even by their absorption into mean pressure values for the month. The significant feature of this chart, however, is the abnormal position and axial attitude of the oceanic high-pressure system, which is so disposed as to

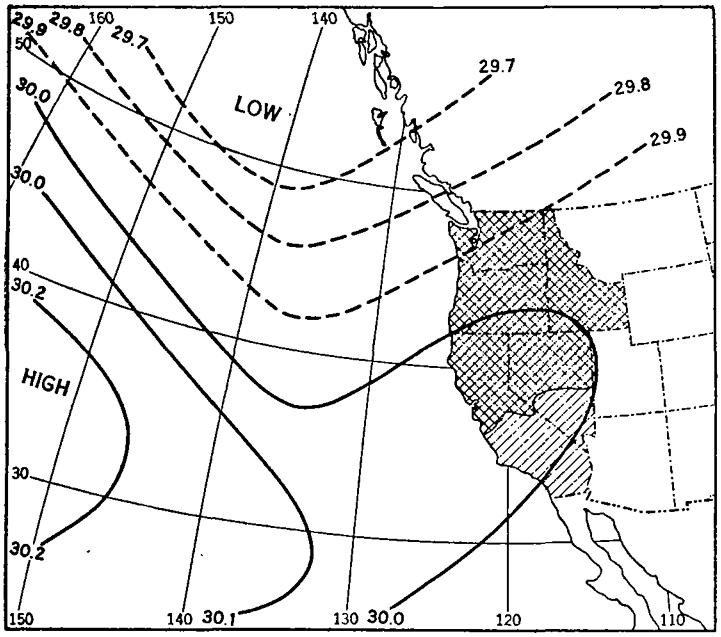


FIG. 3.—October, 1924. Mean 8 a. m. pressure, 7 a. m. at sea, 75th meridian time. A notably wet month over much of the Pacific forecast district. Region of *subnormal* precipitation shown by hatched lines, *supernormal* by cross-hatched lines

imply the displacement of southwesterly or rain-bearing air currents into quite high latitudes.

In contrast to this pressure arrangement is that for the preceding October, when the oceanic high-pressure system lay far to the west, thus permitting easy access in lower latitudes of winds from the southwest or rainy quarter. The effect of the ingress of air from this quarter was so marked that it can not be appreciated by the mere statement that the ensuing rainfall exceeded the normal over a large area. The excess was so extraordinary that in Washington comparative data showed the month to be the wettest October since state-wide records had been kept, a period of 35 years. In Oregon it was the wettest October for the State as a whole since 1900, and for the western division the wettest since 1890. In California the state-wide average for this October had not been equaled since 1899, while for certain localities along the north coast the amounts exceeded any October rainfalls of record.

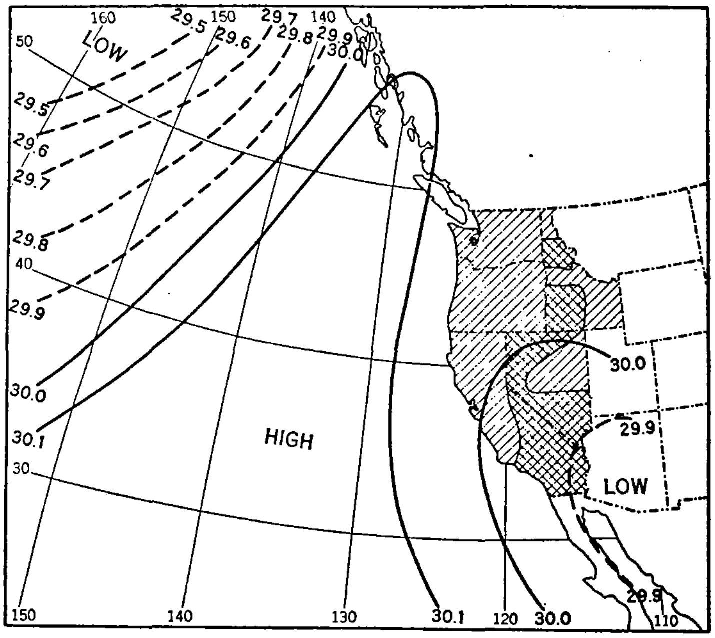


FIG. 4.—October, 1925. Mean 8 a. m. pressure, 7 a. m. at sea, 75th meridian time. A dry month over much of the Pacific forecast district. Region of *subnormal* precipitation shown by hatched lines, *supernormal* by cross-hatched lines

NOTES TO FIGURES 1 AND 2

[1] Total amount, all directions, 0.25 inch.
[2] Only one rain in 10 years; amount, 0.01 inch.
[3] Total, 0.09 inch.
[4] Total amount, all directions, 0.08 inch.
[5] 100 per cent east.
[6] 33 per cent northeast, total 0.01 inch; 67 per cent southeast, total 0.02 inch.
[7] Northeast rain not typical; caused by freak storm of September, 1918; 4.56 inches falling while wind was northeast.
[8] Abnormal north and northwest components caused by rainstorm of September, 1918.

LITERATURE CITED

(1) MONTHLY WEATHER REVIEW, vol. 53. Von Herrmann. Rain-Bearing Winds at Atlanta, Ga.
(2) MONTHLY WEATHER REVIEW, Supplement No. 1. Bowie and Weightman. Types of Storms in the United States and Their Average Movements.
(3) Weather Forecasting in the United States, Washington, 1916.

TWELVE YEARS OF LONG-RANGE FORECASTING OF PRECIPITATION AND WATER LEVELS

By AXEL WALLÉN

[Stockholm, Sweden]

(Translation by B. M. Varney from the Köppen-Heft der Annalen der Hydrographie, 1926)

Each year since 1915 I have published, usually in February, an advance computation of the probable tendency of precipitation and water level in Sweden for the ensuing 12 months. In view of the very considerable period during which these long-range forecasts have been made and tested, I wish to give in what follows a short review of the results.

With regard to the methods used I shall speak briefly, since the principles have been set out more in detail elsewhere.[1] They are based on the existence of a period a few years in length, of an average value of some 28 months, and on a period that averages 11 years, which shows also two secondary maxima and minima within this 11 years. This latter period is very important in the case of lakes that have large storage capacity, e. g., Lake Wenner; on the other hand, its significance is relatively less conspicuous in the case of precipitation changes and as regards the levels of waters not characterized by great reservoirs of that sort.

The method I have found most useful in preparing the forecasts here set forth may be described most simply as a study of the variations of the elements involved, the yearly period of each having first been eliminated; after such elimination these elements showed a period most clearly, the average length of which is 28 months, with, however, considerable irregularity.

If we designate the original monthly values as

$$a_1\, a_2\, a_3 \; . \; . \; . \; . \; .$$

(smoothed by forming running five-month values), and

[1] Axel Wallén, Vanerns Vattenstandsvariationer. Meddelanden fran Hydrografiska byran. 1. Stockholm, 1910.—Les previsions des niveaux d'eau et des debits en Suede. Geograf. Annaler h. 3. 4. 1919.

then call the 12-month values formed of these (thus eliminating the yearly period)

$$b_1\ b_2\ b_3\ .\ .\ .\ .\ .$$

thus:

$$b_1 = a_1 + a_2 + \dots a_{12} = \sum_1^{12} a_i;\ b_2 = a_2 + a_3 + \dots a_{13} = \sum_2^{13} a_i;\ \dots b_k$$

$$= a_k + a_{k+1} + \dots a_{k+11} = \sum_{i=k}^{i=k+11} a_i$$

or these values divided by 12, then the difference between two successive b values, or the difference of the b curve, will be expressed by

$$\Delta b_{i+1} = b_{i+1} - b_i = a_{i+12} - a_i$$

From this it follows that the curve of the b values (freed of yearly period) will rise as long as $a_{i+12} - a_i > 0$; that it will run parallel to the x axis as soon as $a_{i+12} - a_i = 0$; that the curve will fall as long as $a_{i+12} - a_i < 0$. If $a_{i+12} - a_i$ reaches a maximum or a minimum, this represents an epoch in the curve; in the first instance (maximum), and as viewed from the x axis, the curve changes from the convex form into the concave, and vice versa in the second instance (minimum).

If now, beginning with the first appearance of the period of a few years pointed out above, we can extrapolate at least for a short stretch, then we are in a position to compute in advance the corresponding monthly values, or at any rate their magnitude in relation to the value for the corresponding months of the previous year. In the space of time for which one has computed a decline of the b curve, the corresponding a value must be lower than that for 12 months previous. If the curve is passing an epoch, then the difference according to absolute values must be at a maximum.

If the b curve reaches its minimum, then the corresponding a values are like those for 12 months previous. If the b curve rises the a values are higher than 12 months previous; at an epoch this difference is greatest; at a maximum of the b curve the corresponding a values are like those 12 months previous, etc. The assumption that this is a usable method rests upon the fact that the period of a few years is so regular that it allows extrapolation to be carried out with some certainty. If one does not carry this entirely too far, but is satisfied to extend it at the most to a year (in other words, if he is content not to use all of a half period), then this method of procedure is allowable.

In Table 1, I have brought together the a and b values for the rainfall at Stockholm from January, 1921, to May, 1926. From them it is to be observed how the b curve oscillates: minima appear in March, 1921, October, 1922, and December, 1924; maxima in March, 1922, and November, 1923; since the beginning of 1925 the curve is rising. According to the average length of the oscillations, there should be expected a new maximum 14 months after December, 1924; that is, in February, 1926. The precipitation up to and including July, 1926, should be larger than for the preceding 12 months, and thereafter during approximately another 14 months again smaller than in the corresponding months of the previous year.

Forecasts arrived at in this manner may not infrequently fail in case one is dealing with a particular month. The values in the table show small discontinuities. It is therefore advisable not to apply the method to a shorter space of time than that of the five-month values. Neither is it possible to fix in advance the exact time of the maxima and minima of the curve; the forecast failures that result from using this curve are serious. But in spite of this, experience has shown that the forecasts in general give good results, especially so if one content oneself with a somewhat less definite fixing of the epochs of change (at maxima and minima). In this event, in case the forecast includes a period of at least five months, useful results can be gained.

TABLE 1.—*Computation of the b values for Stockholm, 1921–1926*

Month	a	b	$\sum_1^5 b:5$
1921			
January	68	532	489
February	4	476	490
March	6	454	488
April	32	481	*484*
May	10	496	488
June	96	512	502
July	83	497	517
August	45	522	535
September	17	556	555
October	31	588	567
November	36	608	568
December	84	560	582
1922			
January	53	528	606
February	29	627	622
March	40	706	645
April	64	689	**665**
May	30	676	663
June	48	625	646
July	51	618	625
August	144	621	599
September	96	586	589
October	14	546	583
November	23	574	[1] *577*
December	33	586	579
1923			
January	46	594	591
February	32	597	608
March	5	603	632
April	24	662	657
May	58	702	681
June	60	723	710
July	59	714	737
August	147	747	765
September	102	800	790
October	73	840	814

Month	a	b	$\sum_1^5 b:5$
1923			
November	63	848	832
December	54	837	824
1924			
January	37	834	806
February	65	760	781
March	58	753	749
April	64	720	715
May	66	680	698
June	49	664	678
July	56	675	656
August	73	653	639
September	95	606	622
October	40	598	*598*
November	23	577	601
December	38	555	602
1925			
January	48	670	599
February	43	608	609
March	11	583	626
April	56	628	623
May	45	643	627
June	27	652	639
July	171	631	642
August	11	640	637
September	70	646	636
October	84	614	------
November	38	651	------
December	47	------	------
1926			
January	27	------	------
February	52	------	------
March	17	------	------
April	24	------	------
May	82	------	------

NOTE.—In column b, for example, the number shown opposite 1921, VI (June), is the sum of the known values for the months I–XII, 1921, in column a. In column $\sum_1^5 b:5$ the number shown opposite 1921, VI, is the mean of the known values for the months IV–VIII, 1921, in column b.

With reference to the single-month values for Stockholm for 1921, an investigation of them, which is too long to describe here, shows that the percentage of hits is not more than 65. If instead of these monthly values we take rainfall sums for the different periods included in the forecasts, we get the result set forth in Table 2. It is evident that the forecasts were successful in ten cases out of eleven. For the sake of comparison, I have also given the normal values of precipitation for the periods concerned.

As an example of the preparation of a forecast on the basis of Table 1, we take the following case from the recent period. In February, 1925, we knew the maximum of the b curve in November, 1923, on the basis of which we could compute, by extrapolation, a minimum for January, 1925. Accordingly, from July, 1925, heavier rainfall than for the preceding 12 months must set in. During the months March to June, 1925, that is, precipitation must be slighter, and that from July, 1925, to February, 1926, heavier, than that which fell during the 12 months preceding. With respect to the values for single months these forecasts were verified except for August and September, 1925, and for January, 1926, as the comparison in Table 3 shows.

TABLE 2.—*Results of the long-range advance computation of precipitation amounts*

Period	Rainfall amounts (mm.)		
	Normal	Forecast	Actual
March, 1921–June, 1921	156	<169	144
July, 1921–February, 1922	413	>364	378
March, 1922–December, 1922	499	>440	543
January, 1923–February, 1923	70	< 82	78
March, 1923–October, 1923	398	[illegible]487	528
November, 1923–February, 1924	171	>134	219
March, 1924–May, 1924	111	> 87	188
June, 1924–February, 1925	458	<600	465
March, 1925–June, 1925	156	<237	139
July, 1925–February, 1926	413	>416	501
March, 1926–May, 1926	111	>112	123

TABLE 3.—*Example of the results of long-range advance computation of precipitation for individual months*

Month	Rainfall amounts (mm.)	
	Forecast	Actual
1925		
March	<58	11
April	<64	56
May	<66	45
June	<49	27
July	>56	171
August	>73	11
September	>95	70
October	>40	85
November	>23	38
December	>38	47
1926		
January	>48	27
February	>43	52

In this case, also, the epoch falls in summer, and for it the forecast proves untrustworthy. The high July value is somewhat misleading, too, since the heavy precipitation is made up of heavy local showers. As for the period sums, Table 2 shows a good agreement, because for March–June a preciptation below 237 mm. was forecast and the actual was 139 mm.; for July, 1925, to February, 1926, the forecast gave more than 416 mm., the actual being 501 mm.

The purpose of these forecasts is not so much to give an advance computation of the precipitation for a particular month as it is to furnish an advance estimate of our lake levels for practical use in navigation and for the regulation of the lake levels. It is precisely for this purpose that the precipitation which has occurred during a long period over a larger area is quite as significant as the exact forecasting of water levels. . . . The generalized precipitation forecasts since 1915 compared with the amounts of precipitation observed in Svealand, and compared also with the corresponding previous year's rainfalls as well as with the normal values, . . . [together with] the generalized forecasts of water levels and the levels observed in Lake Siljan in Salarna [2] . . . show that the rainfall tendencies forecast for Svealand were verified in 13 to 14 cases out of a total of 15, and tendencies of water levels in 15 cases out of 16. Such percentages of hits may well convince one who does not demand too much of the method that it has a practical value.

[2] The author presents two tables embodying all these forecasts and their verifications.—*B. M. V.*

BLUE-SKY MEASUREMENTS

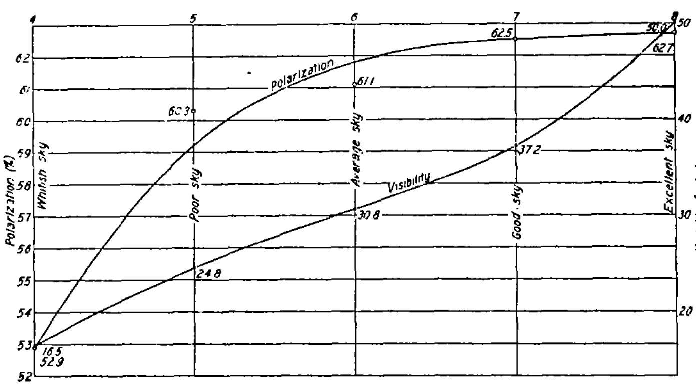
By IRVING F. HAND

[Weather Bureau, Washington, June 30, 1927]

During the latter part of 1925 Dr. F. Linke, of the Universitats-Institut fur Meteorologie und Geophysik, Frankfort on the Main, Germany, sent a series of color-match cards to 17 first-class meteorological services, one being the United States Weather Bureau. Commencing with January, 1926, the blueness of the sky has been noted at the Solar Observatory, American University, District of Columbia, on days when both solar radiation and skylight polarization measurements have been made. Linke states in his letter that the first measurements of the blueness of the sky of which we have record were made by H. B. de Saussure in Europe 150 years ago, and just a hundred years later the work was taken up by H. Wild. Although measurements of this kind have been made more or less frequently in Europe since the resumption of this research by Wild, but few have been made in this country.

The color-match charts consist of a series of 14 cards of graded hues ranging from almost white to a very dark blue, care having been taken to insure permanency of color and trueness of shade. The observation consists in selecting a card which when held against the blue sky 90° from the sun and in its vertical will most nearly match the color of the sky, which at this point is, generally speaking, the darkest. It is also the point of maximum polarization of skylight.

At Washington all the observations made to date cover the range of only the five cards numbered 4 to 8, inclusive. Skies whiter than that represented by card No. 4 are unfit for solar radiation measurements at normal incidence, while skies darker than No. 8 have not been observed at this station. We may therefore, for the sake of convenience, arbitrarily designate the cards as follows: No. 4, whitish sky; No. 5, poor sky; No. 6, average sky; No. 7, good sky; and No. 8, excellant sky.



As will be seen from the figure there appears to be a very close relation between the blueness of the sky and horizontal visibility. This is to be expected as water vapor and dust both whiten the sky and decrease visibility.

The relation between sky color and the elements, visibility, polarization, solar radition intensity at 2 air mass (zenith distance of the sun 60°), dust particles per cubic centimeter, relative humidity, vapor pressure, and