sometimes go before recurving is unknown, but Kimball suggests that some may cross the Pacific to Japan.[12]

As to velocity of movement, Redfield[13] reports that some move slower than any he knew of in the Atlantic, but not slower than some in the Bay of Benegal. On the other hand, some of the recent storms, for which the information is rather full, as for example the severe storm of September, 1918, moved nearly 300 miles in 24 hours.

As to severity: Tropical cyclones in this region, as in all others, vary greatly in intensity. Unusually severe storms are uncommon. The avera e storm is not so severe perhaps as the average typhoon, or West Indian hurricane, and many are not destructive to shipping, just as many typhoons and West Indian hurricanes are not destructive to shipping. But on the other hand the records indicate that scores of boats have been wrecked by storms in the northeast Pacific, and it does no good to try to ignore these storms or to say that they afford no appreciable danger.

As to frequency, the list given above suggests that two or more tropical cyclones occur on the average each year off the west coast of Mexico. Twenty-six are recorded in 11 years, 1849–1859, and 24 in 13 years, 1880–1892. In one year, 1855, seven were recorded.

[12] J. H. Kimball, *loc. cit.*

[13] Redfield, *loc. cit.*

A METHOD FOR THE CALCULATION OF NORMAL FROST DATES FROM SHORT TEMPERATURE RECORDS.

By W. B. VAN ARSDEL.

[Brown Co., Berlin, N. H., July 8, 1922.]

A few months ago the writer had occasion to examine the records of five or six cooperative Weather Bureau stations in a certain small area with a view to estimating frost risk in that area. It chanced that some of these stations had only a short record, and, accordingly, the direct averaging of frost dates, etc., was out of the question as a method of any trustworthiness, especially since some of those few years had passed without any recorded frost. Under these circumstances it was necessary to use an indirect method of computation, based on the temperature record. The occurrence of a minimum temperature of 32° or below was taken as the equivalent of a killing frost.[1] Then from the available data the smoothed curve of "normal" daily minimum temperature was drawn, and the dispersion of actual minima about the mean minimum determined. With this material it was possible to calculate the frost data usually required, namely, probable dates of first and last frost, and length of growing season in four out of five years. A search of the literature on the mathematical treatment of frost data has failed to reveal any reference to previous use of the method in question.

The fundamental idea on which the method is based is that the "average" date of, say, the first killing frost in the fall is the mean abscissa of a curve whose ordinates represent the joint probability that frost will occur and that it shall not previously have occurred (since spring); in other words, the probability that the *first* frost will occur, plotted against date, is the same curve as the frequency distribution of first frost over, say, a 100-year period, and will correspond to the same average date. It should be noted that given two stations with identical normal daily minimum temperature curves, frost will occur first at the station where actual temperatures disperse most widely about the mean; the calculation could be very greatly simplified if this dispersion could be assumed to be Gaussian, but in fact it is found to be so asymmetrical that the Gaussian formulas are useless, and graphical treatment is preferable in this case to the use of either Pearson's or Tolley's skew formulas.

[1] The use of a temperature criterion of frost occurrence, while suffering from the grave drawback that damage to vegetation is not a direct function of temperature alone, still possesses several important advantages. (See, for instance, "Killing frost and length of growing season in various section of Kentucky," Ferdinand J. Walz, MO. WEATHER REV.: 45, 348, 1917, and "Weather forecasting the United States," W. B No. 583, p. 178.) Mr. William G. Reed comments in a private communication as follows: "In general, we have found that temperature methods of determining frost dates are more definite, and probably more accurate, than reports of killing frost. * * * Killing frost is really not a meteorological phenomenon at all, but it is so tied up with various questions of plant pathology that the term means different things at different times and different places."

The smoothed curve of normal daily minimum temperature can not, of course, be determined very accurately from only 4 or 5 years record. A more precise method which is usually possible consists in utilizing the monthly histogram giving the normal daily minimum of a near-by station of 20 years' or longer record, averaging the differences in monthly means at the two stations during the 4 or 5 years of simultaneous record at both stations, applying the differences so found to the long record, and smoothing the corrected histogram to a continuous curve.

The dispersion of actual minima about the mean is determined directly in ogee form, recording as "probability that the temperature will be lower than *n* degrees above or below the mean." Table 1 summarizes the dispersion of August and September minima about the mean determined from Figure 1. The data are taken from the records of the cooperative observer at Berlin, N. H., 23 years observations being available from which to draw the mean curve.

TABLE 1.

Deviation from mean	Negative.					Positive.				
	25–20	19–15	14–10	9–5	4–0	1–5	6–10	11–15	16–20	21–25
Number of cases	0	6	20	37	49	63	50	17	2	0
Number of cases with lower temperature than given deviation	0	6	26	63	112	174	224	241	243	243
Probability that temperature will be lower than given number of degrees from the mean	0	0.025	0.107	0.260	0.461	0.715	0.920	0.992	1.00	1.00

The ogee curve is drawn through plotted points −15, 0.025; −10, 0.107; −5, 0.260; 0, 0.461; +5, 0.715, etc. (See fig. 2.)

The probability of frost occurrence can now be plotted against date by determining at, say, five-day intervals, the distance of the mean minimum temperature curve from the 32° line and reading from the ogee curve (fig. 2) the probability of occurrence of such a deviation from the mean. Figure 3 was drawn in that way from the given data.

It is now necessary to determine the probability that on any given date frost shall not previously have occurred; the values of Figure 3, subtracted from unity,

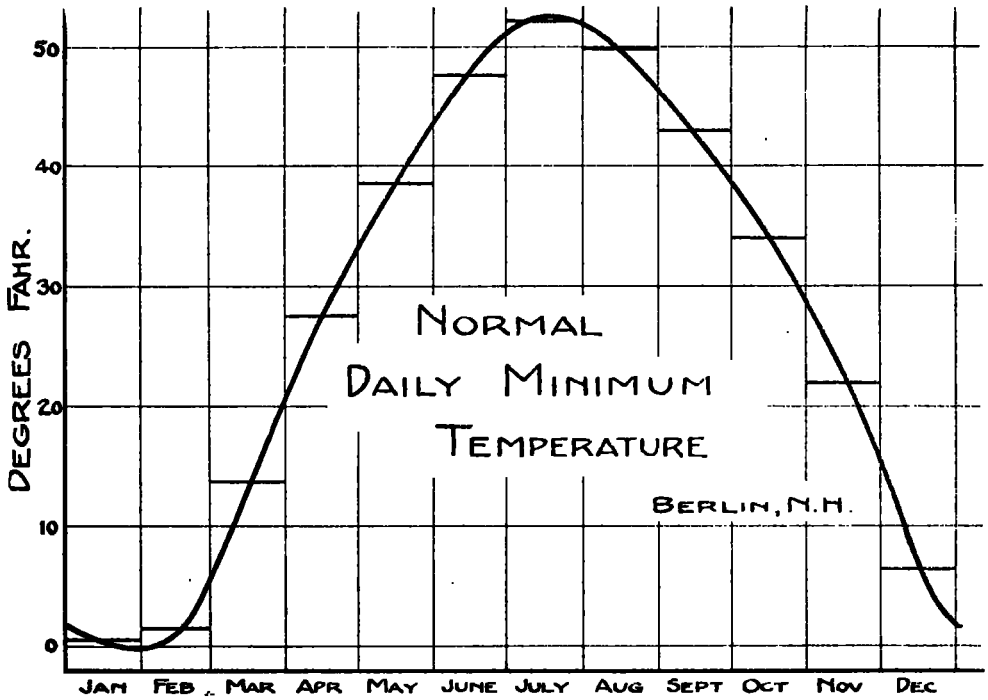
NORMAL
DAILY MINIMUM
TEMPERATURE
BERLIN, N.H.
DEGREES FAHR.
50
40
30
20
10
0
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC

FIG 1.

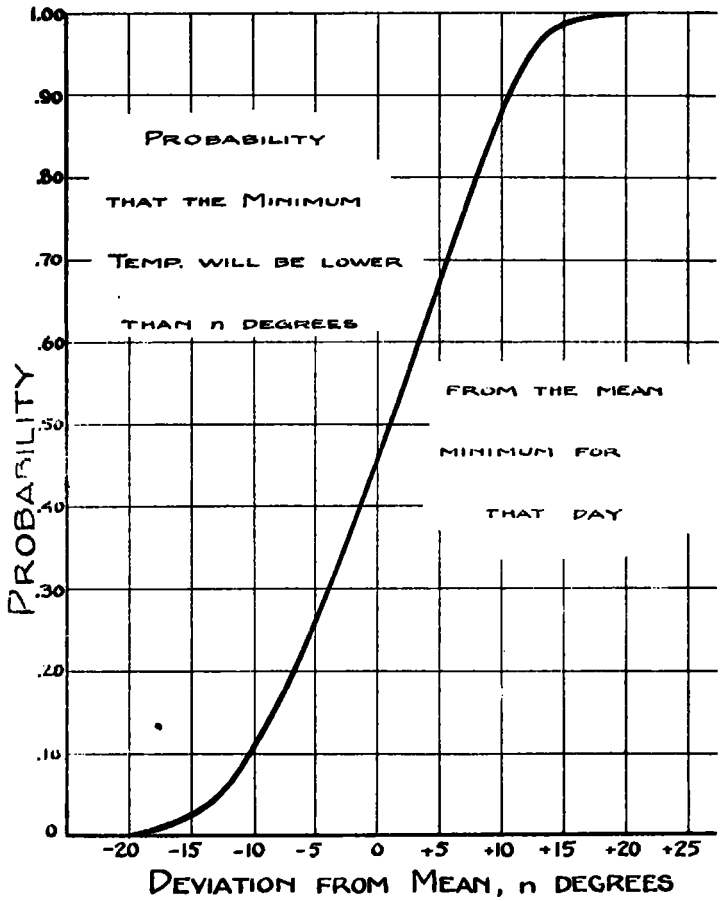
PROBABILITY
THAT THE MINIMUM
TEMP. WILL BE LOWER
THAN n DEGREES
FROM THE MEAN
MINIMUM FOR
THAT DAY
PROBABILITY
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-20 -15 -10 -5 0 +5 +10 +15 +20 +25
DEVIATION FROM MEAN, n DEGREES

FIG. 2.

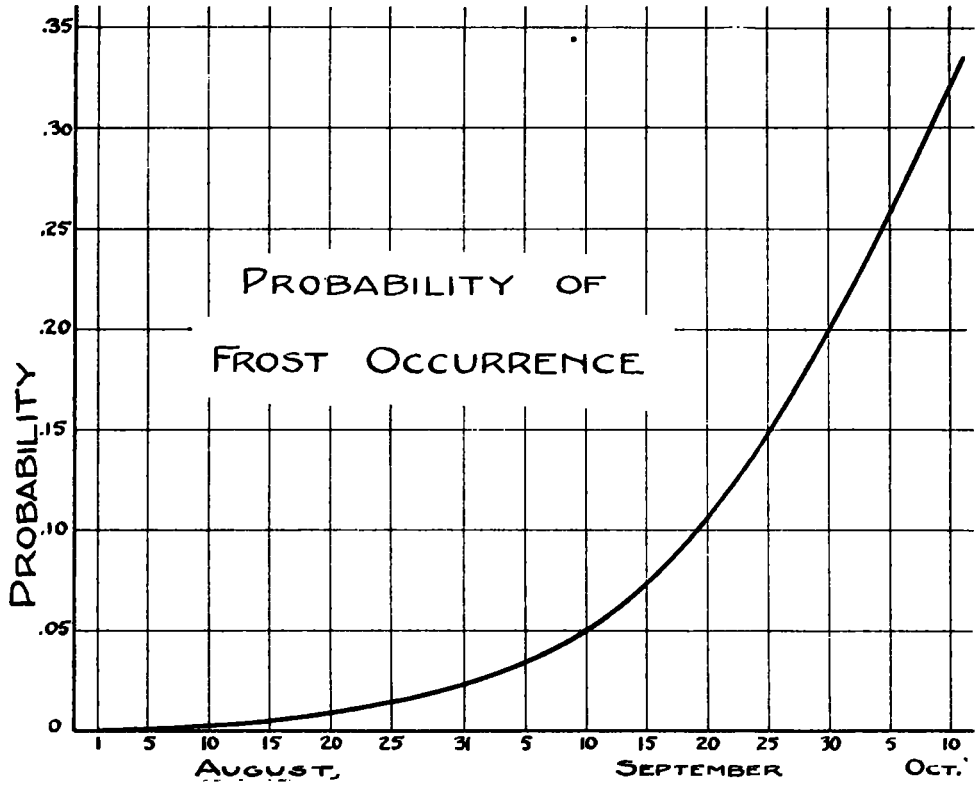
PROBABILITY OF
FROST OCCURRENCE
PROBABILITY
.35
.30
.25
.20
.15
.10
.05
0
1 5 10 15 20 25 31 5 10 15 20 25 30 5 10
AUGUST
SEPTEMBER
OCT.

FIG.

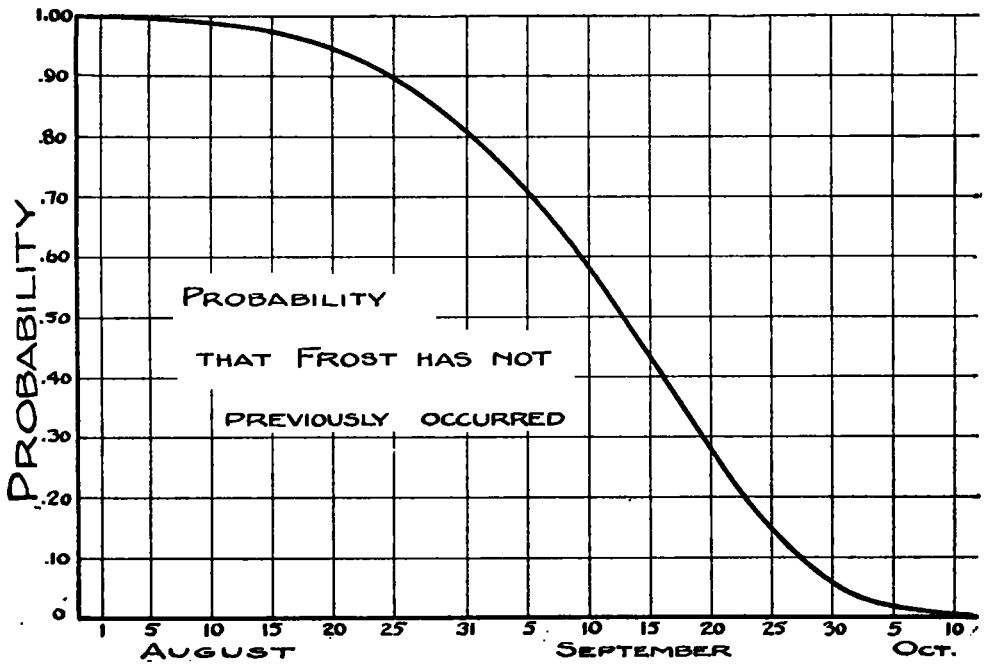
PROBABILITY
THAT FROST HAS NOT
PREVIOUSLY OCCURRED
PROBABILITY
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
1 5 10 15 20 25 31 5 10 15 20 25 30 5 10
AUGUST
SEPTEMBER
OCT.

FIG 4.

give the probability that frost will *not* occur on a given date, and the desired quantity is evidently the continued product of these daily probabilities, starting far enough back in the summer so that the first terms are approximately unity, and ending with the day before the one in question. The arithmetical work can be rather simply performed by writing the logarithms of the probabilities in a column and adding on a machine, taking a subtotal after each number is added. The negative logarithms should be used rather than the negative characteristics with positive mantissa. The antilogarithms of the tabulated subtotals are the desired probabilities, to be plotted against date. (See fig. 4.)

The probability of the *first* occurrence of frost on a given day can now be calculated, since it must be the product of the probabilities (*a*) that frost will occur at all on that day, and (*b*) that frost shall not previously have occurred; that is, it is the product of the ordinates of Figures 3 and 4. The product is plotted (along with a similar one calculated for the spring) in Figure 5. Now this curve can be regarded as the frequency distribution of first-frost occurrence, and the mean value of the date can be determined in the usual manner. For the data in question, i. e., at Berlin, N. H., the average dates are May 30 and September 13, the average length of growing season 106 days. Actual frost records for 25 years give as average dates June 1 and September 14, or 105 days growing season, while the frost record for the years 1918–1921, which furnished the temperature-dispersion data, gives May 28 and September 19. The temperature calculation results in average dates which are not only much nearer to the long-period average, but especially with regard to the spring date are also inherently more precise.

Previous writers on the occurrence of frost have usually regarded its occurrences as being distributed normally about the average date.[2] The curves of Figure 5 are, however, markedly asymmetrical, and the reason is quite obvious; at a station so far north as Berlin, N. H., the 32° line is within "striking distance" of the normal minimum temperature curve during almost the entire summer, so that the tails of both frost-occurrence curves are long on the summer side; on the other hand, beyond the maxima of these curves the temperature drops rapidly toward the winter months (see fig. 1), frost becomes certain every few days, and the winter-side tails are relatively short. As a matter of fact, the curves are so asymmetrical that the most probable date of last frost in spring (i. e., the mode of its curve) is three days earlier than the average. In a climate such as that of the Florida Peninsula the opposite is true—the winter-side tails are long, and the most probable date is on the summer side of the average. For stations in a central belt, and particularly for a group of stations containing examples of both kinds of asymmetry it is quite likely that the distribution will be approximately symmetrical.

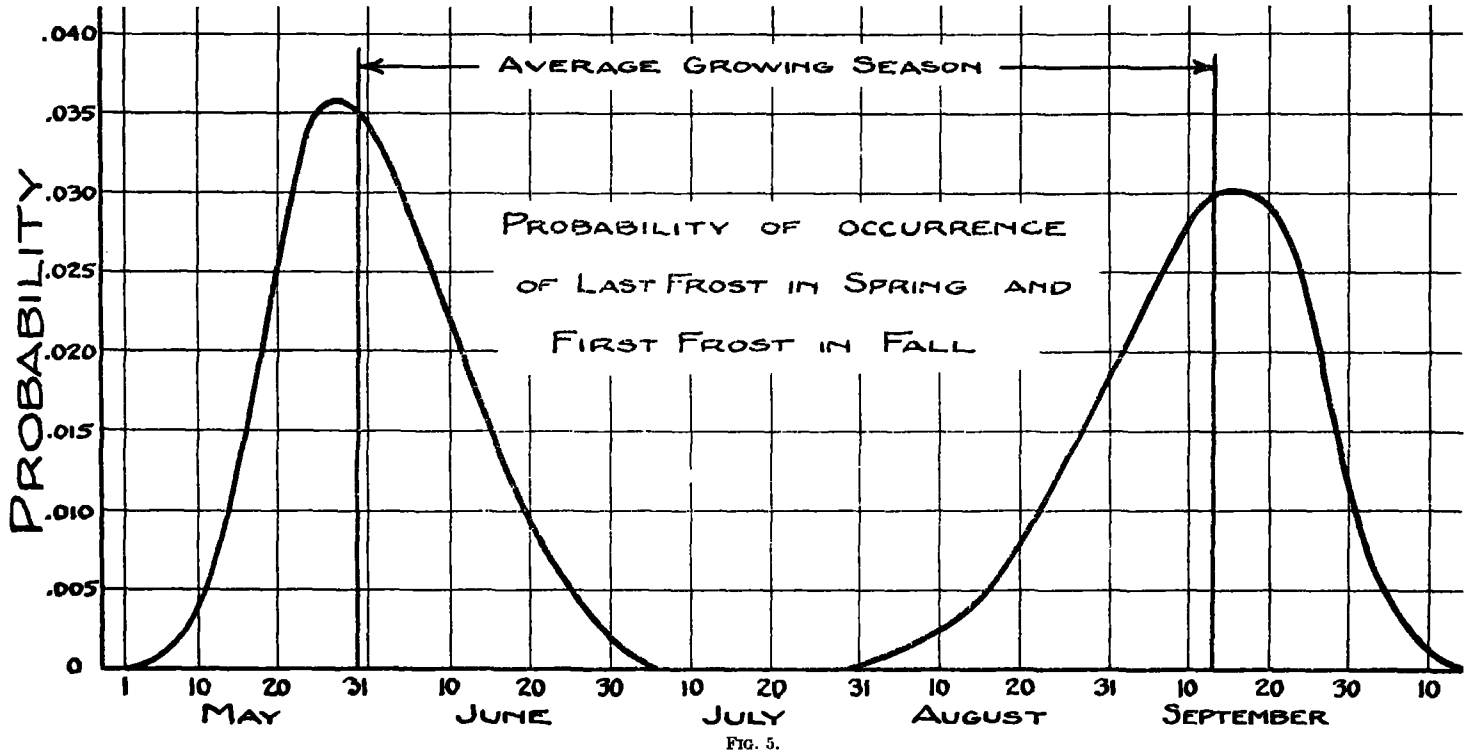

FIG. 5.

The length of growing season in four out of five years apparently may mean either of two things: (*a*) The number of days between the dates when the probabilities that frost will not occur again (in the spring) and that it has not yet occurred (in the fall) are both $0.895 \times 0.895 = 0.80$); or (*b*) the maximum number of days which is consistent with a product of these two probabilities equal to 0.80, regardless of their equality. In either case, the required figures may be read from Figure 4 and a similar curve for the spring. For this station, case (*a*) gives 68 days, June 18 to August 25, case (*b*) gives 69 days, June 19 to August 27. It is, of course, true that this calculation is only approximate, since the dates of spring and fall frost are undoubtedly correlated, and the joint probability of the two events is not simply equal to the product of their probabilities; such correlations as have been observed, however, would not change the result markedly.

A final word as to why any more accuracy can be claimed for the temperature method than for the simple

[2] See, for instance, "Probable growing season," by W. G. Reed, MO. WEATHER REV. 44, 509 (1916). The deviations from the normal date are tabulated for a large number of stations and a single frequency curve drawn for the entire group. This curve is shown to be approximately Gaussian.

averaging of frost dates for the same number of years. The actual dates of last frost are dispersed over at least two months in the spring, so that, for instance, the average for the four years 1888–1891 inclusive is June 17, and for 1897–1900 inclusive, May 21; the variability of minimum temperature is much less erratic, so that ogee curves drawn like Figure 2 for various other periods of four years would all check fairly closely with that one, drawn for 1918–1921.

DUST OVER THE NORTH ATLANTIC.

By WILLIS EDWIN HURD.

[Weather Bureau, Washington, D. C., July 18, 1922.]

On the 12th of May, 1922, the Dutch cargo steamer *Yildum* was about 250 miles off the west African coast, in approximately 14° north latitude, 21° west longitude, For more than three days the vessel had experienced winds from north to northeast, force 1 to 5, with a hazy atmosphere. At daybreak of the 12th the *Yildum* was found to be covered with a deposit of reddish-brown dust, a sample of which was forwarded to the Weather Bureau with his meteorological report by the observer, Second Officer W. Mulder. A microscopic examination of the dust particles furnished by the *Yildum* was made by the U. S. Bureau of Soils. Their geographical source was not definitely determined, but it is assured that they are not of volcanic origin.

The Dutch S. S. *Hagno* was in latitude 8° 11′ N., longitude 50° 5′ W., at 8 p. m. of May 13, when a reddish mist or haze was observed along the horizon. The haze continued throughout the 14th, wind constantly from a northeasterly direction, force 4 to 5. On the afternoon of the 15th, in latitude 5° 21′ N., longitude 45° 2′ W., a heavy shower and sudden change of wind cleared the air, the rain bringing down a "kind of red sand or dust."

Mr. G. MacGregor, second officer of the British S. S. *Dundrennan*, made the following report in a similar connection:

> 11th to 15th May: Lat. 7° 47′ N., long. 44° 26′ W., to lat. 18° 44′ N., 53° 22′ W. (L. M. noon). The hazy weather recorded was apparently due to the fact that the air was laden with a very fine reddish-brown sand similar to that found in the Harmattan winds experienced off the west coast of Africa.

The observed winds during the period were E. by S. to E. by N. force 4 to 7.

The British S. S. *Parima* noted the prevalence of a fine white haze while en route from St. Kitts and other islands to Barbados, May 13 to 18. It was sometimes so dense as to obscure land 1 to 2 miles distant. The observer concluded that as Mount Pelee was said to have been in slight eruption (the writer has been unable to obtain any confirmation of such recent activity), the haze might thus be accounted for.[1]

The citations given are the only ones thus far received by the Weather Bureau in which dust was actually reported over the north Atlantic during May, 1922, or in which abnormal haze conditions were given especial notice. Observations from a number of vessels, however, indicate a vast area over which haze occurred between the 9th and 23d of the month. The easternmost known limit of observation of the haze or dust was about the 21st meridian, in 14° or 15° north latitude; the westernmost, in the Caribbean Sea and the Gulf of Mexico.

The latitudinal width of the haze area seems to have been greatest about mid-ocean, between the 5th and 35th parallels. The American S. S. *Harvester* observed haze as early as the 9th in 35° north latitude, 41° 17′ west longitude. This date is the same as that of the first observation reported from the African coast area. The *Harvester* noted haze daily until the 13th, when in lat. 33° 40′ N., long. 53° W. The Dutch S. S. *Hagno* reported the most southerly observation.

Concluding from the foregoing data, the assured fact is that a considerable quantity of dust was very early in the month, if not actually late in the preceding month, derived from some African desert region, carried to sea, and there caught up in the northerly and easterly winds of the trades belt, where in some cases it was observed positively as dust; in others noted only as haze. From the 6th to the 10th of the month the area of high pressure was considerably disrupted by cyclonic conditions, which in all probability were instrumental in carrying the dust so abnormally to the northwestward beyond the trades, where it was observed by the *Harvester*.

This is the second recent instance of observations of dust at sea being reported to the Weather Bureau by its marine observers. The previous instance is that given by the American S. S. *Santa Rosalia*, April 15, 1921, in the Yellow Sea, coincident with the passage of a severe extratropical cyclone over the Mongolian Desert. The dust carried by the northwesterly winds of this disturbance fell over an area extending eastward at least as far as Japan. In the Yellow and Eastern Seas visibility was so reduced as to interfere with navigation.

Soil history in its relation to erosion and stratification is replete with world-wide instances of the movements of dust material by the winds. The drier the locality of course the more rapidly is this surface accumulation wind-blown and distributed. The deposition of soil dust in some localities is local and considerable in a brief period; in other regions there is a slower, steadier, and more widespread carrying on of this condition. The total amount of dust swept by the sirocco from the Sahara Desert to Europe year after year during the last 30 centuries has been calculated[2] as equivalent to an average of at least 5½ inches, less over the British Isles and northern Germany, but more than that over the southern countries. Indeed, the Sahara dust has been distributed not only over Europe but over parts of Africa, Asia, and the Atlantic Ocean. Dust from Australia has been borne a distance of about 1,500 miles to New Zealand, and the yellow detritus from interior China has likewise been transported far to sea.

Severe major cyclonic storms are likely to catch up many tons of fine material and carry much of it as they progress. In cases of violent local storms like desert whirlwinds a quantity of dust may be taken far aloft, where it passes from the brief control of the ascensional currents and spreads out into the great horizontal wind systems.

It is a dispersion of the former type that is instanced in the dust observations of April, 1921, in the western Pacific, and quite possibly a dispersion of the second type which has been herein especially discussed as affecting so great an area of the north Atlantic.

[1] Since writing the foregoing, the writer has seen a copy of *The Meteorological Magazine* of London for July which contains an extract from the *Barbados Advocate*, May 23, 1922. Attention is there called to the extraordinary "prevalence of a low hanging mist which has shut off the horizon" over the Carribean Sea from Barbados to St. Kitts and almost to Demarara. The idea that the phenomenon was due to volcanic dust, at first prevailing, was later discarded. But "no scientific explanation of the phenomenon has yet been offered."—*W. E. H.*

[2] Free, E. A.: Movement of soil material by the wind. *Bulletin No. 68*, Bureau of Soils, 1911, p. 99.