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REPORT OF THE CHIEF OF THE WEATHER BUREAU, 1935

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., August 13, 1935.

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, 1935.

Sincerely yours,

W. R. GREGG, *Chief.*

INTRODUCTION

In the last annual report a brief account was given of the action that had been taken in the initiation of a more progressive and forward-looking program in meteorological service, along the lines recommended in a report by the Science Advisory Board. The most important recommendation was that relating to air-mass analysis and its more extensive and detailed use in forecasting. Other recommendations were largely designed to assist in the carrying out of this one. They include training of personnel, an extension of the airplane-observation program, and an increase in the number and greater detail in the character of surface observations. Since no additional funds were provided for the purpose, there was no recourse except to make a modest beginning in the realization of these objectives through reorganization and adjustment of existing service and cooperation with various Government departments and with other agencies. Some progress has resulted, and an account of it will be given in later sections of this report. First, however, it is believed well worth while to comment briefly on the value and the indispensability of cooperation in the organization and maintenance of meteorological service.

COOPERATION A VITAL FACTOR IN METEOROLOGICAL SERVICE

Probably in no other branch of the Federal service is cooperation a more vital factor than in the Weather Bureau. Generally speaking, it is of mutual benefit to the Bureau and to the cooperating agencies. It may be considered under three chief heads, international, governmental, and nongovernmental.

INTERNATIONAL COOPERATION

One of the finest examples of international cooperation and good will exists in connection with the science of meteorology. For more than 60 years the directors of national meteorological services have been meeting regularly to exchange ideas and information, and especially to secure harmony and standardization in important fields where otherwise effective cooperation would be impossible. Meteorology is essentially world-wide in its scope. No country, however large its geographic area, is of sufficient size to be independent of other countries in providing its people with an adequate weather service.

The history of government-supported meteorological organizations covers a period of about 75 years. Institutions concerned in some degree with meteorology existed earlier, but they had no official status. Several conferences of officials affiliated with government meteorological services were held in Europe in the early seventies, but a permanent organization was first effected at Rome

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

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in 1879. At the present time, there are 105 meteorological or closely related scientific services organized through their directors into what is known as the "International Meteorological Organization." Actually, only 54 countries are represented owing to the fact that in some instances several organizations operate independently of each other, although supported by the same government. The International Meteorological Organization is subdivided into commissions, each under the direction of a president. These subcommissions deal with more or less distinctive phases of meteorological work. Only directors can be members of the major organization, but the subcommissions are composed of an unlimited number of technical employees of the national services and a few outstanding scientists who have no official affiliations. Membership in the subcommissions, each of which includes one or more directors, now totals about 260 persons.

The International Meteorological Organization is wholly voluntary and is devoid of control by national treaties or conventions. Its recommendations are expressed in the form of resolutions, adherence to which is only a moral obligation. Meetings are held sexennially. This year (1935) the regular sexennial meeting will be held at Warsaw, Poland. Subcommissions meet as frequently as circumstances warrant, usually every 2 or 3 years. Most of them will meet this year at Danzig or Warsaw in September and, according to custom, just prior to the major meeting. The representatives from the United States Weather Bureau will be the Chief of the Weather Bureau and the Chief of the Division of Climate and Crop Weather.

Details of the cooperation accomplished through the International Meteorological Organization and its subcommissions are too numerous to be specified and described here. At the last sexennial meeting, held in 1929 at Copenhagen, 109 resolutions were adopted, covering a wide range of activities. Although many of them did not directly concern the United States Weather Bureau, all had international cooperative aspects and some of them were of great importance to every national service.

Exchange of observations is the most important feature of international cooperation. This is effected principally by radio, but cable and telephone are employed in some instances. Collateral features of the exchange are internationally standardized definitions, codes, etc., without which intelligent application of the data would be impossible. Cooperation with Canada is most complete. From a meteorological standpoint, there is no boundary line. Most Canadian reports are received at United States forecast centers as promptly as at Toronto and, similarly, observations made at United States stations are as promptly sent to Toronto. Exchange arrangements also exist with Mexico, the Philippines, and the Far East, and with the several independent meteorological organizations in the West Indies.

Twice each day, at 11 a. m. and 11 p. m., eastern standard time, bulletins are transmitted by radio directly from the Weather Bureau Office in Washington through the Navy radio stations at Arlington and Annapolis for the benefit of European meteorological services. These bulletins contain about 100 reports representative of weather conditions in North America and reports from ships in the western Atlantic. Correspondingly, twice daily, about 5 a. m. and 5 p. m., eastern standard time, bulletins containing about 100 European land-station observations and reports from ships in the eastern Atlantic are broadcast from the powerful Rugby station in England for the benefit of meteorological services in North America. These bulletins are copied at United States Navy radio stations and are made available immediately to the Weather Bureau.

COOPERATION WITH OTHER GOVERNMENT BUREAUS AND DEPARTMENTS

Every possible effort is made to take full advantage of the facilities of all agencies of the Government in securing and transmitting weather observations from both land and sea. In return, forecasts and warnings based on these data and on the Weather Bureau's own far-flung network of reporting stations are made available to those organizations.

DEPARTMENT OF AGRICULTURE

The bureaus in the Department of Agriculture with which cooperation is most extensive are the Forest Service, Office of Experiment Stations, Agricultural Economics, and Agricultural Engineering.

The forest fire-weather-warning service is one of the most active projects of the Weather Bureau. Its primary purpose is to issue weather forecasts for the large forested areas of the country during the season of fire hazard and especially to warn of weather conditions which favor the inception and spread of forest fires. For this purpose daily observations of weather conditions in the forests themselves are required. Meteorological stations, equipped with necessary instruments, are established therein. There are at present nearly 700 stations of this class. Employees of the Forest Service, State forestry services, and in some instances private owners of large tracts, mostly at lookout and ranger stations, serve as observers. They forward the reports by telegraph or telephone to the Weather Bureau offices from which the fire-weather warnings are issued.

In California there is a unique form of cooperation by the Forest Service in supplying a truck equipped with radio and meteorological apparatus for the use of the Weather Bureau in visiting large fires and furnishing weather reports and forecasts directly to those who direct the work of fighting the fires and preventing their spread. This subject is presented more fully later.

Lightning causes more fires in the forests of the far Western States than any other single agency. Forecasting of lightning storms is of great importance in enabling those charged with protection of the forests to make preparations for combating such fires as they occur. Study of lightning statistics with the general weather conditions accompanying thunderstorms is essential to successful forecasting. Lookouts, rangers, and other forestry employees record lightning occurrences at several hundred places in the forests and make them available to the Weather Bureau for study.

The Forest Service cooperates very actively also in the measurement of snow depth in the mountainous sections of the western part of the United States. This is a project of considerable difficulty, and the cost of establishing special stations at high levels would be very large. Many of the measurements are made by forest rangers as a part of their regular duties without any appreciable additional cost to the Government.

The Office of Experiment Stations cooperates chiefly by providing weather observations that are made by its field personnel and transmitted to the Weather Bureau for use in its weather and crop service. The observations are made daily and are summarized each week as a basis for the Weekly Weather and Crop Bulletin which makes possible a running appraisal of the development of crops as influenced by weather conditions.

Cooperation is maintained also with the Bureau of Agricultural Economics in its crop-reporting work. Information as to current and past weather conditions as affecting growing crops and farm operations, collected through the Weather Bureau's extensive network of weather-crop observers and correspondents, is furnished at frequent intervals for use in the preparation of the regular monthly crop-condition report issued by the Crop Reporting Board. In some cases weekly weather and crop bulletins are issued jointly by the Weather Bureau and the State statisticians' offices of the Bureau of Agricultural Economics.

Active cooperation with the Bureau of Agricultural Engineering is of comparatively recent date. Under the terms of an agreement entered into by the two Bureaus and approved by the Secretary of Agriculture, the Weather Bureau will make available to the Bureau of Agricultural Engineering such mountain snowfall data and general run-off forecasts as that Bureau may need in providing more detailed forecasts for specific irrigations projects. On its part the Bureau of Agricultural Engineering will furnish promptly to the Weather Bureau all data that it collects. These, together with records obtained by other agencies, will be published by the Weather Bureau as heretofore. Moreover, the two Bureaus will cooperate in the development of new equipment and methods of measurement and in other investigations in this very important project.

WAR DEPARTMENT

The War Department cooperates with the Weather Bureau in a very complete way, chiefly through its Signal Corps, Air Corps, and Engineer Corps.

Meteorological observations are virtually useless in current service unless immediately transmitted to a wide network of stations where they can be promptly charted, analyzed, and issued in the form of bulletins and forecasts. While this is taken care of in considerable part through contract with commercial companies, there are some regions where such facilities are lacking

and in these cases the radio stations of the Signal Corps transmit weather observations regularly and promptly for use either locally or to the United States for inclusion in the Weather Bureau's general system of reports. For example, from 2 to 6 observations are made daily at 15 places in Alaska where Signal Corps radio stations are located. These reports are utilized in connection with the weather information and forecasts furnished by the Weather Bureau for airway operations in that Territory. Reports from 10 of the stations are transmitted twice daily to Seattle for distribution to Weather Bureau offices in the States. Again, weather bulletins containing observations taken at meteorological stations in Mexico and broadcast twice daily from Chapultepec, near Mexico City, are copied by the Signal Corps station at Marsh Field, Calif., and are made available to the Weather Bureau for distribution to its forecast centers and airway stations in the western part of the United States.

The Signal Corps cooperates also in providing upper-wind data from pilot-balloon soundings made at a number of military flying fields. These observations are used by the Weather Bureau to supplement its own. The cooperation in this case is not one-sided, as the meteorological service of the Signal Corps is similarly supplied with the complete network of Weather Bureau reports, both surface and upper air, in connection with the issuance of forecasts and warnings for purely military purposes.

A notable advance in cooperation was accomplished during the past year in connection with the organization of a country-wide network of airplane-observational stations. One of the participants in this program is the Air Corps. At eight of its flying fields daily flights are made, weather permitting, to a height of approximately 17,000 feet. A more extended account of the work is given later. The cost of a commercially operated station of this type is about $10,000 per year, whereas the cost to the Air Corps is very slight, since pilots and equipment are already available and the flights are made as a part of the pilots' training.

The Engineer Corps cooperates with the Weather Bureau in connection with its river and flood service. Readings are made of river stages at about 100 of its river gages, and these are made immediately available for use in daily forecasts of all principal rivers throughout the country. These are of special value at times of floods. The Weather Bureau likewise furnishes its own data to the Engineer Corps as an aid in its operations.

NAVY DEPARTMENT

Cooperation with the Navy Department is similar, in many respects, to that with the War Department. Upper-air data of wind direction and velocity are secured at a number of pilot-balloon stations at flying fields of the Bureau of Aeronautics and transmitted to the Weather Bureau. Moreover, at eight of these fields daily airplane flights are made as a part of the Bureau's regular aerological program. In addition, frequent airplane observations are made from naval vessels in coastal waters and transmitted promptly to the Weather Bureau.

The Office of Communications provides cooperation of outstanding value and importance, both in the collection of surface reports transmitted from naval and commercial ships, and in the dissemination of bulletins and forecasts to marine interests, to foreign countries, and to the public generally. Only a brief summary can be given here.

About 10,000 observations from ships at sea are collected each year by naval radio stations.

Mexican and Central American reports are transmitted by the radio station of the Pan American Airways Co. at Brownsville, Tex., to the naval radio station at Pensacola, Fla., and thence by the latter to the Weather Bureau at Washington. This is a twice-daily service.

Observations are made at naval radio stations at 4 isolated places, 1 in Alaska, 2 in the Pacific, and 1 in Cuba, and transmitted to designated Weather Bureau offices in the States.

Observations taken in far eastern areas (China, Japan, Philippines, etc.) are collected at Manila and transmitted daily by naval radio to the Weather Bureau offices at San Francisco and Washington. The U. S. S. *Houston*, operating in the Far East, collects weather reports by copying weather bulletins broadcast from stations and from ships in those waters. These reports are also repeated to the Weather Bureau offices in San Francisco and Washington.

Similarly the naval radio station at Dutch Harbor, Alaska, copies weather reports broadcast from radio stations in eastern Siberia and transmits them to Weather Bureau offices in Seattle, San Francisco, Juneau, and Washington.

Without such cooperation, it would be difficult or impossible to obtain highly valuable reports from these distant or isolated areas.

Extensive broadcasts of weather information from the United States, Alaska, Canada, West Indies, and from ships are made two or more times daily for the benefit of marine, agricultural, and aviation interests. The broadcasts include forecasts and warnings. Some 25 naval stations participate in this program, but the most extensive bulletins are those broadcast from Washington (NAA and NSS) and San Francisco (NPG) by remote control directly from the Weather Bureau offices. These two bulletins give data in such completeness as to enable vessel masters to prepare weather maps on shipboard.

An important feature of the Weather Bureau's work in ocean meteorology is its statistical section. Weather observations are made on large numbers of ships of all nations. These are entered on standard forms and sent by mail to the central office at Washington, where they are summarized and the results turned over to the Hydrographic Office for publication on pilot charts and in pilot books. The main items of information are the average wind direction and force; average barometric pressure and tracks of storms; summaries of fog conditions; and, more recently, special summaries in great detail, applicable to the planning and conduct of ocean aviation.

TREASURY DEPARTMENT

The Coast Guard cooperates very effectively and extensively with the Weather Bureau in several ways. At about 50 life-saving stations storm warnings are displayed, whenever issued by the Bureau. These displays consist of flags by day and lights at night.

Weather observations are made by employees at numerous life-saving stations on the Atlantic and Gulf coasts and on the Great Lakes and transmitted to Weather Bureau offices over Coast Guard telephone lines and by radio. This cooperation is of inestimable value in connection with the issuance of hurricane warnings. For the most part the Coast Guard stations are located at isolated places on the coast from which observations are especially needed and from which reports, especially of tides and swells, could not otherwise be obtained.

The Coast Guard cooperates also during the ice-patrol season, by furnishing observations from its cutters, including in recent years upper air wind data from pilot-balloon soundings.

DEPARTMENT OF COMMERCE

Cooperation with the Department of Commerce is provided chiefly by the Bureau of Air Commerce, the National Bureau of Standards, and the Bureau of Lighthouses.

The Bureau of Air Commerce has organized an extensive system of communications, both radio and teletype, along all of the principal airways in the country. At numerous points on these airways where it is necessary to have weather observations made, although there is no need for the assignment of highly trained meteorologists, employees of the Bureau of Air Commerce make the observations and transmit them to Weather Bureau offices. Reciprocally, at points where meteorologists are assigned they assume the duty of operating the communications facilities, including in many cases the broadcasting of weather reports and forecasts. A great advance has been made during the past year in this cooperation which is now close and effective and altogether eliminates unnecessary duplication of personnel and cost throughout the airway service.

The National Bureau of Standards provides valuable cooperation in the calibration of Weather Bureau equipment, the facilities of the wind tunnel being made available for this purpose. That Bureau also furnishes material aid in testing supplies of various sorts, to determine whether or not they meet the specifications set up in securing bids.

Cooperation with the Bureau of Lighthouses is similar to that with the Coast Guard. At 17 lighthouses storm signals—flags by day and lights at night—are displayed whenever received from the Weather Bureau.

POST OFFICE DEPARTMENT

Forecasts are telegraphed each week day to postmasters who are supplied with a simple stamping outfit composed of rubber type. The forecasts are stamped on addressed cards and distributed by mail in the nearby territory. In other cases the forecasts are posted in the post offices or are given out on telephone call.

DEPARTMENT OF THE INTERIOR

The Geological Survey and the Weather Bureau both maintain river gages. In the last 2 years a successful effort has been made by these two services to coordinate the work in a way that will prevent overlapping and will make it possible to use the same gages at approximately 60 stations, thereby decreasing the cost of installation and maintenance and giving an improved service. The Geological Survey is interested largely in the amount of water available for consumptive use, while the particular interest of the Weather Bureau is in forecasting river stages from day to day and issuing flood warnings. The objectives are different, but the basic data necessary in obtaining them are the same. A large number of the common gages are checked and repaired by the Geological Survey, the Weather Bureau paying the salaries of the observers. Also, the Survey furnishes this Bureau with rating curves and is in turn furnished telegraphic reports of heavy rains which enable the engineers to reach isolated streams promptly in order that they may make observations of flood run-off.

Other cooperating agencies of this Department are the Bureau of Reclamation, the Bureau of Indian Affairs, and the National Parks Service, all of which furnish daily, and at times more frequently, observations during the season of fire hazard in forested regions. Equipment is furnished by the Weather Bureau. The observations are useful in supplementing the Bureau's own data as a basis for fire-weather forecasts.

The Geological Survey and the Bureau of Reclamation also make evaporation measurements for the Weather Bureau at some of their stations in arid and semiarid regions.

COOPERATION WITH NONGOVERNMENTAL AGENCIES

It is quite out of the question to give anything like a complete account of the cooperation that the Bureau receives from thousands of individuals and hundreds of organizations of various kinds. Effort will be made merely to list some of the outstanding cases.

Data of high statistical value are provided in observations made at about 4,500 stations throughout the United States and its possessions. In some cases the cooperating agency is a commercial firm, a railroad, a power company, an agricultural college, or a university, but for the most part the observers are individuals whose only compensation is the assurance that they are contributing to a most worthy project, that of making possible an accurate appraisal of the climatic characteristics of all parts of the country.

Of the same type is the cooperation received from the masters of vessels of every maritime nation, whose observations, when summarized, likewise define the climate of the seas. Some 1,300 ships participate in this program.

More recently the upper air is receiving attention, and we have a constantly enlarging cooperation from air-transport companies which furnish, chiefly through their pilots, highly valuable information regarding weather conditions encountered in their flights.

More than 350 commercial radiophone stations throughout the country provide a valuable service in broadcasting forecasts and other information without cost to the Government. These radio broadcasts and the newspapers constitute the most extensive and effective method of distributing forecasts and warnings. Many millions of people are reached through these agencies.

MONETARY VALUE OF COOPERATION

It is impossible to give even an approximate estimate of the cost saved to the Government through the utilization by the Weather Bureau of the facilities of other bureaus and departments and through outright cooperation by individuals and organizations outside of the Government. The figure would be well up in the millions. For instance, the cost of operating the 4,500 cooperative

climatological stations, if the observers were paid only $5 per month, would be $270,000 per year.

The observations made by the personnel of the Bureau of Air Commerce along the airways as a part of their regular duties would cost approximately $500,000 each year, if observers were employed for that service.

The cooperation of the War and Navy Departments in the airplane-observational program saves in the neighborhood of $150,000 per year.

Although other cases of cooperation outlined in this report would individually yield smaller savings than those cited, the total would be impressive. Cooperation yields many other benefits, however, in addition to the financial. It is more vital to the efficient organization and maintenance of meteorological service than is the case with any other public endeavor. It will be broadened and extended still further as circumstances warrant.

WEATHER OF 1935 MORE FAVORABLE THAN 1934

The severe and unprecedented drought of 1934, which seriously affected agriculture in the United States, did not carry over to an appreciable extent into the 1935 crop-growing season. Following the extremely hot, dry summer of last year, the fall months brought timely rains which produced soil moisture sufficient to permit the seeding and to promote the early growth of winter grains in practically all sections from the Great Plains eastward, except in the southwestern Plains where moisture continued insufficient.

In the western mountains, the winter months had much heavier snowfall than during the preceding winter, assuring a better water supply for irrigation than was available for the summer of 1934. Thus, except in the southwestern Plains, the crop-growing season of 1935 began under much more favorable conditions than that of 1934. The Southwest, comprising principally southwestern Nebraska, western Kansas, southeastern Colorado, western Oklahoma, northwestern Texas, and northeastern New Mexico, continued extremely dry till about the middle of May when heavy rainfall relieved the situation. Previous to the rains, there was in this area extensive and very destructive soil drifting by wind action, and the most severe, frequent, and widespread dust storms ever experienced in this country occurred. Rainfall had been deficient for a long time, and the soil became extremely dry, thus facilitating drifting and dustiness with any appreciable wind movement. On several occasions during March and April considerable dust was carried through the atmosphere as far east as the Atlantic coast.

During the spring months, moisture, as a rule, was ample over nearly all the principal agricultural areas of the country. In fact, frequent heavy rainfall kept the soil entirely too wet over large areas of the central valleys which seriously delayed spring plantings in many sections. In addition, abnormally cool weather retarded germination and growth, further contributing to the lateness of the spring-planted crops. Damaging floods occurred in some places, especially over a belt extending from the lower Ohio Valley westward to southwestern Nebraska and eastern Colorado; many hundreds of thousands of acres of bottomland crops were destroyed. However, over most of the Midwest, where severe drought prevailed in 1934, the generous rainfall of the spring of 1935 was very favorable, especially in the central and northern Great Plains, and in general the weather was much more favorable than during the preceding year. By the beginning of summer the effect of the 1934 drought had largely disappeared, fewer than normal agricultural localities being in need of moisture. However, July was extremely warm, and precipitation was scanty in many sections of the country, with the result that, by the close of that month droughty conditions had become reestablished over large areas of the Great Plains and Rocky Mountain States, being especially severe in the southern plains.

Rainfall for the first half of 1935 (January–June) was in marked contrast to that of 1934. For the country as a whole, the 1934 percentage of normal for this period was 79 and the 1935 average 109 percent of normal. Table 1 shows, by State averages, the percentage of normal precipitation for the several States for the first half of 1935, and also the percentages of the 1935 averages as related to those of 1934 as a base.

TABLE 1.—*Precipitation by States, January–June 1935*

State	Percentage of normal	1935 compared with 1934	State	Percentage of normal	1935 compared with 1934
	Percent	*Percent*		*Percent*	*Percent*
Alabama	97	103	Nevada	112	168
Arizona	146	242	New England	106	99
Arkansas	145	180	New Jersey	81	86
California	106	197	New Mexico	108	167
Colorado	110	164	New York	94	108
Florida	79	59	North Carolina	89	87
Georgia	84	80	North Dakota	104	202
Idaho	87	106	Ohio	94	155
Illinois	130	242	Oklahoma	132	181
Indiana	111	199	Oregon	84	109
Iowa	113	219	Pennsylvania	86	114
Kansas	120	179	South Carolina	71	70
Kentucky	148	211	South Dakota	104	195
Louisiana	118	106	Tennessee	117	131
Maryland and Delaware	109	110	Texas	130	140
Michigan	91	148	Utah	106	187
Minnesota	104	165	Virginia	112	114
Mississippi	113	127	Washington	100	108
Missouri	144	249	West Virginia	120	159
Montana	78	103	Wisconsin	98	140
Nebraska	123	230	Wyoming	105	146

STUDIES IN AIR-MASS ANALYSIS AND ITS PRACTICAL APPLICATIONS

The Weather Bureau, if it would not fall hopelessly behind similar institutions elsewhere, must keep informed of every increase in our knowledge of scientific or theoretical meteorology, a requirement that entails continuous and extensive reading and study. It is equally imperative that this Bureau itself also make additions to our understanding of atmospheric and weather phenomena. Finally, the Weather Bureau must keep fully informed of all meteorological arts—all applications of the science of meteorology to practical needs of every kind, in planting, harvesting, shipping, from protection, forest-fire warnings, flood warnings, and the thousand and one other things, great and small, that affect our prosperity, our comfort, and our health. Such of these arts as would benefit this country the Weather Bureau must and does adopt and then, if need be, adapts them to our own conditions.

One of the most conspicuous and useful services of meteorology is that of forecasting the weather. The common method of making these forecasts is to picture symbolically on a map the existing weather at a given instant over a greater or less territory, and then to deduce from this synoptic map what the weather will be at various places during a specified coming period, such as 12, 24, or 36 hours from the time the charted observations were made. Until recent years the only map of this kind in common use consisted essentially of isobars (lines of equal pressure, reduced to sea level), isotherms (lines of equal atmospheric temperature near the surface), and symbols for cloudiness, wind direction and velocity, and such other weather facts as might be available and helpful to the weather forecaster. All the time, however, it was recognized that while some weather changes are home-made, by local heating and cooling, most of them are owing, mainly, to the replacement at a given locality of air in one condition by air of some other condition, and to the interactions of these different masses of air with each other. Clearly, then, a synoptic map giving the boundaries, or fronts, of the different masses of air over a given large territory, together with the states and conditions of these masses and the directions and speeds of their movements, also could be used, like the isobaric maps, in forecasting the coming weather. It is not obvious, however, from which of the two synoptic maps, the isobaric or the frontal, one could most clearly foresee the coming weather. Presumably some combination of the two, such as the one which for years has been evolving at the Weather Bureau, would be better than is either alone.

But what would be the best combination that at the same time is practicable, that does not require data too expensive to obtain, and that can be so quickly mapped as to insure a well-considered forecast very soon after the observations on which it is based were made? This important question the Bureau is trying

to answer as speedily as may be consistent with caution. To this end three young men, highly trained in the technique of constructing synoptic frontal maps, are making such charts at the central office of the Weather Bureau from both the morning and the evening observation for the entire United States and adjacent territory. These charts are the subjects of four round-table discussions every week with those of the Bureau's staff who are engaged in actual forecasting, and a few others who, though not forecasters, are familiar with the underlying theories. Much benefit has resulted to all concerned from these free discussions, and frankly searching, though always constructive, criticisms.

Work in this line is progressing. A reasonably successful system of forecasting must not be altered unless and until it is doubly certain that the proposed alteration is really an improvement. But immediately an improvement is clearly demonstrated the means of making it effective must and will be found.

AIRPLANE OBSERVATIONS AND THEIR USE IN FORECASTING

In 1931 airplanes were substituted for kites. The number of upper-air observations by airplanes available to the forecaster was increased to 25 within the last 2 years. These observational data have been employed in diagnosing the vertical extent and structure of the cold- and warm-air masses that cause and maintain our cyclonic and anticyclonic systems. Temperature-height graphs are prepared daily at each of the district forecast centers for all of the airplane stations received. At each point of inflection of the temperature curve, readings of relative humidity are entered. From these graphs it can readily be seen where the humidities at the usual cloud and precipitation levels are increasing and what the temperature lapse rates are in such regions.

In addition, they permit an estimate of the slope of the frontal surfaces which separate the air masses. Information of this kind with the aid of the pilot-balloon data, which consist of wind velocities and directions, aids the forecaster in determining when and where precipitation will occur.

At present it is universally recognized that any appreciable precipitation is caused by the lifting of air masses, which results in decrease in temperature. If this lifting and resultant decrease of temperature are carried far enough, precipitation will ensue. The problem is to tell just how far this lifting will be carried. It may be brought about by frontal action either along the cold front or warm front, by thermal convection, where no front is involved, or by orographic action. To assist in determining this question in the particular case, vertical cross sections of specific humidity and potential temperature can be drawn. Graphs in the form of adiabatic charts, tephigrams, and emagrams can all be prepared from data obtained from airplane ascents. From several of these, but probably more readily from the emagram, can be determined the amount of frontal lifting required to produce precipitation. If no fronts are present, the probable maximum temperature for the afternoon may be determined from the emagram, which indicates how much afternoon heating will be needed to cause instability and thunderstorms. In fact we may say that data obtained from the airplane observations are enabling us to tell more positively whether or not precipitation will occur and to evaluate more definitely the physical causes which operate to bring it about.

CONSOLIDATION OF METEOROLOGICAL AND COMMUNICATION ACTIVITIES AT AIRPORT STATIONS

During the past year the Weather Bureau and the Bureau of Air Commerce mutually agreed to combine the meteorological and communication activities at airports wherever practicable with a view to improving efficiency and effecting all possible economies. Arrangements were made to combine the services at the following 35 airports:

Abilene, Tex.
Albuquerque, N. Mex.
Amarillo, Tex.
Bellefonte, Pa.
Big Spring, Tex.
Boise, Idaho
Boston, Mass.
Buffalo, N. Y.
Charleston, S. C.
Cincinnati, Ohio
Columbus, Ohio
Detroit, Mich.
Elko, Nev.
Fresno, Calif.
Greensboro, N. C.
Indianapolis, Ind.
Jackson, Miss.
Kingman, Ariz.
Kylertown, Pa.
Medford, Oreg.
Memphis, Tenn.
Moline, Ill.
Murfreesboro, Tenn.
North Platte, Nebr.
Oklahoma City, Okla.
Pasco, Wash.
Pendleton, Oreg.
Phoenix, Ariz.
Reno, Nev.
Richmond, Va.
Rock Springs, Wyo.
San Diego, Calif.
Spartanburg, S. C.
Wichita, Kans.
Winslow, Ariz.

At large centers where weather maps and meteorological personnel were needed to render a specialized service, the Weather Bureau personnel was retained and the Bureau of Air Commerce personnel reduced. Under this arrangement the Weather Bureau personnel is now engaged to a considerable extent in communication work. At other airports, where the demand for weather maps and meteorological advice was not great, the Weather Bureau personnel was withdrawn. The pilot-balloon work was moved to the Weather Bureau office in the city, or to some nearby point, and the surface weather observations were turned over to the Bureau of Air Commerce personnel. The consolidation made it possible for the Weather Bureau materially to strengthen its service at the 10 airway forecast centers by providing the personnel and assignment of forecasters for 24-hour daily service. The arrangement permitted the Bureau of Air Commerce to extend its network of communications to other airways over which service had not been provided. The meteorological and communication services at important airports are now on a practicable and efficient basis, and duplication of effort has been eliminated.

THE VALUE OF FOUR MAPS A DAY IN THE AIRWAY SERVICE

For a number of years the Weather Bureau has recognized the need of improving the general weather service by the issuance of four maps a day. The cost, although relatively not large, has prevented the inauguration of the service because of the limited funds available. The framework for such a service was laid during the past year through reorganization of service for airways. The consolidation of meteorological and communication activities with the elimination of the airway sectional maps, which covered 4-hour periods, and their transmission as such by teletype, made this beginning possible. Some of the savings in funds which resulted from the reorganization were used in providing a few additional reports, and with increased time available on Bureau of Air Commerce teletype circuits, more complete meteorological data were transmitted for the preparation and analysis of Nation-wide maps at airport stations, covering a 6-hour period.

The 8 a. m. and 8 p. m. maps, prepared at airport stations from the regular collection of Weather Bureau signals, cover an area from Honolulu to Bermuda and from northern Alaska to southern Mexico. The 2 a. m. and 2 p. m. maps are prepared from selected airway sequence reports and off-airway station reports which cover the entire United States.

Weather maps on a 6-hour basis can be used more advantageously than on any other time basis. Many years ago it was recognized by meteorologists that the time interval between weather maps should be equal and that the basic observations should be taken at the same time at all stations day after day. This was the basis for the original establishment of 8 a. m. and 8 p. m., eastern standard time, observations and weather maps.

It was recognized from the beginning that more frequent maps were needed for the intensive service which aviation demanded. In 1929 the sectional 3-hour weather maps were inaugurated, but it was apparent that the area covered by these maps was not as extensive as it should be. A change was made in 1932 to 4-hourly airway sectional maps covering increased area. These also were too limited and had a further disadvantage in that the period was an odd multiple of the 12-hour basic period. The recent change to 6-hour maps reduced the disadvantages heretofore experienced. Moreover the 6-hour maps coincide in time with the maps prepared by a number of foreign meteorological services and will later permit the exchange of reports with other countries when funds are provided for placing the general weather service of the Bureau on a 6-hour basis.

This service for airways was inaugurated on May 1, 1935. Forecasts are issued four times a day covering a period of 8 hours in advance. When conditions warrant, special forecasts are issued between the 6-hour periods, based on 3-hour intermediate sectional maps which are prepared from the network of airway reports. The present plan is the most efficient yet devised and has some distinct meteorological advantages which no other timed system possesses.

UNIFORM PROCEDURE IN PREPARING MANUSCRIPT MAPS

On March 1, 1935, standardized procedures for drawing manuscript maps at all Weather Bureau offices and airport stations were put into effect. Uniformity in the use of symbols and other entries on maps and in drawing

isograms is secured by this standardization, which is valuable for many reasons, but chiefly to aviators and others who have occasion to examine maps at different offices of the Bureau and also for the Bureau's own employees who are transferred from one field station to another. The symbols adopted by the Bureau were made to conform as nearly as practicable to international usage.

REORGANIZATION OF THE HURRICANE-WARNING SERVICE

For many years prior to July 1, 1935, the hurricane-warning service of the Weather Bureau was centered at Washington. Radio weather reports from ships in the areas frequented by hurricanes and meteorological observations from island and coastal stations in those areas were collected at Washington only. The reports were charted and advisory and warning messages were distributed from the Washington center for the benefit of shipping and residents of island and coastal communities. This is one of the most important services of the Bureau. It has been instrumental in saving many human lives and millions of dollars' worth of property.

Owing to the cost of repeating the observations to Weather Bureau offices on the South Atlantic and Gulf coasts, it was necessary to confine the information provided those offices for public service to 2 or 3 daily telegrams containing brief statements as to the location, intensity, and probable movement of the storm with notification of such warnings as were indicated by the reports collected. Personnel and facilities were inadequate for a continuous operation of the service for 24 hours each day. There was a hiatus between the daily 8 p. m., eastern standard time collection of reports and the collection 12 hours later. During this 12-hour period tropical storms sometimes progressed rapidly, which made it difficult in some instances to collect observations at a center far removed from the storm zone and to distribute timely warnings to the threatened areas.

Funds in the amount of $80,000 were provided the Weather Bureau in the agricultural appropriation bill for reorganization and extension of the hurricane-warning service. Plans for the new form of service were prepared so that promptly on July 1, 1935, a special teletype system was set up by the Bureau to connect 10 stations on the coast with the new hurricane-forecast centers at Jacksonville, Fla., and New Orleans, La. Daily collection of land-station reports and observations by radio from ships in the region frequented by hurricanes will be transmitted over this teletype circuit. When tropical storms are in progress, additional observations at 6-hour intervals or oftener, if necessary, will be furnished to the teletype system with personnel on duty continuously 24 hours each day. This system enables the two forecast centers to receive reports and issue warnings with the dispatch that is possible only with direct communication service operated exclusively for that purpose. A superior information and warning service in connection with hurricanes is now available to the public in the areas served by Weather Bureau offices in the coastal sections of the South Atlantic and Gulf States.

Another hurricane forecast center will be located at San Juan, P. R. The areas to be served by the three centers are:

San Juan: Caribbean Sea and islands east of longitude 75° W. and south of latitude 20° N.

New Orleans: That portion of the Gulf of Mexico and its coast west of longitude 85° W.

Jacksonville: Remaining portions of the Atlantic coast, Caribbean Sea, and Gulf of Mexico areas, and islands and coasts south of latitude 35° N.

Warnings for the Atlantic coast north of latitude 35° N. will continue to be issued from Washington.

Incidental to the hurricane-warning-service reorganization, a new forecast center has been established at Jacksonville for North Carolina, South Carolina, Georgia, and Florida (except the extreme northwest portion) and ocean areas contiguous thereto.

POSSIBLE REFINEMENT OF FLOOD FORECASTING THROUGH THE USE OF RECORDING INSTRUMENTS

A flood is produced naturally in a primary drainage basin by the continued falling of rain or melting of snow at a rate greater than the maximum rate at which water can be discharged from the basin. In the United States a flood

caused by snow alone is rare, and the forecasting of floods caused by rain falling on a snow mantle cannot be reduced to a formula. This discussion, therefore, will be confined to those floods caused solely by rain, and will be applicable only to primary basins in which the short time between the fall of heavy rain and the occurrence of the resulting flood makes it necessary to base forecasts more on rainfall data than on upstream river gage readings.

The season of the year, the preceding weather, and the drainage basin's topography, geology, and vegetal mantle are essential factors that must be considered in flood forecasting. Assuming that these data are all available and have been given proper places and weights in a formula, there still remains to be obtained the most important factor of all, namely, the hourly amounts of rainfall. This is not available in a complete form under the present system. The total amount and the approximate period in which the rain fell are readily obtained. The forecaster knows, for instance, that 2 inches fell in less than 12 or 18 hours, but he does not know that 80 percent of it fell in 2 hours, and that light showers occurred during the remainder of the period. This is a handicap, but in spite of it valuable flood forecasts are being made and are the means of saving human lives and property. Frequently these forecasts do not give the exact height of the crest and the hour of its occurrence, but they are sufficiently definite to enable the inhabitants of the threatened area to take the precautions necessary to protect their lives and property. The forecaster knows, however, that, given hourly amounts of rainfall for coordination with the continuous records of river stages now being made available through the recent cooperative and constructive work of the Weather Bureau and the Geological Survey, he could evolve formulas that would enable him materially to refine his flood forecasts. He could predict with considerable assurance and definiteness both the height and the time of the flood's crest, instead of expressing his forecasts in rather general language.

Continuous records of river stages are being obtained from recording stations constructed in the last 2 years with funds allotted by the Public Works Administration, and a similar advance in strengthening the method of measuring rainfall would not only make possible the refinement of flood forecasts in primary drainage basins but would also be of inestimable value in agriculture, soil conservation, and all branches of hydraulic engineering. The needs of the flood forecaster alone seem not to have had enough weight to bring about the installation of the required number of recording rain gages, but in the last few years other users of rainfall data have, individually and through their various organizations, been making insistent demands and endeavoring to provide means for the establishment of a network of these gages. The Weather Bureau, therefore, is hopeful that in the near future its flood forecasters may have available enough additional rainfall information to enable them to give to the residents of a threatened valley the exact height and time of arrival of a coming flood.

SOME RESULTS OF WORK IN MARINE METEOROLOGY

Further noteworthy improvement in accuracy of ships' meteorological instruments and reports was brought about during the year as a result of a program for critical review of mail returns, attended by numerous inspections and tests of instruments. In many cases shipping companies generously provided replacements for instruments found inaccurate, and the faithful efforts of ships' officers observing and reporting weather at sea were thereby made more effective.

Special research was pursued during the year along two lines. Files of ocean-weather observations were in part reexamined from the point of view of the needs of overseas aviation. Water-temperature investigations were continued and broadened.

All available data for an immense area in the tropical Pacific were intensively studied, and definite advances in our knowledge of the climate and meteorology of this hitherto obscure ocean region were obtained. The knowledge will bear upon prospective development of trans-Pacific air routes to the Philippines and Australia. Much work in this field remains to be done.

In water-temperature research special attention was devoted to testing the hypothesis, held in some quarters, that the variations in sea-surface temperatures along the Gulf Stream and at its origins in the Caribbean Sea can be made a practical basis for forecasting the weather of succeeding months over the eastern part of the United States. Mathematical correlation methods rigorously applied to this problem have so far brought mostly negative conclusions.

However, these studies are gradually laying a foundation for approach to the question whether, over longer periods of time running to several years or more

in length, there may not be found cycles of sea-surface temperature variation of relatively small size but perhaps important as an influence upon some of the long-term aspects of our weather history, such as the drought of 1934. This is an ultimate objective of the water-temperature researches, which are being continued.

THE FIRE-WEATHER SERVICE

The fire-weather service, to which previous reference has been made, is one of the relatively small, but highly important activities of the Weather Bureau. It is conducted as an aid to fire-protection forces in the forestry services of the country. The problem of controlling forest fires is a difficult one involving heavy expenditure of time and money and at times requiring the services of large forces of men. The efficiency of fire control is largely dependent upon forestry officials being prepared for emergencies as they arise in proportion to the seriousness of the fire hazard. Since weather, more than any other factor, is responsible for the degree of fire hazard, forecasts covering those weather elements of direct bearing upon the fire-control problem are invaluable to the protection forces.

The fire-weather forecasting service was first offered to forestry interests in the States on the Pacific coast. It received such a favorable response that it has since been extended to forested areas under protection in other sections of the country. At present, forecasts are provided during periods of fire hazard to Government, State, and private forestry agencies in California, Oregon, Washington, Idaho, Montana, Minnesota, Wisconsin, Michigan, the Adirondacks, the New England States, and the southern Appalachians.

The plan of operation is essentially the same in all fire-weather districts. Meteorological substations are maintained at numerous places within the forested areas, and reports from these stations are transmitted daily by telephone or telegraph during the seasons of hazard to the headquarters of the forecaster for each district, seven in number. These reports, in conjunction with the general weather map, are used as a basis for the formulation of specialized forecasts which are telegraphed or telephoned to fire-control officers of the district, or else are broadcast by radio on exact schedules.

In the California district there is an additional and special method of operation conducted in cooperation with the United States Forest Service. An automobile truck, fitted with office, meteorological and radio equipment capable of sending and receiving messages, is utilized. This truck unit, accompanied by a forecaster and a radio operator, virtually comprising a forecasting office on wheels, proceeds to every large forest fire. Observations are received by radio, and forecasts and advices are issued to those in charge of the fire-fighting crews on the ground. This arrangement offers distinct advantages over the method employed in other districts in that the forecaster becomes an integral and active part of the protective system, issuing minutely localized and adapted warnings and advices for immediate use. Operation of this mobile unit has been so successful that its use in other districts is urged.

In addition to the forecasting work, each fire-weather forecaster cooperates with forestry agencies in the conduct of research work leading to the improvement of forecasts and contributing to knowledge of the relationship between weather conditions and the various degrees of fire hazard.

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