UNITED STATES DEPARTMENT OF AGRICULTURE
U.S. WEATHER BUREAU
WASHINGTON, D. C.

August 29, 1931.

Report (administrative) of the Chief ... 1931

SIR: I submit herewith a report of the work of the Weather Bureau during the fiscal year ended June 30, 1931.

Respectfully,

C. F. Marvin

Chief.

Hon. ARTHUR M. HYDE,
Secretary of Agriculture.

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Report of the Chief of the Weather Bureau

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LEGAL FUNCTIONS OF BUREAU

In order that readers interested in the study of these periodical reports of the activities and service of the Weather Bureau may be informed regarding the duties of this bureau, it seems appropriate to cite briefly the specific acts of Congress which outline and define the functions of this Federal organization.

In the act of Congress transferring the meteorological work of the Signal Office to the Weather Bureau of the Department of Agriculture, approved October 1, 1890, the duties of the service are thus summarized:

> The Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, shall have charge of forecasting the weather; the issue of storm warnings; the display of weather and flood signals for the benefit of agriculture, commerce, and navigation; the gaging and reporting of rivers; the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation; the reporting of temperature and rainfall conditions for the cotton interests; the display of frost, cold-wave, and other signals; the distribution of meteorological information in the interest of agriculture and commerce; and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, as are essential for the proper execution of the foregoing duties.

All the meteorological work of the Government developed under these and older equivalent laws applicable while the Weather Bureau was a part of the Signal Corps of the War Department, up to the advent of civil aviation.

With the passage of the air commerce act, approved May 20, 1926, it was considered expedient to legally define the duties and responsibilities of the Weather Bureau relative to air navigation, by the following new legislation:

Section 3 of the Act entitled "An Act to increase the efficiency and reduce the expense of the Signal Corps of the Army, and to transfer the Weather Service to the Department of Agriculture," approved October 1, 1890, is amended by adding at the end thereof a new paragraph to read as follows:

Within the limits of the appropriations which may be made for such purpose, it shall be the duty of the Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, (a) to furnish such weather reports, forecasts, warnings, and advices as may be required to promote the safety and efficiency of air navigation in the United States and above the high seas, particularly upon civil airways designated by the Secretary of Commerce under authority of law as routes suitable for air commerce, and (b) for such purposes to observe, measure, and investigate atmospheric phenomena, and establish meteorological offices and stations.

It seems proper to make the general statement that under these specific laws, as supported by the current annual appropriations, the activities of the bureau in all its varied lines are in a state of wholesome growth, development, and efficiency. From its very nature our work is intimately identified with reporting the constantly changing picture of the passing weather. As such we must, and we believe we may justly claim to be, figuratively "up to the minute" in our knowledge of atmospheric conditions, not only over the continental United States and its possessions, but through international cooperation and exchanges, over the greater part of the Northern Hemisphere. This alertness to existing conditions by means of extended systems of frequent observations and reports engenders habits of promptness and efficiency that are reflected in all the work of the bureau.

It is this same widespread system of frequent simultaneous observations and reports that forms the basis for the daily forecasts, warnings, and advices as to near-future weather conditions.

Thus it is seen that the forecaster, from his position of up-to-the-minute knowledge of present weather all over the world, aspires to perform the duty imposed upon him by the laws cited above by telling the public just what he thinks the weather is going to be. Even though certain conjectural factors surround the effort, the bureau believes it is fully justified in claiming that its forecasts of storms, floods, cold waves, hurricanes, etc., constitute a very valuable public service.

EXTENDING THE PERIOD OF FORECASTS

Throughout its history, the bureau has made efforts to extend the period over which successful forecasts could be issued as far as practicable. With the advent of radio, giving us a more complete picture of world weather conditions, the bureau inaugurated some years ago its so-called weekly outlook, in which the forecast is made to cover approximately a week in advance. Furthermore, within its organization, studies have always been in progress to determine, if possible, methods by which forecasts for months, seasons, and even years in advance could be formulated, and such studies still constitute a part of the program of research within the bureau organization. It is believed that the views of the bureau are in accord with those of leading meteorologists throughout the world, that up to the present time no sufficiently conclusive scientific basis has been found on which to make successful forecasts of this character.

It may be mentioned again that there appear to be three methods of approach in this matter, namely, (1) the direct physical process of cause-and-effect relationship between known physical causes and attendant weather conditions; (2) the so-called periodicities or cyclical recurrences of weather phenomena, either in the sequence of conditions themselves or as correlated to some astronomical or other sequence of events; (3) the mathematical correlations between the present weather in one locality with either past weather in the same locality or the past weather in some other locality. It is only fair to say that the bureau has conducted very intensive investigations in one or the other of these possible lines of approach without as yet having found

a sufficiently sound basis yielding possibilities of successful forecasting. Furthermore, the bureau is abreast of the information in these fields to be found in the literature contributed by other students, in the United States and elsewhere.

OBSERVATIONS AND REPORTS

The need for more detailed information from the existing network of stations reporting to the Weather Bureau and a further enlargement of the field of observation has become urgent. Demands for specialized forecasts, clamors for extending the forecasts beyond the periods now covered, the increasing distances traveled by man in comparatively short time intervals, all combine to make it more essential than heretofore that weather information be collected speedily not only from the North American continent but from the adjacent oceans and considerable portions of other continents.

Progress toward these ends has been made in the past year. Plans were completed to secure by telegraph much-needed additional data from the existing stations of the Weather Bureau and of the Canadian Meteorological Service. Detailed information concerning barometric changes taking place during the three hours preceding the observation, reports of relative humidity, and data regarding time of occurrence and character of precipitation are the more important items provided for in the new scheme.

Furtherance of the international selected-ship program, described in previous reports, is yielding an increased number of ships' weather reports from the North Atlantic. Additional ships of United States registry were secured for making reports by radio to the Weather Bureau when in the Atlantic west of 35° W. and to European meteorological services when east of 35° W. In addition, a beginning was made in the selected-ship service for the southern Atlantic, Caribbean Sea, and Gulf of Mexico.

In accordance with the program of international cooperation, radio reports were received by the Weather Bureau in increasing numbers from ships of foreign registry when in the

western Atlantic. These are included in bulletins along with observations from our own reporting ships and broadcast for the benefit of marine and other interests.

Reports from United States and foreign selected ships in the eastern Atlantic, transmitted to European services, have been included in a bulletin transmitted to the Weather Bureau. During the past year a new arrangement was set up whereby ship reports from the eastern Atlantic and weather information from representative land stations in Europe and Asia are transmitted twice daily to the Weather Bureau from the British Meteorological Service through the powerful radio station at Rugby. These bulletins are being copied by the Navy radio station at Bar Harbor, Me., and forwarded to the Weather Bureau by land line. This service from Rugby corresponds to a similar bulletin containing reports from ships west of longitude 35° W. and land observations from stations in the United States, Canada, Alaska, Central America, the West Indies, etc., which is broadcast twice daily directly from the Weather Bureau in Washington through the Navy station at Arlington for the benefit of European meteorological services. Through these cooperations an excellent exchange of meteorological information between America and Europe is secured.

Preparation of general forecasts and warnings as well as specialized information was facilitated by the increased number of ship reports available from certain areas of the Atlantic and by the international exchanges.

FORECASTERS IN TRAINING

Increasing demands upon the Weather Bureau for special forecasts to serve aviation, forest protection, and numerous agricultural and other interests, have made it imperative that an ample corps of trained and experienced forecasters be available. To this end the bureau has established a class of forecasters in training, funds for the purpose having been first added to the appropriations for the fiscal year just ended.

Selections for the class were made from among the employees

of the bureau having the requisite educational qualifications and experience in the general work of the bureau. Training of this group began at the central office in Washington where intensive instruction was given in the preparation of weather maps and practical experience was gained in making daily forecasts of weather and temperature. A series of lectures on meteorology and the application of mathematics and physics to forecasting problems was an important part of the class work.

As this training progressed, the six members of the class showing the greatest aptitude for the work were chosen to continue, and the others were given appropriate field assignments.

At the termination of the detail in Washington, these six employees were assigned in pairs to three important field forecast centers, those in Chicago, Denver, and San Francisco. Instruction in meteorology and related phases of physics and mathematics is being continued by correspondence from the Central Office.

GENERAL WEATHER CONDITIONS OF THE YEAR

Perhaps never in the history of the country, certainly not in the history of the Weather Bureau, has there occurred such a long period of deficient precipitation over such a large section of the country, designated by the term "drought," as has prevailed for the past 12 to 15 months. This entailed such serious consequences to the agricultural and industrial conditions of the country as to deserve particular descriptive discussion.

As a result of the concentrated attention by the several experts of the bureau to statistics and reports of the drought conditions and diversities of views among them as to just how droughts should be defined and their characteristics classified, a small committee was formed to propose a specific definition. For this purpose the views of certain leading field officials were invited. It is believed appropriate to give here a brief outline of the work of this committee, whose full report will be otherwise published.

There was a complete unanimity of opinion among the field men on what seemed to them to be the insuperable difficulty of formulating a definition of drought that would apply to all cases that might arise. The committee, of course, could no more define drought in all of its phases than it could religion, for example.

From the beginning the committee recognized the futility of attempting to formulate a definition against which some objection would not lie, but it had hoped that out of the discussion a method of comparing previous droughts with those of the present and those which may come in the future would arise.

On the basis of the findings of the committee the bureau will hereafter compile the following-named major characteristics of droughts, whereupon it will be possible to present an accurate picture of the drought in its essential features:

Duration.
Deficit of rainfall with respect to the normal for the time and place.
Amount of past moisture, as indicated by the rainfall previous to the beginning of the drought, for example, within the previous month.
Area involved.

Statistics of areas involved in past droughts are not available, and it is doubtful whether it is now possible to compile them. The idea of making a rigid comparison of past with present or future droughts in respect of area involved is beset with difficulties, but statistics collected will be valuable hereafter.

In the last 30-odd years several voluntary attempts have been made to compile the rainfall statistics for previous droughts. The committee referred especially to the compilations made at New York City and Nashville, which were published in the Monthly Weather Review for November, 1914, and September, 1925, respectively.

The idea which the committee had in mind was not to set an

arbitrary figure which shall be considered as indicative of severe drought, but rather to have compiled for the stations east of the Rocky Mountains (roughly) statistics upon periods of deficient rainfall.

The specific definition to which these considerations led the committee is as follows:

Drought: A lack of rainfall so great and long continued as to affect injuriously the plant and animal kingdoms and to deplete water supplies both for domestic purposes and for the operation of power plants, especially in those regions where the rainfall is normally sufficient for such purposes.

In connection with these views of the experts on the question, the following more detailed account of weather conditions for this fiscal year is of interest.

In the report of the work of the Weather Bureau for the fiscal year ended June 30, 1930, details of the unprecedented drought of last summer were given up to and including August. The following is a brief summary of conditions for the subsequent months of 1930, for the year as a whole, and for 1931 through July.

After the disastrous summer drought, the fall months of 1930 brought substantial relief throughout the Southern States, and also rather generally in all sections from the Mississippi Valley westward to the Rocky Mountains, practically all parts of these areas having more than normal rainfall. Deficiencies continued, however, from the Ohio Valley northward and eastward, particularly in the middle-Atlantic area, where most places had only about half the normal, or even less, especially the Virginias, Maryland, and Pennsylvania. The fall rains in the winter-wheat belt were opportune, and very favorable in permitting the preparation of land and the seeding of grain, and in promoting good germination and early growth. They were also helpful for fall crops of all kinds in the Southern and South Central States.

Complete records for the 12 months of 1930 show that Oregon, Missouri, Tennessee, Kentucky, Indiana, Ohio, Michigan, West Virginia, Virginia, Maryland, Delaware, New Jersey, Pennsylvania, New York, and New England had the driest year on record. In Kentucky, West Virginia, and Virginia, the 1930 rainfall was 20 per cent, or more, below the previous low record, while in Maryland it was about 30 per cent below the lowest for any year since state-wide data have been maintained. Forty of the forty-eight States had below-normal rainfall. The final figures for the year as a whole conclusively show that the 1930 drought easily takes first place for severity in the climatological history of the United States.

Following the fall rains over wide areas, the winter (December-February) was remarkable for abnormal warmth and dryness over much the greater portion of the United States. The temperature averaged from 4 to 16 degrees above normal in central and northern areas of the country, and there was a marked absence of extremely cold weather, with subzero temperatures confined to the Northern States. Precipitation was generally scanty. It was the driest winter of record in Alabama, Indiana, Illinois, Michigan, Wisconsin, Iowa, Minnesota, North Dakota, Montana, Wyoming, and Oregon, and the driest since 1900-1 in New York, New Jersey, Pennsylvania, Maryland, West Virginia, Kentucky, and South Dakota, and, with one exception, the winter preceding, also in Virginia. Only five States had as much as normal rainfall.

The accumulation of snow in the western mountains which supplies water for irrigation purposes was also markedly deficient. In western Utah, Nevada, Arizona, and practically all portions of the Pacific Coast States, the winter ended with the smallest, or nearly the smallest, supply of stored snow in the mountains that has been known for 20 years. Also the shortages were marked in Montana, especially from the crest of the Continental Divide eastward. The least shortages were in the Rocky Mountain States from central Wyoming southward, where some drainage areas had about the normal amounts. New Mexico was the only Western State having as much as the normal winter snowfall.

The spring months (March-May) of 1931 had very favorable

rains, mostly above normal, throughout the Atlantic areas. In the central valley States, where drought was severe last year, the totals for the season were near normal, though all States between the Rocky and Appalachian Mountains had deficiencies, with the greatest shortages centering in the Northwest, principally in North Dakota and Montana. Except in the Northwest and in some more western districts, the spring season had sufficient moisture rather generally for crop needs. At the beginning of summer, the Atlantic area and the Ohio and middle-Mississippi Valleys were much better supplied with soil moisture than at that time last year, but the Northwest had considerably less than a year ago, and rain was badly needed over considerable areas.

June was very warm in the North, and extremely dry in much of the South, especially the Southeast, while the Northwestern States continued markedly deficient in moisture, particularly the eastern Great Basin, Idaho, Montana, and the Dakotas. The acute drought condition that developed in the Northwest was due to a combination of deficient precipitation in the present year, coupled with an accumulated shortage in recent past years. In Iowa and North Dakota this is the third year with deficient rainfall, and in Montana the fourth, while in Minnesota it has been deficient every year since 1919. In other sections there was sufficient rain to maintain crops in generally good condition, especially in much of the area that suffered most last year.

July was warm and dry in the central and northern sections of the country, especially in the western and northwestern Corn Belt, but in the South and East there was mostly abundant rain, and crops made unusually good progress. Small grains in the Northwest suffered severely from the heat and drought, while corn, potatoes, and other row crops deteriorated badly in many places from the western Lake region and upper Mississippi Valley westward. There was insufficient moisture for pastures and hay rather generally in the central valleys and the Northwest, and much feeding of stock was necessary in many central-northern localities, but in the East and South conditions, as a whole, were highly favorable.

Table 1 contains a summary of precipitation data for all

States, arranged geographically, since the beginning of the 1930 growing season, up to and including July, 1931, as follows: Spring, summer, and fall of 1930; winter of 1930-31, and for the months of March to July, 1931, separately. The contrast between this summer's rainfall and that of last year has been especially marked over a wide belt extending from the central-Mississippi valley eastward to the Atlantic ocean, where last year's shortages were the greatest. For example, the average July rainfall last year in Arkansas was only 20 per cent of normal, compared with 157 per cent this year; Tennessee, 54-110; Missouri, 24-81; Illinois, 30-88; Indiana 53-91; Kentucky, 30-93; West Virginia, 41-106; Virginia, 38-117; and Maryland 36-105.

(over)

Table 1. Percentage of normal precipitation by seasons, spring, 1930, to winter 1930-31, and for March,--July, 1931

	1930				1931				
	Spring,	Summer,	Fall,	Winter, 1930-31	March,	April	May	June	July
New England	95	89	79	71	116	89	127	164	114
New York	97	85	68	71	76	112	136	93	137
New Jersey	68	87	75	62	107	78	100	131	92
Pennsylvania	80	62	52	62	84	99	132	90	121
Md. & Delaware	64	48	41	61	117	92	125	92	105
Virginia	62	51	52	67	96	110	138	75	117
N. Carolina	67	69	94	70	85	116	120	52	102
S. Carolina	75	71	116	72	75	106	131	46	91
Georgia	95	75	151	68	62	84	99	41	83
Florida	155	93	113	110	171	167	85	32	82
Alabama	78	66	182	62	66	80	84	35	105
Mississippi	93	47	154	70	80	45	90	55	181
Louisiana	79	56	165	93	89	48	73	42	100
Texas	98	56	139	132	121	73	66	61	118
Oklahoma	93	67	98	118	136	84	62	50	113
Arkansas	93	36	131	74	89	54	69	65	157
Tennessee	86	50	97	66	71	81	67	43	110
Kentucky	50	43	61	56	78	112	63	66	93
West Virginia	64	53	44	67	89	117	130	73	106
Ohio	65	56	66	53	62	134	85	92	98
Indiana	54	61	80	42	79	90	74	94	91
Illinois	57	60	93	40	86	79	106	82	88
Michigan	82	62	69	54	92	60	103	111	60
Wisconsin	83	81	80	46	101	48	49	114	57
Minnesota	92	69	126	37	108	43	75	95	66
Iowa	78	83	85	39	95	78	65	83	71
Missouri	59	54	111	69	100	81	97	60	81
Kansas	96	84	149	60	168	93	76	54	70
Nebraska	130	89	138	53	158	56	63	64	57
South Dakota	87	74	124	37	114	36	63	69	52
North Dakota	83	67	115	40	113	31	55	67	116
Montana	85	68	120	38	92	48	43	52	116
Wyoming	87	143	103	41	105	73	84	67	98
Colorado	87	123	103	59	88	67	94	83	57
New Mexico	85	103	123	118	118	228	92	56	95
Arizona	160	123	110	120	20	166	83	179	103
Utah	91	161	121	35	58	75	67	41	79
Nevada	139	85	157	42	51	87	45	96	38
Idaho	110	93	94	51	154	66	41	46	45
Washington	90	56	71	79	177	95	52	222	24
Oregon	85	47	70	45	133	67	37	185	2
California	95	26	78	51	38	75	95	249	44

RIVER AND FLOOD CONDITIONS

There were no important floods in any part of the country in the year that ended on June 30, 1931. In fact, on account of the protracted period of dry weather many streams were unprecedentedly low. In the Mississippi system the lowest stages were above the confluence of the Ohio; over the Ohio basin there was enough rain to give stages below Cairo that were comparatively higher than those that prevailed in the upper valley. The St. Louis stages are fairly representative of the entire drainage of the upper Mississippi Basin, as the increment between the mouth of the Missouri and the mouth of the Ohio is small, and at St. Louis, between July 1, 1930, and June 30, 1931, the range in water level was from 13.3 feet down to 1.9 feet below zero. Daily readings have been made at St. Louis since January 1, 1861, and in the entire series of records no like period of low stages can be found. It can, therefore, be safely said that less water reached Cairo from the upper Mississippi in the year ended June 30, 1931, than in any other year for which records are available. This can be said despite the fact that low-water readings are not as nearly comparable as high-water stages. Some low stages are caused by severe freezes, and others are due to the fact that the river, unaided by dredges, will cut its way through bars in a protracted period of low stages. (The stages that have prevailed at St. Louis since June 30, 1931, are lower than those of a year ago.)

There was no necessity for the issuance of flood warnings, but the period was valuable for the river forecasters, in as much as it afforded an opportunity for the uninterrupted study of forecasting methods, based on the long series of data that are available at most river-district centers.

Requests for river-stage data have increased considerably, on account of the development of all branches of hydraulic engineering. In the past year especial attention has been given to the accurate recording of low-water stages, as the demand for low-water data is second in importance only to the extremely high stages.

Gage and bench-mark descriptions have not been published since 1928. This information is used constantly by hydraulic engineers, and it is being thoroughly revised by publication in Daily River Stages for 1931.

Weak spots that have appeared in the observational and reporting system have been strengthened where possible by the addition of river-stage and rainfall stations.

In the Colorado Basin work has been continued on an intensive scale to enable the forecasting of the discharge of the lower Colorado, in cubic feet per second. These forecasts have been largely for use in preliminary work in connection with the Hoover Dam, and as construction work progresses they will become still more valuable.

Advantage has been taken of the low water to repair and adjust river gages. The encouraging progress that has been made has been, of course, due in good part to low rivers, but it was in a greater measure made possible by the assignment of two Weather Bureau men to the technical inspection of river gages, and to the repair work shown to be necessary by the inspections. Weather Bureau problems, involving the forecasting of both ordinary stages and flood heights, differ so greatly from other hydrologic problems that it has been found quite necessary to have instrument men trained in Weather Bureau practice, and thoroughly familiar with the public demands that must be met by the bureau, to make the surveys at and around the river-gage stations. More instrument men are needed, but under the existing conditions no effort is being made to obtain them.

Valuable aid has been given the bureau by the Army engineers and engineers of the United States Geological Survey, in the repair and adjustment of gages. In most cases the Weather Bureau has reimbursed the cooperating services, by a transfer of funds, for the work done. In other cases the work has been performed on a purely cooperative basis.

Snowfall measurements in the mountain snow fields of the Western States have been continued. This work is rapidly assum-

ing a character that is more local than the Weather Bureau can properly handle, and efforts are being made to reach an agreement under which the bureau will carry on general observations or measurements that may be considered representative of large regions, while towns, and irrigation or power plants, will make the very intensive surveys in the smaller basins from which they draw their supplies of water.

AEROLOGICAL ACTIVITIES OF THE BUREAU

It is well understood that there has been, since the passage of the air commerce act in 1926, a very active extension of the work of the Weather Bureau in its aids to the navigation of the air, and this topic has been well covered from year to year in the reports as submitted. Notable extensions were made in this program of work during the last fiscal year, and at the same time the urgency for economy has called for special consideration, resulting in very appreciable savings being made from the appropriations. This has been brought about, without impairment of the service, by the elimination of some of the least important features and by the postponement of some part of the program of fixed expenditures, awaiting more urgent need thereof on the part of transport activities. Naturally, the depression has affected the latter activities and lessened the urgency for extensions originally contemplated. This policy of conservatism will characterize the program of work for the ensuing year.

WEATHER BUREAU STANDARD OF ANEMOMETRY

Stations of the Weather Bureau, from their origin, about 1872, to the close of 1927, used only one fixed type of Robinson 4-cup anemometer for all measurements of wind movement and velocity. The cups were of hemispherical form, 4 inches in diameter, mounted on slender steel arms nominally 6.72 inches from the axis of revolution to the centers of the open faces of the cups.

Between the years 1888 and 1890 these anemometers were given a somewhat limited series of calibration tests, first by means of a hand-driven whirler installed in the large closed court of the Pension Building. When this equipment was used at

night, when the air within the great court was exceptionally still, the anemometers could be whirled in a great circular path about 56 feet in diameter. Limited to hand power, however, the test velocities did not exceed about 35 miles per hour.

Subsequently the performances of the anemometers were checked in the high natural wind velocities which occur with frequency on the summit of Mount Weather. To give strength to the results for higher velocities, flat, thin pressure plates normally exposed to the wind stream were also tested for pressure coefficient per unit area.

The results of both lines of tests have been completely sustained by the wide extension of aerodynamic knowledge made possible by the advent of aeronautics and the development of wind-tunnel test laboratories of the highest order.

Briefly presented, the results of the investigation ending in 1890 are as follows:

Under ordinary open air conditions, relatively thin flat plates, ranging from 1 to 3 feet square, exposed normally to the wind will experience a total wind pressure, in pounds per square foot, given by the equation

$$P = 0.004 \frac{B}{30} W^2 \qquad (1)$$

In this equation B represents the average barometric pressure. The ratio $B \div 30$ is needed in case wind-pressure values are desired at localities which are some distance above sea level. The wind velocity represented by the term W must be the true or corrected velocity if derived from indications of the cup anemometer. The tests led to the conclusion that this true velocity could be obtained from the standard 4-cup anemometer by the following equation:

$$\log. W = 0.509 + 0.9012 \log y \qquad (2)$$

in which y is the linear velocity of the centers of the cups, that is, the indicated velocity $V \div 3$.

The pressure formula (1) is believed to still quite correctly represent wind-pressure conditions on engineering structures in the open air, and it has also been found that the table of true wind velocities by equation (2) as published in 1890 when extended far beyond the highest test velocities to indicated velocities of 120 miles per hour, gives what the latest tests show are true wind velocities within a variation which attains a maximum difference of less than 2 miles per hour at 120 miles per hour indicated velocity.

These very satisfactory interpretations of the performance of the Robinson 4-cup Weather Bureau standard anemometer were attained by the present chief of the bureau in his former position in charge of the Instrument Division.

While it was quite unknown how really reliable at high velocities were the tests made in 1890, arrangements were made in 1922 with the director of the Bureau of Standards to carry out, in the wind tunnels of the bureau, new tests of various cup anemometers at the highest attainable velocities. This new undertaking was entrusted to Sterling P. Fergusson, of the Instrument Division of the Weather Bureau, assisted by his associate, Roy N. Covert. Officials in charge of the wind tunnels at the Bureau of Standards cooperated in the most cordial way to make a thoroughgoing success of the very considerable number of tests carried out, and the body of observational results are believed to be among the very best of this character available up to the present time.

About this time John Patterson, now director of the Canadian Meteorological Office, also undertook, independently, certain tests of the cup anemometer, and was led to the conclusion that the 3-cup wheel presented certain advantages over the 4-cup wheel. On the basis of Mr. Patterson's work, 3-cup wheels were given very extended tests in the Weather Bureau experiments at the Bureau of Standards, with the ultimate result that beginning January 1, 1928, instructions were issued to all Weather Bureau stations to replace the old standard 4-cup anemometer by new instruments of the 3-cup type. The essential features of this action have been published in the Monthly Weather Review for April, 1924.

In order to meet the needs of aeronautics, particularly with reference to the phenomenon of gustiness of the wind velocities and its effect upon the problem of airship manoeuvring and operation, the chief of the bureau himself undertook certain investigations, by means of very light magneto types of anemometers, and in the course of these certain questions arose leading him to an entirely new analysis of the original observational data obtained in the tests at the Bureau of Standards. This work has been carried out with unusual thoroughness, because it developed that some of the claims for superiority of performance of 3-cup anemometers were by no means borne out by his rigid method of analysis. Moreover, all parties engaged in these studies are in perfect agreement concerning the performance of 4-cup anemometers, about which decidedly the largest body of test information is available. In contrast to this, the wind velocities of the 3-cup anemometers, as shown by at least one or more station records, are in conflict with corresponding records previously made by the 4-cup anemometer.

These circumstances, taken in connection with the fact that the test of the performance of the 3-cup anemometer has been represented thus far only by certain graphic diagrams, and is not on any very definite, tangible basis corresponding to the definite equation like No. 2, established in 1890, it has been decided to be most proper for the bureau to return to the 4-cup standard, on or before January 1, 1932, if practicable. This will bring about the greatest homogeneity in wind movement velocity records of the bureau from its earliest days to the present time. The records accumulated during the interim between 1928 and 1932, while the 3-cup anemometer was used as the standard, will be coordinated in some proper way with the old and new records from the 4-cup instruments.

In order to make this brief report of the researches upon anemometry fairly complete, it is necessary to present the principal mathematical equations which suffice to completely represent the performance of any Robinson anemometer having cups from 4 inches, or somewhat less, in diameter to 5 inches or slightly over, on arms ranging from 3 or 4 inches long to 10 or 15 inches in length.

For such anemometers it is found that if $\underline{L}$ = length of arm then

$$\underline{b} = \frac{5247.8 - 17.78\,L}{L + 0.7976} \qquad (3)$$

In this equation $\underline{b}$ is a number which expresses the maximum or limiting number of turns which the cup wheels tend to make per mile of wind travel as the wind attains higher and higher velocities. At low and moderate velocities our investigation shows that cup wheels of all kinds make a relatively small and moderate number of turns per unit wind travel. For each cup wheel this number increases, rapidly at first, thereafter more and more slowly, and approaches asymptotically to the value $\underline{b}$ as hurricane wind velocities are attained. This quantity $\underline{b}$ is a fundamental characteristic of the performance of each cup wheel, and as equation (3) above indicates it is dependent quite wholly upon the length of the cup wheel arms.

It is quite certain there are minor secondary effects upon the value of $\underline{b}$, due to the size and number of cups (doubtless limited to 3 or 4) frictional restraints active at high velocities, as well as structural features of the cup wheels. While the whole body of tests made at the Bureau of Standards were quite diverse and generally self-consistent, nevertheless it was quite impossible to definitely segregate and evaluate the minor secondary effects mentioned from irregular accidental variations, and it is gratifying to find that this important limiting value of the constant $\underline{b}$ for all cup-wheel anemometers such as used at meteorological stations can be computed in any case by equation (3)

As we have mentioned, the actual number of cup-wheel turns per unit of wind travel depends upon the velocity itself. Let this number be represented by $\underline{N}$ and the true velocity $\underline{W}$, hence the product

$$\underline{NW} = \text{cup-wheel turns per hour}$$

Now in all practical uses of cup-wheel anemometers a certain arbitrary number, like 500, is chosen in the old standard anemometer, or 640 in the 3-cup instrument, as the assumed constant num-

ber of cup-wheel turns per mile of wind travel. These numbers are incorporated in the fixed gear trains of the instruments, and in practically all station anemometers, so-called mile marks are electrically registered, thus giving what is called the indicated velocity $\underline{V}$. Calling the arbitrary chosen number $\underline{A}$ we have another product -

$$\underline{AV} = \text{cup-wheel-turns per hour.}$$

Finally, the basic equation of all anemometry becomes

$$\underline{N\ W} = \underline{A\ V} \qquad (4)$$

and our whole investigation gives us for any anemometer

$$\underline{V} = \frac{bW\ (W - Wo)}{A\ (W + a)} \qquad (5)$$

In this equation $\underline{Wo}$ is a small friction constant for low velocity effects, and represents the velocity of the wind which is just adequate to keep the cup wheels in very slow motion. We have found it best to assign a fixed value to this constant of from 0.5 to 1.5, according to whether the axis turns very freely, as in ordinary instruments, or with some resistance as in the magneto anemometers. The constant $\underline{a}$ is also a small one like $\underline{Wo}$. Both are nearly the same for all anemometers tested; and the value of $\underline{a}$ ranges from about 2.0 to 3.0 for instruments like the 3 and 4-cup standards.

The findings show that under like conditions of friction, size, construction and choice of gear train, as represented by $\underline{A}$, 3-cup and 4-cup anemometers perform practically alike.

Supplying the final numerical values to equation (5) we get the working equation for the old 4-cup standard, as follows:

$$\underline{V} = \frac{681.1\ W\ (W - 0.67)}{500\ (\underline{W} + 3.04)} \qquad (6)$$

This equation will be found to give almost the same values of $\underline{W}$ and $\underline{V}$ as equation (2) within the velocity range of $\underline{V}$ between 10 and 120 miles per hour, but (6) may be safely extended to indicated velocities as high as 200 miles per hour, and values will check out closely with the highest observed tests at nearly 140 true, or 184 miles per hour indicated velocities.

More complete details of this subject will be published in the Monthly Weather Review.