PAPERS ON CLIMATOLOGY IN RELATION TO AGRICULTURE, TRANSPORTATION, WATER RESOURCES, ETC.

IMPORTANT PROBLEMS IN CLIMATOLOGY.

By Prof. FRANK H. BIGELOW.

INTRODUCTION.

The data furnished by climatology, including the temperature, precipitation, and wind at numerous points in the United States, is intended to bring out the features belonging to local conditions, as distinct from the more general meteorological features of the United States. While these two subjects are in some respects too closely interwoven to be distinguishable, they yet hold something of the relations of cause and effect, the climatological conditions at any station being the result of the general circulation of the atmosphere as modified by the distribution of ocean and land areas, and the topography of mountain ranges and plains in their relations to the prevailing winds. The data of climatology are, therefore, more commonly regarded as practical matters, while meteorology is considered as a somewhat theoretical, or speculative subject. This view of climatology as practical is strengthened by the facts that the farmer, the transporter, the manufacturer, and the consumer see in the prevailing temperature and rainfall the sources of these important weather conditions, paying little attention to the greater problems of the circulating currents that produce them. Furthermore, the meteorological problems are uniformly of a more complicated and difficult type than the climatological problems, so that it is inevitable that they should be studied only by a small class of specialists who are adapted by their training to such work. In recent years the development of interest in water resources, at the hands of engineers engaged in irrigation and power plants, by foresters concerned with the growth of trees in various habitats as regulated by temperature and precipitation, by the needs of farming in its intensive features, the greater value of water as regards its use in soils, its destructive power in soil erosion and transportation, its importance in the navigation of streams, and its destroying capacity in times of floods, all these interests have combined to place upon climatology a series of new questions that demand scientific attention.

In order to meet this demand more fully, the Chief of the Weather Bureau has separated its current publications into two general parts, placing climatology and its problems in the new MONTHLY WEATHER REVIEW, and meteorology and its problems in the Mount Weather Quarterly Bulletin. Also, a new monthly, to be called the Hydrological Journal, will be issued to collect the data of the river stages and discharges as furnished by the Weather Bureau, the Geological Survey, the Reclamation Service, and the engineers generally. It will, of course, be impossible to keep the border lines of these three lines of work entirely distinct because they essentially overlap, and the solution of a problem in one of them is only possible by borrowing from the others, and indeed from science generally. For example, the subject of evaporation begins in climatology with the water areas produced by precipitation, its laws can be discovered only by theories derived from thermodynamics and the kinetic theory of gases, and it goes over into meteorology which contains the laws of the circulation of currents bearing the vapors of evaporation to form clouds and rain or snow in very distant places.

In planning and discussing these new methods of publishing the data collected by observers in the United States, it appears that many persons have only a vague idea of the nature of the problems that ought to be discussed in the new MONTHLY WEATHER REVIEW, and it is proposed to mention some of the subjects in a very general way that ought to have the attention of our correspondents.

TEMPERATURE.

In Bulletin S, Temperatures and Vapor Tensions of the United States, 1909, are given the mean monthly and annual values of these quantities reduced to homogeneous systems. There are 64 stations having records from 31 to 33 years, 14 with records from 26 to 30 years, 10 with records from 21 to 25 years, 20 with records from 16 to 20 years. A method is given for reducing stations having short records to the equivalent of a long record by using the data contained in this report. In temperature records the observations of 25 to 33 years are enough to give reliable normals and departures, so that these standard values will not require modification for a long while to come. In climatology there are other short-record stations in each State that ought to be reduced to the long-record standard, in order to render more harmonious and regular the systems of monthly departures used in practical matters. By subtracting the mean monthly normals from the current normal of the successive years, a series of departures can be obtained for a large number of stations for the given month and year. If these departures are entered on a base map the variation of the temperature from the normal system of long record can readily be built up, and if lines of equal departure are drawn a map will be formed like Chart IV in the July, 1909, MONTHLY WEATHER REVIEW. Similar departure charts have been constructed from January, 1873, to June, 1909, for each month and year, making $36 \times 13 + 6 = 474$ charts. The series will be continued henceforth in the regular MONTHLY WEATHER REVIEW, thus making these monthly charts continuous from January, 1873. Preparations are being made to print these charts on the stations by the chalk plate process, so that all stations and students interested can have working copies. It is perceived that by interpolation the departures at any point on the map can be found for a series of years based upon the long-record system, and by comparing with the corresponding departures at a short-record station, the correction can easily be found for reducing the latter to the long-record homogeneous system. In this way the important cooperative stations of the United States will be reduced to a homogeneous system, and thus improve our departure columns in Table I of the MONTHLY WEATHER REVIEW.

NORMALS, CONSECUTIVE MEANS, DEPARTURES, AND RESIDUALS.

Unfortunately, it is not possible to secure a true normal of precipitation in as short a record as in the case of the temperature. An inspection of the charts and tables in Abstract of Data, No. 3, The Annual Precipitation of the United States for the Years 1872 to 1907, shows how wide the swing may be away from the mean value for a long series of years. It becomes necessary to make a distinction between departures and residuals. When the variation from a long-record mean is persistent in one direction for several years it is proper to compute the consecutive means for the years taken in short groups, as five for example, stepping along in consecutive groups. The value of a current year minus the normal gives the departure; the value of the current year minus the consecutive mean gives the residual. If the normal and consecutive mean agree then the departure is equal to the residual. This is likely to be the case in southern California and the Southwest; the residuals differ very much from the departures in the east Gulf States and in other districts. It is necessary to use this distinction whenever studies are made on the secular variation of the climate. There are other precautions which must be made when the variations in one country are compared with another. Thus, for long records the phases of one cycle can not be compared with another unless reduced to a definite period before correlation. The 11-year cycle of solar action with its four subordinate phases ranges from 8 years to 14 years, and it is evident that a set of departures which are jumbled together in a table without classification for period will simply cut themselves to zero in a numerical summation, and produce a negative result due merely to faulty computation. When stations in the Tropics are compared with stations in the temperate zones the fact of inversion in the system of departures and residuals must be fully reckoned with in the construction of comparative tables. This inversion effect is due to the general circulation of the atmosphere as impelled by variations of the solar radiation.

PRECIPITATION.

It may be noted that the departures of temperature and of precipitation are likely to be of opposite signs. An example may be found by comparing Charts IV and V, July, 1909, MONTHLY WEATHER REVIEW, where the areas of defective temperatures agree approximately with the areas of excess of rainfall. It becomes evident, therefore, that the ability to forecast monthly or seasonal departures of temperature would carry with it an indication of the probable rainfall for a given region. The ultimate purpose of securing departure systems is to discover a method of forecasts for weather and climatic conditions. This problem is exceeding complex and it will probably take much study to accomplish the desired purpose. Our observations of solar data are meager and crude, and our departures and residuals have been too full of bad workmanship to permit them to be used in this comparison. The International Solar Commission is gradually acquiring homogeneous data and the problem is being carefully studied in many quarters of the world.

The proper catchment of rain and snow, and the measurement in water equivalent, has always been a perplexing question. The ordinary 8-inch rain gage, with funnel, works well enough for rain, where the action of gravitation makes the drops fall quite vertically into the measuring circle of the gage, but it is not satisfactory in the case of falling snowflakes where the horizontal wind effect overcomes the vertical gravitation effect. If rain and snow fall vertically any proper apparatus will work for catching it; if the rain and snow are blown horizontally no form of apparatus is free from difficulties. Snow is transported horizontally by wind currents to such an extent that it becomes of primary importance to separate falling snow from drifting snow. For this purpose several experiment stations for comparative observations have been established in the Rocky Mountain and Pacific States. At each of these stations there have been set up plain and louvered snow bins, 10-foot platforms, 10-inch standpipes 10 feet high, and simple vertical snow scales divided into feet and tenths. The bins are cubical boxes, 5 feet on a side, set on a frame so that the top is 10 feet above the ground, and they are provided with a short ladder and door for access. The louvered bins have plain louvers on the lower half of the inside to control the swirling eddy currents, and a semicylindrical wire screen louver on the outside along the top to control the direction of the outside horizontal currents around the mouth of the bin. It is not only necessary to separate the horizontal component from the vertical component of the snow as it falls, but to hold the snow in the bin after it has once fallen within it. The curved louvers are adapted to the former purpose and the plain louvers to the latter. Snow usually falls during a comparatively light wind, but this is followed by high winds which blow it about. Our experiments so far indicate that the platform is swept or filled by mere drift so much as to be useless; the standpipe and the short rain gage can not catch a fair amount in the narrow orifice; the snow bins are by far the most promising mode of attacking this snowfall problem yet tried. If a fair catch of snow can be guided into and held in the bin it will be easy to accumulate this in reservoirs containing salt to produce water, and oil to prevent evaporation. Such a combination will make an apparatus for storing the snow and water falling in remote places, as in the mountains, which can be visited only at intervals for the record. A series of such bins in the mountains will enable us to compute the general snowfall conditions before transportation occurs by means of wind and stream flow, and from these data it will be possible to build up a system of local relations between the fall of the season and the flow in the streams heading in the snows. This is a large and difficult problem and will require much skill for its solution.

WIND AND TOPOGRAPHY.

The general rain and snowfall of a region depends upon its relation to the mountains, plains, and ocean areas, because these are connected with the general circulation of the atmosphere. Local precipitation is largely controlled by these terms, and they should be thoroughly and systematically analyzed. The existence or nonexistence of forests and soil covering depends upon the temperature and relative moisture of prevailing winds in the given locality. Should these change decidedly the forests will follow, in order to conform to the dominating climatic conditions. At one time the winds must have been entirely different from what they now are in Arizona, New Mexico, and the Southwest, as testified by the gigantic petrified forest trees there found. It follows that reforestation of nude country should carefully consider the prevailing winds and their probable moisture contents before spending money in that direction. Old forests can be replaced if similar climatic conditions continue to exist, but not otherwise.

The drying and withering of vegetation depends upon the wind action, and it may be very restricted in its area as modified by the topography of a mountainous country. The entire question of evaporation of water from soils and plants, as well as the rate of transpiration, is closely connected with the prevailing wind action, and much work remains to be done in this direction. The Forest Service has recently established an experimental laboratory at the Coconino Forest, 12 miles from Flagstaff, N. Mex., and another at Fremont, Colo., and it is proposed to carry on proper researches in these problems at other stations. The Weather Bureau is cooperating in this matter by furnishing apparatus and advice so far as practicable.

RUN-OFF, SEEPAGE, DISCHARGES, FLOODS, LAG, AND FORECASTS.

Taking a large mountainous region, having a rough surface topography, when rain or snow falls on the area it is soon collected into the gulches, in streams, and rivers which carry off all that escapes the prevailing evaporation. Since observations are not usually well distributed in such a country, being for the greater part limited to the low levels, it is a difficult problem to connect together the total precipitation and the run-off. If the vertical component of the precipitation can be separated in the case of snow from the horizontal drift by means of the snow bins, then it can be assumed that the vertical lines drawn upward from each station will pierce an ideal plane drawn horizontally just above the mountain tops. A number of snow falls at points through this plane will give the data for integrating the total snowfall through this plane. When the vertical loss by evaporation is once measured and computed approximately, the remaining snowfall, reduced to water equivalent, is the total that accumulates in deep drifts, or runs off promptly in the streams. No work of this kind has been accomplished in the United States, but it is greatly needed for engineering and irrigation uses.

The relation between the rapidity of the *run-off* or overground flow, and of *seepage* or underground flow, and the nature of control by the condition of the soil, by the prevalence of forest or other covering, is a subject for further study. The *discharges* of the streams take account of the volume of water passing a given cross section area in the unit of time, and it is measured by the stage or height of the stream together with the velocity of the current. The discharge is usually less on a rising stage than it is on a falling stage. *Floods* represent the temporary accumulations of water upon the total area of the watershed of a stream washing down in a long wave through the river channels. Now, there is an interval of time elapsing between that of precipitation and the passage of the water in the streams. Instances are known where the heavy precipitation of one year in the mountains as snow will not reach the streams at a considerable distance till a year has elapsed. That is, the amount of precipitation in any year may be made the means of forecasting the condition of the streams a year later. In other localities the lag is only a few months or weeks, but such facts can be learned only by a systematic correlation of the data of precipitation and the discharges in streams. The dates of disappearance of the surface snow in the open country, *the ravines*, and in the forest should be systematically recorded. The seepage waters, derived from the surface waters entering the soil, have a very considerable lag behind the overground waters in reaching the streams. The *rises* due to underground waters are likely to follow the floods from overground waters by several weeks or even months. The evaporation of water from the soil amounts to an enormous quantity in many places. In the Owens Valley, California, the waters of the Sierra Nevadas hardly reach the Owens River in the neighborhood of Independence, though the distance from the rampart to the river is less than 10 miles and the mountain streams are vigorous on account of slow seepage and rapid evaporation in the meadows. Every locality has such problems of lag and forecast that can be worked out only by observation.

EVAPORATION.

In the summer of 1907 the United States Weather Bureau began a systematic research into the laws of evaporation, with Prof. F. H. Bigelow in charge of the work. A preliminary campaign at Reno, Nev., July to September, 1907, was supplemented by some observations at Indio and Mecca, Cal., 1908, while waiting the necessary Congressional authority to proceed to the main work of the investigation in 1909. Observations were opened in March, 1909, at Indio, Mecca, Brawley, and Mammoth in the neighborhood of the Salton Sea, and four strong towers were built near the Salt Creek Bridge, one on the land, one in 25 feet of water at the bridge, one in 40 feet of water about three-fourths of a mile out, and one in 55 feet of water $1\frac{1}{2}$ miles out in the Salton Sea. The towers project 45 feet above the water and are heavy enough to stand in the severe storms without much swaying. Simultaneously stations were established in different parts of the country in cooperation with the Reclamation Service and the Geological Survey, and records have been received from Boise, Hermiston, North Yakima, Klamath Falls, Fallon, Lake Tahoe, Phoenix, Engle, Carlsbad, Mitchell, Rupert, California, Ohio, and Birmingham, Ala. These observations are being discussed and they disclosed the problems to be solved in a very satisfactory manner. It may be said generally, that the results obtained first at Reno, Nev., have been fully confirmed. The observations have been executed by numerous observers, some of them being very skillful in the use of the apparatus, and they have been made with different classes of instruments. The difficulties that appeared at Reno are inherent in the phenomena of evaporation, which is very complex, and they can not be explained by the efficiency of the observers or the apparatus. Beginning with the old Dalton formula, for the unit of time,

$$E_0 = C\,(e_s - e_d)\;(1 + Aw).$$

The correlative formula is:

$$E_0 = C\,(e_t - e_d)\;(1 + Aw).$$

where e_t is the vapor pressure at the dry air temperature, e_s that at the water surface temperature, e_d that at the dew-point temperature. Each of these formulas have been amended in our computations to their respective improvement, but neither of them meet the requirements of the problem. To amalgamate them in the form,

$$E_0 = C\,(e_t + e_s - 2e_d)\;(1 + Aw).$$

is to produce a mixed case inferior to each of the components. The formula first used at Reno has been fully verified as the most effective, and its relation to the Dalton formula discovered. Unfortunately, evaporation is a more complex phenomenon than is indicated by these simple forms. The coefficient C is not constant during the day, for two or three reasons; also, it moves in an annual cycle of considerable amplitude. The evidence is, that we are dealing with a hyperbolic function, $C = xy$, which implies products and ratios rather than simple differences, and the relations between e_t, e_s, e_d are by no means simplex, but complex. At the Salton Sea the towers in the heat of summer penetrate nearly through the vapor blanket, and the evaporation from bottom to top proceeds by stages which give fine examples of the variations between these terms. Similar coefficients emerge from the computations in different parts of the United States, and it is quite certain that the formulas deduced at the Salton Sea will be applicable in all climates, that is in all variations of temperature and vapor pressure. The wind term is likewise complex, and the velocity changes rapidly from the ground to 10 feet above it. The size and location of the evaporating pans, also, have important effects, because of the conduction of heat in the metal to the water and to the ground. The amount of change of the water temperature, that is the rise of temperature in the forenoon and fall in the afternoon, are probably functions of the rate of surface evaporation. The cycle of a year's observation at the Salt Creek Bridge will be completed in June, 1910.

CIRCULATION.

The prevailing circulation of the atmosphere controls the resulting weather conditions, that is the climatology. If the prevailing winds are directed in certain directions for a series of months or years the climatology follows them. There are strange anomalies occurring in this matter of general circulation whereby the winds seem to change their habitat, if one can so describe the conditions, and this entails a whole cycle of changed circumstances. Unfortunately, meteorology has made so little progress in the study of the general circulation that the subject is little better than chaotic in its nature. The observations of temperature, wind vectors, and vapor contents in the higher strata of the atmosphere have only become available for study during the last 10 years. Even this meager data is enough to show that the theories of the general circulation as discussed by Ferrel, Oberbeck, and other meteorologists, are entirely incapable of taking satisfactory account of the facts. Bigelow showed by the cloud observations of 1897–98 that Ferrel's canal theory must be modified, there being no important flow of air from the equator to the poles in the upper levels, with return currents in the lower levels, and a neutral plain separating them. Rather, there are leakage currents from the Tropics into the temperate zones in the lower levels, producing the large centers of action, and the smaller wandering cyclonic and anticyclonic circulations. A fairly complete discussion of the vortex motions in the tornadoes, hurricanes, ocean, and land cyclones has been published in the MONTHLY WEATHER REVIEW, showing that a large amount of work must yet be expended on the local land and ocean cyclones.

More recent unpublished studies on the general circulation have made important progress in this subject. The observed distribution of temperatures in all levels up to 13,000–16,000 meters has been correlated in all latitudes from the equator to the poles; a method of computing the corresponding pressures, densities, gradients of temperature and pressure, the wind velocity and air coefficients has been worked out, which is already very promising. This takes account of the vertical convection upward in the Tropics, downward in the high pressure belt, together with the resulting trade winds; the horizontal overflow, somewhat greater in middle latitudes in the upper levels than in the lower levels, and its relation to the great eastward drift can be fully discussed; the variations of temperature in longitude and the effect in breaking up the general circulation by means of leakage currents can be deduced by the extension of the method. The application of such data to many localities is a work that will cost much labor, but the result will be to change climatology from a merely statistical subject of normals and departures into one of scientific procedure. If the laws of the modification of the local circulations can be worked out, there will follow the possibility of arriving at the laws of seasonal forecasts as regards the temperature and rainfall of special regions. It is entirely probable that the proper scientific approach to the problem of seasonal forecasts is to be along this line, however, it will require the labors of many students to do the necessary work of computation and discussion. It, also, seems quite likely that as soon as students more clearly perceive the nature of this great problem, the number of workers will increase.

RADIATION.

If the circulation of the earth's atmosphere is the cause of the local distributions of temperature and precipitation observed in climatology, we know that the solar radiation is the immediate source of the energy that drives the circulation. The subject here becomes complicated because the study of radiation in any easy way is hindered by the presence of aqueous vapor in the atmosphere considered as an absorbing layer of gases. The incoming radiation suffers three principal depletions: (1) by scattering and deflection upon the atoms, molecules, and dust or ice particles of the air, (2) by the absorption of short wave-length radiation chiefly in the outer or isothermal layer, (3) by the absorption of the somewhat longer wave lengths and other occasional long wave lengths in the lower aqueous vapors. In order to suitably observe solar radiation, it follows that regions of dry air, and air free from dust, are most advantageous. The atmosphere over the eastern districts of the United States is loaded with aqueous vapor and transported from the Gulf of Mexico, while the extreme southwestern districts, New Mexico, Arizona, and southern California are relatively free from vapor, being shielded by the mountain ranges of the Pacific coast. Some high-level stations and some desert stations in the Southwest are peculiarly adapted to study solar radiation. There are several lines of research which indicate that the solar radiation is variable, and it is of primary importance to establish a series of long-continued homogeneous radiation observations for this purpose. The irrigated district in the Imperial Valley, having very clear, cloudless skies, and comparatively low wind velocity, is a most promising place for a station. A suitable equipment for the climatological station at Brawley, Cal., should be considered in this connection.

SOLAR PHYSICS.

Numerous answers to questions in solar physics will probably follow the solution of similar problems for the earth's atmosphere. The relations between the temperature distribution and the velocity of the air in different levels follows similar laws, through the action of gravitation upon the resulting densities of the air masses. Apparently, by the observations on the surface, the solar disk is at the same temperature in all latitudes, and yet the large change in the velocity of rotation of the gaseous envelope in different latitudes, 26.70 days at the equator and 31.00 days at the poles for the photosphere, 26.00 days at the equator and 29.00 days at the poles for the upper chromosphere, must be the result of temperature distributions in order to conform to the laws of general motion. The outer gaseous layers of the earth's atmosphere are nearly isothermal, but the lower ones have a well-known decrease of temperature from the equator to the poles. Similar deep-seated changes in temperature are to be expected on the sun, but the two systems are probably inverse to one another.

The incoming radiation is accompanied by magnetic and electrical effects. If corpuscles are expelled by the sun and transported to the earth in light waves, they should make a disturbance of the diurnal magnetic field centered about the solar meridian, by every analogy, if their energy is expended within the outer layers. The diurnal magnetic variations are evidently distributed about the diurnal temperature changes in two entirely parallel systems centered at about 2 o'clock in the afternoon. Since this temperature distribution is confined to the lower layers of the atmosphere it should follow that the incoming solar radiation has diurnal magnetic effects, controlled by the lower rather than by the outer layers. The corpuscles and absorbed radiation in the outer layers probably produce the irregular magnetic storms.

ECONOMIC STATISTICS.

There are numerous practical questions in climatology concerned with engineering, transportation, and agricultural interests. Careful statistics should be collected of the financial losses by floods to engineering structures, in order to study their efficiency in regard to the work called upon to be done by them. The sudden release of snows in the mountains by dynamic heated winds, and the best method of forecasting their recurrence should be studied for each locality. The effect of hurricanes upon sea walls, protecting breakwaters, and jetties is an important subject of research. The damage to buildings by high winds, and the architectural problems of their strength of resistance should be worked out. The railroads are interested in the washouts produced by rainfall, originally well distributed, but concentrated by run-off into dangerous destructive torrents of short duration. The railroads in the deserts and in the mountains of the West are expending large sums of money building dykes and protecting walls, and yet they possess only meager climatological data. The subject of the navigation of inland waterways depends upon the amount of snow and rainfall that is carried into the river channels. The effect of rainfall and evaporation upon soil fertility, the effect of winds and wind-breaks upon the vegetation in the fields call for careful examination.

In short the problems open to climatology and meteorology in their mutual relations cover a vast catalogue of work. It is proposed to publish in the MONTHLY WEATHER REVIEW the more practical aspects of these problems, and in the Mount Weather Bulletin the more theoretical studies, and papers are solicited for each publication.

AVERAGE ANNUAL RAINFALL OF PORTO RICO, W. I.

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In the latter part of 1898 a station of the first order of the United States Weather Bureau was established in the city of San Juan, the capital of the newly acquired tropical island of Porto Rico. In the following year substations to the number of 30 or more were established over the island, at which the daily extremes of temperature, the amount of rainfall, the direction of the wind, and the general state of the weather were recorded daily. These substations were from time to time increased in number, and at the present time weather records are available for more than 50 localities for periods varying from 1 to 11 years. At 4 stations the observations antedate the American occupation: At San Juan extending back to 1870, at Canóvanas and at Mayagüez to 1889, and at Luquillo to 1896.

All of these records are now being reduced, under the direction of the Chief of the Weather Bureau, in the preparation of a