The above statement of the general principles which obtain in forecasting for the Pacific coast, are in close accord with the conception of the problem as presented in this paper.

RECORD-BREAKING RAINFALL IN JAMAICA IN JANUARY, FEBRUARY, AND MARCH, 1921.

(Excerpts from *Jamaica Weather Report*, Feb. and Mar., 1921, p. 4.)

The mean rainfall for the entire Island during February was somewhat over twice the normal. Moore Town, in Portland Parish, had a total fall of 27.73 inches during the month, while at Belvedere, in the same parish, there was a 24-hour fall of 9.05 inches. The average precipitation for the Island was 7.22 inches—the greatest amount for any February in 50 years. It is worth noting that the average rainfall for January of this year was 10.87 inches, being the greatest of any January on record. The rainfall for March was 84 per cent above normal.—*H. L.*

APPLIED CLIMATOLOGY IN CALIFORNIA.

551.58 (794)

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau Office, San Francisco, Calif., May 17, 1921.]

SYNOPSIS.

The work done at a climatological section center of the Weather Bureau furnishes good evidence of the many and varied applications of climatology. These are not known to the general public, and even professional meteorologists have but a limited appreciation of their extent and variety. The practical applications of climatology in California are here briefly enumerated and described in the hope that the survey may be of interest and perhaps of value in other climatological sections, and with a desire that it may inspire similar surveys of other regions. In California the Weather Bureau acts as a meteorological and climatological center of information and clearing house, and supervises the gathering and publication of a small fraction of the data available. Municipalities, industries, public service corporations, business houses, resorts and institutions maintain climatological stations and secure data which are of great practical value in agriculture, manufacture, industry, mining, transportation, aviation, conservation, public service, advertising, public health and recreation.

INTRODUCTION.

Because of its vast size, its wide range of latitude, its uneven topography and the contrasts of climate which result therefrom, California presents great variety in the uses and applications of climatology, a variety which is probably not equaled by any other State. The following is a brief survey of applied climatology in California, a field which is so extensive that only the salient features can be here referred to.

WEATHER BUREAU ACTIVITIES.

Practically all of the meteorological and climatological activities of the United States Government in California are conducted by the Weather Bureau. While this is the largest single organization engaged in the task of accumulating meteorological and climatological data and making the same available for public use, its activities represent only a small fraction of the total work of this kind carried on in this State. The Weather Bureau serves as a meteorological and climatological clearing house. But the demands for detailed data are so extensive, and these demands are increasing so rapidly that the limited appropriations allowed the Weather Bureau do not permit it to render as complete service as might be rendered with more liberal appropriations.

Briefly stated, the Weather Bureau maintains 11 regular first-class stations, situated at the following places: San Francisco, Los Angeles, Sacramento, Fresno, San Diego, Eureka, Red Bluff, San Jose, San Luis Obispo, Independence, and Point Reyes. The first named is the district forecast center and the climatological section center. Special attention is paid to river and flood data at Sacramento, Fresno, and Eureka. Marine vessel movements are reported at Point Reyes. Storm warning stations are located at eight prominent points along the coast. In addition, approximately 300 climatological substations are maintained, but the observers at only about 10 per cent of these receive nominal compensation (because of special observations and service required), the others being volunteer and unpaid cooperative observers. At all stations special attention is paid to precipitation data, since precipitation is the most important element of climate in California. The Weather Bureau has the cordial cooperation of all the various agencies engaged in gathering weather data, but the extent of the cooperation varies, since the Bureau is unable to supervise the gathering and the publication of more than a small fraction of the data available.

MUNICIPAL CLIMATOLOGY.

The municipal governments of two cities, Oakland and Santa Barbara, have installed the complete meteorological equipment of a first-class Weather Bureau station, including the triple register. In Oakland the apparatus forms part of the equipment of Chabot Observatory, a suburban observatory which is maintained under the auspices of the board of education and is open to public inspection during certain hours. It is a combined meteorological and astronomical observatory, ideally and permanently located on a large tract of land at the edge of the city. At Santa Barbara the municipality has installed complete meteorological apparatus on the grounds surrounding the home of one of its prominent residents. More than $1,000 has been expended in standard equipment with the hope that the Weather Bureau may eventually take over the same and maintain a first-class station at this place.

The city of San Francisco is at present building an aqueduct which will eventually bring water to the city from the Hetch Hetchy Valley, almost 200 miles distant. Since climate and particularly precipitation is an important factor in construction, water supply and hydroelectric power, the municipality maintains two weather stations in the drainage basin, namely, at Hetch Hetchy and Lake Eleanor.

Likewise, the city of Los Angeles, whose aqueduct is complete and in operation, maintains several climatological stations along its route, notably at Fairmont and in the Owens Valley.

The city of San Diego also maintains such a station at Barrett Dam, a link in its water supply system.

The city of Vallejo, the municipality adjoining the United States Navy Yard at Mare Island, has recently installed 36 standard 8-inch rain gages in an elevated valley which it proposes to use as a drainage basin for its future water supply, if the precipitation there comes up to expectations.

A number of communities maintain climatological stations under the supervision of a city official, usually

the city clerk or the city engineer. Among such cities are Pasadena, Santa Cruz, Livermore, Oceanside, Placerville, and Santa Maria.

In connection with flood-control and water-supply investigations, an intensive survey of precipitation in southern California is being conducted on the basis of data secured at a large number of special rainfall stations in the immediate vicinity of Los Angeles. This investigation was provided for by an agreement made between the Honorable Secretary of Agriculture and the Board of Supervisors of Los Angeles County. It is expected to continue for 10 years or more.

CLIMATOLOGY AT EDUCATIONAL INSTITUTIONS.

Partly for the purpose of securing needed data and partly for educational purposes, various educational and research institutions maintain climatological stations. The University of California maintains four such stations, besides two evaporation stations. At the observatory on the main campus of the University in Berkeley a climatological station is maintained under the auspices of the Department of Geography. Another station is maintained at Lick Observatory, on the summit of Mount Hamilton, altitude 4,209 feet, this institution being a part of the university's Department of Astronomy. A feature of the equipment at this station is the use of a considerable number of self-registering meteorological instruments, which are of particular interest to visitors. The observatory is open to the public daily, and occasionally during evening hours. Another station is maintained at Davis, the seat of the agricultural division of the university, where the instruments are attended to by the Department of Irrigation Investigations. A fourth station is maintained by the university's Department of Forestry near Santa Monica, at a forest experiment station.

The Carnegie Institution of Washington, at its solar observatory on the summit of Mount Wilson, altitude 5,704 feet, maintains a first-class station. Data from this elevated station are of considerable value in weather forecasting for southern California, as well as in the study of water resources. The data are also used to aid aviation, which is rapidly growing in importance in California.

A completely equipped, first-class meteorological station is maintained by the University of Santa Clara, in the valley of the same name, and about 3 miles distant from San Jose. The equipment of the observatory also includes astronomical instruments and a seismograph. The director is Rev. J. S. Ricard, S. J., who has long been a student of long-range weather forecasting as based on sunspots.

Pomona College, in southern California, also maintains a climatological station. The data are used for educational purposes, and also in fruit-frost investigations, as the station is in the heart of extensive orange and lemon groves. The science department of Lakeport High School maintains a station at the home of one of its instructors. Another station is maintained at Raja Yoga Academy, of the Theosophical Institution, on Point Loma, a prominent headland at the entrance to San Diego Bay. The station is maintained under the supervision of Prof. F. J. Dick, who has designed and constructed a novel seismograph, which forms part of the observatory equipment.

AGRICULTURAL CLIMATOLOGY.

While most climatological data obtained in California are used directly or indirectly in agriculture, certain stations are maintained primarily for this purpose. The variety of applications in scientific agriculture is extensive, as is apparent from the following:

The Spreckels Sugar Co. maintains an experiment station at the headquarters of the company in the town of Spreckels, near Salinas, in Monterey County. Near the mammoth sugar refinery there has been erected a modern scientific laboratory, which includes in its equipment all the standard meteorological instruments found at a first-class Weather Bureau station, including a triple register, evaporation pan, and air and soil thermometers of various kinds. Sugar beets alone form the source of supply of the sugar manufactured here. Investigations have shown that there is an intimate and complex relationship between weather and the sugar content of beets. The optimum weather condition has never been determined exactly, as it varies with soil, elevation, latitude, and time of planting. Moreover, it has been recognized that the optimum weather for the production of sugar in beets is not the best weather for the production of seed. As a result of these conclusions, the experiment station has established a considerable number of climatological stations in the extensive sugar-beet fields near the coast of central California and in the interior valleys. Another company, the Union Sugar Co., with headquarters at Betterva, also maintains a climatological service of its own, but on a less extensive scale.

In the field of horticulture citrus fruit receives more attention than any other crop. Owing to the sensitive character of citrus-fruit trees, and because of the fact that certain kinds of citrus fruit, notably lemons, mature on the same tree throughout the year, climate naturally determines the districts available for successful culture. The bulk of the crop is grown in southern California, largely because of the absence there of severe or prolonged cold. However, the foothills of the interior valleys of central and northern California have been found to be well adapted for citrus-fruit culture, and the acreage is increasing from year to year. Because of the greater amount of sunshine received, the most northerly orange groves, those near Oroville, invariably produce the first mature oranges every autumn. Fancy prices are received for such fruit when offered in eastern markets during the Thanksgiving and Christmas demand. It is perhaps unnecessary to add that climatological data form an important consideration in the successful production of citrus fruit. The application of such data relates principally to frost, orchard heating, smudging, irrigation, sunshine, hot waves, fumigation, "June drop," insect pests, and favorable harvesting and storage conditions. Nearly all the large citrus-growing regions have climatological stations, and the instruments are usually situated in or near fruit groves. On the official weather maps issued at certain Weather Bureau stations and in data published by the daily press observations appear under the heading, "Orchard Temperatures." Among the most prominent orchard climatological stations are Pomona, Redlands, Riverside, Porterville, Lemon Cove, Lindsay, Oroville, and Yorba Linda.

Successful date culture on a commercial scale requires tropical or semitropical weather conditions. Frosts or prolonged low temperatures can not be endured by the date palm, and the mean temperature of the air must be relatively high. On the other hand, the water requirements are light, and the palms will flourish in what appears to be a sandy desert, provided that the temperature conditions are favorable. These peculiar conditions are found in the Coachella Valley, where the United States Bureau of Plant Industry has introduced the culture of the date palm on an extensive scale. About 70 different

species are now under experimental cultivation at the Indio experiment station. Most of the seedlings were originally imported from Africa or from southern Asia. Seedlings of the varieties best adapted to California conditions are already available for distribution. One of these varieties, "Delget Noor," has been found to be adapted for general cultivation in the Imperial Valley, that great "inland empire" destined some day to be a vast agricultural region, but as yet comparatively undeveloped. Climatology has contributed in no small measure to the successful introduction of the date palm. Meteorological instruments form an important part of the equipment of the Indio experiment station and of the Mecca substation.

Death Valley is of scientific interest because here the highest natural shade temperature ever recorded with a standard thermometer, namely, 134°, occurred on July 10, 1913. Nearly every year the highest temperature officially recorded in the United States occurs here. This valley, which is mostly below sea level, is about 50 miles long and 400 feet to 8 miles wide, and lies between precipitous mountain ranges. It contains but one permanent human habitation. The latter is known as Greenland Ranch, because the green appearance of the alfalfa, grown under irrigation there, is in marked contrast with the brown desert surrounding. In the pioneer days the ranch was known as Furnace Creek Ranch, also an appropriate name because of the unbearable heat during summer months. The ranch is owned and maintained by the Pacific Coast Borax Co. as a source of food supply for the miners employed in the mountains nearby. The foreman of the ranch acts as cooperative observer for the Weather Bureau, and the climatological station is a feature of the equipment of this unique and isolated community. The rain-gage is not often used, as a whole year sometimes goes by without measurable precipitation.

Less than 10 years ago the United States Department of Agriculture introduced rice culture into California on a commercial scale in the flood plain of the Sacramento River. This land, worthless for most ordinary purposes, was found to be well adapted for rice growing. The new industry grew rapidly, and recent harvests have been valued at many millions of dollars. The limiting factor seems to be inadequate water supply to satisfy the high water requirements of rice. Because of drought and the large use of water by rice growers the Sacramento River above the city of Sacramento was almost pumped dry during the summer of 1920. Climatology again contributed essential data in the introduction and development of the industry. Of particular importance are precipitation and river-stage data in connection with the irrigation of the rice fields. At Dodgeland, in the heart of the rice-growing district, the Weather Bureau maintains an evaporation station in cooperation with the Dodge Land Co., one of the largest interests in the valley. The University of California also maintains an independent evaporation station in the valley in connection with its rice experiment station. The same institution maintains another evaporation station in the Imperial Valley, where cotton culture has been introduced on a commercial scale. The experiments with cotton have resulted in the production of a high-grade, long-staple cotton, which commands a premium in price because of its advantages in the manufacture of automobile tires. Recently cotton culture has been introduced into the San Joaquin Valley with conspicuous success.

An experiment station maintained by the United States Bureau of Plant Industry at Chico has been used mainly as a plant introduction garden. Here imported species of trees, shrubs, and plants are tested before general distribution is made. Climate is an important consideration in these experiments, and the climatological data gathered here form an essential part of nearly every report. Of popular interest at present is the attempt to introduce the bamboo to the agriculture of the United States. Of the several species under culture it is hoped that at least one will be found adapted to production on a commercial scale.

The United States Reclamation Service maintains an experiment station at Orland, and here also climatological data are an important consideration. This is the administrative center of the Orland project, where reclamation on an extensive scale has made possible "the growing of two blades of grass where but one grew before."

A climatological survey is at present being conducted on a large tract of land owned by Mr. William Randolph Hearst, and situated in the vicinity of San Simeon. This tract, at present uncultivated, will be surveyed with the object of determining which kinds of agriculture will be best adapted for the different portions of the tract. A number of standard climatological stations have been established at strategic points on the tract. The survey is being made by the San Francisco engineering firm of Thomas Means.

A similar tract, partly under cultivation and partly devoted to grazing, is situated a few miles south of Bakersfield at the extreme southern end of the San Joaquin Valley. A climatological station is maintained as a part of the headquarters equipment.

The Grangers' Union, an association of ranchers in San Benito County, also maintains a climatological station at headquarters in Hollister.

INDUSTRIAL CLIMATOLOGY.

The largest single industry which keeps systematic climatological records is the Southern Pacific Co. Approximately 250 Southern Pacific Railway station agents keep temperature and precipitation records. The thermometer employed usually consists of an ordinary mercury thermometer, and at most stations it is simply nailed to the side of the railroad station building without an inclosing shelter of any kind. The instrument is read three times a day. The rain-gage used is but 3 inches in diameter. Monthly reports are forwarded to the company's headquarters in San Francisco. The data are used by the engineering and freight-claim departments, but as the data are obtained from instruments which are not recognized as standard, they are of little value for comparative purposes.

The development of hydroelectricity is one of the leading industries in California to-day. Because of the absence of coal deposits and the rapidly vanishing oil supply, hydroelectricity is destined to become increasingly important. For obvious reasons, hydroelectric power companies are much interested in climatological data, especially precipitation and evaporation. Climatological records are kept at nearly every hydroelectric generating station and at most reservoirs. Moreover, records are kept at many of the dams to determine the loss of stored water through evaporation. Most of the instrumental equipment used by the power companies is

standard. As the rain-gage is invariably an 8-inch standard, the precipitation data are comparable with those of hundreds of other rainfall stations. The power companies are naturally interested in the snowfall at high altitudes, since packed snow is really stored water which will become available upon melting. The management secures needed information from regular daily observations and from periodical snow surveys. Such snow surveys are also made by the Weather Bureau, by the State engineer, and by Prof. J. E. Church, jr., of the University of Nevada. Private, State, and Federal observers cooperate in this work. Cooperative stations of the Weather Bureau are situated at 15 power houses or reservoirs.

Mining companies are also dependent more or less upon climatic conditions, particularly with reference to precipitation, stream flow, and hydroelectricity. Cooperative stations of the Weather Bureau are situated at four gold mines, Grass Valley, Bishop Creek, Helen Mine, and Kennedy Mine, and at one quicksilver mine, Idria. The American Trona Corporation has recently erected a large plant on the site of an old lake bed in San Bernardino County, in the midst of the desert. Potash, borax, and other chemicals are extracted from the brine and residual deposits of the vanishing lake. The complete equipment of a first-class meteorological station is in operation here, including a triple register and an evaporation pan. The United States Smelting, Refining & Mining Co. operates a number of copper mines in extreme northern California. Fumes from a large smelter at Kennett are claimed to have influenced unfavorably the agriculture of a large territory surrounding, and much litigation has resulted. In order to secure climatological data needed in contesting these claims the company has installed complete first-class meteorological stations at Kennett and Redding. In addition, a service which includes about a dozen substations is maintained, each of the latter stations being equipped with thermometers, shelter, raingage, and wind vane. (It is of interest to note in passing that when the company established the latter service it was unable to purchase an inexpensive wind vane in the market, as there are apparently none on sale, so the instruments had to be made to order.)

The extraction of salt from sea water is an important industry in the San Francisco and San Diego Bay regions. Since temperature, sunshine, precipitation and evaporation are important factors in the evaporation of the brine, most of the plants are equipped with meteorological instruments. The Weather Bureau maintains a standard evaporation station at the Chula Vista plant of the Western Salt Co. near San Diego.

The transportation of oil through pipe lines is an important industry which is also dependent upon climatological conditions. There are hundreds of miles of such pipe lines in California through which the crude oil is pumped from the oil fields to the refineries. The latter are situated along the coast, and convert the crude oil into various petroleum products, particularly gasoline. It has been found that temperature plays an important part in the economy of oil transportation by pipe line. For this reason may of the pumping plants have been equiped with thermometers. The Weather Bureau maintains cooperative stations at four oil pumping plants, namely, Dudley, Maricopa, Middlewater and Coalinga.

At Crockett, on San Francisco Bay, is situated one of the world's largest refineries for the manufacture of cane sugar. The crude brown product of Hawaiian sugar cane is brought by steamer to this plant for refining. Many elements influence the process of sugar refining as practiced here, and the meteorological elements are among the most important. There are more than 60 instruments of various kinds in constant use, and a trained assistant devotes his whole and undivided attention to these. The meteorological elements of special significance are temperature, pressure, relative humidity and vapor pressure. To a less extent similar data are kept at beet-sugar refineries at Spreckels and Betteravia.

The production of silk through the culture of silk worms is an infant industry in the United States. The Seriterre Co. is experimenting with the culture of silk worms and the growing of mulberry trees at Seriterre, near Oroville. Thus far the success of the venture has exceeded early expectations. Whereas in foreign countries the culture of silk worms has been limited to air-temperature extremes of 63° F. and 85° F., at Seriterre the culture has been carried successfully through temperature extremes of 48° F. and 107° F. Mr. Guy Wilkinson, one of the prime movers in the venture, has expressed the opinion that the success is due to the stable absolute humidity and absence of marked changes in temperature from day to day. A privately equipped meteorological station is in operation here. There appears to be no good reason why California can not produce silk on a large scale.

Many business houses have found that it is to their own and their customers' interests to keep climatological records. The Marysville Water Co. has erected a meteorological kiosk in the center of a city park. The McCloud River Lumber Co. maintains a climatological station in a private park, the precipitation data being of special value in connection with winter logging operations. General stores in Newman and Cedarville also maintain climatological stations. The First National Bank of Turlock has recently established a similar station. Petaluma has become the most important poultry and egg producing center in northern California largely because of the prominence given by the Chamber of Commerce to the fact that the climate of the region is ideally adapted for poultry. Experimental attempts to convert solar radiation into mechanical energy by means of sunshine engines are being carried on in the desert portions of southeastern California, a part of the region of greatest sunshine in the United States.

At Planada a development company has erected and maintained a first-class meteorological station, including a triple register. In many other towns climatological records are kept by holding corporations, boards of trade, and chambers of commerce.

The development of water resources and the distribution of water for irrigation and for domestic use is intimately related to precipitation and evaporation Climatological records are kept by nearly every water company and irrigation district.

Over 150 airplanes are in use in California to-day, and the demand for aerological data is growing. Transcontinental air mail arrives at and departs from San Francisco daily. The Los Angeles Chamber of Commerce has a separate Department of Aeronautics and Meteorology. Besides the balloon school at Arcadia and the aviation school at North Island, in San Diego Bay, there are numerous flying schools. Commercial aviation companies maintain services available for sightseeing, advertising, and speedy travel. During the summer dry-season the United States Forest Service

maintains an aeroplane forest fire patrol. The Weather Bureau offices at San Francisco and Los Angeles disburse special information daily for the benefit of aviators. Aviation is possible throughout the year.

Newspaper offices are centers of public information in many small towns. Climatological stations are maintained by newspapers at Antioch, Brawley, Redlands, Fort Bidwell, and St. Helena.

CLIMATOLOGY OF RECREATION AND HEALTH.

The national forests and national parks of California are great playgrounds which offer recreation and health facilities to large numbers of persons every year. The United States Forest Service cordially cooperates with the Weather Bureau in securing climatological data which are of interest in recreation, as well as in connection with water supply, grazing, conservation, and protection from forest fires. Some of the climatological stations maintained by the Forest Service are supplied with anemometers in addition to the usual equipment of a cooperative station.

Climatological records are also kept at Glacier Point and at the superintendent's headquarters in the Yosemite National Park; also at Giant Forest in the Sequoia National Park. Various tourist hotels like Del Monte and Squirrel Inn find it good business policy to maintain a climatological record for use in advertising. Records are kept for the same reason at Venice, a beach resort, and at Avalon, an island resort. Many sanitariums in southern California keep climatological records in connection with the scientific treatment of patients. The United States Public Health Service hospital at Arrowhead Springs and the State hospitals at Napa and Stockton also maintain climatological stations for the same purpose. At the State penitentiary at Folsom detailed climatological records are kept at the headquarters of the warden.

From the standpoint of personal comfort and human health the significant features of California climates are light precipitation in most regions, the division of the year into wet and dry seasons, abundant sunshine throughout the year, absence of extreme temperatures, mild winters, and extreme dryness in the southern portion. The latter region is especially suited for convalescents. The entire coast of California serves both as a winter and a summer resort.

PRACTICAL CLIMATOLOGY.

In addition to the practical applications of climatology noted above, there are numerous features which can be enumerated but briefly here. It has been remarked that "we do not have weather in California, we have climate." To a large extent the statement is true. Moreover, in this State water is wealth, and "irrigation water is the lifeblood of the State." Furthermore, future development appears to be dependent upon hydroelectricity, a field of activity which still offers opportunities. A leading San Francisco newspaper recently stated editorially that the greatest problem facing California for the next 10 years is the conservation and use of every drop of rain which falls in the State.

The concentration of the manufacture of motion pictures in southern California is really a result of a favorable climate which makes it possible to work out of doors in comfort nearly every day of the year. California is also the greatest producer of seeds, primarily because climatic conditions favor the production and the harvesting of many varieties of vegetable and flower seeds. The coast region is well adapted for the wholesale production of beans, since the persistent summer fogs furnish sufficient moisture during the rainless season. Bulbs are now being grown on the northern coast because of cool, moist, and frostless climatic conditions. Olives are grown successfully on a commercial scale in the foothills, where frosts are infrequent.

Other miscellaneous facts follow. The determination of water rights is of such magnitude and importance that a State commission has been created to attend to the details. One San Francisco instrument manufacturer has sold over 1,000 rain gages, and other manufacturers have sold almost as many. In the course of a year the San Francisco office of the Weather Bureau reluctantly declines more than 300 offers of individuals who are willing to keep climatological records without compensation if the necessary apparatus is furnished. Rainfall is considered of such importance that when precipitation occurs the data are invariably given first-page space in the leading daily newspapers. Thousands of windmills in the agricultural regions are in operation daily during the dry season pumping water for irrigation purposes. The railroads which cross the Sierra Nevada Mountains are able to operate only because of snowsheds. Mountain observatories at Lick Observatory, Mount Wilson, Squirrel Inn, and Summit are collecting data which offer the student of mountain climatology excellent research material. Insurance against unfavorable weather is a legitimate activity which has become firmly established in California, and is destined to grow to large proportions in the future. The principal kinds of unfavorable weather for which insurance is now purchased are frosts, hail, floods, and rainfall during the fruit-drying and rice-harvesting seasons.

These are only the most conspicuous examples of the practical application of climatology in California.