II. AVERAGE ANNUAL PRECIPITATION IN THE UNITED STATES FOR THE PERIOD 1871-1901.

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The chart of average annual precipitation, accompanying this paper, is based primarily upon the observations of the United States Weather Bureau and of its immediate predecessor, the United States Signal Service. The work of voluntary observers in coöperation with the Smithsonian Institution, the Signal Service, and the Weather Bureau has also been utilized.

The total number of rainfall stations used in constructing the chart was 734, classed, according to length of record, as follows:

Number of stations having a record—	
Of 30 years or more	140
Of 20 to 30 years	183
Of 10 to 20 years	329
Under 10 years	82

These stations are not uniformly distributed throughout the United States, there being more stations in the Northeastern States than elsewhere. If the 734 stations were uniformly distributed, there would be a single station to each 4,100 square miles or an average distance apart of about 65 miles. The average distribution in the more thickly settled parts of the country is about one station to 2,500 square miles; in the sparsely populated regions, a single station sometimes represents an area of as much as 16,000 square miles, although the average is much less.

The observations used in the preparation of the chart cover the fundamental period 1871 to 1901, for which time continuous records have been obtained from about 125 stations. These stations fulfill most of the requirements of the so-called fundamental stations except as regards exposure. In the great majority of cases the exigencies of the service have necessitated not one but several removals from one building to another, so that homogeneity of exposure has been out of the question. The only check on the integrity of the observations is that which is afforded by the internal evidence of the records. It should be remembered that for each week from April to September and for each month of the year the weekly and monthly rainfalls are charted and studied both as to geographic distribution and as to the relations which they sustain to the seasonal average. It is, therefore, a comparatively easy matter to detect a marked change in the amount of rain caught at any single station and to refer it back to the cause. Small changes, due to altered exposures, can not, of course, be detected by weekly and monthly comparisons. It is probable that the errors introduced by the several removals were not of uniform sign, and that the excess of one period was offset by the deficit of another. A few cases have occurred where the new exposure of the gauge gave less than 80 per cent of the rainfall proper to the station. In all such cases the exposure of the gauge was changed and an appropriate correction applied to the imperfect record.

The records of the short series stations in some cases have been extended up to the full period by a process of extrapolation, based upon the assumption that the ratio which subsists between the rainfall at any single station and a near-by station, or group of stations, having the same climatic characteristics, is practically constant. Owing to the sparseness of the observing stations it was not always possible to secure as many as three fundamental stations for reduction purposes, and in a few cases records of fifteen to twenty years in length were accepted without correction.

The stations used in preparing the accompanying chart XXX-41 with their geographical coordinates, length of record, and altitude above sea level are given in detail in the following table.

In drawing isohyetals for a single month the fidelity with which the actual rainfall may be represented on the finished chart is largely a question of the scale of the map. The original manuscript maps from which the charts of rainfall, published in the Monthly Weather Review, are reproduced, is drawn on a scale of 1-10,000,000, or $\frac{1}{160}$ of an inch to a mile. This scale is not large enough to permit charting all of the available rainfall data. Thus, in Massachusetts, with an area of 8,040 square miles, but 6 of the 22 stations which report monthly can be charted. In general, not more than one-third of the total number of rainfall reports are charted each month.

Although the last ten years have been fruitful in extending the network of rainfall stations and in improving the quality of the observations, the richness of material so noticeable in preparing the current monthly precipitation charts immediately vanishes when we attempt to construct a chart of average precipitation for a period of thirty years. The total number of stations available for New England, the Middle Atlantic States, the Lake Region, the Ohio Valley, the middle and upper Mississippi Valley, and in the lowlands of California is sufficient; elsewhere, however, the number of stations is not sufficient.

In preparing the accompanying chart, isohyetals were drawn for every 5 inches of rainfall, beginning with the isohyetal of 10 inches and concluding with the isohyetal of 60 inches. The interval above the isohyetal of 60 inches varies from 10 to 20 inches.

From the one hundred and first meridian westward to the eastern slope of the Cascade Range, in Washington and Oregon, and the Sierras in California, almost all of the available records have been placed on the chart in small figures. In the mountain regions it will be noticed that the figures in some cases are greater than is indicated by the shading of the region. In Colorado, for example, the main mountain mass in the central portion of the State has been shaded to correspond to 15 inches of precipitation annually. There are six widely separated points within the area of 15 inches that have over 20 inches annual precipitation, viz:

Breckenridge, elevation	9,524 feet, 28 inches;	10 years record.
Clear View, elevation	9,500 feet, 24 inches;	12 years record.
Climax, elevation	11,325 feet, 34 inches;	7 years record.
Pikes Peak, elevation	14,134 feet, 30 inches;	17 years record.
Santa Clara, elevation	8,500 feet, 32 inches;	7 years record.
Summit, elevation	11,300 feet, 31 inches;	6 years record.

These stations are not disposed around the main Rocky Mountain chain so as to point to any simple relation between orography and rainfall. Some of the heaviest rainfalls in the State occur with surface winds blowing from the northeast or from the plains against the eastern face of the mountains. Again, heavy snows occur in winter on the southern slope of the Arkansas divide with southeast to south winds, while in other portions of the State precipitation occurs with northwest to north winds, in the rear of an area of low pressure. With these facts before us it did not seem advisable, in the absence of specific data, to attempt to follow, except in a very general way, the topographic features of the State, and since the valleys and parks between the high-level stations have a rainfall of less than 20 inches, it seemed best to let the shading show the minimum rainfall for the region as a whole and to place on the chart the values for the higher level stations.

The figures on the chart stand approximately in the location of the station. The orographic features of the surrounding country may be seen by an inspection of the accompanying hypsometric chart (XXX-39), reproduced by permission and through the courtesy of the Director of the United States Geological Survey.

A portion of the State of California has been left unshaded because of insufficient data. No data are available for the crest of the Sierra Nevada in that State, except along the line of the Union Pacific Railway. Following are the observation stations on that line in their order, crossing the range from the eastern or Nevada side to the western or California side:

Station.	Elevation.	Annual precipitation.
	Feet.	*Inches.*
Reno, Nev	4,484	5.4
Boca, Cal	5,535	20.0
Truckee, Cal	5,818	27.0
Summit, Cal	7,017	46.5
Cisco, Cal	5,939	49.6
Emigrant Gap, Cal	5,230	52.4
Iowa Hill, Cal	3,825	52.2
Colfax, Cal	242	46.6

The distance from Colfax, in the valley, to the summit of the Sierras is but 51 miles. The rainfall is practically the same at both stations. About 30 miles north of the line of railroad, on the western flank of the Sierras, there are two rainfall stations, Edmanton and La Porte, both in Plumas County. The average for seven years at La Porte (corrected) is 77 inches; at Edmanton, 70 inches. The evidence of these stations, in connection with that afforded by the line of stations along the railroad, would seem to indicate that the zone of maximum precipitation on the Sierras lies, not on the summit of the range, but between the 3,500 and 5,500 foot levels, respectively.

The relation between rainfall and topography is perfectly plain when a mountain mass, as the Sierra Nevada, lies at right angles to the rain-bearing winds. When, however, the rain-bearing winds are divided by the intrusion of a wedge-shaped mountain mass and the winds flow along its sides parallel with its general direction, but not over its crest, the relation becomes somewhat obscure. This is true in part of the northern rim of the basin of the Great Valley of California. North of the mountain mass of which Shasta is the culminating peak, the rainfall diminishes to less than 20 inches, while to the southwestward, as at Delta, in the shadow of the mountains which rise to an elevation of 7,000 feet, in Trinity County, immediately to the westward, the rainfall rises to 61 inches annually (18 years' observations). If a north and south line be drawn from the forty-first to the forty-second parallel about 20 miles west of Shasta it would pass over a region whose rainfall ranges from 18 inches at the north end of the line to 56 inches at the south end. It is manifestly impossible to portray such sharp variation on the accompanying map (XXX-41), whose scale is $\frac{1}{12000000}$.

The purpose of a rainfall chart, as understood by the writer, is not to furnish accurate detailed data to the engineer, but rather to serve as a graphic aid in quickly determining the general geographic distribution of rainfall.

For the region east of the Rocky Mountains the present chart is probably as accurate as can be had for some time to come. From the Rocky Mountains to the Pacific the chart presents the broad features of distribution only, leaving the details to be worked out when we shall have more observations, both for mountain and valley stations.

Geographical coordinates, elevation, length of record, and
AVERAGE ANNUAL PRECIPITATION
for rainfall stations in the United States and Canada for the period 1871-1901.

Stations.	Latitude.	Longitude.	Elevation.	Record.			Average annual precipitation.
				From—	To—	Years (inclusive).	
ALABAMA.	° ′	° ′	*Feet.*				*Inches.*
Auburn	32 40	85 30	826	1855	1894	12	51.20
Decatur	34 35	86 58	577	1879	1901	18	49.61
Greensboro	32 41	87 30	220	1855	1901	45	52.48
Mobile	30 41	88 02	69	1871	1901	30	63.10
Montgomery	32 23	86 18	219	1873	1901	29	51.82
Valleyhead	34 30	85 30	1,058	1885	1901	16	56.93
ARIZONA.							
Flagstaff	35 12	111 37	6,907	1888	1901	5	*24.39
Fort Apache	33 40	109 45	5,600	1872	1901	26	18.74
Fort Bowie	32 08	109 23	4,781	1867	1894	25	14.95
Fort Defiance	35 43	109 10	6,500	1852	1901	12	13.12
Fort Grant	32 36	109 53	4,780	1866	1901	29	14.76
Fort Huachuca	31 20	110 20	4,785	1886	1901	16	15.94
Fort Mohave	35 02	114 36	600	1859	1901	24	5.62
Gila Bend	32 59	112 46	737	1890	1901	11	5.05
Holbrook	34 55	110 10	5,047	1887	1900	13	8.06
Maricopa	33 08	112 02	1,190	1875	1901	21	5.37
Natural Bridge	34 26	111 34	4,990	1890	1901	12	*21.12
Phoenix	33 28	112 00	1,108	1876	1901	18	6.92
Prescott	34 33	112 28	5,318	1865	1901	30	15.30
San Carlos	33 16	110 27	3,456	1881	1901	20	11.95
Signal	34 22	113 35	1,652	1889	1901	12	6.98
Texas Hill	32 48	113 40	355	1879	1900	17	3.17
Tucson	32 14	110 54	2,404	1867	1901	34	11.37
Williams	35 10	112 02	6,700	1888	1899	6	*16.31
Yuma	32 44	114 36	141	1875	1901	25	2.88
ARKANSAS.							
Arkansas City	33 33	91 08	145	1882	1901	15	*49.19
Camden	33 32	92 48	123	1855	1901	14	*52.13
Dardanelle	35 13	93 09	330	1886	1901	13	44.42
Fayetteville	36 08	94 15	1,350	1870	1901	11	43.78
Fort Smith	35 22	94 24	418	1837	1901	35	40.82
Helena	34 33	90 36	197	1865	1901	27	56.78
Keesees Ferry	36 29	92 45	750	1881	1901	20	47.73
Little Rock	34 45	92 06	298	1879	1901	22	50.63
Mount Ida	34 34	93 38	....	1872	1895	13	51.68
Newport	35 34	91 09	233	1885	1901	13	50.23
Pine Bluff	34 15	91 59	215	1887	1901	10	*50.00
Stuttgart	34 32	91 24	228	1888	1901	13	50.27
Washington	33 34	93 41	660	1840	1901	33	52.74
CALIFORNIA.							
Anaheim	33 50	117 55	170	1878	1900	23	11.53
Antioch	38 00	121 48	46	1879	1900	22	12.57
Aptos	36 58	121 54	102	1885	1900	16	*24.23
Athlone	37 15	120 25	210	1885	1898	11	11.54
Auburn	38 54	121 50	1,360	1871	1899	29	33.58
Bakersfield	35 22	119 00	394	1889	1900	12	*4.89
Benicia Barracks	38 02	122 08	64	1849	1892	37	16.20
Bishop	37 20	118 19	4,450	1884	1900	17	4.27
Boca	39 25	120 05	5,535	1870	1900	31	20.14
Bowman	39 27	120 34	5,400	1871	1887	16	69.80
Borden	36 58	120 04	274	1875	1895	20	8.70
Caliente	35 17	118 41	1,290	1876	1900	25	10.63
Calistoga	38 38	122 34	363	1873	1900	28	35.01
Campo	32 37	116 30	253	1877	1894	10	19.80

Geographical coordinates, elevation, length of record, and AVERAGE ANNUAL PRECIPITATION for rainfall stations in the United States and Canada for the period 1871-1901—Continued.

Stations.	Latitude.	Longitude.	Elevation.	Record.			Average annual precipitation.
				From—	To—	Years (inclusive).	
CALIFORNIA—continued.	° ′	° ′	*Feet.*				*Inches.*
Camp Wright	39 45	123 00	1,800	1864	1883	10	42.50
Cedarville	41 30	120 02	4,675	1859	1901	7	*16.69
Cherokee	39 42	121 32	......	1871	1884	11	44.92
Chico	39 43	121 51	193	1871	1899	29	22.36
Colfax	39 8	120 57	242	1870	1900	31	46.63
Colton	34 02	117 22	965	1877	1900	24	10.47
Corning	39 58	122 12	277	1886	1900	15	20.79
Covelo	39 40	123 15	......	1881	1894	13	*37.95
Crescent City	41 45	124 12	50	1859	1901	16	70.22
Crokers	37 48	119 53	4,453	1896	1901	5	50.84
Cuyamaca	32 58	116 35	4,800	1887	1901	10	29.98
Davisville	38 33	121 43	51	1872	1900	29	16.55
Delano	35 57	119 26	319	1876	1900	25	6.06
Delta	41 00	122 23	1,138	1883	1900	18	*61.36
Descanso	32 50	116 40	3,500	1896	1901	6	19.55
Dunnigan	38 54	121 58	65	1877	1900	24	19.10
Dunsmuir	41 12	122 16	2,285	1889	1900	12	56.30
Eldorado	38 41	120 51	1,609	1889	1900	12	37.18
Elmira	38 27	121 57	75	1886	1900	15	22.29
Escondido	33 18	117 08	650	1876	1901	13	13.90
Eureka	40 48	124 11	64	1887	1901	15	45.11
Fallbrook	33 23	117 09	700	1876	1900	25	17.30
Farmington	37 56	121 01	111	1877	1900	24	16.33
Fernando	34 16	118 26	1,066	1878	1900	23	14.19
Folsom City	38 40	121 10	182	1872	1900	29	23.61
Fort Bidwell	41 53	120 11	4,640	1863	1893	27	19.64
Fort Crook	41 10	121 20	3,500	1858	1869	10	24.50
Fort Gaston	41 05	123 15	397	1861	1892	28	54.60
Fort Miller	37 00	119 40	402	1851	1864	6	17.68
Fort Ross	38 35	123 05	100	1875	1900	25	50.71
Fort Tejon	34 55	118 44	3,422	1855	1901	12	15.12
Fresno	36 43	119 49	332	1877	1901	24	9.34
Fruto	39 21	122 27	624	1889	1900	12	20.93
Galt	38 16	121 17	49	1878	1900	23	18.17
Georgetown	38 55	120 51	2,750	1873	1900	28	57.22
Gilroy	36 59	121 33	193	1874	1900	27	19.55
Goshen	36 21	119 24	286	1875	1899	19	7.67
Hollister	36 51	121 25	284	1874	1900	27	12.31
Hornbrook	41 50	122 50	2,154	1887	1894	6	13.70
Humboldt	40 46	124 10	50	1854	1896	32	37.10
Hydesville	40 32	123 58	400	1883	1899	11	*37.65
Independence	36 50	118 10	4,598	1865	1901	17	5.58
Indio	33 49	116 14	20	1878	1900	23	2.43
Ione	38 21	120 56	287	1878	1900	23	19.90
Jolon	36 00	121 15	960	1882	1899	17	18.28
Keeler	36 35	117 50	3,622	1884	1900	16	2.76
Keene	35 12	118 40	2,705	1877	1899	20	14.31
Kennedy Gold Mine	38 15	120 45	1,500	1892	1900	9	*37.04
Kingsburg	36 39	119 33	301	1879	1899	19	8.73
King City	36 12	121 06	332	1887	1900	14	10.65
Knights Landing	38 47	121 41	45	1878	1900	23	18.32
Kono Tayee	39 02	122 57	1,325	1874	1900	19	22.74
Lagrange	37 42	120 28	293	1868	1899	31	16.71
Laporte	39 45	121 00	5,000	1894	1900	7	*77.67
Lemoore	36 17	119 51	227	1879	1899	19	7.53
Lewis Creek	36 12	118 58	456	1879	1890	10	12.00
Livermore	37 40	121 45	485	1871	1900	30	15.30
Los Angeles	34 03	118 05	330	1877	1901	24	15.64
Los Banos	37 04	120 46	121	1873	1900	28	7.62
Malakoff Mine	39 22	120 50	3,200	1884	1899	6	61.84
Mammoth Tank	33 07	115 17	257	1878	1900	23	1.81
Marysville	39 09	121 35	67	1871	1900	30	18.35
Mendocino	39 18	123 48	......	1871	1890	14	51.50
Merced	37 19	120 30	171	1872	1900	29	10.26
Modesto	37 38	120 58	90	1871	1900	30	9.96
Mojave	35 03	118 11	2,751	1877	1900	24	4.79
Monterey	36 37	121 52	15	1875	1900	25	15.15
Mount Hamilton	37 20	121 38	4,209	1881	1900	20	32.19
Napa	38 18	122 17	20	1877	1900	24	23.81
Needles	34 50	114 35	491	1892	1900	9	2.79
Newman	37 20	121 00	92	1889	1900	12	1.23
Nevada	39 10	121 00	2,580	1864	1900	30	15.80
Newhall	34 25	118 33	1,200	1877	1900	24	55.62
Ogilby	32 45	114 50	354	1890	1900	11	11.10
Orland	39 45	122 12	254	1883	1900	18	17.02
Pajaro	36 53	121 44	31	1873	1894	20	19.52
Palm Springs	33 40	39 30	584	1889	1900	12	3.53
Paso Robles	35 38	120 41	723	1887	1900	14	15.00
Pigeon Point	37 12	122 21	150	1875	1899	14	15.28
Point Arenas	38 54	123 36	6	1875	1899	15	32.32
Point Conception	34 26	120 24	258	1876	1899	14	10.01
Point Reyes Light	38 00	123 00	650	1889	1901	11	22.30
Portersville	36 04	119 02	461	1889	1900	12	8.44
Ravenna	34 26	118 17	2,358	1879	1897	11	9.90
Red Bluff	40 10	122 14	309	1872	1901	30	23.81
Redding	40 36	122 27	565	1875	1900	26	13.29
Sacramento	38 35	121 30	71	1849	1901	52	19.45
Salton	33 29	115 53	263	1888	1901	12	*2.79
San Diego	32 43	117 10	87	1871	1901	30	9.40
San Francisco	37 48	122 26	60	1849	1901	52	22.83
San Luis Obispo	35 18	120 39	201	1869	1901	29	20.92
San Mateo	37 34	122 19	22	1874	1900	27	20.71
Santa Barbara	34 23	119 40	100	1868	1900	33	16.59
Santa Monica	34 00	118 28	50	1879	1899	12	13.74
Scott Valley	41 45	123 02	2,570	1859	1891	32	24.70
Sisson	41 19	122 18	3,555	1889	1900	12	*36.41
Spadra	34 03	117 46	705	1874	1894	16	12.80
Summit	39 19	120 27	7,017	1871	1900	30	46.58
Sumner	35 44	119 00	422	1874	1888	13	5.10
Templeton	35 30	120 41	773	1886	1899	12	17.70
Traver	36 27	119 30	291	1885	1894	9	*8.45
Visalia	36 20	119 17	348	1870	1901	15	10.04
Volcano Springs	33 16	115 34	220	1889	1900	12	*1.70
Weaverville	40 47	122 58	2,000	1869	1894	16	38.60
White Water	33 54	116 39	......	1877	1884	6	5.37
Woodland	38 42	121 59	63	1873	1900	28	17.74
Yreka	41 45	122 32	2,635	1872	1900	28	16.91
COLORADO.							
Blaine	37 30	102 30	3,400	1887	1901	10	16.85
Breckenridge	39 30	106 00	9,524	1889	1901	10	*28.11
Cheyenne Wells	38 48	102 22	4,259	1889	1901	9	16.29
Clear View	37 10	104 55	9,500	1889	1901	12	23.76
Climax	39 25	106 05	11,325	1888	1896	7	*33.75
Colorado Springs	38 51	104 47	6,032	1871	1901	17	14.35
Denver	39 45	105 00	5,281	1871	1901	30	14.07
Durango	37 15	107 50	6,534	1886	1901	10	16.80
Fort Collins	40 35	105 02	5,000	1872	1901	17	14.00
Fort Garland	37 25	105 23	7,937	1858	1883	22	12.60
Fort Lewis	37 15	107 57	8,500	1880	1891	11	17.20
Grand Junction	39 05	108 25	4,608	1885	1901	12	*8.57
Hamps	39 10	103 25	5,500	1891	1901	10	13.29
Hoehne	37 15	104 20	5,721	1891	1901	10	13.16
Las Animas	38 04	103 12	3,899	1881	1901	18	11.71
Leroy	40 34	102 56	4,380	1889	1901	12	14.90
Montrose	38 30	107 56	5,796	1885	1897	11	9.84
Pagoda	40 30	107 30	7,000	1891	1901	11	19.54
Parachute	39 32	108 05	5,105	1889	1901	12	10.71
Pikes Peak	38 50	105 02	14,134	1873	1894	17	29.72
Pueblo	38 18	104 36	4,753	1869	1901	17	12.27
Rangely	40 05	108 45	......	1894	1901	6	8.06
Santa Clara	37 25	104 45	8,500	1894	1901	7	*32.28
Summit	37 28	106 35	11,300	1876	1892	6	*30.96
Yuma	40 02	102 40	4,128	1890	1901	11	17.12
CONNECTICUT.							
Hartford	41 42	72 04	36	1870	1901	32	46.83
New Haven	41 18	72 56	45	1804	1901	50	46.44
New London	41 21	72 05	90	1871	1901	31	46.55
DISTRICT OF COLUMBIA.							
Washington	38 54	77 03	112	1871	1901	31	44.10
FLORIDA.							
Archer	29 30	82 30	77	1883	1901	15	55.67
Brooksville	28 33	82 22	220	1892	1901	10	57.72
Eustis	28 45	81 45	200	1890	1901	11	49.44
Fort Meade	27 46	81 50	80	1851	1901	18	53.50
Jacksonville	30 20	81 39	14	1871	1901	30	53.32
Jupiter	26 57	80 07	28	1888	1901	14	59.57
Key West	24 33	81 49	10	1832	1901	54	38.39
Lake City	30 12	82 40	216	1857	1901	14	54.20
Merritt Island	28 18	80 41	22	1878	1901	24	51.54
Pensacola	30 25	87 13	56	1879	1901	22	57.64
Puntarasa	26 36	82 14	14	1871	1888	12	43.54
St. Augustine	29 54	81 18	25	1876	1901	23	49.47
Tallahassee	30 27	84 16	200	1872	1901	15	58.19
Tampa	27 57	82 27	30	1840	1901	29	53.13
GEORGIA.							
Americus	32 03	84 14	362	1876	1901	15	48.31
Atlanta	33 45	84 23	1,050	1859	1901	32	52.01
Augusta	33 28	81 54	183	1871	1901	31	48.08
Blakely	31 23	84 57	300	1889	1901	11	54.18
Forsyth	33 00	83 55	735	1874	1900	22	53.24
Point Peter	33 57	82 59	1,000	1889	1901	12	50.51
Poulan	31 28	83 55	365	1890	1901	11	50.06
Rome	34 16	85 08	627	1878	1901	20	50.67
Savannah	32 05	81 05	87	1837	1901	53	50.19
Thomasville	30 53	84 01	330	1878	1901	20	53.17
Toccoa	34 37	83 21	665	1879	1901	17	58.14
Walthourville	31 44	81 38	......	1878	1886	6	*46.00
IDAHO.							
Boise	43 34	116 08	2,768	1864	1901	29	14.16
Fort Sherman	47 42	116 38	2,198	1881	1897	14	25.12
Kootenai	48 22	116 30	2,195	1889	1901	12	25.75
Lake	44 36	111 20	6,700	1890	1901	11	17.36
Lewiston	46 23	117 00	757	1864	1901	19	16.85
Moscow	46 40	117 00	2,569	1892	1901	10	23.17
Murray	47 40	116 00	2,750	1893	1901	8	*40.40
Oakley	42 15	113 57	4,191	1893	1901	8	7.98
Paris	42 13	111 25	6,018	1893	1901	8	11.49
Pocatello	42 52	112 29	4,482	1892	1901	10	13.20
Soldier	43 25	114 59	5,200	1894	1901	7	*13.98
Swan Valley	43 10	112 00	5,434	1894	1901	7	14.43
ILLINOIS.							
Aurora	41 47	88 08	676	1879	1901	19	36.48
Cairo	37 00	89 10	359	1871	1901	30	42.29
Chicago	41 52	87 38	823	1870	1901	31	33.64
Galesburg	40 56	90 22	786	1861	1878	12	33.00
Greenville	38 50	89 25	635	1882	1901	18	42.93
Griggsville	39 41	90 40	650	1882	1901	19	35.36
Marengo	42 15	88 37	842	1850	1901	50	34.54
Mattoon	39 29	88 24	724	1869	1901	21	39.72
McLeansboro	38 07	88 35	462	1882	1901	12	41.00

Geographical coordinates, elevation, length of record, and AVERAGE ANNUAL PRECIPITATION for rainfall stations in the United States and Canada for the period 1871–1901—Continued.

Stations.	Latitude.	Longitude.	Elevation.	Record. From—	Record. To—	Record. Years (inclusive).	Average annual precipitation.
ILLINOIS—continued.	° ′	° ′	*Feet.*				*Inches.*
Mount Carmel	38 27	87 49	424	1884	1901	17	41.45
Peoria	40 42	89 36	475	1856	1901	46	34.36
Philo	39 59	88 08	771	1885	1901	16	35.34
Springfield	39 48	89 39	644	1879	1901	22	37.90
Winnebago	42 17	89 12	900	1857	1901	23	33.29
INDIANA.							
Angola	41 36	85 00	1,052	1884	1901	16	38.40
Columbus	39 13	85 56	632	1884	1901	17	37.27
Evansville	38 02	87 29	370	1858	1901	18	45.45
Farmland	40 11	85 10	1,101	1882	1901	14	36.81
Huntington	40 52	85 30	741	1882	1901	13	36.77
Indianapolis	39 46	86 09	698	1871	1901	30	42.40
Laconia	38 05	86 07	530	1866	1895	25	43.20
Lafayette	40 28	86 54	667	1854	1901	20	36.90
Logansport	40 45	86 22	625	1854	1901	20	35.19
New Harmony	38 10	87 54	350	1853	1883	27	39.71
Richmond	39 51	84 53	850	1852	1901	27	41.16
Rockville	39 46	87 10	1,100	1887	1901	13	37.45
Spiceland	39 48	85 18	1,025	1863	1890	28	39.80
Vevay	38 46	84 59	525	1865	1901	34	43.36
Worthington	39 09	87 00	540	1882	1901	19	42.24
INDIAN TERRITORY AND OKLAHOMA.							
Arapaho	35 30	98 55	1,575	1893	1901	8	27.07
Burnett	35 10	97 10	1,200	1892	1901	10	32.12
Eufaula	35 22	95 35	617	1887	1897	9	36.96
Fort Gibson	35 50	95 20	510	1836	1890	27	35.10
Fort Reno	35 33	98 01	3,200	1883	1901	17	27.36
Fort Sill	34 40	98 23	1,200	1870	1901	29	29.37
Fort Supply	36 33	99 32	1,901	1873	1894	15	22.46
Fort Towson	34 01	95 12	300	1836	1854	14	50.80
Fort Washita	34 14	96 38	645	1843	1860	15	38.30
Healdton	34 09	97 25	....	1889	1901	11	33.65
Mangum	34 49	99 29	1,600	1892	1901	10	25.26
Oklahoma	35 26	97 33	1,218	1890	1901	11	30.94
Tulsa	36 08	95 56	700	1887	1901	14	33.48
IOWA.							
Afton	41 16	94 25	1,223	1871	1901	14	33.98
Algona	43 15	94 05	1,500	1861	1901	22	27.25
Amana	41 47	91 55	721	1875	1901	25	32.80
Charles City	43 05	92 43	1,012	1875	1901	17	29.40
Clarinda	40 43	95 18	1,044	1872	1901	17	31.14
Clinton	41 51	90 10	591	1865	1901	27	35.48
Cresco	43 32	92 10	1,855	1871	1900	28	30.60
Davenport	41 30	90 39	706	1871	1901	30	32.73
Des Moines	41 36	93 38	780	1878	1901	23	32.36
Dubuque	42 30	90 40	680	1851	1901	47	34.18
Fort Madison	40 37	91 28	600	1848	1901	47	37.08
Hampton	42 30	93 20	1,200	1877	1901	14	31.28
Independence	42 29	91 57	850	1867	1901	32	31.58
Keokuk	40 25	91 21	600	1871	1901	30	35.28
Logan	41 39	95 47	900	1866	1901	26	32.85
Monticello	42 13	91 15	880	1855	1901	45	35.18
Muscatine	41 26	91 05	586	1846	1894	49	38.80
Oskaloosa	41 18	92 36	750	1875	1901	17	30.00
Sibley	43 24	95 43	1,512	1875	1901	16	26.44
Sioux City	42 35	96 27	1,258	1887	1901	12	24.97
Sac City	42 25	95 00	900	1870	1901	22	30.47
KANSAS.							
Coolidge	38 00	102 00	3,341	1892	1901	9	*14.19
Dodge	37 45	100 01	2,524	1874	1901	27	20.63
Downs	39 30	98 25	1,488	1878	1897	19	25.42
Ellinwood	38 21	98 35	1,841	1874	1901	12	26.33
Emporia	38 24	96 12	1,132	1879	1901	22	31.67
Englewood	37 03	99 59	1,955	1888	1901	12	21.09
Eureka Ranch [a]	38 56	99 33	2,320	1868	1901	32	21.80
Horton	39 40	95 31	1,186	1888	1901	12	31.44
Independence	37 13	95 41	794	1872	1901	30	36.58
Lawrence	38 58	95 44	849	1861	1901	36	35.82
Manhattan	39 12	96 37	1,125	1858	1901	40	29.90
Oberlin	39 48	100 32	2,539	1887	1901	14	23.36
Rome	37 09	97 24	1,216	1886	1901	14	26.70
Salina	38 50	97 36	1,225	1882	1901	17	26.57
Topeka	39 03	95 39	884	1858	1901	23	32.90
Viroqua	37 00	101 57	3,215	1871	1901	10	*17.07
Wallace	38 54	101 35	3,253	1870	1901	22	*17.42
Wichita	37 41	97 20	1,358	1888	1901	13	29.70
Yates Center	37 53	95 43	1,040	1879	1900	21	34.30
KENTUCKY.							
Bowling Green	36 58	86 25	600	1880	1901	14	47.62
Burnside	37 00	84 37	773	1885	1901	13	49.21
Canton	36 50	87 57	300	1889	1900	11	46.00
Catlettsburg	38 24	82 27	544	1887	1901	14	42.93
Earlington	37 16	87 28	370	1889	1901	11	49.96
Greensburg	37 16	85 33	581	1887	1901	14	46.65
Lexington	38 02	84 33	995	1872	1901	17	44.04
Louisville	38 15	85 45	551	1871	1901	29	44.97
Mount Sterling	38 10	84 55	930	1889	1901	11	46.76
LOUISIANA.	° ′	° ′	*Feet.*				*Inches.*
Alexandria	31 18	92 23	77	1882	1901	19	56.72
Amite	30 44	90 28	130	1882	1901	12	61.68
Baton Rouge	30 26	91 11	41	1843	1899	27	59.41
Grand Coteau	30 27	91 58	93	1883	1901	19	53.43
Jessup	31 33	93 32	80	1836	1845	10	45.60
Lake Charles	30 12	93 07	22	1873	1901	13	54.02
Liberty Hill	32 23	92 46	....	1885	1901	16	50.38
Monroe	32 29	92 02	100	1882	1901	17	*52.91
New Orleans	29 56	90 03	25	1836	1901	50	55.70
Paincourtville	30 01	91 01	....	1890	1901	10	58.95
Port Eads	29 9	89 15	7	1881	1901	11	56.08
Shreveport	32 30	93 40	249	1871	1901	30	46.58
MAINE.							
Bar Harbor	44 23	68 12	50	1885	1901	16	47.92
Cornish	43 44	70 51	784	1856	1901	46	46.66
Eastport	44 54	66 59	40	1873	1901	27	44.16
Fairfield	44 35	69 35	90	1886	1901	32	38.35
Flagstaff	45 05	70 20	1,400	1895	1901	6	*41.45
Gardiner	44 14	69 48	76	1837	1901	59	43.43
Houlton	46 07	67 49	470	1836	1896	16	38.39
Kineo	45 32	69 40	1,100	1895	1901	5	*39.02
Mayfield	45 04	69 40	1,000	1885	1901	15	45.13
Orono	44 56	68 44	137	1870	1901	29	44.81
Portland	43 39	70 15	95	1871	1901	30	42.79
Rumford	44 30	70 37	600	1861	1901	11	43.49
MARYLAND.							
Baltimore	39 17	76 37	13	1817	1901	63	41.55
Cumberland	39 39	78 45	700	1871	1901	29	33.46
Fallston	39 30	76 24	300	1870	1901	28	46.73
Mardela Springs	38 30	75 39	25	1888	1899	11	44.74
Mount St. Marys	39 43	77 20	720	1867	1901	20	44.37
St. Inigoes	38 10	76 20	10	1871	1879	7	46.70
Solomons	38 20	76 27	20	1892	1901	10	*42.68
Sunnyside	39 20	79 27	2,440	1893	1901	9	54.25
Woodlawn	39 39	76 04	....	1865	1875	11	47.79
MASSACHUSETTS.							
Amherst	42 22	72 32	267	1836	1900	65	44.51
Boston	42 21	71 04	18	1818	1901	84	45.26
Fitchburg	42 36	71 50	700	1861	1901	38	42.29
Nantucket	41 17	70 06	14	1847	1901	28	38.76
New Bedford	41 39	70 56	100	1813	1901	88	43.99
Pittsfield	42 27	73 15	1,084	1894	1901	7	*43.59
Taunton	41 54	71 06	30	1874	1899	24	46.79
Williamstown	42 42	73 13	690	1823	1901	30	39.68
Worcester	42 16	71 49	483	1841	1901	44	46.68
MICHIGAN.							
Adrian	41 58	84 11	1,240	1871	1901	23	38.90
Alma	43 24	84 37	750	1887	1901	14	*31.26
Alpena	45 05	83 30	609	1872	1901	29	33.86
Calumet	47 24	88 12	1,250	1887	1901	13	32.00
Charlevoix	45 13	85 20	610	1887	1901	11	31.66
Detroit	42 20	83 03	597	1836	1901	51	31.95
Escanaba	45 48	87 05	608	1871	1901	27	32.99
Grand Haven	43 05	86 18	620	1871	1901	28	34.32
Grayling	44 40	84 48	1,134	1887	1901	12	*33.20
Harbor Beach	43 51	82 31	630	1887	1901	14	31.65
Kalamazoo	42 20	85 38	900	1876	1901	25	35.30
Lansing	42 44	84 26	883	1863	1901	38	31.65
Lathrop	46 08	87 13	1,142	1888	1901	9	32.32
Marquette	46 32	87 35	710	1857	1901	38	32.48
Ontonagon	46 53	89 31	620	1859	1873	12	25.64
Port Huron	42 58	82 26	639	1836	1901	35	31.47
Reed City	43 44	85 28	1,016	1877	1886	9	*33.70
St. Ignace	45 50	84 50	630	1887	1901	12	30.88
Sault Ste Marie	46 28	84 22	642	1836	1901	42	30.82
Traverse City	44 45	85 40	598	1871	1901	30	36.30
MINNESOTA.							
Beaver Bay	47 12	91 18	657	1858	1874	15	27.90
Duluth	46 48	92 06	672	1870	1901	31	30.16
Grand Meadow	43 42	92 37	1,338	1887	1901	12	28.80
Lake Winnibigoshish	47 21	94 08	1,290	1857	1901	13	26.92
Long Prairie	46 00	94 59	1,299	1893	1901	9	*25.88
Minneapolis	44 58	93 15	856	1866	1901	34	28.75
Moorhead	46 54	96 55	935	1881	1901	21	24.12
Morris	45 30	95 58	1,170	1885	1901	16	22.88
New Ulm	44 19	94 30	821	1864	1901	19	25.42
Ripley, Fort	46 10	94 24	1,130	1850	1895	30	27.00
Rolling Green	43 45	94 35	753	1887	1901	14	25.55
St. Paul	44 56	93 05	800	1836	1901	53	26.99
St. Vincent	48 56	97 14	804	1880	1895	15	19.14
Wabasha	44 30	92 15	850	1857	1901	13	28.79
MISSISSIPPI.							
Biloxi	30 26	88 56	24	1893	1901	7	64.10
Brookhaven	31 34	90 29	430	1870	1901	17	57.49
Canton	32 36	90 00	228	1882	1901	17	51.16
Columbus	33 31	88 28	250	1855	1901	39	54.03

[a] Eureka Ranch combined with Fort Hayes.

Geographical coordinates, elevation, length of record, and AVERAGE ANNUAL PRECIPITATION for rainfall stations in the United States and Canada for the period 1871–1901—Continued.

Stations.	Latitude.	Longitude.	Elevation.	Record.			Average annual precipitation.
				From—	To—	Years (inclusive).	
MISSISSIPPI—continued.	° ′	° ′	*Feet.*				*Inches.*
Greenville	33 27	91 01	126	1887	1901	14	*52.25
Meridian	32 22	88 44	375	1889	1901	9	*57.52
Vicksburg	32 22	90 53	247	1840	1901	47	52.75
Water Valley	34 09	89 35	300	1886	1901	16	51.28
Waynesboro	31 41	88 38	191	1882	1901	9	*55.93
MISSOURI.							
Birch Tree	36 59	91 29	998	1893	1901	8	*46.77
Conception	40 22	94 40	982	1883	1901	12	35.20
Columbia	38 58	92 14	784	1889	1901	12	37.52
Glasgow	39 15	92 52	749	1872	1901	22	34.55
Hannibal	39 41	91 20	534	1854	1901	12	*35.90
Hermann	38 41	91 28	516	1874	1901	26	38.06
Ironton	37 38	90 37	925	1878	1901	23	*44.11
Kansas City	39 05	94 37	963	1870	1901	26	36.09
Lebanon	37 42	92 41	1,265	1878	1901	12	44.38
Miami	39 18	93 15	622	1847	1901	52	35.80
Oregon	39 59	95 09	1,113	1855	1901	46	36.12
Princeton	40 25	93 32	1,026	1888	1901	14	37.22
St. Louis	38 38	90 12	567	1836	1901	65	40.70
Springfield	37 12	93 18	1,324	1882	1901	15	44.12
MONTANA.							
Crow Agency	45 42	107 34	3,040	1879	1901	19	*14.38
Columbia Falls	48 25	114 15	2,800	1893	1901	8	*21.83
Bozeman	45 41	111 03	4,900	1868	1898	16	21.21
Fort Benton	47 50	110 41	2,730	1869	1900	16	13.40
Great Falls	47 28	111 15	3,350	1892	1901	10	13.21
Glendive	47 06	104 31	1,900	1889	1901	12	16.31
Havre	48 34	109 40	2,505	1880	1901	21	14.25
Helena	46 34	112 04	4,110	1880	1901	18	14.63
Kipp	48 40	112 58	4,149	1894	1901	7	*21.37
Lewiston	47 01	109 30	4,292	1881	1901	12	17.61
Martinsdale	46 27	110 19	4,800	1890	1901	12	15.70
Miles City	46 25	105 49	2,371	1877	1901	24	13.00
Missoula	46 54	114 10	3,225	1870	1900	19	15.93
Poplar	48 08	105 10	2,200	1882	1901	14	*15.70
Troy	48 25	115 58	2,250	1895	1901	7	23.36
Virginia City	45 10	112 00	5,600	1871	1898	17	15.50
NEBRASKA.							
Fort Robinson	42 50	103 24	3,764	1883	1901	18	16.38
Genoa	41 25	97 40	1,584	1876	1901	26	26.94
Hay Springs	42 40	102 38	3,821	1886	1901	13	18.93
Hebron	40 09	97 34	1,421	1886	1901	14	26.42
Imperial	40 31	101 31	3,278	1890	1901	7	*25.29
Lincoln	40 49	96 45	1,189	1875	1901	19	26.39
Marquette	40 58	98 00	1,830	1880	1900	20	25.47
Minden	40 30	98 56	2,162	1849	1901	33	29.43
North Platte	41 08	100 45	2,821	1867	1901	34	17.66
Norfolk	41 59	97 23	1,532	1873	1901	11	23.38
Omaha	41 16	95 56	1,105	1857	1901	33	30.39
Ravenna	41 02	98 54	2,028	1878	1901	24	24.62
Santee	42 49	97 43	....	1871	1901	10	22.31
Sidney Barracks	41 09	102 59	4,096	1872	1894	15	14.90
Tecumseh	40 21	96 11	1,114	1878	1901	20	31.60
Valentine	42 50	100 32	2,598	1885	1901	14	19.75
Whitman	42 00	101 30	3,599	1890	1900	7	*14.43
NEVADA.							
Austin	39 29	117 01	6,211	1877	1900	10	*12.88
Battle Mountain	40 38	116 52	5,311	1870	1900	25	7.11
Camp McDermitt	41 58	117 40	4,700	1866	1893	20	13.70
Carson City	39 10	119 46	4,720	1875	1901	24	11.59
Halleck	40 58	115 27	5,229	1870	1900	25	8.42
Hawthorne	38 33	118 34	4,569	1884	1900	14	*3.21
Hot Springs	39 49	119 02	4,072	1870	1900	26	3.65
Humboldt	40 38	118 14	4,236	1870	1900	29	5.57
Palmetto	37 26	117 40	6,500	1890	1900	10	*14.37
Pioche	37 56	114 26	6,110	1877	1893	10	*12.41
Reno	39 33	119 47	4,484	1870	1900	25	5.42
Toano	41 07	114 26	5,975	1870	1900	29	8.08
Tybo	38 20	116 27	6,500	1890	1900	9	*9.89
Winnemucca	40 58	117 43	4,344	1870	1901	31	8.54
NEW HAMPSHIRE.							
Bethlehem	44 10	71 35	1,470	1892	1901	9	*40.47
Concord	43 12	71 29	550	1853	1901	45	39.99
Hanover	43 42	72 15	603	1834	1901	52	36.13
Lakeport	43 35	71 30	....	1857	1895	23	42.90
Nashua	42 46	71 29	120	1885	1901	16	42.93
North Conway	44 01	71 01	575	1887	1901	13	44.18
Mount Washington	44 16	71 18	6,279	1871	1890	16	83.50
NEW JERSEY.							
Atlantic City	39 22	74 25	52	1873	1901	27	39.94
Dover	40 54	74 34	619	1867	1900	14	*49.99
Freehold	40 15	74 16	187	1874	1900	23	49.18
Newark	40 44	74 10	140	1843	1900	55	48.09
New Brunswick	40 30	74 27	61	1854	1900	47	47.30
Newton	41 04	74 45	678	1879	1900	11	*48.00
Trenton	40 14	74 45	60	1865	1900	28	49.00
Vineland	39 29	75 01	119	1867	1900	29	46.97

Stations.	Latitude.	Longitude.	Elevation.	Record.			Average annual precipitation.
				From—	To—	Years (inclusive.)	
NEW MEXICO.	° ′	° ′	*Feet.*				*Inches.*
Albert	35 59	103 50	4,700	1890	1901	11	16.76
Albuquerque	35 05	106 39	5,200	1850	1901	19	7.58
Carlsbad	32 28	104 05	3,122	1889	1901	6	11.85
Fort Bayard	32 46	108 02	6,040	1867	1901	24	13.11
Fort Craig	33 38	107 00	4,619	1852	1884	21	10.89
Fort Stanton	33 29	105 38	7,500	1856	1895	19	18.26
Fort Union	35 54	104 57	6,835	1851	1901	37	19.95
Fort Wingate	35 29	108 31	6,649	1865	1901	33	13.85
Gallinas Spring	35 12	104 31	5,272	1885	1901	17	16.00
Lordsburg	32 20	108 41	4,245	1881	1901	16	8.14
Mesilla Park	32 20	106 45	3,873	1892	1901	9	9.40
Santa Fe	35 41	105 57	7,013	1850	1901	42	14.52
Roswell	33 28	104 29	3,570	1889	1901	6	*18.21
NEW YORK.							
Albany	42 39	73 45	97	1826	1901	74	39.14
Angelica	42 18	78 03	1,340	1856	1901	13	38.97
Auburn	42 55	76 28	715	1827	1901	31	35.98
Buffalo	42 53	78 53	767	1832	1901	47	37.64
Cooperstown	42 42	74 57	1,250	1854	1901	48	39.26
Elmira	42 05	76 50	860	1852	1901	9	33.19
Gouveneur	44 25	75 35	400	1833	1874	23	31.15
Honeymead Brook	41 50	73 45	450	1884	1901	17	41.89
Humphrey	42 14	78 21	1,950	1883	1901	18	44.46
Ithaca	42 27	76 29	817	1828	1901	41	32.75
Keene Valley	44 10	73 51	1,000	1879	1901	10	34.40
Lowville	43 47	75 33	900	1827	1901	34	35.41
New York	40 43	74 00	314	1836	1901	66	45.42
Oswego	43 29	76 35	335	1844	1901	46	36.80
Oxford	42 28	75 32	958	1829	1901	35	38.97
Penn Yan	42 42	77 04	750	1829	1901	56	28.90
Plattsburg	44 41	73 26	125	1840	1901	38	29.45
Potsdam	44 41	74 57	394	1828	1897	25	30.29
Rochester	43 08	77 42	523	1830	1901	72	33.22
Utica	43 06	75 13	473	1826	1892	41	41.89
NORTH CAROLINA.							
Abshers	36 20	81 05	....	1897	1901	5	*60.00
Asheville	35 33	82 30	2,250	1857	1901	21	43.13
Chapel Hill	35 58	78 54	500	1856	1901	16	48.36
Charlotte	35 13	80 51	773	1871	1901	25	50.01
Hatteras	35 15	75 40	11	1874	1901	27	63.35
Highlands	35 05	83 25	3,817	1878	1901	13	79.37
Kitty Hawk	36 00	75 42	8	1875	1901	26	55.03
Lenoir	36 00	81 28	1,186	1871	1901	28	52.04
Linville	36 05	81 50	3,800	1895	1900	6	*62.80
Murphy	35 05	84 02	1,614	1872	1901	19	61.43
Oak Ridge	36 15	80 00	1,013	1890	1901	12	48.99
Raleigh	35 45	78 37	376	1866	1901	21	48.94
Southport	33 55	78 01	34	1875	1901	26	50.12
Weldon	36 24	77 30	81	1872	1901	29	46.53
Wilmington	34 14	77 57	78	1871	1901	31	52.04
NORTH DAKOTA.							
Berlin	46 23	98 30	1,470	1891	1901	9	*21.94
Bismarck	46 47	100 38	1,674	1874	1901	27	17.76
Fort Abercrombie	46 24	96 46	935	1860	1901	22	23.78
Fort Stephenson	47 35	101 30	1,655	1867	1894	15	15.92
Fort Totten	47 57	98 57	1,565	1869	1890	21	17.80
Fort Yates	46 11	100 34	1,670	1882	1901	20	16.58
Gallatin	47 23	98 00	....	1889	1901	12	17.22
Pembina	48 56	97 10	750	1871	1901	22	20.54
Williston	48 09	103 35	1,875	1866	1901	34	14.22
OHIO.							
Canton	40 49	81 23	1,070	1882	1901	19	39.35
Cincinnati	39 06	84 30	628	1835	1901	67	41.42
Cleveland	41 30	81 42	762	1855	1901	46	35.69
Columbus	39 58	83 00	824	1878	1901	23	37.63
Findlay	41 00	83 35	782	1886	1901	12	36.44
Hudson	41 16	81 29	1,153	1838	1901	32	37.63
Jacksonboro	39 30	84 30	975	1868	1901	33	38.64
Logan	39 35	82 19	740	1883	1900	16	41.17
Mansfield	40 48	82 30	1,154	1887	1900	11	43.59
Marietta	39 28	81 26	650	1817	1901	74	42.07
North Lewisburg	40 12	83 32	1,095	1852	1901	49	40.14
Portsmouth	38 42	82 53	527	1830	1901	69	40.75
Sandusky	41 25	82 40	629	1859	1901	43	34.73
Steubenville	40 25	80 41	670	1830	1871	39	41.34
Toledo	41 40	83 34	628	1861	1901	40	32.48
Wauseon	41 36	84 07	800	1871	1901	28	39.00
OREGON.							
Albany	44 35	123 02	214	1866	1901	20	44.60
Ashland	42 01	122 33	1,940	1889	1901	17	20.15
Astoria	46 11	124 00	20	1850	1901	39	77.75
Baker City	44 50	117 50	3,471	1889	1901	12	*19.92
Bandon	43 05	124 15	55	1878	1900	22	66.69
Camp Harney	43 00	119 00	....	1867	1880	11	10.80
Cascade Locks	45 40	121 50	125	1879	1901	21	80.37
Eola	44 57	123 05	500	1870	1892	22	39.60
Fort Klamath	42 41	121 50	4,200	1864	1889	10	21.90
Gardiner	43 25	124 11	72	1889	1901	10	80.17
Glenora	45 30	123 33	....	1892	1901	10	135.84
Government Camp	45 20	121 50	3,580	1896	1901	6	*103.56

Geographical coordinates, elevation, length of record, and AVERAGE ANNUAL PRECIPITATION for rainfall stations in the United States and Canada for the period 1871-1901—Continued.

Stations.	Latitude.	Longitude.	Elevation.	Record. From—	Record. To—	Record. Years (inclusive).	Average annual precipitation.
OREGON—continued.	° ′	° ′	*Feet.*				*Inches.*
Grants Pass	42 27	123 20	964	1889	1901	12	31.35
Happy Valley	43 00	118 30	4,200	1890	1900	10	*20.51
Heppner	45 20	119 30	1,950	1889	1899	9	*21.42
Hood River	45 42	121 28	920	1891	1901	10	42.42
Joseph	45 19	117 03	4,400	1889	1901	12	17.71
Lakeview	42 00	120 12	5,060	1883	1901	9	17.14
Newport	44 39	124 02	68	1891	1901	8	72.20
Pendleton	45 40	118 45	1,074	1890	1901	11	14.75
Portland	45 32	122 43	154	1858	1901	32	45.28
Prineville	44 20	120 57	3,000	1892	1901	10	11.63
Roseburg	43 13	123 20	518	1877	1901	24	35.26
The Dalles	45 33	121 12	106	1850	1901	32	18.09
PENNSYLVANIA.							
Altoona	40 32	78 24	1,181	1859	1901	17	33.44
Bethlehem	40 36	75 23	250	1877	1900	21	43.29
Carlisle	40 12	77 14	500	1839	1900	22	41.84
Confluence	39 57	79 26	1,324	1874	1901	25	45.26
Dyberry	41 37	75 18	1,100	1867	1900	28	39.37
Emporium	41 30	78 15	1,050	1889	1901	13	44.25
Erie	42 07	80 05	713	1873	1901	28	39.27
Franklin	41 24	79 50	955	1840	1901	24	42.51
Gettysburg	39 49	77 15	624	1839	1895	25	39.07
Girardville	40 47	76 18	1,605	1886	1901	16	52.91
Grampian	41 00	78 38	1,400	1864	1901	27	45.11
Harrisburg	40 16	76 52	377	1877	1901	24	41.60
Lewisburg	40 58	76 55	450	1856	1901	19	41.25
New Castle	41 02	80 21	809	1870	1894	17	36.54
Philadelphia	39 57	75 09	117	1798	1901	85	41.47
Pittsburg	40 32	80 02	842	1836	1901	57	35.68
Warren	41 57	79 14	1,137	1885	1901	17	43.18
RHODE ISLAND.							
Block Island	41 10	71 36	27	1880	1901	22	45.09
Providence	40 50	71 24	155	1831	1901	70	46.01
SOUTH CAROLINA.							
Aiken	33 32	81 40	565	1854	1894	23	48.10
Beaufort	32 26	80 41	28	1887	1901	15	46.98
Charleston	32 47	79 56	48	1738	1901	94	48.72
Cheraw	34 42	79 57	144	1882	1901	13	46.14
Columbia	34 00	81 03	351	1850	1901	19	48.68
Camden	34 15	80 31	222	1849	1901	42	44.42
St. Stephens	33 26	79 50	73	1892	1901	9	*51.21
Statesburg	33 55	80 23	19	1881	1901	19	48.70
Yorkville	34 59	81 13	680	1867	1901	15	47.97
SOUTH DAKOTA.							
Aberdeen	45 27	98 26	1,300	1890	1901	9	25.66
Ashcroft	45 45	103 54	3,192	1892	1901	9	13.98
Flandreau	44 02	96 36	1,565	1890	1901	12	23.22
Fort Meade	44 26	103 28	3,624	1879	1896	16	18.81
Fort Randall	43 04	98 42	1,245	1857	1892	32	20.96
Fort Sully	44 39	100 39	1,600	1869	1894	25	17.33
Kimball	43 43	98 59	1,788	1886	1901	15	19.44
Huron	44 21	98 14	1,306	1881	1901	20	20.67
Oelrichs	43 12	103 14	3,336	1890	1901	9	20.68
Pierre	44 22	100 21	1,572	1891	1901	10	*16.78
Rapid City	44 04	103 12	3,234	1881	1901	15	15.92
Yankton	42 54	97 28	1,233	1873	1901	26	25.58
TENNESSEE.							
Andersonville	36 30	83 58	1,167	1883	1901	15	49.97
Ashwood	35 36	87 08	725	1879	1901	22	51.40
Elizabethton	36 18	82 12	1,575	1869	1901	9	*47.23
Chattanooga	35 04	85 14	762	1879	1901	23	52.71
Clarksville	36 28	87 20	520	1854	1901	32	47.91
Florence	35 53	86 30	560	1883	1901	18	47.35
Greeneville	36 10	82 50	1,581	1869	1901	17	45.66
Johnsonville	36 07	87 59	364	1885	1901	16	47.22
Knoxville	35 56	83 58	1,004	1854	1901	33	50.04
Memphis	35 09	90 03	397	1850	1901	34	50.97
Nashville	36 10	86 47	546	1839	1901	37	49.15
Rogersville	36 22	83 00	1,212	1883	1901	16	*45.86
Savannah	35 20	88 25	450	1883	1901	19	50.83
Silverlake	36 30	82 45	2,600	1898	1901	4	*50.20
Waynesboro	35 25	87 40	1,050	1884	1901	16	47.63
TEXAS.							
Abilene	32 23	99 40	1,738	1885	1901	16	24.22
Amarillo	35 13	101 50	3,676	1892	1901	10	21.55
Austin	30 16	97 43	650	1856	1901	37	33.51
Brenham	30 02	96 02	350	1885	1901	12	38.30
Burnet	30 56	98 01	1,395	1889	1900	9	28.62
Camp Eagle Pass	28 39	100 30	800	1849	1901	28	23.06
Corpus Christi	27 49	97 25	18	1846	1901	14	26.28
Cuero	29 03	97 09	177	1883	1901	10	33.76
TEXAS—continued.	° ′	° ′	*Feet.*				*Inches.*
Dallas	32 55	96 38	466	1889	1901	9	33.22
El Paso	31 47	106 30	3,762	1850	1901	38	8.84
Fort Brown	25 50	97 57	57	1850	1901	28	25.52
Fort Clark	29 17	100 25	1,050	1852	1901	28	21.87
Fort Concho	31 55	100 17	1,950	1872	1889	15	23.70
Fort Davis	30 40	104 07	4,700	1855	1891	20	18.10
Fort McIntosh	27 29	99 31	460	1849	1900	34	19.05
Fort Ringgold	26 27	98 47	230	1849	1901	38	19.80
Fort Stockton	30 50	102 35	4,952	1859	1899	14	16.10
Fort Worth	32 43	97 15	670	1849	1901	8	34.32
Fredericksburg	30 20	98 45	1,742	1877	1901	17	28.32
Galveston	29 18	94 50	54	1868	1901	33	48.13
Houston	29 48	95 19	53	1882	1901	12	45.20
Mount Blanco	33 55	101 01	....	1886	1901	13	15.33
Palestine	31 45	95 40	510	1882	1901	19	44.14
San Antonio	29 27	98 28	701	1849	1901	31	28.41
Waco	31 35	97 08	424	1867	1901	14	34.80
Weatherford	32 57	97 57	864	1882	1901	8	30.80
UTAH.							
Corinne	41 34	112 06	4,232	1870	1901	31	11.75
Deseret	39 05	110 08	4,541	1891	1901	7	7.26
Fort Duchesne	40 35	109 50	5,000	1888	1901	14	6.46
Levan	39 34	111 53	5,010	1889	1901	11	16.00
Moab	38 36	109 29	4,000	1889	1901	12	7.43
Parowan	37 51	112 51	5,970	1890	1901	11	12.14
Ogden	41 14	111 58	4,307	1870	1901	29	14.15
St. George	37 13	113 50	2,880	1877	1901	12	6.73
Salt Lake City	40 46	111 54	4,366	1857	1901	41	17.27
Terrace	41 32	113 33	4,544	1870	1901	22	4.55
VERMONT.							
Burlington	44 28	73 12	346	1828	1901	59	32.92
Lunenburg	44 28	71 44	1,124	1848	1892	44	39.60
Newport	44 57	72 18	750	1869	1889	15	42.96
Northfield	44 09	72 38	871	1887	1901	14	34.02
Strafford	43 52	72 25	50	1873	1897	24	39.97
Vernon	42 47	72 32	310	1885	1901	16	45.77
VIRGINIA.							
Bigstone Gap	36 59	82 52	2,000	1891	1901	11	*51.70
Birdsnest	37 25	75 52	40	1869	1901	31	49.56
Cape Henry	36 56	76 00	18	1874	1901	28	50.80
Christiansburg	37 05	80 23	2,160	1885	1901	12	38.29
Dale Enterprise	38 40	78 45	1,350	1880	1901	22	42.75
Lexington	37 44	79 24	946	1869	1901	26	40.83
Lynchburg	37 25	79 09	681	1871	1901	30	44.07
Marion	36 48	81 26	2,124	1873	1901	17	43.10
Norfolk	36 51	76 17	91	1871	1901	31	50.40
Richmond	37 32	77 27	99	1850	1901	24	44.41
Spottsville	37 02	76 53	15	1888	1901	11	50.33
Woodstock	38 54	78 30	927	1889	1901	8	*45.29
Wytheville	36 55	81 05	2,235	1860	1901	29	42.17
WASHINGTON.							
Cedonia	48 15	118 10	3,000	1894	1901	8	20.06
Colfax	46 55	117 20	2,300	1881	1901	12	23.61
Ellensburg	47 00	120 35	1,577	1884	1901	13	8.86
Fort Canby	46 16	124 03	14	1874	1899	24	65.07
Fort Colville	48 57	117 57	1,963	1859	1880	18	17.30
Fort Simcoe	46 30	120 50	....	1857	1899	11	12.50
Lakeside	47 50	120 00	985	1891	1901	11	12.80
Lind	46 58	118 40	1,363	1897	1901	4	11.85
Loomis	48 35	119 30	1,200	1894	1901	6	*13.48
Moxee Valley	46 40	120 30	1,000	1891	1901	9	8.62
Neah Bay	48 22	124 32	40	1863	1901	18	112.40
Olympia	47 05	122 50	15	1877	1901	24	55.37
Port Angeles	48 07	123 06	29	1883	1898	12	29.35
Seattle	47 38	122 20	123	1890	1901	9	35.85
Spokane	47 40	117 25	1,793	1881	1901	20	18.16
Tacoma	47 16	122 23	31	1888	1901	13	52.31
Vancouver	45 40	122 30	50	1849	1901	23	35.63
Walla Walla	46 02	118 20	1,000	1857	1901	31	17.42
Waterville	47 40	120 05	2,624	1890	1901	10	13.35
WEST VIRGINIA.							
Beverly	38 45	80 00	2,250	1894	1901	8	*52.00
Elkhorn	37 44	81 24	1,885	1892	1901	9	46.09
Charleston	38 25	81 31	598	1887	1901	14	44.90
Glenville	38 56	80 54	696	1888	1901	14	*48.64
Harpers Ferry	39 20	77 45	350	1889	1901	11	35.31
Helvetia	38 30	80 10	....	1877	1889	12	54.60
Hinton	37 50	81 00	1,400	1890	1901	11	*39.51
Morgantown	39 39	79 59	894	1873	1901	19	47.08
Parkersburg	39 16	81 36	638	1885	1901	16	42.78
Rowlesburg	39 28	79 32	1,402	1884	1901	15	*41.83
Weston	39 01	80 27	824	1885	1901	14	48.22
Wheeling	40 07	80 42	637	1882	1901	16	40.00

Geographical coordinates, elevation, length of record, and AVERAGE ANNUAL PRECIPITATION *for rainfall stations in the United States and Canada for the period 1871-1901*—Continued.

Stations.	Latitude.	Longitude.	Elevation.	Record. From—	Record. To—	Record. Years (inclusive).	Average annual precipitation.
WISCONSIN.	° ′	° ′	*Feet.*				*Inches.*
Grantsburg	45 47	92 04	1,100	1889	1901	8	30.60
Greenbay	44 31	88 00	616	1886	1901	15	31.28
Hayward	46 01	91 30	1,197	1889	1901	7	29.31
Koepenick	45 23	89 11	1,683	1890	1901	11	30.56
La Crosse	43 49	91 15	714	1872	1901	29	30.92
Madison	43 05	89 24	955	1855	1901	25	30.66
Manitowoc	44 05	87 39	616	1861	1901	38	29.11
Meadow Valley	44 12	90 15	974	1891	1901	9	29.78
Medford	45 10	90 20	1,420	1889	1901	11	32.04
Milwaukee	43 02	87 54	681	1870	1901	31	31.17

Stations.	Latitude.	Longitude.	Elevation.	Record. From—	Record. To—	Record. Years (inclusive).	Average annual precipitation.
WYOMING.	° ′	° ′	*Feet.*				*Inches.*
Cheyenne	41 08	104 48	6,084	1870	1901	31	12.96
Fort Bridger	41 18	110 32	6,643	1858	1890	15	9.54
Fort Fetterman	42 50	105 29	5,250	1868	1892	14	13.90
Fort Fred Steele	41 47	106 57	7,640	1869	1886	11	10.10
Fort Laramie	42 12	104 31	4,270	1849	1901	22	15.14
Fort McKinney	44 23	106 46	5,000	1886	1894	8	*9.99
Fort Yellowstone	44 58	110 41	6,370	1886	1901	13	19.90
Four Bear	44 22	108 49	6,500	1893	1901	6	11.95
Lander	42 50	108 45	5,372	1880	1901	13	13.45
Lusk	42 47	104 27	5,007	1889	1901	12	12.80
Sheridan	44 49	107 00	3,750	1891	1901	8	*11.14

Canadian stations furnished by Prof. R. F. Stupart, director meteorological service, Dominion of Canada.

Canadian stations.	Latitude N.	Longitude W.	Elevation.	Length of record.	Mean annual precipitation.	Record— begins—	Record— ends—
	° ′	° ′	*Feet.*	*Years.*	*Inches.*		
St. Johns, N. F	47 34	52 42	125	29	54.63	1872	1900
Sydney, N. S	46 10	60 10	55	27	50.28	1874	1900
Halifax, N. S	44 39	63 39	118	27	57.03	1874	1900
Grand Manan, N. B	44 47	66 46	49	17	47.25	1884	1900
Yarmouth, N. S	43 50	66 02	65	11	50.33	1880	1900
Charlottetown, P. E. I	46 14	63 10	38	26	41.62	1875	1900
Chatham, N. B	47 03	65 20	21	27	41.29	1874	1900
Father Point, Que	48 31	68 19	20	24	32.99	1877	1900
Quebec, Que	46 48	71 13	296	27	41.72	1874	1900
Montreal, Que	45 30	73 35	187	28	40.99	1874	1901
Bissett, Ont }	....	....	....	24	30.46	1877	1900
Rockliffe, Ont }	46 12	77 55	472	....	....	....	....
Ottawa, Ont	45 26	75 42	330	18	32.60	1883	1900
Kingston, Ont	44 13	76 29	285	27	32.81	1874	1900
Toronto, Ont	43 39	79 24	350	61	33.72	1840	1900
White River, Ont	48 20	86 20	1,252	12	24.79	1889	1900
Port Stanley, Ont	42 40	81 13	592	27	34.42	1874	1900
Saugeen, Ont	44 30	81 21	656	25	34.21	1876	1900
Parry Sound, Ont	45 19	80 0	635	25	38.27	1876	1900

Canadian stations.	Latitude N.	Longitude W.	Elevation.	Length of record.	Mean annual precipitation.	Record— begins—	Record— ends—
	° ′	° ′	*Feet.*	*Years.*	*Inches.*		
Port Arthur, Ont	48 27	89 12	644	11	24.76	1880	1900
Winnipeg, Man	49 53	97 07	760	28	20.98	1873	1900
Minnedosa, Man	50 10	99 48	1,690	18	16.45	1883	1900
Qu' Appelle, N. W. T	50 44	103 42	2,115	18	16.08	1883	1900
Medicine Hat, N. W. T	50 01	110 37	2,161	17	13.80	1884	1900
Swift Current, N. W. T	50 20	107 45	2,439	15	15.47	1886	1900
Calgary, N. W. T	50 02	114 02	3,389	17	14.87	1884	1900
Banff, N. W. T	51 10	115 35	4,542	6	21.91	1895	1900
Edmonton, N. W. T	53 33	113 30	2,158	18	15.83	1883	1900
Prince Albert, N. W. T	53 10	106 0	1,402	16	14.91	1885	1900
Battleford, N. W. T	52 41	108 30	1,620	10	13.93	1891	1900
Kamloops, B. C	50 41	120 29	1,193	12	11.63	1888	1900
Victoria, B. C	48 24	123 19	85	10	38.14	1881	1900
Barkerville, B. C	53 02	121 35	4,180	13	33.56	1888	1900
Spence's Bridge, B. C	50 23	121 20	770	21	8.81	1872	1900
Stratford, Ont	43 23	81 0	1,191	25	36.04	1860	1900
Coldwater, Ont	44 38	79 40	....	15	37.28	1886	1900
Missanable, Ont	48 21	83 28	....	12	22.36	1889	1900
Cartier, Ont	46 40	80 50	....	14	23.86	1887	1900

(3) REMARKS BY PROF. C. F. MARVIN.

Accepting the precipitation data as being approximately correct, the first consideration that presents itself in the matter of charting it is the well-known fact that all precipitation is characterized by great local variation, even within limited areas, and it can not therefore be supposed that observations at relatively widely separated stations within any particular region should be very closely accordant. On this account it is obvious that where stations are widely scattered the data at the best but imperfectly show the precipitation over the whole area. A marked difference in the topography may of itself cause still greater variations in the precipitation throughout any region.

In making a precipitation chart, therefore, one is confronted at once with a dilemma: (1) He must either distribute the observed precipitation proportionately over the entire region comprising that field of observation, or (2) he must indicate the area surrounding each station throughout which the precipitation may be assumed to be the same as observed at the station. If these latter areas do not overlap, then blank areas are left within which no records of precipitation are available. The second method is preferable for scattered stations, but the first is almost universally followed, faulty though it may be.

In the case of mountainous countries and regions marked by conspicuous topographical features we are confronted with an additional complication. It is generally believed, and is in fact true, that the precipitation on mountain summits and elevated ridges is, with some exceptions, greater than on the valleys and plains. This knowledge may be gained even without the aid of rain-guage readings. In fact it generally happens that actual measurements of precipitation are not available in mountainous regions. In charting precipitation over such a region it may be argued that the excess of precipitation believed to exist on the summits should appear in some way on the charts, but the amount of this has rarely been measured, nor is the extent of territory covered sharply defined, and the student preparing the charts finds a most serious difficulty in deciding upon the amount of precipitation attributable to the summits and in determining or defining the limits of the area over which any excess should appear. A chart embodying hypothetical features is so largely a product of individual imagination that it will probably prove acceptable only to the individual who makes it.

Judgment in these matters may be guided by the following considerations:

The total precipitation over the entire land and water surfaces of the globe is obviously equal to the total evaporation from the same surfaces. When we consider only land areas no definite relation can be formulated between the precipitation, evaporation, etc. It is obvious, however, that the entire precipitation over land areas is disposed of in the three following methods:

(1) A portion of it soaks into the ground; (2) another portion flows through the streams and rivers to the sea; (3) a third portion evaporates direct from the soil and river surfaces and thus returns to the atmosphere. Throughout any particular area the measurement of the precipitation may give only a part of that which actually falls. In some cases, however, the observed precipitation may be in excess of that which actually falls over the region. In the present state of our knowledge it appears vastly more difficult to measure seepage and the evaporation going on over an area than to measure the rainfall. In some cases, however, fairly accurate measurements of the run-off of the rivers can be and have been made so that it can, to a certain extent, supplement the measurement of rainfall in the formation of precipitation charts. The relation between the precipitation over a drainage basin and the run-off from the rivers is that the latter must be less than the precipitation. When, however, one attempts to construct a precipitation chart by redistributing the water represented by the run-off in rivers throughout the area upon which it fell as precipitation, he must not only allow for seepage and evaporation, but he is confronted with all the difficulties already mentioned of distributing precipitation over regions for which no observations have been made, and the statement already made is repeated that a rainfall chart in which unmeasured rainfall is arbitrarily assigned to regions to which it is supposed to belong is so largely a product of individual imagination that it will probably not be satisfactory to any except the individual who makes it. It would seem, in fact, that where engineering and scientific interests demand greater detail and accuracy in charts of precipitation than is now attainable by the proportional distribution of the precipitation as observed over the region embraced, then the only scientific and possible remedy is the increase in the number of stations, especially in regions of marked irregular topography.

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(4) NOTE BY CLEVELAND ABBE.

Every general weather service now publishes its rainfall records with such fullness that they are available for the use of those who wish to study special problems, such as the occurrence of destructive rainfall, the average quantity of rainfall, the number of rainy days, the duration of droughts, the depth of snow, etc. Not only are the numerical data published for each station, but all agree as to the desirability of presenting the data graphically as maps of rainfall. But the principles that should be followed in constructing these maps have, so far as we know, never been codified and confirmed by any decision of the International Meteorological Congress or by any conference between individual meteorologists and statisticians.

Recent discussions in the Monthly Weather Review and especially the articles and charts in the present number by Mr. Henry Gannett and Prof. A. J. Henry draw renewed attention to the difficulties that attend the measurement of local rainfall and the construction of maps showing the total general rainfall for any region. We, therefore, may presume to offer the following suggestions with regard both to the gauges, the stations, and the treatment of the data:

(1) It is well known that all ordinary accurate rain gauges exposed to the wind catch less rainfall, and especially less snowfall than they should, because of the effect of the wind

in forming eddies and deflections that carry away the raindrops and snowflakes that should be caught in the mouth of the gauge. The stronger the wind at the mouth of the gauge so much greater the deficit.

(2) Gauges whose mouths are shielded from the wind by special construction of horizontal screens or shields, as in the shielded gauge of Prof. Joseph Henry, or that of Prof. F. E. Nipher, show a very small deficit, if any; so, also, do gauges that are protected from the wind by a small open fence or vertical screen around the gauge, as in the methods of Wild and Boernstein; and so, also, those that are located on a depressed roof, as observed by Hellmann, or those that are protected by the parapets of the roofs, as at most Weather Bureau stations. There is, therefore, no doubt that gauges can be so constructed or so placed as to counteract the ordinary effect of local winds in diminishing the catch.

(3) It has been shown (see Monthly Weather Review, 1899, p. 466) that gauges at different altitudes above the ground, but otherwise similar and freely exposed to the wind, show deficits that increase with the altitude, presumably because the stronger winds at the higher gauges produce larger deficits. A comparison of two or more similar gauges, located near each other but at different heights, affords a means of obtaining an approximate correction to the readings of the lower gauge, by which to obtain the rainfall approximately free from the wind effect. If this principle be applied to the best forms of shielded or protected gauges it should give us better results than when applied to ordinary unprotected gauges.

(4) Gauges of a variety of forms exposed to the same wind give different results, owing to the fact that the wind effect varies with the shape, the proportions, and the sizes of the gauges. The differences between two such gauges sometimes varies with the square of the wind velocity. (See G. E. Curtis, Rainfall on Mount Washington.)

(5) Gauges exposed in apparently unobjectionable localities in the same field show variations from each other of 5 per cent, apparently owing to the variations in the strength of the wind, produced by the ordinary irregularities of the ground; therefore measurements agreeing within this limit may be considered as having the same weight or as identical. (See G. Hellmann, "Berlin Regenfeld.")

(6) In view of the preceding paragraphs, all gauges that are unduly exposed to severe winds, whether on open plains, or hilltops, or high buildings and which therefore catch much less rain than actually falls, should be excluded from use in preparing a rainfall map, unless proper corrections can be applied. In general every gauge should have its special protection, so that there be no doubt as to its records. Fortunately there is but a small percentage of badly exposed gauges. Those that are so located as to be well protected from the direct action of the wind may be used for rainfall maps, since, even though placed in exposed locations, they do not necessarily give deficient rainfalls.

(7) Rainfall is largely affected by the minute details of local orography. The station may be too much sheltered by neighboring buildings or trees, so that too little rain falls on the ground. When the wind is forced up a mountain side it is likely to give more rain than when blowing over a horizontal plain, but it gives correspondingly less rain over some regions to the leeward of the mountain. When the wind blows from a lake or ocean onto the shore of a flat country it gives more rain over the land near the water than over the lake itself or over the land distant from the lake. These are some of the natural cases of actual variation in rainfall, so that the chart of isohyetals is much more complicated than the chart of contour lines. It is very rare that rainfall stations are close enough together to enable us to draw isohyetals showing all these details. The rainfall on Barbados is one of the few instances where it is practicable to study in detail the connection between rainfall and topography.

An extreme case of the relation between rainfall and altitude is presented by the records for the island of Ascension, which lies in the southeast trade-wind region. This island consists essentially of a mountain (known as Green Mountain from the days of the earliest navigators) and a lowland which is mostly to the west of the mountain and which, although dotted by hillocks, has an average altitude of scarcely a hundred feet. It is very rare that rain falls on the lower part of the island, partly because of its position in the dry trade-wind region and partly because the lowlands are to the leeward of Green Mountain. The southeast trade is deflected upward and sideways over and around this great mountain. As the air ascends and cools abundant cloud is formed around the summit of the mountain, but as the air proceeds onward toward the west or west-northwest, it rolls over and over on itself, forming a regular series of isolated clouds, stretching in a straight line for a hundred miles to the westward. These clouds represent the tops of successive waves of air. They look like a series of cigar-shaped rolls and even the largest of them rarely allows a drop of rain to fall. Although little or no rain, properly so called, falls on the island, yet the summit of Green Mountain enveloped in clouds is a beautiful picture of green verdure, and the drip from leaves and twigs is carefully collected and preserved for the use of the naval garrison at the landing on the leeward side of the island. This case illustrates the general principle that the excess of rainfall on the windward side over that on the leeward side must depend upon the height to which the currents of air are forced up by the obstacle, and the general laws of this relation must be very analogous to those deduced by Prof. F. Pockels (see Monthly Weather Review, April, 1901), for the case of the formation of clouds on mountain slopes.

(8) A chart showing details of the distribution of rainfall must be based on the total precipitation either for a definite month or year or for the average of a number of similar months or years. In any case all the rainfalls that are charted should relate to the same fundamental group of months or years. The variation of rainfall from month to month or year to year is just as great as the variation of rainfall from place to place. Our charts should present the geographical distribution of the average rainfall during the same period of time for all parts of the chart. The chart should be a chronological as well as a geographical unit. To this end all the rainfall records of short periods must be reduced, as accurately as possible, to what they presumably would have been

if the series had extended throughout the whole of the fundamental period of the chart.

The fundamental stations of any chart are those for which we have complete records at gauges that have not been changed as to pattern, exposure, methods of observation, and record during the whole of the fundamental period of the chart. If changes in the location of the gauges or in other important matters have been made, the different parts of the series must be reduced to uniformity with some one of the positions used, presumably that which was occupied the longest time; if possible, the whole record should be corrected for the wind effect. These changes in the average observed rainfall induced by changes of site and by strength of wind are important, but liable to be less important than the changes introduced by the omission of the reduction to the fundamental number of years. Any short series of observations may be extended chronologically up the full fundamental length by a process of extrapolation, and we may plot the result along with the fundamental data for the fundamental stations.

Experience has shown that when stations are near each other three years of record may by extrapolation give a fair ten-year average and a ten-year record may by extrapolation give a thirty-year average. (See Angot, Rainfall of Europe.) The following example is based on data taken from Professor Henry's Bulletin B, p. 22. The average rainfalls at Amherst, Providence, Boston, and New Bedford are given by Henry for six successive decades, 1837-96, as in the following table. Let us assume that the record (49.4) for Providence for the fourth decade is unknown and that we require it before we can obtain the desired average for sixty years at that place. The numerical process assumes simply that the total rainfall is distributed according to some simple law throughout the region. We first take the average of the five known decades at all four stations. We then for Amherst, Boston, and New Bedford, respectively, express the rainfalls for the fourth decade as fractions or ratios of that for the remaining five decades.

Assuming that each of these fractions for Amherst, Boston, and New Bedford has an equal chance of holding good for Providence, we apply each to the Providence record for the five decades and compute the hypothetical value of the missing fourth decade. The average of these three values, 47.18, 51.09, and 51.51, gives the desired interpolated rainfall, 49.92. We might have varied the process by plotting these three ratios upon a chart and graphically interpolating, so as to find the best ratio for Providence, which when applied to the Providence average would have given almost the same result.

Decades.	Amherst.	Providence.	Boston.	New Bedford.
1837-46	41.5	38.4	41.3	38.8
1847-56	45.6	43.9	46.5	40.4
1857-66	45.5	45.1	54.5	42.1
1867-76	45.6	49.4	52.6	48.4
1877-86	42.2	50.8	46.8	44.6
1887-96	45.4	51.1	47.1	49.6
Average of six decades	44.13	46.45	48.13	43.98
Average of five decades	44.04	45.86	47.24	43.10
Ratio of fourth decade to average of five decades	1.0349	....	1.1136	1.1230

The mean, 49.92, as computed for the assumed missing decade at Providence, agrees with the actual observations during that decade, 49.4, within a half inch, and if it had been used instead of the observed figure would have given a mean for sixty years of 46.54 instead of the 46.45 that resulted from actual observations. By this process we reduce all short records up to the fundamental length of period and thus obtain all the actual rainfall measurements that are available for our chart.

In reducing the average of a short series at a minor station up to the average of the longer fundamental period for which the chart is constructed, we tacitly assume that the average rainfall during the missing years at the minor stations has been proportional to the rainfall during those same years at the fundamental stations. The above illustration shows how nearly this is true for Providence, R. I., as compared with the other three stations in its neighborhood. Stations that are farther removed or have intervening obstacles would not show such favorable results. A general consideration of the similarity of records at more distant stations may be seen from the exhaustive discussion by Hann (Vienna Sitzungsb., 1902) of the rainfall from 1725 to 1900 at Padua (45° 25′ N., 11° 55′ E.), from 1764 to 1900 at Milan (45° 25′ N., 9° 10′ E.), and from 1813 to 1900 at Klagenfurt (46° 40′ N., 14° 20′ E.). Klagenfurt is 145 miles northeast of Padua, and Padua is 140 miles east of Milan. Hann shows that the absolute variability of the average rainfall for periods of 5, 10, 20, 30, or 40 years, expressed in percentages of the annual rainfall, agrees very closely at the three stations. Hann also shows that the simultaneous departures of the means of 30 years or 40 years from the means for 100 years, pursue parallel courses at Padua and Klagenfurt, but an opposite course at Milan, the extreme departure being 8 per cent negative and 6 per cent positive; in other words, the mean of any group of 30 or 40 years is still liable to differ either way from the mean for a century by 6 or 8 per cent of the average rainfall. Incidentally it may be mentioned that in these three long series of rainfall measurements Hann finds a clear demonstration of the existence of the 35-year period, announced by Brückner, but no clear evidence of a dependence of the rainfall upon the frequency of the sun spots. There is a very decided tendency for dry or wet years to occur in groups of two or three; groups of four such years occur twice as often for dry years as for wet years. In the same way groups of two or three dry or wet months frequently occur, and groups of four or five wet months are more frequent than such groups of dry months.

The idea of a "fundamental interval of time" to which all data for shorter intervals should be reduced as accurately as possible by a process of chronological and geographical interpolation is one that applies equally to charts of isobars, isotherms, and all other meteorological data. In every case the charts of data must represent the same unit of time. Isometric lines for various intervals, such as 30 years and 5 years, must not be mixed up together. If we make this mistake, then numerous details will appear on the chart that have been introduced by special irregularities of short groups of years and which should disappear in a chart that truly represents the whole fundamental interval.

(9) In drawing isobars and isotherms, it has always been recognized that our stations are not sufficiently numerous to

enable us to present all the details of pressure and temperature near the surface of the ground, nor do meteorologists need such detail. If it is desired to use meteorological data to represent only the general distribution of pressure and temperature in the atmosphere, we accomplish this best when the observed data are reduced to one uniform plane above or below the network of stations; hence the isotherms and isobars belong specifically to that plane. If one knows his elevation relative to that plane, he may then use the same scale of reduction and ascertain his own local pressure or temperature.

A similar consideration pertains to the rainfall. The measured rainfall represents the fall that would be caught at any point in the vertical or the slanting columns of falling rain between the station and the cloud; therefore the rainfall charts already belong, without further reduction, to a horizontal plane that may be located anywhere below the rain clouds. The irregularities of the distribution of rainfall on this plane are of two kinds—(a) local, depending on the wind effect at the mouth of the gage, or on the bad location of the gage to leeward or to windward of trees, houses, walls, and cliffs, none of which affect the original rainfall itself, and all of which must be avoided or allowed for by the observer; (b) general, such as the influence of the attempt of the wind to blow over a mountain; the passage of the wind from the ocean to the land, or vice versa; the distribution of rain in a river valley or around a storm center, or to windward of a mountain range. It is to these general influences that the rain itself is originally due, and in so far as the raindrops fall in parallel lines, either straight or curved, the rainfall measurement will be the same, no matter at what elevation the rain gage may be placed above the sea or below the rain clouds.

10. The amount of detail that we shall be able to present and the scale of our chart depends on the number of stations available per square mile and on the more or less complex relations between the orography, the winds, and the oceans. In the case of less than 3,000 stations available for the United States, or an average of 1 per 1,000 square miles, or an average distance of 35 miles apart, we can only present the most general features, and any attempt at minutiæ is both premature and misleading.

Over large areas of land there will generally occur regions for which we have no actual rainfall observations, and for these some will desire to estimate the rainfall, relying upon analogy, extrapolation, or other sources of information; but the meteorologist will generally decide that in the absence of actual records it is his duty to leave these spaces blank on the rainfall map, and let others make estimates appropriate to their own needs and knowledge.

In constructing meteorological charts it is common to draw full lines where information is supposed to be reliable, but dotted ones where it is decidedly hypothetical. This is not practicable in rainfall charts if we adopt shading instead of isohyetals. In such cases, also, it is best to leave those areas blank for which we have only unsatisfactory or indifferent data.

11. In order to eke out the scanty fragments of rainfall data, it will be necessary to draw the isohyetals or to shade the rainfall charts by calling to our aid whatever is known with regard to the general laws of rainfall. Precipitation depends upon certain atmospheric peculiarities, namely, the direction, velocity, temperature and humidity of the wind, and the evaporation from the ground or the ocean. Precipitation also depends upon the following peculiarities of the location, viz, the height and slope of the hills, the trend of the lines of the mountain ranges and the nearness of the mountains to the ocean, and the intrusion of cold northerly winds.

The influence of the elevation of the land is theoretically explained by Pockels (see Monthly Weather Review, April, 1901), but ordinarily it must be estimated empirically. Thus S. A. Hill (Met. Zeit. 1879, XIV, p. 161) shows that in the northwest Himalayas, as we rise above the plains at their base, we have a distribution of relative rainfall, as shown in the following table:

Altitude above sea.	Relative rainfall.	Altitude above sea.	Relative rainfall.
Feet.		*Feet.*	
1,000	1.00	7,000	2.44
2,000	2.52	8,000	1.70
3,000	3.40	9,000	1.00
4,000	3.70	10,000	0.46
5,000	3.56	11,000	0.20
6,000	3.10		

This study shows that in this region the maximum rainfall occurs at an elevation of about 4,160 feet, and, in general, Hill states that the rainiest stations in India all lie at an altitude of about 4,000 feet, including even Cherrapunjee, on the Khasia Hills, and the stations on the Ghats. He also adds that it is well known that the maximum zone of rainfall in the Ghats is lower down on the windward or ocean side than it is on the leeward or land side.

All our knowledge of the relation between rainfall and altitude shows that when we have determined the altitude of the zone of maximum rainfall we may then utilize that knowledge in extending our isohyetals from known stations a little way up or down into the unknown country. But we can not do this safely unless we have ascertained the altitude of the maximum zone for any given locality.

12. If forest areas actually contribute to increase the quantity of rain, as maintained by some, we should make our isohyetals accommodate themselves to the forests; but we can not accept this theory. At first thought it may seem plausible that the existence of a forest or a grass-covered plain may be taken as a sure indication that some definite quantity of rain annually falls in that region. However, we are prevented from utilizing this idea by our knowledge of the fact that the growth of plants is due quite as much to favorable soils, favorable temperatures, and other considerations as it is to rain, so that it is not safe to use the plants as a definite index to the quantity of rain.

13. In general a forest cover retains on an average 25 per cent of the total annual precipitation, especially, of course, the snow. Four-fifths of this, or 20 per cent, is evaporated and never reaches the ground; the remaining 5 per cent does reach it by dripping or running down the larger branches and trunks. The evaporation from the forest soil is about one-fourth of that from similar soil in open fields. The vol-

ume of water retained in the soil is larger in the forest than in the open land at elevations up to 500 meters, but it is smaller at elevations above 800 or 900 meters. The growth of forest trees consumes only a small amount of water as compared with that consumed by crops on cultivated soil. The permeability of the soil to water is increased by the penetration of the roots of the trees, so that by absorbing water deep into its soil the forest has the same general influence on run-off as is produced by a reduction of the general slope of the ground. Owing to the quantity of soil moisture and subterranean water within a forest, the springs and streams are larger and more constant. By virtually diminishing the slope, forests tend to repress floods and distribute water more evenly.

14. Again, so many measurements have been made of the flow of water in rivers and so many comparisons with the observed rainfall that one might hope to argue from this flow or run off back to the original rainfall over the watershed. It is found that, in general, the flow in the rivers is from one-half to three-fourths of the rainfall for those cases in which both quantities have been satisfactorily measured, but the ratio depends on soil, soil covering, and slope, and it does not appear that it can be known beforehand with any great accuracy. Each value of the ratio of the rainfall to run off pertains to special regions and special circumstances, so that it is not allowable to apply it to other regions or to a general calculation of the average rainfall from the known flow of water into the river.

In conclusion, then, we believe that the chart of rainfall must be made to depend wholly upon rainfall measurements themselves, and only when this is properly done can we use the chart to study out the relation between rainfall and the various matters that interest agriculturists and engineers. It will not do to use imperfect rainfall measurements to determine the quantity needed for plant growth or for river flow and then argue back in a circle from the forests or run-off to the rainfall.

The following extensive series of selections from publications and correspondence will serve to substantiate the above conclusions, and to show the details of modern practice as to the construction of rainfall charts.

(5) PROF. J. HANN.

In his "Lehrbuch der Meteorologie," 1901, pp. 350–352, Prof. Dr. Julius Hann has the following remarks relative to the increase of rainfall with altitude above sea level:

The cause of the increase of precipitation during the winter season at ordinary altitudes is to be sought in the fact that the precipitation caused by the presence of high land experiences at first an increase with increasing altitude, but afterwards a decrease for higher altitudes. There is, therefore, an altitude of maximum precipitation, and at greater altitudes than this the greater frequency of precipitation does not counterbalance the diminution in its intensity. The ascending masses of air become colder and contain less vapor, therefore their precipitations are always lighter. At the greatest altitudes we have principally drizzling fog and the finest light snow. The altitude of the zone of maximum quantity of precipitation depends on the average degree of saturation of the ascending mass of air, on its relative humidity, and the temperature at which condensation begins. In the winter time large relative humidity and low temperature act together to reduce the altitude of the maximum zone; in the summer time, with drier air and higher temperature, the zone is pushed up to a higher altitude.

Observations show that the summits of the German "Mittelgebirge" belong in general in the winter time to the maximum zone of precipitation, but in summer time the zone extends far above them. Unfortunately observations in the Alps do not yet suffice to establish the altitude of the maximum zone in summer, but Erk has shown that for the winter season the maximum zone of precipitation on the north side of the Bavarian Alps is frequently located at 600–1,000 meters above sea level.

Hellmann, in a comprehensive comparison of the monthly rainfalls, expressed in percentages of the annual sum for the German Mittelgebirge, has especially described the occurrence of the prevailing winter rainfall, and has shown that whereas in the "Sudeten" at altitudes of more than 900 meters summer rains prevail, yet in the "Schiefengebirge" of the Rhenish provinces and in the Vosges, even at altitudes of 300 or 400 meters, most of the precipitation belongs to the colder half of the year.

The explanation of this is easily seen. First, in central Europe the winter precipitation is in general heavier as we go from south to north or from east to west, or in general toward the northwest and, second, the annual distribution of rain is more uniform in that same direction, hence, also, the excess of the summer rain diminishes in the lowlands. Therefore we see that the level at which the inversion from prevailing summer rains to prevailing winter rains takes place, is lower as we pass from south to north and from east to west.

In fact, Supan deduces a second higher level of inversion from the results of rainfall measurements in the Belgian Ardennes, as compiled by Lancaster. In this region the lower zone of prevailing summer rains in the lowlands extends up to an altitude of about 350 meters, which is the lower level of inversion, and here begins the middle region of prevailing winter rains on the plateau lands. But this region extends only up to about 500 meters, where again the prevailing summer rains begin, so that this latter altitude may be considered as a second level of inversion. In fact, on the Pic du Midi there would seem to be three levels of inversion, as shown by the following results of observation:

Locality.	Altitude.	Precipitation.		
		Winter.	Summer.	Annual.
	Meters.	*Cm.*	*Cm.*	*Cm.*
Tarbes	308	36	46	83
Bagnieres	555	64	65	129
Plantade	2,366	99	114	213
Pic du Midi	2,860	97	64	161

Immediately above Bagnieres the winter rains begin; Plantade has summer rains; the summit again has prevailing winter rains. The maximum zone of the winter rains—as shown by a graphic presentation—appears to lie at 1,300 meters in the winter season and 1,900 meters in the summer. In this maximum zone there falls 103 cm. in the winter season and almost 150 cm. in the summer.

When a low-lying basin is surrounded by Mittel ebirge, or at least on the side from which the prevailing rainy winds come, this has a heavy winter precipitation, whereas the inclosed basin in the winter time receives less precipitation, because the clouds that then float at a low level have already deposited their moisture on the outer or windward side of the inclosing hills. On the other hand, the higher clouds of summer lose relatively less precipitation on this ring of hills, and therefore can bring a more abundant rain to the mountain valleys, to which must be added also the local showers and thunderstorms that are missing in the winter season. Therefore, in such regions, analogous to depressions, the summer rains exceed those at the same elevation in the country outside. An example is shown in the following table:

Place.	Percentage of rainfall.	
	Winter.	Summer.
Plains of Saxony	18.5	36
Mountains of Saxony	21	32
Central and southern Bohemia	15	40
Great Hungarian Plain	20	33
Transylvania (Sieben bürgen	15	40

The altitude of the zone of maximum precipitation is found to be 1,300 meters in the northwestern Himalayas; 1,400 meters in the Ghats, and about 1,000 meters in Java. In the English lake district the maximum rainfall is at 550 meters.

With reference to the distribution of rainfall over the earth's surface, Hann has the following remarks on pages 354–360:

Strictly speaking, we know something about the distribution of the quantity of rainfall on the land only, because on the ocean the marine observations record only the frequency of precipitation. Supan (Geog. Mitth., Heft VIII, 1898) has endeavored to fill up this gap in our knowledge, at least for the Atlantic and Indian oceans, by means of some reasonable assumptions as to the relative depth of rainfall.

But even on the continents there are broad regions in which there is not a single rain gauge and where, therefore, in place of measurements we must substitute more or less rational estimates. No meteorological element is so dependent as is the quantity of rainfall on local conditions for its occurrence, or so often shows unexpected differences at neighboring localities. It is therefore easily understood that every effort to represent graphically the distribution of rainfall over the earth's surface (as has been done successfully for pressure, temperature, and even cloudiness) must stumble upon the greatest difficulties and uncertainties. A reduction of local rainfall to sea level is quite impossible, since its variations with altitude above the sea follow no general rule. It therefore requires a certain boldness to publish a rainfall chart of the whole globe, showing lines of equal quantity of rainfall, as was first done by Elias Loomis first in the American Journal of Science in 1882, and afterwards an improved edition in 1889 in his Contributions to Meteorology.

But the need of a perspicuous presentation of the distribution of such an important meteorological element as the rainfall over the whole earth's surface is so pressing that Alexander Supan decided to prepare a new rainfall chart of the globe on the basis of the greatly increased mass of observations, but confining himself to a presentation of only six gradations of rainfall:

	Millimeters annually.
Slight rainfall	0 to 250
Moderate rainfall	250–500
Moderate rainfall	500–750
Moderate rainfall	750–1000
Abundant rainfall	1000–2000
Abundant rainfall	over 2000

By this means the arbitrary features are limited to defining the boundary of each rainfall region, and the map attains more scientific precision and comprehensiveness. The new rainfall chart by Supan, which is republished in this present Lehrbuch,[a] will form the basis of our few remarks on the general distribution of the quantity of rain.

[a] See also Supan, Pet. Geog., Mitth. Ergänzungsheft 124, 1898, and August Heft, 1898: Buchan and Herbertson Bartholomew's Physical Atlas, Meteorology, 1899: A. J. Herbertson, The distribution of rainfall over the land, London, 1891.

The most general features of rainfall distribution on the earth's surface are conditioned by the general circulation of the atmosphere.

In the tropical belts, where the ascending motion of the air is the most active and takes place on the largest scale, and where the air is also richest in aqueous vapor, in consequence of the high temperature and the great extent of the warm ocean, the average quantity of precipitation is also greatest. On the other hand, at the boundaries of the Tropics and in subtropical latitudes, where the air that has risen in the interior of the tropical zones has again sunk to the earth's surface, there falls, on the average, the least rain of all; indeed, there occur here large regions where regular precipitation is entirely wanting. The great steppes and the arid belts in both hemispheres belong principally to these latitudes. In the next higher latitudes, as has already been explained, the numerous large and small atmospheric whirls cause more or less abundant precipitation, and therefore the annual quantity of precipitation increases, but only afterwards to diminish in still higher latitudes in the neighborhood of the circumpolar regions, in consequence of the low temperature and the slight capacity of the air for aqueous vapor. In the polar regions themselves the quantity of precipitation is very small, because the air has too little moisture, especially in winter.

From these points of view we easily understand the zonal distribution of the rainfall.

John Murray has attempted to estimate the average quantity of rain that falls on each zone of latitude on the basis of Loomis's rainfall chart. The results to which he has attained are, of course, only rough approximations, and relate only to the continents. They are as follows:

MEAN RAINFALL ON ALL CONTINENTS BY ZONES OF LATITUDE.

Latitude zone.	Precipitation.	Latitude zone.	Precipitation.
° °	*Cm.*	° °	*Cm.*
N. 80–70	38	S. 0–10	203
70–60	40	10–20	132
60–50	59	20–30	71
50–40	61	30–40	75
40–30	59	40–50	113
30–20	73	50–60	112
20–10	102	60–70	107
10– 0	212		

The largest quantity of rain falls in the equatorial regions between 10° north and 10° south latitude. The rainfall diminishes toward the sub-tropical latitudes, where it reaches a minimum; beyond this it again increases. The southern hemisphere beyond latitude 30° has a larger rainfall than the northern, because it has no great dry region of an interior continental surface which in the northern hemisphere attains a great extent in the neighborhood of the fiftieth degree of latitude.

General remarks on the local causes of variations in the distribution of rainfall.—Originally all the aqueous vapor contained in the atmosphere comes from the ocean, which covers two-thirds of the earth's surface, and proportionally even more than this in the warm zones. The ever moving atmosphere carries the aqueous vapor to the very center of the largest of the continents. The diffusion of aqueous vapor, although it goes on slowly, also contributes its part to a rather uniform distribution of vapor, at least so far as temperature permits. Since the vapor condenses over the continents and falls as rain or snow, therefore the moistened surface of the earth and the water that accumulates in the depressions become a secondary source of atmospheric moisture and precipitation. Large lakes, and especially regions covered with dense vegetation sustained by rainfall, give back much aqueous vapor to the atmosphere and favor the formation of precipitation. But every chart of rainfall shows how relatively slight is the influence of the lake upon the local increase of precipitation. The heavy summer rains of the interior of Russia and even of western Siberia come from the aqueous vapor that is carried landwards from the Atlantic Ocean and the North Sea by the prevailing west and northwest winds, where it is condensed in the wandering cyclones as general land rains in the cyclones that enter these countries from Europe, or as thunderstorm rains in the local ascending currents of air. The moistened soil now again gives up aqueous vapor, and thus the same vapor originally derived from the ocean can enter many times over into the vertical circulation and appear again and again as precipitation. But since in the winter season and over the continents of the higher latitudes the low temperature reduces the water contained in the [local] atmosphere to a minimum, therefore again the principal source of the summer rains can only be the aqueous vapor brought into the interior from the ocean. Even the small quantity of snow that falls in winter is brought hither from the ocean by the cyclones.

Again, after months of drought the tropical rains that occur in the interior of the continent can be fed only by oceanic aqueous vapor. We see what quantities of moisture the sea breezes bring far into the interior of the country by considering the general land rains of central Europe, which often last many days, with northwest winds, and give rise to great floods—where, moreover, the saturated air at relatively low temperatures represses the local evaporation.[a]

Hence we find that in general the quantity of precipitation diminishes as we proceed from the coasts toward the interior of the continents. In fact, the great continents, especially where the mountains interfere with the rain-bearing winds from the ocean, are deficient in rainfall, even to the character of a desert, as in the interior of Asia and the interior of North America. Where ranges of mountains along the coast form a wall to prevent the penetration of damp oceanic air, there the dry or rainless region may occur quite near the ocean, as, for example, in Australia, whose eastern coast has heavy precipitation, whereas the plains on the lee side of the coast range are quite dry.

It is particularly to be remarked that in the winter season, and especially in the cold winters of high latitudes, mountain chains form a much more effective screen against the transportation of aqueous vapor from the ocean than they do in summer. The land on the lee side of a mountain range is therefore relatively and also absolutely drier in winter than in summer. On account of the higher temperature with which the ocean winds can in summer time pass over the mountains in a saturated condition, they bring to the land beyond the mountains a greater or less quantity of aqueous vapor, depending on the altitude of the mountains, and allow heavier summer rains to fall there. Therefore, whereas in summer time the rainfall diminishes on the windward coast because the level of the plane of condensation now lies higher than in winter, the rainfall increases on the lee side, and therefore the difference between the rainfalls on the two sides is more or less diminished.

After these preliminary remarks we can consider the general features of the distribution of the quantity of precipitation over the continents.

We remark first that in the Tropics the east sides of the continents and the islands are in general richest in rain. It is the aqueous vapor that is brought directly from the ocean by the prevailing east winds or the trades that is so abundantly condensed on these shores, especially when the shore rises rapidly as we go inward. The abundant rainfall is prolonged into the temperate zones from these tropical regions along the east coast of Asia and North America, and extends beyond the fortieth degree of north latitude, because in that region in the summer time the ocean wind blows with a more or less monsoon character. The same occurs on the east coasts of Australia, South Africa, and South America, but, on the other hand, under the same latitudes the west coasts are much poorer in rainfall.

But in the higher latitudes, where on the polar side of 40° the west winds begin to prevail, the comparative relations are entirely reversed. The most remarkable and typical illustration is shown in South America. In both hemispheres beyond 40° of latitude the west coasts are very rich in rain, as is shown by the rainfall chart of northwest Europe and America, South America, and New Zealand. Indeed, such great quantities of rain fall on these coasts as in some places to equal the rainfall of the tropical zone.

In general the heaviest rain falls wherever steady winds coming from a warm ocean encounter elevated lands.

In the middle and higher latitudes on the continents, rains also fall abundantly over a flat country, where the great atmospheric whirlwinds are frequent and, therefore, along the so-called paths of centers of low pressure, especially those that are most frequented. Examples of this are found in North America, in the region of the Great Lakes, in Denmark and southern Sweden, also in the Hungarian plains, which latter, in spite of their continental position and their being surrounded by mountains, receive on an average more rain than the low plains of Moravia and Bohemia, although these lie much nearer to the Atlantic Ocean. In fact, over Hungary there passes a storm path that is much frequented by the atmospheric whirls that are traveling from the Mediterranean and the Adriatic toward Poland. On the other hand, Moravia and Bohemia are rather far removed to one side from the paths of the Atlantic whirls that are passing over England and Denmark into the North Sea.

But everywhere the quantity of precipitation increases on the slopes of the mountains on account of the ascending motion of the air that more frequently occurs there and the consequent cooling that leads to the condensation of aqueous vapor. Every special rainfall chart of any country has, therefore, a great similarity to the hypsometric chart itself. * * *

It is certainly to be remembered that the extreme rainfalls are almost invariably confined to a small region and are local phenomena. That region of the globe that on the average receives the greatest quantity of rain is certainly the archipelago of the East Indies and the northern coast of Australia and New Guinea.

On the other hand, over broad regions of the globe, the annual rainfall is either entirely wanting or confined to a few centimeters. Probably there is no region absolutely rainless in which no rain falls in the course of many years. Even in the Sahara and on the west coast of Peru, rain occasionally falls in the course of a year, and often it is very heavy. The Polar regions belong to the driest portions of the earth in absolute measure, since often there are only 10 or 20 centimeters of precipitation in the course of a year. But in spite of this, there is no want of moisture because of the low temperature and the frozen soil. The same quantity of precipitation has an extraordinarily different import according to the local climate.

[a] Supan and Brückner have lately pointed out the ordinary underestimate of local evaporation, and have shown that the evaporation from the surface of the land plays a very important part in the origin of summer rains. * * * Only one-fourth of the precipitation on the surface of the land flows back to the ocean in the rivers. Therefore a large part of the precipitation must be derived from the evaporation from the land. That is to say, we measure the same quantity of water that came originally from the ocean many times over in our rain gauges; it is often condensed and immediately evaporates again. * * * When, therefore, we ascribe two-thirds of the precipitation to the aqueous vapor brought from the ocean this will appear to be a low estimate.

(6) PROF. A. SUPAN.

In 1898 Prof. Dr. Alexander Supan, the editor of Petermann's Mittheilungen, published an exhaustive memoir on the distribution of precipitation on the islands and continents of the globe. We submit the following translation of some portions of this memoir, bearing directly upon the present question:

It is well known to me that a rainfall chart of the globe will meet with the approbation of geographers rather than meteorologists. Even Julius Hann, whom we geographers with pride refer to as the chief of climatologists, allows that the chart of the quantity of rainfall can have only a didactic and not a scientific value. It is maintained that the measurements are not yet sufficiently numerous to exclude the arbitrary features introduced by the draftsman. Even to-day this reproach is justified up to a certain degree. Although we now possess average values for about 4,000 rainfall stations, yet, unfortunately, these are distributed very unequally. More than half of them belong to Europe, and even here there are broad regions, such as northern Russia and Turkey, that have only sporadic series of observations. But if we allow that the European stations are a sample of what we ought to have, then for all the land area of the earth we should need over 20,000 stations, or five times as many as are now at our disposal. And even with these we should not be able to do much more than to construct a schematic presentation.

In no other of the climatological elements do local influences play so important a rôle as in precipitation. The more varied is the surface of the land and so much the more rapidly the relative altitudes change, therefore so much the denser must be the network of stations. Two points come especially into consideration—the location of the place with reference to the prevailing rain winds and its absolute altitude. We know that the windward side has more rain than the leeward side and that the precipitation increases up to a certain altitude and then again diminishes, and in such a way that the altitude of the zone of maximum precipitation decreases the nearer we approach the poles.

And now consider the complicated variation of these conditions in a mountain range like that of the Alps or in a mountainous country having the complex structure of central Germany. The distribution of rain in a relatively simple portion of the latter, namely, in Silesia, has lately been graphically studied by J. Partsch. This essay is of the highest interest as a study of methods. Although 528 station records were at his disposal (for five years only but simultaneous), still this scarcely sufficed to bring out the influence of the orography on a rainfull chart on the scale of 1/1,000,000, and for some mountainous regions even this scale is too large. More than 730,000 stations would be necessary to enable us to draw a rainfall chart for the whole land portion of the globe with the accuracy with which Partsch has done it for Silesia. We may, therefore, judge of what may be done with 4,000 stations only. Consider further how unequal the material is. Outside of the civilized countries we should be very happy if we had five or ten year averages and not infrequently are we reduced to single years of observations, whose utilization of course requires the greatest circumspection. But even longer series of observations are with difficulty comparable with each other when they belong to different epochs. Furthermore, we know the difficulties of the measurement of snow, especially of drifting snow, which fills us with some distrust of the mean precipitation for the higher latitudes. Even the establishment and the construction of the instruments are of importance, but in only the rarest cases can these be controlled; from this point of view Hellmann has discovered many errors in the rainfall charts of Germany. In the tables published by Partsch for Silesia, we find Oderberg with 511 mm. and the neighboring Annaberg with 727 mm.; both these averages refer to the same epoch. The comparison with other neighboring stations at once shows that the figure given for Oderberg is erroneous; but what a confusion would prevail if we had no control at hand? It is in fact an unattractive problem to erect a building with such material. But still the problem must be solved. The chartographic method is the vital principle of comparative climatology. Humboldt's chart of isotherms first established this science, and yet how insufficient was its basis—only 57 stations. If Buchan had been too cautious we should to-day still have had no isobaric charts of the globe. The construction of a rainfall chart has, however, to contend with still greater difficulties because the distribution of precipitation depends so much on local circumstances that ofttimes these completely obliterate the influence of the principal factors. And we have no means by which to eliminate the local character from the measurements, and especially we have no method of reducing total rainfall to sea level. The consequence of this is that we need a much more comprehensive collection of observations than for the graphic presentation of the distribution of other meteorological elements. But if we keep this restriction in mind we can not see why such a rainfall chart should be of less value than the charts of isotherms and isobars. Where gaps occur it is the place of the accompanying text to justify the chartographic presentation. It is an advantage of the chartographic method that can not be overestimated that, even in doubtful cases, it forces us to recognize shades of special importance in the meaning of the words, whereas in tabular presentations the defects of the network of observations remain unimportant and the presentation can skillfully conceal these so that we either do not notice them or can not bring the author to task for having overlooked them. * * *

It has been mentioned above that we can bring against rainfall charts the objection that they leave too much play for arbitrary features introduced by the draftsman. If we acknowledge that this danger exists, still it is diminished so much the more in proportion as we enter less into the details. I consider that it is not allowable to introduce more than six grades at the present time for all land portions of the globe except for Europe, the United States, and India, and the greater part of the islands. If these grades increase in extent as we go upward (namely 250 mm. for the lowest stage and 1,000 mm. for the upper stage), this has a twofold reason, the first because in the lower grades differences of 250 mm. are practically much more important than in the higher stages, and second because very considerable depths of rainfall are, so far as our experience goes, not spread over large regions. In our chart of total seasonal rainfall we have restricted ourselves to four grades, partly because of the smaller scale of the charts and partly also because the quantity of rain in any season varies from place to place more than the quantity of annual rainfall.

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Having shown that the winter rainfalls, in general, cover broad areas of country, while the summer rainfalls are local showers, often accompanied by thunder, Supan gives, on pages 40–43, a study of the relation between altitude in the interior of the continent or islands and the increase of rainfall, especially winter rains, from which we make the following extract:

In the region of prevailing winter rains, wherever we have a sufficient amount of observational material, we find a relative increase of the precipitation with the altitude in the colder half of the year. For instance, in Scotland, on the coast, in the lowlands, and in the deeper valleys the winter rain never attains 60 per cent of the total annual; while the whole of the western highlands has 61 or 62 per cent. The same phenomenon is repeated in the region of prevailing summer rains. In this respect the table compiled by Paul Schreiber for the individual zones of altitude in the Kingdom of Saxony is very instructive, and the following values are deduced therefrom:

Altitude.	Rainfall.			Increase with altitude.			Winter, per cent of annual.	Summer, percent of annual.	Annual range in per cent of annual.
	Winter.	Summer.	Annual.	Winter.	Summer.	Annual.			
Meters.	*mm.*	*mm.*	*mm.*						
100	221	351	572	1.00	1.00	1.00	38	62	9
300	280	398	678	1.31	1.13	1.18	41	59	8
500	337	444	781	1.53	1.26	1.35	43	57	7
700	396	490	886	1.80	1.39	1.55	45	55	6
900	454	536	990	2.06	1.53	1.73	46	54	5
1,200	540	606	1,146	2.44	1.73	2.00	47	53	4

Throughout the whole year the precipitation increases with the altitude, but much more rapidly in the winter half than in the summer half. Consequently, the annual period also changes, and if the Harz Mountains were high enough we should finally attain a level where the winter rains and the summer rains are equal. We should call this the reversing level, and above it winter rains would prevail.

But a mountain that is of the same height as those of Saxony must penetrate upward into the region of winter rains if the annual periodicity at its base were somewhat different from the preceding. The above table gives us the means for computing the altitude of the reversing level for different cases. The winter rains at an altitude of 100 meters and expressed as a percentage of the total annual rainfall, must be increased from 38 to 41 in order that the level of inversion should be depressed down to the top of the highest summit of the Harz Mountains. For different values of this percentage of winter rains, as shown in the following table, the level of inversion would have the corresponding values shown in the second column.

The first column gives the winter rains at 100-meter altitude expressed as a percentage of the total annual rainfall. The second column gives the corresponding computed height at which winter and summer rains are of equal amount.

Per cent.	Altitude.	Per cent.	Altitude.
	Meters.		*Meters.*
42	900	46	250
43	700	47	200
44	550	48	150
45	480	49	120

I attach no importance to the absolute values of these figures, for they rest upon the unproven assumption that the rate of increase of the precipitation with altitude is constant; but this much at least we may conclude, viz, that the level of reversal is lower in proportion as the precipitation in the lowlands is uniformly distributed throughout the seasons, or, in other words, in proportion as the annual rainfall variation is smaller.

When we consider that in Germany the annual variation diminishes as we pass from the south toward the north and from the east toward the west, we must expect that the altitude of the plane of reversal will diminish in the same directions, and, consequently, that in the northern and western portions the land surface of any given altitude may have winter rains, while in the south and east the same altitude participates in the summer rains. This, in fact, is demonstrated in the collection of high stations that we owe to Hellmann. (See Met. Zeit., 1887, p. 84.) I arrange these in three groups, as follows:

Locality.	Altitude of the lowest station that has prevailing winter rains.	Locality.	Altitude of the lowest station that has prevailing winter rains.
SOUTHERN SERIES.	*Meters.*	CENTRAL SERIES—continued.	*Meters.*
Bohemian Forest	850	Odenwald	334
Suabian Plains	210	Haardt	490
Black Forest	773	Hunsruck	395
Vosges	338	NORTHERN SERIES.	
CENTRAL SERIES.		Harz	570
Thuringian Forest	630	Sauerland	460
Rhon	760	Westrheinisches Schiefergebirge	177
Spessart	490		

The irregularities in this table are partly accidental, resulting from the small number of high stations, but also partly real and resulting from the location of the station. If a range of mountains stretches more or less nearly perpendicular to the direction of the prevailing rain wind, then the winter rainfall on the windward side is not only absolutely but also relatively heavier than on the lee side, and consequently the level of reversal instead of cutting through the mountain range horizontally must rise toward the lee side. An excellent example of this principle is afforded by the Riesengebirge.

	Altitude.	Rainfall.			Percentage of annual.	
		Winter.	Summer.	Annual.	Winter.	Summer.
Southwest slope Upper Elbe	490	499	464	963	52	48
Schneekoppe, Summit	1,603	599	584	1,183	51	49
Northeast slope, Wang	873	589	642	1,231	48	52
Northeast slope, Eichberg	349	299	383	682	44	56

The winter rains of Aix-la-Chapelle are also undoubtedly controlled by the location, since the altitude of the plane of reversal is considerably higher in the Belgian Ardennes. I have computed the following mean values from the excellent collection of Belgian rainfall stations by Lancaster:

Altitude (meters).	Number of stations.	Total rainfall.			Increase with altitude.			Per cent of annual.	
		Winter.	Summer.	Annual.	Winter.	Summer.	Annual.	Winter.	Summer.
		Mm.	*Mm.*	*Mm.*					
Below 100	70	332	368	700	1.00	1.00	1.00	47	53
100–200	29	371	415	786	1.12	1.12	1.12	47	53
200–300	14	435	449	884	1.31	1.22	1.26	49	51
300–400	10	455	459	914	1.37	1.25	1.31	50	50
400–500	7	505	452	957	1.52	1.23	1.37	53	47
Over 500	5	485	525	1,010	1.46	1.40	1.44	48	52

Here we see the change from the summer rains of the lowlands to the winter rains of the plateaus begins at an altitude of about 350 meters. But this table is also instructive in another respect: The rainfall increases with the altitude for a while and then again diminishes. The maximum zone lies at 1,300 meters in the Himalayas, 1,400 in the Ghats, about 1,000 in Java, and about 500 meters altitude in the English Lake districts. Hann has shown from theoretical considerations (see his Climatology, Vol. I, p. 298) that the seasonal changes of this maximum level proceed in such a way that it rises with increase of temperature, as is also shown from its geographical distribution. Now, our table for the Ardennes gives a numerical value for this increase. We see the summer rains increase from level to level, but the winter rains increase only up to the fifth level, and then again diminish. At the same time the annual period changes at the highest level. At an altitude of 447 meters Lutremange still has prevailing winter rains, but at 467 meters Gouvry has summer rains again. Therefore, in the Ardennes we learn to recognize two levels of reversal, and we have here the following stratifications:

A lower zone of summer rains.
 A lower level of reversal at about 350 meters.
A zone of winter rains.
 An upper level of reversal at about 450 meters.
An upper zone of summer rains.

We may conclude that the upper level of reversal rises toward the east in the same way as does the lower level from the fact that Hollerath, which lies about 25 kilometers east of Malmedy, in spite of its altitude of 612 meters, still has winter rains.

In the European region of our chart of precipitation, and in all seasons of the year, the mountains appear as insular results of winter rains in the midst of regions of summer rains. This holds good not only for the German central mountains, but also for the French, where these islands of winter rainfall in all probability are more extended than we at present can demonstrate. Outside of Europe in the region of the lowest category of annual ranges such occurrences are certainly present, but, with one single exception, observations are still wanting. This one case relates to the southern half of the Atlantic States of North America, which constitutes the most extensive of all hydro-meteoric islands thus far known. We select here as an example five Mississippi stations between the Gulf and the mouth of the Mississippi, and utilize only the simultaneous observations of 1870–1888 in order to anticipate all objections:

Stations.	Distance from the sea.	Altitude.	Rainfall.			Per cent.		Annual range.
			Winter.	Summer.	Annual.	Winter.	Summer.	
	Km.	*M.*	*Mm.*	*Mm.*	*Mm.*			
New Orleans	50	16	730	862	1,592	46	54	5
Vicksburg	310	68	784	706	1,490	53	47	6
Memphis	610	98	727	625	1,352	54	46	5
Cairo	825	109	563	539	1,102	51	49	4
St. Louis	1,000	174	405	556	961	42	58	8

That the precipitation should be distributed in the summer season more uniformly than in the winter is quite normal, but on the other hand it is abnormal that the winter rains should not only not diminish toward the interior but should increase. From November to April Vicksburg receives more rain than New Orleans, and in February this increase extends even to Cairo. This can only be attributed to the increasing altitude above sea level.[a] The factor L, that is to say, the aqueous vapor derived by evaporation from the surface of the land, first has the upper hand in St. Louis in the summer, but over the eastern plateau the winter rain stretches up the Ohio River. This insular occurrence is combined with a region of very small annual rainfall.

In countries with sharply defined summer maxima we might expect that at least in high mountain ranges winter rainfalls would occur, but the alternations of the high Alpine stations give a negative answer to this expectation. From the Wendelstein, 1,727 meters, up to the Sonnblick, 3,100 meters, all have decided summer rains. The same is also true of Pikes Peak, in the Rocky Mountains, although winter rains occur on its western slope at 3,500 meters. An exception occurs on the Pic du Midi, in the Pyrenees, but we must not forget that on the northern and southern slopes the annual distribution of rainfall is very uniform. The observations discussed by Klengel are of the highest interest in this respect, because three layers of reversal are present here. Going from north to south we have the following stations:

Stations.	Altitude.	Rainfall.			Increase with altitude.		
		Winter.	Summer.	Annual.	Winter.	Summer.	Annual.
	M.	*Mm.*	*Mm.*	*Mm.*			
Tarbes	308	365	464	829	1.00	1.00	1.00
Bagneres	555	641	645	1,286	1.76	1.39	1.55
Plantade	2,366	994	1,135	2,129	2.72	2.45	2.37
Pic du Midi	2,860	974	638	1,612	2.67	1.38	1.94

The winter rains begin immediately above Bagneres; Plantade has summer rains; the summit of the peak again has winter rain. This depends upon the changes of the zone of maximum rainfall. If we consider the curves showing the rate of increase we shall see that the maximum zone is at 1,300 meters altitude in the winter and at 1,900 in the summer. The winter curve rises at first rapidly to 1,030 mm. and then gradually sinks; the summer zone of maximum precipitation has nearly 1,500 mm., and the comparison with the above figures shows that the rainfall diminishes rapidly in both directions.

[a] Possibly a different explanation may be found.—C. A.

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(7) MR. HENRY GANNETT.

With regard to the influence of forests, cultivated lands, or arid lands, as such, on the amount of local rainfall, Mr. Henry Gannett has expressed himself very clearly in the following paragraphs which we quote from page 375 of the Monthly Weather Review for August, 1901:

An example of the persistence of error is the belief that the presence or absence of forests has an influence upon the amount of rainfall. Some keen observer long ago detected the fact that forested regions enjoy a heavier rainfall than those not forested, and jumped to the conclusion that rainfall is produced by forests, and as a corollary that the removal of forests diminishes the rainfall. * * *

The situation is simply that the cart has been placed before the horse. Want of rain prevents the growth of trees; want of trees does not prevent rain. This position is generally accepted among physical geographers, but the majority of the people still reverse cause and effect.

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(8) MR. HENRY GANNETT.

Under date of February 5, 1902, Mr. Henry Gannett writes:

The relief of the earth's surface has a great influence upon rainfall. Theoretically it should be so, and all precipitation measurements and observations of stream flow and vegetation sustain the theory. The fact that rainfall is greater upon mountains than upon the adjacent lower country is a matter of common observation. Other things being equal, the higher the mountain above its base the greater is the rainfall which it receives.

Vegetation is influenced by two elements of climate—temperature and precipitation. The fact that a region is forested is, in general, the best of evidence that it enjoys a greater rainfall than a neighboring region which is not forested. Furthermore, the species of trees indicate, and, indeed, roughly measure, the amount of precipitation. The Sierra Nevada, for instance, bears upon its long western slope a succession of tree species which indicate very closely not only the temperature but also the amount of precipitation. These timber belts are well recognized and have been traced over great areas. Under similar temperature conditions the bottom of the yellow-pine belt indicates a certain isohyetal line which, in the southwestern United States, is very nearly that of 20 inches annually.

Direct measurements of rainfall form therefore only a part, and a very small part, of the data concerning the distribution of rainfall, which is available for preparing maps. The relief of the country, combined with our knowledge of the laws governing precipitation, the extent and character of the tree vegetation, and the volume of streams relative to their drainage areas, furnish a large body of additional data. These are of especial value, since they commonly relate to regions in which we have few gauge measurements.

If, in preparing a rainfall map, only the gauge measurements are used, ignoring these additional sources of information, the map is not only imperfect but positively incorrect. It is, for instance, certainly incorrect to show the area occupied by the Sierra Nevada with the same precipitation as measured at Fresno, Stockton, or Owens Lake; or the area of the Wasatch range, from the measurements at Salt Lake City; or that of the Colorado Mountains, from measurements at Denver, Leadville, or Grand Junction, yet that is what would be done if the gauge measurements only were used.

To what extent of detail the relief of the country should be recognized on a rainfall map depends entirely on the scale of the map. If as small a scale as that of the United States Daily Weather Map[a] be used, the influence of only a few of the greater ranges and plateaus can be expressed. Generalization is necessary here, just as in a topographic map drawn upon a small scale.

(9) PROF. B. E. FERNOW.

Under date of February 6, Prof. B. E. Fernow, of the School of Forestry, Cornell University, Ithaca, N. Y., writes as follows:

I agree with and share all the wishes of Professor Jefferson, but I also admit all the reasons of Professor Henry (Monthly Weather Review, November, 1901), why these wishes can as yet not be gratified. While as a student of biology, and especially ecology, I should, with Professor Jefferson, like to have correct rainfall data, I believe with Professor Henry that existing means—i. e., imperfect rainfall gauges and deficient number of stations make it impracticable to secure them, and the desirable improvements hardly lie in the direction of correcting admittedly poor data by an uncertain formula.

Professor Henry does not perhaps state as strongly as he might his objections to Professor Jefferson's proposition to correct rain-gauge records and to make allowance for mountain influences.

If I am suspicious now of rainfall data, when they are records of actual observations, such as the rain gauges permit, I would certainly not look at them with more confidence if I knew they represented "doctored" facts. I prefer to do the doctoring myself when I think that thereby they may be improved.

Under present conditions I believe the corrections would be impracticable, but I also believe that improvements in rain gauges are possible and most desirable, and in so far I would join with Professor Jefferson in asking for improvements.

Meanwhile let us have, so far as mere records are concerned, nothing but facts, unadulterated—with the fractions of inches of rainfall usefully omitted—and not hypothetical ones. When it comes to discussion of the observations the matter assumes a very different aspect.

It has perhaps been overlooked that as far as the meteorologist is the recorder of observed facts, he is in an entirely different position from the geographer or climatologist, the interpreters and generalizers of these facts; the two must present the facts differently.

Perhaps there is also a misunderstanding as to what the isothermic or isohyetic lines on meteorological maps mean, or, should I say, ought to mean with our present insufficient outfit. To me they mean only a graphic method of presenting actual observations—in aiding the eye to quickly see in which places (of observation) the same conditions existed at the same time. To avoid conceiving these lines on the record maps as anything else, it might be wise not to smooth them, but have straight lines connect merely the points of equality If this were done, nothing but the mere facts are represented and nobody will suppose that areas of equality are intended.

When the climatologist or geographer proposes to use these facts for generalizations, then, to be sure, a certain amount of philosophy—facts not observed in loco, but in general physical laws, influences of configuration, etc.—must be adduced to make a reasonable interpretation and useful application.

The meteorologist's business is to make the bricks as accurate and perfect as he may, whatever the use to which they are to be put. The climatologist, the biologist, the geographer, are the builders who must have sense and knowledge how to use them.

For the geographer and climatologist, then, I consider it right to take into consideration the probable influence of configuration, elevation, etc., and to make his rainfall and temperature areas conform to these probabilities, with the actual facts as a basis. I repeat again, it must not be overlooked that he is concerned only in generalizations, and not in such details as the meteorological recorder is.

If the Weather Bureau, from time to time, issues climatic and not meteorological maps, then in these, to be sure, one would expect such use of their data as conform to our general knowledge of physical facts and laws.

You ask "to what extent can a rule that applies to one mountain be extended to other mountains in distant parts of the country?" Who knows? I know this much, that mountain peaks in lower Arizona, nearly as high as Mount Washington, say 5,000 feet, have no power of condensation and remain arid, while those exceeding that height are covered down, to points far below the 5,000-foot level, with a forest growth—the result of precipitation. I believe with Professor Henry that local variations will be sufficient to prevent any valuable generalizations.

"Is the connection between forests and rainfall so definite as to warrant attributing heavier rainfall to a forest region as compared with an adjacent bare region?"

As you know, I consider that, as far as observed or measured data are concerned, nothing definite is known regarding this connection.

The philosophy of the causes of rainfall would warrant us in assuming that if an extensive area were covered with unbroken dense forest cover—such cover as would protect the soil against insolation, creating a large area of cooler, more humid air—its rainfall conditions would be different from those of an extensive area entirely devoid of this cooling influence. But I take it that, in order to be appreciable and of practicable value, there would have to be a certain proportion between these conditions of the soil cover and the other meteorological and topographical factors that are involved in causing precipitation.

As a rule, at least in settled parts of the country, there is alternation of open field and wooded area, and here, I should be inclined to think, the influence of the wooded part would.

[a]The daily map here referred to is on the scale of 1/10,000,000; the rainfall maps of Messrs. Gannett and Henry and the relief map, all in this current number of the Monthly Weather Review, are on the scale of 1/12,000,000; the regular monthly rainfall map of the Monthly Weather Review is on the scale of 1/25,000,000.—Ed.

counteract the influence of the open country and average conditions would prevail as compared with the extremes of unbroken forest or open plain.

I believe common observation supports this philosophy, although measurements of any value are entirely absent in spite of the attempts to obtain them by the German and Austrian forest meteorological stations. The trouble here lies in the difficulty of excluding or discounting all other influences except the one to be measured, namely, the forest cover, and in the general inability of the rain gauge to measure. I should therefore consider it a risky advance beyond our knowledge to "doctor" the facts in this direction.

Let me close this very hasty letter with the wish that a broad-gauge policy may permit the Weather Bureau to advance methods of meteorological inquiry and statement of which we are so much in need.

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(10) PROF. B. E. FERNOW.

Again, under date of March 21, 1902, Prof. B. E. Fernow says:

In reply to the query, "To what extent does the presence of a forest demonstrate the fact that a certain amount of rain is being received annually?" I can only answer that we have no data on which to base even a guess; moreover the absence or existence of a forest growth is always dependent on more phenomena in combination than the one factor of rainfall, which may even be the least important, although a necessary one.

That there is a relation between moisture conditions and the existence of certain floras, hence of forest growths, is well known, and the moisture conditions may become so precarious that, *in combination with other conditions*, they lead to forestless conditions. But it is not the amount of rainfall, at least not directly and primarily, that produces the distribution of forests. No one factor can be so segregated from all others as to account for the complex phenomena of distribution of life. Rainfall and relative humidity must be at once placed in relation to temperature and all other factors influencing life; in tree growth especially, what I call the transpiration factor, is determinative, namely, the relation of available water supplies at the root (which also depend on soil conditions) to the consumption at the crown by the transpiration of the leaves, due to temperature, relative humidity, character and velocity of winds, especially during the period of active vegetation.

Above timber line, although precipitation is ample and relative humidity is high, forest growth is absent, partly because of thin soil, combined with steep slope, which can not retain sufficient moisture, partly because of low temperature and, still more, liability to frequent frosts, and because of several other causes. In the desert and plain, forest growth is absent, because relative humidity and high temperature, and especially dry winds, make more demands upon the transpiration current than the roots can supply. Note that the rainfall during the period of vegetation is about the same at Dodge, Kans., as in Philadelphia, but the dissipating influences, the evaporation or transpiration factors are very different.

It has been asserted that tree growth or forest growth can not exist where the relative humidity sinks below 50 per cent during the period of vegetation and the precipitation below 50 mm. Yet, while we may accept these lowest limits, in combination with the factors of evaporation and soil conditions usually found in such places, as generally true, we must also admit that, if the latter factors are modified, for instance by protecting mountain ranges or improved water storage in the soil, forests may still be absent, because the mechanical means of establishing them in competition with other forms of vegetation were deficient, but it does not argue that forests could not be grown there, and, in fact, forests have been grown where they were not found by nature in Russia and in our own country and elsewhere.

I would conclude that rainfall is not the most important or controlling factor in forest distribution; that it is almost impossible and futile, certainly impracticable, to segregate any one factor as controlling; that the combination of factors, which I call the transpiration factor (which I admit is intangible, except in conception), controls in most cases the existence of forest growth.

The distribution of our species and the possibility, practically attested, of transporting them succesfully from one set of rainfall conditions to regions of entirely different rainfall would go a long way to make the existence of a very direct relation doubtful.

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(11) MR. F. H. NEWELL.

Under date of February 4, 1902, Mr. F. H. Newell, hydrographer, United States Geological Survey, writes as follows:

For at least twelve years I have been studying some of the rainfall statistics gathered by the Weather Bureau, and have given especial attention to your rainfall maps, and have frequently talked with General Greely, Professors Harrington, Moore, Henry, and others about the method of presentation of the data. I have come to regard your normal rainfall map, not as absolutely worthless, but rather as misleading in telling only a part of the truth and in ignoring matters of common knowledge. I have never republished your map in any of the reports or papers I have prepared privately, but, whenever I have had occasion to use such map, have redrawn it, using Mr. Gannett's sketch as a guide.

The Weather Bureau rainfall map is undoubtedly fairly good for the more thickly settled part of the United States, where there is not a great diversity of topography, but for the western two-fifths of the country it is very misleading, because it ignores the great mountain ranges and the great differences in precipitation due to their presence. For example, in looking out of the window of the office of the Weather Bureau in Denver we can see snow storms and rain storms upon the higher summits of the Rockies, and those of us who have surveyed and camped through these mountains are well aware of the heavy precipitation, and yet the Weather Bureau apparently ignores the fact. The same is true of the Wasatch, Cascade, Sierra Nevada, and other great mountain masses of the continent. There are few, if any, stations for observation of rainfall within these mountains from which come the important streams vital to the development of the West.

If we measure the amount of water flowing out from some of these mountain streams and find the total volume delivered during the entire year, and then compare this with the precipitation as shown by the Weather Bureau map, we reach the astonishing conclusion that in some instances over 100 per cent of the rainfall reaches the streams. At one time I spent several months studying these anomalies and came to the conclusion that the Weather Bureau statistics of rainfall do nof go far enough to be of any value whatever in the study ot river flow for the more important streams. It seems to me that either the maps should be left blank for these great mountain masses, thus frankly confessing that no information is available, or that careful approximation or intelligent guesses should be made by men who are thoroughly familiar with the mountains and know from personal experience something of the distribution of rainfall.

Reference has been made to the desirability of correcting rain-gauge records for height, etc., but this seems to me to be splitting hairs, for, as pointed out, it is useless to discuss decimals when the units are in error. The rain gauges at the city stations are probably well cared for, but those in the country and in charge of volunteer observers are frequently in deplorable condition. In my studies of river flow, I have taken pains to visit a great many Weather Bureau gauges in the hands of volunteer observers, and the more of these I see the less confidence I have in figures of rainfall obtained in this way, excepting as the results of one observer are confirmed by numerous others and agree with the evidence deduced from general topographic information.

It is stated by Professor Henry that "each section director is expected to visit stations in his district and correct faulty exposures, when such are suspected to exist." I understand, however, that such inspection exists in theory rather than in fact, since the funds available for such inspection are extremely limited, and unless railroad passes are obtained it is impossible for the section director to travel over his district. Moreover, his duties are so varied that as a matter of fact he rarely is able to gain a personal knowledge of the country for many years. In fact, I question whether in the western half of the United States more than 1 or 2 per cent of the rain gauges have ever been inspected by a competent person.

The result of these erroneous reports appears in the anomalous figures occasionally published. I have rarely visited a volunteer observer and found the gauge in good condition. Frequently there is water standing in it from the last rain storm.[a] Sometimes it is near a shed or tree. Even at army posts, where the meteorological instruments have been confided to the care of the hospital assistants, the conditions are sometimes faulty.

I might write pages of incidents and complaints of the inaccuracy of rainfall observations, but I appreciate the surrounding circumstances and know that at best the observations of rainfall represent not so much absolute as relative differences, and that it is only by comparing considerable numbers of observations with each other that we can arrive at general conclusions as to the distribution of the precipitation. To exhibit our full knowledge of the distribution of rainfall we must take into account other factors beyond the rain gauge, taking what lawyers would term "judicial cognizance" of matters of common knowledge. We know, for example, that there are more frequent and longer storms upon the mountain masses than over the broad valleys where people live. This is attested by the luxuriant growth of vegetation and by the rivers which drain the uplands, and yet, ignoring this fact, maps of precipitation are made based wholly upon the single fact of rain-gauge measurements made in the valleys.

It is not possible, on a small map of the United States, to show the minor elevations of one or two thousand feet, such as those of New England, but the Appalachian Range should always be given, and also the principal range of the Rocky, the Cascade, the Sierra Nevada, etc. Omissions of this and disregard of other climatic effects seem to me to render the Weather Bureau maps practically valueless as regards other than the broad valleys of the country.

(12) MR. F. H. NEWELL.

Again, under date of February 17, Mr. F. H. Newell writes as follows:

I have been giving particular notice to some of the maps of the monthly reports of the State weather services. It seems to me that in compiling these too little attention is paid to local topography, oval lines being sketched with respect solely to the points of observation when they might be deflected to skirt along the mountain masses, in accordance with the known facts of precipitation. A most incongruous condition also results when the rainfall maps of two States are placed side by side, each having been made independent of the other and without any regard to the great mountain masses. The result, it seems to me, is not creditable to the Weather Bureau, because it seems to indicate a blind following of scattered data without regard to other well-known phenomena.

Take the last maps of annual precipitation, just received, those for New Mexico and Colorado, place them adjacent, and note the extreme lack of coincidence and disregard of all mountain masses and probable direction of storms. Some of the most rugged mountains in the country lying in the southwestern portion of Colorado are shown as having less than 10 inches of rainfall, while on the other hand the broad desert of the Montezuma Valley is given 15 inches or more. There is a little circle of 25 inches around Pikes Peak and around one or two mountains, but the remaining great mountains upon which there is probably an equal or greater precipitation are left out.

Taking the same data, I have asked one of our men, who is familiar with the topography, to sketch a rainfall map, with the result that his drawing, while equally true to the data obtained, brings what seems to me to be a far better showing, and one which can not be open to the charge of neglecting well-known geographical facts. The lines of equal rainfall, instead of being meaningless ovals, are deflected along the mountain masses and separate the broad valleys, upon which we know there has been little precipitation, from the elevated regions where, from the appearance of the snow and from the volume of water discharged by the rivers, we know that there has been a heavy precipitation.

(13) PROF. GEORGE L. GOODALE.

Under date of March 20, 1902, Prof. George L. Goodale, Botanic Gardens, Harvard University, Cambridge, Mass., writes as follows:

In answer to the question "Do special types of forests give any definite information as to the annual rainfall or melted snow?" I am compelled to say that this must be answered now in the negative. With acquisition of new data, it may be and probably will be answered affirmatively.

The optimum conditions of vegetable activity are well known for many plants, and the functional relations are so well understood that from two known quantities one can estimate an unknown quantity. For instance, given the heat and moisture available, one can state what the luxuriance probably is. Or, given the luxuriance and one of the two factors just referred to, the other can be judged. Thus, if one knows the luxuriance and the available heat, the amount of moisture necessary to bring about this luxuriance is easily conjectured or, perhaps it is better to say, calculated.

If one could know whether a given forest of white pine is stunted or thrifty, or, to be more precise, could know its rate of growth, and at the same time should know the mean annual temperature, the amount of rainfall could be fairly determined. Now, it is questionable whether enough is yet known in regard to the rate of growth of our mountain forests, and in regard to the mean annual temperature in those districts, to make it worth while to guess as to the rainfall. With more accurate data as to rate of growth and either of the two factors referred to, it will be practicable to deduce the other factor.

[a] Of course the rain water will always remain in the gauge until measured.—C. A.

But, on the whole, it appears as if, in the forest districts, especially in the mountains in question, it might be wise to establish stations in which meteorological and forestry problems could be worked out together.

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(14) PROF. C. S. SARGENT.

Under date of March 20, 1902, Prof. C. S. Sargent, Arnold Arboretum, Jamaica Plain, Harvard University, writes as follows:

The rainfall, particularly on high mountains, appears to be so greatly influenced by local causes other than forest growth that I should not think it would be safe to make any such generalization as you suggest. I should suppose that the character of a mountain forest would be largely influenced by temperature—that is, by altitude—but that the size of the trees would be dependent on moisture, and that a mountain forest of large trees would indicate a larger rainfall than a forest of smaller trees of the same kind.

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(15) PROF. JULIUS HANN.

In the matter of utilizing the presence of forests as a guide in drawing isohyetal lines, the opinion of Prof. Dr. Julius Hann was recently expressed in conversation with Dr. C. Abbe, jr., in Vienna, as follows:

When there are but few rainfall stations it is proper to draw isohyetal lines provided it be distinctly stated that the locations of these are estimated, and provided that the basis of estimation be distinctly stated, and that, furthermore, the rainfall actually observed be clearly entered on the map and properly distinguished from the supposed rainfall. A map whose isohyetals are based principally upon the existence or nonexistence of forests and the altitudes or orography of the country can only have value as a pedagogical aid to the presentation of the laws according to which it was constructed, but has no scientific value because it has no sufficient number of actual measurements of rainfall to support it. It is doubtful whether the estimated ratio of run off, or the discharge of rivers, to the precipitation over the river basin is known with sufficient accuracy or can in any case be estimated so as to enable us to reconstruct an accurate system of isohyetal lines even when the measurements of the streams are satisfactory. When there is no measurement of run off or of rainfall it would not be justifiable to draw and publish even hypothetical isohyetes. In Austria, where there are long series of observations at numerous stations representing mountain tops and valleys, the isohyetes are drawn in accordance with observations and on large scale maps and without introducing hypotheses. Of course it is easier to draw maps on a very small scale, as is done in those of the United States that are sent to Vienna. In regions not otherwise provided for it is desirable to establish gages that will hold a week's or a month's supply of rain and read them as often as it is practicable for a man to visit them, so that we may at least get the monthly and annual sums. In Austria such gages usually give higher readings than the sum of the observations made in the usual manner at 9 a. m. daily.

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(16) PROF. JULIUS HANN.

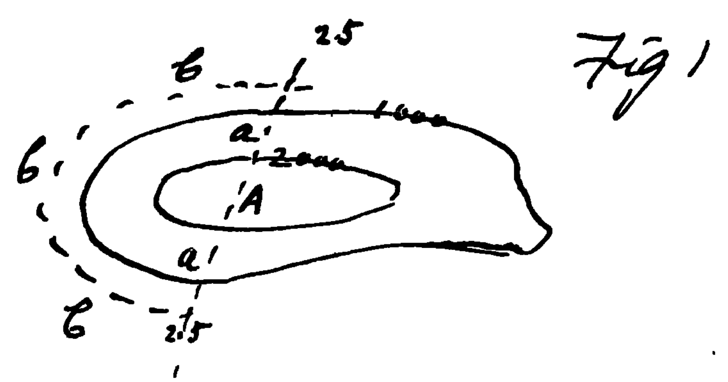
Again, under date of Vienna, April 6, Prof. Dr. Julius Hann writes as follows:

The question that you submit to me is rather difficult to answer. It is so much the more difficult because in your case (of the Monthly Weather Review charts) you have to do with isohyetal charts for individual months and not the average isohyetals for a long period of years. In the latter case the general rules for the increase of rainfall with altitude and the local rules with reference to the prevailing direction of the wind are to be applied approximately to the determination of the actual distribution of rain; for a special month the influence of the direction of the wind can scarcely be estimated, and still less so the influence of altitude. The presence of forests (for example, in the western portion of the United States, in the Rocky Mountains, etc.), is indeed to be regarded as an indication that from certain altitudes upward in that region more rain falls than below, but there is absolutely no basis for any estimate as to the amount of this surplus, and any isohyetals thus drawn on the chart would be purely arbitrary. The quantities of run-off from the rivers are such also that they can scarcely be used; the ratios for the reduction from run-off to rainfall vary extraordinarily in a region like that of the United States, especially in the dry West.

In those portions of Europe for which the best class of charts of mean annual rainfall have been constructed (see the list in my Lehrbuch, pages 359–360) the conditions are more simple. But here also even the charts of rainfall distribution for the average of many years are very unreliable for really mountainous countries (see, for example, the Isohyetals of Switzerland, by Billwiller), but they are better in the region of the Mittelgebirge (in Bohemia, near Saxony).

My opinion is that there is no well-established basis for drawing isohyetal charts for individual months—having regard to altitude, wind direction, or the distribution of forests—that shall represent anything more than a subjective work of the imagination. In so far as the distribution of rain thus presented departs from the quantities actually measured it is arbitrary, and every draftsman will produce a different picture. Such charts may even be hurtful and productive of error, if it is forgotten that in many places they are purely hypothetical. When one looks at something that is well drawn, he generally assumes it to be correct. Even the expert can not, of course, without some reserve, divest himself of the impression made by such a chart. Therefore I can not advise you to present such purely hypothetical charts to the public.

But one circumstance to which you allude can lead to a material improvement of the monthly charts of rainfall, viz, the introduction of the isohypsen or contour lines for each thousand feet of elevation. This addition to the charts will contribute to the accuracy with which you originally draw the lines of equal rainfall, since the student will not be likely to draw his isohyetals in very improbable style right over mountain heights, but will more likely follow the contour lines.



For instance, without being guided by the contour lines, one might, in Fig. 1, draw the isohyetal 2.5 right over the summit at "A," whereas by taking this summit into consideration it would seem better to draw the isohyetal around as at C C C and merely inscribe the words "more than 2.5" on the summit, which in fact also comes nearer the truth. One might, moreover, think that he should take account of the prevailing direction of the wind; but in this case one would have to draw a special chart for each rainfall in the month and for each direction of the wind and then compile the monthly chart from the summation of these individual charts. But this is not practicable. Moreover, as is shown by the distribution of rainfall in the lake district of Cumberland in northwestern England, mountains of 2,000 or 3,000 feet in height, or even higher, do not form a rainfall divide, especially not in the warmer regions and the warmer seasons. In northwestern England [and similar locations] the greatest rainfall occurs beyond the watershed and there is no appreciable difference between the rainfall on the windward and lee sides. The very great influence of the details of the configuration of the earth's surface contributes to this. These differences, which are often quite unsuspected, are only to be recognized by direct measurements.

The only improvement that I can recommend is the introduction of the contour lines into the rainfall charts, so that they may be taken into consideration in drawing the isohyetals under the most probable assumption that the same quantity of rain falls at the same level and that more falls at greater altitudes, which may be expressed by the words "above .... inches." According to this principle the charts of average isohyetals in Europe are constructed, in doing which definite quantities of rain are assumed for the higher elevations, the estimates being made proportional to the increase with altitude, as determined by measurements made elsewhere, a process which seems allowable in charting the general average distribution of rainfall for many years.

In the eastern portion of the United States where there are no high mountains could not contour lines of 500 feet be drawn? For even this slight elevation has some influence on the rainfall, and one ought not to draw isohyetals directly across such elevations.

(17) PROF. H. GRAVELIUS.

Under date of April 9, 1902, Prof. Dr. H. Gravelius, of Dresden, editor of the Zeitschrift für Gewässerkunde, writes as follows:

If a rain ma) utilizes different shades of a certain color, I do not think it advisable that, on the same map, forests and more elevated regions should be marked by other dark tints. For, firstly, if we consider the matter only from a purely meteorological point of view, there is no need to distinguish especially the regions of forests, as will be seen, for instance, from Dr. Hamberg's inquiries into the influence of forests on the climate of Sweden. On the other hand, in connection with hydrographical researches, it may indeed be desirable to distinguish forests, but this should be done by some other sign than a shade of the color used in showing the rain areas. No doubt, in all questions regarding water supply, the forests will be of considerable importance, but from late European researches it seems not to be so in respect to the purely climatological question of the geographical distribution of rainfall. A region of sufficient yearly amount of rain may be expected to be one of good forest growth, but we are in no way allowed to consider *a priori* a well-forested district as one of greater amount of rainfall than any adjacent region con trolled by the same geographical conditions (i. e., elevation distance of the ocean, windward or leeward exposure, etc.).

Further, as to the influence of elevation, another consideration takes place. In this respect, no doubt, the scale on which the map is drawn becomes a matter of controlling importance. If this scale is large enough, then the isohyetal lines will, sometimes in quite an astonishing manner, reproduce the relief of the land as determined by contour lines or isohypsen. This fact is, for instance, well demonstrated by Dr. Hellmann's map of eastern Prussia, where even moderate elevations are precisely characterized by the lines of equal amount of rain. An analogous result may be drawn from a rain map of the Kingdom of Saxony that I published two years ago.

Finally, I come to the following conclusions:

(1) Rainfall maps designed for the *practical use* of engineer and hydrographer should always be published only on a relatively large scale and therefore only for a somewhat restricted area.

(2) If, for any special cause, it is desired to show on the map the forests and the relief of the land, simultaneously with the distribution of rain, the latter should be given only by isohyetal lines without using any kind of shading.

This latter method is used by the "Centralbureau" of Baden.

I think that from maps drawn according to this mode it may be seen that the area of a mountain top having heavy rainfall is not *always* negligible by comparison with the areas of lowlands having an average rainfall.

(18) H. SOWERBY WALLIS, ESQ.

Under date of March 1, 1902, Mr. H. Sowerby Wallis, director of the British rainfall system, writes as follows:

I have read with much interest the discussion on the reduction of records of rain gauges in the Monthly Weather Review for November, 1901, and should like to indorse Professor Henry's protest against the proposal that rain records should be corrected.

Gauges in bad positions can not yield satisfactory results by correction, and it must be recognized that the records of any individual gauge may apply to an extremely limited area. But to suggest the wholesale correction of rain records appears to me—after 30 years devoted entirely to rainfall—equivalent to saying that we should determine the precipitation by the scientific use of the imagination.

That in constructing physiographical maps, allowance must be made for elevation where there is absence of information is obvious, and it is probable that for the central regions of continents considerable accuracy might be attained in correcting records, but for coast regions where there is a well-marked rain-bearing wind, as for instance in the British Isles, any process of correction could only lead to hopeless confusion.

The impossibility of arriving at any allowance for elevation has been proved over and over again during the last 30 years before Parliamentary Committees on water supply.

In conclusion I may quote a paragraph from British Rainfall, 1896, written by my friend, the late G. J. Symons, giving the mean rainfall at 17 stations within an area of 20 square miles in the English lake district:

Some persons are fond of generalizations; we are not sure that the results obtained in this inquiry will be useful for that purpose; it seems to us that the influence of position with respect to hills and valleys is far greater than that of altitude. We have tried grouping the reduced means according to altitude, and here is the result:

	Mean.
	Inches.
Above 3,000 feet (3 records)	94
2,500 to 2,999 feet (3 records)	77
2,000 to 2,499 feet (1 record)	126
1,500 to 1,999 feet (3 records)	112
1,000 to 1,499 feet (8 records)	145
500 to 999 feet (2 records)	83
300 to 499 feet (5 records)	111

A corresponding relative variation would be found in most parts of Britain.

(19) DR. C. HART MERRIAM.

Under date of March 20, 1902, Dr. C. Hart Merriam, Chief of the Biological Survey, Department of Agriculture, writes as follows:

Your question as to the possibility of basing rainfall maps on the distribution of forests or of animal life is an interesting one, and one to which I have given much attention. In my opinion it must be answered in the negative. Humidity has more to do with the distribution of life than has rainfall.

The great difficulty in studying such problems as this is the insufficiency of the climatic data. As a rule the data are not plotted with sufficient detail for our purposes. For instance, we now know very exactly the distribution of large numbers of animals and plants in the far West, particularly in California, but we have no maps which pretend to show the distribution of temperature, humidity, or rainfall on a scale in any way approaching the necessities of the case. Furthermore, when we come to temperature, nearly all the published maps show its distribution by arbitrary periods, which have absolutely no relation to agriculture or zone distribution, and which appear to be worthless for scientific biology.

If we could have maps of the West coast region, taking in, say, Washington, Oregon, California, and Nevada, showing the distribution of humidity by months, and isotherms giving the total quantity of heat for the period of growth and reproduction, and also isotherms showing the mean average temperature of the hottest six weeks of summer, plotted on a large scale map, we should have the foundation for an intelligent study of the climatic control of agriculture and of the geographic distribution of our native plants and animals.

(20) PROF. R. F. STUPART.

Under the date of April 11, Prof. R. F. Stupart, director of the meteorological service, Toronto, Canada, says:

With regard to the preparation of rainfall charts, we have nearly finished tabulating the material for rainfall charts of the Dominion, and I have been quite in doubt as to how the isohyetals should be drawn. However, I am inclined to think if stations are far apart, as in our northwest territories, it will be better to give simply the rainfall at stations, as on the South African and Australian charts. In other cases where stations are not very numerous, I am almost inclined to interpolate strictly between them, making no allowance for surface features, unless, perhaps, where higher lands lie immediately to the eastward of water surfaces. Is not the forest influence too doubtful a quantity to allow for?

(21) PROF. W. H. BREWER.

Under date of April 11, 1902, Prof. W. H. Brewer, of Yale University, New Haven, Conn., writes as follows:

I do not think that special types of forest give any definite information as to the annual (amount of) rainfall and snow. It is rare indeed that forests occur where the amount of annual rainfall is less than 18 or 20 inches, unless it may be in regions in which the rain falls at the right time to be most available. The *range* of annual rainfall has so much influence that the average annual rainfall may give very misleading inferences, the droughts of exceptional years are such an important factor.

Trees are long-lived, and the exceptional dry years (or periods of several successive dry years) may, and probably often do, prevent forests in some regions where the average rainfall would be sufficient if more uniform.

It seems to me to be a general rule that the range of annual rainfall is much greater in dry climates than in wetter ones; apparently the less the average rainfall the greater the relative range, and this, taken with the allied factors involved, would vitiate conclusions as to the actual amount the forests might indicate.

Some years ago I looked up the matter of the actual range (with another object, however, than its relation to forests), and take my illustration of what I mean from my old figures, which, however, were in most cases deduced from unsatisfactory data.

Here in New Haven, from 1871 to 1889, or 18 years, the minimum rainfall was 39.46 inches; the maximum 60.26 inches (the greatest recorded here). If we state the ratio after the fashion of the old arithmetics of my "district school" days we have

$$39.46 : 60.26 : : 1 : x = 1.53.$$

According to the tables compiled by Professor Loomis for New Haven, and extending over about a hundred years, the driest year of the whole period had two-thirds as great rainfall as the wettest. At Wallingford, near here, during 18 years the ratio was 1 : 1.40. At Providence, R. I., from other data for 28 years, 1 : 1.59; Cambridge, Mass., for the same 28 years (1849–1876), 1 : 1.48.

I think that in that great originally forest-clad region, from from Maine to Alabama, we have no place where the rainfall of the driest year will not be more than half that of the wettest one.

Probably the same is about true of central and northern Europe. Observations in Paris from 1688 to 1871 or 183 years (according to a statement I have seen)—gave the ratio 1 : 1.44 for this whole period, which is much less than the lifetime of our oldest trees.

When I was in Denver last summer I could but notice the spread of trees with cultivation there, at Colorado Springs, etc., and where (as I was told) trees did not flourish unless irrigated or within reach of irrigating waters, I found trees where thirty-odd years earlier it was treeless. When I got home I looked up the rainfall from such data as I have. I had only a few years—Denver, 1891–1900, inclusive (lacking 1892). The range was: Minimum, 8.48 (in 1893); maximum, 21.43 (1891); ratio, 1:2.53.

In California, and about which I was formerly more interested, and using the rain year (from July 1 to June 30), and according to the figures I had: At Sacramento, thirty years (1849–1880), minimum, 4.7; maximum, 36.4; ratio, 1:7.75.

At San Francisco, twenty-four years, ratio, 1:6.65. In 1896 I was told by one of the officials that at the reservoir south (where their great dam is building) the amount of water falling at that place in the wettest years was ten times as great as in the driest years.

I saw a statement in Nature a few years ago as to rainfall in Sydney, Australia, and from the figures the ratio was 1:3.58.

No rainfall appears to be too great for forests to flourish. The uncertainty would be in a climate where the average was less than 20 inches, but might extend to where it was considerably above this.

Shrubs will grow and form dense chapparal where the dry years are very dry, and some species will flourish where there may be a succession of several "rainless" years.

Now forests require for their existence a rather complicated set of conditions, of which average rainfall is one, not too excessive droughts another, certain conditions as to soil another, and other plant competitors. Much of the prairie region east of the Mississippi River has abundant rainfall for forests, but has in some places unfavorable conditions for the seed to root at all, in others for the young seedlings to long survive. Then there are mechanical conditions of soil; and even other factors, as mountains, come in to aid in the preservation of trees, and so on.

So that I think that in regions near the limits of rainfall permitting natural forests the existence or absence of forests, or even of trees, would be too uncertain an indication on which to base any but the most general conclusions.

It seems to me that it would be permissible, in compiling your rainfall charts, for regions where instrumental data are lacking, to draw the isohyetes according to your best judgment from all the indications, and print some arbitrary sign (as for instance (?)), with the stated information that it indicates "inferred rainfall" or "amount inferred from the vegetation," or by some other statement. The compiler of the chart is supposed to have used all the data and information at his command, and he is also supposed to have very much more information than those for whom the information is compiled and the chart prepared, and better let them have it, even if only very generally correct.

I excuse the old geographers for making maps with such information as they had. Heylon's and Mercator's maps told us more of the geography of Central Africa than any I had in my best school days, 150 years later. They put it down, "to the best of my knowledge;" subsequently the more careful men omitted what was not authenticated.

(22) GEORGE W. RAFTER, C. E.

Under date of April 15, 1902, Mr. George W. Rafter, civil engineer, writes as follows:

As to the best method of representing rainfall data on a map, probably the object in view in making the map will to some extent govern. Thus the writer, on Plate 98 of his "Report on the Water Supply of the Deep Waterways Through the State of New York," [a] has had occasion to represent that portion of the State of New York which especially pertains to deep waterways and which, indeed, includes nearly the whole of the State. The facts shown thereon are the name of the place, the mean rainfall, the number of years for which the mean is taken, and the topographical elevation above tide water. Considerable time was spent in drawing isohyetal lines, but without accomplishing anything very satisfactory. Indeed, so many discrepancies appeared as to render, in the writer's opinion, the drawing of isohyetals impracticable at the present time. The only way they can be drawn is by ignoring a number of stations, which, so far as the writer is aware, there is no reason for ignoring.[b]

As to the accuracy of such maps, the writer knows no reason why the indications of the New York Rainfall Map—drawn without isohyetals—are not fairly correct. The mean rainfalls, generally speaking, represent a long enough period of time to eliminate minor inaccuracies of observation.[c] Probably, however, on maps of the entire United States, with isohyetals drawn, there is necessarily more or less approximation, due not only to lack of stations, but to inaccurate and conflicting observations. The question may with propriety be asked, whether there is not a more satisfactory method of representation than that commonly pursued.

Is there an increase of rainfall, with increase of elevation? In order to show some of the conditions obtaining in the United States, the following discussion of this question has been prepared.

This matter has been referred to by the writer in the discussion of Mr. Noble's paper on Gagings of Cedar River, Washington,[a] and the statement was made by me that in the State of New York both conditions obtain. The Hudson River catchment area shows a higher precipitation at the mouth of the river than it does at its source in the Adirondack Mountains, while the Genesee River shows the opposite, namely, higher precipitation at its source than at its mouth. In England it is almost universally true that precipitation increases with altitude,[b] but in this country it is by no means a universal rule. Indeed, the opposite frequently occurs.

According to a table of average monthly, annual, and seasonal precipitation in Mr. Turner's monograph on the Climate of New York State,[c] it appears that the coast region, which includes the following stations: Block Island, R. I., East Hampton, Setauket, Fort Columbus, New York City, Mount Pleasant, Tarrytown, White Plains, Croton Dam, and North Salem, has an average annual precipitation of 44.93 inches. With the exception of Block Island, these stations are all in the State of New York and not far from the coast, and they range in elevation above tide water from 16 feet at East Hampton to 361 feet at North Salem in Westchester County. The average elevation of the coast region is 132 feet. The records vary in length from 7 years to 49 years, with a total of 195 years. Five of the stations are in Westchester County.

As given by Mr. Turner, the Northern Plateau includes Constableville, Lowville, Fairfield, Johnstown, Pottersville, Elizabethtown, Keene Valley, and Dannemora, in the counties of Lewis, Herkimer, Warren, Essex, and Clinton. According to his table, the average annual precipitation is 38.97 inches. The elevation of the stations above tide ranges from 600 feet at Elizabethtown, to 1,356 feet at Dannemora, with an average elevation of 973 feet. The records vary in length from 4 to 22 years, with a total of 73 years.

Again, the Western Plateau, which includes stations in Cattaraugus, Wyoming, Allegany, Steuben, Livingston, and Chemung counties, has an average elevation above tide of 1,307 feet, ranging from 1,950 feet to 525 feet, and has an average annual precipitation of 35.58 inches, while the Hudson Valley, which includes stations in Putnam, Orange, Dutchess, Ulster, Columbia, Albany, Rensselaer, and Washington counties, has an average elevation of 230 feet above tide, with an average annual precipitation of 38.46 inches. The records range from 9 years to 65 years, with a total of 277 years.

The Great Lake Region of this State, with an average elevation of 494 feet, has an average annual precipitation of 35.17 inches, while the Central Lake Region, with an average elevation of 690 feet, has an average annual precipitation of 43.41 inches.

Mr. Turner's table is calculated for the calendar years, from January–December, inclusive. Further data may also be obtained from this excellent table.

In Table No. 24 of the Upper Hudson Storage Surveys Report for 1896[d] there is given the mean precipitation of the Upper Hudson catchment. The stations therein included are Albany, 1825–1895, sixty-nine years; Glens Falls, 1879–1895, seventeen years; Keene Valley, 1879–1895, seventeen years; western Massachusetts, 1887–1895, eight years: Northern Plateau, 1889–1895, six and one-half years; Lowville Academy, 1827–1848, twenty-one years; Johnstown Academy, 1828–1845, seventeen years; Cambridge Academy, 1827–1839, thirteen

[a] Published by the State. Albany, 1897.

[b] Should not Mr. Rafter have reduced the data to a uniform fundamental interval of time?—Ed.

[c] An average for 30 years is needed in order to sufficiently reduce the error introduced by groups of dry and wet years.—Ed.

[a] Trans. Am. Soc. C. E., Vol. XLI, pp. 1–26.

[b] See Mr. Sowerby Wallis's testimony to the contrary in extract No. 28.—Ed.

[c] The Climate of New York State, by E. T. Turner, C. E., late meteorologist of the New York Weather Bureau. Fifth Ann. Rept. of New York Weather Bureau, 1893. Reprinted in 8th Ann. Rept. of that Bureau, 1896.

[d] Published by the State of New York in 1897.

years; Fairfield Academy, 1828–1849, twenty-one years, Granville Academy, 1835–1849, fifteen years. Assuming the Northern Plateau as a unit (*i. e.*, grouping several locations as one station), the total number of years is 199½, and the mean of all is 37.4 inches. A reference to the rainfall map in the Report to the United-States Board of Engineers on Deep Waterways,[a] will show that this is necessarily an approximation, because of the great lack of stations in the interior of this region.

As regards the catchment area of the Upper Genesee River, there is a very decided increase in rainfall as one goes toward the source of the river. For the years 1889–1896, inclusive, the rainfall in the upper area of this stream was 42.19 inches, while at Rochester for the same years it was 35.64 inches. This statement is especially interesting, because there seems to be a well-marked line dividing the smaller rainfalls of the lower area from the higher rainfalls of the upper. At Hemlock Lake, Avon, and Mount Morris the rainfalls are all low, the average at Hemlock Lake from 1876–1895, inclusive, being 27.56 inches. In 1880 it was 21.99 inches; in 1879, 22.16 inches, and in 1881, only 24.36 inches. We have here three years of exceedingly low rainfall, in which the run-off must have also been exceedingly low. In 1895 the rainfall at Hemlock Lake was only 18.58 inches. The average precipitation at Avon and Mount Morris from 1891–1896, inclusive, was 30.12 inches. In 1895 it was only 25.05 inches. The following are stations at which it was much higher for the years 1891–1895, inclusive: Le Roy, 45.25 inches, and Arcade, 41.60 inches.

These statements of precipitation in the Genesee River catchment area are all based on a "water year," or the year from December to November, inclusive.

An interesting example of decrease of precipitation with increase of altitude is that found as we go west of the Missouri River. At Lincoln, Nebr., with an elevation of 1,647 feet above tide water, the average annual precipitation for eight years, from 1891–1898, inclusive, was 26.31 inches, the range being from 40.08 inches in 1891 to 14.38 inches in 1895. At Fort Collins, Colo., with an elevation of 4,995 feet above tide water, the average annual precipitation from 1891–1898, inclusive, was 14.11 inches; in 1891 it was 17.50 inches and in 1893 there was a minimum of 7.06 inches.

The figures for average precipitation in Nebraska and Colorado are based on a calendar year from January–December, inclusive.

The following are from Russell's Meteorology,[b] illustrating Atlantic Coast rainfalls, and are the averages derived from eighteen years' observations—from 1870–1888. The rainfalls are stated to be fairly representative for large districts of country around the places.

At Jacksonville the Weather Bureau office is at an elevation above tide of 43 feet, while the average annual rainfall is 57.1 inches. At Norfolk elevation of Weather Bureau is 57 feet above tide, and average rainfall is 51.7 inches. At Boston, Weather Bureau office is 125 feet above tide, while the average rainfall is 46.8 inches.

The following illustrate the change as one goes north through the Mississippi Valley. At New Orleans the Weather Bureau office is 54 feet above tide, the average rainfall 62.6 inches; at St. Louis Weather Bureau office 567 feet above tide, average rainfall 37.8 inches; at St. Paul Weather Bureau office 850 feet above tide, average rainfall 28.9 inches.

The following illustrate the Rocky Mountain Region. At Fort Grant, Ariz., elevation of Weather Bureau is 4,833 feet; average rainfall 15.8 inches; at Denver elevation of Weather Bureau 5,300 feet; average rainfall 14.7 inches; at Fort Benton, Mont., elevation 2,565 feet; average rainfall 13.2 inches.

The following illustrate the Pacific Coast region. At Portland elevation of Weather Bureau office is 157 feet; average rainfall 50.3 inches; at San Francisco, elevation 153 feet; average rainfall 23 inches; at San Diego, elevation 69 feet; average rainfall 10.2 inches.

These figures abundantly support the proposition that in the United States the rule of increased precipitation, with higher altitude, is by no means universal. The writer can not say positively, because he has not examined the vast number of records with reference to this point, but he thinks it quite possible that the reverse is more nearly true; that is, owing to distance from the ocean, prevailing direction of the wind, and other causes, it is quite probable that for the entire country precipitation decreases rather than increases with higher altitude.

The decision of this question will depend to some extent upon the steepness of ascent. Thus on Mount Washington—summit, 6,243 feet—which is projected into the air considerably above the surrounding mountains, the rainfall is about 83 inches. In other cases, where the ascent is gradual, no increase is apparent. The same is also frequently true of sharp ascents. On Long's Peak, in Colorado (elevation, 14,271 feet), the rainfall in 1899 was 16.7 inches.

Moreover, the writer has mostly avoided comparatively small differences in rainfall—those not exceeding 2 to 2.5 inches. In such cases the difference is too small to be any certain guide. Especially is this true in the case of the Northern Plateau, where there is still a great lack of stations. The differences between high and low altitudes should be as much as 5 or 6 inches. Again, whether the excess of rainfall occurs in the winter or summer months must be taken into account. If it occurs in the summer, even 3 inches of rainfall may not make more than 0.1 or 0.2 inch in the stream. Rainfall and run-off observations are not yet, nor are they likely to ever be, definite enough to take into account an annual difference of much less than about 1 to 1.5 inches. The writer has ceased to be excessively particular about the total of the annual rainfall. Assuming some considerable length of record, small errors have relatively slight effect. This matter is referred to here because nearly all rainfall records—at any rate, in the United States—have more or less error in them, and while it is desirable to have records as reliable as possible, a few errors do not affect a record very seriously. It is nevertheless very desirable to know the history of a record in order to insure the degree of confidence to be placed in it.

It seems very clear to the writer that the substantial truth of this question of increase of rainfall with increase of elevation is contained in an article by Mr. Alexander in the Monthly Weather Review for January, 1901.[a] According to this article, a mountain range does not per se imply an increase of rainfall. Only when other conditions are favorable will such a result follow from the presence of a mountain range. Mr. Alexander says:

"In regions of high humidity comparatively low mountains may be important agents in bringing about rainfall, whereas in regions of low humidity very high mountains may have little influence."

As to whether the writer would shade mountain areas to show higher precipitation than is given by the data for lower adjacent areas will depend entirely upon conditions. At Mount Washington it would obviously be entirely proper to make such distinction, while at Long's Peak it seems evident that the rainfall near the summit is no greater than in the adjacent plains.

It sometimes happens that the rainfall is greater on one side

[a] Published by United States Congress in 1901.

[b] Meteorology. By Thomas Russell, U. S. Asst. Engineer, New York, 1895.

[a] The Relation of Rainfall to Mountains. By W. H. Alexander, Observer, Weather Bureau. M. W. R., Jan., 1901, XXIX, pp. 6–8.

of a mountain range than on the other. Where a fact of this character is well established—and provided the scale of the map is large enough to do it intelligently—there would seem to be no reason why the rainfall should not be shaded on the side where it is greatest.

As to whether a better method of presenting the data is possible than the usual one of drawing isohyetals and shading the areas between, the writer is not very clear except on one point, namely, that the topographical elevation should appear upon the map in connection with every rainfall, as without this, from an engineering point of view at any rate, the map has very little significance.

As a broad proposition, proximity to the ocean and direction of prevailing winds are the more important reasons for heavy rainfalls without special reference to the elevation. Proximity to the ocean, however, is not a universal cause, as may be seen on reference to the rainfall records at San Francisco and San Diego, Cal. In England, where on the west coast these phenomena are more uniform, the winds are largely from the southwest, bringing the moist warm air currents of the ocean to be condensed on the mountain ranges of from 2,500 to 3,000 feet in height, and here the precipitation is from 80 to 150 inches. On the east coast, however, even quite near the sea, there is a flat, level country, and the rainfall averages from 25 to 30 inches.

(23) PROF. A. WOEIKOFF.

In the Meteorologische Zeitschrift for 1885, Volume XX, pp. 113–138; 201–211; 250–263, Prof. A. Woeikoff publishes an elaborate study of the rainfall in the Malayan archipelago. We extract the following items relative to the relation of the rainfall to prevailing winds and elevations.

Page 116: The rainfall on the north and south coasts of Amboina and Seram differs according to the direction of the wind. The prevailing winds for the four months December–March are northeast or northerly, but during the four months May–August they are southwest or southerly. The distribution of rain is shown by the following table, according to which the south coast has more rain than the north coast during southerly winds but less than the north coast during northerly winds. This illustrates a general principle that holds good the world over, namely, that the sea breezes bring more rain than the land breezes.

Island.	Coast.	North wind, December to March.	Southerly wind, May to August.
		mm.	*mm.*
Amboina	South	521	2,163
Do	North	626	1,209
Seram	South	589	1,605
Do	North	1,095	448

Page 119: The windward side of the Celebes receives more rain than the leeward side in the ratio of 165 to 100.

Page 127: The north coast of Java in the region of Batavia represents a comparatively flat country whose ascent is quite gentle up to the mountains of the interior, which rise rather suddenly. The increase of rainfall as one goes from the coast inward (viz. southward) must therefore be the result of a very gentle general rise of the currents of air. This increase is shown by the records of stations at increasing distances from the coast, as shown in the following table:

Name of station.	Distance from coast.	Altitude of station.	Annual rainfall.
	Kilometers.	*Meters.*	*Centimeters.*
Onrust	0	0	185
Batavia	7	10	206
Meester Cornelis	11	10	206
Passar Mingo	17	35	219
Depok	33	116	301
Bodjong Gedeh	43	116	367
Buitenzorg	58	265	499

Page 131: If we group the stations of long period by altitude, without special regard to the windward and leeward aspects, we get no decided increase or decrease with altitude, or, more exactly, the annual rainfall diminishes up to 1,200 meters and then again above that increases; of course these annual averages include in general both the local thunderstorm rains and the general rains due to broad and deep monsoon winds. The figures are as follows:

Zones of altitude.	Number of stations.	Annual rainfall.
Meters.		*Centimeters.*
0–300	1	329
400–550	3	303
700–1,100	3	234
1,500–1,600	4	307
1,900–2,000	1	389

Page 132: According to Junghuhn, who has spent many years studying the climatology of this region, the zone between 1,500 and 2,500 meters is properly speaking the cloud region, and although in this region the rainfall is more frequent, still it is also less in quantity.

It would seem that, on the one hand, the zone between 0 and 2,000 meters does not show a regular decided increase of rainfall of more than 10 per cent and that, on the other hand, a horizontal distance of 58 kilometers with a vertical rise of 265 meters changes the rainfall from 185 to 499 centimeters, or by more than 150 per cent.

(24) GIFFORD PINCHOT.

In a letter of February 14, 1902, Mr. Gifford Pinchot, Forester, U. S. Department of Agriculture, says:

I find myself unable to reach an opinion as to the extent to which mountains and ridges from which no observations are available should be shaded to indicate heavier rainfall than from adjacent lowlands. While, in my opinion, such heavier rainfall undoubtedly exists, it would be extremely difficult to reach a definite opinion as to its amount.

Your third question with regard to the extent to which a rule that applies to one mountain can be extended to other mountains in different parts of the country is likewise extremely difficult to answer. Local conditions would govern to such an extent that perhaps not even a very general rule could be reached. Altitude and moisture of the climate, together with prevailing winds, would be among the factors to be considered.

Your fourth question is one which, in my opinion, should be answered affirmatively. I believe that there is a sufficient connection between forests and rainfall to warrant attributing heavier rainfall to a forest region, as compared to an adjacent bare region in either one of two cases. First, when the rainfall causes the presence of the forest, and, second, when the forest, as I believe it does to some extent, increases the precipitation. I am well aware that observations are contradictory upon this last point. There are, however, as I think, strong *a priori* reasons for believing that forests influence rainfall, and there are cases, apparently well established historically, where the agricultural conditions and possibilities of great regions have changed coincidently with the destruction of great forests. This whole question being as yet, however, in the realm of controversy, I have rather avoided its discussion hitherto, believing that the argument for forest preservation should be based, for the present at least, on less controversial grounds.

(25) PROF. VICTOR KREMSER.

The German engineers officially charged with the study of the regimen of the larger rivers, the prediction of floods, etc., have published elaborate volumes of text and charts dealing with rainfall and whatever can affect river phenomena. From pages 54 to 56 of the first volume on the Elbe, Berlin, 1898, we quote the following, which is believed to have been written by Prof. V. Kremser:

On the windward side of a mountain range the masses of air must rise, cool, and deposit the excess of moisture on the land. Thus the mountain ranges and even slight elevations of the earth have heavier rainfall than the plains, and thus in general with increasing altitude the quantity of precipitation increases. If, therefore, we consider a neighborhood that is far from the ocean we find that a representation of the vertical elevations in the valley of the Elbe is in general also a picture of the distribution of rainfall. But this is true only in the most general sense, since a more accurate consideration brings to light many modifications. Since the moist air coming from the ocean loses its water either gradually or suddenly, but does not obtain much in return from the evaporation from the soil, therefore the rainfall diminishes as the air penetrates into the interior and at any given altitude the mountain ranges have less rainfall with increasing continentality. Furthermore, the precipitation must be heavier on the moist windward, usually the west side of the mountain range, than on the lee side, since after passing over the summit of the mountain there is no further cause for condensation. On the lee side, where the air descends in the shadow of the rain, a drier region must form. This region must extend far beyond the mountain range, even though the tendency to a descending motion of the air gradually disappears.

These general remarks are abundantly verified by the charts. The greatest rainfall occurs on the tops of the mountains; the least rainfall at the foot on the lee side, whence it increases slowly with increasing distance to leeward. On the average of all our mountain ranges the annual rainfall increases with altitude at the rate of 70–80 mm. of rain per 100 meters of ascent.

That the windward side has more rain than the lee side in the basin of the Elbe can be seen best in the Erzgebirge, where the southeast side is to leeward and the northwest side is to windward, as shown in the following table:

Altitude.	Northwest slope.			Southeast slope.		
	Number of stations.	Mean altitude.	Mean annual precipitation.	Number of stations.	Mean altitude.	Mean annual precipitation.
Meters.		*Meters.*	*Mm.*		*Meters.*	*Mm.*
200–400	21	326	654	9	310	478
400–600	16	501	765	6	490	711
600–800	17	700	833	6	708	730

The fact that for the same altitude the precipitation diminishes as we go inward from the ocean is shown in the following table, in which, in order to compare similar conditions, the windward and leeward sides are tabulated separately:

Mountain range.	Leeward side, altitude 200–400 meters.			Leeward side, altitude 400–600 meters.			Distances from mouth of Elbe.
	Number of stations.	Mean altitude.	Average annual precipitation.	Number of stations.	Mean altitude.	Average annual precipitation.	
		Meters.	*Mm.*		*Meters.*	*Mm.*	*Kilometers.*
Harz	7	243	586	6	463	769	500
Thuringian forest	5	275	510	2	512	685	650
Erzgebirge (southeast side)	9	310	478	6	490	711	800
Bohemian forest	11	371	493	18	474	555	950
Mountain range.	**Windward side, altitude 200–400 meters.**			**Windward side, altitude 400–600 meters.**			**Distances from mouth of Elbe.**
	Number of stations.	Mean altitude.	Average annual precipitation.	Number of stations.	Mean altitude.	Average annual precipitation.	
		Meters.	*Mm.*		*Meters.*	*Mm.*	*Kilometers.*
Erzgebirge (northwest side)	21	326	654	16	501	765	950
Sudeten	42	300	576	22	507	730	1,150
Bohemian forest	21	298	529	34	510	628	1,250

For greater altitudes the number of stations is so small that the results are too greatly modified by local conditions and a fair comparison is not possible.

[NOTE.—We have added a last column in the above table, showing approximately the distances of the respective mountains from the mouth of the Elbe, or the nearest point on the North Sea coast, above which the northwest winds may be supposed to be slowly rising as they flow toward the southeast, carrying the ocean vapor into the highlands of Moravia and Bohemia.—Ed.]

(26) PROF. MILTON WHITNEY.

Under date of May 17, 1902, Prof. Milton Whitney, Chief of Bureau of Soils, Department of Agriculture, writes as follows:

Your inquiry of March 18, relating to the possibility of mapping the rainfall over areas in which there are no rainfall stations by the character of the forest growth has been received and has been under consideration for some time. I do not believe that the character of such growth is any safe indication, except in the most general way, to the amount of rainfall, nor can I claim any more specific distribution of forests in accordance with soil types. As a rule we expect to find hard-wood forests on heavy well-drained loam and clay. Where this occurs in level or gently sloping areas, and even on mountain slopes, hard-wood trees seem to prefer the heavier types of soil. We expect to find the pine on the light, sandy soils of the Atlantic and Gulf coasts as well as in the lake regions and the lighter soils of the mountain areas. We find the chestnut extensively developed on the sandstone or shale ridges with oak, hickory, and maple in the heavier valley lands of the north Atlantic States. We find pine trees on many heavy intractable clay soils, such as the Potomac clays of Maryland and Virginia, and also on many swamp areas. There are, however, so many departures from the general rules that have been laid down that it is not safe to use the forest growth in mapping soils any more than I believe that it would be safe to use the characteristics of the forest growth in mapping the distribution of rainfall. A few examples will forcibly illustrate my position.

It is a well-known fact that (on the Piedmont areas of the Atlantic coast States) on what is known as Cecil clay, which is the heaviest and most productive soil, the native forest growth is of hard wood. After this growth has been removed and the soils cultivated for a few years under superficial methods, the soils deteriorate and are allowed to grow up in old field pine with a sprinkling of stunted oaks, so that now, as a matter of fact, much of this land which was formerly in hard wood is now in pine. We also have the admirable records of the German foresters who have pointed out the succession of trees. This is mentioned quite fully by Storer.

In our soil survey in Allegan County, Mich., last season, we mapped a large area of Allegan sand. We could see no difference in the mechanical or chemical character of the soil, and yet in this case we were compelled to recognize differences on account of the difference in the native vegetation and in the agricultural value of the land. These differences were not indicated in our soil map, but were illustrated on a colored plate which will appear in our next report. Certain areas of this sand near the lake were originally covered with hardwood forests. These are now recognized as some of the best peach soils of the State. In the northern part of the area surveyed—that is, north of the Kalamazoo River—this sand was originally covered with a mixed growth of hard wood and pine. These areas are now recognized as fairly good peach soils. Both of these areas have the same relative position as regards the lake and are presumably under identically the same characteristic conditions. Another portion of the sand upon which white pine originally grew has not been developed up to the present time. Some few clearings are found in which corn, rye, buckwheat, and a few peaches are grown with very indifferent success. On the pine plains proper, formerly covered by a sparse growth of white pine and at present with a sparse growth of scrub oaks, the soil is almost entirely undeveloped and only occasionally small crops of corn and rye are produced, with no financial success whatever.

In the Southern States there are many areas in fine hardwood forests where it would be expected from the soil to find pine, and vice versa.

The most striking example, however, of the apparent accidental distribution of forest growth is in the native and uncleared forests of Florida. There is no difference, so far as can be determined, between the soils and climatic conditions of the hammock lands, which support a vigorous hard-wood growth, and the first quality of high pine land, which supports a very dense growth of long leaf pine timber. Illustrations are given of these two characters of growth in Bulletin 13 of this Bureau, A Preliminary Report on the Soils of Florida, Washington, 1898. Furthermore, there is no difference, so far as can be determined, in the soil or climatic conditions of the second quality of high pine land and what is known as the "scrub." Yet the contrast between these two kinds of native growth is very sharp and exceedingly striking. An illustration is given of this in Plate 5 of Bulletin 13. The soil is a light sand, and on the high pine land supports a vigorous and generous growth of large pine trees, which, when cleared, makes fine truck soils, and produces the tender vegetables in the greatest luxuriance for shipment to the Northern markets.

In the scrub there is a dense growth of scrub oaks and low bushes and plants, rarely exceeding the height of a man's head, all having thick leaves, protected from the loss of water by evaporation by the property that desert plants have of covering the surface of the leaves with an enamel and of turning the leaves up edgewise, to expose as little of the surface as possible to the sun's rays. No grass is found, and only the most hardy desert plants grow. When pines grow, it is an occasional dwarf spruce pine, and not the long-leafed pine found on high pine land. A few efforts to grow truck and oranges have been failures.

I would also call your attention to the curious fact of the occurrence of deadenings which are occasionally found, and to prairie conditions and barrens which are found in many places in the Atlantic coast and Middle West where small or large areas, surrounded by luxuriant forests, have been without tree growth within historic times, with no reason which can be ascribed either to soil or climatic conditions. Many other illustrations of the kind here recorded could be cited to prove my position that the native forest growth can not be safely used as a basis for mapping rainfall conditions, although in a general way such conditions may be useful in climatic conditions as they are in soil investigations, but the limitations to this must be clearly recognized.

Professor Hilgard has called attention in the Tenth Census to the possible use of forest growth in the classification of lands according to their chemical composition and agricultural value, but such rules as are laid down by him are of the most general application. Our own investigations appear to indicate that by the constant growth for many years of certain native plants (or cultivated plants, for that matter), changes occur in the relative amount of plant foods in the soil, so that the proper balance or ration, to borrow a phrase from animal husbandry, is no longer maintained and the soil is suited to other crops and to other forest growth. This, however, is yet but an hypothesis, as our methods of chemical and physical investigation are not sufficiently refined to enable us to investigate the matter at the present time.

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(27) GEORGE E. CURTIS.

In 1882, in order to study the relation between ascending currents and rainfall and to investigate the large rainfall on the summit of Mount Washington, the editor requested that a large number of rain gauges might be distributed to voluntary observers at as many points as possible in the neighborhood of that mountain. A year later, when we came to study the records, it was discovered that a 3-inch gauge of objectionable construction had been issued instead of the standard 8-inch gauge that was originally contemplated, and this change operated to discourage further investigation. But with the hope of settling some points of interest, my assistant, Mr. George E. Curtis, made a study of the effect of the wind and the distribution of rain at the very summit of the mountain and embodied his results in Signal Service Note No. XVI, The Effect of Wind Currents on Rainfall, Washington, 1884. I quote or summarize the following paragraphs relating to the observations made between September 1, 1882, and October 1, 1883, considering only the rainfall, excluding the snow that fell during that year.

After a slight historical summary Mr. Curtis quotes the following recapitulation by Symons (see his Meteorological Magazine for 1878):

The terribly hard-fought battle respecting the reason that a smaller quantity of rain is collected by rain gauges elevated above the surface of the ground is nearly settled, for the following points seem proved:

The greater part of the decrease is due to wind.

The stronger the wind the greater the decrease with elevation.

The less the diameter of the elevated gauge the less will it indicate.

A gauge on the leeward side of a tower may collect as much rain as one on the ground.

A gauge in the middle of a large roof may, notwithstanding its height, collect very nearly the same as the one upon the ground.

We now come to the second and larger question, namely, What variation in the distribution of rainfall due to wind is produced by the *topography* of the country? The practical problems have already been stated, namely, (1) to find over what area the record of a single gauge gives the average precipitation; and (2) to determine from gauges at different stations a law of variation, so that, given the observed precipitation at a few stations, the precipitation for any other locality to which the law applies can be computed. This is practicable only for those countries and districts where, the rainfall being dependent on regular and constant winds, the variations in precipitation are progressive and uniform.

Among the effects of the topography of the country on the distribution of rainfall, the variations in mountain districts are especially noticeable, and it is to these we shall confine our attention. In general, the amount of rain increases with the elevation above sea level up to a maximum plane, after which a decrease takes place. S. A. Hill has shown (see Zeitschrift für Meteorologie, Vol. XIV, 1879) that in the northwest Himalayas, where the rainfall is most remarkable in amount and rate of variation, the observed relative annual amounts can be represented by the following empirical formula:

$$R = 1 + 1.92h - 0.40h^2 + 0.02h^3$$

in which h is the absolute height in units of 1,000 feet above an assumed plane, which is itself 1,000 feet above sea level. From this formula the height of maximum rainfall is computed to be 3,160 feet above the plane, or 4,160 feet above sea level. It is further shown that this elevation is that at which, according to the observed law of decrease of temperature, the southwest monsoon is cooled just below its dew point. This point will be that at which, in the mean, we should expect the maximum precipitation to take place. The result obtained from the empirical formula thus receives a theoretical and deductive confirmation. In the following volume of the Zeitschrift (Vol. XV, 1880, p. 373) Hann has collected observations from stations on the Arlberg, in the western Tyrol, by which the plane of maximum rainfall is shown to be at a somewhat higher level in that region than in India. The highest station, at an elevation of 5,900 feet, has the maximum rainfall. A very rapid diminution takes place on the leeward side, where the stations record only about half the amount of rainfall given by stations of equal altitude on the windward side.

The Report upon the Rainfall of Barbados, by Governor Rawson, giving the results of observations from 1847 to 1874, shows a similar variation with altitude; the amount of rain increases regularly with the height of the station, except in a few localities where the law is masked by other local causes of variation. * * *

The large rainfall recorded at the signal service station on the summit of Mount Washington has seemed particularly worthy of careful study and special observations have been undertaken. The first point of investigation has been relative to the distribution of rain on the summit itself, since it seemed probable that the enormous wind velocity experienced there might produce sensible inequalities, both in the gage readings and in the actual rainfall, wherefore the records of a single gage would not present average results for the whole summit.

From September 1, 1882, to October 1, 1883, comparative observations were made daily with four extra gages, placed 75 feet north, south, east, and west of the station gauge. These extra gauges were cylindrical, 14 inches deep, and surmounted by a small receiving cup 3 inches in diameter. The station gauge was 8 inches in diameter and 2 feet deep.

As the observer reported that the measurement of snow is altogether unreliable for comparative purposes, owing to the velocity of the wind, the observations used in the following discussion are those of rainfall only. The result of this series of observations is given in the following Table I, containing the rainfall only during the thirteen months of observation; the records of each gauge are first tabulated according to the direction of the wind:

TABLE I.—*Rainfall, excluding snow, September, 1882–September, 1883, inclusive, on Mount Washington.*

	A.	B.	C.	D.
NE	1.48	1.31	1.47	1.43
E	0.18	0.15	0.18	0.16
SE	1.24	2.69	1.87	1.65
S	4.33	8.28	6.91	6.40
SW	3.29	4.20	3.85	3.71
W	4.92	5.13	4.02	3.70
NW	20.15	28.23	26.31	24.93
N	1.23	1.20	0.79	0.65
Total	45.82	51.19	48.40	42.63

Location of extra gage: A, 75 feet south of station gage; B, 75 feet east of station gage; C, 75 feet north of station gage; D, 75 feet west of station gage.

This table exhibits discrepancies in the total amounts of rain collected in the several gages, apparently too large to be attributed to errors in collection and measurement. The first result obtained from the observations is, then, that the precipitation varies materially within distances of only 100 or 200 feet. * * *

It will be seen that with a few exceptions, to be noted hereafter, the windward gages record the least rain, the central gages somewhat more, and the leeward gages the most of all. This result is in accordance with the law of variation of rainfall on the roofs of buildings, stated, as we have seen, by Bache, in 1837. Unless the agreement is accidental, we may conclude, therefore, that the wind acts in the same way in affecting the distribution of rain on the summit of Mount Washington as when obstructed by buildings and towers. * * *

Table II contains, however, a few apparently discordant results that must receive a separate examination. A portion will thus be found to be exceptions that prove the rule, or, rather, that show how it is modified by other considerations.

3. A single prominent exception to the principles above stated is found in the excessive record of gauge B as compared with C during southeast winds. * * *

The average of the four gauges gives the following percentages for the relative amount of rain falling during winds from different directions:

NE	0.03	SW	0.08
E	.00	W	.10
SE	.04	NW	.59
S	.14	N	.02

By far the largest part of the whole rainfall is thus shown to occur with northwest winds. We should, therefore, expect that gauge B, which is to leeward with respect to northwest winds, and nearer to the center of the summit than A, would present the largest annual record of all the four gauges if the principles above stated be correct.

In the preceding discussion the records of the station gage, having a receiving surface 8 inches in diameter, have not been included, owing to the fact that its measurements were found to be uniformly much greater than those of the 3-inch gages. The total amount of the station gage, covering the same periods as the totals of the four extra gages given in Table I, was 58.70. * * *

During July, 1883, a series of observations was made with the station gage and a 3-inch gage, in which the latter was placed a short distance from the station gage and located so as to be as nearly as possible under the same influences. In this series of observations the differences due to location and environment are as far as possible eliminated, and a direct comparison of the two gages in collecting rain can be secured. * * * The ratio of the 8-inch gage readings divided by the 3-inch gage readings is $1+0.015\times x^2$, where x is the wind velocity in units of 10 miles per hour.

The discrepancy between the measurements of the two gages varies, therefore, directly as the square of the velocity of the wind, and is due to an insufficient collection by the smaller gage.

By means of this formula the totals of the small gages given in Table I can now be rendered comparable with the totals of the station gage.

The average velocity of the wind during rain was, as nearly as can be determined, about 45 miles per hour. For this wind velocity the formula gives 30 per cent as the factor by which the totals of the 3-inch gauges must be increased in order to correspond to the station record. The totals of the gauges will then be: A 59.57, B 66.55, C 59.02, D 55.42, station 58.70. * * *

(28) PROF. MARK W. HARRINGTON.

In his memoir on "Forest influences," published as Bulletin No. 7 of the Forestry Division of the Department of Agriculture, Washington, 1893, Prof. M. W. Harrington discusses a variety of forest influences. Pages 111–118 are devoted to the question of precipitation over wooded and treeless districts. He says:

When a difference of rainfall corresponding to a difference of forest conditions has been found, there is still occasion for doubt as to which is cause and which effect. There is every reason to believe that with increased rainfall, other things being favorable, there will be an increased growth of trees. The facts at hand do not prove with entire conviction that forests increase the rainfall. The historical method is lacking generally in the character of the data for the beginning of the comparison. Besides, where a change of rainfall is actually shown to be coincident with a change in the forest growth it is not entirely certain that the former is due to the latter; it may be due to what are called secular changes of the rainfall, the reasons for which lie beyond our knowledge. The geographical method is not entirely satisfactory, for the reasons already mentioned. The entirely convincing method depends on observations above forests and with systems of radial stations, as proposed by Dr. Lorenz-Liburnau, and from these there is not yet a sufficient amount of published results.

In a subsequent portion of bulletin No. 7 the present editor was able to show that, owing to the large effect of the wind at the mouth of the gauge, in causing a deficiency in the catch of rain, no observations have as yet been made sufficiently free from this error to allow of their giving accurate results when comparing the rainfall above the forests with that beside them. After reviewing all the accessible and best literature on the subject Professor Harrington leaves the matter entirely unsettled, showing that every attempt to demonstrate that forests tend to increase the rainfall has been unsuccessful and that their influence is entirely inappreciable. Of course, every portion of the land and ocean, by evaporation, contributes something to the moisture and, therefore, to the rain, but evaporation from forests is less than from an equal area of cultivated fields, and is scarcely distinguishable from the numerous other sources of moisture.

As to the influence of rainfall in deciding the existence and the character of the forests and the possibility of inferring from the forests the quantity of rain it is evident that the growth of the forests, like that of any other vegetation, depends upon the supply of water accessible to the roots of the plants. The surface run-off quickly becomes inaccessible. It is the quantity retained by the soil, and, therefore, the character of the soil itself, that is the most important factor.

With reference to this point Prof. B. E. Fernow, in the above-mentioned Bulletin No. 7 on "Forest influences," on page 144, says:

It is the water retained in the capillary interstices of the soil that determines the designation of the soil as moist, wet, or dry. Any surplus above the greatest water capacity is bound to drain off. The measurements of the quantity of water absorbed by soils will show the maximum and minimum water capacities, both of which vary greatly with the depth of the soil. Humus and garden mold with their fine capillaries show the greatest water capacity. The least retentive soil is a coarse quartz sand. Sandy soil may hold 25 per cent of its weight in water; loamy soil, 40 per cent; pure clay soil, 75 per cent. The sandy soils of the north German plain can not by capillarity raise the ground water higher than 1.5 feet above the water plane below the ground, so that the surface strata over regions where the water plane is 2 feet below the surface do not show any greater amount of water than the surface soils in other regions. Mr. F. H. King has shown the conditions under which surface soils are unable to supply enough water, and the same principles must apply to the determination of the possibility of the forest growth. When a forest is once well started, it accumulates a forest litter that is retentive of the little water that reaches it.

(29) PROF. G. HELLMANN.

In compiling his rainfall chart for East Prussia (Berlin, 1900), Prof. Dr. G. Hellmann (one of the highest authorities in relation to rainfall and its measurement) deals with the record for the ten years 1889–1898 and with a region of about 500 square miles, or six times the size of the District of Columbia. Within this area he has 178 rainfall stations, 67 of which have complete records for the whole period and the 111 others have generally completed nine years of record. The latter records are all reduced to homogeneity with the complete decennium, 1889–1898, by means of factors derived from the years for which they have records in common. Dr. Hellmann says:

The precipitation for Pillau is too small, on account of the too free exposure of the gauge to the wind, for in proportion as a rain gauge is exposed to the disturbing influence of the wind so much the less does it catch.

The highest of the East Prussian stations has an elevation of 235 meters. It is of course at some distance east of the shore of the Baltic, but it is not the one that shows the heaviest rainfall, as there are quite a number of low-lying stations that receive more rain. On this point Hellmann says:

The accompanying rainfall chart for the province of East Prussia is prepared in accordance with the tabulated values of the rainfall and with continued reference to the topographic conditions. It shows the distribution of the mean annual precipitation in five different gradations of 50 mm. each. The close dependence of the rainfall on the orography would, of course, be best brought out if a contour map could have been used in exhibiting the rainfall, but the technical difficulties in accomplishing this are especially great in charts drawn on a small scale. Notwithstanding, anyone acquainted with the relief of the country will at once recognize that even in a region that has such slight variations of altitude as East Prussia, still the rainfall chart is to a certain degree a reflection of the relief chart. The present chart of rainfall therefore acquires special interest, because it brings out clearly the fact that, even in a flat country, small elevations exert a decided influence on the quantity and the distribution of the rainfall.

Hellmann shows that, according to his rainfall chart, the precipitation increases rapidly from the coast inward for a distance of thirty miles; then comes a relatively dry region, after which rainfall again increases along a region about a hundred miles from the coast. So that, in general, "the moist air coming from the Baltic is forced to rise, whereby it is cooled and gives more abundant rainfall than it would at the same elevation farther back from the ocean."

As regards the question how long a series of observations is required in order to obtain normal values of the rainfall, Hellmann studies the records for fifty-one years, 1848–1898, at Tilsit, Königsberg, and Klaussen, and the records for the shorter periods at twenty other stations near by. In general, this data seem to show that the average for the last ten years of the fifty is uniformly a deficit as compared with the whole fifty years. The greatest deficit of 10 per cent is in the southeastern part of the province, and the least deficit, zero, is at Tilsit and Memel, in the northern portion. The annual values of the rainfall depart from the mean values by 45 per cent above and below. In a hundred years of records 10 or 12 per cent will be very dry, namely, having only 50 or 75 per cent of the normal rainfall, and 3 or 4 per cent of the years will be very wet, having the same per cent in excess of the normal.[a]

(30) PROF. PAUL SCHREIBER.

An elaborate study of the rainfall in Saxony has been made by Prof. Paul Schreiber, of Chemnitz, and from a summary of his work by Gravelius (Zeitschrift für Gewässerkunde, Bd. III, 1900, p. 48) we make the following summary:

One hundred and sixty-nine stations are available for the rainfall chart, of which 78, or 42 per cent, represent fragments of the fundamental ten years, 1886–1895, and must therefore be reduced to homogeneity with the remaining 91. This proportion may seem large, but is less than the 62 per cent of corrected stations used by Hellmann in his chart of east Prussia. * * * The isohyetals were first drawn on a chart of Saxony, on the scale of 1 to 500,000 and the lines thus obtained were subsequently reduced to one-half of this scale. On this chart only the network of rivers is shown in its principal detail features; the presentation of orographic conditions on a chart of this scale would have only very little value. Even all the rainfall stations can not be charted on this small scale (the area of Saxony is about 2,700 square miles). But in the higher regions of the mountains, or the sources of our rivers, relatively more stations can be shown than in the lowlands. The charts and the tables show how the distribution of the annual rainfall follows the orographic conditions of the surface and that the higher regions of land in general correspond with greater rainfall. This connection is especially clearly shown in those portions that stand out as islands of heavy rainfall within regions of smaller precipitation. * * * The study of the chart suggests that in certain regions where the soil is wet and tends to be swampy the evaporation might play an important rôle in producing these islands of rainfall, but this assumption is not justified, for the rainfalls by months show that the heavy rainfalls in these islands do not occur in the months of greatest evaporation, viz, June to August, so that a satisfactory explanation of their occurrence can not now be given.

Although the chart does in general show the correctness of the general rule that up to a certain height, which is not attained in Saxony, the general rainfall increases with altitude, still it also shows that there are important departures from the rule. We see, in fact, that the altitude above the sea is not the only factor that regulates the distribution of rain. An equally important consideration is the location of the station with reference to the rain wind. Of two stations having the same altitude that on the windward side will have the heavier and that on the leeward side the smaller rainfall. Moreover, small elevations that increase the annual rainfall upon themselves throw a rain shadow over the region to the leeward. The west wind is in Saxony the prevailing rain wind, and the southwest wind comes next to it, and next to that the northwest. But if we consider special months, such as the summer time, we find that the importance of the wind direction changes, and that the northwest is often most important but generally second in importance, and that the north wind often becomes important.

This reminds us of the experience at Mount Washington, where the southeast and southwest winds bring most rain to the lowlands, but the northwest wind to the summit of the mountain.

Finally, Gravelius and Schreiber show that isolated high stations behave like rainfall gauges that are located too high or exposed too freely to the wind, viz, they give a relative deficit of rain.

(31) PROF. ALFRED ANGOT.

The distribution of rainfall in France and western Europe has been especially studied by Alfred Angot. His memoirs in the Annales du Bureau Central Météorologique; "On the rainfall of the Iberian Peninsula" and "On the rainfall of western Europe" give full consideration to the methods of preparing rainfall charts. The monthly, annual, and seasonal charts for western Europe, seventeen in all, are on about the same scale as that of the United States daily morning weather map and as that of the set of climatological maps published by the United States Weather Bureau, and, therefore, twice the scale of the maps ordinarily published in the Monthly Weather Review. These maps show the river systems, whence one may get a general idea of orography, but mountains and contours are not shown, as would undoubtedly be impracticable from the chartographer's point of view. Probably the most satisfactory method of presenting the relation between

[a] Almost the same relations are shown by studying American rainfall records, so that it is not safe to say that the average of 5 or 10 years represents a normal rainfall; these years may happen to form a group of dry or of wet years and may need a very large reduction to the fundamental interval of time. C. A.

rainfall and altitude is to have the relief chart or contour chart printed on transparent paper on precisely the same projection as the rainfall chart, and so superposed that one may, at a glance, appreciate the relationships.

Beginning with Spain and Portugal, Angot proposed to collect data for the fundamental interval of thirty years, 1861–1890, for each European state, as he recognized that it is impossible to prepare monthly rainfall charts with satisfactory precision unless all the data relate to the same years. For the Iberian Peninsula he gives 98 stations, but 11 of these were for periods of less than three years and were not used; 27 were reduced from periods of twenty-five years or more up to the fundamental thirty.

In his memoir, On the Rainfall of the Iberian Peninsula, (Annals of Bur. Cent. 1893) Angot says:

It is necessary that over the whole region the observations should relate to precisely the same years, so that one may avoid comparing a series of relatively dry years observed at one station with relatively wet years at another, thereby falsifying the relations between the pluviometric régimes of these two points. Very few published works on rainfall satisfy the two conditions of uniformity as to years of observation and freedom from breaks due to the changes in the location of the apparatus and changes or irregularities in the distribution of the rainfall from year to year and month to month.

In order to compute the monthly and annual totals of rainfall for the period 1861–1890 at stations where the observations are incomplete, we have proceeded in the following manner:

When the gaps relate only to isolated months the probable amount of rainfall during these months has been computed from that at neighboring stations. For this purpose we have assumed that the amounts of water collected at these stations preserve the same relation among themselves. This law, which is frequently applied, appears to have been first formulated by Mr. V. Fournie, engineer of roads and bridges, in 1864.

If the gaps relate only to a single decennial period, 1861–1870, 1871–1880, or 1881–1890, the two complete periods have been retained and only the mean of the incomplete period has been interpolated in the manner explained further on.

Finally, if the observations comprise less than twenty years, the general mean of the whole period 1861–1890 has been computed by means of a comparison with at least three stations in the neighborhood of the station under consideration. An example will illustrate this method of calculation.

We will take the station of San Sebastian, the first in geographical order in our tables. This station furnishes us with only thirteen years of observations, viz, from 1878 to 1890. In order to obtain the means of the period 1861–1890 the three stations, Bayonne and Aragorri, in France, and Bilbao, in Spain, whose observations comprise thirty years, have been compared. We begin by calculating for the four stations the total amount of rain collected each month during the common period of thirteen years, and then find the ratios of these numbers. The following values were thus obtained:

	January.	February.	March.	April.
Total rainfall 1878–1890.	*Mm.*	*Mm.*	*Mm.*	*Mm.*
San Sebastian	1,433	1,435	1,140	1,969
Bayonne	1,188	1,110	936	1,724
Aragorri	2,182	2,236	1,736	2,386
Bilbao	1,447	1,331	1,237	1,747
Ratios of San Sebastian to each station.				
Bayonne	1.206	1,293	1.218	1.142
Aragorri	0.657	0.642	0.657	0.825
Bilbao	0.990	1.078	0.922	1.127

As the ratios for a particular month may be quite largely influenced by heavy rainfalls unequally distributed at the respective stations, these ratios have been smoothed by taking for any one month the mean of the ratio proper to this month and the half sum of the ratios corresponding to the months preceding and following. Thus, for the ratio San Sebastian ÷ Bayonne in January, we take, in place of the crude number 1,206 directly obtained for January, the number $\frac{1}{2}$ [1.206 + $\frac{1}{2}$ (1.130 + 1.293)] = 1.209 resulting from the combination of the number for January with those for December and February, and similarly for the other numbers. By multiplying the mean depths of rainfall received at the three stations under comparison during the interval 1861–1890 by the corresponding smoothed ratios, we obtain three independent values for the probable depth of rainfall at San Sebastian during this same period, of which values we take the mean. The following numbers illustrate this process:

	January.	February.	March.	April.
Smoothed ratios relative to San Sebastian.				
Bayonne	1.209	1.253	1.218	1.224
Aragorri	0.659	0.650	0.695	0.794
Bilbao	0.997	1.017	1.013	1.115
Mean rainfall, 1861–1890.				
Bayonne	90.3	75.8	95.7	95.1
Aragorri	162.1	147.4	165.1	133.8
Bilbao	106.7	95.7	126.2	106.6
Probable depth of rainfall at San Sebastian as computed for 1861–1890.				
Bayonne	109.2	95.0	116.6	116.4
Aragorri	106.8	95.8	114.7	106.2
Bilbao	106 4	97.3	127.8	118.8
Mean	107.5	96.0	119.7	113.8

Keeping only the round numbers of millimeters, we finally obtain for the computed probable values of the rainfall at San Sebastian during the period 1861–1890 the following monthly and annual numbers, with which we give the mean of the thirteen years of actual observation:

	January.	February.	March.	April.	Annual.
Computed, 1861–1890	107	96	120	114	1,377
Observed, 1878–1890	110	110	88	152	1,474

The values thus computed for the years 1861–1890 differ very much in certain months from the crude mean of the thirteen years of observations. The departures are notably considerable for March and April, and it is easy to assure one's self that the computed numbers are more appropriate than the observed numbers for the construction of general charts and the discussion of the rainfall régime. The average of thirteen years—1878–1890—gives for San Sebastian for March a quantity of rain scarcely more than half that of April; on the other hand, the numbers deduced for the period 1861–1890 give a total for March somewhat larger than that for April, as is found to be the case at all stations in the northern part of Spain. Similarly, the total for August now becomes very nearly the same as that for July, whereas it was much larger during the period of thirteen years for which we have actual observations

The same method of computation has been applied to every incomplete series; the number of stations for comparison has never been less than three and has been four when the series was very short and the comparison stations near at hand. The numbers have not been subjected to any correction other than this reduction to the mean of thirty years. The rainfall stations of Spain are not yet sufficiently numerous to allow of determining in a precise manner the régime of certain regions.

* * * It is especially regrettable that observations were suspended at Lagos, since now there exists no station on the southwest coast between the mouth of the Tagus and that of the Guadalquivir.

The records of the rainfall during each month do not allow us to easily compare the pluviometrical régime of the different stations—that is to say, the manner in which the rain is distributed throughout the course of the year. For this kind of study it is more convenient to reduce all the annual sums to the same value—for example, 1,000—and to calculate for each month the *pluviometric coefficient*—that is to say, the fraction in thousandths of the total annual rainfall which corresponds to this month. * * *

This mode of presentation of the annual variation of rainfall by the fractions of the total annual which correspond to the different months, although on the one hand very advantageous, nevertheless presents, on the other hand, a disadvantage on account of the unequal lengths of the months. The rainfall for February, for example, may be less than that for January or March, and the relative rainfall in February might exceed that of either of the other two months. To remedy this inconvenience, I have proposed two methods which I will mention again here.

If the rain were equally distributed during the whole year there would fall 0.085 of the total rainfall during each of the months having thirty-one days, 0.082 during each of those of thirty days, and 0.077 in February.

By subtracting respectively the proper one of these numbers from the pluviometric coefficient for each month for a given station, we obtain numbers which represent, in thousandths of the total rainfall, the fraction by which the rain collected each month differs from that corresponding to a uniform distribution. These differences, which I propose to call *relative pluviometric departures*, represent at once, independently of the absolute quantity of the rain collected at the station and the unequal lengths of the months, the relative distribution of rainfall during the whole year.

We thus discover dry months and wet months, or minus departures and plus departures.

Instead of subtracting from the pluviometric coefficient for each month that which corresponds to a uniform distribution, we might take the quotient of these two numbers; we would thus obtain the *relative pluviometric coefficients*—that is to say, the ratio of the quantity of rain that actually fell in any one month to that which would be collected if the rainfall were equally distributed during the whole year. Thus at Santiago there falls in January 0.119 of the total rainfall; the proportional part for this month is only 0.085; the relative pluviometric coefficient for January at this station will, therefore, be $119/85 = 1.40$; that for July in a similar manner would be $0.31/0.85 = 0.36$. Thus the dry months would be characterized by a relative pluviometric coefficient less than unity; the wet months by a coefficient greater than unity. This latter mode of presentation of the annual variation of rainfall, although amounting substantially to the same thing as the preceding, will perhaps be preferable to it, because it leads to certain numbers whose immediate signification is plainer. * * * But as the computation is rather longer than for the preceding, we shall consider generally the relative pluviometric departures themselves.

The variability of the rainfall from year to year is deduced from the longer records by the method of least squares, it varies between 8 and 38 mm. for 17 of the Spanish stations.

In his general work on the rainfall of western Europe, Angot (Annales Bur. Cent. 1895) says:

In the study of the distribution of rainfall it is not possible to content ourselves with annual means. Paris, Marseilles, and Berlin, not to cite other examples, receive annually very nearly the same average rainfall; but it is evident that the pluviometric régimes are absolutely different at these three stations. In order to obtain a clear idea of the phenomenon it is necessary to consider periods much shorter than a year. * * *

Next after temperature the rainfall is the most important element of climatology. Notwithstanding the interest that it presents, the study of this phenomenon has never yet been undertaken in a systematic manner. The cause is probably to be found in three special difficulties that this subject presents. (a) The average rainfall received by two stations, even close together, may be very different, for of all the elements the rainfall is that which is most affected by topographic conditions; it is therefore necessary to make use of a large number of stations. (b) As the quantity of rain received at any point often varies from year to year within very large limits, sometimes as much as tenfold for the corresponding months of two consecutive years, the mean values have no significance, unless for each station they are the means of a large number of years. (c) Finally, it is also necessary that the observations should relate to the same series of years, since without this we might be led to compare a relatively dry period observed at one station with a different relatively moist period observed at neighboring stations, which would entirely falsify our results. This last cause of error, to which sufficient attention has not always been given, may cause considerable error, even if we consider quite a long series, such as ten years, for example. Thus, over a great part of Austria the mean rainfall received in January during the ten years 1881–1890 was scarcely one-half of that corresponding to the ten years 1861–1870. The only countries for which to my knowledge any one has as yet executed works on rainfall satisfying the three conditions above mentioned are the British Isles and the Iberian Peninsula. For the former, Mr. G. J. Symons in 1883 published the details of the total monthly rainfalls at 367 stations during the fifteen years 1866–1880; but this extensive work contained only the observations with no discussion of results and no charts. Mr. A. Buchan in 1895 published a résumé, but for Scotland only, of observations made at 324 stations, and reduced them all to the same period, viz, the twenty-five years of 1866–1890. For the Iberian Peninsula I myself published in 1895 the details of all the observations made in that country, 1861–1890, with a discussion of these observations, the general means reduced to the same period of thirty years and 16 charts, which allowed one to easily apprehend the peculiarities in the pluviometric régime of this country. * * *

In the present work, which extends this study to the whole of Europe for the same thirty years, 1861–1890, I have made use of about 275 stations having complete records for this period. The additional stations, to the number of more than 2,000, which have been employed in the preparation of the charts, present more or less important gaps. I have never used any record which did not contain at least ten years' observations. Ordinarily the gaps have been filled up by interpolation, following exactly the method that I have indicated in my studies relative to the Iberian Peninsula. When the gaps were filled the means were taken by periods of ten years, and I have always been careful to verify the mean of ten yearly rainfalls by the sums of the twelve corresponding monthly means. This method of interpolation is quite long, but we can simplify it in a special case in which we possess mean values for the same series of years. For a certain number of stations having complete observations during thirty years we may calculate separately the monthly means of the complete period and that of the short period corresponding to another station. The ratio of these means gives the coefficient by which to multiply the means of the partial series, in order to obtain the probable mean for thirty years.

In order that this method may give good results, it is evidently necessary that the coefficients corresponding to stations in the same region should differ very little from each other. The small differences that these coefficients present in the same month in the groups of British stations thus reduced to a central one, and especially the regular manner in which they vary with the geographic positions of the stations, prove the exactness of this method of reduction. At the same time we see that the reductions can not be neglected. * * *

I give a second example, which is much less favorable because it is drawn from a very mountainous region, where the rainfall régime is less regular than in England, and because the period of observations embraces only ten years. * * *

In this series for the Austrian Alps the coefficients of reduction for any given month form a regular variation depending upon the position of the stations, so that the reduction would seem to have considerable precision; but even in these conditions we can, by means of ten years of observation, calculate the probable average for thirty years with an error of 3 or 4 per cent.

By following the methods thus explained we see that it is possible to compute with sufficient accuracy the probable monthly mean rainfall for the average of a long period, such as twenty years, by means of stations whose observations have really extended over a much shorter period. Of course we must not push this principle too far. A series of three or four years of observations would generally be quite insufficient, and I have never utilized stations having less than ten years of record. The total number of stations thus used exceeds 3,000, and I may add that the observations of each station have always been carefully compared with those of its nearest neighbor, and we have rejected all those that seem to present too large divergences from the others.

[From Angot's table of 271 important stations we copy the following stations that have an altitude of 1,000 meters or more, and also those having the largest rainfalls, namely, those above 2,000 millimeters:]

No.	Stations.	Years of observation.	Longitude east of Paris.	Latitude.	Altitude.	Rainfall.
			° ′	° ′	*Meters.*	*Mm.*
86	Gastein	30	10 48	47 7	1,023	1,073
97	Marienberg	30	8 11	46 42	1,335	707
157	Mont Pezat	30	1 52	44 43	1,000	1,548
258	Beatenberg	29	2 28	46 41	1,150	1,441
260	Bevers	27	7 33	46 33	1,711	827
263	Engelberg	27	6 25	46 49	1,021	1,729
269	St. Bernard	30	4 51	45 52	2,478	1,231
270	Sils Maria	27	7 26	46 26	1,810	952
76	Alt-Aussee	30	11 26	47 39	947	2,058
104	Raibl	26	11 14	46 26	981	2,181

All observations have been uniformly reduced to the same thirty years, 1861–1890, as before explained. The mean monthly rainfalls have been charted on a large scale and isohyetals have been drawn. These large partial charts have been followed in preparing the published reduced chart on the scale of 1/10,000,000. For a phenomenon whose geographical distribution is as variable as that of the rainfall, it is indispensable that the isohyetals be drawn with great exactness; therefore, I have myself drawn the curves in detail, so that nothing was left for the engraver to do but to copy them.

In a general way the distribution of rain is faithfully shown by the charts in those regions that do not offer too many topographical irregularities; but this is no longer the case in mountainous countries. The drawing of isohyetals in very mountainous countries is almost impossible, for one often finds very different amounts of rainfall at neighboring stations, according as they are on the side of a mountain or in the bottom of the valley, or are both situated at the bottom of the same valley but having different orientations. Thus, for example, in the valley of the Inn, the three neighboring stations, Innsbruck, St. Martin in the Gnadenwald and Hall, having the altitudes 573, 837, 1,488 meters respectively, record as mean rainfall for the years 1881–1890, the values 769, 1,002, and 1,226 millimeters, respectively. Under these conditions exact isohyetal curves can not be drawn except upon charts of a very large scale and when one has at his disposal a very large number of stations. The charts that accompany this present work therefore represent the distribution of rainfall for very mountainous regions, not in detail, but only in the most general features.

Before studying the distribution of rain month by month, we must consider the general laws that govern this phenomenon. In order that rain may be produced, it is necessary that the aqueous vapor contained in the air shall be condensed very rapidly; a slow condensation gives only clouds or fog. The mixture of two masses of air, both of them saturated, but at different temperatures, is, as we know, powerless to furnish any appreciable quantity of rain. The formation of rain is therefore dependent on the sudden cooling of the air. This cooling can be produced directly, as when a mass of warm moist air passes over a colder region; but the rains produced by direct cooling are relatively of little importance. In fact, cooling affects only the layers of atmosphere near the ground. Moreover, the rapid inflow of air, and even the formation of rain itself, are efficient causes of the warming up of the soil.

By far the more important cause of the production of rain is the cooling by expansion which accompanies every ascending movement of the air. The laws of this cooling are well known. The ascending movements of the air can originate in three different ways, corresponding to which are three different classes of rain: (A) Certain ascending movements take place in connection with the general circulation of the atmosphere; for example, the ascending currents of the equatorial regions; the convectional rains correspond to these movements. (B) Other ascending movements accompany barometric depressions and thunderstorms over a greater or less part of their extent; these give birth to cyclonic rains or thunderstorms. (C) Finally, whenever aerial currents encounter mountains or even slight elevations of the soil, they produce mechanically on the flanks of these mountains ascending movements from which there result the so-called orographic rains.

We should add that the initial temperature of the air exerts a preponderating influence on the intensity of the rainfall; the warmer the air the more moisture it contains for a given percentage of relative humidity and the more liquid water it will give up for the same lowering of temperature. The influence that is most prominently manifested on the rainfall charts is that of the orography. It has often been said that a rainfall chart is only a rough copy of the hypsometric chart of the same region, but in fact the rainfall chart is far more complicated. On the side of a mountain exposed to the wind, the rain increases with altitude, at first rapidly, but we can easily see that this increase is not indefinite. If the mountain is sufficiently high, we observe a zone of maximum rainfall at a certain altitude, above which the diminution is very clear. An analogous phenomenon is produced if the mountainous mass is very broad; the rainfall is especially heavy on the border of the mass, whereas the central part receives far less rain. The charts that we publish offer a striking example of this in the region of the Tyrolian and Austrian Alps. In every case without exception the center of this mountainous region gives a minimum of rain relative to its northern and southern flanks. The influence of the orography is very clear; every chain of mountains shows a maximum of rainfall. The smaller elevations sometimes suffice to develop very appreciable maxima. Another cause of complexity in the rainfall map arises from the fact that the air, after having precipitated upon the flank of the mountain a large part of the water that it contained and after having surmounted the obstacle, is now much poorer in vapor and less capable of producing rain than if this obstacle had not existed; therefore to the leeward of every maximum of rainfall there should be a minimum. This occurrence of a minimum to the leeward of a maximum with reference to the direction of the prevailing wind is also very clearly shown on the maps of European rainfall. This double influence of the orography, which produces at the same time maxima and minima of rainfall in neighboring regions, is the principal cause of the complexity of the rainfall charts.

In order to study the manner in which the rainfall is distributed month by month, it does not suffice to directly compare the monthly means of various stations among themselves, since the absolute quantities of rain vary very much from one station to another. This comparison is facilitated by dividing the monthly means by the annual total; the quotients, or monthly pluviometric ratios, represent the fractional parts of the total rainfall independent of the absolute quantity of rain. The numbers thus obtained differ but little for any given month, for all the stations within a large area; they are therefore far more convenient than the absolute heights for studying the pluviometric régime. The monthly fractions present one small inconvenience resulting from the inequalities of the months. In order to represent the pluviosity in a simple and exact manner, I have proposed to calculate the pluviometric coefficient for each month by taking the ratio of the quantity of actual rainfall to that which would have been observed if the rain had been distributed uniformly throughout the year. If the pluviometric coefficient for any month is less than unity it shows that less water has fallen than corresponds to a uniform distribution. The months will be dry or wet according as their coefficients are less or greater than one. * * * By these examples and especially by comparing the charts of pluviometric régime or relative pluviosity with those that give the actual depth of rainfall we see how much more simple is the consideration of relative pluviosity than of absolute quantity.

(32) PROF. A. J. HENRY.

In Bulletin D, The Rainfall of the United States, by Alfred J. Henry (1897), the author has collected all accessible records, including such long ones as that for eighty-three years at New Bedford and sixty years at St. Louis. We quote as follows:

With regard to the elevation of the Weather Bureau gauges, high above ground on the roofs of large flat buildings: In general, it does not seem possible to avoid the conclusion that the observed amount of precipitation falls short of the true amount by quantities varying from 5 to 10 per cent of the annual rainfall.

Uniformity of the years of observation: Heretofore it has been sufficient to accept the available registers of the various districts, whether of ten or twenty years' duration as representing the true average precipitation. * * * It will be shown, however, that years of fat and lean rainfall do not alternate in orderly sequence and that a number of consecutive years of heavy rains can not be safely accepted as indicating a permanent increase of rainfall.

Length of record required for a normal: A true normal may be defined as one which will not be materially altered, however much longer the observations may be continued. * * * The writer does not know of a single rainfall register that was established and has been perpetuated under ideal conditions of environment and observational accuracy. In order to obtain the extreme variation and the possible error of a 10-year period, the average of the first 10 years of each register was computed, then dropping the first year the average of a second period of 10 years was computed. Proceeding in like manner, 74 separate combinations of 10-year periods were obtained for the New Bedford record. The average for 83 years is 43.5 inches; that for the 10 years 1884–1893 is 50.4; for the 10 years 1837–1846 it is 38.8. As compared with the mean for 83 years, these decades are in error by 16 per cent and 11 per cent, respectively. In like manner the extreme variations for decades at Cincinnati were 20 and 17 per cent; at St. Louis, 17 and 13; at Fort Leavenworth, 16 and 18, and at San Francisco, 9 and 10. In a similar way the extreme variation of the mean of a 25-year record was 10 per cent. The conclusion is reached that at least 35 or 40 years' continuous observations are required to obtain a result that will not depart more than 5 per cent above or below the normal. The addition of the 5-year period 1892–1896 to the monthly and annual averages up to the end of 1891, as published in Bulletin C, does not materially change the averages heretofore determined except over the west Gulf coast. During the greater portion of the period 1892–1896 drought prevailed in many parts of the United States, and there does not seem to be any law of compensation by which a deficit in one district is balanced by a surplus in another. The local distribution of rainfall is exceedingly erratic; thus the catch of two gauges having practically the same exposure and but a few miles apart may differ as much as 10 or 15 inches in the total of the year.

For convenience of comparison the monthly averages were reduced to percentages of the annual fall. Arranging these by geographic districts, it is seen that the distribution over comparatively large areas is practically uniform, and that the profile of a single station may represent the entire district. We may therefore view the rainfall of the United States not as a single concrete system, but rather as being composed of fourteen separate and distinct types, which are described in detail.

Periods of heavy and light rainfall continuing for two or three years are not infrequent. Professor Henry gives the following centers of groups of dry growing seasons, viz, 1860, 1863, 1870–71, 1881, 1887, and 1894–95. Similar periods for the whole year, but no regular periodicity, are easily detected. A very general deficiency occurred during the ten consecutive years 1887–1896, thus showing how long a series of years is needed in order to obtain normal values. The oscillations from dry to wet, or vice versa, are often very remarkable. Thus on Mount Hamilton, California, 90 inches fell in 1884, but only 18 in 1885, and this contrast prevailed over a great part of the Pacific Coast States and the plateau region. During December, 1889, the whole system of atmospheric circulation and storm movements seems to have been shifted for the time being 5 or 10 degrees to the southward.

(33) C. A. SCHOTT.

The Smithsonian Tables and Results of the precipitation in rain and snow in the United States were compiled by the late Mr. Charles A. Schott, the first edition published in March, 1872, and the second edition in May, 1881. Charts of mean annual precipitation (rain and melted snow) accompany these volumes. Different editions of this chart of annual rainfall are dated August, 1868, March, 1870, and 1877. In general, the charts accompanying the second edition of the text include data up to the end of 1874 and in some cases the end of 1876. For each station all accessible rainfall records are published, beginning in one case, Charleston, S. C., with the year 1738. There is no evidence that the numerous shorter series were reduced by any method of interpolation to homogeneity with one fundamental period. Only in the case where a few months were missing were these interpolated, in order to give complete years. It was very often necessary to accept, instead of melted snow, the observer's rule of taking one-tenth of the depth of the measured snowfall. In the second edition, May, 1881, the charts themselves show by shadings and isohyetal lines every 6 inches of annual precipitation from 8 inches up to 68, thereby attempting to show more detail than would ordinarily be considered advisable in view of the small number of stations and inequalities as to time. Records are given for about 1,500 stations, but only 1,300 were plotted for the compilation of the chart of mean annual rainfall. On these matters Mr. Schott says:

An asterisk affixed to any number indicates that it is derived from less than twelve months of observation. In no case, however, are annual amounts given for which more than three months had to be found by interpolation, which was effected either by using the observed amount at the nearest station during the time required, or by using the means from adjacent years for the same month or months. The first mode of interpolation is quite reliable and was always preferred to the second. The annual means at the bottom of each column in Table B are taken from the preceding Table A whenever the series was not continuous.

The mutual relations and significancy of the tabular results can best be brought out by a graphical presentation. In this form the amount and general distribution of the rainfall over the country can at once be seen, and admits, at the same time, of a close study of its special features. The increased material at disposal since the publication of the first edition of the tables and the importance to the agriculturist of a knowledge of the distribution of the rainfall in the several seasons induced the Institution to enlarge the charts, as well as to construct two new ones, thus presenting five, viz, one for the year and one for each of the four seasons.

For the delineation of the geographical distribution of the aqueous precipitation over the area of the United States, the same base map has been made use of which served for the exhibition of the distribution of the atmospheric temperature, published by the Smithsonian Institution in 1876.[a] It has, however, been improved by the introduction of the mountain systems, and it is believed that the study of the relationship of the distribution of temperature and of rainfall will be facilitated by this uniformity of projection and scale. For the generalization of the results of the greater part of the western and elevated portion of the United States, the scale of the map appears inconveniently large, our material being too limited to adequately cover so large an area, otherwise it is well adapted for the exhibition of the general and the detail features presented in the numerical results. To explain the construction of these charts it suffices to show it for the one exhibiting the annual distribution. All stations for which the observations extend over four or more years were plotted by their coordinates, latitude and longitude, and against the dot was written the amount of precipitation in inches and to the nearest tenth of an inch; for all other stations with series of observations shorter than four years the position was marked as before, but only the nearest whole inch was written against the dot; the relative value of the results was thus, in a measure, indicated in the construction of curves of equal rainfall. These curves were drawn with a free hand among the dots by graphical interpolation, and with due regard to the importance of long and short series. These curves, designated as isohyetal lines, and constructed in the manner of contour lines generally, are graduated for certain equal increments of rain. The difference between adjacent curves resulted from the consideration of the probable uncertainty of the results. If drawn too close—that is, if too many curves were shown—they would exhibit temporary or accidental inflections, which would only tend to complexity and confusion; on the other hand, if the curves were too wide apart there would be danger of losing portions of permanent features in the distribution.

The distinction between long and short series in the graphical process is of importance in a phenomenon of such great variations from year to year and from the same season in different years, and the numbers of the second class given in whole inches were used to complete, modify, and generally to improve the curves resting upon the more reliable data. Special consideration was necessary to select for each chart those particular curves and their graduation which would best bring out its leading features, and further, to facilitate the understanding and the ready interpretation and use of the charts, color shading was introduced. The curves, whether principal or intermediate, are indexed, and can thus be easily followed by the eye, and each chart is supplied with a sufficient explanation to be understood, even when detached from the text. It was neither necessary nor practicable, from want of space, to indicate on the charts the individual stations and their amount of rainfall, though they are crowded in on the manuscript charts. Thus the number of stations plotted and utilized for the chart of the mean annual distribution is about 1,300, and the numbers are larger for each of the season charts. Comparing the new with the old rain charts, the superiority of the former will be apparent; and while perhaps too much detail was given on the charts of the first edition, which, through the increase of observations, is now known not to form part of permanent features, but arose from insufficient data at that time, yet the apparent distortion of the curves, when the two sets are compared, may be produced by small changes in the amount of rainfall; and, while the general features are preserved, the present charts will bring them out only more prominently and broadly.

[a] Smithsonian Contributions to Knowledge, No. 277, "Tables, distribution, and variations of the atmospheric temperature in the United States" By Charles A. Schott. Washington, 1876.

(34) ALEXANDER BUCHAN, ESQ.

In the magnificent Atlas of Meteorology, published as Volume III of Bartholomew's Physical Atlas, London, 1899, there is given a list of meteorological services and stations, from which it would appear that there are about 30,000 stations for observing rainfall scattered over the continents and islands of the world. The regions that have one or more to every 40 square miles are Jamaica, Barbados, St. Kitts, Great Britain and Ireland, Denmark, Saxony, the Straits Settlements, Victoria, and Mauritius. For the greater part of the world there are only scattered stations; for Europe and the United States, India and Australia, the general average is about one for every 2,000 square miles. Notwithstanding this apparently large number of stations, yet, when we come to make up a rainfall map, we find so many short or broken series that the actual number available is reduced to a third of what we appear to have. The Bartholomew atlas has collected together nearly all that is known about rainfall, and the following remarks by the editors are appropriate to the present occasion. On pages 1 to 4 Alexander Buchan says:

The use of the rain gauge dates as far back as the time of Leonardo da Vinci, but as rain gauges continued long to be placed on houses and other objectionable situations, the observations in only a few cases are comparable with those now made. Not until the middle of the present century can the quality of the observations and the number of rainfall stations be regarded as sufficient to represent this all-important factor of climate with a first approach to accuracy. * * * The maps of this atlas show in the most conclusive manner that the rainfall of any particular region is determined by the prevailing winds of that region, considered in the first place in relation to the regions from which they have come, and, in the second, the physical configuration and the temperature of that part of the earth's surface over which they now blow. It is then seen, for example, that the maximum rainfall is precipitated by winds which, having traversed a large breadth of ocean, come up against and blow over a mountainous ridge lying across their path; and the amount deposited is still further increased if the winds pass at the same time into higher latitudes or through regions the temperature of which is constantly becoming colder. * * * The rainfall is unusually small or even nil when the prevailing winds have not previously traversed a considerable extent of ocean or have crossed a mountain ridge and advance at the same time into lower latitudes, that is, into regions the temperature of which continues to become higher, * * * and this peculiarity is presented in the most pronounced form when the winds arriving from the ocean blow out immediately from a well-marked anticyclone which presses close toward the shore, that is, out of a region characterized by great atmospheric dryness. * * *

From the immense importance of the rainfall in relation to our economic needs and from its intimate and vital connection with changes of weather, stations for its observation require to be more thickly planted than has as yet been done. Leverrier was not far from the mark when he urged the parochial observation of rainfall. In mountainous regions more rainfall stations are much needed, especially in connection with the water supply of our great centers of population and probably the great extension of the use of water power in industry. Until this be done, the engineers' demand can not be met for a statement of the rates of increase of rainfall with increased height under different climatic conditions.

(35) A. J. HERBERTSON, ESQ.

On page 17 of the text of Bartholomew's Atlas of Meteorology, Mr. A. J. Herbertson says:

"In rainfall maps the actual mean rainfall values are entered without any correction for altitude, and then the isohyets are drawn. In preparing rainfall maps for the months, account should be taken of their different lengths. All the monthly rainfall maps in this atlas, except those for the United States of America, show rainfall values reduced to one-twelfth of a year. The isohyets on these monthly maps have therefore two meanings: (1) The figures attached to them show the mean monthly rainfall expressed in terms of one-twelfth of a year; and (2) the lines also represent an actual precipitation during the month, differing slightly from the values marked on them and the exact amount of which will be found on consulting the Table XII." [According to this table 100 mm. of rainfall in one-twelfth of a year corresponds to 101.8 in 31 days, or 98.6 in 30 days, or 92.5 in 28¼ days.—ED.]

(36) PROF. VICTOR KREMSER.

In the Meteorologische Zeitschrift for July, 1900, Vol. XVII, pp. 289-317 and 337-355, Prof. Dr. Victor Kremser, in the course of his review of the climatic conditions of the Memel, Pregel, and Weichsel, discusses the distribution of rainfall from several points of view, but we will summarize only that which relates to the variation with altitude. The distance from the sea, in and of itself, seems not to be so important as the other factors, such as the distribution of storms, the direction of the wind, etc. With regard to altitude the following tables show a variation in the rainfall gradient, depending on the peculiarities of location.

Lower Weichsel in Prussia.			Pregel and coast regions.		
Mean altitude.	Number of stations.	Average precipitation.	Mean altitude.	Number of stations.	Average precipitation.
Meters.		*Mm.*	*Meters.*		*Mm.*
48	27	486	42	27	557
136	21	535	136	16	592

In the valley of the Weichsel, on the northwest slope of the Prussian territory, 14 stations, having an average altitude of 129 meters, gave an average annual precipitation of 592 mm., whereas on the southeast slope, 14 stations with an average altitude of 146 meters gave an average annual rainfall of 557 mm. In the valley of the lower Weichsel the precipitation increases toward the south and east, and the effect of elevation is shown in the preceding table.

In the upper Weichsel region we have the following figures:

Mean altitude.	Number of stations.	Average precipitation.
Meters.		*Mm.*
178	4	610
249	30	699
351	9	763
565	14	844

By combining both altitudes and horizontal distances, Kremser shows that with one exception there is always a diminution of precipitation as we go from the west toward the east. As regards the influence of the general trend of the coast of the Baltic Sea, he shows that along a line stretching eastward 4 stations gave a mean rainfall of 483 mm.; stretching northward, 8 stations gave 543; stretching westward, 6 stations gave 658.

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Chart XII. Average Annual Precipitation in the United States for Thirty-two Years, 1870-1901.

Figures indicate rainfall in inches.

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