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REPORT OF THE CHIEF OF THE WEATHER BUREAU, 1937

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
WASHINGTON, D. C., *August 23, 1937.*

Hon. HENRY A. WALLACE,
Secretary of Agriculture.

DEAR MR. SECRETARY: I submit herewith a report of the work of the Weather Bureau during the fiscal year ended June 30, 1937.

Sincerely yours,

WILLIS RAY GREGG, *Chief.*

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INTRODUCTION

In science and its application to human needs progress is seldom, if ever, a process of steady development. Rather is it characterized by a series of accelerations or sudden spurts interspersed with periods of quiescence, sometimes of retrogression. Meteorology presents a striking example of this cyclic tendency. For a brief period, under the guiding hand and brain of Aristotle, it flashed out in brilliance, then slumbered for 20 centuries. The Renaissance which began a hundred years ago bids fair now to eclipse many fold any former achievements and to bring meteorology to a position of dignity and usefulness quite on a par with that held by other utilitarian sciences. None other can indeed contribute more to human efficiency, to human welfare, and to human happiness than can meteorology, and most of them not nearly as much.

The fiscal year that closed June 30, 1937, afforded some forceful and dramatic examples of the important, at times tragic, part that unfavorable weather plays in human affairs and of the highly constructive role that an efficiently organized weather service can assume in mitigating the effects of such weather. There was the drought of the summer of 1936. Unfortunately dependable predictions for more than a few days in advance are not yet possible, but the day-by-day summaries and analyses of conditions throughout the country, coupled with

National Oceanic and Atmospheric Administration
Report of the Chief of the Weather Bureau

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short-period forecasts, provided information to the various Government agencies and to the Red Cross which enabled them to reduce suffering and loss to a minimum.

Paradoxically enough, there came in less than half a year one of the most disastrous floods of all time. Economic losses were enormous but they would have been almost infinitely greater had it not been for timely warnings, which likewise kept the deaths resulting from the flood to a comparatively small number.

The year saw also record-breaking freezes in the citrus-fruit districts of California; and a series of aircraft crashes, part of which were caused by unfavorable weather. It is no secret that practically the entire citrus-fruit industry of southern California would have been wiped out if protective measures had not been taken in response to the Bureau's warnings of extremely low temperatures. Almost complete loss actually occurred in groves which had not been provided with heating equipment.

The aircraft accidents emphasized very forcibly that the time is still a long way off, if indeed it ever comes, when weather can be left out of the reckoning in planning aerial flight. And it is proper to point out that, against the few accidents that occurred, hundreds of flights were either postponed or canceled because of warnings of bad weather, and many potential accidents were thus prevented. This is a point often lost sight of. Much is heard of an occasional failure, but little, if anything, about the many lives and the hundreds of millions of dollars' worth of property saved by ships being held in port when storm warnings are hoisted; by special provision for heating or refrigeration of perishable fruits and garden truck when a cold wave or a hot wave is predicted; by concentration of fire-fighting forces at threatened points when weather conditions are favorable for destructive fires in the great forests of the country; and by the transfer of people and property to safer places when a hurricane or a flood threatens.

Almost infinite are the contributions that a wide-awake meteorological service can make to the economic and social life of a people. Yet so prone has man been, until recently, to accept the weather as an unknown quantity in the mathematics of buying and selling, that the possibilities of making use of a knowledge of the weather and its ways are even yet only partially realized. Much still remains to be done in acquainting the public with the manifold types of service, statistical, informational, and prognostic, for a variety of human activities that are available and of high value to them, and in coordinating the service of the Bureau with the functions of relief agencies when disasters threaten.

Special attention is being given to what we have referred to as "an occasional failure." Unfortunately failures do occur in all lines of human endeavor, including meteorological service. Perhaps they will never be entirely eliminated. The important thing is that we recognize their existence and that we concentrate in efforts to bring their number down to an "irreducible minimum."

Within the limits of its resources the Bureau is now doing this very thing. Chief requirements for success in bringing about improvement are: More frequent reports of surface conditions from a closer network of stations; a higher standard of instrumental equipment used on ships, in order to secure more accurate and more detailed data as to conditions over the oceans; a much more complete program of sounding the upper air, undoubtedly one of the most fruitful sources of improvement, as yet barely tapped; and, in many respects most important of all, research and still more research, in order that full and effective application may be made of the more abundant and more accurate observational material that is slowly becoming available. A most hopeful sign for the future is the increasing attention that is being given to basic research by all of the principal meteorological services of the world, and it is the purpose of the Weather Bureau to play a leading part in this field. Of great significance and assistance in this connection is the action taken in recent years by educational institutions in organizing high-grade meteorological departments, embracing both advanced training and research.

In the following pages will be found brief summaries of what is being done in the various lines of the Bureau's service. With insufficient funds even for its ordinary routine functions, progress in bringing about the improvements that are possible and that are vitally necessary in the public interest is slow, but it is definite. As previously stressed, the contribution that a highly efficient weather service can make to the economic and social welfare of a people is very large. Only the opening chapter of the possibilities has thus far been written, although the changes that are now taking place give us some glimpses perhaps of the type and character of service that the future will bring.

METEOROLOGICAL RESEARCH

Active research progressed on a number of problems covering a wide field in meteorology and its practical applications. The results of research by the Weather Bureau are made generally available through the medium of the Monthly Weather Review which, in addition to its function of promptly disseminating climatological and weather data for public use, also provides limited facilities for the publication of contributions to meteorology by personnel of the Bureau and, to a small extent, by others.

Among the more important research papers of most general interest that appeared during the fiscal year may be mentioned: The synoptic air-mass analysis studies by Stephen Lichtblau, Upper Air Cold Fronts in North America (vol. 64, pp. 414–425), and B. Holzman, Synoptic Determination and Forecasting Significance of Cold Fronts Aloft (vol. 64, pp. 400–414); the initial contributions to an investigation of North American cold waves by H. Wexler, Cooling in the Lower Atmosphere and the Structure of Polar Continental Air (vol. 64, pp. 122–136), and Absorption of Radiation by Water Vapor as determined by Hettner and by Weber and Randall (vol. 65, pp. 102–104); a further contribution to the mathematical investigation of flood forecasting by R. T. Zoch, On the Relation between Rainfall and Streamflow—II (vol. 64, pp. 105–121); a comprehensive summary of investigations in long-range forecasting by H. H. Clayton, Long-Period Weather Changes and Methods of Forecasting (vol. 64, pp. 359–376); a study of one of the significant phenomena of hurricanes by I. R. Tannehill, Sea Swells in Relation to Movement and Intensity of Tropical Storms (vol. 64, pp. 231–238); the early parts of a comprehensive investigation in meterological optics by E. W. Woolard, The Geometrical Theory of Halos (vol. 64, pp. 321–325; vol. 65, pp. 4–8, 55–57) with tables computed by C. M. Lennahan; and a contribution to the important subject of ultraviolet insolation by W. W. Coblentz, Methods of evaluating Ultraviolet Solar Radiation in Absolute Units (vol. 64, pp. 319–321).

AIR-MASS ANALYSIS

Although still handicapped by lack of sufficient funds and facilities, the work in air-mass analysis and its applications to forecasting was continued and further developed at the Central Office. The systematic training of selected field personnel was continued to the limited extent possible; and plans were formulated for further extension of the work in the field as rapidly as practicable. Steady progress has been made in the technique of frontal, kinematic, and thermodynamic analyses of surface synoptic maps, upper-air maps, and vertical cross sections through the free atmosphere, and in the prognostic interpretation of these analyses.

Important advances were effected in the coordination of this work with that of the official forecasters at the Central Office. In particular, the 1:30 a. m. and 1:30 p. m. maps, analyzed in detail by the trained personnel of the air-mass section, have been used as a guide for rapid and reliable analyses of the 7:30 a. m. and 7:30 p. m. maps by the forecasters. This procedure has been of material aid to the forecasters in the frontal analyses; the forecasts are expedited, and frequently are issued with more confidence because of greater assurance of a correct analysis of the current map.

The analysis of the 7:30 a. m. map is transmitted daily over all teletype circuits, for use in the field.

Research work accomplished during the year included an investigation of upper-air cold fronts, and studies of air-mass conditions during great floods in eastern United States; a new summary of the characteristics and progressive modifications of air masses over the United States, based on recent data from airplane soundings, was begun.

Under an allotment from the special research fund provided by the Bankhead-Jones Act, an investigation of cold waves in North America was carried on in cooperation with the Canadian Meteorological Service, Massachusetts Institute of Technology, and Bureau of Agricultural Economics. Cold-air masses form from warmer air in the far North during the Arctic winter, by the upward propagation of radiational cooling over the snow-covered continent, until eventually an outbreak occurs in the form of a cold wave which sweeps southward over Canada and the United States. Detailed observations were made of meteorological conditions during the development and subsequent outbreaks of cold air by means of airplane soundings, terrestrial radiation measurements and snow-surface temperature observations at

Fairbanks, Alaska; Fort Smith, Canada; and Fargo, N. Dak.; and a statistical and theoretical study of these and other data was carried on at the Central Office, to investigate the physical processes of the formation of the cold-air masses and the dynamical mechanism of their southward release and propagation. Significant progress was made toward a clearer understanding of these phenomena, although the usefulness of the data for the purpose was limited by the fact that the winter was an abnormally warm one in Alaska and northern Canada; the results of this study should be of considerable value in improving the accuracy and extending the range of cold-wave predictions, and in the solution of other meteorological problems.

LONG-RANGE WEATHER FORECASTING

The active carrying forward of the project of relating precedent temperatures and rainfall at 60 foreign stations with subsequent temperature and rainfall conditions in the United States was impossible owing to lack of W. P. A. funds under which the work was conducted in the previous year. However, group indices of barometric pressure, developed by Sir Gilbert Walker and known as (1) the southern oscillation and (2) the North Atlantic oscillation, were related with temperatures in 12 districts of the United States with time intervals of one quarter, two quarters and three quarters. The North Atlantic oscillation seems to have little relation to temperature conditions in the United States; only 4 correlation coefficients out of 144 were 0.30 or more. The southern oscillation, which gave 28 coefficients out of 144 with values of 0.30 or more and 5 with values of 0.40 or more, apparently shows some significance as a prediction factor. For example, the Atlantic and Gulf States in winter show a positive relation, and the Plateau and Pacific States a negative relation with the southern oscillation two quarters and three quarters preceding. In the summer season, the South Atlantic and Gulf States and the Ohio and Mississippi Valley and Plains States seem to show a negative relation with the southern oscillation three quarters before. It is proposed to work out correlation coefficients between Indian monsoon rainfall and temperatures for the 12 United States districts.

A survey was made of studies that are being pursued in Europe and it was found that a very limited amount of such work is being done. The most active country in investigations of this kind is Germany, where there is a specially organized bureau devoted entirely to long-range forecasting work. The method employed is mostly statistical but partly synoptic. The results of the 10-day and monthly forecasts are said to be satisfactory. However, before undertaking work of a similar nature in this country even in an experimental way, it is proposed to check carefully the results of the German forecasts.

The problem of long-range forecasting is an extremely complex one and progress of investigations in this field is necessarily slow. It is becoming evident that new approaches will be required and it remains for someone with vision to suggest new leads that are not now apparent.

SOLAR-RADIATION INVESTIGATIONS

The observations and investigations of solar radiation which have been conducted by the Bureau for many years are of basic importance in a wide range of meteorological, physical, engineering, biological, and medical problems; and the data are in great demand. This work was strengthened during the year by several improvements in the instrumental equipment and observational technique, the addition of accurate continuous registration of the visible component of radiation from sun and sky at Washington, D. C., and the initiation of absolute measurements of ultraviolet insolation.

IMPROVEMENTS IN EQUIPMENT

As a result of continued investigations carried on in cooperation with the National Bureau of Standards 35 high-power ceiling-light projectors were procured. They project a 500,000 candlepower beam with a spread not greater than 4 degrees. In order to realize the advantage of the more intense beam, base lines are being increased from 500 feet to 750 or more. Measurements of ceilings up to 10,000 feet are being reported.

In order to aid observers in the determination of pressure changes temperature-compensated barographs in which the pressure scale is magnified two

and one-half times and the time scale increased to permit hourly time arcs on the record charts have been provided at 120 stations.

During recent years there have been introduced along airways simple devices for indicating wind direction by means of four electric lamps actuated by the wind vane through contact mechanism. Plans have been made to provide wind-vane bearings equipped with eight contacts instead of four, and also indicators of more pleasing design. This arrangement will permit determination in the office of the position of the wind vane to 16 points of the compass.

A device to make a continuous indication of direction by means of a light spot moving on a dial synchronous with the vane is in course of development in the Instrument Division.

Ten anemometers in which the results of extended experiment and tests have been embodied in actual construction by a contractor have been procured. It is planned to send these to stations chosen to represent widely differing service conditions in order to learn their performance in actual service. They were designed for use up to 150 miles an hour.

A special anemometer, without dials, but equipped with 1/60-mile contact mechanism is now being produced. It is based on sound principles of design and construction and is inexpensive. Plans are under way to procure a number of them for use along airways and elsewhere where measurements of momentary velocity are desired.

Corrosion-resistant steel is now employed exclusively for thermometer backs. In order to reduce weight they are thinner than the aluminum backs formerly used. This has led to some difficulty in mounting them in the older supports, but section directors are finding solutions to overcome this difficulty.

The anathermoscope reported last year is still in the experimental stage. A number of experimental flights with this device were made at Oakland, Calif., airport.

AEROLOGICAL OBSERVATIONS

RADIOMETEOROGRAPHS

The development of radiometeorographs was pursued during the year in cooperation with the National Bureau of Standards. A number of these instruments were released with balloons at Omaha, Nebr., together with the recording type of meteorographs, during November, the international month for 1936, with encouraging results. Experimental flights were also made at Washington, D. C. A modified type of instrument was constructed in the Instrument Division, using a cam, shaped in the form of an Archimedes spiral, for making contacts whereby the range of both the pressure and temperature elements can be extended over 360° of the Olland cycle. An improved type of contact mechanism was designed which makes a positive electrical connection of short duration, thereby avoiding ambiguity of the record. Considerable progress was made in the development of air-driven motors and electric motors operated by flashlight batteries. A governor has been designed to provide a uniform rate of speed. The perfection of these features should eliminate difficulties of clocks stopping at low temperatures. A number of the radiometeorographs developed by Harvard University were purchased and comparisons made with the Government types. Evaluation apparatus was designed and calibration methods developed. A number of the Weather Bureau-type instruments were constructed by a commercial concern and purchased by the Bureau. Study was also made of the types of instruments developed by the California Institute of Technology and foreign governments. By the end of the fiscal year, it was possible to place orders for a considerable number of each of several types of these instruments for regular use at four stations during 1937–38.

COOPERATION

Very close cooperation has continued with the Bureau of Air Commerce in the airway service of the Bureau and with the War and Navy Departments in airplane observations. The War Department continued to make daily flights at the eight Army fields listed in the report for last year, and the Navy Department added Coco Solo, Canal Zone, and St. Thomas, Virgin Islands, to the seven Navy stations shown last year. The Bureau increased to 12 the number of stations where these flights are made under contract with commercial flyers, by adding Miami, Fla.; Oakland, Calif.; Salt Lake City, Utah; and Sault Ste. Marie, Mich.

IMPROVEMENT IN THE METHOD OF MEASURING UPPER-AIR WINDS

In order to determine wind directions and velocities at higher elevations than is now possible with 6-inch pilot balloons, double theodolite observations were started, using 16-inch balloons. When a sufficient number of these two-theodolite observations have been made, the mean ascensional rate will be determined and the larger balloons substituted for the smaller ones in regular single theodolite observations. By virtue of their more rapid ascent and the larger size, not only can they be followed to greater heights and distances, but they will also shorten the time required to make these observations.

INTERNATIONAL MONTH

During November, the international month for 1936, the Bureau made daily sounding-balloon observations at Omaha, Nebr. At the request of F. Paneth, Imperial College of Science and Technology, London, England, air samplers were attached to six of the balloons. Five of the samplers have been found and returned to Professor Paneth for analysis of the helium content of the atmosphere at great heights. Thirty-five out of a total of 37 sounding-balloon meteorographs, released during the month, have been found and returned to the Bureau, where the records are being evaluated. These data will be forwarded to the International Aerological Commission for publication, together with those obtained simultaneously throughout the world.

SERVICE IN AID OF AIR NAVIGATION

Approximately 120 6-hourly weather-reporting stations for airway service were established in areas where meteorological reports were not available. To supplement this program, over 100 of the existing teletype or radio hourly reporting stations along the airways were equipped with additional instruments for the taking of special 6-hourly observations which are run in sequences over the teletype and radio circuits. This program has resulted in a much more complete network of observations for use in connection with the preparation of detailed weather maps at all airport stations along the airways, the analysis of meteorological situations, and improved airway forecasts.

A program of collecting two reports, instead of one, for each airplane clearance from stations along airways not equipped with teletype or radio, was put into effect. The first clearance report is collected about an hour prior to departure and the second just before departure, thus permitting a comparison between them to determine whether conditions are improving, growing worse, or remaining unchanged.

The instrumentation of about 35 important airports along the airways was improved by the installation of ceiling projectors which project a more intense beam of light for illuminating a spot on a cloud layer at night as a means of determining the height of the layer.

The service was strengthened in the United States by the assignment of additional personnel to understaffed stations. Some improvement of service in Alaska and Hawaii was effected by establishment of several new weather-reporting stations on a cooperative basis.

A new airway general supervising and forecast center was established at Arlington, Va. (near Washington, D. C.), during the year, bringing the number of such stations to 11.

There are now 52 first-order airport stations where weather maps, hourly weather reports, pilot-balloon observations, and meteorological advice or forecasts are available. In addition to those, there are 228 stations rendering hourly weather observations, 370 airway stations rendering weather observations at regular times, or on call, to serve scheduled flights, and 132 off-airway stations rendering reports every 6 hours in the airway weather network, or a total of 782 stations. Additional reports from stations in Canada, Mexico, and Central American countries, and from ships at sea, are received. Selected groups of reports from the above are relayed by teletype and radio to all Weather Bureau airport stations every 6 hours for the preparation of weather maps. The 11 airport stations, located at Newark, N. J.; Arlington, Va.; Atlanta, Ga.; Cleveland, Ohio; Chicago, Ill.; Kansas City, Mo.; Dallas, Tex.; Salt Lake City, Utah; Portland, Oreg.; Oakland, Calif.; and Burbank, Calif., supervise the service in their respective districts and issue 6-hourly airway regional and terminal forecasts for the periods 4:30 a. m. to 12:30 p. m.;

10:30 a. m. to 6:30 p. m.; 4:30 p. m. to 12:30 p. m.; and 10:30 p. m. to 6:30 a. m., eastern standard time, based on observations made at 1:30 and 7:30 a. m. and p. m., eastern standard time.

EXPANSION OF THE FIRE-WEATHER SERVICE

The fire-weather service was supplemented during the year by the addition of four new mobile forecasting units assigned to headquarters at Mount Shasta, Calif.; Portland, Oreg.; Seattle, Wash.; and Missoula, Mont. These four units, with the one provided by the United States Forest Service several years ago, and which is now operating in southern California with headquarters at Pasadena, have extended the advantages of this form of intensified service to all western districts, covering the principal forests (Government, State, and private) of California, Oregon, Washington, Idaho, and western Montana.

These mobile units do not replace the service which heretofore has been given in the districts in which they are located. They provide an additional and a more complete and satisfactory aid in the direct control of major forest fires. Observations are collected and charted and daily forecasts are issued from the several headquarters during the season of fire hazard. These forecasts are for the major forests and are localized as conditions warrant. On the other hand, service from the trucks is directed toward a particular fire that is in progress. In effect, the forecaster moves his office and facilities to the scene of the fire where he will be in close touch with those in charge of the fire fighting, and can immediately give information of any expected change in weather conditions which will affect the behavior of the fire.

A mobile unit is essentially a portable meteorological office built into a standard truck chassis and provided with observing, charting, and communication facilities. It is manned by a forecaster and radio operator who always accompany the truck. They must adapt themselves to conditions where the fire is raging; and therefore a camping outfit, tanks for oil, gasoline, and water must be carried with the truck. Communication is provided by a radio receiver and transmitter and by a portable telephone which may be connected with forest telephone lines. Electric current to operate the radio equipment, lights, etc., is furnished by a portable gasoline-driven generator which forms a part of the truck equipment.

Determination as to when the truck shall be sent to a fire rests with a central dispatcher, who usually is an official of the Forest Service charged with fire-suppression work. After arrival at the fire, the unit becomes an integral part of the fire-fighting organization. The first action is to choose a suitable location for the truck and then to set up the meteorological instruments, erect the antenna, and put the radio equipment in readiness for service. The forecaster studies conditions surrounding the fire and familiarizes himself with local topography.

Data for the preparation of synoptic maps showing surface and upper-air conditions are collected and charted. This information is obtained from broadcasts of weather reports made through Navy and Department of Commerce stations and through direct contact with Forest Service radio stations located, for the most part, in forests. Periodic conferences are held between the forecaster and suppression officials for the purpose of formulating plans for control of the fire based on existing and expected changes in weather conditions.

Weather information and forecasts are always of high value to fire fighters. Frequently they are vital. Knowledge as to the force and direction of winds is of particular importance when backfiring is contemplated. A major advantage of the mobile unit is that the forecaster becomes a part of the fire-fighting force, and all of his predictions are directed specifically toward the control of that particular fire.

The relatively frequent occurrence of serious fires and the fact that fire hazard is more or less continuous throughout the season in Western States are reasons for first introducing mobile forecasting units in western fire-weather districts. Extension of such service to central and eastern districts is contemplated when facilities for doing so become available.

EXPANSION OF RIVER AND FLOOD SERVICE

Great floods have occurred in our principal rivers throughout recorded history, and will continue to occur in the future. Plans for flood control promise

to reduce their magnitude and protect favorably situated areas, but as long as communities and industry find it profitable to occupy that portion of the stream channel intended by nature for the passage of floodwaters, accurate and timely forecasting and the methodical evacuation of stricken areas must be integrated into the national plan of river regulation and control. The Weather Bureau fully recognizes its responsibilities in the matter of improving its forecast service to meet changing conditions and the demand for more refined and timely forecasts, but has been limited by the amount of funds available for the purpose.

During the past year increased funds have made possible a beginning on a program to organize the United States into eight hydrologic districts. Within each district an intensive study of the relation of rainfall to run-off will be made, the results of which will be utilized in the development and improvement of river-stage forecasting methods. Two of these districts, one located in the Missouri Valley and the other in the upper Mississippi Valley, have been organized and good progress has been made in the work during the comparatively short time they have been in operation.

The great floods in the Eastern States in March 1936 and in the Ohio and lower Mississippi Valleys in January and February 1937 have forcefully brought to the foreground the necessity for establishing hydrologic districts throughout the whole of the country with the least possible delay. Particularly are they essential to forecasting at important points in headwater areas and in the smaller river basins.

An important step in the expansion of the flood-forecasting service has been made possible under a project in which the Weather Bureau, the Geological Survey, and the Commonwealth of Pennsylvania are cooperating. The objectives of this project are to provide the means of inaugurating a modern, scientific river-forecasting service throughout Pennsylvania, and to establish new sources of basic hydrologic data which are necessary to the program of forecasting and which are indispensable to the design and operation of flood-control works. The project embraces the development of a dependable means of transmitting promptly rainfall and stream-flow data from the index watersheds to the flood-routing and forecasting offices. Approximately 130 recording rain-gage stations are being located in the watersheds of the Allegheny, Monongahela, Susquehanna, and Delaware Rivers. These rain gages are being established on three circuits over which experienced hydrologic engineers will travel on schedule, attending and servicing the gages, and, in season, conducting snow surveys.

Fifteen additional river-gaging stations, 17 daily rainfall stations, and 58 occasional-reporting rainfall stations were established during the year. These stations included many which have been closed since July 1933.

EVAPORATION

Water conservation in many localities must be accomplished through storage reservoirs. The principal loss to stored water is evaporation, the characteristics of which much remains to be learned.

The Bureau has attempted to meet the needs of those using evaporation data in maintaining a system of about 75 class A evaporation stations throughout the country; and while the evaporation work of the Bureau is now on a fairly satisfactory basis, much remains to be done. About 20 new evaporation stations equipped with standard Weather Bureau instruments have been established during the last 2 years. All of these stations are on a cooperative basis with other agencies, the Bureau furnishing the instrumental equipment and the cooperating agency the station site and attendance.

Detailed descriptions of more than 150 evaporation stations using both standard Weather Bureau equipment and other types have been secured and made a part of the records. Observations from most of these stations are now regularly received and will be published when practicable.

Four of the new stations established were in the Great Lakes region in cooperation with the Office of the Chief of Engineers, War Department, in a study of evaporation for all seasons of the year. As nearly as possible the temperature of the water in the evaporating pan is kept the same as that of the water in the Lakes. It is expected that this study will yield interesting and valuable results.

SNOWFALL

In most of the western fourth of the United States human activities are, in a great measure, limited by the amount of water available. In great expanses of this region the rainfall is insufficient to supply the consumptive needs, and recourse must be had to the conservation of water from melting snow in the mountainous areas. To accomplish this many reservoirs have been constructed to conserve the water and mete it out to users when needed.

The operators of these reservoirs, and those charged with the duty of allotting water to users, find it essential to know the approximate water yield that may be expected from the mountain snow fields, and to know the time and rate at which these waters will reach the users on the lower reaches of the various streams. This information can best be obtained through careful and systematic measurement of snowfall, supplemented by snow surveys which determine the depth and water content of the snow mantle. Snowfall data are obtained at the various Weather Bureau stations throughout the country and snow surveys are conducted in cooperation with the Bureau of Agricultural Engineering and with other Federal and non-Federal agencies. Extensive data are now published by the Weather Bureau for the Columbia and Colorado River Basins and for other sections of the Western States.

Research work in connection with shielded snow gages of the storage type has been carried on at Salt Lake City, Utah, for the past several years. Future plans include extensive research in snow hydrology and the development of methods to estimate quantitatively the run-off from the snow mantle.

PROGRESS IN MARINE METEOROLOGY

During the year good progress was made in the compilation of marine meteorological data, in the preparation of summaries for publication on the climates of oceanic and coastal areas, and in investigation of meteorological conditions as reported in observations taken on ships at sea. Much of this advance was made possible by the special project conducted at New Orleans, La., as described in last year's report.

THE MARINE PROJECT AT NEW ORLEANS, LA.

Under sponsorship and technical supervision of the Weather Bureau, the special project of the Works Progress Administration at New Orleans, La., brought nearly to completion the large task of compiling and summarizing more than 5,000,000 observations taken on ships at sea during the years 1880 to 1933, inclusive. Work was begun on the records for 1934 and 1935. Summary cards were prepared for practically all 5° squares of the navigable oceans to show, as averages for the whole period of years, the conditions of wind and weather and the frequency of fogs and gales. This work was near completion at the close of the year. These cards are to be preserved in filing cabinets so as to afford ready reference to weather records, by months, for any part of the oceans. The data on the summary cards are being used also to prepare monthly charts of the oceans showing climatic conditions graphically. This latter work was only partly completed at the end of the year.

A large amount of labor was required in this compilation. Ships' weather reports usually contain observations made on several days during a voyage, and they cannot be averaged in the same manner as land-station observations. It is necessary to transcribe the individual observations on separate slips and sort them, by ocean squares, before tabulating them or reducing them to punch cards. Copying, checking, sorting, and tabulating involved millions of individual operations.

Several special compilations were in progress at the end of the year. Tabulations of barometric-pressure distribution over the world by months, 1901–30, were begun. A beginning was made also in preparing maps of ocean-weather conditions in certain months in order to study their relation to dry and wet periods in the Southern Plains States. Another compilation of large proportions was in progress at the end of the year; when completed it will show the history of ocean temperatures (air and sea surface) in all 5° squares having sufficient observations to justify tabulation.

In addition to marine observations, considerable progress was made in treating other classes of data. The largest operation in this phase of the project is the tabulation of rainfall records of the United States on a weekly basis, not yet completed.

PUBLICATION OF WEATHER SUMMARIES IN THE AID OF MARINE NAVIGATION

All meteorological information on the Pilot Charts and in other publications of the Hydrographic Office for the benefit of navigators is supplied by the Weather Bureau. During the year meteorological chapters contained in Sailing Directions of the Hydrographic Office were rewritten as the volumes in this series were revised. Text and tables were compiled and furnished for publication during the year for the volumes pertaining to the China Sea, the eastern part of the Caribbean Sea, and the west coast of Mexico and Central America. Similar manuscripts, including upper-air data, were completed for publication in Naval Air Pilots of the West Indies and Central America.

Revision of the weather summaries, wind roses, and frequencies of fogs and gales shown on the Pilot Charts of the North Pacific Ocean was begun prior to the end of the year. Publication of new data will begin with the North Pacific Pilot Charts of January 1938. This revision has been needed by navigators for many years but was not feasible until the data were compiled in the New Orleans project previously mentioned. A revision of the meteorological chapters of a new Hydrographic Office edition of The Practical Navigator, by Nathaniel Bowditch, was also accomplished during the year.

The monthly publication, Weather on the Oceans, a separate of the Monthly Weather Review, which is published by the Weather Bureau, contained during the year several special articles of interest to the mariner, chiefly on storms at sea.

RESEARCH IN MARINE METEOROLOGY

The determination of temperature normals of the sea surface of the Gulf of Mexico, the Caribbean Sea, and the western North Atlantic Ocean by months was nearly completed during the year, and charts showing the normals are being prepared for publication as an aid to Weather Bureau forecasters and for the information of private organizations interested in conditioning of ships' cargoes. A large number of thermograms from ships were edited, annotated, and prepared for use by research students in oceanography and meteorology. Several thousand water-temperature observations transcribed from ship reports were sorted and filed by months and by 1° squares for use in temperature-history studies. From this compilation, charts showing diurnal march of air and water temperature in the Gulf of Mexico, Caribbean Sea, and adjacent North Atlantic waters were prepared. An intensive study of ships' weather reports from North Pacific waters, with particular reference to frontal meteorology, was carried on during the year, with the object of improving weather reports from that area.

Similar studies of ships' reports in other areas gave further aid in the formulation of revised instructions for marine meteorological observers, the supply of the previous edition of these instructions, issued in 1929, being exhausted. The manuscript for the revised edition (Circular M, sixth edition) was prepared during the year and was sent to press at the close of the year.

The new instructions, which provide for more detailed and precise observations than the old, are based on the most recent specifications of the International Commission for Synoptic Weather Information. Special attention is devoted to the proper method of describing the weather at time of observation, so that the true thermodynamic state of the atmosphere may be known. Likewise the proper procedures for obtaining air and sea-surface temperatures are given in considerable detail in an attempt to increase the accuracy of these observations, which in many cases have been found to be quite unreliable.

Another result of the study of average weather conditions on the oceans was the completion of a manuscript for a publication on the weather of the North Pacific Ocean for the information of ocean travelers. This publication, Average Conditions of Wind and Weather, North Pacific Ocean, is now in press. A similar publication for North Atlantic waters (including the Gulf of Mexico and the Caribbean Sea) was issued in 1936.

The cooperation of the Bermuda Biological Station was secured in servicing sea-water thermographs on two steamships voyaging between New York and Bermuda. These records are used in meteorological and oceanographic studies.

IMPROVEMENT IN MARINE BAROMETRY

The Weather Bureau has no funds for furnishing standard instruments to its marine observers, hence it must enlist the aid of shipmasters and shipowners

in improving their own instrumental equipment. Owing to the friendly attitude of marine interests, there has been further success in securing replacements of defective instruments, thus yielding an increasing degree of accuracy in marine weather observations, an important factor in weather forecasting. During the year ended June 30, 1937, defective aneroid barometers were replaced on 68 reporting ships, and action by the Weather Bureau to secure further replacements is under way.

HURRICANE WARNING SERVICE

The hurricane-warning service of the Bureau also was strengthened during the fiscal year by an inspection of meteorological stations in the Bahamas. Reports from a limited number of these stations are transmitted daily to the Weather Bureau and from the others in the group when a tropical storm is in the vicinity. The accuracy of such reports is, therefore, of vital importance in the successful forecasting of storms approaching the Florida coast from the east. The inspection by a Bureau official was arranged through cooperation with the Government of the Bahamas and was carried out by use of a United States Coast Guard seaplane. Fourteen of the twenty stations on the islands were visited. A thorough check was made of the instrumental equipment at each of these stations. Defective instruments were replaced and additional equipment supplied where needed. Instructions in observational work and care of instruments were given, and comparative barometer readings were made and corrections furnished. Preliminary arrangements were also made for obtraining reports of tide and swell from stations favorably situated for the purpose.

HURRICANE INVESTIGATIONS

The Bureau, in cooperation with the Massachusetts Institute of Technology, equipped four stations (Jackson, Miss.; Maxwell Field (Montgomery), Ala.; Augusta, Ga.; and Habana, Cuba) with approximately 120 meteorographs and sounding balloons to be released during the passage of a hurricane. The signal for the release of the balloons was to be given by the Bureau forecasters in Washington. The balloons were to be released at intervals of one-half hour or greater, depending on the position of the station with reference to the storm center and its rate of movement; the closer to the center and the greater the rate of movement the shorter were to be the intervals. Such observations would provide valuable pressure, temperature, and humidity data, portraying the vertical structure of these storms, and would furnish important information in aid of forecasting. Since no hurricane passed the stations, the balloons were not released. Preparations have been made for a similar project this year, with an increase in the number of stations. The new arrangements provide for the following observing points: Vicksburg, Miss.; Maxwell Field (Montgomery), Ala.; Macon, Ga.; Raleigh, N. C.; and two mobile stations in Cuba. The stations are selected so that they lie near the usual paths of hurricanes and are sufficiently far from the coast so that the instruments will fall on land after the balloons burst. The instruments are tagged, and the finder is requested to return them to the Weather Bureau, for which a payment of $3 is made.

HORTICULTURAL PROTECTION

The horticultural-protection service is a highly specialized and important activity of the Weather Bureau, conducted as an aid in frost protection, chiefly in intensively cultivated subtropical sections where during the winter season many hundred millions of dollars' worth of citrus groves and winter truck farms vie with the frost for existence. During the spring blossoming period service is maintained also in various deciduous-orchard sections of the far West. The problem of reducing or preventing annual frost losses is one of primary concern to thousands of fruit growers, as the work and expense of bringing costly groves and orchards to maturity may be rendered a total loss in a single night of severe frost. Moreover, one freeze may wipe out the profits of several years, with disastrous results not only to the individual but to the entire community.

Effective measures of frost control have been devised. However, these require large expenditures for grove-heating equipment and fuels and at times require the services of much additional emergency labor. The efficiency of these frost-control measures lies in organization and preparedness

so that when warning is given the whole frost-fighting machine quickly can be brought into action and remain alert until all danger is past. Since the weather, especially critical temperatures, is the sole factor involved in the frost hazard, detailed forecasts of temperature at numerous stations spread intensively over local areas are indispensable for efficient and intelligent use of grove-heating equipment.

The forecast information, supplied by the horticultural-protection service, enables the growers to plan their heating work well in advance so as to eliminate entirely all periods of useless operation and keep the frost-fighting expense at a minimum. Experience has shown that large-scale grove heating seldom succeeds when attempted without adequate weather information and timely forecasts.

THE PACIFIC STATES

Heavy crop losses during freezes led California citrus growers to burn coal in crude baskets, made of chicken wire hung in the trees, as early as 1897. When the Weather Bureau's horticultural-protection work began, in 1917, oil-burning heaters had largely replaced those designed for burning solid fuel, but frost-protection methods had progressed but little along other lines, either in California or in other Pacific States, where heaters had come into use to protect deciduous fruits. Cheap, inaccurate thermometers, heaters with too small capacity to burn through the night, oil containing an excess of asphaltum, water, and sulphur, lack of knowledge of critical temperatures, ignorance of the principles of orchard heating, and, most important of all, lack of detailed, accurate temperature forecasts, had caused so many failures to save crops that orchard heating had come into general disfavor. The acreage equipped with heaters was steadily declining at the time the Weather Bureau's horticultural-protection work began.

The first few years of this project were devoted almost entirely to experimental work. New types of thermometers were designed, especially suited for orchard-heating operations, and made available at reasonable prices through growers' cooperative purchasing agencies. Arrangements were made to service and check these for accuracy at the beginning of each frost season. The principles involved in orchard heating were explained at meetings of citrus-fruit growers and also in published articles and bulletins. Experiments showed definitely that smoke, which theretofore had been credited with saving crops, was of minor importance. Critical temperatures for various fruits, buds, and blossoms were determined. Temperature surveys were made in different fruit districts to show locations of colder and warmer areas on frosty nights, and the absurdity of claims for "frostless belts" was demonstrated. Influence of cover crops on orchard temperatures was investigated. Frost marking of pears and apples was studied. Improved and standardized orchard-heater oils were developed in cooperation with oil companies, and improvements in design of lighting torches were suggested. Various frost-protection methods were investigated and tested; but it was soon found that orchard heating, properly handled, would protect trees and crops during the most severely cold periods likely to occur, and that no other method was as economical, practical, or dependable.

In the fruit frost service, localized daily forecasts of minimum temperature, local wind conditions, temperature inversion or "ceiling", the time heating should begin, and other similar information are given in most cases directly to the public by radio. These forecasts contain every item of information needed to assist the grower in protecting his crop from frost. California citrus acreage equipped with orchard heaters has increased steadily during the last 15 years to approximately 75,000 acres in 1937.

THE JANUARY FREEZES IN CALIFORNIA

The freezes of January 1937, which broke all records for low temperatures and duration of freezing weather in southern California, afforded opportunity for a remarkable demonstration of the effectiveness of orchard heating. Despite utterly inadequate storage of heating fuel, damage to crops and trees was almost unbelievably small in the light of experience in previous freezes far less severe. Damage in groves properly equipped for heating was negligible. In districts where a large percentage of the orchards were adequately heated, the scattered intervening orchards not equipped with heaters received protection from the neighboring heated groves and showed little or no damage. This effect of "mass heating" was the outstanding feature of the cold period.

Tree damage was confined almost entirely to districts in which there was little or no orchard heating and to orchards located on the windward fringes of well-protected districts. The heaviest damage occurred in sections normally warm, in which protection had been considered unnecessary, while the normally colder areas, well equipped for protection, suffered practically no injury. The lowest temperature recorded in a citrus grove, 13.5° F., was in a district normally warmer than the average in which there were no orchard heaters. In an unprotected grove in a normally colder district, in which approximately 90 percent of the orchards were heated, the lowest recorded was 20.3°. This shows the effect of mass heating.

Approximately 81,900,000 gallons of oil were burned during the freezes, costing about $4,000,000. Other costs of protection are very difficult to estimate. Growers who saved their crops actually profited by the freeze, since better prices received for sound fruit far more than paid the heating costs.

LARGE SAVINGS FROM WEATHER BUREAU WARNINGS

Warnings well in advance of both freezes made possible the mobilization of all agencies for the transportation of additional orchard-heater fuel from refinery storage to the citrus districts. On the strength of these, for example, one railroad company brought on fast train schedule more than 150 oil-tank cars to southern California from the San Francisco Bay district. Since fuel supplies ran dangerously low before the end of the cold period, despite the most heroic efforts on the part of the transportation companies, a few growers who had spent large sums for protection lost their crops on the last night because of inability to secure fuel. The freeze warnings of the Weather Bureau are credited with the prevention of a catastrophe. Cooperation of a powerful radio station made it possible to talk directly to the growers at critical times.

The California citrus crop returns to the State in excess of $100,000,000 per year, and advance warnings of dangerous temperatures have resulted in saving sufficient fruit in one night to pay the cost of the horticultural-protection project for a generation. Frost protection benefits consumers through assuring a larger supply of good fruit in a freeze year and by stabilizing prices.

Recipients of the service carry approximately one-half the cost of the Weather Bureau's horticultural-protection work, insuring local interest and guarding against the continuation in any district where its practical value is not demonstrated continuously. In recent years localized forecasts have been made in deciduous-fruit districts in connection with spraying operations, and of weather unfavorable for fumigation, spraying, or dusting operations during the spring, summer, and autumn in southern California citrus districts.

SERVICE IN FLORIDA

Following the disastrous Florida freeze in December 1934, funds were provided by the Federal Government and the State of Florida to establish a cooperative horticultural-protection service in that State. During the winter of 1935–36 five districts were organized in the west-central portion of the peninsula, where there is heavy concentration of citrus plantings. Reports containing localized minimum-temperature forecasts and other information essential to protecting citrus and truck crops against frost damage were broadcast during the frost-danger period several times daily, on a staggered time schedule, by networks of important Florida commercial radio stations. Initial work was so well received that additional funds have been provided to extend the service. During the coming winter most of the Florida Peninsula will be covered with an organization of additional horticultural-protection field districts.

Service at present is largely of a pioneer nature, and the educational and research activities have been stressed. Research work to determine the critical temperatures of citrus fruits and garden truck commercially grown in the State is in progress; also to determine the efficiency of grove heating under Florida weather conditions, using heaters designed to burn local fuels, as well as with open wood fires quite commonly used. Studies of temperature inversions are being prosecuted, using for this purpose high steel towers and also ground stations located on hill slopes. Growers' meetings at which the principles of grove heating are discussed are being held so as to direct the local work in frost protection along lines which experience and experiment have proved to be effective and safe.

LIBRARY

The Weather Bureau library has the largest collection of meteorological literature in the world. It is extensively used by the technical staff of the Central Office, and by the field stations of the Bureau, as well as other governmental organizations and private institutions. Of late the demands on the library have increased because of both the natural growth of the Weather Bureau service and the increasing interest in meteorological research. Nearly 200 periodicals are received by it, about 50 of which are purchased; the remainder are received by exchange with the Monthly Weather Review, or are gifts. Many of these periodicals deal solely with meteorology; all contain items of interest for meteorologists from time to time. The library also receives publications from meteorological services and institutes throughout the world. During the year just closed improvements were made in the reading-room facilities of the library.

Shortly after the late C. F. Talman took charge of the library in 1908, he started the compilation of a dictionary of meteorological terms. His material for this dictionary consists of cards with much useful information to meteorologists. He added to this card collection continuously. Even in its present unpublished form the collection is of great value to the Weather Bureau, but its publication would enable the entire meteorological world to benefit from it. It was the plan of the Weather Bureau to relieve him of charge of the library in July 1936, thus to allow him time to get this large and important card collection in shape for publication in book form. His death, however, made it necessary to appoint a committee consisting of officials from the library and Meteorological Research Division to study ways of getting this material in shape for publication, and a good beginning has been made. The library continues to add new words to this card file as they are found in the literature, so that when this monumental Meteorological Dictionary and Reference Book is published it will be up to date. It will give etymologies, definitions, literature references, and discussion of all the terms used in meteorology.

THE YEAR'S WEATHER

Following the severe drought and high temperatures extending through the spring and summer of 1936, described in last year's report, substantial rains during the latter part of August relieved droughty conditions over many northern and eastern sections of the country. The moisture benefited late crops, revived pastures, and improved the condition of the soil for plowing and for seeding of winter grains.

September, in marked contrast to the summer months, had more than normal rainfall over most sections of the country east of the Rocky Mountains, with the monthly totals outstandingly large from Texas and New Mexico northeastward over the central valleys. Texas, Oklahoma, Missouri, and Iowa had more than double the monthly normals and many other States substantially more than the usual September rainfall. However, a considerable area in the Northwest continued relatively dry.

THE AUTUMN

For the 3 autumn months, September, October, and November, precipitation was above normal over a wide belt extending from the Southwest northeastward to and including the Ohio Valley and lower lake region. These rains were opportune and very favorable for the seeding, germination, and early growth of wheat, though at the beginning of the winter additional moisture was needed in the western portion of the Wheat Belt. From the Mississippi Valley eastward the autumn season brought mostly ample moisture for the needs of vegetation.

THE WINTER OF 1936–37

There were no marked abnormalities in December or February weather. However, January was characterized by marked extremes of both temperature and precipitation in different portions of the country. There were excessive rainfall and disastrous floods in the Ohio Valley and two severe freezes in the far West, especially in southern California, where heavy damage to citrus fruits and truck occurred. At the same time, abnormally warm weather prevailed in the more eastern States, especially the Southeast, where all vegetation became abnormally advanced, in many cases fully a month ahead of an average season.

The winter brought above normal precipitation to nearly all sections of the country, with heavy snow in the Central-Northern States. For the 3 months, December, January, and February, precipitation was above normal everywhere, except in South Dakota, Nebraska, Oklahoma, Texas, and New Mexico, with many States having more than one and a half times the normal for the season.

THE SPRING

The spring of 1937 began with plenty of moisture in the soil nearly everywhere east of the central Great Plains—too much in places—while winter snows in the higher western mountains had stored ample moisture rather generally for summer irrigation. The greatest snowfall reported for the period from December to April was 642 inches at Paradise Inn, Wash.

For the 3 spring months, March, April, and May, rainfall was much heavier than during the spring of 1936 throughout the Mississippi and Ohio Valleys and in the northern Great Plains. However, a belt extending from eastern New Mexico and western Texas northward to Canada had very little precipitation, and by the middle of May severe drought prevailed in most of this area. The latter part of May and the first part of June brought heavy rains to these sections, which temporarily relieved droughty conditions, but a generally dry period followed, and by the middle of July rain was again needed in most of the area. The percentage of normal precipitation in the different States from September 1936 to June 1937 is given in table 1.

TABLE 1.—*Percentage of normal precipitation, by States, September 1936 to June 1937*

State or section	1936				1937					
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Alabama	85	77	52	145	175	94	76	164	110	86
Arizona	128	106	99	166	153	131	180	19	100	157
Arkansas	141	160	81	125	294	63	63	65	71	120
California	35	99	4	137	81	170	154	86	24	200
Colorado	124	100	42	103	101	126	110	55	63	136
Florida	65	130	70	109	65	164	140	174	84	86
Georgia	123	145	50	148	166	109	76	193	63	95
Idaho	56	24	8	94	88	150	78	178	45	138
Illinois	187	118	83	131	261	70	39	142	78	124
Indiana	142	163	117	101	321	77	39	143	86	121
Iowa	190	71	41	131	210	96	94	117	99	81
Kansas	172	92	14	137	212	67	115	39	84	82
Kentucky	121	128	101	114	361	70	30	111	99	106
Louisiana	70	68	97	91	180	60	105	74	69	115
Maryland-Delaware	74	112	39	175	233	104	59	176	101	131
Michigan	155	111	58	107	123	102	30	145	74	103
Minnesota	72	35	86	185	193	130	70	185	121	76
Mississippi	69	67	80	123	228	74	73	84	77	107
Missouri	209	124	73	138	287	69	52	104	80	102
Montana	70	58	36	112	88	106	81	80	26	106
Nebraska	83	24	36	99	161	32	128	47	74	86
Nevada	71	136	14	185	124	168	94	62	55	47
New England	87	130	59	188	127	82	102	117	142	126
New Jersey	122	100	37	172	176	63	73	129	82	125
New Mexico	173	52	72	86	68	130	164	44	259	165
New York	93	138	91	119	166	87	84	121	110	142
North Carolina	119	184	82	165	215	101	47	166	52	90
North Dakota	73	20	55	83	144	107	51	138	75	121
Ohio	107	157	97	84	312	67	49	127	100	168
Oklahoma	256	97	25	102	152	30	101	68	72	95
Oregon	69	7	5	94	96	132	95	209	66	273
Pennsylvania	63	113	85	133	196	78	58	161	87	109
South Carolina	110	203	76	154	190	100	66	219	57	100
South Dakota	44	31	124	64	150	65	129	78	78	104
Tennessee	101	142	85	141	312	81	39	96	115	87
Texas	240	93	60	86	111	28	134	34	61	88
Utah	54	156	62	195	142	140	118	77	102	72
Virginia	105	125	46	165	253	102	42	181	73	120
Washington	76	23	12	118	56	142	84	216	62	283
West Virginia	62	140	92	120	235	107	52	117	89	115
Wisconsin	95	91	49	141	189	171	36	132	84	68
Wyoming	62	93	70	96	82	126	97	94	75	146

OHIO AND LOWER MISSISSIPPI VALLEY FLOODS OF JANUARY AND FEBRUARY 1937

An outstanding feature of the year's weather was the unprecedented rainfall that produced disastrous floods in the Ohio and lower Mississippi Valleys, in January and February 1937. These floods were caused by a prolonged period of heavy to excessive rain over the Ohio Basin, which began on December 26, 1936, and continued with little interruption until January 25, 1937.

Throughout most of this period there was a pronounced stagnation of air masses, with persistent high pressure over the Bermuda-Florida area and also over the Northwestern States, with a trough of low pressure between them, centering over the Ohio Valley. This pressure distribution resulted in an almost continuous northward and northeastward movement of great quantities of moisture-laden tropical air over the lower Mississippi and Ohio Valleys, while air masses of polar origin moved southward, almost continuously, over much of the western half of the United States. The extremely heavy rainfall over the Ohio Valley and portions of adjacent areas was, in general, caused by the persistent trough of low pressure being so located, with relation to the very deep areas of high pressure on both sides, that the line of contact between the warm, moist air from southerly regions, and the cold air of polar origin lay somewhere over the Ohio Valley much of the time. The rapid forcing aloft of the moist air of tropical origin resulted in excessive precipitation over an area the major axis of which closely paralleled the Ohio River.

Although this was a midwinter flood, accumulated snowfall was not a contributing factor; practically all of the water came from current rain. The ground was thoroughly saturated, and lack of vegetation contributed to maximum run-off possibilities. During the first half of the period the rainfall was sufficiently heavy to put the lower Ohio and its lower tributaries into moderate flood. On the main stream, flood stage was reached first at Cairo, Ill., on January 9; at Evansville, Ind., January 10; and at Cincinnati, Ohio, January 18. During the second half—from the 13th to 24th, inclusive—rainfall was exceedingly heavy, the area of greatest intensity being located along the Ohio River from the vicinity of Cincinnati to its mouth, extending somewhat south of the river near the mouth, and into Arkansas.

This concentration of excessive rainfall resulted in the highest river stages of record in the main stream from immediately below Point Pleasant, W. Va., to the mouth at Cairo, Ill., and in the lower Mississippi River from Cairo to the mouth of the Arkansas River. At Cincinnati the crest stage of 80.0 feet was 8.9 feet higher than the crest of the great flood in February 1884, which stood as the record stage at that point for more than 100 years, and at Louisville the crest was 10.4 feet higher than the record stage in that year. It is significant to note that record-breaking stages occurred in the lower portions of many Ohio tributaries, while in the upper reaches flood stages did not occur.

One of the characteristics of this flood was the long duration of high stages. The river remained above flood stage at Cairo and Paducah 48 days; Evansville, 39 days; Louisville, 22 days; and Cincinnati, 17 days. In the upper reaches of the river the fall was rapid after the passage of the crest but much slower in the lower portions.

The flood-forecasting service of the Weather Bureau functioned in a highly satisfactory manner. From the beginning of the rain period river-stage forecasts and flood warnings were issued regularly at the various forecast centers and given wide distribution. All flood forecasts were promptly relayed to the national headquarters of the American Red Cross, where they were used in formulating plans for relief activities. On account of the long continuation of excessive rainfall the time interval in the final crest-stage forecasts for the river above Cincinnati was necessarily of short duration, as the river ceased to rise in that section within 30 hours after the rain ended. Below Cincinnati accurate final crest-stage forecasts were issued for extended periods ranging from 3 days at Louisville, 6 days at Evansville, 9 days at Cairo, and 14 days at Memphis, to 31 days at New Orleans.

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