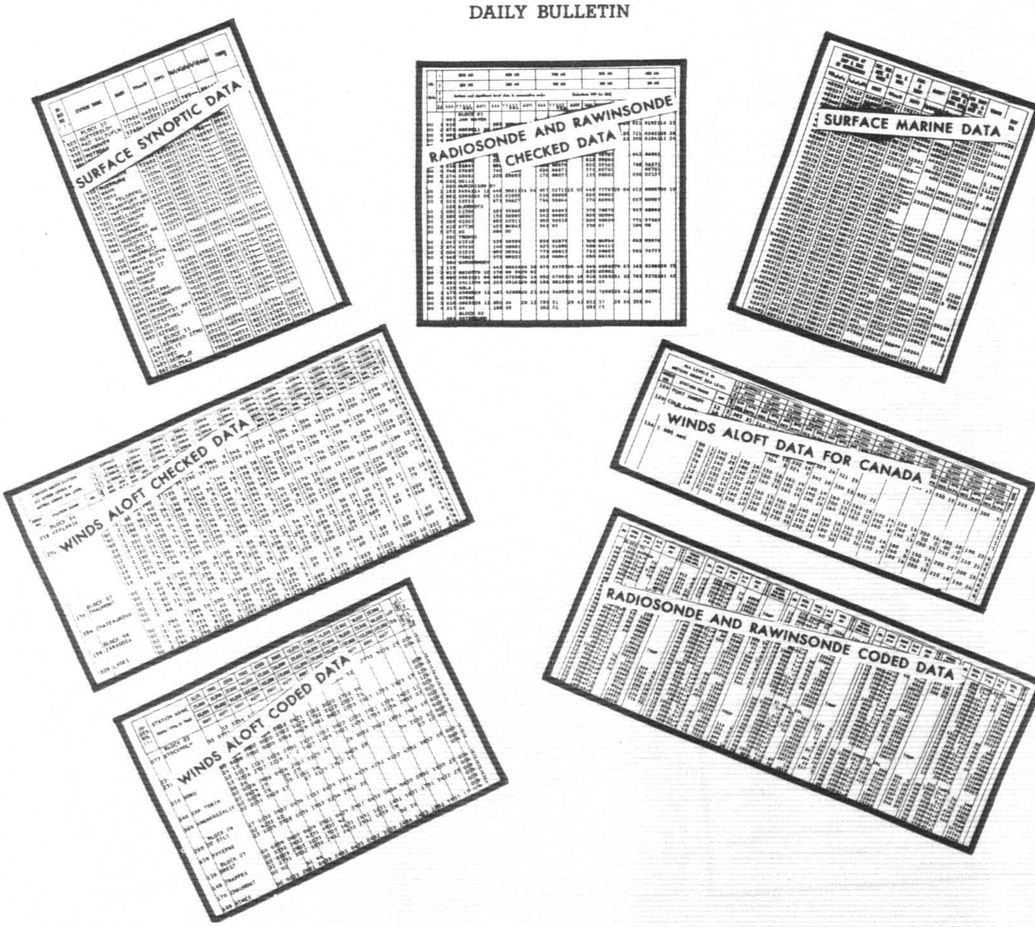


Figure 35.

U. S. NAVY SUMMARIES

INVENTORY OF
UNPUBLISHED CLIMATOLOGICAL TABULATIONS

Figure 36.

U. S. AIR FORCE SUMMARIES

INVENTORY OF UNPUBLISHED CLIMATOLOGICAL TABULATIONS

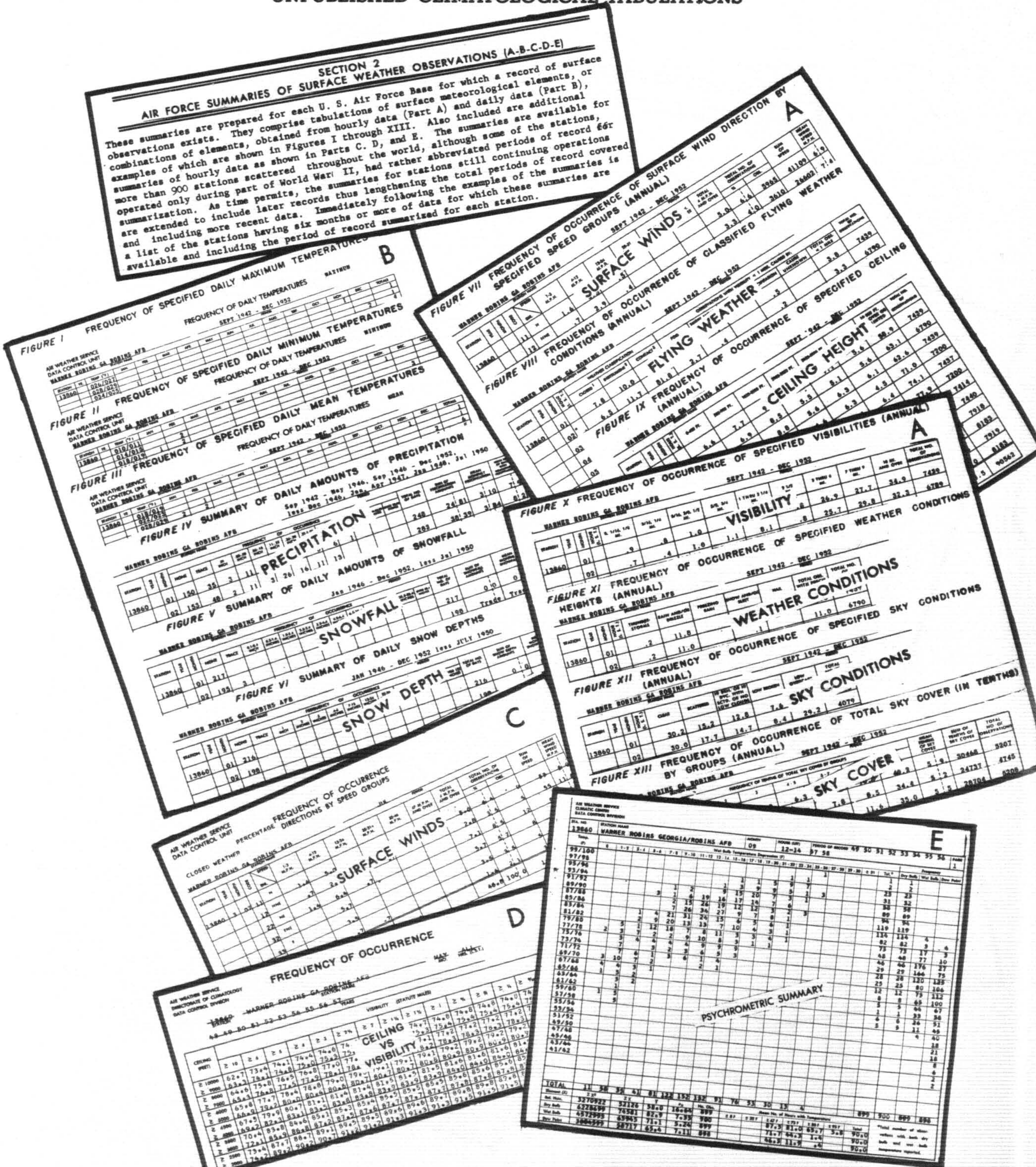


Figure 37.

INTERNATIONAL GEOPHYSICAL YEAR

Meteorological Observations

Figure 38.

572771 O - 60 - 4

3.6 DIRECT OBSERVATIONS

Meteorological observations are predominantly measurements utilizing scientific instruments but some elements, such as cloud type or precipitation type, must be recorded from visual observation. In certain circumstances, such as aboard ships at sea, a few elements must be estimated that are normally measured by instruments at "first-order" land stations.

Upper air (aerological) observations are entirely instrumental measurements, with the sensing devices usually carried aloft by a balloon, though rockets also serve as vehicles for meteorological instruments. Routine upper wind measurements are realized through the tracking from the ground of a balloon which is likely to have a radar-wave-reflecting target attached. Averages computed over small increments of time and altitude are used to construct the routine upper wind record. This practice is followed to minimize instantaneous fluctuations.

Advances in electronics now permit the introduction of a new type of observation -- the pictorial representation of cloud systems. Photographs of radarscopes and photographs made from orbiting satellites comprise a new pair of climatological records which have already served as valuable research tools.

Surface observations are typically "point" observations of a number of weather elements made at hourly intervals over a period of a few minutes. An element such as sky cover or cloud amount may be considered to be an "areal" element but it is observed from an established ground location. Surface observations are beneficial to climatology in direct proportion to the number of years for which they continue without relocation of instrument sites and changes of nearby environment.

Routine weather observations, which contribute the bulk of climatology's raw material, are not instantaneous observations. Observations limited to a few seconds are generally taken for special purposes such as investigations of microclimate.

Some surface elements are measured in a cumulative manner. Precipitation amount for a 24-hour period is an outstanding example. Precipitation totals also are derived for shorter periods -- as little as one hour in routine climatological work.

Most commonly observed elements such as pressure and temperature are described by single quantities having one unit of measurement each. However, wind has both direction and speed. In mathematics and statistics such a quantity is called a vector, which is described in the next chapter.

3.7 DERIVED OBSERVATIONS

In addition to direct observations, a number of derived quantities are treated as fundamental meteorological measurements as defined below.

a) Density,

$$\rho = 0.3486 \left(\frac{p - 0.377e}{T}\right)$$

where T = temperature in degrees Kelvin (°K)
p = pressure in millibars (mb)
e = vapor pressure in mb

b) Moisture elements:

vapor pressure in mb,

$$e = e_w - A(t_d - t_w)\frac{p}{1000}$$

where A is the so-called psychrometric ventilation constant (different for water and ice), t_d is the dry bulb temperature, t_w the wet bulb temperature in degrees Celsius or Centigrade (°C), and e_w the saturation vapor pressure in mb for wet bulb temperature.

saturation vapor pressure in mb,

$$e_s = \exp\left(1.8091 + \frac{17.269425t}{237.3 + t}\right) \quad \text{(Tetens)}$$

where exp denotes the exponential and t is measured in °C.

specific humidity,

$$q = 0.622\frac{e}{p}$$

mixing ratio,

$$r = \frac{m_v}{m_a}$$

where m_v is the mass of water vapor and m_a is mass of dry air with which the water vapor is associated.

absolute humidity,

$$d_v = \frac{m_v}{V}$$

where V is volume occupied by the mixture.

relative humidity,

$$U = \frac{r}{r_w} \times 100$$

where r is the mixing ratio at pressure p and temperature T and r_w is the saturation mixing ratio at same p and T levels.

c) Difference elements:

<u>thickness in meters (m) between two levels,</u>

$$\Delta z = 14.635(T'_1 + T'_2) \ln \frac{p_1}{p_2}$$

where T_1' and T'_2 are virtual temperatures of the lower and upper levels, respectively,

$T' = T\left[\frac{1 + r/E}{1 + r}\right]$, E is the ratio of molecular weight of vapor to dry air (usually 0.622), and ln signifies the natural logarithm.

<u>lapse rate,</u>

$$\gamma = \frac{T_1 - T_2}{z_2 - z_1} \cdot 10^3$$

gives the temperature decrease with height per kilometer. Air temperatures T_1 and T_2 are measured at heights z_1 and z_2, in m, respectively.

d) Heating and cooling requirements:

<u>heating degree days,</u>

$$D = 65 - \frac{(t_x + t_n)}{2}$$

where only positive differences are considered and t_x and t_n are daily maximum and minimum air temperatures in degrees Fahrenheit (°F), respectively.

<u>temperature-humidity index,</u>

$$T.H.I. = 0.4(t_d + t_w) + 15$$

where t_d = dry bulb temperature and t_w = wet bulb temperature in °F.

e) Refractive index:

in two of its various forms,

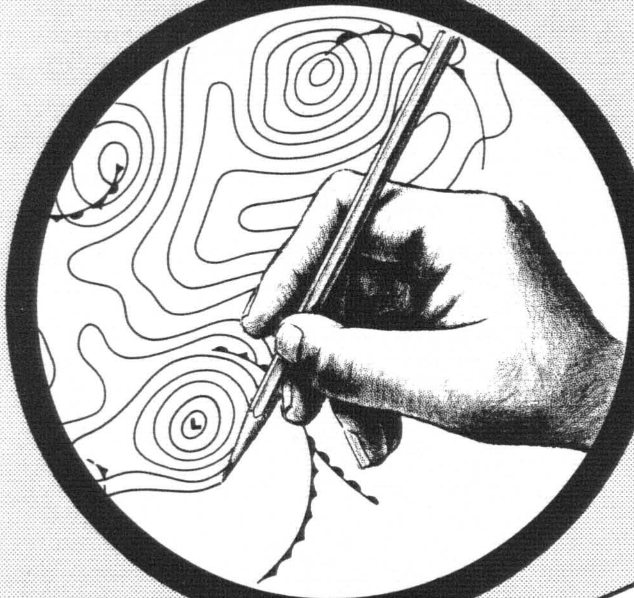
$$N = \frac{77.6}{T}\left[p + \frac{4810\ e_s\ U}{T}\right]$$

or

$$\beta = \frac{79.0}{T}\left[p + \frac{4800\ e_s\ U}{T}\right] + .012h$$

where h is height in feet above ground.

Variations in the above definitions occur and copies of previous tabulations or requests for current work should specify the exact relationships used or desired. Adhering to the above will reduce ambiguity in future tabulations.

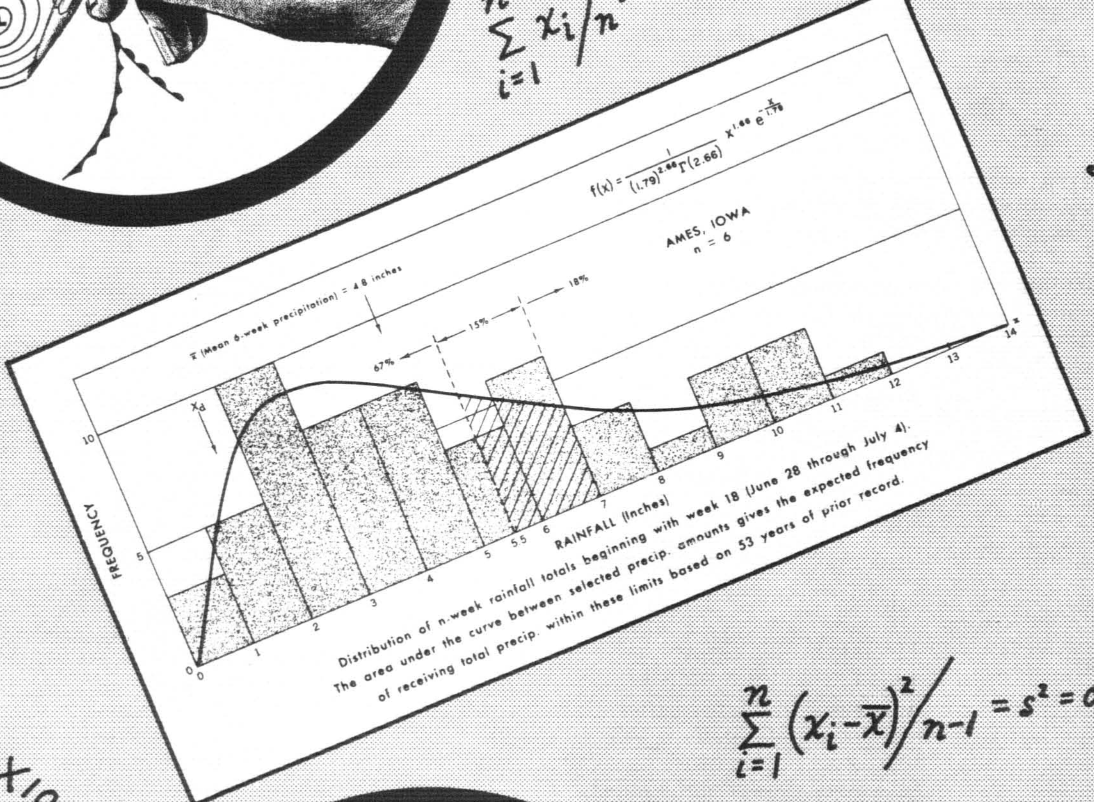


Pearson

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$$

$$\sum_{i=1}^{n} x_i / n = \bar{x} = \hat{\mu}$$

$$\chi^2$$



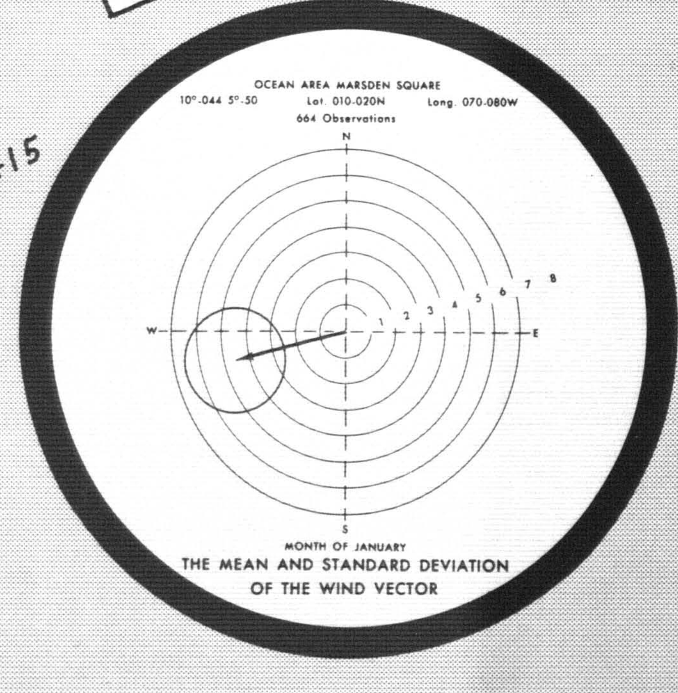
$$U = \frac{r}{r_w} \times 100$$

$$\sum_{i=1}^{n} (x_i - \bar{x})^2 / n-1 = s^2 = \hat{\sigma}^2$$

$$THI = 0.4(t_d + t_w) + 15$$

Student

Gauss



Chapter 4

METHODS

Summary, Graphical, and Statistical

4.0 ANALYTICAL METHODS

Climatological analysis uses principles and techniques of meteorological, numerical, and statistical analysis. Previously formulated techniques are applied wherever possible but quite often unique methods must be devised to meet unusual problems and special data characteristics. Adaptations of methods from both meteorological and numerical analysis are applied to both raw and summarized data.

Analytical treatments of individual observations regularly include the following:

a) Conventional meteorological (isopleth) analysis of historical synoptic daily weather maps.
b) Interpolation of missing observations.
c) Extrapolation of incomplete upper air soundings.
d) Non-routine verification of observations of questionable accuracy.
e) Interpretation of observations incompletely identified, annotated, or documented.
f) Establishment of methods for proper combining of similar observations coded differently.
g) Interpretation of portions of codes that are ambiguous (to a computing machine).

Analytical treatments of summarized observations include:

a) Isopleth analysis for climatic maps.
b) Graphical analysis of frequency distributions, scattergrams, etc.
c) Interpolation to fill gaps in summarized observations. (Monthly averages, etc.)
d) Nomogram preparation. (Code and climatological units, conversions, verification guides, etc.)
e) Verification of tabular and graphical summaries.
f) Ratio and differential analysis for reduction of "single" station data from changing sites to a common or single location.
g) Selection of stations or areas representative of larger regions.

A weather system project (433-L) initiated to provide selected elements (sea level pressure from surface charts and height and temperature from constant pressure charts) at grid-points over the Northern Hemisphere resulted in supplemental extrapolation to extend the conventional isopleth analysis and thus serve as a basis for a statistical approach to forecasting.

Due to the sparsity or total lack of data over vast areas of the Northern Hemisphere, particularly in the low latitude where objective procedures are needed most, analysts were required to supply non-existent analysis in order that interpolation could be effected; continuity, level to level relationships, supplementary historical charts, and other tools were combined with individual analytical experience to accomplish this job. Although limited in use, data thus obtained supply a real need in "blank" peripheral areas. These pressure, temperature, and height values were punched on cards and then converted to magnetic tape for use in designing and verifying weather forecasting methods.

The task of selecting stations representative of larger regions often arises when time is short or funds are limited. To be effective in these circumstances, the basis for selection and companion regionalization must be limited generally to one or two weather elements and oriented toward a specifically defined problem at hand. Often stations must be initially eliminated from consideration through detailed survey of records available for their completeness, consistency, homogeneity, and conformity to established observing practices. In such problems, the quality or rigor of results usually varies directly with the amount of time allowed for survey analysis and selection but with a maximum fixed by the inherent quality of the data. There are many interesting and ingenious variations of the methods cited above but space does not permit full description. Statistical methods will be treated in greater detail, however.

4.1 CLIMATOLOGICAL STATISTICS

Statistical principles and techniques are presently applicable to some of the analytical treatments cited above. As research and development work continues, statistical methods will be adapted more and more to problems in climatology. In fact, greater understanding of the consistencies and variations in the atmosphere is dependent largely upon more accurate observations, more precise documentation of the observations, and further developments in the field of statistics. Most standard statistical methods and their theoretical bases, explained fully in many textbooks [24, 43, 50, et al], are merely mentioned in this chapter. Methods of specific climatological use are discussed in somewhat greater detail, including selected examples.

4.2 CLIMATOLOGICAL SERIES

The methods of statistical analysis apply to climatological data because, to a large extent, if these data are properly taken, sequences of such data behave like random variables. Since statistical analysis only applies to samples from populations of data the sequences of climatological data must be defined so as to be samples from populations. To accomplish this we define a climatological series as a sample series of data consisting of one climatological value each year of the record being considered. Thus the thirty January average temperatures for a thirty year record form a climatological series. The 30 January-1st precipitation amounts form a climatological series. The 90 February, March, and April monthly precipitation amounts do not form a climatological series but are samples through different populations and are therefore different climatological series, hence they must be dealt with as three separate series. The series of 3720 hourly temperatures for a five year record during March does not form a climatological series because there are 24 x 31 different populations and hence really 744 different climatological series are involved. Under certain circumstances such populations can be mixed together, as were the February, March, and April series above, but the individual climatological series and populations must be first defined so that the exact meaning of the mixture of populations is defined in advance of statistical analysis.

Climatological series variables may be either discrete or continuous. Discrete series variables are usually counted values such as the number of days with precipitation greater than 0.10 inch for each of 30 June's or the number of times the visibility is less than 1 mile, during each of 30 July's. Continuous series variables are usually measured values such as temperature and precipitation, e.g., the series of 30 totals of spring precipitation (each the total of March, April, and May).

A climatological series is never more than a sample from a single population assumed to behave as if it were infinite in extent and having the climatic properties such that the observed climatological series is a random sample from that infinite population, i. e., a sample drawn in a manner independent of the individual magnitudes of the members of the infinite population.

4.2.1 THE FREQUENCY DISTRIBUTION

The frequency distribution is the basic tool for describing and analyzing the population. This is accomplished by estimating the characteristics of the population frequency distribution from the sample or climatological series as tallied in class intervals which are divisions of the range of the climatological variable. The number of class intervals is best taken to be between 10 and 20. This divides the difference between the largest and smallest value or range of the climatological series into from 10 to 20 equal divisions. The procedure for division into class intervals is best illustrated by the following example for August precipitation amounts (in mm) for Geneva, Switzerland: The 30-year record for 1927-56 given in the following table is used.

Table 3. August Precipitation (mm), Geneva, Switzerland

Year	p	Year	p	Year	p
1927	250	1937	78	1947	54
28	147	38	79	48	72
29	83	39	85	49	49
30	108	40	18	50	110
31	171	41	105	51	100
1932	62	1942	48	1952	125
33	67	43	41	53	57
34	119	44	44	54	206
35	157	45	133	55	107
36	23	46	158	56	144

To find a class interval for this climatological series we follow our rule: The highest value is 250 mm and the lowest 18 mm. This gives a range of 232 mm. Since 20 mm is a convenient division and gives 13 divisions, this is a suitable class interval. Tallying these by classes we obtain the following table of precipitation p and frequency f:

Table 4. Frequency Distribution of August Precipitation (mm), Geneva, Switzerland

p	f	p	f
0-19	1	100-119	6
20-39	1	120-139	2
40-59	6	140-159	4
60-79	5	160-179	1
80-99	2	180-199	0
		200-219	1
		220-239	0
		240-259	1

If these frequencies are plotted as blocks proportional to f on the scale of precipitation, the histogram of precipitation for Geneva is obtained, as in figure 39. The f's may be divided by 30, the number of years in the climatological series, to obtain the relative frequencies in each class interval. These sample values are estimates of the probabilities in the population of precipitation amounts in the various class intervals.

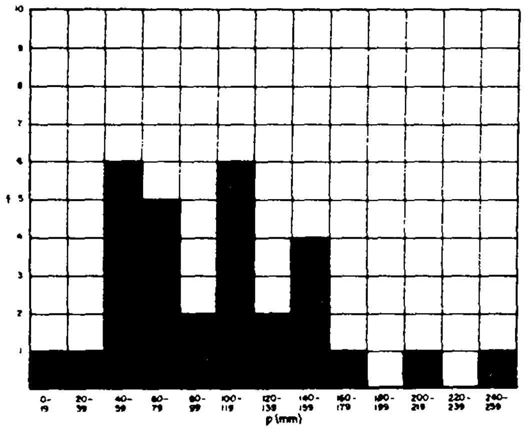


Figure 39. Histogram of August Precipitation (p), Geneva, Switzerland

4.2.2 CUMULATIVE DISTRIBUTION

Usually the climatologist is more interested in estimates of probabilities over several class intervals which are more conveniently obtained from the cumulative distribution. Also, the cumulative distribution provides better estimates of the probabilities since the arbitrary division into class intervals, as in table 4, tends to waste some of the information on the population given by the climatological series.

To obtain the cumulative distribution the data are first put in order as in the following table:

Table 5. Cumulative Distribution of August Precipitation (mm), Geneva, Switzerland

m	p	F	m	p	F	m	p	F
1	18	.032	11	72	.355	21	119	.677
2	23	.065	12	78	.387	22	125	.710
3	41	.097	13	79	.419	23	133	.742
4	44	.129	14	83	.452	24	144	.774
5	48	.161	15	85	.484	25	147	.806
6	49	.194	16	100	.516	26	157	.839
7	54	.226	17	105	.548	27	158	.871
8	57	.258	18	107	.581	28	171	.903
9	62	.290	19	108	.613	29	206	.935
10	67	.323	20	110	.645	30	250	.968

The F's are the cumulative relative frequencies or estimates of the cumulative population probabilities and are obtained by the formula $F = m/(n+1)$ where m is the mth value in order of magnitude of the climatological series and n is the number of terms in the climatological series, in this case 30. The division by $(n+1)$ instead of n gives a better estimate of population probabilities, especially at the ends of the distribution. It can be shown that $m/(n+1)$ gives the best simple estimate of the probabilities.

The F's give the probabilities that precipitation is less than any value shown in the table. For example, the probability that p is less than 62 mm is 0. 290 and greater than 62 mm is 1 - F = 0. 710. Note that when probabilities are estimated for a continuous random variable such as precipitation, it is a misunderstanding of sampling principles to use the wording "equaled or exceeded" or "less than or equal to", for the probability of any exact value occurring is zero. The probability that it is between 62 and 125 mm is 0. 710 - 0. 290 = 0. 420. Thus the cumulative distribution gives all the information available from histograms, and much in addition, since it uses every value of the climatological series individually to obtain the probability estimates. The sample cumulative distribution may also be put in graphical form by plotting F on the ordinate against p on the abscissa and connecting the points by straight lines, as in figure 40. Climatological series with discrete variables may also be treated in a similar manner.

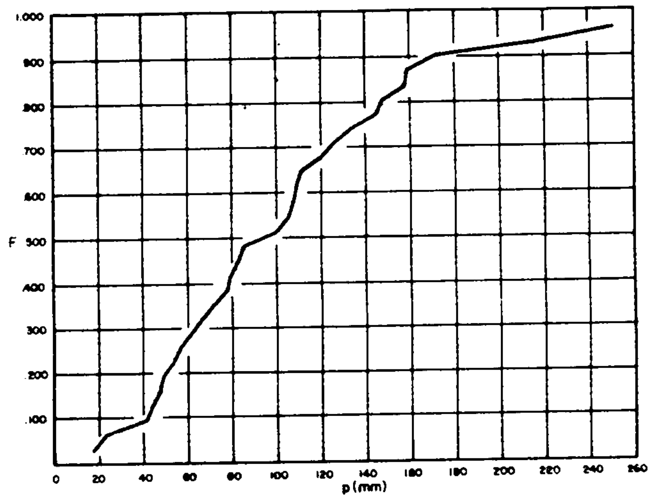


Figure 40. Cumulative Distribution of August Precipitation (p), Geneva, Switzerland

The average temperatures (°C) for August for Geneva shown in table 6, may be analyzed in a similar fashion as another example. The series has been arranged in order of magnitude in table 6.

Table 6. Average August Temperature (°C), Geneva, Switzerland

m	t	F	m	t	F	m	t	F
1	16.9	.032	11	18.6	.355	21	19.8	.677
2	17.4	.065	12	18.7	.387	22	19.9	.710
3	17.5	.097	13	18.7	.419	23	20.3	.742
4	17.8	.129	14	18.9	.452	24	20.4	.774
5	17.9	.161	15	18.9	.484	25	20.7	.806
6	17.9	.194	16	19.2	.516	26	20.8	.839
7	18.1	.226	17	19.3	.548	27	20.9	.871
8	18.3	.258	18	19.5	.581	28	20.9	.903
9	18.5	.290	19	19.5	.613	29	22.0	.935
10	18.6	.323	20	19.7	.645	30	22.9	.968

Note that since the record length is the same, the F's are the same as in the previous table, and hence have the same interpretation as previously. The estimated probability that the average temperature for August at Geneva is less than 20. 3°C is 0. 742 and that it is greater than 20. 3 is 1 - 0. 742 = 0. 258. The mean recurrence interval or return period (i. e. the average time between occurrences) for values exceeding any value t is 1/(1 - F). Hence for temperatures exceeding 20. 3° the mean recurrence interval is 1/0. 258 or about 4 years.

4. 2. 3 HOMOGENEITY OF DATA SERIES

A data series is said to be homogeneous if it is a sample from a single population. Hence by definition a climatological series is homogeneous and elementary probability analysis must be applied only to climatological series. The previous temperature and precipitation series were, of course, analyzed on the assumption of homogeneity. If a series is not homogeneous, adjustments must be made so that statistical estimates will be valid estimates of the population parameters applying to the last terms in the series or such that they are estimates obtained from a hypothetical homogeneous series including the latest data as elements.

In cases where instrument exposures have changed it is necessary to make a statistical test to insure homogeneity. Many of the older methods of testing for homogeneity were incomplete in the sense that they provided inadequate criteria for accepting or rejecting the hypothesis of homogeneity. The valid test of homogeneity is a statistical test of hypothesis which provides an hypothesis of homogeneity (null hypothesis) and a rule for accepting or rejecting this hypothesis on the basis of probability of occurrence. Thus if the probability of the evidence for homogeneity is small, it is concluded that the series is heterogeneous; if it is large, the decision is for homogeneity. The rule specifies the probability limit (significance limit) beyond which the hypothesis of homogeneity would be rejected and some alternative to homogeneity accepted. In most instances distributions on the null hypothesis and the alternatives to homogeneity are difficult to specify, hence the so-called non-parametric tests ordinarily must be used.

The alternatives to homogeneity in a series of meteorological data are usually slippage of the mean, trend, or some form of oscillation. Since these alternatives, especially the latter, may be difficult to specify exactly, it is best to use a non-parametric test which does not require exact specification of these alternatives or the null distribution. A well-known non-parametric test which is sensitive to all of these alternatives is the run test provided by Swed and Eisenhart [51]. This test is made by counting the number of runs, u, above and below the median or middle value in a naturally ordered series and testing this by means of a table of the distribution of u. The test is best illustrated by applying it to the Geneva August average temperatures. These are given in their historical order in table 7.

In table 7 it is seen that the median or middle value is between 18. 9 and 19. 2. It may be taken as half way between these two values or 19. 05. Using this value the entries in table 7 may be marked with a B if they are below this value and with an A if above this value. The runs then are marked as sequences of A's and B's. The total number of runs is seen to be u = 15.

Table 7. Runs for Observed Temperature Series (°C), Geneva, Switzerland

1927	17.4	B	1937	19.5	A	1948	18.9	B
1928	20.9	A	1938	18.6	B	1949	20.7	A
			39	18.6	B	50	19.7	A
1929	18.7	B	40	17.9	B	51	19.5	A
30	18.7	B	41	17.8	B	52	20.3	A
31	16.9	B				53	19.8	A
			1942	19.9	A			
1932	20.8	A	43	20.9	A	1954	18.3	B
33	20.4	A	44	22.9	A			
						1955	19.3	A
1934	17.9	B	1945	18.9	B			
35	18.1	B				1956	17.5	B
36	18.5	B	1946	19.2	A			
			47	22.0	A			

It is clear that too many runs would be an indication of oscillation while too few runs would be an indication of a trend or a shift in the median during the sample record. Hence, if the probability of a u being exceeded is small an oscillation would be suspected while if the probability of being less than a sample u is small a trend or shift in median would be suspected. If the probability of being either greater than or less than u is large then neither oscillation nor trend is suspected and the series is said to be homogeneous or from a single population. To make this test a distribution table of u is required. This is given below: Since the median was chosen, the number of values above the median N_A will equal the number of values N_B below the median; hence the table is for $N_A = N_B$.

Table 8. Distribution Table of Number of Runs (u), $N_A = N_B$

N_A	P 0.10	P 0.90	N_A	P 0.10	P 0.90
10	8	13	19	16	23
11	9	14	20	16	25
12	9	16	25	22	30
13	10	17	30	26	36
14	11	18	35	31	41
15	12	19	40	35	47
16	13	20	45	40	52
17	14	21	50	45	57
18	15	22			

Table 8 gives the lower and upper 0.10 significance limits i.e., for probabilities P of 0.10 and 0.90. These 0.10 significance limits are most satisfactory for many meteorological applications, for, because of frequent high variability, it is desirable to increase the significance limit probabilities since this will increase the chances of accepting the alternative hypothesis. Since u is discrete the u values shown in the tables are those corresponding to the probability closest to 0.10 and 0.90. The maximum divergence from exact probability values is +0.03. If a sample u is below the lower limit, heterogeneity is due to trend or mean slippage, if above it is due to oscillation.

It was seen in table 7 that u = 15 for $N_A = N_B = 15$. The upper and lower limits from table 8 for $N_A = 15$ are 12 and 19. u = 15 is within this range; hence u is not significantly different from u's expected from homogeneous series, and the series is concluded to be homogeneous.

In order to further illustrate application of the runs test the series in table 7 has been deliberately made heterogeneous by subtracting 1°C from each of the first 12 years of record and subtracting 0.5°C from each of the next eight years. The heterogeneous series is shown in table 9.

Table 9. Runs for Heterogeneous Temperature Series (°C), Geneva, Switzerland

1927	16.4	1942	19.4
		43	20.4
1928	19.9	44	22.4
1929	17.7	1945	18.4
30	17.7		
31	15.9	1946	18.7
		47	22.0
1932	19.8	48	18.9
33	19.4	49	20.7
		50	19.7
1934	16.9	51	19.5
35	17.1	52	20.3
36	17.5	53	19.8
37	18.5		
38	17.6	1954	18.3
39	18.1		
40	17.4	1955	19.3
41	17.3		
		1956	17.5

The number of runs is reduced to 11 by the two shifts of the mean which in effect produce a kind of trend. Referring to table 8 at $N_A = 15$ it is seen that the probability of less than 12 runs is 0.10, and since table 9 has only 11 runs, the heterogeneity was found by the test. Of course, it was already known that the heterogeneity was there because it was introduced deliberately. It will naturally be suspected, and correctly so, from this example that the ability of such tests to find heterogeneities when the exact alternatives to homogeneity are not known will not be very good. This brings out the very important point that the best way to determine heterogeneities is to determine their cause in the history of the record. If the history of a record shows changes which could cause heterogeneities and which can be described according to period and character, more powerful parametric tests such as "Student's" t-test may be employed to determine the significance of the heterogeneities. Such tests, however, may only be employed where the periods and character of the heterogeneities are known a priori.

4.2.4 ADJUSTMENT OF CLIMATOLOGICAL MEANS

Heterogeneity in climatological data series is usually due to some disturbing factor such as change in station location or change in exposure. Although in the past attempts have been made to homogenize series having such disturbances, it must be made very clear that it is not possible to homogenize a series in the sense that a new series of individual values is derived with the same properties as a sample from the proper hypothetical population. In other terms if the data from a particular station are unavailable for a particular period of record, it is impossible to reproduce the individual items of the series for that period. The reason for this is that any adjustment disturbs the variability of the series and hence changes the scale or dispersion of the frequency distribution. It is possible, however, to adjust certain statistics of the series so that these adjusted values are, in effect, like those estimated from samples taken from the proper hypothetical population. The most common application of such adjustments is to the means of data series for the purpose of obtaining normals. It is recommended that such adjustments be made if possible only on the basis of a priori known heterogeneities.

It may be shown by theoretical analysis that the classical difference and ratio methods are close to optimum for the adjustment of temperature and precipitation means. Such adjustments are often made to compensate for missing record and to remove heterogeneities. The difference method employs the difference between temperature means of two concurrent homogeneous series as an additive factor on the available series mean. The ratio method employs the ratio of precipitation totals or means of two concurrent homogeneous series as a multiplying factor on the available series total or mean. The adjustments are best illustrated by examples.

The method involves using a supplementary station with a concurrent homogeneous record. This station should be as close as possible to the station to be adjusted as the effectiveness of the adjustment depends on the correlations between the two stations. Usually a station less than 50 miles from the station to be adjusted and in the same climatic regime will serve the purpose. Several supplementary stations may be averaged and used as the supplementary record, but this usually does not increase the correlation greatly. If a supplementary station does not have a complete record, the adjustment may have to proceed by stages using a different supplementary station for each period of record.

4.2.4.1 THE DIFFERENCE METHOD

In table 9 deliberate heterogeneity was introduced into the average temperature record by subtracting 1.0°C from each of the first 12 years, 0.5°C from the next 8 years, and leaving the last 10 years unchanged. It is now assumed that during each of the first two periods the station was moved or the exposure of instruments changed, and that it is desired to adjust the 30-year mean to the exposure during the last 10 years. This is a typical adjustment problem. Other arrangements of the heterogeneities in a record are easily taken into account by a simple variation in the adjustment procedure.

To adjust the means of temperature and precipitation of the Geneva record, given the dates of heterogeneous periods, and therefore also the dates of homogeneous periods, it has been found convenient to use Lausanne as the supplementary station. It is not presumed that Lausanne is the best supplementary station. It is only used because it serves the purpose at hand well to illustrate the adjustment of a known heterogeneity. The adjustment formula for temperature is

$$\bar{y} = a + \bar{x} \qquad (1)$$

Here $\bar{x}$ is the mean for the homogeneous period at the supplementary station corresponding to the heterogeneous period at the station whose record is being adjusted, and $\bar{y}$ is the adjusted mean. The adjustment constant a is estimated by the equation

$$a = \bar{v} - \bar{u} \qquad (2)$$

Here $\bar{u}$ and $\bar{v}$ are the means from concurrent periods of homogeneous record at the supplementary station and station being adjusted, respectively. The process of adjustment for temperature then consists of estimating a, using concurrent homogeneous records at the supplementary station and the station to be adjusted, and substituting this value in turn in equation (1) to obtain the adjusted mean $\bar{y}$. The $\bar{y}$'s for the various parts of the 30-year record are then weighted according to length of period in years and averaged to obtain the adjusted 30 year record.

The means for each period were obtained from table 9 which is artificially heterogeneous. These are shown in table 10.

Table 10. Mean Temperature Adjustment (°C), for Geneva, Switzerland

	Lausanne $\bar{x}$	Geneva-Unadjusted Means	Geneva $\bar{y}$
1927-38	17.9	(17.9)	19.3★
1939-46	18.4	(19.0)	19.8★
1947-56	18.2	19.6	19.6
		Adjusted Record Mean	19.5★

Substituting the homogeneous values for $\bar{u}$ and $\bar{v}$ in equation (2) gives an estimate of the adjustment factor a = 19.6 - 18.2 = 1.4. Inserting this in equation (1) and substituting successively the homogeneous values 17.9 and 18.4 gives the adjusted values $\bar{y}$ = 17.9 + 1.4 = 19.3★ and $\bar{y}$ = 18.4 + 1.4 = 19.8★. Next multiplying the values $\bar{y}$ by 12, 8, and 10, their respective lengths of record, summing these and dividing by 30 gives the weighted mean 19.5★. This is the estimated adjusted mean of August average temperature for Geneva. Note that this compares favorably to the actual value for the undisturbed record 19.3. The procedure provides the best estimate of the hypothetical mean for the 1927-56 record at Geneva based on the homogeneous period 1947-56.

4.2.4.2 THE RATIO METHOD

In order to illustrate the application of the ratio method of adjustment which must be used for precipitation, the Geneva precipitation record for 1927-56 was made heterogeneous as follows: The record was subjected to a scale change by multiplying the precipitation for each of the first 12 years by 1.20 and each of the ensuing 8 years by 0.90, the last 10 years being left undisturbed. The resulting heterogeneous series is shown in table 11.

Before proceeding with the adjustment it is easy to test the homogeneity of the series to provide a further illustration of the use of the run test. Of course, this test is really unnecessary, for the heterogeneities are known a priori. In this instance the median may be readily found, by ordering the data, to be 97.5 mm. The runs of values above and below the median may be marked as shown in table 7. This is seen to give the number of runs

Table 11. Heterogeneous August Precipitation Series (mm), for Geneva, Switzerland

1927	300	1936	28	1947	54
28	176	37	94	48	72
29	100	38	95	49	49
30	130	39	77		
31	205	40	16	1950	110
		41	95	51	100
1932	74	42	43	52	125
33	80	43	37		
		44	40	1953	57
1934	143				
35	188	1945	120	1954	206
		46	142	55	107
				56	144

$u = 9$. Since $N_A = N_B = 15$ as with table 7, the upper and lower significance limits 12 and 19 are the same as previously. The value 9 lies outside of this range; hence the series is not homogeneous. As would be expected u has been made too small by slippage of the mean values for the periods 1927-38 and 1939-46.

Since heterogeneities in precipitation series are scale changes in the frequency distribution, it is proper to adjust for heterogeneities by scale adjustment, i.e., by using the ratio of homogeneous totals. This is seen to be equivalent to adjusting by the ratio of homogeneous means.

By this principle, if y is the precipitation for one unit of the year on the station to be adjusted, and x is the corresponding value for the supplementary station, then

$$\Sigma y = b \, \Sigma x \qquad (3)$$

where the summations are over a period heterogeneous at the station to be adjusted. Thus the estimated total precipitation on a unit of the year for a period of record is equal to the total for the same unit and period at the supplementary station times the adjustment constant b. The adjustment constant b is estimated by the equation

$$b = \frac{\Sigma v}{\Sigma u} \qquad (4)$$

where Σv is the sum of precipitation over the homogeneous period at the station to be adjusted and Σu is the sum for the corresponding period at the supplementary station. This, of course, should be the latest period of record for active stations since it is desired to adjust to a population from which observed values at the active station location will be obtained. The process of adjustment consists in estimating b for a homogeneous period by means of equation (4) and applying equation (3) with this statistic to the heterogeneous periods. The results are shown in table 12.

Table 12. Mean August Precipitation Adjustment (mm), for Geneva, Switzerland

Lausanne	Σx	Geneva Unadjusted Totals	Geneva Σy
1927-38	1602	(1613)	1295★
1939-46	753	(570)	609★
1947-56	1267	1024	1024
		Adjusted Record Mean	97.6

Substituting the values of Σx and Σy from table 12 for the homogeneous period 1947-1956 for Σu and Σv in equation (4) gives $b = 1024/1267 = 0.8082$. Inserting this value for b in equation (3) and successively substituting the homogeneous totals 1602 and 753 gives $\Sigma y = 0.8082 \times 1602 = 1295$★ and $\Sigma y = 0.8082 \times 753 = 609$★ the adjusted values. Finally applying linear weighting and averaging, as in the example for temperature, yields

$$\bar{y} = (1295 + 609 + 1024)/30 = 97.6 \text{ mm} .$$

This is a near optimum estimate of the mean total precipitation for August at Geneva.

4.2.5 ASSESSING HOMOGENEITY IN THE ABSENCE OF ADEQUATE A PRIORI KNOWLEDGE

With most older climatological records station history is, at best, limited. Since these records are of prime interest, Mitchell [42] has proposed a scheme whereby a selected station record is compared with those from surrounding satellite stations. The Weather Bureau is designating several stations most free from radical changes in location, environment, exposure, and observational procedure to be included in a Climatological Bench Mark (CBM) Network. Tentative station selections for this network thus far number 28 in the contiguous U. S., one in Hawaii and one in Puerto Rico. Final approval of these stations, shown in figure 41 for the U. S., is predicated on a homogeneity analysis of their records in order to verify their quality insofar as possible.

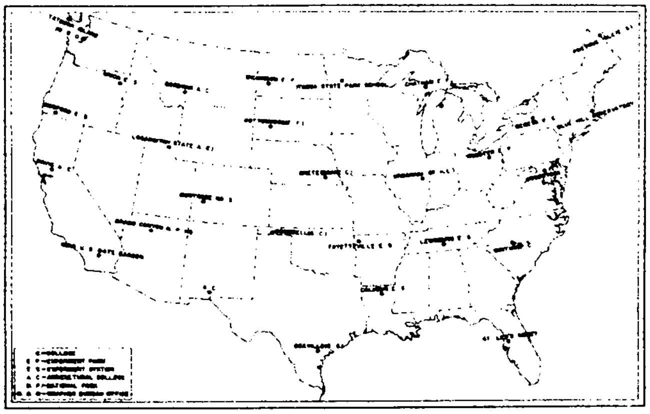


Figure 41. Tentative Climatological Bench Mark Station Network

Mitchell's procedure is applied to monthly average temperatures, separately for each calendar month, from the present time back to the earliest year of available observations. Along with the monthly average temperatures for the Bench Mark candidate station, the procedure requires comparable monthly average temperatures at each of a number of surrounding climatological stations for their full periods of record. These satellite stations typically number between 8 and 15, all located within 50 miles of the Bench Mark candidate station.

Monthly average temperature differences between contiguous years, taken separately for each calendar month, are treated as shown in table 13. The example is for the

Table 13. Homogeneity Analysis of January Average Temperatures at Winthrop College, S. C.

Station Name	Number	Year to year differences in January average temperatures, °F: 1945-44	46-45	47-46	48-47	49-48	50-49	51-50	52-51	53-52	54-53	10-year Means
Caroleen, N. C.	311479	0.4	- 1.6			-14.6	- 1.5	10.9	- 6.0	1.4	4.0	
Concord, N. C.	311975	0.0	- 1.6	- 3.8	10.0	-14.3	- 1.8	10.4	- 4.8	0.6	4.1	
Gastonia, N. C.	313356	0.2	- 1.1	- 2.5	9.0	-13.8	- 2.5	10.3	- 5.5	2.0	2.6	
Monroe, 5 SE, N.C.	315771	0.0	- 2.7	- 2.9	9.5	-14.4	- 2.6	10.4	- 5.0	1.3	6.5	
Shelby, N. C.	317845	0.6	- 0.3	- 4.2	9.9	-14.8	- 0.0	10.8	- 6.5	3.0	3.4	
Transou, N. C.	318964	- 2.0	- 1.0							1.8	4.2	
Chester 2 SW, S.C.	381633	0.5	- 2.1	- 2.6	9.2	-14.8	- 1.0	9.0	- 5.4	3.0	2.1	
Heath Springs, S. C.	384063	1.0	- 1.9			-14.8	- 3.2	12.3	- 6.0	0.8	3.8	
Kershaw, S. C.	384690	0.8	- 0.7	- 3.5	8.4	-12.2	- 2.8	10.2	- 4.7	2.4	1.3	
Rainbow Lake, S. C.	387113	- 0.4	- 0.0	- 3.0	10.4	-13.8	- 2.2	10.3	- 7.4	3.7	2.3	
Winnsboro, S. C.	389327		- 3.8	- 0.8	10.6	-15.6			- 6.0	3.1	1.7	
S, Sum of first differences		1.1	-16.8	-23.3	77.0	-143.1	-17.6	94.6	-57.3	23.1	36.0	
DN, No. of first differences		10	11	8	8	10	9	9	10	11	11	
PN, No. of pairs of differences		10	10	8	8	8	9	9	9	10	11	
M=S/DN, mean first difference		0.1	- 1.5	- 2.9	9.6	-14.3	- 2.0	10.5	- 5.7	2.1	3.3	
CM, cumulative mean, base 20		19.1	20.6	23.5	13.9	28.2	30.2	19.7	25.4	23.3	20.0	22.4
UT, unedited tau index		- 3.3	- 1.8	1.1	- 8.5	5.8	7.8	- 2.7	3.0	0.9	- 2.4	
Winthrop College, S.C.	389350	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	
Average monthly temperature		43.2	44.2	47.9	37.6	52.2	53.5	44.1	49.4	46.0	44.4	46.3
CBM, Departure from 10 year mean		- 3.1	- 2.1	1.6	- 8.7	5.9	7.2	- 2.2	3.1	- 0.3	- 1.9	
Charlotte, N. C.	311690											
Average monthly temperature		42.0	43.4	46.8	37.0	51.6	53.6	42.3	47.8	46.7	43.2	45.4
FO, Departure from 10 year mean		- 3.4	- 2.0	1.4	- 8.4	6.2	8.2	- 3.1	2.4	1.3	- 2.2	
		1944-45	45-46	46-47	47-48	48-49	49-50	50-51	51-52	52-53	53-54	
(CBM) - (UT)		0.2	- 0.3	0.5	- 0.2	0.1	- 0.6	0.5	0.1	- 1.2	0.5	
(FO) - (UT)		- 0.1	- 0.2	0.3	0.1	0.4	0.4	- 0.4	- 0.6	0.4	0.2	

month of January for the most recent decade, 1954-1944, in the Winthrop College, S. C., Bench Mark candidate-station area. Under each column of first differences of January temperature, there appear (a) the sum, S; (b) the number of first differences, DN; (c) the number of pairs of first differences, PN, (used in calculating the standard error of the tau index); (d) the mean of the first difference, M; (e) the cumulative mean, CM, figures from right to left and starting arbitrarily with 20°F; and (f) the unedited tau index, UT, which is determined by subtracting the 10-year average CM from each individual CM value. (This particular array yields a tau index in which no first temperature differences have been deleted because of station moves; hence the term "unedited tau". In actual practice a second calculation of tau, not shown, is completed in which all first differences bracketing known station moves are deleted before computation of DN, PN, M, and CM).

The following steps describe the procedure in more detail:

a) Transpose the average monthly temperatures for each satellite station into a series of first temperature differences, i. e., the differences January 1954 to January 1953 (54-53), January 1953 to January 1952 (53-52), etc., reading right to left in the table.

b) Average each column over all stations to form a new, areally averaged, first-difference series, M.

c) Cumulatively add the new first-difference series (working backward from the most recent year) to obtain what may be called a "reconstructed time series" of temperature, CM, expressed as a departure from an arbitrary constant temperature, 20°F under 54-53 in our example. This constant plus 3.3, the M value under 54-53 yields the CM value 23.3 entered under 53-52, and so on.

d) Average the reconstructed time series, CM, in the most recent 10-year interval of data, and subtract this mean (22.4) from each term of the reconstructed time series. This is the ultimate series, known as the "tau index", which is to be compared with the Bench Mark series, in comparable form, derived as follows:

e) Express the series of monthly average (January) temperatures again as a series of departures, CBM, from the average (January) monthly temperatuse in the same 10-year interval of data as in step d).

f) Subtract the tau index in step d) term by term from the CBM series in step e), and test the resulting difference series for trend and other systematic effects by standard statistical methods. This step can be facilitated by forming 10-year moving averages of the Bench Mark and tau index series and plotting them, as in figure 42.

In order to decide whether a given discrepancy between the Bench Mark and the tau-index series is statistically significant, the standard error of the tau index is computed along with the tau index itself. Then, where the Bench Mark series departs systematically from the tau index by more than two standard errors (deviations) of the tau index, the Bench Mark record is held suspect and subjected to further inspection. Especially if similar deviations are found in the series for other adjacent calendar months as well, this fact is taken as evidence of an inhomogeneity in the Bench Mark station record. Then, either the Bench Mark record is adjusted for the inhomogeneity, or, if the extent of the inhomogeneity warrants, the station is dropped as a Bench Mark candidate.

The Charlotte, N. C. "first order" (FO) Weather Bureau Station record is evaluated in the same manner as the CBM station.

The standard error of the tau index is a function of the number of years, y, back to the reference year (in this case, 1954), and in general increases with increasing y. It may be written

$$S.E.(t_y) = \sqrt{\sum_{i=1}^{y} \frac{1}{(DN)_i} - \sum_{i=2}^{y} \frac{(PN)_i}{(DN)_i \, (DN)_{i-1}}} \; S.E.(e),$$

where DN and PN are defined above, and S. E. (e) is the typical standard error of estimate of the difference between two monthly average temperatures at a climatological station. The quantity S. E. (e) is readily computed from the data as listed in table 13, and in practice is assumed constant among all stations in the satellite network in each decade of available record. It averages about 1°F in most Bench Mark areas.

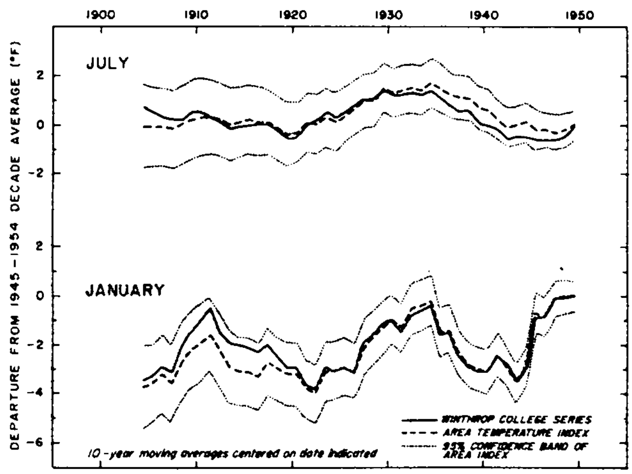


Figure 42. Analysis of Mean Temperatures at Winthrop College, S. C. (Climatological Bench Mark Program)

The above calculations can be graphically summarized, as in figure 42. Here, the Winthrop College Bench Mark series of monthly average January and July temperatures are plotted in comparison with the corresponding tau index series, after each series was converted into 10-year moving averages. The 95% confidence bands of the tau indices appearing in the figure were derived by replotting the tau index series at a distance of twice their own standard error above and below. (The moving average process has little effect on the width of these confidence bands, because successive terms in the tau index have errors that are highly correlated.) In this example, the Bench Mark series is seen to lie everywhere within the 95% confidence bands of the tau index, a fact which attests to the homogeneity of the Bench Mark series.

An identical analysis, in which moving averages are not first taken, can be used to detect large errors in individual monthly average temperatures, rather than to detect persistent inhomogeneities. Moreover, since inhomogeneities such as those due to station moves tend to be similar in different calendar months of the same season, the monthly Bench Mark series and tau-index series can be combined into seasonal series which are considerably more sensitive in revealing such inhomogeneities. The combination of monthly series in this manner is a routine phase of the Bench Mark homogeneity testing program.

In adopting the above method of selecting Bench Mark climatological stations the following characteristics were considered advantageous:

a) There is no necessity to interpolate missing observations, thereby introducing uncertainties into the analysis.
b) The nature, or "shape", of an inhomogeneity is apparent.
c) The supplementary data used to check the homogeneity of the series under test can themselves be purged of the effects of station moves before they are applied in the homogeneity analysis.

Investigations are currently under way to determine optimum tests for monthly and seasonal precipitation records.

4. 3 ESTIMATION OF STATISTICAL PARAMETERS

A statistical parameter is a fixed value which is a function of all of the population values. Thus the mean for a population would be the average of all the values in that population. Since the entire population of values is never known in climatology, it is only feasible to estimate population parameters from samples or climatological series. Such an estimate of a population parameter is called a statistic. A statistic is a function of the sample or climatological series. Statistical parameters may be dealt with only in theory while in practice statistics or estimates of the parameters must always be used.

Since every function of a random variable is also a random variable, statistics are random variables and are therefore subject to random variation similar to that in a climatological series. Every climatological statistic is therefore a random variable which forms a population for which there is a frequency distribution. The variability of this frequency distribution about the population parameter is called the dispersion of the statistic. There are always a number of functions of the sample, or statistics, which estimate the same population parameter. The best of these estimates will have the smallest dispersion. The estimate with the least dispersion will in general extract the most information from the sample on the value of the population parameter. The dispersion of a statistic decreases with increase in sample size hence statistics for long climatological series have less dispersion than those for short climatological series. Since poor statistics have greater dispersion. the use of such statistics in effect discards climatological record, hence is wasteful of usually scarce record length and is to be avoided if possible. An example is the use of the median to estimate the center of a normal (Gaussian) distribution (e. g., a climatological series of temperature which has a distribution close to normal). Both the median and the mean are statistics for the center of a normal distribution. The median, however, has a larger dispersion than the mean and in fact requires about a one-third longer climatological series than the mean to obtain an equally good estimate of the center of the distribution. There are a number of other inefficient statistics used in climatology. Examples are the use of the mean absolute deviation as an estimate of the standard deviation and certain short cut estimates of the correlation coefficient. Statistics with the smallest dispersions are called efficient. It is naturally advantageous to employ either efficient statistics or those with high efficiencies in climatological analysis. If the distribution form is not known little exact information can be inferred about the efficiency of a statistic.

While it is always desirable to use the most efficient statistic available, it is sometimes also desirable, but not necessarily essential in all problems, to have the statistic be mean unbiased or what is commonly known as unbiased. A statistic is said to be (mean) unbiased if the mean of the statistic for m samples of size n approaches its parameter value as m increases without limit or mn approaches the number of values in the whole population. Efficiency and unbiasedness do not naturally occur together. In statistical analysis it is common practice to choose an efficient statistic and make it unbiased if the latter property is necessary, such as in cases where statistics are to be added or averaged.

There are in general two kinds of statistics: (a) Those which are direct estimates of the parameters of a frequency distribution, and (b) those which are estimates of other population properties. The mean and standard deviation are estimates of the population or distribution parameters of the normal distribution. The mean is also an estimate of the population mean or expected value independent of the distribution form.

4.3.1 COMMON STATISTICS OF CLIMATOLOGICAL VARIABLES

The mode is defined as the value of the random variable where the density of probability is a maximum. If the analytical form of the frequency distribution is known efficient estimates of the mode (the peak of the curve) may be obtained by substituting efficient estimates of the distribution parameters and obtaining the maximum of the frequency curve by differentiation. If the analytical form of the frequency distribution is not known, there is no good method of estimating the mode. If the sample is large the center of the class with the highest frequency may be taken as an estimate of the mode. In general the mode is not recommended for use in climatology.

There has been a good deal written about multimodal distributions in climatology. Most of the multimodality observed is caused by mixing small samples from several populations which falsely gives the impression that large samples have been used. In these cases the multimodality is not real but only an effect resulting from improper statistical analysis.

The median of a population is defined as the value of the random variable below which the probability of occurrence is 0.50. If the frequency distribution is known, it may be obtained by integrating up to the value of the random variable where the probability reaches 0.50. If the distribution is not known the median is best obtained by reading the 0.50 value from cumulative distributions plotted from data such as those shown in tables 3 and 4. Rough estimates of the median may be obtained by taking the middle value of an ordered series or if there are two middle values they may be averaged to obtain the median. The median is one of a class of quantities called quantiles which are defined as X_F where F is the probability of X being less than X_F. The median is then the 0.50 quantile. Quantiles should be estimated from fitted analytical distributions where possible as those obtained either from the empirical cumulative distributions or from ordered series tend to be more variable.

The mean is the most used climatological parameter. In most cases it is best to obtain it by summing the climatological series and dividing by the number of years of record. It has two properties: First it is an estimate of the well-known expected value or mathematical expectation, i.e., the mean of the population. This is important in applied climatology for the mean of any linear function of the climatological series is also a linear function of the mean of the series. Secondly, the mean is the center of the normal distribution and is therefore the center of the distribution for climatological series having this distribution. The mean, as computed above, is generally optimum for estimating the expected value for precipitation and optimum for both the expected value and the center of the distribution for temperature.

The moments about the mean, or central moments, are also commonly employed in statistical-climatological work. These are defined for the population R by

$$\mu_r = \int_R (x - u)^r f(x)\, dx. \quad (1)$$

Here μ_r is the rth moment, u is the mean, f(x) is the probability density function or frequency curve, and R is the population interval or region over which f(x) is defined. The unbiased estimate of the second moment or variance is

$$s^2 = \frac{\sum^n (x - \bar{x})^2}{n - 1} \quad (2)$$

The square root of this value is the standard deviation. The higher moments may be estimated by

$$m_r = \frac{\sum^n (x - \bar{x})^r}{n} \quad (3)$$

The third moment is often used to measure the skewness and the fourth moment the flatness or kurtosis of frequency distributions. For these purposes the statistics

$$g_1 = m_3/s^3 \quad \text{and} \quad g_2 = (m_4/s^4) - 3$$

which are estimates of the parameters γ_1 and γ_2 may be employed. For the normal distribution $\gamma_1 = \gamma_2 = 0$. The statistic $a = \sum^n |x - \bar{x}|/(ns)$ is often substituted for g_2 since it has a simpler distribution and tends toward normality faster. Tabular values of a, also a related skewness ratio

$$\sqrt{b_1} = m_3/s^{3/2}$$

are available in Pearson and Hartley's tables [46]. Moments higher than the 4th are ordinarily not recommended for climatological work since they are highly variable for the short climatological series usually available.

Again it should be stated that if good estimates of the distribution parameters are available formula (1) should be used directly for estimating the moments. Another statistic occasionally used is the range. This statistic is not recommended except for very crude work since it has a high variability. Related to the range are the extreme values of record. These are even more highly variable than the range and depend greatly on the length of record. The extreme values for each year may, of course, be fitted by appropriate frequency distributions. Statistics of these distributions give a much better appraisal of individual extremes. For example, quantiles from these distributions are independent of the length of record used; hence, they give valid information about unusual values.

The coefficient of variation (or variability) or relative standard deviation also has been used in climatology. It is defined as the ratio of the standard deviation to the mean, $s/\bar{x}$. The statistic in absolute value depends on the interpretation which can be given the standard deviation. If the distribution is not normal the standard deviation has no simple meaning and hence an individual relative standard deviation has little value. However, it is useful for comparison to other relative standard deviations from populations having the same analytical form of distribution. In this case the ordinary estimate may be an inefficient statistic. A better estimate could be obtained using the proper functions of the estimated parameters in equation (1).

4.3.2 SAMPLING VARIABILITY OF CLIMATOLOGICAL MEANS

The sampling variability or accuracy of a statistic is often measured by its standard deviation which when applied to a statistic is commonly called the standard error. In order for the standard deviation or standard error to have a valid interpretation, the distribution must be near normal. Although the distributions of many climatological series are not normal, the distributions of their means for reasonably long records tend to normality. This is a result of the central limit theorem which states that the distribution of means tends to normal with increasing sample size irrespective of the distributions of individual values providing the second moments exist. Since the second moments exist for the distributions of every meteorological element, their means will be close to normally distributed for reasonably long records, such as 30 years.

The sample standard error of the mean of a climatological series is $s(\bar{x}) = s/\sqrt{n}$ where n is the number of years in the series and s is the standard deviation of the individuals in a climatological series. This is true regardless of the form of the distribution. In case the distribution is approximately normal and the sample size is 30 years or more, confidence limits may be established for the mean. Thus the 0.90 confidence interval for the mean $\bar{x}$ may be expressed as $\bar{x} - 1.64s(\bar{x}) < \mu < \bar{x} + 1.64s(\bar{x})$ where -1.64 and +1.64 are the 0.05 and 0.95 values obtained from a table of the normal distribution. This means that the probability is 0.90 that the true or population value of the mean will lie on this interval. Or, more specifically, if such intervals were computed for successive periods of record of length used for x, 9 out of 10 of these would contain μ.

The confidence interval gives a good measure of the accuracy of $\bar{x}$. As previously in statistical tests, 0.90 probability, the complement of 0.10, has been used because most statistics in meteorology cannot be expected to attain an accuracy justifying a higher confidence that a parameter is on an interval.

In order to determine how close the distribution of means approaches normality, the skewness statistic $g_1(\bar{x}) = g_1/\sqrt{n}$ and the flatness statistic $g_2(\bar{x}) = g_2/n$ may be employed. With an extreme case of skewness and flatness the above statistics could, e.g., have the sample values $g_1 = 2$ and $g_2 = 6$ (a J-shaped distribution) in the original climatological series. According to the formulas above $g_1(\bar{x})$ is reduced to 0.365 and $g_2(\bar{x})$ to 0.2 for a 30-year mean. The small departure from normality shown by these statistics only increases the confidence interval probability from 0.900 to 0.901. The maximum effect at any single probability value will be less than 0.03. Thus even with such extreme conditions of skewness and flatness in the climatological series, the distribution of 30-year means may be assumed to be normal without risk of serious bias in the probabilities.

4.4 GENERAL STATISTICAL METHODS

The basic problems of climatological analysis may be classified into three general types: (1) Problems of specification which occur in the choice of the analytical form of the population. (2) Problems of inference which arise in the estimation of population parameters and in testing hypotheses and establishing confidence intervals on the population parameters. (3) Problems of relationship which occur in relating several climatological variables and in relating climatological variables to non-climatological variables.

The problem of specification is solved by specifying the frequency distribution in the population of the climatological variable. This may be done either empirically or using theoretical reasoning. An empirical specification of the population usually consists simply in assuming the existence of a distribution of probability whose cumulative distribution has the characteristic ogive form. This was the approach followed previously in obtaining the distribution of August precipitation for Geneva. Occasionally, on the basis of examination of numerous samples, a mathematical form of distribution may be specified for convenience of computation. A theoretical specification of the population distribution is always expressed in mathematical form. This form is derived from a consideration of the bounds of the variable; scale, location, and shape behavior; behavior in convolution; etc. A theoretical specification of the normal distribution may result from an application of the central limit theorem.

The estimation part of the inference problem is solved by providing the most satisfactory statistics for estimating the population parameters. As was seen previously, the most satisfactory statistics or estimators will be those having a small dispersion in their distributions. Usually maximum likelihood estimates will provide the best estimates of the parameters.

Confidence intervals for the parameter estimates should always be provided to give a measure of their accuracy. Tests of hypothesis may also be made to ascertain whether the population meets certain prescribed conditions or whether the parameters differ from other sets of parameters of similar character. Previously, for example, tests were made to examine the homogeneity of temperature and precipitation series. Confidence interval and test of hypothesis problems are similar in that they both involve distributions of the estimates or statistics.

The relationship problem may involve only climatological variables or it may involve climatological and other variables. The first problem arises when functions of climatological variables are needed to replace climatological variables which are not available or to form a new variable which has some special properties. For example, statistics on daily temperatures may be impossible or too expensive to obtain directly and it is required to obtain estimates of these from monthly statistics. The heating degree-day variable is a simple example of a function of temperature which has special useful properties not possessed by temperature. The second type of problem, where climatological variables are related to non-climatological variables, is encountered in every problem in applied climatology. The basic objective in such problems is to develop a relationship which will transform a frequency distribution on the climatological variable to one on the applied variable. A simple example would be a relationship between degree-days and heat consumption in a building which would give the distribution of heat consumption from the distribution of degree-days.

Since many of the inference problems of climatology are closely associated with specification problems, these will be discussed together. The test of hypothesis problem has already been introduced in connection with tests of homogeneity, and space will not allow further treatment. More detail on this subject is readily available in the statistical literature. The relationship problem will be treated separately.

4.4.1 FREQUENCY DISTRIBUTIONS

An example of specification of the population has already been introduced in 4.2.1 where the empirical distribution was specified for August precipitation at Geneva. The only theory employed there was to assume the existence of a population and a random variable and hence the set of cumulative probabilities. In many instances of climatological analysis the specification of an empirical distribution is all that is necessary or justified. It is only where the theory is strong or where several distributions are to be fitted and comparison or smoothing of their statistics is required that theoretical distributions are fitted. A mathematical fit adds little in other circumstances.

Frequency distributions are of two general types, discrete and continuous. In discrete distributions the probability density is a function of a discrete random variable, i. e., one that varies in steps. The most common discrete climatological variable is frequency, e. g., the number of hail storms, days with rain, etc. In continuous distributions the probability density is a function of a continuous random variable. Temperature, pressure, precipitation, or any element measured on a continuous scale has a continuous random variable. Often for convenience a discrete random variable may be treated as continuous. Also, for special application, continuous random variables may be transformed to discrete random variables. Cloud height, for example, is a continuous variable which may be transformed into a discrete variable consisting of heights below and above an arbitrary height h.

While there has been a good deal of consideration given to fitting frequency distributions to meteorological data, much of this has been empirical in nature. Often also the fitting has been done to improperly defined populations such as mixtures of several climatological series which have led to quite anomalous interpretations. Because of lack of space only the most common distributions can be discussed.

4.4.1.1 THE NORMAL DISTRIBUTION

The most important continuous distribution in climatological analysis, and, of course, statistical analysis, is the normal or Gaussian distribution. Its frequency or probability density function is

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp - \frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2$$

where μ is the population mean and σ is the population standard deviation. The parameter μ is best estimated by $\bar{x}$ and σ by s. These are obtained from the sample values x by the relationships

$$\bar{x} = \sum^{n} x/n$$

and

$$s = \sqrt{\sum \frac{(x-\bar{x})^2}{n-1}} \quad .$$

The normal distribution function cannot be expressed in terms of simple functions but must be evaluated by means of function expansions. Many tables of the normal distribution function and related functions have been prepared using the variable $u = (x - \mu)/\sigma$ as argument; u is called a standardized variable. Using this variable the distribution function becomes

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp - \frac{1}{2} u^2 \, du$$

which can be converted to any desired normal distribution simply by varying μ and σ. Thus a single normal table with argument t, which is also a table of the distribution with mean zero and standard deviation unity, may be used to obtain the probabilities for any normal distribution. F(t), of course, gives the probability that u is less than t, 1 - F(t) the probability that u is greater than t, and $F(t_2) - F(t_1)$ the probability that u is between t_1 and t_2.

The importance of the normal distribution in climatology stems, to considerable extent, from the central limit theorem. This causes means and sums of a sufficient number of climatological values to be normally distributed. For example, rainfall climatological series for short periods for which the mean rainfall is small would have very skewed distributions. As the period increases several shorter periods are added together and an increase in the mean occurs. Thus the size of the mean is some measure of how many periods have been added together; hence, as the mean value gets larger the sum of the several component periods approaches a normal distribution. It may be shown that under average conditions, periods with a mean rainfall of 500 mm or more will be close to normally distributed, the greatest discrepancy in probability being about 0.01 at the median. Even for 250 mm means under ordinary conditions the largest discrepancy in probability is only about 0.02.

The normal distribution also provides good fits in most instances to climatological variables which are unbounded above or below, such as temperature and pressure. The sample of data fitted must, of course, be a sample from a homogeneous climatological series. It must not be a sample from mixed populations which in the past has led to erroneous conclusions such as frequency distributions having several modes, etc.

The normal distribution has found wide application in determining the probability of a freezing air temperature occurring before or after a given date in fall or spring [52,33]. The data in table 14 are taken from Shaw, Thom, and Barger [48]. Geary and Pearson's tests for skewness and kurtosis [37] indicate no significant deviation from normality at the 10% and 20% levels, respectively. Actually, in studying a large number of Iowa locations the number of significant cases was found to be no more than expected with a selected probability level.

Table 14. Dates of Last Occurrence in Spring of 32°F or Lower at Alta, Iowa

Year	Date	Code	Year	Date	Code
1893	May 2	= 31	1923	May 12	= 41
1894	Apr. 21	= 20	1924	May 24	= 53
1895	May 19	= 48	1925	May 17	= 46
1896	Apr. 21	= 20	1926	May 3	= 32
1897	May 30	= 60	1927	Apr. 24	= 23
1898	Apr. 14	= 13	1928	Apr. 27	= 26
1899	May 13	= 42	1929	May 16	= 45
1900	May 3	= 32	1930	May 17	= 46
1901	May 12	= 41	1931	May 22	= 51
1902	Apr. 23	= 22	1932	Apr. 27	= 26
1903	May 3	= 32	1933	Apr. 27	= 26
1904	Apr. 26	= 25	1934	Apr. 27	= 26
1905	May 26	= 55	1935	May 3	= 32
1906	May 9	= 38	1936	Apr. 22	= 21
1907	May 27	= 56	1937	May 14	= 43
1908	May 3	= 32	1938	May 8	= 37
1909	May 10	= 39	1939	Apr. 21	= 20
1910	May 4	= 33	1940	May 2	= 31
1911	May 3	= 32	1941	Apr. 24	= 23
1912	May 14	= 43	1942	May 4	= 33
1913	Apr. 27	= 26	1943	May 8	= 37
1914	May 12	= 41	1944	May 6	= 35
1915	May 18	= 47	1945	May 10	= 39
1916	May 2	= 31	1946	May 12	= 41
1917	May 4	= 33	1947	May 29	= 58
1918	May 11	= 40	1948	Apr. 13	= 12
1919	Apr. 25	= 24	1949	Apr. 24	= 23
1920	Apr. 28	= 27	1950	May 7	= 36
1921	May 14	= 43	1951	Apr. 23	= 22
1922	Apr. 19	= 18	1952	Apr. 15	= 14

Mean = May 5
s = 11.4

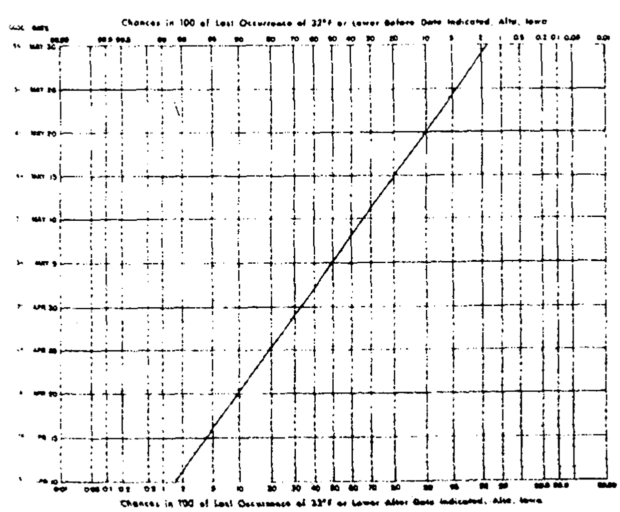


Figure 43.

Utilizing the coded dates in table 14 the sample mean and standard deviation (s) are 34 (May 5) and 11.4 respectively. Using normal probability paper with, say, May 5 $\pm$ 1.96s plotted at 0.975 and 0.025, respectively, the probability of the last occurrence of 32°F or lower being before or after a given date in northwestern Iowa can be read directly from the abscissa in figure 43.

4.4.1.2 THE GAMMA DISTRIBUTION

Since there are a number of zero bounded continuous variables in climatology, it is important to give a distribution which may be used for such variables. The gamma distribution which has a zero lower bound has been found to fit several such variables well [25, 36, 53]. It is defined by its frequency or probability density function

$$g(x) = \frac{1}{\beta^{\gamma}\,\Gamma(\gamma)}\, x^{\gamma-1} \exp - x/\beta$$

where β is a scale parameter, γ is a shape parameter, and $\Gamma(\gamma)$ is the ordinary gamma function of γ, i.e., $\Gamma(\gamma) = (\gamma - 1)!$

The moments in this instance give poor estimates of the parameters. Sufficient estimates are, however, available and these are closely approximated by

$$\hat{\gamma} = (1 + \sqrt{1 + 4A/3})/4A$$

and

$$\hat{\beta} = \bar{x}/\hat{\gamma}$$

where A is given by $A = \ln \bar{x} - (\sum^{n} \ln x)/n$

and ln signifies the natural logarithm.

The distribution function, from which probabilities may be obtained, is

$$G(x) = \int_0^x g(t)\, dt$$

Pearson's "Tables of the Incomplete Γ-Function" [45] give G(u) where $u = x/\sigma$, $\sigma = \beta\sqrt{\gamma}$, $\gamma = p + 1$ and $\beta = 1/\gamma'$; γ' is the same as Pearson's γ which is his scale parameter, whereas we use γ as the shape parameter.

The Gamma distribution has been found to give good fits to precipitation climatological series. In case these contain zeros the mixed distribution function of zeros and continuous precipitation amounts may be employed. This is given by

$$H(x) = q + p\, G(x)$$

where q is the probability of a zero and $p = 1 - q$. Thus when $x = 0$, $H(0) = q$ as it should be. If m is the number of zeros in a climatological series, q may be estimated by m/n.

Most extensive utilization of the Gamma distribution has been made by Thom [54] and Barger et al. [26, 27, 49]. These, and forthcoming publications from the Northeastern Agricultural Experiment Station Region (Project NE-35) list many distribution parameters and probabilities of selected amounts of precipitation, as well as maps and graphs pertaining to each Region and nomograms for estimating probabilities from the parameters.

771 O - 60 - 5

4.4.1.3 THE EXTREME VALUE DISTRIBUTIONS

Often in design problems the climatological variable of interest is the annual extreme, either upper or lower. This arises from the fact that if a designed structure can withstand the highest (lowest) value in a year it can also withstand all other values in the year. Hence, a distribution of annual extreme values furnishes the proper climatological prediction. Up to the present the Fisher-Tippett Type I distribution has been of main interest. It has been widely applied by Gumbel[38]. Its distribution function is given by

$$F(x) = \exp\left[-e^{\pm(x-\alpha)/\beta} \right]$$

Here the negative of the double sign holds for maximum values and the positive sign applies for minimum values. The Type II distribution, which is an exponential transformation of the Type I distribution, also has been employed by Thom [55] but the satisfactory fitting of this distribution is too complicated to give here.

As with most other skewed distributions the moments give poor estimates of the parameters. Lieblein has provided a simple method of fitting the Type I distribution which gives estimates of the quantiles with minimum variance. This is a desirable property for climatological work, for our ultimate objective is always to obtain quantiles or probabilities[41].

The Lieblein fitting procedure involves carefully maintaining the original time order of the climatological series and dividing into suitable subgroups for the computations. The following table of weights is needed in the computations.

Table of Order Statistics Weights

m		$x_{.1}$	$x_{.2}$	$x_{.3}$	$x_{.4}$	$x_{.5}$	$x_{.6}$
2	$a_{.j}$	0.91637	0.08363				
	$b_{.j}$	-0.72135	0.72135				
3	$a_{.j}$	0.65632	0.25571	0.08797			
	$b_{.j}$	-0.63054	0.25582	0.37473			
4	$a_{.j}$	0.51100	0.26394	0.15368	0.07138		
	$b_{.j}$	-0.55862	0.08590	0.22392	0.24880		
5	$a_{.j}$	0.41893	0.24628	0.16761	0.10882	0.05835	
	$b_{.j}$	-0.50313	0.00653	0.13045	0.18166	0.18448	
6	$a_{.j}$	0.35545	0.22549	0.16562	0.12105	0.08352	0.04887
	$b_{.j}$	-0.45928	-0.03599	0.07319	0.12673	0.14953	0.14581

As previously, the sample climatological series is assumed to have n values. Retaining the original time order these n-values are to be divided into subgroups of size m. It will be noted that the table of weights allows m to be chosen from 2 to 6. It is best to choose m as large as possible. Thus, if the sample size is 30, m = 6 would be chosen rather than m = 5. If n is not divisible by m = 4, 5, or 6, an additional weighting will be necessary. First consider that n = 30. The sample is maintained in original time order and divided into k = 5 subgroups of m = 6. The values within the subgroups are then arranged in order according to increasing magnitude. The ith subgroup would then appear as x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}, x_{i6}. All ordered subgroups are then arranged in a table as follows:

x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	
x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	
x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	
x_{41}	x_{42}	x_{43}	x_{44}	x_{45}	x_{46}	
x_{51}	x_{52}	x_{53}	x_{54}	x_{55}	x_{56}	
$S_{.1}$	$S_{.2}$	$S_{.3}$	$S_{.4}$	$S_{.5}$	$S_{.6}$	
$a_{.1}$	$a_{.2}$	$a_{.3}$	$a_{.4}$	$a_{.5}$	$a_{.6}$	
$a_{.1}S_{.1}$	$a_{.2}S_{.2}$	$a_{.3}S_{.3}$	$a_{.4}S_{.4}$	$a_{.5}S_{.5}$	$a_{.6}S_{.6}$	$\sum^{6} a_{.j}S_{.j}$
$b_{.1}$	$b_{.2}$	$b_{.3}$	$b_{.4}$	$b_{.5}$	$b_{.6}$	
$b_{.1}S_{.1}$	$b_{.2}S_{.2}$	$b_{.3}S_{.3}$	$b_{.4}S_{.4}$	$b_{.5}S_{.5}$	$b_{.6}S_{.6}$	$\sum^{6} b_{.j}S_{.j}$

Each column of x's is first summed to obtain the $S_{.j}$. These are multiplied by $a_{.j}$ and summed to obtain the row sum. Next the $S_{.j}$ are multiplied by the $b_{.j}$ and summed to obtain the second row sum.

In the Type I distribution function the exponent $(x-\alpha)/\beta$ is a standardized variable, i.e., it is a variable located at α and scaled in β. If x_p is a quantile in x (a value of x corresponding to F = p), then

$$y_p = (x_p - \alpha)/\beta$$

and

$$x_p = \alpha + \beta y_p$$

Lieblein showed that a minimum variance estimated for a given y_p is given by

$$x_p^* = \sum^{m} a_{.j}S_{.j}/k + (\sum^{m} b_{.j}S_{.j}/k)y_p$$

Thus the minimum variance estimates for α and β are

$$\alpha^* = \sum^{m} a_{.j}S_{.j}/k$$

and

$$\beta^* = \sum^{m} b_{.j}S_{.j}/k$$

For the sample of 30 under consideration they are

$$\alpha^* = \sum^{6} a_{.j}S_{.j}/5$$

and

$$\beta^* = \sum^{6} b_{.j}S_{.j}/5$$

When these values are substituted in the Type I distribution function estimated probabilities are obtained.

In case m = 5 or 6 is not an even multiple of the sample size n, a further simple computation is necessary. Suppose that n = 33 instead of 30. The last three values of the sample climatological series then form an additional subgroup of m' = 3. These values are also arranged in order of increasing magnitude giving x_{61}, x_{62}, and x_{63}. A similar table is formed with the weights for m' = 3 as follows:

x_{61}	x_{62}	x_{63}	
$a_{.1}$	$a_{.2}$	$a_{.3}$	
$a_{.1}x_{61}$	$a_{.2}x_{62}$	$a_{.3}x_{63}$	$\sum^{3} a_{.j}x_{6j}$
$b_{.1}$	$b_{.2}$	$b_{.3}$	
$b_{.1}x_{61}$	$b_{.2}x_{62}$	$b_{.3}x_{63}$	$\sum^{3} b_{.j}x_{6j}$

The estimator for this sample is then as before

$$u^*_p = \sum^{3} a_{.j}x_{6j} + (\sum^{3} b_{.j}x_{6j})y_p$$

Lieblein has shown that the estimator for v_p the quantile for the variable in the sample n = 33 is

$$v^*_p = \frac{km}{n} x^*_p + \frac{m'}{n} u^*_p \quad .$$

This gives for the final estimates

$$\alpha^* = \frac{km}{n} \sum^{6} a_{.j}s_{.j}/5 + \frac{m'}{n} \sum^{3} a_{.j}s_{.j}$$

and

$$\beta^* = \frac{km}{n} \sum^{6} b_{.j}s_{.j}/5 + \frac{m'}{n} \sum^{3} b_{.j}s_{.j} \quad .$$

The fitting of any sample size is a simple variation of the above procedures. For minimum values or lower extremes the magnitude order arrangement in the rows of the computation tables is reversed, i. e., instead of going from low to high values they should go from high to low values. All other parts of the tables remain the same.

4.4.1.4 THE BINOMIAL DISTRIBUTION

This distribution does not in general fit climatological data well because of correlations which occur when the probabilities of occurrence are high enough to meet one of its requirements for application. It is important, however, because it is related to the Poisson and negative binomial distributions which apply respectively for small probabilities (rare events, often uncorrelated) and for correlated events. Because of this relation it has occasionally been used to give simple rough probability estimates to replace the more crude observed extreme relative frequencies. The most important aspect of the binomial distribution for climatological analysis is that it is the distribution of the estimated probabilities obtained from any distribution function, empirical or theoretical. This makes it possible to obtain confidence limits for estimated probabilities and quantiles.

The binomial probability function is given by

$$f(x) = \binom{m}{x} p^x (1-p)^{m-x}$$

where p is the probability of an event occurring, 1-p is the probability of the event not occurring, x is the frequency of occurrence, and x can take the values 0, 1, ... m,. The distribution function is given by

$$F(x) = \sum_{t=0}^{x} \binom{m}{t} p^t (1-p)^{m-t}, \; t=0, 1, \ldots, m \; .$$

This, of course, gives the probability that the frequency is x or less. The probability p is usually estimated by $\Sigma x/n$ where n is the total number of occurrences and non-occurrences of the event. The climatological events which might be considered in this category are widely varied. Examples are hail and no-hail days, rain and no-rain days, days with rainfall less than an amount u and those with rainfall greater than u, observations with visibility less than V and those greater than V, etc. Most of these variables have the limitation that they are correlated and therefore the binomial distribution can be used only for rough biased estimates of probabilities for use where only summarized data are available or quick results are needed.

The important application of the binomial distribution in climatological analysis is in obtaining confidence bands for estimated probabilities. It may be seen that when an estimate F(h) of the probability that $x < h$ is obtained from any distribution function, theoretical or empirical, the probabilities in random sampling are divided into those less than h and those greater than h. These form a binomial distribution. If the sample size is m from which F(h) has been estimated, then the probability that values of F(h) = c/m in random sampling will be below F(a) = p_L is

$$\alpha = \sum_{x=0}^{c} \binom{m}{c} p_L^c (1-p)^{m-c} \quad .$$

Likewise, if the probability that values of F(h) will be above F(b) = p_U is also made α, then

$$\alpha = \sum_{x=c}^{m} \binom{m}{c} p_U^c (1-p)^{m-c} \quad .$$

It is now seen that the probability that F(a) lies between p_L and p_U is $1-2\alpha$. Thus the probability relationship

$$P(p_L \le F(\eta) \le p_U) = 1-2\alpha$$

defines a confidence interval for F(a) with confidence probability $1-2\alpha$ where $F(\eta)$ is the true or population value of F(h). "Biometrika Tables for Statisticians" [46] gives convenient graphs for $1-2\alpha = 0.95$ and 0.99, 0.95 being the smallest confidence probability recommended for climatological work. A level of $1-2\alpha = 0.90$ is better and may be obtained approximately from the National Bureau of Standards "Tables of the Binomial Probability Distribution [59].

If the inverted function notation $h = F^{-1}(c/m)$ is employed, the confidence interval for a quantile h_F may be expressed as the probability relationship

$$P\left[F^{-1}(p_L) < \eta_F < F^{-1}(p_U)\right] = 1-2\alpha$$

This is obtained by simply finding the x values corresponding to $F = p_L$ and $F = p_U$ in the probability confidence interval.

It should be noted that both confidence intervals are independent of the functional form of F which in a sense makes them non-parametric. If the functional form of F is known, parametric confidence intervals may be available which will be shorter than those above; however, some authors simply assume that p and the corresponding quantiles are normally distributed. This can only give a good approximation at values near the middle of F(x). For values of F(x) near 0 or 1, it is better to use the binomial confidence intervals. They are slightly too broad but they reflect the right shape for the distribution of F(h).

4.4.1.5 THE POISSON DISTRIBUTION

When m becomes large and p approaches zero with the mean μ = mp constant, the binomial distribution approaches the Poisson distribution. Thus the Poisson distribution fits events with a small probability. Since this also means for climatological series that a small number of events on the average is found in the annual time interval or a portion of it, the correlation between successive events will ordinarily be small. The distribution, therefore, fits annual hail frequency when the mean frequency is not too high, excessive precipitation events, annual tornado and typhoon frequency, etc.

The Poisson probability function is given by

$$f(x) = \mu^x e^{-\mu}/x! \quad .$$

The distribution function is then

$$F(x) = \sum_{t=0}^{x} \mu^t e^{-\mu}/t! \quad .$$

Here the only parameter is the mean μ which is best estimated by $\bar{x} = (\Sigma x)/n$. Probabilities may be obtained readily from F(x) with the aid of tables of exponentials and factorials.

4.4.1.6 THE NEGATIVE BINOMIAL DISTRIBUTION

The negative binomial distribution is useful in fitting discrete dichotomous random variables in which the individual events tend to be correlated. Thus, when too many events are packed on the average into an annual time interval, this distribution tends to fit better than the Poisson distribution. For example, annual hail days and annual frequency of typhoons tend to be fitted better by the negative binomial distribution when the mean annual occurrence is high. Continuous data should in general not be fitted with theoretical discontinuous distributions unless a simple transformation to a discrete variable is made e.g., to a dichotomous variable. There are a number of bad examples of such misfitting in the meteorological literature. On the other hand the fitting of continuous distributions to discontinuous data is often useful.

A test of hypothesis is available to test the adequacy of the Poisson distribution. Thus, if

$$\chi^2_{n-1} = n\,(\Sigma x^2/\Sigma x) - \Sigma x,$$

where n is the number of years of record, is not greater than the 0.05 value in a chi square table with n-1 degrees of freedom, the Poisson distribution is adequate. If it exceeds the 0.05 value the negative binomial distribution should be fitted.

The negative binomial probability function is

$$f(x) = \frac{\Gamma(x+k)}{\Gamma(x+1)\,\Gamma(k)} \; \frac{p^x}{(1+p)^{k+x}}$$

The distribution function is given by

$$F(x) = \sum_{t=0}^{x} f(t) \quad .$$

The moment estimates of p and k are

$$p^* = (s^2 - \bar{x}) / \bar{x}$$

and

$$k^* = \bar{x}^2/(s^2 - \bar{x}) \quad .$$

where $\bar{x}$ is the sample arithmetic mean and s^2 is the sample variance.

The moment estimates are not always adequate, i. e. efficient enough. Fisher has given a criterion which suggests the use of a better fitting procedure if the efficiency falls below 90%. Thus if

$$(1 + 1/p^*)\ (k^* + 2) > 20$$

the method of maximum likelihood should be used. This method of fitting is too complex to consider here. For details on the method see Thom [56].

4.4.2 CORRELATION AND REGRESSION ANALYSIS

The most important use of correlation methods in climatological analysis is in connection with the correlation between climatological series caused by the natural persistence of the meteorological variable within the year. Correlation problems also occur in connection with compound variables i.e., where two or more variables are combined into a single variable and in connection with the propagation of variability in relationships of theoretical or applied problems. Most other applications of correlation are supplementary to regression analysis.

Regression analysis is applied whenever the objective is to estimate a functional relationship for predicting the values of a variable from one or more others. Its main uses are in relating one or more meteorological variables so that one may be substituted for one or more others and in relating applied variables to meteorological variables. There is also some application to the study of systematic variation of climatological variables in time. However, this aspect is largely of special interest and will not be considered here. In any case the regression analysis in this instance is only a variation of that considered here except that the independent variable is time and the regression terms may be harmonic functions or of some other form.

4.4.2.1 CORRELATION ANALYSIS

In a strict sense correlation analysis in climatology consists largely of accounting for the effect of correlation between climatological series. For example, if the temperature climatological series for the average temperature series for May 1 and 2 have sample variances s_1^2 and s_2^2 then the series for the average of May 1 and 2 has a variance which is affected by the correlation between the May 1 and May 2 series. Similarly the variance of the average of the May 1, 2, ..., m series will be affected by the correlations among the m climatological series. Clearly the climatological series could also be for weeks, months, or any other portion of the year.

Just as it is necessary always to work with climatological series so is it necessary to work with the proper correlation coefficients in the present aspect of climatological analysis. The only correlation coefficients useful in the type of analysis considered here are those computed between the two series in any pair of climatological series. If the two series are for the same element, they will be displaced in time within the year; hence it will be possible to have a whole sequence of such correlations. The pairs of climatological series may be separated by different units of time and so there will be a time lag between them. Because of the time sequential nature of these correlation coefficients and to differentiate them from autocorrelation coefficients they will be called sequence correlation coefficients. The sequence correlation between the ith and jth climatological series is defined as

$$\rho(x_i, x_j) = E(x_i - \mu_i)(x_j - \mu_j)/\sigma_i\sigma_j .$$

The numerator is the expected value of the product of the departures of the x_i and x_j from their respective population means and is called the covariance. The denominator is the product of the population standard deviations of x_i and x_j. The sample estimate of the sequence correlation coefficient is given by

$$r(x_i, x_j) = \sum_{k=1}^{m} (x_{ik} - \bar{x}_i)(x_{jk} - \bar{x}_j)/ns_i s_j .$$

Here x_{ik} is the kth term (year) in the ith climatological series and x_{jk} is the kth term (year) in the jth climatological series and $\bar{x}_i$, s_i, and $\bar{x}_j$, s_j are their respective means and standard deviations.

The sequence correlation coefficient should be carefully differentiated from the autocorrelation coefficient (sometimes called serial correlation coefficient). The seqence correlation coefficient is really a single correlation with a time displacement so that the effect of variation in the mean and standard deviation through the year is removed. The autocorrelation coefficient, on the other hand, includes the variation in the mean and standard deviations. In the methods discussed here it is always wrong to use an autocorrelation coefficient.

For the May 1, 2, ..., m climatological series considered above there are m(m-1) possible pairs of series. Since $\rho(x_i, x_j) = \rho(x_j, x_i)$, there are only m(m-1)/2 different sequence correlations. All of these must be considered in obtaining the variance of the sum and average series formed by summing or averaging for each year. If i and j both run over the same sequence of series, the sample variance of the sum may be expressed by

$$v(\Sigma^m x_i) = \Sigma^m s_i^2 + 2 \sum_{i=1}^{m} \sum_{j>i}^{m} s_i s_j r(x_i, x_j) .$$

This is the variance of the linear function $y = \Sigma x_i$. If the x_i have different weights k_i so that the linear function is $y = \Sigma k_i x_i$, the variance becomes

$$v(\Sigma^m k_i x_i) = \Sigma^m k_i^2 s_i^2 + 2 \sum_{i=1}^{m} \sum_{j>i}^{m} k_i k_j s_i s_j r(x_i, x_j)$$

It may be noted that when the $r(x_i, x_j) = 0$, the relationship reduces to the simple variance formula

$$v(\Sigma^m k_i x_i) = \Sigma^m k_i^2 s_i^2 .$$

If m = 2 and k_2 has a negative sign the formula gives

$$v(k_1 x_1 - k_2 x_2) = k_1 s_1^2 + k_2 s_2^2 - 2k_1 k_2 s_1 s_2 r(x_1, x_2)$$

If $k_1 = 1$ and $k_2 = -1$

$$v(x_1 - x_2) = s_1^2 + s_2^2 - 2s_1 s_2 r(x_1, x_2) .$$

For $r(x_1, x_2) = 0$, $k_1 = 1$, $k_2 = -1$

$$v(x_1 - x_2) = s_1^2 + s_2^2$$

If k = 1/m, so that the linear function is a simple average $\Sigma x_i/m$, the variance becomes

$$v(\Sigma^m x_i/m) = \frac{1}{m^2}\left[\Sigma^m s_i^2 + 2 \sum_{i=1}^{m} \sum_{j>i}^{m} s_i s_j r(x_i, x_j)\right]$$

Thus the average temperature for June has a variance formed from the daily variances and sequence correlations given by

$$v(\Sigma^{30} x_i/30) = \frac{1}{30^2}\left[\Sigma^{30} s_i^2 + 2 \sum_{i=1}^{30} \sum_{j>i}^{30} s_i s_j r(x_i, x_j)\right] .$$

The variance of the total precipitation for June based on the individual daily variances and sequence correlations is

$$v(\Sigma^{30} x_i) = \Sigma^{30} s_i^2 + 2 \sum_{i=1}^{30} \sum_{j>i}^{30} s_i s_j r(x_i, x_j) .$$

Since monthly total precipitation is not very near to normally distributed, there would be more interest in the variance of the mean or normal for n years

$\Sigma^{30} x_i/n$. This is $v(\Sigma^{30} x_i)/n^2$.

All of the formulas also apply where the x_i are the variables of different elements which are observed simultaneously or otherwise. This makes them useful in applied problems where the relationship with the applied variable is linear. For example, the outside air cooling load for an air conditioning system may be closely approximated by the linear relationship

$$q = -k_1 t + k_2 t' + k_3$$

where t is dry bulb temperature, t' is wet bulb temperature and the k's result from purely physical considerations. Since t and t' are nearly normally distributed around ordinary design levels, the variance of q is important. By means of the formulas given above

$$v(q) = k_1^2 v(t) + k_2^2 v(t') - k_1 k_2 r(t, t') .$$

The standard deviation of q is therefore $s(q) = \sqrt{v(q)}$ and the mean of q is given by

$$\bar{q} = -k_1 \bar{t} + k_2 \bar{t}' + k_3 .$$

Thus the normal distribution function $N[q; \bar{q}, s(q)]$ gives the probabilities for climatological predictions based on the distributions of t and t'.

Correlation analysis enters in other ways into climatological analysis, but most of these are closely connected with regression analysis. In fact, wherever relationships are desired between random variables, regression analysis is the proper tool to employ.

4.4.2.2 REGRESSION ANALYSIS

A regression is a functional relationship between an independent random variable and one or more dependent random variables. For a given set of values of the independent variables the regression gives a mean value of the dependent variable. Regression analysis is used in climatology to estimate the constants in functional relationships where these are not given directly as physical quantities. It is used for the establishment of relationships both between climatological series and between climatological series and applied variables. The latter may often be accomplished without climatological series by employing sets of values of the independent variables which are simply uncorrelated within each set and which vary over a range of values equal to the range of values in the climatological series. Thus the relationship between an applied variable and climatological variables can often be established with a short simultaneous record of the two sets of variables.

The first problem in regression analysis is to estimate the constants. This is commonly done by the least squares method applied to the residuals about the regression function obtained when the values of the independent variables have been substituted. The minimization of the residuals of the dependent variable alone requires that the values of the independent variables be fixed or be measured essentially without error. If this condition is not met biases will be introduced in the regression constants. As mentioned above the values of each variable must also be mutually independent. The least squares estimates have certain optimum properties which make the method a desirable one for fitting regressions.

The least square principle is very general and may be applied to almost any type of function. If the regression function is of the form

$$y = R(x_1, \dots, x_k; \beta_0, \beta_1, \dots, \beta_k),$$

the sum of the square residuals may be expressed as

$$\sum^n e_j^2 = \sum^n \left[y_j - R(x_{1j}, \dots, x_{kj}; \beta_0, \beta_1, \dots, \beta_k) \right]^2 = \sum^n (y_j - R_j)^2$$

where j runs over the sample values from 1 to n. The "least square" is obtained by minimizing the sums of squared residuals through differentiating and setting to zero. This gives the so-called normal equations

$$\frac{\partial}{\partial \beta_0} \sum^n (y_j - R_j)^2 = 0$$

$$\frac{\partial}{\partial \beta_1} \sum^n (y_j - R_j)^2 = 0$$

$$\vdots$$

$$\frac{\partial}{\partial \beta_k} \sum^n (y_j - R_j)^2 = 0 \quad .$$

The simultaneous solution of the normal equations gives the least squares estimates of $\beta_0, \beta_1, \dots, \beta_k$.

The regression function R can of course take an infinite variety of forms. As usual the linear forms are the most used. Linear regressions for one and two independent variables are considered here. More complicated functions may be analyzed by finding the proper normal equations by the process given above.

The linear regression equation in one independent variable is best written as

$$y = \alpha + \beta\,(x - \mu) \; .$$

Since measuring x from the mean μ makes the least squares estimate of α independent of that of β. The least squares estimates of α and β are

$$a = \bar{y}$$

and

$$b = \frac{\Sigma y(x-\bar{x})}{\Sigma\,(x-\bar{x})^2}$$

where the summation is over the sample values. The regression equation may then be written as

$$y_c = a + b(x-\bar{x})$$

Frequently it is known by physical means that $\alpha = 0$. In this case the regression equation becomes

$$y_c = bx.$$

There is now only one normal equation which gives the least squares estimate

$$b = \Sigma xy/\Sigma x^2.$$

It is often necessary to test the fitted regression for reality and for linearity. This is best done by the analysis of variance which is a technique devised by R. A. Fisher [35] to analyze the mean squares due to several components of the variation. For the linear regression given above it may be observed that there is a total variability of the y's which is divided into a variability accounted for by the regression, and a variability unaccounted for by the regression or residual variability. This may be expressed conveniently by an analysis of variance table:

ANALYSIS OF VARIANCE

	Sum of Squares	Degrees of Freedom	Mean Square
Accounted for by Regression	$\Sigma (y_c-\bar{y})^2 = Q_R$	1	$Q_R/1$
Unaccounted for by Regression (Residual)	$\Sigma (y-y_c)^2 = Q_T - Q_R$	n-2	$(Q_T - Q_R)/n-2$
Accounted for by Mean (Total)	$\Sigma (y-\bar{y})^2 = Q_T$	n-1	

"Degrees of freedom" is a term used by R. A. Fisher to express the whole number the sum of squares is to be divided by to give the mean square. When the mean has been estimated and therefore fixed only n-1 of the observations may then vary since once the mean is fixed and n-1 of the observations are chosen the nth value is automatically fixed by the fact that the n values must average to the mean. One degree of freedom is therefore taken up by fitting the mean or n-1 degrees of freedom remain for estimating the total mean square which involves the mean. It will not be needed and so is not computed. A further degree of freedom is lost in estimating b; hence there are n-2 degrees of freedom left for estimating the residual mean square. It is seen that the degrees of freedom of the components of variation in an analysis of variance table add to the total degrees of freedom. The sum of squares Q_T and Q_R are obtained from

$$Q_T = \sum^n y^2 - \left(\sum^n y\right)^2/n$$

and

$$Q_R = \left[\sum^n y(x-\bar{x}) \right]^2 / \sum^n (x-\bar{x})^2 \; .$$

The squared correlation coefficient is given by

$$r^2 = Q_R/Q_T.$$

From this it is seen that r^2 gives the proportion of the sum of squares or variability explained by the regression. Thus in using the correlation coefficient as a measure of the goodness of relationship it is best to square it to obtain a realistic estimate of the amount of variability the linear relationship explains. This will, of course, always be less than r.

The analysis of variance table also provides a test of significance of the linear regression. The statistic F is given by

$$F(1,\ n-2) = \frac{Q_R/1}{(Q_T - Q_R)/n-2} .$$

This is to be compared to an F or variance ratio table with 1 and n-2 degrees of freedom at the 0.10 or 0.05 significance level to determine whether a linear relationship really exists. Or, in other terms, whether the mean square explained by the linear regression is large enough in comparison to the residual mean square to decide that the regression is due to a real effect rather than to random sampling.

After learning about tests of significance or tests of hypotheses there has been some tendency to attribute too much importance to them. Thus it might be concluded that if a regression is significant this is all that is necessary, but this is far from true for there are two kinds of significance, practical and statistical. If a regression is not practically significant it is little use to test its statistical significance. However, if it is practically significant then the test of hypothesis must be made to test for reality. For the linear relation practical significance is measured by the squared correlation coefficient, i. e. by what proportion of the total variability is explained by the regression. It may be observed that if $r < 0.50$ i. e., $r^2 < 0.25$, the regression is of doubtful practical use.

If the sample values of the independent variable x can be divided into, say, four or more classes or columns with at least two y- values in each class, a second analysis of variance table may be prepared which will lead to a test of linearity. Such a test will tell whether it might be worth while to fit additional terms of higher degree.

With the data arranged into classes or columns with n_j in the jth column, the total variability may be divided into variability between column means arranged according to increasing x and variation within columns or residual. This leads to a second analysis of variance table:

ANALYSIS OF VARIANCE

	Sum of Squares	Degrees of Freedom	Mean Square
Column Means	$\sum_{j=1}^{k} \sum_{i=1}^{n_{.j}} n_{.j}(\bar{y}_{.j} - \bar{y})^2 = Q_M$	k-1	$Q_M/(k-1)$
Residual	$\sum_{j=1}^{k} \sum_{i=1}^{n_{.j}} (y_{ij} - \bar{y}_{.j})^2 = Q_T - Q_M$	n-k	$(Q_T - Q_M)/(n-k)$
Total	$\sum_{j=1}^{k} \sum_{i=1}^{n_{.j}} y_{ij}^2 - (\sum_{j=1}^{k} \sum_{i=1}^{n_{.j}} y_{ij})^2/n = Q_T$	n-1	

An F-test may be made on this table by computing

$$F(k-1,\ n-k) = \frac{Q_M/k-1}{(Q_T - Q_M)/n-k} .$$

If this F is not significant, then there is no relation between y and x, linear or otherwise. Had there been doubt about both linearity and whether there were a relationship at all, this test could have been made first.

It will be seen from the first analysis of variance table that the fitting of the linear regression leaves $Q_T - Q_R$ of the variability expressed as a sum of squares unexplained by the regression. If a more complicated function is to provide an improved fit, the improvement must come by removing or reducing this residual variability. Hence, this residual sum of squares may become the total for a third analysis of variance table. Since by the least squares principle a maximum amount of variability will be explained by fitting the column means, the residual from this fitting will be the smallest possible. If this residual is subtracted from the residual left by linear regression, the remainder is the amount explained by the column means over what was explained by the linear regression. The analysis of variance is as follows:

ANALYSIS OF VARIANCE

	Sum of Squares	Degrees of Freedom	Mean Square
Column Means about Regression	$Q_M - Q_R$	k-2	$(Q_M - Q_R)/k-2$
Column Mean Residual	$Q_T - Q_M$	n-k	$(Q_T - Q_M)/n-k$
Linear Regression Residual	$Q_T - Q_R$	n-2	

The test for linearity is now made by comparing

$$F(k-2,\ n-k) = \frac{(Q_M - Q_R)/(k-2)}{(Q_T - Q_M)/(n-k)}$$

to the value corresponding to k-2 and n-k degrees of freedom of an F- table. If this is significant the linear regression does not explain all of the variability and it may be desirable to fit higher degree terms.

Once the regression line has been found to be significant in both the practical and statistical senses the next interest will be in what errors are committed in its use. These may be obtained from the confidence interval for Y_c, the true value of y_c and the prediction interval for $(y - Y_c)$, the departure from the true regression. These are found by taking the variance of y_c and $(y - y_c)$ using the regression equation. The square roots of these variances give the required standard deviations. The standard deviation of y_c at x is given by

$$s\ [\,y_c(x)\,] = \left\{ \frac{Q_T - Q_R}{n-2} \left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2} \right] \right\}^{\frac{1}{2}}$$

The 0.90 confidence interval for y_c at a given value of x, $y_c(x)$, is given by

$$P \left\{ y_c(x) - t_{.05}(n-2)\ s\,[y_c(x)] < Y_c(x) < y_c(x) + t_{0.95}(n-2)\ s\,[\,y_c(x)\,] \right\} = 0.90$$

where $Y_c(x)$ is the true value of $y_c(x)$ and $t_{.05}(n-2)$ is the value at 0.05 probability from a table of "Student's" t. It should be remembered that $y_c(x)$ is a mean value, and the confidence interval is for this mean value; it is not the confidence interval for a particular predicted value. This must be obtained from the standard deviation of the observations of the y's with respect to the true regression line. This will include the variation in the points about the sample regression line plus the variation in y_c or the sample regression. This standard deviation at a given x is

$$s\,[\,y-Y_c(x)\,] = \left\{\frac{Q_T - Q_R}{n-2}\left[1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right]\right\}^{\frac{1}{2}}$$

and is sometimes called the standard error of a forecast in statistical language. The 0.90 prediction interval for a predicted value of y at the given x is then

$$P\left\{y_c(x) - t_{.05}(n-2)\,s\left[y-Y(x)\right] < y - Y_c(x) < y_c(x) + t_{.95}(n-2)\,s\left[y-Y(x)\right]\right\} = 0.90$$

where t is the same as in the confidence interval for Y_c.

As in the case of the air conditioning design cooling load [57] there may be two meteorological variables involved, but the equation connecting them with the design variable may *not* have its constants determined physically. In that case the problem is one of regression with two independent variables. Or, on the other hand, the simple linear regression may not account for all the variability and a quadratic might need to be added. This regression can be fitted in the same manner as the two-independent-variable linear regression.

The three dimensional estimated linear regression may be conveniently expressed by

$$x_{1c} = b_1 + b_2(x_2-\bar{x}_2) + b_3(x_3-\bar{x}_3)$$

in which case the estimate $b_1 = \bar{x}_1$. The b's are called the regression coefficients and are estimated from the normal equations which are the two-independent-variable case of the general normal equations given earlier. If the following general notation is used,

$$Q_{ij} = \sum^{n} (x_i-\bar{x}_i)(x_j-\bar{x}_j)$$

then

$$Q_{11} = \sum^{n} (x_1-\bar{x}_1)^2$$

and

$$Q_{12} = \sum^{n} (x_1-\bar{x}_1)(x_2-\bar{x}_2)$$

etc. The normal equations for two independent variables may then be expressed as

$$Q_{22}b_2 + Q_{23}b_3 = Q_{12}$$

$$Q_{23}b_2 + Q_{33}b_3 = Q_{13}$$

or, in matrix notation,

$$Q\begin{bmatrix} b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} Q_{12} \\ Q_{13} \end{bmatrix}$$

In this form it will be readily seen how the normal equations can be expanded for regressions of any number of dimensions. The b's, other than b_1, may be found directly from a simultaneous solution of the normal equations, but it will be found convenient to obtain the solution in terms of the Gaussian multipliers since they will be useful in extending the solutions to any number of independent variables. In terms of the Gaussian multipliers c_{ij} and in matrix notation the first equation is

$$\begin{bmatrix} c_{22} & c_{23} \\ c_{23} & c_{33} \end{bmatrix}\begin{bmatrix} Q_{22} & Q_{23} \\ Q_{23} & Q_{33} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = I$$

or in general for k variables

$$[C]\;[Q] = I$$

where the subscript one does not appear because the x's are taken about their means. Inverting gives

$$[C] = [Q]^{-1}$$

thus the matrix of the c's is the reciprocal matrix of the Q's. The b's are then found from the equation

$$\begin{bmatrix} b_2 \\ b_3 \\ \cdot \\ \cdot \\ b_{2k} \end{bmatrix} = [C]\begin{bmatrix} Q_{12} \\ Q_{13} \\ \cdot \\ \cdot \\ Q_{1k} \end{bmatrix}$$

If

$$D = Q_{23}^2 - Q_{22}Q_{33},$$

the c's are given by

$$c_{22} = Q_{33}/D,$$
$$c_{23} = Q_{23}/D,$$

and

$$c_{33} = Q_{22}/D.$$

The b's are then given by the equations

$$b_1 = C_{22}Q_{12} + C_{12}Q_{13}$$

and

$$b_2 = c_{12}Q_{12} + c_{33}Q_{13}.$$

The solutions for k variables depend on the calculation of the reciprocal matrix of the Q's. This is easily done by the method of pivotal condensation. While the method is simple to apply space does not allow it to be discussed here. For details see Rao [47] or Snedecor [50].

The tests of hypothesis on the regression are again facilitated by the analysis of variance. For this purpose two additional Q forms are needed

$$Q_{1.2\ldots k} = Q_{11} - b_2Q_{12} - b_3Q_{13} - \ldots b_kQ_{1k}$$

and

$$Q_{1.k} = Q_{11} - b_{1.k}Q_{1k}$$

where

$$b_{1.k} = Q_{1k}/Q_{kk};$$

$b_{1.k}$ is the simple regression coefficient between x_1 and x_k.

The multiple regression analysis of variance is then

Multiple Regression A/V

	S/S	D/F
Explained by x_2 and x_3	$Q_{11} - Q_{1.23}$	2
Unexplained by x_2 and x_3	$Q_{1.23}$	n-3
Total	Q_{11}	n-1

where S/S is sum of squares and D/F is degrees of freedom. The multiple regression coefficient is

$$r^2_{1.23} = (Q_{11} - Q_{1.23})/Q_{11}$$

and the significance test for the multiple regression is given by testing

$$F(2, n-3) = \frac{(Q_{11} - Q_{1.23})/2}{Q_{1.23}/(n-3)}$$

The three simple analyses are as follows:

A/V of x_1 on x_2

	S/S	D/F
Explained by x_2	$Q_{11} - Q_{1.2}$	1
Unexplained by x_2	$Q_{1.2}$	n-2
Total	Q_{11}	n-1

The simple correlation coefficient between x_1 and x_2 is then given by

$$r^2_{1.2} = (Q_{11} - Q_{1.2})/Q_{11}$$

and the F- test by

$$F(1, n-2) = \frac{(Q_{11} - Q_{1.2})}{Q_{1.2}/(n-2)} .$$

A/V of x_1 on x_3

	S/S	D/F
Explained by x_3	$Q_{11} - Q_{1.3}$	1
Unexplained by x_3	$Q_{1.3}$	n-2
Total	Q_{11}	n-1

$$r^2_{1.3} = (Q_{11} - Q_{1.3})/Q_{11}$$

$$F(1, n-2) = \frac{(Q_{11} - Q_{1.3})}{Q_{1.3}/n-2}$$

A/V of x_2 on x_3.

	S/S	D/F
Explained by x_3	$Q_{22} - Q_{2.3}$	1
Unexplained by x_3	$Q_{2.3}$	n-2
Total	Q_{22}	n-1

$$r^2_{2.3} = (Q_{22} - Q_{2.3})/Q_{22}$$

$$F(1, n-2) = \frac{(Q_{22} - Q_{2.3})}{Q_{2.3}/(n-2)}$$

From quantities already available in the above tables analyses may be made of the partial regression coefficient $r_{12.3}$ and $r_{13.2}$. These are respectively: the correlation between x_1 and x_2 after the influence of x_3 has been eliminated, and the correlation between x_1 and x_3 after the influence of x_2 has been eliminated. The analysis of variance tables again conveniently provide the terms for the correlation coefficients and their tests of significance. They also provide tests of whether the fitting of x_3 significantly reduces the residual after x_1 on x_2 has been fitted and whether x_2 significantly reduces the residual after x_1 on x_3 has been fitted. This is most important in determining the significance of an added variable, and as will be seen below, an added power.

Partial A/V of x_1 on x_3

	S/S	D/F
Increase due to x_3	$Q_{1.2} - Q_{1.23}$	1
Unexplained by x_2 and x_3	$Q_{1.23}$	n-3
Unexplained by x_2	$Q_{1.2}$	n-2

$$r^2_{13.2} = (Q_{1.3} - Q_{1.23})/Q_{1.2}$$

The test of this partial correlation coefficient and whether x_3 adds significantly after x_1 on x_2 has been fitted is given by testing

$$F(1, n-3) = \frac{Q_{1.2} - Q_{1.23}}{Q_{1.23}/(n-3)} .$$

Partial A/V of x_1 on x_2

	S/S	D/F
Increase due to x_2	$Q_{1.3} - Q_{1.23}$	1
Unexplained by x_2 and x_3	$Q_{1.23}$	n-3
Unexplained by x_3	$Q_{1.3}$	n-2

$$r^2_{12.3} = (Q_{1.3} - Q_{1.23})/Q_{1.3}$$

The test of this coefficient and of x_2 after x_1 on x_3 has been fitted is given by

$$F(1, n-3) = \frac{Q_{1.3} - Q_{1.23}}{Q_{1.23}/(n-3)} .$$

By observing the scheme of formation of the analysis of variance tables for two independent variables the analyses may be extended to any number of variables. The analysis for the second degree equation

$$x_{1c} = b_1 + b_2 x + b_3 x^2$$

can be accomplished using the above methods by simply substituting the squares of the x values for x_3 and similarly substituting higher powers for further linear terms. The only difference is that b_1 will now be obtained from

$$b_1 = \bar{x}_1 - b_2\bar{x}_2 - b_3\,\Sigma\, x^2/n \quad .$$

The Gaussian multipliers will now be found to be a great convenience in obtaining the standard deviations of x_{1c} and $(x_1 - x_{1c})$ from which the confidence bands may be obtained. Let X_{1c} be the true value of x_{1c} for a pair (x_2, x_3). The standard deviations for the three-dimensional regression are then given by

$$s(x_{1c}) = \left\{\frac{Q_{1.23}}{n-3}\left[\frac{1}{n} + c^2_{22}(x_2-\bar{x}_2)^2 + c^2_{33}(x_3-\bar{x}_3)^2 + 2c_{23}(x_2-\bar{x}_2)(x_3-\bar{x}_3)\right]\right\}^{\frac{1}{2}}$$

for particular pairs of (x_2, x_3). The standard error of a prediction is given by

$$s(x_1-X_{1c}) = \left\{\frac{Q_{1.23}}{n-3}\left[1 + \frac{1}{n} + c^2_{22}(x_2-\bar{x}_2)^2 + c^2_{33}(x_3-\bar{x}_3)^2 + 2c_{23}(x_2-\bar{x}_2)(x_3-\bar{x}_3)\right]\right\}^{\frac{1}{2}} \quad .$$

As in the simple two-dimensional case the confidence band may be determined by employing "Student's" t with (n-3) degrees of freedom. For the case of k independent variables the standard deviations become

$$s(x_{1c}) = \left\{\frac{Q_{1.2\,\ldots\,k}}{n-k}\left[\frac{1}{n} + \sum_{i=2}^{k}\sum_{j=2}^{k} c_{ij}(x_i-\bar{x}_i)(x_j-\bar{x}_j)\right]\right\}^{\frac{1}{2}}$$

where the summation is such that the cross product terms occur twice and

$$s(x_1-X_{1c}) = \left\{\frac{Q_{1.2\,\ldots\,k}}{n-k}\left[1 + \frac{1}{n} + \sum_{i=2}^{k}\sum_{j=2}^{k} c_{ij}(x_i-\bar{x}_i)(x_j-\bar{x}_j)\right]\right\}^{\frac{1}{2}}$$

"Student's" t for determining the confidence intervals will in this case have (n-k) degrees of freedom.

4.5 SELECTED APPLICATIONS OF STATISTICAL METHODS

More and more, statistical methods are being utilized in analyzing weather measurements and frequencies. Only a few additional examples, plus references to more complete descriptions in the literature, will be cited here.

4.5.1 CONTINGENCY TABLES

Contingency tables and the related χ^2 test for determining if the cell frequencies depart significantly from the expected number of occurrences in each class are illustrated in tables 15 and 16. The former shows frequencies of wind in a two-way classification by direction and speed. In the last three lines, table 15 also lists the estimates of the wind distribution parameters as defined. Appropriate totals for each row and column are included.

Table 15. Winds Aloft Summary by Direction and Speed

U. S. DEPT. OF COMMERCE
WEATHER BUREAU

{PERCENTAGE / FREQUENCY} OF DIRECTIONS BY SPEED GROUPS

WINDS ALOFT SUMMARY

94326 (STATION) ALICE SPRINGS AUSTRALIA (STATION NAME) APR (MO OR SEASON) RAWINS (TYPE OF OBSERVATION) 35000 (LEVEL) FEET

50 51 52 53 54 55 56 57 58 (YEARS)

SPEED MPH / KNOTS / KPH — DIR.	1-4 / 1-9 / 1-10	5-10 / 10-19 / 11-22	11-15 / 20-29 / 23-33	16-20 / 30-39 / 34-45	21-25 / 40-49 / 46-56	26-30 / 50-59 / 57-68	31-38 / 60-74 / 69-85	39-51 / 75-99 / 86-114	52-77 / 100-149 / 115-172	78-102 / 150-199 / 173-229	≥ 103 / ≥ 200 / ≥ 230	TOTAL ALL OBS. — OBS.	TOTAL ALL OBS. — %	SPEED (KNOTS) — SUM	SPEED (KNOTS) — MEAN
N															
NNE															
NE															
ENE															
E	1											1	1.0	6	5.8
ESE															
SE															
SSE															
S	1											1	1.0	4	3.9
SSW			1	1		1	1					4	3.8	169	42.3
SW		1		1	2	5	1					10	9.6	462	46.2
WSW		3	1	2	6	4	5	1	1			23	22.1	1121	48.7
W	1	2	3	5	5	9	10	8	2			45	43.3	2562	56.9
WNW				1	3	4	1	3				12	11.5	670	55.8
NW		1	1	1	1		3					7	6.7	321	45.8
NNW						1						1	1.0	51	50.5
CALM															
TOTALS	3	7	6	11	17	24	21	12	3			104	100.0	5365	51.6
PERCENT	2.9	6.7	5.8	10.6	16.3	23.1	20.2	11.5	2.9			104	100.0		
MEAN SPEED (KNOTS) BY GROUP	5.8	15.8	25.9	35.5	44.1	52.7	65.2	81.7	108.8						

θ 265	V_r 46.7690	σ_x 30.869	ΣXY 19563.416	ΣV² 325634.647	$n\sigma_y/\Sigma X$ .438-	σ_v/V_r .86	σ_u 25.455	σ_s 20.069	σ_v 21.776
n 104	ΣX/n 46.621-	σ_x 23.157	SUM OF E. COMPONENTS (ΣX) 4848.627-	ΣX² 281285.007	$n\sigma_x/\Sigma X$ .497-	V_r/σ_v 1.42	r -.091	a 1.169	
ψ 162	ΣY/n 3.712-	σ_y 20.412	SUM OF N. COMPONENTS (ΣY) 386.095-	ΣY² 44349.633	$n\sigma_y/\Sigma Y$ 5.498-	$V_r/\bar{V}$ .91	ΣV 5365	$\bar{V}$ 51.6	

σ_x Standard deviation of east components
σ_y Standard deviation of north components
σ_v Standard vector deviation of wind velocity
r Correlation coefficient of north and east components
$\bar{V}$ Average wind speed
V Scalar Wind Speed

σ_u Standard deviation of wind components along the major axis of the distribution
σ_v Standard deviation of wind components perpendicular to the major axis of the distribution
ψ Angle of rotation of the major axis of the wind distribution counter-clockwise from E-W direction
θ Resultant wind direction
V_r Resultant wind speed
σ_s Standard deviation of wind speeds
a σ_u/σ_v

Table 16. Contingency Table of Frequency of Occurrence of Thunderstorms with High Winds at Williamsport, Pa., During July, August, and September (Ten Year Period)

	T	NT	Total
HW	48(15)	24(57)	72
NHW	142(175)	706(673)	848
Total	190	730	920

where HW indicates High Wind

NHW indicates No High Wind

T indicates Thunderstorm

NT indicates No Thunderstorm

The simple two-way classification shown in table 16 makes it possible to judge if thunderstorms are associated with concurrent high winds. The parenthetical frequencies are obtained by multiplication of the row and column subtotals and division by the grand total. The occurrence of thunderstorms with high winds is greater than the expected frequency and the occurrence of no high winds with no thunderstorms is greater than expected. The differences between the observed and the expected frequencies are 33 in all cells. The sum of these differences squared and divided by their respective theoretical or expected frequencies is

$$\chi^2 = (32.5)^2 \left(\frac{1}{15} + \frac{1}{57} + \frac{1}{175} + \frac{1}{673}\right) = 96.5$$

We use 32.5 instead of 33 to correct for the biased probability of χ^2 which results from relatively small sample numbers. Actually, our sample is large enough that the bias is extremely small but the reduction in absolute difference between the observed and expected frequencies is included for illustration. There is only one degree of freedom in table 16 and the value of $\chi^2 = 96.5$ is seen to be much greater even than the value expected with a probability of 0.001. There seems to be little reasonable doubt that the relationship between high winds and thunderstorms is significant.

4.5.2 WINDS AS VECTORS

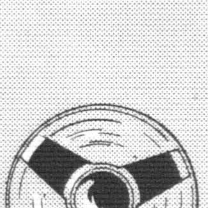
As seen above, wind is described in terms of both direction and magnitude, i.e., wind can be described as a vector. The square of a vector is a scalar; therefore, the vector variance and the vector mean (the mean resultant) are two important wind parameters which can be treated fairly easily. To obtain the vector mean of the wind, individual wind vectors are summed and averaged. To obtain the vector variance of the winds, the wind speeds are squared and summed and the square of the vector mean is subtracted from this sum. Although the vector variance is constant for a particular sample, no real knowledge of the wind distribution is known unless two additional facts are determined or assumed. If the variances along any set of orthogonal axes are equal and there is no correlation between the components, the bivariate circular normal distribution applies. A circle centered at the origin of the vector mean with a radius equal to the vector standard deviation will contain 63% of the wind observations. If, however, the component variances are not equal or the components are correlated, the wind distribution is elliptical. This case and other problems encountered in the vector analysis of winds have been described by Crutcher[60, 31, 32] and Brooks and Carruthers[29,30] in some detail.

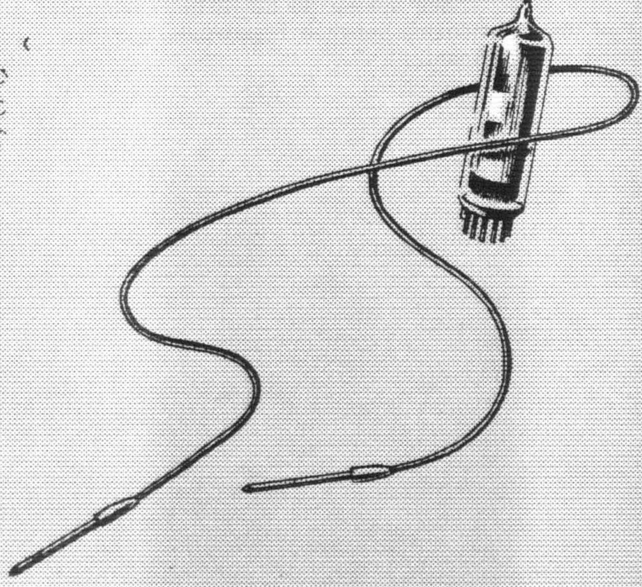
4.5.3 FOURIER ANALYSIS

The methods of Fourier analysis are described in many textbooks. Today the laborious computations required are done expeditiously by high-speed computers so their utilization is much more feasible in describing periodic phenomena; for example, the seasonal changes in temperature or the diurnal cycle in temperature and pressure.

4.5.4 SPECTRUM ANALYSIS

Since World War II a new research tool has been introduced in the literature, primarily by Tukey and Blackman [28, 58], and Panofsky and McCormick [44]. This power spectrum analysis is applicable when the physical form of the periodic tendencies is not known. So far, in meteorology, only suspicions of real periodicity have been observed; most perturbations are not significant. One such study is described by Landsberg, Mitchell, and Crutcher [40]. The theory and applications of power spectrum analysis and the related serial correlation approach are too advanced for description in this presentation of simpler statistical methods.





Chapter 5

MACHINES

Processing and
Computing

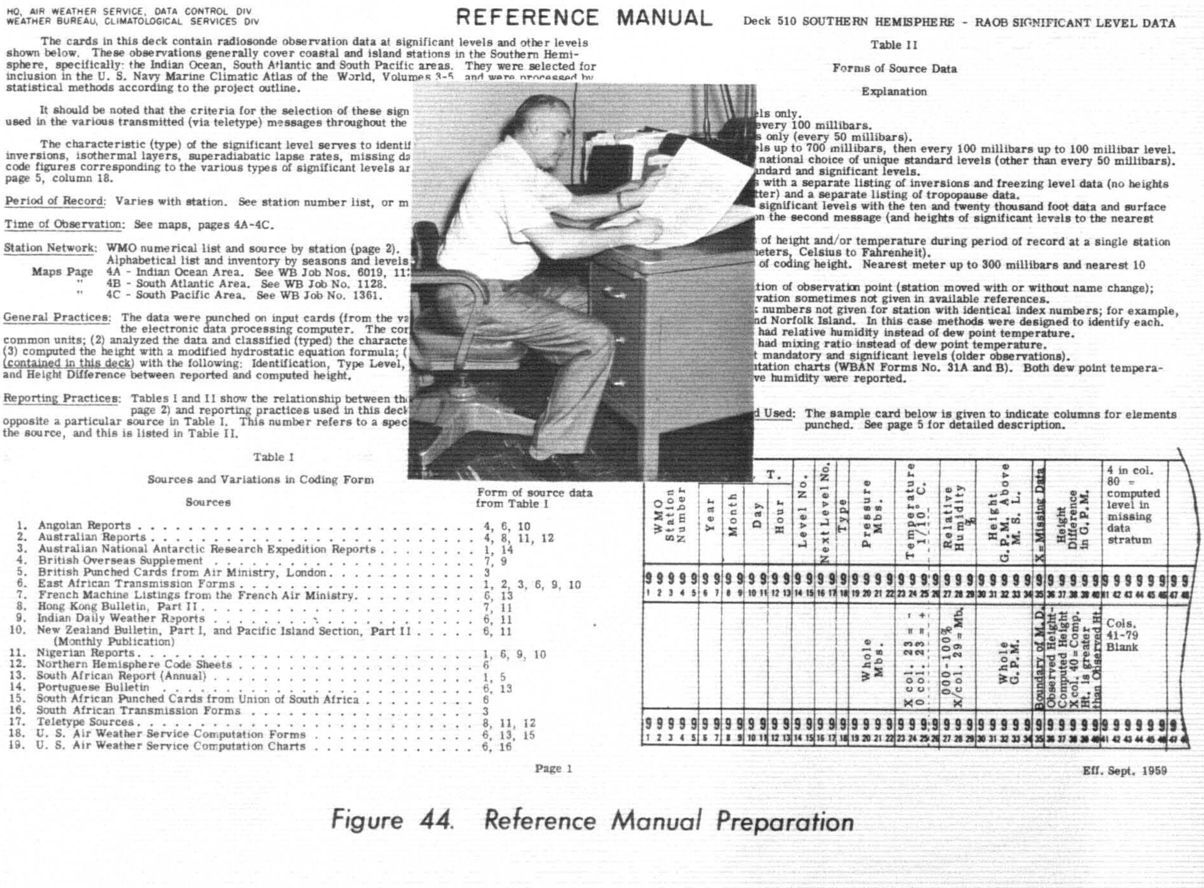
5.0 MACHINES

After Hollerith invented and successfully employed semi-automatic equipment to process the mass of data from the 1890 census, businessmen and scientists eventually realized the advantages offered by such machines in other fields. Suitable equipment became available in the 1930's and the systematic mechanical reduction of weather data began. This application of business machines to the processing and statistical treatment of weather observations has contributed materially to the advance of climatology as a science during the past twenty years. Conversely, new developments in data processing machines have resulted from the need to solve complex climatological and meteorological problems.

5.1 THE PUNCHED CARD SYSTEM

Punched cards are the means of separating weather data into individual recordings of one element or more per observation. The meteorologist or climatologist selects these cards in as many combinations of elements and periods of record as may be necessary to solve a problem. The use of machines to accomplish this climatological work is comparable to a series of language translations. A scientist or business client usually refers a problem involving meteorological data to a meteorologist. After definition and analysis of pertinent weather factors, which may involve considerable inter-communication, operational language is translated into meteorological terms. The meteorologist applies his knowledge of the physical application of weather to the proposed operation. If an immediate solution approach is not apparent, various alternative suggestions can be presented to the client; probability statements and measures of their reliability often can be provided. If the necessary data are not in punched card form and the specifically desired raw data do not exist, the meteorological problem may become an observational problem. Data from a nearby location or from another period of time may be used. This substitution of data may be accomplished using careful meteorological judgment. Such substitution can be justified only if the job requirements are clearly outlined. It is sometimes necessary to modify the requirements of a job to fit the form of existing data. Such problems require an observational specialist who speaks both the language of the meteorologist and of the machine technician. All such changes are discussed with the client to insure a high degree of accuracy and confidence in the end result.

The machine technician speaks the language of cards, codes, digits, and precise logical relationships which contain many exceptions. His is the last step in the series of translations as he speaks "to the machine". He organizes the flow of input data and machine operations to achieve the desired results. The machines used may be simple electro-mechanical punched card equipment or large electronic computers utilizing punched cards or varying kinds of tape input. This technician may be referred to as a project planner or "programmer".


HQ, AIR WEATHER SERVICE, DATA CONTROL DIV
WEATHER BUREAU, CLIMATOLOGICAL SERVICES DIV

REFERENCE MANUAL

Deck 510 SOUTHERN HEMISPHERE - RAOB SIGNIFICANT LEVEL DATA

The cards in this deck contain radiosonde observation data at significant levels and other levels shown below. These observations generally cover coastal and island stations in the Southern Hemisphere, specifically: the Indian Ocean, South Atlantic and South Pacific areas. They were selected for inclusion in the U. S. Navy Marine Climatic Atlas of the World, Volumes 3-5 and were processed by statistical methods according to the project outline.

It should be noted that the criteria for the selection of these sign used in the various transmitted (via teletype) messages throughout the

The characteristic (type) of the significant level serves to identif inversions, isothermal layers, superadiabatic lapse rates, missing da code figures corresponding to the various types of significant levels ar page 5, column 18.

Period of Record: Varies with station. See station number list, or m

Time of Observation: See maps, pages 4A-4C.

Station Network: WMO numerical list and source by station (page 2).
Alphabetical list and inventory by seasons and levels
Maps Page 4A - Indian Ocean Area. See WB Job Nos. 6019, 11
" 4B - South Atlantic Area. See WB Job No. 1128.
" 4C - South Pacific Area. See WB Job No. 1361.

General Practices: The data were punched on input cards (from the va the electronic data processing computer. The cor common units; (2) analyzed the data and classified (typed) the characte (3) computed the height with a modified hydrostatic equation formula; ((contained in this deck) with the following: Identification, Type Level, and Height Difference between reported and computed height.

Reporting Practices: Tables I and II show the relationship between th page 2) and reporting practices used in this deck opposite a particular source in Table I. This number refers to a spec the source, and this is listed in Table II.

Table I

Sources and Variations in Coding Form

Sources	Form of source data from Table I
1. Angolan Reports	4, 6, 10
2. Australian Reports	4, 8, 11, 12
3. Australian National Antarctic Research Expedition Reports	1, 14
4. British Overseas Supplement	7, 9
5. British Punched Cards from Air Ministry, London	3
6. East African Transmission Forms	1, 2, 3, 6, 9, 10
7. French Machine Listings from the French Air Ministry	6, 13
8. Hong Kong Bulletin, Part II	7, 11
9. Indian Daily Weather Reports	6, 11
10. New Zealand Bulletin, Part I, and Pacific Island Section, Part II (Monthly Publication)	6, 11
11. Nigerian Reports	1, 6, 9, 10
12. Northern Hemisphere Code Sheets	6
13. South African Report (Annual)	1, 5
14. Portuguese Bulletin	6, 13
15. South African Punched Cards from Union of South Africa	6
16. South African Transmission Forms	3
17. Teletype Sources	8, 11, 12
18. U. S. Air Weather Service Computation Forms	6, 13, 15
19. U. S. Air Weather Service Computation Charts	6, 16

Page 1

Table II

Forms of Source Data

Explanation

ls only.
every 100 millibars.
s only (every 50 millibars).
ls up to 700 millibars, then every 100 millibars up to 100 millibar level.
national choice of unique standard levels (other than every 50 millibars).
ndard and significant levels.
with a separate listing of inversions and freezing level data (no heights
ter) and a separate listing of tropopause data.
significant levels with the ten and twenty thousand foot data and surface
n the second message (and heights of significant levels to the nearest
of height and/or temperature during period of record at a single station
eters, Celsius to Fahrenheit).
of coding height. Nearest meter up to 300 millibars and nearest 10
tion of observation point (station moved with or without name change);
vation sometimes not given in available references.
numbers not given for station with identical index numbers; for example,
nd Norfolk Island. In this case methods were designed to identify each.
had relative humidity instead of dew point temperature.
had mixing ratio instead of dew point temperature.
t mandatory and significant levels (older observations).
tation charts (WBAN Forms No. 31A and B). Both dew point temperave humidity were reported.

d Used: The sample card below is given to indicate columns for elements punched. See page 5 for detailed description.

Eff. Sept. 1959

Figure 44. Reference Manual Preparation

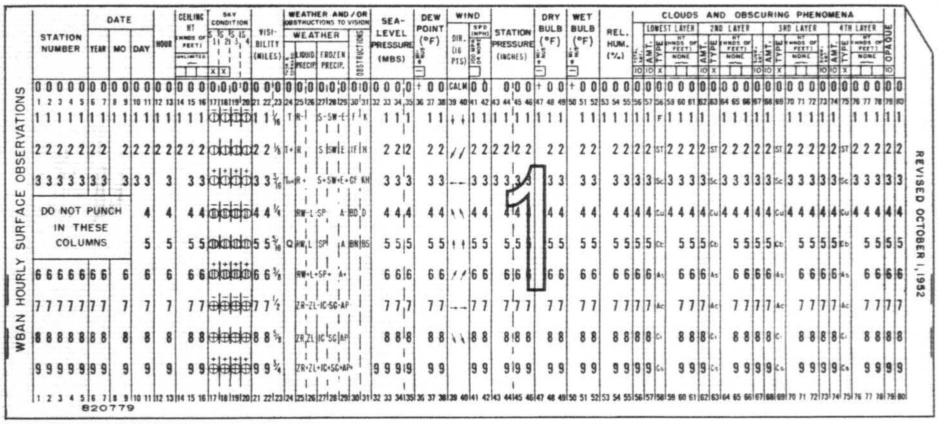


Figure 45. Surface Observation Punch Card

No link in this chain of communication is less important than any other. The specialized knowledge required is too complex to be absorbed by one individual; therefore, each step in planning the statistical results produced by machines is reviewed by various specialists, maximizing the chances that the problem is adequately understood and its solution properly achieved.

5.1.1 PUNCHED CARD FORMAT

The punch card is essentially a paper card of uniform size containing 80 columns in which coded digital or alphabetic data may be punched. Through these punched rectangular holes in the cards, electrical contacts are made to actuate various machines. These cards are punched at central locations by the weather services of the United States and many foreign countries. An example of a surface observation in punched card form is shown in figure 45. Various card forms have been designed to fit the individual types of basic observations. More than 200 different punched card formats (decks) of weather elements are on file in the punched card library at the NWRC. These have been arranged to fit the characteristics of original data to be punched. It is difficult to reduce the number of formats because of variations in the climates of specific areas and certain non-standard practices used in international codes.

The power of the punched card system lies in three related characteristics:

1. One observation, or a specific portion, is recorded on each card; this is a "unit" of record.
2. The uniformity of hole locations allows a consistent form for the data. A hole in the "1" row of card 1, column 27, indicates an observation of light rain and all cards punched similarly within that card deck mean the same thing.
3. Because of this uniformity, the cards can be analysed or "read" mechanically, rather than visually, at relatively high speeds.

The above characteristics lend themselves to verification and analysis of observational data. Unreasonable entries, as determined by observational rules, may be selected for later review by qualified meteorological technicians without interrupting a high-speed machine operation.

Figure 46. Card Punching

5.1.2 ELECTRO-MECHANICAL DATA PROCESSING METHODS

A machine called a "sorter" is used to automatically arrange punched cards in any desired sequence. Analytical requirements dictate the specific pattern of data arrangement; for example, the sequence may be chronological or numerical for a specific weather element.

Many additional operations involving mechanical reading and automatic control are available in standard and specialized equipment. Most of these fall under the heading of "tabulating". This tabulating potential ranges from continuous and simultaneous summation of separate weather elements, at 150 observations per minute, to obtaining a frequency distribution of 60 class intervals of a combination of elements, at 450 observations per minute. Weather elements may be evaluated at more than one location simultaneously, or with established time lags. Summary cards may also be punched by a machine connected to the tabulating machine. These data may be used for further computation. For easier analysis, printed listings of summarized data may be obtained simultaneously at the rate of 18,000 characters per minute on lines containing 120 characters. The application of conventional machine methods is as versatile as the data and the imagination of the project planner will allow. With the exception of the card punch machine and the sorter, the equipment mentioned above depends on removable "plugboards" for control. These control panels furnish a method of quickly and efficiently completing temporary electrical circuits within the machine. Electrical impulses are transmitted through the holes punched in cards and these impulses are routed to the proper functional controls to perform the required analysis. Recurring tasks may be accomplished easily by interchanging these plugboards. Non-routine tasks requiring complex wiring patterns on the panel take considerably longer.

Figure 48. Collator

Figure 47. High Speed Sorting

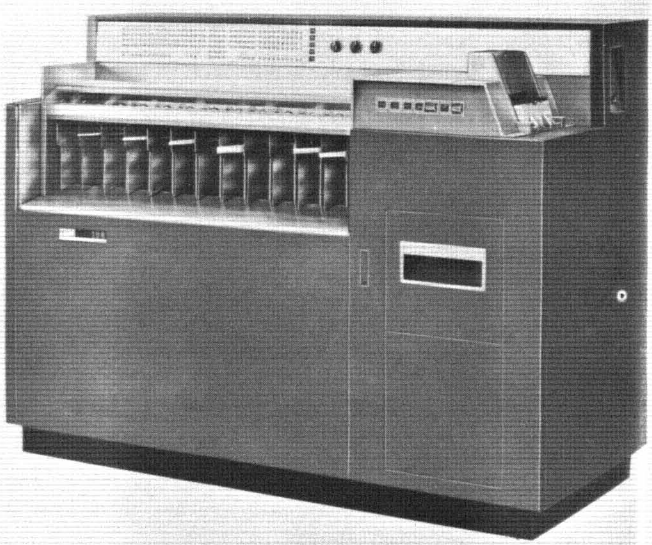


Figure 49. Card Editing Machine

Figure 50. Wiring a "Plugboard"

Figure 51. Reproducing Punched Cards

Figure 52. Accounting Machine

5.2 ELECTRONIC DATA PROCESSING METHODS

Much that has been written in the past few years about automation tends to obscure the fact that the most advanced electronic systems have basically the same functions as the simplest punched card machines - input, processing, and output. The capacity, versatility, and logical ability of the large, modern computer are so great that its basic functions are almost lost in the consideration of its scope and possibilities. Punched card support equipment is necessary even with a medium or large-scale computer system. The simple card punching machine has not been matched economically. Certain types of data which are produced by analogue means, or which can be recorded and read graphically, can be converted to high-speed media by specialized equipment. However, the bulk of weather data used in climatology is still produced manually, and the cold facts of budgets require that the first translation be to the punched card.

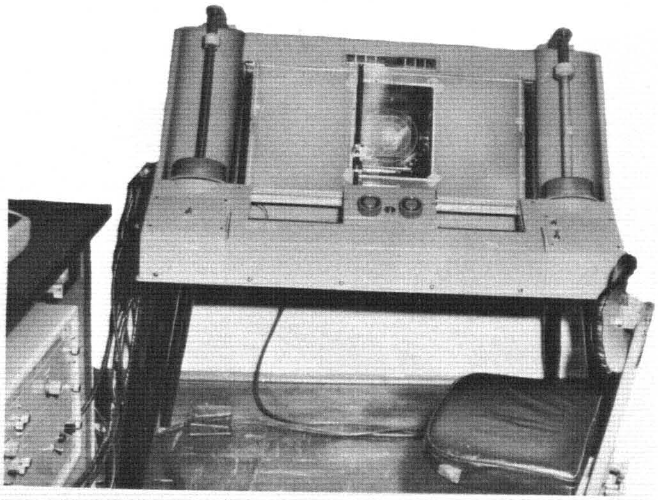


Figure 53. Graph Reading Device

572771 O - 60 - 6

Magnetic tape and microfilm are the two major media produced from electronic technology for high-speed utilization of weather data. The use of various tapes has been developed by the manufacturers of different types of computing equipment. The use of microfilm as a storage and input medium for weather data has been developed through the joint efforts of the United States weather services, the Bureau of Standards, and the Bureau of the Census.

An assembly of two machines, one named FOSDIC (for Film Optical Sensing Device for Input to Computers), has been developed. The other component is a 16-mm. microfilm camera fitted to a punched card feed assembly which permits microfilming of cards at the rate of about 24,000 per hour. This creates a reduction in file space of 150 to 1 and produces a film image which can be used as a direct input medium to the FOSDIC. This machine can re-create the punched cards at the rate of 100 per minute, or can selectively scan up to 10 card columns and punch only cards meeting certain specifications. The use of film as an input medium offers the following advantages: economy, compactness, permanence, and visual readability (when magnified). The disadvantages include: difficulty in correcting errors in the punched observations after they are filmed, and inflexibility in the sequence of the filmed data.

A modified FOSDIC is being developed which will produce the required configuration of electronic impulses for direct entry into a computer or it can produce a magnetic tape from the film. The tape can then be used on other more conventional high-speed computers. The punched card is reproduced on film as a direct image, and on magnetic tape as a symbolic image.

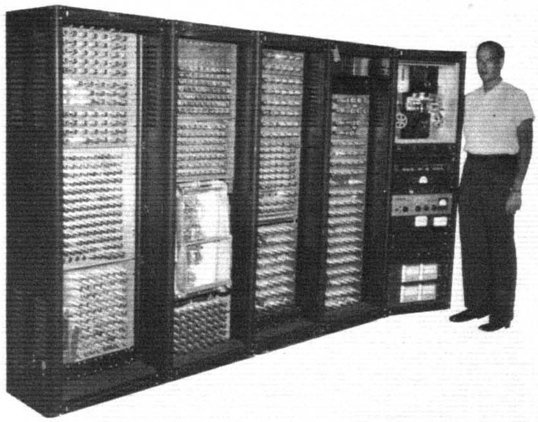


Figure 55. Film Optical Sensing Device for Input to Computers (FOSDIC)

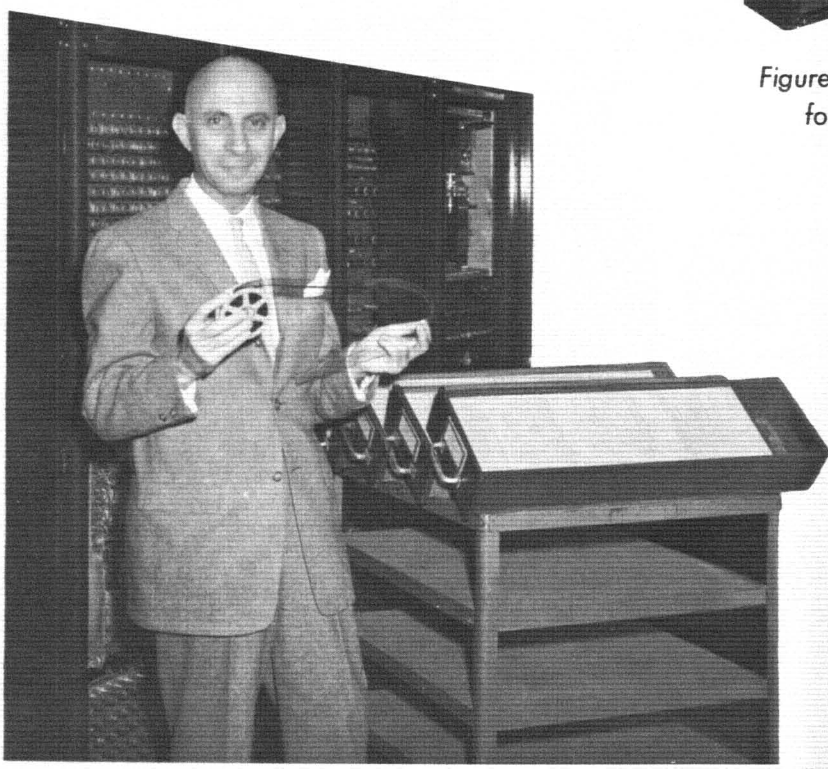


Figure 54. Director, WB Climatology Displays the Reduction of Punched Cards to Microfilm

Figure 56. FOSDIC Punched Card Filmer

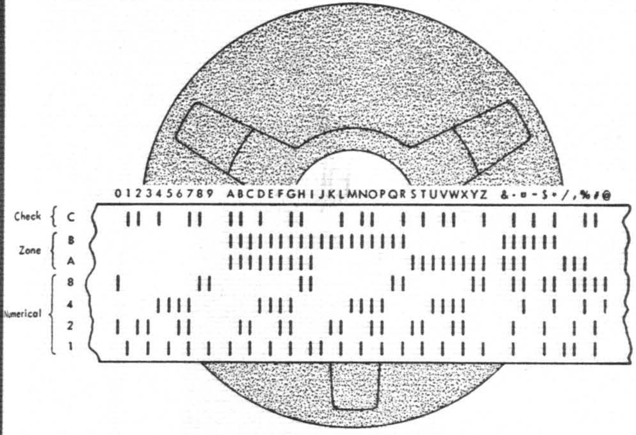


Figure 57. Magnetic Tape Showing "Seven Level Code"

Magnetic tape, like punched paper tape, comes in a continuous strip usually 1/2 inch wide and made of plastic or metal. All tape systems (and cards too, in a sense) utilize some form of binary notation: a position on tape (or in the card) is either magnetized (or punched) or not. The relationship of such binary bits on the tape determines the tape "code". A "seven-level" code is used by the IBM Type 705 employed by the Air Weather Service, for example. Four channels, representing 1, 2, 4, and 8, are required for configuration of the digits 0 to 9. Two additional channels, coded to correspond with the zone or high punches of the punched card, make possible the coding of alphabetic and special characters. The seventh channel is used internally by the computer as a checking device to assure that the characters represented are read and written correctly. An example of magnetic tape is shown in figure 57.

Figure 58. Card Reading Equipment

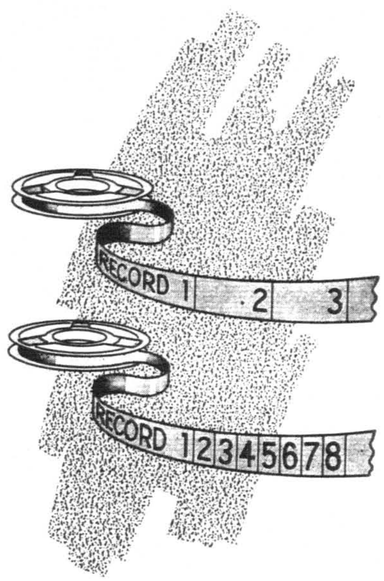


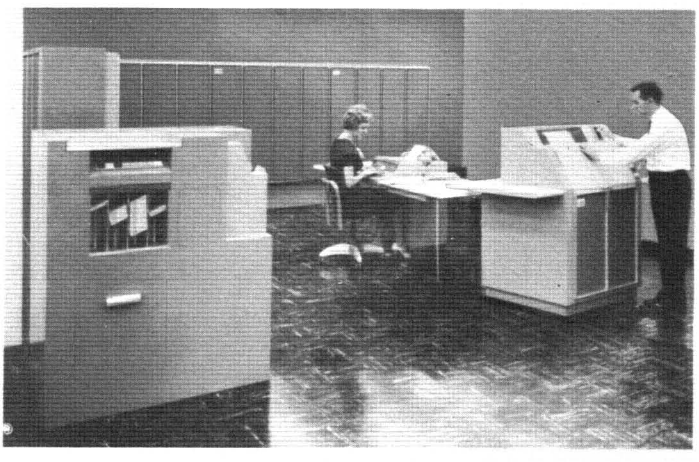
Figure 59. Combining Records on Electromagnetic Tape

To produce a magnetic tape, punched cards are passed through a card reader, which is connected with a tape unit, capable of "writing" the digits on tape. Some flexibility is allowed at this step, in that card formats may be altered, position by position, but no data analysis or alteration of code figures is possible. In the usual application, a tape is an exact copy of the punched cards read. On present equipment, this is accomplished at the rate of 250 cards per minute (333 digits per second for fully punched 80 column cards). Present day magnetic tapes can be written and read by the tape drives at the rate of 62,500 digits per second; even faster equipment is being designed.

The original magnetic tape has a gap following each image or observation recorded magnetically. The tape reader must stop at each gap and this causes a reduction in the speed of making a magnetic tape. Greater speed and data compactness may be accomplished by using the computer itself to make a "conversion" from a single observation to "families" of observations. To do this, the single images on the first magnetic tape are grouped into larger "records". Then the tape is run through the computer and a second "permanent" magnetic tape is made. The grouped images occupy half as much space on the new magnetic tape and the speed of reading the images is greatly accelerated when the computer reads groups of images together.

A primary advantage achieved in recording observations on magnetic tape lies in the flexibility of tape as an input and output medium. Data can be rearranged in content or in sequence. Observations can be standardized and subsequent programming made far more simple. New observations can be added and the rate of effective input can be accelerated. When data are no longer needed, the tapes can be stored compactly or erased for re-use if they have no archival value. More than 50,000 observations, or a 20-drawer cabinet full of punched cards, may be contained on one 12-inch reel of 1/2 inch magnetic tape.

Figure 60. Electronic Data Processing Systems (Computers)



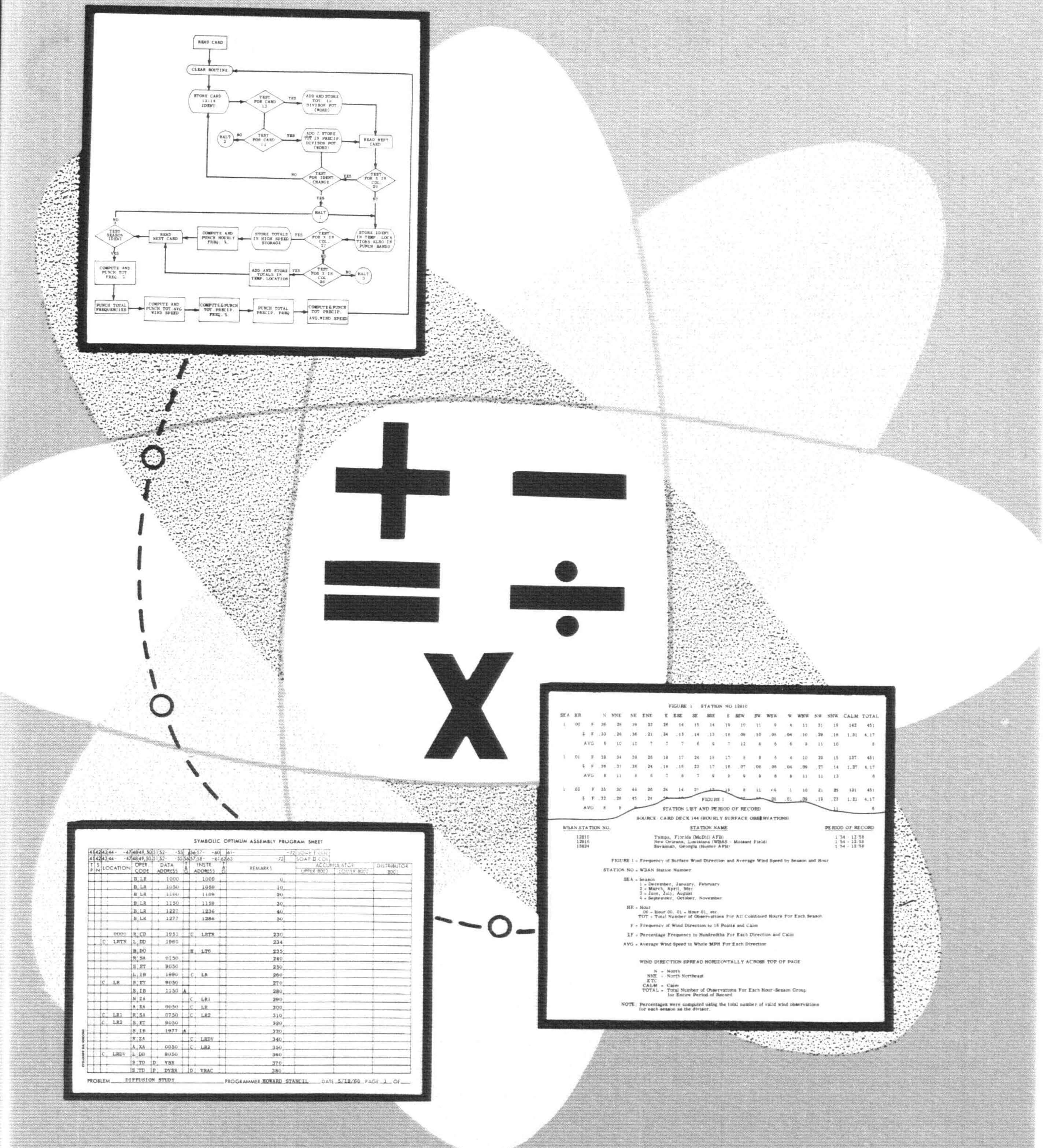


Figure 61. Schematic Diagrams and Machine Listing of a Typical Machine "Program"

Production of Marine Climatic Atlas of the World

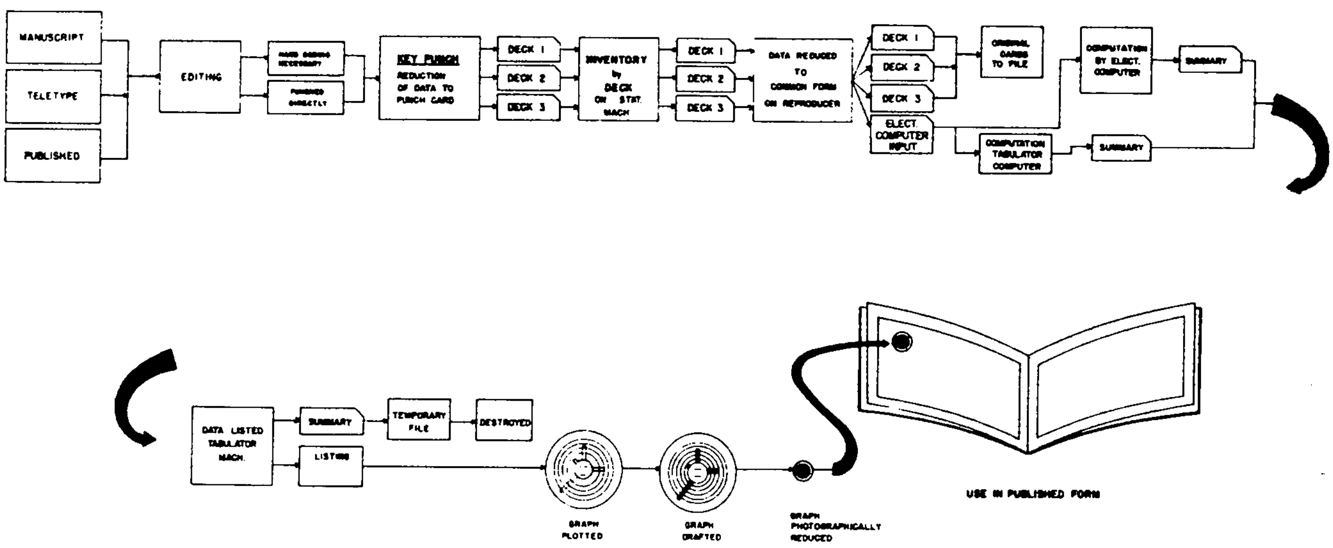


Figure 62.

Electronic computers can perform all climatological operations which are accomplished by conventional punched card equipment. The main purpose of the computer is to perform complex and/or voluminous operations at high speeds. Certain simple tasks, for example, sorting of data, can be accomplished more economically by conventional methods. However fast, the complexity of the computer method necessarily involves many steps, especially in a job of large volume. The "sorter", for example, is a relatively simple, one-operation machine which serves its single purpose efficiently. Practically all machines operate more efficiently if the cards are in some predetermined order and the sorter achieves just that.

It is interesting to compare the philosophy of data processing and the major operational differences between the punched card and electronic systems. The punched card system, by the nature of the equipment, operates on a "parallel" concept. The punched card passes through the machine "all at once", i. e., all fields or elements of the observation at once. All operations which activate tabulation, calculation, or selection are based on the timing of the card as it passes the reading station of the machine. For example, all of the "9's" (refer to the card in figure 45) which are contained in the card are read simultaneously regardless of the meaning or element. The philosophy of wiring the pluggable control panels demands a full knowledge of timing of the card, the times when certain relays are available for action and when certain impulses will be emitted. In parallel, any operation which acts upon more than one card column must act upon them simultaneously. If one action must follow another, it usually requires a separate control panel and a subsequent pass of the data through the machine. This creates a series of operations, in punched card work, going from one type of machine or operation to another. The "program" or set of instructions to be followed is under human control and subject to human frailties.

The philosophy of modern computers, whether using card or tape input, rests on a "stored program" - a serial concept. To obtain a machine program, the problem is first analyzed, then diagrammed into a flow chart. Each step in the flow chart represents some data condition to be expected, or an instruction representing the course of action the machine should follow. This chart allows review of the problem as a whole before any machine time is used. Machine instructions are then written as a series of specified letters, numbers, and characters, intelligible only to a programmer and the specific machine programmed. These instructions are punched on various media such as paper tape, punched cards, or magnetic tape. This program is stored in the high-speed "memory" element of the machine and when the job is run, the machine controls it.

Certain short cuts have been designed to aid programmers. Once a standard operation has been programmed, for example, obtaining square root, the numerical analysis need not be repeated. An autocoder system is used whereby a few symbols call up the necessary detail to calculate square root.

The power of the computer lies not only in its ability to perform high-speed arithmetic calculations, but especially in its fulfillment of "logical decisions". These may be transferring, comparing, or shifting of data, in addition to the input-output operations, depending on the meteorologist's needs. Quite often useful but unrequired operations can be combined with a current job at no extra cost for computer time. The data to be worked, the set of instructions, and the final tabulations are all stored in the memory of the machine for as long as necessary. Answers to problems are written on magnetic tape or printed out. Sometimes the final printing or punching of results is accomplished from magnetic tape without using the computer. This results in a less expensive operation.

Data processing in business and science is the fastest growing endeavor of recent years. Machines and electronic methods are improving so rapidly that computers used today are obsolete almost as soon as they are in operation. The present computers, however, continue to be of enormous value to meteorologists and climatologists. Their technology at present makes time and space correlations operationally feasible. New techniques in applied climatology, in numerical prediction, and related geophysical fields will continue to place heavy demands on the computing facilities of the weather services. Ingenious programmers will continue to make even more powerful computers serve our expanding needs.

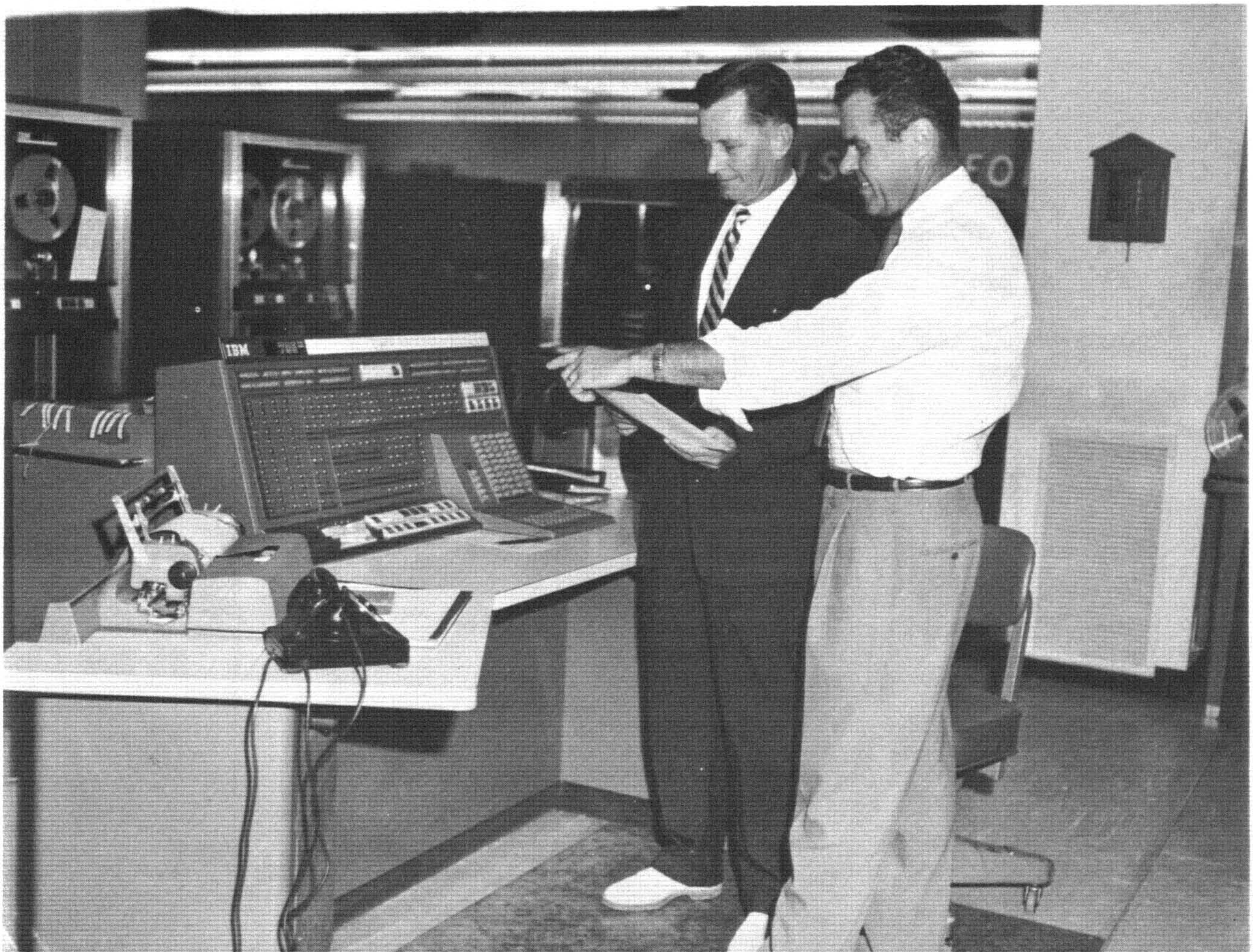
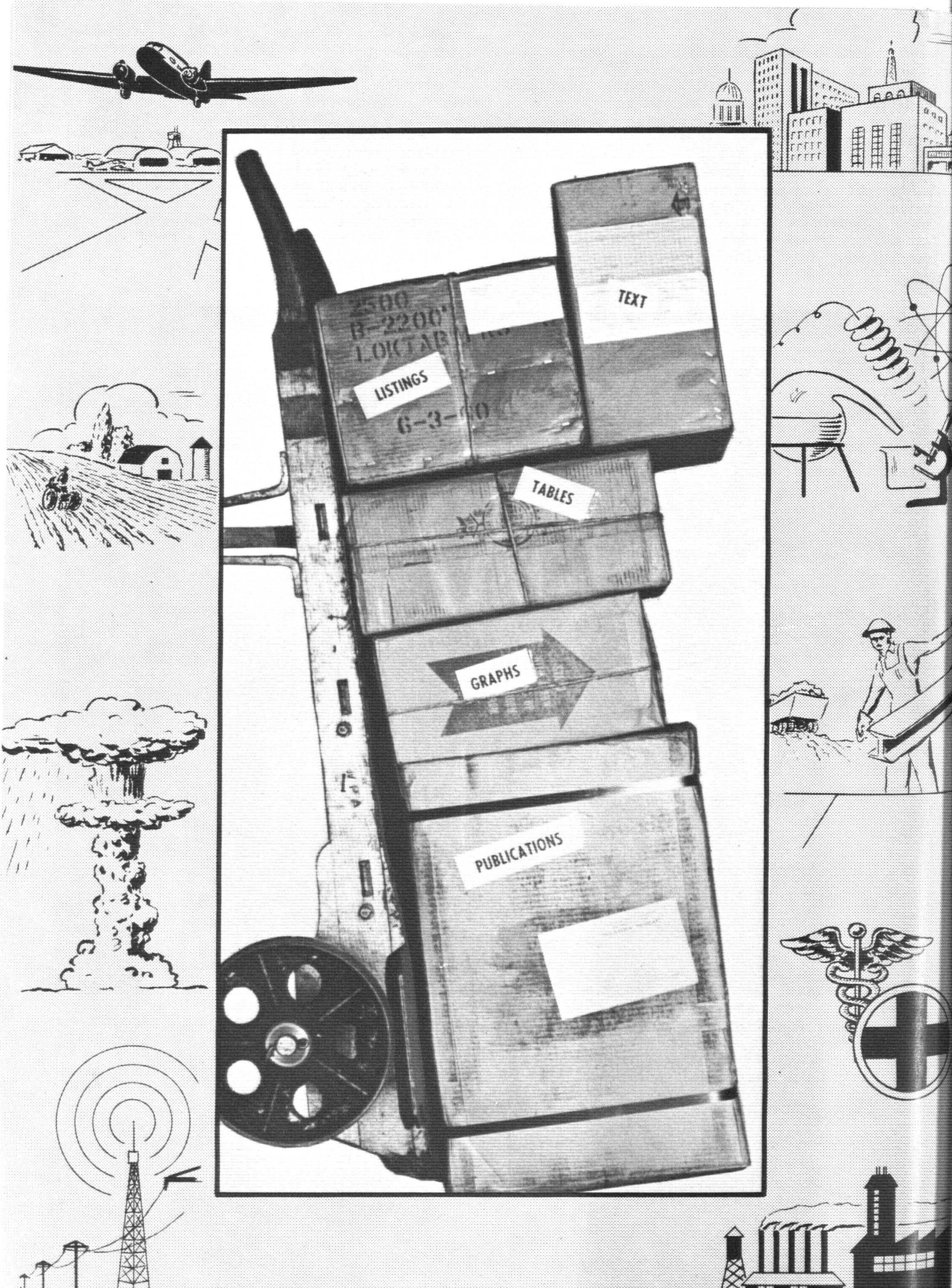


Figure 63. Deputy Director Climatic Center, USAF, and Staff Member DPD, Discuss a Computer Problem


TEXT
LISTINGS
TABLES
GRAPHS
PUBLICATIONS

Chapter 6

THE PRODUCT

Form and Availability

6.0 THE PRODUCT

Since the early Jeffersonian days when climatological summaries were used primarily for agriculture, their uses have grown in breadth comparable with the complexity of our civilization. Most of man's activities are influenced in their immediate aspects by the weather and in their long-range aspects by the climate. Figure 65 shows something of the range of possible applications. It is not surprising to find a growing interest in climatology's contribution to engineering, transportation, agriculture, and many other areas in the biological, physical, and social sciences. Some forms of climatological service are described below. Various sources of data are described in table 17.

6.1 PUBLICATIONS

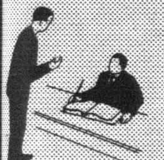
Obviously, the long-range aspects of problems in many of these fields cannot be resolved with weather information available day by day through the usual channels of press, radio, and television. Many can, however, be solved by more or less standardized weather summaries. For these purposes the publications of the U. S. weather services in Chapter 3 may suffice.

Table 17. Principal Types of Climatological Data Available at the NWRC

Types of Records		Procurement Information
ORIGINAL:		
Hourly Surface Climatological Observations Marine Observations Climatological Record Books Upper Air Observations Winds Aloft Observations Autographic Records Aircraft in-Flight Observations		It is possible to obtain photocopies and/or microfilm copies of these records. The cost of photocopies will vary according to the size of the record; such charges are subject to changes as prices of material and labor vary. An ozalid copy of microfilm is the most economical means of obtaining these records; however, this necessitates the use of a microfilm reader. Charges for these reproductions are payable to the U. S. Department of Commerce, Weather Bureau, or the agency preparing the reproductions.
UNPUBLISHED DATA		
Summary of Constant Pressure Data Summary of Winds Aloft Data Climatological Summaries and Tabulations Navy Summaries of Monthly Aerological Records (SOMAR and SMAR) Air Force Summaries of Surface Weather Observations (A, B, C, D, E Summaries)		In addition to the above methods of reproduction, data listed in the "Inventories of Unpublished Climatological Tabulations" are in some cases available in the form of ozalid prints. These are available at about one-third the cost of photocopies.
PUBLISHED DATA		
Climatological Data	monthly	All routine publications printed at the National Weather Records Center and selected publications printed by the U. S. Government Printing Office are stocked at the NWRC and may be obtained upon request and payment of the subscription price prevailing at the time of publication.
Climatological Data	annual	
Climatological Data National Summary	monthly	
Climatological Data National Summary	annual	
Local Climatological Data	monthly	
Local Climatological Data	monthly supplement	
Local Climatological Data	annual	Agencies or individuals may become regular subscribers to publications issued by the Weather Bureau upon payment of the annual subscription price for the publication(s) desired. Non-routine publications are not available at an annual subscription price, but may be obtained upon request and payment of the unit subscription price.
Hourly Precipitation Data	monthly	
Hourly Precipitation Data	annual	
Monthly Climatic Data for the World	monthly	
Climatography of the U. S.	Bulletin W Revised	
Climatography of the U. S.	Bulletin W Supplement	
Climatography of the U. S.	Climatic Guide	
Climatography of the U. S.	Summary of Hourly Observations	Checks and money orders for all publications should be made payable to the Superintendent of Documents, Government Printing Office, Washington 25, D. C., and may be mailed directly to the National Weather Records Center, Asheville, North Carolina.
Climatography of the U. S.	Substation Climatological Summary	
Index of Assembled Meteorological Data	(Hurricane Package)	
Daily Series Synoptic Weather Maps	Parts I and II	

PERSONAL CONTACT REQUEST

On April 8, 1960 a representative from the Picatinny Arsenal Ordnance Corps, Dover, New Jersey, stated that he needed climatological summaries to determine the mean, range, and standard deviation of height of constant pressure surfaces over the Northern Hemisphere.



Result: Existing tabulations were examined. A copy of WB Technical Paper No. 32 was provided. (Reproduction of Chart No. 47 - Oct. 500 mb. illustrates contents of technical paper.)

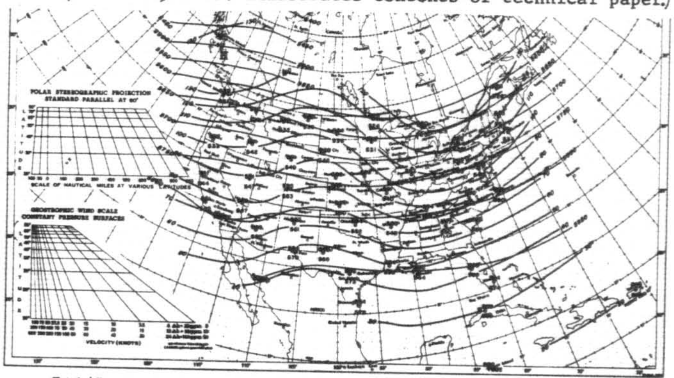


Chart 47 - October average 500-mb. height, with standard deviation, and extremes (gpm.).

RECORD OF LONG DISTANCE TELEPHONE CALL

Name of person calling: Mr. James Smith

Firm name and address: Ann Arbor, Michigan
(he called from Edgewood, Maryland)

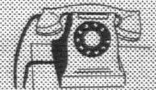
Telephone Number: MU 7-3690

Call Taken by: Messrs. Fox and Whiting

Date: June 24, 1960 Time: 9:15 a.m.

REQUEST:

A representative from the Office of the Scientific Director of the U. S. Army Chemical Corps, R and D Group, located at the Army Chemical Center, Maryland, stated a problem concerning disease statistics and atmospheric pollution. He is associated with the University of Michigan. Tentatively he plans to visit the NWRC June 30, his primary interest being to obtain a deck of daily or monthly summary cards for 35-50 stations for approximately a 15-year period. He said he would probably request a small pilot study which would be followed by a larger order.



REMARKS:

The requester was furnished estimate of costs for securing hourly observations in cards for 3 stations, alternate months for two years, total 26,280 cards, and special summary data on cards, for 50 stations, five-year data for each station.

WESTERN UNION
TELEGRAM
W. P. MARSHALL, PRESIDENT

.KA171 SYA336 PRA125

1958 MAY 21 PM 1 53

LLC020 PD AR=PORTLAND ORG 21 919AMP=
...IONAL WEATHER RECORD CENTER=
US WEATHER BUREAU ARCADE BLDG ASHEVILLE NCAR=

...LD APPRECIATE YOUR WIRING COLLECT TO ME WESTERN UNION MT VERNON WASHINGTON

...THER SEQUENCE BELLINGHAM WASHINGTON TEN AM ELEVEN AM AND NOON OCTOBER 4TH 1956

...NTL NEED THIS INFORMATION FOR COURT CASE TOMORROW MORNING=

J. M. Howe
Attorney-at-Law

DOMESTIC SERVICE
Check the class of service desired; otherwise this message will be sent as a fast telegram
TELEGRAM XX
DAY LETTER
NIGHT LETTER

WESTERN UNION
TELEGRAM
W. P. MARSHALL, PRESIDENT
1206 (4-55)

INTERNATIONAL SERVICE
Check the class of service desired; otherwise the message will be sent at the full rate
FULL RATE
LETTER TELEGRAM
SHORE SHIP

NO. WDS.-CL. OF SVC.	PD. OR COLL.	CASH NO.	CHARGE TO THE ACCOUNT OF	TIME FILED

Send the following message, subject to the terms on back hereof, which are hereby agreed to

ASHEVILLE N C MAY 21 1958

FULL RATE TELEGRAM - COLLECT

MR J M HOWE
CARE WESTERN UNION
MT VERNON WASHINGTON

WEATHER SEQUENCE BELLINGHAM WASHINGTON OCTOBER 4 1956 0928 LST 300 SCATTERED BALLOON 900 BROKEN 2000 OVERCAST 3 FOG 187 5249 WEST 3. 1028 LST 500 SCATTERED ESTIMATED 1000 BROKEN 2000 OVERCAST 7 191 5449 WEST 9. 1128 LST 500 SCATTERED ESTIMATED 1000 BROKEN 2000 OVERCAST 7 194 ,5548 WEST 8. 1228 LST 1500 SCATTERED HIGH BROKEN 7 194 5851 WEST 5

ROY L FOX DIRECTOR
NATIONAL WEATHER RECORDS CENTER

COLLECT
SMB:mac
3:00 p.m.

Figure 64.

RECORD OF LONG DISTANCE TELEPHONE CALL

Name of person calling: Mr. John Doe

Firm name and address: Langley Field, Virginia

Telephone Number: DI 3-4786

Call Taken by: Messrs. Fox, Ritchie, Snelson

Date: June 20, 1960 Time: 9:30 a.m.

REQUEST:

Mr. Doe stated that a purchase order was being forwarded to NWRC for the preparation of the tabulations as requested in the telephone call of June 1, 1960.

The proposed format was acceptable with the following changes: wind speed breakdown to 20 rather than 25 knots; include another group which contains the counts of wind and visibility. Example: Wind speed < 20 knots and visibility ≥ 5 miles.

He wishes to limit the tabulation to the morning hours - midnight to noon.

Mr. Doe further stated that members of his staff would possibly visit the Center in the near future for the purpose of outlining additional work, etc.

cc: PCU
ADM

			WIND		VSBY		WVSB				TOT
STA	MO	CLDS	L20	G20	L5	G5	1	2	3	4	OBS
12867	01	A	75	19	6	88	5	18	70	1	94
	01	B	37	5	5	37	5	5	32		42
	01	C	31	2	3	30	3	2	28		33
	01	D	1341	105	65	1381	65	105	1276		1446
	01	E	242	26	102	166	92	17	150	9	268
	01	F	129	1	24	106	24	1	105		130

CLOUD COVER, WIND VELOCITY, AND VISIBILITY AT SPECIFIED HEIGHTS
WBAN Station No. 12867 - Patrick AFB, Florida

Period of Record: January 1, 1955 - December 31, 1959

Source Deck: Card Deck 144

STA = Station Number

MO = Month

CLDS = Cloud Groups
A = .5 or Less From 4000 Ft. Up To 5999 Ft.
B = .5 or Less From 6000 Ft. Up To 7999 Ft.
C = .5 or Less From 8000 Ft. Up to 9999 Ft.
D = .5 or Less From 10,000 Ft. and Above.
E = All Cloud Amounts Not Covered In A - D.
F = Total Cloud Amount > Than .5 - Height Not Reported.

WIND = Wind Speed:
L20 = Wind Speed Less Than 20 Knots
G20 = Wind Speed Equal To Or Greater Than 20 Knots

VSBY = Visibility:
L5 = Visibility Less Than 5 Miles At Surface
G5 = Visibility 5 Miles Or Greater At Surface

WVSB = Wind Speed and Visibility:
1 = Wind Speed Less Than 20 Knots And Vsby Less Than 5 Miles
2 = Wind Speed Equal To Or Greater Than 20 Knots and Vsby Equal To Or Greater Than 5 Miles
3 = Wind Speed Less Than 20 Knots and Vsby Equal To Or Greater Than 5 Miles
4 = Wind Speed Equal To Or Greater Than 20 Knots and Vsby Less Than 5 Miles

TOT OBS = The Total Number Of Observations In Each Cloud Group.

DOMESTIC SERVICE
Check the class of service desired; otherwise this message will be sent as a fast telegram
TELEGRAM
DAY LETTER
NIGHT LETTER

WESTERN UNION
TELEGRAM
W. P. MARSHALL, PRESIDENT

1206 (4-55)

INTERNATIONAL SERVICE
Check the class of service desired; otherwise the message will be sent at the full rate
FULL RATE
LETTER TELEGRAM
SHORE SHIP

NO. WDS.-CL. OF SVC.	PD. OR COLL.	CASH NO.	CHARGE TO THE ACCOUNT OF	TIME FILED
			1959 JAN 6 PM 5 55	

Send the following message, subject to the terms on back hereof, which are hereby agreed to

RA352 AB473
A LLU361 GOVT PD=TDA PWS KANSAS CITY MO 6 526PME=
=NATIONAL WEATHER RECORDS CENTER=
ARCADE BLDG ASHEVILLE N CAR=

PLEASE FORWARD CERTIFIED COPIES OF WINDS ALOFT REPORTS FOR DETROIT PORT HURON AND FLINT MICHIGAN FOR PERIOD 1200 TO 2400 ON OCTOBER 20 1958=

FEDERAL AVIATION AGENCY=

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

January 9, 1959

IN REPLY REFER TO
FILE C-9.6

NATIONAL WEATHER RECORDS CENTER
ARCADE BUILDING
ASHEVILLE, NORTH CAROLINA

Federal Aviation Agency
4825 Troost Avenue
Kansas City, Missouri

Attention:
Regional Attorney

Gentlemen:

In reply to your telegram of January 6, 1959, we are enclosing Forms WBAN 20 and 20B, Winds Aloft Computation Sheets for Flint, Michigan; Muskegon, Michigan and Toledo, Ohio for hours between 1200 and 2400 October 20, 1958. We have substituted Muskegon and Toledo for Detroit and Port Huron because upper wind observations are not taken at these stations.

Very truly yours,

Gerald L. Barger
Deputy Director

12 photocopies

PERSONAL CONTACT REQUEST

The Soil and Water Conservation Research Branch, United States Department of Agriculture, was interested in doing a limited study on drought conditions in the western part of the United States. Percentile values, along with the means and standard deviation of distributions of monthly precipitation and the monthly evapotranspiration, were needed. In addition, some information on the relationship of the elements among nearby stations was required.

Answer: The monthly total precipitation "P" was transformed b $\sqrt{P} + \sqrt{P+1}$. The potential evapotranspiration was computed by means of the well-known Thornthwaite formula. The means, standard deviations, the distributions of these elements, and the correlations of the elements between nearby pairs of stati were furnished. The 25th and 75th percentile values were mark on the tabulated distribution for comparison with computed the retical percentile values. Data for 16 stations were furnishe

Figure 64. (Cont'd.)

WESTERN UNION TELEGRAM

W. P. MARSHALL, PRESIDENT

RAO11 AA076 1958 SEP 6 AM 7 17

lSA187 GOVT NL PD=TDA PWS ANCHORAGE ALASKA 5=
TIONAL WEATHER RECORDS CENTER=US WEATHER BUREAU ASHEVILLE NCAR=

OM NEAVG-SP 4129.
FORMATION IS URGENTLY NEEDED FOR ASSISTANCE IN DESIGN OF AIR CONDITIONING EQUIPMENT N A CLASSIFIED MILITARY PROJECT NEAR NENANA, ALASKA. INFORMATION DESIRED IS MAXIMUM PERATURE WHICH IS EQUALLED OF EXCEEDING DURING 2 1/2 PER CENT OF HOURS IN JUNE, LY, AUGUST AND SEPTEMBER OVER 10-YEAR PERIOD FROM 1948 THROUGH 1957 AT NENANA, ASKA, WEATHER STATION. ALSO REQUEST AVERAGE RELATIVE HUMIDITY DURING HOURS WHEN QUESTED TEMPERATURE IS EQUALLED OR EXCEEDED. FUNDS IN AMOUNT OF $___ HAVE BEEN LOCATED FOR THIS REQUEST UNDER APPROPRIATION NUMBER 57 X 3300 077-7313 P313-99 595-7(B824AD). PURCHASE ORDER WILL BE FORWARDED UPON DETERMINATION OF COSTS BY YOUR FICE. IT IS REQUESTED THE ABOVE INFORMATION BE WIRED TO THIS OFFICE AS SOON AS SSIBLE.=

DISTRICT ENGINEER CORPS OF ENGINEERS=

WESTERN UNION TELEGRAM

W. P. MARSHALL, PRESIDENT

ASHEVILLE N C 11 SEPTEMBER 1958

DISTRICT ENGINEER
CORPS OF ENGINEERS
ANCHORAGE ALASKA

TWO AND ONE HALF PERCENT OF THE TIME DURING JUN-SEP 1948-57, A TEMPERATURE OF 76 DEGREES F WAS EQUALLED OR EXCEEDED. MEAN RELATIVE HUMIDITY WAS 42 PERCENT DURING THE PERIOD ABOVE THE 76 DEGREE THRESHOLD. FREQUENCY OF OCCURRENCE HOURS BY MONTH FOLLOWS: JUN 220, JULY 433, AUG 73, SEP 6.

NO REPLY RECEIVED OUR TELEGRAM 9/8/58 REGARDING FUNDING. PLEASE ADVISE.

ROY L FOX, DIRECTOR
NATIONAL WEATHER RECORDS CENTER

RECORD OF LONG DISTANCE TELEPHONE CALL

Name of person calling: Mr. Charles Jones

Firm name and address: Cincinnati, Ohio

Telephone Number: CA 4-9153

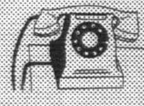
Call Taken by: Messrs. Brewster and Lankton

Date: June 24, 1960 Time: 3:15 p.m.

REQUEST:

Would like to know the temperature at the following stations:

Pittsburgh, Penn., April 4, 1960	11:40 p.m.
Washington, D. C., April 4, 1960	5:40 p.m.
Detroit, Michigan, April 5, 1960	7:50 a.m.



REMARKS:

Called back 3:30 p.m. and gave following information for times requested

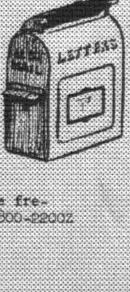
Pittsburgh	41°F
Washington	71°F
Detroit	31°F

imatic Center
t 3, AWS
nex 2, 225 D Street, S. E.
h 25, D. C.

In our letter "AFCRC 59-44, Sites for Geodetic Photo Mission" ted 1 December 1959, we described an experiment by the Geodesy Gravity Branch of GRD in which photographs are to be made from ound sites of high intensity flares ejected from rockets at high titudes. Another rocket firing is scheduled to take place during e second week of March from Wallops Island at approximately 2000Z may be delayed until April). Although camera sites have been lected for this mission, it is desirable to know the probabilities successful viewing from these sites.

The camera sites for this mission are:

Antigua Island
Fernando de Noronha, Brazil
Recife, Brazil
Rio de Janeiro, Brazil
Porto Alegre, Brazil
Ben Guerir AB, Morocco
Torrejon AB, Spain



It is requested that we be furnished by 1 February 1960 the frequency of occurrence of 2/10 clouds or less during the hours 1800-2200Z March and April at each of the above-named locations.

THE COMMANDER:

PERCENTAGE FREQUENCY OF TOTAL SKY COVER ≤ 2/10

AIRWAYS DATA

Station	*Years Available	Hour (GCT)	Percent Freq. Mar	Apr
14011 Madrid, Spain/Torrejon AB	58, 59	18	6.5	25.0
	58, 59	19	8.1	25.0
	58, 59	21	16.1	38.3
	58, 59	22	21.0	43.3

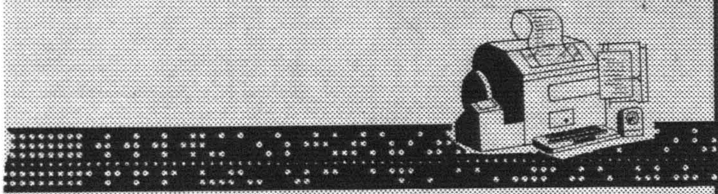
* During the years 1944 and 1945 no instructions were issued concerning summation or non-summation of the individual cloud layers, and no total sky cover was reported. For this tabulation an estimate of total sky cover was used for those years, considering it to be the total of all individual layer amounts reported, a layer of "few" (zero tenths) being added as 0 (zero).

SYNOPTIC DATA

March 40, 41, 44 and April 40, 41, 43

Station		Hour (GCT)	Percent Freq. Mar	Apr
60734	Capital Federal, Brazil (Rio de Janeiro)	1200	6.6	11.1
		0000	18.6	39.8
60792	Porto Alegre, Brazil	1200	20.2	20.7
		0000	39.3	46.2

Figure 64. (Cont'd)



AV 75 GA PLS

DIRECTOR, NATIONAL WEATHER RECORDS CENTER, ASHEVILLE, N.C.

PLS SEND ONE COPY EACH OF CLIMATOLOGICAL DATA FOR KANSAS FOR JAN, FEB, MAR, 1960 AND BILL ADDRESS BELOW. OFFICIAL WEA DATA NEEDED TO VERIFY CLAIM OF BAD WEATHER AS CAUSE FOR CONSTRUCTION PROJECT DELAYS.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

IN REPLY REFER TO
FILE:

IN REPLY ADDRESS
NATIONAL WEATHER RECORDS CENTER
ARCADE BUILDING
ASHEVILLE, NORTH CAROLINA

Reference: Your letter of April 13, 1960

In answer to your recent request for climatological information, we are sending you the following publications:

3 Climatological Data Kansas January and February 1960 March issue will be forwarded when printed) at cents $____

Please sign below on carbon copy of this letter and mail it with your check in the appropriate amount, made payable to Superintendent of Documents, to this office for proper credit.

TOTAL COST $____

Sherman M. Brewster
For Roy L. Fox
Director

___ Above publications have been received. My check in the amount of $____ is attached.

___ ~~Publications are being returned.~~

(Signature)

USCOMM-WB-ASHEVILLE

DOMESTIC SERVICE — Check the class of service desired; otherwise this message will be sent as a fast telegram — TELEGRAM / DAY LETTER / NIGHT LETTER

WESTERN UNION
TELEGRAM
W. P. MARSHALL, PRESIDENT

1206 (4-55)

INTERNATIONAL SERVICE — Check the class of service desired; otherwise the message will be sent at the full rate — FULL RATE / LETTER TELEGRAM / SHORE SHIP

NO. WDS.-CL. OF SVC.	PD. OR COLL.	CASH NO.	CHARGE TO THE ACCOUNT OF	TIME FILED

Send the following message, subject to the terms on back hereof, which are hereby agreed to

1959 APR 8 PM 4 16

RA261 AC369
=A LH 014 PD DL=TDA PWS SUNNYVALE CALIF 8 317PME =
NATIONAL WEATHER RECORDS CENTER= ARCADE BLDG=ASHEVILLE NCAR=

THE FOLLOWING DATA IS REQUESTED FOR ALTITUDES BELOW 100,000 FT. =SPECIFIC MEASURED VALUES (NO AVERAGE VALUES) OF THE DENSITY FOR =EACH DAY IN JANUARY, APRIL, JULY AND OCTOBER OF 1958. SEND MORE=THAN ONE READING PER DAY IF AVAILABLE. =THE ABOVE DATA IS DESIRED FOR THE FOLLOWING GEOGRAPHIC LOCATIONS = 1. NORTHERN UNITED STATES (NEWYORK AREA) =2. SOUTHERN UNITED STATES (CAPE CANAVERAL FLA) =3. WESTERN UNITED STATES (CALIFORNIA) =4. EUROPE (PREFERABLY GERMANY) =

F S LONG = MISSILES AND SPACE DIV=

WESTERN UNION
TELEGRAM

ASHEVILLE N C APRIL 17 1959
MISSILES AND SPACE DIV=
SUNNYVALE CAL 115

ATTN MR F S LONG ESTIMATED COST OF FURNISHING DENSITY AND TEMP DATA AS REQUESTED YOUR WIRE 04089 WOULD BE $----------. WORK COULD BE COMPLETED EIGHT WEEKS AFTER RECEIPT OF YOUR CHECK. STATIONS WOULD BE IDLEWILD, N Y; FT WORTH, TEXAS; SANTA MONICA, CAL; AND BITBURG, GERMANY. YOUR CHECK SHOULD BE MADE PAYABLE TO DEPT OF COMMERCE, U. S. WEATHER BUREAU.

ROY L FOX, DIRECTOR
NATIONAL WEATHER RECORDS CENTER

Dear Dr. Reichelderfer:

We would appreciate receiving information concerning the amount of precipitation for the period January 15 through and including January 30, 1958, for the Chicago, Illinois area and its suburban areas within a radius of sixty miles. At the same time we would appreciate information regarding precipitation for Indianapolis and Marion County for the same period.

To further illustrate the area that we are interested in, we are enclosing herewith a highway map of the state of Indiana. May we inquire if at all possible when checking your 1958 records for the amount of precipitation in the areas named if there should be any outstanding amount of precipitation in the vicinity of the highways on the map enclosed which we have marked, this information be inserted on the map and returned to us.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
May 11, 1960

IN REPLY REFER TO
FILE:

IN REPLY ADDRESS
NATIONAL WEATHER RECORDS CENTER
ARCADE BUILDING
ASHEVILLE, NORTH CAROLINA

In answer to your recent request for climatological information, we are sending you the following publications:

2 Climatological Data Illinois and Indiana, Jan 1958 at cents $____

___ Climatological Data, National Summary, monthly at cents ____

___ Climatological Data, National Summary, annual at cents ____

2 Local Climatological Data, monthly and/or supplement Chicago, Ill. and Indianapolis, Ind., Jan 1958 at cents ____

2 ~~Local Climatological Data, annual~~ Hourly Precipitation Data Illinois and Indiana, Jan 1958 at cents ____

TOTAL COST $____

Please sign below on carbon copy of this letter and mail it with your check in the appropriate amount, made payable to Superintendent of Documents, to this office for proper credit.

Sherman M. Brewster
For Roy L. Fox
Director

___ Above publications have been received. My check in the amount of $____ is attached.

___ ~~Publications are being returned.~~

(Signature)

USCOMM-WB-ASHEVILLE

Figure 64. (Cont'd.)

State of California
DEPARTMENT OF WATER RESOURCES
Sacramento

March 22, 1960

Mr. Roy L. Fox, Director
National Weather Records Center
Asheville, North Carolina

Subject: Weather Records - File No. 243.21

Dear Mr. Fox:

After receiving your letter of February 11, 1960, we are requesting estimates for microfilming the Adiabatic Charts, Forms WBAN 31 A, B, C. We would like all observations listed separately for each of the following stations and periods:

1. Merced - period 1944 through 1956, inclusive
2. Merced - period 1944 through 1955, inclusive
3. Merced - period 1955 through 1958, inclusive
4. Fresno - years 1945 and 1955
5. Santa Maria - period 1944 through 1955, inclusive
6. Oakland - period 1944 through 1957, inclusive
7. Oakland - period 1944 through 1955, inclusive
8. Santa Monica - years 1956 and 1957
9. Long Beach - period 1947 through 1955, inclusive
10. Reno - years 1953, 1955 and 1957
11. Medford - period 1944 through 1955, inclusive

Your attention to this request will be appreciated.

Very truly yours,

Division of Resources Planning

By____________________

Senior Hydraulic Engineer

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
July 21, 1960

IN REPLY REFER TO
FILE: C-5.6

IN REPLY ADDRESS
NATIONAL WEATHER RECORDS CENTER
ARCADE BUILDING
ASHEVILLE, NORTH CAROLINA

State of California
Department of Water Resources
Post Office Box 388
Sacramento, California

Attention: Division of Resources Planning

Gentlemen:

Reference is made to your Purchase Order No. SUB 220503 dated May 9, 1960, your letter of March 22, 1960 and our letter C-5.6 dated February 11.

We have forwarded to you, under separate cover, 94 reels of 35 mm microfilm containing Form WBAN 31 A, B, and C, Adiabatic Charts for selected stations and dates as requested in referenced Purchase Order. (See attached indices for stations and dates.)

We acknowledge receipt of your check no. 010294. Any necessary adjustment to the actual cost of furnishing the microfilm will be the subject of another letter.

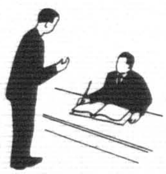
Very truly yours,

Roy L. Fox
Director

PERSONAL CONTACT REQUEST

A representative from the U. S. Army Signal Corps Research and Development Laboratory on March 30, 1960 wished to make a pilot study to determine the variation of densities at various pressure levels for the 12Z hour during 1958 through 1959 between the surface and 10 millibars, the levels for which density are to be computed are surface, 850, 700, 500, 300, 200, 100, 50, 40, 25, 10, using the formula

$$P = 0.3486 \frac{(P - 0.377e)}{T}$$



Result: A copy of a previously tabulated density job was offered and he requested duplicate copies of five stations of this job for levels 1000 millibars through 10 millibars.

STA	LVL	T	DENSITY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
[illegible]	1000	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FREQUENCY OF UPPER AIR DENSITY

STA = Station Number
LVL = Pressure in Millibars
T = Time of Observation
1 = Day (0600 through 1700 LST)
2 = Night (1800 through 0500 LST)

DENSITY = kg/m^3

TOTAL = Total Line Frequency
TOT = Monthly Frequency
M = Monthly Mean Density
SD = Standard Deviation

FORMULAS USED:

$$SD^2 = \frac{N(\Sigma X^2) - (\Sigma X)^2}{N^2}$$

$$DENSITY = \frac{0.3486P - 0.1316 E_s R.H.}{t + 273.2}$$

WHERE:

P = Pressure in Millibars
E_s = Saturation Vapor Pressure in Millibars
R.H. = Relative Humidity
t = Temperature in °C

RECORD OF LONG DISTANCE TELEPHONE CALL

Name of person calling: Mr. William Brown

Firm name and address: Denver, Colorado

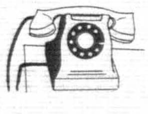
Telephone Number: NE 5-3420

Call Taken by: Ritchie

Date: June 14, 1960 Time: 10:40 a.m.

REQUEST:

Mr. Brown wants a history of surface wind data for at least a 2-year period for Cape Canaveral, Florida. He was told that A and B summaries for this station are available. The so-called history of surface winds was interpreted to be wind rose data based on hourly observations. He also wanted the height of the anemometer and any other pertinent information related to the wind installation.



REMARKS:

Monthly and annual summaries for Cape Canaveral were sent to the customer and he was billed appropriately.

Figure 64. (Cont'd.)

ETC...

ADVERTISING MANAGERS plan regional releases based on climatological probabilities.

ANTENNA design and installation are planned in terms of icing and high wind risk.

ARCHITECTS use meteorological and climatological facts in designing weather "controls" and for planning capacity of heating and cooling systems.

AVIATION ENGINEERS design airport runways and other operational facilities on the basis of standard and low-visibility, windroses, and frequency of excessive surface air temperatures as related to takeoff of high performance aircraft.

BAKERY CHAINS use climatic summaries including temperature and humidity factors in planning production, distribution, and preservation of their products.

BUILDING SUPPLY DEALERS plan for seasonal variation in supply and demand, arrange their stock, and schedule their orders in accordance with seasonal variations in weather.

BUS LINES prepare equipment and stock supplies in accordance with normal climatic changes and seasonal differences.

CITIES buy snow removal equipment according to number of days' use anticipated per season.

COAL DISTRIBUTORS plan for their service requirements and arrange shipment schedules on the basis of normal temperature and heating degree day data.

COMPRESSED GAS DISTRIBUTORS load tank cars according to risk of high temperatures during the ensuing 60 - 90 days.

CONSTRUCTION COMPANIES prepare building estimates and plan work schedules with the aid of information given in climatic summaries. They also use precipitation and temperature records to support requests for time extension on contracts where adverse weather conditions have caused delay.

DAIRY FARMERS plan forage crop species and acreages according to seasonal distribution of precipitation.

DISTILLERIES use climatological information in operational planning with respect to grain harvest, quality, and yield.

DOCTORS OF MEDICINE prescribe treatment in the light of climatic relationship with various diseases and physical handicaps.

EMPLOYMENT OFFICES use climate and crop reports in planning for the movement and employment of transient laborers to areas where harvests are imminent.

ENGINEERING COMPANIES, including specialists in aeronautics, electricity, hydrology, heating and ventilating, and petroleum, constantly use climatic statistics in their planning, designing, and operations.

FACTORIES AND MANUFACTURERS of consumer goods always use climatic data in their plans for improvement of production methods and establishment of new plants in other areas.

FLORISTS, SEED GROWERS, AND DISTRIBUTORS of their products have frequent need for climatic advice regarding normal weather patterns as they affect flowering, seed set, yield, and harvest conditions.

FORESTERS need weather information for seeding, cutting, and fire prevention activities.

FUEL storage and use rates are estimated through air route planning and spacing of refueling facilities.

GAME AND WILD LIFE MANAGEMENT officials regularly refer to climatic conditions and phenological reports as a helpful aid in determining bag limits, open seasons, etc.

GEOGRAPHERS AND GEOPHYSICISTS have frequent need for climatic information in describing the earth and its atmosphere.

GROCERY CHAIN STORES use normals, means, and extremes of climate in sales promotion, warehousing, and transportation of perishable products and weather sensitive items.

HIGHWAY DEPARTMENTS design and support large overhead signs according to high wind statistics.

HOME BUILDERS study frequencies of weather hazards before making estimates and preparing bids for jobs.

HOSPITAL MANAGEMENT finds weather data helpful in its plans for development, renovation, and expansion as well as guidance material for routine operation and emergency demands.

HOTELS AND MOTELS depend on climatological facts in staffing to service the expected number of guests from week to week.

ICE COMPANIES AND REFRIGERATION MANUFACTURERS, DISTRIBUTORS, AND RETAILERS rely on climatological facts in advertising, stocking, and servicing their merchandise.

INSURANCE COMPANIES generally check the climatological records before payment of claims for damages caused by adverse weather conditions. Certified publications or photocopies of original records are often introduced in court cases.

Figure 65.

JET-ENGINE DESIGNERS use every facet of upper air climatology in the development and refinement of space age vehicles.

KEY AND LOCK MANUFACTURERS need information on temperature, precipitation, and humidity to correctly design and select suitable metals for operation of their products in all climates.

LUBRICATING OIL PRODUCERS consult climatic factors and seasonal variations in developing petroleum products for different areas and seasons.
LUMBER COMPANIES use climatological statistics in estimating volume and planning logging for cutting timber and operations, as well as distribution and sale of finished product.

MARINE MANUFACTURERS AND BOATING INTERESTS gauge their production and activity on climatic normals and weather probabilities in the areas they serve.
MARKETING SPECIALISTS for agricultural and textile products use information on climate in their advertising plans and sales programs.

NUCLEAR REACTORS are located in terms of wind direction, temperature inversion, and other climatic conditions affecting fallout of radioactive debris.

OIL REFINERIES consider climatological facts in the location and construction of their plants and the processes of refining their products.
OYSTER FISHERMEN consult climatic guides in preparing their beds and in harvesting the products.

PETROLEUM WELL OWNERS AND ASSOCIATED INDUSTRIES need climatological facts and the services of weather consultants to efficiently set up and carry on their operations.
PHOTO RECONNAISSANCE planners use favorable cloud and visibility statistics as required for photo mapping and aerial survey.
POULTRY AND EGG PRODUCERS AND DEALERS are regular users of climatic information.

QUICK FREEZE PROCESSES have been improved by using psychrometric statistics compiled by climatologists.

RADIO AND TELEVISION STATIONS use climatological statistics in connection with the construction of their towers and other communication facilities.

RAILROADS have been continuous users of climatological data for many years in connection with their plans for construction and operation and as a basis for settlement of damage claims.

SOFT DRINK MANUFACTURERS AND BREWERIES plan their advertising programs, gear their production, and distribute their products with the guidance of seasonal averages and climatic normals.
SPORTING GOODS PRODUCERS use weather statistics in scheduling the delivery of their equipment to the various areas they serve.
SUGAR CANE GROWERS always consider precipitation, temperature, and frequency of severe storms in the planting, irrigation, and harvesting of their crops. Refineries use the same information advantageously.

TEXTILE MANUFACTURERS rely on humidity averages and diurnal variation of this element in planning the printing of textiles, especially if the plant is not equipped with humidity control equipment.
TOBACCO PLANTERS AND MANUFACTURERS always give consideration to climatic conditions affecting growth, curing, and processing of leaf.

UTILITY COMPANIES give climatological data primary consideration in the planning for heavy service loads and maintenance of equipment and facilities during seasons when adverse weather is most frequent.

VITAMIN MANUFACTURERS use weather statistics to help correlate supply and demand of their products.

WARFARE has always been waged with weather facts highlighted in the plans and strategy of military leaders even before the days of Napoleon. Climatological statistics were essential to the plans and campaigns of World War II.

X-RAY, to some extent, and other wavelengths much more, can be affected by climatic variations.

YACHT AND SAILBOAT OPERATORS evaluate the wind speed and direction as well as other climatological elements in the design and operation of their equipment.

ZOOLOGISTS consider weather factors in studying reproduction, survival, and vigor of animal population.

Figure 65. (Cont'd.)

572771 O - 60 - 7

6.2 INDIVIDUAL RECORD COPIES

Another large class of problems can be solved by detailed study of a relatively limited selection of basic observational data. These problems may range from the need for a statement of conditions at a specific time and place as evidence in accident or liability litigation to intensive study of all meteorological data collected in the path of a specific hurricane. For the first of these, certified photostatic copies of available records can be furnished. For the second, a comprehensive "Hurricane Package" of pertinent data is recorded on several reels of microfilm. The facilities for satisfying many requests within this range of complexity are utilized daily by a variety of clients as illustrated in figure 64. A continuing effort is made to determine the requirements of the general public and frequent revisions and additions to the available printed but non-routine condensations are being made.

6.3 SPECIAL STUDIES

In many cases, however, unique specifications require specific analysis. For these purposes, the extensive know-how, equipment, and facilities discussed in previous chapters are put into action. While each job is unique, at least one copy of each resulting tabulation is maintained in information files. New requests are reviewed in the light of these previous summaries and copies are provided to the client at cost of reproduction if pertinent to his problem; or perhaps the method is adapted to his needs. As accumulated tabulations are now numerous, both a visual card file and a punched card indexing system are utilized in locating desired summaries. Figure 66 describes portions of the code used in the punched card index; figure 67 shows a representative job description from the visual card file.

Table A
Statistical Operation
(to be used with each code table)

A	Frequency or cumulative (f)
B	Relative frequency (%) and/or CRF
C	Means, averages or normals
D	Index or listing only
E	Standard deviation
F	Average deviation
G	Extreme (max or min)
H	Range
I	Differences or departures
J	Regression coefficients
K	Persistence or Frequency of Persistence
L	Duration
M	Correlation and/or multiple statistics (computation)
N	Skewness and/or kurtosis
P	Simultaneous conditions
Q	Harmonic analysis
R	Superposed epoch series
S	Power spectrum analysis
U	Restricted conditions
V	Threshold values
W	Time and space continuity arrays
X	Summation (Totals)
Y	Coefficient of variation (variance)
Z	Probabilities

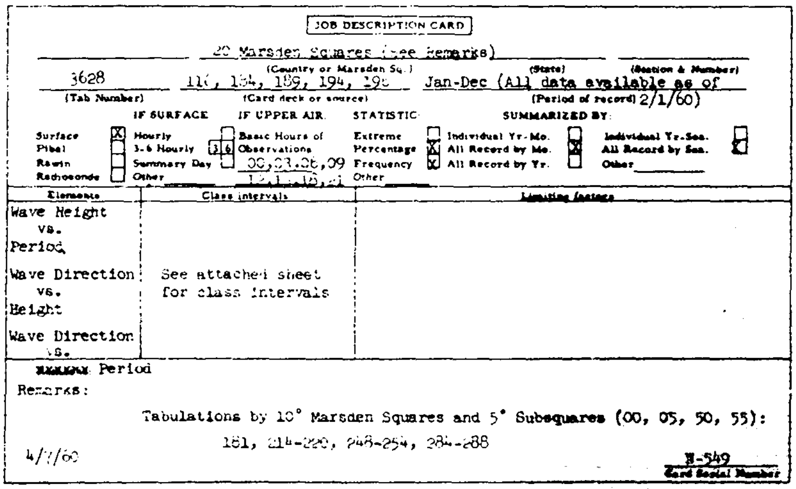
Temperature - Table 0

Code	
000	Temperature (Use 007)
001	Snow surface temperature
002	Maximum temperature
003	Minimum temperature
004	Freezing level data
005	Mean temperature
006	Normals
007	Dry Bulb temperature - DB
008	Wet Bulb temperature - WB
009	Dew point temperature - DP
010	Sea temperature
011	Lapse rate (inversions, etc.)
012	Stability
013	Tropopause temperature
014	Degree days (Base 65°)
015	Virtual temperature
016	Diurnal temperature
017	Frost study
018	Cold period
019	Hot period
020	Temperature gradients
021	Air-Sea Temperature Difference
022	Degree Days (Base 50°)

Wind - Table 1

Code		Code	
100	Wind	118	Precipitation Windrose
101	Gustiness (peak gust)	119	Inversion Windrose
102	Squalls	120	Wind Speeds
103	Wind Shift	121	Extreme Velocity
104	Wind Shear	122	Winds to 8 Points and Beaufort
105	Wind Vectors	123	Directions and Force or Speed
106	Wind Resultants	124	Wind Direction
107	Wind Components	125	Zonal Profiles
108	Vertical Wind Gradient	126	Wind Resultants by Distant
109	Wind Stress	127	Cross Wind
110	Gales - Hurricanes	128	Elliptical wind distribution
111	Maximum Wind	129	Gyroscopic Winds
112	Prevailing Wind	130	Wind Chill
113	Ballistic Wind	131	Effective Wind
114	Wind movement		
115	Vertical Velocities		
116	Wind Rose		
117	Route Summaries		

Figure 66. Some Punched Card Index Code Tables


JOB DESCRIPTION CARD
20 Marsden Squares (See Remarks)
(Country or Marsden Sq.) (State) (Section & Number)
3628 (Tab Number)
116, 154, 189, 194, 198 (Card deck or source)
Jan-Dec (All data available as of 2/1/60) (Period of record)
IF SURFACE / IF UPPER AIR / STATISTIC / SUMMARIZED BY:
Surface [X] Pibal [ ] Rawin [ ] Radiosonde [ ]
Hourly [ ] 3-6 Hourly [3][6] Summary Day [ ] Other
Basic Hours of Observations 00, 03, 06, 09, 12, 15, 18, 21
Extreme [ ] Percentage [X] Frequency [X] Other
Individual Yr-Mo. [ ] All Record by Mo. [X] All Record by Yr. [ ]
Individual Yr-Sea. [ ] All Record by Sea. [X] Other

Elements	Class intervals	Limiting factors
Wave Height vs. Period		
Wave Direction vs. Height	See attached sheet for class intervals	
Wave Direction vs. Period		

Remarks:
Tabulations by 10° Marsden Squares and 5° Subsquares (00, 05, 50, 55): 181, 214-220, 248-254, 284-288
4/7/60
N-549 (Card Serial Number)

Figure 67. Job Description Card

Figure 68.

Gentlemen:

Our special need for meteorological information requires that we have knowledge of certain cloud conditions from the surface to 10 kilometers.

Using the Templehof, Berlin, Germany station please obtain the percentage of occurrence of ten-tenths stratiform type low clouds below specified elevations above ground level, by the base, hour of day and by season (December, January, February - winter, etc.).

These observations should be obtained from hourly punched cards (your card deck 144) for the period January 1949 - December 1957, inclusive.

FREQ STRATUS

STA	AMT	SEA	HEIGHT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
35104	10	DJF	FOG	24	25	26	28	30	31	29	26	27	24	16	17	14	9	11	8	7	12	11	12	11	16	21	19
			0-449	44	45	46	52	59	51	51	48	50	39	40	36	28	25	21	28	37	36	43	49	45	45	39	41
			450-949	80	82	80	96	89	99	98	104	93	89	92	84	80	75	72	75	79	72	87	78	82	75	76	74
			950-1449	43	46	58	48	59	59	64	65	59	61	54	56	63	65	63	54	58	58	52	67	67	59	50	61
			1450-1949	55	38	31	41	48	55	47	35	36	36	42	45	34	31	33	43	40	43	49	32	33	44	43	46
			1950-2449	47	39	41	42	38	41	38	37	35	35	30	26	30	33	40	32	31	40	35	32	31	35	37	43
			2450-2949	23	32	30	33	37	29	33	27	27	20	29	24	22	23	21	24	34	33	30	32	31	28	32	31
			2950-3449	26	40	41	31	32	33	29	32	25	25	23	19	21	20	17	24	19	34	28	37	36	45	42	27
			3450-3949	15	13	14	19	7	10	11	10	10	11	10	11	10	8	7	4	7	8	13	11	14	14	17	17
			3950-4449	19	17	14	18	22	19	20	18	12	13	23	23	19	15	12	14	13	12	20	13	16	16	14	16
			4450-4949	5	6	1	3	6	6	7	3	1	1	1	1	3	5	1	1			4	7	7	2	4	3
			4950-5749	6	7	9	8	9	6	8	8	8	10	9	5	4	8	11	7	9	12	10	9	10	12	11	11
			5750-6749	3	2	3	2	4	3	4	5	1				1	2	2	2	5	4	4	5	4	2	4	5
			6750-7749	1						1		1							1	1		1	2	2	2	1	2
			TOTAL	809	815	810	811	810	810	809	812	811	810	811	809	811	811	808	813	810	809	812	808	808	815	810	817

PERCENTAGE OF OCCURRENCE OF 10/10 STRATIFORM LOW CLOUD BASES;

At or below given altitude classes;
for each of 24 hours (GMT);
for season Dec., Jan., Feb.

Station: Berlin (Tempelhof), Germany

Period of Record: January 1949 - December 1957

Height is in feet above ground level of 150 feet

Stratiform Low Clouds are Stratus, Fractostratus, nimbostratus, stratocumulus, fractocumulus

Cases of dense surface fog obscuring sky are included in tabular data

Last line, "TOTAL" shows total number of all observations for each hour, which are the bases on which the percentages in the respective columns were calculated.

CLOUD FREQUENCIES

Dear Sir:

We have a problem concerning the development of objective characteristics to evaluate the relation between wind direction and other surface elements.

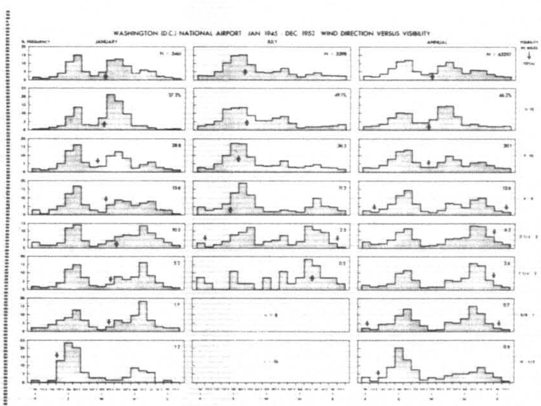
Is it possible to compute correlation coefficients between wind direction observations (without splitting into vector components) and other elements?

First, relations between wind directions versus cloud amount and wind direction versus visibility should be prepared to test whether a climatological map showing relationships between the above elements is possible for future climatological work.

You may use pertinent stations for the study and prepare a research paper on the subject if you desire.

Visibility Versus Wind Direction
Statistical Summary

	Washington, D. C. (WBAS) Jan. 1945-Dec. 1952			Seattle (Wash.) March 1945-Dec. 1952		
	Annual	January	July	Annual	January	July
$\bar{y}$	5.07	4.73	5.32	4.90	4.55	5.44
σ_y	1.16	1.38	.81	1.15	1.33	.79
$\bar{\phi}$	263	277	209	256	111	287
σ_ϕ	90	83	83	94	88	92
$\bar{x}$	222	274	198	243	123	292
σ_x	112	84	85	103	94	95
Wind Direction Classes						
$r_{\phi y}$	-.08	-.04	.05	.07	.07	-.07
$\zeta_{\phi y}$	.29	.33	.23	.12	.13	.10
Visibility Classes						
r_{yx}	.51	-.03	.27*	.45	.02	.38
ζ_{yx}	.60	.22	.29	.49	.43	.41
R_{yx} (unweighted)	.73	.44	.97	.95	.52	.94



CORRELATIONS

Dear Sir:

This is to alert you that I shall soon be visiting you in Asheville. The purpose of this visit will be to establish a program required to process a large quantity of climatic records to develop a new set of design wet-bulb temperatures throughout the United States. A tentative outline follows:

A. Cards will be punched from the wet-bulb distributions available for the period 1934-1939 for 117 stations.

B. All 1948 to date record will be tabulated for all stations for a wet-bulb distribution. A threshold value will be selected for each station. This will be the lower bound of the upper 23% of the distribution

1. Threshold ≥ 65: Frequency of wet bulb Temperature ≥ 83 degrees; one degree intervals 82 through 66 ......

STATION NO. 13876

K	TH	YR	MO	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	64	62	60	55	50	45	40	39	ATH	TOTH	WP
1	75		06					4	11	20	68	169	277	340	378	356	411	365	260	240	150	249	136	67	87	9	3				3600	
			07			2	14	35	82	166	263	439	424	451	468	399	341	222	127	98	48	59	36	19	25	2					3720	
			08		1	3	26	66	95	196	284	512	426	471	433	320	300	155	115	76	36	87	53	28	34	2					3719	
			09					2	9	39	93	175	189	264	286	238	282	201	244	168	158	333	247	178	322	125	42	7			3600	
			TOT		1	5	401	107	197	421	708	1295	1316	1526	1565	1313	1334	943	746	582	392	728	472	292	468	136	45	7			14639	

FREQUENCIES OF WET BULB TEMPERATURES BY MONTH

Period of Record: June - September of years 1935 - 1939

K = Threshold Code Number

1 = ≥ 65

2 = ≤ 64

TH = Wet Bulb Threshold

MO = Month, 06 = June, 07 = July, etc.

83-82-81...39
73-72-71...39 = Wet Bulb Temperature Spread

Frequencies of occurrence of wet bulb temperature

TOTH = Total observations for threshold

NOTE: Numbers appearing in the column headed WP are the thousands digit of the frequency of occurrence of wet bulb temperature under the temperature spread 78°.

DESIGN TABLES

Figure 68. Cont'd.

Dear Director:

In the spring of 1958 your staff computed the drought days and moisture excess in Minnesota and the eastern Dakotas for van Bavel. I believe the job number was 1172. Since the original work was for May through September of 1932 to 1956, further work was done on the Minnesota stations to complete the yearly tabulations. I would like to have an estimate on the cost for completing the yearly computations for the 23 Dakota stations. Since I am relatively sure that this project will be carried out I am enclosing the estimates for the evapotranspiration rates necessary for this study.

				1 INCH			3 INCH			5 INCH			7 INCH			9 INCH			
STA	YR	MO	N	EXCESS	DD	M	EXCESS	DD	M	EXCESS	DD	M	EXCESS	DD	M	EXCESS	DD	M	PRECIP
321766	32	1	31	.00		1.00	.00		3.00	.00		5.00	.00		7.00	.00		9.00	
321766	32	2	29	.14		.60	.14		2.60	.14		4.60	.14		6.60	.14		8.60	.32
321766	32	3	31	.00		.67	.00		2.67	.00		4.67	.00		6.67	.00		8.67	1.00
321766	32	4	30	1.11	10	1.00	.39		3.00	.39		5.00	.39		7.00	.39		9.00	3.12
321766	32	5	31	.80	10	.52	.50		1.83	.50		3.83	.50		5.83	.50		7.83	3.05
321766	32	6	30	.77	10	.00	.00		.70	.00		2.70	.00		4.70	.00		6.70	3.37
321766	32	7	31	.00	28	.00	.00	23	.00	.00	10	.00	.00		.46	.00		2.46	.72
321766	32	8	31	.07	12	.00	.00	12	.00	.00	12	.00	.00	9	.00	.00		1.10	2.67
321766	32	9	30	.00	25	.21	.00	25	.21	.00	25	.21	.00	25	.21	.00	13	.21	.66
321766	32	10	31	1.49	13	.88	.00	13	2.37	.00	13	2.37	.00	13	2.37	.00	13	2.37	2.89
321766	32	11	30	.19		.92	.00		2.60	.00		2.60	.00		2.60	.00		2.60	.53
321766	32	12	31	.00		.93	.00		2.61	.00		2.61	.00		2.61	.00		2.61	.01
ANNUAL			366	4.57	108		1.03	73		1.03	60		1.03	47		1.03	26		18.34

DROUGHT PROBABILITIES
NORTH DAKOTA - SOUTH DAKOTA
Period of Record: January 1932 - December 1956

Station List

32-1766 Cooperstown, North Dakota, etc.

STA = Station Number

YR = Last two digits of Year

MO = Month, 1 = January, 2 = February, 3 = March, etc.

N = No. of Mo. Obs. (Values may be less than the total number of days in a month in event of missing record not in excess of 5 per month.)

1 INCH = 1 Inch Threshold: Values in excess in inches and hundreths and number of occurrences when an adjusted precip was equal to zero (DD).

3 INCH = Same as above but values related to 3 Inch Thresholds

5 INCH = Same as above but values related to 5 Inch Thresholds

7 INCH = Same as above but values related to 7 Inch Thresholds

9 INCH = Same as above but values related to 9 Inch Thresholds

ANNUAL = Total Line for Each Year

DD = Drought Days

M = Moisture for Each Month

PRECIP = Inches and Hundredths for Each Month

BLANK = No Precip

MISSING RECORD = Indicated Missing Record

DROUGHT

Dear Sir:

In order that we may be in a better position to determine whether a certain type of equipment for measuring dewpoint is suitable for use on automatic teletypewriter equipment, we would like to know whether you could ascertain from the punched cards the information indicated on the attached partially completed tabulation?

We would also like information on the number of times each year that the dewpoint at Topeka, Kansas fell below -15 degrees or rose above 80 degrees.

TOPEKA, KANSAS

Ambient Temperature	Dewpoint	Number of Hourly Occurrences									
		1944	1945	1946	1947	1948	1949	1950	1951	1952	1953
100° or Above	+37° or Below					0					
90° or Above	+30° or Below					0					
80° or Above	+22° or Below					0					
70° or Above	+17° or Below					0		2			
60° or Above	+10° or Below					0		2			
50° or Above	+ 3° or Below					0					
40° or Above	- 4° or Below					0					
30° or Above	- 5° or Below					0					
20° or Above	-18° or Below					0					
10° or Above	-24° or Below					0					
0° or Above	-30° or Below					0					
-10° or Above	-38° or Below					0					
-20° or Above	-45° or Below					0					
Dewpoint 80° or Above						0					
Dewpoint -15° or Lower						0	1	1	6	0	4

EQUIPMENT DESIGN DATA

Dear Mr. Roe:

Over the past several weeks your representatives have discussed with our organization the needs for more suitable wind speed design data. These discussions have developed evidence that presently available design data are deficient in several aspects important in engineering work. The major deficiency in published design data arises from the fact that these data do not properly reflect the open country meteorological conditions which are quite different from urban conditions and which are so important in our design problems. Another deficiency results from the method of analysis. This method consisted in simply adopting the highest wind speed (fastest mile) at each station as the design value ..... This can be overcome by employing more powerful modern methods of analysis which provide a constant probability value or set of values for each station. In order to meet our requirements for wind speed design data, please undertake the following program of analysis:

1. Reduce wind speeds to a standard 30 foot level;

2. Compute the wind speeds for the 200, 150, 75, 50, and 25 year recurrence intervals and such other probabilities as may be required in the proper analysis of the data series;

3. etc.

STA	G	LOG B	99.5	99	98	96	95	90	70	50	30	10	N
1157	7.74	3.85651	93.80	85.73	78.34	71.53	69.46	63.28	54.05	49.60	46.19	42.47	12
3851	7.47	3.84634	95.18	86.71	78.97	71.87	69.72	63.30	53.76	49.18	45.68	41.88	17
12810	5.15	3.48514	91.28	79.74	69.62	60.73	58.12	50.52	39.86	35.04	31.47	27.75	29
12832	5.87	3.63933	93.88	83.38	74.02	65.66	63.18	55.87	45.38	40.52	36.88	33.03	30
12842	7.58	3.78425	88.53	80.76	73.65	67.12	65.14	59.23	50.42	46.19	42.94	39.42	12

EXTREME WIND PROBABILITY LEVELS

STA = Station Number

G = Gamma

LOG B = Log Beta

PROBABILITY LEVELS

99.5 = 99.5%	96 = 96%	70 = 70%
99 = 99%	95 = 95%	50 = 50%
98 = 98%	90 = 90%	30 = 30%
		10 = 10%

N = Number of years of record

Gamma or γ Formula: $\lambda\gamma = \frac{N}{\gamma} - \Sigma (\log v_z) + \frac{N\Sigma [(v_z^{-\gamma}) \log v_z]}{\Sigma (v_z^{-\gamma})} = 0$

Beta or β Formula: $\text{Log } \beta = \frac{(\log N - \log \Sigma v_z^{-\gamma})}{\gamma}$

The Probability levels or X values: $X = \text{Antilog} \left(\frac{\log \log F (X)}{\gamma} + \log \beta \right)$

EXTREME WINDS

SPECIAL STUDIES

Figure 68. Cont'd.

TO DCD FR ELIM OBB 27 JAN 59 AT 0848 EST

CL 5774. 2R WEATHER GROUP REQUIRES THE FREQUENCY OF OCCURRENCE OF SUITABLE CONDITIONS FOR MASS FIGHTER FLITS, WITH IN-FLITE REFUELING, FROM LANGLEY AFB TO ENGLAND. THERE ARE 4 STARTING TIMES /0100, 0700, 1300 AND 1900Z/ FOR THE FIGHTERS WITH DIFFERENT TAKE OFF TIMES FOR THE TANKERS. BELOW IS LIST OF BASES WITH TIMES/ PLUS OR MINUS WITH REFERENCE TO THE FIGHTER TAKE OFF TIME/ AND THE REQUIRED MINIMUM CONDITIONS. NOTE THAT LANGLEY HAS TWO TAKE-OFF AND ONE LANDING TIME WHILE HARMON HAS TWO LANDING TIMES. THE DIFFERENCE IN MINIMA DENOTES TAKEOFF OR LANDING.

IF ANY STATIONS ARE NOT ON TAPE SUITABLE SUBSTITUTES/ WITHIN 100 MILES/ MAY BE USED OR THE STATION SHOULD BE DELETED.

THE FOLLOWING ARE THE BASES WITH SPECIFIED TIMES AND MINIMA.

LANGLEY TIME ZERO GREATER THAN OR EQUAL TO 300 AND 1
" MINUS 2 HRS GRTR THAN OR EQUAL TO 300 AND 1
" PLUS 6 HRS EQUAL TO OR GRTR THAN 200 AND ONE-HALF
HARMON PLUS 5 HRS GREATER THAN OR EQUAL TO 200 AND ONE-HALF
" PLUS TEN HOURS EQUAL TO OR GRTR THAN 200 AND ONE-HALF

WESTOVER PLUS 2 HRS EQUAL TO OR GREATER THAN 200 AND ONE-HALF

BENTWATERS PLUS 8 HRS EQUAL TO OR GRTR THAN 200 PLUS ONE-HALF

4. IN ORDER FOR A PERIOD TO BE SUITABLE, EQUAL TO OR ABOVE MINIMUM CONDITIONS MUST EXIST AT ALL BASES AT THE TIMES INDICATED. PEACE AFB CAN BE SUBSTITUTED FOR WESTOVER AND WETHERSFIELD FOR BENTWATERS IF NECESSARY. USE 5 YR POR IF POSSIBLE.

SUIT CONDS FOR MASS FLITES

	0100 GCT		0700 GCT		1300 GCT		1900 GCT	
	CRIT	OBS	CRIT	OBS	CRIT	OBS	CRIT	OBS
JAN	126	154	122	155	110	155	122	155
FEB	119	141	123	142	123	142	118	141
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
NOV	113	137	120	137	114	138	118	137
DEC	129	155	126	155	121	155	124	154
ANN	1619	1808	1587	1810	1588	1814	1585	1809

To : Headquarters, Air Weather Service
Detachment 3, Climatic Center

From: Data Control Division
Asheville, N. C.

Subj: Frequency of Occurrence of Suitable Conditions for Mass Fighter Flights, with In-Flight Refueling, from Langley AFB to Bentwaters RAF Station, based on period January 1952 through December 1956.

Shown in the foregoing tabulation, by month and annually, are the frequencies of conditions suitable for the operation, at each of four separate schedules, based on take-off times of 0100Z, 0700Z, 1300Z, and 1900Z. These are take-off times for the fighters; those for the tankers and all landing times are earlier or later, based on the schedule below. Weather conditions were required to be simultaneously equal to or better than the minima described at the take-off and landing times, for all stations. The conditions meeting these criteria are in the column labeled CRIT; the total number of sets of hourly observations simultaneously available for investigation are shown under the column marked OBS.

HAMPTON VA LANGLEY AFB	At Time Zero	300 feet and 1 mile
	At Time Zero minus two hrs	300 feet and 1 mile
	At Time Zero plus six hrs	200 feet and ½ mile
STEPHENVILLE NFLD E HARMON AFB	At Time Zero plus five hrs	200 feet and ½ mile
	At Time Zero plus ten hrs	200 feet and ½ mile
CHICOPEE FALLS MASS WESTOVER AFB	At Time Zero plus two hrs	200 feet and ½ mile
WOODBRIDGE ENG BENTWATERS RAF STA	At Time Zero plus eight hrs	200 feet and ½ mile

FLIGHT SPECIFICATIONS

Dear Sir:

Our former request to you for dry and wet bulb temperature data from 1945-1946 was made in the expectation that the one year over-lap would permit us to evaluate the homogeneity of a series.

We now feel that it would be desirable to have a portion of the data in the period 8/46-6/47 summarized for 10-day periods in addition to the monthly periods. Each month would contain three 10-day periods as follows: 1 to 10, 11 to 20, 21 to end of month inclusive. A separate summary card would be required for each 10-day as well as each monthly summary. We would also restrict the 10-day summaries to a limited geographical region. This would include all of the North Pacific North of 20°N latitude and the following areas between 20°N latitude and 20°S latitude . . . . .

MS	YR	MO	P	2	AIR TEMPERATURE	8	6	4	2	0	2	WET BULB	8	6	4	2	0
					TEMP	149	365					TEMP	138	338			
096	49	01	1	0	OBS	2	5				0	OBS	2	5			
					AVG	75	73					AVG	69	68			
					TEMP		50					TEMP		48			
096	49	01	1	2	OBS		1				2	OBS		1			
					AVG		50					AVG		48			
					TEMP							TEMP					
096	49	01	1	4	OBS						4	OBS					
					AVG							AVG					
					TEMP	123		52				TEMP	111		48		
096	49	01	1	6	OBS	2		1			6	OBS	2		1		
					AVG	62		52				AVG	56		48		

TABULATION SERIES 'B'

Marsden Square 096

Period of Record: 10 Day Period: 1/49 - 6/57
Monthly: 8/46 - 6/57

Dry Bulb Temperature and Wet Bulb Temperature

Presented in a pattern of 2° Square and '10 Day Period', where applicable, within month and year

MS = Marsden Square Number (096)

YR = Year

MO = Month, 01 = January, 02 = February, 03 = March, etc.

P = '10 Day Period' where applicable
1 = Days 01 through 10
2 = Days 11 through 20
3 = Days 21 through end of month

2 = Tens position of 2 Degrees Square

TEMP = Sum of temperature in Degrees F of Air Temperature on left side and Wet Bulb on right side

OBS = Number of observations

AVG = Average temperature ... °F to whole degrees

8, 6, 4, 2, 0 = Units position of 2 Degree Square

NOTE: Zeros could not be printed, when Air Temperature or Wet Bulb was zero, because of machine limitations.

HOMOGENEITY

Dear Sir:

Thank you very much for your detailed cost estimate concerning the upper air data evaluation for the Greenland project, as well as for the punch-card inventory of Greenland surface data. We are interested in obtaining computations of the interdiurnal change of thicknesses 700/1000, 500/1000, 500/700 and 300/500 mbs. These tabulations should be listed chronologically by year, month, day for each station.

Any questions concerning specific detail may be addressed to this office.

STA	YR	MO	DY	700-1000 THICKNESS	DIF	500-1000 THICKNESS	DIF	500-700 THICKNESS	DIF	300-500 THICKNESS	DIF
18601	50	12	1	2587		4905		2318		3294	
			2	2576	11-	4904	1-	2328	10	3341	47
			3	2556	20-	4890	14-	2334	6	3309	32-
			4	2546	10-	4869	21-	2323	11-	3312	3
			5	2620	74	4986	117	2366	43	3335	23

LAYER THICKNESS WITH DAY TO DAY DIFFERENCES

STA = Station Number

YR = Year

MO = Month, 01 = January, 02 = February, 03 = March, etc.

DY = Day 1 - 31

700-1000 = 700 millibar height minus 1000 millibar height
500-1000 = 500 millibar height minus 1000 millibar height
500- 700 = 500 millibar height minus 700 millibar height
300- 500 = 300 millibar height minus 500 millibar height

THICKNESS = Thickness in whole meters under each millibar height group

DIF = Day to day difference in whole meters under each millibar height group

(Example: Day 2 Dif = Difference from Day 1 to Day 2
Day 3 Dif = Difference from Day 2 to Day 3
If day previous is greater, the difference will be minus (-)
If day previous is less, the difference will be plus (+)
No difference is indicated where days are not consecutive)

NOTE: One observation per day:

The scheduled 0300Z for the period 7/49 - 5/57

0000Z for the period 6/57 - 3/58

INTERDIURNAL CHANGES

Figure 68. Cont'd.

TO Data Control Division   FROM Climatic Center   DATE 9 Sept 1959

Percentage Frequency Distribution by Starting Hours of Favorable Balloon Launching Periods of Duration 2, 4, and 6 Hours

1. Introduction

The length of time to prepare and launch high-altitude balloons depends upon the size of the balloon. Small balloons for carrying light instrument packages or the large man-carrying type are to be used. The time to prepare these types ranges from 2 to 6 hours. [illegible] the surface wind must be light. [illegible] clouds [illegible] the interest of air safety, the sky should be free enough of clouds during the balloon ascent so aircraft may avoid hitting it. The purpose of this request is to obtain summaries of simultaneous occurrence of favorable surface wind conditions and favorable sky conditions for a specific duration and beginning hour at 13 selected stations.

2. Stations, Periods of Record, and Times of Day Summaries for the following Air Force Bases will be required:

23023 Sloan Field, Midland, Texas

The entire period of record should be used, and all the hours of the day will be required.

3. Required Summary

It is requested that a summary be prepared of the monthly percentage frequency of occurrence by observation hours 00, 01, 02, 03, . . . , 23 LST of 2-, 4-, and 6-hour duration periods of simultaneous occurrence of surface wind less than 5 knots and of sky cover less than 5/10. The summaries are requested in the following form, et . . .

PERCENTAGE FREQUENCY DISTRIBUTION
OF FAVORABLE BALLOON LAUNCHING DURATIONS

STATION 23023 — 2 HOUR DURATION

	JAN		FEB		MAR		APR		MAY		JUN	
START HR, LST	% FREQ	TOTAL	% FREQ	TOTAL	% FREQ	TOTAL	% FREQ	TOTAL	% FREQ	TOTAL	% FREQ	TOTAL
00	11.9	360	12.6	366	8.9	372	5.5	328	8.8	351	7.6	342
01	13.3	360	12.8	367	12.3	373	5.5	329	11.6	352	9.0	343
02	12.4	362	13.1	367	10.2	373	9.4	330	11.1	352	10.5	344
03	10.2	362	14.2	367	9.7	373	7.3	329	10.8	352	13.7	344
04	10.5	362	15.5	367	11.5	373	9.4	329	10.5	352	12.2	344
05	9.9	363	12.3	367	12.1	372	9.1	330	10.2	352	12.5	344
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
17	5.0	363	2.5	366	.8	372	3.5	345	2.5	360	2.6	343
18	8.0	363	4.1	366	3.2	372	3.3	330	3.1	352	1.7	343
19	5.8	363	7.1	367	8.1	372	5.5	330	4.3	352	1.8	342
20	8.5	363	8.2	367	8.3	372	5.4	331	4.8	352	2.9	343
21	12.2	362	10.4	367	8.3	372	5.2	330	5.4	353	2.9	344
22	10.8	362	9.8	366	8.1	372	4.9	329	4.8	352	2.9	344
23	12.2	362	9.9	365	7.3	370	6.1	328	6.6	350	5.8	342

THIS SUMMARY PRESENTS, BY MONTH-STARTING HOUR, THE PERCENTAGE FREQUENCY OF OCCURRENCE, TO TENTHS, OF THE FAVORABLE BALLOON LAUNCHING DURATIONS OF 2, 4, AND 6 HOURS FOR THE STATIONS AND PERIODS AS LISTED.

"TOTAL" REFLECTS THE NUMBER OF VALID DURATIONS CONSIDERED FOR EACH MONTH-STARTING HOUR.

DURATIONS ARE CONTINUED INTO AN ADJACENT MONTH, BUT ARE COUNTED IN THE MONTH OF INITIAL OCCURRENCE.

FAVOR[illegible]LE CONDITIONS ARE DE[illegible]INED AS TOTAL CLOUD AMOUNT < 5/10 AND SURFACE WIND SPEED < 5 KNOTS.

OPTIMUM BALLOON LAUNCHING

Dear Sir:

We would like to begin work on the persistence study of wind direction for Jacksonville, Florida.

The tabulations should consist of two (2) parts, persistence for the 10 a.m. - 8 p.m., and the 6 p.m. - 4 a.m. observations. The period of record is January 1950 through December 1959. The data used for this study may be taken from WBAN-1 cards, your Deck 144. This completes our immediate request. If further information is necessary, please feel free to call on us.

YR	MO	10 AM DIR	10 AM TEMP	DA	TOTAL DAYS	CHANGE 79+	CHANGE 34+	NO. HRS 10 AM WIND PERSISTED A	B	C	D	E	F	MAX WS	MEAN WS	PCP	MEAN CA	MEAN DP	MEAN RH
55	01	N	2	12	1	1								10	07	NO	.0	25	37
55	01	N	2	23	1		1							12	10	YES	1.0	46	95
55	01	N	2	24	1									12	11	YES	1.0	39	91

PERSISTENCE STUDY OF WIND DIRECTION
The data used for this study was taken from WBAN-1 Cards, Deck 144.
Period of Record: January 1950 through December 1959

WBAN Station No. 13889 - Jacksonville, Florida

Hours used to determine Persistence 10 AM - 8 PM and 6 PM - 4 AM, with starting hours 10 AM and 6 PM
(Starting hour will be shown on listing.)

EXPLANATION OF HEADINGS ON LISTING

YR = Year
MO = Month
10 AM (6 PM) DIR = Starting direction. Wind Direction at 10 AM (6 PM)

10 AM (6 PM) TEMP = 10 AM (6 PM) Temperature °F
0 = No temperature reported
1 = Temperature less than 30 degrees
etc.
DA = Day
TOTAL DAYS = A 1 will be printed for each day present
CHANGE 79+ = A 1 will be printed in this column if the change in direction in the first six hours is greater than 79° from the starting direction.
CHANGE 34+ = A 1 will be printed in this column if the change in direction in the first six hours is greater than 34° but less than 79° from the starting direction.
HRS 10 AM (6 PM) WIND PERSISTED = The number of hours that the 10 AM (6 PM) wind persisted............
A = A 1 will be printed in this column if the duration of the persistence was 6 hours.
B = A 1 will be printed in this column if the duration of the persistence was 7 hours, etc.........

MAX WS = Maximum wind speed in knots for the observations in the first 6 hours.
MEAN WS = Mean wind speed in knots for the observations in the first 6 hours.
PCP = Gives a yes or no count of precipitation, either liquid or frozen, in the first 6 hours.
MEAN CA = Mean cloud amount for the observations in the first 6 hours.
MEAN DP = Mean dew point temperature in degrees Fahrenheit for the observations in the first 6 hours.
MEAN RH = Mean relative humidity to percent for the observations in the first 6 hours.
TOT = Total for the wind direction, for each temperature class, for the month over the 10 year period for total days, change 79+, change 34+, and number of hours wind persisted.
GRAND TOT = Grand total for the wind direction for the month over the 10 year period for total days, change 79+ change 34+, and number of hours wind persisted.

PERSISTENCE

Gentlemen:

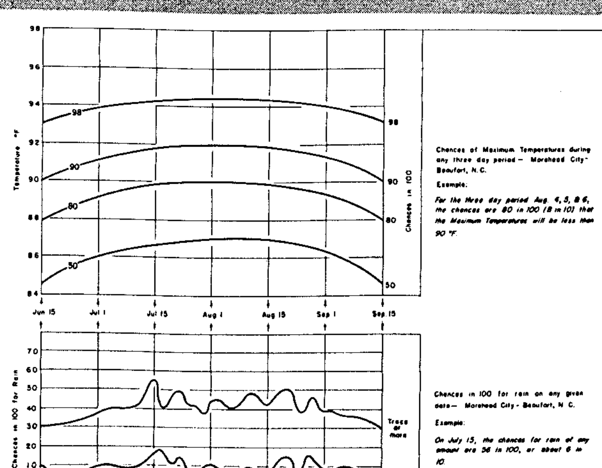
We are preparing a brochure containing a description of recreational facilities and climatic advantages of a beach-resort area in North Carolina, specifically the area around Morehead City-Beaufort.

Please prepare a graphic presentation showing the following:

Probability of:

1. Maximum temperatures during any three-day period (June 15 through September 19 inclusive).
2. Rain on any given date (chances in 100) in same season.

We will be glad to furnish additional information concerning this request if so desired.



PROBABILITY

SPECIAL STUDIES

Figure 68. Cont'd.

Dear Mr. [illegible]:

Our laboratory is now in a position to complete analysis of the radio-climatology of the Middle East and Southeast Asia areas. In order to do this, it will be necessary to obtain additional meteorological data outlined below.

Area 1 -- Eastern Asia
Area 2 -- Southeast Asia
Area 3 -- Middle East

For the present, Area 1 is of immediate interest. This area is defined specifically as the lands bordering on and within 200 miles of the coast of the East China Sea.

The data required includes upper air soundings from all sources in the area. One of our representatives who recently visited your Center has indicated that all foreign upper air data have been transferred to punch cards and that computation and statistical breakdowns necessary for our purposes can be made in a relatively short time.

The atmospheric property affecting radio propagation is the vertical profile of Refractive Index N, which is defined as

$$N = \frac{77}{T}\left(P + \frac{4800\,e}{T}\right) + .012h$$

where T is the absolute temperature, P is the pressure, e the vapor pressure of the air at height h (ft). N values normally vary between 250 and 400 ....

STA	YR	MO	DA	HR	HT M	P	T	RH	B	B-B	HT F	A					G	D	X	N
99333	49	12	18	15	23	1012	26.0	D232	388	0										
99333	49	12	18	15	130	1000	25.3	D225	385	3-	351	004-	1			1				
99333	49	12	18	15	620	945	21.3	D162	357	31-	1959	013-			1	1				
99333	49	12	18	15	1050	900	18.7	D164	367	21-	3369	006-		1		1				
99333	49	12	18	15	1540	850	17.0	D141	364	24-	4976	004-	1			1				
99333	49	12	18	15	1850	820	15.3	D124	362	26-	5993	004-	1			1				
													3	1	1	5	4	9	004-	015-

RADIO-CLIMATOLOGY SURVEY

Area Three

Station 99333 Port Blair, India 12-49 thru 12-50

HT M - Reported Height in meters above sea-level
P - Pressure in millibars
T - Temperature in degrees Centigrade
RH - Relative humidity in percent
B - KP + CRH + 0.12H
K-79/T
C-79/T x 4800 ES/T
B-B BH-BO
HT F - Converted height in feet above surface
A-BB - BO/H + 400 feet
B - Observation group
1 - All A values between +.005 and -.005
2 - All A values between -.006 and -.010
3 - All A values between +.006 and +.010
4 - All others

X - Maximum A value
N - Minimum A value
D - Range-Difference between maximum and minimum A values

All time in GCT

RADIO-CLIMATOLOGY

Dear Dr. [illegible]:

We refer to your letter of October 27, 1958 concurring in a letter from this office dated September 26, 1958 to have certain services performed by your National Weather Records Center, Asheville, N. C., on a reimbursable basis.

We now desire to have additional services performed. These would include extraction of maximum ten-minute, thirty-minute, and sixty-minute intensity data and hourly precipitation amount for significant storms at approximately 30 stations other than those covered by our previous arrangement. (See Attachment).

To determine the rainfall erosion index:

A. General
1. The index is based on individual-storm data.
2. Two facts are needed for each storm:
a. Total rainfall energy of the storm
b. Maximum amount of rainfall in any continuous 30 minute period.

B. Criteria for selection of storms to be included in the study.
1. Include all storms for which rainfall amount is ≥ .50 inch without a 6-hour break.
2. Include smaller storms if, and only if, at least .25 inch of rain occurred in a 15-minute period.

C. Definition of "individual storm for purposes of this study: A period of rainfall beginning at the end of a period of at least 6 hours with no more than a trace of rainfall and ending immediately prior to the next period of at least 6 hours with not more than a trace. Beginnings and endings of calendar days or months have no effect on storm length.

STN	YR	A	B	C	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
12832	36	57	22	73										34		24
		4												21		22
	37	397	119	144		29	17	144	35	38	15	52	32		32	5
		30				13	7	119	29	28	12	18	23		31	3
	AN	577	1155	370	263	386	1440	767	445	1210	1265	1383	1967	261	378	236
		296														

COMPILATION OF RAINFALL ENERGY

STN = Station Number
YR = Year

	A	B	C	JAN FEB MAR APR ... DEC
For each year is given:				
1st Line	Total El for year	Maximum El	Maximum 30 Min. Intensity	Total El by months
2nd Line	Number of storms			Maximum El by months
For Period of Record is given:				
AN 1st Line	Average annual El	Maximum El	Maximum 30 Min. Intensity	Percentage (to hundredths) of total El contributed by each month.
2nd Line	Standard Deviations of Yearly El			

(A) Rainstorms defined as continuous period (not more than 5 consecutive dry hours) of rain totaling .50 or more, or having .25 or more in 15 minutes.

(B) For each storm the values A_{10}, A_{30}, A_{60}, A_H were read as the max 10, 30, 60 minute amounts and the clock hour amounts for the balance of the storm, respectively.

Then, for each storm,

$$El = 2A_{30}\left[\frac{E(6A_{10})}{6} + \frac{E\{3(A_{30} - A_{10})\}}{3} + \frac{E[2(A_{60} - A_{30})]}{2} + \sum_{i=1}^{n} A_{H_i}\right]$$

Where 'E' is kinetic energy in foot-tons, and is function of 'A' interpreted as intensity.

RAINFALL ENERGY

Gentlemen:

In connection with previous correspondence regarding the computation of refractivity, we are listing basic specifications so that you may proceed with the computations.

Under significant level data compute "N" for each level and DN/DH for each level. For each radiosonde observation list the station, year, month, day, hour (GCT), and for the significant level the pressure (mbs), temperature (°C), Relative humidity (%), height (meters), height difference (DH-thickness) of layer of which that level is the upper limit and the preceding level is the lower), N gradient (DN/DH-lapse rate per meter of "N" through the layer DH), Refractive index value N

$$N = \frac{77.6}{T}\left(P + \frac{4810 e_s RH}{T}\right),$$

station elevation (meters), and if no extra cost involved the dry term of N

$$\left(N_d = \frac{77.6\,P}{T}\right)$$

Compute and list the results for each sounding for each station (including those that take 4 soundings per day) for the months of February, May, August, and November. Use a five year record, where available, and the basic period of interest is 1951 through 1957.

STN	YR	MO	DAY	HR	P	T	RH	HOT	DH	DN/DH	N TOT	N DRY	N WET	EL
25223	46	06	05	03	1016	12.7	76				326.7	275.8	50.8	16
					958	10.0	67	492	492	-.053	300.8	262.5	38.3	
					824	1.3	84	1726	1234	-.032	260.8	232.9	27.9	
					772	- 1.6	85	2248	522	-.032	244.0	220.6	23.4	
					743	- 2.5	80	2553	305	-.034	233.7	213.0	20.7	

COMPUTATION OF REFRACTIVITY AND REFRACTIVITY LAPSE RATE PER METER
WBAN STATION NO. 25223 FORT HARDY BRITISH COLUMBIA DOT A

Period of Record: 6/46-12/49

Each horizontal line of print represents a significant level, the first line of each observation being the surface data; the second line, the first significant level above the surface; the third line, the second significant level above the surface, etc.

Each observation is identified by a date and time group located to the left of the surface data.

STN = Station Number

YR = Year

MO = Month (02 = February, 05 = May, 08 = August, 11 = November)

DAY = Day

HR = Hour GCT 03 and 15

P = Pressure in millibars

T = Temperature in °C

RH = Relative Humidity (%)
* = Statistical value (12-22 percent)

HOT = Height above observation point in meters

DH = ΔH = Thickness of the layer; i.e., the 'DH' assigned to each level is the thickness of the layer of which that level is the upper limit and the preceding level is the lower limit.

DN/DH = ΔN/ΔH = The lapse rate per meter of 'N' through the layer ΔH.

N TOT = Refractivity by $N = \frac{77.6}{T}\left(P + \frac{4810 e_s RH}{T}\right)$

N DRY = $\frac{77.6}{T}$

P = Pressure in millibars
T = Temperature in degrees Kelvin
e_s = Saturation vapor pressure for Temperature R
RH = Relative Humidity

N WET = $\frac{373256 e_s RH}{T^2}$

EL = Elevation of the observation point in meters above mean sea level

NOTE: The levels presented were punched from foreign data source and it is assumed that only selected significant levels rather than all levels were available for punching. It is also assumed that the selection of levels by the countries concerned generally followed WMO procedures for selection of significant levels for transmission.

REFRACTIVITY

SPECIAL STUDIES

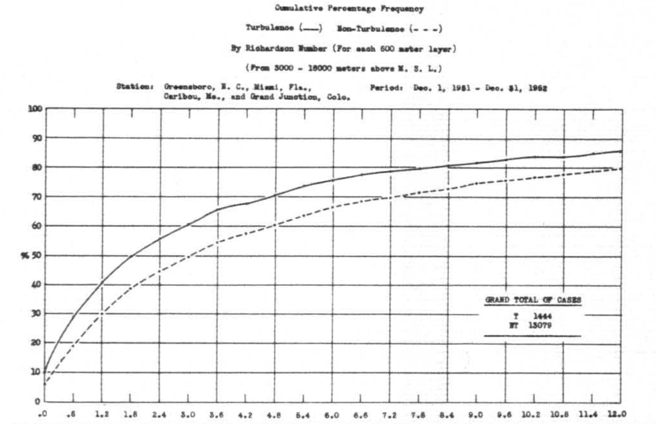
Figure 68. Cont'd.

Dear Sirs:

My thanks for the material you have sent so promptly. I hope to have the report written covering most of this work by the end of this week.

It is agreed that the turbulence program should go forward by processing the data for 600-meter thicknesses instead of 300-meter thicknesses, as formerly. Similar distributions for cumulative percentage frequency and percentage frequency should be made for each station and totaled for all stations for the following only:

Richardson's number, wind shear, lapse rate, wind speed, wind direction, temperature and relative humidity .....



T	139	285	174	123	92	73	60	40	44	36	27	32	21	13	14	13	12	9	10	10	7	Freq.
NT	749	1772	1440	1122	833	664	587	459	390	384	311	242	257	199	172	172	147	146	140	101	113	Table

TURBULENCE

Dear Mr. Fox:

We'd appreciate it if you would proceed with the following wind roses for Phoenix-Sky Harbor Airport, based on the most recent five-year period of weather observations:

1. All weather
2. VFR (Equal to or greater than 1000/3)
3. IFR (Less than 1000/3 but equal to or greater than 600/1 1/2)
4. IFR (Less than 600/1 1/2 but equal to or greater than 200/ 1/2)
5. Closed (Less than 200/ 1/2)

We will want both annual and monthly roses for the above categories ....

		FREQUENCY								PERCENTAGE							
MO	DIR	0-4	5-9	10-14	15-19	20-24	25-29	30+	TOT	0-4	5-9	10-14	15-19	20-24	25-29	30+	TOT
AN	N	681	393	78	39	9	2		1202	1.55	.90	.18	.09	.02			2.74
AN	NNE	365	196	61	29	4		1	656	.83	.45	.14	.07	.01			1.50
AN	NE	1238	489	176	50	7	2		1962	2.82	1.12	.40	.11	.02			4.48
AN	ENE	749	603	109	19	1			1481	1.71	1.38	.25	.04				3.38
AN	E	3840	2867	265	28	2	1		7003	8.76	6.54	.60	.06				15.98

WIND ROSES BY SPECIAL CATEGORIES OF CEILING AND VISIBILITY

Station No. 23183 - Phoenix, Arizona Airport
Period of Record: January 1953 - December 1957

MO = Month, AN = Annual, 01 = January, 02 = February, 03 = March, etc.

DIR = Wind Direction, 16 points and calm

Left side of form for frequency distribution of winds by the following speed breakdowns:
0 - 4 = Zero to 4 miles per hour
5 - 9 = 5 to 9 miles per hour
10 - 14 = 10 to 14 miles per hour
15 - 19 = 15 to 19 miles per hour
20 - 24 = 20 to 24 miles per hour
25 - 29 = 25 to 29 miles per hour
30+ = 30 miles per hour and over
TOT = Total frequency of all wind groups

Right side of form for percentage frequency distribution of winds computed to hundredths of percent.

	Run	Card	Ceiling (Feet)		Visibility (Miles)		Ceiling (Feet)		Visibility (Miles)
All Weather	1	0	All		All				
VFR	1	1	≥ 1000	and	≥ 3				
IFR_1	1	2	600 - 900	and	≥ 1 1/2	or	≥ 1000	and	1 1/2 - 2 3/4
IFR_2	1	3	200 - 500	and	≥ 1/2	or	≥ 600	and	1/2 - 3/8
Closed	1	4	≤ 100	or	≤ 3/8				

R = Run Number
C = Card Number

WINDS AND WEATHER

Dear Mr. Fox:

In connection with our operational activities at Block Island, Rhode Island, we are anxious to obtain an analysis of the Winter wind regime.

Using available records and/or punched cards for the period dating back to 1889, and for the hours of 7:30 A.M. and P.M., please construct wind rose tables as shown on Attachment 1 ......

It is suggested that the data be listed by each year for the Winter season. We are anxiously awaiting these results.

										TOT NO. OBS				
STA NO.	YR	MO	DIR	1-3	4-12	13-24	25-31	32-46	47+	4+	%	OBS	SUM SPEED	MEAN SPEED
14799	89	WS	N		6	4	1			11	6.1	11	136	12.4
14799	89	WS	NE		4	7	8	4	1	24	13.3	24	627	26.1
14799	89	WS	E			6	1			7	3.9	7	145	20.7
14799	89	WS	SE		2	8				10	5.6	10	163	16.3
14799	89	WS	S		2	6	1			9	5.0	9	149	16.6
14799	89	WS	SW		9	16	7	1		33	18.3	33	609	18.5
14799	89	WS	W		9	13	6	1		29	16.1	29	541	18.7
14799	89	WS	NW		16	24	7	6	2	55	30.6	55	1140	20.7
14799	89	WS	C								1.1	2		
14799	89	WS	TOT		48	84	31	12	3	178	100.0	180	3510	19.5

ANALYSIS OF WINTER WIND REGIME
AT
BLOCK ISLAND, RHODE ISLAND

Period of Record: December 1889 thru February 1890, etc.
December 1949 thru February 1950

Hours: 7:30 A.M. and 7:30 P.M.

STA NO. = Station Number
YR = Year (89-99; 00-50)
MO = Month
01 - January 12 - December
02 - February WS - Winter Season (WS 89 = Dec 1889-Feb 1890)

1 - 3 = Wind speed in miles per hour
4 - 12 = Wind speed in miles per hour
13 - 24 = Wind speed in miles per hour
25 - 31 = Wind speed in miles per hour
32 - 46 = Wind speed in miles per hour
47+ = Wind speed in miles per hour (winds ≥ 47 m.p.h.)
4+ = Wind speed in miles per hour (winds ≥ 4 m.p.h.)

TOT NO. OBS = Total number of observations group

% = Percentage of total

OBS = Total observations per direction month

SUM SPEED = Sum of speeds

MEAN SPEED = Mean speed to tenths of m.p.h.

WINTER WINDS

6.4 OTHER SOURCES OF CLIMATOLOGICAL INFORMATION

Many other published, or at least printed, sources of information are utilized (and in many cases have been facilitated by tabulations of descriptions prepared) at Asheville. The following, unless otherwise noted, are distributed by the Weather Bureau:

Letter Supplements

More than 65 Letter Supplements have been prepared by various Weather Bureau Offices on a multitude of subjects, and many of them have been or are being revised. The titles range from "Tornado Facts" (LS 5515) to "Average Date of First and Last 32 Degree Temperature" (LS 5820). The supplements available from NWRC are used to answer repeated requests for similar types of information. An index of titles also is available.

Technical Papers

In this series, number 32, e.g., is published in three parts as follows:

I. Averages for Isobaric Surface (Height, Temperature, Humidity, Density) (1957)

II. Extremes and Standard Deviations of Average Heights and Temperatures (1958)

III. Vector Winds and Shear (1959)

Daily River Stages (Annual)

This publication contains daily river stage data for approximately 625 stations located on the principal rivers of the United States. Miscellaneous information such as mean sea level, elevation of gage zero, drainage area, flood stage, and extreme stages during period of record appears for each river gaging station, and is of particular interest to construction engineers, government agencies, and others interested in highway construction, power development, irrigation, navigation, flood frequency studies, etc.

Mariners Weather Log

The Mariners Weather Log is a bimonthly publication providing information on weather over the oceans and over the Great Lakes. It includes gale data for the Atlantic and Pacific Oceans, articles of current interest, items on marine meteorology or of historical background information, along with a Rough Weather Log covering three recent months and a Smooth Weather Log covering the two months preceding the rough log. The first issue, Volume 1 was for January 1957.

Snow Cover Survey

This publication, issued on an annual basis beginning with data for the winter season of 1940-41, contains snow depth and water equivalent data for some 600 locations in the northeastern United States arranged by river basins. Data for the winter of 1941-42 and 1942-43 were published as one issue. The data are collected by various agencies (governmental and non-governmental) cooperating in the survey and are submitted to the Records Committee of the Eastern Snow Conference.

Airway Meteorological Atlas for the United States and Normal Flying Weather for the United States

The Airway Meteorological Atlas presents graphically the results of two climatic studies over a network of Weather Bureau Airport Stations in the United States. The first study treats average surface conditions of wind and weather, while the second deals with upper air winds based on tabulations of pilot balloon observations. Tables of upper air wind data are also given. The Atlas was prepared in projects of the U. S. Work Projects Administration and printed in 1941.

Normal Flying Weather for the United States was published in 1945. It was prepared in cooperation with the Air Force Weather Service and the Work Projects Administration. Tables present data on general weather conditions, ceiling height, and visibility.

The Daily Upper Air Bulletin

The Daily Upper Air Bulletin was published by the Weather Bureau from unchecked teletypewriter data August 13, 1948 through October 31, 1949, and was sponsored jointly by the Army, Navy, Air Force, and the Weather Bureau. The bulletin contained all of the 0300 GMT and 1500 GMT upper air data reported by North American stations.

A similar bulletin was published by the U. S. Department of the Navy from April 3, 1950 through June 30, 1954. This was the first attempt to collect and print by means of a direct ditto process all of the 0300 GMT and 1500 GMT upper air data reported by teletypewriter by North American stations.

The Weather Bureau resumed publication of this bulletin, with funds provided by the Air Force on December 1, 1954, using the same style and make-up employed by the Navy, and discontinued it on June 30, 1955. Subsequent data are published as a part of Daily Series, Synoptic Weather Maps, Part II Northern Hemisphere Data Tabulations.

Weekly Weather and Crop Bulletin, National Summary (Weekly)

The Bulletin gives a synopsis of weather conditions and their effects on crops and farming operations in the United States, and also shows snow and ice conditions and heating degree days during the winter season.

Terminal Forecasting Reference Manuals

This series of pamphlets contains terminal weather data assembled for Weather Bureau Airport Stations. Each pamphlet includes, for one airport, maps of local topography and climatological information on visibility, ceiling, precipitation, sky cover, surface winds, thunderstorm occurrences, and other weather data which affect aviation. These data are designed for use by meteorologists when advising pilots in connection with the preparation of flight plans and are issued at irregular intervals.

Climate and Man - 1941 Yearbook of the Department of Agriculture

Many sections of the Yearbook are very popular and thousands of the articles are sold as separates. The popularity of the sections stems from the fact that the language is non-technical in nature and understandable to all readers. Not all the sections of the Yearbook are available as separates. The current Weather Bureau pamphlets "Climates of States" update the individual state sections of the book. A complete new volume is in the discussion stage at present.

Daily Temperature and Precipitation Normals

The normals used in the Weather Bureau cover a recent 30-year period. Monthly values for 368 locations were issued in 1954 in a publication called "Monthly Normal Temperatures, Precipitation, and Degree Days," and reissued in 1956 as Technical Paper No. 31 with the same title, for 388 locations. A current revision is being initiated for Weather Bureau "first order" stations.

The above descriptions are taken largely from the Weather Bureau's Key to Meteorological Records Documentation No. 4.1, History of Climatological Publications and Selected Lists of Publications issued at irregular intervals.

CONTRIBUTIONS

6.5 STAFF CONTRIBUTIONS

Technical or professional papers are sometimes produced by NWRC staff members independently or in cooperation with the customer. Abstracts from some of these presentations are given in figure 69. Even though the Center is primarily a data processing activity, such contributions to the science of climatology do result from the solutions of daily problems. While similar published papers are produced by Air Force and Navy staffs in Washington, D. C. and Norfolk, Virginia, e. g., their Asheville counterparts normally function primarily in a supporting role.

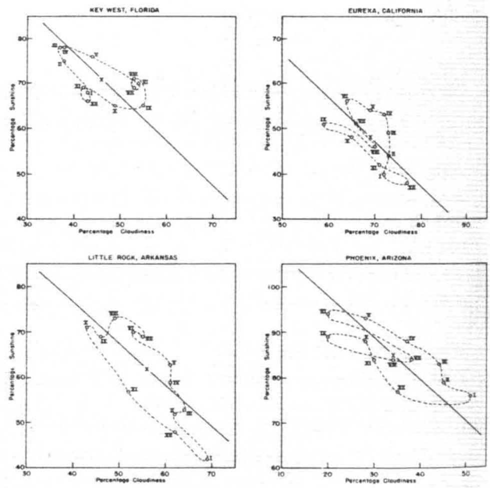
Prepared for publication

SUNSHINE-CLOUDINESS RELATIONSHIPS FOR CERTAIN LOCALITIES IN THE UNITED STATES

Roy L. Fox

This study presents the procedures used and some of the results obtained in determining the relationship between percentage sunshine and percentage cloudiness for United States stations through grouping segments of the mean annual and mean monthly data based on relative amounts of stratiform cloudiness. The groupings are by geographical areas for the mean annual and mean monthly data and, further, by portions of the year for the latter.

These treatments of the mean annual and mean monthly percentage sunshine and percentage cloudiness for recent years for the United States stations provide a means of estimating the former from the latter.



Monthly Weather Review, June 1956

DATA COLLECTION FOR THE NORTHERN HEMISPHERE MAP SERIES

William M. McMurray

A general review is made of the Northern Hemisphere Map Series with emphasis upon data collection from multiple sources. The advantages of an historical analysis are presented with a comparison of analyses as prepared operationally, with immediate deadlines, and historically, after additional data are available.

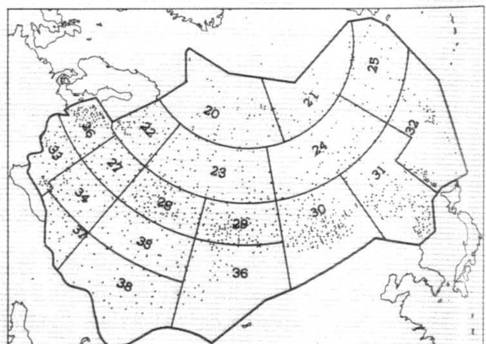
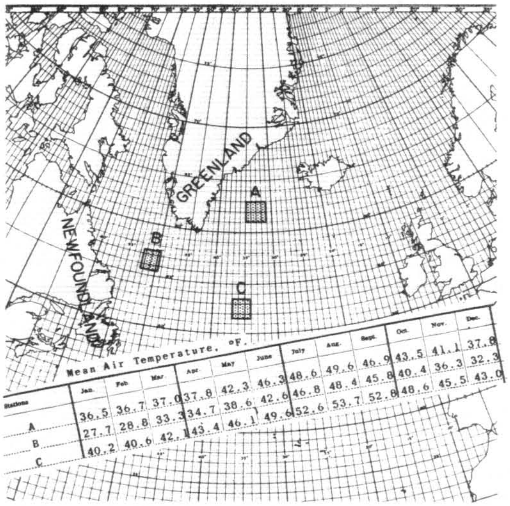


Figure 69.

FROM STAFF

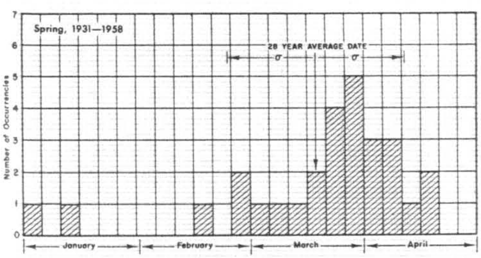


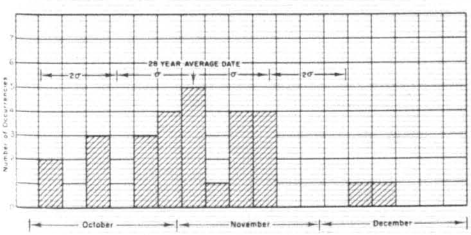
Mariners Weather Log, 1960

THE CLIMATE OF THE NORTHWESTERN NORTH ATLANTIC OCEAN

Norman L. Canfield

The potential to climatology of observations from "weather" ships is briefly reviewed. Observations made during the past decade at three Ocean Stations - A, B, and C - are used to describe some climatic characteristics of a region infrequently traversed by merchant ships. Several weather elements, notably precipitation and wind associated with intense and frequent cyclonic activity, are quantitatively summarized in terms of annual percentage frequency distributions.





Direct Seeding in the South-1959
A symposium, Duke University

WEATHER PLANNING

Gerald L. Barger

Limited surface soil moisture and related increases in surface soil temperature are among the important causes of young tree seedling mortality. If definitions of these conditions in terms of recorded weather data are accurately drawn, probabilities of portions of the available planting and growing season being favorable or unfavorable can be evaluated. Knowing the likelihood of success or failure will permit intelligent selection of planting dates and realistic evaluation of available cultural practices for combating weather hazards.

Data and analytical techniques available through the National Weather Records Center will be discussed and further definition of critical conditions will be invited from the foresters present.

Coordination of climatological planning and weather forecast application as the proposed planting date approaches will be stressed.

Figure 69. Cont'd.

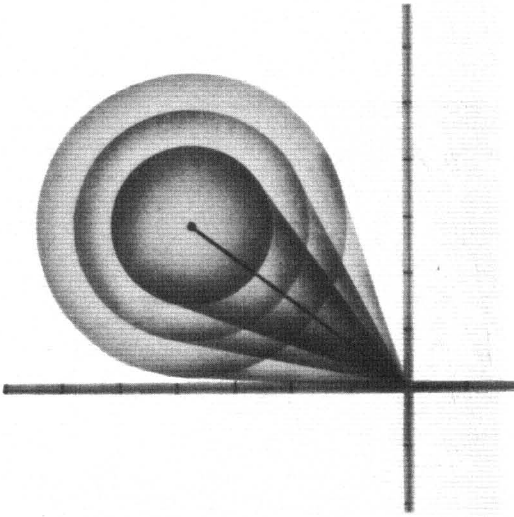
Journal of Meteorology, Volume 14, February 1957

ON THE STANDARD VECTOR-DEVIATION WIND ROSE

Harold L. Crutcher

To depict wind information, various methods of representations have been developed. Each one has its advantages and its disadvantages. Some of these representations are illustrated.

It is the purpose of this article to present a relatively new type of wind rose, termed here a standard vector-deviation wind rose, and to be referred to hereafter as the SVD wind rose. The development of this wind rose has been slow, and its origin perhaps can be traced to the vector-error distribution in measurements employed in the physical sciences. Its development in the meteorological field is discussed.



Monthly Weather Review, November 1959

FRONTAL PASSAGES OVER THE NORTH ATLANTIC OCEAN

Georgia C. Whiting

Graphical and tabular data on the frequency of frontal passages at Ocean Station Vessels on the North Atlantic are compiled from historical weather maps for the years 1945-57. The stabilizing influence of the Gulf Stream is shown by the rapid modification of air temperature at all stations and by the rapid transition of frontal systems. The greatest frequency of fronts is found at the line of initial contact of cooler air with that associated with the Gulf Stream in the westernmost region of the Ocean.

The value of the historical sea level synoptic weather maps as a data source for the climatological study of atmospheric motion systems is emphasized.

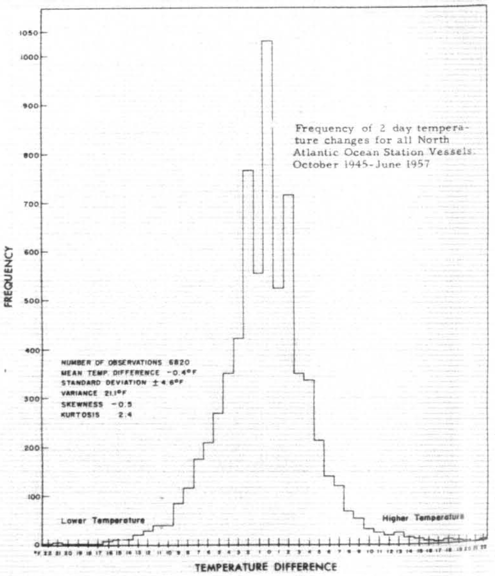
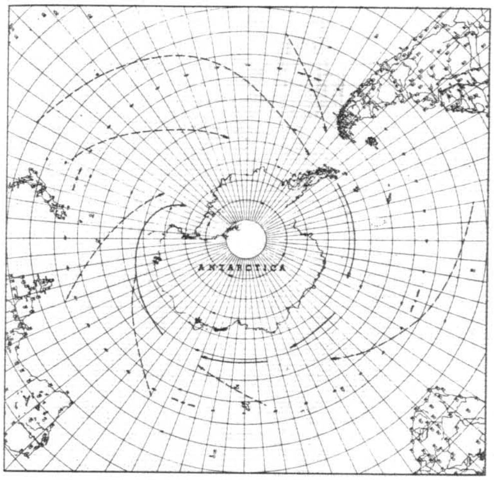


Figure 69. Cont'd.



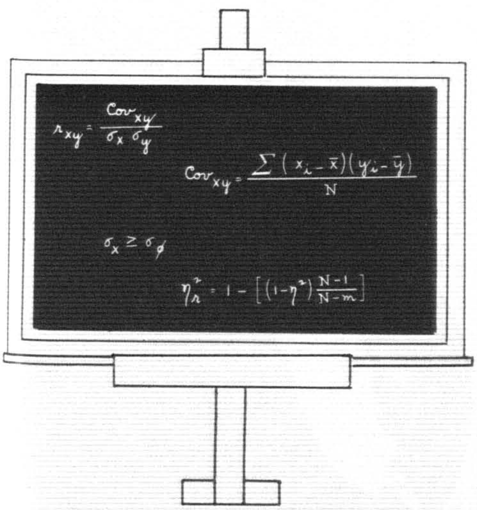
Monthly Weather Review, February 1958

PRINCIPAL TRACKS OF SOUTHERN HEMISPHERE EXTRATROPICAL CYCLONES

John S. Arnett

Two years of Southern Hemisphere synoptic charts completed in Boston, Massachusetts, under the Southern Hemisphere Project of the U. S. Weather Bureau and charts completed more recently, by the South African Weather Bureau, have made valuable new source material available to investigators of weather patterns south of the equator.

A resume of the source of data and methods used in the determination of storm tracks shown on each bi-monthly chart is given.



Current Manuscript Report to the
Office of the Navy Representative

CORRELATION OF WIND DIRECTION OBSERVATIONS AND OTHER SURFACE ELEMENTS

O. Essenwanger

It has been illustrated in this report that statistical characteristics expressing the relationship between cloud cover or visibility and wind direction can be computed with meaningful meteorological interpretation. Several measurements have been suggested and the method of computing has been discussed with samples given.

The linear correlation coefficient r_{yx} by cloud cover (visibility) classes seems to be a fairly good characteristic, although because of the nonlinearity of the relationship, the correlation ratio y_{yx} is more efficient.

Climatological features may also be studied by the linear correlation coefficient R_{yx} which expresses the unweighted relation between cloud cover (visibility) classes and wind direction. The mathematical formulation of the relationship by polynomials proves again that higher order terms affect the functional connection.

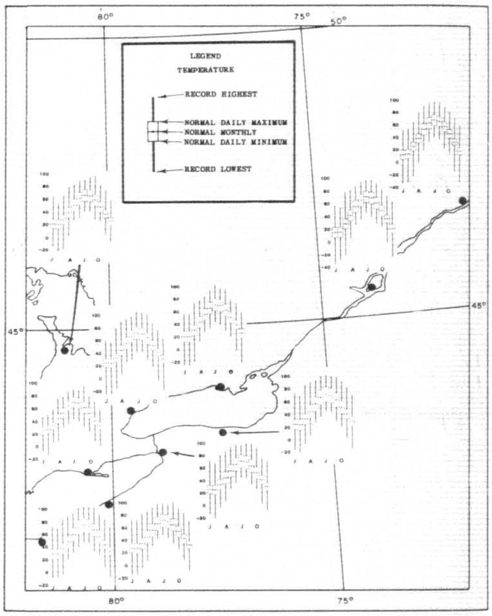
It is recommended that maps of any one or all of these three characteristics be drawn from SMAR tabulations and that areas of strong relationship be studied for similarity to establish a condensed handy booklet for operational use, containing all valuable meteorological information.

Figure 69. Cont'd.

U.S.W.B. Technical Paper No 35

CLIMATOLOGICAL SUMMARIES FOR THE ST. LAWRENCE SEAWAY AND GREAT LAKES

Prepared by Office of Climatology Staff Using the NWRC Facilities



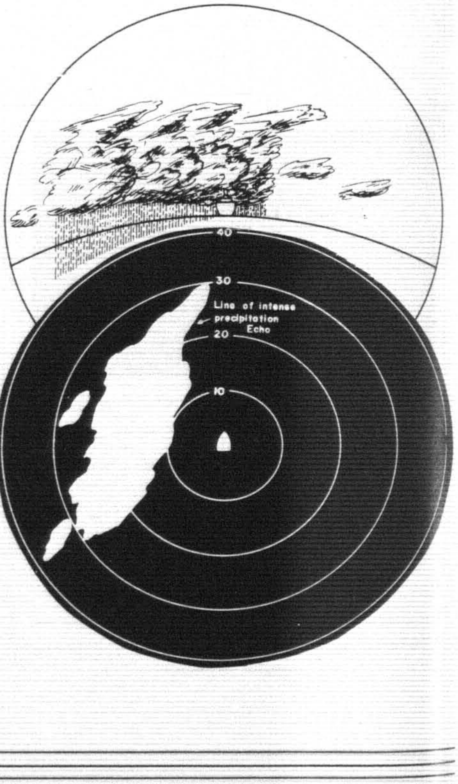
Completion of the St. Lawrence Seaway opens the Great Lakes to deep-draft, oceangoing vessels for the first time. The above publication is intended to familiarize masters, mates, and steamship company officials of vessels now plying the waterway and those who will, in the future, come to use the expanded facilities, with weather conditions and available weather services in that area.

The elements summarized are: storm tracks (cyclones), wind, fog, air temperature, humidity, precipitation, clouds, ice, lake levels, currents, and lake temperatures. Also included in this paper are tables of normals, means, and extremes for 28 cities bordering the Great Lakes or St. Lawrence Seaway between Quebec, Canada and Duluth, Minnesota.

Mariners Weather Log, January 1958

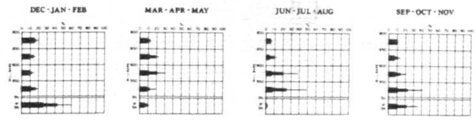
RADAR AND WEATHER

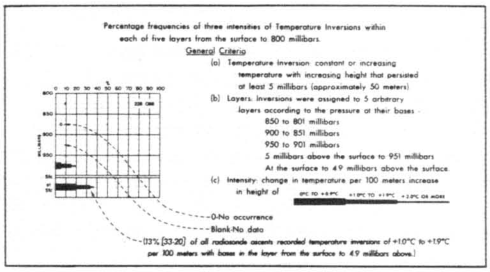
Lawrence E. Truppi



With the increasing use of marine radar on merchant vessels, proper interpretation of radarscope displays becomes essential. One of the most common phenomena appearing on ships' radar is the echo from precipitation in the atmosphere; the term "precipitation" includes rain, hail, snow, sleet, and drizzle. Most marine radars contain special circuits (Anti-Clutter, STC, FTC, Receiver LIN-LOG) whose functions are to reduce precipitation echoes or sea return on the radarscope so as to reveal any objects which might be obscured. However, in order to employ anti-clutter circuits to their best advantage, the person operating the radar must be able to recognize the various forms and configurations of precipitation echoes and adjust the radar set accordingly In addition, valuable meteorological information concerning the location of thunderstorms, squall lines, or tropical storms may be observed on a radarscope. This discussion will consider the recognition of a few types of precipitation situations and atmospheric conditions commonly encountered at sea and their appearance on the PPI scope of a marine radar. The manufacturer's operator's manual should be consulted for precipitation anti-clutter adjustments since these vary from radar to radar.

Figure 69. Cont'd.



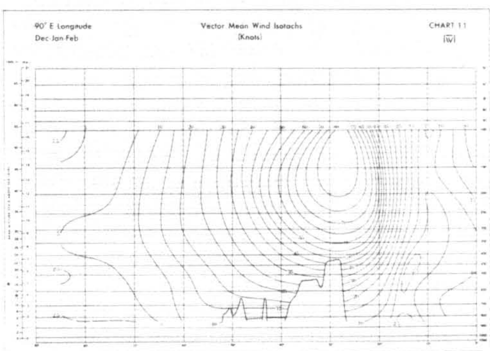


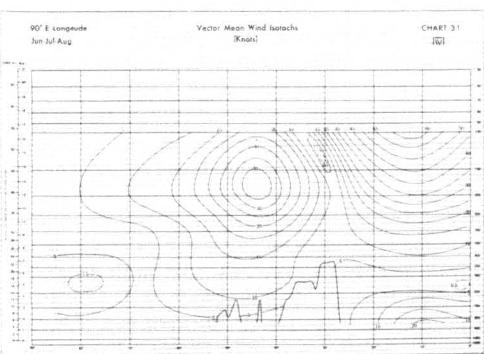
Monthly Weather Review, January 1957

WINDS OF THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE OVER THE UNITED STATES

Marvin W. Burley, Earl M. Ritchie, and Charles R. Gray

Daily wind data from United States stations for six pressure surfaces (200, 150, 100, 80, 50, 30 mb.) for the period April 1951 through January 1956 are used to study upper winds along the 80th and 120th meridians. At 5-degree intervals along the two meridians, mid-season average wind speeds and prevailing directions have been computed and are compared.





Currently being prepared for publication by U. S. Navy

CROSS SECTIONS UPPER WIND STATISTICS OF THE NORTHERN HEMISPHERE

Harold L. Crutcher

Previous study has shown that in many areas wind distributions in the free atmosphere can be described by the elliptical normal distribution. Estimates of the statistical parameters in the distribution function are obtained from actual observations. The U. S. Navy, in NAVAER 50-1C-535, published a number of wind statistics in chart form. These charts provided analyzed statistics for several constant pressure surfaces for four seasons on a Northern Hemispheric basis. From those charts the reader may extract sufficient information to construct theoretical or elliptical wind distribution graphs or tables for any desired location within the geographical limits of the analyses.

Applications of data extracted from these charts are many. Specifically, some of these are in the fields of ballistics, fallout of radioactive debris, and long range planning for military and commercial air transport as well as in rocketry problems.

The presentation of data at constant pressure levels does not provide a direct idea as to the distribution of wind statistics at intermediate layers. Therefore, vertical cross sections of wind statistics have been prepared. These have been made by the analysis of data obtained from interpolated grid point values of the constant pressure charts, NAVAER 50-1C-535. These cross-sections depict the salient features of the atmospheric circulation of the Northern Hemisphere between 850 mb. and 100 mb.

Figure 69. Cont'd.

6.6 REQUESTING CLIMATOLOGICAL DATA

As mentioned earlier, facilities are maintained at Asheville for servicing the climatological requirements originating within the civilian and military branches of the government and from all other public as well as private organizations or individuals.

6.6.1 U. S. WEATHER BUREAU SERVICES TO PUBLIC AND PRIVATE ORGANIZATIONS AND INDIVIDUALS

Since the Weather Bureau is a public agency authorized to perform services in the general public interest, it does not undertake the solution of private problems at public expense. By an act of Congress*, however, these problems may be attacked, provided the government is reimbursed. Engineering, business, etc., either directly or through private meteorological consultants, may request services. In addition, work may be performed for other federal agencies under separate legislative authority**, with reimbursement effected through transfer of funds.

The reimbursement in all cases is solely to defray the expenses incurred by the government in satisfying the specific requirements to the best of its ability. This cost may range from a nominal charge for copies of records to many thousands of dollars for a complete analysis of data.

Weather Bureau offices and officials submit requests through their respective operational and administrative channels, since NWRC has essentially no direct funding for supporting other sections of the Bureau. Only very limited amounts usually are allocated to the NWRC for servicing small jobs and these are primarily for other government agencies when reimbursement procedure costs would exceed the amount transferred.

* Act of May 27, 1935, Title 15, U. S. Code 189A, Public Law No. 74

** 31USC686, Economy Act of 1932

6.6.2 NAVY SERVICES

The Office of the Naval Weather Service controls the Navy participation in the joint activity of the Asheville operation. Correspondence requesting the utilization of its capabilities should be addressed to:

Director, Naval Weather Service
Navy Department
Washington 25, D. C.

The magnitude of Navy participation is based on the Navy's known and estimated needs for climatological information and on budgetary limitations. The estimated naval need is based upon the actual requests that have been received in previous years. After appropriation and allotment of funds for the fiscal year, a continuing basic program of action is developed whereby the known needs can be fulfilled, and within which the estimated needs can be met as they arise. Requests may exceed the estimated needs either in number or magnitude, in which case special funds and other arrangements are necessary. When this cannot be done, priority lists are established and future budget estimates are made so that the work can be done when funds are made available.

6.6.3 AIR FORCE SERVICES

Requirements for climatic support to units of the Air Force and the Army should proceed through military channels to Director, Climatic Center, USAF, 225 D St., S. E., Washington 25, D. C. Non-weather elements of these services are advised to first consult local representatives of the Air Weather Service whenever possible. Needs of contractors of the Air Force and the Army should be directed through the contracting office to the Climatic Center, USAF, at the address given above.

6.6.4 SEMANTICS OF A REQUEST

Before any one of the three agencies can render the best possible service to the requester, it must have all the necessary information for evaluating the problem. Requests fall generally into three basic categories:

a) Those which specifically require copies or abstracts of basic observational data.
b) Those which deal with general areas and standard analyses which can be satisfied by one or several of the previously published works or unpublished tabulations and summaries.
c) Those dealing with a unique problem which can be satisfied only by a non-routine analysis.

While a precise statement of the problem is essential for all types, it is the last that poses the greatest problem in semantics and communication. It has been proven again and again that in the planning of any sizeable project it is preferable for the client to visit Asheville personally. Here, the meteorologists, climatologists, data processing specialists, and record specialists can explore the problem as a team with the client.

When this is not feasible, the client should present as precise and detailed statement of the desired elements, critical thresholds, etc., as possible. While the non-meteorologist making a request may appear at some disadvantage stating job specifications, the meteorologist, because of his familiarity with the subject sometimes has a tendency to short-cut the detailed statement which would eliminate ambiguity and reduce further correspondence.

The following specifications frequently are overlooked, yet may be quite essential to the preparation of pertinent results:

a) Where the final use of information requested is not classified, and can be outlined briefly, the client should include such information to enable the climatologist to apply his knowledge and experience concerning the pertinence of available data as well as the limitations of the observations.
b) What geographical area and what period of record are of interest?
c) Is information desired on an annual (one composite answer), seasonal (answers for each portion of the annual cycle), monthly (answers for each calendar month) or other basis? If seasonal, will the usual Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), and Fall (September, October, November), be suitable, or is some other grouping desired?
d) Is the change from one time of day to another significant for the study, or should all observations be considered? If diurnal variation is important, what hours of the day can be grouped?
e) While units used in measuring wind speed, tempera-

ture, etc., are not uniform throughout the world, nor are they the same during the complete period of recorded data, they are, in most cases, convertible. To avoid ambiguity, the client should specify whether results are preferred in miles per hour, knots, Fahrenheit, Celsius (Centigrade), etc.

f) Care should be taken not to use, without clarification, words and terms which have varied meaning in the several scientific fields.

g) Wherever applicable, the client should include a rough sketch of the frequency table or other form of presentation he visualizes as a solution to his problem. This simple device replaces hundreds of words.

6.7 POSSIBLE PITFALLS AND PRECAUTIONS

It must be kept in mind that weather observations are taken to satisfy the public requirements by the most economical means. Recent observations have benefited from earlier experience and have been made as general in nature as is feasible. It sometimes occurs, however, that they are far from ideal for answering a specific problem for one or more of the following reasons:

a) The inherent limits of accuracy of observation, coding techniques and verification methods may mask potential factors under investigation.

b) Incomplete or broken records may render them unsuitable for such techniques as harmonic analysis without preliminary and costly preparation.

c) The spatial or temporal distribution of observations may be far too sparse to solve some types of problems.

d) Two or more periods of record may be non-homogeneous as to instruments and exposure, and require careful examination and purging prior to analysis. The wind distribution in figure 70 illustrates the result of biasing the direction readings in favor of cardinal points - a common but not consistent error.

The following more or less related points bear on the difficulties encountered:

a) Many cases arise which require more dense station networks, determination of extremes not normally extracted from the records, analysis of minute-to-minute changes in upper winds, or similar abstractions from the original records. Where suitable records exist, facilities are available for abstracting and punching data for analysis. Such special preparation involves manual effort and is more expensive per unit of information than is the utilization of the readily available data.

b) The reliability of a study cannot be determined without considering such factors as instrumental error, observer bias, lag in response of equipment (radiosonde transmitter unit, for example), limiting angle of rawins, etc. Limitations imposed by analysis procedures are equally important. Punched cards usually available for use are by-products of routine observational techniques and limited checking procedures. Overlooking this fact and other similar

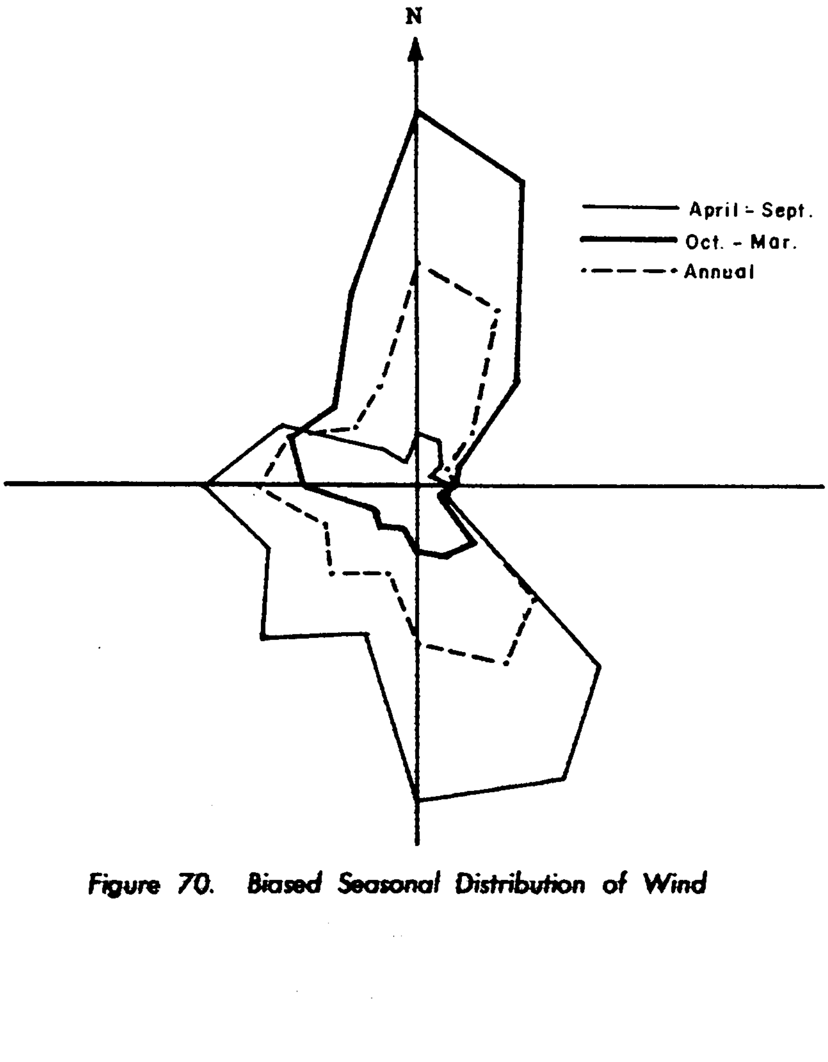


Figure 70. Biased Seasonal Distribution of Wind

572771 O - 60 - 8

limitations while planning the investigation can nullify a large amount of work. Necessary economy in routine operations, for example, dictates that hourly dry bulb and wet bulb temperatures and dew point be punched to the nearest whole degree, and that verification be restricted to certifying that said dew point could have occurred with the given dry bulb and wet bulb values. Such limits are adequate for the initial use of the cards and further refinement cannot be justified; however, an investigator interested in small changes in wet bulb depression might find them inadequate.

c) It is a basic Weather Bureau policy not to interpolate or fabricate routine observations if the data were not recorded on the site. Since some observations are missed in almost any long-term record, the investigator is advised to take this into consideration when planning the project. If the requirements are such that a complete time series is essential, experienced personnel are available to perform interpolation, map reading, or other appropriate operations, or to advise regarding such procedures. This is done only by direction of the client whose specifications require such action after advising that any subsequent measure of the variability of the measurements is suspect.

d) While it is the ultimate aim of data reduction operations to reduce error generated by the processing to zero, reduction of masses of detailed data to a form suitable for analysis by the investigator is a production line operation. It is recognized that, just as observational techniques are subject to error, so also are card punching, verification, and any subsequent card handling and machine processing. In general, machine processing can be considered far more accurate than equivalent manual processing; nevertheless, all reasonable checks are taken to assure the greatest possible accuracy, even to the extreme case of deriving identical results by two different methods for comparison if such accuracy is justified by the problem.

6.8 CONCLUSION

As we have been frank in discussing present limitations, so would we be misleading the prospective client if we closed on the negative note above. We hope we have been able to present the concept of a public storehouse of climatological information and know-how, staffed by public servants with a sincere desire to help solve the problems of anyone who has need of climatological information. Final results are always reviewed for meteorological consistency and pertinence to the original request. While perfection is seldom achieved and there probably will never be a year in which every project undertaken gives complete satisfaction, we are growing in knowledge, facilities, and techniques, and feel we are exerting an ever increasing influence in the growth of the science of climatology. If Climatology at Work arouses new interests, encourages constructive criticism, or brings an additional idea or source of information to bear on someone's weather problem, the climatological support groups at Asheville will be appreciative and gratified.

LITERATURE CITED

Chapter 1

1. Bates, C. C., "Marine Meteorology at the U. S. Navy Hydrographic Office -- A resumé of the past 125 years and the outlook for the future," Bull. Amer. Meteor. Soc., Vol. 37, No. 10, Dec. 1956, p. 519.

2. Conrad, V. and L. W. Pollack "Methods in Climatology," Harvard University Press, Cambridge, Mass., 1950, p. 340.

Chapter 2

3. Advisory Committee on Weather Control Final Report, Vols. I and II, Government Printing Office, Washington, D. C., 1958, 32 and 422 pp.

4. Bates, C. C., "Marine Meteorology at the U. S. Navy Hydrographic Office -- A resumé of the past 125 years and the outlook for the future," Bull. Amer. Meteor. Soc., Vol. 37, No. 10, Dec. 1956, p. 519.

5. Bean, B. R. and J. D. Horn "On the Climatology of the Surface Values of Radio Refractivity of the Earth's Atmosphere," No. 5559, Nat. Bur. Stand., 1958.

6. Conrad, V. and L. W. Pollack "Methods in Climatology," Harvard University Press, Cambridge, Mass., 1950, p. 5.

7. Durst, C. S., "Climate - The Synthesis of Weather," Compendium of Meteorology, American Meteorological Society, Boston, Mass., 1951, pp. 967-975.

8. Geiger, R., "The Climate Near the Ground," Harvard University Press, Cambridge, Mass., 1950, 482 pp.

9. Landsberg, H. E., "Trends in Climatology," Science, Vol. 128, No. 3327, October 3, 1958, pp. 749-758.

10. Magill, P. L., F. R. Holden and C. Ackley "Air Pollution Handbook," McGraw-Hill, New York, N. Y., 1956.

11. Russell, J. A. (Ed.), "Industrial Operations under Extremes of Weather," Meteorological Monographs, Vol. 2, No. 9, American Meteorological Society, Boston, Mass., 1957, p. 121.

12. Sargent, F. II and R. G. Stone (Eds.) "Recent Studies in Bioclimatology," Meteorological Monographs, Vol. 2, No. 8, American Meteorological Society, Boston, Mass., 1954, 121 pp.

13. Shaw, Napier, "Drama of the Weather," Second Edition, Cambridge University Press, London, 1939, p. 70.

Chapter 3

14. Henry, A. J., "Climatology of the United States," U. S. Weather Bureau, Bull. Q, (W.B. 361), Washington, D. C., 1906, p. 5.

15. Kleinschmidt, E., "Handbuch der meteorologischen Instrumente und ihrer Auswertung," Springer Verlag, Berlin, Germany, 1935.

16. McMurray, W. M., "IGY Meteorological Data on Microcards," IGY General Report No. 9, Nat. Acad. Sci., Washington, D. C., June 1960, 142 pp.

17. Meighem, J. Van, "The Conquest of the Third Dimension," Part 1, World Meteorological Organization, W.M.O. Bull., Vol. VII, No. 1, Jan. 1958, pp. 31-38.

18. id. "The Conquest of the Third Dimension," Part 2, World Meteorological Organization, W.M.O. Bull., Vol. VII, No. 2, April 1958, pp. 52-58.

19. Mitchell, C. L. and H. Wexler "How the Daily Forecast is Made," Climate and Man - Yearbook of Agriculture, U. S. Government Printing Office, Washington, D. C., 1941, pp. 582-583.

20. Shaw, Napier, "Drama of the Weather," Second Edition, Cambridge University, London, 1939, p. 116.

21. U. S. Navy, Guide to Standard Weather Summaries, NAVAER 50-1C-534, U. S. Government Printing Office, Washington, D. C., Jan. 1959, 561 pp.

22. Ward, R. DeCourcy, "The Climates of the United States," Ginn and Company, Boston, Mass., 1925, p. 3.

23. Wenstrom, W. H., "Weather and the Ocean of Air," Houghton Mifflin Co., Boston, Mass., 1942, pp. 60-64.

Chapter 4

24. Aitken, A. C., "Statistical Mathematics," Oliver and Boyd, London, 1939.

25. Barger, G. L. and H. C. S. Thom "Evaluation of Drought Hazard," Agron. Journ., Vol. 41, 1949, pp. 519-527.

26. Barger, G. L., R. H. Shaw and R. F. Dale "Chances of Receiving Selected Amounts of Precipitation in the North Central Region of the United States," First Report to North Central Region Tech. Comm. on Weather Information for Agriculture, Agric. and Home Econ. Exper. Sta., Iowa State Univ., Ames, Iowa, July 1959.

27. id. "Gamma Distribution Parameters from 2 and 3-Week Precipitation Totals in the North Central Region of the United States," Second Report to North Central Region Tech. Comm. on Weather Information for Agriculture, Agric. and Home Econ. Exper. Sta., Iowa State Univ., Ames, Iowa, Dec. 1959.

28. Blackman, R. B. and J. W. Tukey "The Measurement of Power Spectra from the Point of View of Communications Engineering," Dover Publications, New York, N. Y., 1958, 190 pp.

29. Brooks, C. E. P. and N. Carruthers "Handbook of Statistical Methods in Meteorology," London, M. O. 538, Air Ministry Met. Off., Her Majesty's Stationery Office, 1953, pp. 1-412.

30. Brooks, C. E. P., C. S. Durst and N. Carruthers "Upper Winds Over the World, Part I, The Frequency Distribution of Winds at a Point in the Free Air," Q. J. Roy. Met. Soc., Vol. 72, 1946, pp. 55-73.

31. Crutcher, H. L., "On the Standard Vector-Deviation Wind Rose," J. Meteor., Vol. 14, No. 1, Feb. 1957, pp. 28-33.

32. id. "Wind Aid From Wind Roses," Bull. Amer. Met. Soc., Vol. 37, No. 8, Oct. 1956, pp. 391-402.

33. Decker, W. L., "Probability of Killing Freezes in Missouri," Bull. No. 555, Missouri Agric. Exper. Sta., Columbia, Mo., 1951.

34. Dixon, W. J. and F. J. Massey "Introduction to Statistical Analysis," First and Second Editions, McGraw-Hill, New York, N. Y., 1951 and 1957.

35. Fisher, R. A., "Statistical Methods for Research Workers," Seventh Edition or later, Oliver and Boyd, London, 1938.

36. Friedman, D. G. and B. E. Janes "Estimation of Rainfall Probabilities," Bull. No. 332, College of Agric., Univ. of Connecticut, Dec. 1957, 22 pp.

37. Geary, R. C. and E. S. Pearson "Tests of Normality," Separate No. 1 from Biometrika, Vols. 22, 27, 28, Biometrika Office, University College, London, W. C. 1, 1938.

38. Gumbel, E. J., "Statistics of Extremes," Columbia Univ. Press, New York, N. Y., 1958.

39. Hald, A., "Statistical Theory with Engineering Applications," John Wiley, New York, N. Y., 1952.

40. Landsberg, H. E., J. M. Mitchell, Jr., and H. L. Crutcher "Power Spectrum Analysis of Climatological Data for Woodstock College, Maryland," Mo. Wea. Rev., Vol. 87, No. 8, Aug. 1959, pp. 283-298.

41. Lieblein, J., "A New Method of Analyzing Extreme-value Data," U. S. Nat. Adv. Comm. for Aero., Tech. Note No. 3053, 1954.

42. Mitchell, J. Murray, Jr., "The Measurement of Secular Temperature Change in the Eastern United States," Unpub. PhD. Thesis, Pennsylvania State Univ., June 1960.

43. Mood, A. M., "Introduction to the Theory of Statistics," McGraw-Hill, New York, N. Y., 1950.

44. Panofsky, H. A. and R. A. Mc Cormick "Properties of Spectra of Atmospheric Turbulence at 100 Meters," Q. J. Roy. Met. Soc., Vol. 80, No. 346, 1954, pp. 546-564.

45. Pearson, K., et. al. "Tables of the Incomplete Γ-function," Cambridge Univ. Press, London, Reissue 1951.

46. Pearson, E. S. and H. O. Hartley "Biometrika Tables for Statisticians," Vol. 1, Cambridge Univ. Press, London, 1956.

47. Rao, C. R. "Advanced Statistics in Biometric Research," John Wiley, New York, N. Y., 1952.

48. Shaw, R. H., H. C. S. Thom and G. L. Barger "The Climate of Iowa, I. The Occurrence of Freezing Temperatures in Spring and Fall," Special Report No. 8, Iowa State College, Aug. 1954, 88 pp.

49. Shaw, R. H., G. L. Barger and R. F. Dale "Precipitation Probabilities in the North Central States," North Central Regional Publication No. 115, Bull. 753, Univ. of Missouri Agri. Exper. Sta., June 1960.

50. Snedecor, G. W., "Statistical Methods," Iowa State Press, Ames, Iowa, 1956.

51. Swed, F. S. and C. Eisenhart "Tables for Testing Randomness of Grouping in a Sequence of Alternatives," The Annals of Mathematical Statistics, Vol. 14, 1943, pp. 66-87.

52. Thom, H. C. S. and R. H. Shaw "Climatological Analysis of Freeze Data for Iowa," Mo. Wea. Rev., Vol. 86, No. 7, July 1958, pp. 251-257.

53. Thom, H. C. S. "A Note on the Gamma Distribution," Mo. Wea. Rev., Vol. 86, No. 4, April 1958, pp. 117-122.

54. id. "A Statistical Method of Evaluating Augmentation of Precipitation by Cloud Seeding," Tech. Report No. 1, Vol. II, Final Report of the President's Advisory Comm. on Weather Control, Washington, D. C., 1957.

55. id. "Frequency of Maximum Wind Speeds," Proc. Amer. Soc. Civ. Engin., Vol. 80 Separate No. 539, Nov. 1954.

56. id. "The Frequency of Hail Occurrence," Archiv für Meteorologie, Geophysik, u. Bioklimatologie, Serie B, Band 8, 2 Heft, 1957, pp. 185-194.

57. id. "A Rational Method of Determining Summer Weather Design Data," Paper Presented at ASHRAE Semi Annual Meeting, Dallas, Texas, Feb. 1960.

58. Tukey, J. W., "The Sampling Theory of Power Spectrum Estimates," Symposium on Applications of Autocorrelation Analysis to Physical Problems, Woods Hole, Mass., 13-14 June 1949, Office of Naval Research, Washington, D. C., 1950, pp. 47-67.

59. U. S. National Bureau of Standards "Tables of the Binomial Probability Distribution," Applied Math., Series 6, 1950.

60. U. S. Navy, "Upper Wind Statistics of the Northern Hemisphere," NAVAER 50-1C-535, Prepared for the Chief of Naval Operations, Aug. 1959.

U. S. GOVERNMENT PRINTING OFFICE: 1960 O - 572771