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REPORT OF THE CHIEF OF THE WEATHER BUREAU, 1938 [1]

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
WASHINGTON, D. C., *August 25, 1938.*

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, 1938.

Sincerely yours,

WILLIS RAY GREGG, *Chief.*

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INTRODUCTION

In the four annual reports preceding this one chief emphasis has been placed on the great importance of (1) a broad, comprehensive program of research and (2) effective cooperation with other organizations, both governmental and nongovernmental, including particularly the meteorological services of all other countries. Unless special attention is given to these two requisites, real progress in meteorological service is impossible.

In the development of any service in which a steady though gradual growth is desirable to enable it to meet progressively increasing demands, it is necessary and stimulating, from time to time, to pause briefly, make a study of what has been accomplished and, to a certain extent, start afresh, concentrating on those parts of the service that are shown to be weakest, and eliminating or reducing those which may formerly have been important but the need for which has largely ceased—in other words, "putting first things first".

When, 4 years ago, in response to recommendations of the Science Advisory Board, a program was adopted which had as its purpose the introduction of new procedures and particularly a change of attitude in the Weather Bureau which would enable it to modernize its service in line with recent thought and

[1] Since the following report was written, the death of Dr. Gregg occurred on September 14, 1938, at Chicago, Ill., where he was attending an aviation conference between the Civil Aeronautics Authority and the Air Transport Association of America.

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

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practice elsewhere, it was fully recognized that there would be an ever-present danger, on the one hand, of drifting back into practices that had long since ceased to be useful and, on the other, of failing to preserve a proper sense of balance among the newer procedures, only recently introduced. An occasional careful survey or "taking of stock," along the lines indicated in the preceding paragraph, is the only sure way to guard against this danger. Such a survey has been made during the past year. It revealed considerable progress. It also showed the need of a reorientation along some lines. By means of a series of conferences and the work of a number of committees important changes have been and are being made, all designed to increase the efficiency of the service in all its branches. Special attention is being given to the training of personnel, to the complete standardization of the service in accordance with international practice, and to research. In the following pages is presented a discussion of these topics, together with brief reviews of the Bureau's activities and a summary of the weather during the fiscal year.

TRAINING OF PERSONNEL

The program of detailing field personnel to the central office, briefly referred to in the last two annual reports, was continued, and its effectiveness was increased by assigning a trained air-mass analyst to the field to give instruction at different stations. Significant results have come from this program, but it has been recognized that it should be supplemented by sending a few outstanding men to educational institutions for advanced instruction. Efforts to secure authority for this purpose were finally successful, in the passage of the Civil Aeronautics Act, approved June 23, 1938. Among its provisions are:

SEC. 304. The Administrator is empowered and directed to make recommendations to the Secretary of Agriculture for providing meteorological service necessary for the safe and efficient movement of aircraft in air commerce.

SEC. 803. In order to promote the safety and efficiency of aircraft to the highest possible degree, the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, shall, in addition to any other functions or duties pertaining to weather information for other purposes, (1) make such observations, measurements, investigations, and studies of atmospheric phenomena, and establish such meteorological offices and stations, as are necessary or best suited for ascertaining, in advance, information concerning probable weather conditions; (2) furnish such reports, forecasts, warnings, and advices to the Authority, and to such air carriers and other persons engaged in civil aeronautics as may be designated by the Authority, and to such other persons as the Chief of the Weather Bureau may determine, and such reports shall be made in such manner and with such frequency as will best result in safety in air navigation; (3) cooperate with any person employed by air carriers in meteorological service; and (4) detail annually not to exceed ten members of the Weather Bureau personnel for training at Government expense, either at civilian institutions or otherwise, in advanced methods of meteorological science: *Provided,* That no such member shall lose his individual status or seniority rating in the Bureau merely by reason of absence due to such training.

The authority contained in section 803 (4) for the detailing of personnel to educational institutions for advanced training is of fundamental importance and significance in the development of meteorological service in this country. Plans are being worked out to put this legislation into effect, to the full extent that funds will permit.

INTERNATIONAL CONFERENCES

The past year has been a particularly active one in international meteorology. The first meeting of the newly formed Commission on Aeronautical Meteorology was held in Paris in June 1937. September 1937 was marked by conferences of Regional Commission III (South America) at Lima, Peru, and of the International Meteorological Committee at Salsburg, Austria, the latter being preceded by meetings of commissions on agricultural meteorology, climatology, synoptic weather, and projections for meteorological charts, and of two subcommissions on medical meteorology and on sea swells. A conference of directors of meteorological services in the southwest Pacific was held at Wellington, New Zealand, in December 1937. Finally, representatives of several countries concerned with meteorological service for trans-Atlantic aviation met at a conference in Dublin, Ireland, during March 1938. The Weather Bureau was represented by one or two officials at all of these conferences. It has membership in nearly all commissions and the Chief of Bureau is a member of the International Meteorological Committee and president of the Commission on Projections for Meteorological Charts and of Regional Commission IV (North America).

Of special importance was the conference held at Lima. It was the first meeting of Regional Commission III, which is composed of the directors of

national meteorological services in South America who are members of the International Meteorological Organization. It was held concurrently with a meeting of the technical aviation conference.

Regional Commission III was organized in accord with a resolution passed by the International Meteorological Organization at Warsaw, Poland, in 1936. Therefore, the Regional Commission III meeting at Lima was not only its first but it probably was the most important assemblage of meteorologists ever held in South America. Moreover, it was the first time that representatives of the United States Weather Bureau have participated in a meteorological conference in South America.

A number of meteorological problems of mutual concern to North America and South America were discussed. Among the resolutions passed was one urging that a similar regional commission (No. IV) be formed to consist of the meteorological services of North America, Cuba, and the West Indies. This and other resolutions were a recognition of the fact that travel between the countries of the Western Hemisphere, especially by airplane, and other business relations on which weather has important bearing, make it necessary that there be more intimate international understandings and coordinations than ever before concerning meteorological work in the Americas.

For many years the meteorological services of Canada and the United States Weather Bureau have been active members of the International Meteorological Organization, and they have had close cooperation with neighboring government meteorological institutions, but there has been no organized regional coordination. Regional Commission IV is being formed, and in due time it is expected that there will be a joint meeting with Regional Commission III.

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 and reports 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 in the Monthly Weather Review may be mentioned: Review of United States Weather Bureau Solar Radiation Investigations, by I. F. Hand (vol. 65, pp. 415–441), a summary and discussion of the solar-radiation observations and investigations of the Weather Bureau to date; On the Relation Between Rainfall and Streamflow—III, by R. T. Zoch (vol. 65, pp. 135–147), a further contribution to the mathematical investigation of flood forecasting; The Geometrical Theory of Halos—IV, (vol. 65, pp. 190–192), and V, (vol. 65, pp. 301–302), by E. W. Woolard, continuing the investigation in meteorological optics begun last year; Formation of Polar Anticyclones, by H. Wexler (vol. 65, pp. 229–236), a further contribution to the investigation of North American cold waves that has been in progress during the past 2 years; On Some Properties of the Water Vapor Spectrum and their Relations to Atmospheric Radiation, by W. M. Elsasser (vol. 65, pp. 323–326), the initial contribution to a comprehensive investigation of the fundamentally important part played by absorption and radiation by water vapor in the atmosphere; On the Thermodynamic Interpretation of Isentropic Charts, by H. R. Byers (vol. 66, pp. 63–68), a discussion of the construction and application of the isentropic chart in the form finally developed by the Weather Bureau; The Normal Temperature Distribution of the Surface Water of the Western North Atlantic Ocean, by G. Slocum (vol. 66, pp. 39–43 and 16 charts), making generally available the data in the records of the Weather Bureau; Shielded Storage Precipitation Gages, by J. C. Alter (vol. 65, pp. 262–265), a report on a long series of experimental investigations of the measurement of snowfall by the Weather Bureau. Two reports dealing with progress in the development of the radiometeorograph appeared: A Series of Radiometeorograph Soundings during February–April 1937, by C. Harmantas and D. P. Keily (vol. 65, pp. 219–229); and Report on the Weather Bureau Radiometeorograph Program, by L. T. Samuels (vol. 66, pp. 93–95). In addition, two important reports on international cooperation among meteorological services were published: Advances in International Meteorology in 1936–37, by W. R. Gregg (vol. 65, pp. 385–387); and International Standard Projec-

tions for Meteorological Charts, by W. R. Gregg and I. R. Tannehill (vol. 65, pp. 411–415).

INVESTIGATIONS UNDER THE BANKHEAD-JONES ACT

With allotments from the special research fund provided by the Bankhead-Jones Act, the investigation of cold waves in North America, which was begun during the preceding fiscal year, was continued in cooperation with Massachusetts Institute of Technology and the Bureau of Agricultural Economics; and a further project for the study of warm and cold anticyclones and the role of ozone as a possible link between solar activity and atmospheric changes was begun in cooperation with the same agencies. These investigations are a part of the general weather- and crop-forecasting research program of the Department of Agriculture.

The upper-air soundings at Fairbanks, Alaska, were made with the radiometeorograph, checked by periodical airplane flights. The statistical and theoretical study of data obtained by upper-air sounding and other special observations at northern stations was continued and has enabled further extensions to be made of the quantitative theoretical-physical explanation of how cold-air masses build up in the far North during winter by radiational cooling at the snow surfaces and by the gradual upward spread of the cooling effect during the Arctic night. The observational program of this investigation has provided the opportunity to demonstrate the applicability of radiometeorograph soundings under extreme conditions; the experience gained will be of benefit in all activities of the service since it is planned eventually to replace all airplane soundings of the upper air by radiometeorographs.

In the theoretical part of the investigation increased emphasis was given to the study of the mechanism by which the accumulated cold air is eventually released and propagated in the form of a cold wave, and a promising beginning has been made in the solution of this problem. The release of cold-air outbreaks seems to be closely related to the circulation aloft of the warmer air in the dynamical warm Highs of lower latitudes. The originally distinct investigations of cold Highs and warm Highs have thus been brought together in a single investigation of the general circulation of the atmosphere between northerly and southerly latitudes.

In the course of these investigations fundamental advances in understanding the dynamics of atmospheric circulation have already been effected, largely by utilizing recent advances in fluid mechanics, particularly the theory of lateral mixing and dissipation in wake streams; and opportunity has been provided to develop and apply important methods that are also of general application in regular daily meteorological and forecasting work—especially the isentropic chart, which gives promise of great usefulness in daily forecasting and in obtaining and understanding of weather abnormalities such as periods of flood or drought. The large-scale features of atmospheric circulation determined by cold and warm anticyclones are of fundamental significance for the large-scale trends, changes, persistencies, and abnormalities of weather that are especially important for long-range forecasting.

In the study of the possibility that ozone in the upper atmosphere may act as a link between solar activity and meteorological phenomena in the lower atmosphere, a survey of present knowledge has been completed; and it is planned to start observations of ozone in the United States to investigate the correlations between ozone distribution and weather which have previously been found to exist in Europe.

AIR-MASS ANALYSIS

Progress has continued in the development of frontal, kinematic, and thermodynamic analysis of synoptic maps and vertical cross sections. In particular, investigations have been made of upper-air cold fronts and upper-air pressure maps and the results put into daily use. Upper-air charts of conditions on isentropic surfaces have been developed and their application in daily forecasting extensively studied. The properties, progressive modifications, and distinguishing characteristics of the air masses of the United States have been summarized anew and have shed new light on air-mass modifications and resulted in a simpler and more practical classification of North American air masses. Improved and simplified cross sections have been developed; improved methods for the thermodynamic interpretation of charts and cross sections have opened up new lines of investigation that have led to preliminary conclusions about the dissipation of fronts at high levels which partly invalidate

the Norwegian conception of the occluded cyclone. General-forecast studies have also been continued as in the past.

PROGRESS IN APPLYING NEW SYNOPTIC AIDS TO DAY-TO-DAY FORECASTING

In the development of the science of weather forecasting there has been a sort of friendly competition between the practical and the theoretical schools. When observations were confined largely to surface conditions, most of the contributions came from the practical side because it was difficult to shape the practical problems into a form susceptible of treatment by the then-known physical methods. Later, as an increasing amount of information from the free air was made available by means of kites, sounding balloons, pilot balloons, mountain observatories, etc., more and more theoretical contributions appeared. Thus was narrowed the gap that existed between the practical and theoretical schools and, while there still remains a gap, it is surely and steadily decreasing.

Clouds, the observation of which gave us our first, though incomplete, knowledge of the free air, were supplemented by sporadic observations of pressures, temperatures and humidities from kites and sounding balloons carrying meteorographs. These in turn were followed by regular once-a-day and later by twice-a-day pilot-balloon programs. It was not, however, until the inauguration of daily airplane observations from a network of stations that sufficient information in the vertical was obtained to give a fairly comprehensive picture of the structure of the lower half of the troposphere. Still more recently the radiometeorograph has extended our daily information into the substratosphere and has assured observations even under weather conditions so adverse that planes cannot function.

Following the World War, a series of truly phenomenal advances in forecasting began. The announcement of the frontal concepts by Bjerknes, Solberg, and Bergeron was followed by studies of air masses by Bjerknes and Bergeron in Europe and by Rossby, Willett, and Byers in this country. The next important step was the development of kinematical computations on the movement of pressure systems, fronts, etc., by Petterssen and later by his contribution on frontogenesis and cyclogenesis, etc. The latest advance, which has already demonstrated practical applications and holds out definite promise of further usefulness, is that of Rossby's investigations of flow patterns of moist and dry tongues as shown on the isentropic charts suggested by Napier Shaw many years ago. Many cases of precipitation cannot be explained by means of the frontal concepts. Of those heretofore unexplained cases, the flow patterns on isentropic surfaces explain a considerable number—limited somewhat by the openness of the network of airplane stations and by the fact that such observations are available only once a day.

This series of epochal developments has been made possible not only by systematic daily observations in the free air from a network of stations but also by the recognition of the need for promoting and encouraging studies in dynamic meteorology by some of the more progressive universities and meteorological institutions. There is every reason to expect that, with the development of new tools in the way of concepts, more complete and frequent free-air observational material, and increasingly efficient methods of attack, this wonderful advance of the last decade or so will continue.

About 3 years ago a small group was organized in the Weather Bureau at Washington to carry on a program of instruction and investigation in weather-map analysis based on physical principles in the expectation that such methods would improve the forecasting work of the Bureau. This small group, usually referred to as the "air-mass group," prepares daily a general map, vertical cross-sections, isentropic charts, and energy diagrams when necessary. Conferences are held at 11:15 a. m. at which a leader carries through a complete analysis of the current map and traces the evolution of the fronts and the changes in air masses. Those who attend the conferences, 10 to 15 in number, offer suggestions and take part in the discussions. Following the analysis, the leader presents a map showing his predicted positions of the fronts and the centers of high and low pressure and the pressures to be expected at the centers on the following morning, as well as any indications of new developments of centers and fronts. In presenting this forecast map, the leader describes the kinematic calculations he has made as well as the calculations on the movements of the fronts based on the geostrophic wind scale and gradient winds. He also indicates where the genesis or dissolution of fronts, cyclones,

and anticyclones is likely, giving the reasons for his conclusions. In a general way he points out the regions in which precipitation is to be expected on the basis of frontal considerations and also on those of the isentropic charts. Occasionally an attempt is made to indicate in a general way the future movement of the moist tongue on the isentropic chart.

These conferences serve not only to instruct personnel who are engaged, or will in a short time engage, in forecasting either on the airways or at the district forecast centers, but assist the forecaster on duty by providing a complete and thorough analysis of the morning chart for the current day. This analysis is of considerable value even though it follows the making of the morning forecast.

All have access to published accounts of recent ideas and developments in forecasting; and in the air-mass group all of these that seemed to have any virtue have been given a thorough trial. It is the Bureau's policy to disseminate information regarding these newer ideas and methods to its forecasters just as quickly as possible. To this end, small groups of field men have been brought in from time to time to the central office to attend the daily air-mass conferences and to receive a course of lectures for a period of 2 or 3 months. In addition, one man is attached to the airway service who visits stations where he can be of the greatest help. At present there is hardly a forecast center, either district or airways, that has not had at least one of its men assigned to Washington for this instruction. At the central office, where the forecasters have the benefit of daily contact with the work of the air-mass group, every effort is made to employ these aids so far as possible in the time available in their daily forecast work. After the data are charted, the forecasters have from 15 to 30 minutes to study the situation before beginning the forecasts, whereas a complete detailed analysis requires a minimum of 2 hours. However, with the historical groundwork of a thoroughly analyzed chart of the previous morning and a less complete analysis of the 1:30 p. m., the 7:30 p. m., and the 1:30 a. m. charts, a good deal can be accomplished in the 15 to 30 minutes available. The time is generally sufficient for a rapid placement of the well-marked fronts and the fitting of the isobars to them, as well as for the location of some of the fronts that are not so well marked but which often become important later. The vertical as well as the horizontal distribution of wind, temperature, and moisture is studied in order to get a picture of the air masses and the interactions between them. When frontal considerations do not explain the precipitation, an attempt is made to ascribe it to instability brought about by convergence or convection or to moist tongues flowing up isentropic surfaces. Following this very hurried analysis, a little time generally remains to make calculations of the movement of the more important fronts and the principal centers of low pressure and high pressure by kinematical methods, geostrophic wind scale, or gradient winds. If time is available, calculations are made for the local afternoon conditions, such as for maximum temperatures based on the local aerograph and, during the summer season, of the possibility of afternoon thunderstorms from an energy diagram.

To speed up the work of charting as much as possible and to make the forecaster's maps adapted in a more adequate manner to forecasting from a physical point of view, a number of changes have been made in the organization and charting of the observational data. Instead of wind velocity being entered in miles per hour, it is now indicated by barbs on the wind-direction arrow. Many of the international symbols for present weather have been adopted. The important fronts are drawn on manuscript maps and the isobars fitted to them. Barometric tendencies are entered on the weather map as well as on the pressure-change map. Pilot-balloon observations are plotted for elevations above sea level instead of above surface. State of sky is coded now in four groups, clear, scattered, broken, and overcast, instead of in three as formerly, and the character of precipitation is indicated. Diagrams showing results of airplane and radiometeorograph observations are plotted on graphs having pressure as the ordinate instead of height. Other changes are in contemplation, all looking to a greater use of physical methods in the daily forecast work.

Considerable time and effort have been devoted to finding some generalized method whereby the forecasters could obtain some, at least, of the benefits of a more complete analysis. Lately a special point has been made of prompt preparation of the isentropic charts in an endeavor to have them available to the forecaster in time for use. The best performance so far has been to have them ready between 9:25 and 9:30 a. m. part of the time, which, of course, is rather late. Aside from the question of making detailed analyses to which

reference has been made, it has been realized for some time that the fuller, more complete and better distributed observations available in the last few years have not been utilized to the greatest advantage because of the lack of time for proper study. No way to overcome this difficulty has been suggested that will not involve a very radical and difficult change in present schedules.

It was formerly supposed that a more comprehensive knowledge of weather processes and more complete information regarding them would both clarify and simplify the problem of weather forecasting. In actuality, though the problem has been clarified, it has not only failed to become simpler, it has become many times more complex—yet for that reason far more interesting.

INSTRUMENTAL EQUIPMENT

The chief function of the Instrument Division remains as heretofore to select, procure, and test instrumental equipment for the Weather Bureau and to see that it is employed in a way to insure the soundest results possible. However, methods of accomplishing these results have greatly changed. The recent increase in funds available for upper-air soundings and airway service has attracted the attention of manufacturers and contractors. As a result there has been a great increase in development work by manufacturers and many of them offer the Bureau their wares. Of these wares some represent the work of highly skilled technicians and others that of persons lacking the requisite skill and experience. Present-day regulations practically compel the acceptance of the lowest bid. The result of all this has been to impose an unusual degree of responsibility upon the Division in the preparation of purchase specifications for instrumental equipment for general weather service, airways, and upper-air soundings.

With the fine cooperation of the personnel of the Division there is gradually being built up a set of purchase specifications embodying the results of the experience gained in making previous purchases. However, the intense effort required for this phase of the work hinders the application of the resources of the Division to the improvement and development that it would like to carry on. Still this careful attention to specifications has resulted in many improvements made by manufacturers in the equipment offered.

ANEROID BAROMETERS AND BAROGRAPHS

Specific improvements in the instrumental equipment in the field service should be mentioned. A new aneroid barometer that performs satisfactorily over a range of 3 inches or more in pressure, and under temperature changes varying from near the freezing point to summer temperature, is now being manufactured by an American concern, and is available at a price under $20 each; about 100 have been purchased. An aneroid barograph, well compensated for temperature, is being marketed by an American firm. It is fully equal and, in respect to temperature compensation, superior to instruments of this type previously available. It is available in both 1 to 1 and 2½ to 1 pressure ratio. The latter is being preferred by Weather Bureau meteorologists, and it is expected that within the next 6 months practically the entire Bureau will be equipped with them.

WIND-DIRECTION CONTACTING BEARING

A wind-direction contacting bearing equipped to transmit 8 points of wind direction has been developed, and a dial indicating direction to 16 points by means of 8 lights has been developed to go with it.

Experimental trials of this device equipped with four additional contacts to permit simultaneous operation from one vane to the triple register in one place and an indicator dial or several dials in other places give promise of success.

STORM-WARNING TOWERS

Storm-warning display towers and lanterns have not been eliminated from the picture by radio as many had anticipated. On the contrary, present practice calls for the replacement of oil-burning equipment by electric lights. This is due largely to the extension that has taken place in electric service lines.

A new 85-foot tower built entirely of wrought iron has been procured and erected at Tatoosh Island, Wash. It is confidently hoped that this tower will resist satisfactorily the severe corrosion that takes place at that point.

EXHIBITS

During the year two instrument exhibits were assembled and arranged for display; one, at the Weather Bureau office at Charleston, S. C., in connection with ceremonies conducted by the city of Charleston commemorating the two-hundredth anniversary of the first instrumental weather observations in the United States; the other, at the Benjamin Franklin Institute, Philadelphia, Pa., upon the occasion of the dedication of the Benjamin Franklin Memorial in the Institute building. Both of these exhibits created considerable public interest and were well attended. The Instrument Division has also been in direct contact with representatives of the New York World's Fair and the Golden Gate Exposition in working out details of that portion of the Government exhibits dealing with the weather service of the United States. Both of these fairs are to open during the next fiscal year.

FORECAST AND WARNING SERVICE

ESTABLISHMENT OF STATION ON SWAN ISLAND

Arrangements were made for the operation during the hurricane season of 1938, of a meteorological station on Swan Island, in the Caribbean Sea about 200 miles south of the extreme eastern end of Cuba. The station is maintained in cooperation with the United States Navy, which furnished and operates the radio equipment, the observer and meteorological instruments being supplied by the Weather Bureau. For a number of years this island was utilized by the Tropical Radio Telegraph Co. as an important relay point in its radio service for the United Fruit Co. Observations from Swan Island were obtained regularly until the radio company ceased its major operations thereon. Thereafter, for a few years observations were obtained in August, September, and October by contract with the Tropical Radio Telegraph Co., which sent operators and radio equipment to the island for that specific purpose. This plan had to be abandoned in 1933 because of the large expense involved.

In former years weather reports from Swan Island were highly valuable in connection with the issuing of warnings of hurricanes, and it is satisfying to know that reports will in the future be available therefrom in the event of hurricane occurrences in that region. This station and the one established by the Government of Cuba on Grand Cayman Island in 1935 will ensure regular and reliable observations of special value in the issuance of warnings to Cuba and the southern coasts of the United States.

Like the preceding one, the last season (June 16 to November 15) was exceptionally free from tropical disturbances. Nine were recorded, and only two were of hurricane severity. No part of the United States or its possessions was affected. This was in contrast with the record year of 1933, when 21 tropical storms occurred. Several of them were of hurricane proportions, and much damage was done at places on our South Atlantic and Gulf coasts.

DISTRIBUTION OF WEATHER INFORMATION, FORECASTS, AND WARNINGS BY RADIO

Radio broadcasting stations have been cooperating with the Weather Bureau in disseminating weather information since the first voice programs were begun in 1920. The number of broadcasting stations now cooperating in this work has steadily increased and totaled 450 at the end of the fiscal year.

In an effort to improve this form of service, microphones connected with local broadcasting stations have been established in a number of Weather Bureau offices, and forecasts, weather data, and other meteorological information are given direct by officials of the Bureau. Several additional microphone installations were made during the year, the number now in operation being 30. These announcements are made on schedule several times a day and oftener when severe conditions, such as cold waves, floods, heavy snows, frosts, etc., are impending.

Expansion has been made in distributing weather information from Coast Guard and lighthouse radiophone stations located on the Atlantic, Gulf, and Pacific coasts and in the Great Lakes areas. This service was inaugurated principally for the benefit of fishing boats, tugboats, and other types of small craft. The number of participating radio stations is now 18. Broadcasts are made twice a day, but when storm warnings are issued they are repeated every 2 hours. The cooperation by these Government agencies is highly efficient and benefits not only the owners and operators of small craft but also people for a considerable distance inland.

AEROLOGICAL OBSERVATIONS

RADIOMETEOROGRAPH AND AIRPLANE OBSERVATIONS

In view of the importance of developing satisfactory radiometeorograph observations, three different types of instruments were used during the year for making scheduled observations at Boston, Mass., Burbank, Calif., and Fairbanks, Alaska. The results of these soundings were compared with simultaneous airplane observations and were found to be generally satisfactory. As a consequence, plans were made to use radiometeorographs at six stations during the year beginning July 1, 1938.

Progress is reported in the development of the radiometeorograph at the National Bureau of Standards. The Weather Bureau is cooperating in the financing of this project. A number of these instruments were purchased and used in observations, with generally satisfactory results.

Cooperation was continued with the California Institute of Technology in the development of radio apparatus for obtaining wind directions and velocities in and above cloud layers. This important problem has not yet been solved sufficiently to make possible its use in observation work.

Airplane observations were made under contract with commercial operators at the same 12 stations as during the previous year, except that Chicago was substituted for Miami. The War Department discontinued airplane observations at Boston on December 31, 1937, and at seven Army fields on June 30, 1938.

An investigation of upper-air conditions in and around a tropical hurricane was undertaken in cooperation with the Massachusetts Institute of Technology. Since no hurricanes passed near the stations from which the balloons were to be released, the observations were made in an extratropical cyclone accompanied by heavy rains. A good number of the meteorographs have been found and returned, and analysis of the records will be made jointly by the Weather Bureau and the Institute.

The Weather Bureau again participated in International Month in August 1937 by releasing sounding balloons throughout the month at Omaha, Nebr. Nearly all of these meteorographs have been found and returned and the evaluated data furnished the International Aerological Commission.

PILOT-BALLOON OBSERVATIONS

Pilot-balloon observations by which upper-air winds are measured were inaugurated at two additional stations, located at Huron, S. Dak., and Sacramento, Calif. This brings the total number of stations to 79, including 3 in Alaska and 1 at San Juan, P. R. Action was taken to increase the number of pilot-balloon observations to four per day at all stations in continental United States. Observations with larger (100-gram) pilot balloons, capable of ascending to greater heights than those now in general use, were inaugurated at Las Vegas, Nev., and arrangements completed for similar observations to be made at 13 additional stations. The possibility of using helium instead of hydrogen for the inflation of balloons, in order to eliminate the danger of hydrogen explosions, was investigated and arrangements made whereby it would be used as a trial at a limited number of stations during the fiscal year 1939. The special research project of determining the ascensional rates of different types of balloons and the effects on the ascensional rates of substituting helium for hydrogen, was continued at Washington, D. C.

SERVICE IN AID OF AIR NAVIGATION

Three qualified forecasting assistants were added to the force of each of the 11 airway forecast centers to permit the maintenance of full 24-hour forecasting service and the preparation of supplementary charts necessary for the correct analyses of weather situations. Already this program has shown definite results in the direction of increased accuracy in the airway forecasts and has permitted the issuance of forecasts at 3-hour intervals when especially adverse conditions are present in a district.

One man and a light panel truck were added to each of the 11 general supervising stations for inspection and maintenance work. These inspectors, using the truck for transportation, visit all stations both on and off the airways in their respective districts in some instances four times a year, and while there, inspect the instrumental equipment, train observers in weather reporting, make recommendations for improvement of service, and handle other details which cannot be handled efficiently in any other manner. In addition, instrumental equipment, forms, and other supplies are carried by the inspector, thus saving considerable

amounts otherwise required for transportation. A distinct improvement in the data from substations has been noted since the institution of this program, and it is expected that this improvement will progressively increase as the inspectors become more familiar with their districts.

The instrumentation of about 150 stations was improved by the installation of ceiling projectors that project a more intense beam of light for illuminating a spot on a cloud layer as a means of determining the height of the layer. Similarly, about 120 stations were provided with new open-scale barographs for better determination of pressure-change characteristics; 100 were provided with mercurial barometers for accurate measurement of barometric pressure, and 50 stations were supplied with eight-point wind-direction indicators for accurately determining wind directions to 16 points of the compass or more. This has resulted in increased accuracy of observations from these stations.

New airport stations rendering 24-hour service and taking four pilot-balloon observations each day were established at 10 major air terminals, and one commissioned Weather Bureau employee was assigned in charge of each of 33 stations where formerly the weather-reporting work was performed entirely by noncommissioned airway observers. This has resulted in material improvement in the accuracy of reports rendered from these points and has greatly increased the facilities for proper meteorological service in aid of aviation at important points in the airway network.

The airway general supervising and forecast center at Dallas, Tex., was transferred to Fort Worth, Tex., to permit complete coordination of the receipt and transmission of meteorological data with the facilities of the Bureau of Air Commerce and to provide better contact with airline companies and personnel.

Several new off-airway, 6-hourly reporting stations were established to fill in gaps in the network of such reports. In addition, approximately 40 existing teletype or radio hourly reporting stations along the airways were equipped with additional instruments for the taking of special 6-hourly coded weather reports and the entering of such reports in special sequences run each 6 hours over the teletype and radio circuits. This program has resulted in a strategic increase in the number and distribution of synoptic reports available for use in connection with the preparation of detailed weather maps at all airport stations and the analysis of weather situations and issuance of airway forecasts.

In order that information might be available from strategic points off the airways for the preparation of supplementary weather maps and tracing developments in weather situations which might unexpectedly arise between the 6-hourly collections of synoptic reports, about 20 of the 6-hourly off-airway stations were organized to render reports at the 3-hourly intervals between the 6-hourly reports. Most of these stations are located along the Pacific coast and Canadian border in order to guard against adverse conditions from these areas of sparse reports reaching airways in the United States without advance warning, but others are also located at strategic points in the interior and along the Atlantic coast so that all areas are guarded against the occurrence of such conditions as much as possible.

Fifty-five new teletype stations established by the Bureau of Air Commerce during the year were furnished complete instrumental equipment needed for the taking of hourly or more-frequent weather reports.

There are now 62 first-order airport stations where weather maps, hourly weather reports, pilot-balloon reports, and meteorological advice or forecasts are available 24 hours each day, and there are 33 stations at which a commissioned Weather Bureau employee has been assigned in charge of three airway observers for the taking of hourly or more-frequent weather reports. In addition to these, there are 269 stations rendering hourly or more frequent weather observations, about 140 of which render 6-hourly coded synoptic reports; 314 stations rendering weather observations at regular times, or on call, to serve scheduled flights, and 145 off-airway stations rendering reports every 6 hours in the airway network, 20 of which render reports every 3 hours, or a total of 823 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., Fort Worth, 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,

on the basis of observations made at 1:30 and 7:30 a. m. and p. m., eastern standard time.

REORGANIZATION AND EXPANSION OF THE RIVER AND FLOOD SERVICE

Reorganization of the river and flood service, which is responsible for the prediction of flood and navigation stages in the rivers of the United States, has progressed effectively in three directions: (1) Refinement of the observation and reporting system of effective rainfall in upstream basins of major drainage areas; (2) the analysis of rainfall and storm data for use by the Army in the design of flood-control works; (3) expansion of the mountain-snowfall service in the West.

Changes in the headwater-forecasting service on tributary and headwater streams have been so far confined mainly to the Northeastern States, with special concentration on the Allegheny, Monongahela, Delaware, Schuylkill, Susquehanna, Merrimack, and Potomac Basins. In this program about 160 recording rain gages have been established, many of them by cooperative arrangement with the United States Geological Survey and the Commonwealth of Pennsylvania. In addition, several new river-stage reporting stations have been established and the procedure of reporting refined, so that information on quantities and discharge of river flow may be in the hands of river forecasters from 6 to 24 hours earlier than has heretofore been possible.

The collection and tabulation in readily interpretable form of evaporation data for the country as a whole has progressed rapidly as a W. P. A. project of definite hydrologic value; and of outstanding importance has been the storm study of the River and Flood Division in cooperation with the Corps of Engineers of the Army. The purpose of this work is to deduce by hydrometorological methods, involving air-mass analysis and transposition of storms, the maximum flood-producing characteristics of regions in which the Army has flood-control works in prospect. These studies are conducted on a sound scientific basis and are expected to yield information of permanent value, not only for the immediate purpose of the Army, but also for present or future use in any program for land utilization or soil conservation in the area concerned.

The mountain-snowfall service has been improved by the establishment, in carefully selected areas, of 20 new stations equipped with batteries of five shielded snow gages, and it is expected that a like number will be established during the current year. Ultimately this service will be so organized as to provide accurate snowfall-runoff data for general river and flood forecasting on all significant drainage basins of the West.

In addition to the foregoing specific items, the general administration of the river and flood service is being expanded on a regional basis. The efficacy of this method of organization has now been adequately demonstrated by a year's operation in Regions 1, 3, and 4 (the North Atlantic, the Ohio Valley, and the upper Mississippi sections, respectively) in improved care of equipment, closer coordination of operations with other Government field services, more frequent contacts with observers and consequent improvement in records and reports, and, most important, in furthering the program of headwater prediction. The long-established forecasting methods for stage prediction by gage relationships, reliable though they are for the middle and lower reaches of the streams, are inadequate for the needed forecasting of upstream conditions. Inspections, studies, the installation of self-recording rain gages in headwater areas, and the establishment of highly efficient reporting methods have already produced a substantial groundwork for the advance of this work.

MARINE CLIMATOLOGY AS AN AID TO AGRICULTURE

Many investigators have thought that there is probably a useful relation between meteorological phenomena over the continents and the antecedent conditions over the oceans. To determine whether such a relation exists, it is necessary to know definitely the history of weather fluctuations, both over the continents to be studied, and over the adjacent, and possibly the distant, ocean areas. Such weather histories are available for the continental United States, covering a long period of years, but there are no parallel series of monthly values for temperature and other elements over the oceans. The areal distribution of marine data is very irregular. In many large areas the observations are scanty, and even within selected areas where ocean commerce has provided abundant data, the series of dependable values is relatively short. In the

present state of knowledge every new compilation that adds to the available body of normal or historical marine-weather data is of value to the investigator.

Under the sponsorship and technical supervision of the Weather Bureau the W. P. A. at New Orleans, La., is engaged in making a series of compiliations of meteorological data for the oceans. Approximately 5½ million observations collected from ships, mainly between 1885 and 1933, have been summarized, and the results have been transferred to world charts, which have been submitted for publication in the form of an atlas. Within the limitations of the available data, the normal conditions of wind, cloudiness, rainfall, fog, mist, haze, thunderstorms, and wet-bulb depression are shown by months or seasons for the navigable oceans of the world and temperatures by months for the North Pacific and North Atlantic Oceans.

Additional compilations and charts not to be included in the atlas are being prepared in special sub-projects with the same material serving as basic data. Ocean squares have been selected which are represented by an adequate body of observational data, and series of tables are being prepared for these squares to show the changes in temperature of the air and surface water from month to month and from year to year. Special studies are also being made of general weather conditions over ocean areas adjacent to the United States during abnormally wet or dry periods in the southern Plains States. It is hoped that the information in the atlas and other special data derived from this project will be useful in investigations of long-range forecasting, possibly by indicating a new and more profitable approach to the determination of the relation between oceanic meteorological conditions and subsequent continental weather.

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 by 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 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.

The library of the central office has supervision of the station libraries, and almost every Weather Bureau office, including those at airport stations, has a small station library. Action was taken to increase the volumes in these station libraries, thus increasing the efficiency of the station itself and also enabling each station to be of more service to the public.

Work on the Talman Meteorological Dictionary and Reference Book, which was referred to in the report for 1937, is continuing.

THE WEATHER OF 1938

Since the recent series of severe droughts extending up through 1936, weather conditions have been decidedly more favorable for agriculture. From the eastern Great Plains eastward, rainfall in most areas since the last extensive drought (1936) has not only been sufficient in most places for current crop needs, but subsoil moisture has largely been restored. There have been no widespread, harmful deficiencies in rainfall as during a number of the years immediately preceding. However, in the normally drier western Plains the reaction to better moisture conditions was delayed until the early part of 1938. In this area precipitation in 1937, while considerably more than during the preceding year, continued much below normal, and droughty conditions remained severe in a wide belt extending northward from the southwestern Plains. Moreover, subsoil moisture is yet far below normal in this area.

AUTUMN OF 1937

The weather during the autumn of 1937 was rather less favorable than in the summer of that year because of the scarcity of moisture in much of the western wheat belt which interfered with seeding and caused germination to be slow and uneven in many places. The deficiencies in moisture centered in the upper Mississippi Valley and northern Great Plains. Otherwise, the autumn weather was generally favorable, and grain crops, for the most part, entered the winter in satisfactory condition. The Eastern and far Western States had above-normal rainfall but some interior areas became decidedly dry.

THE WINTER

The winter of 1937–38 was characterized by more-than-normal warmth throughout practically the entire country. This was in marked contrast to the preceding winter, which was decidedly cold in the Midwestern and far Western States. Precipitation during the winter was unevenly distributed, but, in general, most sections west of the Mississippi River had above normal with relative dryness in Eastern States, especially the Southeast where a large area had only about half the normal rainfall. The Southeastern States, notably Florida, suffered heavy frost damage, especially to winter vegetables; otherwise, there was no extensive harm. In Florida cold weather started earlier than usual, with freezing temperatures reported as far south as Arcadia on November 21; early in December freezing extended as far south as the Lake Okeechobee section. Another freeze occurred in this State late in January, causing widespread damage to tender truck. Thereafter the weather was favorable.

THE SPRING AND SUMMER

With the advent of spring there was widespread, frequent rainfall, which supplied abundant moisture for crop needs rather generally, the season as a whole being characterized by warmth and wetness. In much of the interior, wet soil considerably delayed the planting of crops; cool weather during much of June retarded germination of corn. For the country as a whole it was one of the wettest springs of record, all States having above-normal rainfall, except those occupying a narrow belt in the extreme South from Florida to southern New Mexico, a limited northeastern area, and a few localities in the far West. However, a severe spring drought developed in Florida, which damaged truck and citrus fruit, especially the latter. The drought was broken the last of May, and thereafter, under the influence of abundant moisture, citrus groves improved rapidly, and a heavy June bloom developed. The spring brought considerable damage by freezing to wheat in the southwestern winter wheat belt, the unfavorable results of which, together with the deficiency of moisture during the preceding fall, became more apparent as the season progressed. Also, freezing weather caused considerable damage to fruit in the Central and Eastern States. Otherwise, weather during the spring and early summer continued generally favorable for crops, including small grains, except that during part of June dryness in the Dakotas, where subsoil moisture is still scanty, was rather unfavorable for spring wheat. The weather was outstandingly favorable for grass and hay crops. Widespread showers in the Corn Belt about the middle of July were timely and very helpful, while heavy rainfall in the more eastern States in July largely made up the deficiencies in moisture that had accumulated in these sections. In fact, the heavy July rains did considerable damage, heavy locally, to crops, small bridges, etc., in eastern and southern areas from New England to Texas.

For the period January to July 1938, about 90 percent of the United States had above-normal rainfall. All States reported above-normal rainfall except South Carolina, Georgia, Florida, Louisiana, South Dakota, and Washington. This is a very unusual condition for a period so long as 7 months. As compared with the normal, Nevada was the wettest State, with 157 percent of normal rainfall, followed closely by California, with 154 percent. The relatively driest States were Washington, in the extreme Northwest, and Florida, in the extreme Southeast, with 86 and 87 percent of normal, respectively. In most sections the rainfall during this period compared favorably with that for the same months of 1937, except that the Great Plains this year have had much more rain than during the preceding year.

RECENT DROUGHTS

Droughts of varying severity and extent occur practically every year in some parts of the United States, but, fortunately, they usually are not of such severity or extent as seriously to reduce yields of agricultural products when considered from a national viewpoint. However, at rather long intervals a number of years in succession bring what may be called "families" of droughts. These are more frequent and pronounced in the normally drier sections, such, especially, as the western Plains. Any long-time agricultural program that does not take this weather characteristic into account is inherently weak.

The last extended drought of this character in the United States that is broadly comparable to conditions prevailing from about 1930 to 1936, especially the three bad drought years 1930, 1934, and 1936, occurred in the period cover-

ing the latter part of the 80's up to about the middle of the 90's of the last century. Following this there was a series of years with comparatively abundant rainfall, and the current reaction to much more favorable crop weather suggests very strongly that the recent long drought period has about spent itself and that immediate future years will have more abundant rainfall. However, weather history repeats itself. While the successions of relatively long-time dryness and wetness are irregular and as yet not definitely predictable, should there now develop for several immediate future years a return to abnormally heavy rainfall, such as followed previous drought epochs, in the naturally drier midwest sections, a false optimism that favorable weather will continue indefinitely should be avoided. Long-time rainfall records show that such a condition is abnormal and transient and that future years will bring droughts just as severe as those of the recent past. Therefore, a sensible land-use program must take this all-important, basic fact into account by providing an agriculture adapted to the drier epochs rather than a temporary expedient in cultivation that can "get by" only in the wetter years.

Table 1 shows the percentage of the normal March-August rainfall in the principal grain areas for 14 of the driest seasons and for a like number of the wettest seasons since 1886. Of these 14 dry years, a total of 9 occurred in the 2 extensive drought periods as before indicated, 5 in the period 1886–95, and 4 in the period 1930–36, although one of the outstanding wet seasons, 1892, occurred in the first general dry period, and one relatively wet season, 1935, within the more recent period of drought.

TABLE 1.—*Percentage of normal March–August rainfall in principal grain areas* [1]

Year	Montana	North Dakota	South Dakota	Nebraska	Kansas	Oklahoma	Missouri	Iowa	Minnesota	Wisconsin	Michigan	Illinois	Indiana	Ohio	Kentucky	Weighted average
DRY YEARS																
1936	65	43	50	57	52	44	41	58	64	74	71	55	66	77	72	61
1934	69	53	57	48	55	63	61	65	66	78	76	71	78	77	90	65
1930	75	76	81	107	89	81	55	83	78	83	72	58	60	61	47	75
1910	84	67	68	72	79	72	96	62	53	65	78	83	84	71	110	76
1894	99	89	80	55	70	76	76	58	84	84	90	66	78	68	70	78
1931	61	81	63	70	85	83	88	81	79	76	83	92	97	104	92	79
1889	55	62	82	103	120	86	87	85	74	80	87	92	89	79	78	81
1895	70	111	88	89	112	105	102	92	90	73	67	80	64	61	85	84
1926	76	77	77	77	73	48	84	82	78	103	97	95	106	100	95	84
1886	74	89	91	93	98	46	73	59	102	86	93	90	106	93	103	86
1901	98	114	100	88	75	76	59	69	95	86	95	68	83	97	85	88
1925	99	96	82	89	93	76	83	83	95	89	75	78	84	81	75	88
1887	111	107	122	89	90	70	77	61	89	73	71	69	79	82	72	89
1911	109	98	74	78	72	81	73	74	104	99	95	84	91	95	90	90
WET YEARS																
1915	138	107	140	157	160	153	130	122	108	94	96	125	117	104	105	124
1892	113	116	133	114	113	128	116	139	140	135	121	130	133	118	110	123
1927	133	134	127	111	141	132	150	89	94	92	87	144	132	111	123	121
1902	117	123	105	122	137	110	114	151	118	111	117	127	108	104	80	118
1905	101	117	133	137	111	133	113	115	136	127	121	103	122	115	108	118
1908	137	104	112	122	125	150	117	128	129	80	108	112	105	109	110	117
1903	111	105	109	126	123	93	105	133	127	132	115	100	103	106	90	115
1896	101	131	103	117	113	70	113	128	124	109	109	111	127	119	113	114
1888	125	105	100	113	102	90	108	117	114	114	92	117	107	105	107	111
1906	131	119	120	104	106	128	90	94	121	105	95	85	99	101	102	109
1909	121	111	108	89	103	77	104	114	104	98	106	110	125	118	118	109
1912	119	125	99	88	104	99	108	89	97	118	109	110	131	117	130	109
1898	128	92	80	90	114	128	137	99	95	94	93	131	119	114	112	108
1935	83	124	97	107	101	118	129	102	114	105	98	126	124	110	154	108

[1] Data given in order of weighted averages for all States—dry years, 61 to 90 percent; wet years, 108 to 124 percent.

Table 2 shows the percentage of normal summer (June–August) rainfall for the 11 principal Corn Belt States, grouped as in the other case, by outstandingly dry and wet summers. The importance of rainfall to agriculture is shown by the fact that corn yields for the entire United States averaged 23 percent greater for the 14 wettest summers than for the 14 driest for the 11 principal Corn Belt States alone. This difference of 5.3 bushels per acre, on a recent normal acreage, means nearly 500,000,000 bushels of corn a year in favor of the wet summers.

TABLE 2.—*Percentage of normal summer (June–August) rainfall in 11 Corn Belt States*[1]

DRY YEARS

Year	South Dakota	Nebraska	Kansas	Oklahoma	Missouri	Iowa	Minnesota	Illinois	Indiana	Ohio	Kentucky	Weighted average
1936	42	43	31	30	31	57	52	52	57	77	57	45
1894	66	58	70	49	64	42	43	48	55	54	64	54
1913	78	65	41	56	54	66	108	67	81	88	68	68
1930	74	91	84	68	55	82	71	60	61	57	44	70
1933	69	80	86	102	64	68	59	62	62	70	90	73
1934	74	59	50	59	64	86	79	95	100	95	114	75
1893	62	79	98	111	91	81	77	60	59	73	81	81
1910	70	85	80	78	103	65	54	85	94	68	138	81
1918	100	75	60	70	67	102	88	91	92	81	84	81
1922	107	85	84	72	77	94	66	65	71	90	85	81
1901	126	87	66	56	49	62	107	71	83	96	90	83
1886	86	81	106	61	73	36	90	83	125	91	106	84
1929	70	77	94	72	99	83	62	111	108	106	84	84
1931	63	67	74	80	88	83	86	94	105	112	99	84

WET YEARS

1915	159	164	164	169	163	129	116	165	150	139	136	150
1928	112	106	143	136	158	136	134	134	136	129	160	135
1902	103	144	149	70	133	189	117	161	124	126	76	126
1905	143	132	106	111	127	105	140	110	126	119	118	123
1907	101	109	114	105	111	143	113	146	128	113	115	117
1904	98	122	152	156	134	95	104	111	80	89	76	114
1908	109	147	147	145	103	119	111	82	66	84	92	114
1891	91	158	117	117	121	116	95	99	111	107	119	113
1924	105	100	97	89	135	144	113	143	113	103	91	113
1906	107	89	117	164	105	92	115	90	106	121	123	110
1895	84	99	151	168	134	103	93	103	76	68	95	109
1900	118	106	87	87	103	125	129	117	129	103	114	109
1923	136	123	113	88	100	102	92	99	112	103	118	109
1932	96	102	114	132	113	130	85	120	112	92	111	109

[1] Data given in order of weighted averages for all States—Dry years, 45 to 84 percent; wet years, 109 to 150 percent.

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